All-sky GMI Radiance Data Assimilation Global Products from the GEOS-5 System in Support of the GPM Mission

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Motivation and Objective of Study

• Data assimilation, which combines the information from observations and a short-range forecast, is a powerful tool to estimate the initial state of the atmosphere for NWP forecasts. Assimilating satellite observations from microwave imagers such as the GMI in cloudy and precipitating regions can provide critical constraints on meteorological parameters in dynamically sensitive regions and make significant impacts on forecast accuracy for precipitation.

•To expand the existing capabilities assimilating satellite radiance data in clear-sky condition, the NASA GMAO has been pursuing efforts to utilize all-sky (clear +cloudy+precipitating) microwave radiance data in the GEOS-5 Atmospheric Data Assimilation System (ADAS). The project has made considerable progress and the framework to assimilate all-sky GMI radiance data over the ocean is currently being tested for implementation in the GMAO's operational forecast system by early 2017 (Figure 1).

• In this poster, the current status of developing all-sky GMI radiance data assimilation system in the GEOS-5 system and implementation results to utilize GMI all-sky radiance data over Ocean are presented. In addition, work progress and challenges in extending this cloudy and precipitation affected radiance data assimilation framework to utilize all-sky GMI radiance data over land is discussed.

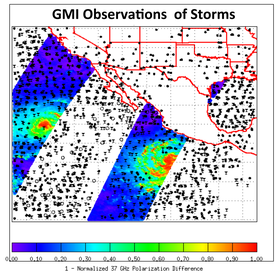


Figure 1. Satellite radiance data assimilated in GEOS-5. GMI radiance data from each channels in clear+cloudy +precipitating regions are assimilated in addition to clear sky radiance data from other microwave sensors like AMSU-A, ATMS, and MHS and IR sensors like AIRS, IASI, and CIRS. Color map: 37GHz polarization difference indicating regions with clouds and precipitations. Black symbols: other satellite observations assimilated in GEOS-5

Goddard Earth Observing System Version 5 (GEOS-5) and GSI Data Assimilation System

The GEOS-5 system consists of a group of model components that can be connected in a flexible manner in order to address questions related to different aspects of Earth System. The main components are the following:

• **Atmospheric General Circulation Model (AGCM)**- Predictive model components for the atmosphere and land (Figure 3). **Catchment Land Model** includes explicit treatment of the spatial variation within each hydrological catchment of the soil water and water table depth, as well as its effect on runoff and evaporation. It also includes a multi-layer global snow model.

• **Ocean General Circulation Model (OGCM)**-Predictive model components for the ocean and sea ice, using a specified atmospheric state to force the ocean.

• **Chemistry-Climate Model (CCM)**- This model includes interactive chemistry component allowing feedbacks between chemical composition and the circulation.

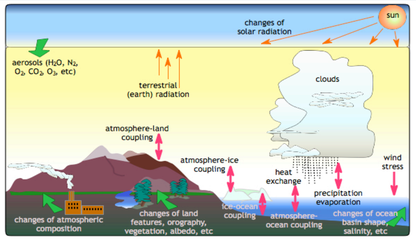


Figure 2. Schematic diagram showing components considered in GEOS-5 AGCM

• **Chemistry-Transport Model (CTM)** – Compute chemical reaction using specified meteorological conditions (winds, temperature, moisture, and clouds)

• The GEOS-5 AGCM employs a finite-volume cubed-sphere dynamical core (Putman and Lin 2007) for hydrodynamics and the physics package (Molod et al. 2012) includes moist processes, radiation, tubulent mixing and surface processes. Notably, the moisture physcis package in GEOS-5 will be enhanced with a two-moment cloud microphysics scheme (Barahona et al 2014) in the next GEOS-5 AGCM system upgrade scheduled for 2017. That two-moment scheme will provide estimates of cloud particle size distributions (PSD) in addition to cloud condensate amounts.

• The GSI combines information from irregularly distributed observations with the GEOS-5 AGCM model state in such a way as to minimize a specified cost function.

• The GEOS-5 ADAS is currently based on Hybrid 3D-EnsVar analysis solver (See Figure 4) and will be upgraded to Hybrid 4D-EnsVar analysis solver by the end of 2017.

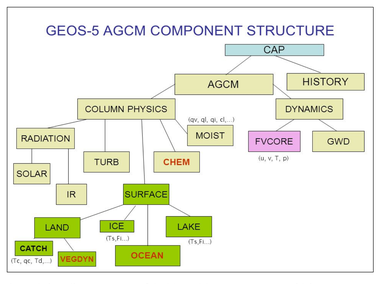


Figure 3 describes structure of GEOS-5 AGCM components, which generates forecasts atmospheric state variables and surface related variables.

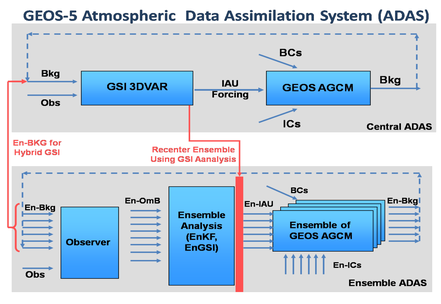


Figure 4 describes GEOS-5 Atmospheric Data Assimilation System (ADAS) which generates atmospheric analyses by combining model background fields and observed measurements.

Assimilation Methodology for All-sky GMI Radiance Data

Table 1: New components added to assimilate all-sky radiance data n GEOS-5 ADAS

New Components added to assimilate all-sky GMI radiance data over Ocean	
Cost Function $J(x_a) = \underbrace{(x_a - x_b)^T B^{-1} (x_a - x_b)}_{\text{Fit to model background fields}} + \underbrace{(H(x_a) - O)^T R^{-1} (H(x_a) - O)}_{\text{Fit to observations}}$	
X_b = Background (first-guess)	Added cloud liquid (ql), cloud ice(qi), rain(qr), snow(qs)
x_a = Analysis	Added ql, qi, qr, qs
O = Observations	New QC gross checks to keep cloud and precipitation affected radiance data
B = Background Error Covariance	Added static B and EnKF B for ql, qi, qr, and qs
R = Observation Error	Developed and assigned observation errors for all-sky GMI radiance data
H = Observation Operator	Evaluate/Enhance CRTM performance in regions with precipitation
Bias correction : Variational Bias Correction (VarBC)	Bias correction predictors in VarBC: constant, lapse rate, lapse rate^2 to correct air-mass related biases. Cloud liquid water path was removed from the original predictors used in the operational GEOS-5 ADAS.

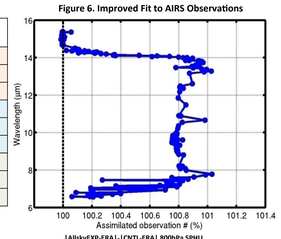
Most of operational NWP centers utilize satellite radiance data in clear sky condition only. To be able to assimilate cloud- and precipitation affected radiance data, GMAO has enhanced the GEOS-5 ADAS by adding new capabilities (shown in red in Figure 5). Current operational GEOS-5 Atmospheric Data Assimilation System (ADAS) is based on hybrid 3D-EnsVar analysis algorithm. It provides flow-dependent and situation dependent background error covariance information for meteorological variables including hydrometeors (i.e. cloud liquid, cloud ice, rain and snow). GMI observations from channels 3, 4, 5, 6, 8, 10, 11, 12, and 13 (19GHz ~ 183.3+/-7 GHz) are assimilated over ocean in the all-sky condition.

Impact Experiments

Figure 5. Improved Fit to MHS Observations

Sensor	Channel & Freq	assimilated data #	O-F RMS
N18 MHS	3 (183.3+/-1 GHz)	+0.7%	-0.3%
	4 (183.3+/-3GHz)	+0.8%	-0.5%
	5 (183.3+/-7GHz)	+0.8%	-0.5%
N19 MHS	3 (183.3+/-1 GHz)	+0.5%	+0.1%
	4 (183.3+/-3GHz)	+0.8%	+0.1%
	5 (183.3+/-7 GHz)	+0.7%	-0.4%
METOP-A MHS	3 (183.3+/-1 GHz)	+0.9%	+0.2 %
	4 (183.3+/-3 GHz)	+0.9 %	+0.2%
	5 (183.3+/-7 GHz)	+ 0.9 %	-0.1%

Figure 6. Improved Fit to AIRS Observations



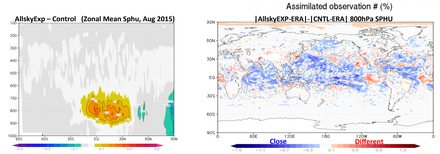


Figure 7. All-sky GMI radiance data assimilation increases lower tropospheric moisture near tropics in the analysis.

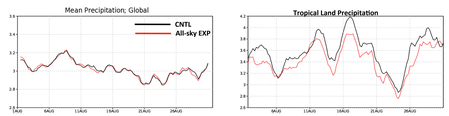
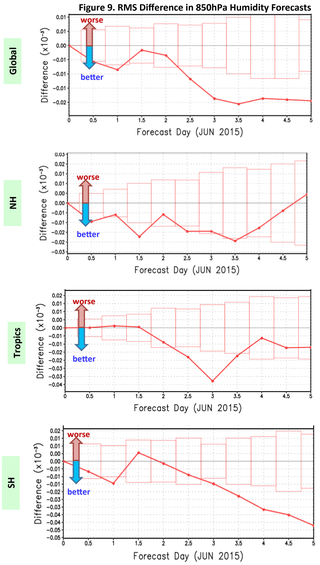


Figure 8. Global mean precipitation remains fairly consistent between Control (CNTL) and All-sky GMI experiment. However, tropical land precipitation in the All-sky Experiment was reduced relative to Control(good thing) .

Figure 9. RMS Difference in 850hPa Humidity Forecasts



Prototypes of GEOS-5 GMI Radiance Data Assimilation Products

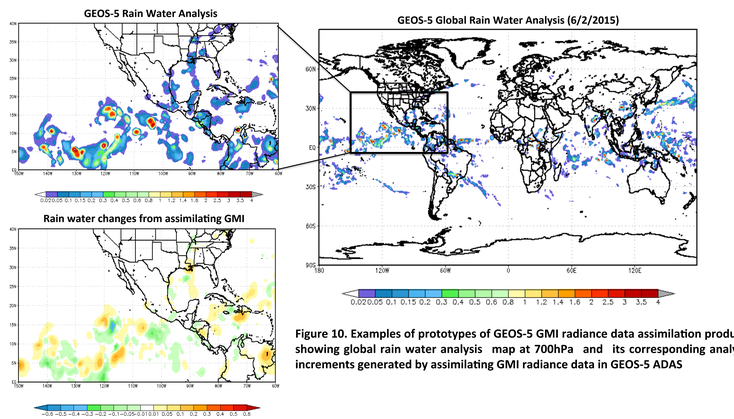


Figure 10. Examples of prototypes of GEOS-5 GMI radiance data assimilation products showing global rain water analysis map at 700hPa and its corresponding analysis increments generated by assimilating GMI radiance data in GEOS-5 ADAS

Latest Enhancements Added to GEOS-5 All-sky Microwave Radiance Data Assimilation System

• **Extension of the all-sky GMI radiance data assimilation algorithm from 3D-Ens Var GSI to 4D-EnsVar GSI** : This change will enhance the use of all-sky GMI radiance data through more frequent updates of flow dependent background error covariance.

• **Applying dynamic thinning distances**: Most of other satellite radiance data assimilated in GEOS-5 ADAS are thinned with 145 km thinning distance to avoid spatially correlated observation errors. Test results (not shown here) demonstrated that assimilating denser data with smaller thinning distance in storm regions resulted in improvements in storm track and intensity forecasts. Therefore, we included a scheme to decide the thinning distance flexible depending on the cloudiness. That is, smaller thinning distance is used for GMI radiance data in cloudy/precipitating regions and the original thinning distance (i.e.145km) is used for GMI radiance data in clear sky region.

• **Capability to assign larger weights for ensemble background error covariance for cloud and precipitation analysis variables:** Currently GEOS-5 ADAS assign weights 0.5 for static background error covariance and 0.5 for ensemble background error covariance for all analysis variables in its hybrid 3D-Ens Var analysis algorithm. However, static background error covariance calculated with NMC method for cloud and precipitation variables do not bring enough information on highly situation dependent and nonlinear characteristics of cloud/ precipitation background error distributions. Therefore, we've added a capability to assign different weights for ensemble background error covariance and static (climatology) background error covariance of hydrometeor variables while keeping original weights for all other analysis variables such as air temperature, humidity, wind, and surface pressure.

Assimilating GMI Radiance Data over Land

• All-sky GMI radiance assimilation over land requires several advancements beyond the existing ocean all-sky methodology. The most critical, yet challenging aspect of land assimilation is properly assigning contributions from the various surface variables in the radiative transfer model. The land surface is highly heterogeneous, and key properties affecting microwave emission such as soil moisture, vegetaion, skin temperature and surface roughness are all highly variable. Moreover, these surface signatures can be easily confused with precipitation signals, especially for low microwave frequency channels.

• Currently, the GEOS5-5 ADAS utilize the built-in the Community Radiative Transfer Model (CRTM) icrowave surface emissivity model to compute the surface emissivity to use in RT solver in CRTM in computing satellite radiances..

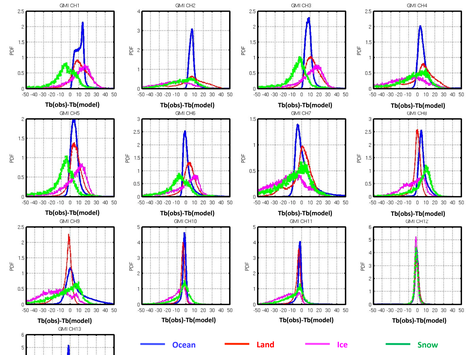


Figure 11: Differences between GMI brightness temperature observations and GMI TB calculated with GEOS-5 short-term forecasts (first-guess) using CRTM model and its built-in CRTM microwave emissivity model.

Employing Microwave Land Surface Emissivity Retrievals in GSI

• Land surface emissivity at microwave frequencies are vary in a complex way with surface types, roughness, and moisture among other parameters.

• Efforts to estimate (retrieve) microwave surface emissivities using channels not assimilated yet frequency close to the frequencies that are assimilated.

• A method developed by Karbou (2007) and currently being utilized in ECMWF (Krzeminiski and Bormann 2016; Baordo et al. 2015) for AMSU-A, MHS, SSMIS data is currently being tested in GSI to improve GMI, AMSU-A, and MHS data assimilation over land.

$$\varepsilon = \frac{Tobs - T^{\uparrow} - T^{\downarrow}\Gamma}{(Tskin - T^{\downarrow})\Gamma}$$

• T: CRTM provided atmospheric contribution to the measured Tobs. (in radiance)
• Tskin: bkg skin temperature (in radiance)
• Γ : CRTM provided net atmospheric transmittance

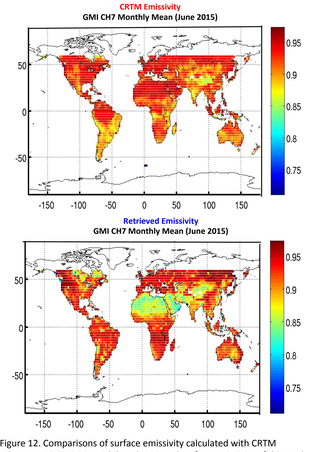


Figure 12. Comparisons of surface emissivity calculated with CRTM Microwave Emissivity Model and retrieved surface emissivity of this study