THE DERECHO OF 19-20 JULY 1983 . . . A CASE STUDY

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ABSTRACT

The widespread severe thunderstorm outbreak of 19-20 July 1983 is presented as an example of the derecho phenomenon. The physical characteristics of this derecho convective system are described. The snyoptic patterns and meteorological parameters associated with the system are examined in detail. Suggestions are made as to what antecedent conditions a forecaster might look for to anticipate derecho development. Furthermore, mesoscale features associated with the convective system's evolution are examined for signs that would point to intensification or weakening of the system.

1. INTRODUCTION

During the summer months operational meteorologists in the Midwest are sometimes confronted with a mesoscale convective system (3) which produces widespread downburst activity (4). This phenomenon, known as a derecho (5, 6, 7) frequently occurs when the areal extent and intensity of the thunderstorm threat is not obvious from the prevailing synoptic conditions.

The derecho of 9-20 July 1983 is a prime example of such an event (Fig. 1). This storm system traveled from northwestern North Dakota east southeastward to northern Indiana, producing widespread downburst activity along a 50 to 180 mile wide swath (8). At least thirty-four persons were injured and property damage was in the millions of dollars. Three weak F1-scale tornadoes (9) occurred with this storm system, but they accounted for none of the injuries and very little of the property damage. Most of the injuries resulted from downburst winds toppling trees (8 injuries) and overturning mobile homes (14 injuries). The falling trees and branches downed power lines, causing hundreds of thousands of homes and businesses to lose electrical service. For both the Northern States Power Co. of Minnesota and the Wisconsin Power and Light Co., this derecho produced the most extensive power failure in company history due to thunderstorm winds. The following sections examine this case in detail.

2. PHISICAL CHARACTERISTICS

Radar data reveal that for most of its existence the 19-20 July derecho took the form of a short bulging squall line (Fig. 2). The squall line developed an extension eastward (or southeastward) from its northern end about 2000 (all times GMT) 19 July, and this feature persisted as the system crossed Wisconsin. This giant Line Echol Wave Pattern (LEWP) configuration (10) has been noted by Johns and Hirt (7) with other derecho events. Note the smaller scale LEWP's along the squall line as indicated by radar overlays. The "bulges" associated with these smaller scale features probably represent individual bow echoes (11; 4).

An outstanding feature of this storm system was its unusually rapid speed of motion in a direction slightly to the right of the mean wind vector (12). The derecho of 19 July covered the 830 nm distance between Williston, North Dakota and South Bend, Indiana in 18 hours, giving an average speed of 46 kt. During the derecho's most intense stage, between Alexandria, Minnesota and Chicago, Illinois, it moved at a rate of 52 kt. This was 5 to 10 kt faster than the mean wind speed! The rapid movement of this system will be discussed further in Sections 4 and 5.

Satellite imagery shows a gradual evolution of the storm system from a small multi-cellular configuration at 1230 (Fig. 3a) to a large convective cluster by 1845 (Fig. 3b). A rapid cooling of the cloud tops and expansion of the cloud shield is indicated during the afternoon as the system crosses Minnesota into western Wisconsin. These satellite imagery characteristics are often accompanied by the occurrence of severe weather (13). In this case, the imagery characteristics correlate with the widening of the gust front (Fig. 2) and the development of nearly continuous downburst activity (Fig. 1). By 2045 (Fig. 3c) a line of very cold cloud tops has developed near the leading edge of the cluster. This configuration continues until about 0245, 20 July (Figs. 3d-3) after which the entire system decays rapidly (Fig 3f). The "leading edge" line of cold cloud tops is a common characteristic of derecho systems (14) and appears to be related to the line of intense convection near the gust front (15).

3. ANTECEDENT CONDITIONS

At 1200 19 July 1983, the derecho is in its' initial stage over northwestern North Dakota and appears as a short squall line (Fig. 2); surface reports indicate that wind damage has occurred. Some questions which forecasters must answer at this time include: 1) will the convective system continue to propagate eastward, and 2) if it does so, will it pose a significant severe weather threat downstream? The numerical prognoses from the National Meteorological Center (not shown) indicate little change in the synoptic scale patterns during the period from 1200 19 July to 0000 20 July. Therefore, the 1200 surface and upper air data have been examined for conditions that might suggest the beginning of a long-lived derecho event.

3a. FORECASTING THE EVOLUTION OF THE CONVECTIVE SYSTEM

The 250 mb chart (16) for 1200 (Fig. 4) displays a relatively strong anticyclonically curved jet stream adjacent to the storm track. A wind speed maximum of greater than 100 kt appears to be located west of International Falls, Minnesota. This pattern suggests that upper tropospheric divergenced is contributing an upward conponent to the vertical motion field in the area where convection is occurring over the northwestern North Dakota (17, 18). Furthermore, the location of the wind maximum at 0000 19 July and the area of height falls to the southeast of the maximum at 1200 (Fig. 4) suggest that the maximum and its attendant vertical motion fields should continue to propagate in the general direction of the upper flow (19).

The antecendent 500 mb pattern (Fig. 5) is similar to that at 250 mb showing an absence of strong short-wave troughs near the area of interest, but indicating relatively strong flow for the time of year. Thus, the pattern resembles the "basic" 500 mb pattern associated with northwest flow (NWF) severe weather outbreaks (20). The accompanying surface chart for 1200 19 July (Fig. 6) indicates a NWF Q1 pattern with the primary quasistationary front extending from a low center in the northern High Plains east southeastward into northern Indiana. Porter et al., (21) and Johns (20) have suggested that with this type of synoptic pattern, the resultant lift from low-level warm advection plays a major role in sustaining convective systems that develop along or north of the quasistationary boundary. Examination of the 850 mb chart for 1200 19 July (Fig. 7) reveals that warm advection is prevalent over the northern Great Plains with pronounced warm advection occurring just south of the area where the derecho is commencing. The data indicate an 850 mb warm advection rate of greater than $1^{\circ}C\ h^{-1}$ over western South Dakota. At 700 mb (Fig. 8) warm advection is also occurring over the northern Great Plains at 1200. Note that warm advection immediately ahead of the convective system (over eastern North Dakota) appears to be more pronounced at 700 mb than at 850 mb. This pattern appears to reflect the sloping frontal surface. The fact that the convection at 1200 is occurring quite far north of the surface boundary suggests that considerable lifting is required for a parcel to break the "cap", i.e. reach the level of free convection (22). The 1200 19 July sounding from Bismarck, North Dakota, which is nearly in the path of the system, reveals that a parcel must be lifted to about 700 mb in order to break the cap (Fig. 9). However, beyond this level the saturated parcel becomes extremely buoyant. Note that the lapse rate of the air mass is nearly dry adiabatic between 700 and 400 mb.

Porter et al., (21) found that their Type II squall line, which occurs in this type synoptic situation, tends to move in a direction paralleling the 850 mb and 700 mb isotherms, and that the squall line continues to persist as long as the low level warm advection pattern continues and the air mass remains sufficiently unstable. Note that low level warm advection is occurring from just ahead of the North Dakota convection east southeastward to Wisconsin (Figs. 7 and 8). Assuming the axis of maximum low level flow shifts eastward in response to the propagation of the upper wind maximum (23), the area of significant low level warm advection should also shift east southeastward along the zone of stronger thermal gradient. Note that throughout this area the air mass is conditionally unstable (Fig. 10). Thus, based on 1200 data, the Porter et al., "rule" suggests that the convective system will continue to propagate as far as southern Wisconsin.

The projected path of the convective system would take it through central Minnesota. Note the relatively high level of free convection at St. Cloud, Minnesota at 1200 19 July (Fig. 10). Examination of the St. Cloud sounding (Fig. 11) reveals a vertical temperature profile similar to that at Bismarck, but with a slightly weaker cap. The higher level of free convection at St. Cloud is due to a scarcity of moisture in the lower 100 mb. However, note the very high values of low level moisture immediately to the south of the St. Cloud area (Figs. 6 and 7). The low level wind field suggests that the moisture is likely to advect into central Minnesota ahead of the convective system.

The forecast track of the convective system has a component towards the quasistationary boundary and crosses into the warm sector east of the Mississippi River. This characteristic appears to be related to the capping pattern. Recall that the 1200 19 July sounding at St. Cloud reveals a weaker cap than is present at Bismarck. Furthermore, the very low levels of free convection found at stations east of the Mississippi River (Fig. 10) suggest that the cap continues to weaken as one travels eastward from St. Cloud. Therefore, assuming there is little change in this pattern, the eastward-moving convection system should develop southward towards the quasistationary boundary as less and less lifting is required in order to break the cap. Note also, since the level of free convection is quite low east of the Mississippi River, independent deep convection may develop in that area if diurnal heating is realized.

3b. FORECASTING THE SEVERE THUNDERSTORM POTENTIAL

Additional questions to be answered include: 1) will the convective system continue to produce severe thunderstorms, and if so, 2) will a derecho develop? The development of severe thunderstorm activity from a self-perpetuating convective system is dependent on several factors. These factors fall into three general categories: 1) the vertical distribution of temperature and moisture, 2) vertical motion, and 3) the vertical wind profile (24, 25); and others.

Generally, the greater the conditional instability of an air mass the greater the potential for severe thunderstorm development (25). Furthermore, conditional instability is strongly influenced by the amount of moisture in the lower 100 mb of the atmosphere. Note that the 1200 19 July surface analysis reveals a band of higher dew points near the primary quasistationary boundary (Fig. 6). This concentration of moisture extends upward through 850 mb (Fig. 7) and contributes to the formation of an extremely unstable air mass (25, 26) in the vicinity of the frontal boundary (Fig. 10). Recall that the sounding lapse rate at Bismarck is almost dry adiabatic above 700 mb and the vertical thermal profile at St. Cloud is similar to that at Bismarck. Therefore, significant upward vertical motion in the layer from the surface to 700 mb should result in the intense convective updrafts necessary for sustaining the thunderstorm system's severe characteristics. The low level warm advection pattern described in Section 3a appears to be an adequate lifting mechanism for realizing the severe potential on 19-20 July 1983 (27).

Miller (25) has observed that severe thunderstorm development does not occur with a Q1 (Type C) surface synoptic pattern when the air mass is near saturation in the lower midtroposphere (the layer from approximately 8000 to 18000 ft above msl). Typically, relatively dry air in that portion of the troposphere contributes to potentially cold air via evaporative cooling. The cooled air provides the negative buoyancy necessary to drive the intense downdrafts associated with most severe weather-producing convective systems (28). Note that at 1200 19 July the concentration of low level moisture near the quasistationary boundary does not generally extend upward through the lower midtroposphere (Figs. 5, 8, 9, and 11). Temperature/dew point depressions of 8°C or greater at 700 mb and 12°C or greater at 500 mb are common throughout the Upper Midwest, suggesting the presence of relatively dry air in the lower midtroposhere. Thus, the vertical moisture profile along the convective system's projected path appears to be favorable for severe thunderstorm development.

The synoptic scale vertical wind shear is an important factor in the circulation of self-pertetuating severe weather-producing convective systems (24, 29). A certain minimum amount of vertical shear appears necessary in order to sustain the relative low level inflow into such systems (30). This minimum value appears to be dependent on characteristics of the hodograph as well as the degree of instability (31). Operational experience suggests that when a severe weather-producing convective system develops in situations involving a high degree of instability, the magnitude of the 850-500 mb shear vector (20) is usually greater than 20 kt. On 19 July the vertical wind shear between the lower level flow (Figs. 6 and 7) and the 500 mb flow (Fig. 5) appears to be sufficiently strong to support organized severe thunderstorm development along the track from North Dakota into Wisconsin. The magnitude of the 850-500 mb shear vector appears to be greater than 30 kt as far east as Green Bay, WI. Over North Dakota and Minnesota the magnitude of the shear vector is aided by a strong directional difference between the upper wind field and the low level easterly flow on the north side of the quasistationary boundary.

In summary, the severe weather parameter values present at 1200 19 July 1983 suggest that the potential for severe weather will continue as the convective system moves east southeastward along the low level boundary. Significant low level warm advection, combined with strong conditional instability, relatively dry air in the lower midtroposphere, and moderately strong vertical wind shear are the keys to anticipating severe thunderstorm development.

3c. FORECASTING DERECHO DEVELOPMENT

The synoptic scale patterns and parameter values present at 1200 19 July 1983 suggest to the forecaster that the convective system over northwestern North Dakota will continue to move east southeastward towards Wisconsin and will continue to pose a severe weather threat. However, the additional question relating to derecho development is more difficult to answer since knowledge about the phenomenon and its environment is limited. Johns and Hirt (7) examined several derecho cases and found some common parameters and patterns. Their work suggests that derecho development is often associated with a synoptic pattern similar to that present on 19 July 1983. Furthermore, derechos appear to be associated with very high instability values, probably higher than those values associated with general NWF outbreaks (20). Note the extreme instability values present along the quasistationary low level boundary on the morning of 19 July (Fig. 10). It appears, then, that low level warm advection along a quasistationary boundary and a very unstable air mass are key elements in the maintenance of a derecho system. The question of derecho development will be discussed further in Section 5.

4. MESOSCALE ANALYSIS AND STORM EVOLUTION

Figures 6 and 12-21 illustrate the mesoscale surface features and surface two-hour isallobaric patterns associated with the 19-20 July 1983 derecho's life cycle. Near initiation time (Fig. 6) the convective system is about 150-200 nm to the north of a quasistationary surface frontal boundary and is moving east southeastward nearly parallel to the boundary. A mesohigh has developed over northwestern North Dakota and a diffuse area of weak pressure falls exists southeast of the mesohigh (Fig. 17). Although the antecedent synoptic conditions (Section 3) favor both the continuation of the convective system and the potential for severe thunderstorm development, the system weakens on its trek across North Dakota and the frequency of severe weather reports declines. This weakening is consistent with the climatologivcal minimum in severe weather event occurrences during the late morning hours in the northern Plains region (32, 33) and is probably related to diurnal variations in both instability and the strength of the low level southerly flow (34, 35). Changes in the latter, of course, would affect the strength of the warm advection field.

By 1800 the system is entering Minnesota and has taken on a linear form again (Fig. 12). Several factors suggest that the derecho is likely to intensify during the early afternoon hours. The air mass is probably destabilizing due to diurnal heating. In addition, the surfcace dew points in the convergence zone have increased to extremely high values, resulting in further destabilization of the air mass near the boundary (36). At 1800 the derecho is moving into this area of locally enhanced instability. Furthermore, the surface wind field suggests that the axis of strongest southerly flow has shifted eastward maximizing low level convergence ahead of the convective system over the southern half of Minnesota. Finally, the 1800 two-hour isallobaric pattern indicates that the rise-fall couplet (37, 38) associated with the storm system is increasing in magnitude and becoming better defined (Fig. 18).

As the convective system moves southeastward through Minnesota it intensifies rapidly, and an expanding swath of nearly continuous downburst activity results.

The squall line bulges southeastward, lengthens, and increases its rate of movement (50-60 kt) (Fig. 2). The satellite imagery shows expansion on the cloud shield and a rapid cooling of the cloud tops with the coldest tops developing along the leading edge of the line (Fig. 3c). By 2100 the pressure in the mesohigh has risen to 1020 mb and a mesolow appears to be developing near the intersection of the squall line and the primary quasistationary front (Fig. 13). The two-hour isallobaric couplet has intensified further (Fig. 19) and strong low level convergence continues along the quasistationary boundary ahead of the derecho (Fig. 13). Since the extremely unstable air mass extends along the quasistationary boundary for a considerable distance and less lifting is required to break the cap as one travels southeastward, it appears likely the derecho will continue to be very intense for the next several hours as it moves rapidly along the boundary.

The derecho does continue its very intense stage as it moves into central Wisconsin at 0000 20 July (Fig. 14). The mesolow is now fully developed and the two-hour isallobaric couplet has become very well-defined (Fig. 20). Significant downburst activity is occurring along a 160 nm front (Fig. 2). The surface wind field suggests the system is moving away from the axis of strongest southerly flow into an area of weaker low level convergence. Thus, upward motion due to warm advection in the boundary layer is decreasing ahead of the system. However, note that the system continues to move southeastward at a very rapid rate (Fig. 2). This rapid movement, faster than the mean wind, is probably related to the intense downdrafts discussed in Section 3b (11, 4). The downdrafts drive the gust front, and the gust front is providing an enhanced source of convergence as the system intrudes into the weaker low level wind fields over southern Wisconsin and northern Illinois (Figs. 14 and 15). Since the level of free convection is relatively low east of the Mississippi River, it appears that the lift generated by the gust front is sufficient to create vigorous new convection as it advances. Therefore, the system continues to be a significant producer of downburst activity as it moves through the extremely unstable air mass between 0000 and 0300.

By 0300 20 July the mesolow can no longer be identified (Fig. 15), and the pressure fall portion of the two-hour isallobaric couplet has nearly disappeared (Fig. 21). Some of the decrease in the magnitude of the fall can be attributed to diurnal pressure rises; however, note that the overall magnitude of the rise-fall couplet has decreased since 0000. This suggests that the original mechanisms producing upward motion, low level warm advection and upper divergence, have weakened, and the 0000 20 July sounding data (not shown) confirm this reasoning. The warm advection fields at both 850 mb and 700 mb are very weak from southern Wisconsin into Indiana. Also, the convective system is moving into the right front quadrant relative to the upper wind maximum. The storm system appears to have remained strong between 0000 and 0300 primarily because of the convergence induced by the rapidly moving gust front. The storm system weakens rapidly after 0300 (Figs., 1 and 16). Stabilization due to diurnal cooling likely plays a part in the derecho's demise. However, probably a more important factor is that the storm system is moving out of the high dew point zone into an air mass that is not as unstable. Note that the air mass has been stabilized locally over most of Indiana and western Ohio by earlier convective activity (Figs. 14 and 15). It appears that the low level convergence induced by the storm system's radid movement is insufficient to sustain vigorous convection in the area of moderated buoyancy. Finally, note that the derecho has been gradually moving away (to the right) from the middle and upper level jet axes (Figs. 4 and 5). Thus, the vertical wind shear associated with the system has been gradually decreasing (See Section 3). With almost all of the severe weather parameters weakening, the convective system ceases to produce downburst activity after 0600.

5. DISCUSSION

The storm system of 19-20 July 1983, provides a well-defined example of the derecho phenomenon. This case illustrates a situation in which a widespread significant severe weather episode occurs when the synoptic pattern appears rather quiescent. Specific characteristics of the antecedent conditons (1200 July 19) provide clues that allow the forecaster to properly anticipate the development and maintenance of severe thunderstorm activity (See Section 3). However, predicting derecho development is a more difficult problem.

It appears that derecho development may often be associated with a quasistationary surface thermal boundary oriented nearly parallel to the midtropospheric flow. When sufficient instability and vertical wind shear are present, this type of synoptic pattern has the potential for development of a short squall line oriented normal to the midtropospheric flow. Low level warm advection and enhanced instability in the boundary zone appear to play an important role in sustaining the squall line as it moves along the low level thermal gradient. If the squall line is to develop into a derecho, the downdraft portion of the system's circulation must become exceptionally strong and be able to sustain the gust front as it moves rapidly in the direction of the midtgropospheric flow. Furthermore, it appears that the degree of conditional instability of an air mass plays a role in the velocity of the gust front. The work of Lilly (39) and others has suggested that the rate of propagation of a squall line becomes greater as the positive buoyancy is increased. Note that the derecho cases studied by Johns and Hirt (7) were accompanied by extremely high values of conditional instability.

The downdraft in a squall line is dependent on 1) precipitation drag, 2) negative buoyancy created by evaporation of precipitation (or cloud particles), and 3) transfer of higher momentum air aloft to the boundary layer (40, 41). Properties of the downdraft air reaching the surface suggest that most of the significant entrainment of environmental flow into the downdraft occurs between 3 and 5 km above ground level (24, 42, 43, 44). Therefore, it would appear that the combination of relatively strong winds and low humidities in the lower midtroposphere are important to derecho development. Since the derecho squall line is nearly normal to the midtropospheric flow, the transfer of momentum from higher levels to the gust front is maximized.

This discussion suggests that 1) low level thermal advection, 2) conditional instability, 3) wind speeds in the lower midroposphere, and 4) relative humidity in the lower midtroposphere are all important factors in derecho development. Additional studies underway at NSSFC may help determine how these (and other) features interact to induce the derecho.

The 19-20 July 1983 case illustrates how, once a derecho has developed, a forecaster can often determine potential changes in the intensity of the system by observing mesoscale changes in the surface parameters and patterns. Physical changes in the system itself as indicated by satellite and radar imagery can also be helpful in indicating short-term changes. Finally, the diurnal climatology of severe weather potential may also influence the life-cycle of derecho systems.

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FOOTNOTES AND REFERENCES

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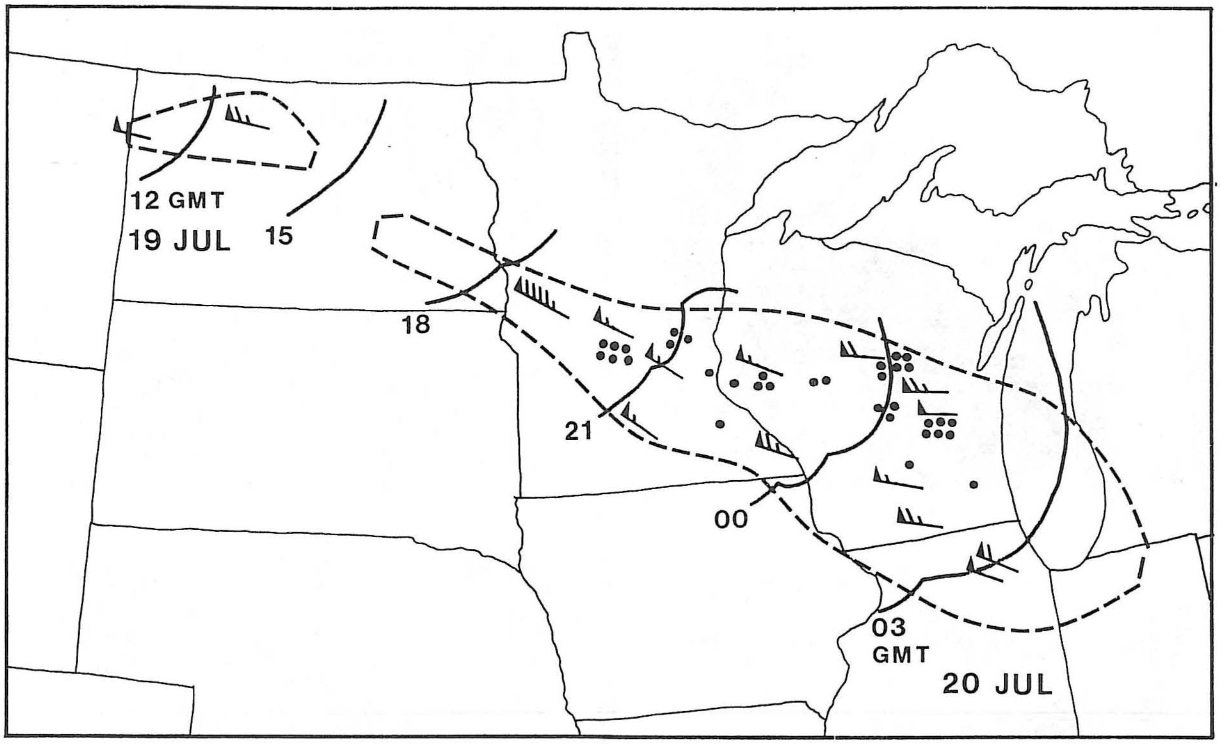

Figure 1. Area affected by widespread downburst activity during derecho occurrence of 19-20 July 1983 (bounded by dashed line). Surface wind gusts indicated by wind flag = 50 kt, full barb = 10 kt, half barb = 5 kt. Dots represent personal injuries. Three-hourly squall front positions indicated in Greenwish Mean Time (GMT).

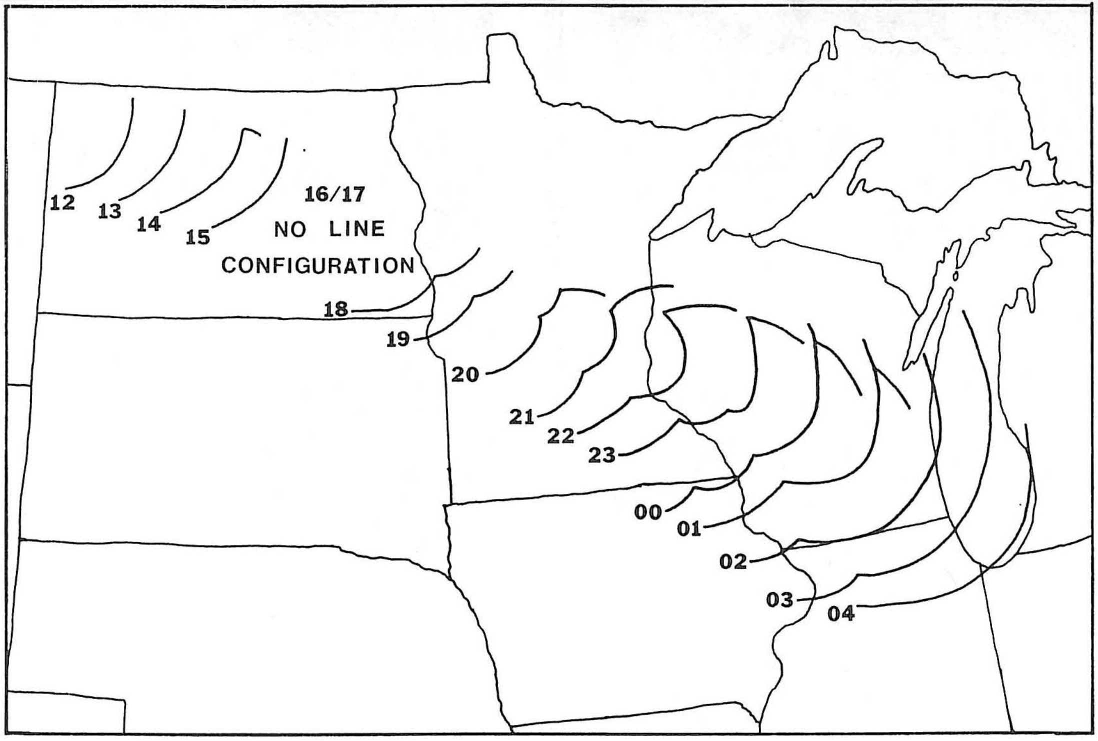

Figure 2. Hourly squall front positions as indicated by convective echoes from radar overlays and coded radar reports. Times in GMT from 1200 19 July to 0400 20 July 1983.

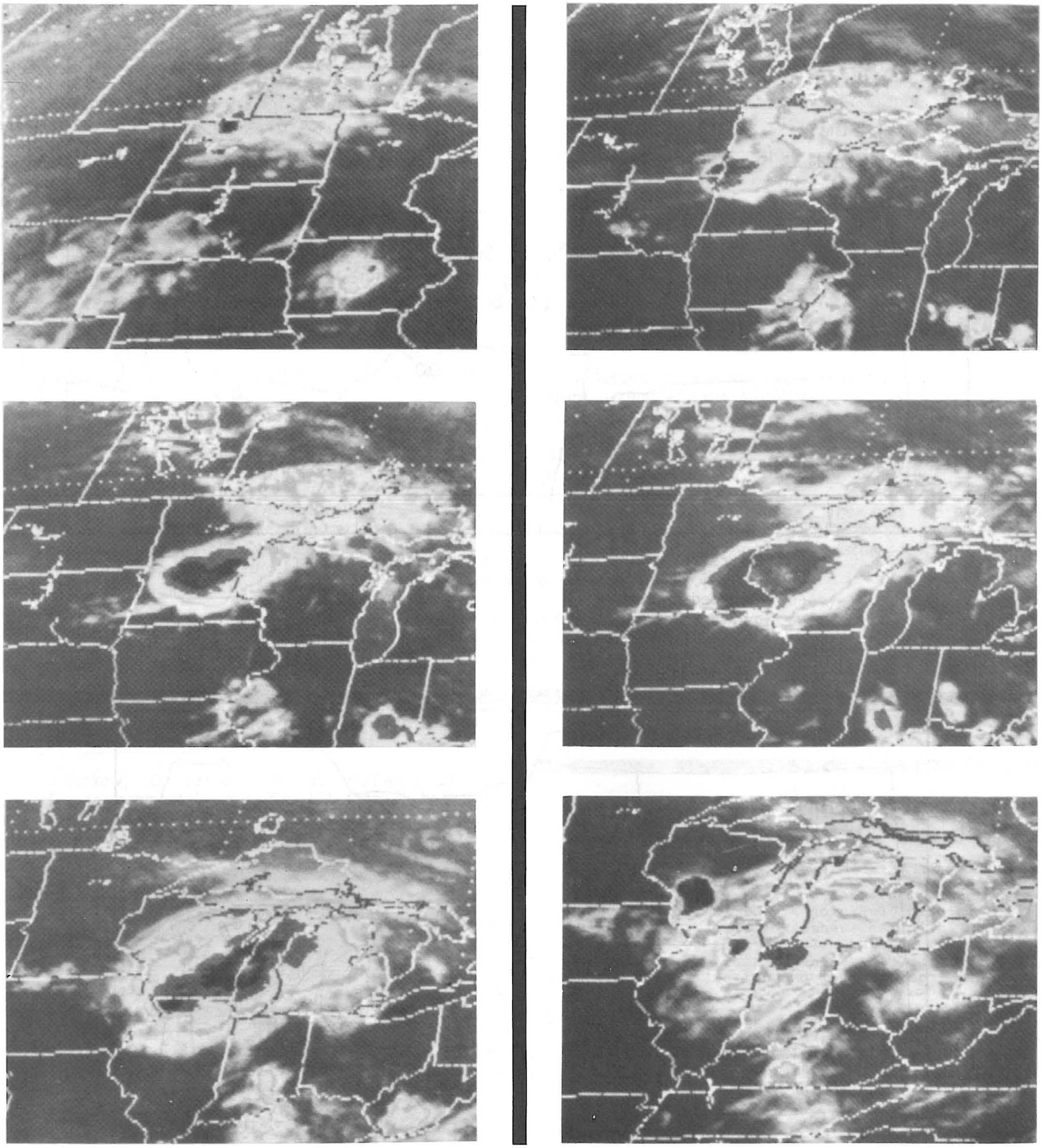

Figure 3. Two-mile equivalent resolution infrared inhanced (MB curve) satellite imagery for 19-20 July, 1983: a) 1230 GMT 19 July, b) 1845 GMT 19 July, c) 2045 GMT 19 July, d) 2315 GMT 19 July, e) 0245 GMT 20 July, and f) 0515 GMT 20 July.

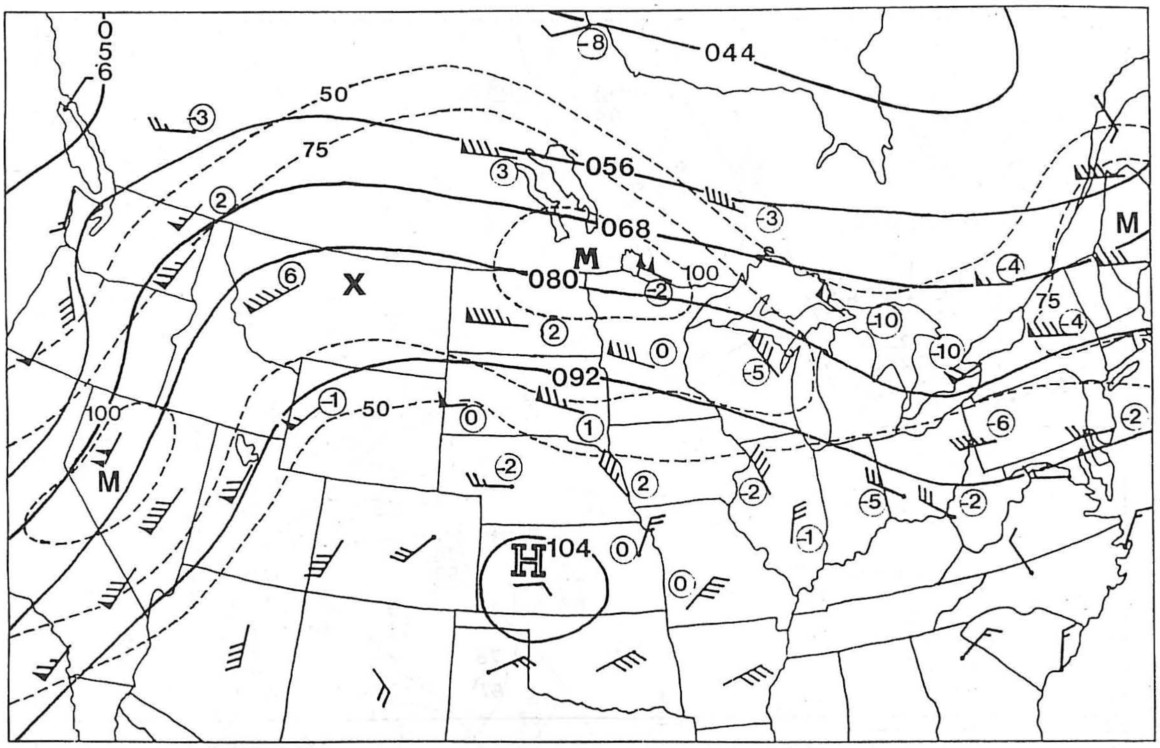

Figure 4. 250 mb analysis for 1200 GMT 19 July 1983. Height contours in decameters with initial digit omitted (solid lines). Wind reports as in Fig. 1. Isotachs in Knots (dashed lines). "X" represents position of wind maximum at 0000 GMT 19 July. Circled values indicate 12-hr height change in decameters.

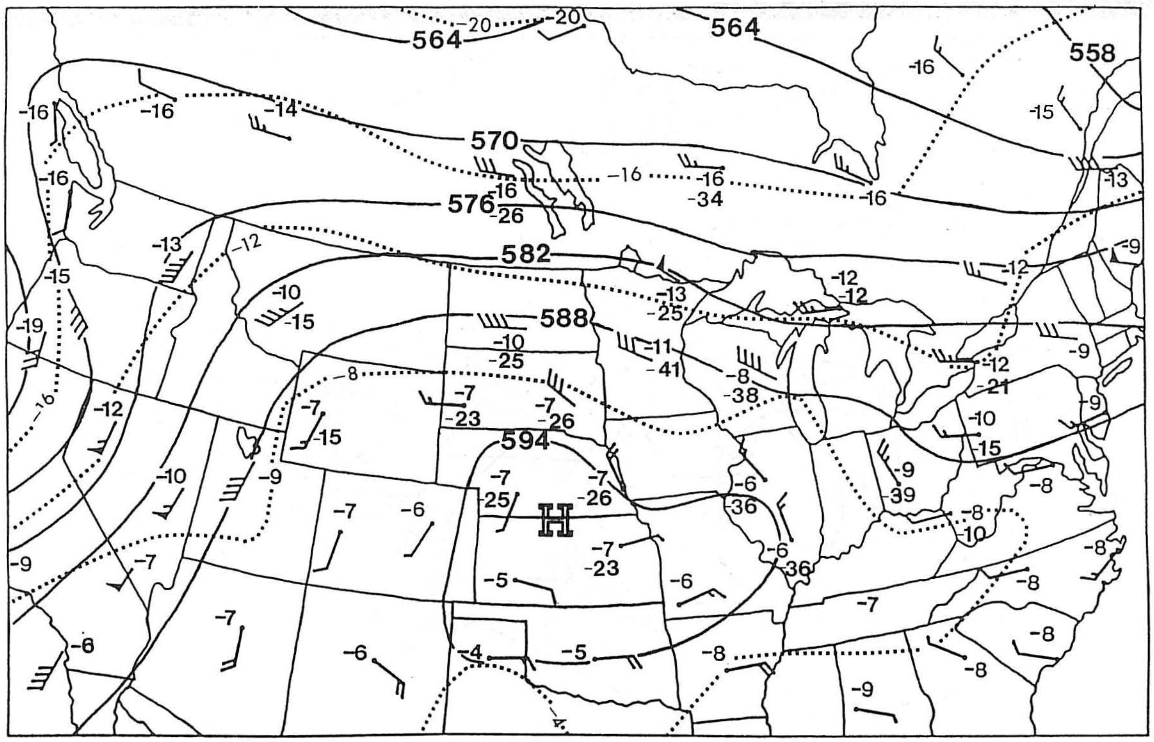

Figure 5. 500 mb analysis for 1200 GMT 19 July 1983. Heights in decameters (solid). Isotherms in deg. Celsius (dashed). Temperatures (Celsius) plotted for all stations. Dew points (Celsius) plotted for selected stations. Wind reports as in Fig. 1.

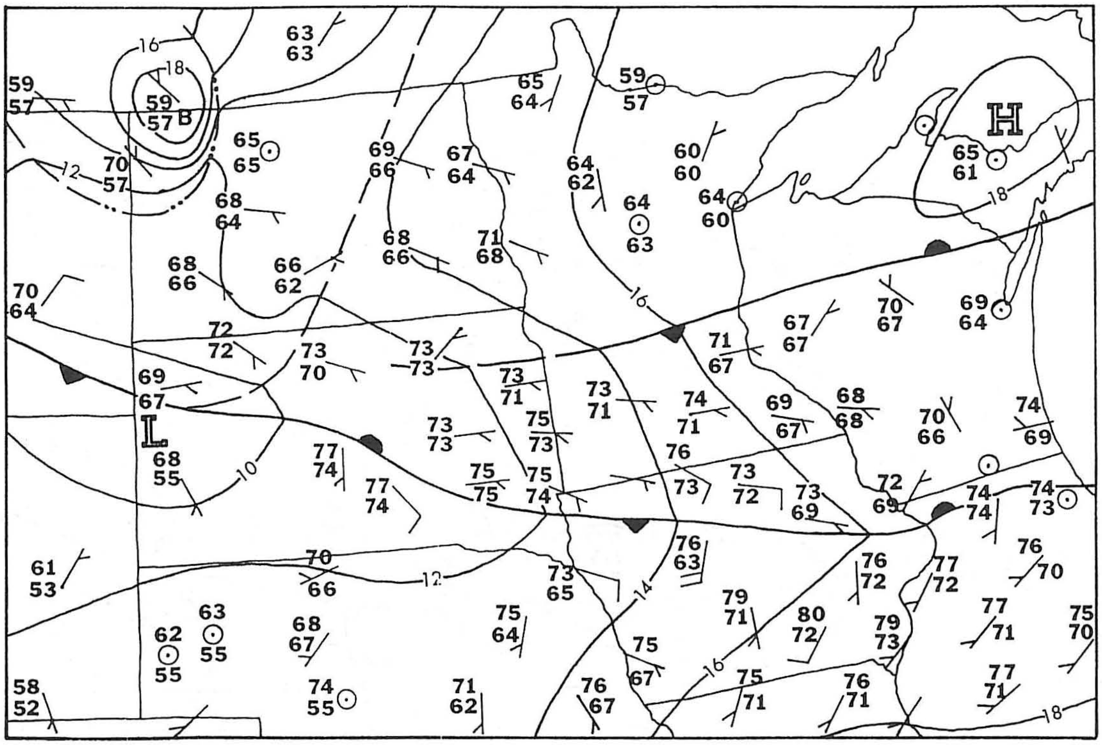

Figure 6. Surface mesoanalysis for 1200 GMT 19 July 1983. Isobars in millibars with first two digits omitted. Wind in knots (gust values plotted when applicable). Temperatures and dew points in deg. Fahrenheit.

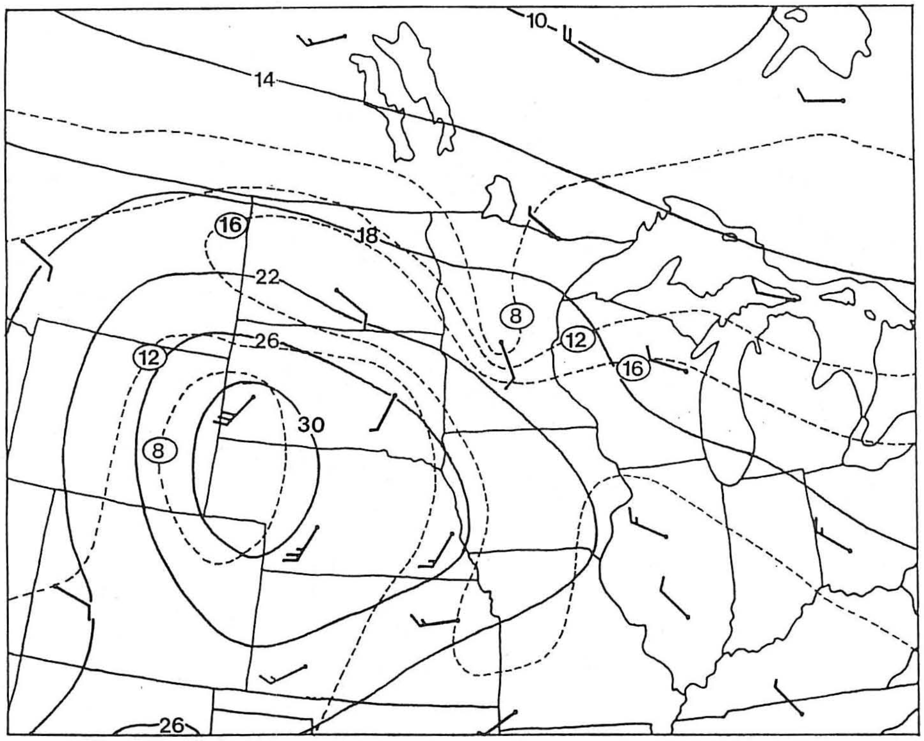

Figure 7. 850 mb analysis for 1200 GMT 19 July 1983. Isotherms (solid) and isodrosotherms (dashed) in deg. Celsius. Wind reports as in Figure 1.

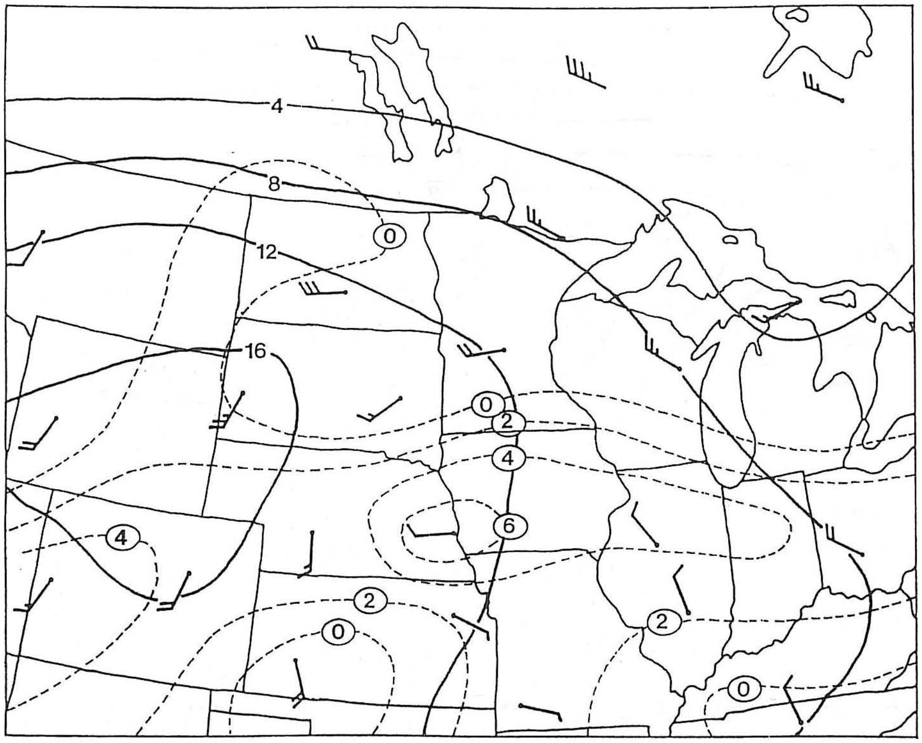

Figure 8. As in Figure 7 except at 700 mb.

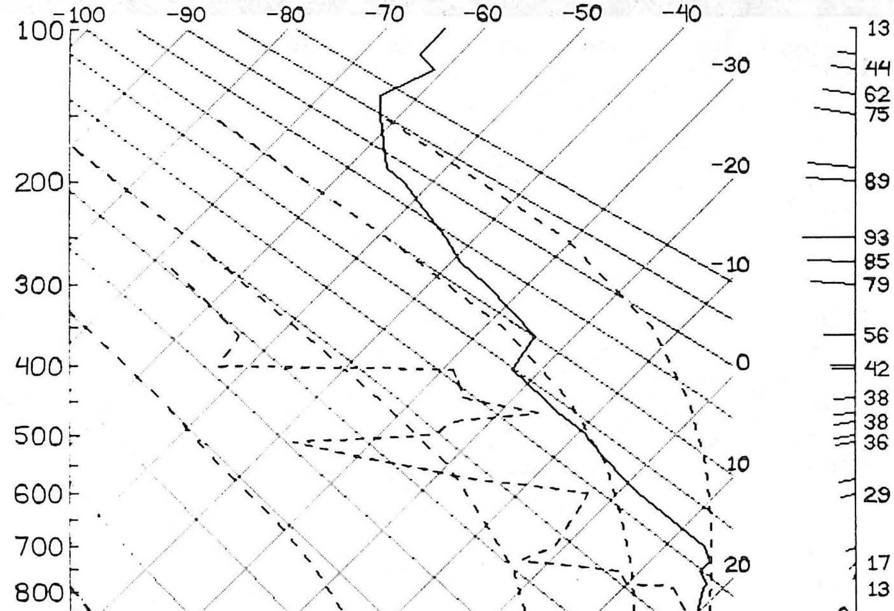

Figure 9. Skew-T, log-P plot of the 1200 GMT 19 July 1983, sounding at Bismarck, North Dakota. Temperatures and dew points in deg. Celsius. Heights in millibars. Wind direction rose and speeds (kt.) on right.

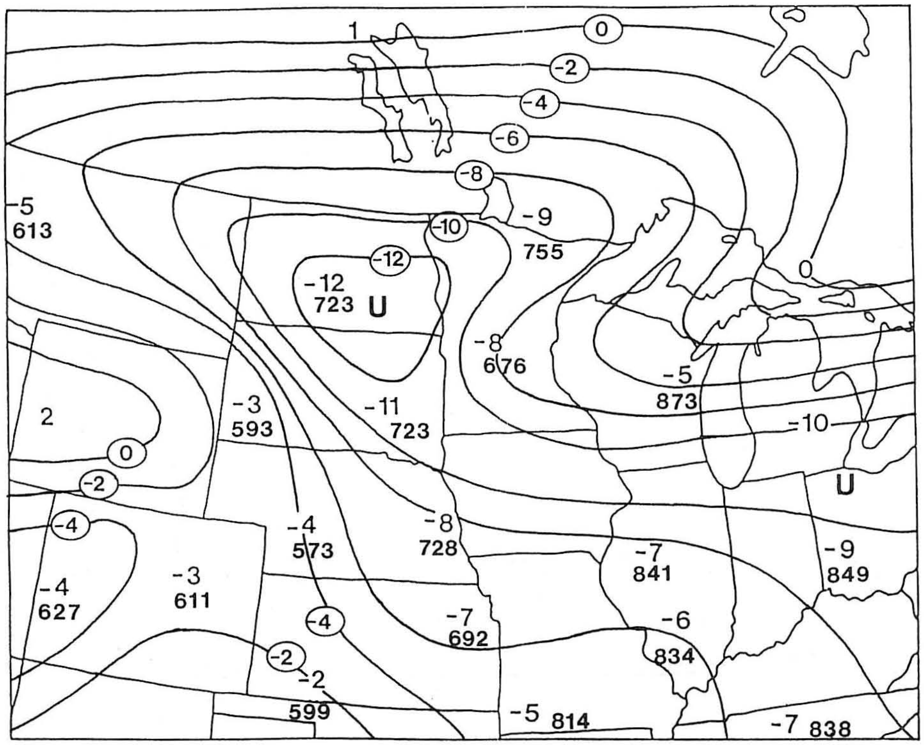

Figure 10. SELS lifted index analysis for 1200 GMT 19 July 1983. Lifted index values and levels of free convection (mb) plotted for stations where available.

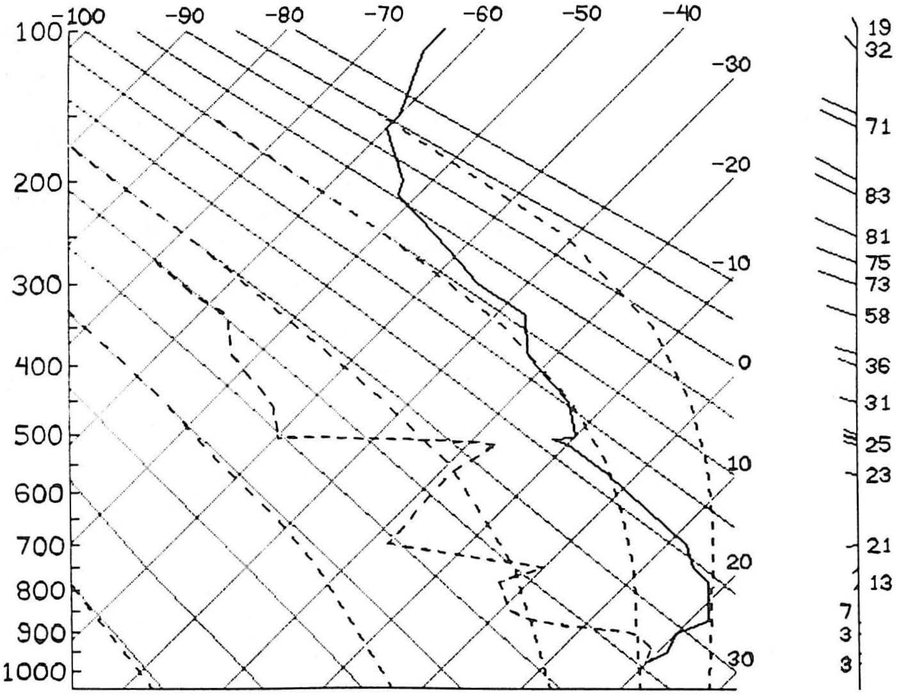

Figure 11. As in Fig. 9 except at St. Cloud, Minnesota.

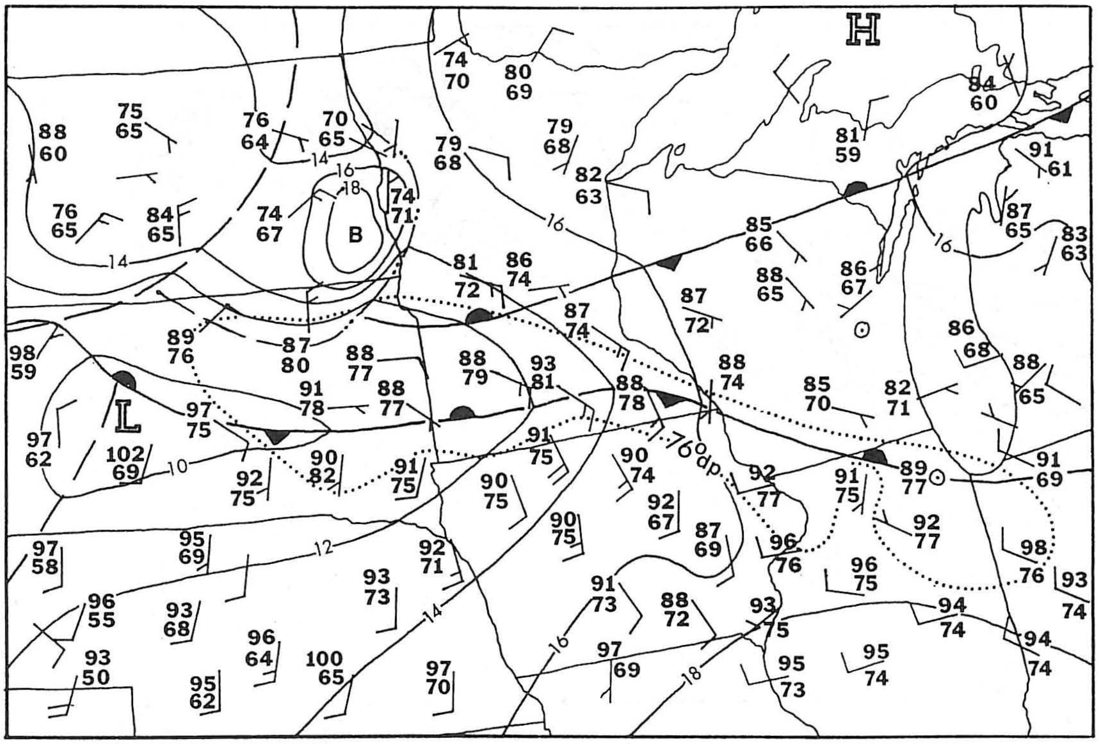

Figure 12. As in Figure 6 except for 1800 GMT 19 July 1983.

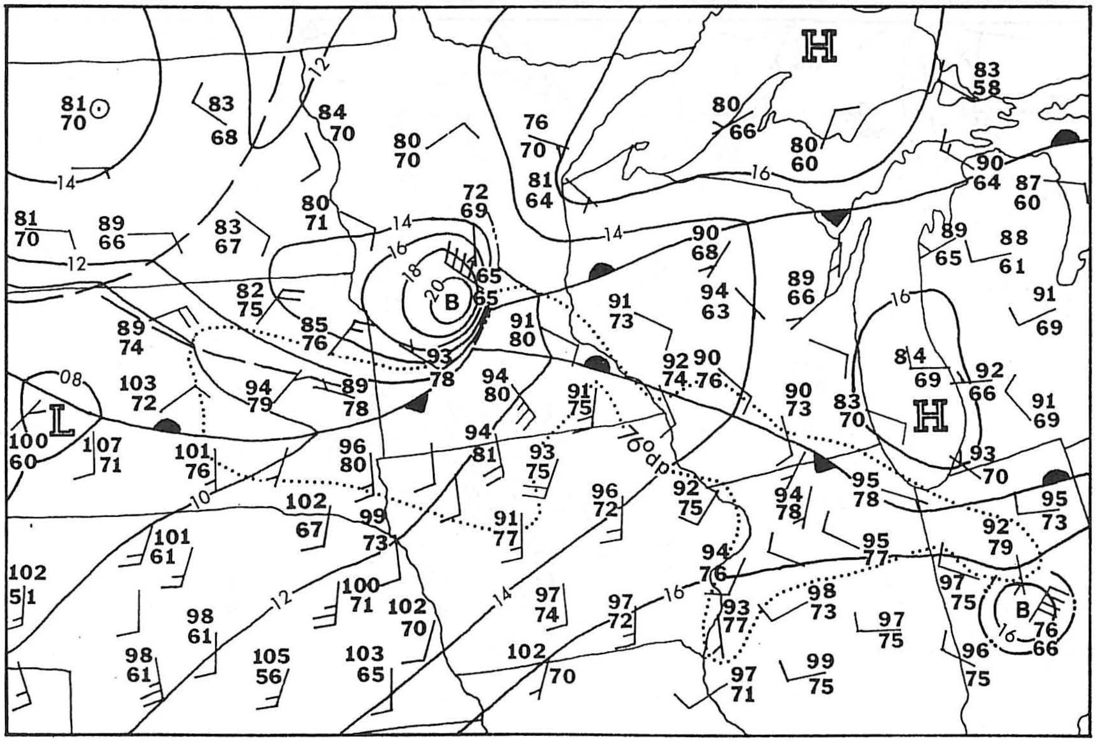

Figure 13. As in Figure 6 except for 2100 GMT 19 July 1983.

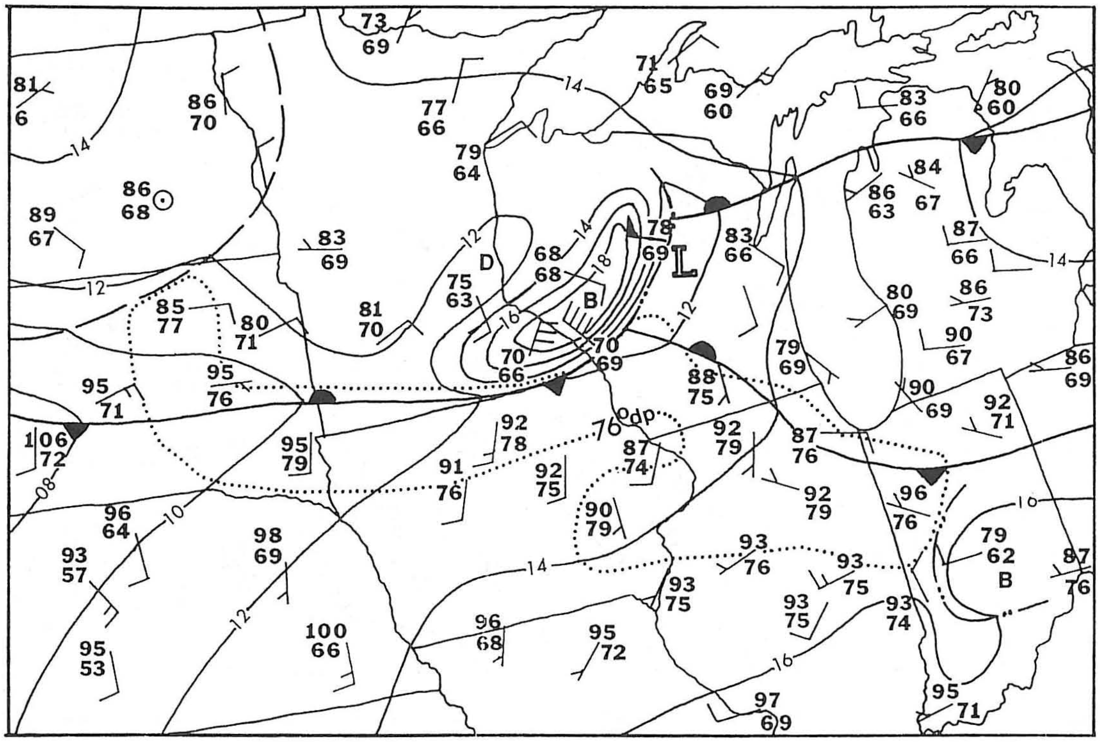

Figure 14. As in Figure 6 except for 0000 GMT 20 July 1983.

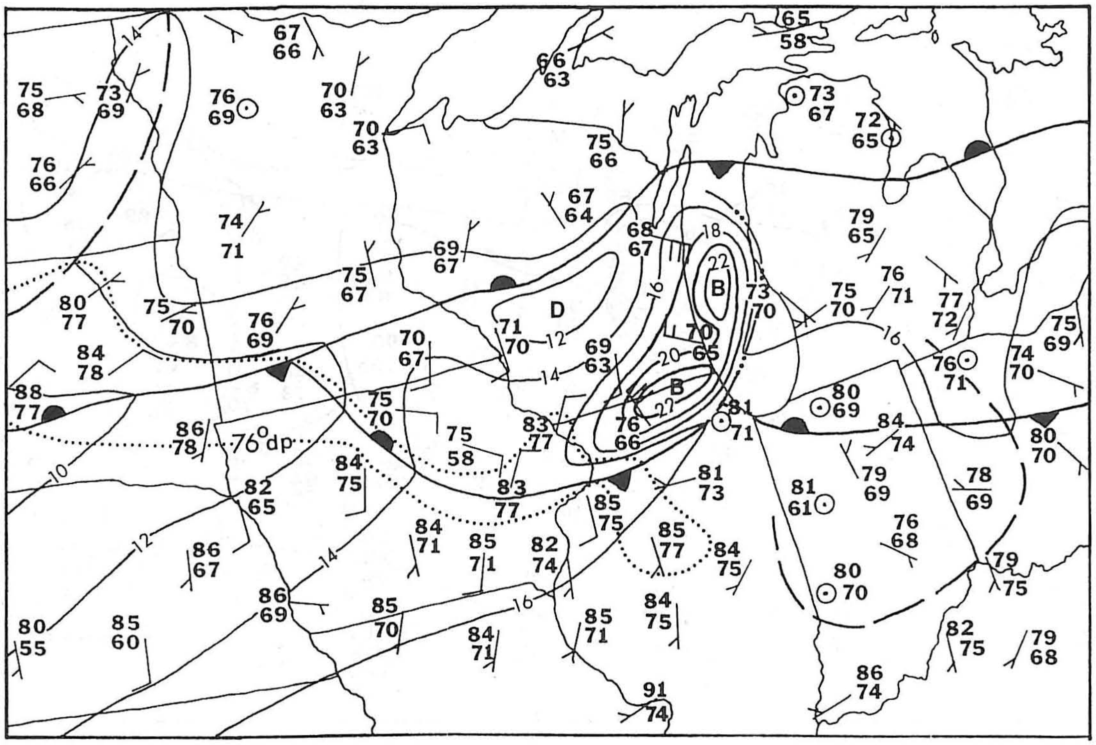

Figure 15. As in Figure 6 except for 0300 GMT 20 July 1983.

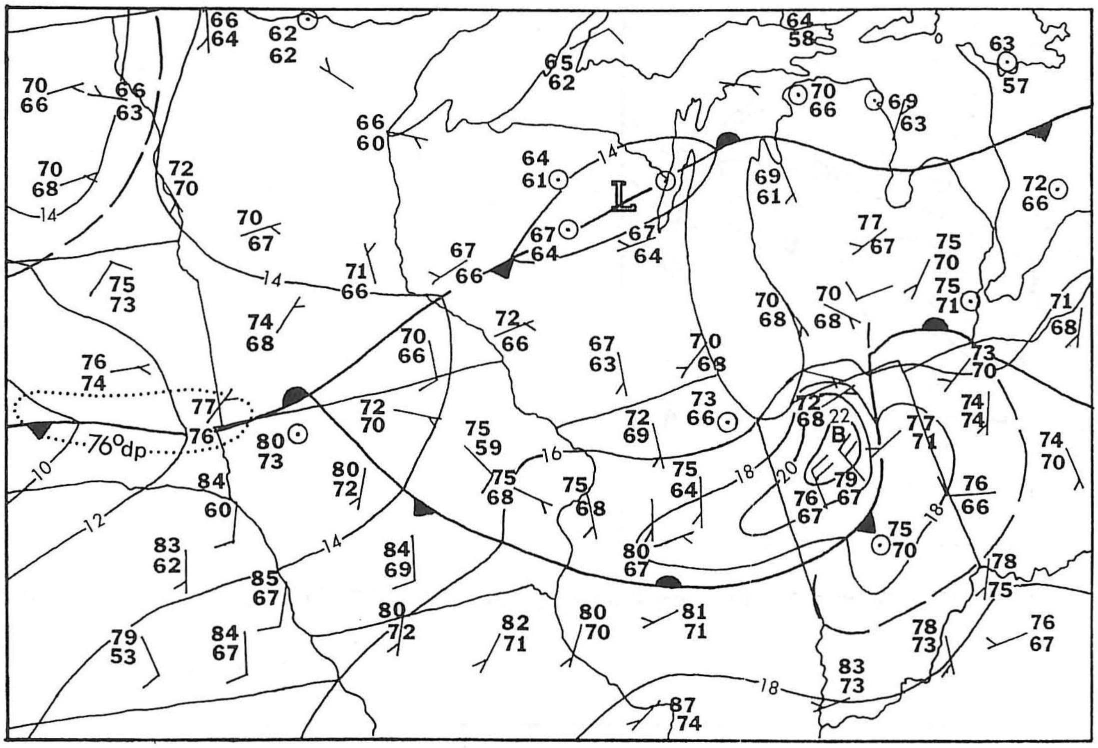

Figure 16. As in Figure 6 except for 0600 GMT 20 July 1983.

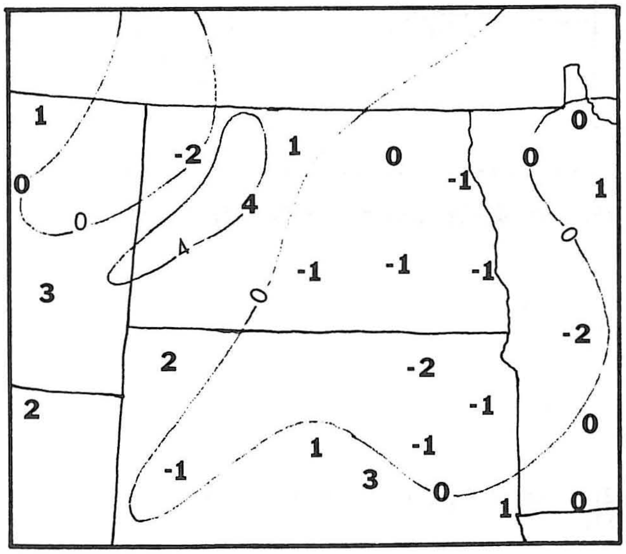

Figure 17. Two-hour altimeter change in hundreths of an inch for 1300 GMT 19 July 1983. Rise isallobars (solid) and fall isallobars (dashed) are at 4 hundreths of an inch intervals.

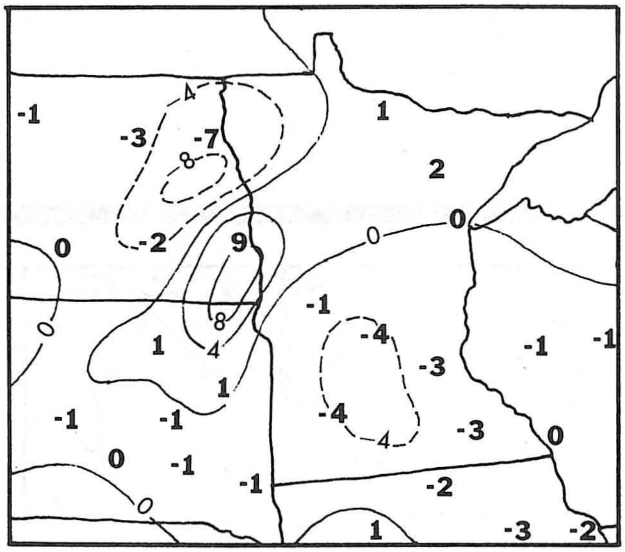

Figure 18. As in Figure 17 except for 1800 GMT 19 July 1983.

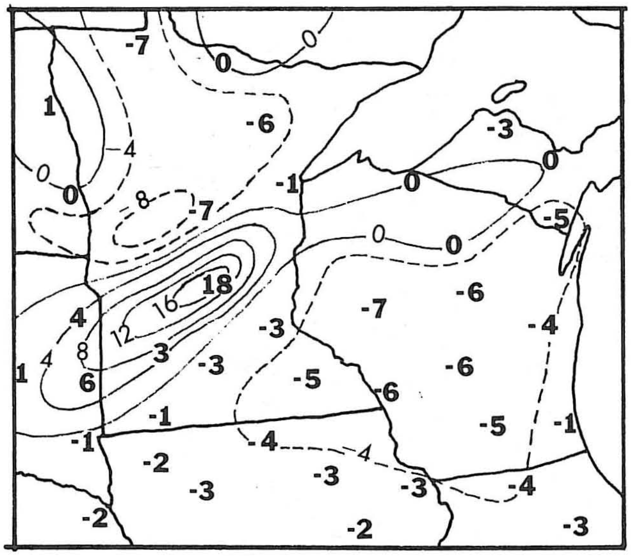

Figure 19. As in Figure 17 except for 2100 GMT 19 July 1983.

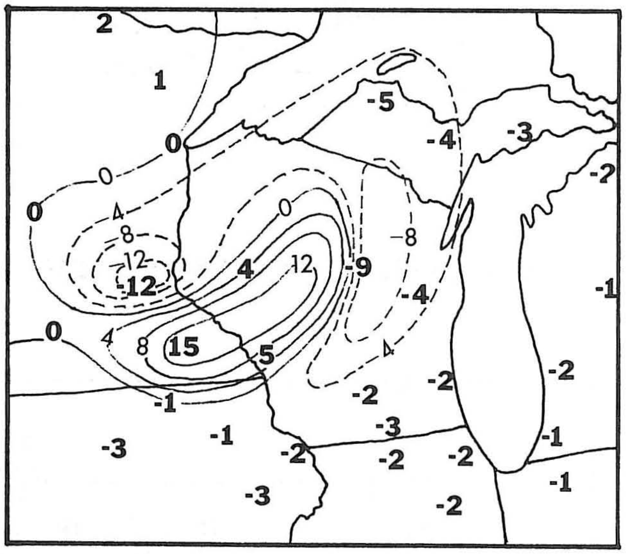

Figure 20. As in Figure 17 except for 0000 GMT 20 July 1983.

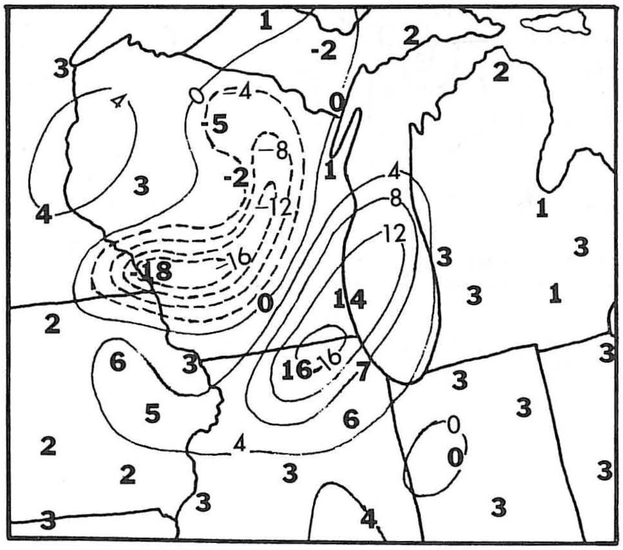

Figure 21. As in Figure 17 except for 0300 GMT 20 July 1983.