Improving Bayesian Precipitation Retrieval with Non-Spherical Ice Particle Radiative Transfer

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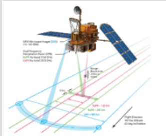
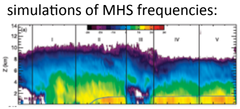
Introduction



NASA's Global Precipitation Measurement Mission (GPM) provides a wealth of both active and passive microwave observations aimed at furthering understanding of global precipitation and the hydrologic cycle. Employing a constellation of passive microwave radiometers increases global coverage and sampling, while the core satellite acts as a transfer standard, enabling consistent retrievals across individual constellation members. The transfer standard is applied in the form of a physically based *a priori* database constructed for use in Bayesian retrieval algorithms for each satellite radiometer via the Goddard Profiling Algorithm (GPROF). The database is constructed using geophysical information and hydrometeor profiles optimized for the best fit to simultaneous active/passive GPM core satellite measurements retrieved through the GPM Combined Algorithm. Initial validation of GPROF rainfall products suggests retrieval errors in particular for convective precipitation over land, as well as issues at high latitudes. In both such regimes, the signal from ice scattering observed at the higher microwave frequencies becomes particularly important for detecting and retrieving precipitation. For cross-track sounder constellation members such as MHS and SAPHIR, this signal is crucial. In Bayesian retrieval schemes, a successful retrieval depends upon observed states being accurately and robustly represented in the database. It is therefore extremely important that the scattering signals associated with precipitation are accurately represented and modeled (and therefore associated with the correct brightness temperature (Tb)) in the retrieval database.

Ice Particles and Passive Microwave Precipitation Algorithms

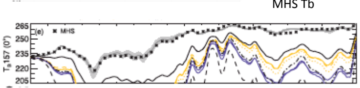
In the current GPM combined retrieval and constellation databases (V4), ice hydrometeors are represented as "fluffy spheres", with assumed density and scattering parameters calculated using Mie theory for spheres. Resulting simulated Tb agree reasonably well at frequencies up to 89 GHz, but show significant biases compared with observations in simulating ice scattering signals at higher frequencies. Many studies can be found in the literature demonstrating that non-spherical ice particles are better able to simulate observed multispectral high frequency microwave Tbs – such as Kulie et al. 2010, who used an ensemble of non-spherical ice particles to improve simulations of MHS frequencies:



Kulie et al. 2010

Cloudsat Z

157 GHzSimulated-Observed MHS Tb



Ensemble simulation vs other particles

In this work the GPROF *a priori* database is recreated using an ensemble of non-spherical ice particles, with single scatter properties obtained from Florida State University and described in Liu 2008. Ice water profiles from the combined retrieval are used as a first guess, and adjusted iteratively following radiative transfer, for optimal agreement with observed 166 GHz H-pol Tbs. The new database is applied for a sample of GPM constellation retrievals and the retrieved precipitation rates compared.

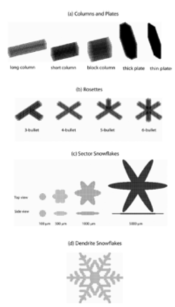
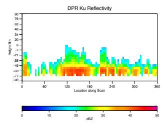


Fig. 1. Shapes of (a) columns and plates, (b) rosettes, (c) sector snowflakes, and (d) dendrite snowflakes. The drawings are made of small dots that are the dipoles used in DDA model simulations.

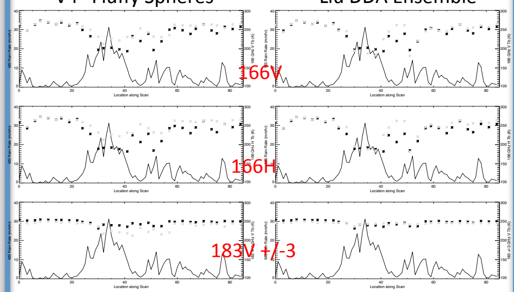
Liu 2008

Radiative Transfer Results



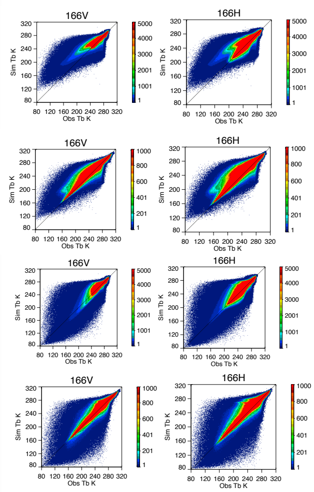
Cross section: precipitation over land

V4 "Fluffy Spheres" Liu DDA Ensemble



(Surface precipitation is solid line, dark symbols observed Tb, gray symbols simulations.)

Using fluffy spheres, algorithm is unable to simulate Tb depression at 166 properly. V4 tries to fix with cloud ice, which still doesn't quite get it there, and overshoots at 183. Non-spherical particle simulation correctly reproduces signal associated with heaviest precipitation



1 Year of simulated TOA Tbs compared to GMI Observed: V4 Ocean

V4 Land

DDA Ocean

DDA Land

* While scatter is slightly increased in the new simulations, the V4 algorithm was unable to ever reach the lowest Tb values (often associated with heavy precipitation) and the DDA runs significantly improve bias*

Tb simulation statistics for 1 year raining land pixels V4

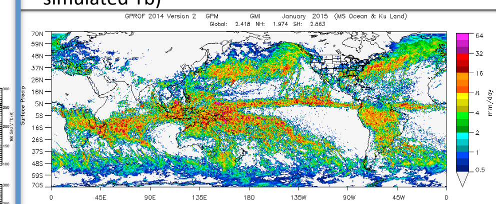
	37V	37H	89V	89H	166 V	166 H	183 +/-3	183+ /-7
corr	0.971	0.972	0.910	0.915	0.894	0.878	0.791	0.883
bias	0.682	2.659	-0.498	2.106	5.442	8.391	-3.940	1.712
RMSE	4.846	8.269	7.872	9.807	12.10	15.71	8.63	8.905

Liu DDA Ensemble

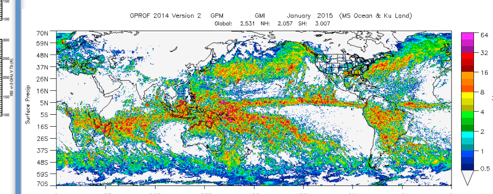
	37V	37H	89V	89H	166 V	166 H	183 +/-3	183+ /-7
corr	0.969	0.973	0.891	0.909	0.887	0.884	0.784	0.843
bias	0.025	1.930	-3.384	-0.863	1.115	3.976	-2.280	1.739
RMSE	4.957	8.030	9.654	9.898	11.41	12.88	8.367	10.40

GMI Retrieval Results: January

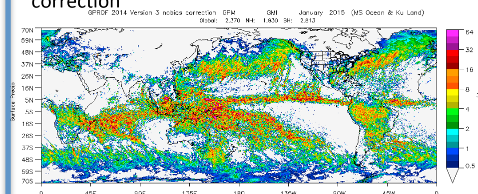
Retrieval Using Observed Tb (goal if perfectly simulated Tb)



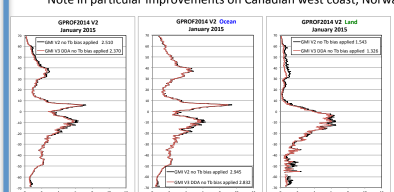
V4 Retrieval



Non-spherical particle database: No bias correction



Note in particular improvements on Canadian west coast, Norway



Decreases in areas of strong convection over land, little change over ocean

Conclusions

A robust, accurate *a priori* profile database is crucial for successful Bayesian-type physical precipitation retrievals such as the GPROF algorithm employed across the GPM constellation. Comparison of 1 year of simulated GMI Tb shows decreased bias as compared to observed Tb when the "fluffy sphere" ice representation is replaced with single scatter properties for an ensemble of non-spherical particle habits calculated using discrete dipole approximation (Liu 2008). While scatter is slightly increased, biases are reduced. Importantly, lower Tbs associated with scattering signals in heavy precipitation are simulated more accurately than in the V4 database. More quantitative analysis is required for assessing the full effect of the changes on the GPROF retrieval, but initial results show a decrease in artificially high precipitation rates over land as a result of the improved simulation of the scattering signal.

References:

Liu, G. (2008). A database of microwave single-scattering properties for nonspherical ice particles. *Bulletin of the American Meteorological Society*, *89*(10), 1563.

Kulie, M. S., Bennartz, R., Greenwald, T. J., Chen, Y., & Weng, F. (2010). Uncertainties in microwave properties of frozen precipitation: Implications for remote sensing and data assimilation. *Journal of the Atmospheric Sciences*, *67*(11), 3471-3487.