7B.8 AN EXAMINATION OF THE SYNOPTIC AND MESOSCALE ENVIRONMENTS INVOLVED IN TORNADO OUTBREAKS FROM HURRICANES FRANCES (2004) AND JEANNE (2004) OVER NORTHEAST COASTAL GEORGIA AND SOUTHERN SOUTH CAROLINA

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1. INTRODUCTION

During the 2004 hurricane season, the Charleston, South Carolina National Weather Service (CHS) County Warning Area (CWA) verified tornado touchdowns with tropical systems Bonnie, Charley, Frances, Ivan, and Jeanne. The two largest tornado outbreaks occurred in September 2004 with the remnants of Hurricanes Frances and Jeanne. Both hurricanes crossed central Florida peninsula from southeast to northwest, then turned north and moved into southwest Georgia and the southern Appalachians. The storms produced a combined 26 tornadoes (NCDC 2004) across northeast coastal Georgia and southern South Carolina. While both hurricanes were similar in strength and size at landfall, and took similar tracks across Florida and southwest Georgia, Frances produced over 3 times more tornadoes (20) than Jeanne (6) across the Charleston CWA.

The Frances tornado outbreak helped to produce new daily, monthly, and yearly records for tornadoes in the state of South Carolina. The 41 tornadoes that occurred in South Carolina on 7 September 2004 shattered the old daily record of 23 tornadoes on 16 August 1994 during the outbreak associated with Tropical Storm Beryl (South Carolina State Climate Office 2004). While the Frances tornado outbreak spanned two days, 6 and 7 September 2004, the Jeanne outbreak was much shorter, beginning and ending through the morning hours of 27 September 2004.

Across the Charleston CWA, there was considerable media coverage for a substantial tornado outbreak with the remnants of Jeanne. This was partly due to the record setting Frances tornado outbreak, which occurred only three weeks earlier. With Frances and Jeanne sharing a similar track and strength, it appeared that the CWA was going to be hit with yet another large tornado outbreak. Favorable tropical tornado parameters such as a low Convective Available Potential Energy (CAPE), deep tropical moisture, and high shear (McCaul 1991), along with our location in the right front quadrant of these land falling hurricanes, would indicate that another large tropical tornado outbreak was indeed possible with Jeanne.

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The synoptic and mesoscale environments associated with these outbreaks will be reviewed. Synoptic factors such as the position of an upper level jet, moisture profiles, and forward speed of the two storms will be examined. Instability, shear, and the location of surface boundaries will be analyzed to see if these parameters enhanced convection during these outbreaks. The use of mesoscale analysis tools and parameters will be discussed and a determination will be made whether such tools could enhance the situational awareness during this type of outbreak.

2. FRANCES

a. Overview

Hurricane Frances made landfall on Hutchinson Island, Florida at 0430 UTC 5 September 2004 as a category 2 hurricane (Beven II 2004). Frances weakened to a tropical storm by 1800 UTC 5 September while moving northwest across the central Florida peninsula at 8 kt. Frances remained a tropical storm as it reemerged over the northeast Gulf of Mexico and began to turn north. Frances weakened to a tropical depression by 0600 UTC 7 September as the center of the storm moved north at 10 kt across far southwest Georgia. By 0000 UTC September 8 Tropical Depression Frances was crossing northern Georgia and would move up the southern Appalachians during the day of 8 September 2004 (Fig. 1).

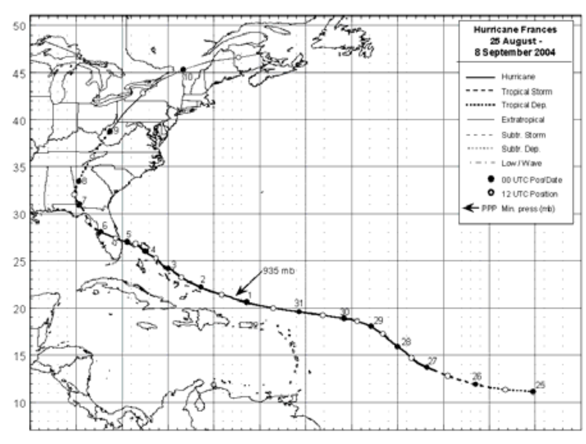

Fig 1. Best track positions for Hurricane Frances, 25 August - 8 September 2004. (Beven II 2004)

b. Synoptic Conditions

On 5 September, high pressure at the surface and at 700-300 hPa was firmly in control over the Southeast and Tennessee Valley, helping to slow down Frances' northward movement across Florida. Satellite images showed a large area of deep moisture and convection over the Atlantic and off the Carolina coast, associated with a weak cutoff 500 hPa low pressure area. An upper ridge over the east began to show signs of weakening as an upper level trough moved through the central Rockies.

A 250 hPa 100 kt jet associated with this central Rockies trough was located over the northern plains by 1200 UTC 6 September. The cutoff low pressure area over the Atlantic and centered east of North Carolina did enhance a jet streak on the equatorward side of the upper low along the Mid-Atlantic coast. This jet streak allowed for strong divergence aloft over the Charleston CWA in the vicinity of the right entrance region of the jet (Fig. 2).

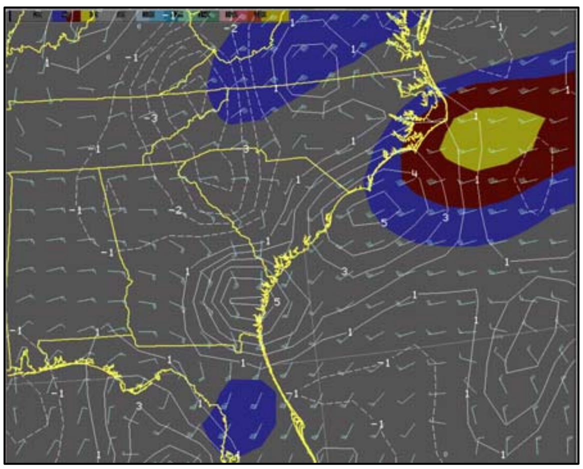

Fig 2. Rapid Update Cycle (RUC) model 250 hPa 1500 UTC 6 September 2004 *isotachs[(shaded 30 kt (blue) 40 kt (red) 50 kt (yellow)], wind barbs and divergence (positive-solid white contour).*

With a strong upper trough moving through the Great Lakes on 1200 UTC 7 September, the 500 hPa ridge was weakening over the Mid Atlantic coast.*Fi* This weakening of the upper ridge allowed for Tropical Depression Frances to increase in forward speed and move northward along the Georgia/Alabama state line. The frontal boundary that had been stationary over the coastal waters became oriented west to east, separating warm onshore flow to the south and a slightly cooler airmass over North Carolina and the Mid Atlantic. This boundary would remain a focus for convection and tornadoes on 7 September.

c. Mesoanalysis

By 0000 UTC 6 September, a large rain shield of moderate to heavy rainfall was moving north toward the southeast Georgia coast as the center of Tropical Storm Frances neared Tampa, Florida. A few discrete cells with velocity couplets began forming along the northern edge of this rain shield over southeast Georgia, where according to 0000 UTC 6 September mesoanalysis images from the Storm Prediction Center (SPC), the 0-1 km Storm Relative Helicity (SRH) was on the order of 400 m^2 s^{-2}. While upper air soundings from Charleston, SC (CHS) and Jacksonville, FL (JAX) indicated lifted indices near -3(°K) and CAPE at 677 J kg^{-1} and 856 J kg^{-1} respectively, SPC mesoanalysis of CAPE showed 1000-1500 J kg^{-1} along the southeast Georgia coast where the discrete convective cells were moving inland.

By 0600 UTC 6 September, two banded areas of convection formed by converging winds over the western Atlantic were slowly moving through the Charleston CWA (Fig. 3). The area of the most intense convection was over the southern third of the CWA and over southeast Georgia where the SPC mesoanalysis showed the best instabilities, shear, and helicity (Fig. 4).

Fig 3. Charleston South Carolina KCLX 0.5 degree base reflectivity at 0555 UTC 6 September 2004.

Five F0 tornadoes occurred over southeast Georgia during the nine hour period from 0000 UTC to 0900 UTC 6 September. This area saw precipitable water (PW) as high as 2.5 inches, 0-1 km SRH on the order of 500 m^2 s^{-2}, and CAPE near 2000 J kg^{-1}.

SPC mesoanalysis showed little change in instability and wind parameters during the day with CAPE averaging 1500 to 2500 J kg^{-1}, 0-1 km SRH near 500 m^2 s^{-2}, and 0-6 km deep layer shear of 35-40 kt. A total of 6 tornadoes, including 5 F1 tornadoes, formed in convection over southeast Georgia and coastal sections of southeast South Carolina between 1300 UTC and 1900 UTC

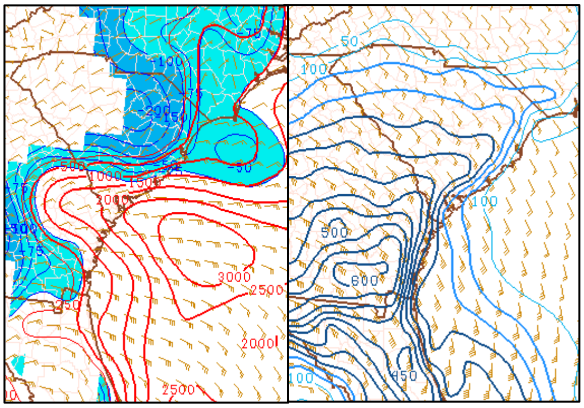

Fig 4. Storm Prediction Center mesoanalysis from 0600 UTC 6 September 2004. CAPE and CIN (shaded contours) in J kg^{-1} (left) and 0-1 km SRH in m^2 s^{-2} *(right).*

6 September. Much of this convection formed in an area of convergence where southeast winds over the Georgia coastal waters converged with an east and northeast wind over coastal South Carolina associated with the western side of the persistent coastal front off the Carolina coast (Fig. 5). SPC had noted the risk of tornadoes through the day mentioning the enhancement of activity due to the frontal boundary off the coast of South Carolina.

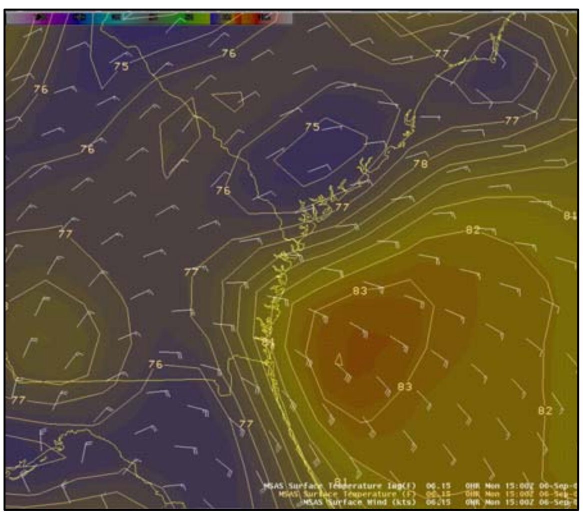

Fig 5. MAPS Surface Assimilation System (MSAS) surface temperature (F) analysis and surface wind (kt) at 1500 UTC 6 September

Rapid Update Cycle (RUC) 500 hPa analysis from 6 September indicated an area of relative humidities less than 40 percent was located across Florida on the southern periphery of Frances. This dry intrusion moved to a position off the Georgia and South Carolina coasts by 0600 UTC 7 September and created a large mid-level RH gradient across the CWA (Fig. 6). This gradient, when coinciding with other favorable tropical tornado parameters, has shown a high probability that a tornado outbreak will occur (Curtis 2004). Four additional F0 and 1 F1 tornado were verified during the predawn hours of 7 September as this mid level RH gradient was present across the CWA. The majority of these tornadoes occurred farther inland over the western counties of the CWA where a weak surface boundary was present.

By 1200 UTC 7 September, SPC mesoanalysis indicted a strong baroclinic zone along the South Carolina/North Carolina border. As a band of convection interacted with this boundary, several discrete convective cells formed and produced three F2 tornadoes and one F3 tornado across the Columbia South Carolina CWA. As deep onshore flow continued during the day, the best shear and helicity values shifted north of the Charleston CWA. As southeast surface winds increased, high theta-e air surged into the CWA during the afternoon hours. Enough instability and shear were still present in the atmosphere that an additional 4 weak tornadoes occurred over western sections of the Charleston CWA in the late afternoon and early evening hours of 7 September.

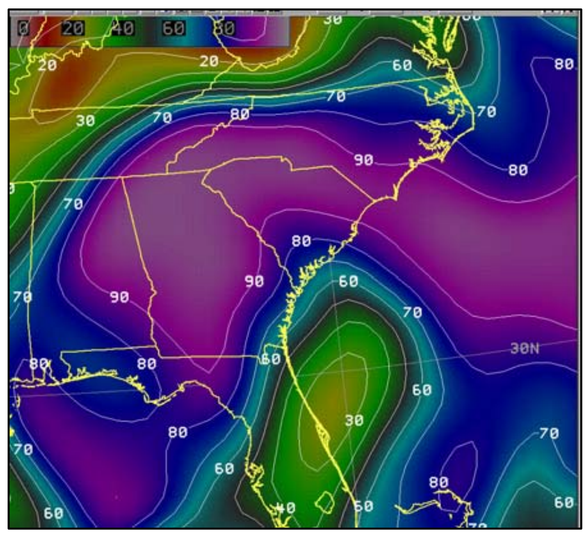

Fig 6. RUC 500 hPa relative humidity 0500 UTC 7 September 2004.

3. JEANNE

a. Overview

Hurricane Jeanne made landfall on Hutchinson Island, Florida at 0400 UTC 26 September 2004 as a category 3 hurricane (Lawrence and Cobb 2004) with maximum winds near 105 kt. Jeanne weakened to a tropical storm at 1800 UTC 26 September about 30 nm to the north of Tampa, Florida. With winds now 55 kt, Tropical Storm Jeanne moved northwest at 10 kt through the Florida panhandle and into southern Georgia before weakening to a tropical depression at 1800 UTC 27 September. Tropical Depression Jeanne moved north at 12 kt through central Georgia before turning northeast and moving through upstate South Carolina during the night of 27 September. By 1200 UTC September 28 Tropical Depression Jeanne was located over south central North Carolina (Fig. 7).

b. Synoptic Conditions

Cool high pressure was firmly entrenched across the eastern seaboard several days prior to Jeanne making landfall in Florida. By 1200 UTC 25 September, surface maps indicated pressures had fallen in the East as a cold front moved into the Ohio and Tennessee River valleys. Behind the front, surface high pressure was centered over Nebraska. While the surface ridge weakened over the east coast, an area of high pressure at 500 hPa centered near the Delmarva was steering Jeanne to the west.

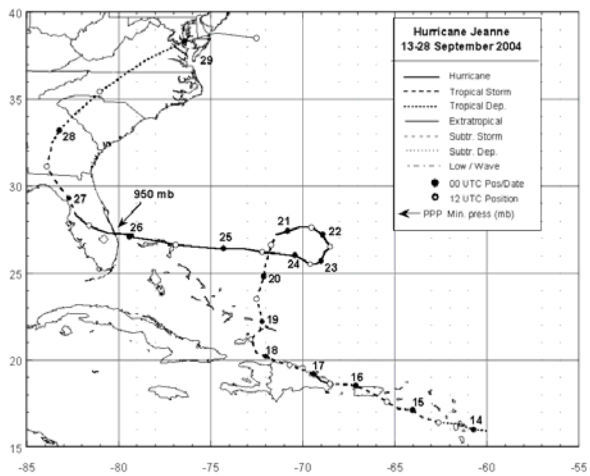

Fig 7. Best track positions for Hurricane Jeanne, 13-28 September 2004 (Lawrence and Cobb 2004).

By 1200 UTC 26 September, the upper ridge had moved farther east into the Atlantic, allowing Jeanne to begin a northward track through the Florida peninsula. The surface cold front to the west of the CHS CWA slowed and became nearly stationary across Tennessee and the lower Mississippi valley. As Jeanne continued to move northward through southern Georgia the morning of 27 September, the weak cold front was drawn southward due to Jeanne's circulation. At 1200 UTC 27 September the front was located across central Georgia, the midlands of South Carolina, and portions of the North Carolina outer banks (Fig. 8).

At 250 hPa level, the RUC analysis at 0000 UTC 27 September indicated a 60-70 kt upper level jet from east of New York City, through central Pennsylvania and down into western Kentucky. This upper jet produced strong divergence over portions of southeast Georgia between 0000 and 1200 UTC on 27 September, the time when the majority of tornadoes occurred with this outbreak. By 1500 UTC 27 September, the anticyclonic upper jet associated with the outflow from Jeanne weakened slightly and shifted north, producing strong divergence but mainly north and west of the CWA (Fig. 9).

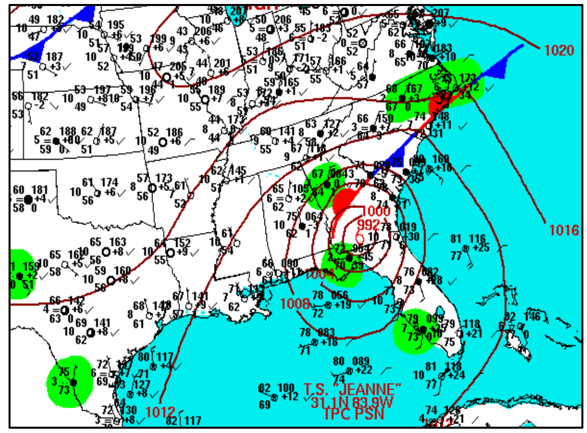

Fig 8. Surface weather map at 1200 UTC 27 September 2004 depicted by the Hydrometeorological Prediction Center.

c. Mesoanalysis

By the morning of Jeanne's landfall, the 1200 UTC 26 September surface analysis showed that light northerly winds had veered to the northeast and moisture advection had increased temperatures into the lower 70s, and surface dewpoints into the upper 60s. In the upper levels, water vapor imagery from that morning indicated very dry air at mid levels across the Mid Atlantic and Southeast.

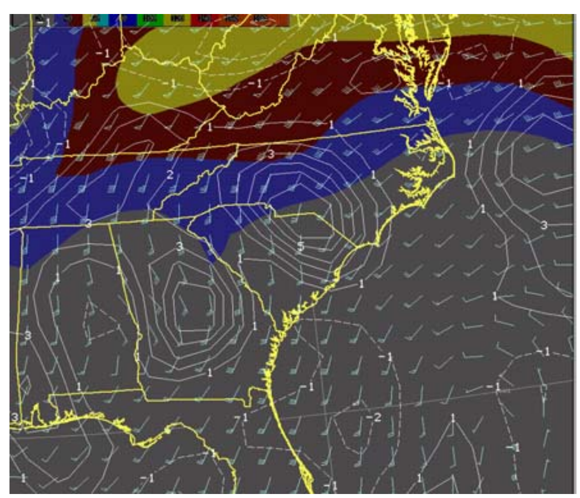

Fig 9. RUC 250 hPa 1500 UTC 27 September isotachs 2004 [shaded 30 kt (blue), 40 kt (red), 50 kt (yellow)], wind barbs and divergence (positive-solid white contour).

This dry air was verified on the 1200 UTC CHS sounding that had PW less than 2 inches and showed considerable dry air and lower humidities above 600 hPa.

The atmosphere remained too dry for widespread convection across the CWA on 26 September, although conditions were to become more favorable across portions of southeast Georgia by afternoon. Wind fields at 850 hPa were forecast to increase to near 60 kt across northern Florida and southern Georgia by 0000 UTC 27 September. In addition, the RUC was showing a very large wind field with 40 to 50 kt 850 hPa winds extending nearly 400 nm to the east of the center of Jeanne. While Jeanne moved north of Tampa and was approaching southern Georgia, SPC mesoanalysis data indicated only modest CAPE of near 500 J kg^{-1} along the coastal areas of the CWA. Lifted index for the area remained low at -1 to -2 (˚K) across the area. Despite the low instability parameters, shear and helicity were quickly increasing across the CWA. By 0300 UTC 27 September, mesoanalysis showed 0-1 km shear and helicity values near 45 kt and 500 m^2 s^{-2} respectively over portions of southeast Georgia.

While strong mid level wind fields showed a marked decrease in areal coverage between 0000 UTC and 1200 UTC 27 September, shear and instability numbers reached their maximum values overnight. A surge of warm moist unstable air up through the Savannah River valley created a theta-e ridge from the southeast Georgia coast well inland to near Augusta, Georgia (AGS). During these predawn hours, precipitable water reached as high as 2.3 inches with CAPE near 1500 J kg^{-1}, LI near -5 (˚K), and 0-1 km helicity near 650 m^2 s^{-2} (Fig 10).

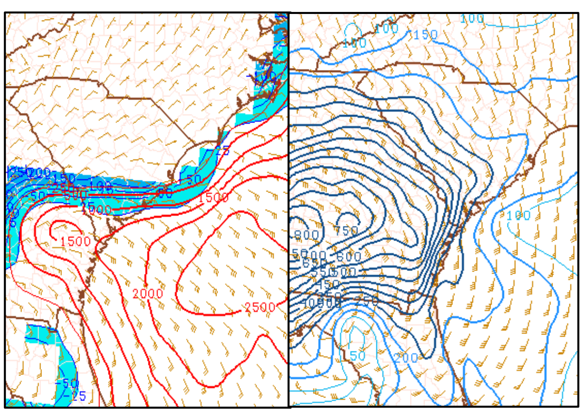

Fig 10. Storm Prediction Center mesoanalysis from 0900 UTC 27 September 2004. CAPE and CIN (shaded contours) in J kg^{-1} (left) and 0-1 km SRH in m^2 s^{-2} (right).

While Jeanne pushed north into southern Georgia during the night, the mid and upper level dry air that was evident surrounding the system the day before was now nearly encircling the storm (Fig. 11). IR satellite images showed much of the deeper convection on the south side of the storm was weakening as the dry air wrapped around and into Jeanne. At 0600 UTC 27 September, water vapor imagery indicated that the dry slot over central Florida would continue to move northeast and place a strong mid level relative humidity gradient across our CWA through at least 1200 UTC. As this gradient lay across the CWA in the predawn hours, 4 F0 tornadoes were verified across the CWA with the majority occurring over southeast Georgia

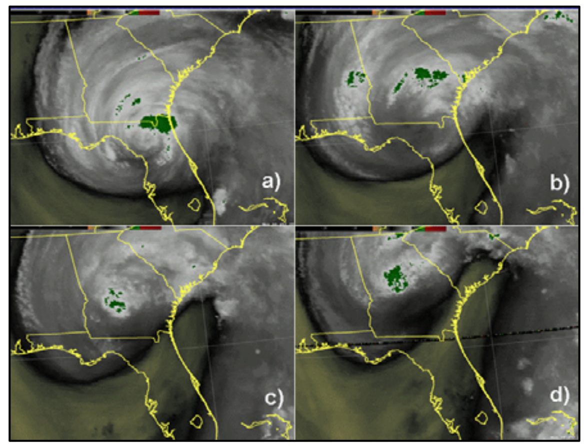

Fig 11. Enhanced GOES water vapor imagery from a) 0045, b) 0645, c) 1245, and d) 1845 UTC 27 September 2004.

The dry slot became the dominant feature through the morning and afternoon hours with only widely scattered convection forming over the CHS CWA. Despite daytime temperatures warming into the lower 80s, CAPE near 2000 J kg^{-1}, and 0-1 km helicity near 300 m^2 s^{-2}, only 2 additional F0 tornadoes formed between 1200 and 1500 UTC across the Charleston CWA. This increase in mid level dry air did increase the chances for stronger convection as the dry slot enhanced buoyancy and thermodynamic profiles. This prompted the SPC to carry a moderate risk of severe weather and tornadoes for coastal Georgia and coastal South and North Carolina through the day on 27 September. It should be noted that given these favorable parameters, 15 tornadoes (14 F0 and F1) were verified in South Carolina north and west of the CWA.

7. COMPARISON

Despite the relatively similar tracks Frances and Jeanne took as they were weakening over north Florida and southwest Georgia, the length of time the Charleston, SC National Weather Service Office spent under warning operations was considerably different. During the Frances event, the period of tornado touchdowns was more than 48 hours, compared to 12 hours with Jeanne. The upper level ridge to the north of the area slowed the forward progress of Frances. This kept favorable values of shear, moisture, and instability for convection across the CWA for a much longer time period. Jeanne met little opposition in its track northward as the upper level ridge to the north had already weakened. In addition, a cutoff low pressure area off the NC coast fed high PW values into the CWA prior to Frances making landfall. With drier air in place prior to the Jeanne landfall, it took much longer for the atmosphere to saturate and be able to support the deep convection needed for tropical tornado development.

In the water vapor imagery, both storms were moving into an area that had mid to upper level dry air already in place. Jeanne however came onshore as a major hurricane and satellite images showed a very organized circulation. Jeanne's strength and organization had major implications as the cyclonic circulation brought very dry air around the southern periphery of the storm helping to erode convection and precipitation on the south side. This dry slot did in fact move over the CWA by the afternoon on 27 September and limit the overall coverage of convection.

Upper divergence associated with a 250 hPa jet was evident during both Frances and Jeanne. Its impact on the Frances outbreak appears to have been more significant, however as the upper low to the northeast enhanced the jet and kept the CWA under strong divergence for 48 hours. In contrast, the area of divergence during Jeanne quickly exited the area to the north and west, leading to a decrease in lift and subsequent weakening of convection.

Like most tropical tornado outbreaks, both the Frances and Jeanne events showed similarities as well. Mesoanalysis showed that during the peak of the events, CAPE, 0-1 km helicity, and shear all fit within the window that previous authors have quantified, e.g., McCaul (1991), etc. In addition, both of these events saw the importance of surface boundaries in the formation of these tropical tornadoes. Although boundaries were more prevalent in the Frances event, both systems saw an increase in tornadoes when convection interacted with these boundaries and convergence lines.

While most tropical tornado outbreaks tend to see a high percentage of diurnal tornadoes, both the Frances and Jeanne outbreaks saw a majority of the verified tornadoes occur between 0000 UTC and 1200 UTC. Sixteen out of the 26 total tornadoes, or roughly 60 percent of the verified tornadoes occurred in this window.

Both outbreaks seem to have had a majority of their tornadoes occur while the CWA was under a strong mid level relative humidity gradient. Curtis (2004) has shown that there is a strong correlation between these large tropical tornado outbreaks and the presence of this mid level dry air at 700 and/or 500 hPa. But as we saw with Jeanne, the outbreak can quickly come to an end when that same dry air moves over the region and changes the thermodynamic structure of the atmosphere. While the dry air may lead to an increase in instability and severity of convection, the decrease in moisture and PW values can be detrimental during a tropical convective event.

8. CONCLUSIONS

Despite having such similar tracks across Florida and Georgia, Frances and Jeanne produced tornado outbreaks that were quite different. Contributing factors to the larger number of tornadoes associated with Frances appear to be a more favorable position of an upper level jet to the northeast of the storm, deeper moisture profiles, and slower forward speed maintaining favorable wind profiles over the CWA for a longer period of time.

With the documentation on these tropical tornado events increasing due to the recent surge in land falling tropical systems, meteorologists are able to use the latest in mesoanalysis programs such as the one from the Storm Prediction Center, to keep better situational awareness on the known parameters that favor these outbreaks. With the recent increase in mesonet data available to the field offices through the internet etc, warning meteorologists have a bright future ahead of them as more data, better analysis programs, and continuing development of new storm parameters are made available.

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