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Tornado Outbreak of April 3-4, 1974; Synoptic Analysis

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Robert M. White, Administrator

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CONTENTS

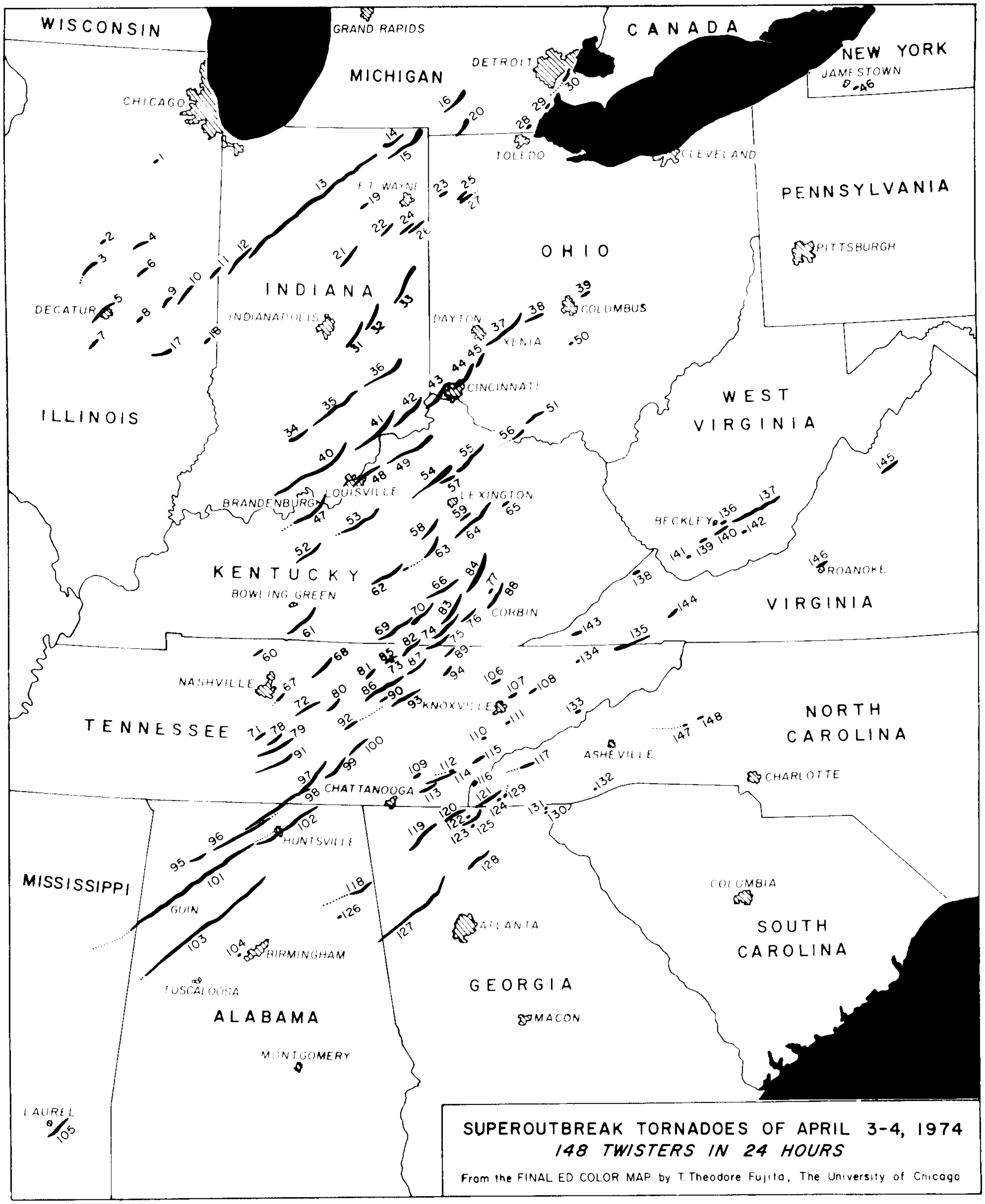


Figure 1 Tornado tracks for the period 1200 CST, April 3 to 1200 CST, April 4, 1974 [Fujita (1975)].

TORNADO OUTBREAK OF APRIL 3-4, 1974; SYNOPTIC ANALYSIS

Lee R. Hoxit and Charles F. Chappell

ABSTRACT

Synoptic scale analyses of the intense spring cyclone that produced the widespread tornado outbreak on April 3–4, 1974, are presented for the period from 1200 GMT April 2 to 1200 GMT April 4. The dynamics and kinematics creating the severe storm environment in the Ohio and Tennessee River Valleys on the afternoon and evening of April 3 are emphasized.

Introduction

The worst tornado outbreak of this century occurred on April 3–4, 1974. Figure 1* shows the tracks of 148 tornadoes that occurred in the 24-hour period from noon CST April 3 to noon CST April 4. The combined path length of these storms was 2598 miles. Additional tornadoes occurred the night of April 2 and the afternoon of April 4. Numerous wind and hailstorms were also reported with this system.

The statistics (table 1) prepared by the National Oceanic and Atmospheric Administration (1974) demonstrate the storm's impact both in terms of human suffering and material damage.

During the afternoon and evening of April 1, a strong baroclinic wave at upper levels moved onto the northern California and Oregon coasts, with the associated Pacific cold front advancing through Nevada and Idaho. This system eventually produced over the eastern U.S. the severe weather on April 3–4 whose evolution is discussed in this report. ■

Table 1

April 3–4, 1974, Disaster Survey Statistics

Storm related fatalities —	*315*
Storm related injuries —	*6,142*
Families suffering losses —	*27,590*
Damage Estimate —	*$600,000,000*

*A larger version of this map in color is available from the University of Chicago Press for a handling fee of 30¢.

Analyses for 1200 GMT April 2, 1974

The first set of charts describes atmospheric conditions on the morning of April 2 (1200 GMT). Standard pressure level analyses and a surface analysis are included.

At 300 mb a trough was located over the Great Basin with the axis tilted north-northwest to south-southeast (fig. 2). This "negative" tilt was also evident at 500 mb and persisted at both 300 mb and 500 mb 12 hours later. This kind of trough orientation is indicative of a southerly transport with westerly angular momentum, and is frequently a signature for amplifying baroclinic waves, which eventually develop upper level closed circulations or vortices. The exit region of a new jet stream maximum was propagating inland over northern and central California.

At 500 mb (fig. 3) the orientation of the baroclinic wave was very similar to that at 300 mb. The isotherms over north central California exhibited a strong temperature gradient which coincided with the axis of the 300 mb

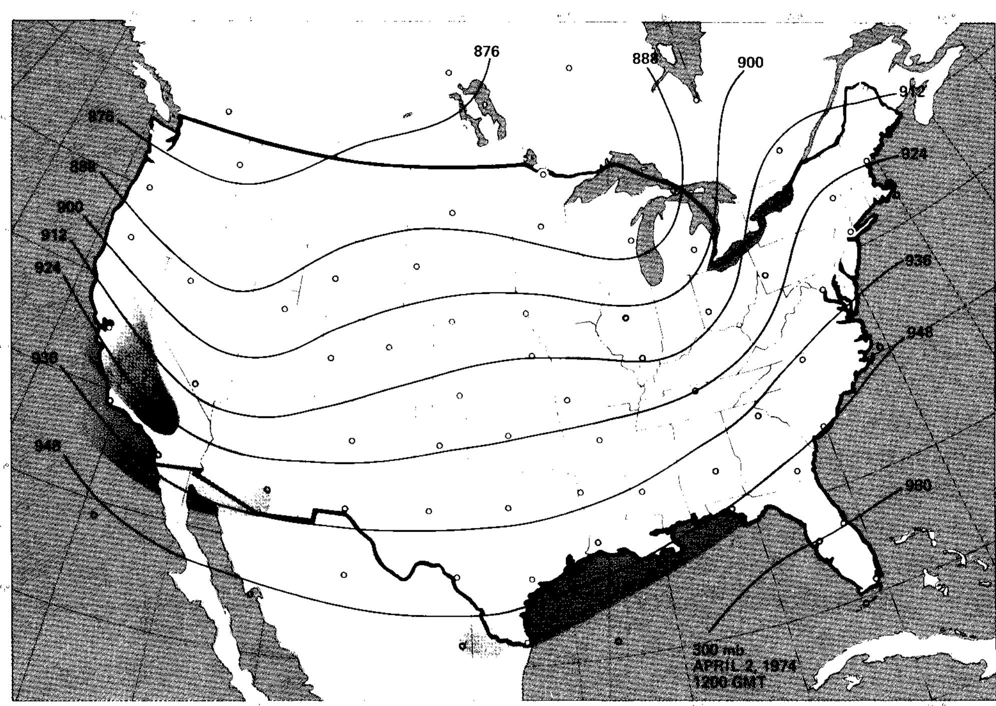


Figure 2 300-mb analysis, 1200 GMT, April 2, 1974. Contours, 120-m intervals; Wind speeds 80-120 kn, orange shading; Wind speeds > 120 kn, gray shading.

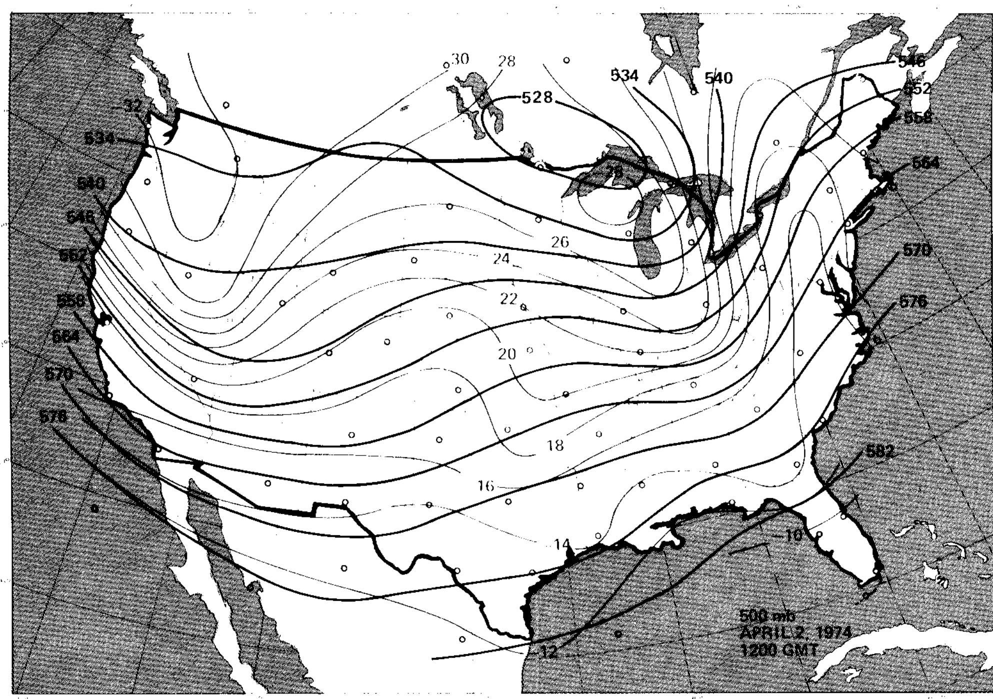


Figure 3 500–mb analysis, 1200 GMT, April 2, 1974. Contours, 60–m intervals; Isotherms, 2°C intervals.

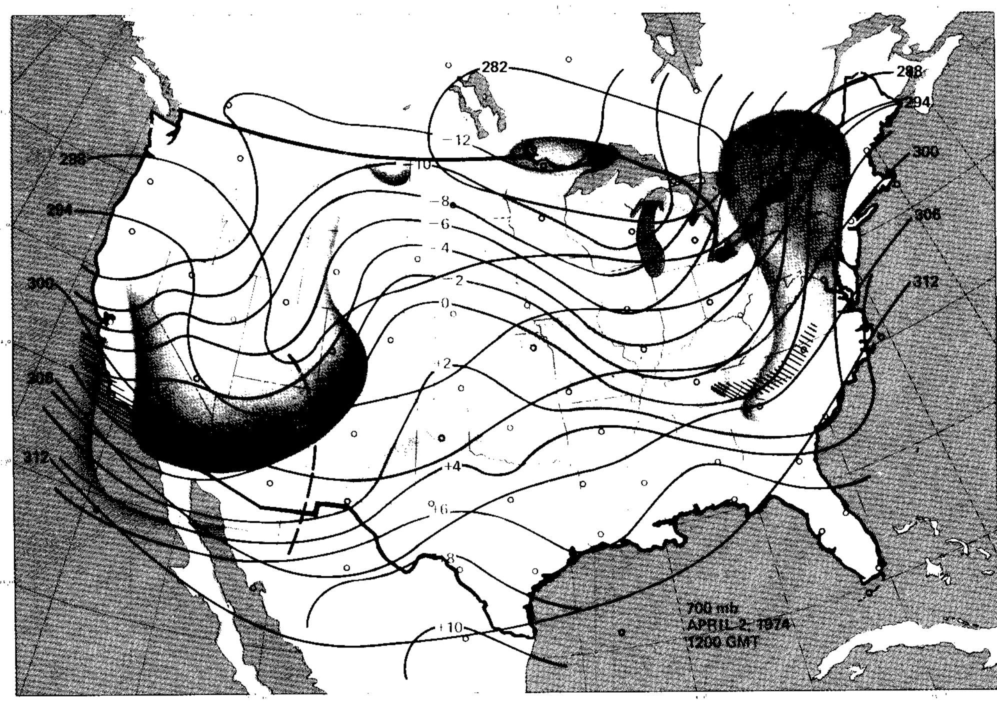


Figure 4 700–mb analysis, 1200 GMT, April 2, 1974. Contours, 60–m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 60 kn, hatched.

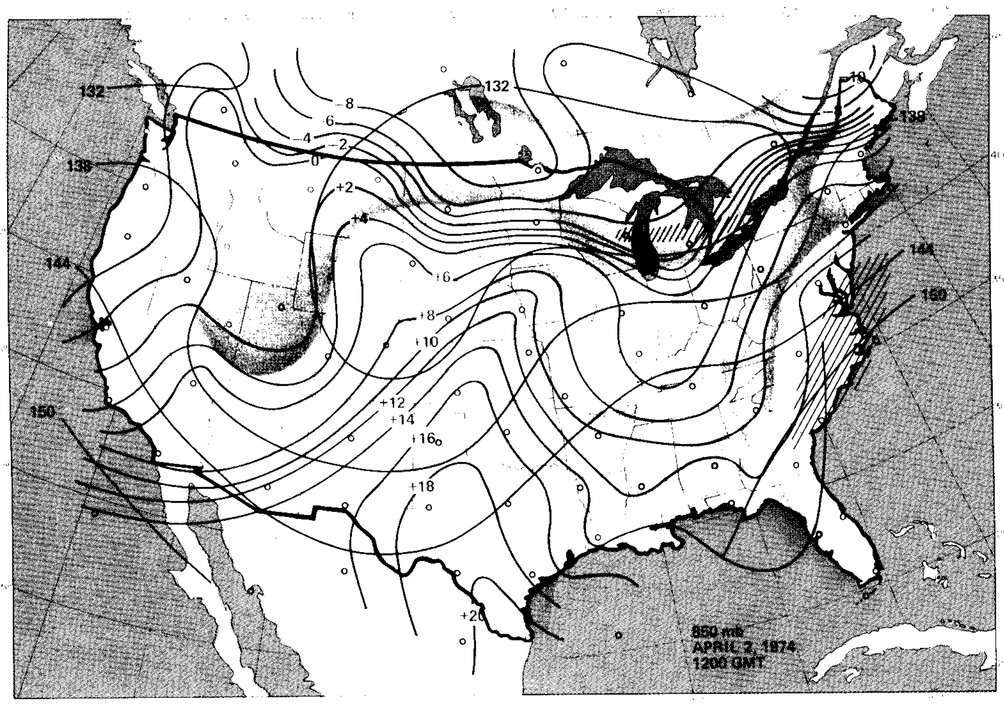


Figure 5 850-mb analysis, 1200 GMT, April 2, 1974. Contours, 60-m intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 50 kn, hatched.

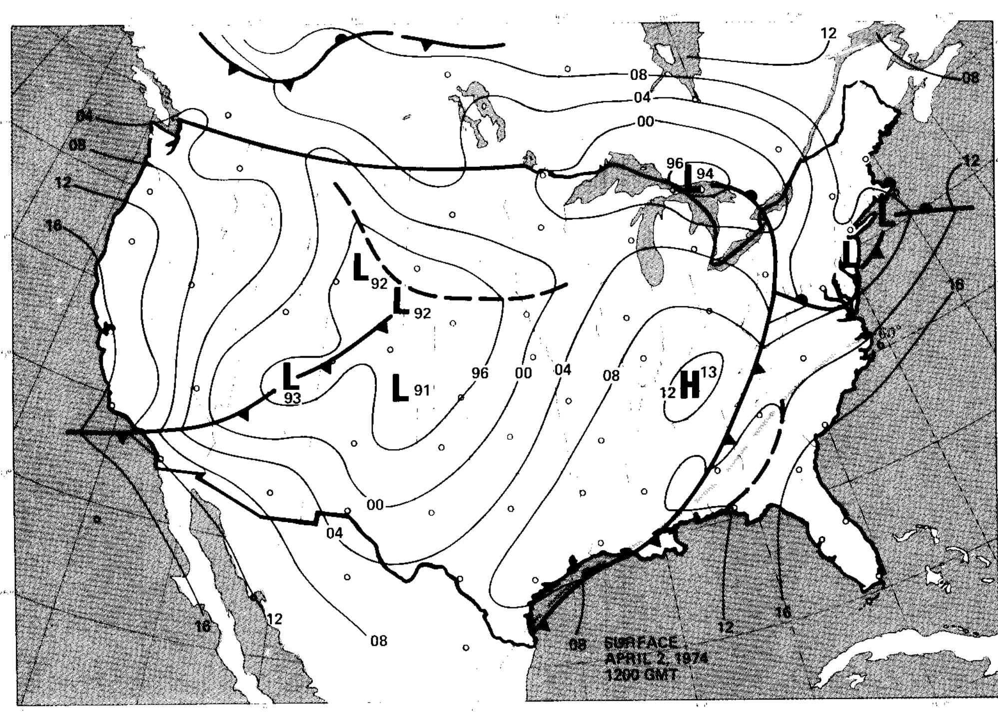


Figure 6 Surface analysis, 1200 GMT, April 2, 1974. Pressures, 4-mb intervals; 60°F isodrosotherm, dashed.

wind maximum. Temperatures associated with the 500-mb trough were quite cold for April as evidenced by the $-30°C$ isotherm in northern Nevada.

At 700 mb (fig. 4), there was a large region of dry air over the south central U.S. and strong cold air advection in northern California, Nevada, and Utah. The strongest winds (60-70 kn) were in a band running from off the southern California coast to central Arizona.

The 850-mb contours (fig. 5) indicate a large but poorly organized cyclonic circulation over the north central U.S. Again, note the broad extent of dry air over the southern plains and lower Mississippi Valley.

Surface pressure falls associated with strong positive vorticity advection in the mid-troposphere resulted in a dynamic low pressure center over southeast Utah (fig. 6). At the same time, several minor low centers formed in the lee-trough just east of the Rocky Mountains. Overall, surface pressures below 1000 mb covered an area approximately 1000 miles in diameter with the lowest pressure (991 mb) over southeast Colorado.

An active squall line was moving through the southeastern U.S. in conjunction with an earlier short wave and cold frontal system. This short wave was moving out to the northeast, and the front was becoming stationary along the Gulf coast. Thus, the warm moist low-level air along the Gulf coast was in position to be advected northward into the central U.S. in response to the developing cyclonic storm over the Great Basin and southern Rockies. Note the position of the 60°F isodrosotherm. ■

Analyses for 0000 GMT April 3, 1974

Figures 7–13 present analyses of data taken on the evening of April 2 (0000 GMT, April 3). An analysis of Lifted Index values and a sounding for Midland, Texas, are included.

At 300 mb (fig. 7) the upper level baroclinic wave over the western U.S. moved rapidly east-southeast and became even more negatively tilted. A well-defined jet stream axis existed from off the northern California coast to southern New Mexico. Maximum wind speeds in the jet stream were near 140 kn from northern California to southern Nevada.

The 12-hour change in the 500 mb thermal field is noteworthy (fig. 8). The combination of an indirect vertical circulation in the jet stream exit region and horizontal cold advection produced a marked cooling in northern

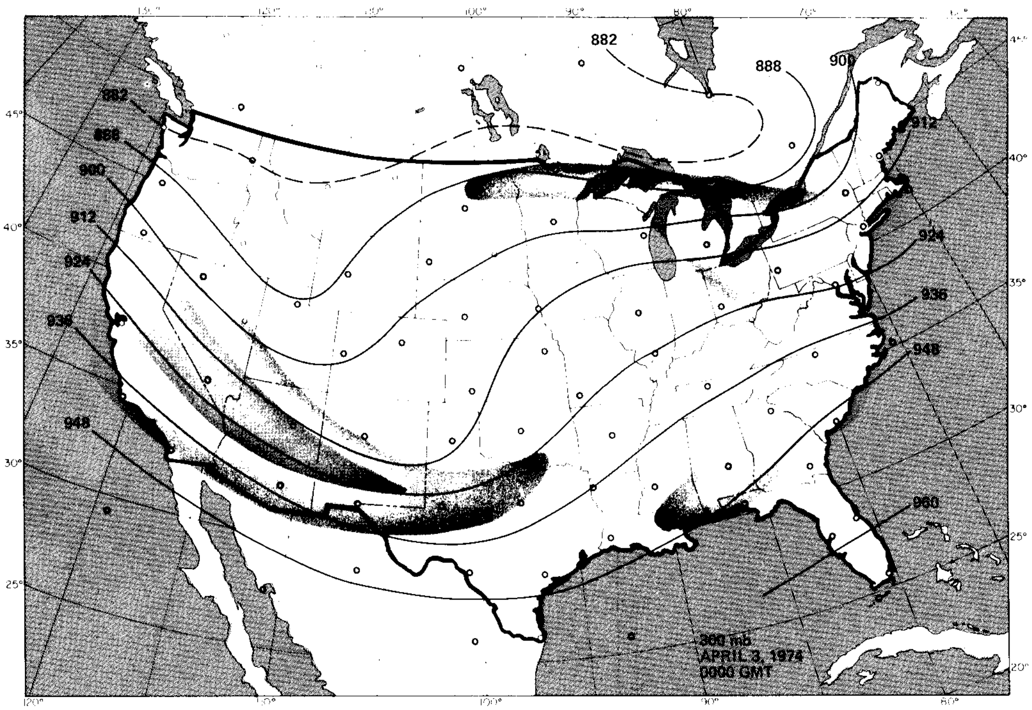


Figure 7 300-mb analysis, 0000 GMT, April 3, 1974. Contours, 120-m intervals; Wind speeds 80–120 kn, orange shading; Wind speeds > 120 kn, gray shading.

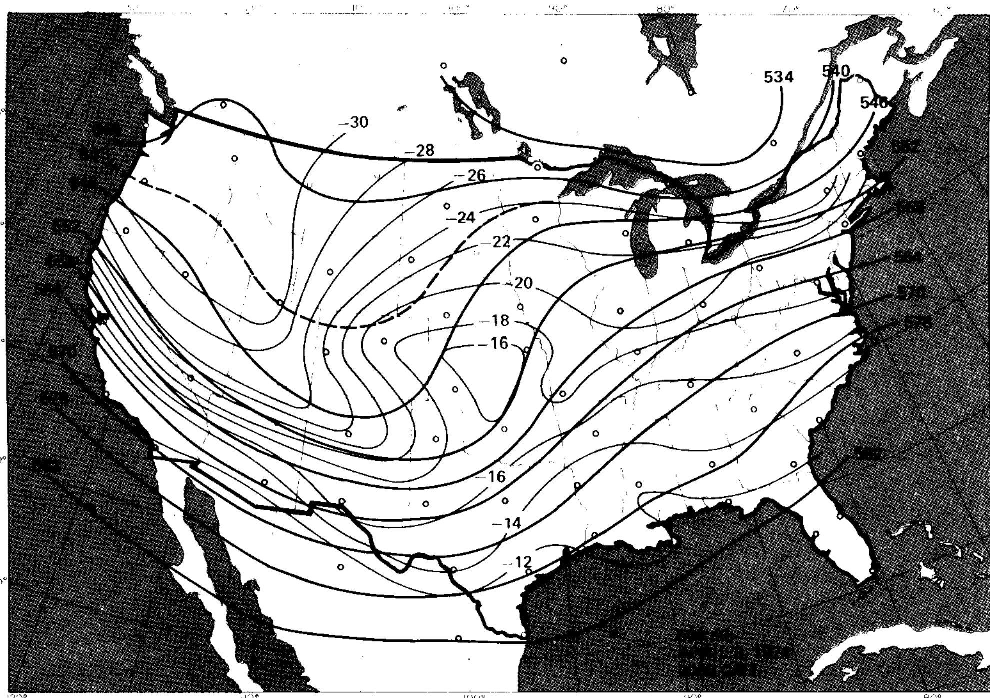


Figure 8 500-mb analysis, 0000 GMT, April 3, 1974. Contours, 60-m intervals; Isotherms, 2°C intervals.

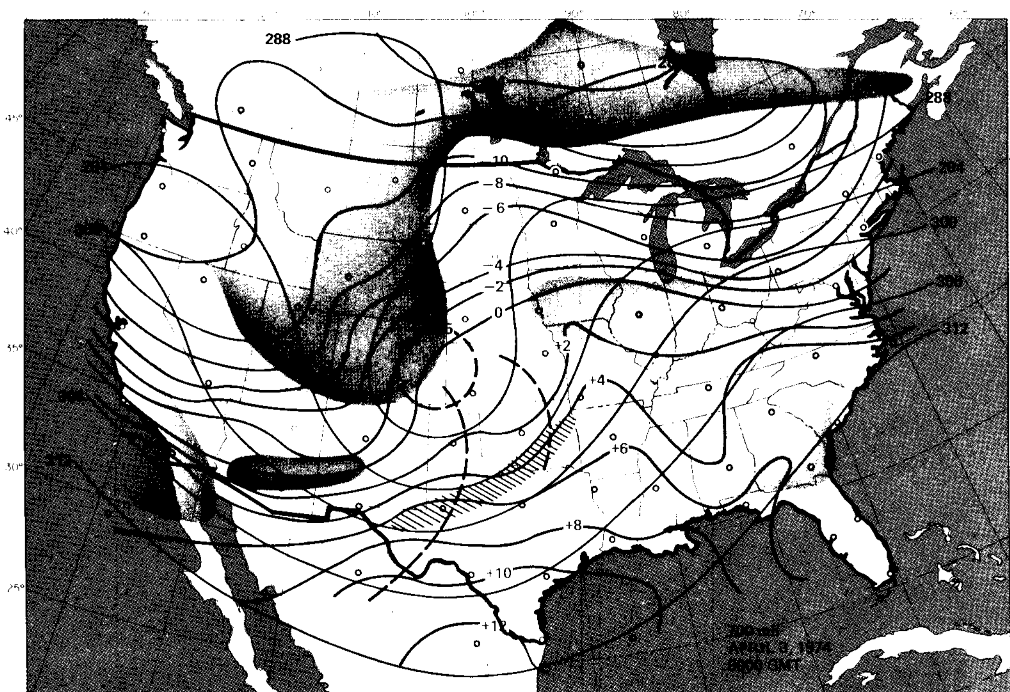


Figure 9 700-mb analysis, 0000 GMT, April 3, 1974. Contours, 60-m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 60 kn, hatched.

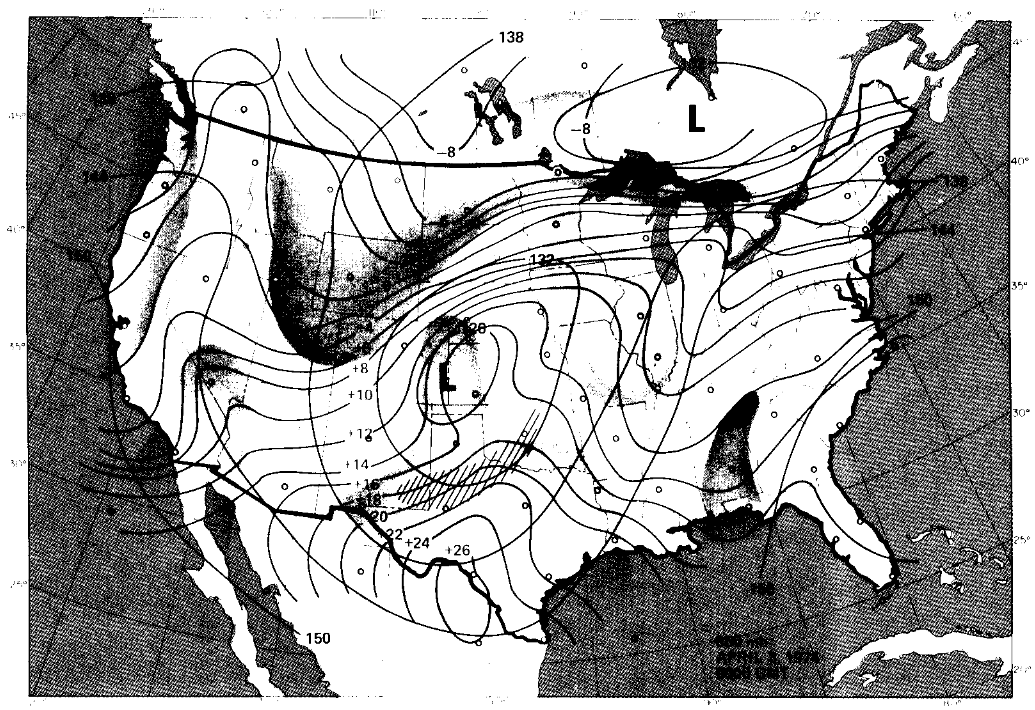


Figure 10 850–mb analysis, 0000 GMT, April 3, 1974. Contours, 60–m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 50 kn, hatched.

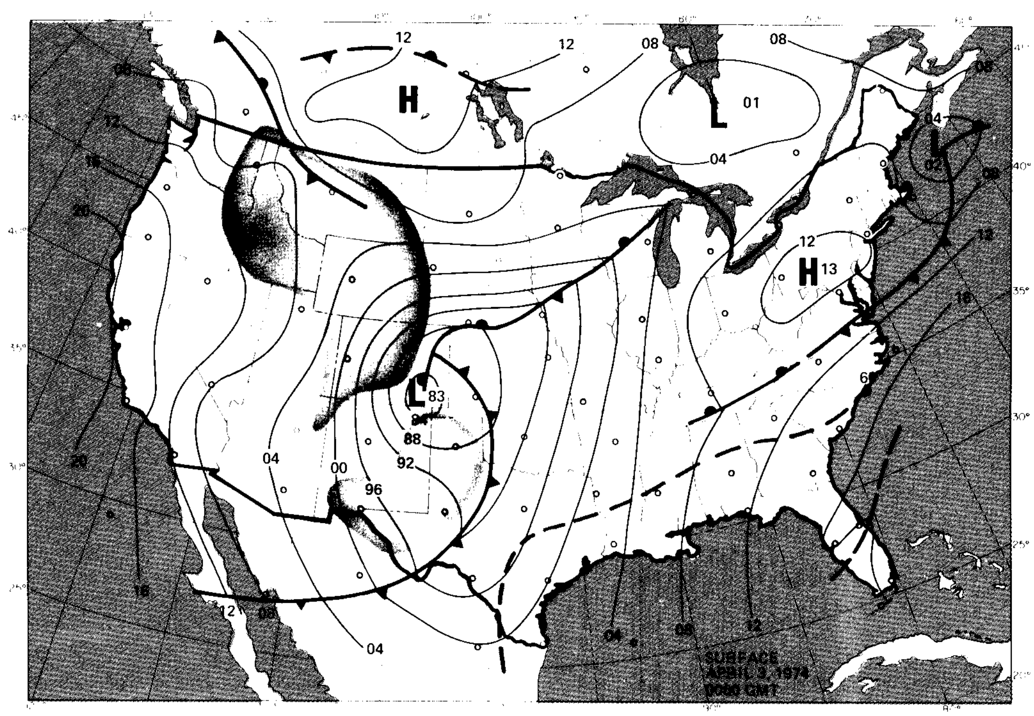


Figure 11 Surface analysis, 0000 GMT, April 3, 1974. Pressures, 4–mb intervals; 60°F isodrosotherm, dashed; Area of precipitation, gray shading; Area of blow dust or blowing sand, orange shading.

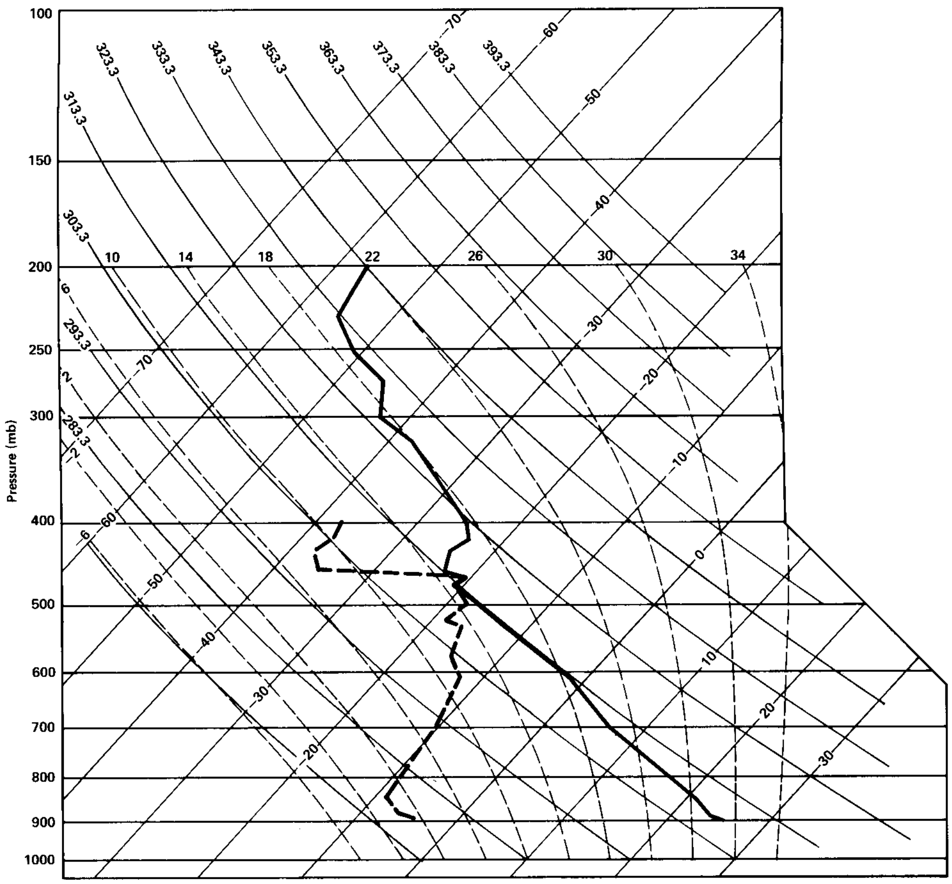


Figure 12 Midland, Texas, 0000 GMT, April 3, 1974.

New Mexico. The Albuquerque sounding, for example, indicated cooling of 7°C at 500 mb during the preceding 12 hours. Meanwhile, the thermal ridge over the central plains intensified and warming of 1–2°C in 12 hours was noted from Oklahoma to North Dakota. A strong baroclinic zone extended from north central California to central New Mexico just to the north of the jet stream axis. Heights were building rapidly along the east coast as the previous short wave continued to move northeastward into eastern Canada.

At both 700 mb (fig. 9) and 850 mb (fig. 10) closed circulations had developed near the Colorado-Kansas border by 0000 GMT. Strongest winds were located in a band extending from southeast New Mexico and west Texas to southern Oklahoma. Large areas of dry air were present south and east of the low center. At 850 mb, dry air covered all of Texas and parts of surrounding states, plus portions of Missouri, Illinois, Iowa, Wisconsin, and Minnesota. At 700 mb, the dry air extended from southern Texas to New England.

At the surface (fig. 11) the dynamic low over southeastern Utah moved eastward into the lee–trough, forming a well organized low center in southeast Colorado with a central pressure of approximately 983 mb. Widespread precipitation had developed northwest of the low center.

Warm moist air was moving rapidly northward in the lower levels over the lower Mississippi Valley as strong southerly winds developed in response to the cyclogenesis over southeastern Colorado. Surface dew points ≥ 60°F extended into central Louisiana and east–central Texas. Within 1 hour after this map time, a squall line developed in central Oklahoma and moved through eastern

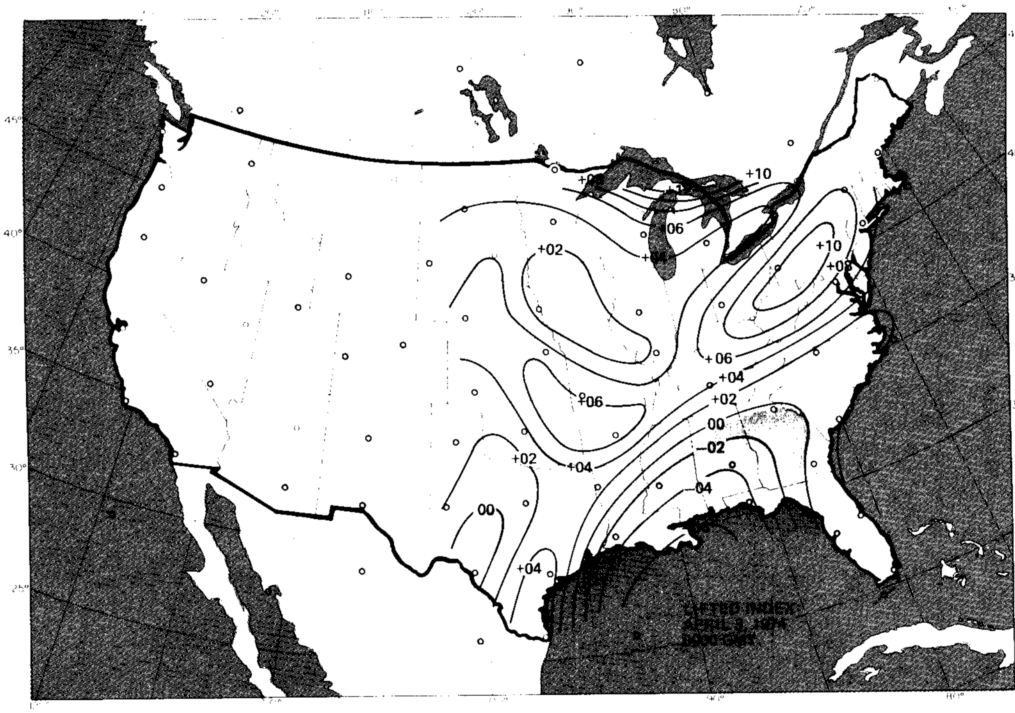


Figure 13 Lifted Index analysis, 0000 GMT, April 3, 1974.

Oklahoma, Arkansas, northeast Texas, and southern Missouri during the night. Two or three tornadoes and isolated hail and wind damage were reported with this first wave of convective activity.

The trailing cold front moved very rapidly through eastern New Mexico, western Texas, and western Oklahoma. Surface wind gusts to 70 mph were reported in eastern New Mexico during the late afternoon. The red area in figure 11 indicates the general region of blowing dust and sand. Danielsen (1975) has documented the frequent occurrence of dust storms in the Southwest 1–2 days before major severe weather outbreaks in the central and eastern U.S. He suggests that strong surface heating in the high desert regions of the Southwest greatly increases available potential energy by creating a quasi-adiabatic lapse rate from the surface to the mid-troposphere. The 0000 GMT sounding taken at Midland, Texas (fig. 12), vividly illustrates this condition. The lapse rate was essentially adiabatic from the surface to 475 mb (approximately 16,000 ft above the surface). Also, the mixing ratio changed little from 850 mb (2.3 gm/kg) to 500 mb (1.8 gm/kg). In these cases, Danielsen suggests, it is appropriate to consider the momentum boundary layer as coinciding with this adiabatic layer. As strong mid-tropospheric winds associated with the upper level wave propagated into the region containing the deep adiabatic layer, horizontal momentum was mixed downward. Low level winds were increased to supergeostrophic values producing the dust storms depicted in figure 11. Winds from the surface to 500 mb at Midland are given in table 2.

Table 2

Wind as a Function of Height
Midland, Texas, 0000 GMT, April 3, 1974

Level (mb)	*Direction (degrees)*	*Speed (kn)*
Surface	*280*	*30*
850	*280*	*49*
700	*255*	*67*
500	*250*	*72*

The Lifted Index analysis for 0000 GMT April 3 is shown in figure 13. The Lifted Index is obtained by first hypothetically mixing the lowest 100 mb of the atmosphere, then lifting by means of the parcel method, and finally subtracting the parcel temperature (in °C) at 500 mb from the environmental temperature at 500 mb. (For a morning sounding, an estimate of the low level temperature change due to surface heating is added prior to lifting). Negative values give an indication of the amount of conditional instability or potential buoyant energy present. At this time, negative values were confined to the Gulf coastal regions and a small portion of southwest Texas.

Circulations necessary to create a severe storm environment already existed over the lower Mississippi, Ohio, and Tennessee River Valleys by the evening of April 2 (0000 GMT, April 3). The combination of strong low level advection of maritime air, and advection and production of warm dry air in the 850–700 mb layer by means of large scale subsidence, was rapidly changing the environment from a stable to a convectively unstable stratification. ■

Analyses for 1200 GMT April 3, 1974

Synoptic data for the morning of April 3 (1200 GMT) gave numerous indications that a major outbreak of severe local storms was imminent. At both 300 and 500 mb a closed circulation had developed over western Kansas (figs. 14 and 15). The jet stream at 300 mb had propagated into north central Texas and eastern Oklahoma. Development of strong winds on the east side of the trough axis suggested that the system would move in an eastward to northeastward direction in the next 12–24 hours. The strong vertical circulations associated with the jet stream exit region continued the eastward generation of a strong baroclinic zone at 500 mb.

The cyclonic circulation at 700 mb (fig. 16) was centered over north central Kansas and had intensified during the preceding 12 hours. The axis of warm dry air now extended from northern Mexico northeastward across the lower Mississippi Valley to Ohio and southern Michigan. The band of winds > 60 kn had propagated eastward and expanded.

The cyclonic circulation at 850 mb (fig. 17) had also intensified. Three areas of winds > 50 kn were associated with this circulation — one located in the cold air and two in the warm sector. Dry air at this level was still largely confined to portions of Texas and Oklahoma.

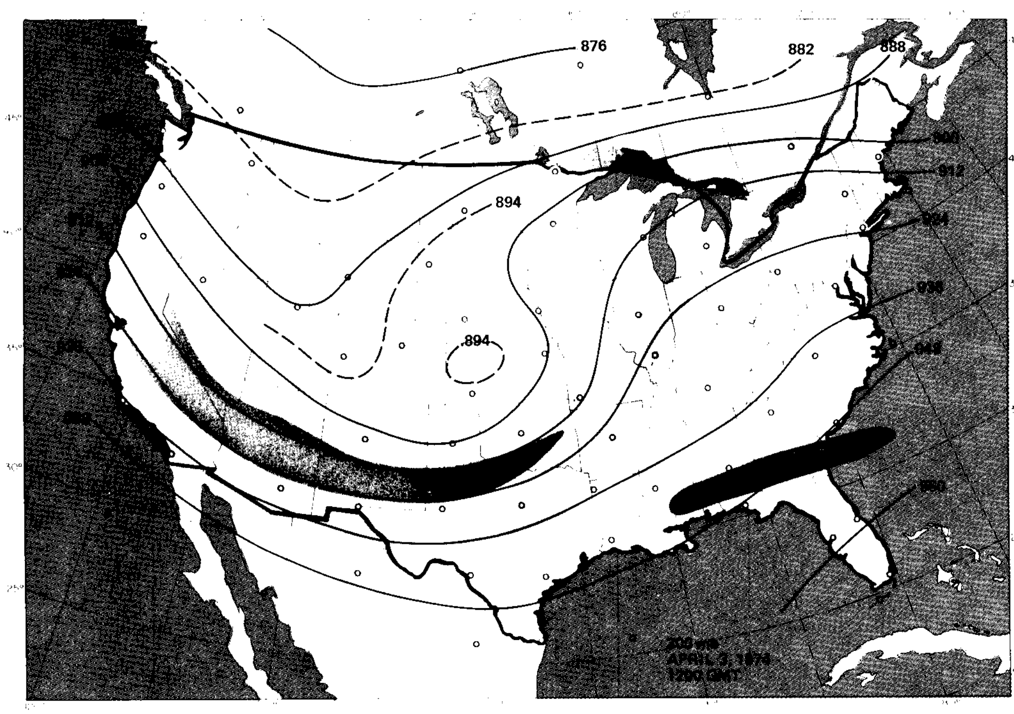


Figure 14 300-mb analysis, 1200 GMT, April 3, 1974. Contours, 120-m intervals; Wind speeds 80–120 kn, orange shading; Wind speeds > 120 kn, gray shading.

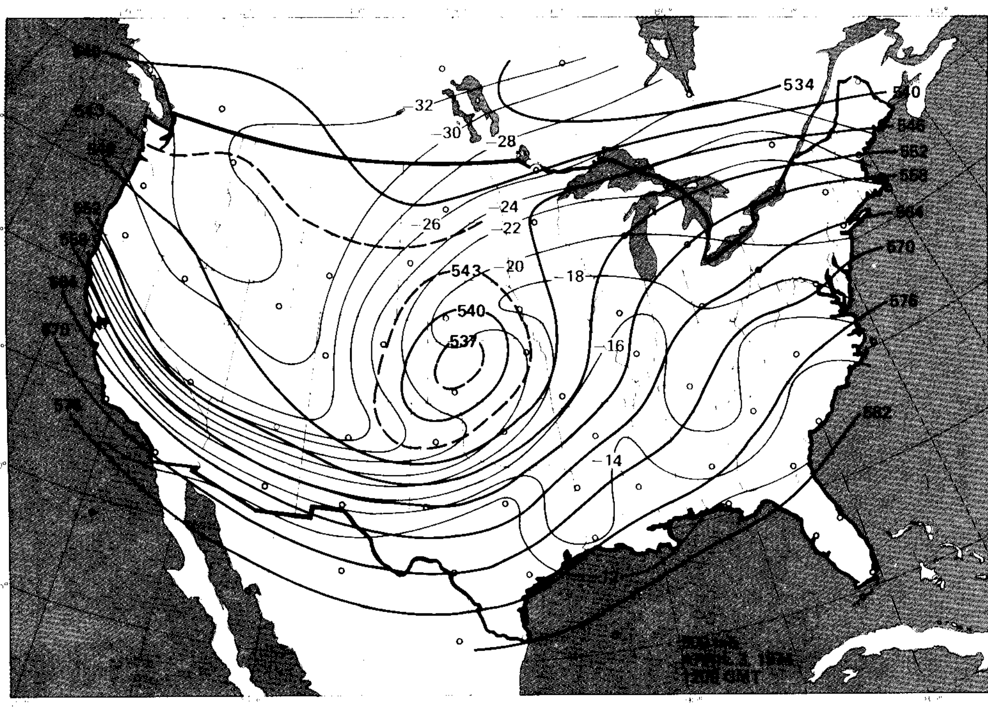


Figure 15 500-mb analysis, 1200 GMT, April 3, 1974. Contours, 60-m intervals; Isotherms, 2°C intervals.

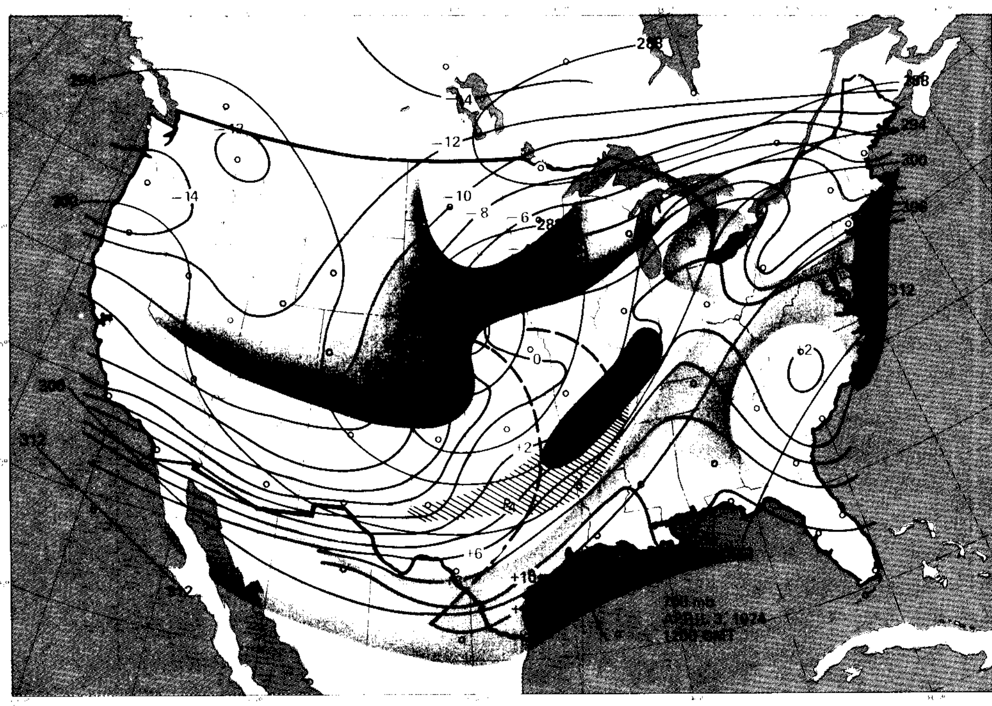


Figure 16 700-mb analysis, 1200 GMT, April 3, 1974. Contours, 60-m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depression ≤ 5°C, gray shading; Wind speeds ≥ 60 kn, hatched.

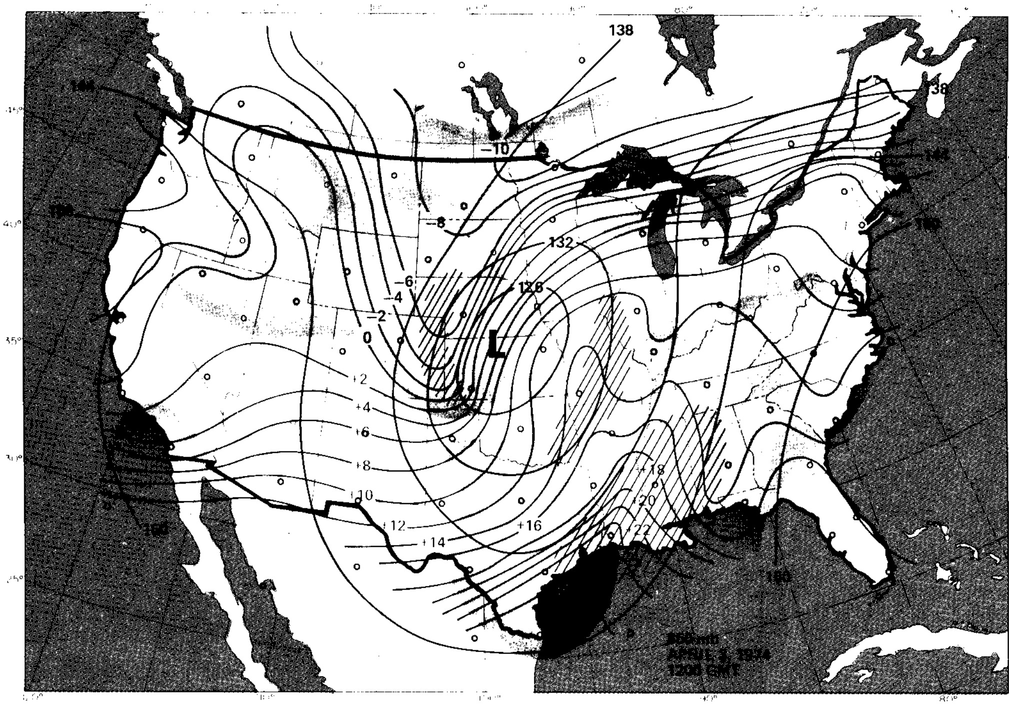


Figure 17 850–mb analysis, 1200 GMT, April 3, 1974. Contours, 60–m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 50 kn, hatched.

Figure 18 illustrates how rapidly a conditionally unstable airmass developed in the northern Gulf and Tennesseee Valley states. (Compare figure 18 with figure 13.) Negative Lifted Indices were found as far north as central Illinois and Indiana. Index values of −08 from the Louisiana coast to northern Tennessee represent near record Lifted Index values for the southcentral U.S. during the first half of April. Also, note the strong gradient in the Index across eastern Texas coinciding with the transition from moist to dry air.

The synoptic scale vertical motions over much of the eastern U.S. at 1200 GMT are shown in figure 19. The vertical motions at 875, 775, 675, and 575 mb are presented. These were obtained from standard rawinsonde derived wind data using the kinematic method for computing vertical motion. The computational grid length was approximately 170 km (i.e., one-half the standard grid length used by the National Meteorological Center). Divergence values were calculated at 50–mb intervals from 950 mb to 100 mb. At the lower boundary (the Earth's surface) the effects of sloping terrain and local pressure tendencies on ω ($\omega \equiv dp/dt$) were included. Vertical integration of the divergence yielded ω values at 50–mb intervals up to 75 mb. These fields of ω were then smoothed using a laplacian smoothing scheme of the form

$$\bar{\omega}_0 = \frac{4\omega_0 + \omega_1 + \omega_2 + \omega_3 + \omega_4}{8},$$

where the subscript o indicates the central grid point, and 1 through 4 indicate the surrounding grid points.

The kinematic method tends to yield areas with large values of ω at the tropopause or higher, owing to the vertical integration of systematic errors in the original data and/or the analysis scheme employed. To minimize these errors an adjustment scheme first proposed by O'Brien (1970) was used. Values

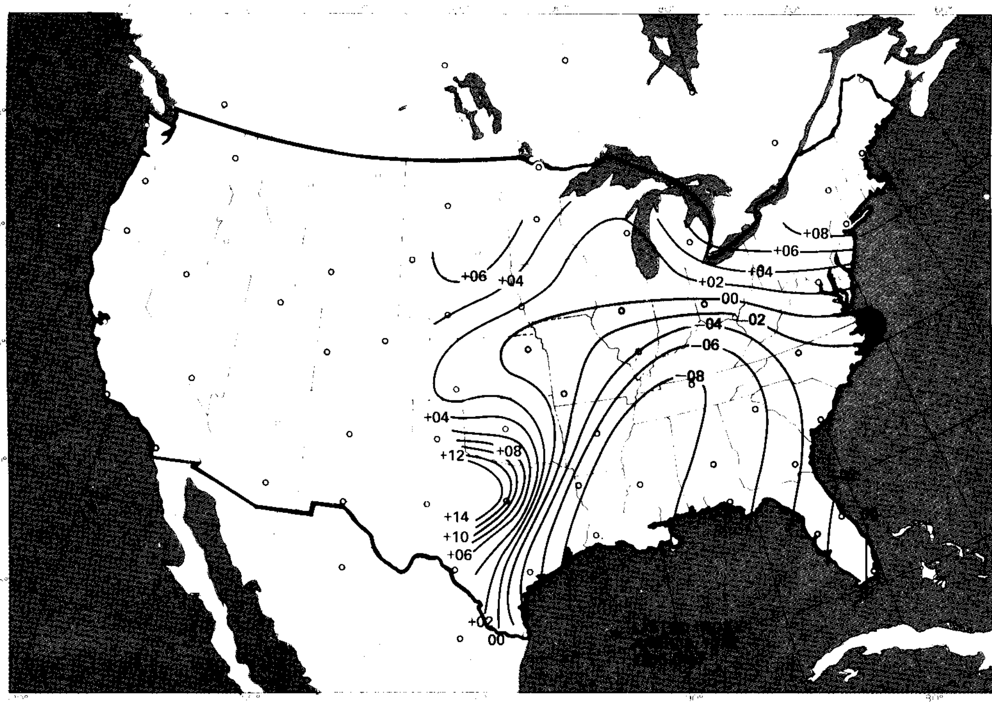


Figure 18 Lifted Index analysis, 1200 GMT, April 3, 1974.

of ω were set equal to zero at the top level (75 mb). Values at the lower levels were then adjusted with the formulation

$$\bar{\omega}'_k = \bar{\omega}_k - \frac{k(k+1)}{K(K+1)}(\bar{\omega}_K - \bar{\omega}_T),$$

where K is the total number of levels (19), k is the level in question, $\bar{\omega}_T$ is the assumed value at 75 mb (level 19) ($\bar{\omega}_T \equiv 0$), and $\bar{\omega}'$ is the adjusted value. At levels below about 600 mb the magnitude of the corrections becomes a relatively small fraction of the residual that existed at 75 mb.

Finally the fields of ω were converted to vertical motion fields with the formulation

$$w = -\frac{\bar{\omega}'}{\rho g}.$$

Two regions with strong upward motion were present at 1200 GMT, one centered over southern Iowa and another over northwest Louisiana. A region of significant sinking motion was located over much of Oklahoma. A secondary region of upward motion existed over the western Carolinas and northern Georgia, while an area of weak subsidence, which increased with height, existed over portions of Illinois, Indiana, Ohio, and Kentucky.

The subsidence over the Ohio Valley indicates that the synoptic scale dynamics were still acting to suppress convection in this region. Comparison with the vertical motion fields 12 hours later shows how dramatically this pattern changed. This rapid change in synoptic scale forcing is considered one of the key factors contributing to the massive outbreak of severe weather on the afternoon of April 3.

A comparison of the vertical motion in figure 19 with the radar summary valid 25 minutes earlier shows a good correspondence between regions of upward motion and precipitation. An exception is over southern Arkansas, eastern Texas, and Louisiana where precipitation had not yet developed in

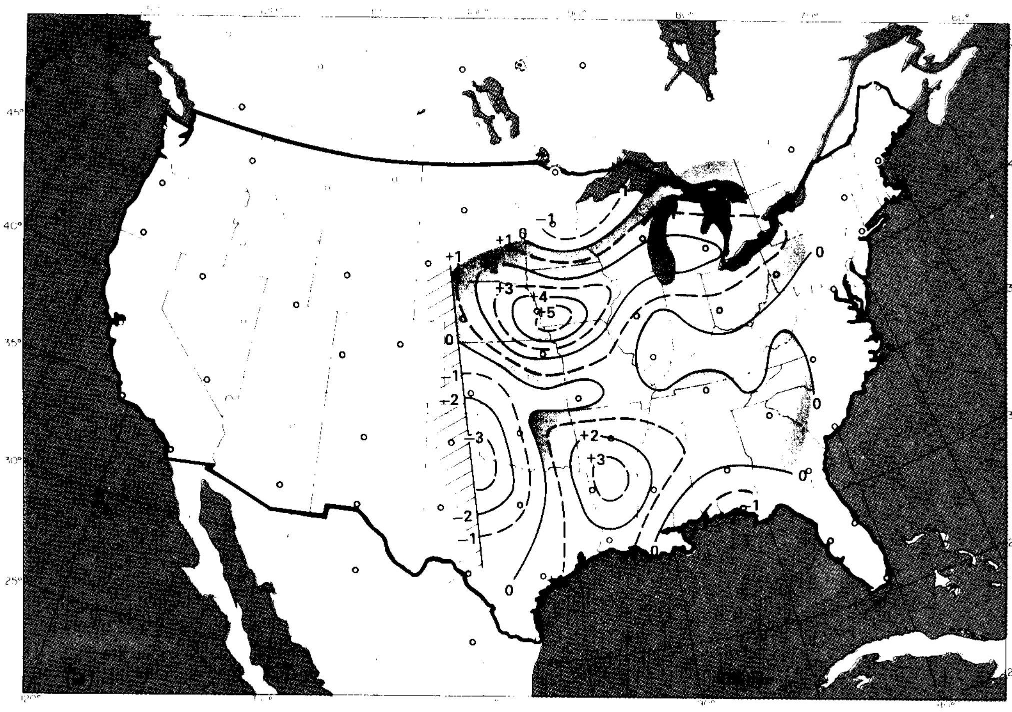
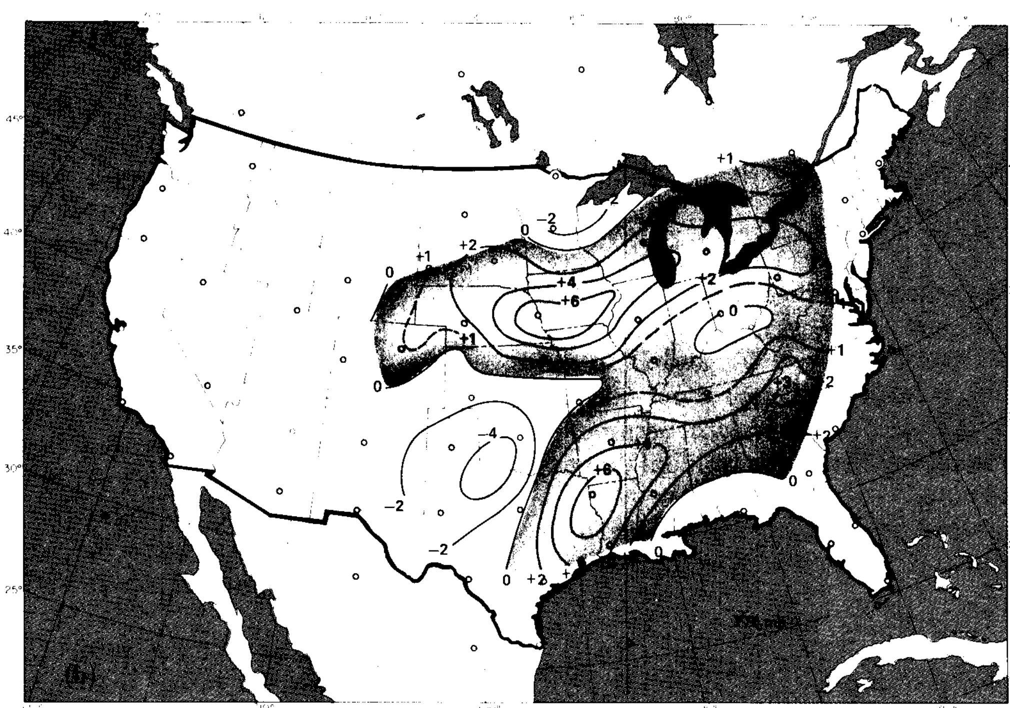


Figure 19 Vertical motion analysis, 1200 GMT, April 3, 1974. (a) 875 mb. (b) 775 mb.



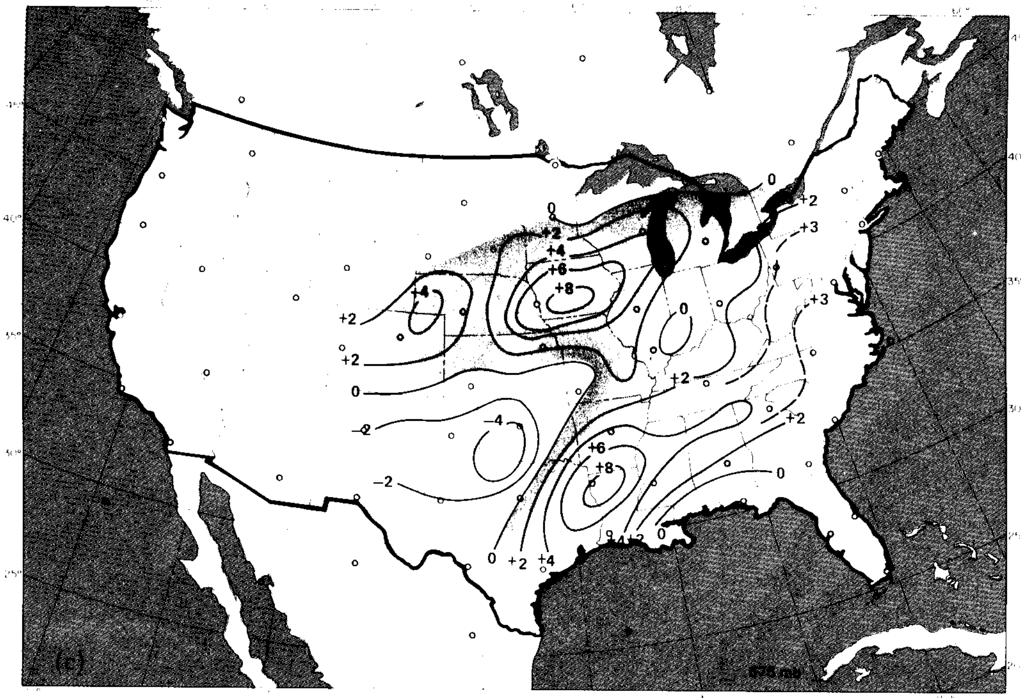


Figure 19 Continued. (c) 675 mb. (d) 575 mb.

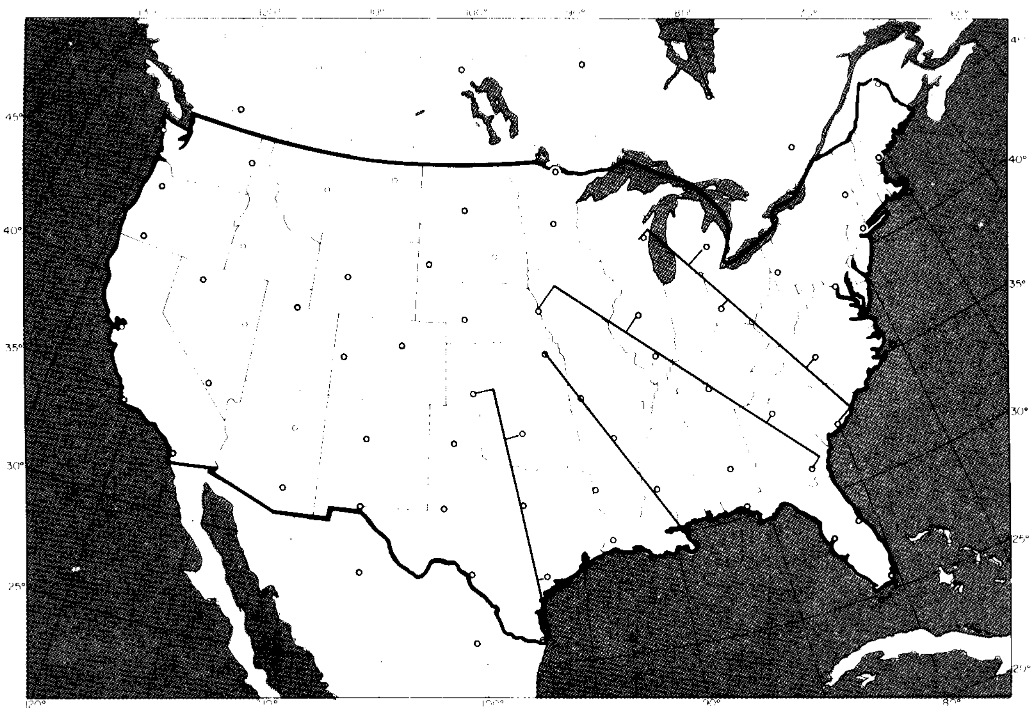


Figure 20 Locations of vertical cross sections.

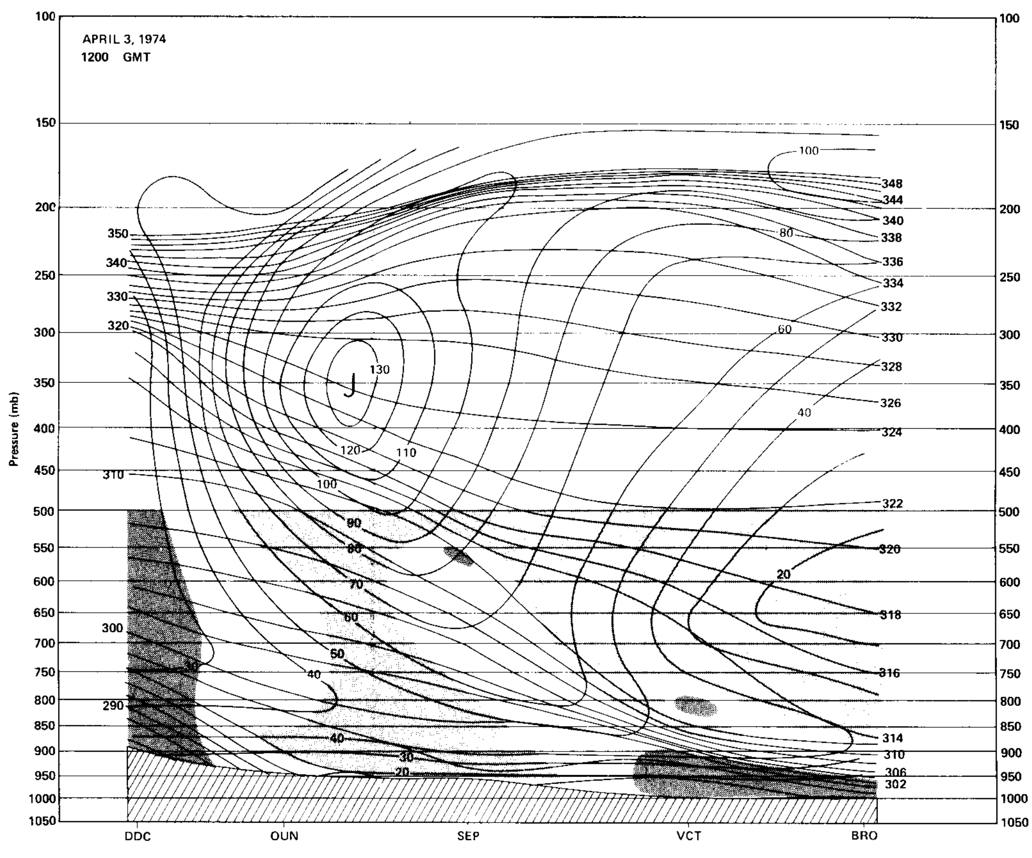


Figure 21 Vertical cross section from Dodge City, Kansas, to Brownsville, Texas, 1200 GMT, April 3, 1974. Wind speeds, 10-kn intervals; Potential temperatures, 2°K intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading.

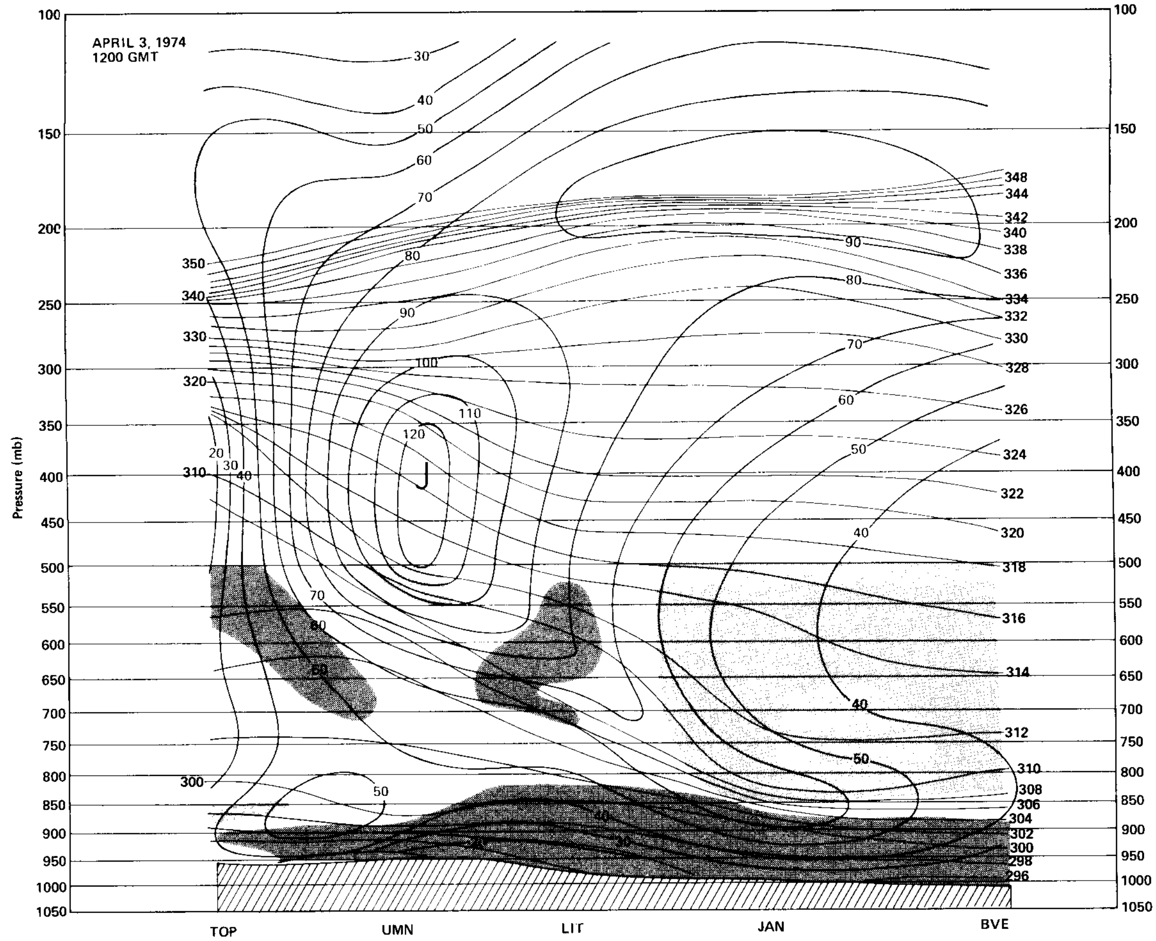


Figure 22 Vertical cross section from Topeka, Kansas, to Batesville, Louisiana (see legend in fig. 21).

response to the synoptic scale lifting.

The horizontal location and extent of four atmospheric cross sections taken through the weather system in the central and eastern U.S. are presented in figure 20. Individual cross sections are shown in figures 21–24. Wind speed analyses are depicted only in regions where wind directions were from south through west.

The cross-section analyses show clearly that moist Gulf air in the lowest 1–2 km was overlain by very dry and potentially warmer air from southern Texas northeastward to southeast Ohio. (Moisture analyses are included only up to 500 mb). Note in figures 21 and 22 that higher wind speeds extended from near the polar jet southward and downward to the top of the inversion along lines of similar potential temperatures. This suggests a transport of horizontal momentum out of the upper and mid-troposphere into the 700 mb region. This subsidence was the dynamic factor in maintaining the inversion, thus allowing the conditional instability to increase markedly before its sudden and violent release.

The polar jet is quite evident in the more western cross sections with maximum wind speeds decreasing in each successive downstream analysis. There is evidence of a weak subtropical jet along the southern U.S. which is most evident in figure 23 between Athens and Waycross, Georgia.

A pronounced wind speed minimum is present over Nashville, Tennessee, in figure 23. This minimum appears to have been temporary and cannot be found in the cross-section analyses 12 hours later. The potential temperature analyses indicate warmer air over

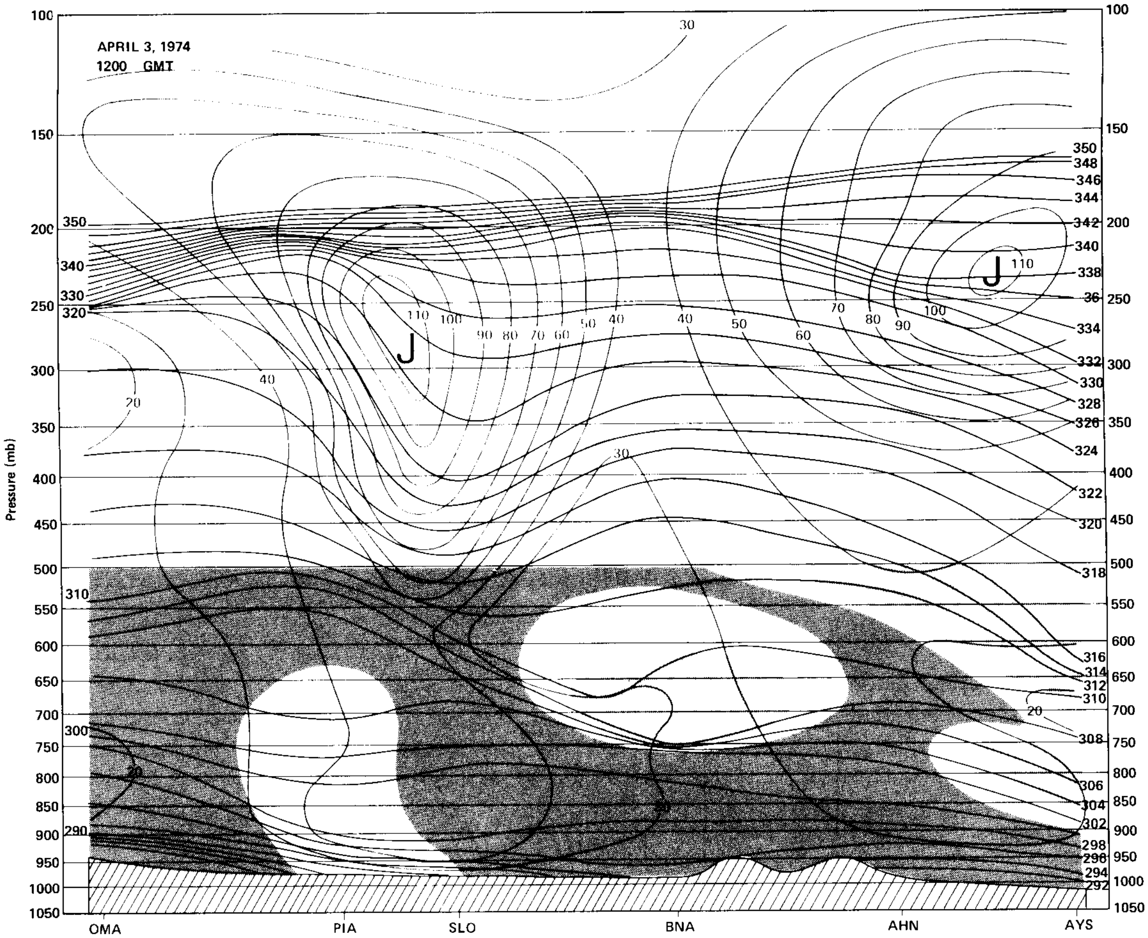


Figure 23 Vertical cross section from Omaha, Nebraska, to Waycross, Georgia (see legend in fig. 21).

southern Illinois in the 500–250 mb layer than over central Tennessee. It is believed that this thermal pattern was a result of the strong indirect vertical circulation around the leading edge or exit region of the polar jet. This type of circulation creates a strong baroclinic zone under the maximum wind region and thereby can contribute to the eastward propagation of the jet stream maximum. It is possible that the light winds indicated over and to the northwest of Nashville reflect a response to this local and temporary reversal of temperature gradient.

The final cross section (fig. 24) portrays conditions ahead of the baroclinic wave and associated jet stream maximum. The weak maximum at 250 mb over Green Bay was not a part of the strong wind band propagating out of Texas and Oklahoma. Strong wind speeds were absent below 500 mb. A surface inversion existed in the Flint to Huntington region, while a stationary frontal inversion was fairly pronounced between Green Bay and Flint.

Figure 25 presents the 1200 GMT soundings for Jackson, Mississippi; Nashville, Tennessee; and Dayton, Ohio. The Jackson and Nashville soundings are classic examples of the so-called Type I tornado soundings. Strong temperature inversions capping the moist low level air are present with a drastic decrease in dew point temperature through the inversion.

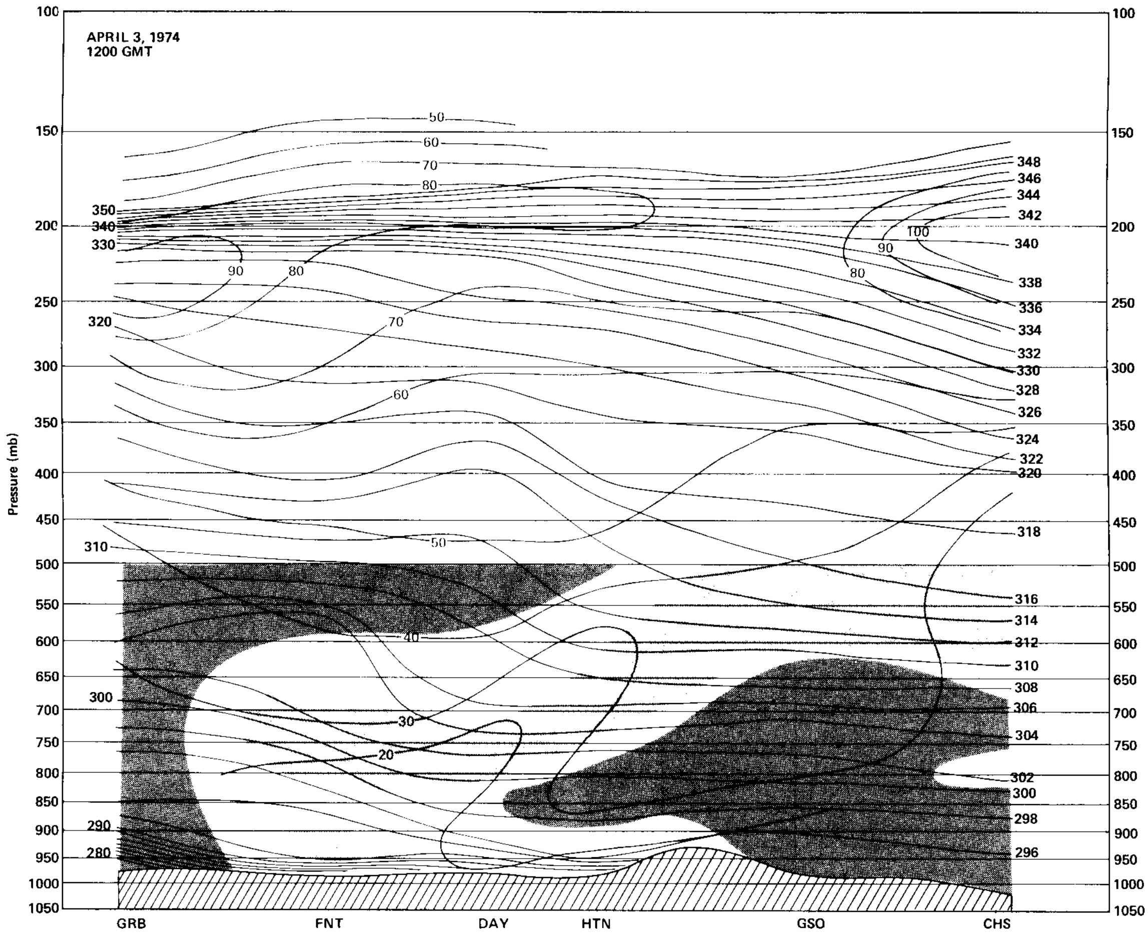
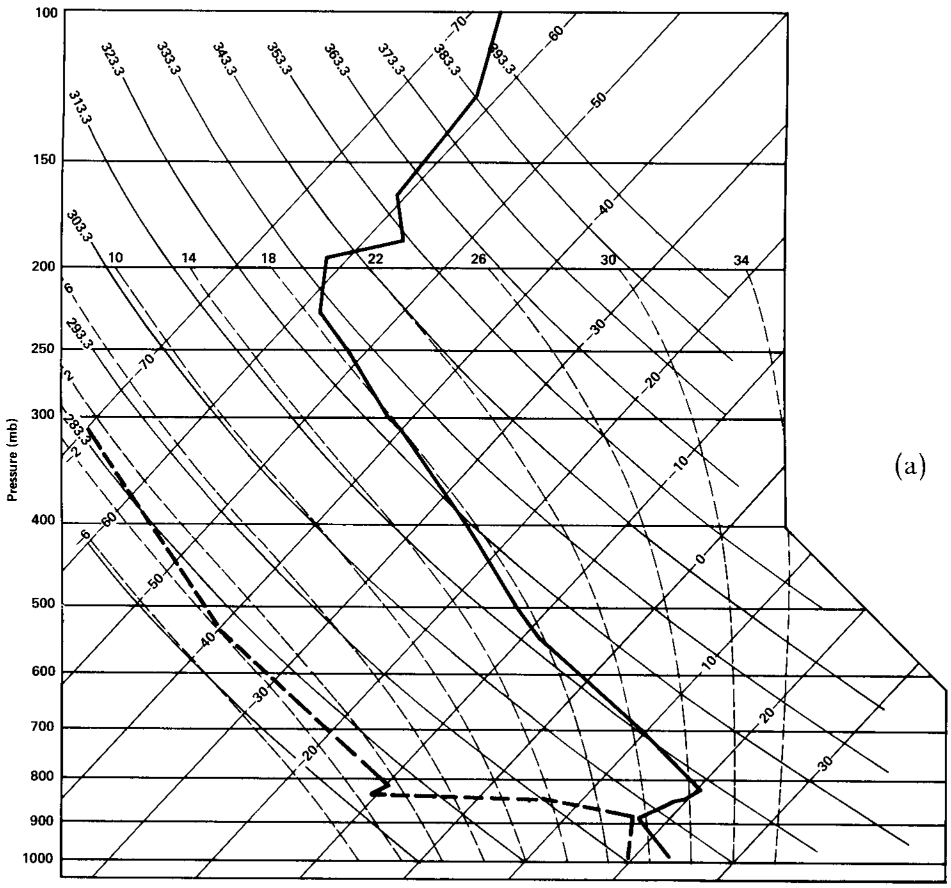


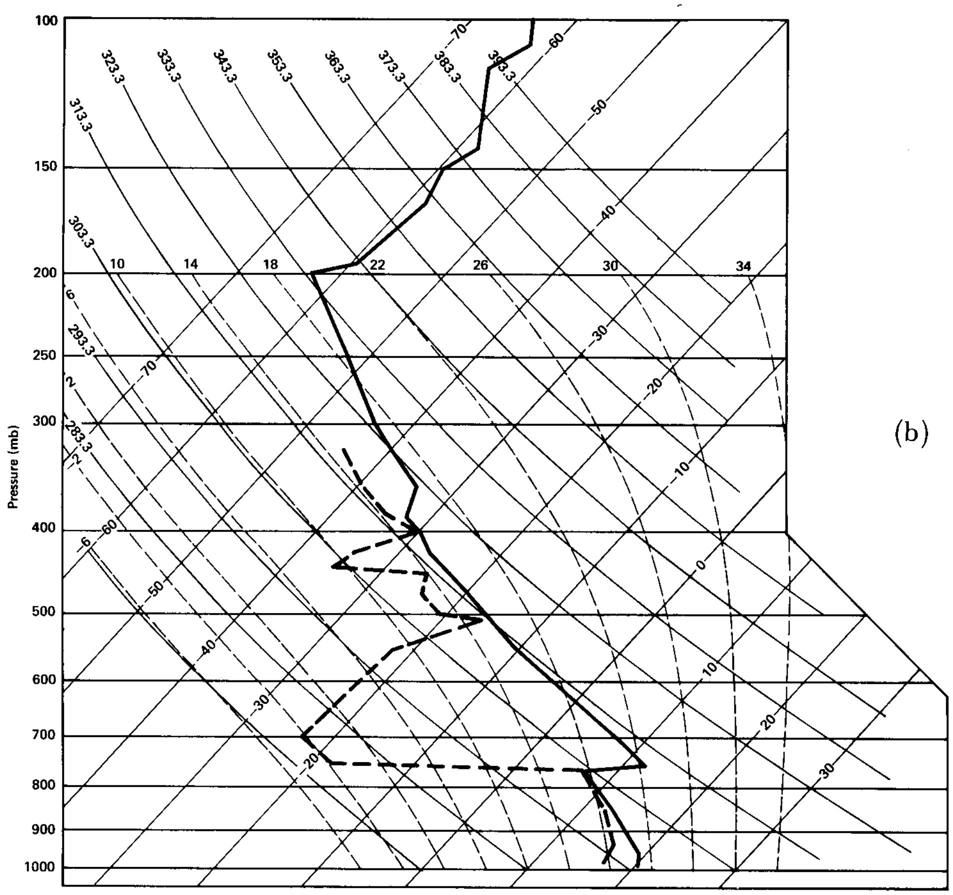
Figure 24 Vertical cross section from Green Bay, Wisconsin, to Charleston, South Carolina (see legend in fig. 21).

The Dayton sounding is much less impressive with no well defined inversion and substantially less moisture near the surface. A region of dry air did exist between 800 mb and 700 mb. The 3-hourly surface series, to be presented in the next section, shows that warm moist low level air was advected into southern Illinois, Indiana, and Ohio as the day progressed. It is likely that Dayton's airmass became by mid-afternoon quite similar to the 1200 GMT sounding taken at Nashville.

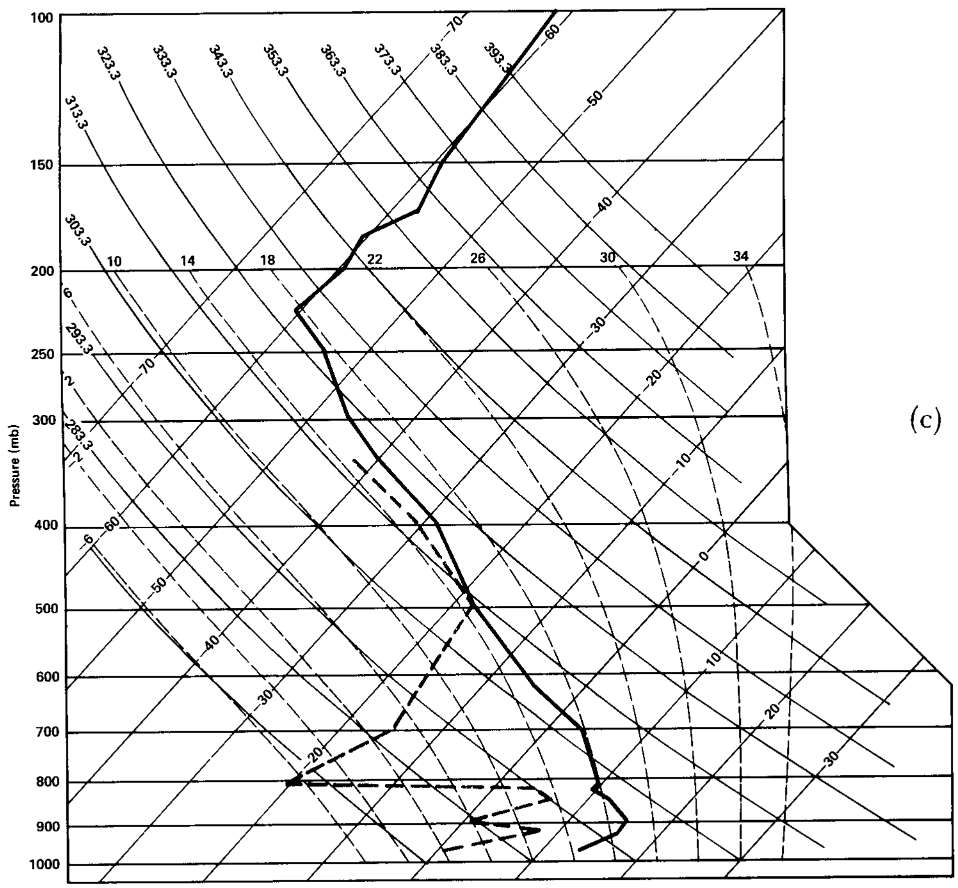
The Jackson sounding was potentially the most unstable of all those taken during the morning of April 3. An undiluted parcel, if lifted from near the surface to above the inversion, would have accelerated to near 200 mb (≈40,000 ft) and ultimately reached an altitude near 60,000 ft. This computed cloud top compares favorably with maximum radar tops of 60,000–65,000 ft observed over Alabama, Kentucky, and Tennessee 8–15 hours later. ■


Pressure (mb)
100
150
200
250
300
400
500
600
700
800
900
1000
313.3
323.3
333.3
343.3
353.3
363.3
373.3
383.3
393.3
303.3
293.3
283.3
10
14
18
22
26
30
34

(a)


Pressure (mb)
100
150
200
250
300
400
500
600
700
800
900
1000
313.3
323.3
333.3
343.3
353.3
363.3
373.3
383.3
393.3
303.3
293.3
283.3
10
14
18
22
26
30
34

(b)



(c)

Figure 25 Selected soundings, 1200 GMT, April 3, 1974. (a) Jackson, Mississippi (b) Nashville, Tennessee (c) Dayton, Ohio.

Three-Hourly Surface, Radar, and Satellite Series

The surface analyses for this series differ in several respects from the surface analyses shown earlier, where emphasis was on large-scale features. Here larger mesoscale features are analyzed. Altimeter settings (in inches of mercury), as opposed to sea level pressures, are employed to define the pressure field. Isotherms, and isodrosotherms for 60°F and greater, are shown in 5°F intervals. The major squall lines and outflow boundaries plus the more prominent mesoscale highs and lows are also depicted.

The radar summaries are essentially reproductions of maps prepared and transmitted by the National Severe Storms Forecast Center in Kansas City, Missouri. Slight modifications were made on two maps to account for missing data over the central plains.

The satellite pictures are enlarged reproductions of photographs taken by the ATS-III satellite positioned over the equator at 70°W. These are visual; therefore only daylight hours are included.

At 1200 GMT the surface low was located in central Kansas with a 28.98 altimeter setting (fig. 26). Five frontal boundaries were associated with this system. The front extending through western Oklahoma and the Texas panhandle was formed as the surface low moved away from the Rockies allowing continental polar air initially over the northern plains to move rapidly southward. The 3-hourly analyses show a significant temperature gradient across this front.

Extending across southeast Kansas, eastern Oklahoma, and central Texas was a second front which brought maritime polar air out of the New Mexico region the afternoon before. This front was shown in the 0000 GMT April 3 surface analysis (fig. 11). The air behind this front was modified by adiabatic warming as it moved off the High Plains and southern Rockies. As a result, it was characterized by only small temperature gradients and wind shifts.

Another airmass was delineated with a boundary from southern Arkansas, through northwest Louisiana, and southeast Texas. This was the leading edge of a warm dry airmass formed by large scale subsidence (superior air). This airmass was in its formative stages at 1200 GMT but became well defined by mid-day. The major characteristic of this boundary was the development of a pronounced gradient in surface dew point temperatures.

A stationary front with a significant temperature gradient extended from the low center to central Michigan. A warm front extended from central Arkansas, through southern Kentucky and southward around the southern Appalachian Mountains to the North Carolina coast. This warm front marked the northern penetration of the very moist maritime tropical airmass from the Gulf of Mexico. Surface dew points $\geq$ 65°F with temperatures $\geq$ 70°F were present over most of western Tennessee.

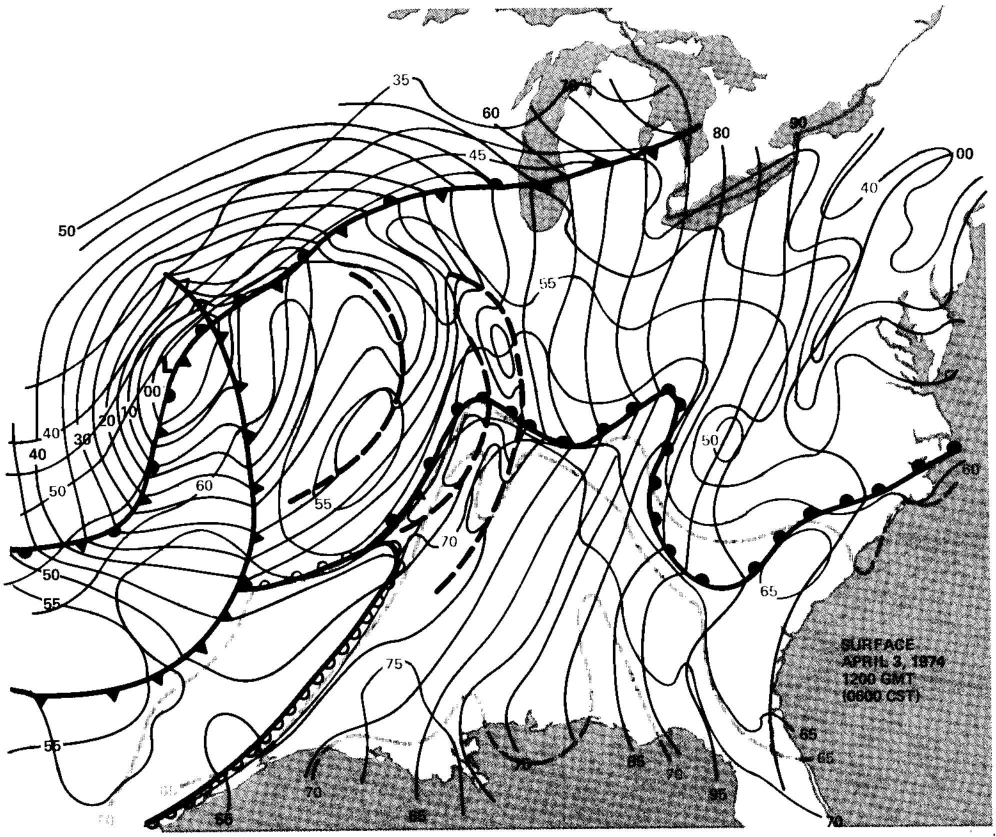


Figure 26 Surface analysis, 1200 GMT, April 3, 1974. Altimeter settings in excess of 29.00 inches, 0.05-inches-of-mercury intervals; Isotherms (orange), 5°F intervals; Isodrosotherms (gray), 5°F intervals for values ≥ 60°F; Squall lines, mesoscale troughs, and outflow boundaries, dashed lines.

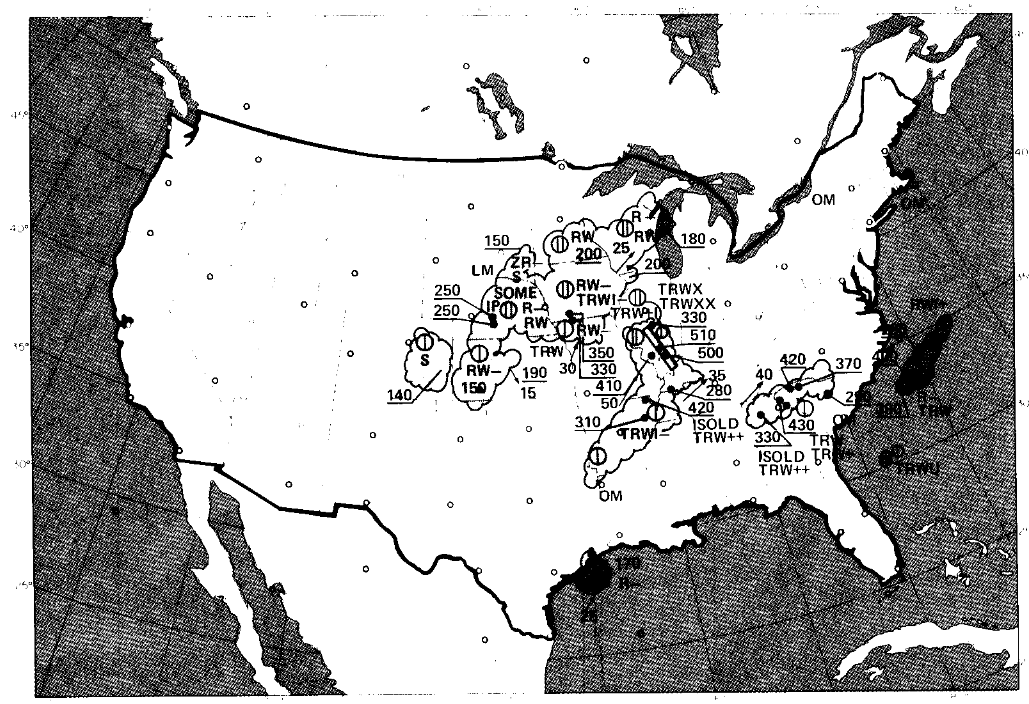


Figure 27 Radar summary, 1125 GMT, April 3, 1974.

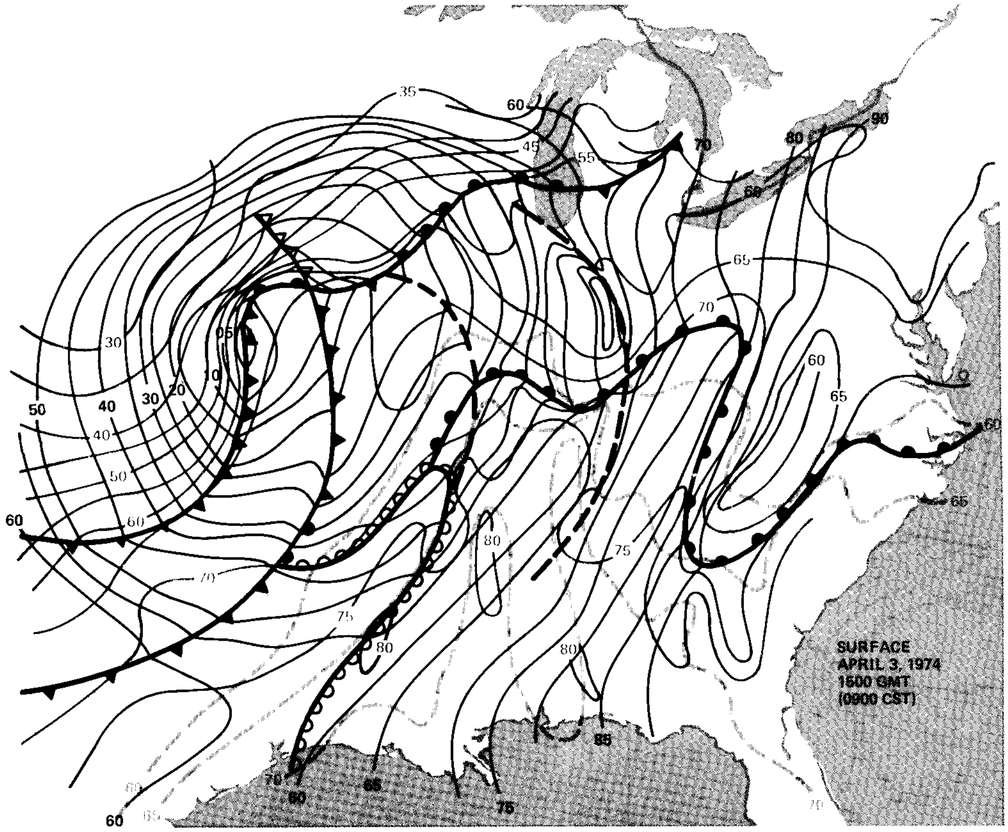


Figure 28 Surface analysis, 1500 GMT, April 3, 1974 (see legend in fig. 26).

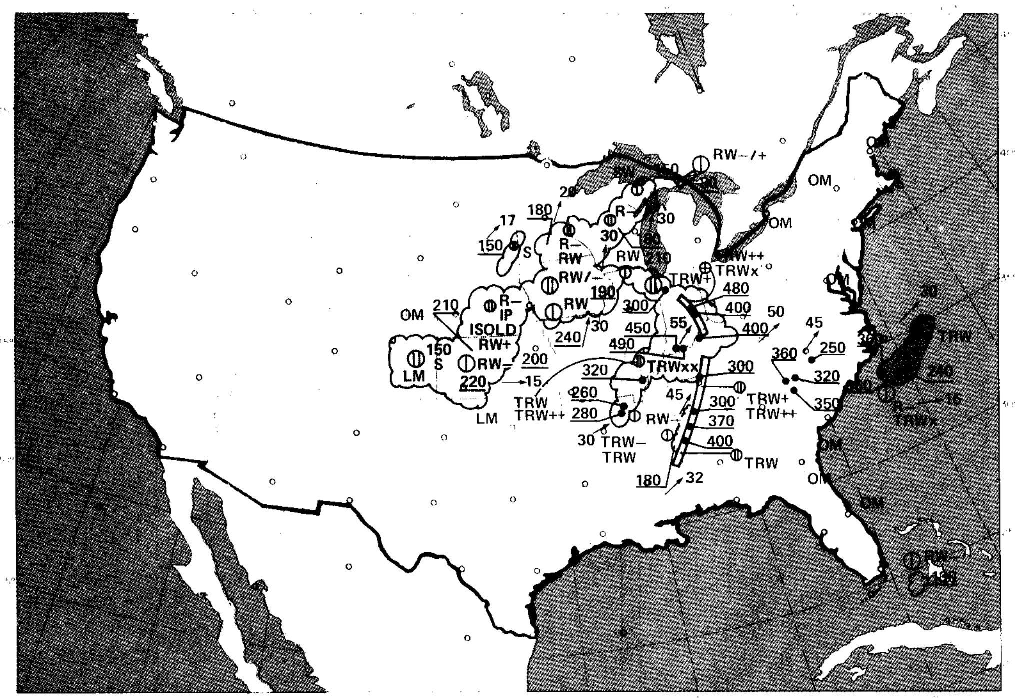


Figure 29 Radar summary, 1435 GMT, April 3, 1974.

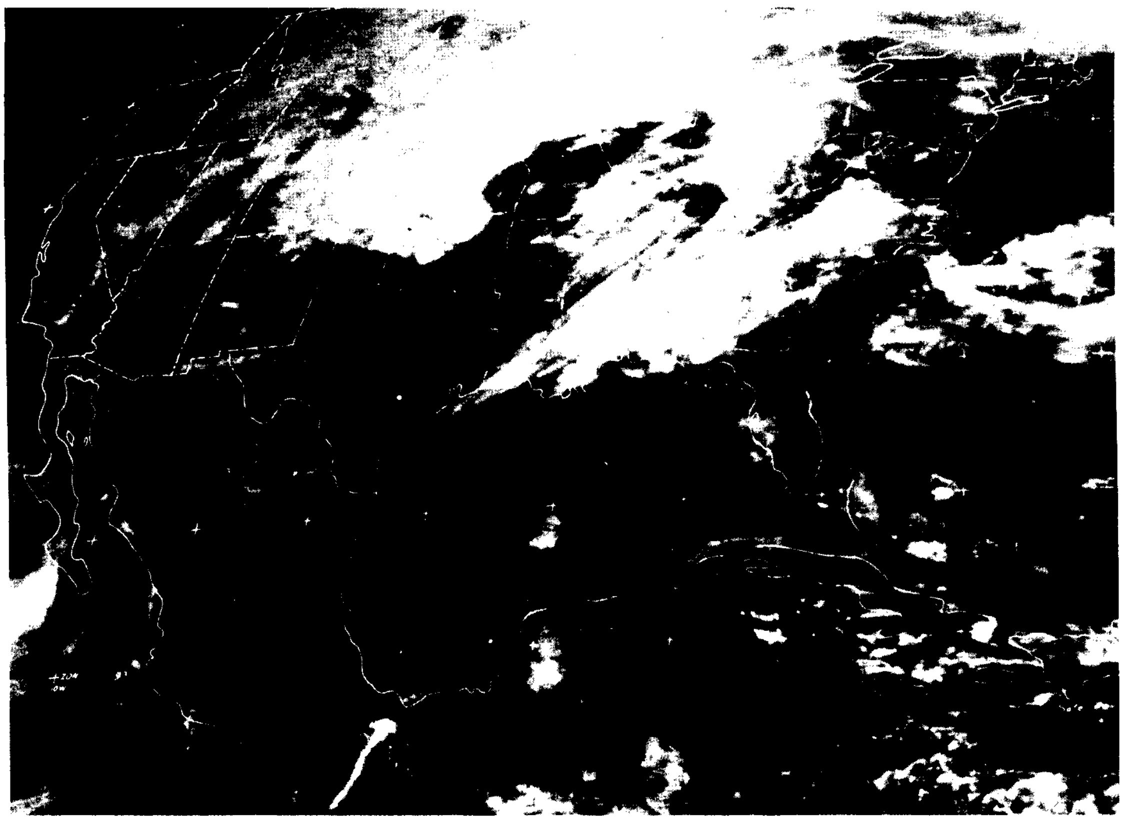


Figure 30 ATS–III photo, 1511 GMT, April 3, 1974.

The radar summary for this period (fig. 27) indicates two principal areas of convection. The first area contained scattered activity over the western Carolinas and northern Georgia. An organized convective line extending from central Illinois through extreme western Kentucky into northeastern Arkansas made up a second area. Detailed analyses of surface reports suggest that two separate lines were present at this time as shown in figure 26. A strong depression wave was located 300–400 km behind these two lines but it contained no organized convection at this time.

As the subsequent surface analyses are presented, the reader should compare these with the radar summaries and satellite photos. Factors of particular interest are:

1) The rapid movement (approximately 60 kn) of the first squall line through the Ohio Valley.
2) The northward movement of the moist surface air into Illinois, Indiana, and Ohio behind the first squall line.
3) Record breaking warm temperatures that developed in eastern Kentucky, southern Ohio, and western West Virginia.
4) The cool air that remained trapped in the southern Appalachian Mountain valleys throughout the day.
5) The development and intensification of the warm dry airmass (superior air) over Arkansas and its subsequent movement into southern Illinois and southwestern Indiana.
6) The continuous advection of surface moisture from the Gulf of Mexico northward into the Ohio Valley.

At 1500 GMT the first two convective lines had moved rapidly eastward and merged into a single squall line (fig. 28). Activity had also developed southward and an organized line now extended from southern Lake Michigan to northwest Alabama. A mesoscale

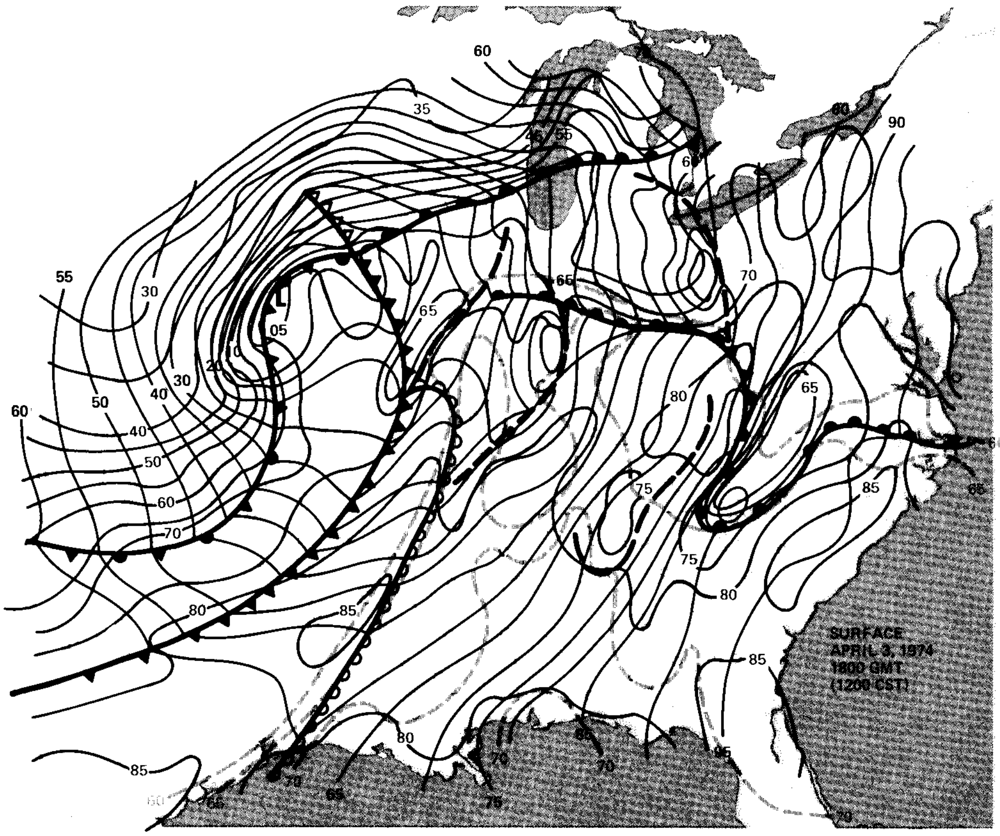


Figure 31 Surface analysis, 1800 GMT, April 3, 1974 (see legend in fig. 26).

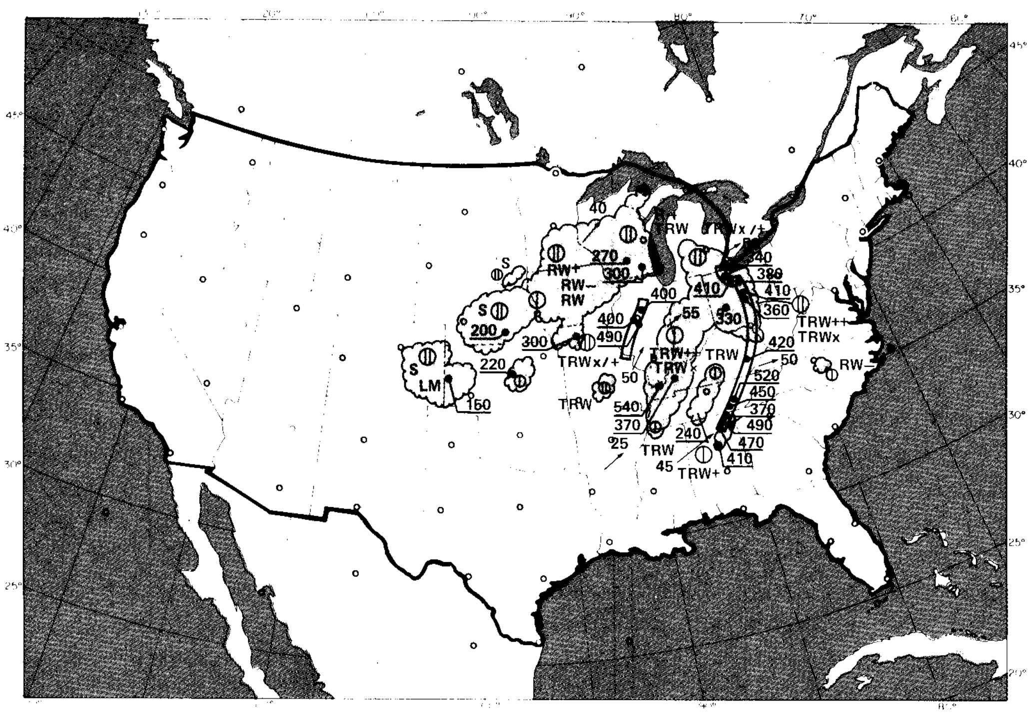


Figure 32 Radar summary, 1735 GMT, April 3, 1974.

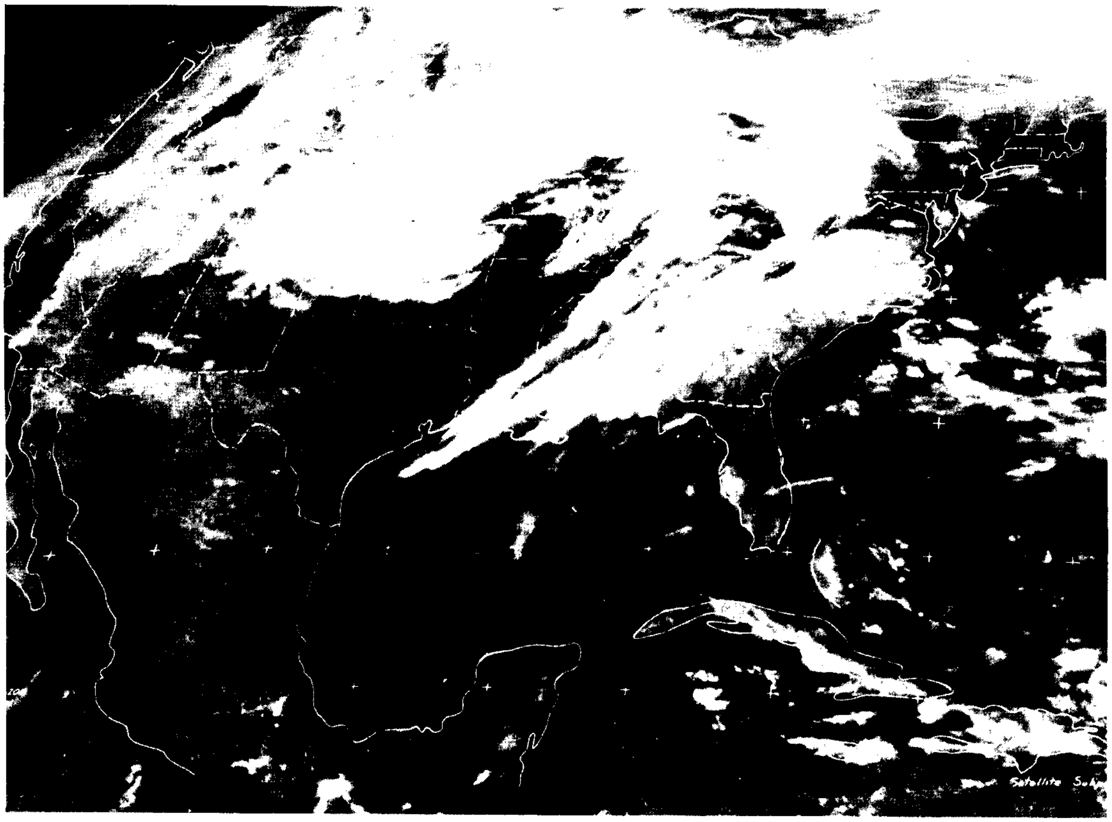


Figure 33 ATS-III photo, 1754 GMT, April 3, 1974.

high was in Indiana behind this line. This convective line was well defined on both the radar summary (fig. 29) and the ATS-III satellite photo (fig. 30). The trailing depression wave had moved eastward to a position near the Mississippi River, and shortly after this map time it triggered a second line of convection.

Figures 31-33 show surface and cloud conditions near 1200 CST or just prior to the onset of most of the severe weather. The first squall line was splitting into two separate lines. The northern half continued its rapid movement through Ohio and over Lake Erie. The southern half was oriented along the Cumberland Plateau. The region where the first squall line apparently weakened and split corresponds roughly to the region of subsidence indicated in the 0000 GMT April 4 vertical motion analysis. Apparently, this subsidence was sufficient to inhibit most of the convection despite strong surface heating. Indeed, the surface heating was enhanced by the relative absence of clouds, yielding record temperatures over portions of eastern Kentucky and western West Virginia. The tendency of low level heating to destabilize the lapse rate was offset, however, by the adiabatic warming aloft acting to stabilize the environment and cap the low level moisture. The second line at noon extended from central Indiana to northwest Tennessee, while a third line was forming from central and southwestern Illinois into east central Missouri. Only the first and third are indicated as having line characteristics on the radar summary (fig. 32). All three lines are detectable on the satellite photo (fig. 33).

By 2100 GMT severe weather reports were numbering approximately 20 per hour with tornadoes constituting about 75% of the reports. The three major convective lines depicted in figure 31 maintained their identity through mid-afternoon (figs. 34, 35, and 36). All three lines were producing tornadoes at

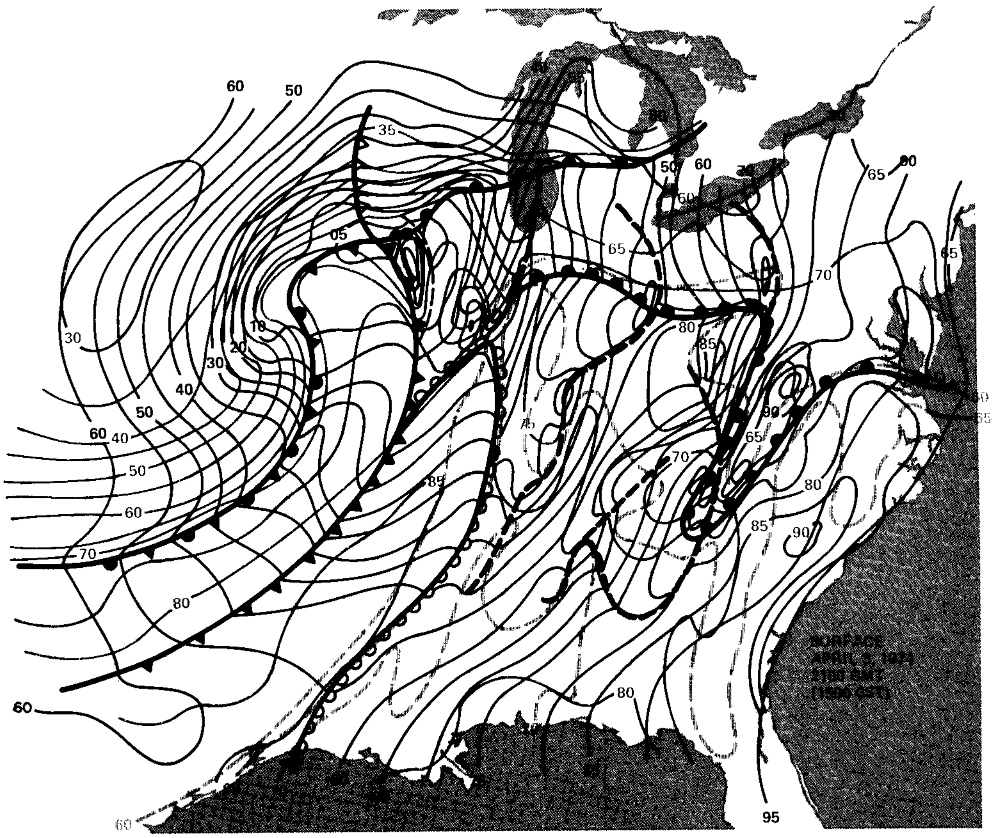


Figure 34   Surface analysis, 2100 GMT, April 3, 1974 (see legend in fig. 26).

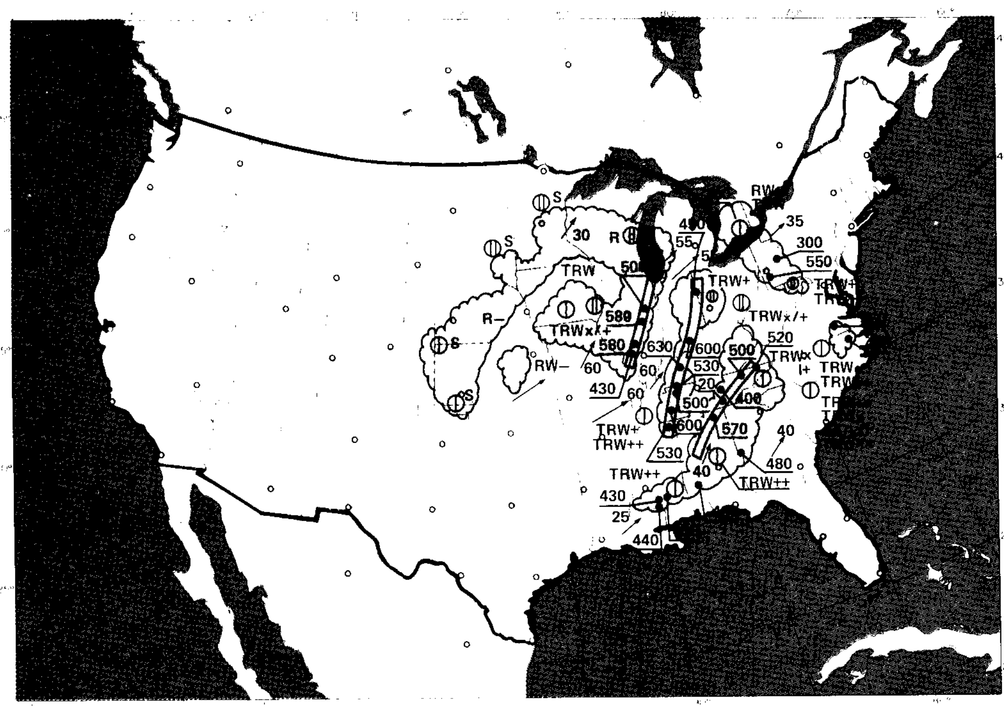


Figure 35   Radar summary, 2035 GMT, April 3, 1974.

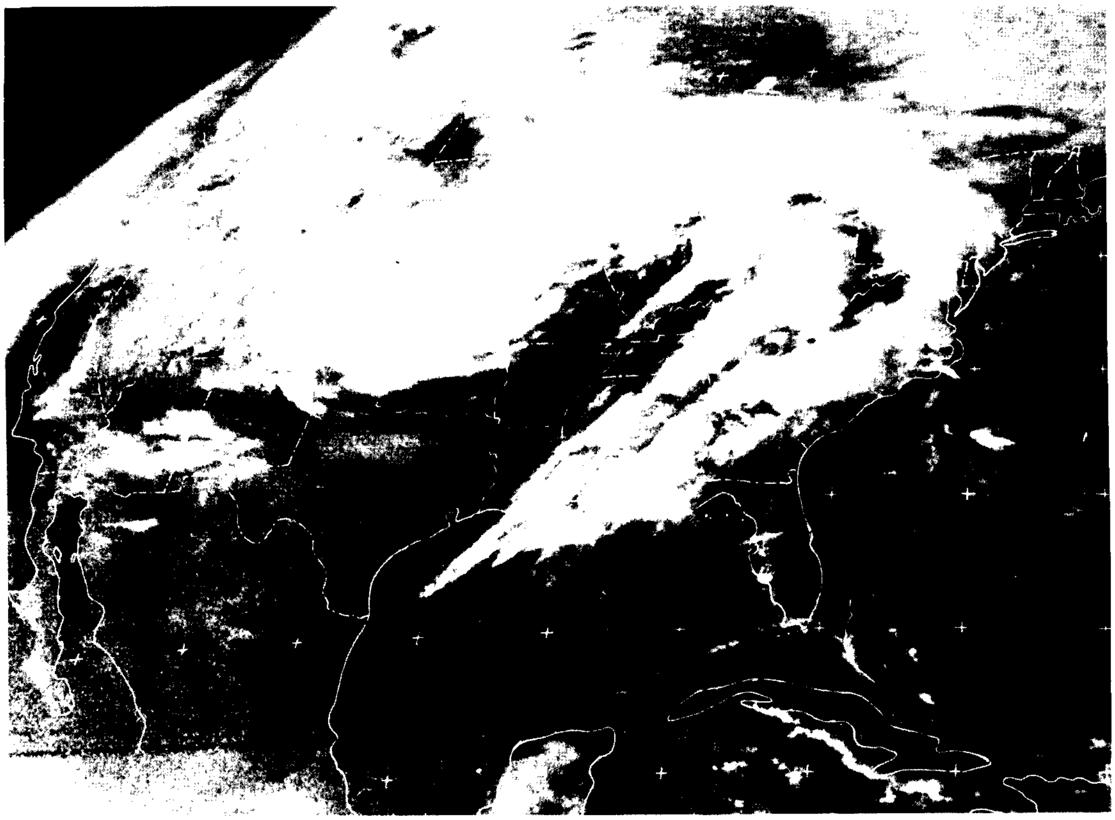


Figure 36 ATS-III photo, 2100 GMT, April 3, 1974.

this time, including the Xenia, Ohio, tornado which occurred at approximately 2040 GMT. The break in the first line over West Virginia was more evident both in the surface analysis and the radar summary. A fourth line was developing over western Illinois.

The low pressure center over Kansas had moved eastward and filled slightly since 1200 GMT. Meanwhile, a new center was developing at the point of occlusion over southeast Iowa.

The warm dry airmass that developed over Arkansas had moved into southeast Missouri and southern Illinois by mid-afternoon. A majority of the stations within this airmass was reporting either haze or dust. Dew point temperatures in the 30–35°F range were being reported along a band from northeast Texas to northeast Arkansas.

Surface analyses for 2100 GMT and 0000 GMT April 4 detected numerous mesoscale weather systems associated with the severe storms. Several meso or bubble highs were noted to the rear of the convective lines, while embedded in the major squall lines were several meso-lows. One of these in northwest Indiana at 0000 GMT (fig. 37) produced an almost continuous tornado track across Indiana including the Monticello tornado. The meso-low on the North Carolina–South Carolina border at 0000 GMT produced hail up to 3 inches in diameter near Charlotte, North Carolina. The radar summary for 0000 GMT is shown in figure 38.

Shortly after 1800 CST most of the severe weather abated north of the Ohio River, and the strongest activity shifted to the south, particularly over northern Alabama.

By 0300 GMT April 4 (figs. 39 and 40), most of the severe weather had occurred. Squall lines continued to be active through the night in the southeastern U.S. and activity intensified to produce several tornadoes from northern Florida to Virginia the afternoon of April 4. ■

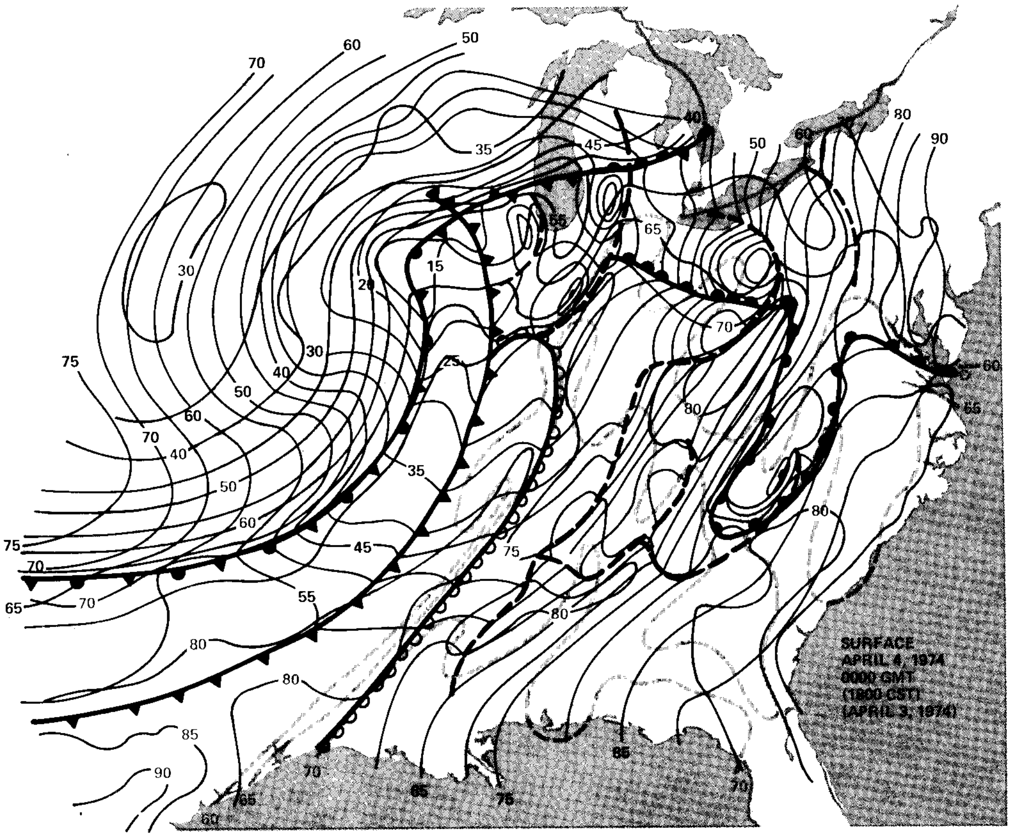


Figure 37 Surface analysis, 0000 GMT, April 4, 1974 (see legend in fig. 26).

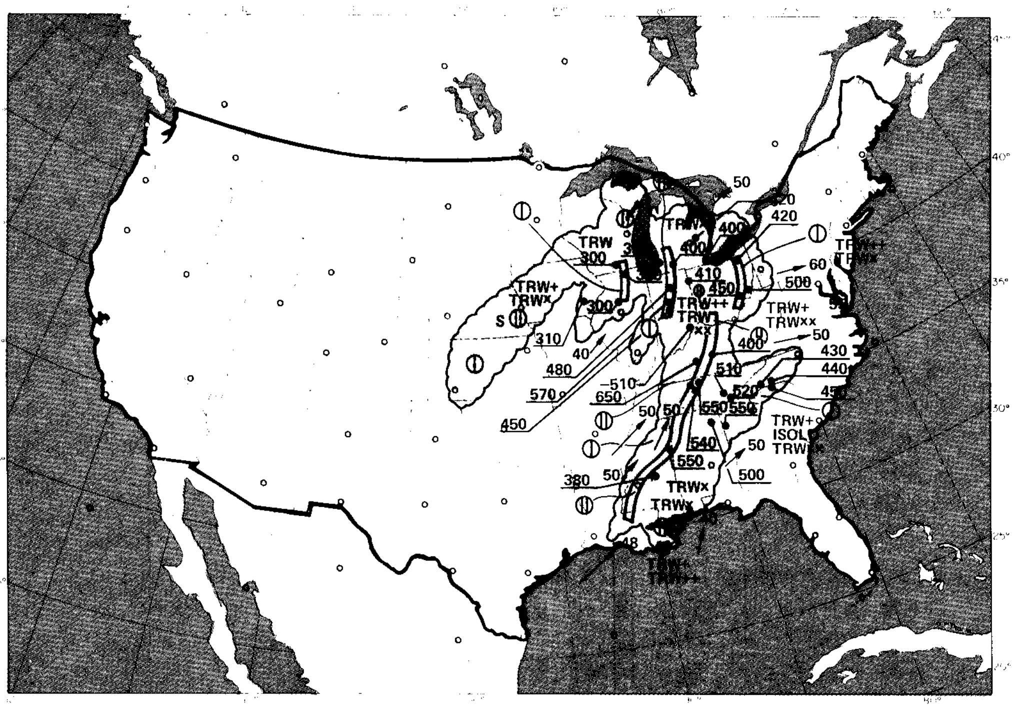


Figure 38 Radar summary, 2335 GMT, April 3, 1974.

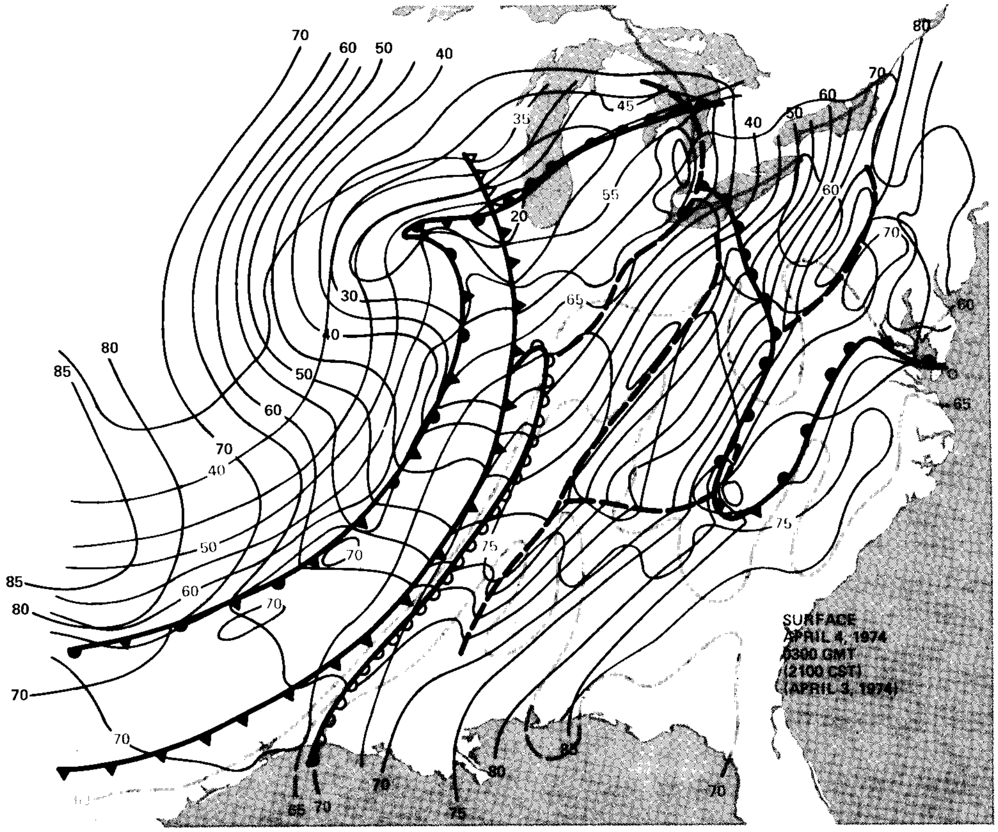


Figure 39 Surface analysis, 0300 GMT, April 4, 1974 (see legend in fig. 26).

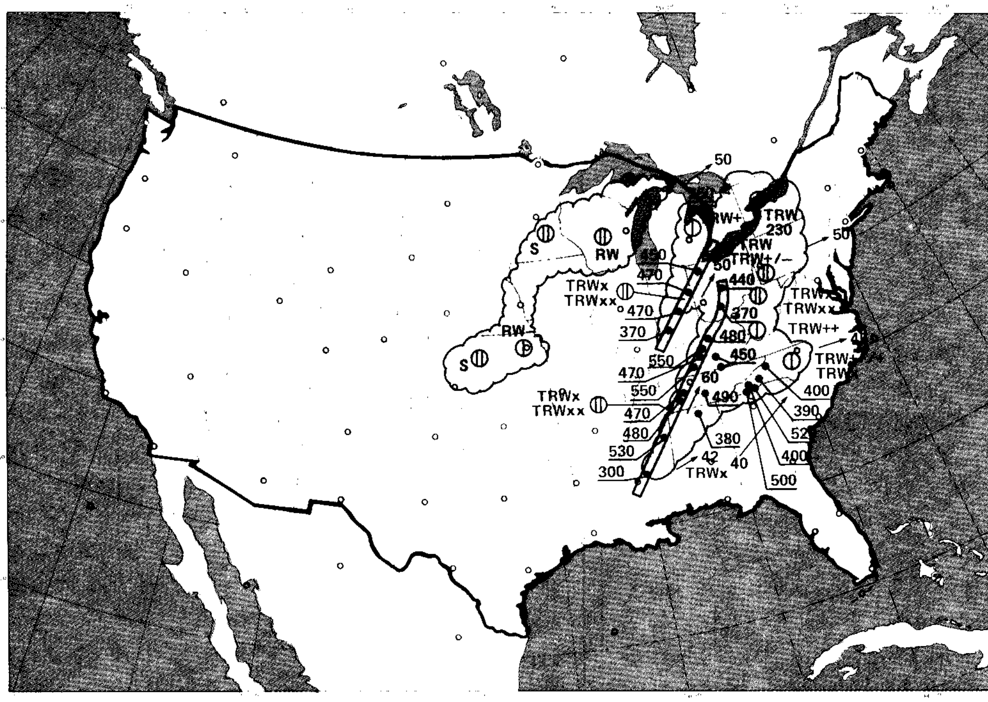


Figure 40 Radar summary, 0235 GMT, April 4, 1974.

Analyses for 0000 GMT April 4, 1974

The previous section followed events at the surface for 3 hours beyond the standard upper air sounding time. This section presents the synoptic scale analyses at 0000 GMT, which was near the peak of severe weather activity.

At 300 mb (fig. 41) the leading edge of winds ≥ 120 kn had propagated northeastward during the previous 12 hours to central Indiana. The band of winds ≥ 120 kn was continuous from the Oregon coast to Indiana. Maximum speeds over Texas were near 150 kn. The closed circulation at 500 mb (fig. 42) persisted and was moving northeastward over southwest Iowa. Despite the indicated cold air advection over central Oklahoma at both 1200 GMT April 3 and 0000 GMT April 4, no significant temperature change took place during the 12-hour period. This suggests that the cold air advection was compensated for by sinking and adiabatic warming along the forward edge of the cold dome. The vertical motion analyses at both 1200 GMT April 3 and 0000 GMT April 4 also show subsidence in this region. The available potential energy released in the mid-troposphere over Oklahoma appears to have contributed to the kinetic energy of the storm system during the day of April 3rd.

Mid and upper tropospheric cooling associated with upper level short waves is often cited as a triggering mechanism for severe convective storms. However, the region experiencing most of the severe weather the afternoon and evening of April 3 warmed 3–5°C at 500 mb from 1200 GMT April 3 to 0000 GMT April 4 (compare fig. 42 with fig. 15). The weak baroclinic zone extending from northwest Arkansas to northern Indiana was generated primarily through warming southeast of the jet axis. It is important to realize that the 12-hour net 500 mb warming over the Ohio and Tennessee River Valleys probably resulted from a combination of several processes, e.g., warm air advection, release of latent heat yielding a net warming, and the combination of synoptic and mesoscale vertical motions effectively cooling in regions of upward motion and warming in the subsidence regions. Overall, the mid-troposphere warmed 3–5°C while air near the surface generally warmed 5–15°C during the same 12-hour period. Therefore, a destabilization of the lapse rate occurred in spite of the mid-tropospheric warming.

The band of winds >60 kn at 700 mb (fig. 43) extended from northeast Texas to Ohio at 0000 GMT. The low level jet (>50 knots) at 850 mb (fig. 44) extended from the Gulf of Mexico northward to eastern Indiana and western Ohio. The propagation of these strong winds into the Ohio Valley during the afternoon of April 3 is believed to have been a key factor in the initiation of severe weather over this region. This produced the rapid time rate of change in the low level divergence patterns (i.e., from weak divergence to strong convergence) promoting a rapid release of the conditional instability.

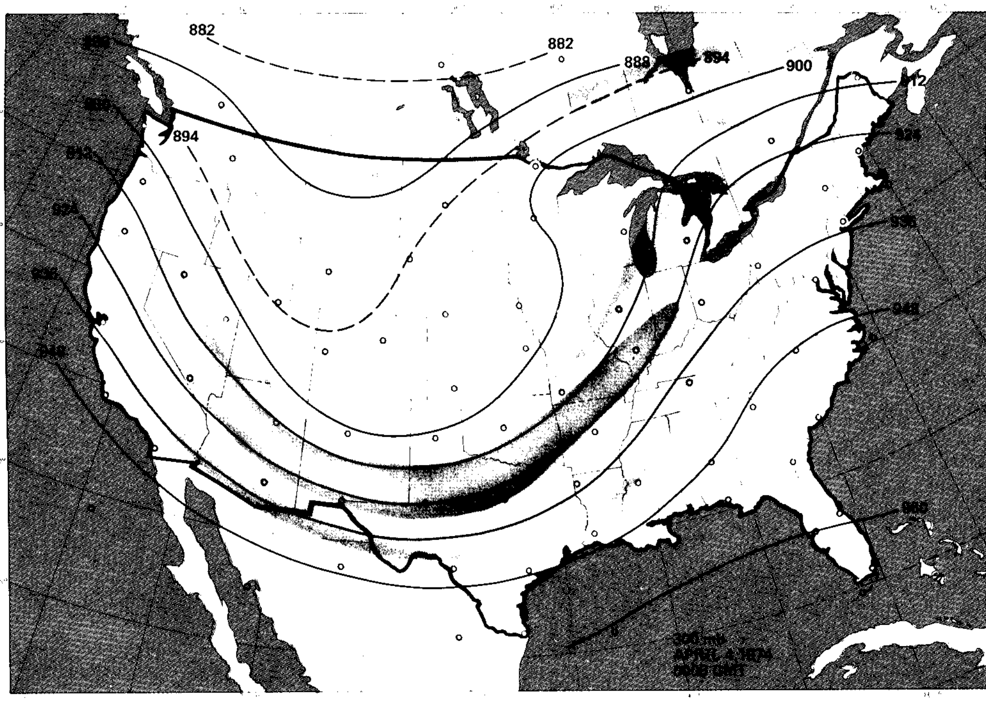


Figure 41 300-mb analysis, 0000 GMT, April 4, 1974. Contours, 120-m intervals; Wind speeds 80–120 kn, orange shading; Wind speeds > 120 kn, gray shading.

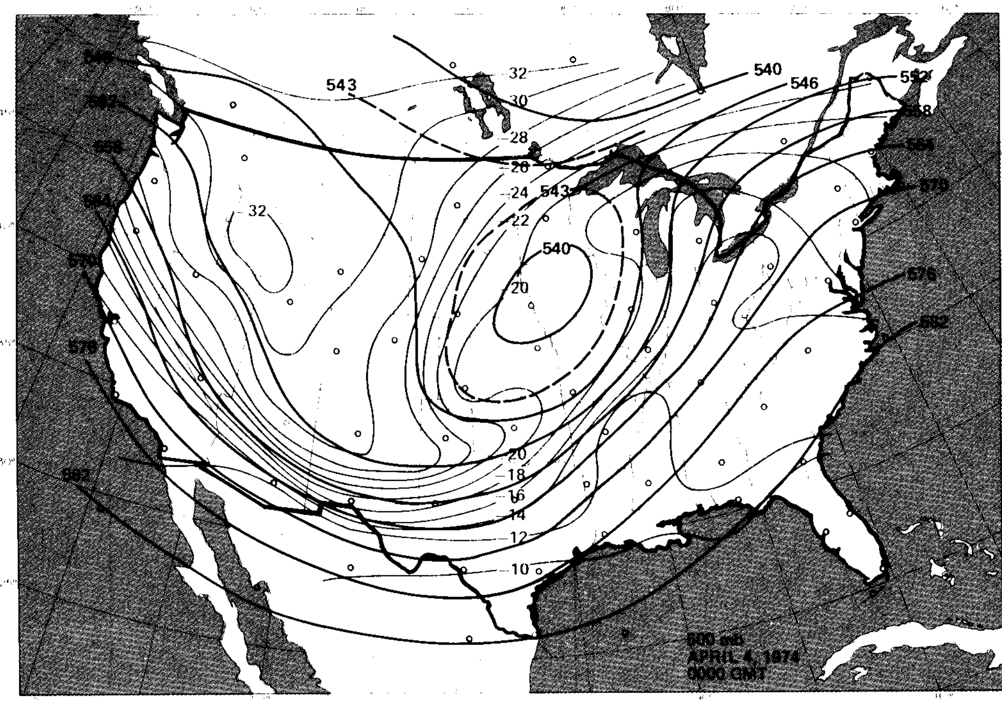


Figure 42 500-mb analysis, 0000 GMT, April 4, 1974. Contours, 60-m intervals; Isotherms, 2°C intervals.

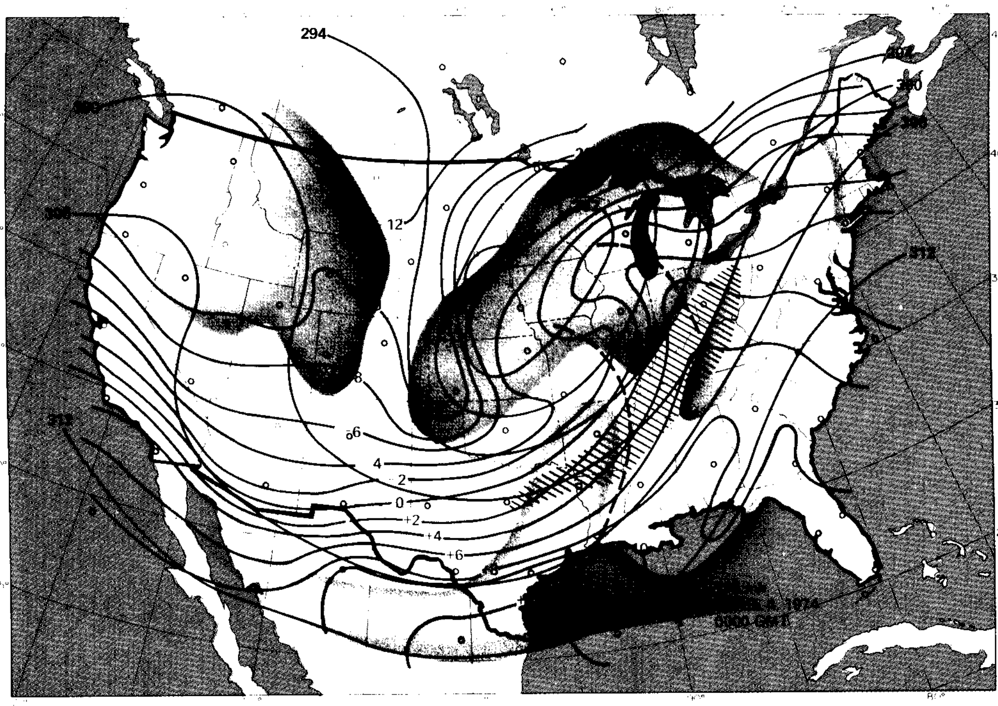


Figure 43 700–mb analysis, 0000 GMT, April 4, 1974. Contours, 60–m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 60 kn, hatched.

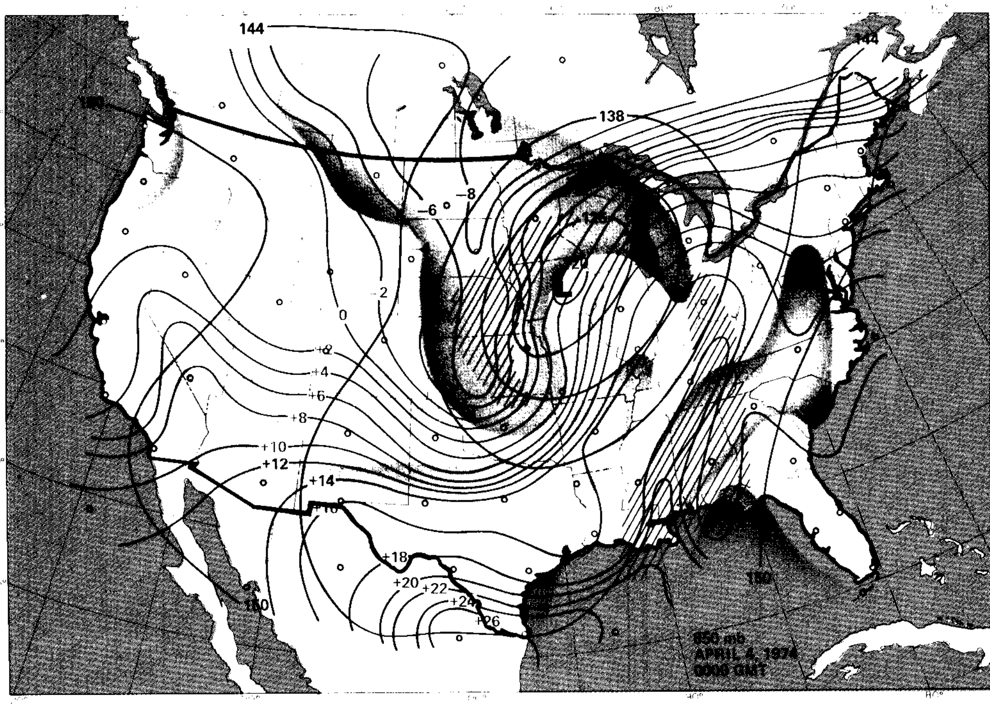


Figure 44 850–mb analysis, 0000 GMT, April 4, 1974. Contours, 60–m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 50 kn, hatched.

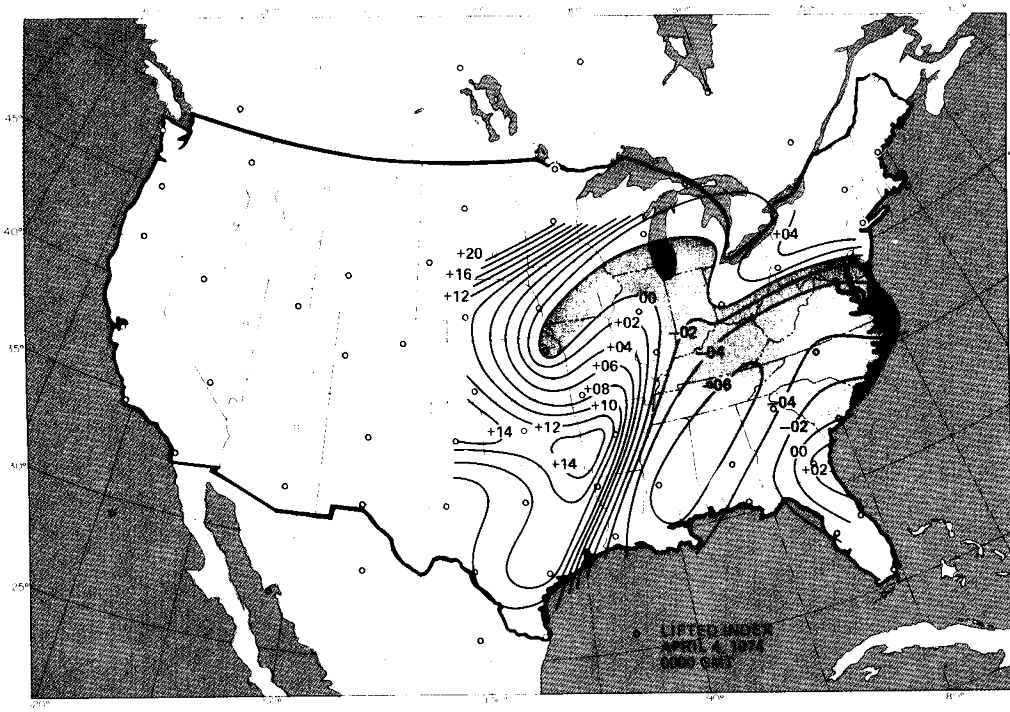


Figure 45 Lifted Index analysis, 0000 GMT, April 4, 1974.

Most of the dry air at 700 mb that was over the Ohio and Tennessee River Valleys had been eliminated through the extensive convection of the afternoon. However, a new tongue of dry air extended from eastern Texas northeastward through much of Arkansas at both 850 and 700 mb. This dry air also extended to the surface as shown in the 3-hourly surface analyses.

The Lifted Index analysis (fig. 45) shows that conditionally unstable air penetrated as far north as southern Wisconsin and southern Michigan. The development of the dry airmass in eastern Texas, northwest Louisiana, and Arkansas created a very strong gradient between this airmass and the most unstable air, which remained over portions of Mississippi, Alabama, and Tennessee.

The vertical motion analyses for the evening of April 3 (fig. 46) indicate the magnitude of the synoptic scale forcing that attended the extratropical cyclone. At 575 mb, upward motion in excess of 16 cm sec^{-1} is indicated over southern Michigan, northeast Indiana, and northeast Ohio. (Since the vertical velocity fields were smoothed it seems reasonable to treat the maximum values as conservative.) There was a secondary maximum of upward motion in excess of 8 cm sec^{-1} at 575 mb over northwest Alabama.

Note the small area of sinking over eastern Kentucky. In the surface analyses it was shown that this region experienced few clouds and very warm temperatures during mid-afternoon with little organized convection until near sunset. These surface events are consistent with the subsidence computed over the region.

The sinking motion over Oklahoma and northeast Texas was mentioned earlier as the warming mechanism compensating for the cold air advection in this area. This synoptic scale subsidence also was apparently the source of the warm dry surface air present over northeast Texas and much of Arkansas.

Figure 1 shows that tornadoes occurred during the afternoon and evening of April 3 from southern Michigan to east central Mississippi. We see from figures 41 to 46 that the more potentially unstable environment was over Mississippi, Alabama, and Tennessee, whereas the strongest synoptic scale dynamics

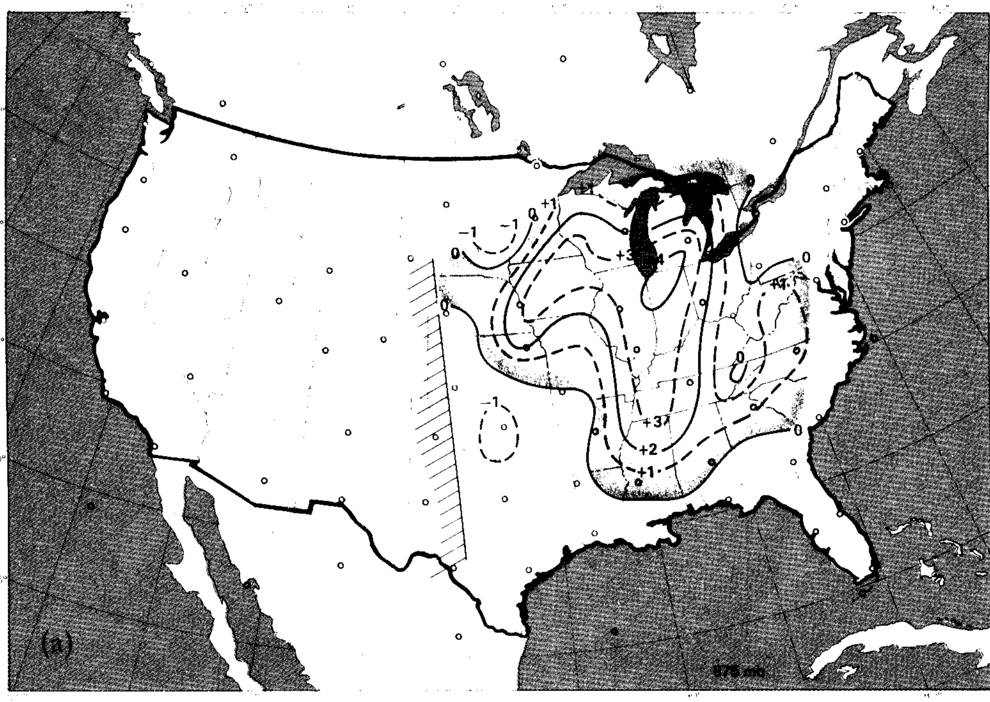
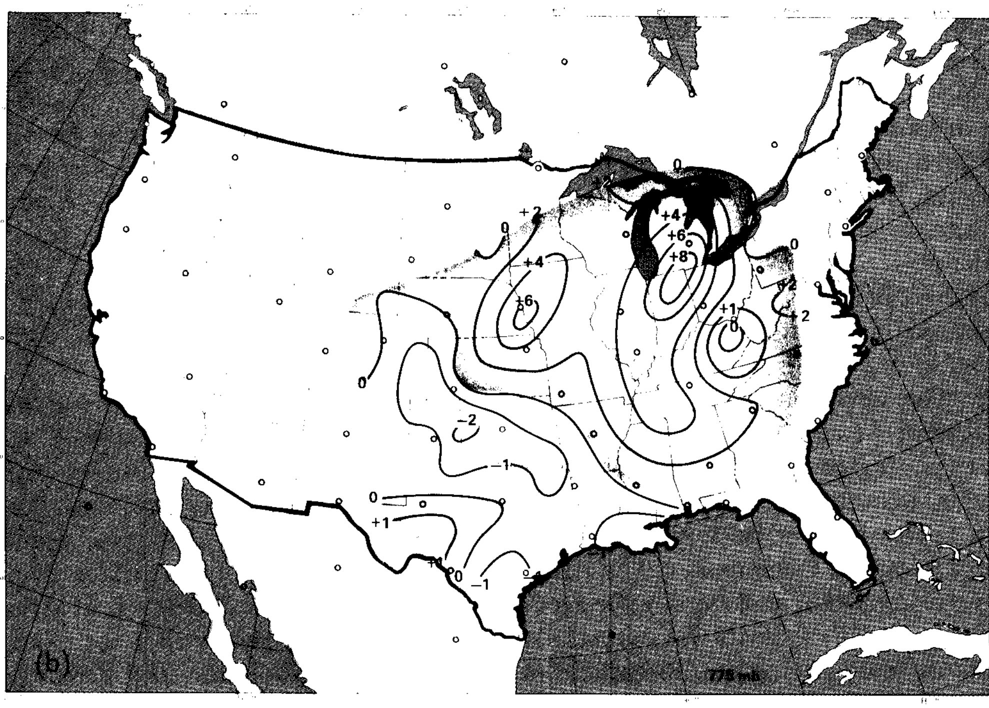


Figure 46 Vertical motion analysis, 0000 GMT, April 4, 1974. Shading depicts areas with upward motion. (a) 875 mb. (b) 775 mb.



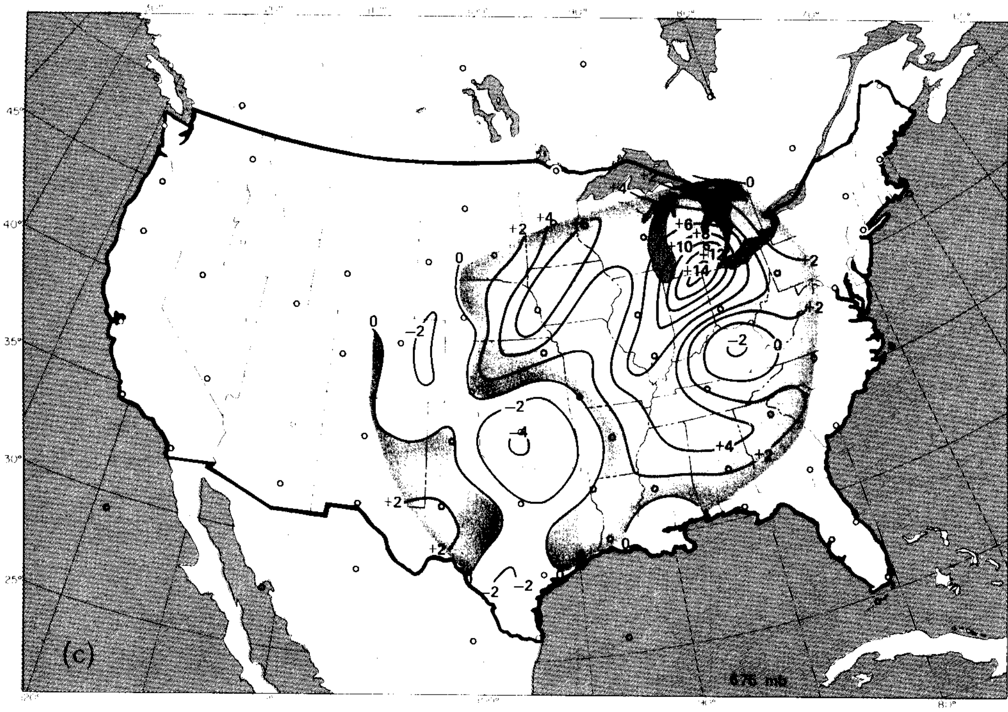
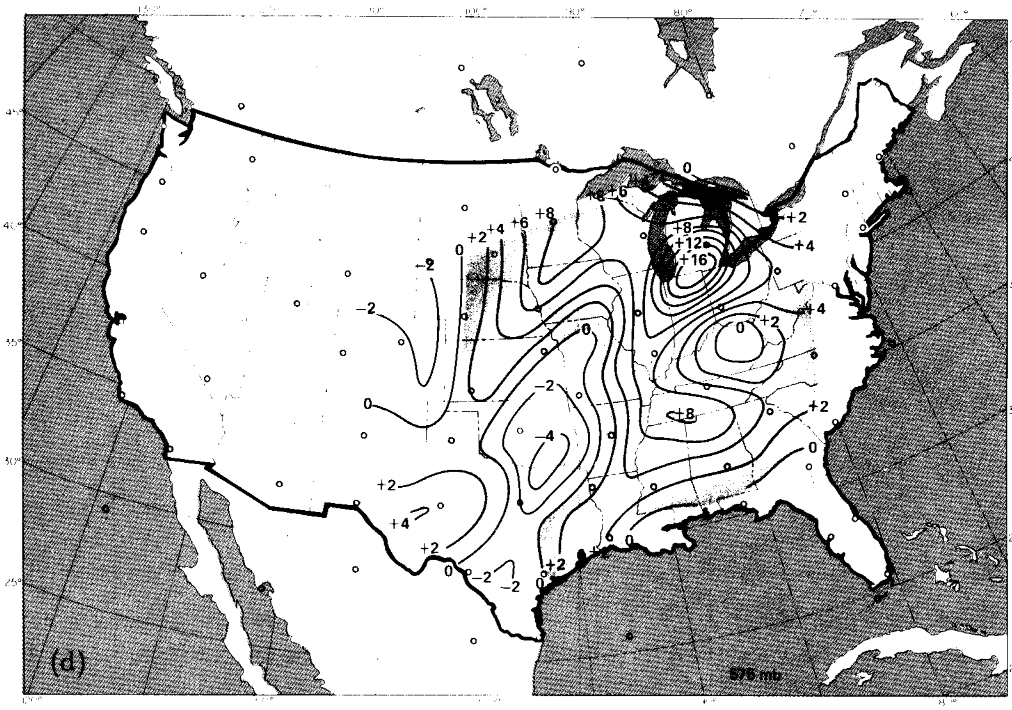


Figure 46 Continued. (c) 675 mb. (d) 575 mb.



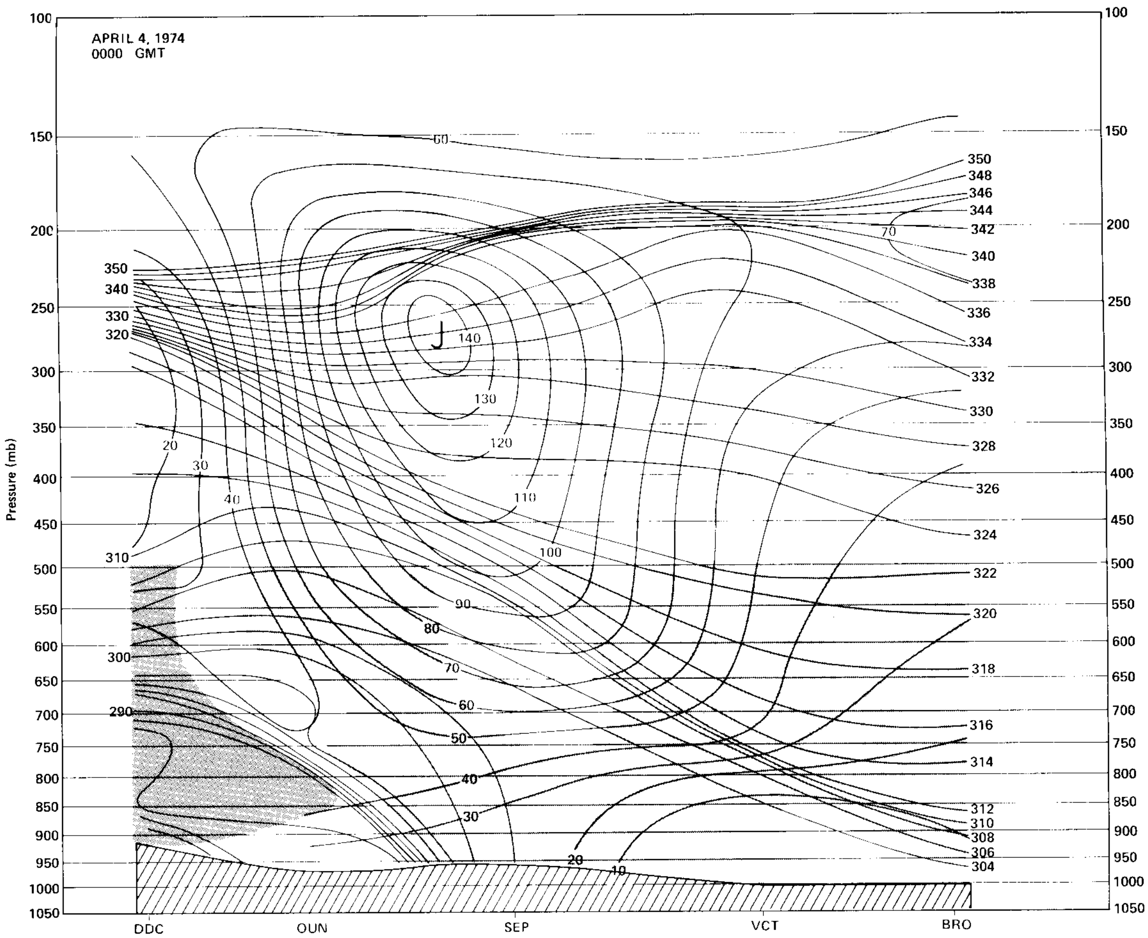


Figure 47 Vertical cross section from Dodge City, Kansas, to Brownsville, Texas, 0000 GMT, April 4, 1974. Wind speeds, 10-kn intervals; Potential temperatures, 2°K intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading.

were north of the Ohio River.

Cross-sectional analyses (figures 47–50) show in more detail some of the dynamic and thermodynamic features indicated by figures 41-46. The cross section from Dodge City to Brownsville shows clearly the strong polar jet associated with this system. Dry air prevailed below 500 mb over most of the area, while the stable layer extending from under the jet axis southward and downward maintained its identity. The strong frontal zone between Stephensville, Texas, and Norman, Oklahoma, accounted for most of the north–south gradient in potential temperature

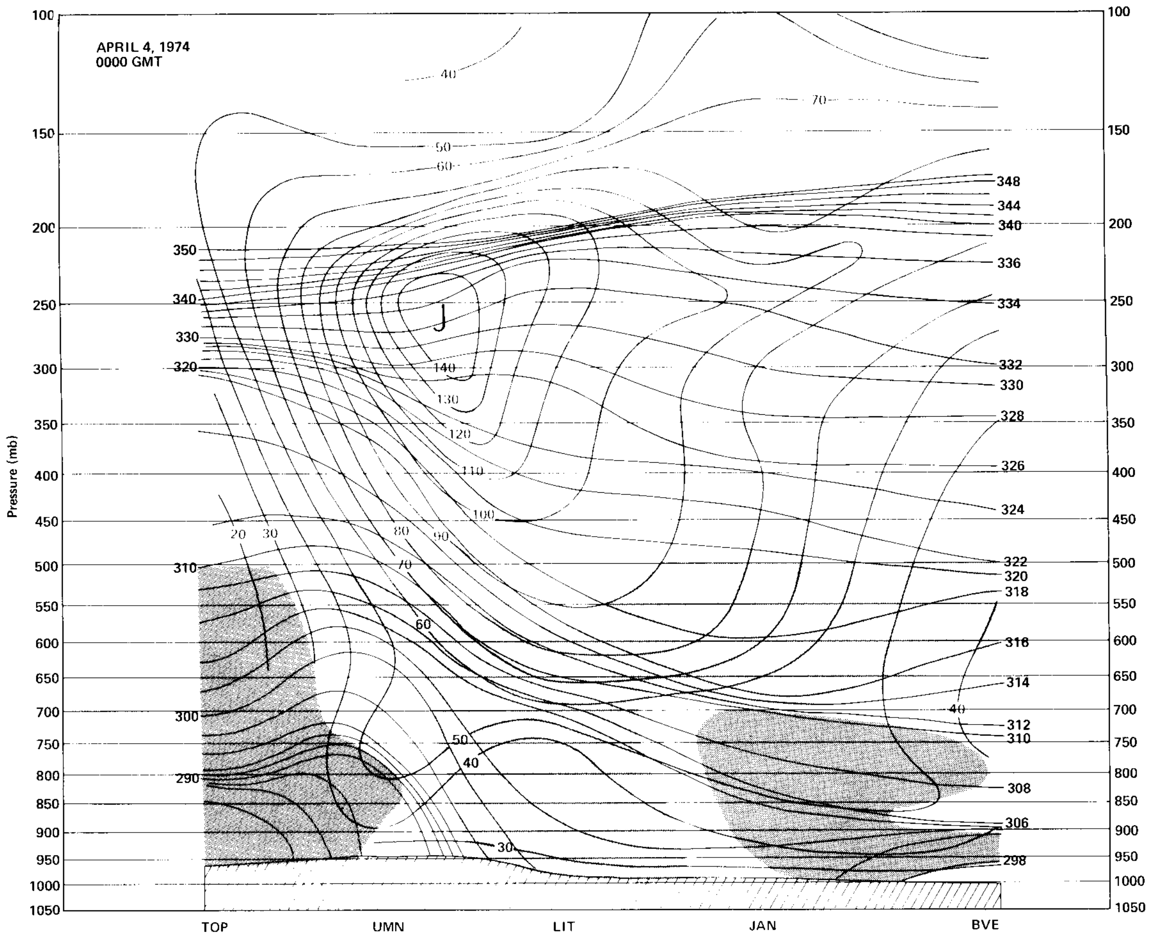


Figure 48 Vertical cross section from Topeka, Kansas, to Batesville, Louisiana (see legend in fig. 47).

near the surface.

The cross section from Topeka to Batesville (fig. 48) cut across all three frontal boundaries to the south of the low pressure center. Weak temperature gradients were associated with the two southern boundaries. The warm dry air over Arkansas extended to near 550 mb. Between Jackson and Batesville, moist Gulf air was still capped by warm dry air above 700 mb. Maximum wind speeds were near 150 kn at 275 mb over the Missouri–Arkansas border. Note that the weak subtropical jet, which had been located between Jackson and Batesville 12 hours

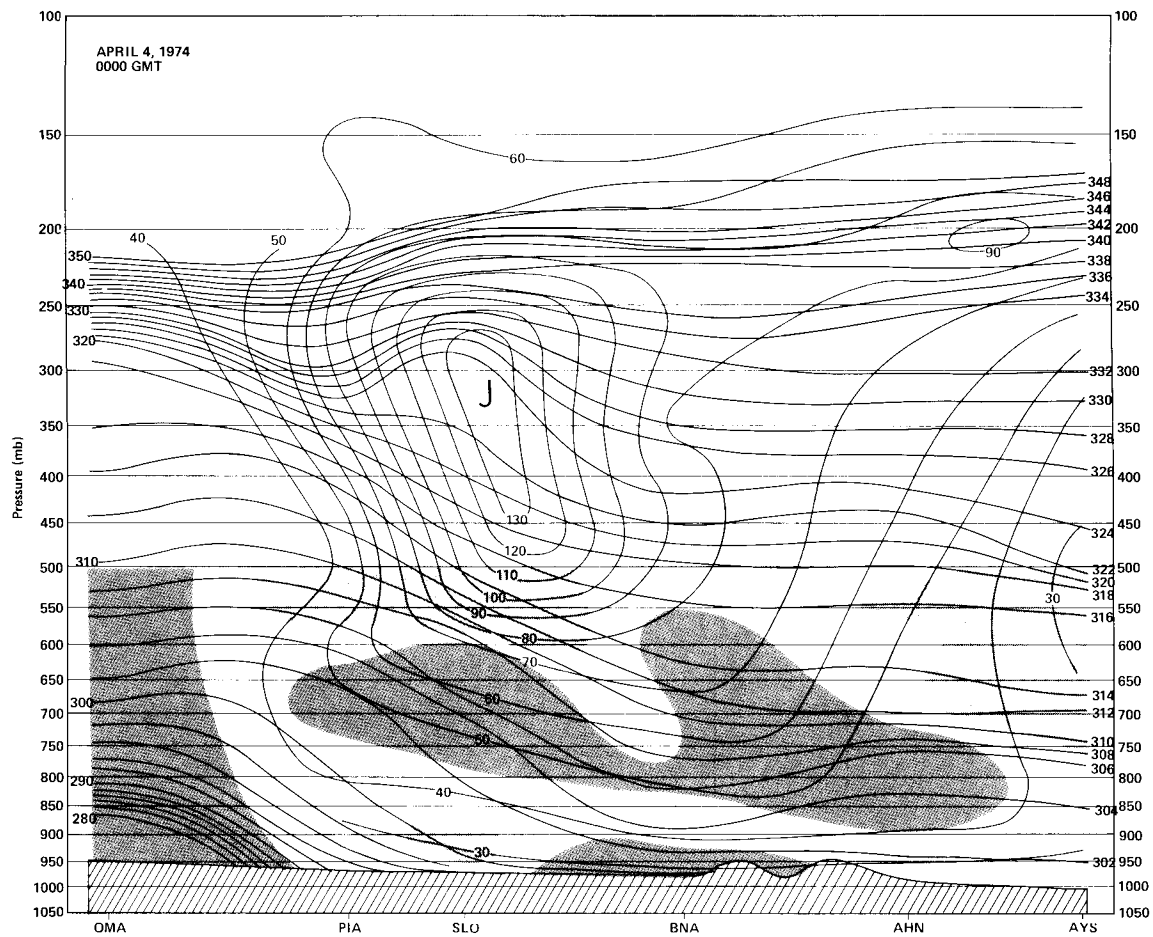


Figure 49 Vertical cross section from Omaha, Nebraska, to Waycross, Georgia (see legend in fig. 47).

before, had essentially disappeared.

Cross sections depicted in figures 49–50 intersect regions where most of the severe weather was occurring. In both, moisture fields indicate that strong convective mixing was occurring. The polar jet just south of Salem, Illinois, had strengthened during the preceding 12 hours but little or no propagation to the southeast occurred. The subtropical jet over southern Georgia had weakened during the same period. This and similar tendencies on the previous cross section suggest that the concentration of tornadoes during the evening hours over northern Alabama and northern

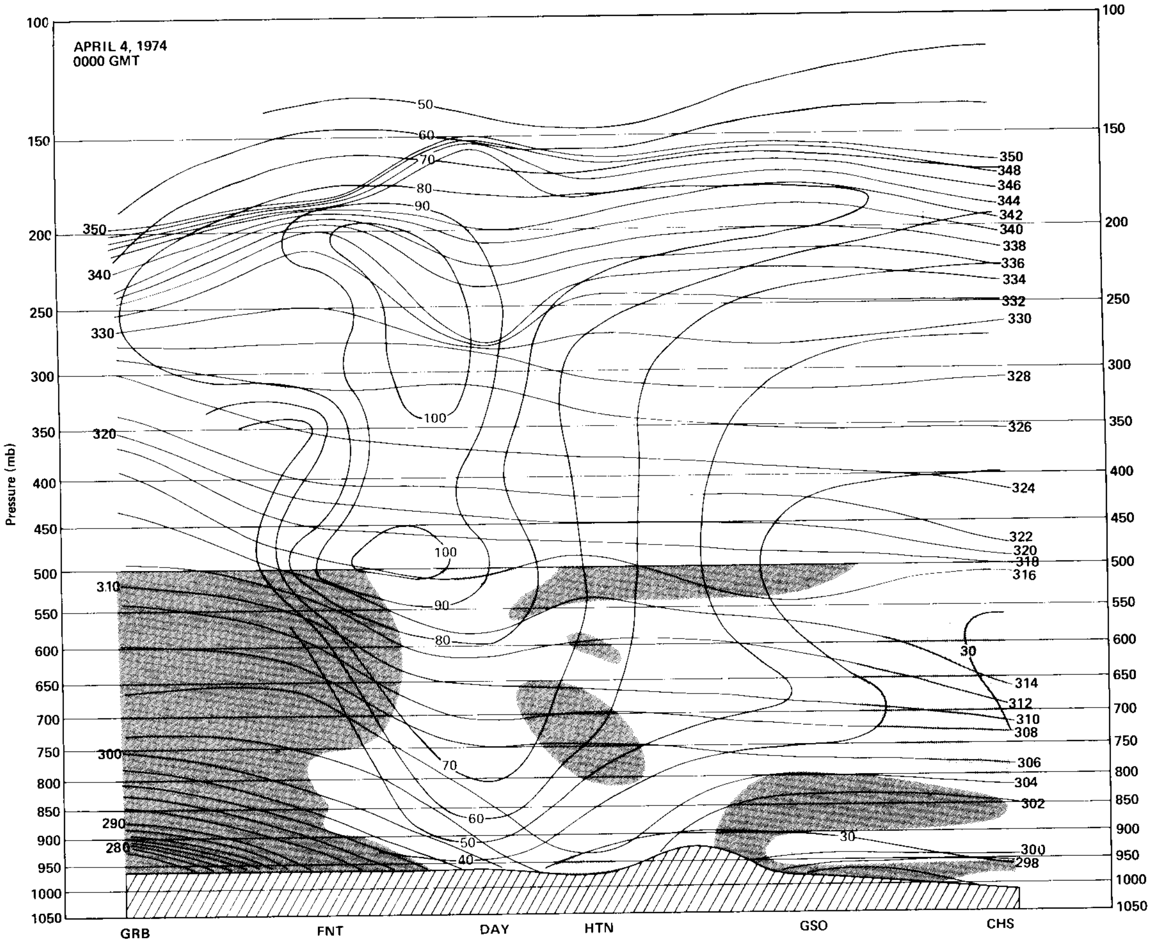


Figure 50 Vertical cross section from Green Bay, Wisconsin, to Charleston, South Carolina (see legend in fig. 47).

Georgia cannot be attributed to dynamic processes of the subtropical jet stream.

The cross section from Green Bay to Charleston (fig. 50) shows major changes from conditions 12 hours earlier (fig. 24). Most notable was the development of strong winds in the lower troposphere in the Dayton–Huntington area. At 850 mb, for example, the maximum speeds were near 65 kn. It was in this region that some very intense tornadoes occurred, including those at Brandenburg, Kentucky; Xenia, Ohio; and Monticello, Indiana. ■

Analyses for 1200 GMT April 4, 1974

Figures 51–56 present analyses valid at 1200 GMT April 4. In general, these analyses show that the upper level perturbation was continuing to move northeastward into southern Canada. This direction of movement was taking the surface low pressure center and much of its dynamic forcing to the north of the conditionally unstable airmass present over the southeast and mid-Atlantic States.

Active squall lines did redevelop from Virginia southwestward to northwest Florida during the afternoon of April 4. Approximately 20 additional tornadoes (not included in figure 1) occurred in Virginia, North Carolina, South Carolina, Alabama, Georgia, and Florida. However, these tornadoes appeared less severe than those that had occurred the afternoon and evening of April 3.■

Summary

Low-level cyclogenesis occurred over the Great Basin and southern Rockies on April 2, 1974, in response to the approach of a very strong upper level baroclinic wave that moved inland from the Pacific. The wave moved rapidly east-southeast and amplified during the day. A strong polar jet propagated into southern New Mexico the evening of April 2, and the surface low organized into an intense storm in eastern Colorado. By sunset on April 2 the central sea-level pressure was near 983 mb and the cyclonic circulation was approximately 1200 miles (2000 km) in diameter.

In response to the deep and expanding surface low over the Colorado-Kansas border, strong southerly winds developed over the lower Mississippi River Valley. During the evening of April 2 and early morning of April 3 moist maritime air streamed northward toward the lower midwest and Ohio Valley states. Above the increasingly moist boundary layer, warm dry air moved from the southwest. Subsidence in the mid-troposphere maintained and enhanced the temperature inversion separating the two air masses. By mid-morning of April 3, the environment was conditionally unstable as far north as central Illinois.

During the daylight hours of April 3 the surface cyclone moved from north central Kansas northeastward to the Iowa-Illinois border. The strong low level convergence fields associated with the storm moved eastward into the Ohio and Tennessee Valleys, the northern Gulf states, and southern Appalachian regions. This large scale forcing along with low level heating over most of the region triggered the intense convection and related severe weather.

The April 3–4 outbreak was extraordinary in several respects. The Xenia, Ohio, Brandenburg, Kentucky, and Guin, Alabama, tornadoes were among the most intense ever recorded. Equally impressive was the fact that the tornado activity covered an unusually large region. Typically a major tornado outbreak affects only two or three states. As a result of the April 3–4, 1974, tornadoes, ten states were declared disaster areas. ■

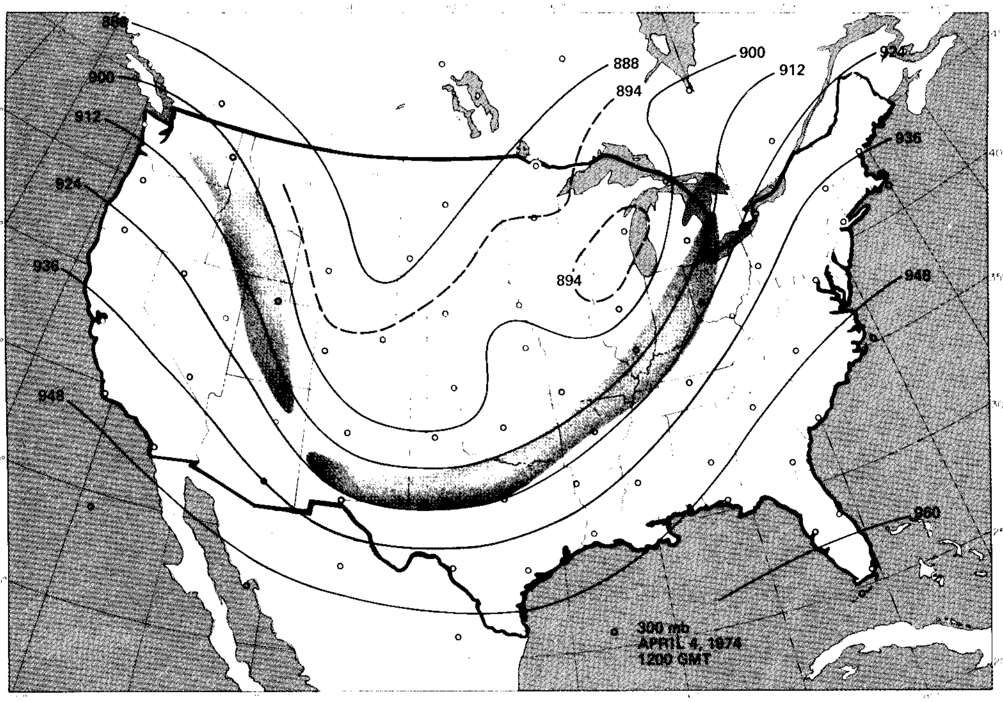


Figure 51 300-mb analysis, 1200 GMT, April 4, 1974. Contours, 120-m intervals; Wind speeds 80–120 kn, orange shading; Wind speeds > 120 kn, gray shading.

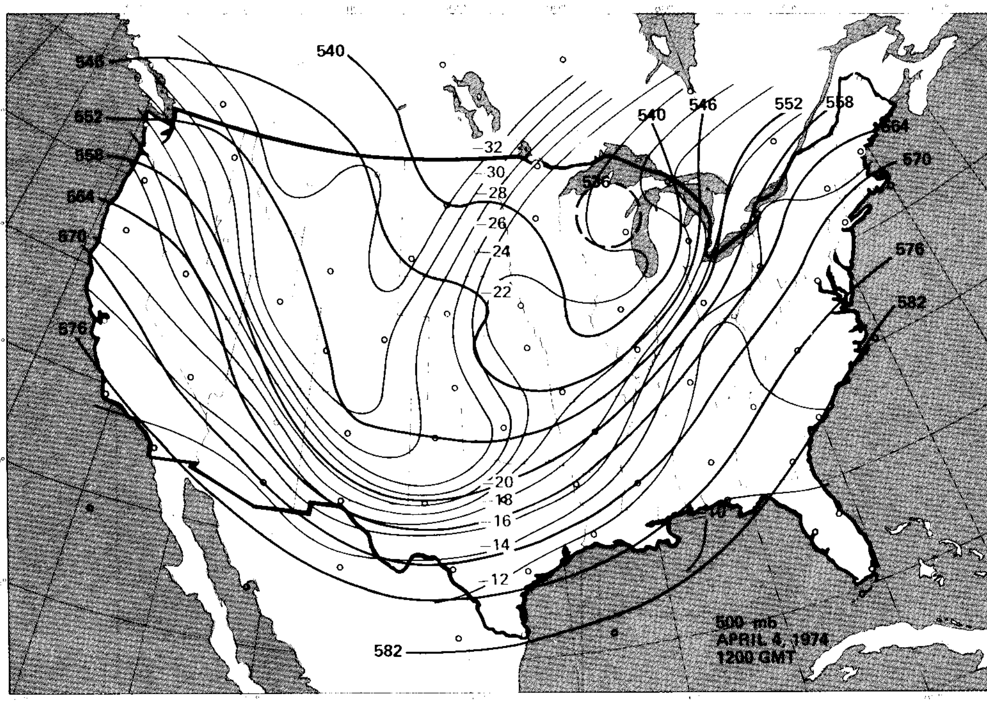


Figure 52 500-mb analysis, 1200 GMT, April 4, 1974. Contours, 60-m intervals; Isotherms, 2°C intervals.

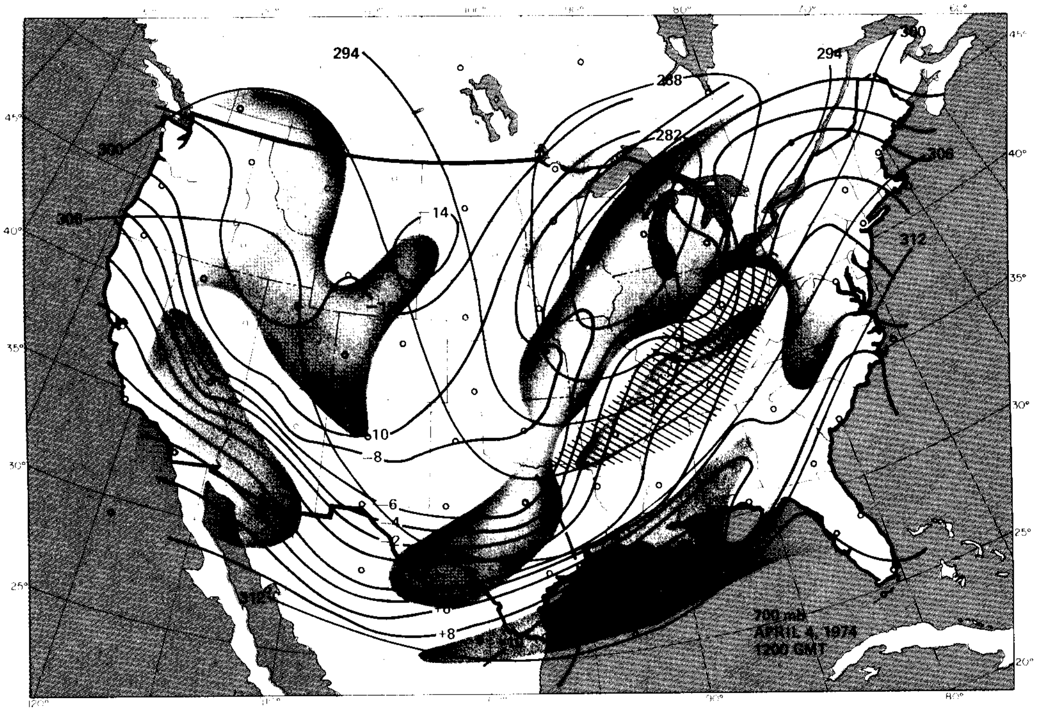


Figure 53 700-mb analysis, 1200 GMT, April 4, 1974. Contours, 60-m intervals; Isotherms, 2°C, intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 60 kn, hatched.

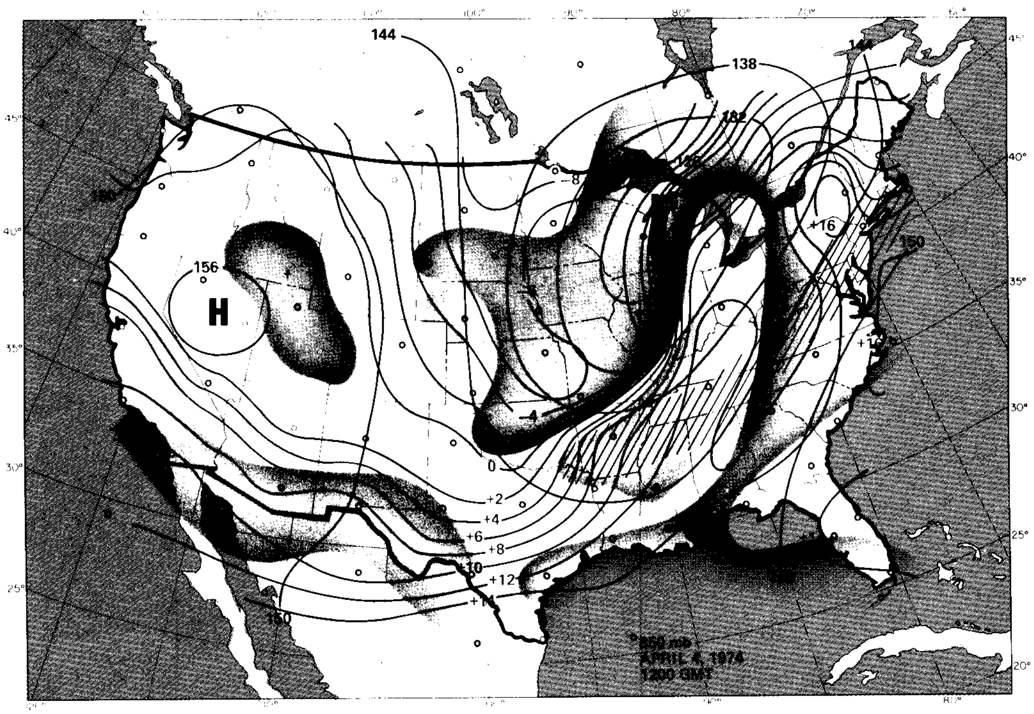


Figure 54 850-mb analysis, 1200 GMT, April 4, 1974. Contours, 60-m intervals; Isotherms, 2°C intervals; Dew point depressions ≥ 20°C, orange shading; Dew point depressions ≤ 5°C, gray shading; Wind speeds ≥ 5 kn, hatched.

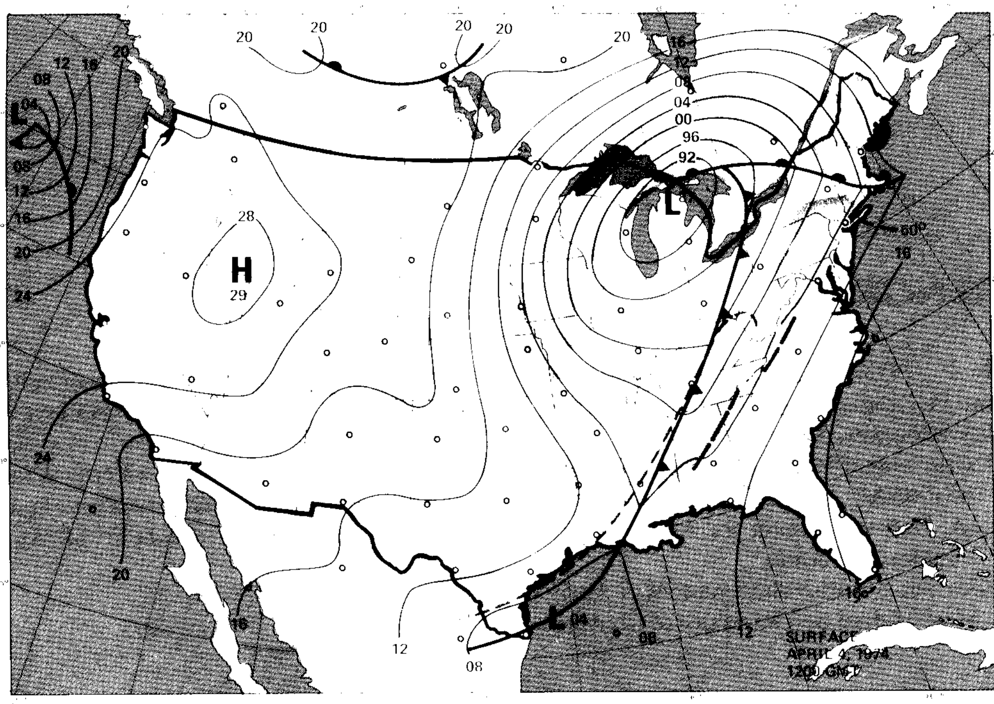


Figure 55 Surface analysis, 1200 GMT, April 4, 1974. Pressures, 4-mb intervals; 60°F isodrosotherm, dashed; Area of precipitation, gray shading.

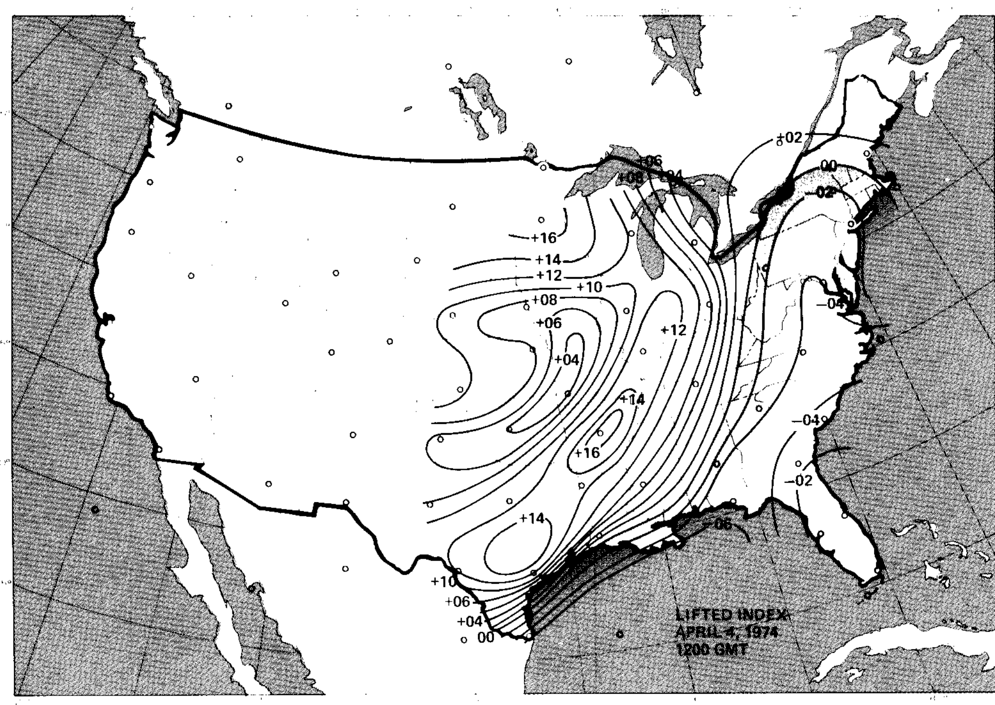


Figure 56 Lifted Index analysis, 1200 GMT, April 4, 1974.

REFERENCES

Danielsen, E. F., 1975. The relationship between severe weather, major dust storms and rapid large-scale cyclogenes, Parts I and II. In: Subsynoptic Extratropical Weather Systems; Notes from the ASP-SSAP Coloquium — Summer 1974, Vol. II. National Center for Atmospheric Research, Boulder, Colorado.

Fujita, T., 1975. Super outbreak tornadoes of April 3–4, 1974. Map printed by University of Chicago Press.

O'Brien, James J., 1970. Alternative solutions to the classical vertical velocity problem. *J. Appl. Meteorol.*, 9:197–203.

National Oceanic and Atmospheric Administration, 1974. National disaster survey report 74-1: Widespread tornado outbreak of April 3–4, 1974. 42 p.

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