Warm-ring Structures in Intense Hurricanes

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Motivation.

Typical hurricanes have a warm-core structure such that the warmest temperatures occur in the center of the hurricane. However, weather reconnaissance aircraft data has observed warm-rings in intense hurricanes. A warm-ring structure results when the warmest temperature anomalies occur on the outer edge of the eye. Schubert *et al*. (2007) suggests the Eliassen transverse circulation equation can model intense hurricanes with a warm-core structure in the upper troposphere but a warm-ring structure in the lower. Although the thermal wind equation was used in the derivation of the transverse circulation equation, the thermal wind equation has not been used explicitly in an attempt to create such a temperature field. This study derives the thermal wind equation from the hydrostatic and the gradient wind equations to analyze the temperature, tangential velocity, and the absolute vorticity profiles. Using observed hurricanes, a warm-ring structure will be simulated with the thermal wind equation as the basis. This research will compliment previous studies that do not explain the warm-ring with the thermal wind equation.

Considerations.

Goal: *create a realistic wind and thermal structure for a hurricane with a warm-ring using the thermal wind equation.*

Hurricanes Cleo (Fig. 1), Hilda (Fig. 2), and Isabel (Fig. 3) all contain qualities to consider in the construction of a hurricane with a warm-ring structure.

- Hurricane Cleo demonstrates a warm-core in the upper troposphere with a weak warm-ring in the lower.
- Hurricane Hilda demonstrates a warm-core aloft.
- The NOAA P3 radial flight profiles from 13 September 2003 show Hurricane Isabel has a warm-ring.

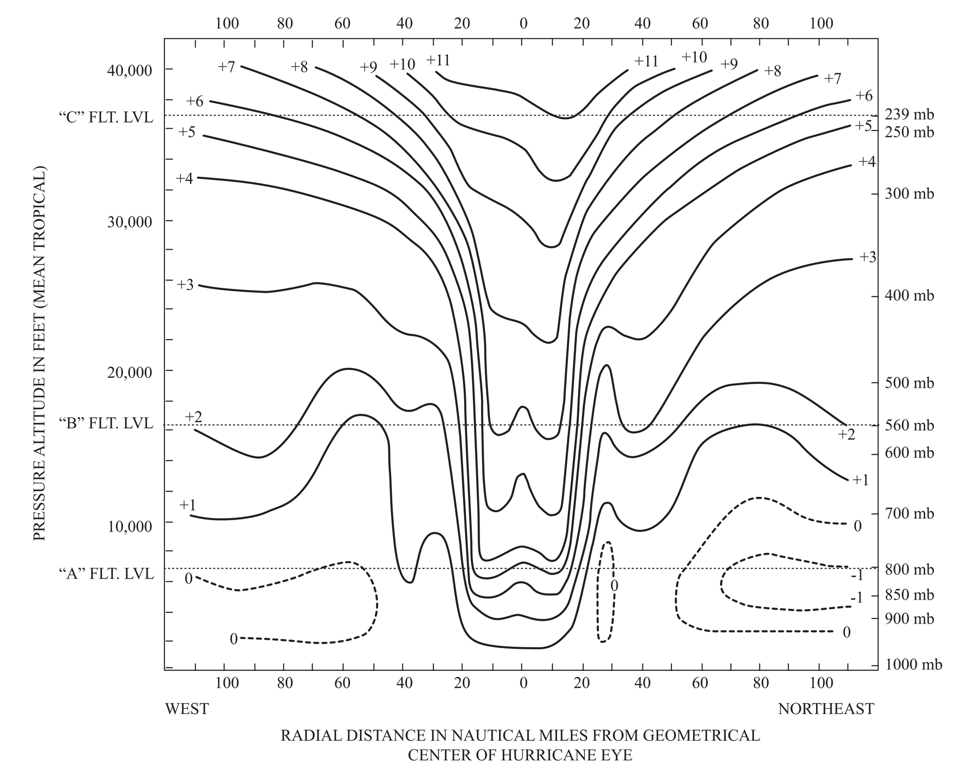

Figure 1. LaSeur and Hawkins (1963)

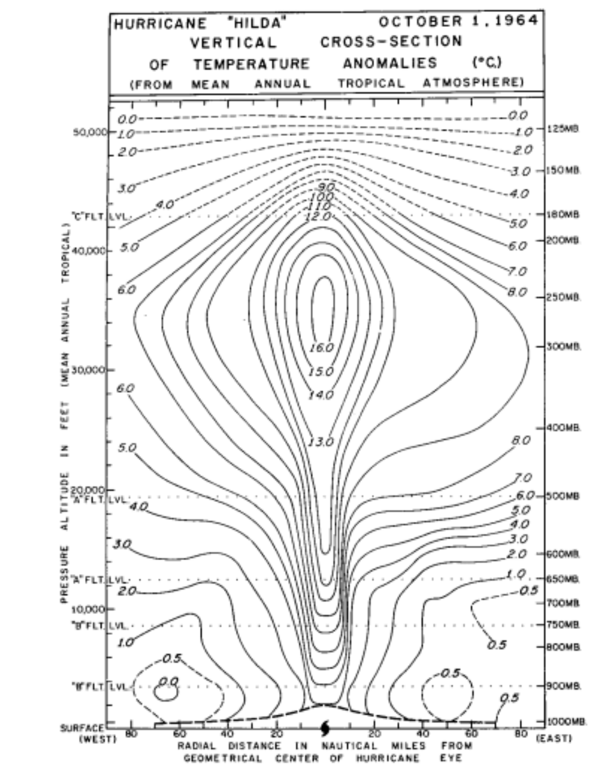

Figure 2. Hawkins and Rubsam (1968)

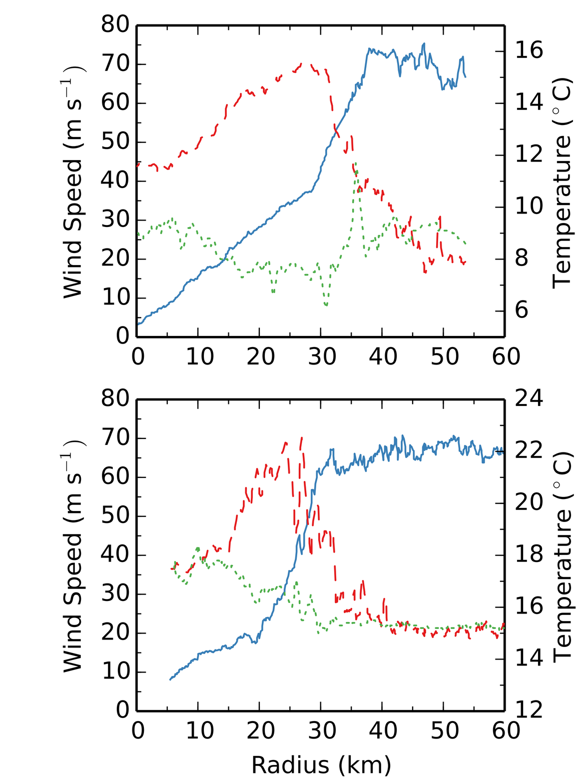

Figure 3. Adapted from Schubert *et al*. (2007)

Methods.

Gradient wind: $\left(f+\frac{v}{r}\right)v=\frac{\partial\phi}{\partial r}$

Hydrostatic: $\frac{\partial\phi}{\partial z}=\frac{g}{T_0}T$

Thermal wind: $\left(f+\frac{2v}{r}\right)\frac{\partial v}{\partial z}=\frac{g}{T_0}\frac{\partial T}{\partial r}$

The thermal wind equation is derived from the gradient wind and hydrostatic equation.

Two methods were attempted to achieve the warm-ring structure.

First method:
- Prescribe tangential velocity profile
- Compute temperature from tangential velocity

Second method:
- Prescribe temperature profile (shown on right)
- Compute tangential velocity from temperature

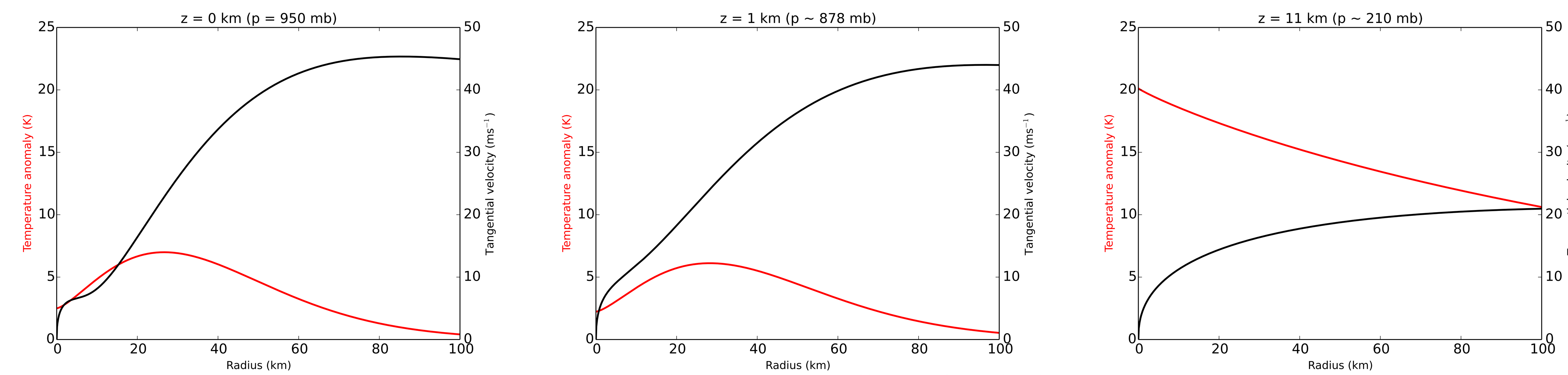

Figure 4. Prescribed temperature profiles at different heights.

Figure 4 illustrates the prescribed temperature profiles at heights above the boundary layer.
- 0, 1 km: warm-ring behavior in lower troposphere
- 11 km : warm-core behavior in upper troposphere

The velocity lines shown are computed from the temperature.

Results.

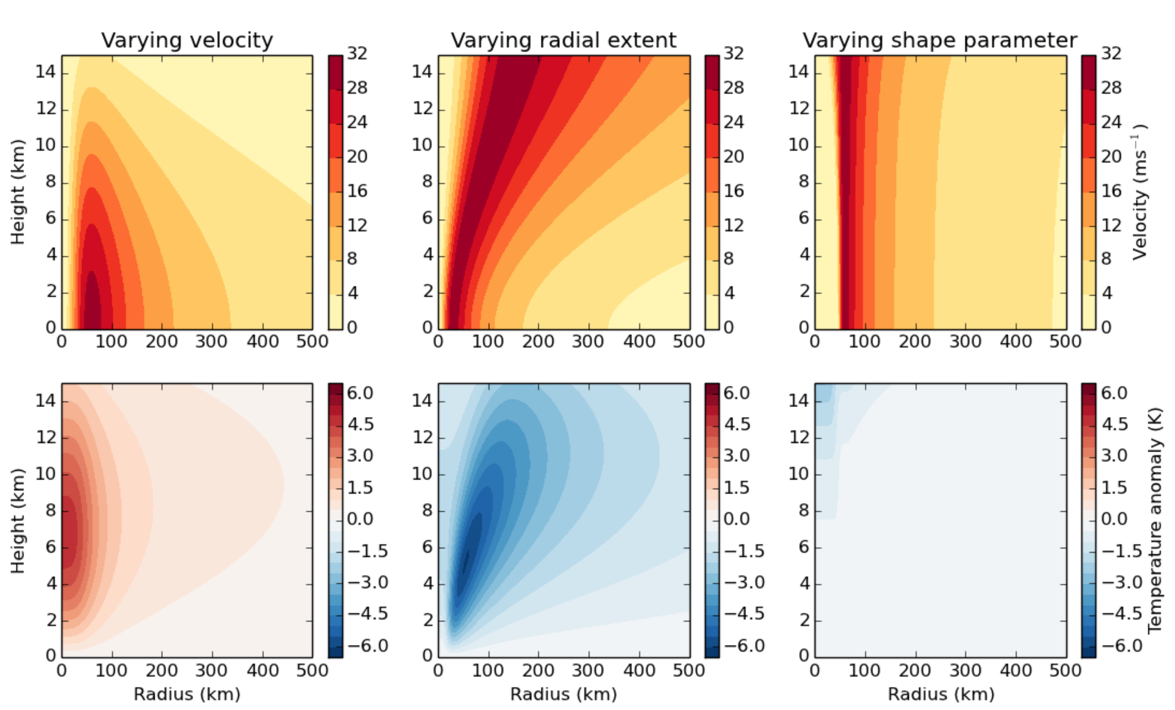

Figure 5. Velocity (top) and temperature cross-sections (bottom).

Temperature is calculated from the velocity field in the first attempt.
- Each column varies a single parameter
- No combination of varying parameters simulated a warm-ring

Thus, this attempt does not achieve our goal.

The next attempt reverses the order by starting with the temperature profile illustrated by the figures in Methods.
- Temperature field is prescribed with a warm-ring structure
- Tangential velocity is calculated from temperature
- Absolute vorticity is calculated from tangential velocity

The velocity and vorticity fields resemble those of a realistic hurricane:
- Tangential velocity reaches a maximum of 50 ms^{-1} classifying this hurricane as a Category 3 on the Saffir-Simpson scale, thus, demonstrating that this occurs in intense hurricanes.
- Tight velocity bands in the first 30 km (in radius) suggest influence by boundary layer processes.
- Positive values of absolute vorticity indicate that the hurricane is moving cyclonically.
- Vorticity also demonstrates some boundary layer mechanism at 15-35 km.

Absolute angular momentum contours dictate the motion of a parcel of air if placed on a contour.

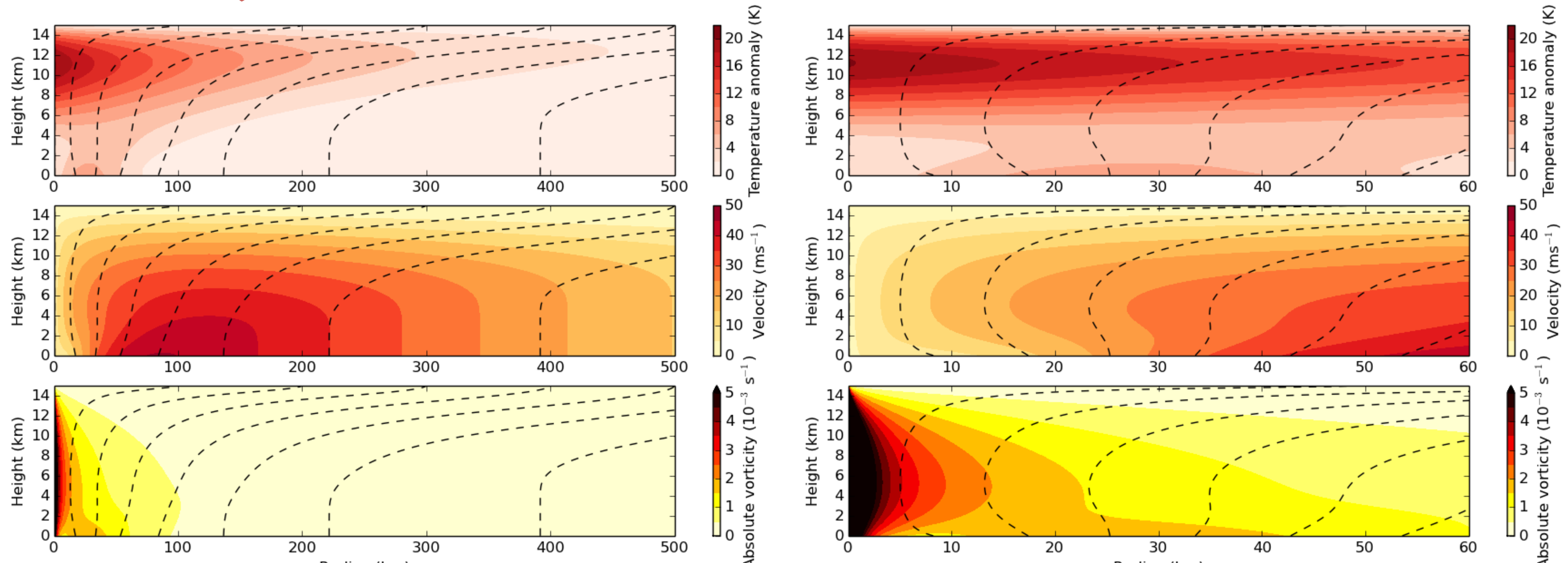

Figure 6. Temperature (top), tangential velocity (middle), and vorticity cross-sections (bottom). Absolute angular momentum contours are drawn in intervals of 100 km (left) and 50 km (right).

Conclusions.

The thermal wind equation can be used to create a realistic, intense hurricane with a warm ring structure.

The thermal wind balance is sufficient to show a realistic velocity field. The resulting velocity field also illustrates the variations necessary for a warm-ring.

Future work.

Schubert *et al*. (2007) discusses subsidence as a mechanism that leads to the warm-ring but the velocity and vorticity fields suggest there is some influence by boundary layer processes.

To further understand the warm-ring, the relative roles of subsidence and the boundary layer should be explored.

References.

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