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OPTIMAL RAIN RATE ESTIMATION IN TROPICAL CYCLONES: VALIDATION OF SFMR REMOTE SENSING RAIN RATES

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1. INTRODUCTION

The Hurricane Research Division (HRD) collects a variety of data sets on hurricanes and tropical cyclones from the NOAA WP-3D hurricane research aircraft during its annual program of research flights. Several kinds of meteorological parameters can be measured or retrieved from passive and active remote sensing instruments and microphysical instruments. It is particularly challenging to estimate rain rates within tropical cyclones over ocean from airborne measurements. The instruments on WP-3D applicable to this purpose are the Stepped Frequency Microwave Radiometer (SFMR), Tail (TA) radar, Lower Fuselage (LF) radar, and the Knollenberg Particle Measurement System (PMS) Optical Array Spectrometer Probe, model OAP-2D-P.

The SFMR measures the microwave emissions from sea surface and intervening precipitation at six frequencies (4.6-7.2 GHz). Both the surface wind speed and the rainfall rate in the column from the aircraft down to the sea surface are retrieved from SFMR brightness temperatures by using the radiative transfer equations (Jones et al., 1981; Black and Swift, 1984). The objective of this study is to analyze and validate the rainfall rate estimates from SFMR by comparing with those from TA radar, LF radar and PMS 2D-P. A cloud classification method (G. M. Heymsfield et al, personal communication) is applied to TA radar data for categorizing the airborne data sets according to whether the rain rates were obtained in regions of convective or stratiform precipitation. Then for each type of precipitation, the probability-matching method (PMM) is used to characterize the statistics of various rainfall measurement strategies. The regression relations in each regime between SFMR data and data from the 3 other kinds of instruments will improve our understanding of rain rate estimation within tropical cyclones and will be helpful to provide hurricane forecasters with real time estimates of tropical cyclone rain rates.

2. DATA

The observations were made on board the WP-3D in Hurricane Bonnie on August 20th, 23rd, 24th and 26th 1998. We deal only with the data taken at a flight level of below 3 km between 1955 and 2423 UTC on 24th and between 1626 and 2207 UTC on 26th in order to avoid the radar bright band at a height of about 4.5 km.

WP-3D TA radar is a vertically scanning X-band (3.22cm) radar with a vertical resolution of 75m between 1-256 bins. It has two types of scanning: continuous scanning (Tilt=0^0) and Fore-Aft scanning (Tilt=$\pm 22^0$). In this study, we apply the data from the scanned ray of nearest looking up (azimuth=0^0) and looking down (azimuth=180^0) to the cloud classification method. Although this method was designed originally for EDOP data, with minor modifications, it was adapted to the TA radar. For matching with SFMR data, the time series of average TA downward reflectivity from aircraft to the sea surface were calculated for every 6 seconds. Also as argued by Marks et al. (1993, hereafter MAW), an 8.2-dBZ correction should be added on TA data to account for the calibration errors of TA radar.

WP-3D C-band (5.59cm) LF radar scans horizontally with a horizontal resolution of 1800 m. Since it never looks down, the LF data used to do the comparisons here is from averaging the reflectivities on the bins of $\pm 5^0$ around the direction of the flight on the range of 7 km away from the airplane for every minute. The 7 km value is chosen to have a gate that is not contaminated by the surface clutter or too far in range (limiting the vertical resolution) and to be sufficiently far away from the radar.

PMS 2D-P measures the drop size distribution (DSD) of precipitation along the flight level at about 12-s sampling period. From DSD, many parameters such as rain rate, liquid water content, ice water content, radar reflectivity Ze, etc. can be calculated. Here we only use Ze and rain rate data.

Rain rates retrieved from SFMR are at a time resolution of 1 second. For getting a more comparable dataset, airborne radar, particle image and SFMR data from the same flights are interpolated or averaged into same time intervals: 12-s.

3. APPROACH

A Z-R relationship is needed to convert the observed radar reflectivity factor Ze into rain rate R, or vice versa. While still controversial, variations of drop size distributions in stratiform and convective precipitation possibly yield significant differences in their Z-R relationships. For this pilot study, we looked at the results of the cloud classification method first and found

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that most of the data we choose are from stratiform precipitation regions. After masking the data points from convective regions, a stratiform hurricane Z-R relationship (Jorgensen and Willis 1982) is used to calculate corresponding dBZs from SFMR rain rates:

$$Z = 269R^{1.35}$$

MAW reviews the essence of the probability-matching method: 1) A sufficiently large space-time sampling domain rather than a point in space or time is necessary to assure the sample of Ze or R is representative. 2) Same time and space resolution is preferred for the parameters to be matched by their cumulative density functions (CDFs). 3) A threshold of rain rates or dBZs is needed to eliminate the problem caused by regions with no rain. The above three key points are employed in this study.

4. RESULTS

Fig.1 shows the CDFs of dBZ values in same time interval calculated for TA, LF radar, SFMR and PMS data (only in stratiform regions). The threshold taken here is 15dBZ to cut off the cloud region that can be seen by radar but not be seen by SFMR and PMS 2D-P. Fig.1 shows, in general, the CDFs are similar. But notice that the PMS CDF curve has a big disagreement with others' in high reflectivity regions. This could be explained by the problems of the 2D-Grey probes used in Hurricane Bonnie: 1) The probes lose significant data to noise; 2) A serious overestimate of the particle elapsed time in the record causes to decrease the apparent number concentration and the estimated rain rates; 3) The small sample volume of PMS could result in an undersampling of the large drops. Also notice that SFMR is not as sensitive as radar to low rain rates (<30dBZ).

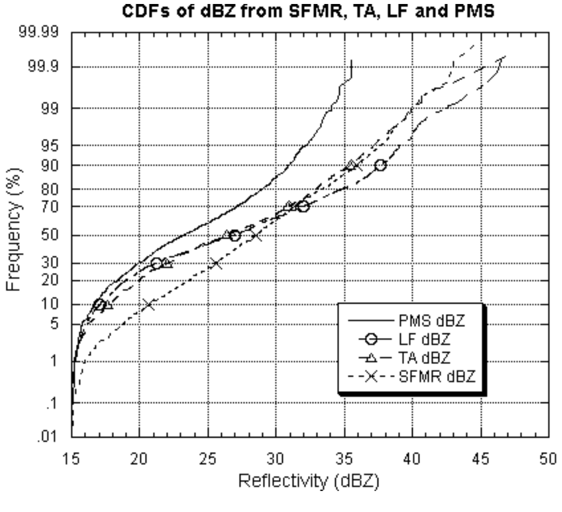

Fig.1. CDFs of dBZ values calculated from TA, LF radar, SFMR and PMS data (only in stratiform regions) for the flights of Aug. 24, 26, 1998 (Hurricane Bonnie).

By applying PMM, the CDFs in Fig.1 are matched and regression relations between SFMR data and data from the 3 other kinds of instruments are obtained (Fig.2). Excellent correlations (about 0.99) are shown for all the linear relationships. However, the relationship between SFMR data and TA radar data is close to 1:1. We believe that this superior result can be explained by the fact that both SFMR and TA radar are looking downward through the whole atmospheric column to the ocean surface.

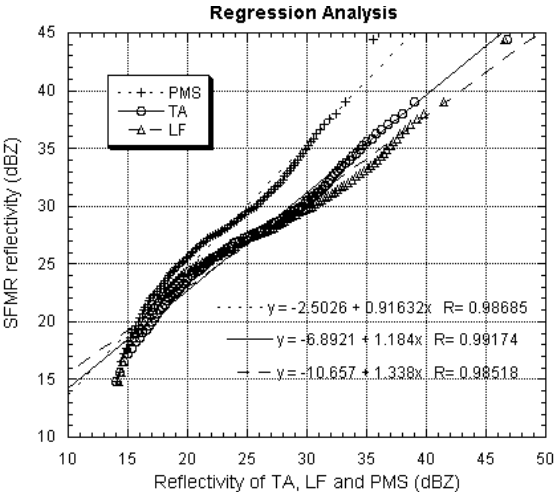

Fig.2. Regressions of the SFMR dBZ vs. TA, LF and PMS dBZ (only in stratiform regions) for the flights of Aug. 24, 26, 1998 (Hurricane Bonnie).

5. CONCLUSIONS AND FUTURE WORK

By comparing SFMR data with airborne radar data, this study shows that SFMR provides an additional and independent useful tool to estimate rain rates and latent heating rates in tropical cyclones.

The future work plan of this study is to choose a tropical storm containing more convective precipitation regions and redo the regression analysis, which will help us to understand how well the SFMR estimates the rain rates from different types of precipitation, and to learn more about its potential limitations.

6. REFERENCES

Black, P.G. and C. T. Swift, 1984: Airborne stepped frequency microwave radiometer measurements of rainfall rate and surface wind speed in hurricanes. *22nd Conf. on Radar Meteorol., AMS*, Zurich, 433-438.

Jones, W. L., P.G. Black, V.E. Delnore and C. T. Swift, 1981: Airborne microwave remote sensing measurements of Hurricane Allen. *Science*, **214**, 274-280.

Jorgensen, D. P., and P. T. Willis, 1982: A Z-R relationship for hurricanes. *J. Appl. Meteor.,* **21**, 356-366.

Marks, F. D., Jr., D. Atlas, and P. T. Wiils, 1993: Probability-matched reflectivity-rainfall relations for a hurricane from aircraft observations. *J. Appl. Meteor.,* **32**, 1134-1141.