5A.3 THE USE OF ENSEMBLE AND ANOMALY DATA TO ANTICIPATE EXTREME FLOOD EVENTS IN THE NORTHEASTERN U.S.

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1. INTRODUCTION

Flooding disasters are high impact events that result in millions of dollars of damages each year and cause more loss of life than most other weather-related hazards. Flood events can be well anticipated, sometimes days in advance, when flood conditions are observed well upstream of the forecast region. However, accurate prediction of the magnitude of extreme widespread flooding events remains an operational forecast challenge.

Two record-setting widespread flooding events occurred in the northeastern U.S. in 2006, affecting large population centers in New York and New England. The first event in May 2006 affected mainly eastern New England, with Massachusetts, New Hampshire and southern Maine being struck particularly hard. The second event in June 2006 affected central and eastern Pennsylvania through central New York. While the potential for heavy rain and flooding was well anticipated across the region during the 2006 events, the magnitude, exact location and impact was greatly underforecasted. Flood watches were issued with at least 12 hours lead time, but forecasted rainfall amounts were roughly half of what was observed.

Flooding rains of 4 to 10 inches (100-250 mm) were predicted. However, in each case, nearly twice the predicted rainfall fell, 8 to locally over 15 inches (200 mm to over 380 mm) of rain, and the flooding affected a larger region than was forecasted. These rain events highlighted substantial under-forecasting of event magnitude by forecast guidance and forecasters. Improvement in magnitude predictability, including longer lead times, will likely have an overall beneficial value for all affected customers.

2. METHODOLOGY

The two recent events of May and June 2006 were compared to other extreme events that affected the northeastern U.S., namely June 1982, May 1984, April 1987, October 1996, November 1996, October 1998, and October 2005. Analysis of these events resulted in recognition of patterns and signals in a variety of sources of guidance to better predict the magnitude of flooding and maximize the warning lead times.

Analysis of the nine events revealed two synoptic patterns that supported extreme precipitation and the resultant flooding. We have named them The Atlantic Flow pattern and Gulf/Tropical Origin pattern.

It will be shown that forecast anomalies of mean sea-level pressure (MSLP), 850 hPa winds, 500 hPa heights and precipitable water (PWAT) from the Global Ensemble Forecast System, also known as the Medium Range Ensemble Forecasts (MREF; Tracton and Kalnay 1993) and Short Range Ensemble Forecasts (SREF; Tracton et al. 1998) will aid forecasters in predicting the magnitude of flooding disasters. Wind anomalies are defined as follows: U winds are east-west, with west winds as positive values and east winds as negative values, V winds are north-south, with south winds as positive values and north winds as negative values. Derived products from the MREF and SREF such as Quantitative Precipitation Forecast (QPF) probabilities and plume diagrams are also valuable sources of guidance in predicting widespread major flooding events.

It should be noted that this study does not include tropical storms and hurricanes since most meteorologists anticipate anomalously high precipitation associated with warm season tropical systems. However, tropical systems can contribute to the magnitude of an event, such as in October 1996 and 2005.

This study also focuses only on the warm season from April through October, when snow pack typically does not contribute to flooding events. It should be noted that there can be some rare exceptions when highly anomalous snow or cold weather occurs in October or April, but none of these types of events were studied.

Finally, weakly forced convective events typical of summer are not included. These events typically produce locally heavy rainfall, which can be well above 8 inches (200 mm) and can cause local flood problems. However, small-

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scale forces such as sea breeze or differential heating regions of convergence typically dominate during these events and the anomaly signals may not be as clear, especially when examined in the MREF and SREF derived fields.

3. RESULTS

3.1 *Characteristics of Atlantic Flow Events*

In the Atlantic Flow pattern, anomalously strong surface high pressure is centered over southeastern Canada, as low pressure tracks east and out of the Tennessee and Ohio Valleys, across the Appalachian Mountains and through Maryland. Figure 1 from the October 1996 event, shows the surface high remains anchored over southeastern Canada (2 standard deviations (SD) above 1971-2000 normals in this case), increasing the pressure gradient, and the southeast wind flow from the surface through 850 hPa. The strong wind flow provides moisture advection off the Atlantic Ocean, and forcing through speed convergence and frontogenesis, similar to what is observed in historical snowstorms (Stuart and Grumm 2006). The anomalous moisture and winds are evident in the PWAT and 850 hPa U and V wind anomalies (Fig. 2).

The Atlantic Flow events are usually of a long duration, with 250 hPa U-winds 1.5 to 3 SD below normal, indicating a system nearly cut off from the steering flow. This is similar to what is observed in historical snowstorms (Stuart and Grumm 2006).

3.2 *Characteristics of Gulf/Tropical Origin Events*

In the Gulf/Tropical Origins pattern, a weak, high-amplitude 500 hPa trough axis is centered through the western Great Lakes, while smaller-scale upper impulses track north and northeast from the Gulf of Mexico or Gulf Stream. The mean 500 hPa trough axis is nearly stationary, resulting in a nearly continuous low-level wind flow from the south and southwest up the East Coast originating from the Gulf of Mexico and/or the Gulf Stream. The nearly stationary nature to the upper trough is also evident in the below normal U-wind anomalies at 250 hPa.

The small upper impulses along the eastern periphery of the 500 hPa trough strengthen the low-level forcing and consequently the southerly 850 hPa wind flow, enhancing the moisture advection and speed convergence in their proximity. The northeastern U.S. is often in the right-entrance region of the 250 hPa jet, indicated by 250 hPa V-winds of 3 or more SD above normal. Sometimes multiple upper impulses track through the eastern U.S. in the span of several days, producing the extreme rainfall. The anomalous moisture and winds are evident in the PWAT and 850 hPa V winds (4 to 5 SD above normal, such as during the June 2006 event, shown in Fig. 3).

Some events can show characteristics of both Atlantic and Gulf/Tropical flow events. These events are characterized by Atlantic flow in the north and northeast portions of the upper low circulation, and Gulf/Tropical flow on the southern and southeastern portion of the upper low circulation. October 2005 and April 2007 are two examples of a combination event, with 850 hPa U and V wind anomalies both exceeding |3| SD from normal. In the extreme case of the 15-17 April 2007 storm, 850 hPa U and V winds in **both** 15 member ensembles exceeded |5| SD (Fig. 4), unprecedented for any other storm in the 5 years that the SREF and MREF have been available.

It should also be noted that in both patterns, upper-level moisture from the tropics is typically entrained into the system producing the extreme rainfall, although it is much more indirect in the Atlantic Flow pattern.

4. LESSONS FROM THE MAY AND JUNE 2006 EVENTS

Based on the patterns presented in Section 3, May 2006 was an Atlantic Flow Event, and June 2006 was a Gulf/Tropical Origin Event. While pattern recognition and conceptual models are important in the initial evaluation of flood potential, there are many sources of guidance from the MREF and SREF that provided signals for widespread extreme flood events 1 to 2 days before the onset of precipitation.

In addition to recognizing the signals in the SREF and MREF anomalies described earlier, there are other derived fields from these ensembles that can be used to increase confidence in forecasting widespread extreme heavy rainfall events. Plume diagrams and probabilities for 2.00 inches (50 mm) of rainfall (Fig. 5) help quantify confidence levels for extreme rainfall amounts.

Two sets of ensemble members depicting plume diagrams define an envelope of solutions bounded by the driest and wettest ensemble members. Based on subjective analyses of the May and June 2006 events, and the most recent northeast U.S. flooding associated with the April 2007 storm, the observed precipitation during these events was two to four times the wettest ensemble member in the plumes, possibly due to unresolved mesoscale or convective precipitation processes.

A comparison of the Islip, NY plume and observed rainfall for 15 April 2007 is shown in figure 6. Note the wettest ensemble member forecasting 3 to 4 inches (80 to 100 mm) of rain, and the observed rainfall across the region of 6 to 10 inches (160 to 250 mm). More heavy rain events will be studied to better quantify the relationship of QPF from plumes and observed rainfall.

Similarly, 24 or 36 hour probabilities of 2 inches (50 mm) can quantify probabilities for 2 inches (50 mm) or more over a region. Probabilities for 2 or more inches (50 or more mm) in 24 or 36 hours are rarely over 50 percent and areal extent is usually limited to less than one state. This is due to the spread within the 15 member ensemble, with probabilities representing the consistency of the ensemble members. Consecutive run temporal consistency is also rare. So, when 24 or 36 hour probabilities of 50 or more percent for 2 or more inches (50 or more mm) of rain is indicated over large areas, plume diagrams can be consulted for evaluation of QPF from the wettest ensemble members, and then adjusted upward if mesoscale processes are expected that could enhance vertical motion.

5. CONCLUSIONS

Prediction of heavy rainfall amounts prior to flooding events is a great forecasting challenge that has significant implications on how users prepare for floods. The relative low frequency of widespread high impact flood events usually results in under-predicting the associated rainfall amounts and areal extent.

New guidance tools can improve the prediction of extreme flood events, such as plumes and probabilities of 2 or more inches of rain. Forecaster confidence can also be increased through conceptual models and identification of anomalous features, such as 850 hPa winds, PWAT, MSLP and 250 hPa winds.

These techniques and tools help assess the magnitude of potential flood events and improve forecaster confidence in the prediction of magnitude and areal extent of extreme flood scenarios. This can result in more accurate information to users who can then improve decision making prior to and during flood events, ultimately reducing the societal impacts of one of the highest impact weather related disasters: extreme flood events.

REFERENCES

Grumm, R.H., and R. Hart, 2001a: Anticipating Heavy Rainfall: Forecast Aspects. Preprints, *Symposium on Precipitation Extremes*, Albuquerque, NM, Amer. Meteor. Soc., 66-70.

Grumm, R. H., and R. Hart, 2001b: Standardized Anomalies Applied to Significant Cold Season Weather Events: Preliminary Findings. *Wea. Forecasting*, **16**, 736–754.

Mesinger, Fedor, Geoff DiMego, Eugenia kalnay, Kenneth Mitchell, Perry C. Shafran, Wesley Ebisuzaki, Dušan Jović, Jack Woollen, Eric Rogers, Ernesto H. Berbery, Michael B. Ek, Yun Fan, Robert Grumbine, Wayne Higgins, Hong Li, Ying Lin, Geoff Manikin, David Parrish, and Wei Shi, 2006: North American Regional Reanalysis. Bull. Amer. Meteor. Society, **87**, 3, 343-360.

Stuart, N.A and R.H. Grumm 2006: Using Wind Anomalies to Forecast East Coast Winter Storms. *Wea. and Forecasting,* **21**,952-968.

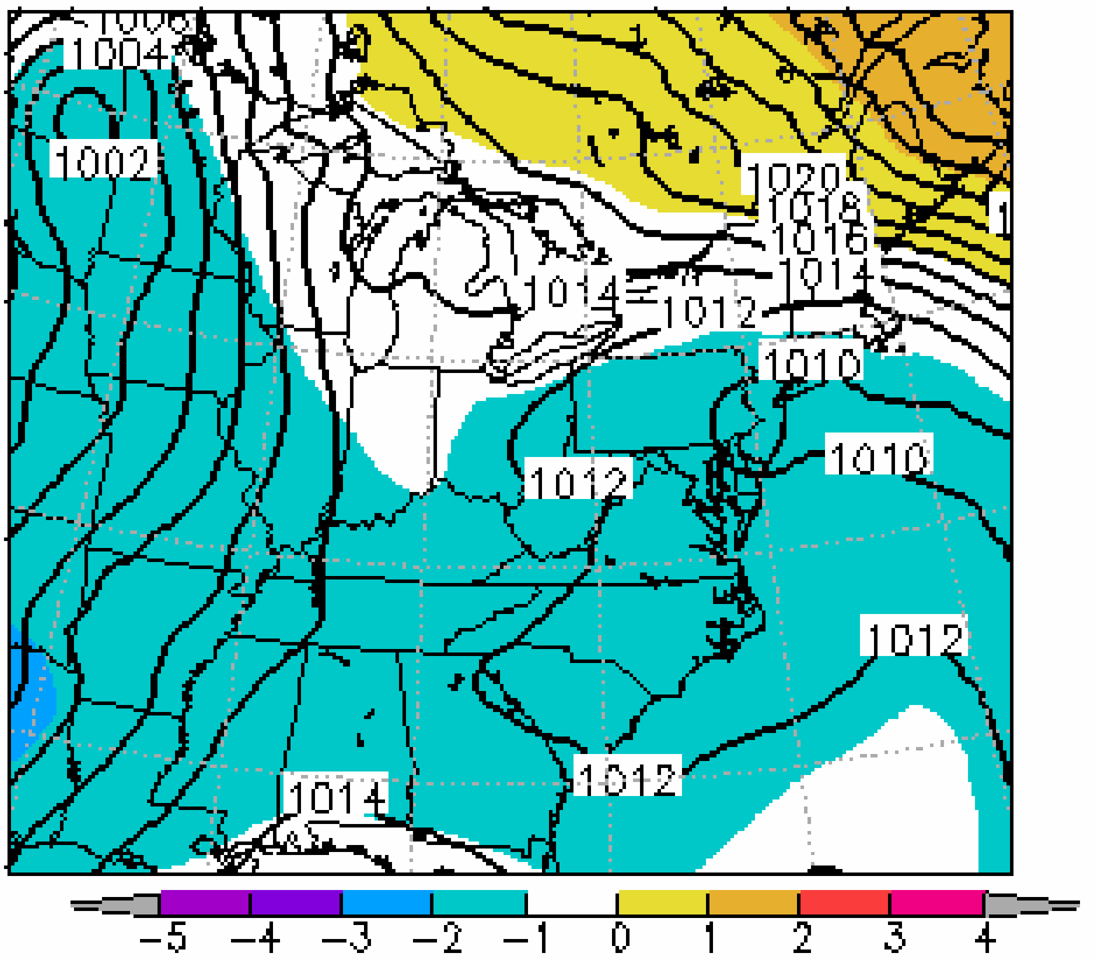


Figure 1. Mean sea level pressure (hPa) and anomalies (color shaded) at 0000 UTC 21 October 1996.

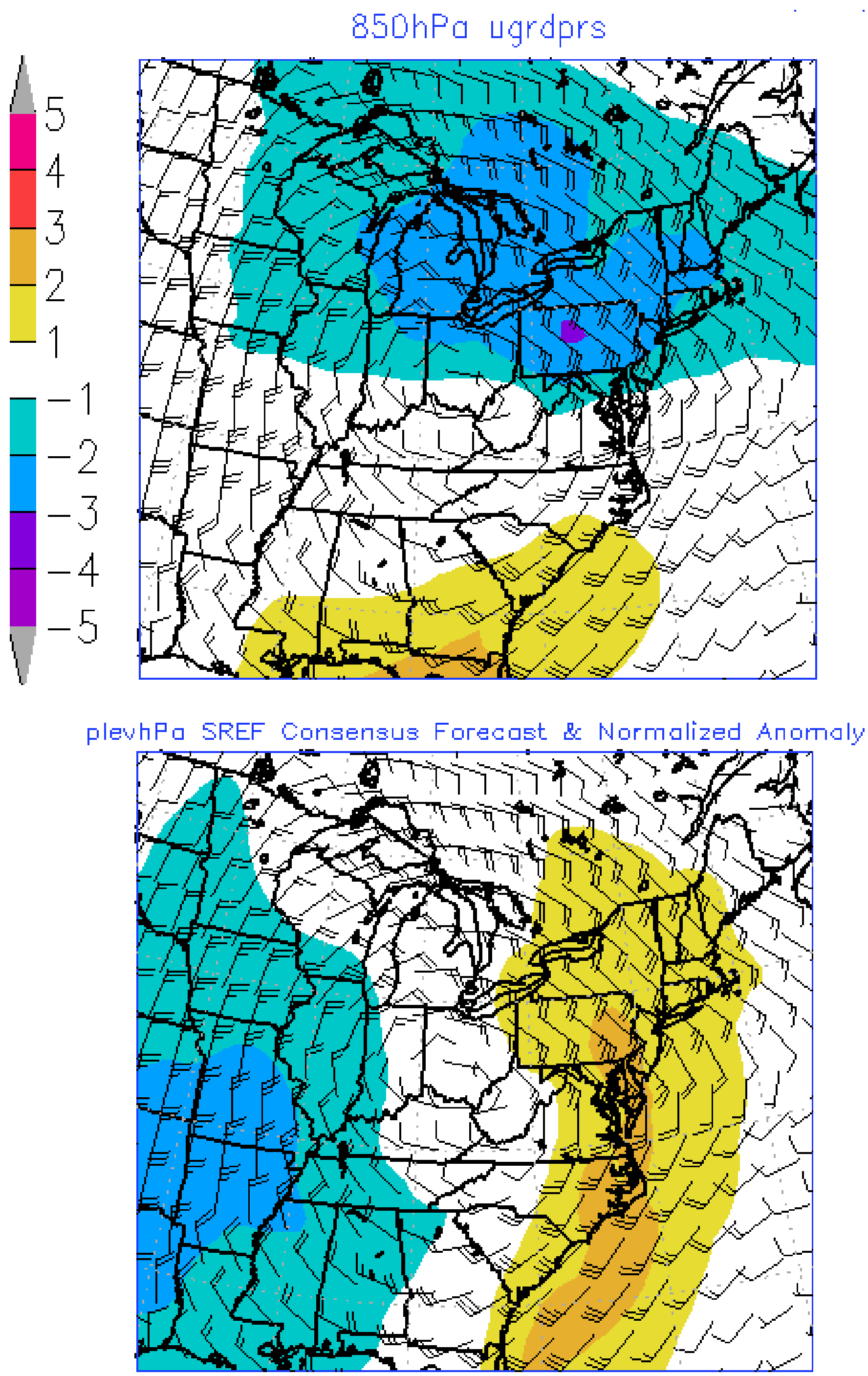


Figure 2. SREF 850 hPa wind barbs (Kt) and anomalies (color shaded) initialized at 0900 UTC 12 May 2006, valid at 09Z 15 May 2006.

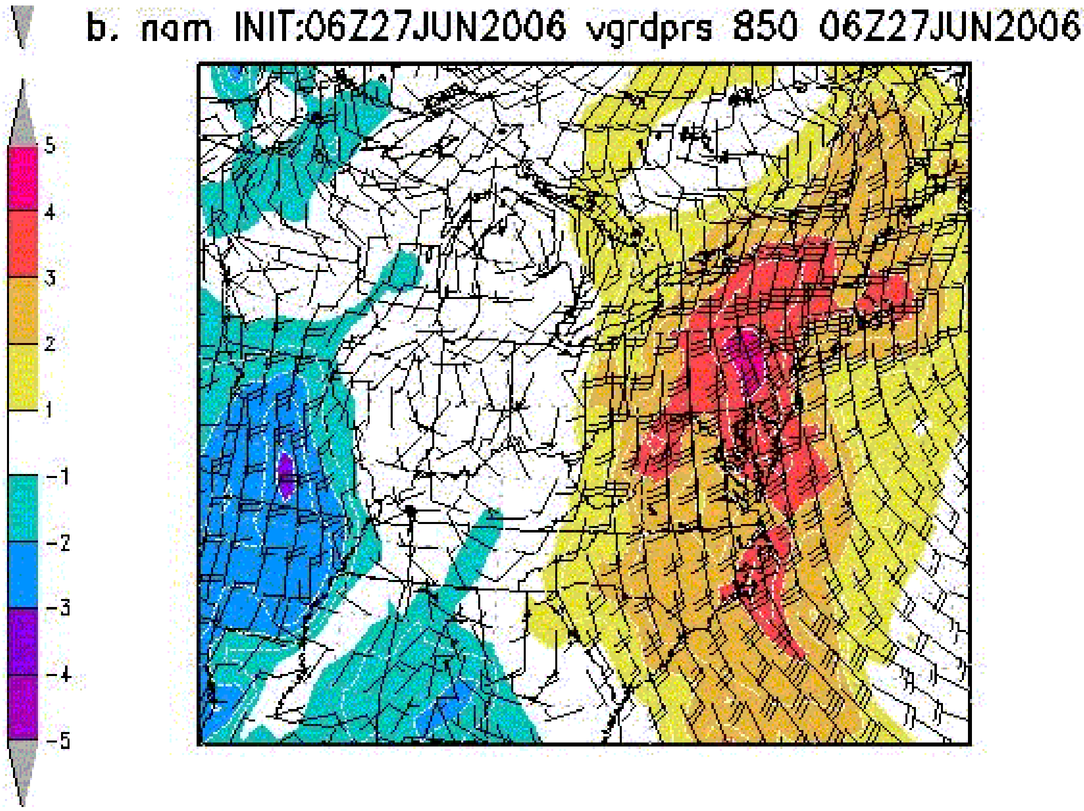


Figure 3. NAM 850 hPa wind barbs (Kt) and V wind anomalies (color shaded) initialized 0600 UTC 27 June 2006.

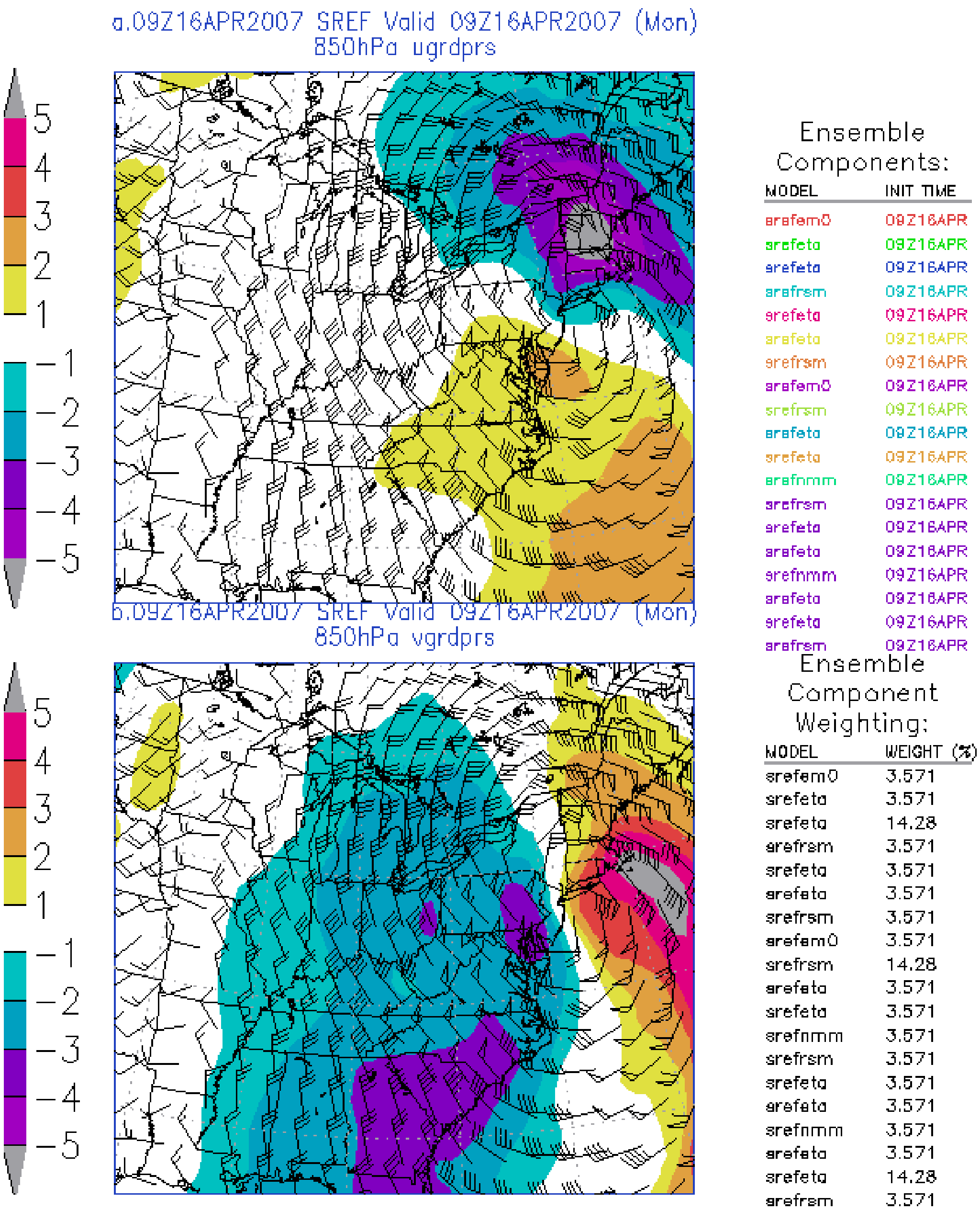


Figure 4. SREF 850 hPa wind barbs (Kt) and anomalies (color shaded) initialized at 0900 UTC 16 April 2007. Note the U and V wind anomalies exceeded |5| SD.

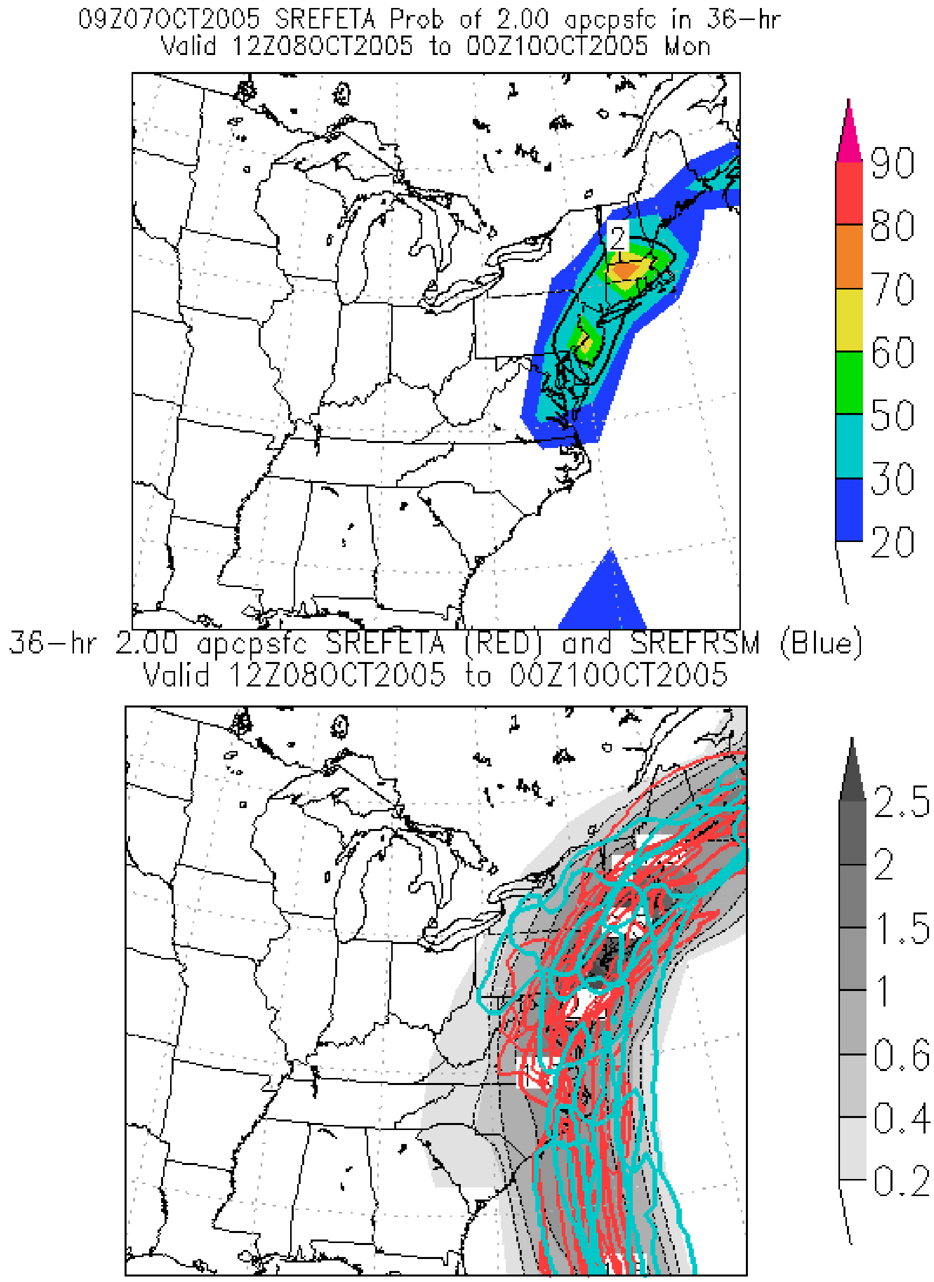
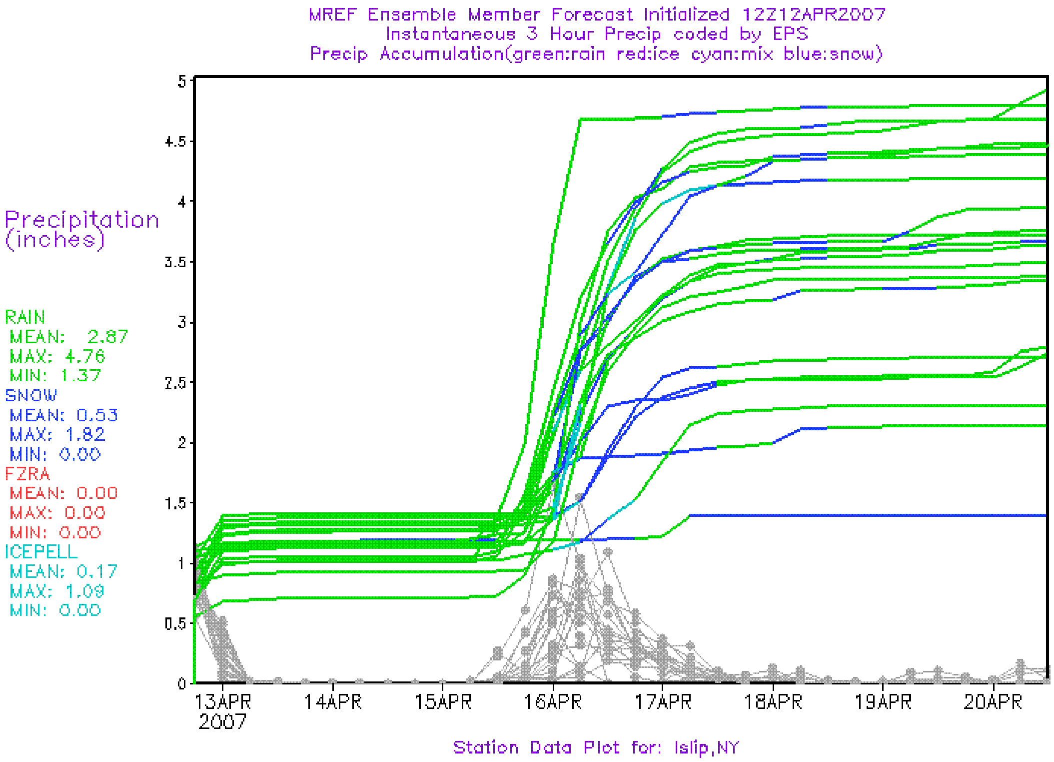


Figure 5. Probability of 2 inches (50 mm) of rain in 36 hours and spread from the SREF initialized 09Z 7 October 2005 and Valid 12Z 8 October 2005 through 00Z 10 October 2005.

a)



b)

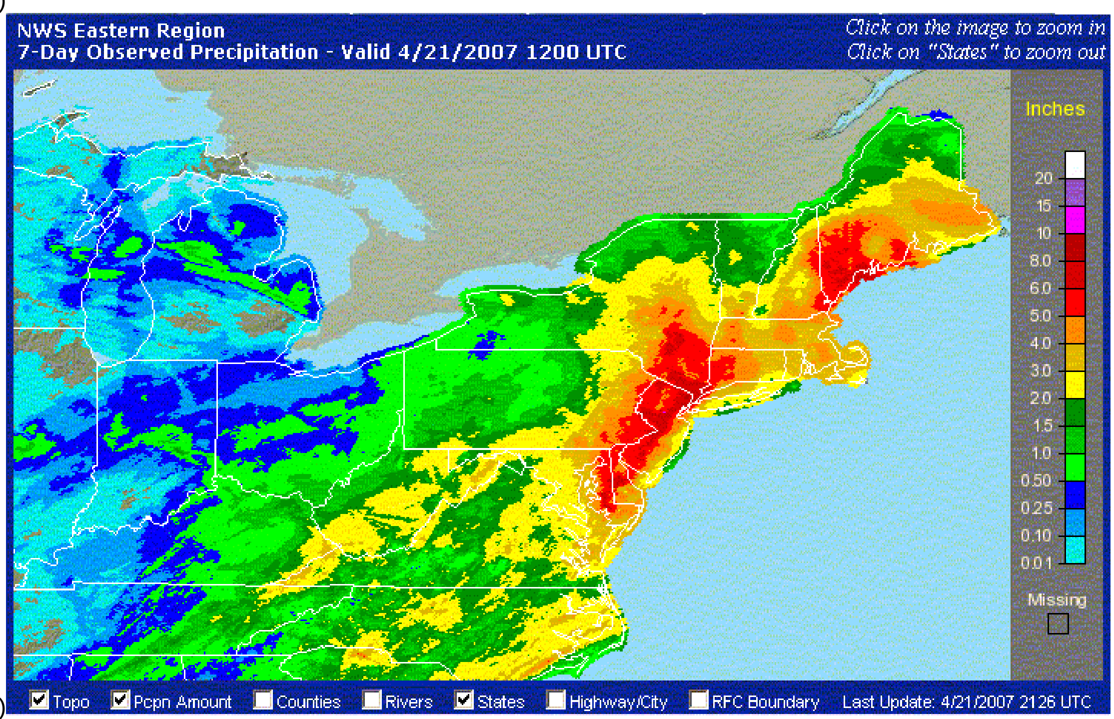


Figure 6. a) MREF Plume diagram showing accumulated precipitation (inches; mm/25) and precipitation type for Islip, NY (ISP) initialized 1200 UTC 12 April 2007, and b) 7-day precipitation accumulation (inches; mm/25)) (courtesy Southeast River Forecast Center).