THE SEVERE CONVECTIVE STORMS OF 14–16 MAY 1990

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Abstract

An analysis of the synoptic and mesoscale processes responsible for four severe convective events over Kansas, Oklahoma and Missouri during 14–16 May 1990 is presented. Emphasis is placed on the importance of low level boundaries, intensification of the low level jet, Q-vector convergence and the presence of moist, convectively unstable air in priming the pre-storm environment for convection. While large scale forcing played a critical role in organizing the first two episodes of severe weather over Oklahoma, Kansas and Missouri, the last two episodes emphasize the role of mesoscale boundaries created by prior convection. Within the limits of available data, the role of mesoscale boundaries is discussed with the goal of alerting the forecaster to the importance of low level boundaries in organizing severe convection.

Backward building Mesoscale Convective Systems (MCS) activity takes place in the region of diffluence of the 850-300-mb thickness contours and Q-vector convergence. MCS's tended to move parallel to the 850-300-mb thickness pattern. Comparisons of actual storm motion to estimates obtained by average winds and wind shear in various layers revealed significant discrepancies probably owing to storm interaction and/or back building processes. Analyses show that this unusual two day period of severe convection was supported by slow moving synoptic scale forcing, which, together with the reinforcement of convection-generated boundaries, refocused activity over the same area for an extended period of time.

1. Introduction

During 14–16 May 1990 severe convection developed over parts of Kansas, Oklahoma and Missouri producing heavy rains, hail, strong winds and a few tornadoes. A unique aspect of this period of severe weather is the episodic nature of the storms which formed and reformed over the same general region at intervals ranging from 6–8 hours. In all, there were five episodes of severe convection during this two day period of which we will examine the first four in detail, as data for the fifth episode were lost due to a lightning-induced power surge which disabled our computer.

Although limited by the standard surface and upper air resolution, it is our goal to diagnose those synoptic and, to the extent possible, mesoscale aspects of the flow which contributed to the initiation and sustenance of convection during the two day period. To a large extent we agree with Doswell (1987) who states that "convective systems depend primarily on large-scale processes for developing a suitable thermodynamic structure, while mesoscale processes act mainly to initiate convection." Thus, we primarily want to diagnose synoptic scale processes from the point of view of their *focusing* the thermodynamic environment favorable for severe convection. However, it is important to remember

that synoptic scale vertical motion will not initiate cumulus convection, but can eliminate "lids" or capping inversions in an otherwise potentially unstable sounding (McGinley, 1986). Very often, in the case of warm season MCSs, low-level warm air advection will provide the necessary synoptic scale lift to release the instability, even in the absence of 500 mb positive vorticity advection (Maddox and Doswell, 1982). Thus, even synoptic scale features can *focus*, on a regional (meso $\propto$) scale, where convection is most likely to erupt. Indeed, this is the task faced by the forecasters in the Severe Local Storms (SELS) group at the National Severe Storm Forecast Center (NSSFC) and the heavy precipitation group in the Forecast Branch at the National Meteorological Center (NMC) on a daily basis: to isolate where this regional scale forcing and focusing will take place.

Section 2 describes the data sets used to study the synoptic and mesoscale environments conducive to severe convection. Numerous diagnostic parameters will be discussed to examine both the pre-convective environment and the refocusing of favorable synoptic scale parameters upstream from the original convection. Section 3 examines the four major episodes in detail with an emphasis on those resolvable features on the synoptic and mesoscales which together focused convection over Kansas, Oklahoma and Missouri. Several of the episodes involved Mesoscale Convective Complexes (MCC) (Maddox, 1980), which were large enough to be defined by the standard rawinsonde network and enhanced infrared satellite imagery.

Propagation characteristics of the storms with respect to various mean winds and shear vectors will be examined to test "rules of thumb" discussed in the literature. For example, Merritt and Fritsch (1984) have noted MCSs tend to move parallel to the 850-300-mb thickness (i.e., along the 850-300-mb geostrophic shear vector). The speed of a MCS is a more difficult parameter to estimate in a forecast mode as it is influenced by the magnitude of the storm-relative inflow, propagation characteristics of the storm, lower tropospheric moisture convergence, etc. Chappell (1986) describes storm motion as the sum of the mean velocity of the cells constituting the storm and the propagation velocity due to new cell development on the periphery of the storm. Understanding storm propagation is critical to forecasting storm motion.

Finally, Section 4 will summarize our understanding of this unique series of "back-building" convection with an emphasis on the importance of boundaries and synoptic scale forcing.

2. Data and Analysis Procedures

For each episode we employed standard upper air data at 12-h intervals, surface data at hourly intervals, half-hourly GOES infrared (IR) and visible (VIS) imagery, and national and local radar summaries. At the surface we plotted iso-

therms, isodrosotherms, and equivalent potential temperature (θ_e) to help diagnose subtle boundaries. Surface moisture convergence (MCON $= -\nabla \cdot q \vec{V}$, where q is specific humidity and $\vec{V}$ is the wind velocity) was also computed to detect low-level forcing and focusing of convection near and along boundaries.

Upper level constant pressure analyses included 850-mb θ_e and MCON, 300-mb divergence, and 850-300-mb thickness. Stability analyses are similar to those described by Moore and Pino (1990) and include such parameters as total totals (TT) and Lifted Index (LI). LI's are based on a 100-mb boundary layer mean potential temperature and mixing ratio which is lifted to its lifting condensation level dry-adiabatically and then to 500 mb moist-adiabatically. The convective available potential energy (CAPE), the positive area above the level of free convection (LFC), and the lid strength index (LSI) (Graziano and Carlson, 1987) were computed to estimate the convective potential and restraint to convection.

Kinematic vertical motions were also computed for the case study, using objectively analyzed fields of u, v, wind components at 18 levels, at 50-mb intervals in the vertical. Vertical motion and divergence were adjusted using the O'Brien (1970) technique with values at 100 mb and the surface assumed to be zero. The adjustments to divergence and ω were a linear function of pressure in this procedure.

These varied data permitted an evaluation of the pre-convective environment and an understanding of storm propagation. Most importantly, we intend to document the forcing and focusing of convection for each episode in this unusually long period of severe convection.

3. Results

3.1 Episode 1

During the evening of 14 May 1990, thunderstorms began developing rapidly over southeast Kansas southwestward into Oklahoma. Throughout the evening and nighttime hours these thunderstorms continued to develop and spread into much of Missouri providing several hours of heavy rainfall (Storm Data, 1990).

A. Large Scale Conditions

Synoptic conditions at 0000 UTC 15 May revealed temperatures in the 80's over Texas and Oklahoma, with dew points in the 60's and 70's over the same region with somewhat cooler and drier air in Kansas and Missouri (Fig. 1). A stationary front extended from the Texas panhandle into central Missouri associated with a region of convergent surface winds. The air mass along and south of this stationary front was very unstable, with LI's at Topeka, Kansas (TOP) and
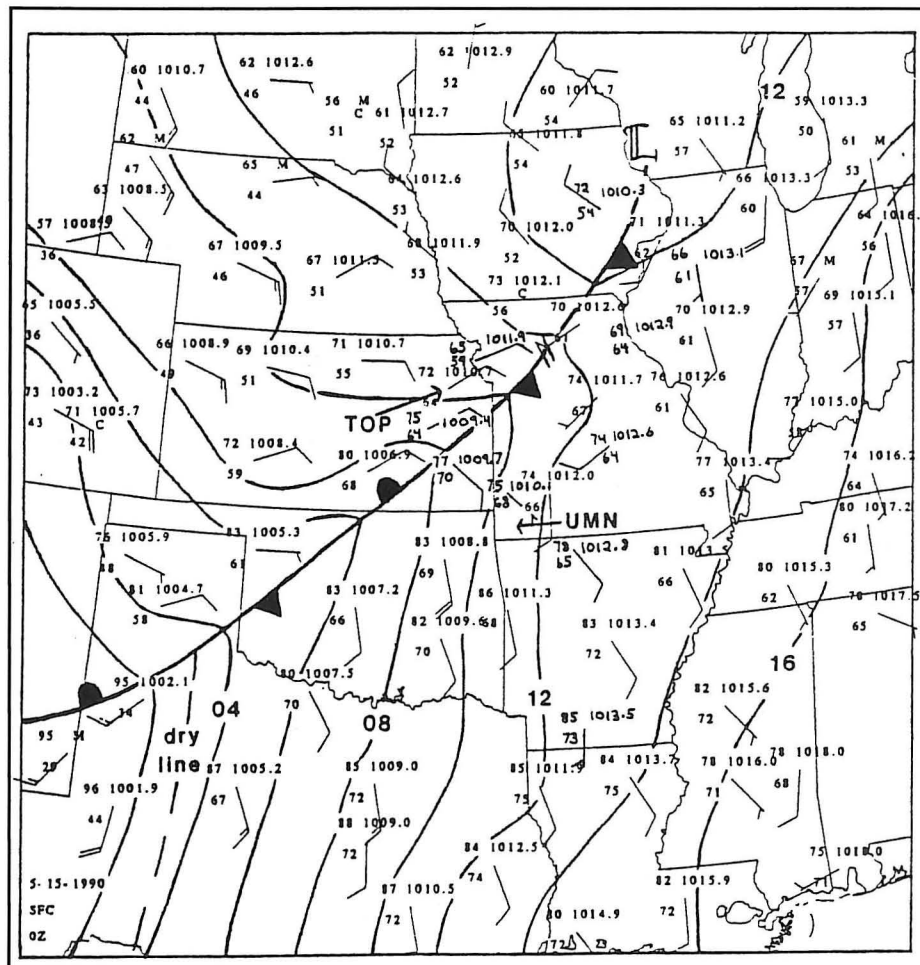

Fig. 1. Surface analysis for 0000 UTC 15 May 1990 reveals location of fronts (indicated by standard symbols). Station model as follows: upper left, temperature in °F; bottom left, dew point in °F; upper right, pressure in mb. Wind barbs are in standard notation.

Monett, Missouri (UMN) of −5 and −8 and TT's of 53 and 59, respectively. CAPE values exceeding 2000 J/kg dominated Oklahoma, Texas, Arkansas, Mississippi and southern Missouri at 0000 UTC 15 May (Fig. 2). LID values generally decrease to the north and the east of Texas, indicating the absence of strong inversions which may inhibit convection.
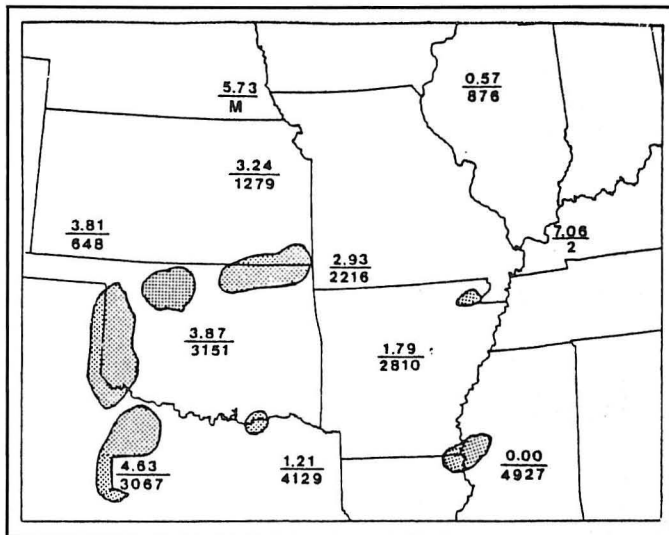

Fig. 2. Central Region of United States with LID (top) and CAPE (bottom) for 0000 UTC 15 May 1990. LID values are in degrees °C and CAPE values are in J/kg. Also, stippled areas represent convective development for same time.

At 500 mb 0000 UTC 15 May (not shown), a trough was entering the northern Rocky Mountains from the west, with broad southwesterly flow over Kansas and Missouri. At 850 mb (Fig. 3a), there was a closed low over Wyoming with a weak short wave in Oklahoma. The low-level jet (LLJ) was strongest in central Texas, with 25 kt (12-5 m/s) at Stephenville, Texas (SEP). The LLJ strengthens considerably overnight; by 1200 UTC, southwesterly winds of 50 kt (25 m/s) are found at SEP (Fig. 3b). This strengthening appears to be partly associated with a jet streak at 300 mb. Examining the 300-mb chart for 1200 UTC (Fig. 4) reveals a 90 kt (45 m/s) jet streak entering Kansas, with height falls over Nebraska, Kansas and Iowa. At 850 mb, height falls were found mainly along and north of the 300-mb jet streak. Having examined several soundings over the same region, it is evident that there is no clear distinction between the winds at upper and lower levels of the atmosphere (i.e., there is no speed minimum between these levels). Height falls at 850 mb (see Fig. 5) centered over western Kansas and Nebraska enhanced the southerly ageostrophic low-level flow over Texas and Oklahoma. The LLJ in this case is likely the lower branch of an indirect thermal circulation in the exit region of the upper level jet streak (Uccellini and Johnson, 1979). The strengthening of the LLJ becomes an important forcing mechanism in that it can provide high θ_e air to further the longevity of thunderstorms.
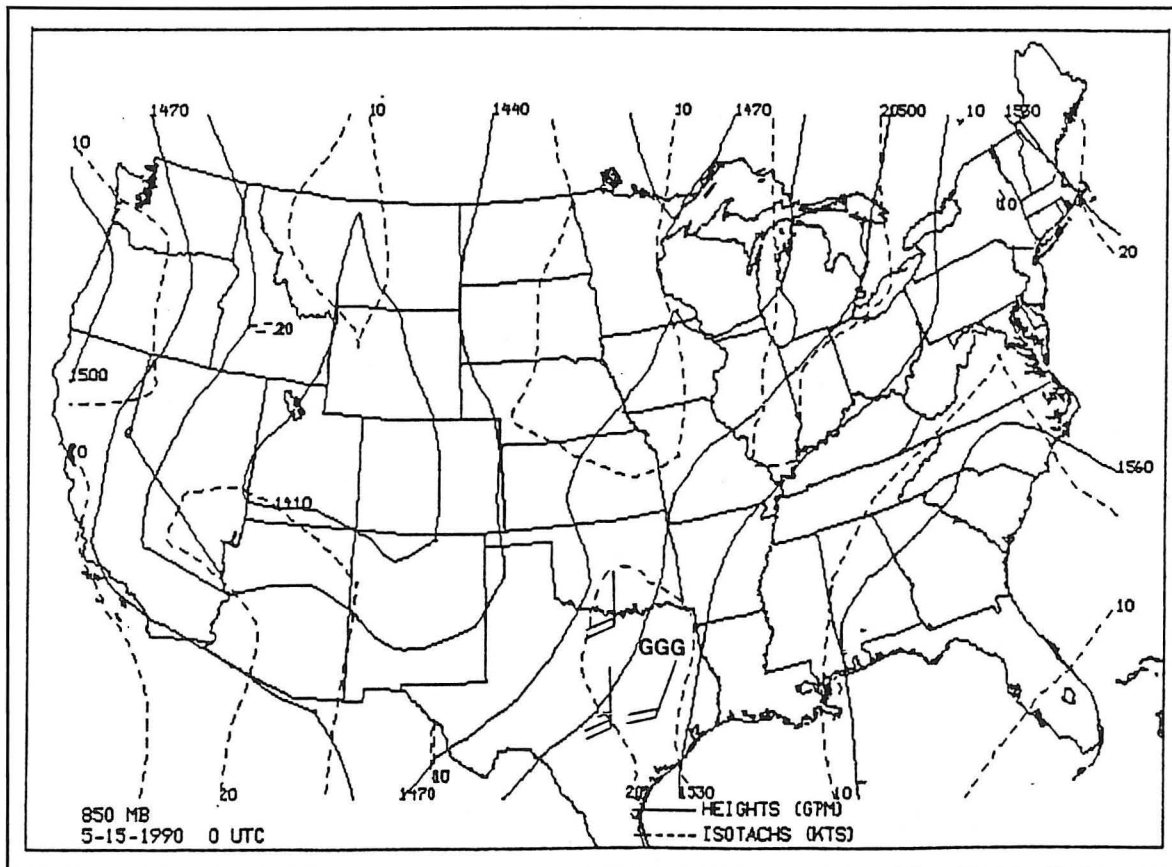

Fig. 3a. 850-mb analysis for 0000 UTC 15 May 1990 displays heights (solid lines) in geopotential meters (gpm) contoured every 30 gpm and isotachs (dashed lines) contoured every 10 kt. Wind barbs are standard notation.
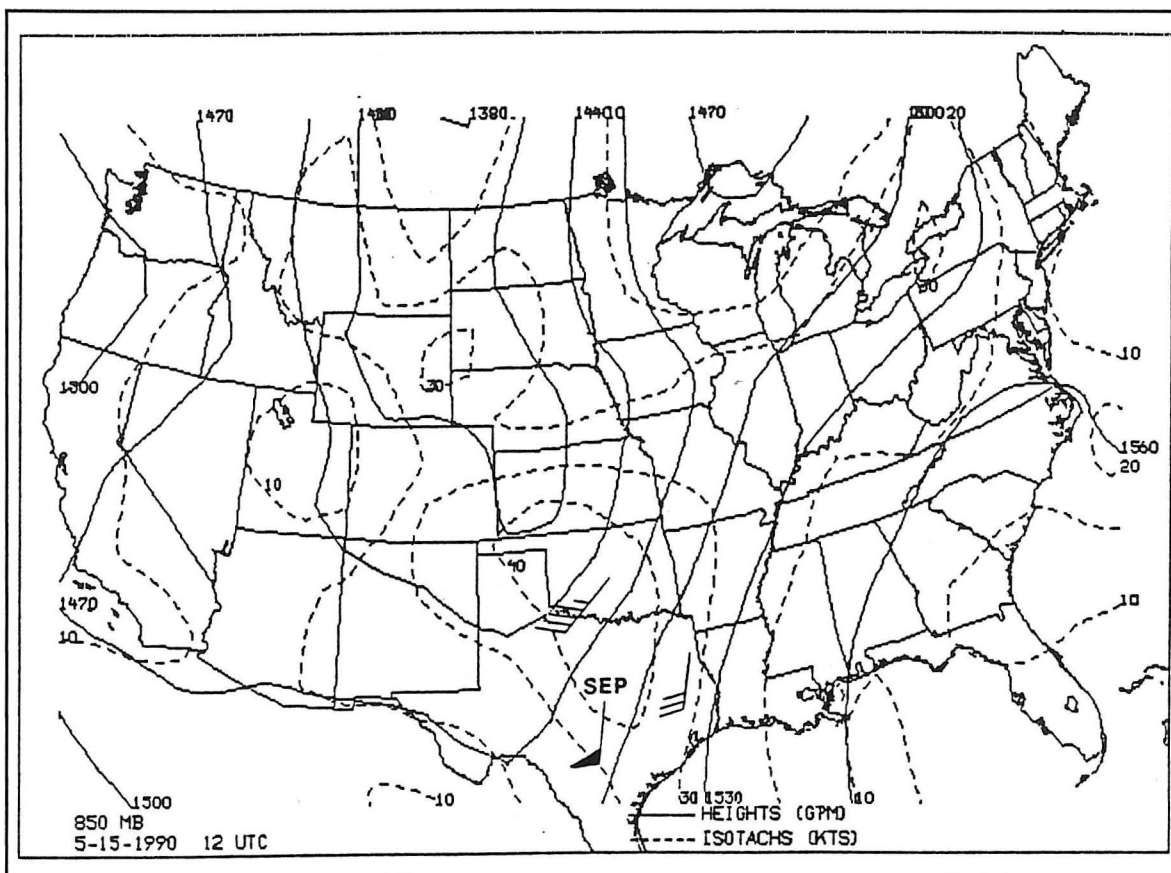
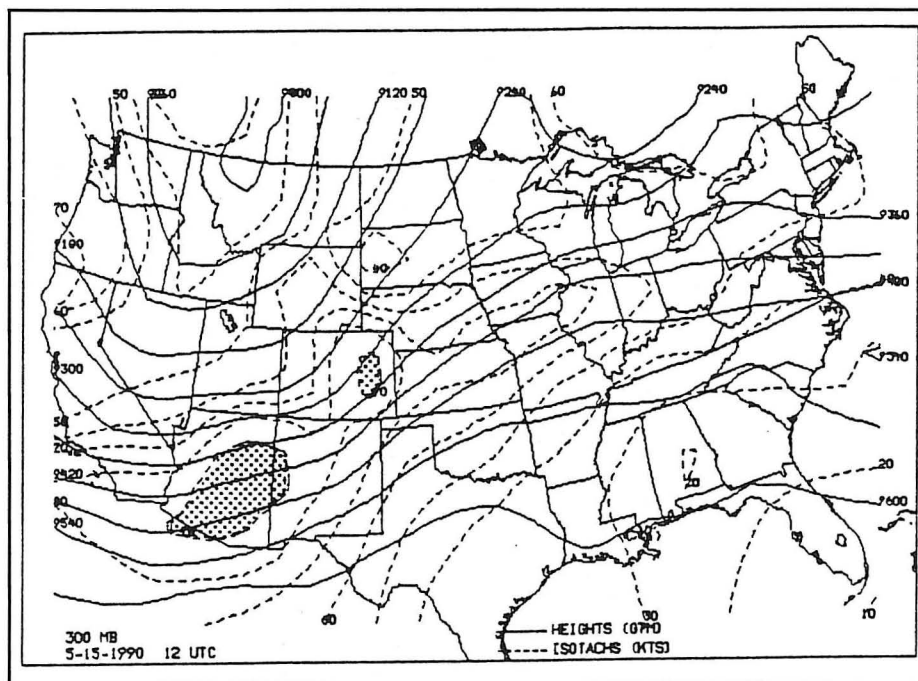Fig. 3b. Same as Fig. 3a, except for 1200 UTC 15 May 1990.

Fig. 4. 300-mb heights in gpm and isotachs in knots for 1200 UTC 15 May 1990. Solid lines are heights contoured every 120 gpm and dashed lines are isotachs contoured every 10 kt. Stippled area denotes winds exceeding 90 knots.
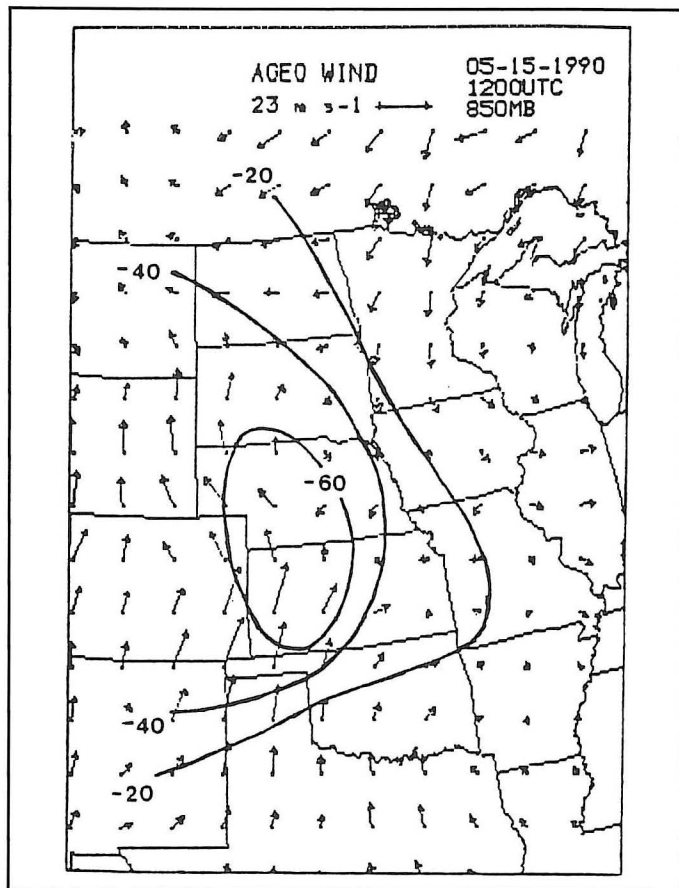
Fig. 5. Ageostrophic component of the winds at 850 mb for 1200 UTC 15 May 1990. Solid lines represent 850-mb height falls in gpm.

B. Thunderstorm Development and Propagation

The thunderstorms in this episode began developing around 0000 UTC 15 May along the stationary front and also along and ahead of the surface MCON axis (Fig. 6a) which parallels the surface θ_e axis (Fig. 6b) extending from south-central Texas into northeastern Oklahoma. Figures 7a–b reveal the increase in thunderstorm activity from 0235 to 0535 UTC. As the thunderstorms continued to intensify, new cells developed to the east of the old cells due to discrete propagation, based upon half-hourly satellite imagery. By 0600 UTC, the thunderstorms merged into a rather large system covering much of Missouri (Fig. 8). The convection in Texas and Oklahoma weakened from 0235 to 0535 UTC apparently since it was forced by solar heating and the diurnal oscillation of the dryline convergence. The more intense activity in Kansas and Missouri was sustained by the continuous inflow of high θ_e air into the now northward-moving frontal boundary. The thunderstorms began to weaken, as they moved southeast parallel to the 850-300-mb thickness lines (Fig. 9), into Illinois and Kentucky, where the environment was less supportive of convection (Paducah, Kentucky (PAH) at 0000 UTC had an LI of 1 and TT of 33). We calculated the storm motion for this case by following the highest VIP level reported by the radar at hourly intervals at UMN, Missouri. We determined the storm motion around 0000 and 1200 UTC to be 291° at 14.4 m s^{-1}, which is slower and more westerly than one would estimate using the 850-300-mb wind shear at UMN which was calculated to be 298°
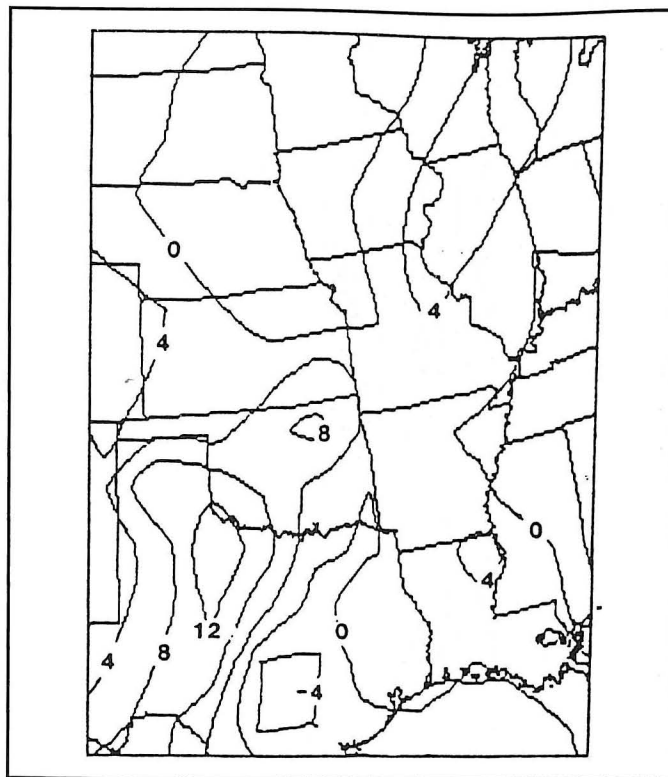

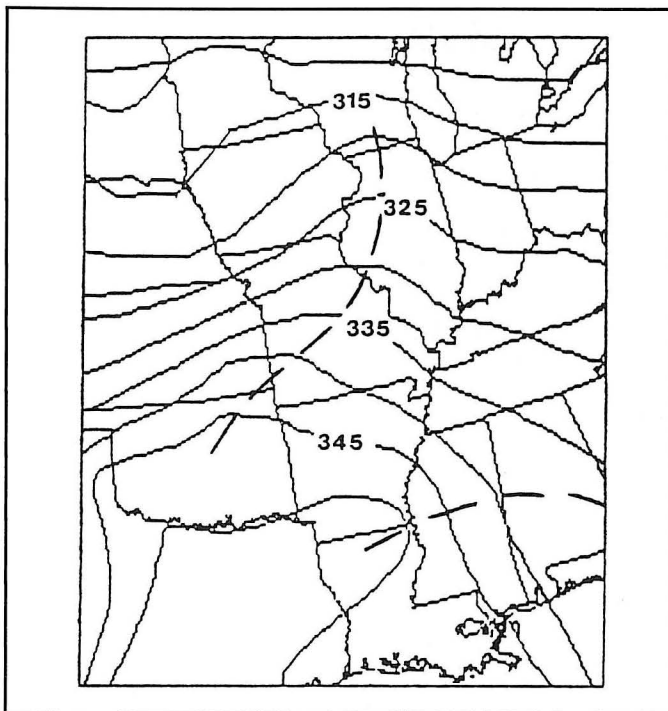Fig. 6a. Surface moisture convergence (* 10 g/kg-h) for 0000 UTC 15 May 1990.

Fig. 6b. Surface equivalent potential temperature for 0000 UTC 15 May 1990, contoured every 5 K. Dashed lines represent location of θ_e axis.

at 19 m/s for 0000 UTC 15 May 1991 and 336° at 28 m/s for 1200 UTC 15 may 1991. The discrepancy between the observed storm motion and that estimated from the 850-300-mb wind shear is most likely due to the effects of storm
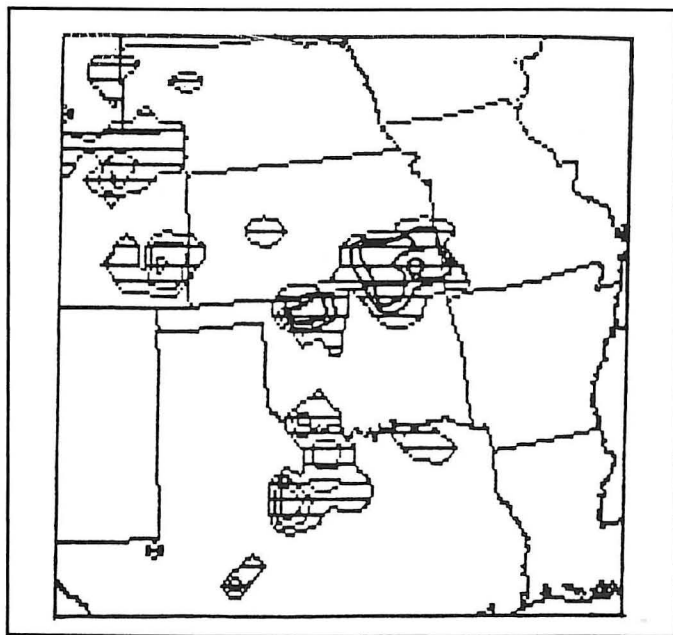
Fig. 7a. Composite radar charts for United States for 0235 UTC 15 May 1990. VIP levels 1, 3, and 5 are displayed.
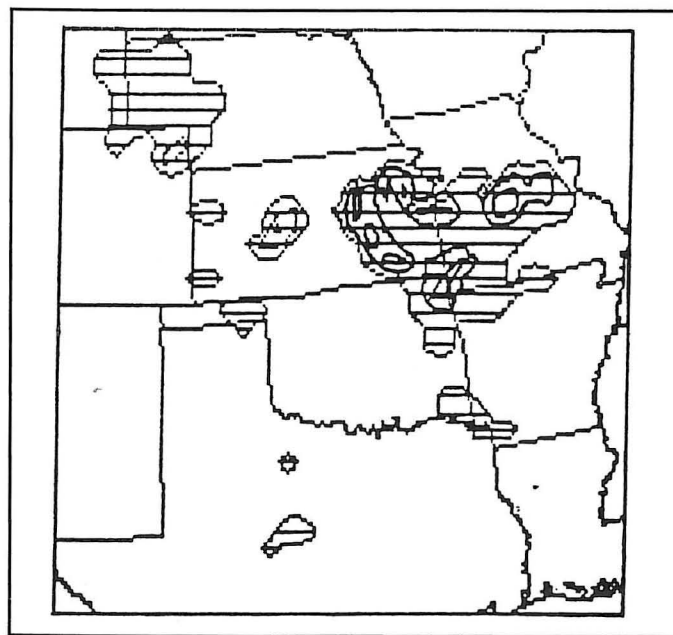
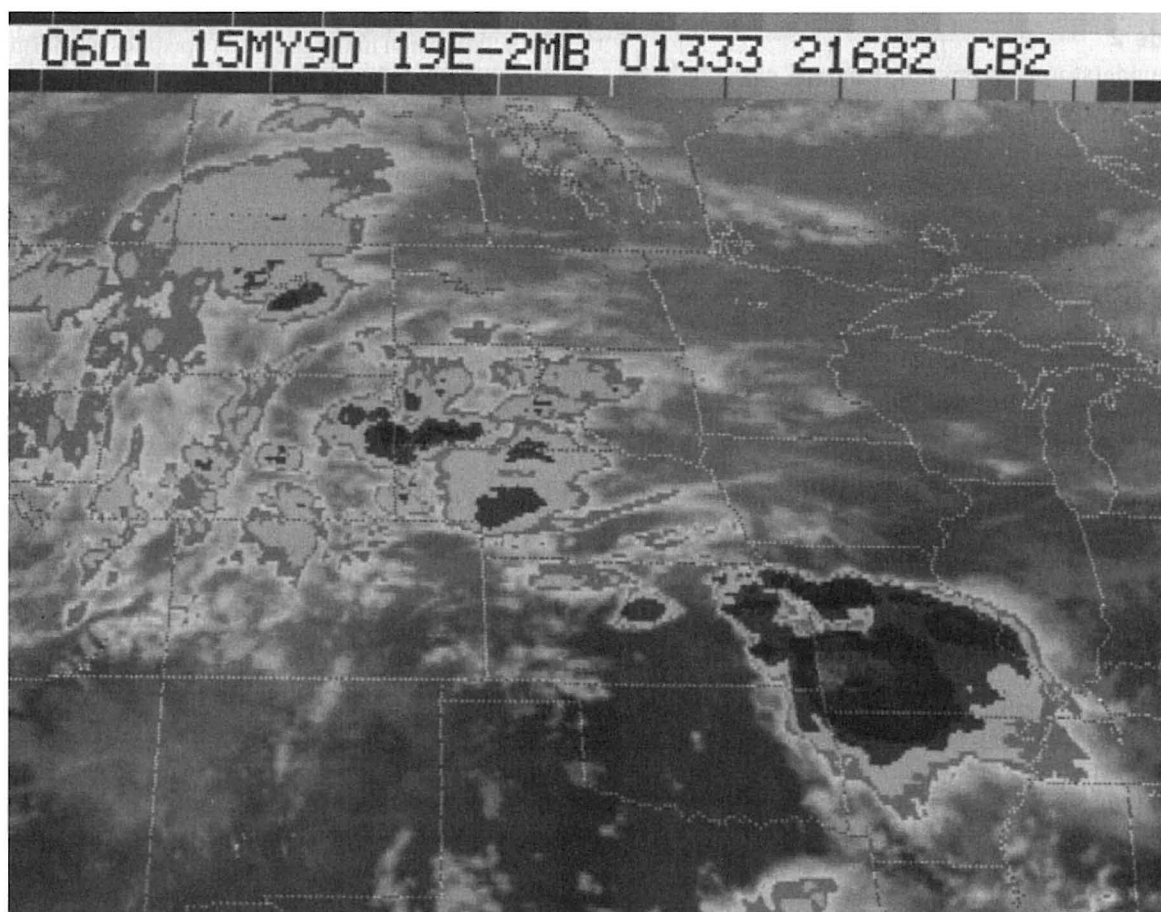Fig. 7b. Composite radar chart for 0535 UTC with same VIP levels as in Fig. 7a.

Fig. 8. GOES east infrared (IR) satellite imagery centered over the central United States for 0601 UTC 15 May 1990 using the standard MB enhancement curve.
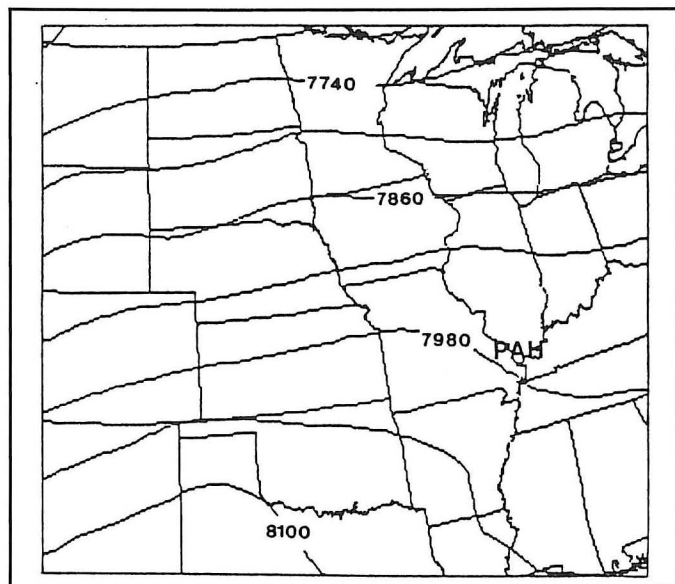
Fig. 9. 850-300-mb thickness for 0000 UTC 15 May 1990 contoured every 60 gpm.

interaction and "back building" of convection which can reduce storm speed as well as alter its direction.

3.2 Episode 2

As the thunderstorms in episode 1 moved east-southeast into Illinois and Kentucky, new thunderstorms began developing in northeast Kansas and north-central Missouri around 1200 UTC 15 May (Fig. 10a). These thunderstorms produced large hail as they moved through Kansas (Storm Data, 1990). By 1500 UTC, the thunderstorms merged to form a large MCC covering much of Missouri (Fig. 10b). By 1700 UTC, the MCC weakened as it moved southeast into Illinois, Indiana, and Kentucky, following the 850-300-mb thickness pattern (Fig. 11).

A. Forcing and Focusing Mechanisms

In the first episode a stationary front was located in Oklahoma and Missouri (Fig. 1). By 1200 UTC 15 May the stationary front had moved north as a warm front into northern Kansas but was disrupted by the convective outflow boundaries over eastern Kansas and southern Missouri (Fig. 12). These outflow boundaries later merged as the MCC evolved, providing lift for further development. It is also important to note that there were several other processes at work to produce the large area of convection. If we compare the temperature advection at 850 mb (Fig. 13) with Fig. 10a, we can see that there is a very good correlation between the 850-mb warm air advection (WAA) (axis extends from western Kansas southeastward into Arkansas) and the colder cloud tops in Kansas and Missouri. The convection is strongest along and north of the 850-mb WAA axis. Remember that the LLJ strengthened considerably between 0000 UTC and 1200 UTC (note, the LLJ is strongest over Texas, Oklahoma, and Kansas, thereby enhancing the low-level WAA). In this way the LLJ serves as a forcing mechanism in the development of the incipient MCC. In addition to the forcing mechanisms in the lower levels of the atmosphere, we find strong diffluence

at 300 mb over Missouri associated with an area of divergence over Kansas and Missouri (Fig. 14). Comparing Figures 14 and 15, one can see that the divergence at 300 mb provided a favorable large scale environment for the convection taking place over Kansas and Missouri.

B. Stability and Upward Motion

The atmosphere over Oklahoma, Kansas, and Missouri, continued to be very unstable and supportive of convective activity (see UMN, Missouri sounding Fig. 16). Also, the vertical wind profile revealed good veering, and shearing which is conducive for strong convection (Miller, 1972). Comparing soundings from 0000 UTC and 1200 UTC at PAH, and Peoria, Illinois (PIA) reveals that locations to the east destabilized during this period. For example, LI's at PAH decreased from 1 at 0000 UTC to −6 at 1200 UTC.

We have briefly pointed out in these first two episodes, major synoptic contributing factors aiding thunderstorm development; however, as we progress through the remaining two episodes, we will see that mesoscale processes played a more obvious role in producing severe convection.

3.3 Episode 3

Thunderstorms continued to persist throughout much of the day on 15 May in most of Missouri and Illinois. During the afternoon and evening, severe convection broke out in a band from central Illinois to central Missouri (Fig. 17). Reports of large hail ranging from ¾" to 2¾" were common over portions of central Missouri (Storm Data, 1990). In this episode the mesoscale interactions were more easily detectable than in the previous episodes as thermal gradients and outflow boundaries were better resolved in the surface data.

A. Synoptic Scale Processes

By 0000 UTC, the surface warm front had moved north into Iowa and northern Illinois. Temperatures were in the 80's over much of the south-central United States. To the north of the front, temperatures were in the 60's and 70's. At 850 mb, a closed low was over central South Dakota with a 30 kt (15 m/s) LLJ in Texas and Oklahoma. Broad southwest flow continued over the region at 500 mb, and at 300 mb, a 100 kt jet streak was moving into Kansas and Oklahoma from the southwest with diffluent heights over Missouri (although it is not clear whether diffluence preceded or was a result of convection).

Q-vectors were computed at 700 mb for 0000 UTC 16 May (Q vectors are computed from the right-hand side of the omega equation and only *imply* UVM). Although it may be argued that a few stations' rawinsonde data were influenced by convection, we chose the Barnes (1973) parameters $\kappa = 111,300$ km^2 and $\gamma = 0.50$, which ensure only a ≤ 3% resolution of those wavelengths ≤ 800 km. This allows us to diagnose only the macro β scale (Orlanski, 1975) waves influencing the Q-vector field.

Figure 18 reveals Q-vector convergence centered over west-central Illinois, along an axis from Texas into Minnesota. This axis of Q-vector convergence (implying UVM) is superimposed upon a diffluent thickness (850-300 mb) pattern seen in Figure 19. Shi and Scofield (1987) have noted that convective development is favored to occur near the "throat" of the 850-300-mb thickness diffluence. In many cases this thickness pattern is associated with backward building of convection.
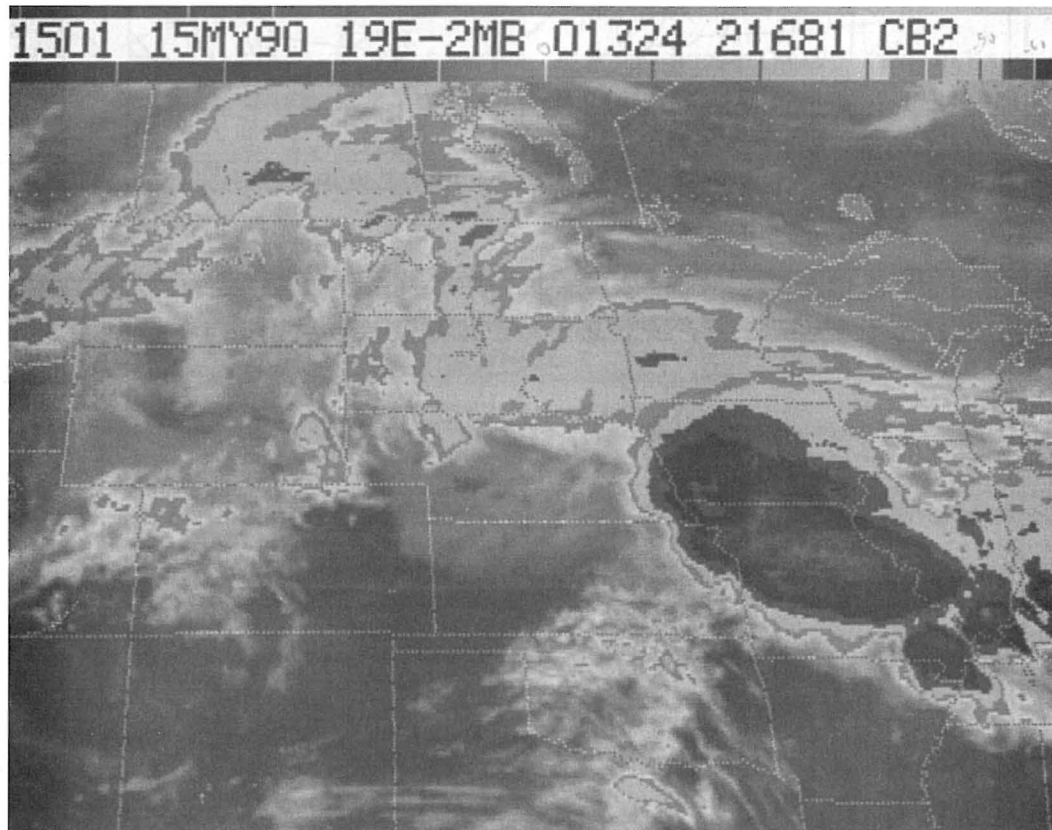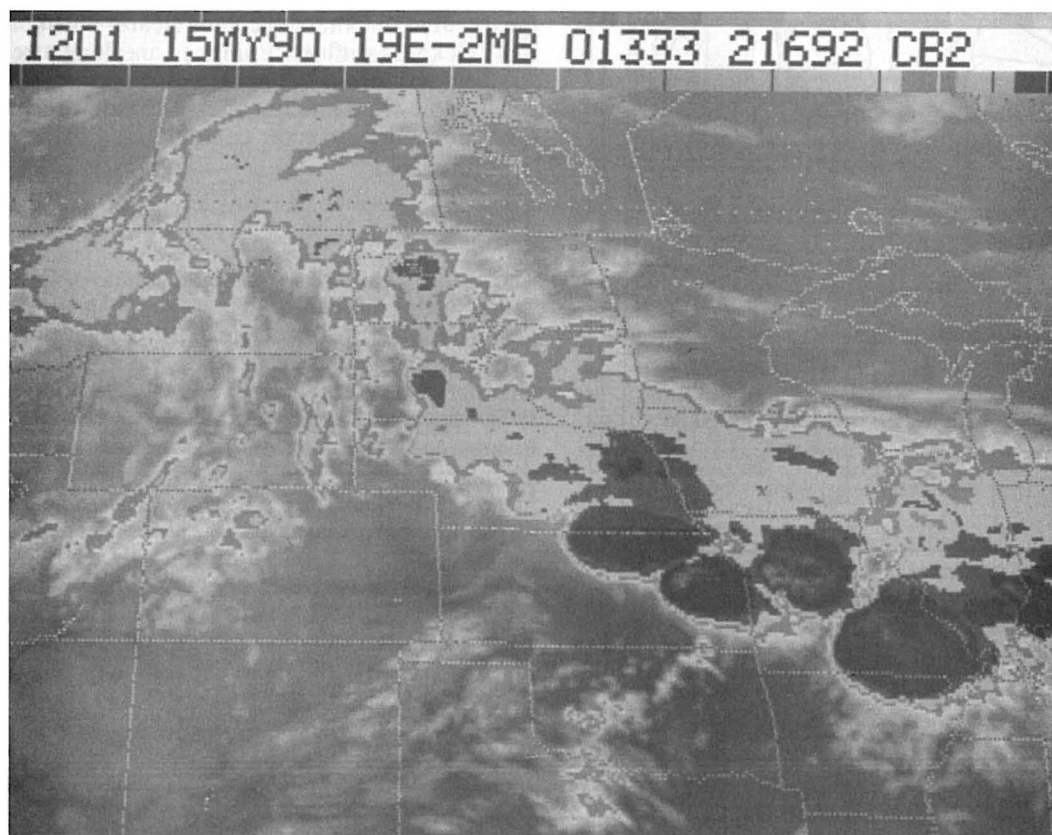
Fig. 10a–b. GOES east IR satellite imagery for 15 May 1990 using standard MB enhancement curve, for 1201 UTC and 1501 UTC, respectively.
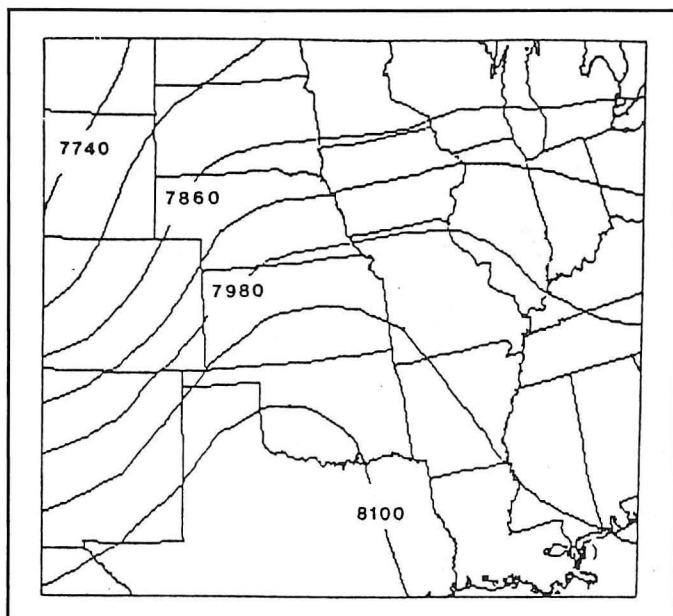
Fig. 11. 850-300-mb thickness for 1200 UTC 15 May 1990, contour interval is 60 gpm.

The relationship between the Q-vector convergence and the diffluent thickness becomes clearer when one recognizes that thickness diffluence implies an along stream or cross-stream variation in the geostrophic wind. Variations in the geostrophic wind and thickness field are precisely the terms involved in the Q-vector computations (Barnes, 1985), i.e.

$$\vec{Q} = \left[\frac{\partial \vec{V}g}{\partial x} \cdot \nabla \left(\frac{\partial \Phi}{\partial p} \right), \frac{\partial \vec{V}g}{\partial y} \cdot \nabla \left(\frac{\partial \Phi}{\partial p} \right) \right] \qquad (1)$$

The authors have noted the occurrence of Q-vector convergence within diffluent thickness fields in several cases, suggesting subject to further tests, that this may be a reliable "signature" of synoptic scale *support* for convection, given an otherwise favorable large scale field. Sanders and Hoskins (1990) have noted this relationship as well in their paper on estimating Q-vectors from basic weather maps.

B. Mesoscale Processes

Thunderstorms persisted throughout the morning and into the early afternoon hours of the 15th across Missouri, producing an overcast, rain-cooled environment over most of the central part of the state from episode 2. Surface data at 2000 UTC 15 May (Fig. 20) together with visible satellite imagery (Fig. 21) and the radar summary (Fig. 17), suggest a
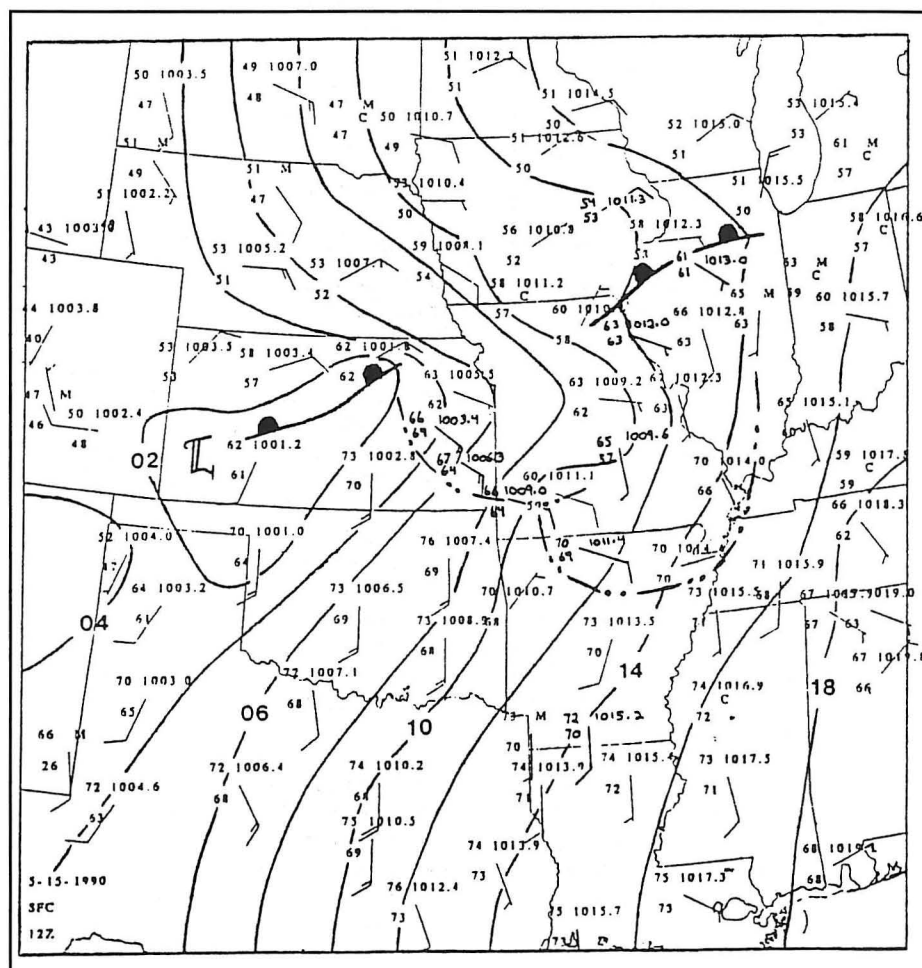

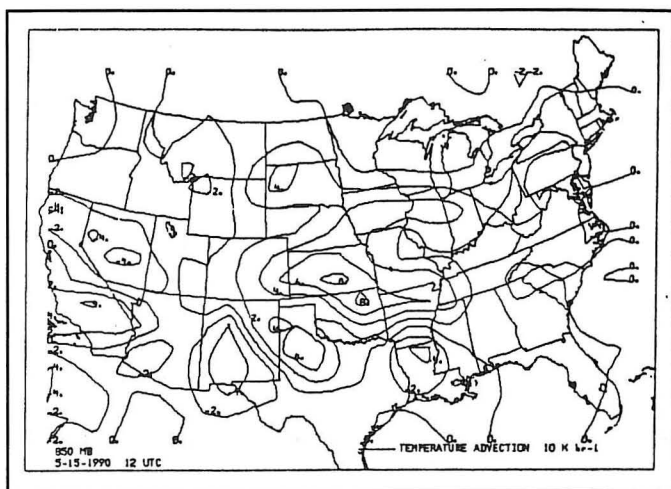Fig. 12. Same as Fig. 1, except for 1200 UTC 15 May 1990.

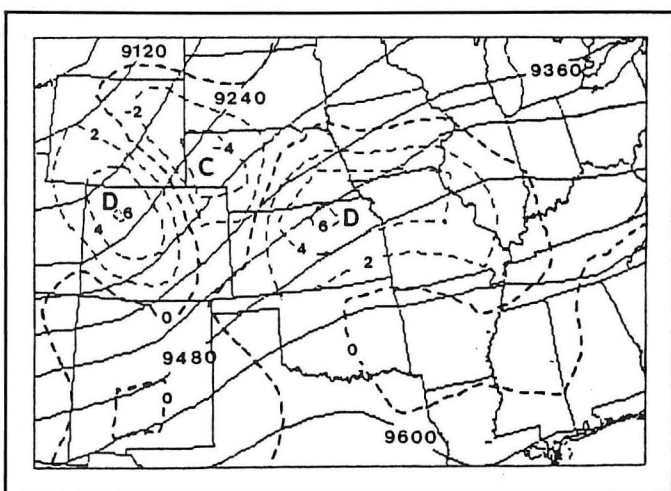Fig. 13. 850-mb temperature advection for 1200 UTC 15 May 1990. Units are *10 K h^{-1} contoured every 2 units.

Fig. 15. Composite radar chart for 1135 UTC for 15 May 1990. VIP levels 1, 3, and 5 are displayed.

Fig. 14. 300-mb heights (solid line) every 60 gpm for 1200 UTC 15 May 1990 and divergence (dashed line) in 10^{-5} s^{-1}.

thunderstorm-induced outflow boundary in eastern Kansas, southern Missouri extending into southern Illinois. Figure 20 shows a very strong thermal gradient over eastern Kansas and southern Missouri. This gradient is certainly a result of the deep clouds and precipitation over the central part of Missouri contrasting with the partly to mostly sunny skies further south (Fig. 21). This thermal gradient was also reinforced by the thunderstorm outflow boundaries which advanced to the south and west in Missouri. As a result of southwest winds in Oklahoma and Kansas in conjunction with this thermal gradient, low-level WAA was occurring over western and southern Missouri. Consequently, despite the fact that most of central and northern Missouri was cloudy with light precipitation the WAA in southern Missouri was significant enough to encourage severe convective development over the northern half of the state which spread southeast into Illinois during the early evening hours.

3.4 Episode 4

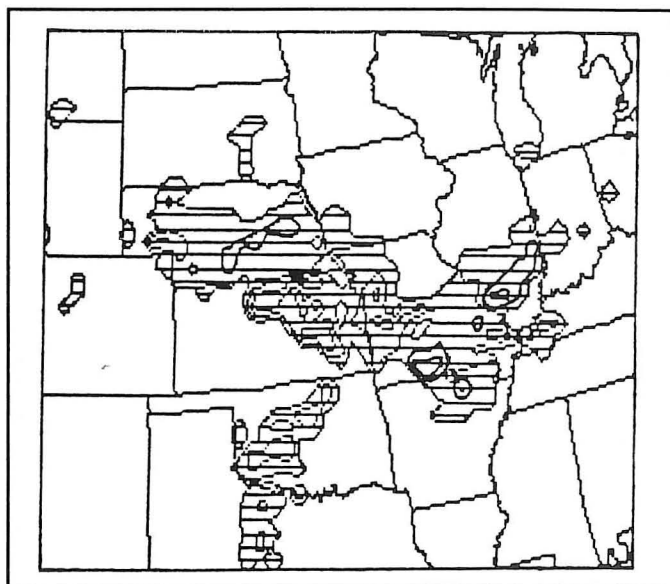This episode is perhaps the most explosive and illustrates the phenomena of "back building" convection more than

any of the other episodes. Thunderstorms underwent rapid development during the late afternoon on 15 May and persisted well into the morning of 16 May, producing large hail and high winds over southwest and central Missouri (Storm Data, 1990). In this episode the rain-cooled outflow boundary from previous convection played a significant role in organizing new convection.

A. Explosive Development in Kansas and Oklahoma

At 2031 UTC visible satellite imagery revealed a narrow line of cumulus clouds extending from south-central Kansas into southwest Oklahoma (Fig. 21) ahead of a thermal axis (Fig. 22) that extended from southwest Oklahoma into Nebraska. This narrow band of clouds moved east and thunderstorms developed quickly in Oklahoma and Kansas (Figs. 23a–c). At the surface, Figure 22 shows a moisture axis extending from eastern Oklahoma into eastern South Dakota. It can be seen that the thermal and moisture axes overlap over eastern Kansas, indicating the presence of warm, moist air over this region, which is conducive to thunderstorm development (Miller, 1972). At 850 mb, a θ_e maximum was detected over central Oklahoma (Fig. 24) in conjunction with a 15 m/s LLJ supplying warm, moist air from Texas. LI's were as low as -6 over most of eastern Oklahoma, eastern Kansas and western Missouri; in addition, an area of convergent Q-vectors was found to the east of where the thunderstorms developed (see Fig. 17).

The thunderstorms that developed in Kansas, moved into Missouri, while the thunderstorms in Oklahoma continued developing and spread southeast along the 850-300-mb thickness pattern (Fig. 19). Although the cells tended to move forward along the 850-300-mb thickness lines, getting a handle on the storm speed is quite difficult. We computed the cell in northern Oklahoma to be moving from 247° at 9 m s^{-1} while the south-central Kansas cell moved from 286° at 4.7 m s^{-1}. We found little agreement with estimates computed from average winds or wind shear in either the 850-300-mb or 700-300-mb layers. This, once again, clearly indicates how

72349 5/15/90 12 UTC MONETT, MO

SI = -6.4   SWEAT INDEX = 509.6
KI = 27.3   TTI = 56.0
LI = -6.3   LID STRENGTH = 0.94
BEST LIFTED INDEX = -7.4   ENERGY INDEX = -17.50 J/gm
SELS LI = -7.3
MAX TEMP BASED ON SELS LI = 76.1 deg F

THE CONVECTIVE TEMP BASED ON THE CCL = 70.0 deg F
The CCL is at 928.5 mb
The EL (CCL based) is at 190.0mb -60.8 deg C

The LCL(BL) is at 901.2 mb
AVG. MIXING RATIO (LOWEST 100mb) = 13.871 gm/kg
The LFC is at 811.0 mb   13.3 deg C
The EL (LFC based) is at 188.9 mb -60.9 deg C

CONVECTIVE AVAILABLE POTENTIAL ENERGY = 1391.4 J/kg
CONVECTIVE INHIBITION = 5.8 J/kg
VERTICAL WIND SHEAR (6000 M - 500 M) = 5.8X e-03 s-1
BULK RICHARDSON NUMBER = 2.7

POSITIVE AREA (CCL BASED) = 1336.6 J/kg
NEGATIVE AREA (CCL BASED) = 0.0 J/kg

PRECIPITABLE WATER = 1.26 in
HEIGHT WET BULB ZERO (AGL) = 9240.9 ft

W MAX BASED ON LFC = 26.32 m/s
DIAM OF HAIL FROM LFC = 4.08 cm   (4.24 cm)

W MAX BASED ON CCL = 25.90 m/s
DIAM OF HAIL FROM CCL = 4.11 cm   (4.27 cm)

DIAM OF HAIL (FM) = 3.76 cm   (3.76 cm)

SFC WIND GUST BASED ON F-M = 65.2 kts
SFC WIND GUST BASED ON FOSTER = 70.1 kts
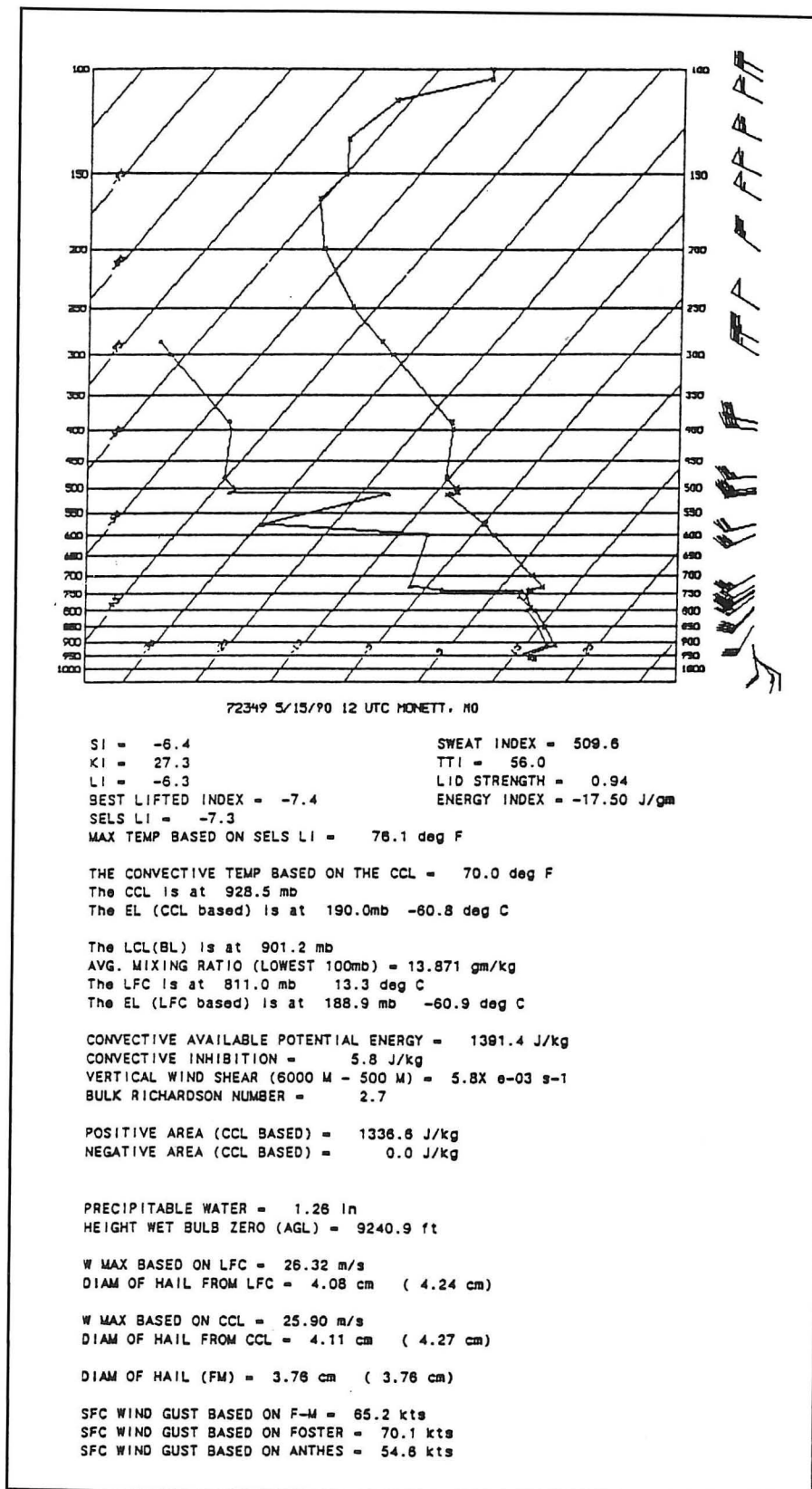SFC WIND GUST BASED ON ANTHES = 54.6 kts

Fig. 16. Sounding and stability analysis for Monet, Missouri (UMN) for 1200 UTC 15 May 1990.

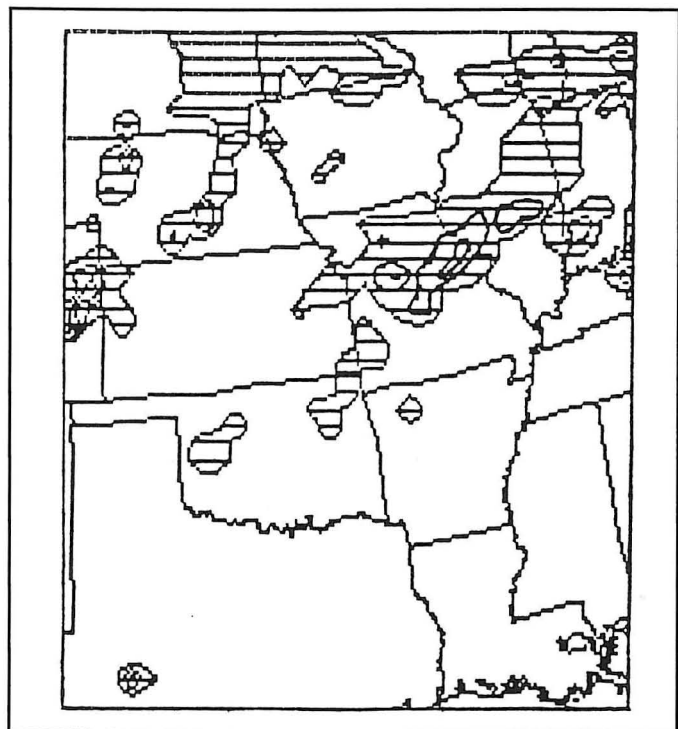Fig. 17. Composite radar chart for 2035 UTC 15 May 1990. VIP levels 1, 3, and 5 are displayed.
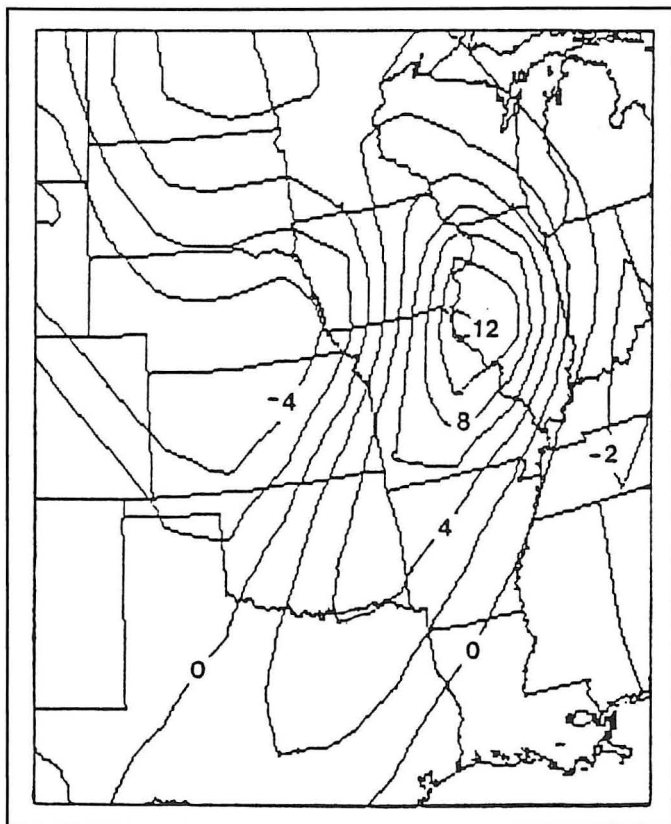

Fig. 19. 850-300-mb thickness for 0000 UTC 16 May 1990, contoured every 60 gpm.

Fig. 18. 700-mb Q-vector divergence for 0000 UTC 16 May 1990. Positive (negative) values imply upward (downward) vertical motion.

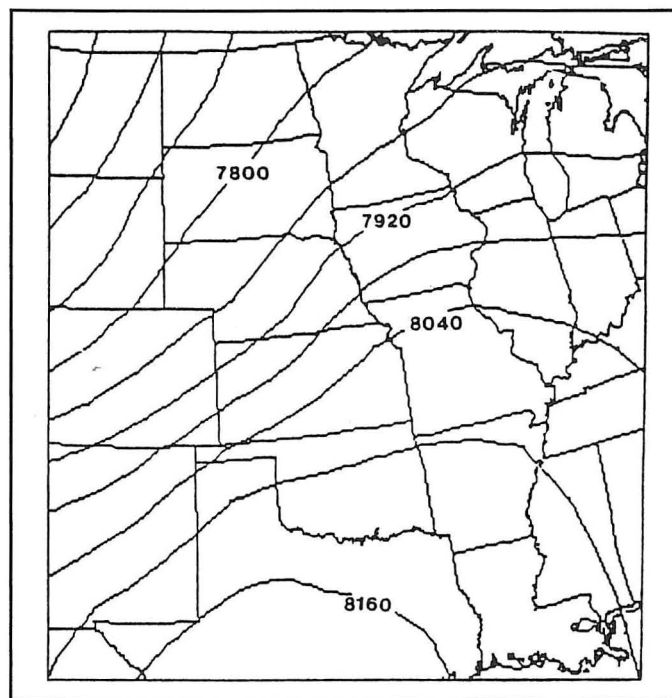estimating storm motion is complicated by the merging of cells and storm interaction.

B. The Mesoscale Connection

This episode exemplifies the importance of boundary layer thermal gradients and outflow boundaries created by previous convection on subsequent convective activity. Previous convection described as episodes 2 and 3 contributed to the strong surface thermal gradient in eastern Kansas and southern Missouri. Southwesterly surface winds acting on this thermal gradient locally enhanced the low-level WAA over southern and western Missouri contributing to storm propagation downstream from the Kansas-Oklahoma convection. In addition, the lack of organized convection upstream from this activity permitted θ_e rich air to advect into the storm environment, thereby aiding storm longevity.

4. Summary and Conclusions

Although each episode could have been examined more closely, for the sake of brevity we have concentrated on pointing out the major forcing and focusing mechanisms within data limitations. As noted by Doswell (1987) synoptic scale processes simply provide a favorable thermodynamic environment (e.g., low LI's, ample low-level moisture) whereas mesoscale processes initiate cumulus convection. As seen in the episodes discussed herein mesoscale processes are often difficult to resolve, even with surface data, due to data resolution and the size of the convective regime. As the convection becomes more organized (e.g., into meso $\propto$ scale clusters), the outflow boundaries and boundary layer thermal gradients become easier to diagnose.

Four episodes of severe convection that took place during 14–16 May 1990 have been examined to diagnose contribut-
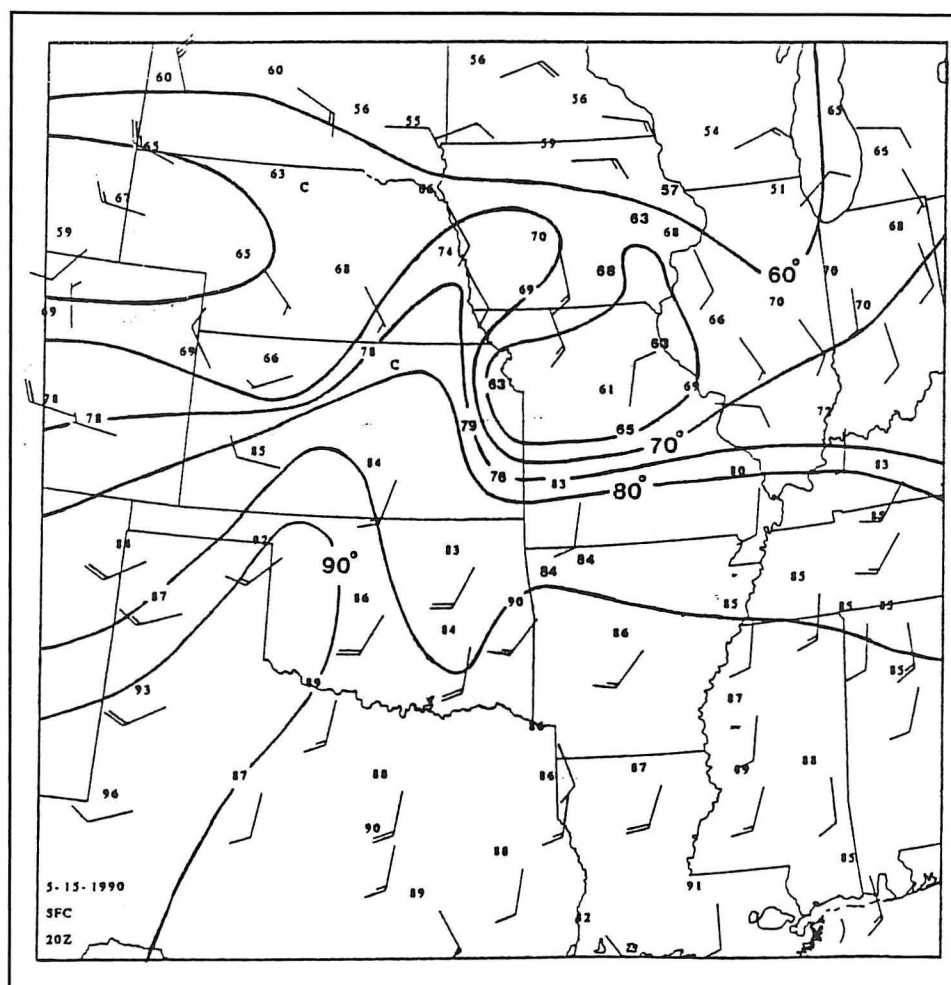
Fig. 20. Surface temperatures in °F (5°F interval) for 2000 UTC 15 May 1990.

ing factors which initiated and sustained strong thunderstorms. In this case study several key processes, acting on different scales of motion, combined to generate and regenerate severe convection over a two day period.

The synoptic scale LLJ advected high θ_e air and provided a lifting mechanism as warm, southerly currents moved north along a warm frontal zone. The LLJ was observed to strengthen throughout the remaining episodes, particularly at night. This seems to be a result of strong height falls at 850 mb in response to a deepening trough over the Rockies and the progression of an upper level jet streak into the region. Convection became organized along maxima of θ_e and moved parallel to the 850-300-mb thickness (i.e., 850-300-mb geostrophic shear vector).

Subsequent thunderstorm development became organized along outflow boundaries established by previous convection. Satellite imagery and radar summaries helped to fill in for the inadequacies of the surface station network to diagnose some of these mesoscale boundaries.

Q-vectors were computed to show areas of synoptic scale *implied* UVM. As noted by Shi and Scofield (1987) convection tends to have upstream development in areas associated with upward vertical motion and diffluent 850-300-mb thickness over the same region. Our results bear this out. Further, this study emphasized the fact, that although one might be

able to estimate where the *first* area of severe convection might erupt from standard data (i.e., large scale parameters), subsequent convection often becomes organized along mesoscale boundaries. The latter boundaries can only be resolved through satellite or radar displays.

Acknowledgments

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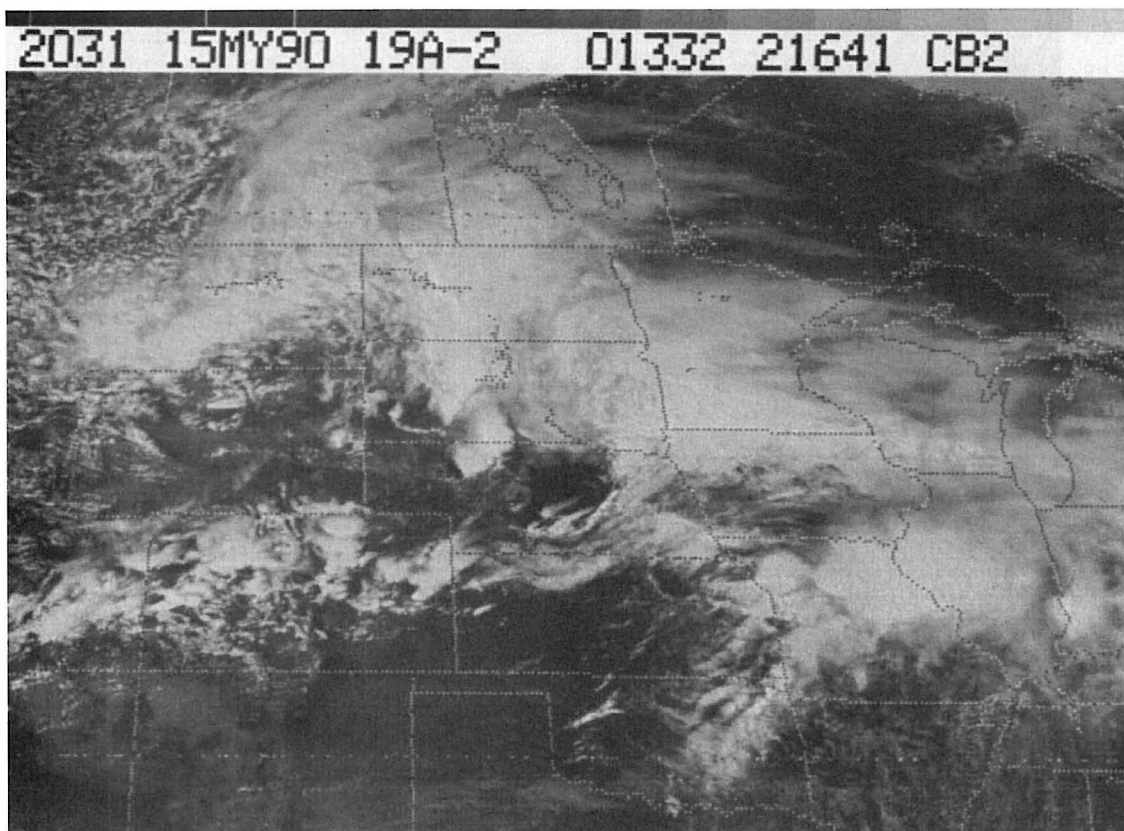
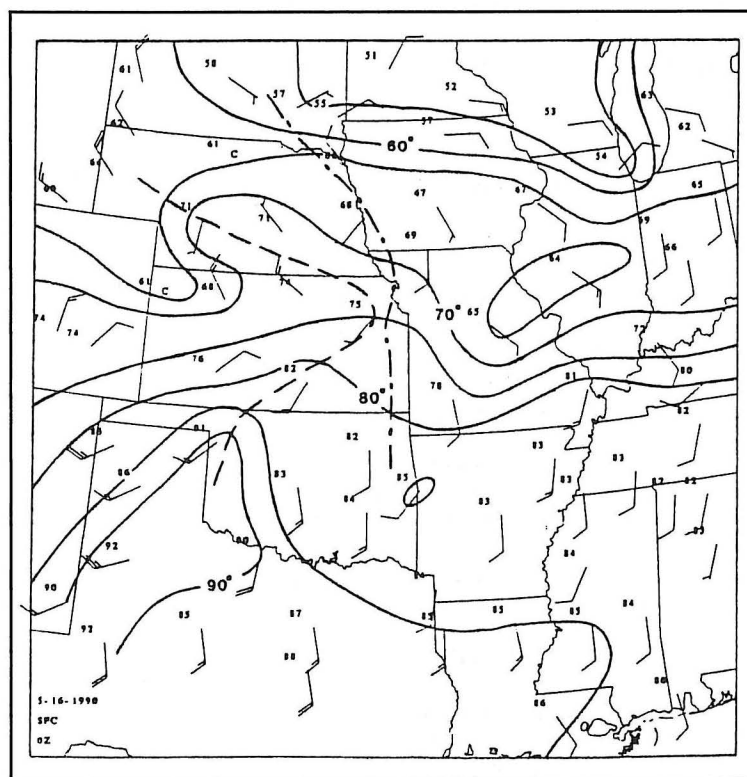Fig. 21. Visible satellite picture for central United States for 2031 UTC 15 May 1990.

Fig. 22. Surface temperatures in °F (5° F interval) for 0000 UTC 16 May 1990.
Dashed line represents the location of thermal axis. Dash-dot line represents
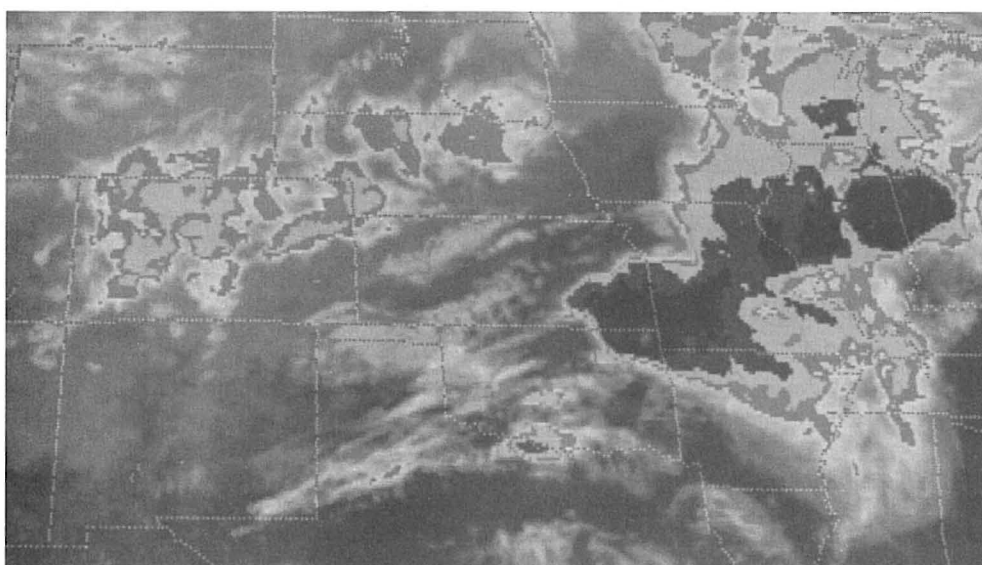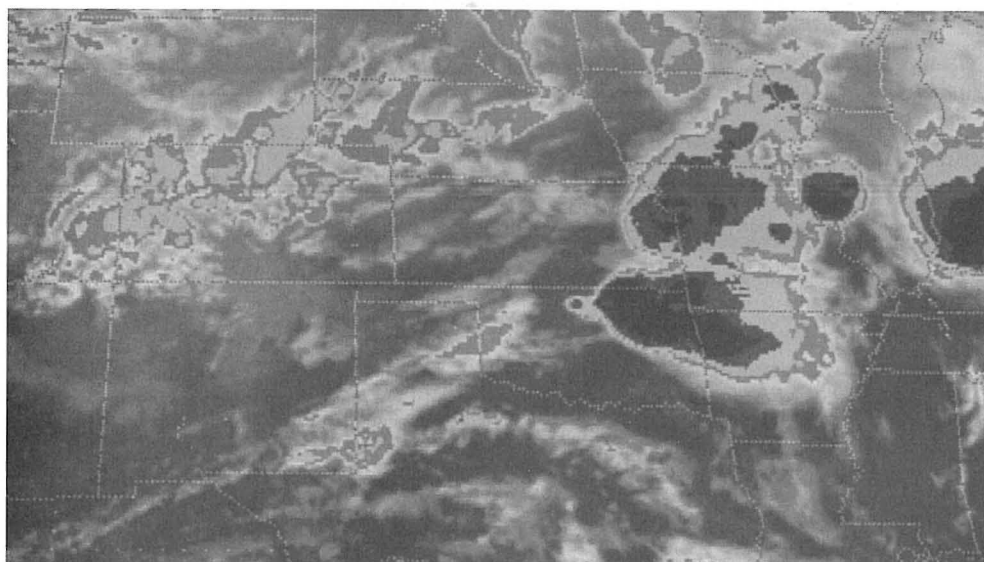the location of the moist axis.

Fig. 23a–c. Series of IR imagery with standard MB enhancement curve for 0001 UTC, 0301 UTC and 0601 UTC 16 May 1990.
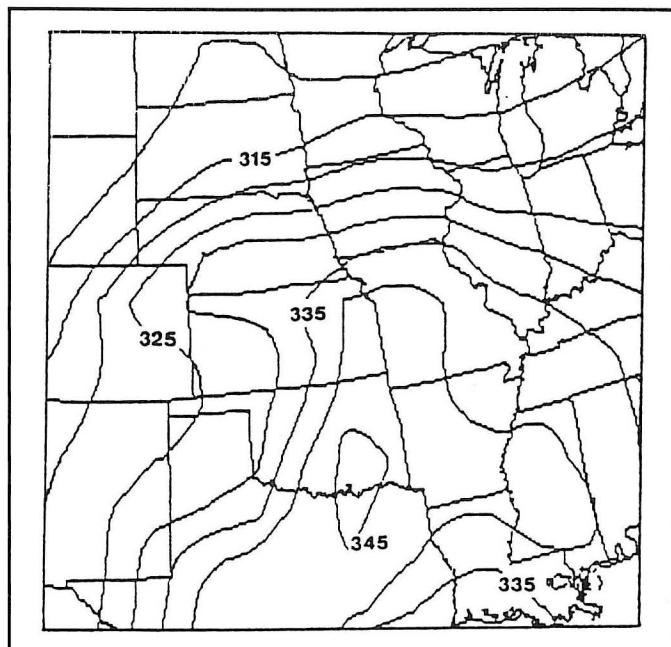
Fig. 24. 850-mb equivalent potential temperature contoured every 5 K for 0000 UTC 16 May 1990.

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