Tools for Improving GPM Constellation Retrievals Over Land

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Introduction

Due to the sparsity of available measurements at the surface, satellite platforms continue to be the best current avenue for precipitation assessment on a global scale, yet satellite rainfall products often show substantial disagreement with regional validation data, particularly at the lowest and highest rain and snow rates. This is particularly an issue over land surfaces, where commonly used passive microwave algorithms are sensitive primarily to ice scattering signals, which may not necessarily correlate with precipitation at the surface in a direct quantitative or consistent way. For this reason algorithms have historically been empirical in nature and validation projects inevitably find that various schemes perform well in areas similar to where they are calibrated and tuned, and poorly in others. This type of approach is necessary due to the high emissivity of the surface in the microwave channels, along with its highly dynamic variability, particularly when ice, snow, or liquid water is present on the surface. NASA's Global Precipitation Measurement Mission (GPM) offers an important and unique opportunity to improve upon empirical passive microwave retrieval techniques by enhancing a constellation of passive radiometers with a core satellite that includes a collocated active precipitation radar. The collocated PMW and DPR observations are used in creating a physically-based precipitation profile database that can be used, along with radiative transfer calculations, to perform consistent retrievals across the GPM constellation.

Two separate issues have been identified for improvement of GPM constellation retrievals over land surfaces moving forward from the early version algorithms. The first, accurately representing ice scattering in the retrieval databases, has been presented previously and implemented in the version 5 GPROF and Combined algorithms. The other is organization of the retrieval databases over land.

Motivation

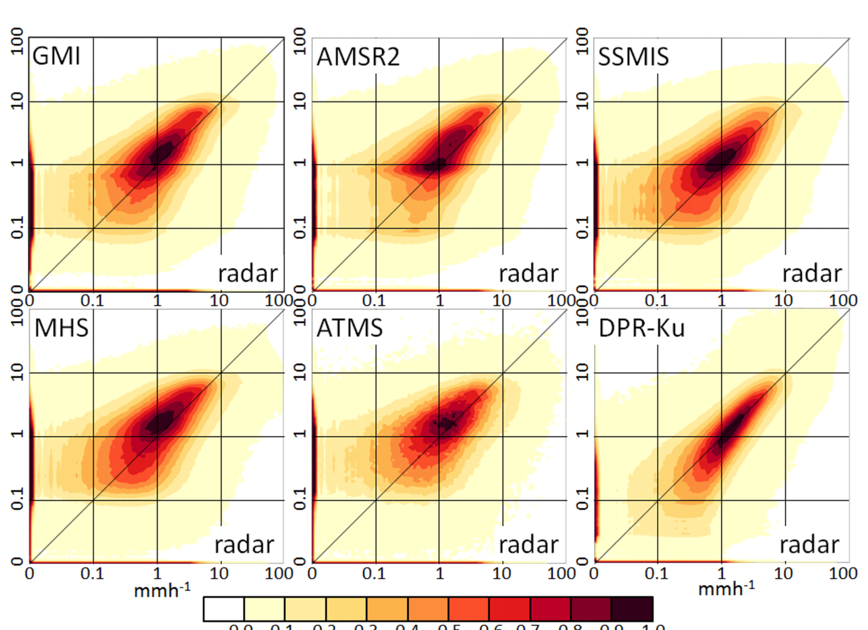


Figure 1: FROM KIDD ET AL. 2017: Normalised density scatterplots of the V05 GPROF and DPR-Ku precipitation products versus surface radar data over the United States region; all products are compared at a nominal resolution of 15x15km (note that zero values are plotted along the x and y axes)

Recent validation work performed by Kidd et al. (QJRMS 2017) shows that the GPROF retrievals over the eastern US tend to overestimate in comparison to surface radar. The DPR-Ku, which is used to create the retrieval database, agrees with the validation data quite well, suggesting an algorithmic issue. By contrast, GPROF retrievals are shown in the same study to underestimate over Europe.

This varies greatly on the instantaneous, local scale. In the February 1, 2014 case study shown below, a retrieval case study shows the GMI retrieval underestimates the heavy precipitation in the convective areas and misses much of the snowfall in the northern part of the swath.

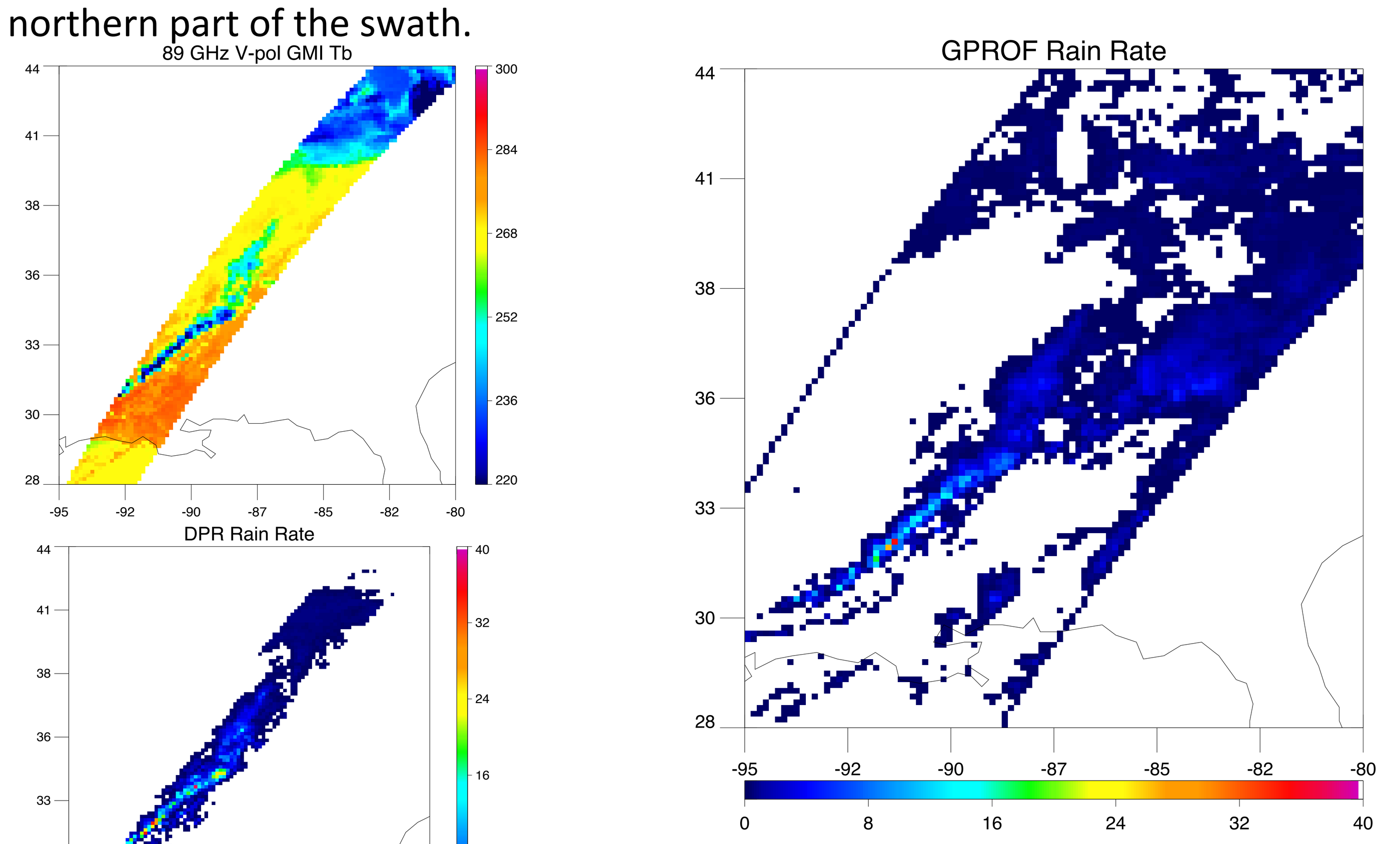


Figure 2: GPM core satellite overpass February 1, 2015. The top left panel shows scattering apparent in the observed 89 GHz GMI Tb. The MS combined rain rate is shown below, with the GPROF retrievals plotted in the panel on the right.

Database

The GPM GPROF retrieval algorithm database includes one year of combined DPR-GMI observations and retrievals which can be used in combination with radiative transfer for application to other constellation members in a consistent retrieval framework. This database contains a wealth of information for examination of connections between observables and other ancillary data fields.

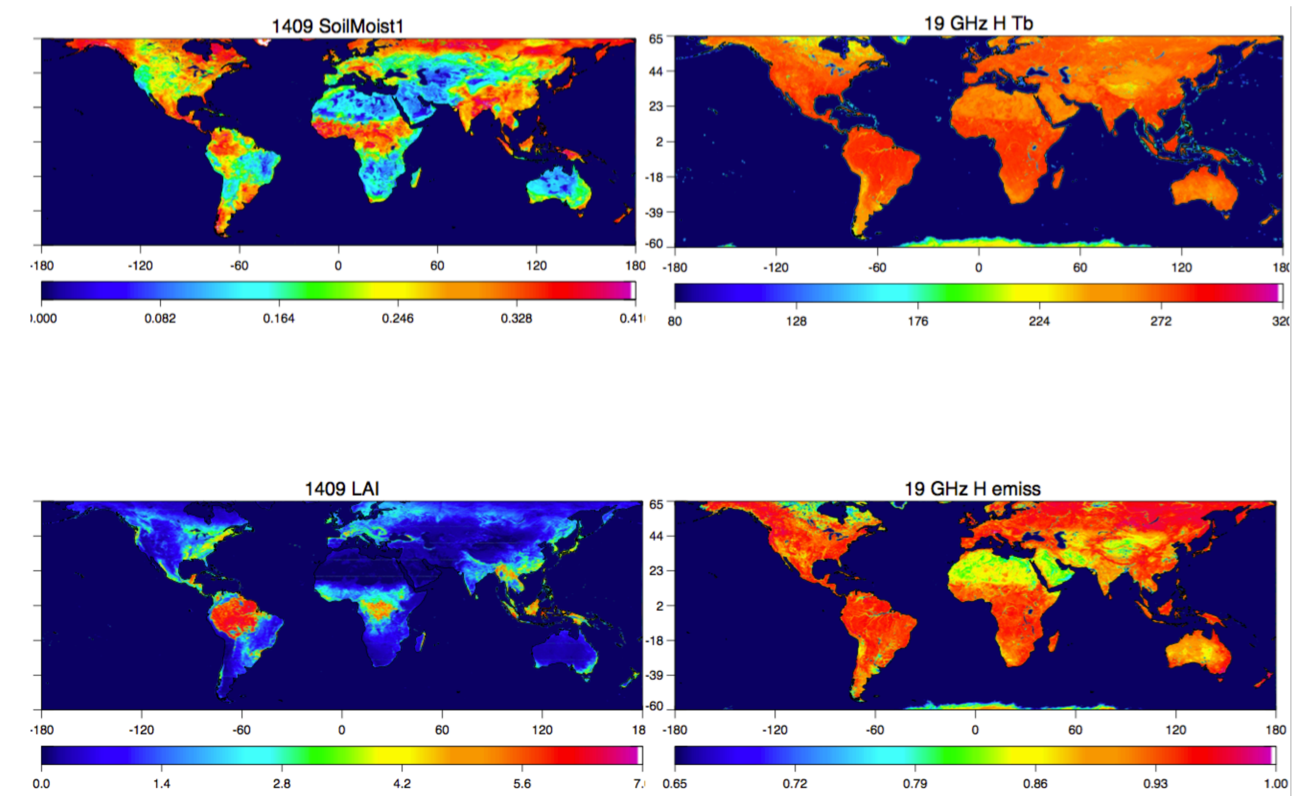


Figure 3: September 2014 GPM observed 18.7 GHz Tb (upper right), retrieved 18.7 GHz emissivity (lower right) along with Noah LSM soil moisture (upper left) and MODIS retrieved LAI (lower left)

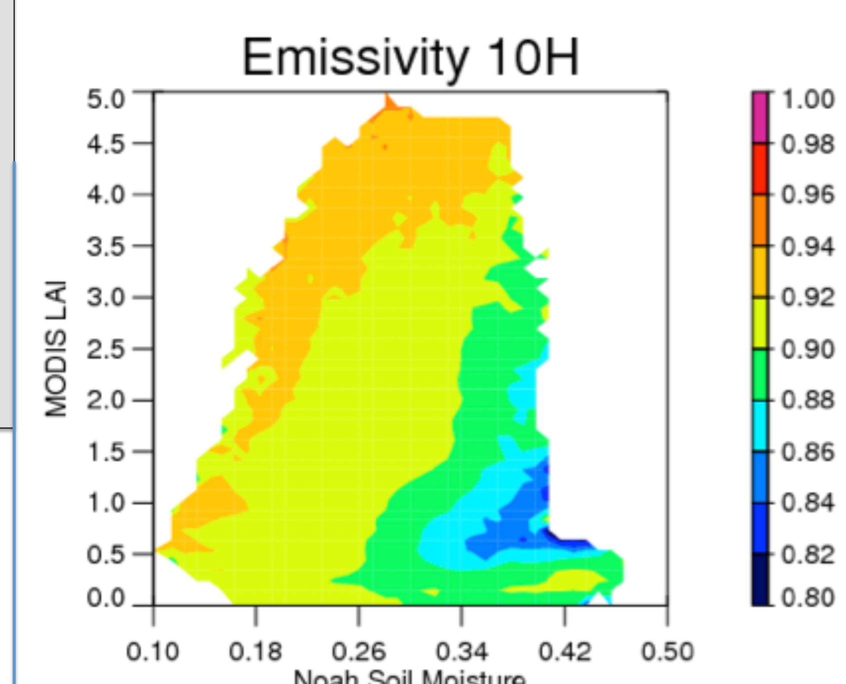
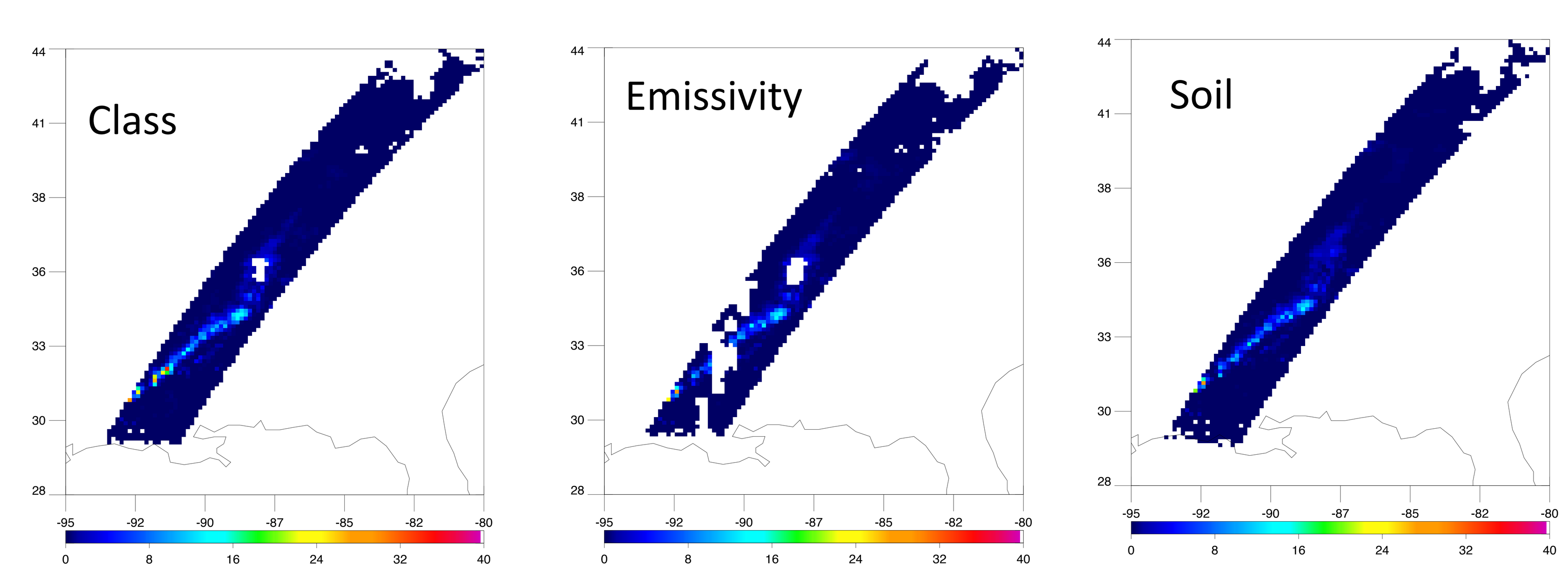


Figure 4: One year of retrieved AMSR-E cloud-free emissivity retrievals as a function of MODIS LAI and model soil moisture at 10 GHz.

In order to examine the relationship between observed Tb, radar rain rate, and surface characteristics, the database is enhanced with several ancillary datasets. Output from the NCEP Noah land surface model (forced using MERRA-2) is attached to each GPM observation along with leaf area index (LAI) retrieved from the MODIS instruments aboard NASA EOS Aqua and Terra satellites. The panel above illustrates the visible relationships between these fields and GMI observations. Previous work (panel to the left) using AMSR-E has demonstrated that soil moisture and LAI are clear indicators of the surface emissivity, an important component of the emission contribution to Tb over land, particularly at the lower microwave frequencies. At higher frequencies, the relationship between ice scattering and precipitation forms the basis of precipitation retrievals. The idea proposed here is that the ancillary data holds information about this component as well.

Implementation

A very simple Bayesian retrieval scheme is used to retrieve precipitation for the case shown in figure 2. The database is indexed in 3 different ways – by the surface classes defined in GPROF, by surface emissivity, and by 4 broad soil moisture categories. This is a very simple test implementation and does not include other valuable ancillary information such as the TPW and 2 meter temperature used in operational retrievals. For this reason results are somewhat low due to the "smearing" effect of averaging over many database pixels. In addition no screening is used, leading to widespread small values of precipitation. No cross-index searching is allowed.

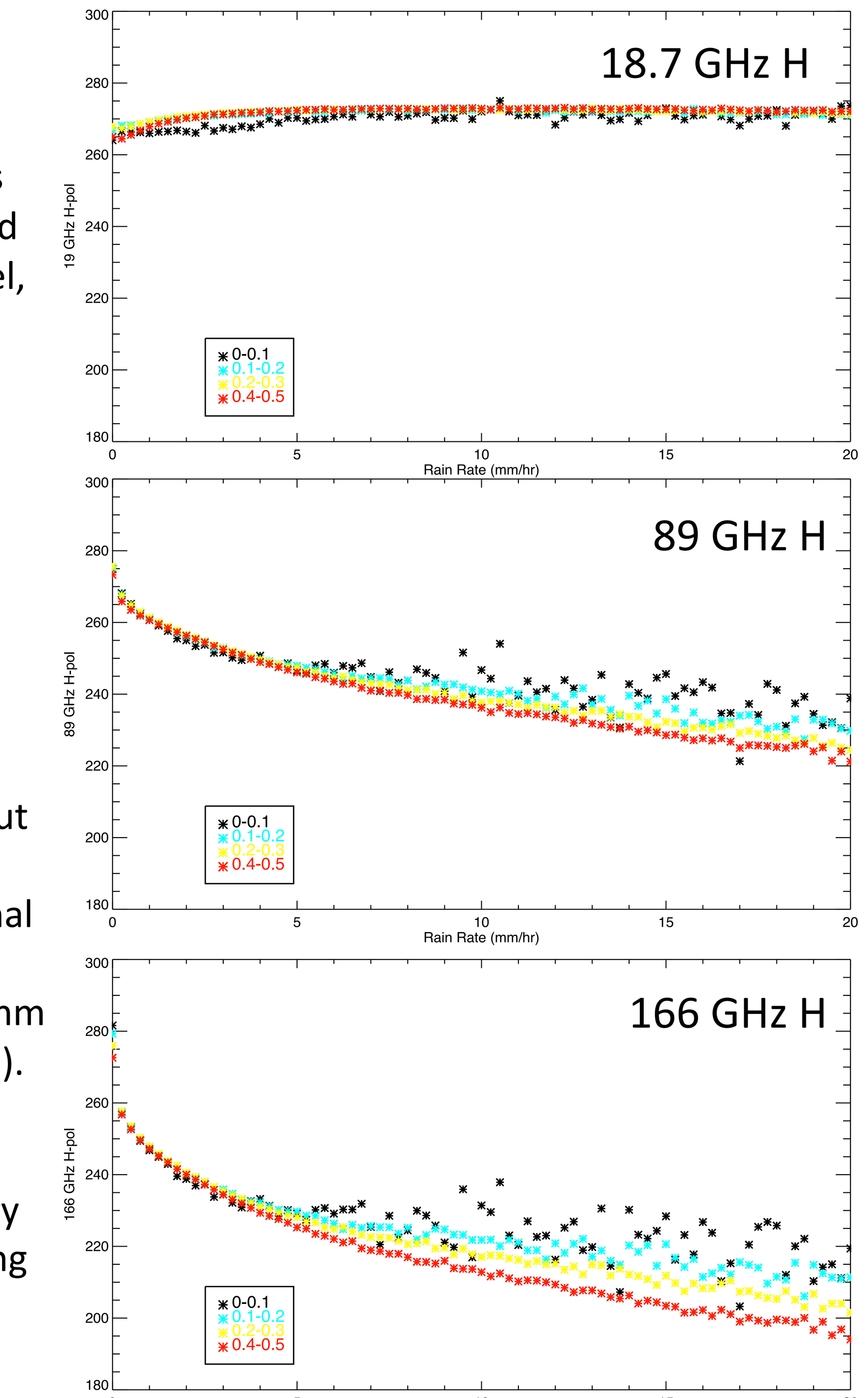


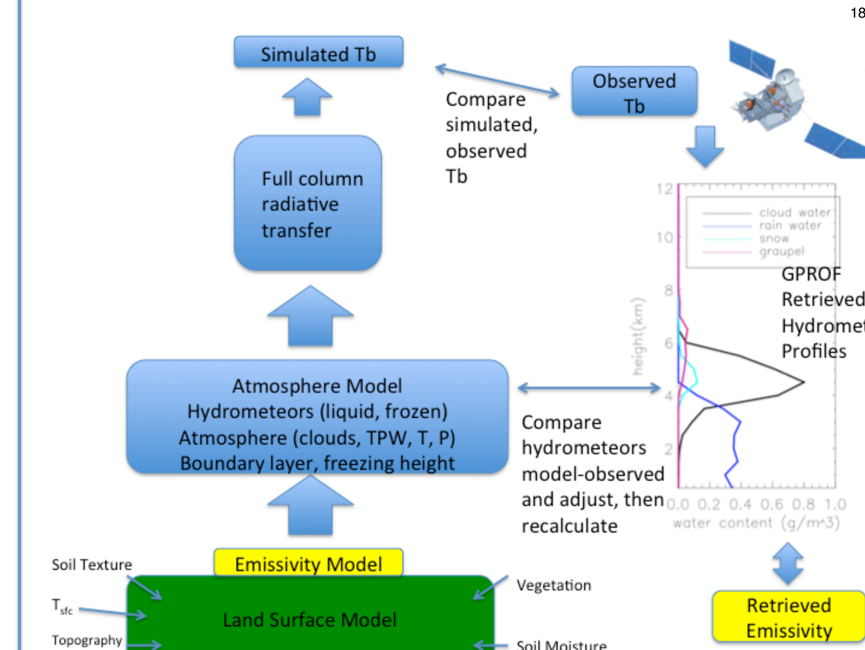
The class-based retrieval is similar to the GPROF result of figure 2. In the emissivity case, no retrieval is performed over inland water pixels due to the emissivity regression algorithm, and values are low due to overstratification of the database (not enough extreme precip values in each bin). The soil moisture implementation places precipitation in the correct areas but smears out the large rain rates due to underconstraining of the database (averaging over too many pixels in the bin). Obviously no conclusions can be drawn from a single, simplified retrieval test case, but this suggests the need for "smart" database indexing scheme in order to improve retrievals over land surfaces, that strike a balance between having enough representation without over-averaging.

Suggested Path Forward

A physically-based Bayesian type scheme such as the one used for the GPM constellation requires both accurate simulation of GPM core observed profiles for use in the constellation databases, and robust representation. On a practical level, database "smart searching" is also necessary. GPROF, the operational GPM constellation algorithm, currently constrains the retrieval search over land using 14 land surface classes defined as areas with self-similar emissivity climatologies.

Previous work along with examples shown here using the full year GPM database suggest that the soil moisture field contains important information about the scattering-rain rate relationship. The plots to the right show the scattering signal as expressed by high frequency GMI Tb plotted as a function of combined algorithm rain rate (x-axis) and soil moisture (colors). As frequency increases, the soil moisture lines separate visibly, suggesting that soil moisture may act as a marker of boundary layer characteristics defining the scattering height.





A possible scheme for investigating this relationship is diagrammed here: A land surface model is coupled to an atmospheric model and matched with GPM core observations. Columns are simulated and optimized to be physically consistent with both models and observations, similar to a combined retrieval or data assimilation scheme. Resulting data could be used for investigating the relationship between observed scattering, the nature of the precipitation, and observed precipitation at the surface. This knowledge could then be applied directly to algorithm improvement in both simulation and retrieval indexing.

Conclusions

Passive microwave precipitation algorithms over land rely on ice scattering signals to retrieve precipitation. Bayesian retrievals such as GPROF as well as other techniques such as the EPC method of Turk et al. 2017, and other more empirical scattering-index type techniques all rely on this signal in some way. Therefore for accurate GPM precipitation constellation retrievals it is crucial that the GPM database applied to constellation radiometers both:

1) Accurately simulate the relationship between scattering and precipitation
2) Contain robust representation of possible observed precipitation profiles

The robustness of the database can be damaged by both over- and under-stratification, and therefore care must be taken in using "smart" constraints.

This work suggests that by incorporating soil moisture as ancillary data into the algorithm, information about changes in the scattering – rain rate relationship can be incorporated into the retrieval. The inclusion of soil moisture also incorporates information regarding the dielectric component of the emissivity which heavily influences Tb at the lower microwave frequencies.

Future work suggested here includes investigation of the soil moisture-boundary layer relationship using a coupled atmospheric-land surface model for investigation into the links between the height of the boundary layer, which defines the scattering signal, and soil moisture. Understanding of this relationship on a physical level will enable determination of the best form of implementation into the retrieval algorithm.