Typhoon kinematic and thermodynamic boundary layer structure from dropsonde composites

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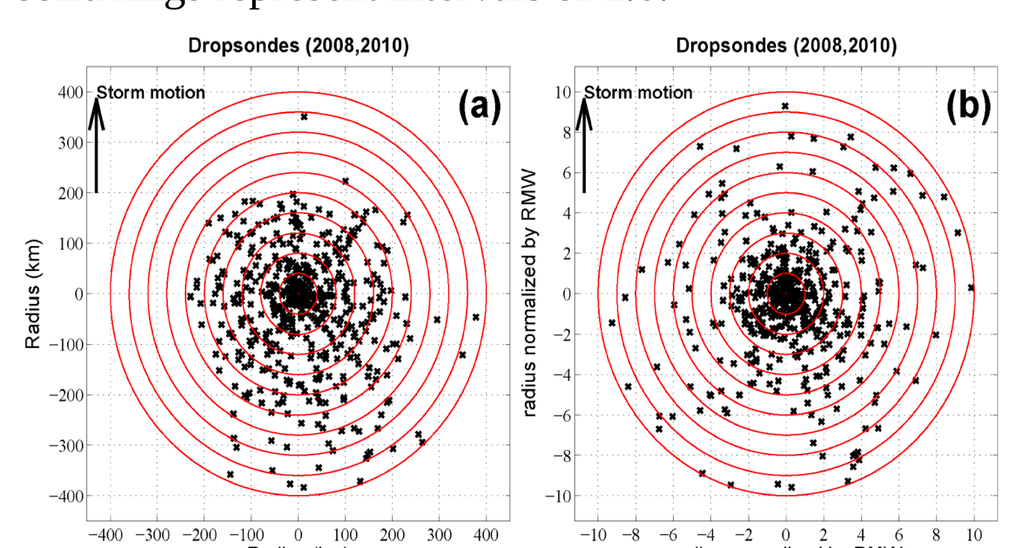
1. Introduction

It is widely accepted that the boundary layer is very important for the development and intensification of tropical cyclones (TCs), regulating the transfer of heat and moisture from the underlying air-sea interface to upper levels. It is noted that the above-mentioned observational studies of the TC boundary layer were all conducted in the Atlantic basin. However, few studies have documented the TC boundary layer over the Western Pacific basin [e.g., Sanger et al. 2014, Ming et al. 2014]. This study takes advantage of recent field experiments conducted in the Western Pacific basin to study typhoon boundary layer structure. We analyze GPS dropsonde data collected during Tropical Cyclone Structure Experiment (TCS08) joint The Observing-System Research and Predictability Experiment [THORPEX; Shapiro and Thorpe 2004], Pacific Asian Regional Campaign (T-PARC) project, and the Impact of Typhoons on the Ocean in the Pacific (ITOP) project in 6 typhoons. The objectives of this paper are to investigate the axisymmetric kinematic and thermodynamic structures of the typhoon boundary layer and to identify the differences in the boundary layer structure between Western Pacific typhoons and Atlantic hurricanes.

2. Data description

- The dropsonde data used in this study were collected by the TCS08/T-PARC and ITOP projects. A total of 1318 GPS dropsondes were processed and analyzed. To study the structures of the boundary layer, we only use dropsondes that have measurements all the way down to the near surface (~50 m). There are only 438 dropsondes which have continuous measurements of wind speed, temperature, and humidity from the flight level to the surface in the storms with sustained wind speed > 33 m s-1 that are used in our final analysis.
- Storm information and number of dropsondes in 2008 and 2010. Storm-relative distribution of GPS dropsondes used in the current study for (a) an unscaled radial distance, where the solid rings represent 40-km intervals, and (b) radius normalized by an estimate of radius of the maximum wind speed (RMW), where the solid rings represent intervals of 1.0.

Storm	Intensity Range ($m\ s^{-1}$)	No. of Sondes
2008 TCS08/T-PARC (188)		
Nuri	35.98–38.55	23
Sinlaku	33.41–61.68	104
Jangmi	46.26–71.96	61
2010 ITOP (250)		
Fanapi	38.55–51.4	57
Malakas	33.41–46.26	88
Megi	41.12–82.24	105



3. Analysis method

Dropsonde data are analyzed and grouped in a composite framework, radius normalized by an estimate of RMW. Values of RMW during the ITOP project are determined using the flight level wind data. During the TCS08/T-PARC project, the flight-level data are not accessible, so RMW is determined by the wind speed at 2 km height level from dropsonde data. We take one flight of typhoon Makalas (2010) as an example to compare the two methods of RMW calculation. Figure 1 shows the flight level wind speed during two eyewall penetrations, the RMW determined at these two times are 32.0 km and 41.7 km respectively. Figure 1 also shows the time series of wind speeds measured by the dropsondes. The center position is determined from the dropsonde location released in the typhoon eye. Based on the distance between the center and location of wind maxima, the calculated RMW is 28.3 km and 35.7 km, respectively. In this case, the error in the RMW estimate using the dropsonde data compared to that from the flight-level data is within 6 km. Note that this is the only reliable method to get the RMW without the flight-level data as the aircraft always released a sonde at the typhoon eyewall.

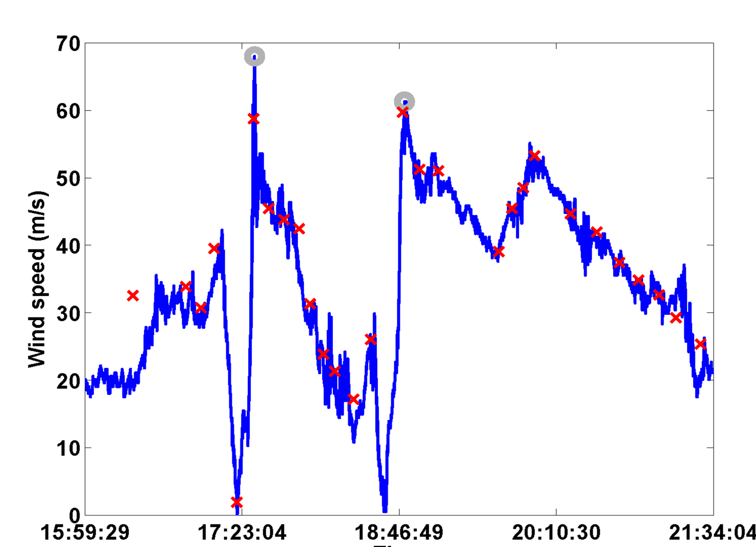


Figure 1. The Wind speed of flight level at 3-km (blue solid line) and dropsonde data at 2-km height level (red crosses) in Typhoon Malakas (2010). The gray cycles mark the maximum wind speed at the flight level.

4. Results

- In both the typhoon and hurricane composites, h_{vtmax} decreases with decreasing radius from the storm center. h_{vtmax} in the typhoon composite is slightly lower than that in the hurricane composite for almost all radii.
- The radial wind velocity shows the peak radial inflow is located at ~150 m above the sea surface just outside r* = 1, with a maximum value of 14 m s^{-1}. Compared to the hurricane composite, the maximum value of Vr in the typhoon composite is weaker. Both the hurricane and typhoon composites show a trend of decreasing h_{inflow} with decreasing radius toward the storm center.
- Compared to the hurricane composite, the typhoon boundary layer is marginally drier in the eye but significantly moister outside the eyewall. The typhoon composite shows a significantly warmer boundary layer in the outer core that is slightly but not significantly cooler in the eye than the hurricane composite. The radial distribution of temperature within the boundary layer shows a decrease of temperature with decreasing radius for both composites, which suggests that the near surface temperature is not isothermal. This pattern is more pronounced in the hurricane composite.
- The humidity of environment in typhoon composite is on average ~7% higher than those in the hurricane composite, suggesting that the environment is moister in typhoons that are included in the composite analysis. The SST is significantly higher in the typhoon composite although the difference is relatively small (~0.18 ºC). The SST difference may result in a warmer and moister boundary layer in the typhoon composite than in the hurricane composite.

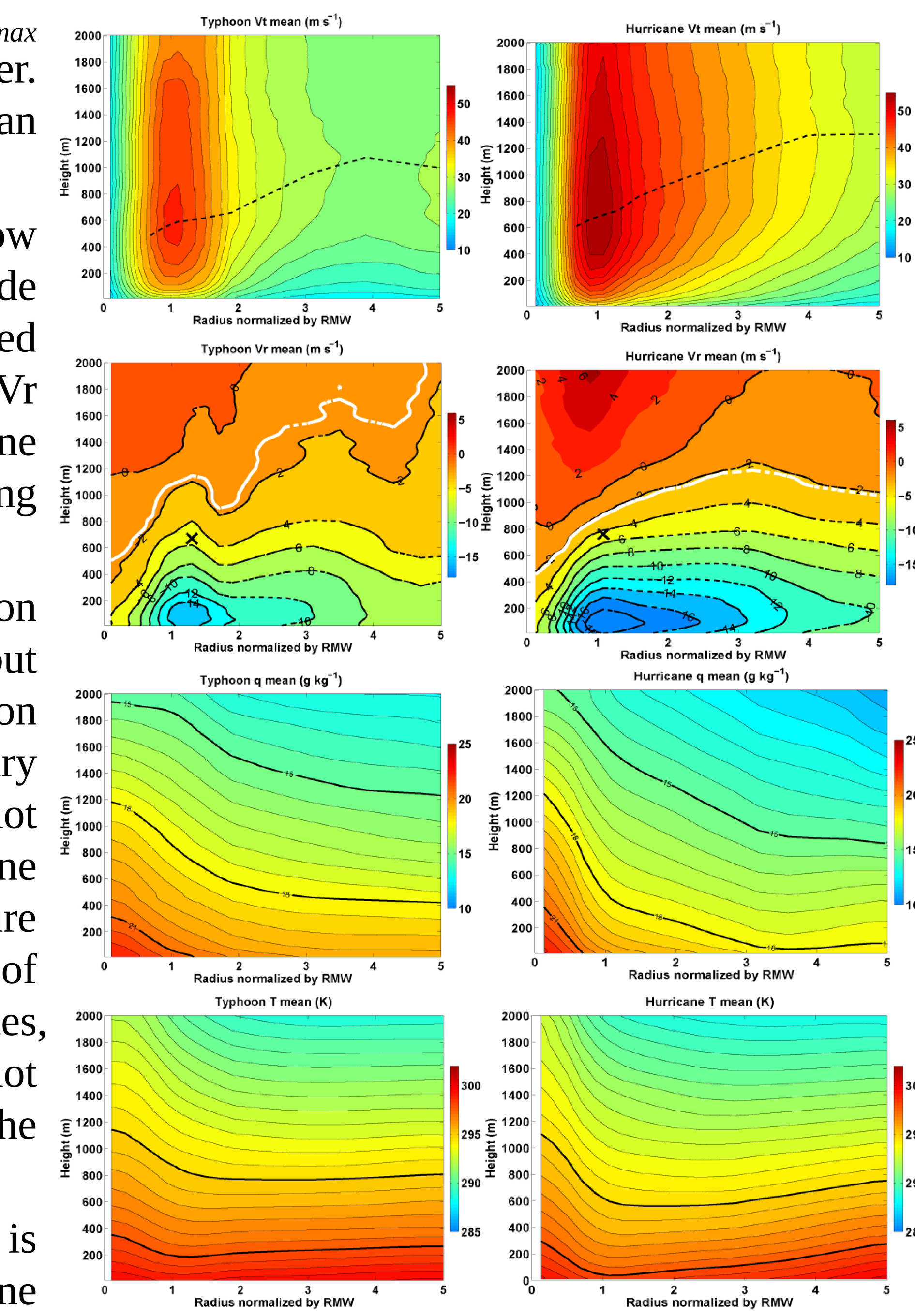


Figure 2 Tangential wind velocity (first line, *Vt* , unit: m s^{-1}); Radial wind velocity (second line, *Vr* , unit: m s^{-1}); Specific humidity (third line, *q* , unit: g kg^{-1}) and Temperature (fourth line, T, unit: K) as a function of altitude and normalized radius from the storm center for typhoon composite (first column) and hurricane composite (second column) .

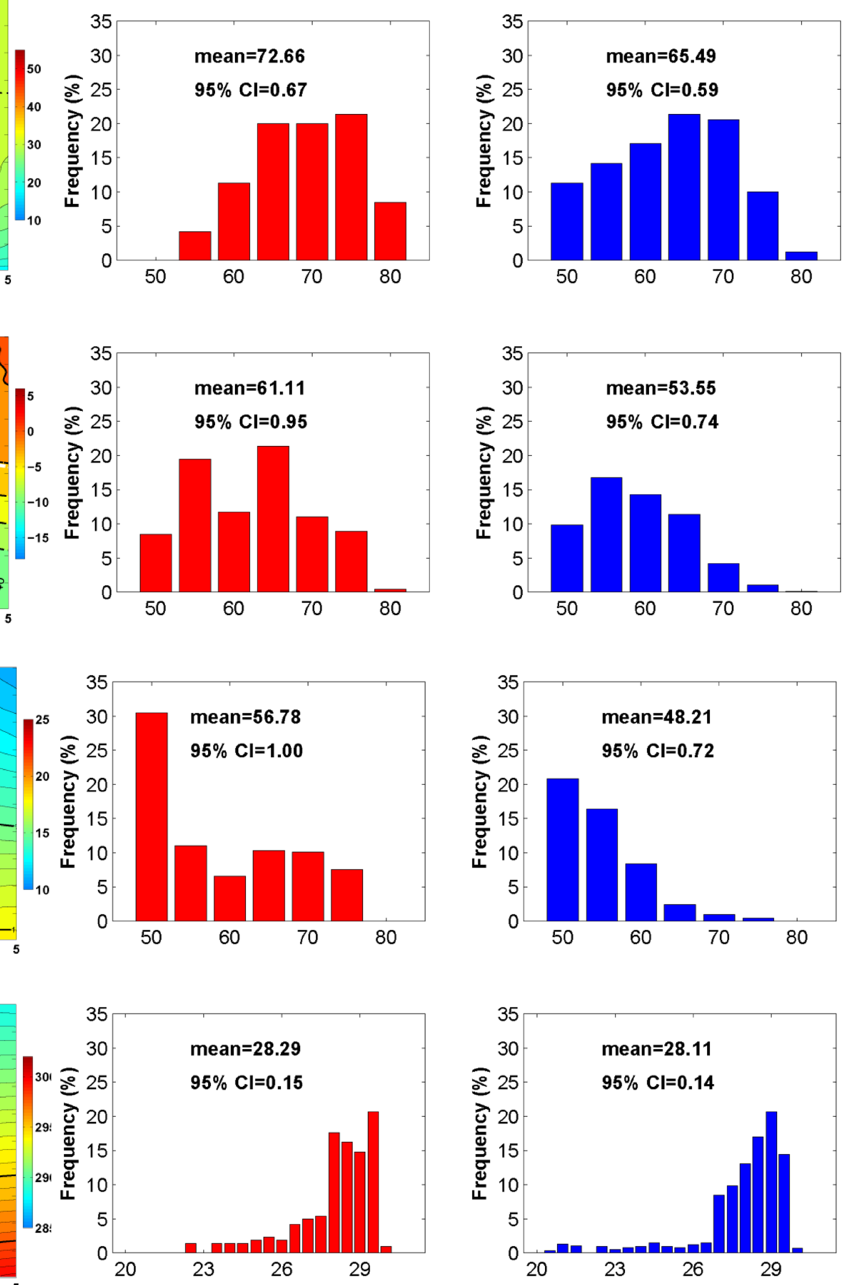


Figure 3 Frequency distribution of 850-700 hPa relative humidity (first line); 700-500 hPa relative humidity (second line); 500-300 hPa relative humidity (third line) and SST (fourth line) for typhoon composite (red) and hurricane composite (blue) .

5. Summary

In this paper, the thermodynamic and kinematic structures, especially the height scales of the boundary layer, are analyzed using dropsonde data from 6 typhoons in the western North Pacific. There is a clear separation of the thermodynamic and kinematic boundary layer scales. It is found that h_{vtmax} is lower than h_{inflow}. All three height scales increase with increasing radius in the inner core region, and the h_{inflow} increases more than the other two height scales. Furthermore, the mixed layer depth and h_{vtmax} have a tendency toward to level off in the outer core region. However, there are still some differences between the typhoon and hurricane composites. Kinematically, the boundary layer depth is generally deeper in the typhoon composite than in the hurricane composite. The main reason for this difference is thought to be due to the difference in the boundary layer inertial stability. The typhoon is moister at lower levels, especially in the outer core region. This may be due to the typical background environment of typhoons, where the summer monsoon provides abundant moisture in the lower and middle levels.

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For further details see the paper:

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