An Analysis of the 28 March 1984 Tornado Outbreak in the Carolinas

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Introduction

On 28 March 1984, a fast-moving, rapidly-deepening cyclone moved across the southeastern United States. Upon reaching the Carolinas, the system spawned 22 tornadoes which claimed 57 lives and 1248 injuries.[1] Extensive damage was incurred after the northeastward sweep of the storm across northern South Carolina through the northeastern portion of North Carolina during the period 2130Z on 28 March to 0315Z on 29 March (Figure 1). Of the documented tornadoes, seven were intensity F4 (Fujita

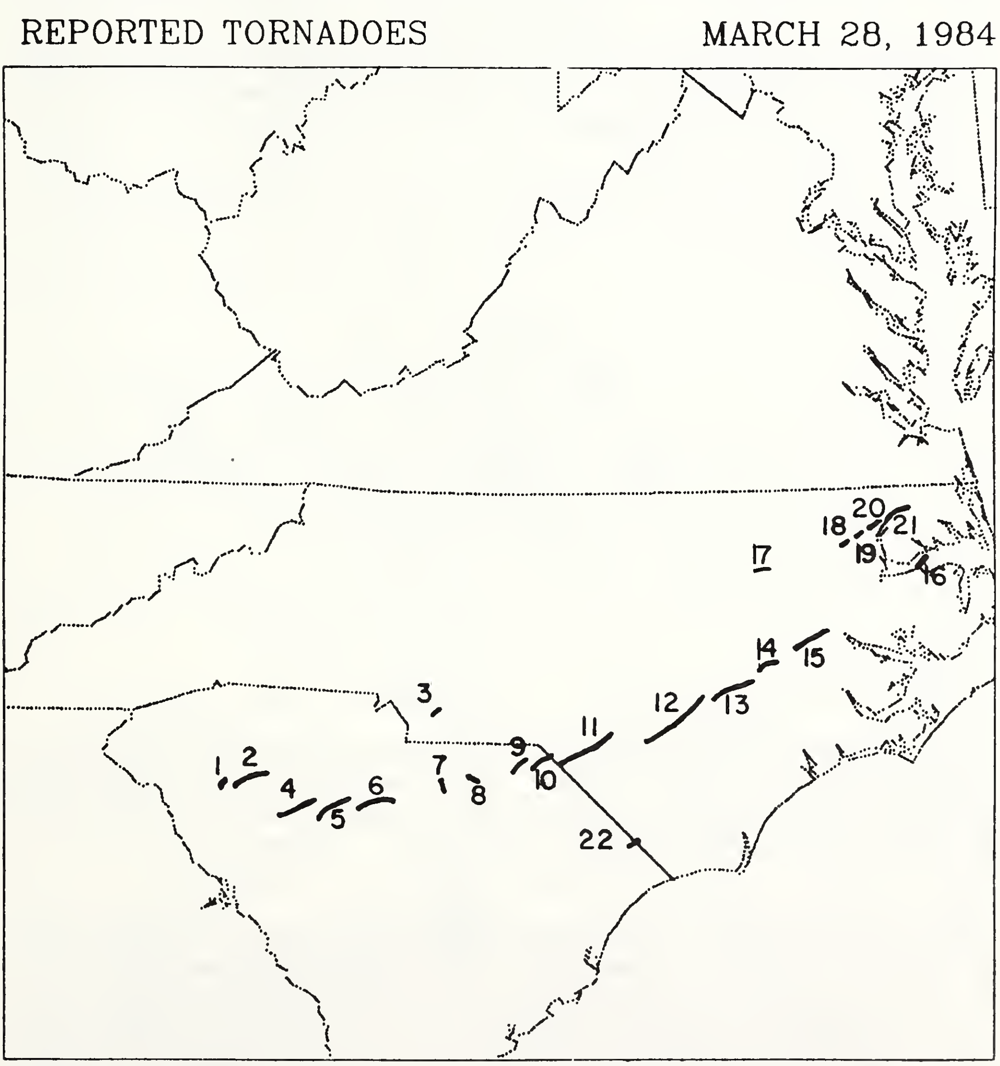

Figure 1. PROAM analysis region displaying 22 tornado tracks of the Carolina Outbreak. Individual tracks are numbered by time from earliest to latest.

1. *Storm Data*, March 1984.

Scale) and five were F3 making this the largest tornado outbreak in terms of casualities and damage since the "Superoutbreak" of 3-4 April, 1974.

In this paper a case study of the 28 March outbreak is presented. The synoptic environment is examined with emphasis focused on the analysis of mesoscale features. The Purdue Regional Objective Analysis of the Mesoscale (PROAM) is employed for the analysis of surface meteorological variables (1). PROAM utilizes data routinely collected and distributed via the FAA 604 teletype circuit and produces objectively analyzed plots for several variable fields such as temperature, pressure, specific humidity, specific-humidity convergence, vorticity, and streamlines. PROAM has proved effective for analysis of mesoscale features in earlier case studies (2) and for identifying severe weather signatures useful in a forecast mode (3). Hourly radar summaries from the National Meteorological Center (NMC) are extensively used for the analysis region. This paper will examine the Carolinas outbreak to diagnose the storm as well as to continue to study the potential of PROAM as a tool for forecasting severe weather.

Synoptic Features

The surface low-pressure system responsible for spawning the Carolina tornadoes was located in northeastern Texas at 0000Z 28 March with minimum pressure at 989 mb. Figure 2 displays the movement of this low-pressure center with the associated

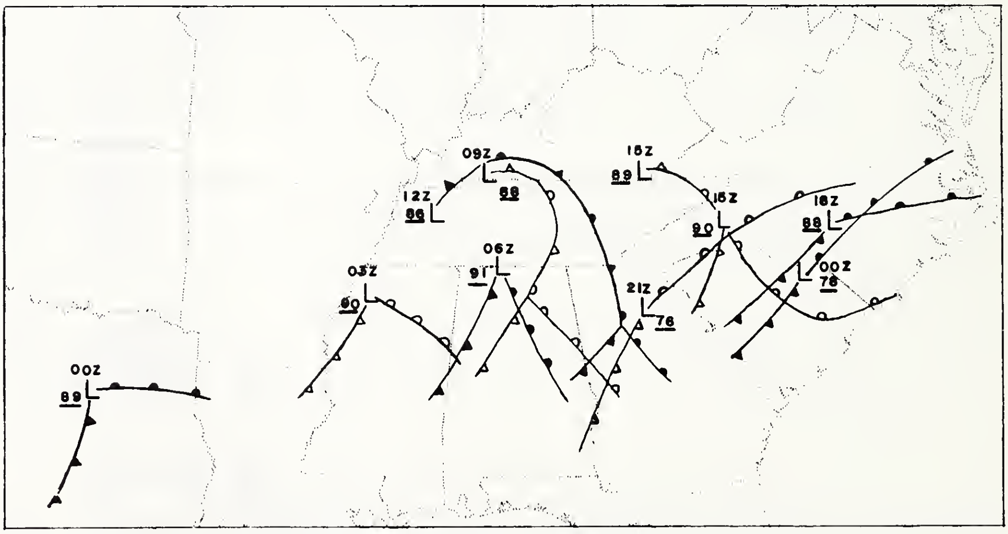

FIGURE 2. Diagram displaying track of the low-pressure system from 0000Z 28 March to 0000Z 29 March in 3-hour intervals. Frontal lobes for even hours are solid and frontal lobes for odd hours are hollow. Central pressure values are underlined and encoded using the standard convention (i.e., "89" = 989 mb).

frontal locations through the 24-hour period prior to the outbreak. The system initially moved quickly eastward, but slowed as it occluded over northern Alabama. By 1500Z, the system was centered in western North Carolina, but the minimum pressure of the storm had changed in magnitude only slightly. By 1800Z, a second low-pressure center began to intensify over central North Carolina. As the system shifted eastward with the progression of the low center, the warm air sector in the western portion of the Carolinas occupied the coastal plain east of the mountains. The warm front began to accelerate due to decreased surface friction over the more uniform terrain (4). This occurred after 1800Z and resulted in a flattening out of the surface frontal wave structure. Minimum pressure values began to decrease with readings of 988 mb at 1800Z, 976 mb at 2100Z, and 978 mb at 0000Z 29 March. At 0000Z, the low center was located at the North Carolina-South Carolina border. The warm front stretched to the northeast into southeastern Virginia and the cold front extended to the southwest into central Georgia.

The potential for severe weather development was supported by upper-air conditions at 0000Z on 29 March (not shown). Flow was southwesterly with strong currents throughout the troposphere. For example, Charleston, South Carolina (CHS) reported winds of 95 kts at the 500-mb level and 120 kts at the 300-mb level (Charleston did not report 850-mb level winds, although nearby Waycross, Georgia (AYS) reported 60-kt winds). The Lifted Index at 0000Z at 29 March at CHS was -7, which indicated a definite severe weather threat.

Examination of the NMC National Radar Summaries (not shown) for hours preceding the Carolina storms revealed a distinct line echo as early as 1535Z (28 March). This line was associated with the cold front and extended from northern Alabama to southwestern Mississippi with the maximum echo top of 31,000 ft (9450 m). At 1638Z, a tornado watch (WT055) was issued for east-central Alabama and most of the northern half of Georgia, reaching the extreme northwestern corner of South Carolina. Maximum echo tops increased during the next few hours. At 1835Z, the maximum reported top was 37,000 ft (11,280 m) over central Alabama and by 1935Z, a 40,000-ft (12,195-m) top was observed over western Georgia. A second tornado watch (WT056) was issued at 1914Z extending from northeastern Georgia across the Carolinas to the coastal plain. Intensification of convective activity continued as demonstrated by increased thunderstorm development (maximum echo tops of 48,000 ft [16,463 m] over northeastern Georgia by 2135Z).

Regional Objective Analysis

Times of the individual tornadoes are charted in Figure 1. The first reported tornado occurred at 2130Z in northwestern South Carolina (Track 1). Tornadic storms continued eastward and entered North Carolina at 0030Z (Track 11) and by 0155Z were raging in the extreme northeastern corner of North Carolina (Track 18).

Figure 3 displays the analyses of the NMC National Radar Summaries translated

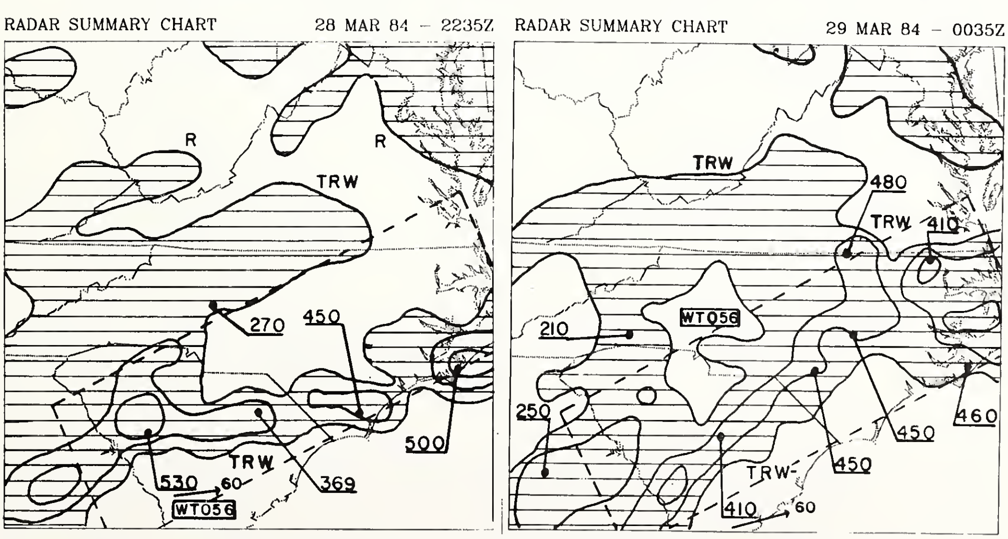

FIGURE 3. NMC Radar Summaries translated onto PROAM analysis region. Contours represent echo-intensity levels of 1, 3, and 5 respectively. Maximum echo tops in hundreds of feet are underlined.

onto the PROAM analysis region for hours 2235Z and 0035Z. During these periods, the development of the storm can clearly be seen by the eastward progression of the maximum echo tops evidenced by the 53,000-ft (16,154-m) top in western South Carolina at 2235Z and the pair of 45,000-ft (13,716-m) tops in southeastern North Carolina at 0035Z. A comparison of the radar summaries with the tornado tracks in Figure 1 shows the maximum tops from 2235Z to 0135Z nearly coincide with a reported tornado. Times and locations of the maximum tops for 2235Z and 0035Z correlate very well to tornado tracks 4 and 11, respectively.

The Radar Summaries in Figure 3 show a very distinct line echo extending from southeastern North Carolina to central Georgia. This line was propagating along the surface frontal position, and from 2235Z to 0035Z displayed a distinctive bend associated with the counterclockwise circulation around the low-pressure center which was at this time located over northern South Carolina. This was also the period of the most intensive tornadic activity.

Figure 4 is the objective analysis of the surface pressure field at 2300Z. The 2100Z analysis (not shown) indicated a pair of low-pressure troughs located over southeastern West Virginia and northeastern Georgia, respectively. The southern trough eventually

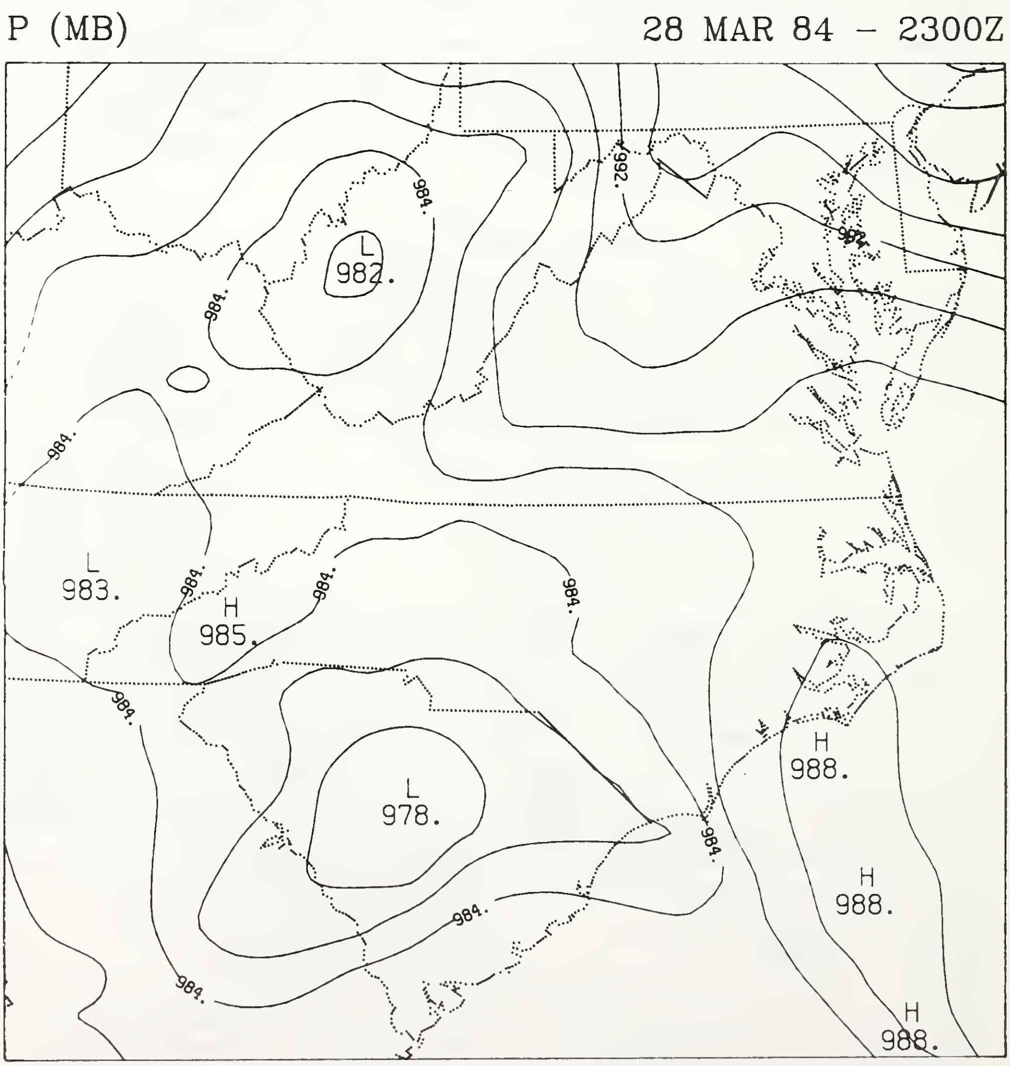

FIGURE 4. Objective analysis of surface pressure. Contour intervals are 2 mb.

deepened and, when compared with the Radar Summaries, appeared very nearly in the same area as the maximum echo top as it progressed eastward. A mesohigh was situated between the troughs at 2100Z in extreme western North Carolina and was apparently due to the outflow from the main storm. This ridge is apparent at 2300Z shown in Figure 4 and later as a bulge in the isobars just north of the southern trough at 0000Z and 0100Z (not shown).

An analysis of the 2300Z surface relative-vorticity field is illustrated in Figure 5. An axis of positive vorticity appeared earlier over western South Carolina at 2200Z

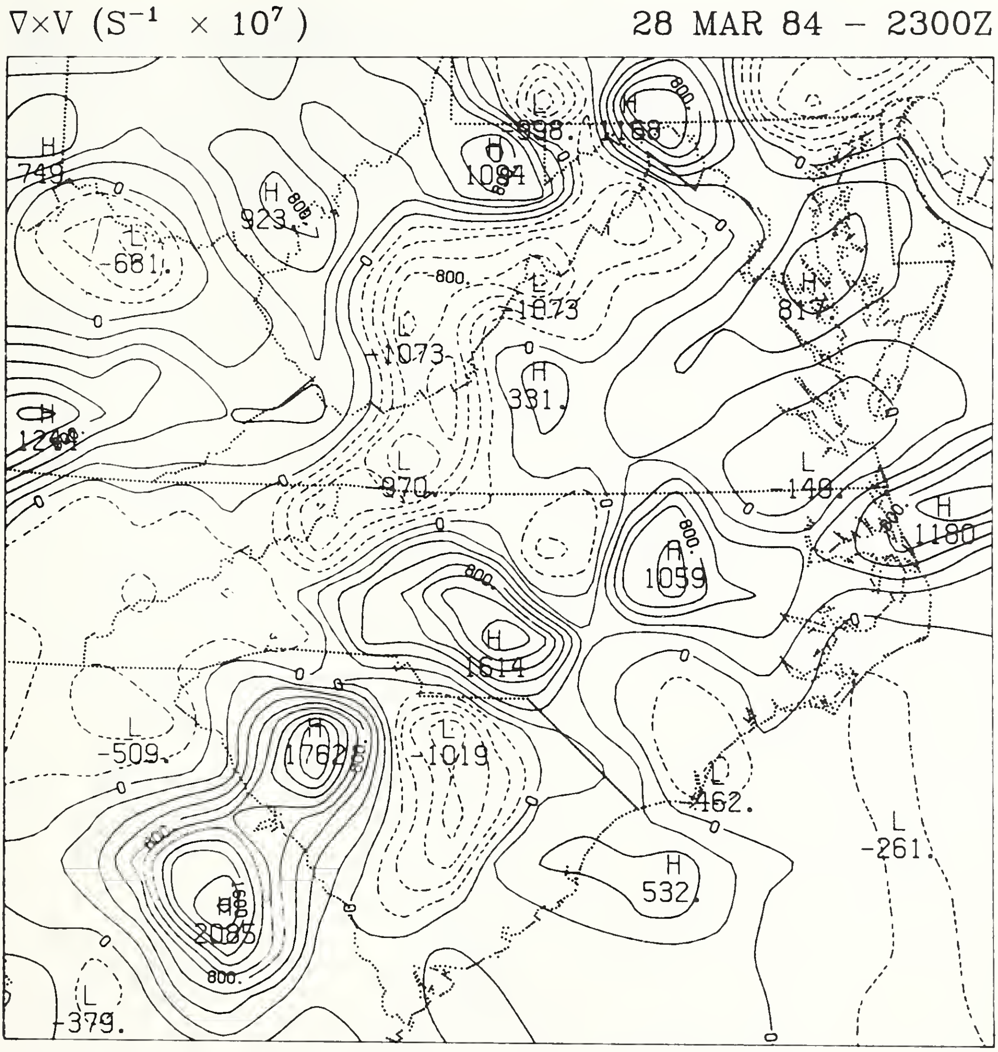

FIGURE 5. Objective analysis of relative vorticity. Solid contours represent positive vorticity and broken lines represent negative vorticity. Contour intervals are $2x10^{-5}$ s^{-1}. Values are scaled by a factor of 10^7.

(not shown) and extended northeastward along the storm line. The axis becomes clearly evident in Figure 5. The vorticity maximum over western South Carolina at 2300Z ($1.762x10^{-4}$ s^{-1}) agrees closely with the maximum echo top on the 2235Z Radar Summary in that area (see Figure 3). Throughout the tornadic period of the storm, this axis of maximum vorticity was coincident with the main storm line. This is important, because areas of strong positive relative vorticity indicate low-level convergence that must lead to compensating upward vertical motion. Therefore, areas of strong mesoscale relative vorticity usually signify areas of strong convection. Storm outflow areas are again evident in Figure 5 by the large areas of negative vorticity northwest of the positive axis.

Figures 6 and 7 display the temperature and streamline objective analyses for 2300Z, respectively. The frontal region can clearly be seen in both analyses. The strong temperature gradient in Figure 6 through North Carolina extending southwest to northeast delineates the frontal boundary. The streamline analysis displays the wind shift at the frontal zone with a distinctly southerly component to the south and a more northerly component to the north.

An interesting comparison can be made between Figures 6 and 7 and the 2235Z Radar Summary (Figure 3). A thermal ridge existed at 2300Z in southern North Carolina (Figure 6). The southerly winds evident from the streamline analysis at that time (Figure 7) ensured that the storm line had an abundant supply of warm, unstable air by low-level advection. Another feature of Figure 6 is the existence of a cold-air pocket in extreme western North Carolina. This feature was evident throughout the period 2100Z

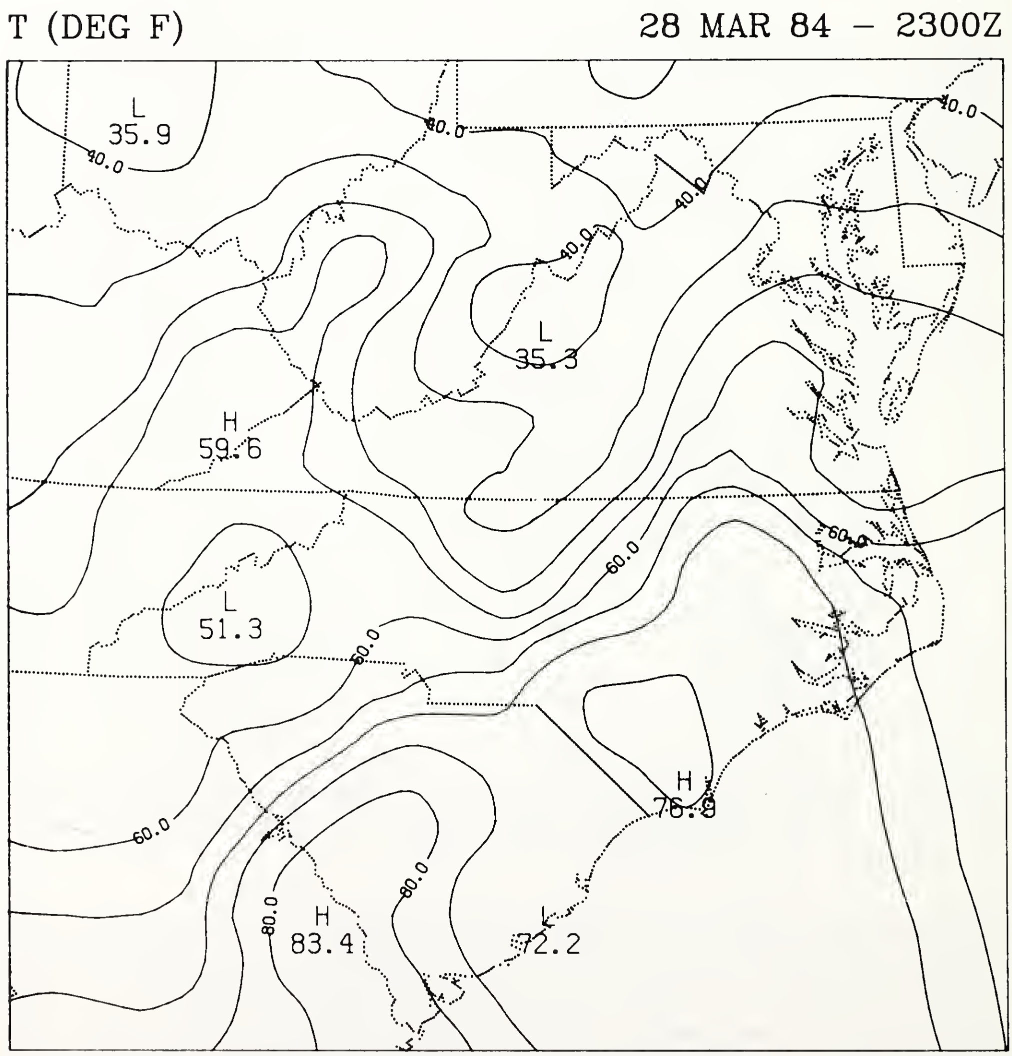

FIGURE 6. Objective analysis of surface temperature. Contour intervals are 5°F.

to 0100Z. It appeared in the same area as the mesoscale pressure ridge shown in Figure 4 and is further evidence of a storm outflow region.

Objective analyses of specific humidity (not shown) indicate an abundant supply of moisture in the warm sector of this system. A ridge of specific humidity was present in eastern South Carolina from 2100Z through 0100Z. The specific humidity in the ridge exceeded 15 g/kg throughout the period. This warm, moist air in this region provided the fuel for the intensification of the storm line producing the severe weather.

Figure 8 illustrates the series of objective analyses of specific-humidity convergence for the period 2200Z to 0100Z. This parameter, when compared to the Radar Summary Charts, provides an excellent indicator of the presence of severe weather. At 2200Z, an axis of maximum-moisture convergence appeared at the western edge of South Carolina. This feature matches the line of maximum echoes at 2135Z (not shown). The magnitude of the specific-humidity convergence maximum at 2200Z was 2.66×10^{-3} g/kg s^{-1}. A ridge in the moisture convergence field is very distinct at 2300Z, forming an axis along nearly the same position as the line echo of the 2235Z Radar Summary. The magnitude of the maximum value at 2300Z was 3.73×10^{-3} g/kg s^{-1}. Such a

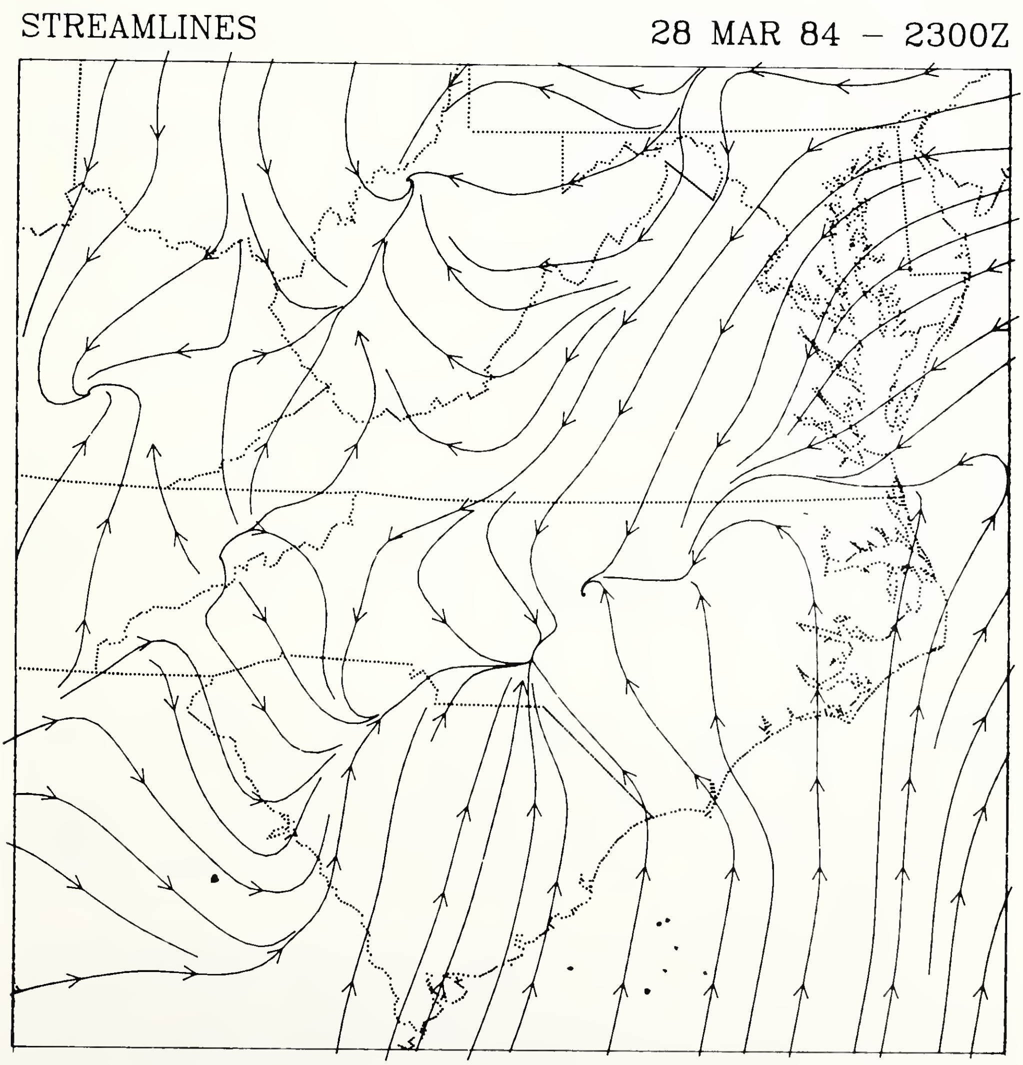

Figure 7. Objective analysis of surface streamlines.

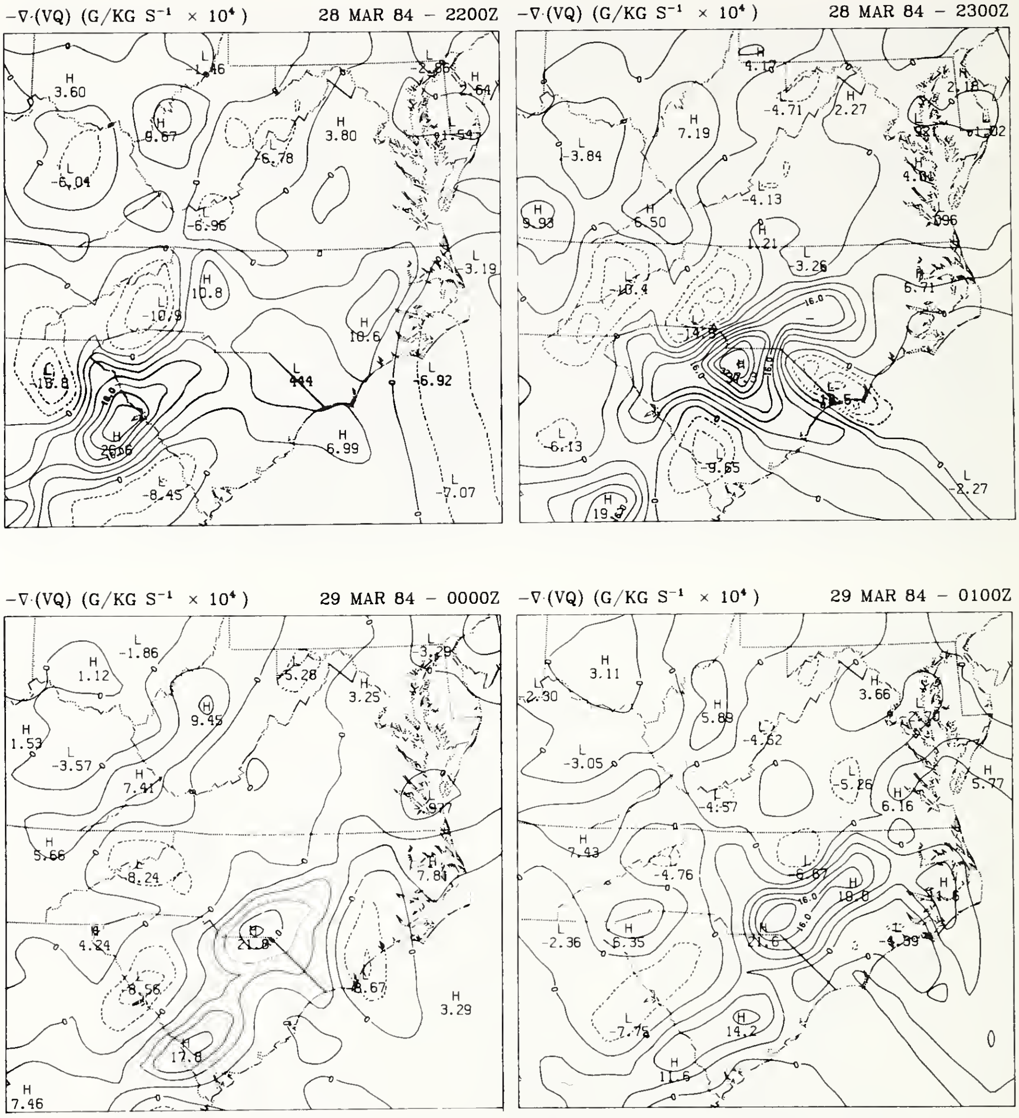

FIGURE 8. Objective analysis of surface specific-humidity convergence. Solid contours represent convergence and broken contours represent divergence. Contour intervals are 1×10^{-4} g/kg s^{-1}. Values are scaled by a factor of 10^4. Note the progression of maxima during the tornadic period of the storm.

significant short-term increase has been found to indicate an intensification in storm activity (2). This case confirmed the earlier work because just after 2200Z, the magnitude of the ridge had decreased slightly, but the maximum again appears in the region of most intense radar echoes. An area of specific-humidity divergence was seen consistently throughout the period in western North Carolina. Along with the evidence presented from the temperature, pressure, and vorticity analyses, this again gives a good indication of a storm outflow region.

PROAM analyses greatly aided in the study of the Carolinas outbreak. The temporal and spatial resolution of the surface-variable fields used enhanced the ability to diagnose conditions prior to and during tornadic events on 28 March. It is hoped that further study of this case will continue to yield more evidence to enable forecasters to more accurately predict severe local storms.

Summary

The 28 March Carolinas Tornado Outbreak claimed more lives than any outbreak since 1974. Seven F4 and five F3 tornadoes were generated, resulting in 57 fatalities and over 1200 injuries. A deep, fast-moving low-pressure system provided the trigger for the development of an intense line of storms, many of which were tornadic.

PROAM analyses were very useful in discussion of the mesoscale features of the outbreak. Radar Summary Charts indicating precipitation-echo intensities as well as maximum echo could be compared to objectively analyzed parameters for a complete picture of the storm development. Specific humidity convergence was the most important variable analyzed, because it directly indicated the presence of severe weather. This provides further evidence for the use of PROAM, in conjunction with other data, as a tool for short-term prediction of severe weather.

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