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USE OF PASIVE MICROWAVE OBSERVATIONS IN A RADAR RAINFALL PROFILING ALGORITHM

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1. INTRODUCTION

One difficulty in estimating precipitation from active space borne instruments (space-borne radars) consists of the fact that frequencies greater than 10 GHz are usually used to limit the antenna size. At these frequencies, the active observations (radar reflectivity factors) are attenuated by rain and specific algorithms that explicitly correct for attenuation need to be employed for rain estimation (Iguchi and Meneghini, 1994). The estimation algorithms for such systems are generally based on the solution of a differential equation (Hitschfeld and Bordan, 1954) derived from the radar equation. It has been shown that two particular solutions may be obtained as a function of way the boundary conditions are set (Iguchi and Meneghini, 1994). A modality to set the boundary conditions is by assuming that the observed reflectivity factor at range zero is not affected by attenuation. Another one is by imposing that the particular solution derived from the general solution of the radar differential equation exhibits the same path integrated attenuation (PIA) as determined from different considerations. Such considerations may be surface return techniques (Iguchi and Meneghini, 1994), mirror image techniques (Meneghini and Atlas, 1989), or radiometer observations (Weinman et al., 1990; Smith et al., 1997). The particular solutions associated with each technique are not necessarily identical. However, if the PIA associated with a general solution is invariant to the way the boundary conditions are set, the particular solutions coincide (Iguchi and Meneghini, 1994). Consequently, two adjustments were proposed (in the attenuation-reflectivity relationships and in the radar constant) to make the particular solutions identical (Iguchi and Meneghini, 1994). The correction in the attenuation-reflectivity relationships, known as the α adjustment technique, is physically better sound in case of a well-calibrated radar because large variations in drop size distributions may cause significant changes in the attenuation-reflectivity relationships.

In this work, we formulate and investigate a combined algorithm for precipitation profile retrievals considering jointly passive and active observations. The formulation addresses some of the wants of previous approaches. It is based on a general solution of the radar differential equation that uses attenuation-reflectivity relationships parameterized as a function of an intercept coefficient N_0^*, in a normalized gamma drop-size distribution model (Testud et al., 2000). The reflectivity-rainfall rate (Z-R) relationships are also parameterized as a function of N_0^*. Using actual airborne radar observations, N_0^*-dependent precipitation profiles are used to simulate four different brightness temperatures (10.7, 19.35, 37.1, and 85.5 GHz) measured by the airborne radiometers. For each profile, the intercept N_0^* is estimated along with the cloud water content and few other variables such that the differences between simulated and the actually observed brightness temperatures are minimized. A bright-band model is included in both the radar and radiometer predictions to account for stratiform precipitation.

2. COMBINED RAIN PROFILING ALGORITHM

The profiling algorithm is based on the estimation of a set of variables consisting of the parameter δN_0^* that measures the departure of the intercept of the drop size distributions from the nominal values, the cloud water content, the ratio of snow content to graupel content, and two parameters describing the melting process in convective cores. We denote $\mathbf{X_r}$ their union state variable vector. The observations include a vector ($\mathbf{T_B}$) of radiometer brightness temperatures at the four frequencies, and vector ($\mathbf{Z}$) of attenuated observed reflectivities. The hydrometeor contents are determined uniquely from $\mathbf{Z}$ as a function of $\mathbf{X_r}$. Then the retrieved hydrometeor contents and $\mathbf{X_r}$ are used to predict the brightness temperatures by a non-polarized plane-parallel model based on the Eddigton approximation. An iterative procedure is devised to minimize the differences between the observed and predicted brightness temperatures. That is, an objective function of the type

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$$F = \frac{1}{2}(\mathbf{T_B^M} - \mathbf{T_B}(\mathbf{Z^M}, \mathbf{X}_r))^{\mathbf{T}} \mathbf{W_T^{-1}} (\mathbf{T_B^M} - \mathbf{T_B}(\mathbf{Z^M}, \mathbf{X}_r)) + \frac{1}{2}(\mathbf{M}_{\mathbf{x}_r} - \mathbf{X}_r)^{\mathbf{T}} \mathbf{W}_{\mathbf{X}_r}^{-1} (\mathbf{M}_{\mathbf{x}_r} - \mathbf{X}_r) \qquad (2.1)$$

is minimized as a function of $\mathbf{X_r}$. Note that a term is introduced in Equation (2.1) to account for “a priori” knowledge on variable $\mathbf{X_r}$. $\mathbf{W_{Xr}}$ and $\mathbf{M_{Xr}}$ are estimated based on cloud model databases.

To minimize the objective function in (2.1), we use a gradient-based optimization technique that evaluates the function’s gradient.

3. RESULTS AND CONCLUSIONS

The methodology was tested using data originating in the Kwajalein Experiment (KWAJEX). Specifically, we used data from the airborne radar (ARMAR) and one of the radiometers (AMPR) to investigate the rain profile retrieval algorithm described above. ARMAR, developed by NASA and JPL, provides data similar to those collected by the TRMM precipitation radar (PR). It operates at a frequency of 13.8GHz, which is the TRMM PR’s frequency, and consists of downward pointing and scanning in the cross-track direction. The AMPR radiometer, developed by NASA and the Georgia Institute of Technology, collects data at four frequencies, i.e. 10.7, 19.35, 37.1, and 85.5GHz and resembles the TRMM Microwave Imager.

Figure 1 shows the PIAs estimated from a surface return technique and resulted from the application of the combined algorithm respectively. One may notice a fairly good agreement between the two estimates. Since the combined algorithm differs from a radar alone rain profiling algorithm just in the way the PIA and consequently the drop size distribution are estimated, it may be concluded the combined algorithm yields results consistent with radar only results but can mitigate situations when the PIA estimates from the surface return technique are not reliable. However, additional investigations including comparisons with independent estimates, such as ground radar estimates, need to be considered for a better characterization of the combined algorithm. The combined algorithm may be applicable to TRMM precipitation profile retrieval, provided that issues such as the reduction of radar and radiometer observations to a common grid and the extension of the algorithm to deal with different pointing vectors of the instruments are addressed.

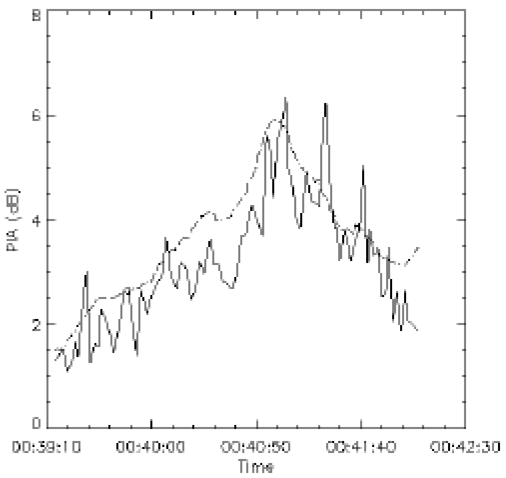

Figure 1. Surface return and combined algorithm retrieved PIA for the August 12, 1999 flight leg. The discontinuous line indicates the combined algorithm.

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