Multi-wavelength Radar Observations of Tropical Cyclone Rainbands Over South Florida

Shaunna L. Donaher and Bruce A. Albrecht
University of Miami, RSMAS
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1. Introduction

Observational studies on the structure of tropical storm and hurricane rainbands have become more prevalent since the end of World War II, when radar began to be used for meteorological purposes (Powell 1990). In the past few decades, the majority of these observations have occurred over the oceans using data from C- and X-band radar collected during research flights (i.e. Barnes et al. 1983; Marks 1985; Jorgensen 1984; Barnes and Stossmeister 1986). There have also been a few studies of rainbands making landfall, some with scanning weather radar (i.e. Skwira et al. 2005) and some with wind profilers (i.e. May et al. 1994). However these landfalling studies are less prevalent due to the challenge of planning for data collection with highly variable landfall potential, as well as the inability to perform research flight at low levels over land. This study presents a unique opportunity to observe 24 tropical cyclone rainbands as they pass over a field experiment site in South Florida. The availability of multi-wavelength radar observations allows us to characterize the vertical structure of these bands and create a high resolution representation of rainbands over land. It is important to fully understand the vertical and horizontal structure of rainband winds and moisture over land, since that is where wind and rainfall can have the largest impact on human activity.

2. Experiment Description/Instrumentation

The original objective of CPS (Cloud Precipitation Study) was to characterize and understand the properties of the small scale vertical velocity and drop size distribution structure of thunderstorm anvils and fair weather cumuli. The field experiment took place in South Florida over 8 weeks in August and September 2008, a time chosen because summertime sea breeze fronts often converge over the center of the peninsula, causing strong afternoon storms. However, this time of year is also in the middle of the Atlantic hurricane season, and we were fortunate to have four tropical cyclones pass through the vicinity of our field site while we were on station. This study is focused on the observations of the rainbands during the four storm passages.

During this study, multiple wavelength radars were operating in an upward facing configuration. The main instruments used in this study are a vertically pointing X-band radar and a 915 MHz wind profiler (Multiple Antenna Profiling Radar, MAPR), that provide a high resolution vertical mapping of reflectivity, Doppler velocities, and winds throughout the column above. Data from the Miami WSR-88D will also be used to supplement the vertically pointing instruments. To complement the radar data set, rawinsonde launches were made 2-3 times daily to illustrate the thermodynamic structure of the atmosphere. Radiative and turbulence flux measurements, rain-gauges, and standard meteorological observations are combined with radar data to help create a more complete understanding of tropical cyclone rainbands and their influence on surface conditions.

Figure 1 illustrates the location of the CPS field experiment in August and September 2008. The experiment was based at the University of Miami South Campus (CSTARS) in Southwest

Miami, FL, about 15 miles west of Biscayne Bay.

Instrument	Technical Specifications	Measurement
Ceilometer	Laser Diode	Cloud-base height with time
Disdrometer (NC State)	50 cm^2 sampling area	Drop size distribution at surface
W-Band Doppler radar (UM)	94 GHz (3.2 mm)- vertically pointing	High resolution Doppler spectra, cloud and precipitation microphysics and dynamics
Microwave Rain Radar (NC State)	35 GHz Vertically pointing	Cloud microphysical properties
X-Band Doppler Radar (UM)	9.4 GHz (3.2 cm)- vertically pointing	Cloud dynamics and precipitation physics
Wind Profiler (NCAR)	915 MHz (32.8 cm)	PBL 3-D winds, inversion height, clouds
Radiosonde	Vasiala RS-92	Atmospheric moisture and wind structure

Table 1. A list of major instrumentation during CPS.

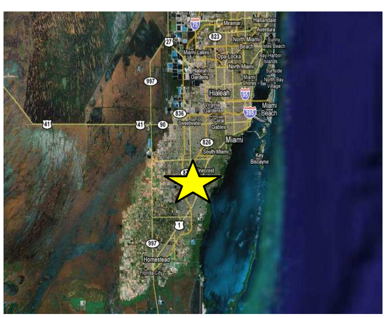

Figure 1. Location of CPS experiment in South FL.

3. Data Set

The four storms with rainbands passing over the CPS site were Tropical Storm Fay (8/17-8/22), Hurricane Gustav (8/30-8/31), Tropical Storm Hanna (9/5), and Hurricane Ike (9/9-9/10). Careful analysis of NWS NEXRAD images shows that we experienced 20 rainbands during Fay, 2 during Gustav, none during Hanna, and 2 during Ike, for a total of 24 distinct rainbands. Because of this large data set, we have data from storms of varying strength (tropical storm to Category 4 hurricane), bands at distances from 100-800 km from the storm center, bands approaching the site from a wide range of directions, and bands lasting anywhere from 15 minutes to 3.5 hours depending on whether they were observed cross-band or along-band (see Figure 2).

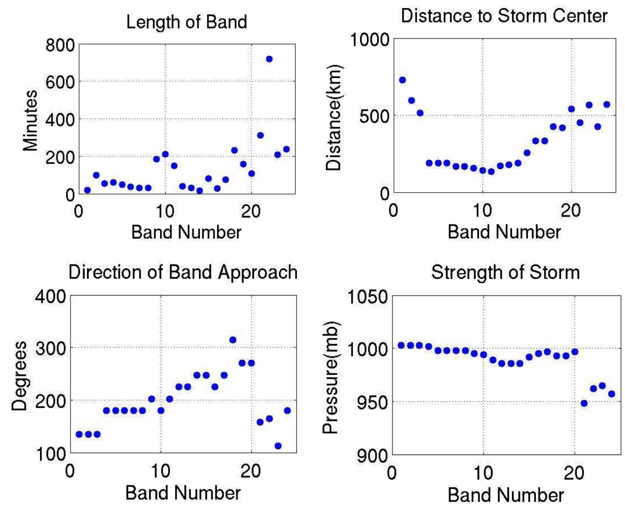

Figure 2. Clockwise from upper left: Statistics of band duration, distance to eye of storm, direction of band approach, and strength of storm. Bands are numbers 1-24 in order of occurrence. Storm statistics are taken from NHC best track data.

4. Preliminary Results

Based on the appearance of band structure from the University of Miami X-band radar, all of the bands are observed to be shallow with reflectivity returns limited to below 10 km, often with a melting layer present between 4.5-5 km. The majority of the bands were observed in cross-band slices, but four were observed along-band, where the band passed over the site length-wise for at least 2.5 hours. Figure 3 shows wind profiler moments from Band 9 on August 19, 2008. This band began with several equally spaced convective elements before a stratiform portion passed overhead for 2.5 hours. During this stratiform period the melting layer is prominent as an increase in both reflectivity and velocity.

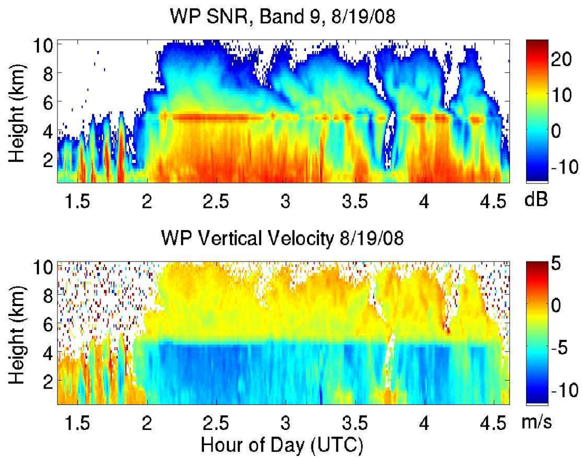

Figure 3. An example of a rainband with a convective portion and a stratiform region. Two moments from the wind profiler are shown: reflectivity (top), Doppler velocity (bottom, where negative values represent downward motion). High negative values of vertical velocity are associated with rainfall.

The MAPR also provides east-west and north-south components of horizontal winds. We converted these winds into radial and tangential winds in order to combine several bands together. The time/height image of this for Band 9 is shown in Figure 4. Looking below the melting level, radial winds show flow towards the eye at low levels with flow away from the eye above 3.5 kilometers. Tangential winds are positive (cyclonic) at all levels, with the peak values occurring between 1-3 km and decreasing with height. Both of these results are in agreement with those observed during Hurricane Floyd by Barnes et al. (1983).

These results are even more pronounced when we composite stratiform periods longer than 30 minutes in six bands (Figure 5). Again we see a circulation with inward radial flow near the surface at about 5 meters per second, reversing to weak flow away from the eye above 3 km. Tangential winds peak from 1-3 km with values of about 25 meters per second and then decrease with height. There is also some evidence of a secondary tangential jet located just above the melting level.

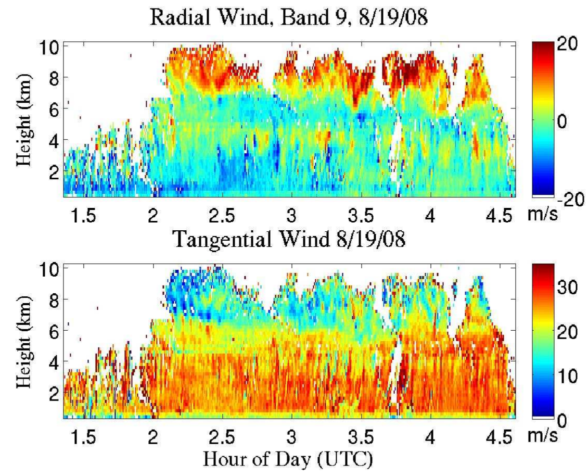

Figure 4. MAPR radial (top) and tangential (bottom) winds during Band 9. Radial winds are positive away from the eye and tangential winds are positive cyclonic.

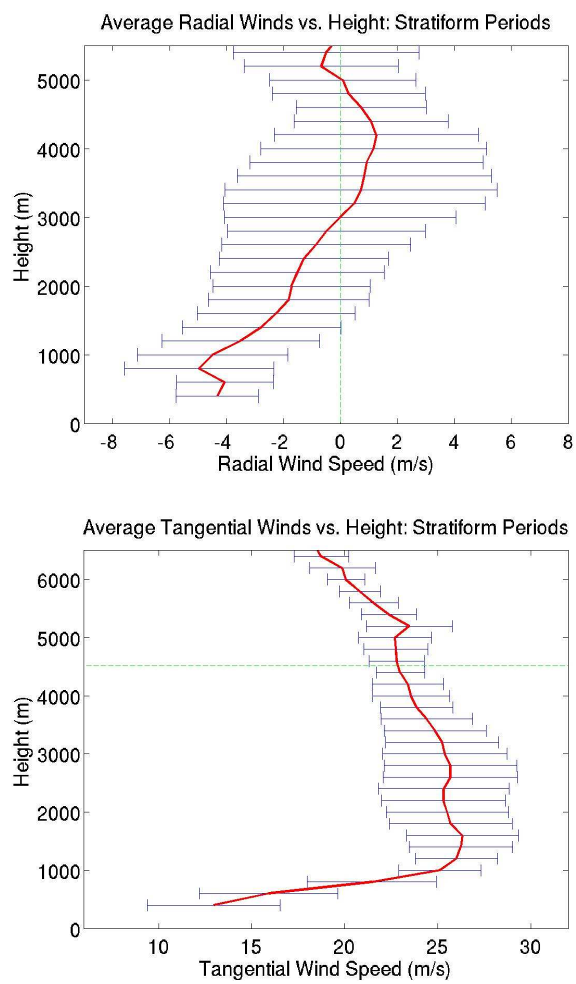

Figure 5. MAPR radial (top) and tangential (bottom) winds averaged during stratiform periods of six rainbands in red. The blue bars show one standard deviation error. The dashed green line in the top plot shows a 0 m/s radial wind speed while the dashed green line in the lower plot shows the average height of the melting layer.

5. Summary

While tropical cyclone analysis was not a primary goal of CPS, we were provided with a unique opportunity to observe 24 rainbands from three different tropical cyclones over an eight week period in the summer of 2008. Some of these bands were convective in nature, some were purely stratiform and some were mixed as they were observed along-band. Preliminary results with vertically pointing radar show that these bands are shallow and often have a bright band located around 5 kilometers. Analysis using the MAPR allows for high resolution mapping of vertical and horizontal winds. Future work will entail combining large scale variations and small scale variations to create an understanding of the factors at work in the boundary layer and at the surface during the passage of these rainbands.

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