# Microwave Remote Sensing and Applications

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# OUTLINE

**Microwave Remote Sensing**

The Advanced Technology Microwave Sounder

ATMS & TROPICS Weighting Function

MW derived Environmental Data Records

23.8 GHz Water Vapor Channel

**Applications (for example)**

Total Precipitable Water (TPW)

Precipitation

**Future Studies**

Microwave Channel Configuration

AI Technology

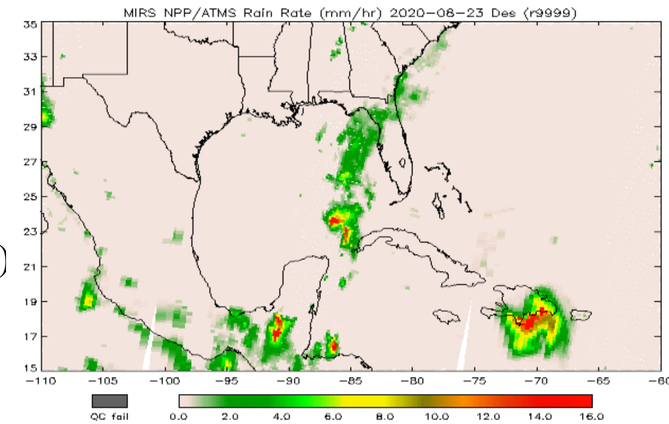
# Microwave Remote Sensing

# Selected Microwave Sensors

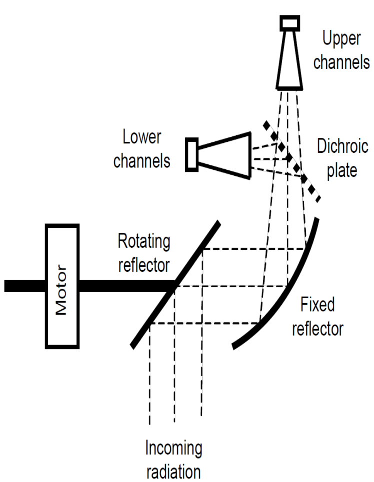
| Sensor | Frequency (GHz) | Viewing | Application | Comment |
|---|---|---|---|---|
| AMSU-A(15), AMSU-B or MHS | 23,31,50-60,88,165,183 | Cross-scan, 2200km, (48x48)-(16x16) | T, H2O, Precipitation, cloud, snow | Mixed(QV,QH) polarization |
| ATMS (22) | 23,31,50-60,88,165,183 | Cross-scan, 2500km, (75x75)-(16x16) | T, H2O, Precipitation, cloud, snow | Mixed(QV,QH) polarization |
| SSMIS (24) | 19,22,37,50-60,91,150,183 | Conical-scan, 1700km, (42x70)-(13x14) | Precipitation, sea ice, surface wind, T, H2O | (V,H,RC) |
| MLS (36) EOS-Aura | 118(9), 190(6), 240(7), 640(9), 2500(5) | Limb, V: 5-85km,H: 300km | T, Chemistry composition, H2O, | |
| AMSR-2 (16) | 6.9,7.3,10.7,19,23,37,89 | Conical-scan, 1450km, (35x62) – (3x5) | Precipitation, SST, sea ice, surface wind | (V,H) |
| TEMPEST-D 6U CubeSAT (5) | 89 to 182 | Cross-scan, 935km, 12.5 to 25km | Precipitation, H2O | Mixed(QV,QH) polarization |

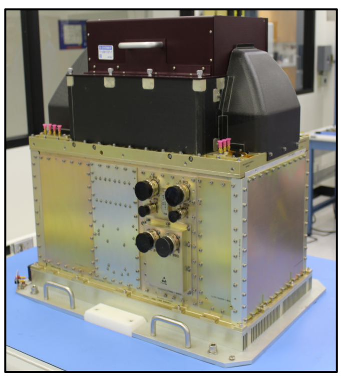
# The Advanced Technology Microwave Sounder (ATMS)

- **Mission:** All weather and global acquisition of temperature and moisture.
- **Satellites:** SNPP (2011), NOAA-20 (2017), JPSS-2 (2022).
- **Instrument Type:** Total power microwave radiometer.
- **Number of channels:** 22 channels.
- **Frequency range (GHz):** 23 GHz to 183 GHz.
- **Nadir resolution:** 74.8 km (K/KA band), 31.6 km (V-band), 15.8 km (W/G band)
- **Scanning Technique:** Cross-track 96 earth FOVs per scan.
- **Swath width:** 2200 km.
- **Coverage/Cycle:** Near-global coverage twice per day.



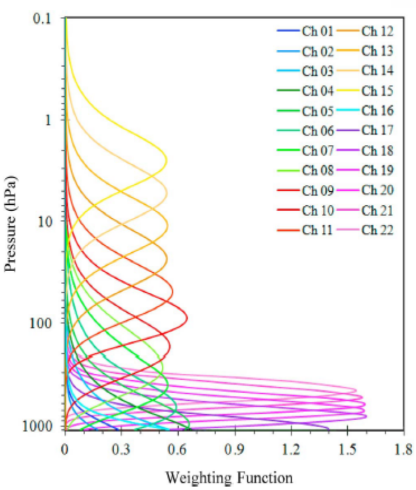

**ATMS antenna and RF feed subsystem**

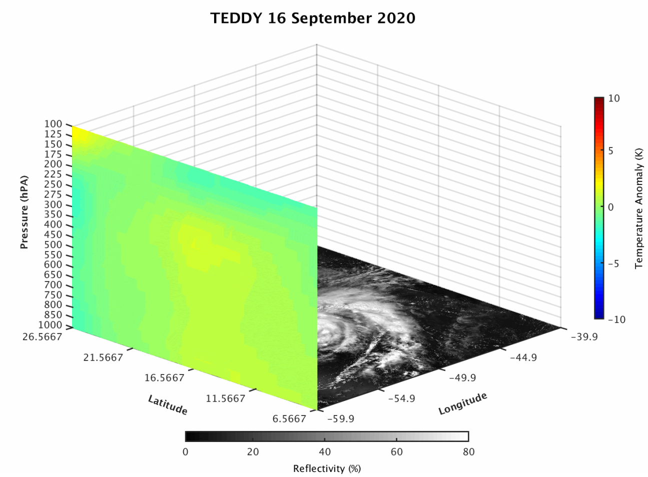


**The JPSS-2/ATMS Instrument. Courtesy of Northrop Grumman**

**ATMS weighting function**

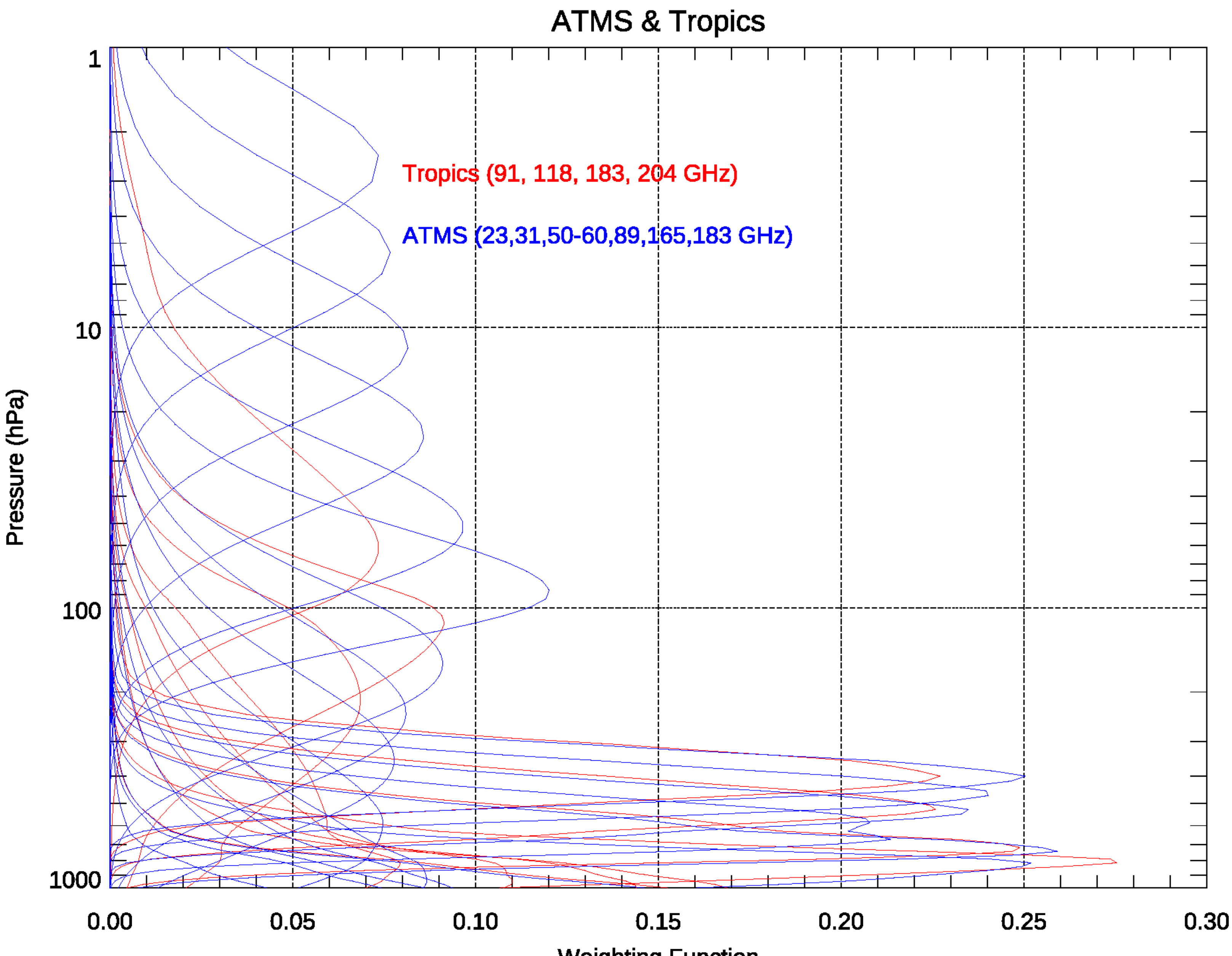



**Hurricane Teddy (Sep 12, 2020 – Sep 27, 2020) 3-D Warm Core Temperature Structure from ATMS SDR data**

***POC: Quanhua (Mark) Liu, ATMS SDR Team Lead***

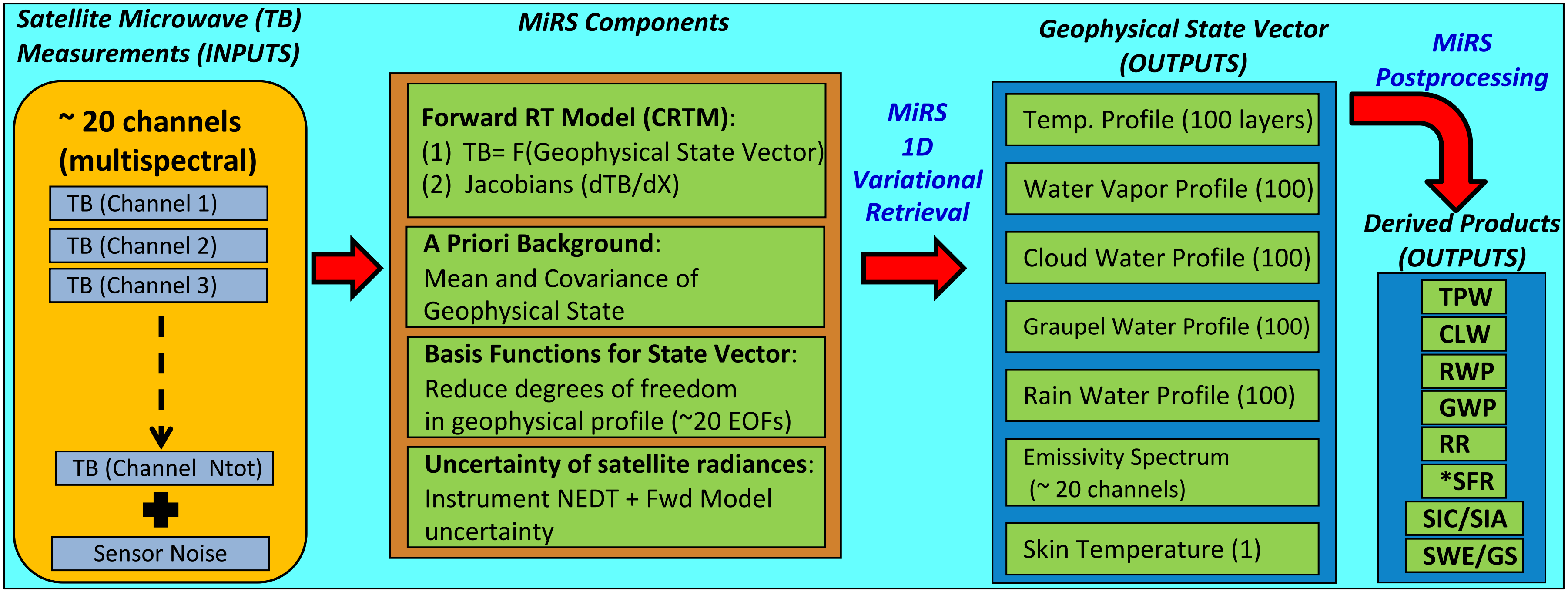
# ATMS & TROPICS Weighting Function



# MW derived Environmental Data Records

- Temperature profile
- Moisture profile
- Cloud liquid water
- Precipitation
- Snow fall rate
- Sea ice concentration
- Total precipitable water
- Land surface temperature
- Land surface emissivity
- Snow water quivalent/Snow cover
- Soil moisture
- Ocean salinity
- Sea surface temperature
- Sea surface wind speed

# MiRS High-level Flow Diagram




- MW Only, 1D Variational Approach: Find the "most likely" atm/sfc state that: (1) best matches the satellite measurements, and (2) is still close to an a priori estimate of the atm/sfc conditions
- Background and First Guess come from a "dynamic climatology" which varies in space and time.
- Details on the MiRS algorithm can be found in the Algorithm Theoretical Basis Document and the MiRS User Manual.

# MiRS Users

Operational users, who have subscriptions on NOAA/PDA (Production Distribution Access) are:

- NWS NHC, NESDIS_VIZLAB, CLASS, STAR, NASA GPM, NAVO, FNMOC, 557TH, NASA JPL, GNC-A, NWC, NWS AWIPS, NWS NCO, CIRA, NASA SPORT, SSEC/CIMSS, NESDIS operational applications: eTRaP, blended RR, National Ice Center (IMS), NWS Forecast Offices,
- NHC TC intensity (POC: Galina Chirokova (CIRA)),
- International Arctic Research Center and GINA, Alaska (POC: Carl Dierking, NOAA Liaison),
- NOAA Climate Prediction Center, CMORPH (POC: Pingping Xie),
- Blended TPW and ALPW (POC: John Forsythe (CIRA))

Downstream products:

- Ensemble Tropical Rainfall Potential (**eTRaP**)
- Blended TPW (and soon blended ALPW)
- Blended Rain Rate
- Snow and Ice Cover Analysis (**IMS**)
- NESDIS Microwave Sounder-based Tropical Cyclone (**TC**) Products: Hurricane Structure and Intensity (HISA), Moisture Flux (MIST, experimental)

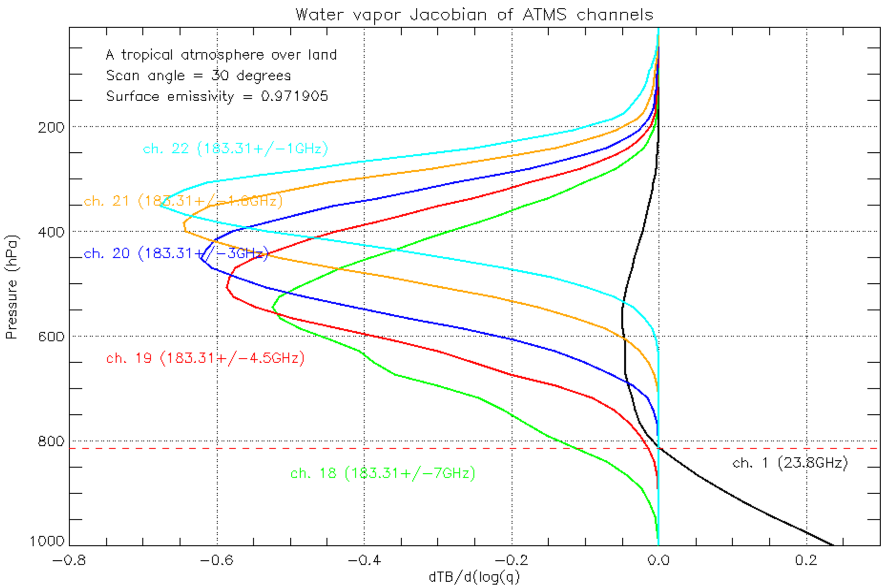
# Total Precipitable Water

# 23.8 GHz Water Vapor Channel

ATMS channel 1 has good sensitivity on water vapor in a boundary layer. However, the sensitivity on total column water vapor (TPW) over land is very small, due to the cancellation of negative sensitivity in upper atmosphere and positive sensitivity from low atmosphere.

The MiRS can generate useful precipitation and water vapor profiles by utilizing information from ATMS channel 1 and other ATMS channels in which ATMS water vapor channels 18 to 22 have the weighting peaks between 300 hPa and 800 hPa.

Without ATMS ch. 1 at 23.8 GHz, the MiRS global TPW retrieval is increased by 12% over land and more 22% over oceans.




Comparisons of MiRS retrieved global total precipitable water (mm) between using all NOAA-20 ATMS channel measurements (operational) and ATMS measurements without channel 1 for March 15, 2019. Values in red color are the relative change in percentage of standard deviation.

| | All ATMS Channels | | | | ATMS without channel 1 | | | |
|---|---|---|---|---|---|---|---|---|
| | Clear | | Cloudy | | Clear | | Cloudy | |
| | Land | Sea | Land | Sea | Land | Sea | Land | Sea |
| **Bias** | 0.099 | 1.687 | 1.646 | 1.286 | 0.482 | 1.942 | 2.467 | 0.870 |
| **Standard deviation** | 2.634 | 1.874 | 2.689 | 2.275 | 2.955 (12.1%) | 2.291 (22.2%) | 3.044 (13.2%) | 3.314 (45.6%) |

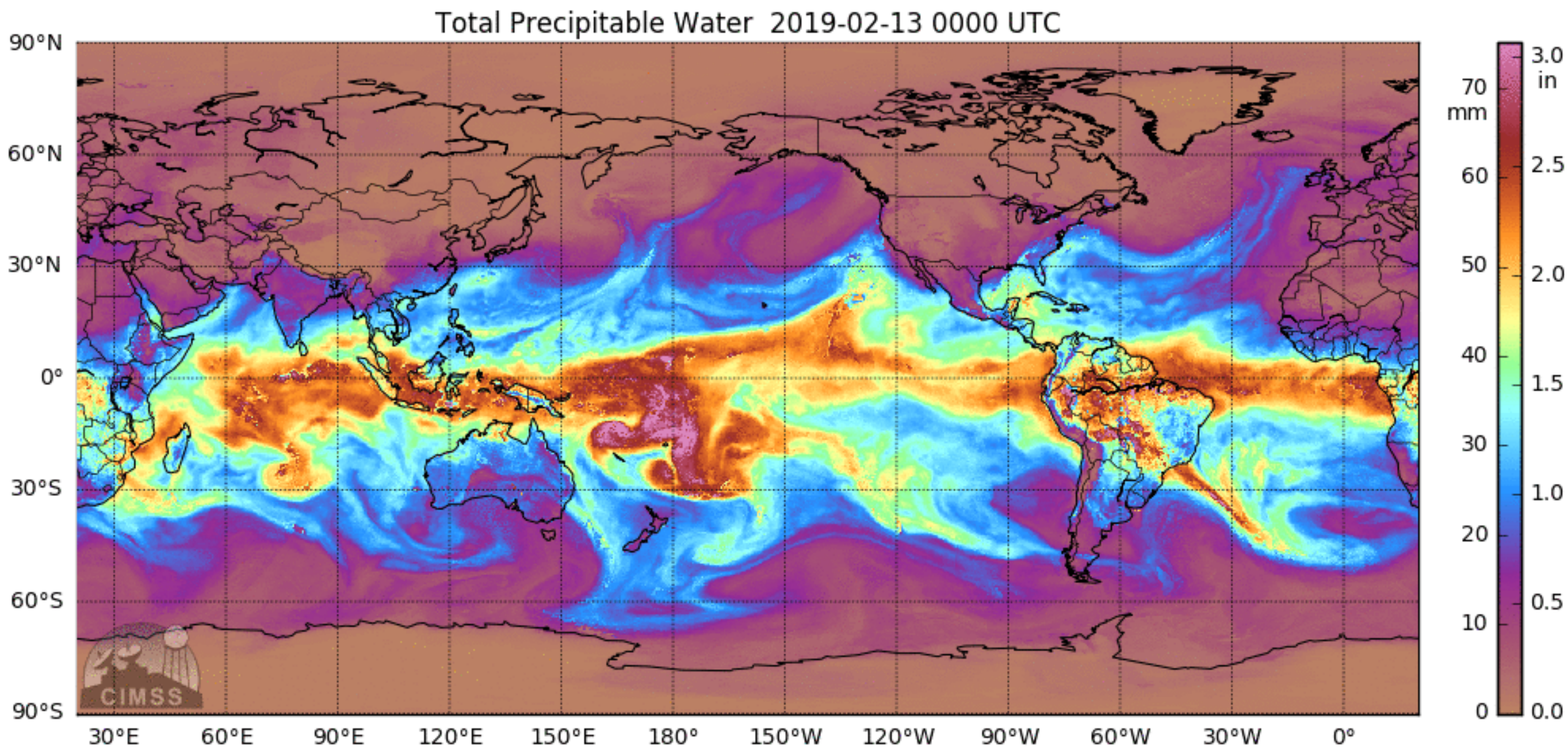
Liu, Q.; Cao, C.; Grassotti, C.; Lee, Y.-K. How Can Microwave Observations at 23.8 GHz Help in Acquiring Water Vapor in the Atmosphere over Land? Remote Sens. 2021, 13, 489. https://doi.org/10.3390/rs13030489

# TPW Applications

- Estimating incoming extreme rain events and flooding,
- Tracking the origin of atmospheric rivers,
- Diagnosing the environment of tropical cyclones,
- Following major aerosol plumes over ocean basins,
- General comparisons with NWP fields for assessing accuracy.

Thank Tony Wimmers (UW) & John Forsythe (CSU) to provide users info and the MIMIC blended TPW.

NHC,TAFB,Honolulu WFO, American Samoa WFO, Juneau WFO, Tropical Analysis and Forecast Branch,Advanced Hydrological Prediction Service – Anchorage, San Juan WFO, Joint Typhoon Warning Center, UK Met Office, Australia BMO, Trinidad and Tobago Met Office,Mississippi State, University of Miami, Jet Propulsion Laboratory,Naval Research Lab – Monterey,University of Antioquia



# Precipitation

- Precipitation is one of the most important essential climate variables (ECVs) indicating the state of the global and regional weather and climate systems;

- Precipitation plays vital roles in daily human life;

- Satellite based precipitation estimates provide pivotal information on the timing, location, and intensity of precipitation especially over ocean and sparsely populated land areas;

- Level 2 retrievals of instantaneous precipitation rate (rainfall and snowfall) consist foundation of satellite precipitation products;

- Level 3 technique, such as the CPC Morphing technique (CMORPH), generates temporal-spatially continuous grid analysis convenient for end users

# PMW Channels
# Used to Derive L2 Retrievals Used as Inputs to CMORPH

1) Global Precipitation Measurement (GPM) mission Microwave Imager (GMI) on GPM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Frequency (GHz) | 10.65 V/H | 18.7 V/H | 23.8 V | 36.5 V/H | 89.0 V/H | 165.5 V/H | 183.31 +/-3 V | 183.31 +/-7 V |

2) Advanced Microwave Scanning Radiometer 2 (AMSR 2) on GCOM-W1

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Frequency (GHz) | 6.925/ 7.3 V/H | 6.925 /7.3 V/H | 10.65 V/H | 18.7 V/H | 23.8 V/H | 36.5 V/H | 89.0 V/H | |

3) Special Sensor Microwave Imager / Sunder (SSMIS) on DMSP F15,16,17, &18

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Frequency (GHz) | 19.35 V/H | 22.235 V | 37.0 V/H | 91.665 V/H | 150 H | 183.311 +/-1 H | 183.311 +/-3 H | 183.311 +/-7 H |

4) Microwave Humidity Sounder (MHS) on N19 & METOP-B

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Frequency (GHz) | 183.31 +/-7 | 183.31 +/-4.5 | 183.31 +/-3 | 183.31+/- 1.8 | 183.31+/-1 | | | |

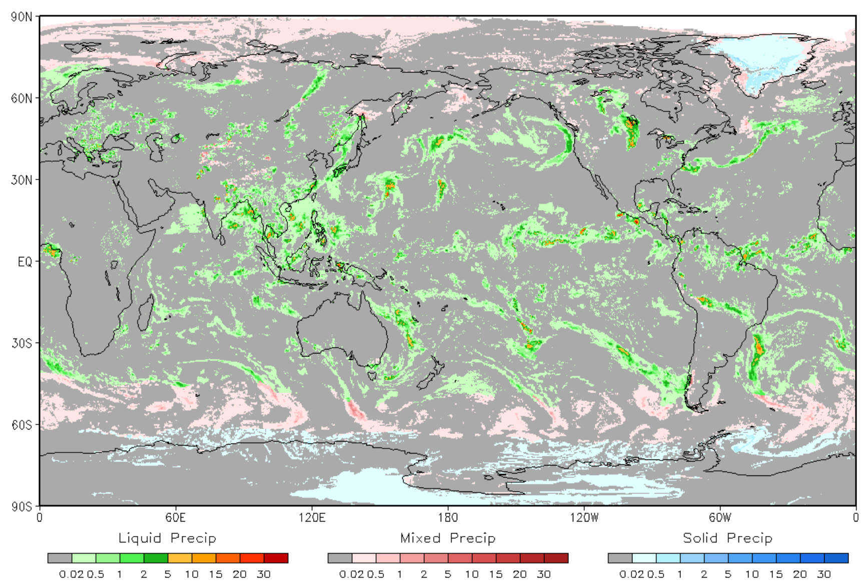
5) Advanced Technology Microwave Sounder (ATMS) on SNPP & N20

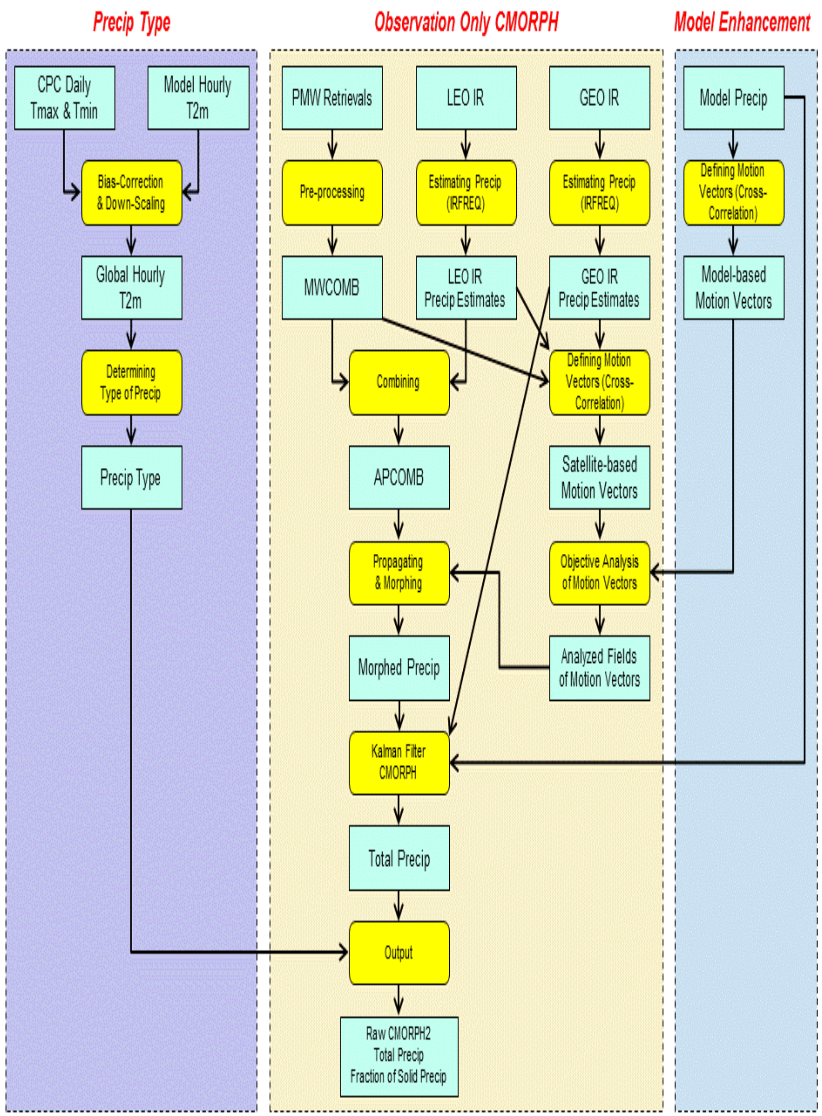
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Frequency (GHz) | 23.8 | 31.4 | 50.3 | 51.76 | 52.8 | 53.596 +/-0.115 | 54.4 | 54.94 |
| | 55.5 | 57.290344 | 57.290344 +/-0.217 | 57.290344 +/-0.3222 +/-0.048 | 57.290344 +/-0.03222 +/-0.022 | 57.290344 +/-0.03222 +/-0.010 | 57.290344 +/-0.03222 +/-0.0045 | 88.2 |
| | 165.5 | 183.31 +/-7 | 183.31 +/-4.5 | 183.31 +/-3 | 183.31 +/-1.8 | 183.31 +/-1 | | |

# Level 2 PMW Retrievals Integrated into CMORPH

- Level 2 PMW retrievals of rainfall and snowfall rate (SFR) inter-calibrated and integrated into CMORPH global precipitation estimates of improved quality;
- In addition to the precipitation intensity, fraction of solid precipitation is also estimated;
- 0.05olat/lon grid over the entire globe;
- 30-min interval produced at a latency of one hour;

- **Sample CMORPH2 for 11:00UTC, 11 Jun., 2021**



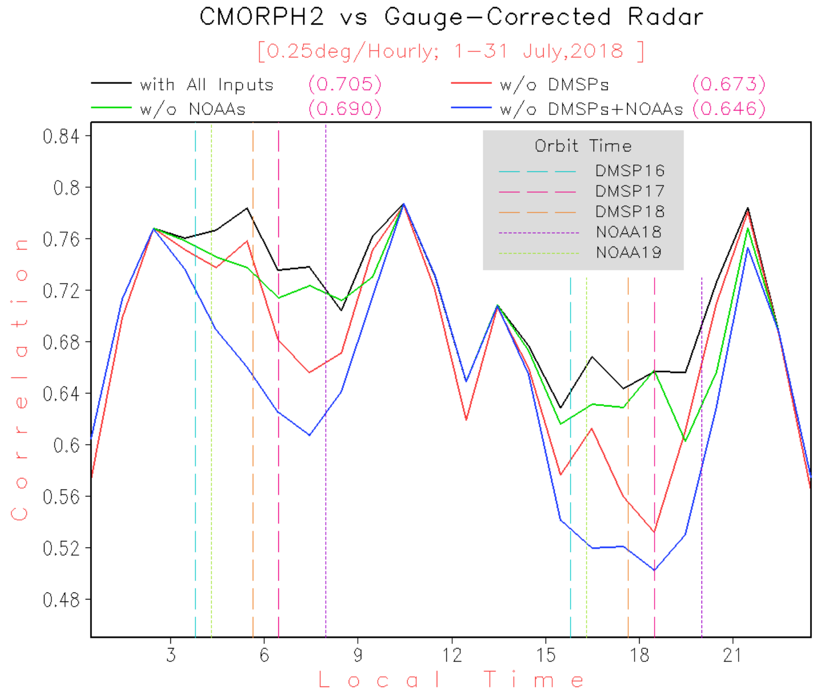



# CMORPH Satellite Data Set Users

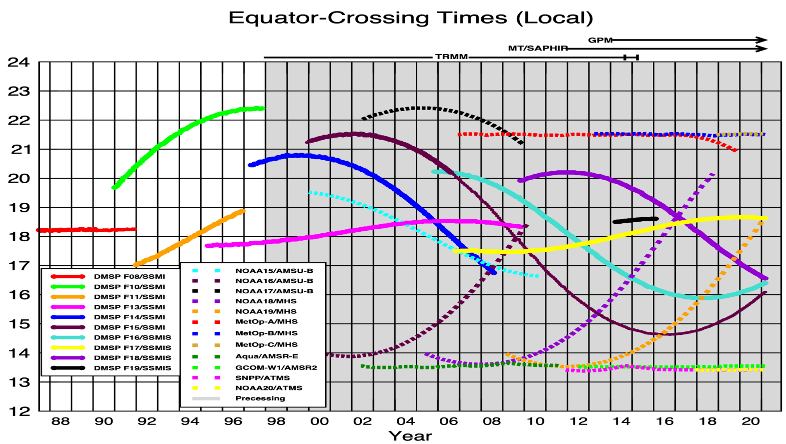
- **NOAA Centers / Offices**
  - *NCEP/CPC* — *Climate / ocean Monitoring and climate model verifications*
  - *NCEP/EMC* — *Forcing Land surface model; model verifications*
  - *NCEP/WPC* — *Weather monitoring and forecasts verifications*
  - *NCEP/HPC* — *Hurricane and tropical monitoring and analysis*
  - *NWS/OWP* — *Constructing high-resolution precipitation analysis before radar era*
  - *NWS/MDL* — *Constructing MRMA QPE*
  - *OAR/NSSL* — *Filling gaps of radar observations*
  - *NWS/Alaska* — *Weather monitoring and forecasts*
- **Other US Government Agencies**
  - *AFWA* — *forcing land surface model*
  - *USDA* — *Global crop monitoring and prediction*
  - *US Army Corps* — *Hydrological engineering planning*
- **International Organizations**
  - *WMO* — *Space based monitoring of weather and climate extremes*
  - *World Bank* — *Risk management*
- **Academics**
  - *Development and verifications of numerical models for weather, climate, and hydrometeorology (flooding)*
  - *Global and regional water cycle and water budget*
  - *Land surface studies*
  - *Oceanic processes and air-sea interactions (mixed layer, salinity, et al)*
  - *Earth system (atmospheric, oceanic, land et al) monitoring*
  - *Health*
- **Industries**
  - *Agriculture / Food*
  - *Insurance / Reinsurance*
  - *Hydrological engineering*
  - *Risk management / natural hazards mitigation*
  - *Commodities*
  - *Tourism*
  - *GIS*

# Maintaining a PMW Consternation is Essential to Ensure Reasonable Quality of Satellite Precipitation Products

- A consternation of PMW carrying satellites of appropriate configuration is essential to the detection and quantification of convection and associated precipitation;
- Even with the current PMW satellite networks (**bottom**), there are gaps of more than 3 hours (e.g. 10-13LST);
- Simulation tests showed sub-substantial degradation in the CMORPH performance in captur the precipitation ans its variations around the time periods of the simulated denied satellites (**right**);




*Correlation between MRMS gauge-corrected radar estimates and CMORPH2 constructed using PMW retrievals from all available satellites (black) and with retrievals from DMSP and/or NOAA satellites dropped. Correlation is computed using co-located data on a 0.25°lat/lon grid over CONUS for 1-31 July, 2018.*



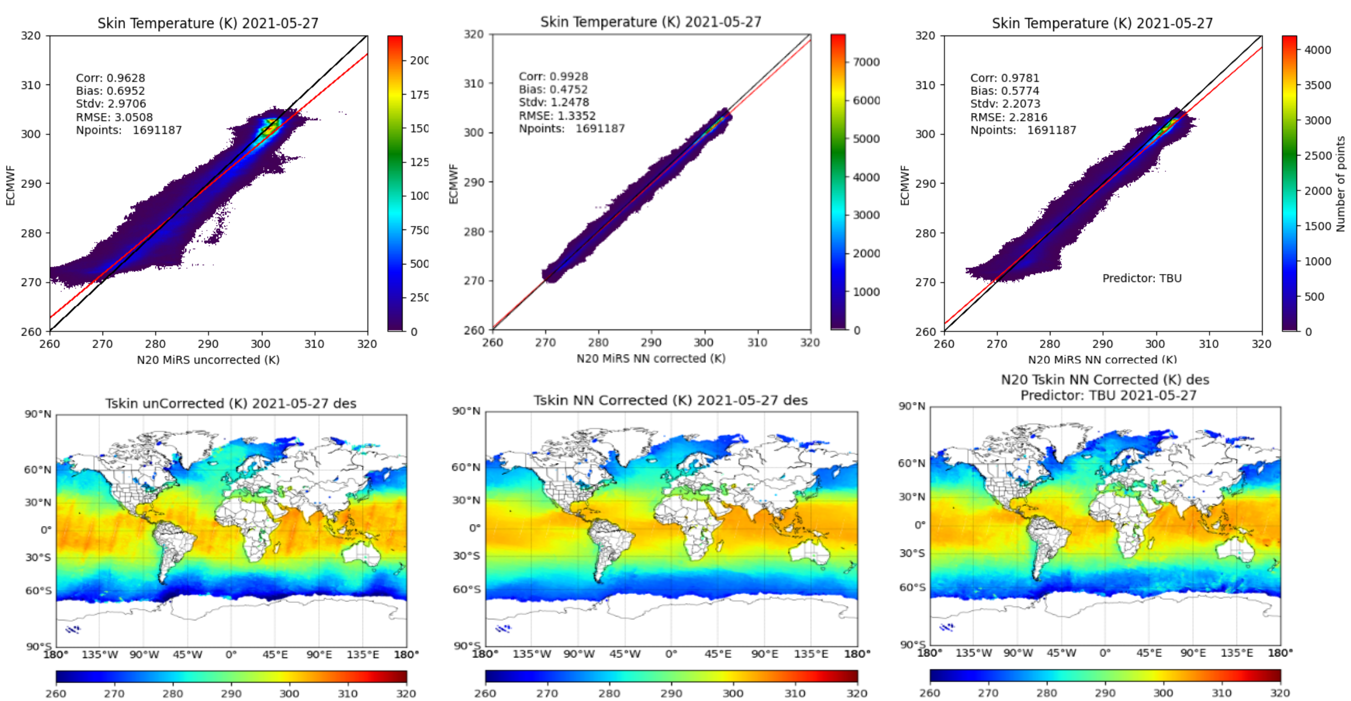

Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 21 April 2021, NASA/Goddard Space Flight Center, Greenbelt, MD.

Orbit time of satellites with PMW sensors
Courtesy of NASA/GSFC Eric Nelkin

# Future Studies

# Highlights: Machine Learning Correction Leads to Improved MiRS Sea Surface Temperature Retrieval

- **Machine learning to correct MiRS sea surface temperature retrievals**: We have tested the benefit of using a deep neural network (DNN) to predict the error of MiRS retrieved sea surface temperature (SST, or Tskin) using ATMS data. If the error, defined as the difference with the collocated ECMWF analysis, can be well predicted it may then be used as a correction to the Tskin retrieval, resulting in an improved retrieval. The experiment used collocated NOAA-20/ATMS and ECMWF data from 2021-05-20 for training the DNN, and data from 2021-05-27 as an independent day for testing. The input predictors were MiRS retrieved Tskin, TPW, and CLW, along with latitude, longitude, and the cosine of the satellite zenith angle. An additional experiment used TBs directly to train the DNN. The figure shows maps of MiRS uncorrected and corrected Tskin from the two DNN experiments, as well as scatterplots comparing the MiRS retrievals with the collocated ECMWF analysis. There is a clear improvement in the corrected retrievals that used MiRS retrievals as inputs (center), with the overall bias reduced from 0.7 to 0.5 K, and the standard deviation reduced dramatically from 3.0 K to 1.2 K.

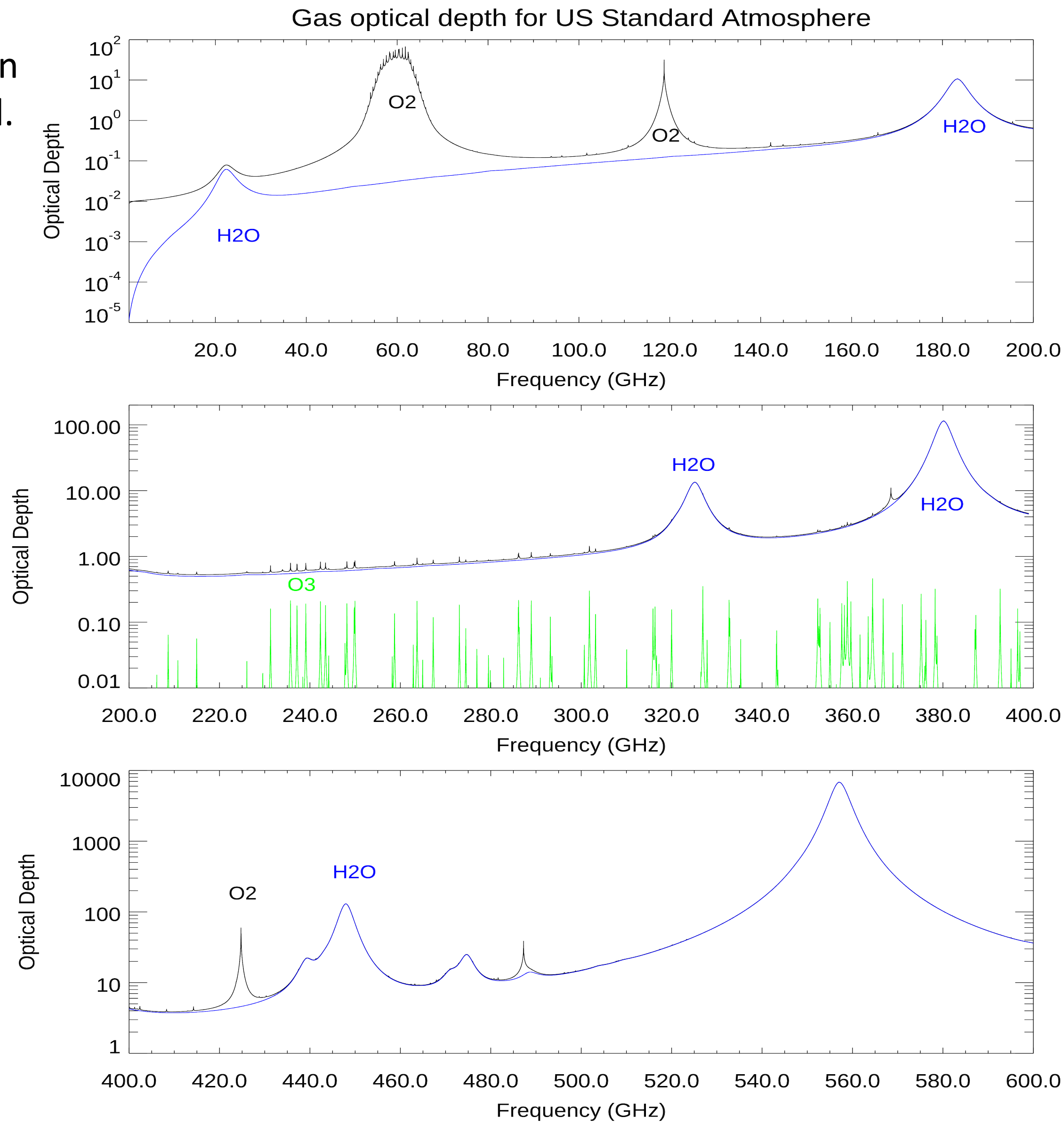



***Results from a deep neural network trained to predict MiRS N20/ATMS SST (Tskin) retrieval errors, which are then used to correct the original operational retrieval. Top row shows scatterplot comparison with ECMWF analysis for 3 experiments. Bottom row show retrieval maps. Experiments are operational (left), DNN corrected using MiRS inputs (center), and DNN corrected using TB inputs (right). The improved SST may have potential for synergistically improving other retrieval products if used in the 1DVAR retrieval.***

# Absorption band configuration

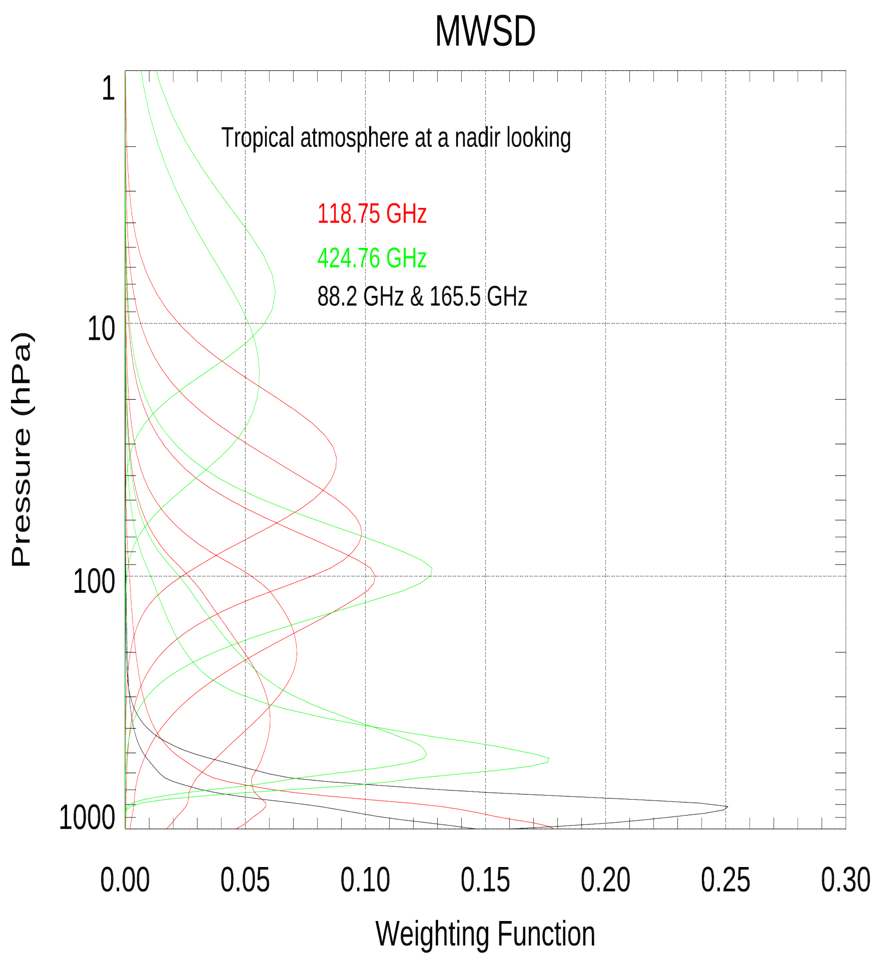
50-70 GHz $O_2$ absorption band is wider and has more absorption lines (33) than that of 118 (1) GHz $O_2$ absorption band.

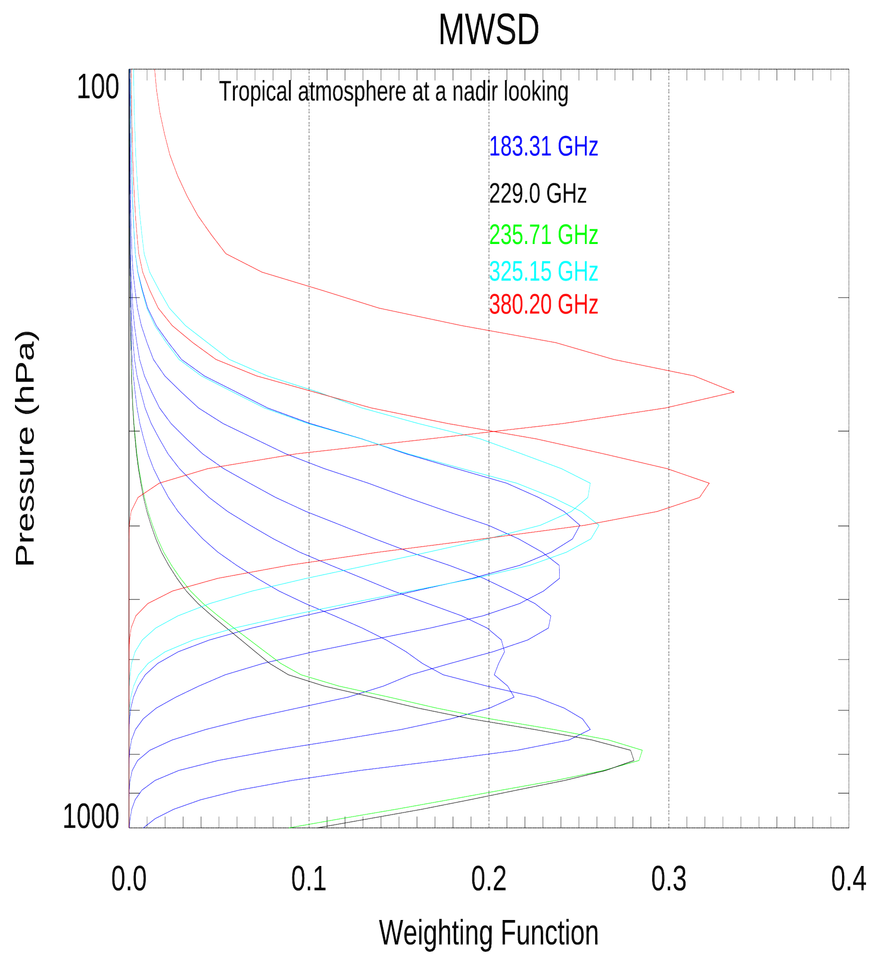
Future absorption/scatterings:
118 & 424.76 GHz $O_2$,
229 GHz,
240 GHz $O_3$
183.31, 325.15, and 380.20 GHz $H_2O$



# Discussion on MW Sounding Channels

In addition to 88.20, 165.50, 118.75 GHz, 183.31 GHz channels,
add 229 GHz channel and channels around 424.76 GHz temperature channels.
add water vapor channels around 325.15 GHz and 380.20 GHz
add channels around O3 absorption at 235.71 GHz



# Challenges for On-orbit Calibration

- Beam pointing accuracy evaluation and correction
- Thermal Vacuum Target Errors
- Striping and Correlated Noise
- Reflector emission correction
- Lunar contamination correction
- Antenna pattern correction
- Polarization misalignment
- Near-field contamination correction