Mesoscale and Synoptic Scale Interactions Leading to Intense Convection: The Case of 7 June 1982

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(Manuscript received 31 July 1987, in final form 8 December 1987)

ABSTRACT

A case study is presented involving an unusually intense mesoscale convective system (MCS) which produced extensive hail and wind damage in northeast Kansas and northern Missouri, including the Kansas City metropolitan area, during the predawn hours of 7 June 1982. The study emphasizes the preconvective period and examines interactions between mesoscale processes and the synoptic scale environment that led to thunderstorm development. The initial storms formed after dark over the western High Plains, in an area characterized by relatively weak convective potential, making the thunderstorm difficult to forecast. Near midnight the convection rapidly intensified into an MCS as it progressed eastward into a much more convectively unstable environment. Several meteorological scenarios that might have led to the initiation and intensification of convection are proposed and examined. These scenarios consider lower tropospheric convergence within an air mass which initially had weak convective potential, and the evolution of this air mass into one that could support moderate thunderstorms after sunset. This work, along with similar studies, illustrates the wide range of complex factors which must be considered in thunderstorm forecast decision making.

1. Introduction

The preconvection setting, initiation, and evolution of an unusually severe mesoscale convective system (MCS) on 7 June 1982 are examined. The storm system was one of the most intense in the Kansas City, Missouri area in recent years. Of 37 nocturnal mesoscale convective complexes documented in 1982 (Rodgers et al., 1983), this event caused the season's most extensive wind damage (NOAA Storm Data). Johns and Hirt (1987) refer to the storm as a derecho, a convectively driven windstorm. The first storms developed over extreme southwest Nebraska just after sunset. A sequence of satellite images shows the preconvection setting (Figs. 1a and 1b), the approximate time of the first thunderstorms (Fig. 1c), and the explosive growth of the storm system (Figs. 1d–f). This MCS produced a wide range of severe weather, as depicted in Fig. 2. Observers reported 60–90 kt wind gusts, large hail, funnel clouds, and at least one tornado. Widespread property damage and numerous injuries resulted from the hail and intense winds (NOAA Storm Data and National Weather Service surface observations). At about dawn, winds estimated at 90 kt swept through downtown Kansas City, damaging trees and buildings and causing widespread power outages. This was a significant meteorological event not only because of the direct impact of its severe weather, but also because it provides an excellent example of complex interactions between mesoscale and synoptic scale processes which often occur prior to and during the initiation of thunderstorms. Doswell (1984), Bluestein (1982), Bosart (1984), Carlson et al. (1983), and Cotton et al. (1983) have studied cases involving such interactions and speculate that processes occurring near the surface usually are critical in storm initiation.

Forecasting convective weather can be broadly described as having two phases. The first involves the identification of fairly large areas (i.e., on the order of 100 000 km^2) where there is, or may develop, a high potential for convective storms. Usually, this step is accomplished through a diagnosis of the large-scale fields of temperature, moisture, and wind, using standard level analyses, and an identification of regions which have the greatest moist thermodynamic instability and favorable vertical wind structure. The evo-

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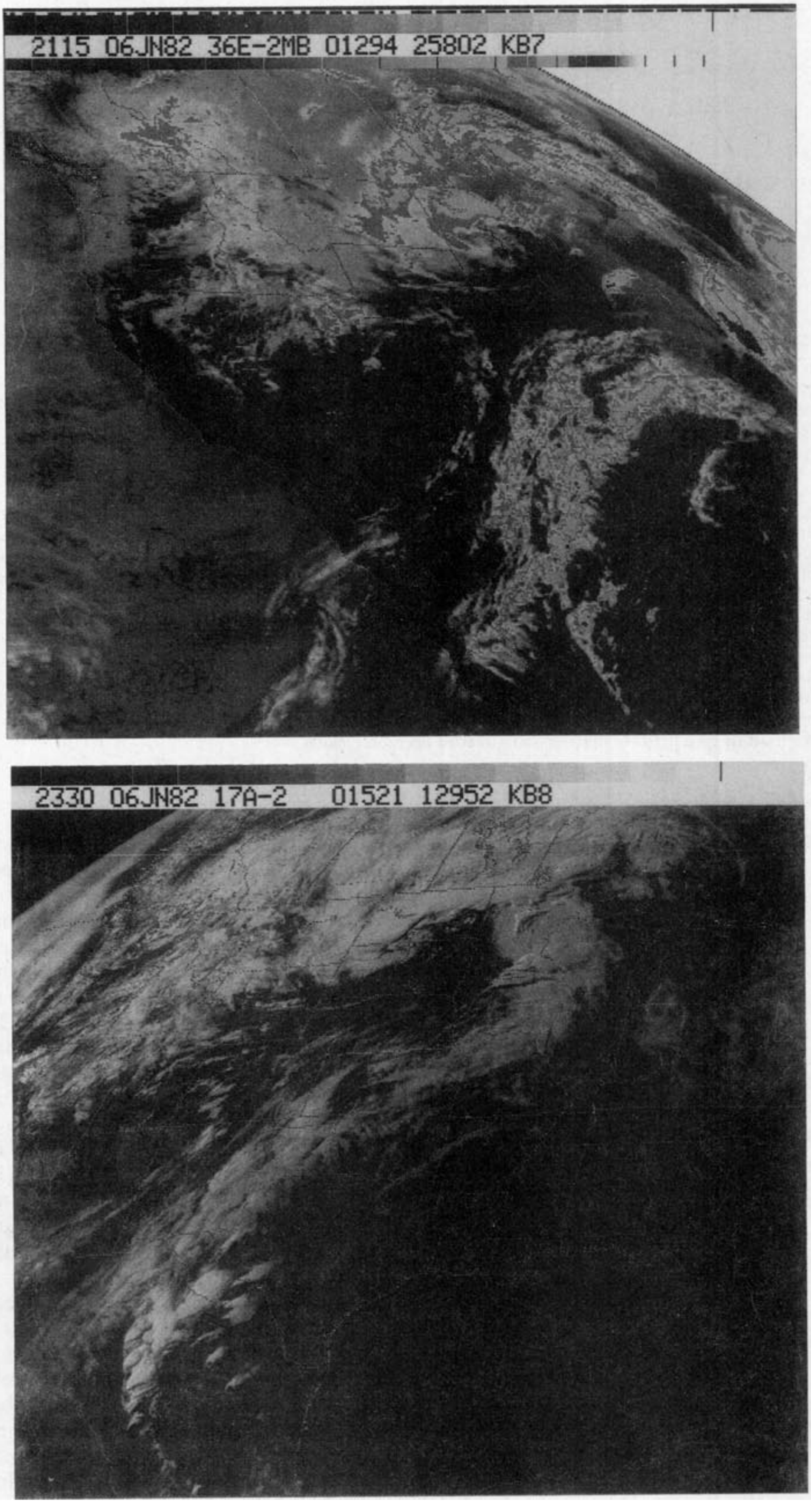

FIG. 1. Enhanced infrared satellite images for (a) 2115 UTC 6 June 1982, (b) (visible image) 2330 UTC 6 June 1982, (c) 0300 UTC 7 June 1982, (d) 0600 UTC 7 June 1982, (e) 0900 UTC 7 June 1982 and (f) 1201 UTC 7 June 1982.

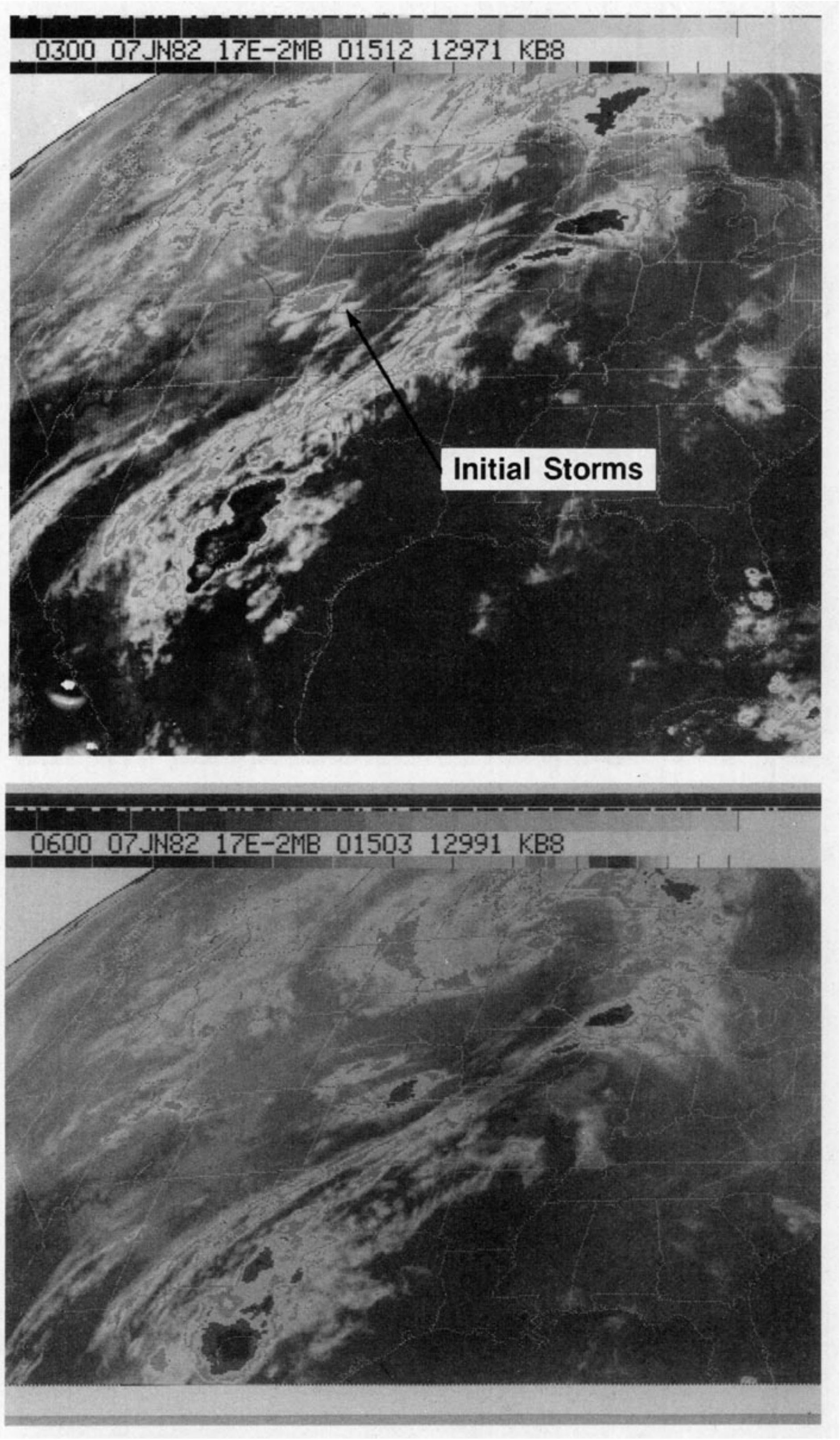

FIG. 1. (*Continued*)

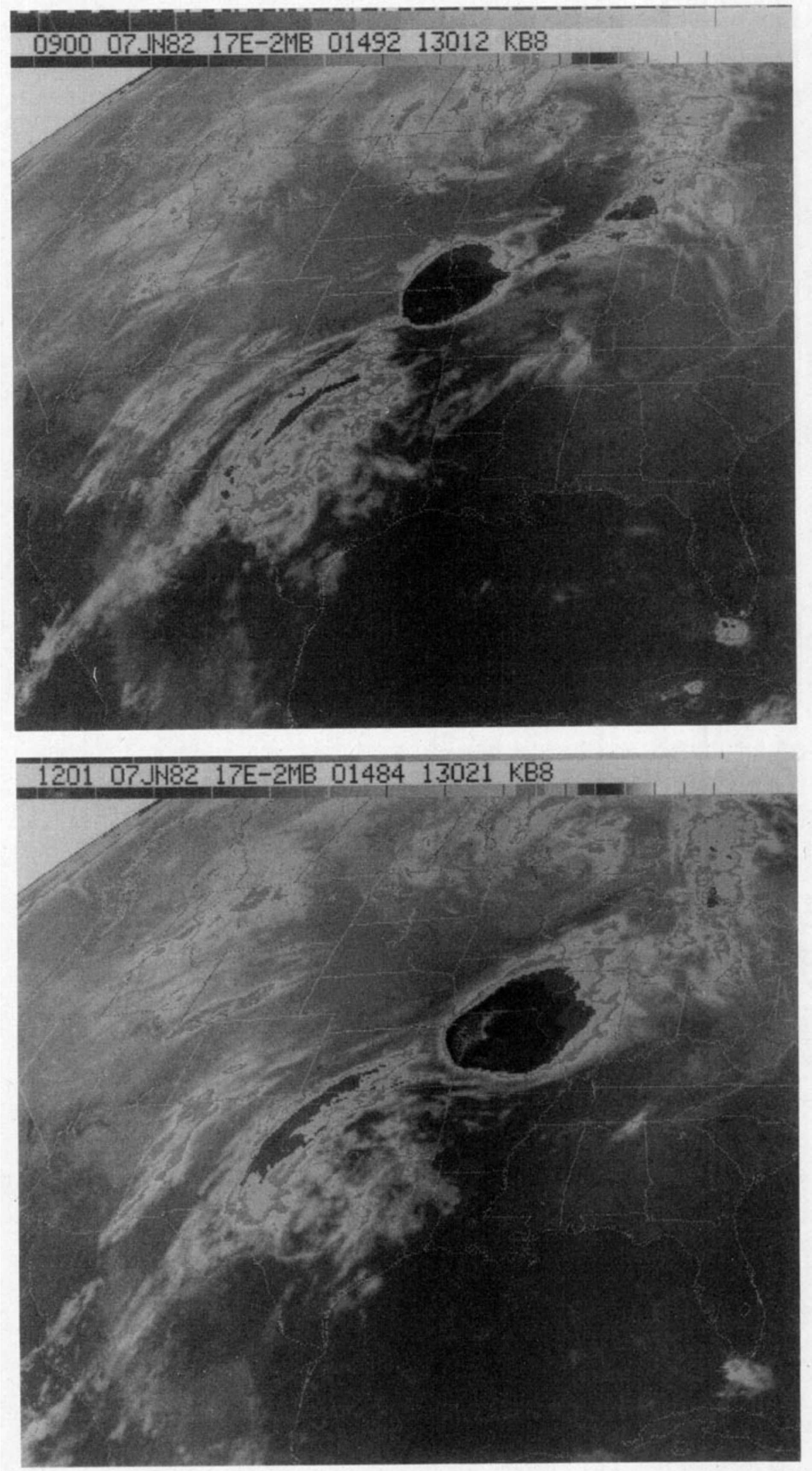

FIG. 1. (*Continued*)

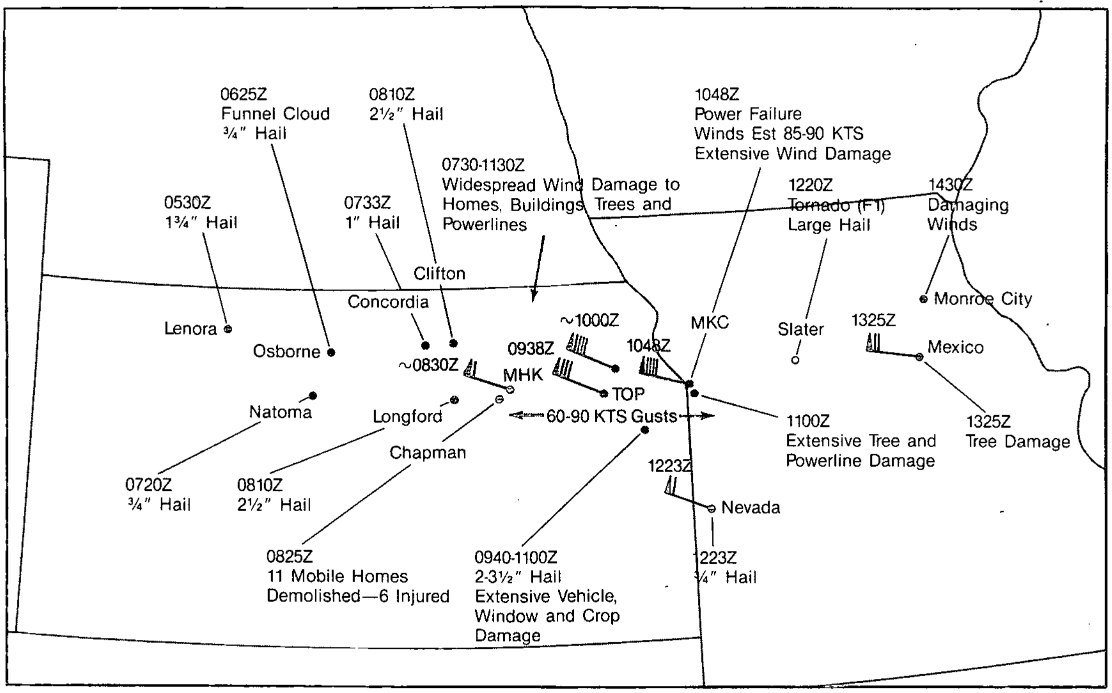

FIG. 2. NOAA Storm Data damage reports and other severe weather reports for 0530–1430 UTC 7 June 1982 for northern Kansas and Missouri. Shading indicates region of greatest wind and hail damage. Wind barbs (kt) and times are observed or estimated peak gusts.

lution of these fields is then forecast (with heavy reliance upon numerical guidance) out to as long as 36 hours. The second phase involves efforts to predict when and where, within these unstable regions, convection actually will develop and/or move. This is a formidable and often impossible task. Unfortunately, attention seems to be shifting away from this second phase in favor of the "nowcast," which emphasizes monitoring the prestorm environment for the first signs of convection, then tracking its evolution using tools such as Doppler radar, satellites, and high density surface networks (e.g., MacDonald, 1984; Schlatter et al., 1985; Smith et al., 1985). While nowcast procedures can improve the way the public is warned of imminently dangerous weather, the emphasis tends to be on existing storms. Aspects of both phases of forecasting are addressed in this study: the evolution of the synoptic scale convective environment as well as the smaller scale processes that are related more to convective initiation. The study stresses the utility of standard datasets in case study research.

2. Preconvection, large-scale setting—0000 UTC 7 June 1982

The surface analysis at 0000 UTC (Fig. 3a) shows a complex pattern of fronts, troughs, and drylines associated with a strong, occluded cyclone over North Dakota. Over northeast Colorado and much of Nebraska mild, dry air had moved southeastward behind a weak High Plains trough. In northwest Kansas surface moisture had increased despite afternoon heating, and a weak dryline had formed between this air mass and the drier air from the west. Soundings in the drier air mass show a deep, nearly adiabatic mixed layer, with strong surface winds (35 kt) and very low equivalent potential temperature (θ_e). A weakening cold front just entering northwest Nebraska is faintly identifiable in the satellite image (Fig. 1b) as a thin line of clouds.

In the lower troposphere, south to southwesterly flow ahead of the leading cold front had brought very moist air (dewpoint temperatures greater than 14°C) northward from Oklahoma across eastern Kansas into Minnesota (see the 850 mb analysis in Figs. 4a and 4b). The cyclonic circulation around a low over southern Colorado also had carried moisture back over western Kansas, indicating that the return flow of moisture behind the front had large-scale support. At 700 mb (Figs. 5a and 5b) the front is indicated by the stronger temperature gradient in southern Nebraska. South of this 700 mb front, hot, dry continental tropical air had flowed northeastward across the central Plains resulting in a pronounced inversion, or "cap" (Carlson and Ludlam, 1968), over the lower level moist air, limiting convective growth because of its higher potential temperature relative to the air underneath. In capping inversion situations, the actual restraint to convection may vary considerably and must be determined by a

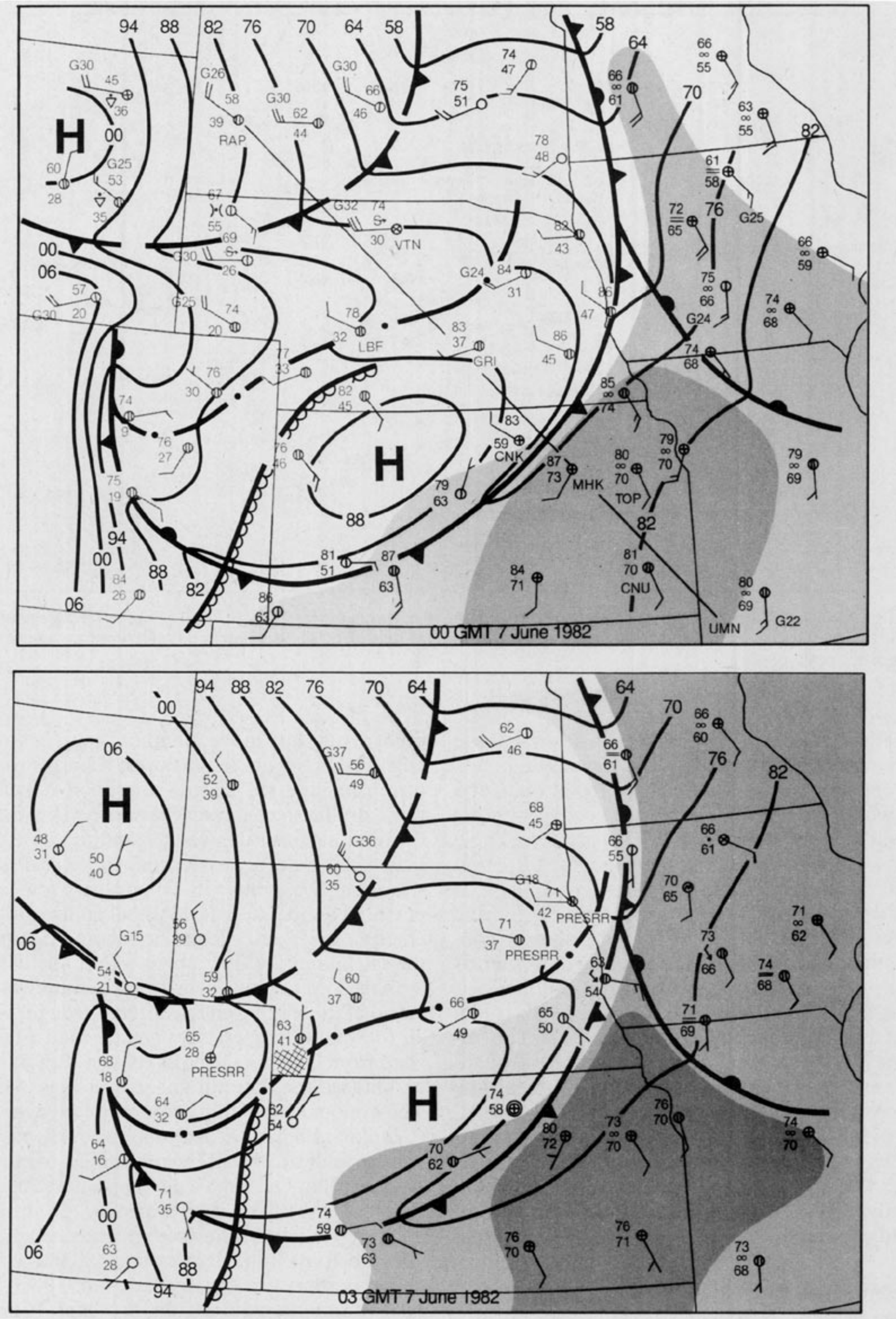

FIG. 3. Surface analyses for 7 June 1982 at (a) 0000 UTC, (b) 0300 UTC, (c) 0600 UTC and (d) 0900 UTC. Solid lines are altimeter setting contours in intervals of 0.06 in. Hg (approximately 2 mb). Fronts, troughs, drylines, and thunderstorm outflow boundary positions are shown using conventional symbols. Station plots are in °F and kt. Shading indicates dewpoints in the 50s (light), 60s (medium), and 70s (dark). In Fig. 3a the northwest–southeast line from Rapid City, South Dakota (RAP) to Monett, Missouri (UMN) indicates the position of cross section in Fig. 12. In Fig. 3b the cross-hatched area in southwest Nebraska is the area of initial thunderstorms.

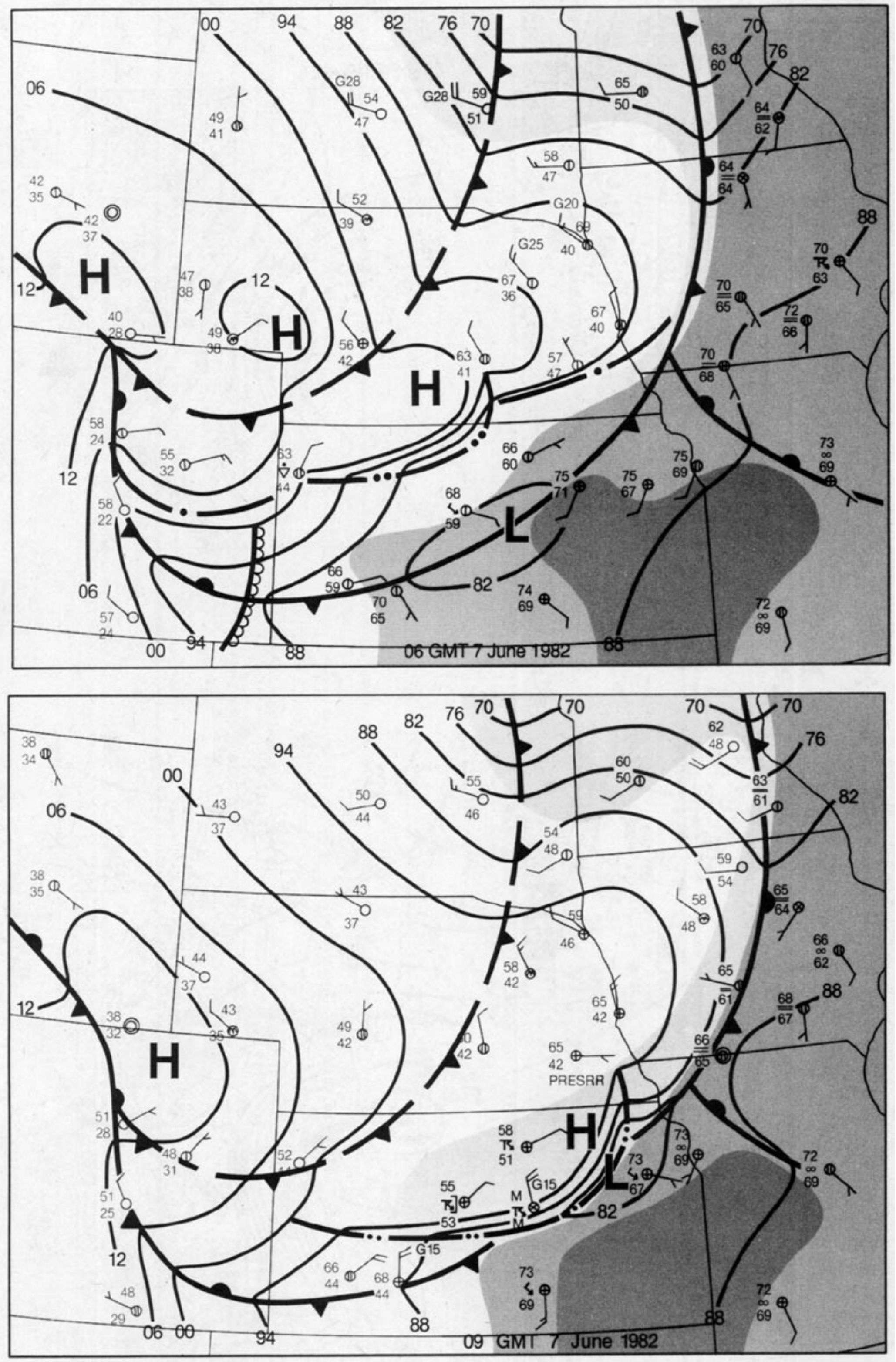

FIG. 3. (*Continued*)

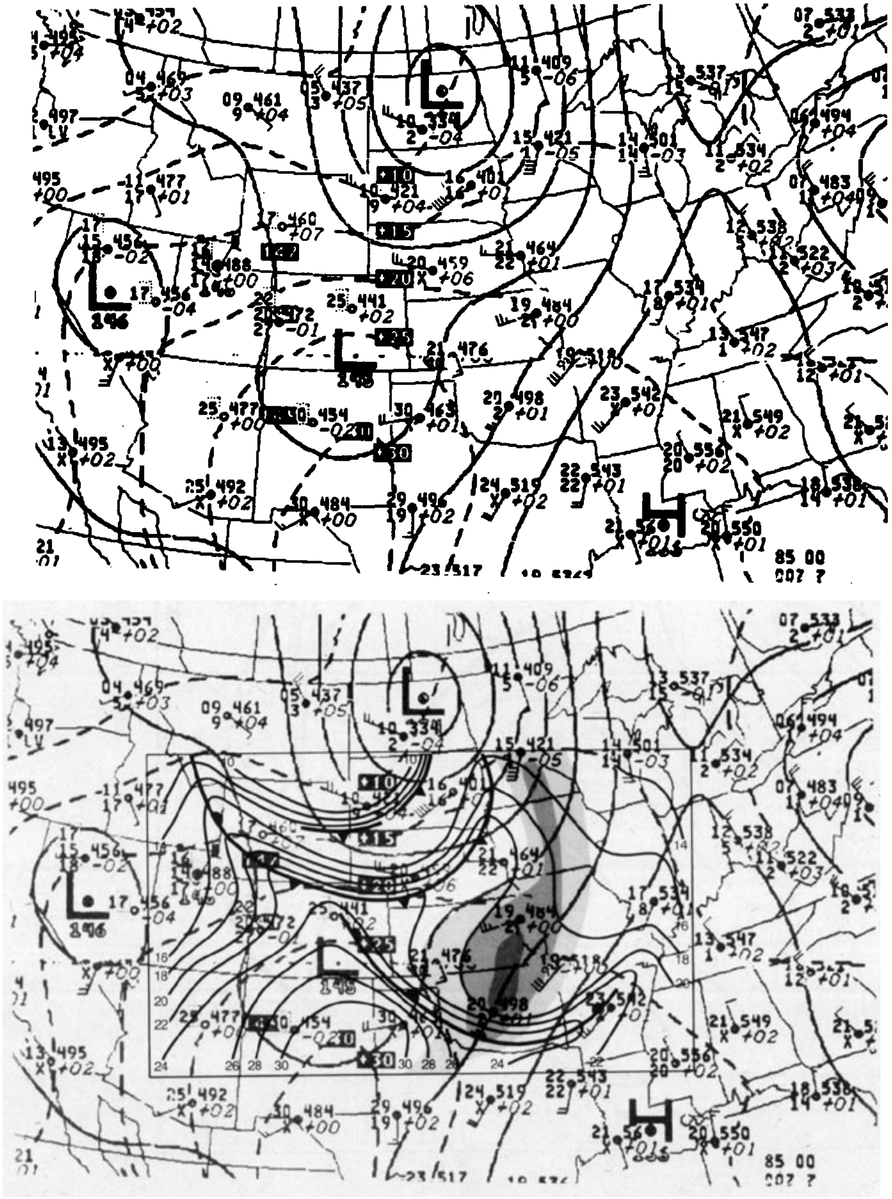

FIG. 4. (a) 850 mb NMC analysis for 0000 UTC 7 June 1982. Solid lines are height contours (dam); dashed lines are isotherms (°C). (b) Reanalysis of 850 mb NMC analysis. Dark lines are isotherms (2°C interval), approximate frontal positions are shown using conventional symbols, and shading indicates dewpoints of 10°C (light), 14°C (medium), and 18°C (dark).

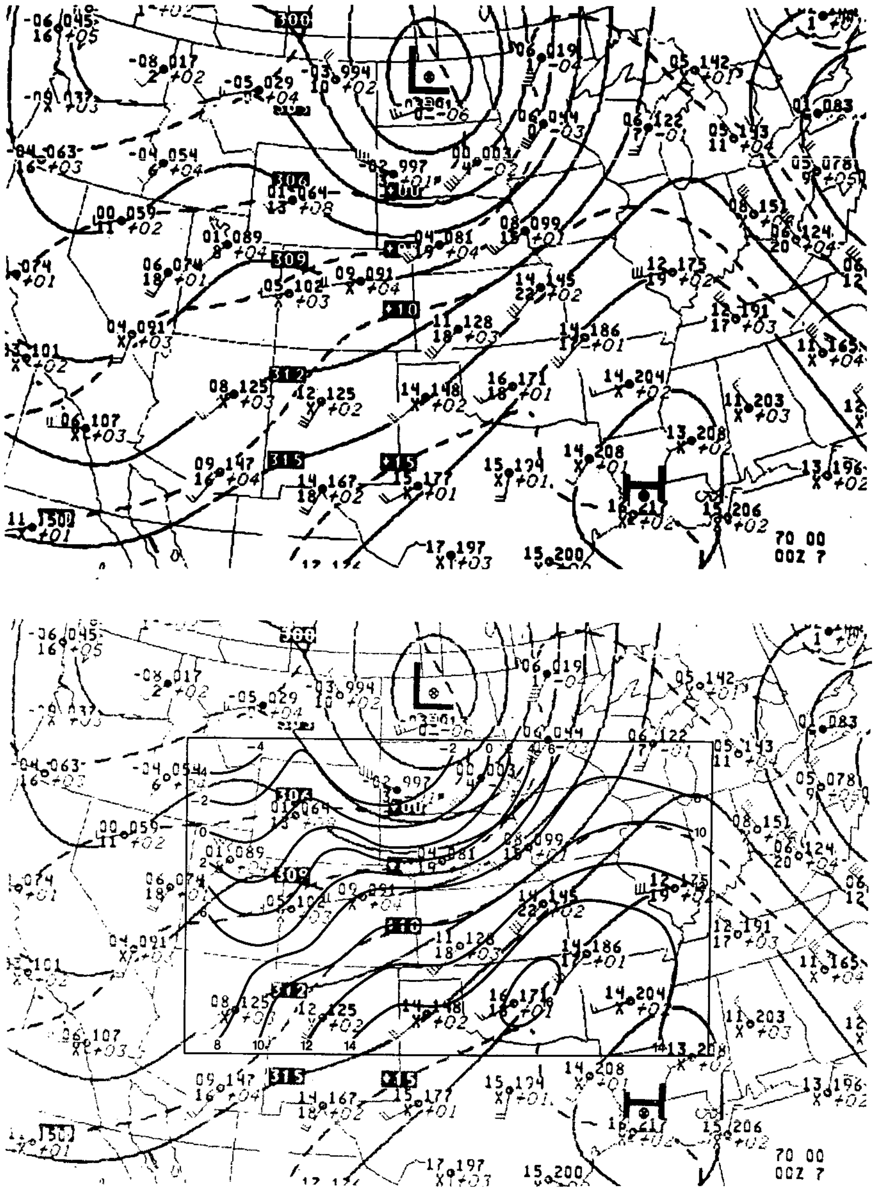

FIG. 5. As in Fig. 4 except for 700 mb NMC analysis. In (b), shading indicates temperatures 12°C or greater corresponding to the "capped" area.

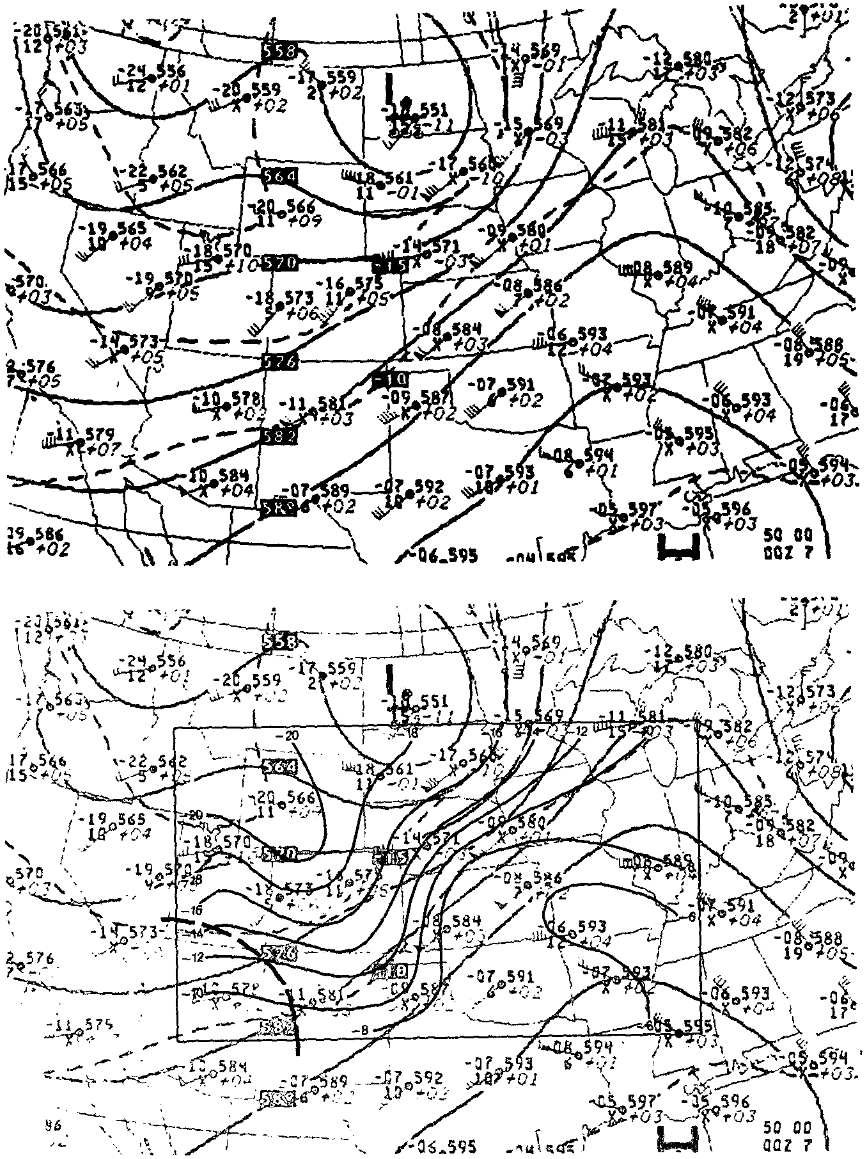

FIG. 6. As in Fig. 4 except for 500 mb NMC analysis. In (b), heavy dashed line indicates the shortwave trough axis.

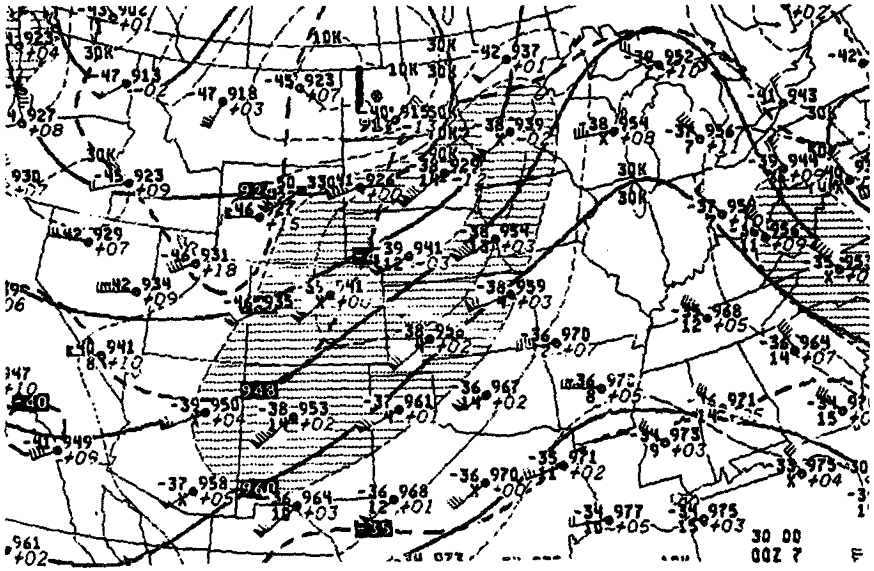

FIG. 7. As in Fig. 4 except for 300 mb NMC analysis. Thin dashed lines are isotachs (kt). Shading indicates 70–110 kt winds. Note cyclonic shear from 30 kt northeast wind at Bismarck, North Dakota and 130 kt southwest wind at Huron, South Dakota.

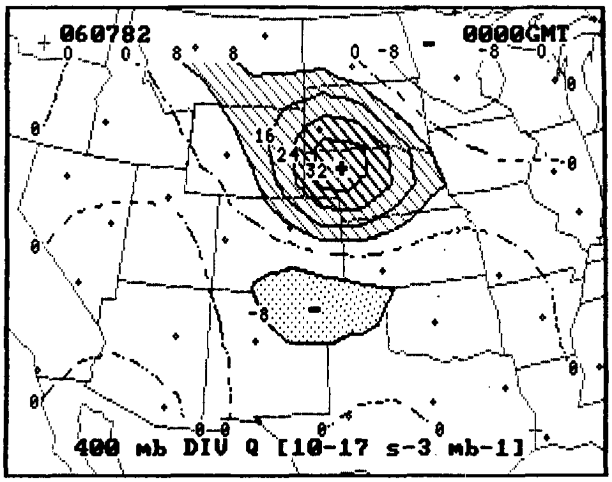

FIG. 8. 400 mb "vertical motion" (actually divergence of Q-vector representation of quasi-geostrophically forced vertical motion in the 500–300 mb layer; 10^{-17} s^{-3} mb^{-1}) for 0000 UTC 7 June 1982. Positive values (diagonal shading) imply downward motion; negative values (stippling) imply upward motion.

careful analysis of the moist thermodynamic stratification for each specific area. For this case, the soundings over the southern Plains states (not shown) suggest the capped area was roughly the region where the 700 mb temperatures were warmer than 12°C. Convection over the southern Plains and eastern Kansas therefore was suppressed in the absence of very strong low-level forcing.

A thermal trough at 500 mb (Figs. 6a and 6b) had moved across the Rockies toward Kansas and Nebraska, with cold advection and backing winds indicated from 700 to 500 mb at Denver and Grand Junction, Colorado. Combined with weak warm advection at lower levels, the temperature lapse rate over the western High Plains was increasing. Also, a weak shortwave trough in the geopotential height field was moving across the Four Corners area into Colorado. This shortwave trough is the upper-level component of the 850 mb low over southern Colorado. It is identified using a higher resolution reanalysis of the geopotential height data (not shown), an absolute vorticity maximum resulting from the shear and curvature in the wind field, and a pocket of minimum stability (see the lapse rate analysis in Fig. 14). Areas of high lapse rates such as this are helpful in defining weak troughs since the overall stability is generally decreased by the upward vertical motion and low-level warm advection that often occur ahead of a troughline.

A strong (130 kt) polar front jet streak was present at 300 mb (Fig. 7) across the northern Plains. The first thunderstorms formed under the right entrance region of this polar jet in southwest Nebraska. At first glance this appears to fit the "rule of thumb" (e.g., Beebe and Bates, 1955; McNulty, 1978; Uccellini and Johnson, 1979) that this is a preferred region for thunderstorms because of its tendency for upward vertical motion. However, a calculation of the large-scale, quasi-geostrophically forced vertical motion field (Barnes, 1985) shows (Fig. 8) that the four quadrant, vertical motion concept for jet streaks does not fit this case. Instead, it shows downward forcing centered over western Nebraska, including the initial storm area. While other contributions to the vertical motion should be considered (i.e., orographics, fronts, diabatic and frictional effects), the implied subsidence may have helped confine the returning moisture to low levels and delayed the initiation of convection until a time of greater convective instability. Figure 8 also shows upward forcing in the same layer associated with the shortwave trough over the Four Corners. The resulting ascent may have contributed to the increasing lapse rate over southeast Colorado. This is an example of the value of actually calculating the large-scale vertical motion forcing instead of relying on qualitative concepts which merely estimate vertical motion.

3. Preconvection thermodynamics and stability

The total totals stability index (TTI; Miller, 1972; see Fig. 9) indicates a wide range of thunderstorm potential. Moderate to high potential (TTI > 50) existed over parts of Oklahoma and Kansas, but much of this area was capped by hot, dry continental air. Across Nebraska, within the dry air mass, the index indicates little likelihood (TTI < 45) of thunderstorms. The area of southwest Nebraska where the storms began is estimated to have had a TTI of about 45, suggesting only slight thunderstorm potential.

The 0000 UTC Topeka, Kansas sounding is presented in Fig. 10. Lower tropospheric features resemble the classic "loaded gun" sounding (Fawbush and Miller, 1952); however, the pronounced inversion above the moist layer was a formidable obstacle to thunderstorm development, especially given the time of day. If thunderstorms were to develop, strong winds would probably accompany the storms, since the wet bulb potential temperature in the dry midlevel air (16°C at about 750 mb) was about 13°C cooler than the surface temperature. Large-scale ascent in the lower layers, resulting from low-level warm advection and positive vorticity advection aloft, may have weakened the inversion by the time the storm moved through the Topeka area, but certainly was not strong enough to eliminate the cap.

The 0000 UTC Denver, Colorado sounding (Fig. 11) is representative of the air mass of the dry, High Plains environment. A surface-based, nearly adiabatic layer was 16 000 and 11 000 ft deep at Denver and North Platte, Nebraska (sounding not shown), respectively. This lapse rate is conducive to downward mixing of high momentum, midlevel air (70–100 kt), and gusty surface winds (approximately 20 kt between 1700 and 2300 UTC). High-level, tropical moisture is evident above the deep mixed layer from 445 to 375 mb.

A cross section of equivalent potential temperature (θ_e) from Rapid City, South Dakota to Monett, Mis-

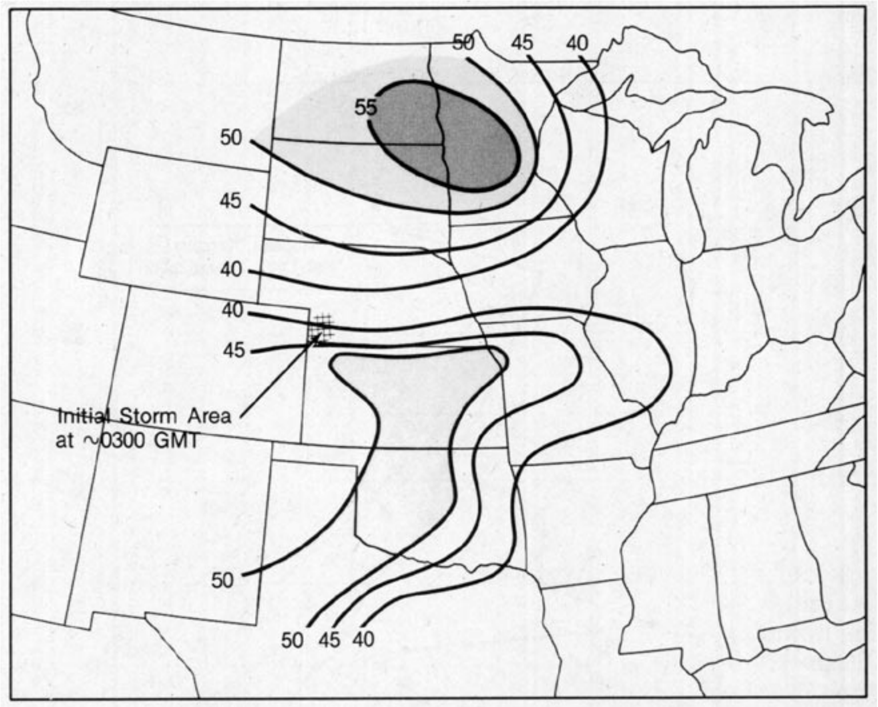

FIG. 9. Total totals stability index for 0000 UTC 7 June 1982. Light shaded area has moderate thunderstorm potential (50–54); dark shaded area has higher potential (55–59).

souri (estimated from 0000 UTC sounding and surface data) is shown in Fig. 12. This orientation was chosen to be nearly perpendicular to the fronts (see Fig. 3a), while including the area in northern Kansas in which the storm underwent rapid intensification. The analysis shows that very high θ_e air (350–360 K) was flowing toward the shallow front at low levels, with much lower θ_e air (320 K) overlying it. The rapid decrease with height of θ_e ahead of the front is characteristic of high convective instability (Holton, 1979). Behind the front, low θ_e values (310 K) within the dry, High Plains air mass show that it could not support moist convection. The air over Rapid City also had relatively low θ_e values (311–315 K) through a deep layer, mainly because of its colder temperatures. The relative humidity analysis emphasizes the dryness of the inversion layer over eastern Kansas and the High Plains (relative humidity generally less than 20%). It can also be seen that ahead of the front (350–360 K air), relative humidity was 80%–90%, showing not only high moist convective potential, but that it was near saturation. Nevertheless, this air would have to be lifted 6500–8000 feet (the approximate depth of the inversion) to reach its level of free convection.

Since the large-scale setting indicated such a wide range of thunderstorm potential and because the setting was apparently changing quite rapidly, this was obviously a difficult situation to forecast properly. The National Severe Storms Forecast Center/Severe Local Storms Unit (NSSFC/SELS) convective outlook (issued at 0820 UTC 6 June and valid for the 24-hour period ending at 1200 UTC 7 June) included a moderate risk of severe thunderstorms in northeast Kansas. The 1500 UTC update downgraded the threat in this area to thunderstorms approaching severe as the morning data indicated that while there was still very unstable air over the Plains, unexpectedly rapid movement of the entire synoptic scale system appeared to be carrying the threat farther east, and much of Kansas would remain suppressed.

4. Possible causes of storm development

Since existing data and understanding are generally insufficient to specify precisely the meteorological processes that lead to MCSs, a number of processes which may have been involved in the formation of this storm system are presented for consideration. These can be separated into two general space-scale categories: synoptic scale processes which contributed to destabilizing the local environment and mesoscale processes which contributed to initial lifting. A provocative discussion on the relationship between these scales of motion and their contributions to convection is presented by Doswell (1987).

a. Large-scale destabilization

It seems evident that in the three hours between 0000 UTC and initial storm development, large-scale processes changed the local environment over southwest Nebraska from very limited to moderate convective

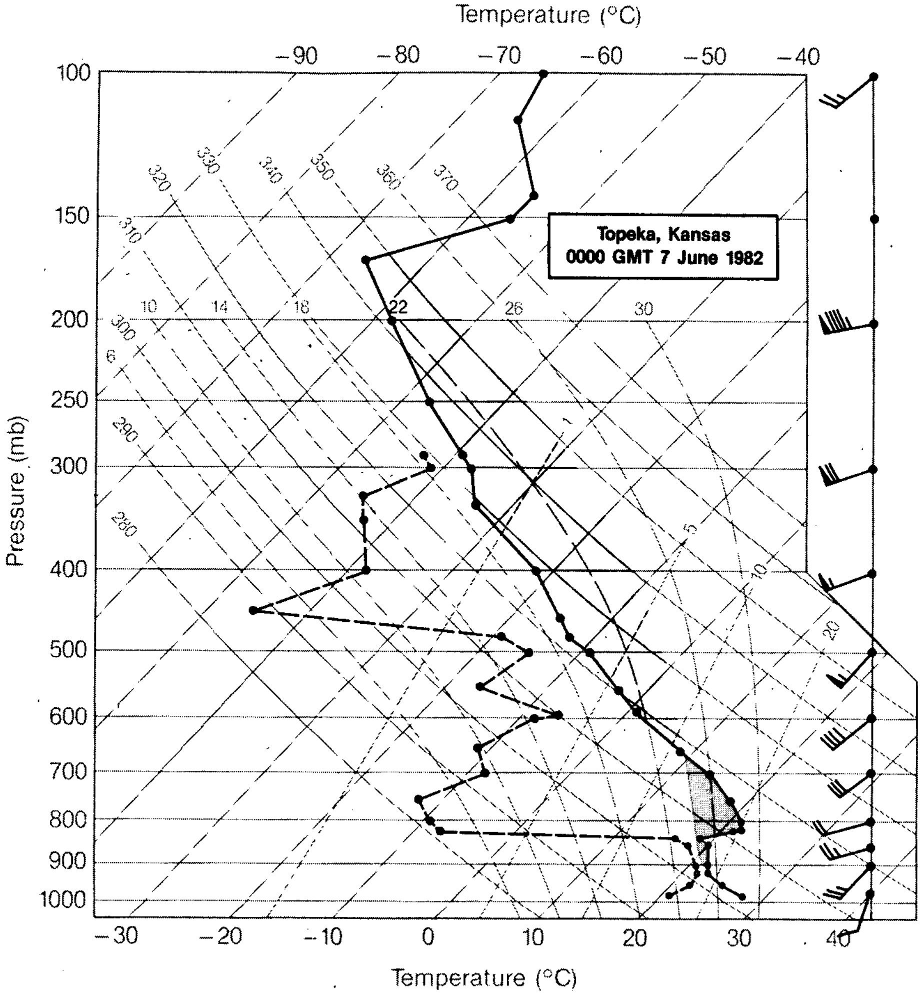

FIG. 10. Skew *T*–log *p* plot of Topeka, Kansas sounding for 0000 UTC 7 June 1982. Solid line is the temperature plot; dashed line is the dewpoint plot. Light (dark) shading indicates positively (negatively) buoyant area. Wind barbs are in kt.

potential. This evolution probably was caused by the southern Colorado 850 mb low moving northeastward, resulting in increased moisture advection, upward vertical motion, and convective destabilization. Referring to the vertical motion forcing shown in Fig. 8, the movement of the 850 mb low and its shortwave support aloft could have been responsible for replacing the large-scale subsidence at 0000 UTC with upward motion by 0300 UTC. Since the quasi-geostrophic diagnosis is not prognostic, it is unclear how these areas of vertical motion forcing changed or moved with time, but it may be that the upward motion field over southeast Colorado translated (advectively and/or dynamically) into southwest Nebraska. If temperature advection is considered alone, the result is the estimated sounding for 0300 UTC over southwest Nebraska shown in Fig. 13. Midlevel moisture was inferred from satellite imagery which showed midlevel cloudiness developing in the area. This thermodynamic profile could have supported convective development consistent with actual surface observations (i.e., a uniform mixing ratio in the subcloud layer, cumulus cloud bases at 10 000 ft AGL, TTI = 58, and strong outflow winds).

This hypothetical change in the local environment supports a concept recently proposed by Doswell et al. (1985). In this concept regional areas of unstable air in the midtroposphere are advected (and/or are dynamically produced) over low-level moist air, creating a deep, convectively unstable environment. In the case of storms forming over the western High Plains, the origin of the unstable air is usually the high terrain of the Rocky Mountains. If the large-scale setting is right, daytime heating in combination with dynamic lift can produce unstable air in the midtroposphere, which is then carried over the Plains to the east. Figure 14 is a composite of some of the key convection parameters, including an analysis of lapse rates in the 700–500 mb layer. The region of very high lapse rates (greater than 9.5°C km^{-1}) over central and southeast Colorado is from the combined effects of surface heating of elevated

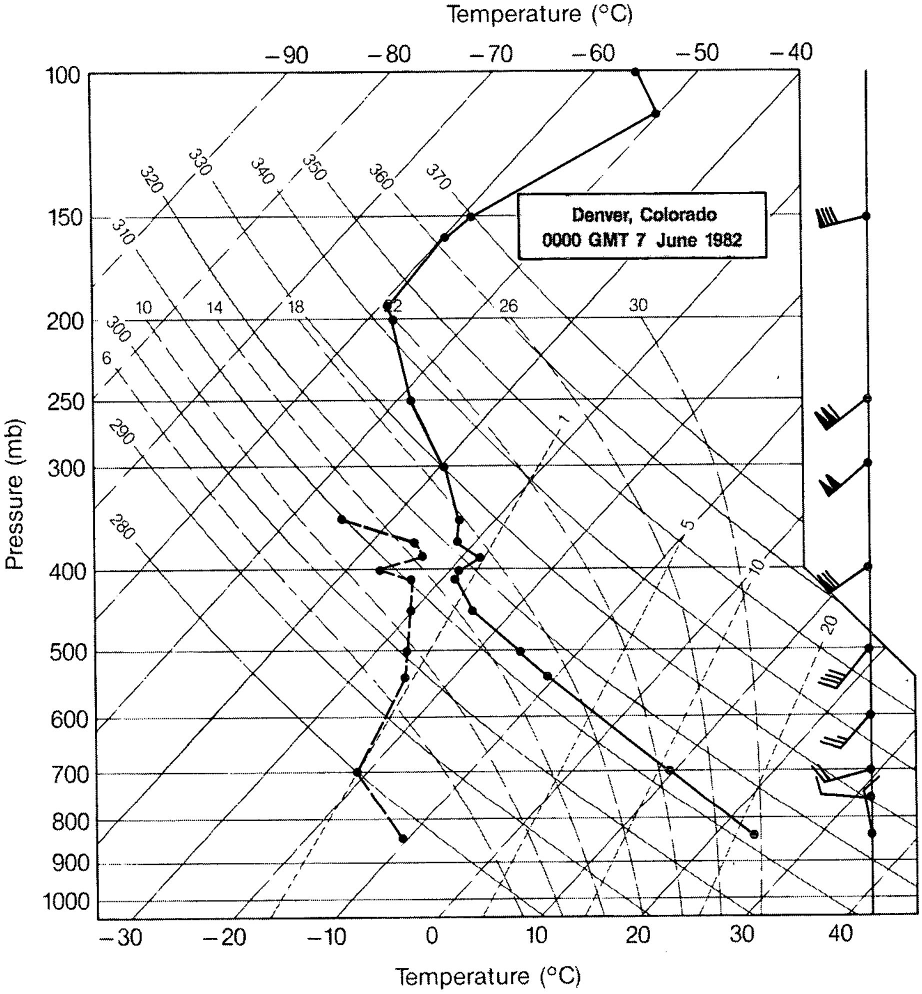

FIG. 11. As in Fig. 10 except for Denver, Colorado sounding.

terrain, differential temperature advection, and upward vertical motion. This unstable air probably flowed eastward over the returning low-level moisture in response to the movement of the shortwave trough and southern Colorado low around the time of initial storm development. Sangster (1984) has suggested that diurnal changes in the low-level wind field may have increased the advection of warm air and moisture into southwest Nebraska, and that ascent of this air led to saturation and to thunderstorm development. While diurnal changes in the winds may contribute significantly to many nocturnal thunderstorms, it appears that in this case the evolution of the unstable local environment by the large scale was somewhat more complex and was probably well underway before sunset.

b. Mesoscale convection initiation

The processes which may have provided the low-level lifting necessary to initiate convection appeared to operate on a much smaller scale than those involved in destabilization. Since satellite imagery (Fig. 1c) shows cloudiness developing at about 0300 UTC in the vicinity of the dryline in southwest Nebraska, the first mechanism proposed involves low-level convergence of the dryline and approaching surface trough. Surface moisture convergence was probably strongest at the intersection of these boundaries. This low-level convergence may have been enhanced by outflows from a larger area of convective clouds which was moving from northeast Colorado into southwest Nebraska (Fig. 1c). The enhanced convergence may have provided the lift for the initial convection.

The origin of the outflow-producing convective clouds over northeast Colorado can be traced in the satellite imagery. The image at 2330 UTC (Fig. 1b) shows that these convective clouds had formed over the foothills of the mountains southwest of Denver. National Weather Service surface observations report that they were high-based (25 000 ft, AGL), virga-producing, convective clouds. The subcloud, dry adiabatic

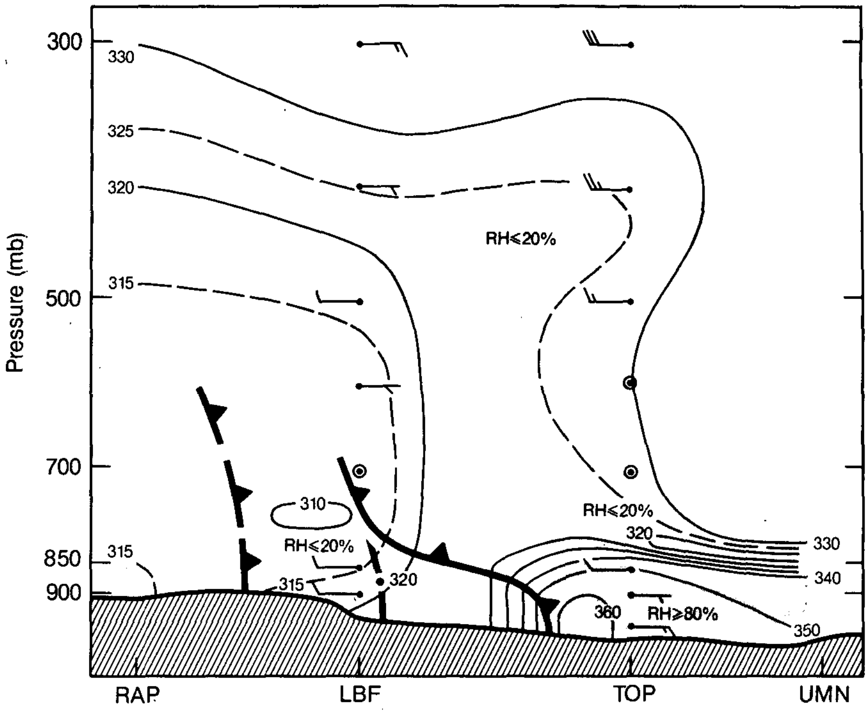

FIG. 12. Cross section of equivalent potential temperature (θ_e, K) from Rapid City, South Dakota (RAP) to Monett, Missouri (UMN) at 0000 UTC 7 June 1982. Fronts and trough are shown using conventional symbols. Dark shading indicates relative humidity ≥80%. Light shading indicates relative humidity ≤20%. Wind components (kt) parallel to the cross section are shown for North Platte, Nebraska (LBF) and Topeka, Kansas (TOP).

temperature profile shown in the 0000 UTC sounding at Denver (Fig. 11) would allow rapid downward momentum transport within the observed environment of strong vertical wind shear. Strong downdrafts and surface outflows from high-based clouds under similar conditions have been discussed by Brown et al. (1982). The reports of pressure rising rapidly (PRESRR) at 0300 UTC from stations behind the surface trough (Fig. 3b) support the strengthening of convergence along the dryline.

The surface trough over southeastern Wyoming is an intriguing feature which seems to be associated with the steeper slope of the front aloft (Fig. 12). Similar troughs which have little or no large-scale support are occasionally seen in the surface wind field after dark moving south-southeast out of the High Plains. These may be stronger or deeper troughs which have lost their low-level identity during the strong daytime mixing over the higher terrain, but once the nocturnal inversion develops they reappear and seem to accelerate. Their role in the initiation of convection, upslope cloudiness, or unexpected drops in temperature should be considered in operational forecasting.

Another possible mesoscale mechanism for initiating convection has been termed "underrunning" by Carlson et al. (1983). In this process, moist boundary layer air flowing northward ahead of a front is overrun by a southwesterly flow of hot, dry continental tropical air originating over elevated terrain to the southwest. Although convective instability is enhanced, actual development of deep convection is suppressed by this "lid" of hot, dry air until the moist low-level air flows out from beneath, or "underruns," the lid along its northern boundary where it is no longer suppressed. Case studies presented show thunderstorms forming along this lid edge where, as in this case, cold advection aloft is decreasing the stability. A cross section showing how this mechanism might relate to this case is presented in Fig. 15. Shown are the frontal zones, mixing ratio, and air masses along a north–south oriented line that includes the initial storm area in southwest Nebraska. The dryline profile (having a shallow moist layer deepening toward the moisture source) is similar to the dryline structure suggested by Siebers et al. (1975). The flow of the air masses in the plane of the cross section suggests that while there is a slight increase in the low-level southerly flow (i.e., at Dodge City, Kansas) toward the front, most of the flow aloft is southwesterly, or parallel to the front. This would make it difficult for underrunning to be a significant process in this case. It also appears (Fig. 15) that in the region of initial storms, the low-level moisture was overrun by the cool, dry, High Plains air rather than by warm air. Finally, the northern boundary of the lid is estimated to have extended from southwest Kansas to northeast Kansas (roughly along the 12°C isotherm at 700 mb; see Fig.

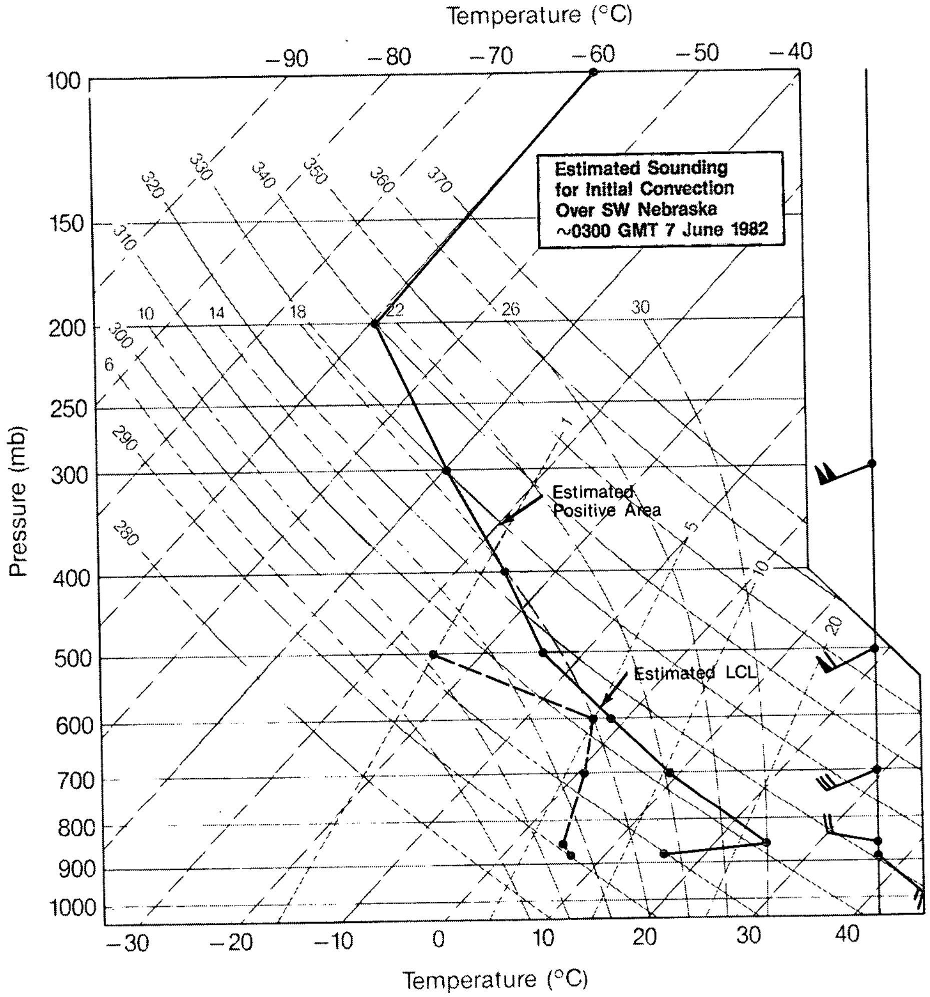

FIG. 13. Skew *T*-log *p* plot of the estimated sounding over the area of initial convection in southwest Nebraska at 0300 UTC 7 June 1982. Format as in Fig. 10.

5b), well south of the initial storm area. If convection had developed where the moist air was underrunning the lid boundary, initial storms might have been expected in central Kansas.

5. Intensification

Satellite imagery shows that the storm system was slow to intensify. It developed on the northwest side of the front where low-level moisture and instability were marginal but increasing. The θ_e cross section (Fig. 12) indicates that early development occurred in 320–330 K air, with only slight convective instability. However, very moist and unstable air was lying to the east where large-scale ascent was occurring. Rapid expansion of the cloud shield began about 0730 UTC. At 0830 UTC the satellite-viewed system met the initiation criteria of a mesoscale convective complex (MCC; Maddox, 1980) and numerous reports of a severe weather began. It appears that this explosive intensification occurred when the system's main outflow pushed southeastward through the frontal zone (Fig. 1e), lifting and releasing the moist potential energy of the prefrontal environment, exemplified by the Topeka sounding (Fig. 10). Low-level air, with θ_e values of 350–360 K and relative humidities over 90%, was feeding into the system, while entrainment of very low θ_e air above the inflow gave the downdrafts an additional intense downward acceleration. Coincident with this intensification, destructive outflow winds of nearly 90 kt were reported in parts of northeast Kansas (Fig. 2). By 1200 UTC (Fig. 1f) the MCC had reached its maximum extent (Rodgers et al., 1983) after having struck the downtown Kansas City area just before dawn.

6. Discussion

The history of this storm is summarized in three parts. First, the synoptic scale data over the area of initial storms indicated only slight convective potential and quasi-geostrophically forced subsidence. Advection of moist, unstable, ascending air, associated with the

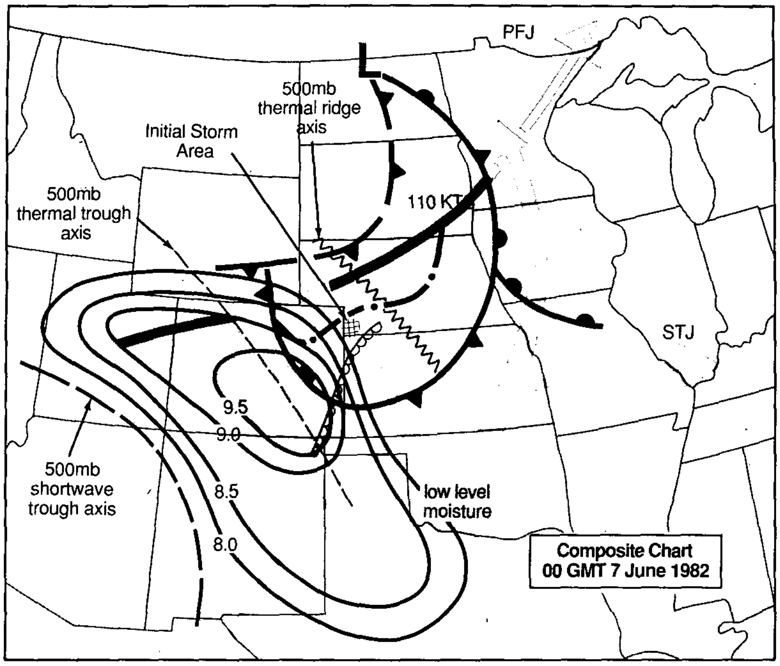

FIG. 14. Composite chart for 0000 UTC 7 June 1982. Solid contours are 700–500 mb lapse rates (°C km^{-1}) with maximum values shaded. Wide, branching arrows are 850 mb moisture axes. Narrow arrows are 300 mb jet axes (PFJ—polar front jet; STJ—subtropical jet) with shaded area of PFJ indicating a 110 kt jet maximum. Surface fronts, trough, and dryline are shown with conventional symbols. 500 mb features are shown.

movement of an upper-level shortwave trough, was significantly increasing the potential. Second, in this destabilizing environment, mesoscale convergence, enhanced by outflows from high-based convective clouds, probably initiated weak thunderstorms along the surface dryline. Finally, these weak thunderstorms gradually moved eastward into an environment increasingly conducive to intense convection. When the

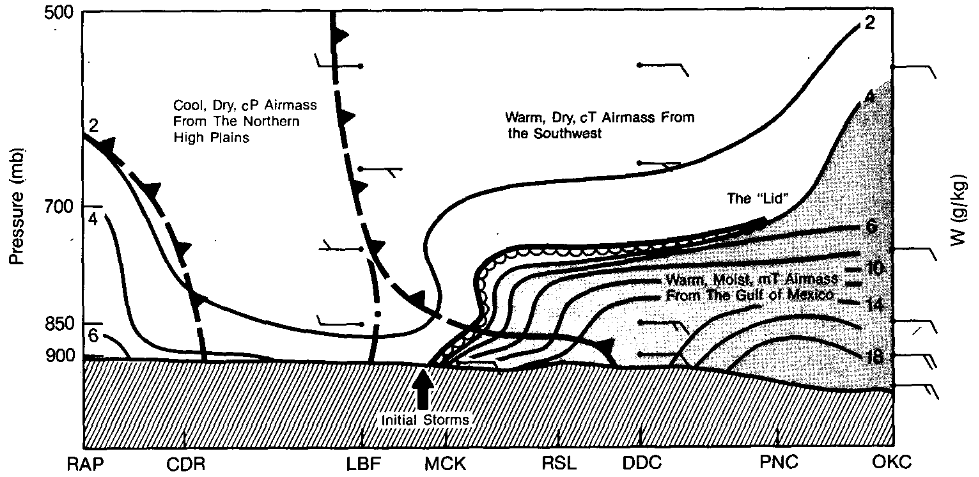

FIG. 15. Cross section from Rapid City, South Dakota (RAP) to Oklahoma City, Oklahoma (OKC) at 0000 UTC 7 June 1982 showing front, trough, and dryline positions using conventional symbols. Solid lines are mixing ratio contours (g kg^{-1}). Dark shading represents maritime tropical (mT) air, light shading represents continental tropical (cT) air, and the continental polar (cP) air is not shaded. Wind barbs (kt) represent components of flow parallel to the cross section.

organizing storm system crossed the frontal zone into the unstable, ascending air, its outflow and inflow were sufficiently strong to overcome the weakening inversion, and the system underwent a dramatic intensification.

While many details of these three stages remain unclear, the storm system seems an excellent example of how synoptic scale processes and features may change the local environment into one capable of supporting moderate convection, and how convective initiation may then result from low-level, mesoscale lifting during a time of marked diurnal changes in the boundary layer. It also suggests that the synoptic scale environment plays a greater role in the evolution or intensification of convective storms than it does in their initiation. The initiation seems to be more closely related to mesoscale processes. For example, if the synoptic scale setting is unfavorable for thunderstorms, convection still may form as a result of mesoscale processes, but it is not likely to organize or intensify into a large thunderstorm system. However, if the synoptic scale is favorable for thunderstorms, the convection seems more likely to evolve into a stronger, more organized and longer lived thunderstorm complex. In this case the initial thunderstorms formed in an environment of marginal convection potential and moved into a very favorable synoptic scale environment.

Operationally, this study may suggest an adjustment in the approach to thunderstorm forecasting. Many thunderstorms originate in areas that are downplayed based on a preliminary evaluation (often from "rules of thumb") of unfavorable synoptic scale vertical motion and limited thunderstorm potential. After such labeling, a forecaster's attention is usually irrevocably directed toward areas where the synoptic scale threat is apparently greater. While rules regarding vertical motion can be useful when applied carefully, it is now as easy to make actual calculations, eliminating the need to rely on rough estimates. With the vertical motion diagnosed, attention should shift back to how the marginally favorable areas might change, how mesoscale processes might initiate convection, and whether thunderstorms will move into more favorable synoptic scale environments. Often, as in this case, a careful mesoanalysis of the preconvective environment is required, since the surface data can provide valuable clues to the initiation process. Mesoanalysis techniques have been outlined by Fujita (1963) and more recently by Doswell (1982). They stress, and it is restated here, that sound conceptual models of mesoscale phenomena are necessary for the forecaster in evaluating and understanding surface observations, especially at night when surface observations become sparse and possibly unrepresentative of low-level conditions because of the nocturnal inversion. Case studies of this type illustrate ways in which severe convective storm complexes begin and evolve. Further, they help refine our concepts of the initiation process and provide an awareness of situations that may recur. However, the ultimate challenge to the operational meteorologist remains that of recognizing subtle clues and responding correctly to the many diverse meteorological scenarios that can lead to thunderstorms.

Acknowledgments. A. A. Rockwood's participation in this project was funded by NOAA Financial Assistance Award NA84RAD05062. We thank our colleagues in the NOAA/ERL/Weather Research Program, especially Drs. S. L. Barnes, F. Caracena, and C. A. Doswell, III, for their interest and discussions regarding this study. The reviewers are also thanked for their helpful suggestions and comments.

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