Microwave Sounder Radiance Assimilation at the Global Modeling and Assimilation Office

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Introduction

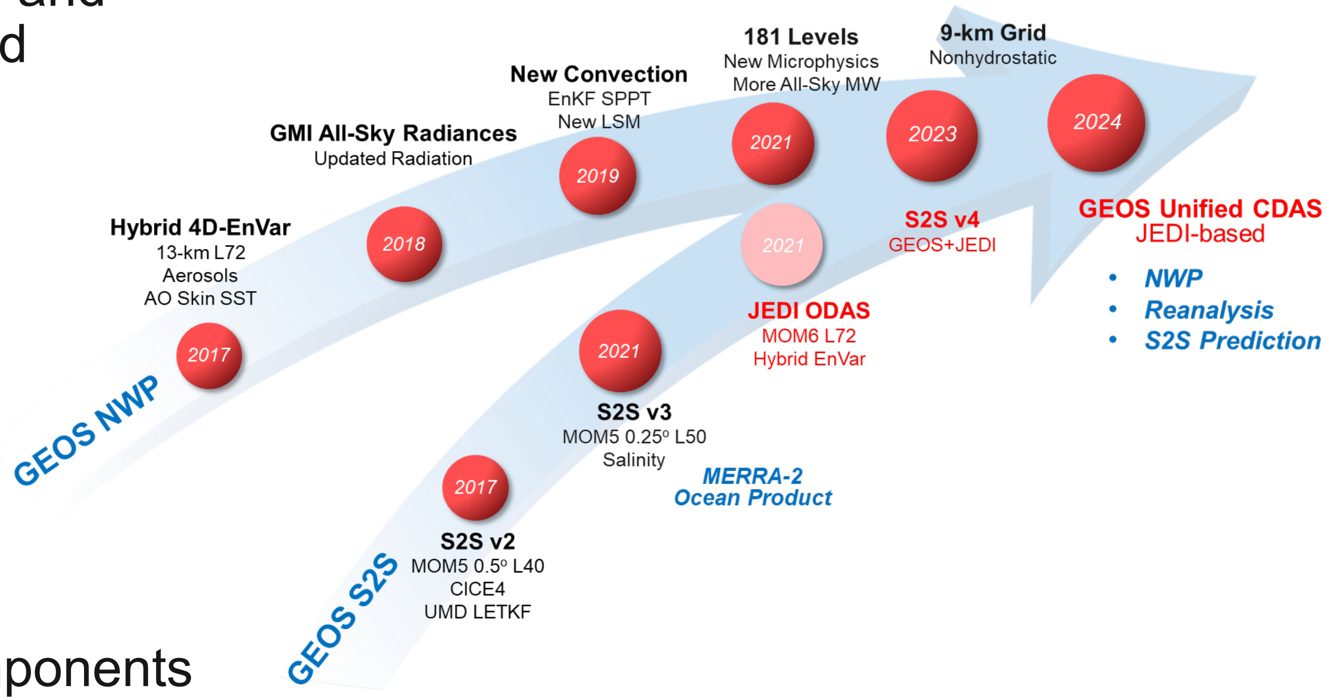
GMAO's core mission is to enhance the value of NASA's observations to understand, analyze and predict changes in the physics, chemistry and biology of the Earth system

We do this:

- Historically: Reanalysis
- Currently: Forward Processing (FP); S2S
- Future: Targeted research, e.g. OSSEs as a decision support tool

Our goal is to collapse the earth system components to a common modeling and assimilation infrastructure

- Fundamental to this goal is the capability of analyzing the four-dimensional atmospheric state



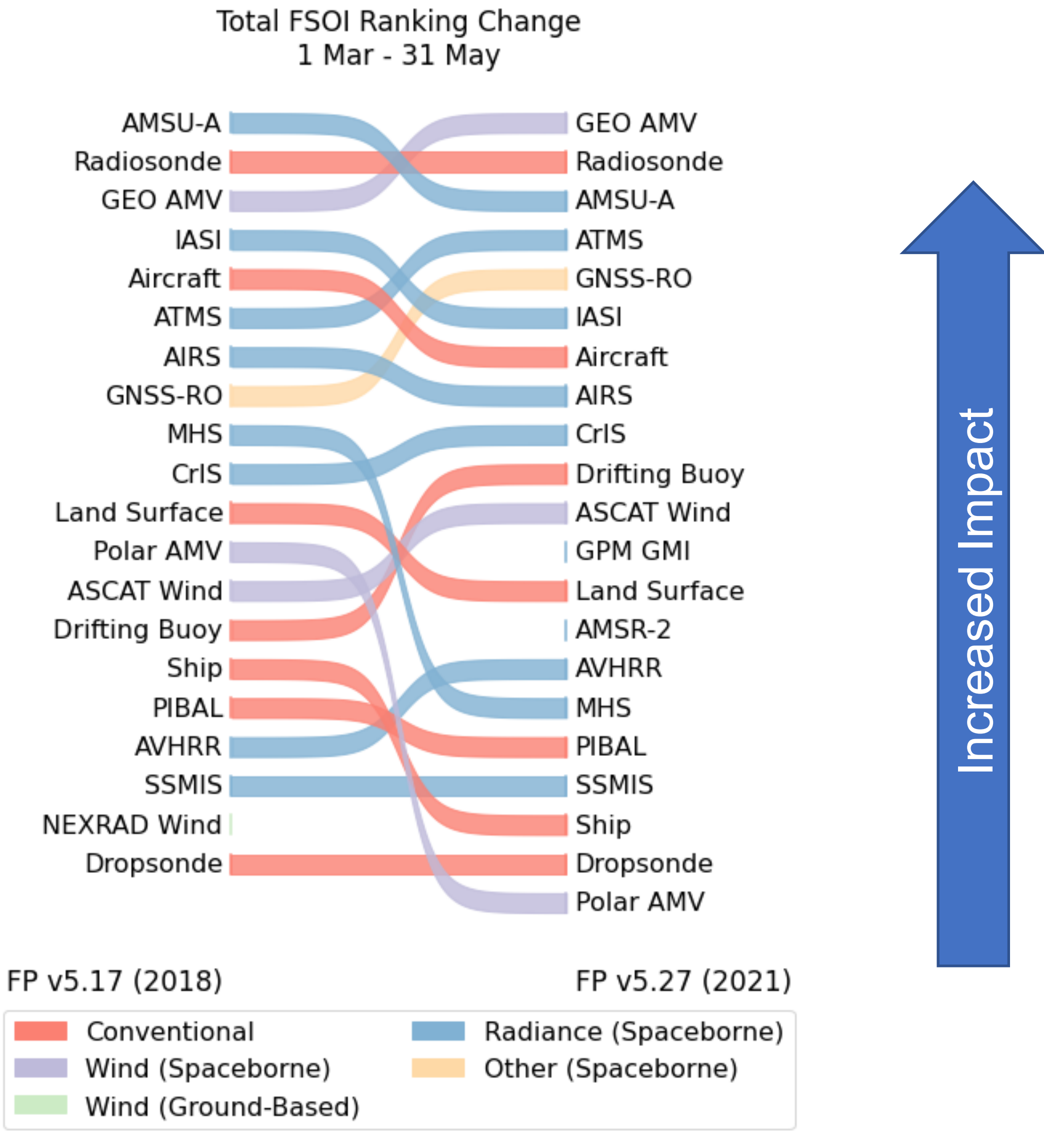
Current State of Radiance Assimilation

Forward processing developments

- 'New observations' – and system developments – are considered 'updates'
- Ultimately constrained by near-real-time availability

Advances in the observing system are apparent through FSOI metric

- Observing System resilience
- Notable differences:
  - Increase in Geo AMVs with GOES-16/17 data streams
  - Drop in AMSU-A, rise in ATMS (addition of NOAA-20)
  - Drop in MHS (loss of PM orbit)



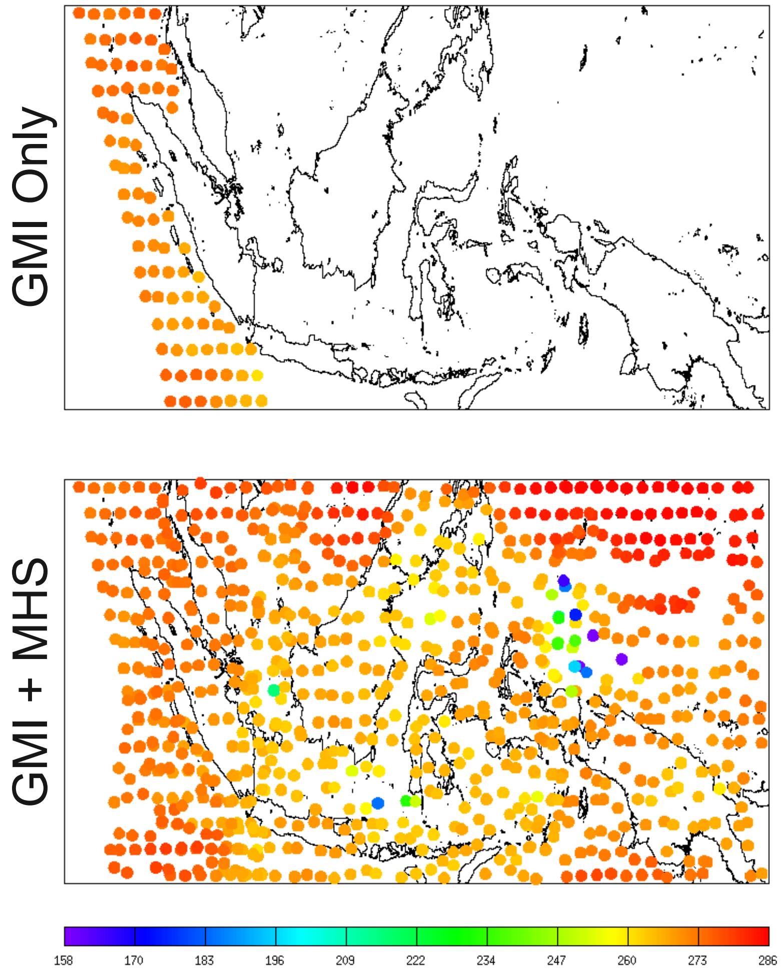
All-Sky Assimilation of MHS Radiances

GMAO has extended their all-sky implementation to include MHS

- Second instrument class after GPM Microwave Imager
- Methods similar for 183 GHz bands

Methodology:

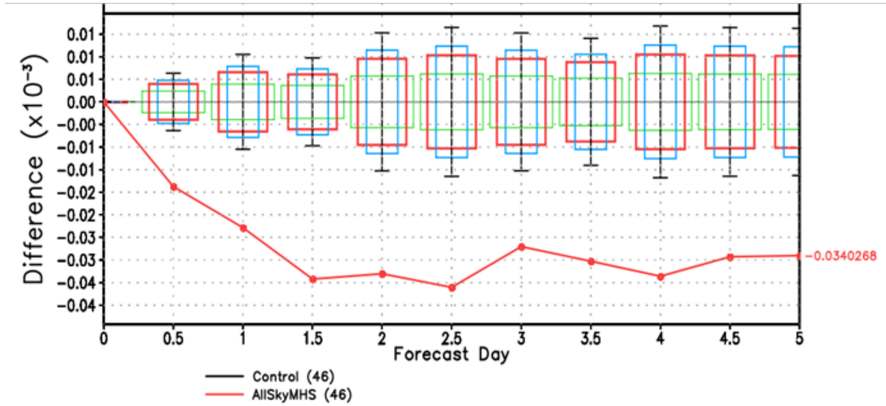
- Extend forward operators to cloud and precipitation-affected radiances
  - New CRTM cloud scattering lookup tables
- Extend assimilation solution to include cloud liquid, ice, rain, and snow
- Situational observation error model
  - Function of cloud index
- Extensions to variational bias correction and new QC for all-sky measurements



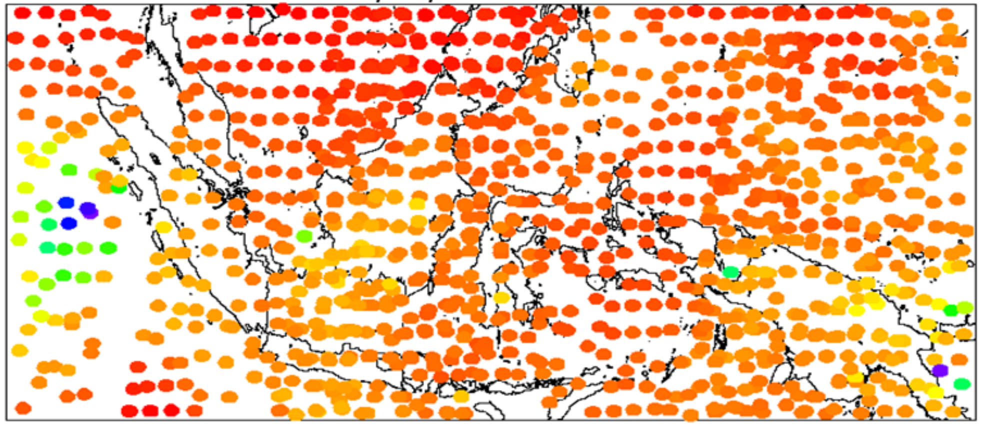
All-Sky Assimilation of MHS Radiances

- Results show that the system is capable of making the necessary wind responses to compensate for changes in the water fields
  - Figure to the right shows wind responses in regions of added convection
- Largest forecast improvements seen in SH, Tropical lower tropospheric humidity
  - Both improved analysis and transport
- MHS All-Sky has passed testing and will be included in our next upgrade

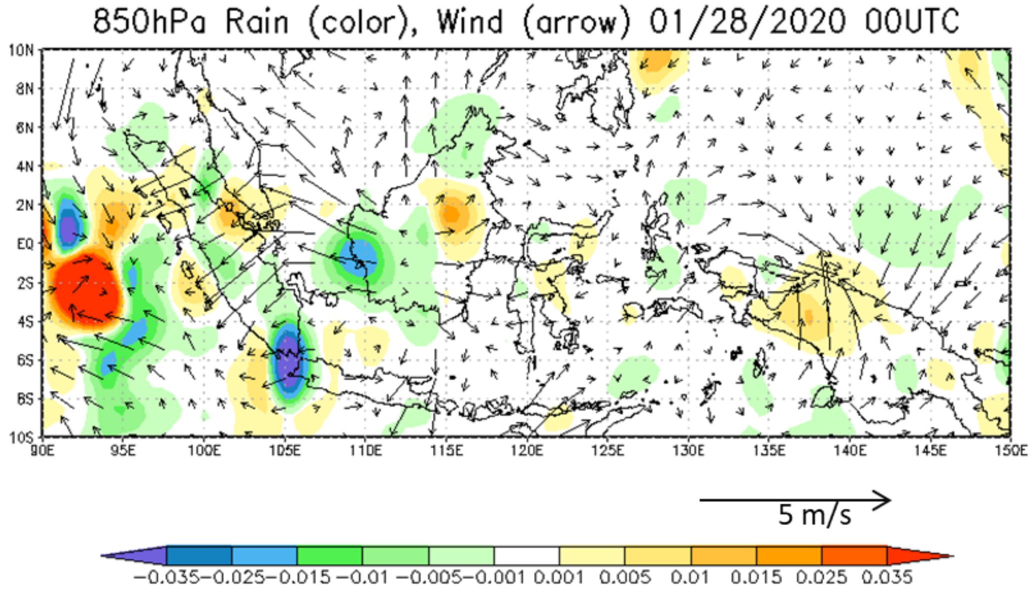
Specific Humidity – 850 hPa
Forecast RMS error difference



Observed all-sky MHS Channel 5 Tb (K)
from Metop-A, Metop-B, Metop-C satellites
1/28/2020 00UTC



GEOS analysis changes made by assimilating all-sky MHS data



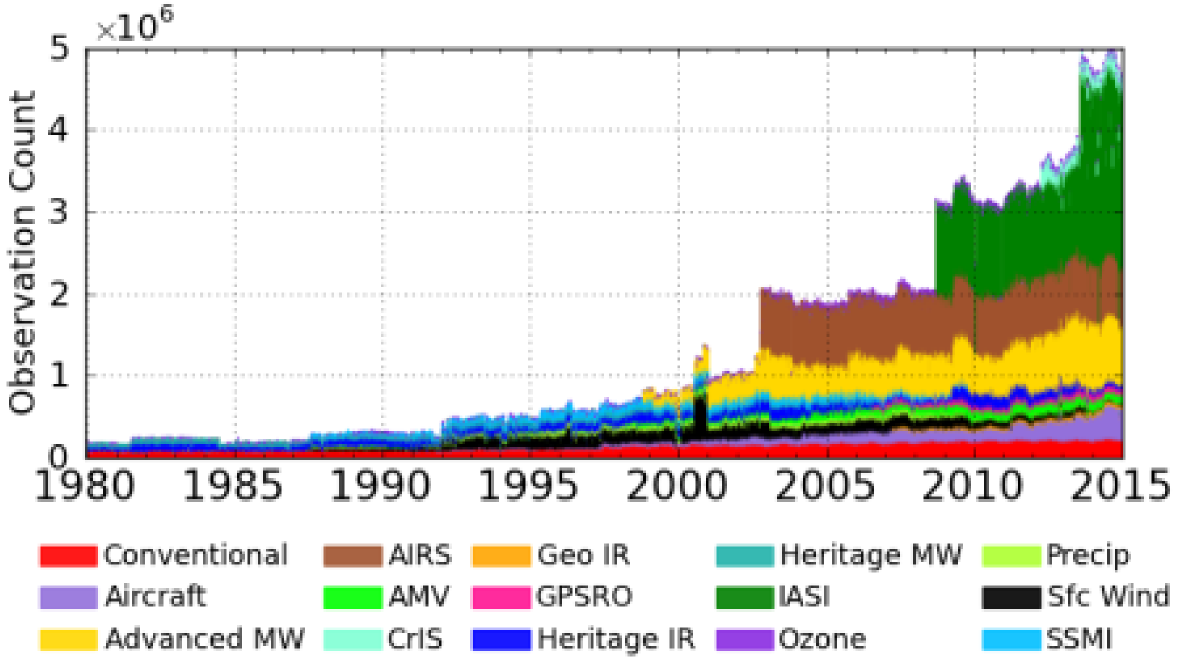
Applying Current Methods to Historical Observations

FP development is motivated by a transition to reanalysis

- FP advancements are performed with reanalysis in mind
  - New data not only feeds FP, but also adds to the retrospective observation baseline
  - The FP starting point is implicitly the beginning of baseline
  - Evaluate feasibility of backfilling observation to include entire data record
- Reanalysis systems do not have a NRT constraint
  - Provides additional motivation to consider observations beyond the scope of operational systems
- The hyperspectral IR still accounts for the largest single type of data
  - Only to increase w/ MTG-S IRS; IASI-NG; NOAA-21, etc.

Next reanalysis slated to be a 21st (ish) century reanalysis

- ¼°, 4D-EnVar (both updates from MERRA-2)



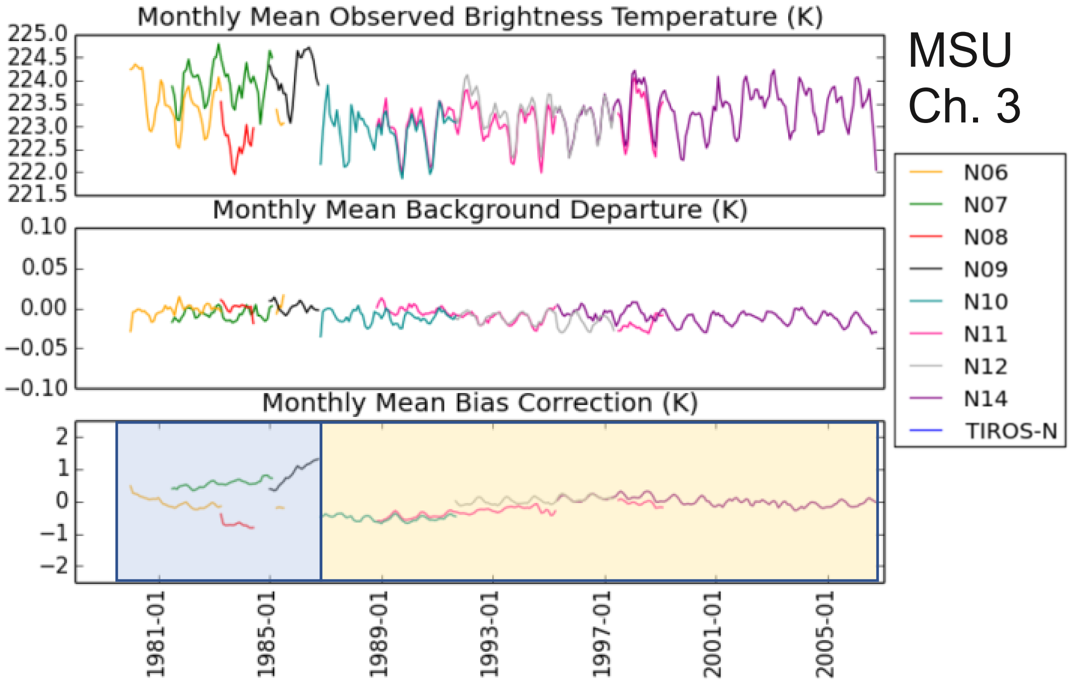
Reassessing Historical Microwave Radiances in Reanalysis

In MERRA and MERRA-2, recalibrated radiances for MSU were considered after 1 Nov 1986

- Bias correction procedure, which accounts for differences in inter-satellite calibration generally keeps background departures consistent

The impact of these recalibrated historical data have not been re-assessed in recent years

- Not being reconsidered for R21C
- Are these data necessary moving forward, or is it better to trust variational bias correction?



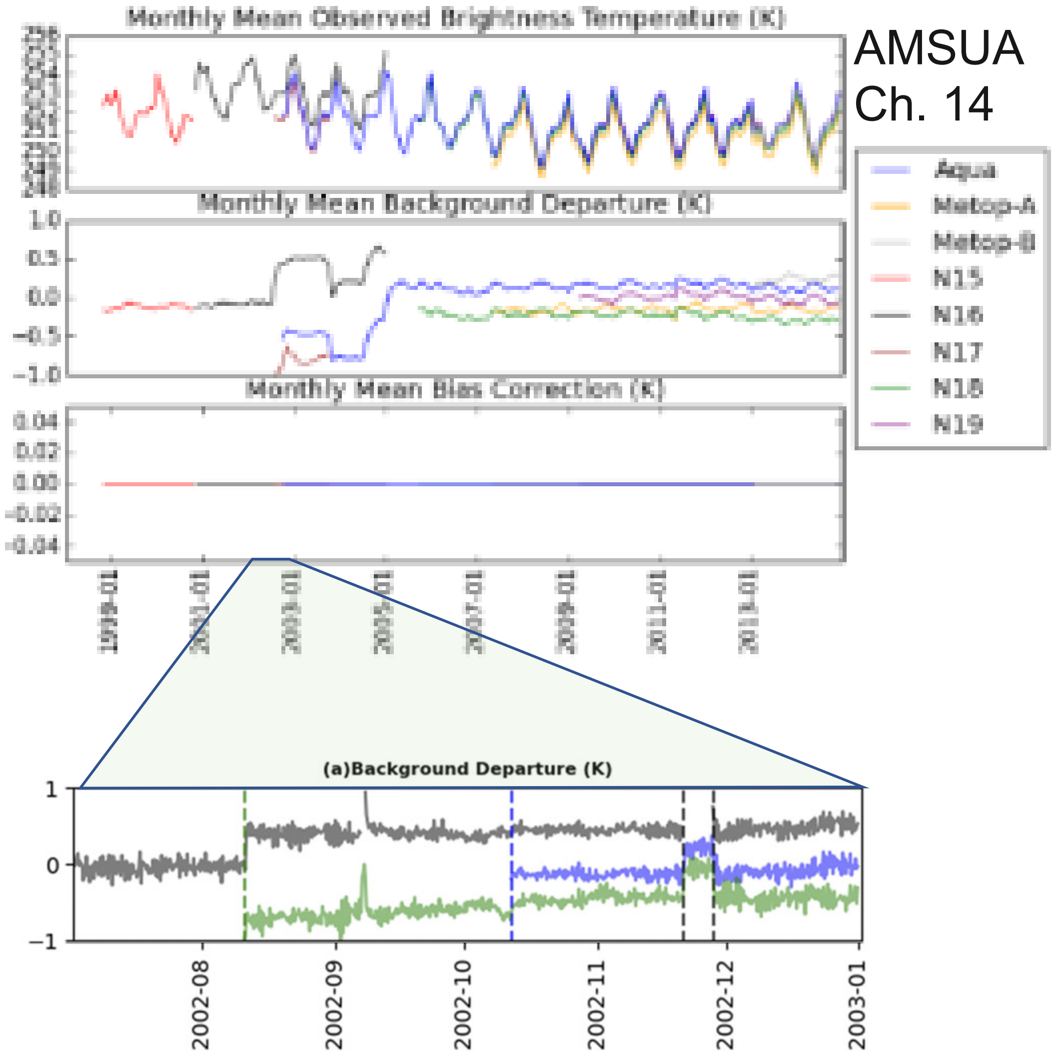
Assessment of Recalibrated Radiances in Reanalysis

From a satellite perspective, microwave sounders @ 50-60 GHz are the backbone of the global satellite observing system

- The most consistent global information content we have from 1978-onward

Even then, we've worked to keep improving our use of the data

- The early ATOVS data record in MERRA (~pre-2005) had inconsistencies in the highest peaking channels
- As Channel 14 is assimilated without bias correction, these inconsistencies aliased themselves on the geophysical fields
  - ~2-3 K changes with data dropouts
- R21C will reprocess these early data



AMSU-A Ch. 14

The Future of Microwave Radiance Assimilation

The future of microwave data is quite diverse

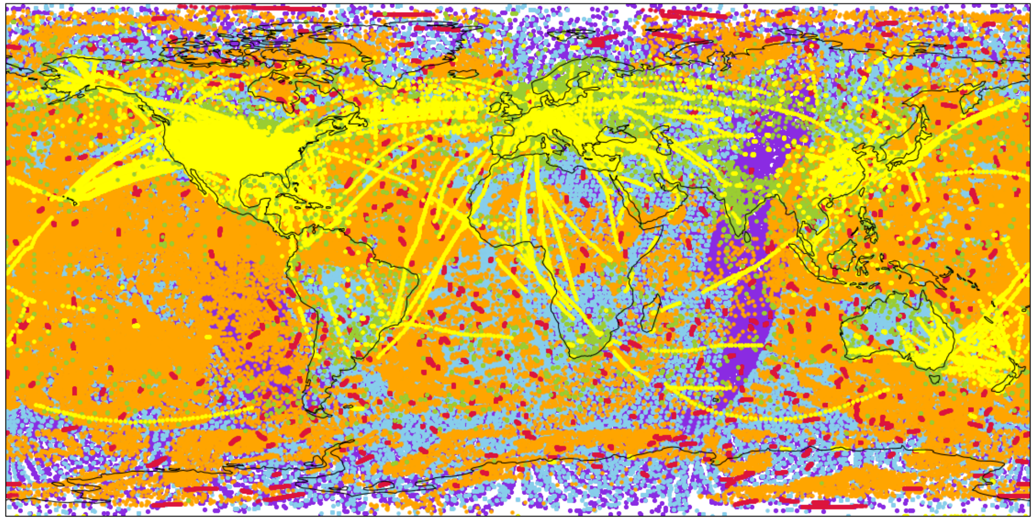
- GMAO has performed some studies considering the possible futures
- Admittedly, there is a lot more work that could be done

Future efforts have considered the potential of hyperspectral microwave and geostationary microwave

Comparing Geostationary IR vs. Microwave Using OSSEs

The GMAO has a broad OSSE capability, which can serve as a tool (in a toolbox of tools) to investigate future observing system architectures

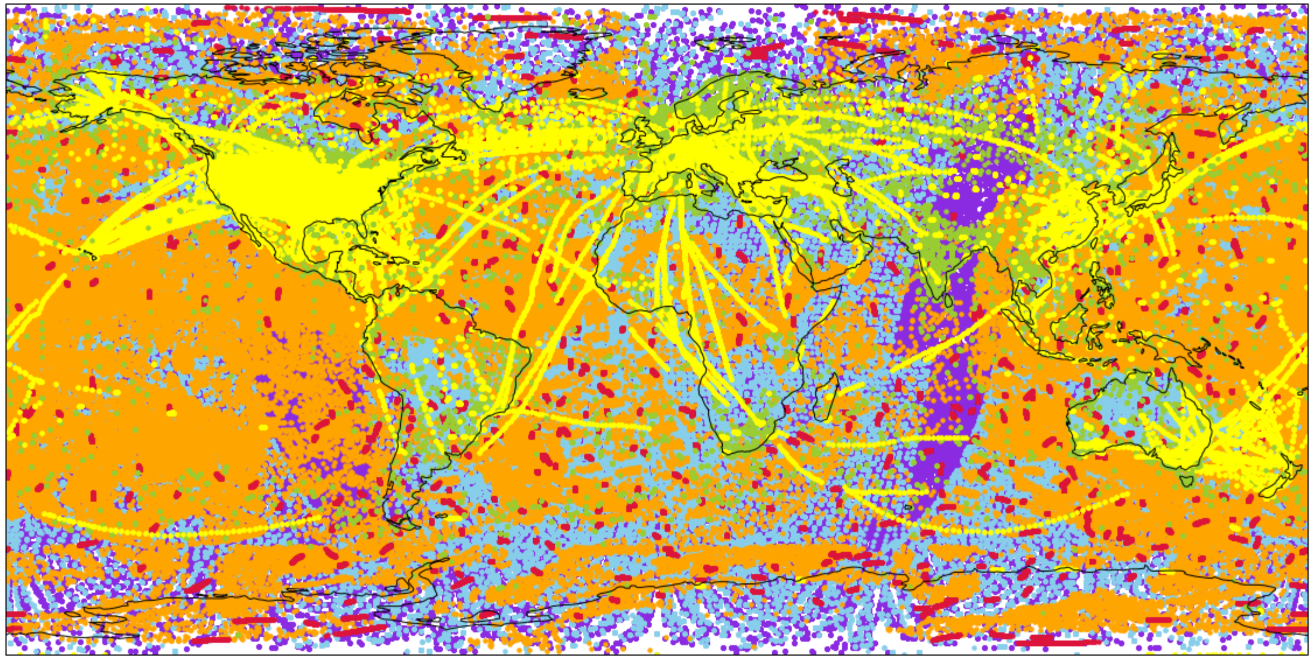
- A full NWP OSSE system based on a 2017 observing system
  - Hybrid 4D-EnVar
  - C180 (~0.25°) spatial resolution, 72 model layers
  - Everything up to and including Metop-B
  - Still lacking NOAA-20, Metop-C, All-Sky measurements
- Additionally, the GMAO has supported simulated OSSE studies for PACE, GEO-CAPE, TEMPO outside of the NWP context



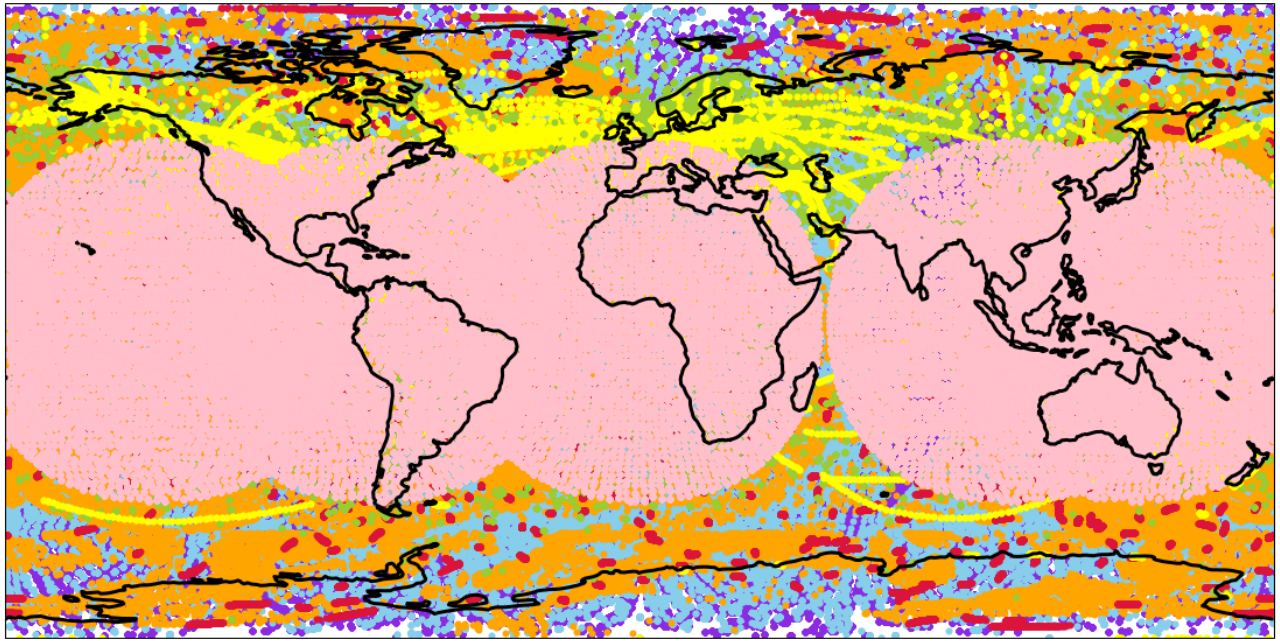
OSSEs however are limited

- Today's approaches
- Today's (yesterday's) observations
- Simulated data – and thus experimental results – are too perfect
- Errors difficult to model

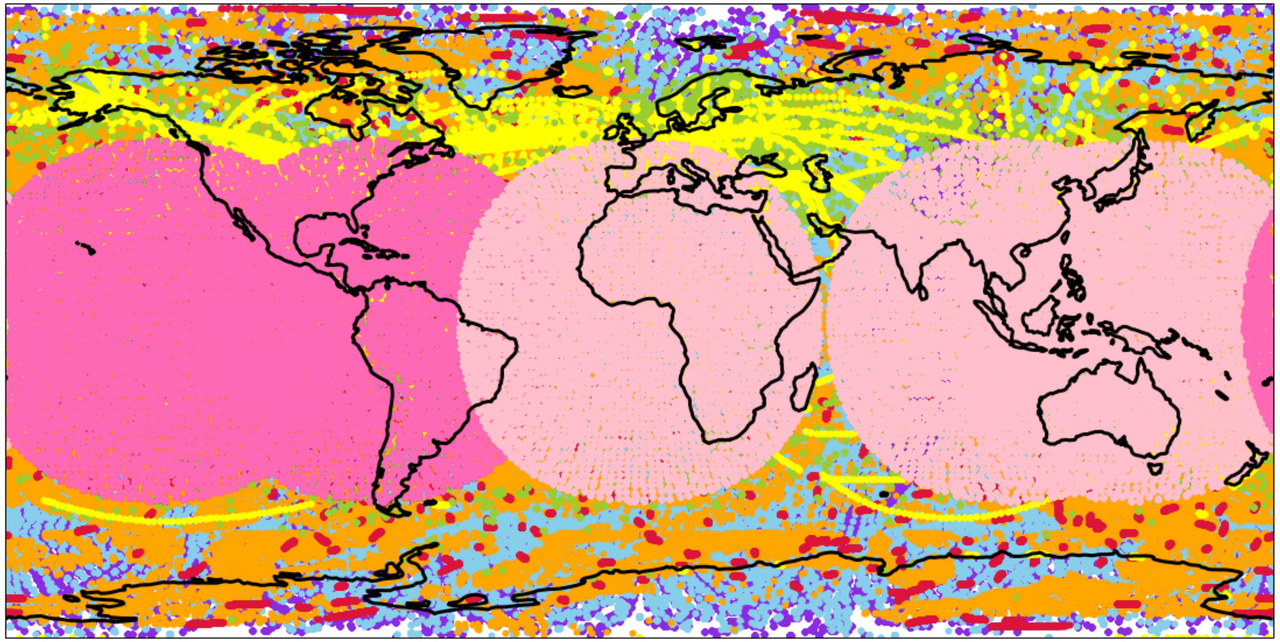
Baseline Observations: Radiances + RO + AMV + SCAT + Conventional



LWFULL: Baseline + 5 Longwave Satellites



MW: Baseline + 3 LW + 2 GOES Microwave



Geo IR vs. Geo MW

LWFULL: Described Previously

– Hourly scans, IRS-like spectral resolution

Longwave Channel Selection: 87 channels

– 70 T/window channels (< 1000 cm-1)

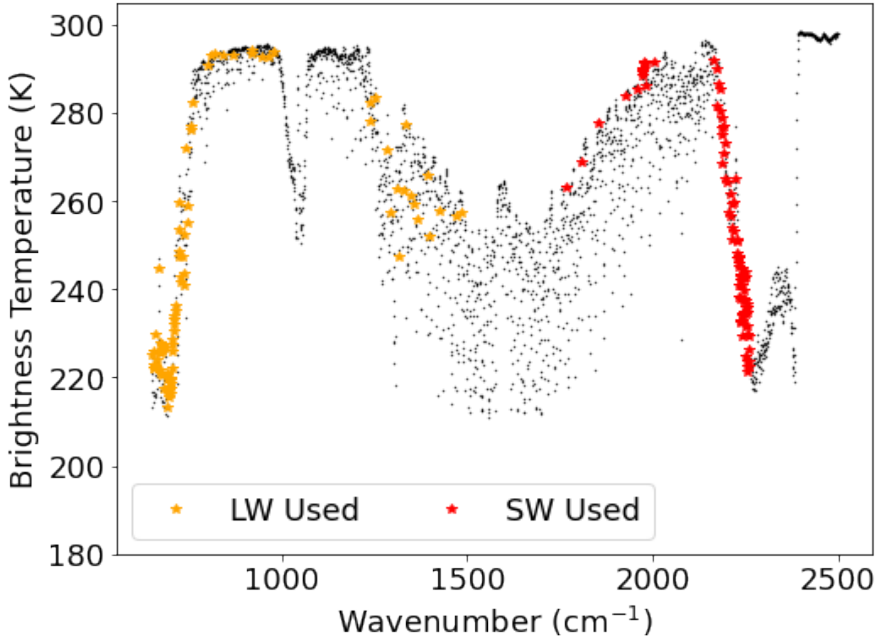
– 17 H_2O_v channels (< 6.7 μm)

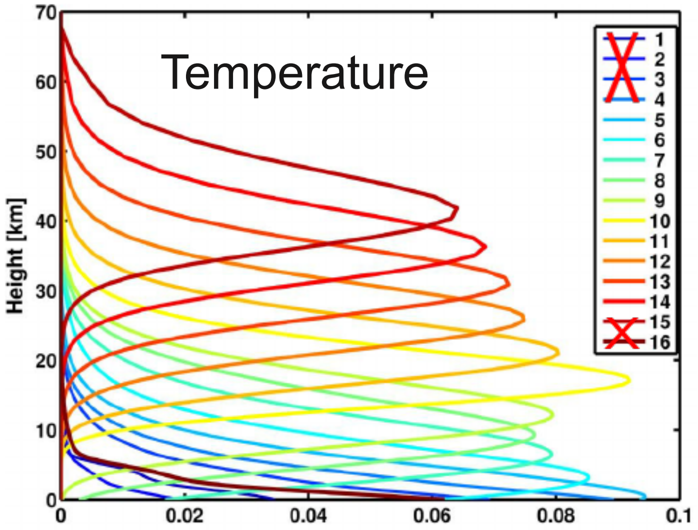
MW: ATMS in GEO Orbit

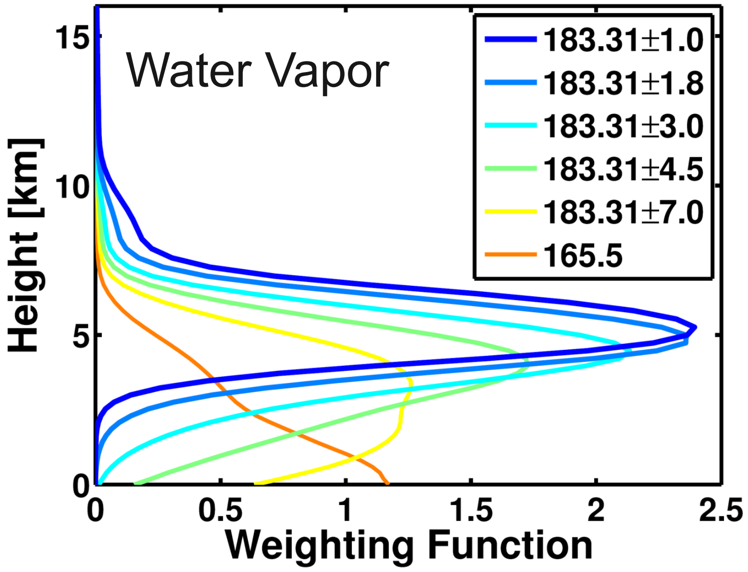
Channel Selection: 17 Channels

– 11 T Channels @ 60 GHz

– 6 channels @ 183 GHz





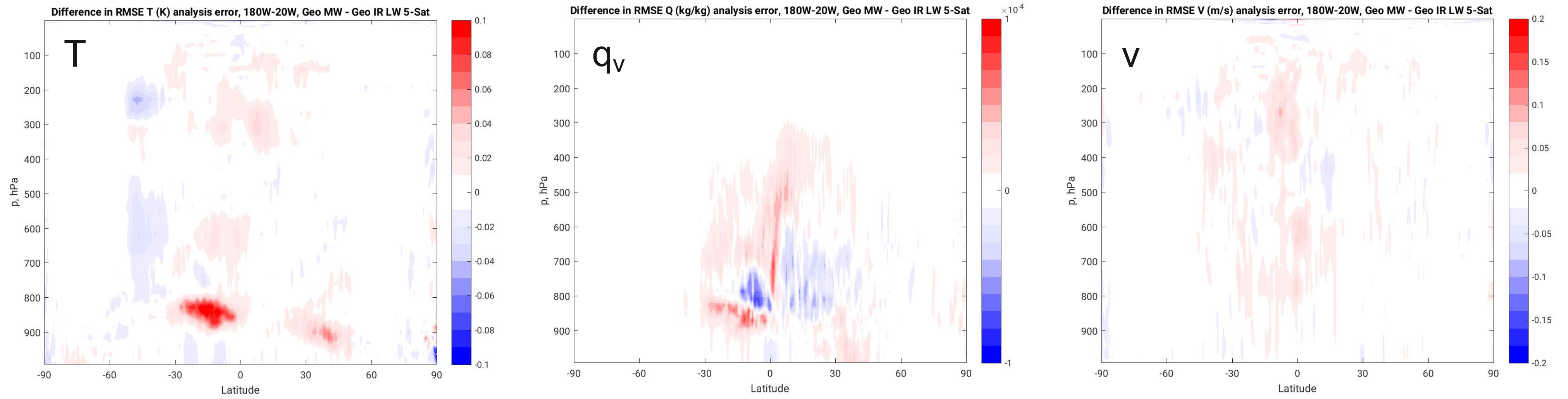


GEO Microwave vs. GEO Infrared

Microwave decreased sensitivity in lower PBL, though slightly improved southern disk T & lower free troposphere water vapor

- For all of these, the difference was a slight reduction in improvement – both IR & MW were generally improved over a GEO Sounder-less control
- Does it matter? GEO Microwave more likely @ 118 GHz:
  - OSSE/ATMS too ‘clear’
  - OSSE doesn’t yet do all-sky assimilation

Change in Analysis RMS Error over GOES Sectors
MW – IR



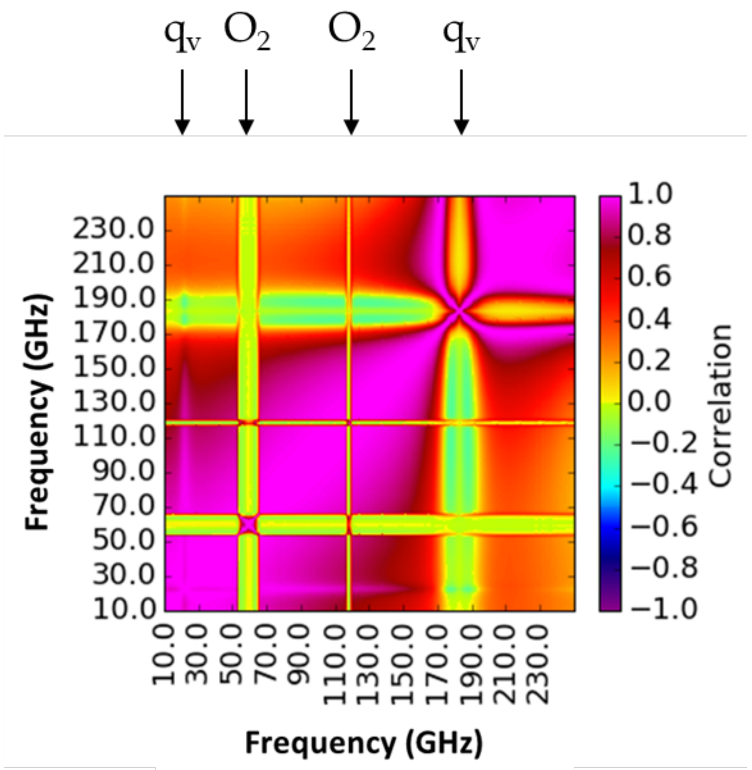
Blue: Improvement
Red: Degradation

Hyperspectral Microwave Sounding

Using the CRTM and leveraging our OSSE system, we've performed preliminary investigations looking at hyperspectral microwave measurements

- Hyperspectral microwave is listed as a potential instrument for a future Planetary Boundary Layer Mission via the NASA PBL Incubation Study Team Report
- Hyperspectral microwave may have a key role in identifying in a future world with more RFI

Correlation matrix compared background departures and showed the four key absorption bands light up



Looking Forward

What is the future of all-sky assimilation for microwave?

- New frequencies are coming/here
  - 118 GHz: NASA Tropics, Orbital Micro Systems GEMS
  - > 200 Ghz: Metop-SG ICI, NASA IceCube
- With 118 GHz comes the onslaught of constellations (Tropics) & commercial data sources (OMS GEMS)

There are still many opportunities to better utilize satellite data

- JEDI hopefully leads towards improved science
  - Better cross-agency and extra-agency collaboration
  - Better code portability
  - More innovative science by disentangling the engineering and the science