11C. 6 HURRICANES THAT DO AND DO NOT SPAWN TORNADO OUTBREAKS: OFFSHORE TRAITS AND THEIR EVOLUTION AT LANDFALL

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1. Introduction

On September 16, 2004 at 0650 UTC, Hurricane Ivan made landfall on the Gulf coast in Alabama and produced an outbreak of 52 reported tornadoes prior to and within the first day of landfall. Less than a year later, on July 10, 2005 at 1930 UTC, Hurricane Dennis made landfall in the Florida Panhandle less than 60 miles from where Ivan had made landfall. Dennis produced only 10 tornadoes with 9 at F0 on the Fujita scale. Both storms were a category 3 at landfall. Studies done by Novlan and Gray (1974) and Gentry (1983) have documented this wide distribution in tornado production within hurricanes. This raises many questions about the tornadic potential of convection in hurricane rainbands.

The favored region for tornadogenesis was either ahead or to the right of track for both hurricanes, approximately 200 to 600 km from the circulation center. The G-IV flights often deploy sondes into the hurricane at this range of radii. For Ivan, out of the 52 tornadoes reported on the first day, about 46 occurred at radii greater than 300 km and 46 also occurred in the right front quadrant with respect to North (Fig. 1). The rest occurred in the right rear quadrant. Dennis' 10 tornadoes occurred at radii greater than 350 km. Those prior to landfall occurred in the right front quadrant while a couple of post landfall tornadoes occurred in the right rear quadrant. This preference for the right front quadrant has been well documented in the studies done by Novlan and Gray (1974) and Gentry (1983).

2. Shear and Stability

The organization and development of severe tornadic storms has been shown to be dependent on the vertical wind shear and instability (Weisman and Klemp 1982, 1984, McCaul and Weisman 1996). Weisman and Klemp suggest a balance between these two variables is an important factor. Too little or too much of either can be detrimental to tornadogenesis. Novlan and Gray (1974) found for hurricanes that produce tornadoes there is a 20 ms^{-1} shear layer that is concentrated in the lower troposphere between the surface and 850 hPa (1500 m). Hurricanes that did not produce tornadoes had half the amount of vertical wind shear in this layer. For our study we will look at the low-level vertical wind shear and how it evolves from the ocean to land.

To measure instability we will use the convective available potential energy (CAPE). We have added the virtual temperature correction to both the parcel and environmental temperature.

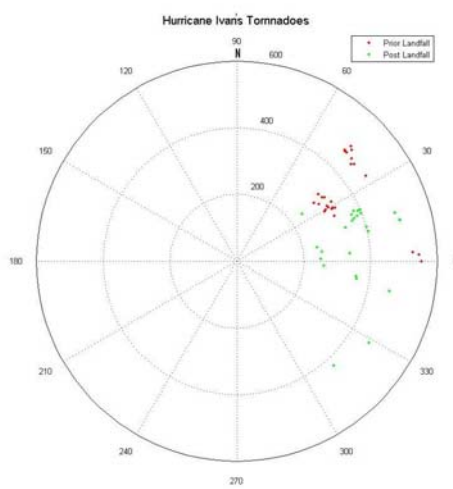

Fig. 1. Hurricane Ivan's tornadoes with respect to North. Red dots are prior to landfall, green dots are post landfall.

3. Research goals

We intend to explore the following issues:

(1) Are there differences between Dennis and Ivan in CAPE, lower tropospheric shear, lifted index (LI) and the bulk Richardson number (BRN)?

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(2) How do these variables differ across the track of each hurricane?
(3) How do these key variables evolve as the hurricane makes landfall?
(4) What kind of synoptic pattern is the hurricane interacting with as it makes landfall?
(5) What is the depth of the vertical shear of the horizontal winds during landfall?
(6) Can the flight patterns used to improve hurricane track forecasts also be used to make forecasts of potential tornadogenesis?

The findings will be discussed in light of prior work including Novlan and Gray (1974), Gentry (1983), McCaul (1991), McCaul and Weisman (1996), Spratt et al. (1997), Bogner et al. (2000) and McCaul et al. (2004).

4. Data

To explore these questions we examine the Global Positioning System (GPS) dropwindsondes (sondes) deployed from USAF and NOAA G-IV and WP-3D aircraft as well as the rawinsondes launched by the NWS sites prior to and during landfall for hurricanes Ivan and Dennis. We believe that this is one of the first investigations that use the GPS sondes from the high altitude NOAA G-IV, deployed primarily to improve track forecasts, to explore the vortex-scale environment that impacts tornadogenesis. We will assess if the typical patterns flown by the G-IV can pay dividends regarding the forecasting of tornado outbreaks associated with a hurricane. This is also the first study of its kind to compare two hurricanes using data over the ocean and land. Both hurricanes were sampled during landfall as well as the previous day or two. Within two days of landfall, aircraft deployed about 136 GPS sondes in Dennis and 131 in Ivan (Fig. 2). During the ocean sampling, the minimum sea-level pressure varied considerably in Dennis as it crossed over Cuba but it was deepening and achieved 930 hPa prior to landfall in Florida. Ivan was steadier, varying between 940 and 930 hPa over the Gulf of Mexico until landfall.

Unfortunately the G-IV aircraft did not sample Dennis the day before landfall. However there are P-3 sondes on this day, although the P-3 aircraft tend to fly closer to the inner core and at lower altitudes than the G-IV. The GPS sondes were post-processed using the Atmospheric Sounding Processing Environment (ASPEN). 17 NWS rawinsondes locations within 1000 km of the hurricane track supply another 120 soundings for each hurricane. All rawinsonde data was collected from the University of Wyoming's atmospheric sounding page. This type of data set is available for most hurricanes that threaten to make landfall in the U.S. which will allow the findings of this research to be applied operationally to future tropical cyclones.

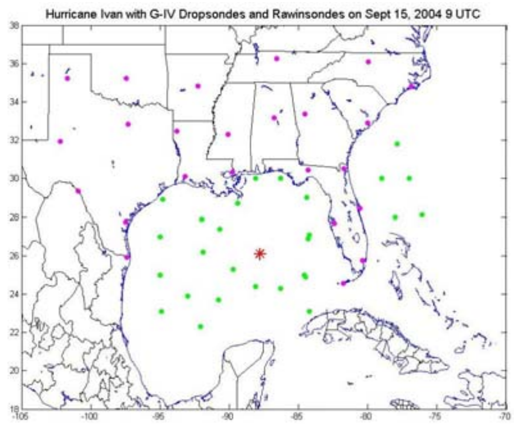

Fig. 2. A sample of Ivan's G-IV dropsondes the day before landfall.

5. Preliminary Results

5.1 *Low-level Shear*

The low-level shear (100-1500 m) shear for hurricane Ivan at radii 300-500 km from the storm center is between 7-10 x 10^{-3} s^{-1} (Fig. 3). This is larger than the maximum of 4 x 10^{-3} s^{-1} found at these same radii by Bogner et al. (2000). A strong 10-11 x 10^{-3} s^{-1} maximum lies in the right rear quadrant with respect to north. For Dennis' the G-IV data is two days prior to landfall as Dennis crosses Cuba. Large shear of 7-10 x 10^{-3} s^{-1} occurs in areas where winds are off-shore of Cuba and Florida. These regions of higher shear are much smaller in area than what was seen in Ivan. Again a strong maximum of 10-11 x 10^{-3} s^{-1} is seen in the right rear quadrant of Dennis. These areas of high low-level shear correspond to the minimum areas of CAPE discussed in the next section.

The low-level shear values over land are still being processed and will be shown during the presentation.

5.2 *CAPE*

The G-IV aircraft conducted two flights on Sept 15, 2004 on the day before Ivan made landfall. CAPE values for the sondes from 1800 to 0000 UTC combined with the rawinsondes over land at 0000 UTC can be seen in Fig. 4. A minimum in CAPE occurs around Ivan with values ranging from 500 to 1500 J kg^{-1} from 300-500 km. Values increase to 2000 J kg^{-1} in the environment surrounding Ivan beyond 500 km. One drop hints at an area of higher CAPE 200-300 km to the right of the center of circulation. A strong gradient in CAPE occurs over the ocean west of the Florida Peninsula. CAPE values range similarly for Dennis with a minimum occurring to the North and East. An east-west gradient in CAPE lies over Florida towards the middle of the Peninsula with values ranging from 1000 to 3000 J kg^{-1}. Surprisingly the CAPE in the environment surrounding Dennis is higher than what was found in Ivan. These results over the ocean agree well with those found by Bogner et al. (2000) who found CAPE values of 1500 to1700 J kg^{-1} at radii 300-500 km from the storm center.

Right before landfall both hurricanes show an area of minimum CAPE to the North and West. To the East, Ivan shows moderate CAPE with values between 1000 to 2000 J kg^{-1} stretching from the Florida Panhandle through western and central Georgia and into South Carolina. Dennis's CAPE field right before landfall shows a sharp minimum over the Florida Panhandle and over the lower Gulf States including Georgia, which may have inhibited supercell formation. Post landfall the CAPE fields over land for both hurricanes are very similar with high values stretching along the southern Atlantic coast. These results coincide well with McCaul (1991) who found a minimum in CAPE to the north and west of the hurricane's center and a maximum of 1000 to 1600 J kg^{-1} at radii 400-800 km to the right of the hurricane center.

6. Discussion

Both storms exhibit similar CAPE fields although Ivan seemed to have slightly higher values on its right side before landfall. Although the shear maxima for both storms were similar in magnitude, the area over which high shear occurred is much larger for Ivan than Dennis. The preferred 300-500 km radii for Ivan's tornadoes may be where there is a balance between optimal low-level shear and moderate instability.

7. References

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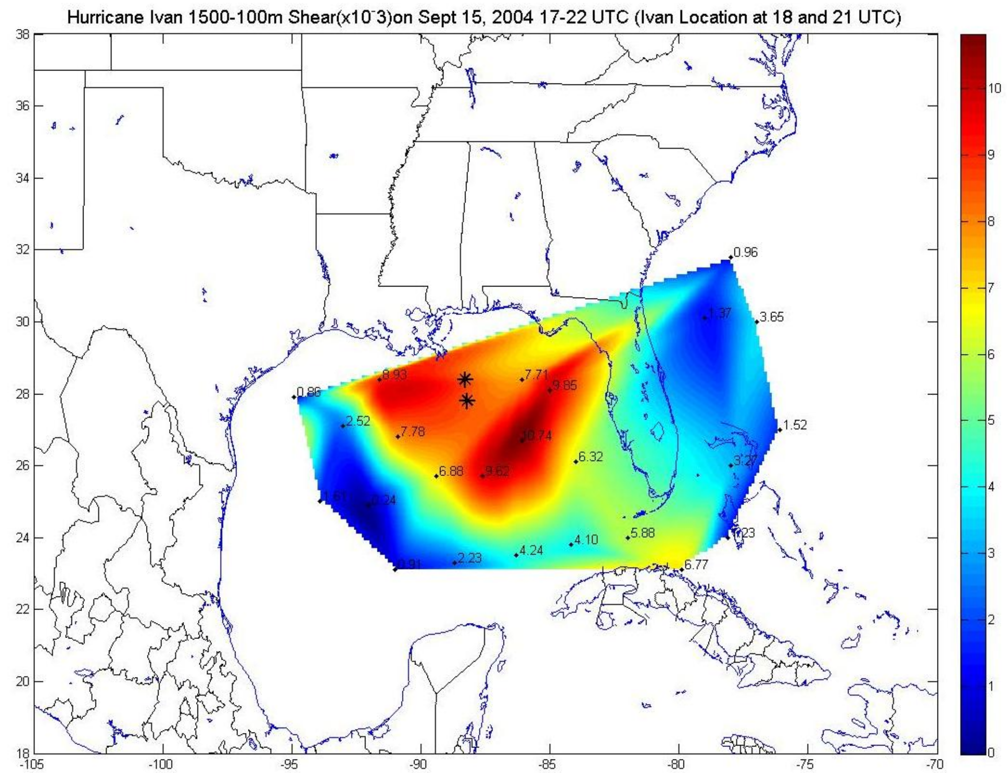

Fig. 3. 100-1500 m shear ($x10^{-3}$ s^{1-}) for Hurricane Ivan. Ivan's Location is given by the black star at 18 and 21 UTC.

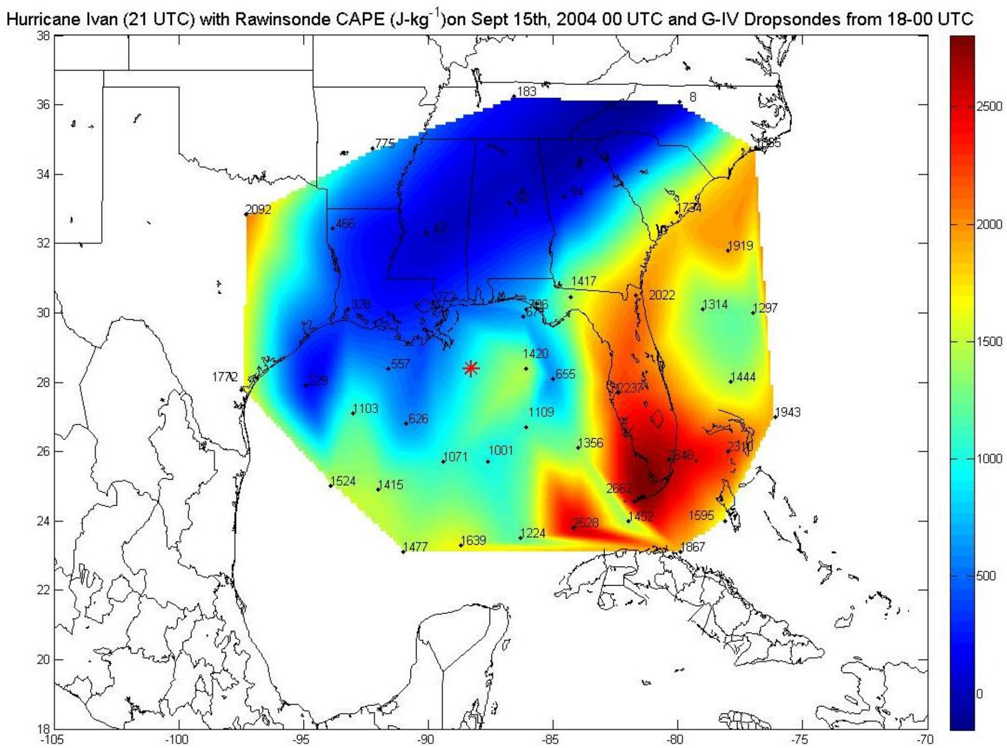

Fig. 4. CAPE (Jkg^{-1}) for Hurricane Ivan. Ivan's location is given by the red star at 21 UTC.