Ivan Was Terrible
17-18 September 2004

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1. INTRODUCTION

The remnants of hurricane Ivan brought heavy rain, wind, and tornadoes to much of Pennsylvania on the 17 and 18th of September 2004. The heavy rains lead to flash flooding and major flooding along the Juniata and Susquehanna rivers in central Pennsylvania on the 18th through the 20th of September 2004. This storm was likely the single most damaging weather event to strike central Pennsylvania since the Weather Forecast Office (WFO) in State College (KCTP) commenced operations in the autumn of 1993.

Hurricane Ivan developed in the Atlantic and moved slowly westward. It struck Grenada of the 7th of September with winds of over 150 mph and continued moving westward striking Jamaica on the 11th and then passing just south of Cuba before making the turn northward toward the Gulf Coast. Initial forecasts focused on landfall in the Florida panhandle. But as the storm moved northward it became evident the storms eyewall would come ashore in Alabama. However, the spiral bands on the east side of the storm brought heavy rains, strong winds and tornadoes to the Florida panhandle. Tidal surges, high waves, and wind blown rains affected the Gulf States from eastern Louisiana to Florida on the 15th and 16th. Officially, Ivan made landfall along the Alabama coast at 0451 UTC (12:51 AM EDST) 16 September 2004. The northern eyewall of hurricane Ivan moved over land near Gulf Shores, Alabama. It was a strong Category 3 hurricane at landfall based on the *Saffir-Simpson* Scale. The eyewall packed 130 mph winds at the surface and produced a significant storm surge. This storm will likely prove to be one of the more significant and damaging storms to strike the Gulf Coast in over 25 years.

Tropical storm Beryl brought heavy rains to central Pennsylvania on the 18th of August 1994. This storm brought a wide area of over 75 mm (3 inches) of rainfall to much of the KCTP forecast area with areas of around 100 mm (4 inches) near South Mountain and in the northern tier counties. Beryl traveled up from the Gulf of Mexico, along the Appalachian mountains before turning eastward across southern Pennsylvania toward the coast. Most of the heavy rains with Beryl occurred with cool conditions at low-levels as the warm tropical air streamed over cooler air at low-levels. Preliminary reports from the storm prediction center (SPC) suggest Ivan produced 29, and 23 tornadoes respectively on the 15th and 16th in the southeastern United States and 58 tornadoes in the Mid-Atlantic region on the 17th of September 2004.

Initially, as the storm approached Pennsylvania it produced steady rains on the 17th. The rains picked up in intensity during the afternoon and evening hours as band on the east side of the storm streamed northward over the low-level cool air entrenched over much of western, central and northern Pennsylvania. Some of these bands interacted with terrain and produced short-lived tornadoes in the evening hours of the 17th. The first tornado likely touched down around 2130 UTC (1730L). It also appears that the persistent northeast winds of 40-60 KTS at 2-5KFT above the surface

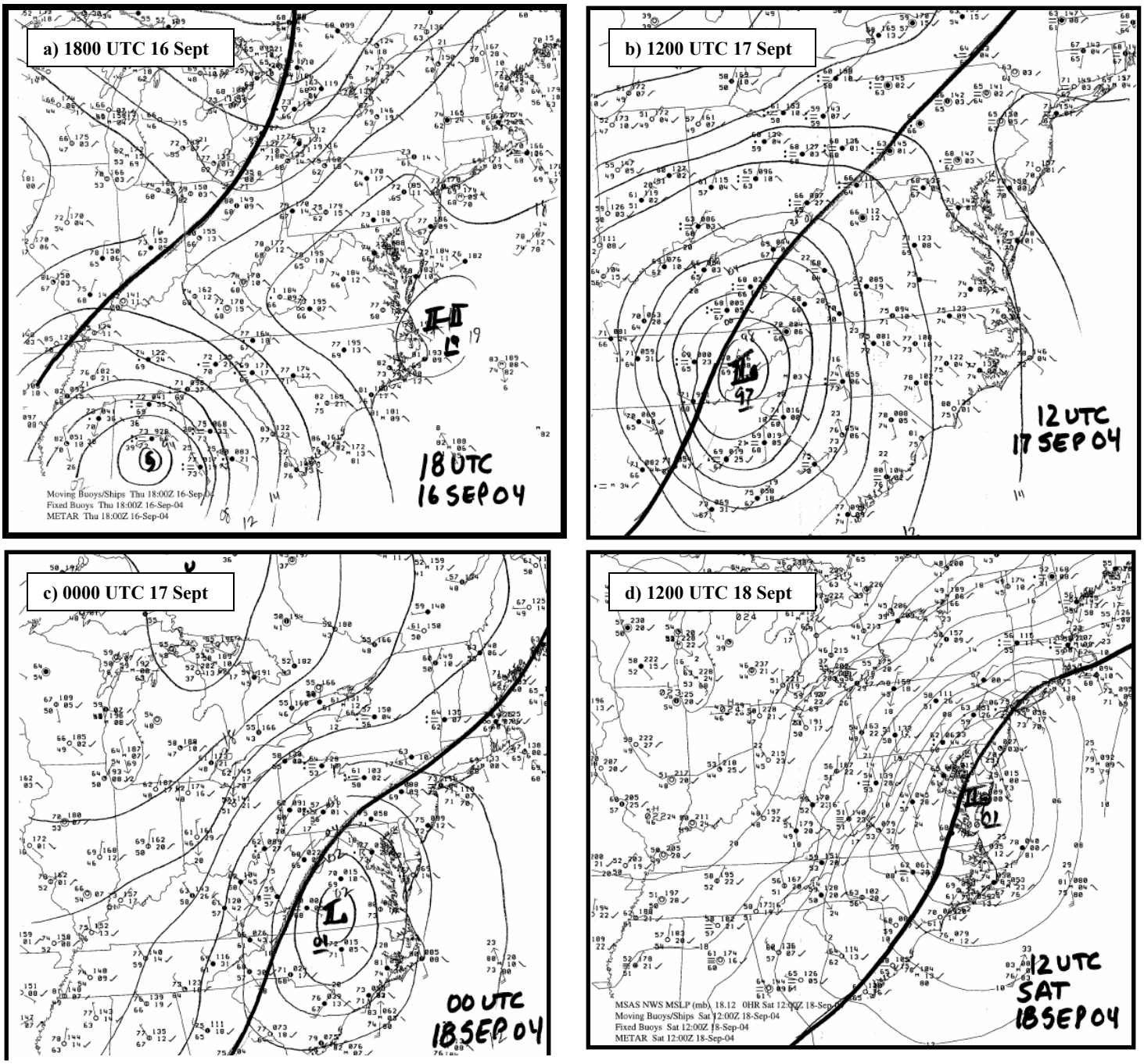

Figure 1 Manual analysis of mean-seal level isobars and fronts from surface plots valid at a) 1800 UTC 16 September, b) 1200 UTC 17 September, c) 0000 UTC 18 September and d) 1200 UTC 18 September 2004. Isobars every 4 hpa and standard symbols for highs and lows. No color but solid lines show the mid-latitude frontal system.

interacted with the terrain to produces wide areas of blow-down. A massive area of blown-down timber was surveyed in Blue Knob State Park where hundreds of acres of trees were blown over, with root balls intact on the eastern slopes of the ridges. The blow-down was likely the result of strong winds, steep slopes, wet soils, and wet leaves which made the trees susceptible to being toppled over.

The most devastating and prolonged problem in Pennsylvania was flooding. The heavy rains, generally 3-6 inches with

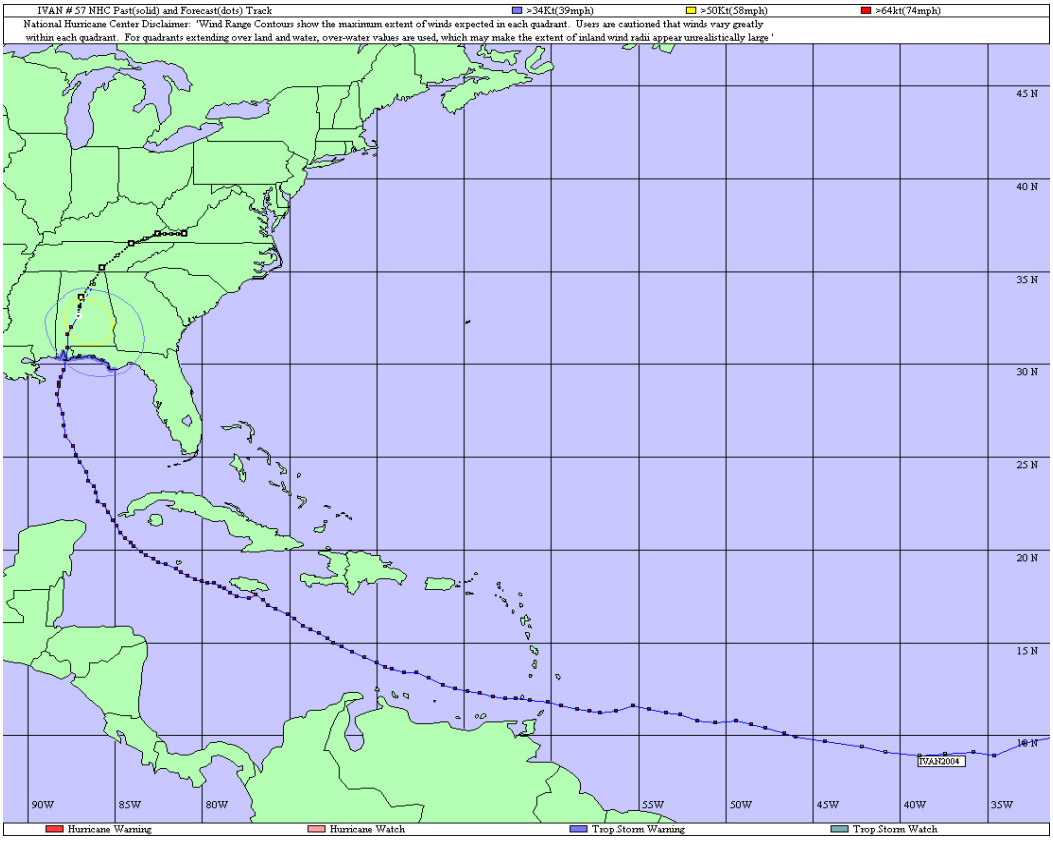

Figure 2 Track of Ivan from the National Hurricane center. The track ends when the storm was no longer considered to be tropical in nature.

locally higher amounts, initially caused flash flood problems on the 17th. This then lead to stream and river flooding. Thirty one of forty seven river forecast points in the KCTP forecast area went over flood stage. Many recorded stages in the top 3-5 events of all time. Two points, such as Williamsburg along the Frankstown Branch of the Juniata River and Bald Eagle creek at Beech creek station established record flood levels. Many points along the Susquehanna and Juniata rivers reached major flood levels. Conditions were as severe as the heavy rain and snowmelt floods of 19-20 January 1996. Tragically, the flooding resulted in two deaths in central Pennsylvania.

Heavy rains on the north side of tropical systems that move into mid-latitudes are not uncommon to central Pennsylvania. The heavy rainfall associated with the remnants of hurricane Frances (9 September 2004) also produced the heaviest rains in Ohio and northwestern Pennsylvania north and west of the track of the surface cyclone track. The remnants of tropical storm Beryl produced a wide area of 75 mm (3 inches) of rain over most of the KCTP forecast area on the 18th of August 1994. Some areas received over 100 mm (4 inches) of rain, mainly in the north central areas and near South Mountain. Most of Pennsylvania was embedded in cool air at low-levels during the rainfall associated with Beryl. These three storms, Beryl, Frances, and Ivan showed the same pattern with the significant area of heavy rains associated with tropical storms in mid-latitudes often occurring in the low-level cool air north and west of the surface cyclone track.

2. METHODS

Radar and satellite data were archived in real-time off the KCTP AWIPS systems. All images of this type were retrieved off AWIPS.

Model data were archived in real-time from the internet these data were then compared to the climatic values of specified fields to determine how significantly these fields departed from normal.

3. RESULTS

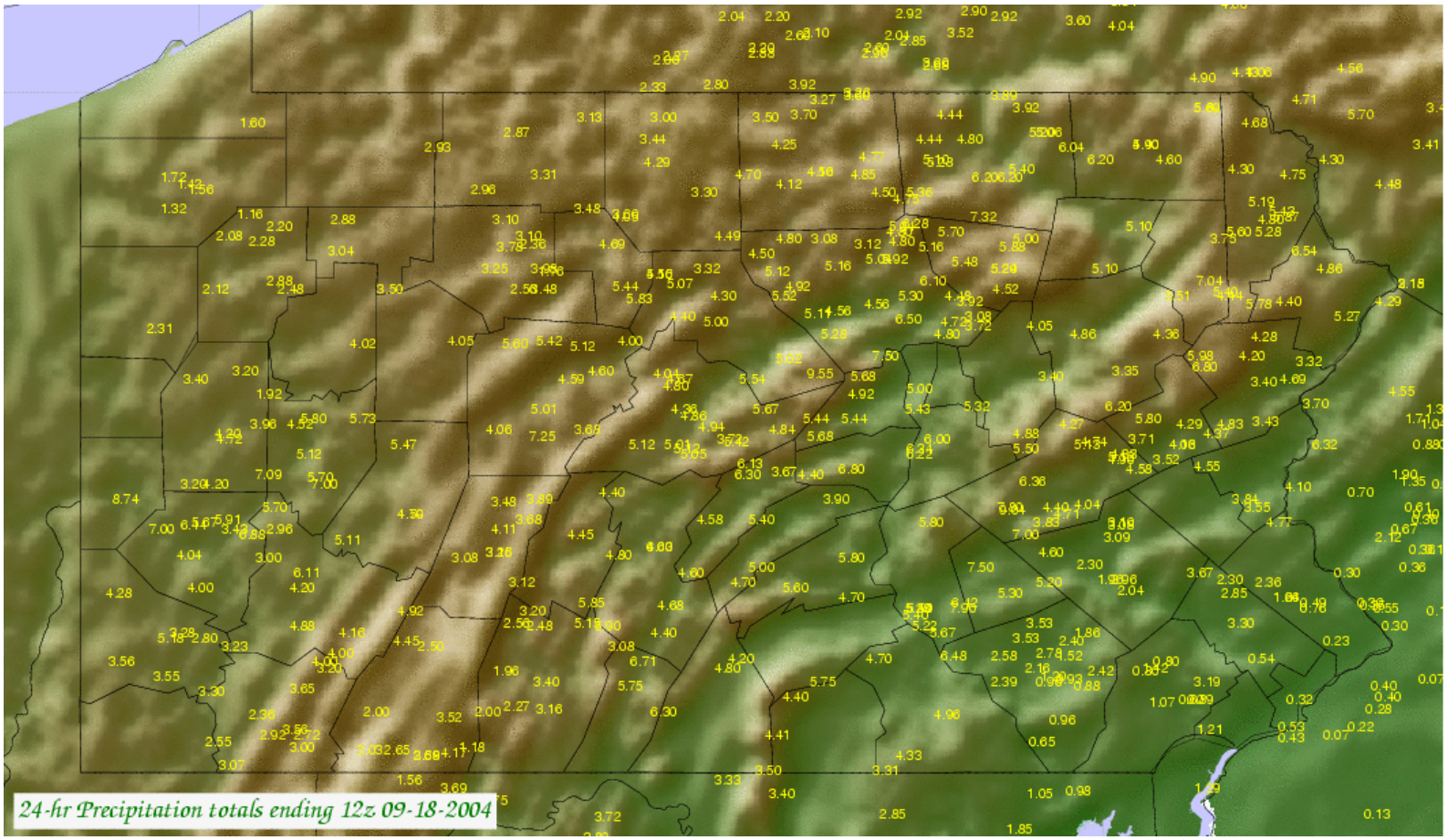

Figure 3 Rainfall plots (inches) associated with Ivan over Pennsylvania shown with a terrain map underlay.

i. Storm track

Figure 1 shows the track of Ivan while it was considered to be a tropical weather system. The National Hurricane Center (NHC) stopped tracking the storm when it became extratropical in nature. The surface analysis at 16/1800 UTC (Fig. 2a) shows the storm over northern Alabama with a cold front moving into Ohio. This front interacted with the storm as it transitioned from a tropical to an extratropical storm. By 17/1200 UTC (Fig. 2b) the storm was over eastern Tennessee and was in close proximity to the frontal boundary and began to move toward the east.

By 18/0000 UTC (Fig. 2c) the storm was over Virginia and was no being longer tracked by NHC (the mid-level circulation would drift anticyclonically back into the Gulf of Mexico and become a tropical storm again on the 22nd). The strong gradient between the high to the northwest north of the storm produced strong easterly flow over Pennsylvania. Ahead (East) of the storm warm tropical air was streaming over Virginia, Maryland, and southeastern Pennsylvania. The frontal boundary likely contributed additional lift which produced the heavy rains in western and central Pennsylvania (Fig. 3). Most of the tornadic activity was confined to areas east of the storm (Fig 4), in the warm tropical air.

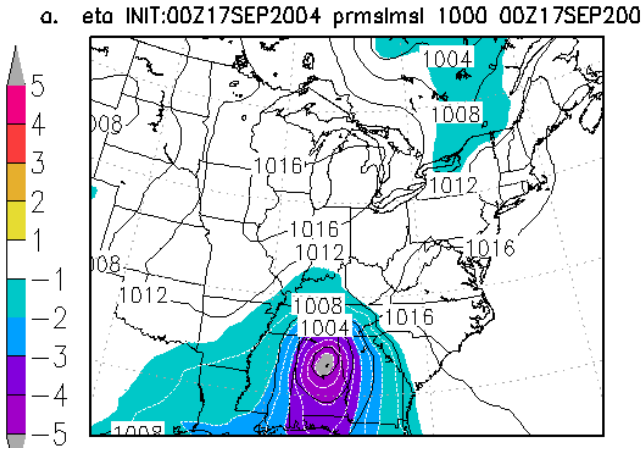

Figure 4. ETA 00-hour forecast of MSLP valid at 0000 UTC 17 September showing isobars and the departures from normal in standard deviations.

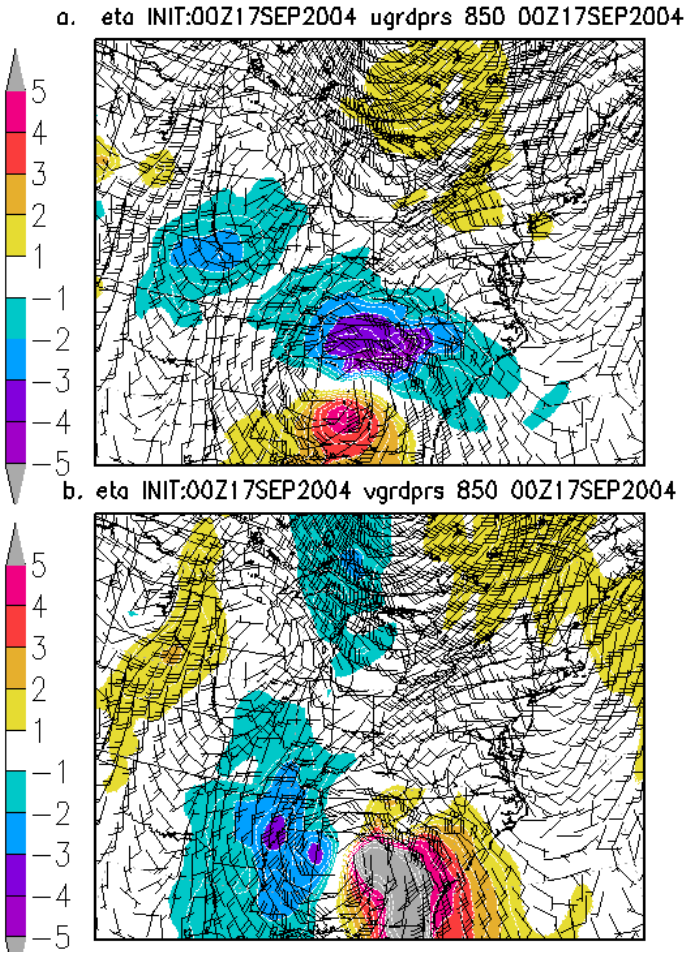

Figure 5 Eta 00-hour forecasts valid at 0000 UTC 17 September 2004 showing 850 hPa winds and a) U-wind and b) V-wind anomalies.

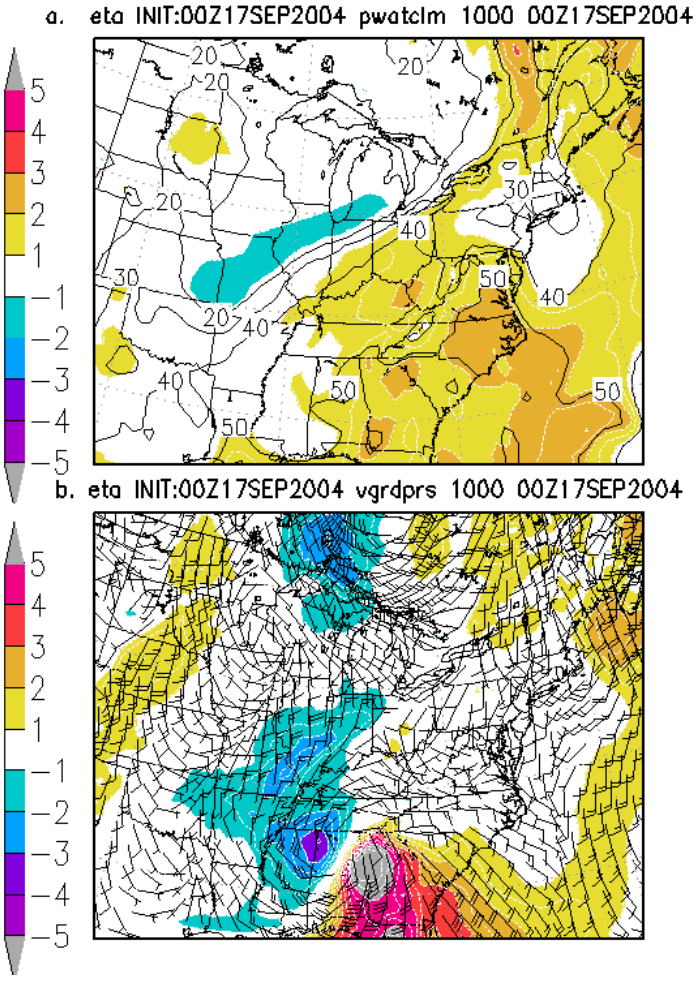

Figure 6 As in Figure 5 except for a) precipitable water and anomalies and b) 1000 hPa winds and V-

ii. Climatic anomalies

Like all tropical storms, Ivan was associated with large climatic anomalies in terms of mean-sea level pressure and low-level winds. The precipitable water anomalies, though large, were not exceptional. The MSLP anomalies initialized in the Eta at 0000 UTC 17 September were on the order of -5 SDs below normal (Figure 4). The Eta initialized strong 850 hPa wind winds with V-wind anomalies on the order of 6 SDs above normal southerly winds (Fig.5b). From a wind anomaly perspective, the winds over Florida and Georgia were extremely strong and anomalous which likely contributed to the strong tornadic activity in this region on the 16th.

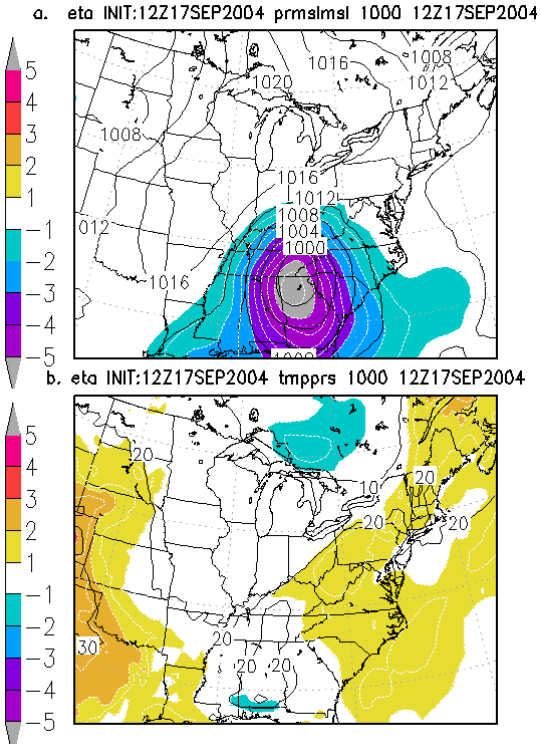

Figure 7 Eta 00-hour forecasts valid 1200 UTC 17 September 2004 showing a) MSLP and anomalies and b) 1000 hPa temperatures and anomalies.

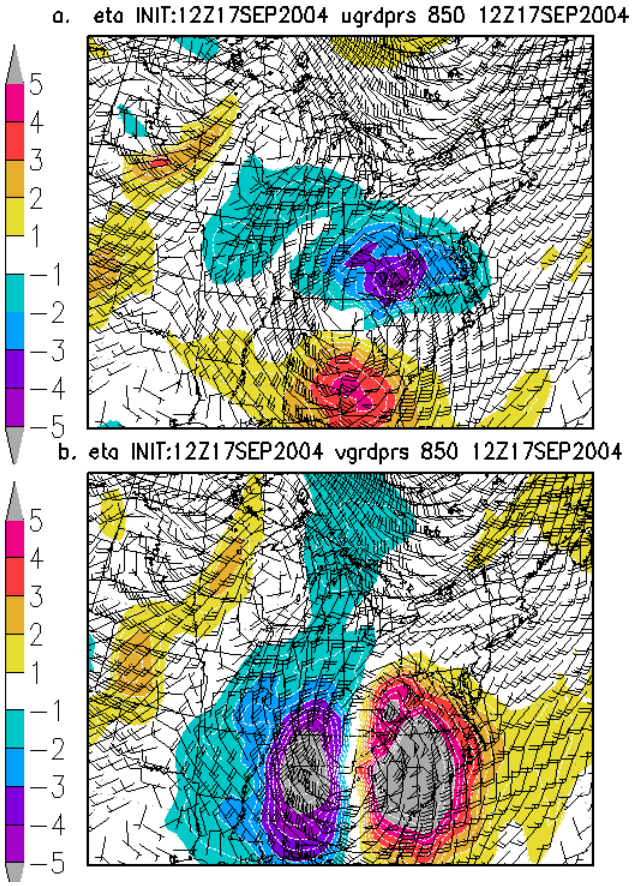

Figure 8 As in Figure 7 except showing 850 hPa winds and a) U wind anomalies and b) V-wind anomalies.

The easterly winds north of the low-center were also impressive (Fig. 5a). These values were on the order of -4 to -4.5 SDs below normal. This suggested strong “cold” conveyor belt north of the low-center. This signature is a good signal for heavy rain, especially on the windward slopes of the Appalachian Mountains. The precipitable water (PWAT: Figure 6a) values were on the order of 40-50 mm (~2 inches) and a were 1-2SDs above normal. Suggestive of heavy rainfall, but the anomalies were not as impressive as those associated with hurricane Frances.

As the storm moved northward, it continued to maintain a deep cyclone central pressure, which by 1200 UTC 17 September was in excess of -5.5SDs below normal (Fig. 7a). The 1000 hPa temperature field showed warm air over most the eastern United States and an implied frontal boundary and cooler air in the Mid-West.

The system retained an extremely strong and anomalous low-level 850 hPa jet at 1200 UTC 17 September (Fig 8). The focus of the southerly jet was over the Carolina’s and Virginia. The intense jet implied incredible low-level shear in the warm tropical air east of the cyclone track. Not surprisingly this was a major tornado day for parts of Virginia, and before the day ended, Maryland and southern Pennsylvania.

The intense low-level jet focused flow toward the central Appalachian Mountains. This is a classic East Coast heavy rainfall signature.

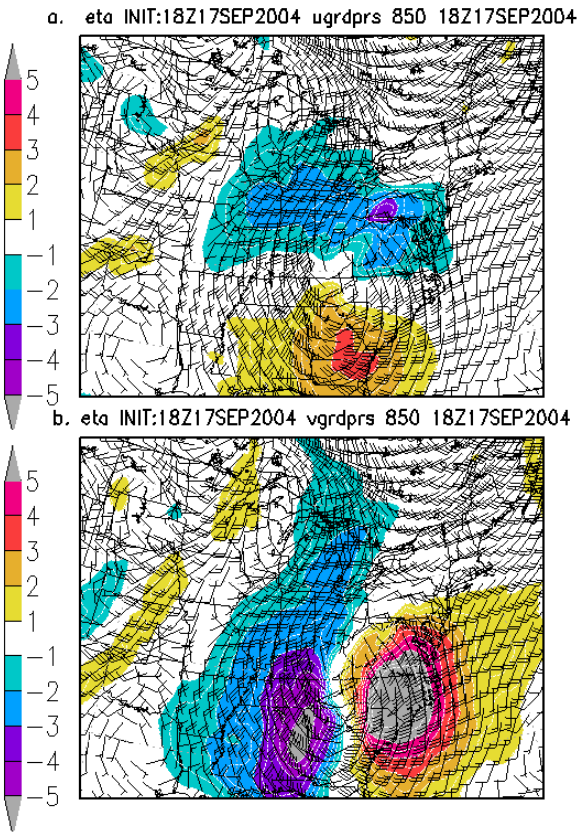

Figure 9 As in Figure 8 except valid at 1800 UTC 17 September 2004.

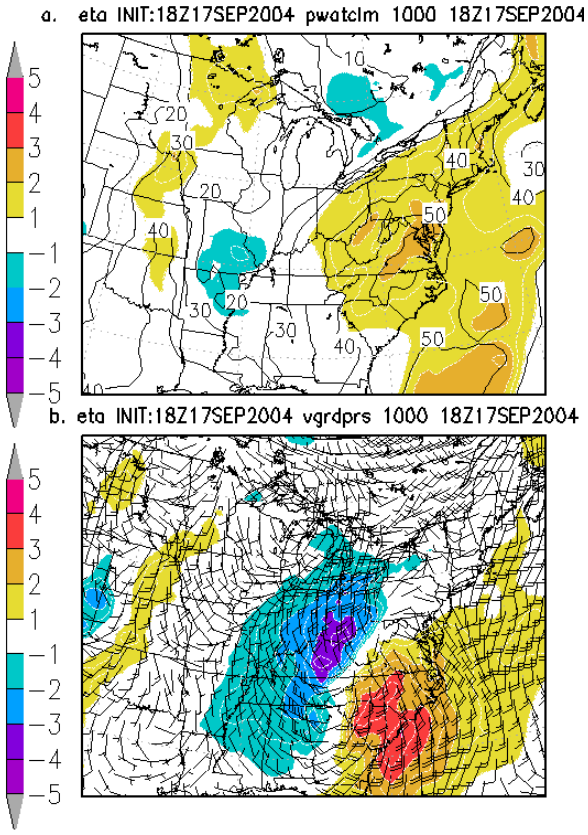

Figure 10 As in Figure 7 except valid at 1800 UTC 17 September 2004.

By 1800 UTC, the anomalous low-level easterly jet was over south-central Pennsylvania (Figure 9). Combined with +2SD above normal PWAT (Fig. 10a) anomalies, heavy rains were falling over the region at that time. This low-level jet would slowly lift north and eastward of the course of the next 12 hours. This combined with the tropical moisture contributed to the heavy rainfall over central Pennsylvania.

The strong low-level winds at 850 hPa with the +5SD anomalous winds (Fig. 9b) likely contributed to the tornadic activity in Virginia during the afternoon hours of 17 September 2004. The nose of these strong winds was aimed at south-central Pennsylvania. Note that at lower levels, the 1000 hPa wind maximum was focused closer to the surface cyclone center in Virginia. Farther north, the winds over Pennsylvania were generally from the east-northeast. Despite the anomalous PWAT values, shallow cold air was resident over Pennsylvania. The PWAT anomalies were associated with humid air of tropical origins lifting over a shallower frontal boundary. This added lift and moist air resulted in the 3-6 inch rainfall that affected the region between about 1500 UTC 17 September and 0800 UTC 18 September 2004. Eastern Pennsylvania had rain into the late morning hours of the 18th.

The impact of the low-level jet can be seen in the GOES infrared and visual images valid at 2045 and 2232 UTC respectively on 17 September 2004 (Fig. 11). The images show a narrow feeder band from North Carolina to northern Virginia. The most intense storms, based on cold cloud tops, were over Virginia. This band proved to be a prolific producer of locally heavy rains and tornadoes. The cloud shield shows

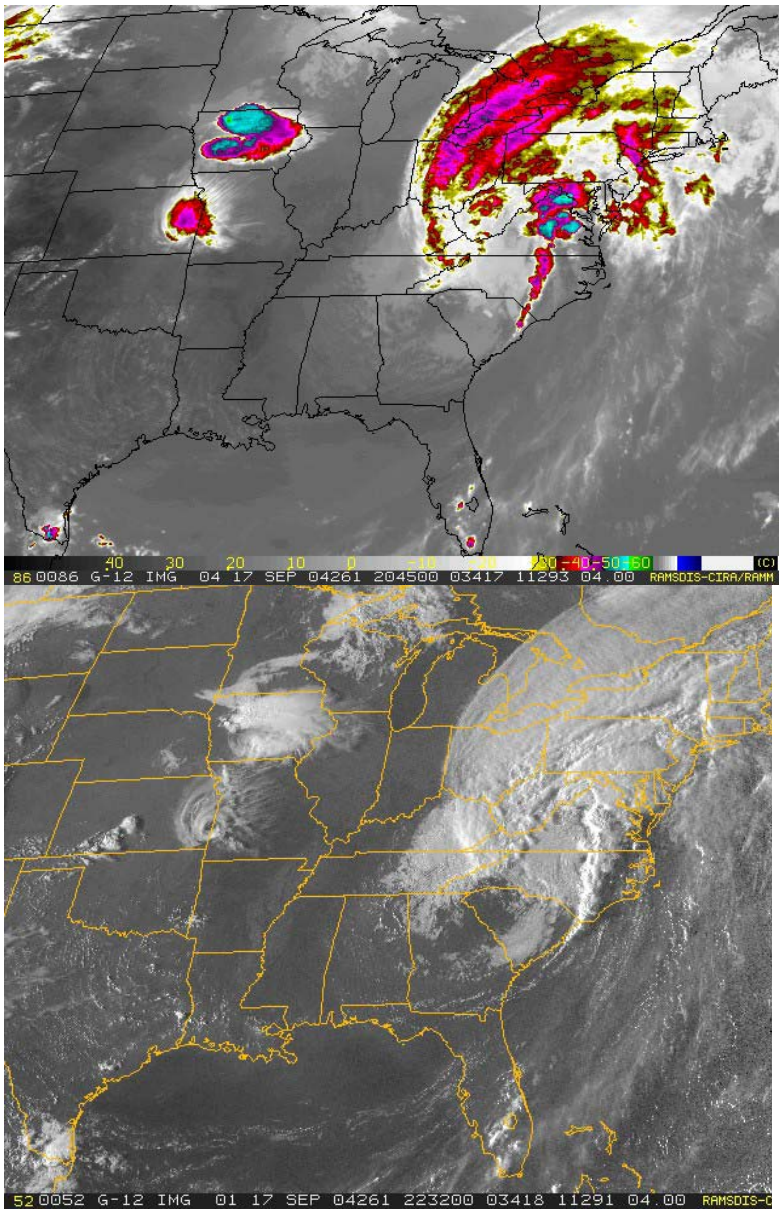

Figure 11 GOES IR image valid at 2045 UTC and visual image valid at 2232 UTC 17 September 2004.

a large area of deep clouds over Pennsylvania, where the tropical air was over running the low-level stable air mass, resulting in heavy rains in the low-level anomalous easterly flow.

iii. Winds and blow-down

Most of the substained wind damage in Pennsylvania was weak in nature (F0 and weak F1). This made distinguishing between tornadic and straight-line wind a difficult challenge. Normally, with a tornado, the damage pattern is enhanced in the direction of the large-scale winds. This is normally in the same direction as the tornadoes movement. Therefore, any tornadoes during the evening of 17 September should have been moving from south-southeast to north-northwest. The blow-down impacts are Ivan are summarized by following this link.

iv. Tornadoes

Storms which were characterized as having been associated with tornadic winds were confined to those affected by the feeder bands east of the low center. The stronger tornadoes and more numerous tornadoes occurred over Virginia and Maryland.

In Pennsylvania most of the tornadic storms occurred in feeder bands and each had a significant Mesoscale circulation feature in the band when viewed using storm relative velocity products (SRM). An example of a feeder band and two circulations

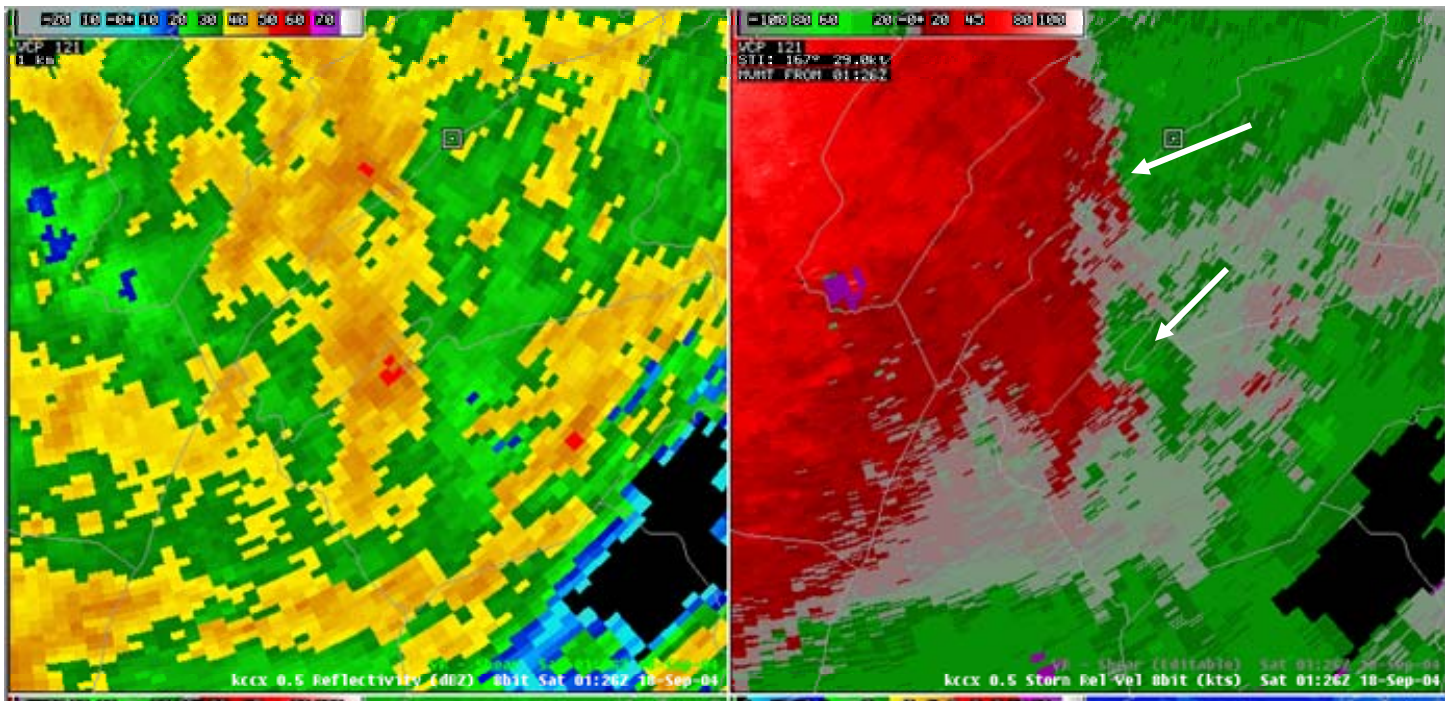

Figure 12 KCCX low-level reflectivity and storm relative velocity from the 0.5 degree slice valid at 0126 UTC 18 September 2004. White arrows show to circulation centers. The southern one resulted in 2 known tornado touch downs.

along the band is shown in Figure 12. The band was oriented from a general south to north direction and elements along the band were moving toward the north. The southernmost circulation center, over the Cumberland-Perry County border at 0126 UTC likely produced one of the two verified tornadoes Franklin and Cumberland Counties.

The warm tropical air did reach into the southeastern counties of central Pennsylvania (Fig. 2c). Temperatures and surface dew points reached into the lower 70s in the later afternoon and evening hours. It was in this warm unstable air where the spiral bands east of the low center produced the tornadoes in the evening hours of 17 September 2004. For brevity, only one example was presented here.

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4. Conclusions

Remnants of Ivan produced a wide range of extreme weather including heavy rains, high winds, and tornadoes. The heavy rains produced both flash and river flooding which resulted in two reported deaths as the direct result of flooding.

The system tracked to the south and then east of central Pennsylvania. This put the region under the threat area for widespread heavy rains. In the classic model, the cool low-level easterly flow north of the tropical low center, with the warm tropical air flowing above it, is an ideal location for widespread heavy rains. Similar to Frances and Beryl, this scenario led to very heavy rain fall in central Pennsylvania.

The heavy rains resulted in both flash and river flooding. The Fransktown Branch at Williamsburg set a new record flood level due to the heavy rains. Scores of bridges were washed out and hundreds of roads had to be repaired due to the rainfall and the resulting flood waters. High waters in a stream drowned a 2 year boy in Blair County and a man and his vehicle were swept away in a raging stream resulting in another death.

The remnants of hurricane Ivan also produced several tornadoes in southern Pennsylvania. Most of the tornadic activity was confined to locations in the warm humid tropical air mass.

In the cooler air, strong winds channeled by the mountains produced blow-down. In some areas, such as central Bedford County, it was difficult to distinguish between blow-down and tornadic damage. Based on reports from spotters and those victimized by the storm, the area near Bedford, which had some serious flooding along the Raystown Branch of the Juniata river, were hit both a tornado and strong low-level winds.

It appears that a skipping tornado moved through the region around 0030 UTC. This storm produced wind damage to 1, damaged crops and sheared off trees about 10-15 feet of the ground as it moved from southeast to northwest across the region. Later in the evening strong winds produced blow-down after 0400 UTC as the low moved eastward across Virginia and the cooler low-level air and the strong low-level jet entered the area. This explains the varied damage pattern and the variation in the times of the reports taken from the Bedford area.

This multi-faceted event was a difficult event to handle. The heavy rains and tornadoes came in rapid succession. Flooding became an issue as tornado warnings were going out. River flooding problems quickly became a problem too. The damage caused by the blow-down further complicated the situation. This was likely the first event where blow-down was experienced and documented in the KCTP forecast area.

5. Acknowledgements

The National Weather Service would like to thank the many Emergency Managers in central Pennsylvania for timely reports, access to damage areas, and their time. The Bedford County EMA group facilitated the lead authors access to three hard hit areas. The Pennsylvania Department of Conservation and Natural Resources provided valuable data on the blow-down. The superintendent at Blue Knob proved to be helpful, knowledgeable, and friendly. He led the lead author for a hike along one of the ridges to access the damage. He also provided maps and details as to how the event unfolded. He and his staff worked hard to keep visitors to the park safe during a dangerous storm.

Many individuals at the National Weather Service in State College

worked long hard hours during this event. Many also contributed to the data included in this report.

Storm surveys were conducted by David Ondrejik, Bruce Budd, John LaCorte and Richard Grumm. Data analysis were provided by John LaCorte and Paul Head. Mike Dangelo. Mike Dangelo facilitated storm survey teams by taking on extra work in the office 20-21 September. Web data for quick use and display were provided by Ron Holmes, Mike Dangelo, Peter Jung, and John Lacorte. Many of whom are included as authors for their efforts.

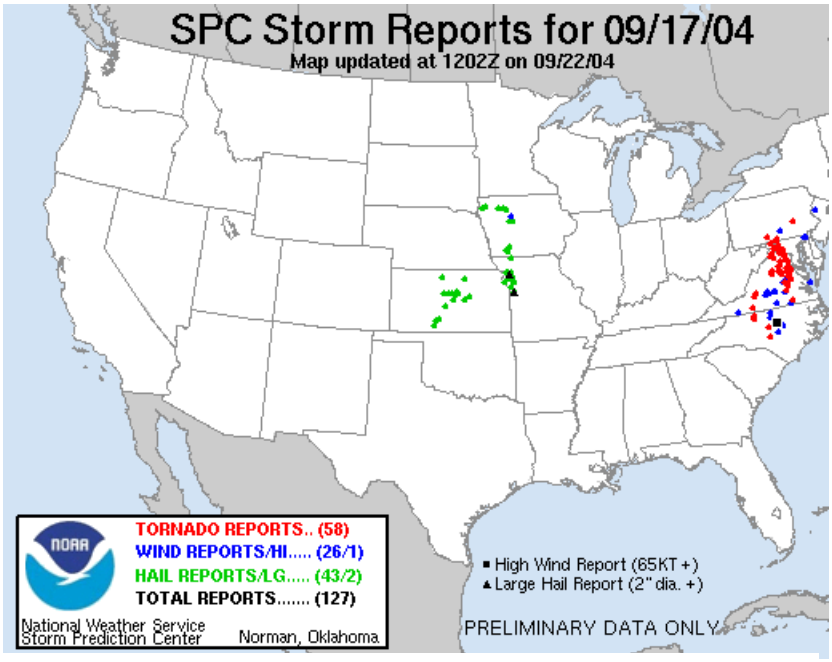

Figure 4 Storm Prediction Center storm reports for 17 September 2004. Red triangles denote preliminary tornado reports.

Appendix of related data

a. Tropical storm Beryl August 1994

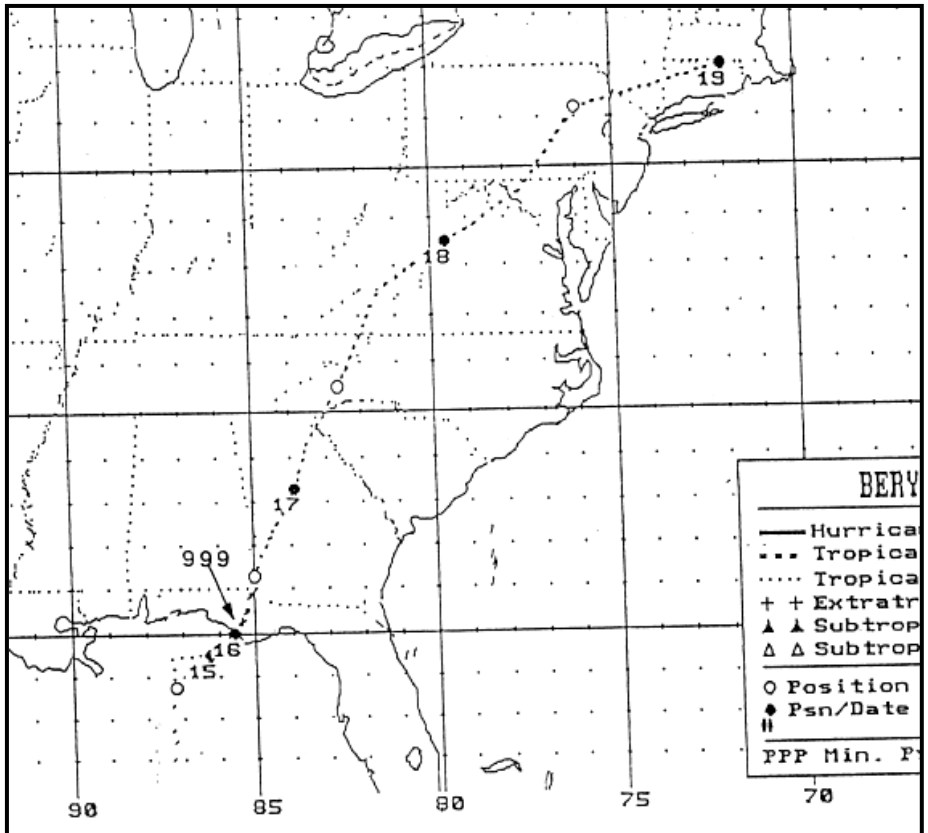

Fig. 1. Best track positions for Tropical Storm Beryl, 14-19 August 1994.