# 9B.3 THE GENESIS OF HURRICANE 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. 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.

Early on September 22nd, Humberto was a tropical depression with a minimum central pressure of 1010 hPa. The storm was located in the Atlantic basin at about $27^0$ N latitude and $66^0$ W longitude. The movement was to the north-northwest at about 4 m/s. Humberto would continue moving to the north and eventually would recurve to the northeast. When the first GPS sondes were being jettisoned, late on the 22nd, Humberto had reached tropical storm strength and would intensify further to a category 2 storm late on the 23rd. Figure 1 shows a plot of pressure as a function of time for the three days of the experiment. The dropwindsondes on the 22nd were jettisoned from approximately 18:30 UTC to 22:00 UTC when the minimum central pressure was near 1000 mb.

Various theories for the genesis of tropical systems have been proposed. The two major theories that have been proposed are Conditional Instability of the Second Kind (CISK) and Wind Induced Surface Heat Exchange (WISHE). CISK attributes hurricane growth to the interaction between individual thunderstorms and large-scale moisture convergence. The release of latent heat in the troposphere leads to a lowering of the surface pressure which in turn increases the secondary surface circulation. In WISHE the intensification of a hurricane depends on the fluxes at the air-sea interface to increase the equivalent potential temperature ($\theta_e$) of the boundary layer air. As a parcel with warmer $\theta_e$ 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. Observations of mature tropical cyclones (Hawkins and Imbembo, 1976) show that the maximum temperature perturbation exists in the upper troposphere, consistent with both WISHE and some interpretations of CISK.

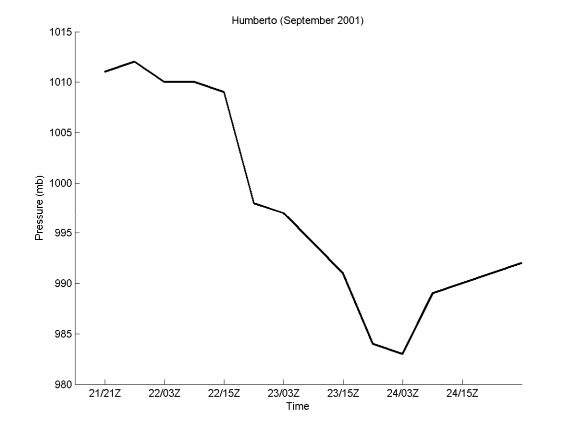

Figure 1: Plot of pressure as a function of time for hurricane Humberto (September 2001)

The goal of this study is to investigate the thermodynamic and kinematic fields of Humberto as it intensified from a tropical depression to a tropical storm on the 22nd of September, 2001. The main focus will be on developing an understanding of the potential mechanisms involved in the formation of a nascent eye. The following analyses provide

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clues as to how a warm core and the accompanying circulation might form.

## 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, Humberto's mean sea level pressure fluctuated by only a few hPa. 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.

## 3. PRELIMINARY RESULTS

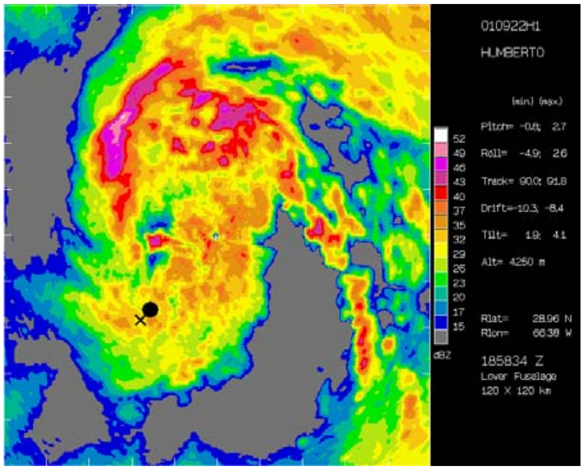

Figure 2: Lower fuselage radar of tropical storm Humberto at 18:58 UTC on September 22$^{nd}$, 2001. Colors indicate reflectivity in dbz. Black dot indicates the area of lowest surface pressure. "X" marks the location of sonde 012615134.

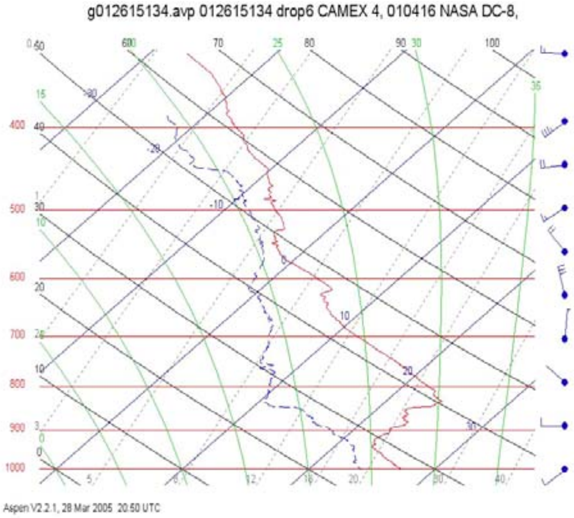

Figure 3: Skew-T of drop 012615134 jettisoned at 18:54 UTC on September 22nd 2001.

Reflectivity fields as shown in Fig. 2, reveal that an arc of deep convection, oriented north to east, is located 40-50 km from the nascent circulation center. The black circle displays the point of lowest surface pressure as constructed from our composited fields. GPS sondes jettisoned near the area of lowest pressure show an overlying dry adiabatic layer with dew point depressions that exceed 10 C centered around 800 hPa. Figure 3 displays a Skew-T of one such dropwindsonde jettisoned close to the circulation center. This sonde location is also marked by a black "X" on the radar image in Fig. 2. In the upper troposphere thermodynamic conditions are similar to the surrounding environment with no evidence of the expected positive temperature perturbation that has been observed in mature hurricanes (e.g., Hawkins and Imbembo 1976). Figure 4 shows an east to west vertical cross section through the circulation center of Humberto as it was deepening into a tropical storm. The maximum temperature anomaly in Fig. 4 is located in the lower troposphere between one and three kilometers. The warm, dry layer (Skew-T, Fig. 3) in the lower troposphere has a thermodynamic structure which closely resembles the region under a stratiform precipitation region in a tropical squall line (e.g., Zipser 1977). The hydrostatic effect of this warm layer has been estimated based on a comparison with the structure of other soundings on the periphery of Humberto. This layer can account for a reduction of pressure between 7-9 hPa, which accounts for more than 70% of the observed pressure deficit. This structure is unlike what one expects if concepts summarized

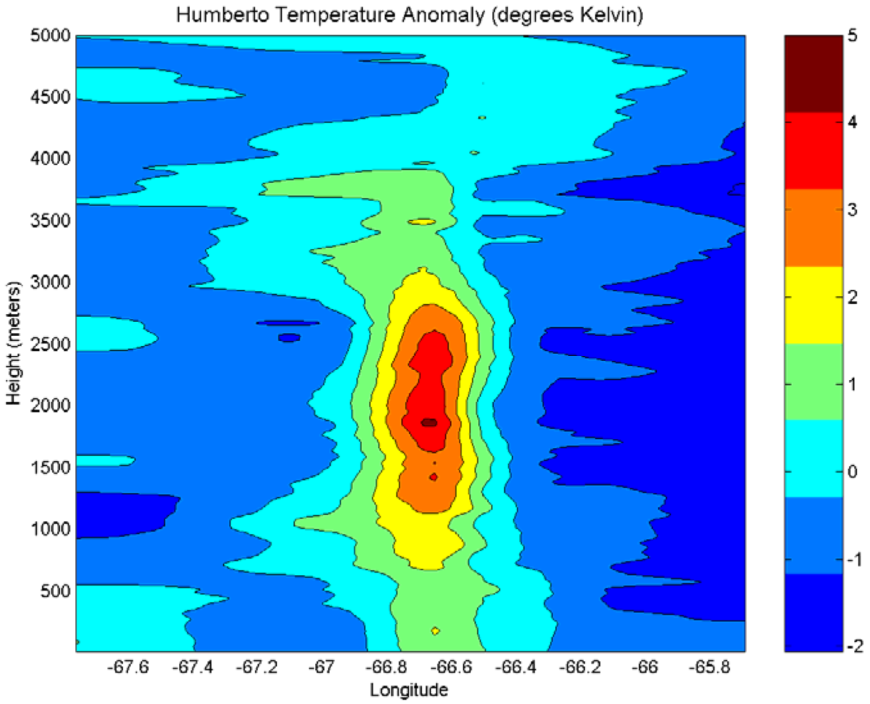

Figure 4: Vertical cross section in the east west direction through the circulation center of tropical storm Humberto. Colors represent the temperature anomalies (degrees Kelvin) at constant height levels.

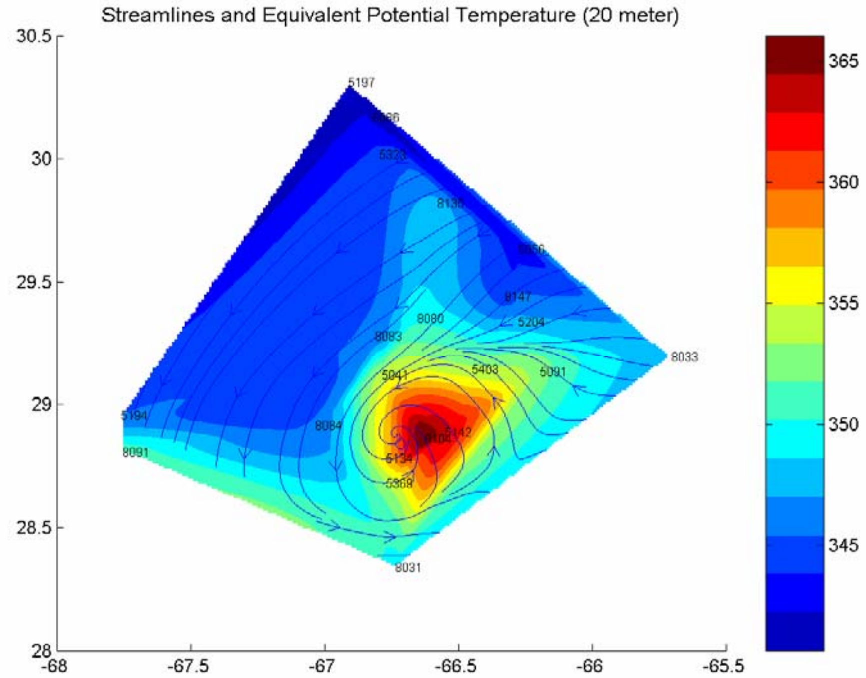

Figure 5: A map of streamlines and equivalent potential temperature at a height of 20 meters. Color bar shows corresponding values of equivalent potential temperature. Also shown are the locations of the GPS dropwindsondes (each 4 digit number is a dropwindsonde).

by the WISHE theory (Emmanuel 1986) were responsible for genesis.

Figure 5 is a map of equivalent potential temperature and streamlines. There is an obvious area of confluence about 50 kilometers to the north east of the circulation center. This feature matches well with the reflectivity field shown in Fig. 2. As seen in the Skew-T (Fig. 3), the surface circulation center is capped by a temperature inversion located at around the 850 mb level. We hypothesize that this capping inversion allows the low level inflow to increase its equivalent potential temperature via fluxes from the sea surface. The Skew-T's for dropwindsondes 8104 and 5142 (location can be found in Fig. 5, east of circulation center) are not shown here but they display classic MAUL (moist absolutely unstable lapse rate) signatures. This implies that there is strong dynamic forcing in this area of the nascent eye. Dropwindsonde 5142 differs from the other Skew-T's near the circulation center in that it contains multiple weak inversions. The weaker inversion might allow for buoyant surface air to break through the cap. We speculate that high energy air is flowing out from under the capping inversion on the north side of the nascent eye. This might allow the high energy air to escape and begin the formation of an eyewall.

## 4. DISCUSSION

The analyses for the 22nd September demonstrate that the warm core is located in the lower troposphere, not the upper levels, and is due to a subsiding warm dry layer, not higher $\theta_e$ air moving up the eyewall column. Only later does the ascent of increasingly higher and higher values of $\theta_e$ build the temperature perturbation in the upper troposphere. The juxtaposition of the stable layer in the lower troposphere inhibits premature ascent and allows the boundary layer air to achieve higher energy content via the fluxes at the surface. We speculate that the warm layer in the lower troposphere is the initial cause of the pressure reduction at the surface and is thus a potential mechanism for TC genesis.

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