Appendix A

GLOSSARY OF SELECTED TERMS

Adiabatic Chart. Any thermodynamic diagram plotting temperature against either log p or $p^{0.288}$ and containing dry adiabats, either saturation or pseudo-adiabats, and saturation mixing-ratio curves.

Autoconvection. If the lapse exceeds 3.4°C/100 m, density increases with height and the layers will over-turn spontaneously. This situation arises in shallow layers due to surface heating and also develops aloft due to evaporative cooling of virga and hydrometeors into dry air. Such overturning, without other trigger action, is called "autoconvection."

Bubble; Bubble High. It frequently happens that precipitation and vertical currents associated with thunderstorms induce small anticyclones (i.e., shallow domes of cooled air) causing slightly higher pressure, complete with clockwise circulation, of the order of 50 to 300 miles across. These transitory small highs have the effect of a different air mass and unstable air overrunning them may form squall lines on their leading edge. Such cells are called "bubbles."

Chinook. In the western United States, a foehn wind is commonly called "Chinook," after an Indian tribe of the northwest.

Convective Condensation Level, abbreviated "CCL." If surface air is heated from below until adiabatic ascent brings it to saturation, the level at which this occurs is called the "Convective Condensation Level." This may be found on an adiabatic chart by starting at the mean mixing ratio of the surface moist layer (or lowest 150 mb, whichever is most representative) and ascending this constant mixing ratio line to its intersection with the sounding. This point is at the Convective Condensation Level.

Convection Temperature. The surface temperature that must be reached to initiate convective currents that will extend high enough to reach saturation. The convection temperature is found on an adiabatic chart by ascending from the mean dew point to the moist layer along the mixing ratio curve to the sounding, then descending along the dry adiabat to the surface pressure.

Convergence. When streamlines approach each other, the region is said to exhibit "confluence." When wind speeds diminish downstream, "Speed convergence" is indicated. Both are usually indicative of mass convergence.

Cross Totals Index. The 500-mb dry-bulb temperature subtracted from the 850-mb dew point.

Destructive local storm, abbreviated "DLS." DLS comprise tornadoes, hail, and thunderstorm gusts over 50 knots at the surface.

Dew-Point Index. The difference between the 500-mb temperature and the mean dew point of the moist layer raised along a pseudoadiabat to 500 mb. This index varies less with diurnal surface heating than the Stability Index.

Diffluence. The rate at which adjacent flow is diverging along an axis oriented normal to the flow.

Divergence. Regions wherein streamlines diverge are said to exhibit "diffluence." Wherever wind speeds increase downstream, "speed divergence" is indicated. Both are usually indicative of mass divergence.

Downrush. The strong downward-flowing air currents associated with thunderstorms.

Downrush Temperature. The temperature found by lowering the Wet-Bulb-Zero down a pseudoadiabat to the surface pressure. This closely approximates the temperature of downrush currents in thunderstorms when they reach the surface.

Dry. Air is considered very dry if its relative humidity does not exceed 50 percent. Air is considered moist if its relative humidity is not less than 65 percent. Intermediate values of relative humidity are moderately moist.

Dry Instability Index. The difference between the surface temperature raised along a pseudoadiabat to 600 mb and the sounding at 600 mb. If an inversion exists below 600 mb such that the temperature raised from its top would give a larger index, then this latter value is used.

Equatorial Air. An air mass that invades the Gulf Coast region from time to time. It has very high temperature and high moisture content. It is

usually conditionally and convectively unstable, without a significant inversion or dry layer.

Foehn. A warm, dry wind that descends the leeward side of mountain ranges. Its characteristics are the result of forced ascent, during which it absorbs the heat of condensation of its moisture, then descent, during which it warms at the dry adiabatic rate ("Chinook" of the northwest United States).

Front. A surface, line, or zone where one or more meteorological elements vary rather abruptly; a "discontinuity." The primary AFGWC criterion for the identification of a front is its usefulness in forecasting rather than any set of objective criteria.

Gust. A sudden brief increase in wind speed. Particularly, the gusts associated with the violent downrush that comes out of the base of a thunderstorm and spreads out horizontally at the surface.

Hail. Precipitation in the form of ice. In forecasting, it is assumed that hailstones are spherical and the size is given as the diameter in inches.

Height. As used by the AFGWC, heights are those measured on an adiabatic chart, either simply by noting the pressure, or by applying the "ICAO Standard Atmosphere Altitude" scale from the surface pressure upward. For example, the Level of Free Convection may be noted at 650 mb, the depth of the moist layer 3,000 feet, and the wet-bulb freezing level at 8,200 feet. The last two would be determined from the surface pressure without correction for temperature.

Humidity. Three measures of humidity are commonly used, according to the purpose:

1. Relative humidity is used in determining whether air is saturated or unsaturated, and the amount of moisture relative to saturation. Air is considered "moist" if its relative humidity is 65 percent or more, "dry" if its humidity is 65 percent or less, and "very dry" if its relative humidity is 50 percent or less.
2. Mixing ratio is used as a measure of the absolute amount of water vapor available.
3. Dew point in severe-weather forecasting is used at the surface only, purely as a matter of convenience, due to its being the only measure of humidity that is reported. It must be compared with the temperature to determine the moistness or dryness of the air and must be compared with the pressure to determine the amount of water vapor available.

Instability. The term "potential" is used in AFGWC to describe all forms of instability that require an activating mechanism for realization. Thus, "potential instability" includes latent instability, convective instability, conditional instability, and even stable situations that are forecast to become unstable due to anticipated changes. Usually when "instability" is mentioned, "potential" is understood, as indicated by one of the various indexes (Showalter, Lifted, Totals, etc.). It is believed that absolute instability occurs in the natural atmosphere though it may be temporary, and the superadiabatic lapse rates reported in radiosonde observations are often significant. Mechanical instability, leading to autoconvection, exists when the lapse rate exceeds about 10°C/1,000 feet. It is believed this situation arises not only in a shallow surface layer on hot days, but also in the upper air when precipitation falls into and rapidly evaporates within a dry layer.

Isotach. Line of equal wind speed.

Lifted Index. Measure of potential instability computed by lifting the mean moisture in the lower 3,000 feet of the atmosphere moist adiabatically to 500 mb and subtracting the temperature at this point from the reported 500-mb free-air temperature.

Level of Free Convection is the level at which a parcel of air lifted dry-adiabatically until saturated; and saturation-adiabatically thereafter; would first become warmer than its surroundings, in a conditionally unstable atmosphere. Found at the pressure level where the mean wet-bulb temperature of the moist layer, raised along a pseudoadiabat, first intersects the sounding.

Mean; Average. Usually taken as the arithmetic mean, i.e., the quotient of the sum of a set of values divided by the number of values in the set. In severe-weather forecasting, the mean is usually estimated by eye (e.g., the mean dew point of the moist layer is normally the dew point in the middle of the moist layer, assuming a linear dew-point laps rate).

Mesoscale. That scale of atmospheric motions of characteristic dimensions too small to remain readily identifiable on the macroscale synoptic maps. Results of mesoanalysis reveal systems which have definite order, pattern, and chronological continuity such as *mesohighs* and *mesolows.*

Saturation Adiabat. Commonly used for pseudoadiabat, or whatever curve appearing on an adiabatic chart to indicate the lapse rate with upward motion of saturated air (used synonomously with "moist adiabat").

Severe Weather Threat (SWEAT) Index. An empirically-derived index used to specify and predict areas of potentially severe convective weather.

Shear. The difference in wind velocity between two contiguous air currents generally measured to the right of the jet or maximum wind axis.

Showalter Stability Index. The difference between the 500-mb temperature and the wet-bulb temperature of the 850-mb level raised along a pseudoadiabat to 500 mb.

Significant Moisture. A 6-degree or less temperature dew-point spread at any level, or a dew point of -17°C or warmer at 500 mb, or 0°C or warmer at 700-mb.

Smoothing. The p ocess of eliminating insignificant or unimportant irregularities in isolines of a parameter analyzed on a map or diagram (usually done by eye in ordinary weather analyses). In severe-weather forecasting, irregularities are of the greatest importance; smoothing is minimized.

Storm. Short for thunderstorm; or area of thunderstorms and associated severe phenomena, hail, strong gusts, and tornadoes. These are local in nature in contrast to extensive frontal systems and hurricanes.

Streamline. A curve whose direction at every point coincides with the instantaneous direction of the wind. Not to be confused with paths or trajectories. Streamlines show the synoptic pattern of the wind direction, which is usually similar to, but not identical with the pressure pattern.

Structure of the Atmosphere. Vertical distribution of the magnitudes of temperature, humidity, and stability of a representative air column or parts thereof.

Surge. A relatively sudden and vigorous movement, of an air mass, or an air-mass property, in some particular direction. Also used for pressure increases not explained by the more usual meteorological patterns.

Thunderstorm. A cumulonimbus cloud that produces thunder and/or lightning, sometimes hail, gusts, and tornadoes; set off by convergence, frontal activity, orographic lift, or surface convection.

Tornado. Any destructive wind gust or whirl associated with a pendant funnel or tubular cloud of very limited horizontal extent (when over water, a waterspout).

Total Totals Index. The sum of the Vertical and Cross Total Indexes.

Uprush. The updraft in a thunderstorm. The speed of the ascending current in a thunderstorm has never been measured directly, but may be estimated from the size of hail produced and from study of a sounding representative of the air producing the thunderstorm.

Vertical Totals Index. The 500-mb dry-bulb temperature subtracted from the 850-mb dry-bulb temperature.

Waterspout. A tornado over water.

Wet-Bulb Temperature. No distinction is made between the wet-bulb temperature, which is the lowest temperature to which a sample of air may be cooled by isobaric evaporation of water into it, and the pseudo-wet-bulb temperature, which is that of a parcel raised dry adiabatically to saturation, then returned pseudoadiabatically to its original pressure. The wet-bulb temperature curse, actually the pseudo-wet-bulb temperature curve, is used to a great extent in severe-weather forecasting.

Wet-Bulb-Zero. The height in the environment sounding of the wet-bulb at the intersection of the 32°F (0°C) isotherm on the adiabatic chart. It is assumed that this is an indication of the height of the freezing level, in a storm column, that might develop in the air mass.

Wind. The horizontal component of air motion over the surface of the earth.

Appendix B

THE SEVERE-WEATHER SITUATIONS 3 AND 4 DECEMBER 1964

SECTION A—GENERAL

The Vertical and Cross Totals were analyzed for 2-degree intervals on Figure 54. The barbed isolines represent Cross Totals (CT) beginning with a value of 18, and were drawn with regard for the moisture influx and low-level wind flow. Thus, the area of maximum CT over northwest Louisiana extended to the ENE in the strong low-level wind flow (shown by solid black arrows) curving from the western Gulf toward Nashville. Although the 18-CT line enclosed a rather large area, the significant 500-mb moisture (depicted by cross-hatching) was limited over much of the map, and little probability existed that middle-level moisture would be advected into Georgia, Alabama, and South Carolina during the following 18 hours. It was more likely that any thunderstorm occurring over these sections during the forecast period would consist of the remnants of activity forming over the very unstable areas in Arkansas and Louisiana. Since this was an early evening chart, additional surface heating could not be expected to influence thunderstorm development, and the occurrence of activity would be associated with other significant features at the surface and aloft.

SECTION B—FAVORABLE FACTORS

In the unstable area of the Cross Totals analysis extending from Fort Worth to Nashville and southward into southeast Louisiana there were several significant factors favorable for severe weather.

a. The air mass was very unstable.

b. The air mass was likely to be lifted over a warm-frontal boundary extending from south of Oklahoma City to between Shreveport and Little Rock, on toward the northeast of Jackson, Mississippi.

c. Speed and directional convergence were evident in the low-level wind field — for example, between Little Rock and Nashville and between Shreveport and Little Rock. Also, there was a strong low-level jet (shown by solid black arrow) over Shreveport.

d. A weak wave at 500 mb was located along a Midland, Texas-Oklahoma City axis. This wave caused a significant-moisture tongue at 500 mb, which indicated that considerable vertical motion and positive vorticity advection was moving toward the area of greatest instability.

e. Dryer and much warmer low-level air was evident by the 850-mb dry-line symbols to the southwest of the threat area. This dry-line orientation resulted in a strong moisture and temperature gradient nearly perpendicular to the low-level flow from Houston toward Shreveport. This moisture and temperature contrast is one of the basic ingredients of a severe-weather outbreak.

f. A well-defined mid-level jet was apparent from Midland through southern Arkansas and into eastern Tennessee. Jets of this type are conducive to severe-weather development and indicate a preferred zone for significant vertical motion.

SECTION C—STABILITY INFLUENCES

The static CT's and VT's indicated considerable thunderstorm activity throughout the area bounded by the 20-CT isopleth. However, for the forecast to be worthwhile, the area had to be reduced. An examination of the VT's (the small crossed circles) showed that they were most signficant in the dry air over south central Texas on an axis through Shreveport to Nashville. This axis lay along the mid-level shear, and a Total Totals area of 50 to 52 was present over northeast Texas, northwest Louisiana and southern Arkansas.

SECTION D—SEVERE-WEATHER FORECAST

It was unlikely that the Vertical Totals would increase south of northern Louisiana or north of southern Tennessee since the time of day prevented any addition of heat to the lower level, and cold-air advection aloft appeared to be improbable south of a line from Shreveport to Chattanooga. Therefore, the resulting forecast called for a heavy thunderstorm area along an axis from near Memphis to just east of Nashville, and a severe area from northeast Texas toward Memphis.

Since the major criteria for tornadic activity had been or would be reached within the next few hours in the area around Shreveport, tornadoes were forecast for a point near Tyler, Texas to near Eldorado, Arkansas. Also, light thunderstorms appeared most probable over the remainder of Louisiana and eastward

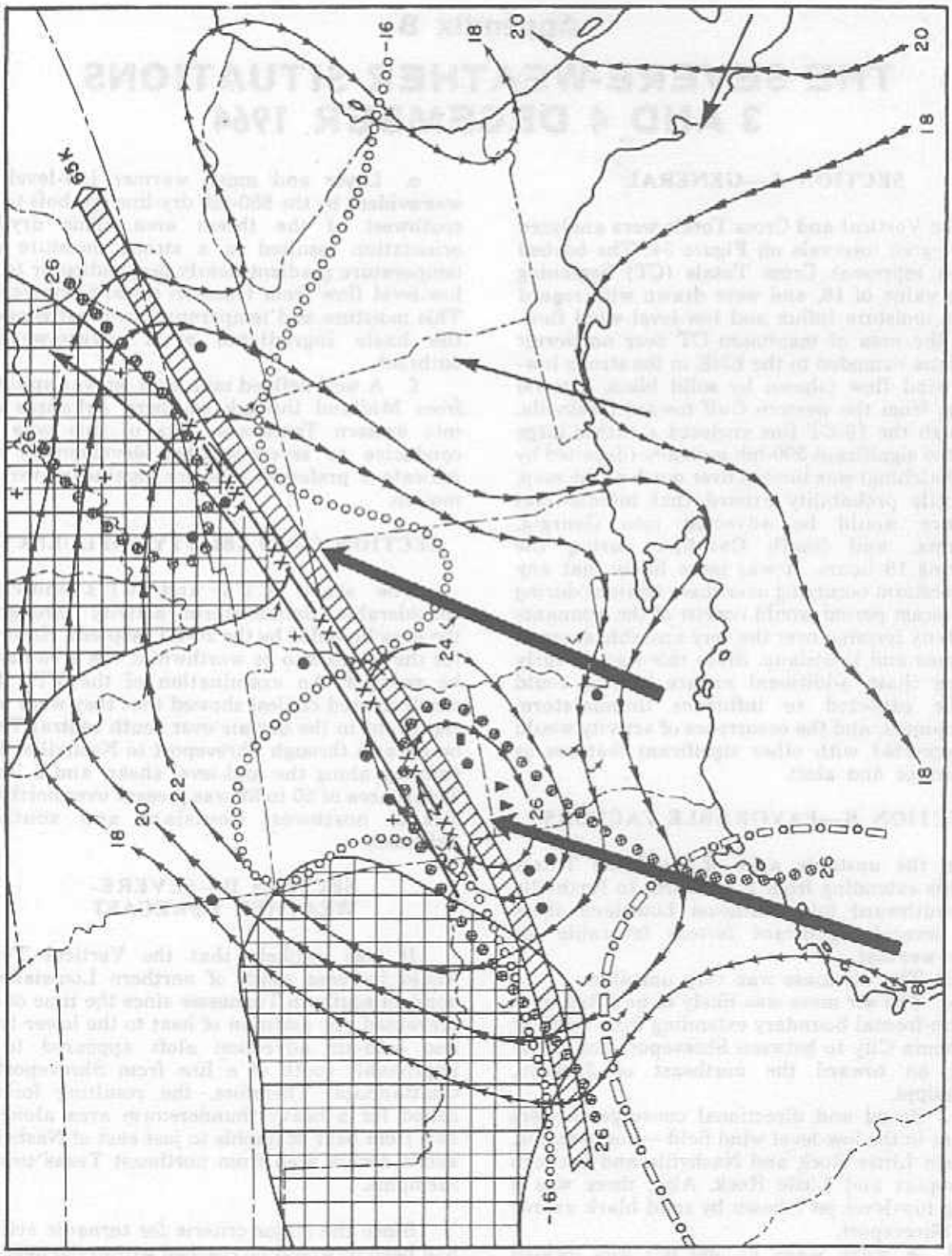

Figure 54. Composite Chart for 0000Z 3 December 1964 showing Cross Totals, low-level wind flow, significant 500-mb moisture, and activity during the period 030000Z to 031200Z.

into Mississippi during the forecast period. These scattered thunderstorms were not likely to develop in a haphazard fashion over the area since the middle and upper levels were quite dry. Development was expected to spread ahead of the outbreak from the northwest and west. Conditions over much of the Florida penisula were quite favorable for convective thunderstorms, but no additional low-level heating would be available. Thus, it was unlikely that isolated activity would occur, but if it should, it would be confined to the coastal waters of southern and southeastern Florida.

SECTION E—ANALYSIS OF SITUATION ON 3 DECEMBER 1964

Heavy thunderstorms developed rapidly near 0200Z within a 50-mile radius of Shreveport and two tornadoes were sighted. One tornado was sighted 30 miles northeast of Shreveport at 0300Z and another 25 miles north of Shreveport at 0330Z. Thunderstorms spread east and northeast (as shown in Figure 55) with hail reported in southern Arkansas and heavy thunderstorm activity in central Tennessee. Activity over Florida was confined to a few lightning reports during the night at Key West. The severe thunderstorms formed and moved in clusters without an organized squall line developing — typical of a Type A synoptic pattern. The importance of the intersecting low-level jet and the middle-level shear zone was illustrated in this situation since the most intense outbreak occurred at this intersection. A study of the area within a 50-mile radius of Shreveport a few hours prior to severe development, revealed that the synoptic features required for violent thunderstorms were concentrated in that area. That is:

a. The air mass was critically unstable with a Cross Total of 26, Vertical Total of 26, Total Total of 52, and Lifted Index of -6.

b. Low-level moisture was concentrated in a rather finite area.

c. The area was traversed by a strong low-level jet.

d. The area was directly south of a marked middle-level jet.

e. The low-level jet intersected this middle-level wind band within the threat area.

f. There was a steep moisture and temperature gradient to the southwest of the threat area and a low-level wind was blowing across this gradient.

g. The degree of instability was increasing since low-level warm air was running northeastward under progressively colder air at 500 mb.

h. There was evidence of significant positive vorticity advection into the threat area as seen by the 500-mb moisture over Oklahoma and Northern Texas.

It is often the case with Type A synoptic patterns that a low-level dry influx from the southwest aids triggering. In this situation the thunderstorm outbreak continued eastward during the night, but abated in intensity as a result of mixing, which diffused the sharp boundary between the moist and dry air.

SECTION F—DIFFERENCES IN THE PATTERNS

At 031200Z it was evident that another severe-weather situation was possible (Figures 56 and 57). The primary difference between the patterns on each of the two days was that on the second day the approach of a much stronger 500-mb short-wave trough through western Oklahoma and west central Texas was evident and was associated with a pronounced north-south maritime polar front. This upper-air feature was to be the last short wave in the series, and indications were that the whole system would push south and east out of the country in the next 24 to 36 hours. The general stability pattern was quite similar to the previous day with considerable potential instability evident as far west as the Fort Worth-Dallas area where Total Totals of 52 to 56 were present. With the maritime polar outbreak approaching a line from Fort Worth to San Antonio to Laredo, careful and immediate attention should have been given on the second day to the area around Fort Worth and Dallas. This area under these conditions was a good example of the Type B tornado situation with dryer and warmer air to the southwest of the threat area, and strong low-level flow across this boundary. (The first day was a Type A pattern.) Also, there was an intersecting frontal system moving from the west. Since the developing low-level jet lay to the east of the Fort Worth-Dallas area, and the mid-level jet had become less well-defined, the possibility of tornadoes was remote but serious consideration was given to the possibility of wind and/or hail.

Wind did not appear to be a serious problem for the second day since the thunderstorms that developed shortly after 1200Z were all located over the cold surface layer north of the surface warm front position. Thus, the downrush differential would not be especially effective. Also, there was not much chance of developing a localized mesoanticyclone or bubble since the layer near the surface was already cooler than could be realized from the downrush air. Normally this area would be preferred for hail occurrences but in this instance two conditions were working against it:

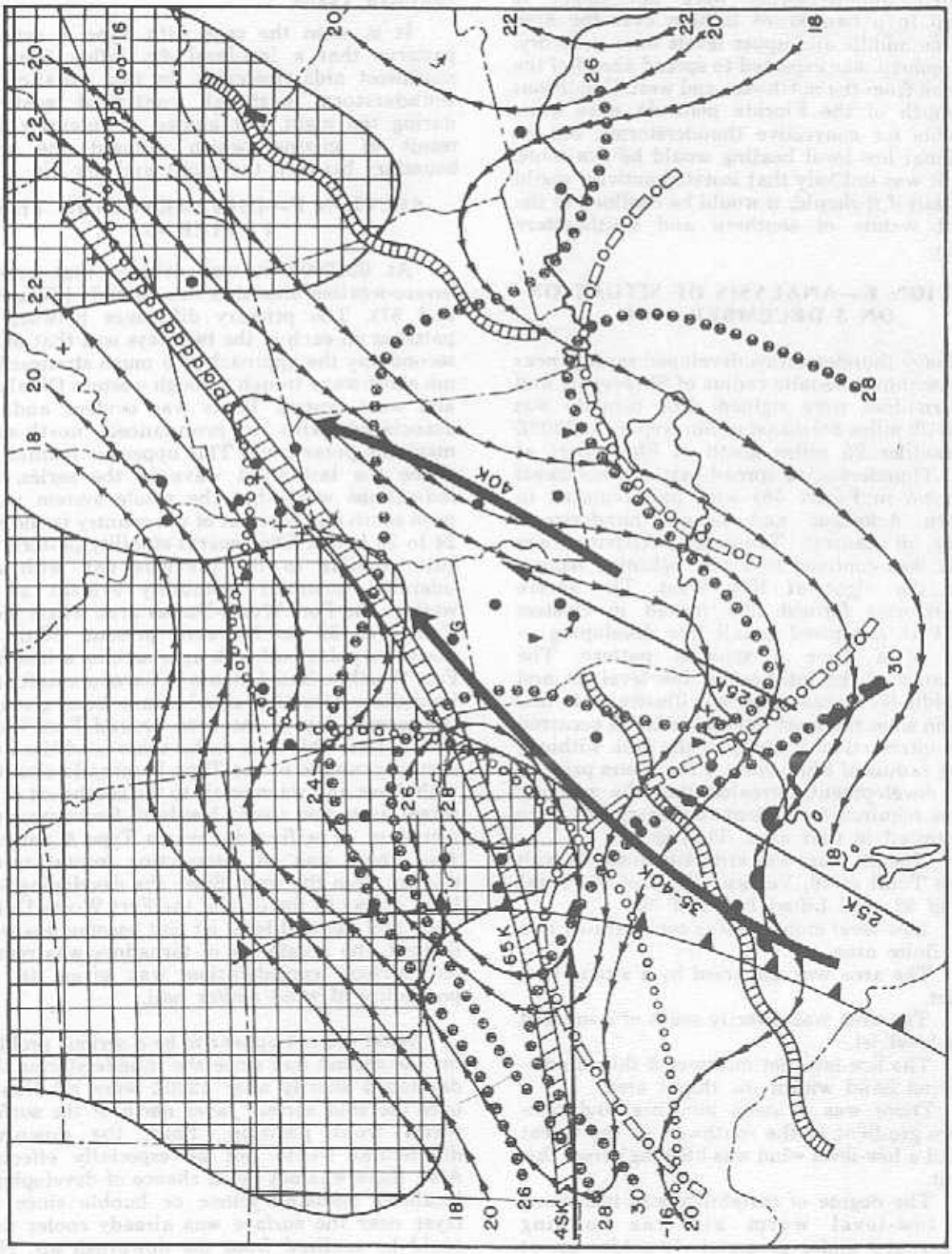

Figure 55. Composite Chart for 1200Z 3 December 1964 showing parameters of interest and activity during the period from 031200Z to 040000Z.

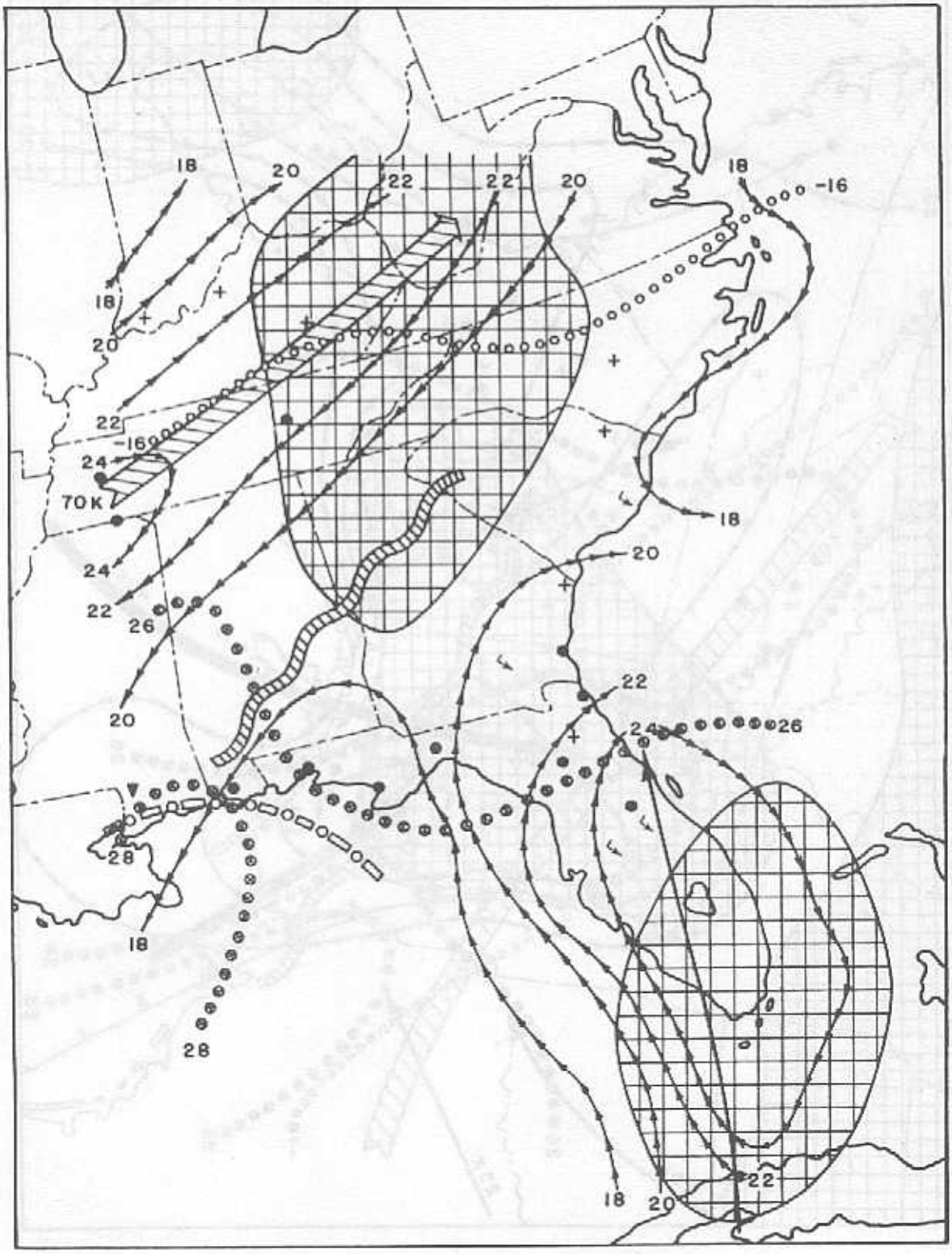

Figure 56. Composite chart for 1200Z 3 December 1964 showing parameters of interest and activity during period 031200Z to 040000Z

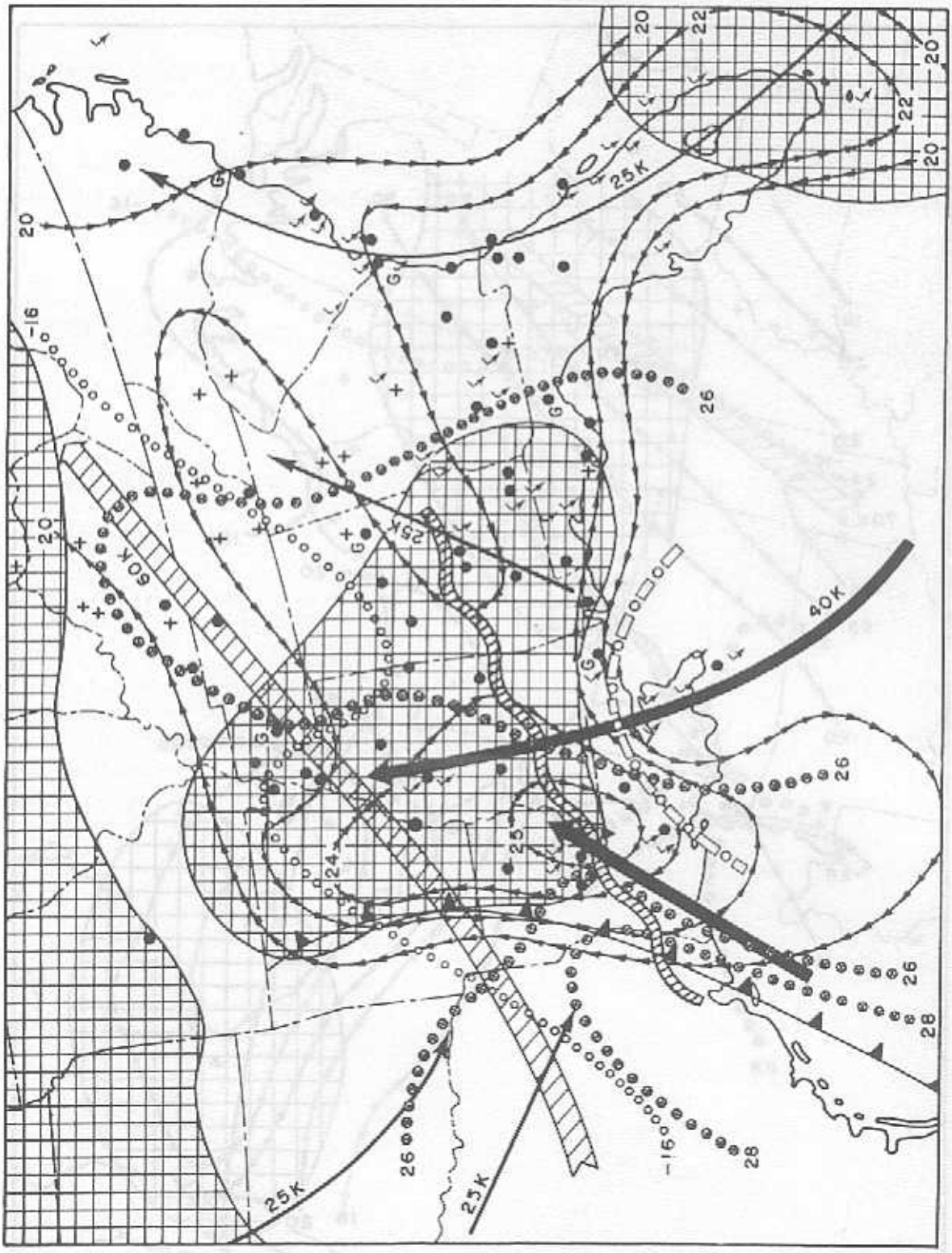

Figure 57. Composite chart for 0000Z 4 December 1964 showing parameters of interest and activity during period 040000Z to 041200Z

a. Time of day; and

b. The wetness of the air column. Extrapolation of the dry air in the middle and lower levels indicated that the important second condition would not be changed before activity moved further eastward. Since the outlook had forecast scattered thunderstorms for south central and southeast Oklahoma, and north central Texas during the morning, no amendment was issued. By 1500Z scattered thunderstorms accompanied by heavy rain formed a well-defined squall line extending from just south of Tulsa, Oklahoma through Sherman, Texas to 30 miles southwest of Dallas. This line was just ahead of the maritime polar front and north of the dry 850-mb boundary. No winds or hail were reported until the squall line reached the Fort Smith-Texarkana-Lufkin line later that afternoon.

The forecast for the 1800Z outlook was simplified since an active squall line was already in existence. The area of primary concern again appeared to be in southern Arkansas and northern Louisiana, since most parameters previously mentioned as necessary for severe activity were forecast to converge in that particular zone. The low-level jet appeared to be developing along the San Antonio-Shreveport-Nashville line with the only change likely to be a shift eastward of the maritime polar front. The front and squall-line forecast movement indicated that the low-level jet should back slightly and move into a position over Lake Charles, through Monroe, Louisiana and northward toward Memphis by evening. The dryer warmer air to the southwest of the area was expected to persist until pinched off by the maritime polar front, which would permit a cross-gradient flow to continue into Louisiana and southern Arkansas. Stability was forecast to decrease over these areas since significantly warmer low-level air would be advected into the area while the 500-mb temperature field would remain essentially unchanged. The middle-level jet, while not well-defined, seemed to be trying to organize itself along the Midland-Fort Worth-Nashville line. The short wave at 500 mb continued ENE creating a strong vertical-motion field over the threat area during the late afternoon and evening. With these considerations, it seemed reasonable to forecast severe thunderstorms and a few tornadoes along an axis from Lufkin, Texas to near Greenville, Miss. This axis fits the region of climatological tornado maximum for December for this area.

A second area of high climatic frequencies for December tornadoes is near Houston. This is of particular interest since the Houston area on this date is very close to the boundary of the warm dry air and the moist air to the east. Extrapolation of the squall line placed the hot-dry boundary by late afternoon in the vicinity of Houston, where a Total Totals of at least 52 was expected. Also, if the middle-level jet formed along the predicted axis, it was probable that the 500-mb shear zone would lie further south along the Houston-Lake Charles line. Thus, the southwest portion of the tornado area included Houston and curved eastward toward Alexandria, Louisiana. The warm dry air in the lower levels over southeast Louisiana did not appear significant at this time, but required consideration since the low-level jet was expected to shift eastward and since more moist and cooler low-level and middle-level air was present north of the area.

SECTION G—ANALYSIS OF SITUATION OF 4 DECEMBER 1964

The Total Totals just north of the surface warm front were observed to be near 47 in the morning. The 18-Cross Total line covered a large territory, but the absence of 26 or even 24 Vertical Totals over much of this area appreciably reduced the thunderstorm probabilities. Thus, much of the area can be eliminated from consideration except for western and southern Alabama, southern Georgia, the Carolinas, and Virginia. It was unlikely that any major change in stability would occur over these areas during the 12-hour outlook period. Also, it was unlikely that thunderstorms from the west would spread into these sections before 0600Z.

Along the Gulf Coast through southern Georgia and northern Florida (Figure 54), the Vertical Totals were favorable for convective activity but 700-mb and 500-mb moisture was lacking. It was discussed in Chapter 8 that when this region had dry air aloft, activity was not necessarily prohibited, but that development was restricted to widely scattered cells. Further south, over southern Florida, upper-level moisture was available, hence scattered thunderstorms were forecast. Isolated thunderstorms were not forecast along the Gulf Coast and over northern Florida, but should have been in view of the Total Totals of 46 to 50 over much of this area. Thunderstorms did occur as shown on Figure 54. Further west heavy thunderstorms were forecast through southern Arkansas into western and northern Mississippi, and through Louisiana and east Texas — surrounding the tornado and severe thunderstorm area previously mentioned.

The position of the squall line by 2100Z was from 100 miles north of Little Rock to Texarkana to just east of Houston. Heavy activity was reported along the line with strong gusty winds,

heavy rain and hail southwest of Texarkana, west of Shreveport, and in the vicinity of Lufkin, Texas. A tornado was observed (near 1900Z) four miles north of Ellington AFB, Houston, while the air base reported thunder and wind gusts to 32 knots. Tornadoes were reported between 2200 and 2300Z forty to seventy miles ESE of Shreveport, and at 0200Z in the vicinity of Alexandria. Also, heavy thunderstorms were reported near Memphis during the evening with the last reported at Anniston, Alabama about 0800Z. By 0600Z the thunderstorms had spread to near the Nashville, Tennessee-Burwood, Louisiana line, and had continued eastward ahead of the frontal system during the night and next morning.

An unforecast tornado was reported northwest of Gulfport, Mississippi at 2100Z. This storm was associated with a group of isolated convective cells. The occurrence of this storm is an important clue since the post-analysis of the 0000Z data disclosed that the tornado most likely occurred in conjunction with the primary low-level jet just north of the hot/dry 850-mb warm front, in an area of increasing instability, and in the vicinity of the middle-level wind shear to the south of the jet.

An examination of the next chart, 040000Z, confirmed the predicted changes in the 031200Z pattern. The maritime polar front extended from just past Shreveport to east of Galveston. The hot dry air had been modified and cut off by the advancing front which helped to explain the cessation of tornadic activity after that reported near Alexandria at 040100Z. The low-level jet had shifted eastward with the main branch almost north-south through Louisiana and Mississippi and another branch from the southwest over Lake Charles then toward Alexandria. The middle-level jet developed and was well-defined from Midland through Texarkana to Nashville. The middle-level shear zone was from south of San Antonio to Lake Charles to Jackson, Mississippi and on toward Montgomery, Alabama. It should be noted that the Alexandria report was in close proximity to the intersection of the southwesterly low-level jet with the shear zone, and was in an area of well-defined low-level convergence. The isolated tornado northwest of Gulfport occurred very close to the intersection of the low-level jet and the edge of the middle-level shear zone. Also, the activity around Memphis and Jackson, Tennessee was near the intersection of the main low-level jet and 500-mb jet.

The 42-knot thunderstorm report after midnight in the Anniston, Alabama area was near the shear zone and it seemed likely that the low-level jet had shifted eastward by this time to cover the Anniston area. In fact, the low-level winds for 0600Z showed that Montgomery's wind had increased to 45 knots from the SSW at 400 feet. No further reports of significant weather were received after this report probably because there was an increase of stability in the air mass ahead of the system. Also, the cold air aloft developed a more northerly track, and the low-level and middle-level dry sources were overtaken by the squall line or cut off by the cold front.

Appendix C

THE SEVERE STORMS OF 11 FEBRUARY 1965

SECTION A—GENERAL

On 11 February 1965 a major outbreak of severe thunderstorms, tornadoes and damaging windstorms occurred over a 14-hour period along a line extending from just WSW of College Station, Texas into north central Alabama. This situation is an excellent example of the use of the Totals indexes as well as other prediction parameters available to the forecaster. The tornado pattern was essentially Type B with an active squall line moving ahead of an almost north-south maritime polar front, and intersecting a well-defined warm-frontal boundary along a line from near Austin, Texas to Shreveport to Memphis, and ENE into North Carolina. At 1200Z the squall line was active from eastern Oklahoma to west of Tyler, Texas and southwestward to Cotulla, Texas. Thunderstorms were occurring all along this line, with a few reports of heavy rain and moderately gusty winds. The squall line and its parent cold front were moving eastward at about 22 knots with the thunderstorm cells moving more than twice that speed toward the NNE. Surface dew points were dropping substantially in the westerly flow to the rear of the cold front. An examination of the 1200Z composite chart showed that the squall line was moving into an area increasingly favorable to the production of severe thunderstorms and the time of day was becoming more favorable for the production of such activity.

SECTION B—FAVORABLE PARAMETERS

Many of the favorable parameters usually associated with violent thunderstorms had already or would shortly be ahead of the squall line over portions of east Texas and the northern half of Louisiana. The stability analysis showed the Cross Totals to be a very unstable 26 in a corridor extending along the San Antonio-Shreveport axis, with a probable maximum of 29 or 30 over the central portions of eastern Texas. These CT's suggested that the development of tornadic storms was likely especially when coupled with the Vertical Totals of 28 to 30 for an extremely unstable Total Total of 60. The Lifted Index at San Antonio was -6 and Shreveport 0. It was interesting that the Total Totals pattern, even at 1200Z, quite accurately predicted the major path of activity even into northwestern Alabama. Since the position of the first significant southerly low-level flow appeared to be along an axis extending from McAllen, Texas through College Station toward Tyler, it was reasonable to expect squall-line intensification along this axis, and further intensification in the vicinity of the low-level jet located from Brownsville through Shreveport. The area of instability as well as the low-level jet was expected to show some eastward movement during the day.

At 500 mb the southern and eastern periphery of a strong band of middle-level winds was evident from Del Rio, Texas to San Antonio to Tyler, Texas, and then northeastward through northwestern Arkansas creating an effective horizontal shear zone near the most unstable area. Cold air was available at 500 mb with the -16°C isotherm intruding into northwestern Louisiana and southwestern Arkansas from central Texas. At 850 mb a strong contrast between the warm moist air over the threat area and the hot and much dryer air to the southwest was apparent, since temperatures of 17 to 21°C and dew points of -3 to +5°C were common to the southwest of the surface warm front as compared with values of +15 and +12°C to the northeast of the front. Also, there was a well-defined cross-gradient low-level flow across this boundary.

SECTION C—THE SEVERE-WEATHER FORECAST

The prediction was based on the expectation that the air column over the threat area would become more unstable along the axis of the low-level flow, and that mesolow development would likely take place where the squall line intersected the warm frontal boundary in the area of strong low-level wind flow. Positive vorticity advection and vertical motion were evidenced not only by the 500-mb moisture at Shreveport but also by the thunderstorms already developing along the squall line.

Considering the above, the forecast was for severe thunderstorms, tornadoes, and locally damaging winds 60 miles either side of a point about 30 miles north of College Station, Texas along an axis into the Tupelo, Mississippi area. This decision meant accepting a risk that the surface warm front would edge northward out of the area displacing the zone of activity more to

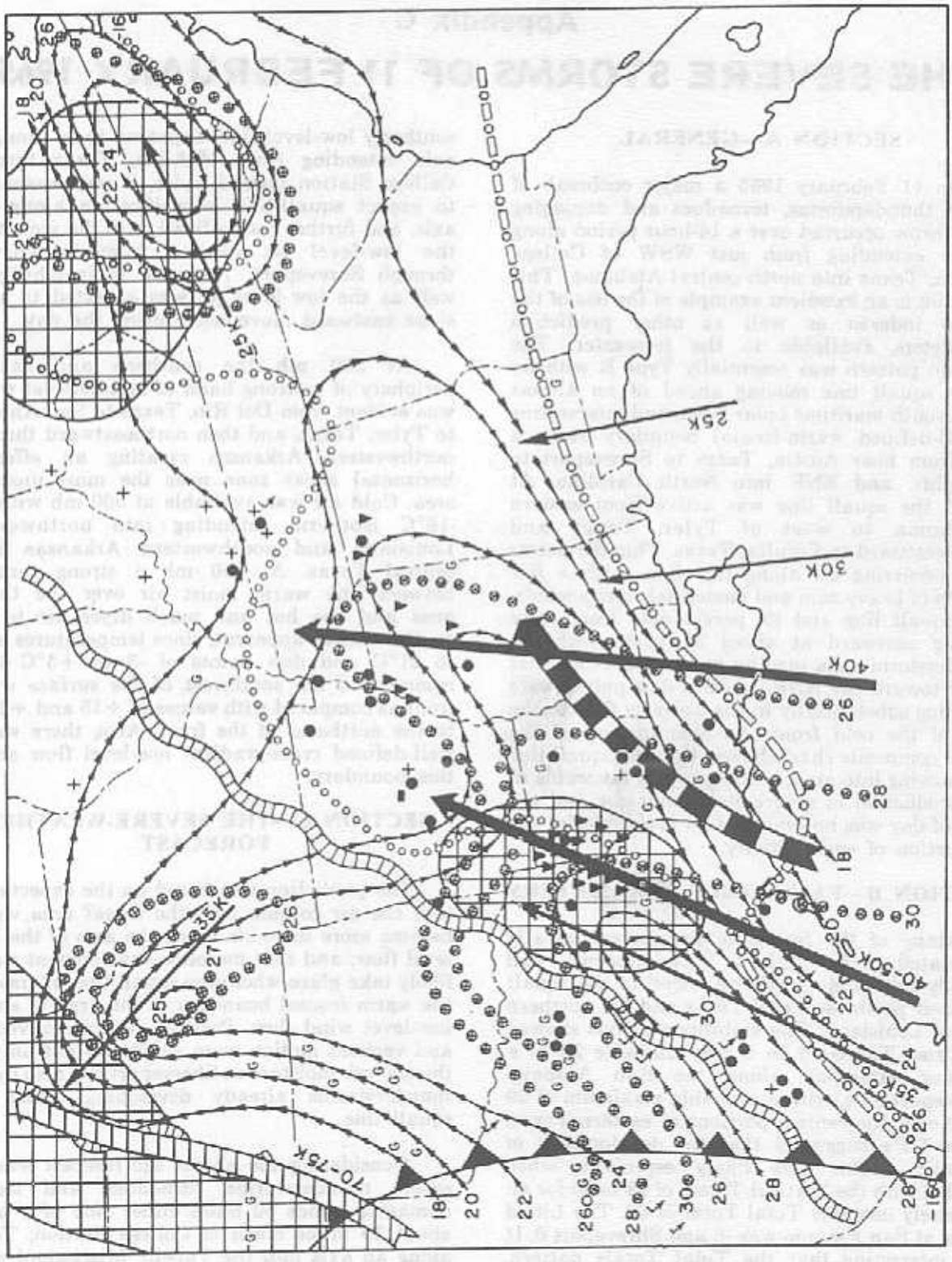

Figure 58 Composite Chart of major features for 1200Z 11 February 1965. Includes the Activity During the Period from 111200Z to 120000Z.

the northeast. However, thunderstorms and moderate to heavy rain would probably continue along the north of the front keeping the lower layers relatively cool and discouraging any significant warm-frontal advance northward. The long axis seemed justified in view of the regular movement of the front and squall line, the general pattern of instability, and the low-level wind and moisture field. Also, the time of day was favorable, and the middle-level jet and its horizontal shear zone was expected to drift eastward. While the Total Totals pattern indicated that thunderstorms would continue during the day and spread eastward with the squall line, there was little or no activity through the Gulf Coastal States. There were two good reasons for this:

a. Supporting 700-mb and 500-mb moisture for convective activity was not in evidence to the south of the warm front.

b. The Vertical Totals were well below the critical value of 26, and the Cross Totals were below the threshold value of 18 over Florida and the coastal sections of Georgia, Alabama, and southeastern Louisiana.

The situation was different over North Carolina and southern Virginia. Vertical and Cross Totals were high with Total Totals of 50. The Moisture was apparent at 500 mb in both the Huntington and Greensboro soundings. Thunderstorms which occurred in the low-level convergence of the warm front before daylight in eastern Tennessee and extreme western North Carolina, were expected to redevelop and spread eastward. While the Totals indexes indicated "green"-type thunderstorms, the coolness of the air near the surface tended to inhibit gusts, and extrapolation placed the activity off the coast before significant surface heating would occur. The intrusion of strong totals northward from Oklahoma into northern Kansas was of considerable interest. This nose of unstable air with a Total Total of at least 52 presented a strong stability gradient over a relatively short distance. The Omaha sounding showed Vertical Total values of 20 and Cross Total values of 19. The strongest southeasterly low-level winds in this region were perpendicular to the horizontal stability-index gradient in north central Kansas and southeastern Nebraska. Also, this region was under the influence of a well-defined middle-level jet of 70 to 75 knots with the horizontal shear to the right of the jet on the order of 20 to 25K/90 nm.

SECTION D—RESULTS AND POST ANALYSIS

The combination of unstable overrunning coupled with the favorable vertical-motion field and deep moisture resulted in 15 to 22 inches of snow on an axis extending from near Concordia, Kansas to Omaha. Most snow accumulation occurred between 110900Z and 111800Z.

The severe activity shown on Figure 58 occurred from 111200Z through 120600Z—a period of 18 hours. The squall line continued eastward and southeastward after the last severe report from Tuscaloosa, Alabama, but weakened rapidly as the squall line moved further away from the parent cold front and into less unstable air. By 121500Z the activity had diminished into rain showers.

Appendix D

THE TYPE B SEVERE-WEATHER OUTBREAK OF 26 NOVEMBER 1965

SECTION A—GENERAL

On 26 November 1965 a strong Type B severe-weather outbreak occurred over Illinois and portions of south central Missouri and northeastern Arkansas. The activity consisted of tornadoes, locally damaging windstorms and isolated large hail which spread east and northeast during the later afternoon and evening from the Bradford, Illinois—Harrison, Arkansas line into southern Michigan, Indiana, and portions of Arkansas, Kentucky, and Ohio. This outbreak was unusually strong for the time of year and was considered worthy of a detailed analysis.

The classification of this storm system as a Type B pattern was determined by a close examination of the 261200Z upper-air charts. Warm and rather dry air was evident over Kansas, Oklahoma and Texas and was being advected to the ENE on a 50- to 55-knot jet in the lower levels (Figure 59). This dry tongue was adjacent to a well-defined pocket of moist air lying over Missouri, eastern Iowa and Illinois. A more southerly low-level jet was evident in this moist air, and extended from Shreveport to Little Rock into western Illinois. A strong cold front was located from southeastern Colorado into east central Nebraska and eastern South Dakota. Dry air over Kansas, Oklahoma, and western Missouri was colliding with cooler and more moist air to the ENE, and was being carried by strong WSW flow at 700 mb (Figure 60). There was a major 700-mb trough moving from the northwest toward the threat area. Strong cold-air advection at 500 mb (Figure 61) was in evidence by an analysis of the isotherms, height, and temperature falls. This analysis indicated that a strong short wave was moving out of the western plains.

All the above factors coupled with the associated 850-mb and 700-mb features suggested a Type B outbreak, with a squall line forming ahead of a moving major surface system and with little likelihood of air-mass recovery, and the repetition of activity usually associated with a Type A pattern.

SECTION B—FAVORABLE PARAMETERS

The parameters associated with the development of severe thunderstorms and tornadoes were present in both number and strength on the 1200Z charts. In addition to the strong convergence in the 850-mb flow between these dissimilar air masses and the approaching cold front, the low-level temperature ridge was lying well to the west of the moisture ridge. Checking this parameter against Table 1 classified this particular feature as *strong*. The low-level jet in both the dry and moist air also was classified as strong. While the low-level moisture barely meets the *moderate* criteria at the 850-mb level, some moisture increase was likely during the day.

The secondary 850-mb dry line extending from southeastern Oklahoma through northwestern Arkansas and central Kentucky south of the Ohio river was also of considerable importance. Its location and future movement determined a southern limiting boundary for activity and a zone of intersection once a squall line developed. Also, intersection of this particular feature with the 850-mb warm front and the low-level jet was a favored area for mesolow development.

At 700 mb the dry-air intrusion was upwind of the threat area and dry and moist air were positioned adjacent to each other from north central Arkansas eastward through Kentucky over the secondary 850-mb dry line. Since the wind flow paralleled this feature over these areas little displacement north or south was expected. The 700-mb no-change line associated with the western trough was well-defined from eastern South Dakota to Topeka, Kansas to central Oklahoma. A second 700-mb no-change line from southern Michigan to the east of Dayton, Ohio to northwest of Nashville was associated with a weakening line of nocturnal thunderstorms. Table 1 classified the western no-change line as *strong* and the wind flow crossed the line at an angle of greater than 45 degrees.

Another important factor to be considered was the strong band of 700-mb winds in the dryer air over Kansas, Oklahoma, and Missouri. This orientation placed the strongest intrusion of dry air against the mid-level moist air west of the Mississippi River in Missouri, and indicated that the zone of steepest moisture gradient and most rapid rate of advective moisture change during

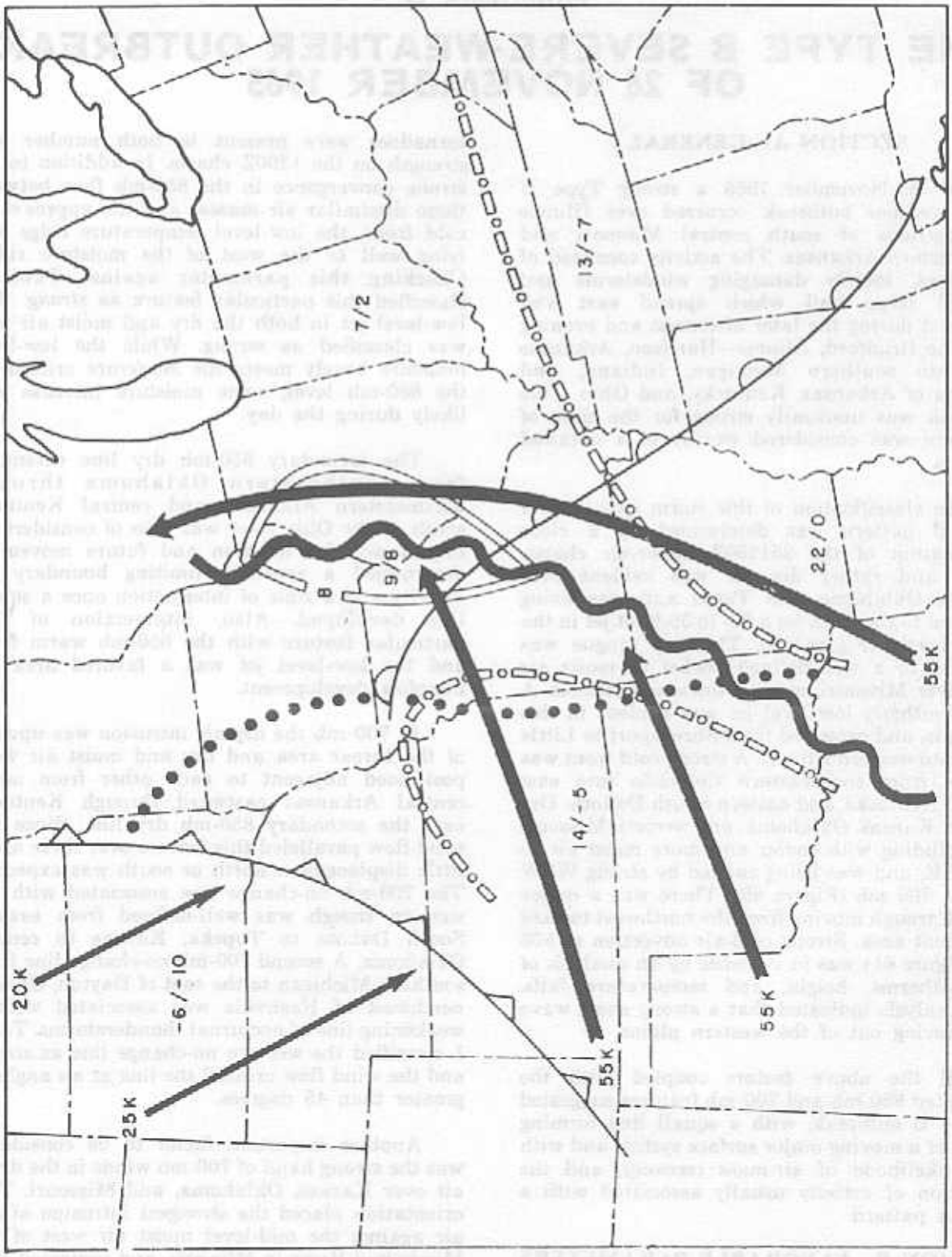

Figure 59. Major features of the 850-mb chart at 1200Z 26 November 1965.

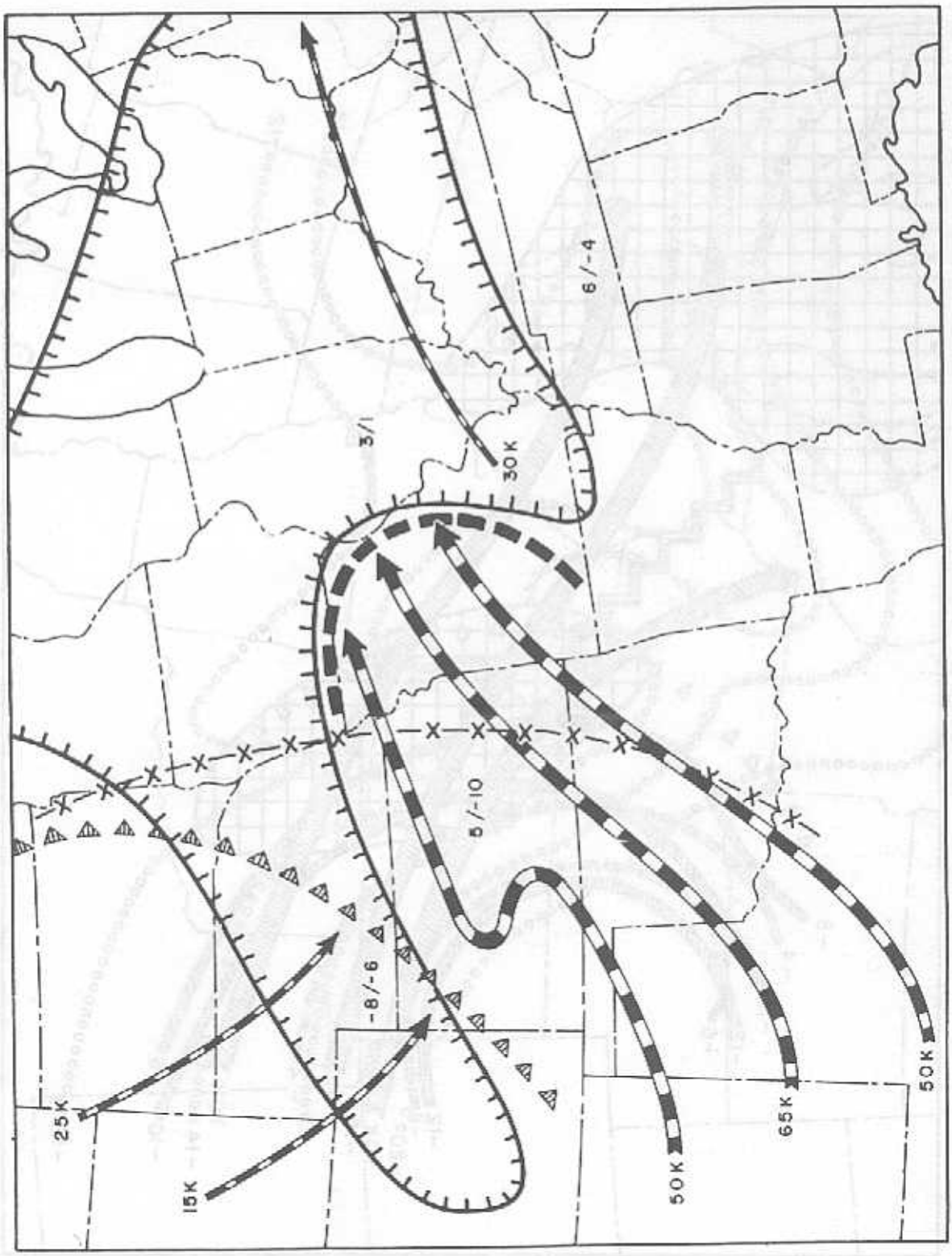

Figure 60. Major features of the 700-mb chart at 1200Z 26 November 1965.

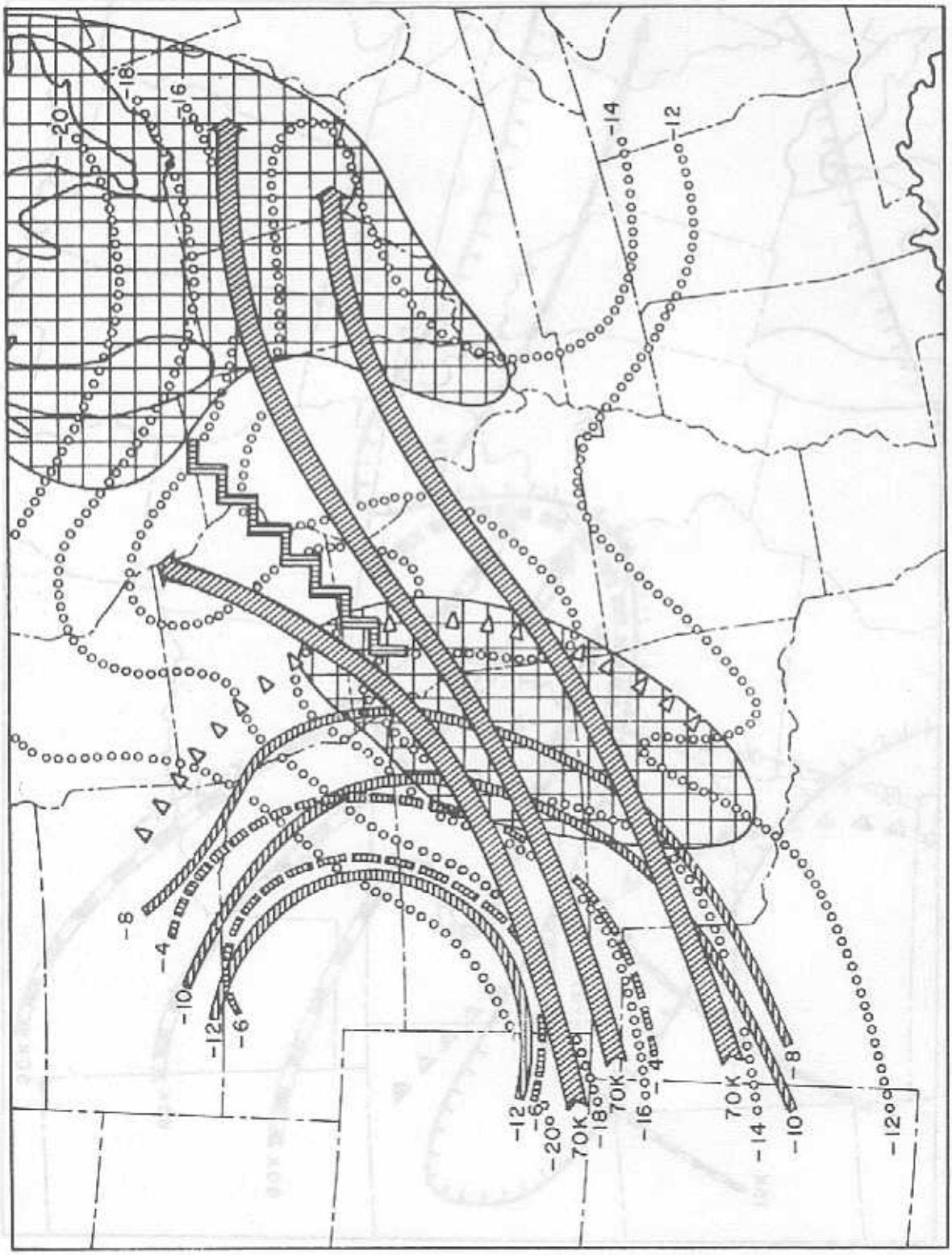

Figure 61. Major features of the 500-mb chart at 1200Z 26 November 1965.

the day would probably lie along the Illinois border southwest of the Springfield-Peoria area.

The 500-mb thermal trough from southwestern Minnesota through central Iowa and central Missouri was favorably oriented to be advected eastward. The cross-isotherm flow was quite strong and indicated continued moist cold-air advection into the warmer tongue to the east. The jet band at this level was broad but well-defined and showed diffluence from north central Missouri into northern Illinois. There was horizontal speed shear to the south of this jet zone which extended from Amarillo to Oklahoma City into southern Illinois and southeast Indiana. The 12-hour temperature and height falls to the rear of the leading thermal trough at 500 mb were indicative of strong active vorticity acceleration. Also, the presence of significant 500-mb moisture at Topeka, Columbia, and Oklahoma City could only be accounted for by vertical motion, since moisture was not advected into the area. Table 1 placed the mid-level jet in the *strong* category and the 500-mb positive vorticity advection from the 1200Z NMC barotropic prog was classified as *strong*.

Considering the remaining parameters from Table 1, the Totals Index (Figure 62) was calculated to be 52 to 54 over south central Iowa as early as 1200Z with a larger area covered by 50's as analyzed. The Lifted Index was calculated to be on the order of minus six. Thus, the available instability met the *strong* criteria.

The 12-hour surface pressure change over southeastern Minnesota and central Iowa amounted to a 12-millibar fall which placed it in the *strong* category. The axis of the Wet-Bulb-Zero heights taken from the 1200Z soundings and shown on the Composite Chart, Figure 63, extended from Dodge City, Kansas to Peoria, Illinois with values near 9,000 feet above the earth's surface. This height is in the *strong* classification as well.

An examination of the 850/500-mb thickness chart showed the thickness ridge to be well-defined from southeastern North Dakota through southwestern Minnesota into central Iowa, central Missouri, and northwestern Arkansas. The ridge was located in the zone of maximum anticyclonic thermal wind shear, the squall-line formation would be close to this ridge line as the line of no 12-hour thickness change (which overlays the 700-mb no-change line) approaches.

SECTION C—POST ANALYSIS OF FORECAST AND OBSERVED ACTIVITY

The surface chart for 1800Z shows the major surface features associated with the morning upper-air patterns. This chart was one hour prior to the first indication of squall-line development picked up on radar. A line of thunderstorms and rainshowers, began forming along the maritime polar front along the Ottumwa, Iowa—Kirksville, Missouri—Sedalia, Missouri line at 1900Z, and by 2200Z an active and severe squall line was located from southwest of Rockford, Illinois to east of Peoria, Illinois through Springfield, Illinois and southwestward to a point northwest of Harrison, Arkansas. The first severe reports were the destructive tornado northeast of Peoria and a windstorm near St. Louis at 2200Z, and 35-40-knot thunderstorm gusts at many stations along the squall line.

By 270800Z the squall line had moved to a position from eastern Ohio, through eastern Kentucky, to Tuscaloosa, Alabama, to Lafayette, Louisiana, and had degenerated into a line of heavy showers accompanied by strong northwest gusts.

The salient features, from the 1200Z charts discussed above, are shown on the Composite Chart Figure 63, along with the reported activity for the 26th of November. A check of the 1800Z surface pattern showed that the initial squall-line development occurred very close to the maritime polar front from the low center southward through Iowa and north central Missouri. This development was very close to the 1200Z position of the 850/500-mb thickness ridge and ahead of the morning position of the 700-mb and 850-mb lines of no-temperature change. Intense low-level convergence was expected between the advancing dry low-level air and the moist air further east since the low-level jet and moisture ridge will tend to hold, or even curve cyclonically, because of the position of the deep surface low. This convergence was expected to cause a strong moisture gradient close to the surface front shortly after noon. The 700-mb dry intrusion was leading the low-level dry tongue which is a favorable condition for severe activity. The result of all of these features, coupled with the apparent cooling in the thermal trough at 500 mb, was expected to result in eastward displacement of the area of greatest instability to a position just west of the 1200Z position of the low-level jet.

The broad middle-level jet pattern and the availability of the middle-level dry air upwind, over a rather broad north-south front, indicated that once the squall line developed it would affect a large area in its eastward movement. The large instability area also indicated a widespread pattern of severe weather. Since the most favorable location for family-type tornado outbreaks with the Type B pattern is usually

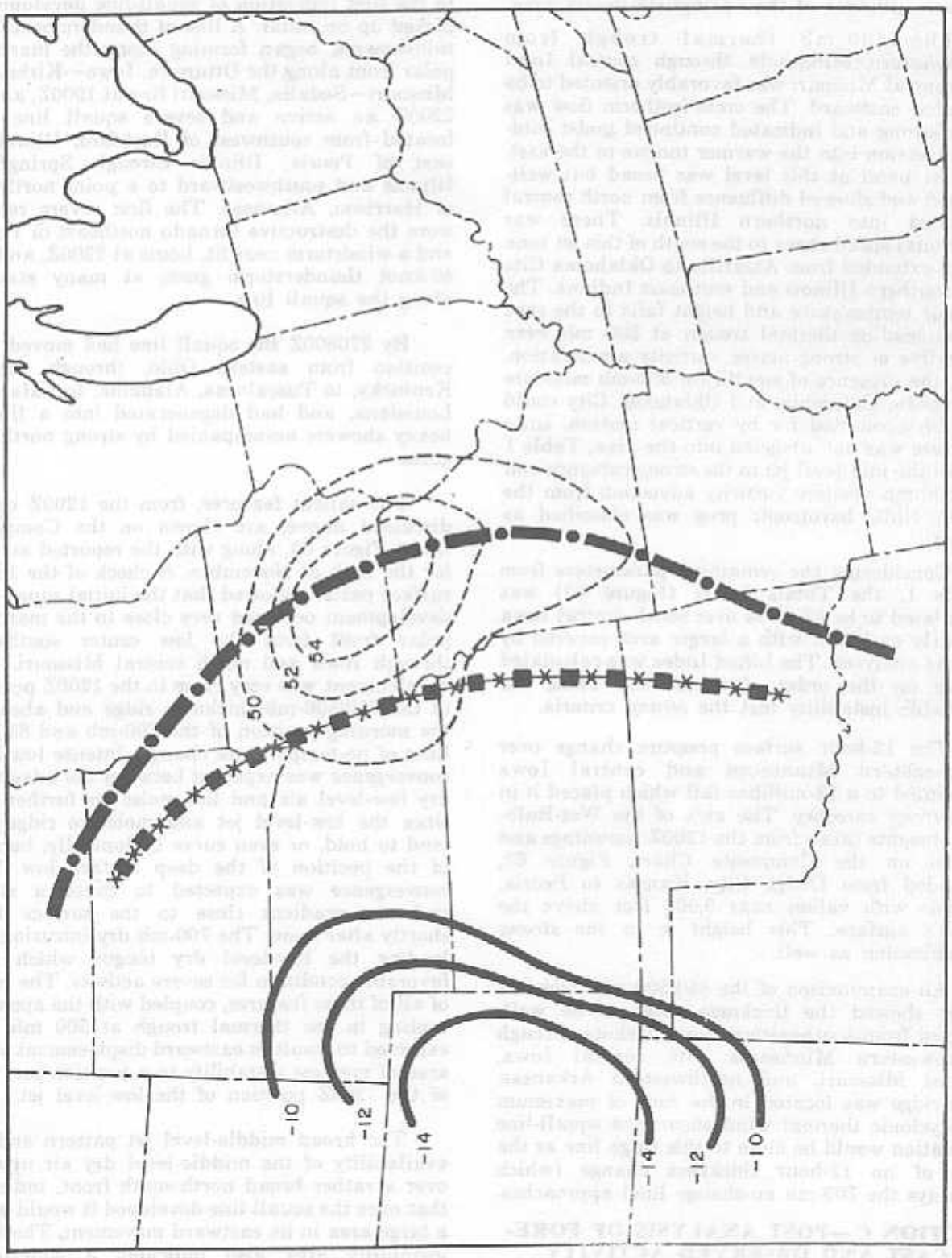

Figure 62. Total Totals analysis and 850/500-mb thickness change at 1200Z 26 November 1965.

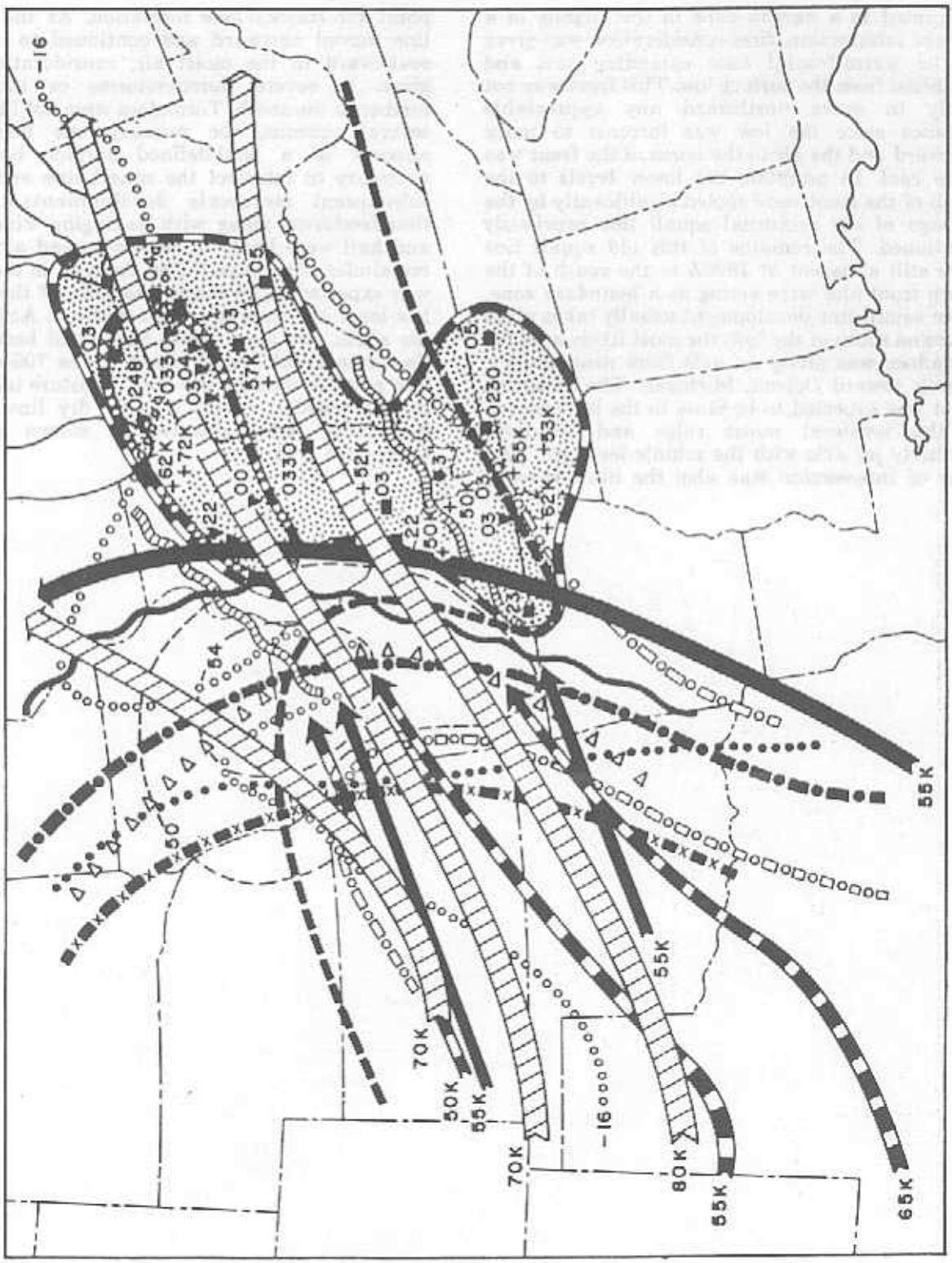

Figure 63. Composite Chart of the 1200Z 26 November 1965 data. Includes the severe activity during period 260000Z to 261200Z.

associated in a narrow zone in the vicinity of a surface intersection, first consideration was given to the warm-frontal zone extending east and southeast from the surface low. This front was not likely to move northward any appreciable distance since the low was forecast to move eastward and the air to the north of the front was quite cool. In addition, the lower levels to the south of the front were cooled significantly by the passage of the nocturnal squall line previously mentioned. The remains of this old squall line were still apparent at 1800Z to the south of the warm front and were acting as a boundary zone. Since squall-line development usually takes place near and south of the low, the most likely area for tornadoes was along an axis from near Quincy, Illinois toward Detroit, Michigan. The inception point was expected to be close to the intersection of the low-level moist ridge and low-level southerly jet axis with the middle-level jet. This area of intersection was also the most favored point for mesocyclone formation. As the squall line moved eastward and continued to develop southward in the moist air, consideration was given to severe thunderstorms or tornadoes further to the south. Tornadoes were not likely for several reasons, the primary one being the absence of a well-defined surface boundary necessary to intersect the squall line and cause subsequent mesoscale developments. Severe thunderstorms along with damaging wind gusts and hail were likely to be widespread along the remainder of the squall line. Activity in the north was expected to be limited because of the cooler low-level air north of the warm front. Activity in the south was expected to be limited because of the presence of dry air south of the 700-mb dry line and the shallow low-level moisture indicated by the position of the 850-mb dry line. These boundaries were effective as shown on the Composite Chart.

Appendix E

THE TOPEKA, KANSAS, TORNADO OF 8 JUNE 1966

SECTION A—GENERAL

The Topeka, Kansas tornado of 8 June 1966 is an interesting study of the feasibility and value of the forecast parameters of Table 4 over a rather restricted area. The use of the forecast parameters resulted in a successful operational tornado forecast for the morning of the 8th. The forecast was based on the 08/1200Z surface and upper-air data, and 09/0000Z data presented a point in time midway between the first tornado occurrence in central Kansas and the last in northwest Missouri. The destructive storm at Topeka began almost at 09/0000Z.

SECTION B—STORM HISTORY

The first tornado was reported shortly after 08/2100Z just south of Great Bend in central Kansas and the last near 09/0230Z north of Kansas City. Evidence indicates that there were two major tornado tracks associated with the storm system (Figure 77). The first track extended from south of Great Bend, Kansas, across Topeka and ended at the southwest corner of Midcontinent Airport, 15 miles north of Kansas City. The second was from north of Salina, Kansas, across Manhattan, Kansas, to just southwest of St. Joseph, Missouri. Also, a third storm track of lesser intensity extended from Hutchinson, Kansas, to just southwest of Olathe, Kansas. The number of tornadoes involved is unknown but examination of the various tracks indicated the probability of 6 to 8 individual storms within the system. The Topeka tornado began on the ground from about 30 miles WSW of Burnett's Mound on the southwest edge of Topeka, continued across the city, and went aloft at the northeast corner of Topeka. The storm then moved eastward in a skipping fashion with the last visible damage at Midcontinent International Airport in northwest Missouri. This track would indicate a path of total and intermittent destruction of some 65 miles.

The Topeka storm is a particularly good example of the Type B tornado pattern. Figures 64 through 77 show the salient features of the surface and upper-air analyses including a plot of the activity reported. The isolated windstorm shown southwest of Lincoln, Nebraska was associated with the northern portion of the squall line (Figure 77), and under an area of diffluence at the jet level (Figure 68). This activity was short-lived since it was well north of the surface warm front. The activity in central Oklahoma occurred along the western edge of the 850-mb and 700-mb moist tongue where strong moisture was present in an area of moderate horizontal speed shear just east of the 500-mb cold trough. Also, a large angle of intersection existed between the strong low-level jet and the speed shear zone.

The single hailstorm east of Quincy, Illinois, occurred near the surface warm front under the strong eastern 700-mb dry intrusion, and reasonably close to the upper jet.

The Quincy storm cell was moving rapidly under the influence of the strong middle-level flow, and the tornado reported northeast of Rantoul, Illinois, was associated with this system. The early morning outbreak on the 9th in Chicago and the activity in northwest Missouri of the previous evening were most likely connected with the Topeka storm complex. A study of the movement of the upper jet indicated that the storm impulse steered along the track of the upper jet (Figure 75). The speed of translation was about 37 knots which is compatible with the strength of the middle- and upper-level flow.

SECTION C—DISCUSSION OF THE PARAMETERS

Table 5 summarizes the parameters affecting the threat area at 08/1200Z and 09/0000Z. From the 08/1200Z data it is apparent that only two weak parameters (instability and a high Wet-Bulb-Zero height) would have to be more favorable in order that severe thunderstorms or tornadoes could be confidently forecast. Most parameters usually appear weak in the early morning data so the severe-weather forecaster has to carefully and correctly assess the changes to be expected in space and time to arrive at an accurate forecast of the threat area and the start of activity. However, in the Topeka case, the 1200Z data indicate that nearly all of the parameters favor the development of severe weather. Early morning thunderstorms modified the Topeka sounding resulting in a moist and quite stable air structure. A careful study of the 1200Z Composite Chart (Figure 70), in

Table 5 - Summary of Topeka Parameters

	1200Z		0000Z		
	VALUE	Rating	VALUE	Rating	SOURCE OF DATA
500-mb Vorticity	Yes	S	Yes	S	Barotropic or Baroclinic Prog
Lifted Index	±0	W	-6	S	Plotted Sounding
Totals	35	W	54	M	Thickness Chart
Mid-Level Horizontal Shear Zone	45K/90 nm	M	55K/90 nm	S	500-mb Chart
High-Level Horizontal Shear Zone	100K/90 nm	S	95K/90 nm	S	Jet Chart
Low-Level Jet	45K	S	35K	S	850-mb Chart
Low-Level Moisture (Dew Point)	10°C	M	15°C	S	850-mb Chart
850-mb Max-Temp Field	West of Moist Ridge	S	West of Moist Ridge	S	850-mb Chart
700-mb No-Change	40°/35K	M	80°/35K	S	700-mb Chart
700-mb Dry Intrusion	40°/40K	M	60°/35K	S	700-mb Chart
12-hr Sfc Pressure Falls	-	-	-6.3-mb	S	Sfc Chart
500-mb Height Change	-50M	M	-60M	M	500-mb Chart
Height of Wet-Bulb-Zero	11,600 ft	W	9,800 ft	M	Plotted Sounding
Sfc Pressure Threat Area	1009.3 mb	M	1003 mb	S	Sfc Chart
Sfc Dew Point	64°F	M	70°F	S	Sfc Chart
Winds Veer With Height	Yes		Yes		Composite Chart
Speed Differential	No		Yes		Composite Chart
Intersecting Upper & Lower Jets	Yes		Yes		Composite Chart
Increasing Sfc Temp	Yes		+11°F		Surface Chart
Falling Pressure	Yes		-6.3 mb		Surface Chart
Increasing Dew Point	Yes		±6°F		Surface Chart
Thickness Ridge Apparent	Yes		Yes		Thickness Chart
Thickness No-Change	Yes		Yes		Thickness Chart
Level of Free Convection	770 mb		790 mb		Plotted Sounding
Favorable Synoptic or Mesopattern	Yes		Yes		Surface Chart

conjunction with the surface map (Figure 64), definitely placed the eastern half of Kansas and northern Missouri in the primary threat area. The surface low was progged to move ENE at 20 knots. This movement would cause the axis of maximum pressure falls to traverse the area and the warm front would provide a boundary of intersection for any squall line. The warm front was not expected to move northward rapidly because the early morning squall line (Figure 64) had cooled the air over much of eastern Kansas and western Missouri slowing the northward spread of warm air at the surface. The positions of the 500-mb, 700-mb and thickness no-change lines, and the location of the thickness ridge, indicated favorable conditions for squall-line development. Also, deep cold advection was moving into the area of increasing temperature, dew point, and instability over central Kansas and western Oklahoma during the afternoon (Figure 69). As shown on the surface chart the squall line formed from northwest of Salina to southwest of Hutchinson, Kansas, about 2000Z, and gradually grew to the north and south (Figure 64).

As shown in Table 5, the parameters at 0000Z had intensified. Tornadic storms had been occurring for three hours prior to 0000Z and the Topeka tornado occurred at 0015Z. At 1200Z a summary of the parameters showed 4 strong, 7 moderate, and 2 weak compared with 12 strong, 3 moderate and none weak at 0000Z. These are the static values taken directly from the data with no adjustments for anticipated changes. In actual forecast practice both sets of data would be further adjusted. For example, the 1200Z data would be adjusted for the threat area at the expected time of development. Such an adjustment should bring the parameters more in line with the actual conditions at 0000Z. The two weak parameters would be modified by the addition of heat and moisture in the low levels, coupled with dryer advection in the middle levels, and cooling in the upper levels. Other considerations of the surface and upper-air patterns would indicate several of the moderate-rated parameters should increase in intensity. In addition, the 12-hour surface-pressure fall forecast would be rated moderate to strong based on the track and forecast pressure near the low center. A similar procedure would be used for the remaining parameters. All values shown are for the Topeka area which was the center point of the most destructive activity.

SECTION D—SUMMARY

The Composite Chart at 09/0000Z (Figure 76) is an excellent example of the concentration of the important and varied tornado-forecast parameters in a geographically restricted area. The primary area of instability represents Total Totals of 54. The moist ridge at 850-mb and the low-level jet are in perfect alignment. The 850-mb temperature ridge is west of the moist tongue and dry air is available upstream to the west and southwest of the threat area. At 700-mb dry air is available upwind of the threat area and is being advected into the area at 35 knots by WSW winds. The 700-mb no-change line is well-defined and near the surface squall line. The thickness ridge has moved to the east of the area and the squall line is located about 100 miles behind it. The upper-level jet tranverses the threat area and is significantly stronger than the low-level jet. The two jets intersect at a large angle. The presence of so many of the forecast parameters of strong intensity over a large area is no more unusual than the frequency of destructive tornadoes associated with family-type storms. It is when these parameters are concentrated over a particualr area that the more widespread and violent outbreaks occur.

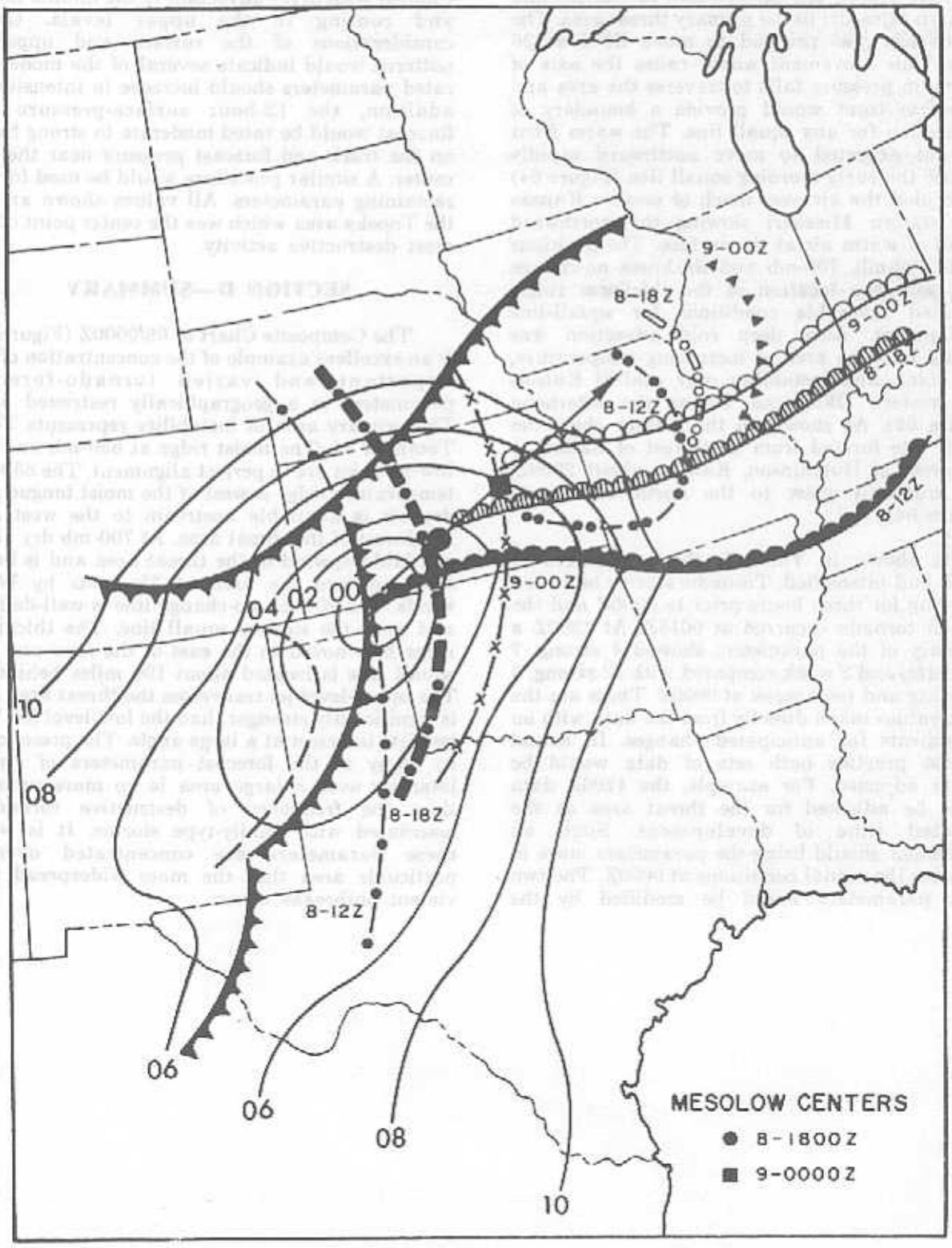

Figure 64. Location of major surface features during period 08/1200Z to 09/0000Z. Isobar analysis is for 08/1200Z.

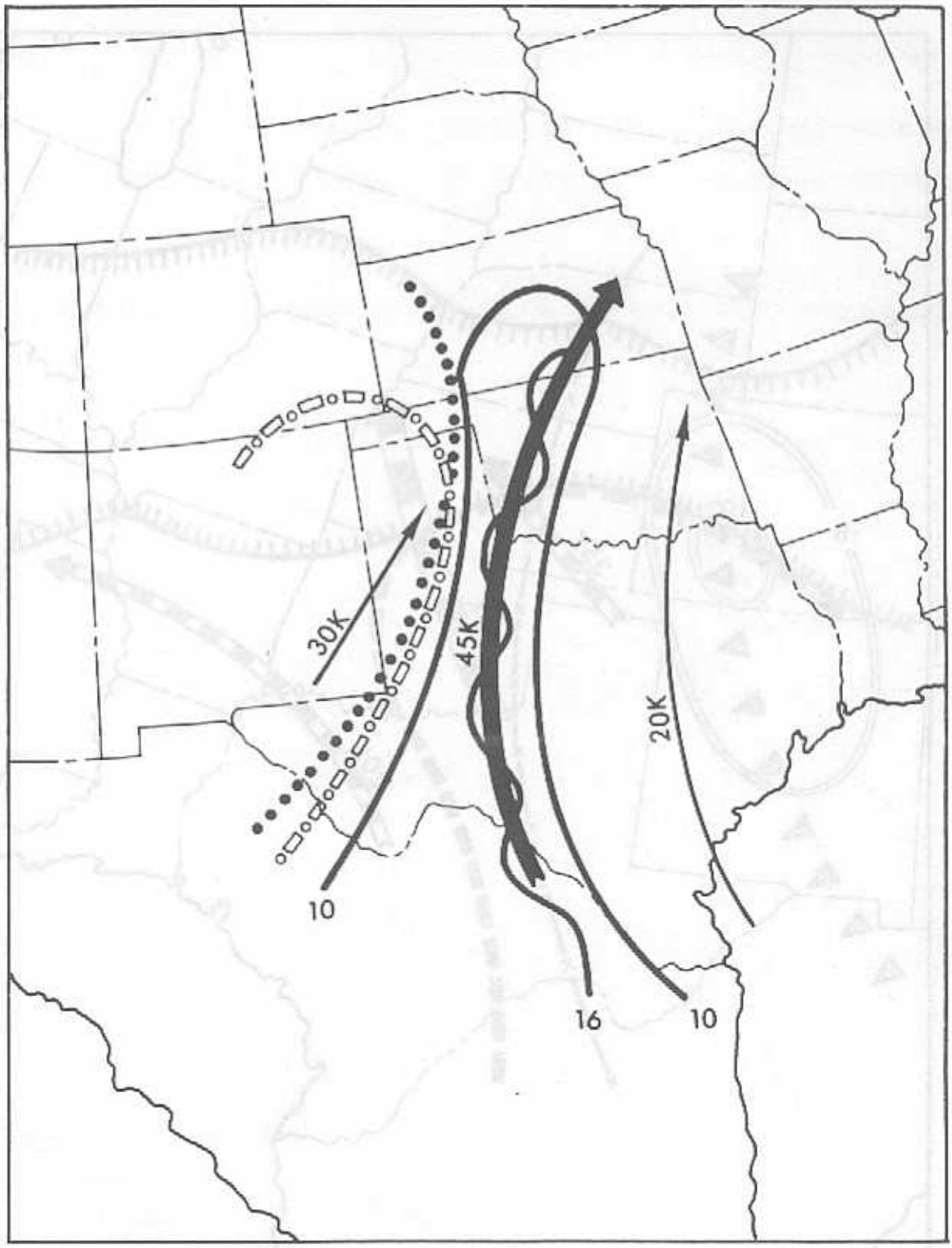

Figure 65. Major features of 850-mb chart for 08/1200Z. Solid-line isopleths are dew points.

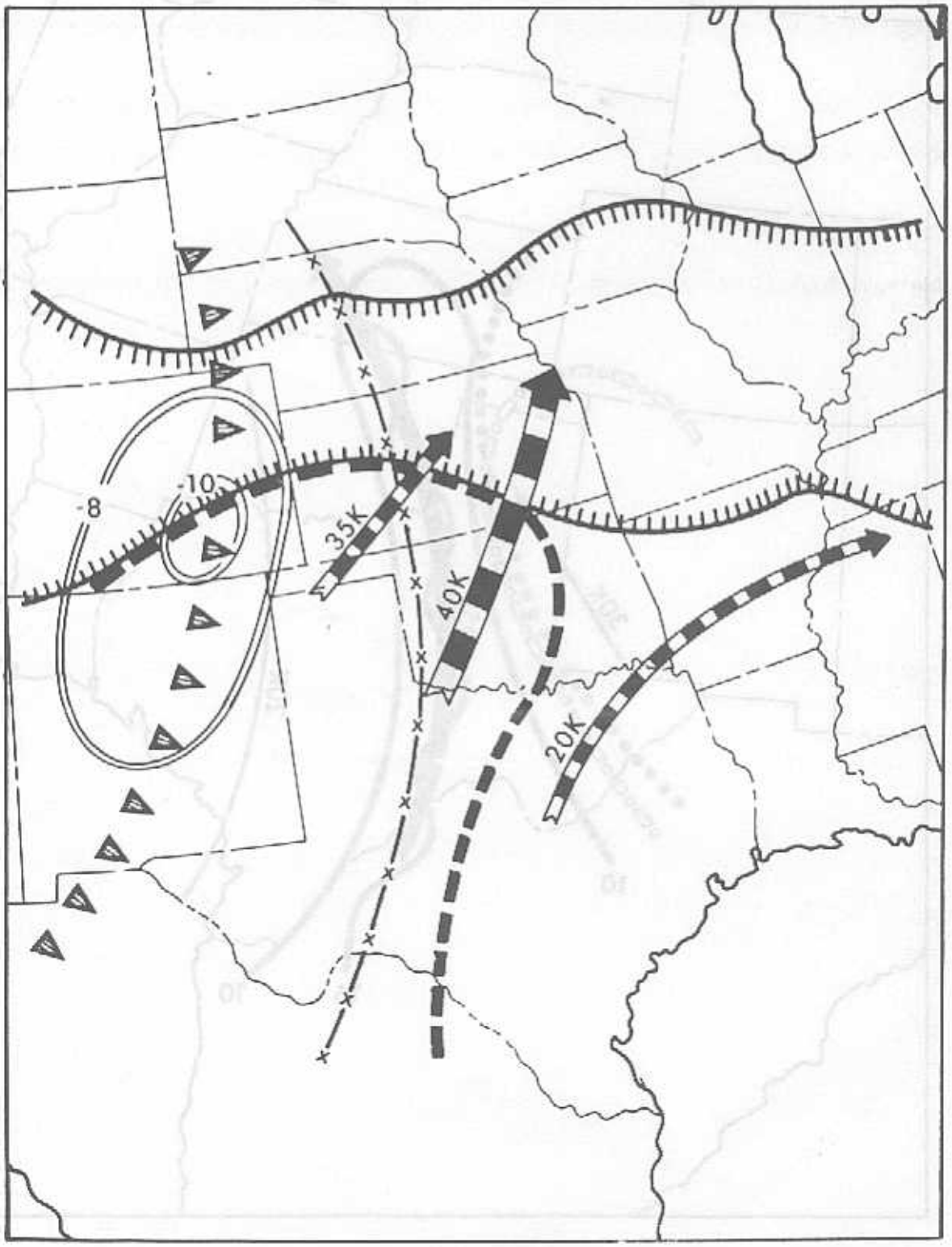

Figure 66. Major features on 700-mb chart for 08/1200Z.

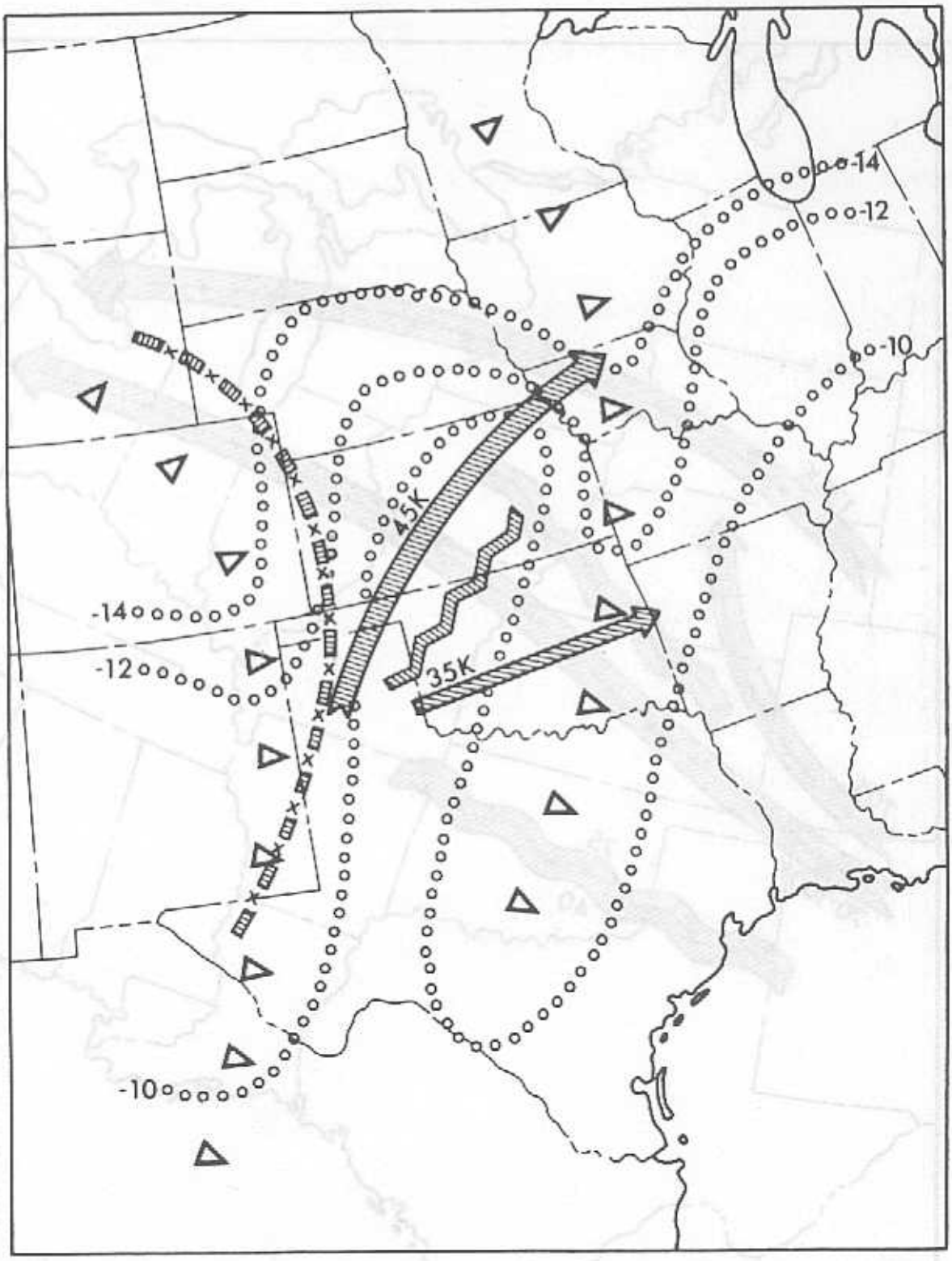

Figure 67. Major features on 500-mb chart for 08/1200Z.

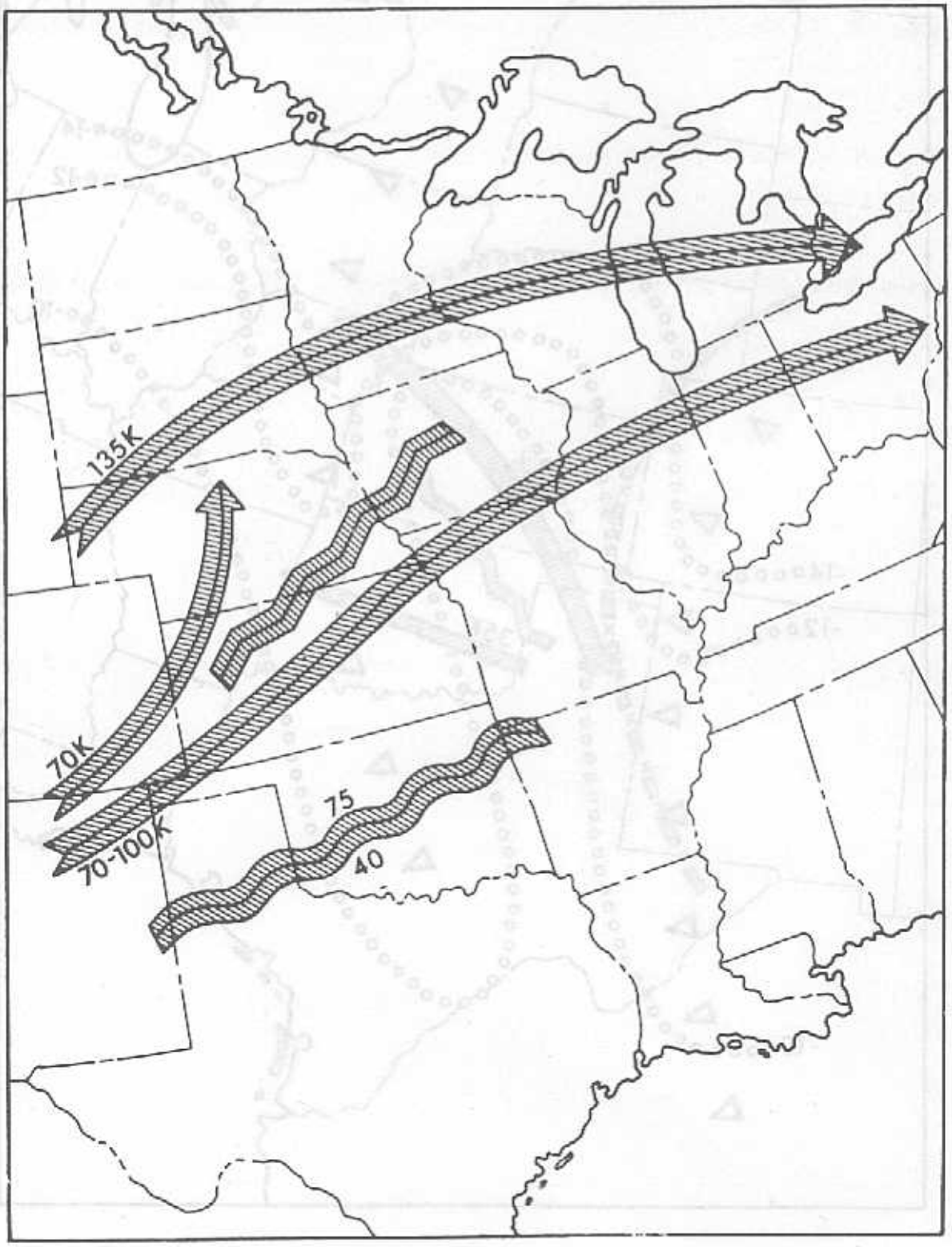

Figure 68. Upper-level jet features at 08/1200Z.

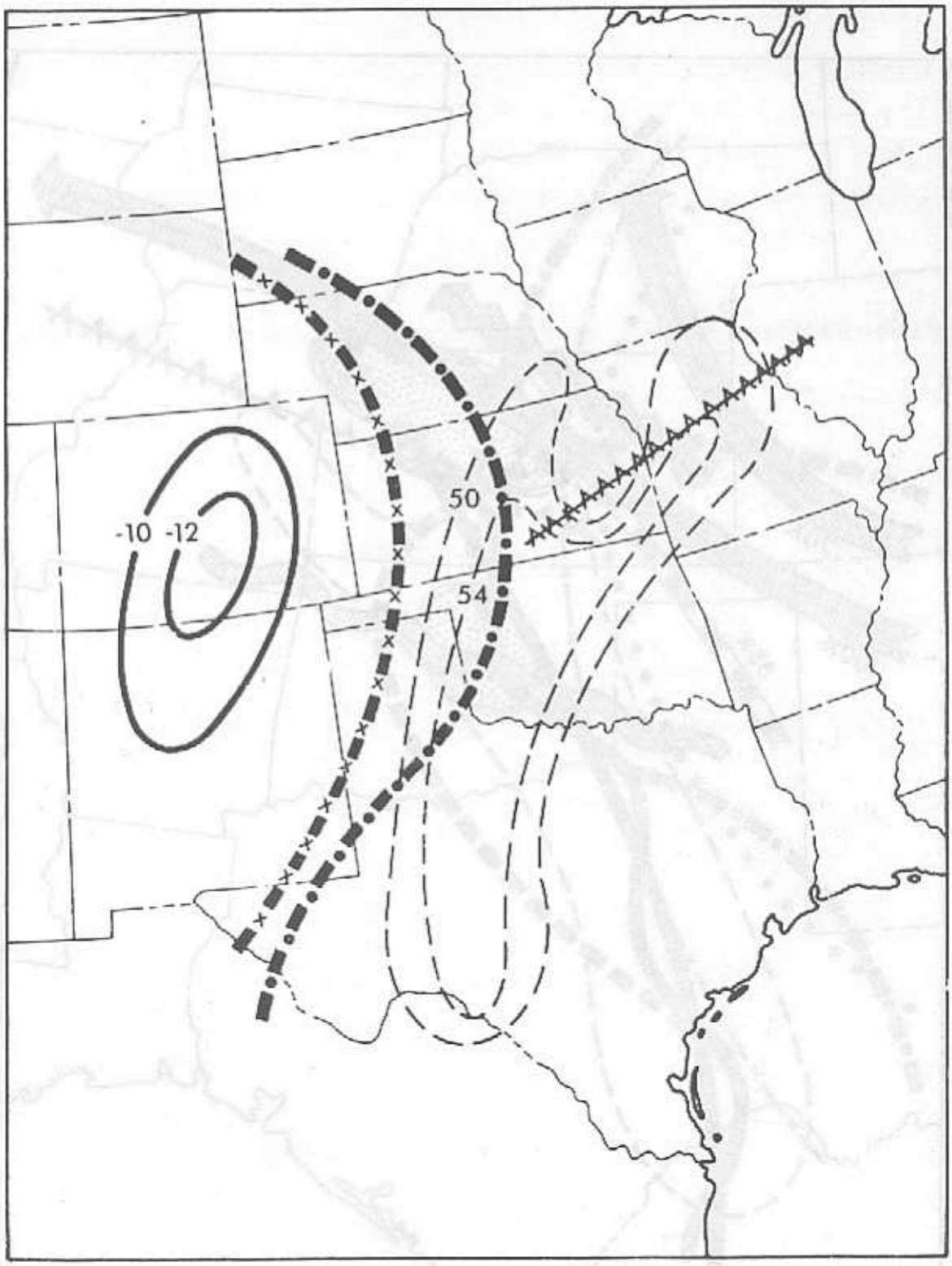

Figure 69. Thickness change, no-change line, thickness ridge line, and Total Totals at 08/1200Z. Also shows zone of anticyclonic wind shear.

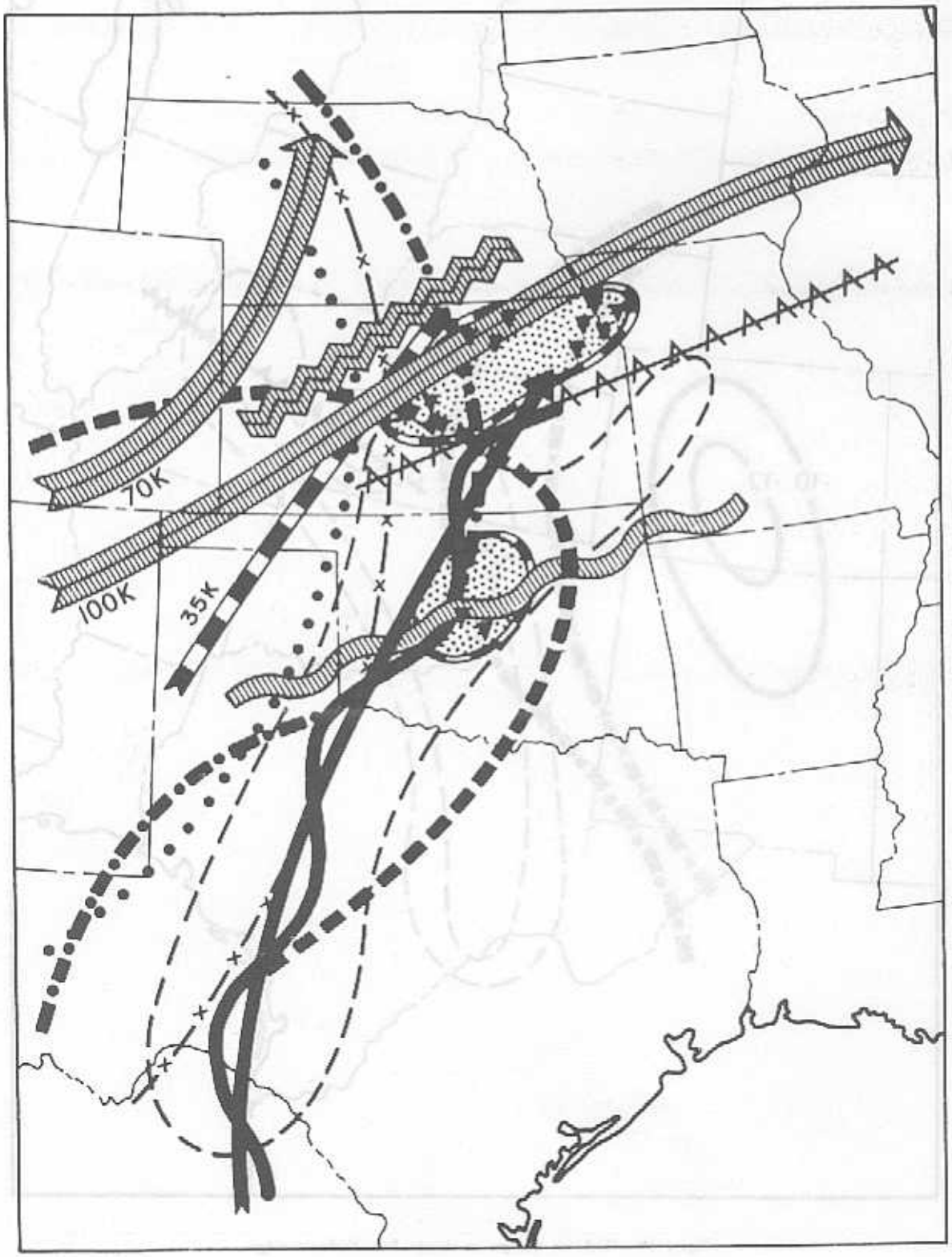

Figure 70. Composite chart for 08/1200Z. Stippled areas show activity during period 08/1200Z to 09/0000Z.

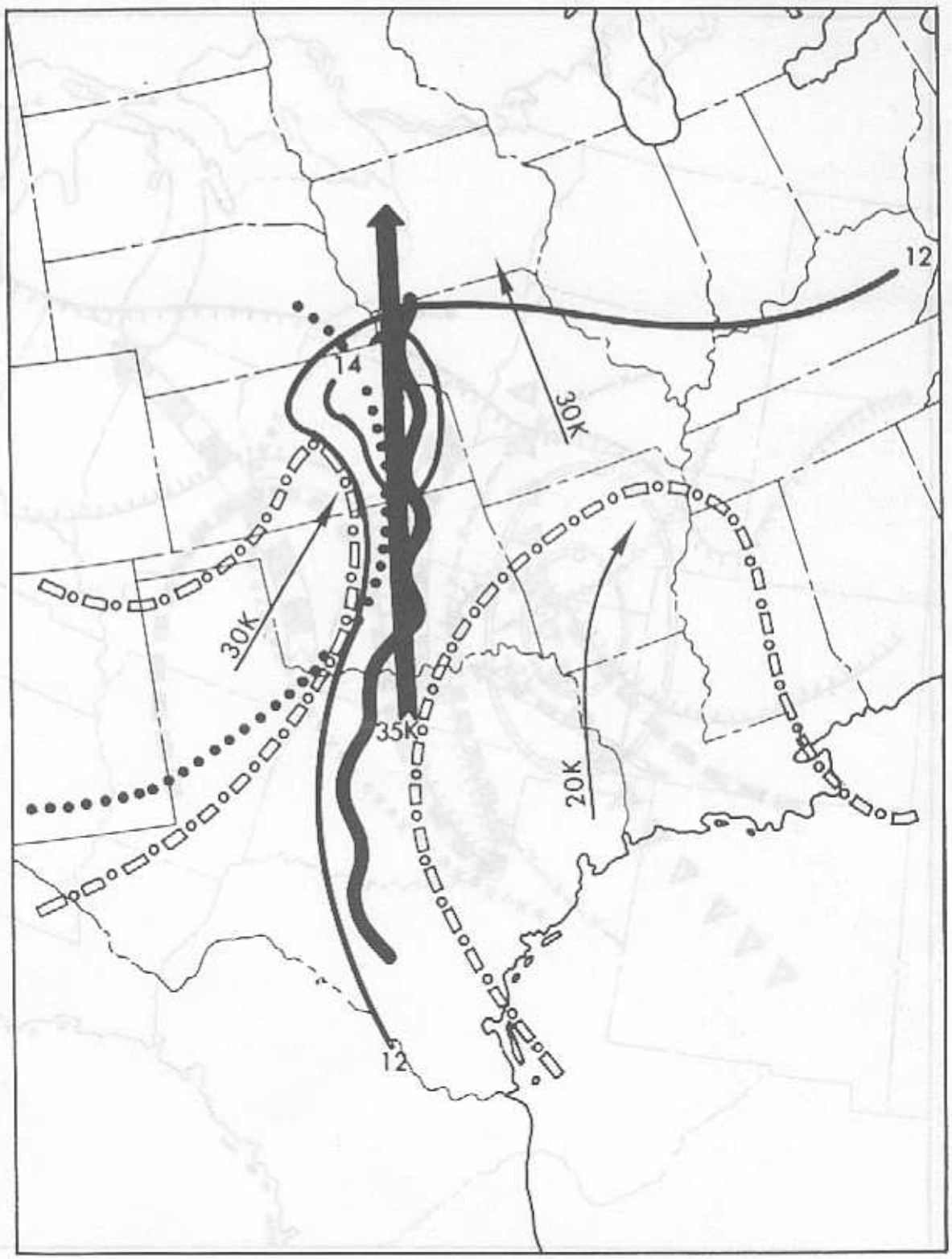

Figure 71. Major features of 850-mb chart for 09/0000Z. Isopleths are 850-mb dew points.

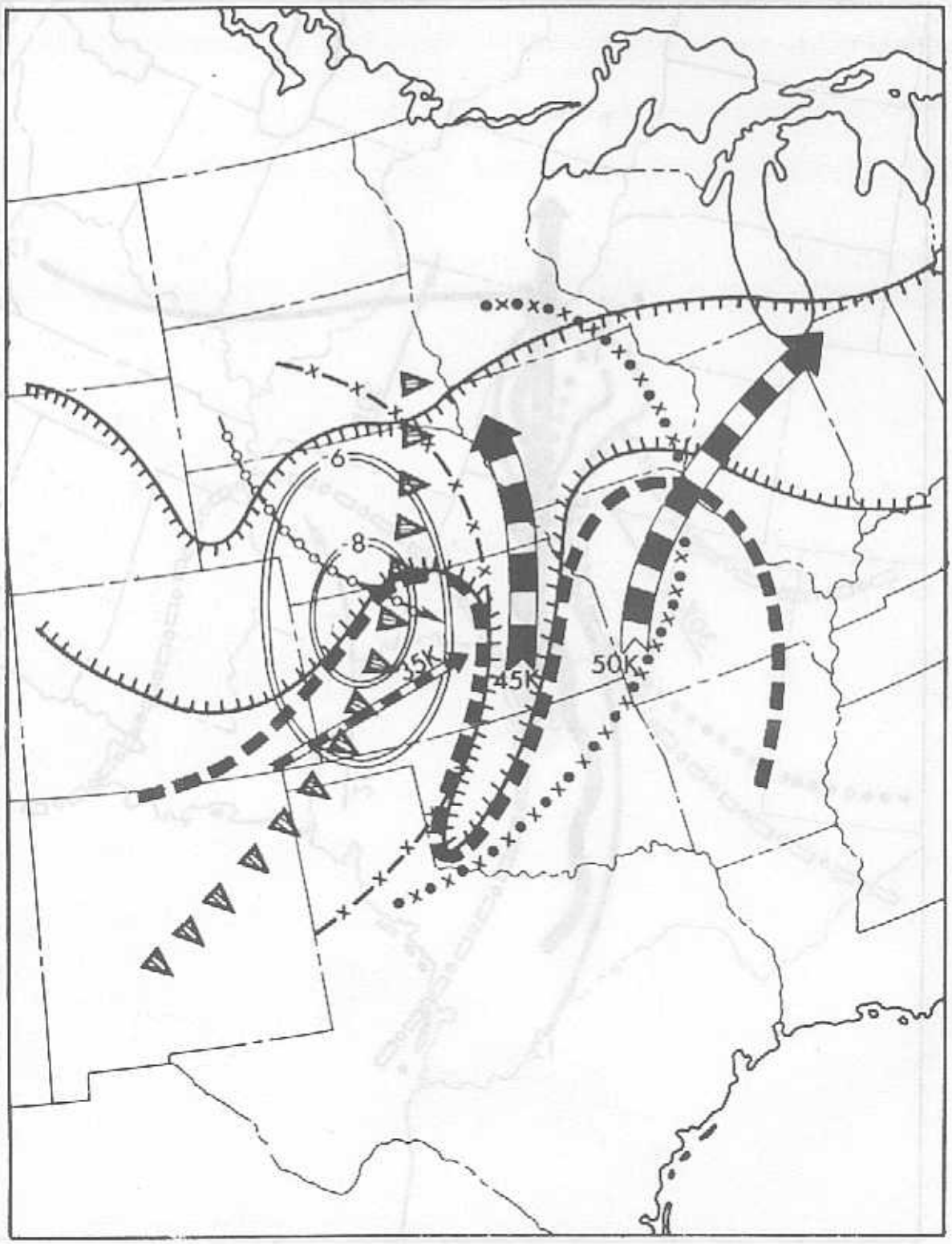

Figure 72. Major features of 700-mb chart at 09/0000Z. Arrow is the direction of the axis of cold air advection.

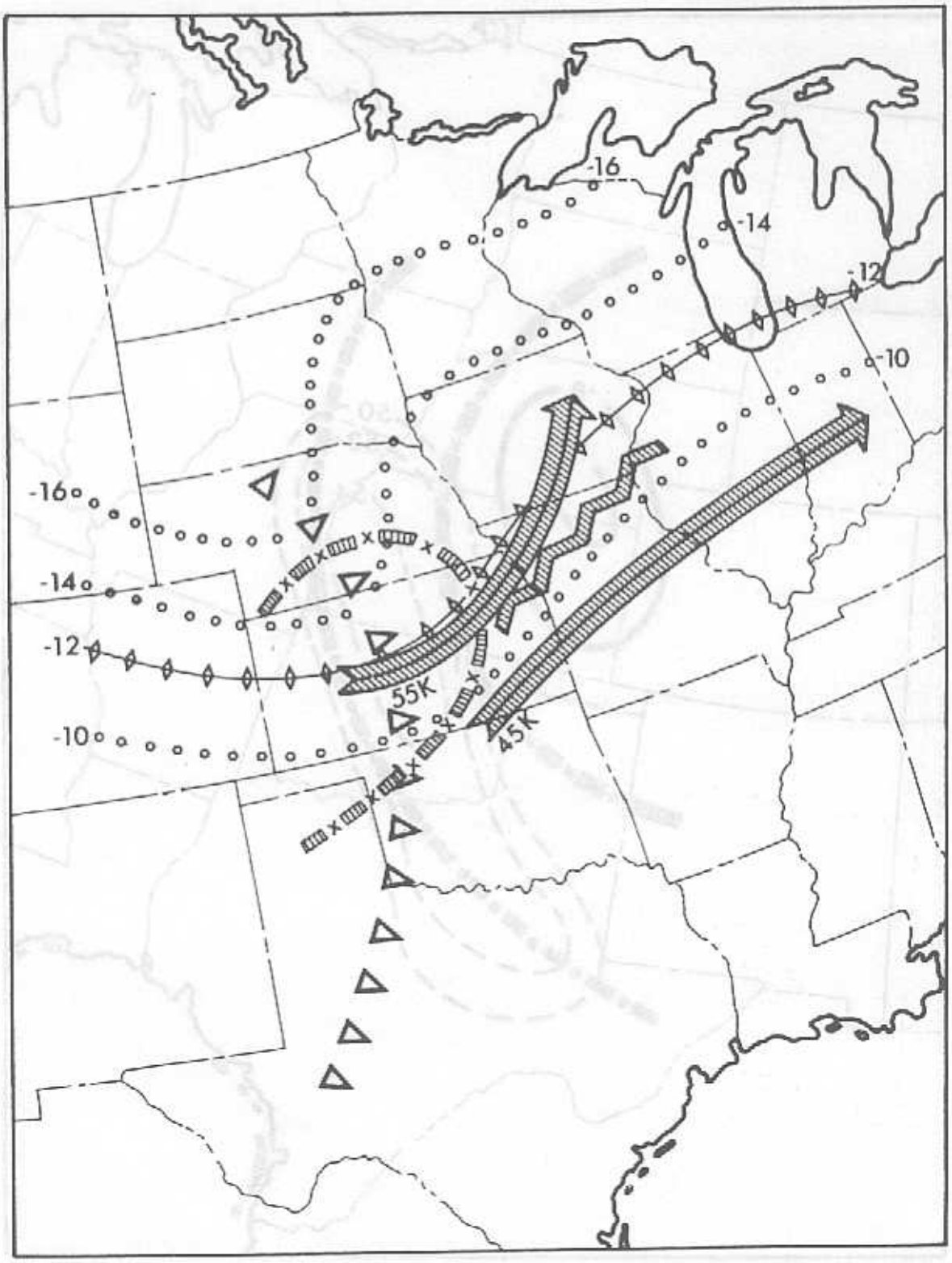

Figure 73. Major features on 500-mb chart at 09/0000Z. Note the -12°C critical temperature line

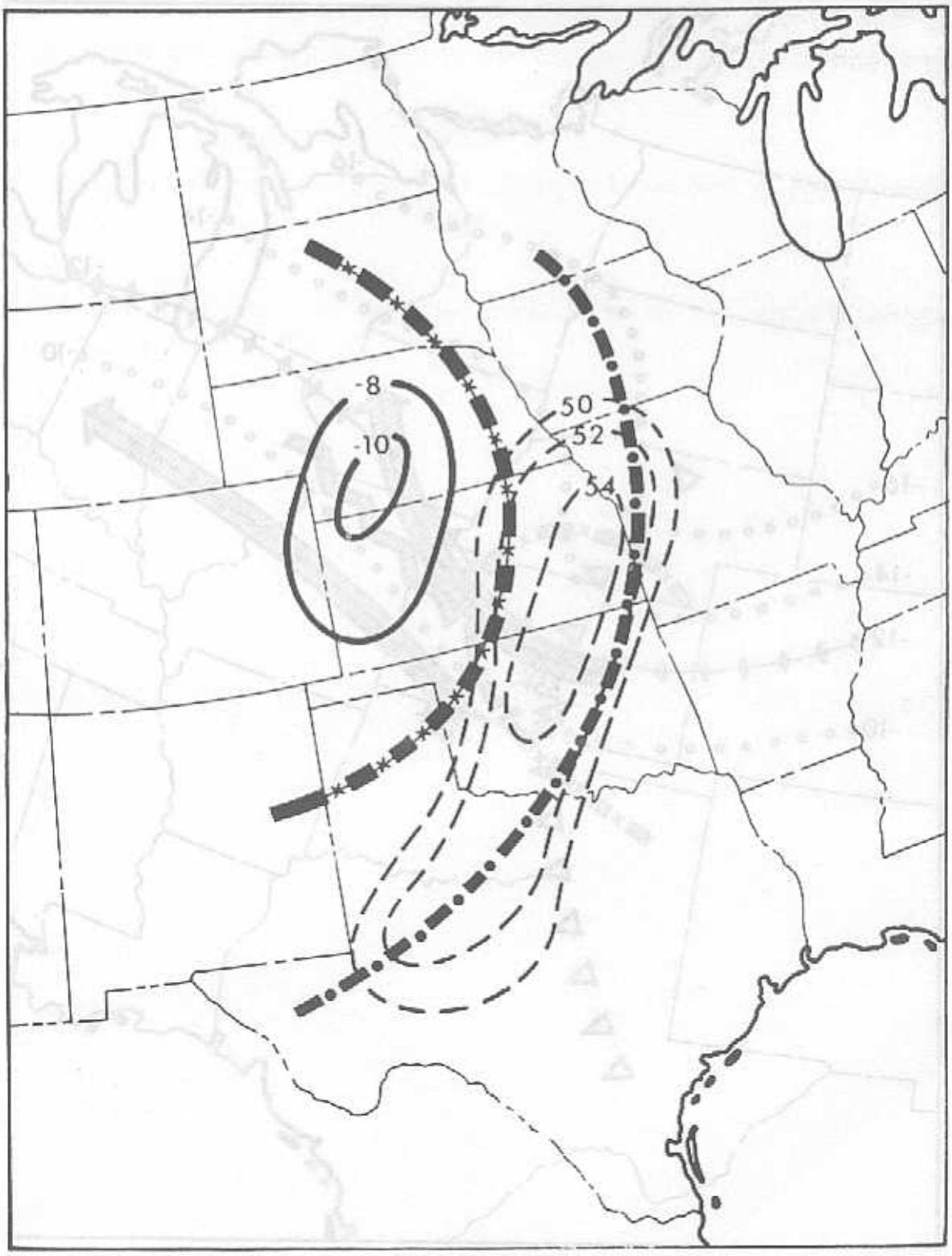

Figure 74. Thickness parameters and Total Total analysis for 09/0000Z.

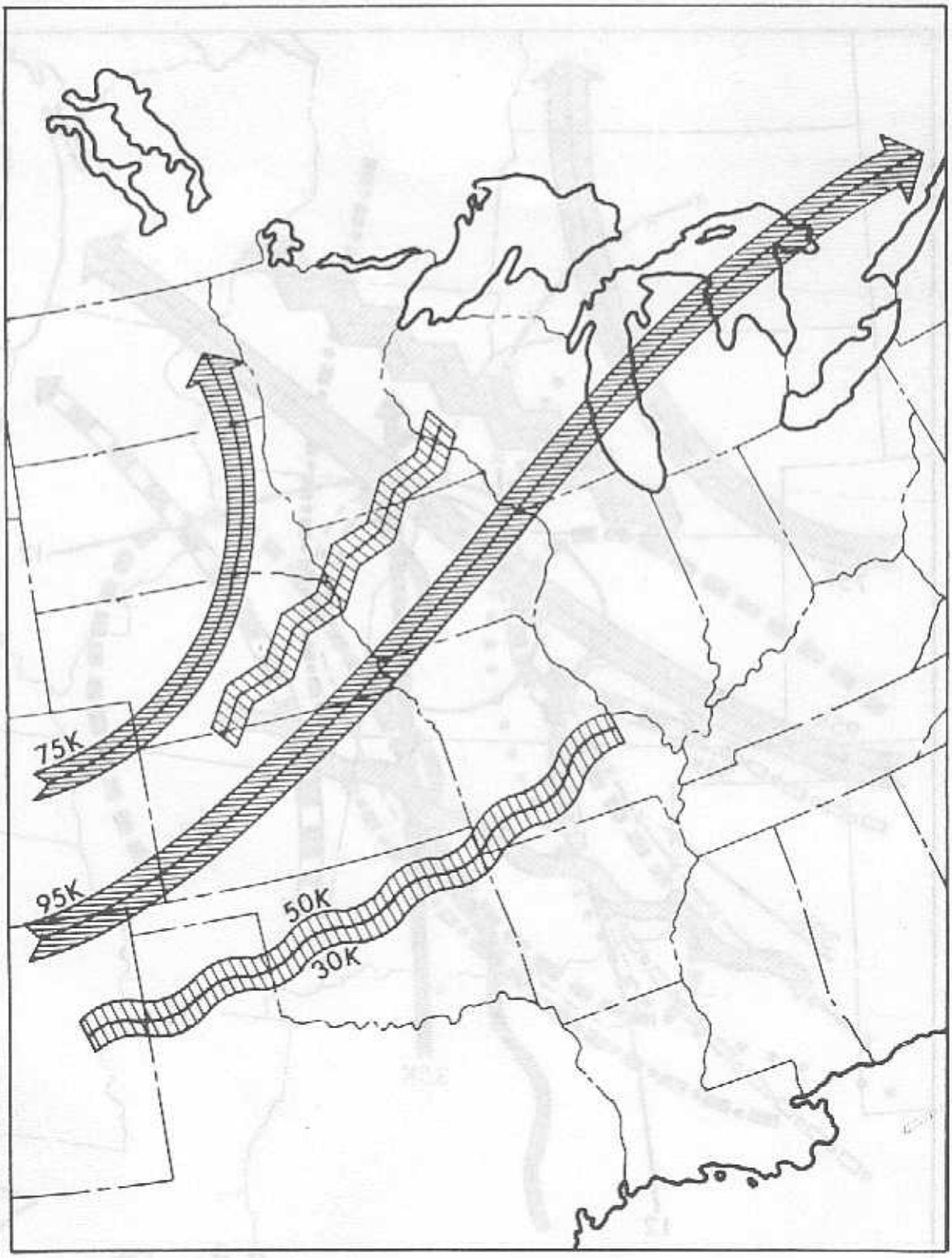

Figure 75. Upper-level jet features at 09/0000Z.

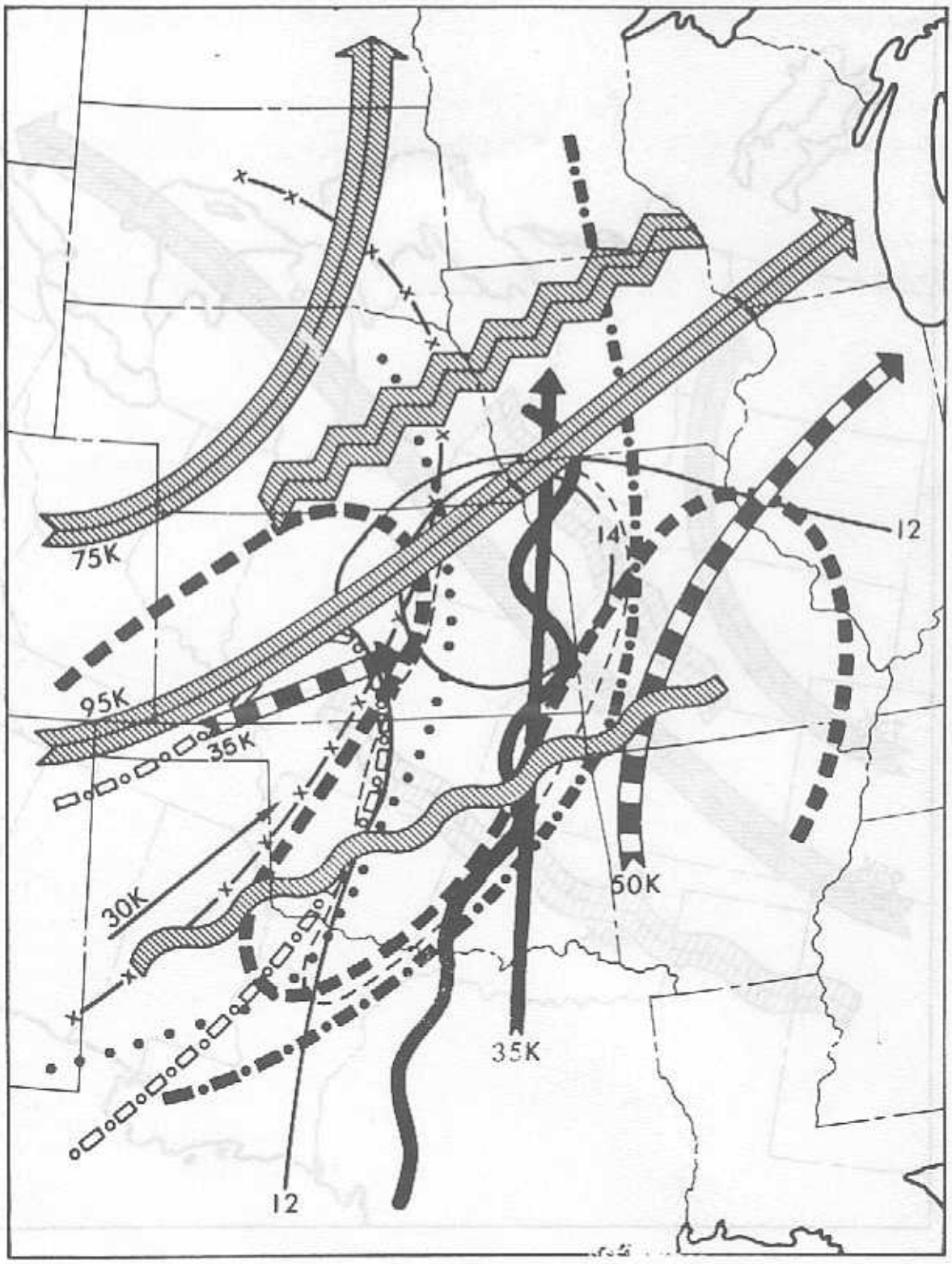

Figure 76. Composite Chart for 09/0000Z.

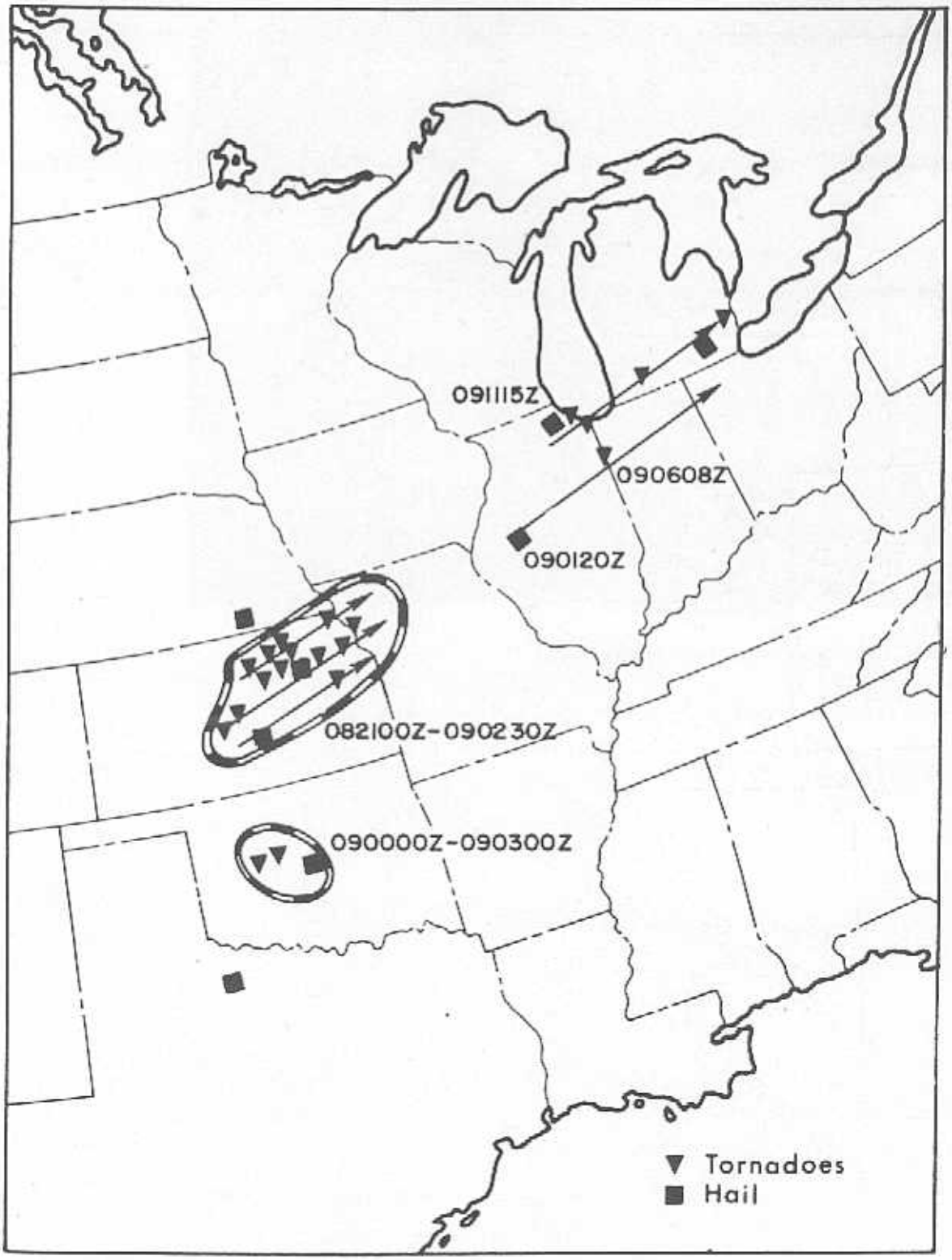

Figure 77. Activity Chart for period 08/2100Z to 09/1200Z.

Appendix F

THE USE OF AUTOMATED PRODUCTS IN SEVERE WEATHER FORECASTING

SECTION A—GENERAL

The availability of AFGWC computers coupled with the concentration of highly competent programmers, specialized technicians in electronic display, skilled forecasting personnel, and the vast, continuously updated AFGWC data base provides severe weather forecasters with far more timely and accurate forecast tools than previously available. Current and prognostic fields of those surface and upper-air parameters described in detail in this report are in the hands of the severe weather forecaster in sufficient time for full consideration in producing the Military Weather Warning Advisory. These products negate the former need for time-consuming, manual prognoses of the various important parameters in space and time and naturally result in a more uniform appraisal of the future severe weather potential over the conterminous United States by forecasters with varying degrees of experience in this highly specialized field.

SECTION B—AUTOMATED PRODUCTS

Fine mesh 12-, 24-, and 36-hour prognoses of the 850-, 700-, and 500-mb fields are available at two hours plus 20 minutes after receipt of the early SLAM data. These prognoses are available on standard 1:15,000,000 upper air charts computer printed and displayed through the AFGWC Selective Display Model (SDM). Currently, these charts display gridded values approximately 100 miles apart of temperature, dew point spread, wind direction and speed. It should be emphasized that the values chosen for display are limited only by the availability of data at any given level and there are many other display options open to the forecaster.

The AFGWC Boundary Layer Model (BLM) provides advisory forecasters with fine mesh 12- and 24-hour prognoses of temperature, dew point, pressure contours, and winds for selected levels from 50 through 1600 meters above ground level (AGL) to supplement the upper-air prognoses. The BLM 50-meter chart is used as primary guidance for the surface prog. It depicts the D value and wind fields providing sufficient information to analyze the pressure field and locate the forecast position of fronts and troughs. This chart is supplemented by 50-meter temperature and dew point and maximum and minimum temperature progs. AFGWC also utilizes the BLM 600-meter wind prog fields as an aid in forecasting strong gradient gusts, and the 900-meter temperature and dew point progs to better assess the stability of the air columns.

Current fine mesh analysis of the 850-, 700-, and 500-mb charts also are available through the SDM at 1 hour plus 25 minutes after the SLAM data. These charts consist of contoured temperature fields and wind direction and speed. In addition, computer plots of data for each upper air station are available for hand analysis of important parameters, including 24-hour changes in heights, temperatures, and dew point spreads. Any chart described in this report is available from the AFGWC data base — including, for example, the 850-/500-mb thickness and totals chart described in Chapter 8.

AFGWC resources also made it possible to develop a unique index designed specifically for indicating the most probable area or areas of tornado and severe thunderstorm potential. This index, termed the Severe Weather Threat Index or SWEAT, is available to AFGWC forecasters in fine mesh gridded form and consists of a current analysis plus 12-, 24-, and 36-hour prognostic fields. The 36-hour fields are fine mesh interpolation of coarse mesh 36-hour progs. The SWEAT Index is described in detail in Section C.

SECTION C—THE SEVERE WEATHER THREAT INDEX

The requirement for an index to specify and predict areas of potentially severe convective weather has long been recognized by the AWS and civilian meteorological community. The need for such an index stems from the following limitations:

a. Operationally reliable dynamic models capable of forecasting very small scale features such as tornadoes, or even small parent cyclones, are not currently available.

b. The forecast procedures which were used by the Military Weather Warning Center (MWWC) at Kansas City, Missouri, limited the

forecast period to approximately 12 hours because most of the effort was expended on analyses. Centralized forecasts of unique severe weather predictors were not available on facsimile circuits; therefore, additional efforts were required to prepare manual forecasts. Automated production of operational forecasts at Kansas City was limited by the capabilities of the computer available there. The same constraint prevented expansion of severe weather forecasts outside the conterminous United States.

c. Most procedures described in this report are only semi-objective. The constant turnover of forecaster personnel, usually concentrated in the summer months, resulted in the loss of almost irreplaceable expertise in this esoteric area of forecasting. An ever-present and very intensive training effort was required to keep the severe weather forecasts at a consistently high level of quality. A new approach was needed to augment experience with objectivity.

The transfer of the MWWC function to the AFGWC provided the opportunity to apply unique resources to the problem. For the first time, the proper combination of ingredients was available — a vastly improved current and predicted environmental data base, together with required meteorological know-how, programming expertise, and computer hardware.

SECTION D—DERIVING THE SWEAT INDEX

Case studies collected through the years at the MWWC provided the foundation for developing a Severe Weather Threat (SWEAT) Index. A study of 328 tornadoes and experience gained in daily forecasting determined which parameters to consider and the relative weights to be assigned to each parameter. Several constraints were imposed:

a. The index must be computed from U.S. selected-level radiosonde (SLAM) data available approximately one hour after observation time. This allows an automated plot of the SWEAT Index available about one hour and 15 minutes after observation time and gives a means of rapidly appraising the current air-mass potential.

b. The index must be computed from fields currently stored in the AFGWC prediction data base. This facilitates automated prognoses of the SWEAT Index without a major revamping of the data base.

c. The parameterization must use reported and predicted values directly, rather than relying on derived parameters or complex pattern recognition.

Under the above constraints, using our empirically derived weighing factors, the SWEAT Index was developed to the present form [6].

$$I = 12D + 20(T-49) + 2f8 + f5 + 125(S+0.2)$$

where

I = SWEAT Index

D = 850-mb dew point in degrees Celsius (if D is negative, the term is set to zero)

f8 = speed of 850-mb wind in knots

f5 = speed of 500-mb wind in knots

S = Sin (500-mb - 850-mb wind direction)

T = "Total Totals" in degrees Celsius (T is the sum of the 850-mb temperature and dew point, minus twice the 500-mb temperature; if T is less than 49, the term 20(T-49) is set to zero)

The entire shear term, 125(S+0.2), is set to zero if *any* of the following conditions are *not* met: 850-mb wind direction in the range 130 through 250 degrees, 500-mb wind direction in the range 210 through 310 degrees, 500-mb wind direction minus 850-mb wind direction positive; and both the 850- and 500-mb wind speeds at least 15 knots. Note that no term in the formula may be negative.

Application of this formula to past tornado and severe thunderstorm cases resulted in the distribution of SWEAT Index values versus observed weather shown in Table 6. The

cumulative distribution of SWEAT Index values versus observed weather is shown in Table 7. A severe thunderstorm, as defined here, is one which is accompanied by gusts of at least 50 knots and/or hail at least 3/4-inch in diameter. A tornado case is defined as the occurrence of five or more tornadoes in the same general area. A severe thunderstorm case is defined as the occurrence of a combination of five or more severe thunderstorms and/or tornadoes (0-4 tornadoes) in the same general area. The cases are mutually exclusive; i.e., no tornado cases are also included as severe thunderstorm cases, although in some instances both kinds occurred on the same day but in different areas. SWEAT Index fields were analyzed from station data for the synoptic hour (0000Z and 1200Z) closest to the occurrence; hence, values were interpolated in space but not in time.

Table 6 - Distribution of SWEAT Index values versus observed weather

	SWEAT Index Value						
	200	2-300	3-400	4-500	5-600	6-700	7-800
Tornado Cases	0	0	1 (a)	23	27	5	1
Severe Thunderstorm Cases	0	4 (b)	27	36	30	4	1

(a) Actual value 375 (b) Lowest value 272

Table 7 - Cumulative Distribution of SWEAT Index Values Versus Observed Weather

	SWEAT Index Value						
	≤200	≤300	≤400	≤500	≤600	≤700	≤800
Tornado Cases	0	0	1 (a)	24	51	56	57
Severe Thunderstorm Cases	0	4 (b)	31	67	97	101	102

(a) Actual value 375 (b) Lowest value 272

From Tables 6 and 7, it appears that the SWEAT Index threshold value for tornadoes is about 400, and for severe thunderstorms about 300. Remember, only cases where severe weather was *known* to have occurred were considered. Nothing can be inferred about "false alarm" rates. It must be emphasized, however, that the SWEAT Index is only an indication of the potential for severe weather. A high SWEAT Index for a given time (either observed or predicted) does not mean that severe weather is occurring or will occur. Some type of triggering action is necessary to realize the potential. Experience has shown that, although high SWEAT values can occur in the United States during the morning (1200Z) without concurrent severe convective weather, the potential is usually realized if the predicted value for the afternoon and evening is also high. Although low observed values of the SWEAT index almost certainly mean there is no severe weather occurring, values sometimes increase dramatically during a 12-hour period. For example, at 1200Z, 8 June 1966, Del Rio, Texas (DRT), had a SWEAT Index of 508 while Topeka, Kansas (TOP), showed 293. Twelve hours later (0000Z, 9 June 1966) the value at DRT dropped to 232 with no activity occurring while the value at TOP jumped to 573. One of the most powerful and destructive tornadoes on record slashed through Topeka, starting about 0000Z, 9 June 1966. (See Appendix E.)

The SWEAT Index should not be used to predict ordinary thunderstorms. Use of the shear term and minimum values for the stability (Totals) and wind speed terms were specifically designed to discriminate between ordinary and severe thunderstorms. For the prediction of ordinary thunderstorms, a stability index such as the "Lifted Index" or "Totals" is more applicable.

In addition to the early SWEAT analysis and prognoses mentioned above, AFGWC forecasters are provided with a modified SWEAT Index based on the BLM current analyses, and 12- and 24-hour prognoses. This procedure substitutes data at a terrain following level for the 850-mb lower reference level used in the early SWEAT. By using the BLM analysis and forecast data, the 850-mb temperature, moisture, and wind are replaced with BLM data for 900 meters above ground level (AGL). An adjustment is made to the "Totals" term to compensate for the varying thickness of the 900-meter AGL/500-mb layer. This results in a floating index (over the terrain) which has proved more reliable in high terrain areas. The early SWEAT has been retained for use with SLAM data, as well as for areas where BLM forecasts are not available. Several examples of SWEAT analyses and prognoses are shown in Figures 78 through 80.

A further refinement was added to the BLM SWEAT package in the fall of 1971. This consists of a single chart which depicts the forecast *maximum* SWEAT value for each grid point for the 24-hour period following the 1200Z and 0000Z data base times. Also depicted is the Z-time this maximum value is expected. This chart has proven very successful in real-time operation and its application to a specific case is shown in Figure 81.

SECTION E—AN OPERATIONAL CASE

On the 21st of February 1971, a series of destructive tornadoes moved through portions of extreme northeastern Louisiana and over most of western, north-central, and northern Mississippi. The number of tornadoes reported exceeded fifty, but subsequent air and ground investigation indicated only three primary, nearly parallel, paths of damage (Figure 82). The first of this violent series of tornadoes was reported at Delhi, Louisiana, shortly after 2100Z. The last report, at 0123Z, 22 February, was from the second and longest track, which covered approximately 120 miles. Several reports of multiple funnels were received along portions of the three tracks. These storms were the most concentrated of a series of tornadoes which occurred during the three-day period 21-23 February 1971 in the Gulf Coast states eastward into the Carolinas and Virginia.

The tornado forecast parameters used by both the AFGWC and the Severe Local Storms Unit (SELS) of the National Weather Service at Kansas City were evident in profusion on the surface and upper air charts for 1200Z on the 21st. A telephone discussion and exchange of information between the AFGWC and SELS forecasters resulted in agreement that the primary threat area would include the northwest portion of Louisiana and most of Mississippi, and that the activity would start during the early afternoon. Figures 83 through 90 graphically portray the most important features at the 850-, 700-, and 500-mb levels for data base times of 1200Z, 21 February, and 0000Z, 22 February 1971, including composite charts used by the AFGWC for these times.

Figure 91 depicts the composite chart valid for 0000Z, 22 February, made from 12-hour prognoses from the data base for the 850-, 700-, and 500-mb levels. A comparison with the verifying composite chart made from actual 0000Z observations (Figure 90) clearly shows the accuracy of the fine-mesh forecasts in this instance.

The early 12-hour forecast SWEAT Index field valid 0000Z, 22 February (Figure 92), showed values exceeding 650 over northern Missisippi. These values were well over the tornado threshold value of 400 and the highest yet seen up to that time on prognoses using the present form of the SWEAT Index formula. Utilizing the forecast composite chart and the progged SWEAT Index values plus the favorable surface synoptic pattern, the AFGWC Advisory Forecaster indicated tornadoes and severe thunderstorms over the threat area during the afternoon and evening of the 21st. The 24-hour SWEAT forecast indicated eastward and southward movement of the threat area, with values just above 500, by 1200Z on the 22nd. Tornadoes occurred over the southern half of Alabama and Georgia during the night and continued into the early morning of the 22nd.

The relative strength of the parameters at 1200Z, 21 February, and the forecast values for 0000Z, 22 February, derived from AFGWC products are shown in Table 8. This is a modified version of the tornado parameter worksheet depicted in Table 5, Appendix E. Note that the SWEAT Index has been added to this worksheet with values of less than 350 considered weak, 400 to 500 moderate, and greater than 500 strong. The rating of the other key parameters is shown in Table 1, Chapter 5.

Table 8

SEVERE THUNDERSTORM AND TORNADO PARAMETER WORKSHEET

AREA	ADVISORY NUMBER	DATE	ADVISORY VALID
LA-MS-AL	86	21 FEB 71	21 / 18 Z to 22 / 06 Z

PARAMETER	1200Z ANAL		0000Z PROG		REMARKS/VERIFICATION
	VALUE	RATING	VALUE	RATING	
SWEAT	500-550	S+	500-666	S	MAX PROGGED OVER CNTRL & NRN MS
TOTALS	58	S+	58-60	S	
LIFTED INDEX	-5	S+	-7	S	
PVA	30°	M+	40°	S	
500 MB HT FALLS	-200M	S	-200M	S	
500 MB JET	95K	S-	90K	S	
850 MB MOISTURE	11°	M+	13	S	
850 TEMP RIDGE	W OF MOIST RIDGE	S	W OF MOIST RIDGE	S	
LO-LEVEL JET	45-55K	S	50K	S	
700 MB DRY INTRUSION	——	S	——	S	
700 MB NO-CHANGE TEMP	WINDS CROSS ∠ 20°	W+	WINDS CROSS 20-40°	M	0000Z DATA ACTUALLY STRONG S
WINDS VEER WITH HEIGHT	YES	—	YES	—	
WINDS INCREASE WITH HEIGHT	YES	—	YES	—	
INTERSECTING UP AND LO JETS	YES	—	YES	—	
SFC DEW POINT	62°	M+	66°	S	
SFC PRESSURE THREAT AREA	1008	M+	1002	S	
FALLING PRESSURE	YES	—	YES	—	
INCREASING SFC TEMP	YES	—	YES	—	
INCREASING DEW POINT	YES	—	YES	—	
THICKNESS RIDGE	YES	—	YES	—	
THICKNESS NO-CHANGE	YES	—	YES	—	
MESO OR SYNOP PATTERN	FAVORABLE		FAVORABLE	—	

REMARKS

MARKED DIFLUENCE OVER THREAT AREA AT 1200Z AND PROGGED FOR 0000Z.

NUMEROUS TORNADOES OCCURRED FROM N.E. LA INTO MS AFTN AND EVNG.

AFGWC FORM AUG 71 0-25

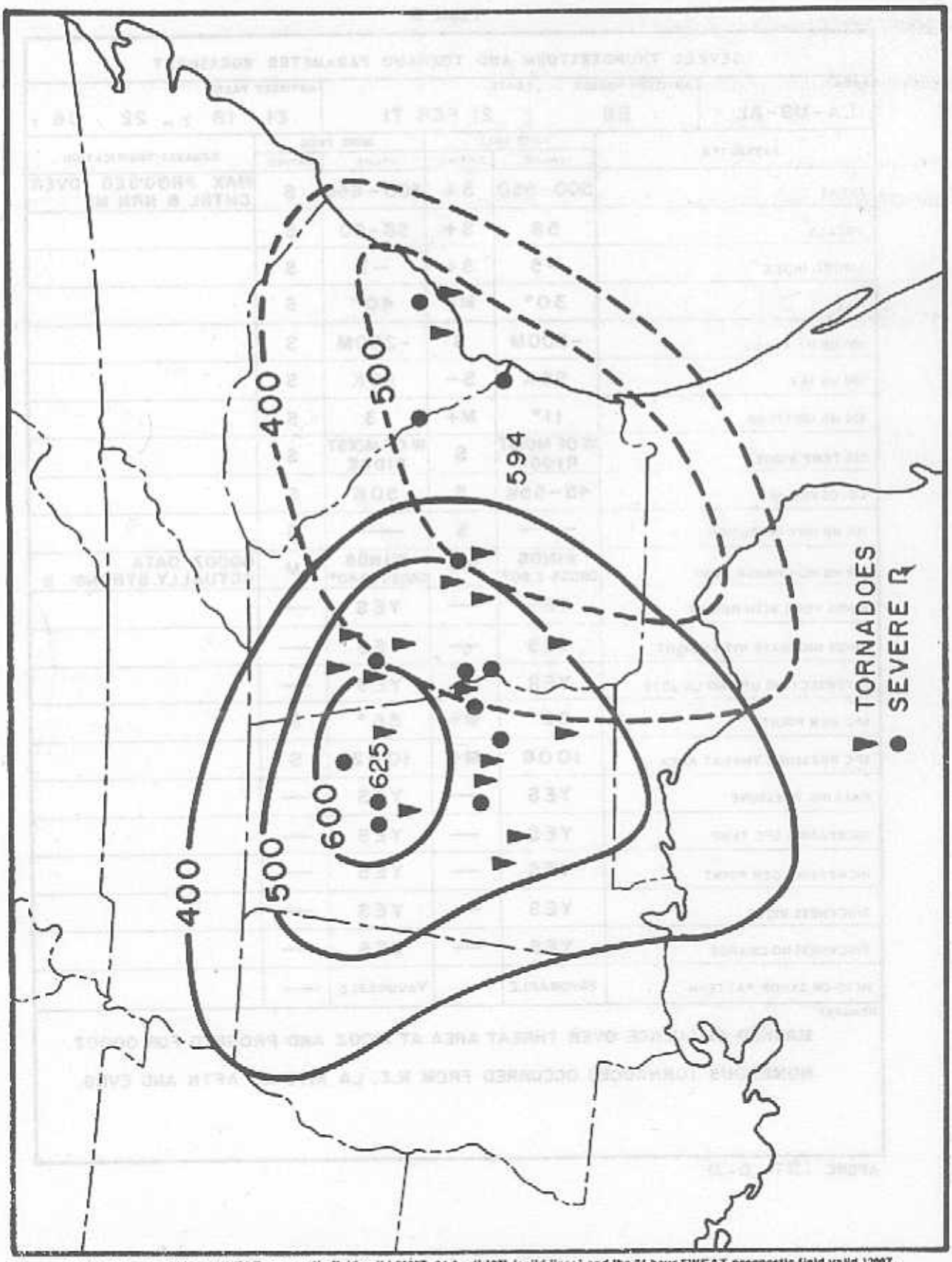

Figure 78. The 36-hour SWEAT prognostic field valid 0000Z, 24 April 1971 (solid lines) and the 24-hour SWEAT prognostic field valid 1200Z, 24 April 1971 (dashed lines) and locations of tornado and severe thunderstorm occurrences. Activity began at 1335Z, 23 April in northeast Alabama and spread east and south into Georgia and southern South Carolina with the last report near Charleston at 0925, 24 April.

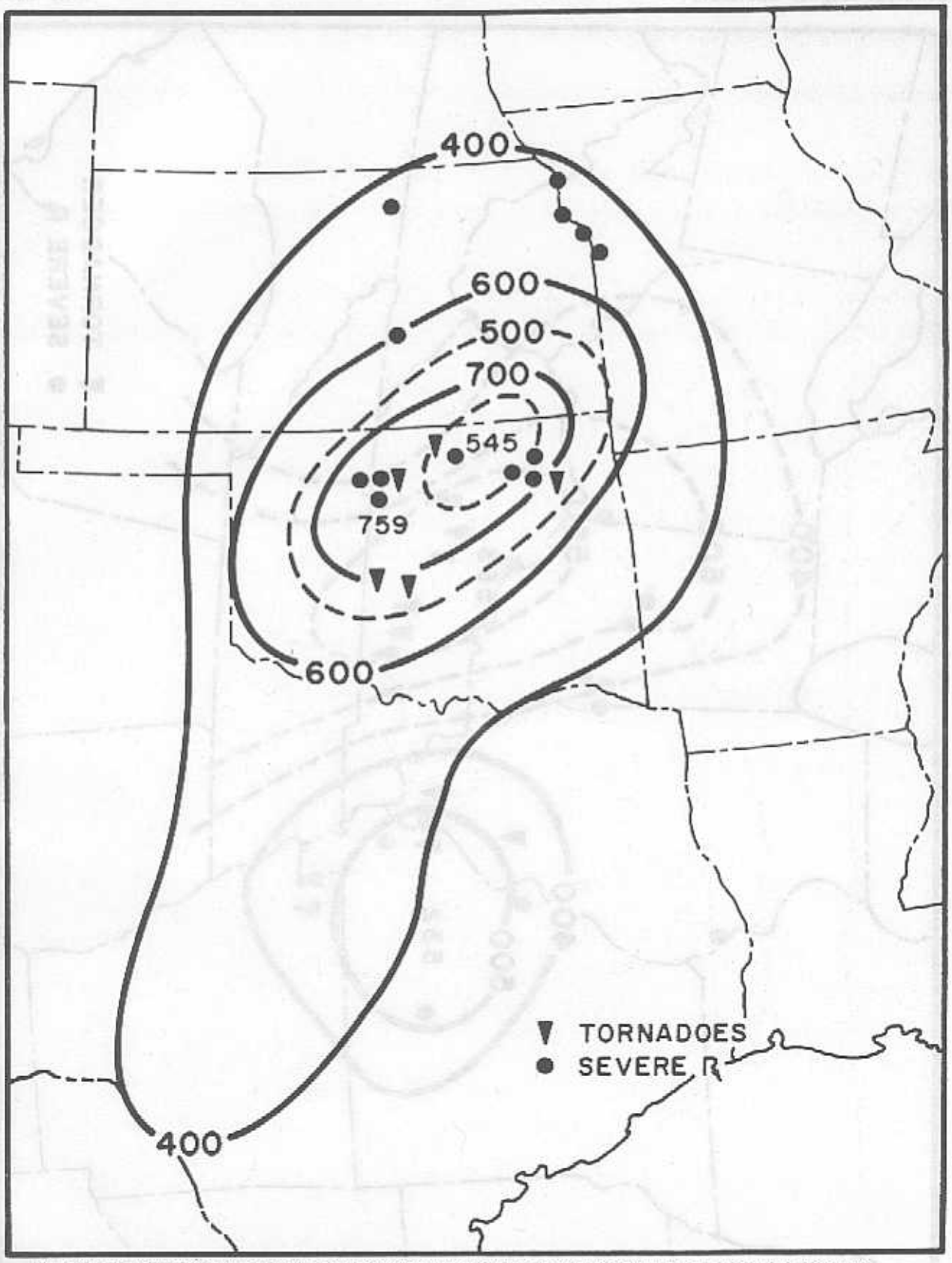

Figure 79. The 12-hour SWEAT prognostic field valid 0006Z, 27 April 1971 (solid lines), verifying SWEAT values (dashed lines), and tornado and severe thunderstorm occurrences from 2200Z, 26 April to 0515Z, 27 April. A tornado and hail stones over three inches in diameter were reported near Enid, Oklahoma.

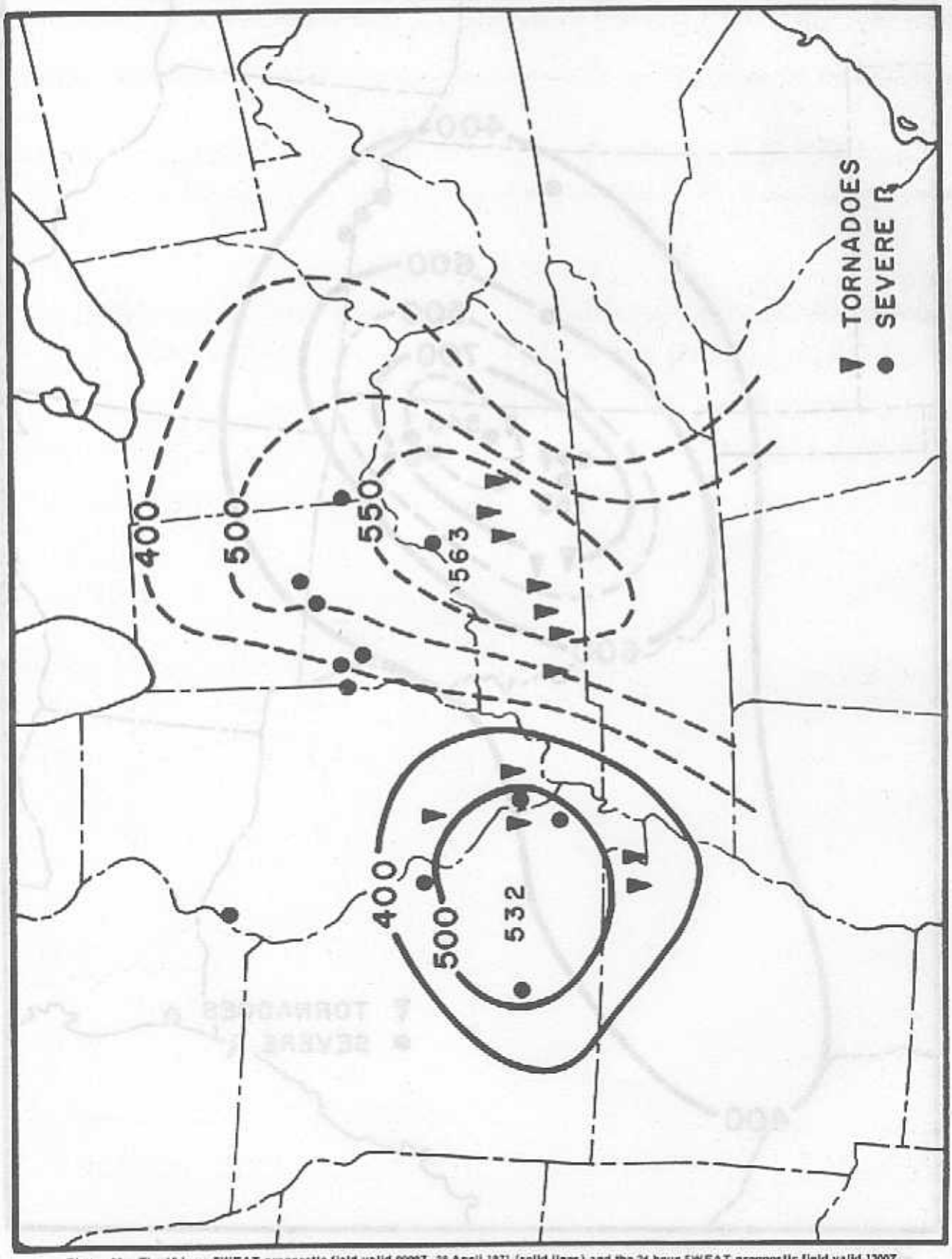

Figure 80. The 12-hour SWEAT prognostic field valid 0000Z, 28 April 1971 (solid lines) and the 24-hour SWEAT prognostic field valid 1200Z, 28 April 1971 (dashed lines) and tornado and severe thunderstorm occurrences. Severe weather first occurred near Fort Leonard Wood, Missouri at 2022Z, 27 April and spread eastward with the last report near 0500Z, 28 April south of Lexington, Kentucky.

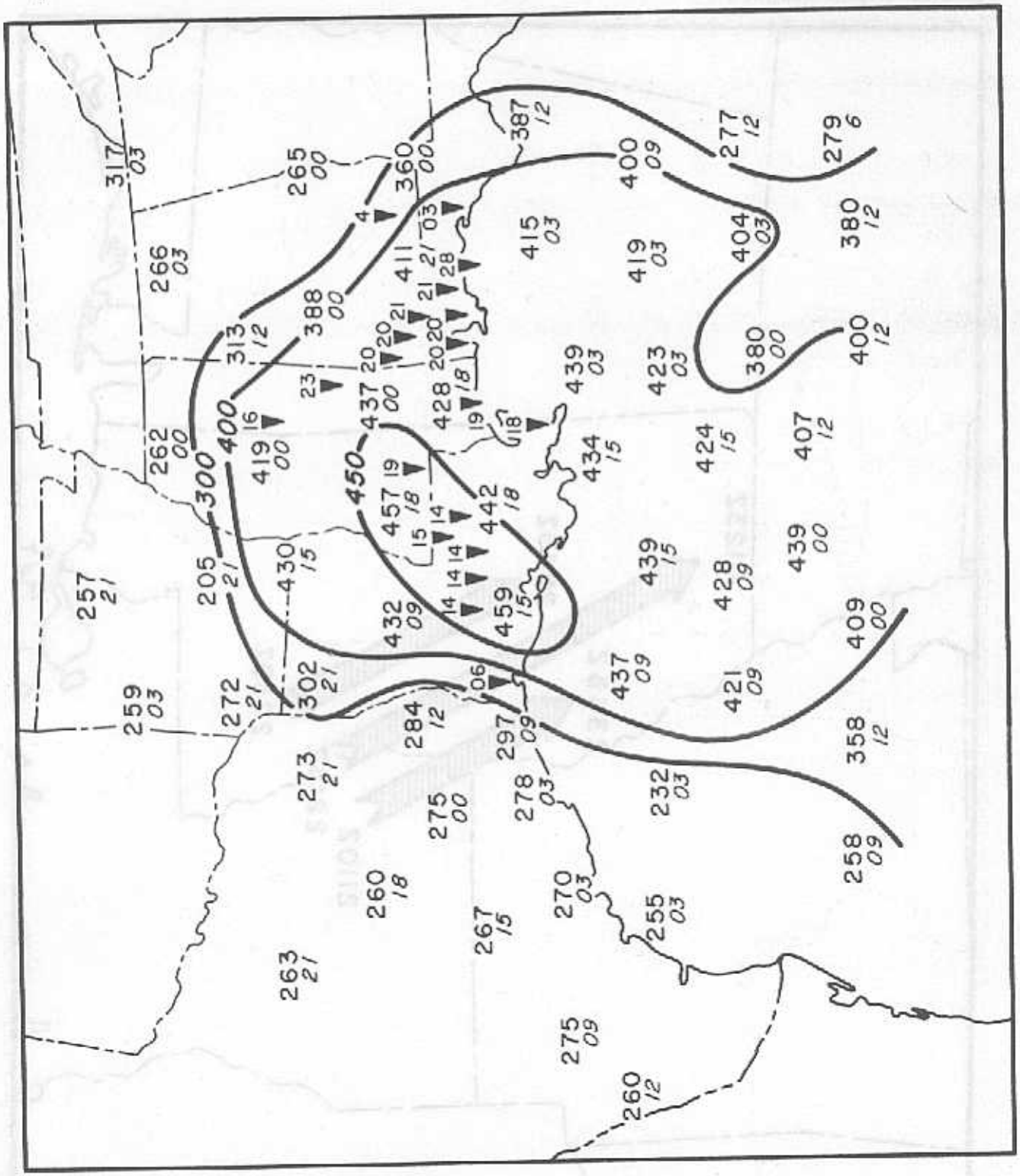

Figure B1. The AFGWC BLM maximum SWEAT index value (top number) and forecast Z-time of the maximum (bottom number) for selected grid points for the 24-hour period beginning 0000Z, 16 September 1971. Also shown is an analysis of the maximum SWEAT values and the location and Z-time of tornado occurrences.

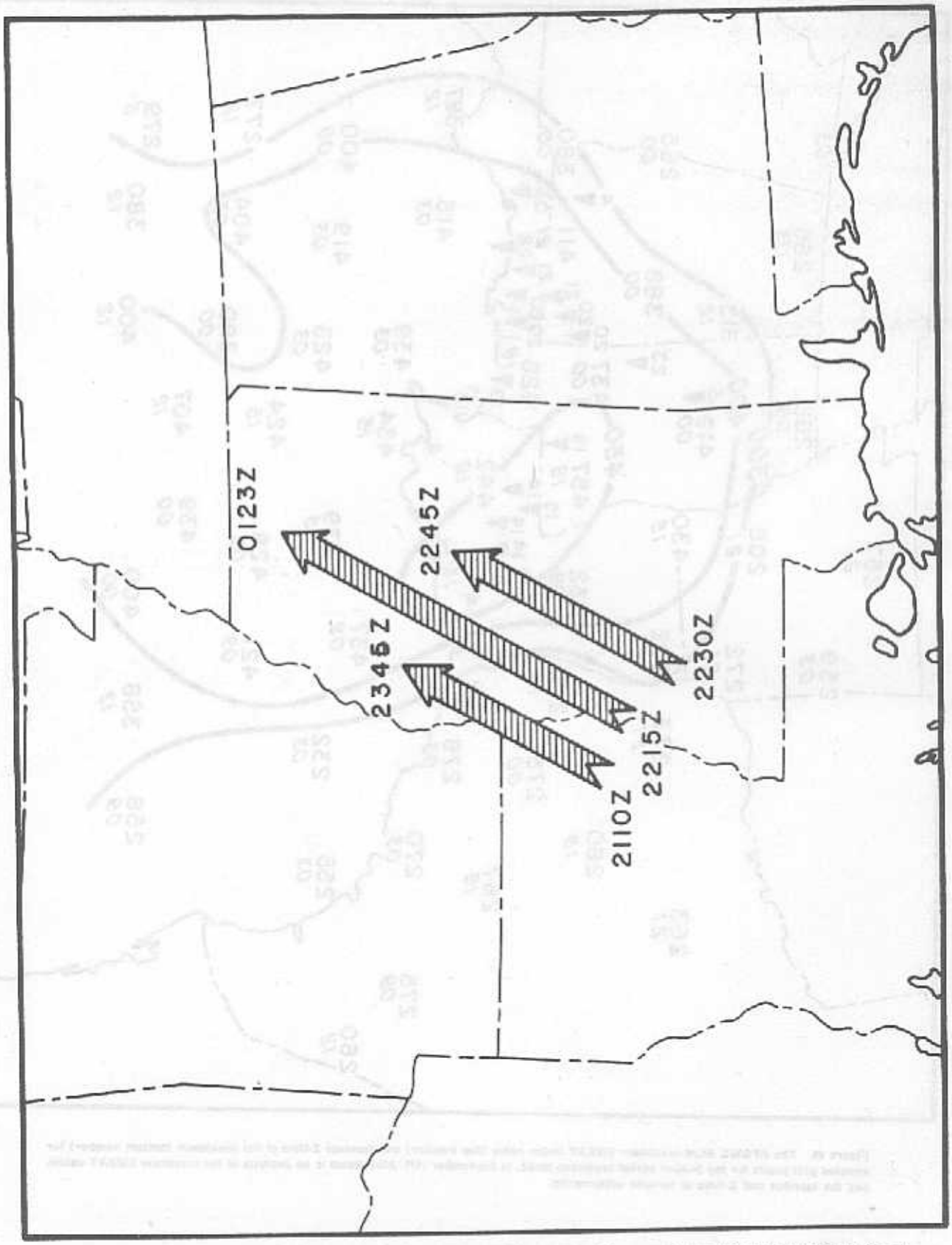

Figure 82. Primary damage tracks of tornadoes over Louisiana and Mississippi which occurred from 2110Z, 21 February to 0123Z, 22 February 1971.

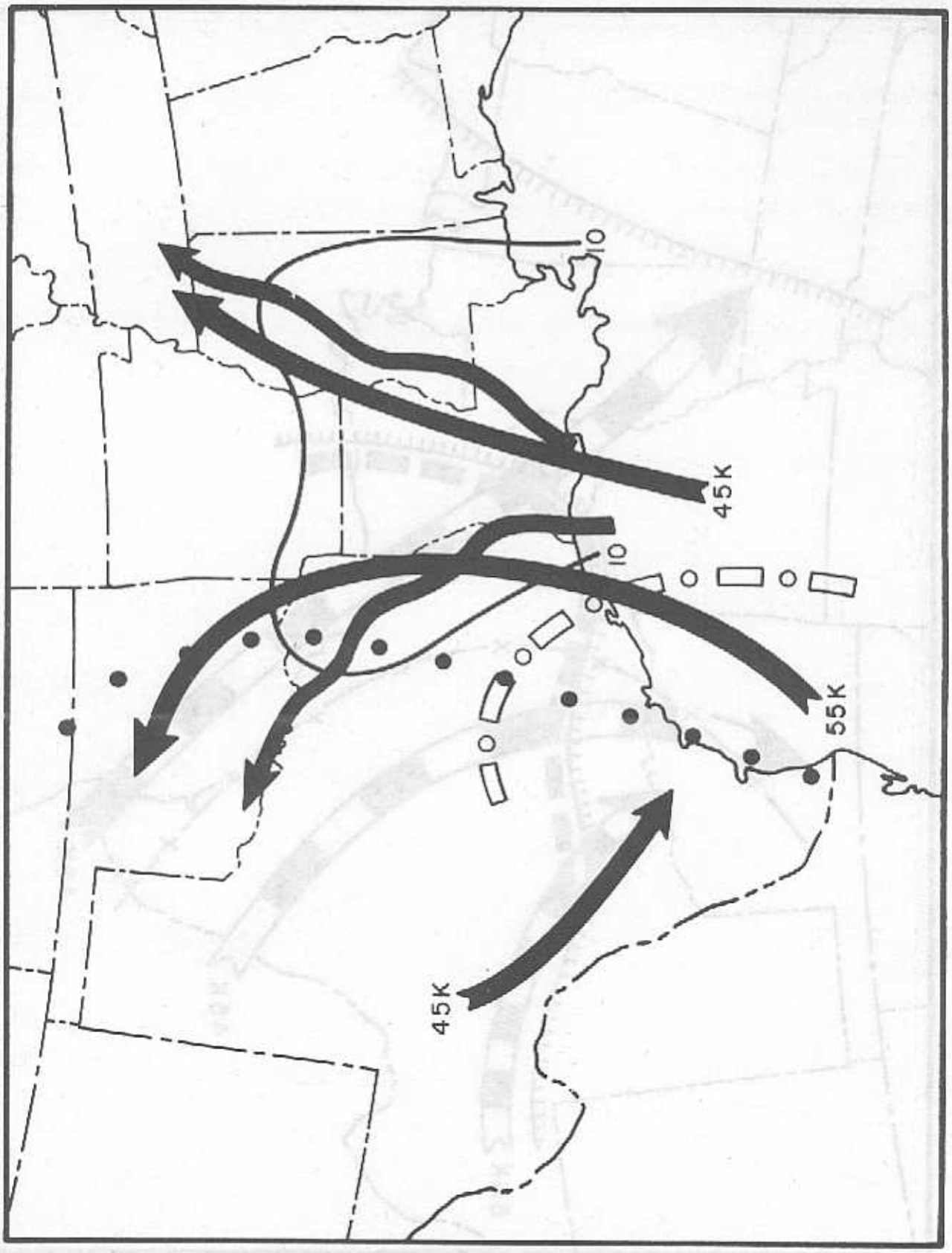

Figure 83. Major features of 850-mb chart at 1200Z, 21 February 1971.

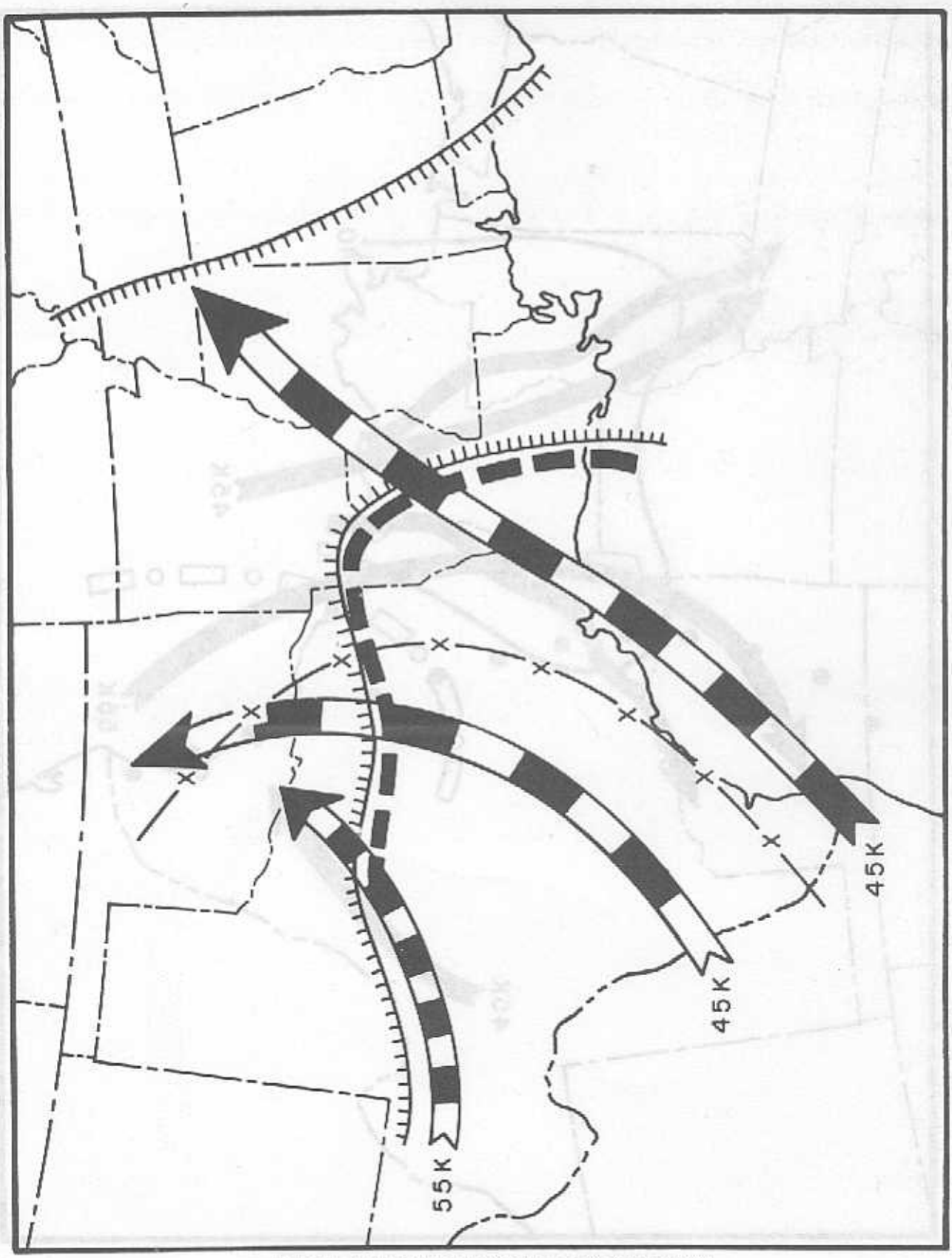

Figure 84. Major features of 700-mb chart at 1200Z, 21 February 1971.

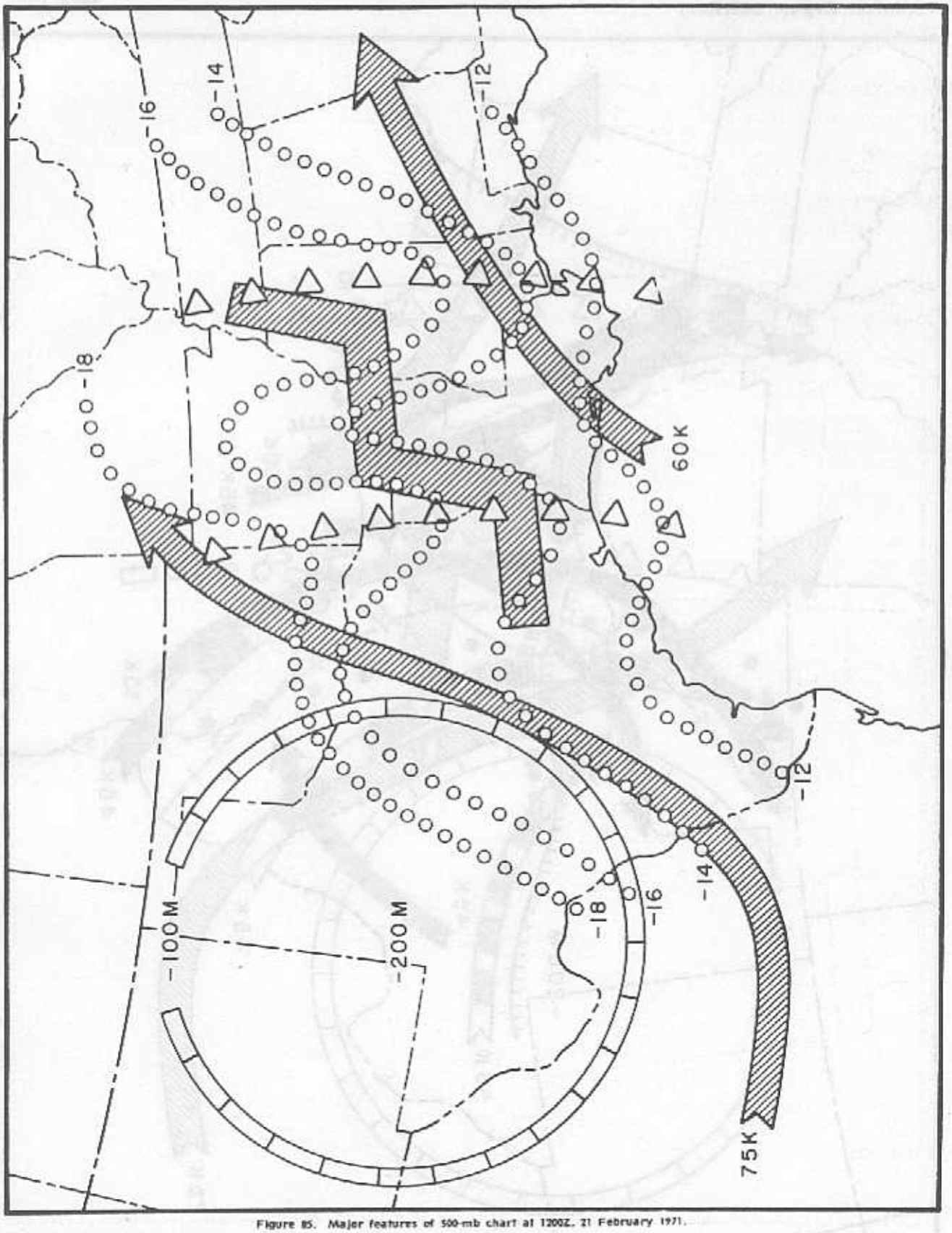

Figure 85. Major features of 500-mb chart at 1200Z, 21 February 1971.

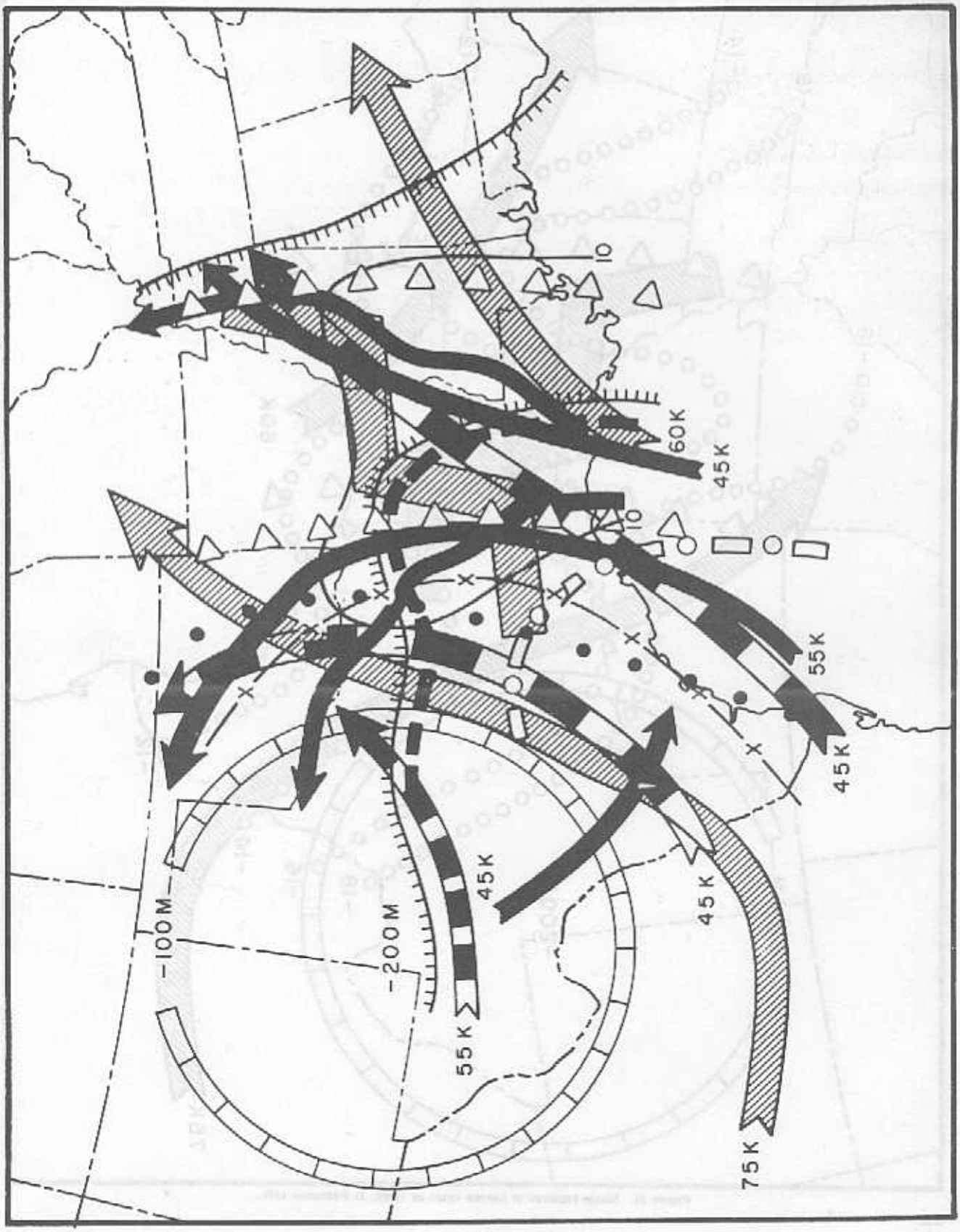

Figure 86. Composite chart for 1200Z, 21 February 1971.

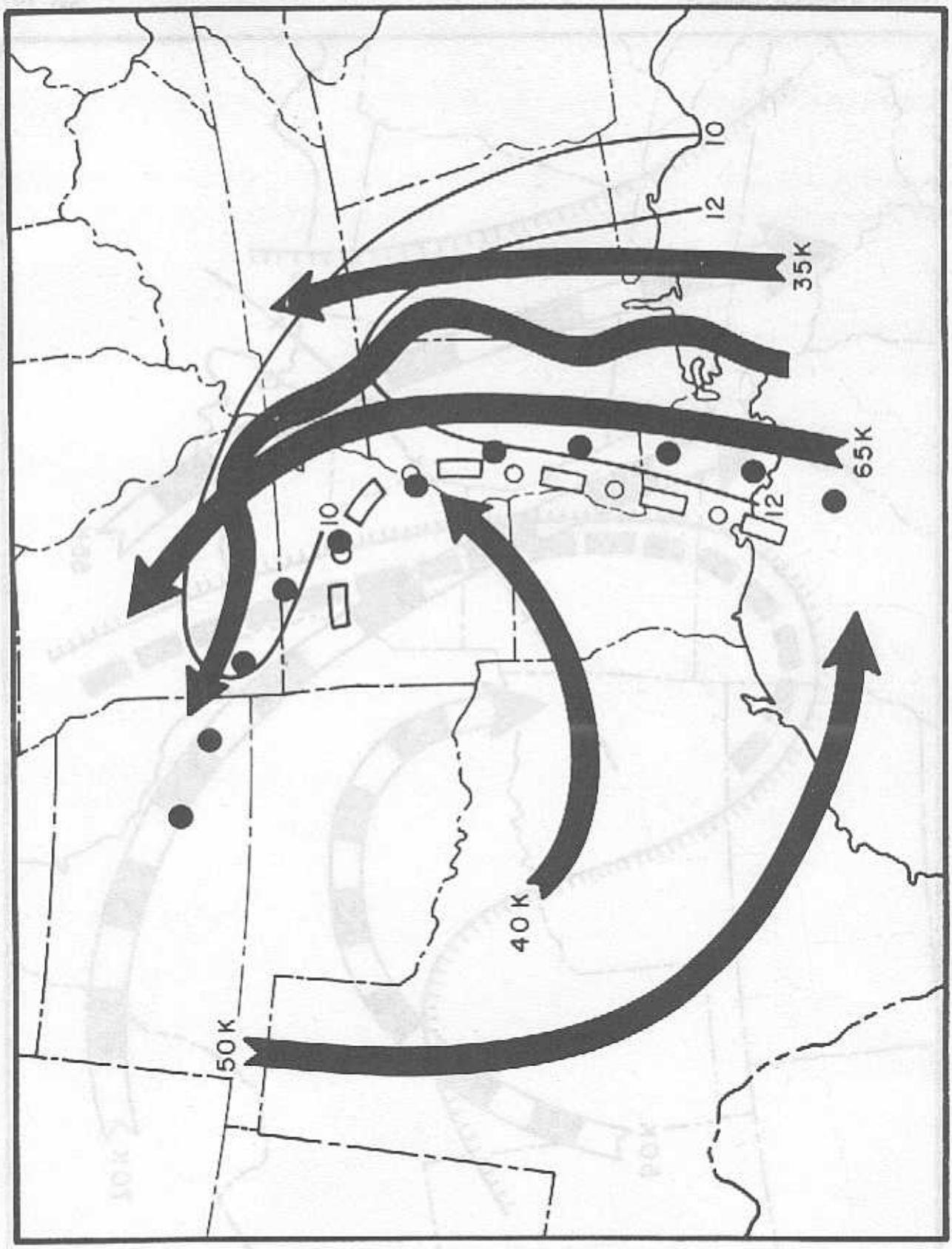

Figure 87. Major features of 850-mb chart at 0000Z, 22 February 1971.

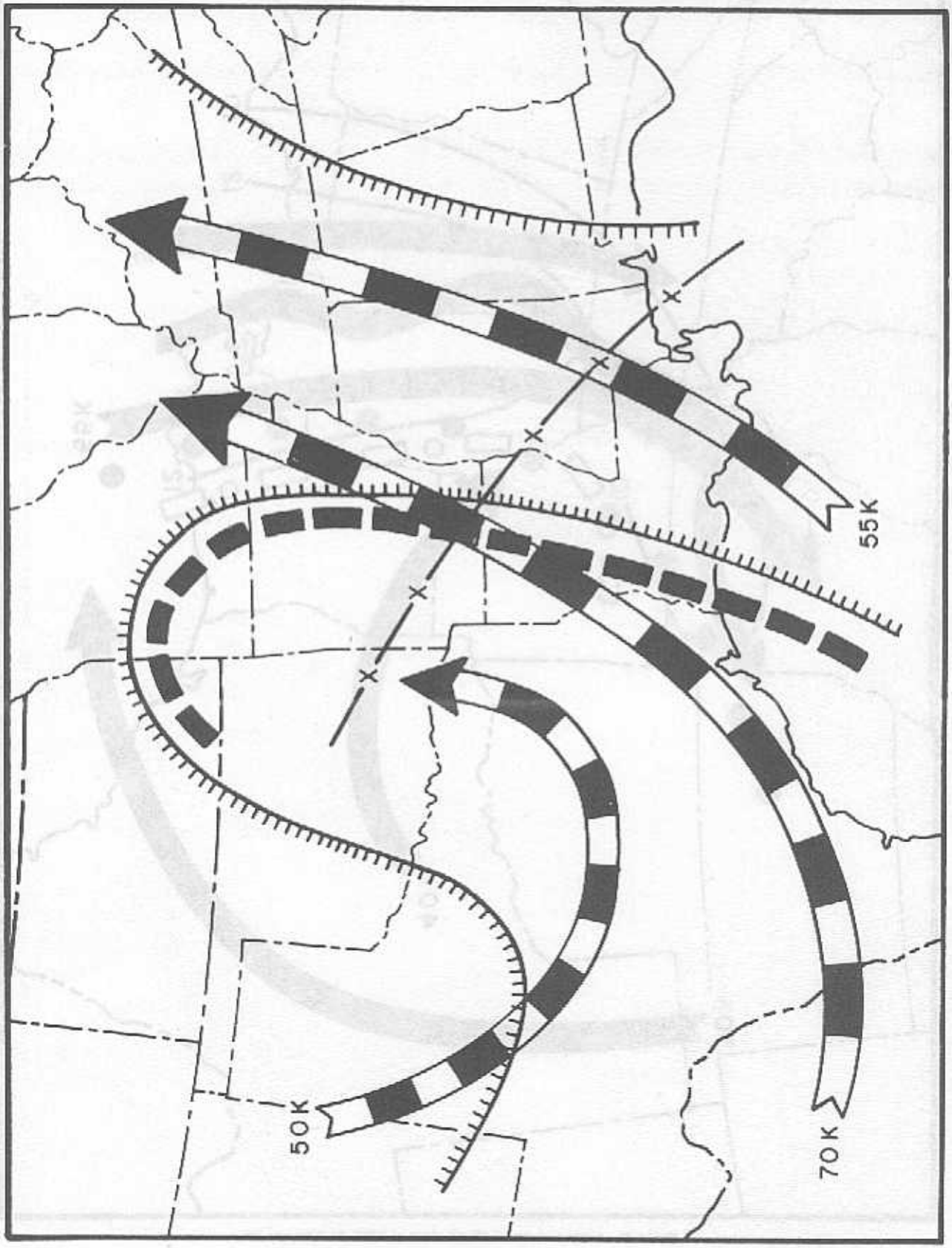

Figure 88. Major features of 700-mb chart at 0000Z, 22 February 1971.

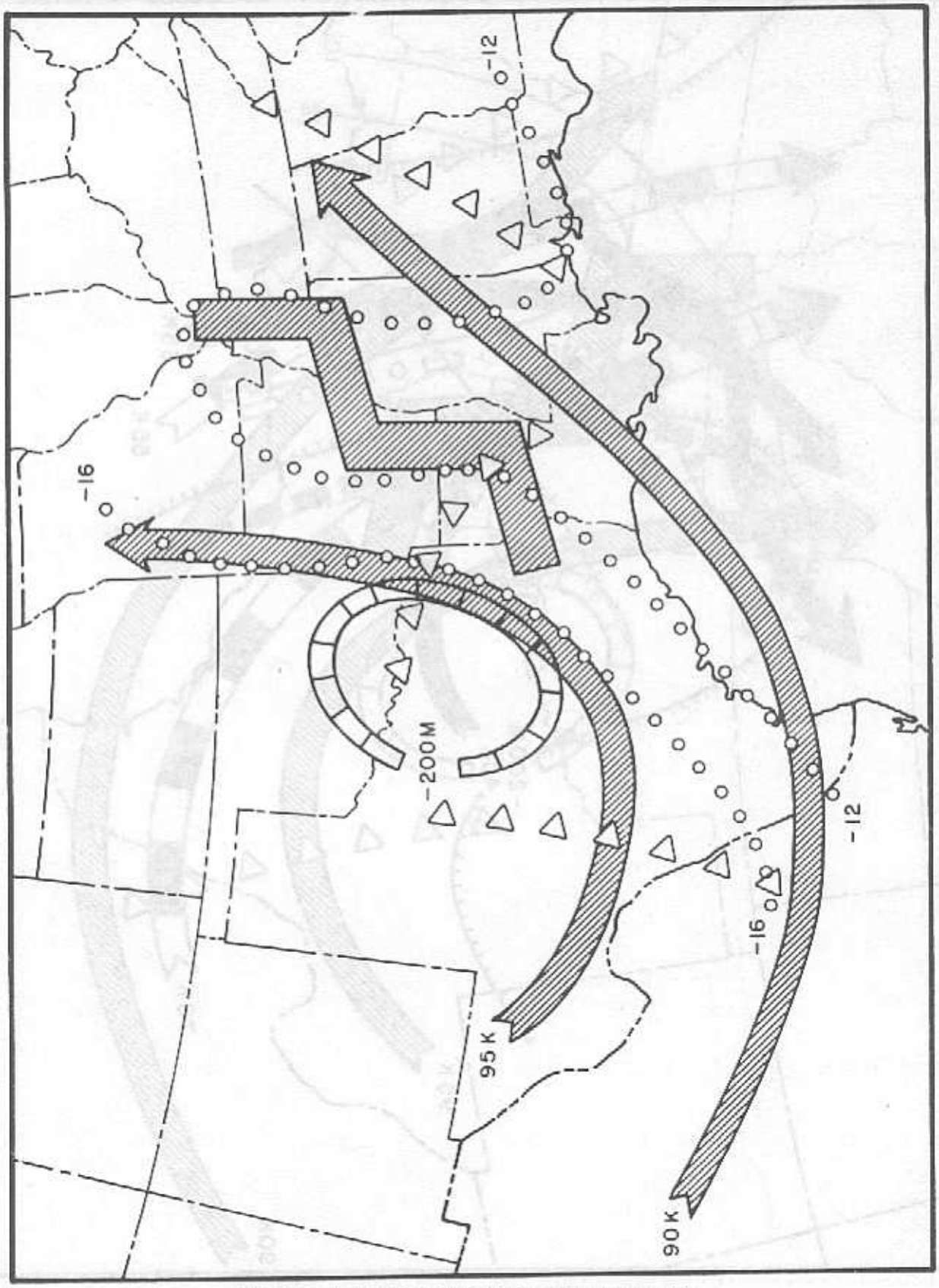

Figure 89. Major features of 500-mb chart at 0000Z, 22 February 1971.

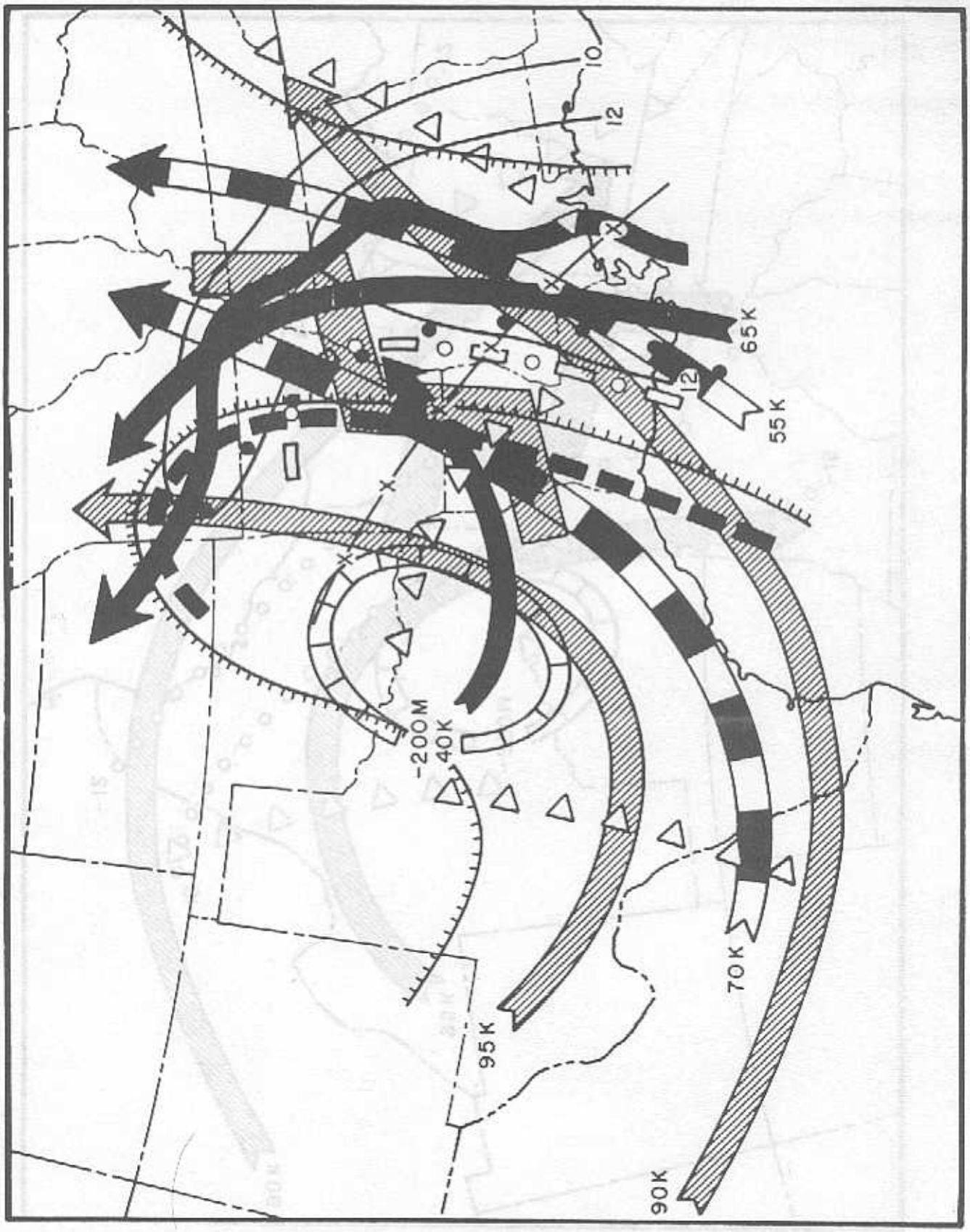

Figure 90. Composite chart for 0000Z, 22 February 1971.

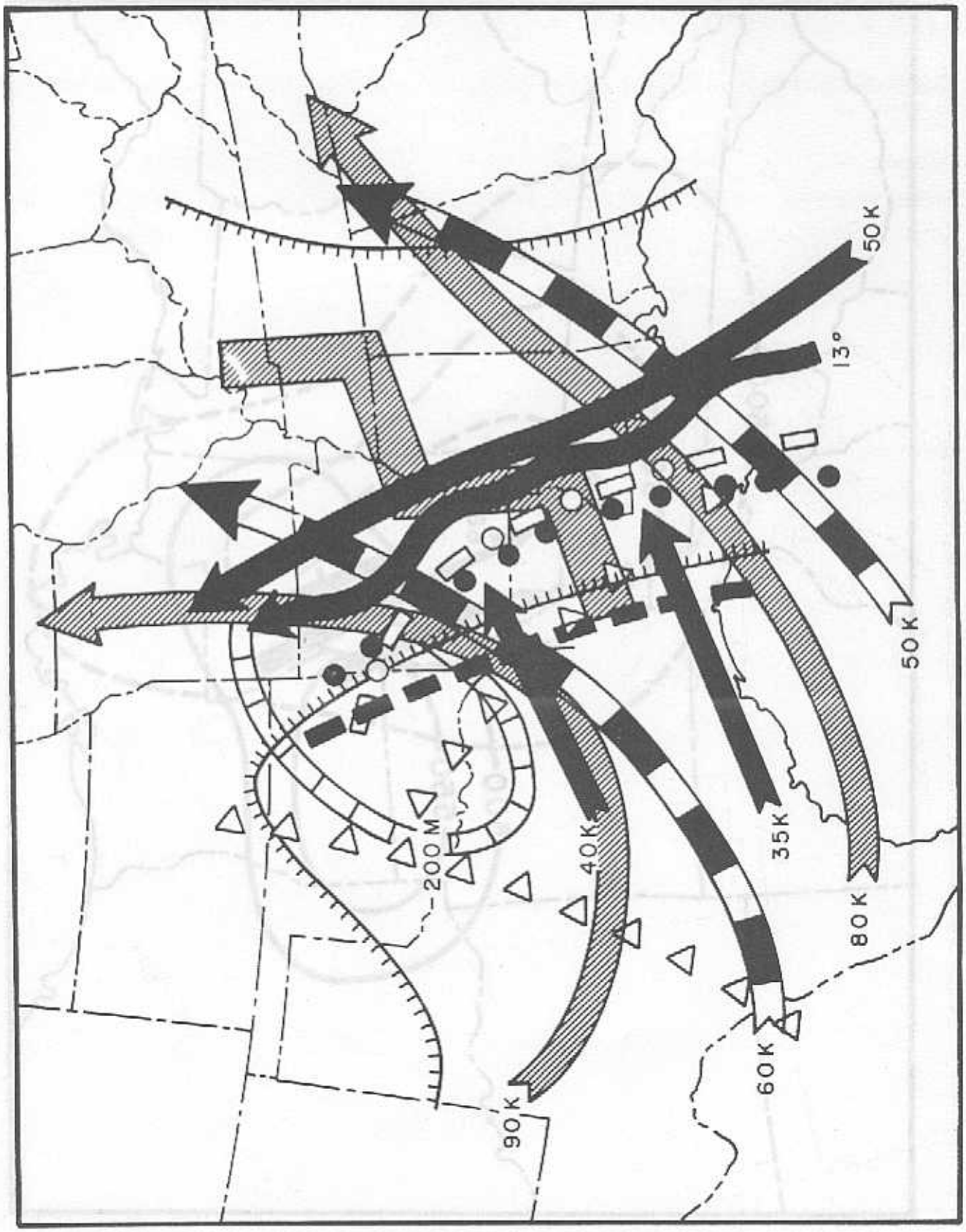

Figure 91. Composite chart valid at 0000Z, 22 February 1971 based on 12-hour prognoses.

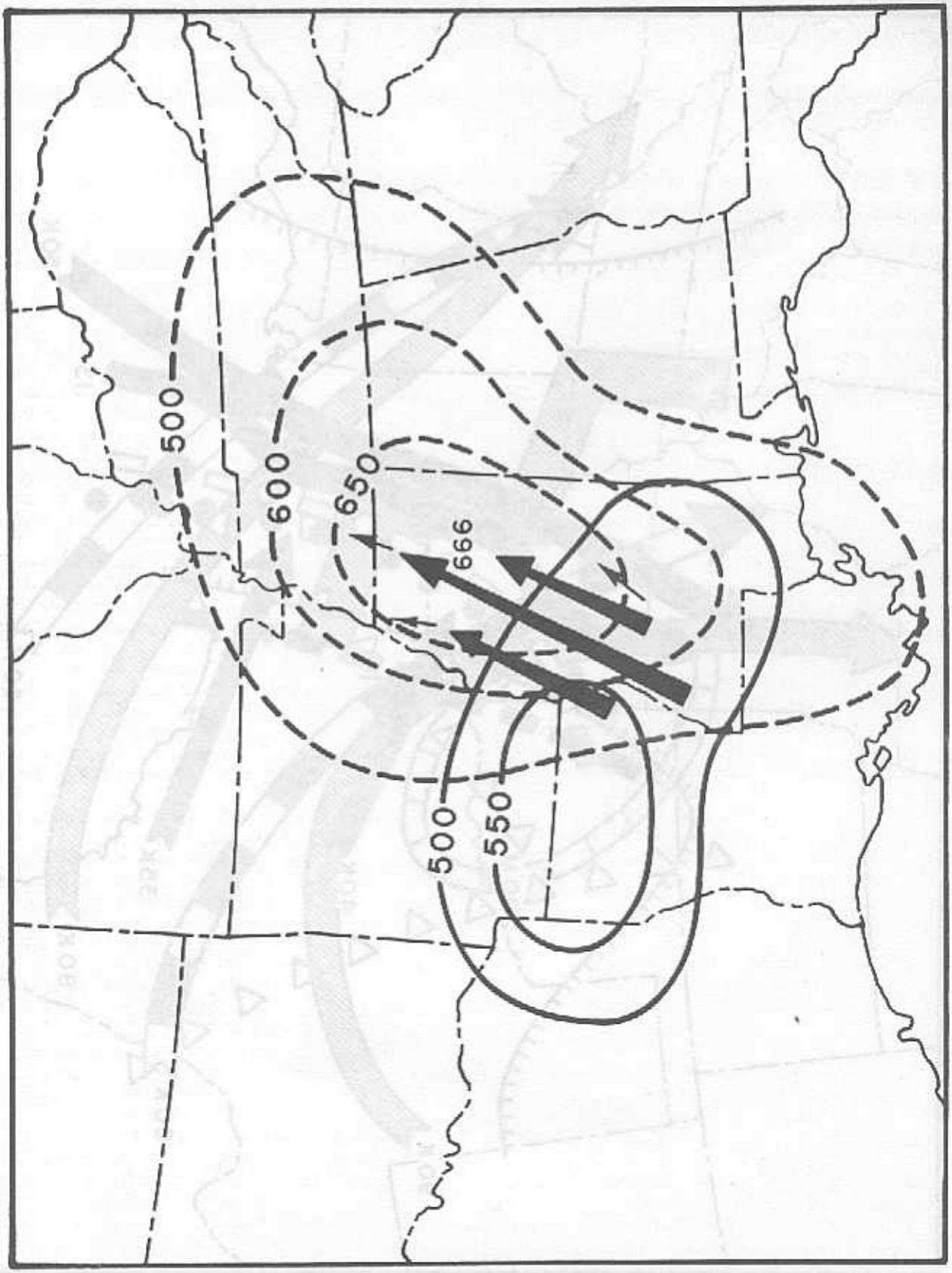

Figure 92. Fine mesh gridded SWEAT analysis for 1200Z, 21 February 1971 (solid lines) and the 12-hour SWEAT prognostic field valid 0000Z, 22 February 1971 (dashed lines). The three major tornado tracks from Figure 82 are superimposed on the figure.

Appendix G

THE FORT RUCKER, ALABAMA TORNADO OF 13 JANUARY 1972

SECTION A—GENERAL

At 0725Z, 13 January 1972, a destructive tornado struck the Enterprise-Ozark area in the southeast corner of Alabama. Several million dollars in damage, which included total destruction of a number of helicopters, was inflicted at Fort Rucker, Alabama; major damage was also suffered in the nearby Ozark area. This tornado was one of a series that hit southeast Alabama, northwest Florida, Georgia, and South Carolina on 13-14 January 1972. This case study is included because this type of tornado is the most difficult to forecast, i.e., they are not associated with identifiable synoptic or even mesoscale features such as lows, organized squall lines, warm fronts, etc. In these instances, we are trying to forecast microscale phenomena using a macroscale network. This case study also illustrates the usefulness of the SWEAT Index in identifying areas of rapidly increasing instability.

SECTION B—SYNOPTIC SITUATION

At 1200Z, 12 January 1972, a decaying warm front was evident along the Gulf Coast extending from near New Orleans across northwest Florida and off the east coast near Savannah, Georgia. This boundary became progressively diffuse during the day allowing tropical air from the Gulf of Mexico to spread inland. Figure 93 shows the surface chart for 0000Z, 13 January. Southerly flow of air from the Gulf dominates the entire southeast United States with the closest frontal system located in the Missouri-Oklahoma area. Isolated thunderstorms occurred over the southeast United States during the period from 12/1200Z to 13/0000Z but no severe weather was reported.

The composite chart for 13/0000Z (Figure 94) delineates the important parameters at that time. At 500 mb, the thermal trough extending from western South Carolina through central Georgia into northwest Florida was probably a contributing factor to the thunderstorm activity which occurred during the day and into the evening of 12 January over portions of the southeast United States. A second and stronger 500-mb thermal trough associated with a 30 m/12 hour height fall area extended from northeast Arkansas into northwest Louisiana and on southwestward. Close examination of the 500-mb wind field revealed a relatively weak short wave over southwest Mississippi and southeast Louisiana just ahead of the thermal trough. The 500-mb numerical prognosis indicated this minor short wave would move rapidly eastward and be located over western Georgia by 13/1200Z. This minor short wave triggered the initial outbreak of tornado activity, the first tornado occurring nine miles north of Pensacola, Florida at 13/0340Z and the Fort Rucker tornado at 13/0725Z. The last tornado report in this initial outbreak occurred at 13/0743Z. At 13/0000Z, several parameters favorable for severe weather were either in existence or progged to be present within the next 12 hours. These parameters (Figure 94) consisted of a low level jet over the threat area, the presence of dry air upwind, a moderate 500-mb jet, and increasing low level moisture. Parameters not favorable at this time included low level (850 mb) flow parallel to the low level and mid level (700 mb) dry/moist boundary, Severe Weather Threat (SWEAT) Index values less than critical, lack of a strong trigger, sparse RADAR detected activity, and the complete absence of a surface boundary or organized pressure fall pattern.

The composite 12-hour prognostic chart valid at 13/1200Z (Figure 95) indicated that nearly all the parameters would fall into place by this time. The SWEAT Index values were forecast to increase over the threat area with values over 400 at 13/1200Z reaching the northwest Florida coast (SWEAT values isopleths valid at 13/1200Z not shown in Figure 95 to reduce cluttering). In addition, the AFGWC Boundary Layer Model forecast maximum SWEAT values for the 24-hour period from 13/0000Z to 14/0000Z showed a dramatic increase with values exceeding 400 occurring over a large area of the southeast United States and a peak value of 573 occurring along the northwest Florida coast. A fairly strong 500-mb short wave was progged to be over eastern Mississippi. Increasing low level moisture was apparent and both low level and 500-mb jets were forecast to continue over the threat area. While the low level dry/moist boundary was present, flow patterns were not favorable for its eastward progression. This was off-set, however, by the

Table 9

SEVERE THUNDERSTORM AND TORNADO PARAMETER WORKSHEET

AREA SRN AL — FL PNHNDL — NW FL-SW GA	ADVISORY NUMBER 48-49	DATE 130000Z JAN 72	ADVISORY VALID 13/ 00Z to 13/12 Z

PARAMETER	0000Z ANAL VALUE	0000Z ANAL RATING	1200Z PROG VALUE	1200Z PROG RATING	REMARKS/VERIFICATION
SWEAT	343	W+	350-400	W M +	BLM MAX 450-573 21-00Z(S) 1200Z 400-468(M)
TOTALS	52	M+	52	M	1200Z 51-54(M)
LIFTED INDEX	-5	M+	-5	M	1200Z -5 (M)
PVA	W	W+	M	M	1200Z (M)
500 MB HT FALLS	-30	M	-40	M	1200Z -40(M)
500 MB JET	50K	M	50	M	1200Z 60K (S)
850 MB MOISTURE	8'	W+	10°	M	1200Z 13° (S)
850 TEMP RIDGE	OVR MOIST RIDGE	M	W OF MOIST RIDGE	S	1200Z WEST OF MOIST RIDGE (S)
LO-LEVEL JET	30K	M	30K	M	1200Z 40K (S)
700 MB DRY INTRUSION	CROSSTHERMS AT 10° ANGLE	W+	CROSS AT 40° 45K	S	STRONG DRY INTRUSION UPSTREAM 1200Z (S)
700 MB NO-CHANGE TEMP	NOT EVIDENT	—	NOT EVIDENT	W	1200Z EVIDENT (S) 40K AT 50° ANGLE
WINDS VEER WITH HEIGHT	YES	—	YES	—	1200Z YES
WINDS INCREASE WITH HEIGHT	YES	—	YES	—	1200Z YES
INTERSECTING UP AND LO JETS	YES	—	YES	—	1200Z YES
SFC DEW POINT	66°	S	66°	S	1200Z 68° (S)
SFC PRESSURE THREAT AREA	1013	W	1011	W	1200Z 1010 BECAME MORE FVRBL FORENOON (W)
FALLING PRESSURE	YES	M	YES	M	1200Z YES (M)
INCREASING SFC TEMP	LITTLE CHANGE	—	LITTLE CHANGE	—	COOLED SLIGHTLY DUE TO R ACTIVITY
INCREASING DEW POINT	SLIGHT	—	YES	—	YES 1200Z
THICKNESS RIDGE	NOT EVIDENT	—	—	—	NOT EVIDENT
THICKNESS NO-CHANGE	NOT EVIDENT	—	—	—	NOT EVIDENT
MESO OR SYNOP PATTERN	POOR	—	POOR	—	BECAME MORE FVRBL DURING FORENOON

REMARKS

FIRST TORNADO 130725Z ENTERPRISE-OZARK AREA AL.
20 MORE TORNADOES DURING PERIOD 131200Z TO 141125Z ACROSS SRN AL-NW FL-W CNTRL AND SRN GA INTO CNTRL S.C.

forecast position of the 700-mb dry/moist boundary accompanied by strong cross flow from dry to moist air. It is also significant to note that by this time the low level temperature ridge would no longer coincide with the low level moisture ridge, but would retrogress westward causing a more volatile situation.

The composite chart made from the actual 13/1200Z data, shown in Figure 96, indicates all parameters in the moderate to strong category. A summary of the severe weather parameter values from the 13/0000Z analysis, the 13/1200Z prognosis, and the verifying values at 13/1200Z are shown in Table 9. After the initial outbreak of tornadoes from 13/0340Z to 13/0743Z, including the one which hit Fort Rucker at 13/0725Z, the tornado activity ceased for approximately 4 1/2 hours and then resumed again at 13/1215Z and continued throughout the remainder of the 13th and into the early morning hours of the 14th. A map showing the location and time (to the nearest hour) of the tornado and severe thunderstorm occurrence is included as Figure 97.

SECTION C—RADAR ANALYSIS

Analysis of data from five weather radars in the area supports the contention that a weak 500-mb short wave trough, passing through Alabama and the Florida panhandle into Georgia, triggered the initial tornado outbreak between 13/0340Z and 13/0743Z. The trough triggered intense thunderstorm activity as it moved eastward. Radar echo tops in the area of the trough were consistently higher than surrounding tops throughout this period. Furthermore the trough-induced favorable development area propagated eastward at the same speed as the trough itself.

Figure 98 shows selected examples of scope photographs taken every ten minutes at the Apalachicola, Florida, WSR-57 radar. The photo series covers the period 13/0320Z to 13/0720Z (times are approximate because the camera clock and interval timer malfunctioned). In all photographs, Fort Rucker is indicated by an open circle at 338 deg/100 nm. In the first two photos, Pensacola, Florida, is indicated by an open circle at 292 deg/123 nm.

The photo series shows that the Pensacola tornado (0340Z) and the Fort Rucker tornado (0725Z) came from the *same parent thunderstorm complex*; or more precisely, the Fort Rucker tornado was spawned from a thunderstorm which *had converged with the Pensacola storm*. The 0320Z photo shows the Pensacola parent thunderstorm echo, which, with tops in excess of 40,000 ft MSL, moved northeastward with a speed which gradually increased from 12 knots at 0320Z to 25 knots at 0600-0640Z. At 0520Z, a new thunderstorm complex began to form south of the mature system. Subsequent photographs show the new system intensifying and converging with the mature storm. The echo convergence is apparent in the 0640Z photo, and the 0720Z photo seems to indicate the new thunderstorm complex grew at the expense of the old system. At the time of echo convergence, the Centreville, Alabama, WSR-57 radar indicated tops of 51,000 ft MSL for this complex. Apalachicola reported 40,000 ft, and the truth is likely to be somewhere between these values. In any case, this echo complex had either reached or was penetrating the 40,000 ft tropopause by 0640Z. Its antecedent, the Pensacola storm has echoes at, near or slightly exceeding the tropopause throughout most of the period 0340-0640Z. Interestingly, at the time of echo convergence, the Pensacola thunderstorm complex, which had been moving at an average of 21 knots for more than three hours, accelerated to 40 knots, a more characteristic speed for severe weather echo systems. No change in the direction of motion was noted. The merged thunderstorm complex continued northeastward with tops penetrating the tropopause until at least 0812Z. It was this complex which spawned the Enterprise-Fort Rucker tornado.

This photo series shows no hooks, protrusions, pendants, weak echo regions or other echo signatures signifying severe convective weather. This is not surprising since none of these echoes was closer to the radar than 100 nm. Furthermore, the 250 nm PPI range was used for photography and the receiver was operated at full gain. Considering the echo range alone, at 100 nm, a beam at zero degrees elevation would be positioned 6,600 ft above the ground and would have a diameter of more than 21,000 ft. Under these circumstances, hooks and weak echo regions cannot be expected; therefore, a combination of radar reflectivity factor, tops and movement should be used to identify severe storms.

In this case, tops, movement and the *previous history of the storm* were the prime radar indications. As indicated by Darkow in papers presented at the 14th Radar Meteorology Conference (1970) and at the 7th Conference on Severe Local Storms (1971), and as reported in AWSTR 243, a parent thunderstorm complex that produces one tornado is quite likely to produce another. In fact, the probability of multiple tornadoes from a single parent storm is sufficiently high that meteorologists should routinely assume "more tornadoes are on the way," provided the parent storm shows no marked signs of dissipation or decay.

SECTION D—SUMMARY

This study illustrates the synoptic situation accompanying the occurrence of tornadoes in a Type II air mass which occurred (at least the initial outbreak) without a well-defined triggering mechanism. The tornadoes resulted from increasing instability throughout the period and the passage of several short wave troughs at 500 mb. The initial outbreak of severe weather occurred with a relatively minor short wave; this was followed by a repeat of severe activity associated with the following stronger short wave. Even though the synoptic features were not well defined and the triggering mechanisms were diffuse in this case, the analyzed and forecast SWEAT Index values were quite useful in pinpointing the potential area for severe weather activity.

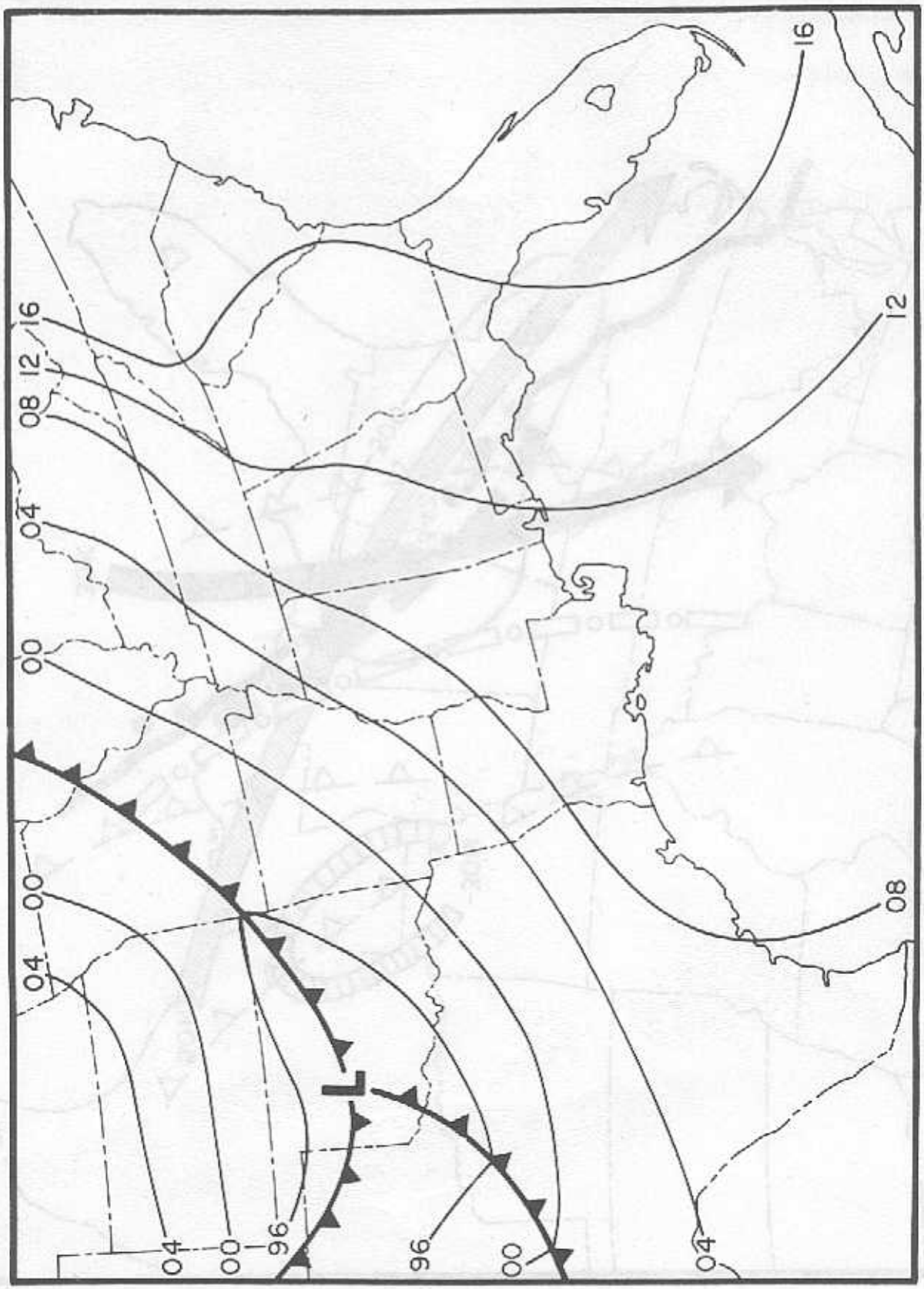

Figure 93. Surface chart for 0000Z, 13 January 1972.

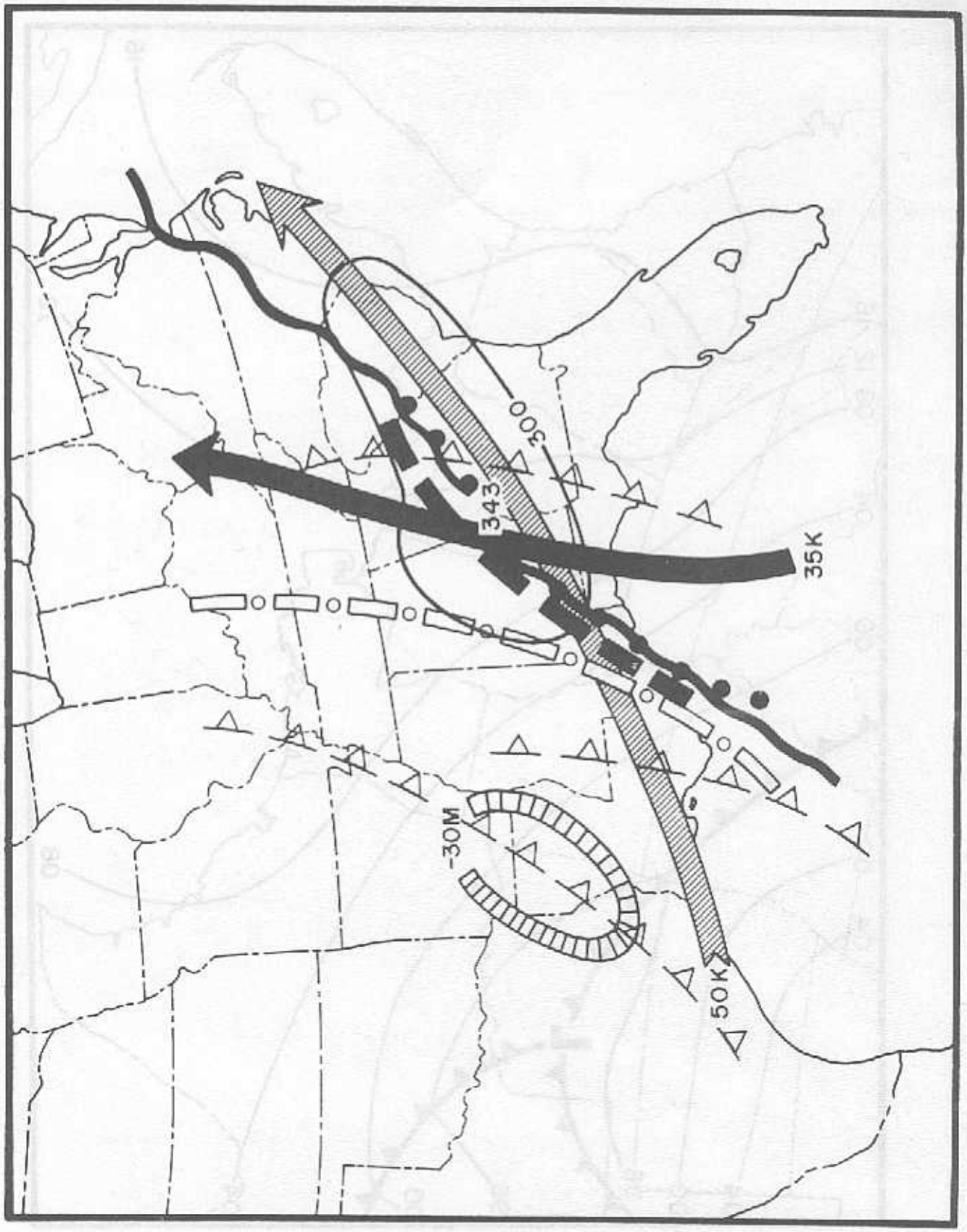

Figure 94. Composite chart for 0000Z, 13 January 1972.

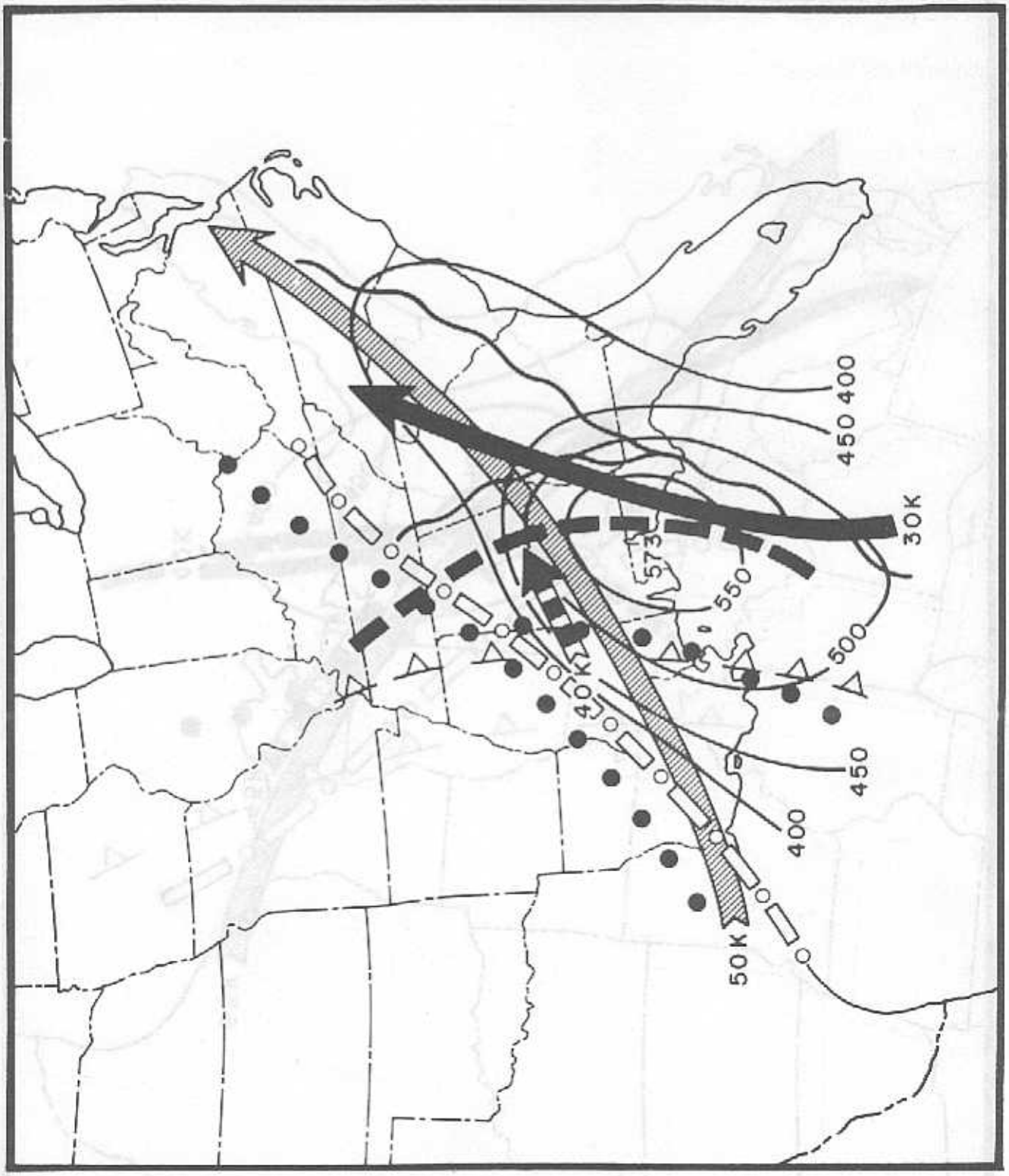

Figure 95. Composite prognostic chart valid 1200Z, 13 January 1972. Maximum forecast SWEAT index values for 24-hour period beginning 0000Z, 13 January 1972 shown by solid isopleths.

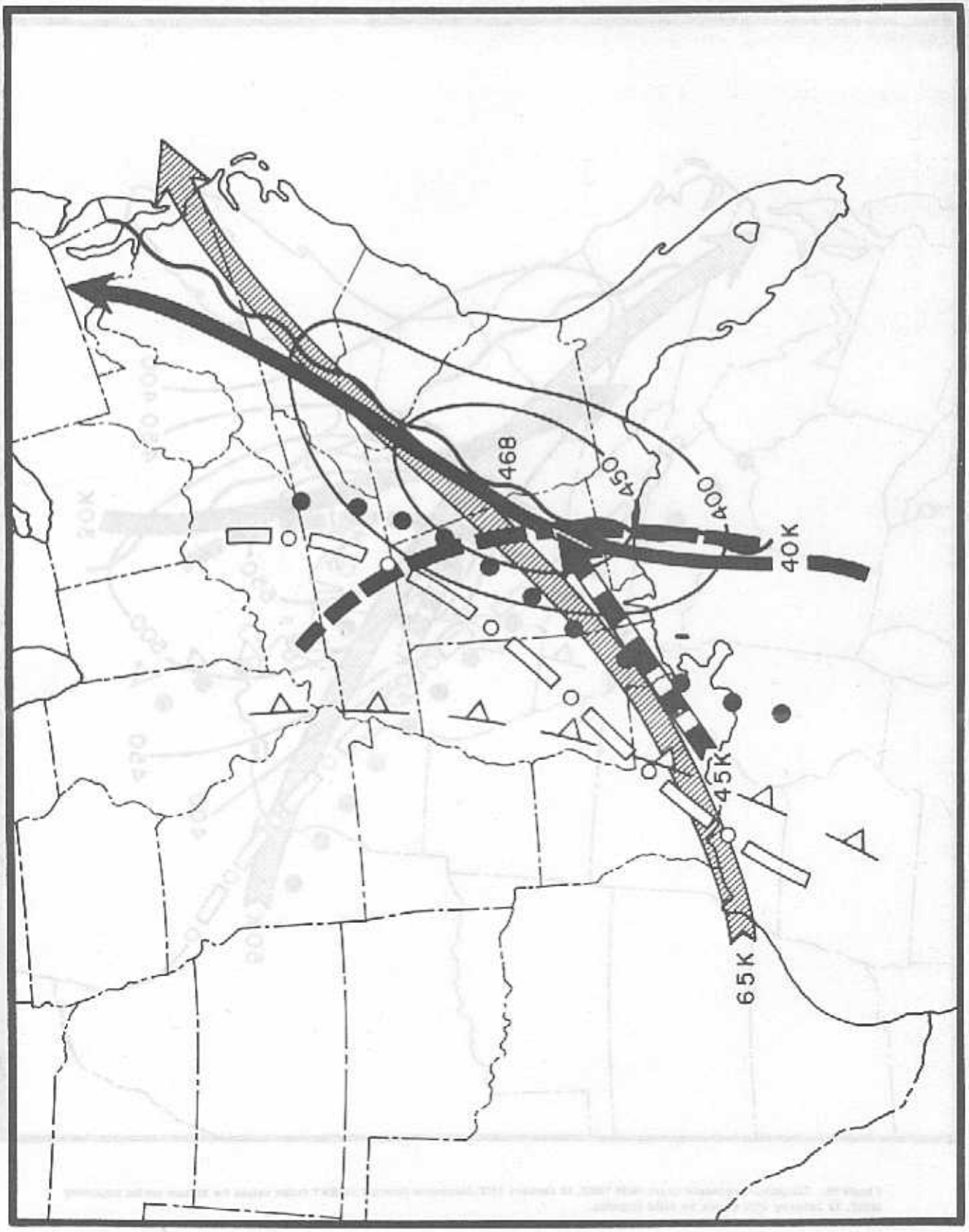

Figure 96. Composite chart for 1200Z, 13 January 1972. SWEAT Index values observed at map time shown by solid isopleths.

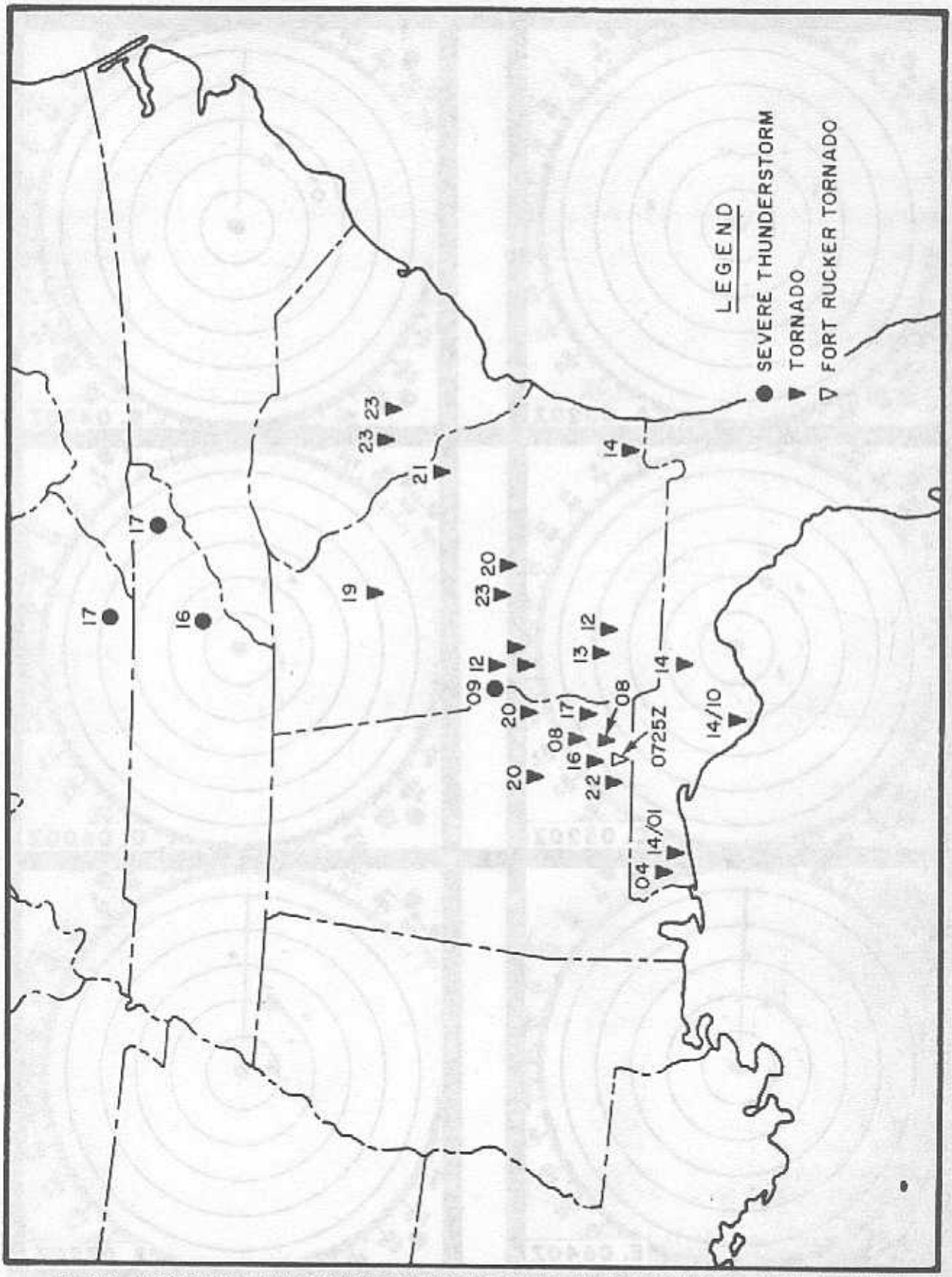

Figure 97. Location and time (to nearest hour of Z-time) of tornado and severe thunderstorm occurrences on 13-14 January 1972 (all occurrence on 13 January 1972 except where 14 precedes Z-time).

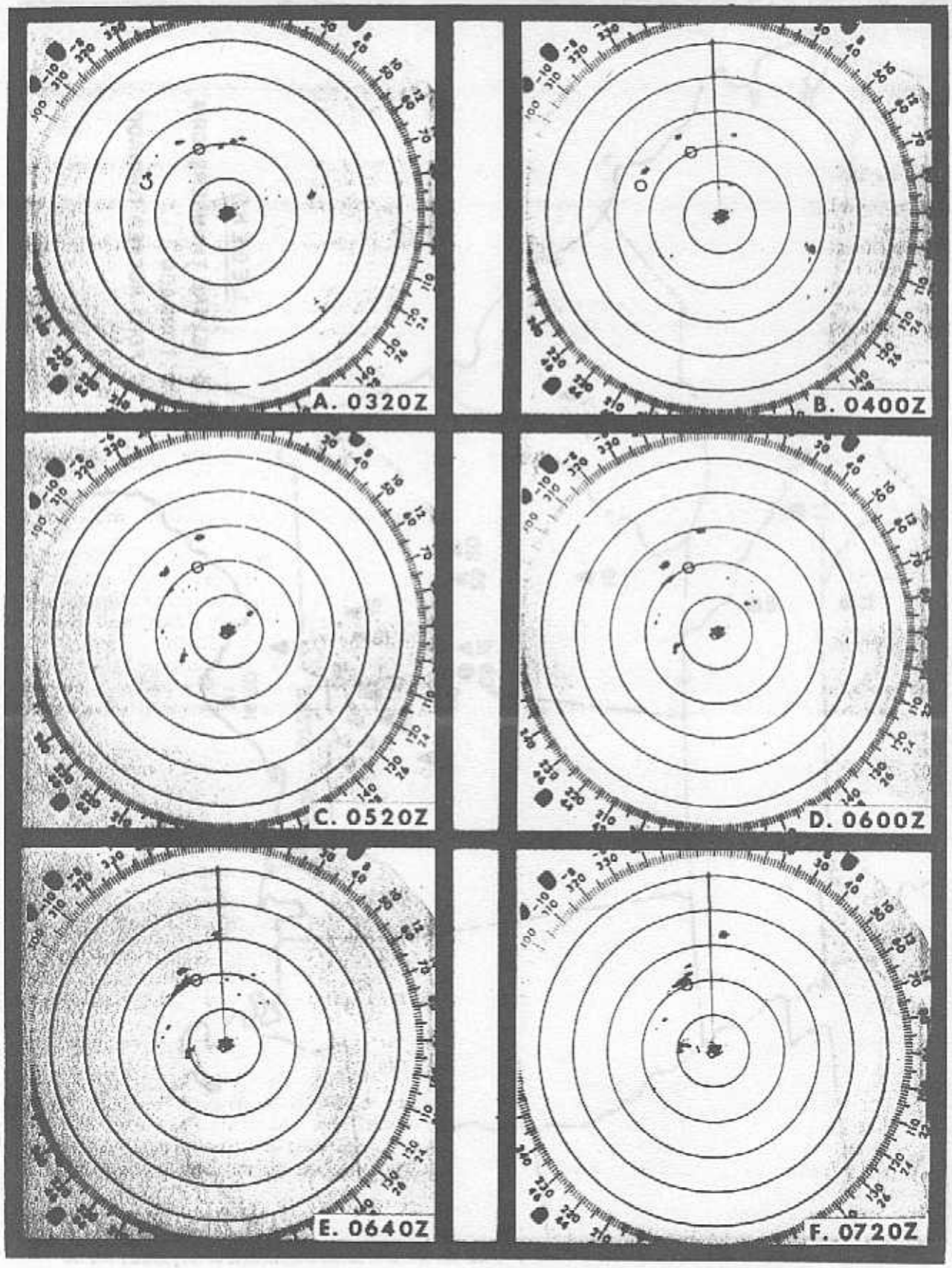

Figure 98. Photographs of the PPI scope of the WSR-57 storm detection radar at the Apalachicola, Florida Weather Service Office on 13 January 1972. Scope range is 250 n. mi; range marks are at 50 n. mi. intervals.

Appendix H

CHART SYMBOLOGY

SECTION A—GENERAL

The number of levels and the variety of parameters needed to analyze a typical severe-weather situation require special symbols and color schemes to organize the information analyzed on the manuscript chart.

SECTION B—PROCEDURES, SYMBOLS, AND COLOR SCHEMES

The following procedures, symbols, and color schemes are used in actual practice, and Figure 99 is a handy guide which can be unfolded to be referred to as the report is being read.

a. The surface chart is completed in black pencil with frontal systems and other lines of discontinuity depicted by standard printed map symbols. The major 12-hour pressure fall centers are entered using the symbol "Δ P."

b. The positions of significant dry lines and dry prods (tongues) at 850 mb are entered in red using an alternating dashed line and circle representation.

c. Shears and convergent zones in the low-level flow are indicated by solid red arrow-tipped lines, and low-level jets are shown by double-line shaded arrows. Jet speeds are often shown near the upwind end of the arrows.

d. The axes of low-level moisture areas are indicated by solid green arrows, and axes of areas of major moisture advection are shown as double-lined, shaded, green arrows. Often moist tongues are outlined as double green-shaded lines.

e. Principal 850-mb temperature ridges are denoted by a line of solid red dots.

f. Frontal positions and other lines of discontinuity at the 850-mb level are entered in red.

g. Significant areas of moisture at 700 mb are shaded lightly in brown.

h. Dry-air tongues at 700 mb are outlined in dashed heavy brown lines.

i. Well-defined lines of 12-hr no-temperature change associated with significant troughs at 700 mb are denoted by brown solid X's and dashes.

j. Frontal positions and troughs at 700 mb are entered in brown using standard printed map symbols.

k. Significant wind flow at 700 mb is entered using brown arrows with the axes of maximum-wind flow denoted by double-line arrows. Special attention is given to the wind flow between the dry and moist areas, and the location of near-by jet axes.

l. Temperature ridges or other desired features of the 700-mb temperature field, are entered in brown using heavy-shaded circles. Thermal troughs are often shown as brown open triangles.

m. The positions of thermal troughs at 500 mb are entered on the Composite Chart as open blue triangles, and a sufficient number of isotherms necessary to define the 500-mb thermal field are entered as dashed blue lines.

n. The 500-mb Critical Temperature for the season of the year is often shown as a heavier shaded dashed blue line. The Critical Temperature is that temperature during a month or season which, if exceeded in the direction of cooling, is highly correlated with thunderstorm occurrences.

o. Significant wind flow in the middle levels, including the jet band, is depicted by a solid heavy blue arrow, horizontal zones of speed shear by open blue wavy lines, and zones of diffluence by jagged blue lines.

p. Significant height fall areas at 500 mb are shown as solid blue double lines and temperature fall areas as broken double blue lines.

q. Similar features at the 200-mb level are frequently entered using the same symbols as shown for the middle levels except the shaded areas are purple.

r. The 850/500-mb thickness ridges are depicted as solid black dashed lines and the 12-hour no-change thickness line by solid black X's and dashes.

s. Thickness falls are shown as solid black double lines.

t. The Total Totals analysis for 50° and greater, by 2° or 4°-isopleth intervals, are entered as dashed orange lines.

u. The Lifted Index determined from the analyzed raobs is often entered as open black dashes.

v. The 500-mb barotropic or baroclinic progged areas of maximum vorticity for the forecast period are outlined and shaded in yellow.

w. The SWEAT Index is entered for values of 400 or greater, using solid orange lines.

SECTION C—PARAMETER SYMBOLS

A number of symbols are used on activity charts to denote the severe weather observed.

a. Thunderstorms are entered as solid circles;

b. Tornadoes are solid triangles;

c. Lightning is an arrow with the shaft bent at a 90° angle.

d. Damaging winds are a "plus" symbol; and

e. Hail occurrences are entered as solid squares.

Figure 99 is a fold-out aid to be used while the reader studies the many figures in this report.

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13. ABSTRACT
This is a revision of AWSTR 200 issued in July 1967.

This collection of notes discusses the various types of severe-weather air masses, how severe weather systems form, which parameters best define the existence and intensity of severe weather, and how to use local information to better forecast the occurrence of phenomena at individual stations. Specifically, wind gust and hailsize forecasting techniques and the usefulness of various stability indexes are presented. Also, a chapter on severe weather in tropical air masses is included. A number of detailed case studies are in the report to help the reader visualize how forecasting concepts are applied, and to emphasize the importance of forecasting experience. The revised material concentrates on the application of computer-derived aids to severe weather forecasting produced by the Air Force Global Weather Central. Foremost among these aids are analyses and prognoses of the Severe Weather Threat (SWEAT) Index.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Severe weather forecasting						
Tornado forecasting						
Thunderstorm forecasting						
Hail forecasting						

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CHART	PARAMETER	ENTRY	COLOR	SYMBOL*
Surface	Fronts, Isobars, Transitory Discontinuities	Already on Base Map	Regular Pencil	
	Hot/Dry Prod	Same	Regular Pencil	
	12-Hour P Falls	Same	Regular Pencil	10 ΔP
850 MB and/or Low-Level Wind and Moisture Field	Dry Lines or Dry Prods	Mandatory	Red	
	General Flow	As Required	Red	25K
	Low-Level Jets Max-Wind Values	Mandatory	Red	45K
	Horizontal Speed Shears	Optional	Red	35K 45K
	Convergent Zones	As Required	Red	
	Fronts, Troughs, Squall Lines	Optional	Red	
	Temp Ridges	Mandatory	Red	
	Axis of Cold Advection	Optional	Red	
	Axes of Moisture	Mandatory	Green	
	Max-Moisture Influx	Optional	Green	
	Moist Tongues	Optional	Green	10
700 MB	Dry Tongues, Prods or Intrusions	Mandatory	Brown	
	Moisture	As Required	Brown	
	12-Hr No-Change Lines	Mandatory When Well Marked	Brown	
	Fronts/Troughs	Optional	Brown	
	Thermal Troughs	Optional	Brown	
	General Wind Flow	As Required	Brown	30K
	Max-Wind Axes	Mandatory	Brown	50K
	Significant Height Falls	Optional	Brown	-6
	Significant Temp Falls	Optional	Brown	-5
	Temp Ridges	Optional	Brown	

* These symbols are for black and white charts. A few color symbols used at MWWC differ slightly from what is presented here.

Figure 99 List of the parameter symbols used in the figures of this report.

CHART	PARAMETER	ENTRY	COLOR	SYMBOL*
700 MB	Convergent Zones	As Required	Brown	
	Axis of Cold Advection	Optional	Brown	
	Diffluent Zones	Mandatory	Brown	
500 MB and/or Mid-Levels	Thermal Troughs	Mandatory	Blue	
	Isotherms	Mandatory	Blue	-20 -20
	Critical Seasonal Temperature	Optional	Blue	
	General Wind Flow	As Required	Blue	50K
	Jet Flow	Mandatory	Blue	80K
	Diffluent Zones	Mandatory	Blue	
	Horizontal Speed Shears	Mandatory	Blue	
	Significant Height Falls	Optional	Blue	-12
	Significant Temp Falls	Optional	Blue	-6
	500-mb Moisture	Optional	Green	
Jet and/or Trop Chart	Jet Flow	As Required	Purple	
	Speed-Shear Zones	As Required	Purple	
	Diffluent Zones	As Required	Purple	
	Jet Max	Optional	Purple	
850/500 MB Thickness Chart	Thickness Ridges	Mandatory	Black	
	12-Hr No-Change Thickness Line	Mandatory	Black	
	Significant Thickness Falls	Mandatory	Black	-12 -6
	Total Totals	Mandatory 50 and Above	Orange	50
	Zones of Marked Anti-Cyclonic Wind Shear	Optional	Black	
RAOBS	Lifted Index	Optional	Black	
	Level of Free Convection	Optional	Black	
Vorticity Progs	Max Positive Vorticity Advection	Optional	Yellow	
SWEAT Analysis Prognosis	Severe Weather Threat Index	Mandatory	Orange	400 500

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