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FORECAST ISSUES RELATED TO THE UNPRECEDENTED SEVERE AND HIGH WIND EVENT OF DECEMBER 2006

by
*Greg A. DeVoir**
and
Richard H. Grumm
National Weather Service Office
State College, PA 16803

1. INTRODUCTION

A historic late season severe weather and high wind event affected the northeastern United States on 1 December 2006. Over 130 reports of severe weather were received (Fig. 1), making this the latest and largest northeastern United States severe weather outbreak on record. It produced the first 3 December tornadoes in Pennsylvania since record-keeping began in 1950. Specifically, these included an F1 tornado in Greensburg, an F1 tornado in Halifax and an F2 tornado in Fairview Heights, Pennsylvania. The Halifax tornado was the first fatal tornado on record in Pennsylvania in the month of December, and the Fairview Heights tornado was the first ever December F2 tornado in Pennsylvania.

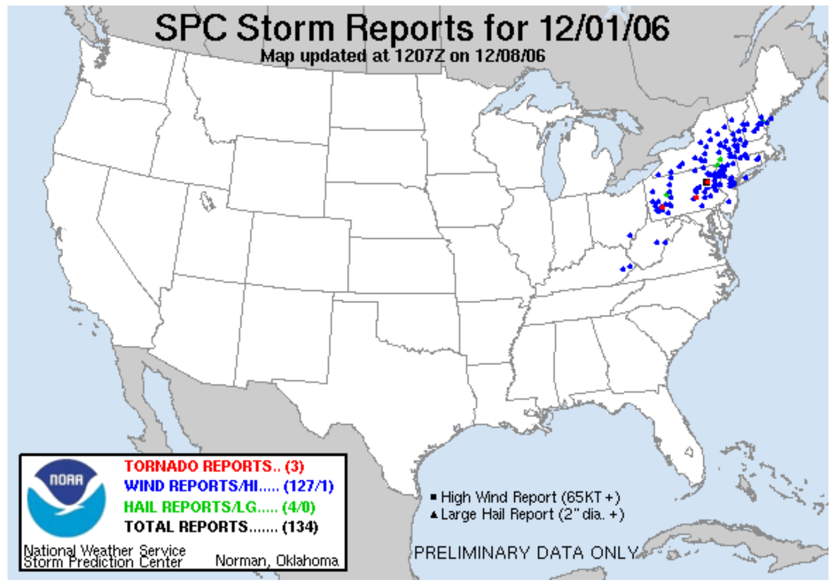

Figure 1. National Weather Service Storm Prediction Center (SPC) storm reports for December 1, 2006.

A composite of National Weather Service Severe Thunderstorm and Tornado Warnings issued during the event (blue and red, respectively) along with severe wind and hail reports is shown in Figure 2. The majority of the damage was produced by severe thunderstorm wind gusts, which occurred from the late morning and early afternoon over western Pennsylvania and in the mid to late afternoon across south central and eastern Pennsylvania. In addition to the severe reports, widespread non-convective wind damage occurred behind the wave of severe convection.

This paper examines forecast issues related to this unprecedented event. The National Centers for Environmental Predictions (NCEP) Ensemble Prediction System (EPS) and operational numerical model output are examined, with the focus on the ability of these systems to forecast the magnitude and scope of this unusually strong, late season convective event. It will be shown that both the EPS and deterministic model data successfully identified the potential for a significant severe weather event 2 to 3 days in advance. These data assisted in refining medium and short range forecasts leading up to the widespread outbreak.

2. METHODS AND DATA

The NCEP ensemble prediction system (EPS) output were used in real time and archived from the NCEP data site. The NCEP medium and short range ensemble forecast system (SREF and MREF respectively) data, along with

* *Corresponding author*: Greg DeVoir, National Weather Service Office, State College, PA 16803.email: greg.devoir@noaa.gov

operational deterministic runs of the NCEP North American Mesoscale model (NAM) and Global Forecast System (GFS) models were examined in real time and archived for later display. Emphasis was placed on identifying key forecast fields and their departures from normal for this highly anomalous severe weather outbreak.

The map of severe weather was provided by the Storm Prediction Center (SPC). Satellite imagery was obtained from the local Advanced Weather Interactive Processing System (AWIPS) archive and some satellite data was retrieved from the RAMSDIS satellite imagery website.

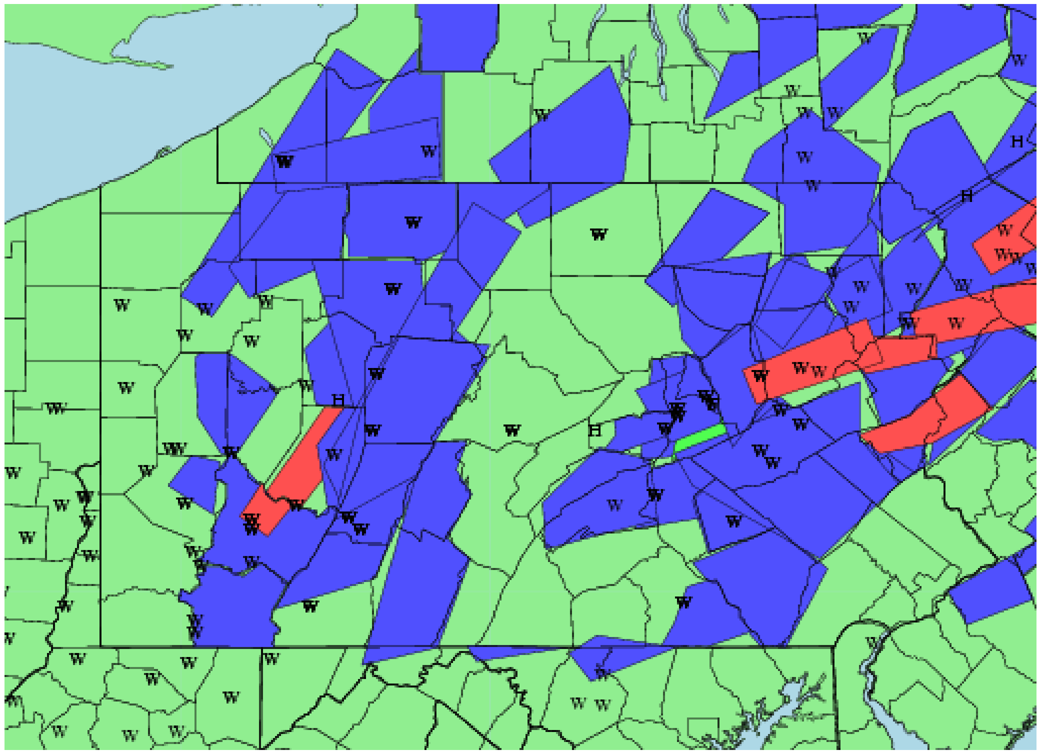

Figure 2. Graphical plot of National Weather Service storm warnings and location of severe storm reports. Blue shading denotes Severe Thunderstorm Warning issuances, and red depicts Tornado Warning issuances. W indicates damaging/severe wind gust exceeding 58 mph and H indicates hail ¾" or larger.

Radar data was obtained from the local AWIPS archive. Additional imagery was obtained from the University Corporation for Atmospheric Research (UCAR) radar site. Model data overlaid on satellite data was obtained from AWIPS using GOES imagery and the 40km RUC projection data.

3. OVERVIEW

a. Summary of Antecedent Conditions

The antecedent conditions associated with this event included a surge of abnormally warm and moist air into the eastern United States and an intrusion of arctic air into the western United States. The intersection of these two air masses produced an intense early-season winter storm from the southern and central Plains northeastward to the western Great Lakes. On the cold side of the storm, heavy snow occurred in many locations from the Texas panhandle northeastward to central Illinois, as seen in the 1815 UTC GOES visible imagery on 1 December (Fig. 3).

Ahead of the cold front, unseasonable to record warmth enveloped the eastern third of the country on 30 November and 1 December 2006. In central Pennsylvania, new daily *and monthly* record high temperatures were established for 1 December at Williamsport Pennsylvania (70º F), while Middletown, Pennsylvania set a new daily record high of 75 degrees F. In addition to the unseasonably high temperatures, dew points in excess of 60F were observed at many locations, unseasonably high values for Pennsylvania during the month of December. The resulting deep convection would feed on this anomalous warmth, producing a record severe outbreak.

b. *Ensemble and Numerical Model Forecasts*

Deterministic GFS model runs captured the potential magnitude of the event more than 72-hours in advance. Figure 4 shows 850 hPa forecast u-wind anomalies (Fig. 4a) and the v-wind anomalies (Fig 4b) from the 1200 UTC 28 November 2006 run of the operational GFS, valid at 1800 UTC 1 December 2006. The 850 hPa v-wind component was forecast to exceed

75 knots, corresponding to a positive anomaly of +4 to +5 S.D. above normal. Similarly, 850 hPa u-component forecast wind anomalies were +3 to +4 S.D. above normal at 1800 UTC 1 December 2006, with magnitudes exceeding 60 knots.

Figure 5 shows the 850 hPa forecast wind anomalies from forecasts initialized at 1200 UTC 28 November 2006 MREF, valid at 1800 UTC 1 December 2006. Note the weaker winds and smaller anomalies as compared to the single higher resolution deterministic GFS (Fig. 4). Due to uncertainty in the timing of the frontal system at longer forecast ranges, both the MREF and SREF forecast anomalies were markedly smaller than those indicated by individual deterministic model runs.

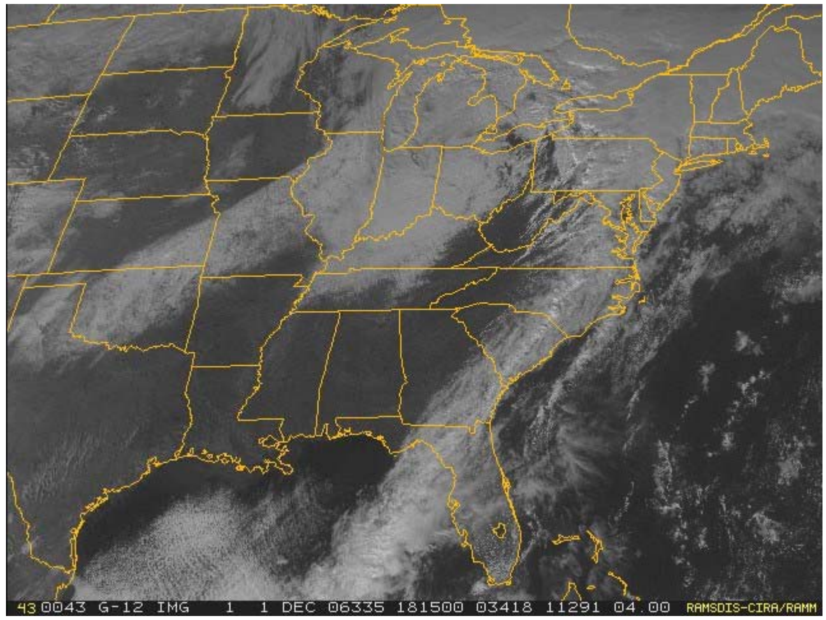

Figure 3. GOES visible imagery at 1815 UTC. Arrows indicate location of heavy snow from northern Texas through central Missouri. Upper level dry slot is evident nosing into southwest Pennsylvania behind initial line of convection extending from the eastern Great Lakes southward to the Florida Gulf Coast.

The upper panel of Figure 6 shows a spaghetti plot of precipitable water (PW) from the 1200 UTC 28 November 2006 MREF, valid at 1800 UTC 1 December 2006. The lower panel of Figure 6 shows the consensus (ensemble mean) MREF forecast and normalized PW anomalies valid at 1800 UTC 1 December 2006. The consensus MREF forecast captured an anomalous plume of high PW, but indicated significant timing differences among its members, as evidenced by the large variation (shading) shown in the top panel of Figure 6. This spread suggested timing issues associated with the frontal system between individual MREF members. Averaging of the individual members produced a dampened anomaly signature in the MREF as compared to the deterministic solution from 1200 UTC 28 November 2006 runs. The weaker winds in Figure 5 verse Figure 4 are likely related to these timing issues.

At shorter forecast lengths (not shown) the timing differences among MREF and SREF members decreased and the anomalies from both EPS trended toward the deterministic GFS and NAM forecast anomalies (not shown).

c. *Convective Evolution*

Thunderstorms developed ahead of the system over Alabama, Kentucky and Ohio early on 1 December, with over 46 severe weather reports before 1200 UTC including a tornado in Alabama. The initial convection from Ohio brought severe weather to western Pennsylvania from bowed line segments (Fig. 7) mixing down the anomalously strong 850 hPa winds (see Fig. 4a).

This activity was aligned with the leading edge of the upper-level dry slot, as shown in the GOES water vapor image (Fig. 8). This first area of convection weakened as it moved into the central portion of the state during the early afternoon hours. However, by mid-afternoon within the dry slot deep convection initiated over south-central Pennsylvania and swept eastward (Fig. 9). It is hypothesized that this second wave of convection was associated with a cold front aloft (CFA: Locatelli et. al 1998; Locatelli et. al 2002a and 2002b) and with a surface trough, which swept across the region during the afternoon hours.

Figure 10 shows a cross section from the 09-hour forecast of the 1200 UTC 1 December 2006 NAM12 model valid at 2100 UTC 1 December 2006 when the secondary line of

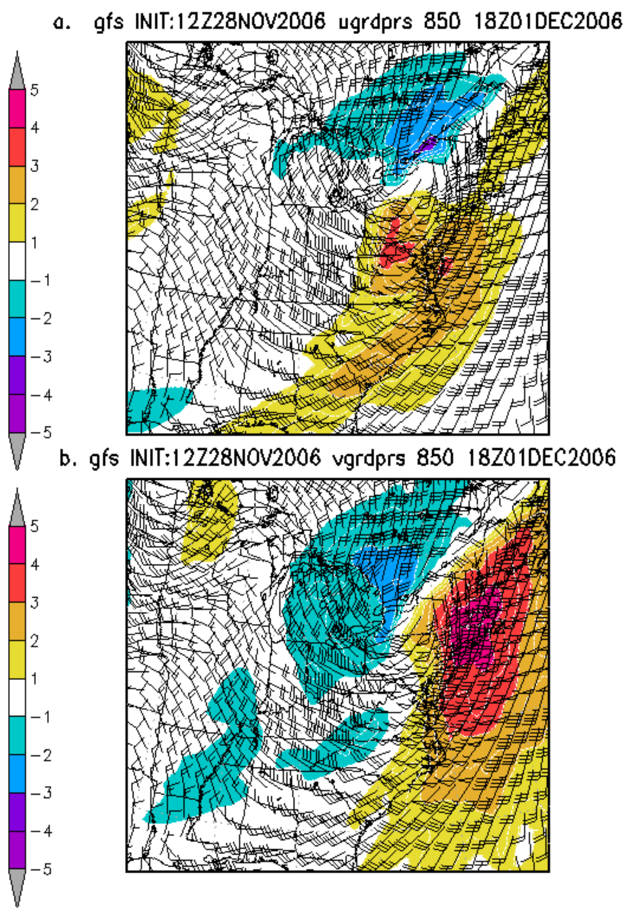

Figure 4. GFS initialized at 1200 UTC 28 November 2006 showing 850 hPa winds (kts) and a) u-wind anomalies (shaded) and b) v-wind anomalies. Winds are in knots and anomalies in standard deviations from normal.

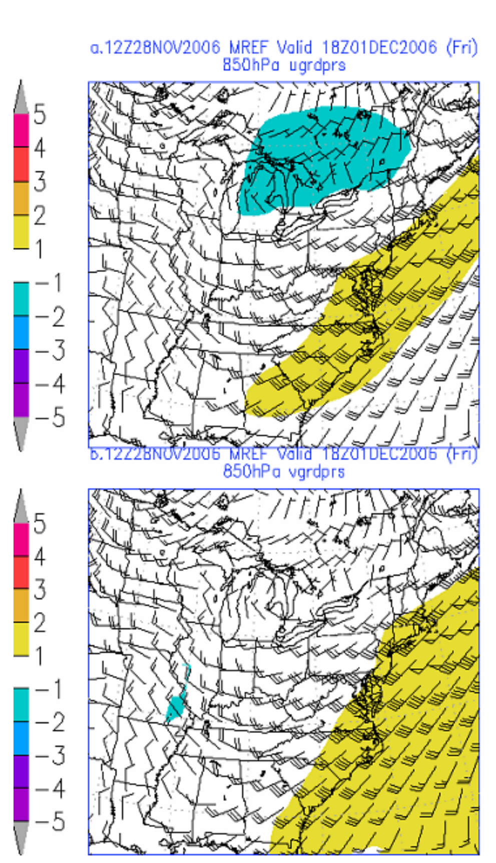

Figure 5. GEFS forecasts initialized at 1200 UTC 28 November 2006 valid at 1800 UTC 1 December 2006 showing mean 850 hPa winds (kts) and a) u-wind anomalies and b) v-wind anomalies. Anomalies are in standard deviations from normal.

convection was near its peak intensity. A quick comparison with Figure 9 shows that the area of nearly vertical saturated equivalent potential temperature lines is nearly coincident with the location of the secondary line of convection over south central Pennsylvania. The areas of computed CAPE indicate colder air aloft (the CFA) was forecast to progress ahead of the surface trough (solid blue lines) bowing to the right in the image above and out ahead of the surface front. The NAM12 09-hour forecast cross section fits the idealized model of the CFA as shown by Rose et al. (2002), showing skill in forecasting the CFA evolution and resultant convection in the near- to short-term.

5. CONCLUSIONS

A historic late season severe weather and high wind event affected the northeastern United States on 1 December 2006. This event produced over 130 reports of severe weather across the eastern United States and the 3 latest tornadoes observed in the State of Pennsylvania. This was one of the largest late season severe weather events in the eastern United States. Model and EPS forecasts showed signals which indicated the potential for an anomalously strong late season event. Additionally, short term forecasts implied that the CFA may have triggered some of the severe convection over Pennsylvania during the afternoon hours of 1 December 2006.

The NCEP guidance was able to forecast both the surge of anomalously high precipitable water (PW) and strong low-level southerly winds into the affected region ahead of the cold front. PW anomalies were on the order of 2 to 3 standard deviations above normal. Behind the front, strong westerly winds associated with the non-convective high wind event were also well forecast. The EPS data indicated some uncertainty with the timing of the frontal system. The spaghetti plots of the PW field (Fig. 6) showed this effect.

In this case, the most significant aspect of there having been a secondary line of convection form is that it propagated eastward into an anomalously warm and moist environment that was prime for convection (no previous shower activity had affected the south central to southeastern portion of Pennsylvania that morning). With surface temperatures in the 70s and dew points in the 60s along with strong vertical wind shear and shear profiles conducive to strongly rotating and potentially tornadic storms, the stage was set for a major late-season severe weather outbreak.

6. REFERENCES

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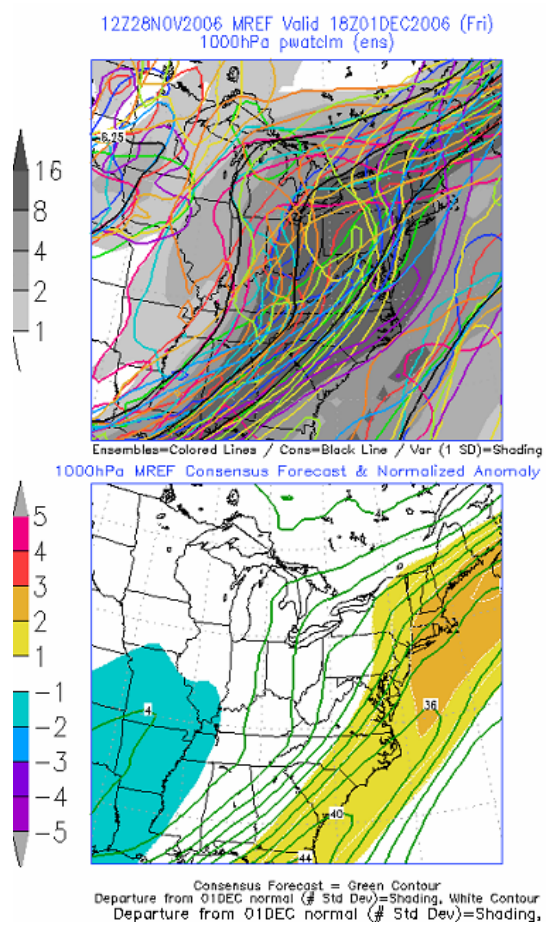

Figure 6. Top panel shows spaghetti plot of MREF precipitable water and degree of member spread (shaded) from the 1200 UTC 28 November 2006 MREF. The MREF consensus forecast of precipitable water is shown in the bottom panel.

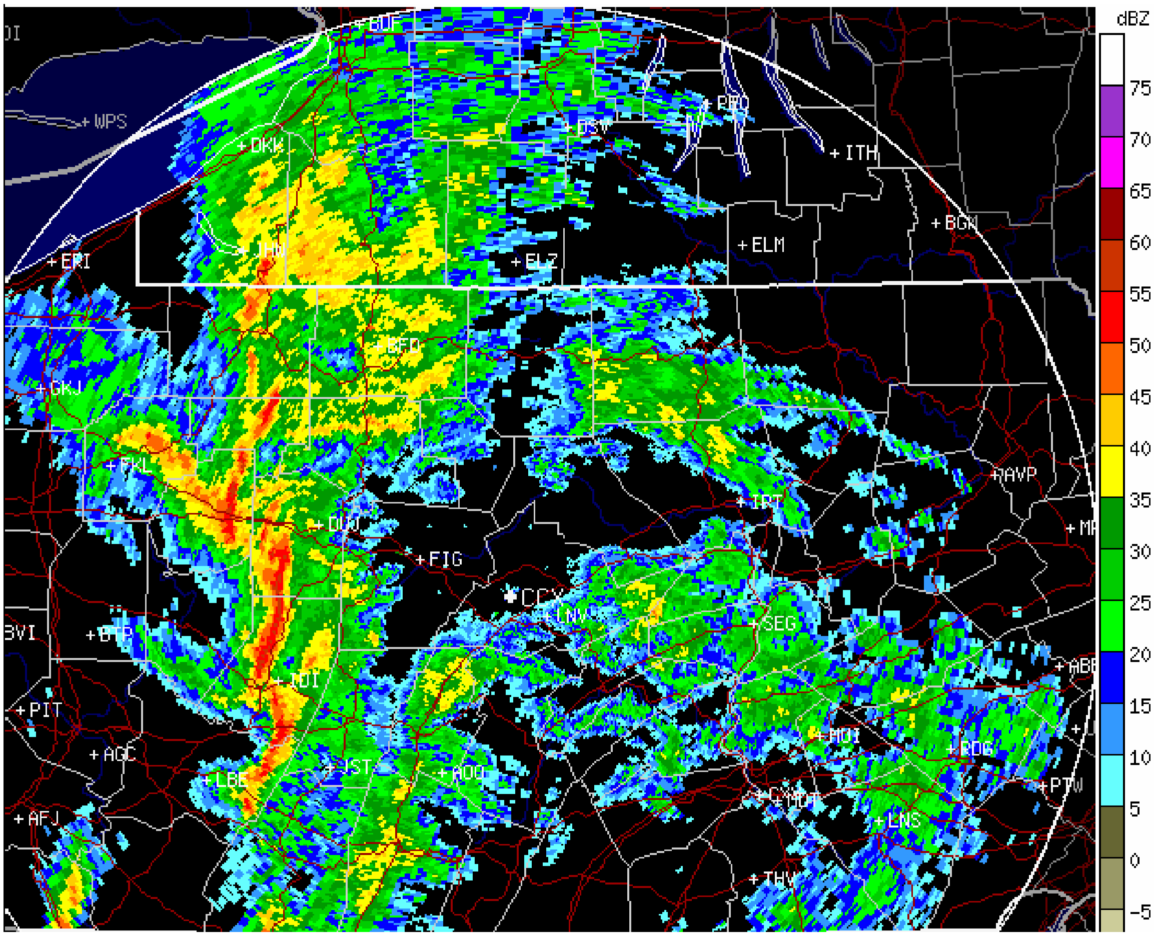

Figure 7. KCCX radar 0.5 degree base reflectivity valid at a) 1701 UTC 1 December 2006. Image courtesy of the UCAR website (www.rap.ucar.edu/weather/radar).

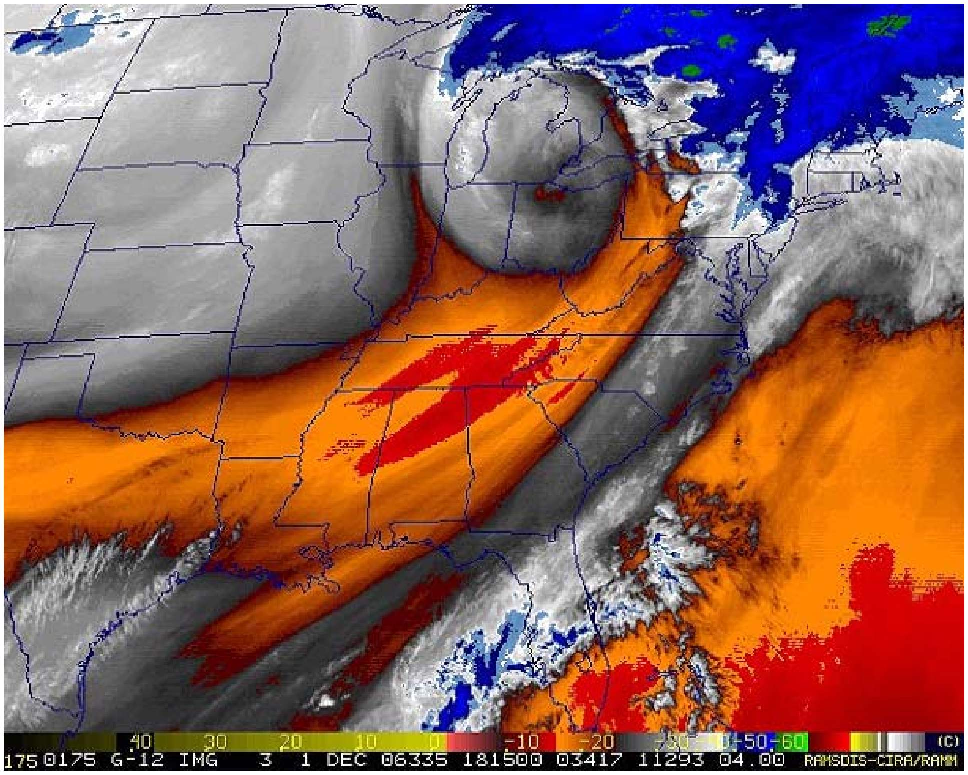

Figure 8. GOES water vapor imagery over the eastern United States valid at 1815 UTC 1 December 2006.

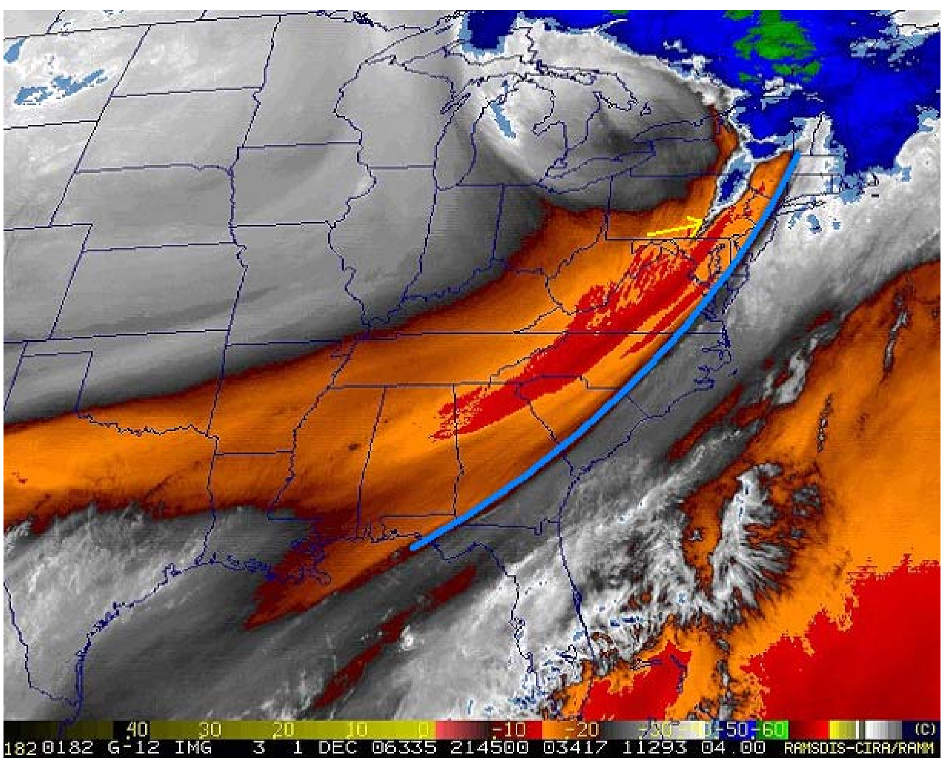

Figure 9. Same as Fig. 8 except valid at 2145 UTC 1 December 2006. The yellow arrow points to the secondary line of convection initiated by the surface trough associated with the CFA, which is indicated by the solid blue line.

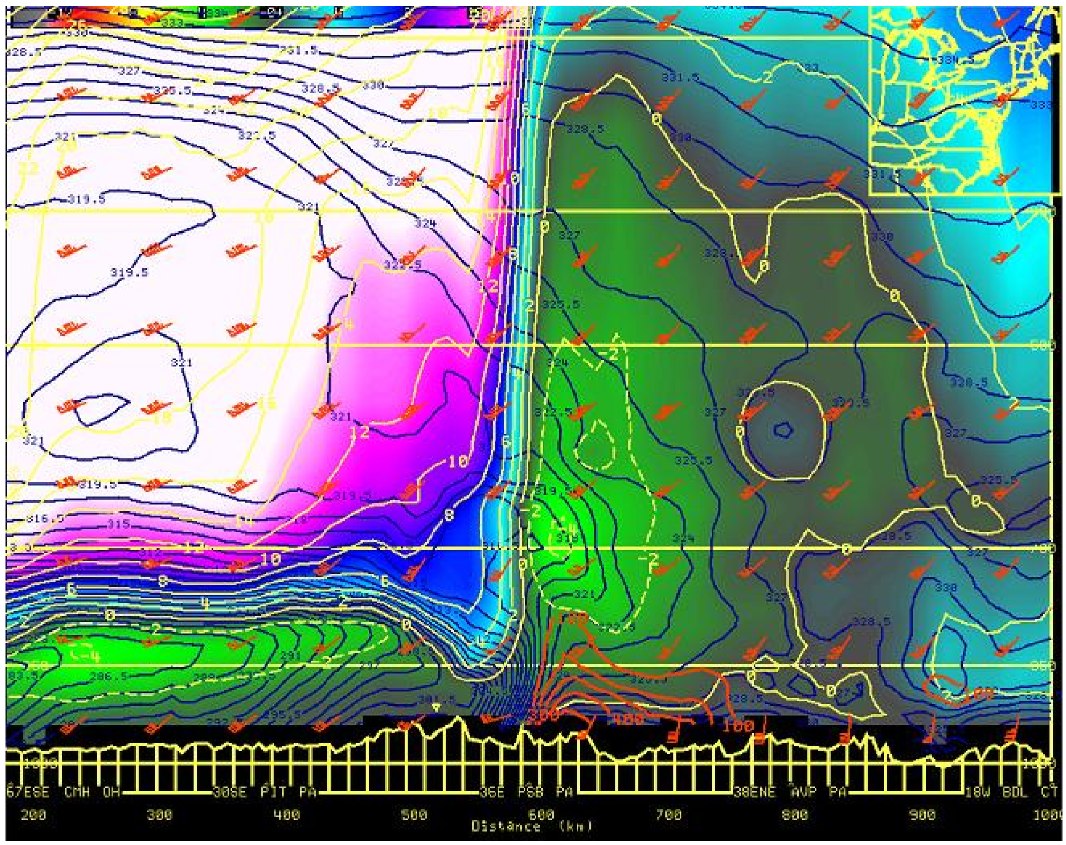

Figure 10. NAM12 09-hour forecast initialized at 1200 UTC 1 December 2006 showing a cross section of saturated equivalent potential temperature (solid blue contours), computed CAPE (red contours), surface-based Lifted Index (LI – yellow contours) and winds (orange barbs) along a line from southeast Ohio to western Connecticut as shown in the upper right.