Observations for a Changing Planet: NOAA's Future Geostationary Satellites

June 11, 2024
CALCON Meeting, Logan UT

NOAA
National Environmental Satellite, Data, and Information Service

Pam Sullivan, GOES-R/GeoXO Program Director

Since NOAA's GOES-R satellite launched in 2016, the satellites in this series have observed:

- *135 Atlantic basin tropical storms, including 7 Category 5 hurricanes,*
- *124 deadly tornadoes in the U.S.,*
- *>178 large-scale winter storms in the U.S.,*
- *>300,000 wildfires in the U.S.,*
- *>60 volcanic eruptions,*
- *143 U.S. $1B+ disasters with damages >$1T,*
- *Countless storms with damaging lightning, wind, hail, ice, and snow,*
- *Daily conditions that pose danger to life and property including extreme heat and cold, high rainfall, flooding, fog, and smoke,*
- *And the hottest years recorded on the planet.*

GOES-16, 17, and 18 Update

GOES-16

- In operational service as GOES East since December 2017
- Continuing to monitor thruster anomaly with mitigations in place
  - Developing high inclination orbit conops to extend fuel life

GOES-17

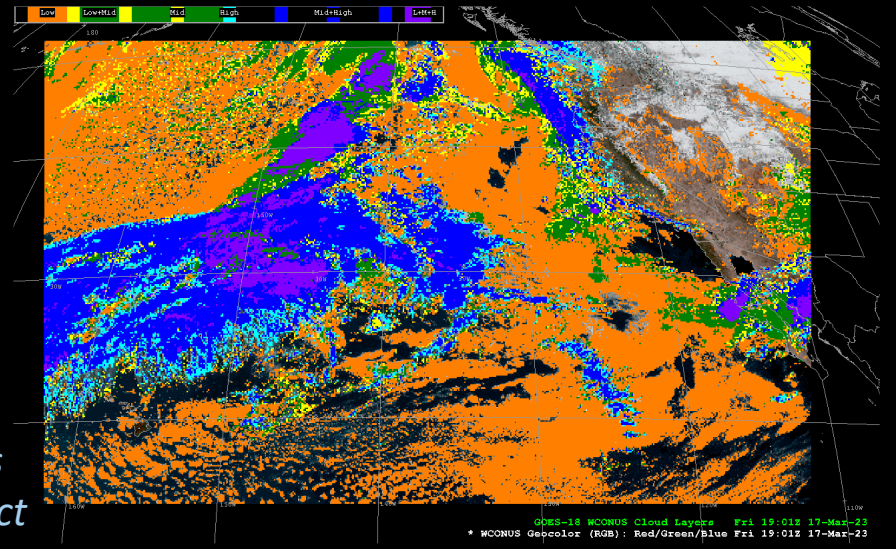
- In on-orbit storage at 105° W

GOES-18

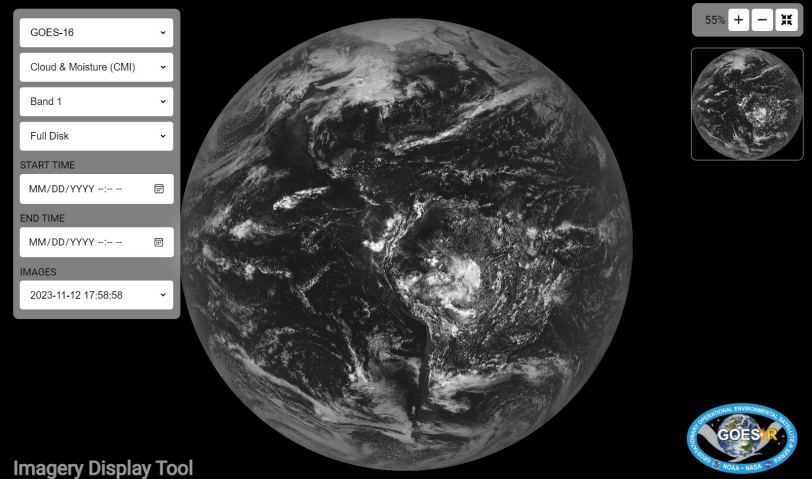
- In operational service as GOES West since January 2023

Ground and Data Products

- Completed system-wide server replacement
- Transitioning L2 products to enterprise versions
- Working to bring new products into operation
- Prototyping L2 data generation in the NESDIS Cloud

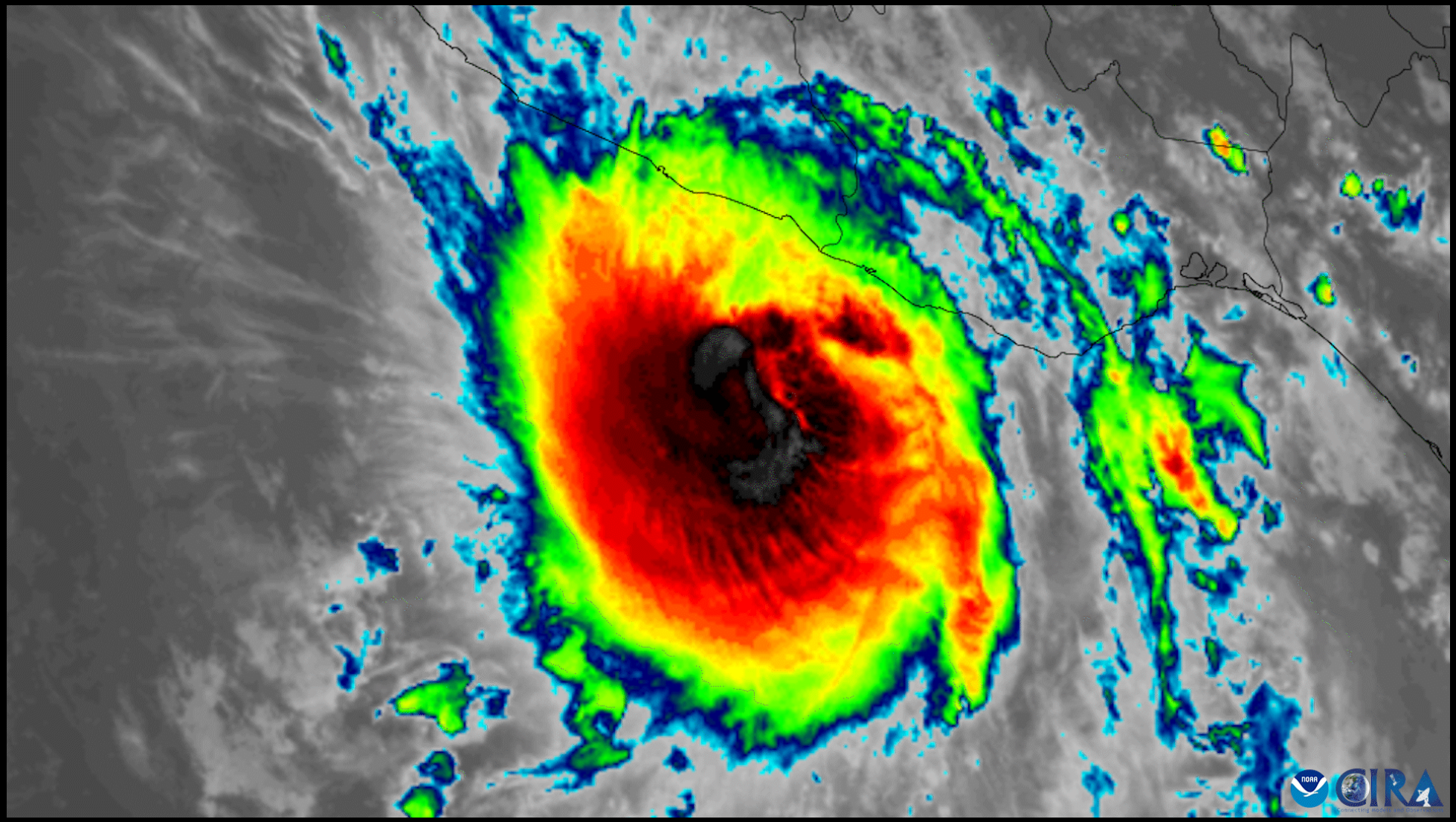


New Cloud Cover Layers Product



L2 Product Generation In NESDIS Cloud

Category 5 Otis Makes Landfall near Acapulco



High Winds in Hawaii while Dora Passses to the South

GOES-18 water vapor imagery with GFS MSLP analysis overlaid.
Satelliteliaisonblog.com

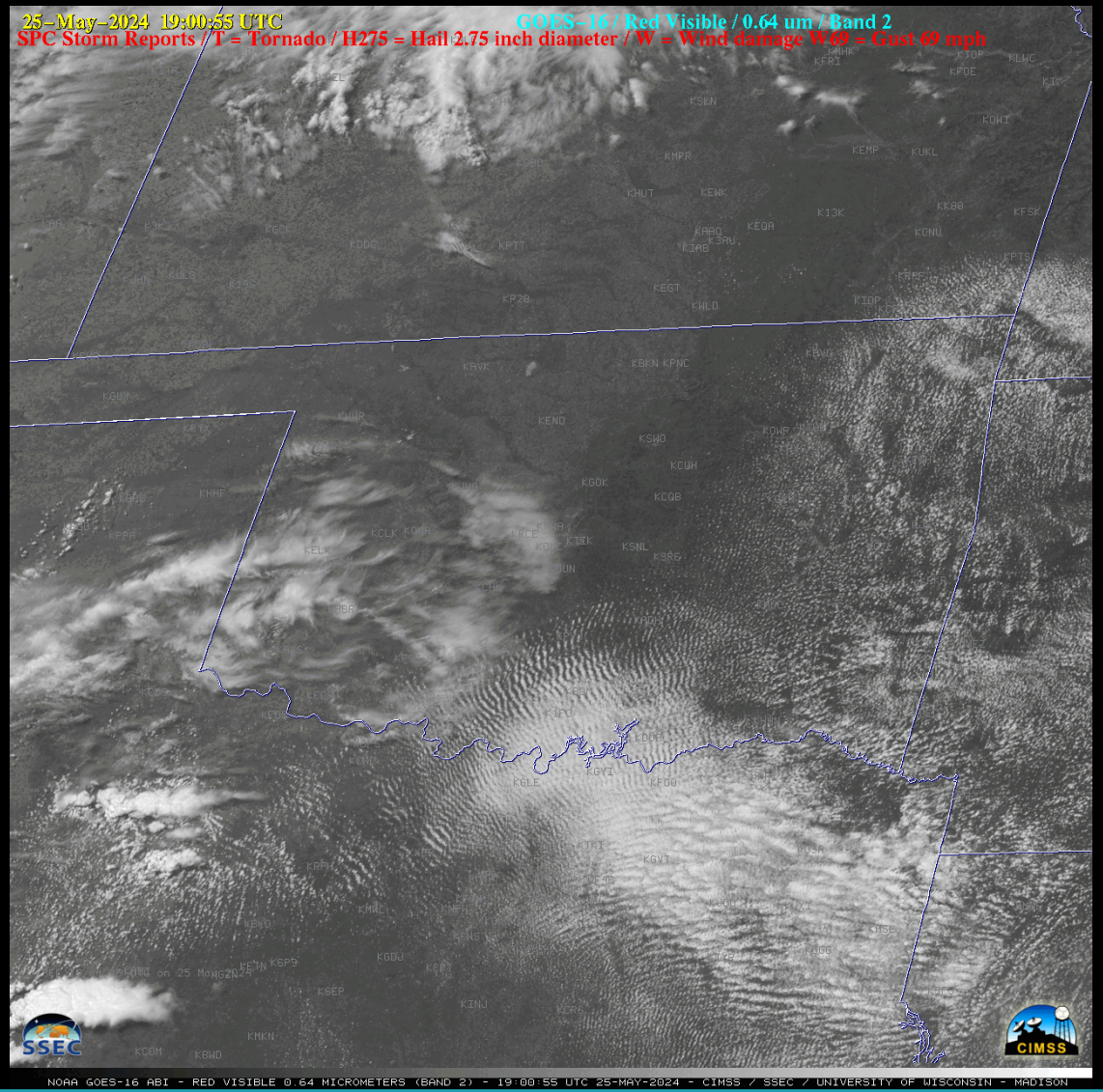
Maui Wildfires

GOES-18 Geocolor with Ch07+Ch06+Ch05 overlay. Satelliteliaisonblog.com

Wildfire Smoke from Quebec reaches NYC

Courtesy: Getty Images

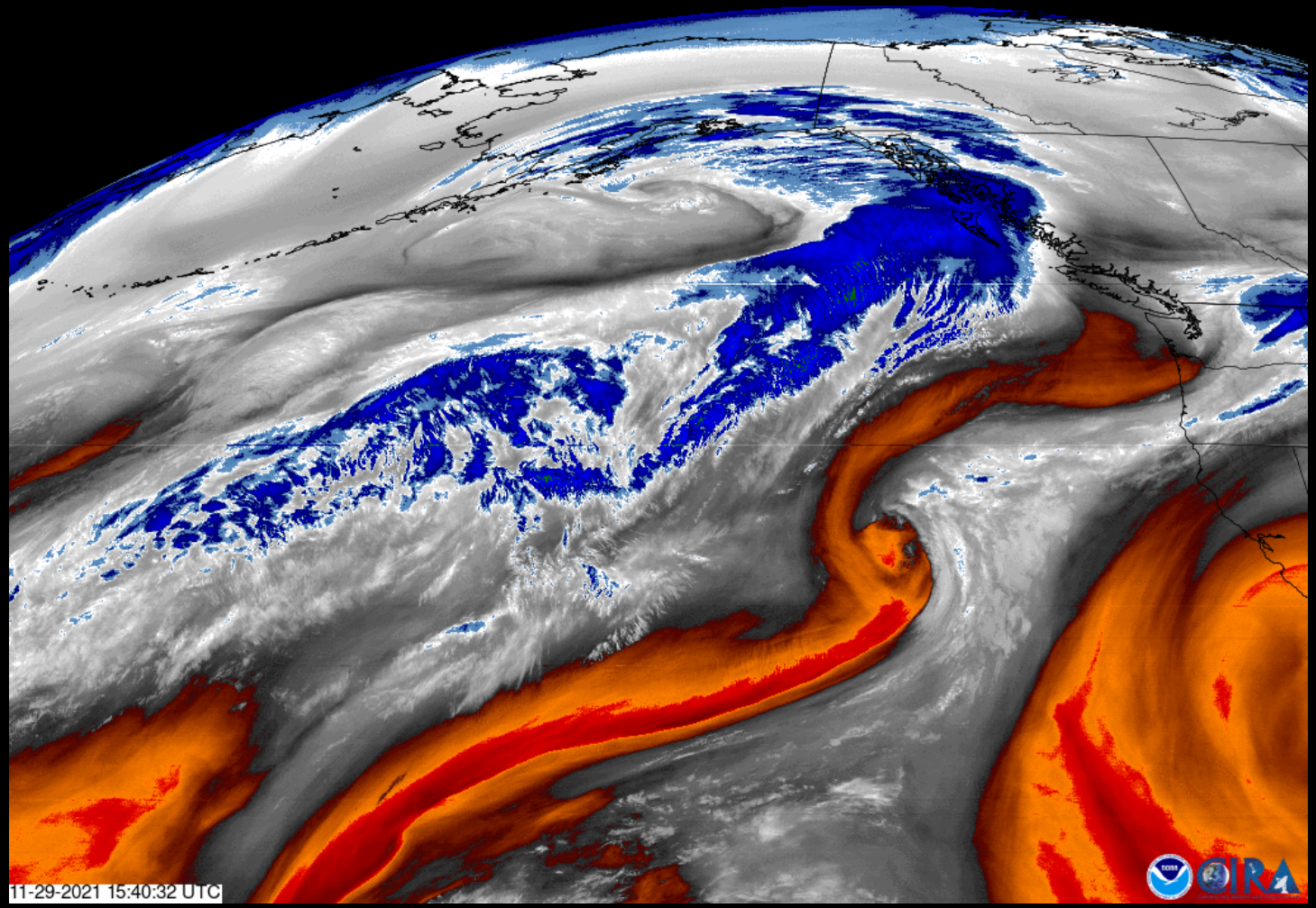
Deadly Storm Tracks across TX and OK



Storm produced hail of diameter 3.5 inch, and multiple tornados.

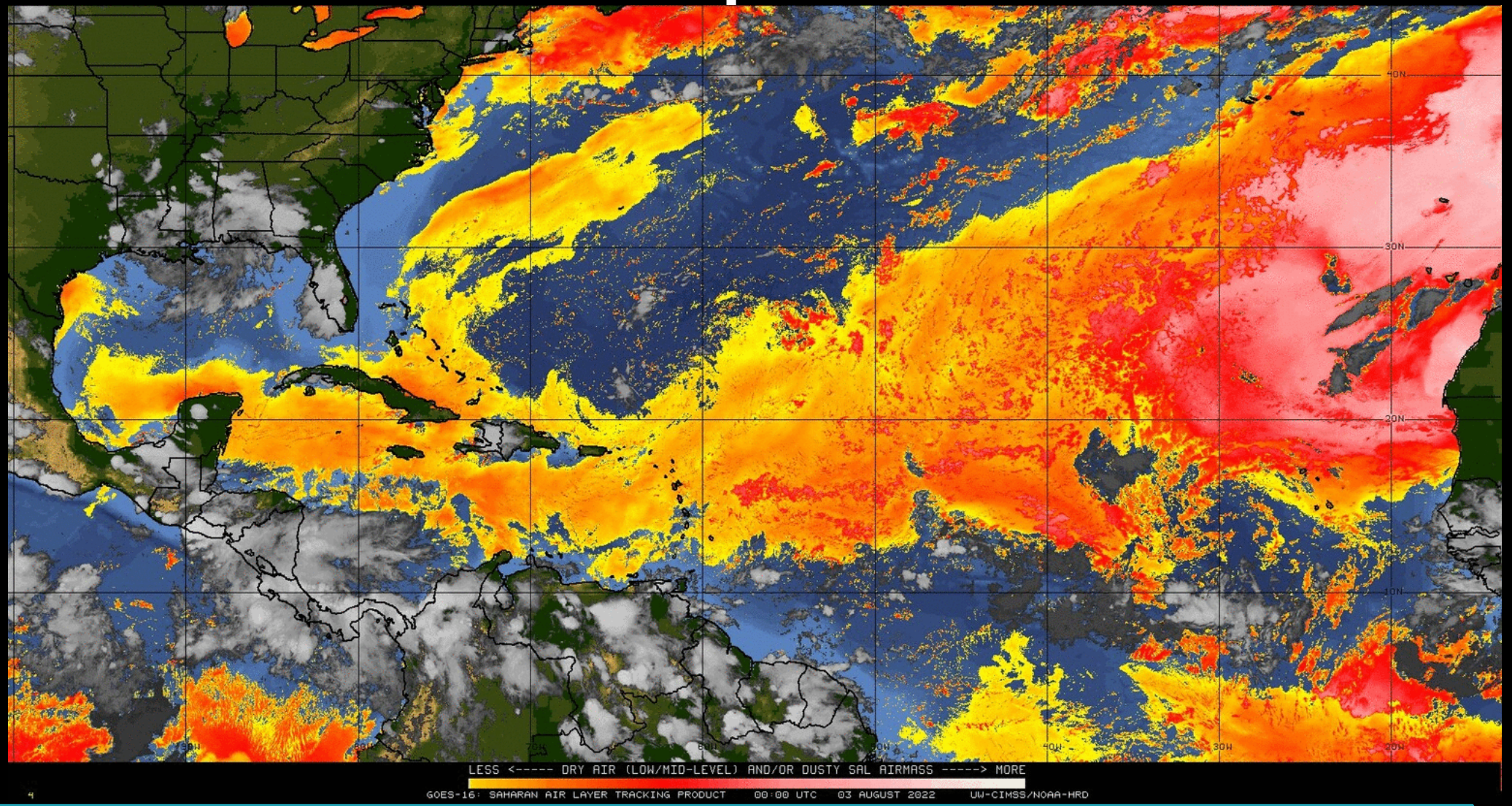
GOES-16
Vis/IR Sandwich
Product

“Atmospheric River” Causes Flooding in British Columbia



The GOES-17 6.9um water vapor channel shows an atmospheric river that brought >2ft of rain to parts of western Canada.

Saharan Air Layer Dust reaches Southeast US



GOES-16 Split Window Difference SAL Product

ABI Detects Methane Leak

GOES-R Advanced Baseline Imager (ABI) can detect high point source emissions of methane.

NOAA is in the process of transitioning this capability, developed by Harvard University, to its operations.

Daniel Varon (Harvard University)

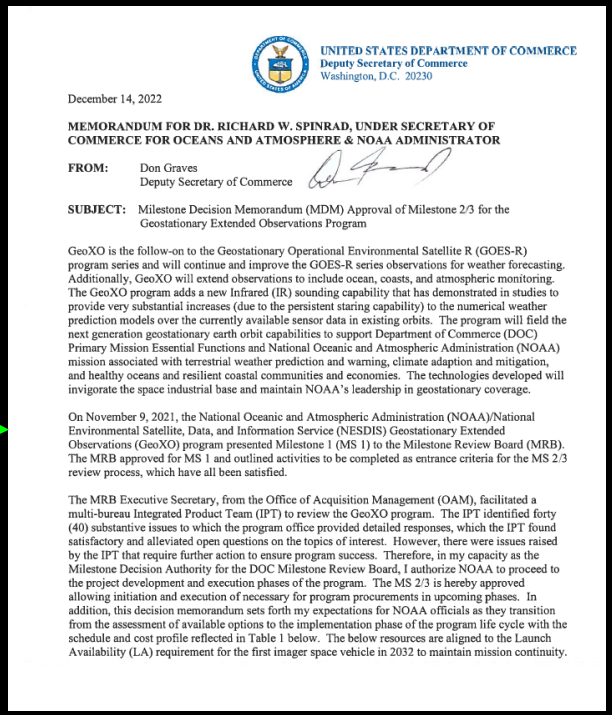
GOES-R Development Ends, GeoXO Begins

- The last GOES-R satellite, GOES-U, launches in 2024
- While GOES-R satellites will operate into the 2030s, replenishment is needed in 2032 for continuity

GOES-U at Lockheed preparing for launch on June 25, 2024

- To provide continuity after GOES-R, in 2020, NOAA began planning its next-gen system by surveying user needs and defining requirements
- In 2022, the new GeoXO program was approved for implementation by the Dept of Commerce

2022 DOC Decision Memo baselining GeoXO and approving implementation



UNITED STATES DEPARTMENT OF COMMERCE
Deputy Secretary of Commerce
Washington, D.C. 20230

December 14, 2022

MEMORANDUM FOR DR. RICHARD W. SPINRAD, UNDER SECRETARY OF COMMERCE FOR OCEANS AND ATMOSPHERE & NOAA ADMINISTRATOR

FROM: Don Graves
Deputy Secretary of Commerce

SUBJECT: Milestone Decision Memorandum (MDM) Approval of Milestone 2/3 for the Geostationary Extended Observations Program

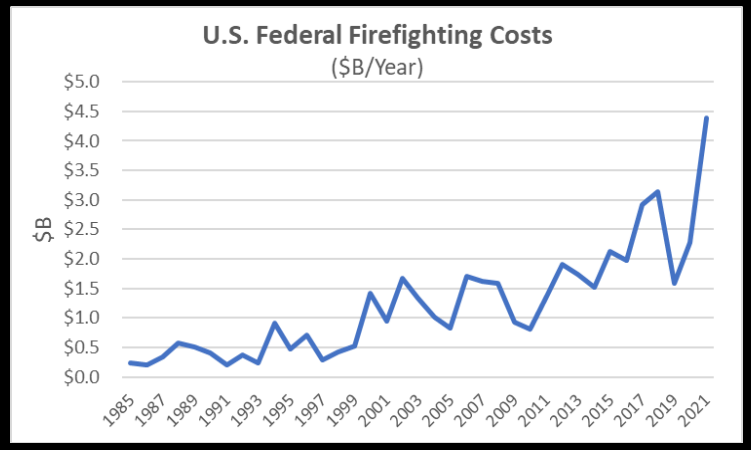
GeoXO is the follow-on to the Geostationary Operational Environmental Satellite R (GOES-R) program series and will continue and improve the GOES-R series observations for weather forecasting. Additionally, GeoXO will extend observations to include ocean, coasts, and atmospheric monitoring. The GeoXO program adds a new Infrared (IR) sounding capability that has demonstrated in studies to provide very substantial increases (due to the persistent staring capability) to the numerical weather prediction models over the currently available sensor data in existing orbits. The program will field the next generation geostationary earth orbit capabilities to support Department of Commerce (DOC) Primary Mission Essential Functions and National Oceanic and Atmospheric Administration (NOAA) mission associated with terrestrial weather prediction and warning, climate adaption and mitigation, and healthy oceans and resilient coastal communities and economies. The technologies developed will invigorate the space industrial base and maintain NOAA's leadership in geostationary coverage.

On November 9, 2021, the National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS) Geostationary Extended Observations (GeoXO) program presented Milestone 1 (MS 1) to the Milestone Review Board (MRB). The MRB approved for MS 1 and outlined activities to be completed as entrance criteria for the MS 2/3 review process, which have all been satisfied.

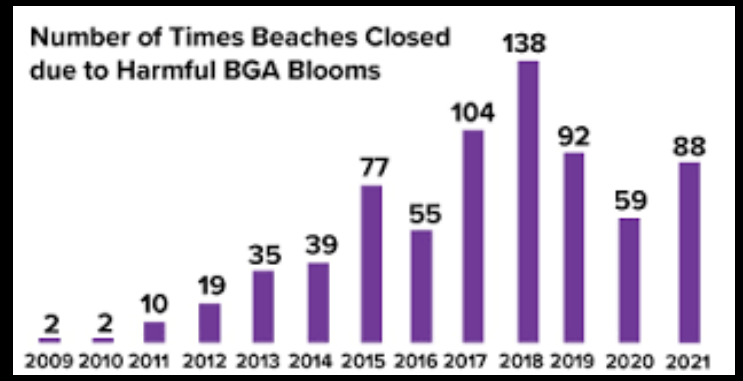
The MRB Executive Secretary, from the Office of Acquisition Management (OAM), facilitated a multi-bureau Integrated Product Team (IPT) to review the GeoXO program. The IPT identified forty (40) substantive issues to which the program office provided detailed responses, which the IPT found satisfactory and alleviated open questions on the topics of interest. However, there were issues raised by the IPT that require further action to ensure program success. Therefore, in my capacity as the Milestone Decision Authority for the DOC Milestone Review Board, I authorize NOAA to proceed to the project development and execution phases of the program. The MS 2/3 is hereby approved allowing initiation and execution of necessary for program procurements in upcoming phases. In addition, this decision memorandum sets forth my expectations for NOAA officials as they transition from the assessment of available options to the implementation phase of the program life cycle with the schedule and cost profile reflected in Table 1 below. The below resources are aligned to the Launch Availability (LA) requirement for the first imager space vehicle in 2032 to maintain mission continuity.

Planning for the Planet in 2030 & Beyond

- **Wildfires are growing in size and frequency**: higher spatial resolution imagery will detect fires earlier, and atmospheric composition measurements can track where dangerous smoke travels
- **Beach closures are increasing:** ocean color observations will more precisely and more frequently monitor the presence of harmful algal blooms
- **Link between air pollution and mortality more clearly understood:** real time measurements of air quality will enable more accurate warnings and improve controls, with likely advancements to health outcomes
- **Hurricanes are becoming stronger and intensifying more rapidly:** improved imagery will detect storm generation and intensification sooner
- **Forecast needs are increasing:** real time hyperspectral sounding data, along with advanced numerical models and high performance computing, will enable more accurate, more timely, and longer-range forecasts



U.S. Federal Firefighting Costs



N.Y. State Beach Closures

Planned GeoXO Capabilities

Continuity of Weather and Hydrological Services	Enhancements for Weather and Hydrological Services	Enhancements for Oceans, Coasts, and Climate Services
• Visible/Infrared Imager • Lightning Mapper (LM) • Receipt/relay of signals from Data Collection System (DCS) platforms and relay of commands to them • Data rebroadcast using commercial services for High Rate Information Transmission, Emergency Managers Weather Info Network, Imagery	• Hyperspectral IR Sounder • Spatial and spectral resolution improvements for Imager • Potential spatial resolution improvement for Lightning Mapper • 2X the channels for DCS relay	• Ocean Color (OC) Instrument • Atmospheric Composition (AC) Instrument

GeoXO AC and OC Instruments will build on experience from NASA research instruments; shown here: NASA's TEMPO, launched in 2023.

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

GeoXO Constellation

GEO-West

Visible/Infrared Imager
Lightning Mapper
Ocean Color

GEO-Central

Hyperspectral Infrared Sounder
Atmospheric Composition
Partner Payload

GEO-East

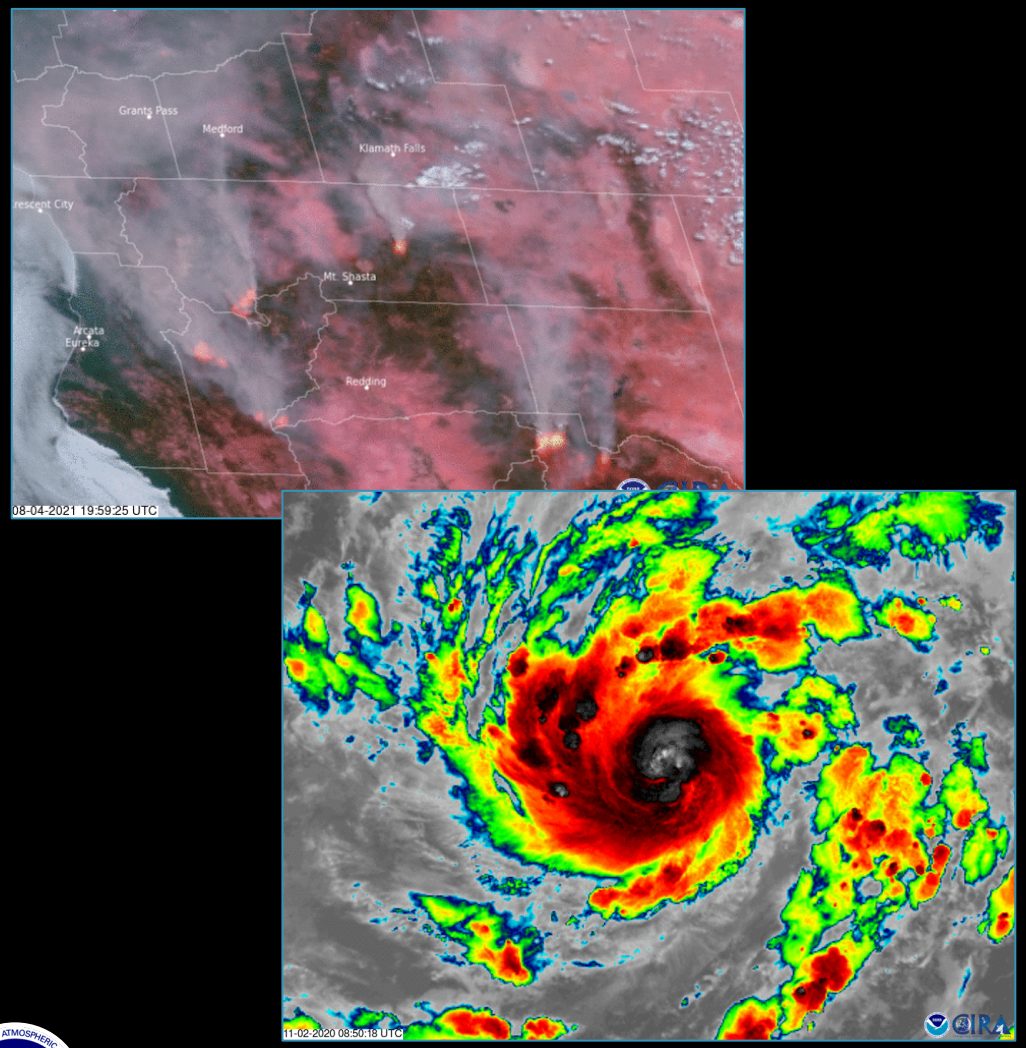
Visible/Infrared Imager
Lightning Mapper
Ocean Color

NOAA Satellite Operations Facility, Suitland MD

Command and Data Acq. Station Wallops VA

Consolidated Back-Up, Fairmont WV

GeoXO Imager (GXI)



APPLICATIONS

- Hurricanes: pinpoint location, estimate intensity, and determine speed and direction
- Wildfires: identify dry vegetation, locate hot spots, monitor wind conditions to predict spread, track smoke plumes, and map burn scars
- Dangerous weather: detect and track damaging winds, dust, high rainfall, flooding, sea and lake ice, and snow
- Severe storms: predict and diagnose storm intensity
- Numerical weather modeling: input wind speed/direction
- Aviation: detect hazards such as turbulence, icing, low clouds and fog, and volcanic ash
- Air quality: monitor hazardous airborne particulates
- Climate: cloud trends are an important climate variable

GXI Performance & Calibration Requirements

ABI CONFIGURATION

	Wavelength (μm)	Band	GSD
VNIR	0.47	Band 1	1 km
	0.64	Band 2	0.5 km
	0.865	Band 3	1 km
	1.378	Band 4	2 km
	1.61	Band 5	1 km
	2.25	Band 6	2 km
MWIR	3.9	Band 7	2 km
	6.185	Band 8	2 km
	6.95	Band 9	2 km
	7.34	Band 10	2 km
	8.50	Band 11	2 km
LWIR	9.61	Band 12	2 km
	10.35	Band 13	2 km
	11.20	Band 14	2 km
	12.30	Band 15	2 km
	13.30	Band 16	2 km

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	6.95	Band 11	1 km
	7.34	Band 12	2 km
LWIR	8.50	Band 13	2 km
	9.61	Band 14	2 km
	10.35	Band 15	1 km
	11.20	Band 16	2 km
	12.30	Band 17	2 km
	13.30	Band 18	2 km

Key Calibration Requirements

- Emissive channels (3.9 to 13.3 μm)
  - End-end, full aperture, on-board calibration
  - NIST traceable absolute accuracy ≤ 1 K (1σ) at 300 K
  - Cal to cal repeatability 0.2 K
- Reflective Channels (0.47 to 2.25 μm)
  - On-board calibration
  - Absolute accuracy ≤ 3% (1.378 μm 4%) (1σ)
  - Cal to cal repeatability < 0.2%
- Characterized spectral response functions, varying by band
- Polarization characterization

ABI to GXI Resolution Improvement

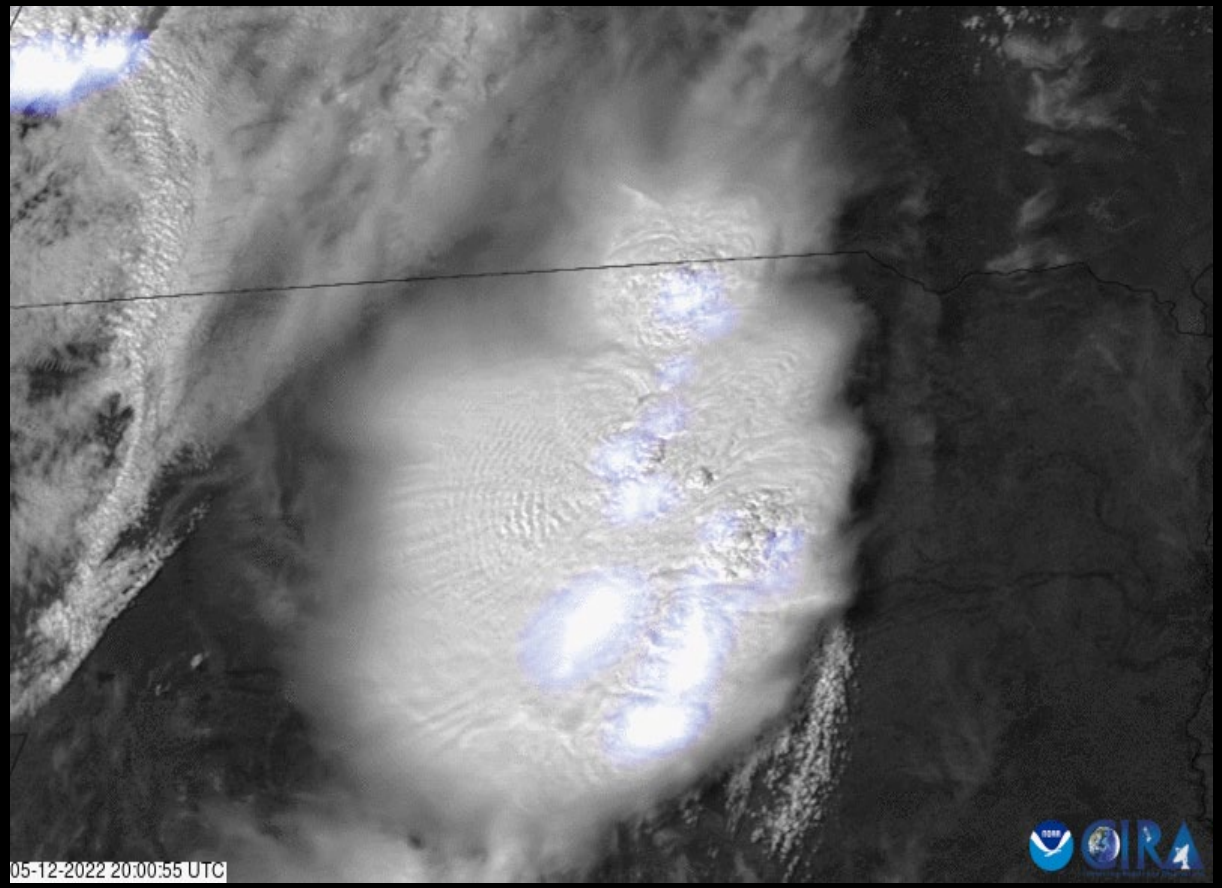
Grass Fires in Oklahoma from March 31, 2023

Observed GOES-16 ABI 3.9 µm channel from 3/31/2023 from the Meso sector over Oklahoma from 1830 - 2010 UTC

Simulated 3.9 µm 1 km resolution band from GXI for the same times as the ABI loop. It's based on 4 VIIRS passes from 1830, 1921, 1943, and 2012 UTC

Courtesy of Jason Apke, CIRA

GeoXO Lightning Mapper (LMX)



APPLICATIONS

- Severe storms:
  - Warnings for thunderstorms, tornadoes, and damaging winds
  - Improve short-term weather model forecasts
  - Improve precipitation forecasts
  - Aid diagnosis and warning for tropical storms
  - Augment radars by filling spatial/temporal gaps, especially over oceans and mountains
- Aviation: safety of airport and aircraft operations
- Wildfires: locate potential wildfire ignitions and guide early responders
- Climate: lightning is an indicator of inter-annual to decadal change, and a key variable to validate climate models

LMX Performance & Calibration Requirements

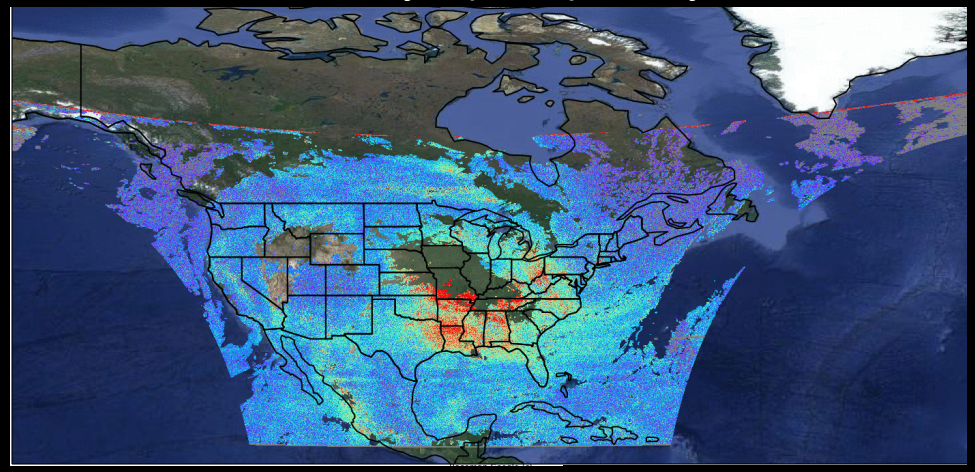
Parameter	Performance Requirement
Geographic coverage	84%
Ground sample distance (nadir)	8 km
Spectral Band	777.4 nm
Frame Rate	500 Hz
Data Latency	10 sec
SNR (daytime)	4
Navigation error	84 urad
Event detection	70%
False events	5%

Key Calibration Requirements

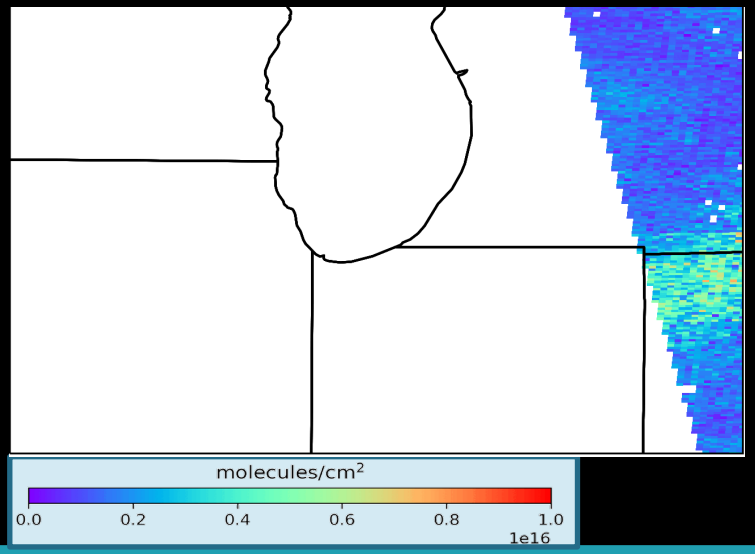
- Reflective Channel (0.777 µm, 1 band)
  - No on-orbit calibration requirement
- Characterized spectral response function over varying angle of incidence for coverage area
  - Spectral resolution 0.002 µm

GeoXO Atmospheric Composition (ACX)

Formaldehyde (HCHO) Density



Nitrogen Dioxide Tropospheric Column Density



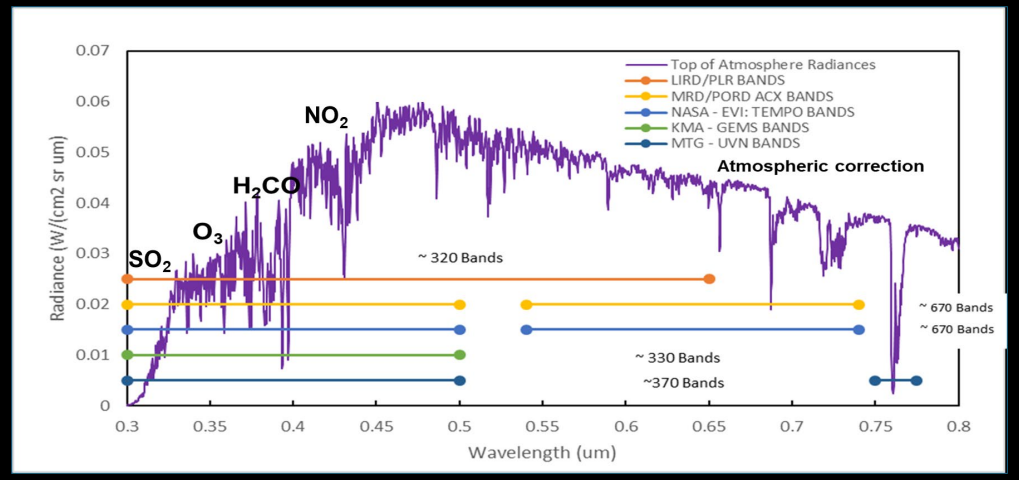
TEMPO imagery,
Courtesy SAO Dr X Liu

APPLICATIONS

- Air Quality Forecasting
  - Improve air quality forecasts to mitigate health hazards including premature deaths
- Air Pollution and Hazards
  - Detect hazardous pollutants including nitrogen dioxide, formaldehyde, smoke, ash
  - Support emergency response by tracking hazardous plume dispersion from wildfires, industrial accidents, and volcanic eruptions
  - Assess crop loss due to air pollution
- Climate
  - Monitor emissions related to aerosol formation and greenhouse gases
  - Persistent diurnal ozone monitoring

ACX Performance & Calibration Requirements

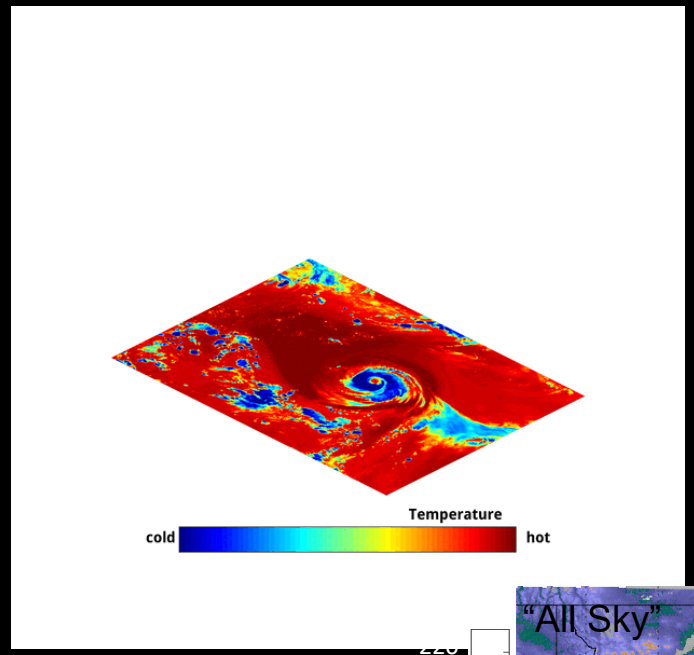
Observation Parameters	
Coverage	CONUS, southern Canada, northern Mexico and Caribbean
Spatial Resolution	5x5 km^2 @ nadir
Temporal Resolution	60 min
Spectral Coverage / Resolution	UV: 300-500 nm Vis: 540-740 nm Both @ 0.6 nm With 3x sampling



Key Calibration Requirements

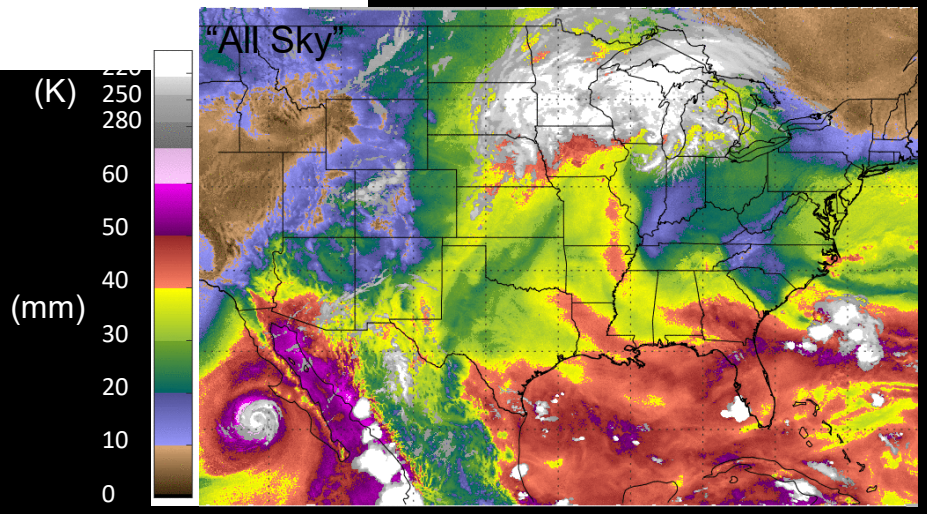
- Reflective Channels (0.300 – 0.500, 0.540 – 0.740 µm, hyperspectral)
  - On-board calibration absolute accuracy < 3.0% (1σ)
  - Repeatability < 0.2%
- Characterized spectral response functions, varying by band
  - Spectral resolution ≤ 0.6 nm, ≥ 3 samples/element, center known to 0.02 nm
- Polarization sensitivity < 5%

GeoXO Hyperspectral Sounder (GXS)



3d data cube of temperature, humidity and winds from a simulation of GXS observations of a hurricane (UW/CIMSS)

Total Precipitable Water

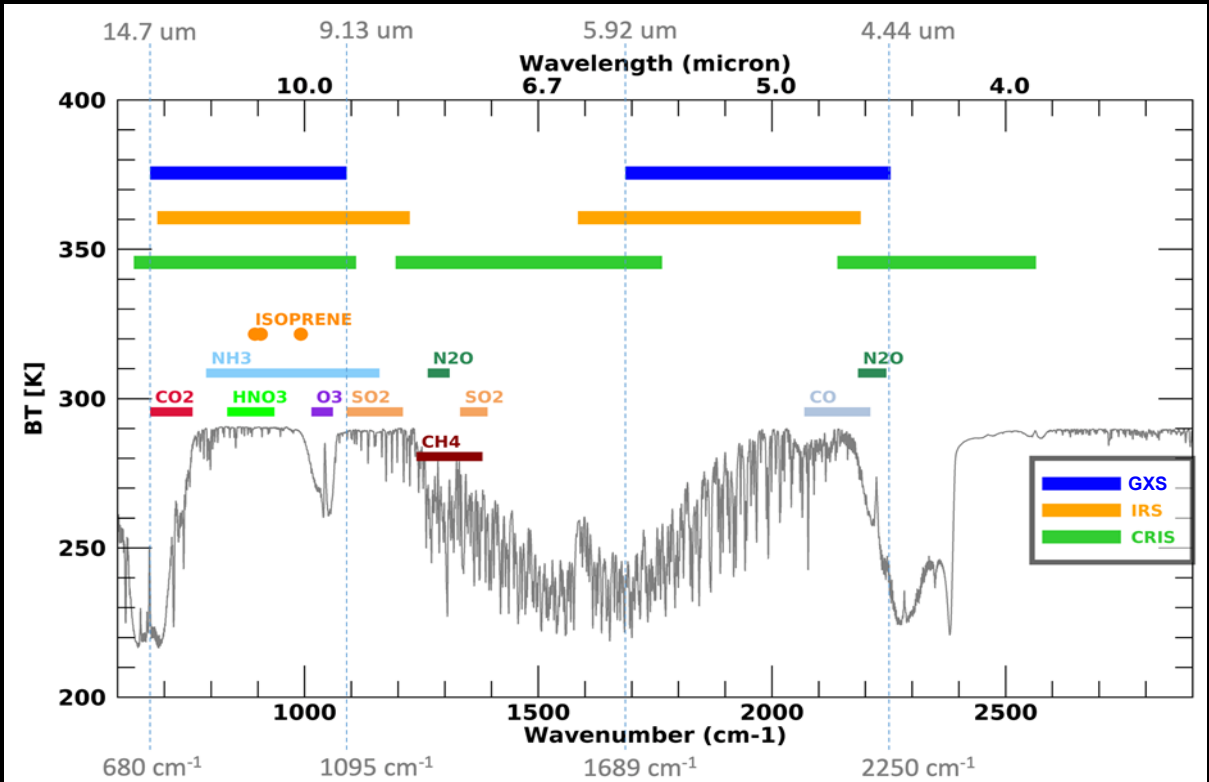


APPLICATIONS

- Improve Numerical Weather Prediction
  - Global, Regional and Meso Scales
  - Improve tropical storm track and intensity
  - Improve forecasts of convection
- Now-casting (short-term forecasts)
  - Near-storm mesoscale analysis
  - Winter weather
  - Convective (location and intensity)
  - Critical layer temperature/moisture fields
  - Enable Warn on Forecast
  - Determine precipitation type
  - Real time comparisons to model guidance
- Fire weather: forecasting winds, humidity, smoke
- Aviation: forecasting icing
- Air quality monitoring

GXS Performance & Calibration Requirements

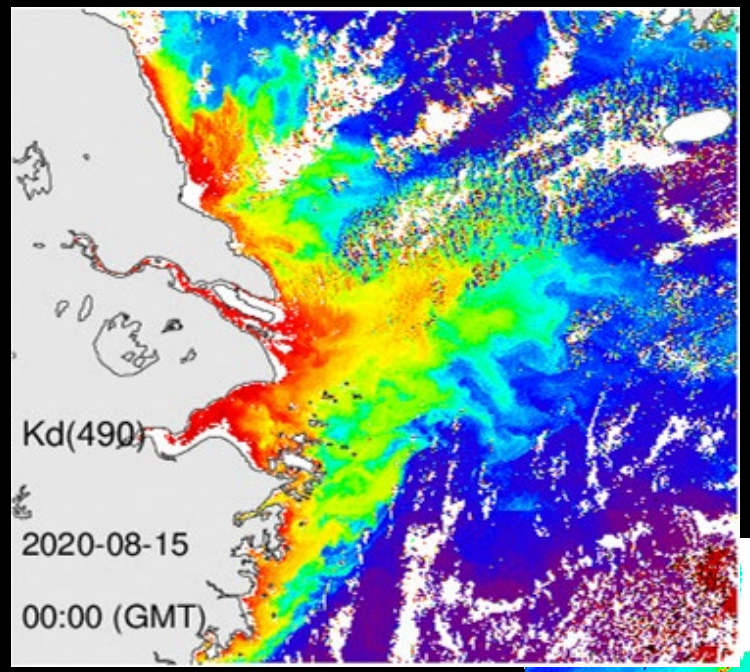
Spectral Range	GXS baseline (cm^{-1}, nm)
680 - 1095(cm^{-1}) 14.7 – 9.13 (um)	0.625, 10.3
1689 – 2250 (cm^{-1}) 5.92 – 4.44 (um)	0.625, 1.72



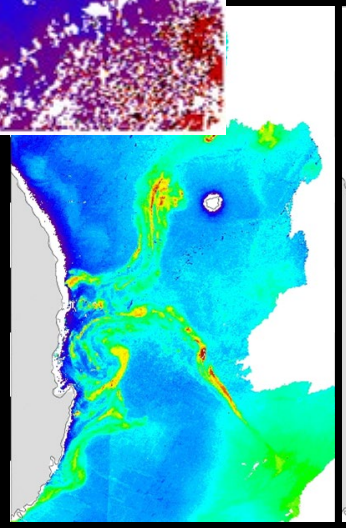
Key Calibration Requirements

- Emissive channels (680 – 1095 cm^{-1}, 1689 – 2250 cm^{-1} (or 14.7 – 9.3, 5.92 – 4.44 µm, hyperspectral)
  - End-to-end, full aperture, on-board calibration
  - NIST traceable absolute accuracy ≤ 1 K (1σ) at 300 K
  - Cal to cal repeatability 0.2 K
- Characterized spectral response functions, varying by band
  - Spectral resolution 0.625 cm^{-1} (0.00172 – 0.010.3 µm)
- Polarization characterization

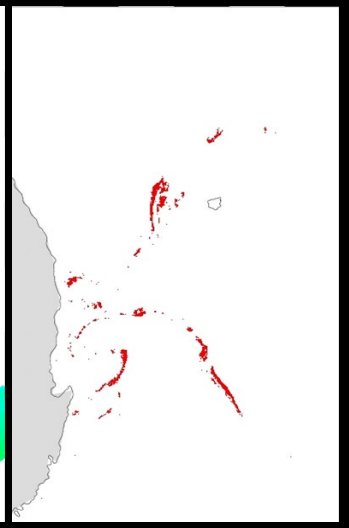
GeoXO Ocean Color (OCX)



Diffuse attenuation coefficient, a measure of water clarity.



Chlorophyll-a



HAB Warning

Imagery from South Korea's GOCI

APPLICATIONS

- Public Health and Safety
  - Harmful algal bloom (HAB) detection
  - Water quality assessment
  - Oil spill detection and tracking
  - Hazardous sea fog detection
- Fisheries, Aquaculture, and Ecosystem Management
  - Chlorophyll concentration measurement
  - Phytoplankton type determination
  - Refined estimates of fisheries yield
  - Identification of sites suitable for aquaculture
  - Protection of shellfish stocks
  - Fishing efficiency (less time/fuel used to locate fish)
  - Protection of endangered species and habitats
- National Defense and Security
  - Diver and submarine visibility
  - Optical and sonar communication

OCX Performance & Calibration Requirements

Observation Parameters	
Field of Regard	Able to scan hemispherically but focused on EEZs: EEZ East (coastline out to EEZ plus Caribbean including Puerto Rico, Gulf of Mexico, plus Great Lakes) -or- EEZ West (coastline out to EEZ plus EEZ Hawaii plus southern Alaska)
Spatial Resolution	300 m at nadir
Temporal Resolution	180 min *(Studying potential to improve to 120min)*
Spectral Coverage	Hyperspectral: • 20 nm resolution for 0.35-1.02 µm • 10 nm resolution for 0.67-0.68 µm
Signal-to-Noise	>400:1 between 0.35 and 0.39 µm, >600:1 between 0.39 and 0.89 µm, achievable SNR reported to 1.02 µm

Key Calibration Requirements

- Reflective Channels (0.350 – 1.02 µm, hyperspectral)
  - On-board calibration, absolute accuracy < 2.0% (1σ)
  - Cal to cal repeatability < 0.2%,
- Characterized spectral response functions, varying by band
  - 10 nm at 0.667-668 µm and 20 nm elsewhere, ≥ 2 samples/element
- Polarization sensitivity < 3% and polarization characterization

Calibration Methodologies

Radiometric Calibration Pre-launch

- **GXI:** Blackbody references for IR channels,
  Uniform source for VNIR channels
- **GXS:** Blackbody references for IR channels
- **LMX:** Uniform source for lightning band
- **OCX:** Uniform source for VNIR channels
- **ACX:** Uniform source for VNIR channels

Spectral Calibration: Pre-launch

- **GXI:** Independent piece part measurements and end-to-end (E2E) spectral calibration
- **GXS:** Independent piece part; E2E spectral calibration
- **LMX:** Independent piece part; E2E spectral calibration
- **OCX**: Oversampled spectral response; independent piece parts; E2E spectral calibration
- **ACX:** Oversampled spectral response; independent piece parts; E2E spectral calibration

Radiometric Calibration: Post-launch

- **GXI:** Blackbody and space for IR channels;
  Solar diffuser for VNIR channels
  Simultaneous Nadir Overpass (SNO) for LEOs
  Limited Vicarious Calibration (VicCal)
- **GXS:** Blackbody references for IR channels
- **LMX:** No calibrator; employ VicCal to GXI
- **OCX:** Solar diffuser; limited VicCal; SNO with LEOs
- **ACX:** Solar diffuser; SNO with LEOs and maybe GEO

Spectral Calibration: Post launch

- **GXI:** Relative spectral response during post-launch testing; SNO with LEOs
- **GXS:** SNO with LEOs
- **LMX:** Not planned
- **OCX:** Known solar and atmospheric absorption features; potential SNO with LEOs
- **ACX:** Known solar and atmospheric absorption features; potential SNO with LEOs

OCX Vicarious Calibration

NOAA's Marine Optical BuoY (MOBY)

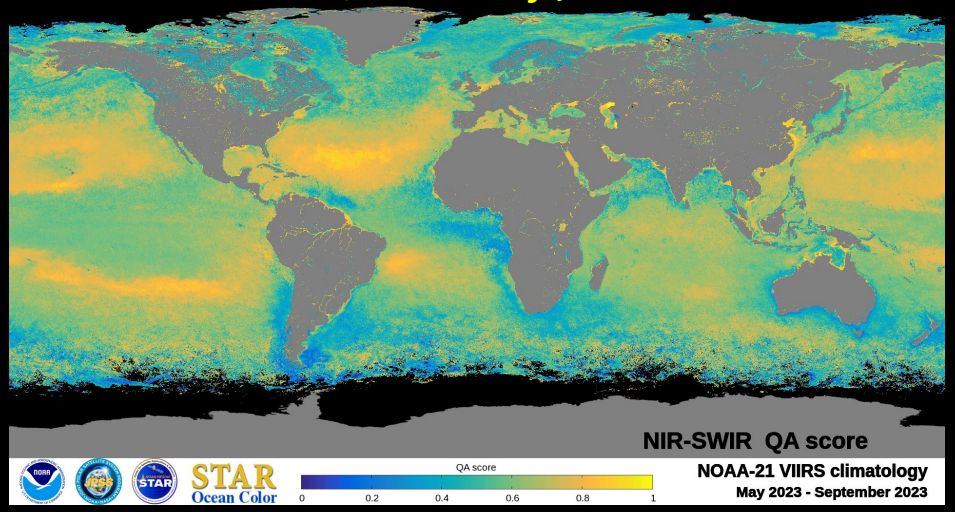
- System Vicarious Calibration is essential to achieve ocean color performance goals
- MOBY is consistent; continuous data connecting ocean color satellite sensors since 1997
- Direct traceability to NIST standards
- Hyperspectral: 1 nm resolution for 0.35-0.90 µm

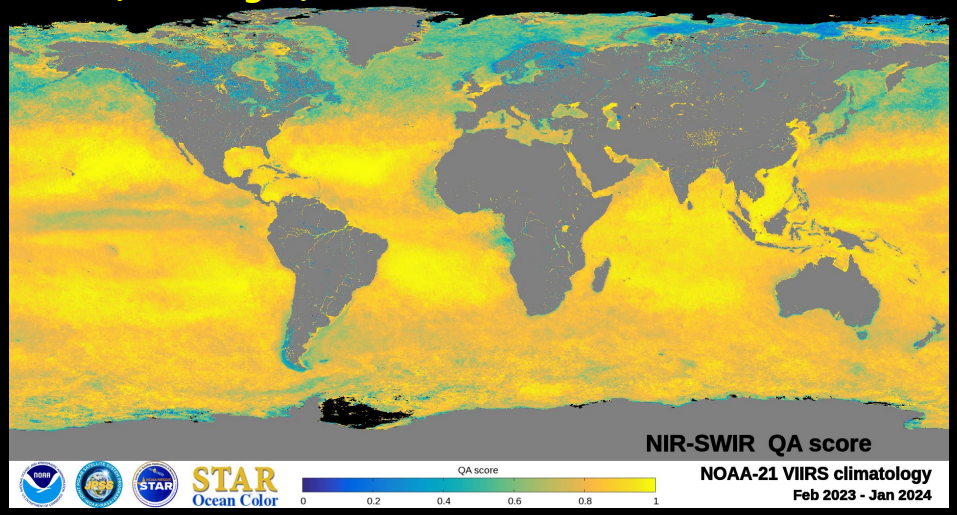
NOAA Ship-mounted Spectral Calibration

- Pilot study to install automated hyperspectral radiometers on multiple NOAA ships

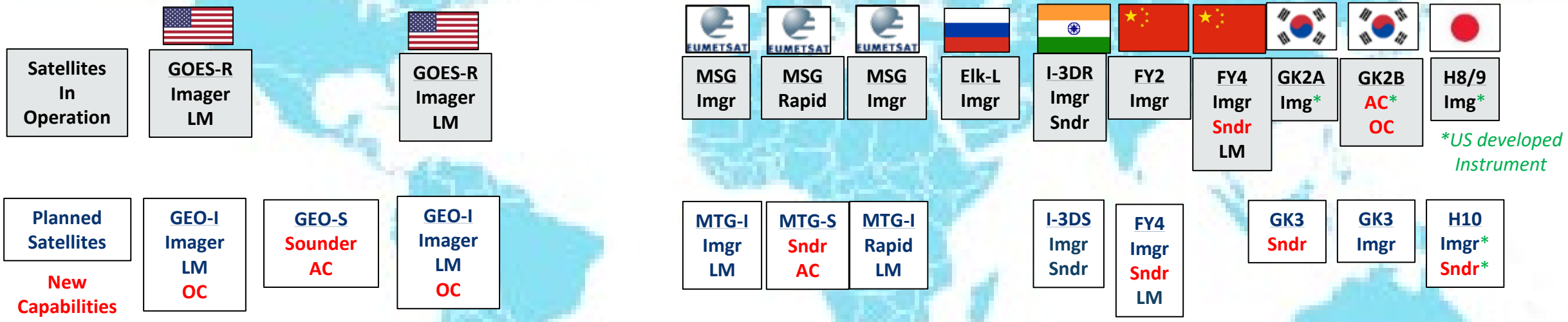
Dynamic Above-water Radiance (L) and Irradiance (E) Collector (DALEC)

VIIRS NIR-SWIR QA score: left, without vicarious calibration, and right, with MOBY vicarious calibration.



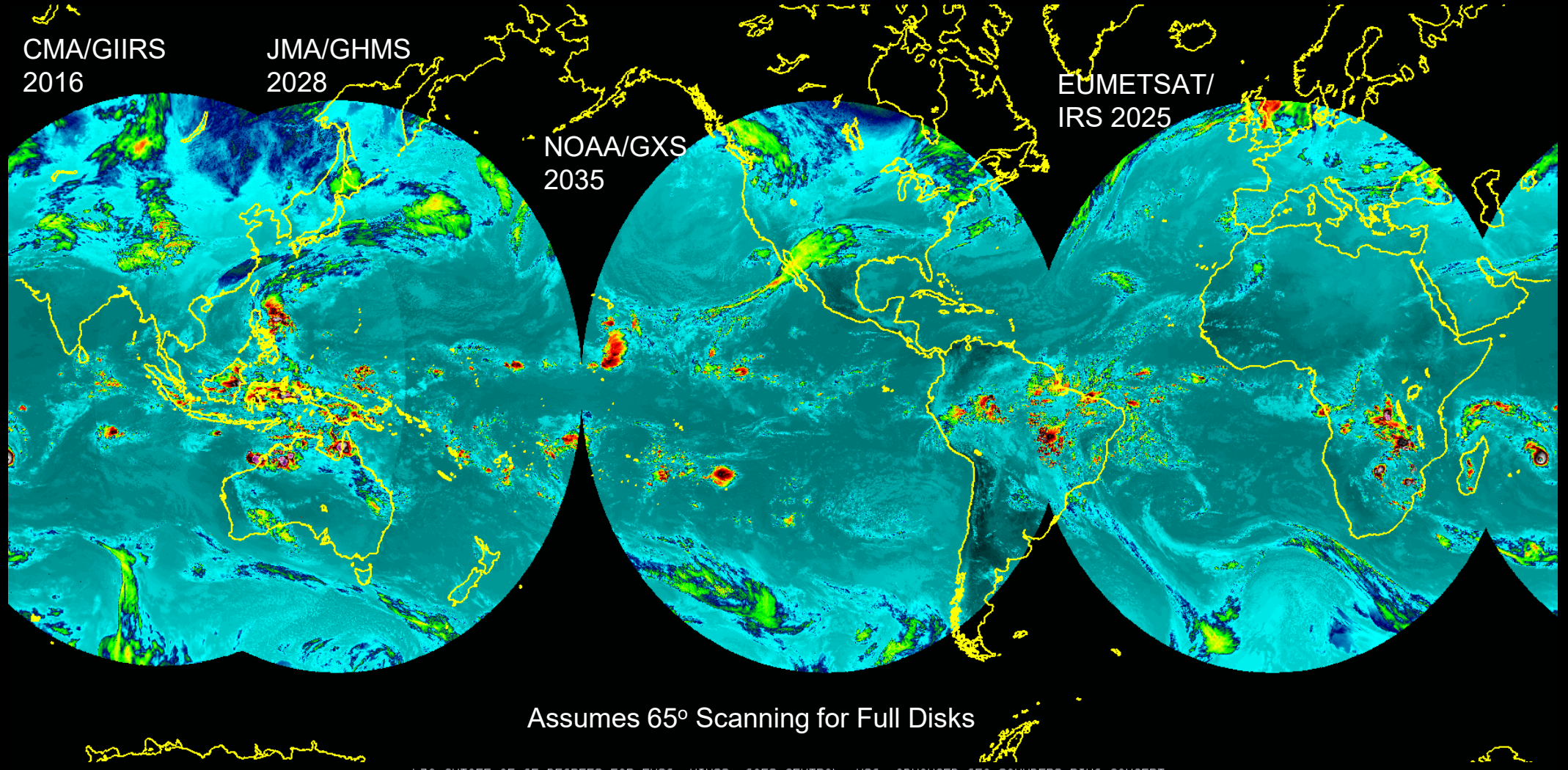


U.S. in the GEO Ring of Meteorological Satellites



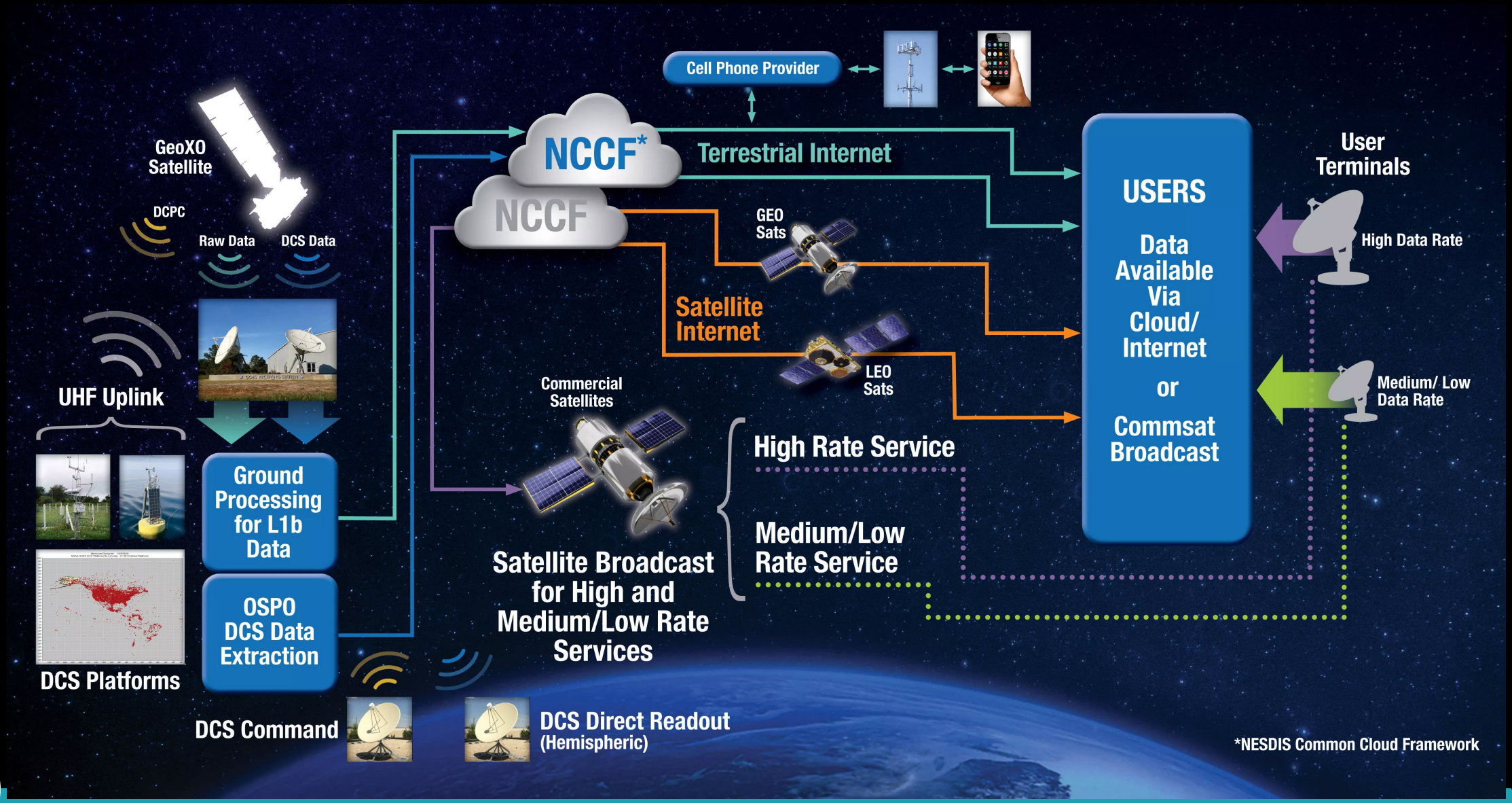
New capabilities for GeoXO allow NOAA to meet World Meteorological Organization objectives; match or exceed European and Chinese capabilities; encourage Japan and Korea to acquire U.S. instruments; and enable global real time sounding observations to be integrated into NWP.

GEO Ring of IR Sounders

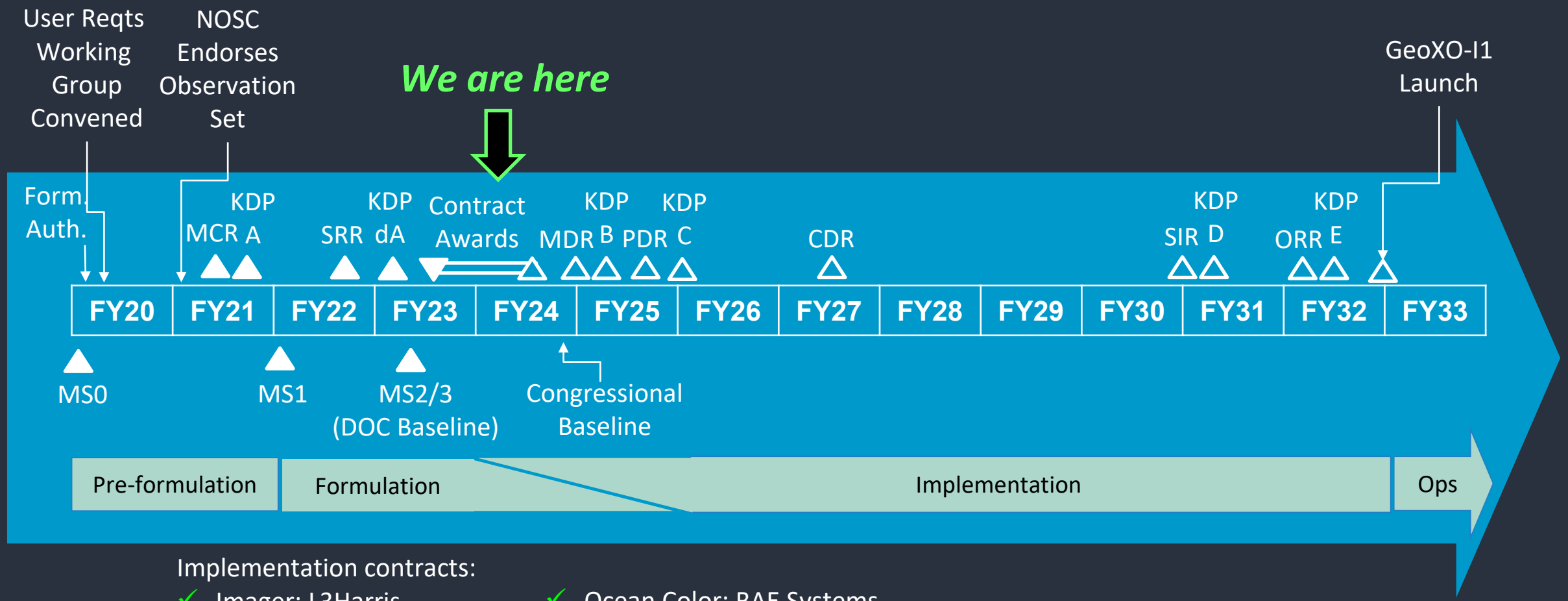


Assumes 65° Scanning for Full Disks

GeoXO User Data Distribution



GeoXO Timeline



Implementation contracts:

- ✓ Imager: L3Harris
- ✓ Sounder: BAE Systems
- ✓ Atmo. Comp.: BAE Systems
- ✓ Ocean Color: BAE Systems
- \- Spacecraft: target award June 2024
- \- Lightning Mapper: target award August 2024

Summary

- NOAA's GEO satellites provide the only persistent observations of weather across the Western Hemisphere, providing essential information for public safety and efficient economic activity across multiple sectors
- The GeoXO program will provide the required continuity following GOES-R and also extend observations to include monitoring of atmosphere, oceans, and climate to meet growing environmental and health challenges facing our nation and planet
- Expertly planned and executed calibration techniques will ensure GeoXO data meets accuracy requirements for the user community

GeoXO will maintain and advance U.S. observational capabilities through 2050

https://www.nesdis.noaa.gov/GeoXO