A RADAR PROFILING ALGORITHM DESIGNED FOR USE WITH MULTIRESOLUTION RADIOMETER MEASUREMENTS

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1. INTRODUCTION

Over the past decade, the Tropical Rainfall Measuring Mission (TRMM) satellite has made rainfall measurements over the global tropics and subtropics using both passive and active microwave sensors. These measurements have provided unique insight into the tropical hydrologic cycle and its response to intra- and interannual variability. Although zonal means are in good ($<10\%$) agreement between the TRMM microwave imager (TMI) and precipitation radar (PR) rainfall algorithms, significant uncertainties remain in some regions where these estimates differ by as much as 30% over the period of record [1]. The upcoming Global Precipitation Measurement (GPM) mission will provide global estimates from a core satellite consisting of a dual-frequency radar and radiometer and a constellation of radiometer-only satellites. The constellation satellites will use a Bayesian scheme [2] based upon a database of precipitation profiles that will be built by the core satellite. Thus, a better understanding of the biases between radar- and radiometer-only methods is desired, especially as they relate to global variations in the structure of precipitation systems that may depart from assumptions required by either single-instrument algorithm.

In this study, we have developed a radar profiling algorithm that can be incorporated into a larger radar+radiometer retrieval framework. The modular nature of the framework provides the opportunity to test the sensitivity of the retrieval to the inclusion of different measurements, retrieved parameters, and models for microwave scattering properties of hydrometeors. The radar profiling algorithm and combined framework are described in section 2. In section 3, the methodology is applied to TRMM overpasses at the Kwajalein and Melbourne, FL TRMM Ground Validation (GV; [3]) sites.

2. ALGORITHM DESCRIPTION

We implement a Hitschfield-Bordan [4] style profiling algorithm, that is, the vertical profile of hydrometeor is retrieved via internally consistent relationships between reflectivity Z, hydrometeor content W, and attenuation k. This is similar to the method employed the standard TRMM rain profile product 2A25 [5]. Since the most significant source of attenuation at the PR frequency is in the rain layer, the 2A25 algorithm employs a single parameter ϵ which is used to adjust the $Z-k$ and $Z-R$ relationships to match an estimate of the path-integrated attenuation (PIA) provided the the surface reference technique (SRT; [6]), when available. By contrast, the microwave brightness temperatures (T_Bs) at the frequencies observed by TMI are also influenced by other factors including the surface emissivity, water vapor, cloud water, and precipitating ice. Thus, we define three parameters (ϵ_{DSD}, ϵ_{ICE}, and ϵ_{CLW}) that modify the rain drop size distribution (DSD), ice particle size distribution (PSD), and total cloud liquid water path (LWP), respectively. Profiles are cloud water and rain type come from the GPROF database

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([2],[7]), water vapor, surface wind, and non-raining cloud water are interpolated from a non-raining retrieval [8], and the bright band model is based on [9].

The larger framework within which the profiling algorithm is incorporated begins with the definition of a scene consisting of hundreds or even thousands of PR pixels. The microwave T_Bs corresponding to the profiles derived the profiling algorithm are simulated with a radiative transfer model [10] and convolved to the TMI fields-of-view (FOVs). A variational optimal estimation scheme [11] is used to minimize the cost function of the scene:

$$\Phi = (\mathbf{y} - f(\mathbf{x}))^{\mathrm{T}} \mathbf{S}_{\mathrm{y}}^{-1} (\mathbf{y} - f(\mathbf{x})) + (\mathbf{x} - \mathbf{x}_{\mathrm{a}})^{\mathrm{T}} \mathbf{S}_{\mathrm{a}}^{-1} (\mathbf{x} - \mathbf{x}_{\mathrm{a}}), \tag{1}$$

where $\mathbf{y}$ is the measurement vector (consisting of TMI T_Bs and SRT PIA estimates), $\mathbf{x}$ is a vector consisting of ϵ_{DSD}, ϵ_{ICE}, and ϵ_{CLW} at each PR pixel, f is the radiative transfer model, $\mathbf{x}_{\mathrm{a}}$ is the *a priori* state vector, $\mathbf{S}_{\mathrm{y}}$ is the measurement covariance matrix, and $\mathbf{S}_{\mathrm{a}}$ is the *a priori* covariance matrix. The measurement and model errors are fairly well-defined in the literature (*e.g.*,[12], [10], [8]), however, the retrieval is also sensitive to $\mathbf{S}_{\mathrm{a}}$. Lacking definitive globally representative measurements of the uncertainty in these parameters, we set the uncertainty of ϵ_{DSD} such that the radar-only implementation of our profiling algorithm is unbiased relative to 2A25 globally. The uncertainty in ϵ_{ICE} is set to provide good mass continuity in the column and reproduce the observed 85 GHz T_Bs well; however, due to difficulties in modeling the scattering properties of ice hydrometeors, this uncertainty is fairly large. Since rain water and cloud water have similar microwave absorption signatures, the uncertainty in ϵ_{CLW} plays a strong role in modulating the rainfall retrievals in the combined TMI+PR framework. Thus, we consider this a free parameter in the retrieval and utilize comparisons with GV data to provide an optimal value.

3. COMPARISON WITH GROUND VALIDATION

The Kwajalein Ground Validation site, located on a small atoll in the central Pacific Ocean, is an ideal site to test the combined algorithm because of its oceanic location, where the radiometer has the potential to add the most information to the radar. Although GV rain products are available since 1998, only recently have calibration problems been addressed and dual-polarization capability added ([13], [14]). We find that uncertainties of 50-200% in ϵ_{CLW} provides estimates that are within 10% those of the GV radar, with an optimal value slightly greater than 100%. The 2A25 estimates for the same period underestimate the GV amount by 20%.

An independent validation test was performed by comparing retrieval results to those from the standard 2A53 GV radar products over Melbourne, FL for the years 2006-2008. There is much month-to-month and year-to-year variability as to which retrieval method (2A25, radar-only profiling algorithm, combined algorithm) best matches the co-located GV totals. The GV Z-R relationship is based on monthly gauge accumulations, whereas there are only 10-20 overpass events each month, with just a few of these dominating the total rainfall. Thus, the average rain DSD that determines the monthly Z-R relationship may be quite different than that in the overpasses, especially considering the gauges are all on land whereas the retrievals compared here are all over the ocean. Nevertheless, the total accumulated rainfall is only 3.5% higher than GV, while 2A25 underestimates the GV total by 4.5% and the default DSD overestimates it by 12%.

4. SUMMARY

In order to better understand the differences between global rainfall maps produced by the TRMM TMI and PR operational products, a combined framework has been developed. The key component of this method is a radar profiling algorithm with three variable parameters representing the ice PSD, rain DSD, and cloud LWP, which are then adjusted to match both radar estimates of the PIA and radiometer brightness temperatures. Comparisons with ground validation data show that a single value representing cloud water uncertainty can be tuned to match gauge- and polarmetric radar-based rainfall totals within 5% at

Melbourne, FL and Kwajelein, respectively, despite the differences in climate and geography at these two sites.

5. REFERENCES

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