GPM Radar Radiometer Combined Algorithm. Formulation and evaluation

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Goal

Develop and evaluate an ensemble based methodology for precipitation retrieval from satellite combined radar and radiometer observations

Motivation

- Precipitation retrievals from passive satellite microwave observations are challenging because the associated mathematical problem is ill posed
- Combined radar radiometer retrievals are potentially superior to single instrument retrievals because they facilitate the explicit retrievals of an extended set of precipitation related variables
- Although mathematically well formulated, combined retrievals methodologies are difficult to implementation and apply in practice
- Ensemble based methodologies are relatively easier to implement than other methodologies, yet they
  - Are robust
  - Deal appropriately with nonlinearities
  - Provide uncertainties for the final products

Combined Retrieval Methodology

General Description

- (1) The combined retrieval methodology is based on the generation of an ensemble of radar-only retrievals
- (2) An ensemble of high-resolution (radar resolution) brightness temperatures is derived from the radar-only retrievals
- (3) The low-resolution (satellite) brightness temperature information are determined trough convolution
- (4) The most likely high-resolution brightness temperatures and associated retrievals are derived through the ensemble Kalman based minimization of a cost function

$$J(\mathbf{TB}_{\mathbf{DPR}}) = \frac{1}{2}\left(\mathbf{TB}_{\mathbf{obs}} - \mathbf{TB}_{\mathbf{sim}}(\mathbf{TB}_{\mathbf{DPR}})\right)^T \mathbf{W}_{\mathbf{TB}}^{-1}\left(\mathbf{TB}_{\mathbf{obs}} - \mathbf{TB}_{\mathbf{sim}}(\mathbf{TB}_{\mathbf{DPR}})\right) + \frac{1}{2}\left(\mathbf{TB}_{\mathbf{DPR}} - \overline{\mathbf{TB}_{\mathbf{DPRens}}}\right)^T \mathbf{W}_{\mathbf{TB}_{\mathbf{DPRens}}}^{-1}\left(\mathbf{TB}_{\mathbf{DPR}} - \overline{\mathbf{TB}_{\mathbf{DPRens}}}\right)$$

Implementation Details

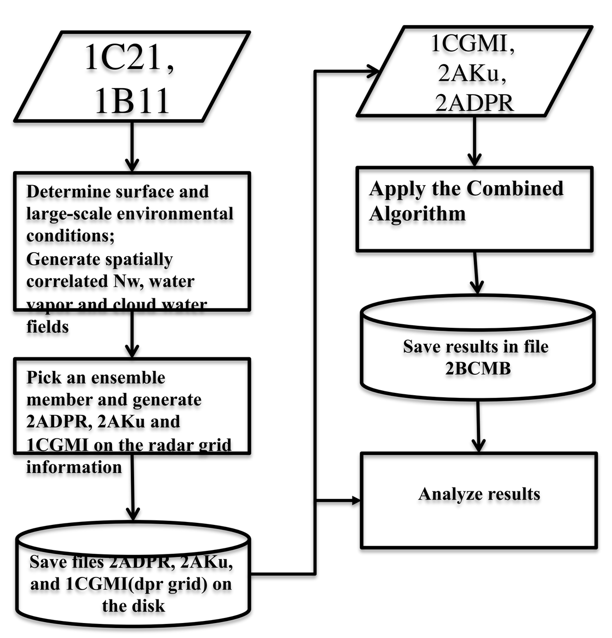
- An ensemble of radar observation vectors is simulated from randomly generated X=[Nw] using the HB algorithm
- Radiometer clear sky retrievals are derived and the surface conditions are interpolated into precipitation areas
- The clear-sky brightness temperatures (based on the clear sky retrievals) and the precipitation affected radar-resolution brightness temperatures are convolved at radiometer footprint resolution
- Randomly generated Nw profles are spatially correlated
- Simultaneously, spatially correlated RH and cloud water profiles are generated
- A vector of simulated brightness temperatures and radar observations, Y=[Tb, ZmKa, PIAKa, PIAKu], is derived for each radar profile
- Unknown X and its associated uncertainty are updated along with Y using
- $X=X+cov(X,Y)(cov(Y,Y)+R)^{-1}(Y-Yobs)$

Implementation status

- The algorithm is fully implemented.
- The GPM Toolkit is linked to the code. In addition, the netcdf library is linked to the code and additional non-PPS variables can be saved in netcdf format.
- The code is parallelized using the OpenMP paradigm
- Automatic code generation is used to efficiently and consistently investigate diverse scenarios.

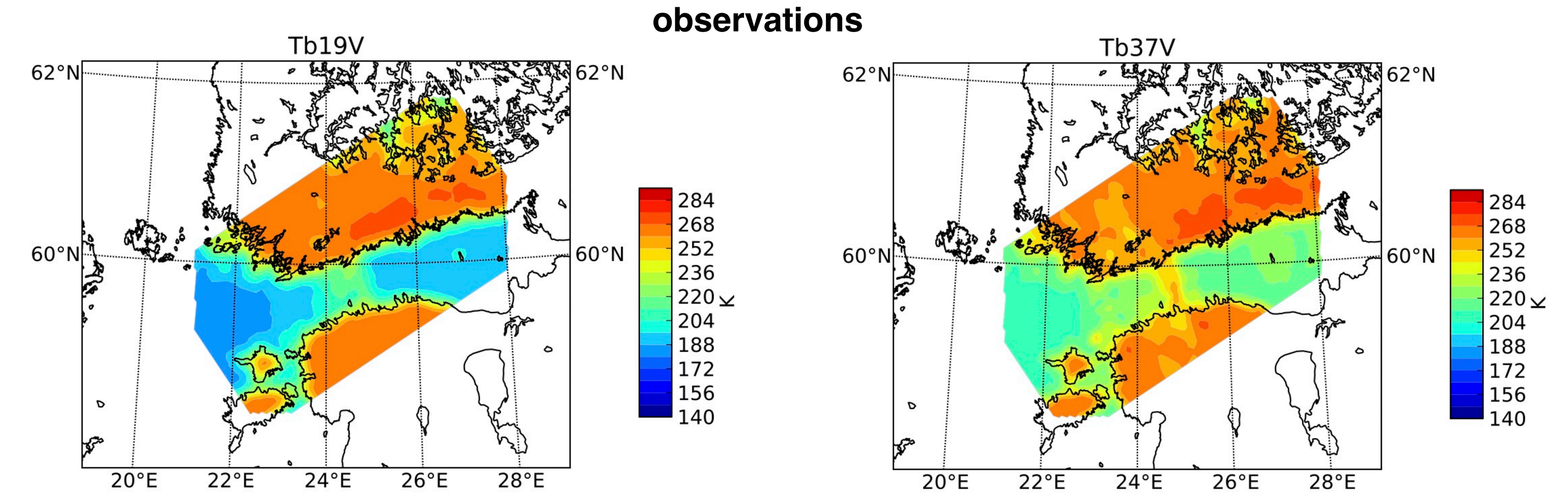
Testing

- To evaluate this algorithm, TRMM observations are used.
- A single frequency radar-retrieval algorithm is applied to TRMM PR observations to derive vertical PSD profiles consistent with both the assumed PSD intercepts and the TRMM PR observations.
- Over oceans, TRMM Microwave Imager (TMI) observations are used to derive surface conditions and parameterized information regarding the vertical distribution of water vapor and clouds in rain-free fields of view (FOVs). The surface conditions in rain FOVs are determined by interpolation of rain-free FOVs. The vertical profiles of water vapor, water and ice clouds are statistically prescribed in rain FOVs.
- Over land, the surface conditions are determined based on TELSEM surface emissivity atlas. The water vapor information is set based on NWP analyses.
- The TMI derived surface conditions, the PR derived PSDs and the statistically prescribed water vapor and cloud profiles are used to synthesize Ka-band radar observations and associated (PR resolution) brightness temperatures at the GMI frequencies
- The precipitation estimates derived from the synthetic observations are compared to reference precipitation assumed in the observation synthesis.

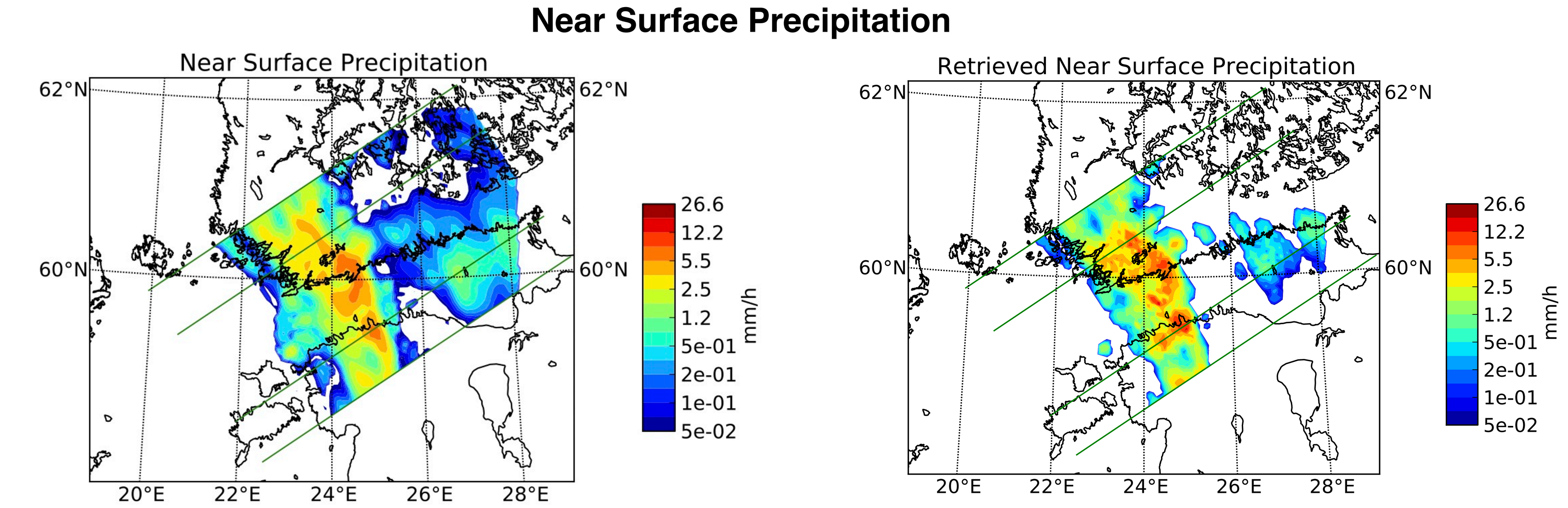


Cloud Resolving Model-based Results

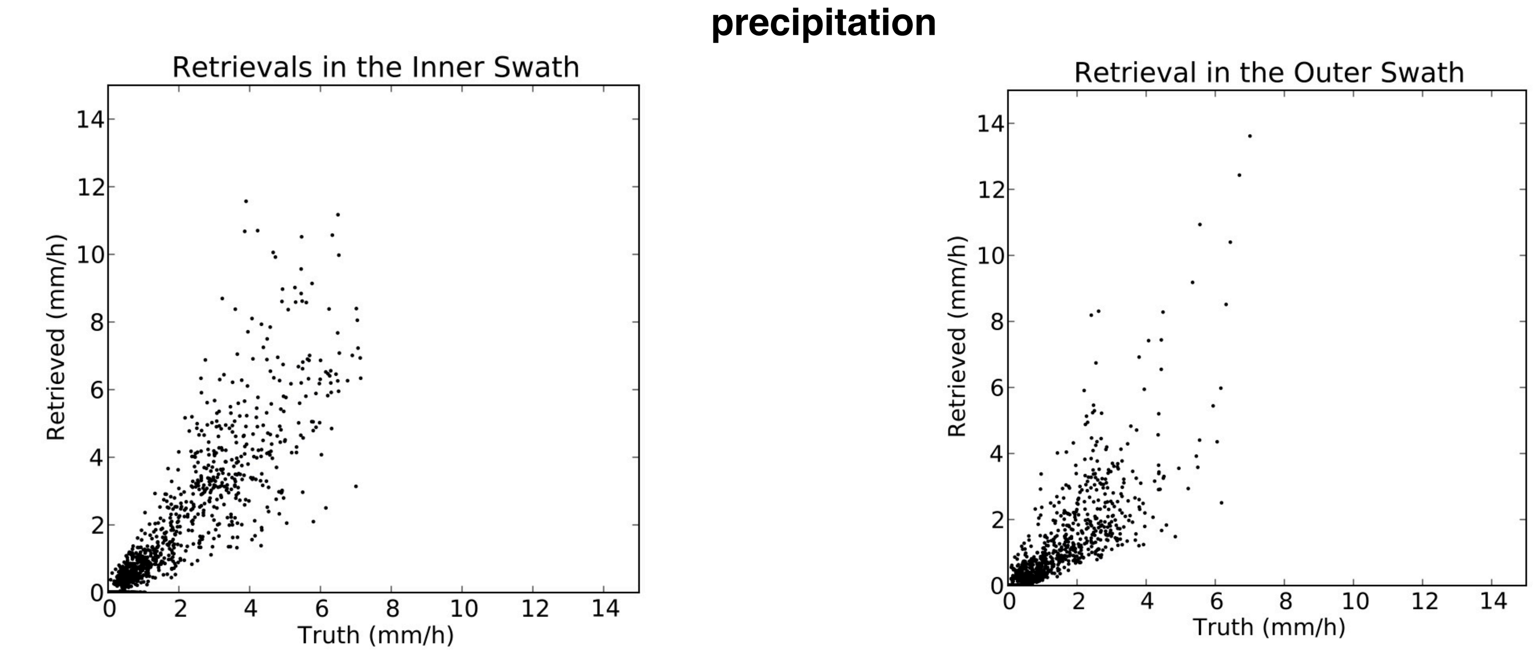
Examples of synthetic radiometer observations



Near Surface Precipitation



Scatter plots of retrieved vs. true precipitation



Conclusions

- Ensemble-methodologies appear to be effective in combined retrievals
  - Dual frequency radar-only retrievals are superior to single frequency retrievals
  - Combined retrievals are superior to dual frequency radar only retrievals
- Implementation is simple, easy to understand, parallelize and extend
- The large number of operations required to derive a solution does not appear to be a problem
  - Sequential processing of observations is an effective way of reducing the problem dimensionality

Future Work

- Further evaluate the retrieval framework using simulated and field campaign data
- Analyze the framework's performance in the radiance space
- Analyze the impact of microphysical parameterizations uncertainties and limitations on the retrieval accuracy
- Investigate multi-model ensembles
- Analyze and reconcile the large discrepancies between the enKF combined and 2A25 results

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