SENSITIVITY OF COMBINED RADAR/RADIOMETER RETRIEVALS TO OBSERVATION AND MODELING UNCERTAINTIES

Mircea Grecu[1,2] and William S. Olson[1,2]
[1]University of Maryland, Baltimore County
and
[2]NASA Goddard Space Flight Center,Greenbelt, MD

## 1. INTRODUCTION

A major challenge in precipitation estimation from satellite active microwave observations arises from the fact that precipitation particle size distributions (PSDs) vary considerably in space and time, which makes the determination of one-to-one relationships between radar observations and precipitation amounts difficult. To mitigate these difficulties, various approaches have been developed to independently estimate the total path-integrated attenuation (PIA) and use it as additional information that allows for a better determination of PSD. Independent PIA estimates may be derived from the Surface Return Technique (SRT, Meneghini et al., 2000) and radiometer observations (Weinman et al. 1990). However, the use of independent PIA estimates in precipitation estimation from space-borne radar observations is not always optimal. This is because the SRT estimates are unreliable for low PIA values, while the radiometer estimates depend on the vertical distribution of precipitation. A better use of SRT and radiometer information can be achieved through combined radar-radiometer retrievals requiring that the precipitation estimates simultaneously satisfy the radar, radiometer, and SRT observations within the measurement error. Such an approach was developed by Grecu et al. (2004) for Tropical Rainfall Measuring Mission (TRMM) observations.

All components and parameterizations in the combined algorithm are deterministic; however, the parameterizations used in the combined algorithm are subject to uncertainties. To assess the impact of these uncertainties on retrievals, a Monte-Carlo experiment, during which the deterministic parameterizations are allowed to vary within acceptable limits, is performed. The results are analyzed statistically, and the retrieval sensitivity is quantified. Based on the findings, an improved combined algorithm, less sensitive to uncertainties, is proposed.

*Corresponding author address:* Mircea Grecu, NASA Goddard Space Flight Center, Greenbelt, MD 20771. E-mail: mgrecu@umbc.edu

## 2. METHODOLOGY

The combined retrieval from passive and active observations requires the minimization of a functional that evaluates the differences between the TRMM Microwave Imager (TMI) radiometer observed and model predicted normalized polarizations, NP, the precipitation radar (PR) predicted and SRT-derived PIA, and the similarity between the covariance of retrieved PSD intercept, $N_0^*$, and PSD intercept derived from polarimetric radar observations. The functional to be minimized is given bellow

$$\frac{1}{2}\left(\mathbf{NP^M}-\int_E \mathbf{G}(A)\mathbf{NP_A}(A,\tilde{\mathbf{X}}_\mathbf{Q},\tilde{\mathbf{N}}_\mathbf{0}^*)dA\right)^T \mathbf{W}_T^{-1}\left(\mathbf{NP^M}-\int_E \mathbf{G}(A)\mathbf{NP_A}(A,\tilde{\mathbf{X}}_\mathbf{Q},\tilde{\mathbf{N}}_\mathbf{0}^*)dA\right)$$
$$+\frac{1}{2}\left(\mathbf{M}_N-\tilde{\mathbf{N}}_\mathbf{0}^*\right)^T \mathbf{W}_N^{-1}\left(\mathbf{M}_N-\tilde{\mathbf{N}}_\mathbf{0}^*\right)+$$
$$+\frac{1}{2}(\mathbf{PIA_S}-\mathbf{PIA}(\tilde{\mathbf{X}}_\mathbf{Q},\tilde{\mathbf{N}}_\mathbf{0}^*))^T \mathbf{W}_{PIA}^{-1}(\mathbf{PIA_S}-\mathbf{PIA}(\tilde{\mathbf{X}}_\mathbf{Q},\tilde{\mathbf{N}}_\mathbf{0}^*))$$

where $\tilde{\mathbf{X}}_\mathbf{Q}$ is a vector containing the water content variables to be estimated, $\tilde{\mathbf{N}}_\mathbf{0}^*$ is a vector of PSD intercepts, and **W** are covariance matrices indicating the confidence in the observations and physical/numerical models used in the retrieval. Variables $\tilde{\mathbf{X}}_\mathbf{Q}$ and $\tilde{\mathbf{N}}_\mathbf{0}^*$ satisfy exactly the radar observations.

The minimization is performed using a gradient based technique. It may be noted that the solution of the retrieval problem depends on the values of covariance matrices **W**. Larger values (in terms of a mathematical norm) indicate smaller confidence. A methodology for estimating **W** is presented in Grecu et al. (2004). In addition to that, we investigate other sources of uncertainty, such as the vertical variability of PSD intercepts, the variability in the attenuation-reflectivity relationships and hydrometeor content electromagnetic properties in the bright band, and uncertainties in $\mathbf{W_{PIA}}$ estimates. Results from this investigation are presented next.

## 3. RESULTS

A Monte-Carlo experiment involving synthetic retrievals is conducted to assess the impact of uncertainty in bright-band modeling, vertical variability of PSD intercept, and $\mathbf{W_{PIA}}$ on retrievals in conducted. That is, observations are synthesized from cloud model simulations, assuming given vertical profiles of PSD intercepts and given bright-band models. Retrievals are done assuming a constant PSD intercept, a brightband model statistically consistent but different from the one used in synthesis and various values of $\mathbf{W_{PIA}}$. Results reveal that although the random errors increase when the additional uncertainties are considered, the retrievals are still unbiased if $\mathbf{W_{PIA}}$ is specified correctly. It is also found that for correctly-specified value $\mathbf{W_{PIA}}$, the PR-only algorithm and the combined algorithm provide nearly identical results. Because in real-life applications $\mathbf{W_{PIA}}$ may not be correctly estimated only from a surface return analysis, we chose to set $\mathbf{W_{PIA}}$ based on the condition that the PR-only algorithm (not the official one, but the one used in our combined formulation) and the combined algorithm yield statistically the same results. Nevertheless, the combined algorithm is still preferable because it is characterized by smaller random errors. Fig. 1 shows monthly rain estimates from the combined algorithm applied to TRMM observations. Zonally averaged monthly means from the combined and the official version 6 2A25 (Iguchi et al, 2001) and 2A12 (Kummerow et al, 2001) are presented in Fig. 2. One may note quite good agreement among the three algorithms. Shown in Fig. 2 are also the predicted and observed 19 GHz emission indices (the emission index being defined as one minus the normalized polarization).

**4. SUMMARY**

A method for estimating precipitation profiles from multifrequency, multiresolution, active and passive microwave observations is examined in this paper. A Monte-Carlo experiment is conducted to determine the optimal covariance matrices in the method and their impact on the results. The method is applied to one month of TRMM TMI and PR data. Results show that estimates consistent with both TMI and PR observations can be obtained with the method. The results are also consistent with estimates from the 2A12 and 2A25 version 6 algorithms.

*Acknowledgments.* This study was supported by the NASA TRMM Project.

**References**

Iguchi, T., T. Kozu, R. Meneghini, J. Awaka, and K. Okamoto, 2000: Rain-profiling algorithm for the TRMM precipitation radar. *J. Appl. Meteor*., **39**, 2038-2052.

Grecu, M., W. S. Olson and E. N. Anagnostou, 2004: Retrieval of Precipitation Profiles from Multiresolution, Multifrequency Active and Passive Microwave Observations**.** *J. Appl. Meteorol.*, **43**, 562–575.

Kummerow, C, Hong, Y., Olson, W. S., Yang, S., Adler, R. F., McCollum, J., Ferraro, R., Petty, G., Shin, D.-B., Wilheit, T. T.. 2001: The Evolution of the Goddard Profiling Algorithm (GPROF) for Rainfall Estimation from Passive Microwave Sensors. *J. Appl. Meteorol.*, **40**, 1801–1820.

Meneghini, R., T. Iguchi T., T. Kozu, L. Liao L., K. Okamoto, J. A. Jones, and J. Kwiatkowski, 2000: Use of the surface reference technique for path attenuation estimates from the TRMM radar. *J. Appl. Meteorol.,* **39**, 2053-2070.

Weinman, J. A., R. Meneghini, and K. Nakamura, 1990: Retrieval of precipitation profiles from airborne radar and passive radiometer measurements: Comparison with dual-frequency radar measurements. *J. Appl. Meteorol*, **29**, 981-993.

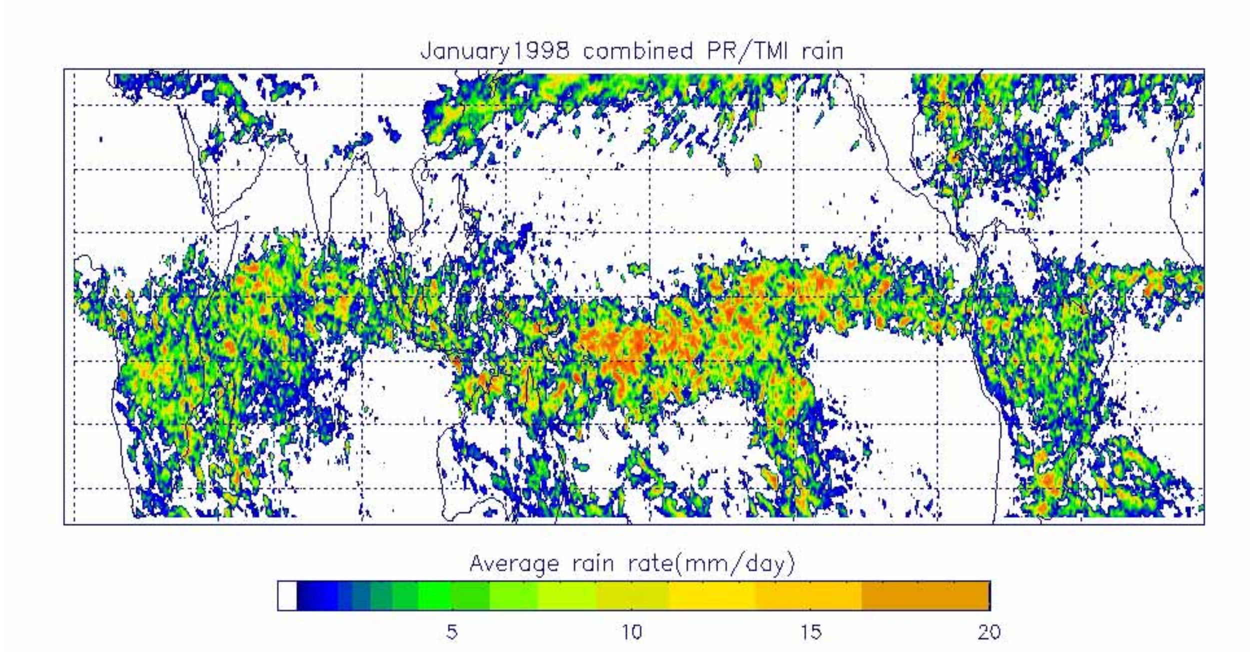


Fig.1: Monthly rain estimates from the optimal NPCA for January 1998. The resolution is 0.5 by 0.5 degrees.

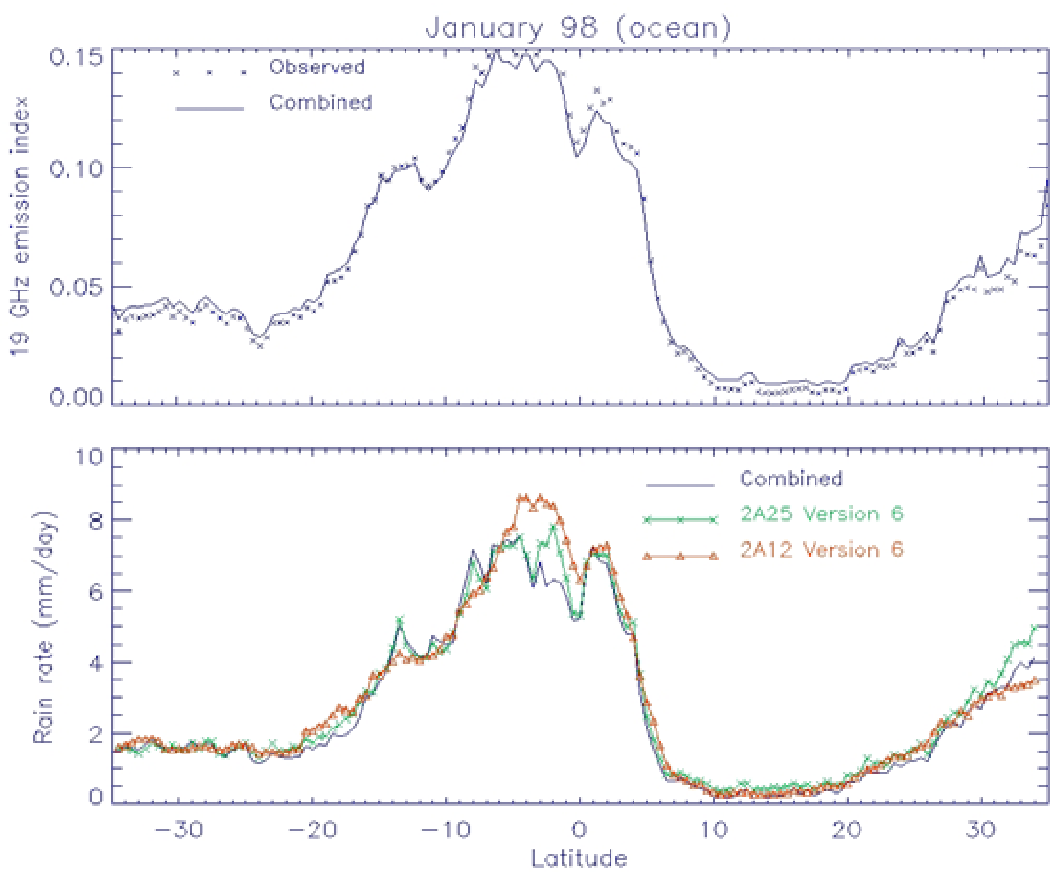


Fig 2: Top panel: Zonal averages of observed and calculated emission index at 19 GHz. Bottom panel: Zonally averages monthly rainfall from NPCA, 2A25 version 6, and 2A12 version 6.