Impact assessment of all-sky TROPICS microwave observations on the NASA GEOS analyses and forecasts and progress to use the data in the JEDI-GEOS analysis system

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NASA Goddard Earth Observing System (GEOS)

GEOS-Forward Processing (FP)

Forecast Model

- GEOS AGCM: C720 L72 (12.5 km)
- GOCART aerosols (6 species, 18 bins)

Meteorological Analysis

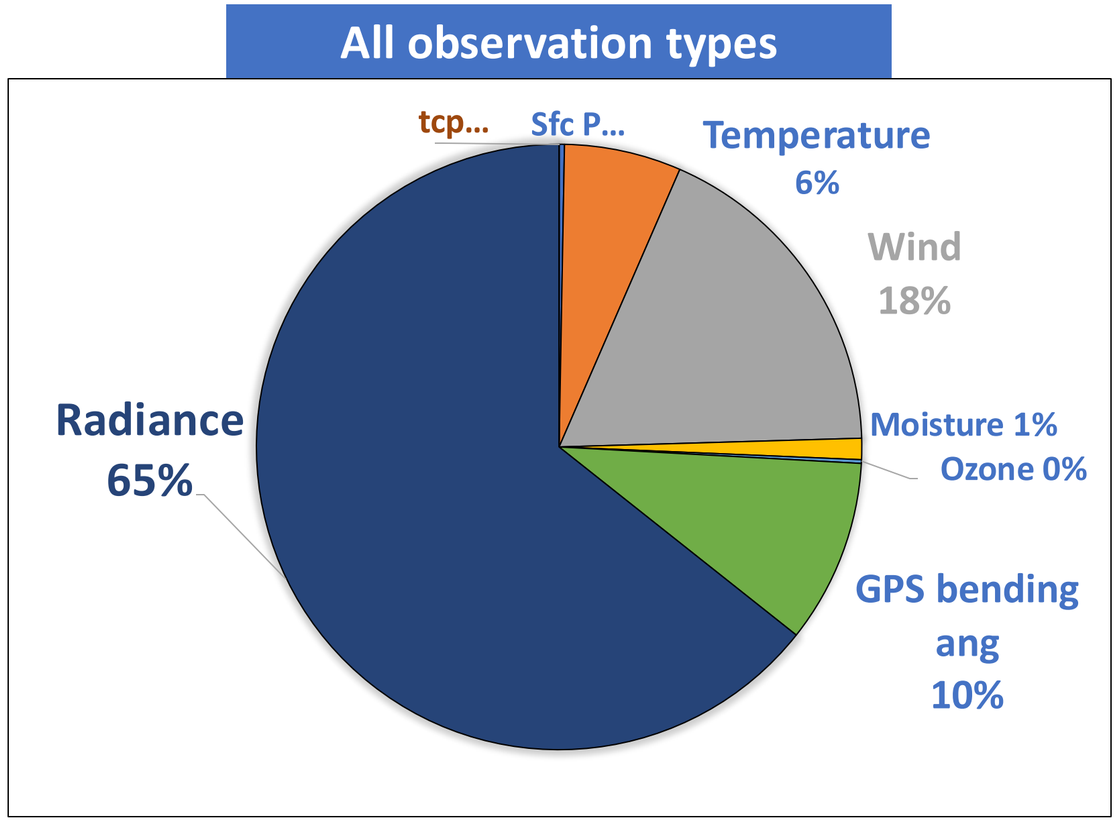
- Hybrid 4D-EnVar: 1152x721 L72 (25 km)
- 32-member EnKF: C180 L72 (50 km)
- VarBC for radiance and aircraft data

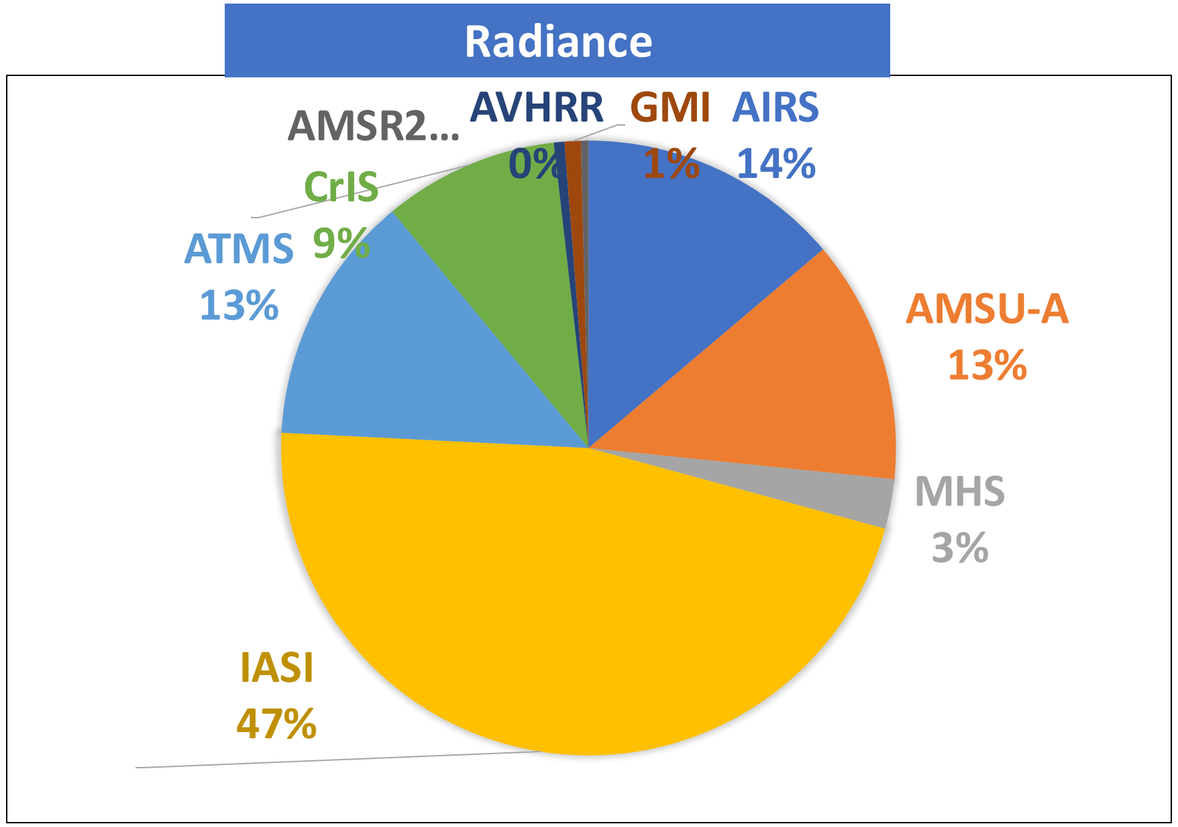
Aerosol Analysis

- 2D PSAS (12.5 km) & LDE for 3D speciation
- AOD from MODIS and Aeronet

GODDARD EARTH SCIENCES

Observations assimilated in GEOS-FP

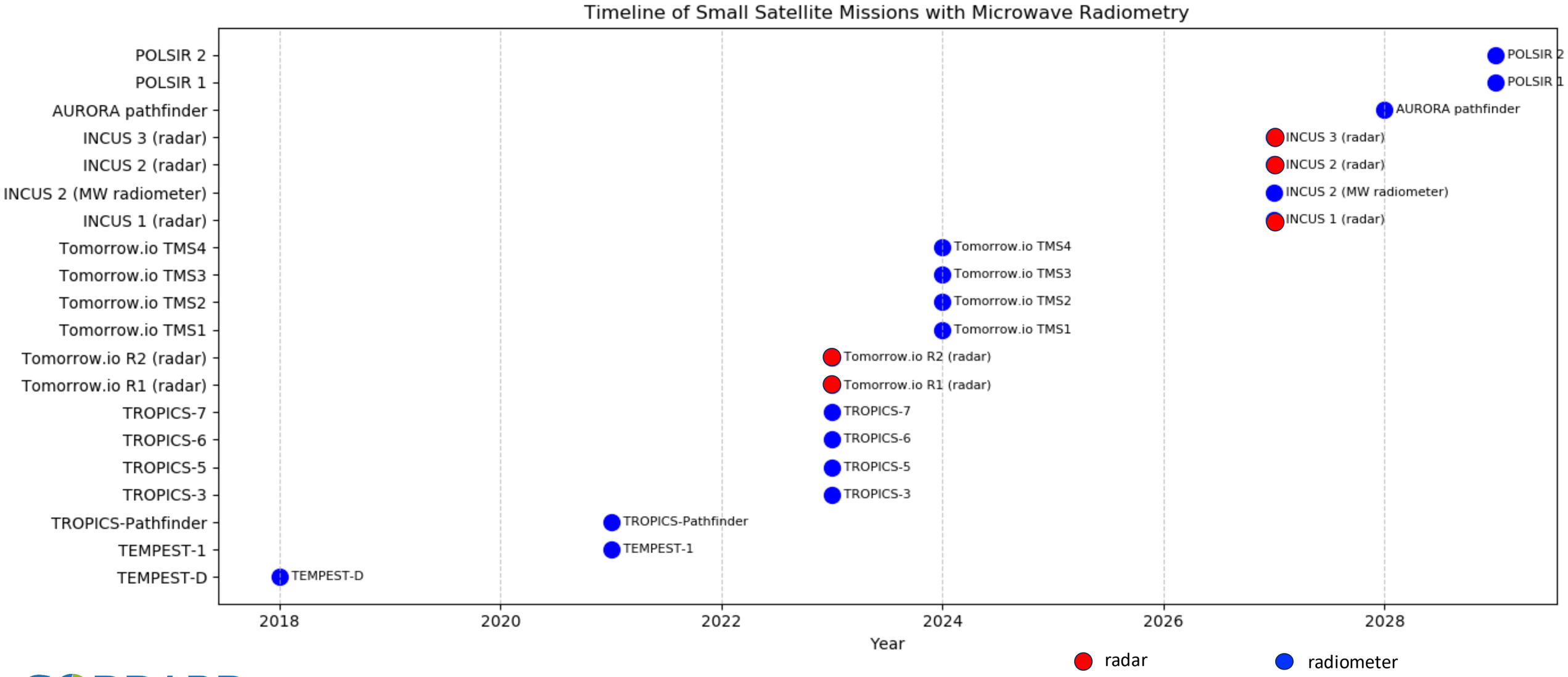




- **All-sky MW**: GMI, AMSR2, MHS
- **Clear-sky MW**: AMSU-A, ATMS, SSMI/S
- **Hyperspectral IR AIRS, CrIS, IASI:** correlated observation error, mostly LW and some water vapor and ozone channels

- In addition to the RO data from operational satellites, the use of commercial RO data from Spire and PlanetIQ
- Ozone: S-NPP OMPS Nadir Mapper, MLS level ozone, Aura OMI, OMPS Limb Profiler

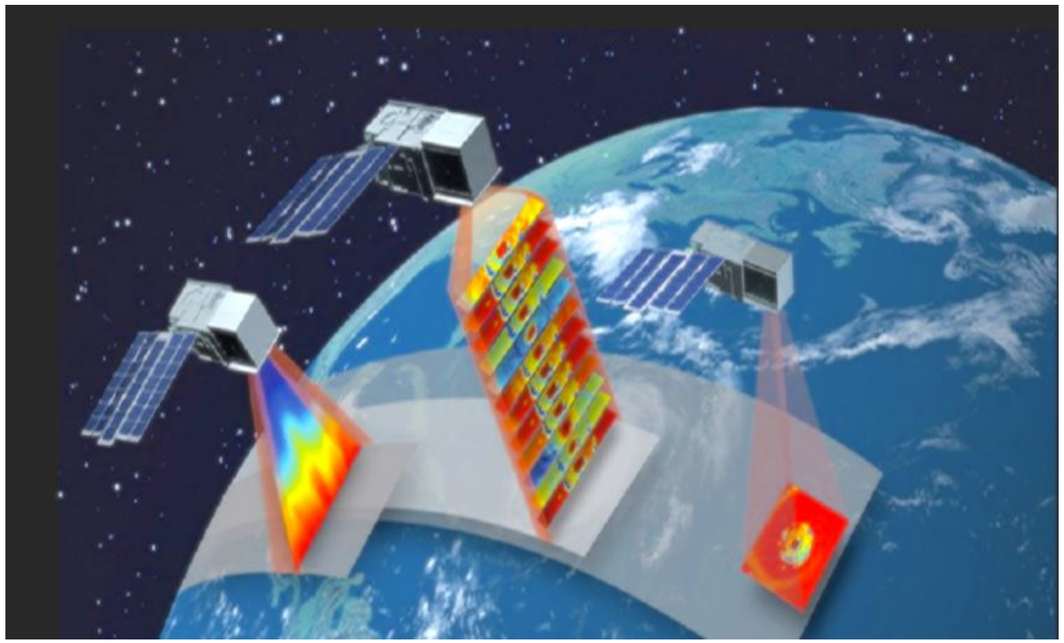
Small Satellites with MW Sensors



NASA TROPICS Mission

- 3U cubeSat cross-track temperature and water vapor microwave sounder
- 12 channels (91 GHz ~ 204 GHz)
- 550 km and 30° inclination orbit (no observations at high latitudes). TROPICS Pathfinder data has global coverage. Swath 2000km, Resolution 17km~27km at nadir
- Total five TROPICS including Pathfinder were launched sucessfully.

Channel	Central frequency (GHz)	ATMS Channel	MHS Channel	
1	91.655+/-1.4	88.2	89.0	dirty window
2	114.50	-	-	T-sounder
3	115.95	-	-	
4	116.65	-	-	
5	117.25	-	-	
6	117.80	-	-	
7	118.24	-	-	
8	118.58	-	-	
9	184.41	183.31+/-1.0	183.31+/- 1.0	WV-sounder
10	186.51	183.31+/-3.0	183.31+/-3.10	
11	190.31	183.31+/-7.0	190.31	
12	204.8	-	-	dirty window (high freq)



NWP experiments for TROPICS constellation : DATA

CubeSat	L1B Data Product Maturity	Remaining Calibration Issues	Beginning of GPS Issues	Note
TROPICS-01	Beta → Provisoinal-1 → **Provisional-2**	a) Orbital bias (Ch4-Ch8) b) geolocation	2-Aug-2023	Aug. 2021-Dec 2023 (deorbited on July 29, 2024)
TROPICS-03	Beta → Provisioinal → **Validated V1.0**	a) higher-than-expect scan bias b) high lat. bias (Ch. 7 & 8) c) potential calibration dropouts d) geolocation	26-Sep-2024	**Active** (since June 2023)
TROPICS-05	Beta → Provisional → **Provisional V0.2**	a) high residual channel mixing (Ch. 4-8) b) higher-than-expect scan bias c) high lat. bias (Ch. 7 & 8) d) geolocation	12-Oct-2024	**Active** (since June 2023)
TROPICS-06	Beta → Provisional → **Validated V1.0**	a) high lat. bias (Ch. 7 & 8) b) potential calibration dropouts c) geolocation	20-Aug-2024	**Active** (since June 2023) On 24-Feb-2024, TROPICS-06 had geolocation degradation due to loss of timing signal
TROPICS-07	Beta → **Provisional V0.2**	a) Ch. 7 & 8 extreme latitude bias b) ant. Temp. vs scan doesn't follow RTM		Data available only for 06/15/2023-07/31/2023 (Bus communication error afterwards)

Courtesy of Vince Leslie (MIT)

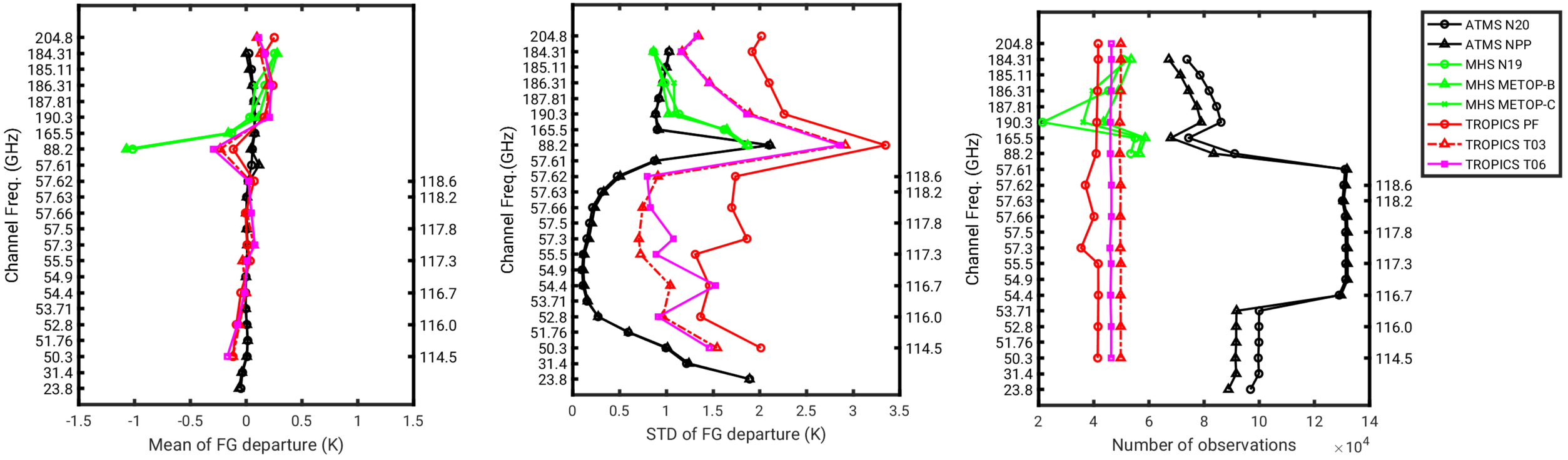
Status of NWP experiments for TROPICS constellation

Ongoing NWP Experiment period: July 15 ,2023 – September 6, 2023

	TROPICS-01	TROPICS-03	TROPICS-05	TROPICS-06	TROPICS-07
Bufrization	V	V	V	V	V
DA system developments	V	V	V	V	V
NWP impact assessment with beta, provisional data	V	V	V	V	Vert limited data from TROPICS-07 and sparse. Not included in the experiments.
NWP impact assessment • **Latest calibrated data** • **Updated GEOS** • **New control** • **Updated CRTM codes and coefficient files**	In progress	In progress	In progress	In progress	

TROPICS data assimilation in NASA GEOS
Radiance Data Comparison with TROPICS, ATMS, and MHS

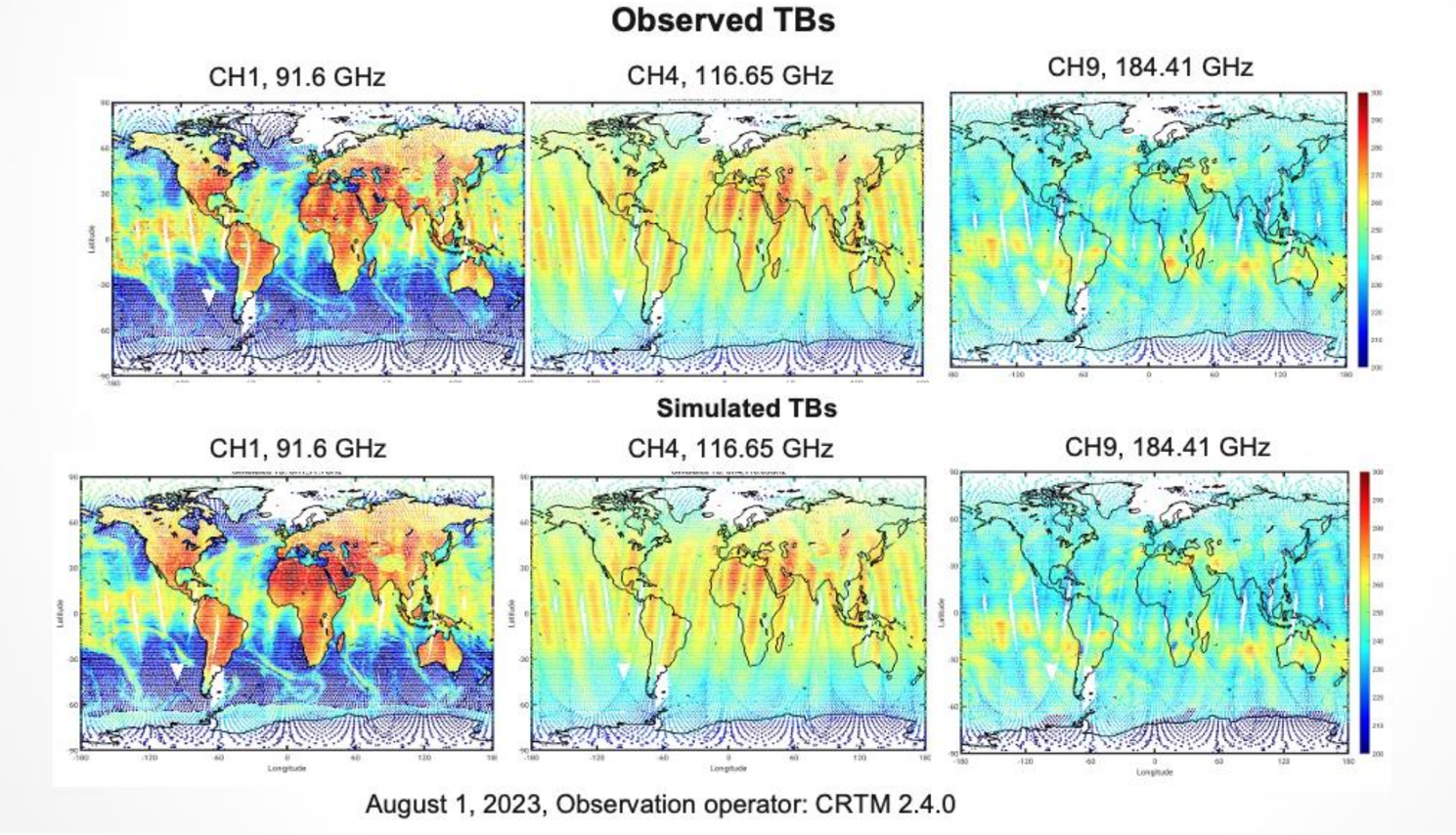
Bias and standard deviation of first-guess departures (i.e. Obs-Model), and number of observations assimilated in clear-sky condition over the Ocean during August 1-6, 2023. The variational bias correction method was applied within the GEOS atmospheric data assimilation system.



- TROPICS data exhibit a larger standard deviation of First-guess(FG) departures compared to MHS and ATMS data.
- Overall, bias show good agreement, but further examination of FG departures reveals remaining biases in some 118GHz temperature sounding channels.

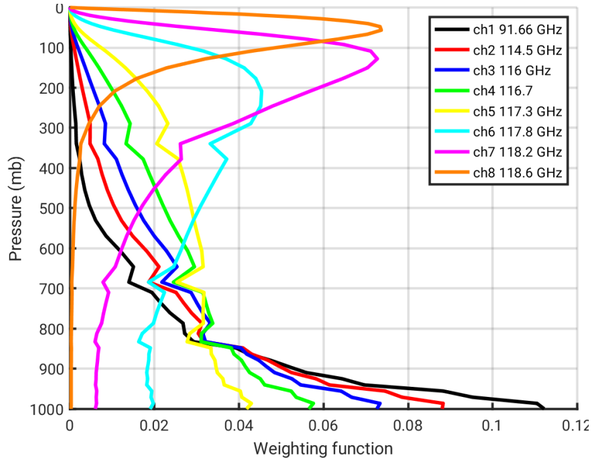
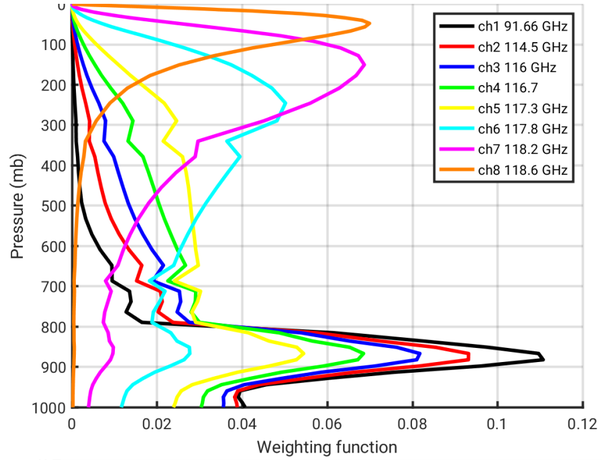
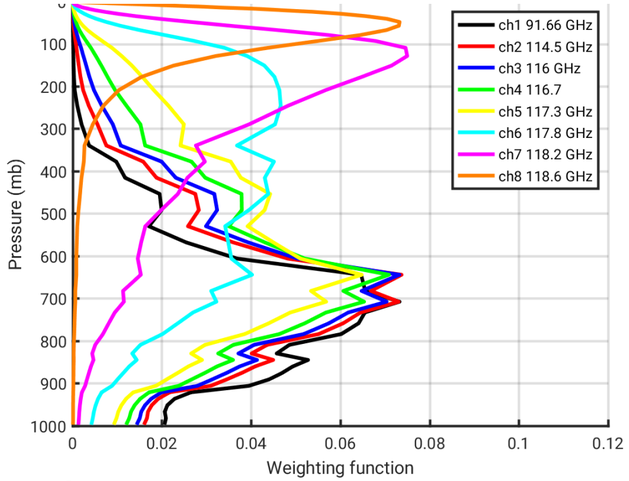
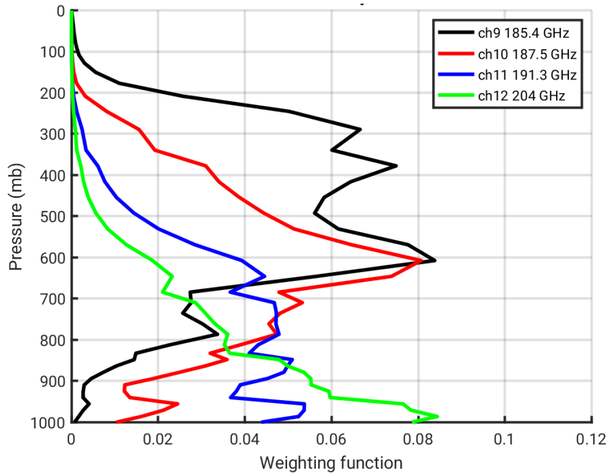
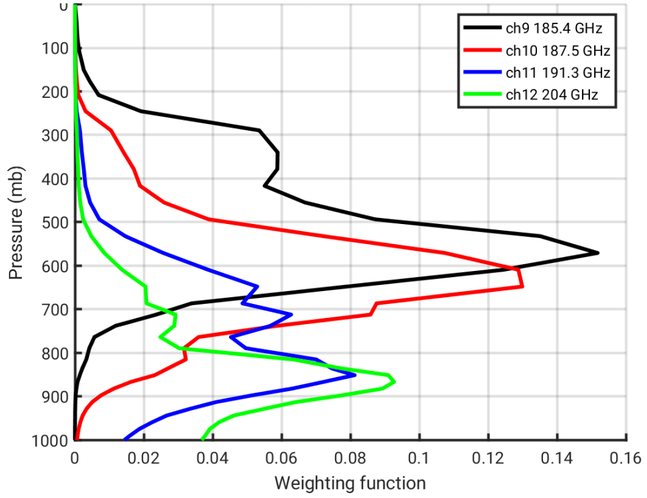
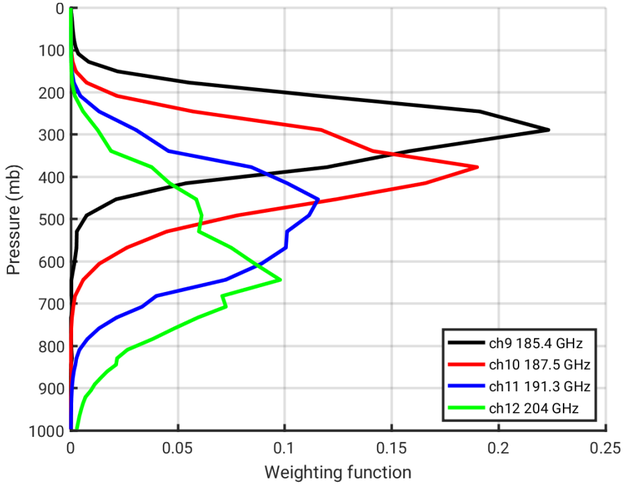
TROPICS Radiance Data Assimilation Framework in GEOS

- Hybrid 4D-EnVar based GSI system with variational bias correction (VarBC) method,
- Observation operator: CRTM 2.4.0 for all-sky TROPICS TB calculation. **CRTM 2.4.1-jedi.1** is being tested.
- QC procedures: Sensitivity to emissivity over non-oceanic sfc types, topography height, scan angle, gross check for large O-F
- Observation error model: Geer and Bauer (2011) using scattering index values calculated with CH1 and CH12.
- Developments to put this framework in JEDI/SWELL system in progress



TROPICS 12 Channels' Weighting Function

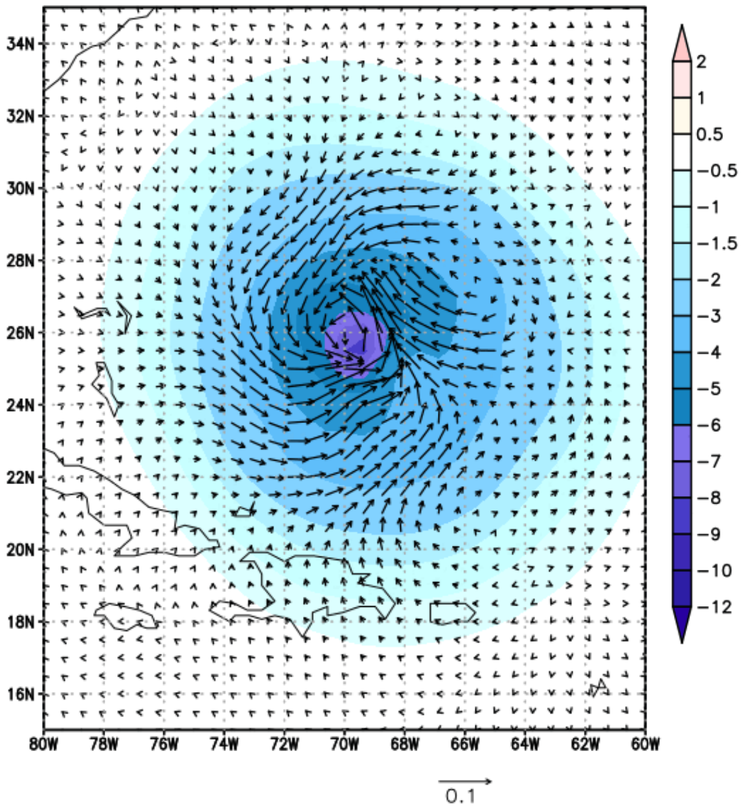
Calculated with CRTM and GEOS short-term forecasts (08/27/2023 averaged for subtropics)

	Clear Sky	Non-precipitating Cloudy Sky	Precipitating Sky
Ch 1 - 8			
Ch 9-12			

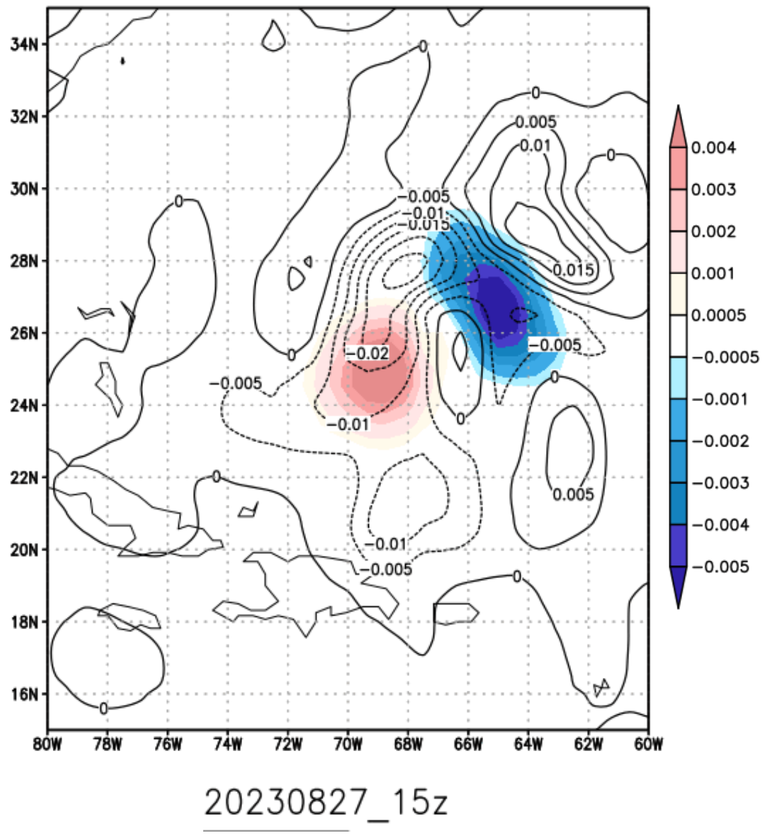
- In clear-sky condition only. We can see that channels 1 through channel 5 and channels 11 and 12 have large contribution from surface.
- In cloudy and precipitating sky conditions, we can see that channels 5 through 12 provide information from different altitude.

Single observation point experiment: Analysis Increments

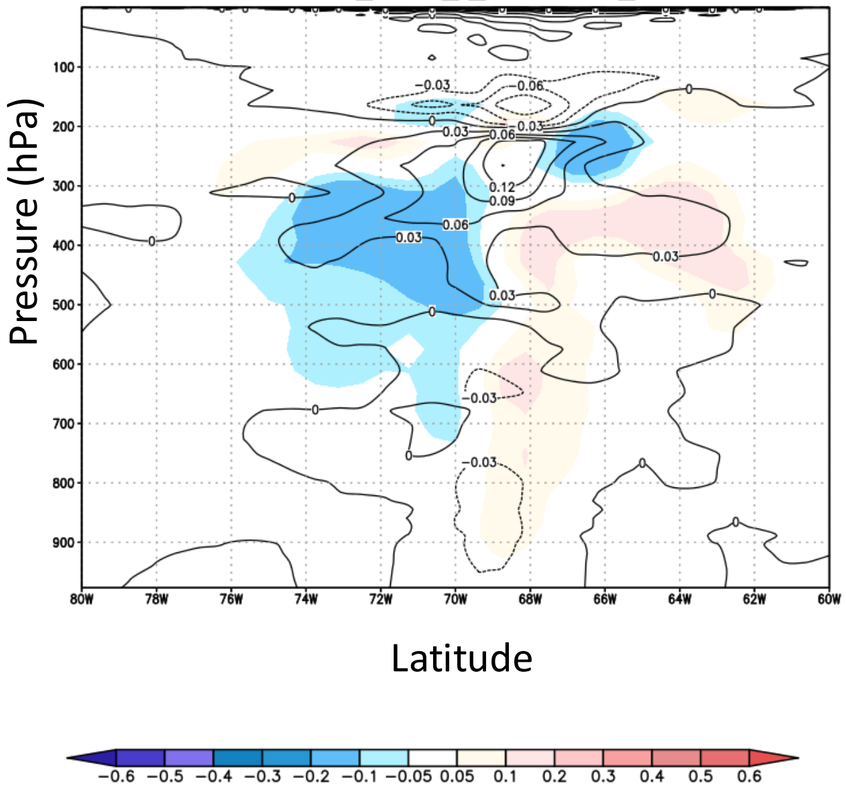
Shade: **sfc pressure** increment (Pa)
Arrow: 850hPa wind increment (m/s)



Shade: 850hPa rain increment (g/kg)
Contour : 850hPa specific increment (g/kg)



Shade: V-wind increment (g/kg)
Contour : Temperature increment (g/kg)



- Left figure: Analysis increments for surface pressure and 850hPa wind. TROPICS data employed in this experiment lowers the surface pressure near the center of the storm and wind analysis also shows increment of anti-clockwise winds which re dynamically consistent.
- Middle figure: 850hPa rainwater and humidity are adjusted following the storm system movement.
- Right figure: Vertical cross section of V-wind and temperature increments. TROPICS data increase cyclonic winds in deep layer in this case study.

TROPICS data assimilation in NASA GEOS
Impacts on NWP forecasts

- **Global Forecast Impacts**: Overall, the impacts on global forecasts are neutral to slightly positive.
- **Local Impacts**: Local features, such as storm tracks, show more significant benefits compared to global impacts.
- These results are preliminary and subject to further refinement.
- **Ongoing Improvements**: To enhance data impacts, further tuning of the data assimilation framework is underway, including improvements to the superobbing procedure, observation error model, and quality control procedures.

Northern Hemisphere

Variable	Pressure Level	COR	RMS
Forecast Day		1 2 3 4 5	1 2 3 4 5
Geopotential Height	10		
	70		
	100		
	250		
	500		
	700		
	850		
SLP	1000		
Specific Humidity	10		
	70		
	100		
	250		
	500		
	700		
	850		
Temperature	10		
	70		
	100		
	250		
	500		
	700		
	850		
U-Wind	10		
	70		
	100		
	250		
	500		
	700		
	850		
V-Wind	10		
	70		
	100		
	250		
	500		
	700		
	850		

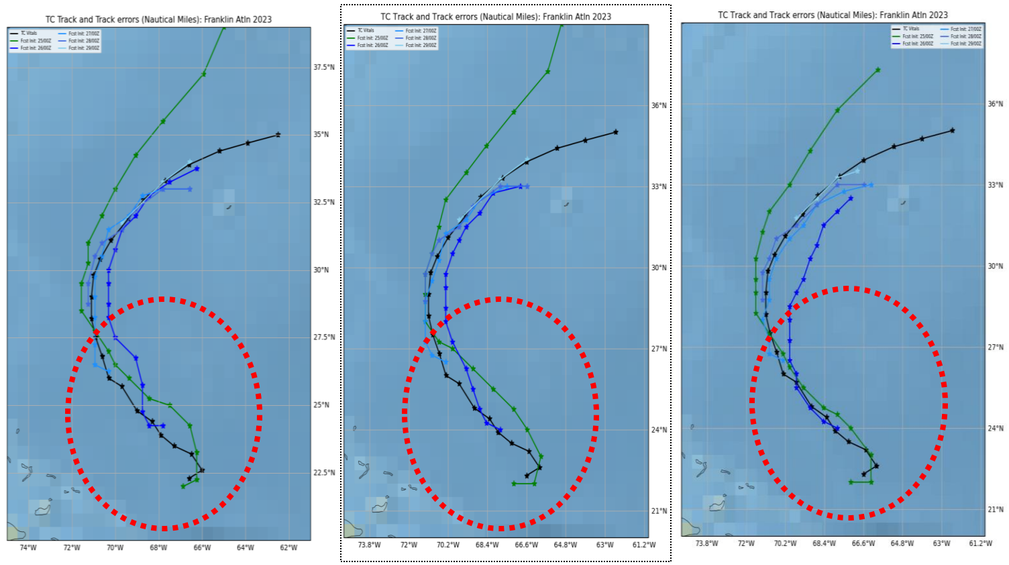
Southern Hemisphere

Variable	Pressure Level	COR	RMS
Forecast Day		1 2 3 4 5	1 2 3 4 5
Geopotential Height	10		
	70		
	100		
	250		
	500		
	700		
	850		
SLP	1000		
Specific Humidity	10		
	70		
	100		
	250		
	500		
	700		
	850		
Temperature	10		
	70		
	100		
	250		
	500		
	700		
	850		
U-Wind	10		
	70		
	100		
	250		
	500		
	700		
	850		
V-Wind	10		
	70		
	100		
	250		
	500		
	700		
	850		

Tropics

Variable	Pressure Level	COR	RMS
Forecast Day		1 2 3 4 5	1 2 3 4 5
Geopotential Height	10		
	70		
	100		
	250		
	500		
	700		
	850		
SLP	1000		
Specific Humidity	10		
	70		
	100		
	250		
	500		
	700		
	850		
Temperature	10		
	70		
	100		
	250		
	500		
	700		
	850		
U-Wind	10		
	70		
	100		
	250		
	500		
	700		
	850		
V-Wind	10		
	70		
	100		
	250		
	500		
	700		
	850		

Forecast skill scorecards from TROPICS data assimilation experiments for August 2023. Green indicates improvement while red represents degradation.



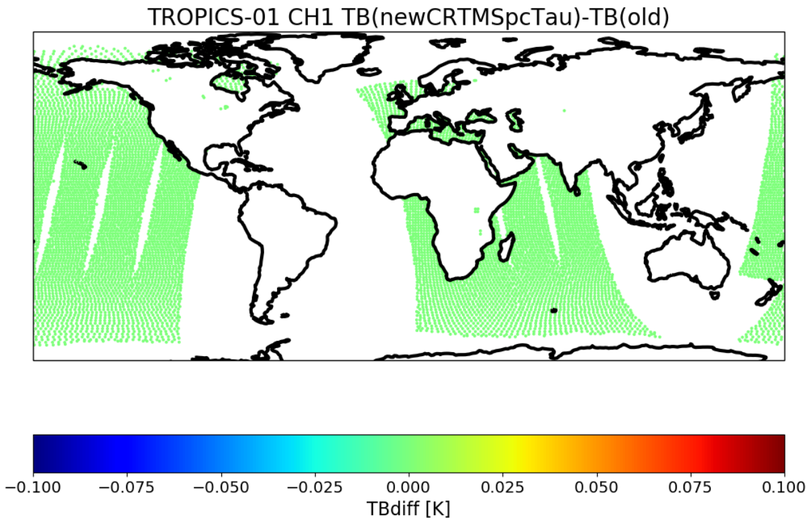
Control | **Control + TROPICS01** | **Control + TROPICS-01 + TROPICS-03 + TROPICS-06**

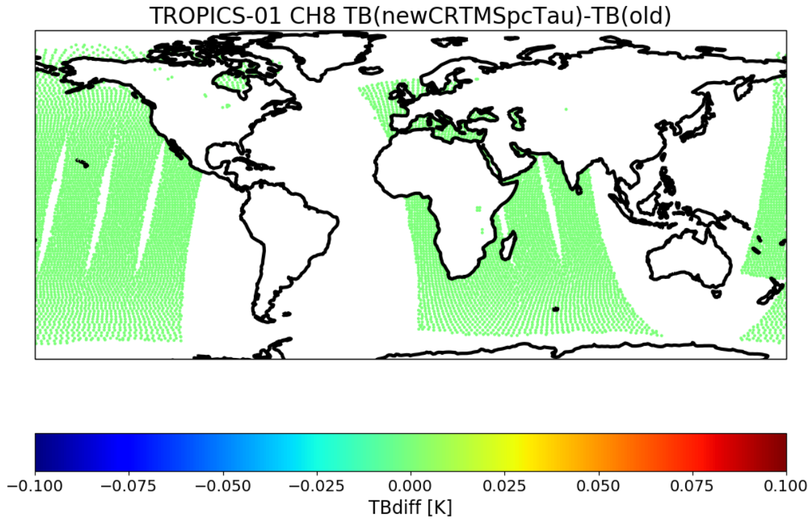
Impacts on GEOS forecasts of the 2023 Hurricane Franklin track. The “Control” experiment assimilated all observations currently used in GEOS-FP.

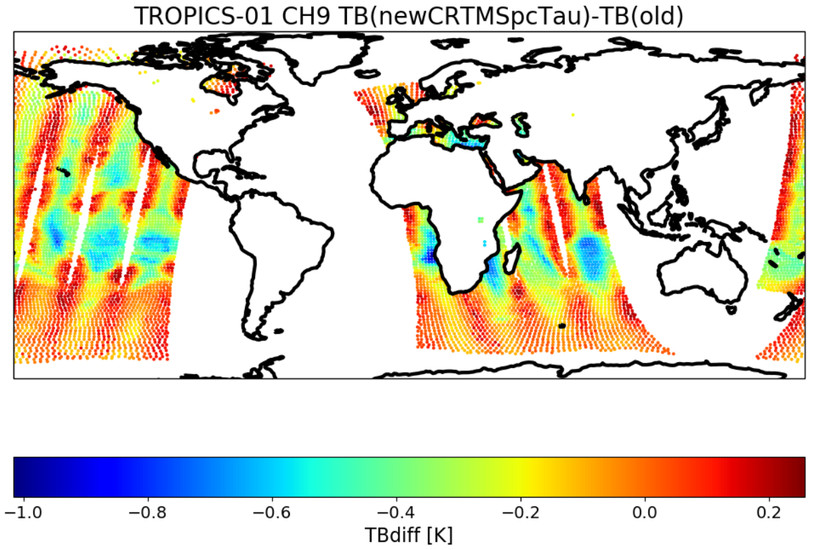
Work in progress

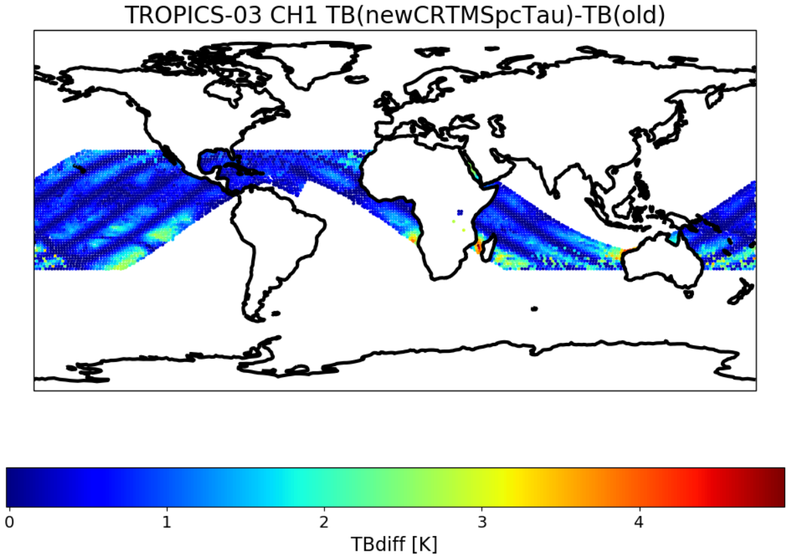
- **Observation data quality is improving as calibration and geolocation issues are addressed by the calibration team.**
- **The GEOS system now uses a new control run, incorporating recent developments.**
- **CRTM update : CRTM 2.4.1-jedi.1.**
- **Updated TROPICS spectral and tau coefficient files**
- **Updated CRTM cloud scattering coefficient file**
- **Superobbing procedures for all-sky MW radiance data including TROPICS data**

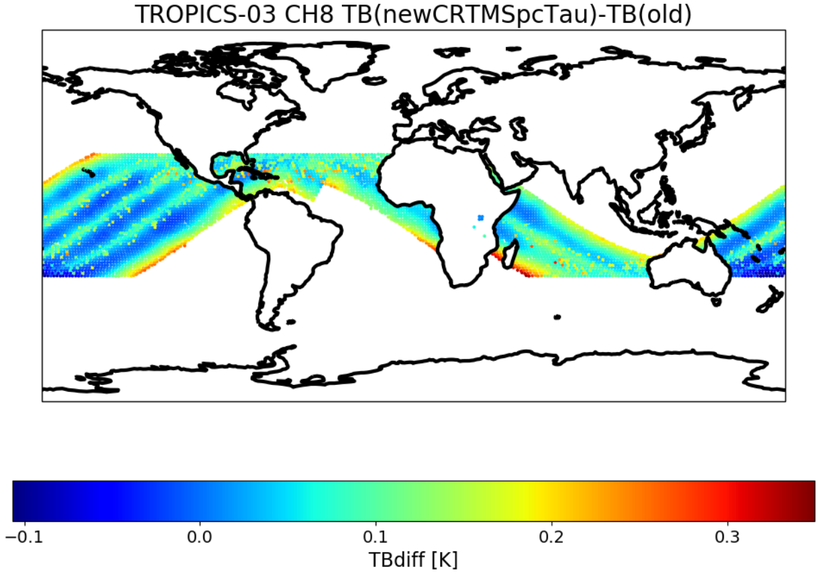
Work in progress : CRTM TROPICS Spc/Tau Coefficients update

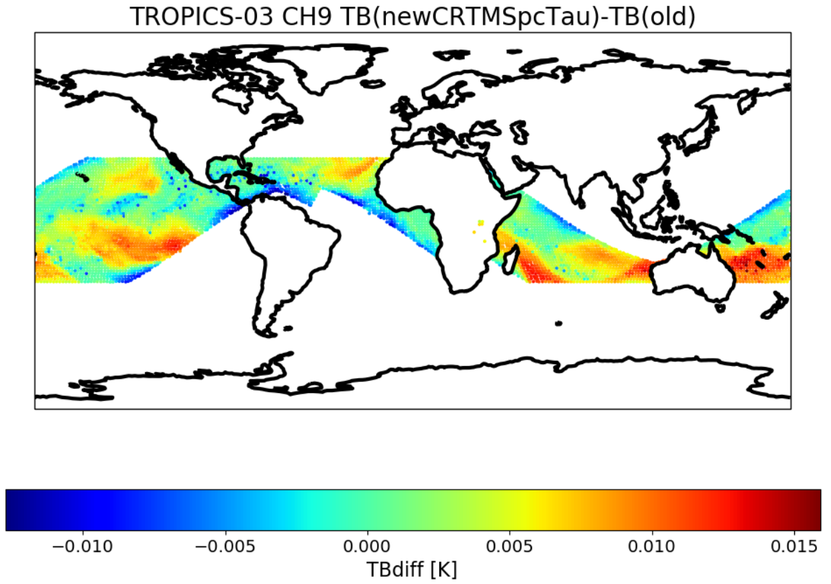






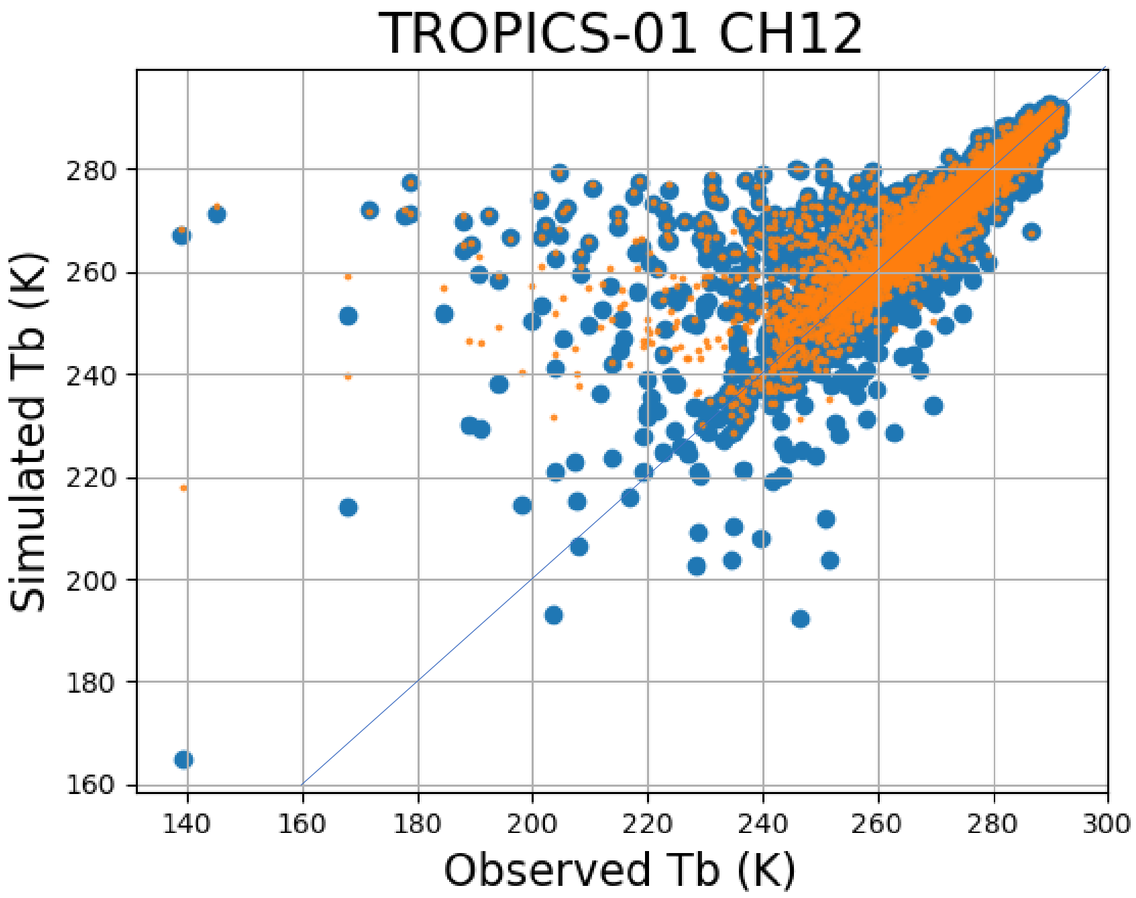


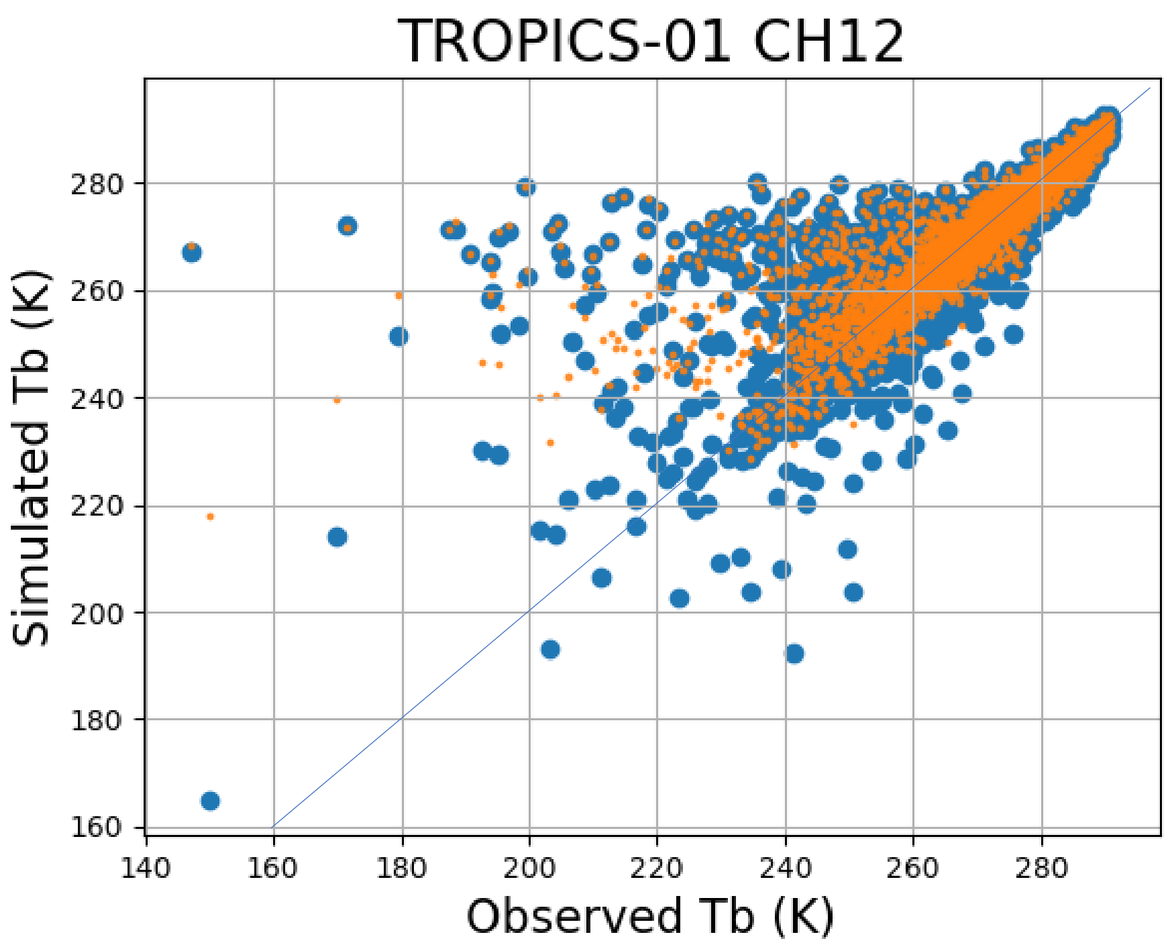




Work in progress : Cloud Scattering Coefficient Update

With Superobbing with 3x3 spatial averaging





Scattering coefficient being used for all-sky DA in GEOS system (Liu's 3-bullet rosette DDA)

CloudCoeff_DDA_Moradi_2024.nc4

Work in progress : JEDI

- All-sky TROPICS radiance DA components tested in GSI are being integrated into the JEDI/SWELL framework.
    - HOFX has successfully generated simulated observations using UFO.
    - Initial engineering tests included limited quality control procedures, allowing TROPICS data to be assimilated in a single cycle in JEDI/SWELL framework.
- Plans are underway to apply all updates, including CRTM coefficient updates, cloud scattering coefficients, and superobbing procedures for TROPICS, within the JEDI/SWELL framework.

Summary

- All-sky data assimilation framework to use five TROPICS CubeSats have been developed in NASA GEOS system

- Initial assessments using pathfinder data and provisional data sets demonstrate that the TROPICS data bring valuable information in GEOS analyses by adjusting temperature, moisture, hydrometeors, and dynamic variables in storms.

- Observing system experiments (OSEs) are in progress with latest updates in GEOS system for impact assessments using latest calibrated data set, updated CRTM package, Spc and Tau coefficients, and cloud scattering coefficients