



GPM Microwave Imager Radiance Data Assimilation to Improve GEOS Global Analyses and Forecasts of Clouds and Precipitation

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^{1,3}Amal El Akkraoui, ^{1,3}Wei Gu, ^{1,2}Dan Holdaway, and ¹Ron Gelaro

1. NASA Global Modeling and Assimilation Office (GMAO)
2. GESTAR
3. SSAI



Outline

- Motivation and objectives of assimilating all-sky GMI radiance data
- Goddard Earth Observing System (GEOS) model
- GEOS Atmospheric Data Assimilation System (ADAS) and framework to assimilate GMI data
- Impacts of GMI data assimilation on GEOS analyses and forecasts
- Prototype of GMI radiance assimilated global atmospheric and surface analysis products
- Work in progress



Motivation

- Large numbers of radiance data contain cloud and precipitation signal, and these are currently discarded through quality control processes in the atmospheric data assimilation system.
- Microwave imagery from satellites can be a significant source of information for clouds and precipitation.
- Extending radiance data usage to gain more information on atmospheric states in cloudy region that can be beneficial to improve severe weather forecasts.



Objectives

- 1) To develop required components to assimilate all-sky GMI radiance data in GEOS system
- 2) To examine impacts of GMI data assimilation on NWP forecasts including severe weather forecasts
- 3) To produce prototype of all-sky GMI data assimilated GEOS Global Atmospheric and Surface Analysis Products

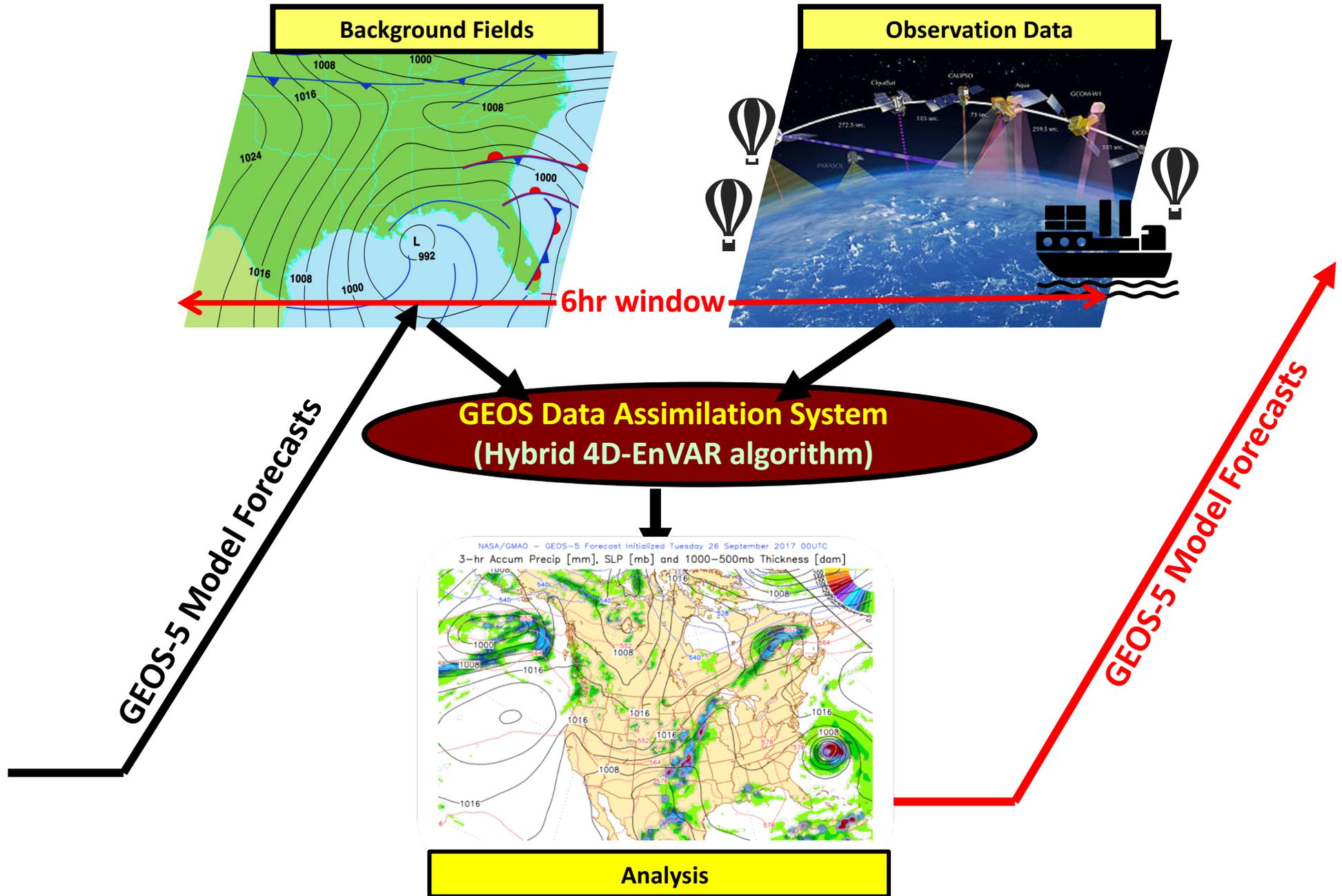


Goddard Earth Observing System (GEOS)

- The GEOS systems are being developed in the GMAO to support NASA's earth science research in data analysis, observing system modeling and design, climate and weather prediction, and basic research.
- The GEOS-5 system consists of a group of model components such as
 - Atmospheric General Circulation Model (AGCM),
 - Ocean General Circulation Model (OGCM),
 - Chemistry-Climate Model (CCM),
 - Chemistry Transport Model (CTM).

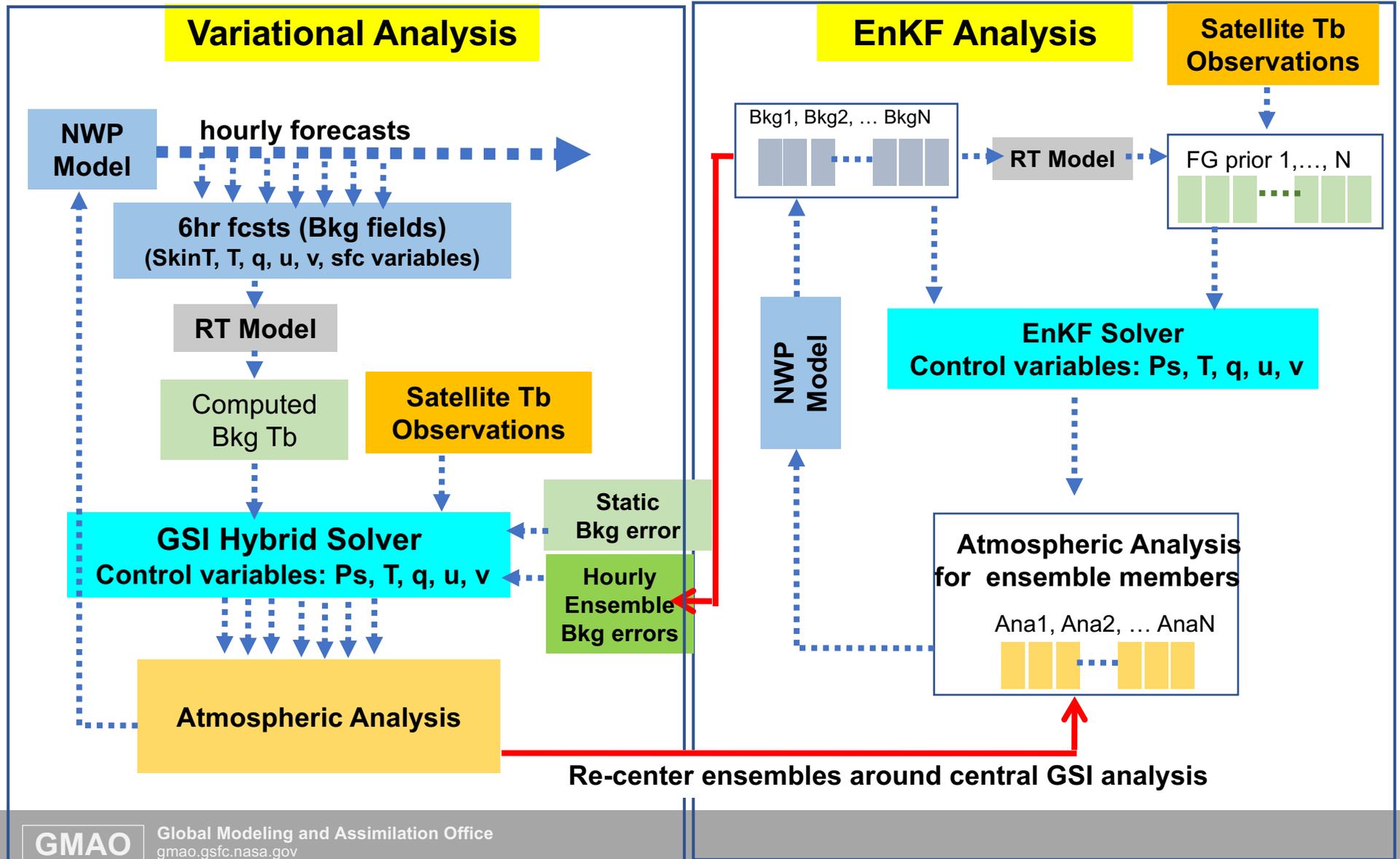
Note: The AGCM is the predictive model components for the atmosphere and land. Catchment Land Model includes explicit treatment of the spatial variation within each hydrological catchment of the soil water and water table depth, as well as its effect on runoff and evaporation. It also includes a multi-layer global snow model.

Atmospheric Data Assimilation System in GEOS



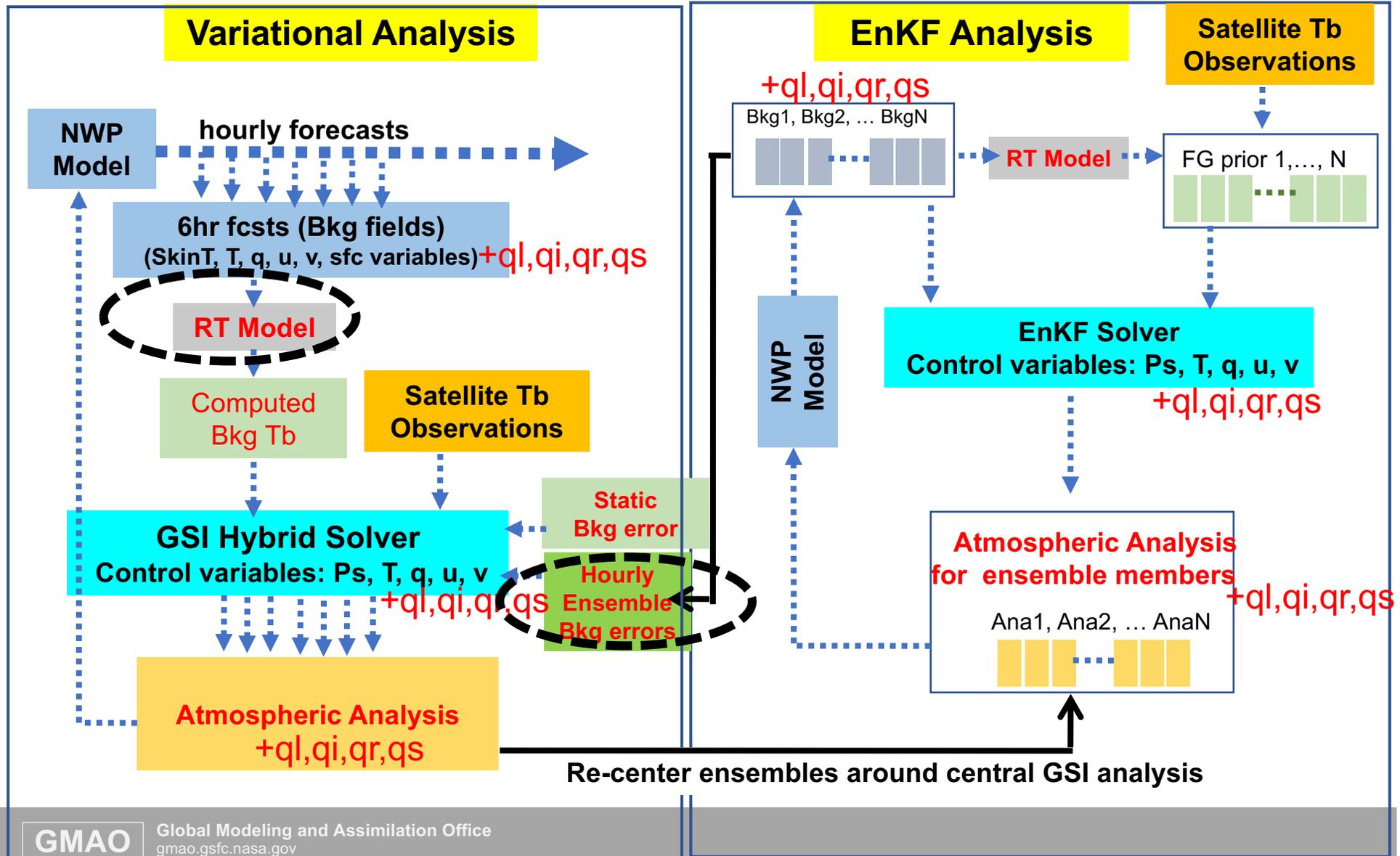


Hybrid 4D-EnVar Data Assimilation System



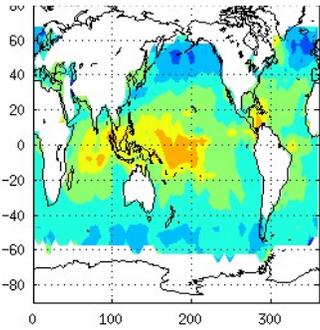


From Clear radiance DA to **All-sky** radiance DA

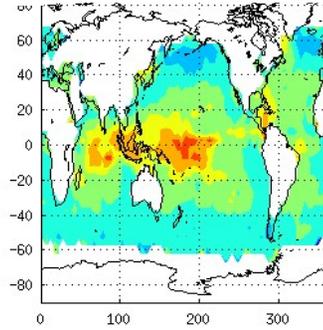


Monthly Mean of $TB_{obs} - TB_{model}$: GMI CH10

CRTM 2.2.3(MIE,
reff=500 μ m)

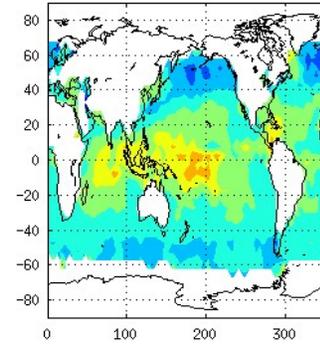


CRTM 2.2.3 (DDA,
reff=500 μ m)

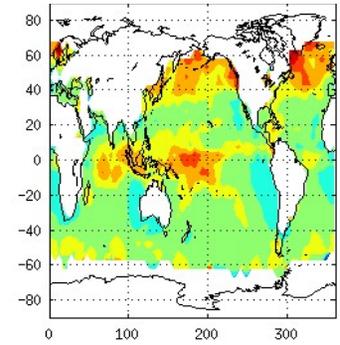


DDA :
Liu(2008)

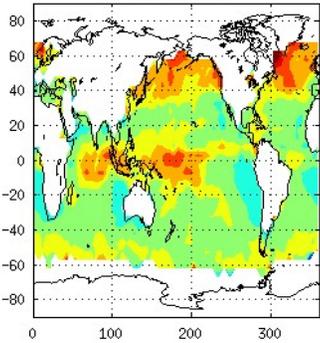
Soft Sphere



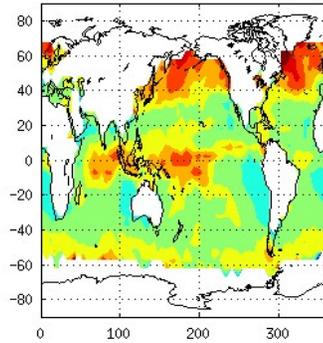
Long column



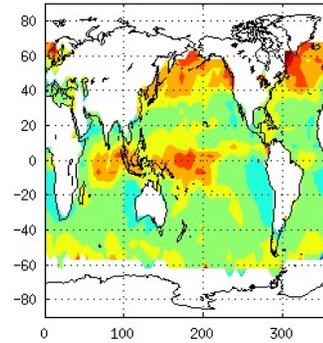
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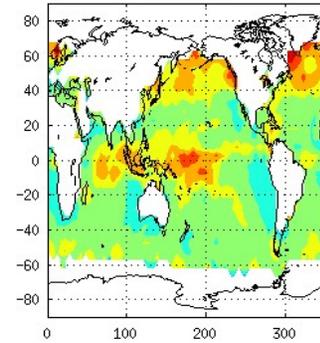
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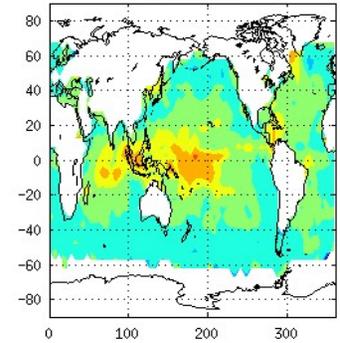
Thick Plate



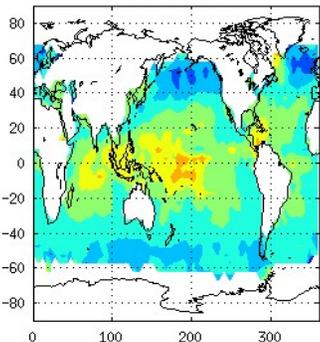
Thin Plate



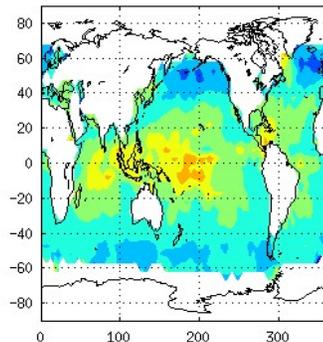
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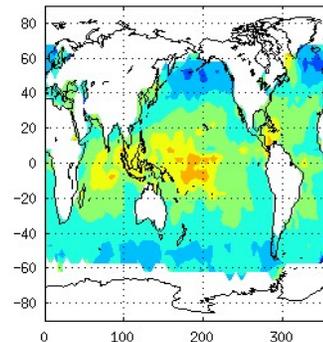
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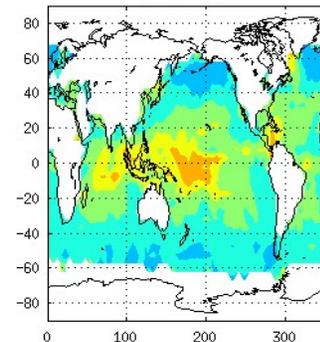
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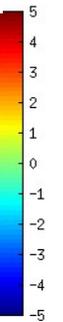
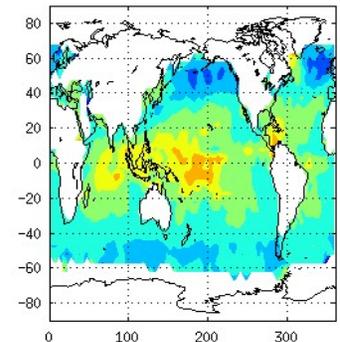
6-bullet



Sector Snowflake

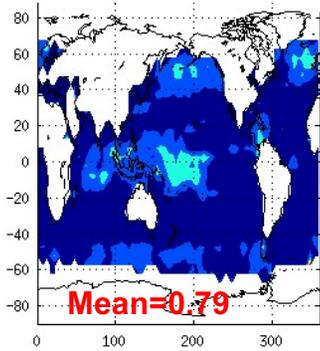


Dendrite

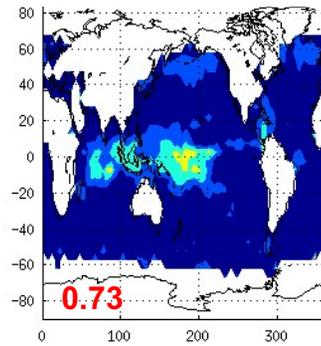


Monthly RMS of $TB_{obs} - TB_{model}$: GMI CH10

CRTM 2.2.3(MIE,
reff=500 μ m)

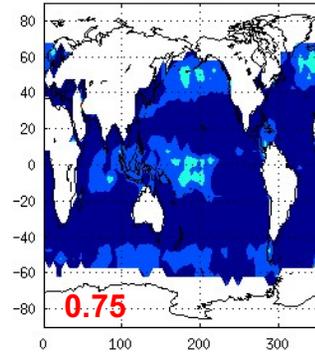


CRTM 2.2.3 (DDA,
reff=500 μ m)

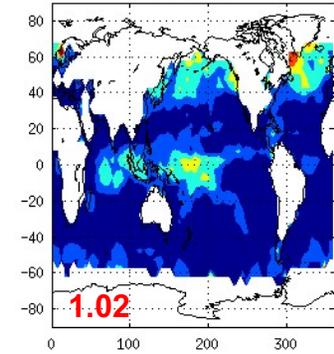


DDA :
Liu(2008)

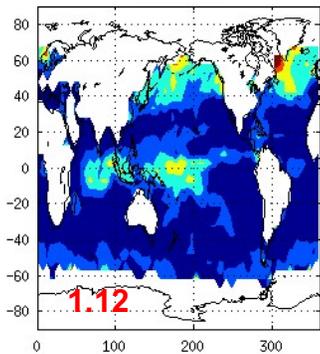
Soft Sphere



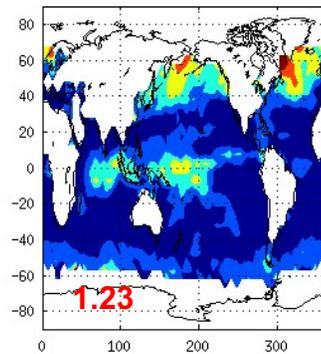
Long column



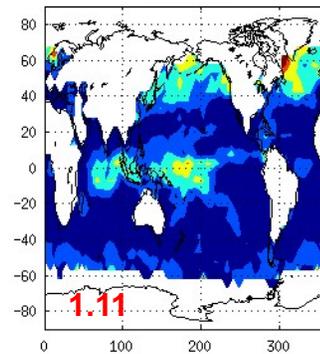
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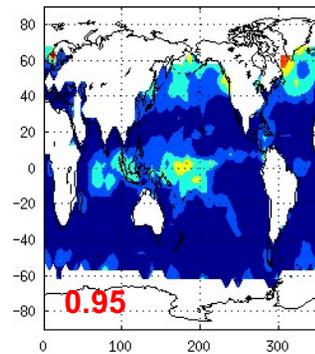
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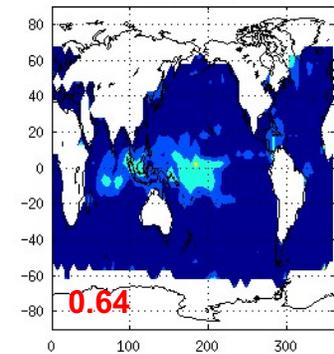
Thick Plate



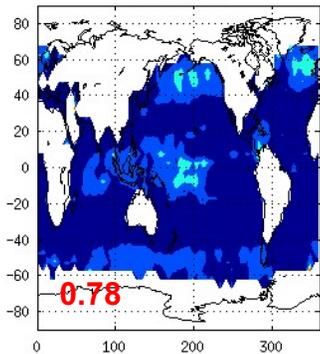
Thin Plate



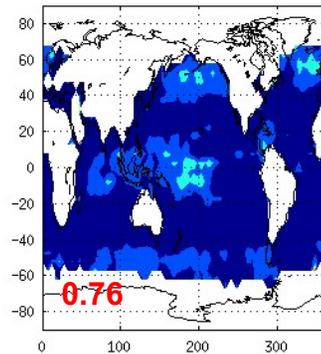
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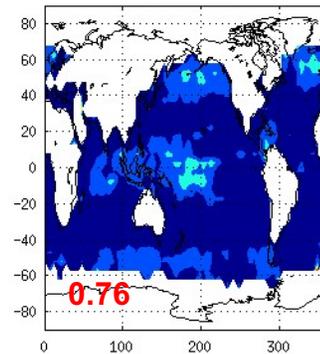
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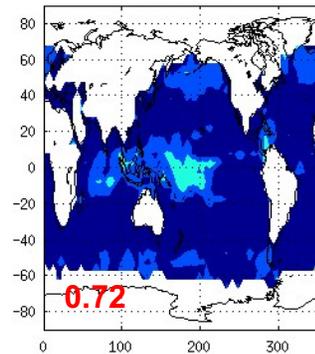
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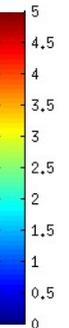
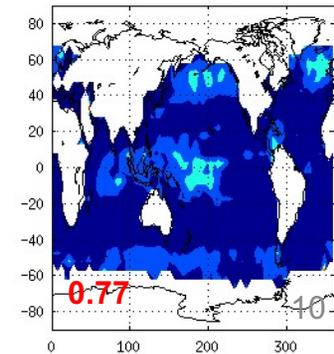
6-bullet



Sector Snowflake



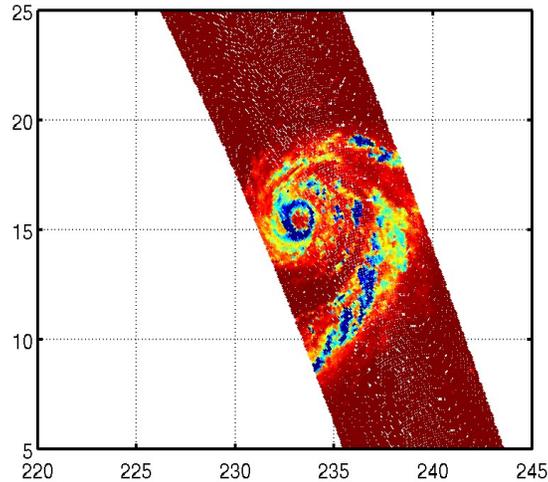
Dendrite



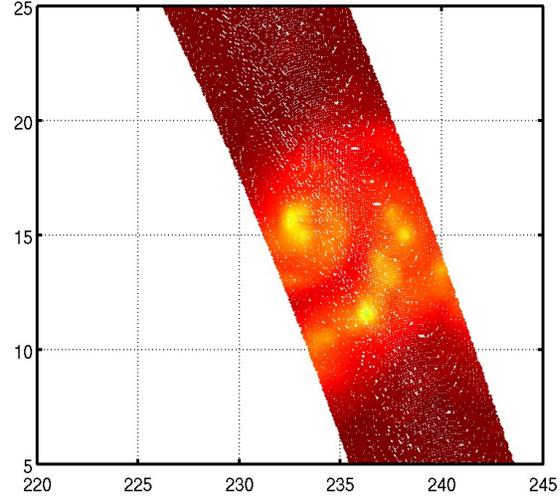


Comparisons of Simulated GMI TBs

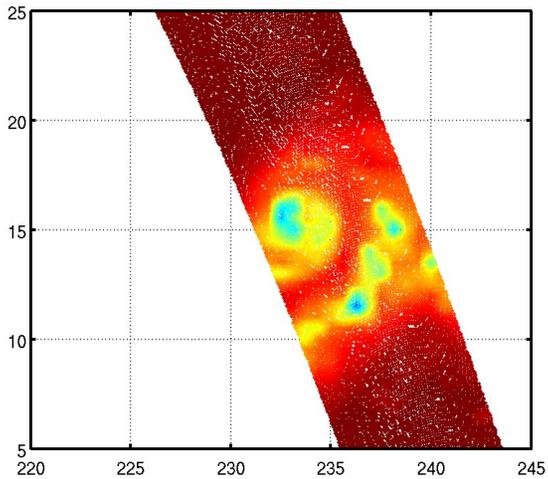
Observation: GMI 166 GHzV TB



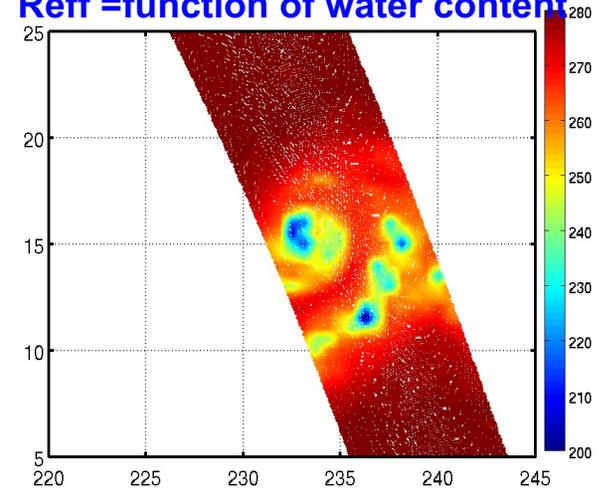
Simulation: CRTM V2.2.3 CloudCoef (Mie)



Simulation: CRTM V2.2.3 CloudCoef (DDA)
Reff= 1000 μ m



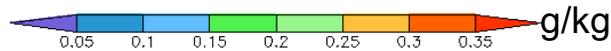
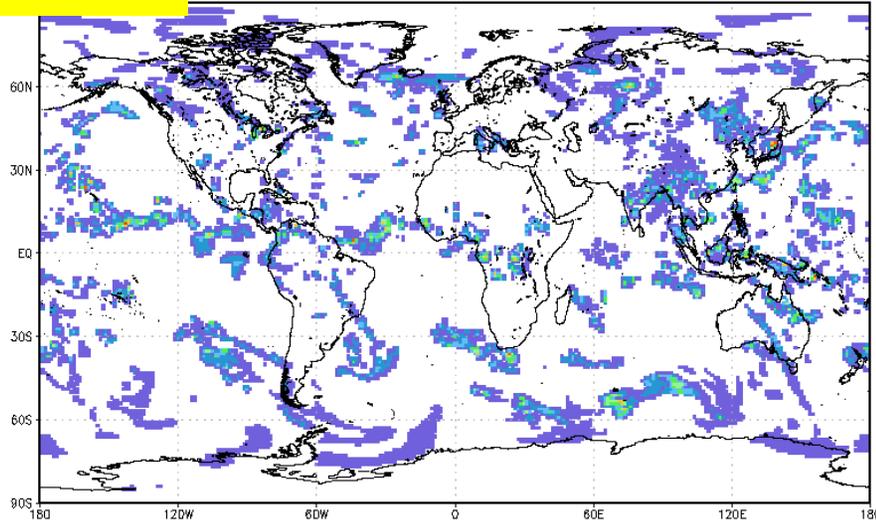
Simulation: 3-bullet (DDA)
Reff =function of water content



Background Errors

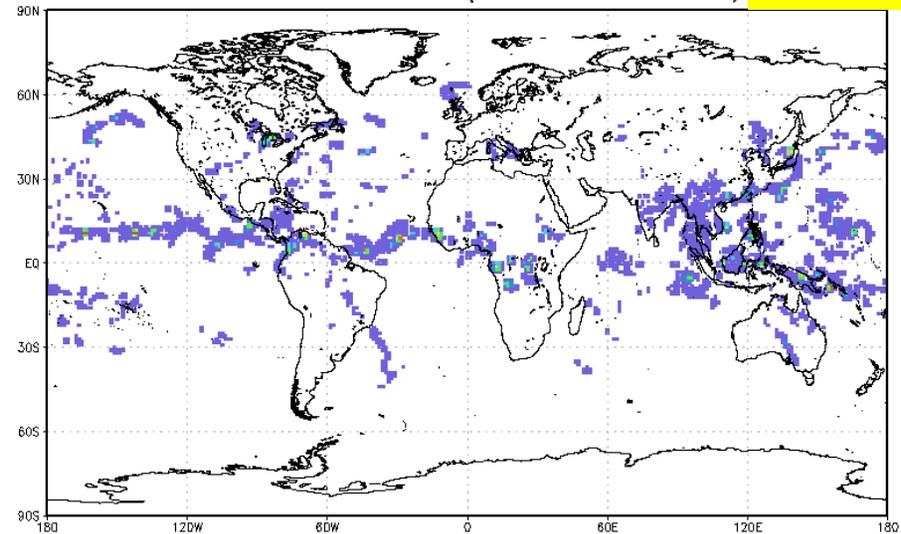
Cloud
Liquid
Water

700 hPa CLW (Ensemble mem001)



Rain
Water

700 hPa Rainwater (Ensemble mem001)



09/08/2016 06UTC

- 32 ensemble members from NASA GMAO's GEOS-5 system
- Horizontal: 0.5 deg (Ensemble member forecasts)
12.5 km (central GEOS forecasts)
- Vertical: 72-levels

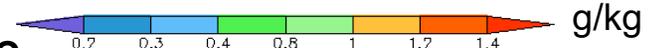
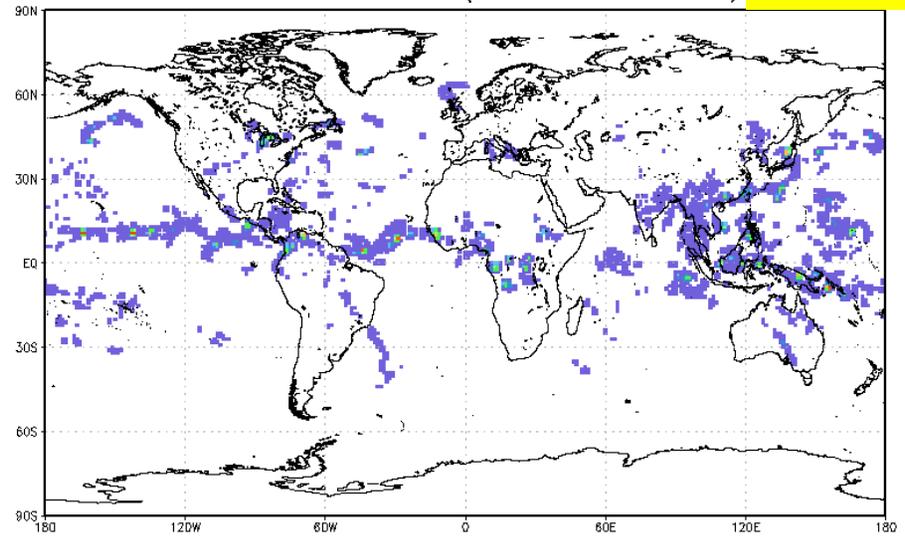
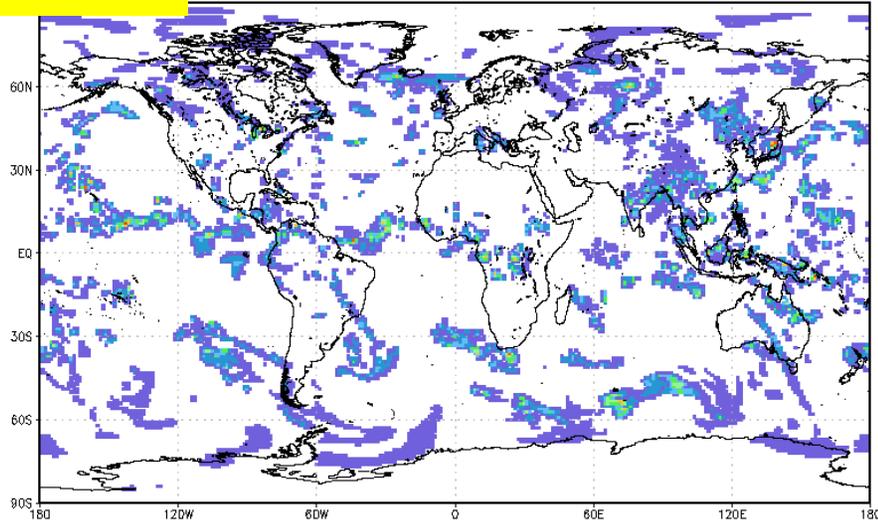
Cloud
Liquid
Water

Background Errors

Rain
Water

700 hPa CLW (Ensemble mem001)

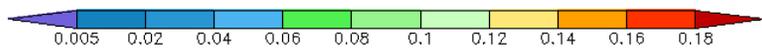
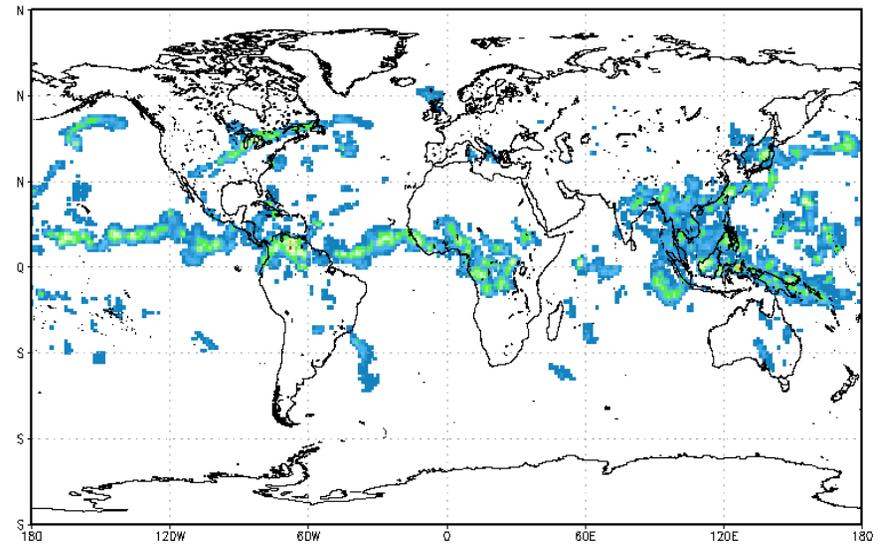
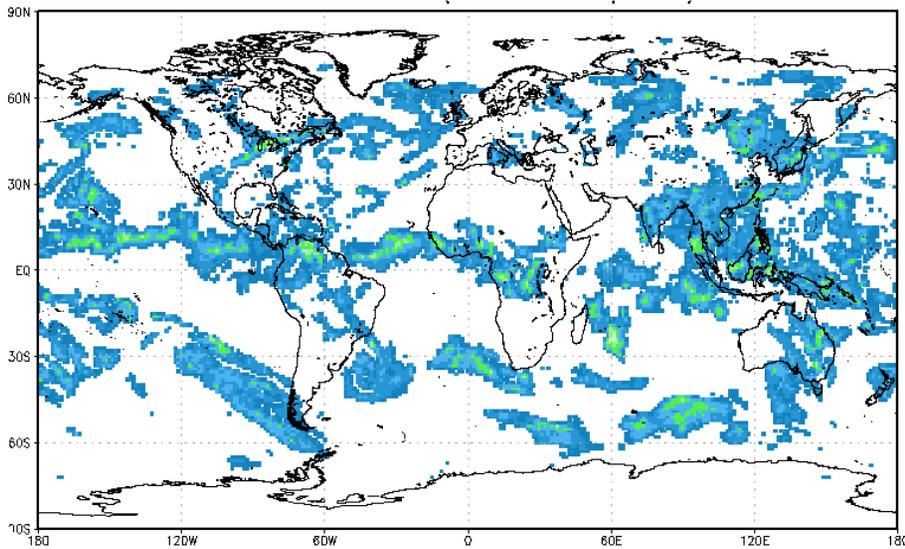
700 hPa Rainwater (Ensemble mem001)



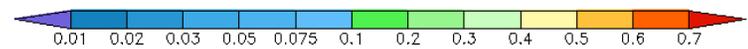
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STD of Cloud Liquid at 700 hPa

STD of Rain Water at 700 hPa



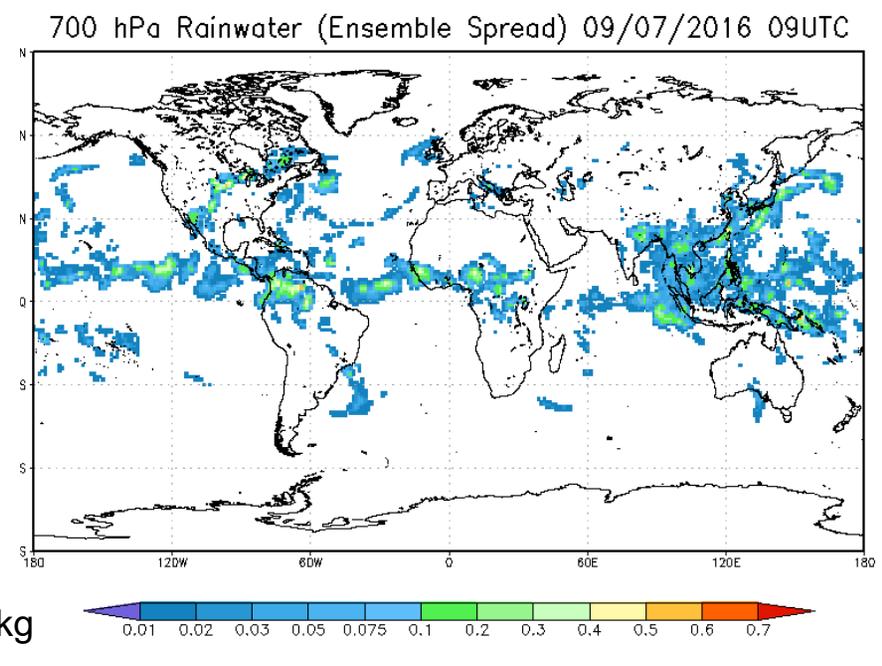
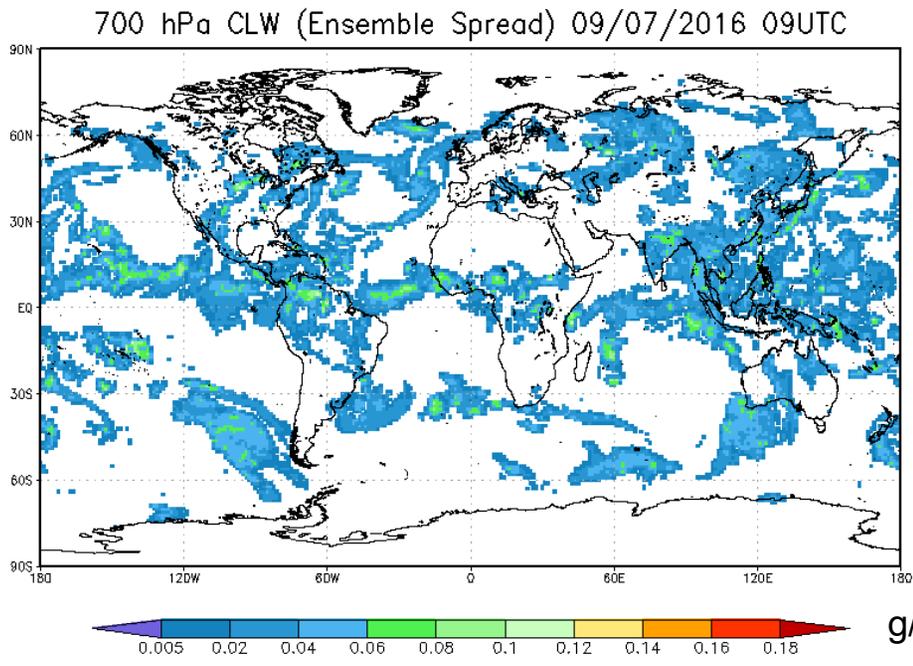
g/kg



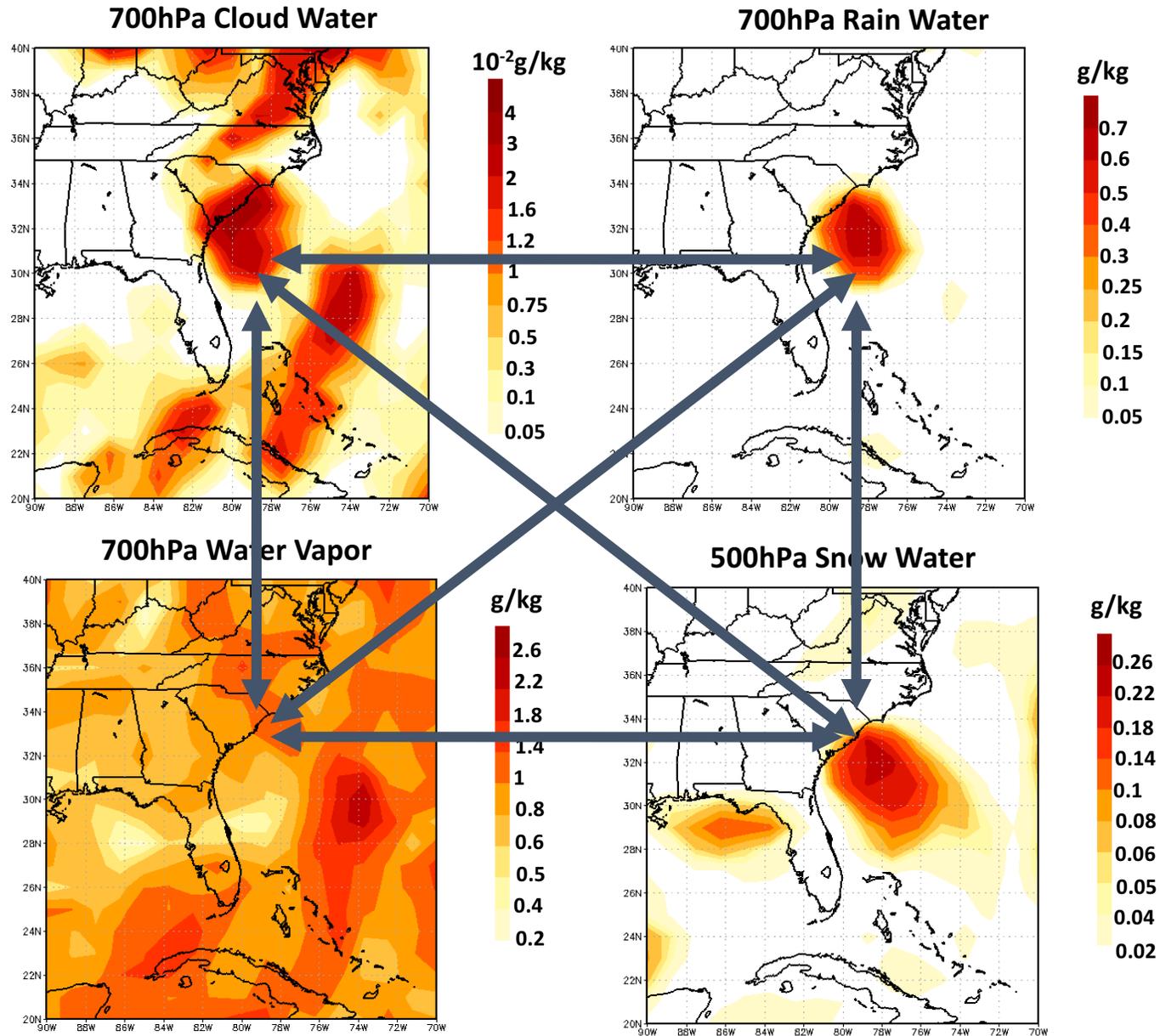
Background Errors



Hybrid 4D-EnVar Atmospheric Data Assimilation System
: Flow dependent background errors changing with time



Correlated Background Errors between Variables





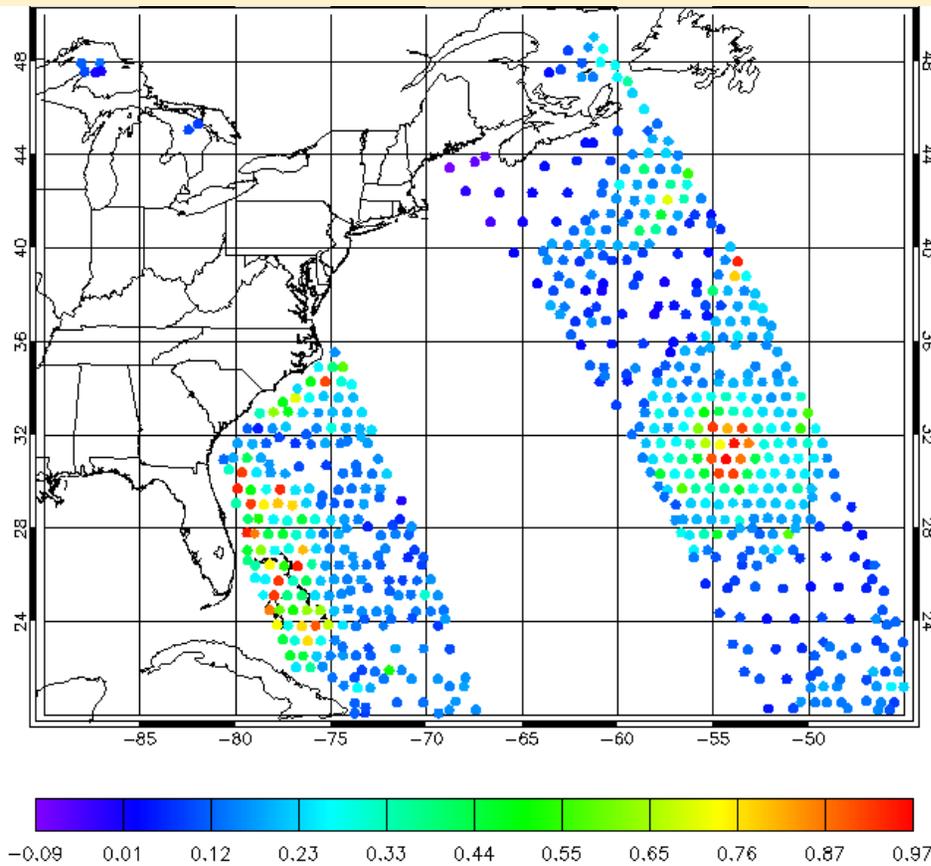
For more details on the GMI all-sky Tb data assimilation methodology including observation error, quality Control, bias correction, moisture control variables, and thinning thinning, please visit [poster #247](#) this afternoon.



Impacts of All-sky GMI Data Assimilation

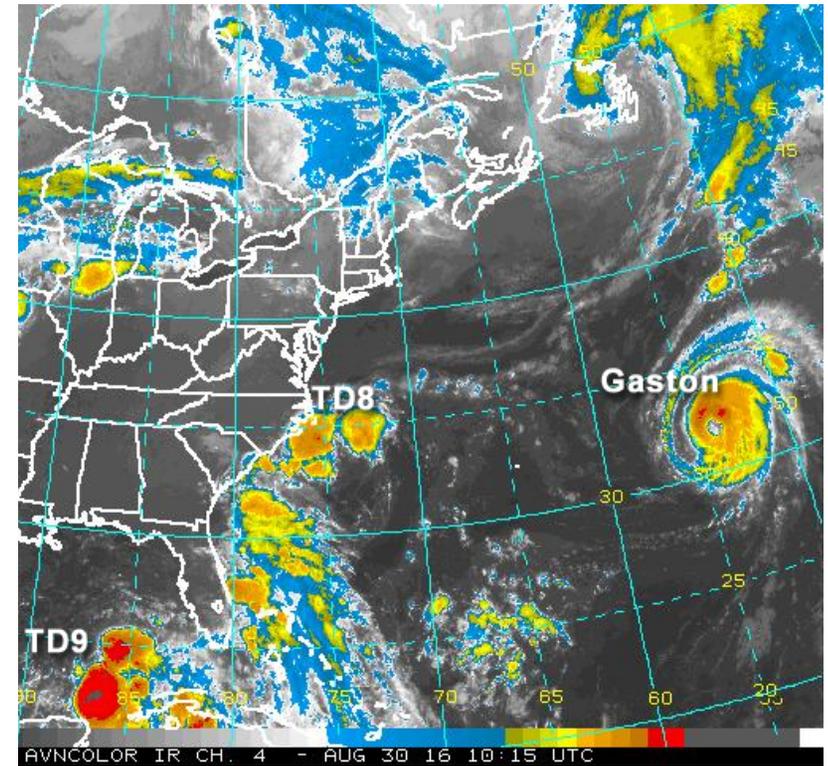
Case Study: Hurricane Gaston (2016)

GMI Observations
(1-Normalized 37 GHz TB polarization difference)



08/30/2016 0300 UTC~0900 UTC

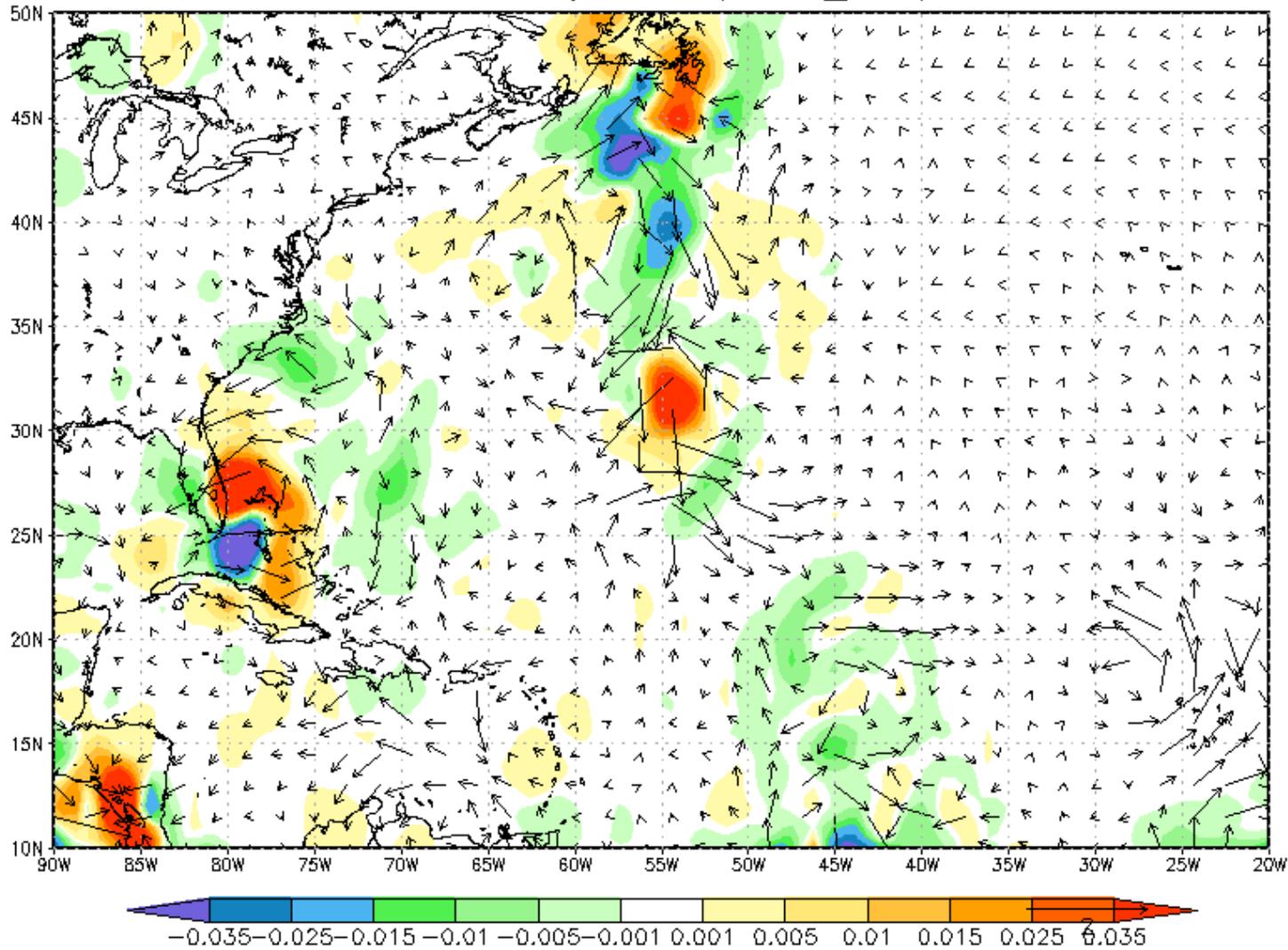
GOES IR





Analysis Changes by All-sky GMI data

850hPa qr,wind (0830_03z)



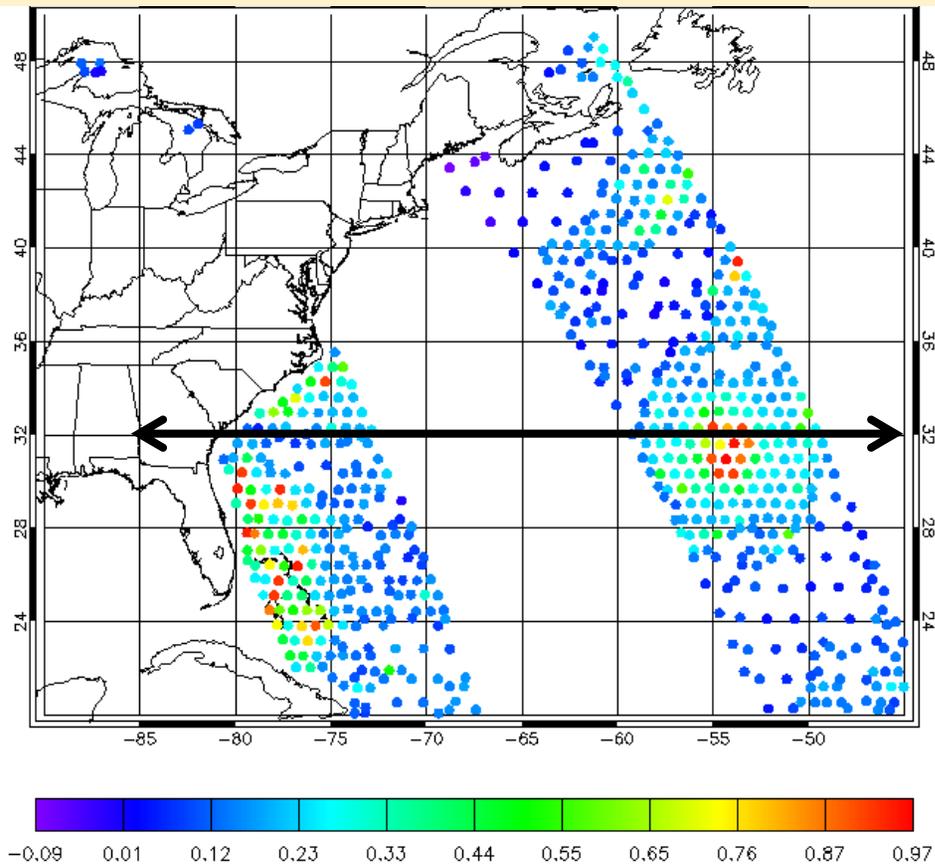
GMI radiance data from channels 3, 5, 6, 7, 10, 12, and 13 are assimilated.



Examine Impacts from Different GMI Channels

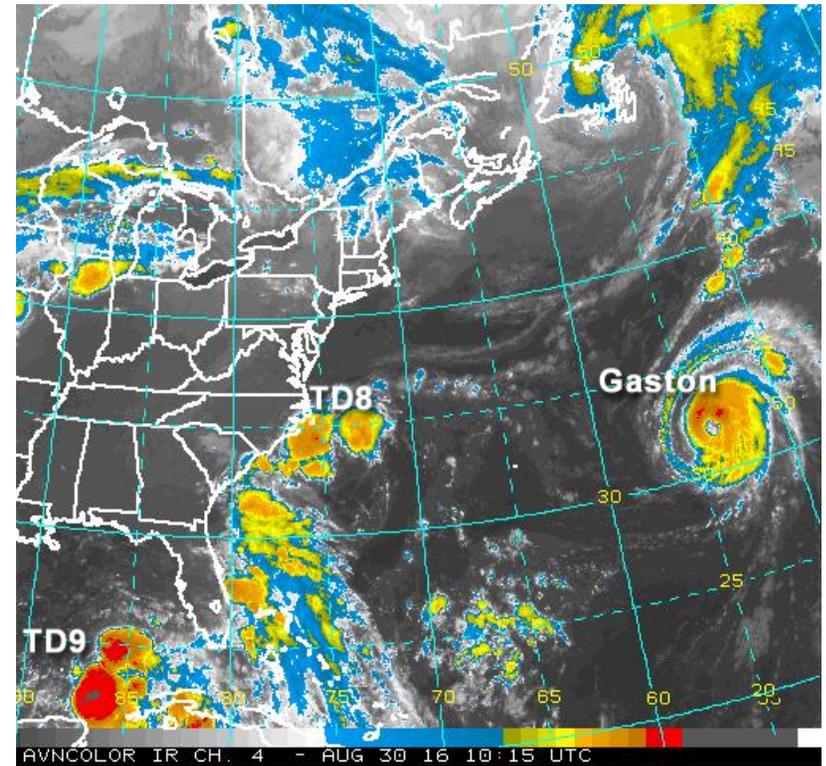
Case Study: Hurricane Gaston (2016)

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08/30/2016 0300 UTC~0900 UTC

GOES IR

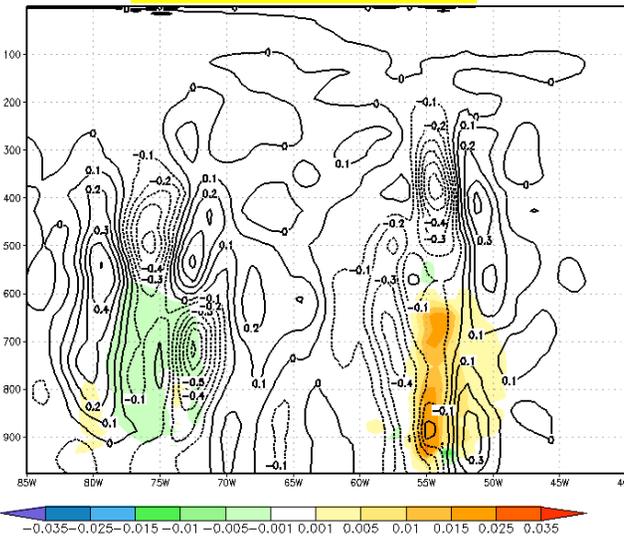


Impacts from Different GMI Channels

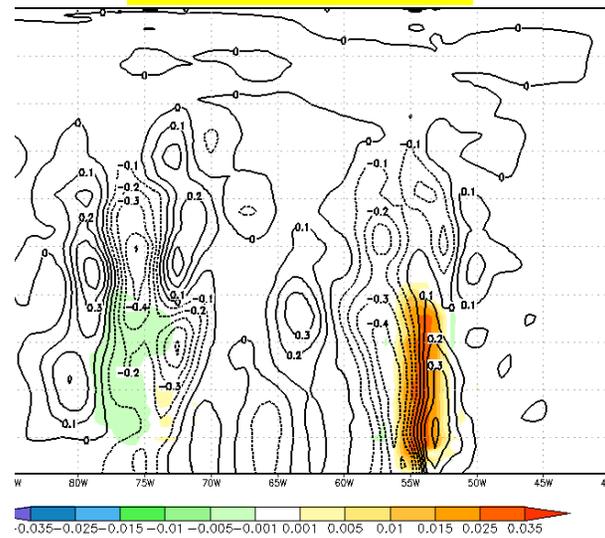
Color: Rain water changes in analysis (g/kg)

Contour: V-wind changes in analysis (m/s)

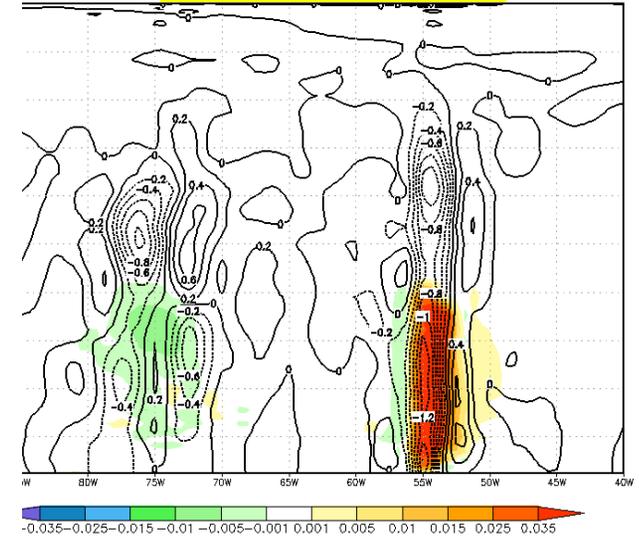
CH 3



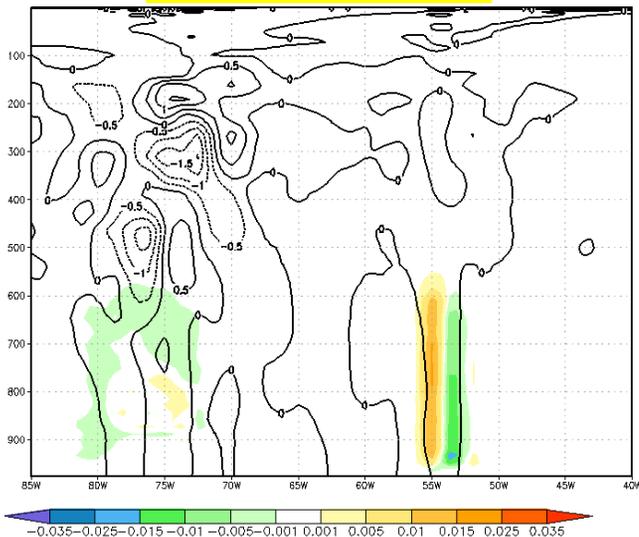
CH 5



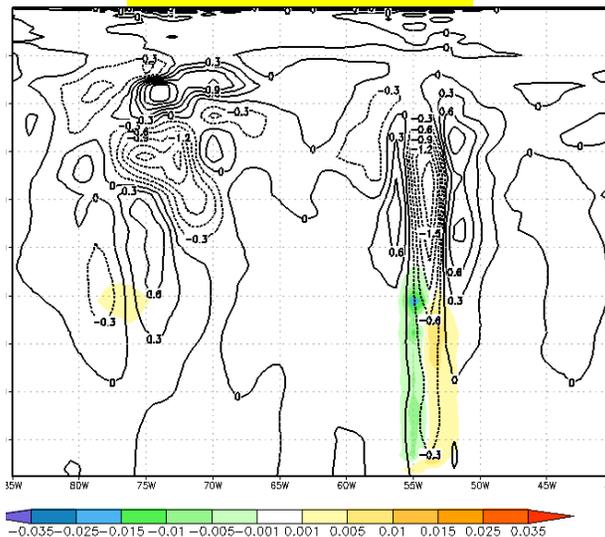
CH 6



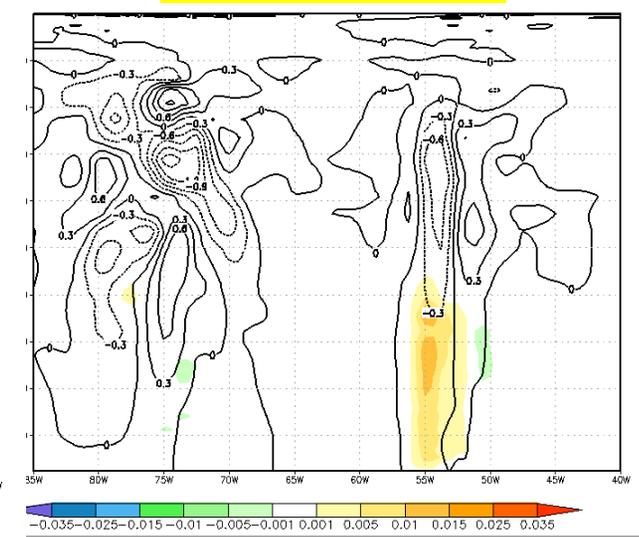
CH 10



CH 12



CH 13

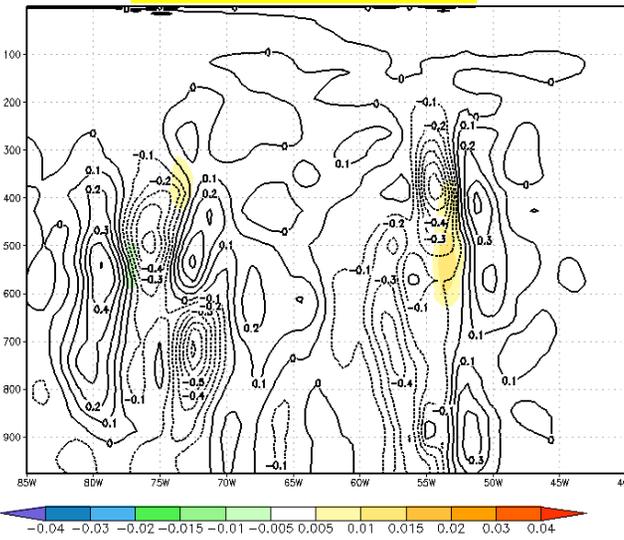


Impacts from Different GMI Channels

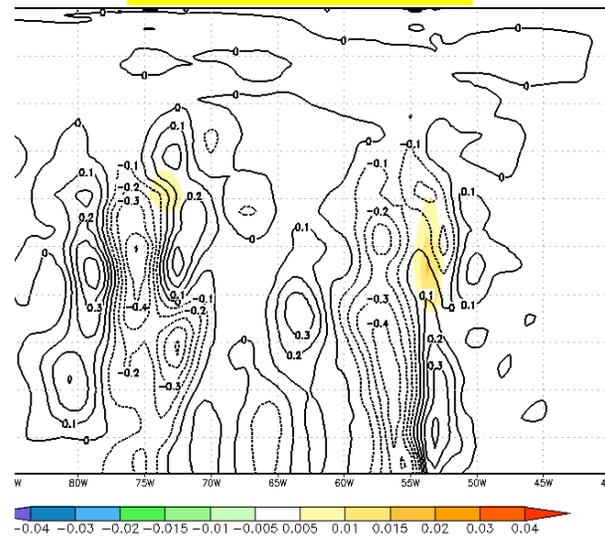
Color: Snow water changes in analysis (g/kg)

Contour: V-wind changes in analysis (m/s)

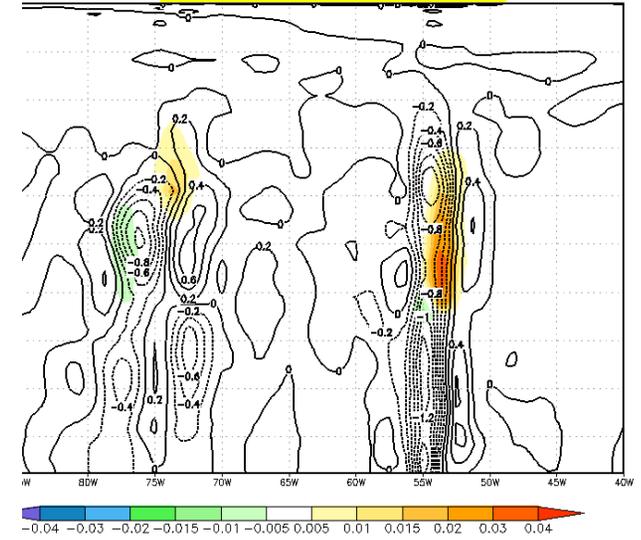
CH 3



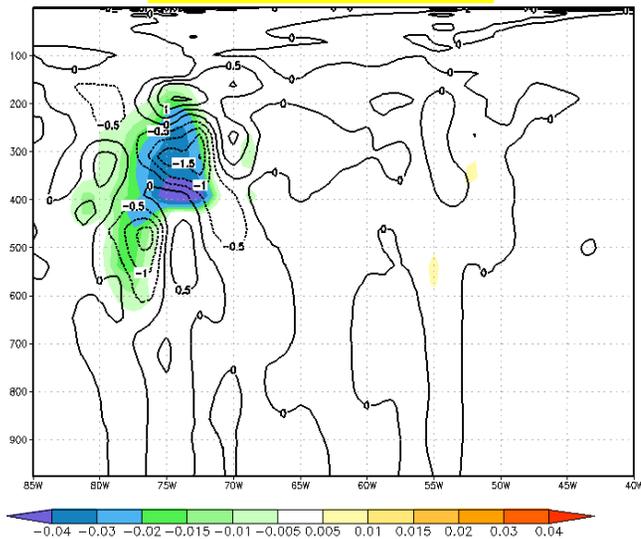
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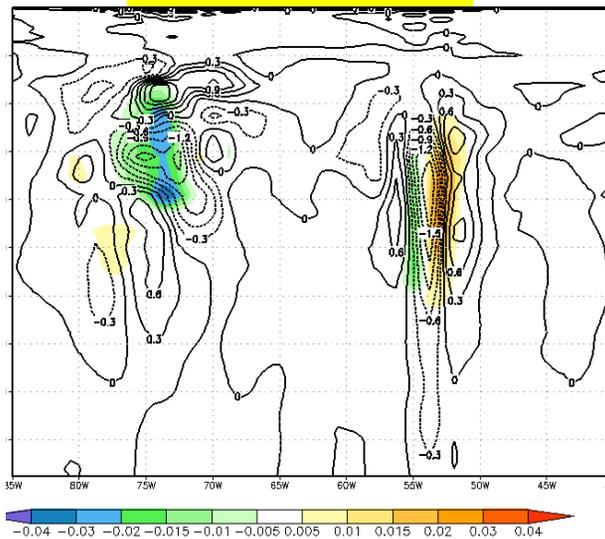
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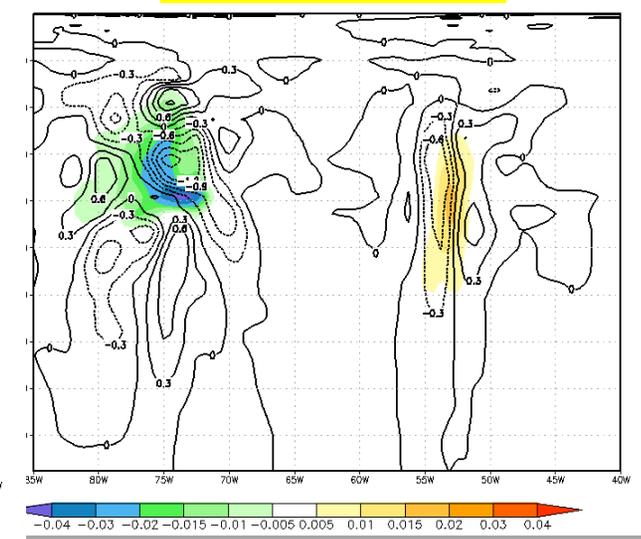
CH 10



CH 12



CH 13

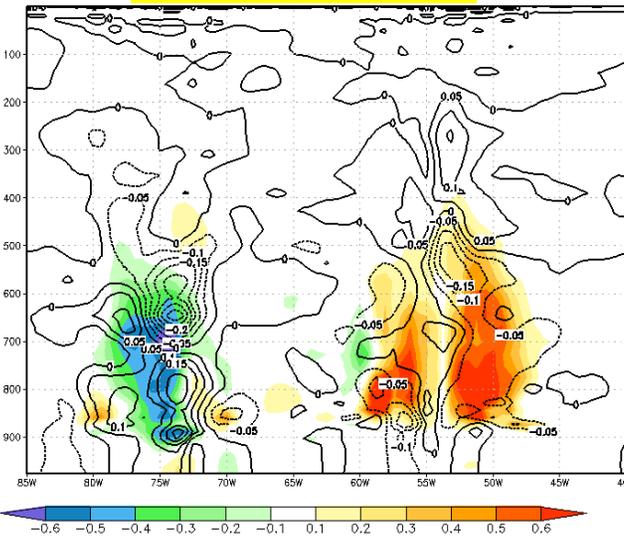


Impacts from Different GMI Channels

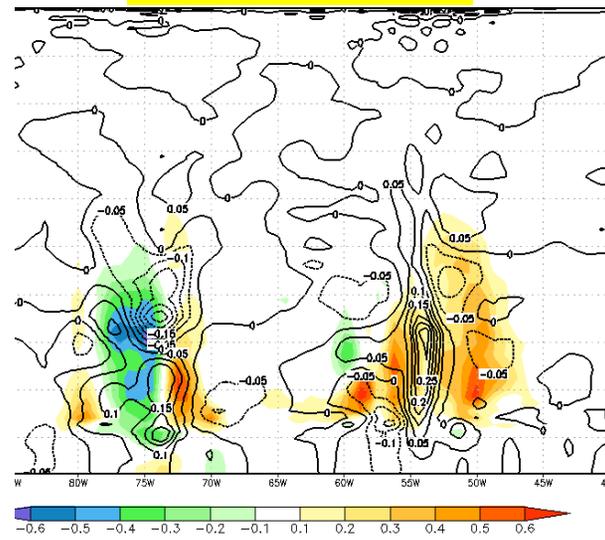
Color: Water vapor changes in analysis (g/kg)

Contour: Virtual Temperature changes in analysis (m/s)

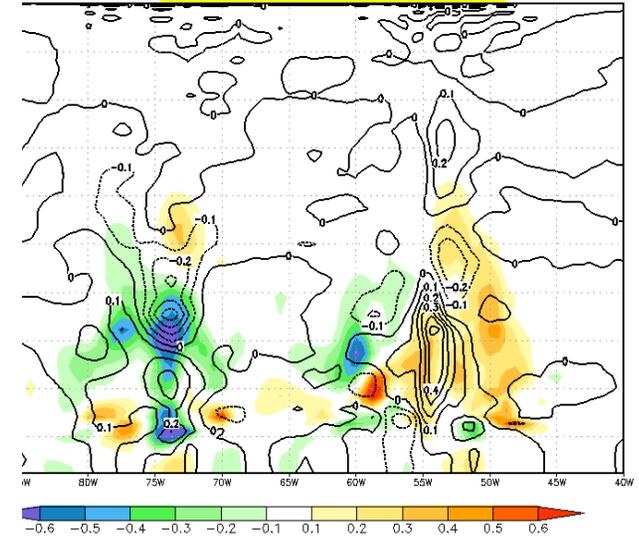
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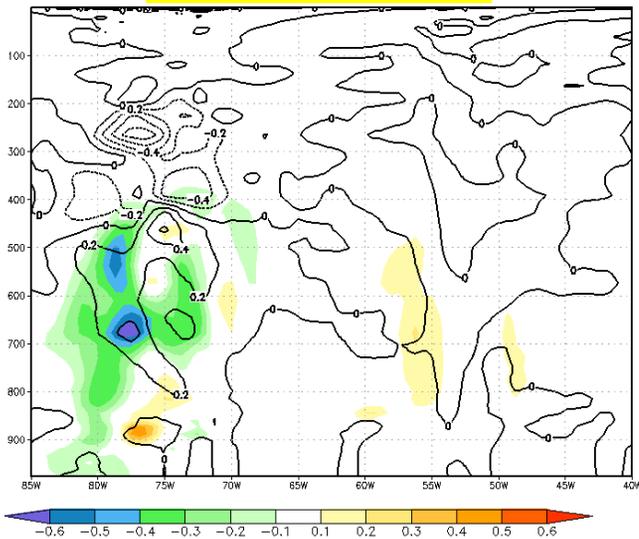
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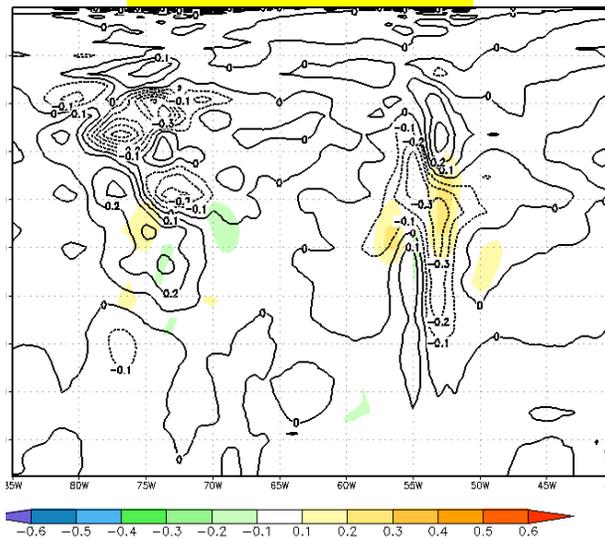
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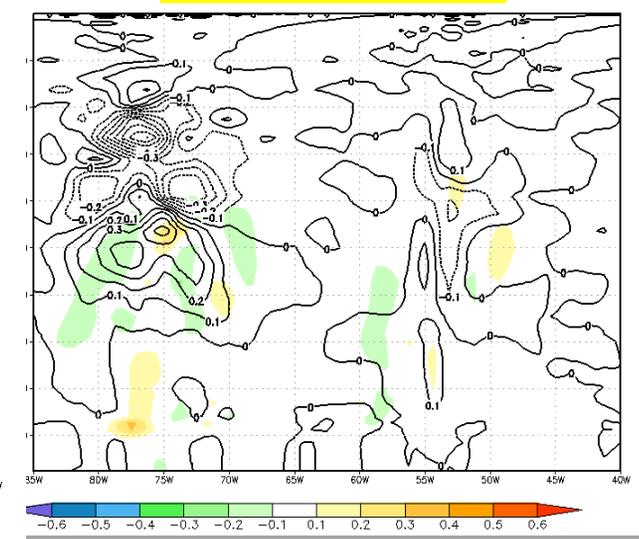
CH 10



CH 12



CH 13

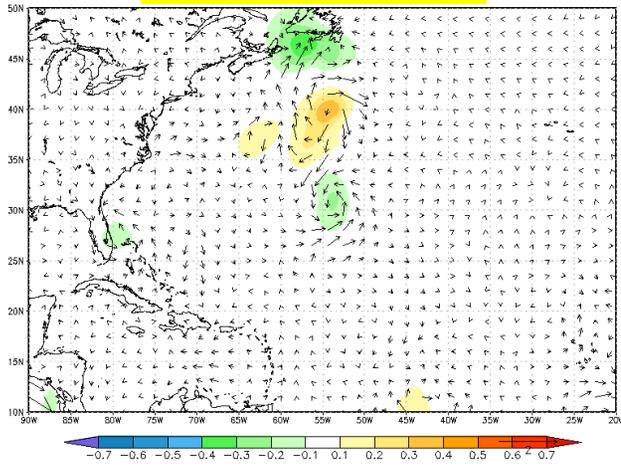


Impacts from Different GMI Channels

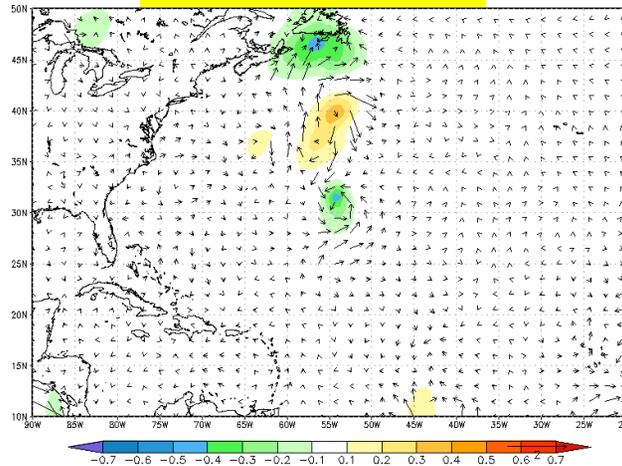
Color: Surface pressure change in analysis (hPa)

Contour: Surface wind changes in analysis (→ 2 m/s)

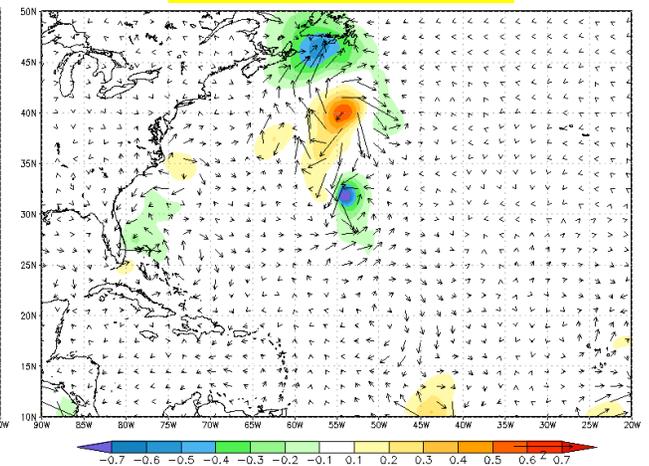
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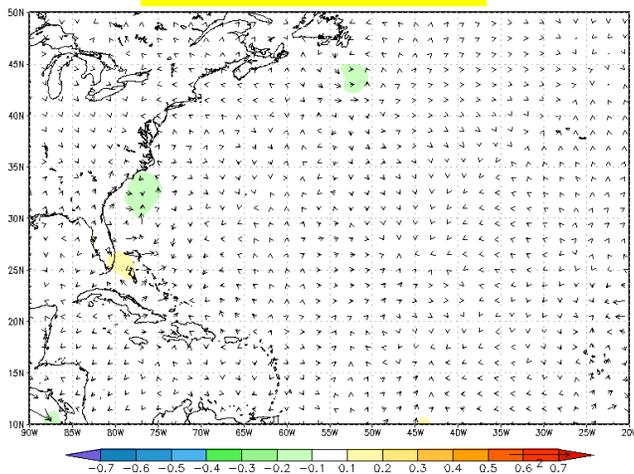
CH 5



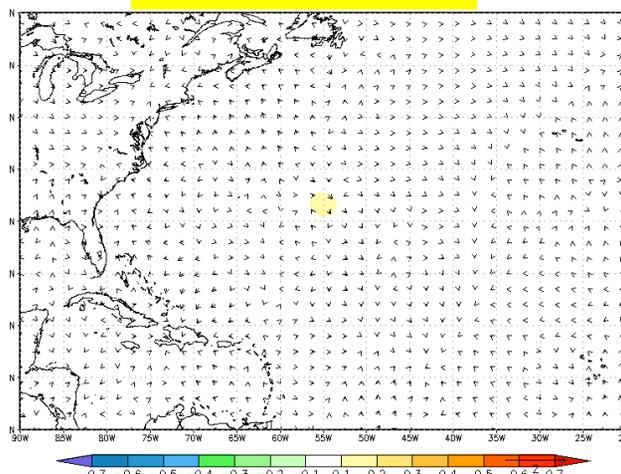
CH 6



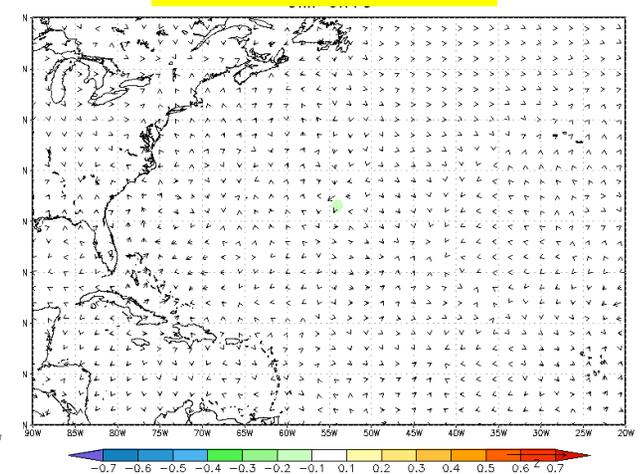
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CH 12

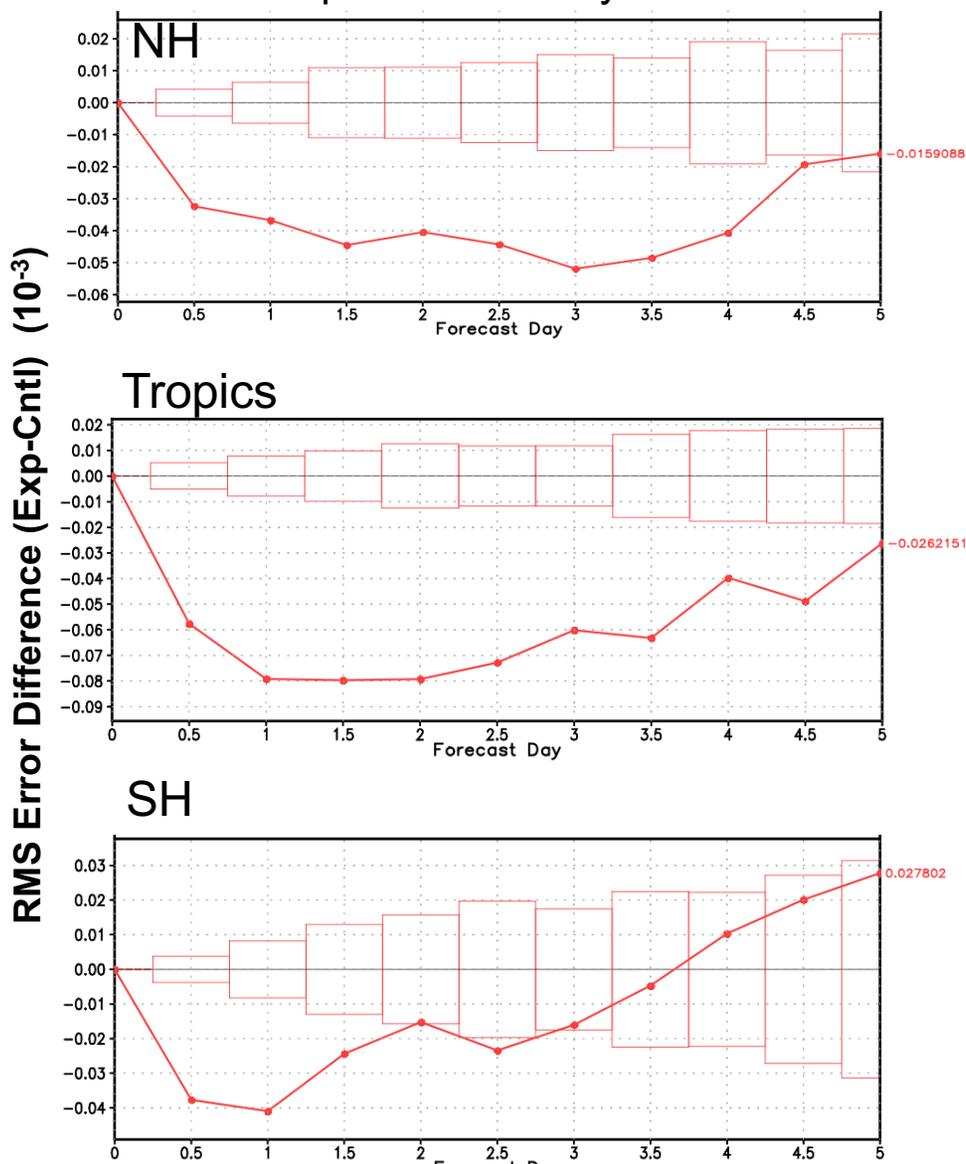


CH 13

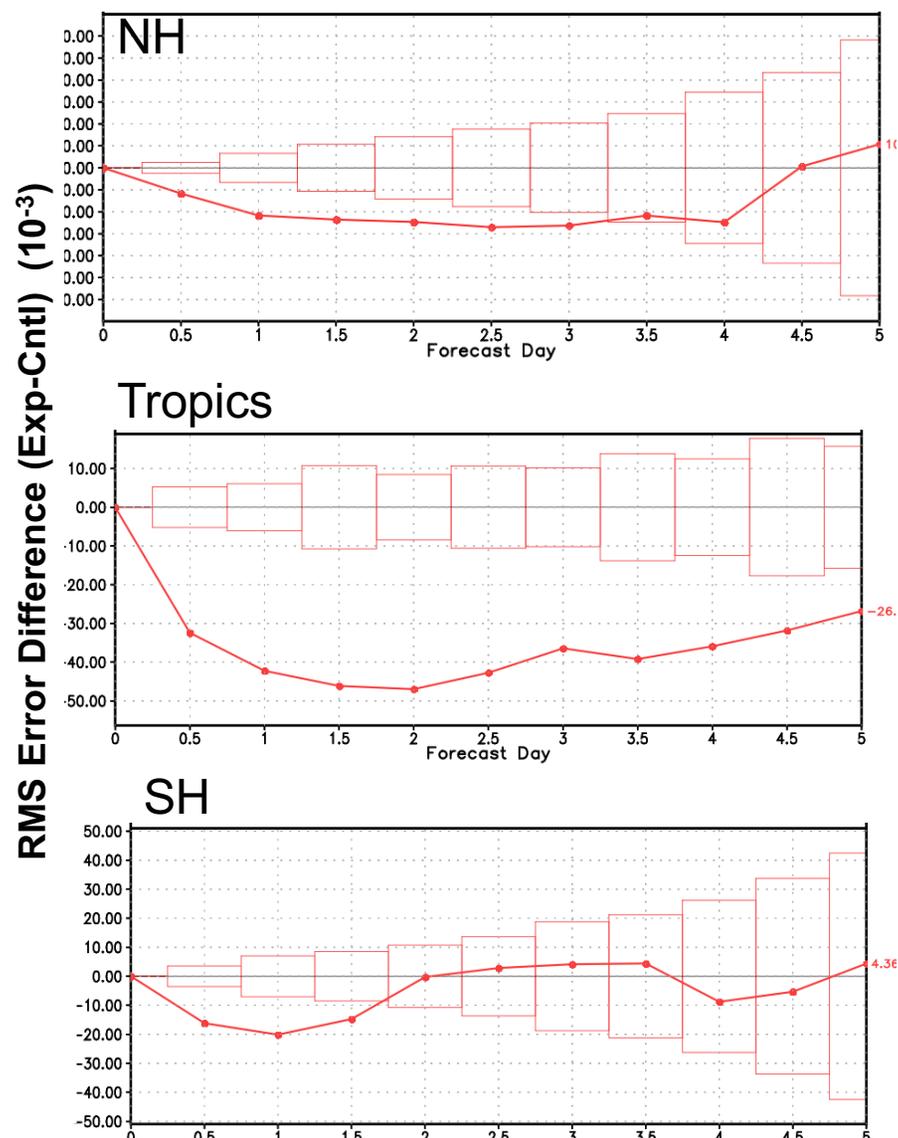


Impacts on GEOS Forecasts

850hPa Specific Humidity RMS Error



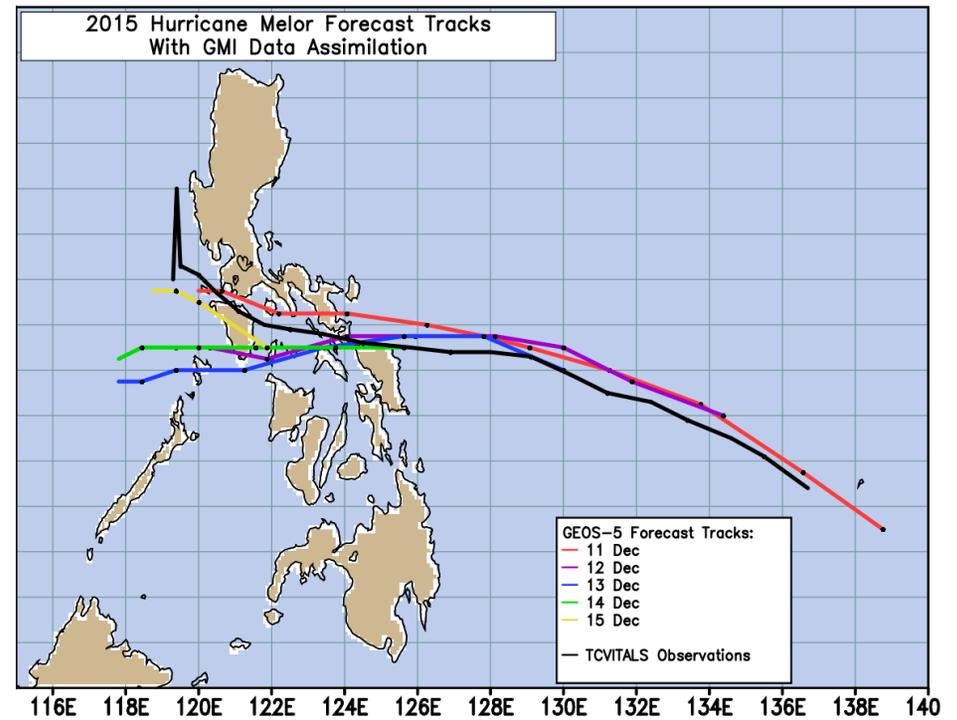
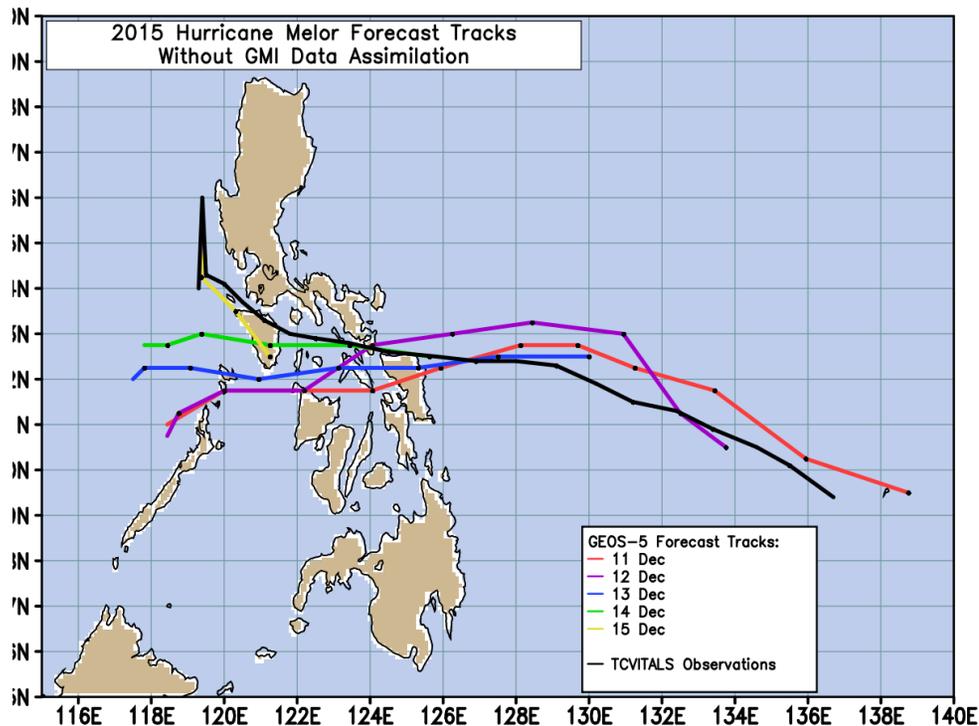
850hPa Temperature RMS Error



All-sky GPM Microwave Imager (GMI) improved the lower tropospheric humidity and temperature forecasts, especially in the tropics.



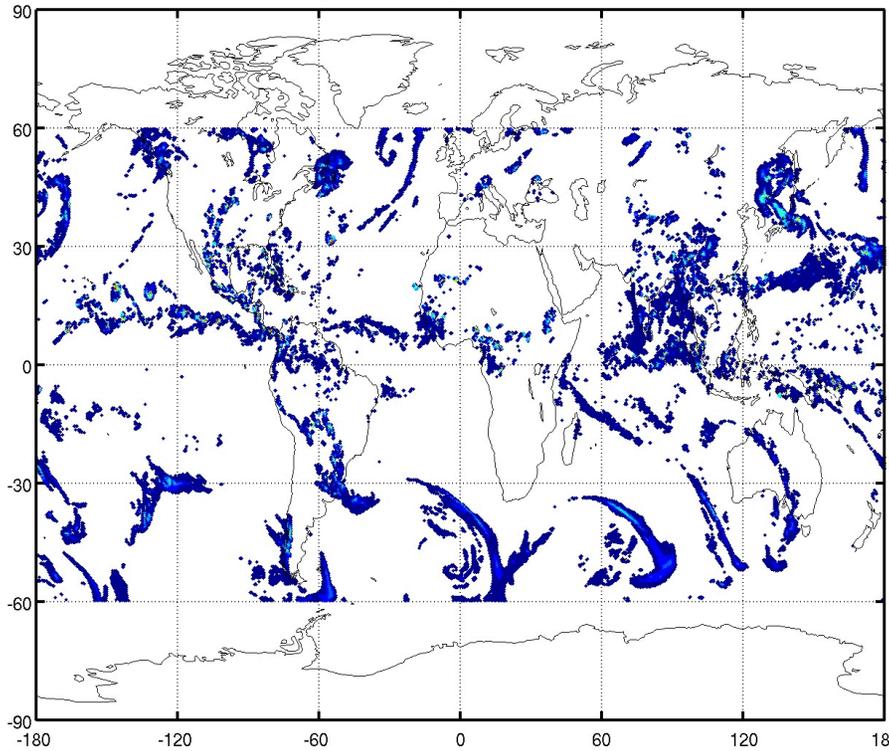
Impact on Hurricane Track Forecasts



- A noticeable positive impact of all-sky GMI radiance assimilation on hurricane track forecasts was identified for Hurricane Melor, which occurred in the western Pacific during Dec. 2015.
- More hurricane case studies to understand the impacts of all-sky radiance data are in progress.

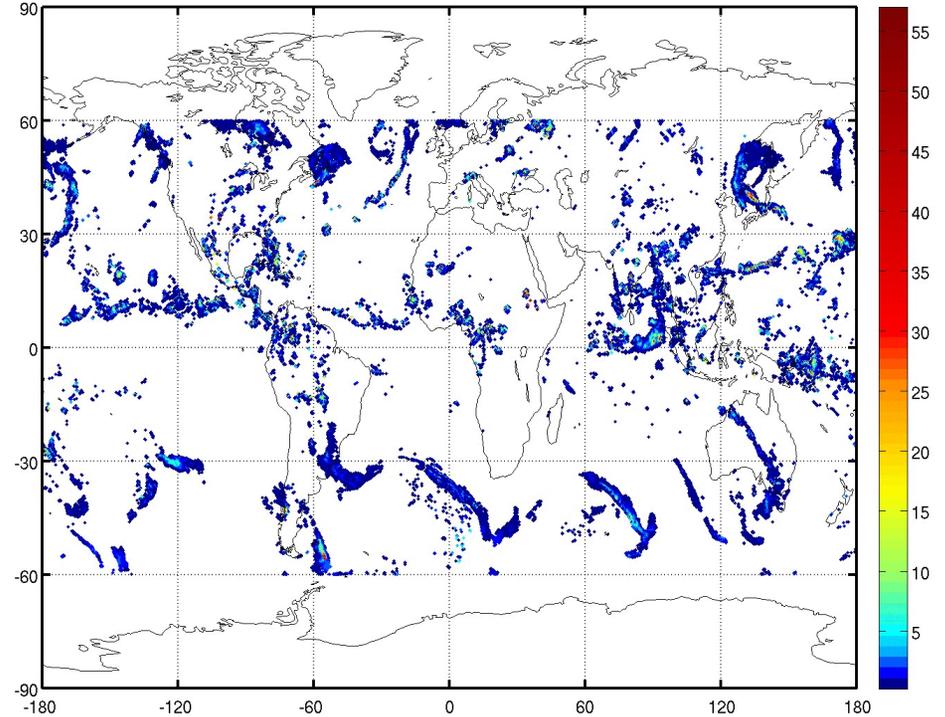
Prototype of GMI Data + Other Satellite Data Assimilated Global Atmospheric & Surface Analysis Products from GEOS

GEOS Precipitation Analysis, 08/31/2016 0030UTC



**GEOS Analysis
Surface precip (mm/hr)**

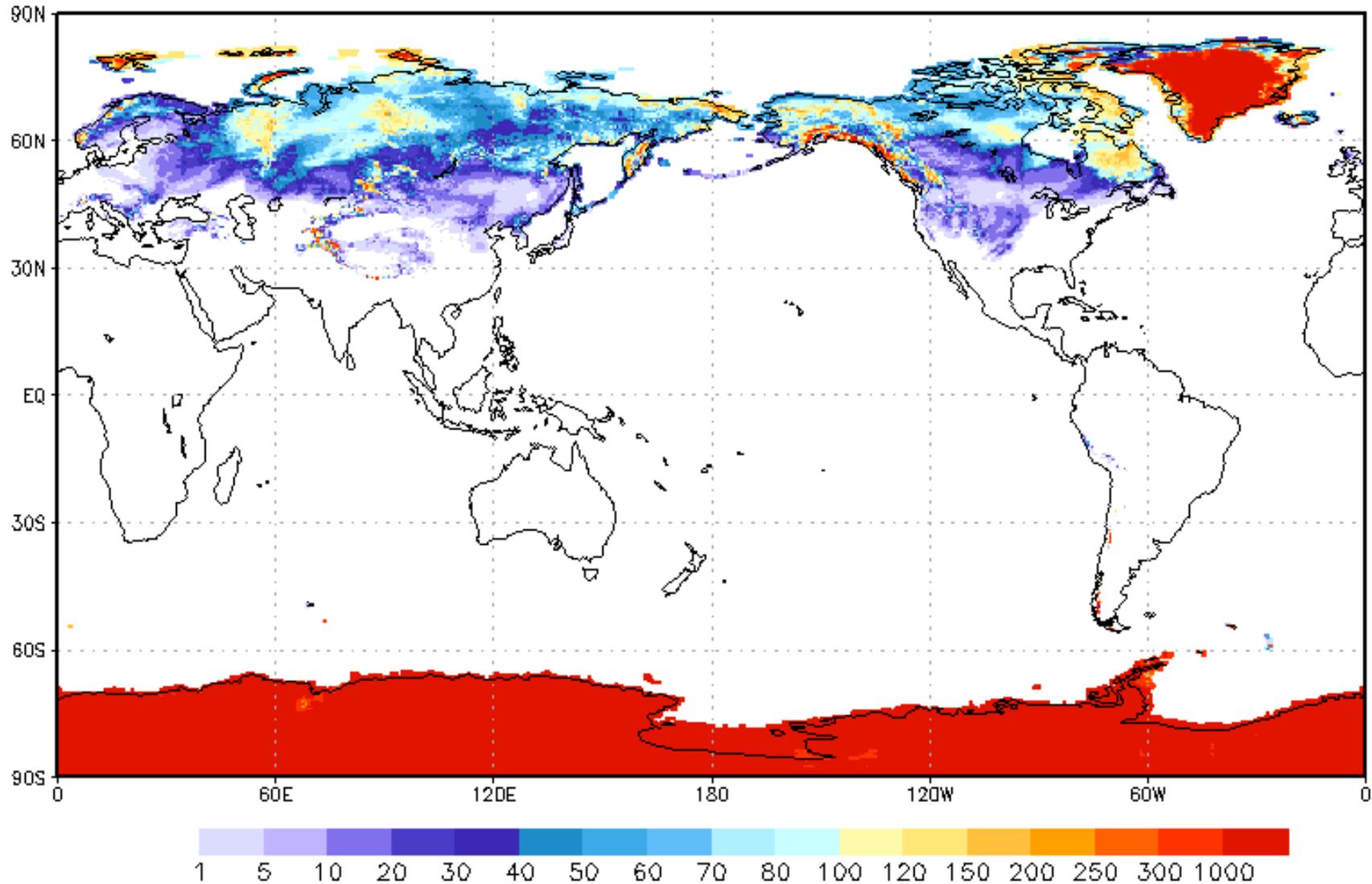
IMERGE (PrecipCal, 08/31/2016 0030UTC)



**IMERGE
precipCal (mm/hr)**

Prototype of GMI Data + Other Satellite Data Assimilated Global Atmospheric & Surface Analysis Products from GEOS

GEOS-5 SNOW MASS 20151201 00Z





Work in progress

- Extending all-sky GMI radiance data over land, snow, and ice surface by employing dynamically retrieved surface emissivities in calculating Tbs.
- Experiments to assimilate cloud and precipitation affected radiance data from other microwave sensors such as MHS, ATMS, and AMSU-A
- Enhancing all-sky DA framework with
 - adaptive data thinning (more data in cloudy condition than clear sky condition)
 - correlated observation error in the analysis process
 - testing with different form of moisture control variables (e.g. log...)



Thank you!



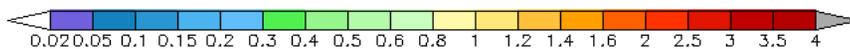
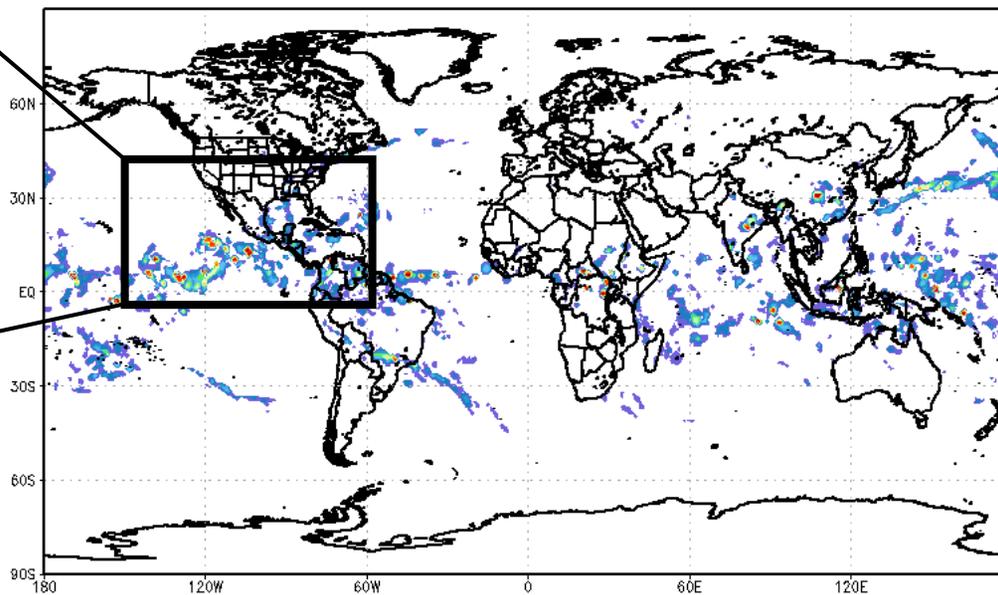
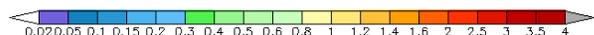
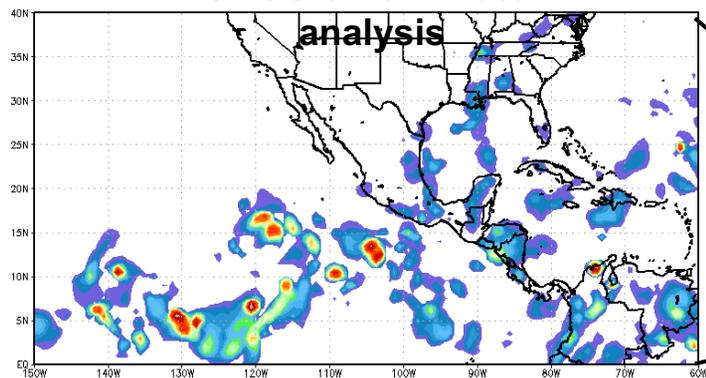
Backup



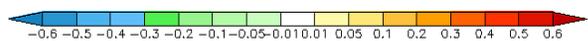
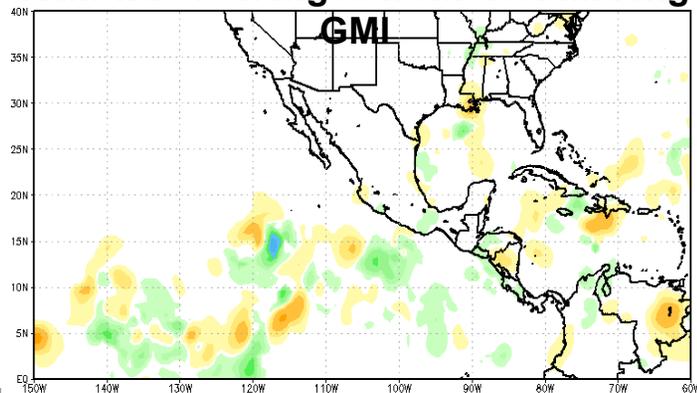
Assimilate GMI data over ocean in hybrid-3DVar system:

(1) 4 types of hydrometeorors (ql, qi, qr, qs) as state and control variables. (2) Symmetric observation error model (Geer et al.) (3) Only observation data in clear sky conditions are utilized in bias correction coefficient updates in assimilating all-sky microwave radiance data. (4) 0.5degree experiment results indicate that GMI data make positive impacts on lower troposphere humidity forecasts. Currently testing with other updates in GEOS-5 system to include in the next GEOS-5 ADAS upgrade.

GEOS-5 Rain water analysis



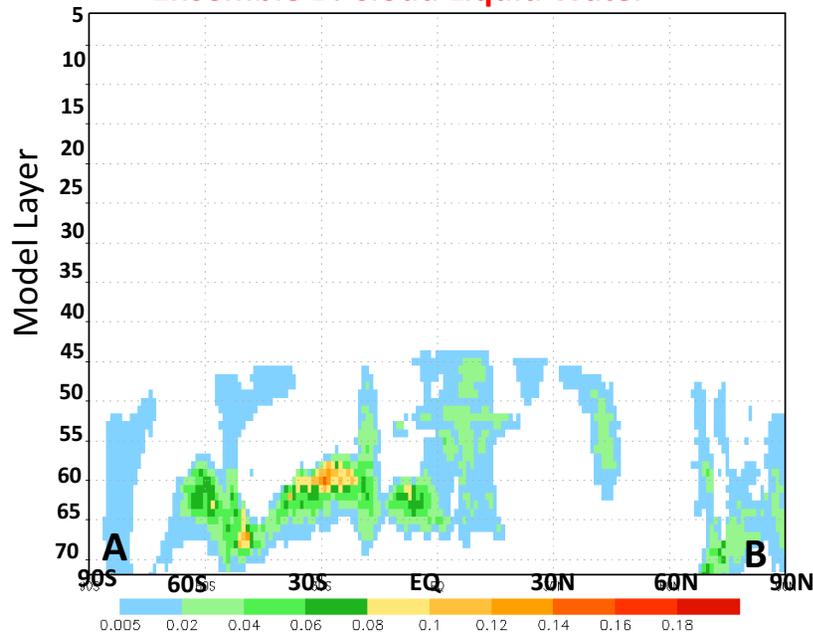
Rain water changes from assimilating GMI



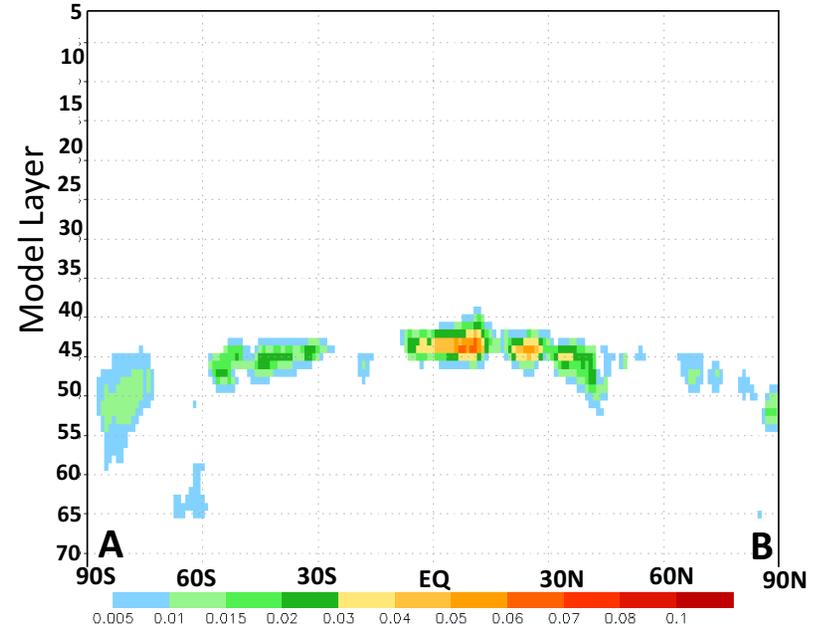
Ensemble spread for clouds and precipitation



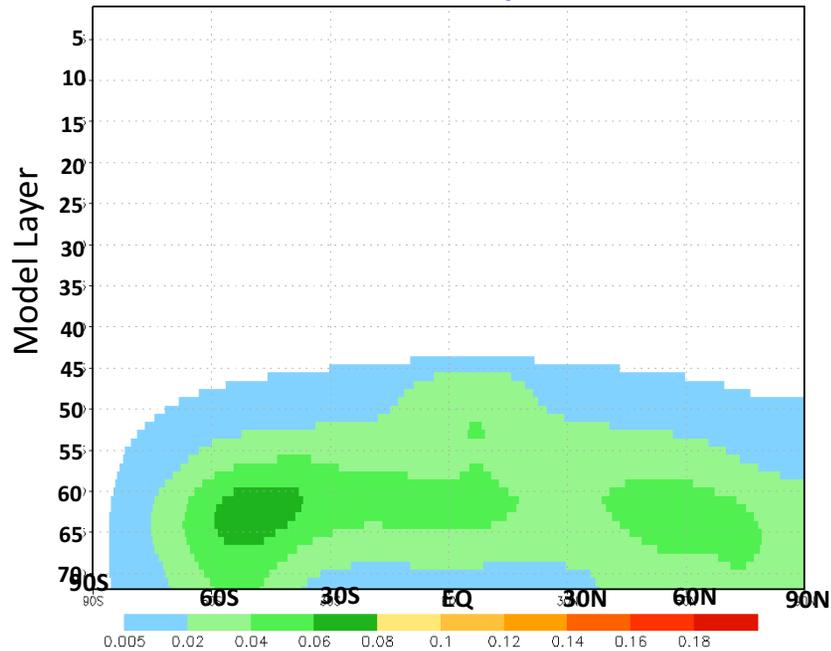
Ensemble B: Cloud Liquid Water



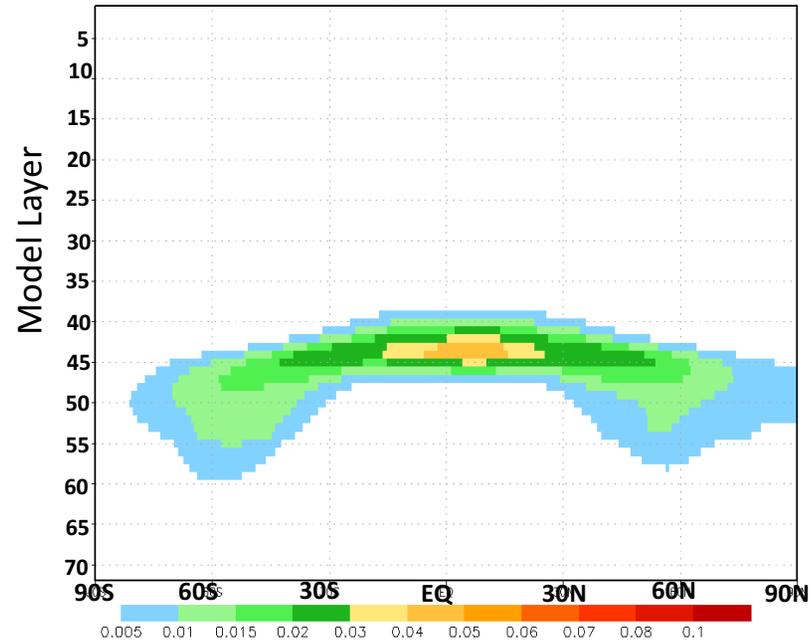
Ensemble B: Cloud Ice Water



Static B: Cloud Liquid Water



Static B: Cloud Ice Water



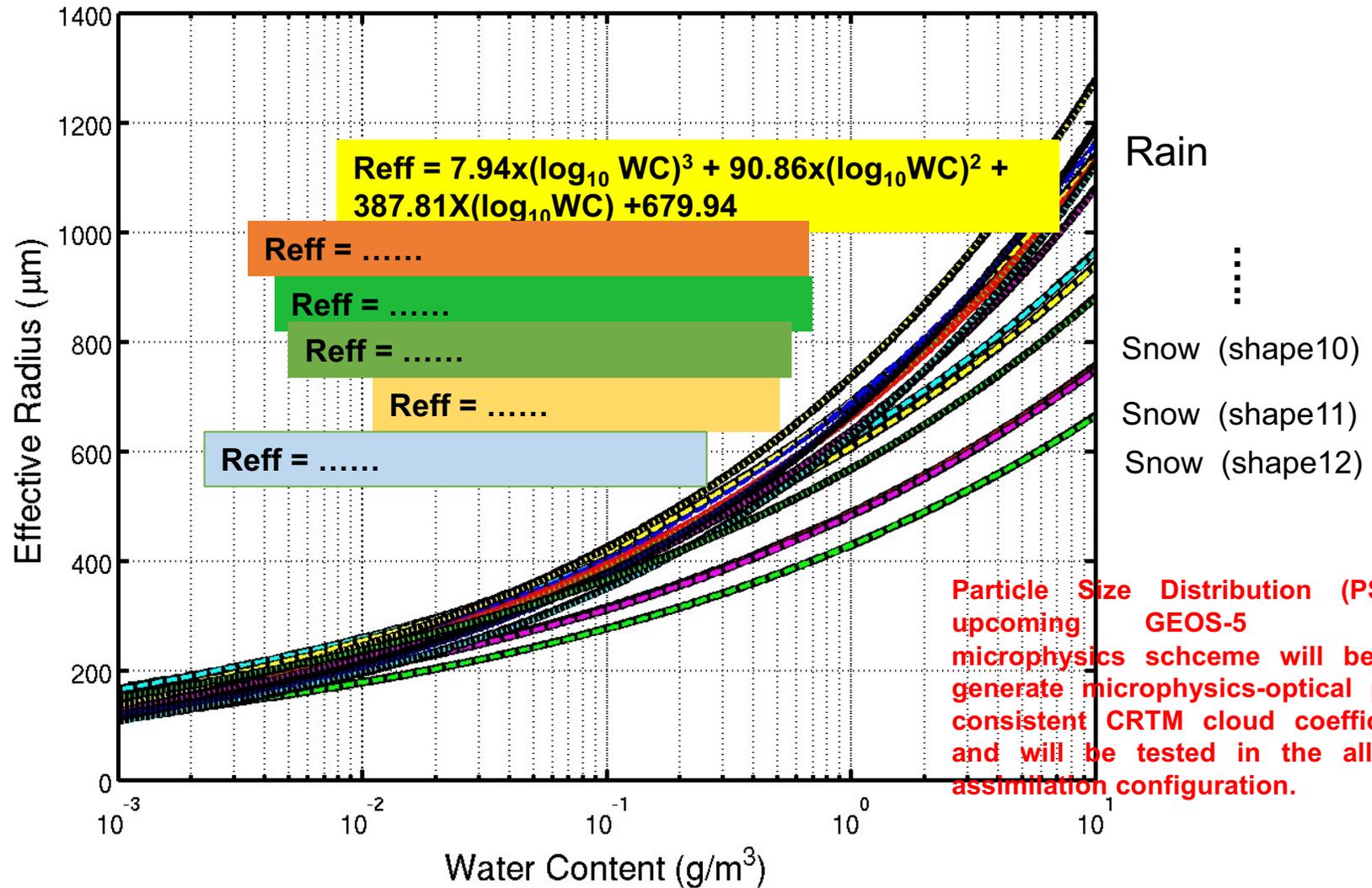


Partitioning Liquid precip & Frozen precip in GEOS

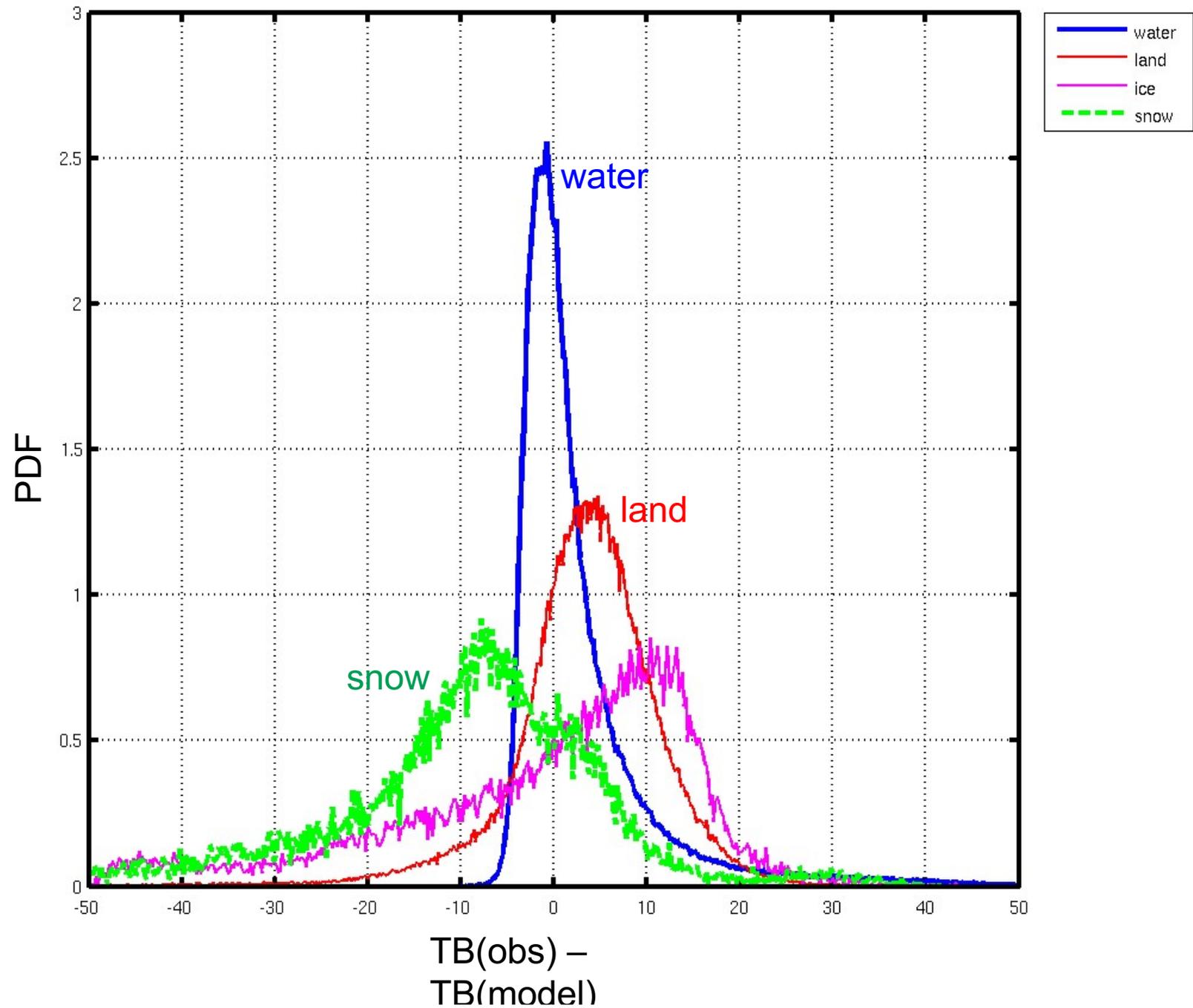
- **Single moment:** partitioning of ice and liquid based on T. Snow and Rain: Microphysically, that is ice and liquid are subject to microphysical processes eventually becoming snow and rain. Rain freezing if needed is based on T.
- **Double moment:** partitioning of ice and liquid based on ice nucleation and linked to the aerosol (Dust, black Carbon and organics). Snow and Rain also result from microphysics. Rain freezing if needed depends on droplet volume to mimic ice nucleation.
- **In summary:**
1-Moment: depends mostly on T.
2-Moment: Depends mostly on Aerosol freezing.



Particle Size Distribution



GPM Microwave Imager CH6



Microwave Land Surface Emissivity Retrieval in GEOS

- Land surface emissivity at MW frequencies are vary in a complex way with surface types, roughness, and moisture among other parameters.
- Estimating (retrieving) microwave surface emissivities using channels not assimilated yet frequency close to assimilated channels.

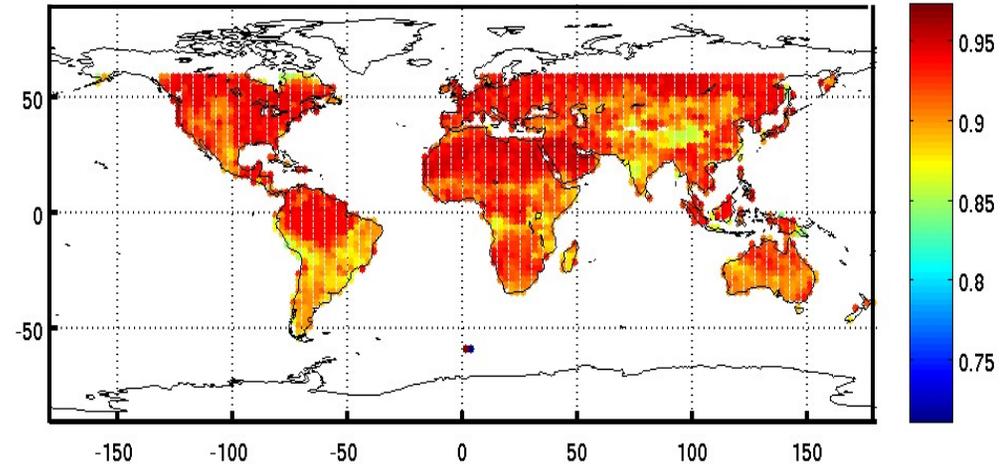
$$\varepsilon = \frac{T_{obs} - T^{\uparrow} - T^{\downarrow}\Gamma}{(T_{skin} - T^{\downarrow})\Gamma}$$

T: CRTM provided atmospheric contribution to the measured T_{obs} . (in radiance)

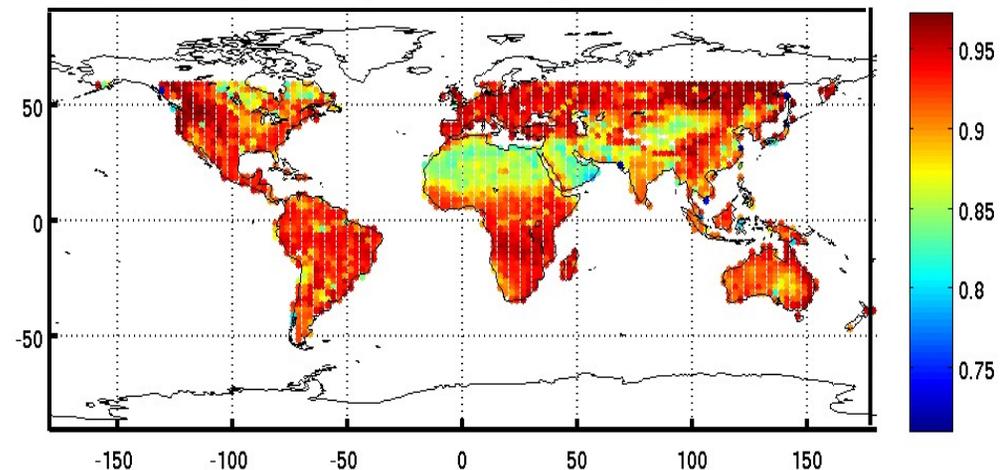
T_{skin} : bkg skin temperature (in radiance)

Γ : CRTM provided net atmospheric transmittance

GMI 37GHz Hpol Surface Emissivity (CRTM)



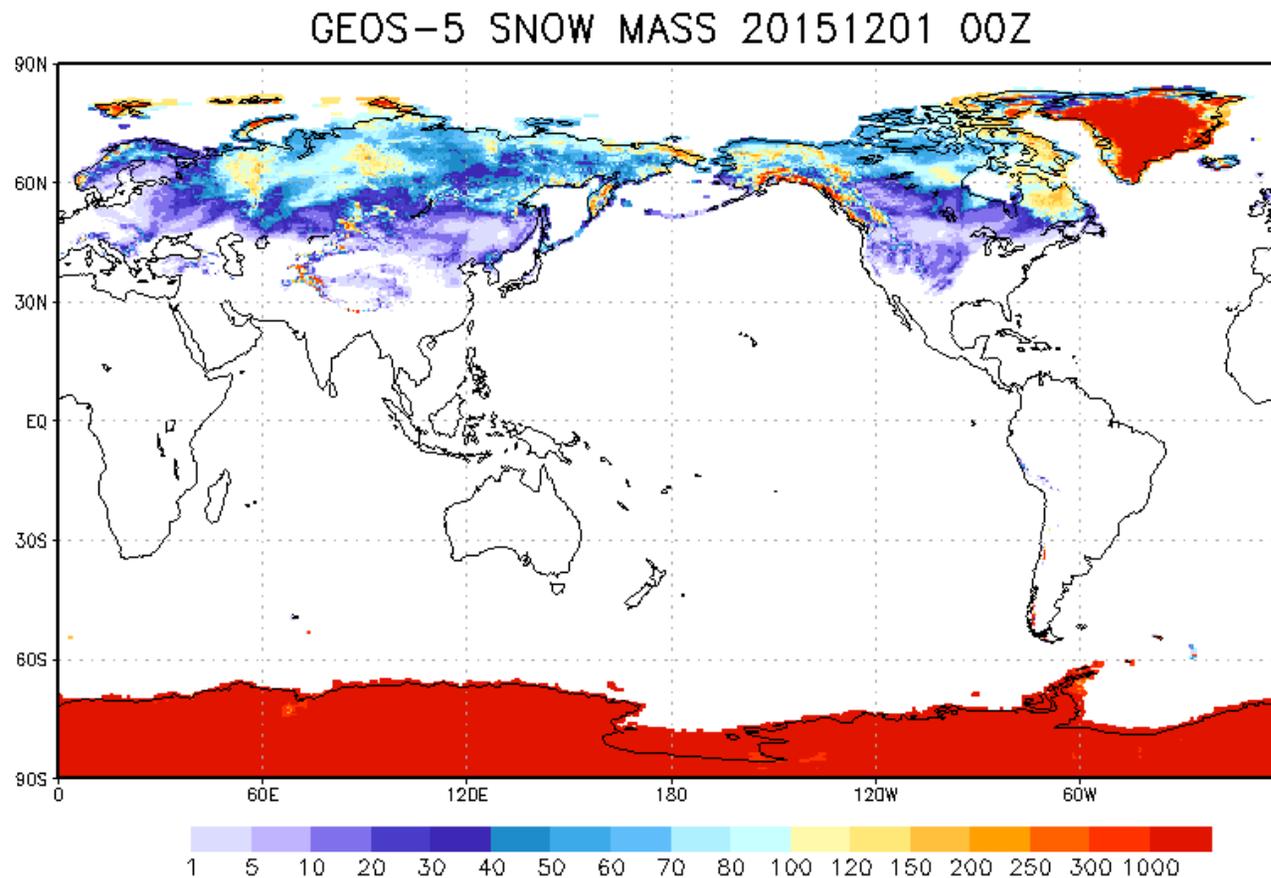
GMI 37GHz Hpol Surface Emissivity (Retrieved)



Challenges related with surface emissivity



- Uncertainty in emissivity retrievals caused by falling snow and snow on the ground

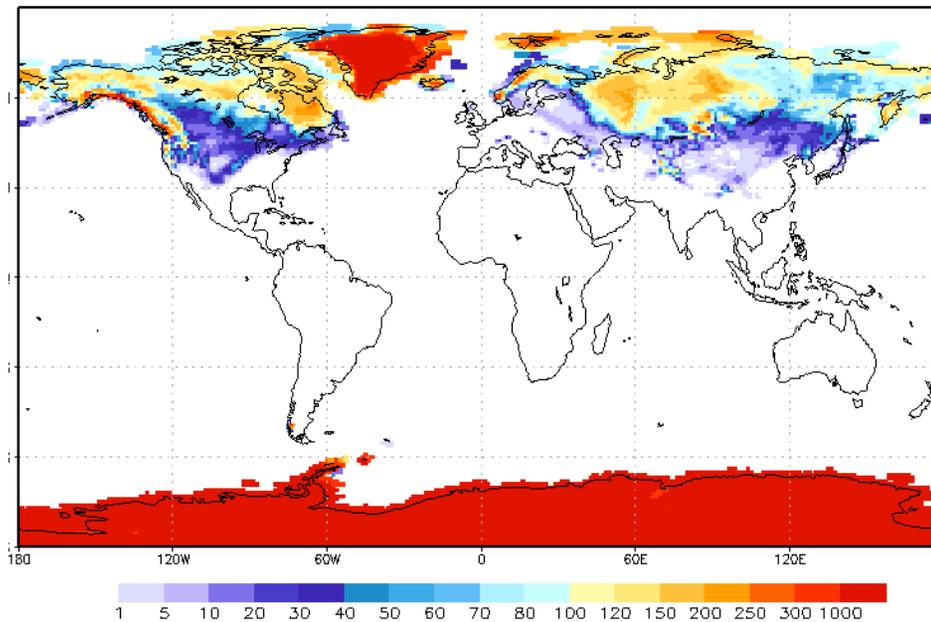


Challenges related with surface emissivity

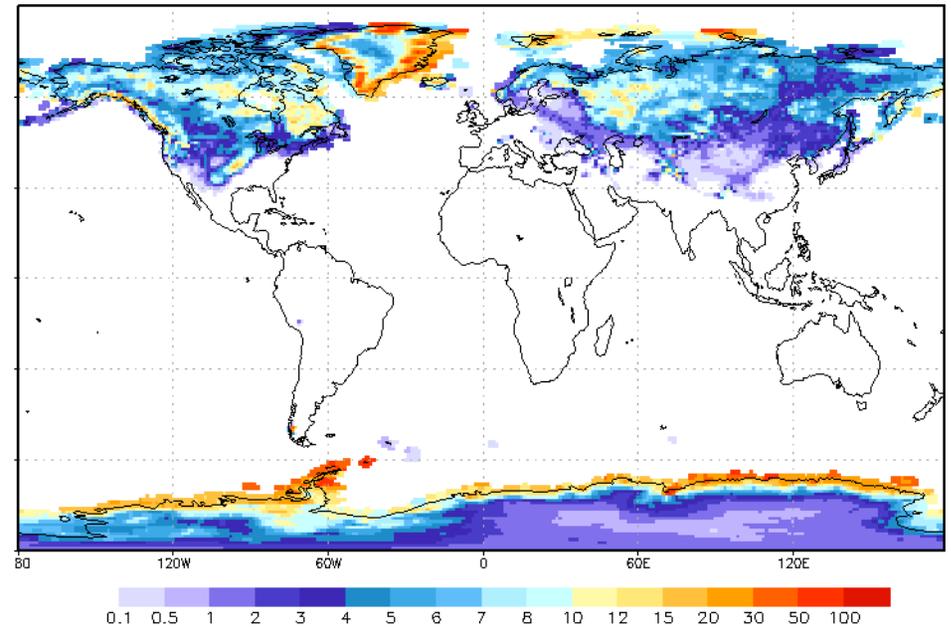


Uncertainty in emissivity retrievals caused by falling snow and snow on the ground

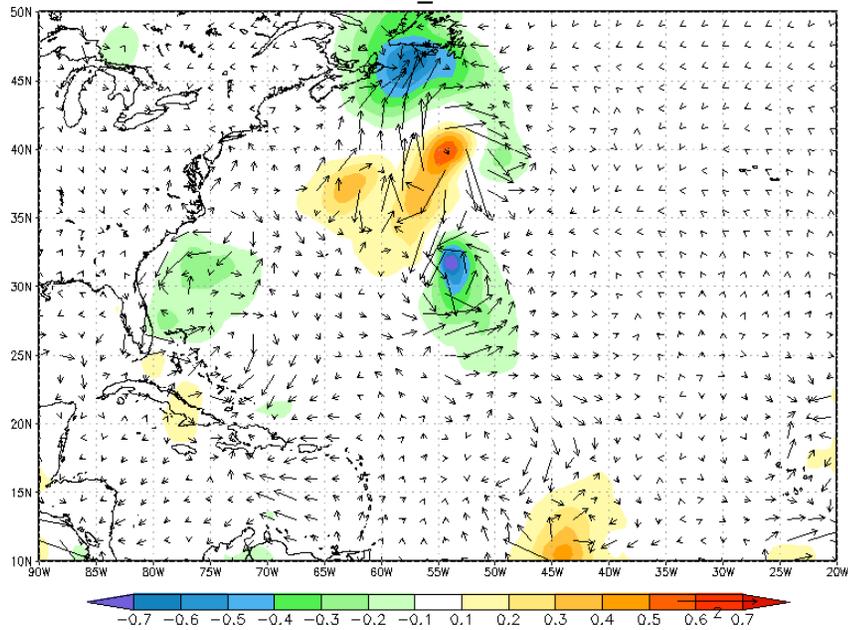
GEOS-5 Snow Mass Ensemble Mean (20151229 18Z)



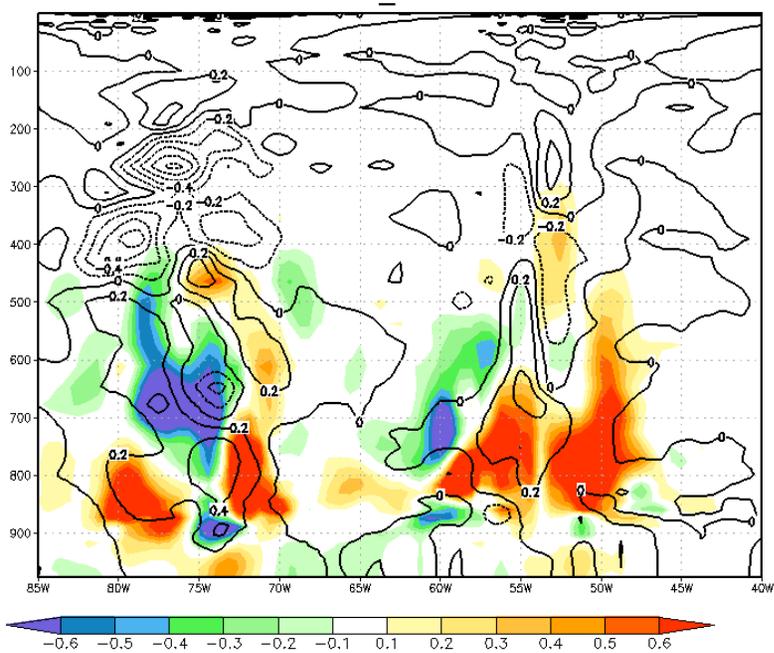
GEOS-5 Snow Mass Ensemble Spread (20151229 18Z)



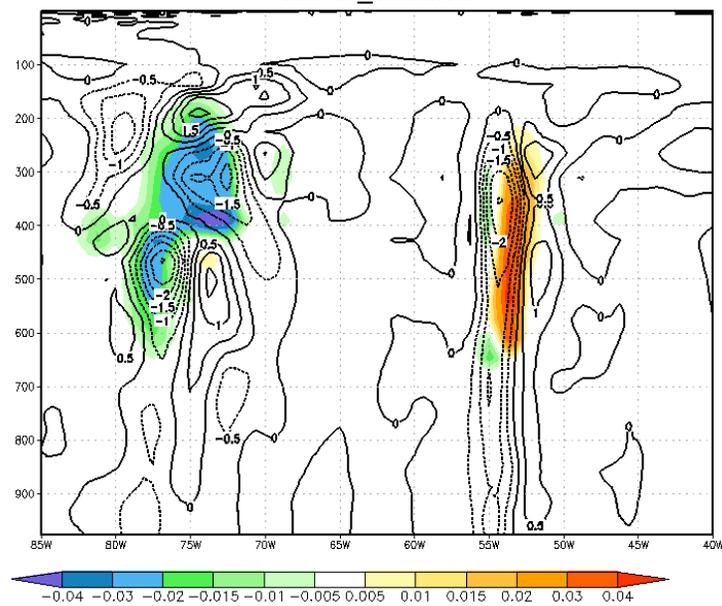
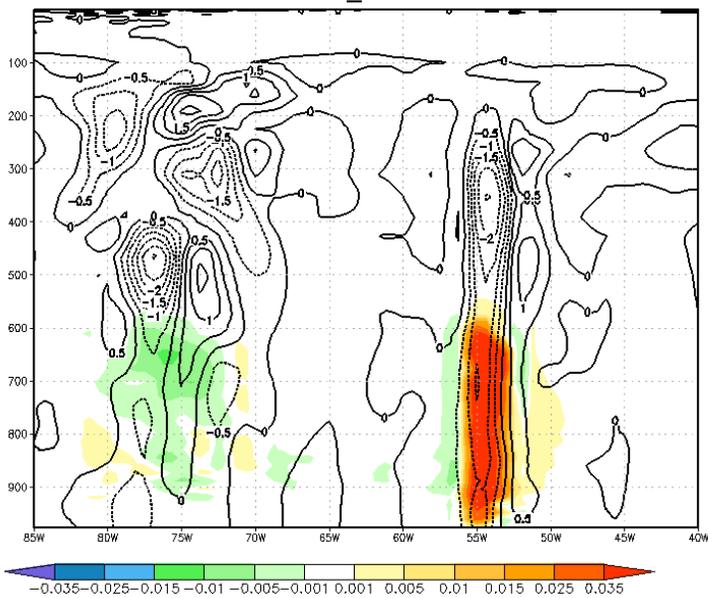
Analysis Changes by All-sky GMI data



GMI all_channels

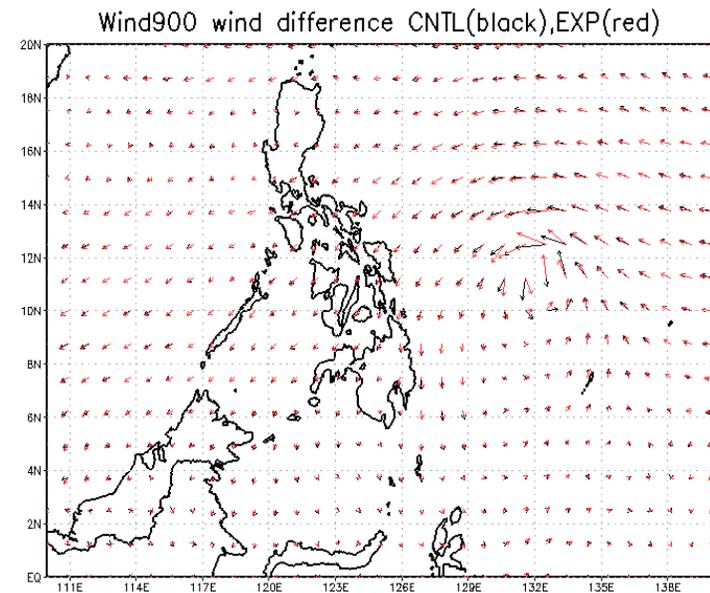
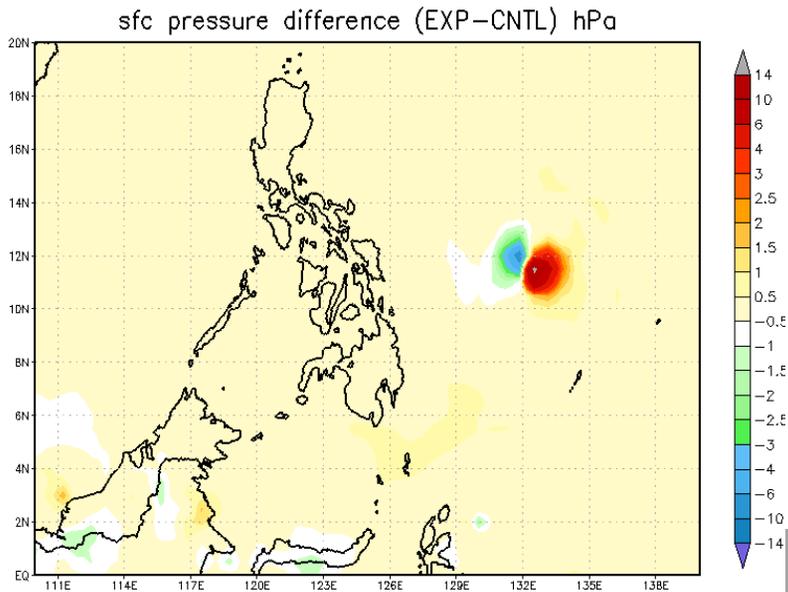
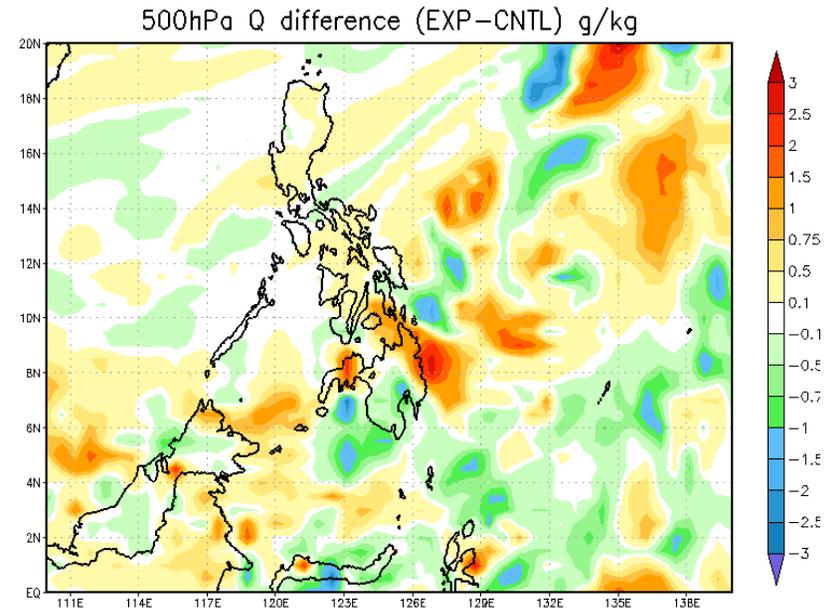
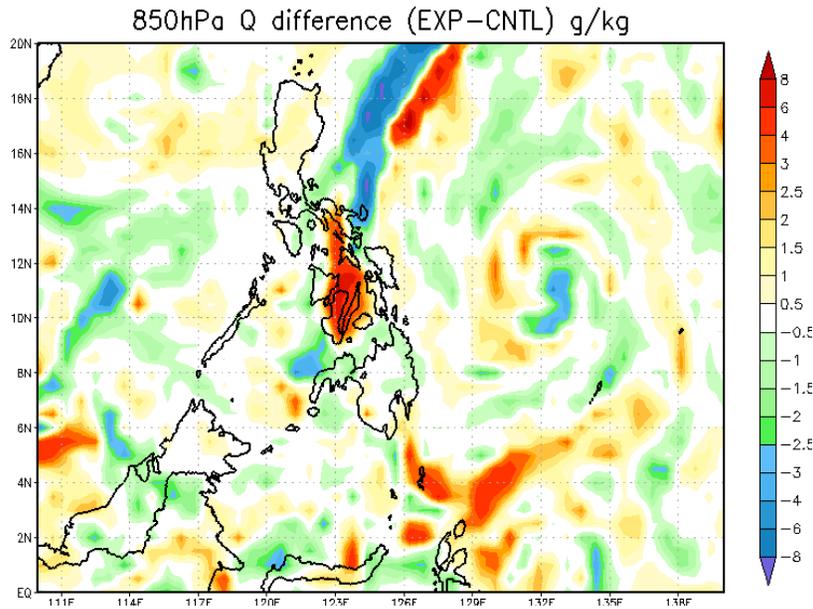


GMI all_channels



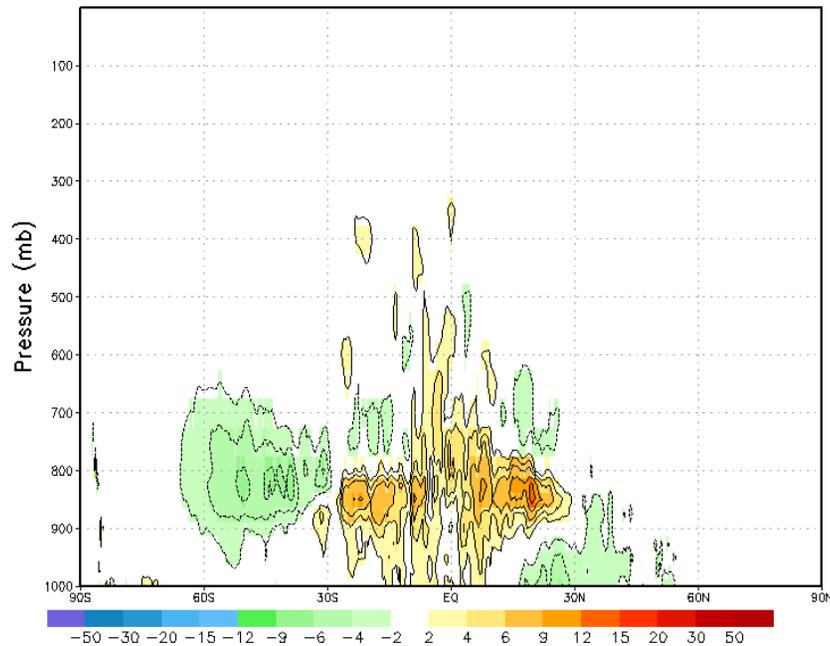


Difference of Analyses (Exp – Control) : 12 Dec 2015, 12UTC

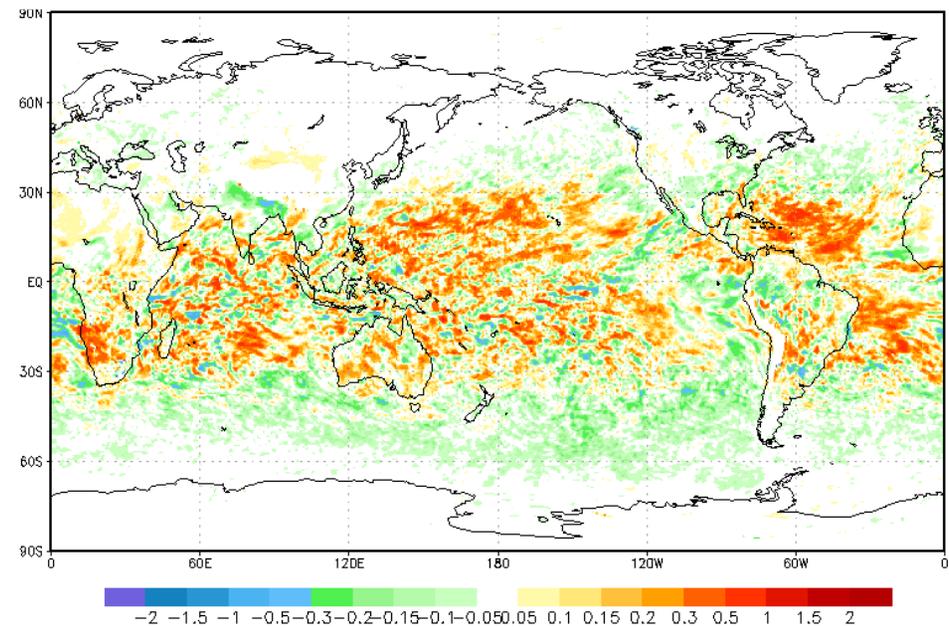


Impacts on GEOS Atmospheric Analyses

Difference of Monthly Zonal Mean Specific Humidity
(Allsky GMI – NoGMI)



Difference of Monthly Mean 850hPa Specific Humidity
(AllskyGMI – NoGMI)



- All-sky GPM Microwave Imager (GMI) data increase lower tropospheric humidity in the GEOS analyses.
- The data generally have a significant impact on the lower tropospheric humidity and temperature analyses, especially in the tropics, which leads to improved forecasts of these quantities