Combined Satellite Radar-Radiometer Precipitation Algorithm for GPM, Based Upon Ensemble Filtering

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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

Radar-only Retrieval

- An ensemble of radar observation vectors Y=[ZmKa, PIAKa, PIAKu] is simulated from randomly generated X=[Nw] using the HB algorithm
- Randomly generated Nw profiles are spatially correlated
- Simultaneously, spatially correlated RH and cloud water profiles are generated
- Unknown X is updated along with Y using
- $X=X+cov(X,Y)(cov(Y,Y)+R)^{-1}(Y-Yobs)$

Combined Retrieval

- 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
- A sequential Kalman filtering methodology similar to that used in the radar-only retrieval modules is applied to further refine the solution based on the differences between simulated and observed brightness temperatures

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.

Code Structure

Main	Data Management	Clear Sky Ret	Interpolation/ Projection	Combined	Radar Only	Radiative Transfer	Math	Mie/ Absorbtion	I/O
main.c	f90DataTypes.f90	screenocean.c	interpol.f90	radarRet.rend.f90	ensFilter.cc	clearSky.cc	random.f90	readTables.f90	readpr.newToolKit.c
mainf.new.f90	f90Types.f90	sst.rend.f90	dsphere2.f90	beamConvP.f90	fModelFortran.f90	emissivity-sp.f	linsys.f90	mie3.f90	writeNetcdf.rend.c
	allocateMem.rend.f90	geomask.c	resampGMI.rend.f90	beamConvSet.f90	fhb1.f90	radtran.f	band.f90	absorb.f	binaryOut.c
	nbin.f90		dPRgrid.f90	geophysEns.f90	retTablesInt.f90	rterain.f90	dsvdc.f90	mie-melt_lam.f	writeCMB.rend.c
	allocMemC.c				gaussNewton.cc		linpak.f	iceoptic.f	writegif.f90
	cloud.f90						sort3a.f	watoptic.f	
	weightModule.f90						isnan.c	mg-ell.f	
								mie-sphere.f	
								epswater.f	
								melting.bauer.f90	
								gcloud.f	

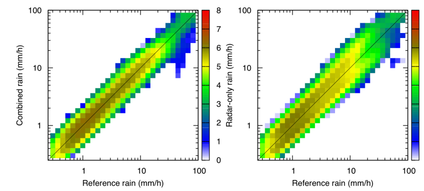
Testing

- To evaluate this algorithm over oceans, 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.
- 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.
- 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.

Synthetic Observation-based Results

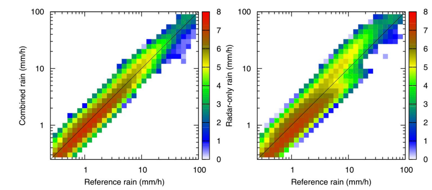
Convective Rain

Bias/ Algorithm	Negative Nw bias	Positive Nw bias
Combined	-13.5	17.9
Radar-Only	-21.8	42.8



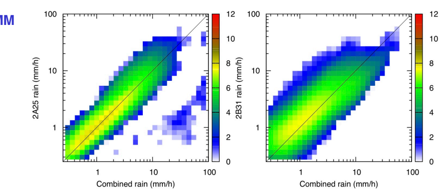
Stratiform Rain

Bias/ Algorithm	Negative Nw bias	Positive Nw bias
Combined	-20.3	20.2
Radar-Only	-29.1	55.7



Comparison with existing TRMM products

- The combined retrievals are highly correlated to version 7 2A25 and 2B31 products
- However notable discrepancies are apparent for some profiles
  - These discrepancies might be caused by precipitation miss-classification or largely erroneous SRT PIA estimates



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
- Perform similar analysis focusing on the inner swath where both Ku and Ka observations are available
- 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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