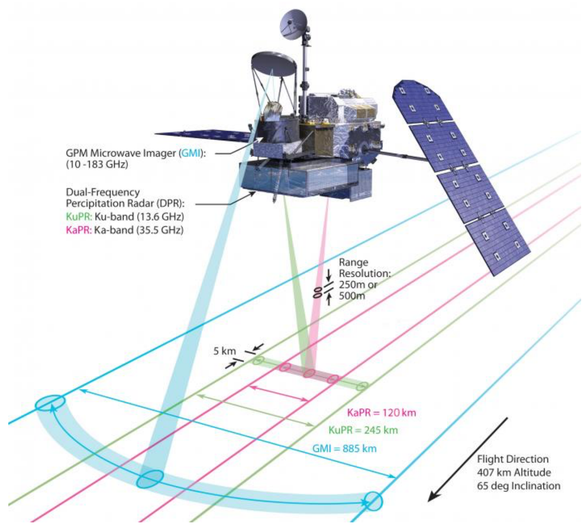
Challenges and Strategies for Combined Active/ Passive Precipitation Retrievals

S. Joseph Munchak[1], W. S. Olson[1,2], M. Grecu[1,3]

1: NASA Goddard Space Flight Center; 2: University of Maryland, Baltimore County JCET; 3: Morgan State University

Overview of the Combined Retrieval Problem and Similarities to the Data Assimilation Problem

The remote sensing of precipitation by means of radar measurements and passive microwave radiometer measurements progressed along mostly separate paths until the launch of the TRMM in 1997. Spurred by the simultaneous measurements from its Precipitation Radar (PR) and microwave imager (TMI), motivation increased to develop products that made use of both instruments in order to better understand biases in the single-instrument products and to develop a superior precipitation dataset using all available measurements. These efforts continue with TRMM's successor, GPM, which provides an additional radar frequency, sounding channel measurements, and coverage into high latitudes.



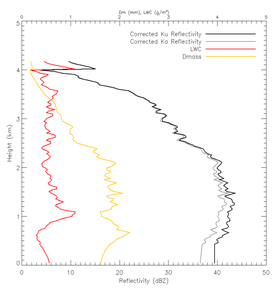
Precipitation retrievals from radar or radiometer are fundamentally under-constrained by observations alone. Thus, the goal of a physically-based retrieval algorithm is to minimize forward model error in simulating observations from the retrieved state variables, while constraining the state variables to realistic values, effectively minimizing:

$$J = (\mathbf{X}-\mathbf{X}_a)^T\mathbf{S}_a^{-1}(\mathbf{X}-\mathbf{X}_a) + (\mathbf{Y}-f(\mathbf{X}))^T\mathbf{S}_y^{-1}(\mathbf{Y}-f(\mathbf{X}))$$

This is fundamentally similar to data assimilation in numerical weather prediction, where the goal is to produce an initial state that will provide an accurate forecast, with the major difference being the dynamic nature of constraints on the state variables.

Strategies and Approaches to Combined Radar/Radiometer Precipitation Retrievals

Variational (1D)



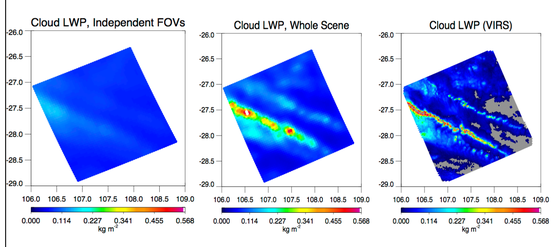
Cost function is minimized for each profile. State variables can describe PSD at each vertical level as well as non-precipitation parameters (cloud water, water vapor).

Pros:
-Computationally efficient

Cons:
-Requires co-located (or deconvolved) radiometer Tbs.
-Can't account for 3D effects (radiation "leakage", slant path)
-Does not converge for strongly nonlinear forward models

Example: MiRS (Boukabara et al, 2011)

Variational (3D)



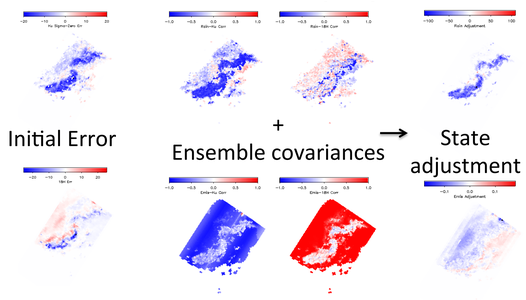
Cost function is minimized over a scene. State variables describe a few parameters per profile (e.g., profile-averaged PSD parameters).

Pros:
-Explicitly account for 3D geometry (slant path, mismatched radar/radiometer fields-of-view, 3D RT)

Cons:
-Computationally expensive (limits number of parameters per pixel that can be retrieved)
-Does not converge for strongly nonlinear forward models

Example: Munchak et al. (2010)

Ensemble (1D)



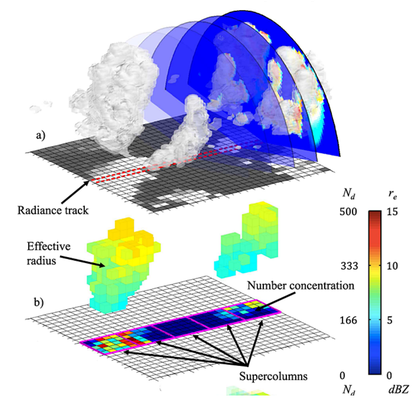
Multiple solutions to Ku radar profile are generated with different PSDs, cloud water, humidity profiles. Ensemble covariances are used to adjust each solution to match other observations (TBs, Ka reflectivity).

Pros:
-Computationally efficient
-Better for non-linear forward models

Cons:
-Requires co-located (or deconvolved) radiometer Tbs.
-Can't account for 3D effects (radiation "leakage", slant path)

Example: GPM Combined

Ensemble (3D)



1D ensemble method extended to 3D scenes. Benefits from realistic spatial correlations between state variables – most similar to NWP DA?

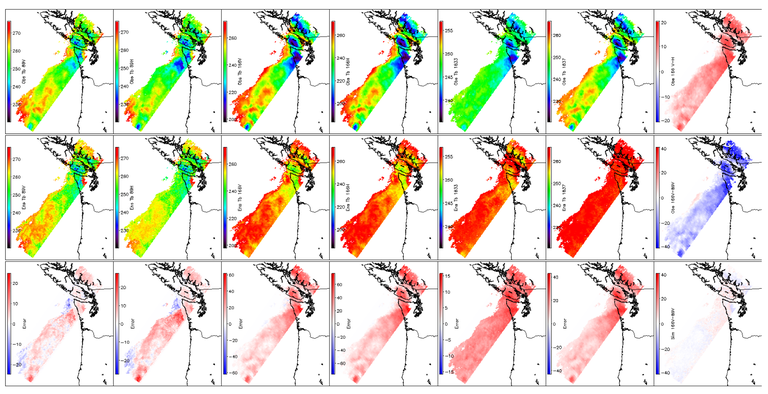
Pros:
-Explicitly account for 3D geometry (slant path, mismatched radar/radiometer fields-of-view, 3D RT)
-Better for non-linear forward models

Cons:
Computationally expensive

Example: Fielding et al., 2014

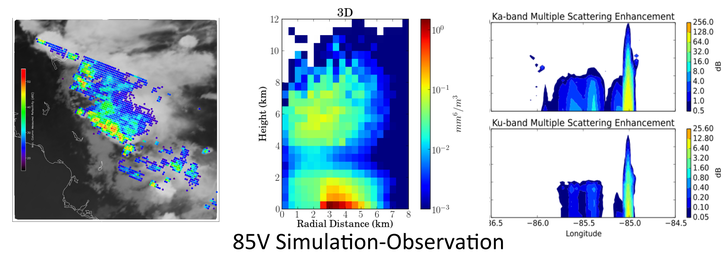
Challenges for Retrievals: Advanced Forward Models and Realistic State Constraints

The GMI channels at 166 (V&H), 183+-3, and 183 +-7 GHz provide additional opportunity to observe light precipitation and better constrain precipitation ice particles, but radiative transfer modeling must be adequate to simulate these frequencies when forced to match the observed radar reflectivities as well.

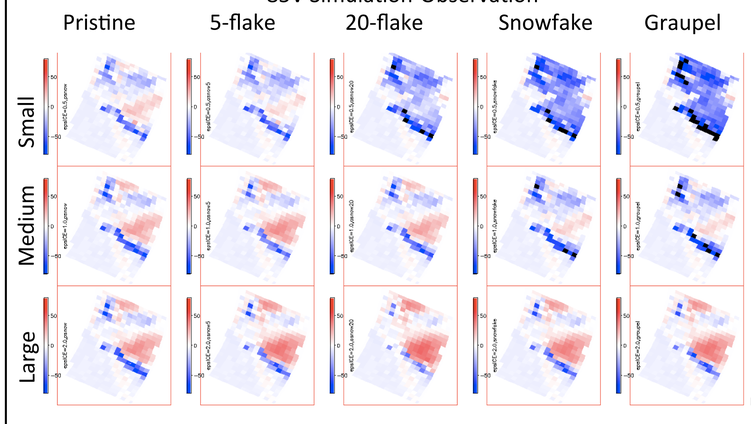
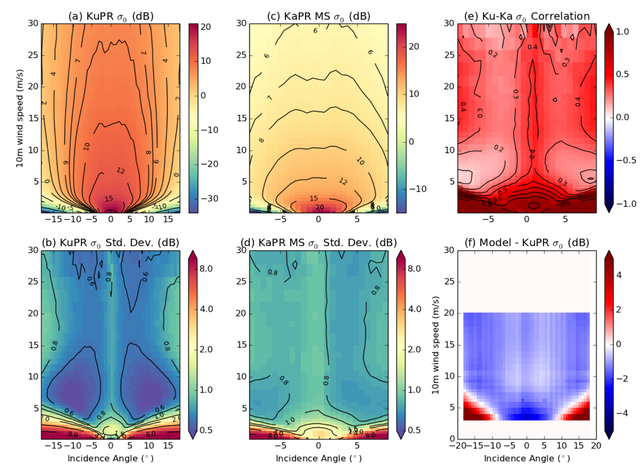


Some key parameters that are well-observed, yet poorly modeled in current GPM retrievals include the enhancement of scattering with frequency and the polarization difference at 166 GHz. Three-dimensional, fully polarized models with realistic particle scattering physics and preferential orientations will be needed to make full use of these observations.

Spaceborne radar at the frequencies (Ku and Ka) and resolution (5km) of GPM DPR suffers from severe multiple scattering (MS) and non-uniform beam filling (NUBF) effects. Since these reduce the information content of observations near the surface, they are a source of error and bias if not accounted for correctly. NUBF can also lead to biases in simulated brightness temperatures when a 2D radiative transfer model is used.



85V Simulation-Observation



A common theme among the retrieval strategies above is the need to constraints on the state variables. These may take the form of spatial (vertical and horizontal) correlations between the retrieved PSD variables as well as realistic representations of the cloud water and relative humidity profiles within precipitation, along with surface emissivity and radar backscatter cross-section, including effect on ongoing or recent precipitation (GMI-derived wind-backscatter model is shown below). Environmental properties that have a weakly constrained by observations, but still needed for forward modeling (temperature profile) are also needed and usually derived from ancillary (model analysis or forecast) data.