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A Look Back at the Peeks Creek, North Carolina, Debris Flow of 17 September 2004 and the application of Lessons Learned to the Excessive Rainfall Events in 2013.

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ABSTRACT: On the evening of 17 September 2004, excessive rainfall from the remnants of Hurricane Ivan produced a debris flow that followed the drainage of Peeks Creek in Macon County, North Carolina. The trigger appeared to be a burst of intense rainfall that occurred near the end of a prolonged period of precipitation associated with Ivan. The precipitation fell over an area with wet antecedent soil moisture brought about by excessive rain from the remnants of Hurricane Frances nine days earlier. The debris flow resulted in four fatalities and nine injuries, and destroyed 16 homes. To this day, the Peeks Creek debris flow remains the single deadliest weather-related disaster since 1994 in the area of responsibility of the Greenville-Spartanburg National Weather Service (NWS) office. The aftermath of the Peeks Creek disaster opened a dialogue between the meteorological and geological community in western North Carolina. The benefit to the meteorologist has been a greater understanding and situational awareness of weather patterns that lead to an increased risk of landslides and slope failures. Collaboration between the North Carolina Geological Survey and the NWS resulted in the adoption of language the NWS could use in flood warning products to highlight the threat of landslides. The lessons learned from the Peeks Creek disaster were successfully applied during the wet period across the mountains of North Carolina in 2013. A comparison will be made between the more familiar tropical cyclone patterns that favor increased landslide activity with the more subtle weather pattern during the first half of 2013.

INTRODUCTION

The National Weather Service (NWS) office located at the Greenville-Spartanburg International Airport (GSP) in Greer, South Carolina, more than tripled in size in terms of function, scope, and personnel in 1994 as the result of the modernization and restructuring of the NWS. The GSP office assumed responsibility for 16 counties across the mountains and foothills of North Carolina in October, 1995 (Fig. 1). Over the first ten years of operation, weather forecasters at NWS GSP became aware of a relationship between heavy rain and increased slope movements across the mountains of North Carolina through occasional reports of rock slides and “mudslides” received from the public, media, and emergency managers during and after flood events. However, as of 2004 forecasters lacked an understanding of that relationship and were unaware of research from the geological field that had explored such a relationship (e.g., Eschner and Patric 1982; Neary and Swift 1987).

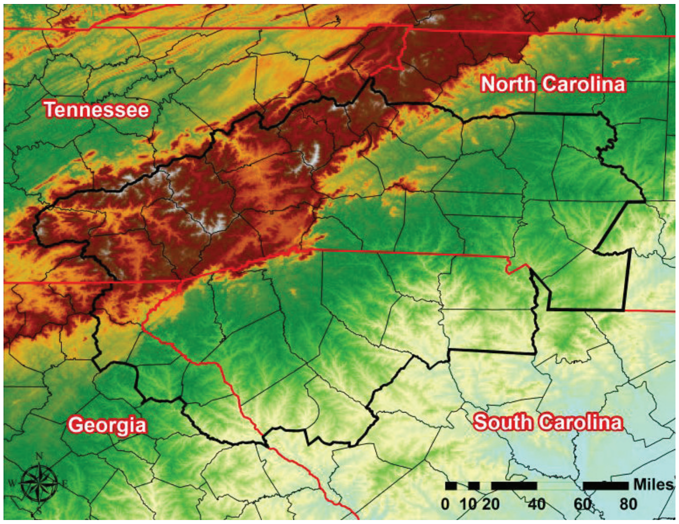

Figure 1. County Warning Area of the Greenville-Spartanburg National Weather Service Office, outlined by the thick, black contour.

On the evening of 17 September 2004, excessive rainfall from the remnants of Hurricane Ivan produced a debris flow that originated at approximately 4420 feet ASL on the northeast side of Fishhawk Mountain, and then followed the drainage of Peeks Creek, in Macon County, North Carolina (Lamb 2004). The trigger appeared to be a burst of intense rainfall that occurred near the end of a prolonged period of precipitation associated with Ivan, over an area with wet antecedent soil moisture as the result of excessive rain from the remnants of Hurricane Frances nine days earlier (Wooten et al. 2008). The debris flow resulted in four fatalities and nine injuries, and destroyed 16 homes. To this day, the Peeks Creek debris flow remains the single deadliest weather-related disaster since 1994 in the area of responsibility of the NWS GSP office.

The aftermath of the Peeks Creek disaster opened a dialogue between the meteorological and geological community in western North Carolina, specifically among NWS offices at GSP and Blacksburg, Virginia, and the North Carolina Geological Survey (NCGS). The benefit to the meteorologist has been a greater understanding and situational awareness of weather patterns that lead to an increased risk of landslides and slope failures. As a result, forecasters at GSP have been able to recognize the threat from more familiar tropical cyclone patterns that favor increased landslide activity as well as more subtle wet weather patterns, such as the pattern seen during the first eight months of 2013 associated with several landslide events (Wooten et al. 2014, 2015). Collaboration between the NWS, NCGS, the United States Geological Survey, and other state and local entities resulted in the adoption of language the NWS could use in flood watch and warning products to highlight the threat of landslides (Bauer et al. 2011). Using this enhanced wording, NWS forecasters at GSP were able to convey the landslide threat during the wet period across the mountains of North Carolina in 2013.

Comparisons are made between tropical cyclone activity, the relatively wet weather period in 2013, and the relatively dry weather period in 2008 in an effort to highlight weather patterns that favor a higher threat of landslide activity and those that suggest a lower threat.

WEATHER PATTERNS RELATED TO LANDSLIDE ACTIVITY

The relationships between high antecedent soil moisture, heavy rain, and increased landslide activity across the southern Appalachian Mountains have been well documented in the scientific literature (e.g. Wieczorek et al. 2009). In spite of the body of research, mostly from the geological community, the ability for weather forecasters at GSP to effectively issue warnings for landslide hazards has been elusive. Lack of knowledge of the underlying geomorphology has always been a severely limiting factor in this effort. However, situational awareness of weather patterns affecting the southern Appalachians that lead to wet soil conditions that might serve as a precursor to an increased landslide threat has been easier to grasp. While tropical cyclones attract a great deal of attention because of their disproportionate share of landslides produced (Fuhrmann et al. 2008), more subtle weather patterns exist that also pose a landslide threat.

Tropical Cyclone Activity

Some of the most devastating landslide events have occurred in situations when two organized low pressure systems, often of tropical origin, produced excessive rain across the mountains of North Carolina on the order of days apart, as in 1916, 1940, and 2004 (Fig. 2). For the purposes of the

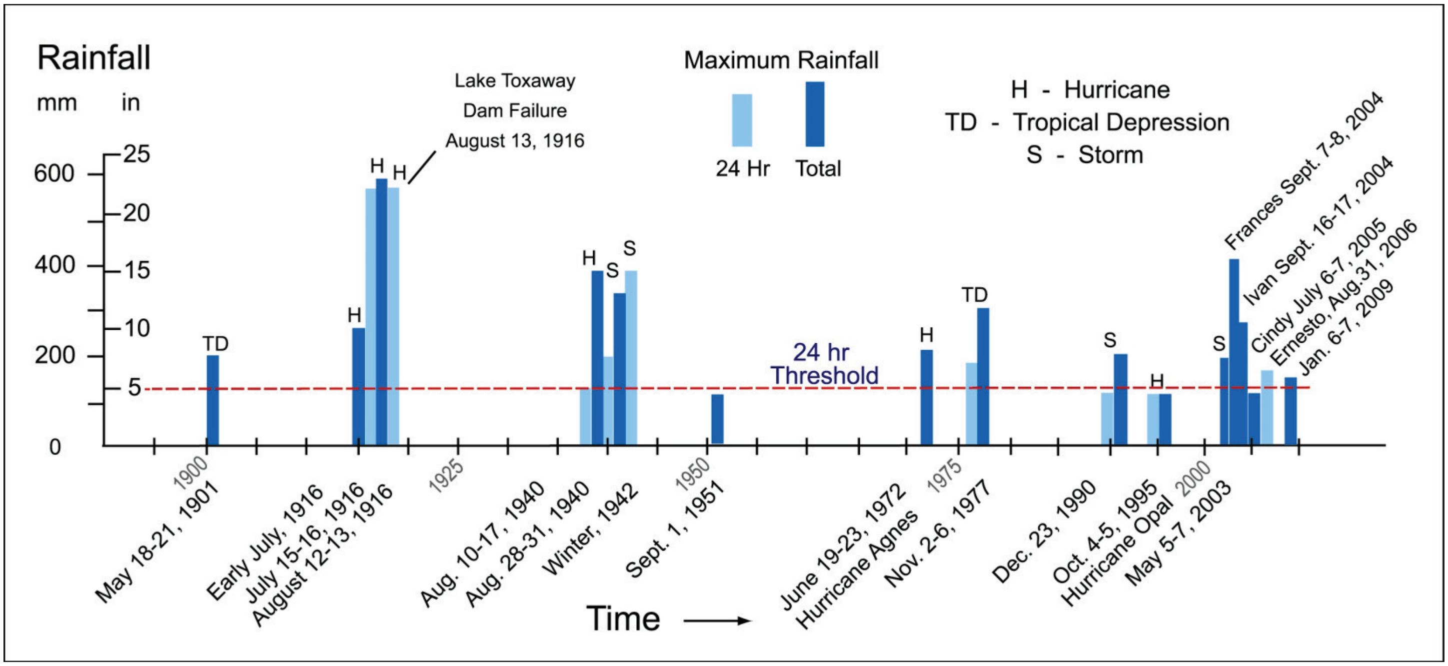

Figure 2. Rainfall amounts for selected landslide events across the mountains of North Carolina, 1900 - 2009. Adapted from Wooten et al. (2007).

study, a circle with radius of 300 km centered on Waynesville, North Carolina, was used to capture tropical cyclones that moved in close proximity to the southern Appalachian Mountains region. Within the 165 year period of record, 88 tropical cyclones passed through the study area or approximately one every two years (Fig. 3). Fifteen hurricane seasons featured multiple tropical cyclones that affected the study area, or once every eleven years. The list was narrowed to include only situations when successive storms occurred over the area within a two week window, as in August 1940, leaving five instances (Table 1), or a return period of 33 years. Of the five years when this condition was true, two of the years were 1916 and 2004. Thus, on three occasions, two tropical cyclones passed within a two week period that have not, to our knowledge, produced enough rain to cause significant landslide activity.

Several research studies into the precipitation distribution around tropical cyclones determined that the highest rainfall favored the area along and to the right of the cyclone track and often shifted to the northwest quadrant of the storm as it

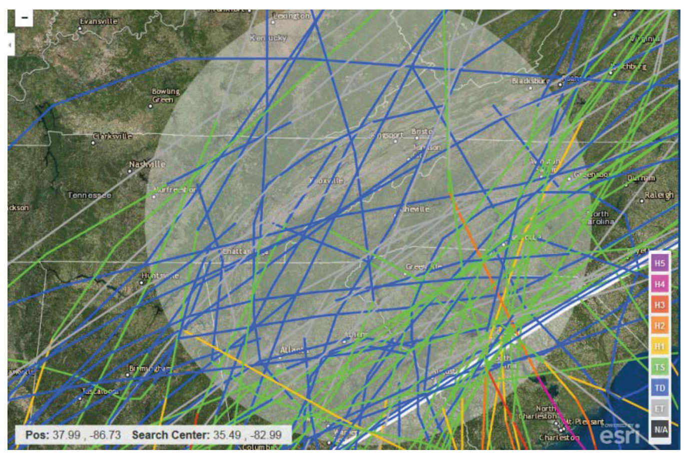

Figure 3. Tropical cyclone tracks passing within 300 km of Waynesville, NC, for the period 1851 to 2016. Intensity is indicated by the color bar on the lower right of the figure.

experienced extratropical transition. The storms in July 1916, and the remnants of Frances and Ivan in September 2004, followed a track that research suggested would put the mountains of North Carolina in a favorable quadrant for heavy rain (Fig. 4). This was not the case in August of 1928 and 1952, and September of 1979. In these other three cases, the track of one of the tropical cyclones remained east of the mountains of North Carolina [Storm 1 (1928), Able (1952), and David (1979)]. Excessive rain was not reported at Asheville, NC, with any of the three storms that passed to the east and significant landslide activity was not documented. Strictly from a pattern recognition standpoint, cases where two tropical cyclones moved across or to the west of the spine of the Appalachians in quick succession produced enough rainfall to trigger numerous landslides, and cases where one of the storms moved east of the mountains did not.

Table 1. Tropical cyclones that affected the mountains of North Carolina in the same year within a two week period.

Year	Name	Date
1916	Storm #2	10 July
	Storm #4	15 July
1928	Storm #1	11 August
	Storm #2	16 August
1952	Un-named	28 August
	Able	31 August
1979	David	5 September
	Frederic	13 September
2004	Frances	8 September
	Ivan	17 September

Wet Weather Patterns

Significant landslide and debris flow events have also occurred during periods with very little tropical activity, such as December 1990, May 2003, and more recently, the first seven months of 2013. In these cases, recurring rainfall from the passage of fronts associated with mid-latitude low pressure systems had a cumulative effect on soil moisture. Considering the case of 2013, rainfall at the Asheville Regional Airport, used as a proxy for the North Carolina mountain region, was well above normal through the spring and summer months (Fig. 5). In fact, Asheville broke the all-time annual rainfall record in 2013. A pronounced upward trend in rainfall was observed in May, June, and July.

Rather than view multiple storms responsible for the above normal rainfall, the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis data set (Kalnay et al. 1996) was used to draw out characteristics of the overall pattern looking at atmospheric anomalies on a seasonal time scale (Fig. 6). At 500 mb (a level meteorologists typically associate with the "steering flow" for low

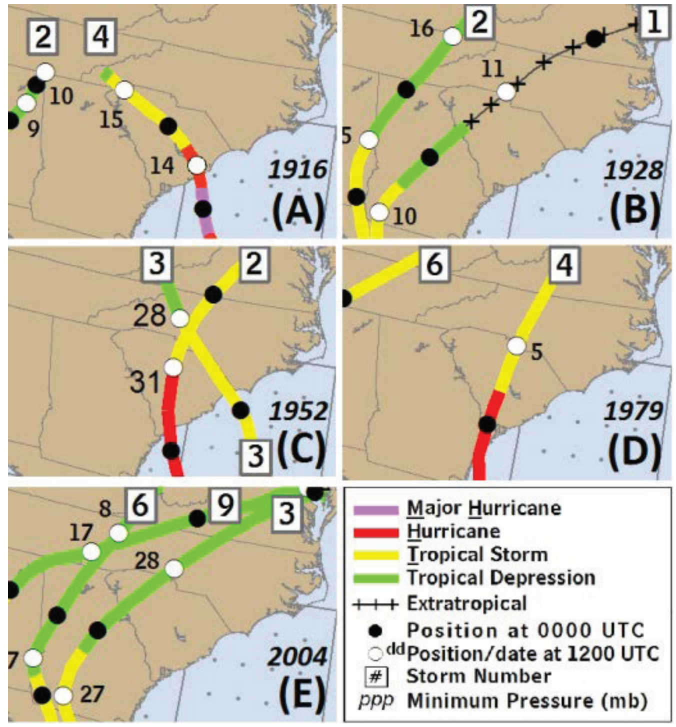

Figure 4. Tracks of tropical cyclones listed in Table 1 for (A) July 1916; Storm #2 and storm #4, (B) August 1928; storm #1 and storm #2, (C) August 1952; Un-named storm [3] and Able [2], (D) September 1979; David [4] and Frederic [6], and (E) September 2004; Frances [6]. Ivan [9], and Jeanne [3]. Tropical cyclone tracks were taken from The National Hurricane Center.

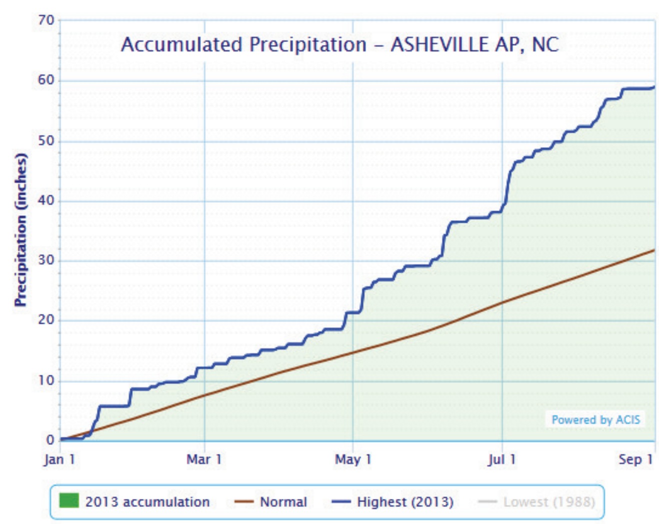

Figure 5. Accumulated precipitation at the Asheville Regional Airport, NC, from 1 January 2013 to 1 September 2013. Source: NOAA Online Weather Data, xmACIS.

pressure systems), a negative height anomaly was seen centered over Memphis, Tennessee. The anomaly suggested a combination of slightly deeper or more frequent waves of low pressure at mid-levels of the atmosphere. Although no anomaly of sea level pressure was detected, a large positive anomaly was located in the vicinity of Bermuda. This suggested a stronger than normal Bermuda high for this time of year, the flow around which would favor the advection of more warm and moist air into the southeastern United States. This was borne out by the large positive meridional wind component anomaly off the east coast at 850 mb, a level typically viewed as important for moisture transport east of the Rocky Mountains. The extension of the positive anomaly westward across the Carolinas, and the slight negative anomaly in the zonal wind component, supported the idea that southerly winds were stronger than normal during this time period, which probably resulted in higher moisture transport from the Atlantic and Gulf of Mexico. Situational awareness of this pattern was more important in mid-2013 as conditions only gradually became more favorable for landslide activity over a period of several months.

Dry Weather Patterns

Consideration of weather patterns that favored abnormally dry conditions, such as the period from 2007 through most of 2008, also has had value to the forecaster to avoid mentioning landslide concerns in flood watches and warnings. The

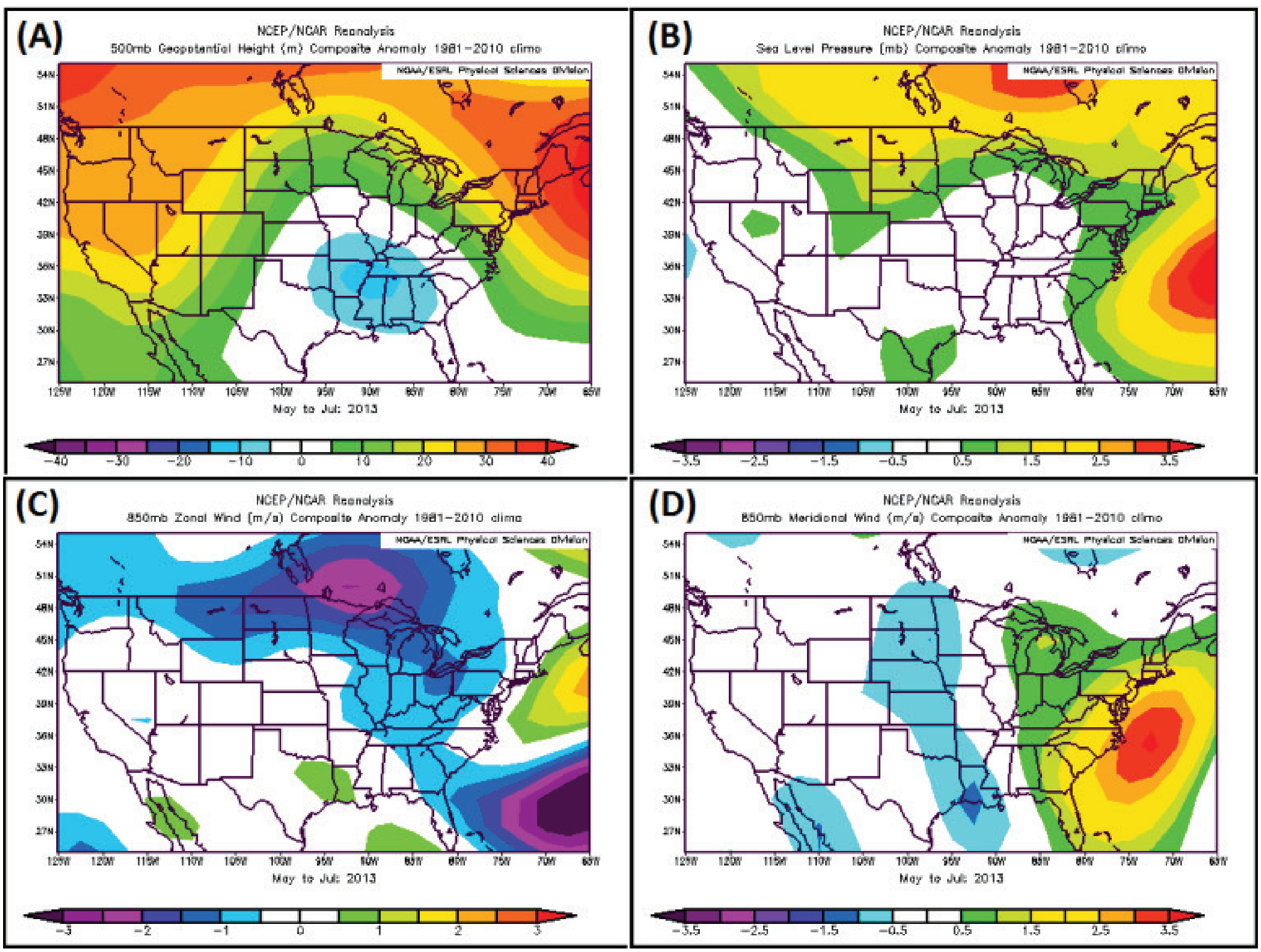

Figure 6. NCEP/NCAR Reanalysis of composite anomaly for the period May-July 2013 for (A) 500 mb geopotential height; m, (B) sea level pressure; mb, (C) 850 mb zonal wind; m s-1, and (D) 850 mb meridional wind; m s-1.

accumulated precipitation trace at Asheville showed the return of a significant negative departure beginning by May of 2008 and continuing well into the summer months (Fig. 7). The NCEP/NCAR Reanalysis for the period from May through July of 2008 (Fig. 8) showed a very large negative height anomaly at 500 mb over the upper Great Lakes region and Ontario, Canada, for the period from May through July of 2008. The strength of the anomaly suggested a persistent upper low in that vicinity that forced a dip in the jet stream across the eastern half of the United States that would favor fast-moving weather systems. A similar anomaly was noted in the sea level pressure field, which suggested that the center of most low pressure systems remained well to the north. The zonal wind component at 850 mb had a very strong positive anomaly from the mid-Mississippi Valley to the Great Lakes that extended to the east coast, which

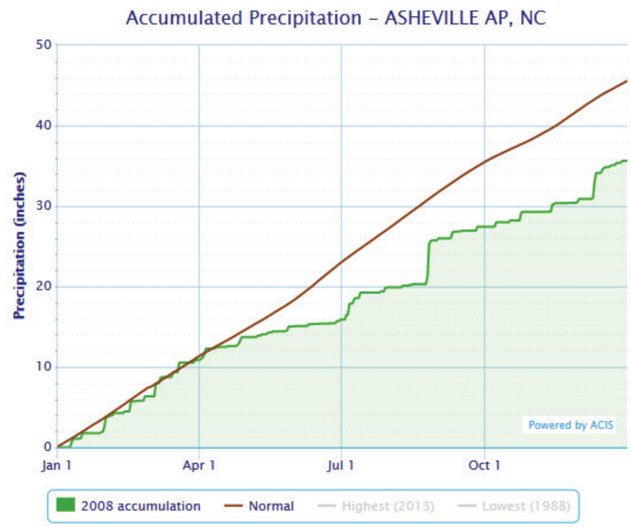

Figure 7. As in Fig. 5, except for the calendar year 2008.

confirmed the idea that a stronger than normal flow off the continent persisted through the period. The pattern favored fast moving fronts that failed to tap

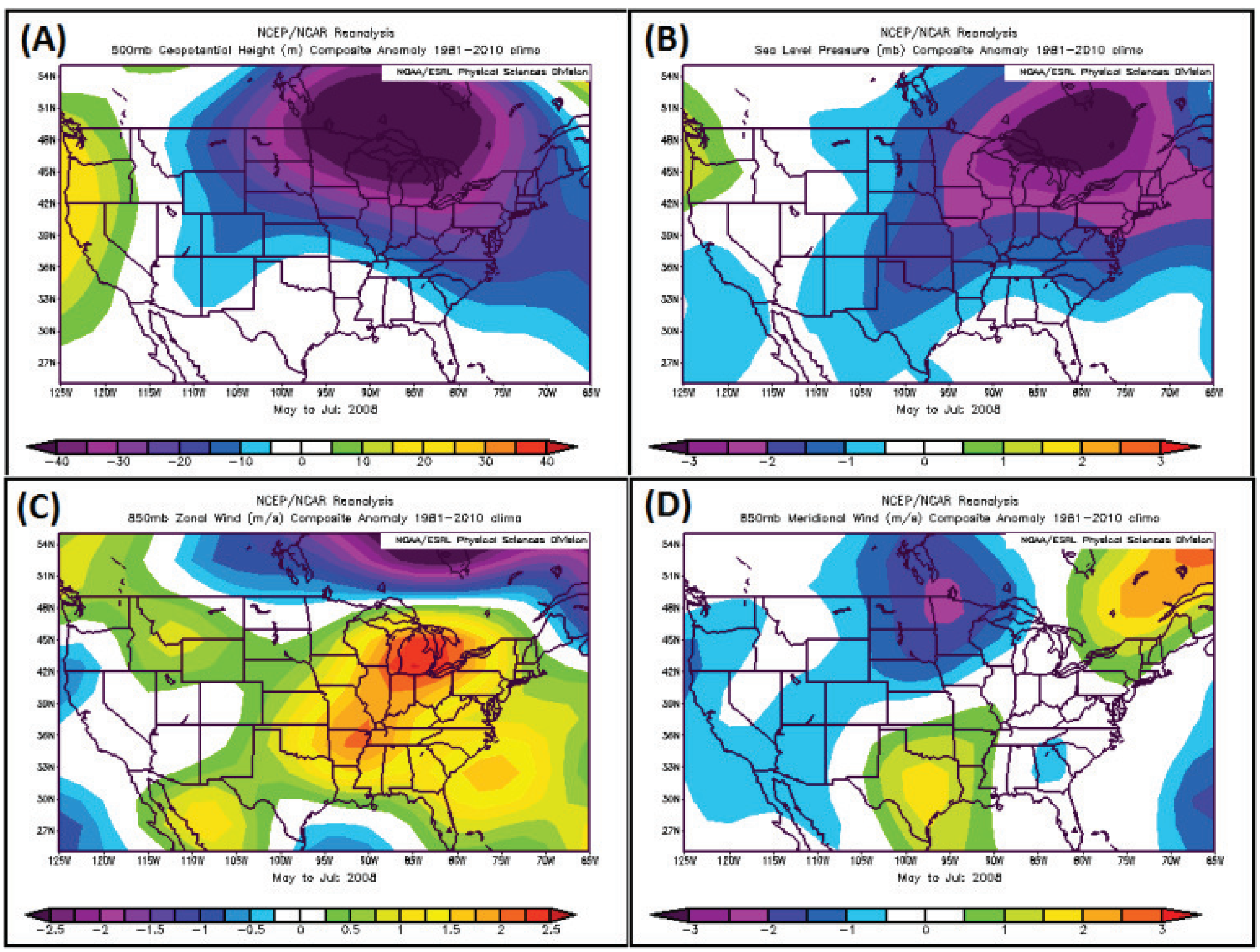

Figure 8. As in Fig. 6, except for the period May-July 2008.

moisture from the Gulf and Atlantic, which contributed to below normal precipitation. The pattern for much of 2007, while markedly different with a large ridge of high pressure centered over the Ohio Valley and Midwest, also favored dry conditions as the mountains of North Carolina were cut off from moisture sources.

APPLICATION TO POTENTIAL LANDSLIDE EVENTS

Forecasters at GSP understand that issuing a Flash Flood Warning specifically for landslide activity remains difficult because of the geomorphology problem. However, on the meteorology side, advances in spatial analysis and remote sensing of heavy rain hold promise for improvement (Keighton and Corrigan, this volume). In the meantime, forecasters do well to help the public and emergency managers anticipate favorable conditions for landslides in the 24- to 36-hour time frame before an event, as the NWS has done with similar phenomena that strain the limits of predictability. This is accomplished in the Flood Watch phase with specific wording that targets users that might be at risk, with the idea that someone might take appropriate action even if a landslide or debris flow happens before a warning is issued.

Such was the case during the first week of July 2013, when the North Carolina mountains were subjected to a persistent flow of moisture from the Atlantic on the periphery of a large high pressure center off the coast of North Carolina and to the east of a quasi-stationary surface boundary oriented north-south and extending from Mobile, AL, to northern Indiana at 1200 UTC on 3 July 2013 (Fig. 9). The 48-hour quantitative precipitation forecast issued by the Weather Prediction Center (WPC) at that time indicated the potential for greater than 3 inches (or greater than 75 mm) of rain across parts of the southern Appalachians (Fig. 10). Armed with the knowledge of wet soil conditions, forecasters at GSP expanded and extended an existing Flood Watch to cover the North Carolina mountain forecast zones through the day on 5 July. Special wording about the potential for landslides was included across the mountains, particularly owing to the holiday weekend. The additional wording consisted of the phrase "holiday campers and those participating in outdoor activities…especially in the mountains…should use extreme caution as heavy runoff on already saturated mountain terrain could trigger landslides." However, an opportunity was lost to include more robust wording as actual rainfall was two to three times as high as forecast (Fig. 11). The excessive rainfall triggered several landslides, including a debris flow on an unmodified slope along Herron Branch in Jackson County, NC (Wooten, personal communication).

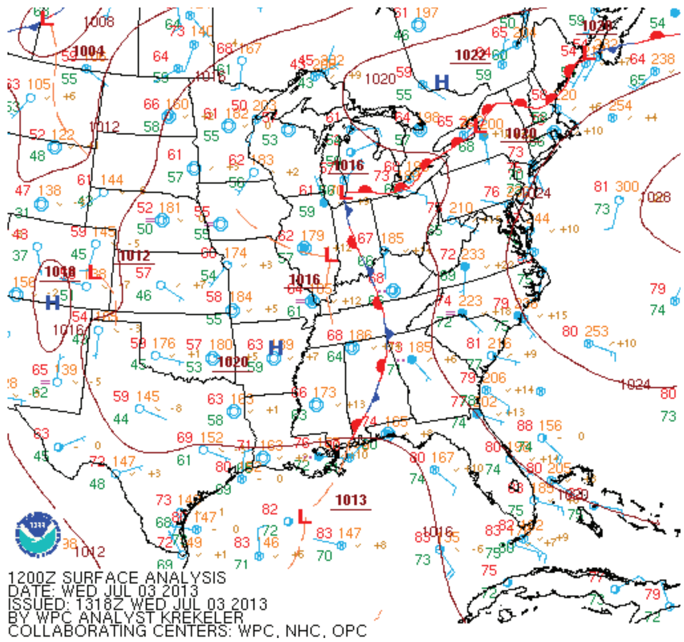

Figure 9. WPC Surface analysis of sea level pressure (mb) and fronts at 1200 UTC 3 July 2013.

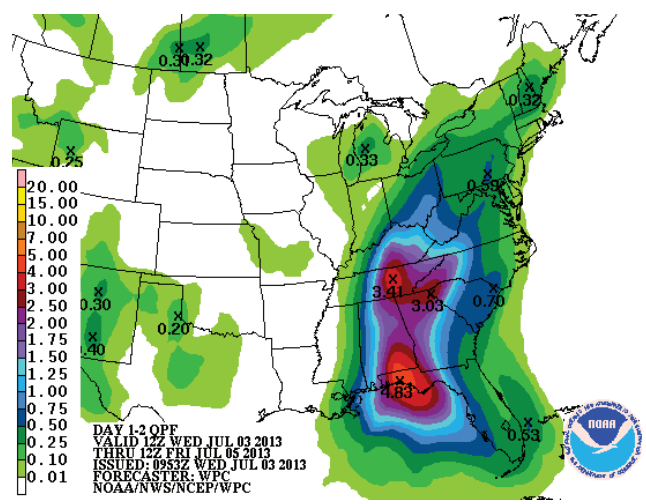

Figure 10. WPC forecast of quantitative precipitation amount issued 0953 UTC on 3 July for the 48 hour period valid through 1200 UTC 5 July 2013.

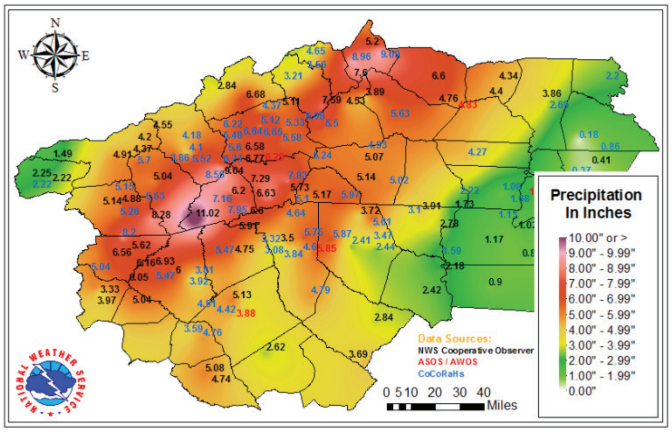

Figure 11. Rainfall across the GSP area for the 96 hour period ending 1200 UTC on 5 July 2013.

CONCLUSIONS

Since the Peek's Creek disaster in September 2004, weather forecasters at GSP have gained experience and understanding of weather patterns that favor excessive rainfall, and by extension the potential for landslide activity, across the mountains of North Carolina. The passage of two low pressure systems of tropical origin on a track across or to the west of the Appalachians over a span of less than two weeks has resulted in some of the more devastating debris flow cases in the past, but has been a climatologically rare event. However, more subtle wet weather patterns on a seasonal time scale that supported stronger flow of moisture from the Atlantic and Gulf of Mexico, such as the pattern during the first half of 2013, have been equally conducive to increased landslide activity even without the passage of a tropical cyclone. Forecasters maintained situational awareness of the favorable weather pattern in 2013 and conveyed the increased threat to the public prior to the landslide events in July.

Future research to better quantify rainfall thresholds for increased landslide activity, specific to the mountains of North Carolina, would be extremely beneficial to meteorologists. Additional guidance as to appropriate rainfall thresholds for landslide activity on modified slopes would also be helpful.

ACKNOWLEDGEMENTS

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