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A LOCALIZED SEVERE WEATHER EVENT OVER SOUTHWESTERN OHIO ON AUGUST 24, 1996

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1. INTRODUCTION

Around 0600 UTC (0200 EDT) on 24 August 1996, a sub-severe thunderstorm complex was moving east-northeast across southern Indiana and northern Kentucky. At the same time, an area of showers was dropping southeastward across northern Indiana and Ohio. By 0700 UTC, the stronger storms associated with these systems had merged, causing an overall intensification of the resultant convective system. One storm in particular became severe, producing damaging winds across a relatively localized area in southwestern Ohio.

The meteorological conditions just prior to and during this severe thunderstorm event are examined in this paper. For this study, both the Eta and NGM 0000 UTC runs from 24 August were utilized for diagnosing various meteorological features. Specifically, Section 2 describes the synoptic scale features associated with this event, while Section 3 looks at the thermodynamic environment in place across the Ohio Valley. Section 4 delves deeper into the mesoscale environment that contributed to this severe event, while Section 5 shows the evolution of the severe storm as depicted by WSR-88D radar data. Concluding remarks are presented in Section 6.

2. SYNOPTIC OVERVIEW

The 6-hr forecast (valid at 0600 UTC) from the 0000 UTC Eta model run on August 24 indicated that a weak surface frontal trough would be positioned east-west across the southern portion of Ohio and southern Indiana (Fig. 1). An enhanced area of surface-based convergence associated with this frontal trough was also noted over southwestern Ohio. A well-defined surface moisture boundary, illustrated by the tight dewpoint gradient (Fig. 2), was forecast to be just north of the surface trough. Moderate instability was forecast south of the frontal trough as Eta model CAPE values were indicating an area of 800-1200 J/kg across most of Kentucky (Fig. 3), while weaker instability (<800 J/kg) was forecast between the surface frontal trough and the moisture boundary.

At 850 mb, a northeast to southwest-oriented trough of low pressure was forecast by the NGM across Ohio by 0600 UTC (Fig. 4). At the same time, a sharp quasi north-south θ_e gradient was forecast across the northern two-thirds of Indiana and Ohio. According to the NGM, weak 850-mb wind convergence (Fig. 5) was forecast for northern Indiana and also for northern Kentucky and southern Ohio. At 700 mb, the axis of strongest upward vertical motion(not shown) was forecast by the Eta to lie across northern Kentucky and West Virginia. However, an east-west cross section taken across southwestern and south-central Ohio (Fig. 6) indicated that deep upward motion, with a maximum core centered near 450 mb, was forecast.

A mid-level shortwave trough was forecast by the Eta model across southern Michigan at 0600 UTC, with well-defined Positive Vorticity Advection (PVA) evident across most of Ohio (Fig. 7). However, the strongest forcing associated with this shortwave was forecast to move across northern Ohio. At 300 mb, a strong jet stretching from the southern Great Lakes to northern New England was forecast by the NGM (Fig. 8). Note the associated upper-level wind divergence over northern Kentucky and southern Ohio.

The NGM model forecast orientation of the mean cloud-layer shear vector, i.e., the 850-300 mb thickness pattern (not shown), which according to Merritt and Fritsch (1984) correlates well with the direction of movement of meso-β scale convective elements (MBE), suggested that the east-southeast moving convection over northern Indiana and northwest Ohio would eventually merge with the convective system moving east-northeast across northern Kentucky and southern Indiana. Although their research focused on movement of MBEs that were embedded within the larger Mesoscale Convective Complex, they indicated similar movement could be attributed to that of smaller convective systems. Thus, given that a merger of these convective systems appeared likely, intensification was inevitable (Schmocker et al. 1998).

3. THERMODYNAMIC ENVIRONMENT

The Wilmington, OH sounding (not shown) from 0000 UTC on August 24 indicated moderate instability with a surface-based CAPE of nearly 2300 J/kg, and a Lifted Index of -7°C. Also, a $\Delta\theta_e$ of 25 K between the surface and 700 mb was noted, which according to Atkins and Wakimoto (1991), is favorable for wet microbursts ($\Delta\theta_e$ values greater than 20 K). The low-level wind profile indicated weak cold air advection, with little potential for rotating storms. At this time, no other index suggested a high potential for severe thunderstorm activity.

The surface temperature and dewpoint fell a few degrees between 0000 UTC and 0600 UTC. Modifying the sounding to reflect the 0600 UTC surface conditions gave a CAPE value around 1000 J/kg and a Lifted Index of -4°C. The $\Delta\theta_e$ decreased to around 15 K, which according to Atkins and Wakimoto (1991), would still allow the potential for wet microburst activity ($13 \text{ K} < \Delta\theta_e \leq 20 \text{ K}$).

4. SUB-SYNOPTIC SCALE ENVIRONMENT

At 0300 UTC, a surface analysis (not shown) identified a modest moisture gradient, where dewpoints in the upper 60's to around 70 °F were observed across southwest Ohio, while dewpoints across northern Indiana and northern Ohio were in the lower to middle 60's. By 0600 UTC, this moisture gradient had strengthened. Surface dewpoints had risen to 70°F across a narrow band which extended as far northeast as central Ohio, thus encompassing all of southwest Ohio. Meanwhile, dewpoints in the upper 50's were observed just to the northwest of this area in northeast Indiana. This enhanced moisture gradient allowed for increasing surface convergence, thus providing a stronger focus along which thunderstorms could form or intensify.

According to Uccellini et al. (1987), the right rear entrance region of an upper level jet is the favored location for the development of a transverse ageostrophic secondary circulation. This circulation converts available potential energy into kinetic energy, thus enhancing the upward vertical motion. Referring back to the forecast position of the 300-mb jet in Fig. 8, note that the right rear entrance region of this jet was positioned over southwest Ohio. Generating a cross section perpendicular to this jet allows examination of any effect that a transverse ageostrophic secondary circulation might have on enhancing the upward vertical motion in the vicinity of southwest Ohio. Indeed, Figure 9 illustrates the enhanced vertical motion forecast over southwest Ohio and north-central Kentucky around the time the convection intensified.

Q-vector analysis of the 6-hr forecast valid at 0600 UTC indicates enhanced Q-vector convergence across the Ohio Valley region through a rather deep low-level layer. In the 1000-850 mb layer, Q-vector convergence was forecast to be particularly focused across southwest Ohio (Fig. 10). Sanders and Hoskins (1989) explained that a Q-vector indicates direction of the ageostrophic motion in the lower portion of the identified layer, and points toward the region of enhanced ascent. Referring back to Fig. 9, this can be clearly shown when noting the Direct (D) secondary transverse ageostrophic flow centered around 700 mb. The lower portion of this circulation (around 850 mb) points to the area of enhanced ascent. Thus, vertical motion tends to be upward when a field of Q-vectors is convergent.

The potential for enhanced (possibly severe) thunderstorm activity existed based on the evaluation of real-time observations, and their incorporation into the forecast model guidance output. Surface-based convergence, coupled with upper-level jet dynamics, over an area classified as moderately unstable, would provide the environment for this enhanced thunderstorm activity. Any deep convection that were to develop would interact with the drier θ_e air aloft, and according to Atkins and Wakimoto (1991), could produce wet microburst activity. Below is a look at WSR-88D radar data and how the storm-scale features evolved.

5. RADAR ANALYSES

WSR-88D radar data (not shown) from Wilmington, OH(KILN) indicated that at 0607 UTC, an area of showers and thunderstorms, associated with the frontal trough, was moving northeast across southeastern Indiana and northern Kentucky. This area extended as far east as extreme southwestern Ohio. These storms were producing heavy rainfall and frequent lightning, but none had reached severe limits (hail $\geq$ .75 in; winds $\geq$ 50kts). During this same time, another area of showers associated with the mid-level shortwave trough was moving southeastward across east-central Indiana and west-central Ohio.

Propagation appeared to play a significant role in the eventual merger of these two convective systems. Recall that overall movement of a storm is determined by the relative effects of both advection and propagation. Storm propagation may be influenced by both internal and external factors. Some of the internal factors which appeared to drive this propagation include updrafts/downdrafts and the precipitation cascade (NOAA 1993).

By 0631 UTC, low level reflectivity data showed that the storms which were earlier located across east-central Indiana and west-central Ohio had moved southeastward (Fig. 11). Propagation, or the new cell development associated with the stronger storms in this area of convective activity was to the southeast. Meanwhile, the storms previously observed over southeast Indiana and northern Kentucky had moved northeastward into extreme southwest Ohio. Propagation associated with the stronger storms in this area of convection was to the northeast.

Between 0631 and 0648 UTC, propagation with the strongest storms was such that a merger over southwest Ohio was likely. It should be noted, however, that between 0648 and 0718 UTC, the KILN WSR-88D experienced an outage, and radar data during this period were lost. By 0718 UTC, when the radar data collection had resumed, it was apparent that the storm merger was occurring across eastern Butler County in southwest Ohio. Rapid intensification was evident at this point as reflectivity values greater than 50 dBZ increased dramatically in areal coverage throughout the lowest 20 kft of the storm. This resulting convective system evolved into a bow echo, moved eastward into northwestern Warren County at 0723 UTC, and persisted through 0748 UTC (Fig. 12 shown at 0738 UTC).

Schmocker et al.(1996) indicated that a Mid-Altitude Radial Convergence (MARC) signature is a reliable predictor of damaging winds at the surface. This signature represents convergence in the mid-altitudes of the storm (~7-22 kft AGL), with radial velocity difference values greater than 50 kts giving as much as 10-30 minutes lead time on the arrival of damaging winds at the surface. The radar outage mentioned previously prevented an analysis of this MARC signature before 0718 UTC. However, when the bow echo moved into Warren County to the south of the town of Franklin at 0723 UTC, a MARC signature of about 50 kts (Fig. 13) was evident at 3.3°(~8 kft AGL).

Schmocker et al. (1996) also indicated that the MARC signature often precedes the formation of a cyclonically rotating Book End Vortex (BEV) on the left flank of a bow echo by 12 to 18 minutes. The BEV helps focus the rear-inflow jet, which plays a crucial role in supplying potentially cold and dry mid-level air to aid in the production of convective and system-scale downdrafts (Weisman 1991). A BEV developed on the north end of the bow echo by 0723 UTC. Associated storm relative velocity data at 0.5° indicated rotational velocity values around 26 kts in the vicinity of the town of Franklin (Fig. 14). A cross section of storm relative velocity data (not shown) from this same time shows that rotation was evident through the lowest 14 kft of the storm, with the strongest rotation observed through the lowest 5 kft. Also, a rear inflow jet, noted by enhanced dry slotting in the reflectivity imagery, became evident by 0733 UTC near the town of Franklin, and persisted through 0748 UTC (Fig. 15).

The rotational velocity (not shown) associated with the BEV weakened to less than 16 knots by 0728 UTC at lower levels even though the storm-relative convergence remained strong aloft in the vicinity of the apex of the bow. Between 0738-0748 UTC, rapid weakening of the bow echo was observed as the MARC signature diminished in intensity. The storm continued to weaken as it moved east into a less unstable environment.

Light to moderate structural damage occurred in association with the MARC signature which corresponds to areas impacted by passage of the bow echo's apex. This included downed trees and traffic lights on a path from Middletown, OH, to the north side of Lebanon, OH. The most significant damage occurred, however, near the town of Franklin, OH, where the BEV displayed the strongest rotation. Here, numerous trees were downed, a shed was destroyed, and structural damage occurred to several homes.

6. CONCLUSION

On 24 August 1996 at 0600 UTC, two separate sub-severe convective systems approached southwest Ohio. One system, which advanced from the southwest, was driven by low-level frontal convergence in a moderately unstable environment. The other system, which closed in on southwest Ohio from the northwest, was maintained principally by mid-level dynamics in a weakly unstable environment. As these two convective systems approached each other, the surface moisture gradient strengthened, contributing to enhanced surface-based convergence.

Correspondingly, upper level divergence was noted over the Ohio Valley in association with the right rear (RR) quadrant of an upper-level jet. According to Uccellini et al. (1987), the RR entrance region of an upper-level jet is the favored location for the development of a transverse ageostrophic secondary circulation. Indeed, such a feature was forecast in this case, and would act to enhance the upward vertical motion in the vicinity of southwest Ohio. Examination of Q-vectors supported this, as a concentrated area of Q-vector convergence was forecast for this time through a rather deep low level atmospheric layer over southwest Ohio.

The thermodynamic environment just prior to this time was examined through analysis of the Wilmington, Ohio sounding from 0000 UTC on August 24. What was most obvious was the moderate instability (surface-based CAPE values of nearly 2300 J/kg), as well as a θ_e difference of 25 K between the surface and mid levels (700 - 500 mb). The magnitude of this θ_e difference not only denoted drier air aloft, but according to Atkins and Wakimoto (1991), was well within the range favoring wet microburst activity. Coupling of the surface-based convergence features with the forecast upper-level jet dynamics over an area classified as moderately unstable would provide the environment for enhanced thunderstorm activity across southwest Ohio. Any deep convection that developed would interact with the drier θ_e air aloft, and would have the potential to produce wet microburst activity.

Just prior to the merger of these two sub-severe convective systems, the NWSO Wilmington, Ohio WSR-88D experienced an outage. After about 30 minutes of down time, full operational capability returned to the radar. At this time when data collection resumed (~0718 UTC), it was apparent that the storm merger had commenced over southwest Ohio. Rapid intensification was evident as reflectivity values greater than 50 dBZ increased dramatically in areal coverage throughout the lowest 20 kft of the storm system. Transformation into a bow echo soon followed.

At 0723 UTC, a MARC signature of 50 kts was evident in conjunction with this developing bow echo. Schmocker et al. (1996) indicated that a MARC signature, represented by radial velocity convergence of 50 kts, or greater, across the mid-levels of a storm, is a reliable predictor of damaging surface winds 10-30 minutes prior to occurrence. Indeed, light to moderate structural damage occurred in association with this signature.

Also noted by Schmocker et al. (1996), the MARC signature often precedes the formation of a cyclonically rotating BEV by 12-18 minutes . This feature was noted at 0723 UTC, but on the north end of the bow echo. The period during which radar data were lost prevented determination of whether or not this

MARC signature was a valid precursor of the BEV. Nonetheless, the most significant wind damage from the convective system occurred in conjunction with this BEV signature.

All told, there appeared to be a number of model indicators that pointed to the potential for severe weather across southwest Ohio, with a target time for occurrence somewhere in the vicinity of 0600 UTC on August 24. Diagnostic analysis, along with incorporation of real-time observations, is imperative for the determination of severe weather potential in the absence of strong surface-based forcing.

ACKNOWLEDGMENTS

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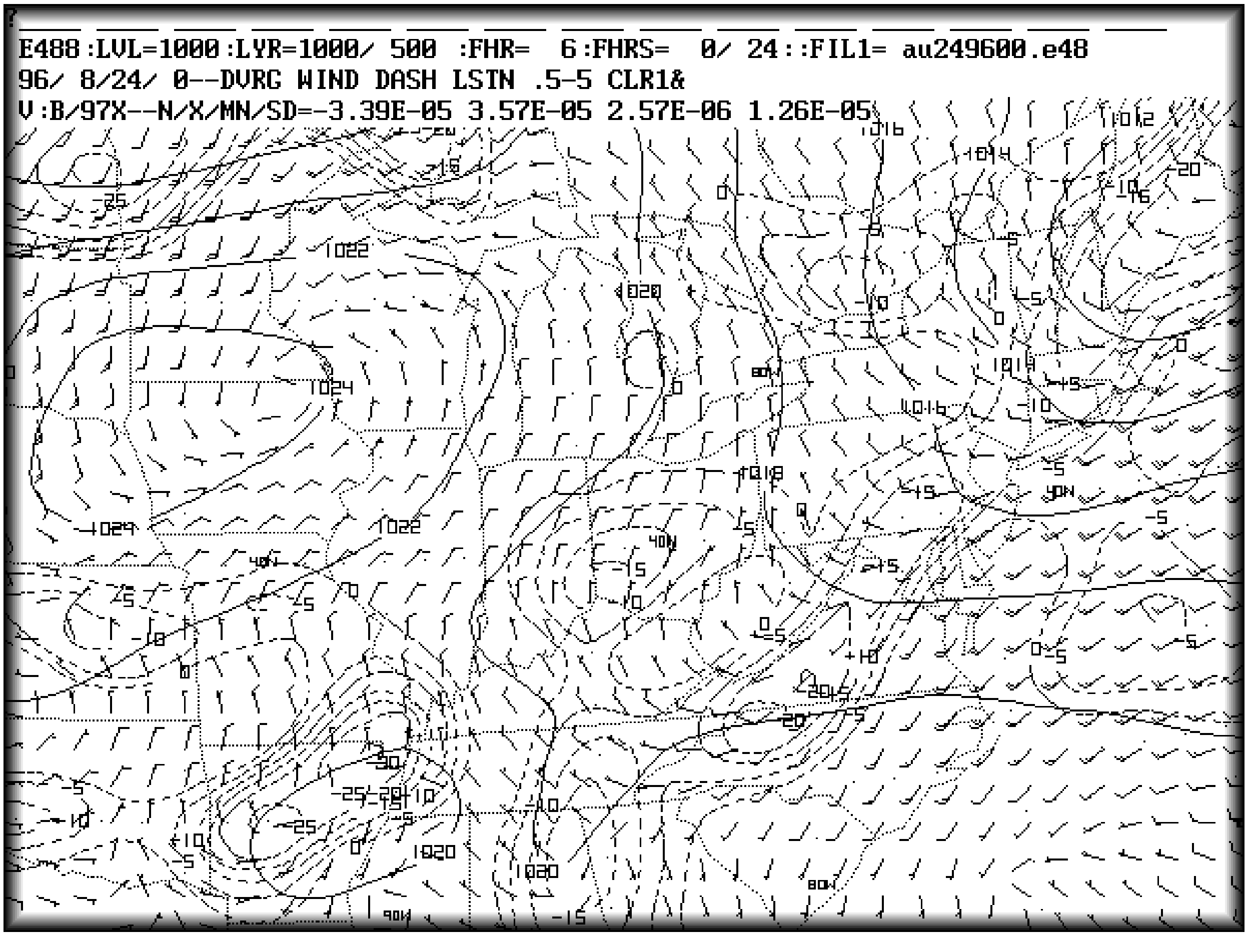


Figure 1. 6-hr forecast of surface pressure (mb), winds (kts) and convergence (dashed) from the 0000 UTC Eta model on 24 August 1996.

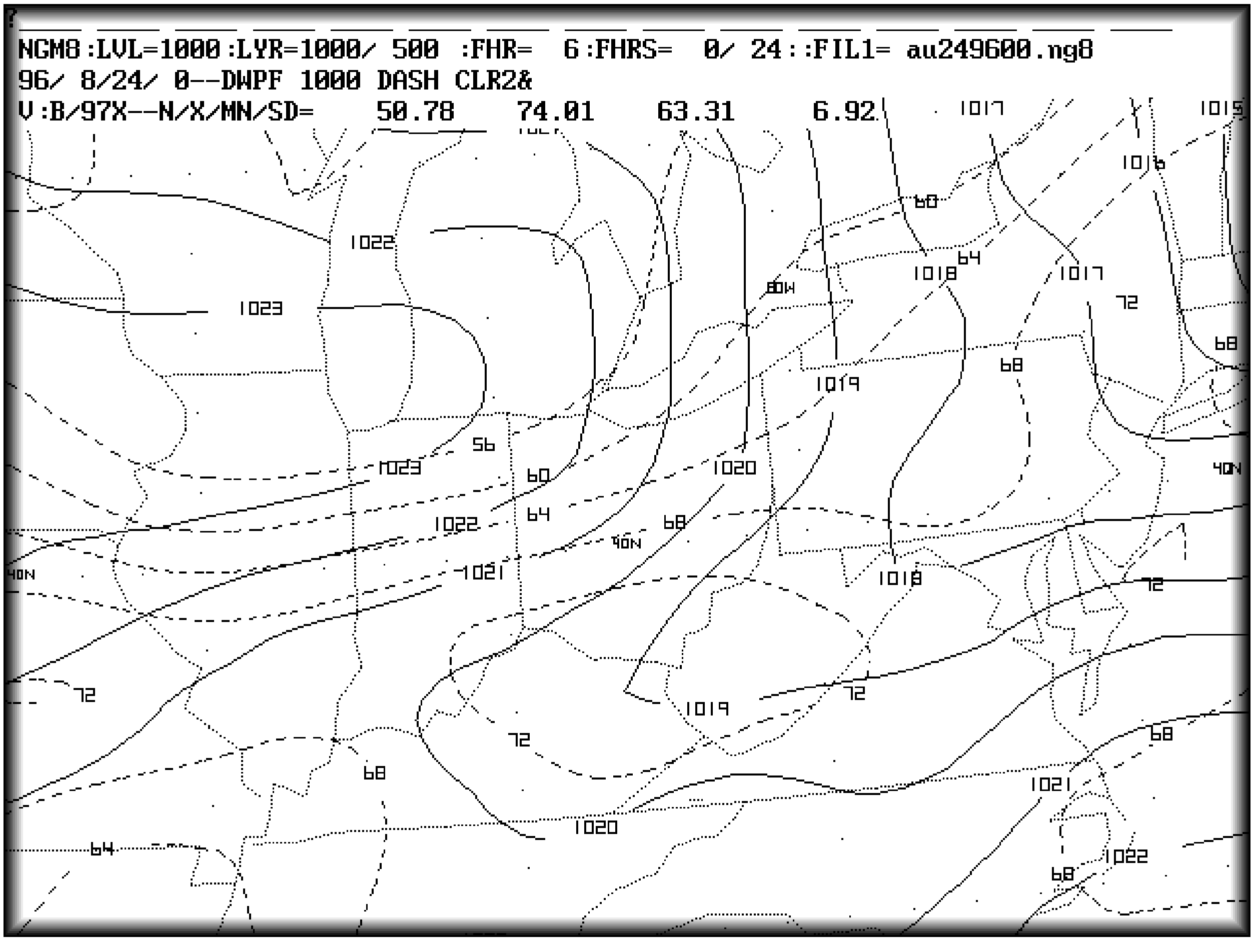


Figure 2. 6-hr forecast of dewpoints (dashed) from the 0000 UTC NGM model on 24 August 1996. Surface pressure (solid) also indicated.

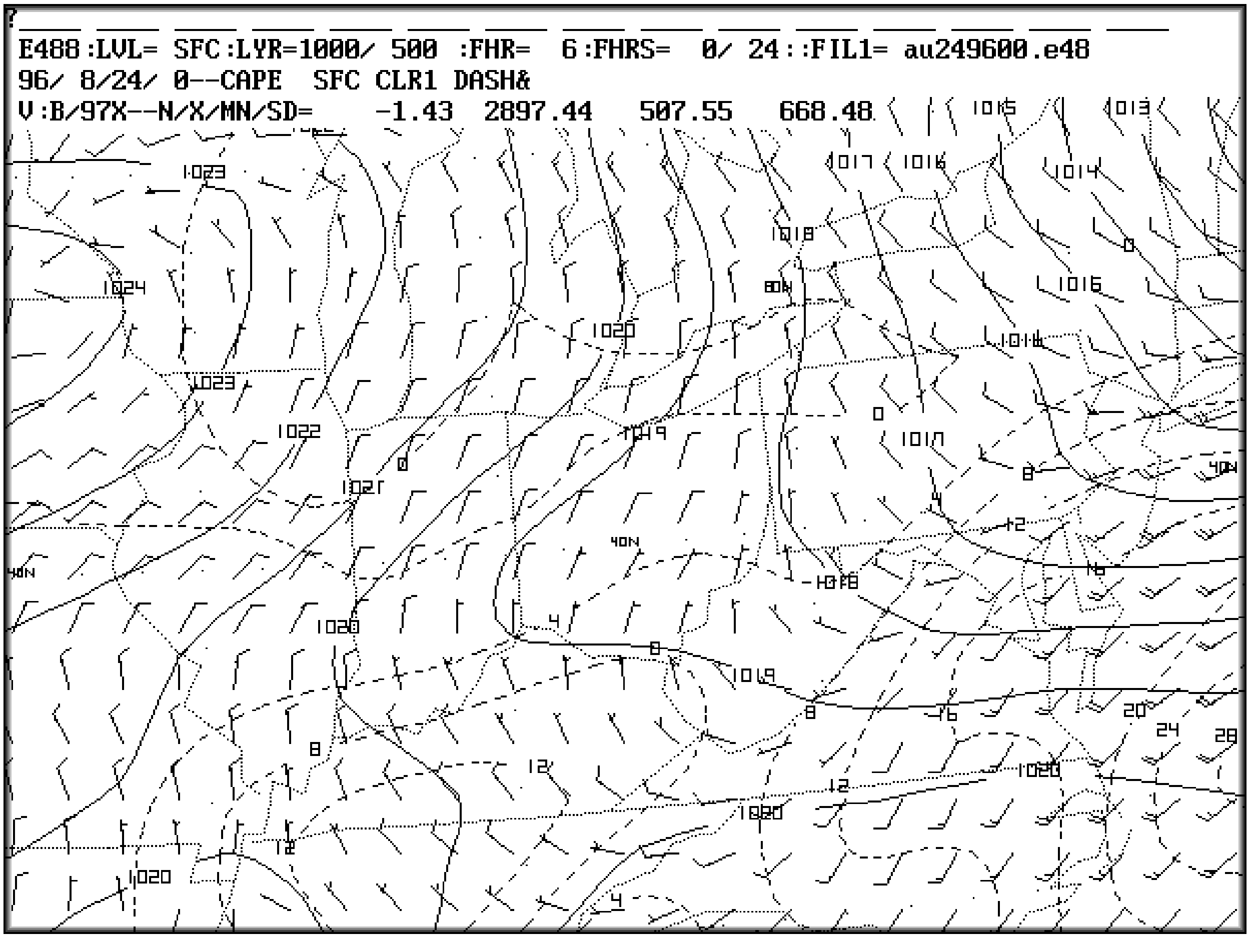


Figure 3. 6-hr forecast of surface-based CAPE (dashed) from the 0000 UTC Eta model on 24 August 1996. Values in J/kg x 10^2. Surface pressure (solid) and winds (kts) also indicated.

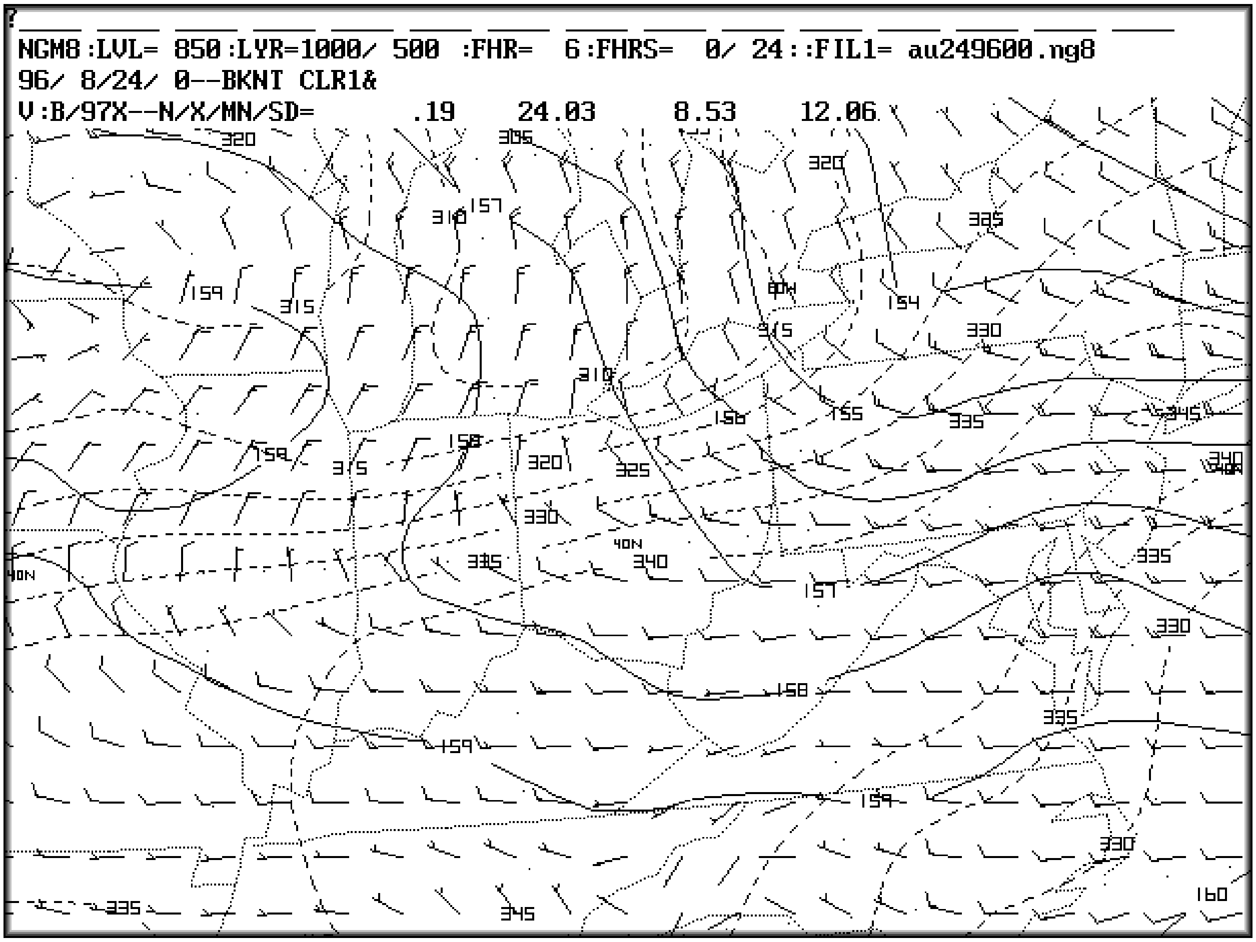


Figure 4. 6-hr forecast of 850 mb heights (dm), winds (kts), and θe (dashed) from the 0000 UTC NGM model on 24 August 1996.

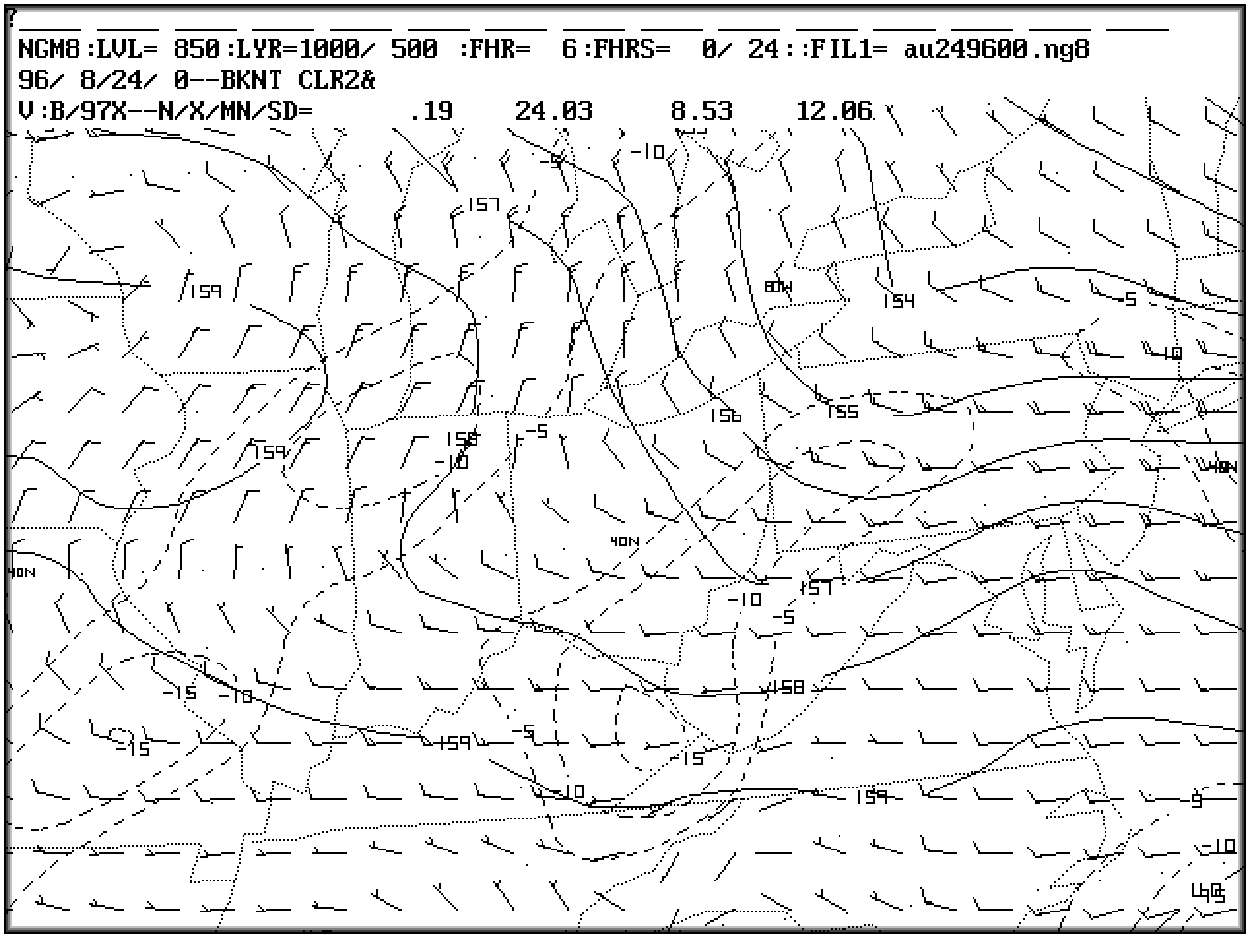


Figure 5. 6-hr forecast of 850 mb convergence (dashed) from the 0000 UTC NGM model on 24 August 1996. Heights (solid) and winds (kts) also plotted.

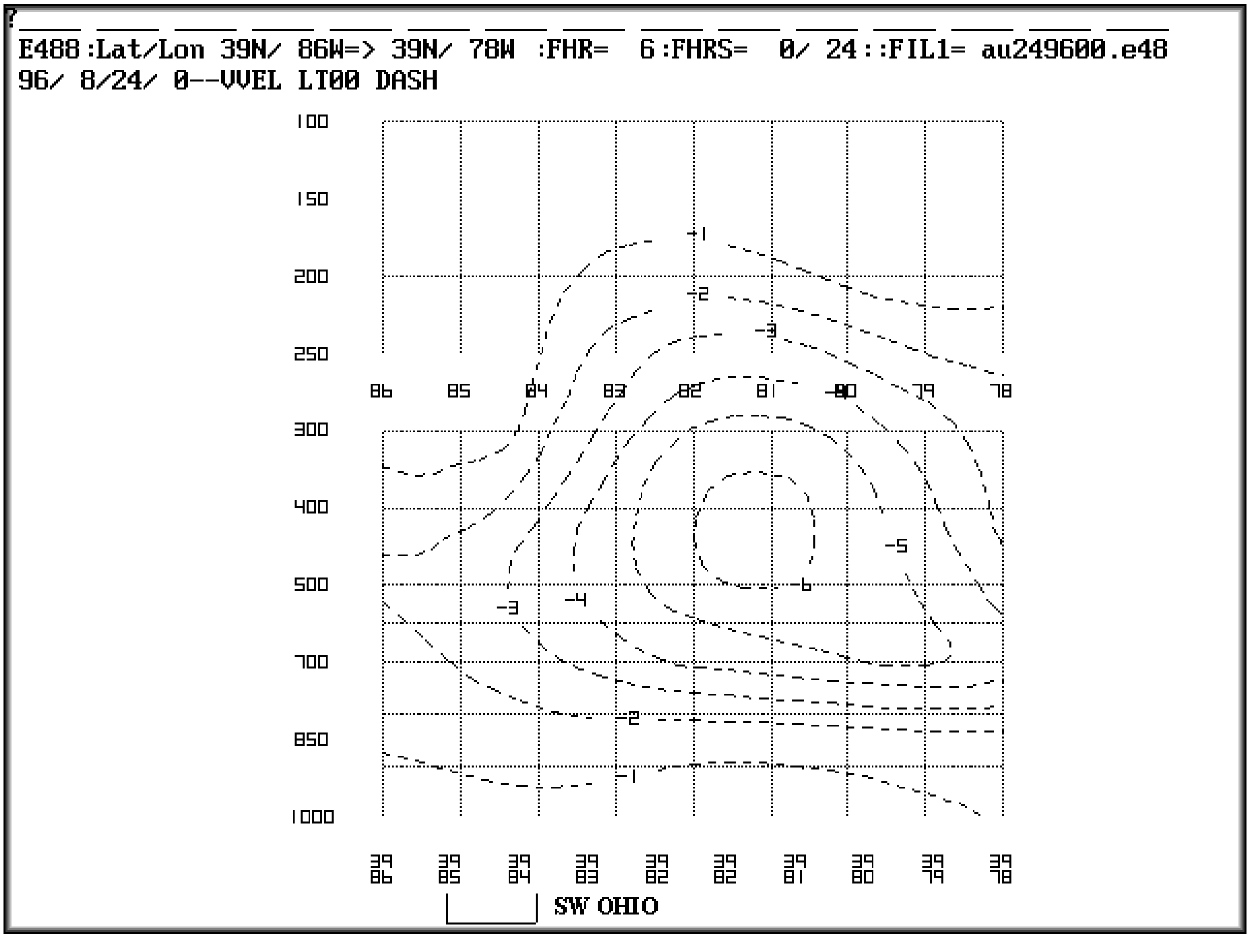


Figure 6. 6-hr forecast of upward vertical velocity (microbars/sec) from the 0000 UTC Eta model on 24 August 1996. Cross section oriented east-west across southwest Ohio.

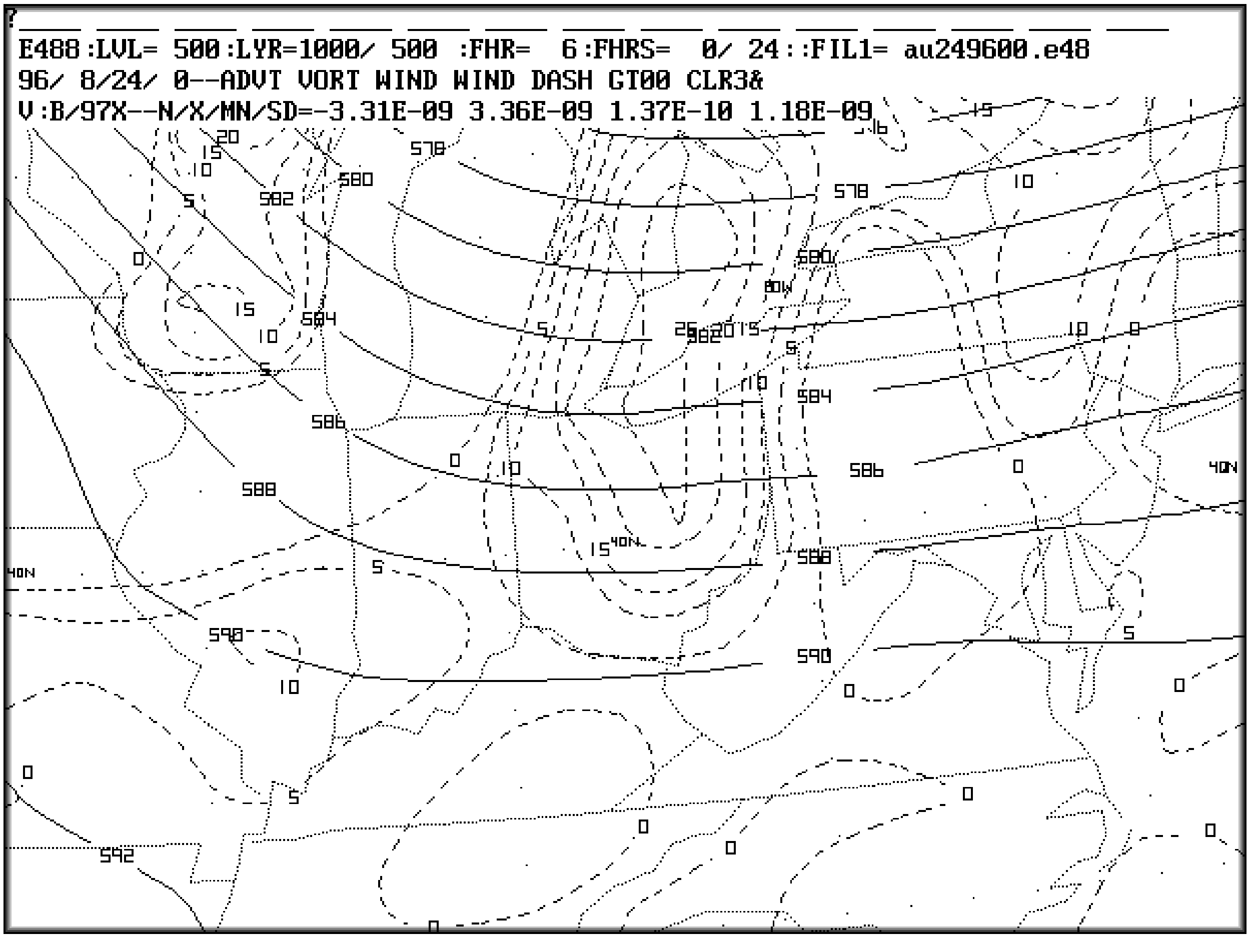


Figure 7. 6-hr forecast of 500 mb heights (dm) and positive vorticity advection (dashed) from the 0000 UTC Eta model on 24 August 1996.

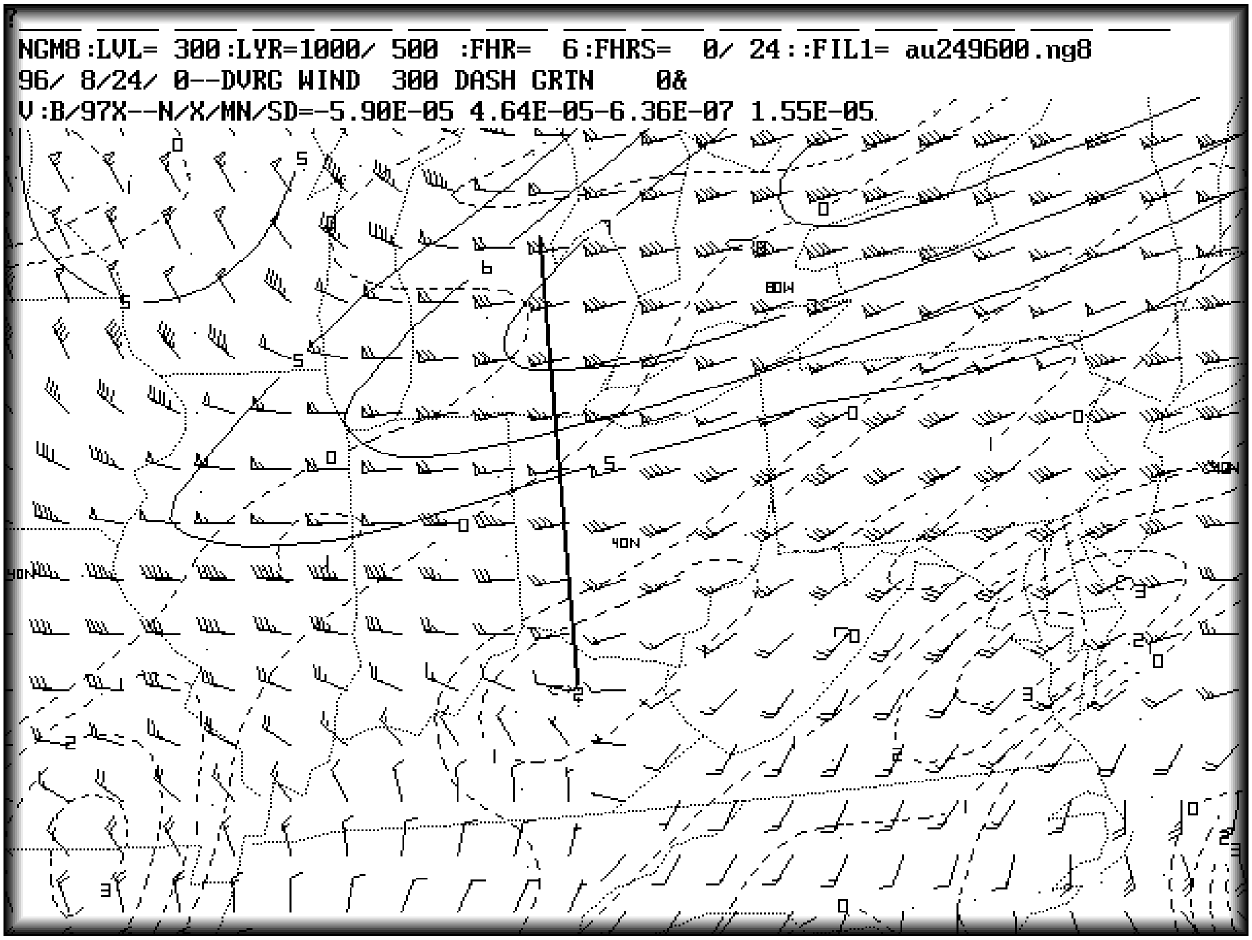


Figure 8. 6-hr forecast of 300 mb heights (dm) and divergence (dashed) from the 0000 UTC NGM model on 24 August 1996.

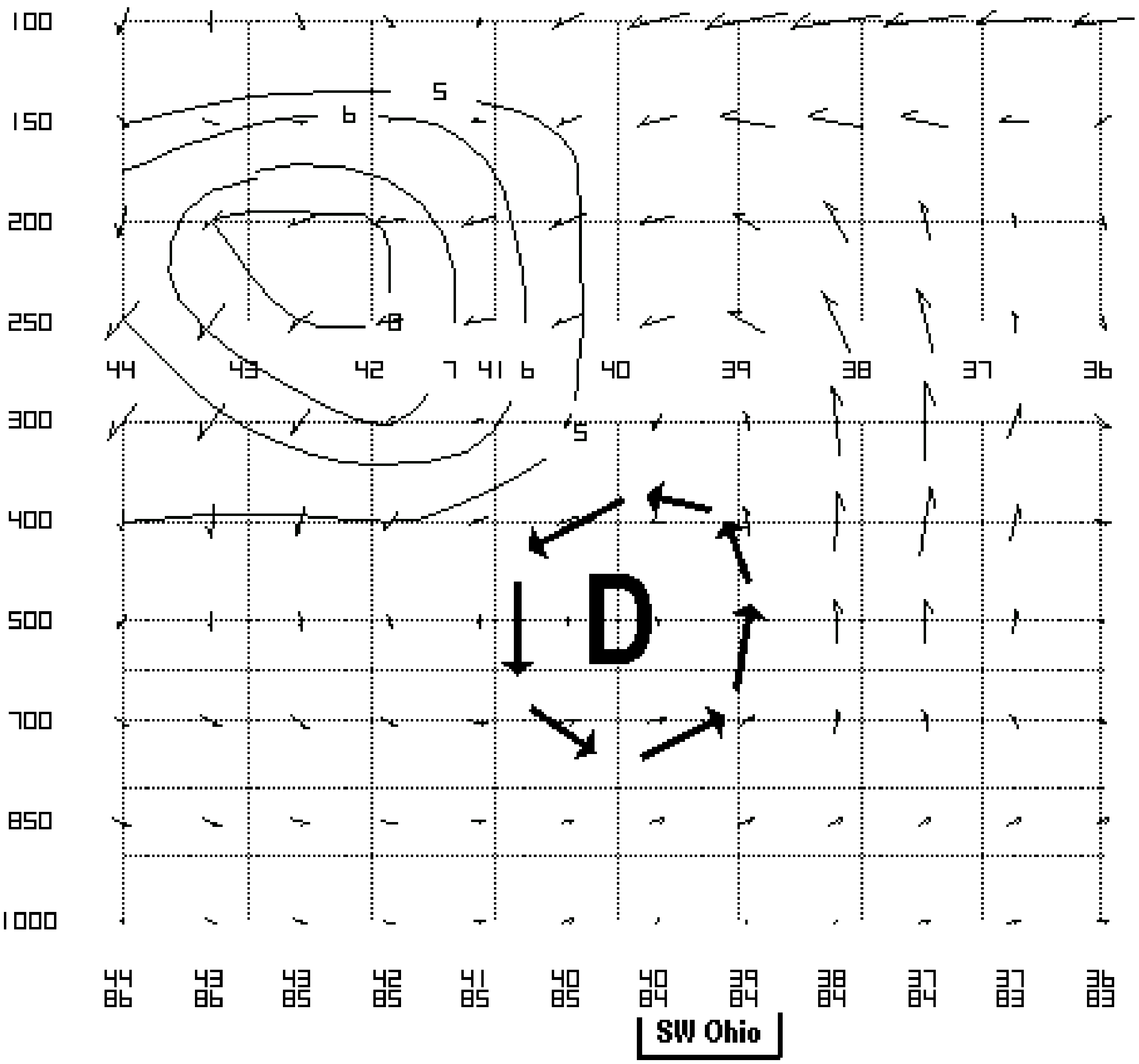


Figure 9. Cross section showing 6-hr forecast of winds greater than 30 kts (solid) and resultant vertical/tangential motion of ageostrophic wind (arrows) from the 0000 UTC Eta model on 24 August 1996. Direct transverse ageostrophic secondary circulation noted by “D”. Cross section location plotted on Figure 8.

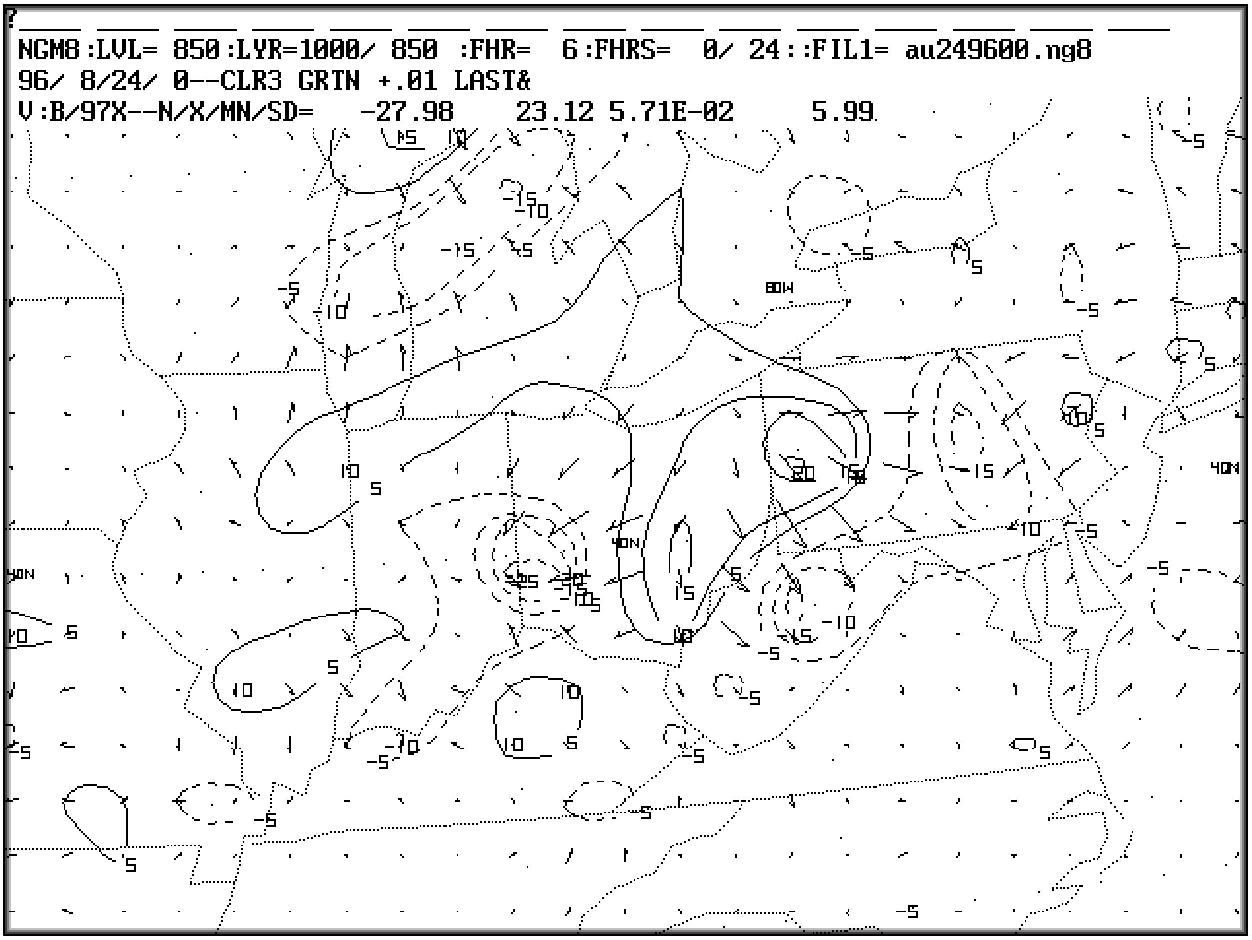
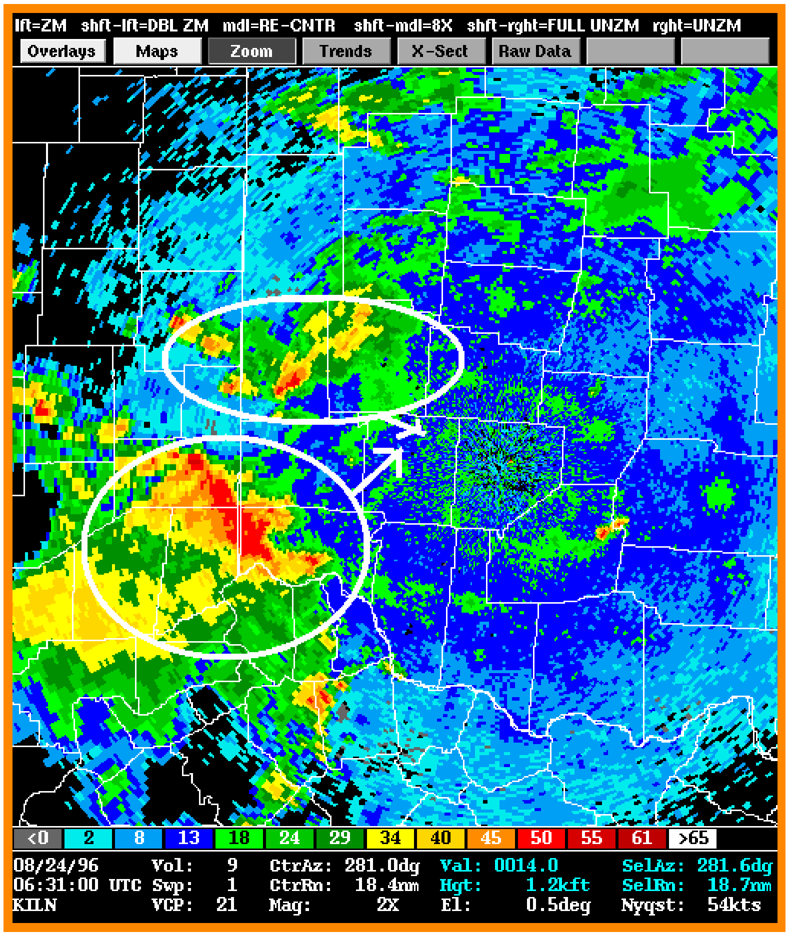


Figure 10. 6-hr forecast of Q-vectors (arrows) and Q-vector convergence (dashed) for the 1000-850 mb layer from the 0000 UTC NGM model on 24 August 1996.



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06:31:00 UTC  Swp:   1   CtrRn:  18.4nm  Hgt:    1.2kft SelRn:  18.7nm
KILN          VCP:  21   Mag:        2X  El:     0.5deg Nyqst:  54kts
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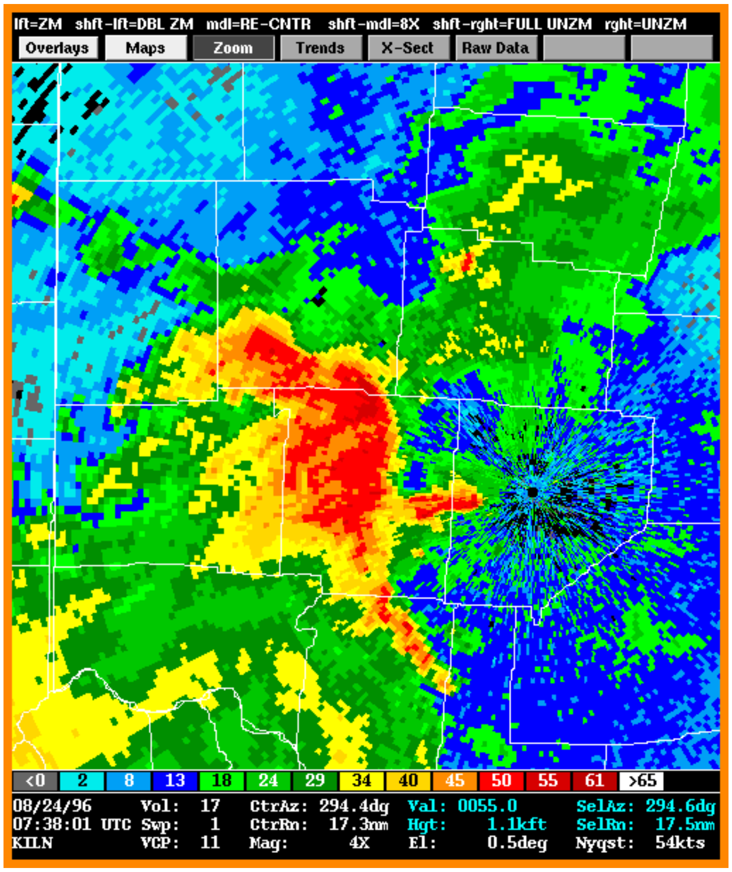
Figure 11. Wilmington, Ohio WSR-88D Base Reflectivity from the 0.5° elevation angle at 0631 UTC on 24 August 1996. Two distinct convective systems marked.



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KILN          VCP:  11   Mag:        4X  El:     0.5deg  Nyqst:  54kts
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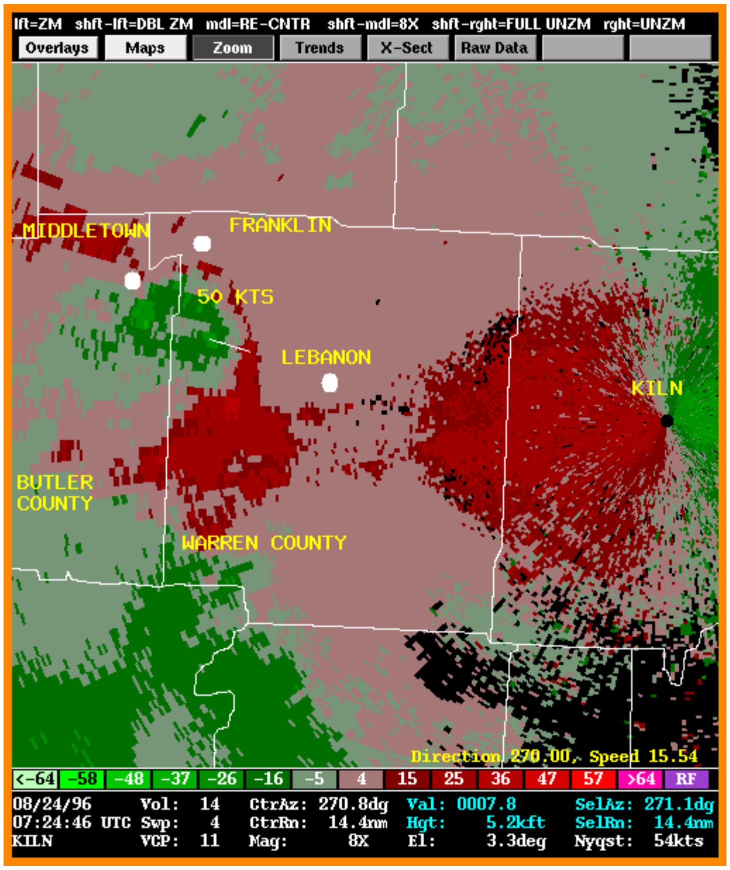
Figure 12. Wilmington, Ohio WSR-88D Base Reflectivity from the 0.5° elevation angle at 0738 UTC on 24 August 1996.



Direction 270.00, Speed 15.54

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08/24/96         Vol:  14   CtrAz: 270.8dg  Val: 0007.8      SelAz: 271.1dg
07:24:46 UTC Swp:   4   CtrRn:  14.4nm  Hgt:      5.2kft  SelRn:  14.4nm
KILN             VCP:  11   Mag:         8X  El:       3.3deg  Nyqst:  54kts
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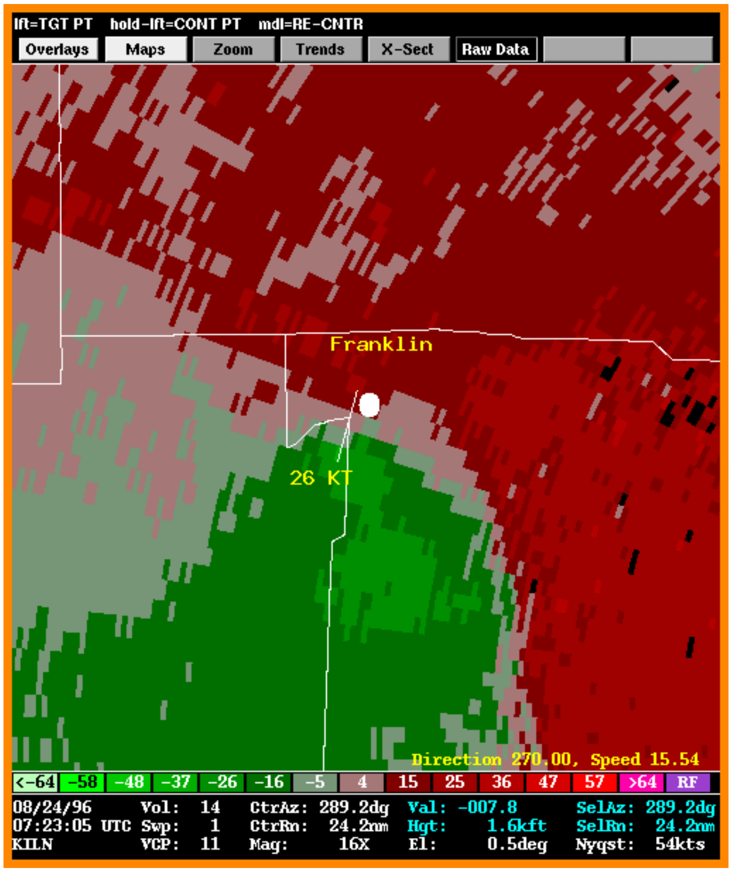
Figure 13. Wilmington, Ohio WSR-88D Storm Relative Velocity Map from the 3.3° elevation angle at 0724 UTC on 24 August 1996. Image zoomed in over Warren County in southwest Ohio.



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07:23:05 UTC  Swp:   1   CtrRn:  24.2nm  Hgt:    1.6kft  SelRn:  24.2nm
KILN          VCP:  11   Mag:      16X   El:     0.5deg  Nyqst:  54kts
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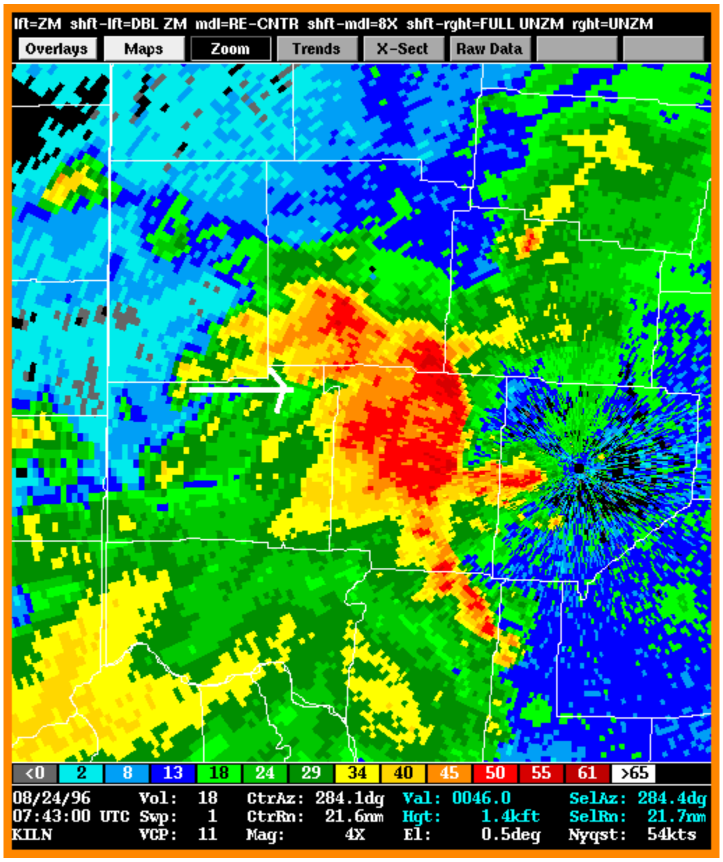
Figure 14. Wilmington, Ohio WSR-88D Storm Relative Velocity Map from the 0.5° elevation angle at 0723 UTC on 24 August 1996. Image zoomed in over northwest portion of Warren County in southwest Ohio.



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07:43:00 UTC Swp:   1   CtrRn:  21.6nm  Hgt:      1.4kft  SelRn:  21.7nm
KILN             VCP:  11   Mag:        4X  El:       0.5deg  Nyqst:  54kts
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Figure 15. Wilmington, Ohio WSR-88D Base Reflectivity from the 0.5° elevation angle at 0743 UTC on 24 August 1996. Dry slot observed (arrow) over northwest portion of Warren County in southwest Ohio.