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THE SYNOPTIC CHARACTERISTICS OF THE 4 NOVEMBER 1992 TORNADO OUTBREAK IN NORTH CAROLINA: A LOW-TOP, WEAK-REFLECTIVITY SEVERE WEATHER EPISODE

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1. INTRODUCTION

On 4 November 1992, 11 tornadoes (all F0 or F1 in intensity) touched down in the coastal plain of North Carolina. The first F0 tornado occurred at 2200 UTC, 5 miles southwest of Columbia in Tyrrell county. Subsequent tornadoes were observed in Cumberland, Johnston, Scotland, Hoke, Moore, Harnett, Hertford, and Wayne counties of North Carolina. The last tornado (F1 intensity) occurred at 0115 UTC in Wayne county, approximately 1 mile west of Goldsboro.

Tornado path lengths were generally less than 1 mile. However, one tornado in Hertford county produced a path 1.5 miles long, and another near Goldsboro in Wayne county had a path length of 2 miles. Characteristic damage as a result of the tornadoes was exemplified by minor damage to homes, barns, vehicles, and trees.

In this study, synoptic analyses were used to diagnose the potential for severe thunderstorm development on 4 November 1992. In addition, soundings and hodographs were generated by using the Skew-T Hodograph Analysis and Research Program (SHARP; Hart and Korotky 1991) workstation, in order to examine the atmospheric stability and low-level wind shear profile. The Turbo Upper-Air (UA) Program (OMEGA Diagnostics; Foster 1988) was also used extensively for the analysis of synoptic variables.

2. SYNOPTIC ANALYSES

a. Surface Features

Figure 1 depicts the surface analysis at 1800 UTC, 4 November 1992 (4 hours prior to the first tornado). An outflow boundary was analyzed through central Georgia, which was the result of convective outflow that occurred several hours earlier. The thunderstorms were associated with a cold front that extended from western New York, southward along the western edge of the Appalachian mountains and through central Alabama. At 2100 UTC, the outflow boundary, or thermal/moisture boundary (Vescio et al. 1993), was located over the coastal plain of North and South Carolina (Fig. 2). At 2100 UTC, surface temperatures and dew point temperatures east of the boundary were in the mid 70s(°F) and around 70°F, respectively. The surface temperatures and dewpoints west of the boundary were around 60°F and in the upper 50s, respectively, where overcast skies and patchy light rain were observed. Overcast skies over coastal sections of the Carolinas became broken between 1800 and 2100 UTC, which contributed through surface heating to the increase of the temperature gradient along the thermal/moisture boundary. However, by 0000 UTC on 5 November (Fig. 3), the thermal/moisture boundary was less defined over the coastal plain of North Carolina as the surface temperature gradient decreased. The dew point gradient remained virtually unchanged. Throughout the severe weather episode, surface convergence was enhanced by south winds around 10 kt to the east of the boundary, while light and variable winds remained to the west of the boundary.

b. Upper-air Analysis

At 0000 UTC on 5 November, an 850 mb low-level jet was present over the coastal Carolinas (Fig. 4). The 0000 UTC sounding taken at the Weather Service Office (WSO) in Cape Hatteras, NC (HAT) indicated a 35 kt wind at 850 mb, while the WSO Charleston, SC (CHS) radiosonde measured the 850 mb wind to be 40 kt. Due to technical problems, the wind was not reported for the first 10,000 ft for the WSO Greensboro, NC (GSO) sounding.

The graphics produced by the UA program are based on North American observed upper-air data (including the GSO sounding). This technique interprets the absence of wind data as calm conditions. Consequently, the upper-air data for the GSO sounding needed be edited. This was accomplished by comparing the GSO wind plot with wind data from surrounding upper-air stations, and then interpolating and changing the GSO upper-air data in the UA program. New UA products were generated and then compared with the unedited products. After careful analysis, it was determined that there was no significant difference in the presentation of the products at 850 and 700 mb. This was most likely due to the smoothing of the data in the unedited products. Hence, the UA figures depicted in this study are the original unedited graphics.

The 850 mb jet along the Southeast Coast transported higher dew point temperatures (+6 to +14°C) into central and eastern North Carolina (Fig. 5). Moisture advection values ranged from 1 to 9 g kg^{-1} hr^{-1} (Fig. 6). However, temperature advection was not substantial (Fig. 7), with values of 0°C 12 hr^{-1} to -2°C 12 hr^{-1} observed over the eastern Carolinas. According to Doswell (1982) a significant increase in low-level moisture through dew point advection often contributes more to destabilization of the atmosphere than does temperature advection. For this case, there was substantial moisture convergence, with values as high as 14 g kg^{-1} hr^{-1}) over southeastern North Carolina (Fig. 8).

Mid-level drying was evident at 700 mb (Fig. 9), with a 14°C dew point depression over CHS. According to Doswell (1982), this is another important variable that contributes to severe weather development. Mid-level drying is often indicative of subsidence. The subsidence can cause relative warming of the mid-level environment, which can in turn establish a cap that inhibits convection. However, if the cap is broken, explosive development can occur. The southwest wind at 700 mb appeared to transport lower dew point air from South Carolina over North Carolina.

The analyses of low-level thermal advection, and 500 mb geostrophic vorticity fields, were performed to assess the potential for large-scale vertical motion over North Carolina on 4 November 1992. It can be inferred that the increase in the surface temperatures east of the thermal/moisture boundary increased the thickness in the lower layers over eastern North Carolina, which resulted in a tighter thickness gradient along the thermal/ moisture boundary. At 0000 UTC, positive vorticity advection (PVA) was evident at 500 mb over central and eastern North Carolina (Fig. 10). A short wave trough axis and vorticity maximum ($12 \times 10^{-5}s^{-1}$) were located over Georgia. Additionally, some degree of geostrophic vorticity appeared to be present at 850 mb due to speed shear (Holton 1979) resulting from the relatively weaker winds at Athens, GA (AHN), Waycross, GA (AYS), and Huntington, WV (HTS) when compared to the winds along the coast.

Thermal advection and differential geostrophic vorticity advection may lead to upward vertical motion. Therefore, an analysis of 700 and 500 mb Q-vectors (Hoskins et al. 1978) was used to assess the large scale vertical motion. Layer Q-vector analyses were not performed due to limitations of the UA Program software. Figure 11 illustrates the 700 mb Q-vector analysis, with the magnitude of the convergence/ divergence represented by the size and direction of the arrows. The larger the magnitude of the arrow, the larger the upward or downward vertical motion. Small converging arrows over central North Carolina imply weak but discernible synoptic scale upward motion. This same Q-vector pattern was also present at 500 mb (Fig. 12), implying that large scale upward vertical motion probably existed in the 700 to 500 mb layer.

Typically, severe thunderstorms occur either in the right-rear or left-front quadrants of the upper-level jet where divergence, which is induced by the ageostrophic circulations associated with the jet streak, is at a maximum (Doswell 1982). However, the 0000 UTC 5 November 300 mb isotach analysis (Fig. 13), illustrates that the Carolinas were not under either of these quadrants.

It should be noted that normally, one should analyze several levels when searching for upper-level jet streak features. The single 300 mb level was chosen for this study, because the upper-level jet streaks were located well to the north and west (i.e., over the Great Lakes and Mississippi Valley; Fig 13) of the study area of interest.

3. ATMOSPHERIC STABILITY AND VERTICAL WIND SHEAR

Figure 14 shows the 0000 UTC 5 November 1992 GSO sounding, as displayed by the SHARP workstation. At 0000 UTC, the atmosphere was relatively stable, with a Lifted Index (LI) value of +2. This was primarily due to the cool surface temperatures on the west side of the thermal/moisture boundary. As a result, the Convective Available Potential Energy (CAPE) was 0 J Kg^{-1}, the Total Totals (TT) index was 43 and the K Index was 31. The

TT of 43 was relatively low, due to a layer of dry air between 850 and 700 mb, but still indicated that isolated thunderstorms were possible.

Two other dimensionless parameters, the Bulk-Richardson Number (BRN; Weissman and Klemp 1982) and the Energy Helicity Index (EHI; Johns et al. 1990), can assist in the diagnosis of the potential for severe weather. A BRN of 45, or below, generally supports supercell thunderstorms, while a BRN above 45 supports multicell storms. An EHI greater than 1.00, indicates there is sufficient wind shear and CAPE for possible tornadic development. Figure 15 shows the 0000 UTC 5, November 1992 HAT sounding. This sounding exhibited a LI of -4 and a CAPE of 1665 J kg^{-1}. There was sufficient low-level moisture for isolated thunderstorms as indicated by a K index of 23 and a TT of 34. Additionally, the BRN value was 43 and the EHI was 1.59. Of course, the BRN and EHI values from GSO were unavailable due to the lack of wind data in the lowest 10,000 ft of the 0000 UTC sounding.

The wind fields used for the SHARP soundings and hodographs are based on actual upper-air data (Hart and Korotky 1991). However, wind fields on hodographs are depicted in 500 m increments, and are subject to interpolation by the SHARP program when converting data based on heights in units of feet to units of meters. Consequently, some of the winds from the radiosondes are not depicted on hodographs. Ground and storm relative winds are calculated based on the actual wind data from radiosondes. Often, the calculated wind is nearly the same, except when winds are not reported, such as in the first 10,000 ft of the 0000 UTC, 5 November GSO sounding. Hence, the hodograph from HAT (Fig. 16) was used.

The 0000 UTC, 5 November 1992 hodograph from HAT illustrates speed and directional shear (substantial veering with height), which is characteristic of hodographs favoring right-moving supercells (Klemp 1987). The Storm Relative Helicity (SRH) in the 0-3 km layer was 198 m^2s^{-2} (units henceforth dropped), based on an estimated storm motion of 256° at 25 kt. However, the actual storm motion during the severe weather episode was 240° at 25 kt, as depicted by the Weather Surveillance Radar-1957 (WSR-57) at Wilmington, NC (ILM). Substituting this storm motion produced a SRH of 149. The determination of the actual storm motion is described later in Section 4.

Davies-Jones et al. (1990) determined median values of helicity for various tornado intensities. According to their results, a SRH of 150 supports F0-F1 tornadoes, therefore, the SRH values of 149 or 198 that were generated by using the HAT hodograph supported the possible development of F0-F1 tornadoes.

The low-level storm inflow was from the east and southeast, which is important to consider when analyzing reflectivity fields for hook echoes, appendages, and inflow notches on radar. Strong inflow from any direction can create an inflow notch (echo-free region on the leading edge of a thunderstorm in radar base-reflectivity) oriented in the same direction. Some degree of cyclonic rotation in a thunderstorm can be inferred in the region to the left of an inflow notch. Moller et al. (1990) and Doswell et al. (1990), described these features associated with high precipitation supercells characteristic of the southeastern United States. Low-level storm inflow, in addition to SRH, may also dictate whether a thunderstorm will acquire rotation (Lazarus and Droegemeier 1990). Rotating storms do not develop if the storm inflow is less than 10 m s^{-1}, or approximately 20 kt. The mean low-level (0-3 km) inflow at GSO (not shown) was 18 kt. However, as previously stated, the first 10,000 ft of the GSO sounding were not reported. Hence, the 18 kt inflow was considered erroneous and the 25 kt low-level inflow, depicted on the HAT hodograph was used.

4. RADAR PRESENTATION OF STORM STRUCTURE

Through intense scrutiny of the WSO ILM WSR-57 radar film, it was determined that the mean storm motion during the severe weather event was 240° at 25 kt. As noted before, this storm motion resulted in a SRH of 149, which indicated the possibility of F0-F1 tornadoes. Further analysis of the WSO ILM WSR-57 radar film illustrated that some of the thunderstorms, even though they were low-topped in nature, possessed severe characteristics. These characteristics alerted forecasters at the Weather Service Forecast Office (WSFO) at Raleigh-Durham, NC (RAH) of possible tornadoes. Inflow notches and/or appendages were occasionally visible on the WSR-57 radar imagery around the time of the tornado occurrences.

Figures 17-19 depict radar reflectivity returns that were traced directly off still frames from archived radar film. DVIP levels are contoured as follows: DVIP 1 white; within contours DVIP 2 gray; DVIP 3 black; and, contour within contour; no echoes. Only the radar echoes associated with the thermal/moisture boundary are depicted. Figure 17 illustrates the radar reflectivities observed at 2347 UTC. Two minutes later, a tornado occurred in Cumberland County, 9 miles northeast of Fayetteville, at approximately 320°, 67 n mi from the radar antenna (henceforth, all references to distance will be from the radar antenna). Two inflow notches are apparent over southern Cumberland County. Note that the apex of the inflow notches are oriented toward the northwest and are most open toward the southeast. This correlates well with the low-level storm inflow depicted on the HAT hodograph.

A tornado was observed in Johnston County, 10 miles south of Smithfield, at 0015 UTC, 5 November, at a range of 341° at 69 n mi. Radar reflectivities at 0018 UTC (Fig. 18) indicated a small inflow notch with a DVIP 2 return just south of Goldsboro. Please note the echo-free area just northwest of the inflow notch and DVIP 2 return, just south of where the tornado touched down 3 minutes prior to the radar depiction.

Figure 19 depicts radar reflectivities at 0114 UTC, 5 November. The first tornado occurred 2 miles south of Goldsboro while the second occurred 1 mile west of Goldsboro. Inflow notches with the characteristic northwest/southeast orientations are indicated as small appendages near GSB. The WSO ILM WSR-57 radar observer reported a hook echo in a special observation at 0107 UTC, with an azimuth and range of 354° 67 n mi, perhaps indicating the incipient tornado that occurred at 0115 UTC.

5. SUMMARY

On 4 November 1992, 11 relatively weak tornadoes occurred over the coastal plain of North Carolina. Damage to homes, barns, vehicles, and trees was basically minor. The tornadic thunderstorms formed along a strong surface thermal/moisture boundary, where synoptic and mesoscale features combined to produce a favorable environment for severe convection. WSR-57 radar imagery indicated that the thunderstorms were characterized by low echo tops and low reflectivities, while inflow notches and appendages were occasionally discernible.

The SHARP workstation is a valuable tool for determining severe weather potential. Observed soundings and hodographs can be easily modified to reflect changing, and anticipated atmospheric conditions. SHARP can calculate low-level SRH and wind shear values, which have been determined to be critical for forecasting the development of mesocyclones and tornadoes. Through the use of SHARP, it was determined that there was sufficient instability, moisture, and vertical wind shear to support the development of severe thunderstorms.

The UA program is another valuable tool that can be used to analyze synoptic-scale conditions to determine severe weather potential. However, the upper-air observations that are used in the program, must be closely scrutinized for missing data or errors, to ensure that the graphics do not misrepresent the actual atmospheric conditions. Through the use of the UA program, it was determined that there was sufficient synoptic-scale upward vertical motion, resulting from vorticity and geostrophic wind/temperature relationships (i.e., quasigeostrophic theory) to assist in the development of convection. Although not used in this study, it should be mentioned that the PC-GRidded Interactive Diagnostic and Display System software (PC-GRIDDS), which was written by Dr. Ralph Petersen, is another tool that is very useful for quasigeostrophic applications.

Finally, this case study was an example of storm structure and evolution, as related to tornadogenesis, that is very different from "classic" midwestern United States examples of supercells (particularly during the cold season from October to March). The severe weather of 4 November 1992 occurred with low-top, low-reflectivity thunderstorms. The storms developed along a thermal/ moisture boundary, which is a fairly common phenomenon in the Carolinas during the transition between warm and cold seasons.

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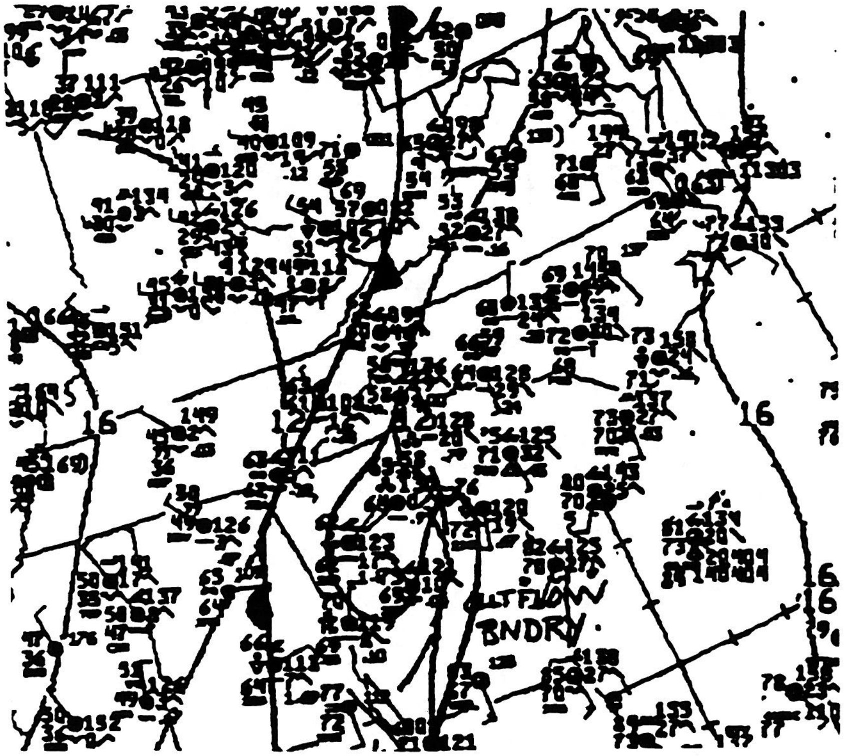

Figure 1. 1800 UTC, 4 November 1992 surface front and isobar analysis.

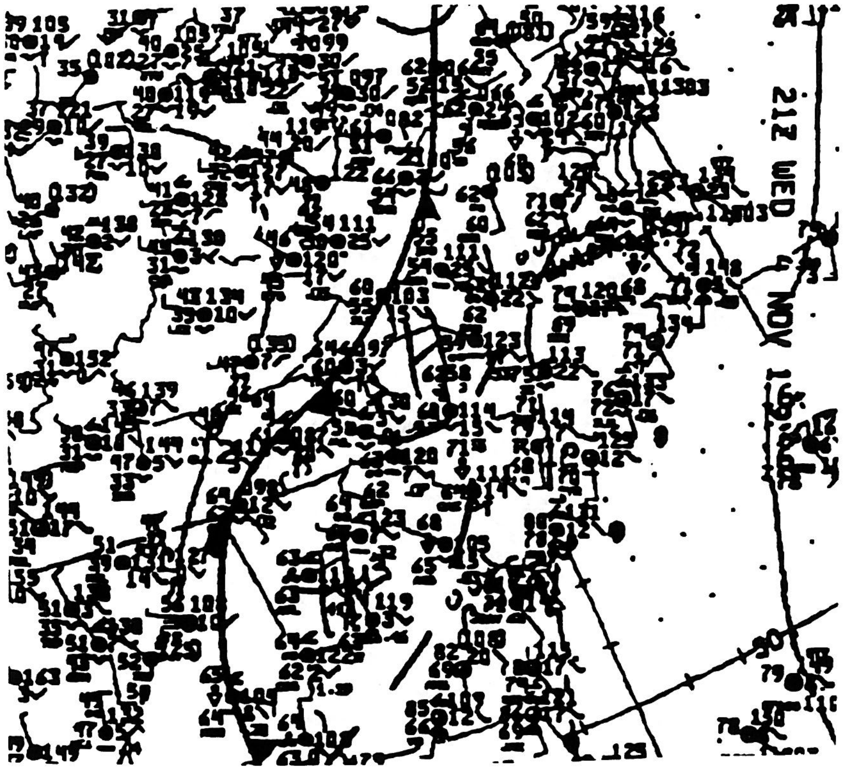

Figure 2. As in Figure 1, except for 2100 UTC 4 November 1992.

Figure 3. As in Figure 1, except for 0000 UTC 5 November 1992.

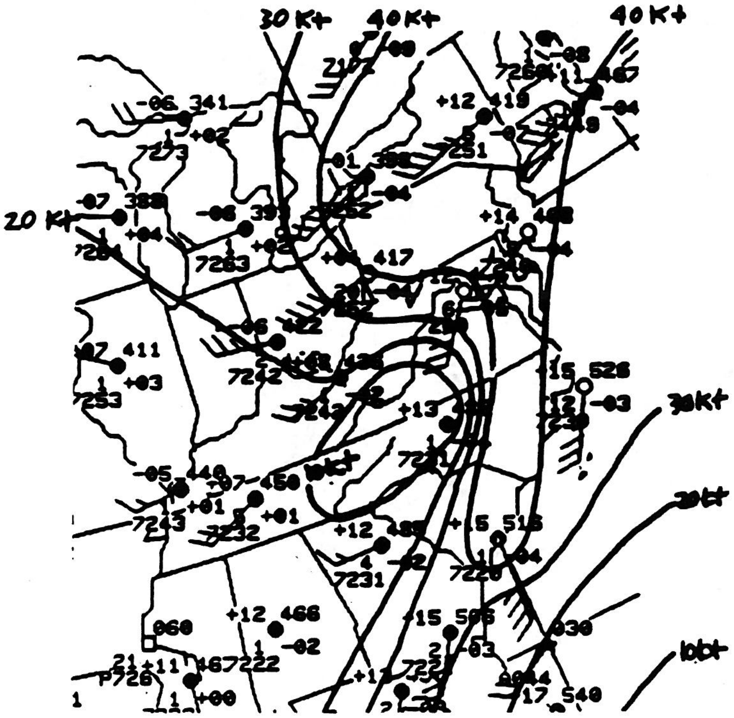

Figure 4. 0000 UTC, 5 November 1992 850 mb plot and isotach analysis.

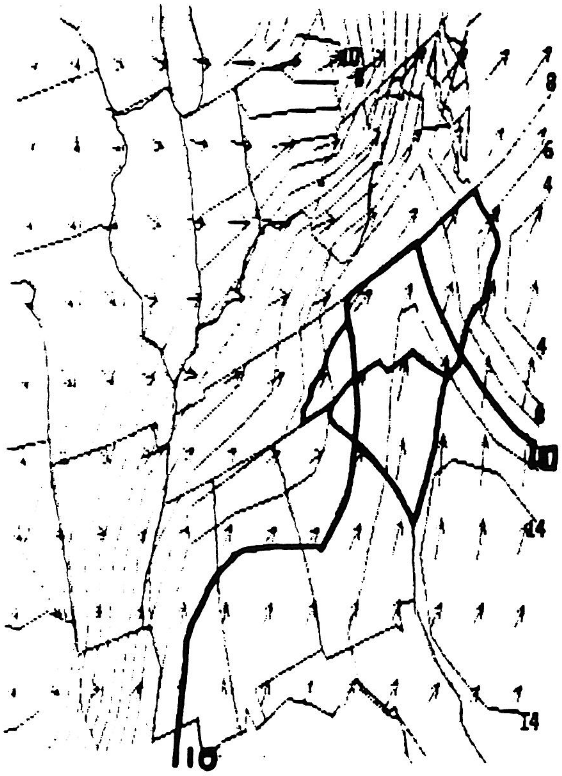

Figure 5. 0000 UTC, 5 November 1992 850 mb dewpoint (°C) analysis and wind plot (kt). From the UA program (Foster 1988).

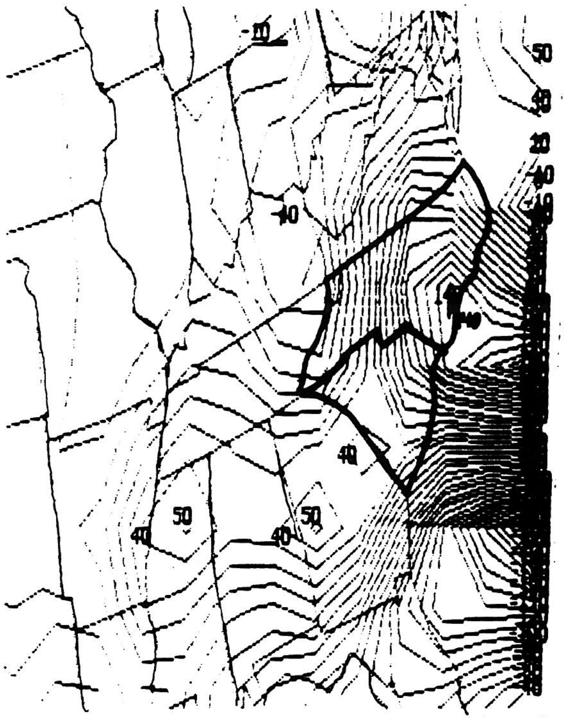

Figure 6. As in Figure 5 except for the 850 mb moisture advection (g $kg^{-1}10hr^{-1}$). From the UA program (Foster 1988).

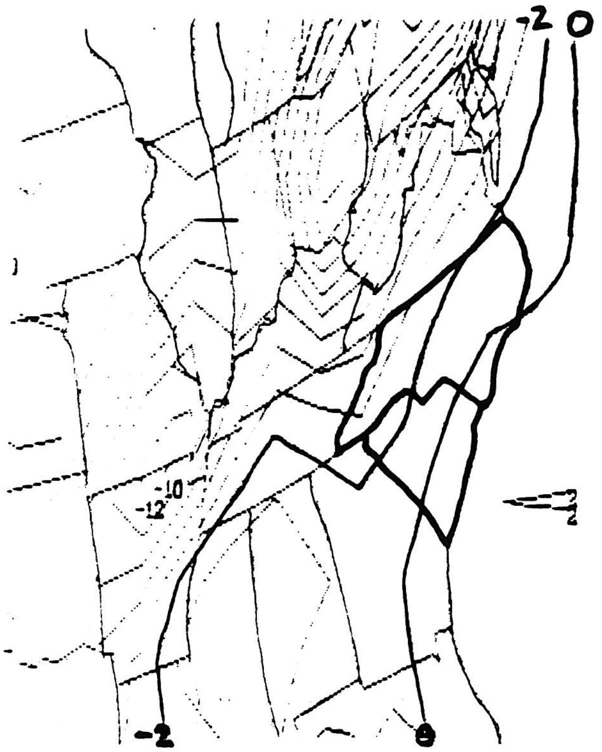

Figure 7. As in Figure 5, except for 850 mb temperature advection (°C 12 hr^{-1}).

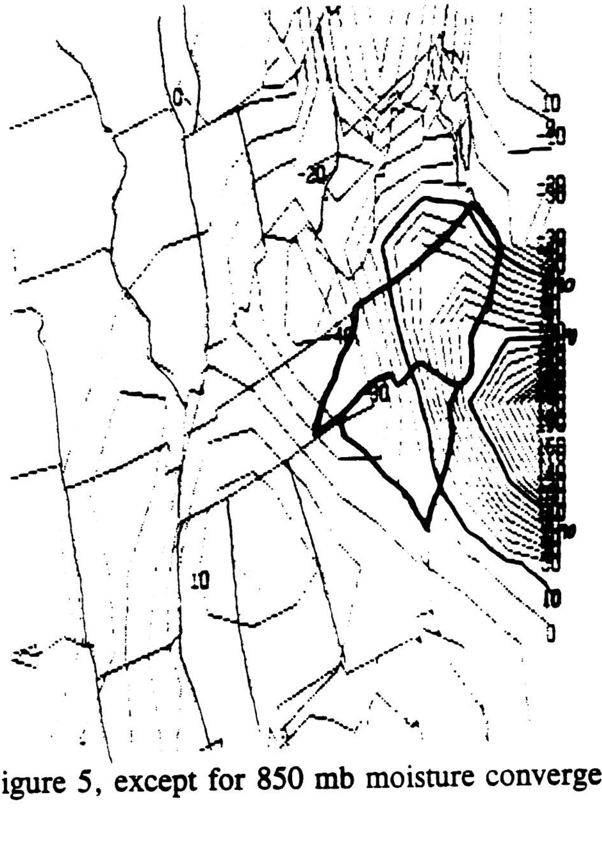

Figure 8. As in Figure 5, except for 850 mb moisture convergence (g kg^{-1} 10 hr^{-1}).

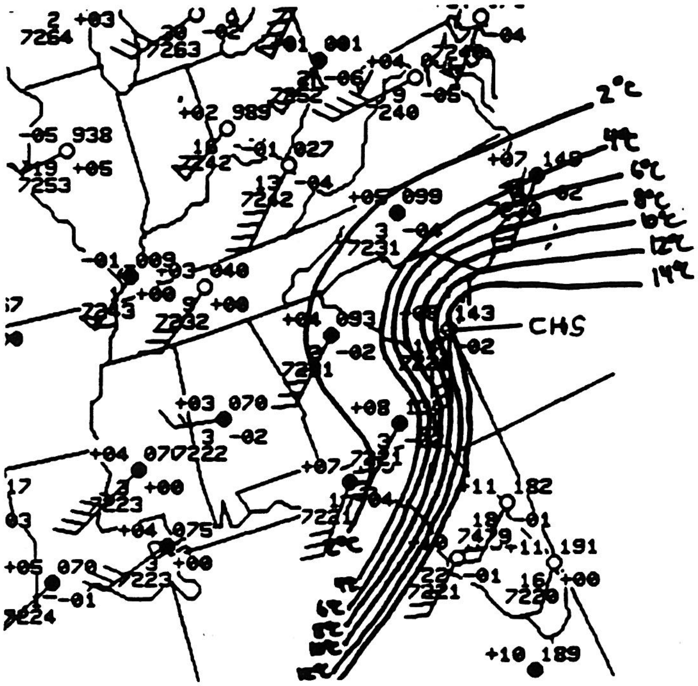

Figure 9. 0000 UTC, 5 November 1992, 700 mb plot and dew point depression analysis (°C).

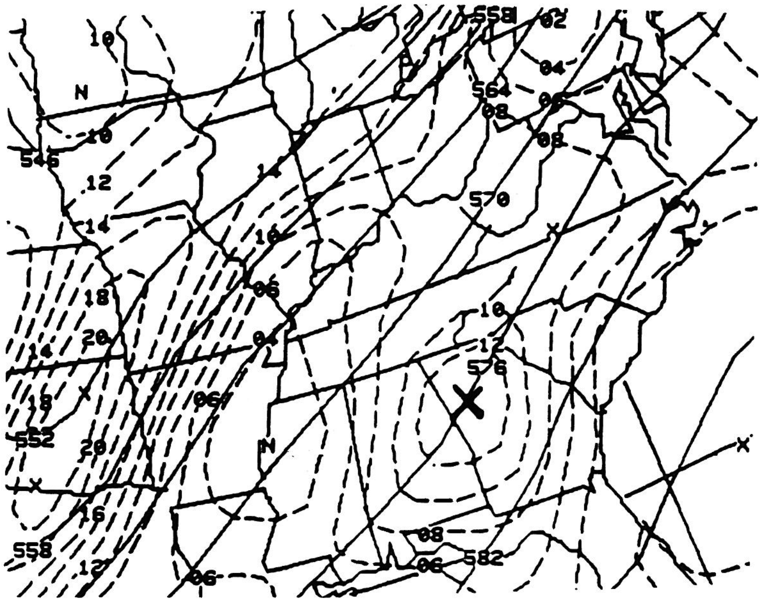

Figure 10. 0000 UTC, 5 November 1992, 500 mb 00-h NGM height (dm) and vorticity ($\times 10^{-5}$ s^{-1}).

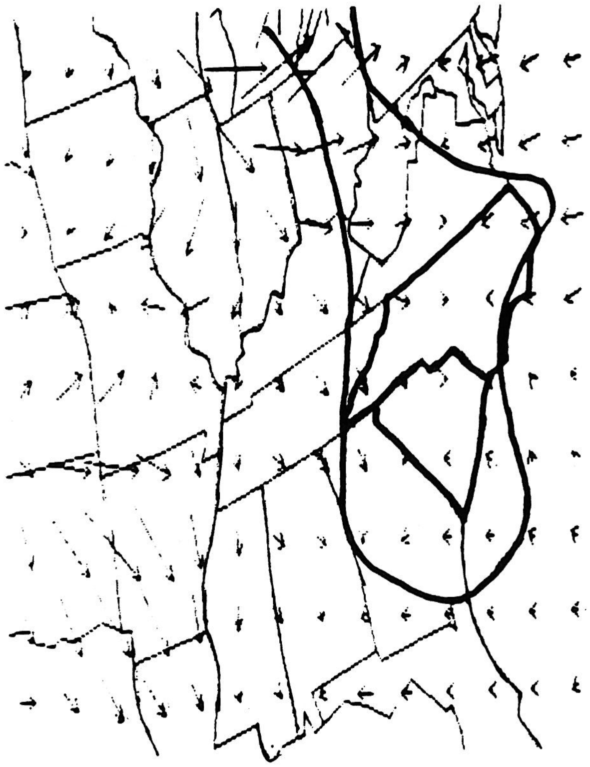

Figure 11. 0000 UTC, 5 November 1992, 700 mb Q-vector analysis. The bounded area denotes convergence of Q. From the UA program (Foster 1988).

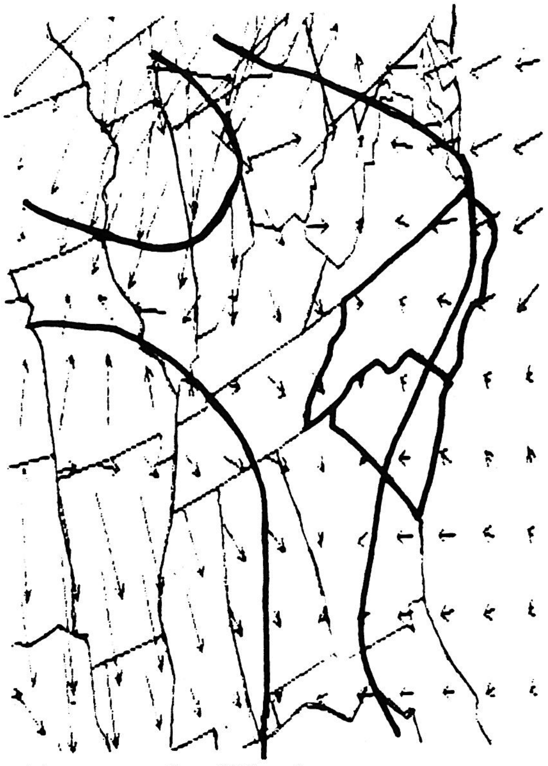

Figure 12. As in Figure 11, except for 500 mb.

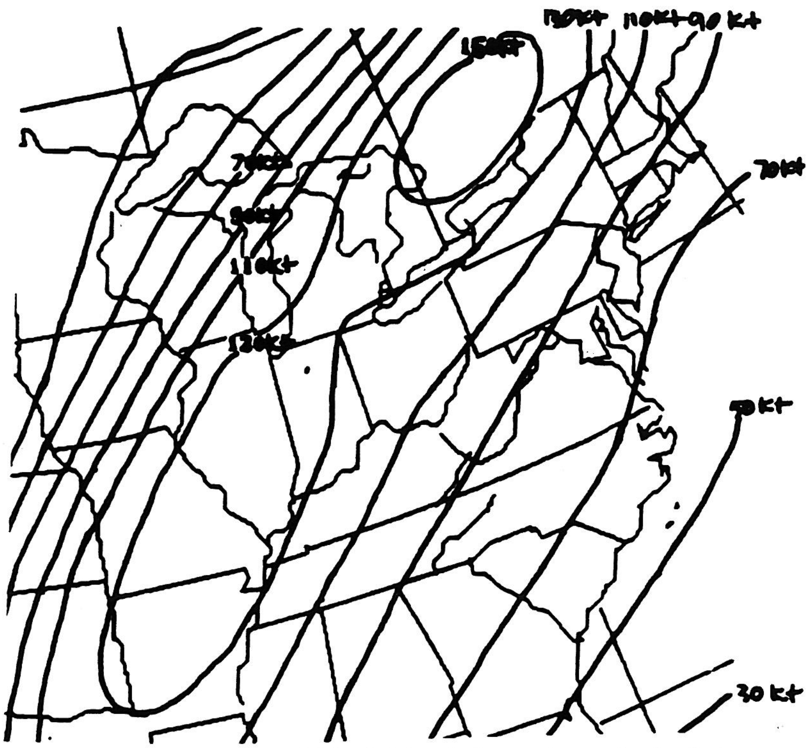

Figure 13. 0000 UTC, 5 November 1992, 300 mb isotach analysis (kt).

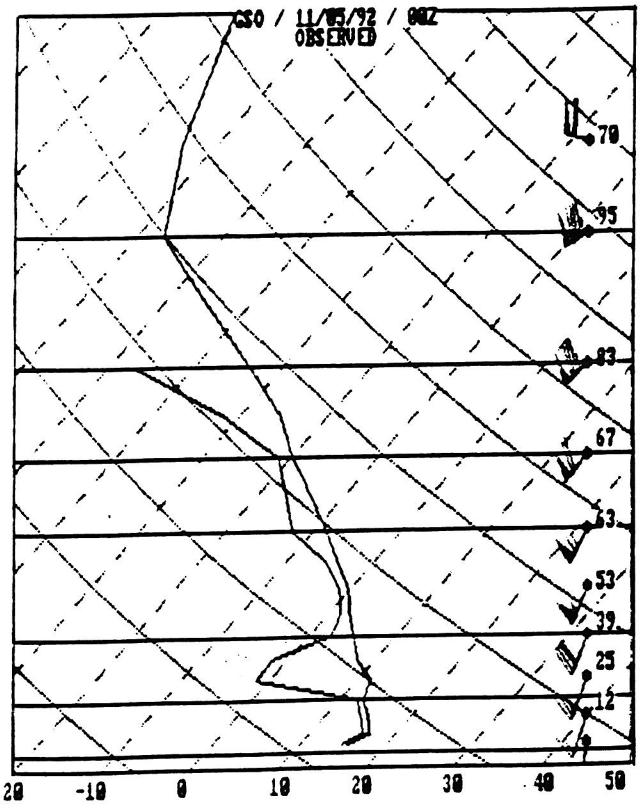

Figure 14. 0000 UTC 5 November 1992, Greensboro, NC (GSO) sounding. From the SHARP workstation (Hart and Korotky 1991).

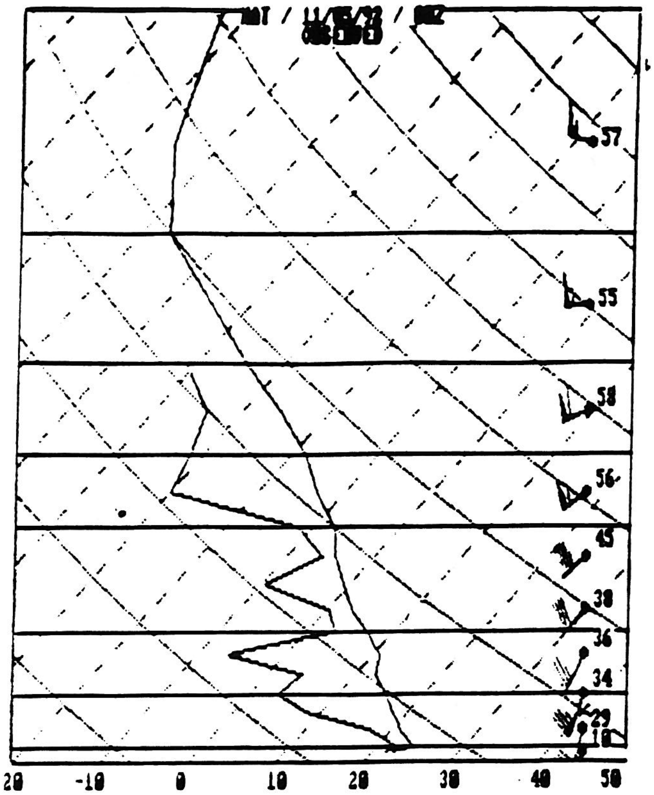

Figure 15. As in Figure 14, except for Cape Hatteras, NC (HAT).

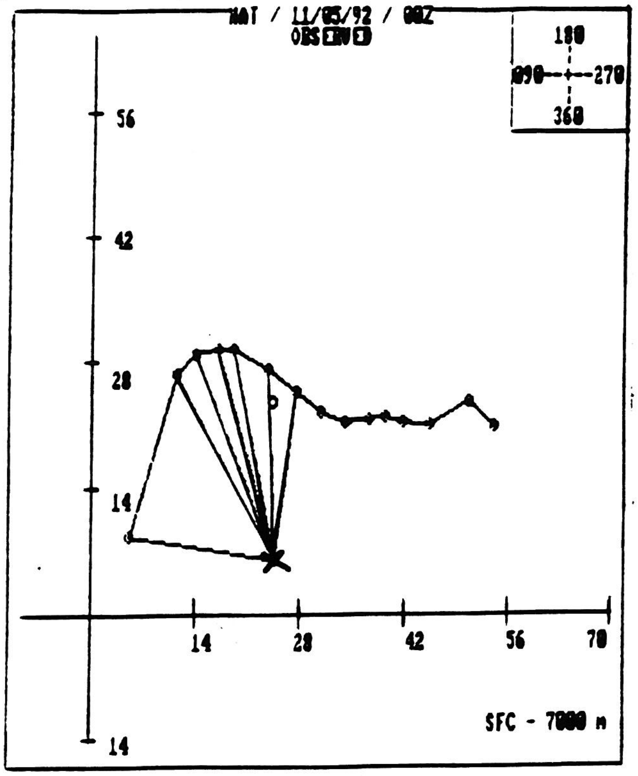

Figure 16. 0000 UTC 5 November 1992, Cape Hatteras, hodograph. Note the low-level storm motion vector denoted by the X. From the SHARP workstation (Hart and Korotky 1991)

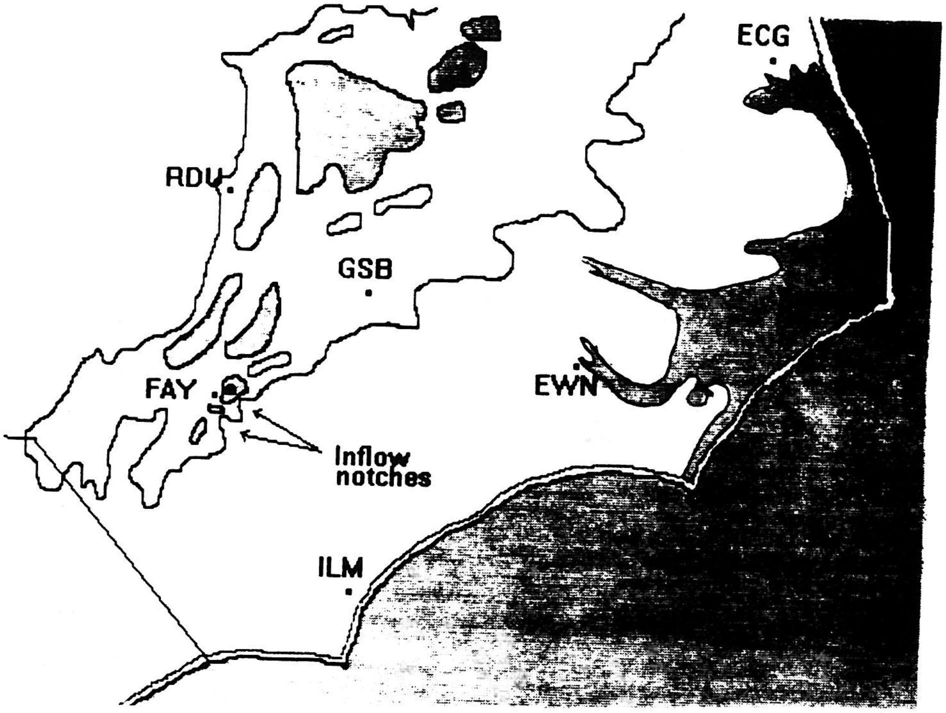

Figure 17. 2347 UTC, 4 November 1992, Wilmington, NC (ILM) WSR-57 radar reflectivity. The 1st contour denotes DVIP Level 1 returns, the 2nd contour (gray shaded) denotes DVIP Level 2 returns, and the 3rd contour (black) denotes DVIP Level 3 returns. Note the inflow notches (marked by the arrows) just southeast of FAY.

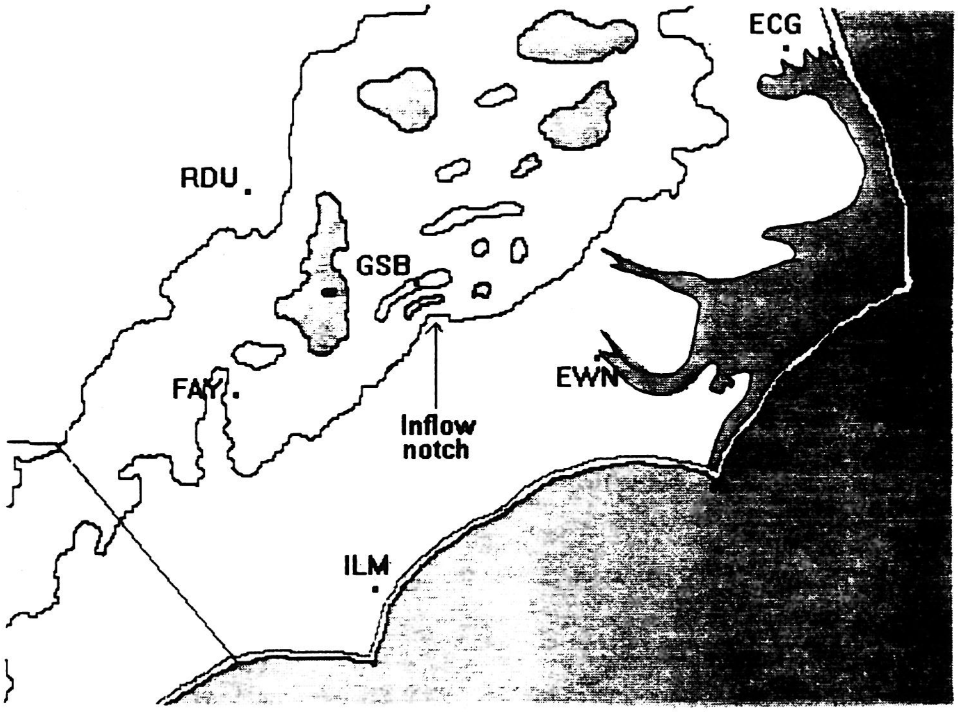

Figure 18. As in Figure 17, except for 0018 UTC 5 November 1992. Note the inflow notch (marked by the arrow) south of GSB.

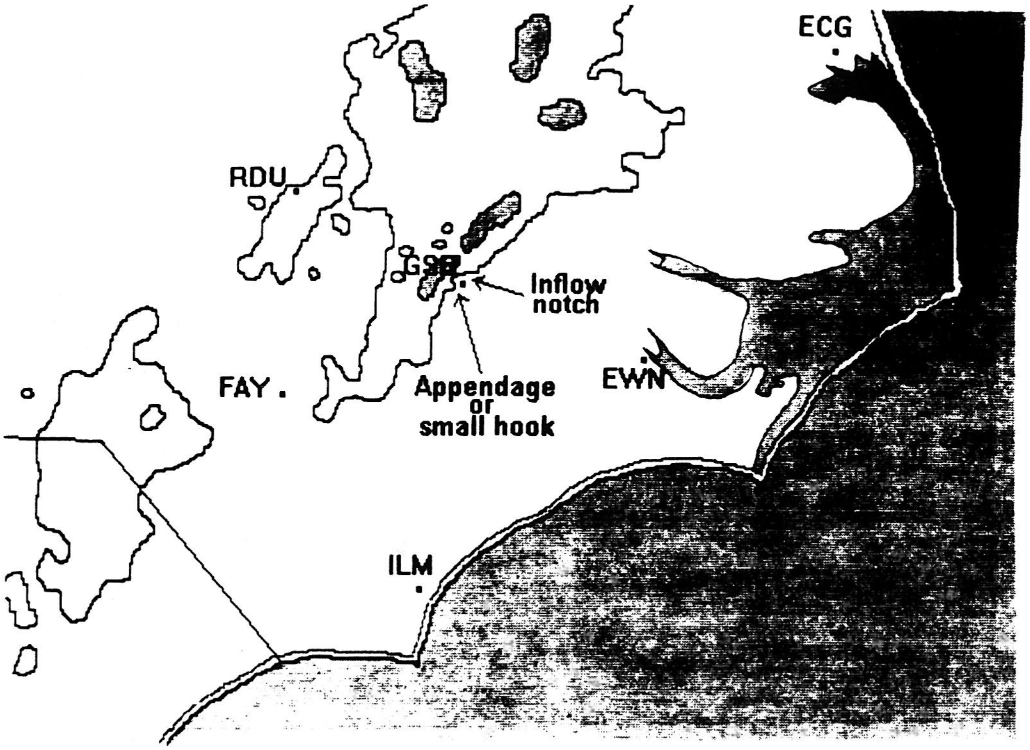

Figure 19. As in Figure 17, except for 0114 UTC 5 November 1992. Note the inflow notches (marked by the arrows) just southwest of GSB.