13C.1 THE DISTRIBUTION OF SURFACE WINDS IN PACIFIC TYPHOONS

Ryan T. Ellis * and Steven Businger
University of Hawaii, Honolulu, Hawaii

1. INTRODUCTION

Low-level wind data from the WSR-88D in Guam obtained from Typhoon Dale (1996) and Typhoon Keith (1997) were analyzed for coherent structures known as roll vortices. Consistent with the results of previous observational studies of rolls in the hurricane boundary layer, velocity anomalies associated with rolls were found in the boundary layer of both storms (Wurman and Winslow (1998), Katsaros et al. (2000), Morrison et al. (2005), Lorsolo et al. (2008)).

The results presented here can be used to help validate theoretical and numerical models of coherent structures within tropical cyclones (Foster 2005). Moreover, the wind variations documented in this study have application for wave run-up and the structural wind damage potential in tropical cyclones.

2. DATA AND METHODS

Tropical cyclone data were obtained from the Guam WSR-88D radar during Typhoons Dale and Keith to analyze coherent structures known as roll vortices in the typhoon boundary layer. Level II NEXRAD data were used in this study.

A velocity azimuth display (VAD) technique was used to obtain a residual velocity field by subtracting the sinusoidal component of the radial velocity from the Doppler velocity field to assess roll activity (Fig. 1). Roll vortices were documented during a six-hour evaluation period for each storm. Storm relative roll location, wavelength, depth, aspect ratio, momentum flux, roll vorticity, as well as asymmetries in roll updrafts and downdrafts were explored. VAD wind profiles were created using Doppler velocity data to determine the depth of the roll circulation. New research shows the effects of terrain and convective elements, such as rainbands, on the formation and maintenance of rolls.

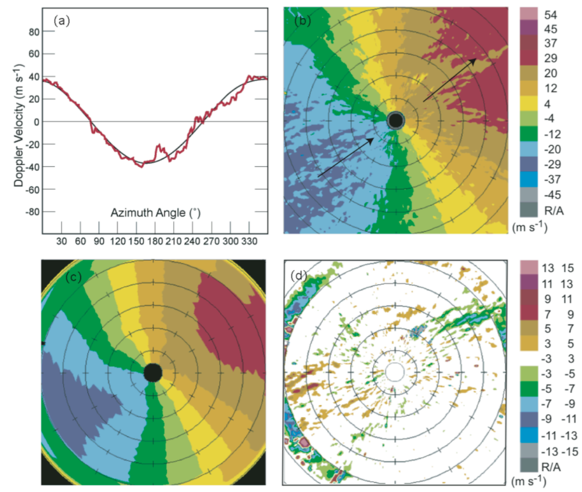

Fig. 1. (a) Radial velocity (red line) at 5 km from the radar and sinusoidal component (1st harmonic) of the radial velocity (black line) from Morrison et al. (2005). (b) Example VAD of WSR-88D Doppler velocity, (c) sinusoidal component of the radial velocity, and (d) residual velocity field (d) with 2 km range rings from the Guam WSR-88D at 0955 UTC on 2 November 1997 during Typhoon Keith. Velocity scale for (c) is same as shown for (b).

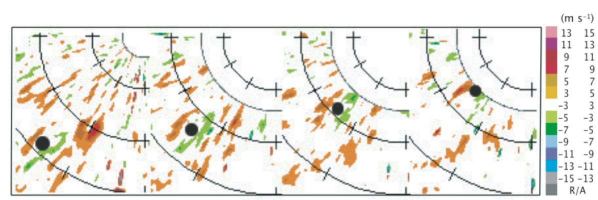

Fig. 2. A roll circulation is tracked from the Guam WSR-88D during Typhoon Keith. Each frame is ~25 s apart at subsequent higher elevation angles. Range rings are 2 km apart with hatches representing 30° swaths. Ring without hatches represents the beginning range of observations.

Finally, signatures of transverse circulations normal to the mean flow were explored. Convergence and divergence patterns and wind speeds observed perpendicular to the mean flow are presented here.

3. RESULTS

In total, 99 cases of roll vortices (as defined by this study) were observed. A total of 678 Plan Position Indicator (PPI) scans were examined with roll activity present in 312 of these scans, or ~46% of the time. Rolls were found to cover ~50% of the

* *Corresponding author address:* Ryan T. Ellis, Univ. of Hawaii at Manoa, Department of Meteorology, 2525 Correa Road, HIG350, Honolulu, HI 96822;e-mail: rtellis@hawaii.edu

area scanned by the radar in non-convective situations and ~10% of the area scanned in convective situations. Enhanced terrain was found to reduce the genesis of rolls by ~75% in Typhoon Keith.

The location of roll observations was mapped relative to storm center (Fig. 3). Combining the results of this study and Morrison et al. (2005), rolls were observed in all four quadrants of tropical cyclone. Rolls were most likely to be found at an elevation angle of 1.4° and a distance of 3-6 km from the radar. This translates to a height of ~100 – 200 m above ground level (Fig. 4).

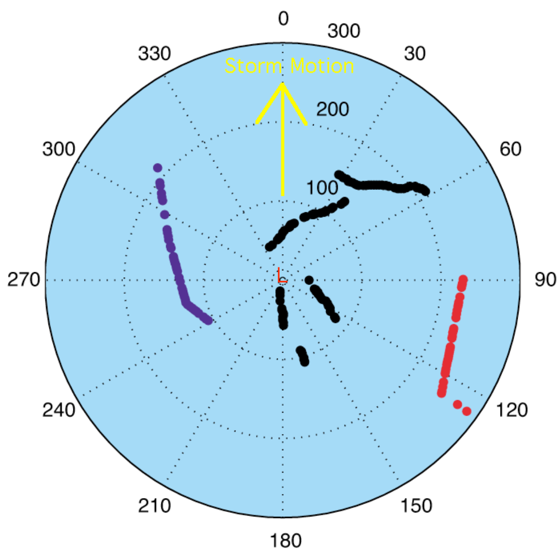

Fig. 3. Storm-relative roll locations for Dale (red) and Keith (blue) compared with rolls observed in M2005 (black). The zero degree mark refers to the direction of storm motion.

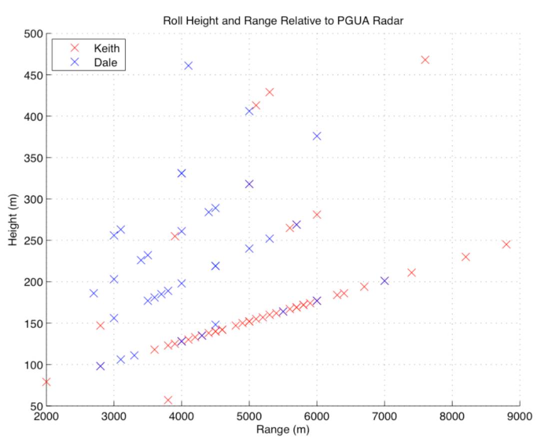

Fig. 4. Height and range of initial roll observations by the WSR-88D radar in Typhoon Dale (blue) and Typhoon Keith (red).

A typical boundary layer roll in a hurricane environment has a wavelength of ~1400 m and a depth of ~700 m, and an aspect ratio of 2:1. Positive and negative horizontal velocity anomalies, associated with roll circulations, average ~7 m s^{-1} and the areal-averaged momentum flux generated by a typical roll is 8-9 m^2 s^{-2}. This value increases to ~17 m^2 s^{-2} when considering momentum flux associated with downdraft portion of the roll only and ~20 m^2 s^{-2} associated with the roll updraft. Orientation of the rolls is consistently ~2° to the left of the mean wind and the vertical component of vorticity produced by rolls in on the order of 10^{-2} s^{-1}.

Foster (2005) noted asymmetries in the analytical analysis between the updraft and downdraft portions of roll circulations. In the analytical solution, vertical velocities were ~1.4 m s^{-1} in the updrafts and ~ -1.1 m s^{-1} in the downdrafts. The vertical velocities estimated in Dale and Keith also showed that the estimated updrafts were larger than the downdrafts. Rolls updrafts were estimated to be ~2.1 m s^{-1} and downdrafts ~ -1.9 m s^{-1}. Estimated values in this study tended to be larger than those predicted by the analytical solution, as was the case in Morrison et al. (2005). Theoretical results from Foster (2005) showed an average roll to have a horizontal velocity anomaly of 2.2 m s^{-1}, wavelength of 1004 m, depth of 500m, aspect ratio of 2.4, and orientation of 3.5° to the left of the mean wind direction.

VAD profiles revealed typical roll circulation of ~700 m deep. The results from Typhoons Dale and Keith also showed that the roll circulation as a whole can occur at different levels in the atmosphere.

Evidence of roll vortices was also documented by the WSR-88D at a direction perpendicular to the mean flow. Although smaller than the positive and negative residual velocities documented parallel to the mean flow, the radar depicted 25 cases of transverse roll circulation in Typhoon Keith at average wind speeds of ~5 m s^{-1}. Convergence and divergence associated with the transverse flow gives some evidence supporting the idea that updrafts in rolls may be slightly larger than the downdrafts. Transverse circulations were more likely to be found one elevation angle higher the along flow cases of rolls.

4. CONCLUSIONS

Doppler radar derived low-level winds on Guam during Typhoons Dale (1996) and Keith (1997) were analyzed for coherent structures. The results yielded the first observational analysis of roll vortices in tropical cyclones over the Pacific Ocean. These data support the conclusion that rolls are significant in the boundary layer of tropical cyclones over the Pacific Ocean.

This study shows that in order to assess the percentage of the area of the tropical cyclone affected by rolls, the structure of each individual storm and its surrounding environment must be taken into account. This research concluded that rugged terrain had an adverse effect on the genesis of rolls in Typhoon Keith. This effect can increase or decrease depending on the height and the alignment of the underlying terrain. Rainbands and other convective areas in Typhoon Keith also proved to deter roll genesis. To better assess the affect of rolls on the tropical cyclone boundary layer it is first necessary to evaluate the storm structure to determine how much of the storm is covered by convective areas. Once this is determined, a better estimate of roll coverage for an individual storm can be obtained.

While it is difficult to quantify exactly to what extent roll circulations affect the energy budget of the tropical cyclone, it is reasonable to argue that they represent a significant portion of the energy budget and should be at least parameterized, if not resolved in the boundary layer schemes of tropical cyclone forecast models. The results presented here provide a validation target for future theoretical and numerical modeling work on roll vortices and hurricane boundary layer structure.

Acknowledgement. We thank Dr. Gary Barnes and Dr. Thomas Schroeder for their insight to the content of this project. We are grateful to Peter Dodge for his help with the radar analysis program and to Jennifer Meehan for support with data analysis. This study was supported under contract from the United States Army Corps of Engineers (#W912HZ-05-C-0036)

5. REFERENCES

Foster, R. C., 2005: Why rolls are prevalent in the hurricane boundary layer. *J. Atmos. Sci.,* **62,** 2647–2661.

Katsaros, K. B., P. W. Vachon, P. G. Black, P. P. Dodge, and E. W. Uhlhorn, 2000: Wind fields from SAR: Could they improve our understanding of storm dynamics? *John Hopkins APL Tech. Dig.,* **211,** 86–93.

Lorsolo, S., J.L. Schroeder, P. Dodge, F. Marks: An observational study of hurricane boundary layer small-scale coherent structures. *Mon. Wea. Rev.* 2008 early online release, posted January 2008.

Morrison, I., S. Businger, F. Marks, P. Dodge, J. A. Businger, 2005: An observational case for the prevalence of roll vortices in the hurricane boundary layer. *J. Atmos. Sci.,* **62,** 2662-2673.

Wurman, J., and J. Winslow, 1998: Intense sub-kilometer boundary layer rolls in Hurricane Fran. *Science,* **280,** 555–557.