16C.6 COMPOSITE AND CASE STUDIES OF PRECIPITATION DISTRIBUTION IN U.S. LANDFALLING TROPICAL CYCLONES

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1. Introduction

Forecasting precipitation associated with landfalling tropical cyclones is a great challenge for the meteorological community due to unpredictability in wind speed, storm surge, and precipitation. Compounding the problem are outside influences, from the synoptic to mesoscale. A case study is presented here of Tropical Storm Marco (1990), which was responsible for 7 deaths and $57 million in damage in the southeast United States (Mayfield and Lawrence, 1991). From 1200 UTC 9 October through 1800 UTC 13 October 1990, Marco interacted with a large-scale trough, a strong upper-level jet, a coastal front, and two other tropical cyclones. The purpose of this paper is to further examine these interactions to better explain Marco's precipitation distribution. Additional figures beyond those shown here can be found at http://www.atmos.albany.edu/student/srock/marco.htm.

2. Data and Methodology

Gridded (0.25° x 0.25°) daily precipitation was obtained from the Unified Precipitation Dataset (UPD), a 24 h (1200 UTC to 1200 UTC) accumulated total over the United States. Storm track data is from the National Hurricane Center's best track positions. Synoptic data is from the NCEP/NCAR Global Reanalysis on a 2.5° x 2.5° grid (Kalnay et al., 1996; Kistler et al., 2001). Surface data over land are from NCEP's ADP Global Surface Observation dataset and the U.S.A.F. DATSAV3 dataset, while marine data is from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). The General Meteorological Package (GEMPAK) was used for plotting the data.

3. Storm Track and UPD Analysis

Tropical Storm Marco originated off the coast of Cuba around 1200 UTC 9 October 1990. From there, it traveled slowly northwestward and increased in intensity. Marco tracked north along the west coast of the Florida Peninsula, with winds at one point measured at 28 m s^{-1}. Eventually, Marco made complete landfall near Cedar Key, Florida around 0000 UTC 12 October. Although weakening since just before landfall, the cyclonic disturbance was tracked as a tropical depression through Georgia and South Carolina, where it stalled, weakened, and dissipated.

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Figure 1 shows the total UPD precipitation from 1200 UTC 9 October through 1200 UTC 13 October 1990, as well as the archived best track. Maximum values of over 25 cm of rain fell within this four day period. A further look at day by day UPD analyses provides further insight into the observed rainfall distribution. Figure 2 shows a plot of 24 h precipitation ending 1200 UTC 11 October. Note the northward bulge in heavy precipitation (totals over 100 mm) which stretches through North Carolina and Virginia for this 24 h period. However, at 1200 UTC 11 October, Marco is west of Tampa, Florida, so this northern precipitation maximum can not be directly imputed to Marco.

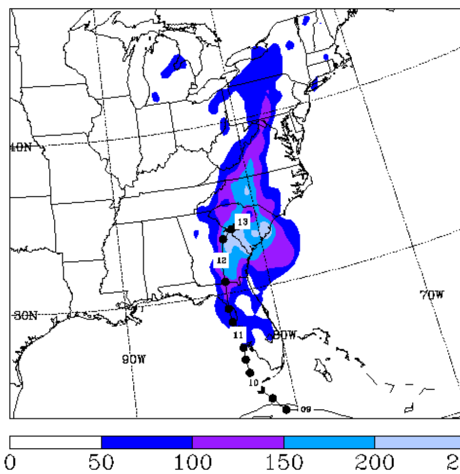

Figure 1. Storm track and total precipitation (mm) from 1200 UTC 9 October to 1200 UTC 13 October 1990.

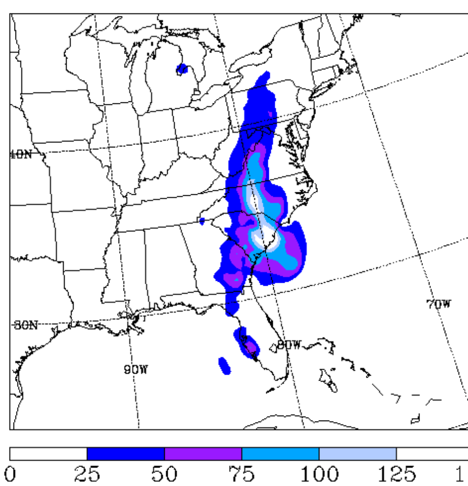

Figure 2. Total UPD precipitation (mm) for the 24 h period ending 1200 UTC 11 October.

4. Synoptic Analysis

At 0000 UTC 9 October 1990, twelve hours before Marco was officially designated as a tropical depression, the remnants of Hurricane Klaus approached the United States coast. Although Klaus weakened to the point that it was no longer tracked as a tropical system, high θ_e air associated with the storm continued to move toward the Georgia/South Carolina coast. At 1200 UTC 9 October, a large-scale positively-tilted trough east of the Rockies dominates the flow over the eastern two-thirds of the United States. This trough is too far north to interact with Marco directly, but there is a potential for shortwave vorticity maxima to swing through the base and influence Marco as it moves north.

By 0000 UTC 10 October 1990, a 20 x 10^{-5} s^{-1} 500 hPa vorticity maximum over Kansas begins to swing through the base of the large-scale trough (not shown, see website). Over the next 36 h, this vorticity maximum deepens and approaches the Appalachian Mountains. The moisture from Klaus has continued to move toward the Georgia/South Carolina coast, bringing warm, moist air over land. Also, there is a strong 200 hPa jet throughout this period, with an equatorward entrance region positioned over the Southeast coastal states. The combination of the mid-level cyclonic vorticity advection and upper-level jet entrance region provide strong forcing for ascent over the moist remnants from Klaus (not shown, see website). At 1200 UTC 11 October, Marco is due west of Tampa, Florida, suggesting that the northward bulge in precipitation seen in Fig. 2 is likely a result of this synoptic forcing.

Heavy precipitation continues over Florida, Georgia and the Carolinas through the rest of Marco's lifetime. By 1200 UTC 12 October, the strong 500 hPa vorticity maximum has passed through the trough and lifted out, but a strong 200 hPa jet right-entrance region remains over the southeastern United States. Through this period and the next 24 h, Marco seems to be in good position with the 200 hPa jet for a potential extratropical transition (Jones et al., 2003). However, as can be seen in Fig. 1, Marco's track veers toward the east while the horizontal storm speed slows. Hurricane Lili approaches the United States coast quickly from the east. Marco and Lili potentially undergo binary interaction (Prieto et al., 2003), which would cause Marco to tend to track to the south and east, while Lili would be forced to the north and west. This is consistent with the track of both Marco and Lili, and at least partially explains why Marco did not undergo an extratropical transition and dissipated over South Carolina.

5. Surface Analysis

Mesoscale surface features also play very important roles in Marco's lifetime. As is the case with many landfalling tropical cyclones, local orography can play a vital role in forecasting precipitation distribution. Most notable is the formation of a coastal front stretching from Florida along the coast through the Carolinas. Coastal fronts [e.g. Bosart et al. (1972)] usually form with a low-level high pressure system to the north of the front. In this case, a low pressure center to the south (Marco) allows for surface easterly flow to be blocked against the mountains with associated inland coastal front formation. Both a distinct wind shift and thermal boundary can be seen in eastern Georgia and South Carolina as Marco nears and makes landfall (not shown, see website). Moisture from the dying remnant of Klaus likely collected along the inland coastal front boundary. Low-level convergence and warm-air advection along and to the west of the coastal front boundary likely contributed to ascent and copious precipitation in a moisture-rich environment. Precipitation mechanisms will be discussed more fully in the presentation.

6. Summary

Tropical Storm Marco never reached hurricane force, but was still a huge part of a prolific rain-producing system which caused $57 million in damage. Marco's interaction with moisture remnants from Hurricane Klaus acted to enhance a coastal front boundary along the southeastern Atlantic coast. Although an extratropical transition was possible for Marco after landfall, binary interaction with Hurricane Lili off the East Coast prevented Marco from connecting to the upper level system.

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