15A.5 The Rapid Intensification of Hurricane Guillermo (1997)

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1. Introduction

From 0600 UTC on the 2nd of August to 1200 UTC on the 3rd of August Hurricane Guillermo (1997) deepened 54 hPa over the eastern North Pacific, easily exceeding the thresholds that define rapid intensification (RI). The NOAA WP-3Ds observed a portion of this RI (Fig. 1) with similar two-aircraft missions on consecutive days. The aircraft jettisoned 70 successful Global Positioning System dropwindsondes (GPS sondes) during the two days that reveal how conditions in the lower troposphere on the quadrant scale evolved within 250 km of the eye. Kossin and Eastin (2001) and Eastin et al. (2006) have focused on the dual Doppler analyses of the eyewall to demonstrate eye-eyewall exchanges that impact the intensity of the TC. We will concentrate on what can be learned from the GPS sondes.

2. Potential causes to RI

Passage over warmer water resulting in an increase in the inflow energy content to the eyewall, a reduction in the vertical shear of the horizontal wind, enhanced upper level divergence, concentric eyewall cycles, greater subsidence warming in the eye and convective outbreaks in the eyewall are all factors that can contribute to RI.

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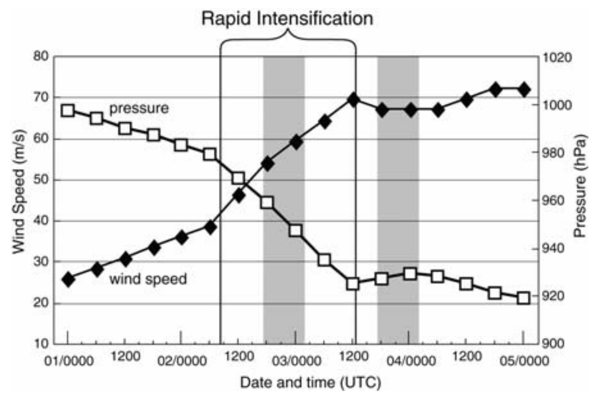

Fig. 1. Best track 1-minute sustained 10 m wind speed (m s^{-1}, left ordinate, solid diamonds) and surface pressure (hPa, right ordinate, open squares) as a function of time for Guillermo. Two gray columns identify times when NOAA aircraft sampled the TC and vertical lines delineate entire period of rapid intensification.

Case studies of Hurricane Opal (e.g., Rodgers et al. 1998, Bosart et al. 2000, Shay et al. 2000, and Hong et al. 2000) have highlighted the role of several of these factors.

For Guillermo (1997) there are synoptic scale clues suggesting that RI is possible, based on the Statistical Hurricane Intensity Prediction Scheme (SHIPS, DeMaria and Kaplan 1994, Kaplan and DeMaria 2003). The SHIPS technique includes the examination of five predictors: previous 12 h intensity change, sea surface temperature (SST), low-level relative humidity, vertical shear of the horizontal wind, and the difference between the current intensity and the maximum potential intensity (MPI, Emanuel, 1988). Tropical cyclones undergoing RI had less deep tropospheric shear (-3.6 m s^{-1}), warmer SSTs (0.9°C), and more 850 – 700 hPa relative humidity (4.3%) than those that did not. However, less than 2% of the entire sample examined by Kaplan and DeMaria (2003) satisfied the thresholds for all five predictors and only ~10% of the RI cases occurred when all thresholds were satisfied. The results demonstrate that a “perfect environment” for RI is quite rare, few hurricanes undergo RI despite ideal conditions, and those that do undergo RI do so largely in less than ideal conditions. This suggests that the internal dynamics of the hurricane must be largely responsible for RI. The GPS sondes provide a view of the inner few hundred km of Guillermo and offer some clues to RI.

3. Questions

We will concentrate on the following questions.

(1) Does the eyewall reflectivity become more symmetric, with taller echo tops, higher rain rates, a smaller diameter and greater net latent heat release during RI?

(2) Are the expected increases in θ_e occurring only under and near the eyewall or do these increases extend well into the strength region?

(3) Is the increase in the tangential wind component constrained only to the eyewall region or does it also extend well beyond the inner core?

(4) Does the inflow become more symmetric, stronger and deeper through the intensification period?

(5) How do the rainbands within 250 km of the circulation center evolve as the TC deepens? Does a more robust eyewall suppress nearby bands?

(6) Is there evidence that downdrafts are becoming less effective in limiting the boundary layer θ_e, and thus allowing the TC to intensify?

4. Data

The Guillermo dataset provides an excellent opportunity to document the changes of a hurricane’s inner core in the lower troposphere as it deepens from 954 hPa to 929 hPa between the two missions. GPS sonde data are used to create lower tropospheric (10 m – 4000 m) composite thermodynamic and kinematic fields during and subsequent to RI. Nearly identical flight patterns allow for direct comparison between the two intensities.

We assume steadiness for each 6 h sampling period and produce vortex scale fields derived from the GPS sondes with respect to the circulation center. Difference fields are created by subtracting 2 August fields from those derived from 3 August. Lower fuselage and tail radar reflectivity views of the inner core of Guillermo are readily comparable given the nearly identical sampling strategy executed on each day.

5. A subset of the results

a. large scale factors

Guillermo was located over 29-30 °C water that exhibited weak meridional gradients. Relative humidity in the mid-troposphere was nearly constant prior and during RI at about 75%. Guillermo was far from its maximum potential intensity (MPI, Emanuel 1988). The hurricane was steered westward by a strong ridge located to the northeast. The change in winds over the 200–850 hPa layer, calculated over a radius 200-800 km, initially favored a forecast of RI, however during intensification the “shear” increased from about 3 to over 8 m s^{-1}. The large scale deep layer shear remained close to the threshold (~10 m s^{-1}) where one might expect a negative impact on TC intensity (e.g., Landsea 1993).

b. fields derived from the GPS sondes

The data from the GPS sondes can be used to create horizontal slices from a few hundred m below the aircraft altitude to near the sea surface. The difference in the storm relative tangential wind speeds (V_T, Fig. 2) from the 2nd to the more intense 3rd reveals that the annulus where this component increased is confined to the inner core or somewhat less than 100 km radius. Speeds increase there as much as 15 m s^{-1}. On the periphery of the analysis V_T decreased several m s^{-1}, demonstrating that the outer core strength region is not following suit with the eyewall and adjacent region.

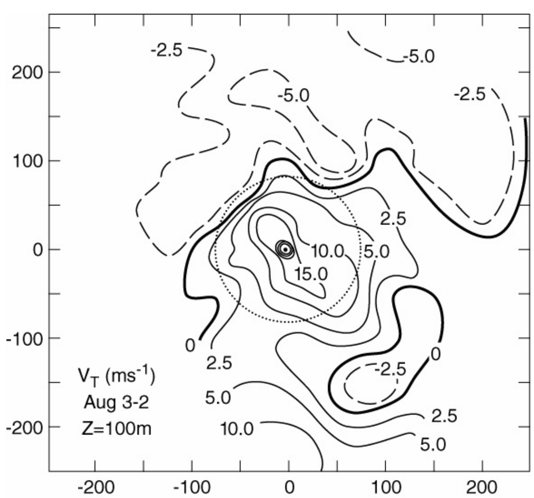

Fig. 2. Difference field (contours are every 2.5 m s^{-1} till 5.0 m s^{-1}, then every 5 m s^{-1}) for the tangential wind component (3 August – 2 August) at 100 m altitude. Positive differences (increases) are solid lines and negative (decreases) are dashed. Distance from circulation is displayed in km along the x- and y-axis. The black dotted ring marks the 75 km radius from the circulation center.

The evolution of the storm relative radial wind component (V_R) at 100 m is shown for the two days (Fig. 3). Note that the inflow is highly asymmetric on August 2nd with most of the inflow at 75 km radial distance coming from the SE. On August 3rd, when the central minimum pressure is 29 hPa deeper, the inflow has become much more axisymmetric and has increased to over 20 m s^{-1} around the eyewall. This coincides with the more complete eyewall as seen by radar.

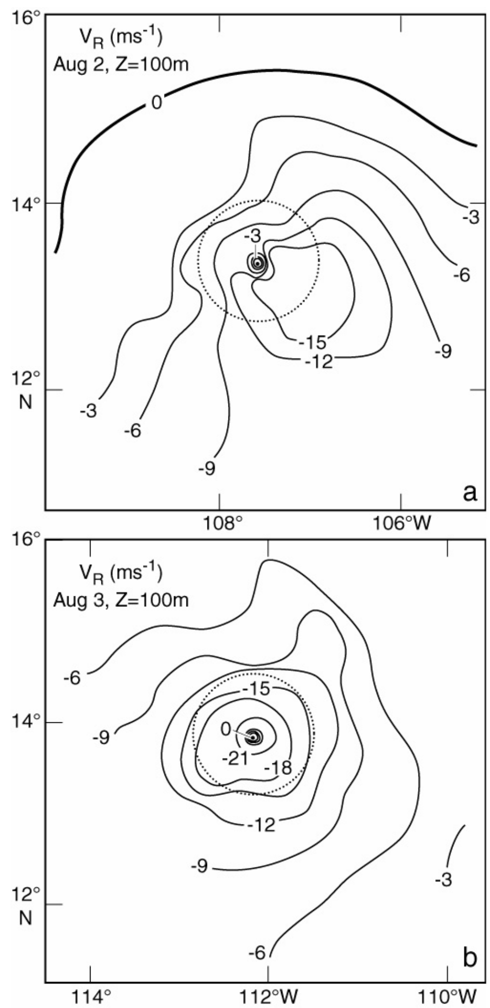

Fig. 3. Radial wind field (contours every 3 m s^{-1}) shown at 100 m altitude for (a) 2 August and (b) 3 August. Negative values are inflow. The black dotted ring marks the 75 km radius from the circulation center.

The equivalent potential temperature (θe) difference field at 100 m altitude

(August 3rd fields– August 2nd fields, Fig. 4) shows two regions where θe has increased substantially. The important increase occurs largely within 75 km radius with the eyewall and eye increasing over 10 K. There is also an increase exceeding 10 K on the eastern periphery of the analysis but this could not be responsible for the RI.

From the 2nd to the 3rd the rainbands that dominate the eastern side of the TC are maintained. What appears to be crucial is that an annulus adjacent to the eyewall, on the order of 50 km in radial extent, is established that is capable of undergoing a rapid increase of θe.

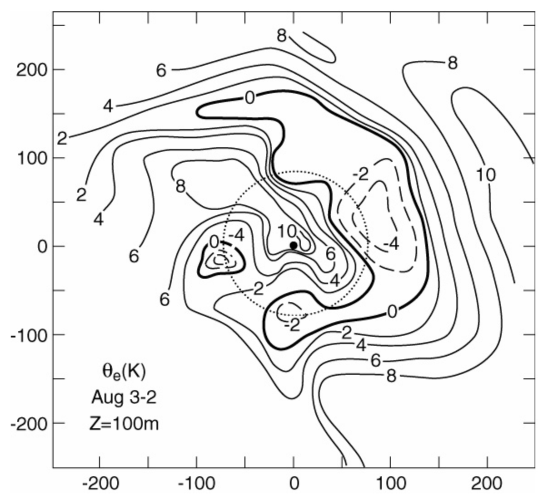

Fig. 4. Equivalent potential temperature difference (K, 3 August – 2 August) at 100 m altitude for the Contours every 2 K. Solid contours are positive (increases) and dashed are negative (decreases). The black dotted ring marks the 75 km radius from the circulation center.

6. Discussion

SHIPS variables prior to deepening reveal that Guillermo could undergo RI but during intensification the shear more than doubled in magnitude. Initially Guillermo was far from its maximum potential intensity, but most TCs fail to reach their MPI (Evans 1993) and often are tens of hPa weaker than the theoretical limit. The only time RI is not apparently possible is when a TC is already close to its MPI.

There are several factors correlated with the RI of Guillermo(1997) that include greater, more axisymmetric mass and moisture flux to the eyewall, a concomitant increase in latent heat release within 60 km of the eye, and development of an annulus adjacent to the eyewall where wind speeds and energy content of the inflow increase rapidly. Perhaps the key initial process is the spiraling inward of the eyewall, that will be shown at the conference, that results in the establishment of a smaller diameter and more complete eye. We will discuss the reflectivity fields and the fields derived from the GPS sondes within the context of prior Guillermo studies by Kossin and Eastin (2001) and Eastin et al. (2006).

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7. References

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