



Satellite Data Assimilation at the GMAO

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30 September 2020

Community Meeting on NOAA Satellites

Introduction

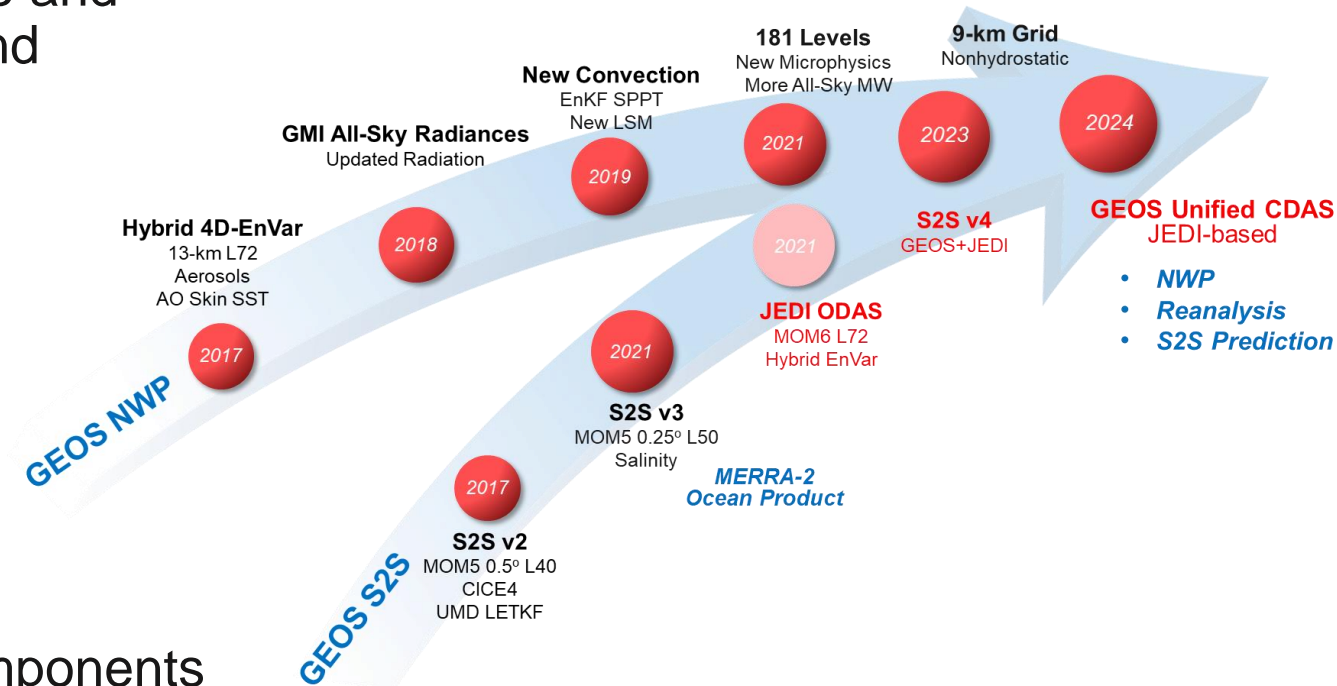
GMAO's core mission is to enhance the value of NASA's observations to understand, analyze and predict changes in the physics, chemistry and biology of the Earth system

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



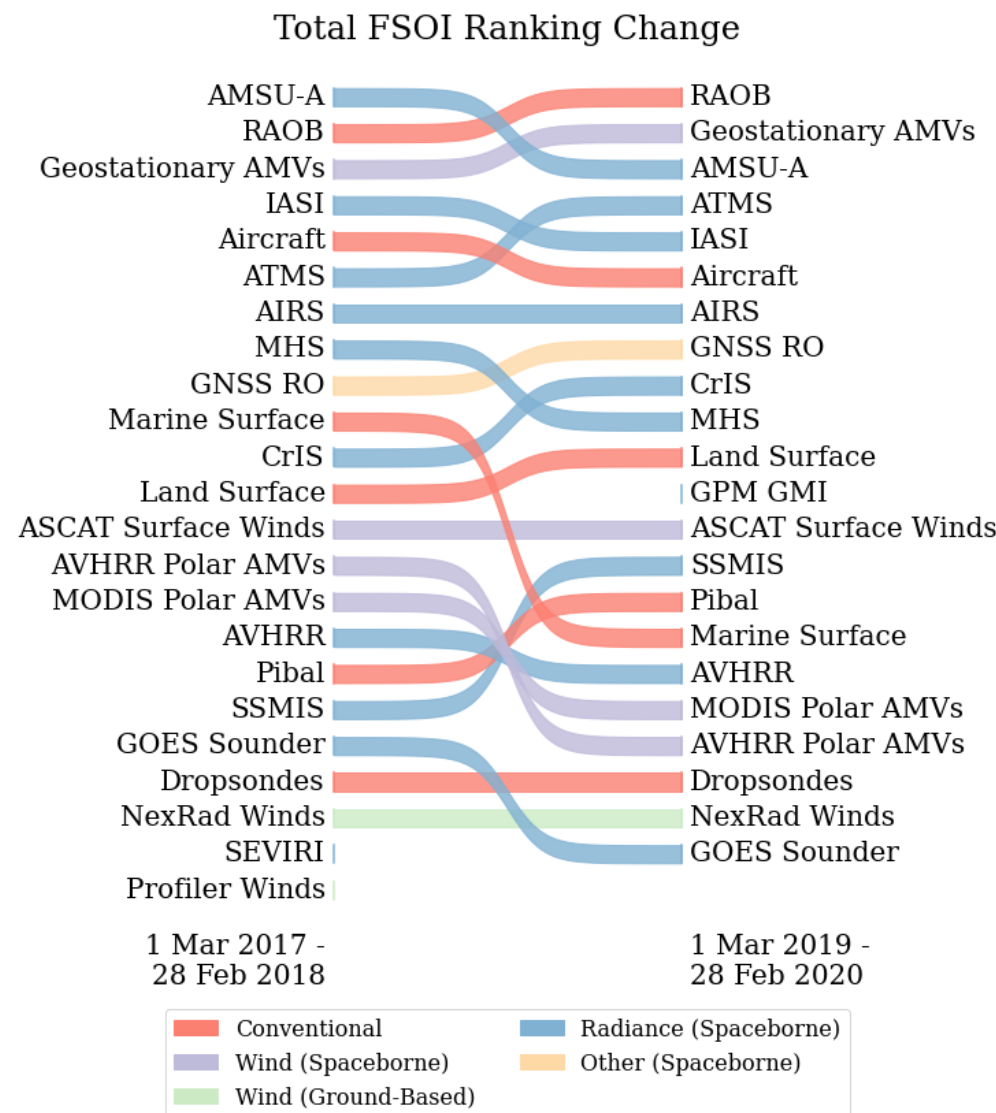
Current State of Radiance Assimilation

Forward processing developments

- ‘New observations’ – and system developments – are considered ‘updates’
- Ultimately constrained by near-real-time availability
- Many of the forthcoming slides are recent or upcoming FP updates

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)



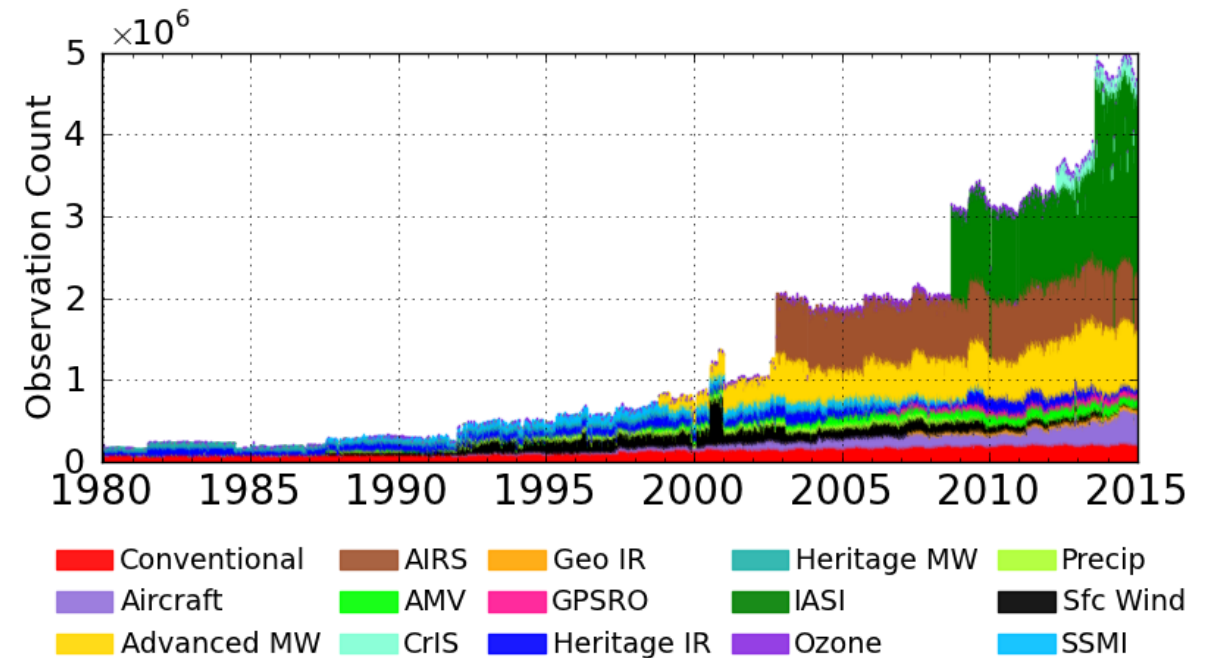
Applying Current Methods to Historical Observations

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

- Drive chemistry reanalyses, serve as prototype GPM Level 4 product
- ¼°, 4D-EnVar (both updates from MERRA-2)



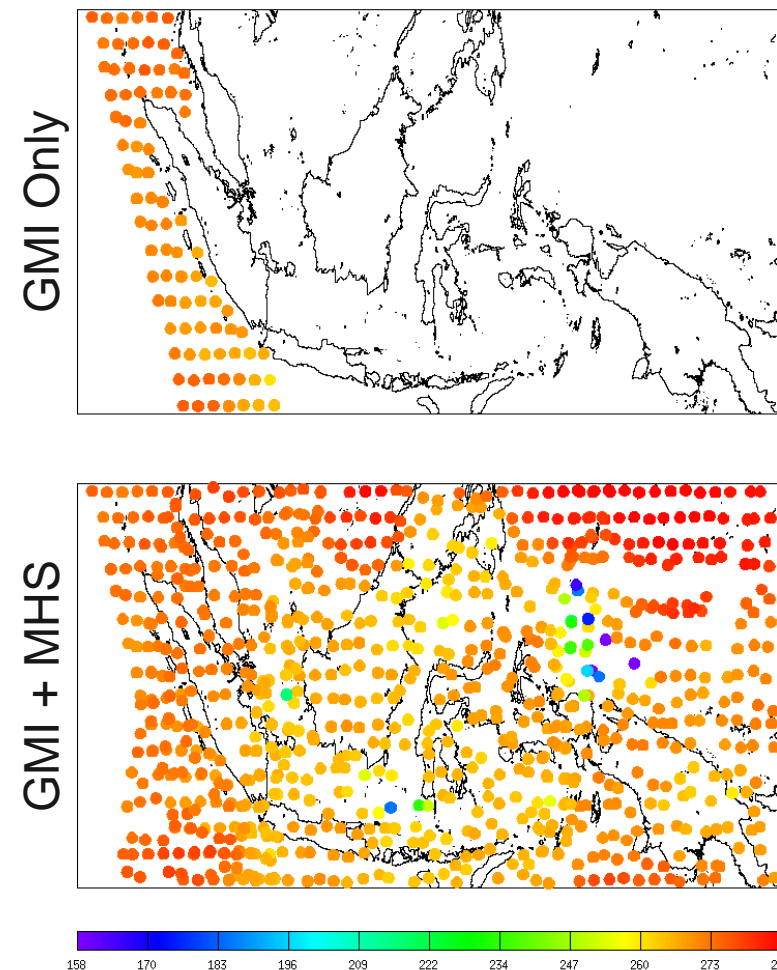
All-Sky Assimilation of MHS Radiances

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 Radiance

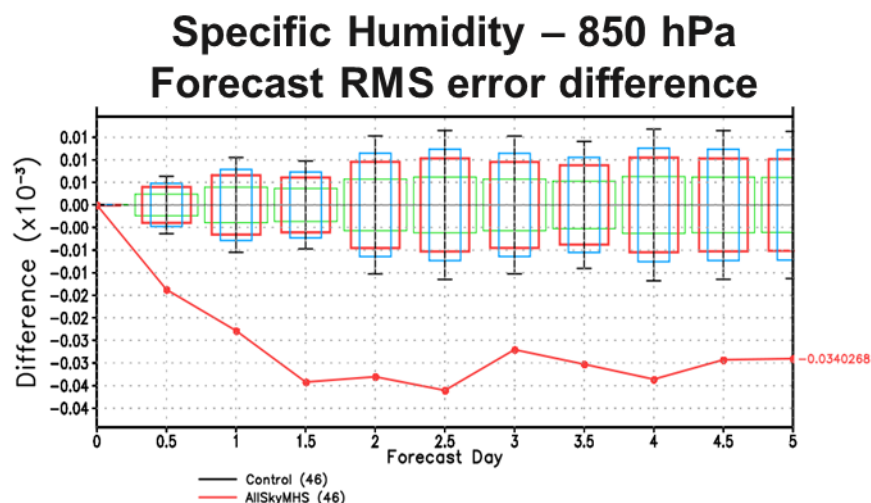
Results show that the system is capable of making the necessary wind responses to compensate for changes in the water fields

- Figure to the right shows wind responses in regions of added convection

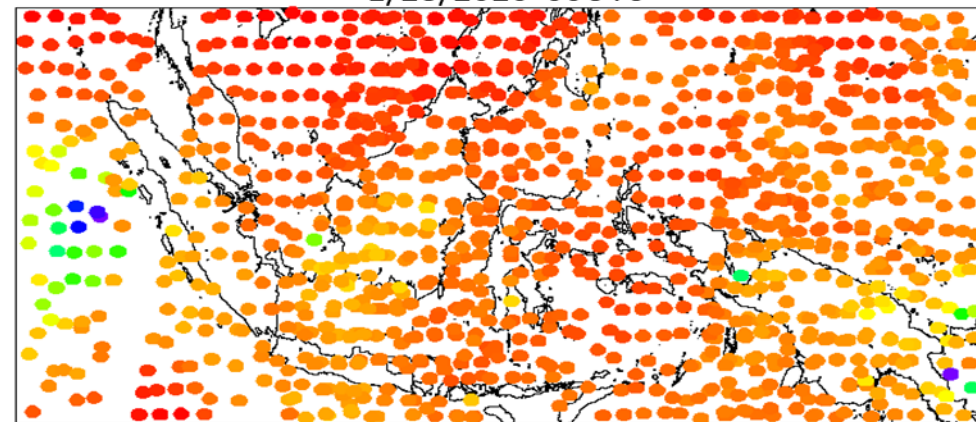
Largest forecast improvements seen in SH, Tropical lower tropospheric humidity

- Both improved analysis and transport

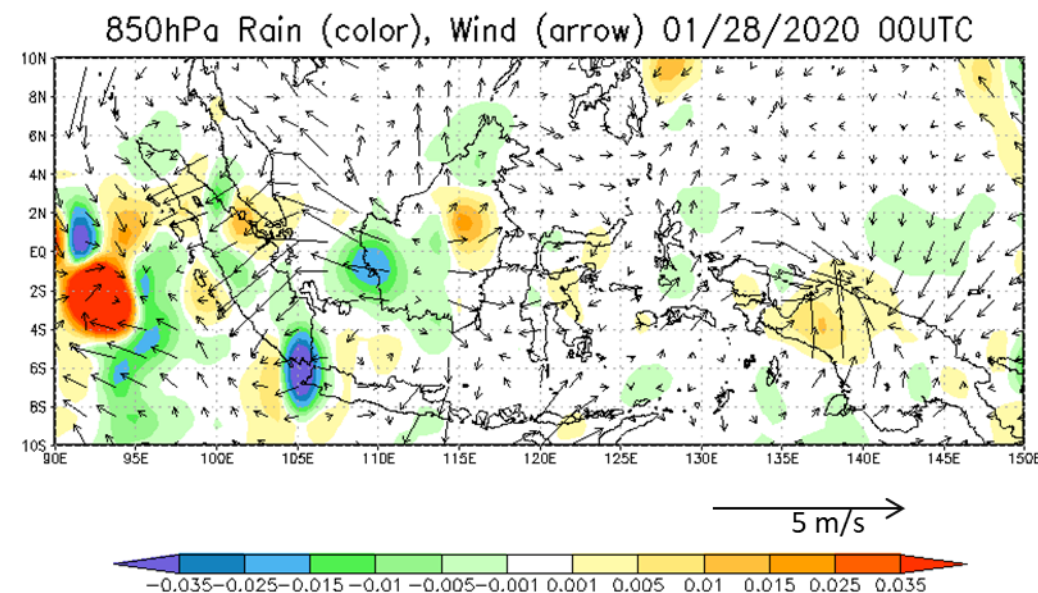
MHS All-Sky has passed testing and will be included in our next upgrade



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



Ozone Radiance Assimilation

Infrared channel selections were extended to include radiances in the 9.6 μm ozone band for CrIS, AIRS, and IASI

- Added to system including MLS, OMI and OMPS-NM

Radiances were shown to enhanced, improved resolution of tropical wave-1 ozone signal at 300 mb

- August 2018 monthly mean percent difference against control

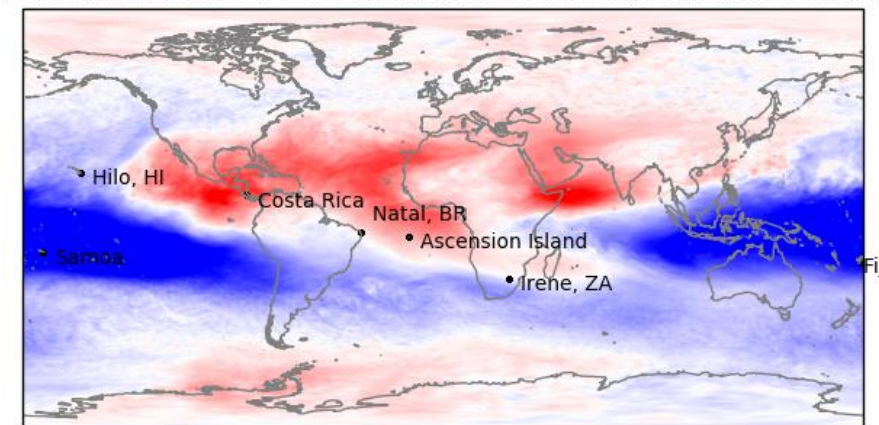
These changes reduced systematic errors against ozonesondes

- Reduction of bias compared against SHADOZ ozonesondes

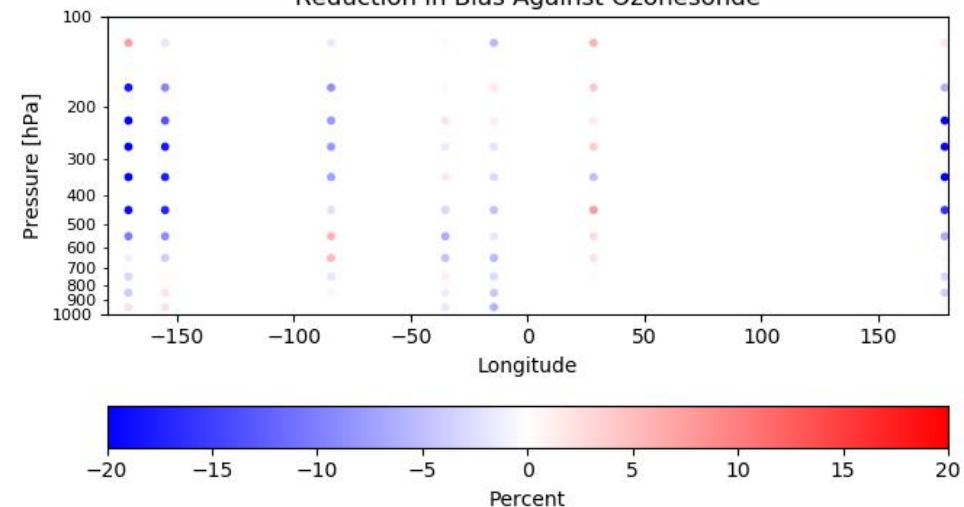
Additional testing has shown similar improvements without MLS, OMI, or replacing MLS with OMPS-LP

O₃ radiance assimilation has passed testing and will be included in our next upgrade

Percent Difference O₃ Concentration at 300 hPa Experiment vs. Control



Reduction in Bias Against Ozonesonde

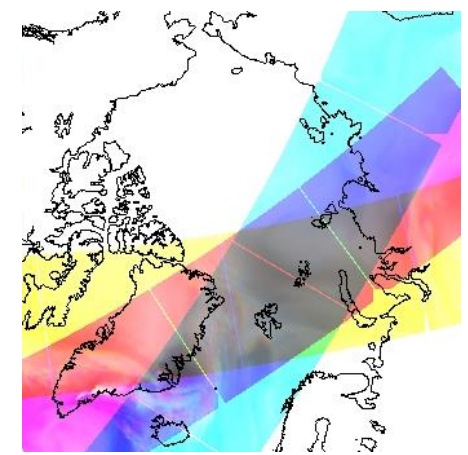


AIRS Atmospheric Motion Vectors

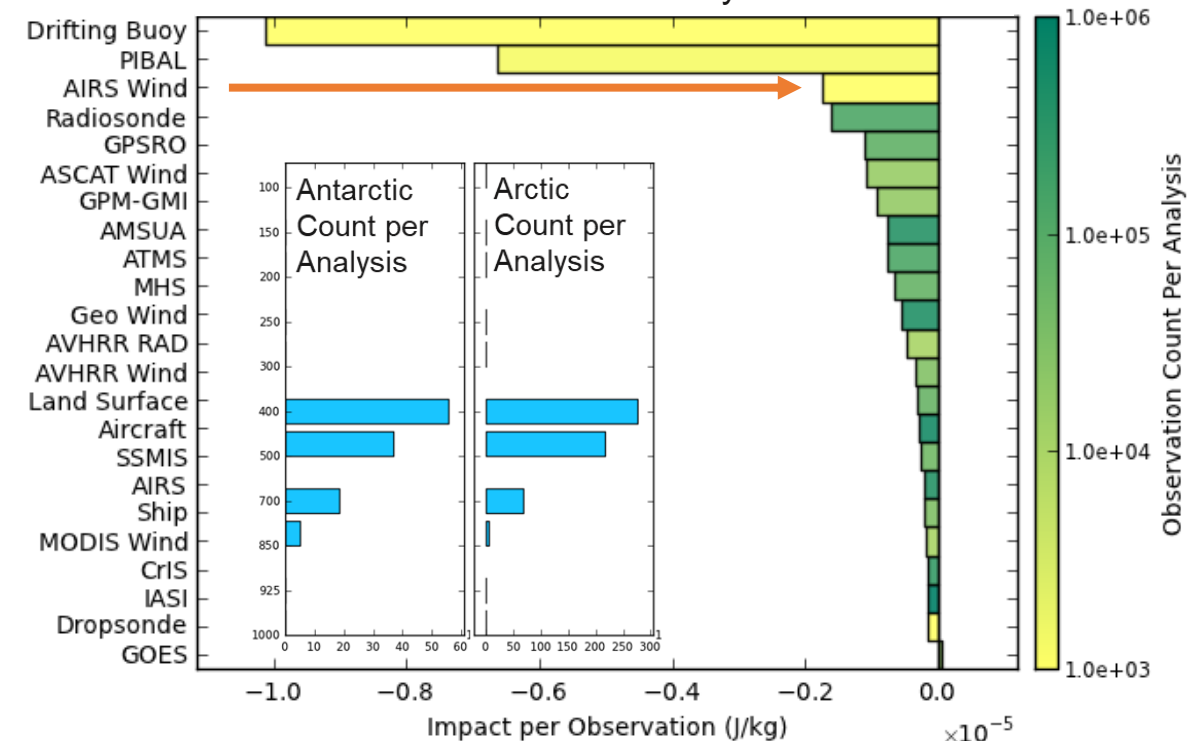
The utility of using atmospheric sounders to perform feature tracking in retrieval space has been investigated using the AIRS instrument

- Observations are few in count
 - Poor spatial resolution
 - Poor temporal overlap (satellite period)
- Observations did show a large per-observation FSOI
 - These AMVs are filling a mid-tropospheric data gap that is missed from MODIS and AVHRR-derived AMVs
- These results are applicable to future constellation approaches being considered

Being extended to CrIS shortly under NASA ROSES/TASNPP funding (PI: Dave Santek, U. Wisc./SSEC)



Global FSOI per Observation
1 June 2018 – 31 July 2018



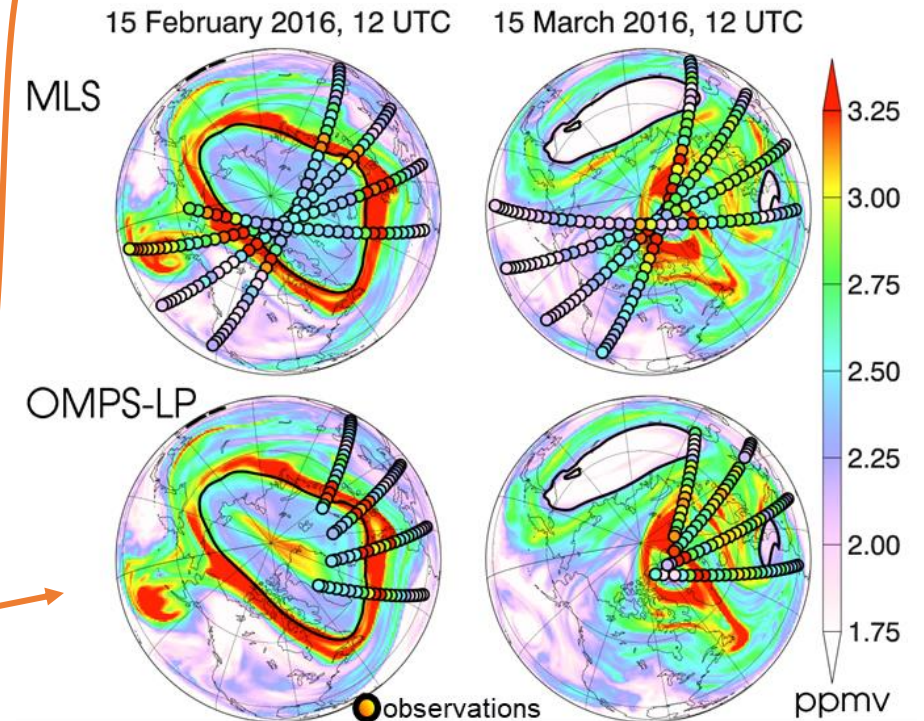
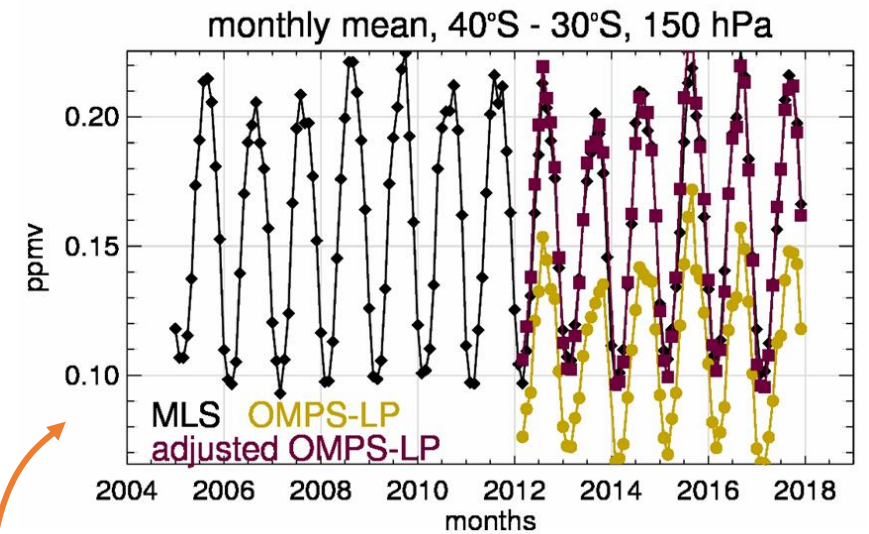
Assimilation of OMPS-LP Profiles

In addition to the OMPS Nadir Mapper, the GMAO has investigated the utility of assimilating profiles from the OMPS Limb Profiler

- The Microwave Limb Sounder on NASA EOS Aura has long been leveraged at the GMAO in FP and reanalysis
 - OMPS-LP can serve to extend the MLS record as it nears the end of its life
- Limb profilers are essential for the detection and monitoring of ozone recovery
 - Recovery trends *highly altitude dependent* but are conflated with significant interannual variability

Experimentation shows similar results between MLS and OMPS-LP assimilation

- Requires homogenization correction between MLS and OMPS-LP
- Ozone concentration on 480 K potential temperature surface show similar results from two instruments



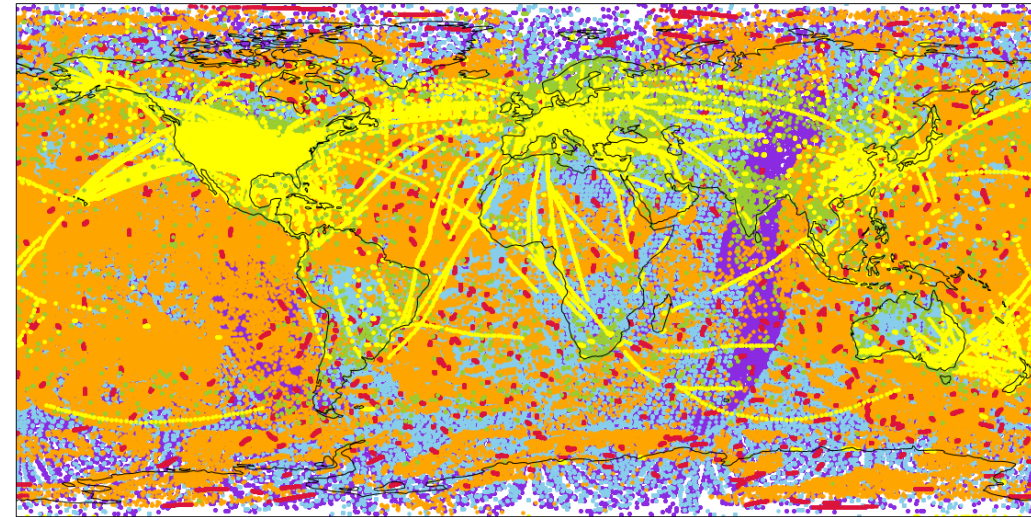
The Future of Radiance Assimilation

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 ($\sim 0.25^\circ$) 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

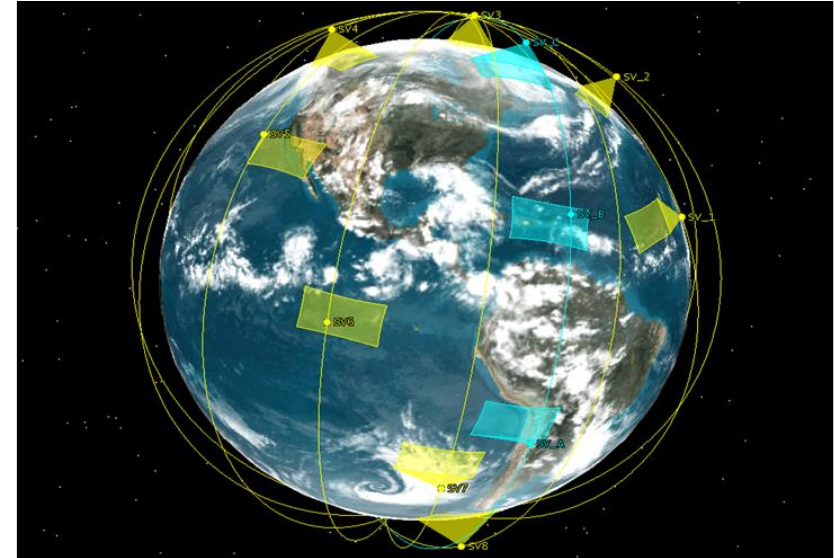
- Today's approaches
- Today's (yesterday's) observations
- Simulated data – and thus experimental results – are too perfect
- Errors difficult to model



Investigating the Utility of LEO Infrared Sounder Constellation

MISTiC™ Winds provide High Spatial/Temporal Resolution Temperature and Humidity Soundings of the Troposphere

- The observing strategy is to retrieve atmospheric state and motion via LEO Constellation of MicroSats
 - Infrared spectrometer sampling the midwave
 - With the constellation approach, temporally subsequent sets of retrievals can then be used to perform feature tracking and retrieve atmospheric motion vectors (AMVs)
- Main goal of the study is to investigate the potential impact of these observations of both the wind and radiance information from the constellation

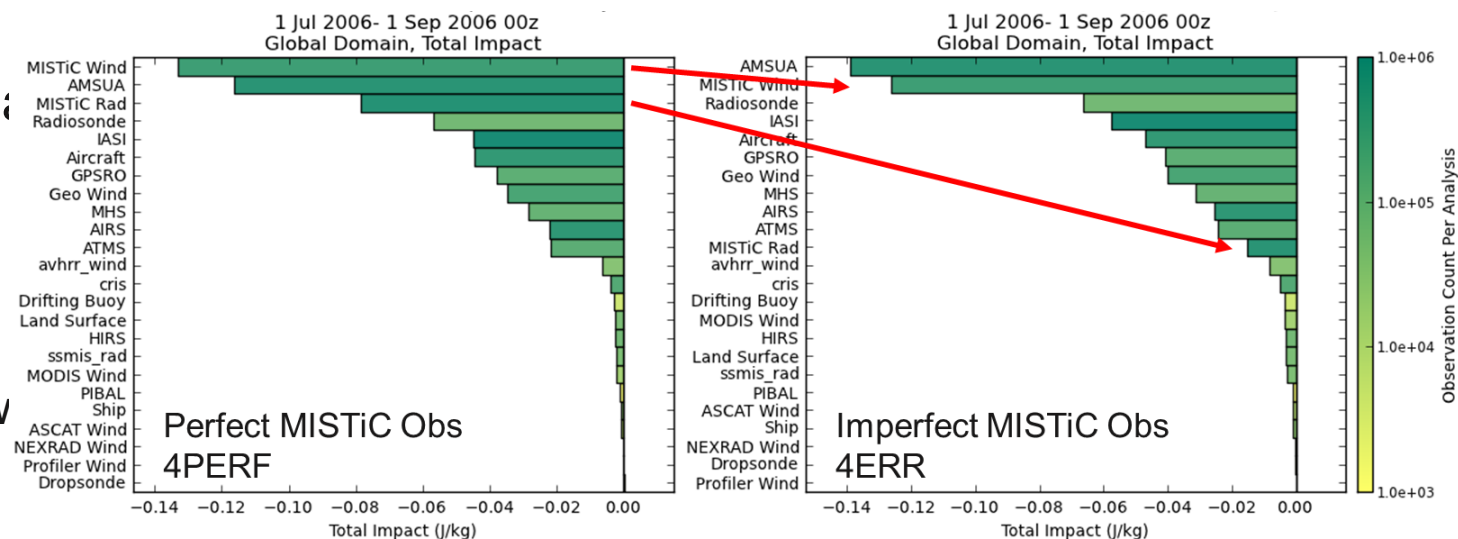
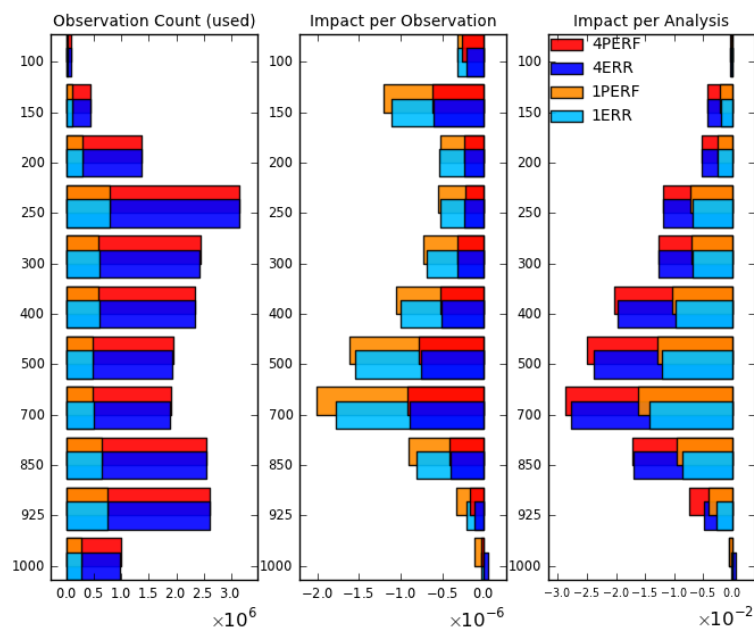


MISTiC Winds = Midwave Infrared Sounder for Temperature and humidity in a Constellation for Winds

Investigating the Utility of LEO Infrared Sounder Constellation

Results showed that by including real errors, much of the radiance impact lost in the $4.3\ \mu\text{m}$ CO₂ temperature sounding channels

- Assimilation shortcomings
- Corresponds well to NESDIS TMP w



Simulated AMVs showed that largest FSOI was seen in the mid-troposphere

- Filling a data void that is sparsely observed by the baseline geostationary imagers

The OSSE illustrates that if the proposed observing strategy can fill the mid-troposphere AMV gap that there will be an impact

- Agrees with real data results seen using AIRS AMVs and ESA Aeolus

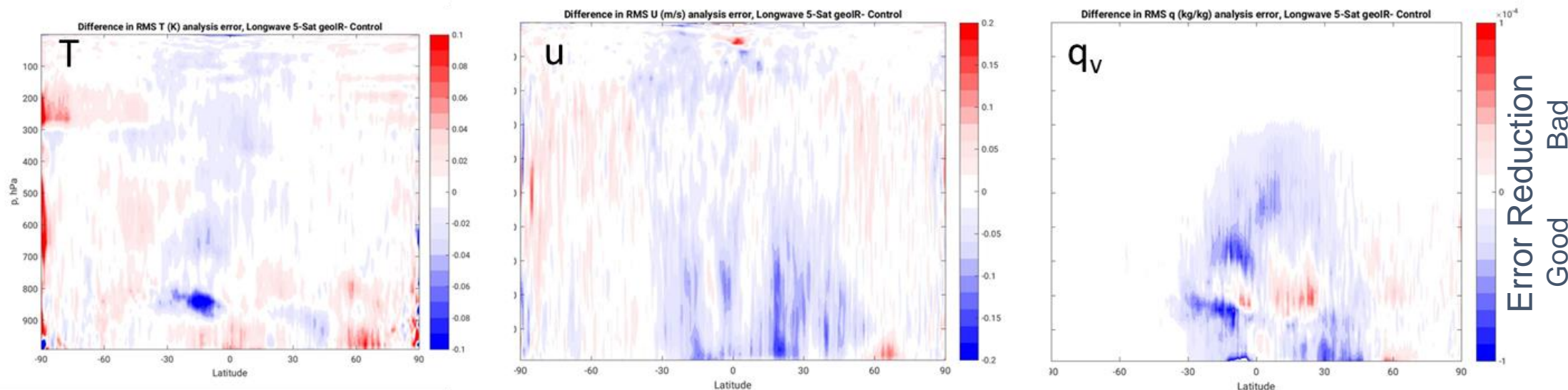
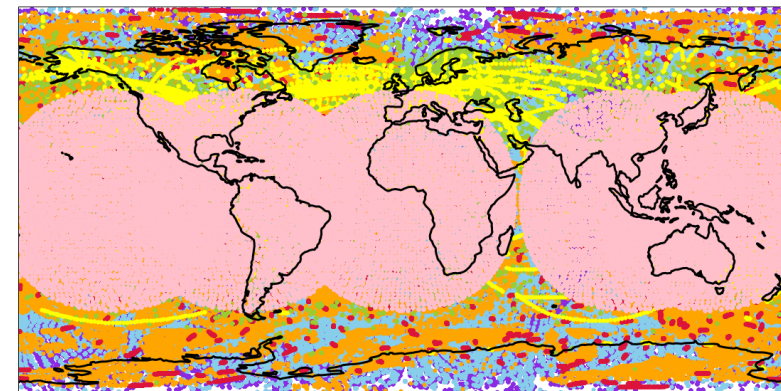
Investigating the Utility of Geostationary Infrared Sounders

A set of OSSEs considering the impact of a constellation of hyperspectral IR sounder from GEO were performed

- Considered MTG-S-like instrument (SRF, temporal sampling)
- Analysis error reductions show that the most coherent signals were in wind and water vapor

Considering the existing polar fleet of IR sounders, the new information content is temporal

- Validation of the ‘tracer effect’, the 4D analysis procedure extracts wind information from the sequential temporal sampling



Other NESDIS Community-Relevant Updates

Correlated Errors in Hyperspectral Infrared

- Upcoming implementation of CrIS-FSR will be accompanied by spectrally-correlated observation errors

Extending GEOS Aerosol Analysis beyond MODIS

- Current aerosol assimilation depends on Aeronet and two MODIS instruments
- Extending the aerosol assimilation to include both VIIRS and ABI/AHI imagers

Extending fire emissions to VIIRS

- Currently depends on MODIS instruments

Currently supplies tailored products to CERES Science Team for algorithm processing

Looking Forward

What is the future of all-sky assimilation?

- New frequencies are coming/here
 - 118 GHz: NASA Tropics, Orbital Micro Systems GEMS
 - > 200 GHz: Metop-SG ICI, NASA IceCube
- All-sky in the Visible and Infrared

The Role of Legacy Instruments

- GMAO (R. Todling) is participating in multi-agency assessment of NOAA-15 to -19
- The role of these instruments in filling the Late AM/Early PM orbits

Spatial/Spectral/Temporal Resolution in the infrared

- How much spectral information is too much spectral information?
- Spatial thinning/hole hunting/etc.
 - A renewed emphasis on cloud-clearing?
- Chemistry radiance assimilation in the future

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