14C.4 The Evolution of Thermodynamic Structures in the Inner Core of Humberto (2001)

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1. Introduction

During 3 consecutive days in September 2001, over 200 Global Positioning System dropwindsondes (GPS sondes) were deployed from NOAA and NASA aircraft as tropical storm Humberto intensified to a category 2 hurricane and then weakened to a category 1.

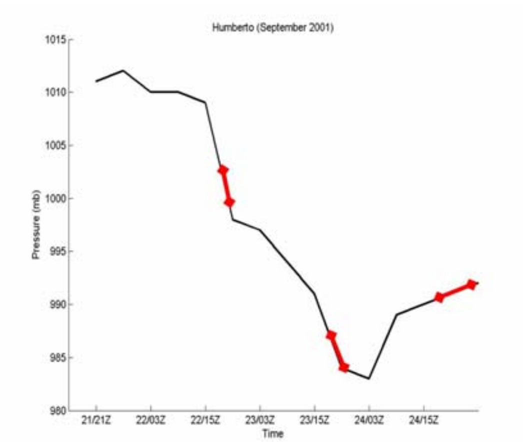

Figure 1: Plot of pressure as a function of time for hurricane Humberto (September 2001). Red arrows show times at which Humberto was sampled.

The 2 NOAA WP-3ds deployed GPS sondes from altitudes of 1.5 km and 4 km and were concentrated within 200 km of the circulation center. The NASA DC-8 and ER-2 sampled both the inner core and the environment, launching GPS sondes from above 11.5 km and 16 km, respectively. This combined effort has made Humberto the most densely sampled hurricane with GPS sondes to date.

2. Data and Analysis

The GPS sondes collect data at 2 Hz so they provide high vertical resolution of about 6-7 meters. Wind errors from the sondes are on the order of 0.5 m/s while temperature and pressure errors are on the order of 0.2^{0}C and 1.0 hPa, respectively. Relative humidity errors average less than 5%; however sensor wetting can still be a problem. The drops were initially processed using The Atmospheric Sounding Processing Environment (ASPEN) program. After processing the data with ASPEN, the data were corrected in a similar fashion to the study done by Schneider and Barnes (2005). From this corrected data we have developed multiple horizontal and vertical fields using cubic splines, objective analysis techniques and subjective analysis. During the approximately 4 hours of dropwindsonde deployment, on each of the three days of sampling, Humberto's mean sea level pressure fluctuated by only a few hPa (Fig. 1). We have assumed steady state and composited the sondes with respect to the circulation center. These fields have been combined with the lower fuselage radar data from the NOAA WP-3ds.

We have developed multiple horizontal fields based on the GPS sonde data using cubic splines, objective analysis techniques and subjective analysis and have combined these fields with the lower fuselage radar data from the NOAA WP-3ds. Developed from the horizontal fields, vertical cross sections of various thermodynamic variables are constructed for each of the three days of sampling. Radial-height cross sections of the temperature perturbation and equivalent potential temperature (θ_e) will be compared to the structures expected from WISHE theory. Inflow path-height sections of θ_e will reveal where the boundary layer is accumulating energy. Convective available potential energy (CAPE) and convective inhibition (CIN) are also calculated.

3. Study Objectives

We intend to compare the structures seen in Humberto, as it evolves over the three days of sampling, with the structures that should be present if the WISHE theory is responsible for intensification. According to the standard view of the creation of a warm core that is summarized by WISHE theory (Emanuel 1986, 1991), the maximum temperature perturbation should be found in the upper atmosphere. In WISHE the intensification of a hurricane depends on the fluxes at the air-sea interface to increase the θ_e of the boundary layer air. As a parcel with warmer θ_e reaches the eyewall, it will ascend along a warmer moist adiabat than the previous parcel. Moist adiabats diverge with height resulting in the greatest temperature differences between the eyewall and the environment in the upper troposphere. Past observations of mature tropical cyclones (Hawkins and Rubsam, 1964, Hawkins and Imbembo, 1976) confirm that the maximum temperature

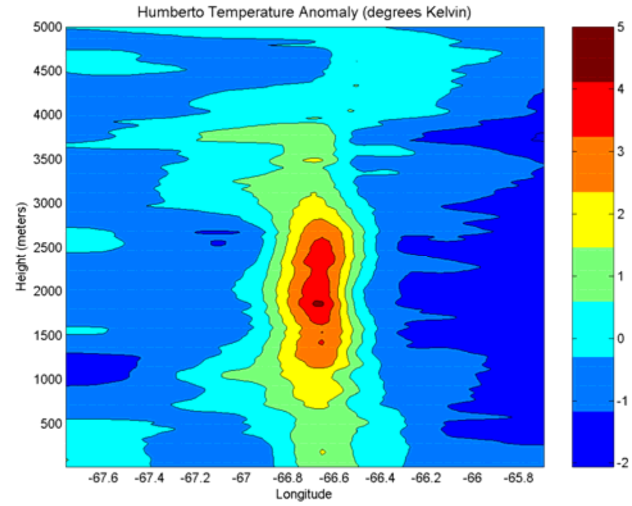

Figure 2: Vertical cross section in the east west direction through the circulation center of tropical storm Humberto on 9/22/01. Colors represent the temperature anomalies (degrees Kelvin) at constant height levels.

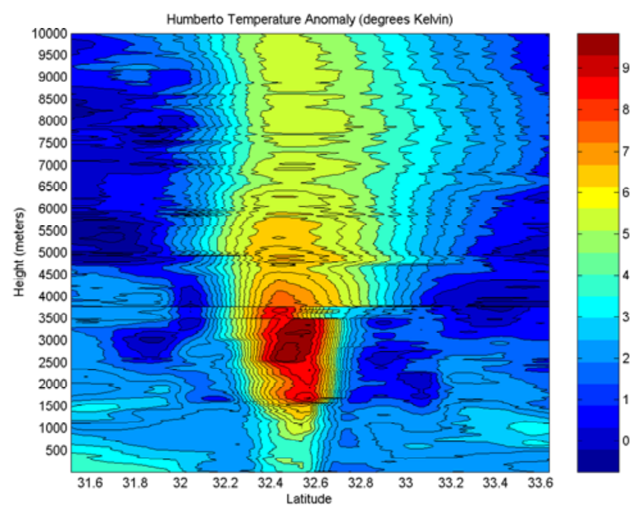

Figure 3: Vertical cross section in the southwest to northeast direction through the circulation center of hurricane Humberto on 9/23/01. Colors represent the temperature anomalies (degrees Kelvin) at constant height levels.

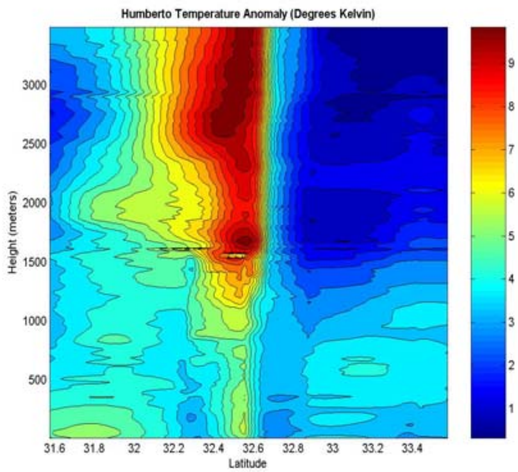

Figure 4: Vertical cross section, from north to south, through the circulation center of hurricane Humberto on 9/23/01. Colors represent the temperature anomalies (degrees Kelvin) at constant height levels.

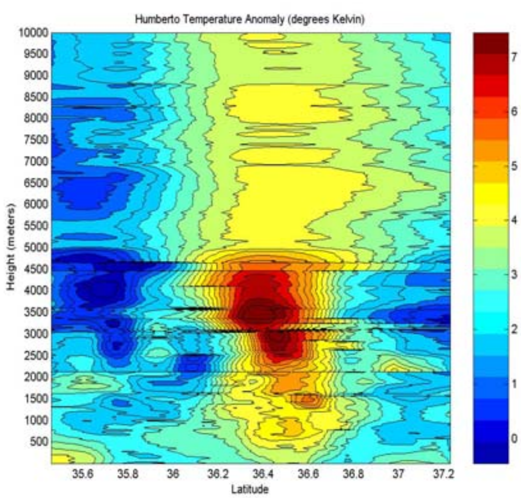

Figure 5: Vertical cross section in the southwest to northeast direction through the circulation center of hurricane Humberto on 9/24/01. Colors represent the temperature anomalies (degrees Kelvin) at constant height levels.

perturbation exists in the upper troposphere.

4. Preliminary Results

On the 22nd when Humberto is a tropical storm, a maximum temperature perturbation of 6° Kelvin (Fig. 2) is found between 1 and 3 km, under a region of stratiform precipitation. The upper troposphere shows minimal warming of about 1° Celsius. θ_e in the nascent eyewall as measured from the WP-3ds is found to be sourced from the boundary layer under the low level warm core. On the 23rd as Humberto strengthens to a category 2 hurricane the maximum warming is located between 3 and 5 km and has a magnitude of about 9° Kelvin (Fig. 3). This is in contradistinction to what would be expected if the intensification of the storm was viewed from the perspective of WISHE theory. The low level warm core is asymmetric (Fig. 4) and the largest temperature perturbations are found adjacent to the northern eyewall convection. To the south, where eyewall convection is absent, convective inhibition (Cin) values are high forming a cap. Streamlines reveal that the air gains energy in this region before it is lifted into the convection. Values of convective available potential energy (Cape) also increase in this area. Surprisingly, the eye contains Cape values of over 1000 J/kg. θ_e in the convective area of the eyewall, measured by the lowest flying NOAA WP-3d, shows θ_e that is closest in value to the boundary layer eye air. This suggests the possibility of eye to eyewall mixing. As Humberto weakens and becomes a category 1 storm on the 24th, the maximum warming is again found in the lower troposphere (Fig 5) and has a magnitude of about 7° Kelvin.

5. Discussion

The structures found as Humberto is sampled over the three days show that other processes besides WISHE are involved in intensification.

Although the upper atmosphere does show moderate warming when Humberto is above hurricane intensity, the maximum temperature perturbations are found in the lower troposphere. These cross-sections suggest that subsidence warming in the eye (Franklin, 1988, Jorgensen, 1984) and adjacent to the eyewall might have a larger role in the intensification process than previously thought. The arrangement of the convective elements in relation to the low level warm core provide clues to storm intensification and maintenance that break from the axi-symmetric view often used by numeric models.

7. References

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