



# Impact of satellite radiance data assimilation on GEOS atmospheric analysis and forecasts in Tropics

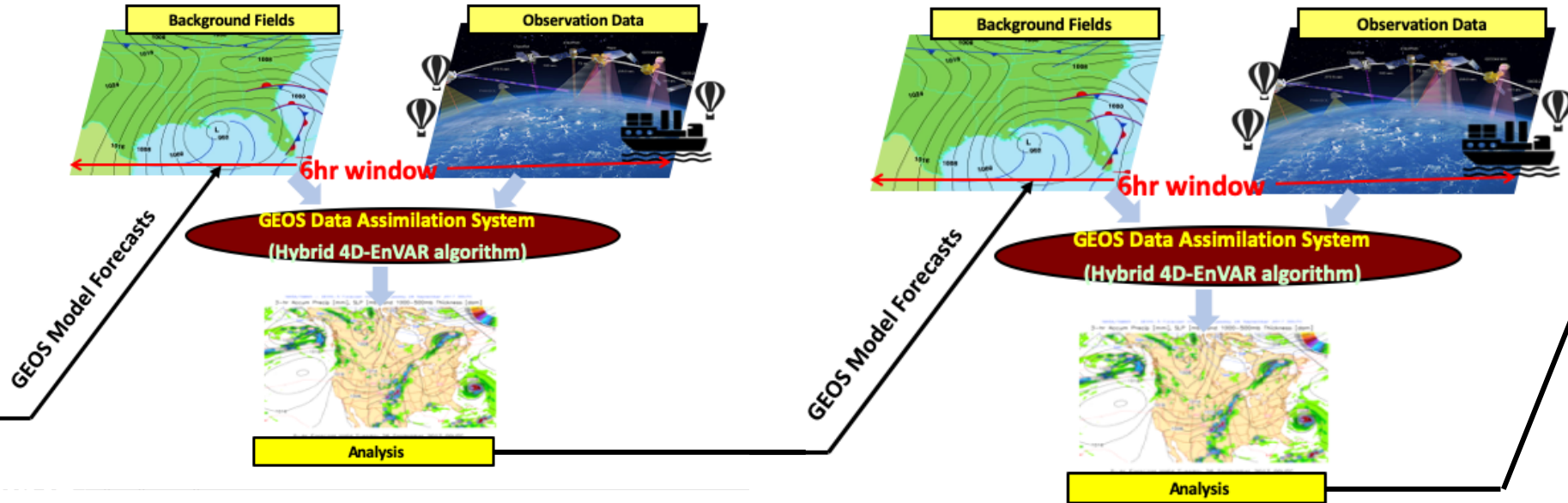
**Min-Jeong Kim**

NASA Global Modeling and Assimilation Office (GMAO)  
Morgan State University / GESTAR

# Atmospheric Data Assimilation System in GEOS



- The Goddard Earth Observing System (GEOS) is a global NWP system used at NASA GMAO for applications across a wide range of spatial scales, from kilometers to many tens of kilometers.
- GEOS atmospheric data assimilation system is currently based on Hybrid 4D-EnVar algorithm.
- It combines GEOS short-term forecasts and observations during 6 hour window and estimates analysis. This analysis is used as initial fields for GEOS forecasts next cycle.



# How can Data Assimilation Help make better NWP forecasts of Tropical Cyclones?

Tropical Cyclone need three main factors to develop:

- **Warm SST, Moist air, Low wind shear**

If we have better analyses

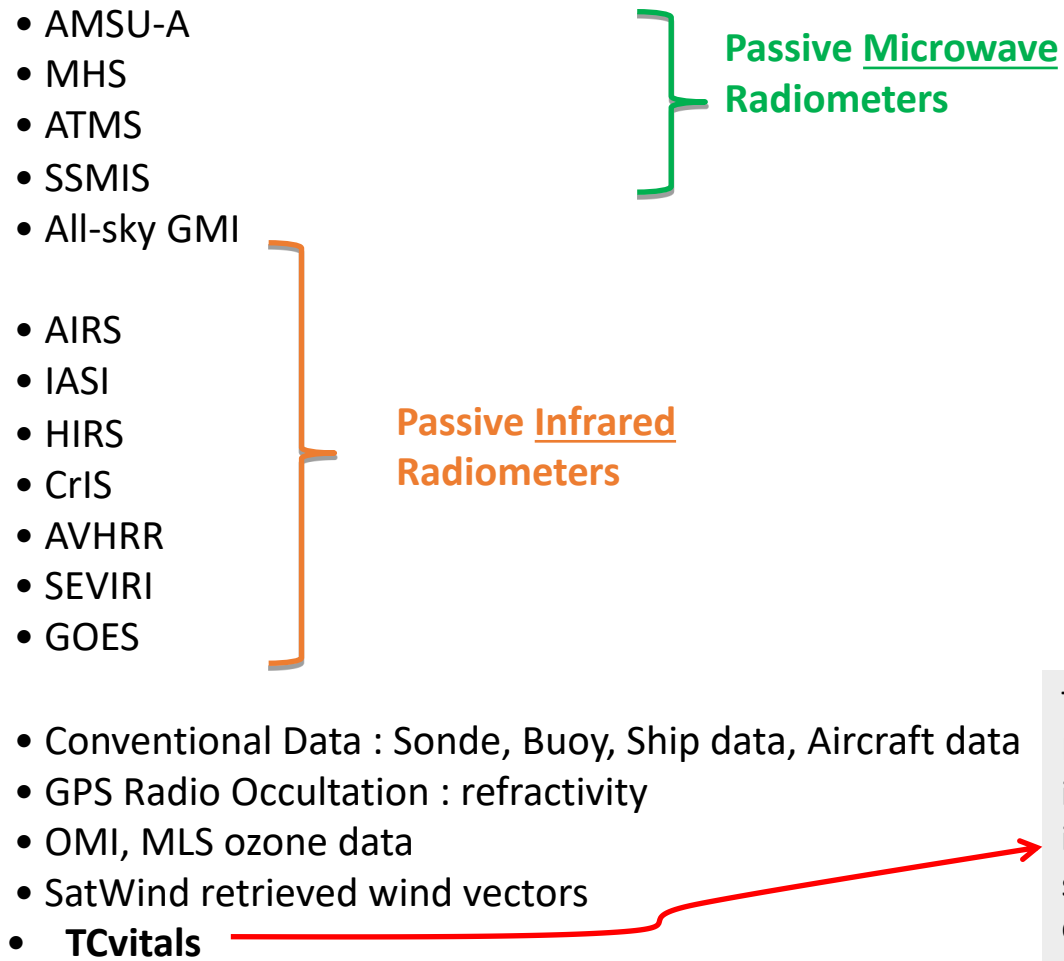
- **Temperature distribution**
- **Atmospheric wave patterns, Low/High Pressure pattern**
- **Wind distributions**
- **Moisture distributions**
- **SST distributions**

**Assimilating various  
observation data can  
improve these!**



We will more likely have better NWP skills in Tropical Cyclone forecasts.

# Data Currently Assimilated In GEOS Forward Processing (FP) System



The TCVitals is an archive of Cyclone Message text files that contain information such as cyclone location, intensity, horizontal wind and pressure structure, and depth of convection created in real time by forecasting centers.

# Data Denial Experiments

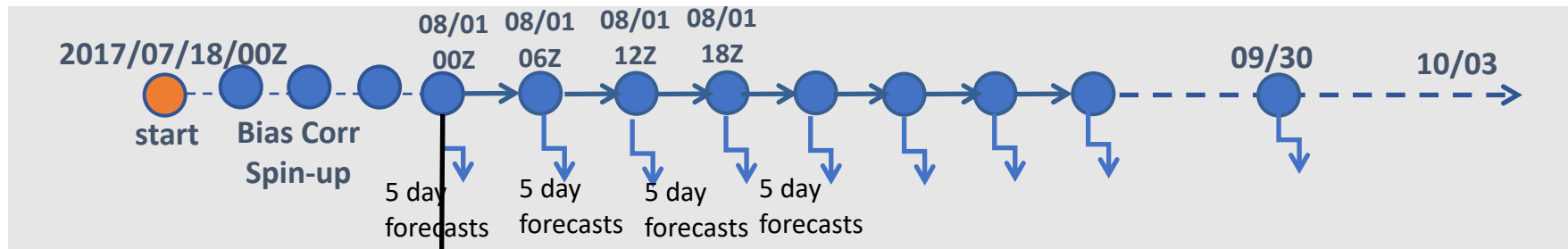
- How much is assimilating observation data actually helping GEOS improve Tropical Cyclone forecasts?
- What different types of observations do in our system for Tropical cyclone analysis and forecasts?

- ☐ **Control:** All available observation data are assimilated
- ☐ **NoMW:** Not assimilating data from microwave sensor
- ☐ **NoIR:** Not assimilating data from IR radiometer
- ☐ **NoTCVital:** Not assimilating TCvital data
- ☐ **Free Run:** No data are assimilated

# Experiment Setup



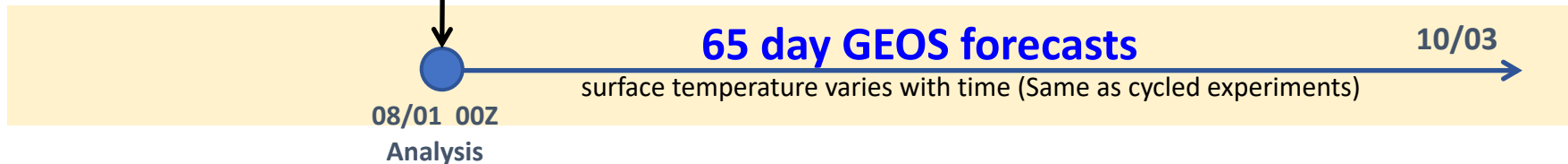
Data assimilation implemented every 6 hour



- Data assimilation algorithm: **Hybrid 4D-EnVar**
- $0.25^\circ$  (forecast).  $0.5^\circ$  (analysis) horizontal resolution
- 72 vertical levels
- NoMW and NoIR experiments: Ensemble backgrounds are replayed using Control.

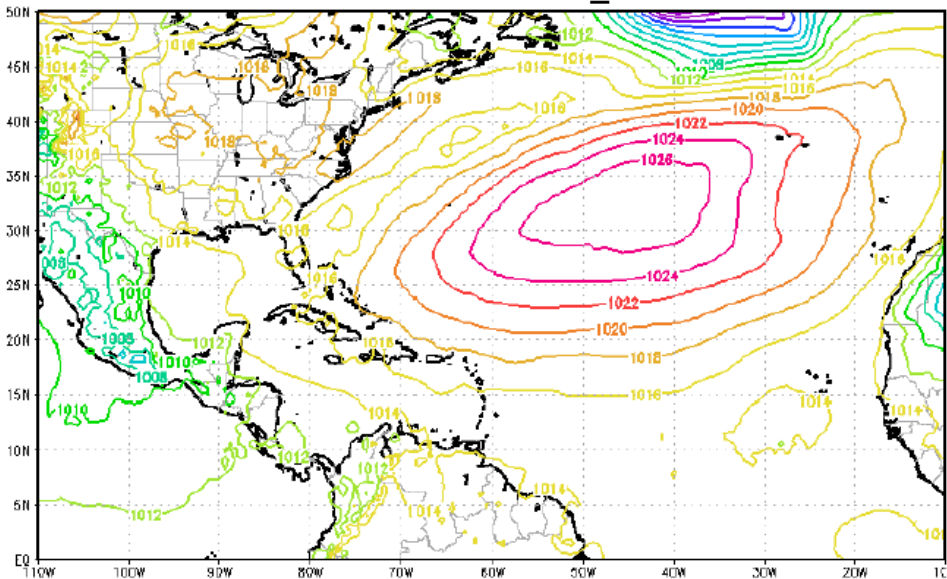
Free Run

**65 day GEOS forecasts**

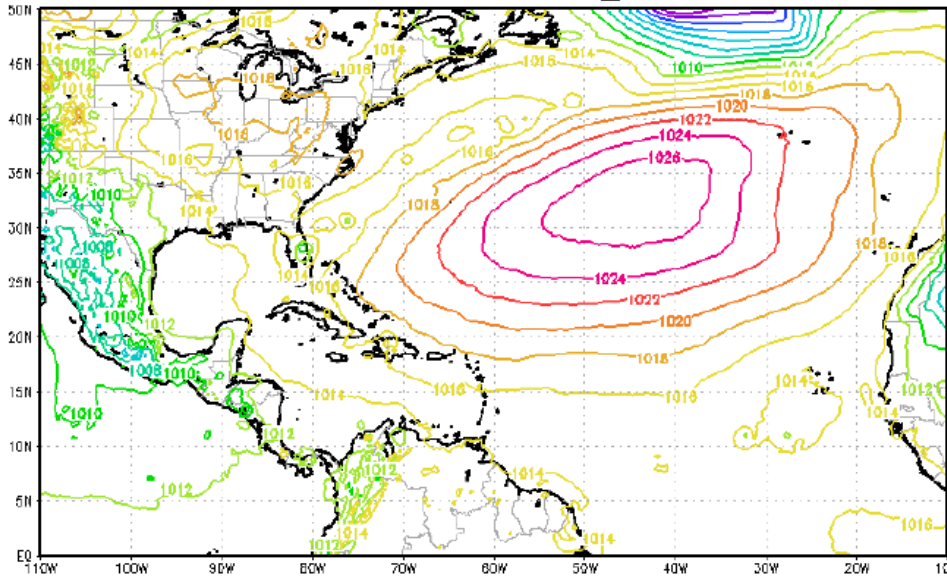


## Sea Level Pressure (SLP)

**Control** 20170801\_00z

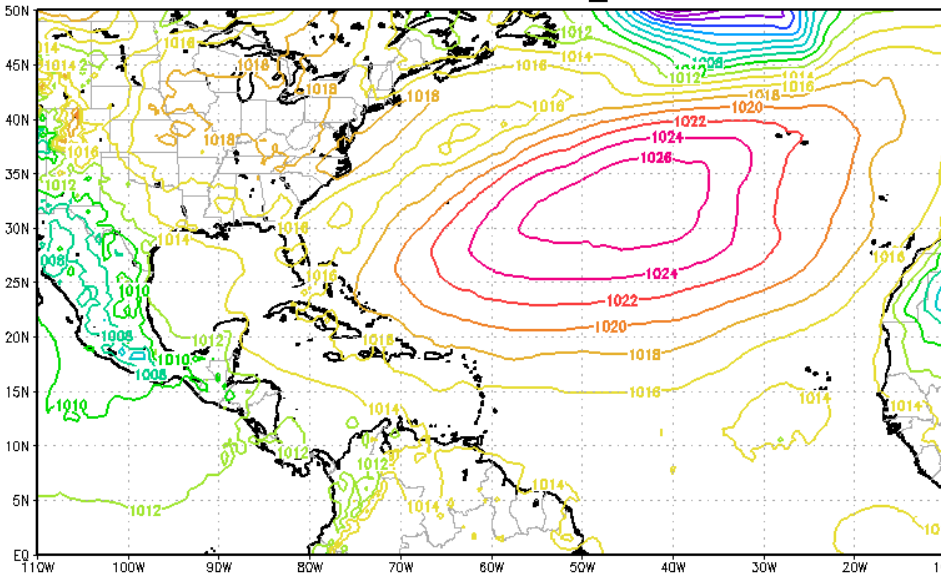


**FreeRun** 20170801\_00z

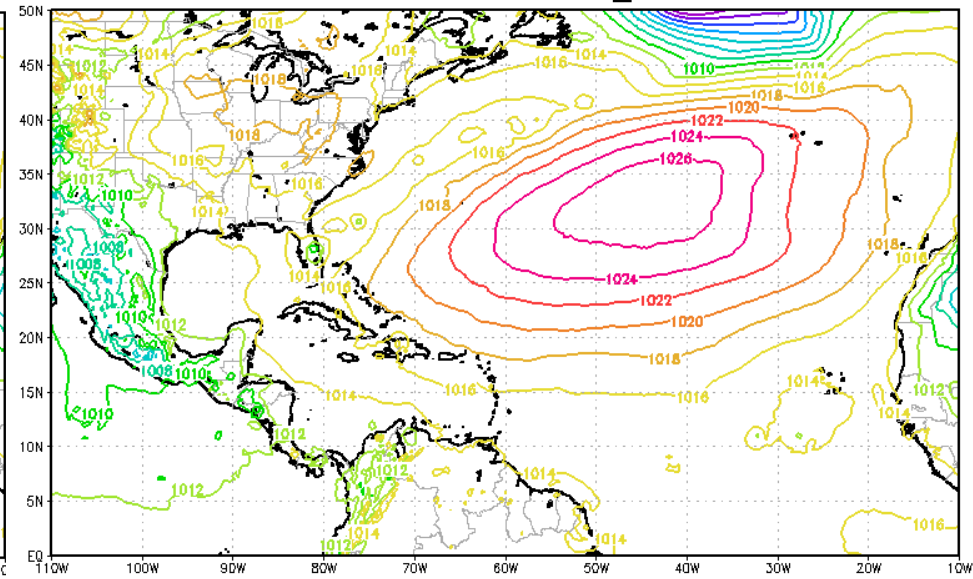


## Sea Level Pressure (SLP)

**Control** 20170801\_00z

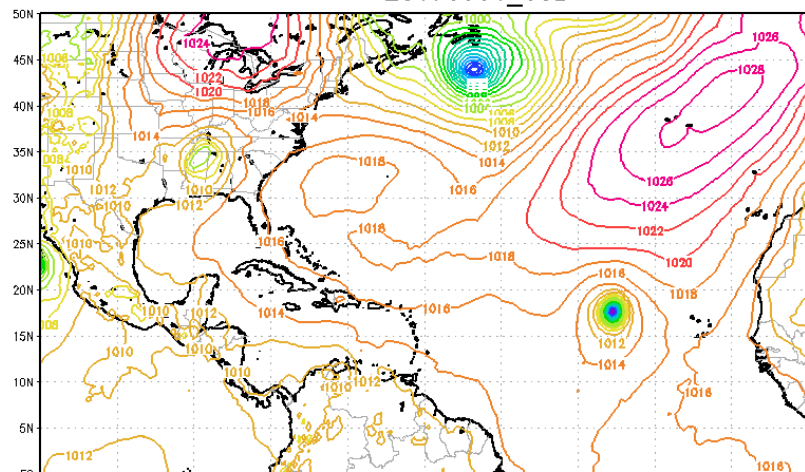


**FreeRun** 20170801\_00z



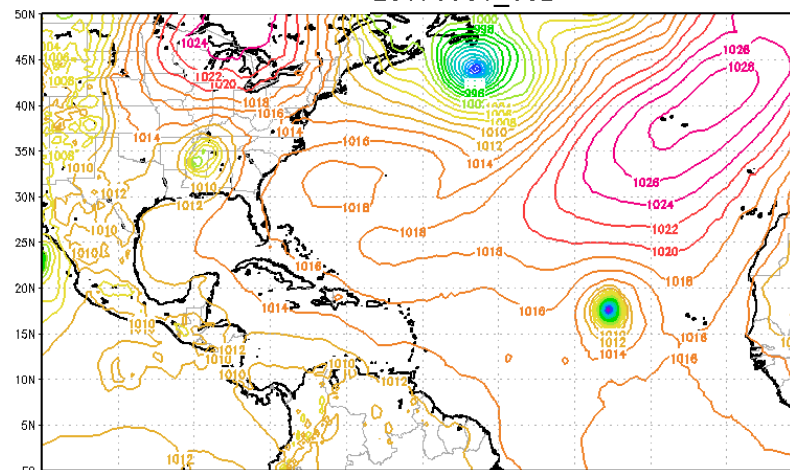
**Control**

20170901\_00z



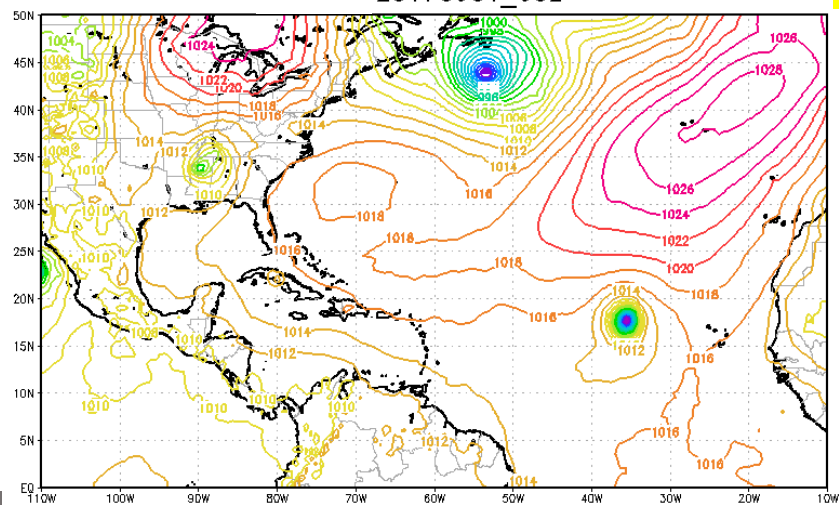
**NoMW**

20170901\_00z



**NoIR**

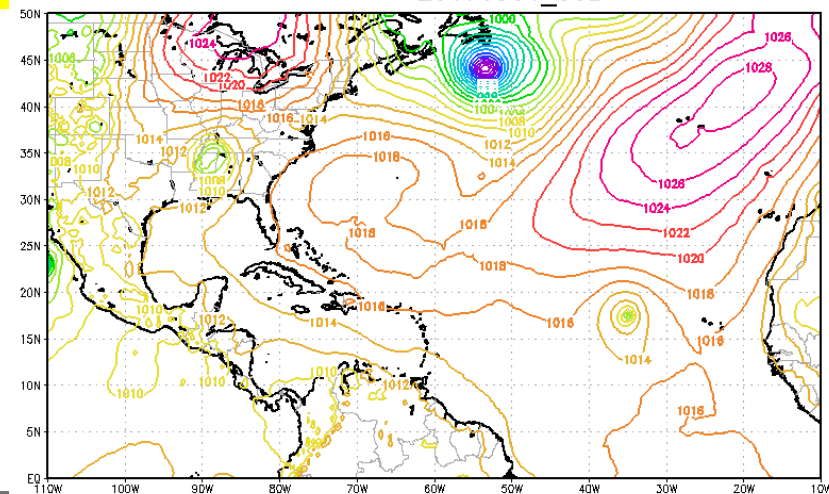
20170901\_00z



**SLP**

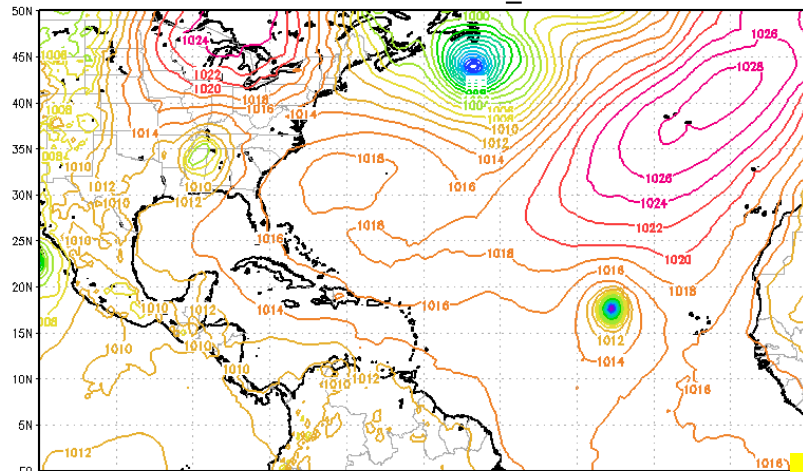
**NoTCvital**

20170901\_00z



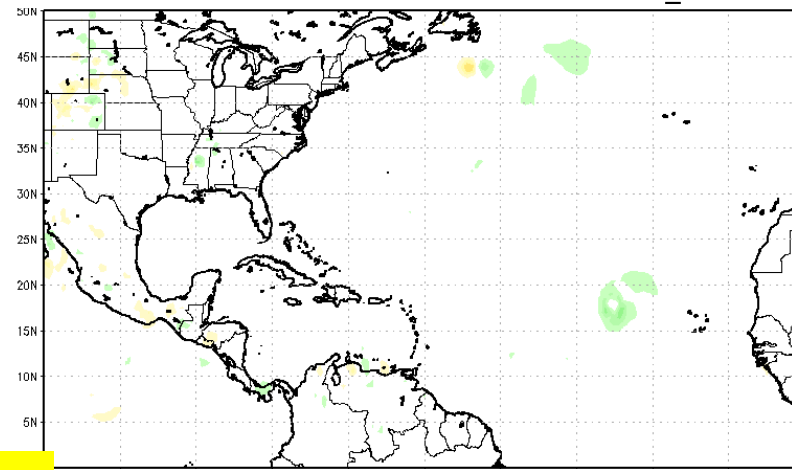
**Control**

20170901\_00z



**NoMW-Control**

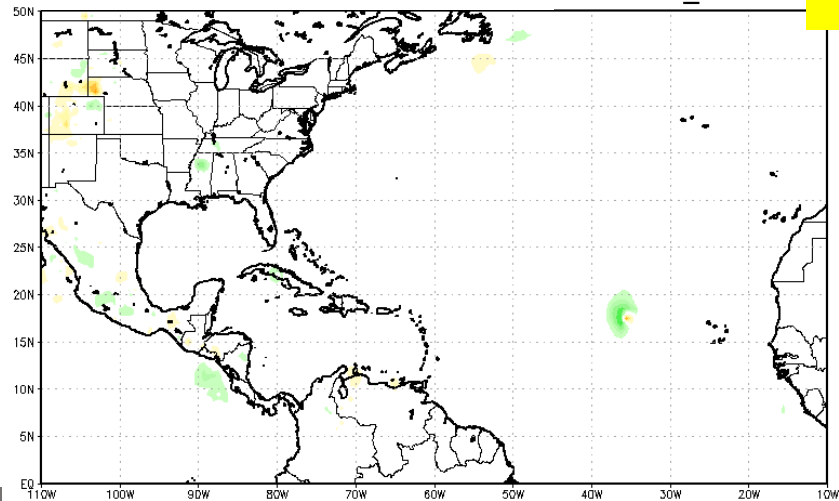
20170901\_00z



**SLP  
(mb)**

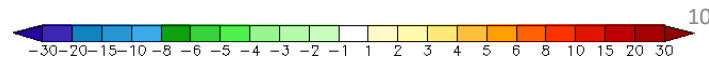
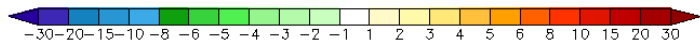
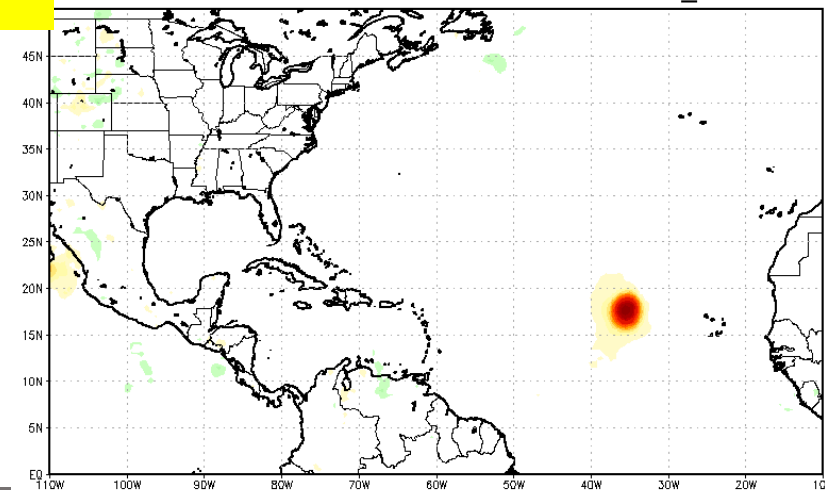
**NoIR-Control**

20170901\_00z



**NoTCvital-Control**

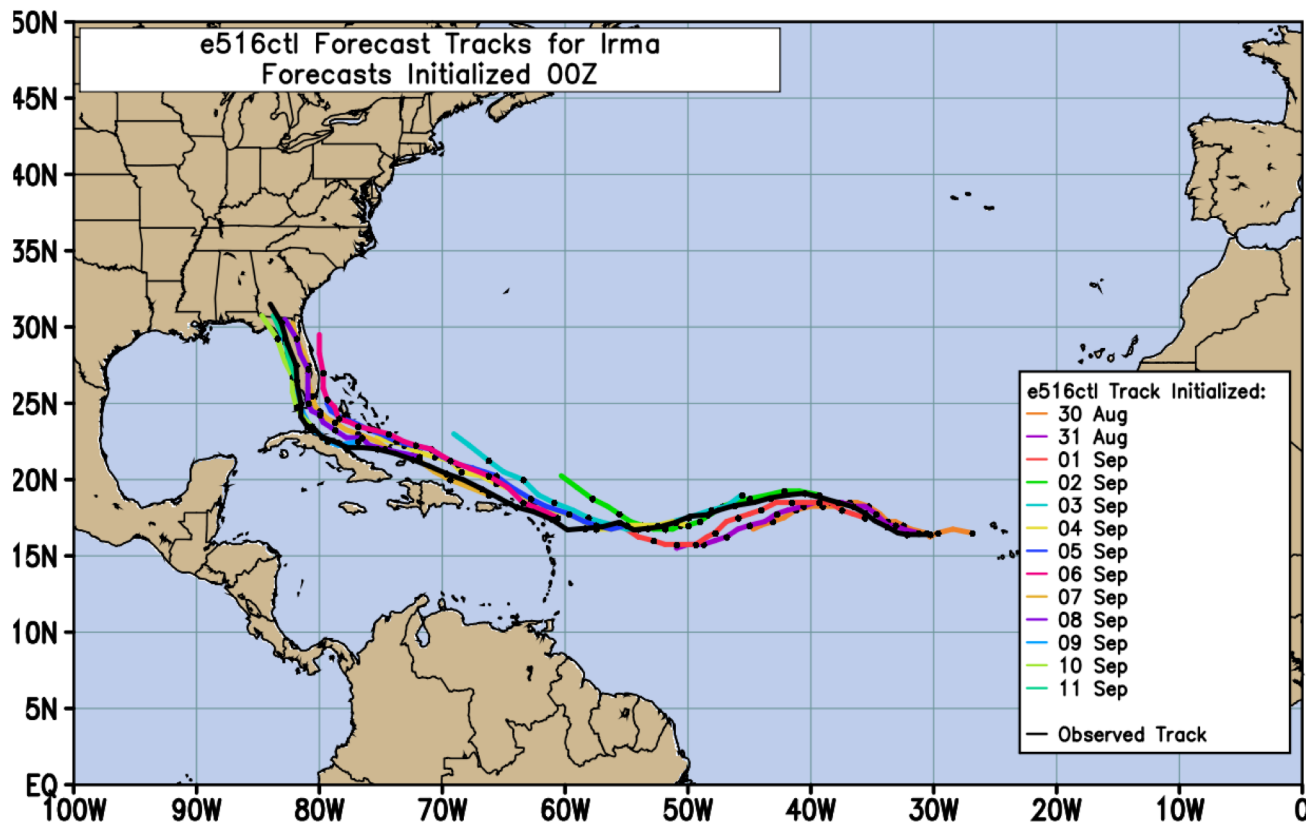
20170901\_00z



10

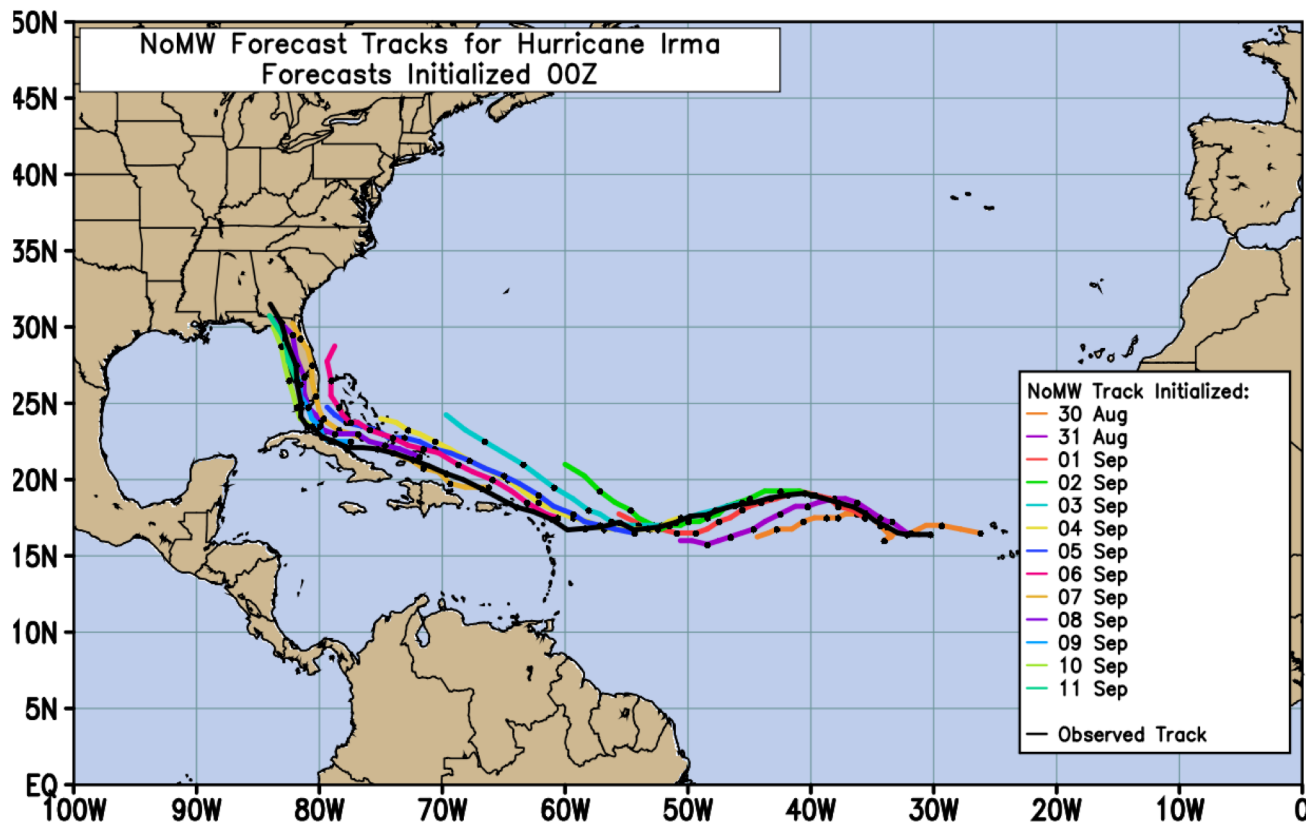
# Hurricane Track Forecast (Irma)

Control

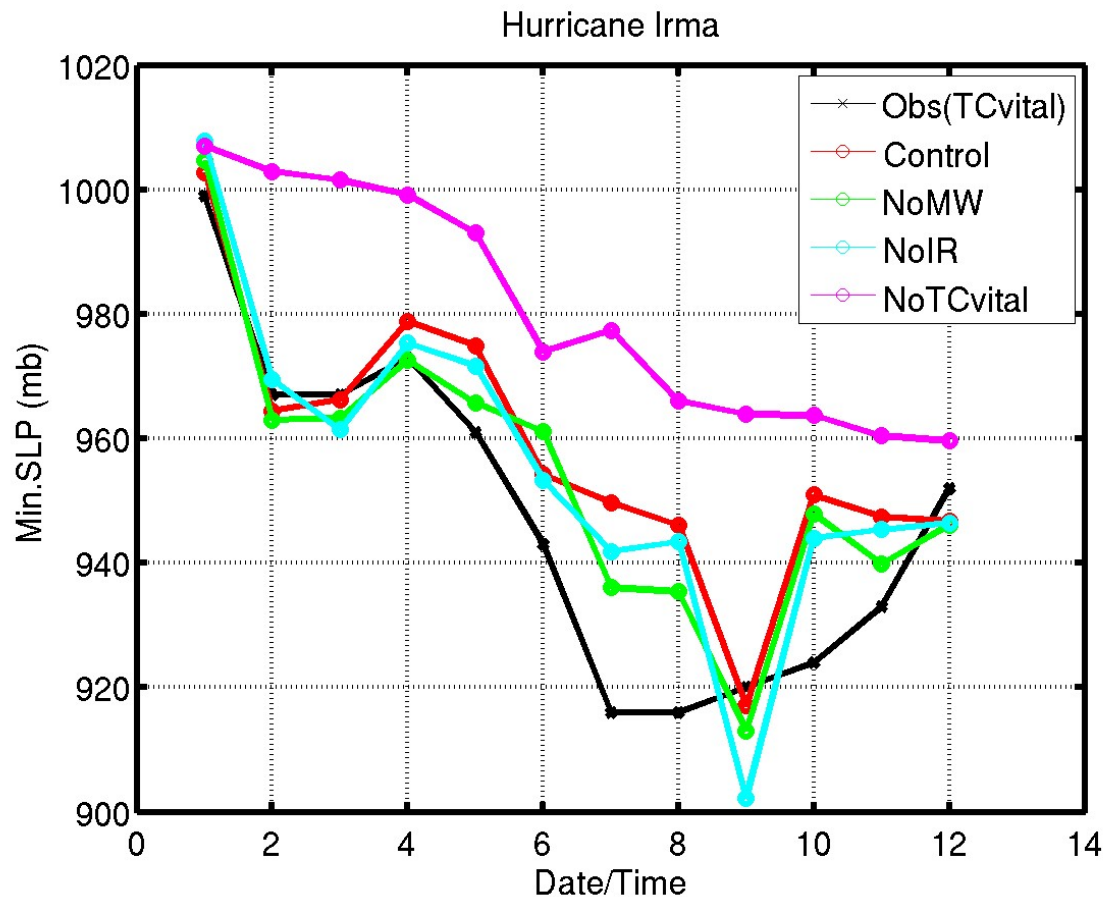


# Hurricane Track Forecast (Irma)

NoMW



# Hurricane Intensity Comparisons in Analyses



- Without Tc vital, intensity in analysis seems very weak. That is, in this hurricane Irma case, the Tc vital played an important role to make the analyzed intensity close to the observation.
- NoMW or MoIR show similar intensity evolution to the control run. That is because if there is no mw data, the IR sounders provide analysis information that was provided by the mw and vice versa.

# Lessons learned from this experiments so far...

- **Assimilating observations for better analyses is super important for Tropical cyclone analysis and forecasts.**
  - \* Conventional data seem most critical to analyze pressure systems and waves patterns that link to formation and propagations of tropical cyclones
  - \* Satellite MW and IR radiance data seem improving especially Tropical cyclone tracks by analyzing detailed humidity and temperature distributions over ocean.
  - \* TCvital data seem to help intensity analysis and forecasts rather than hurricane track forecasts.



# All-sky Microwave Radiance Data Assimilation in GEOS

# All-sky Microwave Radiance Data Assimilation in GEOS

- ❑ By enhancing GEOS analysis system with all-sky data assimilation capability, GMAO extended radiance data usage to gain more information on atmospheric states in cloudy and precipitating regions. The above shall improve GEOS analyses and weather forecasts.
- ❑ On July 11<sup>th</sup>, 2018, Global Precipitation Measurement (GPM) Microwave Imager (GMI) observations were implemented into the GMAO Forward Processing (FP) system
  - Assimilation of GMI radiances in near-real-time
  - Active assimilation under all-sky situations, eliminating previous limitation to those unaffected by clouds and precipitation
- ❑ This all-sky system is currently extended to assimilate data from other microwave sensors such as MHS, ATMS, SSMIS, SAPHIR, ...

# Assimilation of cloud- and rain-affected radiances



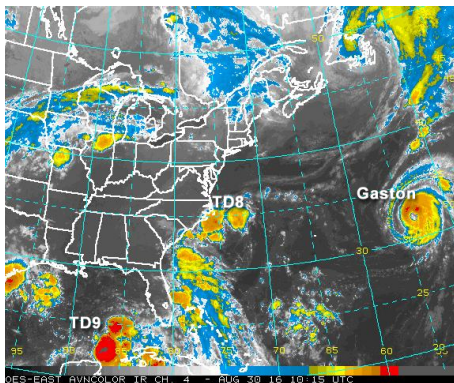
Significant changes were made in GEOS Atmospheric Data Analysis System to assimilate cloud and precipitation affected radiances.

- **New state and analysis variables** for hydrometeors such as **liquid cloud, ice cloud, rain, and snow** were added.
- **Background error** for hydrometeors were added.
- **Observation error models** (symmetric error model, Geer and Bauer 2011) were built and tuned.
- **Bias correction methods** and **quality control procedures** for all-sky microwave radiance data were developed.
- **Enhancing cloud and precipitation optical properties in the Community Radiative Transfer Model (CRTM)** which plays a role as observation operator converting GEOS model fields to radiances measurable by GPM Microwave Imager.

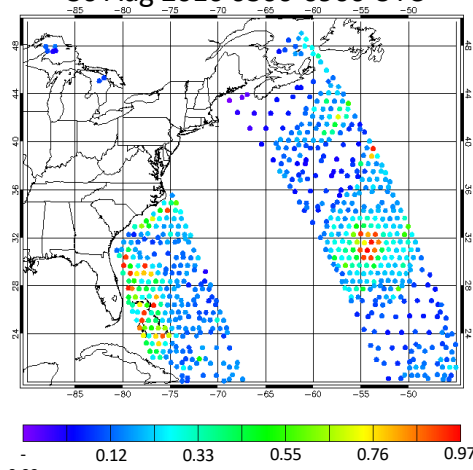
# Dynamic adjustments in precipitating regions



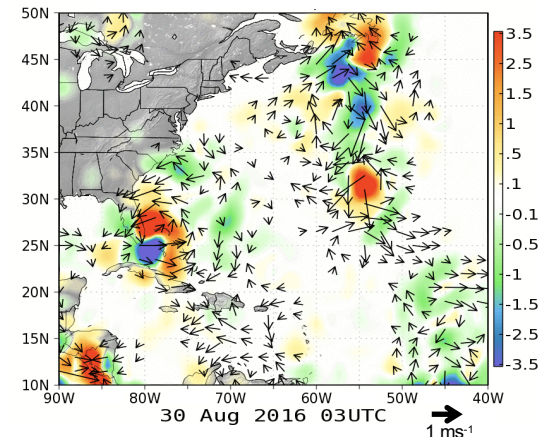
**GOES East IR Imagery**  
30 Aug 2016 1015 UTC



**GMI 37-GHz Tb Polarization Diff**  
30 Aug 2016 0300-0900 UTC



**Analysis Increments 850hpa wind, rain**  
30 Aug 2016 0300-0900 UTC

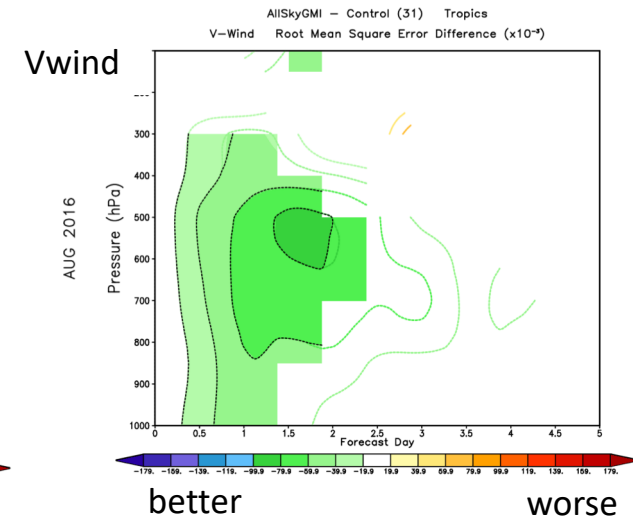
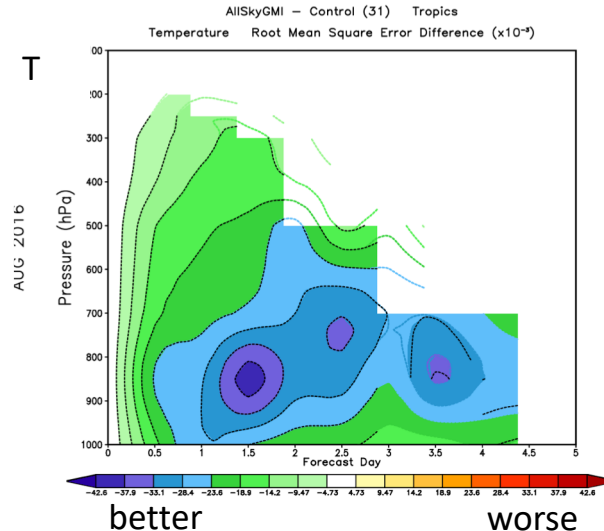
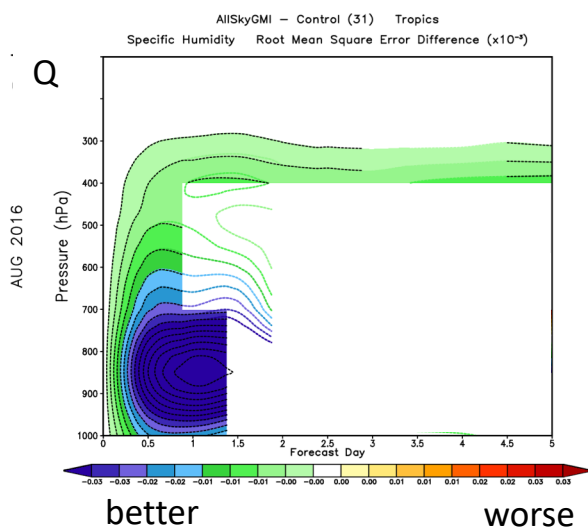


- The ensemble background incorporates correlated errors between different analysis variables implicitly in the GEOS analysis system. Therefore, In addition to hydrometeors, dynamic variables such as wind, temperatures, and pressures are adjusted by assimilating all-sky microwave radiance data in hybrid 4D-EnVar.
- To illustrate that, this slide shows the analysis changes from a simple experiment assimilating only GMI radiance data.
- Figure on the left shows observed GOES East imagery indicating the location of Hurricane Gaston And Figure in the middle shows the observed all-sky GMI data points assimilated in this case study.
- In the figure on the right hand side, color shade shows the horizontal distribution of analysis changes made in 850 hPa rain water mixing ratio by assimilating GMI data. In addition, it is noticed that cyclonic wind changes are clearly generated in the analysis where large precipitation increments are generated near the center of hurricane.
- These changes in both the analyzed moisture and dynamic variables through assimilation of microwave radiance data contribute to GEOS forecast improvements

# Impact of GMI all-sky radiances on forecast skill



- The addition of GMI radiances had the largest impact in the Tropics.
- Specific humidity was significantly improved in the short term (0-72 hour) forecasts.
- Similar improvements were seen in mid and lower tropical tropospheric temperature and winds.
- Other modeling and initialization improvements included in the FP upgrade retained these improvements into the medium range.



# Final Remarks

- ❑ GMAO has implemented all-sky GPM Microwave Imager (GMI) in GEOS FP, increasing not only the number of satellites observations assimilated but also the types of variables analyzed.
- ❑ All-sky GMI data made significant positive Impacts on GEOS forecasts especially for lower tropospheric water vapor, temperature, and winds.
- ❑ All-sky system developments were made to be able to share the codes with NOAA NWS.
- ❑ All-sky techniques in GEOS are currently being extended to other microwave sensors such as MHS, ATMS, AMSU-A, and AMSR-2.
- ❑ Looking forward to testing TROPICS data in our GEOS all-sky system!