6D.1 **RETRIEVAL OF HYDROMETEOR PROFILES IN TROPICAL CYCLONES AND CONVECTION BY A COMBINED RADAR-RADIOMETER ALGORITHM**

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1. INTRODUCTION

Airborne and satellite-borne radar and radiometer on the same platform provide a very powerful tool to estimate ice water content (IWC) and liquid water content (LWC) profiles in tropical precipitation systems. Although radar-only (Iguchi et al. 2000) and radiometer-only (Kummerow et al. 1996) precipitation algorithms have been developed and used extensively, recent studies demonstrate various ways in which the opportunities to estimate hydrometeor profiles and cloud characteristics improve by combining radar and radiometers. One common characteristic of most of the combined approaches is that they are not fully based on physical models, but partially dependent on *priori* statistical relationships (TRMM 2B31, Haddad et al. 1997) or *a priori* cloud model database (Marzano et al. 1999; Olson et al. 1996). Among a few fully physical algorithms, Skofronick-Jackson et al. (2003)'s approach emphasizes high-frequencies (>150 GHz) and cannot be implemented to TRMM satellite observations; Grecu et al. (2003, submitted manuscript) provides a fully physical technique that has been applied to TRMM observations, but it uses the same N_0 (interception coefficient in drop size distribution (DSD)) for rain, snow, and graupel, and cannot retrieve a reasonable hydrometeor profile in the ice region, although its rain rate retrieval is comparable with ground radar observations. In this study, we formulate and investigate a similar physical combined technique that estimates different N_0 values for rain, snow, and graupel, and which provides physically meaningful estimates for both IWC and LWC profiles consistent with both radar and radiometer observations.

2. RETRIEVAL METHOD

The combined algorithm developed here uses radar reflectivity derived hydrometeor profiles as input to a forward radiative transfer model (RTM, Kummerow et al. 1996) to retrieve the profiles of ice and liquid precipitation contents by minimizing the differences between observed brightness temperatures and simulated ones by adjusting N_0 iteratively. In this application of the RTM to tropical ocean rainfall systems, only 4 hydrometeor types (e.g., cloud liquid water, rain water, snow, and graupel) are considered.

To derive water content M from radar reflectivity factor Z, we make use of the normalization approach of an exponential or gamma DSD (Testud et al. 2001). With this approach, any two integrated rainfall parameters (X, Y) can be expressed as $X=mN_0^{*(1-n)}Y^n$, where N_0^* is the normalized N_0 and is equivalent to N_0 for an exponential DSD. In this equation, m is independent of the shape parameter μ in a gamma DSD and n is weakly dependent on μ. The coefficients m and n can be computed from fits to experimental data. For instance, Viltard et al. (2000) gives a Z-M relationship scaled by N_0^* as $M=3.067438 \times 10^{-6} N_0^{*0.455} Z^{0.545}$, which is valid for temperatures between 273 and 293 K and μ=1. In this study, for the rain region, we use a Z-LWC relationship developed by Mircea Grecu (personal communication) using polarimetric radar observations from Florida. This Z-LWC relation has coefficients very close to those above. In the ice region, we develop a N_0^* scaled Z-IWC relation by fitting 2D probe DSD measurements for temperatures below 253 K and applying it into all ice regions by assuming that this relationship is very weakly sensitive to the temperature (Viltard et al. 2000). The relationship is $IWC=2.26 \times 10^{-5} N_0^{*0.412} Z^{0.588}$, where N_0^* can be N_{0s}^* (for snow) or N_{0g}^* (for graupel). Since we are concerned with both ice water and rain water, a parameterization of snow and graupel fraction profile is needed to simulate brightness temperatures at 37 and 85 GHz. From microphysical measurements in field programs, Stith et al. (2002) find that stratiform precipitations above melting layer has no graupel in significant amounts, so we assume all snow. In the convective rain region, unfortunately, the amount of graupel varies from case to case, so we refer to the hurricane modeling results by Lord et al. (1984) and assume that graupel reaches its maximum at 6 km, and snow reaches its maximum at 12 km. In the iterative inversion process, the simulated annealing method (Goffe et al. 1994) is used.

3. APPLICATION TO CAMEX-4 DATA

Observations from Convection And Moisture EXperiement-4 (CAMEX-4) are used in the retrieval algorithm. The data from 2 instruments on the ER-2 aircraft are the main input to the algorithm. One of them is the Advanced Microwave Precipitation Radiometer (AMPR), a four channel scanning passive microwave radiometer measuring fully or partially polarized radiation at 10.7, 19.35, 37.1, and 85.5 GHz. The other is the NASA ER-2 Doppler radar (EDOP) that is an X-band (9.6 GHz) Doppler radar with fixed nadir and forward pointing beams with a beam width of 2.9°. Validation data are from 2D-P and 2D-C probes on the DC-8 aircraft.

A collocated dataset is obtained from 4 flights during Sep. 09, 22, 23, 24, 2001, 2 of them are from Hurricane Humberto, one of them from Tropical storm Humberto,

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one from a Gulf of Mexico thunderstorm. To facilitate collocation of passive and active microwave measurements from the AMPR and EDOP, only the nadir-view data from these instruments are considered. For comparison with the retrieval, the IWC profiles are also calculated by applying empirical Z-M relations to EDOP reflectivity measurements, in which Z-IWC relationship is from Black (1990, therefore radar-only method).

Fig. 1 shows the scatter plot of retrieved IWC versus 2D probes IWC at DC-8 flight altitude from 8.5 to 11 km in this dataset. Of the 613 data points, we estimate that the ER-2 and DC-8 observations match within 1-2 km cross-track and within 1-2 minutes for most of them. The mean values of both retrieved and 2D derived IWC are 0.19 g/m^3, but the correlation coefficient is only 0.75, so a lot of scatter might be due to the mismatch of the two airplanes and the very different sample volumes of EDOP, AMPR and 2D probes. Also IWC estimated from 2D probes has about $\pm$25% uncertainties on average (Heymfield et al. 2002). The uncertainties of our combined algorithm come from 1) assumption of snow and graupel fraction profiles, especially in convective region (The correlation coefficient between retrieved IWC versus 2D probes IWC is 0.88 for stratiform region and low down to 0.53 for convective region); 2) a very small portion of profiles that fail to converge in the iteration process; 3) the use of same N_0*'s in radar retrieval and radiative transfer computation. As pointed out by Viltard et al. (2000), a higher N_0* is required in radiative transfer calculation comparing to radar retrieval to get a better agreement with observed brightness temperatures especially in higher frequencies.

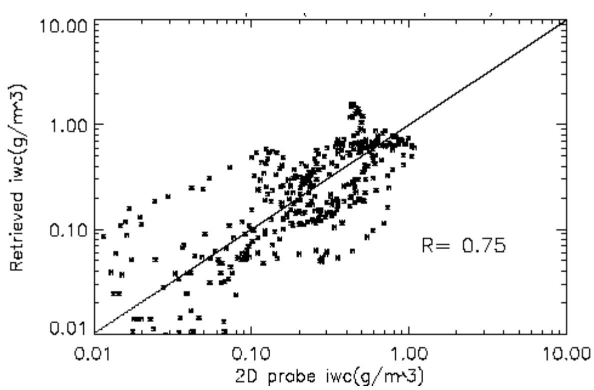

Figure 1. Retrieved and 2D probe derived ice water content comparison for CAMEX-4 matched samples at DC-8 flight altitude. Correlation coefficient is indicated.

For comparison, Fig. 2 is same as Fig 1., but y-axis is for the IWC derived by the radar-only method. It is apparent that the radar-only method, with a mean value of 0.14 g/m^3, systematically underestimates the IWC comparing to 2D probe measurements and the combined radar-radiometer retrievals. As the classical Z-IWC relation in hurricanes, Black (1990)'s regression was obtained from very limited aircraft datasets at flight altitude about 6 km; it is impossible to represent all the situations in the nature. However, our combined radar-radiometer algorithm adjusts the DSD for each profile to obtain a best agreement with radiometer observations, this kind of physical adjustment represents an promising improvement of radar-only empirical retrievals.

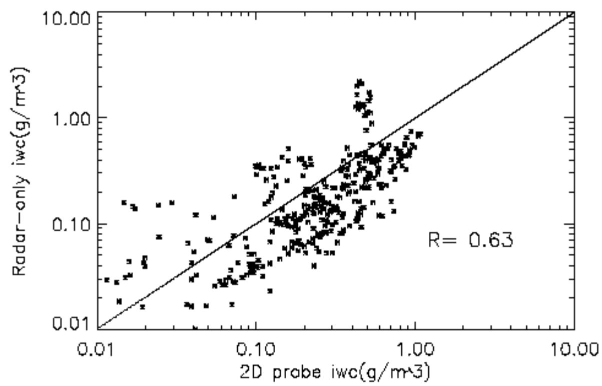

Figure 2. Same as in Fig. 1, but y-axis represents radar-only method derived ice water content.

4. CONCLUSIONS AND FUTURE WORK

A combined radar-radiometer algorithm for retrieving hydrometeor content profiles in hurricanes and tropical ocean precipitations is developed and tested by aircraft data. The good agreement between our retrieval and 2D-probe microphysics measurements shows that the combined method could improve the radar-only retrieval. Applications of the algorithm to Tropical Rainfall Measuring Mission (TRMM) Microwave Imager and Precipitation Radar observations will be the subject of a future investigation by the authors.

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