Status of NOAA's GeoXO Hyperspectral Infrared Sounder (GXS)

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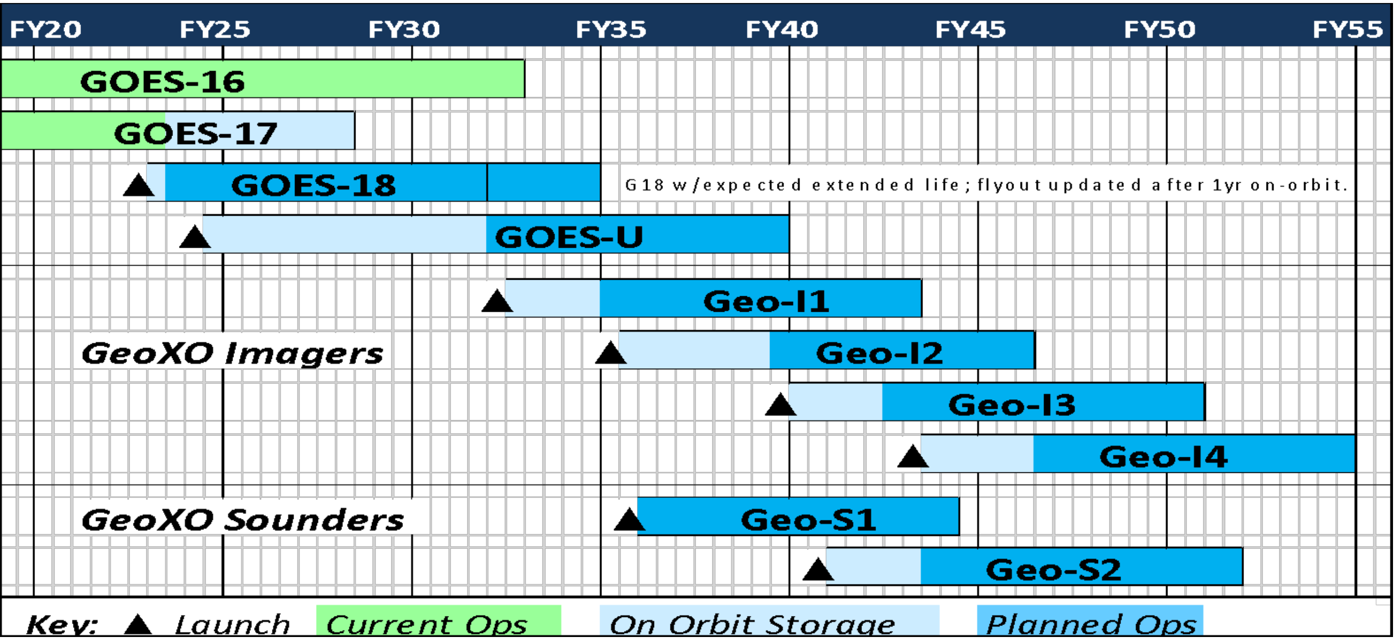
GeoXO Constellation
GEO-West
Visible/Infrared Imager
Lightning Mapper
Ocean Color
GEO-Central
Hyperspectral Infrared Sounder
Atmospheric Composition
Partner Payload
GEO-East
Visible/Infrared Imager
Lightning Mapper
Ocean Color

Program and Sounder Schedules

- GeoXO Life Cycle Cost estimate is ~$19B, covering development and operations over 2021-2055
  - Includes 16 Earth-observing instruments, 6 NOAA spacecraft, 6 launch vehicles, ground system, spacecraft and data product ops, rebroadcast services, and partner data acquisition



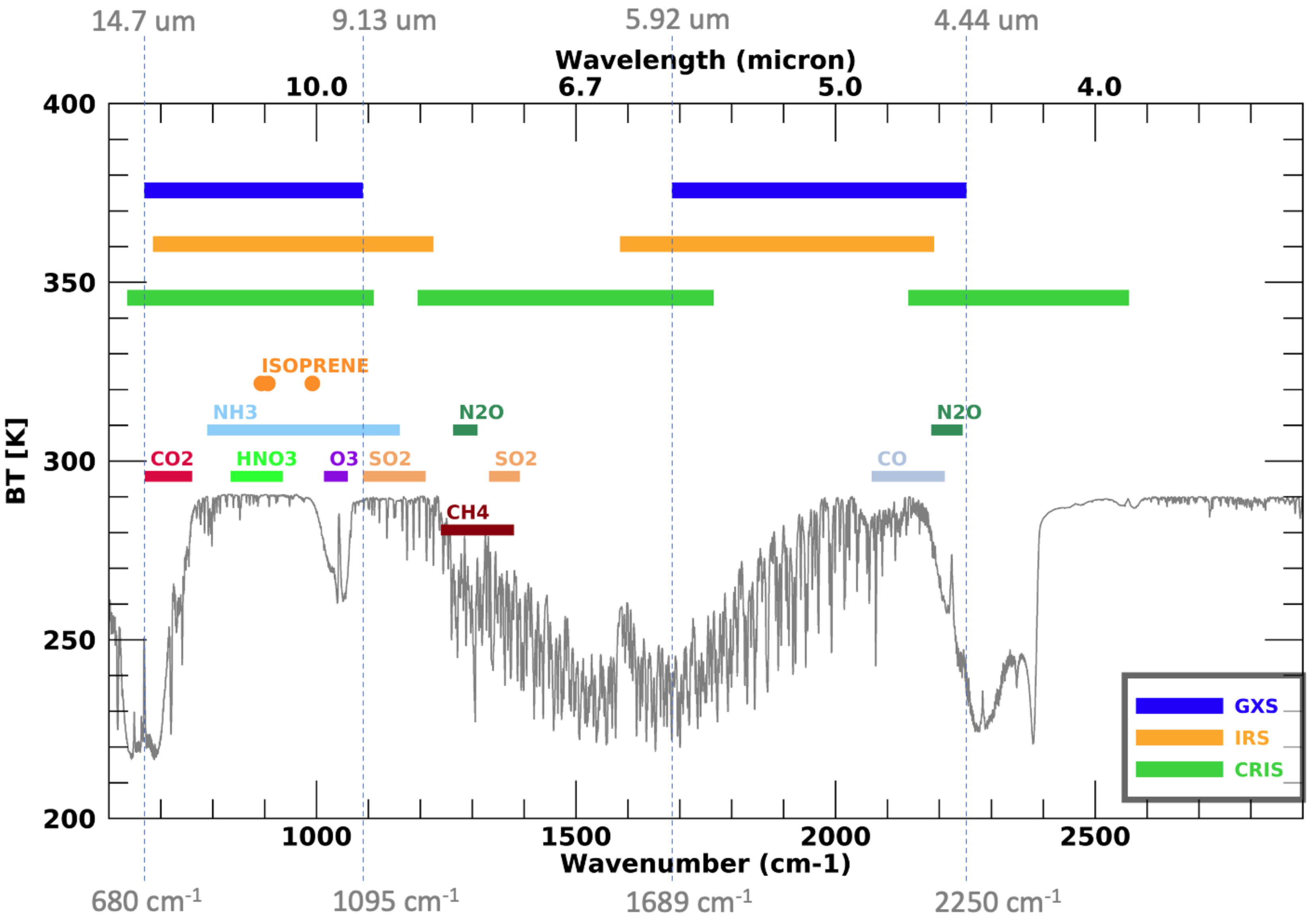
Sounder Formulation

- 2020 BAA Studies
- 2022 Phase-A Studies
- early 2023 RFP Release
- late 2023 Vendor Selection

GXS Spectral Coverage

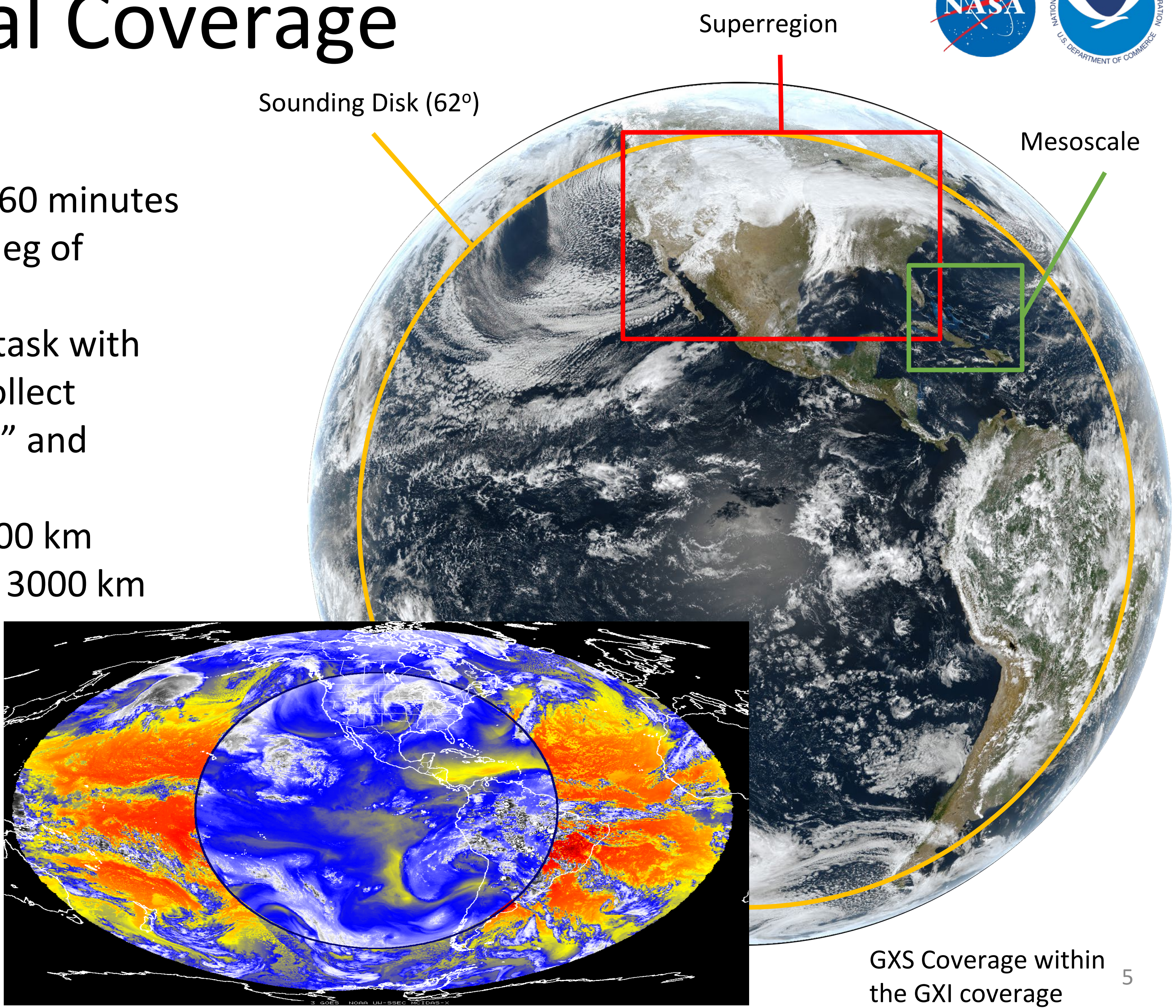
- The GeoXO IR Sounder (GXS) is a hyperspectral sounder that provides atmospheric soundings for forecasting, numerical weather prediction, and environmental observation

- Provides information for: Temperature and Water Vapor Profiles, Atmospheric Composition including Carbon Dioxide, Carbon Monoxide, Ammonia, Nitric Acid, Nitrous oxide, Isoprene



GXS Spatial Coverage

- GXS will scan the Sounding Disk every 60 minutes
  - Sounding Disk extends out to 62 deg of zenith angle.
- GXS will be commandable for custom task with regions interspersed in any order to collect sounding areas such as “superregional” and “mesoscale”.
  - Mesoscale region is 1000 km x 1000 km
  - Supperregional area is 5000 km x 3000 km
  - Example potential scan operation
    - Sounding disk @ 120 minute
    - Superregional @ 60 minute
    - Mesoscale @ 7 minute
- Pixel resolution is 4 km at nadir



GXS Coverage within the GXI coverage

GXS Requirements in RFP

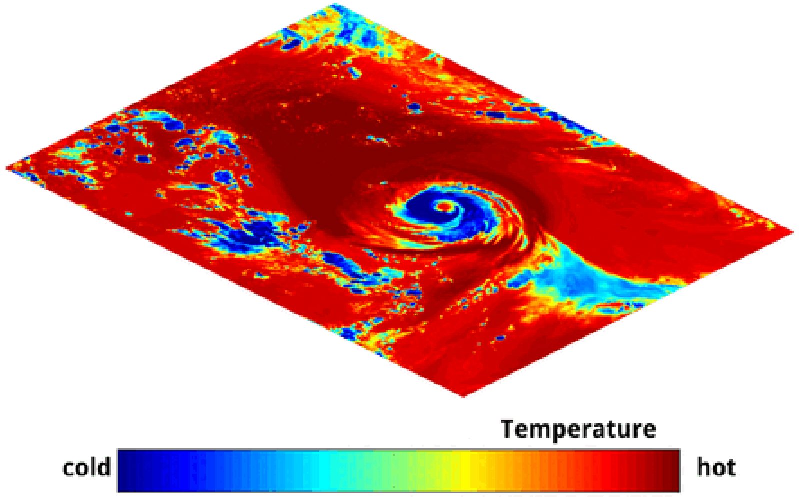
Requirement	Value
Spectral Range	4.44-5.92 µm and 9.13-14.7 µm
Spectral Resolution	0.625 cm^{-1}
GSD	4 km
Refresh Rate	60 minutes for Sounding Disk
NEdN (mW/(m^2 sr cm^{-1}))	0.06 for 1689 - 2250 cm^{-1} (228-234 K scene) 0.2 for 800-1095 cm^{-1} (218-234 K scene) 0.352 for 718-800 cm^{-1} (224 K scene) 0.352-2.5 for 680-718 cm^{-1} (224 K scene)
Ensquared Energy	70%
INR	42 µrad navigation

GXS Activities

GeoXO Current Activities

- NOAA/STAR + UW/CIMSS (Zhenglong Li + Tim Schmit) to support GeoXO formulation and simulation capabilities.
- UW/SSEC (Bill Smith and Qi Zhang) project using JPSS/CrIS + GOES-R/ABI to provide a proxy data source for GeoXO GXS
- NOAA/ESRL (Steve Weygandt,Haido Lin, Curtis Alexander) and others assimilating CrIS over Alaska as proxy for GeoXO GXS.
- NASA GMAO on using OSSE for estimating GXS Impact.
- UW/SSEC (Dave Tobin) study PCA creation and usage and optimizing impact of CrIS to support GXS.
- GeoXO created a GXS value assessment and an economic benefit study (see links)

GXS Visualization from UW/CIMSS



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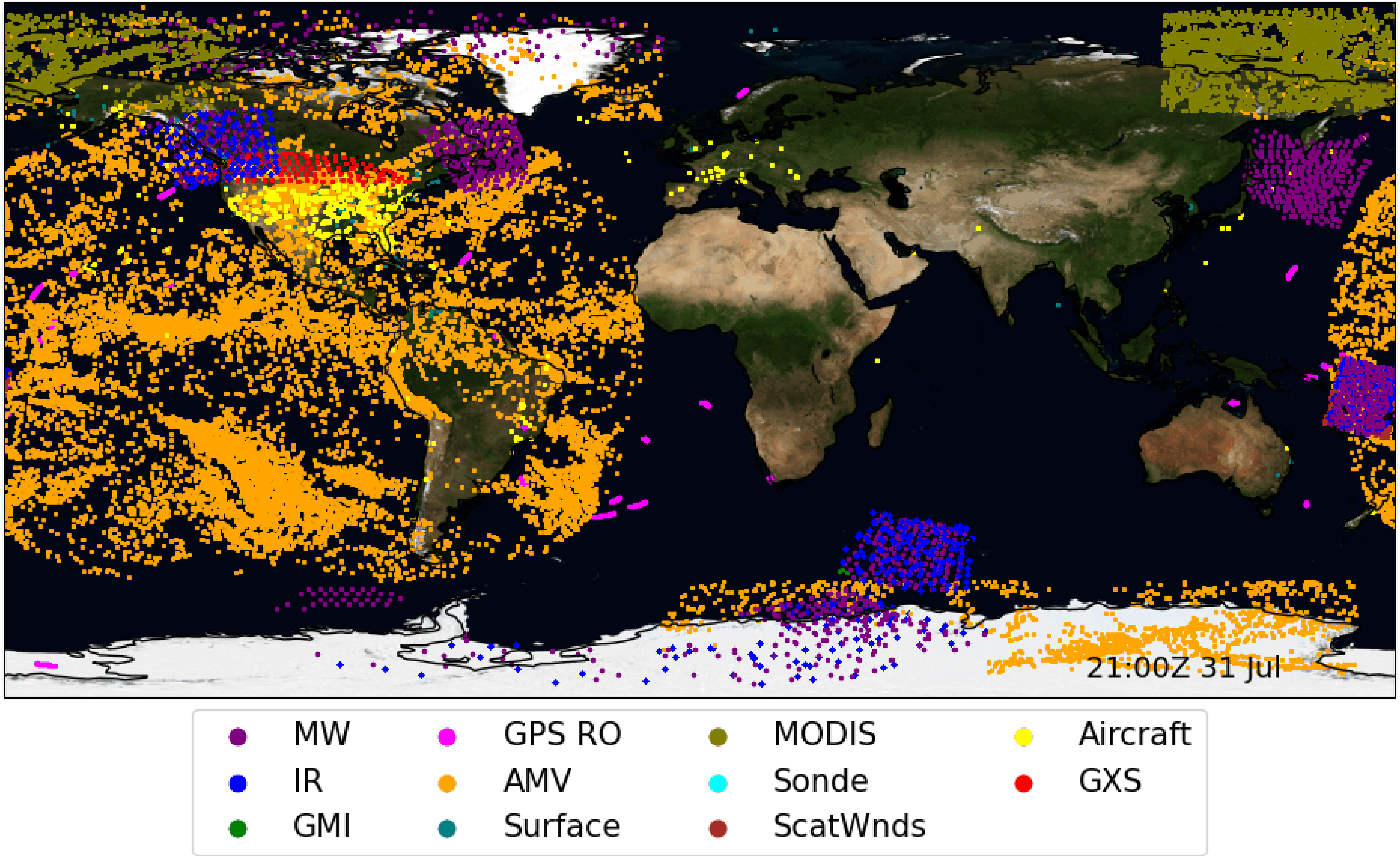
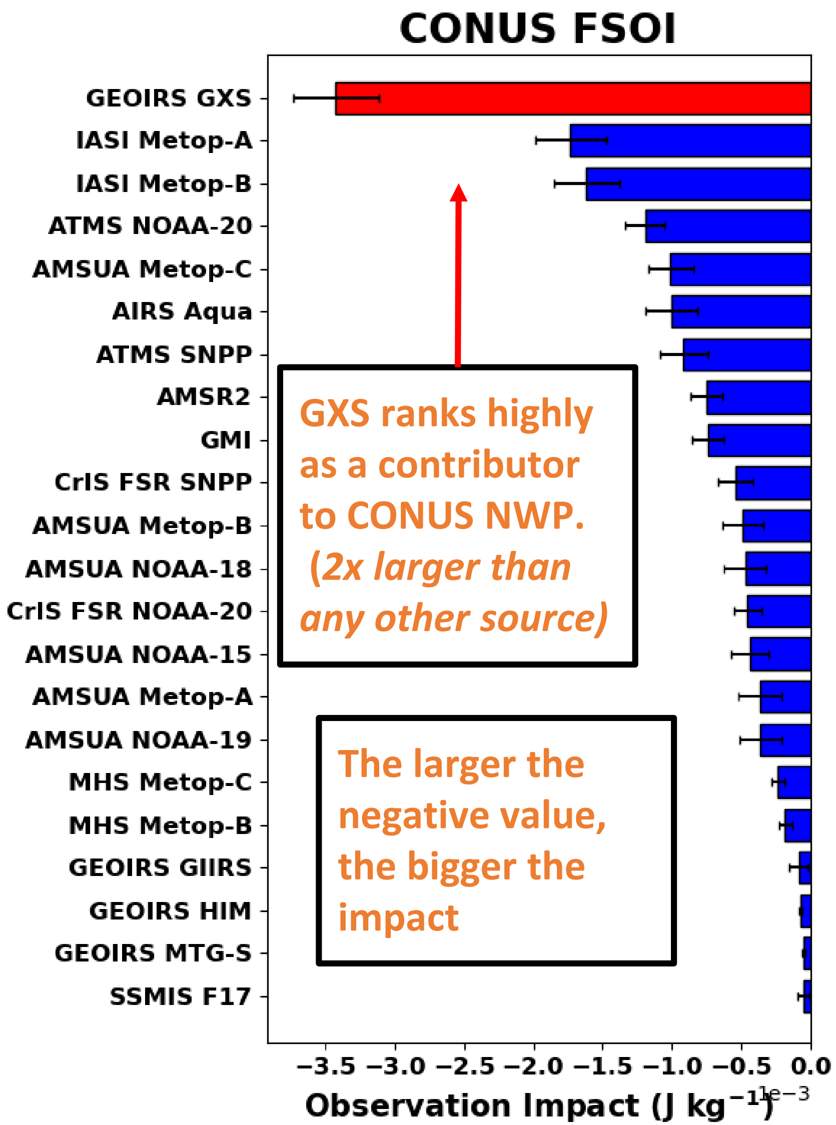
Observations in GMAO's GEOS

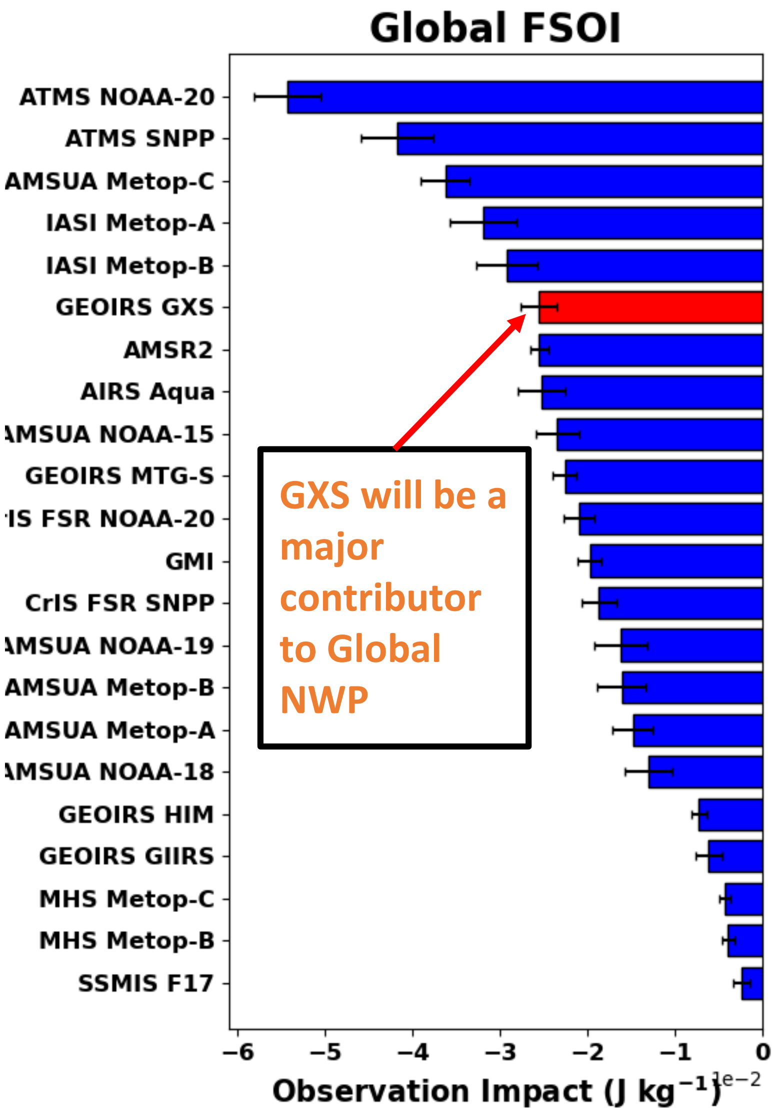


GMAO GEOS Estimates of GXS Impact on CONUS and Global Forecasts

Credit: NASA GMAO

- The NASA GMAO has supported GeoXO by running Observing System Simulation Experiments (OSSEs) to study the impact of a GEO IR Sounder.
- Forecast sensitivity to observation impact (FSOI) estimates observation impacts on a 24-hour forecast of total wet energy.
- Negative FSOI indicates that the assimilation of an observation decreased the 24-hour forecast error.
- These images show the relative impact of a GEO IR Hyperspectral Sounder to Global (right) and CONUS (left) NWP compared to the 2020 global observation suite.
- Other GMAO results show that GXS improves forecasts out to 5 days.

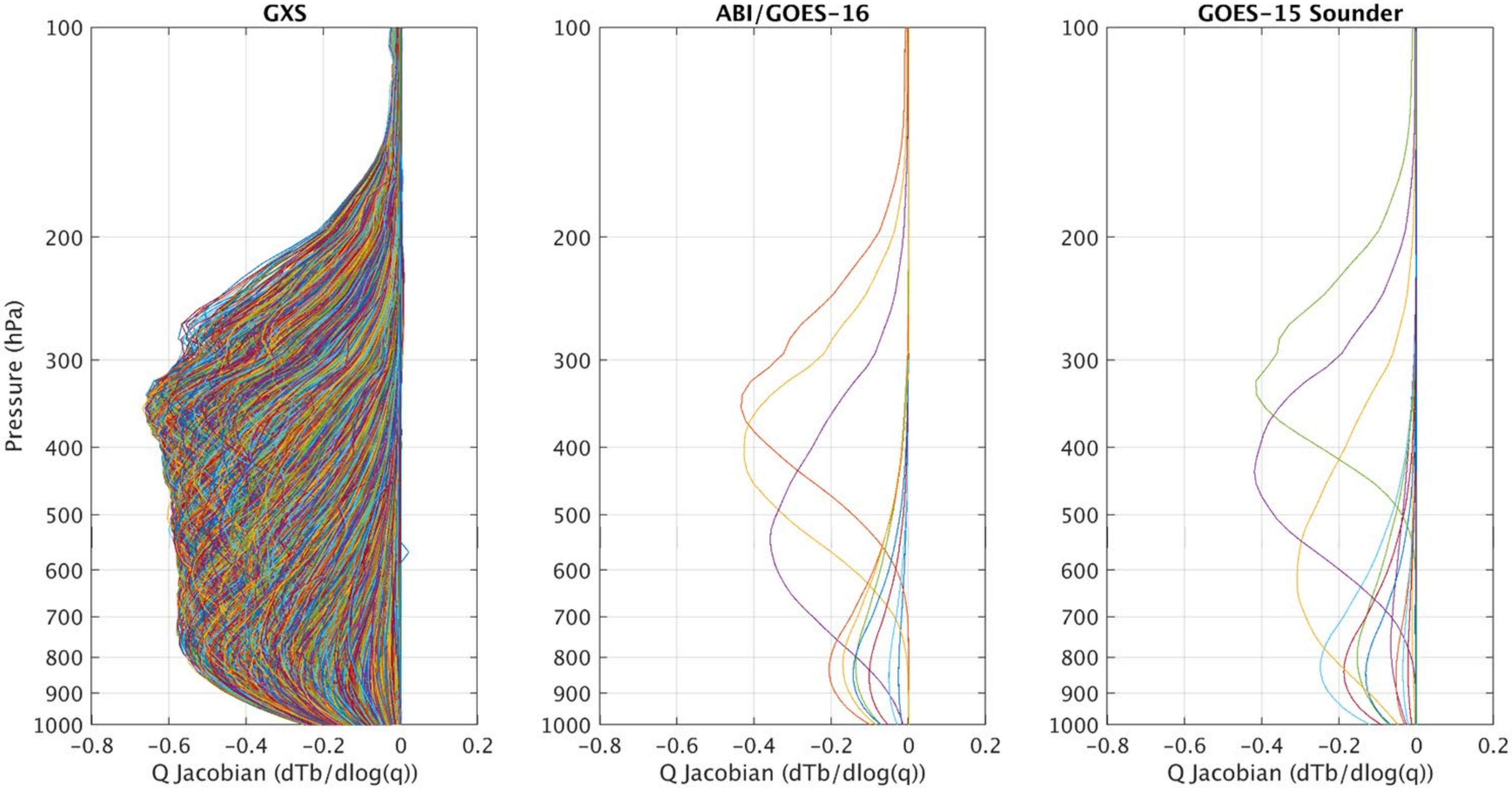




These results are updated from those recently published in the AMS/JTech (https://doi.org/10.1175/JTECH-D-22-0033.1) with a more recent forecast model and data assimilation system

GeoXO GXS Moisture Weighting Functions

- GeoXO IR-Sounder (GXS) Science Working Group has computed the Weighting functions for the nominal specifications of GXS.
- Weighting functions (aka Jacobians) show where in the atmosphere information comes from.
- These plots show the weighting functions for moisture.
- These are also important for picking channels for data assimilation, although as many as possible should be used.

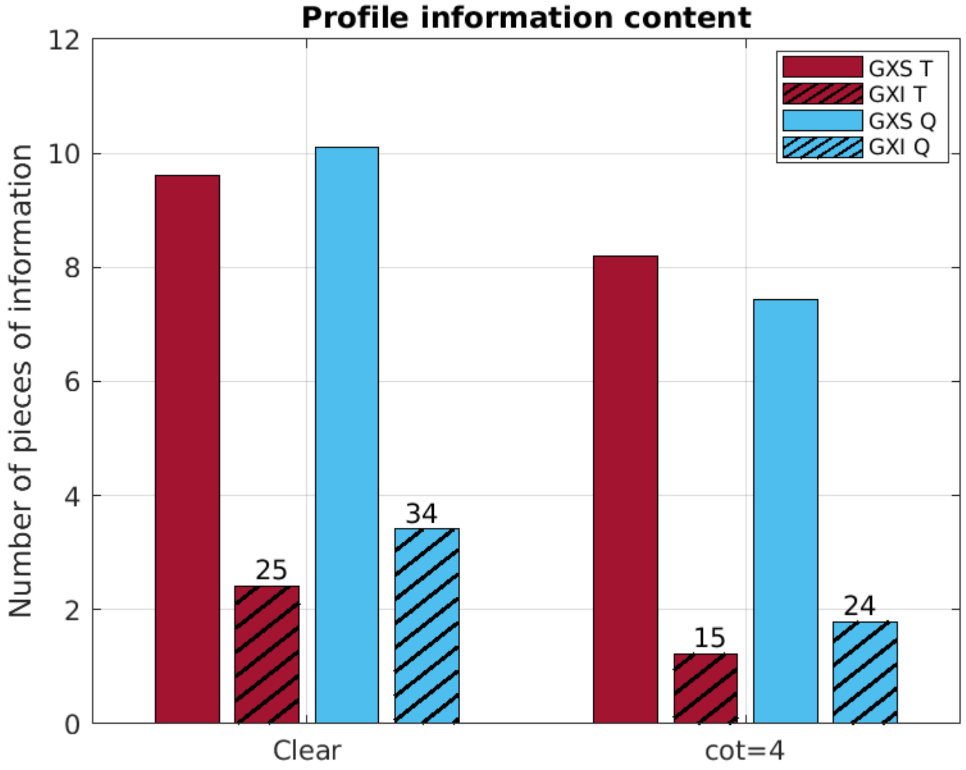


They show how much more vertical information GXS will provide compared to ABI or the previous GOES Sounders, this is in part to the many more overlapping spectral bands.

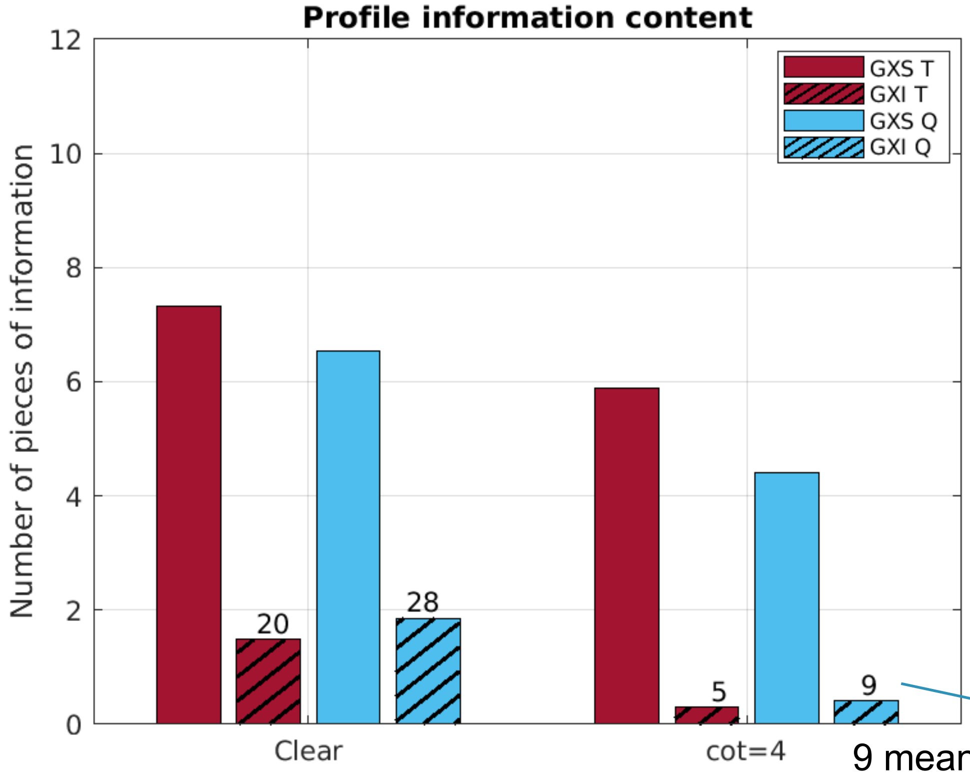
UW/CIMSS

GXS information content is much more than GXI

Cloud top pressure = 300 hPa



Tropical atmosphere profile



Midlatitude winter atmosphere profile

GXS has 3-5 times more vertical information than the GXI in clear skies, and 4-20 times more vertical information than the GXI in thin clouds

9 means GXI has 9% of moisture information content compared with GXS when COT is 4.

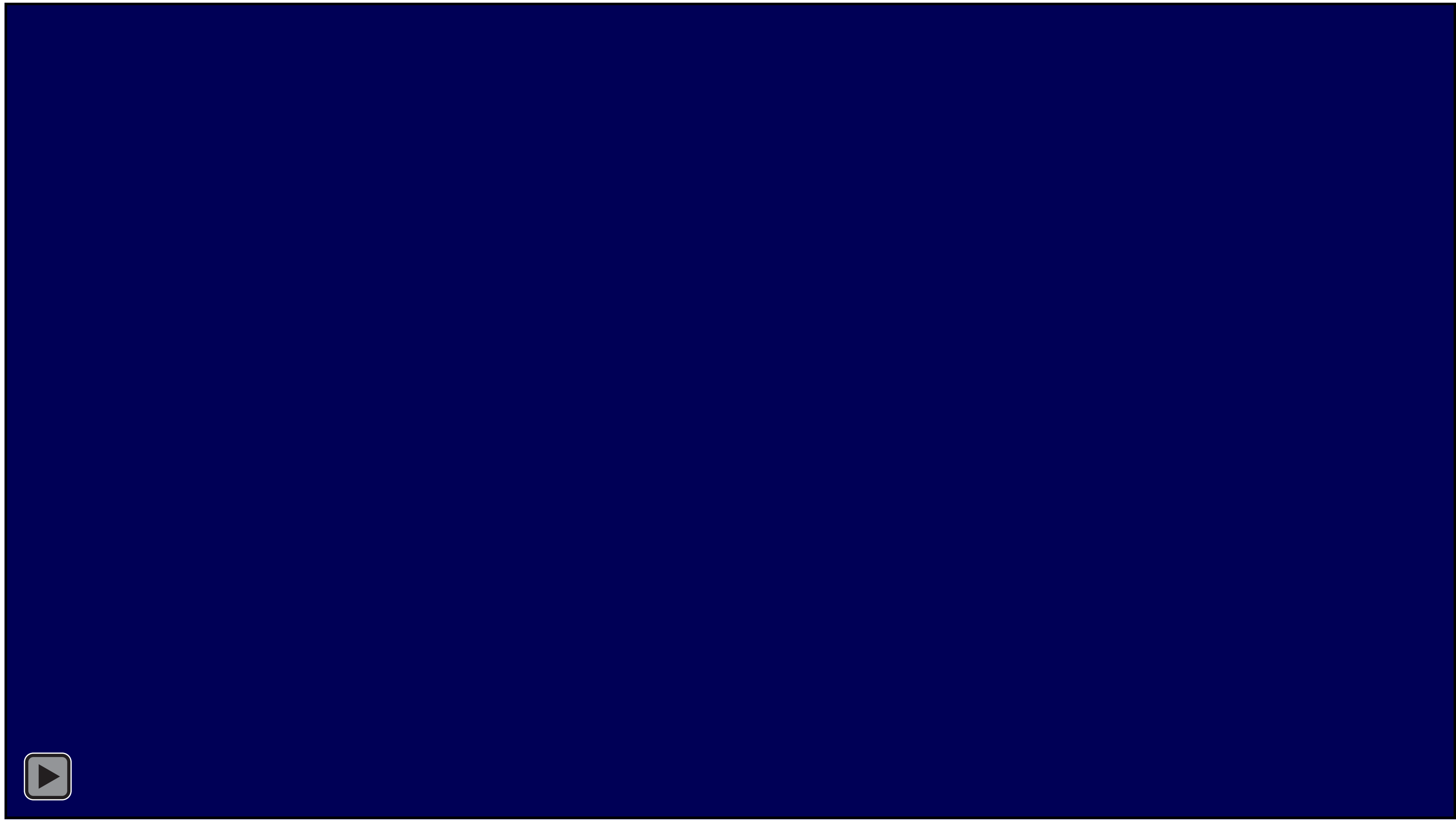
- Numbers on top of bars show the percentage (%) of information content from GXI compared to GXS
- High clouds reduce information content of T/Q, but significantly less impact from GXS

Effect of GXS on a hurricane forecast

Animation of the five-day forecasted total precipitable water from the (red) control and (blue) GXS experiments at the time of an Atlantic hurricane. The hurricane's 6-hourly center is indicated for the

- (yellow) “truth”,
- (red) control, and
- (blue) GXS experiments.

For this forecast, the GXS experiment better estimates the track, especially the landfalling location at about 72 hours.

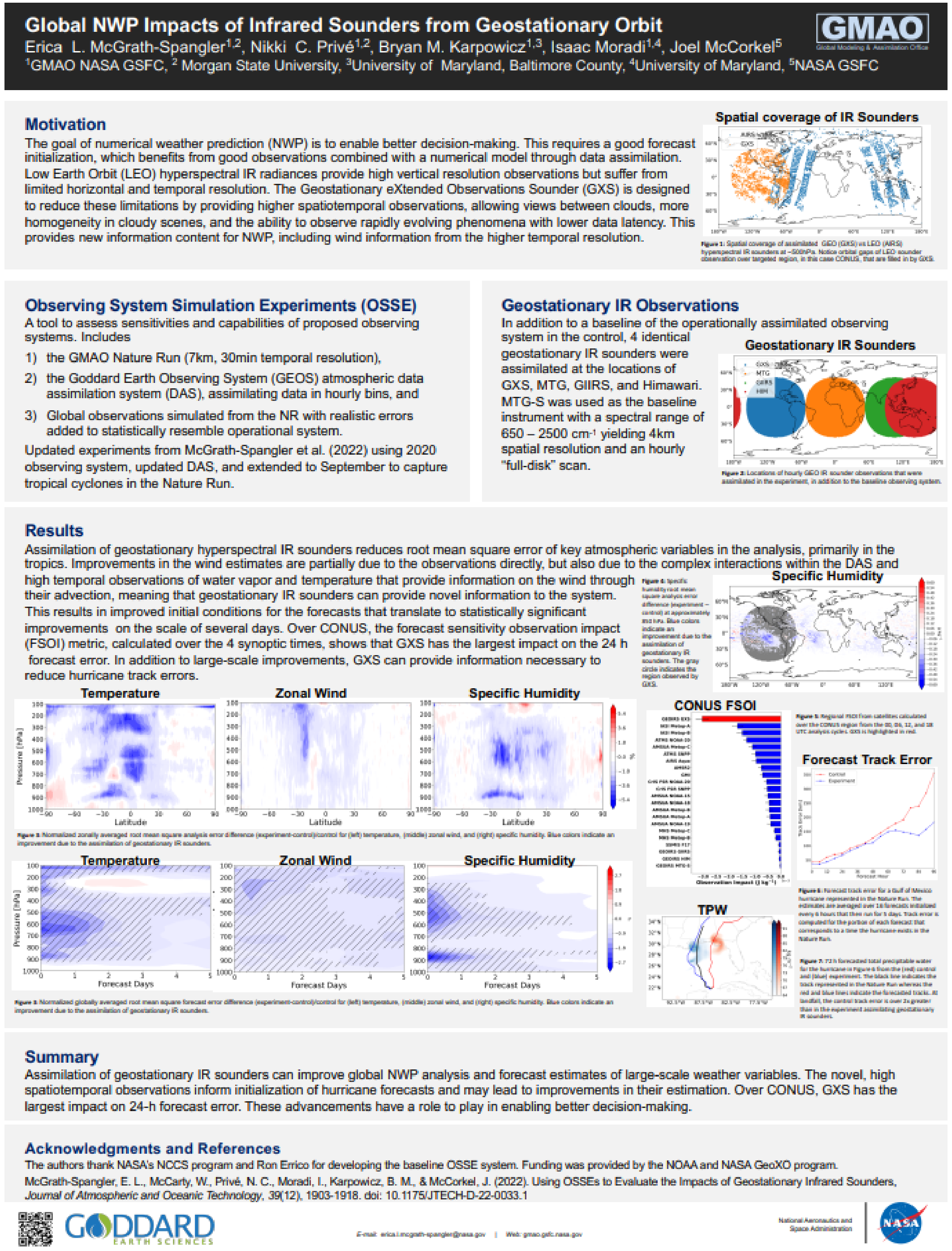


Future Plans

- We continue to seek help in GXS advocacy.
- GeoXO is eager to use the MTG/IRS as proxy data source.
- GeoXO is coordinating its sounder research with other agencies.
- We plan to hold a sounder retrieval test-bed to see which algorithmic techniques are best suited for the GXS applications. All are welcome.
- GeoXO will contribute to the NESDIS Satellite Proving Ground Calls to seek innovative ideas and those that combine GXS with our other sensors.

Check Out this GXS Poster!

- Evaluate impact of geostationary IR assimilation on NWP using the GMAO OSSE
  - Can calculate error directly because the “truth” (i.e. the nature run) is known
- Largest analysis impact occurs in the tropics and is predominantly beneficial
- Better initial conditions leads to statistically significant improvements in forecasts
  - Temperature, specific humidity, even tropical cyclone tracks
  - Wind improvements due to interactions between the observations and the forecast model
- Over the contiguous United States and averaged over the 4 analysis cycles, GXS has the largest beneficial impact on the 24 h forecast error reduction


Global NWP Impacts of Infrared Sounders from Geostationary Orbit

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GMAO

Motivation

The goal of numerical weather prediction (NWP) is to enable better decision-making. This requires a good forecast initialization, which benefits from good observations combined with a numerical model through data assimilation. Low Earth Orbit (LEO) hyperspectral IR radiances provide high vertical resolution observations but suffer from limited horizontal and temporal resolution. The Geostationary eXtended Observations Sounder (GXS) is designed to reduce these limitations by providing higher spatiotemporal observations, allowing views between clouds, more homogeneity in cloudy scenes, and the ability to observe rapidly evolving phenomena with lower data latency. This provides new information content for NWP, including wind information from the higher temporal resolution.

Spatial coverage of IR Sounders

Observing System Simulation Experiments (OSSE)

A tool to assess sensitivities and capabilities of proposed observing systems. Includes

1) the GMAO Nature Run (7km, 30min temporal resolution),
2) the Goddard Earth Observing System (GEOS) atmospheric data assimilation system (DAS), assimilating data in hourly bins, and
3) Global observations simulated from the NR with realistic errors added to statistically resemble operational system.

Updated experiments from McGrath-Spangler et al. (2022) using 2020 observing system, updated DAS, and extended to September to capture tropical cyclones in the Nature Run.

Geostationary IR Observations

In addition to a baseline of the operationally assimilated observing system in the control, 4 identical geostationary IR sounders were assimilated at the locations of GXS, MTG, GIIRS, and Himawari. MTG-S was used as the baseline instrument with a spectral range of 650 – 2500 cm-1 yielding 4km spatial resolution and an hourly “full-disk” scan.

Geostationary IR Sounders

Results

Assimilation of geostationary hyperspectral IR sounders reduces root mean square error of key atmospheric variables in the analysis, primarily in the tropics. Improvements in the wind estimates are partially due to the observations directly, but also due to the complex interactions within the DAS and high temporal observations of water vapor and temperature that provide information on the wind through their advection, meaning that geostationary IR sounders can provide novel information to the system. This results in improved initial conditions for the forecasts that translate to statistically significant improvements on the scale of several days. Over CONUS, the forecast sensitivity observation impact (FSOI) metric, calculated over the 4 synoptic times, shows that GXS has the largest impact on the 24 h forecast error. In addition to large-scale improvements, GXS can provide information necessary to reduce hurricane track errors.

Specific Humidity
Temperature
Zonal Wind
Specific Humidity
CONUS FSOI
Forecast Track Error
Temperature
Zonal Wind
Specific Humidity
TPW

Summary

Assimilation of geostationary IR sounders can improve global NWP analysis and forecast estimates of large-scale weather variables. The novel, high spatiotemporal observations inform initialization of hurricane forecasts and may lead to improvements in their estimation. Over CONUS, GXS has the largest impact on 24-h forecast error. These advancements have a role to play in enabling better decision-making.

Acknowledgments and References

The authors thank NASA's NCCS program and Ron Errico for developing the baseline OSSE system. Funding was provided by the NOAA and NASA GeoXO program.

McGrath-Spangler, E. L., McCarty, W., Privé, N. C., Moradi, I., Karpowicz, B. M., & McCorkel, J. (2022). Using OSSEs to Evaluate the Impacts of Geostationary Infrared Sounders, *Journal of Atmospheric and Oceanic Technology*, 39(12), 1903-1918. doi: 10.1175/JTECH-D-22-0033.1

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