Infrared Radiance Assimilation at the GMAO

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Introduction

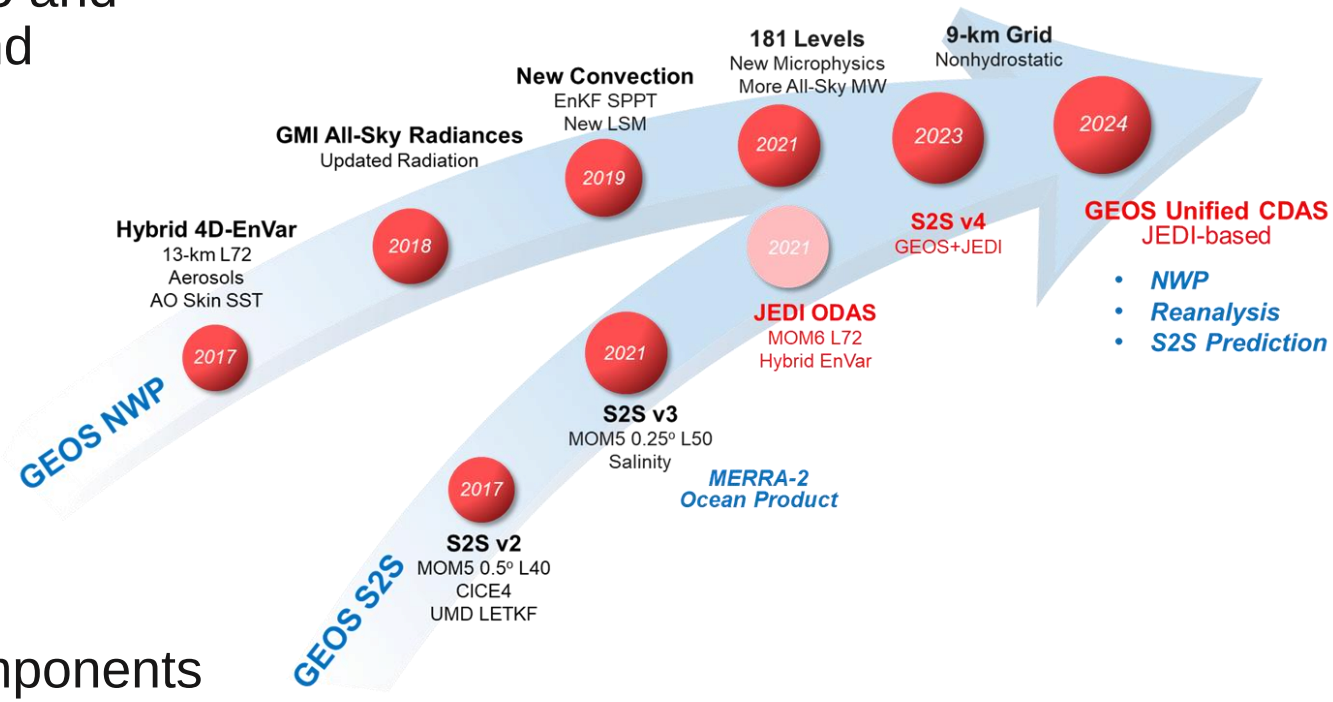
GMAO's core mission is to enhance the value of NASA's observations to understand, analyze and predict changes in the physics, chemistry and biology of the Earth system

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



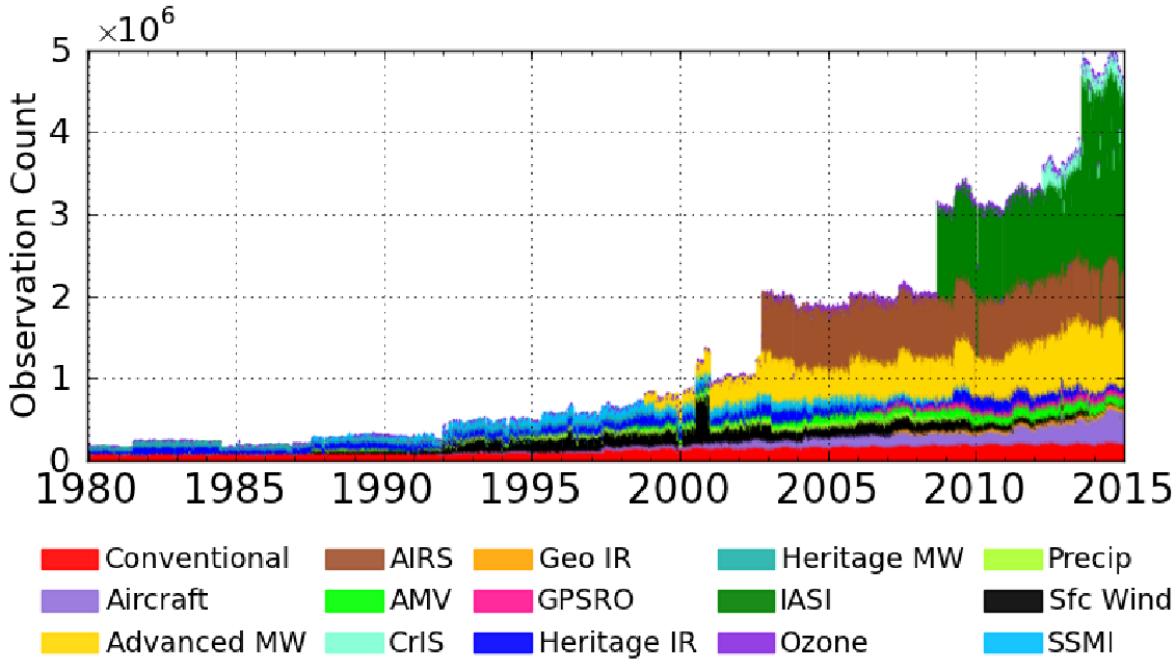
Applying Current Methods to Historical Observations

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)



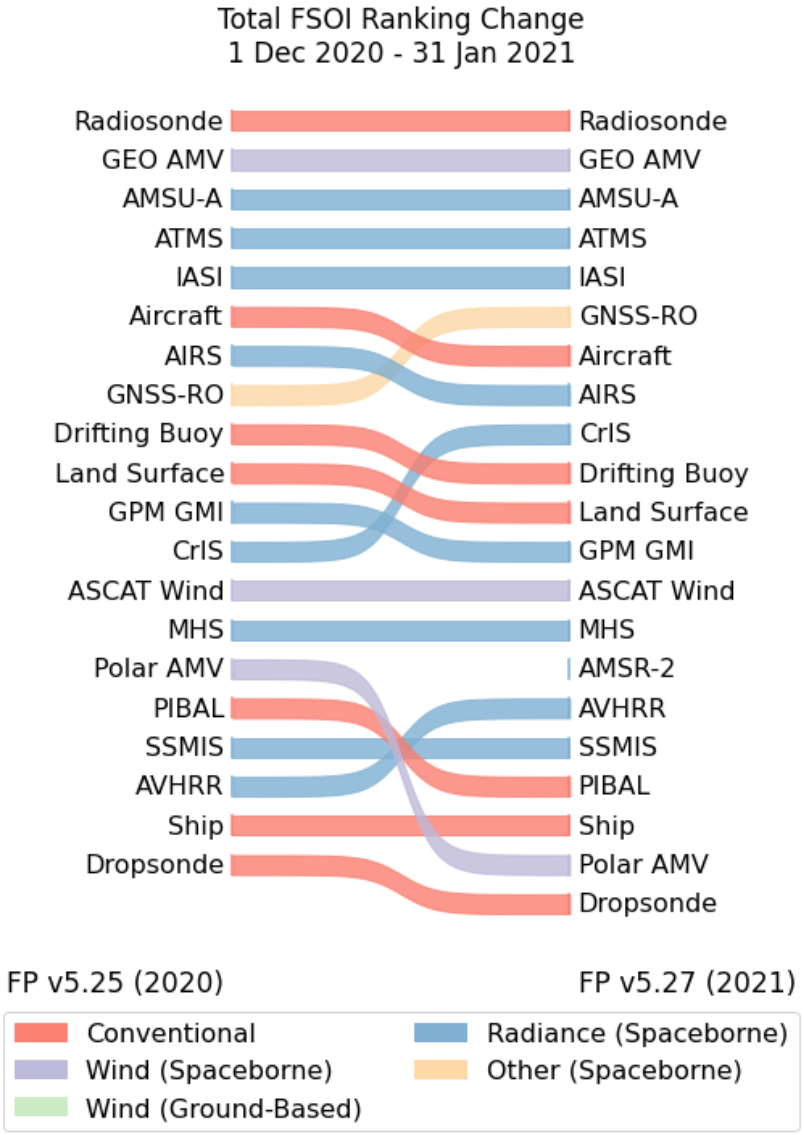
Current State of Radiance Assimilation

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:
  - Batch of new RO (incl. COSMIC-2)
  - Rise in CrIS



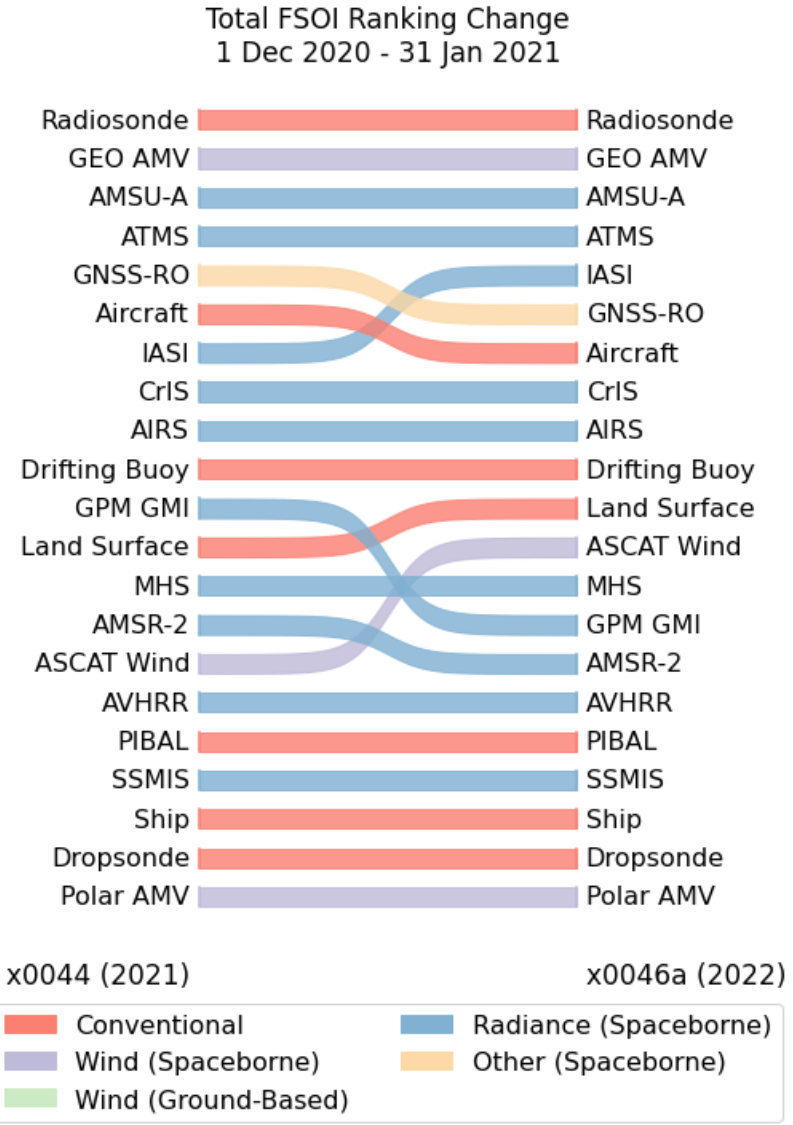
Current State of Radiance Assimilation

Our next candidate system will be fairly consistent with the current system

- Three IASIs in testing
- Implementation will only have two with Metop-A decommissioning

Note the consistent significance of infrared sounders

- This talk aims to show recent and ongoing efforts to improve the use and understanding of these data in the context of the GMAO



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

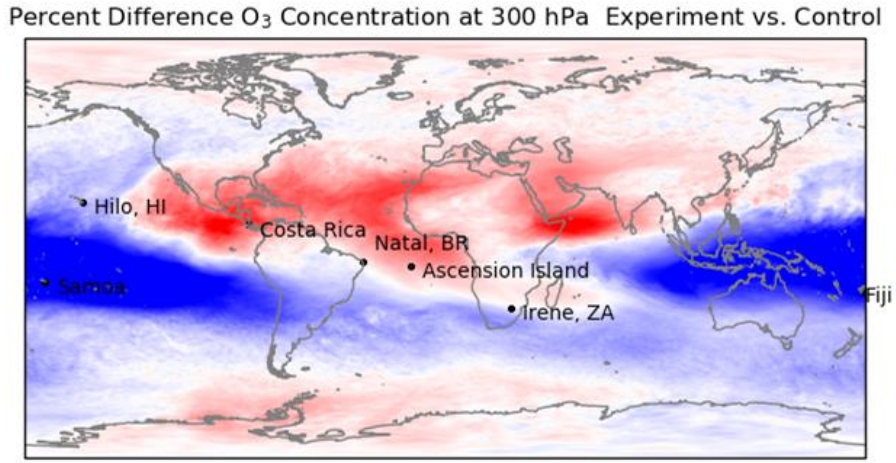
Radiances were shown to enhanced, improve resolution of tropical wave-1 ozone signal at 300 mb

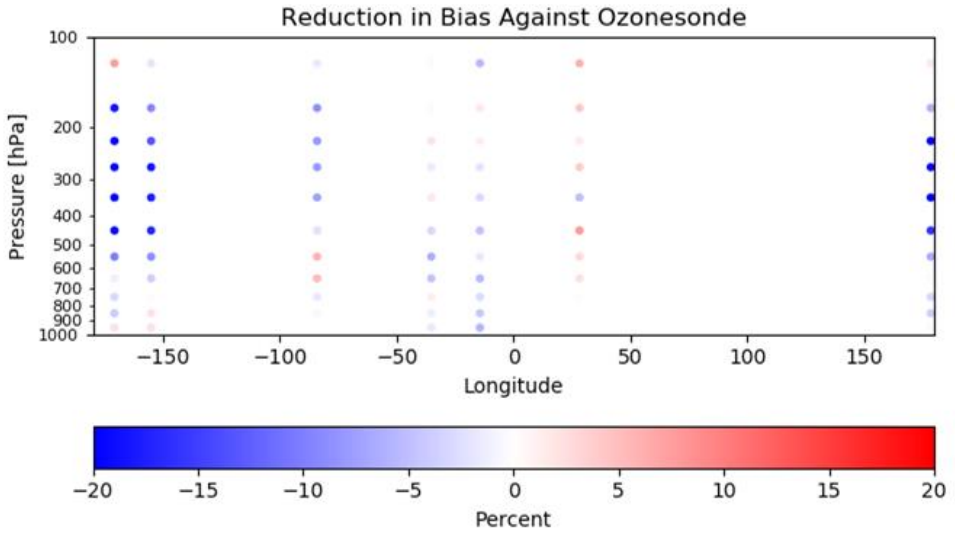
– August 2018 monthly mean percent difference against control

These changes reduced systematic errors against ozonesondes

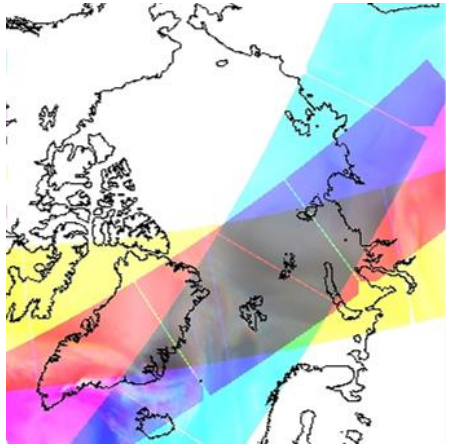
– Reduction of bias compared against SHADOZ ozonesondes

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





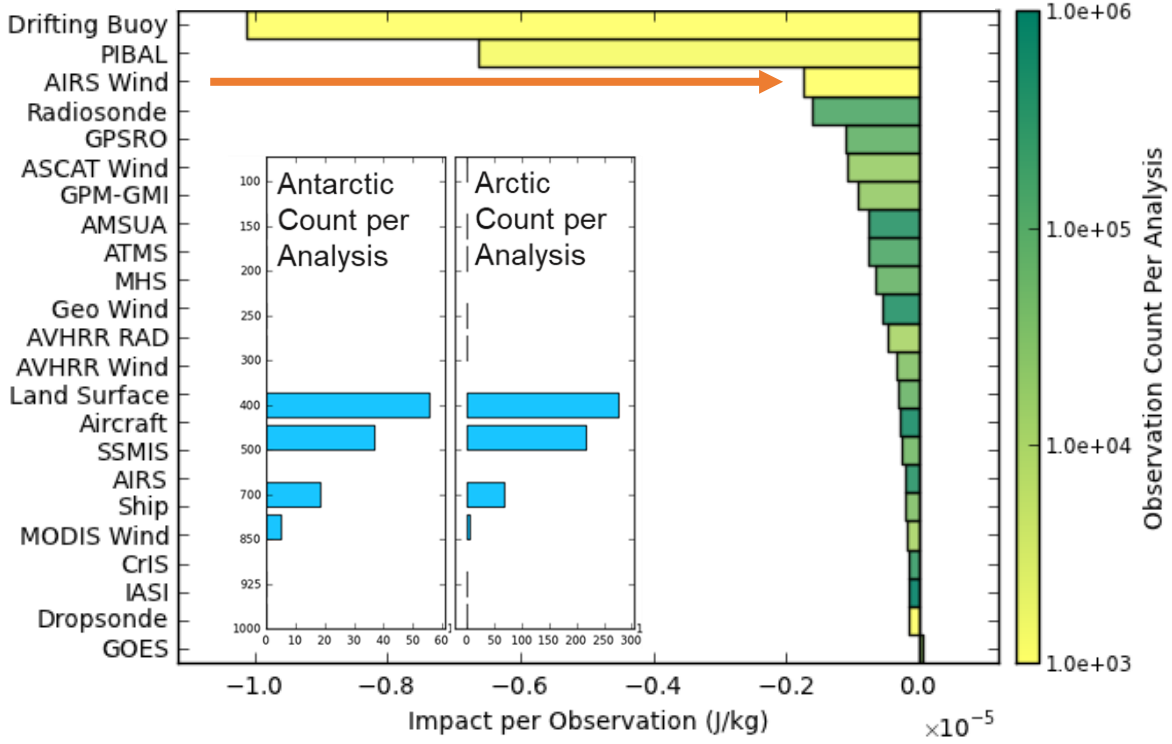
AIRS Atmospheric Motion Vectors



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

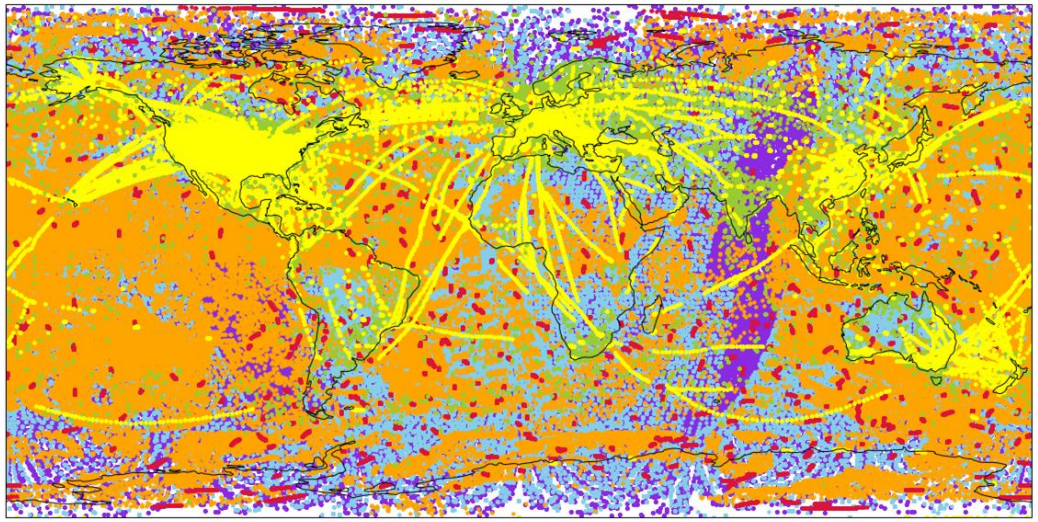
Global FSOI per Observation
1 June 2018 – 31 July 2018



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 (~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



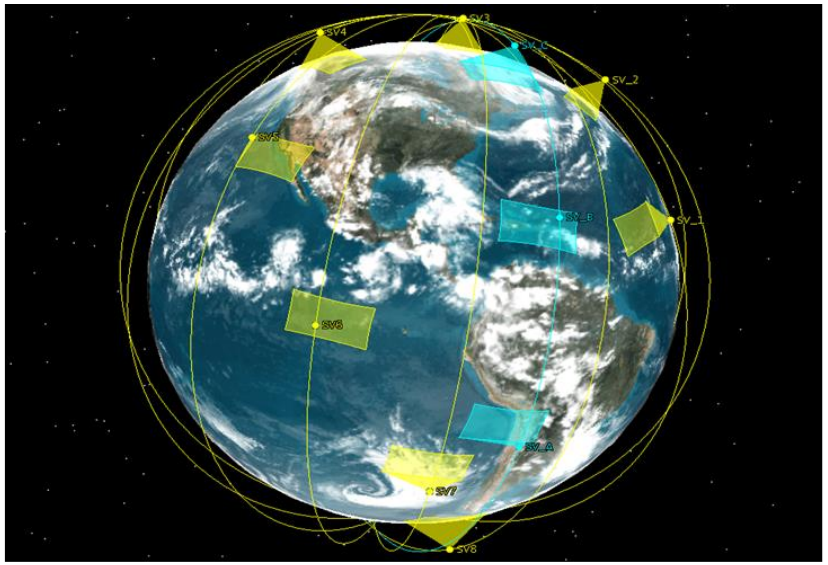
OSSEs however are limited

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

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

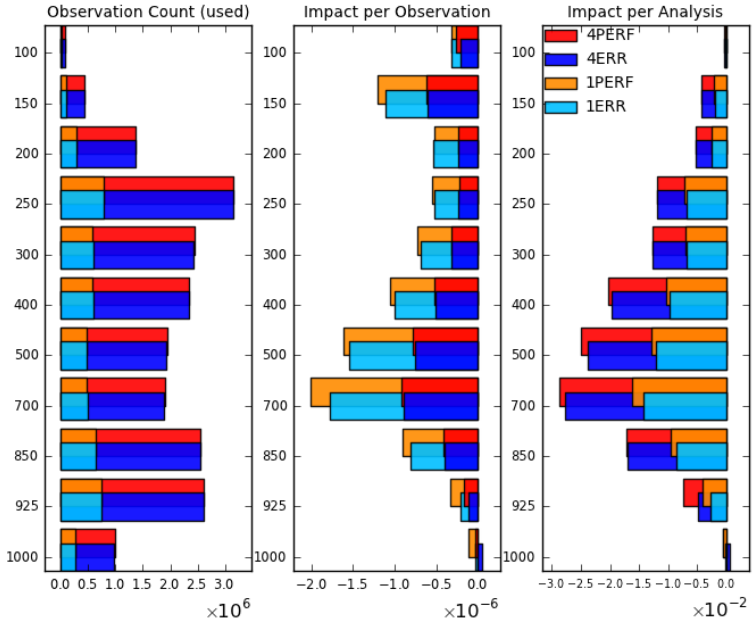


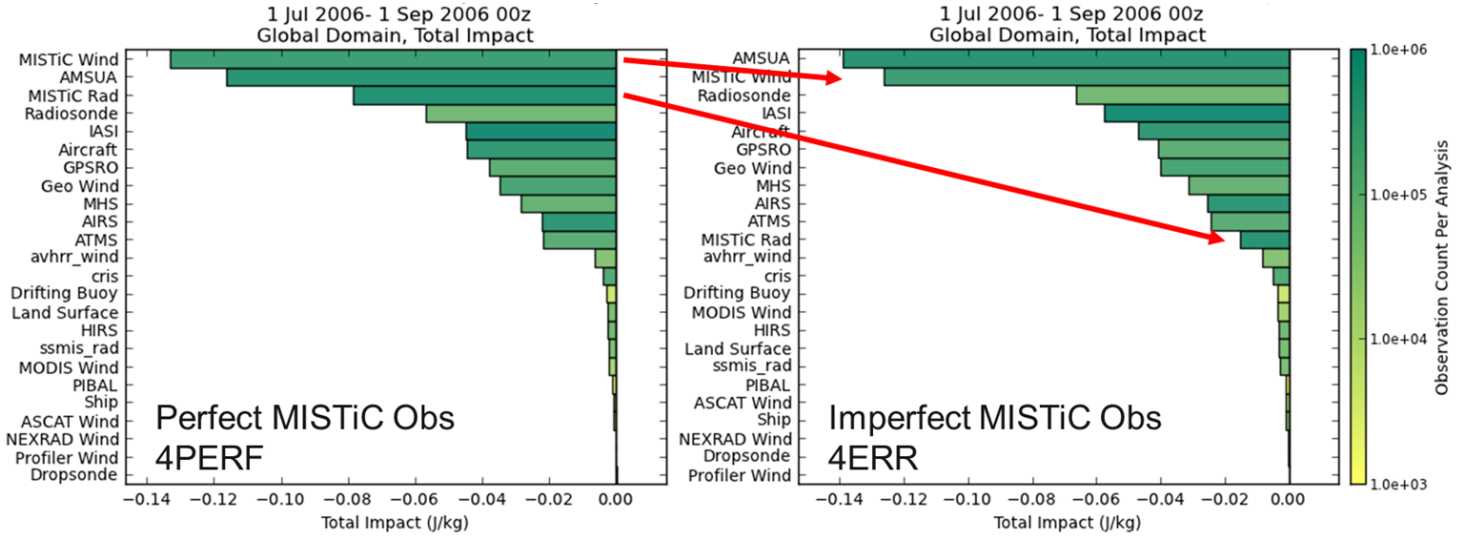
MISTiC Winds = Midwave Infrared Sounder for Temperature and humidity in a Constellation for Winds

Investigating the Utility of LEO Infrared Sounder Constellation

Results showed that by including realistic errors, much of the radiance impact was lost in the 4.3 μm CO2 temperature sounding channels

- Assimilation shortcomings
- Corresponds well to NESDIS TMP work to exploit this band





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

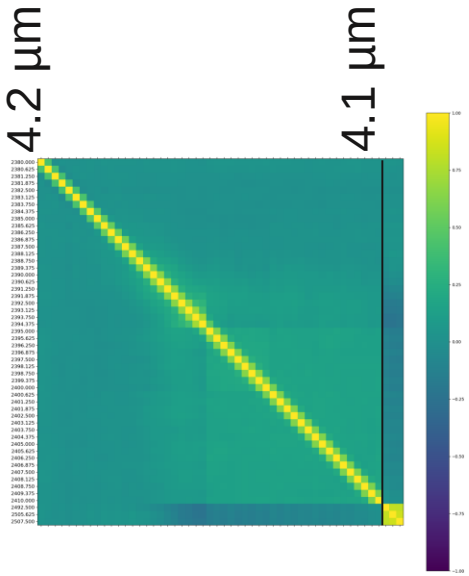
Shortwave Radiance Assimilation – Moving from OSSE to Real Data

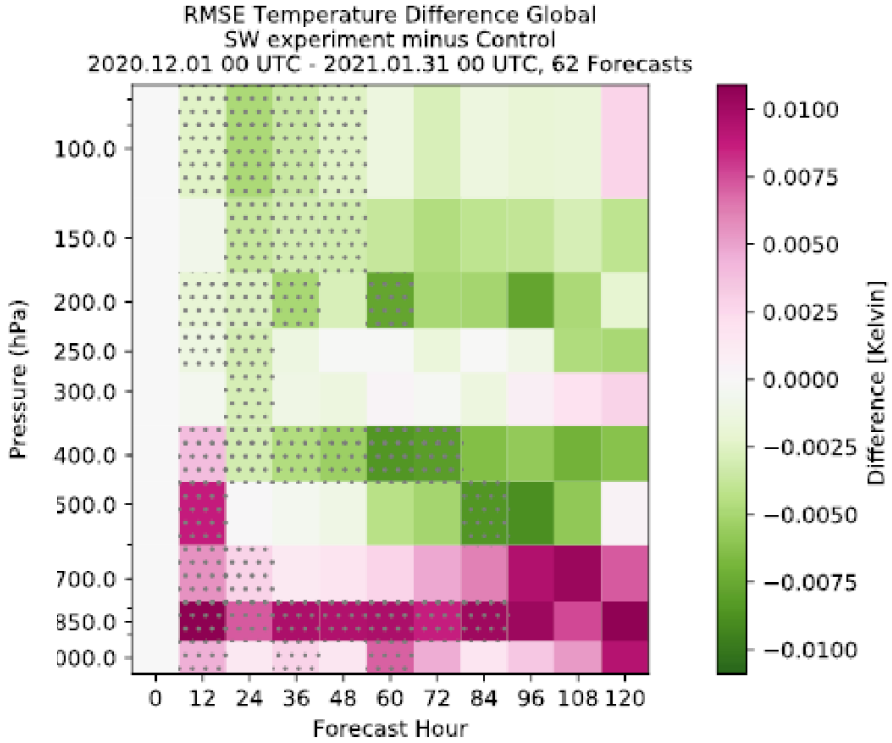
GMAO has collaborated with team @ STAR to further investigate the Longwave vs. Shortwave question

- Results are generally mixed
- The most apparent signals of degradation is in the lower troposphere
  - Seen most strongly in T (right); also in q
  - Does anything replace the information content lost from the 10-12 μm dirty window

Outstanding Questions

- Correlated errors (right) show broad, low-level correlations across many bands
- CrIS interchannel correlations from apodization unaccounted for in this experiment





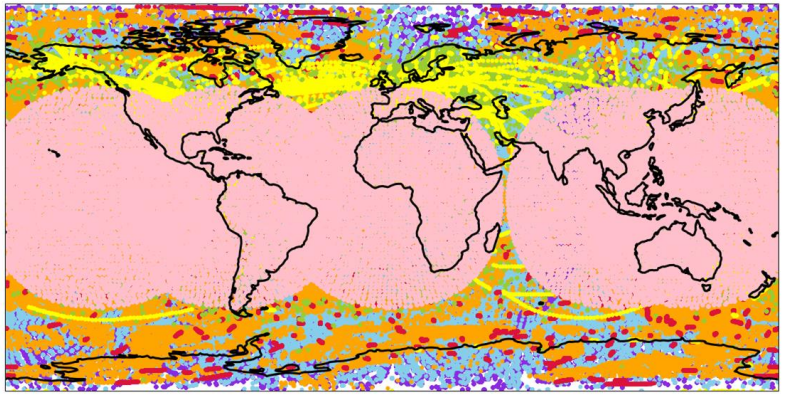
Investigating the Utility of Geostationary Infrared Sounders

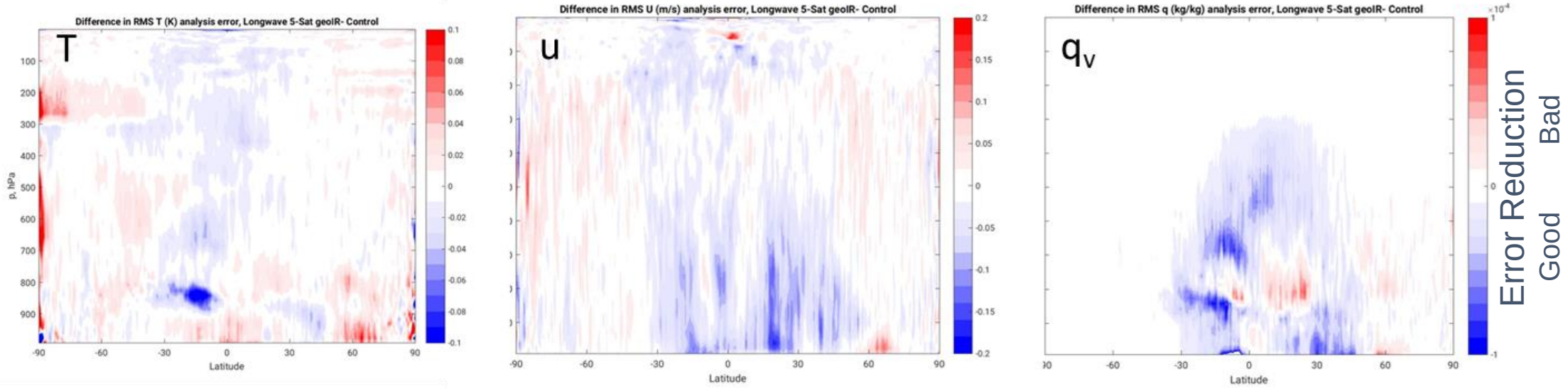
A set of OSSEs considering the impact of a constellation of hyperspectral IR sounder from GEO were performed

- 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





Improved Use of Surface-Sensitive Channels over Land

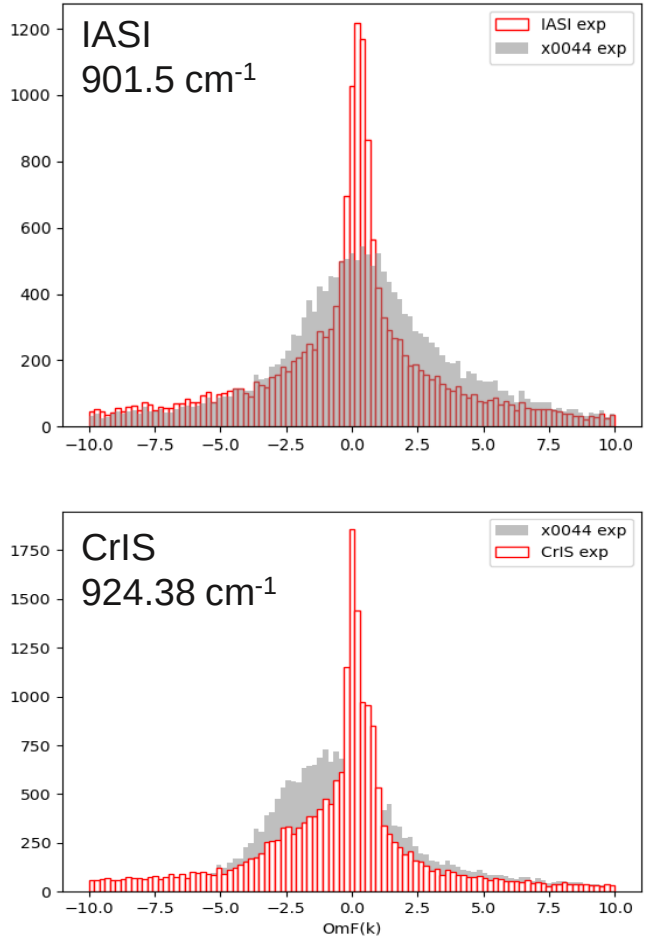
Effort is underway to better characterize first guess of land skin temperature

- Assume emissivity
- Retrieve LST

An issue with the current analysis procedure is that LST is taken directly from the model

- First guess potentially flawed
- LST solved on model grid
- Uncertainties in emissivity, regardless of observation wavelength, will intertangle

However, retrieving your LST as a function of your background may alias atmospheric uncertainty onto LST



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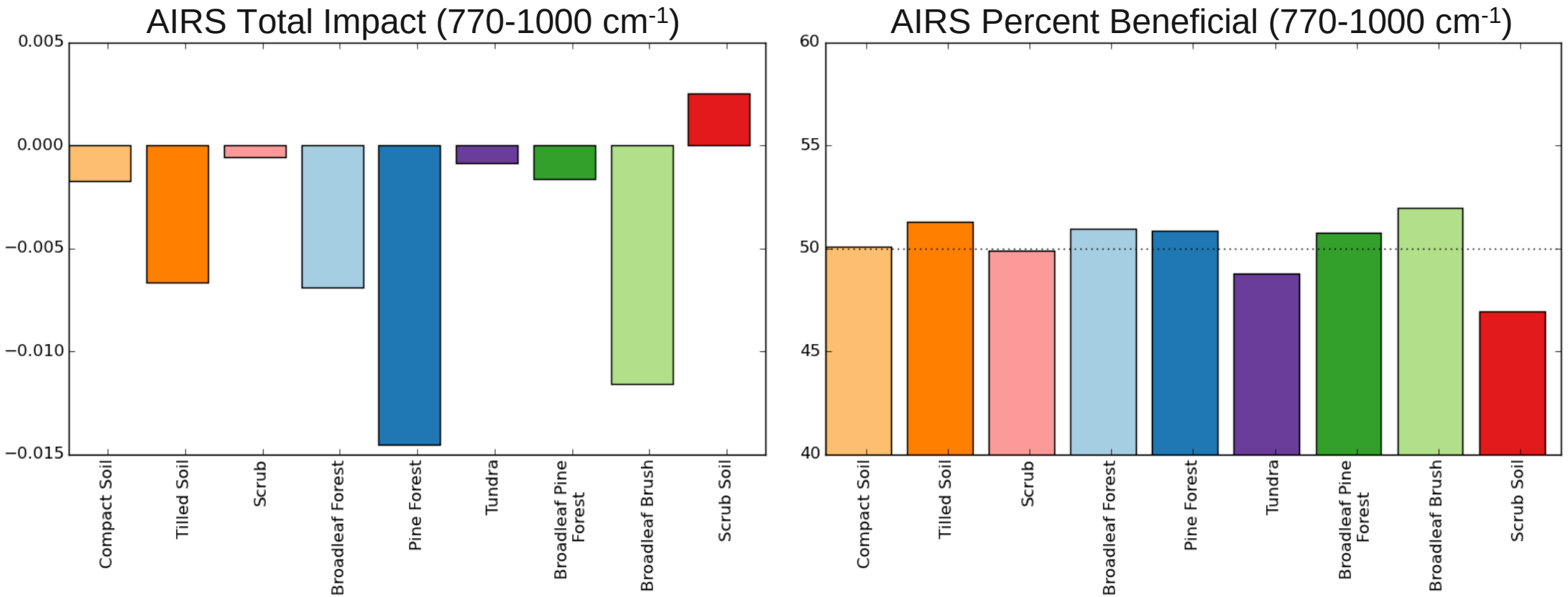

Emissivity in the GSI is coarsely defined over land based on predefined surface characterization (other than snow-covered)

– This all ties to the need for improved surface characterization for all radiances

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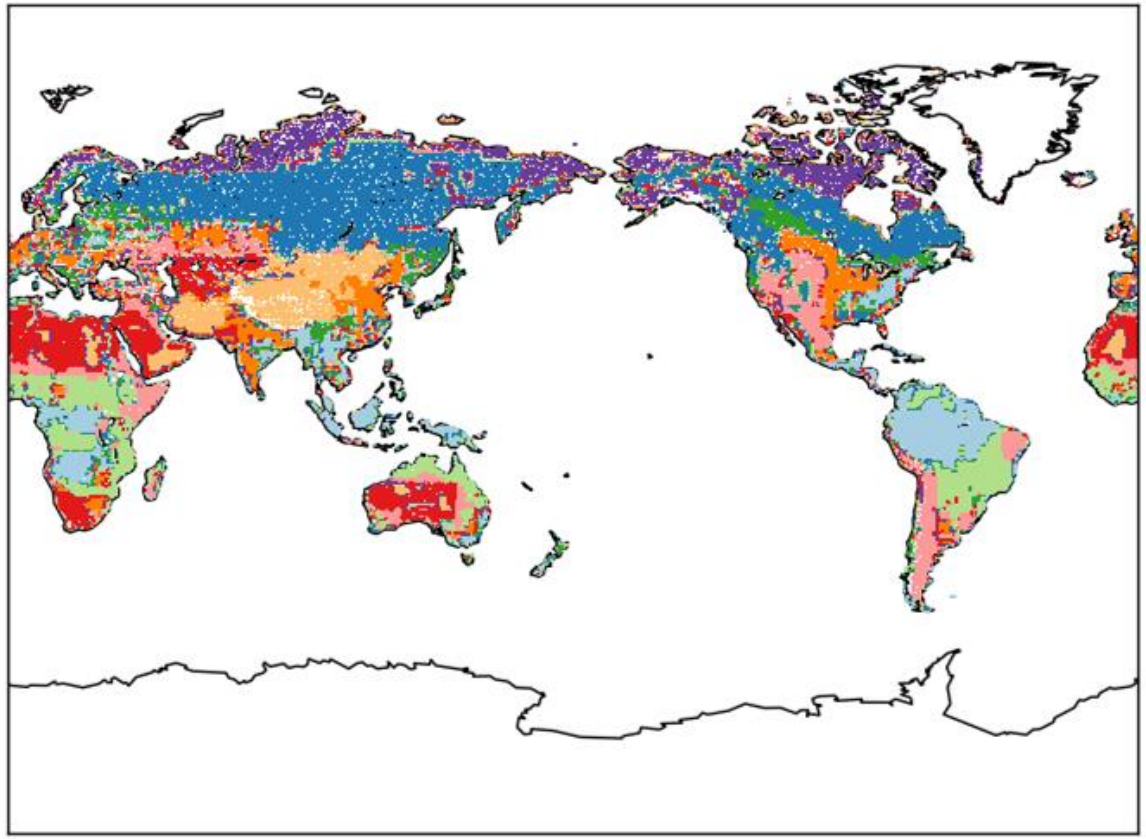

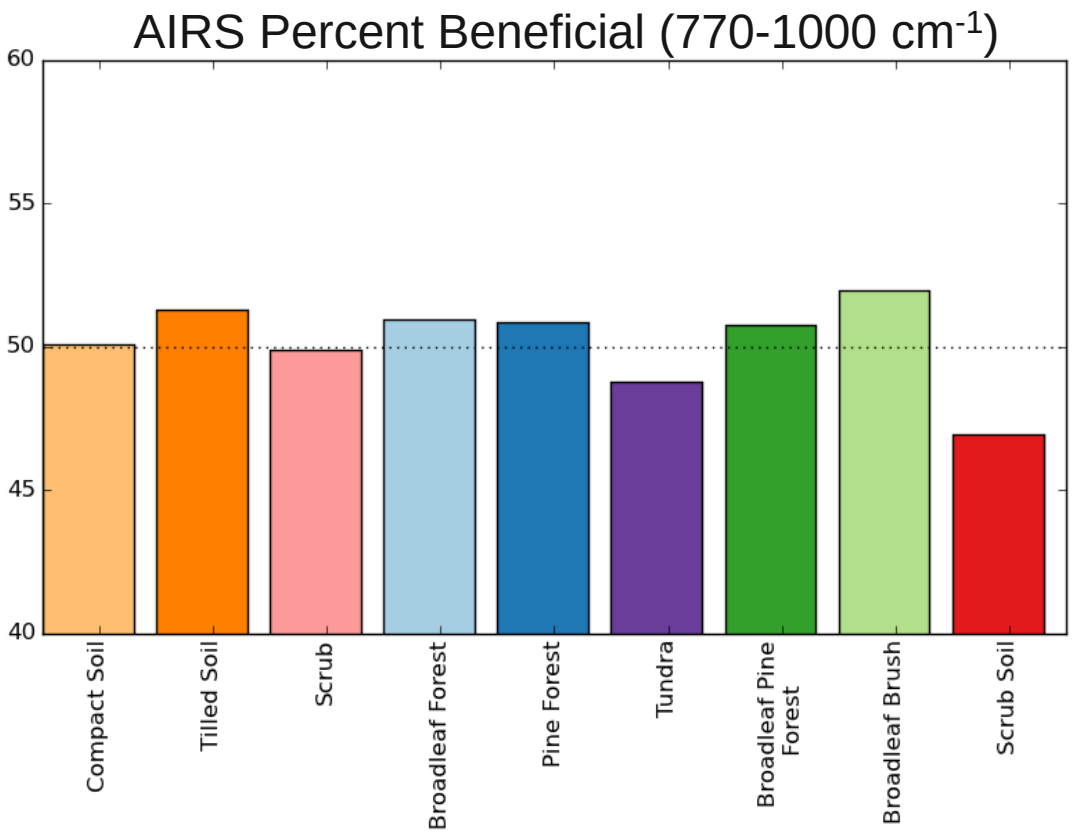

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Other Infrared-Relevant Studies

Correlated Errors in Hyperspectral Infrared

- Current production implementations utilize correlated errors for hyperspectral infrared sounding
- These errors will become more important with the advent of geostationary and miniaturized sounders

Aerosol impacts on the infrared

- Heavy aerosol loading causes scattering in the thermal infrared
- Studies showed that the aerosol forecasts within GEOS can be used to improve RT calculations
- Somewhat costly; never implemented

Improved use in the stratosphere

- The increase in radio occultation data may serve as a more appropriate anchors to variational bias correction procedures
- Ongoing work aims to better exploit channels sensitive to the upper-stratosphere

Looking Forward

What is the future of infrared sounding?

- With geo on the horizon, are we prepared?
  - Are there improvements to be made to better utilize temporal information content
  - Tracer effect seen from water vapor bands, but can ozone radiance assimilation better characterize stratospheric winds?
- Are smallsats inevitable? Does this continue to motivate the improved shortwave assimilation question?

What are the agency's priorities?

- For NASA, the planetary boundary layer is an incubation-class designated observable in the decadal survey
- What information in the infrared is there, what can be better-exploited, and how do retrievals and data assimilation tie together?
- How much spectral information is too much spectral information? (particularly w.r.t. chemistry)

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