All-sky GPM Microwave Imager (GMI) Radiance Data Assimilation in NASA GEOS-5 System for Global Cloud and Precipitation Analyses

[1,2]Min-Jeong Kim

[1,2] Jianjun Jin, [1]Will McCarty, [1]Ricardo Todling, [1,3]Amal El Akkraoui, [1,3]Wei Gu, [1,2]Dan Holdaway, [1,2]Jong Kim, [1]Ron Gelaro, and many others

1. NASA Goddard Space Flight Center
Global Modeling and Assimilation Office (GMAO)
2. GESTAR
3. SSAI

13th JCSDA Technical Review Meeting & Science Workshop on Satellite Data Assimilation

Outline

1. **Overview**

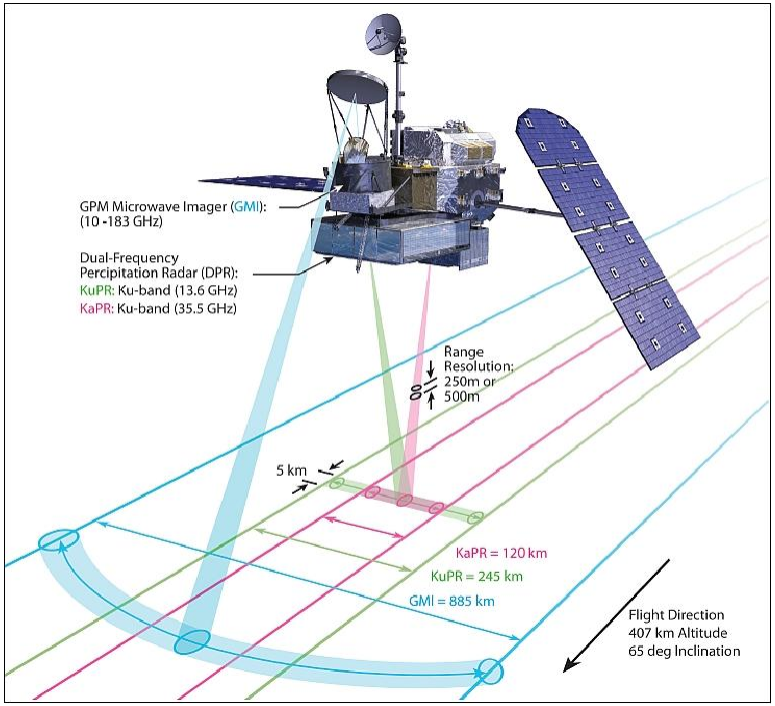
- GPM Microwave Imager
- Difficulties in assimilating cloud and precipitation affected microwave radiances
- Examples of microwave brightness temperature distributions in cloudy regions using GMI observations

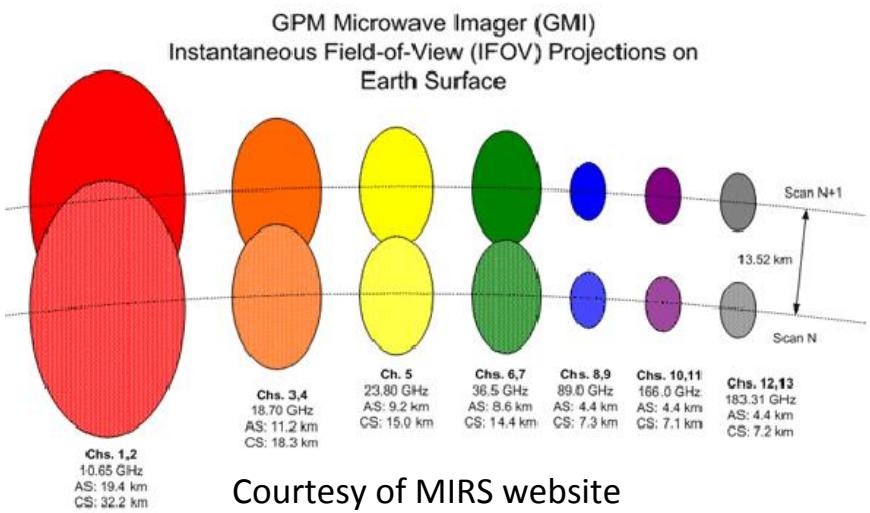
2. **Modifications made in GSI to assimilate all-sky GMI radiance data :**
   Observation operator, background error, observation error, quality control, etc..

3. **Preliminary results from a case study**

4. **Future plans**

Global Precipitation Measurement (GPM) Microwave Imager (GMI)





Courtesy of MIRS website

- **GPM was launched on February 27, 2014.**
- **Two instruments:**

- Dual frequency Precipitation Radar (DPR)

- GPM Microwave Imager (GMI):

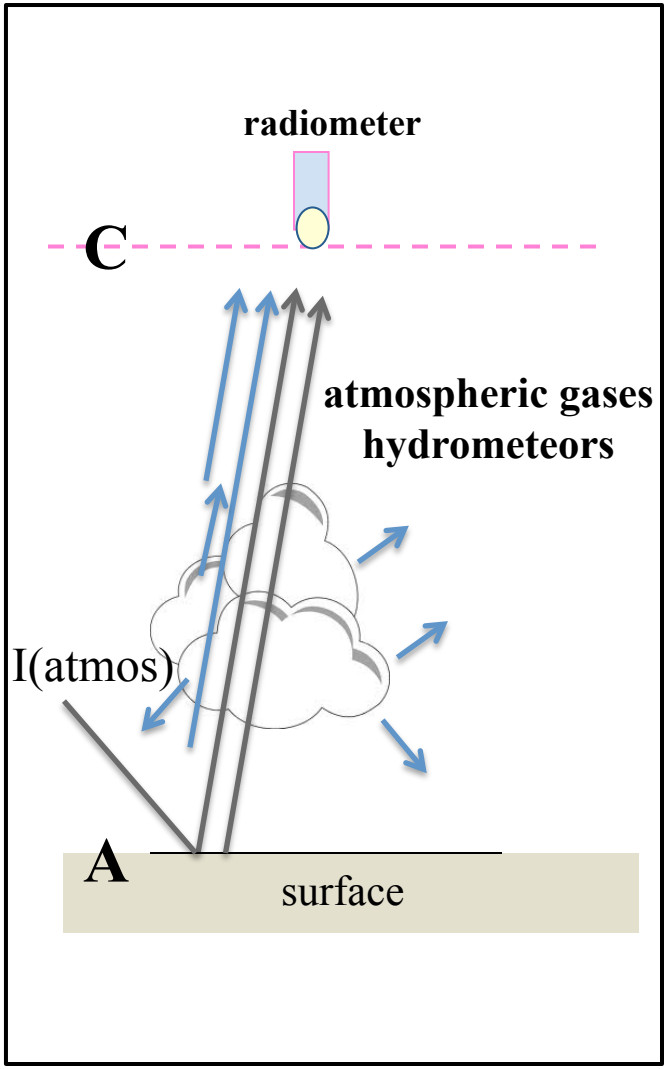
*** Conical scanning**

*** 65degree inclination angle**

*** 904 km swath on the Earth's surface**

*** 13 channels between 10.65 GHz and 190.3GHz. (4 millimeter-wave channels in addition to TMI channels.)**

Difficulties in Assimilating All-Sky MW Radiance Data



- Simulating precipitation affected radiances requires various microphysics parameters such as size distribution.

- Scattering effect caused by hydrometeors is difficult to parameterize accurately in radiative transfer models.

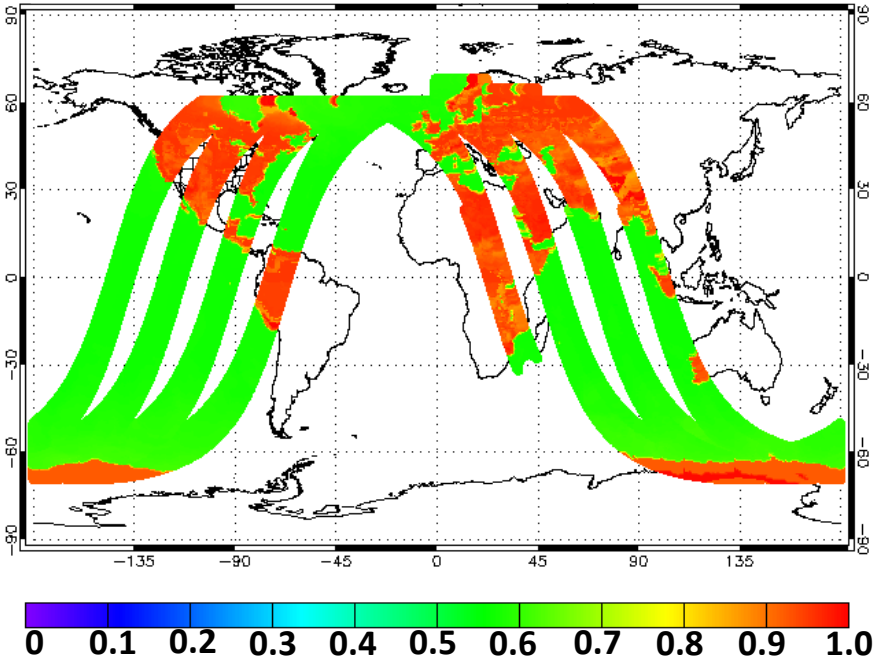
- Surface emissivity, depending on surface characteristics.

  * Ocean: salinity, skin temperature, surface roughness, and ocean foam caused by wind speed affect ocean surface emissivity

  * Much more challenging over land

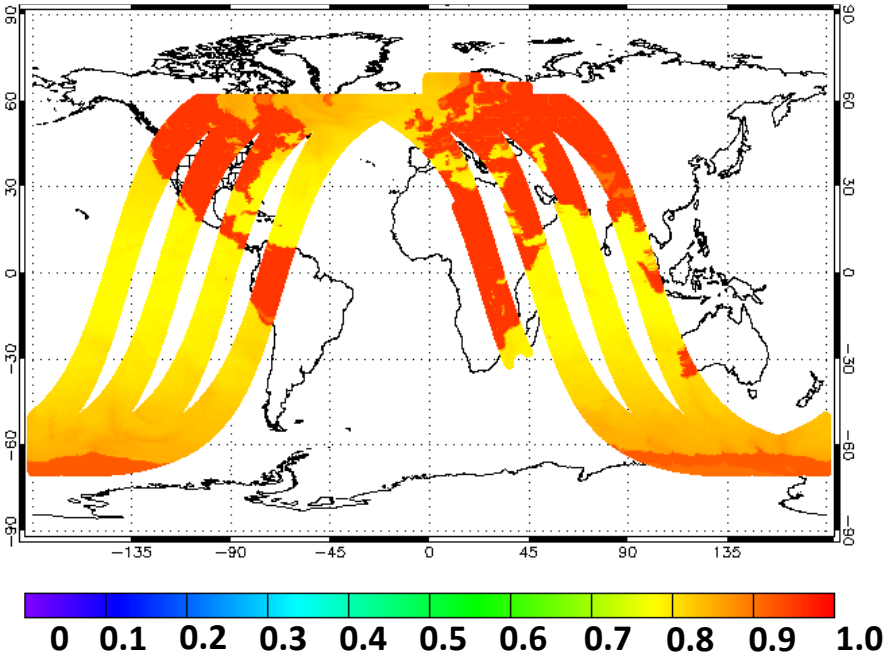
Surface Emissivity

GMI CH3 (19 GHz Vpol)



Ocean: ε ~ 0.56
Land: ε ~ 0.99

GMI CH10 (166 GHz Vpol)

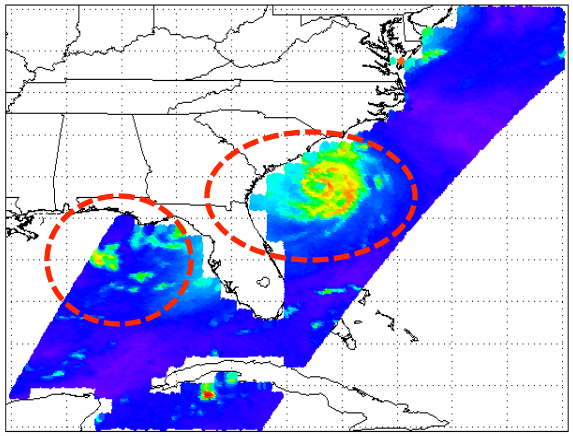


Ocean: ε ~ 0.78
Land: ε ~ 0.95

- **Tb over the ocean is lower than Tb over land at microwave frequencies**
- **Tb over the ocean at lower microwave frequencies is lower than at high microwave frequencies.**

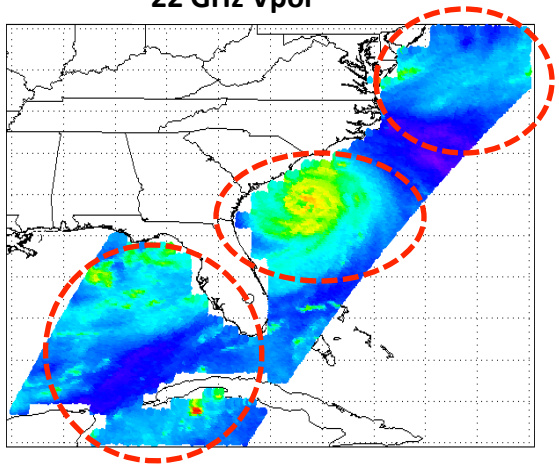
GMI Observations: Brightness Temperature (Tb)

18.7 GHz Vpol



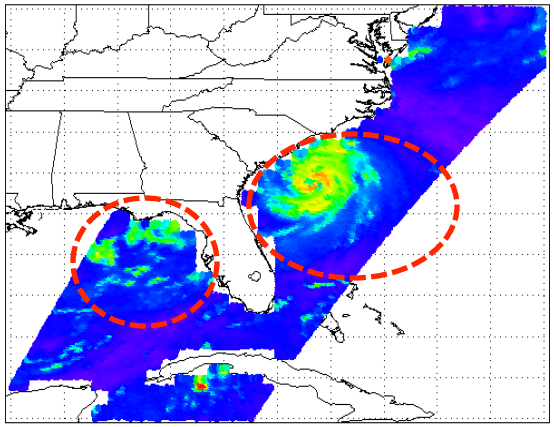
200 209 218 226 235 244 253 261 270 279 288

22 GHz Vpol



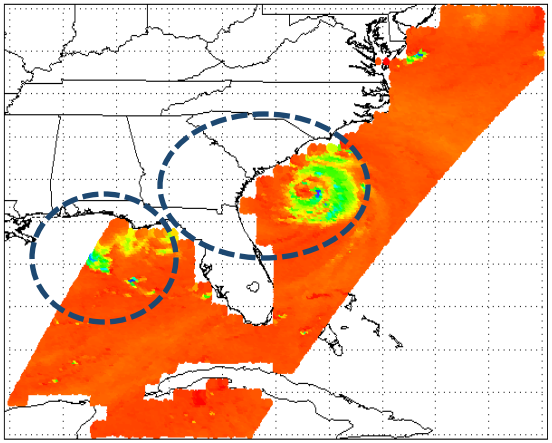
231 236 242 248 254 260 265 271 277 283 288

36.5 GHz Vpol



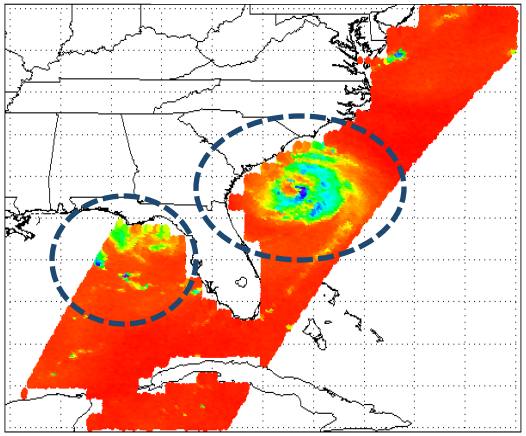
217 223 230 237 243 250 257 263 270 277 283

89 GHz Vpol



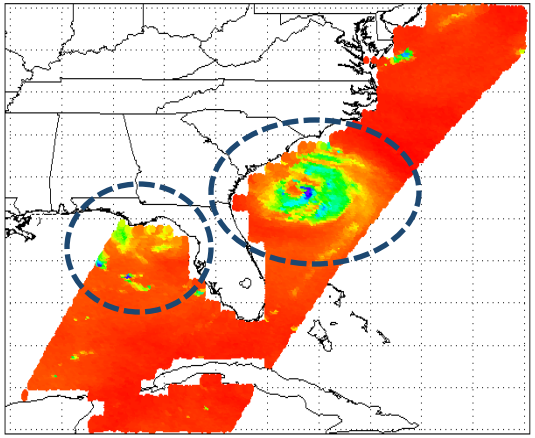
113 131 148 166 183 201 218 236 253 270 288

166 GHz Vpol



02 121 139 157 175 193 211 230 248 266 284

183.3+/-7 GHz Vpol



103 120 137 154 172 189 206 223 240 258 275

Modifications Made in GSI for All-sky GMI Radiance Data Assimilation

Components for Radiance Data Assimilation

$$J(x_a) = \underbrace{(x_a - x_b)^T B^{-1} (x_a - x_b)}_{\text{Fit to model generated background fields}} + \underbrace{(H(x_a) - O)^T R^{-1} (H(x_a) - O)}_{\text{Fit to observations}}$$

x_b= Background (first guess field) --> Add clouds and precipitation (ql, qi, qr, qs)

x_a= Analysis --> Add clouds and precipitation (ql, qi, qr, qs)

O= Observations --> Keep cloud and precipitation affected radiance data.

B= Background error covariance --> Static B + EnKF B including ql, qi, qr, qs

R = Observation Error covariance (= instrument error + representativeness error + forward operator error)

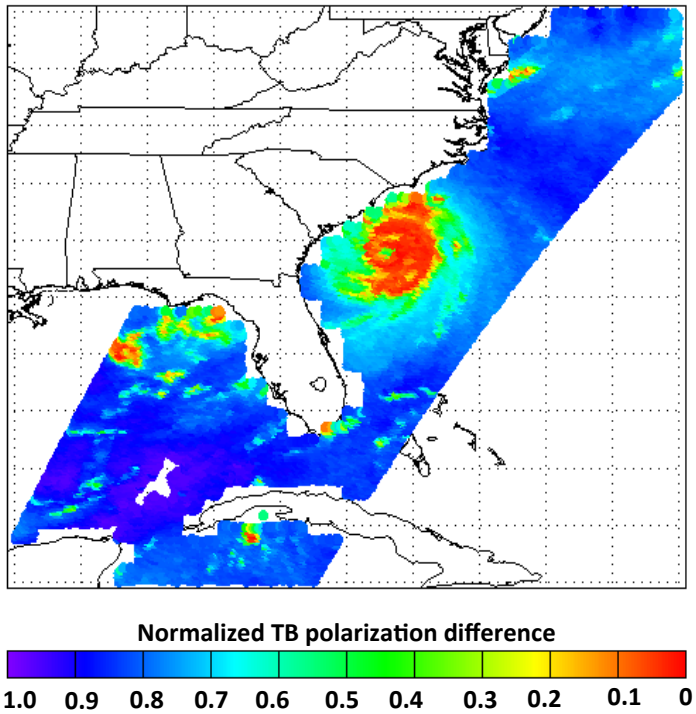
--> Assign observation errors proper for all-sky condition

H = Observation operator

--> Evaluate/Enhance CRTM performance in regions with precipitation

A Case Study: Hurricane Arthur (3 July 2014, 12Z)

GMI Observations (37GHz)



- Stand-alone analysis
- Only GMI data assimilated.
- Background fields and Ensemble background errors are from one of cycled Hybrid experiments.
- 20km thinning distance was used for GMI observations to take a closer look at performance of various analysis system components.

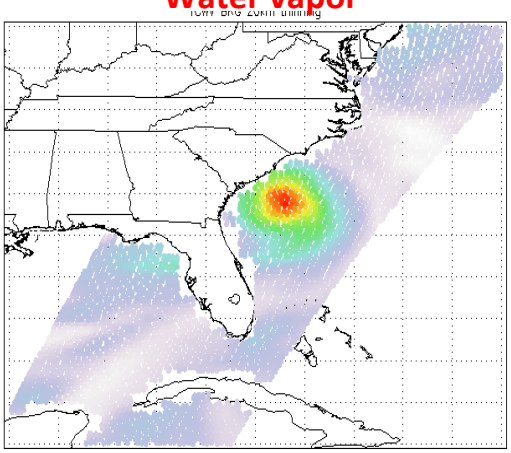
➢ Observation operator: Is the observation operator able to simulate GMI radiance properly in stormy region?

➢ Quality control: What criteria for gross check should be applied for all-sky GMI data?

➢ Analysis increments: What effects do GMI radiance data assimilation have on clouds, precipitation, and water vapor analyses?

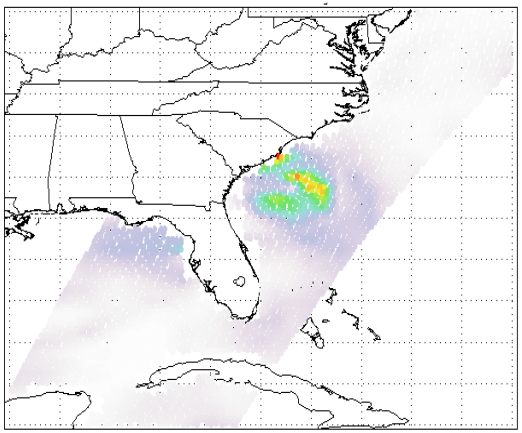
Observation Operator: Interpolating 0.5 ˚Background Fields to Obs. Locations

Water vapor



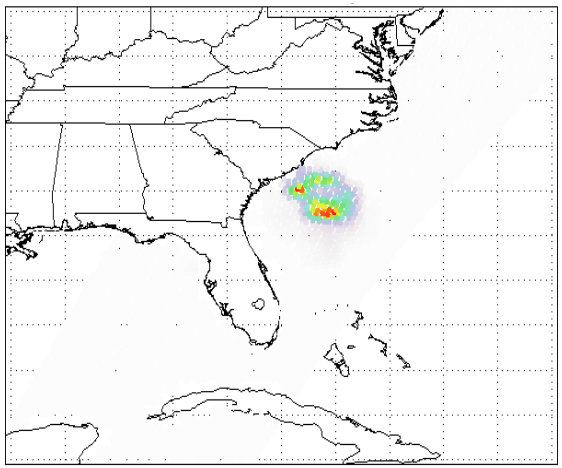
179 197 215 232 250 268 286 303 321 339 356 kg/m²

Cloud liquid water



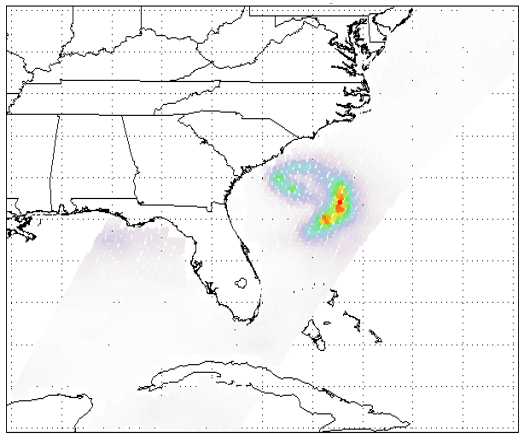
0 0.05 0.09 0.14 0.18 0.23 0.29 0.32 0.37 0.41 0.46 kg/m²

Rain water



0.0 0.7 1.4 2.0 2.7 3.4 4.1 4.8 5.5 6.1 6.8 kg/m²

Snow water



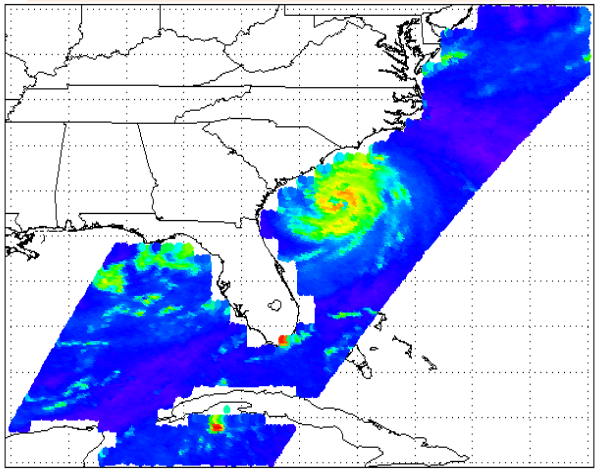
0.0 0.2 0.5 0.7 1.0 1.2 1.5 1.7 1.9 2.2 2.4 kg/m²

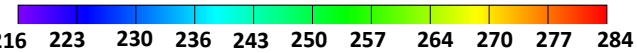
Observation Operator

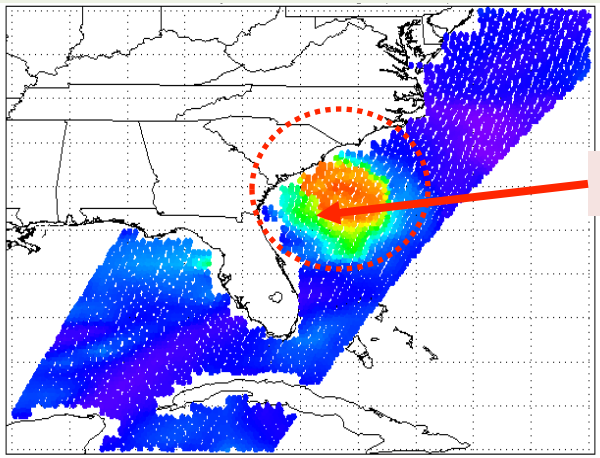
Observed TBs

CRTM Calculated Tbs with Bkg fields

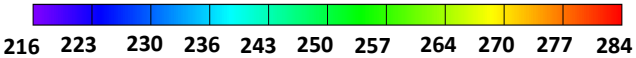
GMI 37 GHz



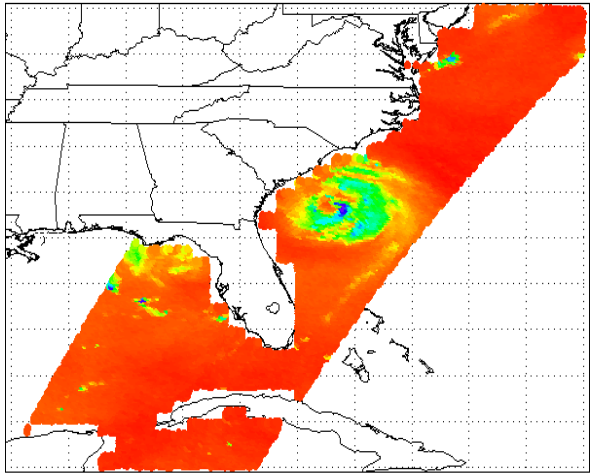


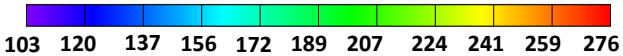


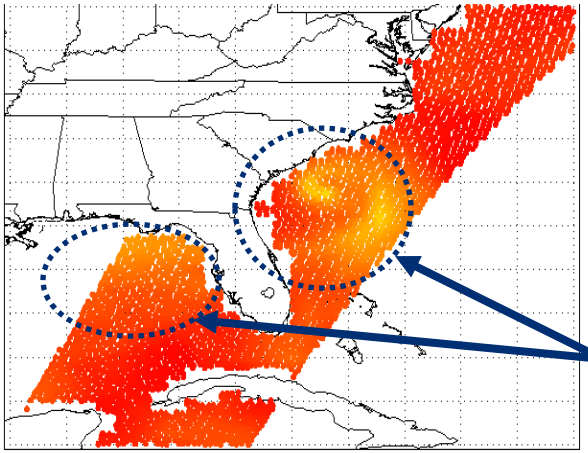
Too warm



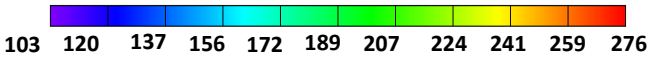
GMI
183.3+/- 7 GHz



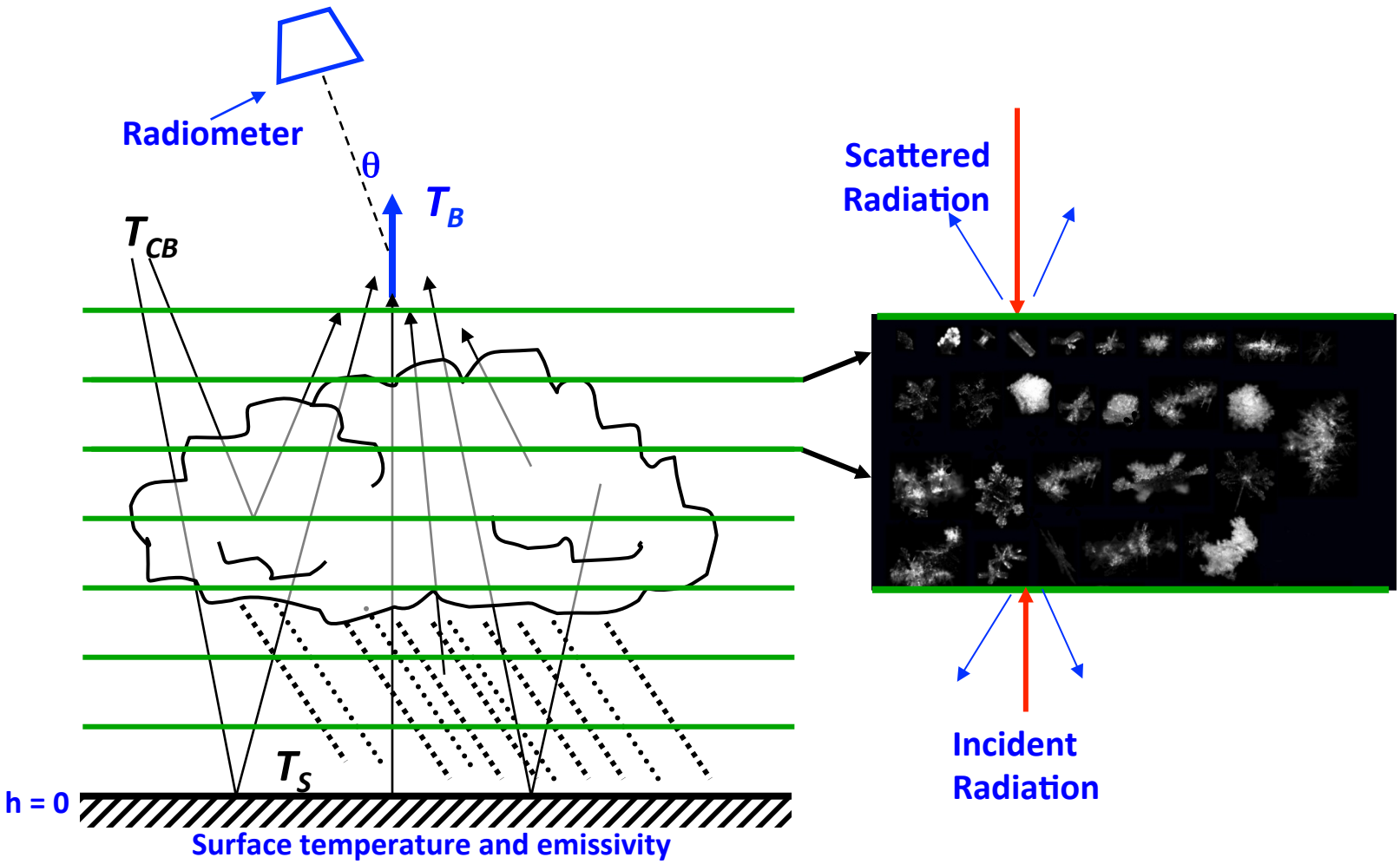




Not cold enough

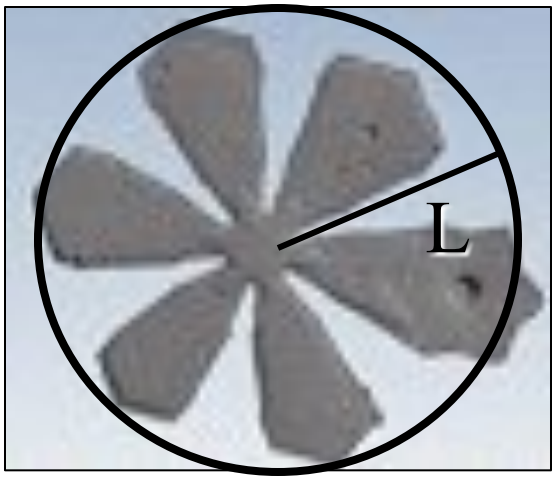


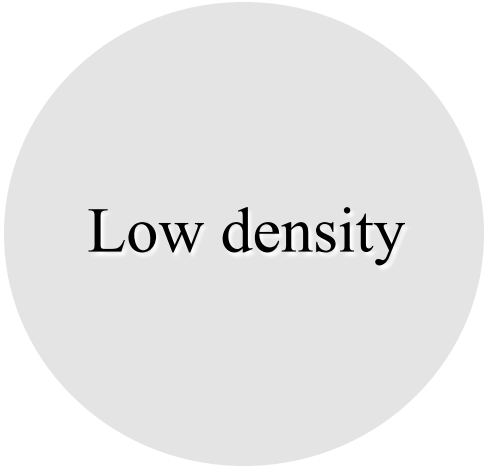
Radiative Transfer Process in Cloud and Precipitation



Mixed Medium Dielectric Constant

Current CRTM cloud coefficients are based on Mie calculations with mixed medium dielectric constants.





- Keeping the large dimension

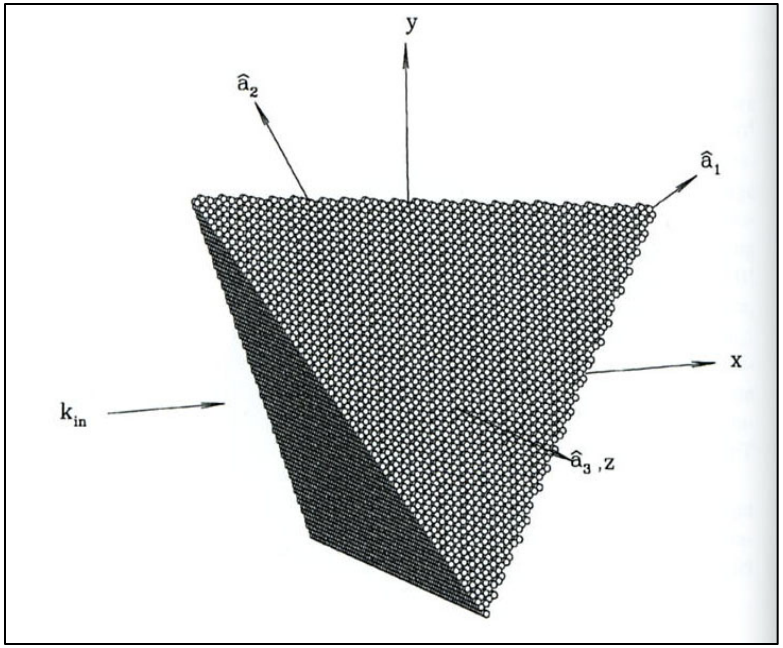
Valid at L << Wavelength

Discrete Dipole Approximation (DDA) Method

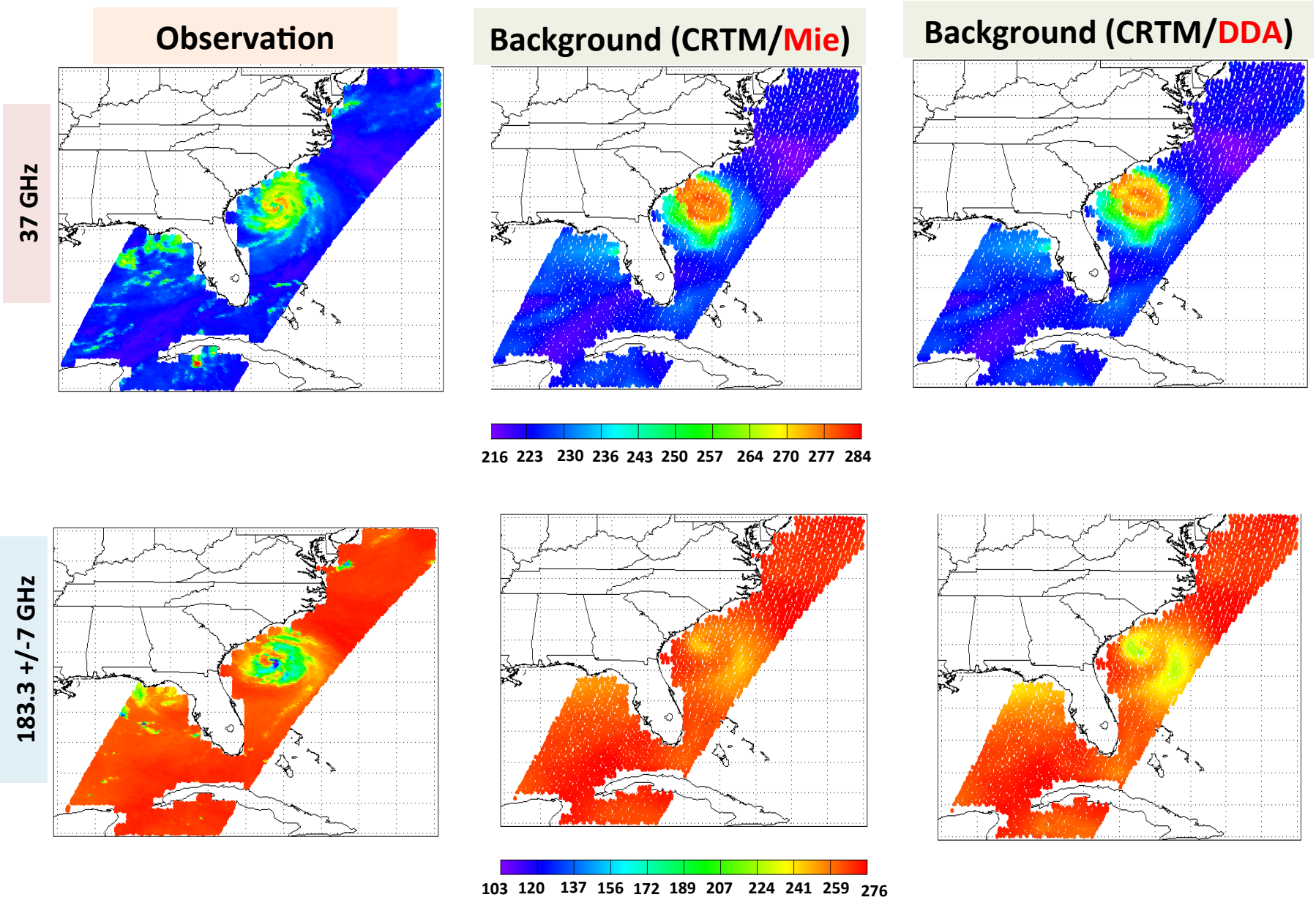
The upcoming version of CRTM cloud coefficients are based on scattering parameters calculated with DDA method.

- **The DDA is a method for computing scattering of radiation by particles of arbitrary shape.**

- **In the DDA method, an actual target is approximated by an array of dipoles.**

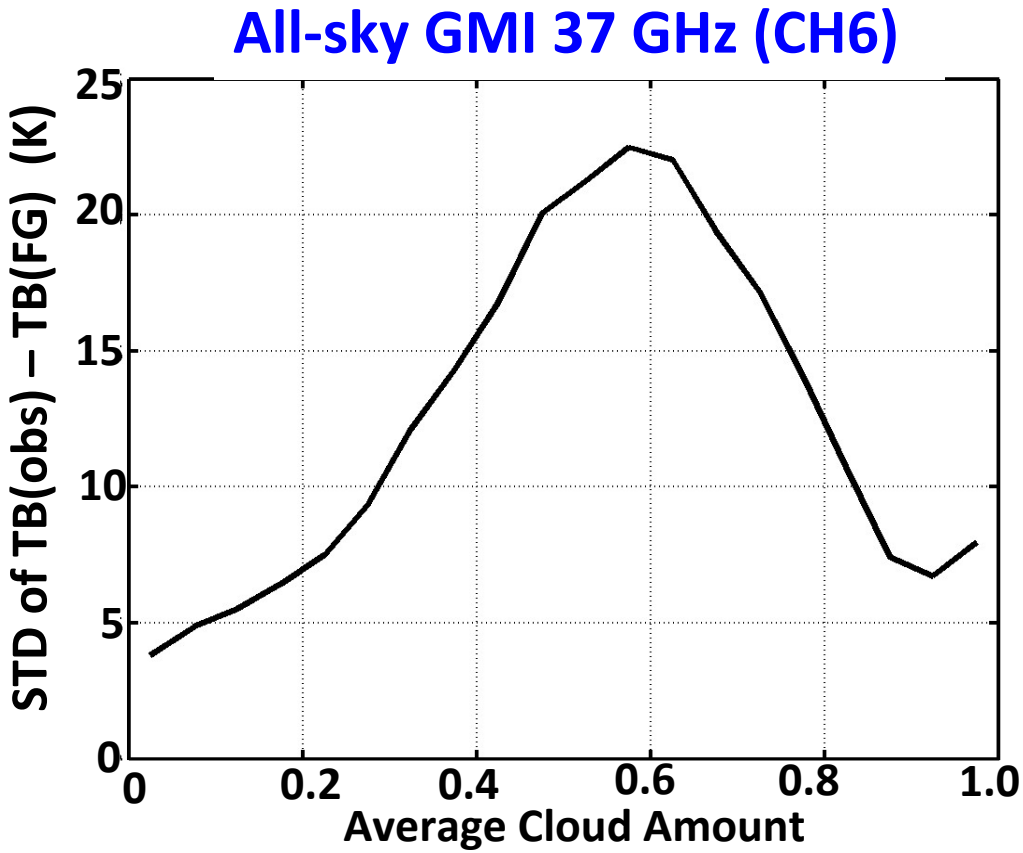


From Mishchenko et al (2000)


Observation
Background (CRTM/Mie)
Background (CRTM/DDA)
37 GHz
183.3 +/-7 GHz
216 223 230 236 243 250 257 264 270 277 284
103 120 137 156 172 189 207 224 241 259 276

Observation Errors for All-Sky GMI

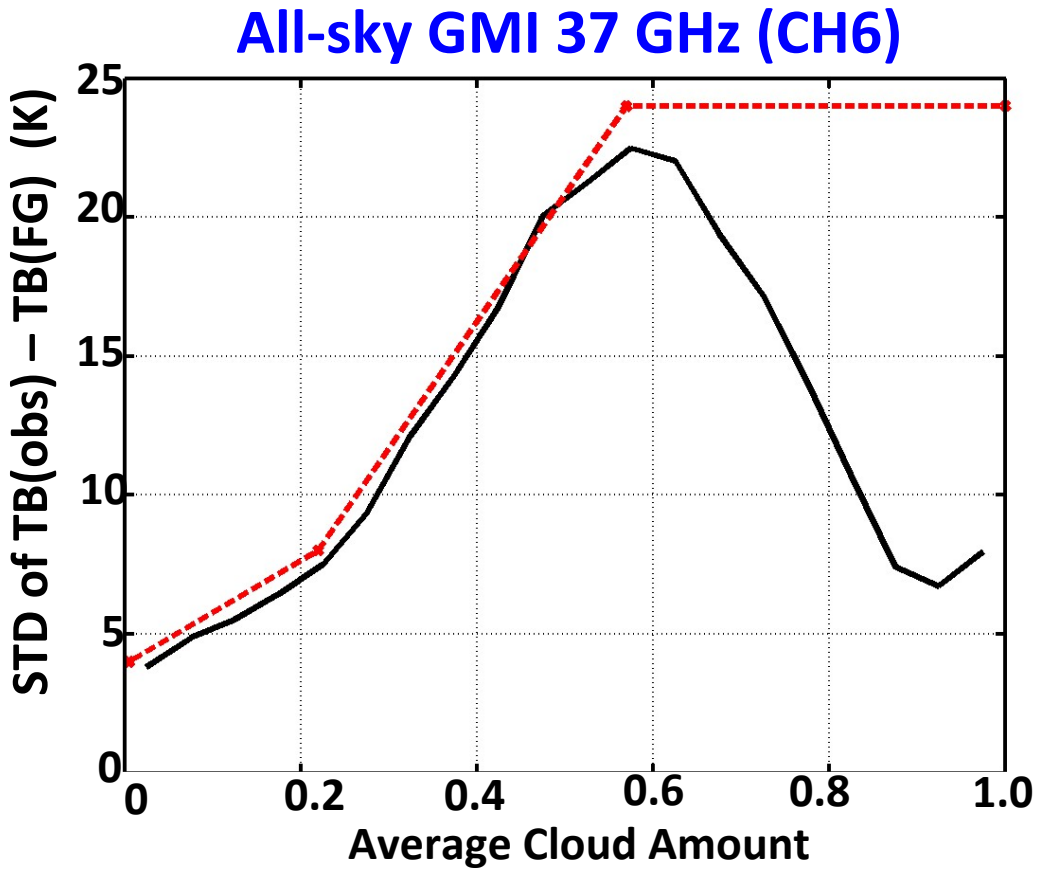
- **Observation error is defined as a function of cloud amount.**
- **Smaller errors in clear sky and larger errors in cloudy and precipitation situation**



Mean of observed and first-guess(FG) cloud amount derived from 37 GHz polarization difference

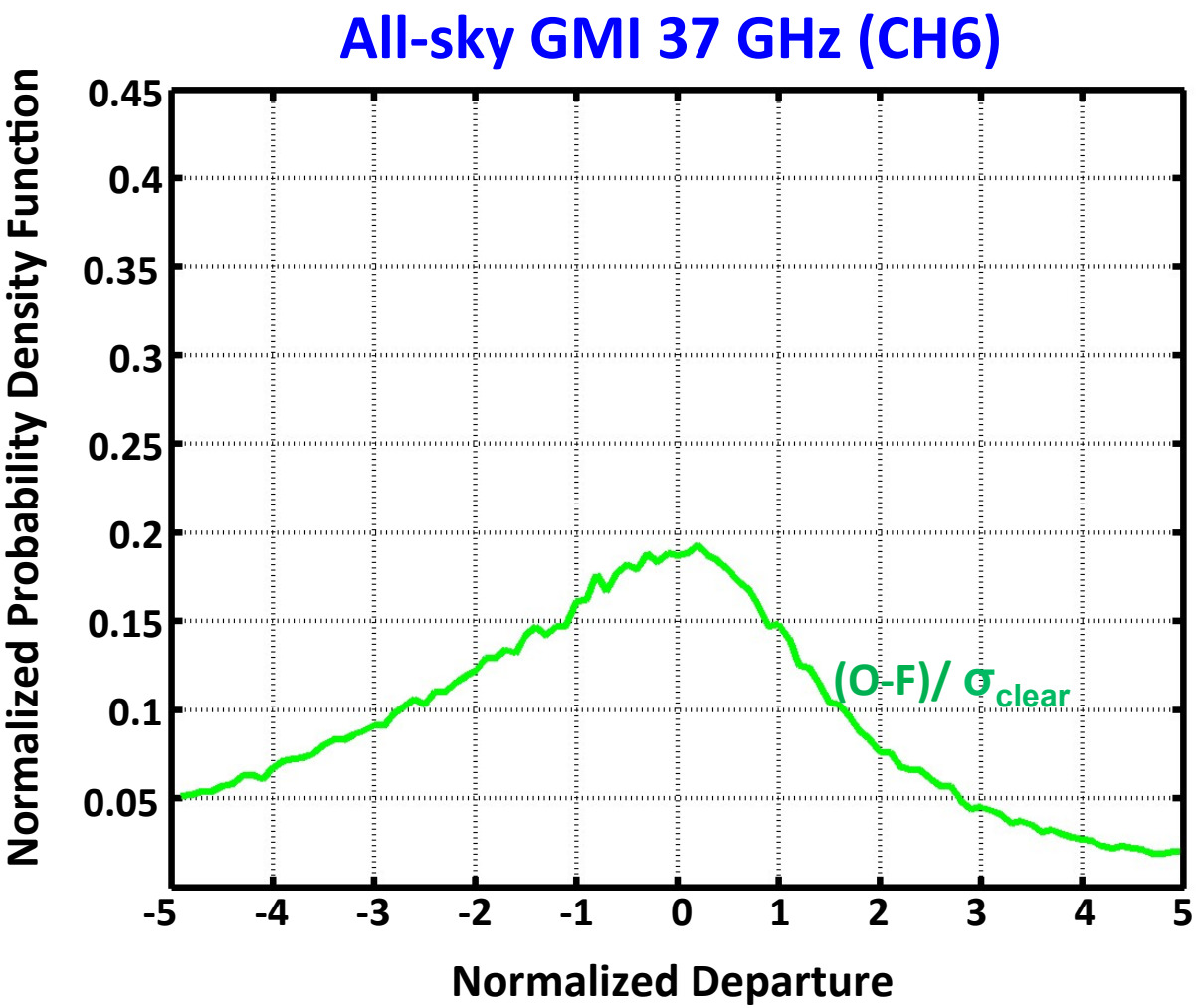
Observation Errors for All-Sky GMI

- **Observation error is defined as a function of cloud amount.**
- **Smaller errors in clear sky and larger errors in cloudy and precipitation situation**

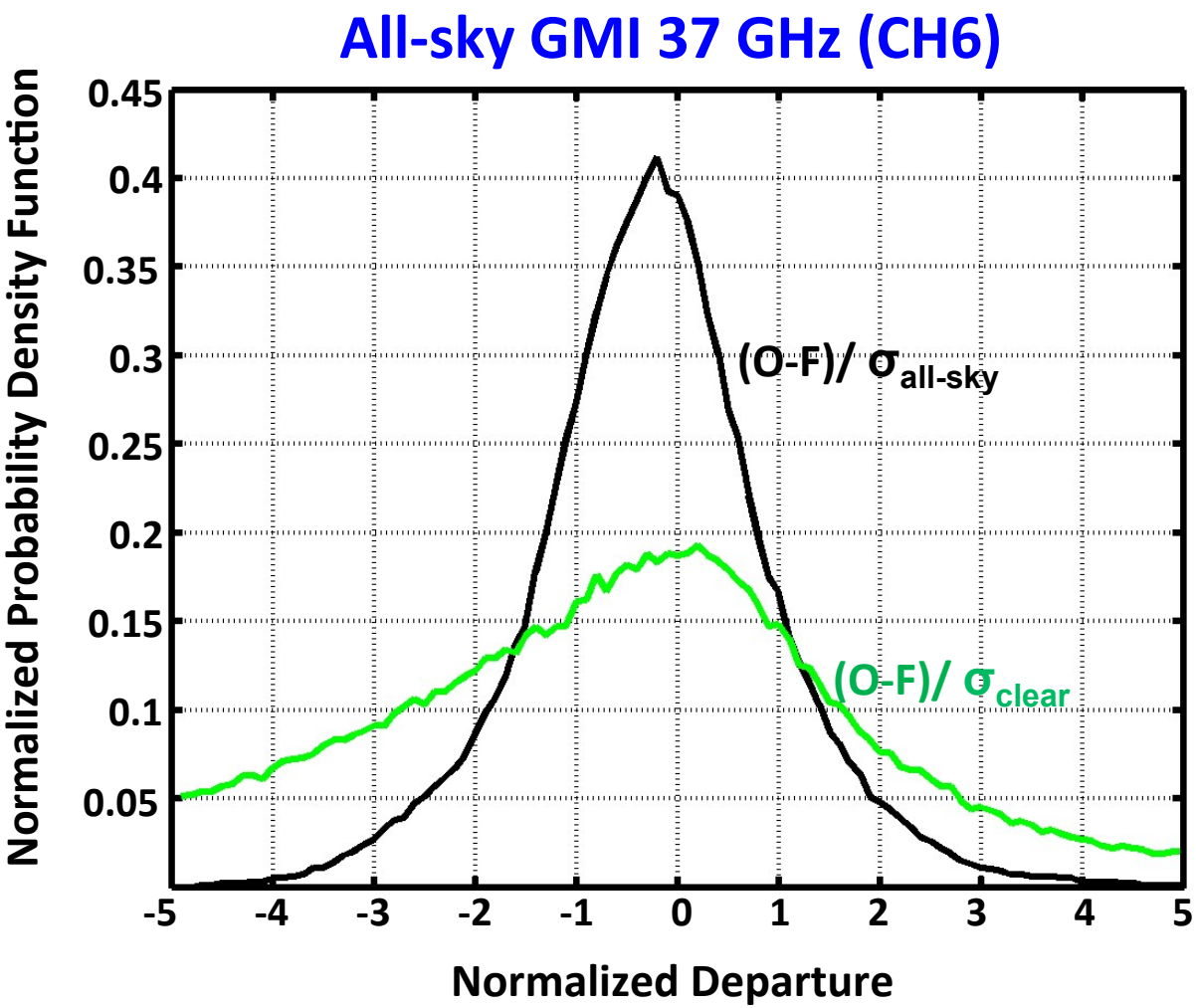


Mean of observed and first-guess(FG) cloud amount derived from 37 GHz polarization difference

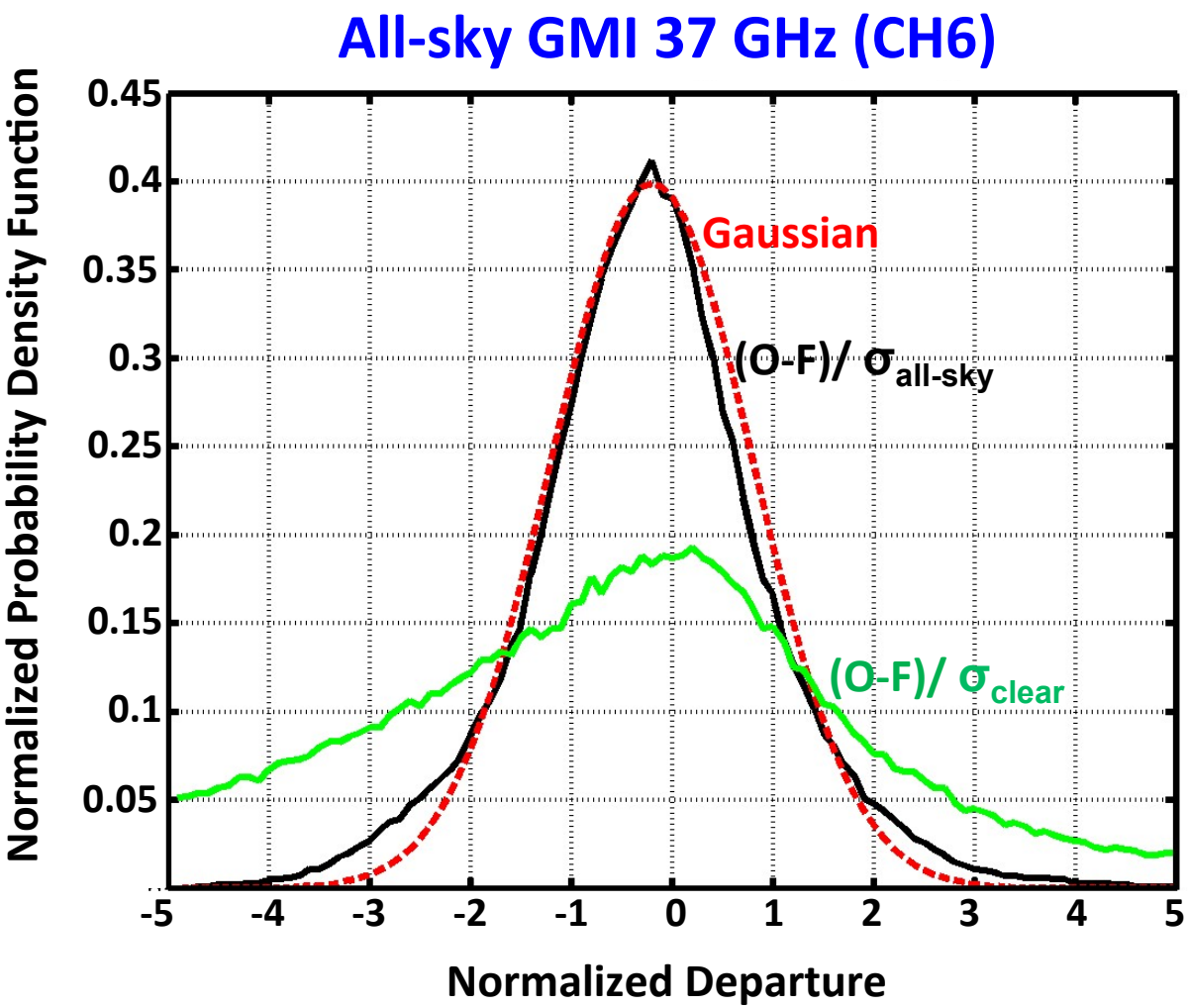
Does All-Sky GMI's O-F Satisfy Gaussianity ?



Does All-Sky GMI's O-F Satisfy Gaussianity ?



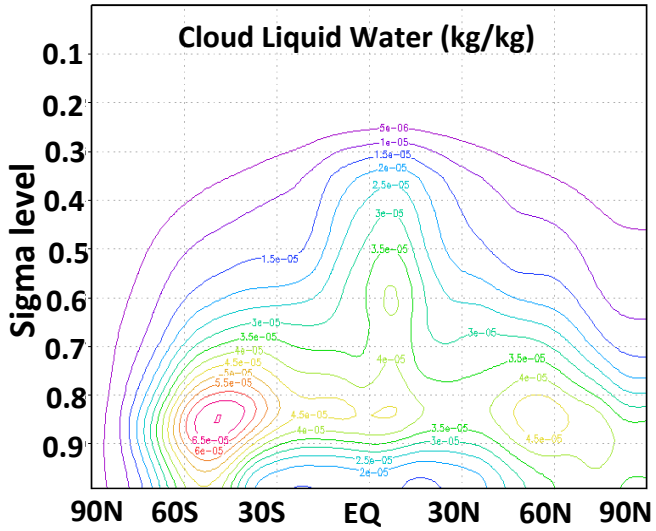
Does All-Sky GMI's O-F Satisfy Gaussianity ?

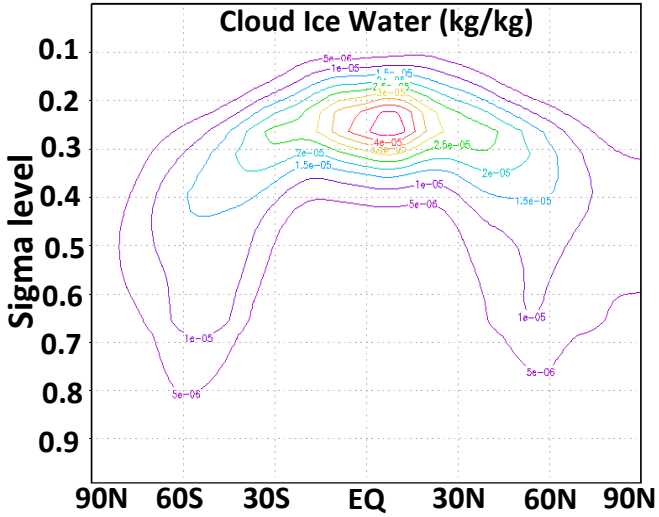


Cloud dependent observation errors help distributions to be more Gaussian.

Background Error Covariance for Clouds

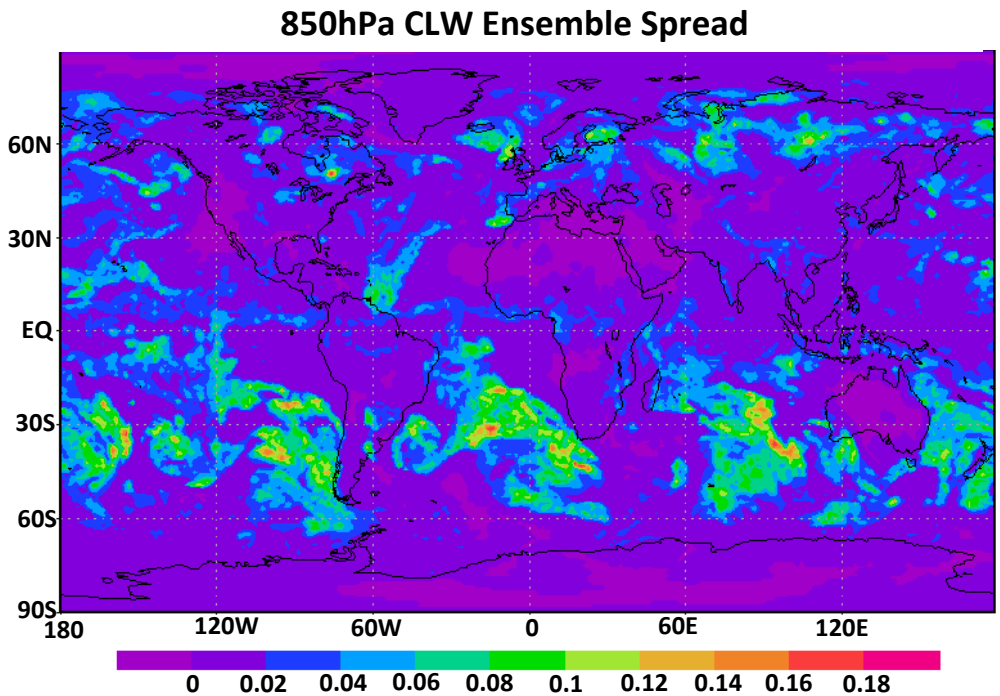
Static Background Error



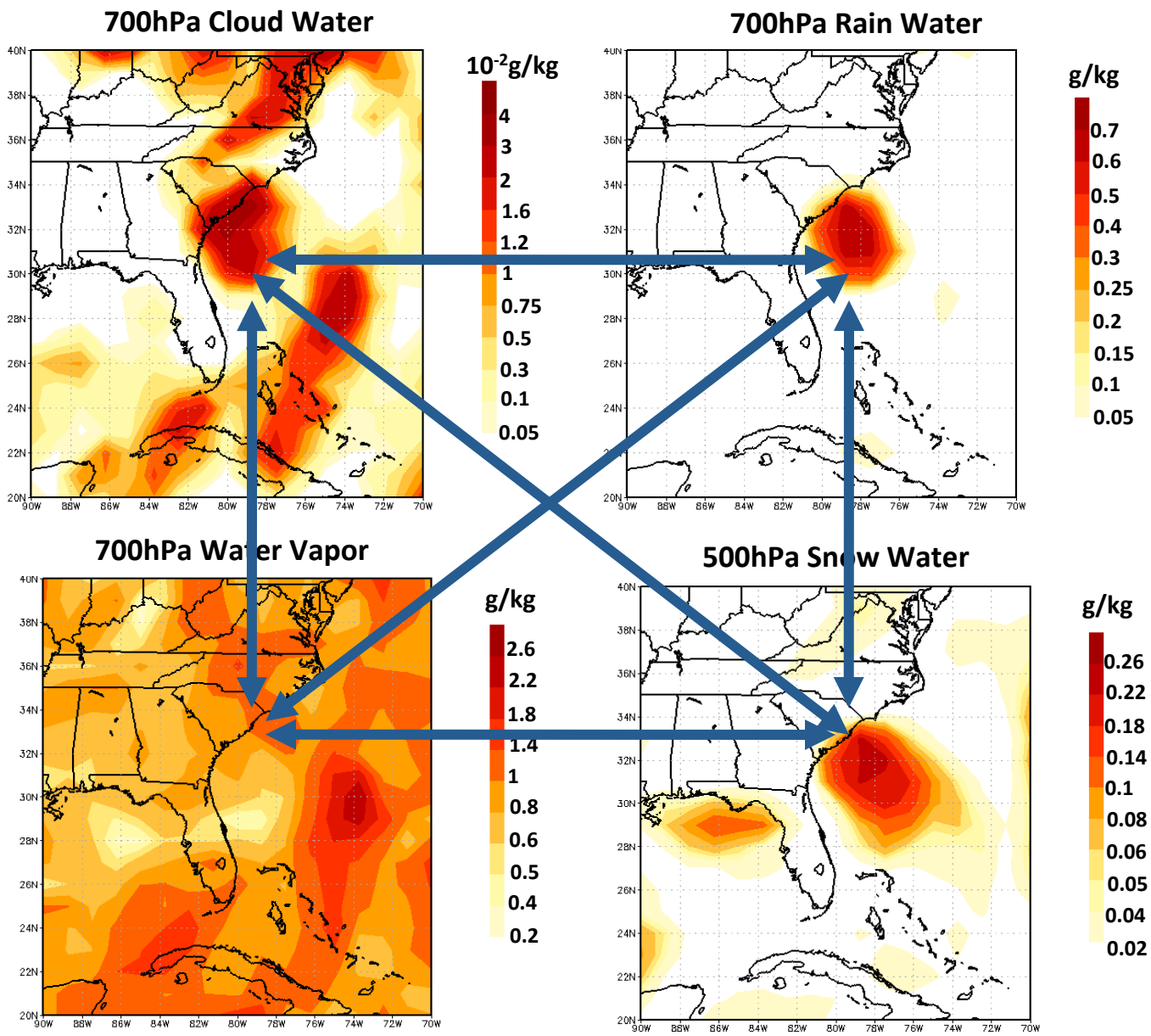


Hybrid GSI system combines these two

Ensemble Background Error



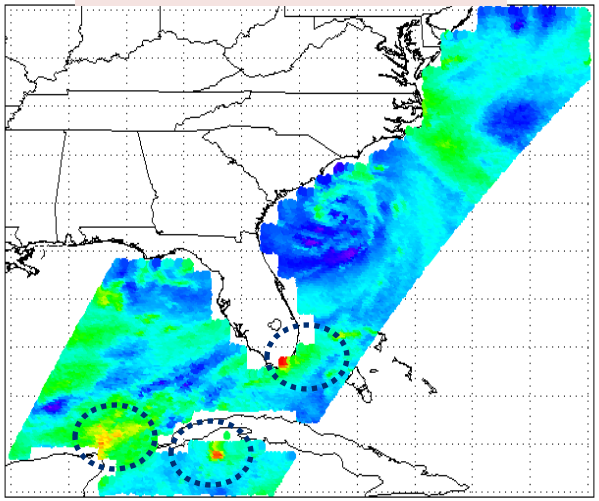
Ensemble Spread



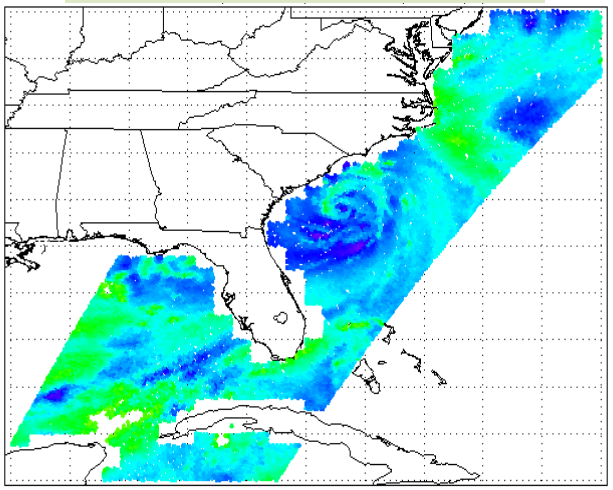
Quality Control :Gross Check using Normalized Departure

37GHz

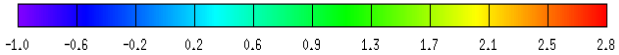
Before QC

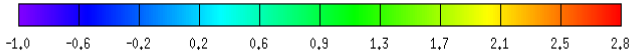


After QC



Normalized departure

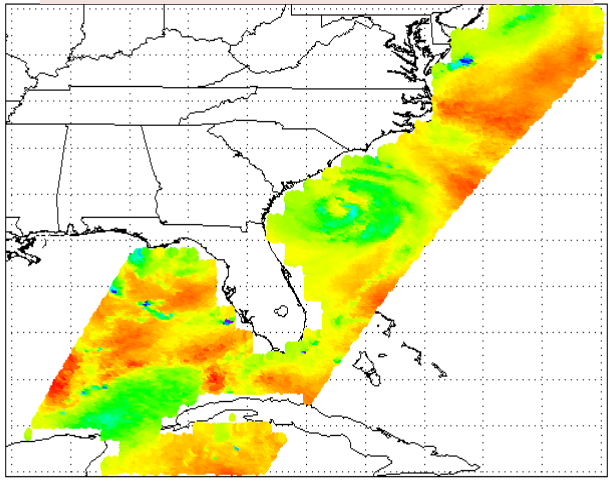




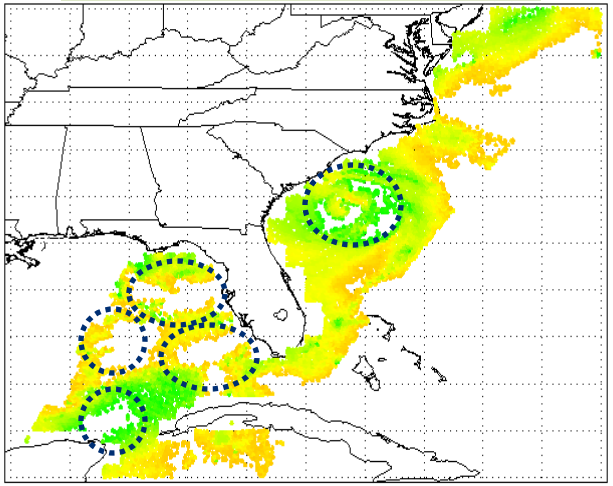
Low frequency channels:
Keeping most observations except for unscreened land contamination.

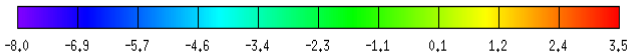
183.3+/-7GHz

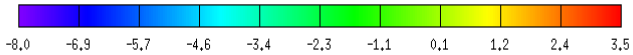
Before QC



After QC







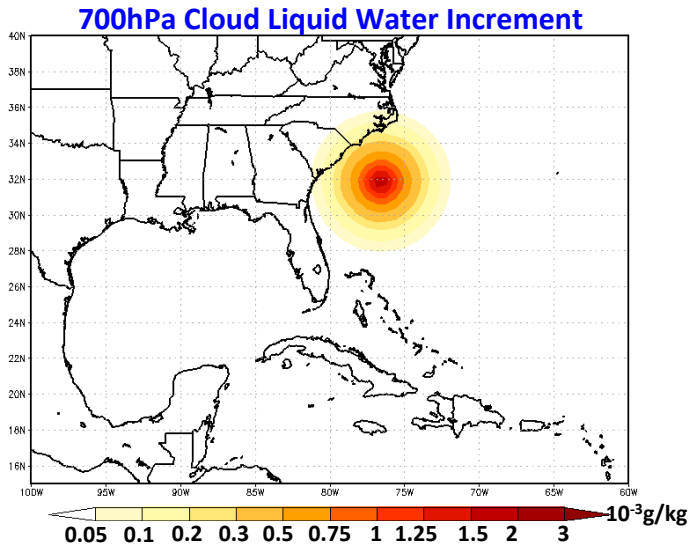
High frequency channels:
Removing data in the regions with too much discrepancy between observed clouds and background clouds

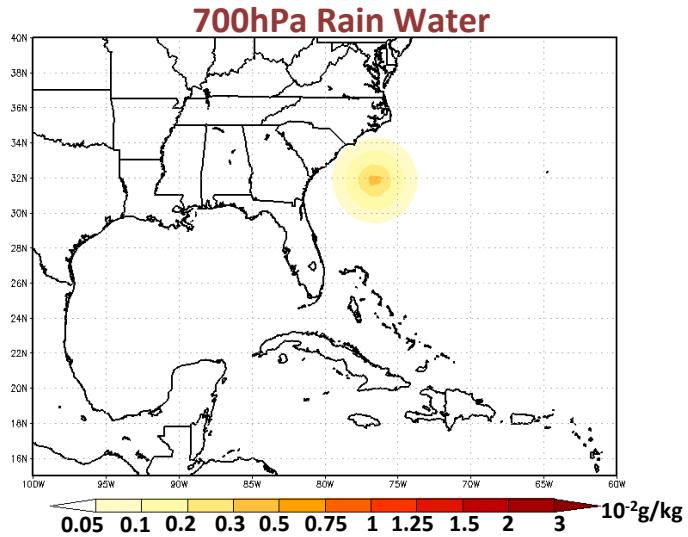
Preliminary Results

Single Obs Point Test

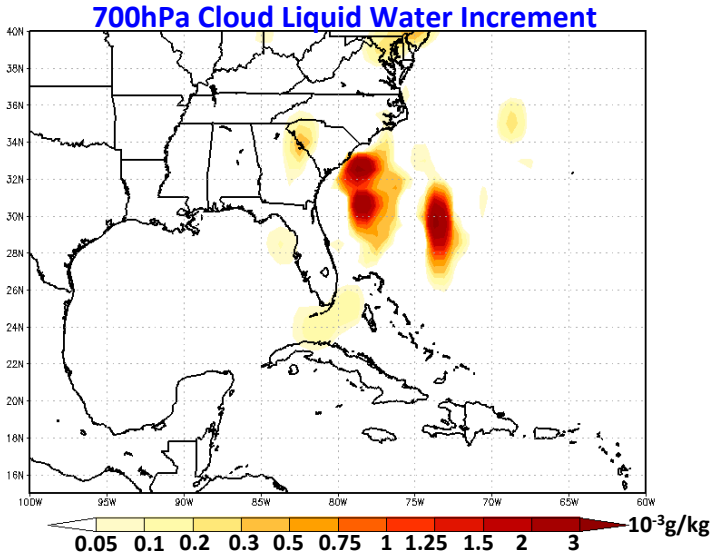
- Test with GMI observations at one observation location.
- Observed cloud&precipitation >> Background cloud & precipitation
- 9 GMI channels (channels 3, 4, 5, 6, 8, 10, 11, 12, and 13) were used.

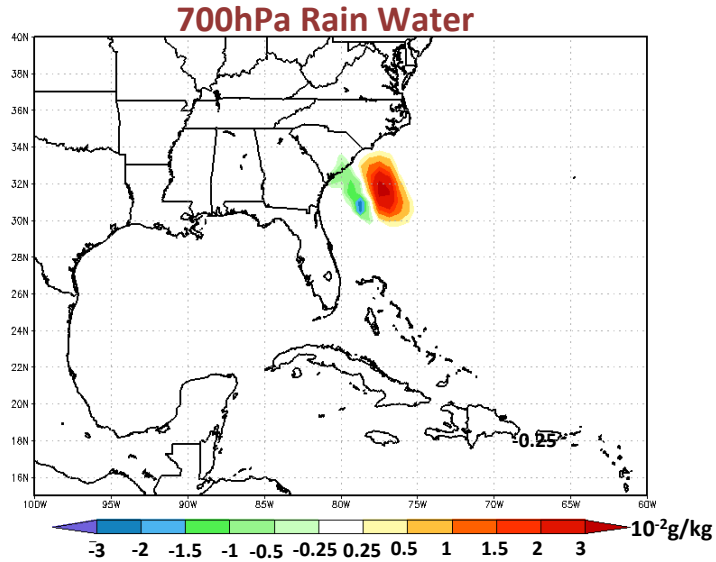
3DVAR





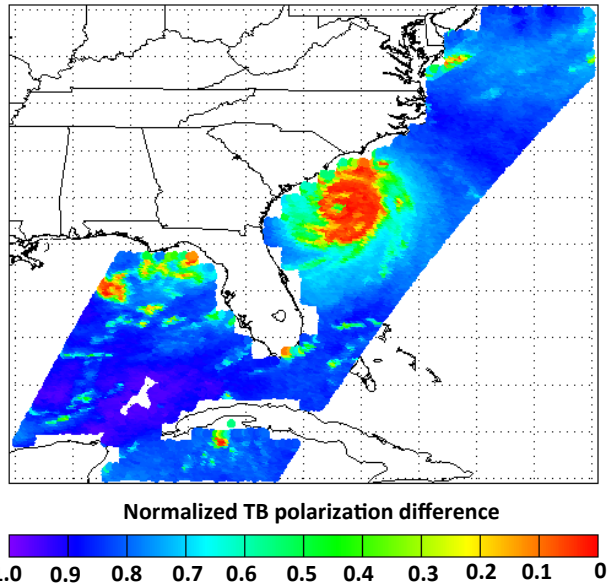
Hybrid



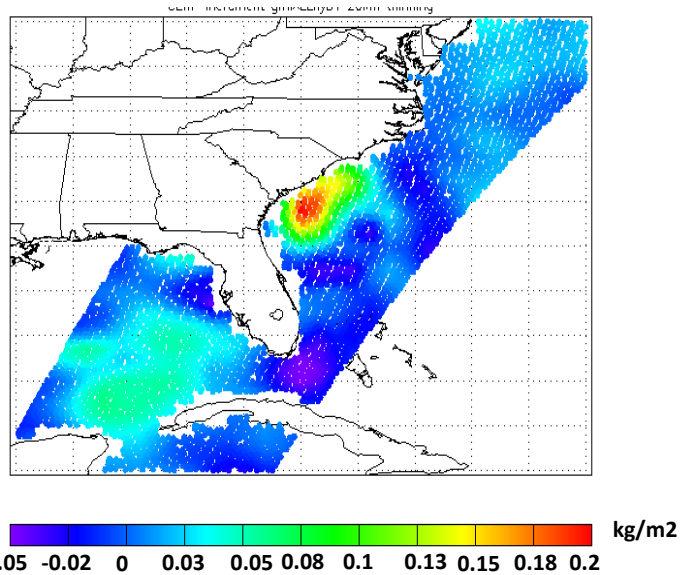


Cloud and Precipitation Analysis Increments from Assimilating GMI Data

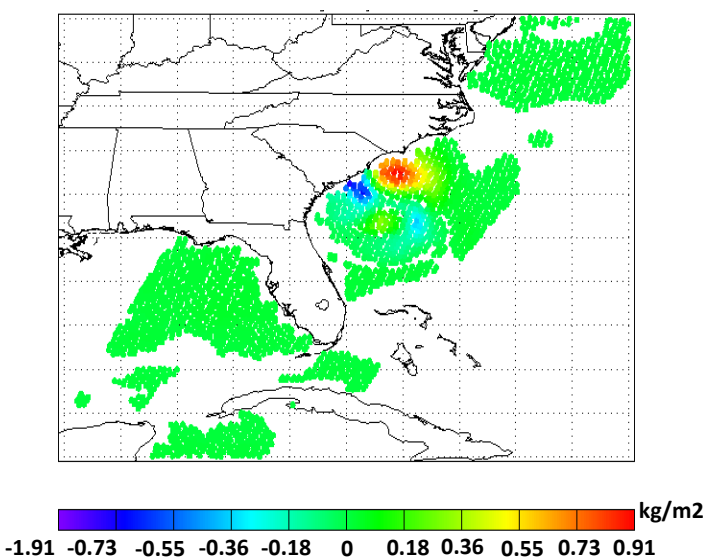
GMI Observation (37GHz)



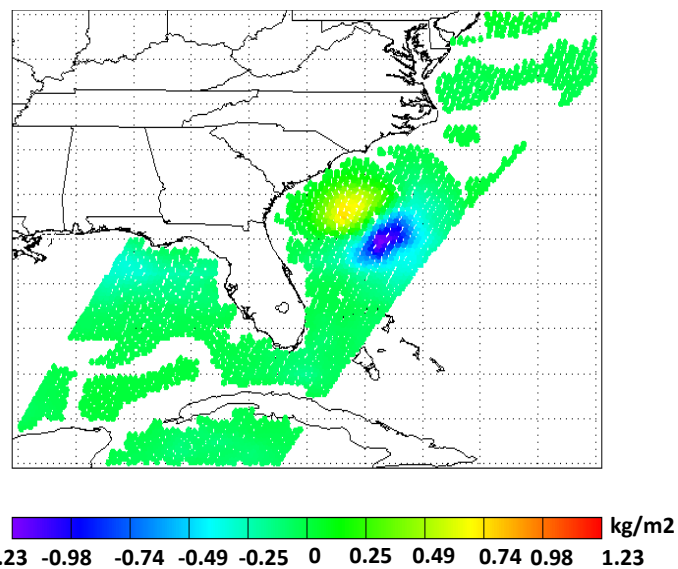
Cloud liquid water



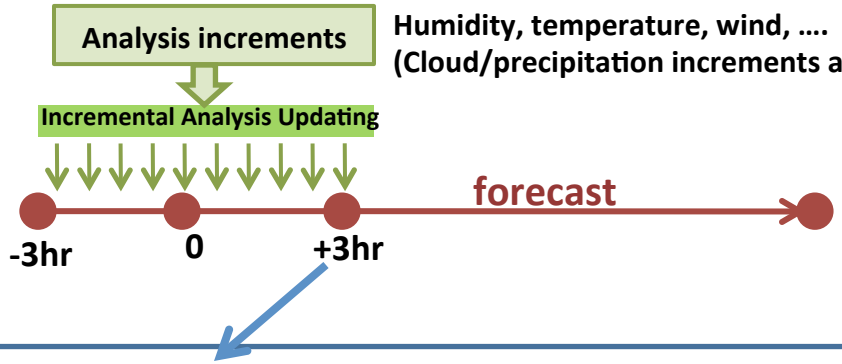
Rain water



Snow water



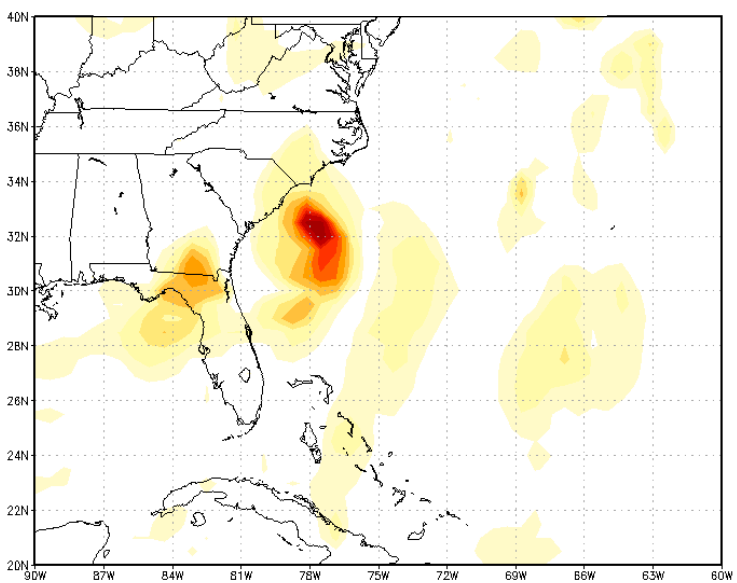
Impacts of GMI Radiance Data on GEOS-5 Precipitation Forecasts



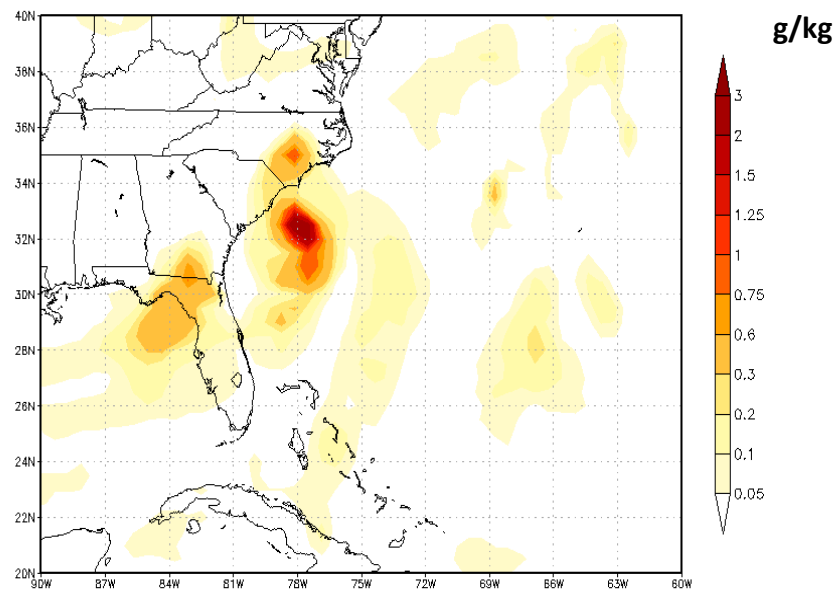
Humidity, temperature, wind, ….
(Cloud/precipitation increments are not applied back to forecast model yet..)

6hr surface precipitation (PRECTOT) forecasts

Conv, other satellite observations +
No GMI data assimilated



Conv, other satellite observations +



Future Work

1. Examine the impacts of all-sky GMI radiance data assimilation on GEOS-5 forecasts through cycled experiments using the hybrid system.

2. Expand ocean-only all-sky GMI framework to utilize GMI data over land.
   - Improving precipitation over land will be beneficial for land surface modeling.
   - Improved surface background fields will be beneficial for calculating surface emissivity to assimilate microwave radiance data over land.

3. Apply and test GMI all-sky radiance data assimilation framework in the 4D-EnsVar system currently in development at the GMAO.