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A HEAVY RAINFALL AND SEVERE WEATHER EPISODE IN CENTRAL SOUTH CAROLINA
PART II: Thermodynamic and Kinematic Features Leading to Severe Convection

Michael D. Vescio
National Weather Service Forecast Office
Columbia, South Carolina

1. INTRODUCTION

On 22 October 1990, an isolated severe weather event occurred in central South Carolina. Between 2200 and 2300 UTC, a single thunderstorm created a non-continuous damage path from near the city of Orangeburg in central Orangeburg County to western Calhoun County south of St. Matthews. A funnel cloud was spotted 2 miles north of Orangeburg at 2220 UTC. The funnel cloud moved north-east and touched down briefly about 5 miles south of St. Matthews at approximately 2250 UTC (Figure 1). A survey of the damage in Calhoun County indicated that the tornado was of F2 intensity (Fujita 1971). Three trailers, a portion of a brick house, and a small concrete building were totally demolished. Five injuries, one serious, occurred. There was also straight-line wind damage on the campus of South Carolina State College in Orangeburg. A college official reported a few trees uprooted along with some roof damage.

At first, it did not appear that atmospheric conditions were favorable for severe weather. However, a close examination of the synoptic features (Vescio 1991), particularly the environmental wind shear, revealed that conditions were indeed conducive to severe thunderstorm development. A detailed analysis of the wind shear as well as the stability indices at Charleston (CHS) will be presented. Some mesoanalyses from ADAP (AFOS Data Analysis Program) just prior to the tornado occurrence are examined. Many of the analyses were not definitive. This was most likely due to the sparse surface observing network in South Carolina. Finally, some operational problems in severe weather detection are discussed. It is speculated that additional information from the WSR-88D and ASOS systems would have been beneficial for this case.

2. ATMOSPHERIC STABILITY

Figure 2 is the 1200 UTC, 22 October sounding for CHS (this sounding is used for discussion since it is the closest rawindsonde site to the severe weather activity). The sounding revealed a conditionally unstable atmosphere above a shallow radiation inversion. Dewpoint depressions generally were low except for a pronounced dry layer between 600 and 700 mb.

The National Severe Storms Forecast Center (NSSFC) has developed criteria for potential thunderstorm coverage/severity based on the stability indices plotted in Figure 2 (NWSTC 1988). The thresholds for each index are displayed in Table 1. From the 1200 UTC sounding for CHS, the Showalter Index (SI) of +1 and the Lifted Index (LI) of -1 indicated possible thunderstorms if a strong trigger was present. The K Index (KI) of 26 indicated only widely scattered thunderstorms, while the

Total Totals (TT) of 44 indicated isolated or a few thunderstorms. Based on these indices, a forecaster might have expected a few thunderstorms to develop but stay well below severe limits.

At 0000 UTC on October 23rd (Figure 3), which is less than 2 hours after the damage reports, and therefore probably a reasonable approximation to the atmospheric environment at the time of the tornado, the sounding at CHS had changed slightly from the previous one at 1200 UTC. The moisture at low levels persisted. The dry air at mid-levels expanded, extending from 500 to 720 mb. The indices were slightly more favorable for convection. The SI of -1 and LI of -4 indicated probable thunderstorms. The TT increased to 46 and was indicative of scattered thunderstorms. Judging from these three indices, the atmosphere destabilized somewhat during the day. This was accomplished primarily by differential temperature advection. That is, slight warming occurred at low levels (850 mb and below), with slight cooling at the 500 mb level. Figure 4 is a 850 height and temperature plot for 1200 UTC, 22 October. At this time, there was weak warm air advection over the southeast U.S. The temperature at this level increased from +14 to +15°C at CHS by 0000 UTC. At 500 mb (Figure 5), a pocket of slightly cooler air (-9°C) was upstream of CHS over Georgia at 1200 UTC, 22 October. The temperature at this level did, in fact, decrease to -9°C at CHS by 0000 UTC.

While the other indices denoted an increased probability of thunderstorms, the KI showed a reduced threat, decreasing to 18. This can be explained through an examination of the mathematical formulation for this index:

$$K = T_{850\ mb} + Td_{850\ mb} - T_{500\ mb} - (T - Td)_{700\ mb}$$

Where T and Td are the temperature and dewpoint temperature, respectively. Although the atmosphere had destabilized, the K index lowered because of the last term in the above equation. The influx of dry air at 700 mb caused dewpoint depressions to sharply increase, from 10 to 19, reducing the KI. From this analysis, it is obvious that the value of the KI is dependent on mid-level moisture. However, moisture at 700 mb is not a prerequisite for thunderstorms. In fact, dry air at mid-levels can be a very important factor in severe thunderstorm development (Doswell 1982), and may also play a key role in tornadogenesis (Lemon and Doswell 1979).

Even if the information just presented was available prior to the tornado occurrence, one would still not necessarily expect severe thunderstorm development based solely on the values of the indices. The major drawback of the indices is that they only consider atmospheric stability (or instability). Although the stability of the atmosphere often dictates whether thunderstorms develop, the environmental wind shear is often a major factor determining the severity of the storms once they do develop.

3. THUNDERSTORM DEVELOPMENT IN STRONG VERTICAL WIND SHEAR

As an updraft grows in a sheared environment, it tilts the horizontal vortex lines embedded in the mean flow into the vertical. This enables the storm to acquire rotation about a vertical axis, assuming the inflow is sufficiently strong. This type of storm was first called a supercell by Browning (1964). The supercell is the most dangerous of all convective storm types. It accounts for most damaging tornadoes and is typically accompanied by strong downburst winds and large hail. Due to its quasi-steady nature, the supercell can persist for several hours and produce damage over a wide area.

Numerical studies by Weisman and Klemp (1984) and Klemp (1987) simulated thunderstorm evolution in environments with various shear profiles. Results indicate that a clockwise turning of the shear vector over the lowest 3 to 5 km in a moderately unstable atmosphere favors the development of right moving supercells when the magnitude of the shear is high. Recent research by Davies (1989) and Johns et. al

(1990) indicate that the shear in the lowest 2 km may play the biggest role in supercell development.

4. CONVECTIVE PARAMETERS THAT INCORPORATE WIND ENVIRONMENTS

The Sweat Index (SWI) is an indicator of severe thunderstorm potential that considers both stability (using the total totals index) and the vertical wind shear (specifically the shear between 850 and 500 mb). The Air Force developed this index, suggesting a threshold of 300 for severe thunderstorms. Values exceeding 400 indicate a potential for tornadoes (Miller 1972). The SWI at CHS for 1200 UTC was 276. However, by 0000 UTC, October 23, the SWI had increased to 350.

Weisman and Klemp (1984) showed that the preferred storm type based on the stability and shear profile could be predicted from the Bulk Richardson number (BRN). The BRN, which is essentially CAPE (Convective Available Potential Energy; the positive area on a thermodynamic diagram) divided by the density weighted shear over the lowest 6 km, is an attempt to combine these two important parameters into one index. Their study indicated that supercell formation is generally confined to values of BRN between 10 and 40. The AFOS program CONVECTA (Stone 1988) uses sounding data to generate values of shear, CAPE, and BRN (as well as many other parameters). For 1200 UTC, the CAPE at CHS was only 140 J/Kg and the shear (density weighted) was 29 J/Kg giving a BRN of 5. However, by 0000 UTC, the CAPE and shear had increased to 1160 J/Kg and 35 J/kg, respectively, yielding a BRN of 33.

5. HODOGRAPHS

Figure 6 is the hodograph generated by the Skew-T/Hodograph Analysis and Research Program (SHARP) (Hart and Korotky 1991) for CHS at 0000 UTC, 23 October. The surface wind was modified to 125^{o} and 4 kt, which approximates the observed wind flow at reporting stations nearest the storm location. The storm relative wind vectors are plotted by using a storm motion from 230^{o} and 20 kt. This was the approximate motion of the tornadic storm based on a time loop from the radar at CHS and the storm reports. The hodograph indicates a moderate amount of clockwise shear, particularly at low levels. A clockwise turning hodograph favors the development of right-moving supercells.

Storm relative (s-r) helicity, which is the dot product of the storm relative wind and vorticity integrated through a given layer, is an important parameter for supercell formation (Lilly 1986). Helicity values over the lowest 3 km can be determined operationally, given a storm motion, from rawindsonde soundings to assess severe storm potential. Davies-Jones et al. (1990) calculated the 0-3 km (s-r) helicity from proximity soundings for 28 tornadoes with varying intensity. Helicity values ranged from 160 to 990 m^2s^{-2}, with higher values corresponding to stronger tornadoes. Of the 28 tornadoes studied, 12 were classified as strong (F2-F3). The median s-r helicity for these tornadoes was 330 m^2s^{-2} with a range from 300-499 m^2s^{-2}.

A 0-3 km helicity value of 196 m^2s^{-2} was calculated from the 0000 UTC sounding at CHS based on the observed storm motion. Although the tornado in this case was classified as F2, and the helicity was below the range given by Davies-Jones et. al. (1990) for strong tornadoes, it was above the lowest value of 160 m^2s^{-2} within their data set. Leftwich (1990) points out that conditions in the immediate vicinity of the storm may significantly affect the s-r winds. In this case, the helicity in the near-storm environment may have been greater than that calculated from the wind profile for CHS.

6. ADAP OUTPUT

Numerous objectively analyzed products can be generated by ADAP (Bothwell 1988). Since surface data are required for the ADAP products, the sparse surface observing network throughout South Carolina presents a limitation to the utility of the ADAP fields. However, a few of the analyses indicated increased thunderstorm potential prior to the tornado occurrence. Figure 7 is the surface potential temperature advection (graphic STA on AFOS) for 2100 UTC. At this time, weak warm air advection was occurring over all but the northwest portion of the state. In addition to the implied upward motion and atmospheric destabilization, warm advection, from the thermal wind relationship (Holton 1979), leads to veering winds with height, which increases the potential for storm rotation.

Figure 8a is the surface streamline and wind plot (graphic SSW on AFOS) for 2100 UTC. Although the wind flow was nearly unidirectional in the severe weather area, speed convergence was evident. Figure 8b is the surface moisture flux convergence (MFC) field (graphic SMC on AFOS) at 2100 UTC. The MFC is a good field to examine since it includes both mass convergence, which leads to upward vertical motion, and moisture advection, which destabilizes the atmosphere (Waldstreicher 1989). At this time, an MFC maximum was over southern South Carolina. The severe weather area was downwind of the maximum in a tight MFC gradient, which, according to Waldstreicher (1989), is a preferred area for storm development.

7. SUMMARY AND DISCUSSION

On 22 October, 1990, an isolated severe thunderstorm spawned a tornado of F2 intensity in central South Carolina. Due to the presence of only marginal instability, severe weather was not considered a serious threat. However, results from this case indicated that conditions were indeed conducive to severe thunderstorm development. The environmental wind shear was strong, and increased significantly at CHS between 1200 and 0000 UTC. Also, low-level warm advection, and surface moisture convergence, acted to destabilize the atmosphere and may have provided a trigger for convection.

This case illustrates some common problems which currently exist in operational detection of severe weather. Since severe weather was not expected, primary attention was diverted to flash flooding because heavy rain was falling over saturated ground (Vescio 1991).

Once the severe weather developed, some other problems arose. The initial reports, which were received from generally less reliable sources, were difficult to believe since the radar at CHS was displaying a storm with only moderately high reflectivities (maximum VIP level of 4) and relatively low tops (30-35 thousand feet). Also, the efficiency of the local warning radar at CAE (5 cm) was greatly reduced by a wet radome, and attenuation from precipitation. The combination of these factors made the issuance of timely warnings difficult.

It appears that the new WSR-88D radar would have been very useful for this case. The WSR-88D system will have many fully-automated features including severe weather algorithms. Even if attention was focused on the flooding potential rather than the isolated convection, alarms based on these algorithms might have been triggered to warn a forecaster if a mesocyclone (or tornado vortex signature) was detected. (Note, one should not rely solely on the alarms.)

The added spatial and temporal resolution of surface observations with ASOS may have been beneficial, as well. Pressure perturbations, and strong damaging winds that frequently accompany severe convection may have been resolved. This information could have been a valuable diagnostic tool for assessing thunderstorm severity.

Finally, wind profilers, such as the ones operating in Colorado and being installed in the central U. S., would have been a valuable aid. The wind shear at CHS increased considerably between 1200 and 0000 UTC. Since the tornado occurred just prior to 0000 UTC, the wind information from the sounding at CHS was available only after the fact. With the profiler, and output from the WSR-88D velocity azimuth display (VAD) algorithm, wind information can be obtained on a much higher temporal and spatial resolution.

8. REFERENCES

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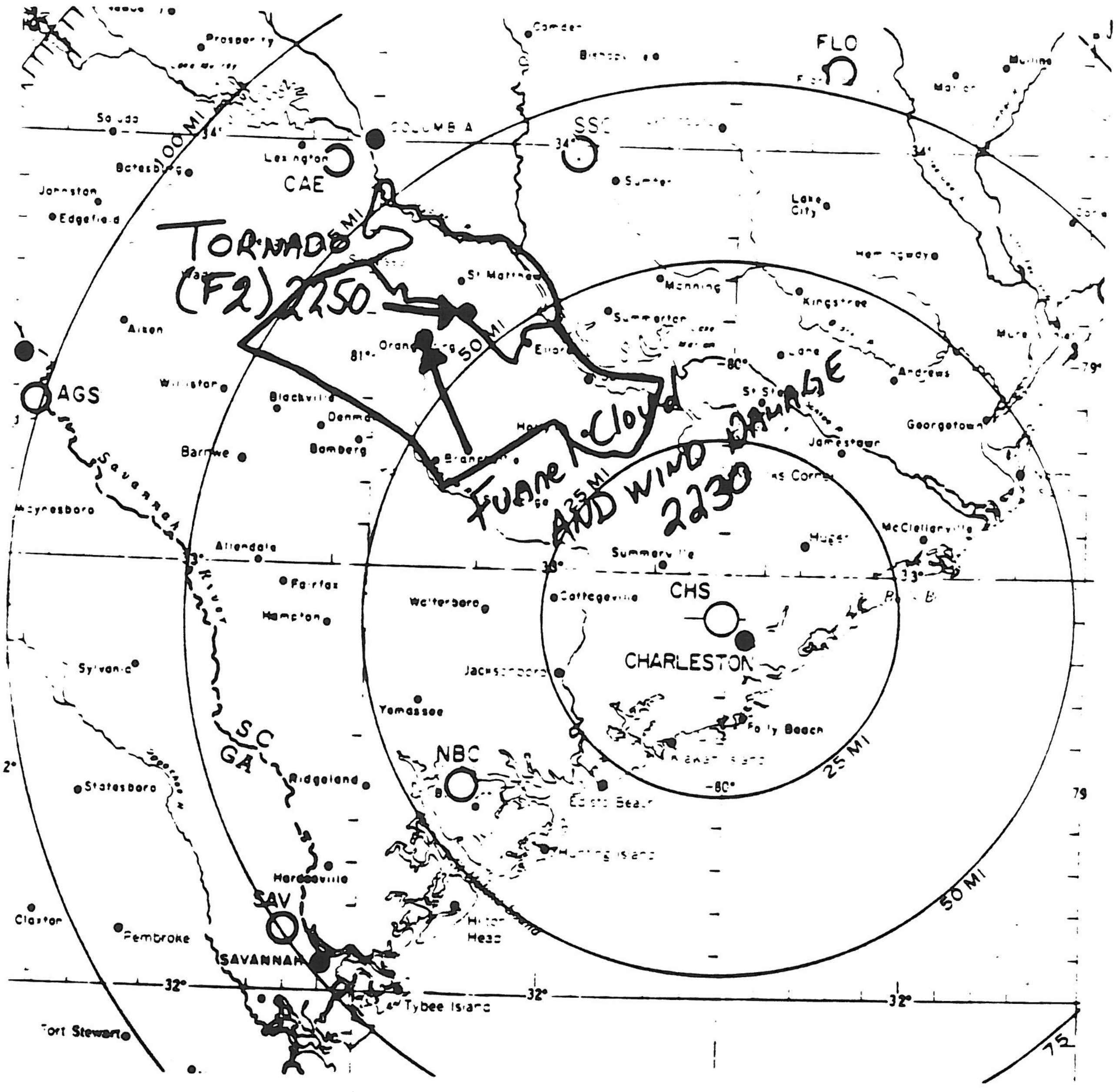

Figure 1. Location and time (UTC) of severe weather occurrences.

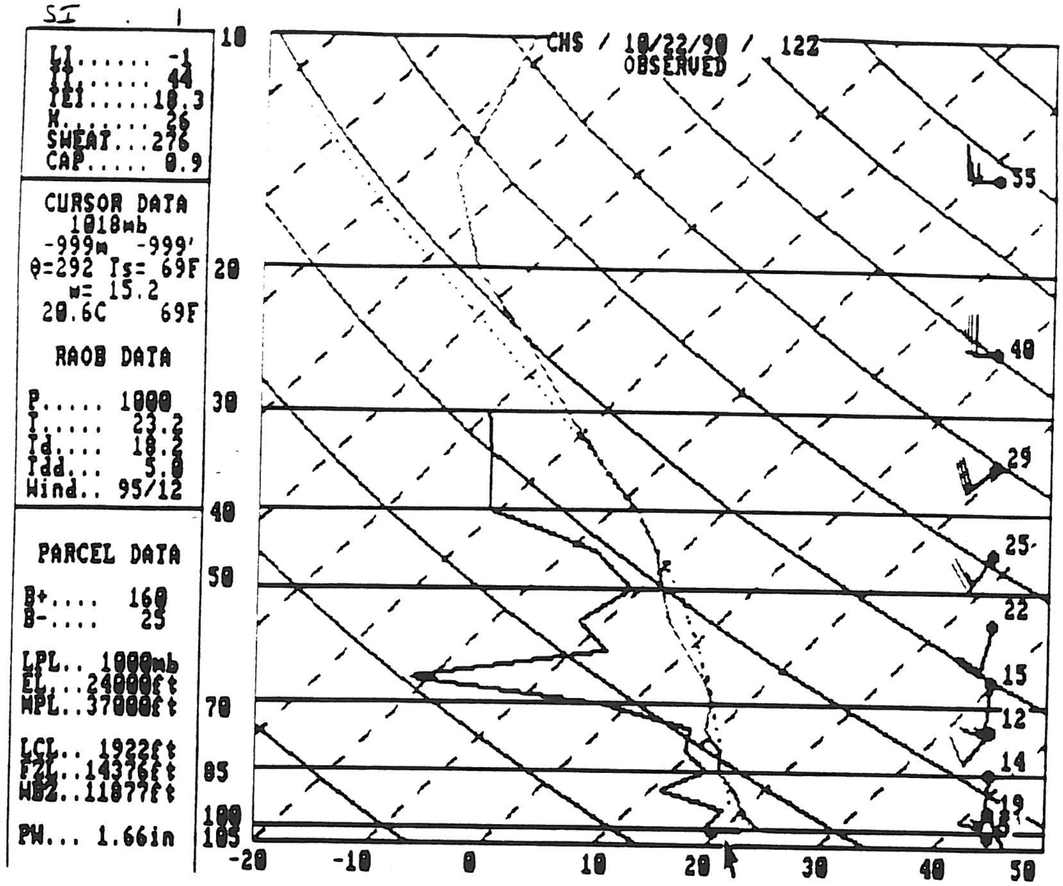

Figure 2. 1200 UTC, 22 October 1990, sounding for Charleston, SC (CHS).

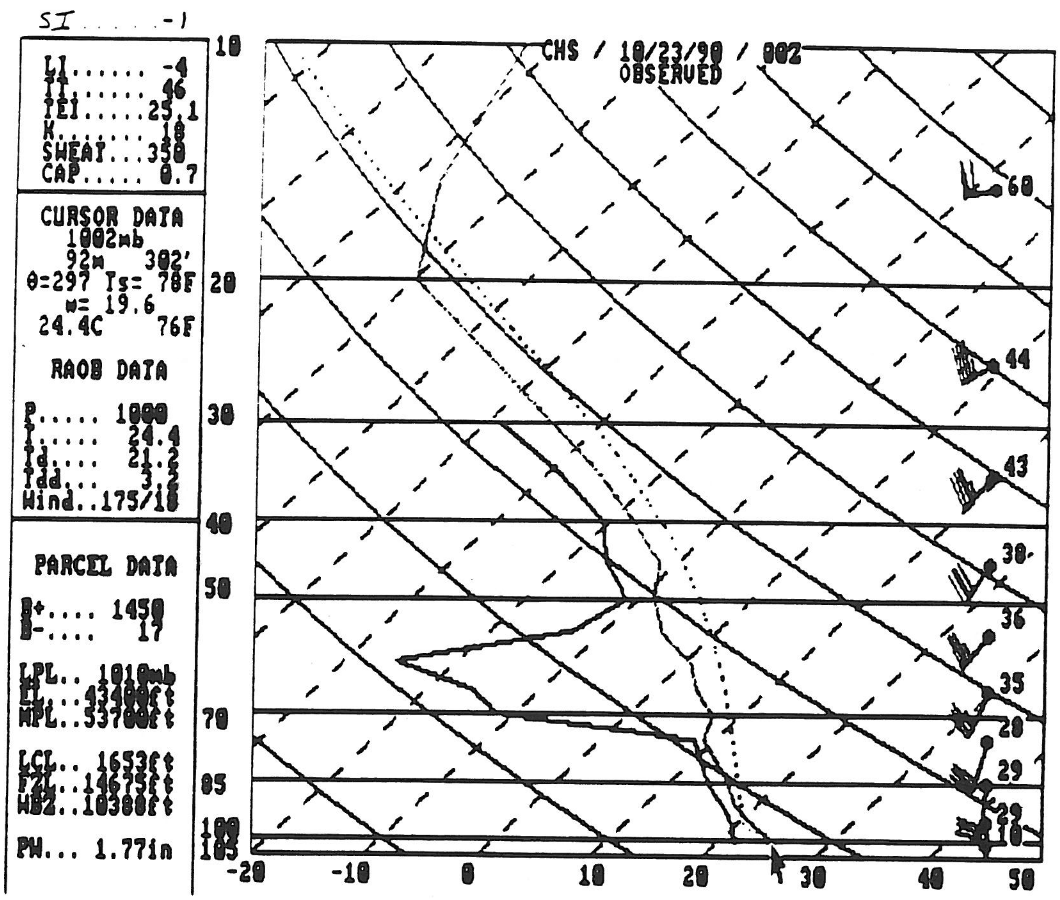

Figure 3. 0000 UTC, 23 October 1990, sounding for Charleston, SC (CHS).

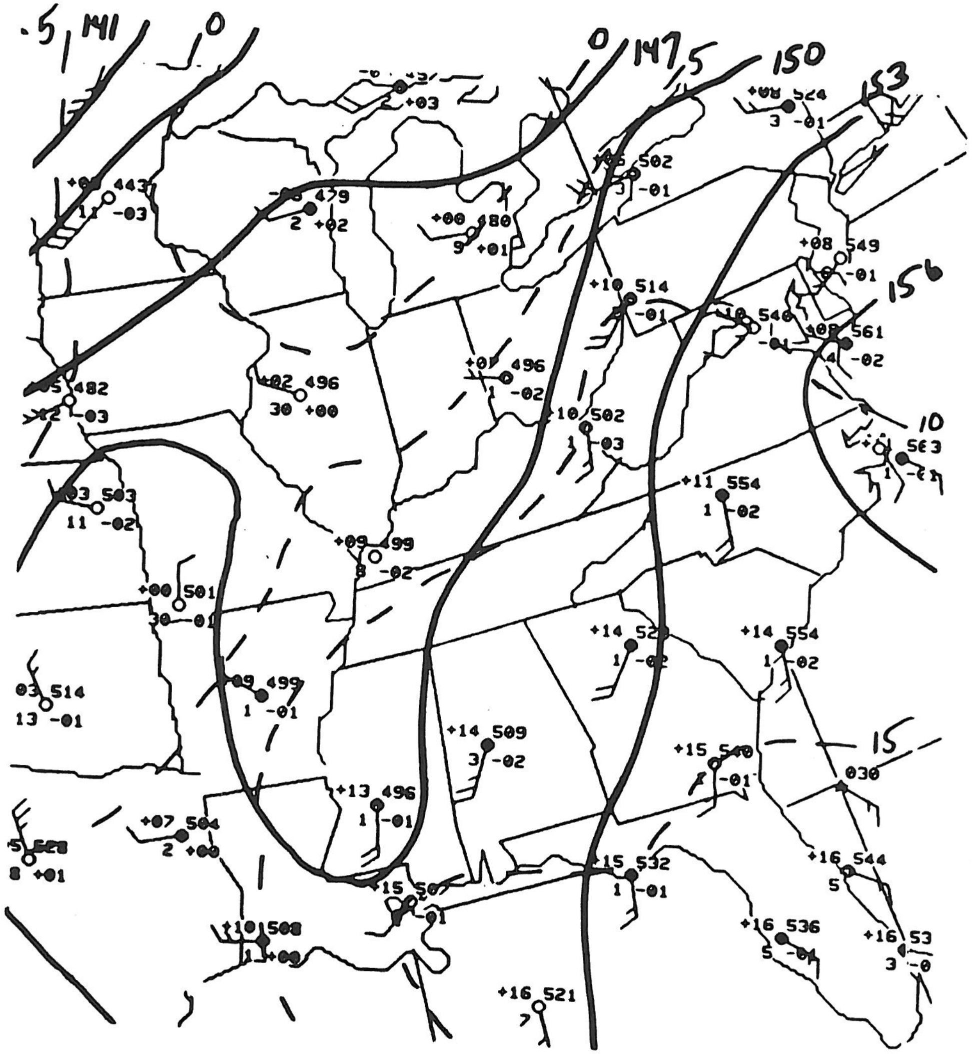

Figure 4. 850 mb Analysis for 1200 UTC, 22 October 1990. Solid lines are height contours (30 m), dashed lines are isotherms (5°C).

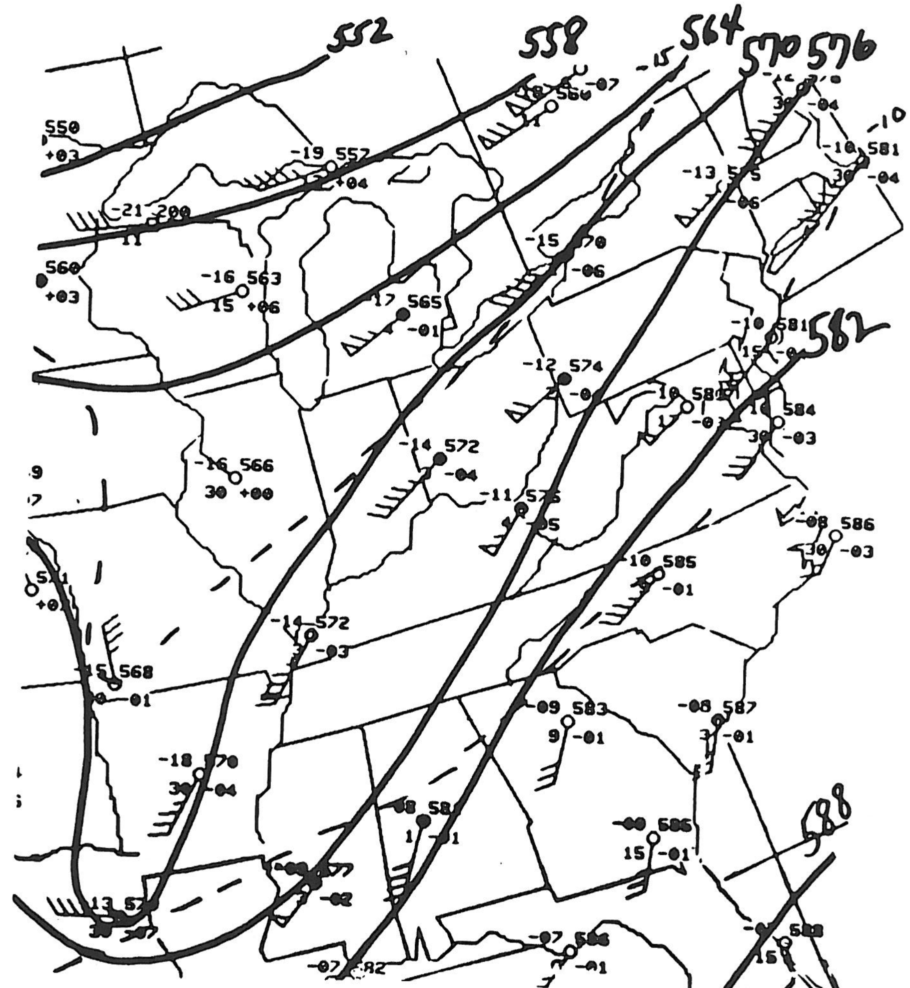

Figure 5. 500 mb Analysis for 1200 UTC, 22 October 1990. Solid lines are height contours (60 m), dashed lines are isotherms (5°C).

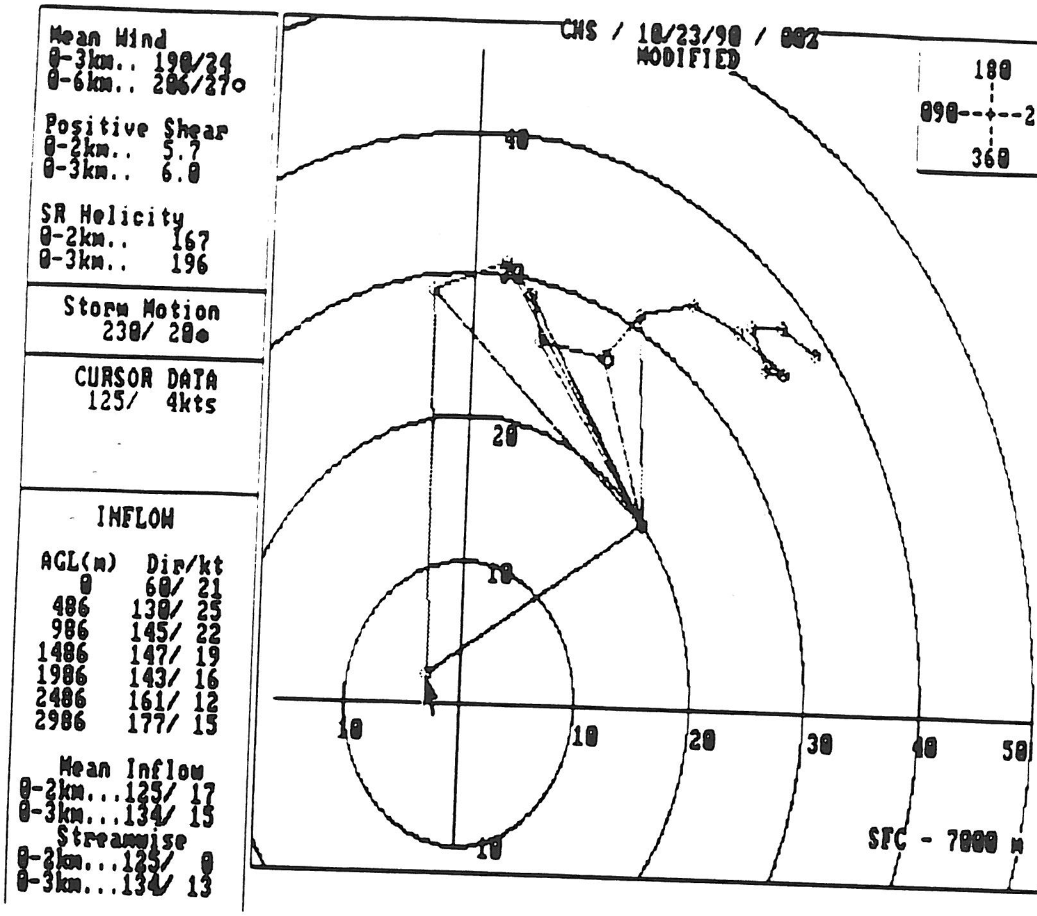

Figure 6. CHS hodograph for 0000 UTC, 23 October 1990.

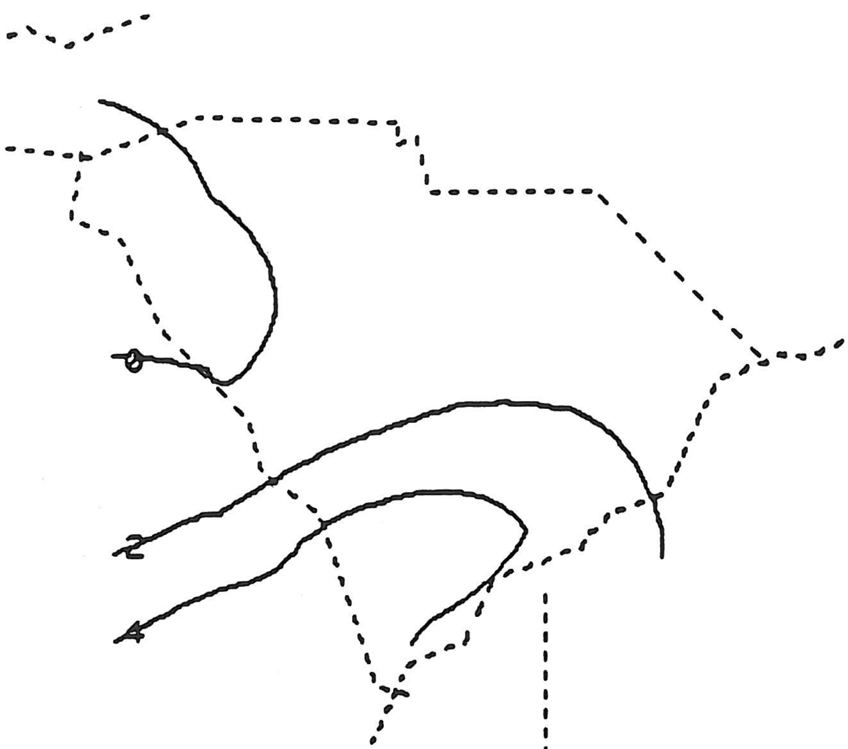

Figure 7. Surface theta advection (STA) (^{o}F hr^{-1}) for 2100 UTC, 22 October 1990.

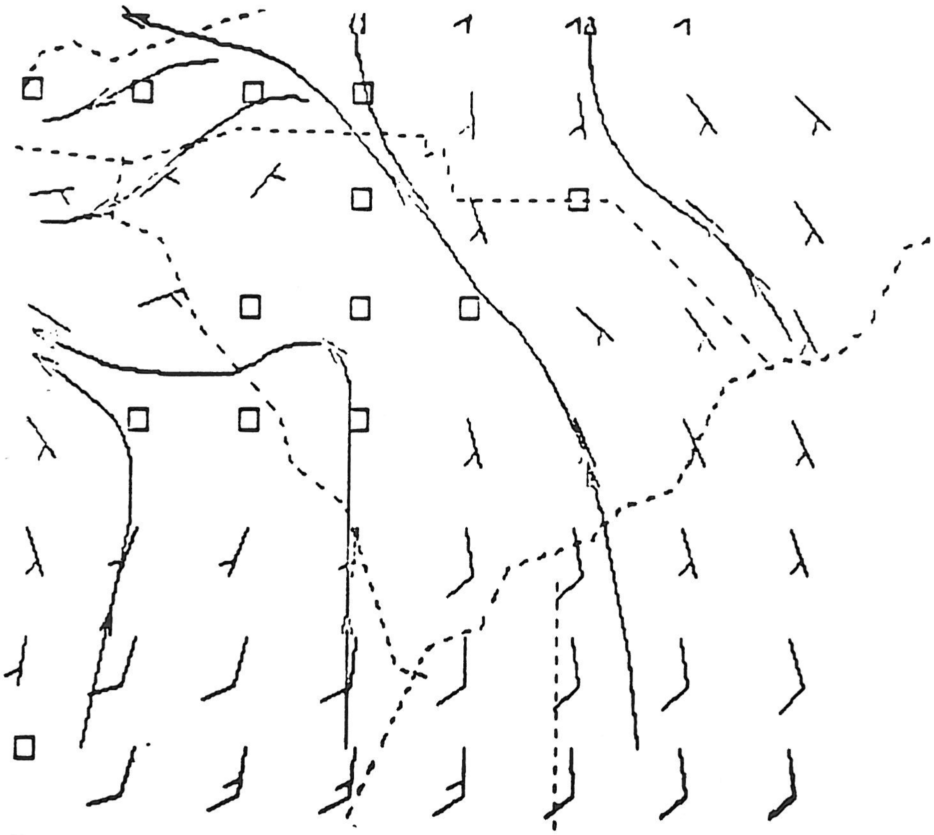

Figure 8a. Surface streamline and wind plot (SSW) for 2100 UTC, 22 October 1990.

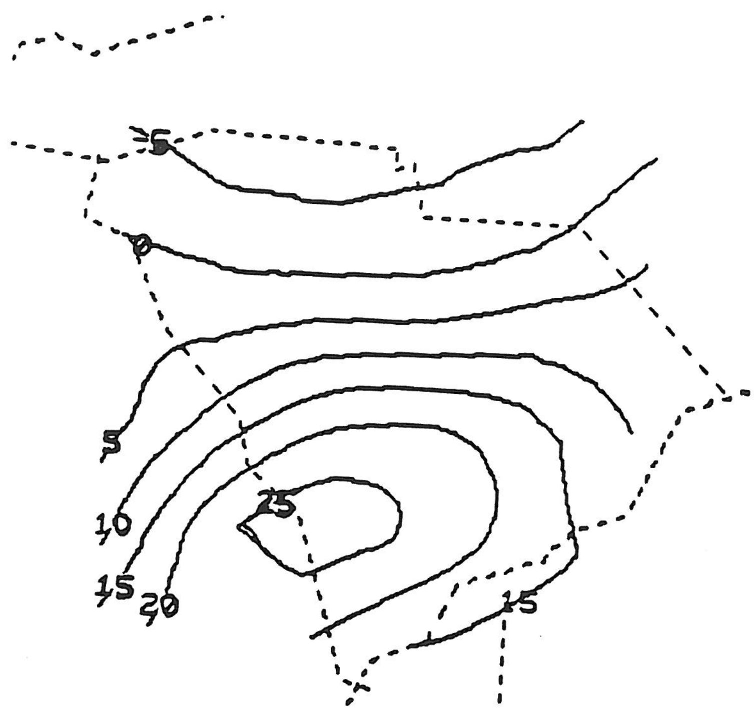

Figure 8b. Surface moisture flux convergence (SMC) ((g kg^{-1} hr^{-1})*10) for 2100 UTC, 22 October 1990.

POTENTIAL THUNDERSTORM COVERAGE/SEVERITY BASED ON SELECTED STABILITY INDICES

LIFTED INDEX	INDICATIONS
0 to -2	possible thunderstorms with a strong trigger.
-3 to -5	probable thunderstorms
-6 or less	severe thunderstorm potential

SHOWALTER INDEX	INDICATIONS
3 to 1	thunderstorms possible with trigger
0 to -3	probable thunderstorms
-4 to -6	heavy thunderstorm potential
-7 or less	severe thunderstorm potential

K INDEX	INDICATIONS (FOR AIRMASS STORMS)
< 20	no thunderstorms
21 to 25	isolated thunderstorms
26 to 30	widely scattered thunderstorms
31 to 35	scattered thunderstorms
> 35	numerous thunderstorms

TOTAL TOTALS INDEX	INDICATIONS
44-45	isolated or few thunderstorms
46-47	scattered thunderstorms
48-49	scattered thunderstorms, isolated severe storms
50-51	scattered thunderstorms, few severe, isolated tornadoes.
52-55	few to scattered severe storms, few tornadoes
56 or more	scattered severe storms and tornadoes

Table 1. Thresholds for coverage/severity of storms based on various stability indices (from NWSTC 1988).