Extreme Weather and Society

Sheila Lakshmi Steinberg
William A. Sprigg *Editors*

Extreme Weather, Health, and Communities

Interdisciplinary Engagement Strategies

Springer

Extreme Weather and Society

Series editors

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Extreme Weather and Society examines people, place and extreme weather, from an emerging trans-disciplinary field of study. The series explores how abrupt and trending changes in weather alter physical environments and force community responses challenged by cultural practices/interpretations, politics, policy, responsibilities of education and communication, community health and safety, and environmental sustainability for future generations. The series highlights extreme weather alterations to different physical and social environments to better explore how people react and respond to extreme weather. The hallmark of this series is the innovative combined inclusion of social and physical science expertise. Extreme Weather and Society contains single and multi-authored books as well as edited volumes. Series Editors are currently accepting proposals, forms for which can be obtained from the publisher, Ron Doering (ron.doering@springer.com).

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Editors

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Foreword

Everyone remembers his or her first experience with extreme weather. I grew up in northern New Jersey and the early 1950s brought an especially active series of tropical storms. In 1955, Hurricane Diane roared through the Northeastern United States. I vividly recall the street where I lived crisscrossed with downed oak and elm trees and the city impassable for miles around. As a child, the storm was the most exciting show I had ever witnessed. Downed electrical wires sparked at the curbsides and neighbors scrambled to check on their homes and each other. I soon saw my neighbors pulling large branches from the roofs of their homes and covering the damage with tarps. I heard the fearful whine of chainsaws and the grunting and chugging of heavy equipment, backhoes, and grapple-skidders. The roadways were slowly cleared. For some reason we had not lost water supplies, though electricity was out for about 10 days. I felt like quite the little frontiersman as I went out to collect scrap twigs and dried branches that could be burned in the fireplace to keep our home warm during the 10 days (although I don't think we really needed the warmth, the adults probably needed some task to keep us boys busy).

My experiences were tame compared to those of the children in New Orleans in 2005 or those in Coney Island 2012. When bad outcomes ensue, such as the inundation of New Orleans with Hurricane Katrina, we initially blame them on an "Act of God," but before long we realize that this act of nature has been amplified by shortsighted design and inadequate building codes. The disaster of Katrina was magnified by bad levees, slapdash building, and residential siting in inundation zones. All made worse by a dysfunctional system of local governance, especially the police department. The New York region is overall wealthier than New Orleans and was better prepared for Superstorm Sandy, but the populations at risk were far larger. Similarly, though, in the case of Sandy, many of the bad outcomes were predictable and could have been prevented, such as the inundation of NYU Medical Center and of the city of Hoboken, or the loss of $100 million worth of new railroad rolling stock because it had been thoughtlessly sidelined parked in a known flooding zone.

Extreme weather events allow us to see our communities at their best, and sadly at their most unseemly. The communities that are the most resilient—the ones that function well and recover most quickly—bring to their recovery an important mix of financial and infrastructure assets that are perhaps the most critical element in resilience and recovery. In "Tornado Alley" people living in brick homes with basements and with steel tiedowns for the foundations and roofs survive violent windstorms better than do the low income persons living in trailer parks. People with financial assets, such as a remote vacation home or a large SUV to help evacuate them in order to stay with unimpacted relatives, managed Hurricane Katrina far better than those with few resources. Those with adequate homeowners' insurance policies rebuilt far sooner, and they rebuilt homes that were "up to code" and more resilient than the ones damaged or destroyed. And in the same way, those living in countries where national assets can be rapidly deployed to assist also manage more effectively than those with more limited assets.

Protecting health and being resilient in the face of extreme weather requires more, however, than solid financial resources. It requires a *narrative* of survival and of recovery. And that narrative must be personal and connected not just to the family, but also to the community, municipality, and jurisdiction. Studies of recovery after disasters demonstrate that families and neighborhoods where there was strong pre-existing social capital, namely community organizations, churches, and a strong volunteer culture, as well as competent and effective local governance, recovered from calamities more quickly than those without this. Communities that lack financial and social capital are more likely to fail to recover from disasters and end up in a diaspora; with persons and families scattered thousands of miles in every direction. This is what happened to many of the poor in New Orleans after Hurricane Katrina. At times a diaspora is exactly what is needed—not all locations are suitable for human habitation or redevelopment. For example, swampy areas subject to regular flooding may be good farmland but they are unlikely to be ideal for residential building. Desert areas can be turned into agricultural land, or even cattle feedlots, but only with enormous inputs of energy, water, and agricultural chemicals, including fertilizers and pesticides. Creating habitation on unsuitable land is rarely a good long-term investment.

In my role in public health I have had substantial experience in health leadership roles following various crises and disasters. When I was with the California Department of Public Health, we had to address droughts, immense wildfires, floods, earthquakes, mudslides, as well as civil insurrections. When I was head of the National Center for Environmental Health at CDC we had to address hurricanes in Florida, massive floods along the Mississippi Valley, and inundations in the low country, and even the Piedmont on the East Coast, particularly the Carolinas. My Center developed and administered the National Pharmaceutical Stockpile, which was directed and funded by Congress to be mobilized in the event of terrorism and pandemic threats; it was first deployed on September 11, 2001. In addition, CDC's Refugee and International Health group was located in NCEH; it was frequently called on to respond to refugee crises in many parts of Africa, the Middle East, Asia, and elsewhere. Each of these crises brought its own set of needs and different demands for response. And each of the various assistance groups tended to bring its own set of skills and supplies, ranging from drinking water and meals-ready-to-eat, all the way to temporary shelters and portable surgical hospitals. But in my own experience, the assets and help most often needed more than any other were: good intelligence (what is going on with whom, where, when, and for how long), solid management, and robust communication.

While these needs seem self-evident, they are rarely concurrently present, and I assert, the most commonly neglected need following these crises is *effective communication*. Many times I have been in the room with elected officials, physicians and health leaders, public safety personnel including police and fire, and emergency management experts, where each one narrowly focused on his or her own expertise. And then each looked to a third-party “expert” to confront a critical and urgent element of the response—that essential element is: *communication*. Yet, each of these leaders would delegate the task of communications to someone else: a public relations expert, or to a writer, or to a telegenic junior staff member. These “experts” frequently persisted in the belief that providing distressed disaster victims a list of facts once a day is adequate communication. But they fail to realize that effective community engagement is a two-way process. This near-predictable behavior reflects a fundamental misunderstanding of communication. *Communication is **not** merely talking to or at people.* Communication is—not just talking—but listening. Communication only occurs as a two-way activity. Just as every child is told “you have two ears and one mouth because you’re supposed to listen twice as much as you speak,” so those responding to extreme weather events and disasters need to hear and behave in the same way. Those in leadership roles must be listening clearly and synthesizing information, planning ahead; not merely directing traffic or offering dictates. Members of the community who are suffering must be conversed with, not just in their own language, but also in their own dialect and educational level. It is important to understand the cultural aspects and norms of the communities as you plan to communicate and take action around extreme weather events.

When I was in North Carolina following Hurricane Floyd, I visited many of the shelters that had been set up in the school gymnasia and armories. I repeatedly heard the community members express anxiety about epidemics of typhoid. After listening to distraught members of the public express fears about a typhoid epidemic, we would patiently explain that there were no typhoid bacilli in the area and that the likelihood that this would occur was negligible. Our reassurances were dismissed. People who were frightened, isolated, and distraught repeatedly insisted that they wanted “typhoid shots,” an activity I considered worthless, especially compared to all the other more urgent needs that people had. Then I hit on it—the most common health threats in these situations resulted from drinking contaminated water and food; these needs were being well taken care of. But after major disasters such as earthquakes and tornadoes, the most common injury people sustained was puncture wounds to the feet. The landscape was covered with pieces of lumber, broken boards, and other debris with wood shards and exposed nails sticking up. After the wearing of personal safety equipment such as heavy-duty work shoes, the most important health protective contribution we could make to these folks was to raise their immunity to tetanus, or lockjaw. Yet puncture wounds were seen as a personal threat and liability, perhaps the result of carelessness, rather than a community or public health threat. To respond to an actual public health danger to the community, we then set up clinics to administer a tetanus toxoid vaccine in the form of TDap shots. The immunity to tetanus would be far more useful and last ten years, and also to the good, they received boosters against diphtheria and pertussis (whooping cough). The act of waiting in line with one's neighbors and receiving this useful injection carried far more benefit, both medically and in terms of anxiety reduction, than almost any other action we could have taken. Listening is what created this community benefit. This kind of clinical management at a community level is somewhat similar to actions taken in clinical medicine, where what the patient is saying they are worried about, and what the doctor knows they should be concerned about, are not in agreement. In these situations the patient needs to feel listened to and well cared for, and the doctor must with good conscience do what is best for that person.

Climate experts say that extreme weather will be on the increase because of planetary warming and our ignoring the community health signs and symptoms of global, unchecked dependence on fossil fuels. Sea levels have been rising at the rate of about a centimeter per decade, which means that oceans are about a third of a foot higher than they were during Hurricane Diane. Storm surge and saltwater intrusion into freshwater resources create greater threats to safety, health, and infrastructure. Warmer atmospheres hold not just more energy but hold more water vapor, and the combination of more heat and more humidity can be deadly in our densely populated cities.

Experts say these weather extremes will become not just more frequent but more violent. And weather will not impact merely little neighborhoods but will lead to impacts on large populations. Where droughts prevail and arid lands expand, wind storms will carry even more dust around the world to downgrade air quality and exacerbate respiratory consequences.

Diminution of the Himalayan glaciers and the relative drying up of the Ganges River and the Brahmaputra River, combined with sea-level rise in the Bay of Bengal, will lead in this case to large population migrations. Increasing numbers of drought events worldwide would combine with sea-level rise, and the inevitable salination of aquifers used for drinking water, livestock, and irrigation will drive ever larger population migrations. Population migrations always come with major health impacts, and too many start with war and terrorism. And as with everyone's early life experiences with violent weather, the impacts will be unforgettable. Sadly, the children of tomorrow will have many more weather stories to tell; stories with little charm and a great deal of preventable terror.

The following chapters are a sample of how society has dealt with extreme weather events, concerns for human health using interdisciplinary approaches to community engagement. They tell of life-threatening moments of terror and of chronic, life-restricting consequences of extreme weather. They take us through the painstaking cycle of research, education, and payoff, with fewer lives at stake, healthier communities, and a higher regard for climate and weather. Significantly, they remind us of the need for interdisciplinary and cross-cultural participation in coping with weather extremes.

January 2016

Richard J. Jackson
Chair and Professor, Environmental Health Sciences
Professor of Urban Planning
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Editors and Contributors

About the Editors

Sheila Lakshmi Steinberg Ph.D. is Professor of Social and Environmental Sciences at Brandman University-Chapman University System, Irvine, CA. The theme throughout her research is examining people and their relationship to space and place. Dr. Steinberg's research interests include environmental sociology, research methods, social inequality, community, geospatial research (GIS), and policy. Dr. Steinberg has always been interested in weather, climate and society from living in so many different parts of the U.S. Recently, she co-authored a book entitled GIS *Research Methods: Incorporating Spatial Perspectives* for Esri Press and has also co-authored chapter on this topic entitled "Geospatial Analysis Technology and Social Science Research" in the *Handbook of Emergent Technologies*, Sharlene Hesse-Biber, Editor, Oxford University Press 2011. In 2006, she co-authored a book for Sage Publications entitled, *GIS for the Social Sciences: Investigating Space and Place*. In 2013, she joined Brandman University where she now teaches courses related to social and environmental sciences.

William A. Sprigg Ph.D. Yale University, is Research Professor Emeritus, University of Arizona, the current and founding director of the World Meteorological Organization's Pan-America Center for airborne dust forecasting and research associate of the Public Health Institute in California. He is a member of the American Meteorological Society's Board on Environment & Health, the Chinese Academy of Sciences Committee for Digital Earth Observations, and the Serbian Program of Basic Research, Environmental Protection and Climate Change. Former positions include Distinguished Professor at California's Chapman University, Director, U.S. National Research Council Board on Atmospheric Sciences and Climate, head of the U.S. National Climate Program Office, and architect of the U.S. Climate Program. He participated in the first Intergovernmental Panel on Climate Change. Authoring a number of technical publications on climate and, most recently, on his current research interests, airborne dust and human health, Dr. Sprigg continues his interests in interdisciplinary research and science policy.

Contributors

Peter Berry Ph.D. is a Senior Policy Analyst with the Climate Change and Health Office at Health Canada (Government of Canada) where he has worked since 2001. While at Health Canada Peter has conducted research in several areas related to climate change including health risks to Canadians, adaptive capacity of health systems, health vulnerability assessment, and communicating climate change risks to the public. As part of Health Canada's initiative to help Canadians protect themselves from extreme heat he co-authored a number of guidance documents for public health officials. Peter actively collaborates with researchers within and outside of Canada to facilitate public health adaptation. He is a contributing author for climate change and health vulnerability and adaptation assessment guidelines that were released by the World Health Organization in 2012 and to the Intergovernmental Panel on Climate Change Special Report on the Management of Extreme Weather Events. He was a lead author for the Health Chapter of the Government of Canada climate change and impacts assessment update that was released in July 2014 and is currently on an expert advisory committee for a vulnerability assessment for the island state of Dominica.

Olivia Burchett Porter M.A. grew up in Trinity and Wilmington, North Carolina. She obtained her Bachelor's degree in Political Science and International Studies from the University of North Carolina at Chapel Hill in 2005. She served as a United States Peace Corps volunteer in Busia, Uganda, from 2007 to 2009. Olivia joined the University of New Orleans urban and regional planning program in 2012, and worked as a Graduate Research Assistant for the UNO Center for Hazards Assessment, Response and Technology (UNO-CHART). She received her Master's degree in urban and regional planning in 2014. She currently attends Loyola University of New Orleans College of Law, and is pursuing a J.D. with a Certificate in Environmental Law. Loyola University of New Orleans, New Orleans, Louisiana.

David Driscoll Ph.D. is the Director of the Institute for Circumpolar Health Studies and Associate Professor in the College of Health at the University of Alaska, Anchorage. He is a medical anthropologist and epidemiologist with a specialization in the application of interdisciplinary and mixed method health research designs to assess the social and physical determinants of community health. Dr. Driscoll conducts research to develop and evaluate evidence-based risk communication, health promotion, and disease prevention interventions for rural, isolated, and culturally-distinct communities. He has published widely on his research, including in the *Journal of Rural Health*, *Health Promotion Practice*, the *International Journal of Circumpolar Health*, and the *Journal of Health Communication.*

Mary Hayden Ph.D. (NCAR) is a behavioral scientist with over 15 years of experience working on weather, climate, and health-related linkages. Dr. Hayden received her Ph.D. in Health and Behavioral Sciences from the University of

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Michael Hayes Ph.D. is currently Director for the National Drought Mitigation Center (NDMC) located within the School of Natural Resources at the University of Nebraska-Lincoln. He became the NDMC's Director in August 2007 and has worked at the NDMC since 1995. The NDMC now has 20 faculty and staff working on local, tribal, state, national, and international drought-, climate-, and water-related issues. Dr. Hayes' main interests deal with drought monitoring, planning, and mitigation strategies. He is currently a co-chair on the Implementation Team for the National Integrated Drought Information System (NIDIS). Dr. Hayes received a Bachelor's Degree in Meteorology from the University of Wisconsin-Madison, and his Master's and Doctoral Degrees in Atmospheric Sciences from the University of Missouri-Columbia.

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Daniel P. Johnson Ph.D. is currently Associate Professor of Geography and Department chair of the IUPUI Department of Geography. He holds an M.S. in Information Science from Indiana University and a Ph.D. in Geography from Indiana State University. Daniel is also the director of the Center for Aerial Unmanned Systems Imaging (CAUSI) at IUPUI. His research interests include Medical Geography, Extreme Heat Events, Remote Sensing, and Human Health.

Richard L. Krajeski D.D. has served the Presbyterian Church and the ecumenical community as an ordained pastor for over 50 years and the disaster response community for 30 years. Rev. Krajeski spent 40 years as a pastor in the mountains of Kentucky and West Virginia and now lives and works in the delta area of Southern Louisiana—all places of "economic, environmental and human extraction." He is active in environmental and social justice ministries. Dick's academic background includes degrees in philosophy and theology. His doctoral studies were in the area of applied technology, sustainable development, and ethics. He has been instrumental in introducing the concept of mitigation, vulnerability, and resilience to the disaster and mission ministries of the religious community. Rev. Krajeski is a founding member of the international Gender and Disaster Network, the Natural Hazard Mitigation Association, and Lowlander Center. He is a Fellow in the Society for Applied Anthropology.

Erica D. Kuligowski Ph.D. is a sociologist in the Community Resilience Group in the Engineering Laboratory at the National Institute of Standards and Technology. Dr. Kuligowski holds a Ph.D. in Sociology from the University of Colorado at Boulder, as well as a B.S. and M.S. in Fire Protection Engineering from the University of Maryland, College Park. Dr. Kuligowski's research interests are human behavior in emergencies, including preparedness, response and recovery behaviors, behavioral modeling, emergency communications, and the modeling of social systems.

Shirley B. Laska Ph.D. is Professor Emerita of Sociology at the University of New Orleans. She is an environmental sociologist with a community dynamics specialty. She has served as Professor of Sociology at Dillard University, Loyola University of New Orleans, and the University of New Orleans where she created the Center for Hazards Assessment, Response and Technology (UNO-CHART) a center that trains graduate students and emphasizes applied collaboration with communities to reduce their vulnerability to natural and technological risks. She is the co-founder of the Lowlander Center, a nonprofit which helps coastal Louisiana communities and their residents create solutions to climate change challenges particularly sea level rise, as they live with an ever-changing coastline and land loss while visioning a future that builds capacity and resilience for place and people.

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Barbara Mayes Boustead Ph.D. is a meteorologist and climate program leader at the National Weather Service in Omaha, Nebraska, with a career that has also taken her through its headquarters in Silver Spring, Maryland, and through the office in Davenport, Iowa. A Michigan native, Barbara obtained undergraduate degrees from Central Michigan University in 2000, with majors in Meteorology, Geography, and English, and minors in Mathematics and History, followed by an M.S. in Meteorology from The Pennsylvania State University (2002) and a Ph.D. in Climate Assessment and Impacts from the University of Nebraska (2014). Her professional interests include climate, historical weather events, severe and extreme weather, and improving communication of weather and climate concepts. Barbara is married to another meteorologist, Josh, with a beloved son, Jaxon. Barbara researches the weather and climate events from all of the Laura Ingalls Wilder books, with a blog at http://www.bousteadhill.net/wilder_weather/ and on Facebook ("Wilder Weather").

Margaret M. Moodian Ed.D. is a nonprofit leader and educator from Orange County, CA, who serves on the boards of directors of Tias Arms, which is a nonprofit that assists abandoned children affected by HIV/AIDS in South Africa, and the Blind Children's Learning Center. At Brandman University, which is part of the Chapman University System, she serves as a tutorial assistant professor of humanities and social sciences. Additionally, Dr. Moodian is as a Delta Gamma PRO, which means she speaks to Delta Gammas and other members of the Greek community around the country about topics such as leadership and self-esteem. She earned a doctorate degree in education and a master's degree in Psychology from Pepperdine University, and a bachelor's degree in Fine Arts from Chapman University. Her dissertation focuses on the leadership traits of female Fortune 1000 board members.

Michael A. Moodian Ed.D. has served as a faculty member in various capacities for the Chapman University System since 2007. Dr. Moodian's first book, titled *Contemporary Leadership and Intercultural Competence* (Sage), was released in 2009. The book is cited by the Association of American Colleges and Universities in establishing national learning standards. Governor Jerry Brown appointed Moodian to the State of California Commission on Judicial Performance in 2015. Additionally, he chairs the Santa Margarita Catholic High School Consultative School Board, and serves as founding chair of the United Nations Association of Orange County Advisory Board, a member of the UC Irvine Olive Tree Initiative Advisory Board, and an executive board member and former chairman of the World Affairs Council of Orange County. Moodian earned a doctorate degree in Education from Pepperdine University and a master's degree in Communications from California State University, Fullerton.

Kari C. Nadeau M.D., Ph.D. heads the Sean N Parker Center for Allergy Research in the Stanford University School of Medicine with a vision to find the causes and cures of allergies and a mission to transform the lives of patients and families through innovative science and compassionate care. A graduate of Haverford College (summa cum laude) in biology, Dr. Nadeau received her M.D. and Ph.D. in Biological Chemistry and Molecular Pharmacology from Harvard University. She interned and served residency in pediatrics at the Children's Hospital Boston, Harvard Medical School. From 2003 to 2006, Dr. Nadeau was a fellow in Asthma, Allergy and Immunology at Stanford/UCSF and a postdoctoral fellow in human immune tolerance mechanisms in asthma and allergy. Today she holds a Naddisy Family Foundation endowed faculty position in Pediatrics and Otolaryngology. Dr. Nadeau has obtained FDA approval for two biologics in Autoimmunity and Oncology. She is a member of the California American Lung Association Medical Board, a Fellow in the American Academy of Allergy, Asthma and Immunology, a member of the American Society of Clinical Investigation, and serves on the Environmental Health Policy committee for the American Thoracic Society. She has authored or co-authored more than 110 original papers.

Kristina J. Peterson Ph.D. facilitates The Lowlander Center, a nonprofit organization that helps create solutions through education, research, and advocacy, beginning at the community level, helping, communities seek solutions to living with an ever-changing coastline and land loss, while visioning a future that builds capacity and resilience. Dr. Peterson is a founding member of the National Hazards Mitigation Association, collaborated with FEMA's Project Impact, worked with CWS Disaster Services and holds a Ph.D. in Urban and Regional Studies, University of New Orleans. She was made a fellow in the Society of Applied Anthropology, received the Prince Award for outstanding dissertation, the William Gibson Environmental Award in 2010, the Rural Sociology Society's 2014 Service to Rural Communities Award, and a citation from the State of Maryland for work on social and economic justice. She serves on the advisory board of the Thriving Earth Exchange, of the American Geophysical Union and the Building Resilience Workshop.

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Rosina Philippe A lifetime resident of coastal Louisiana, and an Elder/Historian of the Atakapa-Ishak/Chawasha Tribe, Ms. Philippe is an advocate for preservation of traditional cultural and heritage practices and a grassroots activist. Her work is focused on partnering with leaders from other communities, and various organizations/groups, to work for environmental sustainability of coastal, traditional, and historied communities. These alliances are forged to address issues of: Climate Change, Economic Instability, Environmental Justice, Gentrification, and Coastal Restoration/Preservation; issues that are familiar to most of our communities and have plagued its peoples for generations. As a guest lecturer, she speaks on recognizing accountability, and identifying contributing factors and entities in relation to these issues. Ms. Philippe is a firm believer that people facing similar problems, through informed education and information sharing, have the power to affect positive long-term changes; and through collaboration, take charge of their own destinies, building toward a more resilient and sustainable life.

Mary M. Prunicki M.D., Ph.D. joined the Sean N. Parker Center for Allergy Research at Stanford University in July 2014. Her current research focuses on the Fresno, CA pediatric population. She investigates the effects of ambient air pollution on the immune system, especially in children with asthma. Dr. Prunicki studies T cell immunology, with an emphasis on Tr1 and Th17 cells.

She received her Ph.D. from Northwestern University and her M.D. from Southern Illinois University. After a career hiatus to raise her small children, Dr. Prunicki resumed her research career by becoming a National Institutes of Health re-entry scientist.

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David A. Robinson Ph.D. is Professor in the Department of Geography at Rutgers University. Since 1991 Dr. Robinson has also served as New Jersey's State Climatologist. He earned a bachelor's degree in Geology at Dickinson College in Carlisle, PA and a doctorate in Earth Sciences at Columbia University. He spent several years as associate research scientist at Columbia's Lamont-Doherty Earth Observatory prior to arriving at Rutgers in 1988. Dr. Robinson's research interests are in applied climate, especially related to New Jersey, and in climate dynamics and change, particularly focused on global snow cover. He is a contributor to the Intergovernmental Panel on Climate Change and to the National Climate Assessment, and sits on the National Academy of Sciences' Board on Atmospheric

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Austin C. Stanforth M.S. is a doctoral candidate in Applied Earth Sciences at IUPUI. He holds an M.S. in Geographic Information Science from Indiana University, and his research interests include remote sensing interpretation, geospatial analysis, environmental analysis, epidemiological studies, and human/environment interactions. Austin is a member of the American Meteorological Society's Board on Environment and Health. His current work is focused on integrating remote sensing, Geographic Information Science, and anthropogenic variables to identify social-spatial vulnerability patterns in urban environments.

Nicole Wall M.S. is a Research and Outreach Specialist for the National Drought Mitigation Center (NDMC). Her expertise is in applied sciences and public participation. Her past experiences have included working for a nonprofit in Lincoln, Nebraska, where she worked with various neighborhood associations in visioning activities and on public participation for some of the City of Lincoln's water-related projects. Nicole also worked for the University Nebraska Medical Center for two years, writing materials to foster a team-based approach to diagnostic skills in medical students. She has led the coordination of numerous workshops relating to drought while being at the NDMC. For two years, she served as co-facilitator for the Republican River Task Force, which was established by Nebraska Legislative Bill 1057. Currently, she is involved in the new Drought Risk Management Research Center that has been funded by the National Oceanic Atmospheric Agency & the National Integrated Drought Information System.

Olga Wilhelmi Ph.D. is a geographer with over fifteen years of experience working at the National Center for Atmospheric Research (NCAR). Her research focuses on societal risk, vulnerability, and adaptive capacity to extreme weather events and climate change. Dr. Wilhelmi leads NCAR Geographic Information Science program and works on developing spatial methodologies for integrating information from physical and social sciences. Her current projects explore linkages among weather-related hazards, urban environment, social vulnerability, and human health.

Introduction: Extreme Weather, Health and Communities: Why Consider the Connections?

William A. Sprigg and Sheila Lakshmi Steinberg

Abstract This chapter introduces the importance of thinking about interdisciplinary approaches to examining extreme weather, health and communities. Weather extremes are a challenge. In sudden storms, long periods of drought, heat waves or cold spells, people either cope or suffer the consequences. World populations today are facing extreme weather in many forms, including excessive heat, mega-storms, tornados, floods and drought. This is weather that threatens the health, safety and wellbeing of rich and poor alike. Special challenges emerge for those who lack the wealth and social power to prepare for or move away from extreme weather threats. This chapter presents the rationale for the chapters that follow, and the detailed case studies of radical weather and the problems left behind: the people harmed, the physical environments altered and the lasting health issues. It explores the connections among them, the best practices in community response to them, and the successes of interdisciplinary tactics in dealing with them across various geographies, customs and cultures.

Weather extremes have been a challenge since life on earth began. Whether caught in sudden storms or subjected to long stretches of extreme drought, heat or cold, people must either cope or suffer the consequences of changing weather and environments. The world continues to face extreme weather in the form of excessive heat, mega-storms, tornados, flooding and drought. These events often pose major health threats to communities around the world. Effects of such environmental health challenges are especially significant for vulnerable populations that lack the economic wealth and social power to prepare or move away from extreme weather threats. Poorer populations are often relegated to living in environmentally marginalized areas, and as a result, experience greater suffering.

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This book focuses on radical weather and the problems left in its wake: the people harmed, the places affected and the lasting health issues. It explores the connections among them. Detailed case studies are presented of how people from various geographies cope with different types of severe weather. This volume adopts a unique interdisciplinary approach drawing upon expertise in both natural and social sciences. It contributes a socio-scientific integrated perspective on interdisciplinary community engagement to combat extreme weather and to preserve health.

Extreme weather around the world is having a major impact. Hurricanes tend to leave scars on communities and the landscape for decades, and Katrina's path through Gulf of Mexico coastal marshes in 2005 is no exception. In 2015, Hurricane Patricia "became the strongest hurricane on record in the Western Hemisphere" (NOAA 2015). It was the most intense Western Hemisphere hurricane on record—with 879 mb/25.96″ and 200 mph sustained windspeed at it's peak intensity measured on October 23, 2015. Patricia broke records previously set by Hurricanes Linda and Wilma. A week later, on November 2, 2015, in a very rare event for the Arabian Sea and Gulf of Aden, Cyclone Chapala hit the coast of Yemen with torrential rains causing large scale flooding and landslides. According to NOAA and NASA satellite estimates, Yemen received several times its average annual rainfall in less than two days!

In December of 2015, India experienced unprecedented flooding and monsoons (Lesiter 2015) after following an October where extreme temperatures climbed above 122 °F (Burke 2015). In 2012, the United States experienced the most extreme weather since 1910, when record keeping began. This includes Hurricane Sandy (discussed in Chaps. 2 and 3 of this volume), a storm that will be remembered for a long time. On 30 August 2015, Hurricane Fred had the distinction of forming further east in the tropical Atlantic Ocean than any previous hurricane since satellites began their storm surveillance, and possibly the first hurricane since 1892 to strike Cape Verde islands (Carlowicz 2015), less than 600 km west of Dakar, Senegal.

Since January 2012, the United States alone experienced 2188 days of record heat, 1094 days of record rainfall and 245 days of record snowfall (Natural Resources Defense Council 2015). These major environmental changes come at significant cost in social and health consequences. Places need to be armed with a spatial understanding of their resources, risks, strengths, weaknesses, community capabilities, and social networks before severe weather strikes. Understanding the relationships between health, community strengths and social patterns permits governments and communities to prepare for action before extreme weather strikes. Knowing the people and communities involved, and understanding their interaction with their environment, is good preparation for extreme weather and the associated risks.

The aims of this book are to:

- Provide case studies of extreme weather events that illustrate health consequences for places (urban and rural), for socioeconomic status (rich and poor), and for a variety of geographies around the globe.

- Present interdisciplinary strategies for community engagement built around their existing social strengths and patterns of interaction.
- Explore the relevance of space and place in understanding extreme weather, health and communities.
- Develop a spatial understanding of weather and how it can be integrated with social factors for more accurate and effective preparation and disaster mitigation.

It is important to note that in practice, severe weather is climate's tool for helping to redistribute energy and to attain a stable climatic state. Earth's climate today is moving away from the instrumented, historical norm. Unnoticed at first, except by a few scientists and a few unlucky souls who live where weather and climate work the hardest to redistribute and balance Earth's energy budget, the consequences of climate transition are becoming more evident and widely known (United Nations 2015; IPCC 2014).

Throughout time, societies have developed strategies to cope with weather extremes. Early arid-land farmers trapped moisture for their crops when the cold of night coaxed tiny fractions of water from the air and soil that would condense on the undersides of stones placed to shelter seeds and tender stalks from the heat of day. As farming became more sophisticated, small gardens expanded into commercially viable sources of food, and farmers surrounded broad fields with tall trees to block strong winds that eroded arable soil and evaporated valuable water. When people could not cope with severe weather they migrated with different consequences, as in the legendary American dust bowl of the 1930s (Sarafoglou and Sprigg 2015). Today, as land and resources have become largely claimed, a weather-ravaged community cannot easily pick up and move. Weather extremes create particularly difficult challenges for vulnerable communities.

This book is written for readers who come from many places, many experiences and many professions—and for students seeking cross-disciplinary understanding of how others have applied social and environmental science, communication and public policies together to face the extreme hazards of weather and climate. It is written for the curious and informed citizen anywhere in the world who will try to influence policies that guard against the health and safety hazards of extreme weather. We trust the text is suited for a variety of disciplines that examine the relationship between communities, environment and health. It will also be a useful text for first-responders in storm related emergencies, for city and township leaders and administrators, and for local, regional, and national public health and emergency management principals the world over.

Each of our contributing authors considers how a particular severe weather event manages to disrupt social, economic and environmental systems, and how local communities have responded. We focus on extreme weather consequences for human health, but it soon becomes obvious that these issues do not exist in isolation. Maintaining community health in the face of environmental changes is a theme that runs throughout the volume.

1 The Power of "Interdisciplinary"

Our book highlights the strength that comes from maintaining interdisciplinary approaches to participant engagement and problem solving. Innovation occurs through interdisciplinary engagement. In other words, "when you bring together people to interpret and understand the data from different backgrounds, they may naturally generate synergistic thoughts or suggestions" (Steinberg and Steinberg 2016, p. 373). Developing best practices for how to face and respond to severe storms and extreme, long-lasting meteorological events are derived through interdisciplinary study and planning. Each chapter in our book reflects the diverse experiences and perspectives of experts from different areas of expertise including meteorology, public health, anthropology, sociology, community development, spatial analysis, medicine, engineering and history. They are true case studies that contain lessons to be applied for the next severe weather challenge—perhaps at another time, another place, and possibly under threat of a different type of extreme weather event. In this regard, participating authors have had to become, at least to some degree, interdisciplinary.

The volume begins in Chap. 2 with climatologist Dr. David Robinson's examination of whether the 2012 "super storm" hurricane Sandy and the aftermath will have changed the status quo of preparations, warnings and responses to severe storms in the American coastal states of New York and New Jersey. Dr. Michael Moodian follows in Chap. 3 with a discussion on the politics of severe storms, including Hurricane Sandy, and whether elected officials have, or should have, a grasp of extreme weather issues. Just how do our elected leaders fare when put to the test?

The full range of actions to reduce urban health consequences of extreme heat waves, from the research that reveals the problem, to the citizens who approve the resources to counter the consequences, is told by this volume's co-editor, Dr. Sprigg, in an end-to-end story (Chap. 4) on how global health problems of windblown desert dust may be reduced significantly in a proposed Dust-Health Early Warning System, the concepts of which depend on interdisciplinary collaboration, rapid and effective communication, and state-of-the-science environmental observations and weather models to forecast dust storms and their downwind dust concentrations.

Drs. Peter Berry and Gregory Richardson (Chap. 15) capture the important lessons of all the previous case studies in one comprehensive, end-to-end example focused on community health resilience to extreme heat.

All effective preparations or responses to severe storms include interdisciplinary engagement of people and a sense of time and place. The chapters within this volume are case study testimonials. Co-editor Dr. Sheila Lakshmi Steinberg's Chap. 5 presents a theoretical model for extreme weather, environmental change, place and community health followed by a community-based strategy for establishing interdisciplinary engagement for effective communication and trust among all parties across different geographies. These points emerge again in Chap. 6, written by Drs. David Driscoll and George Luber, who focus on community engagement and health effects of extreme weather in the Artic. This is followed in Chap. 7 by a collection of co-authors led by Drs. Kristina Peterson and Shirley Laska, with co-authors Rosina Phillippe, Olivia Burchett Porter, Rev. Richard Krajeski, and Drs. Sheila Lakshmi Steinberg and William A. Sprigg—Chaps. 6 and 7 provide completely independent studies of indigenous populations and extreme weather in the very different environments of Alaska and the Gulf of Mexico coastal states. Both chapters highlight similar challenges that indigenous, Native American communities face with changing environments and having to adjust community patterns of environmental interaction. Indigenous populations in both the Coastal Southern U.S. and Arctic Alaska are challenged to cope with changing weather extremes and environments to maintain robust health and sustainable living.

In general, people develop patterns of settlement, commerce and industry around particular places, local climate and resources. Cities and towns were built along coastlines or rivers to facilitate transportation and energy, which were, and still are, susceptible to storm surges and floods. Extreme weather has threatened patterns of life in most places around the globe. Chapter 12 by Barbara Mayes Bousted examines the literary narrative of Laura Ingalls Wilder, and presents an historical account of American settlers' struggles with extreme weather in the U.S. Midwestern prairie in the late 1800s. Coping with extreme weather at that time depended more on the will, knowledge and skill of the individual, and less on central government and formal community structures. Still, lessons learned from the successful experiences of those who did cope with extreme unpredictable winter weather, for example, helps lay the foundation for future community and regional planning in other times and places.

This book also explores the health challenges of extreme heat brought about when stagnating or persistent weather patterns bring extended periods of above normal temperatures, especially into urban communities. Drs. Olga Wilhelmi and Mary Hayden (Chap. 8) and Austin Stanforth and Dr. Daniel Johnson (Chap. 9) lay out applied spatial research strategies, scientific data and the substance behind the issue. Their work is revealing background for Chap. 15 by Drs. Berry and Richardson, who describe Health Canada's "Heat Alert and Response Systems" and case studies for Ontario, Winnipeg and Windsor, Canada.

Drought, another longer-term, persistent weather extreme that puts community health and wellbeing at risk is addressed in Chap. 10, by Drs. Michael Hayes and Nicolle Wall, who focus their attention on drought and public engagement in the United States, and in Chap. 11, by Dr. Jyotsana Shukla, who bases her research in India and raises the little known and even less discussed mental health accompaniments to weather extremes, in this case torrential periods of rain and flood. The bane of all who try to implement measures of risk prevention—gaining support for a "what if" extreme weather and health risk scenario when there are many current demands on existing community resources—is addressed in Dr. Shukla's Chap. 11.

Chronic Obstructive Pulmonary Disease (COPD), asthma, cardio-vascular illness and Valley fever are among the health risks triggered by extreme weather conditions in Fresno, California. Drs. Mary Prunicki and Kari Nadeau discuss best practices in Chap. 13 for both ends of a weather spectrum. On the one hand, health-hazardous pollutants from normal daily activities are trapped in stagnant air under persistent atmospheric temperature inversions. On the other hand, strong, gusty winds raise inhalable desert dusts, mold spores and other health hazards from the desert floor.

No volume dedicated to the health consequences of extreme weather can avoid the implications of hurricanes and tornados. Drs. Erica Kuligowski, Franklin Lombardo and Long Phan in Chap. 14 use a mixed-methods approach to analyze community preparations, actions under extreme duress, and assessment of emergency plans in the aftermath of the devastating Joplin, Missouri tornado on May 22, 2011. The storm killed 161 people, damaged some 8000 structures and caused billions of dollars in damage. Chapter 14 looks critically at warnings and communications, community responsibilities before and after this event, and the insights that make this a lesson in emergency management applicable well beyond this storm and this state.

Finally, we hope you will enjoy reading this book. We feel it is a useful perspective for understanding people, place and their relationship with extreme weather. In order to respond adequately to extreme weather, people and communities must be connected first, through place-based strategies. Trust and action naturally follow if a solid, interactive community foundation is established, which we believe is best achieved through interdisciplinary collaboration. We hope the case studies presented here represent strategies for action and preparation that can be implemented, adapted and adopted, for communities small and large, around the globe. The power of preparation begins with this.

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Superstorm Sandy: A Game Changer?

David A. Robinson

Abstract Superstorm Sandy was a late season hurricane that transformed into a monster post tropical storm, making a New Jersey landfall on October 29, 2012. Sandy was a transformative event with respect to its impacts on the natural environment, to changes in forecast and emergency management procedures, and, even more so, to the psyche of those living in coastal states. Seen through a New Jersey focused lens, this chapter will delve into physical and social science aspects of Sandy. Lessons learned and important continuing dialogs will be addressed. For example, the National Hurricane Center has revised watch and warning criteria. Zoning changes that would move homes and businesses away from the shoreline are being discussed and in some cases implemented. Improved means of communication between the forecast community and decision makers, and subsequently in getting the message out to the greater population, are being studied and implemented. Sandy has led to a greater appreciation of the power of Mother Nature and the ever-growing vulnerability of individuals and their communities to storms. However questions remain as to whether New Jersey and other coastal states are better prepared for the next major storm. Was Sandy truly a game changer?

Keywords Superstorm · Nor'easter · Tropical cyclone · Hurricane · Storm surge · Westerlies · Warm/cold core storms · Evacuation · Storm category · Storm track

1 Introduction

Those of us living along the United States East Coast are generally well aware of the threat of a major storm at any time of the year. With such events, there are the attendant threats and consequences to life and property within coastal and inland communities. In middle latitude coastal regions, it can be a strong winter-type

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storm, known along the East Coast as a “nor’easter.” Or it might be a system of tropical origin, such as a hurricane or tropical storm. It might even be a hybrid storm sharing characteristics of both, such as a post-tropical cyclone.

The effects and subsequent natural impacts of such storms are strong winds, coastal flooding (including surge and wave action), heavy rain and/or snow, freezing rain, river (fresh water) flooding, re-sculpting of coastal and riverine landscapes, and damage to trees and other vegetation. Societal consequences may include injury and loss of life, damage to buildings and utility and transportation infrastructure, major disruptions to business and commerce, and enormous and potentially long-lasting consequences to the overall well being of individuals and their communities.

How we prepare for and respond to coastal storms helps determine how effectively we recover from such events. Lessons learned hopefully enhance the level of preparedness when the next storm arrives, and the next and the next. Have forecast improvements been made, are more effective watches and warnings being issued, have modes and methods of hazard communication become more effective? Has infrastructure been hardened to enhance safety and help keep people out of harms way before and during events, while also facilitating faster recovery following a direct hit or even a glancing blow? And what about threats of increasing vulnerability due to a changing climate that holds the potential for stronger or more frequent storms and rising sea level? Though on the other hand, might threats of heavy snow and ice storms be reduced in the warmer decades ahead?

This chapter will delve into physical and social science aspects of coastal storms. A multitude of excellent studies, articles and books have and continue to be generated that are associated with each. Thus, here the focus will be on Sandy, particularly from a New Jersey perspective. Sandy was a late season hurricane that transformed into a monster hybrid storm as it approached and ultimately made a New Jersey (NJ) landfall on October 29, 2012 as a post-tropical storm having hurricane and nor’easter characteristics. The storm wrecked havoc along the Mid-Atlantic coast, in particular within New Jersey and the greater New York (NY) Metropolitan region (Sobel 2014).

This story is told through the eye of a life-long New Jersey resident who has been privileged to serve as the state climatologist for the past 25 years. This chapter will describe the whys and wherefores of Sandy and place it within a broad perspective of NJ geography and past storms. It will posit that Sandy was a transformative event with respect to its impacts on the natural environment, to changes in forecast and emergency management procedures, and, even more so, to the psyche of the state. Sandy has altered how those within the state think of coastal storms and, for that matter, extreme events of most any kind. Lessons have been learned. However questions remain as to whether this coastal state is better prepared for the next major storm. So was Sandy truly a game changer?

2 New Jersey at a Glance

With the focus of this chapter on New Jersey, it is appropriate to introduce some Jersey geography that is germane to the discussion. At 7790 square miles, New Jersey is the fifth smallest state. It lies between 39 and 41 °N and straddles the 74 ° W meridian. The highest location is 1803 feet above sea level at High Point in the far northwestern corner of the state. It has 127 miles of Atlantic coast, approximately 60 miles of Delaware Bay shoreline and shoreline along the Hudson River, NY Harbor, Raritan Bay, the lower Delaware River and coastal wetlands, all of them at or near sea level. Several moderate-size river basins, including the Delaware, Passaic and Raritan, drain the hills and valleys of northern and central NJ. They discharge into coastal bays, as do many smaller rivers flowing out of the south Jersey coastal plain. NJ is approximately 40 % forested, including deciduous hardwoods in the north and conifers within the unique Pine Barrens ecosystem that covers a large portion of south Jersey.

New Jersey has four relatively well-defined seasons, with clashes between cold and warmth that trigger occasional severe weather conditions over the course of any year (Robinson 2009). However, most of the threatening weather and climate events affecting New Jersey fail to reach the extremes experienced in other parts of the United States. This results from New Jersey's proximity to the Atlantic, which moderates winter cold and helps keep summer heat in check. The Atlantic Ocean also inhibits severe thunderstorms, and its waters are not warm enough to sustain the strength of hurricanes arriving from the south.

The dominant feature of the atmospheric circulation over New Jersey is the wind flow from west to east. These prevailing "westerlies" vacillate north and south over North America and vary in strength during the course of the year. Winter brings the strongest westerlies in their southernmost position. Storms form where cold and warm air clash, and on occasion a coastal nor'easter or other strong inland low-pressure system may bring a bout of heavy rain and/or snow. Spring and fall are transition seasons when winter type weather may occur, yet summer heat and severe thunderstorms may also make an appearance. A New Jersey summer without several weeks of heat and humidity is rare. Daylong storms are unusual; however, conditions are frequently ripe for thunderstorms, which may bring flooding rains, strong winds, and dangerous lightning. While land-falling tropical systems are rare, New Jersey is no stranger to tidal and river flooding and the strong winds associated with these summer and fall storms as they pass close by.

With a population approaching 8.8 million, New Jersey is the most densely populated state (U.S. Census Bureau 2015). As a result, it is all but "built out", meaning that most every parcel of land is spoken for. This does not mean the land is fully developed with homes, shopping malls, businesses and the like. In fact, there is considerable open space in many areas of the state. However, with an abundance of people living within its borders, there are many who reside, work, travel through or recreate within areas that are vulnerable to extreme natural events. Not being a region particularly vulnerable to geologic activity, this means that NJ residents are mostly at the occasional mercy of extreme atmospheric and oceanic forces.

New Jersey has 21 counties and 565 incorporated municipalities (New Jersey State Library 2015). The governmental structure is such that “home rule” applies prominently to the manner in which business is conducted in the Garden State. Planning, zoning and emergency services are just some of the aspects of governance that in many respects reside under municipal and county jurisdictions. New Jersey’s economy is diverse, including service, research and development, industrial, and agricultural sectors. The state ranks sixth in tourism, the vast majority of this being at or near the coast. New Jersey has a rich coastal heritage. Day trips or weekly summer stays “Down the Shore” are common and often to the same community or cottage year after year, and generation after generation. Without question, the Jersey shore resides deeply within the psyche and hearts of most state residents.

The nation’s most critical transportation corridor runs through New Jersey and is often found lying close to sea level. This includes the nation’s most heavily traveled highway (NJ Turnpike) and bridge (George Washington). The Northeast Corridor rail line passes through, and two of the nation’s busiest ports are shared with New York and with Pennsylvania and Delaware. Newark Liberty International Airport is one of the nation’s busiest. Major cyber infrastructure also runs through the state.

While the litany of facts and figures discussed above may seem rather distant from a focused discussion on Sandy, they will later help to understand the impacts Sandy imposed on the Garden State.

3 Historic Mid-Atlantic Storms

Sandy followed in a long line of coastal storms that have battered New Jersey and other Mid-Atlantic locations in past decades and centuries. An overview of some of the more notable storms helps to place Sandy in historic context and in some respects explains the whys and wherefores of community and personal action (or inaction) before, during and after the storm. This discussion will touch on tropical storms, hurricanes and nor’easters.

3.1 Tropical Storms and Hurricanes

A tropical storm or hurricane is defined to originate over warm (generally 80 °F or warmer) water in an environment favorable for the percolation of moist, energy-laden air well up into the troposphere (roughly the lowest 45,000 feet of the atmosphere in the tropics and subtropics). In the process, a counter clockwise rotation (in the Northern Hemisphere) to the rising air may be spawned by an atmospheric pressure wave coming off Africa or perhaps from a dying frontal system that has moved from the middle latitudes into the subtropics. These "warm core" storms are "lone wolves", as they best develop in an environment distant from colder air and active horizontal winds at various levels of the atmosphere that tend to shear apart the rising column of air. The strongest storms have very low atmospheric pressure near the surface that is associated with rising air, and high pressure at the upper reaches of the troposphere, which helps to evacuate the rising air away from the storm region, thus promoting further upward motion within the storm "flue". In addition to encounters with shearing environments, these storms weaken when they move over cooler waters or totally lose their moist energy source and encounter surface frictional impedances when they move over land. To be considered a tropical storm, 2-min average wind speeds must be at least 39 mph. Once these sustained winds reach 74 mph the storm is considered a hurricane. Five categories of hurricanes are based only on wind speed, with the lowest, a category 1, followed by category 2 (96–110 mph), category 3 (111–129 mph), category 4 (130–156 mph) and category 5 (157 mph and higher). Given the requirements of warmth at the surface and the relative absence of shearing winds, these storms are most common from mid summer to early fall. While defined by sustained wind speed, tropical systems are also known to deliver exceedingly heavy rainfall and winds that push ocean water toward coasts and may result in a storm surge. A surge can raise coastal waters many feet above normally expected tidal levels. In fact the majority of deaths in tropical systems are from surge and fresh water (rain induced) flooding.

3.2 Nor'easter

A nor'easter is an area of low atmospheric pressure that forms or deepens (pressure decreases) along the U.S. East Coast. These storms blossom from the clash of cold air over eastern North America and mild moist air over the western Atlantic. These ocean waters include the Gulf Stream, a perpetually northward flowing current of warm water from the subtropics. These "cold core" storms thrive from the mixture of air of different temperatures and moisture contents, thus attain their greatest strength within the middle latitudes, especially off the Mid-Atlantic coast. The strongest storms benefit from high altitude jet stream winds to the east of the coldest air that help evacuate rising air within these systems. Thus when the jet stream is in a particularly wavy phase with a dipping wave (trough) over eastern North America and a rising wave (ridge) over the western Atlantic, cold air invading from the north and warmer air off shore clash along the eastern limb of the trough and a major storm may develop and track up the East Coast.

Nor'easters receive their name due to the counterclockwise motion of the low-pressure system wind field, which brings winds toward the coast from the northeast. In Colonial days it was thought the storms moved from northeast to southwest with the winds. That is, until an exchange of letters between Ben Franklin in Philadelphia and his brother in Boston discussing the viewing of a

November 2, 1743 lunar eclipse indicated otherwise. Atmospherically wise Ben realized that they had both witnessed a storm that was moving northeastward, as he missed viewing the eclipse due to clouds accompanied by rain and a northeast wind, while his brother saw it and did not experience the storm until a day later.

There is no precise definition of a nor'easter, though in addition to their location and movement they include strong winds, heavy precipitation that may fall as rain or snow, and generate high tides and strong wave action offshore and along the coast. Given the thermal ingredients necessary for their development, these storms are most common from mid fall through mid spring.

3.3 Historic Storms

Reports of hurricanes from early Colonial times through today are documented in diaries and reports of Mid-Atlantic Colonial settlers and mariners up through U.S. National Hurricane Center (NHC) reports and those of others regarding recent storms (e.g. Ludlum 1983; Savadove and Buchholz 1993; Schwartz 2007, Blake et al. 2013). Seemingly the strongest of the pre 19th century Mid-Atlantic hurricanes occurred in 1635, 1667, 1724, 1778 and 1783. Narratives often focus on lives lost at sea, but also mention the pummeling of coastlines, river flooding, deep snowfalls and destruction within communities.

The most severe hurricane to strike the Mid-Atlantic in the 19th century occurred on September 3, 1821. It is arguably the only hurricane on record to make landfall in New Jersey, coming ashore in Cape May and tracking through the state along a path similar to that of the current Garden State Parkway. Debate continues as to whether it was a strong category 2 or "weak" category 3 storm upon landfall. Damage was severe to woodlands and communities throughout the state, as well as in Philadelphia and New York City. Accounts have led some to consider it a category 3, although others feel that the type of trees in the region and the particulars of building construction suggest what might be category 3 damage in subtropical regions more prone to hurricanes can be achieved with category 2 winds in the Mid-Atlantic. The Jersey shore was sparsely inhabited at this time, thus information on storm surge flooding and impacts to the coastal landscape are lacking.

When speaking of potential hurricane threats to New Jersey, it has long been the practice of this author to state that the best thing about the 1821 storm was that it happened. Eyebrows rise when hearing such words, however this drives home the point that such storms are a possibility in this day and age, eliminating thoughts that they cannot occur across the state. It is worth adding that it is fortunate that the storm struck prior to coastal development. Suffice it to say that since Sandy struck, there has been little need to remind everyone of the 1821 storm in order to make the point. Other notable 19th century hurricanes to impact the region were in 1804, 1846 and 1889.

While there are numerous pre-20th century reports of strong coastal storms that were likely nor'easters and not of tropical origin, the most notable to impact the Mid-Atlantic and offshore waters was from March 11–13, 1888. Multiple books have been written about this white tempest that brought hurricane force wind gusts to coastal areas, multiple feet of snow that drifted to the second floor of buildings in New York City, brutally cold air within a storm that began as rain, and the loss of life in rural and urban communities as well as numerous deaths at sea. This storm is said to have inspired the development of buried utility lines and the subway system in New York City (Caplovich 1987).

The strongest 20th century hurricane to impact New Jersey occurred on September 13–14, 1944. Moving northward approximately 50 miles off the coast, the storm winds and surge resulted in considerable damage to beaches, boardwalks and many buildings along the coast. The hurricane of September 21, 1938 only sideswiped New Jersey from approximately 100 miles off shore, while bringing horrific death and destruction to eastern Long Island and southeastern New England (Brickner 1988). Still, rainfall on the western side of the storm resulted in New Jersey's 2nd greatest statewide rainfall, an average of 7.76 in., since records commenced in 1895. This storm illustrates a typical characteristic of tropical systems as they move through the middle latitudes; the strongest winds are on the right side (typically east side) of the storm and the heaviest rains are on the left (western side). Later in this chapter when Sandy is discussed, the right/left definition will markedly come into play.

While not as destructive a tropical system as the '44 storm or several others in the past, the storm on September 16, 1903 is worthy of mention as it is possibly the only hurricane since the 1821 storm to make landfall in New Jersey. It also took a path somewhat akin to the unusual one of Sandy, as it came toward NJ from the southeast and made landfall near Atlantic City (Hall and Sobel 2013). There is some debate as to whether winds were of sustained hurricane force at landfall, however it was certainly a strong storm that exited the state into Pennsylvania near Trenton. There was considerable damage throughout the region but no reports of a major storm surge or fresh water river flooding (Ludlum 1983).

The most memorable New Jersey nor'easter of the 20th century hit the Mid-Atlantic from March 5–7, 1962. The strongest impacts were on the coast, with major destruction occurring when the storm stalled offshore for several days. This led to a prolonged period of onshore winds that piled water up on the beaches, in the back bays and, onto coastal lands during six tidal cycles. Breaches of Long Beach Island subsequently needed human assistance to mend in order to keep the barrier island intact. Earlier 20th century nor'easters impacted coastal and inland communities, including ones in 1935 and 1953, however they did not pummel the coast to the extent of the 1962 event (Savadove and Buchholz 1993).

Many people still recall the 1962 nor'easter and even hurricanes (or the remnants thereof) that impacted the Mid-Atlantic in 1954 (Hazel), 1955 (Connie and Diane) and Donna in 1960 (tropical systems were first given female names in 1953). This includes the still reigning record Delaware River flooding from the back-to-back 1955 storms. Some may even recall the wind gusts of 108 mph at Newark Airport and the considerable damage across NJ and along the Delaware Bay coast during a November 27, 1950 storm. Although not a nor'easter, this storm also deposited massive snows in the eastern Ohio Valley and West Virginia. Rather it was a powerful rogue storm that traversed the eastern U.S. from North Carolina to Washington, DC and then northwest into Ohio and eventually eastern Canada, demonstrating that not every low-pressure system severely impacting NJ must travel up the coast (Bristor 1951).

3.4 Recent Storms

Certainly, far more citizens are familiar with storms of the past several decades. While most of these events were not as powerful as those mentioned previously, they provide important context when individuals consider the potential impacts of a forthcoming storm. Thus, along with earlier storms, they play an important role for purposes of storm preparation, response and recovery.

Notable hurricanes and tropical storms of recent decades include David (September 1979; the first year where male names alternated with female names), Gloria (September 1985), and Floyd (September 1999). Each impacted daily life in New Jersey due to flooding rains, tree-toppling winds and erosive coastal poundings. Then there was Irene (August 28, 2011), a noteworthy storm, especially as it occurred only a year before Sandy. Thus it played a role with regard to the public response to Sandy warnings. Irene was a hurricane until shortly before landfall in Egg Harbor, NJ. While coastal winds and surge were less than forecast, there was damage to boardwalks and considerable beach erosion. The real story of the storm was inland, where drenching rains falling on soils already soaked from heavy rains earlier in the month, resulted in major flooding throughout north and central Jersey river basins, including the Raritan and Passaic. The Raritan experienced flooding almost to the century-shattering levels of Floyd. Irene was the third largest statewide rain event on record, averaging 7.20 in.

Among notable nor'easters in recent decades, storms that pounded NJ with snow, wind and coastal flooding are ones that occurred in February 1978, February 1983, March 1993 (an inland storm track kept this from being a true nor'easter), January 1996, December 2000, February 2003, January 2005, February 2006, December 2010 and October 2011. Other nor'easters are best remembered for their strong winds and coastal flooding. The most notable of this lot was the December 1992 storm that took down trees around the state and resulted in some of the worst coastal flooding since the 1962 storm. Spring storms in April 2007 and March 2010 brought flooding rains and, especially with the 2010 storm, damaging winds.

Another coastal storm of interest garnered considerable attention during the event and even more so afterwards. This was the "Perfect Storm" that struck the northeastern U.S. and the Canadian Maritimes from October 28 to November 2, 1991. It began as a nor'easter off Atlantic Canada and soon encountered a high-pressure ridge over eastern Canada that blocked the common northeastward path of such a storm, actually forcing it south. The storm next grew in strength as it absorbed a dying Hurricane Grace. Eventually it looped back to the northeast and briefly developed into an unnamed hurricane as it headed out into the North Atlantic. This hybrid storm created memorable damage along the New England and Mid-Atlantic coasts. Coastal New Jersey beach erosion, boardwalk damage and back bay flooding was considerable, and prompted some evacuations (NCDC 2008). While no two storms are ever completely alike, Sandy exhibited some of the same hybrid characteristics and took an unusual path, as did the 1991 storm.

An understanding and appreciation of past storms cannot fully serve to prepare New Jersey for what Mother Nature may have in store today or tomorrow, especially with more people living in vulnerable areas. This is even more apparent when considering that storm characteristics will differ as climate changes and sea level rises. Read on to see how Sandy evolved into one of the most extraordinary, deadly and destructive storms to impact the Mid-Atlantic in several generations, a storm that seemed to be influenced by climate changes already underway.

4 Sandy's Fury

4.1 Genesis and Early Days

By late October, climatology suggests that threats of hurricanes or tropical storms are rather slim in areas where they may blossom, let alone in more distant locations where they may travel. Climatology also tells us that if a storm forms late in the season this is likely to occur in the Caribbean Sea. Thus it was no great surprise on October 22, 2012 when Sandy formed south of Jamaica. Within less than two days the storm reached hurricane status. It was about this time that the European Center for Medium Range Forecasting (ECMWF) numerical forecast model first suggested that the storm would move northward off the East Coast and eventually turn to the west and make landfall somewhere in the Mid-Atlantic region. Quite the unusual forecast, as such a track would be odd any time of the tropical season, let alone at this late juncture when westerly winds (blowing from west to east) begin to increase in intensity across the Northern Hemisphere middle latitudes. Then again, the 1991 Perfect Storm had been temporarily blocked from moving into the North Atlantic by a high pressure ridge—and ECMWF was predicting this to be the general situation with Sandy a week or so ahead. So, given the well-respected quality of the model and the behavior of the 1991 storm, a westward turn could not be dismissed (Mattingly et al. 2015). Over the next few days Sandy moved northward, punishing eastern Cuba on the 25th as a category 3 storm and still strong enough once north of Cuba to maintain category 1 or 2 status for the majority of its northward trek (Blake et al. 2013).

Meanwhile, cold air was plunging out of Canada into the central US as the polar jet stream dipped well south of its most common seasonal position. This was evident in the anomalous snow cover in the Canadian prairies down to the US border. With this trough moving east, it was apparent that a significant early season nor'easter could develop along the East Coast several days ahead.

This raised the very real possibility that what remained of Sandy would join forces with a developing nor'easter and deliver quite a blow to the East Coast as the end of October approached. By October 26th the U.S. National Weather Service (NWS) models had come on board with a forecast track much like that of the ECMWF model and thus the National Hurricane Center issued tropical storm watches and warnings up the coast to Cape Hatteras. The models suggested that Sandy would lose tropical characteristics to the north of Hatteras, well before turning toward the coast. Therefore, the NHC never issued watches or warnings north of there. Rather, issue of storm watches and warnings of many kinds (wind, surf, rain, flooding) were left to local NWS forecast offices and the NWS hydrological forecast center situated in the Mid-Atlantic.

4.2 New Jersey Prepares

By Friday the 26th, with forecasts of a powerful post-tropical cyclone on its way, there were already customers in line at home improvement stores waiting for shipments of electric generators, as all in stock had quickly sold out. The storm was still three days away, yet savvy citizens were already preparing for what promised to be a storm of consequence. How much of this preparation was born of storm experiences in recent years remains unknown, but they surely played a role. It had been only 14 months since Irene caused major flooding and rather widespread power outages, and October 29, 2011 brought record early nor'easter snows that brought down trees, many still laden with leaves, onto homes and power lines. This resulted in weeklong power outages in portions of northern NJ. Add to this a powerful south Jersey derecho in late June 2012 that took down trees and disrupted power, a number of major floods beginning with Floyd in 1999 and some serious snow storms in recent years, and it was clear that residents had been through this "drill" often enough recently and were going to be ready for Sandy.

Or was everyone going to be prepared? After all, why were there lines for generators? Shouldn't they have been purchased long ago in anticipation of forthcoming storms? More importantly, had this region seen a storm of this magnitude in anyone's memory? One thing is certain, well before arriving, the storm caught the attention of emergency management officials, political leaders, the media, and the general population. Within the Office of the NJ State Climatologist (ONJSC), we began to confer with emergency managers and the media. We also made the decision to rapidly develop and bring online a storm web "dashboard" that would include observations from our statewide 52-station NJ Weather and Climate Network (NJWxNet). This was designed to give decision makers such as forecasters in local NWS offices, emergency managers, political figures, and utility officials, along with the media and public, a quick look at evolving conditions.

Important weather observations would be updated every 5 min for all stations. Storm extremes over the past hour, with minute-by-minute extremes for the storm, would be displayed for top-ranked stations. Such observations include sustained wind speed and direction, instantaneous wind gusts and direction, rainfall, temperature, humidity and barometric pressure. Data from these stations are relayed via cellular service to a server at the Rutgers University computer center. Most of the weather stations, including their cell modems, are powered by solar energy. What made the dashboard development all the more challenging was that this would be the first time anything more than hourly updates would be provided from the NJWxNet. We had only begun polling stations more frequently weeks before, and were in the midst of developing a new database and website before "going public" with 5 min observations. However we realized the importance of having this frequent information. We hoped that the rush to release this new dashboard would succeed.

At the time, one questioned whether shore residents were paying attention to forecasts and would get out of harms way. Or were memories of evacuating (or not) for Irene going to influence their decision-making? Irene failed to deliver the punch along the coast that had been feared, with some who left the coast driving into trouble navigating through inland areas impacted by river flooding. In fact one pundit for the Star Ledger newspaper, NJ's most widely circulated daily paper, penned a column following Irene that included the following:

> After Chris Christie's performance in the run-up to Hurricane Irene, we should change our nickname. We're no longer the Garden State. We're the Nanny State. For a few days there, it was impossible to turn on the TV without hearing Christie and New York Nanny Mike Bloomberg tell citizens what they should do for their own good.
>
> In the aftermath of how Irene turned out, here's what I suggest you should do for your own good: The opposite of what Christie tells you. In his handling of this hurricane, the governor seems to have achieved a historic first: He became the first public official to evacuate people in the wrong direction. (Mulshine 2011)

In the opinion of this author, Mulshine should not have published this piece, as his words potentially jeopardized ongoing public safety. One can only trust that his column influenced no one.

4.3 New Jersey in the Cross Hairs

Along came the weekend, with forecasters expressing increasing confidence in a landfall somewhere along the Jersey shore. They also were convinced that a major surge would accompany the storm, along with flooding rains throughout the region. A variety of watches and warnings were being issued by local NWS forecast offices, but the decision of the Hurricane Center continued to be not to issue any warnings of a tropical nature in the Mid-Atlantic. Preparations continued, and upon the urging of local and state officials, individuals began to evacuate coastal communities. But would more people be on the move if NHC warnings were in place?

The absence of such led New York City Mayor Michael Bloomberg to state on Saturday evening that the surge, while significant would not be typical of a tropical system

> Although we're expecting a large surge of water, it is not expected to be a tropical storm or hurricane-type surge. With this storm, we'll likely see a slow pileup of water rather than a sudden surge, which is what you would expect with a hurricane, and which we saw with Irene 14 months ago. (Bloomberg 2012)

This is not to deride or diminish the persistent efforts of public officials such as Mayor Bloomberg and NJ Governor Chris Christie to get the word out that this was indeed going to be a dangerous storm. They performed a tremendous service, with their pronouncements prior to Irene, and even more so before Sandy, striking chords that no doubt saved lives. However clearly, as became evident when the storm hit, their efforts and those of many others were not enough to move everyone out of harms way.

Come Sunday, evacuations of a mandatory nature led to the departure of many, but too many coastal residents remained in their homes. The weather was cloudy, breezy and a bit rainy, with the ocean beginning to get angry as Sandy was growing in size and continued to maintain hurricane strength as it was now moving north off the southeast U.S. coast, not yet turning toward the mainland.

Come mid day the ONJSC Sandy dashboard was launched. The NJ Office of Emergency Management, the local NWS offices and some in the media were directly notified. Word of the dashboard spread quickly, thanks in part to social media. By the time many began losing power later on Monday over 30,000 unique visitors accumulated 130,000 hits on the site. The question now became whether the NJWxNet would remain functioning throughout the storm. Would stations hold up, communication be maintained, the Rutgers computer center stay powered and the dashboard continue to function?

Gary Szatkowski, the Meteorologist in Charge at the NWS Mt. Holly/Philadelphia Forecast Office maintained an active presence on the web and via social media leading up to Sandy. His office is responsible for issuing forecasts, watches and warnings for much of NJ, eastern Pennsylvania, northeast Maryland and all of Delaware, including coastal NJ. As part of the noon NWS storm briefing released by his office on Sunday the 28th he included this "Personal plea":

- If you are being asked to evacuate a coastal location by state and local officials, please do so.
- If you are reluctant to evacuate, and you know someone who rode out the '62 storm on the barrier islands, ask them if they would do it again.
- If you are still reluctant, think about your loved ones, think about the emergency responders who will be unable to reach you when you make the panicked phone call to be rescued, think about the rescue/recovery teams who will rescue you if you are injured or recover your remains if you do not survive.
- Sandy is an extremely dangerous storm. There will be major property damage, injuries are probably unavoidable, but the goal is **zero fatalities**.

- If you think the storm is over-hyped and exaggerated, please err on the side of caution. You can call me up on Friday (contact information is at the end of this briefing) and yell at me all you want.
- I will listen to your concerns and comments, but I will tell you in advance, I will be very happy that you are alive & well, no matter how much you yell at me.
- Thanks for listening.

Szatkowski (2012: Slide 12 from 10/28 briefing packet)

This is one of the most impassioned statements imaginable from an individual in such a governmental position of responsibility. As a result of Szatkowski's bold words, his overall communication with the public, official decision makers and the media, and his leadership of the forecast office throughout Sandy, the Star Ledger later recognized him as one of the dozen heroes of Sandy. He was the only government individual to be so recognized.

4.4 Storm Day: Monday Morning

Out at sea, Sandy remained a hurricane on Monday morning. This was unexpected, as forecasters believed that by Sunday the storm would morph into a post-tropical cyclone. Why the hurricane remained so strong for so long remains open to study (Galarneau et al. 2013). Sandy was beginning to be influenced by the developing nor'easter and that may have injected some energy into the warm core tropical system, despite this development ultimately contributing to Sandy's demise. Perhaps the biggest influence were the above average sea surface temperatures (SST) along the East Coast. New Jersey was in the midst of its 22nd consecutive month with above average temperatures (1981–2010 mean), an unprecedented run on the plus side since statewide observations began in 1895. This anomalous warmth was also experienced elsewhere in the Mid-Atlantic and off shore waters. In fact, a post-storm study running a forecast model with, first, the observed above average SSTs and second, with long-term average SSTs, found that in both runs the storm took basically the same track; but, when the average SSTs were used, the model produced a weaker storm upon landfall (Magnusson 2014).

Along the NJ coast, Monday morning arrived with rain falling rather heavily in south Jersey and winds beginning to gust in the 30s to low 50s mph range along the coast. Some remaining residents noticed that the morning high tide was exceedingly high. In fact, coastal waters were about the highest that Irene had delivered, which at the Sandy Hook tide gauge situated at the very northern end of the NJ coast, was the fourth highest on record and less than a half foot below the record high of 10.1 feet during Hurricane Donna. Some ocean water washed over Route 35 between Seaside Heights and Point Pleasant. This morning tide proved to be a blessing, serving as a wakeup call to some residents who were initially convinced that they could and would ride out the storm at home. Now they recognized that the "main event," the landfall of Sandy, was still 12 hours away, right in line with the next high tide. They evacuated, no doubt saving the lives of some of these individuals and potentially lives of emergency responders who might have been called to rescue them. Thus, in this regard the earlier pronouncement of Mayor Bloomberg of a gradual build up of storm waters was correct. However, that evening a sudden surge arrived, something he suggested would not occur.

4.5 Storm Day: Afternoon

By early Monday afternoon, conditions began to deteriorate further, particularly along the beachfront. Winds were now gusting from 40 to the low 60s mph and rain was falling throughout the state, continuing much heavier in the south. It was now apparent that landfall would be in the vicinity of Atlantic City. With this, it became evident that northern NJ would be spared exceedingly heavy rainfall and river flooding, as this area would be on the *right* side of the storm track. While this was fortunate, it seemingly failed to register with citizens and the media. Even well after the storm, some to the north spoke of heavy rain and river flooding during Sandy, perhaps confusing conditions with Irene a year earlier or with the surge that came up streams and rivers. South Jersey would bear the brunt of the heavy rain, but with sandy soils and smaller streams and rivers in this region, the flood threat would not be major. Sandy was beginning to morph into a hybrid storm but still retained its hurricane status. Part of the change was an expansion of the storm's dimensions. This spread out the core energy but meant that winds were now howling over a huge expanse of the Atlantic, pushing more and more water toward a wide coastal area. The NWS was forecasting a record surge arriving close to high tide, making it all the more certain that this storm was going to be unlike any storm to strike the region since meteorological records have been kept, let alone in any living person's memory. Yet still, the message was not getting to or registering with some citizens and decision makers, an unfortunate circumstance that would soon lead to needless terror, death and damage.

By late afternoon, easterly winds were gusting to hurricane force along the Jersey beaches. Inland, winds were strengthening. Rain was falling in central and northern Jersey. However, through late afternoon conditions were not unlike a modest nor'easter blowing through. Mass transit was shut down across the region and most every business and retail establishment closed. When the sun set at 6 pm all knew that the main event was imminent. Any preparations for the storm should have been completed long ago. Everyone should now be safe in locations as far from danger as possible. It was destined to be a long, dark night.

4.6 Storm Day: Evening Landfall

During the early evening, inland winds picked up quickly as Sandy was downgraded (finally) from a hurricane to a post-tropical cyclone. The storm was never a nor'easter, though one can contend that in the absence of Sandy such a storm would have developed and been a strong one. In fact, with the same atmospheric pattern persisting into November, a nor'easter arrived on November 7–8 that dumped up to 13″ of snow in Freehold, NJ, 15 miles inland from the northern coast where several inches of snow also fell, covering damaged beaches and storm debris.

Upon a 7:30 pm landfall in Brigantine, the community immediately north of Atlantic City, the still-expanding storm had a warm core with cold-core, middle latitude characteristics wrapped around it. Along the coast, high tide was approaching and the gauge at Sandy Hook was recording a water level 3.2 feet above the previous record when it was destroyed by the pounding of the waves atop the still rising water. The surge was inundating beach communities and pouring into Raritan Bay and up local streams and rivers. Ten miles inland in New Brunswick, the Raritan River was out of its banks and flowing onto adjacent Route 18, not from freshwater moving downstream as had been the case in Irene, but rather from water surging up the river. Damaging, life threatening surge waters were flowing into a Woodbridge neighborhood west of the NJ Turnpike where it was hard to imagine a surge would ever reach. Harbor waters were inundating Hoboken, while in the Hackensack Meadowlands the largest sewage plant in NJ, a major NJ Transit rail yard filled with cars and engines, and local communities were being swamped.

Inland winds picked up in intensity after nightfall with trees beginning to topple and power beginning to fail across much of the state. Along the coast, surge and wave action was devouring beaches and dunes, opening several breaches in the barrier peninsula in the Mantoloking vicinity, gobbling up homes, tearing up boardwalks, and pouring sand into communities. Initially, waters in Barnegat Bay, which parallels the central coast behind the barrier peninsula and Long Beach Island, did not rise too quickly, as the bay was somewhat sheltered from the easterly winds that were pounding coastal beaches. However, at about 8:30 pm, with the core of the storm onshore and beginning to move across south Jersey, the wind direction abruptly shifted to the south and with it waters were pushed northward up the Bay. Individuals, who just minutes earlier wondered if conditions would get as bad as predicted, were frantically calling emergency officials asking to be evacuated as water poured over bulkheads, into yards and eventually through homes.

Those who chose to ride out the storm in coastal communities were wondering if they would survive the night. Tragically some did not, drowning in their homes. This was particularly true on Staten Island, NY, where 18 drowned. In NJ, four drowned, two were in their homes. A student of the author chose to ride out the storm on Long Beach Island and fortunately survived to show photos of several feet of water invading his one-story home during the height of the storm. He came close to climbing into the attic or onto the roof, not knowing how high the water might rise or if the house would remain intact.

Meanwhile, many inland residents were in the dark, hearing trees crashing down amidst the roar of the wind and feeling their homes shake as some trees hit the ground or house. Many retreated to internal rooms or basements, wise decisions, as trees came through roofs into rooms where some would normally have been sitting or sleeping. Many later reported experiencing more fear than ever before while in their homes. Tragically during the storm, falling trees killed five individuals; two of whom perished inside homes. Mid evening hours found inland and coastal areas buffeted by wind gusts in the 50 to the mid 70s mph range.

My home lost power at 7:30 pm (not to return for four days), leaving me to conduct a live 11 pm interview on a special edition of NJTV news via Skype on a laptop computer. Communication was via remote cellular means, and I was illuminated by two small flashlights, making me look a bit like a jack-o'-lantern; perhaps adding some humor to what otherwise was a tremendously serious situation. Throughout the evening I had been able to monitor winds and other weather variables via the dashboard and coastal water levels via USGS and NOAA websites. Knowing my home state quite well, I was able to speculate (later proven rather accurate) that NJ and surrounding areas had indeed taken a tremendous pounding and we were not quite yet out of the woods. I expressed grave concern regarding what would be discovered come daybreak, particularly along the coast, but also inland (NJTV 2012). The storm's backlash continued in some areas, including along the Delaware Bay coast where the change in wind direction was pushing water up onto the low-lying shore.

5 Sandy's Aftermath

Shortly after midnight the worst of the storm had passed in most areas. Water was slowly receding, waves were not pounding as hard, and the wind and rain were beginning to abate. A post-storm survey determined that the water level had risen to 14.4 feet at Sandy Hook, or 4.3 feet above the previous record high water level. This equates to a storm surge (height of the water above what it normally would be at a given time of the tidal cycle) of close to 9.5 feet. The maximum surge arrived close to high tide and during a phase of the lunar cycle when tides are typically high. This provided a near worst-case scenario for the northern coast and adjacent tidal waters. As Sandy made landfall, the surface barometric pressure fell to a state record minimum of 27.92 in. of mercury. This shattered the previous single location record minimum of 28.36 in. during a 1932 nor'easter. In fact, the entire southern two thirds of the state saw the pressure fall below the previous record minimum. This was the lowest pressure on record observed onshore along the East Coast north of Cape Hatteras. The peak wind gust in NJ was 91 mph at the NJWxNet station in Seaside Heights. Elsewhere in the state, winds gusted over 70 mph along the coast north of Atlantic City, and 60–75 mph over inland central and northern counties, coastal Delaware Bay and southern Cape May County. Wind gusts of 40–60 mph were recorded over the inland southern third of the State, to the *left* (south) of the storm that tracked into southeastern Pennsylvania by daybreak on Tuesday the 30th. Rainfall was copious to the left of the storm track, amounting to as much as 12.71 in. at Stone Harbor in Cape May County, which equates to about a 200-year return period. Rainfall was generally 5–8 in. south of the storm track. North of the track, totals fell to 2 in. along the Trenton-New Brunswick corridor and from 1 to 2 in. in the northern third of the state.

On Tuesday morning the cloud shield from the storm extended from South Carolina to southern Greenland and from the western Atlantic west to Wisconsin. Several feet of snow had fallen in the mountains of West Virginia. High wind and wave warnings were issued for the shores of Lake Michigan. Severe thunderstorms occurred in Massachusetts, and Montreal experienced a daily record high temperature of 70 °F. Sandy has gone down in the books as one of the largest and most powerful storms in eastern North America history. Across the Mid-Atlantic, shell-shocked residents began emerging from homes and shelters. Perhaps a million trees were down, with utility companies estimating that over 100,000 trees and limbs had to be removed in the process of restoring power to the 80 % of the customers in New Jersey who lost it anywhere from hours to two weeks. Water remained in the streets of Hoboken and other communities. Coastal roads were ripped up, choked with sand or even had homes washed onto them. Fires that had raged during the night in Normandy Beach, NJ and Breezy Point, Queens, NY smoldered.

For those of us in the State Climatologist's Office, it was gratifying to see that the NJWxNet functioned exceedingly well throughout the storm. Of the 52 stations in operation as the storm struck, the fewest reporting during any 5-min interval was 39, and that was at noon on the 30th, well after the storm had left the state. By that evening 45 were active, with the missing seven stations located where AC power was relied upon for modem communication and no generators were available. Clearly, efforts in recent years to install solar power at most stations paid huge dividends. Due to solid station construction and a certain amount of good fortune only a single instrument at one station was damaged during the storm. Every one of the five stations on the immediate coast continued operating and communicating throughout the storm. The Jersey City station in Liberty State Park was flooded with 17 in. of New York Harbor water, which fortunately never reached instrument level. A sonic snow depth sensor at the station recorded this water level. Credit for such a performance goes to NJWxNet field technicians, the cellular service carrier, and the staff at Rutgers main computer center for keeping a generator fueled and functioning until line power was restored.

The intrepid volunteer observers of the national Community Collaborative Rain, Hail and Snow Network (CoCoRaHS), locally managed by the ONJSC, submitted reports as best they could during and following Sandy. Some of these citizen scientists, lacking power or Internet service, called friends and family and asked them to submit their observations online. Others submitted reports once they could get computers back on line, including the Stone Harbor observer who recorded the previously mentioned record rainfall for Cape May County. Two hundred and thirty-three CoCoRaHS citizen scientists contributed rainfall reports, some of them appending anecdotal remarks of storm damage and personal storm experiences.

Damage estimates for Sandy approached at least $50 billion in the eastern U.S. (Blake et al. 2013). The estimated death toll in the US was 72 from direct and 87 from indirect storm impacts. In New Jersey an estimated 39 deaths were attributed to direct and indirect impacts, making this the deadliness natural disaster in NJ history. NJ fatalities included those from falling trees, drowning, loss of power to vital medical equipment, fire, asphyxiation from improper generator use, hypothermia, falls, automobile accidents, and post-storm cleanup (Star Ledger staff 2012).

Stories were told of heroic acts during the storm and of generous outpourings of support in its aftermath. Unfortunately, on the darker side, there were stories of scattered looting, unconscionably low damage assessments by insurance companies, slow or confusing responses regarding government aid, unscrupulous building contractors, controversies over debris removal and alleged price gouging at some, but certainly not most, hotels and stores. Now, several years after the storm, thousands have still been unable to return to their homes or resume a normal every day life. The mental health among many of those directly impacted also continues to suffer.

Meanwhile for the majority of residents who did not suffer significant damage or health issues, once power returned, roads were cleared, trees were removed and homes repaired, life returned to a general sense of normalcy. Almost to a person, most considered himself or herself fortunate. They were only left to talk about how many days they were without power or how long they had to wait on line for gas if it could be found at a station with power. Gas rationing was instituted late in the storm week (by odd/even license plate numbers), but by that time enough stations had power back, and gas deliveries had resumed so that in most areas shortages no longer existed. Infantries of power company workers from many parts of the nation, along with local, state and federal agencies responded to assist in recovery efforts. Private concerns, be they businesses or volunteer organizations, joined in.

One cannot understate the emotional impact Sandy had on state residents. For most, this storm is now the bellwether for what future storms may bring and against which they will be measured. Sandy unified the state and made residents more aware than ever before of their emotional attachment to the Shore. Even if one was not directly affected, it was painful knowing how many fellow citizens were severely impacted and how the shore and beaches they had visited so many times before had taken such a beating. Questions and concerns remain as to whether the Shore will ever again be quite the same, as cottages where families had spent summer weeks may not be rebuilt, possibly replaced by expensive homes built to stricter zoning standards. This chapter will not delve further into the turbulent post-Sandy weeks, months and years. Suffice it to say that when it comes to coastal NJ heritage or culture, Sandy will, indeed, likely prove to be a game changer.

6 Lessons Learned

Sandy was a transformative event in the history of the Garden State, throughout the Mid-Atlantic, and for federal entities such as the National Weather Service. With such a tumultuous event in a region so densely populated and so vulnerable to the power of coastal waters and winds there are clear lessons learned when reflecting back on the days surrounding Sandy. Lessons have already resulted in better practices for the future, and those, we hope, will make the population more aware and better prepared for future storms. While the lessons discussed below emerged from Sandy, many are applicable to any coastal region or areas beyond.

6.1 Seemingly Slight Differences Can Have Major Consequences

A slight difference with a major consequence is, for example, someone being in the right place at the right time, as when a tree falls on a home or automobile and misses the occupant. Another example relates to the physical characteristics of Sandy. For instance, a 70 mph wind has approximately 2.7 times the power of a 50 mph wind. Whether most citizens realize it or not, this cubic relationship between wind speed and the power produced by the wind made all the difference in where and how many trees fell during Sandy. Inland New Jersey is no stranger to 50 mph gusts in a nor'easter, when sideswiped by a tropical system, or during a summer thunderstorm. However gusts exceeding 60 mph are much less common, particularly throughout the broad dimensions of the landscape over which they blew for several hours during Sandy. Thus there was massive tree fall that took lives, brought down power lines and overall did major damage. Interestingly, clusters of enhanced tree fall over multiple acre tracts occurred in scattered locations in central and north Jersey. Some were associated with topographic features that likely enhanced the wind speed. Other blow-down zones were seemingly random and are the source of ongoing study. Still, what people need to realize is that the bulk of the inland wind damage was not caused by hurricane force winds, but rather by winds that were perhaps only 20 mph more than experienced in more common storms. This is a sobering thought when thinking of the consequences of a future storm where winds might frequently exceed hurricane force.

Then there was the timing of the storm. Had Sandy arrived several hours earlier or later, tides would have been several feet lower where the worst of the storm surge struck. Due to the lunar impact on tides, even a change of a week in storm timing would have meant a lower tide. Actually the expected high tide on the morning of the 29th was almost a foot higher than the evening tide. Thus it could be that a colleague whose shore townhouse came within several inches of having its first floor inundated by the high water likely would not have been as fortunate had the storm arrived 12 hours earlier.

On a larger scale, most everyone is keenly aware that the storm track made an enormous difference. Witness the differences in coastal storm damage between southern and northern coastal Jersey, the inland wind damage and resultant magnitude of power outages between the two areas and the 6-in. plus difference in rainfall between north and south Jersey.

6.2 Storm Conditions Do not Change at a Steady Pace

This lesson ties directly into the first point but deserves its own listing. Erratic behavior of a storm can prove to be so important, as individuals may think they are safe 1 minute but find themselves in grave danger soon after. In Sandy this applied to those experiencing a storm surge that quickly inundated their home. It applies also to those within inland communities who saw wind speeds rapidly increase early in the evening and lulls within the strong gusts later in the evening. This may have given some the false impression that they could safely venture outside, only to be struck, and in some cases killed, by falling trees and branches.

6.3 Storms Stronger Than Sandy Are Within the Realm of Possibility

This may be difficult for some to comprehend so soon after the worst storm they may have ever experienced. However, those in the emergency management and atmospheric science communities are keenly aware of this. A look back at past storms provides some perspective, be it the 1821 hurricane throughout the region, the 1944 hurricane along the coast, Floyd and Irene inland, the 1903 storm and its path, and the 1938 storm. Those on Long Island and in southeastern New England do not have to conceive of a much worse case scenario than that of the ’38 storm, but for people in New Jersey a closer look is worthwhile. While heavy rains fell on the state from the ’38 storm, imagine if it had taken a track closer to the Jersey coast, perhaps one like the 1944 storm, or storms Donna, Gloria or Irene. This could have brought about the rains and river flooding of Floyd and, despite the strongest winds remaining offshore, sustained winds and gusts exceeding hurricane force on the west side and a storm surge close to Sandy’s along the entire coast. One could also imagine this storm making landfall somewhere on the coast, like the 1903 storm or Sandy, just a stronger version of either. The 1821 storm should be brought into scenario building too, if only the kind of surge that hit the Jersey coast (it was about 6 feet at the Battery in lower Manhattan) and how heavy the rains were inland were better known.

6.4 Do not Fully Rely on Storms of the Past to Provide a Look to the Future

New Jersey’s climate is warming and sea level is rising. Due to anthropogenic influences, particularly an ongoing increase in greenhouse gases, warming is expected to continue throughout the coming decades. With warming, there will be more moisture in the atmosphere, as the atmosphere holds almost four percent more moisture for every 1 °F increase in temperature. The combination of increased warmth and moisture will create a more energized atmosphere, one primed for stronger storms, assisted, as was seen in Sandy, by warmer sea surface temperatures. This does not mean storms will necessarily happen more often, as it remains uncertain whether the events that trigger storms will be more or less prevalent. However, the magnitudes of storm precipitation and wind should increase, along with resultant fresh water and storm surge flooding and wind damage.

Another factor had a minor affect during Sandy: sea level continues to rise. Approximately one half of the 15-in. rise in sea level along the Jersey coast since the late 19th century is due to the expansion of warmer ocean waters and melting land-based ice. The other half is the result of ground water withdrawal and the compaction and isostatic suppression of southern NJ lands—a lingering effect of the ice sheet that sat over northern NJ and locations poleward 20,000 years ago (Miller et al. 2013). Sea level is projected to rise about 18 in. by the middle of this century and perhaps more than three feet by centuries end. Thus, in the years ahead, a modest tropical storm system or nor'easter will have the potential to raise storm tides to levels only seen in the most severe storms of the past.

6.5 Heed Weather Forecasts

Without question, the Sandy forecasts generated by the ECMWF and the NWS were landmark achievements (Knabb 2013; Uccellini 2013). Forecast models picked up Sandy's genesis in the Caribbean and quickly projected the general track and nature of the storm as it evolved, along with its general progress and landfall as a post-tropical storm. To expert emergency responders, this gave up to a week for preparation. The forecasts were not without flaws. It took time for forecasters to hone in on the landfall location, the storm was stronger than expected as it came onshore, and earlier forecasts of flooding rain in northern and central NJ failed to arise. The devil is always in the details when it comes to even the best forecasts.

Still, not all individuals got out of harms way, some tragically died as a result and others experienced the most frightening evening of their lives. Somehow they did not get the message (more on that shortly) or failed to believe or understand the forecasts they heard.

Despite the general high accuracy of the Sandy forecasts, the forecast community was still subject to a little criticism. This may be due to forecast improvements being accompanied by increased expectations among some individuals. Perfect forecasts are not on the horizon, not in what will always be a chaotic earth-ocean-atmosphere system. However, in many respects what used to be forecast failures are now more likely to be near misses. This goes beyond semantics and is something the forecast community must continue to address scientifically, while working with others to better communicate the whys and wherefores of a forecast.

6.6 Regional Infrastructure Is Too Vulnerable in Severe Storm Conditions

Sandy made it quite clear that a major effort remains to harden or relocate buildings, transportation systems, and utilities that include communication, sewer, natural gas and especially electric. Buildings that are subject to freshwater or coastal flooding need to be eliminated in areas subject to recurrent inundation, or at least raised to reduce potential damage. Otherwise they can be protected by flood control infrastructures such as levees, seawalls, or efforts involving beach, dune and wetland renourishment. The same situation applies to transportation systems. They need to be elevated (e.g. train tracks and roadways) or protected from inundation (e.g. levees around airports or means of preventing water from pouring into rail and road tunnels). Well-conceived plans to relocate movable components of transportation systems must be developed and implemented (or improved) when forecasts warn of severe storm conditions. This includes ships, trains, planes and automobiles.

Communication infrastructure needs to be able to handle an abundance of calls, texts and Internet traffic during critical conditions. Cell towers must remain operable, communication equipment powered, and bandwidth sufficient to handle a heavy load. Water treatment and sewage plants are always near water bodies, making them exceedingly vulnerable to freshwater or tidal flooding. Ideally, they would be relocated to higher ground, but at the least they require sufficient levees surrounding them to remain protected when major storms strike. It is critical that a reliable source of power be maintained at these locations during storms.

A common thread throughout the general lesson of hardening our infrastructure is availability of reliable electrical power. With the vast majority of New Jersey losing power for a time during and after Sandy, never before have so many people been made keenly aware of how electrical power is the glue that keeps the state functioning. Without power, gas stations could not pump gas and supermarkets were closed and had to almost fully restock once power returned. Homes had no heat during the chilly late October and early November days following the storm. Inoperable elevators stranded people, particularly the infirmed and elderly.

Contributing to Sandy power outages, dozens of NJ power substations and switching stations experienced considerable damage and downtime, most by storm surge water. Many other power stations were damaged elsewhere in the State during Irene's fresh water flooding. Quite the lesson learned; water and electricity do not mix! These two storms made painfully clear that infrastructure supporting power generation and supply needs hardening or relocation. Electrical utilities need to harden infrastructure throughout company service areas by better tree trimming efforts and establishing some redundancy within power grids. One cannot expect unfailing service during major storms; however, lessons have been learned from recent storms that should lead to more reliable service in the future. So too, has a lesson been learned that key services need backup generator power in case the area grid fails. For example, post Sandy funding was made available for 52 NJ gas stations to secure generators. Also due to recent storms, owners of a number of businesses and homes have equipped themselves with generators, but they must understand how to use them; gas-powered generators must be properly ventilated or the carbon monoxide they release can be deadly. Seven post-Sandy NJ fatalities are attributed to not understanding this.

6.7 Messaging Needs Improvement

Considerable attention in the post-Sandy era has been paid to means of expressing and delivering information associated with potential storm threats. A look back through the literature finds decades of such discourse. Over time, the amount of available information has increased and the means of packaging and distributing it has evolved. An opportunity, warranting additional studies, presents itself to improve a last and most important step in severe storm risk reduction: getting timely information to those who need it.

One change in issuing National Hurricane Center watches and warnings was implemented shortly after Sandy. The NHC will now continue to generate such advisories even if the storm is expected to or has transitioned into a post-tropical storm, provided that it still poses a significant threat to life and property (NOAA 2013). It will never be known if officials and the public might have acted differently and lives potentially saved had this policy been implemented prior to Sandy.

The U.S. National Oceanic and Atmospheric Administration's Sea Grant program has funded a suite of ten studies to better understand the effectiveness of coastal storm communication strategies, focused on coastal areas of the tri-state region (NJ, NY, CT), which was most affected by Sandy (Sea Grant 2015). One issue being addressed in a few of these studies is the public response to voluntary versus mandatory evacuation. Among residents living in a mandatory evacuation area, barely half (49 %) report having left home before the storm, while another 9 % left as the storm was underway (Monmouth 2013). Using hypothetical storm scenarios, another study showed that expected evacuation rates are much lower when the word "voluntary" appears in an evacuation message (Cuite and Shwom 2015). This study also found that more detailed and personalized information is not always better, as block-by-block evacuation notices may not be any more effective than community-level evacuation notices in motivating action. Another study found that indexical information, such as photos showing storm surge, are likely to make people concerned about storm surge risk than iconic or abstract information, such as a map showing the areas at risk for storm surge (Scherer et al. 2015).

The Cuite and Shwom (2015) study also found that using fear appeals in evacuation communications may encourage coastal residents to evacuate. However, existing fear appeal literature in other areas indicates that if a warning goes too far residents may choose to ignore it. Some real world examples of fear appeals were described in their study, but the actual effects of these are still unclear. For instance, does going so far as to insist on writing social security numbers on the arms of citizens who refuse to evacuate cross the line? Or does the effectiveness of a warning depend on who conveys it and how it is put forth? This also raises questions such as whether Szatkowski's statement from the NWS leading up to Sandy was effective? If so, was it because he was a trusted local source and worded it in a firm and dramatic manner? No doubt these important studies and ensuing discussions will continue as they relate to Sandy and, of course, to other disasters.

Efforts to improve storm messaging are underway in a growing community of individuals who combine expertise in science, social science and communications. For instance, this author is involved in an effort to develop a coastal storm severity index that will generate and convey the forecast strength of an approaching storm with regard to wind, rain or snow, fresh water flooding, and storm surge. The idea is not to develop one synthesized index value. Rather each variable is ranked for its potential severity within a specified region over a selected period. Such information would then be conveyed, perhaps in a color-coded format (an approach similar to The Network of European Meteorological Services Meteoalarm system: http://www.meteoalarm.eu/). Whether this index will be conveyed only to emergency managers (for them to use and potentially distribute as they wish) or directly to the public remains open to discussion. So, too, the desired spatial resolution of the alert area remains uncertain. Integral to the development of variable and regional warning thresholds based on NWS forecast information, considerable study is needed of potential impacts of introducing new terminology within the community.

A discussion of messaging must include how to best utilize media outreach. How can environmental scientists, social scientists and community leaders utilize the visibility and outreach of radio, television, print/online news feeds and social media to better inform the public before, during and following storms? Anyone who has paid attention to this discipline over the past decade realizes its ever-evolving dimensions. Paramount to any ongoing study must be fundamental principles that can be woven into whatever communication vehicle one choses. Among these are knowing the intended audience, utilizing credible sources of information, striving for clarity and consistent timeliness to whatever message is being conveyed, and avoiding "hype."

6.8 Do not Rely Solely on Lessons from Sandy

There certainly is much that has been and will continue to be learned from Sandy. However, no one should become too confident that lessons learned can be applied to all future storms in New Jersey, within the Mid Atlantic region or elsewhere. Of key significance is the fact that the storm struck in the tourism "off season." One must turn to storm threats posed by Irene in late August 2011 and a number of other storms along the Atlantic and Gulf Coast to appreciate the effectiveness of evacuation procedures. Understanding nuances, such as the timing of evacuation orders by day of the week, may prove vital. Was the evacuation of tourists for Irene reasonably successful given the storm was forecast to strike late Saturday? After all, people were near the end of the Saturday-Saturday home rental week. Would compliance have been lower had beachgoers been asked to leave earlier in the week?

7 Conclusion—A Game Changer?

Was New Jersey "Stronger than the Storm," as ubiquitous ads throughout much of 2013 claimed? Perhaps in some ways the State was—as in many cases Sandy brought out the best in people and demonstrated the resilience of New Jersey citizens. Furthermore, despite the tragic loss of too many lives, many millions within harm's way emerged relatively unscathed. Perhaps "Smarter than the Storm" is a more appropriate credo as New Jersey faces the inevitable attack by future storms, with storm tides perched upon rising sea levels and ever more people living in vulnerable areas. Lessons learned from Sandy have already led to what can be considered game changers. The NHC has revised watch and warning criteria. Zoning changes that would move homes and businesses away from the shoreline are being discussed and in some cases implemented. Improved means of communication between the forecast community and decision makers, and subsequently in getting the message out to the greater population, are being studied and implemented.

Sandy, along with other recent coastal storms, has led to a greater appreciation of the power of Mother Nature and the ever-growing vulnerability of individuals and their communities to storms. This a result of increasing population and climate change, including rising sea level. So, too, is increased appreciation of natural coastal defenses such as beaches, dunes and wetlands. However, it is evident that in many instances it is back to business as usual for the state and region while, in some cases, potential game changers are occurring in research and in public discussion. Still, when New Jersey and the surrounding region is tested again, citizens will likely be better prepared and respond more effectively than in the past. Fewer lives will be lost and recovery will be quicker and less painful. Should this occur, we will know for certain that Sandy was a game changer in a very positive sense.

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Extreme Weather: Politics and Public Communication

Michael A. Moodian and Margaret M. Moodian

Abstract This chapter explores three primary topics: the politics, public communication, and public education initiatives related to extreme weather events in the United States. The chapter begins with an overview of the interconnectedness of government agencies in addressing extreme weather circumstances, followed by the role extreme weather calamities can play in politics and political campaigns. Following this, the evolving role of social media as a tool for government agencies to communicate with the citizenry is described. The chapter closes with a description of various mass communication theories and descriptions of how the theories apply to extreme weather events.

Keywords Government agencies · Mass media · Politics of extreme weather · Public communication · Social media

1 Introduction

Hurricane Sandy, which took place in late October and early November of 2012, was one of the deadliest and most destructive and costliest hurricanes of modern times, with estimated damages at more than $68 billion (CNN 2014). To prepare for the incoming storm in New Jersey, Cape May County officials instructed barrier island residents to evacuate, along with voluntary evacuations in Harvey Cedars, Long Beach, Mantoloking, Barnegat Light, Bay Head, Beach Haven, Ship Bottom, and Stafford. To deal with the crisis, Chris Christie, New Jersey's governor at the time, ordered barrier island residents from Cape May to Sandy Hook to evacuate,

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and he shut down casinos on Atlantic City's renowned Boardwalk. Additionally, U.S. President Barack Obama signed a declaration of emergency, which enabled New Jersey to pursue federal funding and other types of support (CNN Library 2014).

Toward the end of October 2012, Hoboken, N.J. Mayor Dawn Zimmer ordered those people who lived in street-level and basement residencies to evacuate because of potential flooding (CNN Library 2014). Additionally, Logan Township residents were instructed to evacuate, while Jersey Central Power & Light informed workers of the need to work longer shifts. Many schools and colleges also were closed, and numerous government agencies worked together to inform the public of storm conditions and communicate necessary actions (Weinberg 2015).

Beyond the evacuation orders and the sheer magnitude of the storm, many Americans may remember a unique encounter between two political leaders of opposing political parties. President Barack Obama (a Democrat) visited the State of New Jersey to review Sandy damage on October 31, 2012. New Jersey Governor Christie (a Republican) greeted him at the Atlantic City International Airport. Reuters (2012) photos of the meeting portray the two men embracing in a comforting hug and surveying damage together. These images of the two political leaders who represent opposing political parties became widespread throughout the country across public media. This bipartisan union between Obama, a Democrat, and Christie, a Republican, was popular among many U.S. citizens, some of whom were perhaps disenfranchised with political polarization that had run rampant between the United States' two mainstream political primaries at that time. However, there was fallout among Republicans as Governor Christie praised the Democratic president so close to the impending Obama-Romney presidential election (CNN Library 2014). Politically, some viewed Christie as turning on his party during a critical campaign time. Hurricane Sandy and New Jersey represented a prime example of how various government agencies came together to address the circumstances of extreme weather, and how politics can play a significant role in calamities related to extreme weather (Weinberg 2015).

1.1 Blizzards Bring Cooperation

Slightly more than two years after Hurricane Sandy, in 2015, a massive blizzard known as Winter Storm Juno struck Canada and the eastern and central portions of the United States (Gawthrop 2015). Six states declared snow emergencies during the blizzard, and some states enforced travel bans: Massachusetts, Connecticut, Rhode Island, and New Jersey. Passenger rail services, flights, and school days were all affected (Gawthrop 2015).

To cope with the blizzard, various agencies worked together to ensure public safety. For example, Pennsylvania's Department of Transportation treated roadways with approximately 350 salting trucks, while Pennsylvania Governor Tom Wolf signed an emergency proclamation to ensure a rapid distribution of state funds (Gawthrop 2015). Local government agencies and leaders such as the Philadelphia mayor, Southern Pennsylvania Transportation Authority, and Philadelphia Office of Emergency Management worked together, closing schools and city offices and cancelling trash and bus services, while ensuring that the train system would run for part of the week (Gawthrop 2015). In Connecticut, Governor Dannel Malloy declared a state of emergency, cancelled travel services and announced a travel ban across the state. The Metropolitan Transportation Authority added additional trains to accommodate citizens traveling by rail. The governor had more than 600 crews treat major roads, and issued a declaration of civil preparedness emergency to allocate resources efficiently (Gawthrop 2015).

In New York, Governor Andrew Cuomo made public statements, urging citizens to prepare for changes to their commutes and to take safety precautions, while the Metropolitan Transportation Authority assisted with road salting trucks and crews. The State Emergency Operations Center, state National Guard, and New York State Police all added personnel to deal with the crisis. The Port Authority of New York and New Jersey prepared hundreds of pieces of snow equipment, the New York State Thruway Authority and New York State Department of Transportation enforced its emergency operations. Mayor Bill de Blasio of New York City banned vehicles from the streets for a period of time (Wiltgen 2015).

In Massachusetts, Governor Charlie Baker declared a state of emergency, a travel ban was announced, and tens of thousands of tons of salt were gathered by agencies such as the Fall River Department of Public Works to treat roadways. Snow farms, or strategically located areas to which snow would be relocated, were ready to store snow after the storm passed. In Rhode Island, Governor Gina Raimondo urged citizens to stock enough food and water in their homes for several days and had to declare a state of emergency (Wiltgen 2015). Meanwhile, in New Jersey, Governor Christie declared a state of emergency, enforced a travel ban, and ordered nonessential personnel off the streets. U.S. President Barack Obama in April 2015 made a federal disaster declaration for the January blizzard, resulting in some reimbursements for blizzard-related damages. Once again, as was the case in response to Hurricane Sandy, numerous government bureaucracies came together to respond to the weather and climate crisis and communicate effectively with the public (Wiltgen 2015).

This book, *Extreme Weather, Health and Communities: Interdisciplinary Engagement Strategies*, explores extreme weather, health and communities from various interdisciplinary standpoints. This chapter particularly explores the interconnectedness of government agencies, the role extreme weather has played in U.S. politics, contemporary public communication methods, and theories of public communication on extreme weather.

2 The Interconnectedness of U.S. Government Agencies

The role of governments in extreme weather responses can be very complex. The United States has different levels of government bureaucracies: federal governments, state governments, and local county and city governments. The federal government is composed of three major branches: the executive, legislative, and judicial. American citizens nationally vote for their president, senator, and U.S. House representative. In state elections, they vote for their governor, legislators, and other positions, and in local elections, voters elect county supervisors, city council members, school board members, and other positions. These elected leaders work with large teams of public administrators to manage public monies and run government services.

In state politics, there are numerous commissions and boards, many composed of commissioners and members appointed by the governor, that oversee or regulate specific environmental aspects that relate to extreme weather (Christensen and Hogen-Esch 2006). For example, the California Coastal Commission, on which six commissioners are local elected officials and six serve as appointed officials, has a mission "to protect, conserve, restore, and enhance environmental and human-based resources of the California coast and ocean for environmentally sustainable and prudent use by current and future generations" (California Coastal Commission 2015, p. 1).

The mission of the Federal Emergency Management Agency (FEMA) "is to support our citizens and first responders to ensure that as a nation we work together to build, sustain and improve our capability to prepare for, protect against, respond to, recover from and mitigate all hazards" (FEMA 2015, p. 1). The first time that work was done to assist with a disaster on the federal level was The Congressional Act of 1803 for a New Hampshire town that had been ravaged by fire. After that, various legislation gave some disaster assistance. FEMA was created in 1979 by an executive order, which brought together a variety of different responsibilities associated with disaster into one agency. From then on, FEMA has delivered the promise in its mission of assisting towns around the country with disasters. By November 2007, FEMA had given aid to over 2700 official disasters (FEMA 2015).

FEMA is constantly increasing its effectiveness to help victims of disasters and their towns. The organization continues to grow from experience and feedback from different parties because its goal is constant improvement in its practices. FEMA provides assistance to individuals who have suffered from disasters. The organization also helps people who speak different languages and have disabilities. It works together with many sections of and organizations within the United States including private companies, nonprofits, federal, tribal and local governments to make sure that the country is safe and ready to respond to and mend from major catastrophes, terror attacks and other crises. FEMA also assists with the logistics of a crisis; it helps deliver supplies that disaster sufferers need. It also helps with hazard alleviation, emergency communications, public disaster communications and continuity programs. FEMA helps families and neighborhoods to prepare for all types of hazards (FEMA 2015).

3 Politics and Extreme Weather: Historical Context

In many ways, an elected official's political capital correlates with how he or she responds to extreme weather events. This chapter will explore how political careers have been ruined due to mishandled crises. "When you are a chief executive, your political fortunes are tied to how you are perceived in your official capacity, not your campaign capacity," said former Democratic Governors Association executive director Nathan Daschle (Haberman 2011, para. 6). "For better or worse, these perceptions are usually defined by one or two major events that happened during your tenure" (Haberman 2011, para. 7), he stated. "These are the 'make or break' moments. [Former presidents] Franklin Delano Roosevelt, JFK, George W. Bush, [and mayors] Rudy Giuliani, Haley Barbour, Bill White, [and governors] Kathleen Blanco … and by extension, [current governor and presidential candidate] Bobby Jindal—all were defined by the catastrophic event that happened on their watch. Competence in day-to-day government is important; Competence in times of crisis is absolutely critical. If you pass this test, you shed your burden of proof. If you fail, there is probably no tomorrow" (Haberman 2011, para. 7).

3.1 New York City

Throughout recent history there have been several noteworthy and diverse cases of extreme weather calamities and differences in how they have been addressed by political leaders. For example, in 1969 a terrible blizzard hit New York, ultimately killing 42 individuals and wounding 288 others. Fifteen inches of snow fell on February 9, 1969, and almost half of snow removal failed because equipment had not been properly maintained (Moser 2011). The city was in standstill for three days. In the borough of Queens, people were forced to stay in their homes. Circumstances were so dire that Ralph J. Bunch, a United Nations representative, sent Mayor Lindsay a note saying that he had never seen snow removal handled so poorly in his 17 years of being a resident of Kew Gardens (Moser 2011). Buses, cabs, delivery vehicles, and garbage removal vehicles were forbidden from operating for many days. The mayor made a special trip to Queens, where he was very poorly received. Citizens yelled at him and said that he should be embarrassed. To add to this, the press excoriated him over remarks he made about the weight and ethnicity of a few women who were heckling him. The incident was recorded but radio news refused to air the story (Chan 2009). Big city mayors after Lindsay, Michael A. Blandic of Chicago in 1979 and Marion S. Barry of Washington, D.C., in 1987, were also publicly criticized for their poor handling of blizzards. Mayor Barry was visiting Southern California to watch the Super Bowl, getting his nails done and playing tennis at the Beverly Hills Hilton when a blizzard consumed the

District of Columbia. Barry was severely ridiculed by people who lived in the city when it almost took a week to eliminate snow from the streets (Moser 2011). Mayor Michael Bloomberg seemed to have learned from these mishaps, because when nearly 27 inches of snow fell in Central Park in 2006, he moved fast to address the situation (Moser 2011).

3.2 Chicago

Chicago Mayor Michael Bilandic made such a mistake with a blizzard snow clean-up that he claims it cost him his re-election in 1979. There were major public transportation postponements, with the mayor being charged with making false statements about how things were being handled. For example, Bilandic claimed that open parking lots were available to accommodate snow cleared from the streets, when this was not the case. In fact, one parking lot was full of vandalized automobiles (Moser 2011). Bilandic also said that airports would remain open, when they were, in fact, closed. He said the Chicago Transit Authority would remain in operation, when the trains actually skipped stations in Chicago's Black neighborhoods, leaving thousands of individuals stranded in below freezing weather. This led to bad press (Moser 2011).

3.3 Denver

A blizzard that hit Denver on Christmas Eve in 1982 is said to have cost Mayor Bill McNichols his election in 1983 (Brown 2006). More than 2 feet of snow fell on the city, creating many issues, including closure of one of the world's busiest airports and streets not drivable. Garbage trucks were ordered to pack snow down to a manageable height. Because of that decision, filthy glaciers were present until the May election, one that McNichols lost to Federico Peña (Brown 2006).

3.4 Fort Worth

On a positive note, after a tornado struck downtown Fort Worth, Texas, on March 28, 2000, a group of city officials who called themselves Team United For the Future (TUFF) created a campaign to interest people in visiting the downtown area (Auer 2001). "The idea was born within a week after the tornado hit downtown," said Marilyn Gilbert, the person in charge of marketing for the Fort Worth Chamber of Commerce. They raised money from some of the bigger downtown businesses. Some of the slogans the group came up with were:

"You can't judge a town by its plywood."
"It's been a whirlwind for weeks, but now we're ready for company."
"When life hands you tornadoes, play twister."

The slogans were unique and somewhat innovative given that they made light of a disaster. These slogans were placed at bus stops, in the windows of businesses, and at entertainment spots. By summer, the town was thriving again and city officials deemed the campaign a success (Auer 2001).

4 Extreme Weather Campaign/Political Influences

Hurricane Sandy put President Barack Obama's 2012 campaign on pause, as he halted his campaign in order to work on storm warning and recovery tasks, including discussions with the National Weather Service about weather patterns and storm forecasts, directing FEMA and other administration organizations about appropriate responses for protection, and finding financial support to help the states affected. Before the storm struck, Obama actually called state governors of states about the approaching storm and inquired about their specific needs. Republican presidential hopeful Mitt Romney made storm-related visits in "swing" states such as Ohio. Romney helped provide people with food, blankets, and sandwiches during his campaign (Marshall 2012).

When New Jersey Governor, Chris Christie, who supported Romney, thanked the president directly and gave him praise on national television, it sent the message that although he is a Republican, Obama had done commendable work in the midst of a crisis. The way that President Obama, a Democrat, handled Hurricane Sandy may have been a major contributing factor to his winning the election. "I wish the hurricane hadn't have happened when it did, because it gave the President a chance to be presidential, and to be out showing sympathy for folks," Romney said. "That's one of the advantages of incumbency" (Marshall 2012; Lavender 2013, p. 1). This quote illustrates how extreme weather can actually play an important role in making and breaking political career opportunities.

Christie was criticized when he was on vacation in Florida while a blizzard was creating severe problems in New Jersey in 2010 (Foley 2012). "This is my sixth winter as governor" (Huey-Burns 2015, para. 10), said Christie, "We've had Hurricane Irene; we've had Hurricane Sandy; for better or for worse, we know how to deal with these situations" (Huey-Burns 2015, para. 10). Learning from his past political mistake, when reporters asked Christie about his political action committee created for the 2016 presidential campaign he said, "The more important issue today is the health and safety of the people of New Jersey" (Huey-Burns 2015, para. 12).

4.1 *Tornadoes and Politics*

There are also instances of tornadoes playing a role in politics. The Governor of Illinois, Bruce Rauner, announced that the tax deadline would be extended for residents of a few counties that were affected by the tornadoes that hit on April 9th, 2015. The deadline was extended to October 31. "These devastated communities should be focused on healing and recovery, not deadlines" (My Stateline 2015, para. 3) said Governor Rauner. "Once families and businesses have had time to recuperate, they can gather the essential paperwork to file and pay their taxes" (My Stateline 2015, para. 3). When two tornadoes hit Illinois on November 17, 2013 the state asked FEMA for assistance in nine counties; they were denied. Governor Pat Quinn stated that that the state would plea for the decision to be changed. "While we appreciate FEMA's partnership in helping individuals and businesses recover, I'm disappointed in this decision" (State of Illinois 2014, para. 2), Governor Quinn stated. "My Administration will immediately work to develop a strong appeal that demonstrates how much this assistance is needed. The state of Illinois will continue doing everything necessary to help our hardest hit communities rebuild and recover from these historic tornadoes" (State of Illinois 2014, para. 2).

On December 19, 2013, Governor Quinn requested federal aid for several communities in the state of Illinois including the towns of Washington and Wayne. Washington Mayor Gary Manier stated, "On behalf of the city and residents of Washington, I appreciate Governor Quinn's continued partnership and support as we recover" (State of Illinois 2014, para. 4). Costs that equaled over $6.1 million were put together in an assessment determined by FEMA and the Illinois Emergency Management Agency (IEMA) at the beginning of December. That amount is less than the federal threshold for the state, which is $17.8 million. This sum was based on Illinois's population multiplied by $1.35. Governor Quinn did everything he could to assist families and towns across the state recover from the extreme weather that struck that year. More than $10 million in federal aid was appropriated to assist everyone affected by the tornadoes that struck on November 17th. Over $2 million in federal grants were given to assist with home rental, house repairs and replacement of items destroyed in the storms. The U.S. Small Business Administration (SBA) also sanctioned over $8.7 million in special loans for individuals and business disturbed by the tornadoes (State of Illinois 2014).

Governor of Hawaii, Neil Abercrombie, was criticized publicly when he was not available to the media and out of the public spotlight when Hurricane Ana struck Hawaii. This was surprising because county mayors were very visible during the hurricane. The governor had been on television so often during earlier storms that he was condemned for his absence this time (Hawaii News Now 2014).

Governors Bob McDonnell, Martin O'Malley, Andrew Cuomo, and Chris Christie seem to have persevered through Hurricane Irene in 2011 with reputations intact. Damages from Irene were upward of $7 billion. "When you are a chief executive, your political fortunes are tied to how you are perceived in your official capacity, not your campaign capacity" (Haberman 2011, para. 6) stated Nathan

Daschle, former Democratic Governors Association executive director. Overall, the examples just shown are but a few of the many cases where weather has played a significant role in the political arena. In the next section we explore the role of social media and communication about extreme weather.

5 Contemporary Public Communication Methods: The Role of Social Media

Social media has become increasingly popular for political leaders and government agencies to communicate with the public. Facebook (2015), the most widely used social media site in the world, reported an average of 936 million active users on a daily basis in March 2015, with 798 million using mobile devices. Facebook reported 1.44 billion active users on a monthly basis, 1.25 billion of which were mobile. Microblogging service, Twitter (2015), reports 302 million active monthly users in May 2015, and 500 million tweets sent per day. Instagram (2015), a photo sharing service owned by Facebook, reported 300 million monthly active users in May 2015, with 70 million photos posted per day. Other popular sites such as LinkedIn, a professional social networking site, Google+, and Pinterest have large numbers of users. These websites allow leaders and agencies to communicate directly and immediately with citizens.

Social media has also become popular for government agencies to communicate with the citizenry, particularly during crises. Appendices B and C display the government agencies and departments with the highest number of Twitter followers, and how the numbers of followers changed from the previous year. There are many instances in which social media is used by agencies to communicate with the public about extreme weather. For example, on Federal Emergency Management Agency's (FEMA's) social hub Web page (http://www.fema.gov/social-hub), the organization states, "The topics we feature on this page can vary from severe weather conditions to disaster response updates." Examples of FEMA tweets (https://twitter.com/fema), often very informative and engaging during emergencies, are shown in Fig. 1.

6 Public Communication Theories

There are many mass communication theories that help explain approaches and methods for communicating with the public about extreme weather circumstances. This section of the chapter will provide an overview of two pertinent theories, the "Knowledge Gap" and "Uses and Gratifications" theories, and will explain how they relate to the reporting of extreme weather. By examining these theories we can gain a better understanding of the various issues related to public communication around extreme weather.

Fig. 1 FEMA tweets

6.1 Knowledge Gap Theory

The Knowledge Gap Theory (Baran and Davis 2011) explores media coverage in cities and towns of different sizes, including urban versus rural communities. It is defined as the systematic difference in the population's less informed and better informed segments. Tichenor et al. (1970) established the theory initially by stating that the news media tend to inform and educate some population segments, specifically people in higher socioeconomic groups, better than the media may inform and educate others. Over time, the differences between the segments of these two groups tend to grow, resulting in an ever increasing knowledge gap. Knowledge Gap Theory explains why local communities confronting escalating societal conflicts, see conflicts escalate, where ordinarily apathetic or apolitical individuals are eventually drawn into the conflict. As time passes, individuals, including those who are uninformed or less informed, make better use of news media and progressively become more knowledgeable about the specifics of the conflict. Another study using Knowledge Gap Theory found that outside media generally pull back from serving a regional or small town audience. Thus, it becomes more difficult for less knowledgeable people in smaller and/or rural communities to gain access to information they may need. Other factors may explain the knowledge gap, including motivation to seek information, the level of existing knowledge, the level of relative social contact, exposure and retention of information, and communication skills (Graber 2000, 2010). Additionally, individuals may work fulltime, raise families, and not have the time to be up to date on different sources of information. In general, the Knowledge Gap Theory implies that all segments of a community will become more knowledgeable and better informed when escalating social conflict has increased the relevancy of knowledge. In addition, more prevalent news coverage from both local and outside or non-local sources of information provides improved access to information. Decreasing the knowledge gap's size may lead to achievement of a solution based on the highest quality information available. Within small communities, local media avoid or severely limit reporting conflicts, forcing residents to obtain information from larger outside media sources. An example of this might be that if there was a toxic spill of chemicals at the local mine in a small, remote, rural community, the local home-town paper did not cover it but the major journal located in a metropolitan city center 4 h away did provide coverage (Graber 2000, 2010).

The role of power and outside intervention can certainly apply to engagement strategies with communities when government agencies attempt to communicate preventative measures before extreme weather calamities occur. As this book emphasizes, extreme weather events can lead to natural disasters that pose major health threats to various communities. Populations that lack wealth and social power are most vulnerable and at risk to impacts from extreme weather. The Knowledge Gap Theory highlights discrepancies between the various degrees to which individuals are informed and how such discrepancies can lead to vulnerability. Therefore, the goal for government services is to consider that not all groups of people have the same access to knowledge and information related to an extreme weather event.

The Knowledge Gap Theory identifies possible troubling gaps between groups, provides various ideas for overcoming potential gaps, and assumes exchange and engagement in communication. However, the theory assumes that these gaps are inherently dysfunctional, it restricts the focus of gaps that involve social and news conflicts, and it cannot address the innate reasons for gaps.

6.2 Uses and Gratifications Theory

The Uses and Gratifications Theory takes a novel approach in that it looks at how the consumer uses the media instead of how the media influences the consumer. The theory focuses on individuals' media uses and the gratifications they seek from that use. In other words, the theory asks why a group is using a media and what they are deriving from the media. Herta Herzog (1941) conducted a study of radio soap operas and concluded that three major types of gratification were persistent—emotional release, wishful thinking, and valuable advice. How groups utilize media can also be a celebration that brings people together. An example, when individuals ritualistically gather to watch specific television programs (Graber 2000, 2010).

Consider contemporary news coverage of extreme weather calamities, along with the longtime news adage "If it bleeds it leads." Through the lens of Uses and Gratification, one may argue that some, perhaps those not directly affected by extreme weather calamities, may find such circumstances entertaining. This point is proven further by the advent of YouTube and "viral" videos that are shared with the click of a mouse.

There has been a recent revival of the Uses and Gratifications Theory. The revival can be explained by a number of factors: technological advances, increased public awareness, and application of theory to the Internet. Katz et al. (1974) created the five main components of the Uses and Gratifications Model: the audience is active and its media usage is purpose oriented; the audience selects specific media; the media compete with other types of sources to fulfill need satisfaction; individuals are aware of their own specific media use; and content interpretation belongs to the audience. Increasingly, with more accessible social media, the interpretation is being left up to the individual, the consumer of the media.

Hurricane Katrina Example News coverage of Hurricane Katrina provides a specific example of this theory in practice. The hurricane was the most costly natural disaster and one of the deadliest hurricanes in the history of the United States (Cooper and Block 2007). News coverage of the hurricane was extensive, from aerial footage to ground coverage of disaster areas and shelter activity at the Louisiana Superdome (Cooper and Block 2007). In many ways, tragic catastrophes such as Hurricane Katrina receive such extensive coverage from the news media because they potentially lead to higher ratings for news providers due to the human drama that occurs.

On a separate note, President George W. Bush received negative publicity during Hurricane Katrina due to two particular occurrences. First, the news media displayed a photo of the president surveying Katrina damage from a plane. Many criticized the president for lacking care for those affected and being detached. Bush eventually would admit that releasing the photograph was a mistake (Mooney 2010). Second, Bush was criticized for publically praising then FEMA Director Mike Brown (or "Brownie" as Bush called him) in front of television cameras. Brown (2015), in fact was widely criticized for his performance in response to the hurricane. Whether it is at the presidential or local government level, extreme weather calamities have played a significant role in politics during the media age, often because elected officials' responses are seen as indicative of their leadership abilities.

7 Conclusion

This chapter presented an overview of the politics and public communication aspects of extreme weather. Communication technologies are constantly expanding. Citizens of the world are gaining faster access to pertinent information, along with a substantial amount of disinformation. It is imperative for government leaders and media outlets to continue to share information that is accurate and timely. Most noteworthy is that both the expanded 24-h news cycle and social media have given citizens access to instant salient information. Governments now have the ability to engage constituents immediately and around the clock. Looking ahead, scholars and practitioners must work toward policies and procedures that ensure greater accuracy and optimum methods of communication and public education. Being educators ourselves, we offer a few example exercises for the classroom in Appendix A. Employing such strategies will ultimately strengthen the sense of community in cities and towns across America or anywhere around the world.

8 Best Practices for Extreme Weather Communication

Our chapter has explored a variety of challenges associated with extreme weather and the media. We conclude with four best practices for extreme weather communication.

Governmental Use of the Media All government agencies, from local municipalities and county governments to state and federal agencies, need to have a strong social media presence. Today, people increasingly get their news from Facebook and Twitter feeds. During instances of extreme weather, social media is an excellent method of immediate communication to and from the citizenry on issues such as where to seek shelter, areas to avoid, and where to obtain supplies. Appendices B and C provide pertinent Twitter information for major government agencies. Reviewing these, one can see a broad spectrum of approaches taken by agencies to communicate with the citizenry. Some agencies, such as FEMA (@fema), provide a model for clear, instant, communication of issues of concern to the public. Other approaches allow agencies to quickly release press releases and official statements. Some communications are updated frequently. Above all, each year, these social media are taking an increasing role in response and access to communication for the general public.

Social Media Plan In addition to government agencies, elected officials and heads of emergency response agencies should have a social media presence and a plan in place for cases of extreme weather events. As discussed in this chapter, public scrutiny of officials is increasing, particularly during extreme weather crises. A social media action plan in which officials engage in direct communication with their constituents during these events should exist.

Apolitical Weather Data Interpretation Weather data interpretation and action should be apolitical. Therefore, when extreme weather information and data are being collected, they should be interpreted for what they are, the basic facts, instead of being politically spun. Far too many instances exist in which the opposite is true. Some officials use the spotlight on crises for political gain. Others will ignore scientific findings in order to appeal to special interests during an extreme weather event.

Create Communication Collaborations An early portion of this chapter discusses the interconnectedness of government agencies. All levels of government, from local governments to state and federal governments, need to commit to collaborating and to a communications strategy, in place, so that the agencies can speak as one voice during instances of extreme weather crises. Governments should focus on being more proactive rather than reactive to extreme weather events. To successfully establish such a strategy, and to best communicate with the people who will be affected by such events, coordinating agencies must have a clear social, cultural and economic understanding of the populations they serve.

Appendix A: Extreme Weather Classroom Exercise

1. This chapter discussed the role of social media in pubic communication. Review some of the Twitter accounts listed in Appendices B and C. Which Twitter accounts do the best job at communicating clearly and effectively with the citizenry? Which accounts are most engaging? Which agencies' accounts are updated regularly? Which ones respond quickly and frequently to citizen inquiries? Consider examining the best agencies' Facebook and Instagram pages as well.
2. The beginning if this chapter discusses how New Jersey Governor Chris Christie's responded to Hurricane Sandy. Two years prior, in 2010, Christie was criticized for staying on vacation in Florida while a major snowstorm struck New Jersey. The state's lieutenant governor was also on vacation at the time. Christie defended himself by stating that the State of New Jersey would have responded the same way, regardless of Christie's location, and that he did not want to break a promise to his son to visit Walt Disney World (Weinberg 2015). Assuming it is true that Christie's location made little difference in the state's response, do you believe it was wise for him to stay out of New Jersey instead of engage his community? Why?

3. Pick a recent extreme weather event and research it. Do you believe the various government agencies involved did an effective job at handling the crisis and communicating with the public? Do you have suggestions for increased government efficiency and effectiveness?
4. Assume you are governor of your state and an extreme weather crisis is upon you. Public transportation will be affected, roads will be closed, and many people will panic. Describe your administration's social media strategy during this ordeal. What would you communicate and how often? Describe your radio and television engagement strategies.
5. Provide contemporary examples of the Knowledge Gap and Uses and Gratification Theories, other than the Hurricane Katrina example discussed, as they relate to extreme weather.

Appendix B: U.S. Federal Agency Twitter Followers (2015) and Percent Change from 2014 to 2015

	Agency	# of Twitter followers	% Change over last year	Accounts
1	The White House	3,470,421	32	@whitehouse, @jesseclee44, @lascasablanca, @macon44, @presssec, @WHLive
2	NASA	2,836,812	110	@NASA
3	Centers for Disease Control and Prevention	2,015,693	18	@CDCActEarly, @CDC_BioSense, @CDC_Cancer, @cdc_ehealth, @CDCEMERGENCY, @CDCflu, @CDCgov, @CDCGreenHealthy, @cdchep, @CDCMMWR, @CDCSTD, @CDCTobaccofree
4	Health and Human Services Department	1,465,949	59	@healthcaregov, @phegov, @AIDSgov, @flugov, @foodsafetyesp, @foodsafetygov, @girlshealth, @healthfinder, @hhsgov, @ikngov, @ONC_HealthIT, @opa1, @womenshealth
5	Smithsonian Institution	732,838	48	@smithsonian, @SmithsonianJobs
6	State Department	595,692	91	@ConnectStateGov, @dipnote, @StateDept, @travelgov, @USEmbassyBern, @USEmbassyCyprus, @usembassy_nz, @vsfsAtState

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	Agency	# of Twitter followers	% Change over last year	Accounts
7	Agriculture Department	847,574	633	@MyPlate, @peoplesgarden, @RuralTour, @ScienceAtUSDA, @USDA, @USDAFoodSafe_es, @USDAFoodSafety, @USDAForeignAg, @usdafsa, @USDAnutrition, @biopreferred, @USDA_APHIS, @USDA_ERS, @usdagov,, @USDAFoodSafe_es, @USDAFoodSafet
8	Federal Communications Commission	500,873	15	@FCC
9	Justice Department	489,779	19	@TheJusticeDept
10	Peace Corps	477,685	19	@PeaceCorps
11	Food and Drug Administration	464,488	71	@FDAanimalhealth, @fdacber, @FDAcdrhIndustry, @FDADeviceInfo, @fda_drug_info, @FDAMedWatch, @FDArecalls, @FDATobacco, @FDAWomen, @US_FDA
12	FBI	412,842	82	@FBIPressOffice, @NewYorkFBI
13	National Institutes of Health	384,107	68	@NCIExhibits, @NIEHS, @NIHClinicalCntr, @NIHconsensus, @NIHforFunding, @NIHforHealth, @NIHforJobs, @nihlib, @NIH_LRP, @nih_nhlbi, @NIH_ODS, @NIHPtRecruit, @NIHSciEd, @NIHWALS, @ORDR, @WomensHealthNIH
14	Environmental Protection Agency	306,311	78	@AIRNow, @energystarbldgs, @energystarhomes, @epaairmarkets, @EPAburnwise, @EPAcleanuptech, @epacolumbia, @epaespanol, @epagov, @EPAgreenbldg, @epaiaplus, @EPAjobs, @epalive, @epanewengland, @epanews, @eparesearch, @EPAsmartgrowth, @epawater, @EPAwatersen
15	Office of Science and Technology Policy	299,938	28	@whitehouseostp
16	Geological Survey	297,602	69	@nationalatlas, @USGS, @USGSAquaticLife, @usgs_click, @usgs_co, @USGSenergy, @USGS_Ethics, @USGS_Idaho, @usgs_kentucky, @usgs_lcat, @USGSLive, @USGSNeb, @usgsnhd, @_usgsnsmp, @USGS_OR, @USGSPodcasts, @USGS_SpecEider, @usgsstore, @USGSted, @USGSTNMRes

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	Agency	# of Twitter followers	% Change over last year	Accounts
17	National Science Foundation	280,540	70	@NSF
18	Education Department	266,811	110	@arneduncan, @ED_Outreach, @edpartners, @EDPressSec, @FreeResources, @OfficeofEdTech, @teachgov, @usedgov
19	National Institute of Mental Health	249,845	100	@NIMHgov
20	USA.gov	235,629	70	@GobiernoUSA, @GoUSAgov, @USAgov
21	Federal Emergency Management Agency	221,545	78	@craigatfema, @fema, @femaregion1, @femaregion10, @femaregion2, @femaregion3 @femaregion4, @femaregion5, @femaregion6, @femaregion7, @femaregion8, @femaregion9, @usfire
22	Securities and Exchange Commission	212,103	5	@sec_investor_ed, @SEC_Jobs, @SEC_News
23	U.S. Agency for International Development	195,357	65	@usaid, @RajShah
24	U.S. Army	173,345	90	@usarmy
25	Defense Department	218,066	81	@DeptofDefense, @DoDSpokesman, @AFPW_Articles, @ArmedwScience, @DoDLiveMil, @thejointstaff
26	Homeland Security Department	151,948	n/a	@dhsgov, @DHSJournal, @dhsscitech, @NTASAlerts, @ReadydotGov
27	U.S. Marine Corps	133,062	143	@usmc
28	United States Holocaust Memorial Museum	124,178	101	@holocaustmuseum
29	U.S. Navy	118,653	295	@navynews, @usnavy
30	U.S. Air Force	116,324	101	@afpaa, @airforcenews, @usafpressdesk, @usairforce
31	National Cancer Institute	97,479	100	@ncibulletin, @NCIcaBIG, @NCICancerCtrl, @NCIExhibits, @NCIHINTS, @ncimcmedia, @ncimedia @nciprevention, @NCIsbir, @NCISymptomMgmt, @NCITechTransfer, @NCItrialsatNIH, @NCItsm3, @smokefreegov, @smokefreewomen, @thenci
32	National Weather Service	96,965	115	@usnwsgov, @NHC_Atlantic

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	Agency	# of Twitter followers	% Change over last year	Accounts
33	Office of the Vice President	82,700	148	@VP
34	Energy Department	74,611	126	@ENERGY, @solar_decathlon
35	National Library of Medicine	71,728	169	@aidsinfo, @medlineplus4you, @ncbi, @ncbi_pubmed, @NLMGlobalHealth, @nlm_harrypotter @NLM_LHC, @nlm_newsroom, @NLM_SIS, @WomensHealthNIH
36	National Park Service	71,664	83	@GoParks, @NatlParkService, @NPSVIPNetwork
37	Fish and Wildlife Service	65,746	109	@USFWSPacSWest, @usfws_wsfr, @usfwshq, @usfwsinternatl, @usfwsmidwest, @usfwsmtnprairie, @usfwsnortheast, @usfwspacific, @usfwsrefuges, @usfwssoutheast
38	U.S. Coast Guard	59,271	66	@Amver, @BoatingCampaign, @cgchealy, @cges, @Flotilla1105, @Flotilla4, @forcecompao, @GloucesterAUX64, @iCommandantUSCG, @uscgaux, @USCGAUXD8CR, @USCG_AWW, @uscoastguard
39	Voice of America	57,137	171	@voa_news
40	National Ocean Service	51,180	69	@usoceangov
41	Navy Seals	50,749	136	@us_navyseals
42	Veterans Affairs Department	49,545	110	@DeptVetAffairs
43	Labor Department	47,764	93	@usdol
44	U.S. Embassy Bangkok	42,871	39	@USEmbassyBKK
45	National Archives and Records Administration	41,679	143	@archivesnews, @dferriero, @discovercivwar, @DocsTeach, @FedRegister, @NARA_RecMgmt, @TodaysDocument, @usnatarchives
46	Secret Service	40,930	45	@SecretService
47	Transportation Department	38,063	66	@RayLaHood
48	Federal Reserve Bank of New York	34,102	137	@libertystecon, @NYFed_data, @NYFed_news
49	Interior Department	33,345	117	@Interior, @usinteriorjobs
50	Small Business Administration	32,674	139	@sbagov

Note FCW Staff (2012b). Retrieved from FCW Staff 2012a

Appendix C: Twitter Handles for Major Public Agencies

	Agency	# of Twitter followers	% Change over last year	Accounts
1	The White House	3,470,421	32	@whitehouse, @jesseclee44, @lascasablanca, @macon44, @presssec, @WHLive
2	NASA	2,836,812	110	@NASA
3	Centers for Disease Control and Prevention	2,015,693	18	@CDCActEarly, @CDC_BioSense, @CDC_Cancer, @cdc_ehealth, @CDCEMERGENCY, @CDCflu, @CDCgov, @CDCGreenHealthy, @cdchep, @CDCMMWR, @CDCSTD, @CDCTobaccofree
4	Health and Human Services Department	1,465,949	59	@healthcaregov, @phegov, @AIDSgov, @flugov, @foodsafetyesp, @foodsafetygov, @girlshealth, @healthfinder, @hhsgov, @ikngov, @ONC_HealthIT, @opa1, @womenshealth
5	Smithsonian Institution	732,838	48	@smithsonian, @SmithsonianJobs
6	State Department	595,692	91	@ConnectStateGov, @dipnote, @StateDept, @travelgov, @USEmbassyBern, @USEmbassyCyprus, @usembassy_nz, @vsfsAtState
7	Agriculture Department	847,574	633	@MyPlate, @peoplesgarden, @RuralTour, @ScienceAtUSDA, @USDA, @USDAFoodSafe_es, @USDAFoodSafety, @USDAForeignAg, @usdafsa, @USDAnutrition, @biopreferred, @USDA_APHIS, @USDA_ERS, @usdagov,, @USDAFoodSafe_es, @USDAFoodSafet
8	Federal Communications Commission	500,873	15	@FCC
9	Justice Department	489,779	19	@TheJusticeDept
10	Peace Corps	477,685	19	@PeaceCorps

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	Agency	# of Twitter followers	% Change over last year	Accounts
11	Food and Drug Administration	464,488	71	@FDAanimalhealth, @fdacber, @FDAcdrhIndustry, @FDADeviceInfo, @fda_drug_info, @FDAMedWatch, @FDArecalls, @FDATobacco, @FDAWomen, @US_FDA
12	FBI	412,842	82	@FBIPressOffice, @NewYorkFBI
13	National Institutes of Health	384,107	68	@NCIExhibits, @NIEHS, @NIHClinicalCntr, @NIHconsensus, @NIHforFunding, @NIHforHealth, @NIHforJobs, @nihlib, @NIH_LRP, @nih_nhlbi, @NIH_ODS, @NIHPtRecruit, @NIHSciEd, @NIHWALS, @ORDR, @WomensHealthNIH
14	Environmental Protection Agency	306,311	78	@AIRNow, @energystarbldgs, @energystarhomes, @epaairmarkets, @EPAburnwise, @EPAcleanuptech, @epacolumbia, @epaespanol, @epagov, @EPAgreenbldg, @epaiaplus, @EPAjobs, @epalive, @epanewengland, @epanews, @eparesearch, @EPAsmartgrowth, @epawater, @EPAwatersen
15	Office of Science and Technology Policy	299,938	28	@whitehouseostp
16	Geological Survey	297,602	69	@nationalatlas, @USGS, @USGSAquaticLife, @usgs_click, @usgs_co, @USGSenergy, @USGS_Ethics, @USGS_Idaho, @usgs_kentucky, @usgs_lcat, @USGSLive, @USGSNeb, @usgsnhd, @_usgsnsmp, @USGS_OR, @USGSPodcasts, @USGS_SpecEider, @usgsstore, @USGSted, @USGSTNMRes
17	National Science Foundation	280,540	70	@NSF
18	Education Department	266,811	110	@arneduncan, @ED_Outreach, @edpartners, @EDPressSec, @FreeResources, @OfficeofEdTech, @teachgov, @usedgov

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	Agency	# of Twitter followers	% Change over last year	Accounts
19	National Institute of Mental Health	249,845	100	@NIMHgov
20	USA.gov	235,629	70	@GobiernoUSA, @GoUSAgov, @USAgov
21	Federal Emergency Management Agency	221,545	78	@craigatfema, @fema, @femaregion1, @femaregion10, @femaregion2, @femaregion3 @femaregion4, @femaregion5, @femaregion6, @femaregion7, @femaregion8, @femaregion9, @usfire
22	Securities and Exchange Commission	212,103	5	@sec_investor_ed, @SEC_Jobs, @SEC_News
23	U.S. Agency for International Development	195,357	65	@usaid, @RajShah
24	U.S. Army	173,345	90	@usarmy
25	Defense Department	218,066	81	@DeptofDefense, @DoDSpokesman, @AFPW_Articles, @ArmedwScience, @DoDLiveMil, @thejointstaff
26	Homeland Security Department	151,948	n/a	@dhsgov, @DHSJournal, @dhsscitech, @NTASAlerts, @ReadydotGov
27	U.S. Marine Corps	133,062	143	@usmc
28	United States Holocaust Memorial Museum	124,178	101	@holocaustmuseum
29	U.S. Navy	118,653	295	@navynews, @usnavy
30	U.S. Air Force	116,324	101	@afpaa, @airforcenews, @usafpressdesk, @usairforce
31	National Cancer Institute	97,479	100	@ncibulletin, @NCIcaBIG, @NCICancerCtrl, @NCIExhibits, @NCIHINTS, @ncimcmedia, @ncimedia @nciprevention, @NCIsbir, @NCISymptomMgmt, @NCITechTransfer, @NCItrialsatNIH, @NCItsm3, @smokefreegov, @smokefreewomen, @thenci

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	Agency	# of Twitter followers	% Change over last year	Accounts
32	National Weather Service	96,965	115	@usnwsgov, @NHC_Atlantic
33	Office of the Vice President	82,700	148	@VP
34	Energy Department	74,611	126	@ENERGY, @solar_decathlon
35	National Library of Medicine	71,728	169	@aidsinfo, @medlineplus4you, @ncbi, @ncbi_pubmed, @NLMGlobalHealth, @nlm_harrypotter @NLM_LHC, @nlm_newsroom, @NLM_SIS, @WomensHealthNIH
36	National Park Service	71,664	83	@GoParks, @NatlParkService, @NPSVIPNetwork
37	Fish and Wildlife Service	65,746	109	@USFWSPacSWest, @usfws_wsfr, @usfwshq, @usfwsinternatl, @usfwsmidwest, @usfwsmtnprairie, @usfwsnortheast, @usfwspacific, @usfwsrefuges, @usfwssoutheast
38	U.S. Coast Guard	59,271	66	@Amver, @BoatingCampaign, @cgchealy, @cges, @Flotilla1105, @Flotilla4, @forcecompao, @GloucesterAUX64, @iCommandantUSCG, @uscgaux, @USCGAUXD8CR, @USCG_AWW, @uscoastguard
39	Voice of America	57,137	171	@voa_news
40	National Ocean Service	51,180	69	@usoceangov
41	Navy Seals	50,749	136	@us_navyseals
42	Veterans Affairs Department	49,545	110	@DeptVetAffairs
43	Labor Department	47,764	93	@usdol
44	U.S. Embassy Bangkok	42,871	39	@USEmbassyBKK
45	National Archives and Records Administration	41,679	143	@archivesnews, @dferriero, @discovercivwar, @DocsTeach, @FedRegister, @NARA_RecMgmt, @TodaysDocument, @usnatarchives
46	Secret Service	40,930	45	@SecretService

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	Agency	# of Twitter followers	% Change over last year	Accounts
47	Transportation Department	38,063	66	@RayLaHood
48	Federal Reserve Bank of New York	34,102	137	@libertystecon, @NYFed_data, @NYFed_news
49	Interior Department	33,345	117	@Interior, @usinteriorjobs
50	Small Business Administration	32,674	139	@sbagov

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Dust Storms, Human Health and a Global Early Warning System

William A. Sprigg

Abstract Arid regions, the source of most airborne mineral dusts, comprise a third of the Earth's land surface, where some two billion people are exposed daily to the fine particles raised by wind. Crossing political borders and travelling on air currents around the world, these particles not only affect the health of local communities, but also put many other populations extant at risk for cardiovascular and respiratory illnesses and a host of other health problems. Risks of exposure are affected by climatic conditions and their local and regional weather characteristics. And today, because of advancements in science and technology we are at the threshold of significantly reducing these health problems. Examples of meningitis, asthma and Valley fever are used to illustrate how risks may be lowered through a Dust-Health Early Warning System. A little more than a half-century of dedicated measurements of particulate air quality and of environmental science enhanced by Earth-orbiting satellites reveal the truth of airborne dust extent, and much of its variability in time and space. These truths have been essential in advancing numerical, dynamical models of the atmosphere that mimic and predict weather systems that loft the airborne dusts that medical sciences and epidemiology are proving harmful. This union of scientific disciplines and services makes possible today a means to improve public health around the world through a Global Dust-Health Early Warning System.

Keywords Aerosols · Particulates · Airborne dust · Fungi · Mineral dust · Haboob · Dust storm · Dust source · Cardiovascular · Respiratory illness · Valley fever · Cocci · Coccidioidomycosis · Asthma · Human health · Health risks

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1 A Global Dust-Health Early Warning System (D-HEWS)—The Motive

In late February 2015, a dust storm covering the Arabian Peninsula lasted several days. Child asthma emergency admissions to medical centers in Dubai jumped more than 20 % and asthma related hospital admissions increased more than 25 % in Abu Dhabi, United Arab Emirates (UAE 2015). While the Arabian Peninsula storm was underway, Korean television was alerting the Seoul population of an Asian dust storm bringing health-threatening dust into their area (Arirang 2015). Neither storms such as this nor their health consequences are unexpected. The World Health Organization (WHO) previously alerted all nations of the connection between cardiovascular hospital admissions and mortality to windblown desert dust (WHO 2006, 2013). In Geneva, just a few blocks away from the WHO, Terradellas et al. (2015) raised the human health problem again at the World Meteorological Organization (WMO).

In the Sonoran desert of North America a dust storm of frightening proportions roared through the U.S. city of Phoenix, Arizona on 5 July 2011 (Fig. 1). It was an American haboob, a storm seen rarely in America except for the arid southwest. Produced from thunderstorms that advanced north from Tucson with downdrafts of

Fig. 1 The Phoenix, Arizona haboob of 5 July 2011 around 7 PM local time looking southwest. See also the time lapse movie (https://vimeo.com/26045314). Photo and movie courtesy of Mike Olbinski, Phoenix, Arizona

110 km/h pummeling the dry, hot desert floor, outflowing winds gusted to 80 km/h raising a cloud of dirt, sand and dust 1800 m high travelling more than 250 km through city, suburbs, farms and ranches along a 160 km front, 18 km deep (National Weather Service 2011). Mike Olbinski, the Phoenix photographer who took the picture in Fig. 1, says that when the dust overtook him, where he had quickly sought the safety of his truck, visibility dropped to zero (personal communication 2015). It was the first and largest of six such storms that occurred that year in Phoenix (Sprigg et al. 2014). On average, one to three haboob-like storms occur in the region each year according to Raman and Arellano (2013).

Airborne mineral dusts range in size, from sand, a little larger than the width of a 70 μm human hair, to smaller, easily inhalable particles of PM_{10} and $PM_{2.5}$. The latter refer to particulate matter of aerodynamic diameter 10 μm and less, and 2.5 μm and less. One micrometer (μm), or micron, is one millionth of a meter. These smaller particles maneuver past the fine hairs in one's nose, into the lung. The finer, $PM_{2.5}$ particles penetrate deep into the lung, and ultrafine particles even enter the blood stream.

Backed by a growing number of studies, arid land mineral dust emissions are shown to contribute to both cardiovascular and respiratory illnesses. Gupta et al. (2012) show that asthma patients experienced significant reduced pulmonary function when exposed to mineral dusts (PM_{10}) that were collected from Rajasthan, the desert state of India. Meng and Lu (2007) statistically analyze respiratory and cardiovascular hospitalizations in Minqin, China, finding that Asia dust events increased both health problems, even reflecting the seasonal characteristics of disease surveillance. Giannadaki et al. (2014) assess global mortality rates from long-term exposure to airborne mineral dusts. More studies include Styer et al. (1995), Ostro et al. (1999, 2000), Lipsett et al. (2006), Cheng et al. (2008), and Goudie (2014). Whether in Kuwait (Thalib and Al-Taiar 2012), Lanzhou (Yan et al. 2012), Seoul (Hong et al. 2010), Sydney (Merrifield et al. 2013), Taipei (Chan and Ng 2011) or El Paso (Grineski et al. 2011), piece-by-piece the harm exacted by windblown dust is being documented.

Yet, more concerns of blowing dust emerge, including eye infections, meningitis, and Valley fever, or coccidioidomycosis: Laniado-Laborin (2007), Sandstrom and Forsberg (2008) and Morman and Plumlee (2013). Stafoggia et al. (2015) are convincing when they link mortality and hospital admissions in Southern Europe with invading Saharan dust. Goudie (2014) chronicles an extensive list of health problems associated with windblown desert dust. And, the U.S. National Research Council (2010) reviewed a Department of Defense effort to understand the health implications of airborne particulates from arid surroundings.

While concerns of public health agencies run the gamut of health complications from windblown dusts, three are elaborated in the following paragraphs: meningitis in Africa, asthma around the world, and Valley fever, or coccidioidomycosis, in the Americas. Addressing these will demonstrate the Conceptual Framework for the global early warning system: global monitoring of dust sources and airborne plumes; forecasts on hemispheric, regional and local geographical scales; and particulate air quality outlooks on climate space and time scales.

1.1 Meningitis

Africa's Meningitis Belt stretches across the sub-Sahara (Sahel) afflicting many of the least developed countries of the world. The timing of major meningitis outbreaks and dust storms from the Sahara appear highly correlated, and Noinaj et al. (2012) hypothesize that Neisseria bacteria, responsible for meningitis, need iron-laden dust to grow and become virulent. Hence, simulating historical events of windblown dust helps to understand whatever role mineral dust may play in meningitis outbreaks across Africa (Pérez et al. 2014; Thomson et al. 2006, 2009; Molesworth et al. 2003). Forecasting near-term Saharan dust storms may lead to reductions in the severity of meningitis outbreaks when the connections between airborne dust and illness are well established and appropriate warning systems are in effect.

Today, the logistics of field research are helped by these forecasts. International organizations including the World Meteorological Organization (WMO), the World Health Organization (WHO) and the Group on Earth Observations (GEO) support research with many African countries in the "Meningitis Environmental Risk Information Technologies" project (MERIT 2012), where the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) has provided observations, forecasts and simulations of airborne dust and dust storms to assess risks and attribution, cause and effect.

Yaka et al. (2008) and Sultan et al. (2005), examining climate time scales, show that wind is associated with meningitis outbreaks. Sultan even suggests that an "early warning index" for meningitis outbreaks could be developed from wind climate variability. It follows, too, that dust emissions will track climate conditions, as soil is anchored by dampening effects of precipitation and by moisture-invigorated plant roots; fresh foliage is an efficient trap for wind-driven sand and dust. Anticipating Africa's climate may inform agencies of future efforts required to face the risks of meningitis.

A long-term drought across the Sahel that began in the early 1970s was a factor behind calls in the U.S. and elsewhere to increase climate research. The Sahel drought and overgrazing led to drying of Lake Chad and, quite possibly, to observed increases in dust, and whatever hitchhikes with it, transported across the Atlantic Ocean. Caribbean and Western Atlantic dust concentrations correlate with rainfall deficits in North Africa (Prospero and Lamb 2003). Iron- and clay-rich soils found in the Caribbean came from Africa. Prospero and Mayol-Bracero (2013) and Prospero et al. (2014) estimate that every year more than 700 million tons of Africa's dust reach the Americas. In the Pacific basin, Schmidt (2014) and Shinn et al. (2000) find that nutrient-laden dust in Hawaiian rainforests is transported from Asian deserts.

1.2 Asthma

Exposure to desert dust is shown to increase risk of asthma hospitalization for children in Toyama, Japan (Kanatani et al. 2010). In Korea, Yoo et al. (2008, 1) report "… significantly higher frequency of respiratory symptoms" during Asian dust events. Yet, other studies have not found the connection, as in investigation of child asthma and airborne desert dust in Riyadh, Saudi Arabia (Alangari et al. 2015) and in Fukuoka City, Japan (Ueda et al. 2010). Watanabe et al. (2015a) found that Asia dust storms reduced pulmonary function in children, with the degree of impact differing with each dust event. Yet, in a companion study of adults with asthma (Watanabe et al. 2015b), pulmonary function scores were not significantly affected by Asia dust, but storms with larger, inhalable sand particles made lower respiratory tract symptoms worse.

On the other side of the world, under the influence of Africa dust outbreaks, Reyes et al. (2014) found conclusively that Saharan dust transported to Madrid, Spain, increased respiratory-caused hospital admissions. The Caribbean Allergy and Respiratory Association found that asthma has increased 17-fold in Barbados and Trinidad between 1973 and the turn of the Century (Shinn et al. 2000; Prospero and Lamb 2003; Prospero and Mayol-Bracero 2013). And, Molinie (2015) relates Africa dust to pediatric asthma on Guadeloupe. In a conflicting study, the Barbados Public Health Laboratory (Blades 2015) found no relationship between asthma and the 50-year record of Saharan dust measured at Ragged Point on the eastern edge of Barbados (Prospero et al. 2014). A general review of the literature shows that the epidemiology of desert dust and asthma is variable, often conflicting and inconclusive. This is at least partly due to what Wijesinghe et al. (2009, p. 1045) conclude as "… inherently difficult to interpret (trends in asthma mortality) because of the many factors that may change in different countries over time." Asthma in Trinidad has been linked to both Africa dust (Gyan et al. 2003) and climatic conditions (Ivey et al. 2003).

Africa dust makes up about half the airborne particulates in South Florida's air during the summer (Prospero and Lamb 2003; Prospero and Mayol-Bracero 2013). And, Saharan dust does not necessarily stop at Florida and the Caribbean. Further west, local sources of airborne dust are implicated in pediatric asthma and acute bronchitis in El Paso, Texas (Grineski et al. 2011), and Morain et al. (2007, 2009, 2010) engaged several state health agencies (and elementary school nurses) to test the efficacy of dust alerts in reducing respiratory, particularly asthma, risk.

1.3 Valley Fever

Exact locations of *Coccidioides* (*C. immitis* and *C. posadasii*) fungi are poorly known. They thrive in the generally hot, alternately damp and dry soils of the New World. When viable and inhaled, they cause Valley fever (coccidioidomycosis or cocci). Humans as well as their pet dogs and cats are at risk (Graupmann-Kuzma et al. 2008). This Valley fever, getting its name from San Joaquin Valley, California, not to be confused with Africa's Rift Valley Fever, is believed endemic only in the Americas, generally from California south and east along the U.S./ Mexico border, well into Mexico and Central and South America (Hector and Laniado-Laborin 2005; Barker et al. 2012). Yet, as we have seen, dust (and we must assume viable *C. immitis* and *C. posadasii*) is carried over considerable distance. Coccidioides fragments are 3–5 μm in size (Galgiani 2013) and would be included along with other dust particles in PM_{10}. Yin and Sprigg (2010) show that significant amounts of dust cross the border into Texas from Mexico during typical dust events, with dust sources in the U.S. also affecting Mexico's air quality. For Valley fever spores, a question remains as to how long in the free atmosphere *Coccidioides* fungi can stay viable. Pappagianis and Einstein (1978) attributed more than 379 new cases of Valley fever in California to a single 1977 dust storm. Windblown cocci spores from a landslide triggered during the 1994 Northridge, California earthquake caused 203 Valley fever cases in Ventura County, California (Schneider et al. 1997). Litvintseva et al. (2014) found human infection of Valley fever and local *C. immitis* spores in soils further north, well outside the known endemic regions for cocci, in Washington State. While spores may be carried to these regions beyond known endemic regions in ways other than severe weather, organism survival is, indeed, possible over long distances. For example, Prospero et al. (2005) captured viable, Saharan-sourced fungi and bacteria in the Caribbean.

Nguyen et al. (2013) review the state-of-the-science of Valley fever. Most cases are slight and unreported. For thirty to forty percent of cases that are documented, symptoms often mimic pneumonia. Common symptoms include coughing, fever, skin rash, feeling tired and difficulty breathing (Galgiani et al. 2005). Among the U.S. States, Arizona records the greatest number of cases. In 2004 about half of the 6000 cases reported nationwide occurred there (Laniado-Laborin 2007). The fact that cocci was not a reportable disease until 1997, and changes in laboratory tests in 2009 and reporting in 2013, have made construction of a long history of cocci impossible. For example, the 2009 change resulted in cocci numbers more than doubling the next year to 11,888 cases (Tsang et al. 2010; ADHS 2012). Treatment for the infection includes antifungal medication. Concerning vaccines, Galgiani (2008) gave a rather pessimistic prognosis that a vaccine to prevent coccidioidomycosis among infants in endemic regions and immigrants of any age would not be cost-effective.

Costs for cocci treatment are not trivial: 2007 Arizona Hospital Discharge Data show 1735 hospital visits for the disease, which translates to about $86 million. Galgiani et al. (2005) and Tsang et al. (2010) have analyzed cost and occurrence statistics for Valley fever in Arizona. Hector et al. (2011) report extensively on statistics for both Arizona and California. In neighboring Kern County, California, the CDC (1994) estimated $45 million for hospital stays and outpatient care between 1991 and 1993. Huang et al. (2015) figure 161 deaths from valley fever occurred on average every year between 1990 and 2008 in the United States. About 30 deaths are attributed to cocci in Arizona each year (Galgiani et al. 2005;

Tsang et al. 2010). According to Flaherman and Rutherford (2007) an average of 70 deaths occurred annually in California between 1997 and 2008.

Yet, it appeared to this author that people were generally unaware of Valley fever, what caused it, and how risks of catching it might be lowered. The value of an early warning system will depend on a community's understanding of the risks if warnings are ignored. Hearing from people who have contracted cocci might reveal clues about populations at risk, and how an early warning *system* might lower that risk.

1.3.1 Interviews with Valley Fever Sufferers

To gain a better understanding of the real impact of Valley fever, this author asked three individuals from Arizona neighborhoods who were under active surveillance or treatment for Valley fever if they would discuss their experiences for readers of this chapter. Two agreed, Mrs. K and Mr. H. Their accounts follow. The third, the youngest and most seriously affected, declined. One clear message from both interviews is that an early warning system must include public education about the disease, mainly because it is not widely publicized and often is misdiagnosed.

Mrs. K, In Her Own Words, June 22, 2015

> I now live in Ohio, but early on a Wednesday morning in 2007 I lived in Southern Arizona and awoke with a bad headache and feeling very tired. Taking aspirin I struggled through that day and night. But Thursday morning the headache had worsened and now was accompanied by a terrible pain in my foot. I was listless and had developed a cough. I had no energy to get out of bed. My husband stayed home from work to tend to me. By Friday I had developed a fever and, along with the headache and joint pain, tired and short of breath, a rash appeared on my legs. We went to an Urgent Care where I was prescribed 'Benedril,' and sent home. The diagnosis: allergic reaction to an unknown factor. Benedril was no help. The rash travelled up my legs, all the way to my neck. My husband took me to the hospital emergency room, for I was in no condition to drive. The triage nurse, seeing the rash on my stomach, gasped and said I had 'cocci,' which I learned later was Valley fever. The attending emergency room physician thought differently, agreeing with the allergic reaction diagnosed earlier at Urgent Care. I was given steroids through an IV and treated as 'outpatient.' The weekend went agonizingly slowly and painfully. My listlessness, shortness of breath, joint pain, cough and rash worsened. On Monday I returned to the emergency room where a blood test for cocci returned negative and a chest X-ray revealed a small spot on my lung. Diagnosis: viral pneumonia. The next couple of days I heard nothing from the hospital as to what really might be wrong with me. I did not believe that viral pneumonia was responsible for all these symptoms! I was referred to a pulmonary specialist, and another blood test for cocci, which again came back negative. Someone, I no longer remember who, said I might have lung cancer!Finally, after nearly two weeks of seeing so many doctors I lost count, a third blood test returned positive for Valley fever. Two weeks of watching the disease advance. At least now we knew the problem and it could be treated, as it should, with an anti-fungal medication, fluconazole. I took the antifungal pill for three months. My hair fell out. My pulmonary symptoms continued intermittently and other symptoms became significantly less severe. None of the previously prescribed treatments had helped at all.Along the way through this ordeal I developed fibromyalgia in my legs, which, according to experts, is often associated with Valley fever. This was a new, very painful, experience. Cocci, it seems, wreaks havoc with one's neural

> system. For two and a half years after catching Valley fever I periodically developed lesions and the same rash on my stomach, the lingering consequences of Valley fever.

When asked whether she knew when she might have been exposed to the cocci fungus, Mrs. K said that it may have happened perhaps a week or more prior to that Wednesday she awoke with such stress. She had been in her back yard when a strong wind suddenly picked up dirt and dust from all around her. Before she could take cover, the dust enveloped her. She talked also about the family dog, Lady (an alias), who developed Valley fever at the same time, coughing, tired and walking with difficulty. Treated with similar antifungal medication over many months Lady recovered. Clearly, Mrs. K's life had been severely changed by Valley fever and would never return to the quality before that Wednesday in 2007 when she first realized she was so ill.

Recollections of Mr. H

Sometimes the case for Valley fever is not as clear. Take, for example, Mr. H (Personal communication, May 18–28, 2015). In 2002, just before moving to the American Southwest, Mr. H had a regular health exam in New Jersey, including a chest X-ray that had revealed no problem. In 2003, just months after arriving in his new home in the Sonoran desert, he "experienced a rash on my arms and legs, and flu like symptoms, including headache, joint pain and a general feeling of fatigue over a ten to fourteen day period." He does not recall having a fever or feeling nauseous. Since the time between infection and emergence of symptoms may be as long as four weeks (Galgiani 2012) he may not even recall when or where he was exposed to the cocci mold spore. He did not seek medical treatment. Being a newcomer to the region he had heard nothing about Valley fever or its symptoms.

He is a smoker and his Arizona internist ordered a chest X-ray in his 2004 annual physical. "Results suggested lung abnormalities, and comparison to the 2002 films evidenced a pronounced difference. Examination by a pulmonary specialist and a full C-T scan preceded a lung biopsy in January 2005. With seven nodules identified clearly by the C-T, the presumptive ingoing position was that I had lung cancer. They were all benign."

"The biopsy was not the closing chapter in my book," says Mr. H. "Although characterized as 'damage or abnormality consistent with Valley fever exposure,' further examination and blood tests did not provide confirmation. The exact cause of my lung nodules is indeterminate. I have an annual lung scan, results of which are compared to all prior records to ascertain if the nodules have changed in size or shape. I have been 'stable' since 2005."

So, is Mr. H "stable" from a case of cocci … or something else? He has definitely suffered from something that negatively impacted his breathing and lung function. One fact is clear. Newcomers to cocci endemic regions are usually unaware of the disease, the symptoms or cause. Sometimes this applies to attending clinicians as well. An early warning system that includes public alerts, first of climatic pre-conditions for Valley fever and then, forecasted dust storms, will educate visitors and all new residents, physicians and clinicians included, of the dangers and ways to lower risks. As of right now however, no such system exists.

Yet, as we shall see in the following pages, one could be operational today by making use of current technology.

1.3.2 Acquired Insights for a Valley Fever Early Warning System

A 2012 NASA-sponsored workshop and consequent study (Sprigg et al. 2012, 2014) makes several recommendations for reducing risk of contracting valley fever. Many of these risks may be lowered through increased cocci surveillance, stabilization of reporting methods, availability of satellite-based remote sensing and advances in dust storm modeling and prediction. New optimism about low cost, effective means of detecting *C. immitis* and *C. posadasii* in the soil (Sheff et al. 2010; Litvintseva et al. 2014; Hasan et al. 2014) opens the way to better define the geographical regions where cocci risks are higher, and where education, storm warnings and mitigation efforts may be most valuable. Too, *C. immitis* and *C. posadasii* thrive only in rather narrow climatic ranges (Kolivras and Comrie 2003a, b; Zender and Talamantes 2005; Comrie 2012), which informs us where potential changes in endemic areas may occur under conditions of climate variability and change. Enhanced cocci surveillance along with routine airborne dust forecasting will improve disease epidemiology and risk avoidance.

2 This Chapter's Focus on Airborne Dust and Human Health

There are, of course, other health effects of wind blown dust, one or two steps removed from this chapter's focus. They would include risks to aviation and highway safety, loss of arable soil and risks to food supplies, and to changes in fresh water storage and availability because dust accelerates melt of mountain snow and ice. Only aspects related to inhalation of airborne dust (and whatever hitchhikes with it) are addressed here.

In a world community of environmental and health scientists, health practitioners and service providers, we are far behind following through on the problem of airborne dirt from nature's back yard. Common wisdom says that inhalation of particulates of any kind is unhealthy, but the focus of research, engineering and service has rested on man-made particles, principally those emissions from industry, energy and transportation. Outdoor natural environmental conditions are difficult to deconstruct. The problem has appeared intractable, as we shall see in 2.1. In addition to the anthropogenic source pollutants, spores, bacteria, viruses, pollens and other organic particles are carried along with mineral dust (Prospero et al. 2005; Smith et al. 2011). They complicate the epidemiologists' world (Watanabe et al. 2011). So, to help those epidemiologists, the mechanisms for cause and effect, from inhalation of dust to negative health outcome, are under medical science scrutiny as well: Ghio et al. (2014), for example, show that human respiratory epithelial cells respond biologically to desert mineral dust, an effect further confirmed in respiratory tract injuries in mice following dust inhalation. And Ichinose et al. (2008) show that mice, exposed intratracheally to mineral dust, particularly silicon dioxide (SiO_2), react with allergic inflammation in the lung—SiO_2 is common in Earth's crust, common in Arizona deserts, and commonly associated with sandstone and silica sand throughout the world.

2.1 The Dust-Health Challenge

Today, with negative health implications better understood, what can be done to stop emissions or avoid breathing this dust *from a third of the Earth's land surface*? These questions are rather intimidating. At first blush it appears the answer is "nothing," because such huge scales are involved. Recall that Prospero et al. (2014) estimate more than 700 million tons of Africa's dust are transported annually across the Atlantic to the Caribbean and Central and South America—about half of the world's annual airborne desert dust. We think of most of the other half also coming from such vast, uncontrollable sources as the Taklimakan, Gobi, Atacama, Simpson and Mohave deserts. These questions, and the usual hesitations that follow, often justify low priority for this research. Nonetheless, after the last decade or two of investigation into these dust sources, development of observation tools and networks, and atmospheric models that mimic pick-up, entrainment and dispersion of dust, the answers are right before us. The once parallel lines of airborne-dust-focused health and environmental sciences may now be aimed to intersect in a global dust-health early warning system. With it, comes a wealth of information for the epidemiology, diagnosis and prevention of all airborne particulate-based illnesses around the world.

- Dust storms, their three dimensional plumes and downwind dust concentrations can be predicted, an opportunity to avoid harmful exposure
- Dust storms and their downwind concentrations can be simulated, an opportunity for epidemiological studies of health consequences when looking into the past … or into the future under changing environmental conditions
- Satellite-based instruments identify, measure and follow dust plumes around the world, a means to warn of approaching trans-continental, global dust movement
- Surface-based remote sensing, a valuable complement to satellite instruments, identify and measure dust plume characteristics, a means to verify model forecasts and health consequences of exposure
- Atmospheric models calculate the back-trajectories of known hazardous plumes to identify their origins, an opportunity to control emissions
- Since dust emissions, even from the major deserts, are characteristically "point" sources, a few particularly hazardous ones may be controlled
- Global, regional and local infrastructures are available to warn of oncoming windblown dust, including weather services, broadcast media, and social networks paced by smartphone technology

- Global, regional and local health infrastructures are in place to respond to alerts and warnings, including the World Health Organization, the International Federation of Red Cross and Red Crescent Societies (IFRC 2013, 2014a, b), the Pan-America Health Organization, the Caribbean Public Health Agency, and public health service offices around the world.

3 Dust-Health Early Warning System—The Means

The underpinning for a Dust Health Early Warning System is available: in the medical, health, biological, and environmental sciences that currently demonstrate why airborne dust is a health hazard and how health risks may be reduced; in the current remote sensing and in situ environmental monitoring technology that reveal the truth of exposure; in the current skill of model forecasts and simulations; and in the infrastructure of current weather, health and information services that international, national and local missions provide. While nonexistent today, a D-HEWS could be assembled quickly from these components to serve global public health and medical communities.

3.1 Atmospheric Dust Modeling

Contemporary airborne dust forecast models can identify the time and place when blowing dust, or dirt, will cause air quality standards to be violated or will be a problem because of its content.

Zavisa Janjic (personal communication, Janjic 2013), in a lecture after receiving the prestigious International Meteorological Organization Prize for 2012, stated "… 10 km resolution medium range global forecasts and high resolution climate studies (are) possible with the NMMB (Nonhydrostatic Multiscale Model on B Grid)." This aim and thrust of research is another cause for optimism. We may relatively soon be able to go beyond the future-climate scenario-building of the Intergovernmental Panel on Climate Change (IPCC) and anticipate, in higher time and space resolution, local and regional dust-related health problems in future climates, not just for current climate conditions, as we do today. *Current* capabilities based on the Nickovic et al. (2001) dust regional model, DREAM, replicate all significant processes of dust mobilization, entrainment, dispersion and downwind wet and dry deposition (Nickovic 2002). In a forecast and simulation system in the U.S. Southwest that depends on state-of-the-science weather forecast models, such as the NMMB (Janjic and Gall 2012), and remote sensing technology and computer power, DREAM has demonstrated 24 to 36-h warnings of respirable dust concentrations on fine grid scales of under 4 km spatial resolution (Sprigg et al. 2014). This includes one remarkable forecast of the American haboob (Fig. 1) that struck the U.S. city of Phoenix on 5 July 2011 (Vukovic et al. 2014). Epidemiologists, public health experts and dust modelers have participated in tests of dust model systems for application in public health (Morain et al. 2007, 2009, 2010; Sprigg et al. 2014). The field of study has progressed such that within the framework of the World Meteorological Organization (WMO) Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS), dust models are now being compared with each other, to see which model structures and their internal components and treatments prove best under different circumstances and conditions (Huneeus et al. 2015).

Recall the potential health risks of very fine (SiO_2) Silica dust (Ichinose et al. 2008) mentioned in Sect. 2. The digitized global database of soil classification is improving (Nickovic et al. 2012) and, when used in model boundary conditions for dust forecasts or simulations, adds a critical parameter for estimating health risk. Harris and Roffers (2012) show how existing geologic and soils data can be used to estimate risk potential for Valley fever. While Fisher et al. (2000, 2012) describe optimum soil environment conditions for *Coccidioides* (*C. immitis* and *C. posadasii*), the soil-dwelling spores responsible for Valley fever (coccidioidomycosis, or cocci), Sprigg et al. (2014) demonstrate how this information can be used in forecast models to assess downwind valley fever risks. As a first-order estimate of cocci high-risk areas, following techniques described, for example, in Steinberg and Steinberg (2015), these and other spatially mapped data locate high-risk, current hot spots for potential cocci spores, which would then form the model boundary condition for *Coccidioides*-laden dust emissions.

3.1.1 Model Forecast and Simulation Verification

Model objective verification is essential for the credibility of every operational forecasting system. Well-defined and conducted verification helps in several ways: An informed user needs to understand the quality of the product; verification guides model development and forecast improvement strategies; and the statistics of verification allow comparison of models with other systems and different forecast methodologies. The latter is of much practical value when selecting the most appropriate forecast system for a given application; the “best” performer in one season or region of the world may not be the best in another season or region. Typically, one wants to know forecast scores, bias (mean error), mean absolute error, root mean square error, and correlation coefficient of surface dust concentration (PM_{10} and $PM_{2.5}$) and aerosol optical depth (AOD).

Verification of a dust forecast is challenging since surface observations of dust concentrations or low visibilities are not always located where the dust is occurring. Satellite observations over land also face problems such as high (and similar) reflectance for both dust aloft and soil below. The two vantage points for dust observations, space-based and surface-based, or in situ, are discussed next.

3.2 Satellite-Based Remote Sensing

Remote sensing from space-based platforms can identify and monitor dust sources and identify and track dust plumes as they drift around the world. Prospero et al. (2002) used satellite technology to identify preferential sources of dust. Morain et al. (2007, 2009) and Sprigg et al. (2008) applied NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), which sees every part of the earth every one to two days, to monitor dust sources in the NASA projects, PHAiRS (Public Health Applications in Remote Sensing) and ENPHASYS (ENvironmental Public Health Application SYStems). The Short-term Prediction Research and Transition (SPoRT) Center at NASA Marshall Space Flight Center uses a MODIS Normalized Difference Vegetation Index (NDVI) to produce a high-resolution, real-time, daily map of areas covered (and not) by vegetation. It has been shown to improve model surface characteristics (Case et al. 2014).

However, when dust becomes airborne over the land from which it originates it is hard to see. Technology improved quickly (Walker et al. 2009; Ginoux et al. 2010) from earlier attempts (Mahler et al. 2006) in the American southwest desert to distinguish airborne dust from the sand and dust of the same colour as the surface below. These new data and analysis methods help identify "point" emission sources from sites that appear to prefer releasing soil to the wind, while areas surrounding them are less apt to do so. Certain of these preferential point sources may be small enough to control.

Aiming to develop satellite tools for public health, Estes et al. (2009) use space-based remote sensing to identify dust storms. Prasad et al. (2010) used satellite observations to study implications of Sahara dust transported into the Nile Delta. Researchers all over the world are using satellite sensors to detect and distinguish airborne smoke, anthropogenic aerosols, dust and other airborne particles. For example, with critical use of satellite observations, El-Askary et al. (2003, 2009) and Fetouh et al. (2013) shed light on the complex nature of windblown dust and anthropogenic pollution over Egypt and the Nile delta region.

Remote sensing technology continues to offer new tools for researchers as well as practitioners to see further, faster and more completely than ever before. Details of particle composition and distribution with altitude are now possible, for example, from instruments that depict a virtual slice or cross-section of the atmosphere as the satellite flies overhead. The CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) satellite, a French–American collaboration, provides such atmospheric profiles (Winker et al. 2004; McGill et al. 2007). Although it is relatively rare to catch a short-term event like an haboob, El-Askary was lucky! A CALIPSO flyby collected data which he analyzed for the date and time of the American haboob as it struck Phoenix on 5 July 2011 (Vukovic et al. 2014).

Satellites provide remotely sensed data from a maze of acronymned instruments useful in detecting and monitoring airborne dust, including the aforementioned MODIS twin sensors aboard NASA's Terra and Aqua satellites, the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi NPP (National Polar-orbiting

Partnership) satellite operated by the National Oceanic and Atmospheric Administration (NOAA), the Multi-angle Imaging Spectro-radiometer (MISR) instrument on Terra, the Ozone Monitoring Instrument (OMI) on the NASA Aura satellite, the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) sensor on CALIPSO.

Detecting bare soil, potential dust emission sites, is but one part of the solution to monitoring dust sources. When the ground is wet, sand and dust are not likely to become airborne. Dust forecasts depend on knowing when this may happen. While some numerical dust forecast systems (e.g. Nickovic et al. 2001) include damping of sources in the model forecast scheme, it is best to have verification, and perhaps even some reliance, on an observation. So, precipitation over potential dust emitting sources is important. Rainfall is measured from space in a collaboration of aerospace agencies from Japan, India, Europe and the U.S. One result is the Global Precipitation Measurement (GPM) Core Observatory satellite operated jointly by JAXA (Japan Aerospace eXploration Agency) and NASA. If you are still counting acronyms, here are three more: the GPM Imager (GMI), which maps precipitation across the land surface, the Dual-Frequency Precipitation Radar (DPR), which detects the intensity of snow and rain at Earth's surface, and NASA's Soil Moisture Active Passive (SMAP) mission, which maps soil moisture and whether the surface is frozen or thawed.

Technically sophisticated resources are globally available to forecast dust emissions and plumes. Most, if not all, dust researchers and forecasters take advantage of them, for example Liu et al. (2011) and Wang et al. (2011) for dust events over China and environs, and El-Askary et al. (2006) and Prasad and Singh (2007) who consider both space-based (MODIS) and surface-based (AERONET) remote sensing for insight on dust storm impacts over India. AERONET is discussed in following sections.

3.3 Surface-Based Remote Sensing and in Situ Observations

While space-based instruments, looking down, provide essential global coverage of Earth's environmental dust conditions, similar technologies, looking up, anchored on the surface, are critical as well. Weather radar and instruments that measure meteorological conditions from points around the world are operated by national weather services linked to global data networks coordinated through the WMO. They are invaluable in verifying weather and dust model forecasts. The WHO monitors air quality to assess risks to human health; data are provided from national networks that serve various purposes, including epidemiology and development and enforcement of air quality standards.

3.3.1 Upward Looking Remote Sensing

A number of short-term, even multi-year research projects use upward-looking remote sensing instruments such as ceilometers (used to measure cloud heights and aerosol concentration), hand held sun-photometers (instruments for measuring direct Solar radiance) and Lidars (Light Detection And Ranging) to measure vertical column characteristics of dust and other aerosols. Data from many of these projects are not immediately available and are generally unannounced and unknown until completion of the project and publication of the results. A Dust-Health Early Warning System cannot depend on these disparate projects for routine model forecast verification. On the other hand, governments have established surface-based remote sensing networks that are dependable, tested, and data-rich, with data easily accessed and widely used.

The Aerosol Robotic Network (AERONET) is a federation of cooperative observing sites around the world using sun-photometers, direct-beam solar measurements that provide daytime AOD (Aerosol Optical Depth) measurements on average every 15-min (Holben et al. 1998, 2001; Dubovik et al. 2000). Established by NASA and the *Centre National de la Recherche Scientifique* (CNRS), AERONET provides information on the optical, physical and radiative properties of dust and other aerosols in the atmosphere. The network is used extensively today as a complement to AOD measurements from space and in airborne dust model verification (WMO 2015). With approximately 400 sites in 50 countries on all seven continents, it is the world's largest ground-based network of sensors for aerosols.

The NASA Micro-Pulse Lidar Network (MPLNET) federated network of NASA and partners around the world measures aerosol (including dust) vertical structure continuously, day *and* night (Campbell et al. 2012). Lidar technology illuminates a target (e.g., a cloud of dust particles) with a laser, measures the distance to it, and analyzes the reflected light. Most MPLNET sites are co-located with AERONET sites. The networks provide vertical profiles of dust (and other aerosol) properties such as optical depth and particle size distribution (Campbell et al. 2010). MPLNET data are used to calibrate space-based lidars such as CALIOP/CALIPSO and to validate and help interpret measurements from NASA satellite sensors such as MISR (Misra et al. 2012). There were 17 active MPLNET sites reported in 2000 (Welton et al. 2001).

The European Lidar Network (EARLINET) provides ground-based information on the vertical distribution of aerosols over Europe. This included 27 stations in 16 countries in 2013 (Pappalardo et al. 2014; Binietoglou et al. 2015). The network was initially a research project established in 2000 to build a multi-year, statistically significant, database of a three dimensional, temporal distribution of aerosols on a continental scale.

3.3.2 In Situ Dust Measurements and Monitoring

Near surface observations of dust concentrations reveal the quality of the air we breathe. How well these observations contribute to health surveillance, epidemiology and dust modelling depends upon their length of record, their continuity, and the extent to which they are part of a coordinated network with high standards of measurement. Dust forecasts and simulations are compared with these observations for quantitative assessment of model skill. However, particulate air quality networks vary across the globe. To address this issue, the United Nations Environment Programme, with the WHO, World Bank, WMO and other international partners are part of a Global Platform on Air Quality and Health, now in the process of developing tools and information for monitoring and assessing air quality and health consequences around the world (WHO 2008; UNEP 2015). For the purpose of this chapter's discussion, air quality networks of the United States, and the way in which the State of Arizona apply them, may serve as a model for the Dust-Health Early Warning System.

The U.S. Example of the Arizona Department of Environmental Quality (ADEQ) operates a network of ambient air quality instruments in order to meet Federal and State air quality requirements. The network exists, fundamentally, to answer the question: is Arizona in compliance with the National Ambient Air Quality Standards (Federal Register 2013) to protect public health and the environment? ADEQ's six $PM_{2.5}$ and fifteen PM_{10} monitoring sites include both filter-based samplers and continuous monitors located across the state. Filtered samples are analyzed for particle metal and chemical composition. The data from them become part of the US Environmental Protection Agency's Air Quality database (AIRNow, http://www2.epa.gov/aqs#_). Individual counties in Arizona also maintain measurement sites that become part of the State and Federal cooperative network. All conform to data management and quality assurance according to national standards.

These data become part of the Center for Disease Control and Prevention (CDC) Environmental Public Health Tracking Network (Meyer et al. 2006; Charleston et al. 2008). Not all U.S. States participate directly in the EPHTN. Arizona does not, for example. Sprigg et al. (2012, 2014) make a case for expanding the CDC network, at least to all western states, where epidemiological studies of windblown dust health impacts are starved for a longer and a more geographically dense record of PM measurements and disease surveillance.

The EPHTN aims for the ongoing assembly, integration, analysis, interpretation, and dissemination of environmental hazard, human exposure and health surveillance data (Meyer et al. 2006; Charleston et al. 2008). The CDC funds 26 state and local health departments to develop local tracking networks that contribute to the national network. English and Balmes (2004) and Wilhelm et al. (2008) give the example of California.

The ADEQ partners with more PM networks, increasing data access for all: the Chemical Speciation Network (CSN), the National Air Toxics Trends Stations

(NATTS), and the Interagency Monitoring of Protected Visual Environments (IMPROVE). The NATTS network is nationwide. The CSN is designed to determine trends in concentration of selected ions, metals, carbon species, and organic compounds in the $PM_{2.5}$ samples. The CSN has about 200 sites nationwide. In 2002 there were 160 sites associated with IMPROVE, most located in the west (UC Davis 2002). The whole is, indeed, other than the sum of the parts.

Furthermore, it is common to cast a broad net for more data on particulate air quality. One example comes from the ADEQ Urban Haze Network, with high-resolution cameras, transmissometers and nephelometers that monitor visibility (ADEQ, Visibility Index Oversight Committee 2003). Vukovic et al. (2014) used Doppler RADAR images to define the three-dimensions of an American haboob. The RADAR's radio waves bounced off the dust particles to reveal a picture of the storm that verified the model forecast.

4 Global Partners in Public Health Applications: Dust-Health Early Warning System—The Opportunity

Epidemiology, medical science and clinical evidence confirm that airborne dust is a health risk. Science and engineering have developed the tools to avoid much of that risk. And, the infrastructure to apply these tools for a healthier world is embedded in the missions of international, national, and local agencies and nongovernmental organizations.

4.1 A Conceptual Framework

The globally successful (Famine Early Warning System) begun in 1985 by the U.S. Agency for International Development, is a model for risk reduction and avoidance (Brown 2008). Research based analyses over an international federation of partners, delivers early warnings of environmental hazards and risks to agriculture and food production. A D-HEWS (Dust-Health Early Warning System) for health services can begin where dust forecast and simulation models are quasi-operational today and where they can be implemented with the earliest and greatest gain. A case in point: the African Sahel and wherever the dust and sand from the Sahara may travel, including to neighbors around the Mediterranean and the distant Caribbean and Americas. On the other side of the world, Asian dust events are a consequence as far eastward as the U.S., and routinely affect nearby Japan, Korea and Taiwan.

4.1.1 Global Dust Movement

The WMO Sand and Dust Storm Warning Advisory and Assessment System (WMO 2015) is operational today with forecasts and simulations of dust plumes on the hemispheric scale, generally depicting the 3-D presence of dust, in varying degrees of optical depth (AOD) or particle concentration, around 50 km spatial resolution. The global networks of observation systems, both satellite- and surface-based, monitor dust sources and plumes in real-time, and provide real-world data for model verification.

4.1.2 Regional and Local Dust Exposure

The synoptic scale forecast of near surface $PM_{2.5}$ or PM_{10} concentrations is ready for validation in routine health and safety service operations (Sprigg et al. 2014). These forecasts, covering, for example, the entire SW United States, have spatial resolutions less than 4 km, fine enough to resolve thunderstorm dynamics and haboob-forming processes (Vukovic et al. 2014). Forecast skills will continue to improve from scientific advances, perhaps, for example, by Janjic's 10 km global forecast model, by an expansion of the lidar system MPLNET, or by faster computers.

Rudiments of the synoptic scale warning system have been tested through the NASA sponsored projects mentioned earlier in Sect. 3.2, PHAiRS and ENPHASYS. Both focused on dust storm emissions of particulates ($PM_{2.5}$ and PM_{10}), their public health and safety consequences in the Southwest United States, how such conditions and their downwind plume concentrations may be predicted, and how to communicate results and find community solutions engaging science, service and the public (Morain et al. 2007, 2009; Sprigg et al. 2008, 2012).

4.1.3 Transdisciplinary Information Exchange (TIE)

The D-HEWS is an opportunity to "go global" with an international version of the CDC's National Public Health Tracking Network (www.cdc.gov/nceh/tracking and www.ephtracking.cdc.gov). The NPHTN attracts the necessary talent in scientists, data managers and practitioners because it addresses a problem that everyone recognizes is important, each participant takes an essential role in a consensus plan, and accomplishments are documented and clear. The TIE for D-HEWS, adapted from the NPHTN structure, is envisioned a catalyst for assembling and distributing information on the sources and makeup of airborne dust, the observed and modeled airborne dust concentrations, and a clearinghouse for the scientific literature documenting potential human health risks.

4.2 Implementation

The WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS), launched in 2007, responding to a request from more than forty countries to help address the health and safety issues surrounding windblown desert dust. From the system's implementation plan (WMO 2015), its purpose is to "… develop, refine and provide a basis for distributing to the global community products that are useful in reducing the adverse impacts of SDS and to assess impacts of the SDS process on society and nature." The WMO confidence in following through is undoubtedly based on many factors, including much improved, worldwide extent of environmental observations and dust measurements, advanced weather models, and the growing number of researchers attacking the problem.

A significant increase in airborne dust-related research publications (Stout et al. 2009), from 150 publications per year to 250 per year, roughly corresponds to greater access to in situ particulate air quality monitoring in the mid-1960s. The number of publications increased steadily to more than 500 per year in 1990, to approximately 900 per year in 1995. By 2012 the number jumped to some 7000 per year, as found in a *Google Scholar* search (WMO 2015) for "atmospheric dust Sahara" alone! Airborne dust forecast and simulation research from this author's team (e.g., Mahler et al. 2006; Yin and Sprigg 2010; Sprigg et al. 2008, 2012, 2014; Vukovic et al. 2014) and that of his contemporaries (e.g., Park and In 2003; Zhou et al. 2008; Grell and Baklanov 2011; Knippertz and Todd 2011; Pérez et al. 2006; Pérez García-Pando et al. 2014; Huang et al. 2015) has been stimulated in the 21st century by greater availability of in situ and space-based observations, computing power and advances in weather forecast modeling (e.g. Tanaka and Chiba 2005; Janjic et al. 2001, 2010; Janjic and Gall 2012; Adachi et al. 2013; Müller and Janjic 2015).

The goals and mission for the SDS-WAS welcome a D-HEWS: (a) delivery of information and technology along with local capability in their use, (b) receipt of information on local dust characteristics and health consequences, and (c) assessment of priorities for research and services. Its mission: enhance WMO Members' ability to deliver timely, quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities (WMO 2015). In 2008, two SDS-WAS regional centres were established in China and Spain. A third node of cooperation that will complete global coverage for the System is under consideration for Pan America. Countries participating now in SDS-WAS number more than fifty (WMO 2015).

The WMO has integrated the SDS-WAS into other global, international infrastructure to add resources and greater assurance of long-term operational stability. The WMO World Weather Research Programme and the Global Atmosphere Watch coordinate the System jointly. In 2014, the World Health Organization (WHO) and the WMO formed a joint office to improve application of research, observations and knowledge of weather and climate in matters of global environmental health. Thus, the mechanism exists for WMO and WHO collaboration in SDS-WAS to understand airborne dust contributions to air quality and human health for today and for future climates. From this collaboration, further ties to public health communities are virtually assured and include the International Federation of Red Cross and Red Crescent Societies the regional Pan-America Health Organization and the Caribbean Public Health Agency, and national and local public health service offices around the world. The charter of the International Federation of Red Cross and Red Crescent Societies (IFRC 2014a) is particularly apt, with a mission to build local capacity within high-risk and vulnerable communities (IFRC 2013) and support national societies to develop the "processes, systems and teams" for acting locally and linking globally (IFRC 2014b).

5 Conclusions: Best Practices in Technology Transfer, Capacity Building, Training and Education

Meiyan et al. (2015, p. 1) state intentions, or best practices, quite nicely for early warning weather systems in general:

> Increased media coverage and a perception of an acceleration in the occurrence of disasters has led to a public outcry for better information that will permit individuals to act in time to save their lives, property and livelihoods from damage. Thus, over the last 50 years, governments and the public have shifted from wanting to know *what the weather will be* to wanting to know *what the weather will do* (to socio-economic systems). Both want to mitigate and reduce disaster risks.

Dust forecasts through the WMO SDS-WAS will, of course, help in real-time risk avoidance. And model simulations of past dust conditions add to the air quality period of record, to building the capacity for epidemiological studies and to a deeper understanding of weather related health issues. Satellite pictures and forecast displays are important for education and raising public awareness of potential risks. Mobile apps and other public media allow rapid transfer of information to and from the public, researchers and forecast operations. Information and technology transfer, training for product production and use, and measures for assessing progress in "capacity building" would be done through "cooperation projects" that have the big picture in mind, integrated within the SDS-WAS, and leveraging health NGOs, local and regional resources, the WHO, PAHO and other intergovernmental agencies. And, research will keep feeding the system with new ideas and improvements.

All the necessary resources to launch a global, coordinated Dust-Health Early Warning System are available. Organizing them into an operational, federated system will require participation of the agencies and institutions that fund and manage them—and a plan. The quickest path to launch is through the agencies and organizations with a global mandate, but all who are integral to the system should be present, at least figuratively, from the beginning. So, local, regional and international health and environmental services will participate, as will medical, health and environmental sciences, without prejudice for either top-down or bottom-up guidance.

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Interdisciplinary Engagement of People and Place Around Extreme Weather

Sheila Lakshmi Steinberg

Abstract Extreme weather poses many challenges regardless of the specific environment. This chapter explores how extreme weather impacts people within their particular geographies by applying a new community engagement model. It answers the question, *why consider space, place and community in the planning process for extreme weather?* This chapter examines how people and place interact to influence community responses to extreme weather. An interdisciplinary community engagement strategy is presented as the best practice to establish effective engagement (communication and interaction) with people before extreme weather strikes. This requires meaningful social networks and trust with communities before planning, action and policy can be created. The best way to achieve meaningful community engagement is by employing a place-based interdisciplinary engagement strategy that builds on local culture, strengths and knowledge.

Keywords Community engagement · Place · Sociospatial · Extreme weather engagement · Place-based policy · Community health · Interdisciplinary

1 Introduction

The original idea for a book about extreme weather, health and communities arose after spending many hours sitting on the sidelines of our son's youth football practices and games. Sitting at these events, I observed some unexpected extreme weather (heat and storms). Clearly "normal" weather and climatic patterns for Southern California were shifting in a way that many community members were unaccustomed to experiencing. For instance, while attending our son's football game one October (a traditionally cooler month in California), unseasonably hot temperatures of 104 °F emerged, but the seven and eight year olds continued

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playing football with no extra water breaks! A similar experience happened while spectating at another game as an unexpected lightening storm broke out of nowhere. Again, the youth football game was not stopped due to the extreme and dangerous weather even though lightning strikes were occurring very close to the stadium! As a parent sitting in the stands I wondered, 'Why aren't they calling the game due to bad weather?' The most likely reason is that no policy for game cancellation due to lightening exists—since it rarely occurs in Southern California. Clearly, this was an example of atypical weather conditions, but local people still engaged with their surrounding physical environment based on previously established patterns and knowledge. By examining relationships between extreme weather, health, community strengths, and social networks, governments and communities can better prepare for action when extreme weather strikes.

Simply sitting and watching people's lack of response to extreme weather day after day spurred me to think that something is changing with the weather, but people are not doing anything to adjust their daily life patterns. To me, this was dangerous.

2 Extreme Weather and Changing Patterns

The term "extreme weather" conjures images of withered and cracked ground, homes being washed away by rising floodwaters or swirling black tornadoes ripping through neighborhoods in a frenetic swirl and sounding like a freight train. Such images have begun to appear with increasing intensity on major news networks on a fairly regular basis!

Images of extreme weather can be very vivid but may also emerge in more subtle forms. For instance, extreme weather is a more subtle ecological forms, when temperatures soar to unseasonal highs unexpected for a particular time of year. The 2015 heat wave in various parts of India produced temperatures of 122 °F on May 26, 2015 which is one degree short of the all time record of 123 °F recorded in 1956 (Burke 2015); this was illustrated in images of melting crosswalk paint dripping across the street. This heat wave resulted in the deaths of 1,100 people.

It seems like everyone has a vivid image of what extreme weather looks like—especially as it has become more common around the world. Increasingly, society is having greater first-hand experience with extreme weather scenarios! Since January 2012, the United States alone experienced 2188 days of record heat days, 1094 days of record rainfall and 245 days of record snowfall (Natural Resources Defense Council 2015). Both domestically and globally, societies are witnessing changing physical environments in the form of extreme weather. In fact, 2015 was the hottest year on record (World Meteorological Organization 2015). Extreme weather has a major impact on how people live, build and develop their communities by altering their surrounding environmental conditions. The years (2011–2015) have been described as the "warmest five-year period on record, with many extreme weather events—especially heatwaves" (World Meteorological Organization (WMO) 2015). In 2012, the United States experienced the most extreme weather since 1910, when record keeping began. Many places are beginning to face extreme weather episodes (e.g. Hurricane Sandy on the East Coast of the United States) not seen in over 100 years including Hurricane Patricia in October of 2015, which was "the strongest hurricane on record in the Western Hemisphere" (NOAA 2015). In December 2015, Chennai India experienced the effect of extreme rain and monsoon, experiencing, "the wettest December day in more than 100 years of records in Chennai" (Leister 2015a, b, p. 1).

2.1 Religious Leaders Note Environmental Changes

Major climatic changes are being noticed by the general public as well as being focused on by major global religious leaders such as Pope Francis, leader of the Catholic Church and His Holiness the Dalai Lama, a monk and more importantly the unrecognized leader of Tibet. In his Laudatoa Si "Praise Me," the theological treat is, Pope Francis said the following, "A very solid scientific consensus indicates that we are presently witnessing a disturbing warming of the climatic system. In recent decades this warming has been accompanied by a constant rise in the sea level and, it would appear, by an increase of extreme weather events, even if a scientifically determinable cause cannot be assigned to each particular phenomenon" (Associated Press 2015, p. 1). Much of Pope Francis's message while visiting the U.S. in 2015 centered on an ecological notion, that "everything is connected" (Cremers 2015, p. 1).

In June 2015, holiness the Dalai Lama participated in a three-day Global Compassion Summit which I attended at the University of California Irvine in Irvine, California. Both Pope Francis and the Dalai Lama have spoken out on a consistent basis about human impact on the environment and our need to be aware of and take action on climate change. The Dalai Lama recognizes the connection between climate change and general health. "The Tibetan Plateau needs to be protected, not just for Tibetans for the environmental health and sustainability of the entire world" (Macaskill 2015, p. 1), noted the Dalai Lama on October 20, 2015. Interestingly, the home into which His Holiness the Dalai Lama was born was situated on a hillside in a place that experienced lots of extreme weather. Here is a description of his home town, "Taktser (Roaring Tiger) was a small village that stood on a hill overlooking a broad valley. Its pastures had not been settled or farmed for long, only grazed by nomads. The reason for this was the unpredictability of the weather in that area" (Official Website of His Holiness the 14th Dalai Lama of Tibet 2015, p. 1).

In 2015 the Dalai Lama participated in the Global Compassion Summit with environmental scientists and activists that focused upon Global Climate Change. Figure 1 shows the Dalai Lama in conversation with noted professor of geophysics emeritus and Secretary of the Navy/Chief of Naval Operations Oceanography Chair at Scripps Institute of Oceanography in LaJolla, California. The fact that there are

Fig. 1 His holiness the Dalai Lama speaking with noted oceanographer Dr. Walter Munk at the global compassion summit, July 2015. Photo taken by author—Dr. Sheila L. Steinberg

religious leaders engaging thoughtfully with scientists in a public forum illustrates an example of interdisciplinary thought and engagement. Ultimately, the integrated and interdisciplinary an approach leads to a more complete and holistic view of a real-world problem.

2.2 *Extreme Weather and Places*

Extreme weather is as an unpredictable and intense force that continues to threaten existing patterns of life and health in places around the globe. Extreme weather has significant social and health costs (National Academy of Sciences 2015). Communities may find themselves proximate to flooding, tornados, extreme heat, blizzards and powerful storms. People develop patterns of settlement, commerce and industry around particular places, the climate, weather and resources.

Throughout the world many cities and towns were built along coastlines or rivers to facilitate transportation, commerce and to provide easy access to energy. The geographic location of such human settlements close to water sources means that more of these population centers are at risk to flooding and powerful storms. Each year, extreme weather creates natural disaster crises around the world that exert huge social and health costs (World Health Organization 2011). Between 2010 and 2012, 700 worldwide natural disasters affected more than 450 million people around the globe (Laframboise and Loko 2012).

Within the fields of public health, meteorology, environmental science and disaster planning, being able to identify populations affected by extreme weather is central to best preserving community health. By taking steps to understand local social and physical environments ahead of time, more effective extreme weather polices can be created. This is especially true in light of changing environmental conditions. In fact, in planning for different types of extreme weather, it is no longer adequate to simply view the "general population" as one homogenous group. Rather, there is an important call to identify vulnerable populations within a particular geography (Schmeltz et al. 2013; Ebi 2006). Every community, city or town has a diverse population, some will speak different languages, hold different values and maintain different social connections. In every community some people are more vulnerable than others due to their social class and often due to their differences.

This chapter examines the social challenges associated with extreme weather. It focuses on how to best meet communication and engagement challenges and addresses how to best preserve community health. I focus on an approach that could be useful to government leaders, policy makers, community members and scientists. This approach centers on how to adequately prepare and establish feasible plans and community structures in place before the extreme weather strikes. When extreme weather crises are on the horizon, it is important that social networks are in place, along with a socio-technologically feasible plan and messaging about how altered and changing environmental conditions will impact the community when storms strike. Such patterns of communication and understanding between scientists and the communities must be established well-before the disaster of extreme weather hits.

A question that emerges is ***what can a collaboration of scientists, policy makers, and community leaders can do to take action before extreme weather strikes?*** Clearly, failure to react produces negative economic results. In this chapter, interdisciplinary strategies to encourage appropriate communication, interaction and action with the diverse public are explored in light of the Extreme Weather Spatial Health Model (see Fig. 3).

3 Extreme Weather Community Health Model

Currently, much of the impact of extreme weather on people's health is not known, but continues to evolve under greater scrutiny (Yardley 2011; World Health Organization 2011). Scientists are paying increasing attention to the impacts of changing climate on human health in both urban and rural environments (Barata et al. 2011; McMichael et al. 2003; Costello et al. 2009). As extreme weather continues to occur, societies face altered physical environments that challenge currently established patterns of interaction and mobility. It is not surprising that people fail to change their already established patterns of interaction with the surrounding physical environment since their mobility and interaction patterns occur more of out of habit and familiarity with a daily routine more than anything else. For example, many rural people will hunt for certain animals according to the seasons and have established expectations about animal location and migration patterns. However, when physical changes occur in ecological environments, it alters animal mobility patterns, which then naturally leads to changed human mobility patterns around hunting. Animals that change their migration patterns may be doing so because of changing environmental conditions and it such cases would be considered an adaptation to their surroundings (Milner-Gulland et al. 2011; Cole et al. 2015). So naturally, local people who hunt these animals must adapt their patterns as well in order to thrive and to find food.

Changing weather and climates have direct consequences for negative health impacts, often simply because the extreme weather is unexpected and sometimes unprecedented in terms of impact. During extreme weather, people may face limited access to familiar, usual food sources because extreme weather makes travel difficult and even dangerous. The health and well-being of certain indigenous populations and communities such as the Inuit, are being impacted by such changes (Wilcox et al. 2012). Wilcox notes, “These changes are physically altering the local and regional landscapes around communities, and disrupt the ability of the Inuit to continue to practice and participate in culturally and socially-important land activities” (Wilcox 2012, p. 539). These activities include traditional subsistence practices such as hunting and fishing.

It is not surprising that extreme and changing weather patterns influence rural populations—who are closely tied to the ebb and flow of natural environments—but its also important to recognize that extreme weather troubles urban dwellers as well. Extreme weather can upset the normal balance and pattern of interaction within the larger environment. Extreme weather alters physical environments for communities, which naturally disrupts the flow of activity within places. Extreme weather essentially disrupts people’s normal daily activities. In a very short period of time, extreme weather can dramatically alter one’s mobility pattern and access to resources for meeting basic needs, such as food, water and shelter. Access to resources may quickly and totally disrupted throughout the entire local environment and region. For instance, when Hurricane Sandy hit New York City and New Jersey, it left many residents without access to clean drinking water, power, food, sanitation and access to services (Schmeltz et al. 2013). The extreme weather event of Hurricane Sandy put residents of two states into a marginalized situation with their surrounding natural environment. In other words—the Hurricane Sandy severely altered the local physical environment with flooding and storms, and the normal pattern of mobility within their surrounding natural environment was severely changed (Fig. 2).

In a case study of Brooklyn’s response to Hurricane Sandy, residents “experienced increased exposure to the elements and limited access to routine medical care” (Schmeltz et al. 2013, p. 800). The impact of extreme weather led to greater exposure to the elements and reduced access to health services, limited access to food and water and increased exposure to an unsanitary environment (Schmeltz et al. 2013).

Another example of how extreme weather impacts physical environment can be seen is in the continent of India, with the December 2015 monsoon rains, the

Fig. 2 Photo of Mantoloking, New Jersey after Hurricane Sandy. *Source* U.S. Coast Guard Accessed on 12/12/15. https://www.google.com/search?q=public+domain+photos+of+hurricane+sandy&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjuyZbosNzJAhUU6mMKHaIsBDQQ7AkIJw&biw=1920&bih=885#imgrc=2wum-4vZAFn3cM%3A

intensity of which has not been seen in the region for over 100 years (Leister 2015a, b). The city of Chennai, India, faced, "the wettest November in more than 20 years as more than 1016 mm (40 in.) of rain fell (NOAA 2015). Major airports had to be closed, especially in the city of Chennai. Many people living in the South Indian region were put at great health risk from flooding that resulted from the storms. Extreme flooding brings disease and reduced access to clean water.

3.1 Description of Extreme Weather Community Health Model

The Extreme Weather Community Health model (see Fig. 3) presents a framework to explore health challenges of punishing weather events. The model portrays the broad impact of extreme weather on community health. Each model component is defined and this is followed by an overall model flow description. A close look at this model begs the question: what can be done to meet the challenges of extreme weather impinging local patterns of local life and mobility? No one can control the weather, but best practices and plans can be put into place to prepare for action before extreme weather strikes.

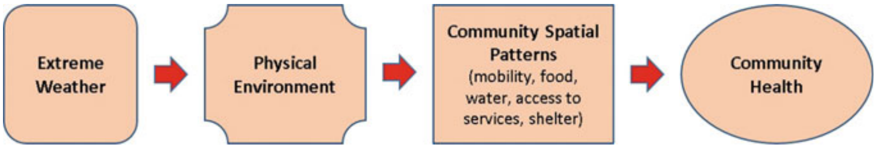

Fig. 3 Extreme weather community health model

Extreme Weather: extreme weather can be defined as meteorological conditions that are life-threatening. This severe weather may take the form of tornadoes, torrential rain, blizzards or snow storms, extreme heat, or intense wind, rain and dust. Extreme weather is a concern for the general population because it presents a set of uncharacteristic and unexpected climate. When this type of weather occurs it is very challenging for people who are not used to it, not prepared for it, and may not even expect it.

Physical Environment: the physical environment can be defined the environment that surrounds people in a particular place. It can consist of natural and/or human created structures. Extreme weather often causes alterations and changes in the surrounding physical environment. This may come in the form of raging floodwaters, tree-toppling windstorms and destroyed built communities.

Community Spatial Patterns: community spatial patterns can be defined as the regular interactions and mobility of people who live in a particular place. These patterns may include where local populations hunt, engage with one another, attend school or participate in a variety of activities related to civic life and engagement. According to the extreme weather environmental health model, patterns of mobility and daily life can be severely impacted by changing weather that is both unexpected and extreme.

Community Health: community health may be defined as the general health and well-being of a population, and its subpopulations, that live in a particular geographic region. In this model, community health will be affected by many factors that begin with extreme weather.

3.2 Model Flow

As we have seen, extreme weather manifests in a variety of forms and is the main driving force (or independent variable) in the model presented here. A particular physical environment can be impacted by extreme weather, but the impact of the extreme weather event will be mediated by local landscape, topography, proximity to water and degree of urbanization. Extreme weather is increasingly a force that is challenging many populations which reside in diverse physical environments. Physical differences exist, such as between urban and rural, or marine and coastal, environments. For example, snow many melt faster in a more urban, heat island, environment (Semadeni-Davies and Bengtsson 1998) than in a more rural, and less built and paved, urban environment.

When extreme weather and flooding destroys homes and businesses, for example, people's mobility is curtailed and household budgets go toward recovery while spending priorities, and the local economy and community services suffer. Once an altered physical environment emerges, attention must be given to the impacts on local community health.

Human health is impacted by extreme weather in many ways, including direct physical injuries, illnesses that result from polluted post-extreme weather environments, water-and-food-borne diseases, infectious diseases, death amongst the very young and the very old and malnutrition and mortality (Barata et al. 2011). Whether someone lives in the city or in the country, there will be daily patterns of interaction and mobility, for example around established home ranges. A home range is a term often used in biology to describe the mobility patterns of animals. The concept of home range can also be applied to people. Everyday people have natural patterns of movement in a particular locale. As we have seen, we go to work and school, we shop for food, and we participate in community activities. During an extreme weather event, people often lose access to these fundamental needs. Usually what follows is a lingering impact on community health. This can be especially important for the elderly, the very young, the poor and members of the community with special needs who already face challenges of mobility. Research by Reckien (2014) found that level of income directly determines the type of impact a population will experience from extreme weather. Reckien (2014, p. 1) from her research in Hyderabad, India explains, "rainstorms affect low-income residents more than heatwaves, while the opposite is true for medium-income respondents" who, she notes, "tend to be less seriously affected by extreme weather in general" (2014, p. 1).

Our next section presents a strategy for how to combat extreme weather including how to prepare and create meaningful interaction and engagement with local populations.

4 Extreme Weather Interdisciplinary Community Engagement

This section presents a strategy for extreme weather engagement, through discussing the important role of context. People's culture, geographic location, occupation and social status within a community all impacts how they interact with the surrounding natural environment. The best way to achieve effective community engagement is to employ that builds on local culture, strengths and knowledge about the local environment.

One learns from past life threatening weather events like Hurricane Sandy. In times of extreme weather, local people often first rely on themselves to respond to the event. This is especially true in more rural environments. Between 21 and 23 December, 1964, a major "thousand year flood" hit Northern California and specifically hard hit was Humboldt County, California where this author once lived (McGlaughlin 2014). "The '64 flood was caused by a deadly combination of weather events that dumped massive amounts of snow in the mountains, followed by warm rains that melted the snow and inundated local watersheds in a matter of hours" (McGlaughlin 2014, p. 1).

The Great Christmas Flood of 1964 happened a few years before I was born, but it was well-discussed in the local lore of Humboldt County. Descriptions of community geography and water levels from the flood are still documented to this day by signs along the U.S. 101 highway. Here is one Humboldt County survivor's brief description of the flood of 1964, "We were a family of 10 … sitting on two pieces of plywood in the attic of our home while the Eel River swirled around us and roared in our ears. A log came through the window and other logs shook the house" (Nunes 2014, p. 1).

Having lived in rural Humboldt County for about 11 years, I became keenly aware that in smaller, remote communities, people often help each other when there is a crises or a need-especially in relation to weather-related events. For life in a rural area, when disaster strikes, people pull together. As one survivor of the 1964 flood, who was 12 at the time noted, "It's funny how people come together in times of need and do extraordinary things. In our case, my family and our neighbors family worked together." She described how her father and a neighbor ventured out into the dangerous flood to bring "his family and his hired hand's family" to safety because it was safer with more than one person going alone. This same survivor notes, "At that point, we were all just one big family trying to get through an enormously stressful situation" (McGlaughlin 2014, p. 1). The fact that helping behavior emanates from within the community is great, but often true recovery means that a community also needs to rely on help from outside the community.

Therefore, if potential helping linkages within and between communities could be created ahead of time, prior to a weather disaster, it would translate into faster response when extreme weather hits. A major part of developing such a response can occur through reaching out to the populace in a particular area or region. In other words, community engagement become tantamount to successful extreme weather response.

4.1 What Is Community Engagement?

So what does the term community engagement mean? The term means a two-way interaction with people who live in a particular place. This type of interaction can occur through a variety of means such as face-to-face, online, using the radio and texting. Past efforts to reach out to populations concerning hazardous weather have often been one-way, that is, the relevant weather service has sent out a message to the public and does not necessarily expect an interaction or even a reply. For engagement to be most effective, a two-way flow of communication is best because this requires acknowledgement and engagement from member of the population. The challenge with enacting a two-way flow of communication is that it is more labor intensive and takes more pre-planning and thought.

5 Why Interdisciplinary?

Interdisciplinary means drawing from a variety of different perspectives with participants having some understanding of most, if not all, the other perspectives or disciplines involved. Interdisciplinary problem solving is very useful because it enables different angles and viewpoints of the problem to be applied simultaneously. One might ask the question: Why does effective problem solving necessitate interdisciplinary thinking? The answer is simple, because using an interdisciplinary perspective provides a better, more comprehensive understanding of the problem.

The notion of interdisciplinary thinking and approaches to extreme weather engagement naturally benefits from the inclusion of various perspectives. This ultimately helps craft a more holistic solution, based on environmental, social and economic systems, which are interdependent. When one thinks about the challenge of extreme weather and health, one realizes just how multi-faceted the issues are. So for instance, the issue of extreme weather can be approached through a variety of disciplines such as Sociology, Geography, Anthropology, Political Science, Meteorology and Environmental Studies. Each of these perspectives highlights a different aspect of the challenge, but each perspective, or field, or discipline, brings valuable understanding and focus. Because multiple disciplines are important to consider, we have settled on the notion of interdisciplinary engagement, which means that a variety of approaches and people with diverse skill-sets and backgrounds are incorporated into the engagement and solution.

It will be important to discuss some terms as we look at this notion of engagement. First of all the term interdisciplinary engagement means working with people using a variety of approaches that consider who they are and where they are geographically. It means engaging with people in the context of their potential role and place. It means that before engaging you must know and understand the population. If this does not occur the result will be unsatisfactory. It is almost impossible to work with people before establishing some sort of normed two-way flow of communication and interaction with them. The goal is to establish important networks that can be put into operation when an extreme weather event strikes.

The most important thing to recognize about engagement is that whatever engagement strategy is selected, it should fit the needs of the population being reached. One may start by asking, 'Who is the local population in a particular geographic area or place?'

6 Place

We define the term "place" as a geographic location that has meaning to a person or group of people. It too may exist physically or conceptually (Steinberg and Steinberg 2008). The definition of place can vary, but one overarching theme throughout is that the term "place" implies that they are all spaces which people have made meaningful (Cresswell 2004, 7). What does this mean? It means that one must be aware of the geography, lay of the land- and more importantly, what physical aspects of the environment are important to local communities. Examining the notion of "place" is important in the study of how changing physical environments due to extreme weather impact people. We consider place when trying to create effective engagement because "emphasizing place highlights climate change's effects where they are felt most acutely, where local strengths are best understood" (Hess 2008, p. 476).

It is important to begin with a discussion of space and place, since these two definitely impact the nature of human interaction with the surrounding environment. Space and place are important factors as one tries to understand a community in the context of its surrounding local environment. The terms "space" and "place" are terms often used interchangeably, but mean different things. The word "space" can be conceptualized as "the distance between places" (Steinberg and Steinberg 2015, p. 12) and is often used to determine position (Steinberg and Steinberg 2008). This is a construct that can be applied both conceptually and in-practice to real geographic distances.

We define the term "place" as a geographic location that has meaning to a person or group of people. It too may exist physically or conceptually (Steinberg and Steinberg 2008). The definition of place can vary, but one overarching theme throughout is that the term "place" implies that they are all spaces which people have made meaningful (Cresswell 2004, 7). Sociospatial Grounded Theory, developed by Steinberg and Steinberg 2006, 2015) lays out an effective approach for understanding place. Here is an overview of some of its components, first to define a geographic area of interest (Steinberg and Steinberg 2015, p. 204).

This would be followed by attempting to best understand the local, social environment, or to "define the community of interest" (Steinberg and Steinberg 2015, p. 205). The idea is that one wants to first understand and then define who lives in the community of interest. Good initial sources for U.S. data are compiled by the U.S. Census Bureau (U.S. Census 2015). One may also talk with local leaders (Steinberg and Steinberg 2015, 208), consult local commercial data sources and perhaps historical records from local government agencies, newspapers, business groups, schools and places of worship.

More information can be found through establishing relationships with local leaders from various sub-groups of the community. In any community, there are going to be leaders who step forward and are visible, but there are also going to be local ethnic and cultural groups that are not overtly visible and may be missed when people are trying to first communicate with people in a particular place.

6.1 *Sociospatial Strategies for Place-Based Policy*

A great way to better understand a local population is through a strategy that contextualizes people where they live, in their place. In other words, this can be described as place-based policy. The ability to develop place-based policy is dependent on sociospatial understanding of the community. The term sociospatial means that one must consider space, place and social indicators in a holistic fashion (Steinberg and Steinberg 2009, 2015). Sociospatial communication means that space, place and social indicators are part of the communication design process. A major challenge when dealing with extreme weather boils down to the simple act of communication. Communicating about extreme weather is clearly not one size fits all! A Sociospatial community engagement strategy occurs through a series of steps that work together to create a holistic strategy of space, community and place. Basically, the approach addresses the role of people within the context of their space and place.

Sociospatial strategies help facilitate place-based engagement. Being able to use a sociospatial perspective helps to enable interdisciplinary understanding of a place and the people who live there. It allows researchers, policy-makers and weather outreach personnel to better understand the larger population within a particular geography.

It is important to understand the role that local populations and physical geographies play in determining potential extreme weather situations and appropriate reactions/responses to these situations. A more important factor to examine is the method or approach used for data capture. To effectively capture the picture or story of people within the context of a particular place/environment requires skills with different methodologies and perspectives. The approach is multi-methods, iterative and involves the knowledge and experience of people who are local or indigenous to a place. It is based on a broad methodological approach called Sociospatial Grounded Theory (Steinberg and Steinberg 2006, 2015). In that approach, people begin to understand a place from the ground up, and based around local characteristics of the environment.

For communication and messaging about extreme weather to be truly effective it must be considerate of the local population and it's culture. So, for instance, if you are trying to communicate to people in a rural area without an extensive Internet service and weak wireless connections, depending on an Internet communication strategy is not likely to succeed. However, another major means of communication that many rural people use—the radio—might be a better strategy for communicating. In many rural communities-the local radio stations often is regional communications hub for many people in the region, especially if it is locally owned and operated. Hence, one must consider the type of population and subpopulations that are under threat of extreme weather events, because "one-size fits all" does not apply! Those who make policy related to extreme weather notification and response should have the motto, *know your people, know your place, before you choose to act*. The strategies that work to communicate with some people in one place may not work in another place simply given the geography and local culture.

6.2 Understanding People Community/Culture

Establishing "community" means generating a sense of oneness or general holism. Community is definitely tied to place. This only evolves through meaningful interaction, which should be two-way, and is based upon trust. Too often, important information tries to be communicated to a certain particular sector of the population, but without prior footwork to establish a solid base and connection.

It is also important to consider stakeholder diversity—part of the process of creating solid place-based policy. Place-based policy means that decisions or actions are created in sync with a particular geography or place (Steinberg and Steinberg 2015, p. 372).

Cultures are shared norms and practices of a people or group. And different cultures definitely exist within a community. It is important to consider the role of culture and how it can vary greatly within a particular place. Culture will also be a mediating factor that influences how different community members will react and respond to extreme-weather.

Place is central to managing health related consequences of climate change (Wilcox et al. 2012). Wilcox et al. (2012) has explained the importance of place being "consider the importance of place … to manage the health-related effects of climate change in locally-appropriate and culturally-relevant manner, and … acknowledging that different groups and populations require different approaches to healthcare programs and service in response to changing climatic and environmental conditions depending on place and geographic location" (Wilcox et al. 2012, p. 54).

Throughout this chapter we have focused much on the concept of community. What do we mean when we say the word "community"? Community is being used to describe a group of people who are situated within a particular geography and who interact with one another on a consistent basis. This group most likely has shared norms, values and language. It should be noted that within a particular geographic region there can be multiple communities. There can be a dominant community with many sub-populations and sub communities; there can be wealthier and poorer members of the population as well. It is very important to be aware of all of these different groupings within a particular geography. If emergency planners, policy makers and scientists reach out to one particular group within the geographic region the other groups will be left behind. This in turn creates further vulnerability for populations that do not speak the same language as the message that is being conveyed. Additionally, it extends beyond language, to also include the populations that may lack certain means of high-tech communication as well.

One might be thinking, why is it important to consider community? It is important because recognition of the population characteristics gives a better sense for how best to best communicate and engage. This is understanding people in a particular place. Community engagement is the vehicle through which this can occur. In identifying the local culture and community, some things to consider are:

- Who are the local populations within a particular geographic area?
- What are the cultural attitudes and values? What were their past practices related to extreme weather responses?
- How do the local populations communicate? What is the best media for communication-face-to-face, email, phone, radio?
- What are local norms and practices for interacting with the weather?
- How do local norms and past experiences with weather translate into action?

By asking these questions ahead of time, scientists, emergency planners and community leaders can be more effective and inclusive in their outreach efforts.

6.3 How Context (Space or Proximity) Influences Outcome

This section examines the challenges to place-based communication and action based around extreme weather. Extreme weather by its nature is a threat to effective and appropriate action and communication around these events. As noted earlier, the unique interdisciplinary engagement approach draws on multiple disciplinary approaches that span both the physical and social sciences. Know the people, know the place, and if you understand risk—one can be prepared for extreme weather. It all hinges on being correctly networked with local people and having a solid plan of action.

Anytime one tries to understand a demographic group it is important to consider where geographically this group is located, especially their proximity to other places, people and political boundaries. For instance, Branton et al. (2007) examined the contextual factors affecting voting patterns on highly charged U.S.-based propositions related to immigration. In the United States, the issue of immigration is hotly contested, especially in states along the U.S.-Mexico border. Anti-immigrant sentiments often prevail in these geographic areas. Studies have indicated that a person's spatial proximity to the border influenced how they vote. The closer one was to the U.S.-Mexico border, the more likely they would support anti-immigrant or "nativist" propositions and policies (Branton 2004). Their study also revealed that Anglo (White) Democrats living closer to the border were more likely to vote in favor of the policies targeting immigrants than Anglo Democrats living further away from the border. Their study also found that Republicans, no matter where they are located are likely to support anti-immigrant policy and legislation (Branton 2004). From these voting examples, one can see that place, space, geography and location matter in terms of social perspectives.

7 Knowledge About the Local Environment

We tend to call the experience and understanding of the local community, local knowledge. In other words, what people do in their community depends on geographic location, surrounding physical environment, type of community, social, ethnic and economic make up of the place. Many times, people who live in a local community possess the best knowledge about their surrounding natural environment. But often the extensive local knowledge is kept inside people's heads and is unfortunately not shared with others. People may think of a 'what if' scenario-such as, 'where will everybody go if a flood or tsunami comes?' But more likely than not, local people who live in a particular place have developed a particular understanding and knowledge about their surrounding environment knowledge and data which they will put into place to make quick decisions and to take action when extreme weather strikes. This is especially true if they are responding to extreme weather situations that they are familiar with and have experienced in the past. It becomes more challenging to react and respond to extreme weather when it is unfamiliar to the local community and may not have already been woven into the local knowledge about place, space and weather. Sippel et al. (2015, p. 225) note, "Dialogue between the parties, therefore, not only allows the science to be framed within one context, but also helps to situate the science in a range of contexts, providing parties with an equal stake in the knowledge construction." Science will be better understood if it is framed within the local context of place and environment, which is usually a part of community knowledge and experience.

When I was a U.S. Peace Corps Volunteer in Guatemala in the early 1990s, I was impressed at how, without access to any formal description of the weather, villagers were keenly aware of local weather patterns and signs for what kind of weather was coming! This was especially true in the case of rain, an important necessity for the famers who lived in my village. After living in Guatemala for a certain period of time, I learned to recognize some of the weather related signs too. What I realized through my U.S. Peace Corps overseas experience is that people living in a particular place really do develop an understanding for their environment and local weather patterns. In those remote, rural, small place, people did not rely upon a centralized form of communication to understand what was happening with the weather, they simply made their own observations. This occurs often out of necessity for maintaining their local livelihoods, especially they are involved in agriculture. Or it could just be a natural skill, developed over time as people live in a particular environment.

What such rural remote villages don't have is the science to back up their actions. What they do have is the best understanding of two important things, (1) regular patterns of the local geography/environment in a particular place and (2) a solid understanding of local people or community members and their patterns and (3) a general understanding of normal weather patterns for their community. Why is this important? It's important because if someone wants to develop policy to combat the challenge of extreme weather, they first need to know something about people in the place and how they interact with their local environment, under both normal and abnormal, extreme weather conditions. Additionally, it will be important to draw in local people's knowledge and experience with their surrounding natural environment as part of the extreme weather planning and policy process.

It should be noted that a community member's past experience and interaction with the local environment naturally directs future attitude, action and response to environmental change. Therefore, it is important to identify physical factors of the context (e.g. rural/urban or desert, woods, or seaside). Higgenbotham et al. (2014) found that in a study of environmental behaviors in Australia, the rural population "was attuned to conditions affecting agricultural productivity: they worried about drought and heat, saw trees dying and changes to seasons and natural rhythms" (2014, p. 699).

7.1 Geographies and Community Type

In any community there are going to be areas physically vulnerable to extreme weather. There can be vulnerable areas in both rural and urban areas, but the nature of the vulnerability will be different. The goal is to be able to understand the structure of the local physical environment and the people who live within these specific place boundaries. One question to consider is what are the biggest threats to the local population? For instance, who lives in a coastal zone? Who lives on a hillside and what happens to that community when it rains? Traditionally, wealthier residents are more fortified and have the resources to cope with the unexpected challenges that emerge through extreme weather, but the general public and poorer populations often lack that choice. When agencies and weather experts begin to realize the diversity of stakeholders living in a community they can better understand what to consider as part of a best strategy for engagement and education with the local people. One must first be able to understand the local physical challenges associated with living in a particular place before actively doing something, like planning for extreme weather. Adopting an interdisciplinary approach enables one to understand policy issues from a number of various perspectives.

Different geographies (e.g. urban, rural, suburban) consist of different types of people and cultures. People will know something about the environment in which they live, and what they need to do to survive there. Their knowledge about their surrounding natural environment usually comes over time and through experience dealing with bad environment under various circumstances.

It has become more common to recognize the important role of local knowledge in defining and understanding a particular emergency situation (Elwood and Leitner 2003; Hoeschele 1998; Sieber 2003; Robiglio et al. 2003; Robbins 2001, 2003). Local response and interpretation of an event boils down to perception, an understanding of the local environmental situation or problem that is occurring based on extreme weather. People who have spent a lot of time in a particular geographic locale, are going to have a fairly good understanding of the ebbs and flows of local and regional climate and weather patterns. This knowledge and understanding of weather in a particular place is something that comes through interaction, persistent and ongoing interaction, with the surrounding natural environs. Unfortunately, many times the knowledge and understanding of the local people who live in a particular place is not effectively drawn upon.

8 Importance of Community Engagement

Scientific experts and leaders of various emergency response organizations often fail to recognize the extremely important local knowledge. What are local knowledge structures and how does one develop them? Perhaps the easiest example is of an American Indian tribe that makes it's living through hunting and fishing in a particular coastal climate. The tribe that subsists on the surrounding natural resources will, organically over time, develop a very solid understanding of regional weather patterns and the geographic presence of particular animals and ecological species.

When extreme weather occurs over some length of time, noticeable changes begin to occur, such as animal migration and the presence or absence of ecological elements. Recently, in Southern California where I live, a marked increase has occurred in the number of different shark species that perpetually hang around various populated beaches in Orange County, California. This situation is unique in that these types of sharks (Hammerhead and Great White) have never appeared on a regular basis so proximate to the Orange County Beaches. Scientists have tried to explain their presence by noting that ocean temperatures have warmed and the fish that the sharks feed on have moved into the area. This creates a health hazard in the sense that if you go swimming in the ocean these days in Orange County, not only do you have to watch out for rip tides but you also must be on the look out for sharks as well! This is a good example of local climate and environment physically changing, with consequences for shark food sources, and overall mobility patterns of the sea creatures.

Often when scientists or "experts" define a situation, the local knowledge and perceptions are left out or ignored. To best prepare and respond to extreme weather, it is central to incorporate any local or "indigenous" knowledge about the places where they live into the planning process. One way to do this is through using an approach called Public Participation Geographic Information Systems (PPGIS). It is a great method to engage local people in defining their situation spatially, where they become involved. The term GIS is an acronym for the word Geographic Information Systems which is really computerized mapping. Local people know their local area and will sense when things start to look a little different and are out of sorts.

This community engagement approach is not without its challenges. It can sometimes produce differing perceptions of the context based on who the observers are and observer bias (Robbins 2003). In his study environmental knowledge in India, Robbins (2003) found that both animal herders and professional foresters viewed the natural resources based on their cultural backgrounds. Basically, local perceptions of a natural resources were influenced by an individual's occupation and experience with the resource. After this study, the researcher noted the need to have a more targeted approach to bring together differing versions of spatial data (e.g. GIS expert versus local indigenous expert).

8.1 Interdisciplinary Teaming for Engagement

The term "interdisciplinary" brings together various aspects and approaches and integrates them into a larger whole. Different approaches for engagement with the public can be assembled, depending on the type of population being focused upon. Is it rural, urban, suburban or a combination? Interdisciplinary team strategies focus on creating teams of people from different backgrounds and areas of expertise that can work together. It also means that different sectors of the local population will be engaged in the conversation.

The question emerges, what is the value of using interdisciplinary teams to manage extreme weather responses and to increase positive health outcomes? Interdisciplinary teams work because there are people on the team with different areas of expertise, some who speak different languages and who bring overarching different skills to the team. Interdisciplinary teams create a better chance of success because the community is being approached through a multi-pronged and more robust process that facilitates more points of possible contact and engagement with the local community. Ultimately that is the greatest strength of an interdisciplinary approach.

To effectively assess a community's environment/health interaction it is imperative to have interdisciplinary approaches. This can help to account for challenges in transportation, mobility and ultimately in different levels and types of health expertise. Extreme weather will bring a variety of physical, environmental and social impacts, therefore a group of people is needed who can best understand and communicate with the public, and listen and react to the experience and ideas that the lay public and communities share. Sippel et al. (2015, p. 225) note, "a mutual exchange of information can support decision-makers' understanding."

9 Place-Based Interdisciplinary Approaches for Extreme Weather Engagement

Place-based Interdisciplinary approaches are built around the local environment and the people who inhabit it. Because local geography and environment often impact the way local people live on a daily basis, including their patterns of mobility, is extremely important when considering place as a design strategies for engaging extreme weather.

When planning local engagement around extreme weather, it is important to engage with communities using place and geography as a focus. This is because people who live shared geography are experiencing similar environmental conditions and extreme weather threats.

A goal of place-based interdisciplinary engagement is health action, taking action that will benefit people's health. This can take many different forms, from administering vaccine to moving people to higher ground if flooding is a threat.

In the field of public health there is the term, "adaptive capacity," which "reflects the ability of health systems to address, plan for, or adapt to adverse climate-related health outcomes and take advantage of new opportunities and benefits" (Berrang-Ford et al. 2012, p.1068). When planning for extreme weather, the same strategy can be employed.

9.1 Navigating Local Geographies

It is important to recognize that there are different levels of people and place. We refer to these as different geographies. The geographies that people operate in are diverse: there are social geographies defined by the boundaries and social networks that groups establish between themselves; conceptual geographies based upon groups' definitions of what places mean; and actual physical geographies or features of the physical environment that influence people and their interactions.

This chapter has presented an interdisciplinary model to understand people and extreme weather and communities in which they live. It is clear that the most successful engagements are built around interdisciplinary approaches that actively consider people in the context of their place—the culture, the local strengths, and their surrounding physical environment. Best practices for creating place-based effective communication strategies are presented next. The following precepts offer recommended actions to help create place-based communications and engagement. From a policy standpoint, if these rules are followed it will present more opportunity for effective action and response to extreme weather.

9.2 Interaction, Establish Consistent & Ongoing Interaction

One should create various opportunities for interaction that will resonate with people (e.g. create activities that foster interaction and sharing). According to the Interactional Theory of Community the definition of community is based upon interaction. The interactional perspective of community is based around the Community Field Theory (Wilkinson 1991). Community Field Theory is relevant to our discussion of interaction because it posits that community consists of three important elements: a locality, a local society and a process of locality oriented social interaction (Wilkinson 1991). The locality can be described as the place where people live and "meet their daily needs together." (Wilkinson 1991, p. 2). The best way to create community is to establish a regularity of patterned interaction. This is where the challenge of geography might come into play. However, within any community there are always places where face to face interaction happens.

Interaction is a shared nature of exchange that people have with one another. The term implies a two-way flow of information in general. This could consist of speech, communication, emails, sign language and other means. It is important for any engagement and communication effort to Establish Connections/Interaction with vulnerable populations. Create and vary opportunities for interaction that will resonate with local people (e.g. allow for communication via a variety of channels, face to face, online, and on radio and television).

Unfortunately, many times the knowledge that scientists possess and attempt to share is not adequately adopted or used by the general public (Saraweitz and Pielke 2007). But why? The most likely answer is because this information has been created in a manner that has not taken the local people or stakeholders into account. In other words the science may lack perspective. Then, too, the information may be too esoteric or jargon filled for a lay public to understand. Klos et al. (2015, p. 239) note, "although end user and expert engagement has been conducted at national and regional scales, there is a need for targeted engagement at finer scales to address the needs of local end users".

9.3 Know Your Culture/Community

It takes effort, time, trust and interaction to establish a culture of trust among scientists, policy-makers and the broader community. Once established, further effort is needed around interaction and trust to keep the already established relationship going. Take time to nurture community and culture, and communication/interaction among scientists, policy-makers and the public can occur in a variety of arenas, such as the workplace, the classroom and the clubs and service groups within the community. If scientist make interaction and communication with local people a priority then better overall channels of communication will be established and a better understanding of stakeholders will occur.

An important part of doing this means that "stakeholder diversity" must be considered. What does this mean? Stakeholder diversity means that, "at the beginning of any policy-making process, it is best to develop an understanding of your stakeholders, their cultures, orientations, responses, practices, and reactions" (Steinberg and Steinberg 2015, p. 373). The best way to understand stakeholder diversity is to consider social and demographic data on a particular place. Such data are usually readily available from a government-developed census. In the United States, a U.S. Census is conducted by the U.S. Department of Commerce every 10 years. Doing so enables both government and anyone with an interest in this topic to access this publicly available information about their communities.

9.4 Understand General Population and Sub-populations

Identify socio-cultural and socio-economic factors (e.g. ethnic culture, social class, first generation student, immigrant). What method is used to identify, understand, engage with and communicate with the stakeholders? What people are impacted by the extreme weather? It is important to recognize that a population's vulnerability varies with geography and social status. The health and well being of people who live in different physical environments is likely going to be impacted differently by extreme weather and climate. The International Monetary Fund has found that, "people in developing economies are more likely to live in high-risk areas, and those countries have a weak infrastructure" (Lafamboise and Acevedo 2014, p. 1). Furthermore, this same study found that "the most vulnerable members of society, both in high- and low-income countries are the major victims of natural disasters."

9.5 Establish Trust

If a particular community group or governmental agency is able to reach out to various sub-communities in a region before the extreme weather strikes it will foster better results for a sustainable period of time. Building trust is another reason for identifying the most appropriate modes of communication for a particular region. As mentioned earlier in the chapter, usually for poorer and more rural regions radio, word of mouth and face-to-face communication are the main way that communication occurs.

Trust means the ability to count on one another and to have faith in the communication and norms of the interaction. Various researchers have noted the importance of trust as central to the communication and engagement process (Cash et al. 2003; Kahan et al. 2012). The common understanding and agreed upon norms of communication and solid interaction is what leads to trust. The best way to establish trust is, as with other tenets, to first understand local community strengths.

A very solid way to create trust is to involve in the process well-respected leaders from all the different communities and sub-communities being engaged. Doing this early on in the engagement process will ensure that those who may be hesitant to interact with an outsider or outside agency will do so if respected leaders are already on board with the team.

9.6 Engage Using Interdisciplinary Teams with Different Sectors of the Community

One goal is to make sure that the teams selected to work together are diverse across gender, age, ethnic and length of time with the company standpoints. Greater diversity of teamwork will produce overall better results. Interdisciplinary teams will explore and test different approaches to communication, and to thinking about important factors, priorities and the order in which they must be addressed in order to ameliorate the impacts of extreme weather events.

It is important to think about engaging with different sectors of the community no matter which of your communication and engagement strategies are employed. This is because different sectors will respond differently to extreme weather challenges. Responses will take form because of different geographic location, different values, and different access to information and understanding about how local events are unfolding. But always, local people will have their networks and strategies for communicating with one another. A good strategy is to tap into some of these already existing local networks to try to achieve the best and most effective communication possible.

One should establish a regularity of patterned interaction. This interaction can occur through a variety of media. But the beginnings of such interaction should be face-to-face, and then branch out to other means, such as digital media and radio.

9.7 Create Two-Way Place-Based Communication

When designing effective stakeholder communication one wants to ensure a solid understanding of the local population and sub-populations before attempting to communicate. A successful model of communication and engagement is about creating meaningful in-roads and social connections with the public. It's also about being able to consider culture as a designing principal for communication. Scientists and weather experts have important knowledge, but the packaging and sharing of that knowledge with people in various places needs to be examined, especially in light of the usual one-size-fits-all approach to communication. When that happens, communications fall short and fail to be effective.

9.8 Choosing a Reasonable Plan for Stakeholders

When it comes to developing local policy there are many things that an organization can put its efforts into. It is important to choose actions that can be accomplished by the team and within the resources available. Once a good strong understanding of people has been developed, including perceptions of cultural norms and values, and their own interaction with the physical environment, the population at risk can be engaged to jointly develop steps for action. If a clear understanding of the population and sub-populations is established, a more efficient use of resources can be made to cope with weather and climate extremes.

It is never too early to plan for extreme weather. Unfortunately, because of competing challenges for communities around the world, such as meeting basic needs of survival, the notion of planning for an extreme weather event often gets lost. However, past practice has shown that being ready, and having a plan in place is the best strategy for effective response to extreme weather. Some questions to answer as part of the extreme weather planning process are: (1) What kinds of extreme weather is expected to be encountered? (2) Where, geographically, is the extreme weather expected to strike? (3) Who will be affected? (4) Where are people going to gather for safety in case of extreme weather?

It is necessary to create an Extreme Weather Community Network before the extreme weather strikes. It is important to think about taking action **before** the extreme weather strikes. Such a network may consist of local community leaders, scientists who understand the local extreme weather threats, and local weather and health agency people who understand what needs to happen for the local population to stay safe or to seek help. It could also include teachers and educators from the local community, along with local media people who understand how to reach people throughout the affected regions.

10 Conclusion

This chapter has laid out a series of challenges and steps for extreme weather community engagement. An attempt has been made to model the various factors that explain how extreme weather effects the community and local public health. Furthermore, an interdisciplinary engagement strategy has been constructed around best practices for scientist/community interaction and engagement. Extreme weather will continue to impact many people and places around the world. It is important to be ready for these evolving climate shifts and any resulting extreme weather.

Ultimately, the best practice is to engage early and often to establish trust and to create solid communication networks with communities before an extreme weather crisis. When extreme weather hits it is often swift and with a severe impact. Therefore, meaningful local networks and place-based plans need to be established prior to the occurrence of extreme weather. Using interdisciplinary engagement strategies will enable the consideration of people in the context of their place as part of the policy process. It is generally good policy (Steinberg and Steinberg 2015). This approach, along with considering stakeholder diversity and actively considering socioeconomic and physical-science data about places, will ultimately lead to more effective action and prevention against extreme weather.

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Engaging Communities to Assess the Health Effects of Extreme Weather in the Arctic

David Driscoll and George Luber

Abstract The environmental effects of climate change are likely having negative impacts on the health of the 13.1 million residents of the circumpolar north. In this chapter, we describe an observational epidemiologic study that collected surveillance data on local environmental changes and associated health outcomes from residents of communities in Northwest, Interior, and Southeast Alaska. To assess the health effects of climate change in Alaska, two rounds of sentinel surveillance data were collected for 12 months, each on unusual weather conditions and the health outcomes associated with those conditions in three ecologically-distinct regions of the state. Qualitative data was also collected utilizing in-depth interviews and community meetings with community residents. We evaluated statistical associations between two exposures; unusual weather conditions and participant changes in travel as a result of unusual weather conditions, with a variety of health outcomes and health outcome mediators. Qualitative responses were analyzed to better understand these associations. We found significant associations between unusual weather conditions and cold-related morbidity and mortality in two rounds of surveillance data collection across the state. The nature and timing of such outcomes were seasonal in nature, and indicated health outcomes from the increasing prevalence of icy conditions in winter, and unusually warm and dry conditions in summer, in northwest and central regions of Alaska. Further, discussions of the surveillance data with local residents provided insights into prospective causal relationships between environmental events and the health outcomes described.

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1 The Setting: The Physical Landscape

Residents of the circumpolar north, those regions of the globe within or bordering the Arctic Circle, are experiencing rapid environmental change to a greater extent than those of other regions. Climate records in Alaska indicate that the average temperature in portions of the state have warmed nearly twice the global average since the 1950s (Huntington et al. 2005; Hinzman et al. 2005). These environment effects are ubiquitous, and have been measured in changes to the circumpolar terrestrial, atmospheric, hydrologic and marine systems, including extreme weather, the degradation of permafrost, loss of sea ice, and warming and acidification of seawater (Huntington et al. 2005; Hinzman et al. 2005; Blunden and Arndt 2012).

Alaska's broad geographic spread includes distinct regions with a diversity of climate vulnerabilities, different populations and various adaptation needs. This chapter focuses on residents of communities in three ecologically-distinct regions of the state; Southeast, Interior, and Northwest Alaska. The Southeast region of Alaska has a cool, moist climate. The average annual rainfall in the region exceeds 150 in., and the annual average snowfall exceeds 36 in. The average high temperature in July is 65 °F, and the average high temperature in January is 39 °F. The Alaskan Interior experiences seasonal temperature extremes. Temperatures can be as low as −60 °F in mid-winter, and as high as 85 °F in the summer. The average annual precipitation is generally low, just exceeding 12 in., but flooding can be associated with rapid snowmelt in the spring and early summer. The Northwest Arctic Borough has a cool to cold climate. Average annual rainfall is 9 in.; average annual snowfall is 47 in. The average high temperature in July is 58 °F, and the average high temperature in January is 5 °F (Fig. 1).

1.1 Climate Change in Alaska: Observed and Expected Changes

1.1.1 Rising Temperatures

Since 1950, Alaska's land surface temperature has warmed more than twice as rapidly as the rest of the United States, with average annual temperature increasing by 3 °F and average winter temperature by 6 °F (Chapin et al. 2014). This rate of warming exceeds that of any other region on earth (Chapin et al. 2014). Looking into the future, Alaska's average annual temperature is projected to rise by an additional 2–4 °F by 2050 (Stewart et al. 2013). If greenhouse gas emissions continue to increase to the end of the century, temperatures can potentially rise as

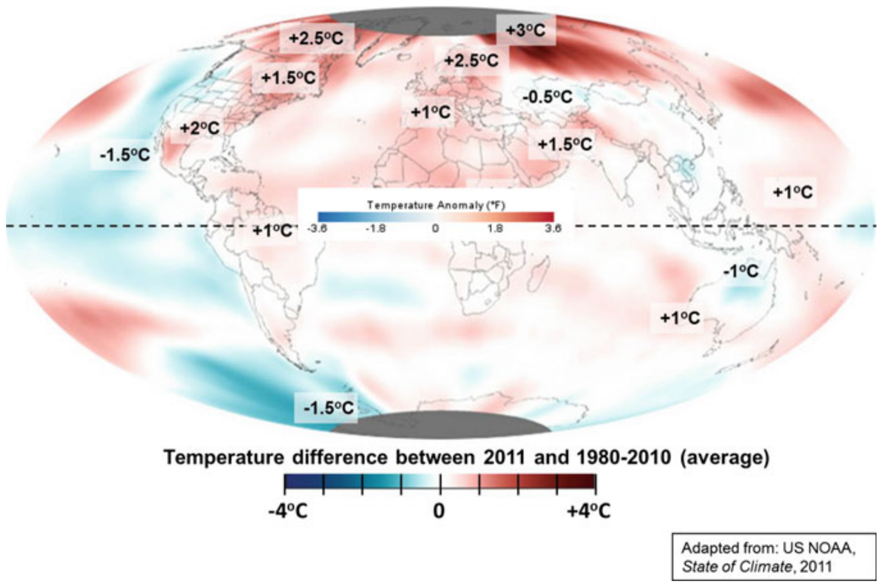

Fig. 1 "Prospects for a Warming Planet: A Tripolar View" Slide used courtesy of Tony McMichael, World Congress of Epidemiology. Anchorage, Alaska: August 2014

much as 10–12 °F in the north, 8–10 °F in the interior, and 6–8 °F in the rest of the state by 2100. Even with substantial emissions reductions, Alaska is projected to warm by 6–8 °F in the north and 4–6 °F in the rest of the state by the end of the century (Chapin et al. 2014). In general, the rate of future warming in Alaska is expected to exceed the global rate. This warming can bring significant changes to the ecology of Alaska. For example, the boreal forest, covering much of the lower latitudes, is generally projected by climate/land-cover models to move northward under a warming climate, which will displace between 11 and 50 % of the tundra within 100 years (Callaghan et al. 2005; Wolf et al. 2008; Tchebakova et al. 2009).

1.1.2 Warming Oceans

The oceans of the world can be considered the "engine" of the global climate; serving to store and transport the energy in the earth's system throughout the globe. Oceans, especially high latitude oceans have shown a strong warming trend in the last century (Rhein 2013). A warming ocean is particularly problematic for Artic communities due the close connections of coastal Alaskan communities to the ocean. An important consequence of a warming ocean is its impact on sea ice. The overall spatial extent of sea ice maximum has decreased from 1979 to 2012 at a rate between 3.5 and 4.1 % per decade, or 0.45–0.51 million km^2 per decade (Comiso 2012; Comiso and Nishio 2008). Sea ice extent at the summer minimum has decreased more rapidly in recent decades; decreasing between 1979–2012 at a rate of 11.5 % per decade, or 0.73–1.07 million km^2 per decade (Comiso 2012). In fact, the Arctic Ocean is projected to become nearly ice free in summer within this century (Chapin et al. 2014).

In addition to a reduction in the extent of sea ice, Alaskan's are also experiencing a reduction in the quality and stability of this ice as a result of its thinning. In fact, the average winter sea ice thickness within the Arctic Basin has decreased 1.3–2.3 m between 1980 and 2008 (Kwok 2009; Kwok and Rothrock 2009; Rothrock et al. 2008). The extent and thickness of sea ice particularly important for coastal communities that rely upon it for transportation to and from hunting areas (Krupnik et al. 2010); thin ice, as one can imagine, is dangerous. Coastal Native Alaskan communities in particular have a close relationship with sea ice as many of the marine mammals that they hunt are found on or near the ice. These include various species of whales, seals, sea lions, and even occasionally, polar bears. Thin ice makes hunting on the sea margin especially dangerous.

1.1.3 Decreased Freshwater Ice and Snow Cover

These changes in sea ice are also mirrored in freshwater ice, where the duration of lake and river ice is decreasing and the average thickness of ice cover has diminished (Wang et al. 2012). The annual winter freeze up is occurring later in the year and the spring break up is occurring earlier, increasing the ice-free season by 24 days, compared with 1950 (Surdu et al. 2014). In addition to seasonal lake and river ice, permanent (multi-seasonal) ice is also seeing a reduction. Worldwide, almost all glaciers have experienced shrinkage (Jacob et al. 2012; WGMS 2008), and in the Arctic, glaciers have been receding at the fastest pace on earth (Thomson et al. 2011). The warming trend in the Arctic is also reflected in the general decline in area covered by snow. From 1967–2012, the spatial extent of snow cover has decreased in the Northern Hemisphere. The largest decline of snow cover, of 53 % was measured in the month of June (Derkson and Brown 2012). In addition to reductions in the amount of area covered by snow, the length of the snow season in the Northern hemisphere has declined by an average of 5.3 days per decade since the winter of 1972–73 (Choi et al. 2010).

1.1.4 Thawing Permafrost

Permafrost, which is a subsurface layer of soil and ice that remains frozen throughout the year, underlies much of interior Alaska. The warming trend in land surface temperature have also affected permafrost temperatures. Since the mid-1980s, Alaskan coastal permafrost temperatures have increased between 6 and 8 °F at 3.3 foot depth. The temperature increase for colder, interior and southern Alaskan permafrost is less, but is nearing the thaw point (Romanovsky et al. 2008). This trend is expected to continue, with some climate models projecting that near surface permafrost will be entirely absent from large parts of Alaska by the end of the century (Jafarov et al. 2012). Surface subsidence associated with thawing of ice-rich permafrost has been occurring in many parts of Alaska over the past 2–3 decades. For example, sites on the North Slope of Alaska have measured an 11–13 cm in surface subsidence over the period 2001–2006 (Streletskiy et al. 2008). This thawing has significant consequences as it can lead to subsidence of the surface material above it, impacting building, and infrastructure such as roads, pipes and power lines.

1.1.5 Changes in Extremes

Alaska is no stranger to extreme weather, and in a future world with climate change, Alaska will experience some significant changes, with some extreme events abating, and some increasing. Observed changes, since 1950, include a reduction in cold nights (characterized as nights with minimum temperatures below the 10th percentile for a given area) and warm days (characterized as days with maximum temperatures above the 90th percentile for a given area) (IPCC 2012). These same trends in temperature extremes are expected to continue into the end of the 21st century with more warm days and fewer cold nights projected (IPCC 2012). Additionally, longer stretches of warm days, or heat waves, are also projected to become more frequent towards the end of the century (IPCC 2012). Heavy precipitation events (rainfall amounts above the 95th percentile for a given location) will also see significant increases (IPCC 2012).

2 The Setting: The Cultural Landscape

Residents of these three regions of Alaska represent a variety of ethnicities. Population centers in these regions include the city and village of Ketchikan and Angoon in the Southeast region of the state, the villages of Healy, Anderson, and Cantwell in Interior, and the villages of Point Hope, Kivalina, and Noatak in Northwestern, Alaska. These eight population centers provide a representative cross-sample of the state's population:

- In 2004 Ketchikan and Angoon had 8044 residents in 1997 families. The racial makeup of the population centers was approximately 60.31 % White, 0.84 % Black or African American, 25.80 % Native American, 6.85 % Asian, 0.20 % Pacific Islander, 0.52 % from other races, and 6.68 % from two or more races.
- In 2000, the villages of Healy, Anderson, and Cantwell had 1600 residents in 375 families. The racial makeup of the three villages was 70.20 % White, 0.30 % Black or African American, 23 % Native American, 1.90 % Asian, 0.70 % Pacific Islander, 0.80 % from other races, and 3.80 % from two or more races.

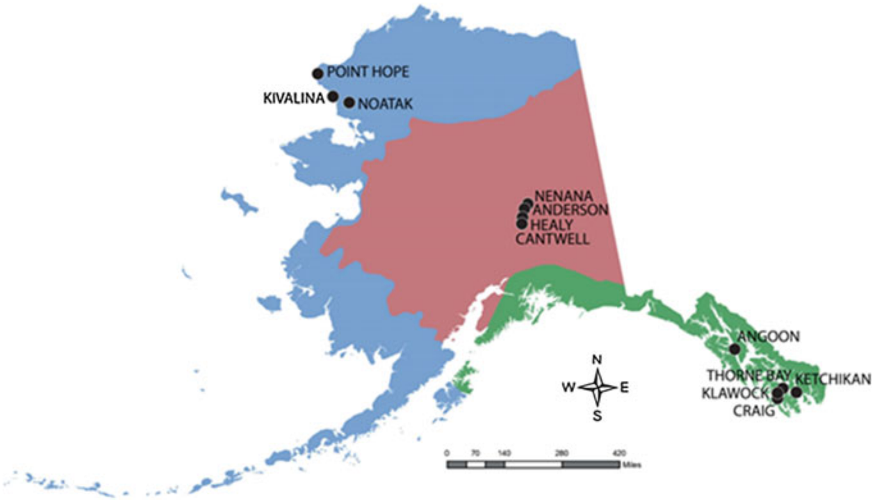

Fig. 2 Three regions of Alaska (we need a source for this figure—did you all make it?)

- In 2000, the villages of Point Hope, Kivalina, and Notak had 1428 residents in 310 families. The racial makeup of the three villages was 8.72 % White, 0.13 % Black or African American, 87.05 % Native American, 0.13 % Asian, 0.13 % from other races, and 3.83 % from two or more races.

Regardless of ethnicity, the residents of communities in all three regions are much more likely than other Americans to practice a subsistence lifestyle. They harvest native plants and berries, as well as various species of fish, including salmon and trout. Finally, they harvest local game, primarily aquatic megafauna such as seals, walrus and whales in the coastal communities, and terrestrial ungulates such as caribou and moose in the interior. Figure 2 presents and image of indigenous house.

Residents of rural and remote communities across the region have provided anecdotal reports of unusual shifts in the behavior and health of fish and game, subsidence of ground and surface water levels, and increasingly extreme local weather patterns. These alterations in the structure and functioning of the ecosystem on which residents subsist, or phenomenological disconnections, are likely to have negative ramifications for the health of human and non-human residents of the region (McMichael 2003; Larson and Anisimov 2014). Health vulnerability to the effects of rapid environmental changes would include increased incidence of injury and disease from intense storms, unusual environmental conditions, and under-nutrition and food and water-borne diseases associated with changes in subsistence food sources.

3 Climate Change, Health Impacts on Arctic Communities

The environmental effects of climate change, defined as regional changes in mean temperature, precipitation, humidity, and wind patterns, have been well documented (Intergovernmental Panel on Climate Change [IPCC], 2013). Studies to assess the health effects of such changes, included extreme weather, in the circumpolar north are challenged by complicated pathways by which adverse health outcomes are manifested in the resident populations. Direct effects of extreme weather may include health outcomes such as hyperthermia, injuries, deaths and illnesses, and increases in subsistence practice-related injuries and deaths. Indirect effects of extreme weather may result from changes in availability of subsistence foods, damage to water sources and infrastructure due to erosion and subsidence; sanitary sewage disposal and usable landfills, and mental trauma (Cochran et al. 2013; Willox et al. 2012).

Changes in availability of subsistence foods may result in an increased reliance on expensive, non-traditional and potentially less healthy food options, and an attendant increase in obesity, diabetes, hunger and heart disease, along with cultural loss and mental health repercussions. Respiratory ailments may result from changes in allergens and in response to air pollution from increased wildfire activity (Huntington and Weller 2005). Damage to water sources and infrastructure may amplify the encroachment of wildlife-borne, waterborne and vector-borne diseases (Parkinson and Butler 2005; Derksen and Brown 2012). Inuit residents of the Rigolet, Nunatsiavut, Canada, for example, perceive associations between a changing climate and many physical and mental health outcomes in their community (Tremblay et al. 2008; Comiso 2012). Additionally, Inuit communities in northern Quebec reported a number of adverse health outcomes from unpredictable weather in a three year study by Inuit Tapirit Kanatami (2014).

Moderating influences associated with cultural, infrastructural, and geographic context represent yet another important consideration when evaluating or seeking to mitigate the health effects of climate change (McMichael 2003). Residents of communities in the northern latitudes that practice the various subsistence strategies described earlier, as well as those that already face a variety of health and socioeconomic challenges, will be most vulnerable to the health effects of extreme weather (Huntington and Weller 2005). Included in these challenges are those rural and remote communities without access to potable water or local health care infrastructure.

Due to the moderating influence of local contextual factors, a study of the health effects of environmental changes in the circumpolar north would benefit from the active engagement and support of local residents. One reason is purely pragmatic; the region has a paucity of secondary data sources for environmental and epidemiological analyses. Given a close connection between indigenous people and their environment and the rapid changes that are occurring, rural Alaskans are in a position to report extreme weather events and other rapid environmental changes, understand the consequences of these events or changes, and offer possible adaptation strategies (Cochran and Huntington 2013).

Long-term residents of rural and remote villages who practice a subsistence lifestyle provide unparalleled expertise in identifying and describing unusual environmental trends and conditions at the local level. The complex association of environmental stressors and social and economic moderators highlight the importance of local knowledge in understanding the health effects of climate change (Hinzman et al. 2005; IPCC 2012). A second reason for local engagement is founded on the concepts of community-based participatory research; despite accentuated vulnerability and awareness of change in climate, northern Indigenous people have had little participation in climate change science (Cochran and Huntington 2013; Ford Vanderbilt and Berrang-Ford 2012).

The following sections describe a recent observational epidemiologic study that collected surveillance data on local environmental changes and associated health outcomes from residents of communities in Northwest, Interior, and Southeast Alaska (Fig. 2). This study was conducted by a team from the Institute for Circumpolar Health Studies (ICHS) to track local environmental events and their perceived health impacts in rural and remote communities in Alaska. This chapter describes the process by which our study methodology was developed, evaluates the effectiveness of that methodology, and presents one of the first epidemiologic assessments of the health effects of extreme weather in the three ecologically distinct regions of Alaska.

An ideal research design would blend the validity of community based participatory research with the rigor of longitudinal, time-series studies. By involving residents in study development, implementation, and analysis, while systematically collecting data on environmental conditions and associated health outcomes over a considerable period of time, such a study design would ensure that the data collected are valid and useful. One possible strategy for the latter would involve syndromic surveillance, which collects information on specific symptomologies or case definitions rather than a clinical or laboratory diagnosis.

Our transdisciplinary study methodology, which involved researchers from public health and various social scientific disciplines working together to integrate their scientific approaches to develop and conduct a community-based sentinel surveillance system for the environmental effects of climate change and their associated health impacts, as well as to elicit community preferences regarding prospective adaptation strategies to mitigate those health effects in the future. We collected surveillance data with participants in two phases; the first in 2010–11 and the second in 2013–14. The mixed-method study design integrated social scientific and epidemiologic methods to develop and collect these data (Fig. 3). Study investigators traveled to prospective study communities and met with local residents to discuss their interest in assessing the health effects of climate change. We worked with interested residents in each of the communities listed earlier to develop surveillance instrument and the protocol for using that surveillance instrument to collect data. Interested community residents who met the inclusion criteria were trained to complete the sentinel surveillance survey of the likely environmental effects of climate change in their regions, and then completed monthly structured surveys of these local environmental events and their health impacts. The survey

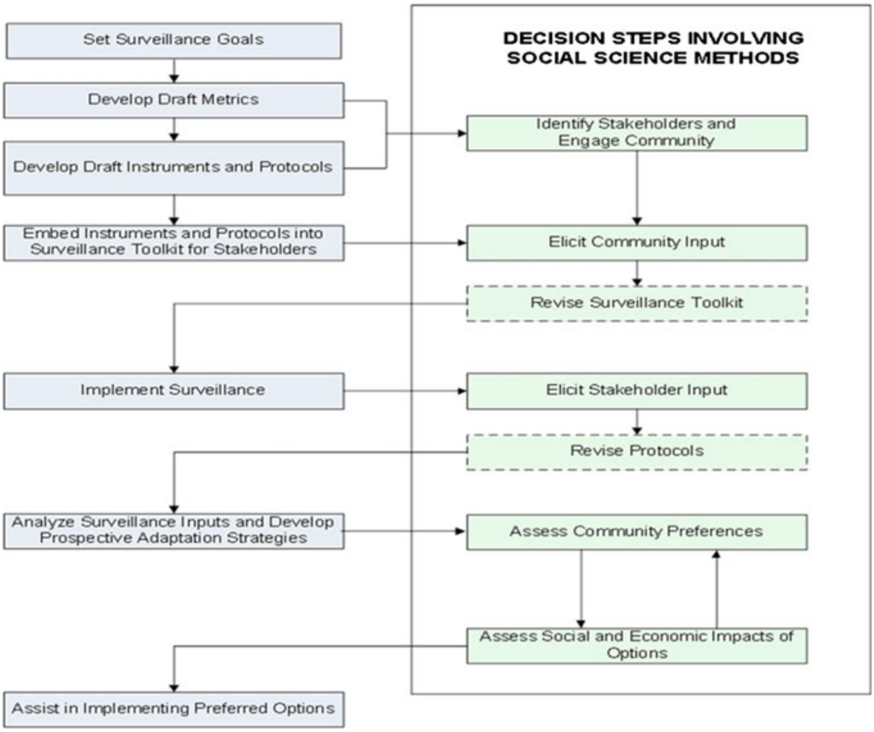

Fig. 3 Integration of public health and social science methods

collected data on unusual environmental conditions, including severe weather events, and the effects of these conditions on health conditions, such as unintentional injuries, respiratory ailments, and food-borne diseases. During this process, several residents used open-ended response fields in the instrument to provide historic, as well as current, observations in order to provide some context for their survey responses.

All residents who provided such historical data were also offered the opportunity to expand on their survey observations in two forms; first, in formal, unstructured interviews to follow-up on responses offered in open-ended response fields in the surveys, and second, in unstructured group discussions of the results of the surveillance data as part of public meetings in each community. Unstructured discussions of surveillance data findings were conducted in the summer and fall of 2012 and 2014. Formal interviews were conducted by researchers from the ICHS with 16 participants in the summer and fall of 2012. All discussions and interviews took place in the study communities, and were conducted in English. The interviews were recorded and then transcribed for analysis by members of the research team.

4 Findings and Strange Weather Patterns

The survey results revealed statistical associations between unusual environmental conditions, including severe weather events, and health outcomes and health outcome mediators in Alaska. Specifically, we found significant associations between severe weather conditions and cold-related morbidity and mortality in two rounds of surveillance data collection across the state. As the following data reveal, the nature and timing of such outcomes were seasonal in nature, and indicated health outcomes from the increasing prevalence of icy conditions in winter, and unusually warm and dry conditions in summer, in northwest and central regions of Alaska. The highest frequency observations offered by study participants were related to changes in weather patterns. Unexpected fluctuations in conditions, often associated with storms of unusual intensity, were described by residents in all three study regions in unstructured interviews in which study participants were invited to expand on their survey responses.

> Long time ago, our weather used to, like in one day, be the same. But then nowadays I noticed like in one day it would change rapidly from shine to rain, rain to windy and windy to sunshine.

One Inupiaq resident of the riverside community of Noatak, who had lived in the community for more than 50 years, described the ongoing relocation of the village away from the encroaching river, and their efforts to reduce that encroachment due to erosion, in his lifetime:

> See that gravel bar out there? That's how far the village was when I was a kid. But it was even further when I was born. It started to erode… My dad, when they he was young, they put wood poles… logs, all the way, and fill it with gravel. That lasted for years, maybe 20 years. Part of it is still up over there.

A former professional logger who now lives in Thorne Bay described one example of an unseasonal weather event, taking place during the previous winter compared to years past:

> The weird thing about that was it was so warm. It was definitely this tropical weather pattern. It wasn't cold rain, it was warm rain… It wasn't a cold fall type storm or winter type storm. Just pouring, pouring, pouring rain; it seemed more tropical. And they have great pictures, the newspapers, because it was so bizarre.

All participants reported observing unusual weather fluctuations, be they unseasonal weather, or unusually rapid variability in weather behavior. Residents of the Northwest and the Interior Alaska were three times more likely to mention weather fluctuations as participants in the Southeast. The eight participants in the Northwest were all subsistence practitioners, and repeatedly mentioned weather fluctuation in direct relation to food security. For example, residents of coastal communities in northwest Alaska traditionally subsist on fish and large aquatic mammals such as seals, walruses, and whales. Hunts for aquatic mammals take place in the late fall, winter, and spring in leads, or long stretches of open water, from a platform of shore-fast ice that extends several miles into the sea. Unexpected warming events or intense storms have been known the break the ice connection to the shore and leave hunting parties stranded on drift ice. These connections to shore-fast, or safe, ice formed a regular corridor for transportation of supplies for hunters and harvested meat from the leads, or ice-locked open water. As the number and intensity of storms has increased, the location and safety of these connections and leads has become difficult to forecast. A resident of Kivalina who had been hunting bowhead and beluga whales for just 20 years observed:

> When I started whaling, we used to go whaling just out here. But as years passed by, we had to move more further down because of the ice has changed, and the leads.

When asked to describe those changes and how long they used to remain on the ice to hunt, this resident responded:

> A month and a half. Nowadays it's probably a month. Because it melts really quickly now. This past year all the inland melted really quickly, flows out to the river and gets soft all over. We have to watch before we go. We might get stranded out there (on the drifting ice) for a week.

5 Threats to Local Lifestyle

The warming conditions in northwest Alaska represent a threat to indigenous winter fishing traditions as well. Last winter, water that usually freezes into navigable ice in November was soft into December, requiring residents to rely on harvests from Kotzebue, Alaska. A resident of Kivalina described how the unusual delay in ice formation in the lagoon resulted in the loss of a fishing harvest of the small whitefish called tomcod, also known as Pollock (Fig. 4):

> Our lagoon was so jagged, so ugly they packed up, they couldn't get in… We are all sad because we love our tomcod… Usually we start around Halloween time, last week of October, when we start our tomcod fishing. This year we still had water. No ice. The ice didn't form. It was slushy.… Really big change. I was really surprised by that. I didn't eat the tomcods from Kotz [Kotzebue] because you can really taste the difference. I love our tomcods, especially the eggs. My kids love them too. So it was kind of sad, about the tomcods. We didn't get one.

Residents of riverine communities in northwest Alaska may travel to the coast to participate in hunts for large aquatic mammals, or remain closer to home and subsist primarily on fish and large ungulates, particularly the massive caribou herds that migrate through the region each fall and spring. In some cases, the regular pulse of migrating salmon and caribou are the lifeblood for these rural and remote communities. As one resident of Noatak described their diet:

> We mainly depend on subsistence because of high cost of flying in food here. So subsistence has a big role in our life here. We depend on caribou, fish.

Fig. 4 An image from the village of Kivalina. Photo courtesy of Dr. David Driscoll

5.1 Changing Food Sources

As a consequence of this reliance on the caribou, residents of Noatak are expert in predicting the timing and direction of the migration. The village elders provide historical knowledge as to the best locations for subsistence hunts, and oversee the egalitarian distribution of the results of those hunts. Many of the observations offered by residents of Noatak related to food security were that the caribou were acting strangely, not following their traditional migration routes, and in one year did not pass the village at all. A resident summed up recent events this way:

> Well the caribou are going fast. We are going to have to do something there. I grew up hunting, my kids grow up hunting. I think we are going to have to do something about that soon. The caribou are declining, not staying steady. If the caribou is gone, the bears are going, and the humans are going…!

Hunting and fishing are not the only, or even the most productive, subsistence activity in Alaska. Gathering berries, greens, and growing what cold-weather crops one can are also common activities across the state. Many residents of communities in the interior and southeast regions of the state commented on changes in the timing and plentitude of local forage. As one resident of Healy observed:

> The abundance of rain and the cold temperatures it stunted germination and the growth from seedlings. Also the berries are late to ripen. Normally by this time of year I would have a shelf of blueberry jam. There's still a lot of green berries here and it's august. I've never seen that before.

A resident of Angoon who had been collecting and storing berries for more than 30 years noticed a link between snow levels in the winter and berry productivity in the fall:

> Seemed like during the winter there's not much snow. When it's like that we wonder about whether we're going to have enough berries. Because when you have a lot of snow, it melts, waters the berry bushes. It depends on how much snow we have. Now, a lot of people are picking berries and they're small, they're not as big as we usually get.

The lack of berries in southeast Alaska represents not only a threat to food security for residents of our study communities, but can also create additional hazards. As one resident of Ketchikan noted:

> There's been a lot of bear activity because the berries haven't been as abundant and the fish aren't out yet. So they're getting into neighborhoods. And in areas where they haven't had bear problems.

Residents of coastal communities in southeast Alaska, more so than other regions of the state, subsist on mussels, clams, and other shellfish. Many residents of communities in southeast Alaska observed an increasing number of warnings related to paralytic shellfish poisoning (PSP). PSP can occur with human exposure to a neurotoxin produced by microscopic algae in shellfish. As one resident of Ketchikan who had himself experienced symptoms associated with PSP after eating shellfish noted:

> They've had larger algae blooms and issues I think in the last couple years. I've only been here 25 years. I'm sure there were times there were serious PSP cases, but I can't recall this many in a year in the time that I've been around.

5.2 Environmental Changes/Challenges to Health

In addition to individual interviews, ICHS researchers conducted community hearings, or open-ended discussions of the survey results, with residents of each study community. These discussions of the surveillance data with local residents provided insights into prospective causal relationships between environmental events and the health outcomes described. For example, an explicit recognition of the association between unusual weather events and unintentional injuries provided insights into such causal factors as unsafe ice or housing conditions, which were obvious to participants but might not have been otherwise identified by project investigators. These discussions tended to be quite far-reaching, with the scope of prospective adaptation strategies encompassing local policies and built infrastructure. This explicit recognition of linkages between individual health outcomes and ecological factors is an intuitive but unexpected benefit of this approach. Moreover, the combination of surveillance, interview, and community hearing data contributed to a more informed assessment of prospective causal relationships between environmental events and the health outcomes described. For example, an explicit recognition of the association between unusual weather events and unintentional injuries stimulated in-depth discussions of unsafe ice or housing conditions, which were obvious to participants but might not have been otherwise identified by project investigators. This mixed method approach (surveys, interviews, and group discussions) informs locally determined and data driven adaptation strategies.

6 Conclusions

The results of this study reveal some important insights into best practices for community engagement in rural and remote communities in Alaska. First, that residents should be involved in the development and implementation of the data collection methodology. This participatory approach allowed us to refine the instrument and the protocol to ensure that we collected the most valid and useful data for the assessment of health effects of climate change. Secondly, that study participants have multiple strategies for providing their insights, both in the form of structured survey data, as well as unstructured interviews, and finally in group discussions of the study findings. This allowed some participants an opportunity to voice their experience who might not otherwise have done so. Finally, the insights gained from any data collection should be discussed with the study participants to ensure that any recommendations be both locally-determined and data-driven. This combination of factors best ensures that any interventions or programs resulting from the study will be adopted and supported at the local level.

The observations and findings discussed here serve to illustrate several important conclusions about climate change and extreme weather in Alaska. To begin, these findings include observations from residents of communities separated by more than 20° of latitude, or 1000 miles, yet the concerns which emerged in our interviews were similar. It is clear that increasingly intense precipitation events, unseasonably warm winter temperatures, and fluctuations in daily weather are of great concern to participants across the entire state. Related to this finding, we found that of all our participant categories, only subsistence lifestyle and gender were associated with differences in perceptions of these shared challenges. Specifically, across the state, subsistence practitioners described challenges to food security, or access to safe and nutritious food, with greater frequency than non-subsistence practitioners, and women described reduced air quality more often than men.

Second, the clear relationship between the effects of climate change and air quality is demonstrable in participants' accounts of their respiratory health. Increased and persistent dust in the northwest and interior and allergens in the south may have disparate causes but lead to increased respiratory health concerns for residents.

Thirdly, we see that climate change is plainly affecting participants' subsistence practices. The ability to procure subsistence foods is culturally and economically important to the residents of rural and remote communities in Alaska. Subsistence foods represent a low-cost and healthy dietary resource for residents of rural and isolated communities across Alaska. Food that is not provided by subsistence practices must be brought into the community by barge, and often must travel an additional distance via airplane. The reduction or elimination of subsistence practices creates greater reliance on processed, store-bought foods. Due to the difficulty in getting food to remote areas, markets are predominantly populated by foods with high added cost and lengthy shelf life. Subsistence food sources can also take on tremendous emotional significance for those who have been enculturated to procure and consume them, such as the resident of Kivalina who refused to eat tomcod from a neighboring town. The existence and effects of these factors may present a realm of further study.

Finally, the deliberate and transdisciplinary process of developing first metrics, then an instrument, and finally a primary data collection protocol in collaboration with both content-area experts and residents of rural and isolated villages in Alaska has resulted in a valid and actionable sentinel surveillance tool for use in a region of the country with few secondary data-sources. It is important to note that engaged and informed community residents are necessary for the successful implementation of such a surveillance system, and thus the exposure or exposures in question must be of sufficient priority to the residents themselves that they are willing to contribute to the ongoing and rigorous collection of primary data. We believe that these local observations of key changes over time in climactic conditions, and their associated impacts, can inform subsequent programs to promote adaptation to climate change in arctic and subarctic communities in Alaska and across the circumpolar north. We look forward to continuing to work with these communities to develop and implement measures to mitigate the health effects of climate change.

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Refining the Process of Science Support for Communities Around Extreme Weather Events and Climate Impacts

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Abstract Native American communities along the Gulf of Mexico, separated in significant ways from contemporary tools and technology, experience and cope with weather extremes in unique and largely unknown ways. From one generation to the next there has been little communication between *science*, where advanced tools of warning and survival can be derived, and *community*, where lessons of "living off the land" can inform science of the most pressing needs and the most practical and useful technologies to fill them. This chapter describes a successful and ongoing science/community relationship to address immediate pressures of extreme weather and the resilience to confront potential threats from forces extant, including climate variability and human exploitation of natural resources. Lessons learned here, particularly those of communication and collaboration, apply around the world where both global science and self-supporting communities have become isolated from one another.

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1 Introduction

This chapter presents a case study of rural people in the context of a changing physical environment and the role that community engagement plays or does not play in that process. The story is interesting and compelling. It focuses on coastal Louisiana in the United States and on perceived environmental changes that are altering long-held principles of sustainable self-sufficiency. Of a May 2015 storm, one who harvests shellfish says,

> The storms are getting stormier, stronger. What used to be normal bad weather, now it is just severe weather, not just bad weather. When you see a little blue cloud in the west you think about running for cover because you don't know what is in it. And lately when you see the storm clouds it is tornado weather.

We also see where local, relatively isolated communities are compelled to engage, to act, in context of larger forces of change extant, from the impacts of oil spills to the consequences of climate. This is also a story of building trust and communication across communities of science and policy. The quote below from an American Indian elder who lives in one of the communities involved in this case study effectively reflects the interplay of science and community engagement.

> (Science/Community) Engagement should go both ways. There is lived science, my life science. And there is learned science. It is not to take away from anyone, but there is other knowledge other than learned science. It is very complex. *-American Indian Community Elder.*

Well-intentioned efforts of university and government science to assist vulnerable communities under environmental threat—threats generally not of their doing or choosing—often fall short of expectations. The observation above from a community elder, one who has experienced many environmental threats and welcomed the learned visitors wishing to help, points to an important, often overlooked, ingredient: science and community "Engagement," with a capital "E," is a two-way street, sharing both "learned" and "lived" science.

Before sharing aspects of our case study, we present a short discussion of where we are coming from theoretically, as authors—to shed a better light on our interpretation of events and the case study.

In this chapter we connect the concept of community to the notion of environmental change and focus particularly on how traditional communities—*communities-of-place*—understand and relate to climatic changes in their own lives.

We believe that how these more traditional, natural-resource based communities respond to climate change will inform how 21st century communities, both traditional and modern, can adapt to change. Additionally, we want to better understand how the dynamics of engagement benefit from meeting people where they actually live and work, in their own small, rural, natural-resource-based communities.

In order to achieve pro-active support for community resiliency and adaptation, we explore the climate change adaptation framings of the limited, but still existent small, rural American communities that rely directly upon the environment for their livelihoods and subsistence. Then we suggest ways to use that knowledge for successful engagement with communities.

The latest effort to support communities experiencing disastrous impacts of severe weather, associated with what we and the community believe is climate change, is adaptation through community engagement. While the phrase does not have a catchy new[1] term such as community resilience, community engagement to adapt to climate change is both very real and very relevant.

By focusing on the notion of "community," we have a better chance of adapting to and achieving resilience from extreme weather, whether related to climate change or not. We do not use the term community in the typical sense of a 'government entity' or a political boundary but rather as a sense of the social bonds that exist in a particular place. Our understanding of community is reflected in *Gemeinschaft* (Tönnies 1996) qualities, which can be defined as a society or group characterized chiefly by a strong sense of common identity, close personal relationships, and an attachment to traditional and reciprocal mutual aid. In other words, Gemeinschaft means strong social relationships and bonds.

Gemeinschaft communities commonly are communities-of-place with caring reciprocal "giving-caring" relationships with the natural "giving" environment. This is an holistic and balanced give-and-take between people who live in a particular place and their surrounding natural environment.

As a means to resilience and adaptation, valuing community is important, given that much of American society inhabits socially detached suburbs or urban environments. Suburban and urban environments could be characterized as a more modern society and, following Tönnies, labeled Gesellschaft, a society or group characterized chiefly by formal organization, impersonal, less connected social relations, the absence of generally held or binding norms. Thus, *Gemeinschaft* implies the existence of closer social relationships or a sense of (rural) community, while *Gesellschaft* denotes a more formally structured society with impersonal ties. It should be noted that urban and rural communities can include characteristics of both.

[1]"New" as used in the human community sense rather than in a purely ecosystem or engineering manner.

1.1 Community and Understanding a Place

It is important to think about how different communities respond to various environmental changes. Many rural communities have a more interactive and subsistence based focus on their surrounding environments. More urbanized environments may be less-subsistence oriented with their surrounding natural environments. In this chapter, we focus on such environmentally attached communities; we concur with those who focus on community as key for understanding and action when environmental changes start to occur. We focus on rural communities because we believe that success in dealing with extreme weather and climate change requires a return to a more sensitive consideration of the environment. However, knowing how to achieve such a goal is still unclear. To say that the goal is *community* resilience or that *community* engagement is the method is not to understand the implication of these ideas. It is dangerous to assume we know what issues rural communities face without rigorous scientific study and some level of experience within these places and communities.

As community researchers, we recognize that there are scientists who come from the Gesellschaft-type urban world who want to contribute to extreme weather and climate adaptation. This can be accomplished through appropriate community engagement. But, most scientists lack the clear community experience to achieve effective responses to such climate-based environmental changes. As researchers, we ask the central question, ***How can scientists collaborate and engage with society to achieve adaptation to changing natural environments'?***

We emphasize participatory collaboration because understanding future extreme weather events is useful in the context of adaptation only if it is shared with a deep understanding and respect of what community members already know and practice.

2 Challenges of Scientists' Community Engagement for Adaptation

2.1 Variety of Environmental Change Signals

The challenge of how science can help communities is as daunting as the challenge of detecting, making sense of and responding to changes in the environment. For example, it is often assumed that changes caused by global warming will be detectable with unique signatures immediately recognized by both scientists and lay citizens alike. Most climatologists expect these signals, or events, will be distinct from an historical climatic norm. In this chapter, we are concerned that over-interpretation of environmental change, or extreme weather changes, be attributed solely to global climate change. Adapting or responding to changes in weather extremes must be taken in context with other confounding processes such as land subsidence and sea level rise—and assaults on the environment such as the BP Gulf of Mexico oil spill of 2010.

2.2 Changing Louisiana Environments

We focus geographically herein on the dying off of the coastal Louisiana marshes. This is currently the result of at least five factors: land subsidence as levees block soil deposition from spring river floods, major storm surges from tropical events, the BP oil spill killing the grasses, salt inundation from oil production channels cut through marshes, and sea level rise. All but the oil spill cause soil to be inundated by salt water, which kills the plants. Two factors, major storm surges and sea level rise, may be caused by climate change.

Other visible environmental changes are happening in the local environments of Louisiana. These include clearly recognizable changes for which global warming may be the trigger. Community members have developed their own understanding of changing local environments from their own observations and from media reports. Obvious changes may be recognizable clearly as suspiciously out of the normal range by members of communities. But even such noticeable changes will likely require repeat occurrences for community members to be convinced that something different is happening and that it is related to large-scale climate change.

2.3 Community Responses

When a community observes new environmental dynamics (such as rising waters and increased flooding) an array of responses may occur once they are noticed. While responses are likely to be similar to responses already taken, some responses to environmental changes may have very new qualities.

The following framing of climate change, and responses to the change, by two Louisiana coastal communities that are extremely dependent upon their surrounding natural environments, will permit examination of the complexity of "responding to climate change" (Anderson et al. 2012).

Community members typically may use responses they have already developed in reaction to other, distinct changes within their environment. That is the efficient approach. Additionally, local people may develop new and innovative responses because they assess that the earlier ways of responding did not work. Much of a community's response to extreme weather depends first upon their past experience and then upon the nature and severity of the current extreme weather encounter. Community responses may be informed by understanding why the new environmental phenomena are occurring. And local people often frame their own decisions about how to respond. Such informed responses may be most successful if considered over a time frame of several events (Apel 1984), such as, how likely is it for hurricane and flooding to occur this year? Community members will likely ask multiple questions including: Is the disruption going to be rare? Is it going to be extremely threatening? If it happens, will it differ from what has been experienced before?

The following sections report how community members perceive and deal with their own environmental changes (Heidegger 1971) through their own words. After outlining findings from the study of the two communities, other stand-alone examples of the appreciation of environmental dynamics will be described. The penultimate section will discuss some of the qualities and conditions of science-community engagement that must exist for environmentally sophisticated communities to become leaders in climate change adaptation, i.e. to be models for other less-environmentally and interpersonally attached communities. From this model can grow the interactive dynamics between society and science that are critically important for even modestly successful adaptation to climate change. First, we begin with a description of our data collection methods.

3 Research Methods

The research for this chapter involved a series of multiple methods including ethnographic observation, unstructured interviews/conversations (Herda 1999; Denzin et al. 2008; Smith 1999, 2012) with a variety of community members in two coastal, traditional Native American communities (Grand Bayou and Pointe-au-Chien) who live on the littoral edge of the coastal Louisiana Mississippi River delta. The remaining observations we include in the chapter come from on-the-ground interactions with members of these two communities along with other coastal Louisiana communities and coastal scientists with whom we work.

3.1 Community Background

One tribe, Grand Bayou Atakapa-Ishak, in Plaquemines Parish close to the main channel of the current Mississippi River path, is indigenous to the area. This area is "home to a small population of indigenous shrimp fishermen and women who have survived 15,000 years in the marshlands" (Nienaber 2012, p. 1). We will refer to this community as **Grand Bayou** since their community is located in a bayou within the marsh and must be accessed by boat. Damage from Hurricanes Katrina (2005) and more recently Isaac (2012) was extensive as was the damage to the environment from the BP oil spill (2010). It is a place where the health and well-being of the community is greatly tied to the surrounding natural environment. While the community has dwindled in the number who live in the "village," significant numbers of members and their offspring of all ages identify with the community and share customary social events in the village such as baby showers, graduations, weddings, birthday parties and funerals.

The second community which we included for this chapter is the **Pointe-au-Chien** in Terrebonne and Lafourche Parishes, located in the most westerly part of the historic Mississippi River delta. Similar to Grand Bayou, the community is located at the water's edge and is home to the Pointe-au-Chien Indian tribe. The tribe is located where they are now as a result of being pushed into the bayou region during the eastern colonial expansion in the early 1700s (Pointe au Chien Tribe 2015). Larger in membership than Grand Bayou, Pointe-au-Chien also experienced severe damage from Hurricane Rita, less than one month after Hurricane Katrina, as well as Hurricanes Gustav, Ike and Isaac, along with suffering severe environmental damage from the BP oil spill. Both Pointe-au-Chien and Grand Bayou communities are surrounded by the petro-chemical extraction industry and oil and gas wells -making them at-risk for disasters due to oil spills in the region.

4 Adaptation Collaboration

This section presents a detailed examination of various collaborations and efforts in research to understand indigenous communities and their responses to changing climate and weather.

The traditional communities that form the focus of this chapter, after Hurricane Isidore and Lili (both 2002), became "teaching communities" on climate change and its impact on them (First Peoples Conservation Council 2012; Leonetti 2010). By "teaching community" we mean that members welcomed outsiders to visit, discuss and learn about the experiences and responses that were taking place in the community. These visitors included, and continue to include, scientists, private foundation leaders, reporters, government agency and non-profit representatives. International visitors have also come from China, Liberia, Australia, Brazil and France. Such conversations can be extremely productive for visitors and communities alike.

One activity initiated by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center with Grand Bayou was to observe how the community mapped the changes occurring in the surrounding ecosystem (Laska 2006). This effort resulted in NOAA learning about vulnerability mapping, used to this day, as a model for other coastal communities. Because the collaboration did not result in a direct benefit to Grand Bayou, NOAA created a brochure, a tool that the community needed, in conjunction with Grand Bayou to help it represent itself at professional and academic meetings external to the community. These collaborations, which continue today, give a clear appreciation of the importance of collaboration for success. As one local resident who participated in the process noted, "We have to learn the language of the other if we are to survive. We are no longer just a bayou community, we are the world and if we are to survive, we need to learn from each other."

While such a model of engagement—visiting—is useful, it is time intensive and may not be so productive as more structured activities. Therefore, the University of New Orleans Center for Hazards Assessment, Response and Technology (UNO-CHART), and later the Lowlander Center, undertook to implement with the communities, problem-solving collaborations that were organized in different ways (Berkes 2009). The balance evolved from methods that were externally driven collaborations, to those that are internally managed by the communities today (Kindon et al. 2010). Following is a description of those programs and how they evolved toward greater self-management. This discussion will lead to our recommendations for a science-intensive collaborative model.

The two study communities have taken the lead on three climate change adaptation initiatives that are informed by applied social science and the practices of federal agency regional practitioners. In the next sections we describe the variety of collaborative research efforts that occurred in the two communities.

4.1 Participatory Action Research (PAR)

An NSF-funded project with Grand Bayou was undertaken before the Katrina (2005) catastrophe. It used a Participatory Action Research (PAR) method of community and specialist engagement (Laska et al. 2005). PAR assumes equal status between community members and scientists/practitioner partners. Its goal is to enhance community members' agency, i.e. their own control of their future. The usual Participatory Research has outside scientists performing a research service for the community rather than supporting the increased capacity of the community members to understand and implement their own actions (Blackburn 1998; Cooke and Kothari 2001). The PAR method for the Grand Bayou collaboration consisted of the core team of social scientists inviting an array of bio/physical and social scientists, environmental science specialists and other representatives of applied government agencies and non-profit organizations to become part of a team of advisors to Grand Bayou as they responded to the consequences of climate change, namely sea level rise (Laska et al. 2005).

While the intent was to form a cadre of experts to support the community, the secondary outcome was that experts learned how to become members of that cadre. The scientists and practitioners brought together for the project learned about environmentally-based communities, learned from the communities and learned how to support them in their resiliency efforts. That is, scientists and practitioners learned what is important to understand in order to partner with the communities (Peterson 2010).

Peterson (2010) applied the concept of *boundary lands* to a consideration of the conditions under which scientists learned best to collaborate with communities. The boat discussed in the next example, Sci-TEK, is an example of a "safe boundary land." The term refers to the social space in which the two groups—community residents and scientists/practitioners can experience successful, non-threatening encounters with one another (Peterson 2010; Berkes 2009). The boundary land can be geographically located in either the community, the academy/practitioners work place or at a neutral site such as a professional or regional meeting or in the field such as on a research boat. Peterson found in which of the sites the scientists learned best about how to collaborate with communities. Unfortunately, but likely expected in hindsight, the scientists were more comfortable when they were interacting with community members in *their* comfort zones—conferences, university settings, field trips—rather than when the scientists were in the communities. Thus, the PAR interactions between community members and scientists/practitioners were seen by the scientists/practitioners as more successful when they occurred at the universities or national professional meetings or on the research boat (Peterson 2010).

4.2 Science and Traditional Ecological Knowledge (Sci-TEK)

A team of geospatial mapping/coastal bio/physical processes experts and social scientists specializing in community engagement undertook a project to elicit the observations of the environment-based members of Grand Bayou and the other communities proximate to Barataria Bay on the west side of the reaches of the Mississippi River (Bethel et al. 2011). A doctoral student and an anthropology graduate student developed the prototype of this model. Then, the success of the initial project resulted in funding by the state of Louisiana Coastal Protection and Restoration Authority (LaCPRA) to develop the collaboration process further. The purpose of the larger project was to quantify the qualitative representations of ecosystems that traditional community members, including harvesters, believed should be considered when coastal restoration projects are developed and implemented. The restoration projects divert fresh water and sediment from the river to create new land and modify the salinity of the area to a more fresh-water regime.

4.3 Effective Engagement Strategies

To obtain the place-based community's opinion about how best to do the restorations, local harvesters were engaged with boats, for professional pay, to develop teaching lesson plans and implement field trips in the target areas for state agency scientists. One of the goals of the collaboration was to achieve balanced conversations on the boats between the two groups of environmental experts—the local seafood harvesters/experts and the scientists employed by the coastal restoration unit. The balance was in the equity of authority of knowledge that was exchanged between the fishers and agents. Harvesters and scientists described to one another what ecological processes they saw, what they understood about these processes and how they came to develop their own knowledge about their surrounding local environments.

Local community knowledge was blended in the conversations and each group benefitted from being shown how the other observed and what they learned. For example, the harvesters were very strong advocates for directing the sediment and fresh water to restore wetlands proximate to existing wetlands rather than in open water, and pressed the scientists to appreciate their thinking. The project was entitled Sci-TEK, short for combining Science and Traditional Ecological Knowledge.

Prior to the boat trips both groups expressed uncertainty as to whether the days spent together on the boats would be productive or only repeats of the tension experienced during public meetings where both groups often disagreed on restoration approaches and found these disagreements repeated in terse sound bites, over and over again. Members of these groups offered little reciprocal respect prior to these boat trips (Bethel et al. 2011; Laska 2006).

The fisher-expert (a person who fishes for a living and is knowledgeable about the community) took the lead when designing the day on the water for the group of research scientists. A lesson plan was informally developed by the fisher-expert who plotted the route and the points of interest in which the whole team would participate. By the end of the boat trips, the study team for the project would often see the harvesters (people who harvest from the sea) and the scientists lingering at the dock to continue their science and collaborative conversations as the research team drove away. One heard the "other" and learned from the other (Levintas 1996; Dussel 2013). The other became a collaborator not an object or an adversary. This was very important in terms of gathering observations. It is important to note that the fishers were not just interviewed as research subject sources for data that the outsider scientists turned into concepts and theories, but also as co-contributors to explanations and understanding (Sillitoe et al. 2002; Fischer 2000). It became evident early in the project that individual science projects such as multiple field sites containing instruments measuring water levels, temperatures and salinity content were important in order to understand ecosystem dynamics; so too were the constant observations of the ecosystem conditions and changes by harvesters using their multiple senses (Peterson 2015; Davis 2010; Leonetti 2010).

Listening, really listening, learning new things from one another about the shared subject matter of coastal ecosystem dynamics, gaining mutual respect for what one knew that the other did not, appreciating that both groups valued the ecosystem and its productivity and were trying their best to envision how to support the future health of the area all came out of the encounter. Such an approach is very costly both financially and especially in the time required to conduct such a collaboration format (Peterson 2015; Gaventa 1993; Park 1993). However, there is evidence that not taking the time, funds, and energy is even more costly. Kent and Taylor (1984) point out that the critics of community engagement who do cost benefit analysis of engagement verses traditional scientific methodologies do not include the very lengthy and costly litigation process that often results from both poor science and disregard of the community.

Boundary land dynamics (Laska and Peterson 2011) were also observed in the Sci-TEK project (Bethel et al. 2014). Following the boat trips, participants of those trips especially harvesters and the scientists from the state agencies, were asked to meet in small groups, but groups larger than on the boats, to review the map outputs from their boat conversations (all of which had been transcribed and coded in an ordinal data set). When they met at the land-based sites, the dynamics were more similar to the public meetings, more adversarial. So the location of the encounters, whether the collaborators feel comfortable in the setting, plays a key role in the success of the collaboration.[2]

4.4 First Peoples' Conservation Council (FPCC) 2012

With the guidance of external partnerships, the coastal tribes initiated development of a conservation council to control and self-direct scientific studies and restoration projects. The First Peoples' Conservation Council (FPCC) of Louisiana was formed in 2012 as an association to provide a forum for any tribal entity in the state of Louisiana. It is a collaborative forum to identify and solve natural resource issues on their Tribal lands, and like its sister organization in Wisconsin, intends to initiate scientific studies with university partners (First Peoples' Conservation Council, FPCC 2012). The importance of this tribal-initiated development is that it represents the community taking clear and purposive action related to the science and study of their changing natural environment.

The Natural Resource Conservation Council, NRCS, has a provision in its federal statutes that permits its support of tribal councils (Leonetti 2010; Cochran et al. 2013). With the mentoring and guiding of the oldest such council, the Wisconsin Tribal Conservation Advisory Council (WTCAC), the Louisiana tribes were able to develop a similar council. The WTCAC is the initiator of research that is pertinent to the health and well being of the environment. Such initiation allows communities to hire the scientists needed as well as grooming its own tribal members for leadership and research roles in physical sciences (Mears 2012; Leonetti 2010).

The First People's Conservation Council (the Council) is an opportunity to give a voice to Louisiana First Peoples on conservation issues at the State and National levels. The current purpose of the FPCC includes both internal and external capacity building to achieve meaningful restoration projects within and surrounding the tribal communities. This occurs through collaboration and training for the tribes

[2]A fisheries biologist presenting to the Society of Applied Anthropology a few years ago outlined a model of engagement for the harvesters and agency scientists who meet to determine fishing seasons and catch size: Always hold meetings that require an overnight so that the attendees can meet and visit at the bar in the hotel. These encounters are experienced as some of the safest locations for honest conversation about contentious issues.

and the development and co-management of conservation projects through education and demonstration (First Peoples' Conservation Council 2012).

Through a strong partnership with the USDA-NRCS, the Council reviews and recommends proposals for conservation projects for Louisiana Tribal Members. The current six member Tribes include: the Pointe-au-Chien Indian Tribe, Grand Bayou Atakapa-Ishak Tribe, Isle de Jean Charles Band of Biloxi-Chitimacha-Choctaw Indians, Avoyel-Taensa Tribe, Bayou Lafourche Band of Biloxi-Chitimacha Choctaw Indians and the Grand Caillou-Dulac Band of Biloxi-Chitimacha-Choctaw Indians.

5 Community Observations and Stories About Changing Environments

In this section we explore some of the observations and stories from local people about their changing environment. These changes often consist of extreme weather events that challenge local people's livelihood and sense of community. A change in extreme weather events also tests former strategies of adaptation and response to other changing physical environments.

The quote below is from a local elder of Grand Bayou who attributes the community's success in surviving hurricane Isaac in 2012, to their prior experience with other storms:

> Yes we did survive it [tsunami-like event during Isaac]. And one of the reasons that we did was because we did have to draw upon the past knowledge of how to deal with water and wind and an adverse situation…. We know how to deal with water in extreme situations.

Traditional interactive knowledge within the bayou community informs everyone that changes they experience now are out of the ordinary from what has been observed over many generations. For example, an early May 2015 storm that hit south Louisiana brought several hours of darkness as if in the middle of the night, but actually occurred mid-morning. One resident, a master gardener who monitors weather closely, stated that she had never experienced anything quite like it in her 80 plus years, nor had she heard stories of any such experience in their past. This same veil of darkness brought with it winds and rain, hail and tornado activity. Recall from the beginning of this chapter, an observation we repeat here, from a "harvester" or one who makes his living from harvesting shellfish, at sea, from a boat:

> The storms are getting stormier, stronger. What used to be normal bad weather, now it is just severe weather, not just bad weather. When you see a little blue cloud in the west you think about running for cover because you don't know what is in it. And lately when you see the storm clouds it is tornado weather.

For the harvesters on the water at the time of the May 2015 storm, their knowledge of past storms was inadequate for what they experienced this time.

They were unable to locate safe harbors suitable for their size boats. One harvester mentioned that this event has made their old way of reading clouds and wind conditions “not good,” obsolete.

The combination of sea level rise and subsidence of the land can force the fisher to choose between personal safety and subsistence harvesting. This conundrum is evident in the following quote shared by a community member interviewed during the study:

> Big boats. We need to get big boats. … That open water is too much. If we get big boats and we don’t get a catch we won’t have any boat. You’ll be pulling a pirogue.
>
> The catch ain’t there, that’s why all the open water, the land (estuaries) have all disappeared. So what’s a big boat gonna do for you?

An experience by the Grand Bayou during Hurricane Isaac was similarly perplexing. The storm, which was a slow moving, Category 2 hurricane, produced a storm surge well beyond the one predicted. The following quote is from one of the local people who experienced something never seen before in this community:

> Isaac is part of a new reality. We had our history of all the past storms and their signatures and we were buying into a lot of the media categorizing of the storms. **But where we were, we saw something that we were not prepared for** at the time so that is a lesson learned. **We had not seen it in that significance in any other time before when the water pulled back out of the bayou, it just kept pulling back and pulling back and everything was calm.** I mean the sun came out and it’s like - we thought we dodged the bullet more or less … the exit took all night … all through the night … all through the night, the water kept going out and going out … and going out until it got to the morning and so we had been up all night watching the event and the winds were blowing, and then in the morning when the sun came up, and things were kind of calm and balmy we went into the house, because we were in the boat … went into the house to get some rest, because we had been up all night. And within maybe 35 to 45 min- the water … (Interviewer: you had no sense it was going to come back?) Not at that rate. You know, that is a lot of water to put in one place. We expected it (tide) to come back but not so fast and not so much.
>
> And when it came back in after all the water was gone … when I say the bayou, that means all the ponds, all the little ravines, everything was kinda dry, so when the water came back in, I would say from the time we left the boat, 40 min later, we came out and the water was already chest high in the yard space, so we got … we got out of the house because it came in with such a rush. The pilings were breaking loose. The ropes were snapping. Bim had to run to go try get his boat to get on it because it was … it was being taken by the tide to the wind. He was up to his chest in water in that short period of time. On the land, the water came in that quick and that fast. It was something that we had never seen happen before. So that was a new reality. And we know that it is a new signature - and we know that we cannot rely … let’s call it a lesson. When they say category one, category two, that may have something but don’t just rely on that because the signature of Isaac was, it was 200 or so miles and it just moved at 4 miles per hour. That was more important than the speed of the wind, and the category or whatever. So that was more important to us. And seeing the way it behaved with the water, so that was another thing, so that’s now part of our history our memory and our knowledge of how to deal with the storms, so we will know to see that. And, when we see that, we will know what to expect. So that was a learning experience.

5.1 A Scientists' Perspective

The extreme weather event just described was so interesting and unique that we sought out scientific information about it to be a companion representation with the tribe's experience. We found Dr. Bob Rabin, Research Meteorologist, NOAA/National Severe Storms Lab, Norman, OK and Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, an attendee at the National Center for Atmospheric Research (NCAR)'s "Rising Voices of Indigenous People in Weather and Climate Science" annual workshop, June 29, 2015, who offered to assist. Dr. Rabin contacted Dr. Suzanne Van Cooten, Hydrologist In Charge at the National Weather Service (NWS) Lower Mississippi Forecast center (LMRFC) in Slidell, LA. She is a member of the Chickasaw Nation. The following quote shows the science perspectives (Suzanne Van Cooten and meteorologist Bob Rabin) of the same storms that many of the local people described earlier.

> The storm, which was a slow-moving Category 1 hurricane (peak wind of 80 mph), produced excessive rainfall and record storm tides at Grand Isle and Shell Beach, well beyond what might be expected for a storm of this category.
>
> Grand Isle and Shell Beach are the closest observing stations to the home of the Grand Bayou tribe, operated by the NOAA National Ocean Services (NOS). Shell Beach is located about 20 miles to the northeast, near Lake Borne. Grand Isle is located about 20 miles to the southwest on the same side of the river as Grand Bayou, near the open Gulf of Mexico. Neither station samples water levels near the Mississippi River and surrounding marshes. At Shell Beach, the record tide occurred near the time of hurricane landfall (red curve, Fig. 1) at 2 am CDT on August 29th. At Grand Isle the highest water level occurred a few hours later (red curve, Fig. 2) at 9 pm CDT. Both stations reported a rapid decrease in water level in the subsequent hours, followed by a leveling off and slight increase by 6am CDT on August 30th. It appears that the second increase in water level at these two locations may have been affected by the astronomical tide. However, the water levels remained up to 3 feet (1 meter) above the expected level of astronomical tide (tide not affected by local conditions) during this time.
>
> The conditions experienced by the Grand Bayou community have similarities to the water level plots described above. However, the more extreme drop and subsequent rapid increase in water level may have been influenced by additional factors such as:
>
> - Low water levels in the Mississippi River prior to hurricane landfall.
> - Slow movement of the hurricane.
> - Hurricane trajectory parallel to the Mississippi River after landfall and subsequent reversal of wind direction with hurricane passage.
>
> Further research is needed to understand the detailed response of water levels in vicinity of the Grand Bayou given the trajectory of this particular storm and antecedent river levels. Records indicate that only 10 major hurricanes have made landfall in Plaquemines Parish from 1900–2010 (ref: NOAA/National Hurricane Center 46). The particular combination of storm trajectory, speed of motion, wind intensity, time of high astronomical tide, and antecedent river level storms could make the observed double water surge a rare, "once in a lifetime," occurrence reflected Dr. Bob Rabin.

The Grand Bayou elder, in an exchange with Dr. Rabin added a very relevant climate change question to the discussion of the changing environmental conditions:

> We knew that we were witnessing “something new;” I use this term because we have the unfortunate history of having storms being part of our “norm.” I wonder if the tsunami-like event can be traced back to or linked with land loss (loss of protection) in Louisiana and climate change in general? Was this convergence of conditions unique in its outcome, or are we witnessing climatic occurrences that will continue to be unpredictable, with ‘new norms’ being created?

This quote illustrates local understanding and observation of environmental change by local indigenous community members in the face of extreme weather. Traditional Ecological Knowledge in the context of this discussion is really TEA Traditional Ecological Anticipation, which helps the community adapt to the future (Berkes 2009; Duerden and Beasely 2006). It could also be understood as EEK, Experienced Ecological Knowledge. Tradition is a living relationship; a dynamic experience that posits change for the present (or future) and the present or future will alter the traditional experience. In other words, community members naturally develop certain skills and adaptive abilities to deal with changes in their surrounding environments. It is not nostalgia. The past is a body of knowledge to anticipate the changing present and future. A modification of Paul Riceour’s (1991) description of the function of history would be to understand past, present and future to have neither linearity nor clear lines of demarcation. Science, like history is not about reporting what was or is, but about creating alternative futures. Learning to anticipate changes in severe weather patterns is a means, or path, to adaptation (Tschakert and Dietrich 2010). The following quote is shared by an indigenous community elder that characterizes these changes in extreme weather and how communities respond to them.

> The world is a living, breathing thing and there is perpetual change and there are seasons. We people, we make those seasons vary, we make them vary by the way we use resources on planet Earth. We are always in flux. We are always changing. And be mindful of what is happening to the world that we are inhabiting. Community Elder Grand Bayou.

5.2 *Changing Environments/Changing Food Sources*

The dialogue between community members revolves around the ways their environment has changed and is changing (Cochran et al. 2013; Tsosie 2010). Human-induced changes are affecting the land, water and air, fueled by the demands of natural resources to support an energy-dependent lifestyle. Changes are both subtle and substantial as one community member stated, “We notice the subtle nuances of change. We live with it daily.” Another community member shares their thoughts when talking about perceived change of species:

> I see a downfall. First of all the seafood we eat. You can't catch crab any more. The fishes are scarce. Before you could catch a bunch of fish, red fish, trout and Brazilian shrimp. And now, the Brazilian shrimp are gone and the white shrimp are in. Change. They used to come in in August and now they are coming in June, hardly. And crabs and the oysters are scarce also. This is affecting how we eat; now we have to eat more chicken and things that are processed and not organic. And it's affecting our health. If we can't get as much seafood as we normally got, we have to buy all of these things that are processed.

Without seafood as the main staple, the communities that depend on the catch for their diets now depend on processed inexpensive foods (Lynn et al. 2013). This change in diet is taking a toll on people's physical and financial health. A nurse from one of the communities observed, "It is vital to our health for some of these things to be addressed because we are finding more sickness, more disease, more people here are dying of cancer".

When one of our researchers asked fellow community members what they were going to do to care for their future, she received this response:

> We are going to have to make some changes ourselves. Our food supply. We are going to not be dependent on food from the grocery store. We are going to have to raise some of our own without fertilizers. When it comes to our seafood we are going to have to try to go to the areas where the water is cleaner and fish there. We are going to have to sustain ourselves. We have to try.

Another community member focused on the loss of land and the impact on safety while harvesting. "The men have been discussing the need for larger boats to withstand the roughness of the water during the unpredictable weather that doesn't have familiar patterns and signatures experienced by the community." Comparing concerns with fishers from the Grand Bayou, the men agreed that larger boats are needed because the water is now open where there used to be land. The land *chieneres*—elevated oak lined ridges in the marshes—were places of safe refuge if a storm developed.

Both communities are cautious about purchasing larger boats in that the cause for the larger boats, the open water, also means disappearance of the estuaries that produce the harvest. "Prices are down and the catch is scarce. Not good for the family. We were depending on a good season. It's not showing itself." Fishers were being offered (in May 2015) 50 cents a pound for their 40–50 count/pound shrimp. "The men are not going out. They can't take what the dock is offering. The dock is stealing from the boats offering 50 cents when they worked all night and have to pay for fuel and ice. They want to get rid of us." The economic challenges of low market price for the catch co-occur with the environmental challenges (Laska et al. 2015).

In 2011, the year after the BP Deepwater Horizon oil disaster, the two communities of Grand Bayou and Pointe-au-Chien initiated an ethno-botany project. They brought together experts that would help their communities identify traditional plants that were part of both communities' earlier diet and medicinal use (Lynn et al. 2013; Kimmerer 2013a, b). While discussing the different names and uses of various bayou plants the discussion also included the change of timing in the flowering and fruiting of plants and its impact on the community and migratory birds. A local community member shared these thoughts on the matter:

> Well I think it is getting harder to be able to make gardens, to be able to know the time to plant things, to grow things. I don't know what we are going to do I mean. We need our gardens to depend on … I think the world can make the changes if they tried. They could stop using the things that are adverse to our body. They can grow, it may not be as fast but it would be healthier.

Another local person commented on the changes as well as the future:

> I'm very concerned. Things are happening so drastically to me that I think that should concern us. Because our way of life and the things we do. If we are going to have a future for our kids … Things are so different. We don't want it to be so drastically different. We want them to be able to catch crabs. The land used to be so high that my daddy planted a big garden. I want to be able to plant a garden myself today. I want to be able to have the kids to be able to do the same.

This quote clearly reflects a strong local concern for the current state of affairs with the local environment and a sense of loss about what was or what used to be the environmental norm for the local region.

5.3 *Observations on Health and Changing Environments*

The intersection of environmental health, the air, water and land, directly impacts the harvest that communities have depended on for generations (Laska et al. 2015). The consequences of water, air and soil pollution have a direct impact on humans and human health, but for residents of certain environments the impact seems of greater proportion. These observations by two community members: "So many changes in our lifetime. I noticed at the times years ago that they didn't suffer some of the things we are experiencing today." And, "A lot of sickness and diseases because at one time there wasn't anyone with asthma, no one had sinus problems, and we seldom ever had colds unless we mixed with people who had them. There was not this kind of thing on the bayou."

The rate of environmental change is unprecedented (Maldonado et al. 2013). The following quotes show how environmental change has been framed by community members in Pointe-au-Chien and Grand Bayou, who have an understanding of the local environment:

"There are expert scientists out there who say changes always happen. That perpetual change always happens and you just have to go along with it." In conversation, another community member replied, "I say that it is not true. For hundreds of years we have been here, there was no change. It is only now that change is happening. Since in the last decade or so that changes are taking place. It is because the things that are being put in the air and a lot of things being introduced into our environment." A third member shared, "There are some changes. The changes are happening at a greater rate, accelerated rate, you'll have to adjust to what is happening in the seasons." One of the community members replied:

> I would say that some of the negative parts have accelerated very quickly. I don't know what it will take to put some of those stuff behind us. We need clean air and clean water. I don't know how it is going to come about but these are a necessity of life. If you have clean air and clear water it will give life. It you don't have them then it cuts your life short.

Residents from both the Grand Bayou marsh community and Pointe-au-Chien community believe that the changes occurring in the atmosphere, the waters and the land around them are exacerbated by the pollution from oil and gas production that occur in their village and all along the Louisiana coast (Laska et al. 2015). They see patterns shifting in the growth of shrimp, the decline of insect and bird species, and the lack of pollinators. Other changes such as seasonal shifts in planting are also noted. As described in the introduction, environmental changes from different aspects of fossil fuel extraction and use, including damage to the ozone layer, all come together in their analysis. These communities are sensitive to change because, as one local person states, "Our life dependency is on the environment." The two communities whose quotes are included in this study mirror observations of other coastal communities within the coastal region. They further highlight what is experienced by coastal indigenous people. It translates to other communities and regions that are so tied to their surrounding natural environment.

6 A Proposal for Collaboration Going Forward: Climate Change, Regional Science and Community Task Forces

Collaborations have emerged from one community, with members of other small-town close-knit communities, and with university-based scientists. In essence, these collaborations have produced useful understanding of people, environmental changes and place. While university-based expert knowledge is useful in local communities' attempts to adapt to environmental change, traditional community understanding of the ecosystem in which they live, their relationship to it and their ability to collaborate is critical to effect successful, adaptive strategies for climate change (Ross et al. 2010).

Scientists and practitioners who come from a world outside of these small rural communities have much to learn in order to make a positive contribution. A person cannot just walk into such small, closely knit communities and say, "Hey let's all collaborate!" Relationships must be established and, most importantly, trust must be built.

Drawing from experience in addressing climate change and employing regional science and community task forces, scientists and practitioners can lay out the strategies and work plans for community collaborations to be most effective and beneficial (West et al. 2008). Following ideas of Participatory Action Research (see, e.g., Reason and Bradbury 2008), a PAR project in Louisiana selected experts with specific varieties of interests important to the community: A Scientific and Traditional Ecological Knowledge (Sci-TEK) project in Louisiana demonstrated best collaboration on one-to-one, face-to-face approaches (for insight on Sci-TEK practices see, e.g. Bethel et al. 2014); the First Peoples Conservation Council works toward managing scientific studies carried out by specialists they will hire. Government agencies look more and more to community members, but respect for the role of science remains constant (Pound 2003; Park et al. 1993). This chapter has examined how science and scientists should collaborate with communities, and what should scientists learn about collaboration to be most effective (Apel 1984). It is important to consider the structure of the science/community collaboration, the training for it, the science content, the format of the science communication and variations of the latter for all communities experiencing climate-based environmental change from extreme weather. Perhaps most important is the need for collaboration, respect and trust.

6.1 *Structure of the Collaboration*

The Coastal Wetlands, Planning, Protection and Restoration Act (CWPPRA) of 1990 (see Fig. 1) created a team of scientists, a taskforce from five federal agencies and a state agency co-located at the U.S. Army Corps of Engineers office in New Orleans to assist implementation of coastal restoration projects funded by CWPPRA (2015). The agencies are the Environmental Protection Agency (EPA), Commerce (National Marine and Fisheries Service), Interior (U.S. Fish and Wildlife Service), Agriculture (USDA) (Natural Resources Conservation Service),

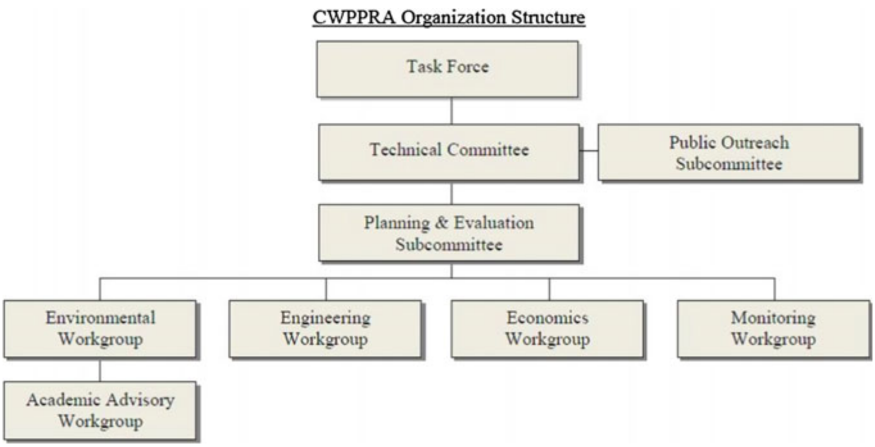

Fig. 1 CWPPRA task force organizational structure (reproduced from CWPPRA task force meeting document, 2015)

the U.S. Army Corps of Engineers and the state of Louisiana's Coastal Protection and Restoration Authority (CPRA) (CWPPRA 2015).

6.2 Value of Co-location

We propose that representatives of other relevant state agencies also be part of the collaboration and, if possible, be physically co-located with the federal agencies. An attempt to create a collaboration that included state agencies, non-profits, and universities working with communities was initiated by Laska and Peterson in (2011) and was titled, "The Oval Table," to note that both Louisiana and the U.S. Army Corps of Engineers sat at the heads of the table. While it functioned, recommendations were made to bring all participants to a common table where all were welcomed and had the same status and power in the dynamics of deliberation.

Louisiana parishes' (counties') governing bodies propose the projects to be implemented with CWPPRA funding. An agency review process determines which projects will be accepted (CWPPRA 2015). Our proposal in this chapter does not pose specific projects, only the collaboration mechanism to conduct them and, eventually, the resources for adaptation projects that would be open for competition just as they are in the CWPPRA program. We use an example of collaboration with local communities addressing climate variability and change. Scientists, by being located within the region, would gain knowledge about the local and regional ecosystem dynamics and interaction with the communities engaged would increase. Trust would grow as communities and co-located scientists collaborate (Park 1993).

A citizen advisory committee could be part of the collaboration. They could be paid for their time. They ideally would be selected on the basis of their individual community engagement history and would represent the communities and the counties. An applicable model of the citizen selection and participation process is that of the Prince William Sound Regional Citizens Advisory Committee. This Committee was formed after the Exxon-Valdez oil spill (1989) to provide an element of citizen/oil industry risk management to the safety program implemented after the oil spill (Prince William Sound Regional Citizens' Advisory Committee 2015; Cochran et al. 2013).

Continuing the proposal for a co-located science team, three existing outreach arms of the federal government (the Sea Grant fisheries agents, USDA Cooperative Extension agents and NRCS District resource conservationists) could help link science teams with the communities. An example of this is happening in Louisiana. One of the senior staff of the LSU Agriculture Center collaborates with a GIS expert from the Louisiana Sea Grant to create storm surge maps that are then shared with members of local communities in community meetings. While both are senior staff members for their respective outreach agencies, not agents themselves, they work closely with agents to ensure the interests of the community are addressed.

6.3 Preparation of Participants—Scientists and Community Residents

Participating scientists would be trained in the same skills as the scientists in the Sci-TEK and PAR projects. Participating communities and their members likewise would have to learn how to work comfortably with scientists—demonstrating their "lived" science and knowledge—and learning from the scientists (Berkes 2009; Mears 2012; Naquin et al. 2015). The key knowledge to be imparted during training has been described in Sci-TEK—"really listening, learning new things from one another about the shared subject matter, gaining mutual respect for what one another knows, appreciating that both groups value the ecosystem and its productivity and recognizing that all are trying their best to envision how to support adaptation to climate (and consequent extreme weather) change in the interest of the ecosystem including but not limited to humans contained herein."

As part of this model of working together, a careful pre and continuing collaboration education process would exist. A commitment to participate from each scientist assigned to the team would be required before being accepted into the team. Scientists would have to achieve high standards of collaboration in order to qualify for the taskforce (Kunde 2007).

Community residents serving on the advisory committee could participate in a training program. They would be asked to contribute to curriculum preparation for the scientists (Huntington 2000). The manner of training could be taken from the Neighbor-to-Neighbor model currently practiced, honoring the Project Impact (PI) methods and program created by FEMA during the 1990s to help make local communities more resistant to disasters. This proved to be quite successful through education and mitigation. In addition, local 'Impact' teams were created among educators, media, non-profits, universities, government agencies, and professional and recreational groups. One such program that grew from the Project Impact model is Tulsa Partners, which still serves as an exemplar model for public safety and awareness. PI showed that multiple entities could collaborate, investigate and make significant changes to make communities safer. A similar approach could be used by others to address coastal issues, disasters and changes due to crises brought about by changes in large scale climate. The Neighbor-to-Neighbor format of this approach assumes that communities learn best from one another. Sprigg and Hinkley (2000) point this out in an assessment of the potential consequences of climate variability in the Southwest United States. They also conclude that "confidences gained during these studies are difficult to achieve; they are lost when the (collaboration) is sporadic." The co-located science approach that we are offering could have the communities learn continually from one another how to collaborate with scientists.

6.4 Content of Science Shared and Scenario Planning

The challenge of how to share information, science and meaningful information across the environment is a valid concern. It is also a necessary part of being adequately prepared for instances of extreme weather that may impact a community. Let us now explore ideas of how to share science with communities that experience or anticipate the consequences of trends in extreme weather. These communities are mainly interested in adapting to these trends, understanding that reversing them is beyond the community's ability (Tschakert and Dietrich 2010; Walker and Salt 2006). So, how does one begin to adapt to these rapidly changing environments and climatic conditions?

Creating scenarios of prospective and desired future conditions is strongly advised as a means to get to the point where communities are aware of current environmental changes and those that are possible in the future. Walker and Salt (2006) in *Resiliency thinking: Sustaining ecosystems and people in a changing world* suggest that building scenarios for what a community wants for their future is essential. When facing extreme weather regime change, a condition that moves the current environmental conditions into a tipping point, people are willing to take the time to imagine their futures (Walker and Salt 2006). When developing scenarios in this manner, the people in collaboration are asked to see their desired future options and weigh them with values. Public elements of hazard mitigation (e.g. sea walls) and extreme weather risk reduction (e.g. forecasts) can be key. Values can include such things as safe water, community networks, safe environments for children, green energy, bike paths, and so on. Scenario building also helps the community evaluate the unintended consequences of development. Greensburg, Kansas is an excellent illustration where an entire community built a futuristic scenario and lived into that vision.

Conversely, scenarios that predict failure of risk reduction due to extreme weather systems are important but difficult to do in a public setting. Communities (especially public officials, utilities, etc.) want to believe they are safe and want that image communicated. More effort will have to be invested in how to build realistic scenarios that communities are willing to 'own' and work with. In other words, to create truthful scenarios.

People of all ages should help build these scenarios. Youth can create a positive vision for what they want the world to be, long after many of us are gone; scientists can test the vision for achievability. Youth are currently active in such climate activities as the Indigenous Climate Change Network (15 years in existence) and Rising Voices (3 years), both Native American initiatives. These are just two of the many indigenous climate change groups that have formed.

Doing such science-based scenario building to prepare for extreme weather events will support the creative, anticipatory, collaborative learning necessary to address anticipated and unanticipated climate events (Hooke 2010). Outreach specialists, citizens and other scientists can call upon regional science teams, respected by the communities, to assist directly in building these scenarios. The authors of this chapter, for example, have acted as a long-term mini-science team for several of the coastal communities. By doing so, both familiarity and trust has been built and sustained.

6.5 Using Stories for Science Communication

Increasingly, storytelling is being used by many parts of society, including business, to talk about adaptation to climate change and the extreme weather it may bring, returning a means of communication to an earlier era of values much like the renewed interest in the dynamics of community (Avraamidou and Osborne 2009; Conle 2003). Three qualities of storytelling make it important. First, it permits the content, in this case science observations and predictions, to be reported in culture-based content. Second, stories permit those who create them and those that hear them to appreciate the relationship among the different dimensions of the story, permitting the representation of different response alternatives in a realistic, i.e. culturally appropriate, manner (Laska et al. 2010; Smith 2012; Kent and Taylor 1984). Finally, story telling can include hopeful alternatives in a realistic, culture-bound story, a quality required by community members who are committed to adapting to climate change. There must be a belief in the possibilities of adaptation, as articulated by one of the Grand Bayou community members:

> It [climate change and weather extremes] is drastic. We need to do something about it … definitely. I don't know what or how *but there are things that can be done*.

7 Conclusions and Lessons Learned: How to Engage Effectively with Communities

In lieu of the usual suggestion for future studies, we make suggestions for future *action* and community engagement. This chapter demonstrates that collaboration is desired by communities to help develop life-sustaining scenarios for their future in the face of extreme weather events and climate change. These life-sustaining scenarios must account for the extreme weather events that redistribute energy for the climate system trying to find a new, stable state.

The coping mechanisms and projects we have shared from the Louisiana region have proven successful in building capacity, skills and trust. They have, as well, built the knowledge necessary to create alternatives for the future. There are stellar examples elsewhere, in this country and abroad, but our focus is on Louisiana which most of the author's call home.

- **Establish Different Types of Collaboration**
  Collaborations can be formal and informal, some coming together naturally, unforced to address a particular issue. The informality of collaboration can be done quickly and without many resources, and dissolved when an issue is resolved. Often the short-lived collaborations can address smaller problems that give community members and scientists alike a sense of achievement. Such celebrations can be witnessed in the development of a community garden or fixing a boat dock. People are more apt to feel vested, and skilled to take on increasingly difficult and complex problems when smaller more immediate issues are part of the solution (Cuomo 2011; Fischer 2000; Escobar 1999).
- **Build Capacity through Collaboration**
  In the absence of a positive collective action people are more prone to retain familiar behaviors even if adverse, when no viable options or resources are available. Building capacity through collaboration, scientist to scientist, between scientist and agencies and communities; inter and intra collaboration in each sector creates a border space for double and triple loop learning or transformative action and knowledge. It provides options and space for building scenarios and provides a doable vision and collective asset for achievement.
- **Create Collaborations Now**
  As climate and weather events create more severe impact on communities and regions, material resources and time will become more precious (Laska et al. 2015). The sooner we build adaptive capacity and science collaborations the more communities will be able to anticipate and address risks and severe impacts with holistic approaches.
- **Increase Capacity/Mitigate Vulnerability to Extreme Weather**
  Ben Wisner (2009) argues that *risk* is determined by the hazard multiplied by the vulnerability of the impact area, lessened by the capacity of the civil society and the measures of mitigation of the locale. Three of these factors, vulnerability, capacity and mitigation, are social dimensions that can be addressed by the types of collaboration presented in this chapter. Wisner's equation is usually understood in the context of lessening the impacts of natural disasters. But, in this case we believe it also applies to reducing the impacts of climate change. We propose that to engage in collaboration is to develop a true public sphere where knowledge can be shared and new knowledge created.
- **Build Collaboration on Trust and Time**
  Collaboration is a slow growth endeavor that builds on trust, trust of skills, trust of process, trust of capacity, trust of knowledge and most of all trust of the other people involved (Peterson 2015). As in learning any new method, there is a learning curve until there is comfort with the process. Given that collaboration takes a diverse public, many people with various skills, knowledge and capacity, there must be time for people to grow into the dialogue and work, a point raised by Sprigg and Hinkley (2000) in the context of assessing social, economic and environmental consequences of climate change. Pushing ahead when not everyone is ready is ultimately counterproductive, but given the shortness of

time to accomplish adaptation, achievement of collaborative capacity by all those involved is paramount. Work and process needs transparency as part of the trust building (Park 1993). Many federal agencies' calls for proposals now include citizen engagement. We suggest that social and environmental scientists and the affected communities be included from the beginning of the process. In so doing the probability of developing a healthy relationship and successful outcome is heightened. Collaboration is a social science specialty.

- **Share Collaboration Strategies with Scientists**
  Some science and professional science organizations such as the American Meteorological Society (AMS) have created workshops and space to introduce physical scientists to Participatory Action Research methods (Kunde 2007; Hooke 2010). The AMS held workshops at their 2007 annual meeting that included Peter Park, one of the leading scholars on PAR. The motivation is to help scientists increase their own capacity and skills to link with local communities for collaborating to solve environmental problems (Hooke 2010). Scientists who are engaged, such as the ones working with the Thriving Earth Exchange of the American Geophysical Union, are realizing that engagement of communities is essential for long-term and complex issues such as climate change.
- **Embrace Different Knowledge Types**
  Peter Park (1993) argues that there are three types of knowledge we use on a continual basis to understand and create new knowledge. He refers to these types as representational/instrumental, relational/interactive, and critical reflective/emancipatory/insightful. Chris Argyris (1994) refers to these stages of learning and creation of knowledge as double loop and triple loop learning, i.e. the continuing iterative process of action/reflection.[3] Most of what science creates in knowledge is through hypothesis-based research that yields representational or instrumental knowledge. Park posits that unless there is a relational and interactive aspect of the data, one cannot move to the critical reflective or emancipatory process of knowledge creation or embedding. Emancipatory knowledge can also be understood as transformative knowledge and anticipatory knowledge. In the situation of extreme weather events, all three types of knowledge become iterative into feedback loops so that anticipatory capacity can be nurtured. As communities and researchers become more adept at relational learning, exchange and building capacity of the other as well as trust, the more the collaboration's capacity is expanded to accommodate anticipatory events. In increasing capacity, lessening vulnerability and taking appropriate mitigation measures, participating communities will have reduced their current and future risk from extreme climate events (Wisner 2009).

[3]Single loop is the positivist approach, hypothesis testing. Double loop is the application but not taking the idea any farther. The triple loop is the process of continuing to refine, i.e. the action/reflection process "ad naseum" (Argyris 1994).

- **Embrace Action Research Models**
  Tscharkert (2010) has embraced action research models to develop what she calls anticipatory learning, and posits that it is essential for learning while experiencing various scales of climate adaptation. Such anticipatory learning builds anticipatory capacity. Daniel Wildcat (2009) proposes that the only research that is worth doing is life-sustaining research. To achieve a positive life sustaining future, Kyle Whyte[4] offers powerful insight into his work with traditional knowledge as a holistic method to envision an appropriate community model. Action research calls for highly creative and imaginative engagement that embraces non-liner systems thinking, and supports placed-based community knowledge. The communities are not blank slates. People are knowledgeable and want to share their knowledge in significant ways that will make a difference. The borderland is ripe for dialogue and problem solving. Community knowledge is essential to harness for co-management of environmental work leading toward a sustainable life-giving future (Wildcat 2009; Kimmerer 2013a, b; Berkes 2009). The communities we have described have opened themselves to being 'teaching' communities. They desire to be co-managers in developing their own future, and have active participants who are willing to get involved. The two case studies shared here illustrate a very powerful step towards attaining the health and overall well-being of people in a particular place or community.
  As our examples demonstrate, methods do exist to help foster successful collaboration between scientists and local residents that could serve as models for all communities. The types of learning to be incurred include good examples of double and triple loop learning that lend themselves to critical change. Some

[4]Whyte (2013)

"It is sometimes assumed that TEK (Traditional Ecological Knowledge) is only instrumentally valuable to climate science because it is observational knowledge collected over generations. However, TEK best refers to a persisting system of responsibilities. McGregor, for example, defines TEK as the relations among "knowledge, people, and all Creation (the 'natural' world as well as the spiritual)…[it is the] process of participating (a verb) fully and responsibly in such relationships, rather than specifically as the knowledge gained from such experiences. For Aboriginal people, TEK is not just about understanding relationships, it is the relationship with Creation. TEK is something one does" (McGregor 2008, p. 145). TEK actually refers to entire systems of responsibilities that are intrinsically valuable insofar as the systems are at the very heart of communities' worldviews and lifeways. The inclusion of TEK in adaptation, management and stewardship strategies is actually about respecting systems of responsibilities. It means creating inclusive research practices that are not only about sharing stories of knowledge, but about sharing understanding of a host of responsibilities that should play integral roles in adaptation, management and stewardship strategies. Institutions that govern or fund research can shelter TEK systems of responsibilities by doing what it takes to ensure their robust participation well beyond the provision of accumulated observations of some landscape. More importantly, TEK concerns tribal strategies for adaptation that are based on tribal systems of responsibilities and the worldviews/cosmologies such systems flow from. Collaboration across science and TEK systems must involve conversations about how different groups of people understand the nature of reality and responsibility (McGregor 2008)."

scientists have been successful in partnering with communities to achieve these more complex changes but there has to be a certain culture of trust established in these instances.

Finally, it is important for scientists to realize that local people's knowledge and experience with environmental change and extreme weather events are vital to effective policy and action. As scientists we often follow a top-down approach—but in this chapter we have explored more community-based participatory models, solutions for action and understanding in light of these global environmental changes. We, as residents of the United States, should be motivated by the challenge and by the example of those who have laid the groundwork for ensuring our future is life-sustaining (Pelling 2011; Wildcat 2009) and this comes through establishing a good, solid base of understanding and respect between researcher and community member. The solution rests with local people, their knowledge, experience and collaborations with others who can respect their local knowledge and ability to act.

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Reducing Vulnerability to Extreme Heat Through Interdisciplinary Research and Stakeholder Engagement

Olga Wilhelmi and Mary Hayden

Abstract Extreme heat is a leading cause of weather-related human mortality in the United States and many countries worldwide. To reduce the negative impacts of extreme heat on human health, it is essential to understand which populations are most vulnerable. In this chapter, we discuss the interdisciplinary facets of extreme heat vulnerability, present a conceptual and analytical framework for characterizing and reducing urban vulnerability to extreme heat, and provide an example of an interdisciplinary project that examines current and future extreme heat risk within the context of North American cities. We focus on a science-policy interface of heat-health research by highlighting the stakeholder engagement as a critical component of the entire research process. We conclude with observations on how this research framework and the stakeholder engagement process can be applied to other public health and hazardous weather studies where decision-making is informed by science.

Keywords Extreme heat · Vulnerability · Stakeholders · Interdisciplinary research · Stakeholder engagement

1 Introduction

Extreme heat is a leading cause of weather-related human mortality in the United States (National Oceanic and Atmospheric Administration 2014) and many countries worldwide (Hajat and Kosatsky 2010). Typically, heat-related negative health outcomes occur when daily temperature exceeds a normal range for a given climate, local setting, and availability of adaptations (Patz et al. 2005). Climate change,

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urbanization, and demographic trends suggest that extreme heat will remain a major hazard in the United States (Intergovernmental Panel on Climate Change 2012; Oleson et al. 2013), disproportionately affecting vulnerable populations. For both public health and climate adaptation planning, it is essential to better understand which populations are most vulnerable and how to reduce the negative health impacts of extreme heat on these populations (Balbus and Malina 2009; Wilhelmi and Hayden 2010; Harlan et al. 2013).

Characterizing and reducing societal vulnerability to extreme heat are complex problems that require the combined effort of several disciplines. It is essential that we are able to understand the interactions among biological, social, and physical systems, in a context-specific environment, and to connect research results to policy. The multifaceted nature of extreme heat vulnerability requires the implementation of effective urban heat mitigation and climate adaptation policies; this in turn necessitates active collaboration among researchers and a wide range of stakeholders (Wilhelmi and Hayden 2010).

In this chapter, we discuss the interdisciplinary aspects of extreme heat vulnerability; present a conceptual and analytical framework for characterizing and reducing urban vulnerability to extreme heat; and provide an example of an interdisciplinary project that examines current and future extreme heat risk in North American cities. We focus on a science-policy interface of heat-health research by highlighting the stakeholder engagement as a critical component of the entire research process. We conclude with observations on how this research framework and the stakeholder engagement process can be applied to other public health and weather hazards studies where decision-making is informed by science.

2 Extreme Heat Vulnerability: An Interdisciplinary Perspective

More than half of the world's population live in cities, where the combined effect of warm summer temperatures and urban heat islands (UHI) produce numerous negative health outcomes (Wilhelmi et al. 2012; World Meteorological Organization and World Health Organization 2015). While local climate, urban meteorology, and the occurrence of extreme heat events play important roles in health outcomes, societal vulnerability often determines the magnitude and the distribution of negative impacts of extreme heat on human health (Wilhelmi and Hayden 2010; Uejio et al. 2011; Harlan et al. 2006, 2014; Johnson et al. 2009, 2012; Rosenthal et al. 2014). Therefore, research on vulnerable populations as well as epidemiological studies on heat-health thresholds has grown significantly over the past decade.

Despite the growing body of knowledge about urban vulnerabilities to extreme heat, the complex interplay of ecological, social, political, and medical factors contributing to heat stress makes it challenging to prevent heat-related mortality.

The complexity of heat hazards also derives from the fact that the thresholds above which there are negative health outcomes vary significantly among geographic regions, across urban–rural gradients and even among neighborhoods within a city (Wilhelmi et al. 2012). Research frameworks on extreme heat vulnerability (Wilhelmi and Hayden 2010) and a number of case studies (Uejio et al. 2011; Harlan et al. 2006; Johnson et al. 2009; Harlan et al. 2012) demonstrate that both urban land cover (a factor in UHI formation) and demographic characteristics contribute to health outcomes.

In large cities with highly variable socioeconomic fabrics, infrastructure and housing types, vulnerability is expected to be even more complex. The relative importance of individual and household heat health risk factors has been investigated in several U.S. cities (e.g., Smoyer 1998; Uejio et al. 2011; Harlan et al. 2012). These integrated neighborhood-level studies show that urban land surface characteristics, associated with UHI formation, coupled with socio-demographic characteristics can be linked with heat-related morbidity or mortality data to identify first order vulnerability indicators and highlight zones of elevated vulnerability within urban areas. Recent advances in geospatial methods and analysis tools allow for spatially explicit characterization of heat-related vulnerabilities even in seemingly homogeneous urban environments (Wilhelmi et al. 2004). Various case studies of local-level urban vulnerability to extreme heat show the importance of interdisciplinary approaches to analyzing and predicting heat-health outcomes (Uejio et al. 2011; Harlan et al. 2012; Heaton et al. 2014).

2.1 Vulnerability

The notion of *vulnerability* has evolved over the past few decades from a concept primarily based on the severity of the natural hazard itself to a much more comprehensive construct involving social capital, poverty level, and access to resources, among other factors (Bankhoff et al. 2003; Eakin and Luers 2006). Here, following Wilhelmi and Hayden (2010), we define vulnerability as a function of *exposure* (i.e., climate and synoptic weather conditions that are exacerbated by the reflective, storage, and transportation characteristics of urban materials and vegetation), *sensitivity* (i.e., the extent to which a system or population can absorb impacts without suffering long-term harm), and *adaptive capacity* (the potential of a system or population to modify its features/behavior so as to better cope with existing and anticipated stresses). Adaptive capacity influences *adaptation*, which refers to the actual adjustments made to cope with the stressors and reduce the risk of negative health outcomes. Vulnerability is also influenced by *drivers*, namely factors that shape the characteristics of the system such as climate change, public policies, and other macro-scale environmental, socioeconomic, and political stressors.

Current thinking in terms of adaptation to heat stress emphasizes technological interventions such as improved infrastructure and access to air conditioning (McMichael 2000; Klinenberg 2002). However, social and economic inequalities that exist at a local level (e.g., access to air conditioning, social isolation) create differential vulnerabilities as well as differential adaptive capacities (McMichael 2000; Klinenberg 2002; O'Brien 2004; Harlan et al. 2006, 2013).

Determining the differential vulnerabilities and adaptive capacities on a local level is essential to reducing negative health outcomes from extreme heat events. Smit and Wandel (2006) note that "in the climate change field, adaptations can be considered as local or community-based adjustments to deal with changing conditions within the constraints of the broader economic-social political arrangements." This highlights the importance of *scale* as internal to the system indicating that what occurs at the household level also affects the community, which is in turn, influenced by the macro forces that shape the ability of individuals to adapt to challenging conditions. Here we refer to *scale* as to the size of a unit at which the problem is studied and analyzed. *Scale* allows us to conceptualize processes and interactions that exist in social and physical structures and represent or generalize these processes in spatial, temporal, and thematic analyses (Montello 2001). Therefore, to associate data on health disparities to a neighborhood scale (i.e. Census block group), it is important to consider the influence of individual/household-scale socio-economic characteristics and behavioral processes, as well as community/city-scale extreme heat preparedness and adaptation programs, as determinants of extreme heat vulnerability and adaptive capacity (Pickett and Pearl 2001).

3 Interdisciplinary Research on Extreme Heat: The SIMMER Project

In 2010–2014, the authors of this chapter participated in a NASA-funded project, the System for Integrated Modeling of Metropolitan Extreme heat Risk (SIMMER), (Wilhelmi et al. 2014). This project focused on understanding extreme heat, human health, and urban vulnerability in present and future climates. The primary goals of the SIMMER's interdisciplinary team were to: (1) advance the methodology for assessing current and future urban vulnerability from heat waves through the integration of physical and social science models, research results, and NASA data; and (2) develop models and tools for building local capacity for heat hazard mitigation and climate change adaptation in the public health sector.

SIMMER employed an extreme heat vulnerability framework (Wilhelmi and Hayden 2010) and focused on specific research objectives: (1) Characterize and model present and future extreme heat events at regional and local scales; (2) Improve representation of urban land cover and its accompanying radiative and thermal characteristics at local and regional scales; (3) Determine the combined impact of extreme heat and the characteristics of urban environmental and social systems on human health; and (4) Characterize societal vulnerability and responses to extreme heat (i.e., mitigation and adaptation strategies).

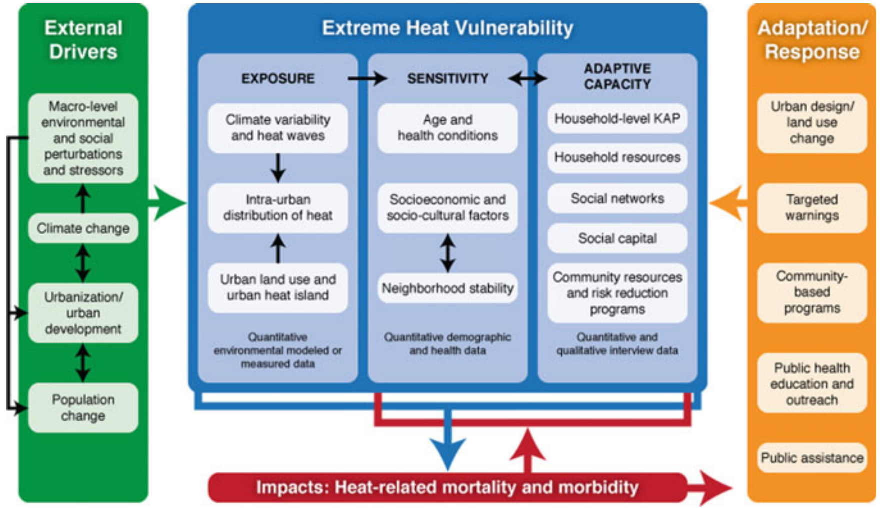

Fig. 1 Extreme heat vulnerability framework (*source* Wilhelmi and Hayden 2010)

In the Wilhelmi and Hayden (2010) framework (Fig. 1), vulnerability is represented as a function of exposure, sensitivity and adaptive capacity. Each of these components of vulnerability consists of a set of dynamic, spatially variable indicators. Exposure to extreme heat can be characterized by the intra-urban distribution of heat, which is influenced by local meteorological conditions and urban land use. Sensitivity is explained by characteristics of the individuals and the communities that make people more susceptible to the impacts of extreme heat, such as age, pre-existing health conditions, socio-economic and cultural factors, and neighborhood stability (e.g., whether people own or rent their homes). Adaptive capacity is characterized by the social and behavioral factors such as knowledge, attitude, and practices with regard to extreme heat, social networks, the household resources for coping with extreme heat, and local-level programs targeted at reducing extreme heat impacts.

Exposure, sensitivity, and adaptive capacity are affected by external drivers, such as climate change, macro-scale socio-economic and environmental stressors, and urbanization trajectories. For example, the pathway of urban development (e.g., large-scale urban agglomerations) can influence urban land use and consequently, the UHI, which disproportionately affects human exposure to excessive heat during the day and nighttime (Wilhelmi et al. 2012). Macro-scale socio-economic stressors, such as economic downturns, affect the sensitivity of the socio-ecological system, through impacts on housing, employment (i.e., decreased neighborhood stability, increased socio-economic disadvantage, limited household resources for cooling), and health conditions of individuals (e.g., limited access to healthcare).

Vulnerability to extreme heat can be reduced by carefully designed adaptation and response strategies. Understanding how each component of extreme heat vulnerability as well as the interactions among the components affect human health within each urban neighborhood and in time (i.e., throughout the day and the summer season) is essential for heat preparedness, response, and long-term adaptation. For example, when the UHI effect amplifies hot summer temperatures and the exposure of urban residents to extreme heat, implementing measures for reducing the UHI through urban planning and building design need to be initiated. In another example, when the people are unaware of the dangerous impacts of extreme heat on human health and are unable to recognize the symptoms of heat stress, public health education and outreach is needed.

The SIMMER project identified and measured each component of the vulnerability framework (Fig. 1) using quantitative or qualitative methods. For example, quantitative measurements included meteorological and remote sensing observations, climate model simulations, population characteristics, mortality records, and close-ended survey data. These types of data were analyzed numerically. Qualitative observations helped to explain and contextualize vulnerability and heat hazard phenomena and included open-ended survey and focus group data. The SIMMER project included regional-and local-scale analyses. The regional-scale study domain covered the contiguous United States and portions of southern Canada at ~ 15 km^2. A local, intra-urban scale (1 km^2; U.S. Census block group) study was conducted in Houston, Texas, the fourth largest city in the U.S. The research team collaborated with scientists and public health practitioners in Houston, as well as Toronto, Canada to ensure that the concepts, methods, and models developed for Houston were applicable to other cities.

Key findings from the SIMMER project included characterizing urban properties in urban meteorological simulations (Monaghan et al. 2014), and the role of adaptive capacity in understanding vulnerability to extreme heat (Hayden et al. 2015). New methods for accurately estimating urban land surface temperature from satellite imagery have been proposed and tested (Hu and Brunsell 2013; Hu et al. 2014). Climate model simulations showed substantial increase in high heat stress days and nights across the United States by the mid-21st century (Oleson et al. 2013). New statistical methods for modeling risk of heat related mortality and morbidity advanced our understanding of heat risk factors, and the spatiotemporal distribution of vulnerability within cities (Heaton et al. 2014, 2015). The results of the entire project have been discussed in the context of public health policies and interventions through a stakeholder engagement process (Hart et al. 2014). We now discuss this stakeholder engagement process in detail as a model for solution-driven interdisciplinary research and connection to policy.

3.1 Stakeholder Engagement

The SIMMER project employed both interactive and iterative processes (Lemos and Morehouse 2005), which included stakeholder engagement from the beginning of the problem definition to the dissemination of the results and co-production of

Fig. 2 Iterative and interactive process of stakeholder engagement

possible problem solutions (Fig. 2). Public health practitioners were our primary stakeholders in both Houston and Toronto; they were involved from the inception of the project, were knowledgeable about the vulnerable populations within their communities, and had been engaged in multiple on-the-ground public health campaigns in their cities. Involvement of public health practitioners from Houston, TX and Toronto, Canada helped to identify a roadmap for not only characterizing social vulnerability to extreme heat, but also ensuring that scientific information and research results could be used to inform public health interventions and initiate dialog for further collaborations on urban environmental health.

Figure 2 illustrates the interactive and iterative nature of the stakeholder engagement in the SIMMER project. We initially engaged public health practitioners in both cities and invited them to participate in the study design to ensure the relevance of the proposed research to their real-world problems. We worked together to identify and map vulnerable neighborhoods within Houston and Toronto; this allowed us to target specific Census block groups for our household-level telephone surveys. Once the data had been collected and analyzed, we met with our stakeholders to determine how our research results could be put into practice and what steps were necessary to reduce population vulnerability to extreme heat. Through this process, knowledge gaps and current best practices were identified; this led to discussions on potential solutions to existing problems related to heat.

Literature shows that involving stakeholders in research can have different models of engagement. Carney et al. (2009) synthesized the literature and identified several approaches to engage stakeholders in research. Among those are (1) study *of* stakeholders (i.e., studying knowledge, perceptions, attitudes, and practices regarding a particular issue); (2) study that includes active input *from* stakeholders (i.e., collaborating and incorporating stakeholders' insights, expertise, and ideas); and (3) study *for* stakeholders (i.e., disseminating research results in a usable and useful format). Below we discuss how the SIMMER project applied all three approaches in the context of extreme heat and human health.

3.1.1 Stakeholders' Knowledge, Attitudes, and Practices with Regard to Extreme Heat in Houston

The decision-making process for the reduction of negative heat-related health outcomes requires input from a variety of stakeholders to ensure the success and sustainability of efforts to reduce vulnerability. Generally, the stakeholders are persons, groups, or organizations that have interests in extreme heat mitigation and response (Wilhelmi et al. 2004). Engaging parties involved in the preparedness and response processes, particularly in the face of projected increases in extreme heat events, is important to developing an understanding of the strengths and weaknesses of existing prevention policies.

We conducted an on-line survey that was delivered to a pre-defined list of stakeholders from multiple sectors, namely public health, energy, local and state government, emergency response, to better understand extreme heat preparedness and response. The objectives of this survey were (1) to better understand roles and facilitate coordination among governmental and non-governmental organizations in response to extreme heat, and (2) to examine stakeholder knowledge of existing preparedness and response plans and strategies for future mitigation/adaptation to extreme heat.

3.1.2 Stakeholder Identification

Potential stakeholders were identified through a three-step process. First, website searches of organizations that appeared to be important partners in reducing vulnerability to extreme heat were identified. Then, staff members on those sites whose job titles indicated they were involved in public outreach, education, heat awareness, were targeted. Finally, additional stakeholders were identified through our collaboration with the Houston Department of Health and Human Services. Thus, stakeholders were drawn from multiple organizations in the Houston area including, for example, the University of Houston Strategic Energy Alliance and the University of Texas Health Sciences Center, non-profit organizations such as the American Red Cross and the Salvation Army, community organizations such as Ready Houston, government organizations representing, emergency management and homeland security, the National Weather Service Office, and public service organizations including utility and transportation companies and local television stations.

3.1.3 The Online Stakeholder Survey

The online survey was developed in collaboration with the Houston Department of Health and Human Services and distributed following a modified version of the Dillman tailored design method (Dillman 2014) to eighty-eight stakeholders that had been identified through the aforementioned three-step process. Emails, surveys, and reminder emails were sent out to stakeholders from April to June 2012. Through this survey, and in keeping with the survey objectives noted earlier, we hoped to: (1) determine stakeholders' knowledge and implementation of measures to reduce the negative health impact of extreme heat, and (2) assess perceptions of the relative efficacy of the existing tools/mechanisms to reduce population vulnerability to extreme heat. Thirty-three of the eighty-eight stakeholders who had been initially identified responded to the survey for a response rate of 37.5 %.

Stakeholders were first asked to identify the organization with which they worked and the type of preparedness and response in which they participated. When asked, "What specific services does your organization provide with regard to extreme heat? Please check all that apply," 45 % of survey respondents indicated that one of their roles in their organization was communication of messages to the public, followed by 36 % who were involved in community outreach and intervention, and 33 % who cited communication with other Houston organizations. Twenty-one percent noted that they coordinated activities among Houston organizations in preparation for heat events while 21 % also indicated that they provide weather surveillance (Fig. 3).

An important component of preparedness and response is determining the stakeholders' perceptions of the efficacy of a particular activity. Stakeholders were asked to determine the effectiveness of specific activities undertaken to manage health risks from extreme heat in Houston. The majority of stakeholders felt that weather surveillance for extreme heat was moderately effective to effective, while UHI mitigation was considered the least effective by stakeholders who rated it moderately to somewhat effective (Fig. 4).

Stakeholders were asked what activities their organizations recommended to their clientele during an extreme heat event. The most often cited recommendations were to stay indoors in an air-conditioned place (47 %), avoid outdoor activity during the hottest part of the day (44 %), and drink plenty of water to stay hydrated (44 %). The activities least often recommended were to use a swimming pool (3 %), followed by taking cool showers (9 %), and exercising indoors in a cool place (9 %).

Because climate projections for Houston show a significant increase in the number of high heat stress days and nights (Oleson et al. 2013), we asked stakeholders to describe how health risks from extreme heat might change in the future. The majority (69 %) responded that that risk of negative health outcomes would

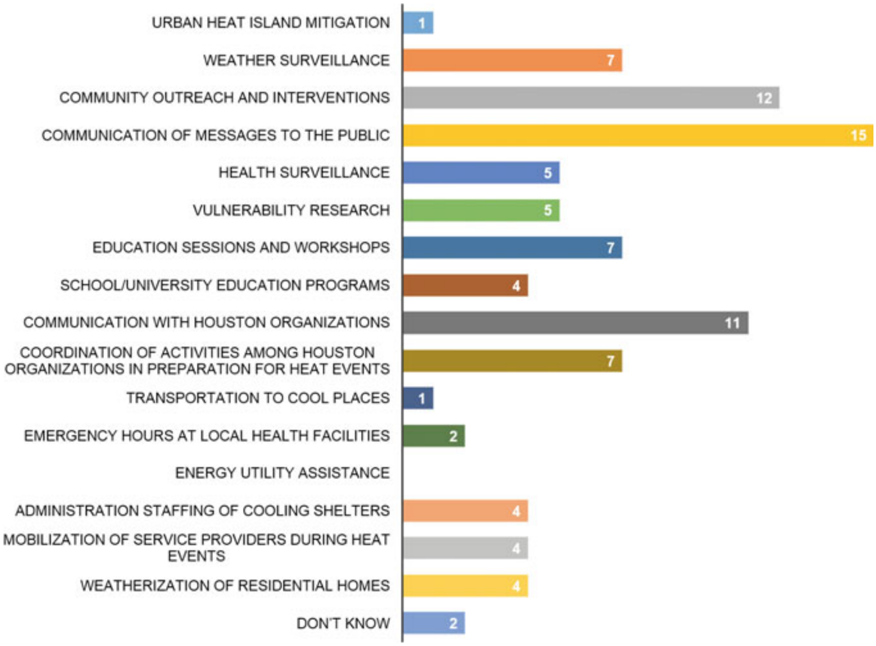

Fig. 3 Number of survey respondents (n = 33) involved in activities specific to extreme heat preparedness and response. "*What specific services does your organization provide with regard to extreme heat? Please check all that apply.*" SIMMER Online Stakeholder Survey

increase in the future because of growth in the population of those with underlying medical conditions (e.g., obesity, diabetes, mental health issues, etc.) as well as the growth in the number of senior citizens in the population (63 %). Other areas of concern were the potential for additional extreme weather-related impacts that might overwhelm the system (59 %), reduced financial resources to cope with the heat (53 %), growth in minority populations (47 %), increased UHI effect (44 %), aging housing infrastructure (44 %), and growth in the number of homeless people in the population (44 %). Far fewer of our respondents were concerned about urbanization (28 %) or increased unemployment (22 %).

In addition to asking how health risks might increase in the future, we were interested in ascertaining what the respondents felt might reduce future vulnerability to extreme heat events (Fig. 5). Fully 38 % of the responders noted that improvements in the preparedness and response capacity would reduce vulnerability, and 34 % of respondents felt that community-based adaptation such as the increased numbers of cooling centers and/or community centers would decrease the risk of negative health outcomes related to extreme heat.

We were also interested in assessing stakeholders' perceptions as to what would improve preparedness and response to extreme heat events from the perspective of their organization. The majority (56 %) felt that increased population awareness of the health risks associated with extreme heat would improve preparedness and

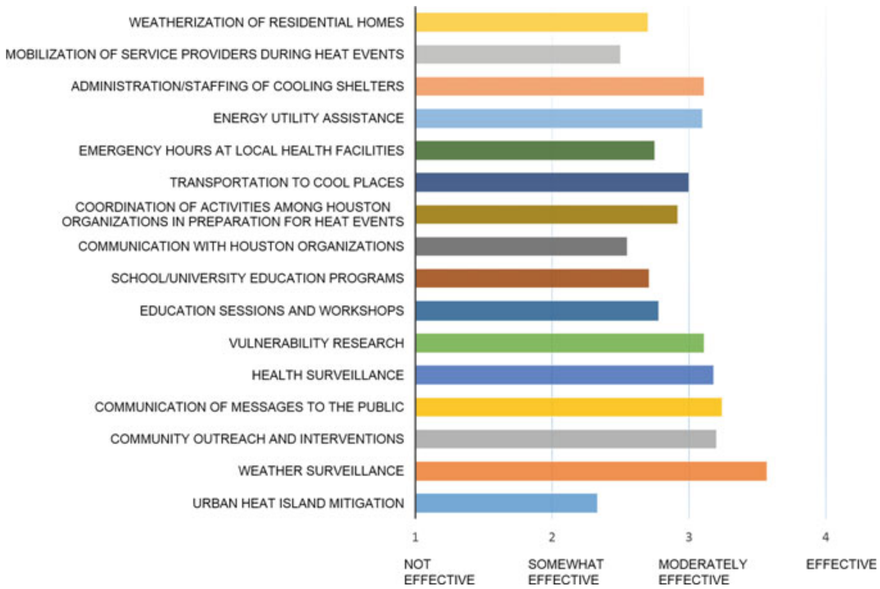

Fig. 4 Stakeholders' assessment of the effectiness of the activities specific to extreme heat preparedness and response. "*How effective are the activities below at managing health risks from extreme heat in Houston on a scale of 1–5 where 1 is not effective and 5 is very effective? Check all that apply*." SIMMER Online Stakeholder Survey

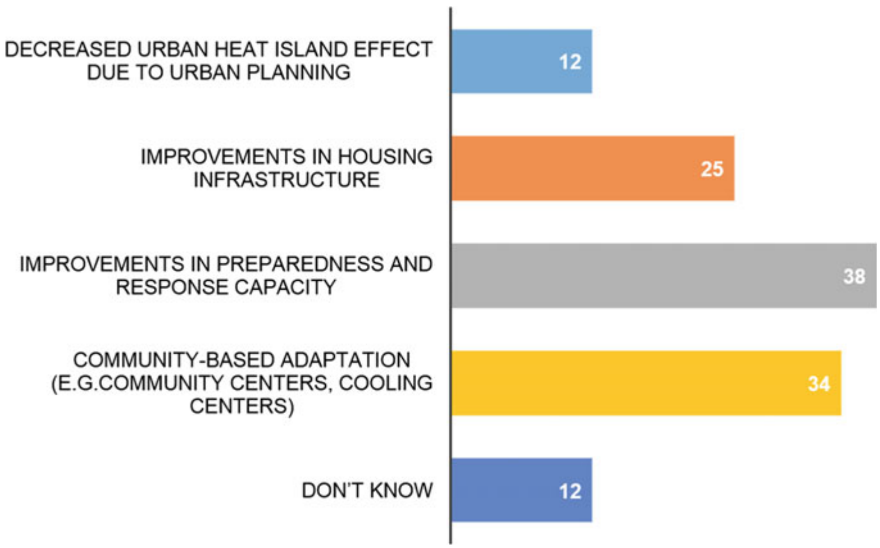

Fig. 5 Percent of stakeholders that identified specific pathways for reducing extreme heat vulnerability. "*Describe how you think the vulnerability to health risks from extreme heat may decrease in the future*." SIMMER Online Stakeholder Survey

response. Thirty-one percent felt that more funding was important. Better preparation for unexpected hazardous events, extension of heat services currently provided by the community or other agencies/organizations, and more communication with the Houston Department of Health and Human Services were considered equally valuable by stakeholders (28 %).

Understanding stakeholders' knowledge and assessment of the efficacy of existing prevention and response activities is critical to developing successful strategies and timely responses in the future. Furthermore, determining opportunities for reducing vulnerability provides a direction for improving on the current strategies.

3.1.4 Extreme Heat Preparedness and Response in Houston: Co-production of Knowledge

Building local capacity for heat hazard mitigation and climate change adaptation was one of the main goals of the SIMMER project. Stakeholder workshops provide an effective mechanism for capacity building which includes a researcher-stakeholder dialog, collaborating on a problem defined in a specific and localized context, and promoting coordination among local practitioners. The stakeholder workshops also present an opportunity to (1) review science and policy accomplishments; (2) identify gaps in extreme heat planning, preparedness and response; and (3) outline activities specific to the gaps that would reduce future heat-related health impacts. A one-day stakeholder workshop, organized by the Houston Department of Health and Human Services and the National Center for Atmospheric Research in 2013 focused on these three objectives in the context of extreme heat and human health in Houston.

The 43 workshop attendees represented diverse organizations in public and private sectors, non-governmental organizations, and academia. The practitioners included experts in public health, policy, emergency management, weather forecasting, broadcast media, transportation, housing and energy management, urban and regional planning. The researchers at the workshop represented a variety of disciplines, including epidemiology, physical, social, and behavioral sciences. The meeting agenda included broad discussions about the vulnerability of Houston residents to extreme heat, presentations about research, existing heat-related preparedness and mitigation programs strategies, as well as local public health initiatives that address the heat-health interactions.

One of the main goals of the stakeholder workshop was to improve collaborations and coordination among local and regional organizations that may be involved in heat-related activities, but do not have working relationships or even knowledge of each other's activities. It is common that organizational hierarchies, funding structures, lack of inter-agency communication, and other institutional barriers prevent coordinated efforts in tackling important social and environmental problems. Given the common interests, close geographic proximity of various institutions, and limited resources within each organization, coordination among local government agencies, non-profit organizations, and the private sector can lead to more efficient process for developing extreme heat mitigation and response programs and services. Long term, this could lead to policy changes based on new data analyses and better coordination among public health officials, city planners, emergency responders resulting in reduced vulnerability among city residents. For example, a coordinated effort among public health and urban planning organizations could lead to reduced exposure to extreme heat in vulnerable neighborhoods through planned changes in green space, urban parks, and cool pavement.

Typically, during workshops that focus on co-production of knowledge and improved coordination, researchers represent one type of actor and act as facilitators. Prioritizing heat-related issues when there are myriad pressing issues facing urban areas is challenging. It is important to provide support for solution-oriented dialog among diverse actors, so that deliberations and planning during the workshop could lead to meeting the participants' shared goals. Mutual learning and identification of concrete steps for addressing the problem at hand are desirable outcomes of the stakeholder workshops. Below we describe specific findings and the action items that were generated at the 2013 SIMMER stakeholder workshop in Houston.

At the Houston workshop, we divided the participants into small working groups; each with a mix of stakeholders from different agencies and areas of work. Their first task was to discuss current gaps and challenges in extreme heat planning, preparedness, and response. The second task focused on identifying specific activities to fill these gaps and reduce future heat-related impacts. Through this participatory approach, six main themes emerged from the working group discussions: (1) Effectiveness of cooling centers; (2) Heat-related advisories, products, and services; (3) Communication and messaging; (4) Policy; (5) Research; and (6) Collaboration and coordination (Table 1).

Table 1 Current gaps in extreme heat preparedness and response in Houston, TX and the proposed solutions to address these gaps

Gaps	Solutions
I. Limited use of and awareness about the *cooling center*	1. Clearly define what a cooling center is and advertise broadly, using different media for different populations (e.g., TV, social media, printed materials in utility bills, booklets in grocery stores) 2. Expand services that are offered by the cooling centers (i.e., longer hours, more activities for different age groups, provision to allow pets, especially during an extreme heat event) 3. Consider using buses as additional, mobile cooling centers 4. Provide transportation assistance to/from cooling centers 5. Investigate whether there are safety concerns among Houston residents about leaving home, traveling to and from cooling centers. Address these safety concerns

(continued)

Table 1 (continued)

Gaps	Solutions
II. Triggers for initiating *heat advisories* are not health related. Lack of heat-related *products and services* for populations with special needs	1. Evaluate threshold for heat advisories using heat health outcomes 2. Provide messages that are health-specific and provide information about cooling options along with heat advisories 3. Consider providing tailored heat advisories (more local, for super neighborhoods[a], for example) or using different messaging for different populations (e.g., elderly, athletes, outdoor workers) 4. Consider issuing heat advisories during or after high-impact events (e.g., hurricanes) that may also affect power loss
III. Lack of effective *communication*, especially to vulnerable populations, about heat-related symptoms, heat hazard, and available resources for heat-health risk reduction	1. Clearly define heat hazard and heat-related symptoms and educate the public early in the season. Introduce *Heat Awareness* day 2. Use multi-media to communicate heat hazards and ways to protect oneself (e.g., Websites, social media, TV, radio, billboards along the highways, utility bills) 3. Integrate heat-related information with hurricane education and communication (e.g., town halls, community meetings; a "Heat" module in "Together Against the Weather" program; booklets in grocery stores, pharmacies, churches, schools) 4. Include specific cooling instructions during heat advisories 5. Reach out to vulnerable populations during heat advisories through door-to-door contact, reverse 911 calls and emergency text alerts. Use addresses from *Meals on Wheels* and WIC databases
IV. Local *policies and procedures* Home Owners Associations and new residential construction does not always take climate or urban heat island into consideration	1. Offer weatherization analyses 2. Provide utility subsidy to population at 125 % of federal poverty levels 3. Incorporate ideas from this workshop into *Houston-Galveston Area Council* hazard mitigation plan 4. Reduce UHI effect: focus on areas with low tree canopy 5. Evaluate HOAs/new construction policies on roof colors and building materials 6. Promote policies that build sense of community 7. Participate in *Neighbors Night Out* program

(continued)

Table 1 (continued)

Gaps	Solutions
V. Additional *research* is needed to investigate extreme heat and human health relationships in the context of air quality, a changing climate, different geography and demographics	1. Investigate relationships between heat illness (e.g., hospital admissions, emergency room visits, and heat distress 911 calls) and heat advisories 2. Investigate how to integrate the SIMMER "Beat the Heat" GIS tool with weather forecast data for more targeted warnings and advisories of heat related illness 3. Investigate cumulative effects of air pollution and heat on health outcomes in Houston 4. Investigate heat-related risks under climate change scenarios 5. Investigate heat-health risk differences among cities in the region 6. Conduct research on acclimatization to heat among different populations
VI. Lack of sustained *inter-agency collaboration and coordination* of heat-related activities. "*Heat champion*" is needed to lead and coordinate heat-related actions and strategies	1. Identify an organization to serve as the "heat champion" to help coordinate activities. Identify "heat" ambassadors in communities, schools, organizations for bottom up public involvement 2. Create "heat" e-mail list of all interested/involved organizations 3. Establish closer collaboration among Health Departments, National Weather Service and broadcast meteorologists 4. Establish closer collaborations among Health departments, National Weather Service, emergency managers, and operators/managers of cooling centers 5. Establish closer collaboration among cooling centers and transportation services 6. Establish closer collaboration among utilities and emergency management (e.g., do not shut off power in a heat event) 7. Establish collaborations among WIC, Meals on Wheels and Health Departments (e.g., booklets or verbal messages to distribute, check on indoor temperature)

2012 Houston Stakeholder Workshop

[a]Super neighborhoods were created to encourage residents of neighboring communities to work together to identify, prioritize, and address the needs and concerns of the broader community. This creates a manageable framework for community action and allows the city to provide services more efficiently. (http://www.houstontx.gov/superneighborhoods/guidelines.html)

For example, one important topic discussed at the workshop was the effectiveness of cooling centers. During heat emergencies, the Houston public libraries and many Multi-Service Centers are designated as *cooling centers*. These cooling centers are open to the public and provide an air-conditioned environment for those who need to escape the heat during the day and cool off. However, many Houston residents, especially some of the most vulnerable ones, are unaware of such services or do not use the cooling centers due to various constraints (Hayden et al. 2015). The stakeholders discussed a number of approaches to address these limitations, including broader and more targeted advertising, expansion of services and working hours, and transportation to/from cooling centers.

Effectiveness of heat advisories as well as more general topics of communication about extreme heat risk and protective actions were among other themes that came out of the stakeholder discussions. The workshop participants discussed more tailored heat advisories that could be issued using place-based heat exposure information and contain specific messaging for different populations (e.g., elderly, athletes, outdoor workers). The stakeholders recognized that more could be done to communicate the extreme heat risk and considered a number of approaches, ranging from establishing a *Heat Awareness* day to multimedia communication and public education strategies. These and other topics are presented in Table 1.

While the workshops can energize and motivate the participants to collaborate and tackle shared challenges, it is not uncommon that the post-workshop activities are limited or non-existent. Even at the Houston stakeholder workshop, it was emphasized that a "*heat champion*" is needed to lead and coordinate heat-related actions and strategies. In the absence of such a person, group or organization, it can be challenging to have a focused and sustained effort in implementing proposed strategies. One approach for keeping the dialogue going is to focus on one tangible product or tool, such as a Geographic Information System (GIS). GIS in general, and participatory GIS, in particular, is an increasingly popular way to connect different stakeholders as well as community members, using geography (or urban space) as a common ground (Barlam 2006). Having a common platform where the stakeholders can visualize and query data about their city, the neighborhoods, and the population can help to create a shared vision, contribute to mutual learning, and provide a mechanism for moving forward to reduce population vulnerability.

3.1.5 Disseminating Research Results to Stakeholders

In the early stages of the SIMMER project, the stakeholders from the public health sector indicated the need for a web-based GIS tool that could synthesize extreme heat observations, model simulations, and social vulnerability research data. "Beat the Heat in Houston" was developed with those recommendations in mind, and the prototype was demonstrated at the stakeholder meeting in Houston. The workshop participants were invited to test the tool and fill out a survey on the tool content, usability, and "look and feel." Five volunteers from weather forecasting and public health sectors completed the testing, responded to an on-line survey and provided feedback on the tool development. In addition to these volunteers, the project partners from Houston Department of Health and Human Services provided detailed comments on the GIS data and functionality that would be useful for the City Government and for the public. Based on these inputs, the SIMMER project produced two GIS-based outputs: a web-based tool, "Beat the Heat in Houston" for the general public and an ArcGIS map package for the Houston City Government. These two outputs were each tailored to specific audiences and to the different types of decision making, which are discussed below.

The city government SIMMER project partners received a map package containing information on vulnerable populations, UHI, health outcomes, relative risk of heat-related mortality (for data description see Heaton et al. 2014), and parcel-based information on the use of air conditioning in Houston residences. The content and the format of this information can be easily integrated with other urban planning and public health GIS systems and serve as a heat preparedness and response platform for Houston. The publicly available on-line "Beat the Heat in Houston" tool contained information about the Houston UHI (neighborhood-specific maximum daily temperature during summer months), locations of cooling centers and other public air-conditioned buildings (including their addresses and hours of operations), and Centers for Disease Control-based recommendations on how to protect oneself from heat. Figure 6 shows the screenshot of the "Beat the Heat" GIS tool.

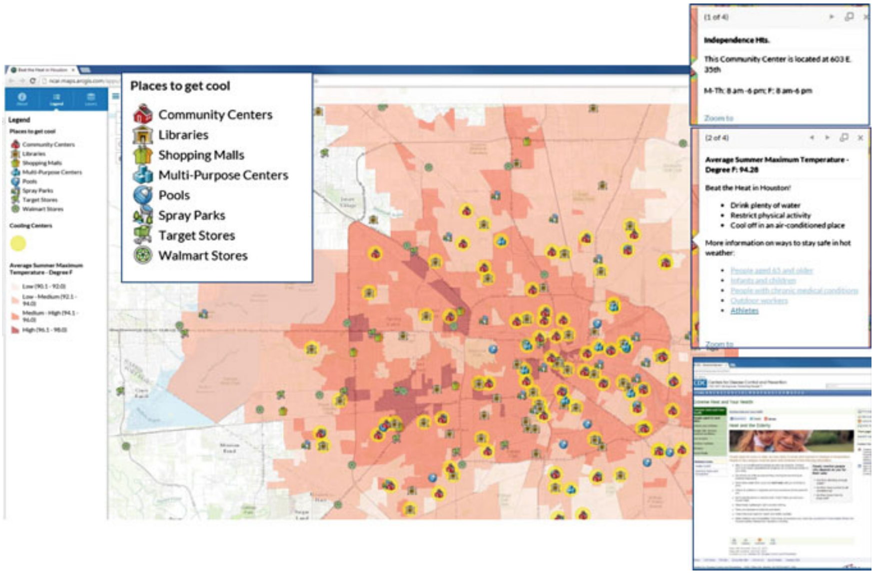

Fig. 6 "Beat the heat in Houston", a web-based tool that provides actionable information to Houston residents about summer heat and ways to cool off

GIS (whether commercial or open source) is an ideal platform for disseminating results of an interdisciplinary, complex project to the stakeholders and the public (Dragićević 2004; Balram 2006). The choice of software depends on the resources and expertise available to stakeholders. Web-based mapping solutions, such as ArcGIS Online, allow users to interact with the data with only a web browser and Internet access. While the public can use simple graphical user interfaces for visualizing information and connecting maps and images with concrete examples of protective actions and behaviors, the decision makers can use GIS for understanding the relationship between extreme heat exposure and social vulnerability as part of the hazard mitigation planning process. GIS has been widely used in hazard mitigation, disaster response, urban planning, and public health interventions and surveillance (Wilhelmi et al. 2004; Radke et al. 2013). Because extreme heat preparedness and response includes all these aspects of decision making, GIS can be useful for reducing future impacts of extreme heat on human health.

4 Summary and Best Practices for Stakeholder Engagement

In this chapter we described the interdisciplinary aspects of extreme heat risk and vulnerability, using concepts, methods and findings from the SIMMER project. Our focus on a stakeholder engagement process and the science-policy interface emphasizes the importance of participatory approaches and provides a framework for linking complex science to decision making. We now synthesize how the overall research framework and specific findings from the SIMMER stakeholder engagement process in Houston can be applied to other locations and public health and weather hazards studies where decision making is informed by interdisciplinary science.

4.1 Decision-Maker Engagement

It is imperative to *engage with local decision makers from the beginning* of the research proposal development to make sure that local needs, issues of concern at all levels (i.e., neighborhood, community, city, and region), and knowledge gaps are considered in the research plan. This will then provide a conduit for stakeholders to ensure that limited resources are targeted to the most vulnerable populations, and it allows for the characterization of vulnerability in a more explicit manner so that underlying disparities can be addressed more effectively.

4.2 Dual Engagement Approach

An integrated *top-down and bottom-up approach* is needed to positively affect health outcomes in response to extreme heat. Stakeholders from multiple sectors and levels of governance, both formal and informal, need to be engaged (Wilhelmi and Hayden 2010). We need to involve stakeholders from multiple levels, including community groups, but we also need to make a concerted effort to reach the actual members of the most vulnerable populations—households within a community. One of the limitations of many studies is a focus on stakeholders outside of the household level; these stakeholders may or may not have a voice that represents the actual community at risk. Bypassing household level decision makers may lead to erroneous assumptions about people's needs and their access to resources; this limitation can be overcome by conducting household surveys, community forums and/or town hall meetings to determine the level of trust in community leaders and other decision makers.

4.3 Early Stakeholder Involvement

Stakeholders must be involved from the inception of the project; however, this is not a one-time engagement. *Regular communication* between the research team and stakeholders is critical. No research project design is perfect from the outset, and may need to be tweaked periodically in order to safeguard not only the integrity of the work, but also to determine whether the needs of stakeholders are being addressed by the research. By engaging in an interactive and iterative process, the focus can remain on the co-production of solutions to the problem.

4.4 Stakeholder Adaptive Capacity

Stakeholders are crucial to building local adaptive and coping capacity to extreme heat, especially when they share common goals and interests. Therefore, an effort should be made to engage stakeholders in heat-health research as well as science-informed decision and policy making. As discussed in this chapter, addressing a complex environmental hazard such as extreme heat requires participation of stakeholders from different sectors (i.e., public health, urban planning, energy, transportation) and from different levels of decision-making (i.e., community representatives, non-governmental organizations, city, county and state officials). While there could be a large number of individuals or organizations who are interested in or concerned with reducing impacts of extreme heat on human health, the direct, day-to-day involvement of these parties in scientific research and/or coordinated preparedness and response activities can vary greatly. Often, resource and time constraints or institutional priority setting limits active participation. While it is essential to have an open and inclusive communication between all interested stakeholders (i.e., though workshops, town hall meetings, or web-based fora), it is also important to have strong leadership and clear guidelines for moving forward. One of the recommendations from the stakeholder meeting in Houston was to identify a "*Heat Champion*"—an individual or an organization who will lead and coordinate heat-related preparedness and response activities. Without *strong leadership* the momentum gained during stakeholder meetings can be lost, once the participants return to their day-to-day lives.

4.5 Relevance to Local Needs

Stakeholder engagement helps to ensure that the research is relevant to local needs and the findings can reach not only the decision makers but also the most vulnerable members of the community. It is important to consider local context, demographics, culture, languages, and history in messaging in particular, and communication strategies, in general. Just like the decision-support tools must be tailored to the users' needs, the messaging about extreme heat and its risks must be tailored to specific audiences. Extreme-heat risk communication that leads to protective actions is an emerging area of research and more work needs to be done to test the efficacy of risk messages targeted at certain sub-populations (i.e., elderly, athletes, outdoor workers). Also, as discussed at the stakeholder workshop in Houston, more work can be done to increase the effectiveness of dissemination of heat-health information by including a variety media (i.e., Websites, social media, TV, radio, billboards along the highways, utility bills, phones). *Providing tailored messages through a variety of sources* helps not only to reach more people but also to make the information more useful.

The findings presented in this chapter are largely based on our work in Houston, Texas. Cities like Houston do not have to wait for a major heat wave or an extreme heat event to be concerned with the impacts of heat on human health. Hot and humid summers are common, thus placing many vulnerable urban residents at risk from heat. There are many other cities around the world that face similar conditions and therefore need to be prepared for reducing future impacts of extreme heat on human health. The *model of stakeholder engagement*, presented here, can be applied in different urban settings, geographies and even cultural contexts. While the number and composition of stakeholders may vary, depending on the local context, the process of involving stakeholders in research, identifying gaps in preparedness and response as well as locally-relevant solutions, can apply in most setting. The transferable key elements of this work are: (1) interdisciplinary, mixed-method research that involves both stakeholders and the community members; (2) participatory process to generate ideas and solutions for reducing future risk.

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Sociospatial Modeling for Climate-Based Emergencies: Extreme Heat Vulnerability Index

Austin C. Stanforth and Daniel P. Johnson

Abstract Heat Waves and extreme heat are frequently not considered to be severe or adverse weather conditions. However, they are the leading cause of weather-related fatalities throughout the world. The misconception of heat is often due to the lack of visual evidence caused by destruction or risk, a commonly reported metric for hurricanes or similar forces. Heat Waves can be visualized through the Urban Heat Island, a phenomenon which exaggerates thermal impact within the built environment. This chapter explores and describes the Extreme Heat Vulnerability Index (EHVI), a local-area model designed for advance warning and mitigation practices related to extreme heat and socioeconomically vulnerable neighborhoods, through example data from Chicago, IL. The disadvantages and shortcomings of previous weather warnings are discussed, as well as how better vulnerability models can improve mitigation strategies to reduce loss of life and improve resource management. Mitigation practices from Chicago, Phoenix, Arizona, and other cities will be discussed to provide examples of the benefit of implementing vulnerability warnings.

Keywords Extreme heat · Urban heat island · Vulnerability modeling · Social vulnerability · Physical vulnerability · Disaster preparation · Disaster mitigation

1 Introduction

Vulnerability studies focusing on human health impacted by weather, or climate, variability have historically been studied from either the physical or social science fields. While both require a multidisciplinary approach, they are divided by the

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central focus of their fields. Physical vulnerability focuses on the configuration or magnitude of the adverse force, while social vulnerability concentrates on a population's ability to adapt or recover from the event regardless of its magnitude. This chapter discusses previous vulnerability assessment methods used to assess extreme heat's impact on human health, outlines data sources needed for such initial analysis projects, and discuss some of their resulting strengths and weaknesses.

Although it is not consistently considered a significant public health concern (Akerlof et al. 2010; Bassil and Cole 2010), heat is currently the greatest weather threat to health, particularly in urbanized areas (Pantavou et al. 2011; Peng et al. 2011). The increased risk is caused by heat induced hyperthermia, heat stroke, and dehydration. Heat also increases the risk of cardiovascular and respiratory morbidity and mortality, demonstrating its significant impact on population health (Luber and McGeehin 2008; Wilhelmi and Hayden 2010; Hondula et al. 2012). Heat vulnerability was chosen for this chapter because of its multifaceted impact on population health. To combat heat health risk, details describing a method of data fusion to improve heat wave mitigation (designed by the authors) combine previously distinct modeling methods for physical and social vulnerability. Our fused method is also applied at smaller resolutions of analysis than most previously implemented models in order to improve accuracy and application. This provides a model with unique benefits, as well as complications, due to the smaller spatial units of analysis. Additionally, this chapter discusses how public servants and volunteers can use vulnerability models to improve mitigation practices, enhance public awareness, and improve community engagement during extreme heat events.

2 Social Vulnerability

Populations who are less able to adapt or survive an oppressive event are identified as having a higher **Social Vulnerability**. This would suggest the vulnerable population's economic status and/or physiology makes them less capable of tolerating the stressful event. The oppressive event could take the form of an environmental stressor (common extreme weather examples include heat, flood, and tornado), could take the form of a financial hardship, such as unemployment, or illness. Models designed to identify socially vulnerable populations utilize social, economic, and various demographic variables to identify populations at an increased risk. The most prominent variables used for these studies include economic, education, race, or age classifications to identify vulnerability status (Cutter et al. 2003; O'Neill et al. 2005; Dolney and Sheridan 2006). It should be noted that many additional variables, subsets, or combinations of the variables could be used, as they will often change or hold different weight depending on the area of interest, for example: access to a heated shelter is less necessary in a southern climate. However, this example should provide a baseline to follow during this chapter (Cutter et al. 2010; Johnson et al. 2013).

Variables used to study social vulnerability identify populations who are less capable of surviving an oppressive event. Generalized examples of ‘at risk’ populations can include an elderly person with a decreased ability to properly regulate their internal temperature during extreme temperature conditions, or impoverished people’s hesitancy to seek medical attention at the onset of heat stroke symptoms (Center for Disease Control 2002, 2006; Changnon et al. 1996). Therefore, social vulnerability scientists work to identify which local socioeconomic attributes, and which combinations of them, are associated with an increased quantity of negative health outcomes during oppressive weather events.

Socioeconomic data is relatively easy to acquire through the U.S. Census Bureau. Historically, the United States federal government had collected data about the country’s population, once every ten years, beginning in 1790. This census was designed to document the distribution of the nation’s economic status, educational attainment, age, race, gender, and a multitude of other information. In 2010, the Decadal Census was converted to the American Community Survey; this new data collection method never collects a true census of the population, but will provide more frequent analytics about the nation’s population through survey collection methods (U.S. Census 2015). Rather than a full census every ten years, the American Community survey collects a sample survey from a small proportion of the population every year. The use of a sample survey suggests that all datasets going forward will only be estimates of the population dynamics; therefore, scientists will need to consider their implementation of this data carefully. Generalized population data derived from the historical census and American Community Survey is publicly available at designated political boundaries (such as counties, census tracts, and block groups) and is sufficient to use in the study of social vulnerability.

The U.S. Census political boundaries are established by political parties, politicians, as a method to organize citizens for voting and implementation of laws/government projects. Due to their organization, the U.S. Census boundaries maintain relatively equal population sizes between boundaries. Additional information on the boundary development and maintenance can be found through the Census website, but generally the division is: States > Counties > Census Tracts > Block Groups > Blocks > residential homes. The available datasets are not designed to allow for the identification of individual people, which is why only generalized data at the block or larger boundaries are available. Average characterizations of residential areas, such as the average income of all residents within the census boundary, provide valuable information about the people who live in a particular area. Population data can be used to identify vulnerable populations by identifying variables of groups who have not demonstrated historical resilience and adaptability to oppressive events. A quick background on some of the more commonly utilized variables will provide a better understand as to why such variables impact vulnerability, specifically during heat events.

2.1 Age

The average age of an individual, or the population in general, can indicate their probability of having pre-existing health conditions or requiring assistance for daily activities (Cutter et al. 2003; Naughton et al. 2002). This is particularly relevant for two age demographics: the very young (5 years and younger) and very old (65 years and older) have been identified in previous studies to experience higher rates of negative health impacts during oppressive weather events. Both the very young and very old must rely on others; often have limited mobility and motor functions which reduces their ability to maintain proper fluid levels or escape an oppressively hot environment (Center for Disease Control 2002; Naughton et al. 2002). Both the elderly and young populations have a higher rate of requiring mobility assistance (walkers, wheel chairs, or weak muscle functions), which requires additional assistance and supervision (Changnon et al. 1996; Ebi et al. 2003; Semenza et al. 1999). This implies more than vehicle transportation to the store; both elderly and young individuals may require the use of a walking aid to move between residential rooms and may have trouble with stairs or uneven surfaces. Limited mobility can make it difficult for them to acquire fluids or relocate to a cooler environment when necessary.

Additional physiological traits commonly present in elderly demographics (such as pre-existing health conditions like cardiovascular or diabetic diseases), can exacerbate health complications caused by external stressors (Ebi et al. 2003; Semenza et al. 1996). For example, during normal thermoregulation, blood vessels dilate to get closer to the skin and release heat; this causes a drop in blood pressure which can induce fainting spells/falls and numerous cardiovascular complications (CDC 2002). Common heat ailments therefore include increased pulse rates, fainting falls, heart attacks, and strokes. Similarly, diabetic individuals have lower kidney function, which can cause individuals to lose fluids at a higher than necessary rate through urination, increasing the risk of dehydration.

Men aged 65 and older have a documented reduction in thirst sensation, which can cause them to not realize how dehydrated they may have become during oppressive events (Semenza et al. 1999). Due to many of these conditions, Whitman et al. (1997) found at least 70 % of the mortalities from 1995 Chicago, Illinois heat wave consisted of individuals who were 65 years of age and older. Although mental and physical disabilities that impact survivability can be present at any age demographic, the rate of impairment is often higher in the elderly due to compounding health implications (Naughton et al. 2002; Semenza et al. 1999). The previously mentioned health complications can also make acclimation to weather difficult for both young and old individuals, which make them particularly vulnerable to early season heat waves (Changnon et al. 1996; O'Neill et al. 2005; Kalkstein and Greene 1997; Naughton et al. 2002).

2.2 Education

A population's level of education is often viewed as an indication of their attention to detail and general knowledge. Individuals who have completed higher levels of education may have a better understanding of human physical health, and a heightened ability to identify and respond to negative health indicators. For example, an individual with a college degree is expected to have taken (and paid attention during) a larger number of health classes. They will potentially have better healthy living habits resulting from those health lessons, and can identify health concerns in other people. People with a higher level of education may have a better ability for abstract thought, which can assist them in identifying inclement conditions (such as high ambient temperature and the need to hydrate) or identify medical issues in the people they are interacting without the need for additional external training, warnings, or alerts to do so. Increased level of education usually indicates better job security, income level, and residential settings, which further reduce their vulnerability (Harlan et al. 2006; McMichael et al. 2008). These improved homes will often have better insulation and their financial situation could allow for the opportunity for external cooling opportunities, like pool memberships or air conditioning (Davis 1997).

2.3 Income

An individual's financial situation is expected to be inversely related to their vulnerability (Changnon et al. 1996; Naughton et al. 2002). In other words, wealthier people are less vulnerable than poorer people. Individuals with higher incomes have increased accessibility to hospitals and generally have homes that include protective elements, like air conditioning (Davis 1997). Wealthier people may also have insurance or financial reserves to recover from oppressive events more quickly. It is often the wealthy, privately insured individuals, who are the first in a population to start rebuilding after a flood or tornado, because they have the ability to pay for repair work before federal disaster funding becomes available. Conversely, populations live in poverty have limited, or no, access too many protective amenities. Air conditioning use is one such amenity; lower income populations may not be able to afford running the utility even if it is present in their home. Air conditioning has been shown to decrease heat mortalities by 50–80 % during inclement weather (Semenza et al. 1996; O'Neill et al. 2005). People with lower incomes often take up residence in older and less insulated housing, which increases their exposure to inclement weather conditions. They also have less disposable income to spend at malls, movie theaters, or community pools which could provide relief during extreme heat events (Changnon et al. 1996). Similarly, low-income populations will be less likely to seek medical help due to a lack of insurance or expendable money.

These examples have provided a brief example of the potential range of social vulnerability. Although these traits have been presented distinctly, in the real world it may not be so clear. Elderly populations are often at increased risk due to their age and health risks and they may also commonly live on a fixed retirement income (Changnon et al. 1996). Elderly people may also live in their original home, built several decades ago, with minimal (or worn out) insulation and cooling systems (Davis 1997). These impacts can compound and increase risk. For these reasons, social vulnerability modeling should include multiple variables, rather than individual variables, to identify the compounding impact on populations.

3 Physical Vulnerability

The second type of vulnerability assessment is known as physical vulnerability, which focuses on the actual event or stressor which impacts a population. This modeling is focused on quantifying the event's oppressive force, intensity, and proximity. Common examples of physical variability studies include identifying flood zones, tornado path, or proximity to other site-specific hazards, such as wild fires. Physical vulnerability predominantly focuses on identifying the locations of hazard, and is often used more to document insurance and disaster relief rather than to understand the oppressive impact to the population. In contrast to social vulnerability, physical models do not indicate whether those who were impacted have the ability, be it financial or physical, to adapt or recover from the impact. However, physical modeling indicates how oppressive, or powerful, the extreme weather event is and will document the magnitude of impact. Simple examples of physical models can include the Fujita Scale (F-scale) for tornados or quantifying the difference between a 1 foot and 10 foot flooding event.

3.1 Heat Vulnerability

A common misconception about heat wave vulnerability is that there is a continuous, or even distribution, of temperature across an area (Johnson et al. 2011; Li et al. 2004; Zhang and Wang 2008; Went and Quattrochi 2006; Chen et al. 2006; Voogt and Oke 2003). This should be attributed to atmospheric meteorological forecasts and measurements, which are reported at county or larger boundary resolutions. The National Digital Forecast Database displays weather data at a 5 km resolution, suggesting the entire population within that boundary experiences the same thermal influence (NOAA—http://www.nws.noaa.gov/ndfd/). The urban heat island (UHI), a phenomenon where urban construction materials increase proximal temperatures (Luvall and Quattrochi 1998; Voogt and Oke 2003), disproves this notion. The discontinuity in heat distribution is caused by man-made, constructed materials (buildings, roads, parking lots) which absorb solar energy and re-emit it as thermal energy, or heat (Jensen 2007; Luvall and Quattrochi 1998).

To experience the impact of the UHI, an individual only needs to measure the temperature difference between a parking lot and a nearby grassy feature during a hot day. Advances in satellite imaging are now able to quantify the UHI's discontinuous nature, commonly known as the micro-UHI. The discontinuous thermal impact is derived from the density and quantity of constructed material within an area. Therefore, a dense commercial and high-rise apartment area will have a higher UHI than a neighboring suburban area (Chen et al. 2006; Zhang and Wang 2008). This quantifiable data can allow investigators to distinguish thermal difference between urban areas and incorporate the values into a vulnerability model (Johnson and Wilson 2009; Johnson et al. 2009, 2011; Cutter et al. 2003; Stanforth 2011). There are three important variables to consider for heat vulnerability modeling.

3.2 Micro-UHI

The thermal influence on a neighborhood, particularly within vulnerable populations, demonstrates the degree to which the local population may be affected. It is particularly relevant for individuals who live in dense urban areas, including high rise apartment facilities, that can absorb and store increased quantities of thermal energy (Cutter et al. 2003; Johnson et al. 2012; Zhang and Wang 2008). The thermal impact is particularly dangerous as built environments continue to emit heat throughout the night, which disrupts the normal diurnal thermoregulation process in humans (Sheridan 2002). Humans have evolved to use natural diurnal temperature changes to survive periods of high temperatures through nocturnal reduction in core body temperature. This process of diurnal thermoregulation reduces body temperature through exposure to cooler evening hours, and allows for the maintenance of safe body temperatures. Since the UHI disrupts this diurnal process by extending warm temperatures during evening hours, it requires individuals to use alternate means to regulate and maintain safe core body temperature, such as through air conditioning. The ability to quantify higher thermal risk areas is relatively unavailable without land surface temperature documentation from remote sensing devices. Although meteorological equipment can be used to quantify ambient temperature, they have significant spatial disadvantages.

Atmospheric temperature readings have a large spatial resolution, at least 5 km, which does not capture the micro-UHI, and in situ sensors do not provide a continuous coverage of a study area. However, Remote Sensing systems designed to document surface temperatures, such as the Landsat satellite series, can record land surface temperature (LST) and provide the continuous variable required to compare urban neighborhoods. It should be noted that thermal satellite or other remotely sensed data is a measure of the land surface temperature (LST) not the ambient air temperature. The two are believed to be related since the LST can heat the near surface air and increase ambient temperature where people live. However, due to the limited number of studies on the topic, a positive correlation between the two cannot be conclusively stated (Li et al. 2004; Voogt and Oke 2003; Weng and Quattrochi 2006). Therefore, documentation of the LST within urban areas can provide a good indication of thermal stress, but not necessarily the ambient temperature, in the local area. LST is a particularly relevant measurement for heat influence during periods of low wind and atmospheric mixing, which is common during heat waves and often exasperated by urban canyon geometry which blocks and channels winds within the city.

3.3 Built-up Environment

Similar to the measurement of LST, the built environment influences the impact of proximal land features on local residents. Dense urban areas may experience multiple negative health influences; increased surface runoff leads to surface refuse and dust/trash can accumulate on impermeable surfaces. For heat studies, impervious surfaces increase thermal stress and disrupt wind patterns, which would normally provide relief from the heat. Density of built environments can be quantified through remote sensing devices, similar to the methods used for heat (Zha et al. 2003). The normalized difference build-up index (NDBI) quantifies the density of constructed features (Jensen 2007). Although this particular algorithm has some inability to discern between constructed features and barren/rocky surfaces, it is not really an issue since barren surfaces are uncommon in urban areas and should therefore rarely impact urban analysis (Zha et al. 2003). The NDBI will identify many of the same areas as the UHI, but in that capacity it can be used to double check the LST measurements or assess mitigation practices like green roofs.

3.4 Vegetation

During photosynthesis, vegetation converts solar energy into glucose and stores the energy for later consumption. This removes a quantity of thermal energy from the local neighborhood and acts as a protective element (Davis 1997; Harlan et al. 2012). Vegetation can also store precipitation, reducing surface runoff, and reduce dust through soil stabilization with their roots. Stabilized soil can reduce surface refuse and asthmatic complications. Therefore, it is easy to understand the multiple ways why vegetation can improve the health and resilience of local populations. Quantification of vegetation can be obtained through many vegetation indexes used in remote sensing studies, the most common being the normalized difference vegetation index (NDVI) (Jenson 2007). This algorithm identifies healthy plant leaves, and is generalized enough for use across a wide variety of climates (Zha et al. 2003;

Jensen 2007). This type of index can identify areas where there is a protective element to local populations. Areas with more vegetation have a natural shield against the oppressive elements of heat to provide protection during inclement conditions (Luvall and Quattrochi 1998; Quattrochi and Luvall 1997; Voogt and Oke 2003; Chen et al. 2006) Fig. 1.

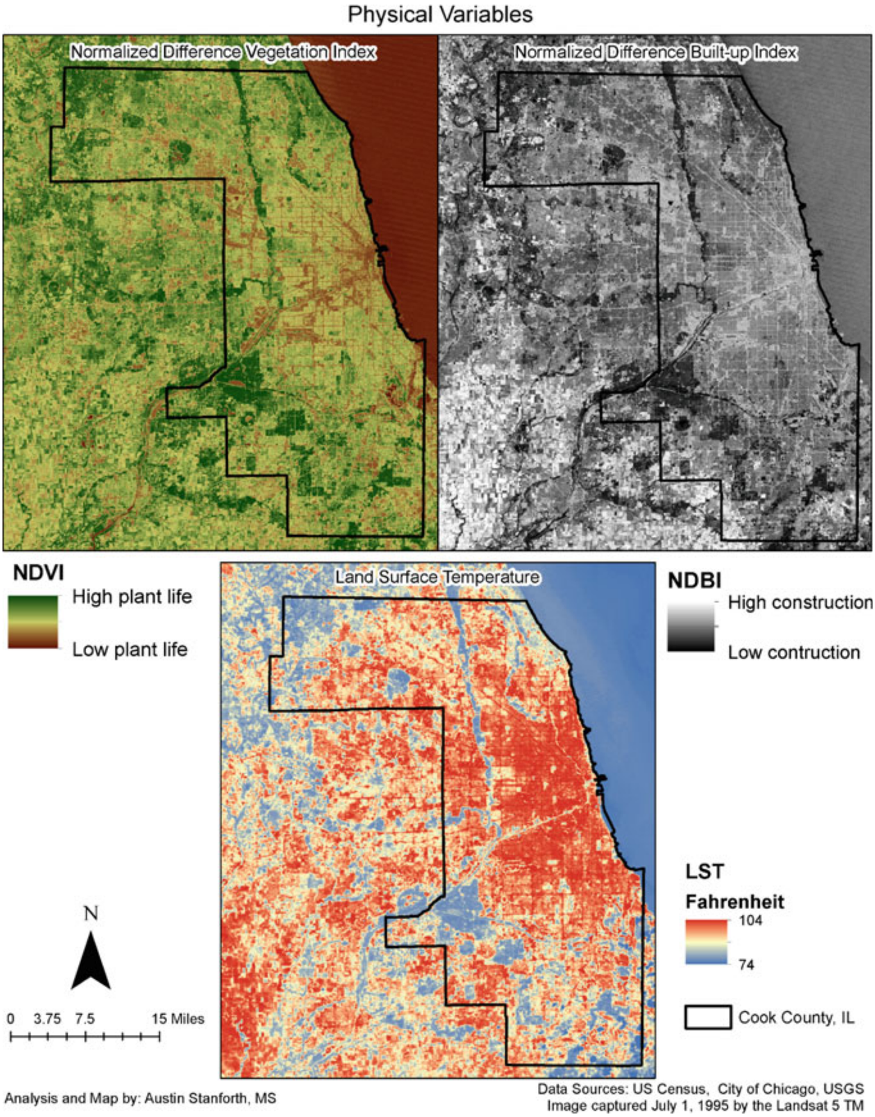

Fig. 1 Comparison images for the physical variables in and around Chicago, Illinois. Note how the *NDBI* and *LST* highlight similar surface feature spaces, while the *NDVI* highlights other regions?

4 Temperature Warnings

As previously mentioned, physical vulnerability studies place less emphasis on the individual or population's ability to adapt or recover from an event. Rather, they focus on the event or degree of influence imparted on the population. For heat waves, the degree of influence is simply the degree or temperature. This variable is often quantified and monitored through weather forecasts conducted by local branches of the National Weather Service (Johnson et al. 2012; Stanforth 2011). Due to the devastating loss of life previous heat waves have caused, the federal government has mandated the implementation of Heat Warning systems across the country (Ebi et al. 2004). Since weather forecasts often maintain a 5 km or larger resolution, this leads to practices that treat large non-uniform areas as continuous temperature patterns and do not factor in the discontinuous nature of urban features. The previously discussed remotely sensed environmental variables should demonstrate why this is an area of concern. Further complications arise as the national warning system often uses a standard specific temperature criteria across the continental United States. Due to the vast area and number of climate features, the application of a single temperature threshold is problematic (Robinson 2001). Discussion with habitants frequently suggest conditions considered uncharacteristically hot in the Pacific Northwest may not raise concern among populations of the dry, desert cities of the southwest (Personal correspondence 2010). This non-location specific implementation of warnings is another reason why heat wave warning systems have received very little interest from the public, because the advertised warnings may not describe inclement conditions in their location, so the population may lose interest.

Some researchers have developed regional, or location specific, warning systems. One of the most well-known, the Kalkstein Heat Health Watch Warning System, analyzes local weather patterns and uses statistical analysis to identify specific local weather conditions related to a significant increase in the reports of heat caused health concerns during previous extreme conditions (Kalkstein 1991; Kalkstein and Greene 1997; Kalkstein et al. 1996). The warning system then uses meteorological forecasts to identify the return of similar weather pattern forecasts to elicit warnings. Although the Kalkstein method has been used throughout the world, it has major shortcomings in its inability to identify 'at-risk' populations. The Kalkstein method uses meteorological forecast data, therefore maintaining the large resolution analysis; it also does not account for socioeconomic status to identify people who are more vulnerable during the projected risky weather pattern (Johnson et al. 2011, 2012; Stanforth 2011). This method can be efficient for the purpose of identifying when large inclement weather fronts are eminent and broadcasting a wide warning to all populations, but does not provide the means to improve mitigation or community prevention practices. The Kalkstein method should, however, receive credit for improving public outreach to emergency management authorities and public awareness of the risks of extreme heat conditions (Kalkstein et al. 2011).

An alternative warning forecast method is Robinson's threshold, which tracks an area's weather patterns over the course of several years. Conditions are considered extreme if they surpass the top distribution values of observed weather events (Robinson 2001). Similar to the Kalkstein method, Robinson's method uses large spatial resolution meteorological conditions. Although Robinson's (2001) method does not use health data to derive risk, it has fewer computational requirements, making it popular among researchers and emergency management offices alike. One consideration lacking in both of these mechanisms is consideration for the diversity of urban features. Due to the UHI, many locations within a city could experience heat wave conditions before their atmospheric forecast systems indicate a threat (Johnson and Wilson 2009; Johnson et al. 2009, 2012). To improve resilience methods, improvements in resolution and understanding of the mechanisms between social and physical space need to be undertaken.

5 Social-Spatial Vulnerability

The application of weather, social, and physical vulnerability derived warning systems, such as those previously mentioned, can improve a population's resilience. However, the application of a single method will not provide sufficient information to identify the best mitigation practices. Inquisitive minds may wonder, 'why not use multiple practices?' The combination of multiple practices within a single system should utilize the strengths of each and provide a better holistic approach (Johnson et al. 2009, 2011; Stanforth 2011). A few approaches have been made, such as those conducted by Reid et al. (2009) and Cutter et al. (2003), which incorporate both physical and social variables.

5.1 Social Vulnerability Index (SoVI)

Cutter et al.'s Social Vulnerability Index, or SoVI, is a national assessment of vulnerability whose smallest unit of measure is at the county level. It incorporates multiple socioeconomic variables, such as age and income. The SoVI includes generic environmental variables, such as urban density which are based on population calculations rather than the quantization of physical variables. It also maintains a large analysis resolution similar to those found in meteorological forecasts. Reid et al.'s (2009) method concentrated on the census tracts of urban areas, but uses a single analysis across the continental United States, similar to the inefficient national standardized heat wave meteorological warning. This study used Land Cover classification to identify the percent of area covered by vegetation as an indicator of environmental influence (Reid et al. 2009). However, since the classification map did not utilize imagery obtained during the time period of inclement weather conditions, the relationship between risk and the environment cannot be conclusively extrapolated. Reid's later publication suggested local-scale testing was a more optimal approach, and regional analysis could not account for small discrepancies in physical or vulnerable attributes (Reid et al. 2012). Despite the advancements over previous systems, both of the described methods maintain large spatial resolutions and do not incorporate temporally-specific environmental variables. To build a more holistic approach to vulnerability modelling, the system should incorporate temporally-specific and multidisciplinary data to assess the interaction of social and physical stressors.

The improved incorporation of multidisciplinary variables requires further understanding of different variable interrelationships. A few simple association examples can demonstrate the relationship between physical and social attributes. Income can impact the selection of available residences, e.g. lower income populations may only be able to afford to live in older or less insulated homes. Older residences commonly have no AC and low income neighborhoods are built in more dense configurations, similar to urban practices, which increases UHI (Davis 1997; Dolney and Sheridan 2006). These combined attributes can lead to a higher risk for heat vulnerability. Conversely, higher property values are often newer residences with more vegetated urban areas or have had more recent construction that can decrease UHI. The newer construction may also have better insulation and opportunity for AC utilization (Cutter et al. 2003; Harlan et al. 2006). Through these examples it's clear how social and environmental variables can be correlated, but variables that generally have little impact on each other can still increase a person's vulnerability. If you recall, our earlier discussion noted a person's age is not directly associated with a specific living condition, but is often related to their level of income.

Elderly populations often have decreased thermoregulation and mobility, which significantly increases risk if they live in an area with high ambient temperature. This is particularly relevant for elderly men, many of whom experience a reduction in thirst sensation and may refuse to use AC because ‘it was not something they needed in their youth’ (Semenza et al. 1999; Davis 1997). Should these stressors combine with a high risk due to income, such as living on a fixed retirement savings, the two variables could compound their impact to increase an individual's level of risk.

5.2 Extreme Heat Vulnerability Index

The previously discussed vulnerability models demonstrated how either social or physical stressors could be used to model vulnerability, and even how they could be interrelated. However, the large spatial resolutions used can negatively impact the analysis due to potential aggregation errors, a complication caused by averaging data over large areas (Stanforth 2011; Johnson et al. 2011; Reid et al. 2012). This spatial resolution limitation within extreme heat studies on urban populations could greatly affect their ability to determine localized variations in risk. A fine scale model would allow for the identification of specific socioeconomic variables that contributes to increased rates of morbidity and mortality in local populations. Therefore, analysis should focus on localized areas and the development of site specific warning systems which are necessary to better contribute to future mitigation plans (Johnson and Wilson 2009; Johnson et al. 2009). This desire to better understand micro-relationships between vulnerability variables motivated the creation of the Extreme Heat Vulnerability Index (EHVI).

First, a method to combine physical and social modeling must be considered. The previously mentioned Reid and SoVI models facilitated the development of spatially specific models, even though such models maintain large spatial regional or county study areas (Reid et al. 2009; Cutter et al. 2003; Harlan 2006). These models use a statistical data reduction method to assess the relationships between variables which could be described as 'indicators of vulnerability', including the financial and age variables found within the US Census data (Stanforth 2011; Johnson et al. 2012).

5.3 *Statistical Modelling*

Statistical modeling processes, such as the principal component analysis, can be used to identify trends in data sets. These trends can identify which variables are positively correlated to negative health impacts within a population. Two sets of data are required to perform such an analysis that includes both dependent and independent variables. Health data can account for the dependent variable; previous vulnerability studies have utilized both mortality and morbidity data (Kalkstein et al. 1996; Semenza et al. 1999). Although both can provide an indication of risk, mortality data can be easier to compile (Johnson et al. 2009, 2011; Stanforth 2011; Johnson et al. 2012). Morbidity records are protected by many privacy laws, including the federal Health Insurance Portability and Accountability Act (HIPAA), and can be easily confounded due to inconsistencies between hospital records for a patient's admittance and discharge. Mortality records and death certificates, although protected, are often a matter of public record and much more accessible. Furthermore, heat mortality records demonstrate the most extreme impact of a heat wave, which this type of modeling should focus on preventing. It should be admitted that some complications exist with heat mortality research, as there remains little standardization for heat mortality classification, and the quantities are often underreported (Bohnert et al. 2010; Iniguez et al. 2010).

5.4 Heat Contributing Mortality Causes

The use of all heat-related mortality causes includes those that list other primary causes of mortality which could have been exasperated by the heat (cardiovascular, asthmatic, diabetic, or similar). This inclusive list has been found to positively identify populations at increased risk during the study period (Whilhelmi and Hayden 2010). Inclusion of heat contributing mortalities is not believed to overestimate the weather's impact (Shen et al. 1998; Whitman et al. 1997). The independent variables consist of local sociodemographic and environmental variables. The social economic data can be obtained through the US Census website, www.census.gov, while satellite data can be acquired through the U.S. Geological Survey's online database, www.USGS.org. Similar data reduction methods used during the previously described SoVI analysis could be implemented into the EHVI study design using smaller spatial units, such as US Census Tracts and Block Groups. The use of census data is beneficial for this type of study because it provides socioeconomic data for analysis and provides boundaries to extract environmental variables through the use of a Geographic Information Science (GIS) system. Additionally, each U.S. Census boundary contains a unique identification code for a standardized identification system to statistically compare the areas among themselves (Stanforth 2011; Johnson et al. 2011). The U.S. Census data also provide a generally standardized population amount within each boundary, naturally reducing some bias from population density.

The EHVI study is unique among the previously described methods because it affords multiple environmental variables with the same weight as the social variables (Johnson et al. 2012). The EHVI uses a data reduction statistical method, in the Johnson et al. (2012) example the Principal Component Analysis (PCA) is used, to categorize variables based on their relationship to health outcomes (the dependent variable). These types of statistical data reduction techniques simplify the data to identify which variables are more correlated to the dependent variable (StatSoft 2015). The EHVI for Chicago was created using mortality from the July 12–16, 1995 heat wave as the dependent variable. This allowed for the statistical analysis to find variables which were correlated, or could be compared, to the population whose health experienced the greatest impact during that particular heat wave. Chicago has a humid continental climate, with an average daily July temperature of 75.56 °F. During the heat wave the temperature ranged between 86.06 and 104 °F, which does not allow for natural regulation of body temperature (Stanforth 2011). Over 700 mortalities were documented during this 5-day heat wave. Of those, 586 have been accepted as being directly or indirectly caused by the meteorological event (Centers for Disease Control 1995; Whitman et al. 1997; Shen et al. 1998; Stanforth 2011; Johnson et al. 2012). Geocoded (mapped or located) mortalities can act as the depending variable in the statistical analysis by extracting the number of mortalities which occur within a single census boundary to match the social and environmental variables (Johnson et al. 2012; Stanforth 2011).

6 Principal Component Analysis Findings

To completely understand the intricacies of a principal component analysis can require some studying, as it can be quite complex. However, the project's results can be discussed in generic terms for simplicity purposes in this chapter. A principal component analysis identifies relationships between variables by identifying clusters or patterns (UCLA 2015). Imagine each independent variable value is plotted along the x-axis of a graph, while the dependent is plotted against the y-axis. The statistical analysis identifies clusters within the graph and reclassifies those attributes as new principal components, which are a composite of the input census and environmental variables in this example. The use of principal components allows for the reduction of variables from the analysis that do not contribute to the analysis, or demonstrate the same information, to reduce dimensions (number of inputs) and therefore simplify the dataset. Only components that explain at least the same amount of variation within the data as any original variable are considered to be a principal component (Kaiser 1960). Statistical nomenclature identifies these as having an eigenvalue greater than 1, and is classified as a Kaiser Criteria. Each input variable can then be identified by how much they contribute to each principal component to identify how important they are to the overall analysis (StatSoft 2015). Variables heavily loaded in the principal components are identified as important, and should be considered in future vulnerability models. Such variables add predictive value for identifying local risk.

6.1 Chicago Heat Wave

With this basic understanding of a principal component analysis, we can demonstrate population impacts during extreme heat events. The data shown in Table 1 represent a sample of the principal component results available from the study of the 1995 Chicago, IL heat wave. In addition to U.S. Census socioeconomic variables, the three previously discussed environmental variables collected by the Landsat 5 Thematic Mapper on July 1, 1995, were included in the PCA analysis, examples of these variable can be viewed in Fig. 1 (USGS, Census). The statistical output illustrates four principal components, which cumulatively explain over 79 % of the data's variability. It can also be thought that the four variables explained 79 % as much as the full list of variables, but has removed variable noise which contributed to some of the remaining 21 %. Of those principal components, the variables which contributed most to these results can be identified. In general, variables that best represent heat mortality (the dependent variable), are the population's age, educational attainment, and income. Race is often cited as being essential for predicting population vulnerability (Cutter et al. 2003); this study shows race can range anywhere between the first and fourth components, depending on the classification, suggesting it may not be as important in this type of analysis for all designations or

Table 1 PCA result sample set for the EHVI analysis. Only variables with large (0.8 or higher) positive or negative component loading are considered highly important to the analysis

Component	Eigenvalue	% Variance explained
1	8.88	46.71
2	2.64	13.9
3	2.24	11.82
4	1.33	6.98
		Cumulative = 79.41 %

	Component loading			
Variable	1	2	3	4
Age 65 and older, female	0.94	0.09	0.21	0.18
Age 65 and older, male	0.93	0.10	0.23	0.18
Age 65 and older: female socially isolated	0.93	0.11	0.15	0.10
White race population	0.90	0.28	0.15	−0.07
Age 65 and older: male socially isolated	0.86	0.19	0.12	0.14
Mean family income	0.85	0.27	0.24	0.23
Per capita income	0.84	0.29	0.20	0.18
Mean household income	0.83	0.26	0.25	0.26
Adult population without: high school diploma	0.83	0.30	0.27	0.24
Asian race population	0.64	0.18	−0.07	−0.39
Age 65 and older. group living	0.49	−0.01	0.10	−0.32
Hispanic race population	0.31	0.91	0.15	−0.02
Adult population with: high school diploma	0.11	0.61	0.06	0.36
NDBI	0.25	0.16	0.90	−0.02
NDVI	−0.36	−0.15	−0.89	0.04
Black race population	0.40	0.03	0.33	0.67
Land surface temperature	0.10	0.10	−0.13	0.94

locations (Stanforth 2011; Johnson et al. 2013). Environmental variables rank lower within the component loading. This was unexpected, as previous studies have found a positive relationship between UHI and heat mortalities, but is believed to be due to the larger resolution of satellite imagery compared to the census boundaries (Johnson and Wilson 2009; Johnson et al. 2009, 2012; Stanforth 2011).

Discussion on the component loadings can either support previous research, and endorse the variables use in future analysis, or can disagree and merit further investigation. Age, education, and financial situation all contain strong placement within the component matrix within this and previous studies (Cutter et al. 2003; Ebi et al. 2003; Harlan et al. 2006; Johnson et al. 2009; Reid et al. 2009; Stanforth 2011). Therefore, these sociodemographic variables are supported for continued use in vulnerability studies. Race was not as significant in our analysis. Since this is contrary to previous studies, additional analysis should be conducted to see whether the low ranking in this study is site specific to the Chicago region in 1995, or due to a confounding error in other studies (Cutter et al. 2003; O'Neill et al. 2005; Stanforth 2011; Davis 1997; Whitman et al. 1997; Schwartz 2005). Confounding variables are important to identify, because if two variables are confounded (similar to one another), individually they do not add any additional information to the analysis. Since confounding variables do not contribute additional info, they may only increase the quantity of variable noise, or might be 'piggy backing' off its correlated partner. For example, if the highest educated individuals in a population also always maintain the highest income, it would be redundant to include both income and education; race may be acting in this way with another variable.

Environmental variables were not very predictive during our analysis, as they were located in the 3rd component, and land surface temperature in the 4th. It had been anticipated these variables would have a stronger relationship with the mortality rate due to previous research associating urban heat proximity to areas of high health impact (Johnson and Wilson 2009; Johnson et al. 2009). The low impact may be explained by an aggregation bias since the environmental variables had less range difference and had moderate resolutions (30–120 m thermal) compared to the census variables (Stanforth 2011). Additional analysis should be conducted on the environmental variables when improved remote sensing data is available to further identify their impact on the analysis.

Although the variables in Table 1 can demonstrate which variables have a greater impact on mortality risk, they do not directly provide information as to where the population living in higher risk is geographically located. Some statistical analysis tools provide a vulnerability output for each political boundary based on the independent variable values it contains. Areas with high rates of elderly, uneducated, and poor populations will be assigned a higher risk value. These can be mapped in a choropleth (themed color) map to visually demonstrate and spatially compare areas of low or high risk (Stanforth 2011; Johnson et al. 2012, 2013). The map allows for the identification of landmarks or locations in the city experiencing a greater number of heat health impacts. A public health or emergency management worker could use such a map to work on mitigation practices to reduce or eliminate negative health impacts. The data does not suggest that mortalities will only occur in high-risk neighborhoods, but can be used to identify populations that require the most or more urgent assistance.

Cities are also frequently changing through population migration and building practices. Additionally, no two cities are alike, they all have distinct demographic characteristics. Therefore, no two cities will exhibit the same vulnerability patterns in regards to their variables or spatial arraignment. It is also expected that patterns of vulnerability will change over time within a single geographic (Johnson et al. 2013). Therefore, this level of analysis must be dynamic and updated through time

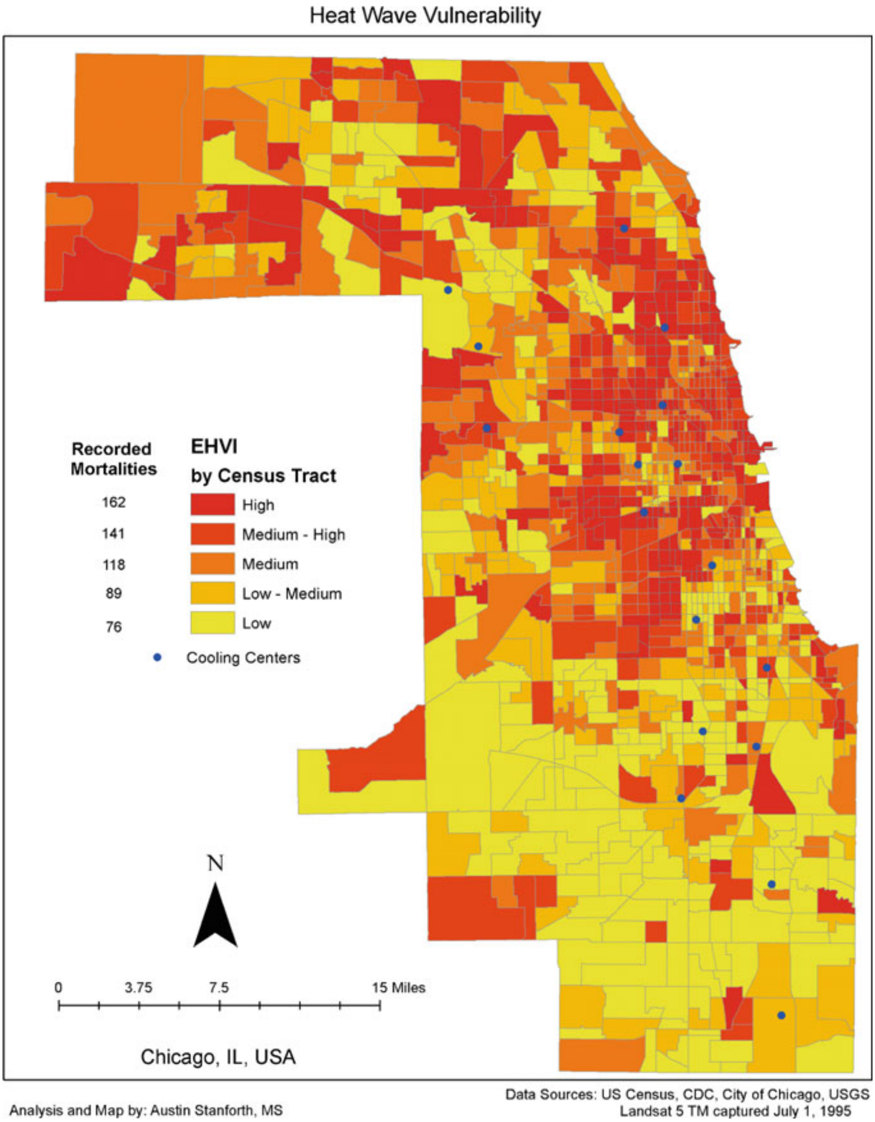

Fig. 2 Extreme heat vulnerability index (EHVI) demonstration for the city of Chicago, IL. Data used for the analysis includes 1990 Census variables and a Landsat 5 TM image acquired July 1, 1995. Note the locations of the cooling centers. Which facilities should public health officials ensure are open during a heat wave?

and across geographical regions. This further demonstrates why a standardized, or national, model for either weather risk or vulnerability will not identify the true nature of the oppressive event. Figure 2 provides an example of the choropleth style map created by the EHVI. It identifies higher risk environments where mitigation practices should be prioritized. The high risk classification is supported by the count of mortalities occurring within each risk rank. High risk boundaries contained a higher rate of mortality than the lower risk boundaries. This style of map can be used to plan mitigation practices and identify local resources, such as proximal cooling centers.

7 Data Hindrance

Most scientists will be able to find a complication or shortcoming within any dataset. Heat vulnerability modeling is no different. One of the most common problems with heat vulnerability research has been the classification of impacted populations, or the dependent variable. Until the heat waves of the middle 1990s, there was no standardized criteria for coroners to identify heat mortalities (Shen et al. 1998; Changnon et al. 1996). This recent standardization has provided only a short window of documented historical cases for study; even now the criteria remains relatively lax (Centers for Disease Control 2002; Donoghue et al. 1997).

Proper identification of heat mortality is very time sensitive because the coroner needs to document body temperature shortly after death. This is often difficult to obtain, as many individuals may have been deceased for many days before their 'lack of presence' is noticed and officials are notified. Therefore, researchers tend to include other mortality classifications when pre-existing conditions which could have been exasperated by heat, such as cardiovascular issues, are listed as a contributing mortality factor (Shen et al. 1998). This inclusive method has provided a better baseline dataset for analysis, but has not been found to overestimate the impact of heat waves on mortality rates (Shen et al. 1998; Schwartz 2005; Bohnert et al. 2010; Iniguez et al. 2010).

The independent variables used for analysis also have shortcomings. Both U.S. Census and satellite data have temporal and spatial resolution limitations. Historical U.S. Census data can be obtained through their website, www.census.gov. Previously, the census had been collected once every ten years, which could cause problems in identifying the local population between collection years. As previously mentioned, the U.S. Census was formally converted to the American Community Survey in 2010. This new survey-derived dataset is designed to provide more temporally relevant data, by sampling a portion of populated areas each year and interpolating the remaining population. This new method will never conduct a full census, which weakens its continued ability to document future population demographics. Since it is the best dataset currently available, all future research will have to acknowledge the potential errors associated with using a sample-derived dataset.

7.1 Satellite Data

Satellite data has similar temporal and resolution limitations. For satellite remote sensing a balance must be made between the spatial (the smallest measurement, or pixel, the instrument can collect data) and temporal (how often an area is recorded) resolutions of a sensor (Jensen 2007). An example of this dilemma might occur when documenting a landscape with a camera. When collecting a wide or panoramic image, the background becomes unfocused but the wide angle allows for the collection of many quick images of the scene. If however, you zoom into a specific area to improve the image detail, you cannot capture as much area in a single shot; rather you must reposition the camera and take additional photos to cover the same amount of area as the wide view shot. This is an oversimplification of what happens with remotes sensing, but should illustrate the balance between collecting detail and big-picture view resolutions. Collecting a high spatial resolution (zoomed) image will collect more detail, but will not cover as large of an area. A wider view does not have the same level of detail, but collects a larger feature area and allows for more rapid collection of images at the same spot. Satellites which collect higher spatial resolution, such as the Landsat with a 30 m resolution, are focused to collect more spatial data and are only able to collect data in the areas once every 16 days.

A satellite with improved temporal resolution, such as the MODerate Resolution Imaging Spectroradiometer (MODIS), collects imagery over the entire Earth each day but has very low spatial resolution. The MODIS's 'zoomed out' image has a spatial resolution between 250 m and 1 km (USGS). This suggests that MODIS may not provide enough detail for highly heterogeneous urban environmental modeling, but can document more homogenous features (forests, agriculture) daily. These limitations must also be considered due to weather, as satellites are notoriously impacted by clouds. With the Landsat's 16 day revisit window, it can be difficult to collect data during a period of interest; if cloud cover is present, it could be a month or more until between the acquisition of useful image data is available over a specific area.

With the limitations of satellite data used to identify the thermal influence on populations, the question could be raised—why not simply stick with meteorological data? The reason is meteorological data has even lower spatial resolution than MODIS. Common weather forecast maps, distributed by local broadcast affiliates, provide temperatures at County boundaries that are on average 230,000 km^2 (U.S. Census 2015). The National Digital Forecast Database is a National Weather Service gridded forecast product, and has a resolution of 5 km (https://www.nws.noaa.gov.ndfd/). These resolutions are not capable of recording the disparities of environmental impact between or within urban neighborhoods. These meteorological tools also do not consider the UHI, as most weather stations are located near municipal airports far away from the urban centers. Since the UHI can increase local temperatures, one can assume the UHI could cause heat wave conditions within specific neighborhoods before meteorological data could identify any risk. Therefore meteorological data cannot provide information to advance the analysis of urban vulnerability modeling.

8 Mitigation Practices—How to Use Vulnerability Models to Improve Health

The usefulness of a vulnerability tool depends upon whether individuals are willing to implement mitigation plans to alleviate the stressors. For instance, knowing seat belts save lives would be frivolous knowledge if car manufacturers failed to install them in vehicles. Similarly, vulnerability models that identify local health stressors are only useful if used to improve mitigation plans. How can a community mitigate high UHI? An urban tree planting organization could use UHI and vulnerability model maps to prioritize planting locations within areas of high UHI to increase vegetation cover, reduce high land surface temperature, and reduce the local thermal risk. If the high risk area has more socioeconomic risk, employment or educational programs could provide more financial security to the area, thereby reducing individual socioeconomic risk.

Models like the EHVI could allow city managers to assess their current mitigation practices. The EHVI map can help assess whether the city's cooling centers are located in areas where they are needed. Sensible urban planning priorities could be established to provide additional centers in areas where current facilities do not cater to the population's need. Maps are also a simple and versatile tools for those with little training. Proactive citizens can read the simple EHVI risk map and identify neighborhoods with a high rate of elderly and shut-in neighbors; during high risk weather they could organize volunteers to aid high risk residents and ensure they are safe. Hospitals can also use this information to assess staffing needs. Hospitals located near highly vulnerable neighborhoods could schedule extra employees and strategically place first responders in high-risk areas to improve their efficiency. Medical facilities located in low-risk areas, however, may not need to schedule as many extra employees during a heat wave; this could reduce the hospital's operating budget.

9 EHVI Mitigation Examples—Practiced and Theoretical

9.1 Cooling Center Assessment

The EHVI, and similar vulnerability models, allows Emergency Management personal to assess their mitigation practices in a way weather forecast models cannot. A simple example of the sophistication of these models for mitigation planning is the previously mentioned assessment of cooling centers within a city. City managers can locate their cooling centers on the EHVI map to see which of

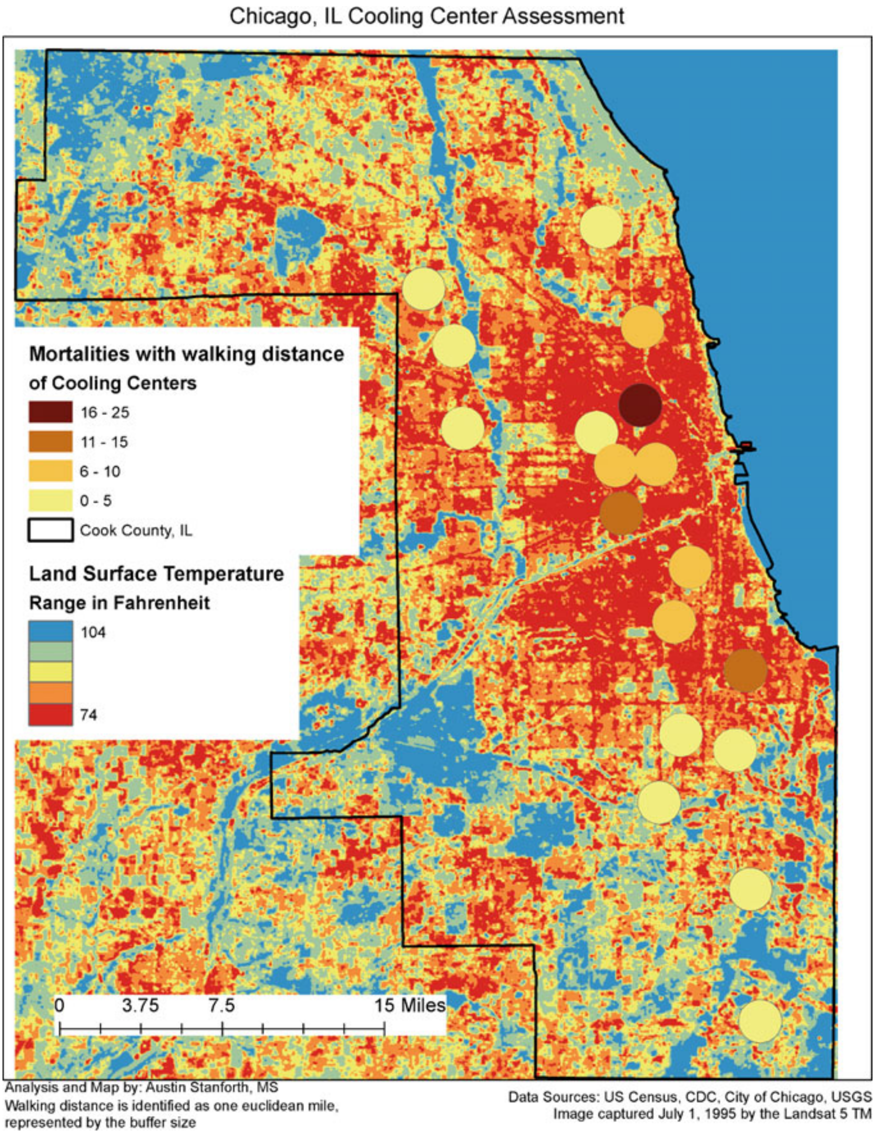

Fig. 3 Cooling center utilization—identifies the locations and quantity of mortalities that occurred within walking distance of each center superimposed on a land surface temperature map

their centers are located within high risk areas; they can also identify new 'best practice' locations to build future centers. Incorporating UHI maps can help management assess whether they should open centers before meteorological forecasts indicate a heat wave. It can also help them identify which centers will require the most staffing. Figure 3 shows one type of assessment for Chicago, IL. First, the map's LST background could identify priority order for the order of opening cooling centers during an imminent heat wave. After the heat wave has passed, it can assist in identifying whether the centers were used appropriately. Figure 3 shows a buffer identifying the quantity of heat mortalities that occurred within walking distance of the center during the 1995 heat wave. One center demonstrates having between 16 and 25 mortalities within one mile of the center. Two additional centers had 11–15 mortalities. This knowledge would allow a manager to investigate why this happened. Was the center not opened appropriately so people could gain access to it? Were the mortalities representative of people who have lower mobility and unable to make it to the cooling center? Or does this cooling center's primary purpose deter marginalized populations from visiting, such as can be the case when a police station is used as a cooling center? Depending on the answers to these questions, the manager can move forward to make their city safer during future heat waves.

9.2 Climate Region Considerations

The advantage of using a model like the EHVI, is that it is a local model. It utilizes local population data, local climate implication, and does not try to compare distinct populations or cultures. As previously discussed, standardized national warnings do not create adequate risk models due to the vastly different climate regions of this country (Hajat et al. 2010). Local populations have various cultural and biological adaptations to heat, depending on where they reside. Local collaborators on the project informed us that some form of air conditioning utility is required in building codes for Phoenix, AZ, due to the frequent high temperatures reached in their arid environment (personal communication 2010). Midwestern states, like Chicago, IL, or Philadelphia, PA, had a much lower prevalence of including cooling utilities in their building practices until after the 1995 heat wave. Philadelphia commonly builds brick and mortar homes, which can increase the urban heat island and even increase internal residential temperatures, similar to a brick oven. Philadelphia collaborates were quick to explain that their residential building practices have been designed to withstand cold winter winds rather than summer's heat (personal communications 2010). As suggested here, these cultural differences show up within building practices, through building codes, and the cultural adaptations of residents' daily lives throughout the world. This make a regional, standardized warning system impractical.

Phoenix is a arid climate, dry and hot all year, while Chicago's summer climate is more mild and humid when heat waves are most problematic. These climate differences can drive different societal habits between the two cities. While Phoenix residents will need to be very cautious about their hydration and fluid intake while they are outside, Chicago residents have the opportunity to cool their core body temperatures by visiting the shores of nearby Lake Michigan, if they have transportation. The response of populations, due to their local climate, is also prevalent in their attitudes toward the weather and mitigation practices. The authors conducted an unpublished telephone survey to identify any patterns in response to residents' impressions of extreme heat events. During this survey, Phoenix residents frequently dismissed the notion of severe or extreme heat. To paraphrase numerous study participants, they disregarded the notion because, "It's always hot". These indifferent attitudes can also stem from acclimation of the climate, since they are acclimated they don't worry about it. However, population sub-groups can have different responses from their neighbors, such as could be the case with 'winter bird' or retired populations who recently moved to the area.

Elderly populations are notorious for not using air conditioning (Davis 1997). Some studies suggest this is in response to fixed financial status, but there are reports of elderly populations who do not feel they need air conditioning because they did not use it when they were young (Naughton et al. 2002). May elderly people may not know, realize, or consider the implications of their aging bodies, which may have a reduced thermoregulatory ability, and assume they are as resilient as they were in their youth. Philadelphia has several service opportunities designed to aid elderly populations, one being the Corporation for Aging (http://www.pcacares.org/). Collaborators from the city identified numerous volunteer opportunities with the center, including an annual "fan drive." Although the use of fans can prove disadvantageous during heat waves, as they reduces sweat's ability to assist in thermoregulation, it does provide an opportunity for the EHVI map to aid volunteers in identifying areas in greater need of assistance (Davis 1997). Similarly, a pastor in Indianapolis, IN expressed interest in using the local EHVI map to guide their youth volunteers to identify high-risk neighborhoods with elderly populations. These youth visited these elderly residents to ensure they had the resources necessary to survive the heat wave.

Other volunteer activities could similarly improve resilience within neighborhoods. Keep Indianapolis Beautiful (KIB) is an organization which manages volunteers to plant trees. The organization's leaders were interested in identifying the best locations, or areas of highest need, to plant trees within the city. Implementing the EHVI and LST maps for Indianapolis, IN allowed the organizers to identify specific neighborhoods that would receive the greatest benefit from tree plantings. Similar organizations could pair up with city officials to identify abandoned lots or spaces where new parks, cooling centers, or urban farming plots could be established. These practices would reduce local heat impacts and improve both air and water quality. Urban farms could improve socioeconomic status and generally improve the quality of life for local residents.

These last two vegetation planning examples are geared towards Midwestern communities, or any environment with a higher precipitation record. Desert environments, like Phoenix, may not benefit as much from tree plantings without the infrastructure to keep them adequately watered. Municipality officials in Phoenix could instead use the EHVI maps to plan new cooling centers or drinking fountains. Additional drinking fountains in high-risk neighborhoods could allow residents to maintain proper hydration while they are outside. Small local municipality pools or 'wading fountains' could similarly be opened when temperatures reach extreme levels. Phoenix could also consider mobile cooling centers practices similar to what has been tested in both Philadelphia and Indianapolis. Municipal buses not in service can be used as mobile cooling centers. These buses could be driven to neighborhoods with higher risk and parked with the air conditioning running. Local residents are able to get on and off the bus to cool down without fee. Vulnerability maps can help identify neighborhoods which may be in more need of the mobile facility, and help assess which neighborhoods could receive the greatest benefit from their presence.

9.3 Residences

People commonly associate their residence with a level of protection from dangerous or oppressive events. However, there are many reasons why a home cannot always provide the protection people assume it should. Low income property value residences can have less insulation, are often older, built in more dense configurations, and lack air conditioning. These characteristics can compound summer temperatures and the UHI, making them dangerous (Davis 1997; Changnon et al. 1996). Many people with lower financial resources have less access to protective environments near their home. Individuals living in poverty, or elderly populations living on a fixed income, have fewer resources to visit air conditioned establishments, such as movie theaters which require an entrance fee, during periods of extreme heat. Patrons must pay to sit in a restaurant, enter a movie theater or museums, and shopping centers or malls similarly elicit purchases for the use of their facilities. Swimming pools may similarly require a membership to gain access. All these options would also require some sort of transportation to reach (Changnon et al. 1996). The condition, or presence, of sidewalks can also inhibit individuals from walking or biking to a protective environment, should they lack an automobile. Lack of transportation and infrastructure maintenance further demonstrates how lower socioeconomic or marginalized populations can have difficulty relocating to safer environments, as these neighborhoods often receive the least upkeep.

Many government-sponsored cooling centers do not charge an entrance fee and can appear like a remedy to solving an extreme heat situation. However, the challenge is that many people who need cooling centers may have limited transportation options or may not feel safe visiting some of these facilities. In many large cities, cooling centers often serve dual purposes. Chicago, IL has been known to advertise their police stations as a cooling center during periods of inclement heat. This type of a cooling center may turn-away many people who could potentially benefit. Freely walking into a police station could be very uncomfortable for people who have criminal records, have witnessed the marginalization of populations they associate with, or whose immigration status is debatable (personal communication 2010). The utilization and/or under-utilization of available resources therefore often depends on the sub-culture of a city. Furthermore, the repair of streets/sidewalks, construction of cooling centers or parks, and general expenditures on mitigation policy are heavily politicized and the value will often be expected to return to local taxpayers or to those supporting the politician. It can be assumed that higher income neighborhoods will have better resource maintenance than the low-income neighborhoods which need the maintenance. Funding allocation is commonly observed with school district distribution of funds. Implementation of an EHVI or similar vulnerability model not only allows for a better argument for distributing funds to areas that need it, but they could potentially be used to provide documentation for FEMA natural disaster grant funding to reduce risk in highly vulnerable areas.

It should also be noted that some individuals do not actively seek out ways to reduce their heat risk, due to a level of concern for their personal safety. This may sound counterintuitive, but it can be common to find closed and locked windows in neighborhoods with higher crime rates during heat waves. Without air conditioning, buildings sealed to reduce theft are also sealed to eliminate air circulation. The operation of kitchen appliances or any number of electronic devices (TVs, computers, fans) give off heat during operation, thereby increasing the ambient temperature within the sealed residence (Changnon et al. 1996). High crime rates will most often drive people to keep their windows and doors locked at night. This causes residents to miss the benefits of cooler night temperatures when diurnal thermoregulation is most important. This is particularly relevant to shut-ins, or those living in isolation who eliminate interaction with the outside world, as it further increases their risk (Naughton et al. 2002).

10 Concluding Remarks

This chapter demonstrates some of the advantages of studying vulnerability to extreme heat at a smaller, more localized scale. Improved understanding and mitigation plans can be made through the use of location-specific weather, environment, and social attributes that help explain why certain populations are at an increased risk. This chapter explored how small scale analysis and modeling for extreme heat vulnerability is advantageous due to the availability of U.S. census and environmental indicators of risk. It was also demonstrated how local cultural attributes or conditions affect responses to risk. National criteria for 'extreme heat' thresholds do not work due to climate differences across the nation and due to cultural responses to local weather acclimation. Low resolution meteorological and physical vulnerability models are not able to account for within city variations of thermal impact due to the effects of the Urban Heat Island. Similarly, national or similarly large models cannot provide the details necessary to assess or improve local mitigation practices. Additionally, local environmental conditions caused by UHIs can cause heat wave conditions before meteorological measurements indicate any risk.

Since variations in socioeconomic status can cause populations to be less resilient than their more financially resilience neighbors, spatially specific vulnerability models must be considered to identify the populations at greatest risk. With numerous mitigation practices available, both economic and environmental, it stands to reason that identifying the best practice mitigation plans would provide for a more complete and efficient reduction in vulnerability. Extreme heat warning systems should therefore focus on micro scale analyses in order to incorporate local variations in the social and environmental variables to reduce health risks by improving location-specific mitigation practices and strategies.

11 Preventative Practices to Reduce Heat Impacts on Community Health

This chapter strives to discuss heat mitigation practices by providing real world examples of risk mitigation. The following is a summation of key points that have been previously addressed to emphasize their significance.

11.1 Heat Mitigation Is Multidisciplinary

Proximity to heat sources is important when identifying the risk of local populations. This can be measured through both meteorological equipment and measurements of the urban heat island. A combination of the two variables will provide a better metric. However, only looking at the heat sources will not identify the population's risk of being affected by the heat. To understand the full risk of a neighborhood, an understanding of the population's ability to withstand or recover from the exposure to heat must also be known. Resilience to heat can be a factor of an individual's physical attributes (good health) and socioeconomic status. An individual with the financial ability to utilize home air conditioning or visit air conditioned establishments, will probably experience less health risks during a heat wave. Knowing the general health resilience and socioeconomic demographics of neighborhoods will be useful when selecting which cooling centers or aid facilities to open during inclement weather. This can allow centers located close to high risk populations to be identified and opened during heat waves. Including factors of both physical and social environments will allow for the creation of improved mitigation practices.

11.2 Heat Waves Are a Local Phenomena

Previously, heat waves were forecasted by a national standardized criteria. As has been discussed previously in this chapter, this is inadequate due to the numerous diverse climates found within the continental United States. The climate conditions between the cool and wet Pacific Northwest states is vastly different from the hot and dry desert conditions of the Southwest. Therefore a standardized criteria for identifying heat waves is inadequate. Heat wave criteria need to be updated for local climate patters and the populations who have acclimated to them. This would likely improve public acceptance of heat wave warnings, improve their knowledge about dangerous weather patterns, and reduce hazardous weather warning message fatigue.

11.3 Heat Wave Vulnerability Evolves with the Population and Location

Population and city characteristics change through time. Population demographics are dynamic, due to both immigration/migration and birth/death patterns changing with medical advances. Cities are also dynamic, as building practices and housing values change. The values of homes or neighborhoods can fluctuate depending on the current, local economic status. Emergency management representatives therefore need to realize that mitigation practices and modeling must also be dynamic to compensate for urban change. Many of these changes will not occur suddenly, except in the case of a disaster, but the option to monitor and update their process should be considered at least annually. Therefore officials should assess their mitigation practices frequently. Assessments can be conducted through epidemiological-style studies to identify whether their mitigation strategies have been effective in previous heat waves. This would allow officials to further improve their mitigation plans before another heat wave occurs.

11.4 Mitigation Is a Local Problem and Requires Local Response

Similar to the discussion of heat waves being a local phenomenon, mitigation needs to be addressed at a local scale. There are many practices that could be used within collaborating communities, such as eliminating entrance fees for community pools or organizing volunteers to visit high risk elderly neighbors during heat events. Longer term mitigation practices, however, require a very local approach. Frequent rain patterns in the Midwest allow for tree planting initiatives to reduce the urban heat island and alleviate thermal stress. This same mitigation plan may be cost prohibitive in arid climates, as trees would require additional attention and water resources to survive. A desert environment may benefit more by making drinking fountains or covered shelters more accessible.

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Drought and Health in the Context of Public Engagement

Nicole Wall and Michael Hayes

Abstract Droughts have profoundly affected societies around the world from the earliest beginnings. A recent estimate from the Centre for Research on the Epidemiology of Disasters (CRED) claims that more than 1 billion people have been affected by drought during the twenty-year period between 1994 and 2013. Because of the characteristics of drought, drought impacts are often difficult to identify and quantify, and this is especially true with public health-oriented drought consequences, including those resulting from low water quantities, poor water quality, mental health and stress, dust and windblown agents, and wildlife intrusion. However, when officials emphasize adopting a proactive risk management approach to address drought, opportunities increase for reducing future public health risks. This chapter provides an overview of drought and describes drought risk management. The chapter ends with several case studies illustrating how public engagement can greatly assist in preparing a region for future droughts. Preparedness for drought is important as the competition for valuable and finite water resources increases, and as climate change potentially increases drought frequency and severity.

Keywords Drought · Health · Engagement · Impacts · Risk · Management

1 Introduction

In 2013, as Brazil prepared to host the 2014 FIFA World Cup, a drought began to develop that targeted the heavily populated southeastern part of the country, which includes São Paulo and Rio de Janeiro, Brazil's biggest metropolitan regions.

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The World Cup came and went, but the drought did not. Reservoirs for the largest of several São Paulo water systems, servicing a population of at least 20 million, shrank to just 5 % of capacity by February 2015. One report estimated that São Paulo had four to six months of water remaining and was "on the edge of an unprecedented public calamity" (Whately and Lerer 2015, p. 4). As the drought continues, the public health impacts are potentially enormous, and some of these impacts, related to both low water quantity and poor water quality, are already being felt in many impoverished neighborhoods. Officials are scrambling for solutions even as the next big global event hosted by Brazil, the 2016 Summer Olympics in Rio de Janeiro, looms. Meanwhile, observers around the world watch what is happening in São Paulo with keen interest, wondering whether São Paulo is now a prototype for their future.

Other recent droughts around the world have provided dramatic examples of the serious and widespread nature of possible public health impacts caused by drought events. In California, the current multiple-year drought is affecting public health in a variety of ways; increased hunger, increased stress, dry homeowner wells and poor air quality from parched forests and wildfires are just a subset of these health-related impacts. The droughts in 2011 and 2012 over large agriculturally productive regions in the United States illustrate how droughts can have major economic impacts within developed nations, as well as affecting food security and global agricultural markets.

In 2010, the drought and heat wave across Russia's wheat belt served as an important reminder that any event negatively affecting the production in an important agricultural region has worldwide ramifications related to food security. Likewise, the 2011 drought in eastern Africa demonstrated how droughts occurring in developing nations, where food costs can easily consume more than 50 % of family incomes, can also have serious consequences. Finally, the drought event in southern Brazil highlights how droughts can potentially threaten the water supplies of major metropolitan areas even in regions where droughts are not necessarily considered a serious problem.

Reducing future drought risks related to public health impacts will rely on proactive risk management. This chapter investigates the relationships between drought and health in the context of public engagement activities, and how public engagement activities build resilience and potentially reduce future public health risks resulting from droughts.

2 What Is Drought?

Drought is a natural hazard similar to several of the extreme events highlighted within this book. The Centre for Research on the Epidemiology of Disasters (CRED 2015) recently reported that there have been 6873 natural disaster events worldwide between 1994 and 2013. Of these events, 322 were droughts, and CRED estimates that they affected 1.1 billion people. In the United States, as in most locations around the world, droughts are considered a normal part of climate. Figure 1 shows

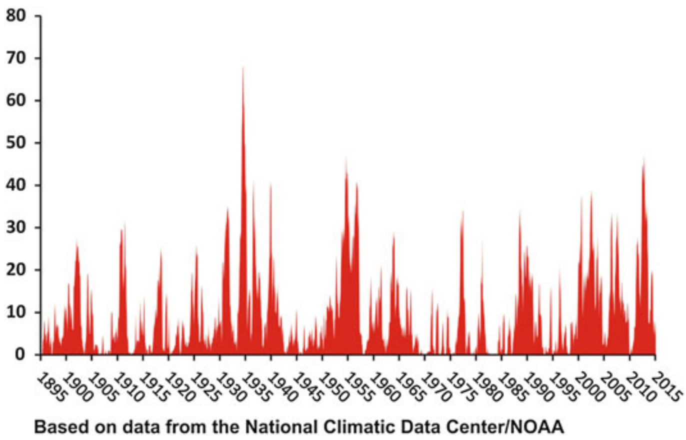

Fig. 1 Percent area of the U.S. in severe to extreme drought (January 1895–February 2015)

Table 1 Billion-dollar droughts (loss/cost estimates normalized to 2012 U.S. dollars using an inflation index) (National Centers for Environmental Information 2015)

Year	States affected	Loss/cost estimate billion
2012	Midwest	>$40
2011	Southern plains	$12.2
2009	Southwest and southern plains	$5.4
2007	Southeast, Ohio Valley, Great Lakes	$5.6
2006	Great Plains, South and West	$6.8
2005	Midwest	$1.2
2002	Western states, Great Plains and much of the eastern U.S.	$12.8
2000	South-central and southeastern U.S.	$5.3
1999	Eastern U.S.	$1.4
1998	Oklahoma/Texas eastward to the Carolinas	$10.6
1996	U.S. southern plains	$7.3
1993	Southeastern U.S.	$1.6
1989	Much of the northern plains	$1.9
1988	Central and eastern U.S.	$77.6

that severe and extreme drought occurs somewhere in the country in almost every year going back to 1895. Table 1 lists the economic loss estimates for recent droughts that have hit the U.S. This table does not include the most recent impacts occurring in California. Estimates from California appear to have the drought losses in the $6 billion range, but climbing as the drought continues.

The unique characteristics of drought, however, cause it to be different from many of the other natural hazards. Gillette (1950) described droughts as "creeping phenomena" because droughts can often develop very slowly over a long period of time, and officials may not recognize that they are in a drought situation until months, or even years, have passed. It can be very easy for everyone to focus on the promise of expected rains during the upcoming weekend or the upcoming rainy season. This natural wait-and-see perspective adds to the challenge of making timely responses in the middle of a drought event. Tannehill (1947) described a second characteristic of droughts that challenge officials dealing with drought events: unlike other natural hazards, droughts do not have a clear, quantitative definition. Rather, droughts are specific to the sources and uses of water in each location and the expectations for that water, which varies widely, even in small spatial regions. Finally, Wilhite and Buchanan-Smith (2005) pointed out that because droughts lack the dramatic visual impacts of other natural hazard events, drought events could escape the attention of the media, public, and officials, contributing to the challenges of a timely response to a drought event until the impacts are often very severe. This is very different from the dramatic photos or videos of tornadoes, floods, tropical cyclones, and other natural hazards.

Given the complexity of drought and its characteristics, it can be useful to consider droughts according to disciplinary perspective. Four perspectives were originally described by Wilhite and Glantz (1985): meteorological, agricultural, hydrological, and socio-economic. The meteorological perspective relates to the precipitation deficit from an expected amount, often measured using a variety of indicators and indices. The relationship between plant water demands and the amount of available water, particularly within the soil environment, best describes the agricultural drought perspective. A hydrological drought perspective highlights longer-term impacts on the hydrological resources of a region such as stream flows, reservoir levels, snowpack, and groundwater. Socioeconomic droughts involve societal or environmental impacts that occur as a result of meteorological, agricultural, or hydrological droughts. Figure 2 is an idealized view representing the timing in each perspective. In reality, however, these four perspectives often overlap. A good example of overlap is how agricultural production that is dependent on irrigation can be affected by a hydrological drought that is affecting the water resources of a region—at the same time the region is not necessarily experiencing much of a meteorological drought.

3 Drought Impacts

Droughts are often dismissed or overlooked because they are identified as a hazard mainly associated with agricultural impacts, which in turn affect the livelihoods of relatively few people within a specific region. Or they may capture attention because they contribute to humanitarian crises in developing nations. Recent droughts, however, show the increasing connection between droughts and food security around

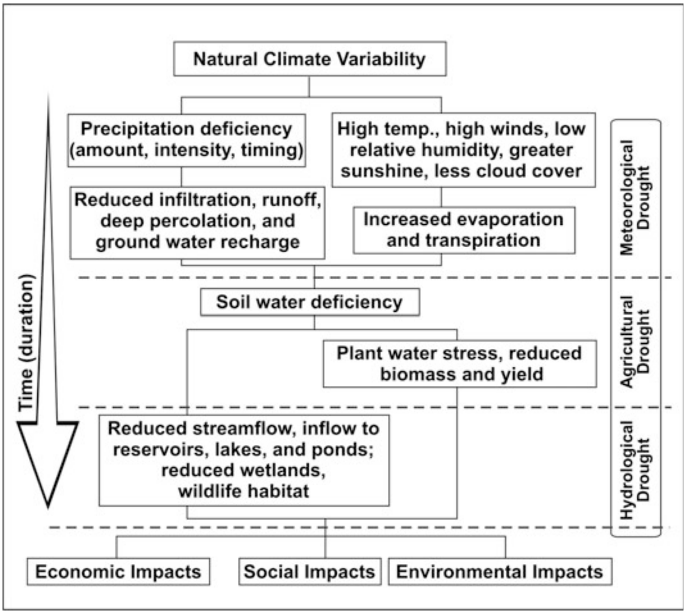

Fig. 2 The disciplinary aspects of drought. *Source* National Drought Mitigation Center, University of Nebraska-Lincoln, http://www.drought.unl.edu/DroughtBasics/TypesofDrought.aspx

the world as a result of global markets and international trade. In addition, recent droughts also show that drought impacts are growing in complexity beyond the agricultural sector as the demands for water grow and the potential competition for dwindling water resources also grows. In the United States, for example, impacts on urban water supplies, energy production, recreation, tourism, ecosystems, transportation, wildfires, and public health have all occurred in recent droughts. Because vulnerabilities to drought vary according to location, drought impacts will also vary by location. Just a few of the factors influencing an area's vulnerability to drought include poverty levels, urbanization, population densities, and land use practices.

For public health, the consequences of drought can be organized into four categories: (1) water quality and water quantity, (2) mental health and stress, (3) dust and windblown agents, and (4) wildlife intrusion. Specific examples for each category will be described but, as mentioned above, overlap between the categories is common.

3.1 Water Quality and Water Quantity Impacts

Good health relies on good water quantity and water quality. Therefore, when droughts affect either or both of these aspects, public health impacts are possible (Stanke et al. 2013). When droughts occur, the first health-related consequences likely relate to water quantity. It is true that in developing nations, droughts can threaten both food and water security directly. The lack of available food can lead to malnutrition and mortality, as well as to listlessness and an increased susceptibility to disease. When combined with governmental breakdowns or strife, drought events can be a contributor to wide-scale famines. Likewise, the decreased availability of basic drinking water supplies for the local populations in developing nations also puts pressure on the health of those populations. The lack of food, water, or both also causes the migration of people, which creates additional public health issues, both during the migration and at the end destinations because of increased crowds and often unsanitary conditions.

Water quantity issues affecting public health are less common in developed nations, but they have been seen in the U.S., for example, when homeowner wells go dry, limiting that source of water supply for those individuals, particularly in rural areas. In these cases, it is often not the direct cause for human mortality or morbidity, as in developing nations, but health-related problems related to the physical toll on the body hauling water. As one example, the U.S. Environmental Protection Agency (U.S. EPA) (2015) estimates that 2.3 million people in New England (approximately 20 % of the population) get their drinking water from private wells. As a result of a severe drought in Maine during 2001–2002, the governor asked for a presidential disaster declaration for the state, largely because of the public health impacts stemming from dry private wells. In his letter to then-President George W. Bush, Governor King (2002) estimated that 2300 families were without running water, and another 18,400 families had well supplies that were threatened. The governor's request was unsuccessful. The only presidential disaster declaration for drought issued to date was for Guam during a drought in 1998, because of the lack of drinking water supplies on that island.

Because these impacts are much less obvious and are frequently overlooked, public health-related risks caused by reduced water quality and low water quantity are often closely linked during drought events. These types of impacts can occur in many locations around the world and in both developed and developing nations. As groundwater levels and hydrological supplies in streams, lakes, and reservoirs decrease, the potential goes up for increased water temperatures and increased levels of harmful chemicals. This can lead to increased salinity and reduced oxygen levels within the water, threatening aquatic species (Bond et al. 2008). Fish kills tend to be a frequently reported drought impact. Less frequently, it is noted that reduced water quality and quantity during drought events increase the need for water treatment where that capacity exists. Increased concentrations of toxins and pollutants may result from industrial and sewage wastewater discharges that would otherwise be at safer concentrations, diluted with normal quantity water levels. These water quality/quantity effects can be detrimental to the health of both humans and the environment. Reduced water quality also results in more water-borne disease outbreaks such as cholera and E. coli (Stanke et al. 2013).

In the U.S., another drought-related public health problem is seen during and after wildfires, particularly in the western part of the country. Wildfires expose watersheds to ash, erosion, and debris that can seriously affect water systems within those watersheds. In 2002, the *Arizona Republic* noted that "ash and debris from the 'Rodeo' fire flowed down the Salt River into Roosevelt Lake…turning the river black with contaminants that could kill the fish in the reservoir and leave it lifeless for months" (McKinnon 2002, p. A1). Following the 2002 Hayman Fire in Colorado, Denver Water sent a notice to customers in one of the watersheds important for Denver's water supply that said "the water runoff…may cause your water to have a smoky/ashy, moldy, dirty, musty, earthy, maybe even astringent taste" (Hayes 2002, p. 223). These two examples illustrate the potential public health impacts droughts and wildfires can have on water quality.

Both water quantity and water quality affect public health indirectly on water-related recreation. Low water hazards can contribute to boating and swimming accidents. Poor water quality can affect recreational activities, closing beaches because of high levels of chemical concentrations or algae. In Nebraska, high concentrations of cyanobacteria in local lakes caused by low water levels have caused a variety of public health impacts.

3.2 Mental Health and Stress Impacts

Drought can also affect mental health. These impacts are difficult to quantify and are not well understood, but there is a growing effort to acknowledge what droughts bring to stress and mental health. Often these effects appear across agricultural communities where potential drought consequences for agricultural production can create stress in families, which in turn can affect physical health, lead to nutritional problems, and cause depression, domestic violence, substance abuse, and suicides. Studies in Australia have linked drought with suicide in rural regions (Guiney 2012; Hanigan et al. 2012).

The effects of drought on mental health and stress can extend beyond the agricultural community, especially where business-related financial pressures caused by drought may occur. In the U.S., the need to haul water into homes because wells went dry caused the same increases in stress-related impacts seen within agricultural regions. It is important to consider how mental health and stress vary between men, woman, children, and the elderly, and between more affluent and poor populations. In one review of the literature of drought-related mental health and stress on children (Stanke et al. 2013), the common themes were related to "worry about family" and "feelings of loss."

3.3 Dust and Windblown Agents

Droughts contribute to airborne dust and windblown agents, and this, in turn, can have a very significant effect on public health. An iconic example of this occurred during the dust storms of the 1930s "Dust Bowl" drought in the central United

States (Sarafoglu and Sprigg 2015). Dust storms still occur, mainly in arid and semi-arid regions around the world. But the incidence of these dust storms increases during drought events, where vegetation recedes and bare ground is exposed, and can impact regions far downwind from the origins of the dust. The harmful effects of dust occur from either the direct trauma of inhaled particulates or by pathogen carriage, influencing the incidents of respiratory, heart, and lung diseases (Sprigg et al. 2012; Stanke et al. 2013). Sprigg et al. (2014) and Stanke et al. (2013) indicate that incidents of Valley Fever in the western United States are associated with the linkages between drought, environmental events, and the responsible fungus spores being carried by wind events.

Like dust, smoke from wildfires can cause significant respiratory problems. Older adults, children, pregnant women, and people with asthma, heart, and lung diseases are particularly vulnerable to smoke, which is comprised of a complex mixture of gases and particulates. The effects of smoke can be from a local wildfire, or the smoke might be carried hundreds of miles downwind from a wildfire event. In the U.S., the number of people with asthma is about 25 million, or about 1 in every 12 people. This number is growing, and it illustrates why more research on the linkages between droughts and public health is needed.

3.4 Wildlife Intrusion

Some of the more commonly reported public health consequences of drought are those that result from increased interactions between wildlife and humans. In recent years, these interactions have included large predators such as bears and mountain lions wandering into urban areas in search of water and food, increased car-animal accidents, increased numbers of snakes and alligators in urban ponds and lakes, and increased spider bites. Animals may also carry various diseases, so increased interactions between humans and wildlife can lead to more disease outbreaks.

The relationship between droughts and mosquito populations, and thus mosquito-borne diseases, is also complex. One might speculate that mosquito populations would decrease during drought events, thus reducing the number of people infected by mosquito-borne diseases. But the interactions between mosquitos, drought, and local environmental factors may actually increase diseases such as Dengue, several encephalitis viruses, West Nile Virus, and Rift Valley Fever Virus (Stanke et al. 2013). It is unknown how drought might affect malaria occurrences.

4 Drought Risk Management

Traditionally, most attention on drought events has focused on how to respond to the consequences as the drought unfolds. This has been true regardless of where droughts have taken place. This reactive approach is “crisis management.” Given the characteristics of drought, it is not surprising that crisis management-oriented responses to drought have often been uncoordinated and untimely (GSA 2007; Wilhite and Pulwarty 2005). In addition, when the attention is focused only on crisis management, the capacity to reduce future drought impacts is limited. On the other hand, a paradigm that focuses on drought risk management attempts to reduce future impacts by improving drought monitoring, planning, and mitigation strategies (Wilhite et al. 2005). This risk management approach is inherently proactive and directed at identifying who and what is at risk, why they are at risk, and how individuals can prepare for and respond to events. In the United States, the National Drought Policy Commission made recommendations in a report submitted to the U. S. Congress (NDPC 2000) that emphasized the Nation's need to focus on risk management, preparedness, and mitigation, including a more comprehensive drought monitoring system. Although the progress of drought risk management around the world has been slow, Wilhite et al. (2005) point out some successes, such as the High-Level Meeting on National Drought Policy (HMNDP), hosted in 2013 by the World Meteorological Organization in Geneva, Switzerland. Country representatives from 92 nations unanimously supported a declaration encouraging countries to develop and implement proactive national policies focused on drought risk management. The Integrated Drought Management Programme, co-led by the World Meteorological Organization and the Global Water Partnership, was then launched to assist.

The concept of drought risk management is illustrated in Fig. 3, the Cycle of Disaster Management. This cycle applies to all natural hazards, which is why some components of the crisis management part of the cycle (such as "reconstruction") work better for hazards such as floods and tropical cyclones. The bottom half of the cycle, representing crisis management, will always be necessary in some form in order to respond to the impacts of a current drought event. However, Fig. 3 highlights that actions of monitoring and early warning, planning, and mitigation

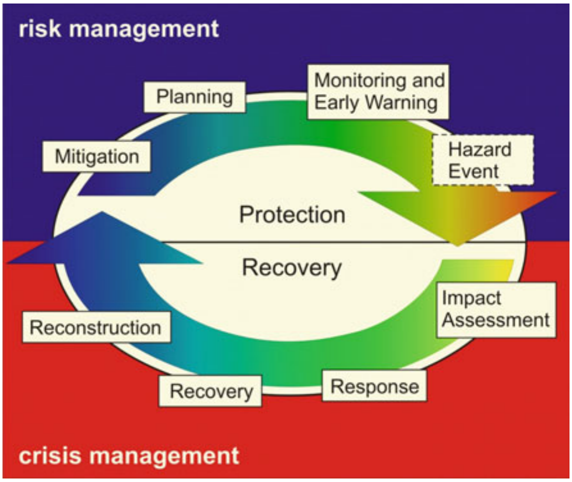

Fig. 3 The National Drought Mitigation Center's cycle of risk management versus crisis management. *Source* National Drought Mitigation Center, University of Nebraska-Lincoln

must take place before future drought events occur in order to reduce the impacts of these future events. These components of the cycle are considered drought risk management.

Drought monitoring involves continuous assessment and anticipation of the natural indicators of drought severity, spatial extent, and impacts. Using this information to encourage response is called “early warning.” Decision makers require accurate early warning information to implement effective drought response activities, recovery programs, and proactive drought policies. Early warning, then, is essential for drought risk management. Early warning connects risk and crisis management (Wilhite and Buchanan-Smith 2005).

When officials engage in drought planning, the second component of drought risk management, the objective is to reduce the impacts of drought by identifying the principal activities, groups, or regions most at risk and developing strategic actions and programs that address these risks, as well as response actions that can be taken during a drought event. Drought plans provide an effective and systematic means to assess drought conditions, identify who and what is at risk to drought events, develop mitigation strategies that reduce risk in advance of drought, and devise response options that minimize economic stress, environmental losses, and social hardships during drought. This overall emphasis on drought planning is fundamental to drought risk management and is applicable at any decision-making level. Incorporating drought planning helps decision makers prepare for multiple hazards, including climate change, and will promote sustainability and natural resource management leading to greater economic and societal security at all levels (GSA 2007). Benefits of drought planning across the United States include improved drought monitoring systems and the delivery of this information to decision makers at all levels. Benefits also include better identification of the risks associated with droughts, improved interactions with stakeholders, improved public awareness of drought, and protection of water resources during periods of shortage (Wilhite et al. 2005).

The third component of drought risk management is the implementation of appropriate drought mitigation strategies. These are specific activities prior to a drought that reduce the long-term vulnerability to droughts. In a study funded by the U.S. Federal Emergency Management Agency (FEMA), the Multihazard Mitigation Council (2005) calculated that a dollar spent by FEMA on earthquake, wind, and flood hazard mitigation provides the nation about $4 in future benefits. Besides the fact that hazard mitigation is a good investment, the Council concluded that continuing analysis of the effectiveness of mitigation activities is essential for building communities resilient to all hazards. This is especially true for drought, which was estimated by FEMA in 1995 to cause more annual economic losses in the United States than any other natural hazard. According to the United Nations International Strategy for Disaster Reduction (2007), the number of methodologies is limited for identifying appropriate drought risk reduction strategies. They concluded, “…it is essential to identify and demonstrate effective approaches and opportunities for drought mitigation and preparedness, including case studies to show examples of good as well as weak policies. Policy makers, scientists, media, and the public often need to see actions-at-work in order to foster buy-into similar efforts" (ISDR 2007, p. 50). Identifying and promoting drought mitigation and preparedness has been part of the National Drought Mitigation Center's (NDMC, http://drought.unl.edu) mission since it was founded in 1995 and is also a key goal of NOAA's National Integrated Drought Information System (NIDIS, http://drought.gov).

The NDMC has been involved in a few drought mitigation efforts related to public health. The first was participation in a Centers for Disease Control and Prevention (CDC) workshop in 2009 that led to the publication of the manual, "When Every Drop Counts: Protecting Public Health during Drought Conditions: A guide for public health professionals" (CDC et al. 2010). The NDMC assisted in editing this guide. The second was the launch of the Drought Impact Reporter in 2005 as the nation's first (and only) tool to collect, catalog, and display impacts occurring in ten different sectors, providing decision makers with readily summarized information. One of the ten sectors includes society and public health information. Finally, the NDMC recently launched another tool, the U.S. Drought Management Database Portal, which is a database of mitigation strategies by sector. One of the sectors included within this tool is society and public health.

5 Droughts and Climate Change

Droughts have always affected humans and are featured in many of the earliest documents, such as the tale of Joseph and Pharaoh in the Bible (Le Treut et al. 2007). Although Fig. 1 emphasizes the normal nature of drought, the looming effect of climate change threatens to alter the dynamics between drought and society, adding more stress and potentially increasing future public health consequences.

It is often said that the best way to understand the future is by understanding the past. Much attention has been given to developing an understanding of past drought events using tree ring data and other paleoclimatology records. Although certainly not diminishing the importance of these paleoclimatological studies, Milly et al. (2008) argue that past climatic conditions may not provide the best representation of the future because of climate change. Droughts around the world will be a factor of any precipitation and temperature change that might occur. The latest temperature projections from the IPCC (2014) indicate that global temperatures will likely increase between 1.1 and 4.8 °C by 2100, depending upon global greenhouse gas policies. Although projections of precipitation are not uniform and have a higher uncertainty in both spatial and temporal scales, it is very likely that extreme precipitation events will increase, particularly in the mid-latitudes (IPCC 2014).

The frequency of some climate-related extreme events is anticipated to increase, which has been supported by recent trends. Since 2000, the number of global climate-related disasters per year is 341. This number is up 44 % and more than 100 % from the 1994 to 2000 and 1980 to 1989 averages, respectively (CRED 2015). For droughts, even if precipitation amounts remain the same or increase somewhat, higher temperatures just about everywhere mean that there will be increased evapotranspiration, meaning more moisture will be lost from both vegetation and soil surfaces. This expected outcome leads to the projection that droughts will increase in frequency and severity. Several other issues are factored into these projections, including the timing of rainfall and the fact that drying soil surfaces exacerbate heat wave events. In addition, projected reductions in runoff from winter snowpack would also reduce water availability.

Many public health challenges remain for addressing drought, given that droughts are a normal part of a variable climate, and that the trends of climate may be making droughts more frequent and severe. Daniel Connell of the Australian National University recently recognized this challenge, saying that drought was a "force of truth" for Australia, and other nations, in that if proactive drought risk management approaches were taken, these could reveal important insights into how to better prepare for climate change (Connell 2010).

6 Engagement Strategies

The International Association of Public Participation (IAP2) uses the slogan, "Good public participation results in better decisions" (http://iap2.site-ym.com/). It is relevant because a key ingredient for successful drought risk management is to incorporate opportunities for public engagement or public participation within the risk management process. The IAP2 presents a helpful spectrum for professionals to use where certain levels of public engagement need to be identified with stakeholders (IAP2 2015). Public participation is more than just involving the public, but rather taking the needed time to discuss and plan how certain decisions, such as research or outreach outcomes, might affect the decision-making process. It requires meaningful objectives and goals in order to provide materials and information that can be communicated so stakeholders can see, from the message, the potential consequences. In general, the practice of public participation might involve numerous techniques (e.g. workshops, surveys, focus groups). Some of these techniques are discussed in more detail in this section and in the subsequent engagement case studies.

The faculty and specialists at the NDMC have worked closely with this IAP2 spectrum model to help plan outreach strategies, including recent efforts in the drought and public health sector. The spectrum encourages practitioners to identify objectives for engagement and stakeholders early, in order to find the most beneficial techniques. The five levels of the spectrum include: *Inform, Involve, Consult, Collaborate, and Empower*. The NDMC has engaged stakeholders in at least four of the spectrum levels. The fifth level of empowerment is sometimes hard to quantify as it takes careful evaluation after the project or event to know if the information or process has made a significant impact in a stakeholder's decision-making. Again, by carefully planning a project's objectives, proper and effective techniques can be used to gain some of the techniques that the NDMC has

Fig. 4 Stakeholders engaged in reviewing past drought impacts on their urban water supply system. Photo courtesy of Nicole Wall, National Drought Mitigation Center, University of Nebraska-Lincoln

used to engage stakeholders, including newsletters and online decision support tools such as the Drought Risk Atlas and Drought Impact Reporter. Workshops, webinars, focus groups, interviews, and surveys are other techniques. In workshops, the NDMC will include participation techniques such as polling, decision grids, World Cafés, and collecting feedback on a public participation "sticky" wall (Fig. 4).

As an example of collaboration and engagement, the NDMC partnered with the University of Nebraska Public Policy Center and others on a National Science Foundation project to conduct a series of educational presentations and focus groups in the fall and spring of 2011 and 2012 in Nebraska about drought and climate change. Six focus groups targeted 121 rural educators, agricultural producers, and the general public in Nebraska to assess knowledge and attitudes about drought and climate change and to identify needs for education. Using a pre-post survey design, focus group participants found that their knowledge, as well as their concerns, of key climate change issues increased significantly following the educational presentations by the project team. These findings suggest that rural communities in Nebraska are concerned about the effects of drought and climate change, and their understanding and attitudes of these issues can change with education and engagement.

Surveys have been conducted in rural Nebraska communities gauging perceptions and attitudes about drought (Allen et al. 2004) and climate change (Vogt et al. 2008). Comprehensive survey efforts, such as the annual Nebraska Behavioral Risk Factor Surveillance System survey (Nebraska Department of Health and Human Services 2013), have been undertaken to gather information on health experiences and behavior among Nebraskans. However, none focused on the human health impacts of drought. Efforts to identify health/climate data collection among the state's agricultural and rural communities were unsuccessful. New proposals for research and outreach are being developed to meet these gaps between drought and human health.

The National Drought Mitigation Center, working with stakeholders, has adapted a variety of public engagement strategies that can be applied to public health outreach, especially in the area of climate change. Since drought spans many different sectors, it is important to think of a holistic, systems approach in public engagement efforts. Because of the complexity of drought impacts, impact and risk assessment must be interdisciplinary. It is essential to bring together the right group of people and supply them with adequate data to make fair, efficient, and informed decisions pertaining to drought risk. This group's knowledge must encompass several aspects of environmental, economic, and social topics. Any shortfall in information or perspective could lead to meaningless or at least questionable results.

6.1 Community Capitals Framework

Another key ingredient for successful drought risk management is to incorporate opportunities for public engagement in the drought planning process. Careful examination reveals that drought vulnerability varies significantly from location to location based upon local resources and characteristics. Therefore, public engagement is needed to build local resilience. This is certainly true when looking at the public health-related consequences of drought. Communities can benefit from previous experiences ("lessons learned") as they begin to address their own mitigation and adaptation strategies. The lessons learned can also help find gaps and barriers that need to be addressed before the next drought occurs. One way to integrate innovative techniques of public engagement in drought planning is by evaluating local drought impacts and discussing them in a context of the holistic community system such as the Community Capitals Framework (CCF) model (Fig. 5).

For instance, research into the factors and dynamics that influence community development and change demonstrate that communities that use and build across their natural (e.g., water), cultural (e.g., values), human (e.g., skills), social (e.g., social networks), political (e.g., ability to influence decisions), financial, and built (infrastructure) capital are generally more economically sustainable (Flora et al. 2004; Emery and Flora 2006). Thus, drought can cause devastating impacts to the very things that are essential for community economic sustainability and growth. Knowing more about the dynamics of the social, economic, and environmental factors that underlie communities, allows NDMC's collaborative research to promote sustainable and resilient communities by helping them identify, protect, and leverage a variety of community resources.

Fig. 5 Community capitals framework model. *Source* National Drought Mitigation Center, University of Nebraska-Lincoln, adapted from Flora and Flora 2004

6.2 Drought Scenario Exercises and Tournaments

The importance of games in education is not new, and recently the importance of games in learning has been categorized as essential. Scientifically, it has been proven good for brain-nerve stimulation and long-term knowledge storage as it creates a "flow state" where learning is enticing because the various game levels require participants at any age to feel challenged but not defeated. Goal-oriented games are also important in the learning process, especially in stimulating creativity. Over the past several years, the NDMC has been involved in several water and drought tournaments and exercises. The Invitational Drought Tournament (IDT), originally created by Agriculture and Agri-Food Canada, has been the template in many of these interactions (Hill et al. 2014). The main goal of this engagement strategy includes building capacity around drought preparedness. The tournament helps a variety of stakeholders identify gaps and vulnerabilities surrounding drought preparedness and mitigation.

The game provides a face-to-face forum for multi-disciplinary stakeholders to discuss climate preparedness and adaptation strategies (e.g., such as those in public health) in a learning environment. The end result is a complete and traceable decision-making process that is based in goal-centered, real-life data scenarios that involve creativity and collaboration. Today's technology lends itself to this interactive and social learning, which is a perfect platform for public health professionals. Tournaments and exercises incorporate a water budget and are utilized in a variety of settings to emphasize the trade-offs, complexities, and interconnectedness of water use decisions during drought and under various water availability scenarios. Target audiences for the game activities have been elementary, middle school, and college students, as well as local, national, and international stakeholder groups. Participants are placed into multi-disciplinary teams that are then guided through a multi-year drought scenario of unknown length, throughout which they work collaboratively to discuss and select adaptation options that will help them better prepare for, adapt to, respond to, and recover from the drought's impacts. The curriculum can be expanded to incorporate evolving game theory and drought- and natural and water resource-related exercises developed for those involved in public health. The products of any tournament can be packaged as a set of online/electronic materials, and the final modules can be transferred to international partners as well.

This chapter concludes with three case studies highlighting how public engagement strategies can address potential public health impacts in the context of drought and climate change risk management.

7 Case Study: Greater Horn of Africa

Africa has seen multiple public health crises related to drought events throughout history. The latest data from CRED (2015) indicate that 41 % of the drought disasters since 1993 around the world have occurred in Africa. In addition to being vulnerable to droughts, Africa will probably be highly vulnerable to the projected adverse impacts of climate change resulting from increased temperatures, changes in precipitation, and increased climate variability. In many regions of the continent, the effects of these changes are compounded by rapid population growth, high poverty levels, social unrest, dependence on rain-fed agriculture, and low adaptive capacity. Given the great uncertainty in climate projections, early warning systems that are robust to evolving climate conditions must be a critical component of successful adaptation and mitigation strategies. Improved performance and application of seasonal forecasts is a critical, no-regrets climate adaptation strategy (Tadesse et al. 2014). But in many parts of the world, forecast systems perform poorly, forecasts are not always tied to user needs, and systematic forecast evaluation and comparison is lacking. In addition, there is a need to understand how forecasts influence the outcomes they are designed to predict. Experts and decision makers often have many challenges in understanding prediction models and products, interpreting model differences, and implementing those model products for societal benefits (including benefits for public health preparedness).

In 2014, the NDMC began a multi-institution collaborative project, funded by NASA, designed to enhance preparedness for extreme climate events (droughts and floods) and anticipated climate change impacts over the Greater Horn of Africa (GHA). This project's objective is to improve and implement new and existing climate- and remote sensing-based agricultural, meteorological, and hydrologic drought and flood monitoring products (or indicators) and improve the usability of these products among various decision makers across the region. Recognizing that engagement strategies and theories of participatory research are important to achieve the objectives and improve decision making, the project incorporated a stakeholder engagement component from the beginning. The stakeholders include participants from a variety of sectors, including public health, and the expectation is that they will be involved in the project for its three-year duration.

The first workshop for the project was held in Addis Ababa, Ethiopia, in August 2014. This workshop included both scientists and the stakeholders involved with the project. The workshop was designed to present the scope of the project, engage the stakeholders/decision makers in the assessment of information requirements, and use feedback to reorient prediction models to address user needs. Several stakeholder engagement strategies were utilized during the workshop to increase scientist-stakeholder interactions and increase both the amount and usefulness of stakeholder feedback. For example, participants were given opportunities for discussing ways in which information could be delivered for easy use and to identify stakeholders that would use and evaluate the climate prediction tools. The CCF and its seven capitals described above were used as a guide for the stakeholder interactions and responses. Pre- and post-participation surveys were given to all participants to measure knowledge, attitudes, and the use of drought/flood prediction and climate-related information. Participants were also asked in the survey about local perceptions of current climate change impacts in the GHA.

Virtually all of the 30 survey respondents (93 %) perceived that climate change was affecting their country. Respondents were asked whether they had seen or heard about impacts (positive or negative) to a predefined list of 63 different resources, assets, and activities, due to climate change and extremes. Responses were mapped to the CCF capitals. Workshop participants identified impacts across all seven capitals. The greatest number of perceived impacts was to natural, built, and financial capitals and the lowest to human and cultural capitals (Table 2). Although the impact list was not comprehensive, these results suggest that the GHA is already having consequences in all of the community assets needed to foster economic development and sustainability and to build adaptive capacity for current and future climate change. Public health is going to be a very important factor given these issues. In comments written during the survey, and from verbal statements made throughout the workshop, participants supported these findings by stating that limited measures are in place for adaptation and mitigation and that a need exists for developing risk-based planning approaches and establishing a platform to build capacity, especially for ongoing socio-economic development that includes health.

During two breakout groups, "Agricultural and Water Impacts" and "Data Gathering-Sharing", participants were asked to consider climate hazard consequences, information sharing, specific information needs, and relevance of climate information in different sectors. Participants said they used weather and climate

Table 2 Workshop participant survey results

Type of capital	Number of perceived impacts			Top 3 perceived impacts from those listed in the survey
	Yes	No	I don't know	
Natural	218	8	35	Biodiversity, water quantity, insect manifestations
Built	211	9	34	Water wells, energy projects, dams, water and climate monitoring equipment (tie for 3rd)
Financial	205	6	50	Agricultural productivity, number of people in poverty, food costs
Political	176	6	74	Political or water-use conflicts, climate adaptation (tie for 1st), water-related policy, satisfaction with governmental leadership
Social	170	8	55	Population migration, social networks and organizations, public awareness of climate/water issues (tie for 2nd), public services
Human	156	5	71	Health/disease, quality of life, education and skills, size of labor force, access to medical treatment (3-way tie for 3rd)
Cultural	136	16	80	Sustainability practices, local foods and cuisines, and gender and age-based roles

information for decisions such as relief and humanitarian aid after disaster occurrence, estimating or forecasting agricultural production, and reservoir operations and flood management (e.g., drainages). They said they currently use globally available online climate information such as daily, decadal, monthly, seasonal, and annual prediction related to general early warning systems, as well as pre-during-post disaster information.

Interactions with workshop participants have been used to determine next steps for the project. The next workshop will take place in July 2015 and will involve coordinating with local hosts and translators to conduct interviews with potential users of the information. As throughout the project, the goal of the second workshop is to again utilize interactive participatory techniques to get to more specific uses and delivery of the information. Connections with the public health sector, and its use of these products and associated information for disaster and hazard preparedness, will be an important component of the workshop.

8 Case Study: Community Capitals Framework and Drought Impact Assessment

Systematic collection and archival of drought-related information on impacts has proved to be very difficult, in part because of the unique characteristics of drought described above. Although many efforts are underway to collect such information [e.g., the NDMC's Drought Impact Reporter, the state of Arizona's initiative for collection called "Drought Watch", and the citizen science precipitation network called the Community Collaborative Rain, Hail, and Snow (CoCoRaHS) network], certain types of impacts [e.g., social, cultural, and human (which includes health)] are harder to capture and consequently less understood, and they are often not a robust part of planning and response (Downing and Bakker 2000; Lackstrom et al. 2013).

Given these challenges, the NDMC is leading an effort using CCF and its seven capitals to assess existing drought impact reports and develop a strategy to increase the breadth of future reporting. Because the CCF is designed to help communities assess their overall sustainability, it is a natural process to also assess the resilience to drought, potentially improving drought planning and mitigation efforts. Classifying drought impacts according to the CCF capitals is an opportunity to examine how changes in one type of capital may influence other capitals. For example, a decline in natural capital, such as water supply, can lead to declines in other capitals, such as financial capital (decreased farm income) or human capital (stress and depression, which are tied to health). Further, the use of this framework can allow for the identification of specific examples of under-reported impacts, which can then be used to develop approaches to effectively record and quantify a larger range of drought impacts.

An example application using CCF was examined for the 2012 drought across the central U.S. Drought-related impacts were studied using the Drought Impact Reporter (DIR) between May 1, 2012, and August 31, 2012, for five states (North Dakota, South Dakota, Nebraska, Kansas, and Texas). The total number of impacts reported during that time across the region was 1687, spread among the various DIR sectors (agriculture; business and industry; energy; fire; general awareness; plants and wildlife; relief, response, and restrictions; society and public health; tourism and recreation; and water supply and quality). The highest reported number of impacts came from agriculture (as would be expected because of the financial losses from drought). In the social and public health category, 220 impacts were recorded, but one could argue that most of the DIR categories are tied to health in one way or another. The second highest number of impacts was reported for the water supply and quality category, which is often tied to public health impacts.

Some of the possible direct and indirect health-related impacts reported for each of the capitals include:

- Human capital: increased respiratory illness, increased heat-related ambulance calls, increased (brown recluse) spider bites, farmers less optimistic about their future, and increased anxieties in the ethanol business;
- Social capital: voluntary and mandatory water reductions (primary health impact due to stress levels and future worry about water supplies), increased demands on volunteer fire and rescue (primary health impact due to stress levels and future worry about water supplies), and working overtime on repairing water mains;

- Cultural capital: cancelled 4th of July celebrations, closed swimming pools, and decreased hunting opportunities (primary impact especially to humans using hunting as part of their food supplies);
- Natural capital: Decline in rangeland grass production (secondary health impact due to financial stress or anxiety, perhaps later tertiary—due to food security and caloric reductions), trees susceptible to pests/disease, algae blooms in ponds (primary consequence to the species in the ponds and also humans using fishing as part of their food supplies), blowing dirt and grass fires (primary impacts to respiratory disease states), and wildlife deaths (primary impact to the species and also humans using hunting as part of their food supplies);
- Financial capital: Decreased crop yields (tertiary health consequence: food security and caloric reductions), increased water and energy rates (secondary health impact due to financial stress or anxiety), closed ethanol plants, and increased firefighting expenses;
- Built capital: Wells shut down, power outages, shifts and cracks in foundations, closed roads, homes destroyed in wildfires;
- Political capital: Activation of water restrictions, state of emergency declarations, improvements to USDA programs, opening of CRP lands for grazing, federal drought aid.

8.1 California

Four years into a serious drought, ABC News reported in April 2015 (Mohney 2015) that the ongoing drought could cause more problems for state residents by creating favorable conditions for infectious diseases such as the West Nile Virus and Valley Fever. The DIR captured several of these reports, including a report on a widespread Valley Fever outbreak in the San Joaquin Valley prison population and the need to find areas of relocation (National Drought Mitigation Center, Drought Impact Reporter 2013). In less than one year, reports indicated that at least 17 rural communities were at an acute risk of running out of water within 60 days and high numbers of rural communities were at especially great risk because of well contamination due to shrinking water supply levels (Zerkel 2014). This news of water shortages and contamination came right after President Obama's announcement that several million dollars would be directed toward aid for the State of California, including at least $60 million for food banks (The White House, Office of the Press Secretary 2014). As the drought continues, many public health officials are bracing for how to handle an increase in anticipated health impacts.

A widespread drought impact analysis for the state would help officials plan for resource allocations and resiliency, especially for rural communities without direct large investments into certain community capital areas (e.g., financial and built). Officials are also watching the link between drought areas and poverty, especially in terms of migrant workers, producers of livestock, and their overall access to groundwater for food production and/or drinking (Community Water Center of California 2015).

Given this context, Watsonville, California, could be a good location to investigate these issues further. Much progress has been made in Watsonville over the years in strengthening their community capital areas. The community is situated in the fertile Pajaro Valley along Monterey Bay. It is surrounded by agricultural land that produces a large variety of fruits and vegetables for the U.S. It also has a very diverse immigrant population, with Hispanic being the most dominant. In 1989, the small community suffered extensive damage from an earthquake, which prompted city officials and citizens to come together to repair the community on all levels and continue to develop more extensive all-hazard plans. Also, giving immigrant populations local voting rights led to empowerment and an investment in the community's future. They have expanded their local economy to embrace business and industry, including one of the largest frozen vegetable companies. Watsonville officials also started to engage their youth and provide them more jobs in the community, which helped bring down a concerning rise in local crime rates (Luther and Wall 2008). With this history of addressing their current and future vulnerabilities, they have been able to solidify plans for their community out to 2030. Watsonville also produced a draft climate change action plan for their community in 2014. It is unknown if drought is specifically mentioned in either of these plans, but the constant stakeholder engagement process and the community's investment in various CCF capital areas has certainly set the stage for increased drought resilience in the community and the potential for reduced impacts, including those public health impacts being observed in other parts of the state.

9 Case Study: Missouri River Basin

The National Integrated Drought Information System (NIDIS) is a U.S. interagency approach created in 2006 to "enable the nation to move from a reactive to a more proactive approach to managing drought risks and impacts" (National Integrated Drought Information Center 2006). It is authorized to coordinate federal drought risk management efforts and to provide drought early warning integrating information and indicators of drought and drought severity. In order to accomplish this, NIDIS is developing a network of regional drought early warning systems (RDEWS), which build on existing monitoring and drought risk management activities. One of those RDEWS has been established to cover the Missouri River Basin (MRB) region in the central U.S.

The kick-off workshop event for the MRB RDEWS took place in Nebraska in February 2014. More than 70 federal, national, tribal, state, and local representatives who work in the area of drought monitoring and management within the MRB attended the workshop. Participants gave updates on the latest drought monitoring, prediction, and planning tools or methods that are applicable to a variety of stakeholder needs. The workshop also included multiple discussions related to data needs and resources to address various impacts and vulnerabilities, including those related to water scarcity, water quality, and public health.

Because there was enough interest from participants to have capacity to cover the public health sector, the sector was featured in a "World Café" participatory breakout session facilitated by the NDMC, University of Nebraska Medical Center, and Nebraska Public Policy Center. The pre-derived questions for the session were gathered from various literature reviews, gaps in the available information related to drought and public health, and numerous discussions with the facilitation leaders. Lastly, based on goals to create an MRB RDEWS, some questions were created to address those future efforts: (1) what health impacts or concerns exist in your communities as a result of droughts? (2) What are the current perceptions related to drought and health impacts? (3) What health-related data or sources of information exist? (4) What programs, trainings, or partnerships exist to address climate-related health issues?

The health session received well-balanced input from various agency stakeholders, such as those who are involved in water quality/quantity and health concerns at federal, state, tribal, and local levels. This session included in-depth discussions on various drought-related health impacts in communities and possible sources of data to use in tracking these impacts more carefully. Impacts such as respiratory illness (asthma specifically) caused by higher temperatures and drier conditions are a huge concern in the Missouri River Basin. Increases in pollen rates and dust or particulates are already an issue for those living in rural areas. Pest and micro-organism increases have been connected to drought. Local water supplies are clearly connected to public health, underscoring the need for tracking water quality impacts more closely. Excessive heat can increase emergency room visits and death rates, especially in groups more vulnerable to the heat such as children, the elderly, people living without air conditioning, and people employed in occupations such as seasonal outdoor labor. Wildfires bring about more smoke-related respiratory illness, and it was noted that hospital evacuations took place in the basin because of neighboring wildfires.

The list of impacts provided an essential awareness of some public health problems caused by drought in the region. Participants still were unclear whether decision-makers in medical facilities within the region were planning for these types of high-impact events that can be either short or long term in nature. In addition, not all groups were represented at the session. For example, missing from the workshop were medical (such as epidemiologists and mental health) professionals, K-12 educators, and health and human services (federal and state level) professionals. However, it was a beginning—and a "kick-off" event. The goal was established that future MRB RDEWS planning activities should encompass discussions with these additional types of stakeholders. Additional discussions that should be high on a priority list include the known increases in mental health crises due to drought, especially when there are significant crop losses and drops in the rural local economy.

9.1 MRB RDEWS Tribal Activities

One of the goals of the MRB RDEWS is to engage tribes across the region and assist with improved drought risk management. The MRB RDEWS is currently working on various activities with tribes in Wyoming, South Dakota, Nebraska, and Kansas. Each of these activities has the potential to involve public health-related impacts, and the intent is to employ appropriate stakeholder engagement strategies to meet the unique needs of the tribes involved.

In part as an outcome of the kick-off workshop and its various discussions in February 2014, interactions have begun with the Wind River Tribes of Wyoming to address aspects of drought risk management, including improved drought monitoring and early warning and drought planning. These interactions have included a variety of engagement strategies including meetings, webinars, and in-person trainings to address climate and drought information needs, planning, and vulnerabilities. The North Central Climate Science Center and the NDMC, along with several other organizations and the Wind River Tribes and their Tribal Water Engineer's Office and Water Board, are partnering on a project that will look closely at the various vulnerabilities (including health) that the tribes face during periods of drought. This will also inform what kinds of drought planning needs and resources are required to address future water and overall health concerns for both tribes.

10 Conclusions

Several high profile natural disaster events over the past quarter century have highlighted how disasters and humanitarian crises can be linked (Leaning and Guha-Sapir 2013). More recently, there is a growing recognition that the public health impacts of all natural hazards, including droughts, and in all regions, need to be addressed in order to identify a location's vulnerability to these impacts and help that location or region become more resilient to future disasters.

To promote this holistic, proactive approach to building resilient societies, it is becoming common to hear and see people and organizations talk about "One" common theme, as in "One World", "One Water", and "One Climate" to link complementary efforts (CAFOD 2015; Knight Center for International Media 2015; OneWorld 2015). Recently, a "One Health" effort has evolved that embraces the close linkages between human, animal, and ecosystem health (CDC 2015). Highlighting these holistic and synergistic interdisciplinary and cross-sectoral approaches is necessary in order to tackle the complex issues related to the nexus of food, water, climate, energy, health, and societies. As one of the complex issues that will likely be exacerbated by climate change, this chapter on drought illustrates how improved early warning and stakeholder engagement, such as the Community Capitals Framework, creates opportunity for iterative dialogues within and between sectors, and between scientists and stakeholders. These opportunities to inform better decision-making will, one hopes, translate into reduced public health impacts resulting from future drought events.

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Extreme Weather: Mental Health Challenges and Community Response Strategies

Jyotsana Shukla

Abstract The health of populations is inseparably linked with weather and climate. Extreme weather events like heat waves, storms, droughts, and dangerous flooding, bring damage and destruction in their wake. Damages to infrastructure and other built environment are easily visible after an extreme weather event. Beside the risks of physical injury and death, extreme weather events create many mental health consequences. It is the developing countries and the poor and vulnerable sections of their populations that are affected most. The capacity of a community to prepare and plan for such extreme weather is an important determinant of the severity of the health consequences. The existing public health and safety systems are significant factors in responding to extreme weather disaster emergencies. Other factors that need attention while responding to extreme weather events include the age, gender, education, medical condition and socio economic status of the affected populations. It must be noted that the extreme weather events also affect agriculture yields and the long-term food security of nations. Therefore, governments, community institutions, non-governmental organizations, international agencies, and individual citizens must give priority to preparing for and adapting to the impacts of all future extreme weather events. This chapter presents an overview of but one often overlooked human health consequence of extreme weather events: mental health following natural disasters and the efforts taken by government, community, and the agencies extant that rush to help, to deal effectively with present and future extreme weather events. The chapter also looks at some of the best practices adopted in response to extreme weather events.

Keywords Extreme weather · Heat waves · Floods · Drought · Typhoons · Cyclones · Mental health impacts · India · Community engagement · Best practices · Psychosocial · Psychological

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1 Introduction

Extreme weather events are rare stochastic events. Easterling (2000) defines two categories of extreme weather. The first refers to extremes in terms of very low or very high temperatures, and the second refers to more complex event driven extremes such as droughts, floods, or hurricanes. We will show that both categories place considerable burden upon people and their ability to cope.

In the recent past, the world has witnessed many extreme weather events, such as droughts, heat waves, floods and cyclones (Knutson et al. 2010). In 2013, in Australia, parts of central Asia, coastal Africa, Central America, and central South America, southern Russia, northwest Kazakhstan, south India, and southern Madagascar observed record warm temperatures (National Center for Environmental Information, State of the Climate 2013). Some other costly weather disasters were witnessed in 2013, including central European flooding in June, the Uttarakhand flash flood in India, Typhoon Fitow in China and Japan, and a drought in much of China. In 2014, typhoon Haiyan killed more than 6100 people and caused $13 billion worth of damages in the Philippines and Vietnam (Heilprin 2014).

2 Extreme Weather and India

The world's largest democracy and second most highly populated country, India, has faced "extreme weather events" at regular intervals in the recent past and continues to face them today. Mumbai, India, attained its highest measured daily rainfall record of 39 in. It flooded the city in July 2005. The heavy rainfall brought a deluge that continued for about a week. This unprecedented extreme weather event killed hundreds of citizens and resulted in the displacement of around 1 million people (Maharashtra Floods 2005; Fact Finding Committee on Mumbai Floods 2006).

The Leh (Ladakh) cloudburst in 2010, in the north of India, with 14 in. rainfall in 2 h, cost more than 200 lives and vast devastation (Ashrit 2010). Many were injured and many went missing, perhaps washed away. Over a thousand houses were destroyed (Gupta and Kapoor 2012).

Flash floods resulting from extremely intense rainfall caused by cloudbursts in Uttarakhand on 16–17 June 2013 affected 12 of the 13 districts of Uttarakhand, with 4 district being most affected. The unprecedented flash floods swept away mountainsides, villages and towns, thousands of people, animals, agricultural fields, irrigation canals, domestic water sources, dams, roads, bridges, and buildings … everything that stood in its way. It devastated more than 200 villages. The villagers whose homes, lands, and animals were swept away were reported to be in a state of shock, after losing their livelihood and all assets (The Hindu 2013).

The state of Jammu and Kashmir, in India, faced its worst floods in over a century, caused by heavy rains, in the first week of September 2014 (National Remote Sensing Centre, Indian Space Research Organisation 2014). The floods led to more than 200 deaths and left more than 150,000 people stranded. Many animals were swept away, along with huge damages to property (Mahr and Bukhari 2014).

As of the writing of this chapter in 2015, the latest in the series of extreme weather events is the heat wave that swept across many states in India, with record high temperatures, more than 10 °F above normal. The heat wave caused more than 2500 deaths. It was one of the five deadliest on record. The victims of this heatwave were mainly the elderly, homeless, and construction workers (Earth Observatory 2015).

Working Group II of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5) (Intergovernmental Panel on Climate Change 2014) anticipates that heat waves, floods and droughts will occur frequently in India as current climate trends continue. According to the IPCC report there will be fewer rainy days, but those days will have heavy rains. It also anticipates more extreme rainfall during monsoons. The report also points out that the agricultural sector in India may be affected adversely, with risks of greater food insecurity and threats to public health (www.teleSURtv.net/english, Mall et al. 2006).

3 Extreme Weather and Mental Health

Direct impacts of extreme weather, i.e. death and injury, are easily visible. People are aware of them. However, extreme weather events also lead to indirect health problems, caused by damaged infrastructure, displacement of population, and change in ecological systems. Both direct and indirect affects may harm the public health system and lead to psychological and social problems. Health care services may become less accessible due to infrastructure damages (Greenough et al. 2001).

Indirect psychosocial (mental health) impacts of extreme weather events require greater attention of government, as well as the general population, to administer to those who are currently affected, and to prepare for even greater casualties should we be facing even more extreme weather events with increasing frequency and intensity as many predict (IPCC 2014). Recent studies show that extreme weather events have many adverse mental health consequences. The general public and policy making bodies need to become aware of these impacts (Shukla 2013).

Extreme weather related catastrophes such as wild fires, severe drought, and flooding, may damage the human psyche. Extreme weather events may cause acute trauma (Weems et al. 2007). People may experience post-traumatic stress disorder (PTSD), depression, and anxiety (Union of concerned Scientists 2010). Feelings of distress following a disaster include being “scared, sad, depressed, numb, helpless and hopeless, frustrated or angry.” People may even deny the existence of any problem or may not perceive the intensity of the problem if they find the problems too difficult to face. They may become resigned to the situation and become cynical (Australian Psychological Society (APS) 2007). Extreme weather may also result in generalized worry, substance abuse, family issues and even intergroup conflict (Doherty and Clayton 2011).

Mental health outcomes in the form of PTSD, prolonged depression, and domestic violence may manifest in days, months and years after the severe event (Doherty and Clayton 2011). In the case of a massive disaster like Hurricane Katrina, no decline in cases of PTSD symptoms was observed even after more than two years (Kessler et al. 2008). Such trauma has also been reported in people who suffered during the Uttarakhand flash floods in India. The PTSD symptoms were present more than two years after the disaster. According to media reports, a few victims who were tracked after more than one year by their relatives had suffered memory loss and required psychiatric interventions.

Research points out that 25–50 % of a population that experiences an extreme weather disaster may suffer adverse mental health effects. An individual's age, coping capacity, and nearness to the event site will also affect the severity of symptoms (Weems et al. 2007a). The intensity of the extreme weather and the type of trauma experienced, e.g. watching someone die, will also determine the severity of adverse mental health. The closer a person is to the site of the disaster, the worse are the impacts on mental health. Other factors include timing and distance of evacuation, the extent of damage to one's home or community, and the extent of family and community support available (Weems et al. 2007b). Research says that for people who lose their jobs post disaster, there is greater vulnerability to psychological symptoms when compared to those who did not experience job loss or disruption (Peek-Asa et al. 2012).

The people who are most vulnerable to adverse mental health impacts of severe weather are those who already have a mental illness, those who are poor, those who do not have survival or comfort resources, and the marginal sections of the society. This differential vulnerability is also apparent globally, where those who live in poor nations are more vulnerable than those who live in wealthier nations. In addition, inside any country, poorer people are more vulnerable to adverse mental health impacts (Doherty and Clayton 2011).

Extreme weather events may also aggravate existing mental health problems in the affected communities or may even cause more mental health problems, thus increasing the responsibility of mental health institutions and systems (Fritze et al. 2008). In vulnerable and affected communities, the social, economic, and environmental determinants of mental health may be disrupted in the wake of extreme weather events (World Health Organization 2003; Fritze et al. 2008).

4 Impacts of Extreme Weather Events on Communities

4.1 Floods

Floods are one of the most common of extreme weather events when compared to other events such as heat waves, droughts, and cold waves. Floods are held responsible for almost 53,000 deaths in the last decade alone. The nature and character of floods and the vulnerability of the affected populations determine the short and long term consequences of this extreme weather phenomenon (Alderman et al. 2012). Floods affect about 30 million people in India every year. The Indian states of Assam, Bihar, Orissa, Uttar Pradesh and West Bengal face floods regularly. It has been observed in recent years that parts of the country that had not previously been prone to flood, now become inundated. For example, the normally drought-prone areas of Rajasthan experienced severe floods in 2006 (Sharma 2009) and again in 2013.

Floods lead to an increase in psychological morbidity, primary care attendance and referrals and admissions to hospitals (Bennet 1970; Abraham et al. 1976; McMichael 2003). There is an increase in psychological symptoms and post-traumatic stress disorders, along with suicides, as reported in the two months after a major flood in Poland in 1997 (International Federation of Red Cross and Red Crescent Societies 1999).

Studies have shown that psychological distress prevails in 8.6–53 % of the population, even after two years of the flood. This psychological distress could cause worse physical illness in the affected populations (Alderman et al. 2012; Wind et al. 2013). The PTSD symptoms do not fade away quickly, even after floods have receded (Health Protection Agency 2011).

Several human factors are especially connected to mental illness after a flood, including the extent of exposure to the flood event and the person's gender, age, and socio-economic status (Health Protection Agency 2011). Thus, flooding can greatly affect people's psychosocial needs and mental health. These consequences of flooding, are a major challenge for public health (Health Protection Agency 2011).

4.2 Cyclones

The term 'cyclone' refers to different types of storms that rotate around an atmospheric low pressure center. Tropical cyclones occur over tropical ocean regions such as the South Pacific and Indian oceans. They are known as Hurricanes in the Atlantic and Northeast Pacific ocean regions and as Typhoons in the Northwest Pacific (GA 2008; BOM 1994).

Low lying, economically poor, environmentally degraded areas along coasts with high population density are particularly vulnerable to tropical cyclones, where the majority of deaths occur from drowning during cyclone storm surge (Noji 2000). Bangladesh has had the most serious consequences of tropical cyclones in the past century due to a combination of meteorological and topographical variables and the intrinsic vulnerability of its people as a low-income country (Pan American Health Organization 1999).

Eight percent of the land in India is vulnerable to cyclones. The coastal areas of India on average experience two or three tropical cyclones every year. India's eastern coasts experience more severe storm impacts than do India's western coasts. Peninsular India is known to be the worst cyclone-affected part of the world (Sharma 2009). At times, the indigenous communities in coastal areas suffer from mental health consequences because their traditional way of life has been disrupted, especially when forced migration or relocation from their historical habitat is a factor (Green 2006).

4.3 Drought

Drought is "a period of abnormally dry weather that persists long enough to produce a serious hydrologic imbalance" (National Oceanic and Atmospheric Administration 2002). It has also been defined as a "period of deficiency of moisture in the soil such that there is inadequate water required for plants, animals and human beings" (Office of U.S. Foreign Disaster Assistance/Centre for Research on the Epidemiology of Disasters 2001).

A worldwide disaster database maintained by the Centre for Research on the Epidemiology of Disasters, covers drought disasters from 1900–2012 and highlights the adverse impacts of drought in nations throughout the world. India and China faced the greatest number of droughts during this period. Countries with the highest drought related mortality rates were China, Bangladesh, India, Soviet Union, Ethiopia and Sudan, in that order (Stanke et al. 2013).

India, one of the most vulnerable and drought prone countries in the world, has been experiencing prolonged and widespread droughts since the mid 1990s and, in subsequent years, with increased frequency (Mishra and Singh 2010; Food and Agriculture Organization 2013; World Bank 2003). It is difficult to document the health impacts of drought. Deciding upon a beginning and end date of the drought is problematic, and drought impacts tend to accumulate over time. Most health consequences are indirect since they are mediated by other factors such as loss of jobs and infrastructure (Stanke et al. 2013).

The main drought related worries are financial wellbeing, household income business pressure and occupational concerns. Other factors include residential mobility, employment, personal relationships, social life and family time, health and family functionality, and mental and physical health (Edwards et al. 2008; Stain et al. 2011). The drought also leads to psychological issues involving inequities in water distribution and conflicts among water users. School attendance is often interrupted, affecting students, their families, as well as school staff, teachers and administrators. Populations often must migrate to safer ground, disrupting bonds of family, friends and familiar environment. There is often poor physical and mental health and a hopelessness and sense of loss (Udmale et al. 2014; Keshavarz et al. 2013; Guha 2012; Karpisheh et al. 2010). Drought has significant social impacts in terms of community social cohesion and participation. Drought triggers anxiety or depression related to less access to recreational activities, higher incidents of heat stroke, and loss of human life (National Oceanic and Atmospheric Administration 2002).

Drought-triggered mental illness mostly affects farmers and farm workers. For those whose earnings sink to lowest levels after drought, higher rates of mental health problems and lower mental health wellbeing scores occur (Edwards et al. 2014).

Attempted suicide is highest among farmers who are particularly vulnerable to drought (Alston and Kent 2008). According to National Crimes Records Bureau of India, the state of Maharashtra registered the highest number of farmer suicides each year in the last decade, most in the Vidarbha region, showing an increasing trend in the worst drought-affected area of India (Patel 2005). However, farmers in the region blame increase in farmers' suicides on inadequate government policies and the ecological and social issues arising from drought, rather than drought itself (Udamale 2014; Keshavarz et al. 2013; Guha et al. 2012; Karpisheh et al. 2010; Bryan et al. 2010).

Psychological responses to prolonged drought also affect one's outlook and sense of hope, including one's sense of connection to their environmental surroundings (Stain et al. 2011). Rural communities and inhabitants are more connected to their environment than urban dwellers, both socially and economically. It is not only the intensity of drought that matters for the mental health of these inhabitants, but the pattern of drought matters too. Specifically, recurrent and long, unbroken periods of drought are more damaging across the entire community (O'Brien et al. 2014). In India, it is said that a typical rural household spends about 15 % of its annual income during festivals (Rao 1999). Since drought affects the income of low-income farmers, they cannot participate as much in festivals when droughts occur. This negatively impacts their social life and mental health (Udamale et al. 2014). A study undertaken in India found that a majority of farmers believed they were not ready or unable to mitigate the impacts of drought. This shows the low resilience and high vulnerability of farmers to drought (Udamale et al. 2014; Ashraf and Routray 2013; Paul 1998; Wilhite et al. 2000).

When drought-related experiences of young people were studied, the mental health impacts of drought were largely reported as negative. Consequences included relationship issues at school and in homes, worrying about families, communities, their futures, money and possible isolation. They sought help from schools, friends and others, and sought information about mental health (Carnie et al. 2011). Young people who had experienced a long-term drought also had higher emotional distress scores than those who had not experienced the long-term extreme drought (Dean and Stain 2010).

5 Displacement Due to Extreme Weather Events

There is a fear that extreme weather events and the consequent destruction of local economies will displace millions of people across the globe in the near future (Brown 2008b; Myers 2015). Population displacement due to climate change is projected to be 200 million people by the year 2050 (Centers for Disease Control and Prevention 2010). This displaced population might face place-based distress due to involuntary migration and loss of connection to their home environments, a phenomenon known as "Solastalgia" (Centers for Disease Control and Prevention 2010). Migrating communities are seen by those who receive them as "a threat to their culture … and as competitors". Migrants are believed to be vulnerable to cultural and racial discrimination in the receiving communities and may experience negative mental health impacts (Myers 2005) such as anxiety, depression, and PTSD (WHO 2002).

Extreme weather phenomena may lead to wars and conflicts. In a study that compared ENSO (El Nino, Southern Oscillation) data for 1950–2004, a two-fold increase was discovered in the probability of wars and conflicts during years affected by El Niños (ENSO is a phenomenon relating large-scale atmospheric wind patterns and warming of tropical Pacific Ocean temperatures that affect climate patterns in widely spaced quarters of the world). The study concluded that El Niño might have a role to play in 21 % of civil strife across the world over the past 50 years (McCarthy 2011).

6 Extreme Weather Events and Community Engagement

A new model for disaster preparedness should include disaster response, preparedness and mitigation policy. It should emphasize preparedness above all, with mitigation as a goal and improved Early Warning Systems (EWS) an important means to achieve it. While emergency response and immediate relief are clearly important, true disaster preparedness includes being able to anticipate the wide range of possible threats and to heed the warning signs (Wilhite 2002). This is why the IPCC activities today are so important for disaster preparedness now and for our children and grandchildren tomorrow.

We must find new ways to adapt and mitigate health risks from extreme weather events (McMichael 2007) and to understand that mental health programs developed in urban contexts need not necessarily apply, and must be modified before adaption in rural situations (Carnie et al. 2011).

Engagement with communities for disaster preparedness has rarely been consistently effective, no matter where one lives. This is a common shortcoming in spite of the personal and tragic consequences of extreme weather events. One explanation for this is that the news media, the usual outlet for community engagement in this context, show images that underscore the helplessness of the ongoing situation. In some cases it is because the sad images shown are of a distant place, giving the impression that the threat is not imminent. Yet another possible explanation is that resources allocated for the many competing social, economic and environmental factors are insufficient, and that the authorities distributing these resources have not explained their allocations in a manner acceptable to the community.

The notion that scarce resources should be allocated to a "what if" type of scenario—for instance, *what if* major extreme weather hits a particular area—does not spur people to action when there are multiple demands on resources. This is one reason why it is difficult to rouse public support to address unspecific *potential* disasters that *may* accompany climate change. Lehmann (2014) touches upon this point, that it is difficult for communities to face the economic and environmental reality of disasters and it might be easier to ignore climate change and the many environmental, economic and social challenges that accompany it.

Adaptation to extreme weather is not a high priority of governments, even though the adverse impacts caused by these events beg a heightened sense of emergency for a long time. Adequate preparation for extreme weather events requires effort and coordination from a number of government departments, agencies and local community focused groups. There is a need to make adaptation to extreme events a mainstream practice by raising the level of awareness and concern among public policy makers and decision-makers, whether in government, in business, in Non-Governmental Organizations (NGOs), or in the home. To deal with emergencies related to extreme weather events, governments must recruit more career emergency responders, such as firefighters (United Firefighters Union—Queensland 2013).

The research community has a responsibility as well: evidence-based research should inform all levels of policy makers of progress while developing tools intended to minimize the psychosocial and mental health impacts of disasters (Health Protection Agency 2011).

Effective policies are needed to curtail flood-related impacts, among the worst of which are morbidity and mortality. This requires an adequate understanding of the potential health impacts of floods. In order to be prepared for dealing with floods and mitigating their devastating impacts, nations need to deal with problems such as refugees driven from famine-plagued neighboring communities, urbanization, increasing burden of diseases, high rates of malnutrition and poor maternal and child health (Alderman et al. 2012).

Comprehensive long-term action plans must be prepared in order to mitigate the impacts of drought. A shift in public policy from drought management to drought preparedness and drought mitigation is much needed. Early warnings of drought with continuous monitoring and decision support systems should be incorporated. Social and community processes to help communities prepare for drought need to be conveyed to everyone, especially in vulnerable regions (National Academy of Agricultural Sciences 2011).

Currently, India is practicing a drought management mechanism that includes institutional and social welfare programs, along with employment generation schemes, with the support of State and Central governments. Communities would be well advised to participate with government to enhance the effectiveness of government planning, mitigation and relief efforts. Steps are taken in India to manage drought impacts by involving local self-government institutions, for example, the Gram Sabha/Panchayat. Taking such steps will reveal the most practical relief work needed, for example, in districts and block-level committees, for sanctioning the necessary funds and monitoring the relief operations, and in NGOs that play such a big role through training and motivating the affected population (Gupta et al. 2011).

Drought mitigation is also managed in India by rural institutions, tribes, international aid agencies and in private sector, philanthropic organizations, community groups, farmers and herders. These efforts are backed by research and development in weather forecasting and in vulnerability and preparedness studies, rainwater and soil management, contingency crop planning and mid-season corrections, along with alternate and diversified land use systems (National Academy of Agricultural Sciences 2011). A case study is shown in the following box. A number of multi-national pilot projects could be undertaken to test the effectiveness of drought management programs and to train emergency responders everywhere as to best practices.

Successfully Managing Drought during 2002

An Indian drought in 2002 was one of the most severe (NAAS 2011). Rainfall was 51 % of normal in July. Its impact was felt over 56 % of the land and it affected 300 million people in 18 out of 29 states in India (NAAS 2011). In addition to the appropriated strategies used by policy makers at state and central levels, in terms of optimum use of available resources and institutional services already in place, the Panchyati Raj Institutions (the local self government institutions) and rural and local self help groups proved to be of great assistance in carrying out community-based drought relief operations. The central government gave large amounts of money to the states. Millions of tons of food grains were given in relief. Billions of rupees were spent on servicing the debt liability and crop insurance claims of suffering farmers. Employment generation schemes were implemented. Fresh water was supplied through roads and railways to over 90 million people (NAAS 2011).

A start has been made to promote awareness and concern for psychosocial impacts of drought. India's drought-prone, cotton-growing belt, the Vidarbha region in eastern Maharashtra, is at the core of drought crises faced regularly by India. A community-based pilot program there, known as 'The Vidarbha stress and health program,' or Vishram, is supporting farmers and their family members in distress in the region since 2011 (Patel 2015).

Efforts should be made to make drought preparedness comprehensive, so that it includes safety nets, such as insured losses and staged levels of enforced water conservation as the drought worsens. Preparedness must become part of normal farm management plans and activities. Timely forecasting of drought, including probable location, and the likely duration and extent of its impacts should be provided. Most importantly, the forecasts should be coordinated with various stakeholders that could be impacted by the drought. This is being done in India by the Indian Meteorological Department, which predicts rainfall patterns for the Indian sub continent. There is also the need to make others aware of droughts before they recur. Having this a priori awareness would help in drought preparedness for outreach and education. This communication with the public is essential for gaining trust and cooperation in drought mitigation strategies, including staged water conservation efforts of government.

7 Best Practices for Extreme Weather Community Engagement

When widespread flooding struck India and Pakistan in September 2014, the relief agency, '*Islamic Relief*,' provided community health services. In coordination with the NGO, '*Doctors For You*,' Islamic Relief provided psychosocial support by organizing meetings with women and youth groups. The program was spread over 20 villages and included measures such as training of community volunteers to provide support to the local populace. More than 1000 children who faced these floods benefitted from 'Child Friendly Centre,' set up in more than 12 locations (Islamic Relief 2014).

Efforts by international agencies such as the United Nations Development Program (UNDP) have gained rich dividends in terms of collective action. The case of people residing in the vicinity of the Mahanadi River delta in the Indian state of Odisha, who face extreme weather regularly, is notable. Widespread flooding occurred here for 6 months from July to December 2014. However, after three months, agricultural water supplies were reduced, leading to declining crops. In the Mahanadi River Delta, the community managed water drainage systems three times in one year to increase the crop yield during flooding. When three of the villages in the Puri district pooled resources to identify their most urgent problems and discover ways to address the increasingly erratic rainfall patterns, they responded with a joint renovation of the Kharbar Canal, a 12-km-long channel that had not been used for a long time. By renovating and cleaning out the river channel the water could drain out much faster, preventing water-logged fields during floods. In the summer months when there is less or no rain, the water flow is reversed to help irrigate their lands. This effort was funded by the Australian Agency for International Development (AusAID). It helped build the resilience of poor men and women to extreme weather events and to reduce the risks they face (UNDP 2012b; Turnbull et al. 2013).

7.1 *Enhancing Preparedness, Reducing Vulnerabilities and Building Resilience*

Research suggests that communities must adapt to severe weather risks using ‘cost-effective, nature-based approaches’ to be better equipped to cope with both unexpected and expected extreme weather events. Past research has illustrated that taking preventive action today may help protect communities and save much money (Davies et al. 2009). The Multi-hazard Mitigation Council (2014) reported that for every dollar spent on preventive action, the United States will save $4 from the future costs of disaster (Grant 2014). Moreover, when there is equitable distribution of resources within a community, nation, or the world, there is greater adaptive capacity (World Health Organization 2005a, b).

In Bangladesh, households with poor physical conditions, less education or income, and insufficient access to weather forecasts and training for coping with disasters were found to be more vulnerable during severe storms than households with these resources; the latter were able to cope with a recent cyclone, for example, by having accessed forecasts, prepared themselves for the cyclone, and had quick access to a storm shelter (Hossain 2015). Thus, reduction of population vulnerability to disasters can be the first line of action for “effective and fruitful” disaster management. A household’s level of intrinsic vulnerability to disaster, such as cyclones and storm surges, is significantly determined by socioeconomic and physical factors (Hossain 2015).

Traditional methods for responding to extreme weather events, such as assessment, mitigation and preparedness that have yielded rich dividends in many cases need to be complimented by sociological or community-based measures, which take a multi-stakeholder approach. It becomes important to involve various sectors and interests from the community to build a stakeholder group that is more representative of community perspectives. Various community oriented and community based solutions have evolved across the world as a result of community representatives and governing authorities working together to deal with extreme weather events.

There is a need to uncover ways and means that help prevent and mitigate the suffering from extreme weather events and assist people in adapting to these events (Kovats et al. 2000; Patz et al. 2000). Emphasis on psychological and psychosocial support and intervention is increasing as part of overall responses to disasters (Kuo et al. 2003). Communities should realize the importance of adopting low cost, feasible and functional risk-mitigation activities, and manage the costs of such activities themselves. This will go a long way in sustaining community risk mitigation practices (Davies et al. 2009).

It is true of many countries that the response to drought is mainly reactive, i.e. crisis management. The result is generally poor disaster 3relief planning. This re-active crisis management strategy should be replaced by a more pro-active strategy (Udmale 2014; Kiem and Austin 2013). Low education, small parcels of land, and low income appear to be major obstacles to farmers’ strategies to adapt to the impacts of drought. Attention must be paid to these constraints as policies for community resilience to drought events are framed (Udmale 2014).

Media coverage and appeals for aid sometime generate huge amounts of aid immediately following an extreme weather event or disaster. At times, considerable aid is wasted due to the haste in delivering emergency aid without benefit of prior planning and organization. Preparation ahead of the disaster will allow responsibility for disseminating resources to fall to the experts who understand community needs and priorities. One should not overlook the role of well-organised and experienced institutions for disaster management, such as the military, especially when long-term recovery is anticipated.

International NGOs who work in tandem with local NGOs and community-based organizations can be very successful in delivering and managing aid. Experienced external aid agencies are recommended to complement recovery efforts and to help avoid the traps of undue haste. They must be prepared to hand over the work they began only when local agencies demonstrate fool-proof arrangements that lead to continued efforts in an organized manner, even after the external aid agencies depart. Disbursal and effective utilization of aid needs a long term, thoughtful and all encompassing approach (Mulligan 2013).

7.2 Importance of Early Warnings, Timely Evacuation, and Emergency Planning

It has been said that, "preparedness pays." If preparedness is given its due, and preparation is made well in advance, the damaging consequences of extreme weather may be reduced significantly. Much effort must be given to train people in the community for extreme weather challenges and responses. This training, of course, will apply as well to emergencies triggered by other events. Local administrative bodies and other stakeholders need to promote these emergency response training activities jointly at school, hospital, institutional and community levels. Training can be on themes such as search and rescue and first-aid, both medical and psychological. This training should be organized regularly, in phases, so as to cover the entire community.

Preparatory efforts should include building capacity in terms of resources, inculcating local leadership and relief and rescue equipment, medicines, food stocks, and drinking water—all to be monitored, replenished and maintained at regular intervals. Research has shown that women may be excellent 'disaster managers,' as many of them actually manage household activities, especially where men traditionally leave the home for work for extended periods of time. Institutes already working at national and regional levels in the area of training may be involved in providing training in a big way. It is also suggested that civil society groups such as NGOs, indegenous groups, community groups, etc. could help monitor emergency preparations and assist community capacity building to follow through.

Improved technologies have led to a decline in the harm delivered by cyclones in recent years (Pan American Health Organization 1999a): satellite-based observation systems and Doppler weather radars are able to detect severe thunderstorms and provide early warnings. In hilly regions, flash floods may happen with very little time to prepare. Since community members and even the staff of some aid agencies are not accustomed to interpreting information from advanced tools such as radars and satellite-based sensors; there is often a delay in analyzing and disseminating important information derived from them. Too often, people have very little time to act. Thus, creating and operating Early Warning Systems (EWS) become a priority, which generally must come from well-funded and interdisciplinary teams extant. An effective EWS would be designed and operated with full communication and participation of all affected parties, including community representatives, local and regional governments, and aid agencies. The effectiveness of any EWS will be judged by the time it would take for people to respond to these warnings—and that requires full and sustained engagement of those being served.

Changes in temperature and precipitation, as well as droughts and floods, may also affect agricultural yields and production. It is known that in some regions of the world the impacts of extreme weather, such as droughts and floods, may undermine food security and endanger human health and well being by causing spread of infectious diseases, malnutrition, and food poisoning. Some of the worst effects may be seen in developing countries and among poor and vulnerable sections of these countries (Confalonieri et al. 2007). An example of creating effective early warning systems for overcoming food insecurity and famine is the Famine Early Warning Systems Network (FEWS NET), which is a collective effort at the global level to deliver early warnings about hazards, food insecurity, and famine (Brown 2008a). The network was created in 1985 by the US Agency for International Development (USAID). The objective and research-based analysis provided by FEWS NET helps governments and relief agencies to plan action to deal with potential famine. With its network of analysts and specialists spread over 22 field offices working in coordination with US government science agencies, national government ministries, international agencies, and NGOs, it produces futuristic reports related to more than 36 of the world's countries most vulnerable to food insecurity. The FEWS NET program helps develop national and regional emergency early warning systems and monitoring and assessment capabilities regarding famine (www.chemonics.com). We recommend that institutions and projects such as FEWS expand to provide information and data to convey warnings, alerts and the implications of drought to communities and stakeholders around the world. These networks need to be extended to include many more countries and regions of the world, so that hazards like famine, may be predicted earlier and the havoc caused by its humanitarian impact can be mitigated.

Evacuation from whatever the disaster, in advance, helps to reduce mental health challenges that appear in the aftermath of severe weather events (Weems 2007b). When the dreaded cyclone Phailin reached the Odisha coast in 2014, the loss to life and property was minimal compared to 15 years earlier when a similar storm, in the same state, led to loss of 10,000 lives. The reason for this low damage was effective storm warnings over several days by the Indian Meteorological Department that provided realistic information about the cyclone and motivated people to prepare and respond. This turned out to be the largest, timely storm evacuation by India. Some 900,000 people were moved to shelters in schools and government offices (Samenow 2013).

In India, the army has carried out most immediate rescue and relief operations. After the flash floods hit the city of Leh in 2010, the civil hospital of Leh was badly damaged and rendered dysfunctional. Search and rescue operations were launched by the Indian Army immediately after the disaster. The injured and the dead were shifted to the Army Hospital in Leh, and mass casualty management was started by the army doctors while relief work was mounted by the army and civil administration (Gupta and Kapoor 2012). Over 200,000 people were rescued by the Armed forces and the National Diaster Relief Force (NDRF) from different parts of Jammu and Kashmir during its worst floods in September, 2014. Three teams of Naval Marine Commandos were also involved in rescue operations (Pandit 2014). Similar operations, on a war footing, were conducted during Uttarakhand floods in June, 2013.

In 2014, another tropical cyclone, Hudhud, slammed into the Andhra Pradesh coast, with torrential rain, great waves, and gale force winds reaching 120 miles per hour, creating widespread damage to infrastructure, affecting communication and power lines, roads, rail, and air traffic in many coastal districts. The immediate impact of the cyclone was greatly reduced by the disaster preparation conducted many days in advance. The most important was the evacuation of some 150,000 residents living in areas along the coast (Hannah 2014).

Emergency planning is one of the most important components of disaster preparedness. Communities must collectively understand what needs to be done before, during and after a disaster. For developing such an understanding, planning would require active participation of women, children and elderly, especially since demographic patterns indicate that many men folk often migrate to cities in search of employment leaving the elderly and very young at home in the more rural areas. After such extreme-weather events, it is also suggested that emergency planning must help build special task forces to address specific tasks. The capacity of these task forces could be increased over time, through training and mock extreme-weather drills. This sort of planning identifies emergency evacuation pathways and possible shelters needed when an extreme weather event or disaster actually strikes. Local government institutions need to work in close coordination with communities during emergency planning.

It usually helps if people have a plan for keeping themselves safe in the event of a severe weather event. A good plan includes where they will meet others, and supplies they may need, such as food, water, and flashlights. This preparedness can help people cope. Osofsky (2007) documents that anxiety is less for children and families who are prepared.

In Australia, Queensland's response to the floods and to Cylcone Yasi was "extremely good" (Cleary 2011) because Queensland's Emergency Services and

Premier had well-developed plans that were communicated and updated regularly. They used concise, clear and repetitive messaging. Hence the public could get the needed information. The three critical elements of this exemplary response were excellent planning, good communication and a strong community response—essential for surviving such extreme events (Cleary 2011).

The Australian government finds its best leaders to guide community pre and post disaster response to the growing number of bushfires, floods and cyclones in the 40–50-year age group (Cleary 2011). Involving people with sufficient experience in disaster preparedness and response is crucial at the very beginning of planning.

7.3 Creating Awareness Through Interdisciplinary Teaming

Everyone should be made aware of the hazards of extreme weather events on public mental health. If communities understand the connection between mental health and extreme weather, their governments may be led to create institutional mechanisms that provide psychological support to affected populations. This would guard against mental health challenges from becoming major public health issues. The health sequence to avoid is allowing stress to adversely affect social and vocational well being that, in turn, feeds back to increase stress and mental health problems. Developing interdisciplinary teams of scientists, health professionals, and community and government leaders will go far in preparations to combat the health challenges associated with extremes of drought and flooding. Shukla (2013) urges psychologists, government leaders, and community organizations to act earnestly now to prepare for mental health issues that may emerge because of changes in the character of severe weather events in periods of climate variability and change.

Research shows that individuals who experience an intense, life-threatening event, first hand, will experience a significantly higher level of concern for mitigation than those who did not have such direct exposure (Vasileiadou and Botzen 2014). Therefore, in order to raise the level of concern about likely impacts of extreme weather, an appeal for support will be most effective if made with the personal circumstances and emotions of the people who suffered most directly. This could be done through public information campaigns about real-life cases, more field visits by government functionaries and corporate officials, and creating possibilities for the general public to participate in the relief and rehabilitation efforts.

Television, radio and newspapers could be tools for spreading weather related information and drought adaptation strategies to the larger community. Alongside government sponsored drought relief measures, community based plans and effective implementation and management can be undertaken to compensate for any failures of relief measures (Udmale 2014).

7.4 Knowledge Sharing

Knowledge generated through research and qualitative analyses must be shared with various stakeholders and community members so that everyone knows the potential risks from disasters and, together, can plan ahead of potential disaster. Knowledge sharing may take newer forms in the Internet era. It may be in the form of online discussions, live reporting by community members, video conferencing, use of community radio, creating local level knowledge and resource and village information centers, using mobile technology for creating applications for creating disaster awareness and preparedness. Along with traditional methods of information sharing and knowledge, public discussions, debates and lectures involving respected experts may help in community awareness.

In essence, people have more day-to-day, pressing business on which to focus, beyond the "what if" of a potential extreme weather event occurring. A need for awareness campaigns exists, at the community-level, on a regular basis, to help share knowledge and information with different sectors of the general public. This should occur in appropriate languages, and on the radio as well as in print, to reach people who are illiterate or without access to print or digital media. Innovative methods at communication such as awareness songs, movies in local dialects on disaster risk reduction, paintings, debate competitions on flash floods in local schools, and story-telling have been variously used by communities and societies in different parts of the world. Local festivals and fairs have been used to create awareness about risks and enhance preparedness, thus trying to build a culture of prevention and resilience (United Nations Development Programme (UNDP) 2008, 2012a).

7.5 Land Use Planning

In the past, houses were built on raised grounds and natural land slopes that were utilized to divert flood-water. Simple early-warning systems were used. Today, the traditional systems have been ignored and the lands that once were the natural slopes for flood-water flow are now used to support increasing urban settlements—houses, hotels and businesses—in growing economic development (Mishra 2014). To achieve this, people at the community-level should be trained to easily identify and recognize hazard prone land regarding the places and the heights to which floodwaters may reach (United Nations Development Programme (UNDP) 2012a). Land use planning and management concepts need to be popularized within communities and local government levels so that disaster prone and risky sites may be identified and prohibited from being built upon.

7.6 Regional Cooperation

Communities vulnerable to extreme weather events need to monitor their environment and their social structures. They must share and disseminate data among themselves in order to issue timely warnings to those most likely to be affected. International platforms provided by regional associations like the SAARC (South Asian Association for Regional Cooperation) and its disaster management center may help in developing a region-specific, coordinated strategy for addressing disaster risks that could involve all stakeholders and sectors. Actions must be synchronized between the administration, the technical institutions, civil society organizations, humanitarian and development agencies and other players (United Nations Development Programme (UNDP) 2012). Knowledge created by technical and research organizations, can be used to prepare comprehensive strategies that can guide, say, the NGOs working in the field.

7.7 Best Practices for Mental Health Care

The WHO (2003) gave certain guidelines for meeting post-disaster mental health challenges. According to their report, national preparedness plans should incorporate a well-organized mechanism of satisfactory social and mental health response in the wake of disasters. It should include training people who are already aware of the local realities so that overall disaster relief is practical and quick. A very significant guideline is that heath care staff should receive supervised, clinical, on-the-job training, by mental health experts. The aim of all these activities, according to the WHO, should be long-term community mental health services and other social interventions.

Two phases of mental health care are apparent. One is the **acute emergency phase** and the other is the **reconsolidation phase**. The acute phase will involve managing urgent psychiatric complaints and organizing outreach and non-intrusive emotional support (Few 2004). In the reconsolidation phase, longer-term social and psychological interventions could be undertaken, such as teaching mental health skills to primary health care workers and following up on psychiatric cases. The WHO (2003) suggests that such activities need not be exclusive, they could be interwoven with already existing coping mechanisms and traditional practices.

Psychologists should be guided by the findings of disaster psychology and target their treatments to achieve the long-term psychosocial adjustment of the people affected. Psychologists can employ individual and group therapies to deal with the indirect mental health consequences of extreme weather disasters (Karlsson 2011).

Relief and rehabilitation post-disaster would include actions such as creating awareness of post-traumatic stress disorder symptoms, and alleviating these by educating and helping people to develop adequate coping mechanisms (Gupta and Kapoor 2012). Mental health data and information must be part of an emergency health care response that can include psychological First Aid, triage, assessment, referral and intervention needs (New South Wales 2000). The mental health-care initiatives can also involve local volunteers, community-based organizations, and professional health personnel during disaster emergencies (Few et al. 2005).

It is equally important to address the psychosocial context post disaster, when the mental health issues are more likely occur (Wind et al. 2013). Wind et al. (2011) suggest that "individual oriented stress reducing interventions," which go to the individual appraisal of losses experienced, social support and coping, could be more effective in reducing mental health outcomes (anxiety, depression and Post Traumatic Stress Disorder—PTSD). These interventions address the social context of the community and promote trust, mutual support and reciprocity. This 'social cohesion' is important in determining the susceptibility to PTSD symptoms and should be taken into account while developing public health strategies (Health Protection Agency 2011).

In Indian culture, it is believed that people can cope with disasters through social cooperation. Nevertheless, disasters do lead to psychological impacts on entire affected populations, especially children. Psychiatrists in India recommend that parents involve themselves more with children who have been affected by weather related disasters, and build a positive environment in order to help children overcome trauma (Muzaffar 2014).

Jabry (2002) suggested that psychological interventions for children in the event of a disaster could include talking about their experience, seeking their perspectives on rehabilitation and on tasks related to future preparedness and restoring their daily routines, including their educational routines, in order to achieve emotional and psychological recovery. In New South Wales (NSW), Australia, a Farmers Mental Health Network was created, with service providers, academicians, government, private agencies, and the NSW Farmers Association. The Network helped to develop a model that covers key issues and the topical areas in which action promoting mental health would be needed (Fragar et al. 2008).

Shukla (2013) recommends that government, the general public, and expert psychologists pay close attention to the findings and predictions of extreme weather and evolving climate regimes. Skills and the capacities to use them must be built so as to meet the mental health challenge of extreme weather events. There is general consensus among psychologists that daily changes in behavior could lead to positive changes in the long run. Behavioral changes should be cultivated in order to tackle the mental health challenge posed by extreme weather events and climate change. Psychologists are still exploring which behavioral changes may be most beneficial and, hence, which to promote (Corner 2009).

There is a need to prepare health plans to provide specific help to victims. Very few countries have national disaster plans that outline steps to identify psychosocial aspects of hazard events or to help deal with them (PAHO 1999). The importance of mental health care in disaster situations is gradually being recognized (Few et al. 2004). For example, the Indonesian government trained over 150 community leaders and health workers to provide mental heath interventions in the Aceh province (WHO 2005a, b). Documents related to mental health emphasize the important role of training and experience (NSW 2000; WHO 2003).

For flood related disasters it is known that well trained disaster workers are effective in counseling and psychological skills. These workers also form connections with other groups and individuals who are part of the relief work. They are aware of policies and procedures that may help the victims (Chatterjee 2005). But, training must equip disaster workers with the knowledge and skills necessary for offering specific help for specific problems. It has also been documented that heavy work pressure, fatigue, and exposure to the dead are serious stressors that increase the risk of disaster workers themselves having mental health issues. Observations in developing countries suggest substantial risk to mental health depending upon the scale of the devastation caused by the disaster (Medicenes sans Frontieres 2004). One also must be more vigilant post disaster, with planned interventions that may last for several years thereafter (Weems 2007b).

Research into the possible human behavioral changes that could alter patterns of consumption of environmental resources is recommended. Efforts need to be made to increase public awareness of the risks inherent in indiscriminate use of earth's resources (Shukla 2013).

Most studies of droughts and floods have been conducted in countries such as the United States and Australia. More studies across different geographies are required to estimate impacts of drought correctly on the mental health of affected populations within a variety of environments.

Greater effort is required from psychologists and behavioral scientists to become future-oriented, and prepared to deal with post-disaster mental health challenges. Psychologists could start to organize themselves into "ready to respond" teams to deal with mental health problems faced during a disaster. Psychologists and other social services would be advised to find ways to help stakeholders cope with anxiety and worry about projections of extreme weather disasters under scenarios of climate change. Each community and its associated local, regional and national government agencies must take the initiative and create the means (including institutions if necessary) to provide psychological support services along with the socioeconomic resources needed to deal effectively with disaster-related adverse mental health impacts (Shukla 2013).

If nations of the world work together to share resources, skills and models for predicting and preparing for extreme weather, the mental health and other risks associated with extreme weather events would be greatly reduced. As of now, competing demands for resources thwart true preparation and policy preparedness for extreme weather events. If climate evolves to create more severe and more frequent weather extremes, the need for preparation and policies will only increase. Currently, the main course of action for communities is to be prepared by taking stock of local resources and preparing policies for action in the face any future extreme weather event. Communities must gear up and get trained to deal with both, the physical and mental health challenges they may yet face.

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Extreme Winter: Weaving Weather and Climate into a Narrative Through Laura Ingalls Wilder

Barbara Mayes Boustead

Abstract The Hard Winter of 1880–1881 was featured in the Laura Ingalls Wilder historical fiction account, *The Long Winter*, as well as in several local histories across the region. Both meteorological records and historical accounts indicate that the winter was particularly long, snowy, and cold. As a result, homestead settlers in the Great Plains and Upper Midwest regions of the United States were stranded for weeks or months at a time, many in inadequate shelters and with fuel and food supplies that ran short. The compelling narrative of Wilder's perspective on the Hard Winter, linking scientific information about the winter of 1880–1881 to a cultural icon, provides a natural vehicle with which to communicate weather and climate concepts. A narrative constructed around *The Long Winter* and other books authored by Wilder provides a means of audience engagement and interest in weather- and climate-related topics, which was at least partially quantified by surveying audiences of the narrative. Overall, the extreme winter weather, combined with a familiar narrative voice, transmits weather and climate understanding to a wide audience.

Keywords Winter · Blizzard · Cold · Laura Ingalls Wilder · Narrative · Historic extreme weather

Blinding snow, driven by winds gusting to 40, 50, 60 miles per hour. Bitter cold. Deep snowpack. Homebound for days, with school canceled and stores closed. Dangerous travel. Cold and snow dragging on and on.

These words could describe winters such as 2009–2010, 2013–2014, or 2014–2015, depending on the part of the country in question. They also could describe a winter written into infamy in one book among a series of children's books—*The Long Winter*, authored by Laura Ingalls Wilder (1940) and written to describe the winter of 1880–1881 in east central South Dakota. The series of books,

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collectively called the *Little House* series, inspired a very popular American television series, *Little House on the Prairie* (1974–1983).

1 A Famous Mid-American Author

Laura Ingalls Wilder (1867–1957), renowned for her children's books centered on her pioneering childhood, was more than an author—she is a part of the cultural fabric of America. Her stories, detailed in a series of eight books, encompass her life experiences in a pioneering family across the central United States from ages 3 to 18. One additional book published posthumously describes her first four years of marriage. As a family, the Ingalls family—comprising Pa, Ma, Mary, Laura, Carrie, and Grace Ingalls—built homes and lives in Wisconsin, Kansas, Minnesota, and Dakota Territory (South Dakota) through the series of books. Four of the books provide insight into the family during their settlement in the town of De Smet, originally in the Dakota Territory and in present-day South Dakota, while Laura was ages 13–18. It was here that Laura met and married Almanzo Wilder, 10 years her senior, gave birth to their daughter Rose, and began her own family life. The experiences in the *Little House* book series were based on events from Laura's own childhood, interspersed with some fictionalized elements woven among the actual events to enrich the tapestry of the stories. Significant weather and climate events, such as the Hard Winter of 1880–1881, were a major part of the book series.

Historians and literary scholars have conducted extensive research on biographical information about Laura Ingalls Wilder (Zochert 1976; Anderson 1992; Miller 1998; Hill 2007; Fellman 2008) and have published books in popular literature. The research has focused on historical facts that support the information presented in the *Little House* books, as well as missing and incorrect information; the life of Laura Ingalls Wilder and her family through her adulthood. Several works (such as Miller 1998; Hill 2007) cover the writing of the *Little House* series, including Wilder's strong collaboration with her daughter, author Rose Wilder Lane. Interest in the life of Laura Ingalls Wilder and her family spills over into related topics, too—even some information about the town of DeSmet, South Dakota (Miller 1994), site of four books in the *Little House* series and one more published posthumously.

Many of the events (including and beyond the weather and climate events) throughout the *Little House* book series can be verified, and the veracity of those events provide a context of trust in her narratives, even when other events are revealed as fiction or fictionalized representations of actual events. In that respect, the Laura Ingalls Wilder books highlight the role that extreme weather played during the late 1800s on the people and places of the upper Midwestern American prairie.

2 Setting the Stage for the Hard Winter

In the fall of 1880, the Ingalls family moved into what would become east central South Dakota along the Chicago and North Western rail line. Settlement followed the narrow steel lines of the railroad into a region of only sparse settlers of European descent amid the landscape formerly occupied by Native Americans. With little history among white settlers and little information exchange with Native Americans to learn more about the region as it was being settled in 1870s–1880s, settlers knew dangerously little about the climatology of the region. Settlers who moved west from New England, the Mid-Atlantic, and the Great Lakes had little or no experience with the blizzards, the more frequent tornadoes, or the periods of drought that had been, at most, rare events in their home climatologies (Schwartz and Schmidlin 2002; Brooks et al. 2003; Namais 1983).

In just the second year that the Ingalls were settled in the area, and the first year that the town of De Smet was incorporated, a brutal winter unfolded across much of the north central United States. Dubbed the "Starvation Winter" (Clark 1893), the "Hard Winter" (Robinson 1904), or the "Snow Winter" in most historical sources, the region was overwhelmed by a series of blizzards and cold snaps (Mayes Boustead 2014). The barrage lasted for six long months in most of the region, and the result was one of the coldest and snowiest winters since settlers of European descent arrived in the region, along with some of the worst flooding ever recorded in the region. Wilder wrote about the hardships of the Ingalls and Wilder families in *The Long Winter*, which was the sixth of her eight-book series. The publisher rejected her original book title, *The Hard Winter,* because it was too scary-sounding for her young audience, but the content was largely unaltered from draft to publication.

Among scholars who study Wilder and her writings, *The Long Winter* is often considered to be the most complete of her stories and is often cited as a fan favorite; it includes the overarching narrative of a family struggle and narrow defeat against the terrifying winter. By the time *The Long Winter* was published in 1940, Wilder's previous books had received national recognition and awards, and she was a well-known author who received fan mail and requests for speaking engagements. Like several of her other books in the *Little House* series, *The Long Winter* was recognized with a Newberry Honor Medal in 1941. Published during and after the Great Depression, the *Little House* books are often cited for their timeless themes that keep them popular to this day. *The Long Winter* contains a dramatic story arch, with a clear villain (the winter weather) that threatens the Ingalls family and a very real threat of harm. The threat encompassed limits to settler mobility and access to food in the American Plains and Upper Midwest.

3 Overview of the Hard Winter of 1880–1881

The foreshadowing of the Hard Winter to come starts early in Wilder's story, beginning in the late summer of 1880. Pa (Charles Ingalls), her father, observes birds flying south early and quickly and muskrats building particularly thick shelters. Wilder's draft manuscript hammers home these themes more than the final published version of the story, painting Pa as a nature-reading sage who knows that the winter will be hard before a fictitious Native American visits town to provide his forecast.

Sure enough, winter began early as a mid-October blizzard swept over the family in their thin-walled claim shanty. A claim shanty can be described as a simply constructed home that many of the early settlers on the Plains used to stake a claim to their property (Herbert Hoover Presidential Library 2015). A cold rain on October 14, 1880, changed to snow overnight, deteriorating to a blizzard that lasted from October 15–17 (Fig. 1).

Climatological data during the Hard Winter are available from several sites in the Plains and Upper Midwest regions, though none that were close to De Smet. The closest sites to De Smet with continuous records that predate 1880 and extend to the current date are Omaha, Des Moines, and Minneapolis/St. Paul. Historical military quarters in Fort Sisseton (about 25 miles west of Sisseton, South Dakota),

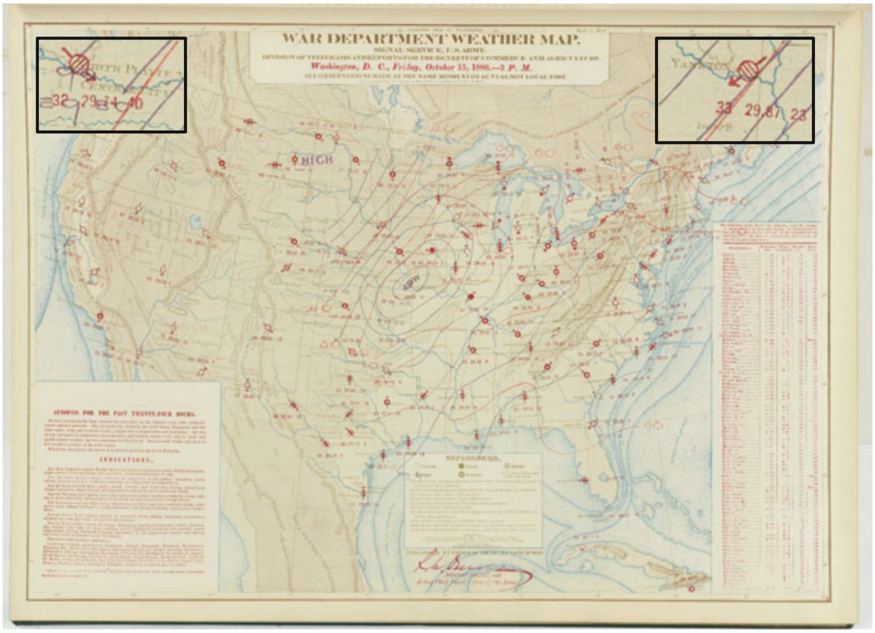

Fig. 1 Surface weather analysis at 2000 UTC (3 PM Eastern Standard Time) 15 October 1880. Yankton, South Dakota (*upper right*), and North Platte, Nebraska (*upper left*), stations are in *insets*

Fort Bennett (under present-day Lake Oahe in central South Dakota), Fort Randall (70 miles west of Yankton, South Dakota), and Yankton have short periods of historical records that were digitized by the former Climate Database Modernization Project. Climate records for Huron began in July 1881, just after the Hard Winter ended.

Observers at Forts Sisseton, Bennett, and Randall indicated that rain changed to snow late on October 14, 1880, with precipitation falling as snow for the next two days, and with gusty winds continuing through October 18. Mild weather returned quickly after the blizzard passed, but winter had struck its warning note. Historically, an October blizzard hits South Dakota roughly once every five years, but these are usually west of the Missouri River (personal communication with the National Weather Service offices in Sioux Falls and Rapid City, South Dakota, 2012). Thus, blizzards in October are rare, though more benign snowfall in October is more common. Even so, in the book *The Long Winter*, the blizzard was enough to scare the character Pa into moving the Ingalls family to town for the winter. As with most other settlers, Pa had moved in from the East, where October blizzards were much rarer, and he was unfamiliar with the climatology of his new home.

Laura's tale, combined with historical weather records, suggest that after the October blizzard, a relatively mild spell settled into the region. During that time, the Ingalls family moved from their claim shanty to the more substantial shelter of Pa's office building in downtown De Smet. Historical records point to numerous snow events from mid-November through December 1880. Laura herself counted four blizzards, from a blizzard that struck during school around early December until a Christmas blizzard marred the holiday. With no routine weather records within about 100 miles of De Smet, it is challenging to identify specific events that would have affected De Smet. However, records around the region clearly indicate no fewer than three snow events at any one site during that time. Minneapolis/St. Paul experienced as many as six individual snow events, with 0.10 inches or more of liquid equivalent precipitation falling while temperatures were below freezing, including eight consecutive days with snow from December 19–26 as liquid equivalent totaled 1.63 inches. Even a climatologically average snow-to-liquid ratio of 13 to 1 would equate to around 22 inches in those eight days alone.

Sometime around early to mid-December in Wilder's account of the Hard Winter, Laura, her sister Carrie, and several other children were caught at school when a blizzard struck. While the veracity of this specific event is uncertain, it is certainly plausible that it did happen in De Smet, as it did in many Plains winters around the region. In Wilder's tale, Laura and the rest of the students stumbled behind the teacher, hoping to run into a building to guide them back to Main Street. Laura herself runs into a building just on the edge of town, saving the children from wandering out into the open prairie where they surely would have been lost. The event as described by Wilder is reminiscent of David Laskin's *The Children's Blizzard* (Laskin 2004). Laskin describes a single blizzard in which hundreds lost their lives, mostly children and teachers stranded at schools when the blizzard struck. Whether the schoolhouse event happened to Laura herself or was a reflection of stories told around the prairies during the Hard Winter, it is symbolic of one of the dangers of blizzards to human life: the sudden arrival and lack of visibility could strand people, including children, away from home, with their lives endangered by venturing out into the storm to find their way home. Weathering the storm by staying in a location would be challenged when shelters, such as schoolhouses, did not have adequate food, fuel, or water to sustain people through a multi-day winter storm.

With all sites reporting snow on December 25–26, 1880, Wilder's memory of a blizzard beginning late on Christmas day is confirmed with high confidence. By the end of December into early January, the vital Chicago and North Western train line had been blockaded by snow from Minnesota westward into South Dakota (Stennett 2007). The last train of the winter passed through De Smet in late December, with snow blockades holding back train traffic at least through April (Fig. 2) and, in some locations, through early May. After late December, the town of De Smet was on its own for food, fuel, and survival.

Fig. 2 Cleaning snow away from the railroad tracks at Kelly's Cut, 0.8 km (0.5 miles) west of Sleepy Eye, Minnesota, in March 1881. Image courtesy of Chicago and North Western Archives

By late December, the town of De Smet already had burned through its supply of coal. The trains were not refreshing the supply as expected, and the prairies lacked trees to burn for fuel. The Ingalls family, like many settlers, resorted to an alternative and much less desirable fuel source: twisting fast-burning hay into sticks that would burn slightly less quickly. Coal was not the only supply that was running short by the new year, though. Food was scarce, as well. Most settlers to De Smet were brand new, as the town itself was not established until the railroad was built in the summer of 1880. New homesteaders had not arrived in time for a full crop in most cases, planting just a few garden vegetables and small fields of crops to store in the pantry and feed the livestock through the winter.

The settlers expected that the train would bring food supplements to help them survive until spring, when they would plant full crops and gardens. When the trains ceased, De Smet and other towns were forced to turn inward to find enough food for their citizens. The manuscript of *The Hard Winter*, the draft version of *The Long Winter*, indicates more of a variety of food on the Ingalls' table than *The Long Winter* implies, with some preserves and stored vegetables breaking up the potato and bread monotony. Even so, a diet consisting largely of a slice of bread for lunch and a potato for a mid-afternoon dinner, with perhaps a dab of preserves or a root vegetable in the mix, is hardly a healthy and complete diet. With such low-calorie consumption, the Ingalls family and others in their situation no doubt suffered from low energy and fatigue, not to mention weakened immune systems and complications of any chronic illnesses (Fig. 3).

In *The Long Winter*, Laura's future husband, Almanzo Wilder, and his friend Cap Garland saved the town of De Smet (and the Ingalls family) from starvation by seeking a farmer who had raised wheat south of town, purchasing his seed wheat to bring back to town for food. Whether this trip occurred is a matter of some controversy among Ingalls and Wilder historians, but there is evidence to support the possibility that it occurred. In Laura's story, the trip occurred on a lone clear February day between blizzards, with a full moon aiding visibility, and with especially cold temperatures. In February 1881, the full moon fell on February 14, in the midst of a particularly active weather period even by Hard Winter standards. All sites in the area received snow on February 14–15. On February 16, the high temperature in Yankton, South Dakota, reached a mere –3 °F, while Fort Randall reached 8 °F. Daily minimum temperatures in the South Dakota sites ranged from –23 °F at Yankton to –34 °F at Fort Bennett. Light snow arrived again on February 17 at Omaha, Yankton, and Minneapolis/St. Paul. Thus, February 16 is a likely candidate for the seed wheat trip, at least meteorologically and astronomically.

In Laura's recollection, the blizzards from around late January through March 1881 ran together into one series of snow storms that assaulted De Smet, letting up for just short breaks before attacking again. Given the frequency of snow events at sites around the region, it is no surprise that her recollection of individual events became blurry. From late January through the end of February, only seven days were snow-free at all sites in the area, indicating a persistent barrage of snow events with little respite. In March, Laura noted that "there might be three days of clear cold, or even four days, before the blizzard struck again." Her recollection that

Fig. 3 Snow blockade along the railroad lines on March 29, 1881, near Winona, Minnesota. Photo courtesy of Chicago and North Western Historical Society Archives, with gratitude to Mr. Joe Piersen

blizzards became less frequent in March is accurate, as breaks between events grew longer and temperatures rose above freezing for increasingly long durations. In fact, historic weather records indicate that March 17–30, 1881, was snow-free across the area, with temperatures above freezing even at the coldest site, Fort Sisseton, for eight consecutive days.

Winter returned for one last gasp between March 31 and April 12, 1881, with four separate snow events that marched across the region. Temperatures dipped below freezing during the events, rising again in between to the 40s and 50s. The last freezing temperature of the season at any site in the region fell on April 16, as winter disappeared just as quickly as it had arrived. Temperatures flipped abruptly to a warm pattern beginning around April 15, and they largely stayed above freezing in the region from that date forward in the spring. While not chronicled in detail in

Laura's book, other than a mention of soggy roads, the abrupt warm-up with such a deep snow pack on the ground contributed to significant and even record-setting flooding. Flooding came in two waves: ice jam flooding initially, as ice broke on the rivers inundated with early melting, followed by extensive river flooding as snow melt swelled rivers from the Dakotas to the Mississippi River mainstem. The floods of the spring of 1881 set records that stood for decades and even into this century, with impacts ranging from the creation of a new oxbow lake near Omaha, Nebraska, to the inundation of numerous towns, including Vermillion, South Dakota.

Though records are scant and likely incomplete, tales of widespread deaths due to blizzard exposure from the Hard Winter are rare. This is in striking contrast to the blizzard of 1888, known as the "Children's Blizzard" because so many schoolchildren died as a result of one storm (Laskin 2004). Speculation could include that no individual storm in 1880–1881 was as intense as that in 1888, or that storms were so frequent during the Hard Winter that fewer people ventured out and thus few people were caught exposed. Whatever the reason, the Hard Winter is not associated with reports of high mortality. It is, however, associated with food deprivation, as the "Starvation Winter" moniker would attest, which certainly influenced the health of those who survived the winter both in the near term and potentially for life.

4 Meteorological Causes and Context of the Hard Winter of 1880–1881

While temperature and the liquid equivalent of precipitation have been recorded in much the same way since the late 1880s, snowfall and snow depth were not routinely measured and reported until around the 1940s in most locations. Thus, describing the severity of the Hard Winter of 1880–1881 scientifically is challenging. While it is relatively straightforward to rank winter seasons by their coldness, it is a little more challenging to try to rank snowfall with such limited snowfall data, and it was unprecedented to rank or classify winters in a way that incorporated both temperatures and snowfall. The Accumulated Winter Season Severity Index (AWSSI, pronounced "aussie;" Mayes Boustead et al. (2015) provided a tool to allow just such a ranking of winter seasons, including the Hard Winter, by their severity. The AWSSI incorporates temperature, snowfall, and snow depth data, assigning a "score" to each day of winter that is summed through the season to create a final tally, and it includes an algorithm to calculate snowfall and snow depth based on temperature and precipitation data to fill in the gaps of historical snow data.

Based on AWSSI rankings, the Hard Winter of 1880–1881 was among the top five most extreme winters at many locations in the region that have reliable and continuous records, such as Minneapolis/St. Paul, Minnesota, Des Moines, Iowa, Omaha, Nebraska, Detroit, Michigan, and Lansing, Michigan. In fact, the Hard

Winter was the most extreme winter since records began in 1872–1873 at Minneapolis/St. Paul.

In addition to allowing the ranking of historical winters like the Hard Winter, the AWSSI allows scientists to place some of the more modern severe winters into context, as well. At Detroit, for example, the winter of 1880–1881 ranks as the second most severe since records began in 1874–1875, nudged out of first place by the winter of 1911–1912 (Mayes Boustead et al. 2015). Of the 10 most extreme winters on record, four occurred during the 19th Century and two more during the late 1970s, both periods well recognized for their cold and snowy winters in the region. The more recent winter of 2013–2014 ranks as the fourth most extreme on record, slightly less extreme than the winter of 1978–1978 and just a bit harder than the winter of 1882–1883. Long-term analysis shows that winters reaching a severity of 1100 or greater in the AWSSI index—the 18 most extreme winters in Detroit—were heavily loaded toward the early period of observations, from the late 19th Century into the early 20th Century. Winters that extreme can and do still occur, as citizens of Detroit in 2013–2014 knew well, but they are less common (see Fig. 4).

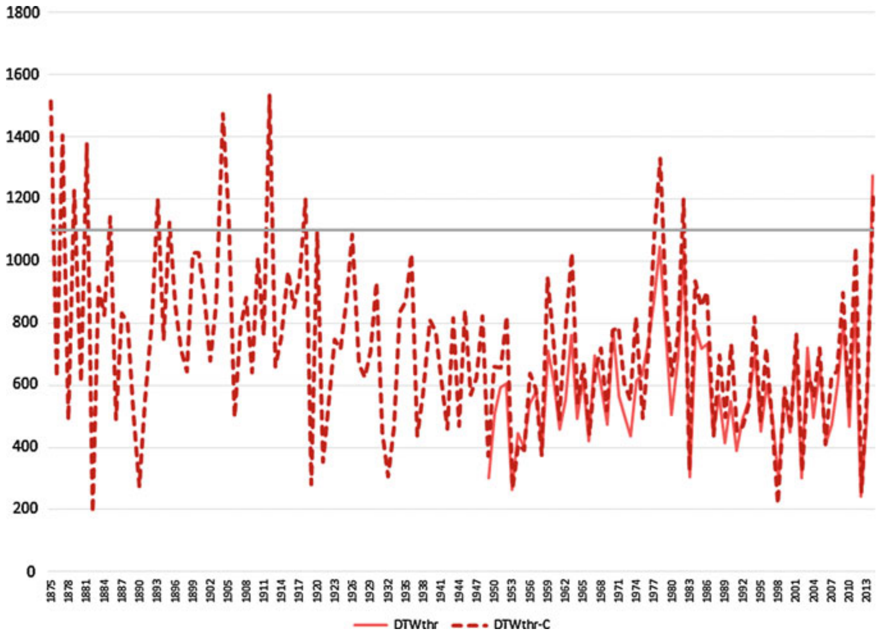

Fig. 4 Accumulated Winter Season Severity Index (AWSSI) historical record for Detroit, Michigan. Note that winters over 1100 in severity, such as the winter of 2013–2014, were more frequent from the 1870s through the 1910s, then rare in the decades since then

4.1 Climate Patterns During the Winter of 1880–1881

The winter of 1880–81 was characterized by two predominant climatological patterns: (1) a very strongly negative North Atlantic Oscillation (NAO), and (2) a weak to moderate El Niño. The North Atlantic Oscillation is defined by a surface air pressure difference between Iceland and the Azores in the North Atlantic Ocean. When that pressure difference is unusually weak (the negative phase), the jet stream tends to be more meandering, allowing north-to-south flow to dump cold air into the eastern and central United States. On the other side of the planet, the El Niño—Southern Oscillation (ENSO) is governed by temperature anomalies in the ocean surface near the equator in the eastern to central Pacific Ocean. When those temperatures are running warmer than usual for a prolonged period—the El Niño phase—they can force the jet stream away from its usual seasonal tracks, sparking temperature and precipitation patterns to change, as well.

On average, the negative phase of the NAO tends to be associated with colder than average temperatures across most of the eastern to central United States, with more negligible effects on precipitation. El Niño, by contrast, tends to be associated with warmer than average temperatures across the northern tier of the U.S., along with a slight tilt toward drier than average conditions in the northern Plains and wetter than average conditions in the southern Plains to Ohio River valley. The opposing tendencies in the northern U.S. can behave like equals in an arm wrestling match when both patterns are weak, sometimes oscillating between tendencies and sometimes with one weakly dominating. But if one pattern is strong and the other is weak, the arm wrestling starts to look like one of the opponents is a weightlifter and the other isn't—the stronger pattern tends to dominate. A recent example of this is in the winter of 2009–2010; the impact of a strongly negative NAO overwhelmed the influence of a moderate El Niño. The result was an NAO-influenced colder-than-normal winter across much of the north central United States, areas that tend to tilt toward warmer-than-average conditions during El Niño winters.

The negative NAO of 1880–1881 was among the strongest since records began in 1864 (Hurrell 2013). The combination of a very strongly negative NAO and an El Niño has occurred in two other winters: 1968–69 and 2009–10. In both of those winters, snowfall in the central United States was above normal and temperatures were near to below normal. The winter of 2009–2010 is particularly close in memory for many in the United States. That winter was marked by several early-season blizzards across the central and eastern United States, a cold snap in January that reached as far south as the Gulf Coast and Florida, and extensive flooding during the spring melt across the central and northern Plains and upper Midwest. The patterns in 1880–1881, however, occurred on a colder background climate state than those in 2009–2010, in the midst of a very cold decade. With the strongly negative NAO, an El Niño, a colder climate, and other factors yet to be accounted, a "perfect storm" of contributing factors pushed the winter of 1880–81 off the charts in severity, ingraining it into the memory of those early settlers and into the storybooks of the beloved Laura Ingalls Wilder. The winter conditions of

1880–1881 clearly impacted the lives and community context for those who experienced them and were significant enough to provide the environmental setting and context for writers in that time and place.

5 Pioneers and Modernistas: Information and Impacts Then and Now

Unlike the fictionalized "Indian warning" tale spun in *The Long Winter*, the De Smet settlers and others in the region had no warning of an impending severe winter or even of any individual blizzard. Their lead time was a matter of minutes to hours, driven by watching for advancing clouds and near-ground white-outs. Even in the modern era, our signals for the potential of a severe winter are often murky and provide little lead time, though we are able to provide accurate forecasts and timely warnings for individual storms. Today, rather than waiting to see the storm, we can view computer models that foretell winter storms days in advance. In that sense, our communities have the advantage of weather predictions that earlier communities lacked. We like to think that we would be more prepared to handle a harsh winter in modern times than our pioneer forerunners, but in truth, modern society remains vulnerable to the impacts of a long, cold, and snowy winter. Winter weather—ranging from cold snaps to snow and ice events—routinely cause injuries and fatalities, in addition to economic loss. Rather than modern society being more or less vulnerable than late 19th Century settlers, we can consider where vulnerability is different.

The moniker "Starvation Winter" was no accident, nor was it an exaggeration. Homesteaders were far more likely than modern citizens to store food to last for long durations. Gardens were picked clean, with fruits and vegetables canned and preserved and root vegetables stored in the cellar. Grains were harvested and stored for both seed and feed, and livestock right on the homestead provided milk and meat. All of these, however, were more indicative of established homesteads with well-broken sod and years of planting and raising livestock. Most of the settlers near De Smet in 1880–1881 were new to the area within just the year, with newly broken sod and small scratched-out gardens. Settlers like the Ingalls family intended to supplement their more meager stores with train-supplied goods brought to local merchants and sold in town. When the trains stopped running, the food supply in small towns like De Smet became exhausted long before winter weather ceased. Settlers pooled their resources to help neighbors stay fed, and they ground their seed wheat into flour or mush to stay alive. Their diets were monotonous and lacked in both vegetables and proteins.

In the modern era, our pantries may have some stored food, with a small array of perishable food in the refrigerator and perhaps a small supply of meat and vegetables stored in the freezer. Rarely do modern citizens, especially in urban and suburban locations, fill the pantry to last through a winter season. We simply do not have the need; grocery stores are abundant, with ever-refreshing stock of perishable and non-perishable fresh and processed foods. Additionally, few urban and suburban dwellers have the space for more than a small garden or perhaps a few chickens, limiting their likelihood to can, preserve, or store food they have grown and raised. Starvation in the United States is a threat limited to poor and underserved populations, concentrated mainly in the most urban and rural of locations and out of sight of the majority of the modern population.

5.1 Vulnerability During Extreme Winter Weather

In a prolonged and severe winter like the Hard Winter, the scattered settlements of the pioneer era were vulnerable to being cut off for extended periods of time. Transportation relied on train, horse or other pack animal, or foot travel, all of which were vulnerable to cutoff during inclement weather. The stoppage of the Chicago and North Western train line during the Hard Winter exemplified the vulnerability of train travel to the elements, as snowplow equipment could not keep up with maintenance. Lines were further blocked or damaged by spring flooding, which was not described in *The Long Winter* but had a significant impact in the region that lingered through the spring. Additionally, human and animal lives were endangered by attempts to travel by foot or pack animal, as the duration of time spent traveling was significantly longer than train travel and left the traveler open to exposure and disorientation while traveling. Pioneer-era settlers were more likely than their modern counterparts to shelter in place during extreme winter weather, relying on their stores of food and fuel to endure prolonged periods of cold and snow.

The flip side of staying sheltered during extreme weather was the threat of isolation. During the Hard Winter, isolation contributed to mental health vulnerability; the downward spiral into depression was captured in *Giants in the Earth: A Saga of the Prairie* (Rolvaag 1927), among other narratives. The isolation of prairie life was difficult enough, and this was even highlighted by Laura herself in the book *These Happy Golden Years* (Wilder 1943), as her host family on her first teaching assignment was led by a woman driven so mad by the isolation that she wielded a knife on her husband in the middle of the night. During the Hard Winter of 1880–1881, the isolation was worsened by the treacherous winter conditions, with impacts ranging from settlers who gave up their homesteads following that winter to those who experienced a form of "madness" from the extreme isolation and ever-present winds.

Transportation in the modern era remains vulnerable in the modern era, perhaps the most vulnerable aspect to extreme winter weather in our society. Modern society emphasizes being unstoppably mobile, and despite cautions from weather and transportation officials, citizens frequently venture into the elements even in the worst of conditions. Vulnerability during travel ranges from running off a rural road in low-visibility conditions to multi-vehicle pile-ups on interstates, all of which can lead to casualties due to trauma caused by incidents or exposure afterwards. Urban and suburban roads are rarely blocked for more than a day or two, but rural roads can remain blocked by snow for several days or more, with isolation still a risk in rural communities.

Closely related to transportation is the threat of exposure to harsh winter weather conditions, due to either being outside in the elements or in an underheated home during cold weather. Pioneer settlers were susceptible to exposure not only during attempts to travel, but also during everyday household chores such as tending to livestock in the barn or gathering water or fuel. White-out conditions made it possible to become disoriented even in the short distance from barn to home, let alone between school or church and home. The infamous Children's Blizzard of 1888 (Laskin 2004) claimed hundreds of victims, mostly children, who were either caught outside during the multi-day blizzard or trapped in schoolhouses without enough fuel.

Citizens today are threatened with exposure largely by leaving their homes to travel. Unlike settlers' homes, which were stocked with fuel to last longer periods if not a full season, modern homes mostly rely on either electricity or gas brought into the home in a network of pipes and wires. A small subset of homes has a back-up heat source such as a wood-burning stove, but these are the exception. In a failure of the power or gas grid, many citizens rely on gas-powered generators or kerosene heaters to warm their homes. The risk of exposure in one's own home has been exchanged for a risk of carbon monoxide poisoning due to improper ventilation while using back-up heat sources. Exposure risk during travel remains at least as widespread of a hazard for modern citizens as it was for settlers, with modern society more reluctant to stay home during extreme winter weather.

With technology such as phones and the internet, modern citizens are rarely truly cut off even when they are stranded at home during extreme winter weather. Even the most rural citizens can remain engaged with society, community, and family from the confines of their homes. Season-long isolation was a greater hazard, by far, in the pioneer era, especially for homesteading settlers who lived too far from the nearest towns to travel safely in inclement weather. Today, schools may be shut down for a day or two, maybe even up to a week during the most extreme winter weather; school buses might skip a few routine stops but generally run as long as school is open. By contrast, schools on the frontier, often a center of community interaction, may have been shut weeks at a time or longer, depending on the travel distances required by the students (usually on foot). If school was open, students still may have been withheld from attending due to the concerns of their parents for safe travel.

6 Narratives and Stories as a Communication Tool

Scientists increasingly are asked to not only perform basic research, but also communicate that research effectively to a range of potential audiences, rather than simply among other subject matter experts. It is incumbent upon the science community to communicate more effectively to a wide range of audiences. Public trust in scientists is fragile and can depend on the interaction between the framing of information and whether the information is being processed by recipients in a heuristic, faster-encoding but lower-elaboration processing pathway or a systematic, high-elaboration pathway (Goodwin and Dahlstrom 2011). Somerville and Hassol (2011) cite specific means for more effective science communication, including using clearer language and inverting the typical pyramid of science communication by starting with a focus on the results and meaning before broadening the message with supporting details about methodology and background information.

Obstacles to communicating climate and weather concepts abound, especially when communicating about climate. Low science literacy may make such communication challenging, though it is just one potential obstacle to understanding climate change and may not be the primary obstacle to addressing it. Scientific literacy among American adults is similar to their European counterparts, answering roughly two-thirds of basic factual scientific knowledge questions correctly (National Science Board 2014). That said, only 74 % of Americans in the National Science Board study correctly answered that the Earth revolves around the Sun. When a quarter of the American population cannot correctly recall a scientific fact taught in elementary science, it is likely that the population will struggle to grasp more abstract scientific concepts.

Audience-tailored topics, or frames, can convey weather and climate information and potentially address some of these obstacles to understanding. Such a vehicle allows non-meteorologists and non-climatologists to gain understanding about weather and climate as it applies to the topic. The rich stories woven by Laura Ingalls Wilder are an ideal frame for communicating weather and climate concepts. The *Little House* books are engrained in American culture, and particularly the Plains and Midwest regions featured in the books; adults and children alike recognize and respond to the stories. The books, which are historical fiction based strongly on the life of the author, provide a common ground from which lessons in weather and climate can be drawn. Weather events and climate extremes are featured prominently throughout the series, though nowhere as strongly as in *The Long Winter*. Other extreme weather and climate events throughout the books include tornadoes, prolonged drought, grasshopper plagues, cold snaps, and blizzard events outside of the Hard Winter. The books thus provide a vehicle for discussing numerous weather and climate events to which a population could be vulnerable.

A narrative can be constructed, through the characters, plots, and settings of the *Little House* series, which enables the communication of weather and climate concepts that range from interesting tidbits, such as documenting correspondence between Wilder's description of individual storms and meteorological records of the events, to complicated concepts, such as localizing impacts of climate change. The concept of bridging between science and the community would benefit from a methodology, an example, and an investigation of how to apply the concept in practice. Thus, there is a need to see the process through from beginning, as a scientific investigation, to end, as a tool for education and communication. The narrative constructed about the weather and climate events in the *Little House* books will be referred to as the "Wilder Weather narrative" through the rest of this chapter.

It is no mystery that a well-crafted story will capture the attention of its audience more than a list of facts. Jones and McBeth (2010) described the relationship between narrative communication and its impact on the attitudes of its audience. A narrative, as described by Jones and McBeth (2010), is a story with a sequence of events, including the elements of setting or context, plot, characters (including both a hero and a villain), and a moral of the story. While it has been noted in many studies that people are inclined to respond to and be persuaded by information that most closely matches their own expectations, it is possible to move people beyond those expectations.

A story that exhibits congruence, or similarity to the life experiences of the listener, is more likely to be received. A break with expectations about the way things should be, referred to as a "breach," is hypothesized to contribute positively to persuading the listener. Likewise, the ability of the storyteller to transport listeners is key to persuasion; the narrative should draw the audience into the narrative so that they become involved with the protagonists, allowing the audience members to "get lost" in the story and return changed by it. Finally, listeners are more likely to be persuaded by a story if they trust the storyteller or source. In particular, Jones notes that the depiction of the hero is critical (Pitzer 2010); if listeners like and relate to the hero, then they are more willing to believe other facets of the story. Jones noted that scientists are reluctant to accept storytelling as a valid means of communicating information (Vergano 2010), specifically citing an instance in which he presented the research to National Weather Service meteorologists, who resisted the idea of telling a story over listing facts. Meteorologists tend to be conservative and reluctant to stray outside their science, besides being among the most reluctant of physical scientists to view climate change as a concern (Doran and Zimmerman 2009). Nonetheless, narratives can be an effective tool to communicate to a non-scientist or non-specialist audience when applied for reasons that include increased comprehension and persuasion to reduce controversy, and with high levels of accuracy (Dahlstrom and Ho 2012).

6.1 The Wilder Weather Narrative

The *Little House* books, and particularly *The Long Winter*, provide a strong narrative foundation to which a storyteller can connect weather and climate information. They include a protagonist or hero, Laura Ingalls Wilder, who is well known and even beloved by multiple audiences. The stories are familiar to their readers, and adding information about weather and climate beyond what is provided in the books or that corrects information in the books allows a credible breach from a story that otherwise meets expectations. Thus, the only element remaining is credibility in the storyteller, an element that can be achieved via affiliation, academic credibility, shared interest in the underlying narrative, and exposure to and comfort with audiences. Collectively, this Wilder Weather narrative can be shaped to the audience and time allotted, expanded as needed, and delivered via multiple media.

From the scientific basis, the goal of the Wilder Weather narrative was to raise weather and climate literacy by focusing on three broad takeaway messages:

1. Know your local climatology; understand and prepare for the range of potential extremes.
2. Climate has changed from the late 19th Century to the present and will continue to change in the future; human activities have caused most of the observed and predicted changes.
3. Know your sources of weather and climate information, and ask questions of meteorologists and climatologists to better understand weather and climate concepts, both in the Laura Ingalls Wilder books and in other experiences.

These messages were conveyed using details from the stories, as well as supporting information from weather and climate research to provide scientific context. For example, the concepts of the El Niño—Southern Oscillation (ENSO) and the NAO were introduced as contributing factors to the severity of the Hard Winter of 1880–1881 (Boustead 2014).

The *Little House* books provide the structure needed to frame the message in a storytelling context. Wilder herself serves as the hero of the story, and weather and climate events are personified as villains. The setting varies by book; in the case of *The Long Winter*, the setting is at the homestead near and in the town of De Smet, Dakota Territory (present-day South Dakota). The conflict or problem in the narrative is that Wilder and her family did not have complete information; resolution is found by determining what we know now about weather and climate events that impacted Wilder and her family. Variants of the Wilder Weather narrative include allowing the storyteller to serve as a detective to uncover the full story behind the clues left by Wilder, establishing Wilder as an early weather and climate observer, comparing awareness and preparedness tactics in Wilder's time to modern efforts, and describing Wilder as an example of living an environmentally-friendly lifestyle.

6.2 Testing the Wilder Weather Narrative

The Wilder Weather narrative was presented to a number of audiences, ranging from Laura Ingalls Wilder fans to meteorologists and climatologists, for the purposes of outreach, education, and engagement regarding weather and climate events in the *Little House* books. A survey evaluation was conducted with three specific audiences, specifically for the purpose of gathering information about perceptions of climate information before and after the presentation. Surveying these audiences with varied backgrounds provided an overarching view of the level of interest in framing weather and climate information with a Laura Ingalls Wilder narrative.

The first audience consisted of fans and scholars of Laura Ingalls Wilder at the LauraPalooza 2012 conference on 12 July 2012 in Mankato, Minnesota. Approximately 75 audience members were present, many of whom had engaged previously with the storyteller at LauraPalooza 2010 via social media and online discussion, by reading *The Homesteader* newsletter features about the work, and/or as an audience of an internet radio show, Trundlebed Tales. Thus, the majority of LauraPalooza attendees already were exposed to and familiar with the Wilder Weather narrative as well as to the storyteller. The LauraPalooza 2012 audience members received updated and more in-depth information that built on previous interactions. The results of these surveys were compared to a survey of a more general audience—rural Nebraskans—who had not been exposed to the Wilder Weather narrative.

For both the second and third audiences, the interaction was the first time that members had heard any part of the Wilder Weather narrative. The second audience was a subset of the National Association of Interpreters Region V meeting in Aurora, Nebraska, in April 2013. The audience of approximately 15 members included national, state, and local park interpreters, extension specialists, master naturalists, and high school to college students. The third audience, students of a graduate-level Climate and Society course in the School of Natural Resources at University of Nebraska during Spring 2013, included a blend of graduate and advanced undergraduate students with a range of climate-related background and experience. In both cases, this was the first engagement of the storyteller with the audiences, and the audiences had a range of exposure to the *Little House* books from no previous experience to high familiarity with the books.

Survey results indicated that audience members who were exposed to the Wilder Weather narrative exhibited high trust in the National Oceanic and Atmospheric Administration (NOAA), other federal agencies, and scientists in general regarding climate information. This high level of trust provides a foundation of trust from audience members in a storyteller who is a scientist representing NOAA or another science-based federal agency. Audience members who completed the survey more correctly identified that a high percentage of scientists agree with the statement that climate change has human causes. Additionally, the narrative audiences perceived significantly greater health, economic, and environmental risks due to climate change than the more general population used for comparison. When asked a series of questions about how they felt during the Wilder Weather presentation given to them, the audiences exhibited particularly high levels of inspiration, focus, careful consideration of all options, thorough consideration of issues, creativity, understanding perspectives different from one's own, and relating the topic to ones already known. The audience groups also exhibited particularly low levels of desire to do something else, boredom, anger, irritation, disinterest, and frustration.

In addition to the quantifiable survey results, more qualitative measures of interest and engagement have been noted through the narrative development and engagement process. The narrative was picked up in 2011 by national (Vergano 2011; Associated Press 2011) and local (Abourezk 2011) media sources. Interest continued as new stories were written (Koerth-Baker 2012) and interviews were conducted (Stateside Staff 2014), particularly during the winter of 2013–2014 that was perceived as another "hard" winter. The author also maintains a blog, *Wilder Weather* (http://www.bousteadhill.net/wilder_weather/), with intermittent postings of articles that either loosely or closely tie weather and climate to Laura Ingalls Wilder, as well as a Facebook presence, "Wilder Weather," with 449 followers as of 12 September 2015, to engage interest and to add visibility to blog articles. While direct measurements of readership of all articles and blog entries is not possible, the continuation of interest in new articles and new angles of press coverage indicates public interest in the narrative.

Does this mean that the Wilder Weather narrative is working? The results at least imply that audiences are attentive and engaged when exposed to the Wilder Weather narrative, especially an audience that has a strong interest in the subject of the narrative as was the case with the LP audience. The level of predisposition of the narrative audiences to be more likely to accept climate change and perceive risks is unknown, but the strong skew toward higher perceived risk and higher perceived consensus among scientists is notable. The audiences exhibited high trust in scientists, and particularly in NOAA, but whether the high level of trust is a result of exposure to a storyteller with a NOAA affiliation is unknown.

The Wilder Weather narrative demonstrates the notion that a scientifically technical research project can be bridged to a general audience, given an effective narrative framework. Such narratives can increase the scientific literacy of general and targeted audiences by raising scientific awareness when enveloped in the frame of a comfortable and effective narrative. Results in this study indicate that the narrative selected could be expanded to other potential audiences, including teachers and students who are reading *Little House* books in the classroom, adults who read the books when they were children, and historians whose interest is sparked by the documentation of past events. Such interactions can help promote awareness of weather and climate topics ranging from hazardous weather preparedness and safety to climate variability and change risk perception that may lead to steps toward adaptation and mitigation.

7 Moral of the Story

Extreme winters, whether historical ones like the Hard Winter of 1880–1881 or more modern ones like those in 2013–2014 and 2014–2015, create a range of impacts on health, safety, and economy. Those impacts may have changed somewhat from the pioneer era to the modern era, but modern technology and understanding of weather and climate does not eliminate the risks faced by citizens during extreme winter conditions. The Accumulated Winter Season Severity Index (AWSSI) does provide the ability to score a winter's severity, allowing impacts to be scaled to that score and providing a means to compare winters through the history of a site as well as among sites. Meteorological analysis also allows the ability to link teleconnection patterns like ENSO and NAO to winter severity, providing clues that might give advance notice to an impending severe winter and allow citizens to prepare. Even so, knowledge that the upcoming winter may be severe still does not alleviate all impacts to society, whether the warning comes from muskrats or meteorologists.

8 Best Practices: Using Narratives for Weather and Climate Engagement

Based on the available research, suggestions for successful engagement on weather and climate topics using narratives with an audience include:

- Develop a narrative based on a recognized story or story archetype.

One of the reasons that the Wilder Weather narrative resonated with audiences is that the author built the narrative around family, as well as Midwestern and Great Plains prairie life, which are integral to the cultural fabric of the United States. An archetype, or a familiar character, theme, setting, symbol, or situation that represents universal patterns of human nature. Common archetypes include "the hero," "the traveler," and the battle of man against nature. Laura Ingalls Wilder is recognized by her own name as well as by the *Little House* name, and her stories include such archetypes. Whether they read the *Little House* book series or watched the related television series, the name and the stories are familiar and comfortable. The narrative serves as a communication bridge from the scientific facts and evidence to be presented to multiple audiences. Similar narratives could be used to convey how past communities have experienced and responded to instances of extreme weather, providing a useful education tool for children and adults alike. By connecting to a known story, or a comfortable archetype, a scientist can reach a more personal connection with an audience.

- Maintain author credibility, including scientific knowledge and honest interest in the narrative topic.

A narrative is most effective when the audience trusts the storyteller, in addition to relating to the story's main character. For this reason, it is important for the storyteller—the scientist—to be a trusted figure. The trust can originate with credentials, such as affiliation with a trusted organization, but audience trust is often built over time and with continued exposure. A storyteller can earn the trust of an audience by exuding genuine interest in the narrative topic, allowing the engagement to become a conversation between peers.

- Weave take-home points of scientific interest into the narrative.

The Wilder Weather narrative pulls weather- and climate-related stories from the *Little House* books, then pulls weather and climate lessons that are relevant to those stories. The stories and lessons are woven together, blending Laura's observations with take-home messages that range from winter weather safety to climate change. By attaching take-home messages to a familiar story, the potential for both increased audience interest and retention increases.

In conclusion, this chapter has highlighted the central role that narrative can play in conveying information about extreme weather. Narrative is a tool that, if used effectively, can elicit powerful human response. It has the capability to educate and prepare populations for adapting to extreme weather conditions in a variety of environmental settings.

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The Air We Breathe: How Extreme Weather Conditions Harm Us

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Abstract This chapter investigates the connection between extreme weather and respiratory health in and around Fresno California, home to over 1 million people. In this chapter, we use Fresno as an important example of a location in the U.S. where its residents are at high risk for short and long term health consequences of extreme conditions of weather. However, there are many other examples of short term extreme weather conditions (forest fires in Yarnell, Arizona) and long term extreme weather conditions (Mediterranean Region) (WHO 2015). Fresno serves as an excellent example since there are combinations of weather, topography, and geography that can be helpful to our understanding of how air pollution affects health. Poor air quality shortens life expectancy, lowers quality of life and, we assert, affects the health and wellbeing of generations to come. Today we see the consequences of air pollution in incidence and severity of Chronic Obstructive Pulmonary Disease (COPD), asthma, cardio-vascular illness and even valley fever, the consequence of inhaling a fungal spore found in the local soils and carried with the wind and mineral dusts of neighboring deserts. Because extremes of temperature, aridity and wind are components of climate and determinants of air quality and respiratory health, strategic planning for public health should monitor and anticipate as best as possible climate variability and change. There is a need to continue to educate ourselves on how climate, extreme weather, and health are linked.

Keywords Particulates · Particulate matter · PM_{10} · $PM_{2.5}$ · Airborne dust · Ozone · Health · Valley fever · Asthma · Weather · Climate · Topography · Geography

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1 The Connection Between Extreme Weather and Health

A typical story, repeated often in slightly different circumstances, is told here to illustrate a common health problem throughout California's central valley. Late in the afternoon of Tuesday, October 14th, 2014, a dust storm envelops a section of Interstate 5 (Herr 2015). Anna is driving on that highway and the visibility is poor, causing her frustration. She is on her way to her toddler's pediatrician. Her daughter, Emily, has been wheezing progressively for several hours and acting out-of-sorts. Her twin, Gianna, typically the healthier of the two, is not wheezing, but her nose has been running and she's frequently coughing. As Anna glances back to check on them, she becomes terrified.

Emily is sleeping quietly, but Gianna appears in distress. Her lips are tinged blue and she is listless. Anna frantically continues to drive with the dust swirling around her, now headed for the emergency room. After a night at the hospital, Anna returns home with her twins. Gianna has been put on asthma medicines and both toddlers are to remain indoors until the air quality improves.

Where is the air so polluted that people cannot spend time outdoors engaged in normal activities? Where is it that hundreds die a premature death due to the effects of poor air quality? Fresno, California is an area where an unusual combination of weather, topography and geography culminate in health challenges to the quality of the air they breathe.

Fresno, California has a population of 1.1 million and growing (United States Census Bureau 2015). Notably, it is the fifth largest city in California. However, it is the largest city inland, because the agricultural industry and affordable housing drew people from the coast to move inland. The population of Fresno had increased by 16 % over the 2000–2010 decade, making it one of the fastest growing areas in California.

With the increase in population, the demographics of Fresno are also changing (Table 1). The number of Caucasians dropped by 4 % from 2003 to 2013 in Fresno

Table 1 Fresno demographics

	Fresno county	California
Population, 2013 estimate	956,102	38,431,393
Population, percent change—April 1, 2010–July 1, 2013	2.8 %	3.2 %
Persons under 5 years, percent, 2013	8.40 %	6.5 %
Persons under 18 years, percent, 2013	29.1 %	23.9 %
Persons >=65 years, percent, 2013	10.9 %	12.5 %
Hispanic or Latino, percent, 2013 (b)	51.6 %	38.4 %
White alone, not Hispanic or Latino, 2013	31.4 %	39.0 %
Foreign born persons, 2009–2013	21.9 %	27.0 %
Language not English spoken at home, 2009–2013	43.7 %	43.7 %
Persons below poverty, 2009–2013	26.0 %	15.9 %

Source United States Census Bureau (2015)

County and the majority of the population is now Hispanic. Both economic and language barriers are commonplace. According to the 2013 US census, 44 % speak a language other than English at home and 26 % live below poverty level. Less than 20 % of adults have a college education (United States Census Bureau 2015).

Fresno is centrally located in California's San Joaquin Valley. The San Joaquin Air Basin is approximately 250 miles long and shaped like a narrow sink. It is surrounded on three sides by mountains and sits at sea level. This topography and the Valley's 3 million residents and 2 million vehicles play a role in air quality, especially when accompanied by stable weather extremes. The situation is a reminder of Donora, Pennsylvania, in 1948, a year that drew nationwide attention to severe circumstances when topography, industry and severe, stable weather coincide (Davis 2002).

An air inversion had persisted over Donora, Pennsylvania from October 26th to 31st 1948, trapping industrial pollutants inside the surrounding mountain topography. People became sick and some died. This episode in Donora contributed in the first steps that led to creating the U.S. Environmental Protection Agency in 1970 (Snyder 1994). As we will explore in this chapter, stagnant air in combination with pollution can have health consequences for people. The climate of the San Joaquin valley has mild, moist winters and hot, dry summers. Precipitation typically occurs in the winter, not summer. Due to valley topography the air is often stagnant and sometimes highly polluted in spite of California's many steps to control health-threatening auto and industrial emissions.

1.1 Airborne Particulates

When extreme weather hits and winds increase, severe dust storms in the Fresno area are likely. The storms are worse if there has been drought and/or poor farming and grazing practices because more dust and the components of loose soil become exposed to the wind. For example, in 1977 a major storm, dubbed the Southern San Joaquin Valley Dust Storm, occurred. During that storm, winds reached 192 mph and blew over 25 million tons of soil from local grazing lands. The drifting sand closed highways and changed the landscape. The blowing dust "dimmed the sun as far north as Reno, NV" which was three hundred miles away (Western Regional Center 2015). Another notable dust storm, named the 1991 San Francisco Dust Storm, arose on Nov 30, 1991. Hundreds of motorists were trapped on Interstate 5 in the San Joaquin Valley, leaving six people dead and more than 50 injured in a series of chain-reaction accidents—all due to the decreased visibility as a result of the extreme weather.

Mineral dust itself is not the only problem when such storms arise. One very large storm in California's Central Valley occurred in December of 1977, triggering an outbreak of Valley Fever (Valley Fever is named after the San Joaquin Valley). Valley Fever is caused by a fungus, *Coccidioides immitis* and *Coccidioides posadasii* that grow in the arid soils of the U.S. Southwest (Brown 2013). The tiny spores are 2–5 μm in size and behave similar to dust in the wind. The storm blew dust and fungal spores as far as Sacramento and the San Francisco Bay (Pappagianis and Einstein 1978). When the spores are inhaled they can cause disease. Symptoms can range from nonexistent to fatal. *C. immitis* appears largely in California, while *C. posadasii* dominates in Arizona and spreads southeastward into parts of Mexico, and Central and South America. And, while cases of Valley Fever have occurred in most counties in California, over 75 % of the cases have occurred in the San Joaquin Valley, adding another dimension to the effects of extreme weather in the region (Brown 2013).

Dust storms and *C. immitis* infections are merely one reason why Fresno's air quality can be so poor: ambient air pollution also plays a role. Fresno traditionally records one of the highest levels of particulate matter and ozone pollution in the U. S. According to the American Lung Association's State of the Air report (2014), Fresno ranks number 4 in the nation for air pollution. Additionally, Fresno is a geographic place that experiences more than one type of extreme weather! In summer, the combination of increased solar radiation, high temperatures, and typically calm winds increases ozone production and highly polluted air for extended periods of time. Dangerous health conditions can result.

Many types of pollution contribute to this poor air quality. Fresno metropolitan area's population increased 16 % between 2000 and 2010, causing the city to expand outward (United States Census Bureau 2015). It has been difficult to keep the public transportation up with the expansion. As a result, more and more vehicles are on the road commuting, increasing traffic and automobile pollutants. Moreover, the state's two main north-south highway corridors, Interstates 5 and 99, are the routes for most long-distance tractor trailers, increasing the exposure to traffic pollutants even more.

Pollution from vehicles is often referred to as TRAP (Traffic-Related Air Pollution). TRAP consists of 4 different types of pollutants. They are a combination of Diesel Particulate Matter (PM), Carbon Monoxide (CO), Volatile Organic Compounds (VOCs) and Nitrogen Oxides (NO_x). Each contriute to various environmental problems. All are exacerbated in severe weather heat waves and long periods of stagnant air under persistent atmospheric temperature inversions.

Dust particulate matter may be either directly emitted (primary PM), or formed in the atmosphere by the reaction of certain gaseous emissions (secondary PM). The particulate matter is classified according to diameter. The smaller the particle, the greater the potential damage to health (Fig. 1). For example, PM_{10} denotes a classification of particles up to and including 10 μm in diameter (one-seventh the width of a human hair). They can enter the lung and cause damage. $PM_{2.5}$ are particles with a diameter of 2.5 μm and smaller, and consist of compounds such as ammonia, carbon, nitrates and sulfate, and very fine minerals and metals. They are small enough to not only enter deep into the lung, but pass into the bloodstream causing or exacerbating diseases such as emphysema and cancer. Wood burning stoves or fireplaces are a significant contributor to PM, producing brown carbon or wood smoke. The San Joaquin Valley is affected by two different PM

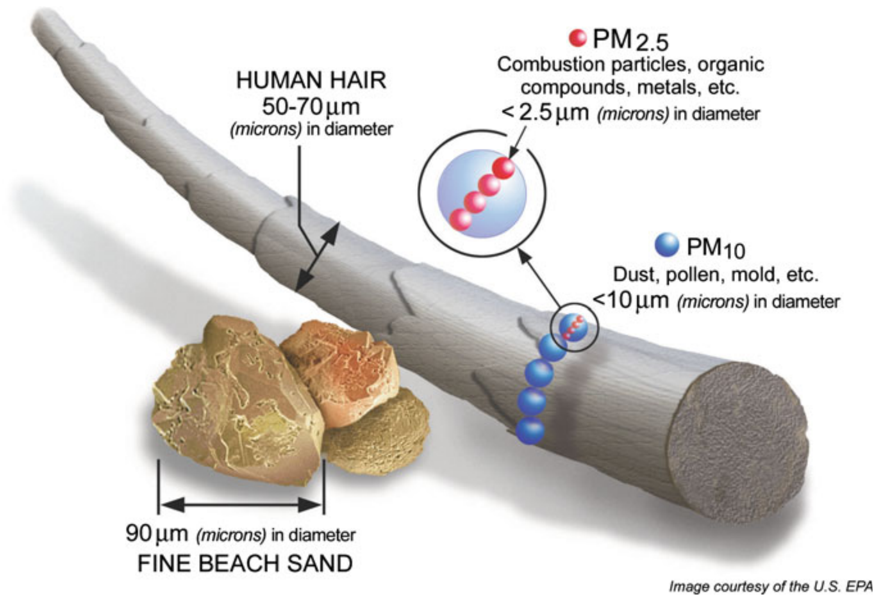

Fig. 1 Particulate matter (PM) is classified according to particle diameter, commonly in categories of PM2.5 (particles 2.5 μm and smaller) and PM10 (particles 10.0 μm and smaller). Dust storm modeling assumes aerodynamic, round particles such as those depicted. Figure courtesy of US EPA

problems—largely secondary PM in the winter and largely primary PM in the fall, making the challenge to control PM levels more difficult.

Lastly, recent research has turned attention to ultrafine particles (UFPs), particulate matter less than 100 nm in diameter. Unlike the larger PM classifications, the EPA does not regulate ultrafine particles. This is due in part because these very fine particles are more difficult to measure and monitor. Yet, UFPs are thought to cause even more harm because their small size allows them to circulate more freely through the body. These particles then may cause inflammation, igniting a cycle of various health problems, including alveolar inflammation and exacerbations of cardiopulmonary diseases (Penttinen 2001).

1.2 *Role of Gaseous Pollutants*

Ozone (O_3), a byproduct of TRAP, is a secondary air pollutant. It is formed when the TRAP components of volatile organic compounds (VOCs) and nitrogen oxides (NO_2, NO_x) react in sunlight. The photochemical smog and ozone gas are a risk to human health, especially when winds are light or calm. Unfortunately, 97 % of summer days in Fresno are sunny and hot, providing ideal conditions for ozone formation (Steiner 2010).

Fresno also contends with other sources of pollution, such as farmland byproducts. The primary industry in Fresno County is agriculture. It totaled $5.3 billion in 2007, making it the number one agricultural county in the nation. There are millions of acres of plowed farmland and 1.6 million dairy cows in the Central Valley.

Dairy cows are a significant source of pollution (Koneswaran and Nierenberg 2008). Cows are fed poor quality feed that cannot be fully digested, causing an increase in methane via flatulence (McGinn and Beauchemin 2005). In 2004, the EPA estimated that 20 % of all man-made methane production resulted from livestock digestion, primarily from cows (Grace Communications Foundation 2015). The manure also produces ammonia (NH3), adding to the pollution in the air.

Geographical Concerns

However, it is not just the air pollution generated in the Central Valley itself that increases pollution levels. Geography and topography make an even greater challenge for air quality: mountains on three sides of the San Joaquin Valley open north towards San Francisco and Sacramento. This situation causes two more problems. First, weather patterns often cause air to flow south, moving pollution from northern areas and depositing it in the Central Valley. (In comparison, often-strong winds in the San Francisco Bay area act to disperse their pollution, improving air quality as a result.) “Foreign,” inherited pollutants from the Bay and Sacramento account for 27 % of emissions in northern San Joaquin Valley versus 11 % in the central region containing Fresno (San Joaquin Valley Air Pollution Control District 2015). Second, the unchangeable topography makes Fresno an extreme weather “pressure cooker.” Typically, without wind and rain the polluted air sits trapped by the mountains on three sides with an accompanying lid of smog. As a result, the inhabitants of Fresno are exposed to pollution for long periods of time, while temperatures rise during hot summers and ozone formation continues.

Poor air quality in itself, however, may not be the ultimate concern for the people of Fresno. The health consequences of air pollution has become a growing problem. It is estimated that over 800 premature deaths are related to air pollution in Fresno each year (Grossi 2014). Some populations are more susceptible to the polluted air than others (Table 2). According to Praveen Buddiga, a Fresno allergist, “The very old and very young are more susceptible and react to the air pollution faster” (Grossi 2014). And, because asthma control requires routine medical care, the indigent, uninsured and underserved are more at risk for uncontrolled asthma. But, the healthy population is at risk too. “It (the Valley) has all the particulate matters, all the dust, all the pollens, so it goes into the respiratory tract of anyone,” said Dr. A.M. Aminian of the Allergy Institute (Herr 2014).

According to the American Lung Association (2014), Fresno has a rate of asthma three times the national average. Asthma affects 9.3 % of children and 8 % of adults in the United States. The healthcare impact is enormous, with 14.2 million office visits, 1.3 million hospital outpatient departments visits, 1.8 million Emergency Room (ER) visits and 439,000 in-patient stays (average stay = 3.6 days) in the U.S. alone. Unfortunately, there were also 3630 deaths due to asthma in the

Table 2 Fresno asthma demographics

Groups at risk	
Total population	704,379
Pediatric asthma	17,604
Adult asthma	44,161
COPD	23,160
Cardiovascular disease	33,502
Diabetes	50,634
Children under 18	198,720
Adults 65 and over	80,542
Poverty estimate	137,451

Source American Lung Association (2015)

US in 2013 (National Center for Health Statistics 2014). Estimates of the direct medical costs of asthma range from \$3.6 billion to \$30.8 billion, and indirect costs range from \$673 million to \$8.2 billion (Rappaport and Bonthapally 2012).

2 Air Pollution and Respiratory Disease

Air pollution has been suspected in a variety of disease processes even prior to the 1950s (Mustafic et al. 2012). Interest has increased in studying the relationship between air pollution and the respiratory system. For example, University of Southern California researchers show that lung development of children is reduced when they are exposed to air pollution (Gauderman et al. 2004). Air pollution may increase the risk for the development of asthma, and has been shown repeatedly to be a major cause of asthma attacks (Jerrett et al. 2008).

Asthma is a chronic inflammatory disorder characterized by airway narrowing, mucus production and airway hyperactivity. All of these factors result in shortness of breath, wheezing and chest tightness. Asthma prevention is essential in preventing attacks, requiring close medical supervision and follow-up. Prevention includes controlling symptoms through asthma medicines and, importantly, symptom reduction by avoiding triggers. Airborne particulates are one of these triggers. Given that $PM_{2.5}$ is small enough to enter around windows and under doors, poor air quality is an indoor issue as well. Moreover, in poor and underserved areas, where access to medical care is not ideal, the health consequences of asthma may have an even greater impact.

However, asthma is not the only lung disease linked to air pollution. We noted earlier that Valley Fever is another air quality related problem in Fresno. The *C. immitis* spores or spore fragments can be inhaled and infect the lungs, typically causing flu-like symptoms or pneumonia (Galgiani 2012). Most cases resolve on their own, but the spores can spread to other parts of the body, such as the skin, joints and brain. Without treatment, if Valley Fever spreads beyond the lungs, it is usually fatal (Laniado-Laborin 2007; Huang et al. 2012). People with weakened immune systems (elderly, chemotherapy patients, expectant mothers in the second half of pregnancy, HIV patients) are at greater risk of Valley Fever.

Chronic obstructive lung disease (COPD), also a disease that makes it difficult to breath, can be exacerbated or triggered by ambient pollution, leading to increased office visits, emergency care, and even death (Ko 2012). Damage from air pollution does not necessarily stop at the lungs. There are other, greater health effects. $PM_{2.5}$ and smaller ultrafine particles can pass through the lungs, enter the bloodstream and go to the heart, kidneys and other organs causing inflammation. The cardiovascular system is one organ-system that is significantly affected by pollution via multiple mechanisms. Studies have confirmed that pollution increases heart attacks (Sullivan et al. 2005; D'Ippoliti et al. 2003). Moreover, a recent study found adverse effects even to healthy women who were exposed to traffic pollutants during exercise, where acute changes occurred in blood pressure, autonomic and micro-vascular function (Weichenthal et al. 2014). Studies of asthmatics during exercise found similar results (McConnell et al. 2002).

The list of autoimmune diseases affected by pollution is growing. Research has shown that diabetes (Engström et al. 2003), certain thyroid conditions (Belin et al. 2004), multiple sclerosis (Oikonen et al. 2003), and lupus (Dahlgren et al. 2007) are all affected by air pollution.

In addition to asthma, young children's health is affected in other significant ways. There is an extensive review of pollution and children's health by Schwartz (2004). For example, it is already well established that second-hand smoke is a risk factor for otitis media (ear infections) in children, along with exposure to air pollutants from other sources (Brauer et al. 2006). Given that ear infections are the number one reason for doctor's visits in childhood (Freid et al. 1998) and the main reason children have surgery or take antibiotics in developed countries (Rovers et al. 2004), the impact on quality of life and associated healthcare costs of air pollution are significant.

Moreover, air pollution can be detrimental to the unborn. Research shows conclusively that smoking exposure can have affects in utero (Li et al. 2000). Investigators have since looked at the impact of pollutants on the birth outcomes with: miscarriage (Pereira et al. 1998); pre-term delivery (Padula et al. 2014; Xu et al. 1995; Ritz et al. 2000; Lin et al. 2001); low birth rate (Padula et al. 2012; Ritz and Yu 1999; Dejmek et al. 1999; Bobak and Leon 1999; Ha et al. 2001; Bobak et al. 2001); and birth defects (Padula et al. 2013a, b, 2014).

What do all of the above health problems that are exacerbated or caused by air pollution have in common? It is the immune system. Basic immune findings are described in the next section to gain both a greater appreciation for the sensitivity of health to extreme environmental conditions and an understanding that these effects will not only affect the current generation, but future generations as well.

3 Air Quality and the Immune System

The immune system is a complexity of various cell types, tissues and messengers that are constantly in flux. White blood cells are a group of cell types that fight infection in the body and protect against foreign invaders. There are various types, each with a different role in keeping the body healthy. We will specifically focus on one of these cell types, the T cells. Research has shown that one type of T cell, regulatory T cells (Tregs), are sensitive to environmental pollutants. Tregs can be characterized as the 'peacekeepers' of the body. They are essential in keeping the body in check so that it regulates inflammation correctly and maintains a healthy immune system.

Several years ago, our team discovered something striking about the blood of some asthmatic patients. First, we noticed that the number of Tregs were lower than normal. Then, we realized that many of these asthmatic children were living in the same region… Fresno, CA.

Given that the Fresno area is well known for high levels of air pollution, we began comparing Tregs levels of children living in Fresno versus Palo Alto, CA, which is a relatively low pollution area. We focused on the levels of one particular type of pollutant, polycyclic aromatic hydrocarbons (PAH), since levels are elevated in Fresno and PAH has been studied in Fresno (Noth et al. 2011). PAHs are created by the incomplete combustion of carbon-containing fuels like coal, oil, gas, and garbage. PAH can remain in the environment for extended periods of time, increasing the likelihood that it will cause negative health consequences.

We found that the number of Treg cells in the Fresno asthmatic children were lower in comparison to the Palo Alto asthmatic children. Furthermore, the healthy children from Fresno had reduced Tregs. The function of Treg cells are vital to the regulation of immune-mediated inflammation and plays a role in many diseases besides asthma, such as allergies, infections and cancer (Taams et al. 2006).

We are concurrently studying a gene called FoxP3, which regulates the development and function of Treg cells. We found that children living in Fresno with asthma had more methylation of FoxP3 in comparison to the children in Palo Alto (Nadeau et al. 2010). This increase in methylation leads to the FoxP3 gene being down-regulated, resulting in decreased number and function of Tregs. Finally, these changes at the cellular level were associated with increased rates and severity of asthma (Nadeau et al. 2010).

The finding that the air pollution in Fresno may cause changes at the level of DNA is disturbing, especially since we are dealing with children. This research points to two important things: (1) Air pollution affects the body's immune system in general, not only the lungs, demonstrating the broad impact air pollution has on health, and (2) Air pollution could cause changes at the level of DNA, providing the opportunity for these changes to be passed on to subsequent generations. Other groups have also found that air pollution can modulate DNA through methylation changes (Tarantini et al. 2009; Ji and Khurana Hershey 2012; Bind et al. 2014).

Now, with advances in technology, it is possible to look at over 40 cell protein markers in a sample of blood, allowing an in-depth investigation of the possible effects of pollution on a single-cell level. We are now comparing the blood from Fresno residents (ages 0–25, both asthmatics and non-asthmatics) across a period of time (1 day–11 years) to examine the short term and long term effects of pollution on the immune system, and on asthma in particular. A land-use regression model was developed that estimates each subject's pollution exposure using data from the Air Quality stations near their individual home and school addresses. The aim is to quantify at the single cell level the deleterious effects of air pollution. Further basic science research is critical to develop a full understanding of this problem.

4 Climate and Extreme Weather and Health

Given that extreme weather conditions have far-reaching health implications, it is important that we look to the future. Temperatures continue to rise in the U.S. and globally (Thornes 2014). The average temperature of the Earth's near-surface air and oceans has increased by 0.74 ± 0.18 °C over the past century (Change 2007; Backlund 2008).

The rise in temperatures is currently and will continue to cause an increase in the intensity of extreme weather events according to the Intergovernmental Panel on Climate Change (IPCC 2014). Whether in droughts or floods, both types of extreme weather will continue and intensify. In the case of Fresno, increased droughts will make dust storms worse and expose more of the population to Valley Fever and to the health affects of many small particles in the dust. Drought is and will continue to hurt Fresno's economy, especially since agriculture is their primary industry. Increased drought in the Valley reduces agricultural production.

Moreover, as temperatures rise, more ozone is produced. Increasing levels of ozone will both trap more heat in Fresno and the surrounding valley. Higher levels of ozone smog are linked to increases in the incidence of respiratory diseases. A study in New York City looked at the effect of outdoor temperature and humidity on hospital admissions for respiratory and cardiovascular disease from 1991 to 2004. They found that for every 1 °C temperature increase above 36 °C, hospitalizations from respiratory- and asthma-related illnesses rose by 2.7–3.1 %, and cardiovascular admissions increased by 1.4–3.6 %. The admission rates for respiratory causes were greatest in the elderly and for Hispanics (Lin et al. 2009).

Drought increases risk for forest fires, a special concern because a large proportion of wildfire smoke emissions are fine particulate matter ($PM_{2.5}$) (US Forest Service 2015). Moreover, wildfires cause rapid, large releases of carbon dioxide to the atmosphere, contributing to the cycle of climate variability (Backlund 2008). Research shows that fires contribute to short-term air quality (Carrico et al. 2005; McMeeking et al. 2005; Westerling et al. 2004; Robinson et al. 2004; Ward et al. 2004). There are many examples of fires impacting air quality far from their location. This is true for both particulate matter (Colarco et al. 2004; DeBell et al.

2004) and gases such as CO and O_3 (Wotawa and Trainer 2000; McKeen et al. 2002; Jaffe et al. 2004; Bertschi and Jaffe 2005). For example, a team of 15 scientists found that a wildfire burning on the border between Alaska and Canada caused significant air pollution in Houston, Texas, which is over 3000 miles away (Morris et al. 2006).

Climate conditions have other health effects, contributing to pollen and mold allergies, for example. Droughts cause allergy season to begin earlier and it will affect the levels and distribution of pollen and mold. Increased temperatures will increase pollen production and extend the pollination period (Emberlin et al. 2002). In addition, increased carbon dioxide (CO_2) levels can increase the allergenicity of pollen by increasing its allergenic compound levels (Rogers et al. 2006). An increased frequency of thunderstorms attributed to climate has been linked to increased bursts of pollens or fungal spores in the air that are, in turn, linked with outbreaks of asthma (D'Amato et al. 2007).

The last example raised here of climate effects in place like Fresno is methane production. Methane is a major contributor to climate. As mentioned previously, dairy farms contribute to high methane levels in the Fresno area. According to the EPA, methane is 23 times as potent a greenhouse gas as carbon dioxide and is the second most important contributor to the greenhouse effect, now accounting for 16 % of global greenhouse gas emissions from human activity (Grace Communications Foundation 2015).

5 Community Engagement Strategies

The first regulatory government agency to address air quality was formed in 1967. This California Air Resources Board (CARB) is under the jurisdiction of the Environmental Protection Agency. It researches the effects of air pollution on the environment and health, and from that information, it develops air quality standards and potential solutions.

Locally, the San Joaquin Valley Air Pollution Control District (Valley Air District 2015) is the regulatory board of CARB. Their function is to create and implement solutions to improve local air quality. Fresno has been trying to overcome the environmental problem and they have had many success stories due to tighter regulations, increased fines, a ban on wood burning, and limits on diesel exhaust production. For example, violations of PM_{10} levels were common in the 1990s, but the SJ Valley was the first air basin (an area with similar meteorological and geographic condition) in the nation to improve PM_{10} levels to meet standards. And in 2013, for the first time, the SJ Valley did not exceed regulations of hourly ozone concentration. Overall, San Joaquin Valley air has steadily improved over the past 15 years.

In addition, residents are now kept informed of air pollution levels so that daily activities may be adjusted accordingly. Schools in Fresno fly color-coded flags to alert students to the air quality: Green means it's OK to be outside, while red is a warning to stay indoors. The district also sends advisories via email alerts, called "Real Time Outdoor Activity Risk" warnings. Whenever the air quality reaches the "unhealthy" level, residents can decide to postpone an outdoor activity such as exercising.

One attribute of the success of the Air Board has been their investment in research regarding the health effects of air pollution. For example, in 2011 the Air Board helped support a study that found asthma and heart attacks increased when particulate matter pollution increased (Hanna et al. 2011). As a consequence of the study, the federal government realized that using a 24-hour average of air quality was not adequate in assessing the dangers of airborne particulates. Short exposures—e.g. several minutes—to very high particulate levels can also be a risk to health (Cassee 2013). The Board also created the Technology Advancement Program (TAP). TAP provides incentives for local universities to focus on research and development of new technologies to reduce air pollution.

The Air Board also incentivizes programs to increase use of environmental-friendly equipment. From 2010 to 2011, more than $60 million dollars in grants were used in the community to retrofit engines, replace and retrofit school buses, provide subsidized cordless electric lawn mowers and provide cleaner usage wood stoves.

In general, the Air board's policies are stringent and necessary. In the Fall of 2014, the Air Board implemented new burning rules that are the strictest in California. Wood burning fireplaces and older wood burning heaters are illegal unless that is the only source of heat available. The Air Board is also allotting more than $2 million to help people purchase modern, environmental-friendly heaters.

However, not everyone in Fresno is content with how local air quality is being regulated. In 2012, a national environmental justice organization sued the U.S. EPA on behalf of Central Valley residents because they felt that there was not enough pressure placed on the Air Board to improve air quality to acceptable standards. (The Center on Race, Poverty and the Environment 2015). They felt that major sources of industrial pollution, such as dairy farms, feed lots and oil rigs were not being adequately addressed. This may be due in part because farm practices are currently exempt from certain parts of the Clean Air Act. The EPA did not respond to the coalition's satisfaction. So, in January 2015, they again sued the EPA as part of a coalition to force the EPA to better regulate pollution from factory farms.

6 Strategies for Future Health Communication

As we look to the future, how can we decrease the effects that climate variability and change will have on air pollution and our health? First, an education campaign in schools that focuses on the effects of air pollution on our health would be motivational. Second, the media and the weather report can be used effectively to educate the public. When high winds are forecast, the media and health services could partner to warn of the dangers of inhaling airborne dust. Newscasts can alert asthma sufferers to avoid high-risk situations and hospital staff can be advised that air quality conditions may likely send more patients into their emergency rooms. Newscasts can inform the public of emerging weather forecast capabilities that bring new tools to the epidemiology of asthma and other cardiovascular and respiratory ailments, including Valley Fever (Sprigg et al. 2014). Even haboobs, severe storms over arid lands that create dense clouds of dust tens of miles long and a mile high, are on the verge of operational predictability days in advance, plenty of time to avoid serious risks to health (Vukovic et al. 2014).

Third, a focus on indoor monitoring and control of pollutants could be important since many people typically spend most of their time indoors. Additional examples of indoor pollutants include tobacco smoke, some fragrances, dust, molds, cockroaches, pet dander and household chemicals. In fact, research has shown that cockroach allergen in utero increased the risk of allergic sensitization at 5–7 years old, and that exposure to PAHs augmented the risk (Perzanowski 2013). To help alleviate indoor pollution, there are various types of devices, each aimed at removing a specific type of pollution from the air. Providing incentives to purchase appropriate in-home air devices would be an immediate step to help those populations especially at risk.

Another approach to reduce pollutants would be to increase penalties for arson. Individuals start 90 % of wildfires in California (CA Wildland Fire Coordinating Group 2015). A zero-tolerance policy with accompanying mass media educational campaigns would be beneficial. In 2009, a man in southern California was the first person sentenced to death for a wildfire arson that killed 5 people. In 2013 a man deliberately started a forest fire in San Bernardino County that resulted in 5 deaths from heart attacks. He was charged with their murders. The rest of the state should follow Southern California's lead when arson results in death. It may reduce the number of wildfires and the toll on life, some of which is immediate and obvious, and some of which contributes to lingering illness and a labored existence.

Finally, a continued investment to support development of alternative energy sources and innovative research is vital. For example, one such innovation revealed in 2015 uses a titanium-containing chemical in the façade of city buildings to reduce smog. In Mexico City, exterior tiles of a hospital were coated with titanium dioxide. The titanium dioxide causes a chemical reaction when activated by sunlight: nitrogen oxides are broken down into less harmful substances, reducing the amount of ozone. This reaction will reoccur as long as there is sunlight. A similar project was unveiled recently in Milan, Italy, in which titanium dioxide is mixed with the building's concrete. Like the hospital in Mexico City, the building will be able to break down nitrogen oxides when struck by sunlight. This concrete could be used in various future structures to decrease the level of smog (Willmott 2015).

Key to the issue of reducing the rate of global warming and climate change is to be aware that individual choices do make a difference. One may choose to live near an airport, for example. But studies show that living near an airport exposes one to increased pollution: Los Angeles International Airport was the largest source of carbon monoxide in California in 2005, and runway congestion, measured by the total time planes spent taxiing between the gate and the runway, is a significant predictor of local pollution levels (Schlenker and Walker 2015). Another choice is whether to fly or drive or teleconference to reduce one's "carbon footprint," as well as reduce pollution around airports. Corporations and academe should take the lead in exploiting teleconferencing, for example. If teleconferencing became a standard for large meetings and annual conferences, the reduction in business travel would be significant. In 2012, 33 % of domestic business trips included air travel versus only 11 % for leisure trips. Less than half (48 %) of business trips are done by car (U.S. Travel Association 2015).

Besides making wiser travel choices, other suggestions for individual contributions include: Eliminate the use of wood burning fireplaces (both indoor and outdoor fire pits), stop the burning of yard waste, use energy efficient toilets and appliances, plant drought resistant landscaping, make mandatory labeling of VOC (Volatile Organic Compounds) index on products and use the lowest VOC-rated products. VOCs have been shown to harm the respiratory system and allergic functioning in children (Choi 2010). Today, however, products are not labeled with their VOC index, and this could be changed with different labeling guidelines.

In summary, this chapter presents the representative location of Fresno, California and how its extreme weather impacts health. As physicians and researchers we can approach health as a program towards overall wellness and acknowledge the interrelationships of many environmental factors, including anthropogenic pollutants and climate change, with singular extreme weather events, such as dust storms and drought. This overall-wellness view allows us to examine the short-term and long-term effects of climate change and global warming on our health.

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Human Response to and Consequences of the May 22, 2011, Joplin Tornado

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Abstract Tornadoes wreak havoc and destruction across the United States every year. One such tornado occurred in Joplin, Missouri on May 22, 2011. This tornado killed 161 people, damaged nearly 8000 structures and caused billions of dollars in damage. This chapter discusses the National Institute of Standards and Technology (NIST) Technical Investigation of the environmental conditions, performance of buildings, emergency communications and human response to the Joplin, Missouri tornado. As a result of this investigation, recommendations to improve public health and safety are currently being implemented. A discussion of these recommendations concludes this chapter.

Keywords Tornado · Joplin · Human behavior · Damage · Windstorm

1 Introduction

> …we didn't stray too far from the front porch, and when we initially got to the front porch the second time the sun was out, although you could see off to the west and slightly to the north of where we lived that it was pretty dark and it was thundering and lightning pretty good; and then we had a little bit of hail. We did not seek shelter in the basement of our home until the trees in our neighbor's yard came down, and we heard the sound, which I'll never forget the sound—never, never, never—you never forget the sound (NIST Interview 31).

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1.1 Background

Tornadoes pose a significant threat to life and property in the United States. In an average year, these windstorms are responsible for the most fatalities and insured losses of any natural hazard in the U.S. For example, in the 10 years from 2001 to 2010, the U.S. *averaged* nearly $1B in insured losses and 56 fatalities per year from tornadoes according to the National Oceanic and Atmospheric Administration (NOAA 2014a). The year following this 10-year stretch was historic in terms of the losses it caused. In 2011, 1691 tornadoes were reported in the U.S., including the greatest number of tornadoes in a single day—200—on April 27th and subsequently the greatest number of tornadoes in a single month with 895. The 2011 tornadoes caused an estimated $10B in insured property losses and 550 fatalities in the United States (NOAA 2014b) and were notable for striking heavily populated areas including Tuscaloosa, Alabama and the Oklahoma City metropolitan area. A tornado occurred on May 22, 2011 in another populated area, Joplin, Missouri as a National Weather Service (NWS) rated EF-5 tornado on the Enhanced Fujita tornado intensity scale (see Sect. 2). This touched down just to the west of Joplin and proceeded to cut a swath through the entire length of the city. The tornado directly affected 41 % of the city's population (20,820 people, out of the 50,175 estimated), damaged or destroyed nearly 8000 structures and caused nearly $2B in insured commercial and residential property losses, and generated approximately 3 Myd^3 of debris (Kuligowski et al. 2014). More importantly, the structural damage and associated windborne debris were responsible for the majority of the 161 fatalities, the most caused by a single tornado since the NWS started keeping records in 1950. Windborne debris was also a major factor in the over 1000 injuries reported from the tornado, which included debris impacts and fungal infections that stemmed from the wounds caused by the debris.

Figure 1 shows an aerial photo of the affected areas in Joplin after the tornado event had occurred. The 'browned out' areas on Fig. 1 are areas that were significantly impacted by the tornado. It is apparent that a large portion of the city was affected. Detailed information on the spatial extent of the damage caused by the tornado, the number of people, and the overall damage sustained by the built environment in the affected area are crucial to understanding the impacts of this disaster on this community. Another important component for highlighting the impacts of this disaster is to understand Joplin residents' prevailing perceptions of the tornado hazard, which guided their response to the event after the warnings had been issued by the NWS. A very important note about this tornado is that it impacted a city with well-engineered structures, including the tallest building in the immediate region (St. John's Regional Medical Center's East Tower, 9-story). Additionally, Joplin has a long history of timely adoption of modern building codes. Yet, despite the longer than average warning time (17 min, national average is 14 min—Kuligowski et al. 2014) in a city with a long history of adopting the latest model building codes, the death toll was unprecedented in the official record

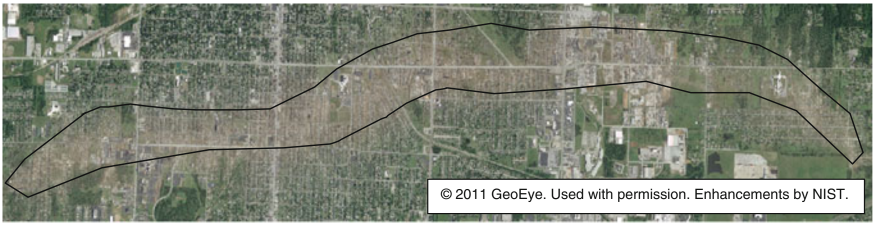

Fig. 1 Aerial photo of Joplin, Missouri after the tornado. Area inside the *black polygon* was most heavily damaged.

for a single tornado. This gives rise to important questions regarding building safety, emergency communication, and human response in tornado.

1.2 Health and Safety Impacts

I didn't think anyone could make it through this (NIST Interview 115).

In addition to the severity of the wind and debris, studies of previous tornadoes have also identified four specific risk factors that can contribute to an increase in injuries and deaths due to tornadoes in the United States. Simmons and Sutter (2011) performed an extensive regression analysis of tornadoes that occurred in the United States from 1950 to 2007 to understand the factors that contributed to injuries and fatalities. Their results indicated that risks of fatalities and injuries were heightened when:

- Tornadoes occurred at night, likely because residents were asleep at this time and less likely to receive warnings.
- Tornadoes occurred during fall or winter months, likely due to a lulling effect during these seasons and individuals' failure to recognize the potential for off-season tornadoes.
- People in affected areas were in manufactured homes during the tornado. The authors found a disproportionate share of fatalities in manufactured homes during less-intense tornadoes (F-1, F-2, and F-3) versus fatalities in permanent homes, which generally occurred in more violent tornadoes.
- The affected area was located in the southeastern part of the United States. The annual tornado rate was found to be negatively correlated with the State casualty index (i.e., rates of fatalities and injuries per million residents), possibly because people in those States accustomed to tornado events are more likely to be prepared (and thus, less likely to experience casualties). Additionally, the coefficient of variation for the annual tornado count, i.e., how consistent tornado event numbers are from year to year, was positively correlated with the State casualty index, possibly meaning that States that are accustomed to experiencing consistent numbers of tornadoes are more likely to be prepared. Finally, the

authors found that the percentage of a State's land covered by forest is positively correlated with the State's casualty index, suggesting that casualties are higher in places where it is more difficult to see approaching tornadoes.

An additional factor that may influence health and safety impacts in tornadoes is warning lead-time (or the time between warning dissemination and tornado touchdown) (Simmons and Sutter 2011). This study found that a warning lead-time of 6–10 min provided the largest reduction in expected fatalities when compared with an unwarned tornado. Overall, warnings with lead times up to 15 min reduce casualties; however, the authors found no additional benefit for warning lead times of 16 min or more.

There are additional risks of injuries and fatalities after a tornado has occurred, especially in populated areas. The CDC highlighted a study of injuries from the Marion, Illinois tornado where 50 % of the tornado injuries occurred after the event during rescue attempts, cleanup and other post-tornado activities (CDC 1982). Also, when tornadoes damage the built environment, they damage other infrastructure systems including power and gas lines. This damage can increase risks of fire, electrocution or explosions within the tornado's damage path. Additionally, injuries directly from the tornado can, and have been documented as causing infections (Neblett Fanfair et al. 2012) that can be fatal if not treated appropriately.

Factors affecting the Joplin, Missouri tornado's deaths and injuries are discussed in further detail later in this chapter. Section 3 of this chapter presents the analysis and results of fatalities and injuries from and a discussion of health and safety impacts of the 2011 Joplin tornado.

1.3 The NIST Investigation

The information presented in this chapter comes from an investigation conducted by the National Institute of Standards and Technology (NIST), a non-regulatory agency of the U.S. Department of Commerce. One of NIST's missions is to *advance measurement science*, *standards and technology in ways that enhance economic security and improve our quality of life*. NIST has several statutory authorities that it can employ, if necessary, to fulfill that mission. These include the National Construction Safety Team (NCST) Act (Public Law 107–231), which was signed into law in October 2002. The NCST Act authorizes NIST to establish and deploy multi-agency, and often multi-disciplinary teams to investigate building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. The purpose of these investigations is to improve the safety and structural integrity of buildings in the United States.

Given the aforementioned unprecedented number of fatalities and injuries, as well as the scope and extent of structural damages caused by the May 22, 2011 Joplin Tornado, NIST conducted a preliminary reconnaissance of building performance and emergency communications during the tornado and deployed four researchers/engineers to Joplin shortly after the event, from May 25–28, 2011. Based on information gathered in this preliminary reconnaissance, NIST formally established a team to investigate the disaster under the NCST Act. The team consisted of the four NIST researchers—with expertise in structural and fire engineering, wind science and engineering, and sociology—and a researcher from the National Oceanic and Atmospheric Administration's National Severe Storms Laboratory (NOAA's NSSL) with expertise in meteorology, severe storms and warnings.

The NIST Investigation's goals were to: (1) study the wind environment and conditions associated with fatalities and injuries, the performance of emergency communications systems and public response to such communications, and the performance of residential, commercial, and critical (e.g., hospital) buildings, designated safe areas in buildings, and lifelines; and (2) develop findings and recommendations that serve as the basis for potential improvements to public safety in tornadoes, including:

- Potential improvements to requirements for design and construction of buildings, designated safe areas, and lifeline facilities in tornado-prone regions;
- Potential improvements to guidance for tornado warning systems and emergency response procedures; and
- Potential revisions to building, fire, and emergency communications codes, standards, and practices.

The following multi-disciplinary objectives, consistent with the aforementioned goals, were established for the NIST investigation:

- Determine the tornado hazard characteristics and associated wind fields in the context of historical data.
- Determine the pattern, location, and cause of fatalities and injuries, and the associated performance of emergency communications systems and public response.
- Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas.
- Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings.
- Identify, as specifically as possible, areas in current building, fire, and emergency communications codes, standards, and practices that warrant revision.

1.4 Chapter Overview

This chapter provides a comprehensive examination of the environmental conditions, performance of the built environment and options for shelter, emergency communication and methods for dissemination, and human response to and consequences of the May 22, 2011 Joplin tornado. To fully examine these factors, NIST adopted a multidisciplinary approach that required the combination of expertise in atmospheric science, wind engineering, structural engineering, construction practices, emergency communication and sociology. Approaching the NIST Investigation of the 2011 Joplin, MO tornado from multiple disciplines enables a comprehensive understanding of the impacts of this disaster (e.g., why the unprecedented number of fatalities), which, in turn, may yield a more comprehensive and effective path for improved life safety and performance of the built environment in future events. Ultimately, problem solving, especially in community problems and health, has been shown to benefit from this integrated perspective (Lasker and Weiss 2003).

Another important perspective of this investigation was geography. A large area of Joplin was impacted by the May 22, 2011 Joplin tornado, but the degree of damage was uneven, in part, due to the variation in tornado intensity throughout the affected area. It was imperative, therefore, to understand the spatial distribution of the severity of environmental conditions and associated damage and how these were related to the health and safety of the community.

Spatially integrated, multidisciplinary methods were employed in the investigation of the Joplin tornado and are illustrated throughout this chapter. Section 2 will discuss the NIST Investigation's data collection and analysis methods. Section 3 focuses on the analysis of the data collected in Sect. 2 with focus on the health and safety impacts in the tornado. Section 4 highlights a protective action model of public response that was created based on face-to-face interviews with survivors of the Joplin tornado. Recommendations and future work identified from the NIST Investigation of the Joplin tornado are described in Sect. 5.

2 Data Collection and Analysis Using Spatially Integrated, Multidisciplinary Methods

2.1 Introduction

Many data were collected over the course of the NIST Investigation. For the purposes of this chapter, the focus will be on four major areas of data collection in Joplin and how these four areas were integrated using spatial and multidisciplinary methods. These four areas were the following: (1) the tornado wind field, (2) design practices and building damage, (3) fatalities and injuries, and (4) emergency communications and public response. Data collection and analysis methods used for each topic area are described in the individual sections below. A more detailed methods description can be found in Kuligowski et al. (2014).

2.2 Tornado Wind Field

The maximum wind speeds generated from the 2011 Joplin tornado were estimated via tree-fall patterns. To estimate the wind speeds, the directions of tree fall for approximately 5000 felled trees throughout the tornado path were digitally traced using post-storm aerial photos obtained by NIST. The tree fall exhibits certain spatial patterns and properties as shown in Fig. 2. These observed patterns and properties were evident over most of the tornado path.

Properties of the observed tree fall, such as the width of tree damage, were measured at a number of locations across the tornado path. These properties were used for comparison and the development of a best-fit tornado vortex model, which will be discussed briefly in the following paragraphs.

For the tornado vortex model, a grid system was set up throughout Joplin at 32 m spacing. These grid points represented trees where time histories of wind speed and wind direction were simulated. The tornado was given an initial starting point based on aerial photos such as those in Fig. 1. The center-line of most intense damage based on aerial photos was chosen to initially represent the centerline of the tornado and the direction of tornado translation. When initializing the model, the tornado vortex parameters were given plausible ranges based on information from previous windstorms in Joplin, archived literature, NWS radar data, post-storm aerial photos and in-person interviews following the storm (Kuligowski et al. 2014).

The tornado vortex model then was translated in 16 m increments throughout Joplin for all parameter combinations. Figure 3 shows an example on the tornado vortex model translating through the spatial grid. Also illustrated in Fig. 3 is the width of tree damage at a particular location. After the translation was complete, properties of the observed tree fall were compared to those of the tornado vortex model, such as the width of tree damage in a number of different locations. The parameters of the tornado vortex model that best matched the observed tree fall patterns were used in the analysis. The maximum estimated wind speed and associated uncertainty estimated from the tornado vortex model were integrated with information on the tornado hazard, building damage, human response and emergency communication (discussed in the following sections) to aid in the investigation of the causes of the disaster. Maximum wind speeds were related to the Enhanced Fujita, or EF, Scale (McDonald and Mehta 2006). In the EF-Scale, an EF-number (e.g., EF-0, EF-1) is associated with a range of wind speeds. These ranges are shown in Table 1. Detailed information on the wind field model used in the Joplin tornado can be found in Kuligowski et al. (2014).

2.3 Design Practices and Building Damage

The performance of buildings in the 2011 Joplin, Missouri tornado varied significantly with their spatial locations within the tornado damage path. Building

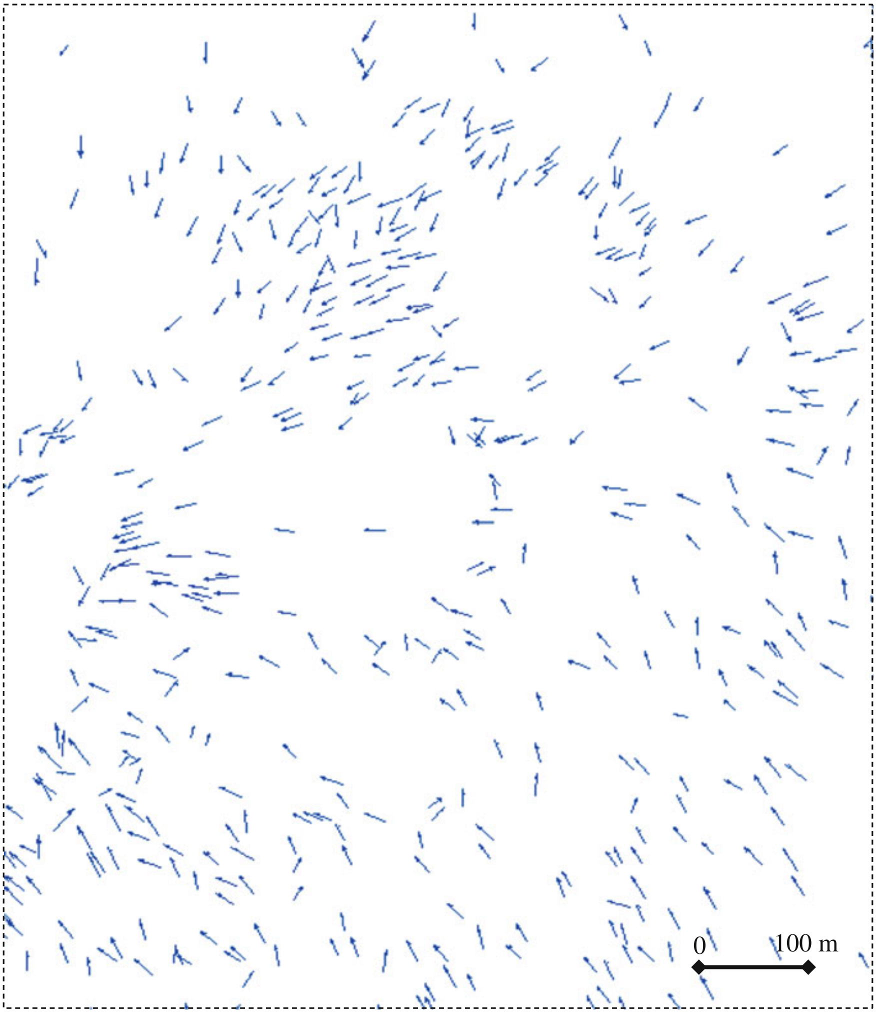

Fig. 2 Example of observed tree fall directions for a location in Joplin. Approximate size is 0.8 km by 1.6 km (Kuligowski et al. 2014)

performance was complex and broad in scope due to the different types and ages of construction and different design requirements from various versions of local building codes dating back to the 1960s. Given the variety of buildings involved, the availability of design information, and the different levels of building performance observed (both in terms of structural integrity and functionality), NIST adopted a data collection method that required detailed design and performance data—forensic engineering data that illustrate causes and sequences of building failures—of 25 structures that are representative, both in terms of structural systems and degrees of damage, of the approximately 8000 damaged buildings. These

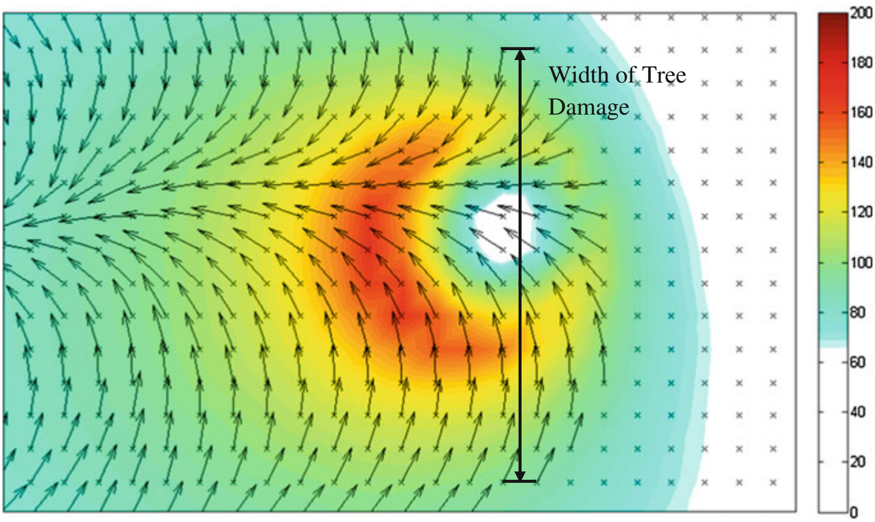

Fig. 3 An example of the tornado vortex model traveling through the grid for a single set of parameters. *Contour values* represent wind speed in mph. *Black arrows* represent direction of tree fall

Table 1 Enhanced Fujita (EF) scale numbers and corresponding wind speed ranges (mph)

EF-number	Wind speed range (mph)
0	65–85
1	86–110
2	111–135
3	136–165
4	166–200
5	>200

included critical, commercial, and residential buildings that were representative of typical construction types for the region (e.g., steel/concrete frame, box-type system [BTS] with concrete masonry units [CMU] or precast tilt-up wall, and wood frame), building functions (e.g., critical facilities such as a hospital, schools, and fire and police stations; high-occupancy facilities such as large retail stores and churches; smaller medical and commercial offices; nursing home and single- and multi-family residences), and levels of damage.

For evaluation of the performance of buildings and lifeline systems in this tornado, NIST adopted the methodology described below with aims to (a) address issues that pertain to whether the structures were designed and constructed in accordance with the applicable building codes, and whether code-level design wind loads would have caused the failures observed in some of the structures surveyed by NIST; and (b) identify construction practices that lead to better performance in tornadoes or practices that can be improved for the same purpose:

- For non-residential buildings that collapsed and for which design information is available, the performance evaluation would include: (1) using the design information to estimate the code-level design wind pressure for the building; (2) using NIST's estimation of the wind environment to establish the tornado hazards affecting the structure; (3) studying the observed failures and computing the loads required to cause such failures, then comparing the failure loads with the code-level pressure to determine if the building would have sustained the failures under code-level loading and (4) identifying the sequence of occurrences leading to the failures based on field observations and analysis of the strengths of different structural components.
- For non-residential buildings that sustained damage to the envelope but did not collapse, the performance evaluation would include: (1) reviewing available design information and using data collected in the field as well as from third parties to develop an understanding of the structural systems of the building; (2) using NIST's estimation of the wind environment to establish the tornado hazards affecting the structure and (3) using field-survey damage data and survivor interview information to explain the effects of the tornado on building performance, both in terms of physical damage and building functionality.
- For residential buildings, given that there were 7411 residential buildings (Kuligowski et al. 2014) that were either damaged or destroyed (about 43 % were built before 1950, and more than 82 % were built prior to 1980), it was not practical to review the performance of all single-family residential structures. Consequently, the investigation reviewed the performance of a few selected multi-family residential buildings in detail (i.e., Greenbriar Nursing Home and Mercy Village Apartments) and reviewed the performance of single-family homes in a general, statistical context based on an aerial photo database provided by Pictometry [see Fig. 4; with color codes indicating damage conditions based on damage classification used by the Federal Emergency Management Agency (FEMA) that include green (light damage), yellow (medium damage), orange (heavy/totaled), and red (demolished)]. The Pictometry database also includes information on construction age for each residential building, as well as the number of stories and whether the residence had a basement below-ground level. This information allows evaluation of the effectiveness of older building codes in terms of wind-resistant design and provides an understanding of the sheltering options available to home occupants at the time of the tornado. The aim was to make representative observations that might be useful in the development of best practices and future design strategies for more tornado-resistant residential construction.

It is important to note that the current wind design practices in the United States do not require residential, commercial or critical buildings and other structures to be designed for tornado hazards (i.e., wind and debris), except for (1) *safety-related structures*, *systems*, *and components of nuclear power plants*, and (2) *storm shelters* and *safe rooms*. Therefore, jurisdictions that adopt building codes, such as Joplin, Missouri, prescribe non-tornadic wind speeds for the design of residential,

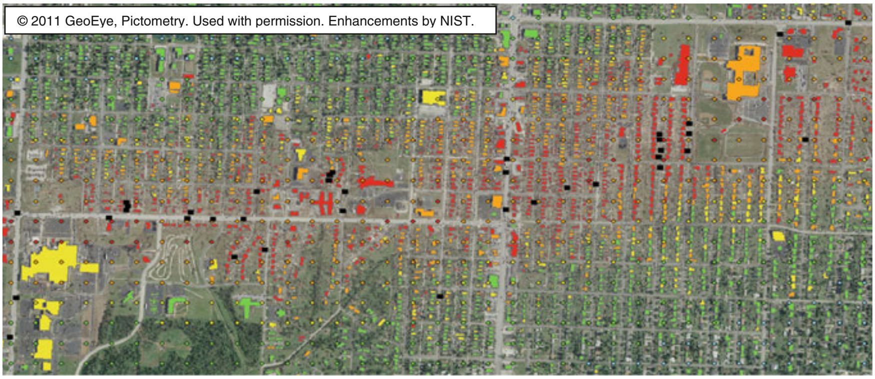

Fig. 4 Image showing locations and intensity of building damage (*green*—light; *yellow*—medium; *orange*—heavy/totaled; *red*—demolished), wind speed (*colored dots*) and fatalities (*black squares*).

commercial and critical buildings. As these various types of construction are not designed for tornadoes, they performed very differently and sustained significantly different effects in the May 22, 2011 Joplin tornado.

2.4 *Fatalities and Injuries*

In order to investigate the behavior and fate of individuals affected by this tornado —both those who survived and those who did not—two main sets of information were collected. First, information was collected on the human injuries and fatalities from the tornado. The purpose of collecting this information was to identify the pattern, locations and causes of fatalities and injuries.

To understand the circumstances surrounding the 161 deaths, NIST collected data and information from its interviews with friends and families of tornado victims, the Missouri State Police Department, the American Red Cross (Disaster Health Services), Facebook pages of the deceased and pages dedicated to the Joplin recovery, stories recorded in three books published on the tragedy (Kansas City Star 2011; Joplin Globe 2011; Turner and Hacker 2011), a LexisNexis obituary search, and death certificates for all victims of the tornado (provided to NIST by the Missouri Department of Health and Senior Services (MDHSS), the Oklahoma State Department of Health and the Kansas Department of Health and Environment's Office of Vital Statistics). The death certificates provided the most information on the deceased, including place of injury, time of injury, description of injury, place of death, time of death, cause of death, gender, occupation, education and marital status.

NIST also obtained two datasets to understand the circumstances of the more than 1000 injuries resulting from this tornado. The MDHSS Division of Community and Public Health provided both datasets to NIST. The first dataset, entitled ESSENCE, included syndromic surveillance data, or data obtained from a systematic process of timely data collection and analysis in order to detect and characterize outbreaks of disease in humans. The ESSENCE database on the May 22, 2011, Joplin tornado injuries contained basic injury information (i.e., chief complaint or injury) from 762 records from residents of Jasper and Newton Counties and 114 records from persons residing outside of these counties.

The second injury-related dataset used by NIST was collected by the U.S. Centers for Disease Control and Prevention (CDC) for the MDHSS to investigate a number of reports of fungal skin infection in people who were injured by the May 22, 2011, Joplin tornado (this investigation was referred to as the CDC EPI-Aid Study). The CDC dataset included injury and personal data from a total of 87 individuals randomly selected by the CDC from the ESSENCE dataset previously described. The data provided to NIST were acquired by the CDC from both medical record chart abstraction and face-to-face interviews, and contained very detailed information on the type of injury and treatment received, as well as the tornado experience (or narrative) from the injured.

The injury/death information as well as victims' and survivors' stories (see Sect. 3 below) were correlated with their geographic location within the damage path to understand the impact of building damage or other environmental conditions on cause of death. More information on the use of the ArcGIS program for this purpose can be found in the NIST Investigation report (Kuligowski et al. 2014).

2.5 *Emergency Communications and Public Response*

Data were also collected on the response of the public before the tornado hit to understand the impact of emergency communication on protective action. The purpose of this section was to understand if particular improvements to the emergency communication system and/or protocols were required based upon the findings of this tornado event.

Information on the public response before the tornado hit Joplin was obtained primarily through interviews with the public, as well as with emergency response personnel. Individuals exposed to the tornado were interviewed to collect detailed descriptions of individuals' experiences with their environment and the meanings that they generated as the tornado event was unfolding around them. Emergency response personnel were interviewed for information concerning Joplin–Jasper County's tornado emergency communications system at the time of the May 22, 2011, Joplin tornado, and its method of operation, and emergency plans and protocols specifying appropriate public protective actions in tornadoes, among other topics.

To recruit participants, NIST published a newsletter, posted flyers in and around the Joplin area, participated in interviews with Joplin area news outlets, and received assistance in getting the word out via Joplin-based emergency officials and business and faith-based organizations. In each recruitment strategy, NIST asked survivors and family or friends of victims of the May 22, 2011, Joplin tornado to please call, text, or e-mail so that NIST might interview them about their tornado-related experiences. Therefore, the sample collected can be considered a 'convenience' sample; i.e., a sample that consists of specific persons of interest, persons who volunteered to participate or interviewees who were suggested to NIST by those who volunteered. The NIST Investigation report discusses the limitations of this approach (Kuligowski et al. 2014). However, NIST ensured that the convenience sample varied by age, geographic location throughout the damage path, and physical setting during the event (i.e., home, business, outdoors, or vehicle), reducing the limitations of this dataset.

After careful consideration, it was determined that a semi-structured interviewing technique best fit the requirements of this investigation. Highly structured (HS) interviews contain a fixed set of questions, often with a set of response options, and are mainly used to collect quantitative data that allow for ease of data comparison from one interview to the next. However, a HS interviewing technique was deemed as unfeasible in this investigation due to the speed at which the NIST team began development of the interview protocol and, at that time, the lack of systematic analysis of Joplin survivor accounts (e.g., available in the media). Unstructured interviews, on the other hand, are conducted more like a conversation between the interviewee and interviewer, where very little structure is provided by a question set. Unstructured interviews allow for the collection of rich, powerful descriptions of the event, but with very little opportunity to compare one interview response to another (which was necessary here). The semi-structured interviewing technique allowed collection of rich, detailed data on tornado experiences (and the ways in which these experiences are interpreted by the interviewee) as well as the opportunity to compare similar types of data. Additionally, this interviewing technique permitted discovery of phenomena and causal patterns that were not originally anticipated and helped interviewees retrieve more comprehensive and accurate memories of incidents.

This semi-structured approach was conducted in two phases. In the first phase, respondents were asked to describe their experiences from the time they first became aware that something was wrong until the moment when they responded to the disaster, such as by sheltering in place. They were asked to speak broadly about their experiences (what they saw, what they did, what they were thinking). The second phase was more structured. The interviewer asked follow-up or clarifying questions about important topics from a pre-established list of probing questions. The probing questions were used to ask about the following topics: awareness of the event, emergency communications received, actions taken, risk perceptions, pre-existing or event-driven injuries or impairments, previous experiences with severe storms, and familiarity with and perspectives on the emergency communications system in Joplin.

In total, NIST interviewed 168 survivors of the tornado, through a combination of in-person and telephone interviews.[1] Respondents ranged in age from 18 to 88, with a mean age of 51. Gender was also well distributed, with women making up 59 % of the sample. A geographic analysis of where respondents were located during the tornado showed that the sample was well distributed across the tornado's path through Joplin (Kuligowski et al. 2014), with a small percentage located outside the area of tornado damage (i.e., EF0 to EF4 wind speeds zones). Interviewees were also distributed by physical setting during the storm: approximately 67 % were at their or someone else's home (or apartment), 14 % were in a private business, 7 % were driving or stopped in a vehicle, 5 % were in St. John's Regional Medical Center (SJRMC), 5 % were in Joplin area churches, and the remaining 2 % of the sample were either located outside buildings or did not specifically state where they were located as the storm struck.

Whereas some data from these interviews (i.e., specifically interviews with friend/families of victims) were used to understand the pattern, location and causes of deaths and injuries as a result of the storm, the majority were used to develop an evidence-based explanation (or conceptual model) of decision-making in the Joplin tornado. The purpose of the development of this model was to identify the reasons why protective actions were or were not taken before the storm hit Joplin and to identify necessary improvements to the emergency communication system and/or protocols. The analysis focused on the information that these interviewees received before the storm, their interpretations of this information and their subsequent behavioral responses related to seeking protection (or taking refuge in the "safest place" available).

The interviews used in developing this conceptual model were from survivors who were responsible for their own protective decision-making, i.e., those individuals who, at some point during the warning period, had to decide for themselves what to do and when to do it (labeled here as "decision-makers"). These are the people for whom publicly-disseminated emergency communication systems are crucial. "Decision-makers" included, for example, people in homes, in vehicles, outdoors or traveling from one place to another before the storm hit. Interviewees were not included who had been told by people in authority when and where to take shelter, or managers or other employees whose role was to instruct others to take shelter (or not). For the development of this evidence-based explanation, 140 of the 168 survivors interviewed by NIST were identified as "decision-makers" and included in the analysis.

The main analysis technique used to develop this conceptual model was the analysis method framework (Framework) originally developed by Ritchie and Spencer (1994). The Framework allows the analyst to classify and organize survivor data into themes, concepts and categories (Ritchie et al. 2003), which can be

[1]10 % of the survivor interviews were conducted with managers and employees of local businesses and institutions, 10 %provided information regarding individuals who died from the storm, and 10 % of interviewees were among the injured.

developed later into a model. This technique involved a four-step process: (1) data indexing, (2) data sorting, (3) data description and (4) pattern detection. This conceptual model is the subject of detailed discussion in Sect. 4.

Additional information about recruitment, interviewing protocol, data collection, and data analysis techniques, including conceptual model development, can be found in the NIST Investigation report (Kuligowski et al. 2014).

2.6 Summary

In summary, the NIST Investigation yielded much important data, both collected and generated. These data included intensity and location of wind speeds as well as damage conditions, performance, and failure mechanisms of affected critical, commercial and residential buildings. Data also included comprehensive fatality and injury information including location, demographic data and the circumstances surrounding a particular fatality or injury. Finally, data were collected on emergency communications and public response through face-to-face and phone interviews. These data included location information and first-hand accounts of the moments leading up to tornado impact. This detailed information in space (and time) was crucial in analyzing the causes of fatalities and injuries and in understanding the decision-making process of the public over the course of the tornado. Figure 4 shows the location and intensity of wind speeds and damage as well as the locations of fatalities for a portion of the damage path. This composite information, as illustrated in Fig. 4, was used to assess health and safety impacts of the tornado and protective action decision-making in response to the tornado, discussed in Sects. 3 and 4, respectively.

3 Analysis and Results of Fatalities/Injuries and Discussion of Health and Safety Impacts

As mentioned earlier, 161 fatalities were attributed to the 2011 Joplin, Missouri tornado. Since one of the goals of the NIST Investigation was to determine the pattern, location, and cause of fatalities and injuries, a large subset of those 161 fatalities were analyzed further. A total of 154 fatalities were “impact-related”,[2]

[2]Other deaths occurred due to non-impact-related factors. Three non-impact deaths occurred in single-family homes where two individuals died of heart attacks due to stress brought on by the storm, and one individual died of pneumonia. In all three of these cases, the storm did not damage the victim’s home, but the death was attributed to the storm due to the stress it caused to the individual. Heart attacks that led to deaths were also determined to be the cause of two of the fatalities that occurred at SJRMC. The sixth and last non-impact-related death was of the police officer killed by lightning in the line of duty on Monday, May 23. All non-impact-related deaths occurred after May 22.

Table 2 Locations of the 154 impact-related fatalities

Location	Number
Outside	*19*
Vehicle	12
Open air	7
Inside	*135*
Residential	90
Commercial	33
Critical	12

which means they were likely caused by debris generated from a partial or complete failure of a building. These 154 fatalities occurred both inside and outside of buildings. The term "outside" is taken to mean in-vehicle or open-air fatalities (i.e., not inside a building). Table 2 shows the number of fatalities that occurred inside critical, commercial and residential buildings and the remaining impact-related fatalities that occurred outside. Details on both the outside and inside impact-related fatalities are discussed in this section.

3.1 Fatalities that Occurred Outside of Buildings

The outdoor sirens in Joplin were meant to instruct all individuals located outside to move indoors, i.e., into buildings. Additionally, both of the tornado warnings disseminated by the NWS provided the following information on actions people should take if they were located outside of structures:

> IF IN MOBILE HOMES OR VEHICLES… EVACUATE THEM AND GET INSIDE A SUBSTANTIAL SHELTER. IF NO SHELTER IS AVAILABLE… LIE FLAT IN THE NEAREST DITCH OR OTHER LOW SPOT AND COVER YOUR HEAD WITH YOUR HANDS.

Some individuals exposed to the Joplin tornado were located outside when the storm hit. One interviewee, caught outside of his home without his keys, was attempting to gain entry. He described the tornado approaching as he attempted to open the front door:

> I grabbed the storm door and opened it up, and I kicked the front door about half a dozen times like you see on the police shows. It didn't budge. Didn't move an inch. And so turned around and our neighbors had been out—the neighbors to the south of us had been out when we got home looking at the sky like everybody does around here. And I thought, well, we can run over there. Well, by the time I turned around and [headed] back to the edge of the porch, it was raining so hard you couldn't see their house 20 feet away. So I ran back to the front door and about that time, over [girlfriend's] shoulder—she had turned around and over her shoulder out in our front yard, a couple 8–foot lengths of 2 by 4 landed in our front yard. And I—that kind of startled us and about that time the corner post that holds up the roof—the whole roof line goes down over the porch, too. And the corner post

that holds it up over the edge of the porch just crumbled, just fell to pieces. The roof started coming down on us (NIST Interview 28).

A total of 19 deaths directly attributed to the May 22, 2011, Joplin tornado were of persons located outside of structures or in vehicles when the storm hit. Another eight individuals from the CDC EPI-Aid Study who were severely injured were also located outside of structures in vehicles when the storm hit them.[3]

Spatial Analysis

To understand the environment to which these individuals were exposed, ArcGIS was used to relate the locations of fatalities and CDC-sampled severe injuries to the near-surface wind-field map (see Sect. 2.2 and Fig. 4 in this chapter for additional description of the methods used). After linking each outdoor fatality and severely injured individual with a specific location on the map, NIST was able to view the location of all outdoor fatalities and all sampled severe injuries along the tornado's damage path.

This analysis showed that the majority of outdoor fatalities (63 %) and of the sample of severely injured persons (88 %) were located in the areas where the tornado was estimated to have produced the strongest wind speeds (i.e., EF-3 or EF-4 wind speeds). Fifty-eight percent of fatalities, and 88 % of the sample of severe injuries, occurred in the EF-4 zone.

In the highest estimated wind speed zones (EF-3 and EF-4), information gathered on the deceased and severely injured reflected individuals being sucked, ejected or thrown from their cars. Interviews with the severely injured provided detailed information about vehicle windows getting blown out or broken by winds or debris, providing opportunities for the storm to push or pull individuals into the debris field and/or send debris flying into cars, causing severe blunt-force trauma or unconsciousness. One interviewee recalled getting pummeled by debris (through broken windows), suffering severe injuries as a result of his van being picked up by the storm. He had turned onto Rhode Island Avenue in Joplin, desperately trying to find someone, anyone, with whom he could take shelter. When he did not see anyone, he noted that he never felt more alone and empty because he could sense something bad was about to happen.

at that moment the windows exploded. I thought the windshield went out first, but actually seeing the photographs, it didn't go anywhere. But everything else. The back window—side panel windows. They all just exploded. And that part I saw in slow motion. I saw the windows—because see, a lot of people talked about feeling pressure and their ears pop. I didn't feel that. My ears didn't pop. My first indication was when the windows exploded—debris came flying through. I'm laying over in the seat. And was laying—I know I was laying there for, you know, a few seconds. I was laying there for ten, fifteen seconds. It's always hard to gauge. But stuff's flying over the top of me.

Then it was like a giant hand picked me up. Didn't pick me up. But it pulled me straight back to about where these red cars were, and everything and that. And I don't know if I hit them. Because it felt like I bumped into something. But the minute I bumped into

[3]CDC dataset via MDHSS, provided to NIST in 2012.

> something, I went straight up. And I went. And I don't really have a gauge how high I went up, except that I felt like I really lifted and went straight up. But now the thing is spinning the whole time. I'm spinning counterclockwise the whole time this is going on. Seconds. It was only seconds. But I saw debris flying around me. And I saw these things breaking apart. And about 30 or 40 seconds later, you couldn't see. You couldn't breathe (NIST Interview 60).

This recollection makes it clear how individuals could be killed or severely injured from blunt-force trauma to the body either inside or outside of vehicles. With the exception of one individual located outside of the Greenbriar Nursing Home, all of the fatally and (sampled) severely injured persons (outside of structures) in the highest estimated wind speed zones (EF-4) were located inside vehicles when the storm hit. This suggests that being caught outside structures and exposed to tornadic wind speeds higher than 165 mph can be very dangerous, due to the tornado's ability to send heavy debris flying into vehicle windows and lift individuals from their vehicles into the storm's debris wall.

Fatalities and severe injuries, although in lower numbers, were also found in zones with estimated wind speeds less than 136 mph (<EF-3). One person was killed outside the emergency room entrance to SJRMC in an EF-2 zone (where winds were estimated to range from 111 to 135 mph). He was thrown from his (outdoor) location and died when a car landed on top of him. Additionally, three individuals died or were severely injured outdoors in an EF-1 zone (winds ranging from 86 to 110 mph). One of these individuals (who died) was located outdoors (without any shelter), attempting to catch her dog who had run away from the house. The other two individuals, one of whom died, were located outside of Walmart (Store #59), each located in a pick-up truck. However, because Walmart was such a large structure, wind speeds varied depending on a person's location in or around the store. The north half of the building experienced a lower maximum estimated wind speed of 120 mph (at a northerly wind direction), while the collapsed south half experienced a higher estimated maximum wind speed of 165 mph (at a west-northerly wind direction). Consequently, it was difficult to determine the maximum estimated wind speed to which these individuals were exposed.

Four fatalities occurred outdoors in estimated wind speeds between 65 and 85 mph. All four persons were located outdoors, not in vehicles when the storm hit. Three of the dead were found in a drainage ditch at or near 3877 East 27th Street in Joplin. The cause of these deaths was blunt-force trauma according to the Joplin coroner; however, it is unclear what role, if any, water inside the drainage ditch played in the outcomes. NWS instructions provided in tornadoes state that "If no shelter is available… lie flat in the nearest ditch or other low spot and cover your head with your hands." However, this ditch did not provide adequate protection for these three individuals, even at a location not exposed to the highest wind speeds. Finally, an additional fatality was found outdoors at 20th Street and Sergeant Avenue. It is unclear whether the individual was killed at this location by EF-0 wind speeds or if he or she encountered the storm in a nearby location with higher wind speeds (i.e., in an EF-1 zone) and was thrown to 20th Street and Sergeant Avenue.

The majority of impact-related deaths in the May 22, 2011, Joplin tornado, however, occurred inside structures throughout the tornado's damage path. Therefore, it is important to understand the types of buildings in which these individuals sought shelter and the protection offered by these buildings, given the tornadic wind environment. The following section examines the environmental conditions, including building performance and wind environment, encountered by people who lost their lives or were severely injured while indoors during the tornado and how these conditions may have influenced their survival.

3.2 Fatalities that Occurred Inside of Structures

NWS warning information advises individuals to seek substantial shelter if they are outside or in vehicles. While it may provide greater protection than being outside, current building design does not consider tornadoes. In the May 22, 2011, Joplin tornado, 87 % of the fatalities attributed to impact-related injuries involved individuals located indoors during the storm. This section addresses the following question: ***Why did 135 individuals die from impact-related or blunt-force trauma wounds to the body when they were located inside structures throughout Joplin?*** To answer this question, NIST analyzed the performance of the structures in which people died, the wind environment to which these buildings were exposed, and the actions of the people inside these buildings.

To understand the environment to which these individuals were exposed, ArcGIS was used to relate the locations of the buildings in which deaths occurred to the near-surface wind-field map (See Sect. 2.2 in this chapter for additional description of the methods used). Deaths occurred in critical buildings (i.e., St. John's Regional Medical Center or SJRMC), commercial buildings and residential buildings. Details on the wind environment, building type, building damage and actions taken by the deceased for all 11 individual buildings, 51 homes (i.e., single-family homes) and 3 apartment complexes (i.e., apartments) in which people died in the May 22, 2011, Joplin tornado are shown in Table 3. Information from CDC's severe injury sample was used to support findings drawn from the fatalities.

3.2.1 Critical Buildings

Fatalities and injuries occurred in one critical building[4] in Joplin, MO—the St. John's Regional Medical Center (SJRMC). SJRMC comprised eight buildings situated in north and south complexes. We focus here on the two towers, West and East, which were part of SJRMC's north complex, because the majority of the

[4]Buildings and other structures that are intended to remain operational in the event of extreme environmental loading from flood, wind, snow, or earthquakes.

Table 3 Summary of fatalities in critical, commercial and residential buildings

Building	Deaths by estimated maximum wind speed in mph (or EF-range)[a]	Building type	Building damage[b]	Basement (Y/N)	Circumstances of the deceased
Critical buildings					
St. John's Regional Medical Center (SJRMC)	12 deaths; up to 170 mph	West tower: 7-story cast-in-place reinforced concrete frame East tower: 9-story steel frame	Medium	No	Four located in ICU, one on the third floor (not in intensive care); others unknown
Commercial buildings					
AT&T store	1 death; 160	Metal frame walls with brick facade	Unrated (demolished)	No	Crushed in back office
Elks lodge	4 deaths; 170	Wood frame	Demolished	No	Attempting to run to cooler
Full gospel church	4 deaths; 150	Wood frame	Demolished	No	Located in nursery
Harmony heights baptist church	3 deaths; 160	Concrete masonry unit/wood frame walls with wood roof trusses	Demolished	No	Located in nursery and library
Home depot	8 deaths; 170	One-story, box-type system building with a long-span roof	Demolished	No	Located toward the front of the store (lumber area)
Meadows healthcare facility	2 deaths; 100	Wood frame connecting structure; rest of building unknown	Heavy/Totaled[c]	No	(Not known)
Pizza hut	5 deaths; 170	Wood frame	Demolished	No	Thrown from cooler
Stained glass theater	3 deaths; 170	Unreinforced masonry walls with brick facade	Demolished	Yes	Above-ground theater area (survivors in basement)
Walmart	3 deaths; 165	One-story, box-type system building with a long-span, flexible-diaphragm metal roof	Demolished (esp. southern half)	No	(Not known)

(continued)

Table 3 (continued)

Building	Deaths by estimated maximum wind speed in mph (or EF-range)[a]	Building type	Building damage[b]	Basement (Y/N)	Circumstances of the deceased
Residential buildings					
Greenbriar nursing home	19 deaths; 170	Unreinforced masonry with wood roof trusses	Demolished	No	Located in hallway
Single-family homes	59 deaths total; 53 deaths in EF-3 or EF-4 zones (36 in EF-4 zone)	Wood frame	54 deaths in demolished area, 5 in heavy/totaled	56 deaths where no basement, 3 deaths where partial basement	All above ground when storm hit; only 20 known to take internal refuge
Apartments	12 in EF-3 or EF-4 zones (9 in EF-4 zone)	Wood frame	Demolished	No	All above ground when storm hit; only 2 known to take internal refuge

[a]Estimated from the wind field model presented in Kuligowski et al. (2014)
[b]Damage can range from light, medium, heavy/totaled, to demolished. Heavy/totaled is defined as: loss of a significant portion of or the entire roof system, thus exposing the building interior to weather damage and compromising the lateral bracing system for walls, but walls remain standing. Demolished is defined as: roof and walls collapsed, entire structure might be shifted off of the foundation and collapsed
[c]It is unclear why this building received a "heavy/totaled" damage rating since the majority of the roof was intact, except for the small connecting structure on the south end of the building. Additionally, this building was surrounded by other buildings with damage rated as light or medium only

patients, visitors and hospital staff were located in these towers on the evening of May 22, 2011. At estimated maximum wind speeds of 170 mph (EF-4), well above the design wind speed required by current building code, the towers primarily sustained damage to their building envelopes and subsequently interiors, but did so without damage to their structural systems or collapse, as shown in Fig. 5. The damage to these buildings included the breakage of almost all vertical glass; damage to the roofing systems, including the loss of aggregate roof ballast, which became wind-borne debris that further damaged the facility and surrounding areas; damage to the interiors, including the breakage or collapse of interior partitions, suspended ceiling systems, furniture, fixtures and equipment; damage to sections of gypsum-metal stud walls surrounding the elevator shaft and to the elevator equipment itself; and water and debris infiltration onto the floors. One person recalls their experience at SJRMC during the tornado, as follows:

Fig. 5 Damage to the towers of the SJRMC due to the tornado (West Tower on the *right*)

> There were medical equipment, x–rays, chairs, etc., flying towards us. All we thought about was covering dad and protecting him. My brother put himself in front and over dad, I was over his back side and a nurse was covering the side of him. The wind was tremendous at that point. The next thing I remember is trying to not fly out of the window and thinking this can't last much longer, they always say it is over in just a few minutes. Then a door from the room hit me in the back and made me fall to the ground (NIST Interview 105).

All five individuals who died at SJRMC on May 22, 2011, had impact-related causes listed on their death certificates (i.e., multiple blunt-force trauma to the body), and four of the five were patients located in ICUs. The causes of death for these patients were determined by the Joplin coroner to be blunt-force trauma; however, it is unclear what role, if any, their pre-existing conditions or the loss of ICU medical support systems played in these outcomes. One additional patient died on the third floor, but this individual was not in intensive care (NIST Interview 7). His or her death was also due to multiple blunt-force trauma to the body. In addition to the five patients who succumbed at SJRMC, seven people were injured at the hospital, but died in other health care facilities days, weeks or months later. These seven deaths were similarly attributed to multiple blunt-force trauma to the body.

3.2.2 Commercial Buildings

A total of 34 fatalities and an unknown number of injuries occurred in nine commercial buildings due to the Joplin tornado. One of these commercial facilities was in the Walmart Store #59, located at 1501 South Range Line Road in Joplin. The

Fig. 6 Aerial photo of the tornado-damaged Walmart Store #59, showing the collapsed south half and uncollapsed north half of the building.

following passage tells a story of a father and daughter who were located in the Walmart at the time the tornado hit:

> They were told by a manager to go to the back of the store. When people only leisurely took heed, the manager tried again, in a "pretty high tone of voice or something, by saying, 'People, this is for your safety. Please move to the back of the store.' And then I guess it dawned on people—they started moving a little faster. And then he said, 'Calm down. Take your time, just be safe—get back there'" (NIST Interview 81). The father and daughter made it as far back as the Electronics section of the store (directly in front of the Site–to–Store area) and waited there, when all of a sudden the lights flickered. The father remembers the ceiling tiles bouncing up and down, and when he heard the sound of the tornado, which sounded to them like a loud train, he told his daughter to get down. They both got down on their hands and knees and waited for the tornado to pass. When it was clear enough for them to raise their heads, the father saw what was an internal building column before the storm, now laying beside them. He also recalled that two people, located right beside his daughter and him, lost their lives that evening (NIST Interview 81).

Figure 6 presents an aerial photo of the tornado-damaged Walmart Store #59.

With the exception of the Meadows Healthcare facility (estimated maximum wind speed of approximately 100 mph), commercial buildings in this study were exposed to estimated maximum wind speeds of 150 to 175 mph. In all commercial buildings classified as demolished,[5] roofs blew off, exterior walls collapsed, and the

[5]The AT&T store was not rated by the GIS database; however, the pictures after the event clearly show a structure that was "demolished" by the storm.

entire structural systems were significantly damaged. The Meadows Healthcare facility, on the other hand, was exposed to lower wind speeds than the other buildings in Table 3. Even so, the damage to this structure was rated as "heavy/totaled".

In all of the commercial buildings, the persons killed or severely injured (within our sample) were located above ground. Only one of the nine commercial buildings discussed in this section, the Stained Glass Theater building, contained an underground space or basement that was available to patrons. In that structure, no evidence was found that any of those killed were located in the basement at the time the tornado hit. Additionally, one individual in the severely injured sample (provided by the CDC) was located above ground in the entrance or doorway area of the theater when injured.

Victims in these buildings were exposed to flying debris or falling building materials and in some cases were sucked from the building out into the storm. At these high wind speeds of EF-3 and EF-4, buildings were so severely damaged that individuals located above ground in these structures were at high risk of blunt-force trauma from the debris field produced by this storm. In the Meadows Healthcare facility, one of the two victims had reportedly been ill with cancer prior to the storm.[6] It is not known if the other victim was also ill when the storm hit. However, both individuals died the day after the tornado. One possibility is that the tornado, even at lower wind speeds, caused sufficient damage to the building to cause individuals who were already relatively frail to pass away.

3.2.3 Residential Buildings

NIST found that 59 people died in single-family homes as a result of the tornado. These 59 people[7] died in a total of 51 homes along the damage path, the majority of which are wood-frame structures. A "demolished" home located within the tornado damage path is shown in Fig. 7. A large majority of these 59 deaths (53 out of 59, or 90 %) occurred in homes that were exposed to wind speeds characteristic of EF-3 or EF-4 wind zones. Of the six remaining deaths, which occurred in lower wind-speed zones, four were in houses that, despite the lower wind speeds, were still judged to have been "demolished." All 59 fatalities occurred in homes where the building damage was rated as either "heavy/totaled" or "demolished," with the majority of fatalities (54 out of 59 or 92 %) occurring in homes rated as "demolished."

Only 3 of the 59 persons killed had access to an underground level of the house. In all three of these cases, the home was equipped with a partial basement, and NIST found that at least two of these three individuals did not access their

[6]According to information that NIST found through a LexisNexis® search of obituaries.

[7]Six sets of 2 people and one set of 3 people who perished were together in the same houses when the tornado hit.

Fig. 7 Demolished home located within the tornado damage path in Joplin. Note the lack of underground access

basements before the storm hit. The circumstances of the third death, including the location where he or she took refuge, if any, are unknown.

Information on the fatalities in residential buildings can also be ascertained from the survivors who were exposed to similar conditions. The findings concerning fatalities in single-family homes are supported by the experiences of the 18 individuals from the CDC sample who were severely injured in such structures. All 18 of these individuals were located in one-story or one-and-one-half-story single-family homes that were rated as "demolished" by the storm. None of these individuals had homes equipped with partial or full basements. Although it is impossible to know if individuals would have survived if their homes were equipped with basements, it is important to note that NIST found that no fatalities occurred in single-family homes demolished by the tornado in which people took refuge in basements.

There were people, however, who survived in single-family homes located within the EF-4 wind zone. NIST spoke with 27 of them. Of these 27, 11 took shelter in basements (full or partial, located in newer homes). Just one of the 27 interviewees sheltered in a crawl space. The use of crawl spaces was rare in the May 22, 2011, Joplin tornado, even though a large number of the damaged homes within the tornado's path were equipped with them (80 %). The remaining 15 of the 27 individuals survived while located in internal spaces on the first floor of their home, including in internal closets or laundry areas (3 people), internal hallways (5 people), or internal bathrooms (7 people). Half of these 15 people, who took refuge in internal, first-floor spaces, specifically noted that the building damage provided some type of protection for them from the storm (i.e., the building wall fell down and provided a tent-like structure over them). Two others who sought internal, first-floor refuges suffered severe injuries in the storm.

In summary, people did survive in their homes within areas subjected to EF-4 or higher wind speeds. Not all of these survivors were located underground during the storm. However, interviewees who were above ground in these wind speed zones mentioned suffering severe injuries or being fortuitously protected by the building damage around them. Although not a residential building, this interview excerpt from Walmart describes how damage from the storm created unintentional protection, similar to the type of protection created in residential structures throughout Joplin:

> and we all jumped off the counter, landing all over each other… And we were just kinda this mass of arms and legs and bodies, and at that point, it was—you know, people were screaming and crying and cursing and praying, and I was praying… The girders broke all around us; they were like crashing down. Nobody really knew what was happening. It was just this horrible roar. I really didn't know how long it lasted… And when it was over, there was a girder on my back, but it was resting—when I say "on my back," it was touching my back, but it wasn't laying on me. The girder had actually landed on one of the older men that could not get off the counter in time up above me, and it was at about a, oh, I wanna say a 45–degree angle. It was resting on the cabinet, and then it went down to a point inside the cabinets. It actually broke—well, the cabinets were pretty much destroyed on that end, but the weight of the girder, it crashed down. But that cabinet where that man was saved all of our lives in there, because it made like this—most of the girders, most of the ceiling girders, when they landed, they just made a cap and landed, mainly right across the cabinets. It made a little pocket inside of those cabinets; a little D–shaped pocket, where we had probably 50, maybe 60 people inside of there (NIST Interview 99).

NIST found that 12 people died in three different apartment complexes as a result of the tornado. At all three sites, occupants were exposed to wind speeds characteristic of EF-3 or EF-4 zones. All 12 fatalities occurred in apartment complexes that were rated as "demolished." These complexes were primarily wood-frame structures not equipped with underground or aboveground protection areas. Consequently, all of those killed were located above ground when the storm hit, and at least one was known to be located inside his apartment (floor level unknown).

Because residential basements were scarce in Joplin,[8] it was important to understand whether any of those who were fatally injured in homes or apartments sought shelter on the lowest floor of the building in an interior room or hallway. Data collected on the fatalities in single-family homes and apartments showed that 20 of the 71 individuals were known to have taken refuge on the lowest floor of the building *and* in an internal location (the locations of 41 individuals were unknown).[9] Data collected on those severely injured in single-family homes and

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[8]Only three of the 71 individuals who died in residences in the Joplin tornado had access to basements. Two of these three individuals did not take refuge in the basement before the storm hit, and the other individual's location within the home is unknown.

[9]The locations of the two fatalities in apartments who took internal refuge (in a bathroom) were counted as "unknown" because it is unclear whether they were in a ground-floor apartment.

apartments showed that 12 of the 19 individuals were known to have taken refuge in internal locations on the lowest floor (2 individuals' locations were unknown). What these findings show is that some individuals in residential facilities, both inside and outside of internal (first-floor) shelters, were severely injured or killed in this tornado.

Greenbriar Nursing home, a residential structure, was the location of 19 deaths from the tornado. The building, an unreinforced masonry structure, was exposed to an estimated maximum wind speed of 170 mph. The structure was later rated as "demolished." It is unclear where the 19 fatalities were located within Greenbriar, but five individuals (from the CDC sample) at the Greenbriar who sustained severe injuries were located in the hallway, a bedroom and a doorway inside the structure. Overall, critical, commercial and residential buildings in which people died were demolished or very heavily damaged by this storm. Larger structures, like the Walmart and Home Depot, sustained large areas of damage and collapse, some of which occurred in areas where people were located. Additionally, even though SJRMC's patient care buildings did not collapse, their interiors were significantly damaged by winds and flying debris and this damage rendered them unusable. May 22, 2011, Joplin tornado fatalities were primarily located in buildings that were exposed to wind speeds within the EF-3 and EF-4 zones. NIST found no evidence that any fatalities occurred to individuals located below grade in this storm.

3.3 Summary

Across both indoor and outdoor settings, the majority of impact-related fatalities (78 %) and the sample of severe injuries (83 %) occurred in areas where the tornado produced the strongest wind speeds in EF-3 or EF-4 wind zones. Sixty-two percent of fatalities and 74 % of the sample of severe injuries occurred in EF-4 zones. Only 8 % of the fatalities and 6 % of the sample of severe injuries occurred in wind speeds less than 110 mph (<EF-2). These data are shown below in Table 4 and mapped in Fig. 8.

Table 4 Wind speed ranges of the 154 impact-related fatalities

Wind speed range (mph)	Number of fatalities	Percentage	Number of injuries	Percentage
65–85 (EF-0)	4	3	0	0
86–110 (EF-1)	8	5	2	6
111–135 (EF-2)	22	14	4	11
136–165 (EF-3)	25	16	3	9
166–175* (EF-4)	95	62	26	74

*Note 175 mph was the maximum estimated wind speed throughout all of Joplin. The actual maximum value in the EF-4 range is 200 mph

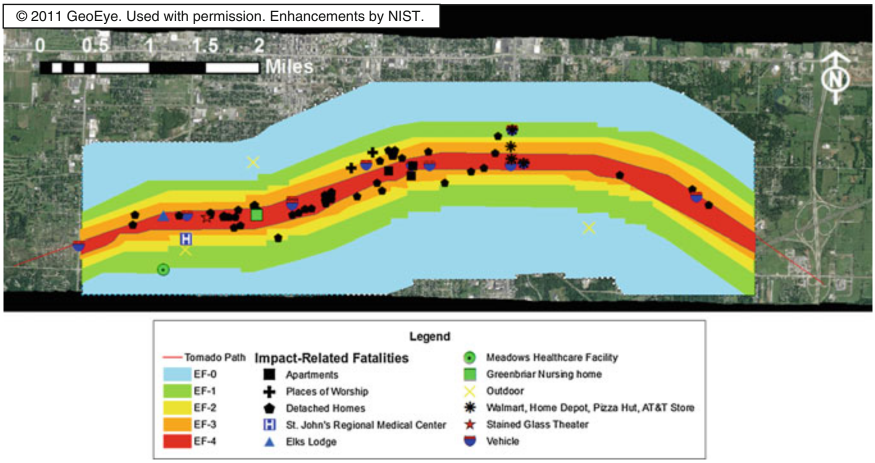

Fig. 8 Graphic showing the location of all 154 impact-related fatalities in relation to the EF wind speed zones (*red* EF-4, *orange* EF-3, *yellow* EF-2, *green* EF-1, and *blue* EF-0).

Overall, the May 22, 2011, Joplin tornado demonstrated that being closer to the center of a strong to violent tornado is associated with a higher chance of fatal injury, both inside and outside of buildings. The tornado produced winds that exceeded the design parameters used for many of the buildings within Joplin, and these winds posed risks for people regardless of whether they were indoors, in vehicles, or outdoors without any protection.

The findings in this chapter reflect that approximately 12 % of the persons killed by this tornado were caught outside buildings, and even outside vehicles, when the storm struck. Some individuals interviewed by NIST, especially among those who were severely injured by the storm, found themselves actually driving into the path of the storm instead of away from it.

> A couple near 20th Street and Delaware Avenue recalled, "the sky had just went all black. You couldn't see anything, and it was raining really hard" (NIST Interview 26). The notion of the tornado, from the driver's perspective, not being "seen" clearly or at all was confirmed in a number of interviews, and corroborated through surveillance videos. An individual driving near West 32nd Street and Westberry Lane mentioned that he "could see a wall of water that was about 200 yards ahead of me and I just assumed that was the straight–line winds" (NIST Interview 15). Another interviewee at 20th Street and Rhode Island Avenue described the tornado as "a wall of clouds moving at me. It was still grey, but it was getting darker, and darker" (NIST Interview 60).

Within the Joplin area, individuals had no access to public, FEMA-approved tornado shelters and very little access to underground locations or indoor storm shelters, either in homes or in commercial buildings. However, residents and visitors throughout the area received 17 min of warning lead-time to find safety from the storm (NWS 2011). Behavior in Joplin and previous tornadoes makes it imperative to understand the role that severe storm forecasting, emergency communication and subsequent public response played in the casualty statistics from this storm. The high number of fatalities observed in Joplin in the high wind speed areas proves the need to consider ways of further protecting life and safety in tornado-prone regions.

Therefore, in the following section, one additional question will be considered: Given the relatively generous warning lead-time provided by Joplin's emergency communication system, ***why did so many casualties occur, especially in places where safer locations were available?***

4 Conceptual Model of Protective-Action Decision-Making; a Path to Best Practices

To answer this question of why so many casualties, it is important to look at the information that people received before the tornado struck, and the influence that this information had on risk perception and subsequent protective actions. NIST was unable to ascertain what emergency information the deceased had received and the subsequent motives or perspectives that guided their actions. NIST also did not have a complete sample of severely injured individuals; even for the sample it did have, only limited data were available concerning the tornado-related information that these individuals received and the actions they took as a result.

However, it was possible to determine the factors that influenced survivors (those injured or not injured) to decide against protective action. Although many interviewees had chosen to take protective action and made it to a "safer place" (indoors, and in internal refuge areas), a majority of these survivors had decided against protective action at some point in their decision-making process. If their rationales can be attributed as well to the deceased, and the authors of this chapter believe that this is a reasonable assumption, then we can begin to identify possible reasons why additional warning lead-time had not necessarily lead to the protection of all individuals in this storm.

We mentioned earlier in this chapter, in Sect. 2.5, that NIST interviewed and analyzed the behavior of a sample of people (n = 140 "decision-makers" out of 168 people) who experienced and survived the May 22, 2011, Joplin tornado to identify reasons why protective actions were or were not taken before the storm hit. In turn, NIST could then identify necessary improvements to the emergency communication system and/or protocols. A model depicting conceptual decision-making in the Joplin tornado is presented in Fig. 9 and described here. The NIST Investigation report provides further detail on this conceptual model (Kuligowski et al. 2014).

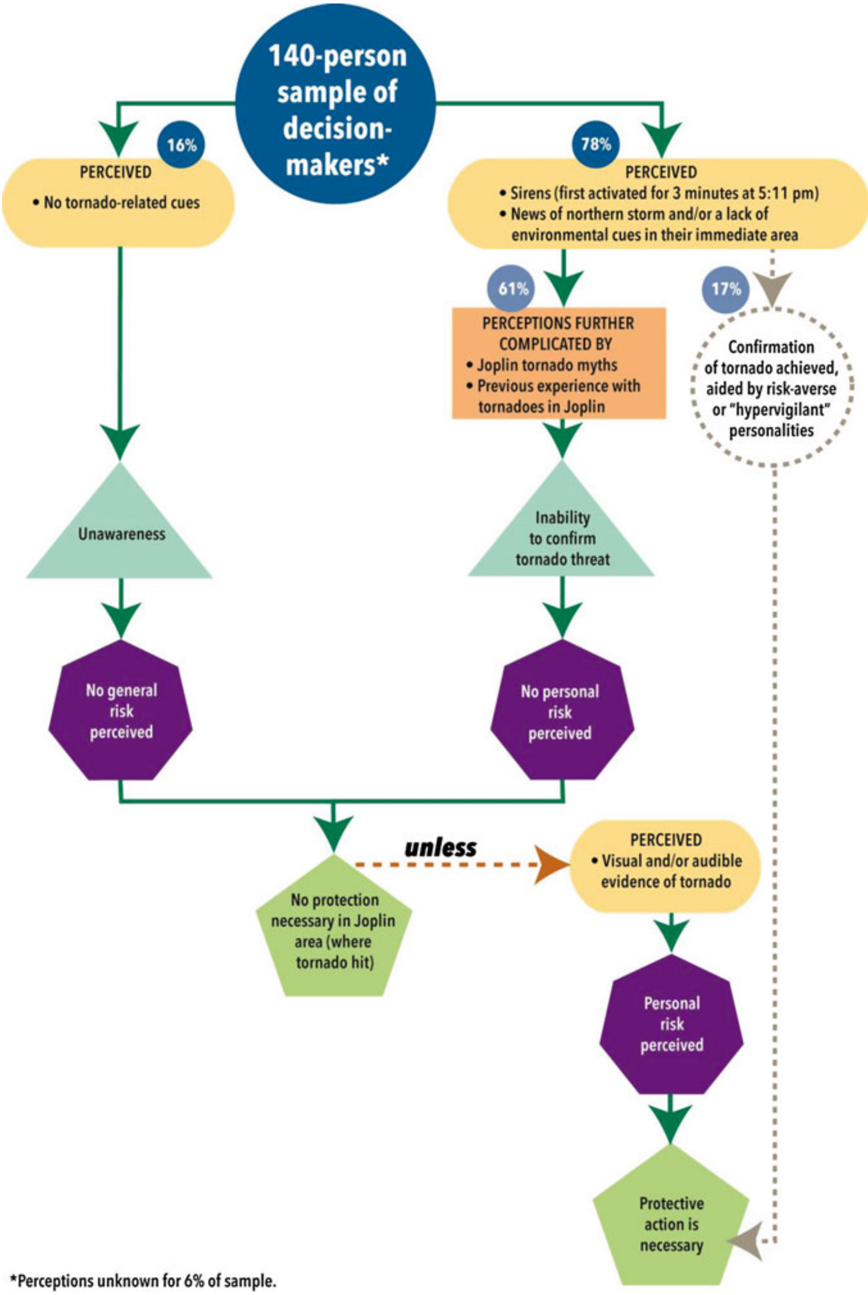

Fig. 9 A model depicting protective-action decision-making

4.1 Protection is Unnecessary

The model shows that a majority of decision-makers decided, at some point before the tornado hit, that the act of seeking protection was not necessary. The conceptual model presents two main reasons for this decision: not perceiving any general risk associated with this event and not perceiving personal risk associated with this event.

4.1.1 Unawareness

In the first case, individuals who did not receive tornado alert- or warning-related cues on May 22, 2011, i.e., those who were unaware that a tornado event was taking place, did not formulate any general risk associated with the event and thus, did not act to protect themselves. Of the 140 survivors included in this analysis, 16 % were unaware that a tornado event was taking place until a family member or friend called and/or the tornado was upon them. The 16 % of decision-makers who fell into this category were distributed among three different awareness states that made the receipt of warning information difficult: asleep, awake with impaired hearing, and awake but disconnected from tornado-related emergency communications.

For example, a couple in their late 80s was watching television before the storm hit, and do not recall receiving any information on the impending tornado. They were both hard of hearing, potentially making it difficult for them to hear outdoor sirens (which others claimed they could hear from indoors) as well as information provided via the television programming that they were already watching. Additionally, extended family members who would normally call and alert them of bad weather were out of town on the evening of May 22. That evening, the wife had noticed that it was getting dark outside. So she went to light candles near the front of the house when the following happened, according to the couple's daughter:

> It just hit right then, and everything started flying, and [the husband] threw her [his wife] down in the hallway and just jumped on top of her and held onto the carpet as best he could, and the floorboards. He said when it was over this whole part of the roof was off (NIST Interview 20).

This couple was caught completely off-guard by this storm, and suffered minor injuries from being thrown around the house during the tornado.

For those disconnected from tornado-related emergency communications, individuals were out-of-range from the city-wide tornado siren system, and/or simply did not hear the sirens from inside their homes. Even though the siren system was meant to alert individuals located outside structures only, there was an overwhelming sense among the interviewees that Joplin-area residents located indoors (especially at home) relied on this technology to alert them as well. These decision-makers were also disconnected from other forms of tornado-related emergency communication, such as NOAA Weather Radios (NWRs) or opt-in subscription services that provide messages to mobile phones in the Joplin area.

4.1.2 No Personal Risk Perceived

In the second case, individuals who were unable to confirm the existence of a tornado, either due to receiving conflicting or uncertain information and/or their pre-existing perspectives on tornadoes in general (formed prior to May 22), did not perceive any personal risk as a result of the weather that day. As an example, an individual located in the Joplin Missouri Stake Center (a place of worship within the City of Joplin) when the tornado hit, discussed his pre-existing perspectives on tornadoes in the following way: "having lived in Missouri for almost 30 years, I had experienced this routine before and was thoroughly expecting the storm to be another one that did no damage, and just passed us by, so I did not panic" (NIST Interview 73).

Of the 140 survivors, 61 % were unable to confirm the existence of a tornadic event until they encountered direct visual or audible evidence of a tornado.

When initial information was given to decision-makers on May 22, 2011, around 5:09 p.m., including the sirens that sounded at 5:11 p.m., little information had been available that would have helped confirm the risk of a tornado threatening the large portion of Joplin that actually touched down beginning around 5:34 p.m. Any public warning information around 5:09 p.m. (until 5:17 p.m.) was related to a *different* storm that weather forecasters were tracking to the north of Joplin, which was heading toward Webb City, Missouri, or Carl Junction, Missouri. A Joplin native remembered that

> the announcer and the weatherman that came on the TV seemed to say the track was, you know, mainly north of town. It wasn't going to be a bother for where I was at towards the south part of town. So, I continued to sit there on the front porch and enjoy the cool air that was, you know, for the day (NIST Interview 58).

After hearing this information and based upon the perceived tendency for storms to track toward the northeast only, interviewees formulated that they were not at risk.

Around this same time, individuals were offered very little environmental cues of an impending storm, also making it difficult to confirm the tornado risk. People looked outside, to the sky, for clues that a tornado was coming and saw only clouds that did not look as menacing as what would accompany a tornado. An interviewee recalled his actions at home that evening:

> The tornado sirens went off once, we walked outside and you couldn't really, didn't really see nothing then, and we went back in and finished eating (NIST Interview 108).

The decision had become as simple as that—if there was nothing in the sky to worry about, then it was appropriate to return to your previous pursuits until something else caught your attention. Some people continued to monitor the weather reports, while others resumed activities unrelated to the weather.

Even after the first set of sirens stopped and time progressed, interviewees who continued to monitor the weather via television or radio (or Internet sources) still did not perceive firm confirmation of a storm likely to affect them. First, the NWS issued a tornado warning at 5:17 p.m. for the storm that eventually struck Joplin; however, the outdoor siren system was not reactivated at 5:17 p.m. Also, interviewees who had been tuned into the news outlets at 5:17 p.m. primarily reported that the media continued to discuss a storm that was to the north of Joplin.

During this time, the inability to confirm personal risk in a timely manner on May 22, 2011, was exacerbated by Joplin–area residents' perspectives on tornadoes in general. When asked about their views on the possibility of severe storms in Joplin, decision-makers in the 140-person sample (and even other NIST interviewees) generally did not believe that tornadoes in Joplin were something that they would witness during their lifetimes.

One factor behind these views was a public perception, which was pervasive among the decision-makers, that false alarms were common in Joplin. One individual described his perspective on storm warnings as follows:

> I grew up in Arkansas and spent a lot of time in Oklahoma, and then Missouri in this area. So, tornado watches are common. But, tornadoes don't always strike, and they're usually small. So, the chances of it truthfully hitting are pretty slim (NIST Interview 10).

Decision-makers seemed to blame the outdoor siren system for over-warning as well, even though the sirens sounded only once per year, on average, for wind-related events.

Even if a tornado did materialize, most interviewees erroneously believed that they would be safe inside the city limits of Joplin. Residents were confident that they would be protected from severe storms and tornado damage, and believed that "it cannot happen to us" based upon tornado tracking beliefs. For example, interviewees believed that severe storms always went around Joplin to the north or the south, creating a mythical "bubble" around their city that protected them from harm.

Finally, some interviewees expressed their confusion regarding the tornado siren protocol. On May 22, 2011, some interviewees were confused about how long the sirens should sound and the reasons why the sirens stopped after 3 min, even though this was Joplin's emergency communication protocol. However, contrary to protocol, Joplin survivors were unsure why the second siren had been initiated (at 5:38 p.m.), since this had not happened in the past, and in turn, did not take action or delayed their action until receiving more convincing evidence of the tornado.

4.2 Protective Action is Necessary

Eventually, at some point, almost all decision-makers decided that protection was necessary before the tornado hit their location. However, just because survivors made the decision to take protective action did not mean that they reached their optimal location before the tornado reached them. As mentioned above, they may have delayed taking protective action because no personal risk was perceived until the tornado was upon them. For example, some individuals who delayed action were in their cars, and simply pulled over to ride out the storm.

There were two reasons why individuals eventually decided that protection was necessary. The first was that confirmation of the tornado was achieved after the initial warnings were provided (at 5:09 p.m. or 5:11 p.m.). The second was that personal risk was perceived, but this occurred as the tornado was approaching. Both reasons are discussed in the following sections.

For 17 % of the decision-makers, confirmation of the tornado was achieved when they received the initial set of warning information (i.e., the first set of sirens at 5:09 p.m. or 5:11 p.m. and/or the news about a northern storm). These individuals took action to protect themselves and their families based upon the same types of information that a majority of individuals in this sample used to decide *against* action. The main reason identified for taking "early action" in this tornado was the nature of decision-makers' personalities and/or pre-existing risk perceptions associated with tornadoes. Two types of personalities are identified here: "risk-averse" decision-makers and "hyper-vigilant" decision-makers. Risk-averse decision-makers claimed to have sought protection every time they had heard the sirens activated before May 22, 2011. Decision-makers categorized as "hyper-vigilant" (7 out of 140) described themselves as generally fearful of tornadoes, although none had actually been through a tornado before.

The majority of decision-makers who eventually decided that protection was necessary did so only after receiving intense cues from the environment (shown as the lower branch in Fig. 9). Intense cues were those visibly or audibly disseminated by the tornado. Actually seeing the massive debris wall heading straight for them or hearing the sound of a freight train caused Joplin survivors to perceive risk and that

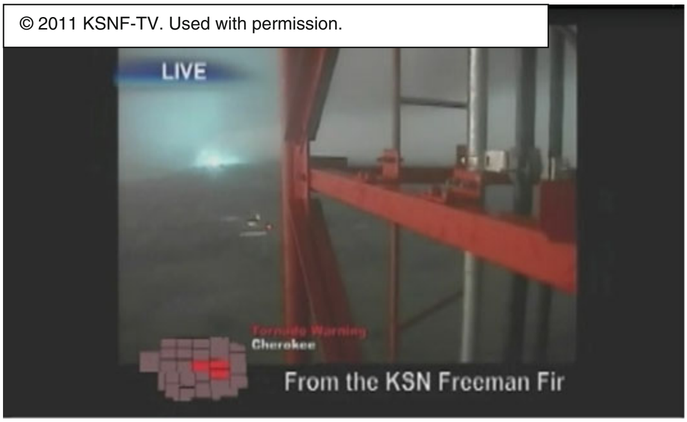

Fig. 10 A visual shot of the 2011 Joplin, MO tornado captured and broadcast by Nexstar Broadcasting [parent company for KSNF-TV (NBC Channel 16)].

they were potentially in trouble. High-intensity cues also included seeing large trees swirling or laying down on the ground, seeing cars or other heavy objects lift or fly off of the ground, and hearing information about the tornado in an urgent tone (e.g., the newscaster who urgently prompted people to "Take cover now!"), based on the image shown in Fig. 10 of the visual shot of the tornado captured and broadcast by Nexstar Broadcasting [parent company for KSNF-TV (NBC Channel 16)]. It was at this point when they realized that protection was necessary if they wanted to escape this tornado unharmed. Seeing or hearing these cues prompted people to take shelter in various locations in buildings, in vehicles or outdoors. Among these individuals, the intense cues triggered cognitions about risk and danger to themselves, their friends and family members. In some cases, the cues were so severe that individuals who were already located in their basements (e.g., "early actors") moved to an internal refuge area (closet or bathroom) within their basement.

Because the majority of decision-makers waited until the last moment to take protective action, their sheltering options were often limited and suboptimal. Joplin survivors frequently had access to below-grade crawl space refuge areas in their homes, yet, they rarely considered these spaces as viable options because of the time required to access them. This forced individuals without basements or tornado shelters to utilize aboveground bathrooms, closets and laundry rooms for safety. Additionally, last-minute decisions caused drivers in Joplin to simply pull over and face the massive storm-which often meant getting hammered with debris or even lifted up into the storm (inside or outside of their vehicle), only to crash down again. Some last-minute decision-makers were caught outside houses and businesses, where they were forced to fight for their lives by holding onto the structure. And, even in some businesses, last-minute decisions left people running to shelter locations as the tornado ripped their buildings apart.

5 Recommendations and Future Work

As a result of the NIST Technical Investigation of the May 22, 2011, Joplin tornado, NIST made 16 recommendations for improvement in three broad areas: (1) tornado hazard characterization for use in design; (2) performance of buildings, shelters, designated safe areas, and lifelines; and (3) performance of emergency communication procedures and systems and public response. A full list of these recommendations with detailed supporting rationales may be found in Kuligowski et al. (2014). These are practice-changing recommendations, aimed to ultimately make significant and measurable improvements to life safety of building occupants, and include calls for reexamination of tornado risks, and development and adoption of tornado-resistant design standard for buildings. Within the purview of this chapter, which focuses specifically on the subjects of human response to and consequences of this disaster event, the NIST Investigation yielded several significant findings and recommendations. These are described in details below.

5.1 Best Practices and Recommendations for Human Health and Community Engagement

NIST found that people's responses to the impending storm, in many cases, were delayed or incomplete, which resulted in some fatalities occurring outside, in vehicles, and among individuals rushing to obtain safer refuge when the tornado struck. Among those who did not respond or delayed their response, NIST found that either the individual or group: (1) lacked awareness of the tornado or (2) did not perceive personal risk associated with this event. Improvements can be made to the emergency communication system for individuals in both instances—i.e., unawareness or a lack of risk perception—to increase the likelihood of achieving higher life safety outcomes after tornado events.

Individuals within the tornado's damage path who were unaware of the impending danger included those with hearing loss, individuals who were asleep before the storm hit, and persons who were disconnected from available modes of emergency communication. Also, the use of NWRs or subscription-based mobile alerting systems was not prevalent among Joplin residents and visitors. Therefore, as part of the investigation, NIST recommended that the full range of current and next-generation emergency communication "push" technologies be evaluated for future use in disseminating alert and warning information. "Push" technologies are those that do not rely on the user to actively search for information. One example of an alerting push technology is outdoor siren systems. However, in Joplin the siren system was designed to alert only individuals who were located outdoors, even though many individuals could hear these alerts inside their homes and businesses throughout the city. Additionally, no associated warning information was disseminated with these alerts on May 22, 2011, causing individuals to have to search for additional information about the event.

New technologies are being explored that deliver both alert and warning information based upon geographic location. One of the newest sources of such technology is the Commercial Mobile Alert System (CMAS). CMAS is a partnership between FEMA, the Federal Communications Commission (FCC), and wireless carriers, that allows public-safety authorities (either local EMs or the NWS) to send 90-character, geographically targeted, text-like alerts to the public through their mobile devices. Unlike most mobile services, this is not an "opt-in" system. Rather, individuals with enabled mobile devices who are within a certain distance of activated cell towers *will* receive the alert messages. These alerts will bypass the regular networks that often bog down due to increased traffic during emergencies.

However, there are limitations associated with this new and exciting technology. For example, notification resources such as cell phones and social networking sites like Twitter have restrictions on the length of individual alert or warning messages. Too, individuals who are sleeping still may not receive these types of mobile alerts, especially those in deeper stages of sleep. Therefore, NIST recommends additional exploration of technologies that are able to reach more vulnerable populations in tornadoes, namely those who are sleeping or have visual and/or hearing impairments.

More recommendations came from the NIST Investigation to increase public perception of risk before tornado events in order to promote more effective and safer responses. Perception of risk is difficult to achieve unless emergency warning information provided is credible, trusted, clear, and consistent. Therefore, NIST recommends the development of national codes, standards, and/or guidance for the creation and dissemination of clear, consistent, and accurate emergency communications for tornadoes. Currently, no federal, state, or local guidance or requirements exist that standardize such systems, resulting in different systems and operating practices (at least for the use of outdoor warning sirens for tornadoes) from one municipality to another. Especially important is the inclusion of guidance on both alerts and warnings. Alerts, such as activation of outdoor sirens or dissemination of social media messages, are meant to grab people's attention, whereas warnings provide information on the nature of the emergency and what actions people should take. Provision of warning information along with alerts could have improved the public's understanding of why the sirens were sounding in Joplin. Understanding could also have been enhanced if the public had received timely and consistent, rather than conflicting, information about weather developments before the tornado struck. NIST recommends that these efforts involve, jointly, emergency management, the NWS, and the media, to avoid conflicting messaging in emergencies.

In order to promote human health and safety, NIST also made recommendations related to building, shelter, and designated refuge area performance. Specifically, NIST found that Joplin residents, especially those of multi-family residential buildings, had either limited option or access to underground or tornado-resistant shelters. Since the majority of the homes in the affected area in Joplin (82 %) lacked basements and only a few commercial buildings were equipped with underground locations, none with tornado-resistant above-ground shelters, most individuals were limited to take shelter above ground in buildings that ultimately sustained heavy damage, or in vehicles. Moreover, there were no community shelters or safe rooms (defined as structures designed in accordance with either the ICC 500 standard or FEMA 361 guidance) in the City of Joplin or Jasper County at the time of the May 22, 2011, Joplin tornado. Above-ground residential crawl spaces were often available for sheltering, although residents generally did not use them during the May 22, 2011, Joplin tornado because they perceived that they had insufficient time to access them or that the crawl spaces would be too difficult or uncomfortable to use as shelters. In addition, while many critical and commercial facilities in Joplin had designated refuge areas and pre-disaster emergency protocols, the locations of these areas were not always selected solely on structural considerations as there are currently no design standards, requirements, or best-practice guidelines for selecting best available refuge areas within existing commercial or critical buildings. Consequentially, several of these areas suffered severe damage and yielded no positive outcomes with respect to loss of life for occupants who took refuge in these areas during the May 22, 2011 Joplin tornado. Perhaps correspondingly, NIST found an overwhelming majority of the fatalities in Joplin (96 %) were caused by impact-related factors (usually labeled by authorities as multiple blunt-force trauma to the body), and a majority of these victims (83.8 %) were located *inside* buildings when they were fatally injured. Therefore, to enhance life safety options for those individuals who can and do respond to tornado emergency communication, several of the NIST recommendations call for (1) the development of the first-ever tornado-resistant design standard for buildings to improve their structural performance in tornado; (2) installation of tornado shelters in new and existing multi-family residential buildings, mercantile buildings, schools and buildings with assembly occupancies to improve life safety of occupants in tornado prone regions; and (3) enhancement of egress systems' enclosures of critical facilities in tornado prone regions.

5.2 Future Research

NIST also recommended longer-term research to promote life safety in tornado events. More specifically, NIST recommends research to identify the factors that will significantly enhance public perception of personal risk and promote rapid and effective public response during emergencies, including tornadoes.

NIST found that the prevalent "take shelter now" trigger in Joplin for individuals responsible for their own protective decision-making (e.g., those located at home) was when they received high-intensity cues, including hearing or seeing the tornado approaching or witnessing others' urgent efforts to seek protection from the storm. One media source, credited by some with saving lives before the tornado hit, had broadcasted a video of the approaching tornado, with the station's newscaster pleading with listeners to "Take cover now!" Both the video and the urgent tone of the broadcaster were highlighted as increasing individuals' perceived risk associated with the event, prompting them to take action before the tornado struck.

The NWS is testing a new method of including stronger-worded text in tornado warning messages for higher-severity storms. However, little research or guidance is available on how to disseminate messages both visually and audibly to increase risk perception. While human factors and ergonomics research is available on ways of increasing alert or message urgency (e.g., through specific types of tones or voice pacing or frequency), little research or guidance is available on the effectiveness of such technologies in disaster situations. Therefore, research should explore various ways to create and disseminate warnings, as well as to train and educate the public to achieve higher levels of perceived risk when a tornado is imminent.

As stated in this chapter, a majority of the people who took action in this tornado were prompted by audible and/or visual cues. From a tornado hazard standpoint, it is important to understand the intensity of environmental cues (e.g., wind speed, debris) that prompt human response, especially in highly populated, urban areas.

However, due to the complexity of the wind speed—damage relationship, understanding of human response in these situations remains difficult. Using other forms of data such as social media to assess past, current or future hazard conditions are necessary. Obviously, the magnitude of the hazard is strongly correlated with the extent of physical damage. Understanding both the hazard and damage conditions and how they are related to human behavior are of high importance. For this reason, NIST also recommended a fundamental review of tornado data available to-date and current methods for assessing tornado risk, and the development of a science-based tornado hazard maps, using up-to-date tornado data with consideration of the spatial extent (e.g., city boundaries) of tornado affected areas, for use in tornado-resistant design of buildings in the future.

6 Overall Summary

An NWS-rated EF-5 tornado struck the city of Joplin, Missouri on May 22, 2011. This tornado caused a record 161 fatalities, damaged nearly 8000 structures, including well-engineered, code-compliant critical and commercial facilities, and inflicted billions of dollars of damage and economic losses. Due to the uniqueness of this event and its impacts, NIST deployed a multi-disciplinary, multi-agency team that included structural and wind engineers, a sociologist, and a meteorologist to Joplin immediately after the event to collect data on the environmental conditions, performance of buildings and designated safe areas, emergency communications and human response to the Joplin tornado. The information collected from the field deployments were used in support of a multi-year NIST investigation of the event, conducted under the NCST Act, which sought to determine the technical factors contributing to the record-setting consequences that resulted from this disaster. We have focused our chapter on the human responses to and consequences of the Joplin tornado.

Of the 161 fatalities, 154 of them were due to “impact-related” trauma from the tornado. These 154 fatalities occurred both outside (open air, vehicles) and inside critical, commercial and residential buildings. Not surprisingly, the majority of impact-related fatalities occurred in areas with the strongest estimated wind speeds and, in the case of building-related fatalities, both the strongest wind speeds and the heaviest damage. In addition to analysis of the impact-related fatalities and injuries, a conceptual model of protective action decision-making was developed based on interviews with Joplin tornado survivors to further understand decision-making in response to tornado cues. The model shows that the majority of survivors who were responsible for their own safety and possibly the safety of others (i.e., decision-makers) decided at some point before the tornado hit, that the act of seeking protection was not necessary. Reasons for not taking protection ranged from not perceiving any tornado-related cues to previous experiences with tornadoes, confusing and/or inconsistent emergency communication regarding the tornado (including outdoor warning sirens), and tornado beliefs about Joplin. It was only when audible or visual cues signaled them to the imminent danger did the majority of the decision-makers within this sample take protective action. Because the majority of decision-makers waited until the last moment to take protective action, their sheltering options were often limited and suboptimal.

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Approaches for Building Community Resilience to Extreme Heat

Peter Berry and Gregory R.A. Richardson

Abstract Climate change is expected to increase the frequency of extreme heat events; observations already confirm this trend in many parts of the world. Extreme heat results in significant increases in morbidity and mortality when individuals and communities are not prepared for it. Vulnerability to the health impacts of extreme heat depends on a number of important individual and community level factors. This chapter presents current knowledge for supporting the development of Heat Alert and Response Systems (HARS) which alert the public and community stakeholders to dangerously hot conditions so that protective measures can be taken that reduce health impacts, particularly on the most vulnerable in society such as older adults, infants and young children, people with chronic illness, and the socially disadvantaged. Information about temperature-mortality associations provide an evidence-based foundation for developing effective measures to protect health. Effective HARS also require engagement with a broad range of community stakeholders to address key vulnerability factors (e.g. role of space and place and socio-economic challenges) and include preventative urban design measures that reduce local heat exposures before they occur. The chapter provides cases studies of Health Canada's collaboration with partners at the provincial and community level aimed at increasing understanding of heat-health impacts, building the capacity to manage growing risks due to climate change and expanding HARS to at risk communities.

Keywords Extreme heat events · Heat Alert and Response Systems · Heat illness · Urban heat island · Climate change adaptation

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1 Introduction

There is widespread evidence of the impacts of climate change around the globe such as increased annual temperatures, changes in precipitation regimes, sea level rise and ocean acidification (IPCC 2013; Patz et al. 2014). Since observations began in 1880, the year 2015 was the hottest on record. It was also the 39th consecutive year that the global temperature was above average (NOAA 2016). Due to the long-lasting nature of greenhouse gases in the atmosphere an additional human-induced warming of 0.7 °C will be realized irrespective of near term reductions in levels of greenhouse gas emissions (McMichael 2013). For the period 1986–2005 to 2081–2100 the increase in average global temperature is projected to be from 0.3 to 4.8 °C, with near-tem warming between 2016 and 2035 expected to be from 0.3 to 0.7 °C (IPCC 2013).

Risks to human health and well-being from climate change are broad. Direct and indirect health impacts are already being observed in both developed and developing countries (McMichael et al. 2006; Costello et al. 2009; Myers and Patz 2009; Berry et al. 2014a; Luber et al. 2014; WHO 2014) and risks are increasing as ecological, social, cultural and economic systems continue to be impacted (McMichael 2009). Knowledge gaps remain concerning attributable disease burdens and projected future impacts. The number, intensity, spatial extent and duration of many extreme weather events such as rain, hail, thunder and lightning, strong winds, and extreme heat events are expected to increase as the climate continues to change (IPCC 2012). For example, a hottest day event in a community that only occurred once every 20 years could likely occur every other year by the end of the 21st century (IPCC 2012). Estimates exist on the projected increase in hot days for a number of cities in Canada (Casati et al. 2013) and in the US. For example, the annual number of 32 °C/90 °F days in New York City could triple by 2050 (from 13 to 39 days) (Patz et al. 2014). Researchers have begun attributing the occurrence of heat wave events, among other extreme weather events, to climate change. Analysis suggests that climate change greatly increased the risk of the record heat waves of 2013 across inland eastern Australia and in Japan (Herring et al. 2014).

A particular concern to human health and vulnerable communities is that mega heat waves are projected to increase in frequency by 5- to 10-fold by the 2050s (Patz et al. 2014). Recent weather events such as the heat waves that affected Europe in 2003 (70,000 deaths) (Robine et al. 2008) and Russia in 2010 (55,000 deaths) (Barriopedro et al. 2011) highlighted the potentially catastrophic consequences of large scale weather disasters on unprepared communities. According to the World Health Organization, in the year 2030, 38,000 additional deaths related to heat exposure are projected to occur globally due to climate change (WHO 2014).

Extreme heat events can also result in significant costs to society. For example, the 2157 excess deaths in the United Kingdom that resulted from the 2003 heat wave are estimated to have cost 2.6 billion pounds. In addition, 1650 excess hospital admissions cost the health system 32 million pounds (Hutton and Menne

2014). Given concern over the growing risks from extreme heat events, health authorities in many countries (e.g., Canada, US, Australia, Spain, France, United Kingdom) and within international health agencies (WHO 2009) have identified heat as a growing public health threat and are developing and implementing adaptation actions to protect people.

Climate change could be the greatest threat to human health of the 21st century (Costello et al. 2009) and actions should be taken by health authorities in all countries to reduce avoidable impacts. This chapter reviews the human health risks from extreme heat events, with a focus on health vulnerabilities and intervention strategies in the Canadian context. It examines current knowledge of adaptation measures that can effectively reduce dangers associated with extreme heat. The chapter discusses consideration of place-based and local context factors for understanding important priority vulnerabilities and designing effective public health interventions. Recent research findings highlight the importance of comprehensive and preventative approaches to preparing communities for extreme heat events—approaches that seek to build the resilience of populations through a wide range of activities—from improved communications about risks and protective behaviours to efforts to mitigate community heat exposure through urban design innovations. To conclude, we draw upon lessons from Health Canada's initiative to increase the resiliency of Canadians to extreme heat events (http://www.hc-sc.gc.ca/ewh-semt/climat/index-eng.php) to provide the reader with practical examples of adaptation planning, stakeholder engagement, and education and outreach activities.

2 Understanding Vulnerability to Extreme Heat

2.1 Health Risks from Extreme Heat

People have the ability to adapt to hot temperatures. However, excess deaths observed in many countries during high temperatures indicates that physiological adaptation is not fully protective (Jendritzky and Tinz 2009). Health is affected by extreme heat when it affects the body's ability to regulate core temperatures; this can lead to skin rashes, cramps, dehydration, syncope (fainting), exhaustion and heat stroke (Health Canada 2011a). Extreme heat events have also been linked to short-term increases in mortality (Bouchama et al. 2007; Kovats and Hajat 2008; Kenny et al. 2010; CIHI 2011; Gamble et al. 2012). People with pre-existing health conditions such as cardiovascular, cerebrovascular, respiratory diseases and neurological disorders are at higher risk (Kenny et al. 2010; Health Canada 2011a). Indirect impacts on health from such events have also been observed. The rate of assaults and domestic violence in Montreal (Quebec) have been linked with hotter weather, particularly when temperatures were above 30 °C/86 °F (Ouimet and Blais 2001).

In the US, between 2006 and 2010 approximately 620 people died each year from exposure to extreme heat, roughly 30 % of all weather-related deaths (Berko et al. 2014). However, because surveillance and monitoring activities based upon the use of disease and heath related problem codes (International Statistical Classification of Disease and Health Related Problem Codes (ICD)) by hospital health coders, coroners, nurse help-lines, and emergency medical service workers do not always identify deaths as being attributable to heat accurately, the actual number of people that die from heat is likely greater (Bassil et al. 2008; Patz et al. 2014). Individual extreme heat events can result in significant loss of life. An extreme heat event in British Columbia, Canada that occurred over an eight day period in the lower mainland area in 2009 resulted in an estimated 156 excess deaths (Kosatsky 2010). In Quebec, Canada an extreme heat event in 2010 resulted in an estimated excess of 280 deaths (Bustinza et al. 2013).

Evidence suggests that in the US the impact of extreme heat on the health of citizens is declining over time. Bobb et al. (2014) found that, among 100 cities, the average reduction in deaths attributable to each 10 °F (5.6 °C) increase in same-day temperature decreased from 51 (per 1000 deaths) in 1987 to 19 in 2005. Similarly, Davis et al. (2002) found statistically significant reductions in hot-weather mortality rates in 3 major northern metropolitan areas (Boston, New York, Philadelphia) over three decades from 1964 to 1994. The findings suggest that Americans are becoming more resilient to extreme heat and this may be due to the success of heat-health warning systems, changes to the built environment (e.g., greening) that are providing more opportunities for cooling during dangerous heat events, improved medical care, increased access to air conditioning, or biophysical adaptations (Bobb et al. 2014; Davis et al. 2002). However, even with these trends, climate change will continue to increase health risks from heat waves (Bobb et al. 2014).

While evidence of increasing resilience to extreme heat suggests progress in efforts to adapt, deaths from these types of events are generally much higher than other types of extreme weather events associated with climate change (Luber and McGeehin 2008; Berry et al. 2014a). There is also strong evidence that an increase in the number of extreme heat events is already being observed in many regions of the world, including Canada and the US, and that they will continue to increase (IPCC 2013). In addition, an ageing population and increased urbanization, with higher exposures from urban heat islands (UHI) will increase the vulnerability of urban dwellers (Luber et al. 2014). Extreme heat may also have less direct, but significant impacts on health through effects on air pollution (Luber et al. 2014; Berry et al. 2014a), mental health (Hansen et al. 2008; Kim et al. 2015), aggression (Anderson 1989) and on critical infrastructure such as power transmission infrastructures (McGregor et al. 2007).

In both the US and Canada extreme heat events are increasing in frequency in many cities (Stone et al. 2010; Luber et al. 2014) and several studies project continued increases in the future due to climate change (IPCC 2013). Figure 1 shows the projected number of hot days and warm nights for a number of Canadian cities such as Winnipeg, Toronto, Montreal and Fredericton. The number of hot days (above 30 °C/86 °F) per year in these cities is expected to double by the end of

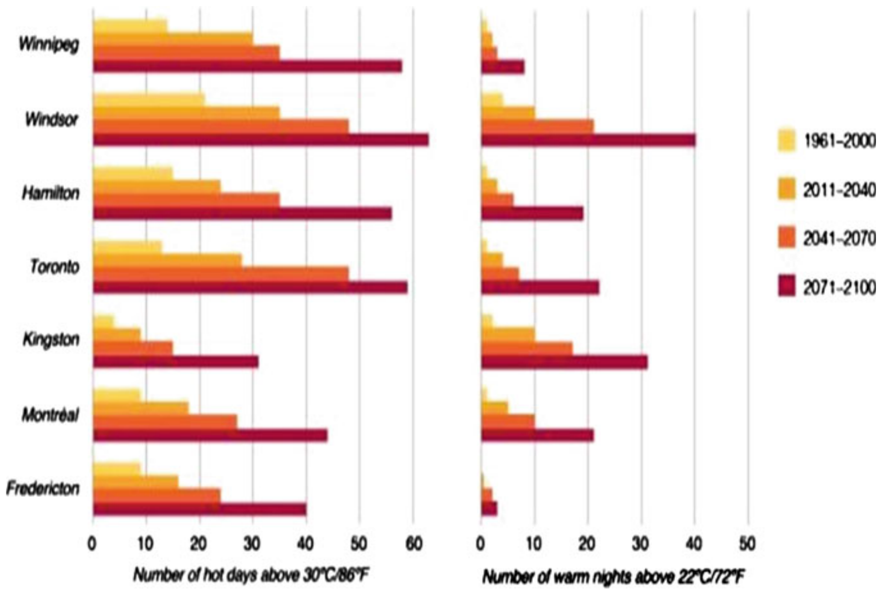

Fig. 1 Projected hot days and warm nights for select Canadian cities. *Source* Casati et al. (2013)

this century, while the number of warm nights for some cities could quadruple (Casati et al. 2013). Warmer nights from rising temperatures and a stronger UHI effect will lead to increase health risks as people may not be able to cool down after hot days (Patz et al. 2005).

With an increase in warmer temperatures and the frequency and severity of extreme heat events, more heat-related illness and deaths in the absence of adaptations are expected (Gosselin et al. 2008; Peng et al. 2011; Martin et al. 2011; Petkova et al. 2013; Benmarhnia et al. 2014; Vardoulakis et al. 2014). For example, a review of 15 Canadian cities suggested that overall, using a 2081–2000 base period, heat-related mortality could triple by 2021–2040, increase five-fold by 2051–2070 and increase by more than eight-fold by 2081–2100 (Martin et al. 2011). In 49 US cities, the EPA (2015) projected that climate change (i.e. more extreme hot days and fewer extreme cold days) could result in a net increase of 2600 deaths annually by 2050 and 13,000 deaths by 2100; greenhouse gas mitigation measures can significantly reduce this health burden (EPA 2015). The City of Chicago, Illinois may experience as many as 2000 excess deaths per year by 2081–2100 due to an increased number of heat waves (Peng et al. 2011). With a 3.5 °C/6.3 °F temperature rise the number of heat deaths in Europe could reach 200,000 per year (Ciscar et al. 2014). Importantly, climate change can exacerbate many factors (e.g. poverty, isolation, dislocation, chronic diseases) that make some populations more vulnerable than others to climate-related hazards such as extreme heat; this may amplify health impacts in the future. Longer-term and higher global temperature increases may mean that people reach the limits of physiological adaptation in some parts of the world (McMichael and Dear 2010).

Knowledge of populations in a community that are at higher risk from heat illness and death allows public health and emergency management officials to disseminate targeted heat-health communications messages and to direct response measures during heat emergencies in the most effective manner. Table 1 provides a list of heat-vulnerable groups and examples of adaptation challenges they face.

Parents need to be particularly careful to not leave children or others requiring assistance in cars during hot weather. On average, 37 children are estimated to die each year in the US from heat in cars Null 2015). Temperatures in cars can rise rapidly (15–30 min) even with relatively cool ambient temperatures. Public awareness and education about how to avoid illnesses and deaths among children in cars can improve child passenger safety (McLaren et al. 2005).

People exposed to heat through a variety of occupations also need to take precautions to avoid serious illness. Occupational heat-related hospitalizations or emergency department visits increased with daily maximum temperature in three different areas of Florida during the summer months (Florida Department of Health 2012 as cited in Adam-Poupart et al. 2014). Similarly, Adam-Poupart et al. (2014) found a strong relationship between occupational heat-related illnesses and exposure to high summer temperatures in the province of Quebec, Canada. Occupational risk factors associated with health impacts from extreme heat included a lack of training and experience, obesity, use of medication, and incomplete knowledge of the main language used in the workplace (Adam-Poupart et al. 2014). Mass gatherings such as festivals, concerts and sporting events can also lead to heat exposure and illness of large numbers of people if precautions are not taken (Feldman et al. 2014).

2.2 *Individual and Community Level Factors that Increase Vulnerability*

Vulnerability to heat-related illness and death is determined by the physiological sensitivity of a person to heat stress, their exposure to extreme heat and their ability or capacity to take protective measures (Health Canada 2011a). A wide range of individual and community level factors influence vulnerability and whether a person suffers ill effects during a heat event (Fig. 2). These factors often work in combination and in complex ways. For example, seniors who take certain medications that predispose them to health impacts of heat stress, live in housing with no air conditioning and/or on higher floors or have limited social networks are at significantly higher risk from extreme heat events than are many other individuals. In the US, hospital admissions among seniors increase during extreme heat (Gronlund et al. 2014). Of the 14,729 people that died in the August 2003 heatwave in France, almost 80 % were over the age of 75 and the risk of dying was much greater for those living at home than for people in hospitals and clinics (Fouillet et al. 2006). In addition, homeless people are at higher risk of heat illness because

Table 1 Heat-vulnerable groups and examples of challenges they may face in adapting to extreme heat events

Heat-vulnerable groups	Examples of challenges
Older adults	• Physiological characteristics that may contribute to increased vulnerability to heat: – reduced thirst sensation – reduced fitness level – reduced sweating ability – increased susceptibility to chronic dehydration • Visual, cognitive and hearing impairments • Agility and mobility challenges • Differing perceptions of risks and vulnerabilities based on life experiences • Reduced literacy • Social isolation
Infants and young children	• Physiological and behavioural characteristics that may contribute to increased vulnerability to heat: – increased body heat production during physical activity – faster heat gain from the environment if air temperature is greater than skin temperature, due to greater surface-area-to-body weight ratio – inability to increase cardiac output – reduced sweating • Dependence on caregiver to recognize heat impacts and take recommended actions
People with chronic illness or who are physically impaired	• Physiological characteristics that may amplify health risks, such as a failing cardiovascular or respiratory system, psychiatric illnesses, renal illnesses • Taking certain medications that affect heat sensitivity by interfering with the body's cooling functions or water/salt retention (e.g. antihypertensives, antidepressants, antipsychotics, anti-Parkinsonian) • Confined to bed or dependence on caregiver, family or friends for assistance with daily living (e.g. water access) • Communication, sensory, cognitive impairment • Characteristics related to health status or behaviour (e.g. chronic dehydration, does not leave home) • Social isolation
Socially disadvantaged individuals and communities: • Low income • Homeless • Living alone	• Limited financial resources to adequately take protective actions • Reduced access to clean water and cool places • Limited access to health care and social services • More environmental exposures (e.g. homeless, living on higher floors with no air conditioning) • Higher rates of alcohol and drug dependency • Social isolation

(continued)

Table 1 (continued)

Heat-vulnerable groups	Examples of challenges
Newcomers and transient populations such as tourists	• Language and literacy barriers for non-native speakers • Cultural differences, such as food consumption habits, clothing choices, pre-existing social or cultural beliefs • Unique media use patterns • Limited knowledge of local alert systems, health and social service programs
Occupational groups	• Environmental and workplace exposures (e.g. farmers, construction workers, miners, tree planters) • Increased physical strain • Variation in health and safety regulations, codes and standards • Irregular exposure to heat (i.e. lack of acclimatization) for new workers with job-related heat exposures and those faced with early season extreme heat events
The physically active	• Greater environmental exposures (e.g. marathon runners, recreational athletes, people who walk or bike) • Increased physical strain • Reduced perception of risks and heat vulnerabilities • Expectation of usual performance in the heat

Source Health Canada (2011a)

of increased exposure to hot temperatures; they often reside in urban cores that experience the UHI effect, are socially isolated, have fewer hydration options and have less ability to access cooling centres (Health Canada 2012). Public health interventions to protect such people from extreme heat must be formulated in such a way as to address these factors. As an example, the City of Toronto provides transit tokens to homeless people during extreme heat events so that they can get to cooling centres (Health Canada 2012).

2.2.1 Role of Space and Place

Space and place can be a key driver for the impacts of environmental degradation and climate change on human health (Smith et al. 2014). Community design and type can play a major role in predisposing populations in certain geographical areas to greater health impacts from extreme heat (Chow et al. 2012). People living in cities often face higher exposures to air pollution, noise pollution, and UHIs. They may also be subject to other pressures such as reduced opportunities for physical activity and rest, high cost of fresh food, overcrowding, alienation, inequity and high crime rates (Proust et al. 2012), all of which can exacerbate the effects of environmental stressors. In turn, rising temperatures and more extreme weather events associated with climate variability and change may have impacts on the most

Fig. 2 Factors that influence individual and community level vulnerability to extreme heat events. *Source* Health Canada (2011a)

vulnerable populations. One study of health effects of extreme heat events in eight diverse neighborhoods in Phoenix in 2003 showed that marginalized populations such as people with lower socioeconomic status and ethnic minority groups were more likely to reside in neighborhoods with greater exposure to heat stress and to have fewer resources to take protective measures (Harlan et al. 2006). An examination of a range of factors linked with heat-health outcomes in the US found that people living in inner cities were the most vulnerable in urban areas (Reid et al. 2009). Disproportionate impacts of climate change on the health of vulnerable populations (e.g. low income and elderly) means that approaches to address climate change and health impacts would benefit most by linking them with considerations of health equity (Connor et al. 2010).

People living in rural areas can also be at increased risk from extreme heat because of more limited resources to take adaptation actions (e.g. fewer medical facilities), fewer cooling options (e.g. no or limited public transport, fewer air conditioned public spaces), greater challenges identifying health-based alert protocols and difficulty reaching the public with heat alerts (e.g. limited media coverage) (Berry et al. 2014b). An investigation of weather-related deaths in the US from 2006 to 2010 indicated that most heat-related deaths occur in the most urban and the most rural counties (Berko et al. 2014). Another study suggested that over this time period higher rates of presentations to emergency departments for summertime acute heat illness were observed in rural areas (Hess et al. 2014). A study of heat-related mortality in British Columbia, Canada showed that hot weather has a relatively higher impact on health in more sparsely population areas (Henderson et al. 2013).

The impacts of climate change on heat and health could have disproportionate impacts of people living in low and middle-income countries in the tropics which experience very hot seasons. One study that estimated work capacity for selected heat exposure levels and work intensity levels found that it rapidly reduces as the Wet Bulb Globe Temperature (WBGT) exceeds 26–30 °C (Kjellstrom et al. 2009). In South-East Asia, climate change may double the annual work hours lost in heat-exposed jobs by 2050 translating into losses of billions of US dollars (Kjellstrom 2015). Higher temperatures resulting from climate change may pose future challenges to the economic and social development of these countries due to impacts on worker productivity (Kjellstrom et al. 2009).

2.3 Vulnerability Associated with Climate Change, Heat and Air Quality

Climate change may increase health risks from poor air quality through increases in aeroallergens, biological contaminants and pathogens (Greer et al. 2008; Schenck et al. 2010). Wildfires constitute another pathway through which climate change can impact health risks from ambient air quality, particularly increases in particulate matter (PM) across large geographic areas. It may also lead to heat and other meteorologically-related increases in ambient air pollutants such as ground-level ozone (O_3) and PM (Ebi and McGregor 2008; Frumkin et al. 2008; Bambrick et al. 2011).

There is a strong correlation in the US between higher daily summer temperatures and poor air quality (O_3) in many cities (Kenward et al. 2014). One study of 91 urban and non-urban counties in the northeastern US found that populations in non-urban areas are also at risk from high temperatures and air pollution levels (Madrigano et al. 2015).

Under future climate conditions and assuming current population levels and regulatory controls, between 1000 and 4300 additional premature deaths are expected yearly by 2050 in the US from ozone and particulate matter health impacts (Luber et al. 2014). Future projections of health risks from climate induced impacts on ground-level ozone and particulate matter levels in Canada suggest increased

Table 2 Climate change and related drivers for key health risks associated with air quality

Air contaminants	Climate change and related drivers	Health risks
Ground-level ozone	• Increased temperatures	• Premature mortality • Respiratory symptoms, inflammation • Impacts on immunological defences • Cardiac effects • Adverse long-term respiratory impacts
Particulate matter—coarse ($PM_{10\text{-}2.5}$), fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$)	• Wildfires • Droughts • Renovations to weatherize buildings	• Mortality • Cardiac outcomes • Lung cancer mortality • Restricted activity days • Respiratory symptoms • Bronchitis • Asthma exacerbation
Aeroallergens (e.g., from trees, grasses, weeds, molds, dust mites)	• Warmer temperatures	• Allergic responses in sensitized individuals • Exacerbation of respiratory diseases (e g, asthma and chronic obstructive pulmonary disease)
Fungi (e.g., and infectious bacteria)	• Moisture in buildings from infiltration of rain or flooding • Poorly designed ventilation and air-conditioning systems • Poor building maintenance	• Respiratory disease • Cryptococcal disease (cryptococcosis) which can result in pneumonia or meningitis
Volatile organic compounds (VOCs) and Semi-volatile organic compounds (SVOCs)	• Dampness in buildings	• Asthma • Allergies
Carbon monoxide (CO)	• Use of portable gas-powered or electric generators, oil and gas furnaces, fireplaces, or candles during weather-related emergencies	• Fire-related injuries and death • CO poisoning

Source Adapted from Berry et al. (2014a)

levels of exposure and/or mortality as well (Lamy and Bouchet 2008; Berry et al. 2014a). Table 2 illustrates climate change and related drivers for key health risks associated with air quality.

Understanding the complex relationships between climate change, temperature and air quality is necessary to develop effective public health interventions for these risks and to maximize health co-benefits of adaptive actions. For example, some public health authorities in Canada issue public alerts when dangerously high temperatures are forecasted and when air pollution presents dangers to health. In such cases, the use of alert messages which avoid contradiction in messaging and possible confusion among the public (e.g. cool down to escape the heat / don't use air conditioning to reduce energy use) is important (Rogaeva and Berry 2014). In addition, while future climate conditions could reverse some of the very significant improvements to air quality and public health over the past few decades (Kenward et al. 2014), great potential exists to maximize benefits to human health through innovative urban designs that reduce risks from extreme heat (e.g. expand tree canopy or paved surfaces) while at the same time improve air quality. One study in the New York Metropolitan area suggested that a future land use scenario involving the transformation of forest and agriculture areas to low density urban development would be associated with higher levels of episode-maximum 8-h ozone concentrations, although there is some geographic variation, where a few areas would experience decreases in ozone concentrations (Hogrefe et al. 2004). More generally, greenhouse gas emissions reductions that reduce the combustion of carbon-containing fuels could result in major decreases in mortality (Haines et al. 2014). Many measures to improve air quality, reduce the UHI and alleviate exposure to heat stress, or reduce the rate of climate change, can provide immediate health benefits.

3 Adapting to the Health Impacts of Climate Change

Growing concern about the health impacts of climate change over the last decade has catalyzed public health officials to develop adaptation measures to protect citizens at risk. Health authorities at national, regional and local levels have begun efforts to manage observed health impacts and prepare for future risks (Panic and Ford 2013; IPCC 2014). However, one study in the US revealed that many governmental authorities at the local level do not feel prepared to protect the health of citizens from extreme heat events (O'Neill and Ebi 2009).

Responsibility for implementation of the broadest scope of health adaptations resides with local and regional decision makers. Community involvement in adaptation planning is critical given the necessity to include information about societal, cultural, environmental, political and economic factors that affect the vulnerability of specific individuals and populations (Ebi and Semenza 2008). This includes knowledge of vulnerable populations and factors that increase or mitigate vulnerabilities at the local level, based on demographics and place.

Measures to reduce health impacts from climate variability and change includes integrating information about future risks into early warning systems, public education and awareness campaigns, strengthening of health care and social services, surveillance of new and emerging diseases and actions that support and sustain health through adaptation in related sectors such as water supply and sanitation, agriculture, infrastructure, energy and transportation, ecosystems and land use management (Ebi et al. 2013; IPCC 2014). Public health and emergency managers cannot act alone in protecting citizens from extremes of weather and climate, since pathways for drivers of health impacts are complex and variegated. Climate maladaptation (i.e. unsuccessful adaptation that increases vulnerability) in other sectors such as agriculture, transportation, urban planning can have significant public health consequences by negatively affecting efforts to protect health from extreme heat.

Evidence suggests that adaptation measures—including the reduction of poverty, improvement of water and sanitation conditions and early warning and response systems—can reduce the health consequences of climate change (IPCC 2014). Health adaptation can have immediate knock-on effects including important health co-benefits that increase the resilience of populations to climate impacts (McMichael and Dear 2010; Cheng and Berry 2013). Adaptations to climate that protect health directly or indirectly can also be cost-effective. For example, Ebi et al. (2004) estimated that Philadelphia's heat wave warning system, which costs about $210,000 to run over a three year period, could provide gross benefits in the order of $468 million (117 lives saved times $4 million) over the same timeframe. Studies estimating health-related cost-benefits of adaptation actions are limited and more research is needed in this area (Younger et al. 2008; Toloo et al. 2013).

4 Actions to Protect People from Extreme Heat Events

Heat-related deaths are largely preventable (Luber and McGeehin 2008; Matthies et al. 2008; WHO 2009; McGregor et al. 2015). Public health interventions that increase the accessibility of air conditioning and increase fluid uptake among vulnerable populations can reduce mortality associated with extreme heat events (McGeehin and Mirabelli 2001). Over the last 15 years, local communities and regional and national governments in many developed and some developing countries have begun adopting proactive public health and emergency management interventions to reduce health risks from extreme heat events (Lowe et al. 2011; McGregor et al. 2015). In the community of Ahmedabad, India the Indian Institute of Public Health in partnership with the Natural Resources Defense Council and Emory University have undertaken a heat-health vulnerability assessment to inform the development of an evidence-based heat preparedness plan. It includes early warning measures and recommendations to reduce health risks and protect livelihoods (Knowlton et al. 2014).

Public health officials have focused on the development of tools to support communication and outreach for alerting community stakeholders and the public when heat events are forecast so that measures can be taken to protect the most vulnerable populations (Younger et al. 2008; O'Neill and Ebi 2009; Health Canada 2012). A number of communities in Canada have developed Heat Alert and Response Systems (HARS) that include a proactive community response (e.g. public health visits to vulnerable populations such as older adults living alone or the disabled) and increased access to services that reduce health risks such as cooling centres and shelters (Berry et al. 2014b). While studies that evaluate the effectiveness of HARS are limited, some have suggested that they contribute to the reduction of morbidity and mortality associated with extreme heat events (Kovats and Ebi 2006; Fouillet et al. 2008; Bassil and Cole 2010). For example, implementation of the heat wave and health alert system in France (Système d'alerte canicule et santé) after the very severe extreme heat event of 2003, is thought to have significantly reduced the health impacts of subsequently strong heat events in 2006, 2009 and 2010 (Ministère du Travail, de l'Emploi et de la Santé 2011). Evidence also suggests that the costs of systems can be small compared to costs of negative health outcomes from extreme heat events (Ebi et al. 2004). The cost of setting up and operating the system in France in 2005 was 741,000 euros, which is far less than the estimated health costs of 500 million euros for the 2003 heat wave (Hutton and Menne 2014). However, greater efforts are needed to develop robust measures to provide adequate protection to the most vulnerable populations as many plans neglect low income people and the socially isolated (Bassil and Cole 2010). Development of HARS should be based on anticipatory adaptation planning for extreme heat events that utilizes information on the relationship between temperature, mortality and place-based factors contributing to vulnerability (Fook 2014).

Recent evidence suggests that health impacts from extreme heat may not only be of concern for urban populations; people living in rural and isolated communities can also be at significant risk (Henderson et al. 2013; Madrigano et al. 2015). Heat Alert and Response Systems often differ in scope, types of public health interventions employed, target populations for outreach and communications and the degree and nature of stakeholder involvement due to differences in local meteorological context, extreme heat planning processes and the capacity to undertake response activities. Adaptation efforts in urban and rural communities are most effective when they address unique challenges (e.g. communicating messages to the public, estimating heat-health burdens, assisting vulnerable populations with cooling options) faced by communities in efforts to protect health (Berry et al. 2014b).

4.1 Health Canada's Approach to Increasing Heat-Health Resiliency and Preparing Canadians for Climate Change

Through its national climate change and health vulnerability assessment, Health Canada identified extreme heat as a key health risk to Canadians, both under current climate conditions and with climate change (Health Canada 2008). To help health decision makers and individuals better prepare for these events it launched a multi-year initiative in 2008 to *Develop Heat Resilient Individuals and Communities in Canada*. Under the initiative, Health Canada worked with provincial and local health sector and emergency management officials and community groups to better understand heat-health risks to Canadians, enhance awareness and knowledge of risks among health professionals, develop best practices for adaptation, build the capacity of stakeholders and partners to protect health and expand HARS to at-risk communities across the country. During the first phase of this project (2008–2011), Health Canada engaged four communities (Winnipeg, Manitoba; a rural region in Manitoba, within the former Assiniboine Regional Health Authority; Windsor, Ontario; Fredericton, New Brunswick) to pilot development of new HARS for reducing heat-health risks.

Each community developed its own pilot approach based on local/regional needs and characteristics; common elements included identification of a lead agency, development and approval of a formal HARS plan, development of community outreach activities, and implementation of communication plans and products. To this end, pilot communities learned from table-top extreme heat event simulation exercises and from research in heat-health vulnerability assessments to develop their respective systems. Through such activities they undertook participatory approaches based upon community consultations with local partners and stakeholders (Morris-Oswald 2009).

From the outset the project was guided by a HARS Advisory Committee that included experts with knowledge and professional experience in the development and implementation of HARS, climate and health adaptation, public health and emergency management, the needs of heat vulnerable populations, and occupational health. A Health Professionals Information and Training Advisory Committee was also established to assist Health Canada's development of guidance for health professionals on diagnosing and treating heat-related illness and preparing health facilities for extreme heat events. Both committees included representatives from target audience groups of planned information products to increase access to the people requiring the information and to influence behavioral change.

4.2 Developing Heat Alert and Response Systems to Protect Health

Implementation of measures to protect health from extreme heat have been effective in some cities. Bobb et al. (2014) found that a decrease in mortality from heat events in the US could be due to a range of factors including expansion of heat-health warning systems and public health response programs in US cities since the late 1980s. However, a sole emphasis on expanding air conditioning to reduce vulnerability could lead public health officials to miss key opportunities to most effectively adapt and mitigate the effects of heat. Other evidence suggests that a robust community response to an extreme heat event in Milwaukee in 1999 based upon an implemented heat plan may have helped to significantly reduce the number of deaths resulting from the event. The 1999 heat wave took 10 lives, far less than a similar heat wave in 1995 that resulted in 91 deaths (Patz et al. 2014).

A review of HARS plans along with guidance documents from Europe, Australia, the US, the World Health Organization, and from the experiences of Health Canada's pilot communities highlighted that effective HARS have the following core elements (Health Canada 2012; Berry et al. 2014b):

Community Mobilization and Engagement—A lead agency mobilizes the community and coordinates necessary activities to implement and evaluate the HARS. It works with local stakeholders to identify and develop alert and response measures tailored to the community, recruit partners to support implementation, and develop HARS plans. This agency also leads the performance review of HARS off-season to support the adoption of needed changes or improvements.

Alert Protocol—The alert protocol is developed with knowledge of specific weather conditions (e.g. heat, humidity) that can increase morbidity and mortality in the community or region. Public health officials use the protocol to alert the public, media, government officials and community stakeholders of the level of risk so that predetermined actions may be taken to protect health.

Community Response Plan—The response plan identifies the measures that will be taken to prevent or reduce heat illnesses and deaths when a heat alert is called. It identifies the participating agencies and stakeholders and roles and responsibilities for implementing the measures. A core component of the response plan includes the direct public health measures aimed at protecting vulnerable individuals who may not be able to take health protective measures themselves (e.g. checking on seniors living alone, distributing water to homeless people). Heat adaptations in the community response plan must address the adaptation challenges faced by vulnerable populations.

Communication Plan—The communication plan sets out the communications activities that support the effective implementation of the HARS. Activities generally focus on raising awareness among various audiences (e.g. the public, public health officials, health professionals, the media) of the risks to health from extreme heat, the need to take protective measures when heat events occur and effective adaptations. The plan identifies appropriate communication channels, mechanisms (e.g. media releases, interviews, website information), target audiences, and messages to support HARS implementation.

Evaluation Plan—The evaluation plan provides direction to the HARS lead and participating stakeholders in efforts to evaluate the system including its processes (e.g. timeliness, relevance, effectiveness, ability to meet local priorities) and the actual outcomes (e.g. reduction of heat-related illnesses and deaths). The results are used to improve performance of the HARS through iterative changes to its components.

Evidence suggests that the following principles and actions increase the effectiveness of HARS (Health Canada 2011b, 2012):

- Using the findings of heat-health vulnerability assessments to identify vulnerable populations and geographical areas to inform development of alert protocols, response measures and communications materials
- Tailoring the HARS to meet local needs including addressing barriers to adaptation
- Including key community partners in the HARS that add value to the system
- Calling heat alerts with a trigger or triggers that were developed with information about the relationships between weather variables and health outcomes in the community or region
- Employing response measures that are proven to reduce health risks among the most vulnerable populations
- Implementing communication strategies and messages that raise awareness and educate about heat-health risks and that lead to behavioural change
- Evaluating the HARS at the end of the season and making needed changes to the system
- Preventing and/or reducing heat exposure in communities and regions through preventative public health actions such as mitigation of UHIs.

4.2.1 Supporting Heat-Health Adaptation Through Proactive Communication and Outreach

Communication to the public and community officials of heat-health risks and of measures that can protect health plays a critical role in HARS implementation (Luber and McGeehin 2008; Health Canada 2011c; McGregor et al. 2015). When extreme heat poses health risks, individuals have a primary role to take protective actions or to help their loved ones stay safe. Health communication information delivered in a timely manner supports heat-health adaptation by vulnerable individuals and their caregivers. Public health and emergency management officials implement communication strategies as part of HARS to provide practical and useful information to health service providers, caregivers and the public to help manage health risks from extreme heat events. However, providing information to vulnerable populations does not guarantee the uptake of health protective behaviours during extreme heat events (Wilhelmi and Hayden 2010). Heat-health communication activities face a number of important challenges related to inadequate perceptions of health threat because of the gradual and less dramatic nature of these events and because of high costs of air conditioning which may pose a barrier to use by some vulnerable people (Luber and McGeehin 2008).

Studies have shown mixed results on the effectiveness of HARS communications efforts. A survey of 908 people in four North American cities by Sheridan in 2007 revealed wide spread knowledge of heat warnings. Yet, of the 46 % of people that took protective actions based on the warnings, most adopted only one measure—avoiding the outdoors. In addition, many people could only name one or two of the recommendations made by public health officials through the warnings

(Sheridan 2007). However, recent studies in Toronto, Ontario (Gower et al. 2011) and Montréal, Quebec (Gosselin et al. 2008) have offered more promising findings regarding the success of heat-health communication activities. In Montréal many people that received information from the education campaign "Cet été, soyez cool!" (This summer, be cool!) took a range of protective measures that included using lightweight clothing, avoiding strenuous exercise, taking a shower or bath to cool down, and keeping hydrated. This information is disseminated through electronic media, print media, promotional materials, the health system or personal support networks (Gosselin et al. 2008).

To be effective, communication strategies and materials must be science based, consistent and targeted to the appropriate audiences (Health Canada 2011c). Collaboration with local and provincial health authorities through Health Canada's heat resiliency initiative revealed the following recommendations for community level heat-health communications activities and approaches (Health Canada 2011c):

- Identify key audiences and their specific communication needs
- Include stakeholders and government partners in communication planning
- Identify clear and realistic communication goals based upon existing resources
- Employ effective communication channels and mechanisms
- Tailor communication products and messages to meet the needs of different audiences
- Develop synergies with existing health promotion campaigns where possible
- Promote through communications activities programs and services that reduce barriers faced by vulnerable populations in taking protective measures
- Consider communication opportunities and challenges faced by different types of communities (rural versus urban)
- Ensure heat-health messages are scientifically sound and do not contradict messages in other health promotion campaigns (e.g. air quality and health, vector-borne diseases, staying active)

Ultimately, HARS need to include proactive communications and outreach activities to identify and provide assistance to vulnerable individuals because simply disseminating heat-health promotion materials will be less effective (Kovats and Ebi 2006). Proactive communication strategies take advantage of multiple dissemination channels (e.g. health networks, interpersonal networks, electronic and print media), are tailored to specific audiences (e.g. use trusted sources and community and group events) and occur over three phases (i.e. before the heat season, during the heat season and during an extreme heat event) (Health Canada 2011c). Communications and outreach activities must be regularly updated based on the latest scientific evidence of heat-health risks. For example, Bobb et al. (2014) found that given recent success in reducing heat-health risks among the eldest segment of the populations (over 75 year of age), future interventions that are broadly targeted to reduce vulnerability over the lifespan should be considered.

Health Canada's Heat-Health Education and Outreach Approach

As part of its initiative to increase the heat resiliency of individuals and communities in Canada, Health Canada has developed a variety of information materials, outreach mechanisms and annual communication strategies to support efforts by individuals and communities to protect people at risk from illness and death associated with extreme heat events. Through consultation with key partners including pilot communities and community organizations (e.g. Canadian Public Health Association, Canadian Medical Association, Canadian Nursing Association, Canadian Red Cross) Health Canada selected target audiences, established communication goals for changing behaviours and developed information products to advance these goals (Table 3).

Case Study—Harmonizing Heat-Health Messaging in Ontario

Ontario is in the process of developing a provincially consistent approach to community management of risks to health from extreme heat. Current measures to protect the public from heat-health risks in Ontario are implemented by a number of public health units and municipalities and range from advanced HARS to very limited activities that simply increase awareness of dangers from heat. This may leave some citizens without resources and assistance during extreme heat events. To facilitate development of a more coordinated approach across public health units, an intergovernmental working group has been established, constituted of public health officials and scientists from the Ontario Ministry of Health and Long-Term Care, Public Health Ontario, local public health units, Health Canada and Environment Canada. The Working Group investigated the status of HARS communication efforts in Ontario to support harmonization of communication approaches and messaging, thereby better protecting public health. In an effort to better understand current heat-health communication practices used in Ontario and identify gaps, two targeted questionnaires were administered in August, 2014. One was sent to 36 Ontario public health units (30 responding) and the other to 390 municipalities (170 responding). The purpose of the questionnaires was to identify how public health units and municipalities are communicating heat alerts (e.g. terminology), what types of heat-health messages are being disseminated to the public, and what population groups are being targeted with these messages.

The findings suggested that a number of public health units and municipalities disseminate heat-health communications to residents while some regions in Ontario do not provide any information on heat-health risks. This gap is prevalent in northern and southern parts of Ontario. Those who do communicate with the public on this issue often communicate in isolation from other jurisdictions, leaving some residents who are exposed to messages from neighbouring jurisdictions struggling to understand alerting terminology and triggers. Analysis of public heat-health messages disseminated by Ontario public health units also revealed broad consistency among messages so that most are unlikely to confuse the public; however,

Table 3 Key elements of Health Canada's heat-health education and outreach approach

Target audience	Communication goals	Information products
Public health officials Emergency management officials Urban planners Non-governmental organizations—for example: • Canadian Public Health Association • YMCA • Canadian Red Cross	• Provide information to support development and implementation of new HARS • Provide information to support efforts to improve existing HARS • Support modification of built environment to mitigate heat • Improve consistency in heat-health messaging across Canada • Build and maintain credibility of Health Canada as a leader on heat-health related issues	Communicating the Health Risks of Extreme Heat Events: Toolkit for Public Health and Emergency Management Officials Heat Alert and Response Systems to Protect Health: Best Practices Guidebook Climate Change and Health: Adaptation Bulletins Adapting to Extreme Heat Events: Guidelines for Assessing Heat Vulnerability Adapting to Extreme Heat Events: Guidelines for Assessing Heat Vulnerability—Workbook
Health professionals—for example: • Dieticians • Respiratory therapists • Occupational therapists • Physiotherapists • Athletic therapists • Personal trainers • Home care providers • Community care workers Non-governmental organizations—for example: • Canadian Medical Association • Canadian Nurses Association	• Increase awareness of heat as a health risk • Increase knowledge of how to diagnose and treat heat-related illness • Increase knowledge of how to prepare health facilities for extreme heat events	Extreme Heat Events Guidelines: Technical Guide for Health Care Workers Extreme Heat Events Guidelines: User Guide for Health Care Workers Factsheets for Health Care Workers
Individual Canadians including vulnerable populations—for example: • Older adults • Parents and caregivers • Children under the age of 4 and their caregivers • Chronically ill persons (e.g. cardiac, respiratory illnesses) • Those who exercise and work outdoors or in hot environments	• Increase awareness of heat as a health risk • Increase knowledge of effective health protection measures	Brochure—It's Way Too Hot! Protect Yourself from Extreme Heat (Seniors) Brochure—You're Active in the Heat. You're at Risk! Protect Yourself from Extreme Heat (Active Canadians) Brochure—Keep Children Cool! Protect Your Child From Extreme Heat (Children) Factsheet—It's Your Health: Extreme Heat Events

some areas for improvement were identified. To achieve better inter-jurisdiction coherence and address information gaps (e.g. symptoms of heat stroke and first response), areas of inconsistencies or inaccuracies in public health messages should be addressed and some messages improved (e.g. include a recommendation to drink liquids before feeling thirsty) (Rogaeva and Berry 2014). As follow-up to the survey, Health Canada reviewed specific messaging from 20 public health units to identify gaps and possibly inconsistent or contradictory messages. Advice on how to strengthen messages based on the scientifically sound heat-messages developed by Health Canada was provided to health officials with the goal of contributing to more harmonized communication efforts in the province.

4.2.2 Testing HARS to Increase Community Preparedness for Extreme Heat Events

Extreme heat events can lead to severe impacts on health when communities and individuals are not prepared for them. Similar to other types of extreme weather events and disasters, extreme heat can affect health due to gaps in knowledge about vulnerable populations, including where they reside, emergency communications, coordination among responding agencies, and resources including surge capacity. Climate variability may change the probability of concurrent events or disasters occurring in a community or region (e.g. severe storm followed by a heat wave). This may significantly raise the possibility of emergency systems and community infrastructures being overwhelmed with adverse impacts on health. Knowledge of existing gaps or weaknesses in emergency plans, partnerships and infrastructures helps to support efforts to increase preparedness for disasters, including extreme heat events.

Table-top exercises that test the community HARS response to extreme heat events bring together partners to discuss a simulated heat event emergency in an informal and safe setting. The exercise often involves decision makers that work through a predefined “simulation” of a heat event in a structured and monitored way to identify gaps and problems with existing response measures and procedures based upon the emergency scenario used (Health Canada 2011d). Extreme heat and health table-top exercises serve to train officials charged with implementing a HARS by focusing on familiarization with procedures and roles and responsibilities as well as to explore the implications of extreme heat during the development of a HARS. Climate change adaptation to the health impacts of extreme heat is supported when table-top exercises are undertaken with one or more scenarios based upon plausible future climate conditions.

Health Canada's Efforts to Support Heat-Health Preparedness Through Table-Top Exercises

The development of HARS to reduce risks from extreme heat is relatively new with the first systems in North America being developed in the late 1990s. Consequently, communities have limited experience using table-top exercises to examine preparedness for extreme heat events and robustness of HARS. In an effort to assist Health Canada's pilot communities (Winnipeg, Manitoba; a rural region in Manitoba, within the former Assiniboine Regional Health Authority; Windsor, Ontario; Fredericton, New Brunswick) test their existing capacity to respond to extreme heat and further the development of their HARS, the department supported one-day table-top simulations in the four communities in 2010. The exercises facilitated discussions among key partners responsible for implementing the HARS plans (e.g. health and social service providers, first responders, emergency response personnel) (Health Canada 2011d). Participants considered a series of worsening extreme heat scenarios (e.g. stresses on the system due to an influx of tourists, power outages and concurrent extreme weather events) for their respective communities in the context of local HARS plans, resources and supporting mechanisms. Communities used results from the simulations about where HARS could be improved to prepare for the next summer heat season. Based on findings from the four simulation exercises, Health Canada published on its website a climate change and health adaptation bulletin "Understanding Community Resilience to Extreme Heat Through Table-top Exercises" to increase awareness of this type of evaluation tool (Health Canada 2011d).

Case Study—Extreme Heat and Health Table-Top Exercise in the City of Winnipeg, Manitoba

As part of efforts to develop a HARS, the City of Winnipeg, with assistance from Health Canada, conducted a table-top simulation exercise at the workshop "Extreme Heat Event Exercise HARS Reality". The exercise was held in Winnipeg on May 26, 2010 and involved 58 stakeholders from a range of governmental and non-governmental organizations (e.g. public health, social services, emergency management, police services, electrical utilities, public transit, first responders, and industry) who have a role in community response to an extreme heat event. The workshop had the following objectives (Health Canada 2010):

- Improve and further develop the HARS and the community's emergency response plan
- Provide a venue through which HARS stakeholders can further understand their roles and responsibilities in an extreme heat event
- Improve communication to stakeholders and the public through enhanced collaboration and coordination

- Identify and further establish critical linkages and partnerships among all stakeholders involved in the HARS

The simulation scenario used by participants was based upon an unseasonably warm and dry summer with a large number of tourists in the area for two large festivals—the 40th Anniversary of Folklorama and Manitoba Homecoming 2010. Once the exercise began, participants were presented with a number of conditions that triggered a response to an extreme heat event including high temperatures, a power outage, shortages of community supplies and large crowds at the festival grounds potentially exposed to high heat conditions. The exercise produced a number of recommendations to enhance the HARS in Winnipeg such as (Health Canada 2010):

Communications—Develop a coordinated strategic communication plan that includes all stakeholders and covers communication activities before, during and after an extreme heat event.
Awareness and Education—Develop and distribute publications that provide information on actions people can take to reduce heat-health risks.
Planning—Organizations participating in the HARS should have a Business Continuity Plan/Emergency Response plan that provides direction in case an extreme heat event occurs and that addresses the needs of vulnerable populations. Plans among stakeholders should be linked to ensure coordinated HARS activities.
Roles and Responsibilities—Increase knowledge of roles and responsibilities among all HARS partners and develop standard operating procedures for the response.
Declaration of Emergency—Develop alert triggers with specific actions for HARS partners associated with each alert level.

Health authorities in Manitoba have used the table-top simulation results to improve efforts to protect populations from extreme heat events.

4.2.3 Preventative Approach to Building Heat Resiliency by Modifying the Built Environment

The design of the built environment—which includes the design of homes, offices, shops, roads, public transit, and parks—can have important impacts on indoor and outdoor thermal conditions in urban areas. The characteristic warming of urban areas, the urban heat island effect, (EPA 2008) is created when impermeable surfaces in cities—such as asphalt roads and parking lots, dark building facades and tar roofs—under the right climate conditions, absorb the sun's radiation and increase both surface and air temperatures. Factors that contribute to UHIs include lack of vegetation, a large area of impermeable surfaces, an urban form (e.g. street canyons) that trap the heat, and anthropogenic heat sources (e.g. factories) (EPA 2008; Dubois 2014). The air temperatures over cities are on average 1–3 °C/1.8–5.4 °F warmer than the surrounding countryside, and up to 12 °C/21.6 °F warmer in places (Oke 1997). During a heat wave, the higher air temperatures in areas characterized by UHIs places added stress on the health of vulnerable people such as seniors and young children (Patz et al. 2005; Harlan et al. 2006; Wilhelmi and Hayden 2010). Increased temperatures in poorly designed outdoor spaces may also discourage people from doing exercise outdoors, thereby having an impact on physical activity levels (Semenzato et al. 2011; Vanos 2015). The more frequent and intense temperatures anticipated because of climate change (Casati et al. 2013; IPCC 2013) could also accentuate urban heat, thereby placing added strain on the health of vulnerable populations.

There is also an important relationship between the design characteristics of buildings and indoor temperatures (Givoni 1992; White-Newsome et al. 2012). Elevated indoor air temperatures are a significant health concern given that North Americans spend a large majority of their time indoors (EPA 1989). Buildings with poorly adapted designs can absorb and trap heat indoors, raising indoor temperatures to levels that are dangerous to the health of residents (Ormandy and Ezratty 2012; White-Newsome et al. 2012). Semenza et al. (1996), in a study investigating causes of death for the 1995 heat wave in Chicago that lead to 700 excess deaths, found that living on the top floor of a building was one of the most important risk factors. In a study of indoor temperatures in 30 different homes in Detroit without air conditioning White-Newsome et al. (2012) found that average maximum indoor temperatures were 13.8 °C/24.8 °F higher than average maximum outdoor temperatures. The authors stated that "indoor exposures to heat in Detroit exceed the comfort range among elderly occupants" and that measures should be taken to retrofit homes to reduce indoor heat exposures (White-Newsome et al. 2012). The higher temperatures found in areas characterized by UHIs can compound indoor overheating that results from design characteristics at the building scale (Mavrogianni et al. 2012).

Measures to reduce UHIs and overheating indoors are complementary. Interventions at the urban scale include increasing vegetation cover by planting trees and shrubs and expanding open spaces, retrofitting buildings to reduce waste heat and improve indoor thermal conditions, and installing cool surface materials such as cool pavements, building facades and roofs (EPA 2008; Rizwan 2008; White-Newsomea et al. 2012; Santamouris and Asimakopoulos 1996). Interventions at the building scale include increasing thermal insulation in the building envelope, maximizing natural ventilation, increasing solar protection (e.g. installing blinds and shutters), and installing energy-efficient appliances (Holmes and Hacker 2007; Santamouris et al. 2011; Coley et al. 2012; Dubois 2014). UHI reduction measures can also have important co-benefits that support community well-being. For example, planting of street trees can help reduce UHIs, as well as reduce energy consumption, improve air quality, enhance biodiversity and reduce stormwater run-off (Tyrväinen et al. 2005). Importantly, actions to reduce UHIs can have significant health benefits. Stone et al. (2014) found that significant reductions in heat-related mortality (40–99 %) could be achieved in Atlanta, Georgia, Philadelphia, Pennsylvania, and Phoenix, Arizona through modifications to the built environment, such as enhanced tree canopies and more reflective, less heat-absorbing surfaces. Improvements in park and playground designs may also contribute to increases in physical activity (McCormack et al. 2010).

Development of Information and Tools at Health Canada to Mitigate the Urban Heat Island

Health Canada has been working with communities since 2009 to help identify the causes of UHIs and support approaches to reduce heat-related illnesses and deaths (Richardson et al. 2015). Health Canada has developed a five pillar approach to its work on heat, health and the built environment. First, stakeholder needs were identified between 2010 and 2011 through a series of workshops across Canada. Subsequently, Health Canada collaborated with communities on pilot projects to develop UHI mitigation strategies, worked with partners in developing UHI-related decision support tools such as heat vulnerability maps and design guidelines, supported research to better understand the health impacts of UHIs, and developed various communication and outreach materials to share best practices with stakeholders.

Since 2012, Health Canada has supported six pilot communities (Windsor, Ottawa, London, York Region and Peel Region in Ontario, and Vancouver, British Columbia) to identify the causes of UHIs and propose and implement intervention strategies. Health Canada encouraged pilot communities to develop multi-stakeholder steering committees that include individuals from municipal departments including public health, urban planning, public works and parks and recreation. These steering committees have been an important tool to prompt interest and support for the projects and advance UHI actions on the ground. The co-benefits of UHI actions have emerged as a key driver for these projects since many of the UHI actions are integrated into plans and policies that address other municipal issues. Reducing UHIs and improving thermal comfort, for example, can be included as a component of a city's urban tree canopy plan or integrated within green building guidelines or standards. Health Canada disseminates results from the community pilot projects to stakeholders across Canada in presentations and case studies with the goal to help raise awareness of these initiatives and spur similar actions by other Canadian communities. In some communities, Health Canada has worked with partners to develop decision-support tools such as UHI maps for evidence-based decision-making. The following Windsor case study is an example of a pilot community project.

Case Study—Measures to Reduce the Urban Heat Island Effect in Windsor, Ontario

The City of Windsor (population 216,000), located directly across the Canada-US border from Detroit, is Canada's southernmost city. Extreme heat is a significant health issue for local residents, particularly for the city's most vulnerable populations. On average, the maximum temperature in the City exceeds 30 °C/86 °F 23 days a year. Climate projections show the number of extreme heat days are expected to almost double over the next 60 years (Casati et al. 2013). The UHI effect, which is pronounced in various parts of Windsor such as the downtown and industrial areas, is expected to exacerbate health risks from heat.

Between 2009 and 2010, the City collaborated with Health Canada to develop a HARS called "Stay Cool Windsor-Essex" (Berry et al. 2011). The HARS identifies when heat becomes a public health concern and activates a communication campaign and an emergency public health response plan aimed to reduce health risks. Windsor and Health Canada have since continued their collaboration, focusing efforts on developing preventative actions that reduce the urban heat island effect and improve outdoor thermal comfort for active living. Between 2010 and 2012, the City developed a comprehensive Climate Change Adaptation Plan (City of Windsor 2012). Among other recommendations, the plan called for the City to complete an urban heat island study. The City has since completed the following steps to help reduce UHIs:

Assessment of urban heat island reduction measures in Windsor (De Carolis 2012)—The City mapped UHIs and then conducted an assessment of UHI reduction measures (such as white roofs, green roofs, street trees). A report was produced with targeted recommendations for action at the local level. Recommendations included installing cool roofs on city-owned buildings, increasing natural area coverage across Windsor, and incorporating thermal comfort considerations in the design of sports fields, playgrounds and parks.

Assessment of thermal comfort in Windsor's parks and playgrounds (Blanchard 2013)—The City conducted an assessment of outdoor thermal comfort conditions in six of Windsor's parks and playgrounds. The report made recommendations about how the City could improve thermal comfort in parks, including planting shade trees, installing built shade structures such as shade sails and gazebos, and installing lighter coloured rubberised mats in playgrounds and sports fields.

Draft Parks Master Plan (2015)—The City prepared a draft "Thermal Comfort" chapter for inclusion in Windsor's updated Parks Master Plan (expected to be published in 2015). The chapter summarizes the scientific literature on thermal comfort and sets out high level design and policy recommendations.

The City used findings from the UHI studies to inform measures to reduce risks from extreme heat. Since 2007, Windsor has installed five green roofs and two reflective roofs on municipal buildings. When roofing materials are ready for replacement, efforts have been made to replace dark shingles with more reflective alternatives. In addition, since Council's approval of the thermal comfort report in 2013, the Parks and Recreation Department has integrated various design features (which include planting trees, installing shade structures such as gazebos, constructing water features such as splash pads, and using lighter coloured artificial mats under playground equipment) into five city parks that were being retrofitted.

Windsor's success in integrating UHI-related considerations into City policy and operations comes down to several factors. First, the UHI projects have had strong local champions and collaboration across departments. The City's Environmental

Coordinator has championed heat resiliency and UHI projects and elected City Councillors and senior managers in departments across the City (including Parks, Engineering, Planning and Forestry) have been receptive to incorporating novel ideas and practices into their work. Another key lesson learned is the importance and utility of UHI maps for engaging key officials such as planners, engineers, and parks staff. These maps have been used as a tool to identify the location of impervious surfaces and to prioritize efforts to both mitigate UHIs and reduce storm water volumes. This case study also demonstrates the importance of leadership within municipal governments in taking adaptation action. In just two years, the City has moved from a study about thermal comfort in parks and playgrounds to having five parks retrofitted with design features such as splash pads, trees, lighter coloured rubberised mats and artificial shade structures.

4.2.4 Multi-sector Collaboration on Heat-Health Adaptation to Achieve Health Co-benefits

Individuals and communities can achieve large health co-benefits through multi-sectoral and integrated approaches to climate change adaptation and greenhouse gas mitigation (Frumkin and McMichael 2008; Haines et al. 2009; Cheng and Berry 2013; Ebi et al. 2013). Significant opportunities to improve health and well-being are forfeited when measures are developed in the absence of such considerations. Taking a preventative approach to climate change and health adaptation by addressing the built environment can have multiple knock-on effects. The second Lancet Commission on Health and Climate Change states that "tackling climate change could be the greatest global health opportunity of the 21st century" (Watts et al. 2015).

Actions that help communities adapt to climate change, reduce fossil fuel use and improve air quality (e.g. designing streets to improve thermal comfort and promote walking and cycling) could have multiple co-benefits including reduced greenhouse gas emissions and lower rates of chronic diseases such as coronary heart disease and obesity. For example, changes in urban design to encourage active transportation can both help increase physical activity levels and build resilience to climate change. Human comfort in outdoor spaces is linked to various climate parameters including air temperature and exposure to sun and wind (Nikolopoulou and Lykoudis 2006). Well-designed outdoor spaces with shade trees, open space and appropriate paving materials can help reduce localized air temperatures and minimize direct human exposure to the sun, both of which increase human comfort on hot summer days and support higher physical activity levels (Brown and Gillespie 1995). The higher rates of physical activity through walking and biking in these spaces in turn helps reduce various health risks such as cardiovascular disease, diabetes mellitus and depression (Younger et al. 2008). Well-designed public spaces (e.g. streets, parks, playgrounds) with trees and vegetation can also help reduce UHIs, which provides additional co-benefits such as reducing greenhouse gas emissions and helping cities adapt to the higher number of extreme days anticipated from climate change (EPA 2008).

A significant concern among health decision makers is that climate change could exacerbate health and socio-economic inequalities due to the projected impacts on more vulnerable populations (Rudolph et al. 2015). However, health focused modifications to the built environment could help mitigate these impacts. For example, maintaining the conditions of buildings (i.e. including homes, offices, and health care facilities) can improve the health of occupants, including people at higher risk to health impacts of extreme heat (e.g. people of low socio-economic status and people with cardiovascular disease). Many conditions associated with substandard housing such as mold, pests, lack of safe drinking water, and inadequate heating or cooling, waste disposal, and ventilation systems can affect health through respiratory illnesses, asthma, infectious diseases, injuries and mental health disorders. Vulnerable populations such as people with low socio-economic status and racial minorities are more likely to have substandard housing and may have underlying health conditions that can exacerbate these health effects (Younger et al. 2008). In addition, changes to the built environment, particularly those that support exercise, can have health benefits for seniors (e.g. lower rates of functional decline and dementia) (Younger et al. 2008), a population group that is highly vulnerable to health impacts from extreme heat.

Case Study—Toolkit for Increasing the Resiliency of Health Care Facilities to Climate Change Impacts Including Extreme Heat Events

Climate variability and change will impact the health care sector and create risks—including risks from extreme heat events—for hospitals and other facilities (Guenther and Balbus 2014; Paterson et al. 2014). Increased admissions to hospital facilities are often observed during extreme heat events (McGregor et al. 2015). During the 1995 heatwave in Chicago 23 hospitals were so overwhelmed by the influx of patients that they had to close the doors of their emergency rooms to new patients (Klinenberg 2002). A more recent heat wave in India in May-June 2015 that caused more than 2500 deaths (Bagcchi 2015) resulted in the government cancelling leave for all doctors in affected areas because hospitals were being overwhelmed with patients suffering from heat-stroke (Bhalla 2015).

Health care facilities play a critical role in treating climate-related illnesses and injuries, caring for patients during and after disasters and participating in community efforts to adapt to and mitigate climate change. Opportunities exist for these facilities to prepare for potential multiple hazards, including extreme heat events, and achieve significant co-benefits by taking simple actions to increase preparedness for climate change (Fig. 3).

Health care facilities, to be resilient, need to assess climate change risks and vulnerabilities in order to be able to adopt adaptive management strategies. A toolkit was developed to do this in Canada. Six health care facilities in three provinces piloted a draft toolkit developed by the Canadian Coalition for Green

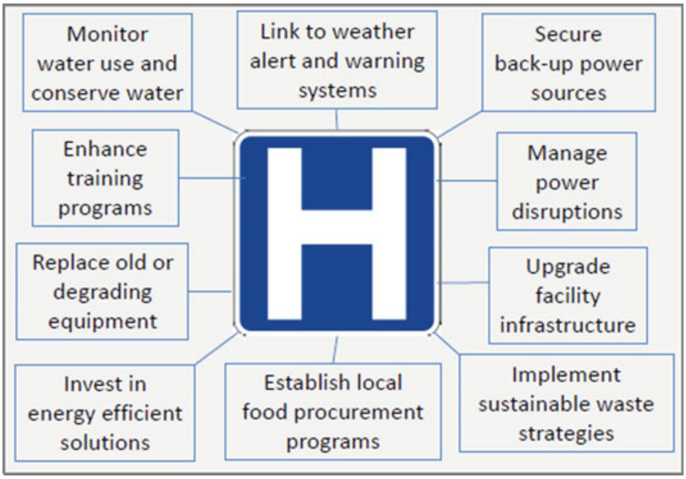

Fig. 3 Examples of climate-resiliency measures for health care facilities. *Source* Paterson et al. (2014)

Health Care (Paterson et al. 2014). The toolkit helps health care facility officials identify gaps in climate change preparedness, direct allocation of adaptation resources and inform strategic planning to increase resiliency to climate variability and change.

The final health care facility resiliency toolkit includes an Assessment Checklist with 82 questions in four areas: general facility information (n = 4), assessing climate-related risks (n = 19), risk management (n = 45), and building capacity to adapt to climate change (n = 14). It includes a Facilitator's Guide with background information on climate change risks to health care facilities and facilitator instructions. A Best Practices Resource Guidebook in the toolkit presents information on effective adaptation measures that may be used to address areas of vulnerability identified through application of the checklist. The toolkit is available for download at: http://greenhealthcare.ca/climateresilienthealthcare/.

5 Lessons for Supporting Heat-Health Adaptation and Building Resiliency to Other Climate Change Impacts

> Collaboration between the research and public health communities is essential for addressing the climate change and human health challenge. We need to ensure that significant research findings are integrated into public health planning, as well as ensure that researchers are addressing the topics of greatest concern. (John Balbus as cited in Kelly 2013)

The urgent challenge posed by climate change for human health represents a problem of enormous complexity (Frumkin and McMichael 2008). Multiple impacts (direct, indirect, cascading, and synergetic) operate through a host of interlinked factors such as population sensitivities, place-based vulnerabilities and the adaptive capacities of associated natural and human systems (Gosselin et al. 2011), all of which need to be taken into account through adaptation. Scientific uncertainty and insufficient information to guide the development, implementation and evaluation of measures to reduce risks to health from climate change are significant barriers to adaptation (Huang et al. 2011). One study in the US identified a lack of knowledge about climate change impacts on health, insufficient expertise to identify adaptation options, and limited human and financial resources as key barriers to taking adaptive actions (Maibach et al. 2008). Significant financial and social costs may arise when adaptation actions are delayed because of such barriers (Snover et al. 2007).

Through its activities with partners to increase the resiliency of Canadians to extreme heat events, Health Canada facilitated development of community level information about vulnerabilities, adaptations and requirements to support and sustain actions by decision makers. Efforts to address climate change impacts on health must recognize the importance and value of local knowledge and of community and regional approaches (Pang et al. 2015). These efforts also need to be based upon meaningful engagement of stakeholders through adaptive management using iterative processes. Such processes support the ability to respond to changes in climatic and non-climatic factors and to advance program goals such as considerations of equity when designing public health interventions (Fook 2014). In addition, broader understanding of socio-economic and cultural characteristics of a population and multi-directional relationships between them is necessary to increase the effectiveness of climate change and health adaptation efforts (Ebi 2011).

Future efforts to adapt to the growing health risks from extreme heat events will benefit from improving knowledge of individual and community level vulnerabilities and of effective adaptation measures within and outside the health sector. Knowledge needs include:

- Climate modeling and projections of future impacts in relevant timescales (Clarke and Berry 2012) for adaptation planning to ensure that communities are prepared for extreme events that may exceed historical trends
- Effectiveness of existing HARS and options to increase their effectiveness
- Application of specific research methods and communication techniques suited to public health decision-making to reduce heat-health risks, such as spatial mapping of vulnerabilities or syndromic surveillance
- Information about how co-benefits can be achieved through cross-disciplinary studies of efforts to reduce greenhouse gases, make communities resilient to climate change impacts (e.g. flood mitigation, UHI mitigation) and adapt to the health impacts of extreme heat (e.g. build social capital)
- Incorporation of land-use patterns into models that project climate impacts related to extreme heat events over time in urban areas (Stone et al. 2010)
- Social and intergenerational equity implications of climate change impacts, resilience actions and cost implications of adaptations

- Nonlinearity and thresholds in climate impacts that could affect health—for example massive tree die-offs due to heat waves
- The impact of increased heat on work productivity (Kjellstrom et al. 2009) and implications for health.

Reducing health risks from extreme heat events requires close collaboration and planning across a number of sectors (Semenza 2011). For example, development of HARS in Health Canada's pilot communities required involvement of representatives from health, meteorology, emergency management, social services, and transportation sectors, among others. Efforts to take a preventative approach and reduce the UHI in a community often must be implemented by other sectors including urban planning, parks, and public works.

5.1 Addressing Vulnerability Factors for Effective Heat-Health Adaptation

Heat-health vulnerability factors—based upon physical, physiological, social and environmental characteristics that predispose populations to heat illness and death—can differ widely among communities. For example, Johnson et al. (2014) found important spatiotemporal variations in health risk to extreme heat events among residents in Chicago, Illinois, Indianapolis, Indiana and Dayton, Ohio between the year 1990 and 2010. Inherent complexity in the understanding and management of heat risks to health requires an interdisciplinary approach to understanding social vulnerability (Wilhelmi and Hayden 2010). Health Canada followed an interdisciplinary approach to support development of heat-health adaptations that were tailored for communities and informed by local knowledge about demographic, decision-making or place-based characteristics that either supported or challenged adaptation efforts.

To develop heat alert protocols and thresholds, pilot communities in Canada used information and data from scientific literature reviews, historical meteorological data, demographic and health outcome data, and information about vulnerability characteristics. The required scientific evidence base to inform early warning systems must therefore be developed through multi-level (federal to local) interdisciplinary collaboration that includes attention to key factors in the community that affect the vulnerability of local populations to extreme heat events (Yardley et al. 2011). Higher level national health authorities can help through consensus definitions of heat-related health outcomes and development of effective surveillance and program evaluation methodologies. Community level public health officials contribute by developing knowledge of local level vulnerabilities and of effective HARS strategies tailored to specific physical and social environments (Yardley et al. 2011).

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