# Structural Changes and Convective Processes in Tropical Cyclones as seen in Infrared and Water Vapor Satellite Data


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## Introduction

- Tropical cyclone (TC) inner-core structure has significant influence on TC intensity, which, despite decades of study, remains an operational challenge.
- Dvorak (1975) developed an algorithm that used geostationary infrared (IR) satellite imagery to determine TC intensity.
  - His algorithm is widely used by operational forecasters today
- Fritz and Lazlo (1993) developed a brightness temperature (Tb) differencing technique to detect convective clouds that extend into the stratosphere.
  - Their method is used to monitor variation in deep convection over time (Olander and Velden 2009).
- **This study builds on these techniques to establish a relationship between the radial structure of eyewall clouds and TC intensity.**
- **It extends the findings of Hazelton and Hart (2013) by providing objective measurements in the TC inner core in basins where aircraft reconnaissance is unavailable, including the strategically important western North Pacific.**

## Data

- Five typhoons from the 2012 typhoon season in the western North Pacific were analyzed during periods with visible TC eyes.
- Geostationary satellite data from MTSAT2 were provided by the Naval Research Laboratory, Monterey, CA.
  - Temporal resolution: 0.5-2 hrs
  - Spatial resolution: 4 km
- Intensity estimates (within 5 kts) were taken from the Joint Typhoon Warning Center via the Automated Tropical Cyclone Forecast (ATCF) system.
  - Temporal resolution: 6 hrs

## Deep Convection Tracker

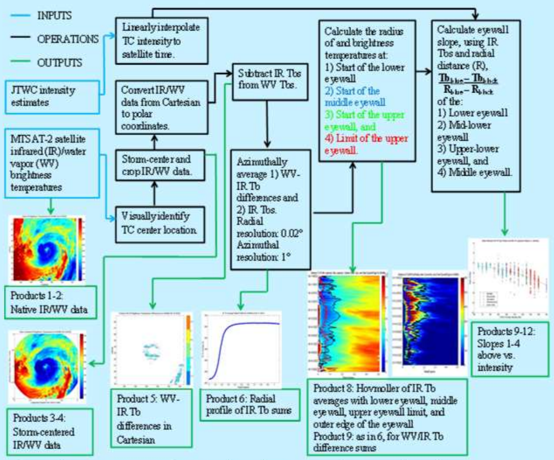


Fig. 1: The Deep Convection Tracker: data, operations, and products.

## Methodology

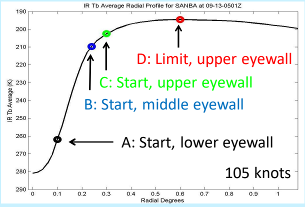


Fig. 2: Radial profile of IR Tb averages in Super Typhoon Sanba at 0501 UTC 13 September 2012. Colored dots indicate inner-core structure.

- **Eyewall sections (lower, middle, upper) objectively determined by:**
  - A) Minimum IR Laplacian
  - B) Maximum IR Laplacian
  - C) First positive WV-IR difference
  - D) Minimum IR Tb
- Brightness temperatures at the maximum IR Laplacian were colder than at the minimum IR Laplacian in 93.9% of the 821 brightness temperature profiles.
- Brightness temperatures at the first positive WV-IR difference were colder than at the maximum IR Laplacian in 88.2% of the cases.

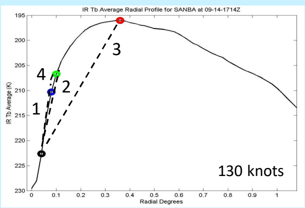


Fig. 3: Radial profile of IR Tb averages in Super Typhoon Sanba at 0132 UTC 14 September 2012. Dashed lines indicate eyewall slope.

- **Eyewall slope (lower, middle, upper) calculated from IR Tbs and radial distances (R); slope=** $\frac{Tb_{blue}-Tb_{black}}{R_{blue}-R_{black}}$

  - ● ● 1) Lower eyewall slope
  - ● ● 2) Mid-lower eyewall slope
  - ● ● 3) Upper-lower eyewall slope
  - ● ● 4) Middle eyewall slope

- The following statistics quantify the relationship between slope and intensity:
  - A quadratic best-fit line
  - Coefficient of determination ($R^2$)
  - Root Mean Square Error (RMSE)

## Results: Eyewall Cloud Temperature

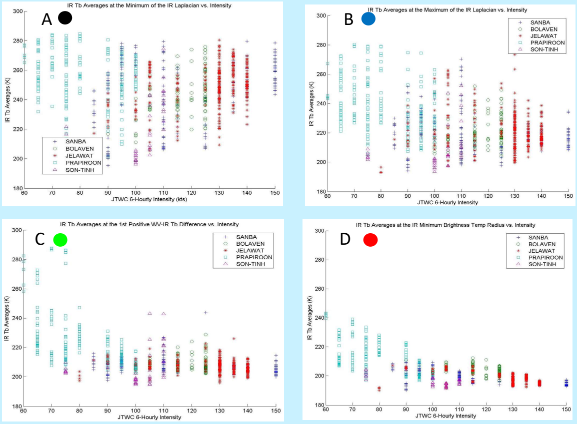


Fig. 4: The MTSAT-2 IR Tbs (K) vs. intensity (kts) at the start of the A) lower, B) middle, and C) upper eyewall, and at the D) limit of the upper eyewall.

### Middle and Lower Eyewall Cloud Temperatures

- In the lower eyewall (A,B), no consistent relationship was apparent between IR Tbs and TC intensity.
  - Physically, this demonstrates that the heights of the base (A) and the middle (B) of the eyewall were not consistently related to intensity.
- However, at the start of the lower eyewall (A), higher IR Tbs seemed to correspond to TC intensity when intensity exceeded 100 knots.
  - Physically, this implies that the base of the eyewall (A) may approach the sea surface as TC intensity increases.

### Upper Eyewall Cloud Temperatures

- In the upper eyewall (C,D), lower IR Tbs were observed during periods of increased TC intensity.
  - Physically, this means that higher clouds corresponded to more intense TCs, as in Dvorak (1975).

**Potential utility: An objective technique to calculate eye diameter and to estimate TC intensity in real time, based on radial profiles of brightness temperatures.**

## Results: Eyewall Slope

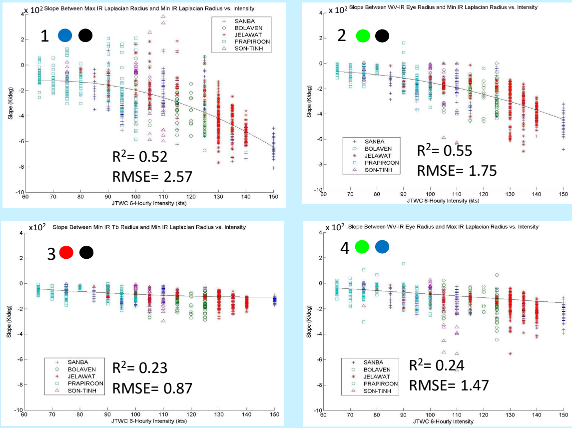


Fig. 5: The eyewall slope (K $deg^{-1}$) for the 1) lower, 2) mid-lower, 3) upper-lower , and 4) middle eyewall.

### Lower and Mid-Lower Eyewall Slope

- For the lower eyewall (1) and mid-lower eyewall (2), increasingly negative slope corresponded to greater TC intensity. Coefficients of determination ($R^2$) were 0.52 and 0.55, respectively.
  - Physically, this indicates that a more abrupt transition between the warm, cloud-free eye and the cold eyewall clouds was associated with high intensity.

### Middle and Upper-Lower Eyewall Slope

- No significant relationship between eyewall slope and TC intensity was observed in the upper-lower eyewall (3) or middle eyewall (4). Coefficients of determination ($R^2$) were 0.23 and 0.24, respectively.
- The lower eyewall (1) and mid-lower eyewall (2) reached a higher magnitude of slope compared to the upper-lower (3) and middle eyewall (4).
  - Physically, this means that the lower and middle eyewall segments were both more sloped than the upper eyewall and were more strongly related to TC intensity.
- Hazelton and Hart (2013) found similar relationships using aircraft reconnaissance data.
  - Here we use satellite data, which is available more frequently, but has lower horizontal resolution than aircraft reconnaissance data.

**Potential utility: An objective technique to estimate TC intensity in real time, based on calculations of eyewall slope.**

## References


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Olander, T.L., and C.S. Velden, 2009: Tropical cyclone convection and intensity analysis using differenced infrared and water vapor imagery. *Wea. Forecasting*, **24**, 1558-1572.