THE 27 MARCH 1994 TORNADO OUTBREAK IN THE SOUTHEAST U.S. THE FORECAST PROCESS FROM A STORM PREDICTION CENTER PERSPECTIVE

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Abstract

An outbreak of significant tornadoes affected the southeast U.S. on 27 March 1994. The event occurred in an environment less "synoptically evident" than many previous major tornado outbreaks. For example, large-scale features usually associated with tornado outbreaks such as a deepening surface low and strong upper-level trough were absent. Jet streak dynamics also did not appear to play a role in this event. Despite some uncertainties regarding the strength of synoptic-scale forcing, it became apparent to National Weather Service (NWS) Storm Prediction Center (SPC) forecasters that a volatile air mass had set up across the outbreak region during the early morning hours of the 27th. Potential instability increased significantly overnight due to low-level thermal and moisture advection, and the wind fields had become very favorable for the development of supercell storms. Moreover, overnight rain helped to establish a quasi-stationary thermal boundary from northern Mississippi into the western Carolinas. Although initial supercell development occurred south of this boundary, other severe storms formed and moved along the boundary throughout the afternoon and evening. In this paper we discuss in detail the pertinent synoptic and mesoscale features leading to this event. Of equal importance is a presentation of the products issued by the SPC as the event unfolded. These products provide insight into the procedures followed by the SPC during severe weather episodes.

1. Introduction

On 27 March 1994, an outbreak of strong and violent tornadoes raced east-northeastward across the southeast U.S., mainly from north-central Alabama and northern Georgia to the Carolinas. Not only did the tornadic supercells develop very early in the day (the first fatality occurred in Alabama before 1700 UTC), but the dozen or so tornado producing storms traversed a long and narrow zone typically less than two counties wide. They spawned tornadoes in parallel tracks, some of which were nearly overlapping. Figure 1 shows the tracks and F-scales of the tornadoes that occurred during this event. A total of 42 deaths and over 320 injuries were attributed directly to the storms, and damage to property exceeded $100 million. Twenty people died in the tornado that struck the Goshen Methodist Church near Piedmont, Alabama. Eighteen fatalities occurred in Georgia and two in North Carolina. The supercell that produced the tornado near Piedmont tracked at least 200 miles from northeast Alabama into northwest South Carolina (Fig. 2).

The National Weather Service (NWS) Storm Prediction Center (SPC) part of the National Centers for Environmental Prediction (NCEP), has responsibility for forecasting all types of severe convective weather. Given the significance of the outbreak along with the less than synoptically-evident pattern (discussed in section 2), an examination of the SPC response is appropriate. In this study, we examine the relevant synoptic and mesoscale features associated with the tornado outbreak, and review the products issued by the SPC as the event unfolded.

2. Synoptic and Mesoscale Overview

The outbreak of significant tornadoes across the southeast U.S. on 27 March 1994 occurred in an environment less "synoptically-evident" than many previous major tornado outbreaks. Large-scale features usually associated with tornado outbreaks (Miller 1972) such as a deepening surface low and strong upper trough were absent. An examination of the 500 mb chart at 1200 UTC 27 March (Fig. 3) revealed no well-defined short-wave troughs embedded in the mean flow. Rather strong west-southwest winds were prevalent across the southeastern U.S., with the main trough position extending from the north-central states southwest into the southern Rockies. The tornado outbreak occurred on the anticyclonic periphery of the polar jet (PJ) which was well to the north.

a. Upper-level forcing

Palmen and Newton (1969) found that the ageostrophic wind, produced in association with parcel accelerations and decelerations in the entrance and exit regions of straight upper-level jet streaks, provide for a four-cell divergence pattern. This results in a thermally indirect

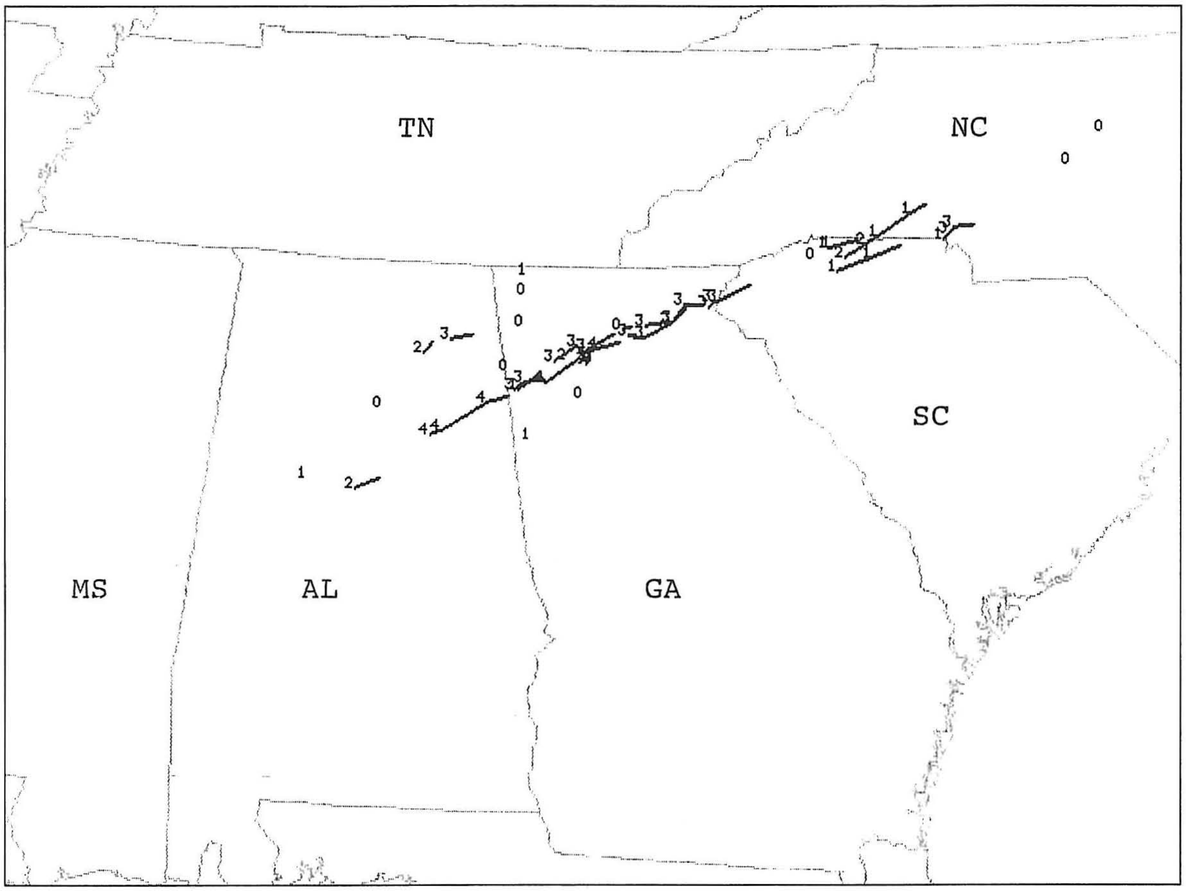


Fig. 1. Tracks of the tornadoes during the outbreak with their F-scales.

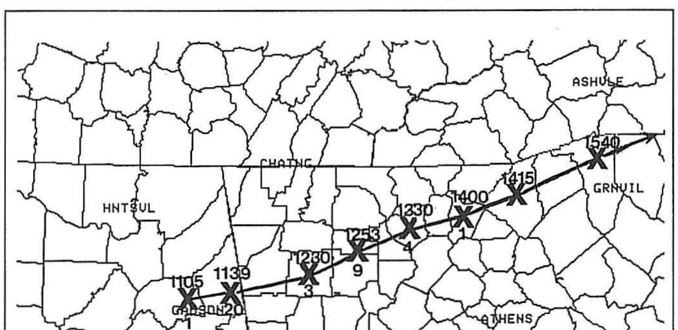


Fig. 2. The Piedmont tornadic supercell track (the town of Piedmont is located at the second "X" from the left). Tornadoes occurred at each "X". Numbers above the "X" are time of occurrence (CST), while numbers below indicate fatalities.

(direct) transverse circulation in the left exit (right entrance) region of the upper-level jet leading to mesoscale ascent, and strengthening of the low-level jet in response to falling pressures (Uccellini and Johnson 1979). Previous studies have shown (e. g., Beebe and Bates 1955) that the PJ and its interaction with the southerly jet at low levels is an important aspect of many tornado outbreak cases. However, McNulty (1978) showed that even when the upper and lower jet maxima do not cross (as was the case for this event), the divergence associated with the right entrance region of the 300-mb jet may provide sufficient forcing for severe convective development, provided the air mass is unstable and a low-level focusing mechanism is present. Given the fact that the core of the upper jet was removed from the area of concern, there was some doubt as to whether or not jet streak dynamics would enhance convective potential. After the event, we examined the possible role of the interaction of the PJ with the subtropical jet (SJ) based on a paradigm developed by Uccellini and Kocin (1987). They suggested that when the cross-stream ageostrophic flow within the left exit region of a subtropical jet is positioned above the right entrance region of a polar jet, a mesoscale enhancement of the ascent region results. Analyses of the upper-level dynamics consisted of quasi-geostrophic **Q** vectors and transverse jet circulations computed from rawinsonde data and from the NWS/NCEP's NGM and Eta numerical weather predic-

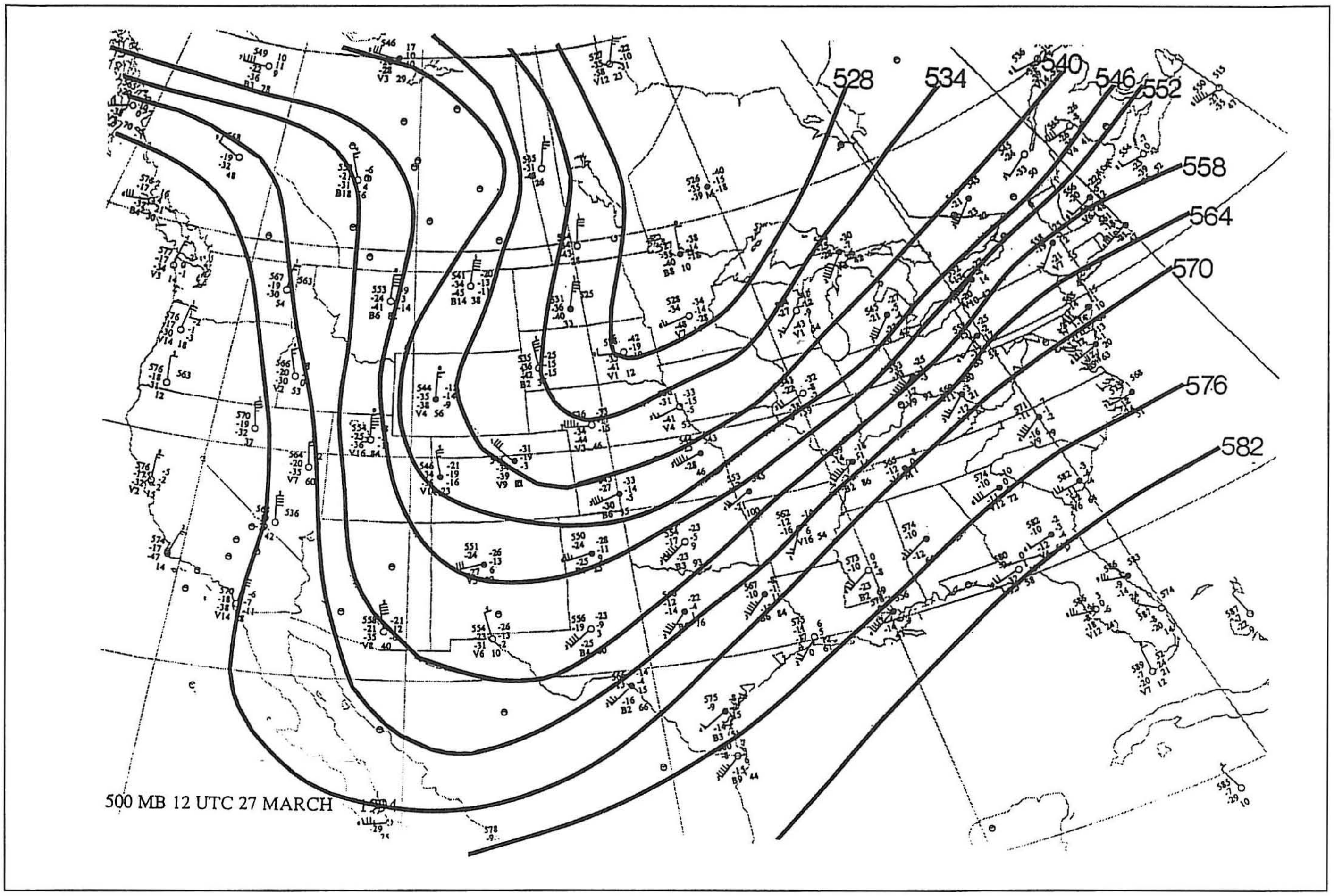


Fig. 3. 500-mb level geopotential height analysis (dm) for 1200 UTC 27 March 1994.

tion model fields. The rawinsonde data were analyzed with the GEMPAK Barnes objective analysis scheme (Koch et al. 1983), which is a component of N-AWIPS. Analyses at 1200 UTC 27 March (Fig. 4) reveal that the left exit region of the 200-mb level SJ was in northwestern Arkansas, well removed from the outbreak region. The kinematically derived vertical motions (including an O'Brien correction) were used in the construction of vertical cross sections transverse to the jet axes. All of these cross sections (an example of which appears in Fig. 5a)

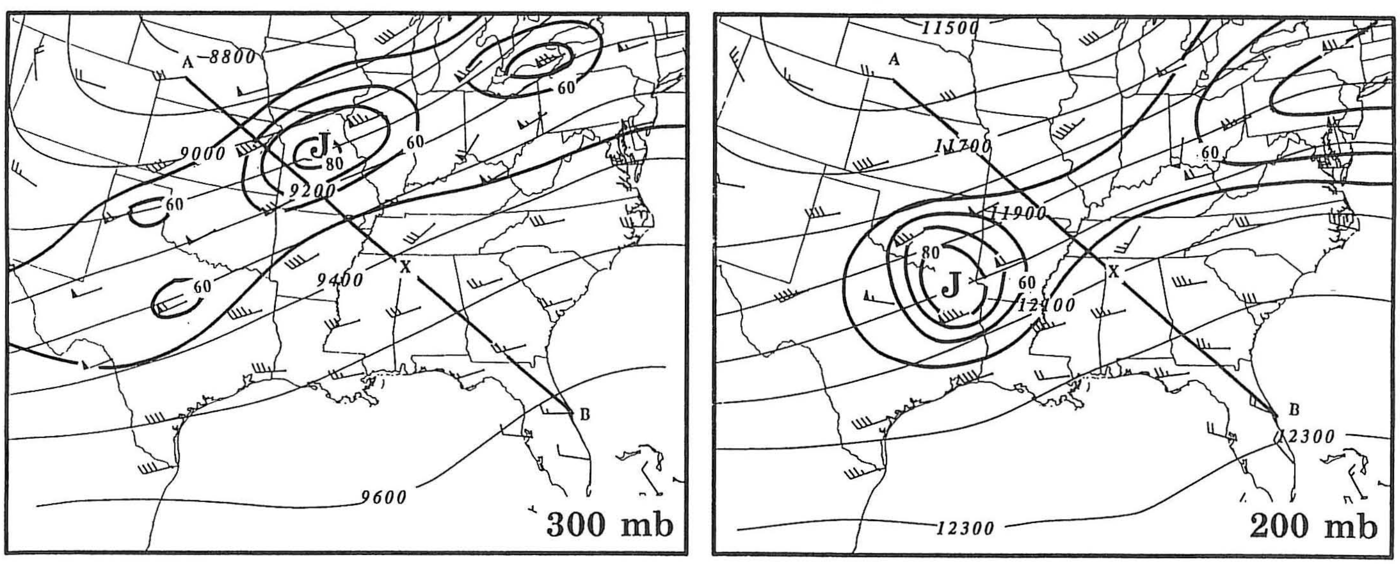
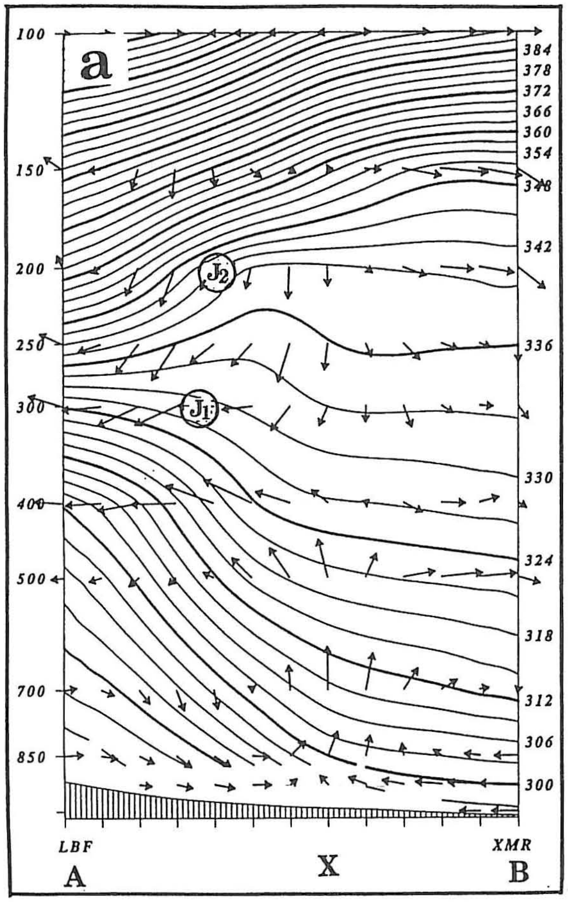


Fig. 4. Upper-level rawinsonde wind vectors (m s^{-1}) and objectively analyzed geopotential heights (m) for 1200 UTC 27 March 1994 at 300-mb and 200-mb levels. Isotachs equal to or greater than 50 m s^{-1} are shown. Location of vertical cross section displayed in Fig. 5a is depicted by line A-B, and "X" denotes the intersection of this line with the location of the surface front in northern Alabama.



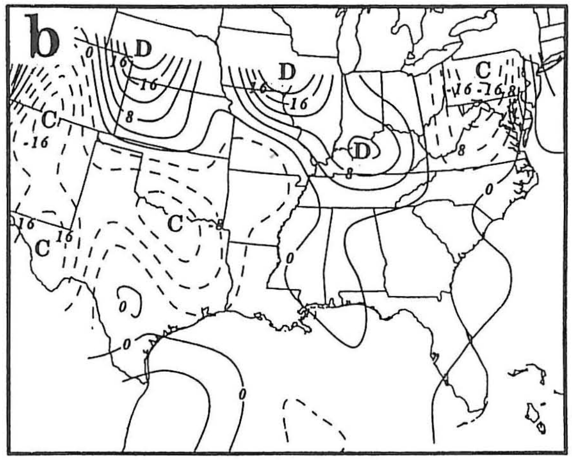


Fig. 5. Analyses of upper-level dynamics: (a) Cross section depicting ageostrophic circulation transverse to upper-level polar jet (J_1) and subtropical (J_2) jet streak and isentropes (solid, 3K intervals). Vertical motions (arrows) have been exaggerated to emphasize the vertical circulations; and (b) Q vector divergence field at 700 mb (solid = divergence, dashed = convergence, contour interval = 4 X 10^{-16} m kg^{-1} s^{-1}). Both analyses are based on 1200 UTC 27 March rawinsonde data.

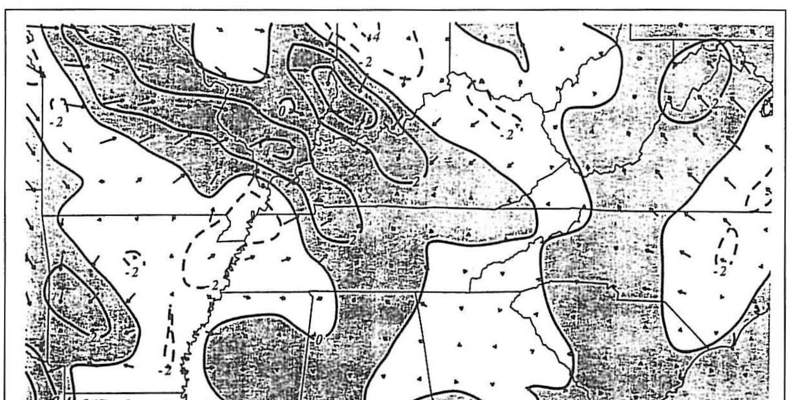


Fig. 6. Convergence of Q vectors (10^{-15}m kg^{-1} s^{-1})at 500-mb level from the 18-h Eta model forecast for 1800 UTC 27 March. Convergence regions are shaded.

clearly showed a thermally direct ageostrophic circulation cell below the level of the jet, with a circulation cell of the opposite sense somewhat evident above this level. While this pattern is entirely consistent with semi-geostrophic straight jet streak dynamics, it does not appear that the right entrance region of the PJ and the left exit region of the SJ were coupled in a sense to promote strong upward motions over northwestern Arkansas. In fact, the strongest upward motion was much farther to the east than would be expected from the interaction of these two jets, namely over northern Alabama (see "X" in Fig. 5a). A comparison of the strongest upward motion in this cell to the **Q** convergence pattern (Fig. 5b) reveals that this cell cannot possibly be explained by quasi-geostrophic forcing. The only nearby area where the **Q** vectors indicate strong convergence (implied upward motion) is over northeastern Texas, which is far removed from both the strong ascent and the outbreak regions.

These conclusions about the lack of upper-level support for lifting over the outbreak region could also be drawn from an analysis of the **Q** vector fields and the transverse circulations produced by the Eta and NGM models. For example, the 1200 UTC initial conditions for the Eta model also showed strong Q vector convergence over eastern Texas, but with the strongest vertical motions within the thermally direct cell being over north-

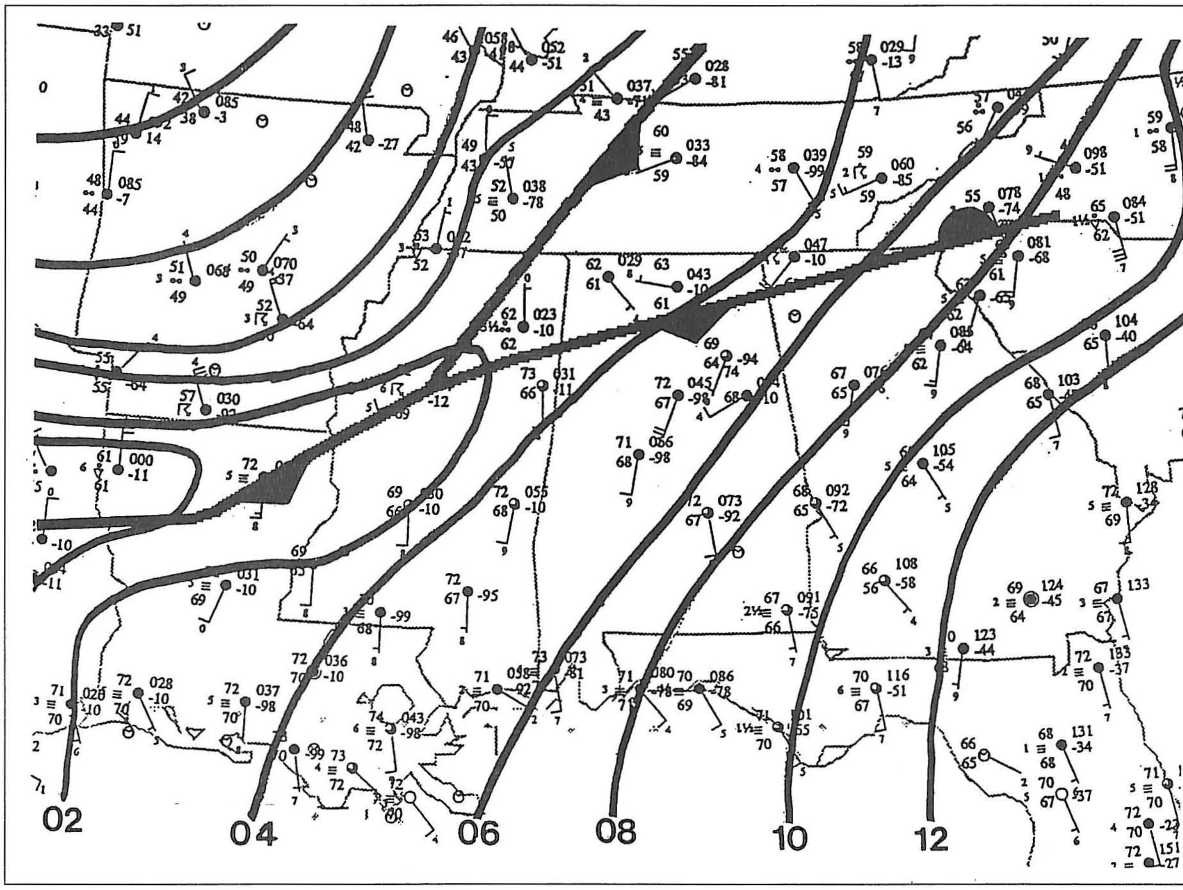


Fig. 7. Surface analysis at 1200 UTC 27 March 1994. Isobars are in 2 mb increments.

ern Alabama. The **Q** vector convergence regions remained far to the west and northwest of the outbreak region in the model forecasts. By the time of the outbreak (1800 UTC), the maximum quasi-geostrophic forcing was over Arkansas and southern Illinois (the 18-h forecast **Q** vector field is presented in Fig. 6). Thus, it is clear that the strong ascent over northern Alabama, the region of the severe convective outbreak, was due neither to the subtropical-polar jet streak interaction process nor to quasi-geostrophic effects, but rather to other processes. Possible explanations for the vertical motion fields over Alabama will be discussed further.

b. Surface features

Overnight rain helped to establish a quasi-stationary front from northern Mississippi into the western Carolinas parallel to the upper flow. The boundary position at 1200 UTC is depicted in Fig. 7. Langmaid et al. (1996) discuss how low-level frontogenesis was the most likely cause for the strong ascent in northern Alabama. Figure 8 is an objective analysis of the adiabatic frontogenesis at 1200 UTC associated with the quasi-stationary front. Although the strongest frontogenetical forcing was over southeast Arkansas and northeast Louisiana (shaded region), a secondary maximum was located over north central Alabama. Several mesolows developed along the front during the day, enhancing convergence and warm air advection at low levels. Koch et al. (1996) showed that frontogenesis increased over northern and central Alabama in association with one of these mesolows. Figure 9 is a surface analysis valid at 1800 UTC. A mesolow was present over northwest Georgia with another across north central Alabama. The third low, along the border between Mississippi and Louisiana, was associated with a second round of severe thunderstorms during the late afternoon and evening as it moved east (Fig. 10). Koch et al. (1996) present evidence from analyses of the available barograph traces and from a mesoscale model that gravity waves played a key role in organizing these mesolows.

Although initial supercell development occurred south of the front in an area where the cap had weakened, other severe storms formed along the boundary and produced tornadoes throughout the afternoon and evening. Knupp et al. (1996) examined radar data for this case and identified a variety of storm structures ranging from isolated classic supercells to high precipitation supercells embedded in convective line segments.

The fact that many of the storms became tornadic in the vicinity of the stationary front is consistent with findings from Maddox et al. (1980). They showed that storms can rapidly evolve into supercells and produce tornadoes as they move either along or across shallow convergence boundaries.

c. Buoyancy and shear characteristics

On the morning of the 27th, it had become obvious to SPC forecasters that a potentially volatile air mass had

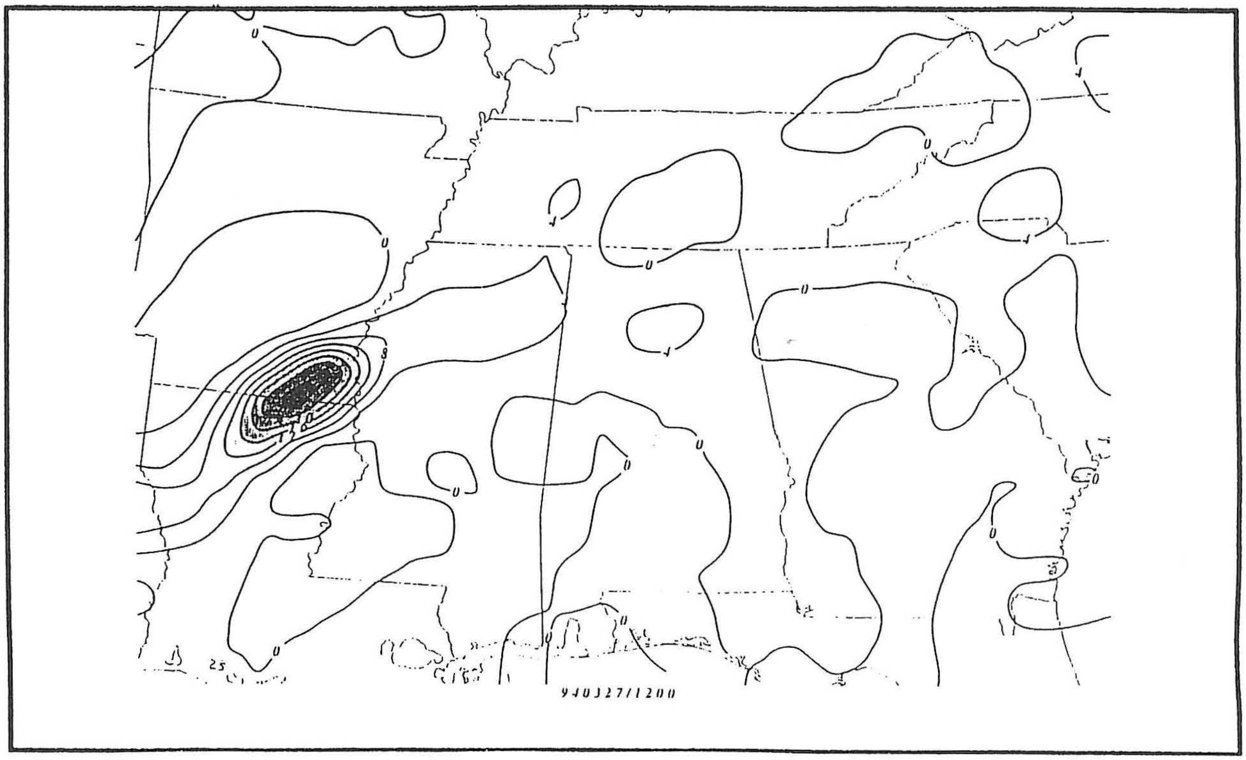


Fig. 8. Surface frontogenesis (Θ 100 km⁻¹ 3 h⁻¹) from Langmaid et al. (1996).

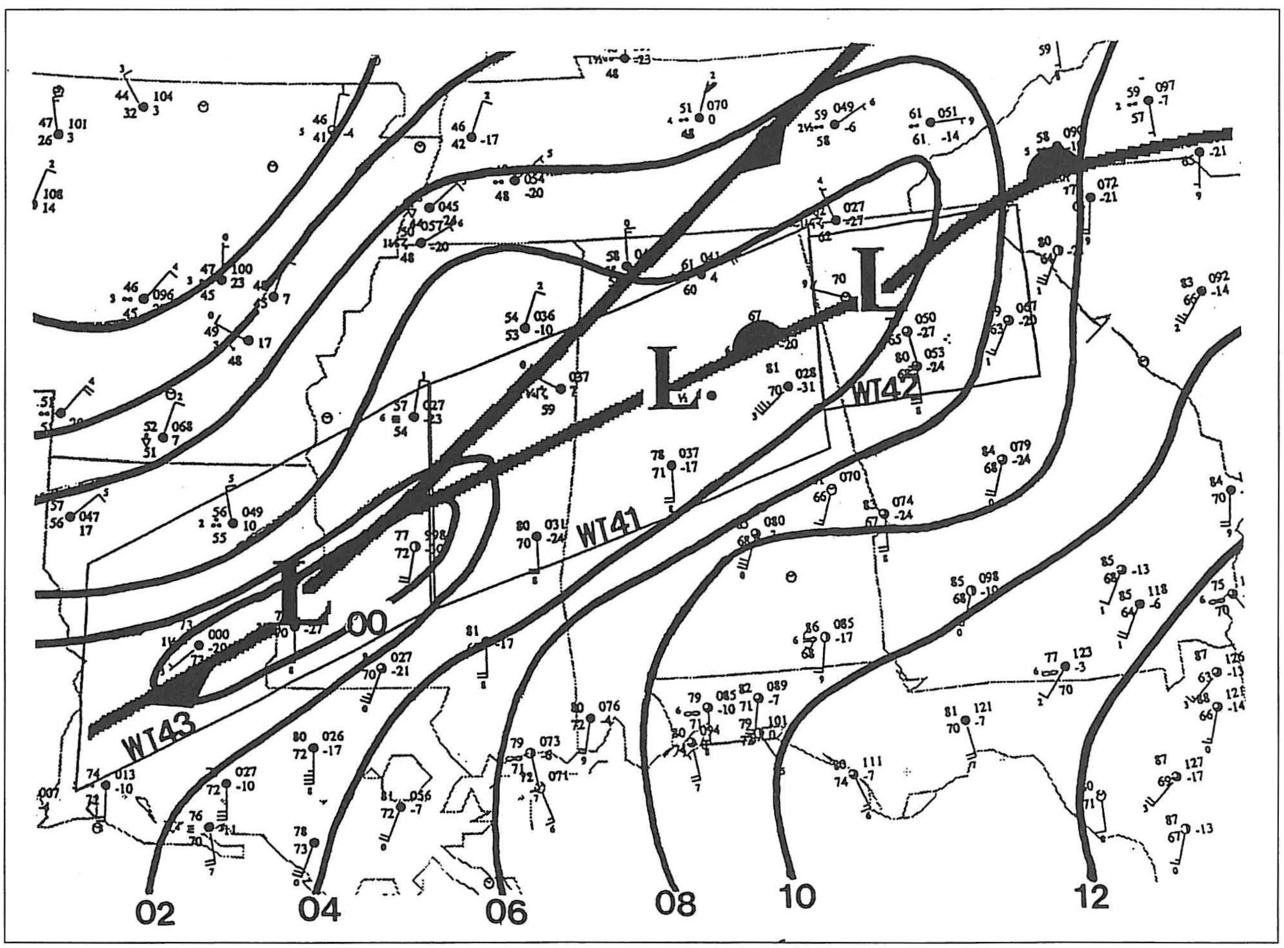


Fig. 9. Same as Fig. 7 except for 1800 UTC. Watch boxes issued during the event are labeled.

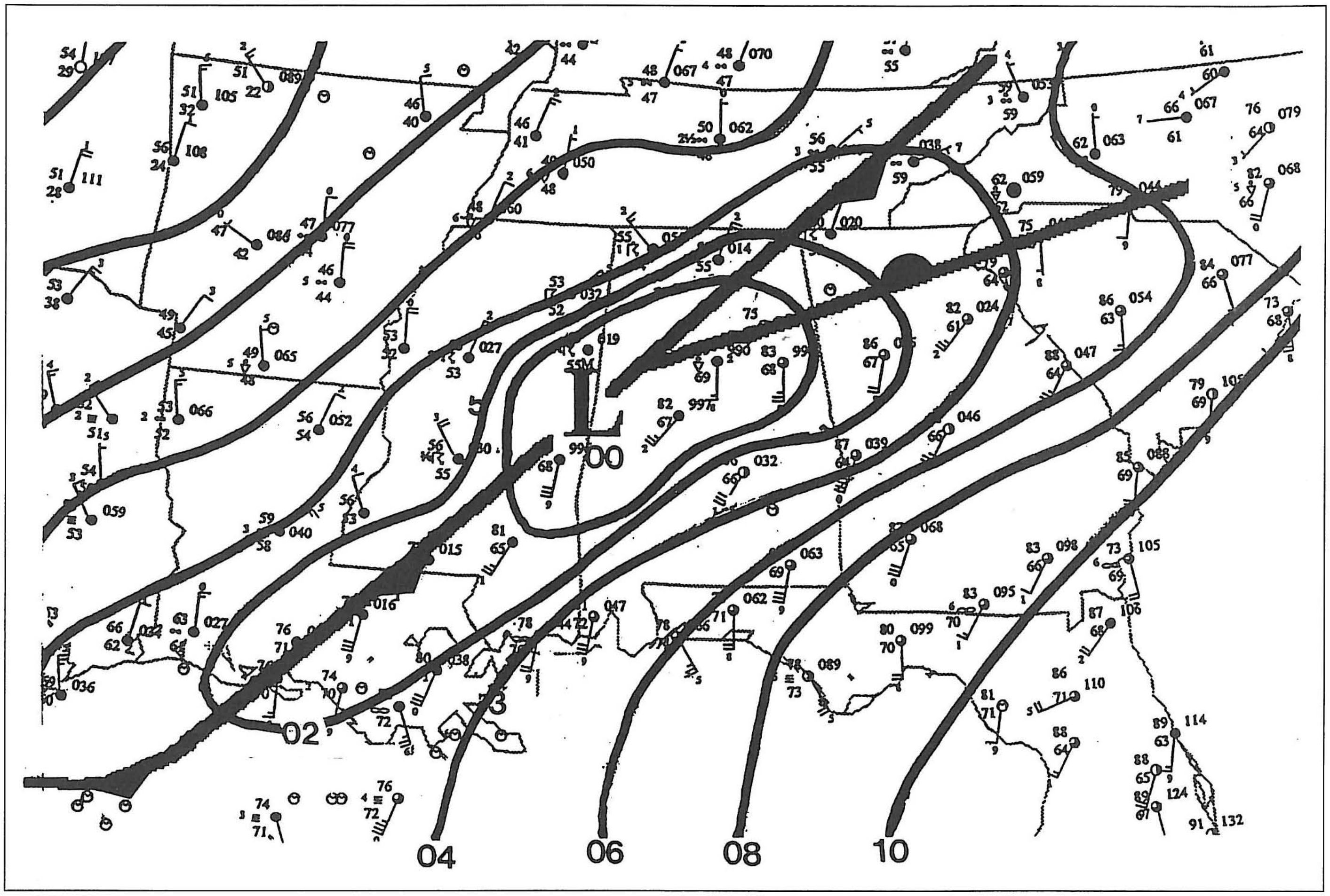


Fig. 10. Same as Fig. 7 except for 2100 UTC.

set up across the outbreak region. Low-level thermal and moisture advection increased the potential instability of the air mass, and the wind fields had become very favorable for the development of supercell storms. At 1200 UTC 27 March, storm-relative (SR) helicities (Lilly 1986) in the 0-3 km layer for a storm moving at 30° to the right of and 75% of the 0-6 km density weighted mean wind, (hereafter referred to as 30R75), ranged from 352 $m^2 s^{-2}$ at Jackson, Mississippi (JAN) to over 746 $m^2 s^{-2}$ at Athens, Georgia (AHN) (Figs. 11 and 12). Davies-Jones et al. (1990) suggested 150 $m^2 s^{-2}$ for a minimum threshold of SR helicity in the 0-3 km layer for supercell storms. Convective Available Potential Energy (CAPE) values were 857 J kg^{-1} and 217 J kg^{-1} at JAN and AHN respectively when lifting the most unstable parcel at low levels. With daytime heating expected, the air mass would become increasingly unstable. Of particular significance was the very weak capping evident on the Centreville, Alabama (CKL) sounding (Fig. 13). A parcel lifted from the surface would experience virtually no negative area. This supports the convective initiation that occurred during the morning.

3. SPC Performance

SPC began focusing on the affected area in the initial Day Two Convective Outlook[1] issued at 0800 UTC 26 March, valid for the time period from 1200 UTC 27 March to 1200 UTC 28 March. The outlook highlighted the forecast of strong wind fields and indicated that the instability would be adequate for a risk of severe thunderstorms over the area eventually affected. However, all numerical models on consecutive cycles under-forecast the amount of instability which actually became available. As an example, Fig. 14 is the 18-h Lifted Index (LI) forecast valid at 1800 UTC from the 0000 UTC 27 March operational "early" ETA model run. LI values of -2 were forecast across the outbreak region. Figure 15 is an objective analysis of observed LI values at 1800 UTC. LI's ranged from -4 to -6 across much of the Gulf Coast region, considerably more unstable than forecast by the Eta.

Another problem with the Eta model solution in this particular case was that it consistently over-forecast the strength of a surface low over the Ohio Valley. As a result, the model shifted the strongest low-level wind fields northward away from the Gulf Coast during Sunday. As it turned out, a well developed surface low did not form with this system over the Ohio valley.

[1] Consult Ostby (1992) for a discussion of forecast responsibilities and products issued at the SPC (formerly the National Severe Storms Forecast Center).

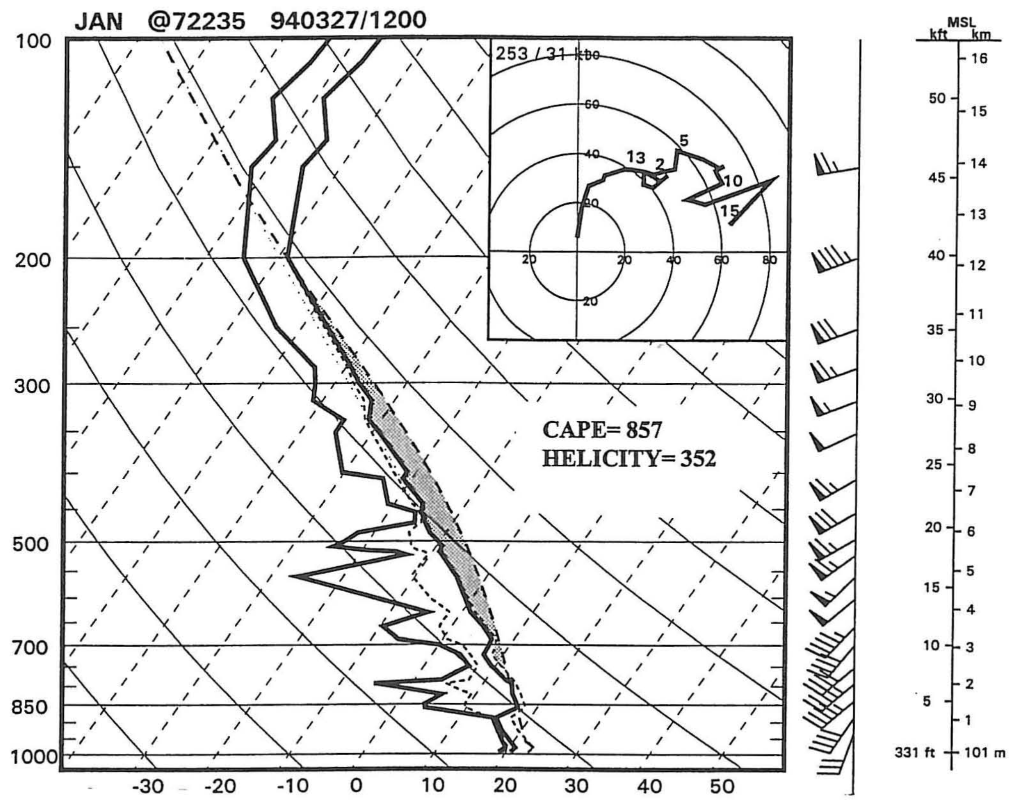


Fig. 11. Skew-T (including most unstable lifted parcel) and hodograph (insert at the upper-right) at Jackson, Mississippi (JAN) for 1200 UTC 27 March 1994. Shaded region denotes CAPE. Wind barbs at the right are 2.5 m s^{-1} (short barb), 5 m s^{-1} (long barb), and 25 m s^{-1} (flag). Thin solid lines sloping up to the left are dry adiabats, whereas dashed lines sloping up to the right are isotherms in increments of 10°C. CAPE and helicity values are labeled.

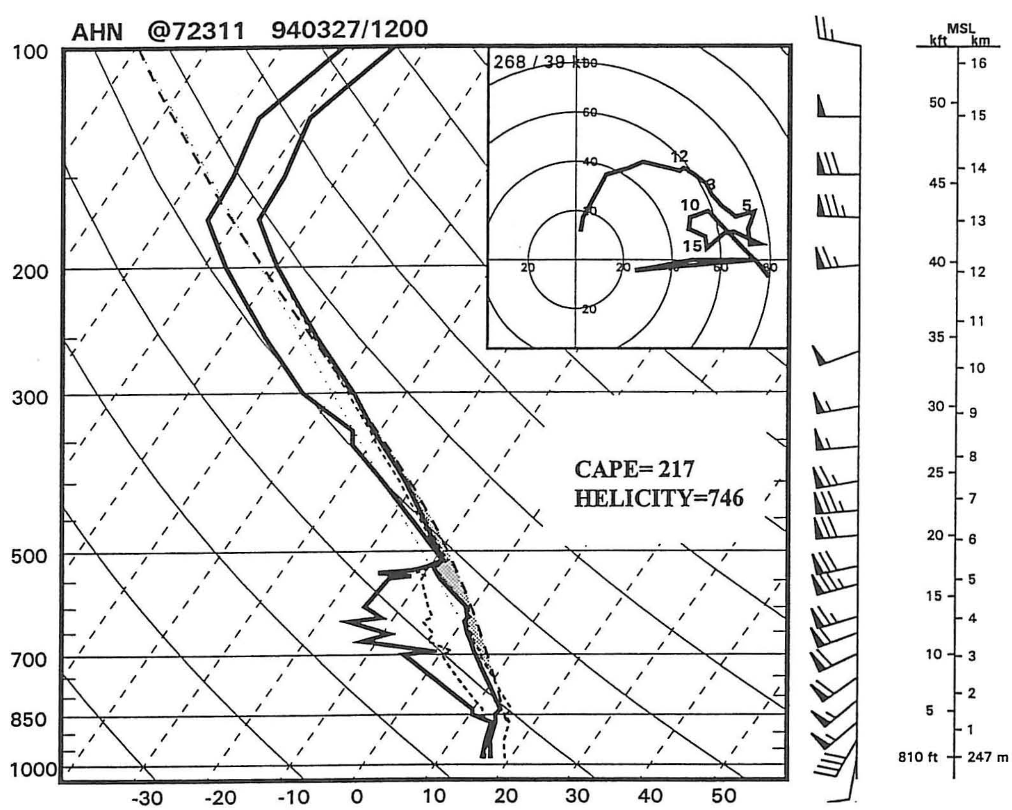


Fig. 12. Same as Fig. 11 except for Athens, Georgia (AHN).

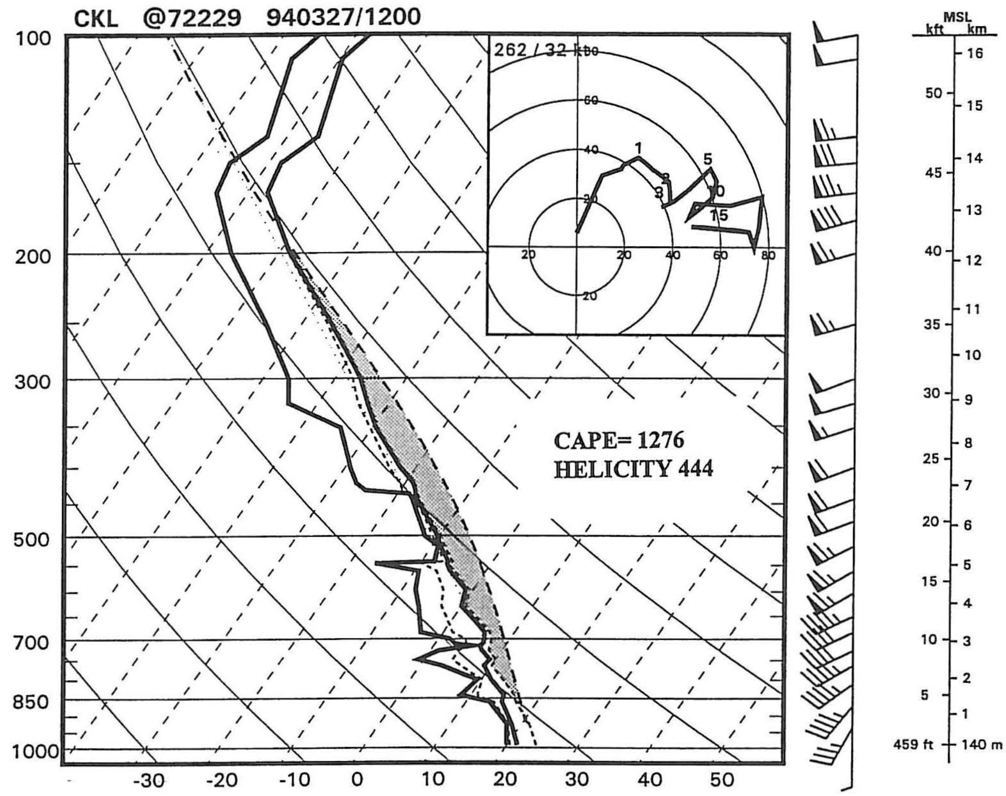


Fig. 13. Same as Fig. 11 except for Centreville, Alabama (CKL).

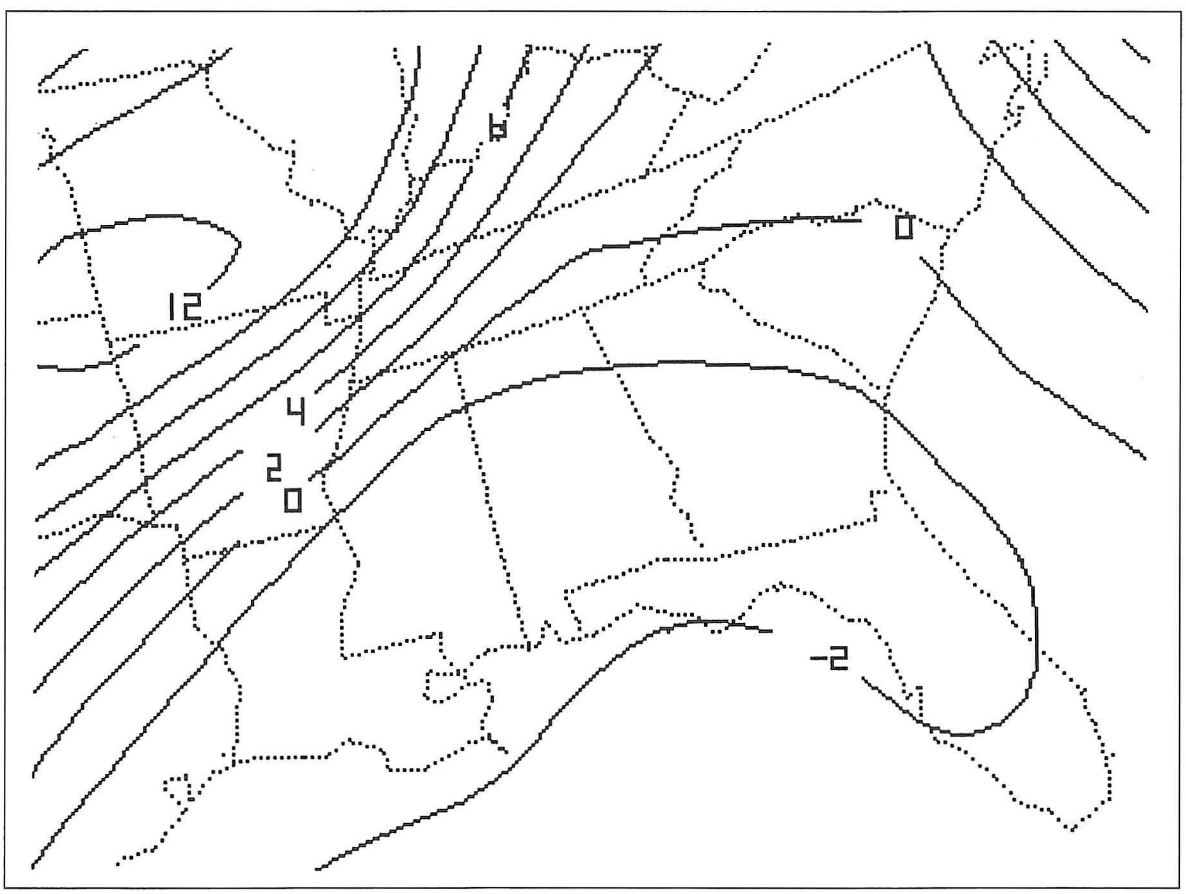


Fig. 14. 18-h "early" ETA model Lifted Index (LI) forecast valid at 1800 UTC 27 March 1994.

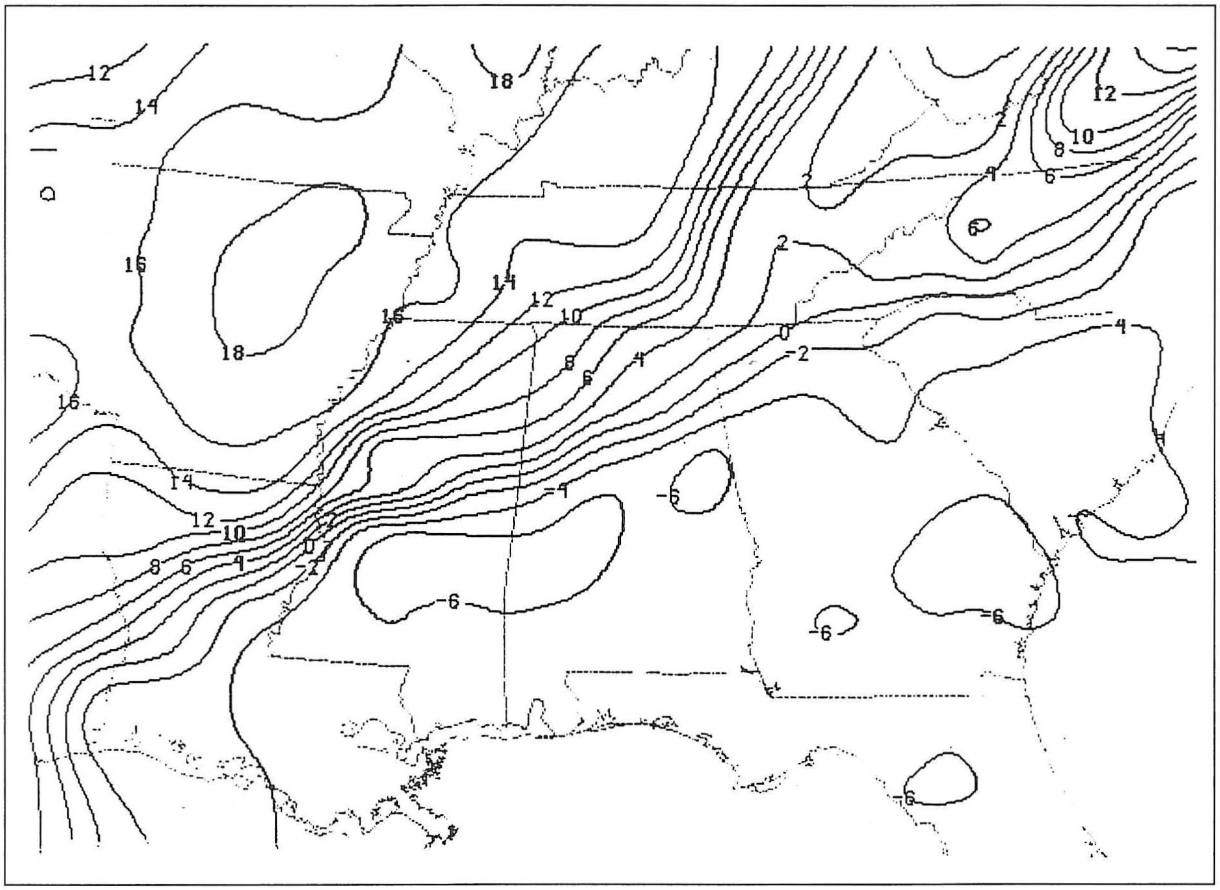


Fig. 15. Objective analysis of observed surface-based Lifted Index (LI) at 1800 UTC 27 March 1994.

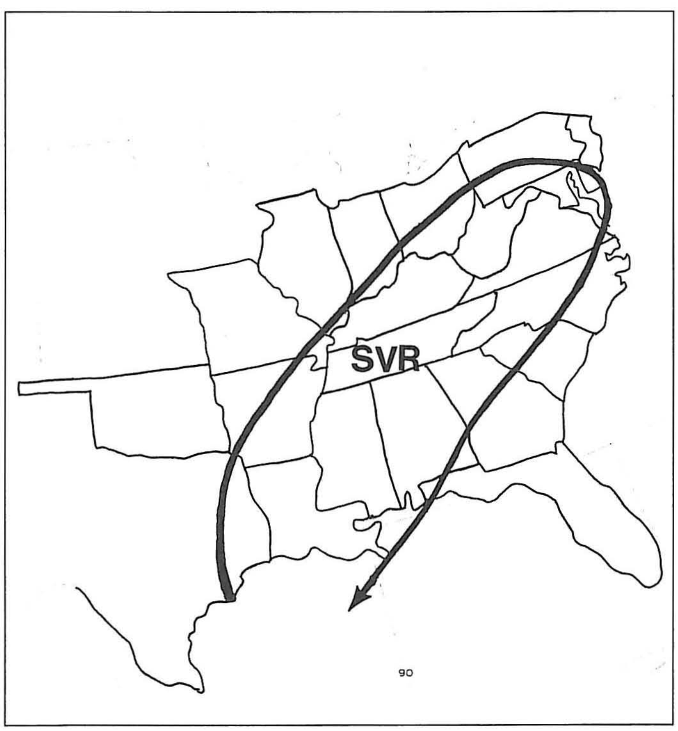


Fig. 16. Day two Convective Outlook graphic issued at 1900 UTC 26 March 1994 for the time period 1200 UTC 27 March to 1200 UTC 28 March 1994. Area encompassed by heavy dark line has a risk for severe thunderstorms.

The second Day Two Convective Outlook (Fig. 16) issued at 1900 UTC on the 26th for the period 1200 UTC 27 March to 1200 UTC 28 March addressed the potential for supercell storms along with the possibility of tornadoes.

The Day One Convective Outlook issued at 0700 UTC 27 March again emphasized the strong wind fields favorable for severe thunderstorm development. The outlook indicated that a "Moderate Risk[2]" of severe thunderstorms existed from eastern Texas through the Gulf States across Alabama (Figs. 17a and 17b). Though the emphasis was on damaging winds due to the expected rapid storm motion, the potential for supercells and tornadoes was also indicated. The lack of a well-defined surface low and pronounced short wave trough moving across the warm sector during the day, as well as a forecast of only moderate instability, precluded a greater emphasis on the tornado potential.

After analyzing the upper air data and examining the relevant soundings taken at 1200 UTC 27 March (refer to Figs. 11-13), it became apparent that a very potent air mass had set up across the Gulf States overnight. The interactive capabilities of the VAS Data Utilization

[2] If the SPC expects severe thunderstorms to occur, a risk category is assigned for a particular region in the Convective Outlook. The three categories used are slight, moderate, and high. The expected aerial coverage and/or intensity of the severe convection increases with each category increase.

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CONVECTIVE OUTLOOK
VALID 271200-281200Z
REF WW 40...VALID UNTIL 1200Z

THERE IS A MDT RISK OF SVR TSTMS TO THE RGT OF A LN FM 40 SW GLS HOU 25 N POE
TUP MSL 25 WSW CHA 15 W LGC DHN 15 W PFN.

THERE IS A SLGT RISK OF SVR TSTMS TO THE RGT OF A LN FM 30 E CRP NIR 40 S AUS
35 SSW SHV GLH BWG LEX CRW 30 SW SHD DAN CAE VLD 40 SE TLH.

GEN TSTMS ARE FCST TO RGT OF A LN FM DRT 25 WNW TXK LIT EVV 35 E
TOL...CONT...ROC 15 E ACY.

VERY STG WIND FIELDS WL CONT OVR THE MDT RISK AREA IN RESPONSE TO W-SWLY MID
LVL WIND MAX OF 70-90 KTS AND 50+ KT S-SWLY 850 MB JET.  THIS WILL CREATE
FVRBL VERTICAL WIND SHEAR PROFILE FROM ERN TX TO AL FOR THE DVLPMT OF SVR
TSTMS TODAY. ABUNDANT LO LVL MSTR CURRENTLY EXISTS OVR THE MDT RISK AREA WITH
SFC DWPNTS ALREADY IN THE UPR 60S/LWR 70S.  AS SFC TEMPS WARM INTO THE 70S AND
PSBLY LWR 80S...AMS WL BCM INCREASINGLY UNSTBL WITH SFC BASED LI'S AROUND -5
AND CAPE VALUES APCHG 1500 J/KG.  SFC LOW OVR WRN TN ATTM WL LIFT NEWD THROUGH
THE OHIO VLY TDA WHILE A COLD FRONT XTNDG SWWD FROM THE LOW ACRS CNTRL AR AND
CNTRL TX WL MOV SLOWLY EWD AS FRONT BCMS SOMEWHAT PARALLEL WITH UPR LVL FLOW.
AS FRONT MOVS EWD THIS MORNING AND AFTN IT WL ENCOUNTER RGN OF GREATER INSTBY
AND CNVTN SHUD BCM MORE WIDESPREAD. ACTVTY SHUD CONT TO STRENGTHEN AND BCM SVR
AS SHRTWV TROF OVR NRN MEX ATTM MOVS INTO THE RGN COUPLED WITH STRONGLY
SHEARED ENVIRONMENT. GIVEN STRENGTH OF WIND FIELDS...SVR TSTMS ARE LIKELY TO
BE FAST MOVG AND POSE PRIMARY THREAT OF DMGG WINDS.  HOWEVER...TORNADOES ARE
ALSO PSBL AS SUF LOW LVL TURNING IN THE WIND FIELDS WOULD SUPPORT PTNL FOR
ISOLD SUPERCELLULAR DVLPMT. S ARE ALSO PSBL LTR/TNGT AS LOW LVL MSTR IN
ADVANCE OF COLD FRONT HELPS DSTBLZ AMS OVR ERN OH VLY AND WRN CAROLINAS.
ALSO...ISOLD SVR TSTMS CURRENTLY INVOF OF SAT WL CONT TO MOVE EWD AND SHUD
MAINTAIN SVR INTENSITY AS IT MOVS OVR S CNTRL/SERN TX NXT SVRL HRS.

...EVENSON...03/27/94
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Fig. 17a. Day one Convective Outlook issued at 0700 UTC 27 March 1994. Contractions are in accordance with Federal Aviation Admin. Handbooks NO. 7340.1L and 7350.6E.

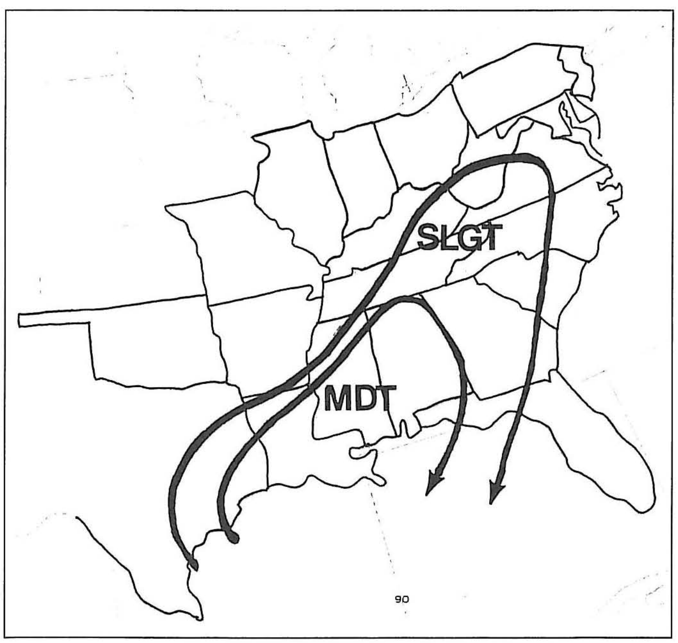

Fig. 17b. Graphic of Day One Convective Outlook discussed in Fig. 17a.

Center (VDUC) work station (Browning 1991) used at SPC were invaluable in fully utilizing the data sources that were available on this day. By modifying the observed morning soundings and model forecast soundings with expected afternoon temperatures and dew points, a full appreciation of the potential of this air mass quickly became apparent. Overnight the entire warm sector, extending from Mississippi eastward into Georgia, had developed an explosive potential waiting for a trigger. The cap on this air mass was weak (refer to Fig. 13) and even though there were no discernible short wave troughs and developing surface lows expected in the area, SPC's concern was greatly increased based on the observed potent air mass structure.

Since some of the parameters typically associated with tornado outbreaks (Miller 1972) were missing, the forecasters decided not to upgrade to a High Risk until they had the opportunity to examine the 1200 UTC model runs which would incorporate the more potent initial conditions. However, the SPC felt that the risk for significant tornadoes was great enough to considerably increase the emphasis on tornado potential. As a result, the 1500 UTC Convective Outlook discussion (Fig. 18a) strongly emphasized the threat for significant tornadoes. The original Moderate Risk area was also extended eastward along the frontal boundary to include the western Carolinas (Fig. 18b) because the AHN sounding (refer to Fig. 12) indicated a very favorable wind profile for supercell storms and considerable air mass destabilization was anticipated across the region during the day.

It was also indicated in the 1500 UTC Day One Outlook that a Public Severe Weather Outlook (PWO) would be released at 1600 UTC. This product is only issued when the SPC expects an outbreak of severe weather that may significantly impact the public. In the PWO (Fig. 19), emphasis was placed on the expected widespread area of severe thunderstorms and tornadoes across the central Gulf Coast into the western Carolinas. The threat for particularly intense tornadoes was also mentioned to reflect SPC's increased concern.

During the formulation of the 1500 UTC outlook, it was noted on radar, satellite, and on the lightning detection network that thunderstorms were already developing in the warm sector across eastern Mississippi into western Alabama. Not only were the storms forming along the well-defined east to west boundary across the northern portions of the two states, but also well to the south. A Mesoscale Discussion (MD) was issued at 1505 UTC (Fig. 20) to inform the field offices of the SPC's concern regarding these newly developed thunderstorms and that a tornado watch might be required.

Tornado Watch #41 (Fig. 21) was issued at 1518 UTC across eastern Mississippi and the northern half of Alabama. The storms rapidly increased to severe levels across northern Alabama and tornado warnings were issued prior to 1700 UTC by the NWS Weather Service Offices in Birmingham and Huntsville, Alabama.

CONVECTIVE OUTLOOK
VALID 271500-281200

THERE IS A MDT RISK OF SVR TSTMS THIS AFTN AND TNGT ACRS MUCH OF CNTRL/NRN MS, CNTRL AND NRN AL, CNTRL AND NRN GA AND PARTS OF THE WESTERN CAROLINAS. THIS AREA IS TO THE RGT OF A LN FM 50 E MLU 25 E TUP 40 NE HSV 40 E CHA AVL 15 ENE HKY 10 SSW GSO 15 N SOP 20 NNW FLO 15 SE AGS 20 S CSG 45 S SEM 40 ESE LUL 25 ESE MCB 20 SSW HEZ 50 E MLU.

THERE IS A SLGT RGT OF A LN FM 15 S PSX 50 SSW CLL 40 SE GGG 25 N MLU 45 WSW BNA 40 SW LOZ 10 E BLF 25 SW SHD 20 WSW RIC 20 SW GSB 15 NNE CHS 30 SE TLH.

GEN TSTMS ARE FCST TO THE RGT OF A LN FM 45 N BRO 30 SE HDO 50 SE BWD 30 S DUA 35 SW JBR 20 E EVV 35 SSW FDY 20 W FKL 20 E IPT 15 E ACY.

POTENT WARM SECTOR HAS SET UP THRU GULF CST STATES OVR GNT WITH MDT TO STG INSTBY AND VERY FVRBL LOW LVL SHEAR ENVIRONMENT NOW IN PLACE. SVRL IMPULSES WILL ROT INTO MS VLY WITH STG MID/UPR LVL JET CONTG TO INTENSIFY ON E SIDE OF TROF. PRIMARY LOW LVL CNVGNC WILL BE WITH E/W BNDRY FROM SRN NC WWD ACRS NRN GA/NRN AL TO INTERSECTION WITH SLOW MOVG COLD FRONT XTNDG SWWD FROM NRN MS ACRS NWRN LA INTO S CNTRL TX.

WARM SECTOR HAS PTNL INSTBY WITH MINUS 4-8 LI/S CAPES OF 2500-3000 J/KG WITH HELICITY ALREADY AOA 300 J/KG AND LIKELY INCRG DURG DAY AS WIND FIELDS AT ALL LVLS BECOME STGR. WARM SECTOR ENVIRONMENT VERY FVRBL FOR SUPERCELL DVLPMT AND ROTATION EVEN IN THE AREA S AND E OF ORGANIZED BOW ECHOES LIKELY IN STG WND FIELDS FOR HIGH WND DMG PTNL. TORNADO PTNL WILL ALSO INCR RPDLY DURG AFTN ANS S/WV TROF NOW S TX ROTS ACRS MDT AREA AND ENHANCES UPWARD MOTION AS WELL AS PRODUCING INCRGLY FVRBL WND PROFILES.

THIS IS A STG MDT SITUATION WITH ONLY THE LACK OF SIG SFC LOW DVLPMT AND QUESTION ON THE UPR DYNAMICS PRECLUDING FROM GOING HIGH ATTM. HOWEVER AFTER A LOOK AT 1200 UTC MODEL RUNS UPGRADE MAY BE NEEDED.

GIVEN THE FVRBL WIND PROFILES AND AIRMASS STRUCTURE PTNL IS THERE FOR MESO LOW FORMATION AND ASSOCIATED SIGNIFICANT TORNADOS.

SVR TSTMS WILL DVLP BY EARLY AFTN ACRS NRN PTNS OF MS/AL AND RACE ENEWD INTO GA AND TNGT WRN CAROLINAS WHERE LOW LVL JET WILL BE FOCUSED.

A PUBLIC SEVERE WEATHER STATEMENT WILL BE ISSUED AT 1600 UTC UNDER THE AFOS HEADING MKCPWOMKC.

...HALES...

Fig. 18a. Day one Convective Outlook issued at 1500 UTC 27 March 1994. Contractions following guidelines as in 17a.

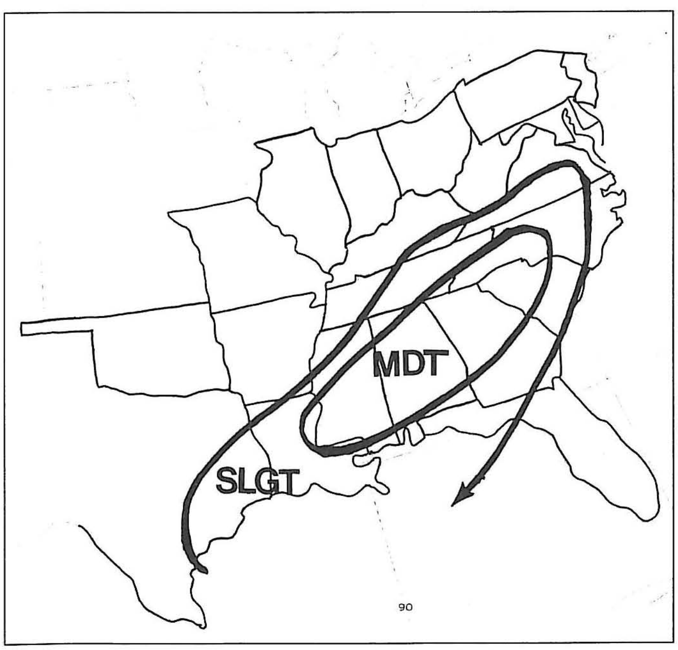

Fig. 18b. Graphic of Day One Convective Outlook discussed in Fig. 18a.

Recognizing the rapid intensification of the storms, with indications from the Maxwell Air force Base, Alabama WSR-88D (KMXF) radar that the storms were rotating and likely producing tornadoes, an MD was issued at 1651 UTC for Georgia indicating that a new tornado watch would soon be needed farther east. The very favorable wind structure observed by both the profilers and the WSR-88D VAD Wind Profile (VWP) product (Fig. 22) assisted in the SPC assessment of supercell potential. Increasing and gradually veering winds with height through a deep layer of the troposphere, resulted in strong vertical shear.

At 1700 UTC, Tornado Watch #42 was issued for all of northern Georgia and included the following enhanced wording in the text message:

"THIS IS A PARTICULARLY DANGEROUS SITUATION WITH THE POSSIBILITY OF VERY DAMAGING TORNADOES. ALSO, LARGE HAIL, DANGEROUS LIGHTNING AND DAMAGING THUNDERSTORM WINDS CAN BE EXPECTED."

While the initial area of tornadic storms was evolving over Alabama into northern Georgia, SPC's attention shifted westward into Mississippi. Helicity calculations in the 0-3 km layer using the wind profiles from the WSR-88D radar at JAN reached 500 $m^2 s^{-2}$ for a 30R75 storm motion (which was a close approximation to the true storm motion). Meanwhile, pressures were falling rapidly in advance of the frontal wave moving from Louisiana into central Mississippi. In addition, water vapor imagery and profilers indicated the approach of a mid-level (700 mb) short wave trough moving out of eastern Texas. Based on these factors, Tornado Watch #43 was issued for eastern Louisiana and portions of Mississippi. The enhanced wording was not incorporated into this watch because the strongest low-level winds were farther east, feeding the storms moving out of Alabama into Georgia.

At 1849 UTC, an MD was issued to alert forecasters and other interested parties in the Carolinas of the serious storm conditions moving toward their region and that a watch would soon be issued. Also in the discussion it was noted that the 1930 UTC Day One Convective Outlook would be upgraded to a "High Risk" of severe thunderstorms.

At 1930 UTC, the high risk outlook was issued indicating that the tornado outbreak already underway would continue. The outlook noted that the special 1800 UTC soundings taken by both JAN and CKL (Figs. 23 and 24) indicated that winds at all levels were stronger than predicted by the Eta model, contributing to very high helicities. In addition, the air mass at each location was very unstable with surface-based CAPE values approaching 3000 J kg^{-1}.

At 1926 UTC, Tornado Watch #44 was issued across portions of the western and central Carolinas, as well as the remainder of northeast Georgia. The watch discussion emphasized the mesolow and supercells tracking out of Georgia.

4. Summary and Conclusions

While classic (textbook) tornado outbreaks do occur, they are rather infrequent. This particular event provides an excellent example of how a tornado outbreak can occur when one or more of the components of a recognized tornado outbreak pattern are absent (Miller 1972). The event happened without the presence of a deep surface low and strong upper-level trough. Jet streak dynamics also did not appear to play a direct role in the development of the severe storms. Nevertheless, the thermodynamics and kinematics of the atmosphere evolved into a favorable configuration for the formation of supercells and strong tornadoes in the vicinity of a quasi-stationary rain-cooled boundary. Forecasters must be aware that significant tornadoes can occur in environments where strong vertical shear and instability coexist, even in the absence of strong dynamic forcing. SPC was able to anticipate the evolution of these important parameters and effectively forecast a significant severe weather outbreak with non-classic characteristics. Throughout the event, the KJAN and KMXF WSR-88D VWP's and area profilers clearly depicted the stronger than forecast mid-level wind fields. These strong winds (35 m s^{-1} at 700 mb) greatly increased the potential for supercell storms. The near real-time display of both lightning and satellite imagery in VDUC was crucial in observing the very early development of thunderstorms that led to the issuance of Tornado Watch #41. The two available WSR-88D's, KJAN and KMXF, did an outstanding job detecting the formations of the many long-lived supercells during the day. They were also instrumental in confirming that a significant severe weather episode was unfolding. This message was conveyed in the products that were issued.

Acknowledgments

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PUBLIC SEVERE WEATHER OUTLOOK
NATIONAL WEATHER SERVICE KANSAS CITY MO
KANSAS CITY MISSOURI
1000 AM CST SUNDAY MARCH 27

...WIDESPREAD SEVERE THUNDERSTORMS WITH TORNADOS EXPECTED THIS AFTERNOON AND
TONIGHT IN THE GULF STATES...

THE NATIONAL SEVERE STORMS FORECAST CENTER IN KANSAS CITY MISSOURI IS
FORECASTING WIDESPREAD SEVERE THUNDERSTORMS AND TORNADOES THIS AFTERNOON AND
TONIGHT OVER THE CENTRAL GULF COAST STATES INTO THE WESTERN CAROLINAS

THE STATES WHICH ARE LIKELY TO EXPERIENCE THE STRONGEST AND MOST INTENSE
SEVERE THUNDERSTORMS INCLUDE...

...MUCH OF ALABAMA, MISSISSIPPI, GEORGIA AND WESTERN PORTIONS OF THE
CAROLINAS...

AN INTENSE SPRINGTIME STORM SYSTEM IS SLOWLY MOVING EASTWARD ACROSS THE GULF
COAST STATES. THERE HAS BEEN A STRONG INFLUX OF VERY MOIST, UNSTABLE AIR OFF
THE GULF OF MEXICO OVERNIGHT SETTING THE STAGE FOR RAPID DEVELOPMENT OF SEVERE
THUNDERSTORMS OVER A LARGE PORTION OF THE GULF STATES TODAY AND TONIGHT.
COUPLED WITH THE UNSTABLE AIR, AN INTENSE UPPER LEVEL JET WILL AID IN THE
FORMATION OF TORNADO PRODUCING SUPERCELLS BY THIS AFTERNOON. A SURFACE LOW
PRESSURE CENTER IS FORECAST TO DEVELOP ALONG THE SLOW MOVING COLD FRONT NOW
EXTENDING FROM NORTHERN MISSISSIPPI INTO SOUTH TEXAS. THIS LOW WILL MOVE
RAPIDLY NORTHEASTWARD INTO THE MID ATLANTIC COAST STATES BY MONDAY MORNING.
THIS FAVORS THE SEVERE THUNDERSTORMS NOW DEVELOPING OVER MISSISSIPPI AND
ALABAMA MOVING ACROSS GEORGIA INTO THE WESTERN CAROLINAS TONIGHT.

GIVEN THE INGREDIENTS IN PLACE THERE IS THE POTENTIAL FOR NOT ONLY VERY STRONG
DAMAGING WINDS AND LARGE HAIL, BUT FOR TORNADOES, SOME THAT COULD BE
PARTICULARLY INTENSE.

ALL PERSONS IN THE THREATENED AREA ARE URGED TO REVIEW SAFETY RULES, AND
LISTEN TO RADIO, TV OR NOAA WEATHER RADIO FOR LATER STATEMENTS AND POSSIBLE
WATCHES OR WARNINGS. THIS IS A POTENTIALLY DANGEROUS WEATHER SITUATION FOR
THE AFFECTED AREAS AND SHOULD BE MONITORED CLOSELY

...JACK HALES...
...NATIONAL SEVERE STORMS FORECAST CENTER...
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Fig. 19. Public Severe Weather Outlook issued at 1600 UTC 27 March 1994.

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SELS MESOSCALE DISCUSSION FOR ..LA/MS/AL/GA..
CONCERNING...SEVERE THUNDERSTORM POTENTIAL...

ISOLD TSTMS HAVE BEGUN DVLPG ACRS PTNS OF CNTRL MS/AL, ALG AND S OF SFC
WRM FNTL BNDRY. MORN RAOBS AND PROFILERS INDC A VERY POTENT AMS ACRS THIS
RGN, WITH IMPRESSIVE HODOGRAPHS AND MDT INSTBY. STLT IMAGERY SUGS THAT
SOME HTG SHUD OCCUR ACRS GULF COAST STATES TDA, FURTHER DESTABLIZING AMS
AND PROMOTING SVR TSTM DVLPMT. DUE TO WEAK MID LVL CAP, STG/SVR TSTMS MAY
BEGIN DURG NEXT FEW HOURS. AREA IS BEING CLOSELY MONITORED FOR PSBL
TORNADO WATCH ISSUANCE.

...HART...03/27/94
```

Fig. 20. Mesoscale Discussion issued at 1505 UTC 27 March 1994. Contractions follow guidelines outlined in Fig. 17a.

BULLETIN - IMMEDIATE BROADCAST REQUESTED
TORNADO WATCH NUMBER 41
NATIONAL WEATHER SERVICE KANSAS CITY MO
9 18 AM CST SUN MAR 27 1994

A..THE NATIONAL SEVERE STORMS FORECAST CENTER HAS ISSUED A
TORNADO WATCH FOR

A LARGE PART OF EAST CENTRAL MISSISSIPPI
A LARGE PART OF NORTHERN AND CENTRAL ALABAMA

EFFECTIVE THIS SUNDAY MORNING AND AFTERNOON UNTIL 400 PM CST.

TORNADOES, LARGE HAIL, DANGEROUS LIGHTNING AND DAMAGING
THUNDERSTORM WINDS ARE POSSIBLE IN THESE AREAS.

THE TORNADO WATCH AREA IS ALONG AND 70 STATUTE MILES NORTH AND SOUTH OF A LINE FROM 70 MILES WEST NORTHWEST OF MERIDIAN MISSISSIPPI TO 35 MILES EAST OF GADSEN ALABAMA.

REMEMBER, A TORNADO WATCH MEANS CONDITIONS ARE FAVORABLE FOR TORNADOES AND SEVERE THUNDERSTORMS IN AND CLOSE TO THE WATCH AREA. PERSONS IN THESE AREAS SHOULD BE ON THE LOOKOUT FOR THREATENING WEATHER CONDITIONS AND LISTEN FOR LATER STATEMENTS AND POSSIBLE WARNINGS.

C..TORNADOES AND FEW SVR TSTMS WITH HAIL SFC AND ALF TO 2 1/2 IN.
EXTRM TURBC AND SFC WND GUSTS TO 75 KNOTS. A FEW CBS WITH MAX
TOPS TO 600. MEAN WIND VECTOR 24045.

D..TSTMS ARE DVLPG RPDLY IN THE WRM SECTOR AHEAD OF COLD FRONT. AMS VERY FVRBL FOR SVR TSTMS WITH VERY STG WND FIELDS AND MDT TO STG INSTBY. WIND PROFILES FAVOR SUPERCELLS AND TORNADOS AS WELL AS BOW ECHO/DMGG WND PTNL.

..HALES..

Fig. 21. Tornado Watch Number 41. Refer to Fig. 9 for location of watch.

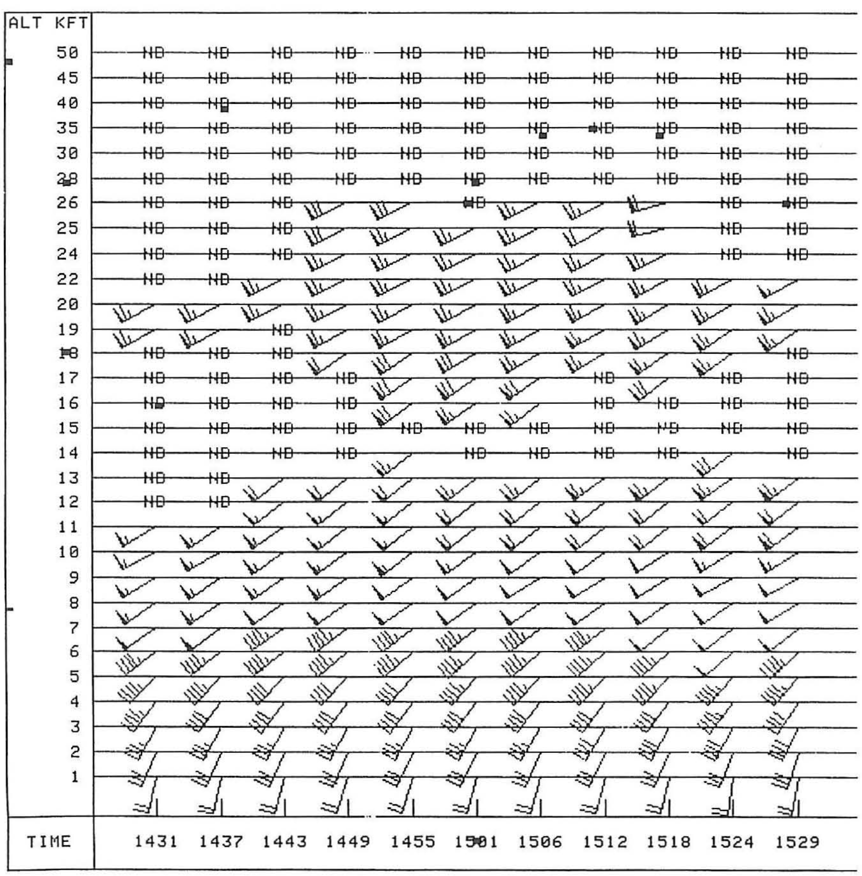

Fig. 22. Time series (UTC) of the VAD Wind Profile (VWP) product from the Maxwell Air Force Base, Alabama WSR-88D (KMXF). Wind barbs and flags are the same as in Fig. 11.

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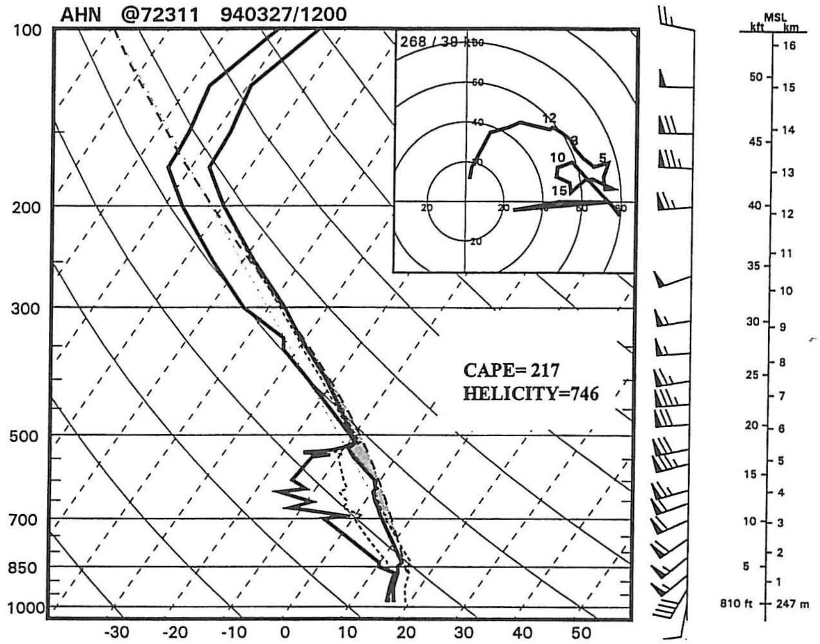

Fig. 23. Same as Fig. 11 except for 1800 UTC 27 March 1994.

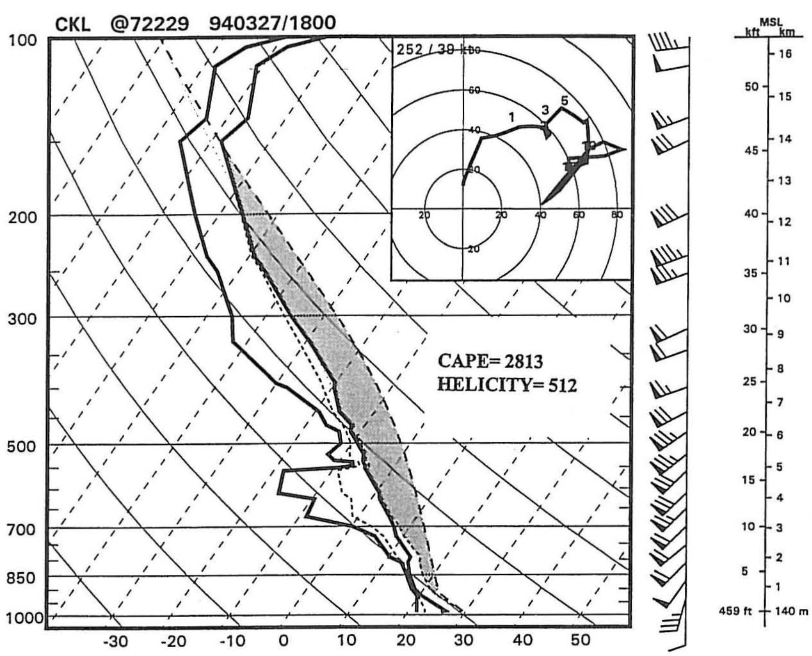

Fig. 24. Same as Fig. 13 except for 1800 UTC 27 March 1994.

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