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# LAND BREEZE THUNDERSTORM ACTIVITY ALONG THE SOUTH CAROLINA COAST

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## 1. INTRODUCTION

The coastal sections of South Carolina experience many different mesoscale features that often produce significant weather. During the summer months, land and sea breeze circulations play an important role in the initiation of thunderstorm activity along the coast. The land breeze was particularly active during the summer of 1990, at times producing nocturnal thunderstorms that greatly influenced the forecasts for the coastal sections.

The warm waters of the Gulf Stream transverse the offshore waters of South Carolina typically between 50 and 100 miles from the coast during the summer months. Nocturnal thunderstorms are very frequent over these waters. This study, however, does not focus on this common type of convection. The purpose of this paper is to look at a much less frequent type of nocturnal thunderstorm.

Land breeze-induced thunderstorms occur along the immediate South Carolina coastal waters. The land breeze thunderstorms form most often during the early morning hours (0400-1000 UTC) within 20 miles of the coast. These storms occur relatively infrequently compared to the nocturnal thunderstorms that form over the gulf stream waters. For example, thunderstorms over the gulf stream occur on almost a daily basis during the summer months, whereas only four cases of near coastal, land breeze thunderstorms (NCLB) occurred during the summer of 1990.

The infrequent, land breeze thunderstorms often developed explosively, and at times produced large hail, frequent lightning, and strong winds. These storms were especially threatening to the marine community because of their close proximity to the coast and tendency to develop rapidly.

## 2. DATA

The availability of coastal wind reporting stations along the South Carolina coast, the upper air observations, and the weather surveillance radar (WSR-57) at WSO Charleston permitted a detailed examination of NCLB activity. The data were analyzed to provide an indication of the conditions favorable for land breeze thunderstorm activity.

The coast line of South Carolina is oriented southwest to northeast, with a number of reporting stations in the southern sections (Figure 1). An upper air site is located at Charleston (CHS). Hourly wind and temperature reports are recorded in downtown Charleston (HRR) with a DARDC (Device for Automatic Remote Data Collection) system. Wind reports at 3-hourly intervals are available from the remainder of the stations. Folly

Beach (FBI) is a C-MAN automated buoy. Hilton Head Island (HHI) and Edisto Beach (EDB) are part of the DARDC wind system. HBR is a report received from a pilot boat that frequently travels to a sea buoy located 15 miles southeast of Charleston.

Nine cases were examined as part of this study. Four of the cases had intense land breeze thunderstorm activity that formed near the immediate coast of South Carolina. These were the only recorded instances of this phenomenon during the summer of 1990. The remaining five cases also had both land and sea breeze winds throughout the day; however the NCLB activity did not occur. Note, not all days with land and sea breezes, but without NCLB activity (non-event days), were included in this study. An attempt was made to examine cases that were in the similar synoptic scale regimes. In this manner, differences between events and non-events could be tied more directly to features in the local environment, rather than larger scale influences. Therefore, non-event cases were limited to those within a few days of the NCLB cases. For example, a case of intense coastal land breeze thunderstorms was observed on August 14. On August 12, land and sea breeze winds occurred, however, NCLB thunderstorms were not observed. Both of these cases will be presented later.

## 3. METHODOLOGY

The strategy for data collection and analysis involved the use of wind reports from the various coastal stations mentioned earlier, and the upper air data from CHS at 0000 and 1200 UTC. The 0000 UTC sounding was used primarily since it provided information about the preconvective environment. The 1200 UTC data were not as useful since the land breeze circulation and convection usually were already underway.

All levels of the sounding were analyzed; however, the surface, 1000mb, 850mb, 700mb, and 500mb levels were emphasized. Several stability indices, such as the total totals, lifted (LI), and K, were evaluated, as well as the corresponding precipitable water values. The data from the coastal wind stations were examined every 3 hours. The winds during the daytime hours (1300-0100 UTC) were used to determine if a sea breeze had developed. The night time wind data (0100-1300 UTC) were examined to determine when, or if, a land breeze occurred.

## 4. SURFACE WIND ANALYSIS

Coastal wind circulations are very common in the summer months. The contrast in diurnal temperatures, combined with very warm sea temperatures (mid 80s in August along the South Carolina coast), and light gradient winds, provide ideal conditions for thermally forced coastal winds (Meyer 1971).

The sea breeze in South Carolina produces an onshore wind typically from the south or southeast, and occurs during the late afternoon or evening. Land breeze winds blow from the west, northwest, or north, and normally occur in the early morning hours. Table 1 shows sea breeze winds during the evening, and land breeze winds during early morning hours,on August 13-14.

| | STATION | | | | |
|---|---|---|---|---|---|
| TIME | HRR | FBI | HHI | EDB | HBR |
| 22 UTC | SE6 | S6 | SE7 | SE6 | SE7 |
| 01 UTC | SE7 | S6 | S8 | S5 | SE7 |
| 04 UTC | SW4 | S10 | SW8 | W8 | - |
| 07 UTC | W3 | SW12 | W7 | W8 | - |
| 10 UTC | NW5 | NW5 | W7 | W8 | - |
| 13 UTC | NW5 | NW7 | W8 | W5 | SW5 |

**Table 1.** Coastal wind observations for August 13-14, 1990.

At 2200 UTC, the sea breeze is evident, with all of the coastal stations reporting south or southeast winds. As the evening progressed, the effects of the land breeze can be seen. The winds veered, blowing from the west by 0700 UTC, and the west and northwest by 1000 UTC. This pattern was typical along the South Carolina coast during the summer of 1990.

Both the land breeze and the sea breeze are important factors for NCLB thunderstorm activity. The sea breeze produces an onshore flow during the afternoon that provides a build up of moisture along the coast. The interaction of the land breeze and sea breeze fronts can produce the convergence necessary to initiate convection (Meyer 1971). The effects of the interactions of the land and sea breeze can be better understood by examining the thermodynamic structure of the atmosphere.

## 5. SOUNDING ANALYSIS

The water temperatures remained at near constant values (mid 80s), with the overnight land temperatures in the mid to upper 70s for the cases studied. The gradient winds were also light. As a result, there was not a substantial amount of variation in the forcing mechanisms for the coastal wind circulations. The land and sea breeze combination is a fairly common occurrence during the summer months. However, thunderstorms do not occur with every case of land and sea breeze circulations. With only subtle differences observed in the land and sea breeze strength, the main focus shifted to the CHS sounding to locate features that could differentiate between the convective and non-convective events.

The 0000 UTC data were first examined. In situations where coastal wind circulations did develop, the low level wind from the sounding reflected these patterns. The upper level winds remained primarily zonal (westerly). All of the winds were quite weak, resulting in little or no shear. Table 2 shows typical upper levels winds at 0000 UTC when coastal wind circulations were observed.

The data in Table 2 indicate the sea breeze winds at the surface, and 1000mb. The winds slowly veer with height. This pattern produces an interesting effect. The low level sea breeze brings in moist air from the south or southeast. The upper level winds, although not strong, are from the west to northwest. This causes the moisture to increase along the coast. The moisture pooling produces large values for the precipitable water. These values are typically in the range of 1.90 to 2.00 inches. This increase in moisture is a factor that favors land breeze thunderstorm development (Pielke and Segal 1986).

| Pressure | Direction | Speed |
|---|---|---|
| SFC | South | 3 kt |
| 1000 mb | South | 3 kt |
| 850 mb | South | 4 kt |
| 700 mb | West | 10 kt |
| 500 mb | West | 17 kt |

K index: 36
Precipitable Water: 1.97 in

**Table 2.** Data from the 0000 UTC, August 14, 1990, CHS sounding.

The NCLB thunderstorm activity was extensive with this moist sounding. The moist layer in these cases is typically very deep, extending well into the middle and upper layers of the atmosphere. Humidity values of 80 to 90% often reach the 500 mb level. Figure 2 shows the temperature and moisture profile for the 0000 UTC, August 14 sounding. This sounding is typical of the moisture profile for NCLB events.

The K-index is very useful in identifying soundings favorable for NCLB activity. The K-index takes into account the moisture at the 850mb and 700mb levels. As a result, high values (32 to 38) of the K-index are found for these cases. As one might expect, the high precipitable water values are also present.

Other indices, such as the LI and the total totals, were found to be insufficient to discriminate between the event and non-event cases. Because of the calculations involved, these indices usually produced similar unstable values regardless if the "moist sounding" described above was present.

Once the coastal wind pattern was established, and a moist sounding such as the one in Figure 2 was present, land breeze thunderstorm activity was extensive. The activity often began near the time of the shift from an onshore to an offshore flow along the coast.

Figures 3a and 3b show the radar observations from the early morning of August 14 (0830 and 0930 UTC, respectively). The noticeable shift of the winds to an offshore flow occurred around 0700 UTC (Table 1). Thunderstorm development also started at this time as small showers near the immediate coast (not shown). Figures 3a and 3b indicate the well developed thunderstorms that occurred at 0830 and 0930 UTC on August 14.

This case was typical of the days that experienced this type of thunderstorm activity. The key factor seemed to be the moist sounding. When the deep moisture was not present, especially through the middle levels, the thunderstorm activity was widely scattered or non-existent. Despite the convergence zone created by the coastal circulations, the NCLB convection was not as widespread with the drier soundings. This lack of moisture was reflected by the lower values for the K index and the precipitable water.

Table 3 reveals another day (August 11-12), when the land breeze occurred. Although the land breeze is not well pronounced at all the coastal stations, an offshore flow occurred between 1000 and 1300 UTC.

| | STATION | | | | |
|---|---|---|---|---|---|
| | **HRR** | **FBI** | **HHI** | **EDB** | **HBR** |
| TIME | | | | | |
| 22 UTC | SE5 | calm | S8 | S6 | - |
| 01 UTC | S6 | S9 | S7 | SW6 | - |
| 04 UTC | SW2 | S10 | S6 | SW6 | S7 |
| 07 UTC | SW2 | SW7 | NE5 | SW5 | SE5 |
| 10 UTC | N4 | S4 | NE2 | calm | - |
| 13 UTC | NW4 | N5 | N7 | NE6 | - |

**Table 3.** Coastal wind observations for August 11-12, 1990.

Table 4 presents the CHS sounding winds from 0000 UTC, August 12. The wind pattern on August 12 was somewhat similar to the pattern on August 14. The 0000 UTC sounding winds were fairly consistent, and both days had coastal wind circulations. While some thunderstorm activity occurred on August 12 (Figure 4), widespread convection like August 14 was not present (August 12 was considered a non-event for this study). By examining the sounding on August 12 (Figure 5), and comparing it to the sounding on August 14 (Figure 2), there is a noticeable difference in the moisture profile. The moisture in the middle and upper levels on August 12 is substantially less than for the August 14 sounding. This dry layer was reflected in the somewhat lower values of the precipitable water and the K-index.

| Pressure | Direction | Speed |
|---|---|---|
| SFC | south | 7 kt |
| 1000 mb | south | 10 kt |
| 850 mb | northwest | 6 kt |
| 700 mb | west | 11 kt |
| 500 mb | west | 11 kt |

K index: 32
Precipitable Water: 1.62 in

**Table 4.** Data from the 0000 UTC, August 12, 1990, CHS sounding.

Figures 6 and 7 show the 0000 UTC sounding and the observed radar summary from July 21, 1990. Note, the large area of moisture in the middle and upper levels (20,000 to 35,000 ft). The precipitable water value for this sounding was 1.97. The K-index was 32. Land breeze thunderstorms occurred on July 21 (Figures 7a and 7b).

## 6. CONCLUSIONS

Two key elements involved in the near coastal land breeze thunderstorm activity appear to be the presence of the coastal wind circulations, and the proper moisture stratification. The moist sounding, especially in the mid to upper levels, seems to be an important factor. Of the four cases that had substantial land breeze thunderstorm activity, all of them had a large moisture area that extended into the middle and upper levels of the atmosphere. The non-events lacked this feature. This increase of moisture along the coast appeared to enhance thunderstorm activity.

The precipitable water and the K-index were very useful for prediction of the moist sounding that would occur before the thunderstorm activity. Values of precipitable water between 1.90 and 2.00 were quite common, with K-index values in the range of 32 to 38. For the non-events, precipitable water values were in the range of 1.46 to 1.73, with K-indices between 21 and 32.

Given the limited number of cases used in this study, these values do necessarily represent thresholds, rather they are ranges that could aid in the assessment of the thermodynamic structure of the atmosphere for these types of events. An individual examination of the sounding is still necessary. The precipitable water and K-index values are generally useful in evaluating the moist sounding. However, small features in strategic locations can drastically impact indices that rely on point values such as the K index. An example of this is the July 21, 1990, NCLB thunderstorm case described earlier. The K-index was 32 at 0000 UTC on July 21. This is the same K-index that occurred on 0000 UTC August 12, a non-event. However, by examining the moisture profiles of the two days noticeable differences can be found. July 21 has considerable moisture in the middle to upper levels, while August 12, has a dry region.

The data set of land breeze thunderstorms for this study consisted only of the four cases during the summer of 1990. Since this type of thunderstorm activity is not a common occurrence, additional data were not available. However, the moist sounding did appear on all cases that experienced NCLB convective activity. A continued examination of similar cases in the future will expand upon this data base, and should provide more conclusive results.

**References**


Meyer, J. H., 1971: Radar observations of land breeze fronts. J. Appl. Meteor., 10, 1224-1232.

Pielke, R. A., and M. Segal, 1986: Mesoscale circulations forced by differential heating. Mesoscale Meteorology and Forecasting, P. S. Ray (Ed.), Amer. Meteor. Soc., Boston, MA, 516-548.

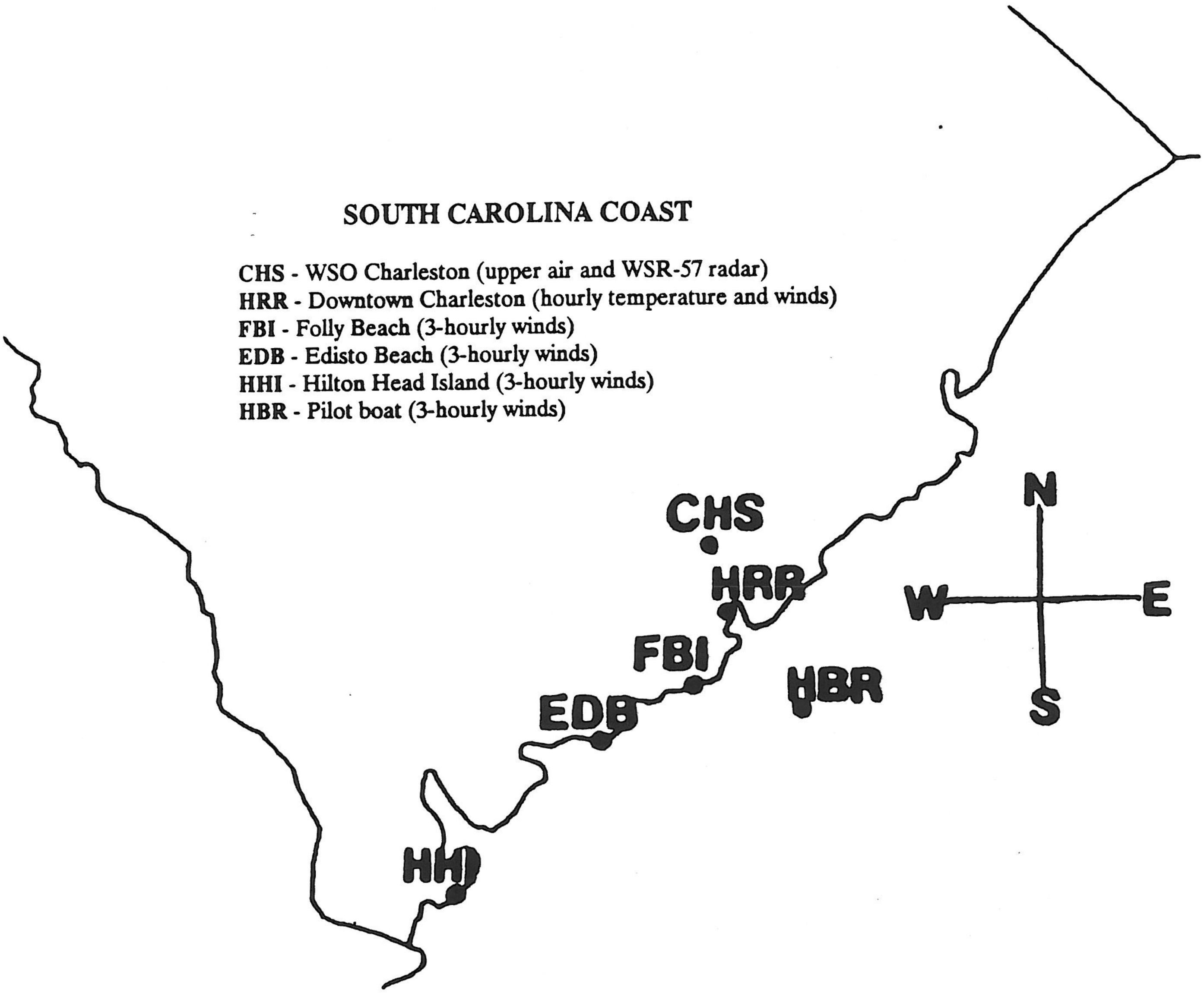


Figure 1. Observation locations for the surface, upper-air, and radar reports.

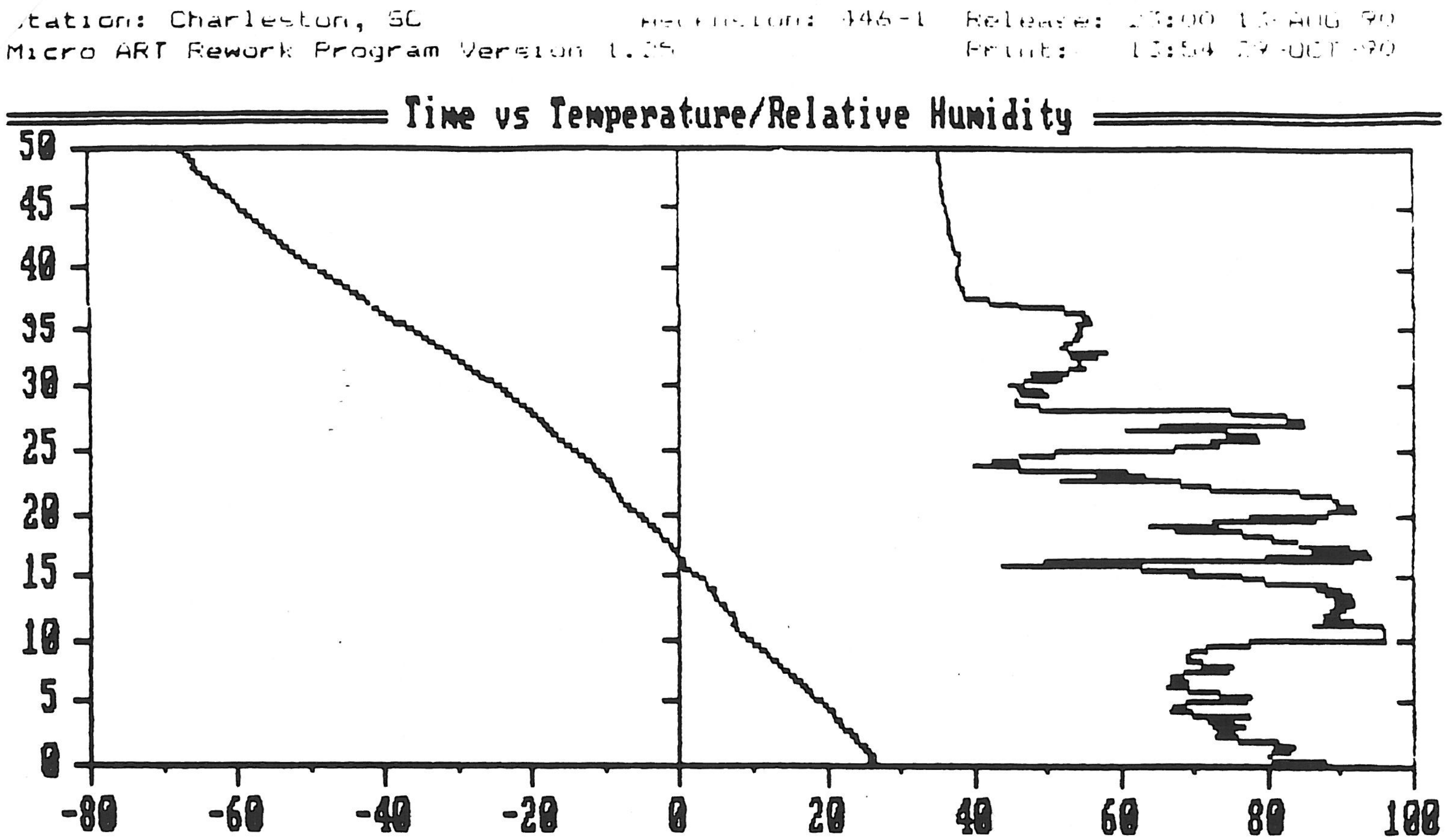


Figure 2. Temperature (°C)/Relative Humidity (%) vs. Time (min) plot of the 0000 UTC, August 14, 1990, sounding for CHS (1 min is approx. 1000 ft).

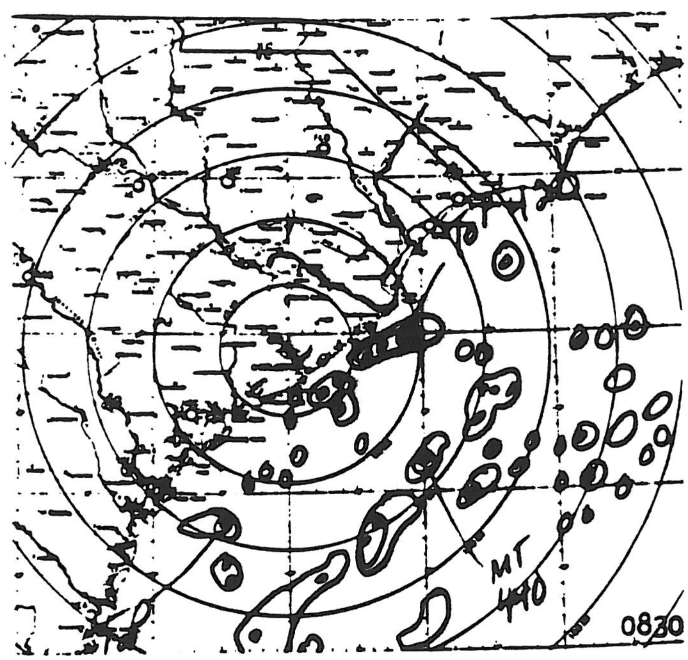


Figure 3a. CHS radar overlay for 0830 UTC, August 14, 1990.

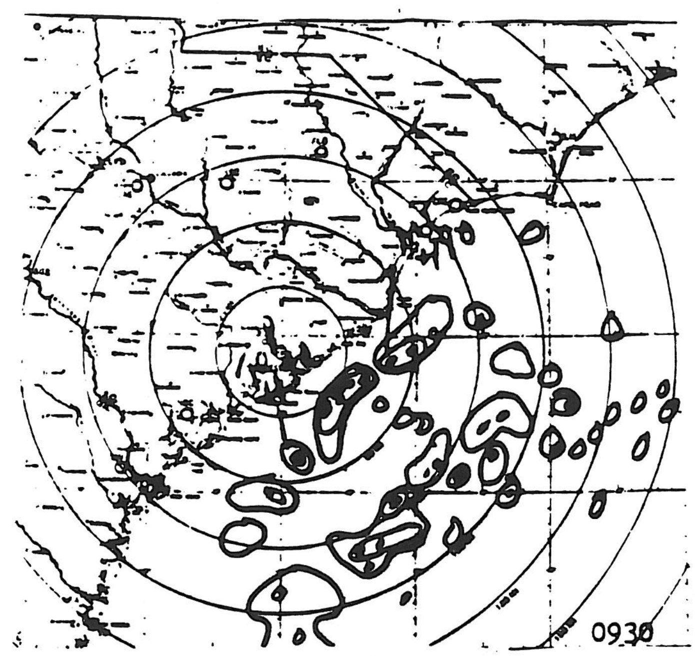


Figure 3b. CHS radar overlay for 0930 UTC, August 14, 1990.

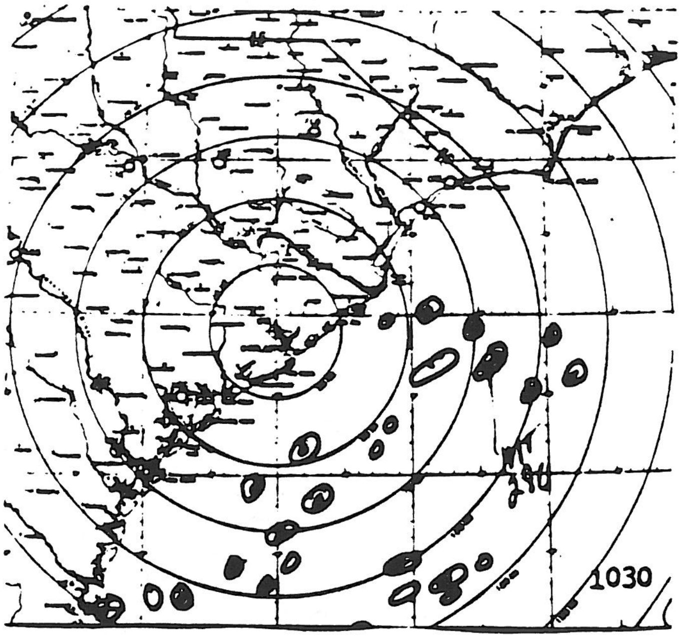


**Figure 4a.** CHS radar overlay for 1030 UTC, August 12, 1990.

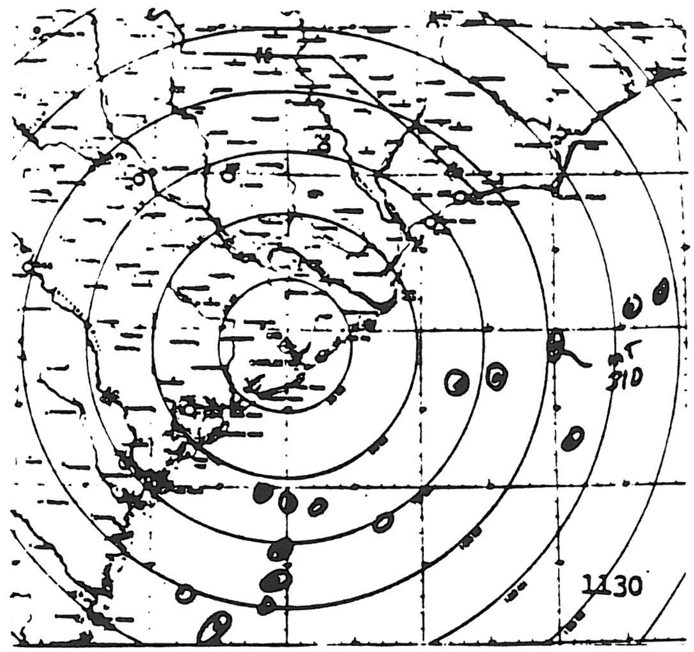


**Figure 4b.** CHS radar overlay for 1130 UTC, August 12, 1990.

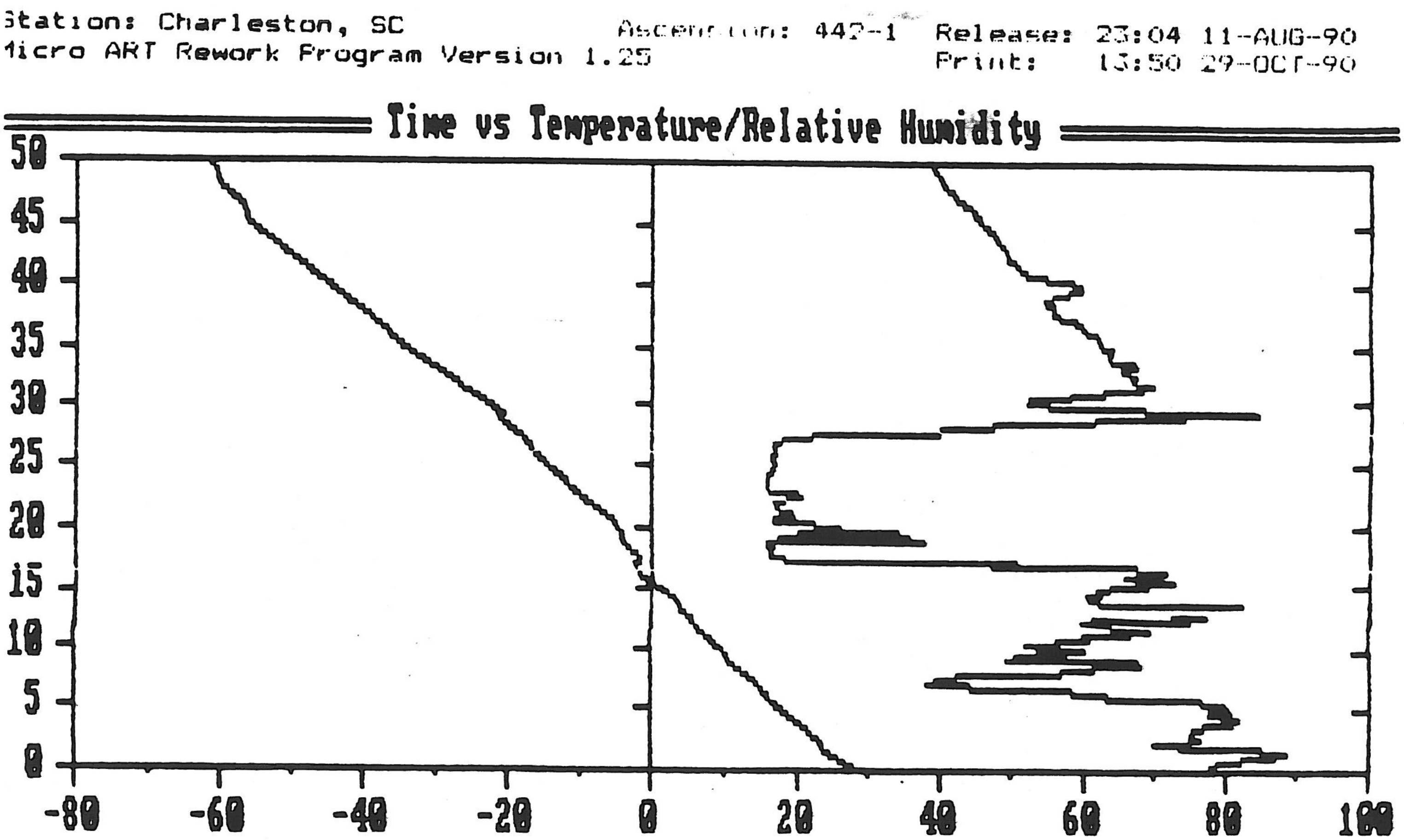


**Figure 5.** Temperature (°C)/Relative Humidity (%) vs. Time (min) plot of the 0000 UTC, August 12, 1990, sounding for CHS (1 min is approx. 1000 ft).

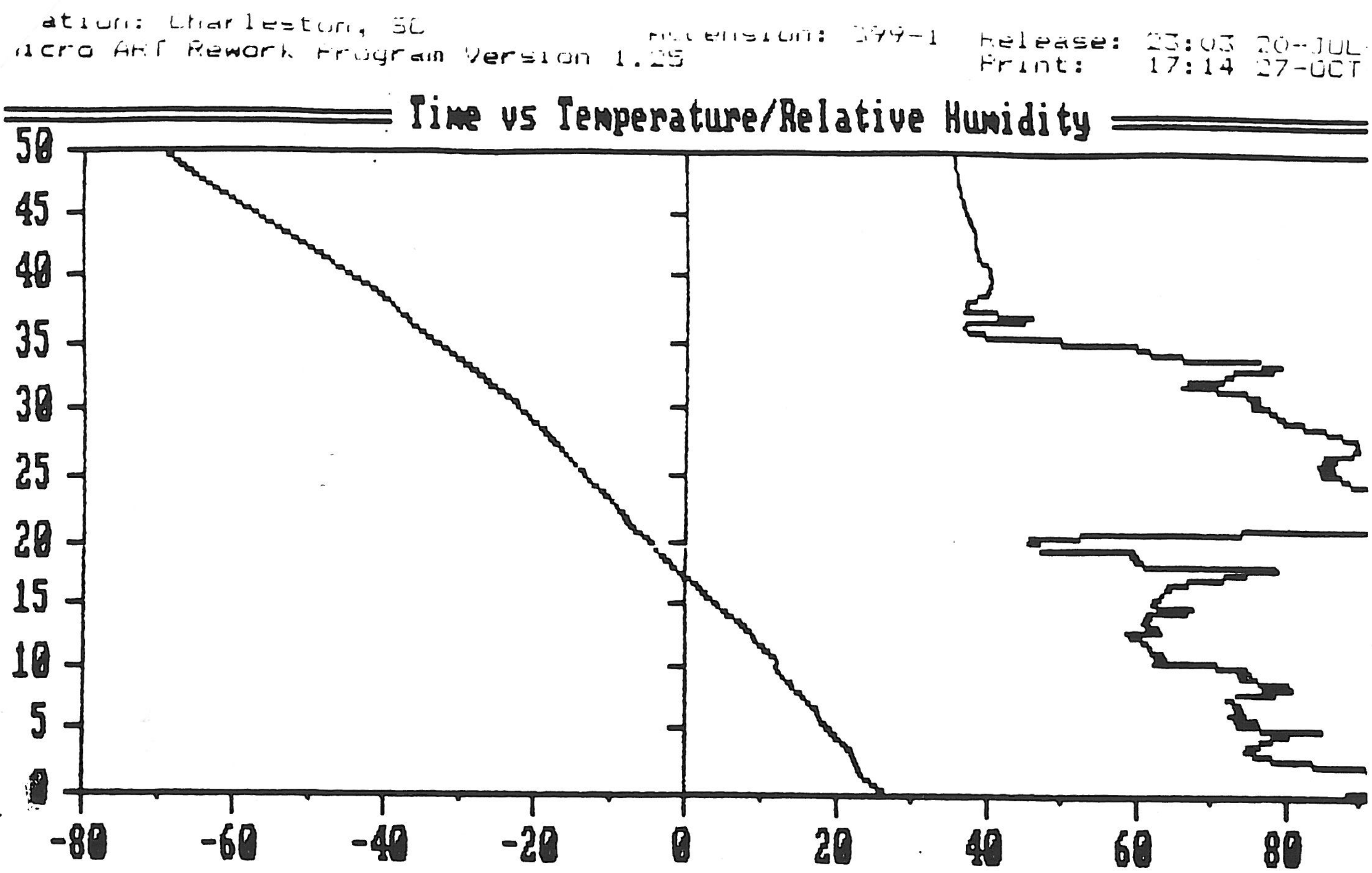


Figure 6. Temperature (°C)/Relative Humidity (%) vs. Time (min) plot of the 0000 UTC, July 21, 1990, sounding for CHS (1 min is approx. 1000 ft).

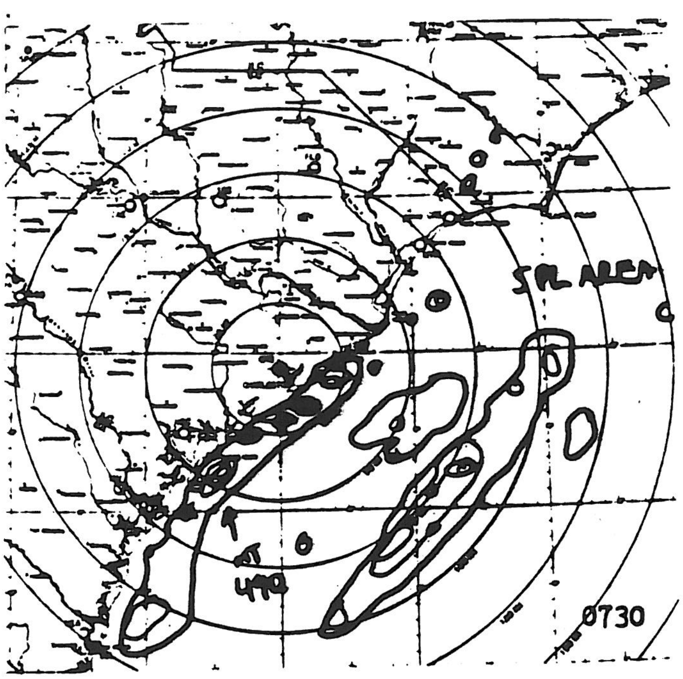


**Figure 7a.** CHS radar overlay for 0730 UTC, July 21, 1990.

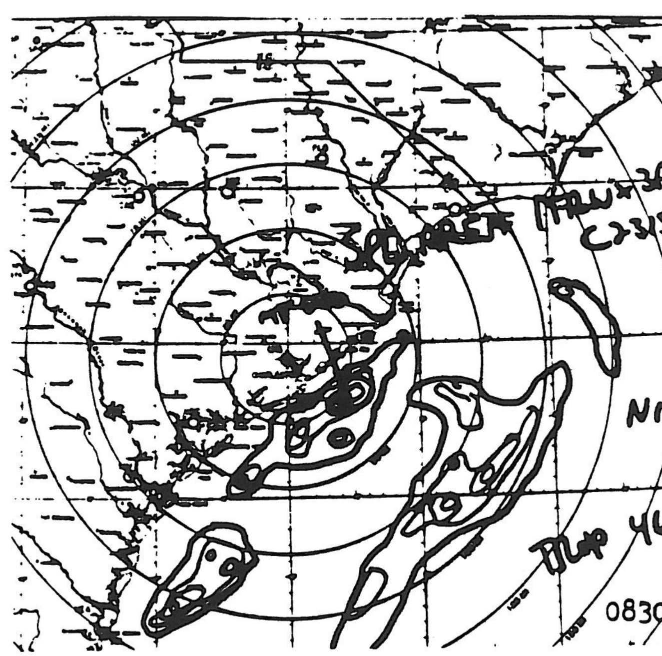


**Figure 7b.** CHS radar overlay for 0830 UTC, July 21, 1990.