Impact Assessment of Microwave Sounder Observations on Small Satellites in the NOAA Global NWP System

Min-Jeong Kim[1,2], Kevin Garrett[3], Narges Shahroudi[1,2], Flavio Iturbide-Sanchez[2], and Erin Jones[4]

(1) Riverside Technology, Inc., Fort Collins, CO, USA, (2) NOAA NESDIS Center for Satellite Applications and Research, USA, (3) NOAA National Weather Service, USA, (4) ESSIC, Univ. of Maryland, USA

NOAA / NESDIS / STAR Center for Satellite Applications and Research

Motivation

- Maturity of small satellite technologies has advanced.
- Small satellites with low size, weight, and power requirements provide an opportunity to reduce the cost associated with the construction and launch of large bus platforms.
- These small satellites, especially in large numbers, may be complementary to existing and planned operational satellite constellations by providing scientific data sets with improved spatial and temporal coverages.
- The NESDIS seeks to evaluate and identify potential impact that small satellite constellations may bring to the numerical weather prediction (NWP) systems and atmospheric retrieval systems used in NOAA.

Goals

- Impact assessment of SmallSat radiance data in NOAA NWP systems and MIRS 1D-Var retrieval system. Early part of this presentation addresses the NWP impact assessment.
- Initial efforts have been focused on the integration of TEMPEST-D and TROPICS-pathfinder data.
- Evaluation metrics for NWP impact assessment : forecast skills, improvements in NWP analyses, fit to other observations
- Evaluation metrics for MiRS: RTM uncertainty and mean bias, observation error covariance, 1DVAR convergence, and comparison of retrieved temperature/water vapor profiles to ECMWF analysis
- Data qualities are evaluated by looking at error analysis

Current Status: NWP assessment

- TEMPEST-D data downloaded for August-Sept 2019, May/June 2020 (40 days with limited gaps in each). Converted all TEMPEST-D data to NCEP BUFR 6-hourly files
- Acquired TROPICS-pathfinder data record July-Nov. 2021. Converted TROPICS data to BUFR 6-hourly files for Sep.17-Nov.30, 2021
- Extended NOAA Global Data Assimilation System (GDAS) to TEMPEST-D and TROPICS-pathfinder data
- **Radiometric quality assessments** for TEMPEST-D and TROPICS-pathfinder : Completed using NCEP global NWP system frameworks.
- **NWP impact assessments** for TEMPEST-D and TROPICS-pathfinder: Completed after performed initial observing system experiments (OSEs)

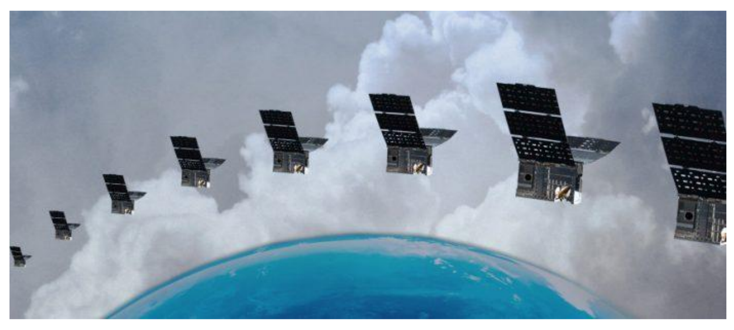
TEMPEST-D Overview

Temporal Experiment for Storms and Tropical Systems (TEMPEST).
A demonstration mission in orbit: TEMPEST-Demonstration (TEMPEST-D)

TEMPEST-D was launched on May 21, 2018

- In preparation for future TEMPEST mission to deploy a constellation of SmallSats for studying cloud and precipitation processes
- Demonstrate the ability to monitor the atmosphere with small satellites
- A proof-of-concept for next generation Earth-observing technologies with lower cost and smaller risk

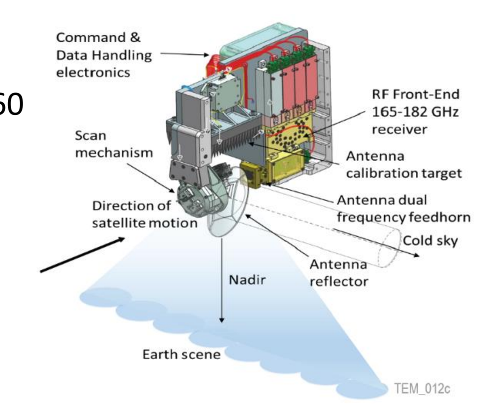
TEMPEST-D was deorbited June 22, 2021



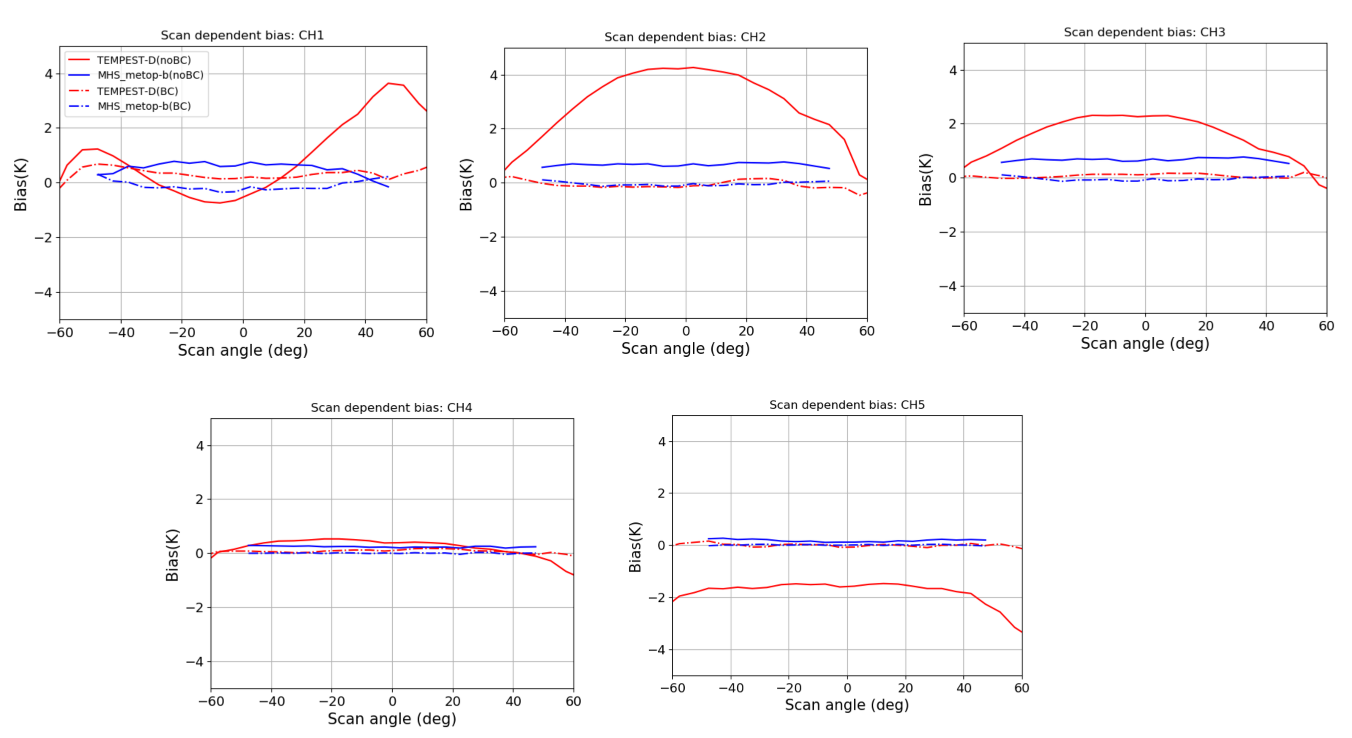
8-satellite constellation concept of TEMPEST providing high temporal resolution observations (https://tempest.colostate.edu/)

Specification	TEMPEST-D	MHS
Number of channels	5	5
Channel Freq. (GHz)	87, 164, 174, 178, 181	89, 157, 190, 183±3, 183±1
Mass	3.8 kg	63 kg
Power	6.5 W	74 W
Altitude	400 km	820 km
Resolution at nadir	12.5 km (25 km at 87 GHz)	15.9 km
Integration time	5 ms	18.5 ms

- Inclination angle = 51.6˚
- ~ 400 km altitude
- Cross-track scanning (-/+ 60 ˚)
- Swath width ~ 825 km
- Data downlink to a single ground station at Wallops Island, Virginia
- Continuous data is rare.

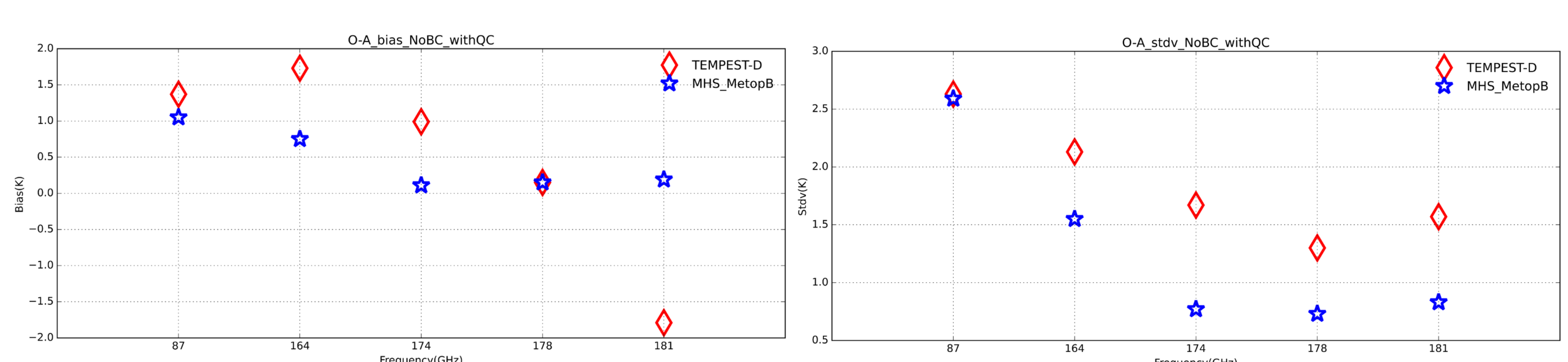


Scan Angle Dependent Bias Assessment:TEMPEST-D



Radiometric Bias Assessment: TEMPEST-D

Observation minus Simulation using GFS Analyses (without Bias Correction)

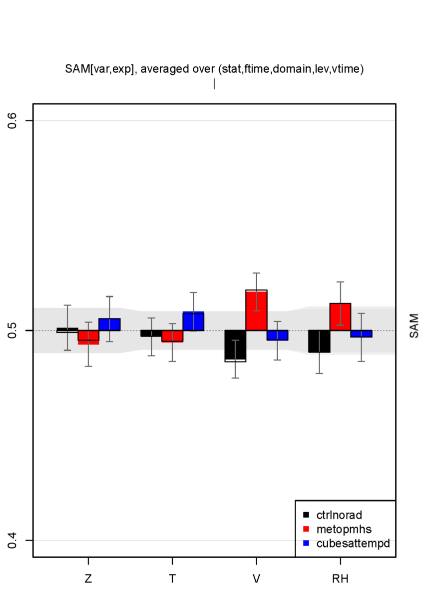


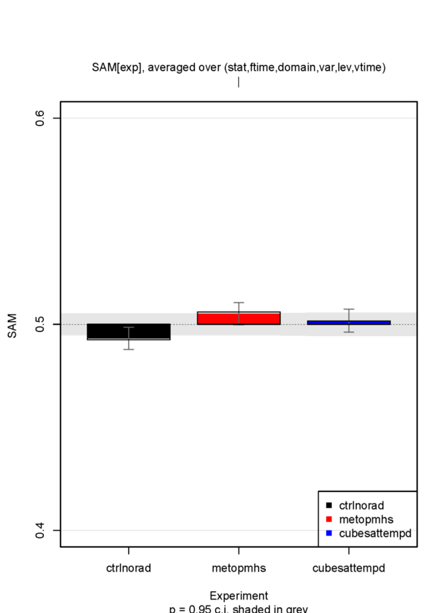
TEMPEST-D Data Assimilation

Observations	OpsConf	Control	MHS	TEMCLR	TEMALL
• IR radiance (AIRS, IASI, CrIS, …) • Microwave radiance (AMSU-A, ATMS, …)					
• Conventional data (sonde, buoy, ship, aircraft, …) • Satellite derived wind data (AMV, OSVW) • GPSRO • Ozone data					
1 MHS					
TEMPEST-D (clear-sky)					

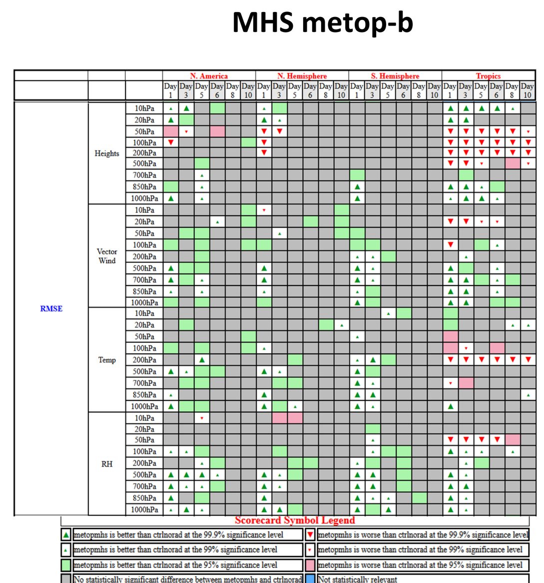
- **Assessment of impacts on NCEP global NWP analysis and forecasts**
- **Data assimilation experiments using Hybrid 4D-Envar GSI algorithm**
- **Horizontal resolution: Model C384 (~25km), 80 ensemble in C192 (~50km)**
- **Period: 8/2/2019 - 9/30/2019**

TEMPEST-D vs. MHS: Forecast Skills

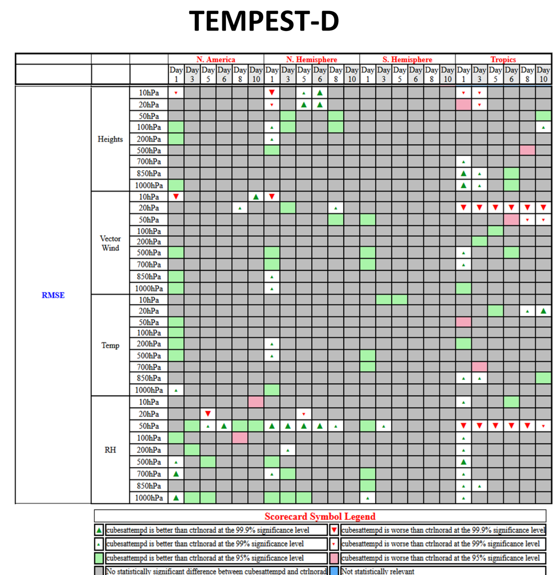




MHS metop-b



TEMPEST-D



TROPICS Overview

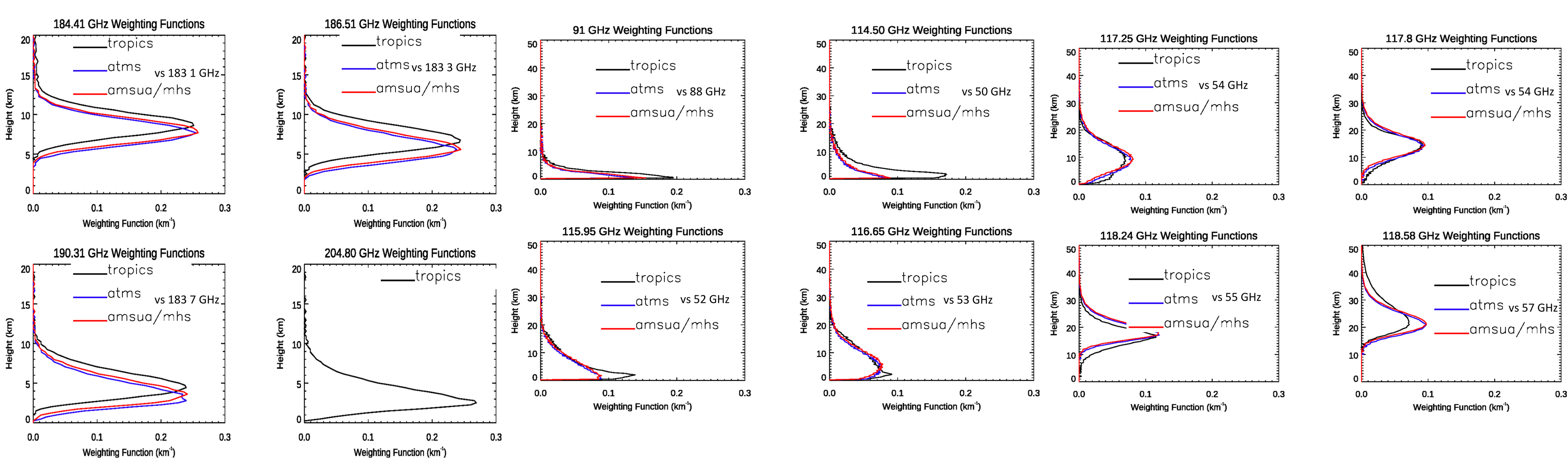
- **3U cubeSat cross-track temperature and water vapor microwave sounder**
- **12 channels (91 GHz ~ 204 GHz)**
- **TROPICS Pathfinder was launched June 30, 2021 successfully from NASA KSC (Technology demo & risk reduction effort).**
- **550 km and 30° inclination orbit (no observations at high latitudes). TROPICS Pathfinder data has global coverage.**
- **Swath 2000km**
- **Resolution 17km~27km at nadir**
- **Six satellites comprise the full constellation but two satellites were lost after the Astra rocket failed to reach to orbit after launching on 12 June 2022.**
- **NASA selected Rocket Lab to launch TROPICS satellites in 2023. The missions, which will take place no earlier than May, will carry two TROPICS cubesats.**

Channel specifications

Channel	Centre frequency (Ghz)	Bandwidth (MHz)	Beamwidth (°) Down/Cross	ΔT_{rms} (K)	Calibration accuracy (K)
1	91.655 ± 1.4	1000	3.0/3.17	0.7	2.0
2	114.50	1000	2.4/2.62	1.0	1.5
3	115.95	800	2.4/2.62	0.9	1.5
4	116.65	600	2.4/2.62	0.9	1.5
5	117.25	600	2.4/2.62	0.9	1.5
6	117.80	500	2.4/2.62	0.9	1.5
7	118.24	380	2.4/2.62	0.9	1.5
8	118.58	300	2.4/2.62	1.0	1.5
9	184.41	2000	1.5/1.87	1.0	1.0
10	186.51	2000	1.5/1.87	0.6	1.0
11	190.31	2000	1.5/1.87	0.6	1.0
12	204.80	2000	1.4/1.83	0.6	1.0

Source:
WJ, Blackwell, Braun, S, Bennartz, R, et al. An overview of the TROPICS NASA Earth Venture Mission. Q J R Meteorol Soc. 2018; 144 (Suppl. 1): 16– 26. doi: https://doi.org/10.1002/qj.3290

TROPICS vs. ATMS Atmospheric Sensitivity

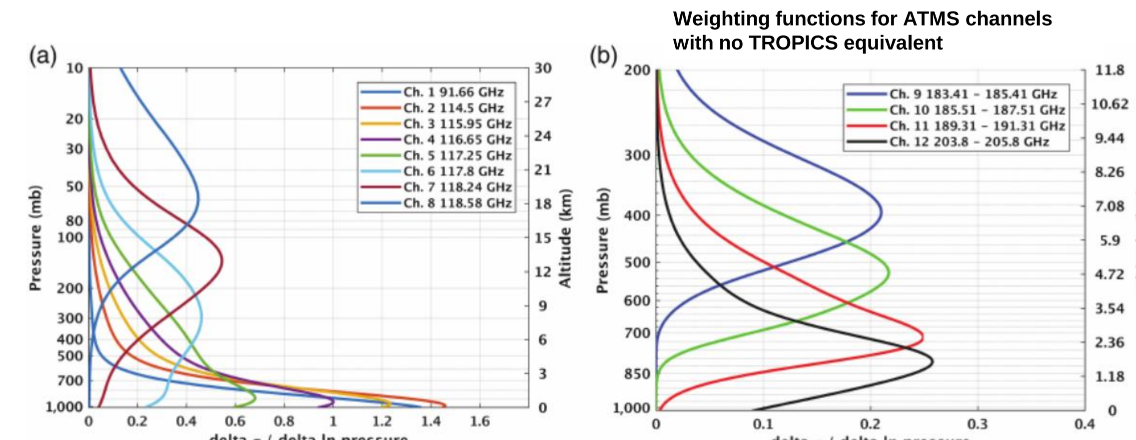


TROPICS coverage in the 183 GHz water vapor absorption line similar to other humidity sounders (ATMS or AMSUA/MHS).

Weighting functions for surface and lower tropospheric temperature sounding channels

Weighting functions for mid-upper tropospheric temperature sounding channels

Weighting functions for ATMS channels with no TROPICS equivalent

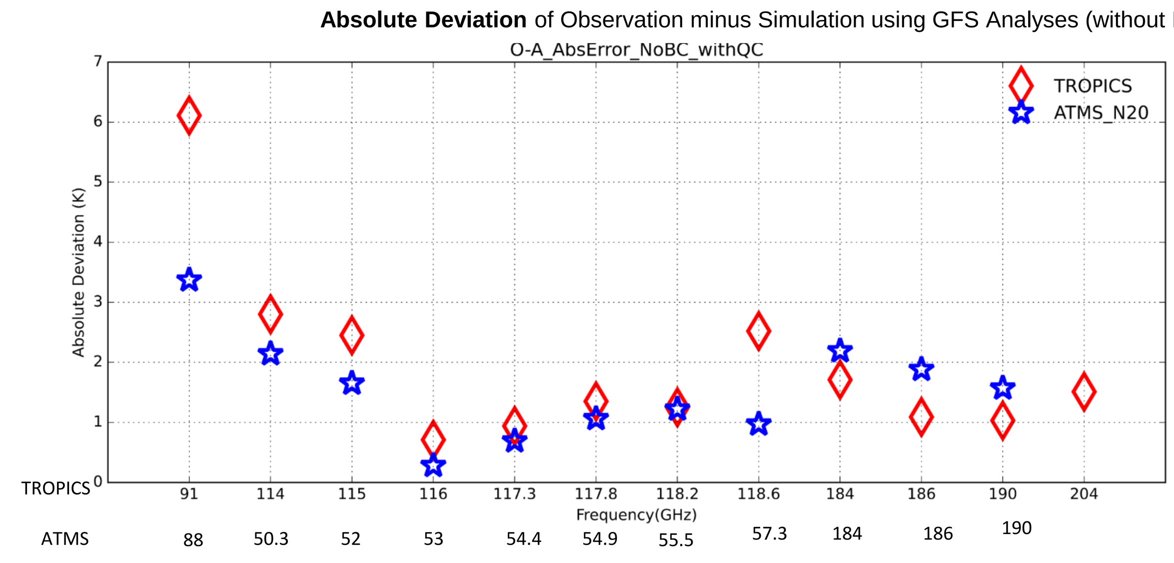


TROPICS does not contain

- **Low frequency (TPW/surface) channels (useful for DA quality control: surface or cloud screening).**
- **Stratospheric temperature sounding channels**

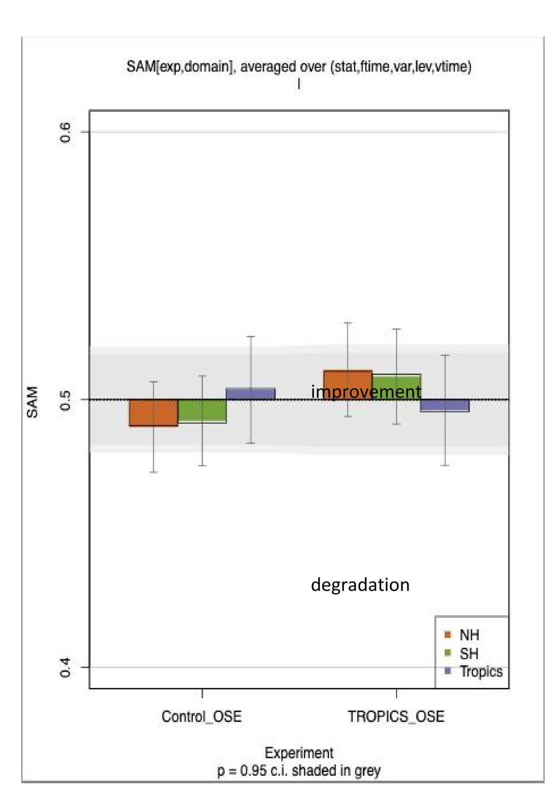
Radiometric Uncertainty Assessment: TROPICS

Absolute Deviation of Observation minus Simulation using GFS Analyses (without Bias Correction)

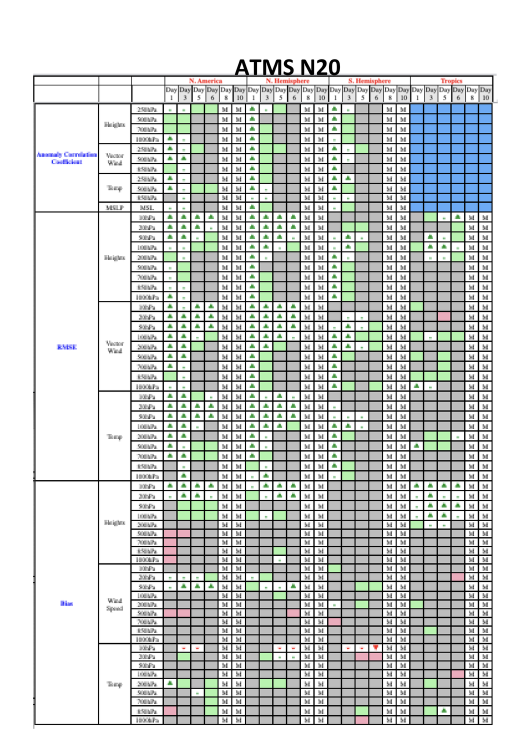


TROPICS radiative transfer model performance is comparable to ATMS overall except 91 GHz channel which shows larger difference between observations and simulations. Considering this channel has large sensitivity to the surface, CRTM surface emissivity model uncertainty can contribute to this result we are seeing here.

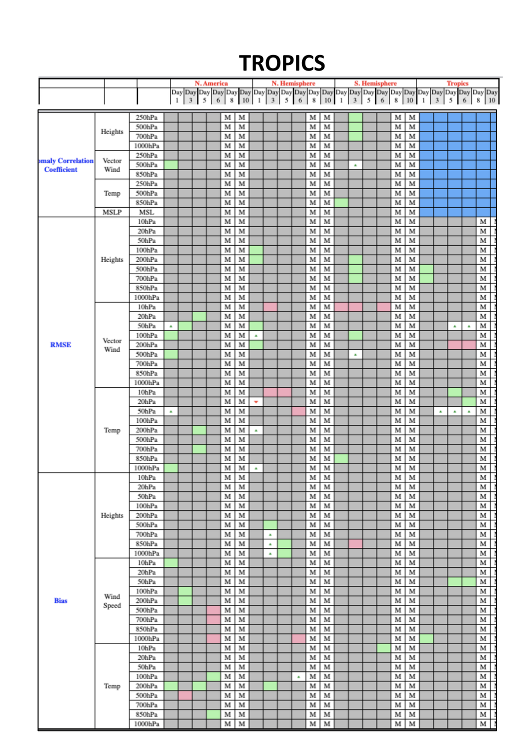
TROPICS vs. ATMS: Forecast Skills



ATMS N20



TROPICS



***TROPICS data made positive impacts on geopotential heights, temperature, and winds, and temperature in all of altitudes**
*** Reduced the biases overall**
*** Magnitudes of impacts are less than the impacts from ATMS data.**