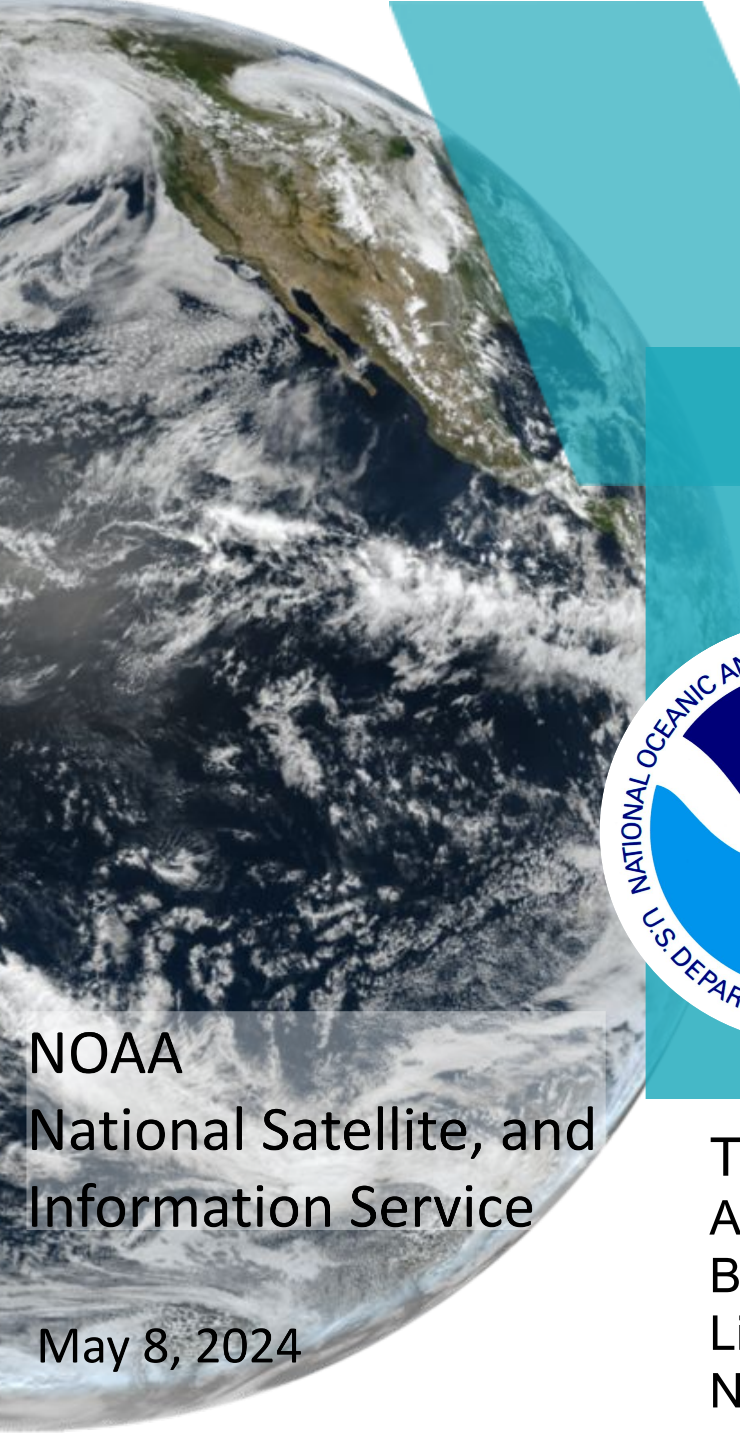
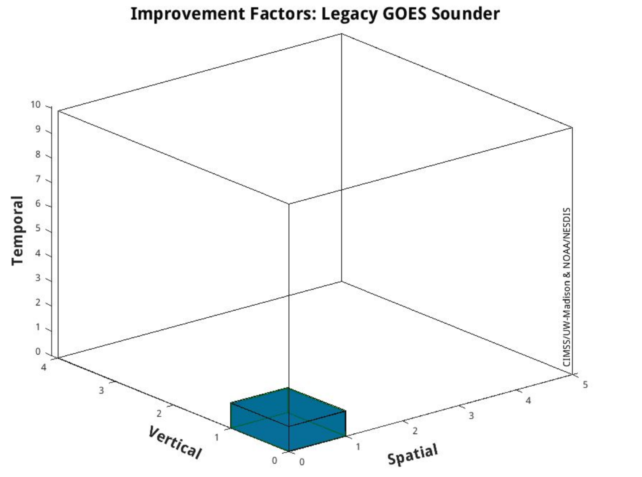




GeoXO's Sounder (GXS): An Introduction

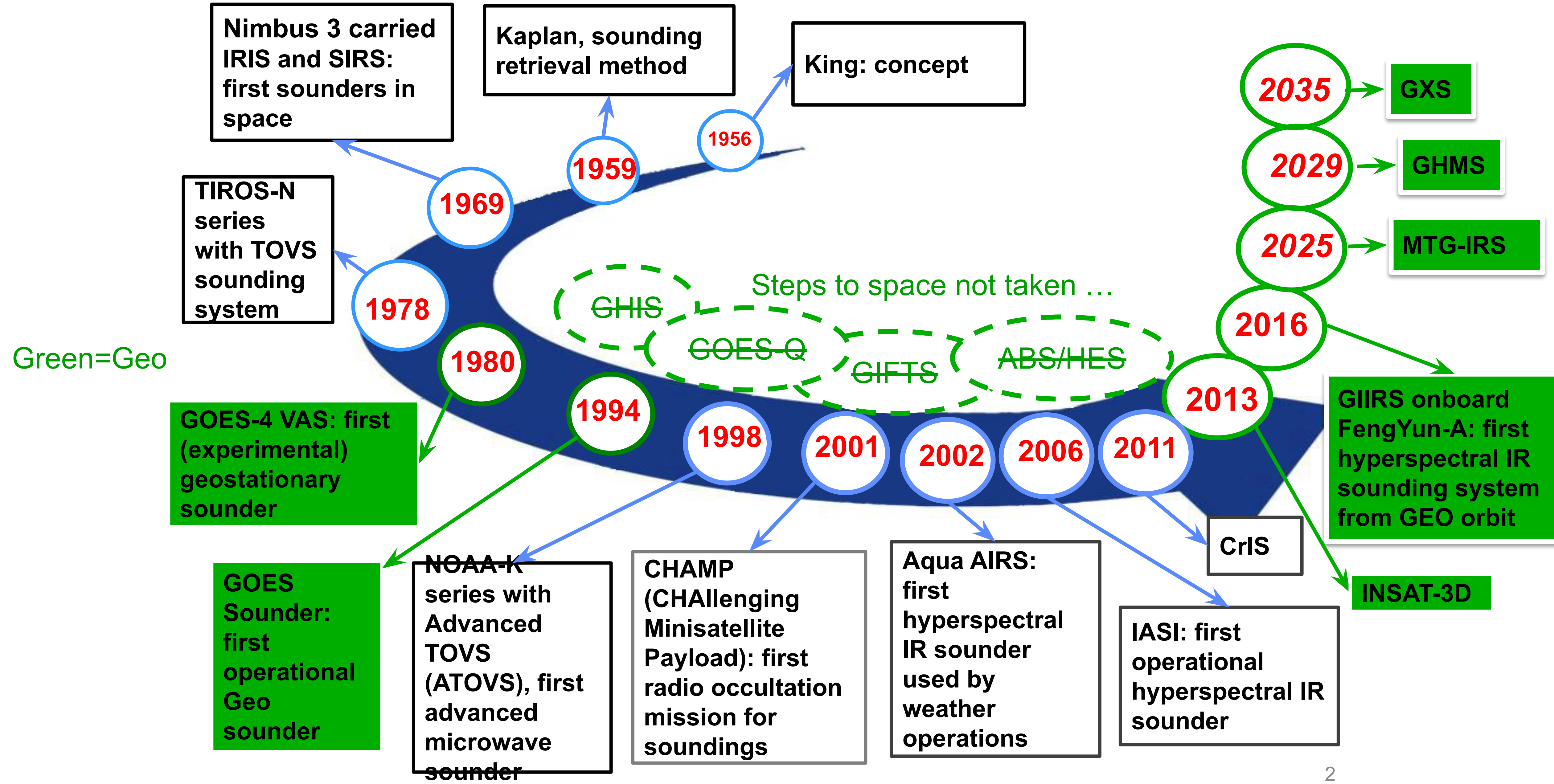
ACX Workshop

Timothy J. Schmit, NOAA/NESDIS/STAR
And many, many others (Frank Alsheimer, Zhenglong Li, Andrew Heidinger, Brad Pierce, Mat Gunshor, Yong Chen, Dave Johnson, Dave Tobin, Scott Lindstrom, Jinglong Li, Pam Sullivan, Michelle Smith, NASA GMAO, Jim Nelson, Allen Huang, etc.)

NOAA
National Satellite, and Information Service

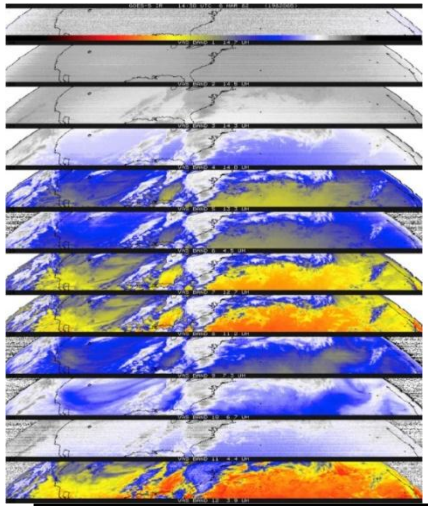
May 8, 2024

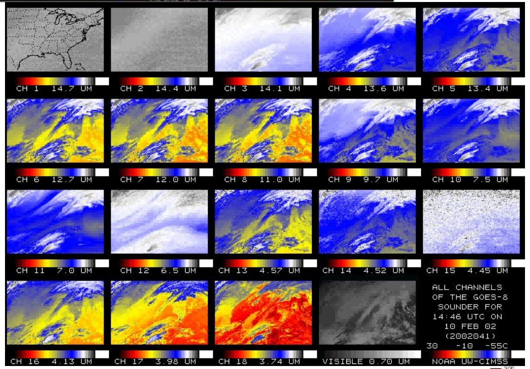
A (short) history of atmospheric sounding from space



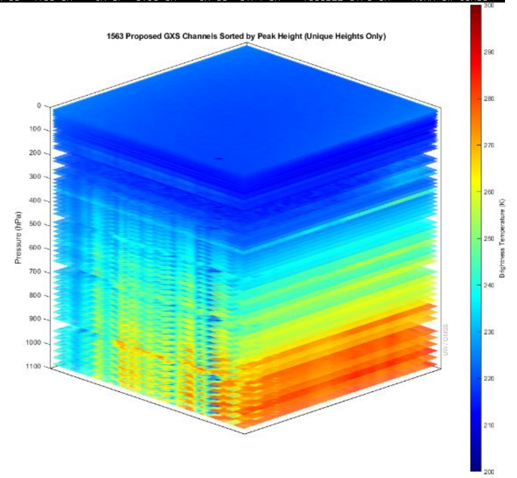
U.S. Geostationary Sounders

Item	# IR bands	Sounding
1st Experimental	12	GOES-4 VAS (1980)
1st Operational	18	GOES-8 (1994)
100x improved	~2500	GXS: High-spectral IR (*2035*)





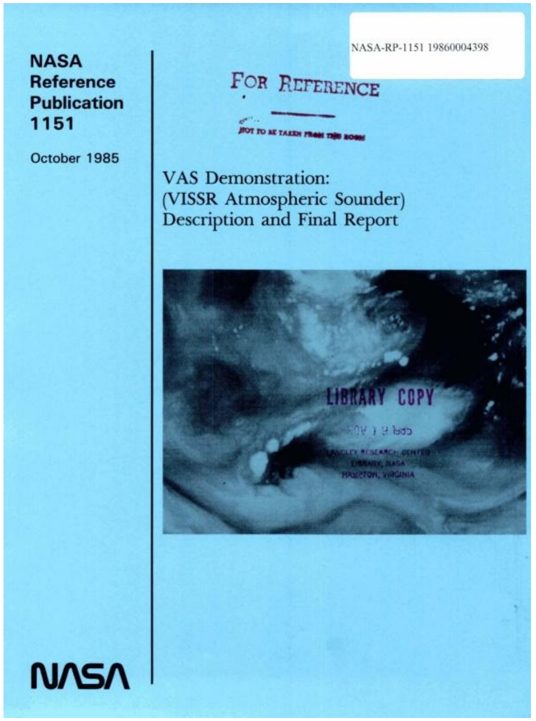
NASA's GIFTS (2000) was built and ground-tested and shown to provide high quality high resolution spectra, but was not able to get space borne.



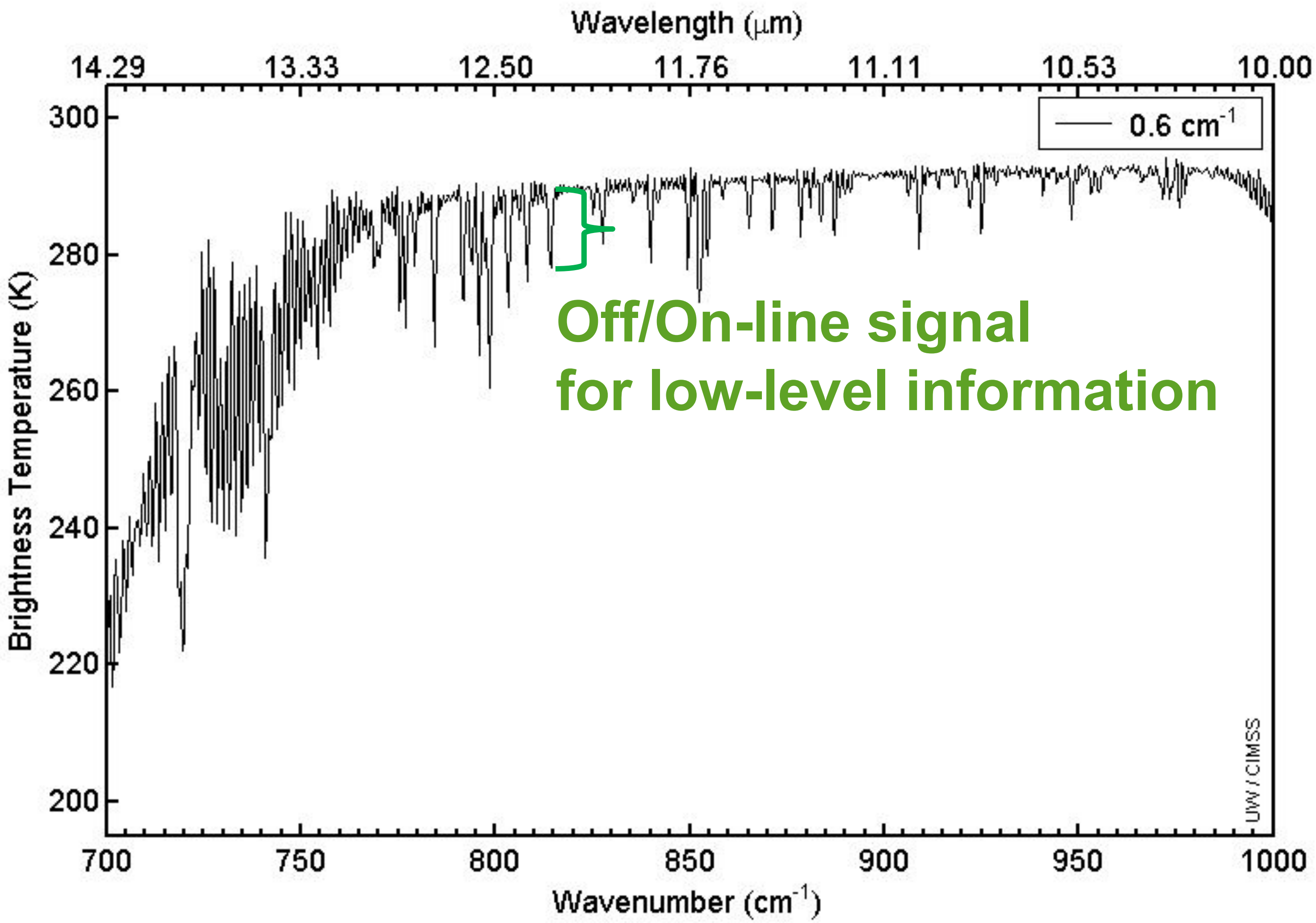
The GOES-R series included advanced imagers, the first geostationary lightning mapper and space weather instruments.

GeoXO GXS Outline

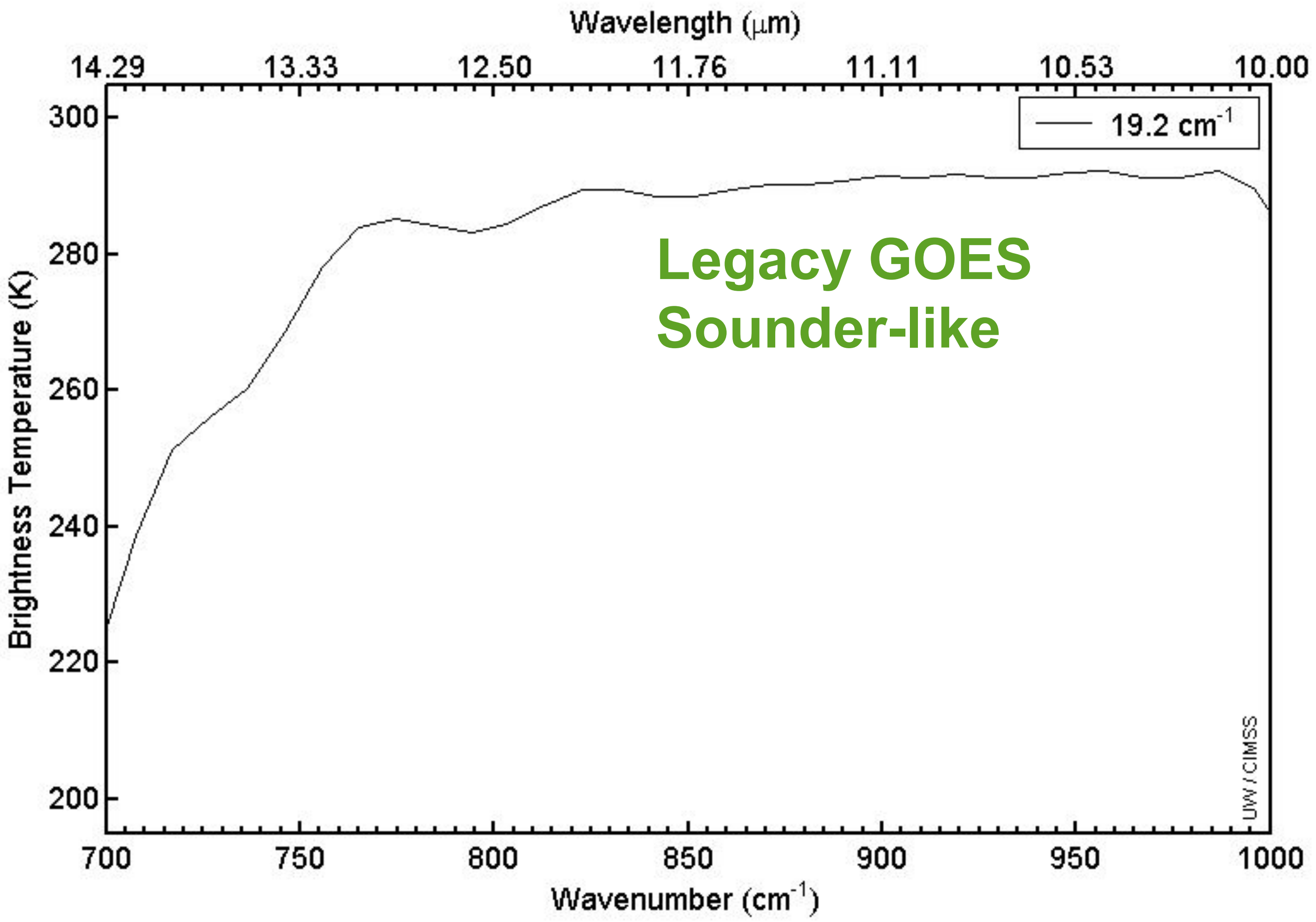
- History
- Where
- What
- Why
  - NWP
  - Nowcasting
  - Trace gases, etc.
- Conclusions
- Resources



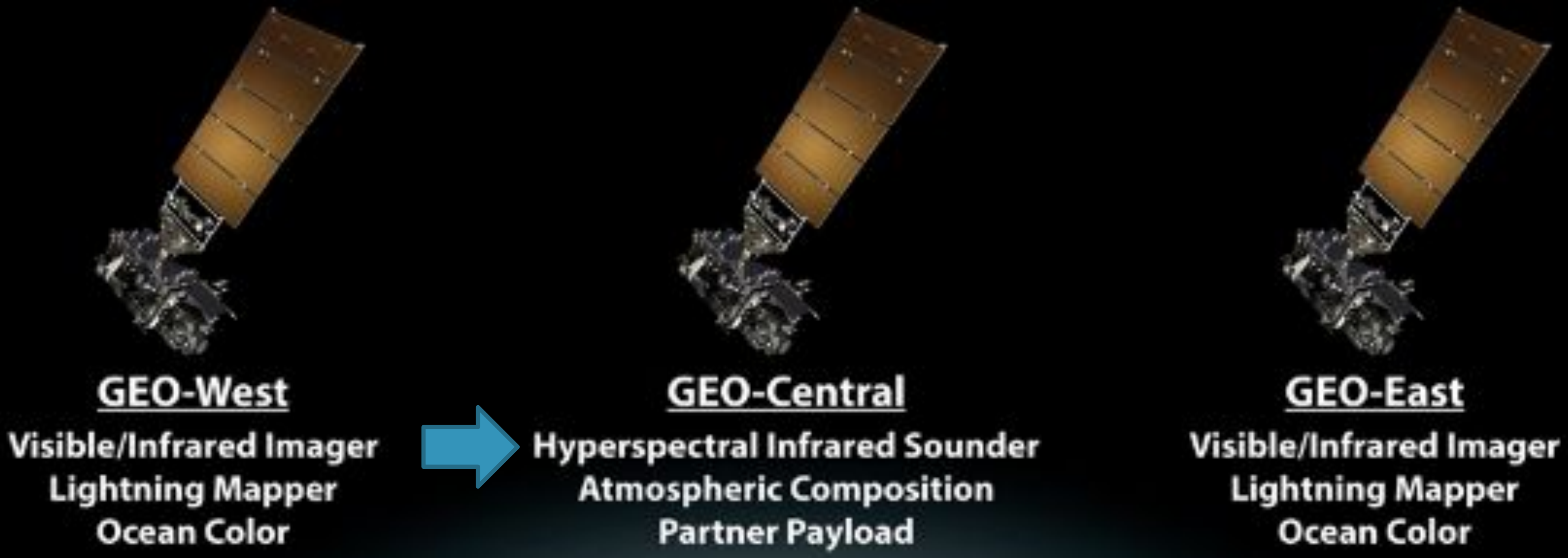
"What about the future? These [VAS Demonstration: Description and Final Report] results are the foundation for future satellites. The VAS [GOES-4] experience suggests that …, and **increased spectral resolution in the infrared region**, **are essential** so that we can obtain soundings … with **improved vertical resolution**. **Geostationary** … **are feasible and would be highly useful**."
(Forward by Verner E. Suomi, **1985**)
[Bolding added]



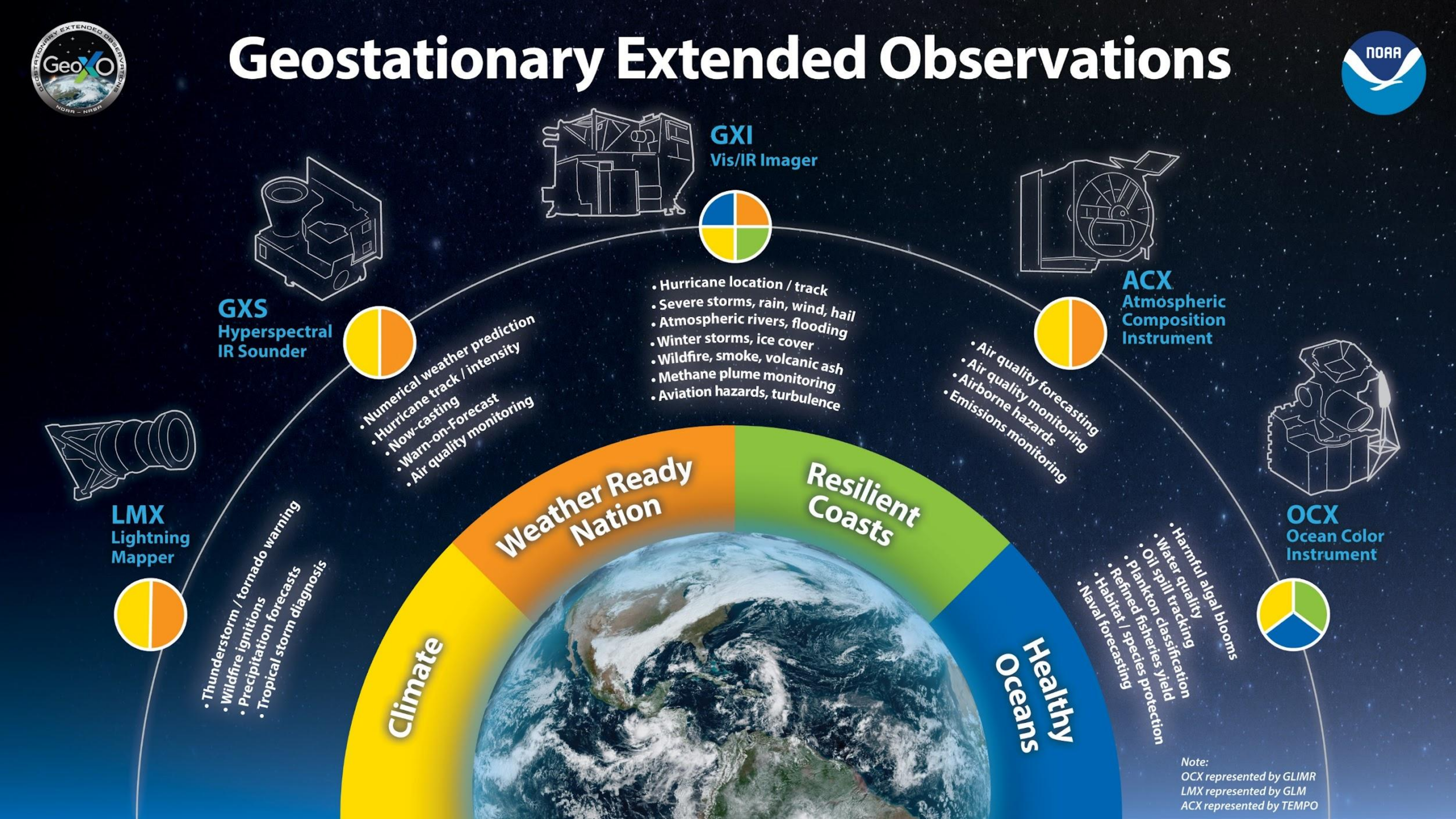
Longwave window region



Longwave window region

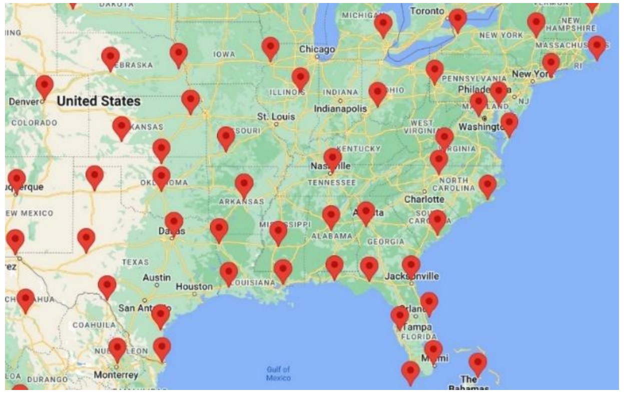


September 2023: NASA selected Ball Aerospace & Technologies Corporation of Boulder, Colorado (now BAE Systems), to develop NOAA's GeoXO Sounder.


Geostationary Extended Observations
GXI
Vis/IR Imager
• Hurricane location / track
• Severe storms, rain, wind, hail
• Atmospheric rivers, flooding
• Winter storms, ice cover
• Wildfire, smoke, volcanic ash
• Methane plume monitoring
• Aviation hazards, turbulence
GXS
Hyperspectral IR Sounder
• Numerical weather prediction
• Hurricane track / intensity
• Now-casting
• Warn-on-Forecast
• Air quality monitoring
ACX
Atmospheric Composition Instrument
• Air quality forecasting
• Air quality monitoring
• Airborne hazards
• Emissions monitoring
LMX
Lightning Mapper
• Thunderstorm / tornado warning
• Wildfire ignitions
• Precipitation forecasts
• Tropical storm diagnosis
OCX
Ocean Color Instrument
• Harmful algal blooms
• Water quality
• Oil spill tracking
• Plankton classification
• Refined fisheries yield
• Habitat / species protection
• Naval forecasting
Climate
Weather Ready Nation
Resilient Coasts
Healthy Oceans
Note:
OCX represented by GLIMR
LMX represented by GLM
ACX represented by TEMPO

Vertical Moisture Information

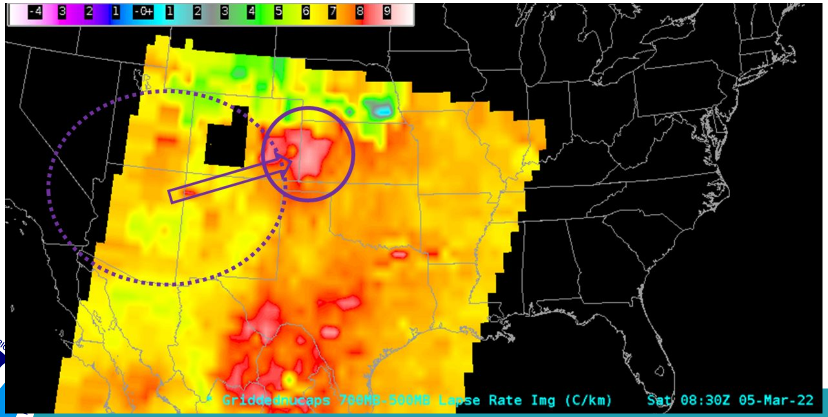
Radiosondes
(2x/day),
scattered (mostly) land locations - used for validations and NWP

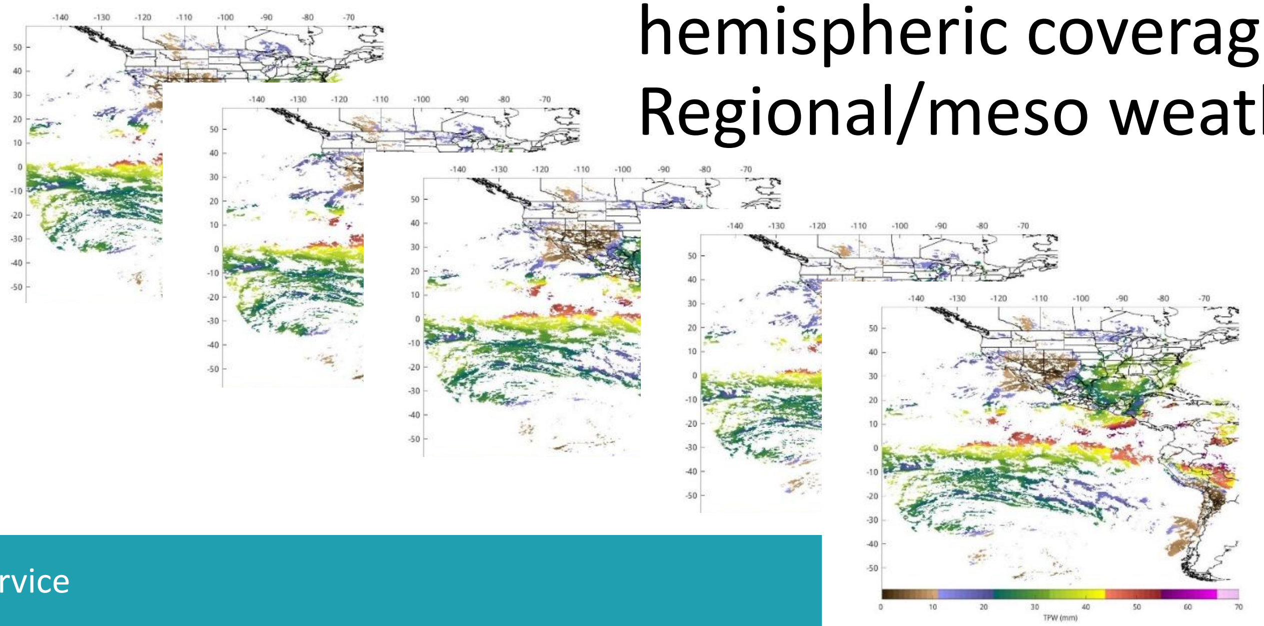


Select Aircraft
Mostly daytime
Airports only

GeoXO Sounder
(at least 30 min), land and ocean, ~4km, hemispheric coverage
Regional/meso weather

LEO passes
(several/day over CONUS), land and ocean, ~14-40km, global NWP

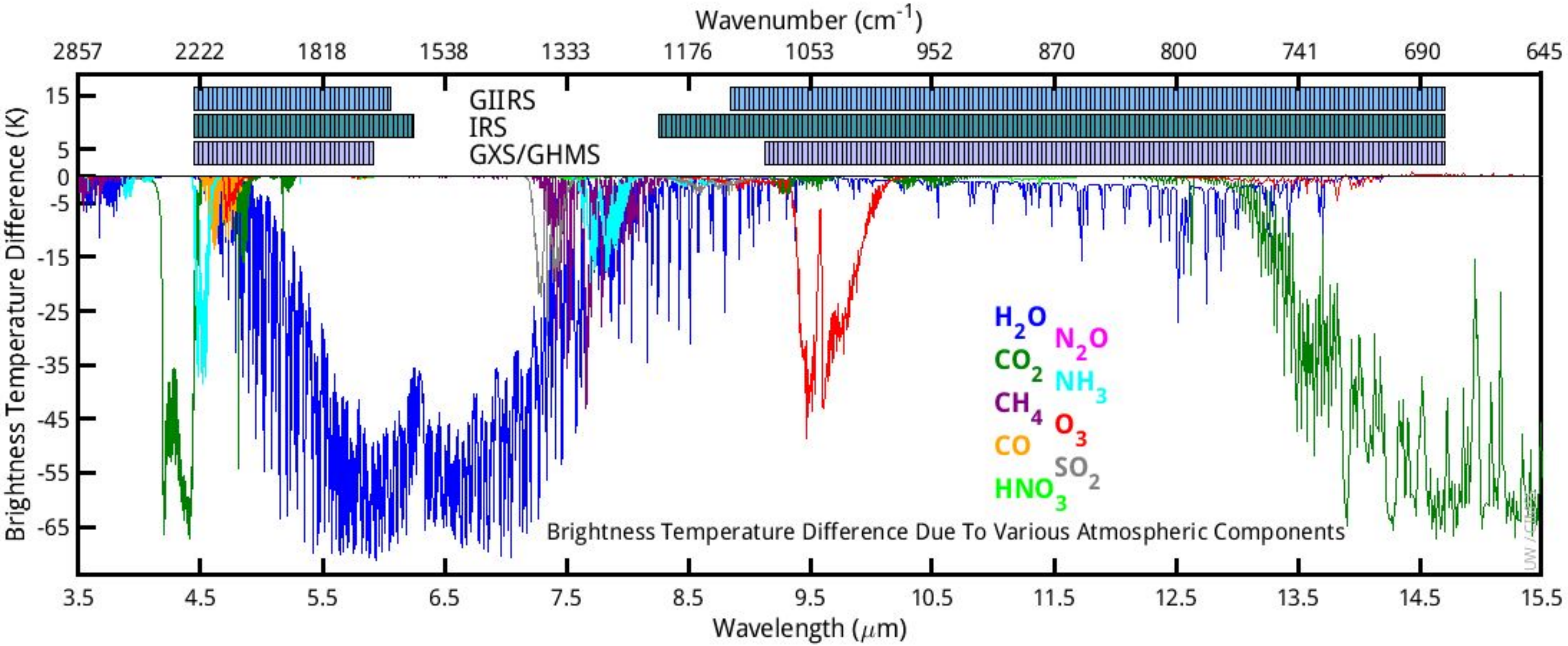




GeoXO Sounder : Summary (What and Why)

Attribute	What	Why
Coverage	Ideally: Sounding Disk as seen from both GOES-East and –West positions; Central satellite position currently planned	The Atlantic for **hurricane development** and **model initializations**, CONUS for the **pre-convective environment monitoring** and the Pacific for both **upstream weather and monitoring moisture (and winds)** over the huge area with little conventional data.
Spatial Resolution	**4 km** (at the satellite subpoint)	**Doubling the clear-sky yields, compared to LEO, for a given time.** Finer moisture gradients to be monitored.
Temporal Resolution	Sounding Disk (30 min) or NH (20 min) + SH (40 min) + Mesoscale (TBD min) (TBD)	Sounding Disk upstream information and hurricane monitoring (**improved track and intensity**), CONUS for pre-convective monitoring and the targeted for regions of extremely active weather. Allows for clouds to move out and obtain more clear sky information.
Spectral Coverage / Resolution	(680 - 1095 cm^{-1} 14.7 – 9.13 µm 1689 – 2250 cm^{-1} 5.92 – 4.44 µm) @ ~0.6 cm-1	Spectral with information related to **temperature, moisture** and support select atmospheric compositions (ozone, NH3, isoprene, HNO3, N20 and CO). Need to resolve, not average out, the critical on/off spectral lines.
Other	**Evolution of the radiances**	Provides critical vertical information on **atmospheric winds** for both nowcasting and NWP applications.

Geo Advanced Sounder-Ring: Spectral



Line-by-Line with various gases completely removed

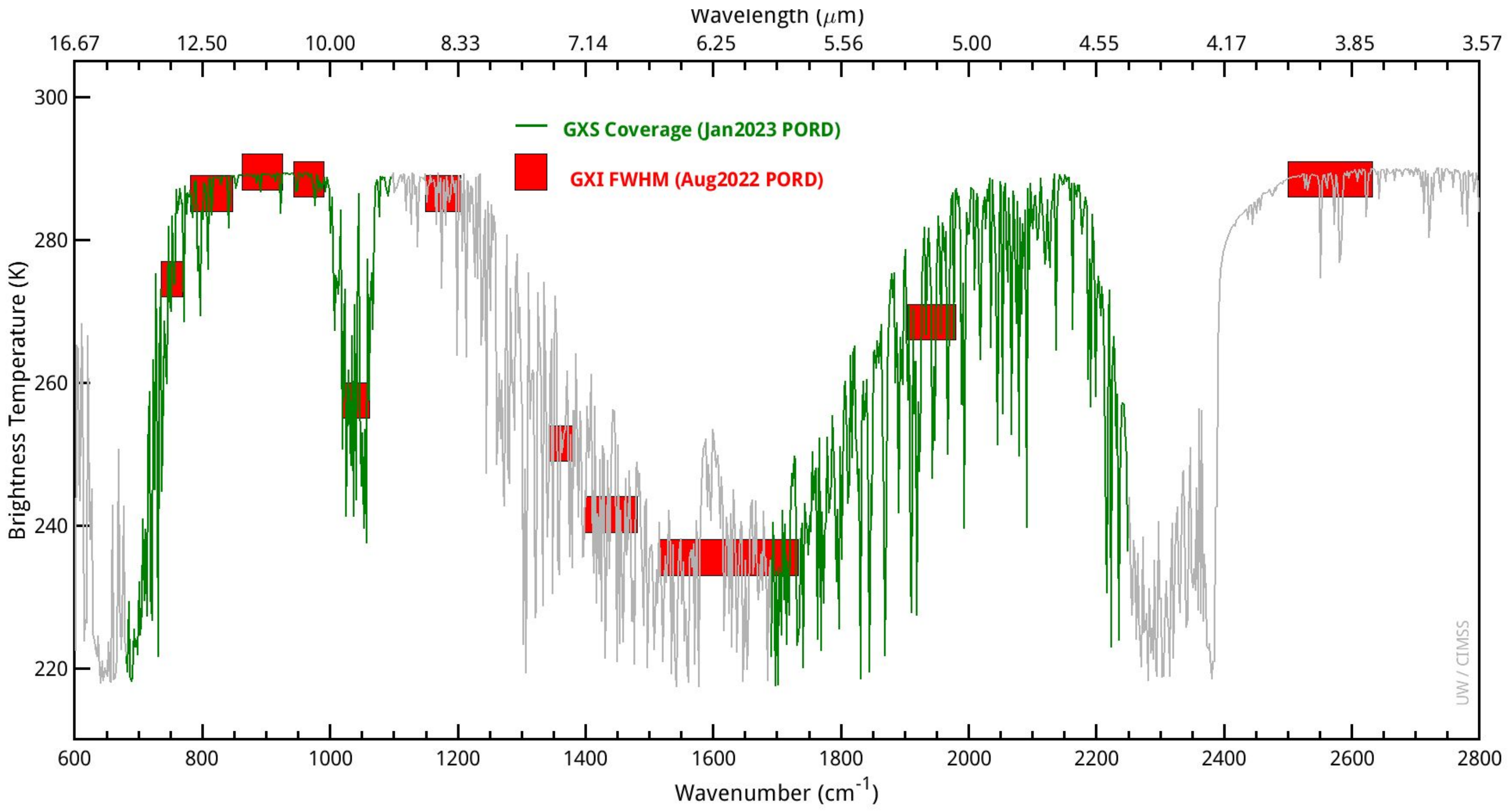
Sounding Spectral Range Table

Band	Wavenumber (cm^{-1})	Wavelength (μm)
LWIR region (temperature, LWIR window, ozone, NH3, isoprene, HNO3, low level moisture)	680- 1095	14.7 – 9.13
MWIR region (vertical moisture, window and temperature, N_20 and CO)	1689 – 2250	5.92 – 4.44μm

Spectral

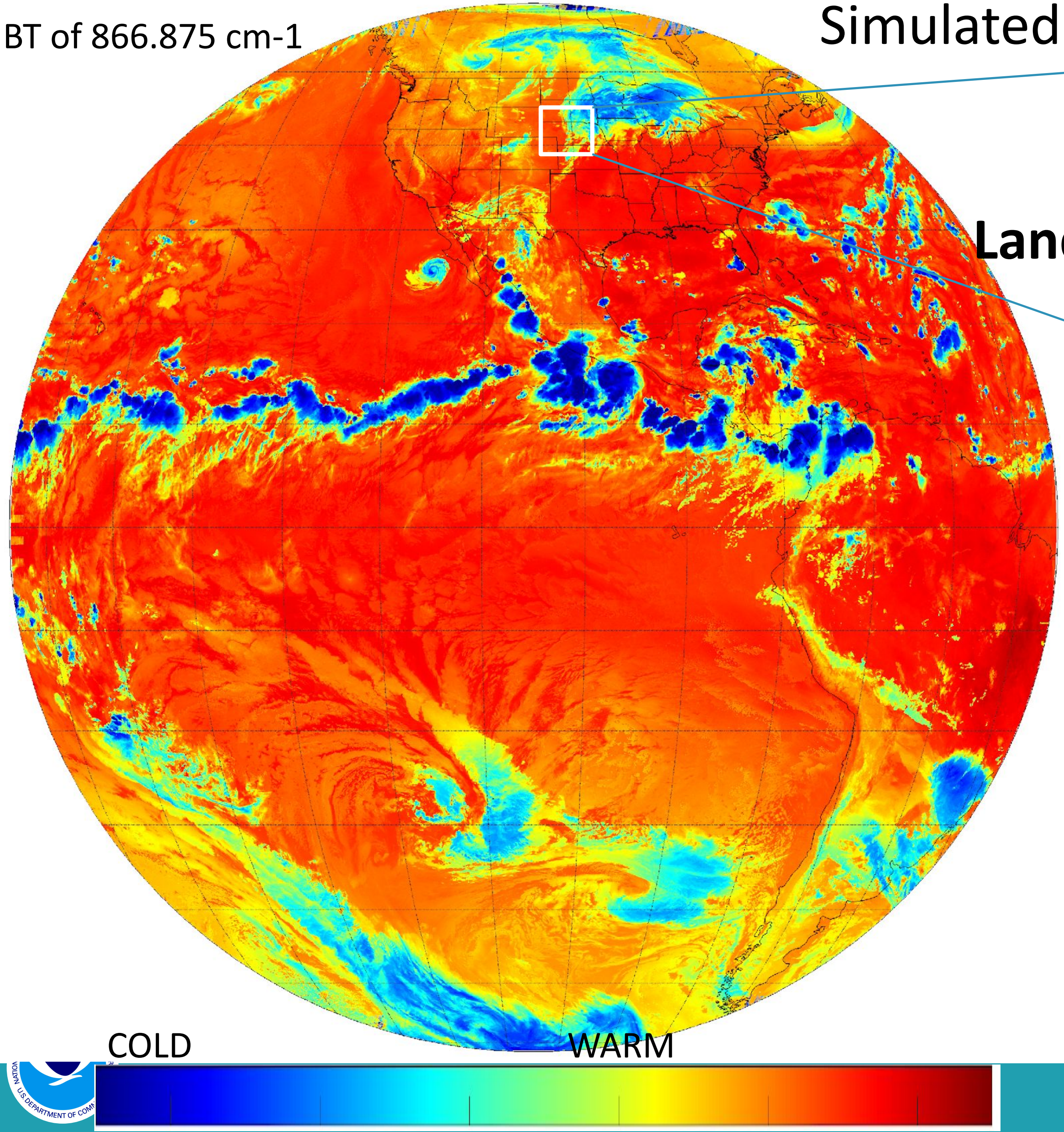
Maximum Width for Sounding Channels Table

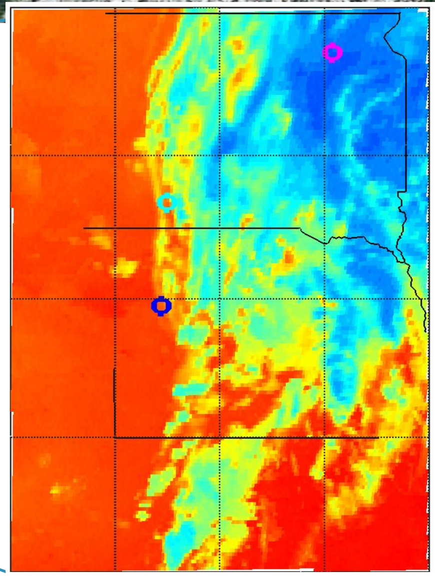
Spectral Range	Wavenumber (cm^{-1})
680- 1095 (cm^{-1}) 14.7 – 9.13 (μm)	0.625
1689 – 2250 (cm^{-1}) 5.92 – 4.44 (μm)	0.625



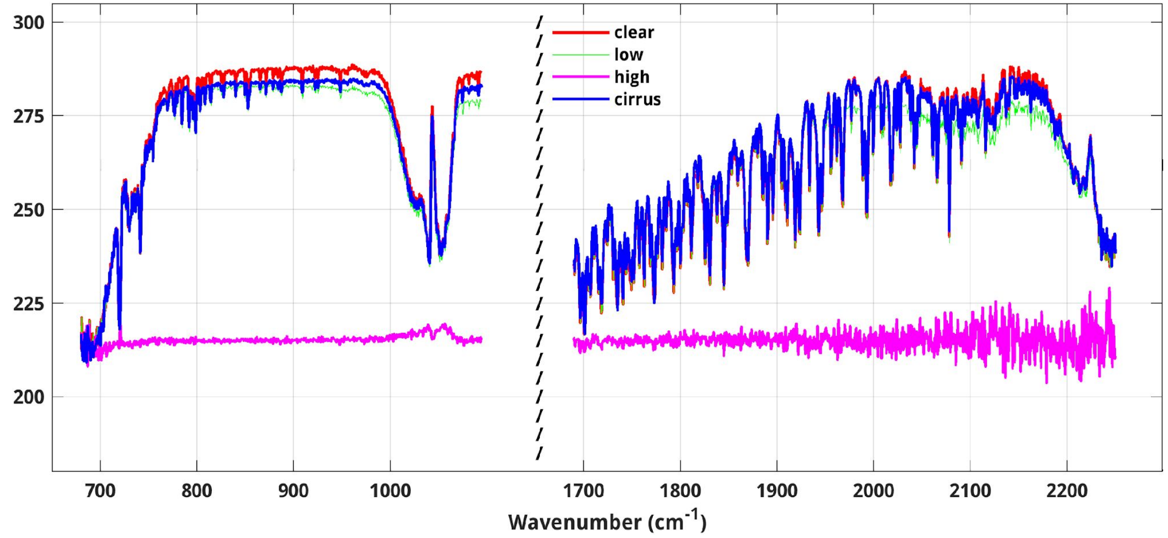
Simulated GXS Full Disk

BT of 866.875 cm-1





Land



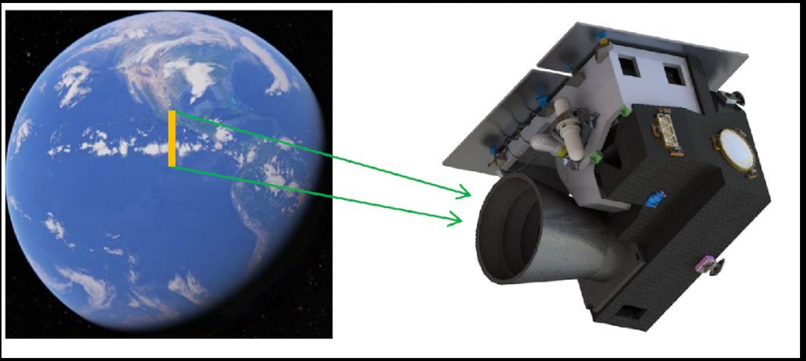
Clear **Low Clouds** **High thick clouds** **Cirrus**

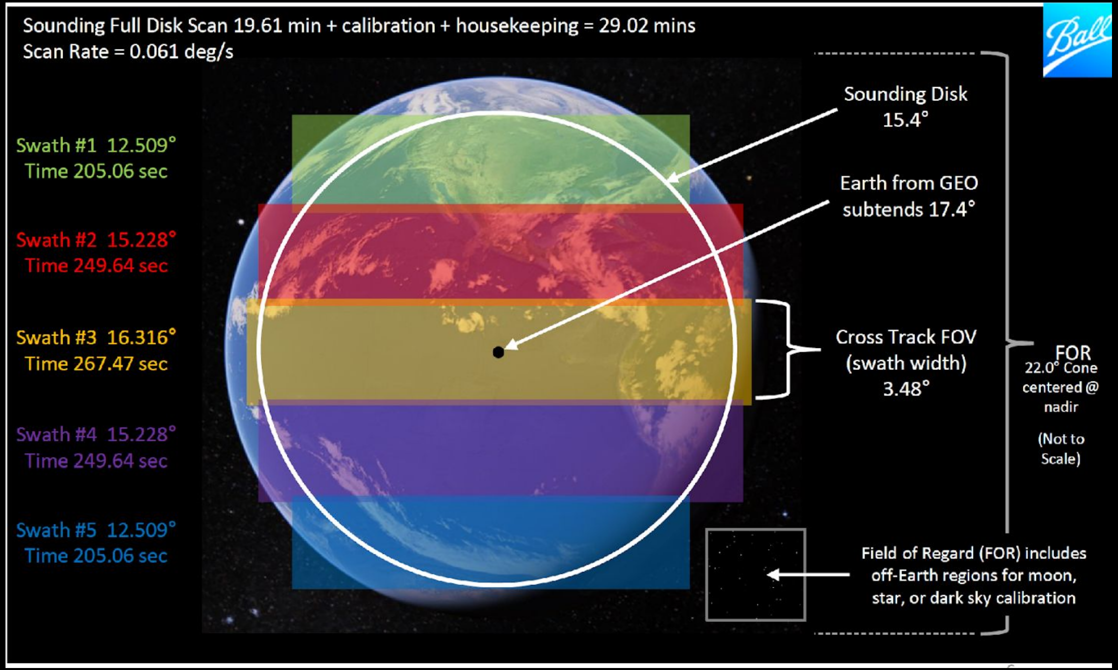
GXS Scanning

Slit oriented N/S and projected onto field of regard
• One slit image samples 3.48 deg of N/S field of view
• Scan mirror slews slit image from West to East over the scan swath
• Swaths are scanned roughly 3.7° per minute
• MWIR and LWIR bands are collected simultaneously and are coincident
1540 MWIR and 1078 LWIR spectral channels

Sounding Full Disk Scan
• Complete in 5 swaths
• Execution Time < 30 mins, including Star Senses/Space Looks, Calibration, and Housekeeping

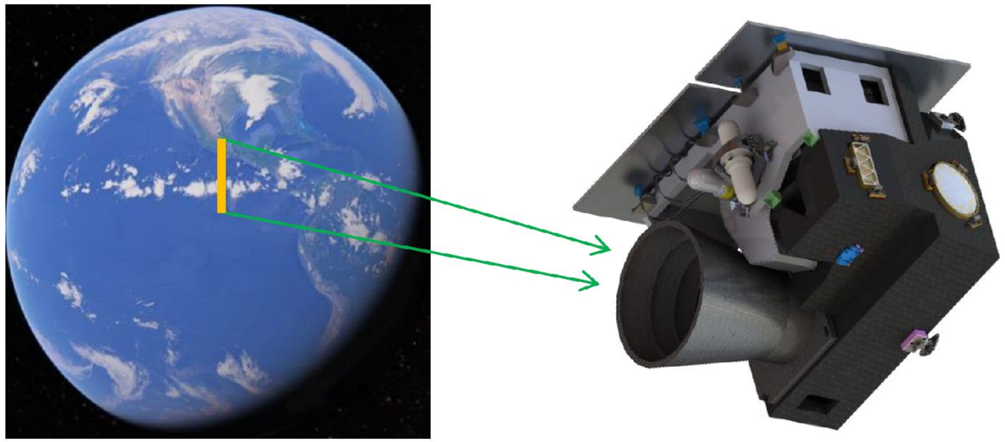
Other Scan Patterns possible, such as hourly full disk with interspersed super-regional and meso scans



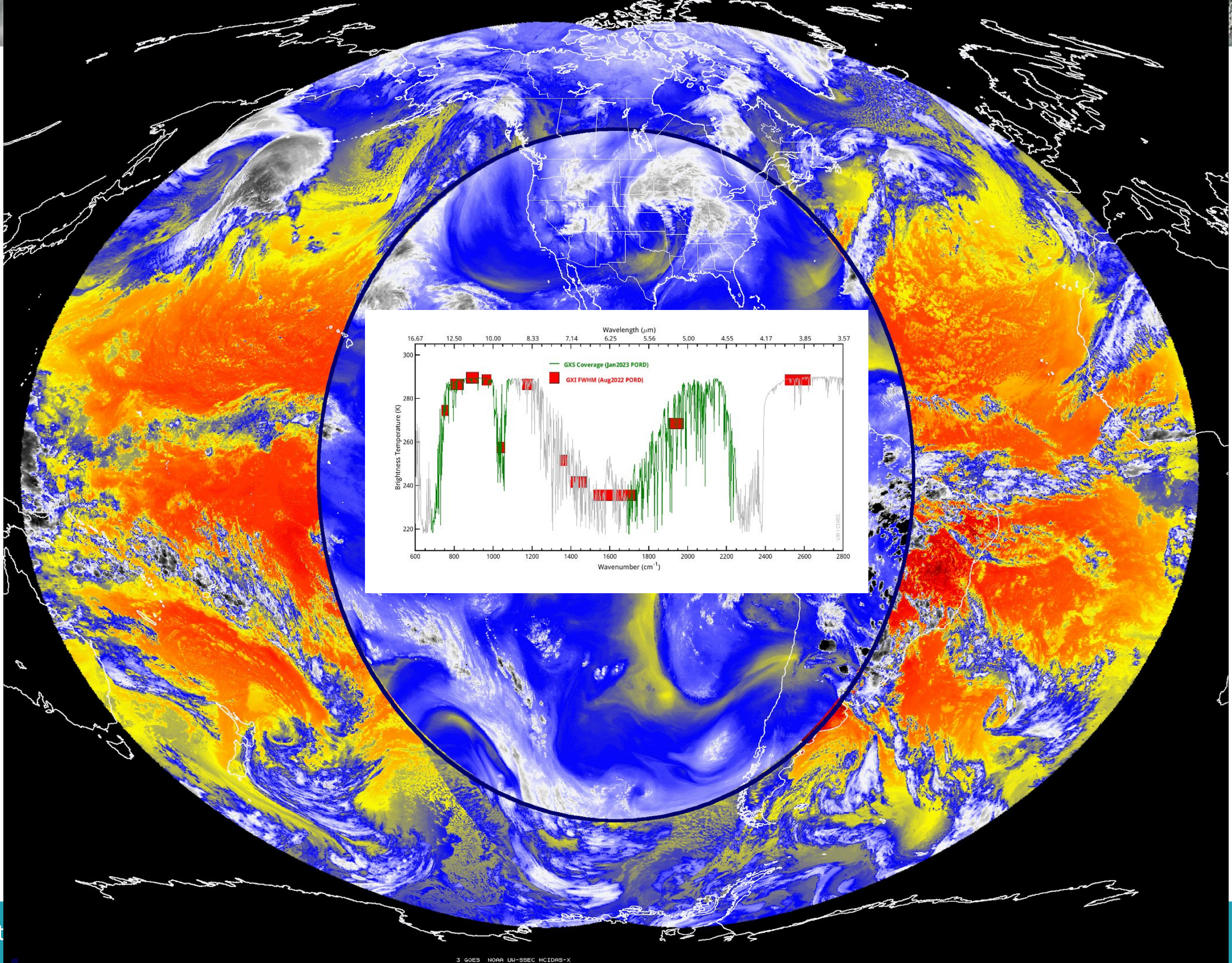


Concept of Scanning the Disk (equal swath time intervals)

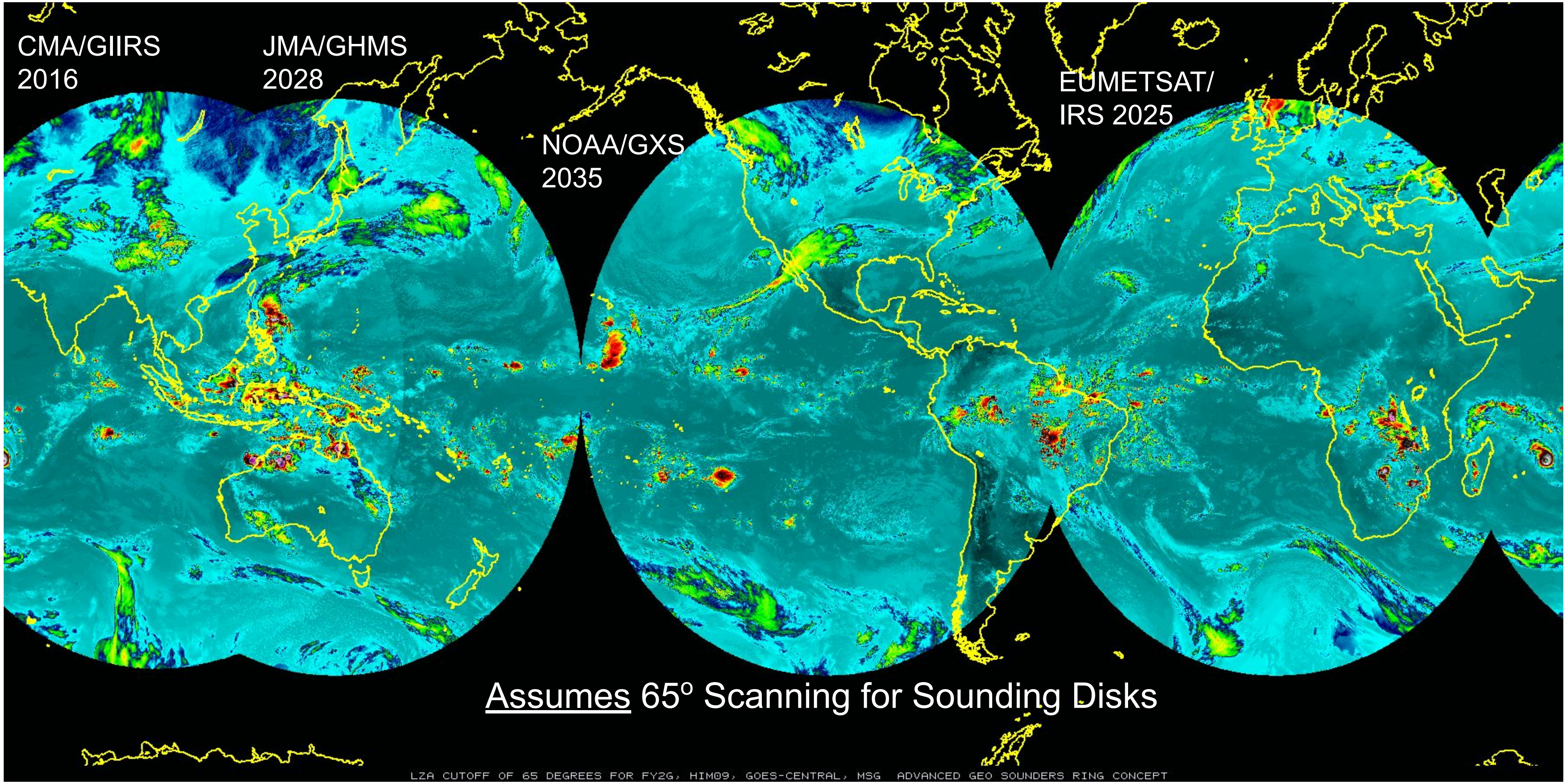
- Slit is oriented N/S and projected onto the field of regard
- One slit image samples 3.48 deg of N/S field of view
- Scan mirror slews slit image from West to East over the scan swath
- Swaths are scanned roughly 3.7 deg per minute
- Approximately 30 min to scan the disk



- Using GXS Simulated data by UW/CIMSS
- Swath overlap not simulated

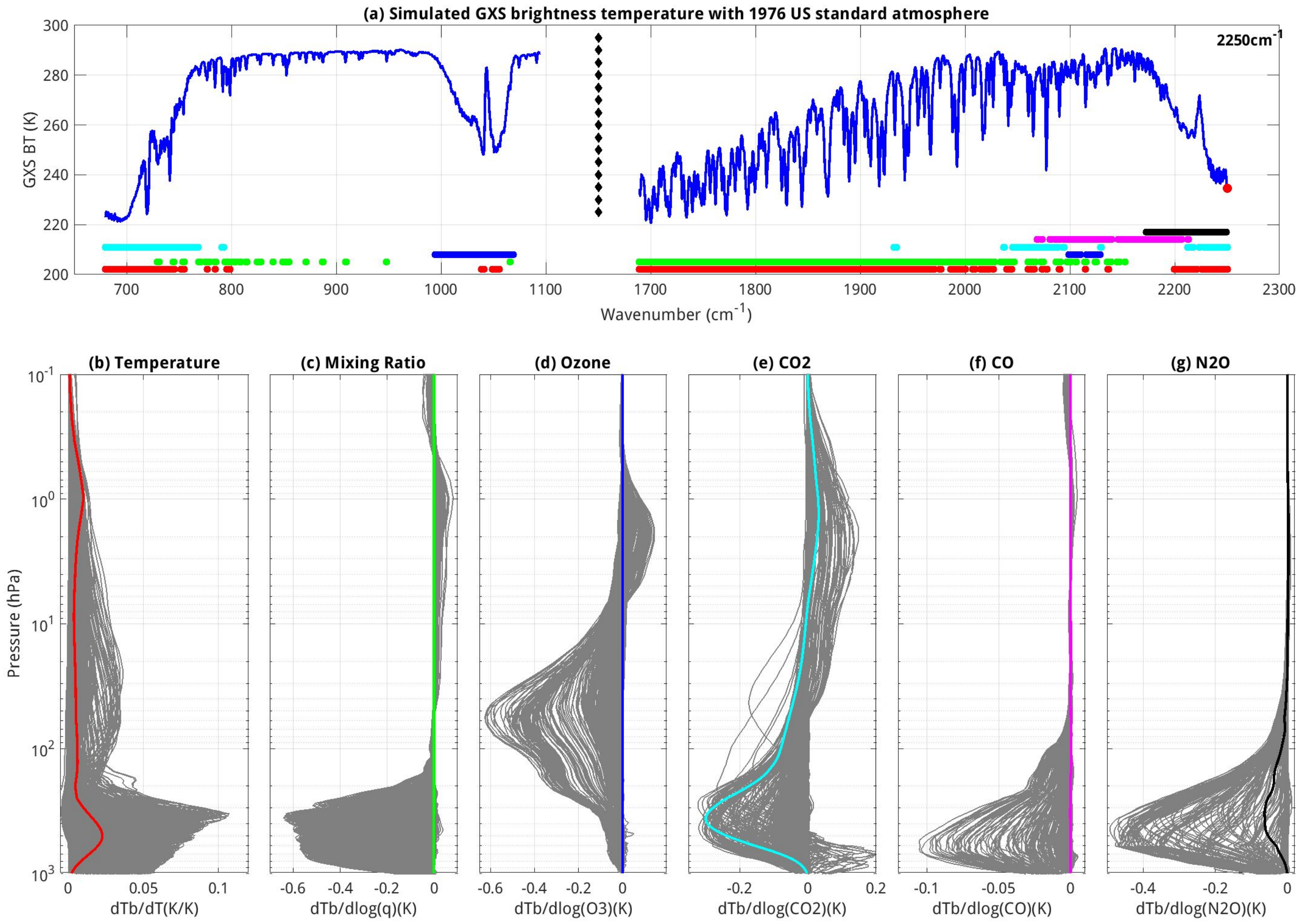

Wavelength (μm)
16.67 12.50 10.00 8.33 7.14 6.25 5.56 5.00 4.55 4.17 3.85 3.57
GXS Coverage (Jan2023 PORD)
GXI FWHM (Aug2022 PORD)
Brightness Temperature (K)
300 280 260 240 220
600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Wavenumber (cm-1)
UW / CIMSS
3 GOES NOAA UW-SSEC MCIDAS-X

Critical Component of the GEO-RING of IR Sounders



WMO WIGOS 2040 includes geostationary hyperspectral IR sounders

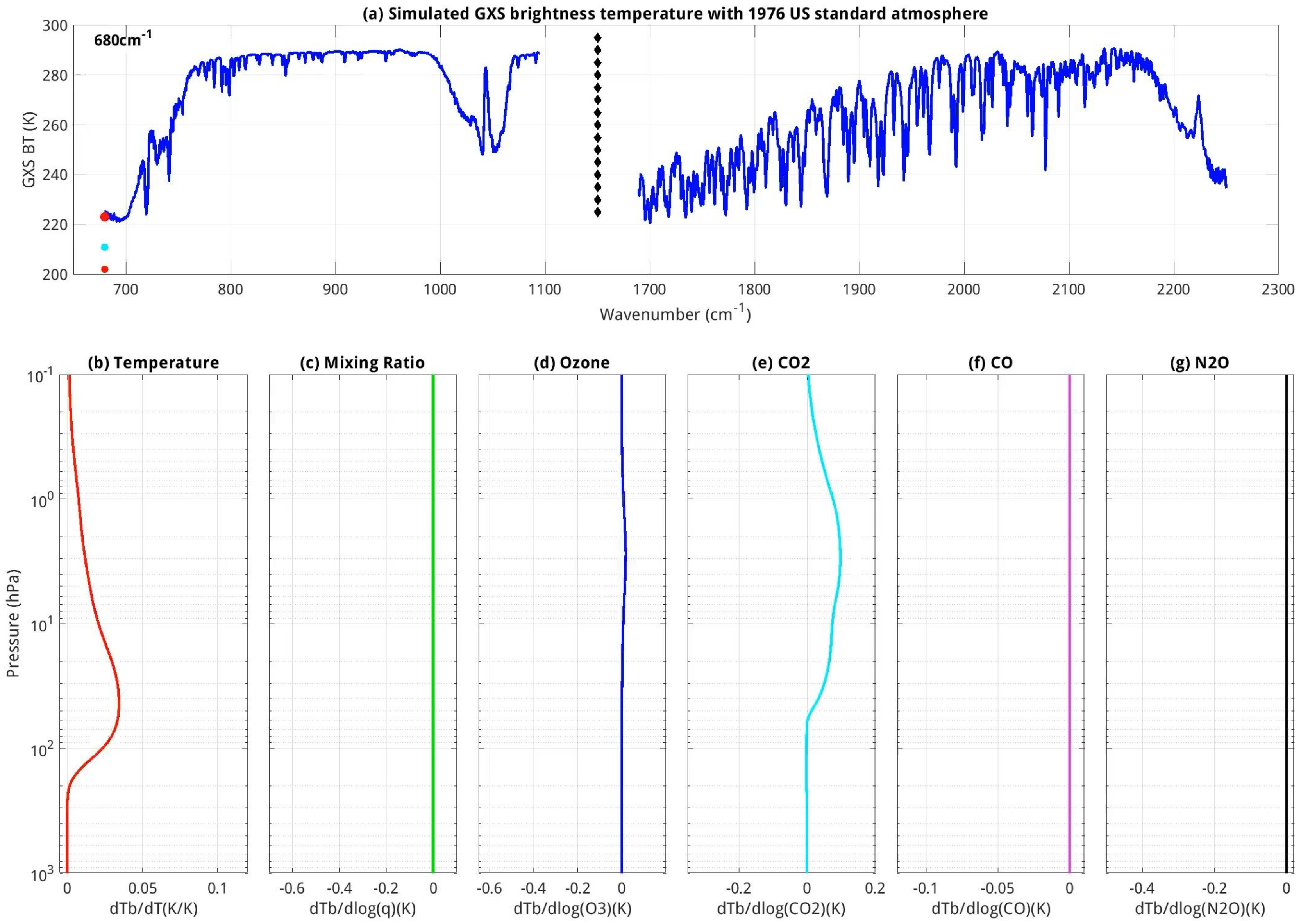
GXS provides abundant sounding information content of T/Q/gases



- 1976 US standard atmosphere
- RTTOV
- GXS: 680-1095cm^{-1}, 1689-2250cm^{-1}
- Hamming apodization

UW/SS
EC

GXS provides abundant sounding information content of T/Q/gases

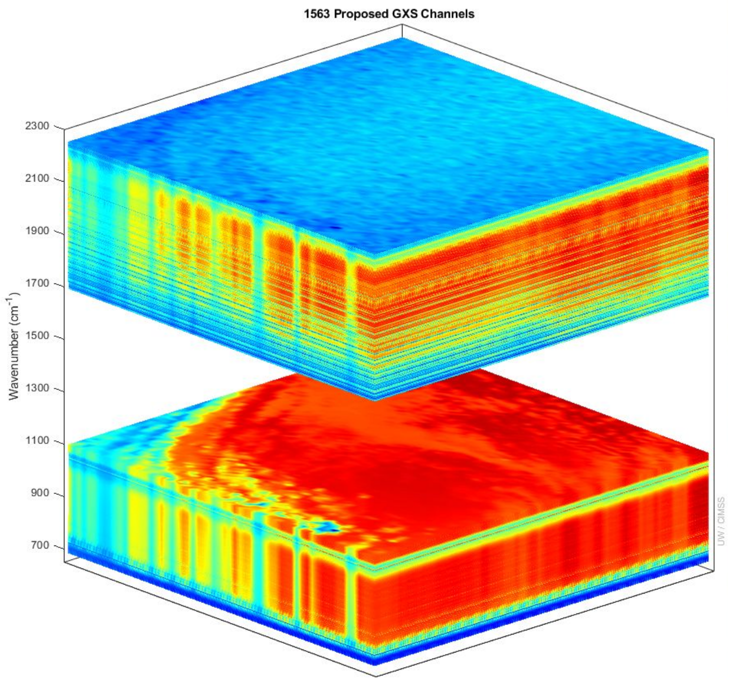


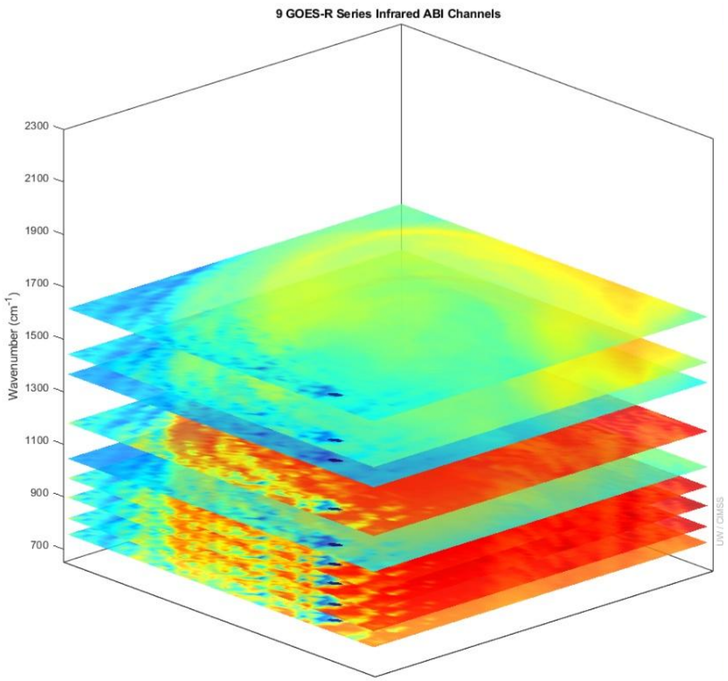
- 1976 US standard atmosphere
- RTTOV
- GXS: 680-1095cm^{-1}, 1689-2250cm^{-1}
- Hamming apodization

UW/SSEC

More spectral bands means more vertical information for temperature and moisture

GXS **ABI**





Number of Independent Pieces of Vertical Information		
Temperature	13	2
Moisture	11	2.5

IASI granule used to show the great improvement of the GXS over previous geostationary capabilities. Not shown are the improved temporal or spatial attributes of the GXS.

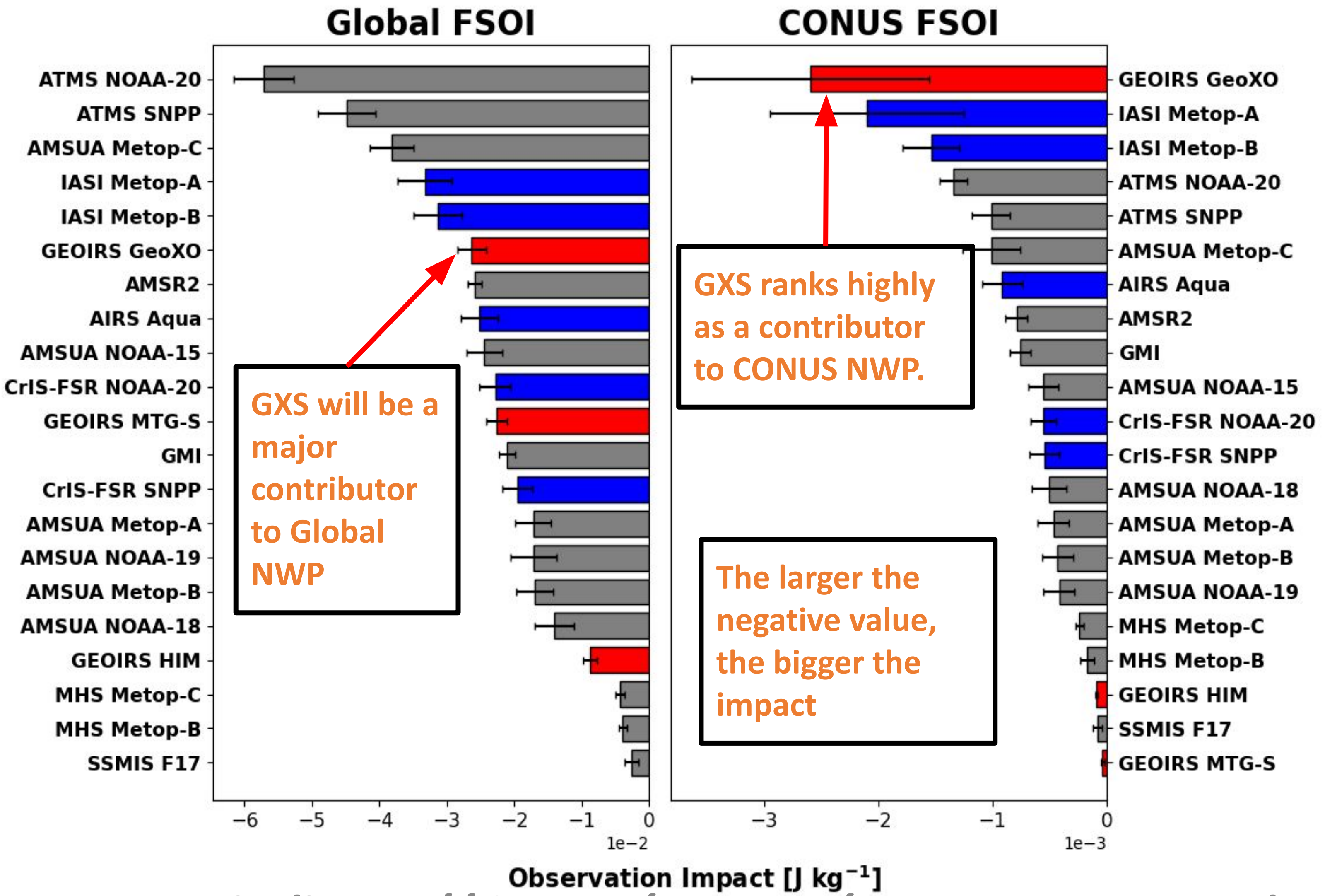
There is more than six times (temperature) and four times (moisture) of number of independent pieces of vertical information compared to the ABI.

And 4-20 times more vertical information than the GXI in thin clouds

GMAO GEOS Estimates of GXS Impact on CONUS and Global Forecasts via Simulations

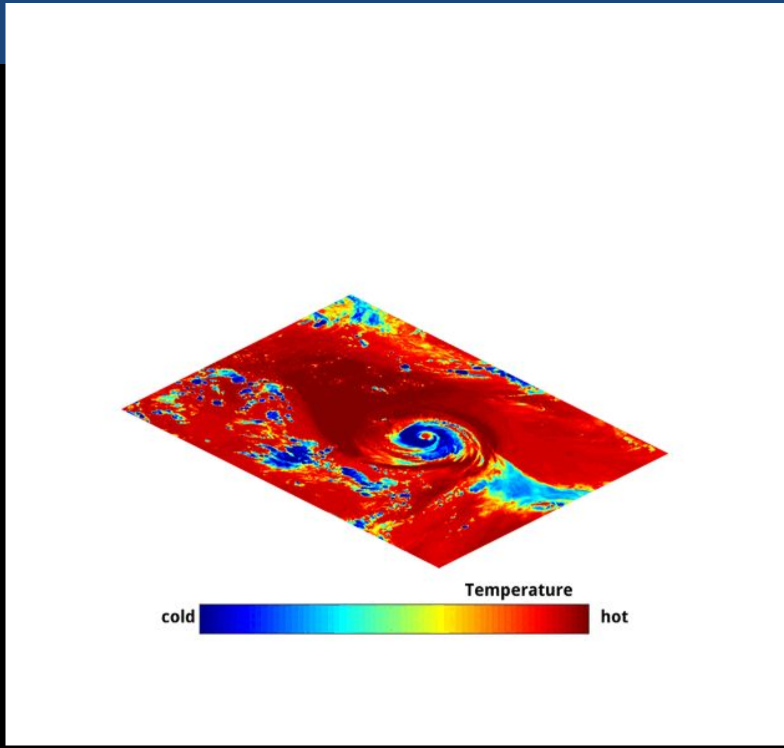
- The NASA GMAO has supported GeoXO by running Observing System Simulation Experiments (OSSEs) to study the impact of a GEO IR Sounder.
- Forecast sensitivity to observation impact (FSOI) estimates observation impacts on a 24-hour forecast of total wet energy.
- Negative FSOI indicates that the assimilation 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.

Credit: NASA GMAO



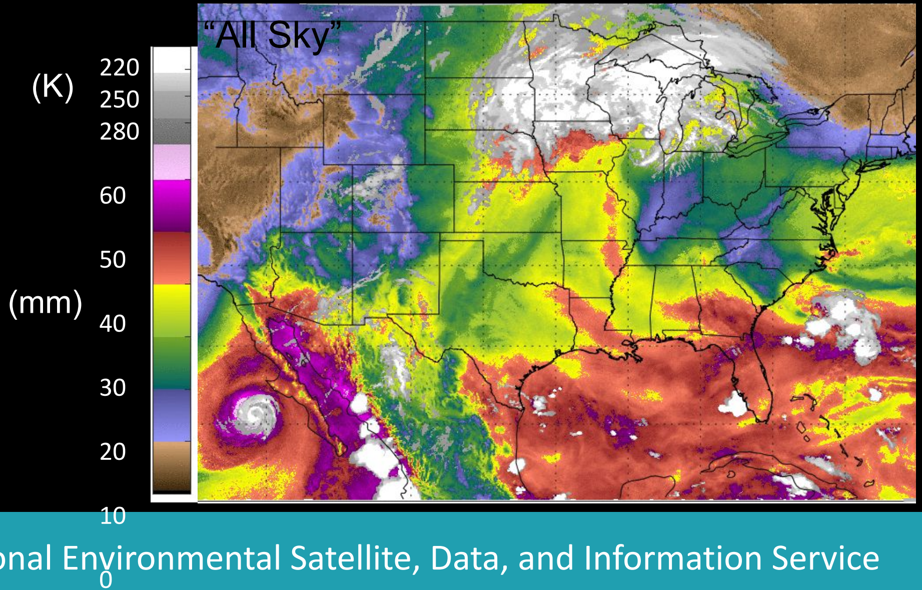
AMS J-Tech: (https://doi.org/10.1175/JTECH-D-23-0141.1)

GeoXO Hyperspectral Sounder



Temperature, Moisture, and Winds concept

Total Precipitable Water



WFO APPLICATIONS

Near-Storm Mesoscale Analysis (before and during an event; compare to model forecasts)

FACETS/T-I-M (provides nearly constant updates to users, not just one warning)

Precipitation Type (improved temperature, moisture and wind profiles)

Fire Weather/Spot Forecasts (wind surges, low-mid level RH, etc.)

Aviation Forecasts (Icing levels, convective turbulence)

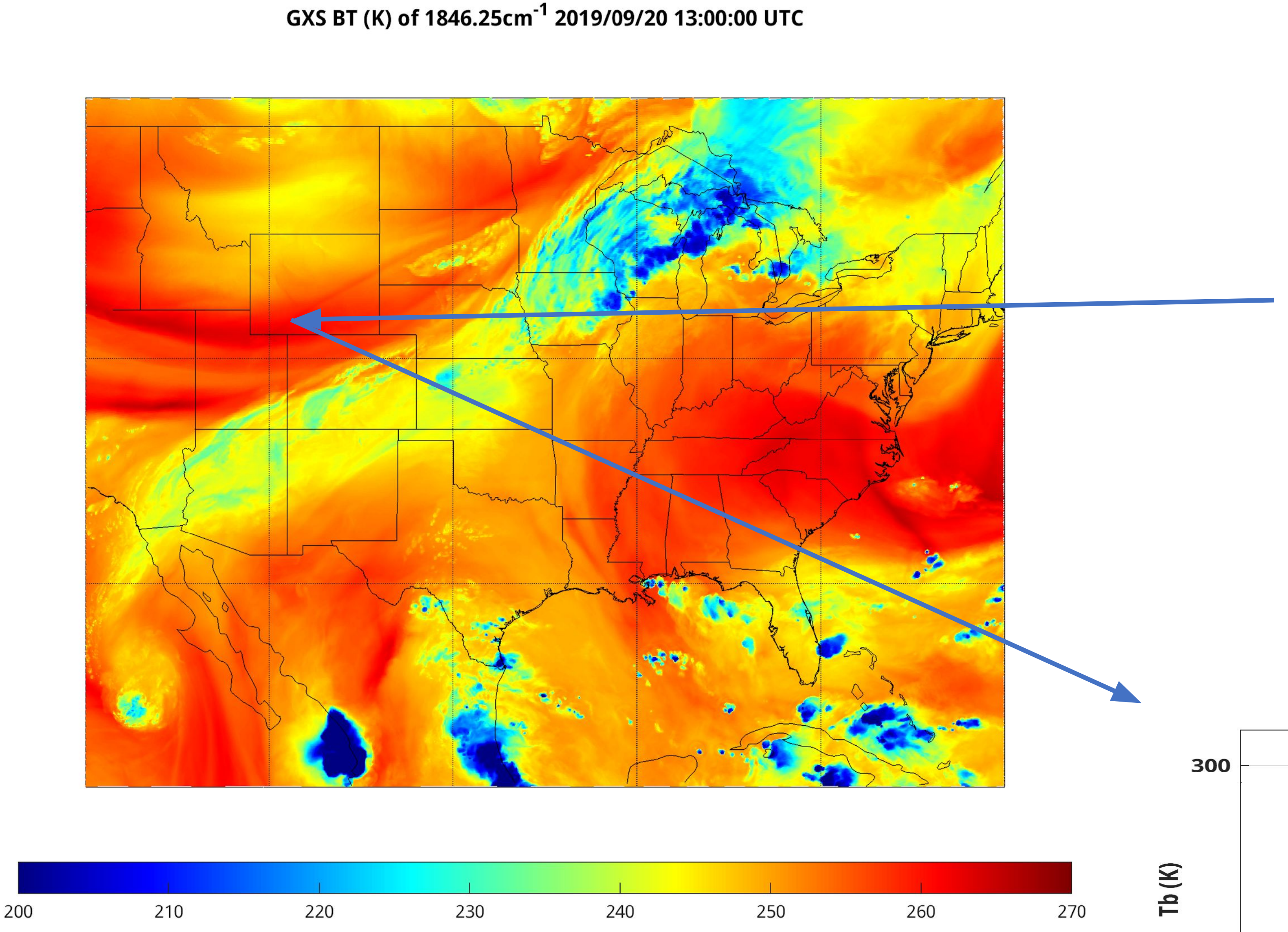
Air Quality (trace gases, ozone, diurnal trends)

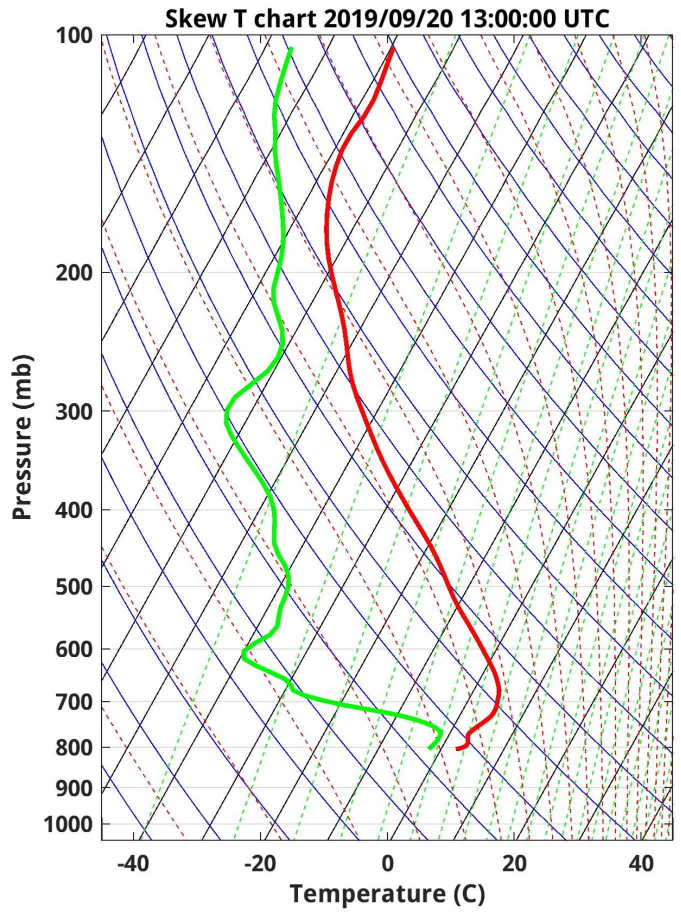
Physical Modeling (input to models, especially on the regional scale)

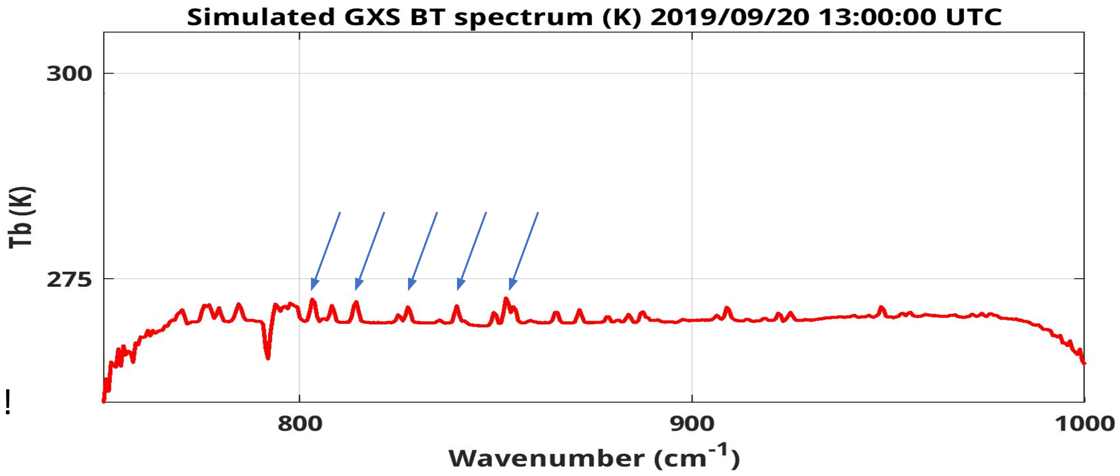
Machine Learning (great opportunity to train with GXS for many critical parameters)

Flash Floods (Moisture transport; Low-mid level boundaries)

Wyoming Temperature inversion seen by GXS

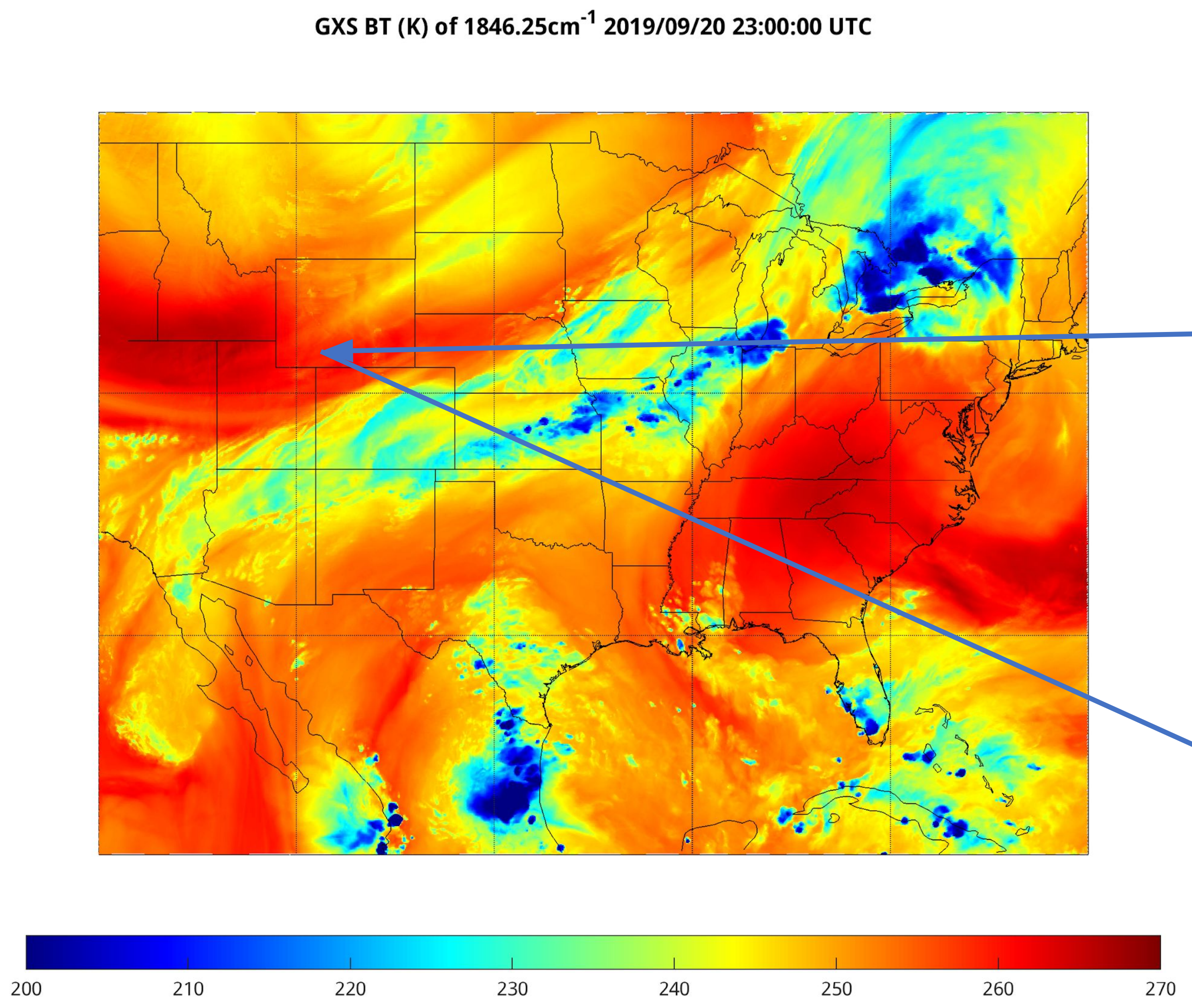


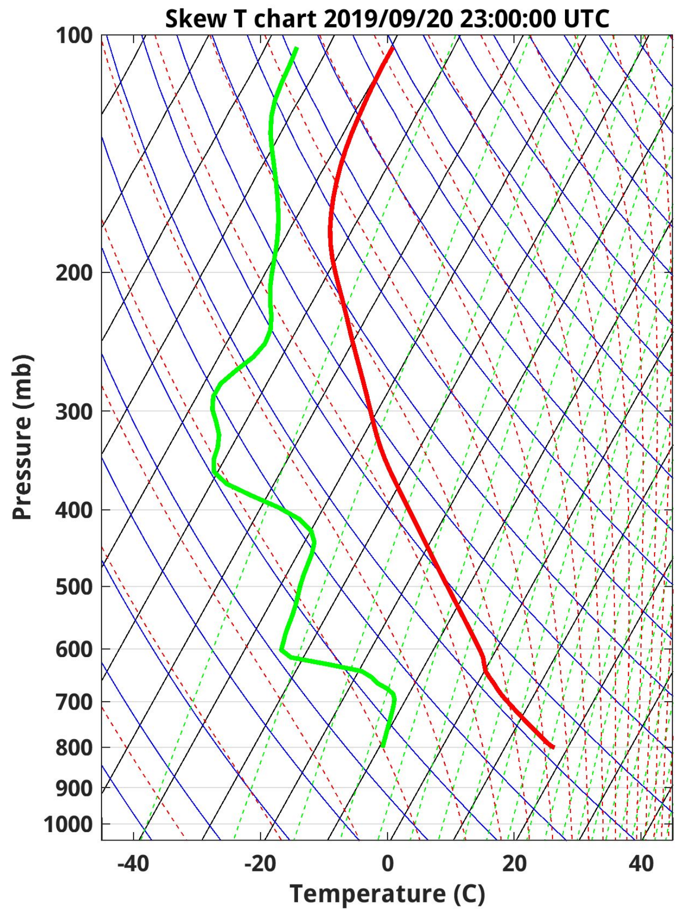


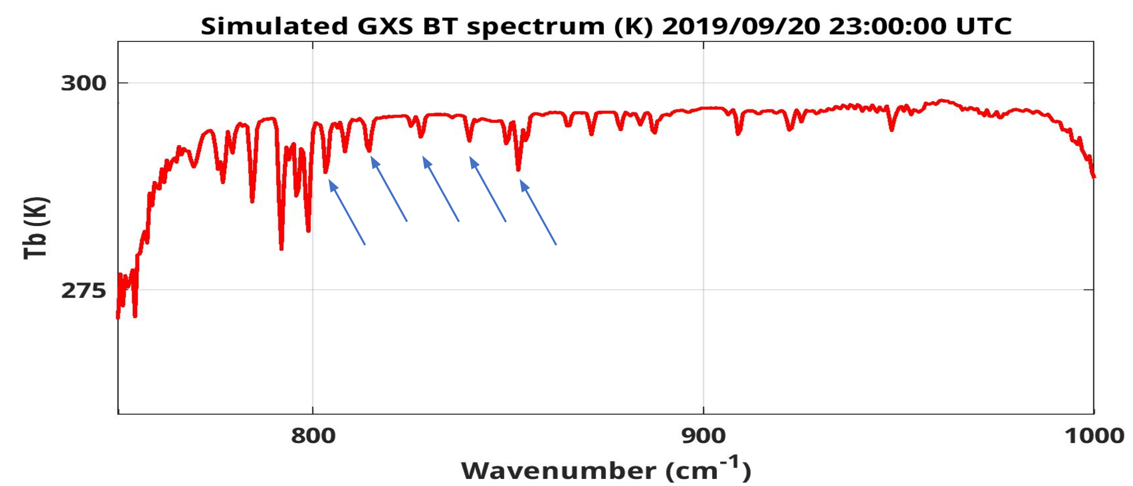


Temperature inversion leads to warmer BT for WV absorption channels in window band!

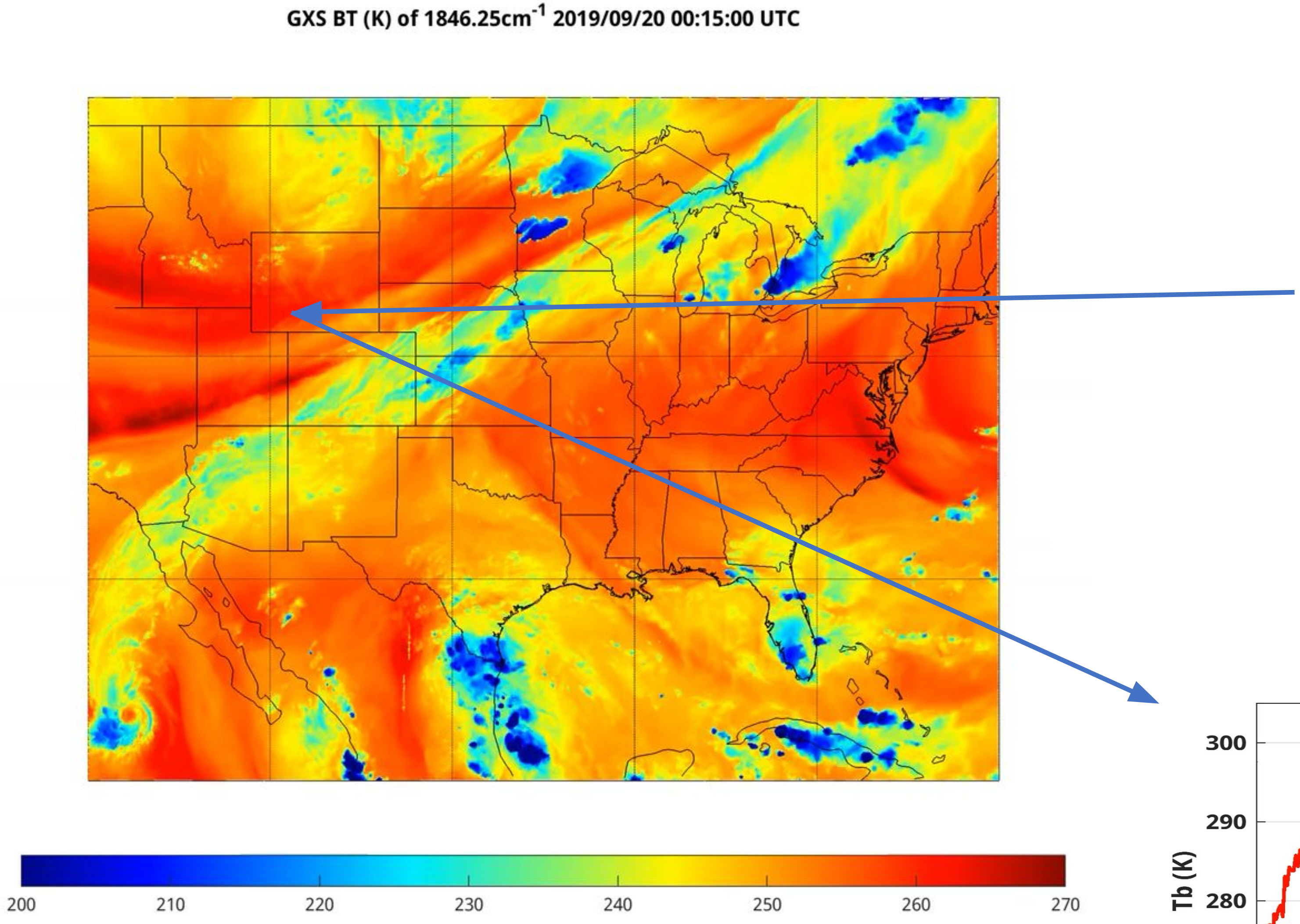
Wyoming Temperature inversion seen by GXS

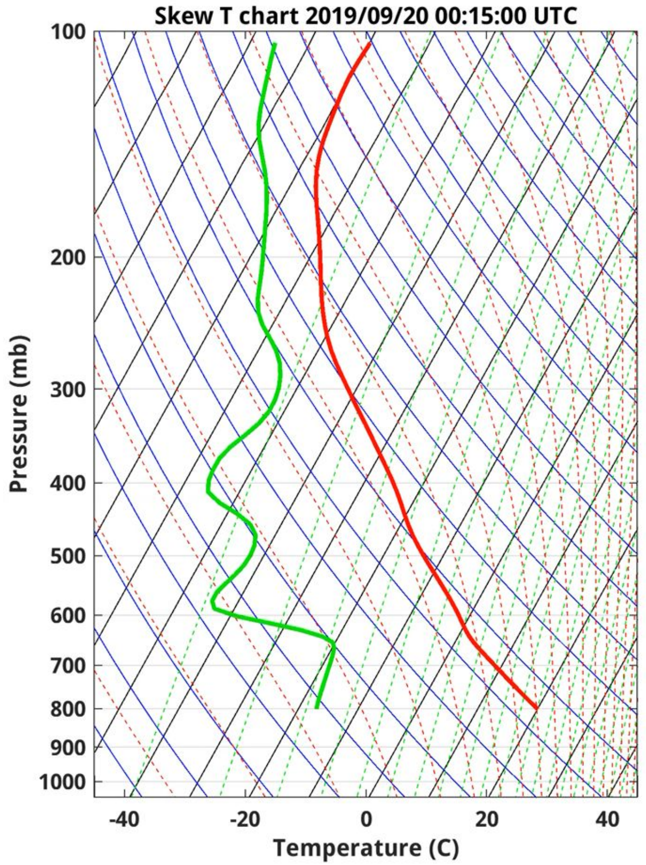


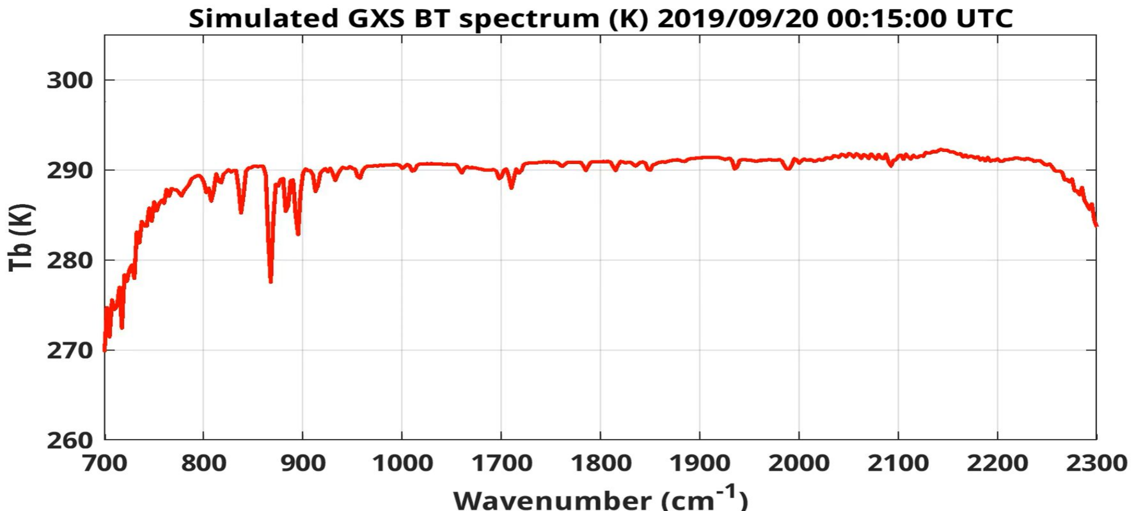




Wyoming Temperature inversion seen by GXS (24 hours)







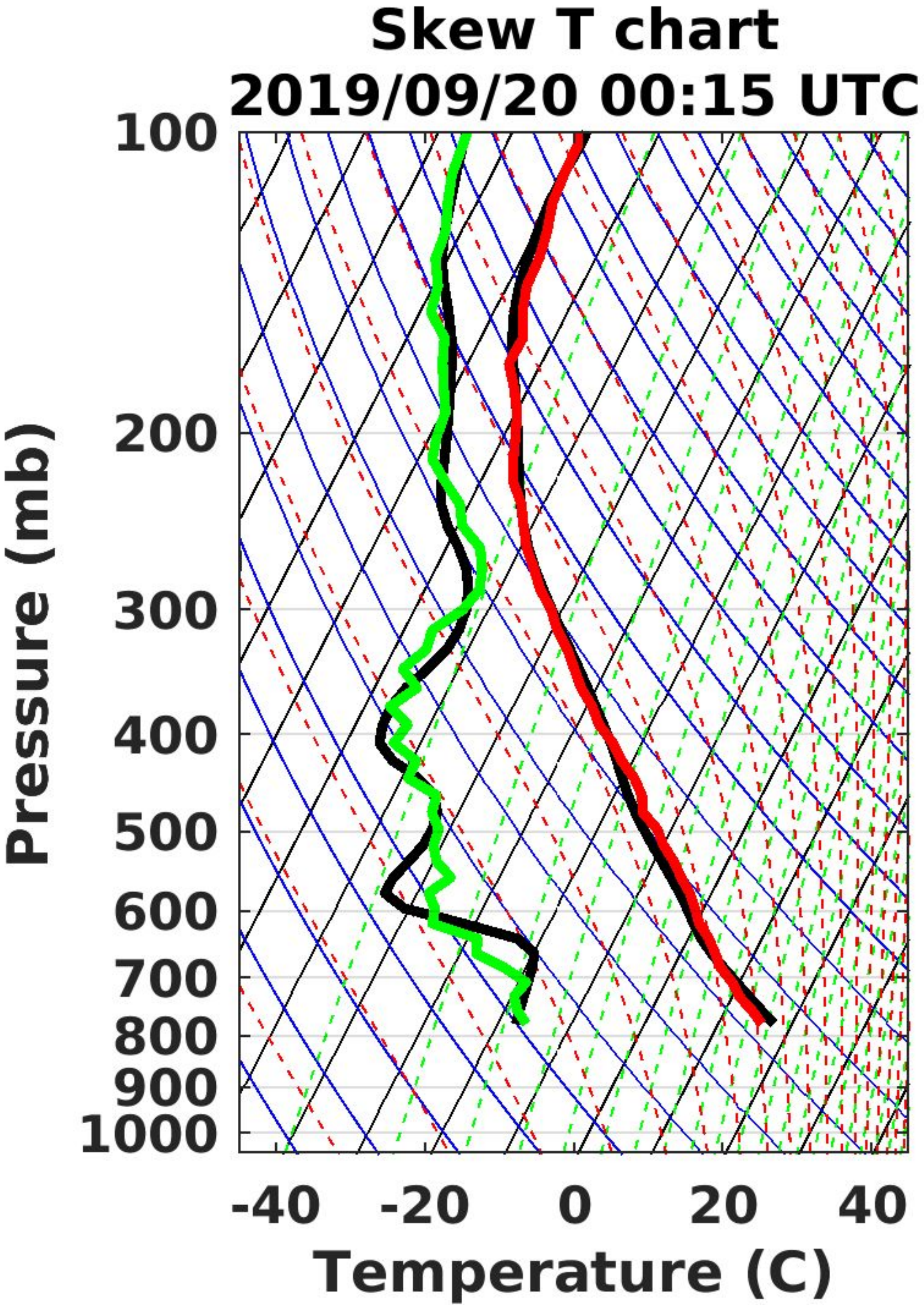
Fingers up: Temperature inversion

Fingers down: No temperature inversion

animation

Simulated when using a Machine Learning retrieval approach

(lat=42; lon = -108.05)



Black lines: true

Red/green lines: pred

Red: T

Green: Td

Surface Pressure of approximately 800 hPa

Need for high spectral & temporal observations

- **High-spectral-resolution observations provide much more information**
  - Imagers average out important vertical information
  - LEO has shown the many benefits, especially on the global scale, lacks time resolution
- Forecasting Applications – fill in critical gaps wrt vertical moisture, wind and temperature
  - **Nowcasting** and **Numerical weather prediction**, especially on the regional/mesoscales
- Additional applications
  - **improve derived products with only advanced imager data**
    - cloud-top properties, atmospheric motion vectors, dust detection, land and sea surface temperatures
  - **New areas**
    - Moisture flux, capping inversion, surface emissivity, trace gases (Ozone and Carbon Monoxide, etc.) and climate
- **Economic impacts** ("billions"…) More with the benefits of 4dvar analysis …
- Critical Component of the **Global Constellation**

Credit: Brad Pierce, UW/SSEC

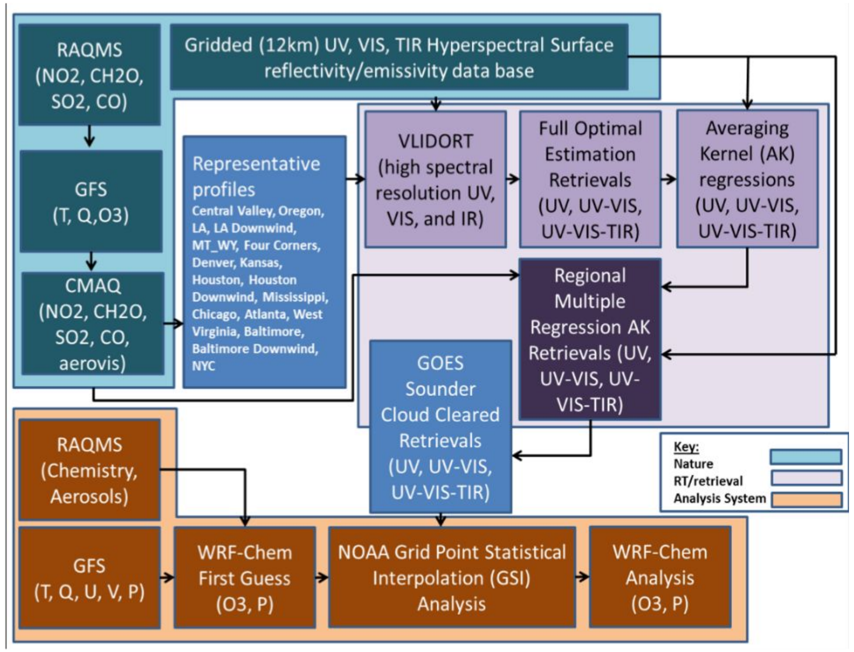
ACX/GXS Synergy

NASA GEO-CAPE Regional Ozone OSSE:

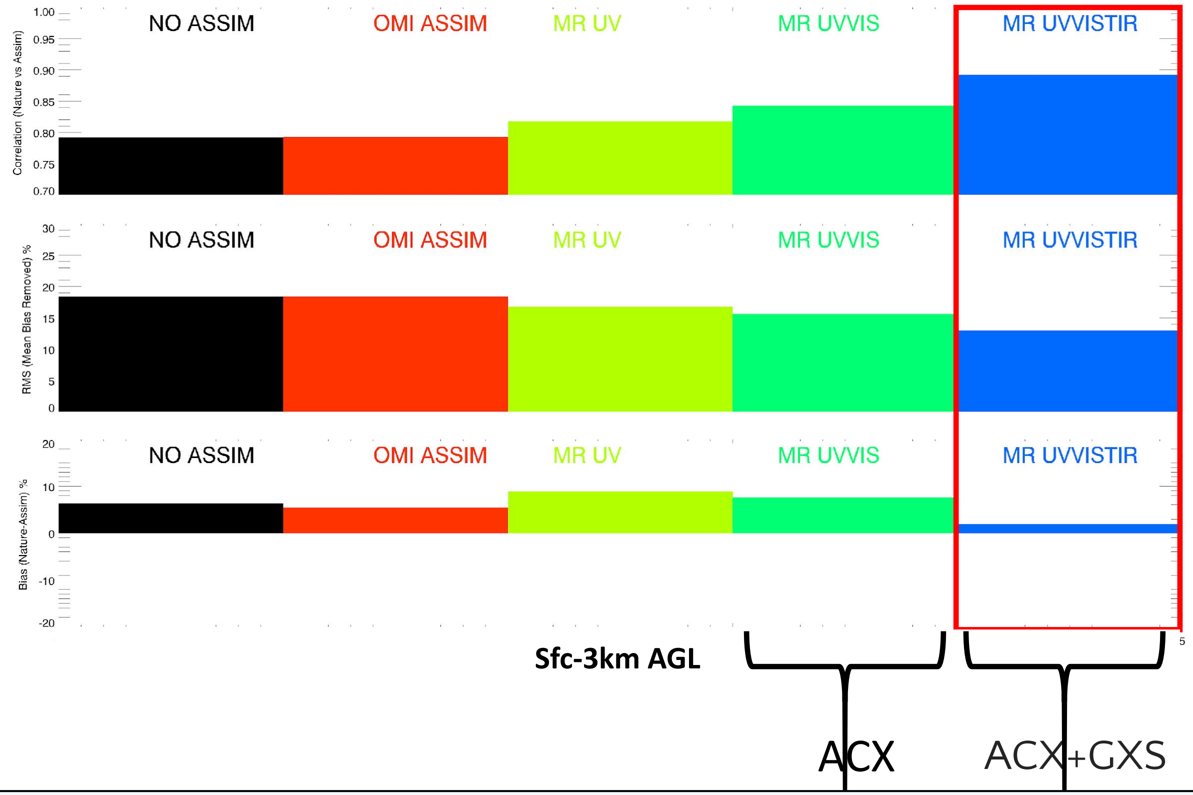
Impacts of combining Multi-Spectral Thermal Infrared (TIR) Geostationary Sounder and Ultra-Violet (UV), and Visible (VIS) Spectrometer Data in Ozone profile retrievals

Method

- CMAQ based Nature Run used to generate synthetic geostationary UV, VIS, and TIR radiances.
- Optimal Estimation multi-spectral ozone retrievals for representative sites.
- Regional retrievals generated using multiple regression (MR) to estimate averaging kernels
- WRF-Chem based Assimilation Experiments using the NOAA 3D-Var analysis system (GSI)



Results: surface-3km ozone



Significant improvement in Correlation, RMS Error, and Bias when geostationary hyper-spectral Thermal IR (GXS) radiances are combined with UV-VIS spectra (ACX)

More Hyper Spectral IR Info

- https://www.ssec.wisc.edu/geo-ir-sounder/other-benefit/
  - Diurnal variation
  - Trace gases
  - Dust
  - Inter-calibration
  - Synergistic application with GEO imager
  - Etc.

SSEC **Geostationary Hyperspectral IR Sounder**
Added value for weather forecasts and many other uses

HOME | OSSE | PROXY | OTHER BENEFITS | HISTORY | ON-ORBIT | IN-DEVELOPMENT / FAQ

"The [ozone] results obtained indicate that the assimilation of synthetic radiances of IRS always has a positive impact on the ozone analysis ... The relative average difference compared to the Nature Run in the ozone total columns improves from -30 % (no assimilation) to almost zero … When considering tropospheric columns the improvement is also significant, from 15–20 % (no assimilation) down to 3 %"

Retrievals of trace gases (ozone, CO, NH3, isoprene, N20, etc.)

Beyond highly accurate temperature and moisture profiles, hyperspectral IR sounders allows retrievals of trace gases such as ozone, CO, isoprene, NH3, N2O, etc. Continuous monitoring of those trace gases from GEO will allow better air quality forecasts by monitoring various precursors. The GXS and GeoXO Atmospheric Composition (ACX) sensor will compliment each other. Of course which gases are possible to retrieve depends on the spectral coverage, resolution, SNR, etc.

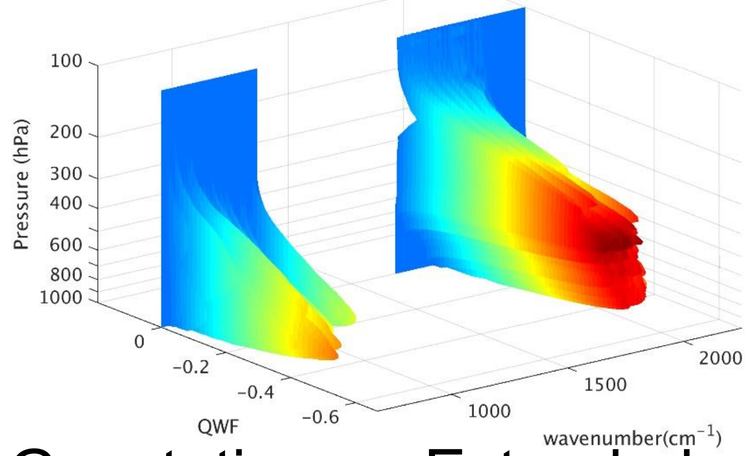
Vittorioso, F., Guidard, V., and Fourrié, N., (2024). Assessment of the contribution of IRS for the characterisation of ozone over Europe, Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2024-24, in review.

Raghuraman, S. P., Paynter, D., Ramaswamy, V., Menzel, R., & Huang, X. (2023). Greenhouse gas forcing and climate feedback signatures identified in hyperspectral infrared satellite observations. Geophysical Research Letters, 50, e2023GL103947. https://doi.org/10.1029/2023GL103947

Wells, K. C., Millet, D. B., Payne, V.H., Vigouroux, C., Aquino, C. A. B., De Mazière, M., et al. (2022). Next-generation isoprene measurements from space: Detecting daily variability at high resolution. Journal of Geophysical Research: Atmospheres, 127, e2021JD036181. https://doi.org/10.1029/2021JD036181

More GXS Information

https://www.ssec.wisc.edu/geo-ir-sounder/



- Home
- OSSE
- Proxy/Simulated
  - Sample SRF
- Other Benefits
- History
- On-orbit examples
- In-development

NOAA NESDIS Tech Report: Geostationary Extended Observations (GeoXO) Hyperspectral InfraRed Sounder Value Assessment Report
https://repository.library.noaa.gov/view/noaa/32921

https://www.nesdis.noaa.gov/next-generation-satellites/geostationary-extended-observations-geoxo

- PORD: https://www.nesdis.noaa.gov/next-generation/geoxo/geoxo-sounder-gxs

Back-up Slides

The Potential Benefits Summarized in 2009

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High-Spectral- and High-Temporal-Resolution Infrared Measurements from Geostationary Orbit

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ABSTRACT

The first of the next-generation series of the Geostationary Operational Environmental Satellite (GOES-R) is scheduled for launch in 2015. The new series of GOES will not have an infrared (IR) sounder dedicated to acquiring high-vertical-resolution atmospheric temperature and humidity profiles. High-spectral-resolution sensors have a much greater vertical-resolving power of temperature, moisture, and trace gases than low-spectral-resolution sensors. Because of coarse vertical resolution and limited accuracy in the legacy sounding products from the current GOES sounders, placing a high-spectral-resolution IR sounder with high temporal resolution in the geostationary orbit can provide nearly time-continuous three-dimensional moisture and wind profiles. This would allow substantial improvements in monitoring the mesoscale environment for severe weather forecasting and other applications. Application areas include nowcasting (and short-term forecasts) and numerical weather prediction, which require products such as atmospheric moisture and temperature profiles as well as derived parameters, clear-sky radiances, vertical profiles of atmospheric motion vectors, sea surface temperature, cloud-top properties, and surface properties. Other application areas include trace gases/air quality, dust detection and characterization, climate, and calibration. This paper provides new analysis that further documents the available information regarding the anticipated improvements and their benefits.

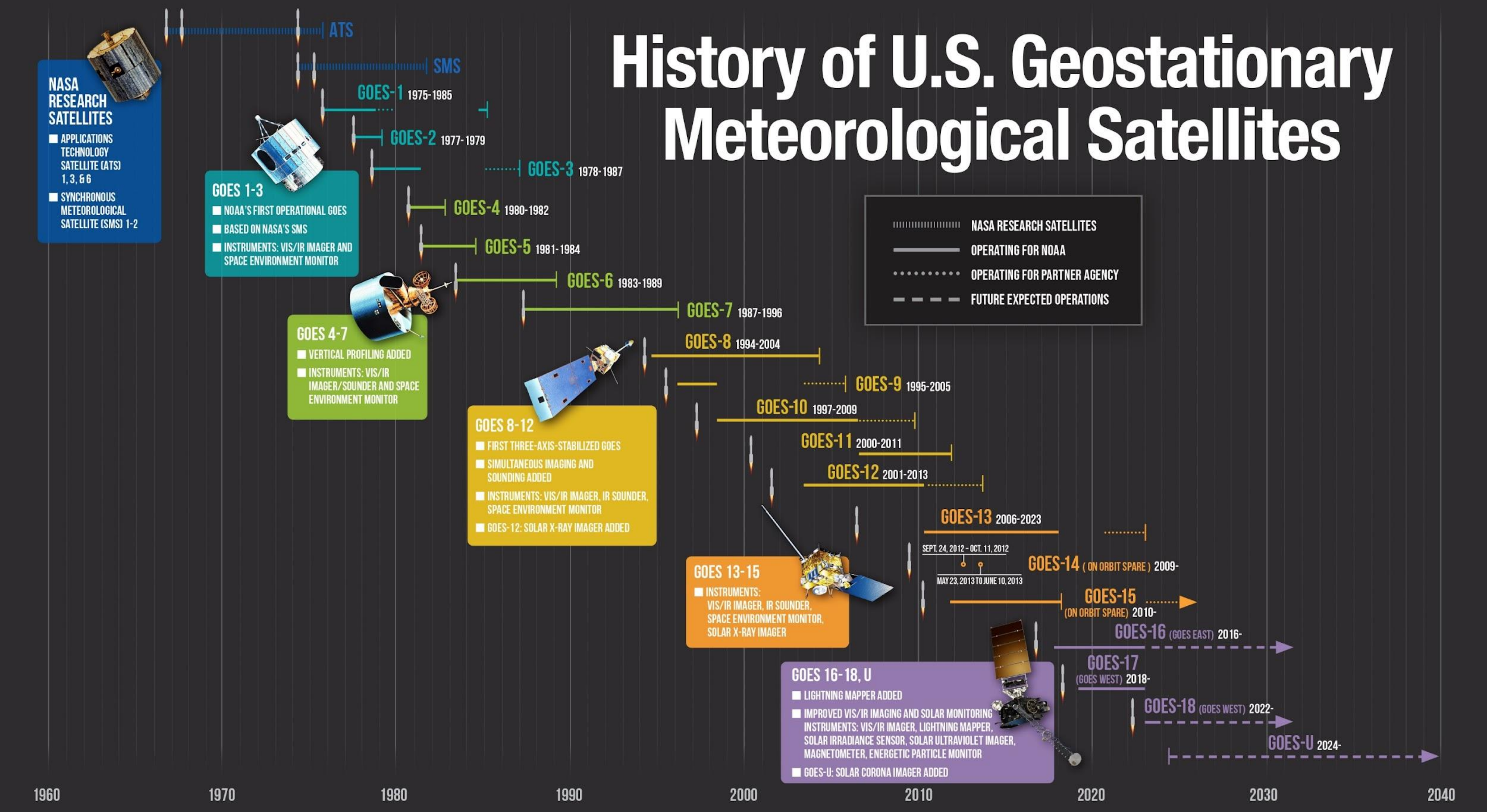
High-Spectral- and High-Temporal-Resolution Infrared Measurements from Geostationary Orbit

https://journals.ametsoc.org/view/journals/atot/26/11/2009jtecha1248_1.xml

What has changed?

The case for geostationary advanced sounders has only strengthened due to advances in instrument and experience from many sensors.

History of U.S. Geostationary Meteorological Satellites



GXS Plans

Sensor

- 2023 – Vendor selected (Ball)
- 2028 – GXS CDR
- 2035 – Launch of first GXS

User Readiness

- 2021 NASA/NOAA GXS Science Working Group
- 2024 GXS Workshop and Science Teams forming
  - includes NASA, NOAA, JCSDA, GMAO, EMC, ESRL and collaboration with EUMETSAT and key individuals like Drs. Louis Uccellini, Bill Smith and Mitch Goldberg

Current and Planned Activities

- Supporting NOAA/EMC to be ready for MTG/IRS
- GMAO and OAR are and will be conducting model impact studies.
- NOAA/ESRL is studying impact of GXS in the NOAA regional models.
- Generation of GXS Proxy Data
- Innovation to determine optimal retrieval approaches (profiles, 3D-winds and trace gases).
- Recent Satellite Book Club (NWS) on the GXS

Thank You

For more information visit

www.nesdis.gov/geoxo

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