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FLASH FLOODING IN SOUTH CAROLINA OCTOBER 10-12, 1990

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1. INTRODUCTION

October is climatically one of the driest months of the year in South Carolina; 1990 proved to be the exception. In October, 1990, torrential rains from the remnants of Tropical Storm Marco, and indirectly from the remnants of Tropical Storm Klaus, produced major flooding across the state. The heavy rain was associated with two distinct events.

Rainfall from the first event began Wednesday morning, October 10, 1990, with flash flooding observed on Wednesday night. This was a Regenerative type heavy rain event (Scofield 1978), with new convection developing upwind and moving over the same area in a train-effect. The event also had tropical-linear characteristics due to its configuration and source, but it was not the classic Tropical-Linear (Squall) type described by Maddox (1980).

Total rainfall amounts of 8 to 10 inches were observed from the south coast at Williams in Colleton County (Figure 1), to the north midlands at Sumter by 1200 UTC, Thursday, October 11 (Figure 2).

Nine counties in the upper coastal plain, and three counties in the piedmont plateau were declared federal disaster areas. At least three earthen dams in Kershaw County, about 25 miles northeast of Columbia, failed; one of which caused the death of four people in a car that was washed off U.S. Highway 1 near Camden. In Sumter County, railway traffic was halted, and several dams failed. In Calhoun County a train derailed off a track eroded by the floodwaters, and then crashed into bridge supports on U.S. Highway 176, collapsing the bridge; one motorist died and three were injured (FEMA 1990).

The second event occurred from late Thursday night, October 11, through Friday evening, October 12, with the worst flooding on Friday morning. The flooding affected mainly the piedmont and foothills, including the Weather Service Office at Greer (WSO GSP), in the western part of the state. The event fit the classic Synoptic-Tropical Storm Remnants type heavy rain event described by Spayd (1984). The heavy rain intensified at night, beneath the upper-level low at the 700-500 mb level, as has been observed previously in weakening tropical storms, after landfall. Total rainfall amounts of 6 to 8 inches occurred over the northern foothills and eastern piedmont (Figure 3). One fatality was reported, along with widespread flooding of streams and some secondary roads.

2. DISCUSSION

2.1 The First Event

At the surface (not shown), on 1200 UTC, Wednesday, October 10, Tropical Storm Marco was located approximately 100 miles west of Key West, FL. Marco had formed between Florida and Cuba during the previous 24 hours. From Marco, an inverted trough extended north-northeast across central Florida to near the South Carolina coast. A slow moving cold front was located from eastern Kentucky to western Alabama.

A band of convection was evident on satellite imagery (not shown) extending from a large area cloudiness east of Cuba, northwestward to the South Carolina coast. During the previous 36 hours, Tropical Storm Klaus moved northwest, skirting the north coast of Puerto Rico. As Klaus came under the influence of an upper low at 500 mb over eastern Cuba, cyclonic shear interfered with the storm's outflow aloft and tilted the storm. This lead to Klaus's eventual weakening northeast of the Dominican Republic, leaving an extensive region of cloudiness.

The 0000 UTC, October 11, 500 mb analysis, revealed winds from the south southeast over the Bahamas and east of Florida, with a 40 kt wind from 180° at Charleston, SC (CHS) (Figure 4). During the previous 12-hours, the cloudiness associated with the remnants of Klaus moved northwest, and was now located in a band of convection about 150 miles wide, from east of the Bahamas to the south Atlantic coast. This band moved onshore between CHS and Brunswick, GA (SSI). The winds aloft paralleled the band of convection. This caused the precipitation to remain nearly stationary, as new convection moved across the same areas, resulting in a train-echo effect.

The Nested Grid Model (NGM) 500 mb analysis at this time (not shown), indicated a minimum vorticity axis extended from east of the Bahamas to the south coast of South Carolina. This was about the time that flash flooding was occurring. This axis was directly above the band of convection. Forecasters at the National Meteorological Ccenter Heavy Precipitation Branch (HPB) have observed similar cases of minimum vorticity axes at 500 mb associated with other heavy rain events (Frank Brody, personal communication). The author has also noted several instances of this co-location. Minimum vorticity axes are not normally associated with significant weather. However, for these events, convection usually develops elsewhere, and then moves beneath the minimum vorticity axis.

In synoptic scale environments conducive to heavy rainfall, the profile (strength and direction) of the winds aloft usually determine the configuration of the heavy rain area. When the winds aloft are strong, as in this case (also typical for diminishing squall lines), the winds blow parallel to the band of convection. This causes the area of precipitation to appear to remain nearly stationary. New convection develops upwind, and moves successively over the same area in a train-effect (Regenerative type event). For lighter winds aloft, the area of heavy rain is not elongated, resulting in a more circular shape, with new convection developing on the inflow side of storm complexes. This is this case in the Mesohigh type event described by Maddox et al. (1979).

Difluence was evident in the wind fields at both 300 and 200 mb at 0000 UTC, October 11, over South Carolina (not shown). The region was also under the right-rear quadrant of a polar jet streak. These two features enhanced convective development by increasing outflow in the upper portions of the thunderstorms, as well as implying large scale rising motion.

The 850 mb analysis (Figure 5) for 0000 UTC, October 11, revealed a 40 kt low-level jet from 170° at CHS. This provided a continuous supply of warm moist tropical air, that enhanced the instability of the air-mass. The 850 mb dewpoint at CHS was 15°C. Goodman et al. 1983 associated 850 mb dewpoints of 10°C or higher, a low-level jet, and a mechanism to focus convection with heavy rainfall events of 5 inches, or more.

The 0000 UTC, October 11, sounding for CHS had a K-index of 36, with a precipitable water value of 2.26 inches. This value, calculated using the AFOS STAB program (Little 1983), was 225% of climatic normal. These K-index and precipitable water values are consistent with those suggested by Maddox et al. (1979) for heavy rain/flash flood events.

Considerable buoyant energy was present prior to, and during this event. The AFOS CONVECT program (Stone 1988), indicated a positive energy index of +51 at CHS at 1200 UTC, October 10, which increased to +68 by 0000 UTC, October 11. The energy index is a measure of the available potential buoyant energy that is converted to kinetic energy as a parcel of air is lifted, from the maximum wet-bulb potential temperature in the lowest 150 mb of the sounding, to the 400 mb level.

At the surface, the inverted trough that was located near the coast early on October 10 intensified and moved inland to the midlands by 0000 UTC, October 11 (Figure 6). The increased low level convergence associated with this inverted trough provided a focusing mechanism for the event. Wind convergence, coupled with the pooling of surface dewpoints in the mid 70s east of the trough, resulted in substantial moisture convergence in the vicinity of the trough.

Rain spread into the south coast and midlands during the morning of the 10th, becoming heavy in the afternoon. Rainfall rates of 2 inches an hour occurred during Wednesday evening over the inland south coast, and eastern midlands, based on reports from cooperative observers. By 0000 UTC, October 11, rainfall of 6 to 8 inches was reported over part of the area. Satellite precipitation estimates from the National Environmental Satellite Distribution Information Service (NESDIS) were very close to the actual rainfall rates reported.

In contrast, the western part of the state received rainfall amounts of 2 inches, or less, from the first event. No flooding occurred over this region, but the rainfall set the stage for a second flood event by increasing the soil moisture.

2.2 The Second Event

By 1200 UTC, October 11, Tropical Storm Marco was moving north near Tampa, FL. A heavy rain event began late Thursday night, October 11, and continued into Friday evening, October 12, as the remnants of Tropical Storm Marco moved across southern Georgia and South Carolina.

At 0000 UTC, October 12, Marco was downgraded to a depression as it moved through southern Georgia. However, the system remained a closed circulation from the surface through 700 mb (not shown). The inverted surface trough continued to shift westward, now located over the Piedmont. At 500 mb, an open trough was associated with Marco. The circulation at 500 mb was evident from the NGM vorticity analyses valid at 0000 and 1200 UTC, October 12 (Figures 7 and 8, respectively).

This 500 mb vorticity center became the focus for the second event, with the heaviest rain falling just to the east of its track, late Thursday night and Friday morning. Spayd (1984) indicated that excessive amounts of rain in decaying tropical systems typically occur at night near the upper-level circulation center.

The upper-level center was evident on satellite imagery as an area of warm-top convection. Warm-top convection (Scofield 1984) is defined as cloud tops that are warmer than -62°C on infrared imagery. Infrared satellite enhancement curves correlate different black-grey-white shades on satellite imagery to the temperature of cloud tops. Temperatures colder than -62°C on the MB enhancement curve appear as repeat grey, while black, dark, medium, and light grey shades depict increasingly warmer temperatures (Parke 1986).

At 0000 UTC, October 12, the K-Index was 35 at Athens, GA (AHN). Precipitable water of 1.81 inches was about 200% of normal.

The surface analysis for 0900 UTC Friday, October 12, is shown in Figure 9. This was just before flash flooding began over the foothills of South Carolina. The cyclonic circulation from the remnants of Marco was still very evident just south of Augusta, Georgia (AGS). The rain diminished temporarily late Friday morning, but increased again from the northern foothills to the midlands during the afternoon, as moisture convergence increased with the passage of the surface low. The rain ended Friday evening as the low moved northeast of the state, and moisture convergence decreased.

3. NMC GUIDANCE

The 1800 UTC Wednesday, October 10, HPB excessive rain outlook outlined an area approaching flash flood guidance that included the south coast, south midlands, piedmont, and the foothills of South Carolina. The mountains were placed in an area expected to exceed flash flood guidance.

Flash flood guidance was quite high; rainfall of 4.5 to 5 inches were needed in 3 hours to produce flash flooding, due to a lack of precipitation across the state during the preceding 2 months. The area forecast to approach flash flood guidance included the western and southern sections of the area that experienced flash flooding. Unfortunately, the north midlands, where the worst flash flooding occurred, were not included in the area expected to approach, or exceed, flash flood guidance.

The HPB guidance was more accurate for the second event. The Quantitative Precipitation Forecast (QPF) guidance issued Thursday, October 11 was for 1/2 to 2 inches of rainfall over the eastern part of the state, and 3 to 5 inches for the mountains and northern foothills. Much of South Carolina was outlined in an area expected to exceed flash flood guidance. This forecast was issued about 15 hours prior to flash flooding in the western part of the state.

4. CONCLUSIONS

The first event was difficult to anticipate for several reasons. The dry weather preceding the event resulted in high flash flood guidance values. The HPB guidance placed the greatest threat of flash flooding over the western part of the state, where the topography is most variable, and historically most of the flash floods in South Carolina occur.

The first event was triggered by two primary factors; the influx of tropical moisture, and the location of the inverted surface trough. The tropical moisture was evident on GOES imagery moving into the state the morning of Wednesday, October 10. The inverted trough, intensified and moved from near the coast early Wednesday, to the midlands by evening. The inverted trough focused and maximized moisture convergence over the midlands, and in combination with an upper flow aligned parallel to the trough, resulted in convection successively moving over the same area in a train-effect. While the threat of larger scale heavy rainfall was apparent, this band of extreme precipitation was an evolving situation that would have been difficult to pinpoint more than about 2 to 3 hours before the event. By the 0000 UTC, Thursday, October 11, the incoming upper-air data only confirmed what was already occurring.

Many previous investigations on flash flood events have resulted in an arsenal of forecast guidance and heavy rain signatures that forecasters associate with excessive rain events. Most flash flood events occur on the meso- and smaller scales (4-400 km), and are a short-range (6 hours or less) forecast problem. However, several heavy rain signatures, such as those described by Maddox et al. (1979), are apparent on the synoptic scale (400 km or greater). Recognition of these signatures can result in longer forecast lead times (12 hours or more), as was the case for the second event.

In addition to being alert for the synoptic scale heavy rain signatures, there is a need to further investigate mesoscale aspects of these events, and develop forecast techniques using currently available tools. One potentially valuable resource appears to be the AFOS Data Analysis Program (ADAP) (Bothwell 1988). Hopefully, further inroads will be made in developing new techniques to better utilize the real-time information available for making short-range forecast decisions.

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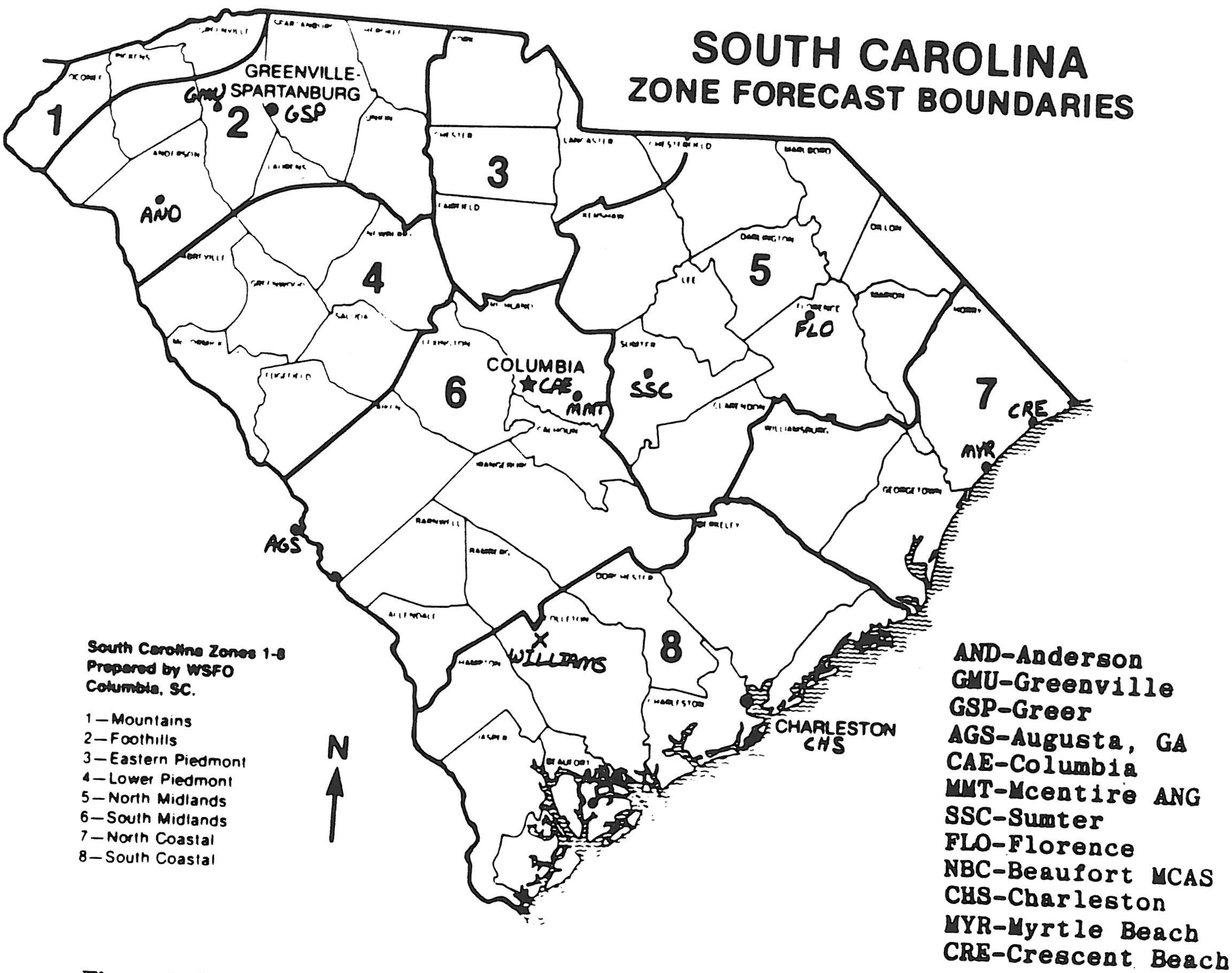

Figure 1. Map of South Carolina. Surface observation locations and public forecast zones are noted for reference.

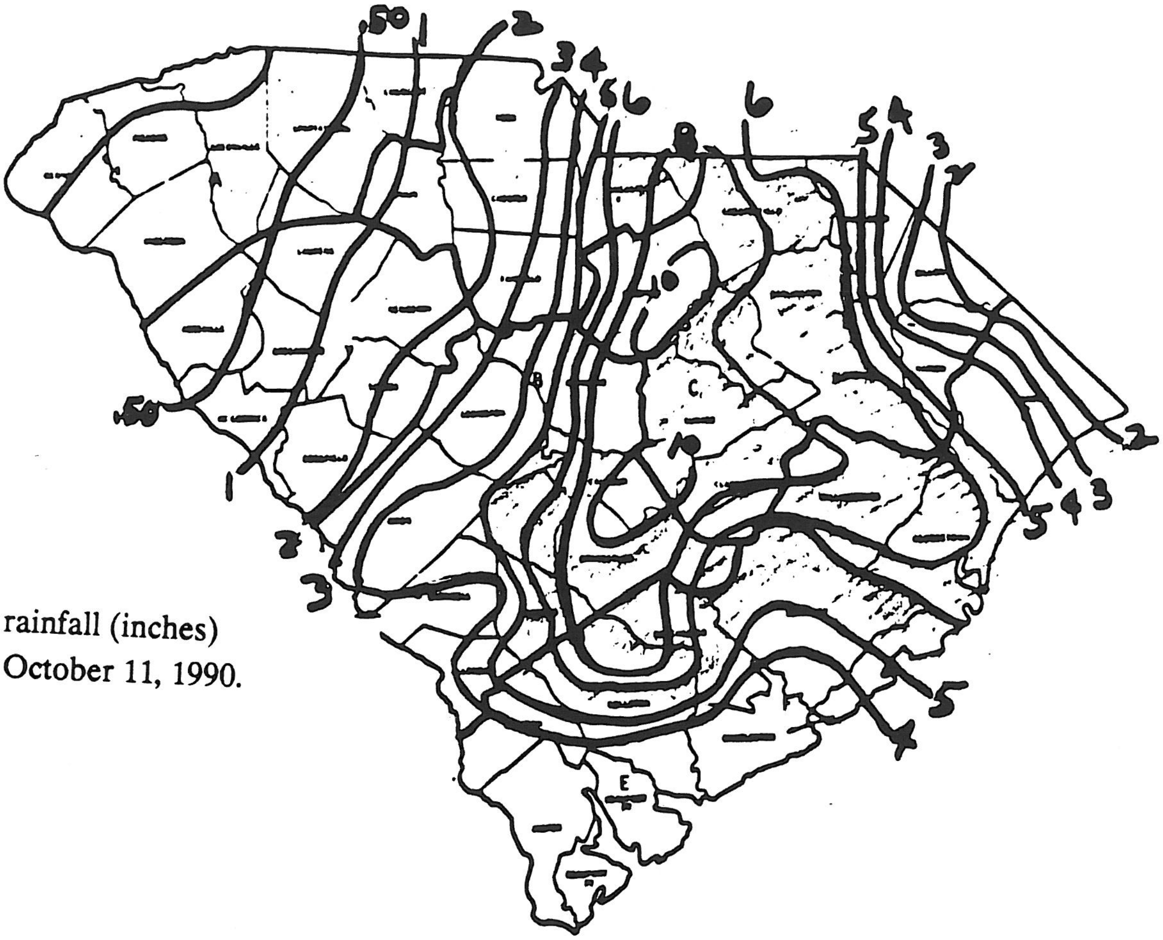

Figure 2. 24-hour rainfall (inches) ending 1200 UTC, October 11, 1990.

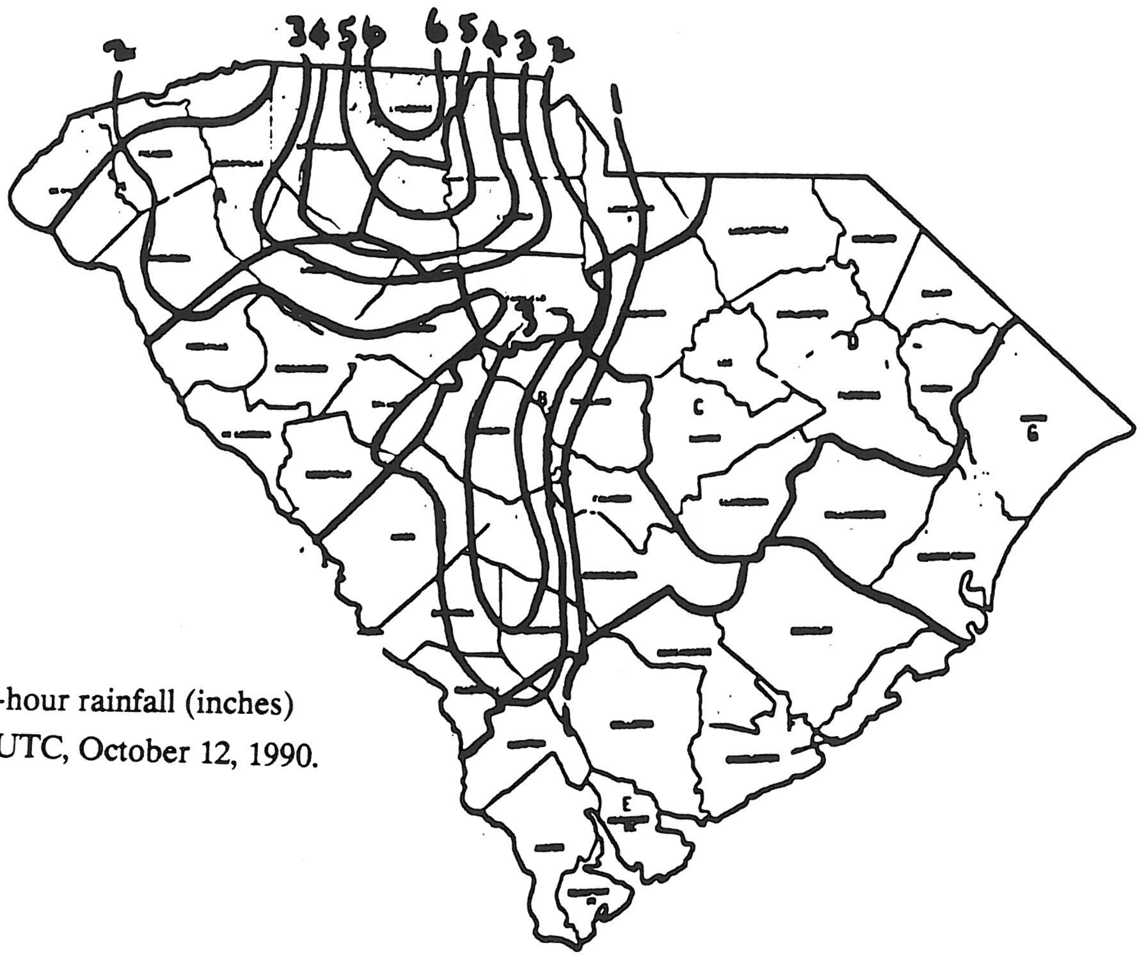

Figure 3. 24-hour rainfall (inches) ending 1200 UTC, October 12, 1990.

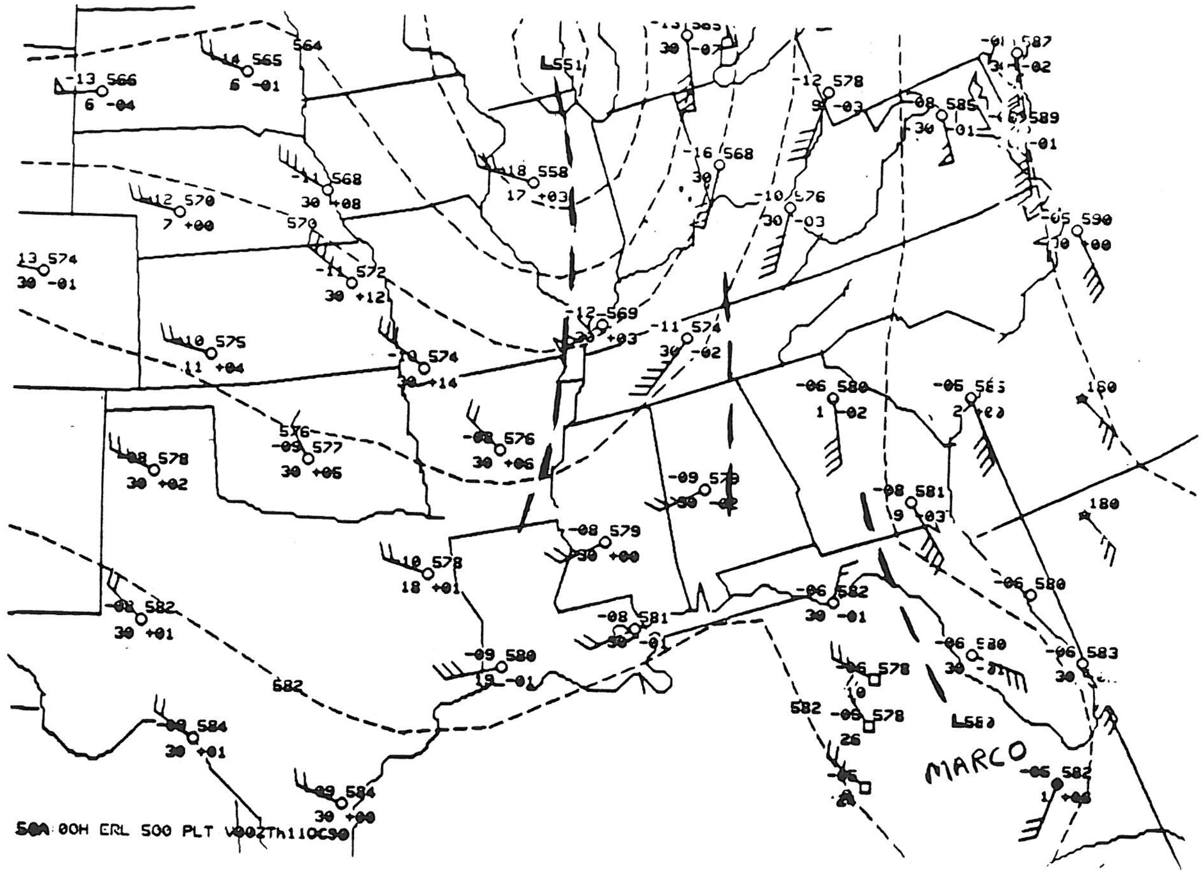

Figure 4. 500 mb analysis for 0000 UTC, October 11, 1990. Dashed lines are height contours. The positions of troughs and Tropical Storm Marco are also indicated.

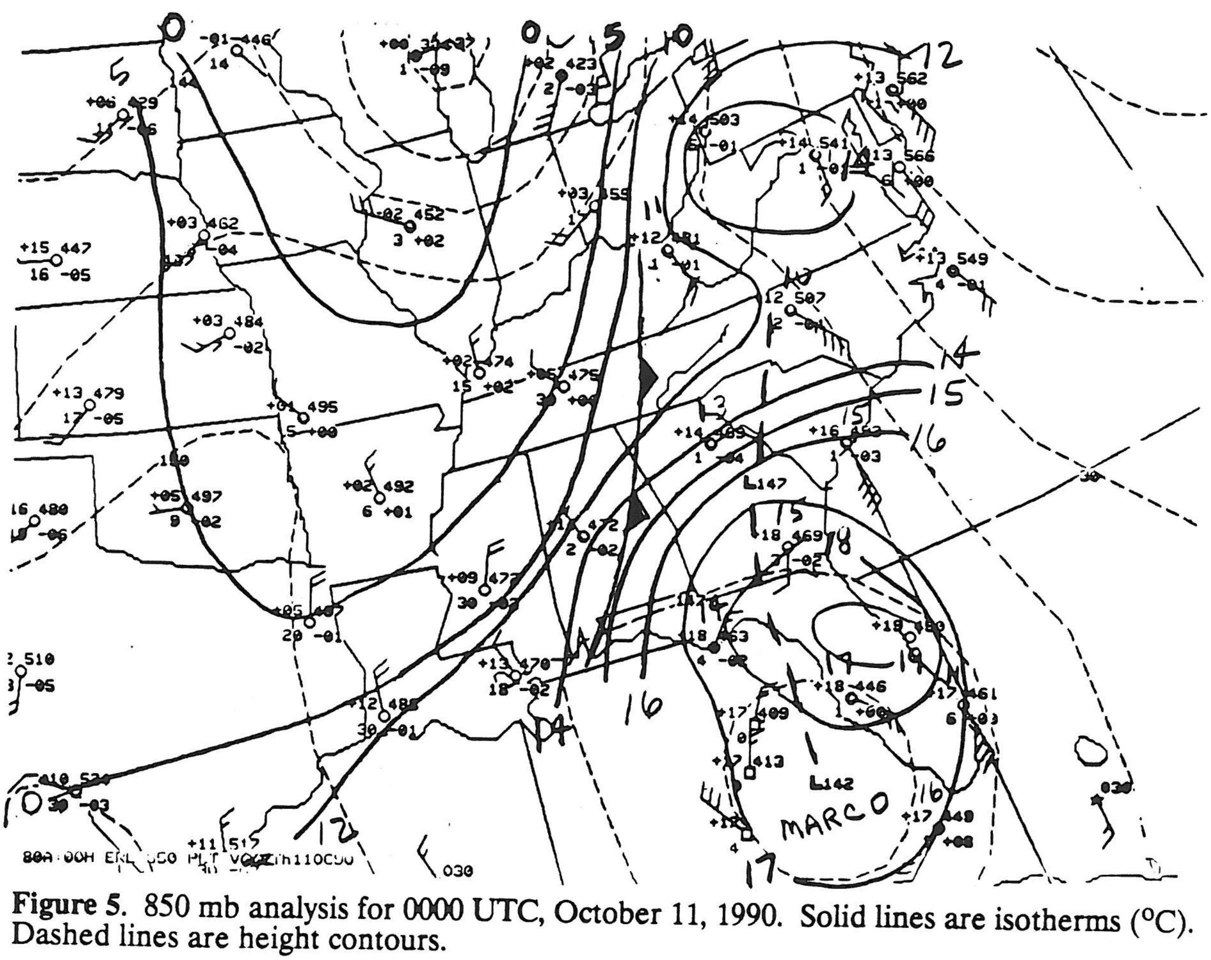

Figure 5. 850 mb analysis for 0000 UTC, October 11, 1990. Solid lines are isotherms (°C). Dashed lines are height contours.

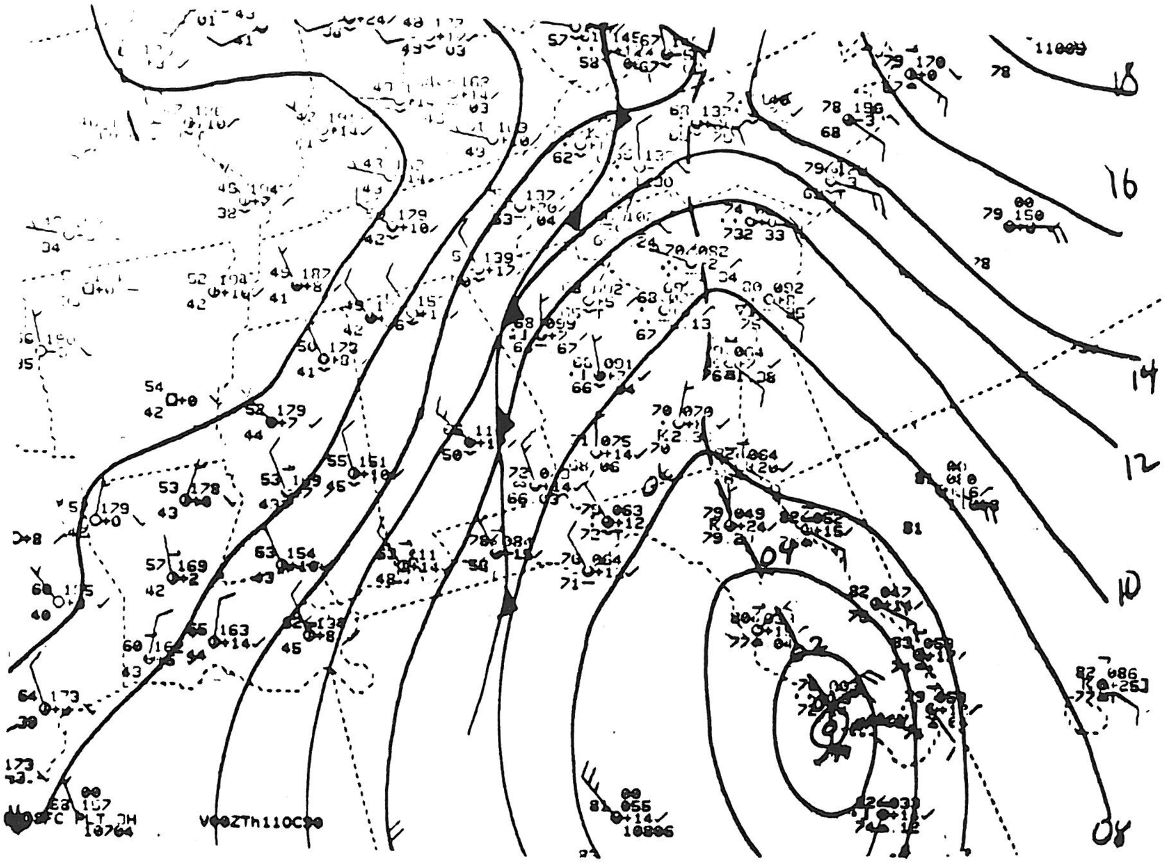

Figure 6. Surface analysis for 0000 UTC, October 11, 1990.

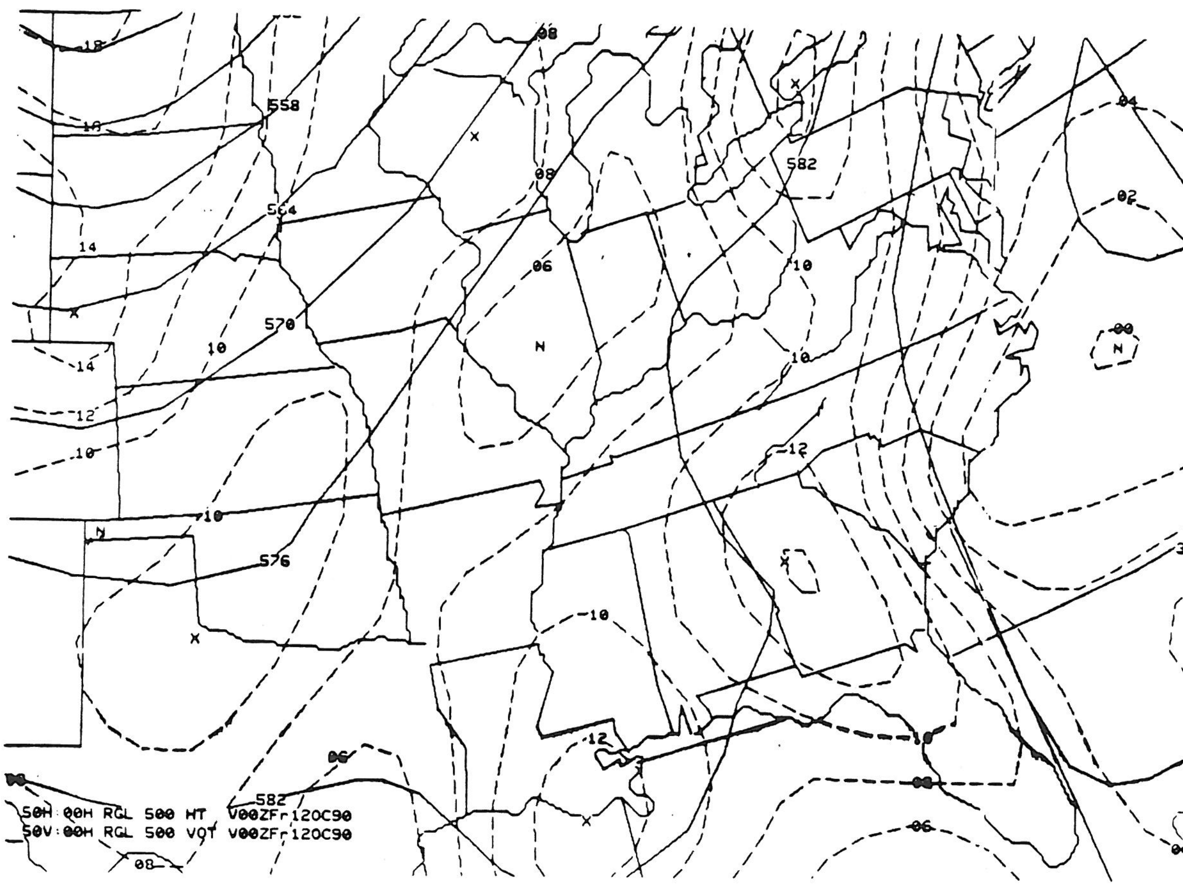

Figure 7. NGM initialized 500 mb heights (solid) and vorticity (dashed) for 0000 UTC, October 12, 1990.

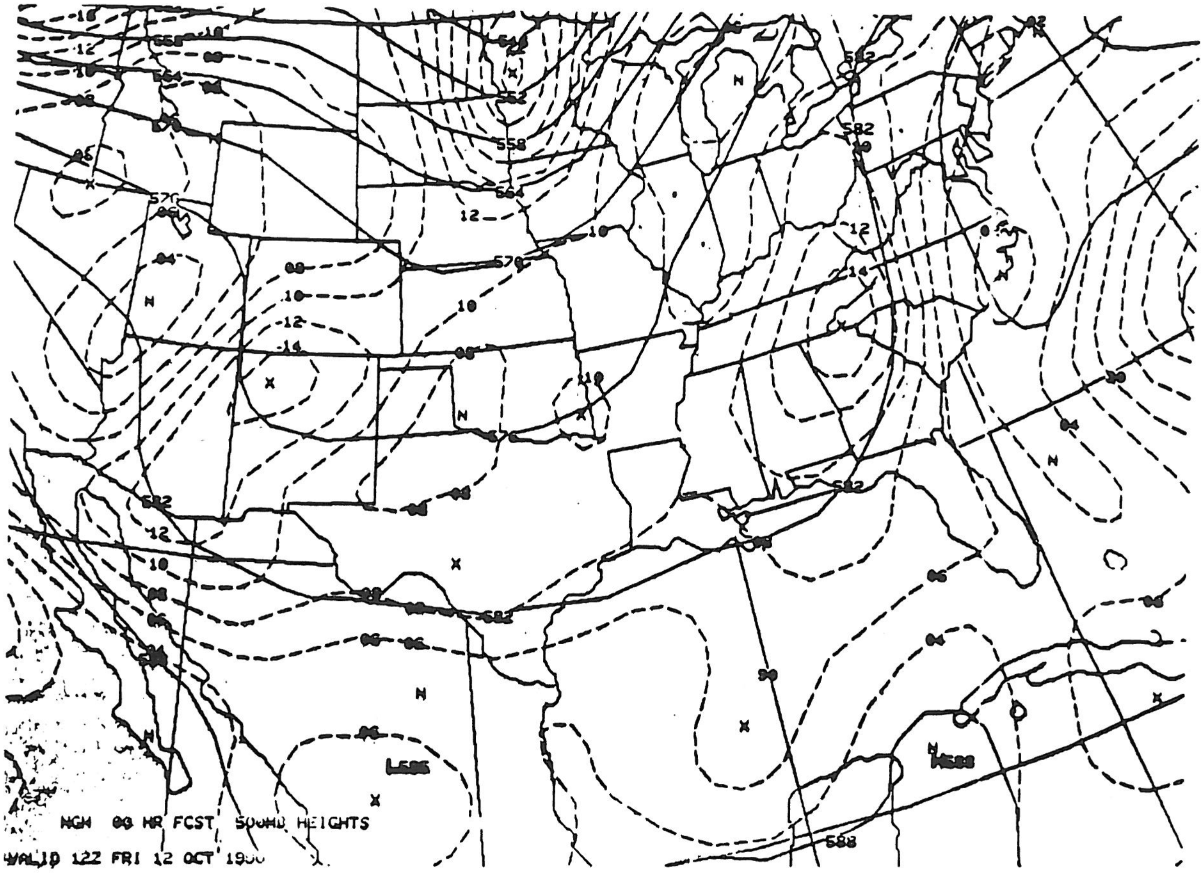

Figure 8. NGM initialized 500 mb heights (solid) and vorticity (dashed) for 1200 UTC, October 12, 1990.

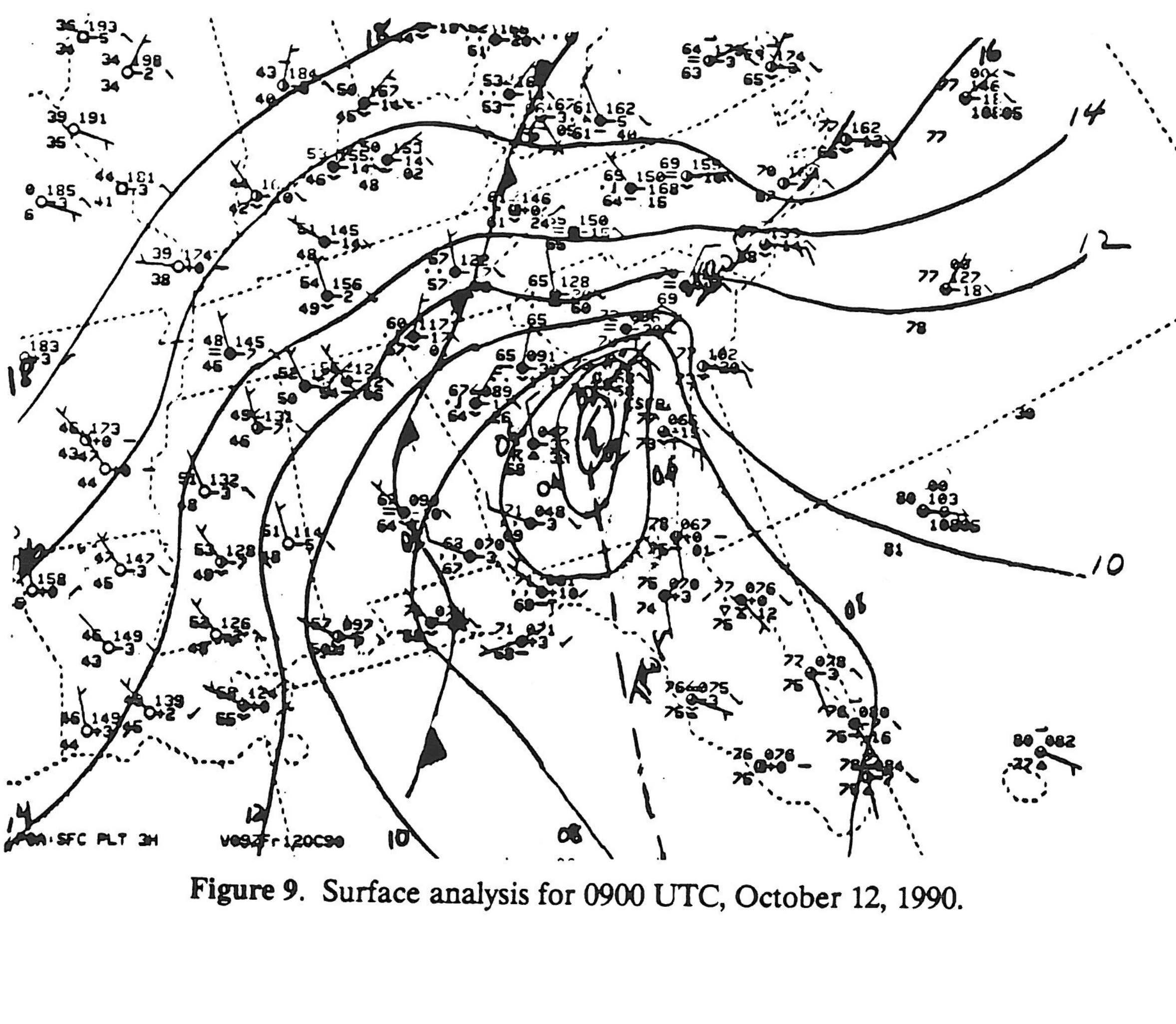

Figure 9. Surface analysis for 0900 UTC, October 12, 1990.