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Mesoscale Aspects of a Marginal Severe Weather Event

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1. Introduction

Late in the day of 6 May 1983 a tornadic severe storm struck Topeka, Kansas. This storm resulted in one fatality, 25 injuries, and considerable property damage. Rated an F3 tornado, its track paralleled that of the infamous 8 June 1966 storm (as noted in the Storm Data report of the 1983 tornado), but was considerably smaller and less intense. In addition to the Topeka tornado, there were 58 other severe weather reports on this day, including four other tornadoes (see Table 1 and Fig. 1).

Apart from its impact on Topeka, this storm day is perhaps more typical of severe thunderstorm days than are the truly major events which occur on a handful of dates in any given year and are characterized by very intense storms (e.g., 11 April 1965 or 3 April 1974). Unfortunately, those singular severe thunderstorm days are often the ones chosen for study. This leads to a distorted picture of not only the synoptic scale settings for severe weather, but also the significance of mesoscale features prior to (and during) severe weather of the more common variety. It is toward the end of addressing this distortion that this study has been undertaken.

Given the fact that major events occur when dynamic and thermodynamic factors mesh properly (see Miller, 1972), there are two possible combinations which can give rise to the more common, lesser severe weather episodes: weak dynamics and strong thermodynamics (see Maddox and Doswell, 1982a,b), or strong dynamics and weak thermodynamics. The 6 May 1983 event includes characteristics of a major event (in limited areas) but certainly begins with limited thermodynamic potential. Severe weather under such circumstances is probably less frequent than when thermodynamics are strong and dynamics are weak. Thunderstorm severity is generally proportional to draft strength, and the physics of convection suggest that strong drafts (both up and down) are far more likely in cases where the thermodynamic instability is great, regardless of the dynamic factors. When the instability is not present at the outset, the dynamic factors must operate to produce it.

The required meshing of dynamic and thermodynamic parameters is difficult to achieve--otherwise severe thunderstorms would be far more common than they are. Generally, this "coming together" must also be phased properly with the diurnal heating cycle, except in those rare cases where everything fits so well that the added impetus of insolation is not necessary. Situations with strong dynamics but initially weak thermodynamics often fail to produce much severe weather because the anticipated instability does not develop. The case to be presented here suggests that events of a mesoscale origin acted to increase the level of severe thunderstorm activity in a region where the large-scale forcing might have been insufficient--the instability did develop but it apparently needed something extra to be released.

2. Large-Scale Setting

Shown in Fig's 2 and 3 are the 500 and 850 mb NMC analyses at 0000 GMT on the evening prior to the event. Clearly, the stage is set for large-scale cyclogenesis over the plains during the next 24 h. A surface analysis at 0300 GMT, shown in Fig. 4, in combination with the 850 mb data, reveals the scantiness of low-level moisture. However, strong low-level flow off the Gulf of Mexico is already present and the anticipated cyclogenesis should act to enhance the influx of moisture. Note also the extreme dryness in west Texas in the low levels.

The impending cyclogenesis is captured rather well in the 1200 GMT LFM run, shown in Fig's 5-7. Especially noteworthy are the 992 mb surface low forecast in extreme eastern Nebraska by 0000 GMT, the dry intrusion into southwestern Kansas, and the narrow band of weakly unstable air forecast into southeastern Kansas.

All these factors led to an early morning (0800 GMT) outlook from the Severe Local Storms Unit (SELS) at the National Severe Storms Forecast Center calling for a "slight risk" of severe thunderstorms in the area shown in Fig. 8 for the period from 1200

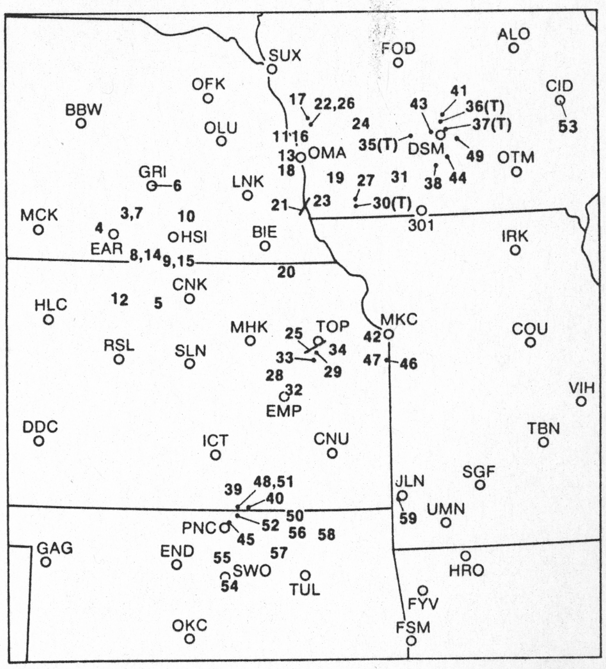

Fig. 1. Severe weather reports from 1200 GMT 06 May to 1200 GMT 07 May. Numbers are plotted at the location of the report and are in sequence. Numbers with (T) following are short-track tornadoes, numbered line segments are tornado tracks. Where more than one report exists at a single location, the report numbers are separated by a comma, and the location is given by the first of the numbers.

Table 1. Summary of severe weather by states. For FPP scales, a dash indicates missing data. Time period is in GMT.

State	Tornadoes (FPP)	Hail	Wind	Period (first-last)
Kansas	1 (332)	10	7	2002-0248
Nebraska	2 (231,01-)	6	7	2015-2350
Iowa	4 (231,1-0,101,212)	3	11	2245-0306
Oklahoma	0	8	0	0130-0427
Missouri	0	1	0	0440-0440
Totals	6	28	25	2002-0440

One tornado (FPP=231) crossed border from Nebraska to Iowa and is counted in both states, but is not counted twice in totals.

GMT, 6 May to 1200 GMT, 7 May. The main features mentioned in the SELS narrative discussion accompanying the outlook were: a developing warm frontal boundary across northern Kansas and Missouri, and the dryline expected to sharpen and push into Kansas from the southwest late in the day.

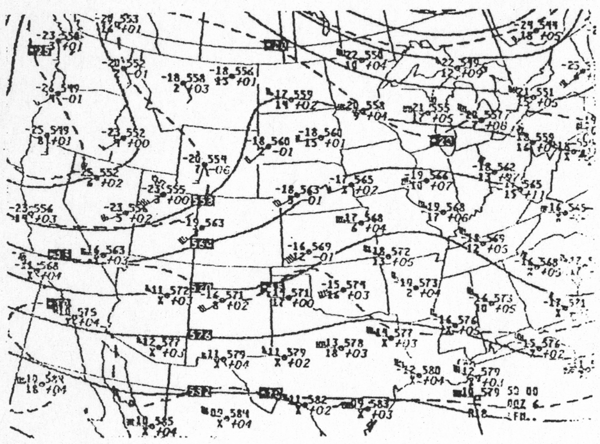

Fig. 2. NMC 500 mb analysis, 0000 GMT 06 May 1983.

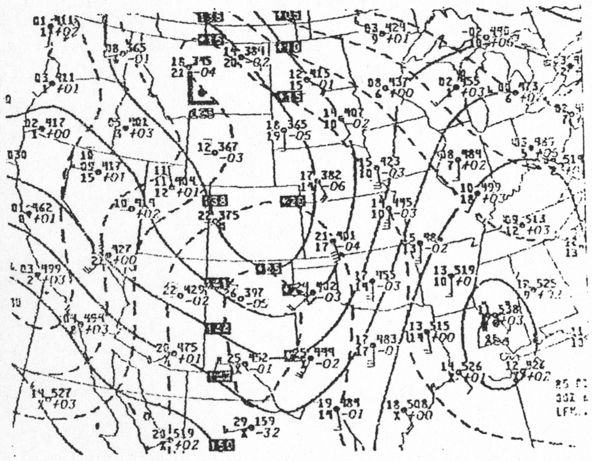

Fig. 3. NMC 850 mb analysis, 0000 GMT 06 May 1983.

3. Details of the Severe Weather Evolution

As a matter of interest, the 0300 GMT enhanced IR satellite image (shown in Fig. 9), reveals a dramatic brightness contrast in west Texas, apparently associated with the dryline. One should also note the scarcity of surface data at this observation time (recall Fig. 4)--if this brightness contrast is indeed a result of the dryline, then in principle one could detect and analyze the position of this feature in great detail, even in the absence of conventional surface data density. Naturally, this is not always possible. Besides, merely knowing a feature's position may not

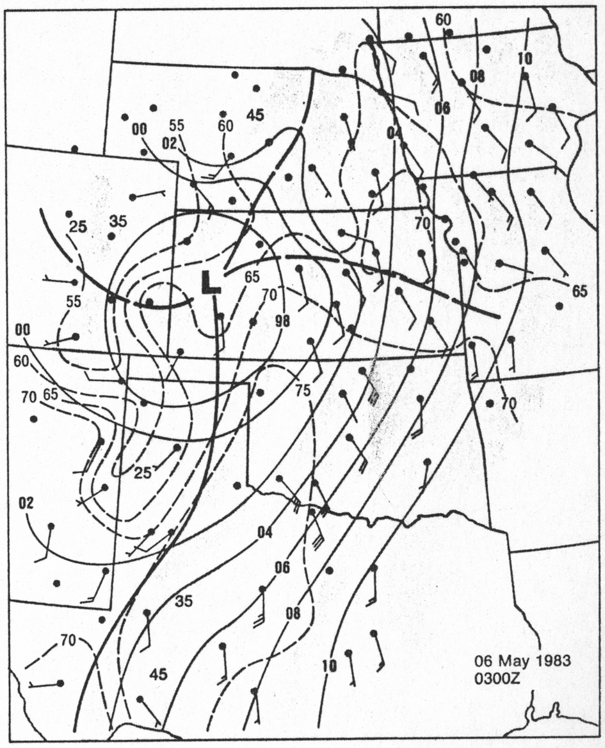

Fig. 4. Surface analysis at 0300 GMT 06 May. Isobars are solid lines (mb), isotherms are dashed lines (deg F), isodrosotherms are indicated by shaded contouring (deg F), troughs are dashed heavy lines, the dryline here is the solid heavy line, but elsewhere is denoted by a heavy scalloped line.

be sufficient information. Note also the convection in central and western Nebraska.

By 1200 GMT, the surface cyclone is beginning to deepen, the dryline has advanced into central Kansas,

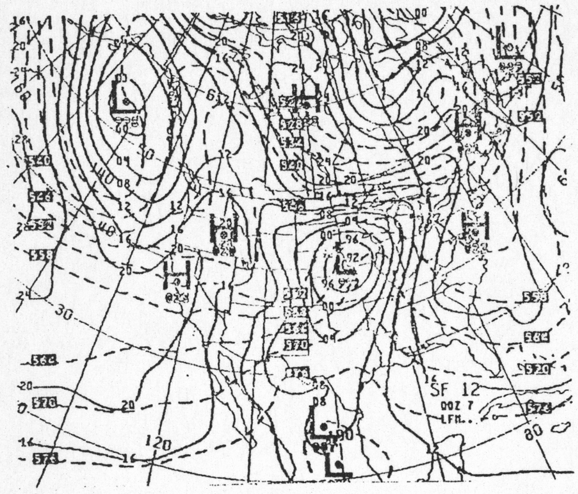

Fig. 5. LFM 12 h MSL pressure/1000-500 mb thickness prog valid 0000 GMT 07 May.

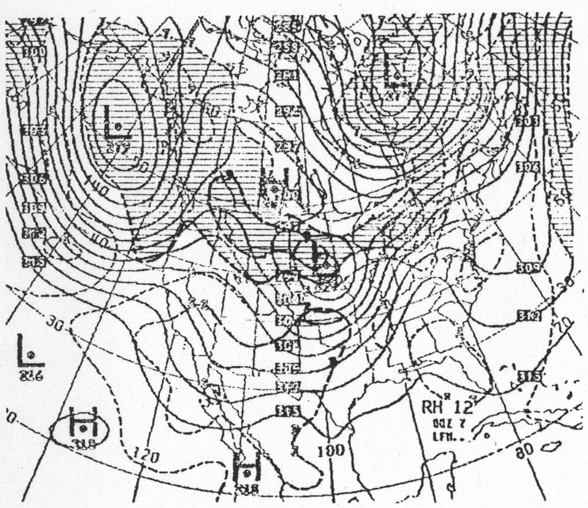

Fig. 6. LFM 12 h 700 mb height/mean sfc-500 mb relative humidity prog valid 0000 GMT 07 May.

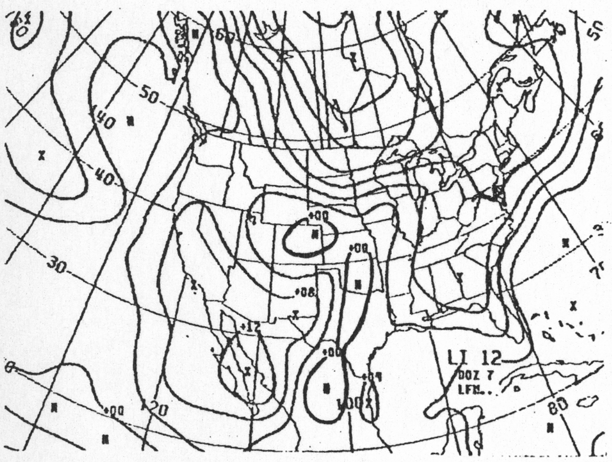

Fig. 7. LFM 12 h Lifted Index prog valid 0000 GMT 07 May.

and the southerly flow in the warm sector has strengthened (Fig. 10). The morning sounding at Topeka (Fig. 11) is characterized by a strong capping inversion (top at about 785 mb), and minimal moisture (~6.5 g per kg in the lowest 100 mb), but is otherwise almost classical in its temperature and wind profile with regard to severe weather potential. At Omaha (Fig. 12) there is a deep, weakly stable layer below 700 mb, a weak inversion just above 500 mb, and low-level moisture comparable to that at Topeka. The Oklahoma City sounding (not shown) is similar to Topeka, but has stronger low-level winds, a bit more low-level moisture (~7.5 g per kg in the lowest 100 mb), and a weak inversion just below 500 mb. The θ-value associated with the top of the low-level

Fig. 8. SELS convective outlook issued at 0800 GMT 06 May valid 1200 GMT 06 May to 1200 GMT 07 May.

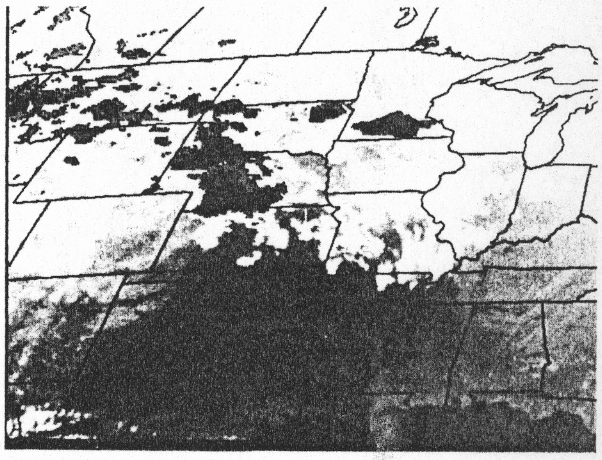

Fig. 9. Enhanced IR satellite image at 0300 GMT using NSSFC CSIS computer. Note the brightness contrast line across west Texas (see Fig. 4), and the dark, linear features in the Texas panhandle, corresponding to the Canadian River valley, and the Palo Duro Canyon.

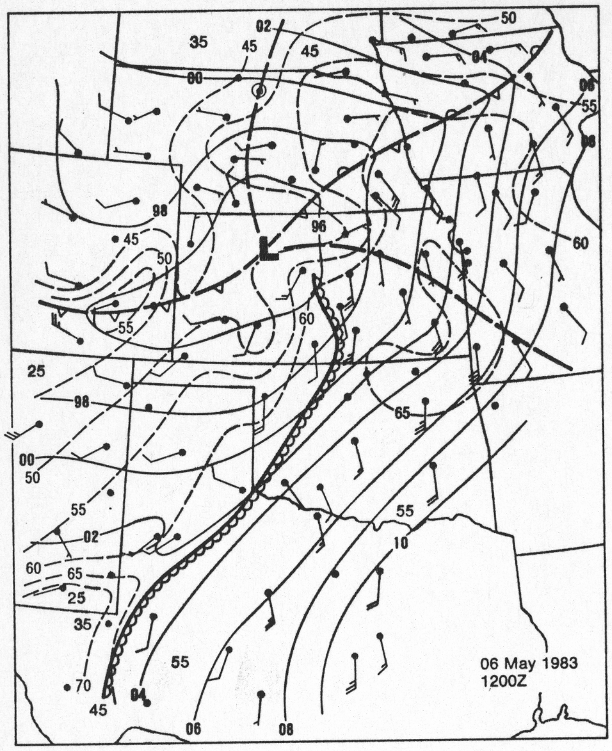

Fig. 10. As in Fig. 4, except at 1200 GMT 06 May. Frontal symbols are conventional.

inversion is about 4°K higher than that at Topeka. The morning Total Totals Index (TTI) is 52 at Topeka, 50 at Omaha, and 48 at Oklahoma City (despite the slightly higher moisture).

By 2100 GMT, the surface picture has changed dramatically (Fig. 13). The low has deepened to about 991 mb, the dryline has sharpened considerably but not advanced very far eastward from its 1200 GMT position, and a strong cold front has pushed out of northwestern Kansas/southwestern Nebraska. Despite many hours of strong southerly flow, surface dewpoints have only crept into the high 50's (°F) in extreme eastern Kansas. Satellite imagery 30 min later (Fig. 14) shows new convection developing over central Nebraska and some towering cumulus in north central Kansas. Note the dust streaks from the Oklahoma panhandle toward the northeast and also northeastward across west Texas into extreme southwestern Oklahoma, each of which corresponds nicely with a dryline bulge.

Fortuitously, the author was on a commercial aircraft which passed through the area of towering cumulus in north central Kansas at about 2230 GMT, and obtained photographs of the developing convection (Fig. 15). Note the clear skies on both sides of the convective line. Somewhat further to the west, to the rear of the developing convection, considerable dust was encountered, extending to near or just below flight level (~30 000 ft).

By 0000 GMT, this convective line had developed rather explosively and was already producing severe weather (Fig. 16). Note the lack of development in southwestern Oklahoma. The surface analysis (Fig. 17) shows that the front extending from the low center in eastern Nebraska (compare this with Fig. 5!) had swept through most of Kansas, with the convection at its leading edge. The Topeka sounding (Fig. 11) at 0000 GMT, with an actual release time somewhat before the nominal sounding time, clearly entered a mesoscale environment just ahead of the approaching severe storm. Note the odd temperature structure, the dramatic wind profile, and the abrupt termination at 604 mb. Using an estimated 500 mb temperature of -17°C gives the sounding a TTI of 62! Below 500 mb, the Omaha sounding has changed significantly--it is now nearly dry adiabatic below 600 mb, the TTI has ballooned to 61, and mid-level winds have increased substantially. The Oklahoma City sounding at 0000 GMT (not shown) reveals that the capping inversion was never broken, despite the intruding dryline bulge into southwestern Oklahoma. The evening TTI from that sounding was only 49 and the mean mixing ratio in the lowest 100 mb never exceeded about 10 g per kg.

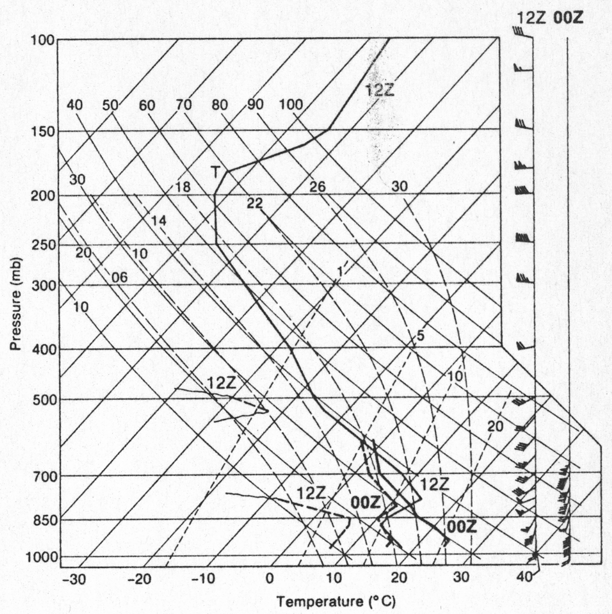

Fig. 11. Topeka, Kansas soundings plotted on a skew-T, log p diagram. Plotting is conventional. Thin lines are at 1200 GMT on 06 May, thick lines are at 0000 GMT on 07 May.

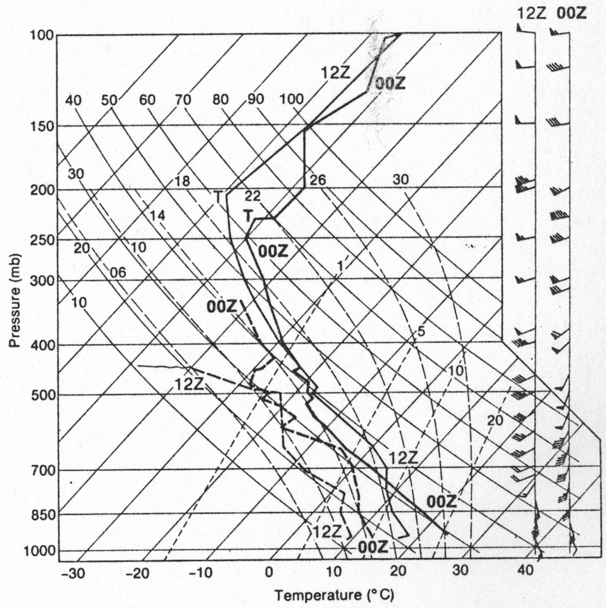

Fig. 12. As in Fig. 11, except at Omaha, Nebraska.

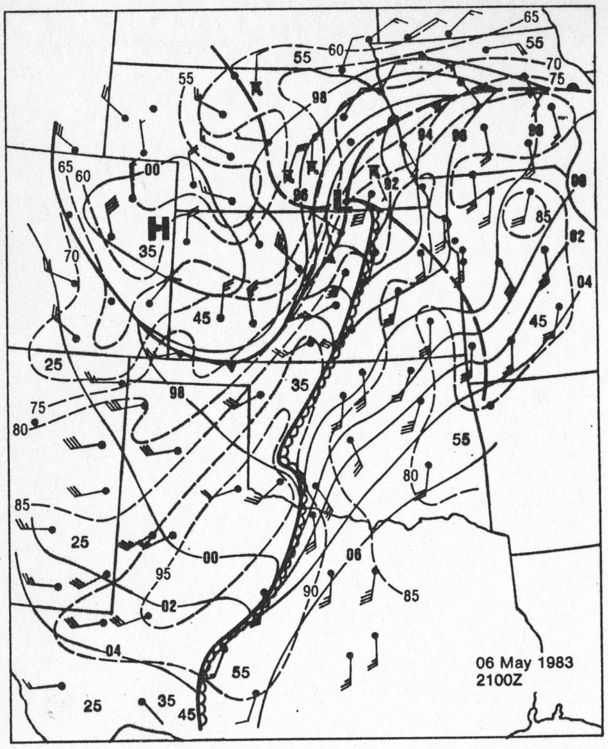

Fig. 13. As in Fig. 4, except at 2100 GMT on 06 May.

4. The Mesocale System

Plotting 2-hourly pressure changes based on altimeter settings reveals an important clue to the event's evolution. The dramatic pressure rises in central Kansas (Fig. 18) had their origins in extreme southwestern Nebraska at about 1600 GMT and seem to have been associated quite clearly with the strong front which swept through Kansas.

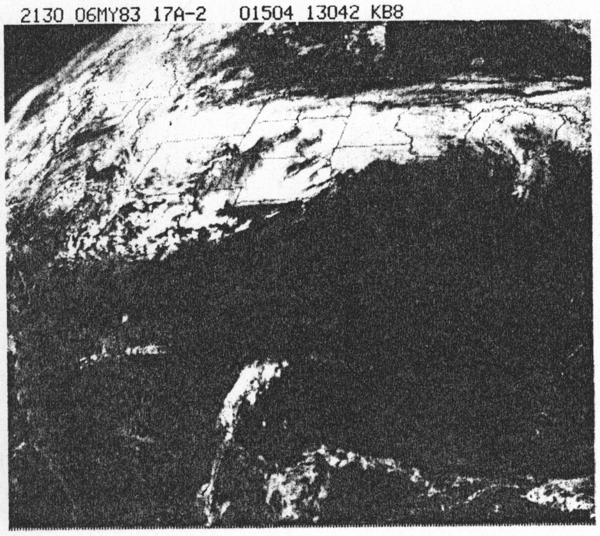

Fig. 14. Visible satellite image at indicated date/time (GMT). Note dust streaks in southwestern Kansas and southwestern Texas, as well as developing cumulus in northeastern Kansas.

The isolated reports of severe weather in central Kansas behind the dryline were associated with short-lived thunderstorms, indicating the intensity of the mesoscale lift ahead of the mesohigh. Since the air was so dry, the convection could not persist, producing only isolated severe reports. When the unstable thermodynamics east of the dryline were influenced by this feature, sustained severe weather was the result.

What is the origin of this mesoscale high pressure system/front? Referring to the surface temperature analyses at 1200 and 2100 GMT, the front does not appear to be associated with an influx of cold air--rather, the gradient develops as air heats up in the clear skies of western Kansas. In many ways this situation bears a striking resemblance to that described by Bluestein (1982), except that the cool air source clearly is not related to snow cover. Instead, one can hypothesize that the cloudy/clear air boundary set up by the previous evening's convection created a situation wherein differential heating could produce an intense thermal gradient. As this situation was contemporaneous with the cyclone development, the cloudy area could act as a source of cool air as the boundary was pushed away from the region where it was formed. Because the air ahead of the front was also behind the dryline, little or no cloudiness and

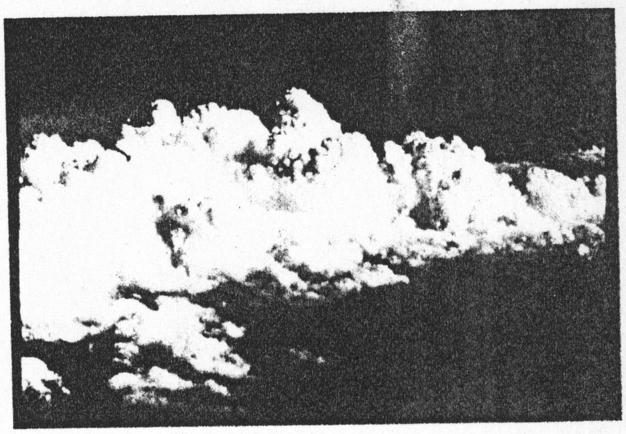

Fig. 15. Photograph taken by author from commercial aircraft at about 2230 GMT, flying at about 30 000 ft, looking ESE.

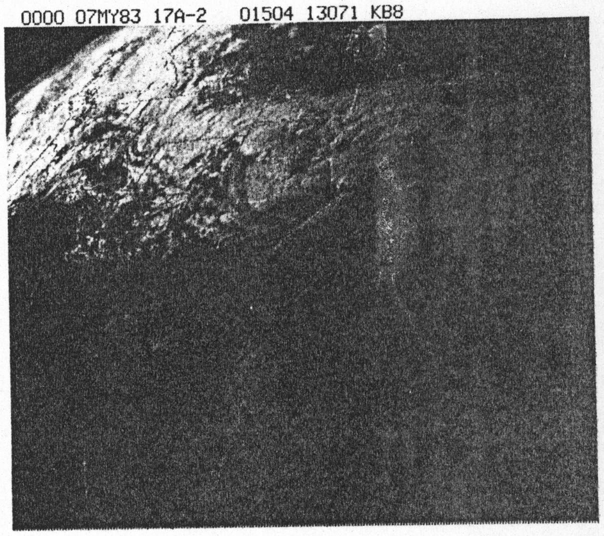

Fig. 16. As in Fig. 14. Note line of severe convection in eastern Kansas, and prominent dust streak into southwestern Oklahoma.

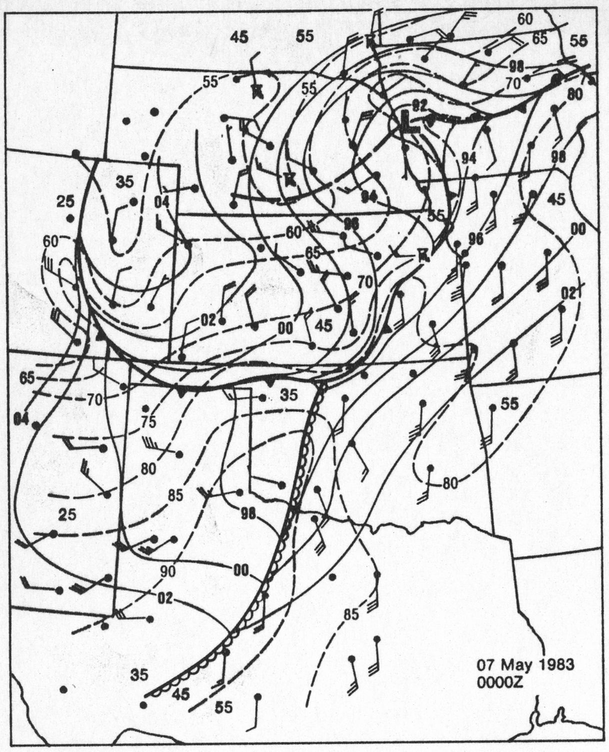

Fig. 17. As in Fig. 4, except at 0000 GMT on 07 May.

almost no convection formed in Kansas until the boundary reached the relatively moist air east of the dryline. The front then acted to reinforce the localized upward motion along the dryline, which up to that time seemed incapable of initiating deep convection, owing to the strong capping inversion.

Once the storms formed, new convection developed southward along the boundary as the front engulfed the dryline, into northern Oklahoma. Presumably, the capping inversion was too strong to overcome farther south in Oklahoma, as mentioned previously. One might also assume that the intensity of the mesoscale frontal forcing was weakening as it moved farther from its source.

5. Discussion

As with any truly mesoscale event, the evidence obtainable with the conventional surface and upper-air data networks does not permit conclusive statements about what actually occurred. However, the scenario presented here for the Kansas/northern Oklahoma activity does not seem to conflict with any of the observations. In this case, a mesoscale high pressure system, apparently not driven by convection directly, seems to play a major role in this event, especially in the sense of allowing the release of instability in a region where it otherwise might not have been tapped. The lack of a strongly intruding dryline suggests that in the absence of this mesoscale high/front, the dryline forcing would not have been enough to overcome the capping inversion. Note that for this event, the concept of "underrunning", as described by Carlson et al., 1983, does not seem to be relevant--instead of the low-level instability being released by moving out from under a stable layer, it certainly appears that the inversion was removed by the effect of localized vertical motion. Further, the changes in the soundings from 1200 to 0000 GMT (described above) suggest that the most unstable stratification developed locally, in the Topeka-Omaha vicinity, rather than being swept out from under a restraining inversion.

For this case, the SELS outlook verified quite well. The strong dynamics, combined with the narrow zone of strong instability (despite unimpressive surface dewpoints) created by processes associated with the cyclogenesis, produced a more or less classical severe weather situation in a rather localized area (eastern Nebraska and Iowa). The Kansas/Oklahoma activity had a more subtle character, since the anticipated developments along the dryline appear to have waited for additional mesoscale forcing.

This example is a good illustration of the problems facing the field forecaster, as well as SELS personnel, in the more typical severe weather cases. The guidance available from NWP models and centralized facilities like NSSFC is necessarily driven by large-scale features in the atmosphere. However, the actual weather is heavily dependent at times on mesoscale events which the guidance cannot treat. In fact, the subtle nature of the events shown here suggests that even hourly surface analysis may not reveal the true nature of the events unless it is

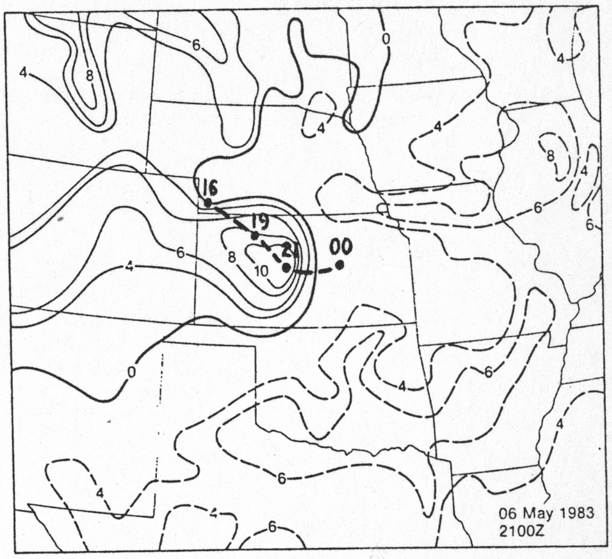

Fig. 18. Analysis of 2-h altimeter setting changes at 2100 GMT 06 May (for the period 1900-2100 GMT), where solid lines are rises (in hundreths of an inch of mercury), and dashed lines are falls. Heavy dashed line shows track of rise center, with selected locations at indicated GMT times shown by large dots.

carefully done, with full knowledge of the range of possibilities inherent on the mesoscale.

What makes this situation more complex is that the LFM guidance was remarkably good in this case, provided that one realizes that the models do not predict mesoscale features. The large-scale cyclogenesis, the position and strength of the surface low and dryline, and similar aspects of the guidance were forecast by the LFM quite well. However, the mesoscale detail must come from some other source. With respect to events in Kansas and Oklahoma, the crucial factor was the capping inversion, so an important issue was whether or not the lift (from any source) would be sufficient to release the instability. Merely giving a value of vertical motion might not have been very useful, either--one needs to know the combined effect of the time history of vertical and horizontal motion on the thermodynamic structure. In effect, a mesoscale model is called for, but in the absence of such in the operational environment, conceptual models in the hands of experienced meteorologists are about as much as we can hope for in the near future.

So who could have anticipated the mesohigh/front in this case? The limited data available are insufficient even to be certain that the concept presented here is correct. This case shows the difficulty of understanding mesoscale processes well enough to recognize them in time to predict them. While it is possible to anticipate the individual elements of this chain of events (the cloudy/clear air boundary, the resulting thermal contrast, the cyclogenesis, etc.), the details of how the elements interact represent a real challenge to the forecaster's art. One can certainly appreciate the variety of means by which mesoscale systems can arise from consideration of this example, but it is also important to recognize the impact such systems have on the sensible weather.

While it cannot be denied that the impressive, widespread outbreaks of severe weather account for the majority of fatalities and, perhaps, property damage, this does not mean that we can ignore lesser events. For one thing, forecasters have to do their job every day, 365 days a year, and they need techniques to help them deal with the forecast on the 360+ days not involving a threat of a major outbreak. For another, the impact of severe weather is no less intense for those involved when it is localized rather than widespread. The need for enhancement of our understanding of mesoscale events (keeping in mind the goal of using that understanding to improve practical forecasting) cannot be overemphasized.

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