NOAA
National Satellite and Information Service

Toward assimilating passive microwave smallsat data in NOAA NWP

Kevin Garrett
NESDIS Center for Satellite Applications and Research

NOAA Microwave Sounder Workshop • July 28, 2021

topics

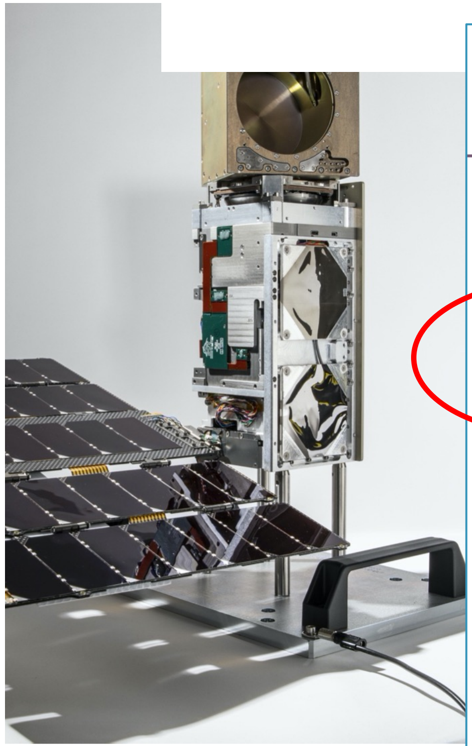
- status of passive microwave (PMW) smallsats
- previous studies
- considerations for NWP
- preparation and plans

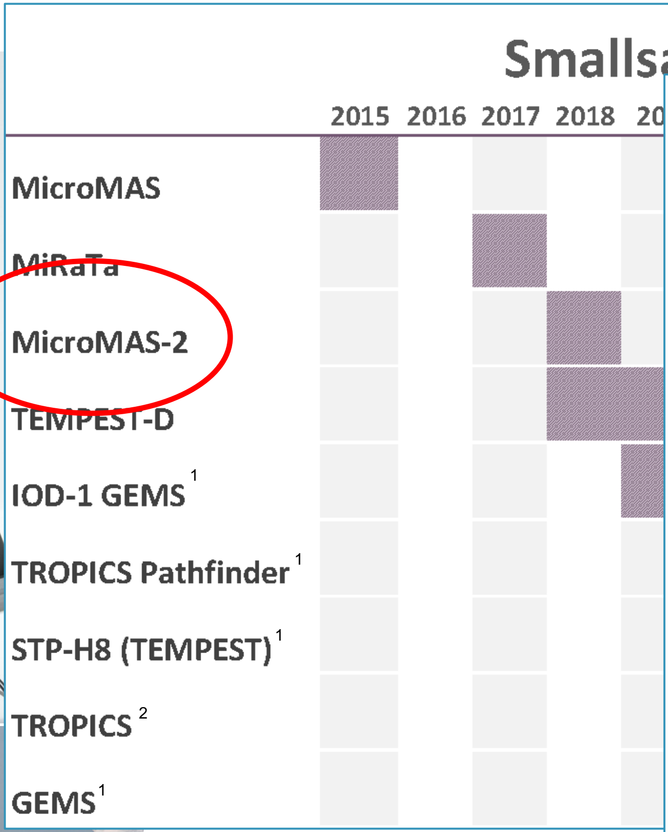
topics

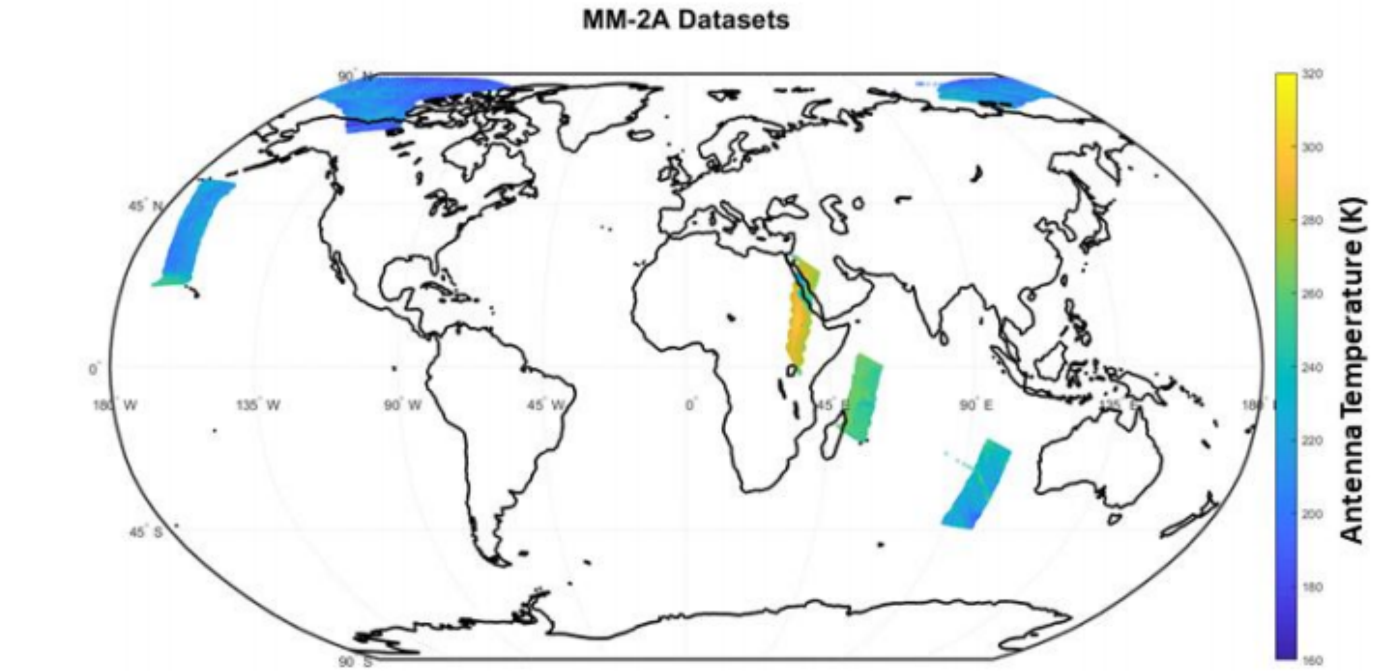
- **status of passive microwave (PMW) smallsats**
- previous studies
- considerations for NWP
- preparation and plans

PMW Smallsat Mission Status

Tropics.ll.mit.edu

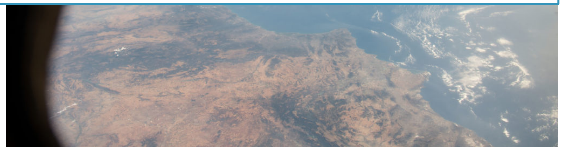






Crews et al. 2021

Fig. 2: Global map depicting the six MicroMAS-2A data segments used for this analysis. In this plot, we show the post-calibrated brightness temperatures measured by Channel 1 (89.0 GHz).



1. Mission end-of-life example
2. 9-year mission life possible

Transporter-2 rideshare mission. Spaceflightnow.com, Coldlife Photgraphy

news.satnews.com

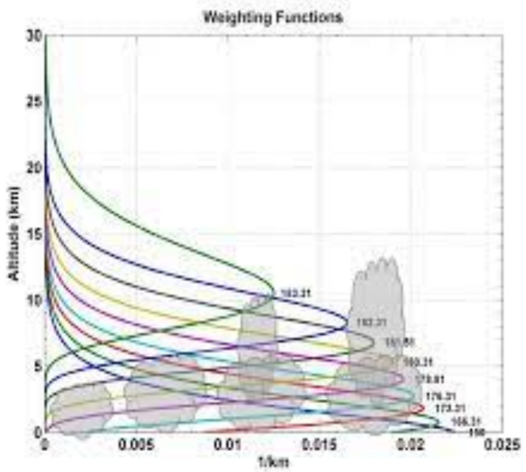
TEMPEST-D Overview

A proposed future NASA mission: **Temp**oral **E**xperiment for **S**torms and **T**ropical Systems (TEMPEST).
A demonstration mission in orbit: **TEMPEST-D**emonstration (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

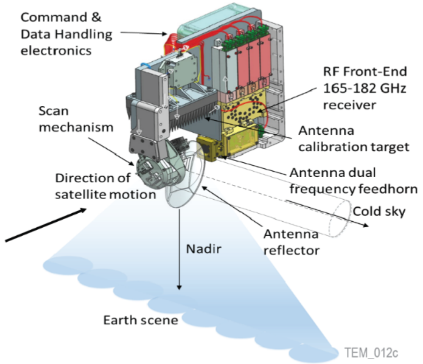
TEMPEST-D was deorbited June 22, 2021

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



Weighting functions within TEMPEST-D spectral region (Reising et al. 2019)

- 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.

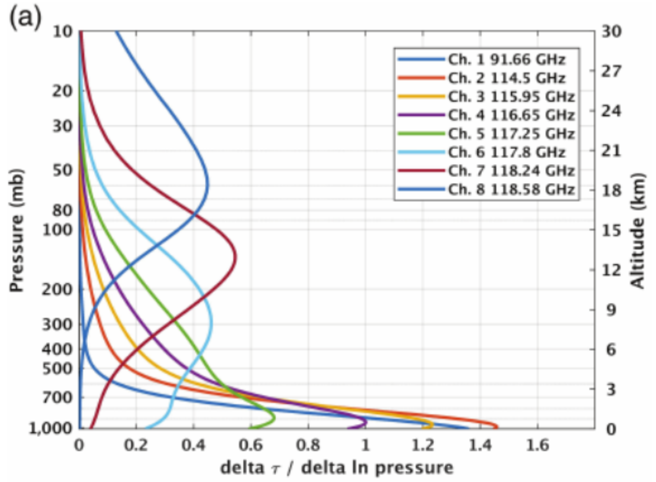


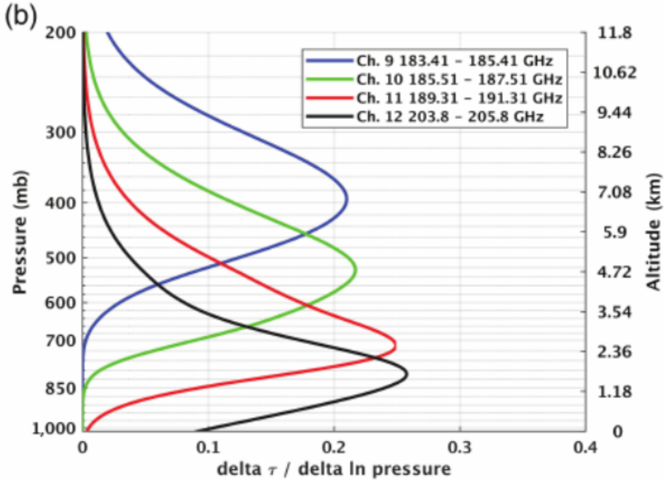
TROPICS Overview

- TROPICS is a 3U cubesat temperature and humidity sounder
  - 118 GHz O_2 band, 183 GHz H_2O, 91 GHz
  - 17 – 27 km resolution at nadir
- TROPICS Demonstration was launched June 30, 2021 successfully from NASA KSC
  - Sun-synchronous orbit

    [Watch the launch video here]

- Full constellation in 2022-2023 (12 satellites, 30 minute revisit times)
  - 600 km and 30° inclination orbit





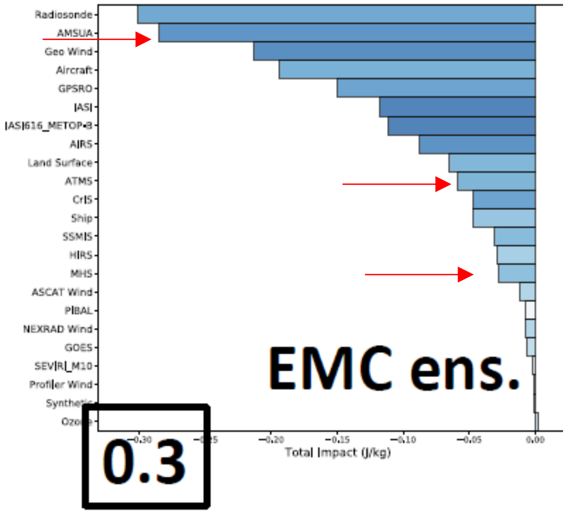
Channel	Centre frequency (Ghz)	Bandwidth (MHz)	Beamwidth (°) Down/Cross	ΔT_{rms} (K)	Calibration accuracy (K)
1	91.655 ± 1.4	1000	3.0/3.17	0.7	2.0
2	114.50	1000	2.4/2.62	1.0	1.5
3	115.95	800	2.4/2.62	0.9	1.5
4	116.65	600	2.4/2.62	0.9	1.5
5	117.25	600	2.4/2.62	0.9	1.5
6	117.80	500	2.4/2.62	0.9	1.5
7	118.24	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

(LEFT) Weighting functions for 12 TROPICS channels **(TOP)** Channel specifications. (Blackwell et al. 2018)

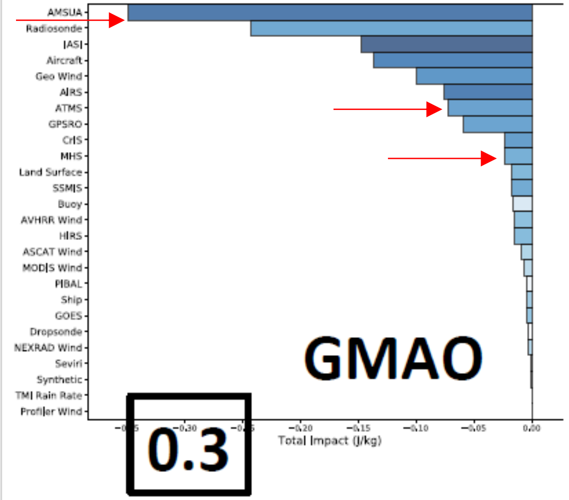
topics

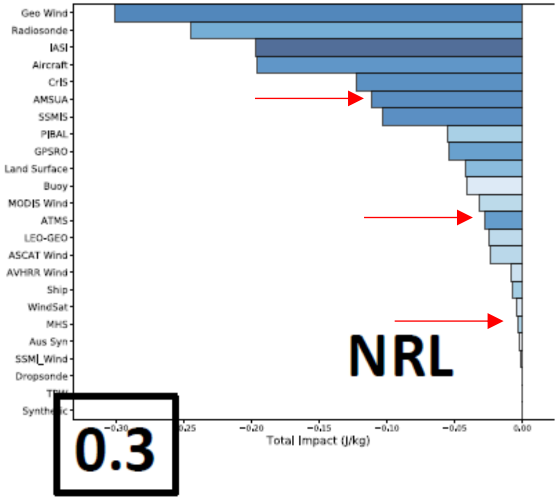
- status of passive microwave (PMW) smallsats
- **previous studies**
- considerations for NWP
- preparation and plans

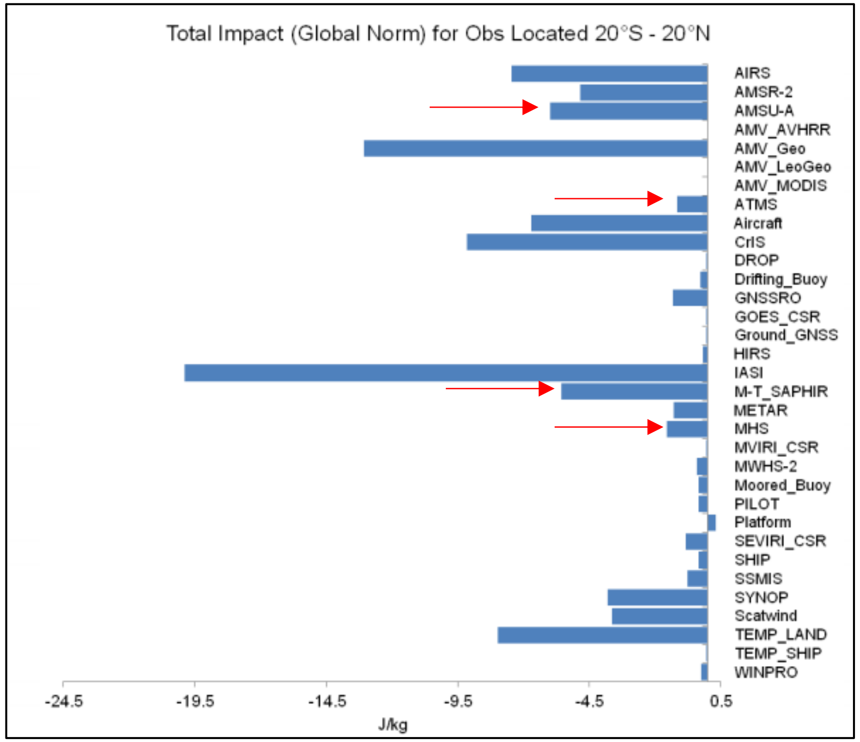
NWP Impact of PMW Sounders



FSOI Total Impact (Dry + Moist Energy (J/kg)) from EMC, GMAO, and NRL showing forecast error reduction per observation type.
(Mahajan et al. 2017)



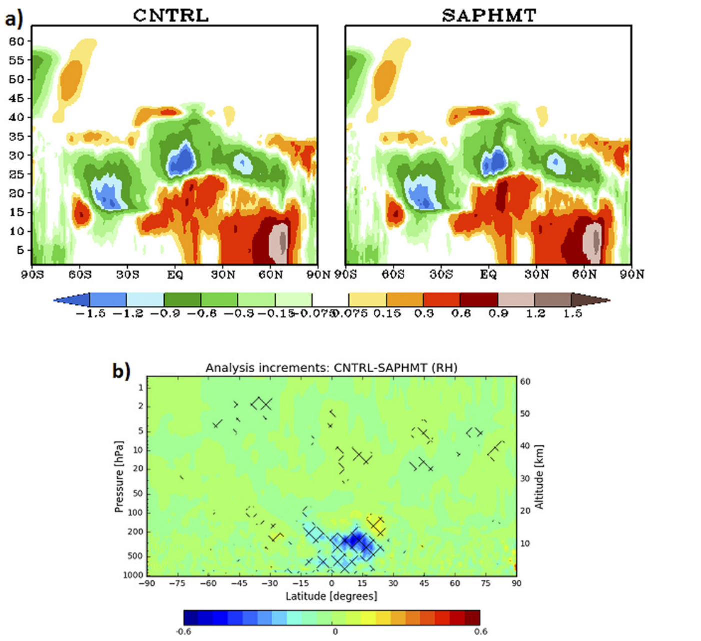




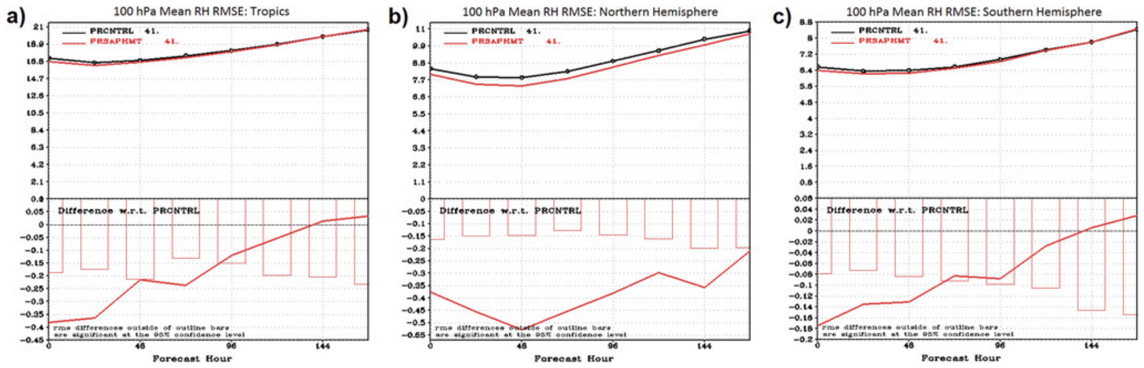
FSOI Moist Energy Norm (J/kg)) from UKMO showing forecast error reduction per observation type in the Tropics only.
(Eyre 2016)

Impact of PMW Humidity Sounders

- MT SAPHIR is a 6-channel humidity sounder in a 10° inclination orbit
- Integrated into NOAA GDAS/GFS
  - Clear-sky/ocean only data assimilated
  - Demonstrated positive forecast impact on upper level humidity
- Assimilated operationally at NOAA since 2018



(**LEFT**) Mean RH analysis increments 7-JUN – 18 JUL 2015 for GDAS without (CNTRL) and with SAPHIR (SAPHMT), and increment difference.



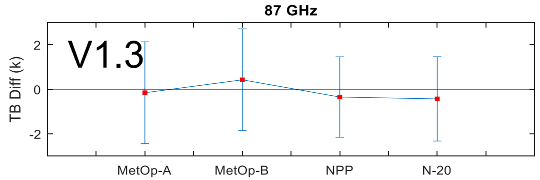
(**BOTTOM**) 100 hPa RH RMSE vs forecast hour for CNTRL and SAPHMT GFS experiments showing significant improvement when SAPHIR is assimilated. (Jones et al. 2017)

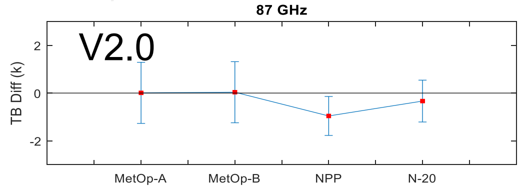
Assimilation of TEMPEST-D

- NESDIS/STAR Community Radiative Transfer Model (CRTM) team extended CRTM to simulate TEMPEST-D for cal/val, physical retrieval, and data assimilation
- NESDIS cal/val evaluated and monitored instrument stability and provided feedback to TEMPEST Science Team
  - Extended the ICVS for smallsat agility https://ncc.nesdis.noaa.gov/SmallSatellite/index.php
  - Assessed performance for v1.3-v2.0 of L1B data including SNO comparisons
  - Provided feedback to improve geolocation accuracy
- **Data quality suggests similar impact in NWP as MHS, SAPHIR**

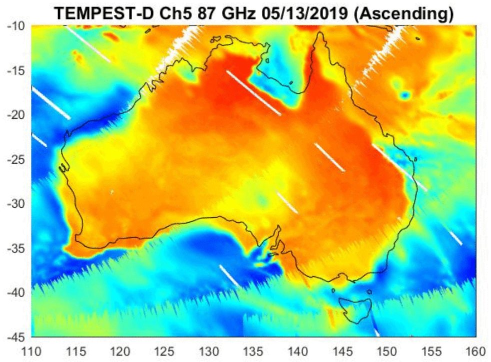
87 GHz channel

Reference sensor Channel (GHz)		V1.3 Rejected SNOs	V1.3 ΔBT	V2.0 Rejected SNOs	V2.0 ΔBT
MetOp-A/MHS	89	4	-0.16±2.29	0	0.01±1.28
MetOp-B/MHS	89	4	0.42±1.82	1	0.04±1.35
NPP/ATMS	88.2	4	-0.44±1.98	0	-0.96±0.82
NOAA-20/ATMS	88.2	6	-0.35±1.81	0	-0.34±0.88

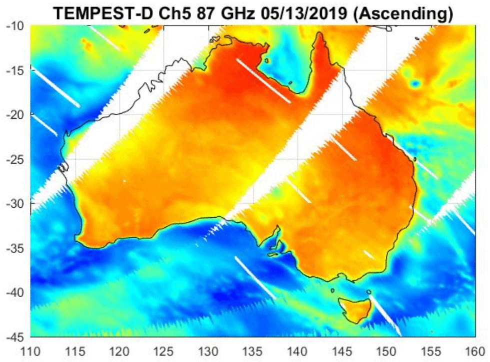




TEMPEST-D 87 GHz (May to July, 2019)



V 1.4



V 2.0

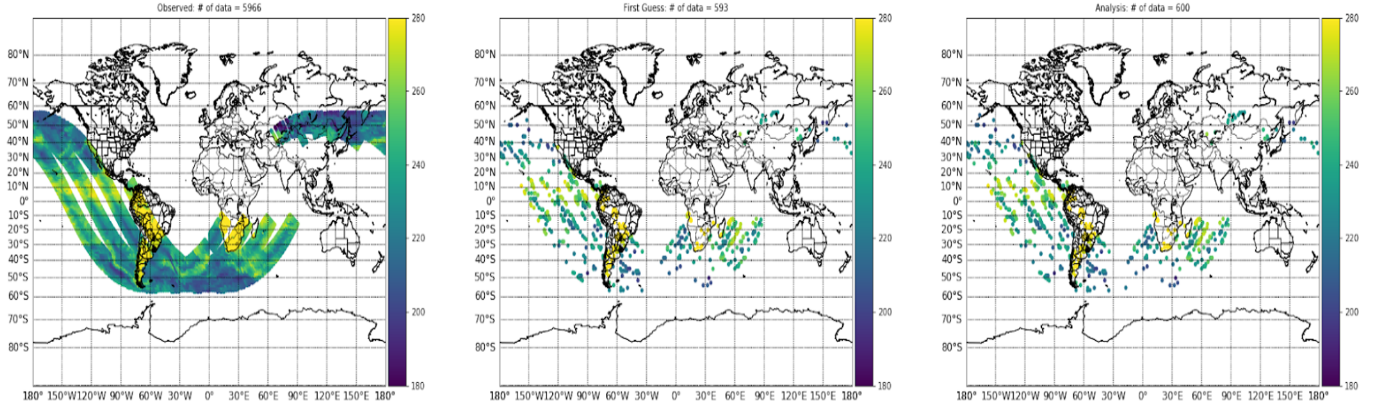
(Figures courtesy Changyong Cao, STAR)

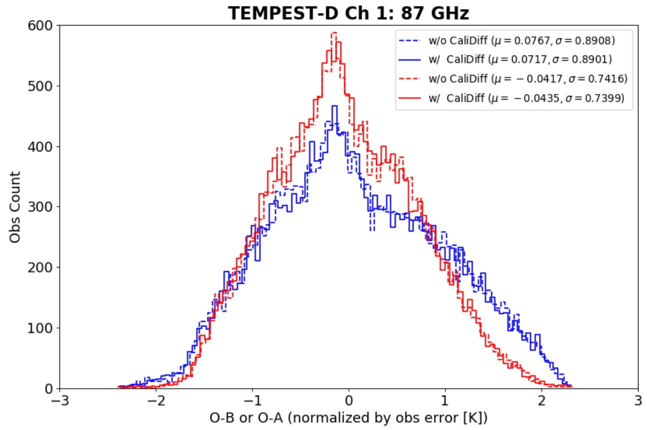
TEMPEST-D Data Assimilation

- CSU/CIRA implemented TEMPEST-D radiance assimilation in NOAA's global data assimilation system (FV3GFS)
  - Developed BUFR encoder
  - Developed Quality Control (cloud detection/removal of cloudy data)
  - Bias correction seeded with MHS bias coefficients (varBC)
  - Ran limited OSEs due to TEMPEST-D data availability (Dec 8-15, 2018)

TEMPEST-D 181 GHz

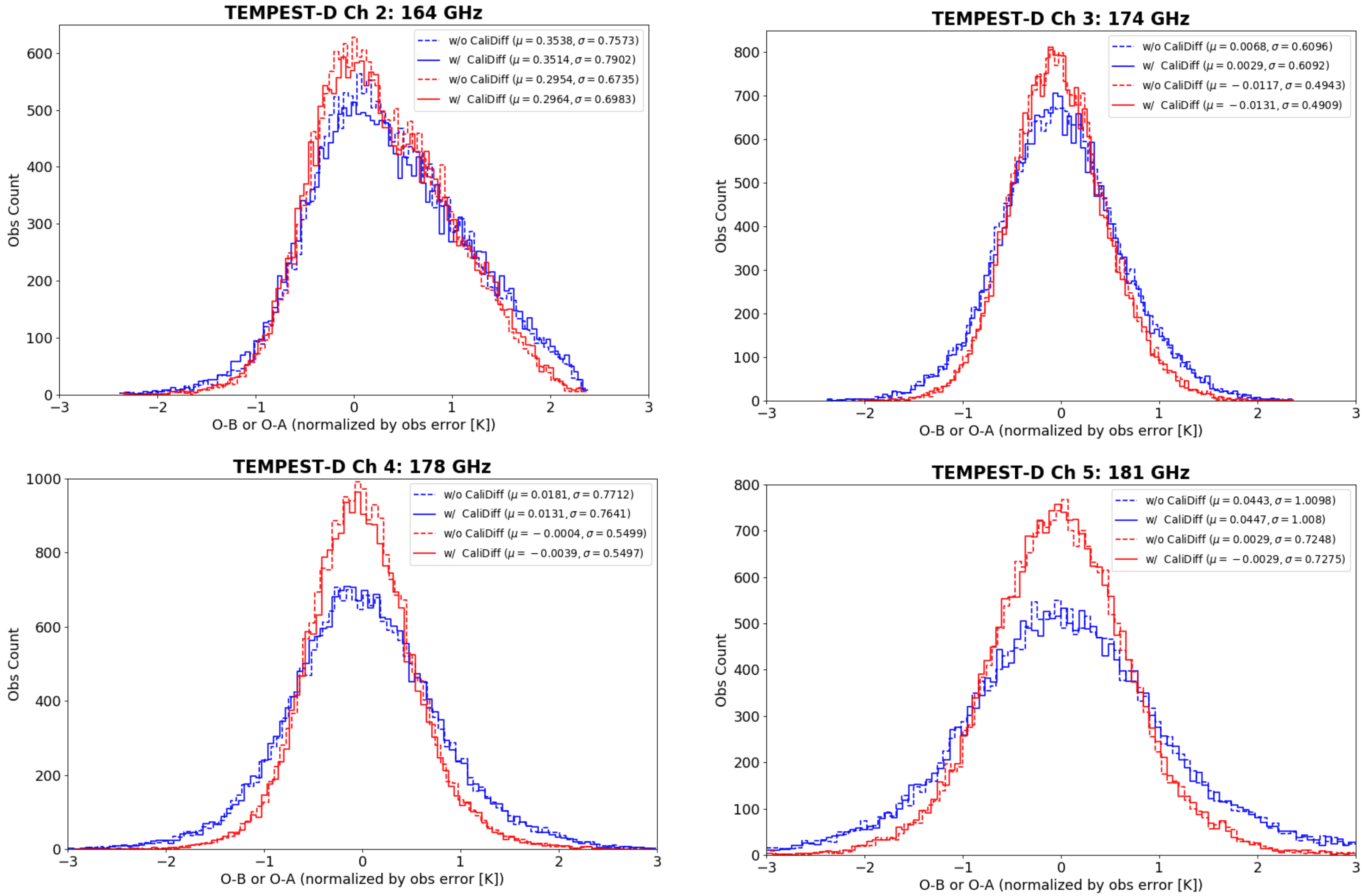
Observed **O-B (after QC)** **O-A (after QC)**





TEMPEST-D 181 GHz Observations, O-B, and O-A for Dec. 8 2018 00Z cycle, and O-B/O-A histograms for period Dec. 8-12, 2018. (Figures courtesy Chris Kummerow, CIRA)

TEMPEST-D Data Assimilation



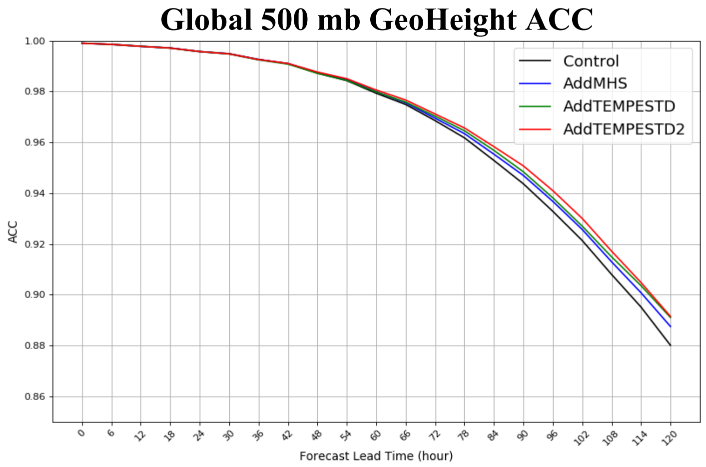
TEMPEST-D Channels 2-5 O-B/O-A histograms for period Dec. 8-12, 2018. (Figures courtesy Chris Kummerow, CIRA)

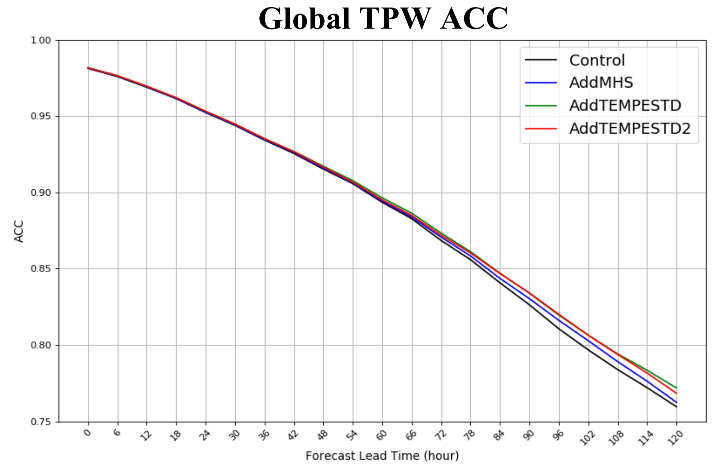
TEMPEST-D Data Assimilation

- 14-day experiment run using the v15 FV3GFS, 4DEnVar at C382 (25 km resolution)
  - Dec 8-12, 2018, May 12-22, 2019. 00Z and 12Z forecast.

	Control	AddMHS	AddTEMPD	AddTEMD2
Conv+Sat Obs Oper.				
Metop-A MHS				
Metop-B MHS				
NOAA-19 MHS				
TEMPEST-D			Chs 1-5	Chs 1, 3-5

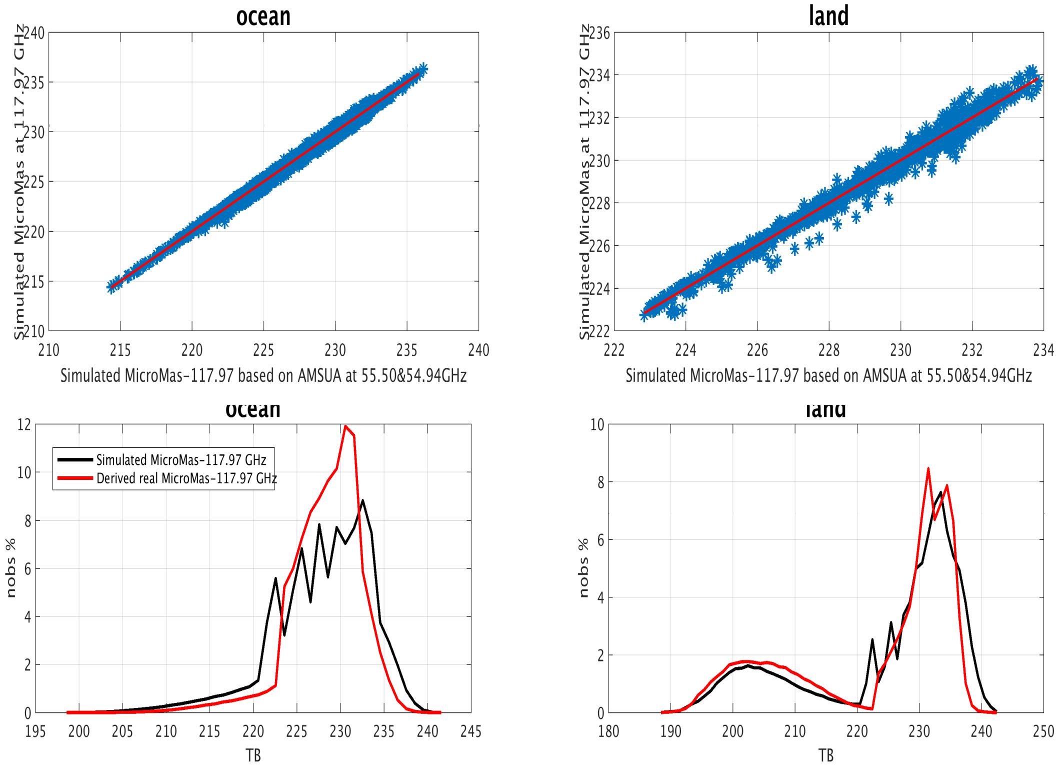
Anomaly Correlation: 500 mb Geopotential Height and TPW





MicroMAS OSSE

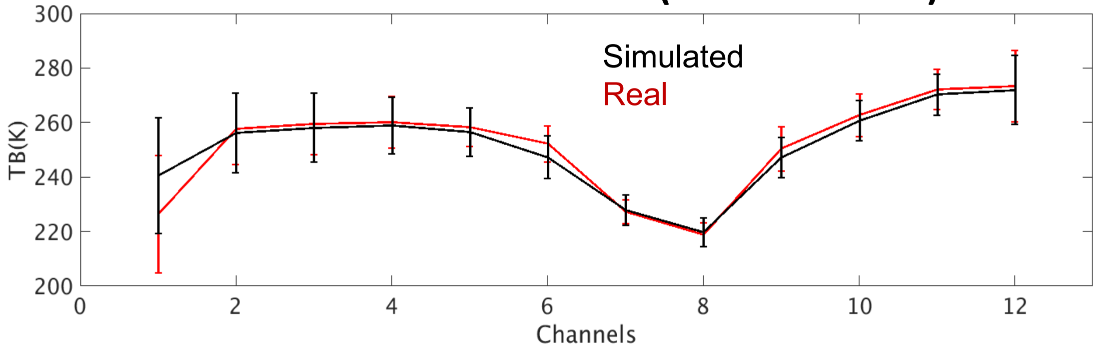
- NOAA conducted an OSSE in 2017 to assess impact of smallsat concepts on global NWP (Shahroudi et al. 2019)
  - Community Global OSSE Package (CGOP)
  - Simulation and validation of MicroMAS sensor (in SNPP orbit)
  - Integration in NOAA GDAS/GFS
  - Impact assessment



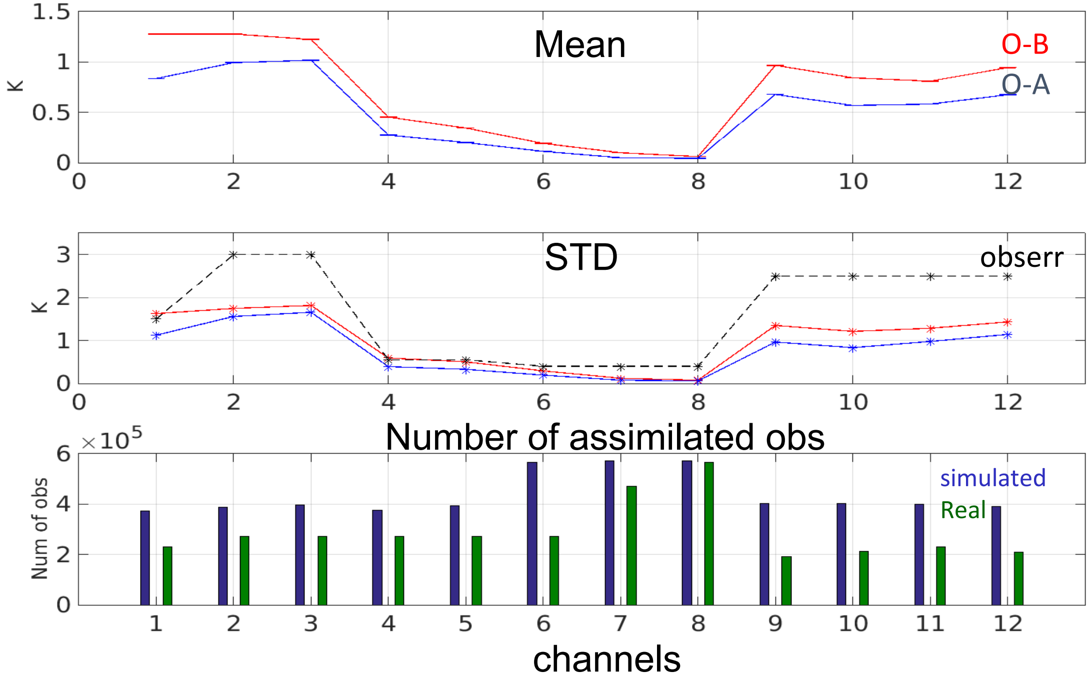
(**TOP**) Simulation of MicroMAS 117 GHz using CRTM vs. using AMSU 50 GHz band over ocean and land and (**BOTTOM**) same as above but shown as distribution.

MicroMAS OSSE

Validation of Simulated MicroMas-2 observations with real ATMS observations (2-weeks mean)



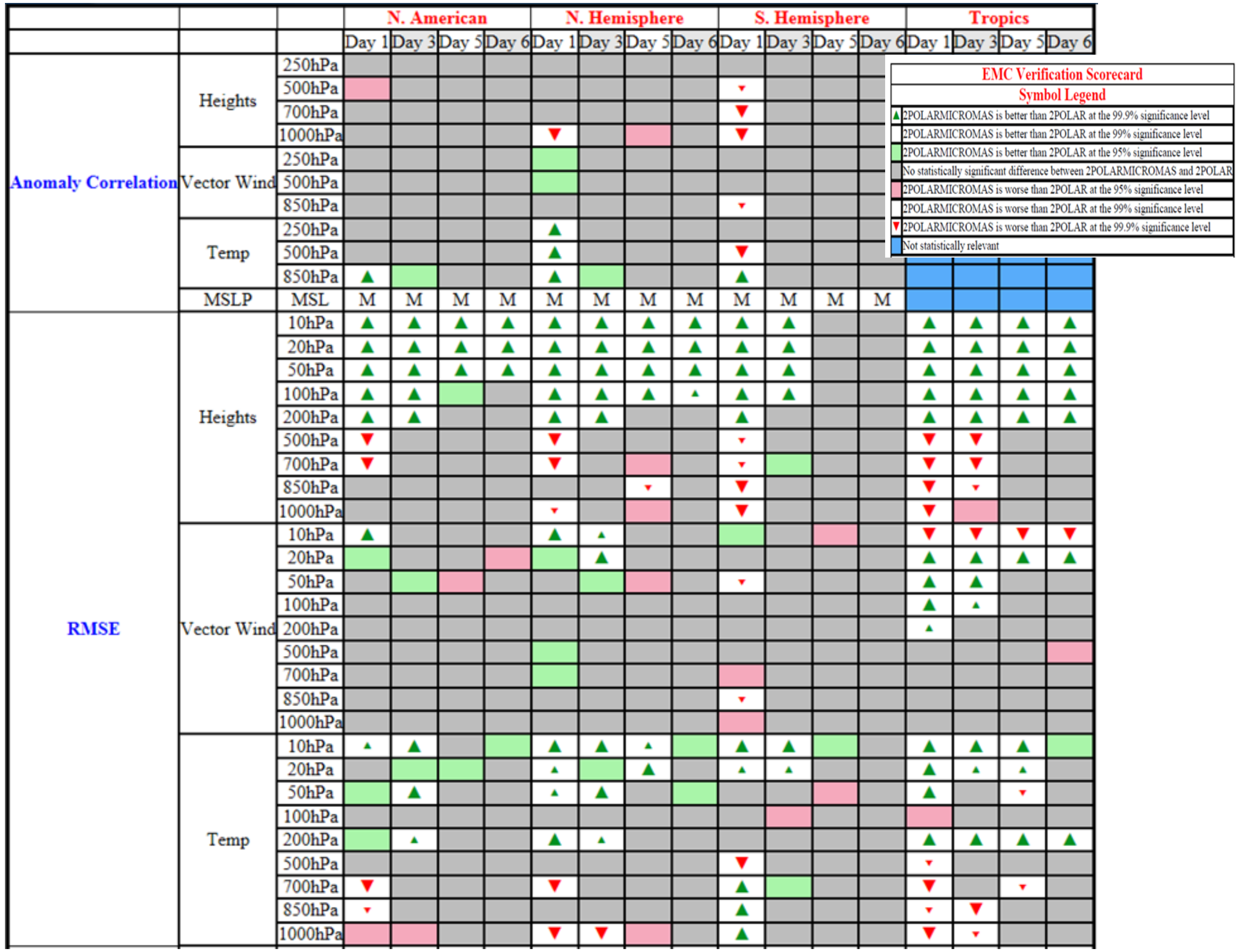
QC of MicroMas-2 Data Assimilation (2-week mean)



(**TOP**) Validation of the simulated MicroMAS data: matches with the ATMS real observations (118 GHz compared with 50 GHz proxies).

(**RIGHT**) O-B,O-A, and number of assimilated observations consistent with reality.

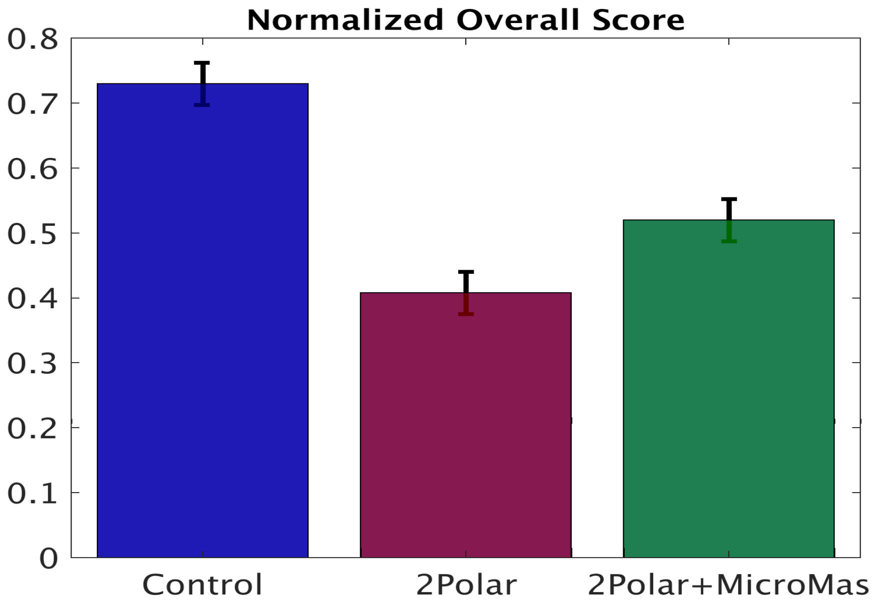
MicroMAS OSSE



NCEP Scorecard

MicroMAS impact assessed as sole platform in PM orbit

- Control is operational configuration
- 2Polar removes afternoon satellites



Overall Forecast Score

topics

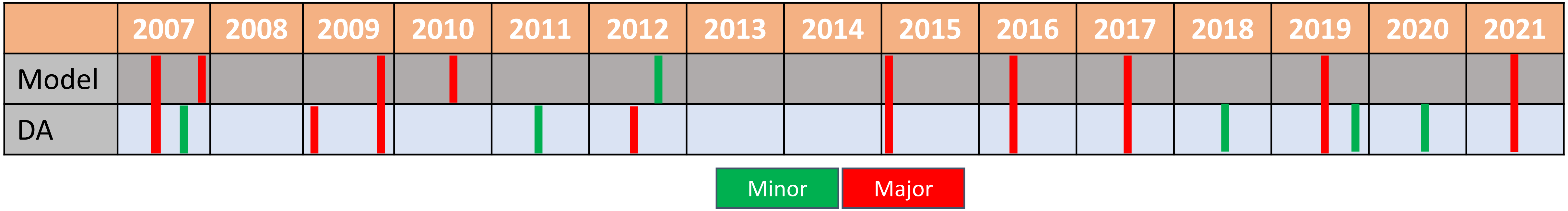
- status of passive microwave (PMW) smallsats
- previous studies
- **considerations for NWP**
- preparation and plans

Key considerations for smallsat data assimilation

- Data quality, stability
- Latency (move to hourly DA cycles for global model)
- Ground processing/data volumes
- Resources (human/compute) for integration and testing
- Longevity/Transition to operations timelines
- Value added
  - Increased temporal refresh
  - Spectral coverage, unique information

Transition to operations

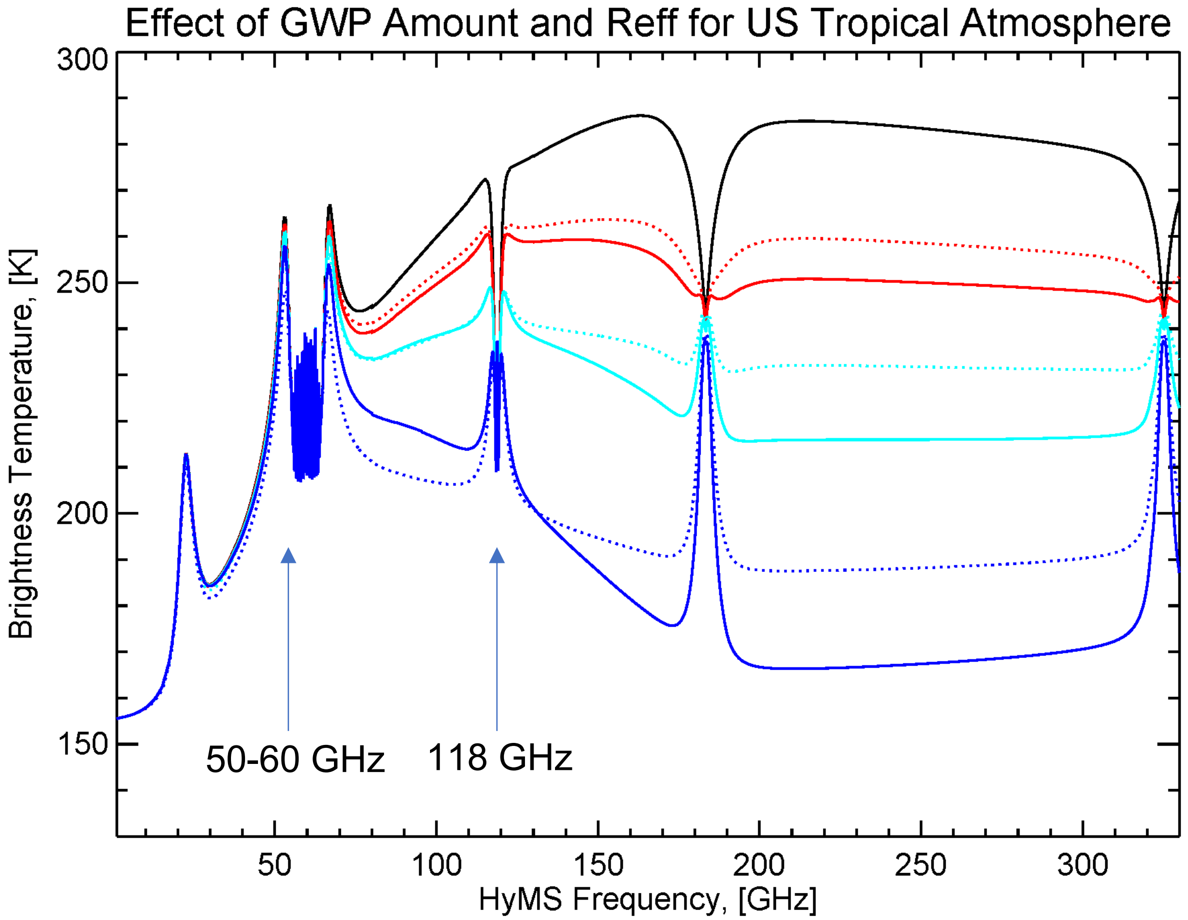
NCEP Global Model and Data Assimilation Operational Upgrades 2007-2021



- NCEP model suite upgrades infrequent
- Potential large numbers of sensors increases time for R2O/T2O
- Requires adequate prelaunch planning, coordination, new tools for evaluation/impact assessment, on-the-fly switch on in operational system

New spectral coverage, information content

New spectral regions require new QC, understanding forward model/all-sky capability/approach



______ Nominal Particle Size (500 microns)
- - - - - Largest Particle Size (1500 microns)
______ Hydrometeor Amount*0.5
______ Hydrometeor Amount*1.0
______ Hydrometeor Amount*2.0

CRTM simulation from 1-330 GHz for varying integrated graupel hydrometeor amounts

topics

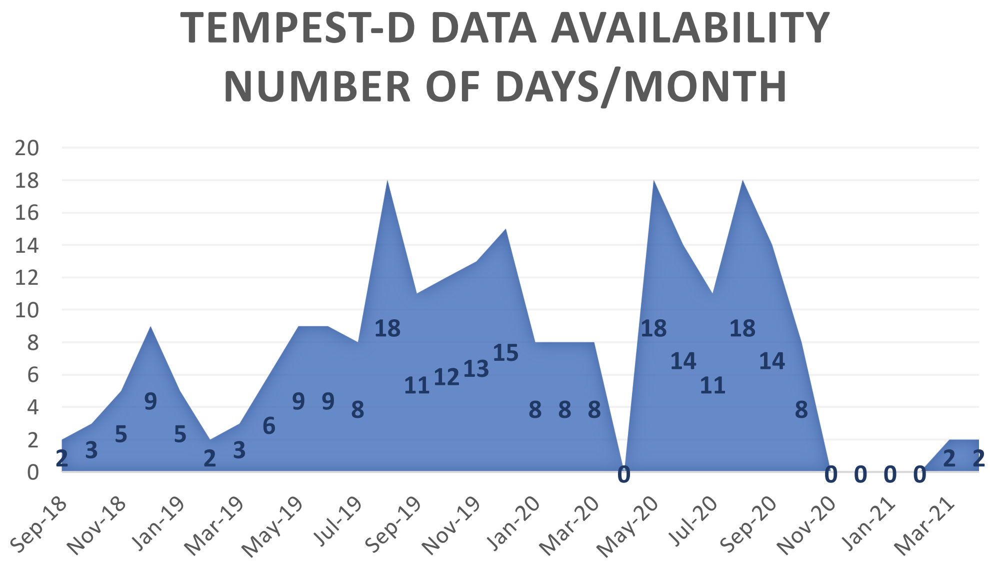
- status of passive microwave (PMW) smallsats
- previous studies
- considerations for NWP
- **preparation and plans**

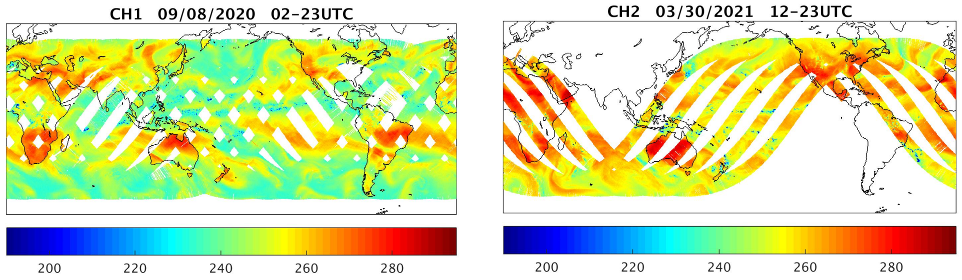
Objectives

- Assess the value of TEMPEST and TROPICS data in NOAA global forecast (How do these sensors and constellation concepts help NOAA achieve its mission?)
- Prepare NOAA systems for future (expansive) smallsat constellations
- Formulate and/or develop methods to accelerate R2O/T2O
- Increase collaboration and coordination with partners (science teams and operational entities)
- Inform NOAA next generation architecture planning

TEMPEST-D/TEMPEST Plans

- Data quality evaluation
  - Verify CRTM coefficients are correct (Ch1)
- Leverage previous TEMPEST-D GSI integration/BUFR
  - Reassess QC, bias correction, observation errors
  - Expand beyond SAPHIR work to all-sky/all-surface
- Run impact assessment (8/9 2019,5/6 2020)
- Assess quality and impact from STP-H8 TEMPEST
  - Latency will be low
  - Coordinate with NESDIS OSGS, OSPO and NCEP/NCO

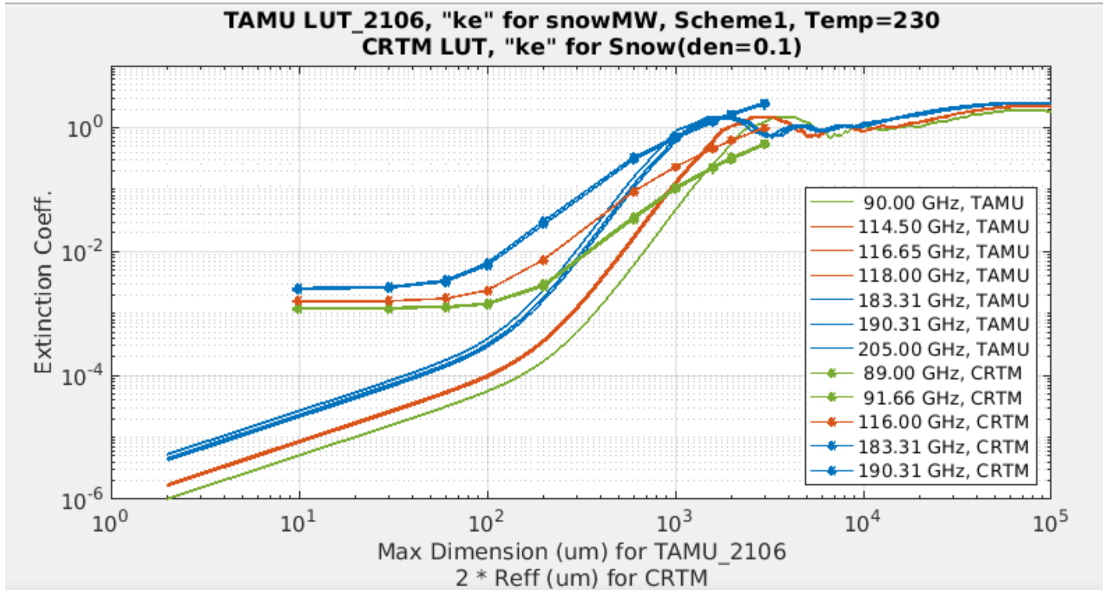




(**TOP**) Number of days per month with TEMPEST-D data available from launch to deorbiting. (**BOTTOM**) Sample TEMPEST-D Ch. 1 and Ch. 2 brightness temperatures from 9/8/2020 and 3/30/2021. (*Source*: tempest.colostate.edu)

TROPICS Plans

- Participate in TROPICS early adopter program
- Gain access to BUFR radiance data
  - NOAA also funding mission for improved product latency
  - Coordinate with NESDIS OSGS, OSPO, NCEP/NCO for BUFR tanks
- Data quality evaluation
  - Verify CRTM coefficients are correct
  - Forward model enhancements (ice cloud optical properties)
- Integration in NOAA FV3GFS
  - All-sky/all-surface. Large emphasis on 118 GHz performance, QC, etc.
- Run impact assessment
- Prepare for broader TROPICS constellation



Comparison of snow hydrometeor extinction coefficient for 90, 118, and 183 GHz regions for the current CRTM optical properties table, and newly developed optical properties from Texas A&M.

New optical properties encompass broad range of ice mass densities, sizes and frequency (1-800 GHz), temperature dependence, consistency across size parameters, and full Stokes polarization.

Thank you!

Thanks to the NESDIS/Office of Systems Architecture and Advanced Planning (OSAAP) Joint Venture Program supporting the TEMPEST and TROPICS evaluation work at NESDIS/STAR

Acknowledgement to the NESDIS/Office of Projects, Planning and Acquisition (OPPA) on support of TEMPEST-D cal/val and data assimilation work through the Technology Maturation Program

References

- Blackwell, W.J., Braun, S, Bennartz, R, et al. 2018: “An overview of the TROPICS NASA Earth Venture Mission.” Q J R Meteorol Soc. 144 (Suppl. 1): 16– 26. doi: https://doi.org/10.1002/qj.3290
- Crews, A. and Coauthors, "Initial Radiance Validation of the Microsized Microwave Atmospheric Satellite-2A." IEEE Trans. Geosci. and Remote Sens., 59, 4, pp. 2703-2714, 2021.
- Eyre, J., “Tropical observations in NWP: availability, impact and future evolution.” ECMWF Tropical Workshop, Reading, U.K., Nov. 2016.
- Jones, E. E., Garrett, K. and Boukabara, S.-A., “Assimilation of Megha-Tropiques SAPHIR observations in the NOAA Global Model,” Mon. Wea. Rev., vol. 145, no. 9, pp. 3725-3744, Sep. 2017, doi:10.1175/MWR-D-16-0148.1.
- Mahajan, R., Auligne, T., Gelaro, R., Langland, R., Groff, D.N., and Hotta, D., “Forecast Sensitivity and Observation Impact (FSOI) Inter-comparison Experiment.” AGU Fall Meeting, San Francisco, CA, USA, Dec. 2016.
- Reising, S. C. and Coauthors, “Early Results and Potential Earth Science Applications: Temporal Experiment for Storms and Tropical Systems Technology Demonstration (TEMPEST-D) 6U CubeSat Mission.” 2019 CubeSat Developers Workshop, San Luis Obispo, CA, April 23-25, 2019.
- Shahroudi, N., Zhou, Y., Boukabara, S.-A., Ide, K., Zhu, T. and co-authors. 2019. Global analysis and forecast impact assessment of CubeSat MicroMAS-2 on numerical weather prediction. J. Appl. Remote Sens. 13, 1. doi:10.1117/1.JRS.13.032511.