P1.33 A COMPOSITE STUDY OF PRECIPITATION DISTRIBUTION IN U.S. LANDFALLING TROPICAL CYCLONES

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1. Introduction

Landfalling tropical cyclones (TCs) in the eastern United States present a difficult forecast challenge due to unpredictability in wind speed, storm surge, and flooding. This problem continues to be of major concern, because although improvements in TC forecasts continue, the population growth in threatened coastal areas increases at an even greater rate (e.g. Sheets 1990).

In 1990, Tropical Storm Marco was the only named tropical system to make landfall in the United States. Between 9 October and 13 October 1990, some areas affected by Marco received over 250 mm of rain. Although a tropical storm for less than two days, Marco was responsible for seven deaths and is blamed for $57 million in damage (Mayfield and Lawrence 1991), mostly due to heavy precipitation and flooding. Most of this damage occurred in Georgia and the Carolinas, although the storm had long before lost tropical storm status.

This poster will focus on the lifetime of Marco, with emphasis on the relationship between Marco and its surrounding environment. This includes interactions with synoptic cyclones, as well as with Hurricanes Klaus and Lili.

2. Data and Methodology

The NCEP Unified Precipitation Dataset (UPD) is used in this study. The 0.25 x 0.25 degree gridded UPD is a daily analysis of 24 h accumulated precipitation (1200 UTC to 1200 UTC) over the United States. Data from the NCEP/NCAR Global Reanalysis (Kalnay et al. 1996) on a 2.5 x 2.5 degree grid and GEMPAK are also used to create standard pressure level maps for a synoptic examination of the case. The data was plotted every six hours, which provides a good base to perform a synoptic overview. Also important to this study is NHC best track data for past tropical cyclones. This is used for both the best track plot, as well as for pointing out the location of tropical cyclone centers on the synoptic plots.

3. Storm Track Overview

Tropical Storm Marco originated near Cuba around 1200 UTC 9 October 1990. It moved slowly northward while slowly increasing in intensity – both in minimum central pressure and maximum wind speed. As Marco tracked just offshore on the western side of the Florida peninsula, 28 m s^{-1} sustained winds and greater than 140 mm of storm total rain were recorded (Mayfield and Lawrence 1991). Marco moved onshore near Cedar Key in the eastern Florida Panhandle soon after 0000 UTC 12 October, and slowly made its way north into Georgia and South Carolina. Even before landfall, Marco had lost status as a tropical storm, and was tracked as the center of a tropical depression.

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4. UPD Analysis

Figure 1 shows a plot of UPD data for the lifetime of Marco, plotted with best track positions and path. Precipitation from 1200 UTC 9 October to 1200 UTC 13 October was summed and contoured (mm, scale below the plot). Most noticeable is the very heavy precipitation centered over South Carolina. Although a first approximation would suggest that most of this precipitation fell along Marco's track while it was in the area, this is not the case. Only about 50% of the rainfall over South Carolina was a direct result of Marco, as will be shown later. Two daily plots of UPD are shown, one for the 24 hours preceding 1200 UTC October 11, and the other for the following 24 hour period (Fig. 2a and 2b, respectively). While Marco is still west of Tampa, Florida, there is a huge areal precipitation maximum of 100 mm or greater which bulges from the South Carolina coast north into North Carolina and southern Virginia. However, the next day's rainfall totals show the maximum further south and west, this time more directly attributable to Marco. Possible reasons for this discontinuity will be examined in the next section.

5. Synoptic Analysis

At 0000 UTC 9 October, the remnants of Hurricane Klaus are moving toward the U.S. coast. Although Klaus is nearly 1000 km from land and does not make landfall as a tropical cyclone, the moisture associated with it does reach the US. By 1200 UTC 9 October, Marco's circulation is recognizable over Cuba. At this time, a large-scale trough dominates the flow over most of the United States. This large trough is too far north to interact with Marco, but smaller shortwave vorticity centers that swing through the base of the trough could interact with the tropical cyclone.

By 0000 UTC 10 October, Marco is situated about 100 km south of Key West, Florida. A 20 x 10^{-5} s^{-1} 500 hPa vorticity maximum begins to swing through the base of the large-scale trough at this time. Over the next 12 hours, this vorticity center will grow in strength, reaching a maximum value greater than 22 x 10^{-5} s^{-1} at 1200 UTC 10 October (Fig. 3a). At the same time, θ_e values greater than 340 K at 925 hPa are already situated east of the Appalachians, while a strong θ_e gradient can be seen behind the Appalachian Mountains, roughly in the same orientation as the mountains (Fig. 3b). It is hypothesized that the high θ_e values over the southeast US are mostly associated with the remnants of Klaus. Even though the circulation from Klaus has basically disappeared, the very moist lower layers still remain.

The 24 h period beginning at 1200 UTC October 10 corresponds with the precipitation shown in Fig. 2. Throughout this period, Marco stays just off the west coast of Florida while still tracking slowly north. At 1200 UTC 11 October, South Carolina and North Carolina sit in the right entrance region of the 200 hPa jet, a region favorable for ascent (Fig. 4a). The strong 500 hPa vorticity center seen 24 hours earlier over Missouri has moved across the axis of the mountains, and also contributes to forcing for ascent through cyclonic vorticity advection (Fig. 4b). The low level environment now has an even stronger θ_e gradient, with its location shifted further south and east (Fig. 4c). Winds over Georgia and South Carolina at this time suggest a cross-gradient flow as well. This warm moist air is a reflection of the moisture remnants of Klaus, but some component of the moisture and winds also may be due to the circulation from Marco.

Over the 24 hours ending 1200 UTC 12 October, the aforementioned strong 500 hPa vorticity maximum moves north and east along the coast, leaving Marco behind. Also at this time, Hurricane Lili moves toward the coast from the east. Although too distant to influence Marco for most of this period, its effects will be much more noticeable later. A 200 hPa jet maximum still exists over the Atlantic coast, although slightly weaker than before (Fig. 5a). Marco is situated in the right entrance region of this jet, as well as in the left exit region of the weak jet streak to the southwest. This jet configuration implies ascent exists over Marco. Unlike the previous 24 hour period, however, there is no strong vorticity center near the East Coast (Fig. 5b). A weak vorticity maximum is situated west of the Great Lakes, but does not appear to affect the local precipitation maximum seen in Figure 2b for this period. High θ_e air is still present at 925 hPa, with the highest values following the cyclone (Fig. 5c). The combination of a very moist lower troposphere combined with synoptically forced ascent at upper levels continues the onslaught of rain.

With a 500 hPa vorticity maximum upstream and a favorable jet structure downstream at 1200 UTC 12 October, the stage is potentially set for Marco to undergo extratropical transition (ET, Jones et al. 2003). This pattern suggests that Marco should increase its speed of movement and be picked up by the upper-level system. However, over the next 24 hours, Lili nears the East Coast of the United States, roughly at the same latitude of Marco (not shown). These two centers of circulation are so close that one can see hints of the Fujiwhara effect, in that these two centers appear to move cyclonically around each other. This means that Marco will tend to move south with time, lessening the chance that it will be picked up by the next trough and undergo possible ET. Thus, the upper-level trough moves northeast, while Marco weakens and dissipates.

6. Summary

Tropical Storm Marco was a prolific rain-producing storm which wreaked havoc across the southern Atlantic coast states from 9-13 October 1990. Precipitation from Marco and predecessor storms during that time totaled over 25 cm in some locations, and caused regions of high water and flooding. The rainfall in this case is not all directly attributable to Marco alone, but also involves complex interactions with other tropical cyclones on various scales. A brief synoptic overview suggests that the moisture from the remnant of Hurricane Klaus contributed significantly to the total rainfall in the early periods of this case. Further study into this case, including surface frontal analyses, will be performed at a later time.

7. Acknowledgments

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8. References

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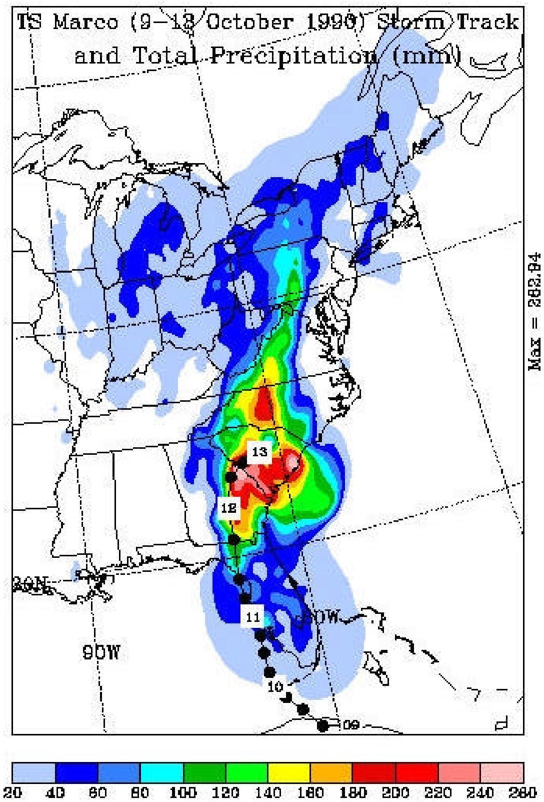

Figure 1. NHC best track position of TS Marco every 6 h (boxed numbers at 1200 UTC each day) and total UPD accumulated precipitation (mm) from 1200 UTC October 9 through 1200 UTC October 13 1990.

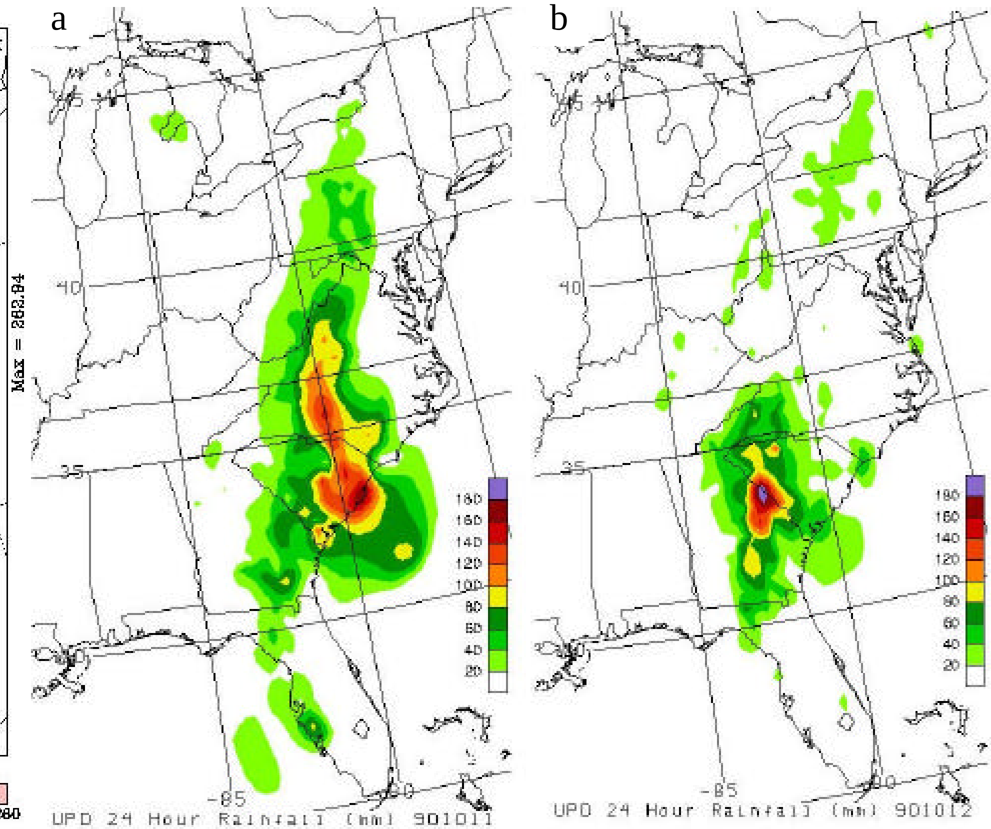

Figure 2. 24 hour UPD total precipitation (mm) ending 1200 UTC for (a) 11 October 1990 and (b) 12 October 1990.

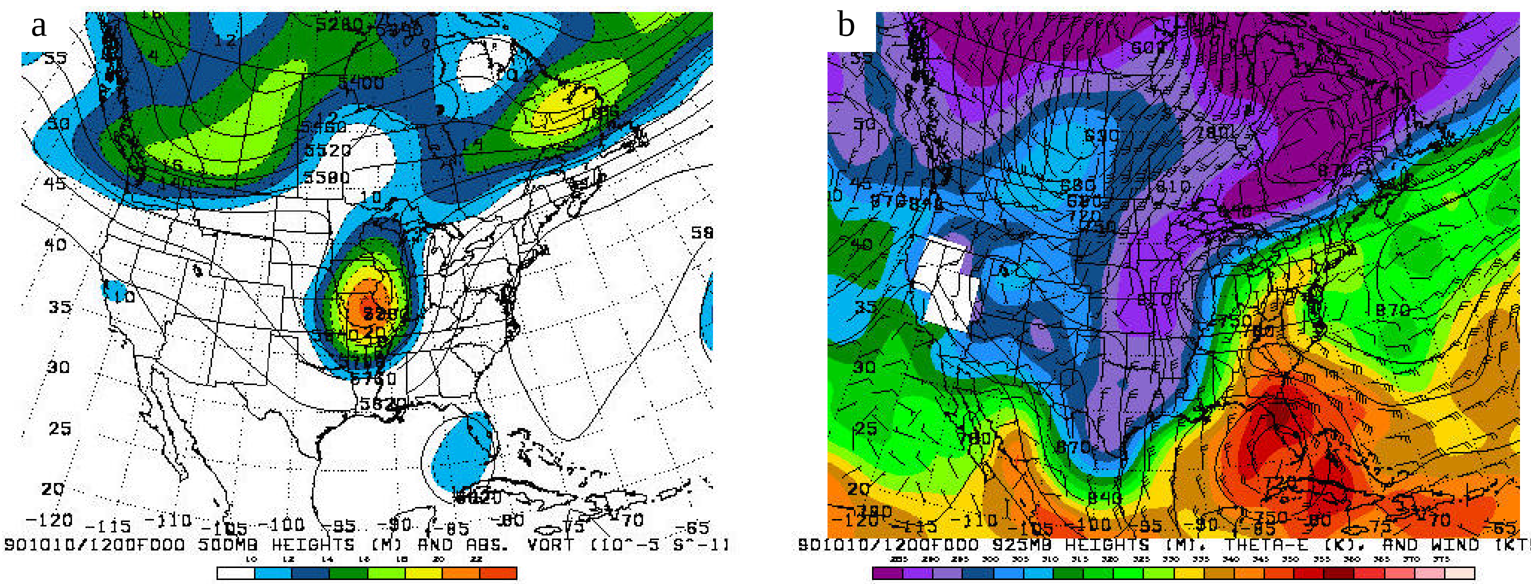

Figure 3. 1200 UTC 10 October 1990 (a) 500 hPa heights (contoured every 60 m), absolute vorticity (contoured and shaded above 10 x 10^{-5} s^{-1}). (b) 925 hPa heights (contoured every 30 m), θ_e (shaded every 5 K), and winds (full barb is 10 knots, half barb is 5 knots).

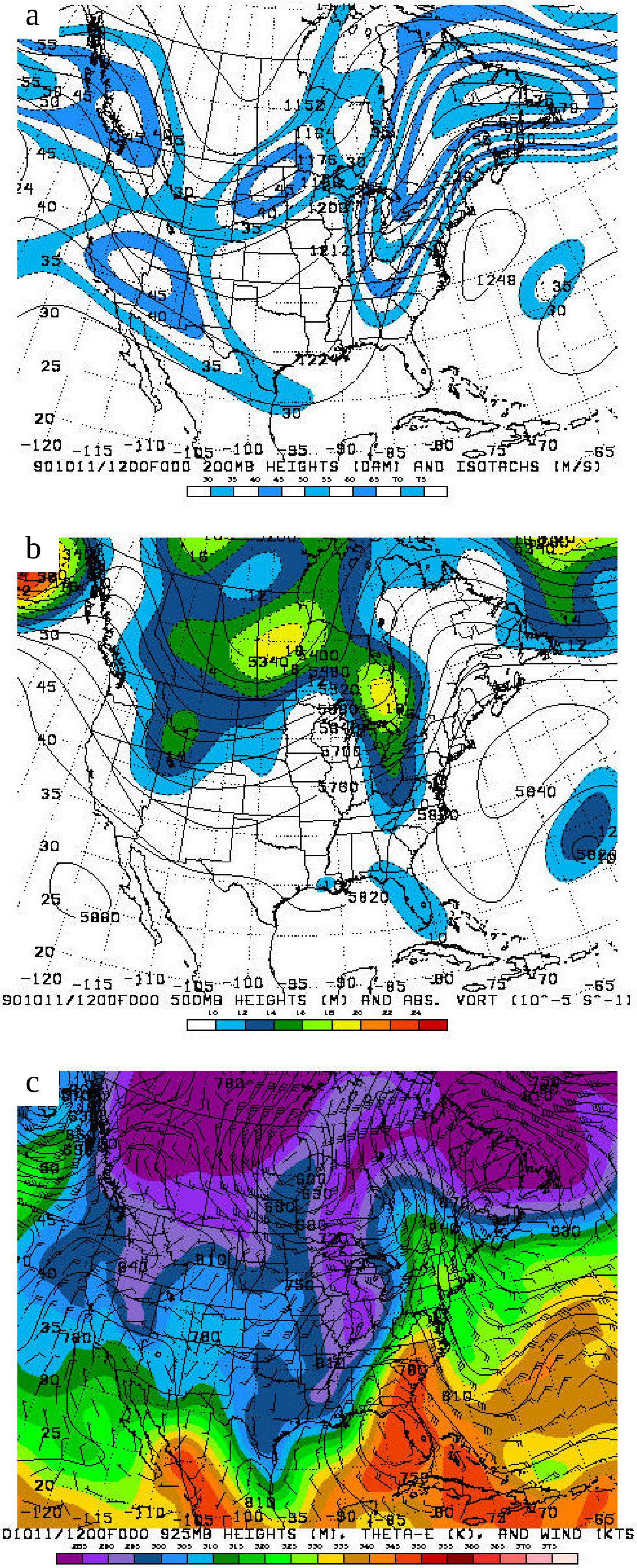

Figure 4. 1200 UTC 11 October 1990 (a) 200 hPa heights (contoured every 12 dam) and winds (shaded every 5 m s^{-1} starting with 30 m s^{-1}). (b) 500 hPa heights (contoured every 60 m), absolute vorticity (contoured and shaded above 10 x 10^{-5} s^{-1}). (c) 925 hPa heights (contoured every 30 m), θ_e (shaded every 5 K), and winds (full barb is 10 knots, half barb is 5 knots).

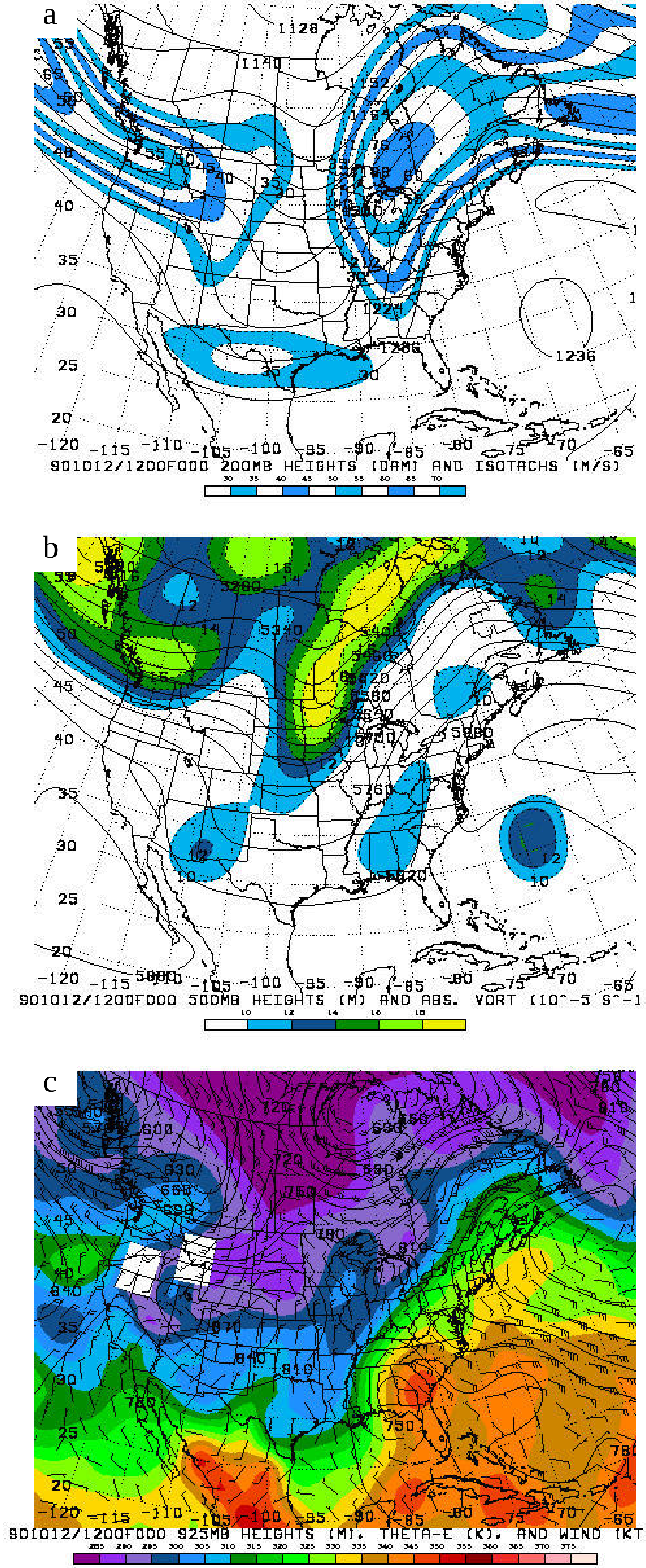

Figure 5. As in Figure 4, but for 1200 UTC 12 October 1990.