NASA Data for Air Quality

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OUTLINE

- Basics of Remote Sensing
- Satellite Aerosol Products
- Satellite Trace Gas Products
- Accessing NASA Data
  - BREAK
- GEOS-CF Air Quality Forecasts
- Bias-Corrected Forecasts

Applied Remote Sensing Training (ARSET)

ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.

Our trainings are:

- Online and in-person
- Open to everyone
- Live, instructor-led, or self-guided
- Provided at no cost, with materials and recordings available from our website
- Often multi-lingual
- Tailored to those with a range of experience in remote sensing, from **introductory** to **advanced**

ARSET offers trainings for:

- Disasters
- Health & Air Quality
- Land Management
- Water Resources
- Climate

https://appliedsciences.nasa.gov/arset

Health and Air Quality Applied Science Team (HAQAST)

"Our goal is to use NASA's data and satellites to pursue cutting edge applied research in order to keep you healthy and safe."

- Use NASA satellite & other data to help solve real-world public health and air quality problems.
- Work around the world on diverse issues related to health and air quality.
- Collaborate with public stakeholders to help guide long-term research.
- "Tiger Teams" pursue short-term, high-impact projects in small groups.

HAQAST

Getting started with NASA satellite data for health and air quality:
https://haqast.org/getting-started/

https://haqast.org/

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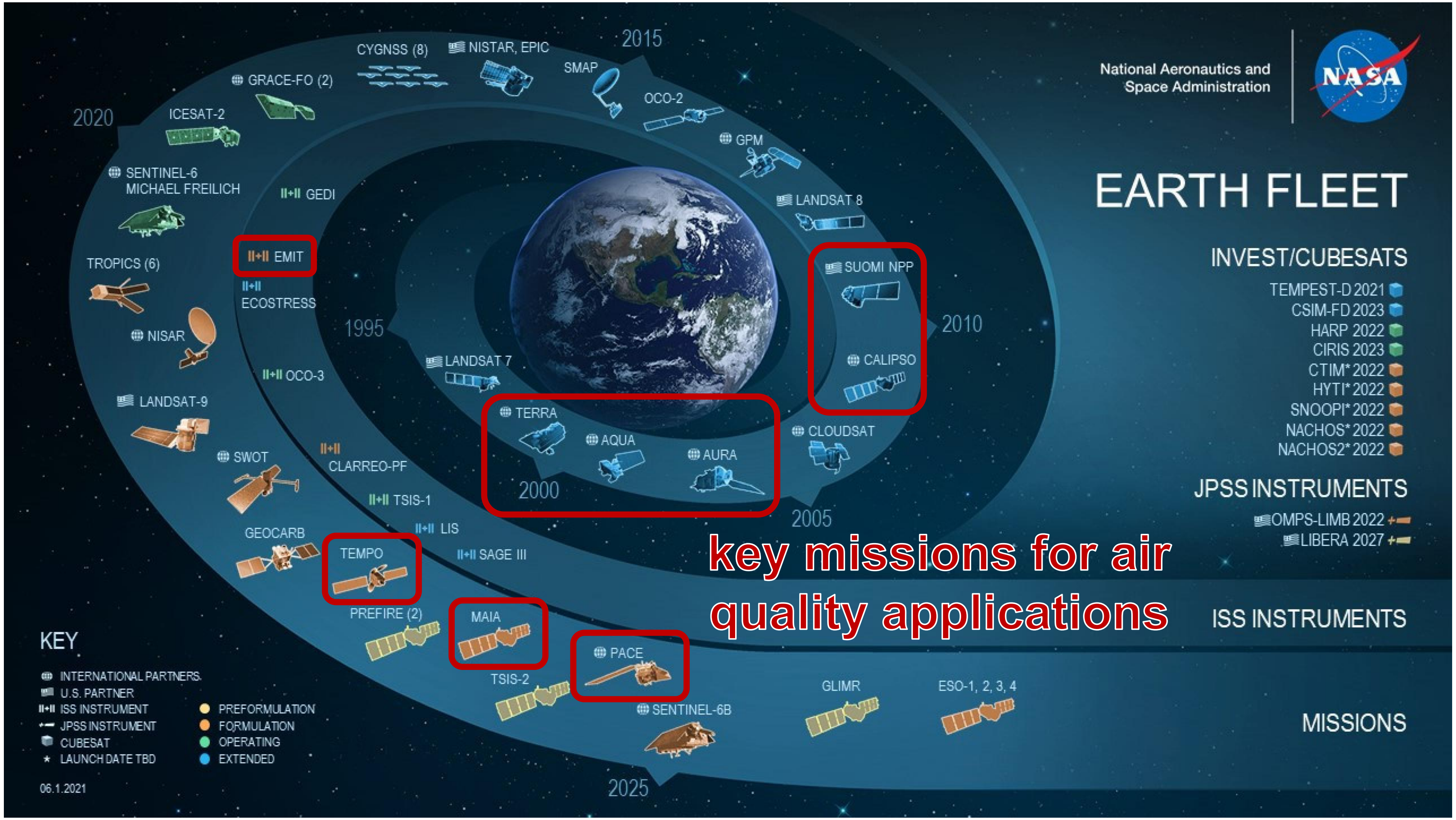
The NASA Earth Observing Fleet

- NASA (and other space agencies) operate fleets of earth observation satellites, many of which have a primary (or key secondary) function of observing the state and composition of the global atmosphere, including properties relevant for air quality applications.
- Satellites provide remotely sensed retrievals of geophysical quantities
- These can be interpreted, with the aid of atmospheric chemistry models, to inform us about surface air quality.



Source: NASA Earth Science https://science.nasa.gov/earth-science

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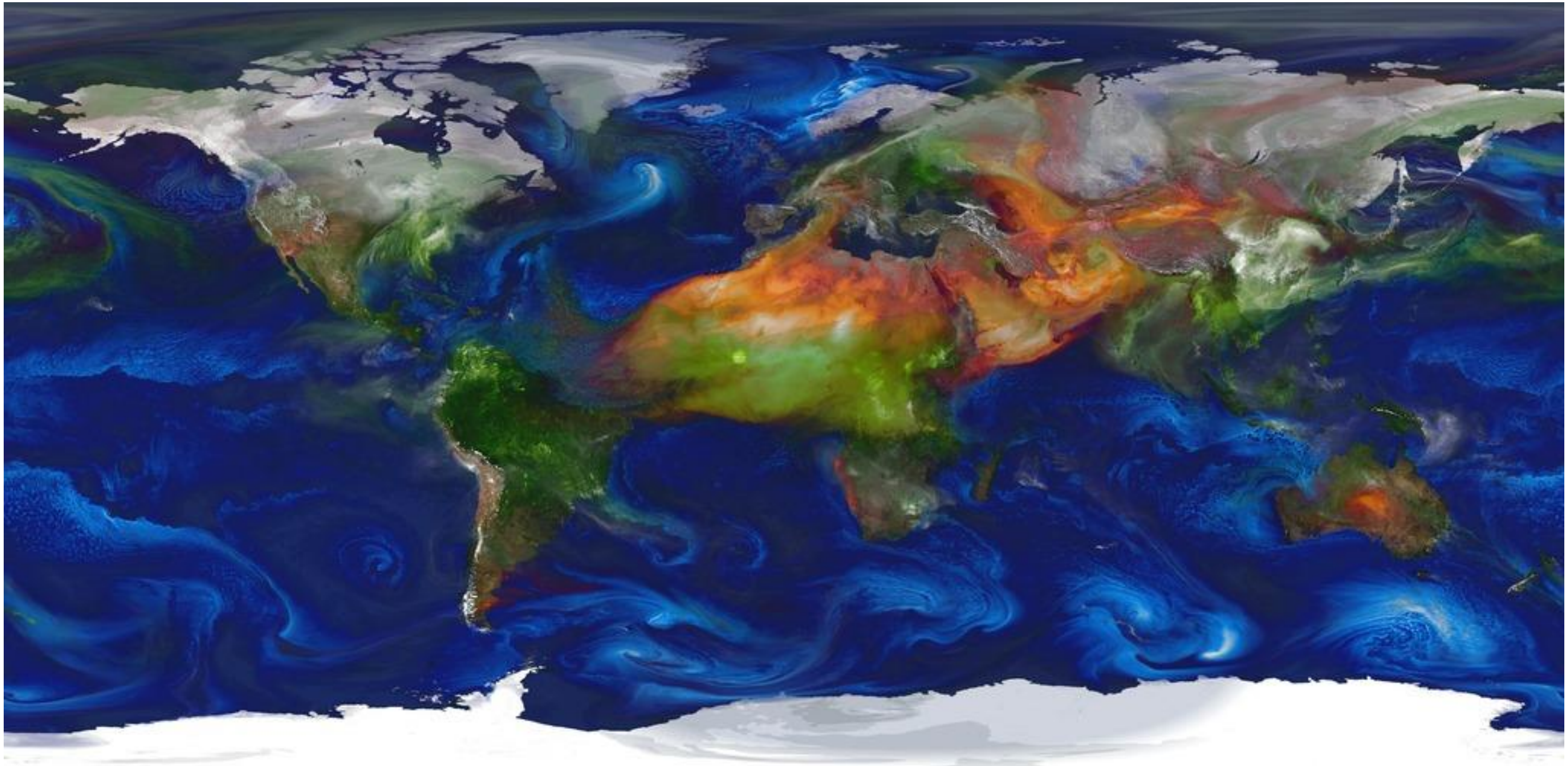
NASA Global Modeling



Source: “GEOS-5 Aerosols Simulation for SC 2014”, Scientific Visualization Studio, NASA GSFC. https://svs.gsfc.nasa.gov/30637

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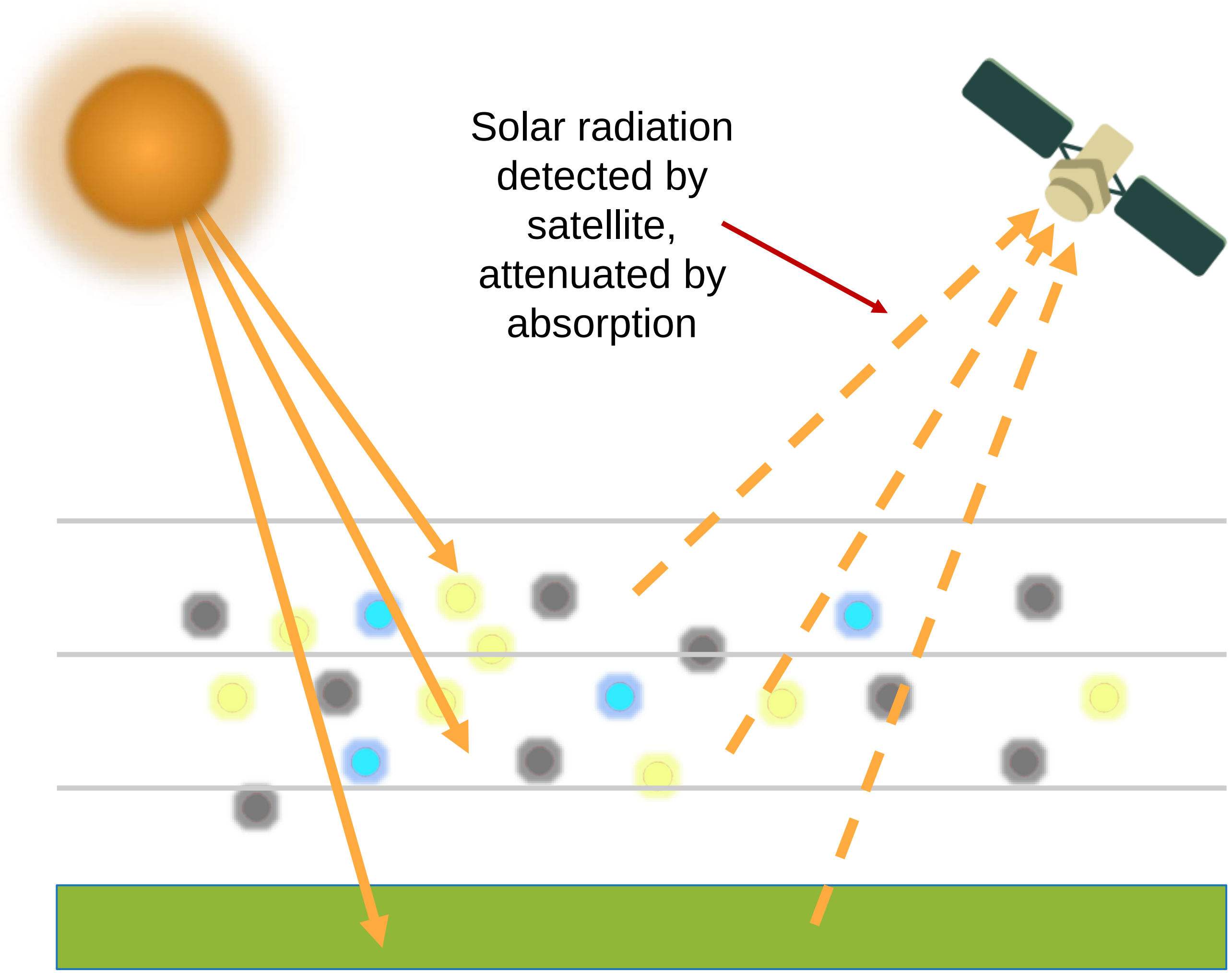
Principles of Remote Sensing

- Satellites detect & quantify backscattered UV, visible, and/or emitted thermal radiation from the Earth's surface and atmosphere.
- Retrieval algorithms use this radiation data and physics-informed models to infer geophysical quantities such as optical depth, particle number density, partial pressure, column amount.
- We can calculate an Aerosol Optical Depth for all aerosols in the atmosphere using the measured scattering and absorption of visible light.
- We can determine a "spectral fingerprint" for many trace gases based on their absorptions and use this to retrieve the trace gas total column density.



Source: Gupta, P.; Follette-Cook, M.; Strode, S.; Malings, C. (2023). ARSET - NASA Air Quality-Focused Remote Sensing for EPA Applications. NASA Applied Remote Sensing Training Program (ARSET). http://appliedsciences.nasa.gov/join-mission/training/english/arset-nasa-air-quality-focused-remote-sensing-epa-applications

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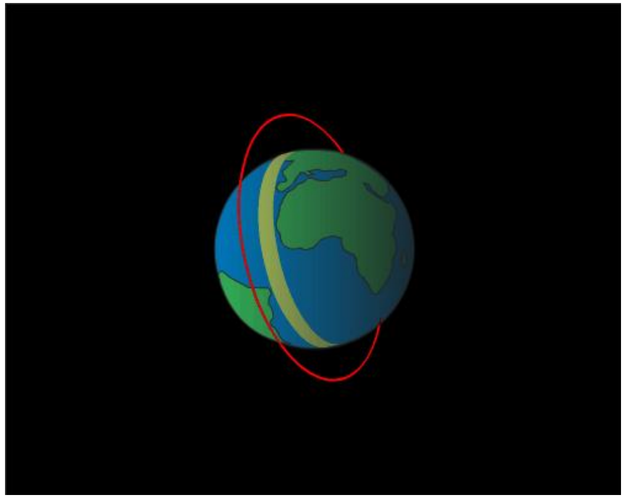
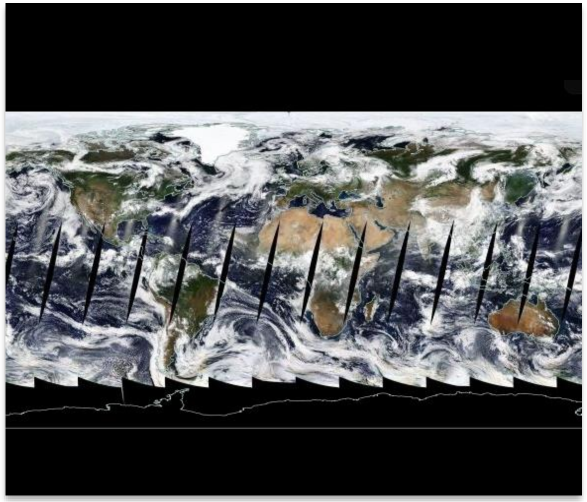
Typical Satellite Orbits

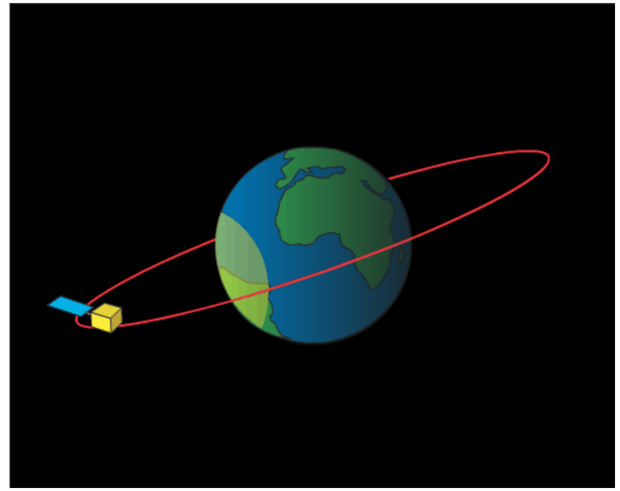


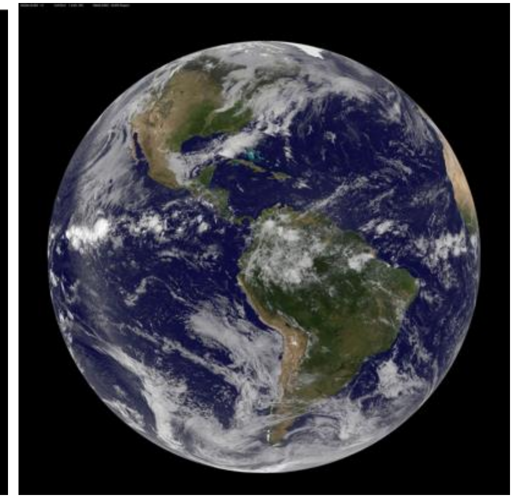


Polar Orbit (LEO)

Sun synchronous orbit ~600-1,000 km above Earth passing close to the North and South poles with passes at **similar local solar time** each day

Most instrument achieve **full global coverage** every 1-2 days





Geostationary Orbit (GEO)

Orbit ~36,000 km above the Equator with the same rotational period as Earth

Appears ‘fixed’ above Earth, offering a **continuous daytime view** of the same place

Always covers the same hemisphere

Source: Gupta, P.; Follette-Cook, M.; Strode, S.; Malings, C. (2023). ARSET - NASA Air Quality-Focused Remote Sensing for EPA Applications. NASA Applied Remote Sensing Training Program (ARSET). http://appliedsciences.nasa.gov/join-mission/training/english/arset-nasa-air-quality-focused-remote-sensing-epa-applications

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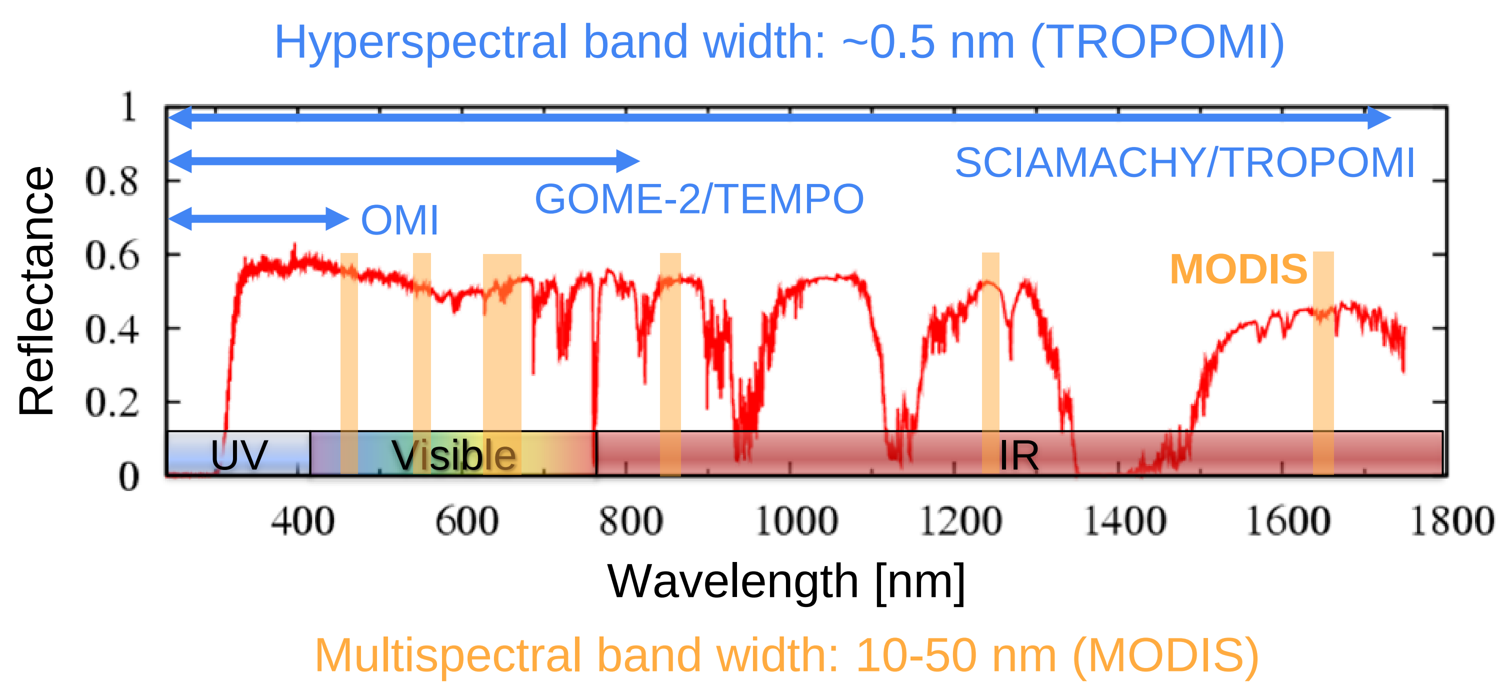
Multispectral & Hyperspectral

- **Multispectral** instruments have larger spectral band widths
  - Coarser spectral resolution is suitable for detecting certain prominent atmospheric features
  - Aerosol optical depth at ~550nm wavelength is generally well suited for measuring ambient particulate matter

- **Hyperspectral** instruments have smaller spectral band widths
  - This higher spectral resolution is necessary for distinguishing the absorption spectra of different trace gases.



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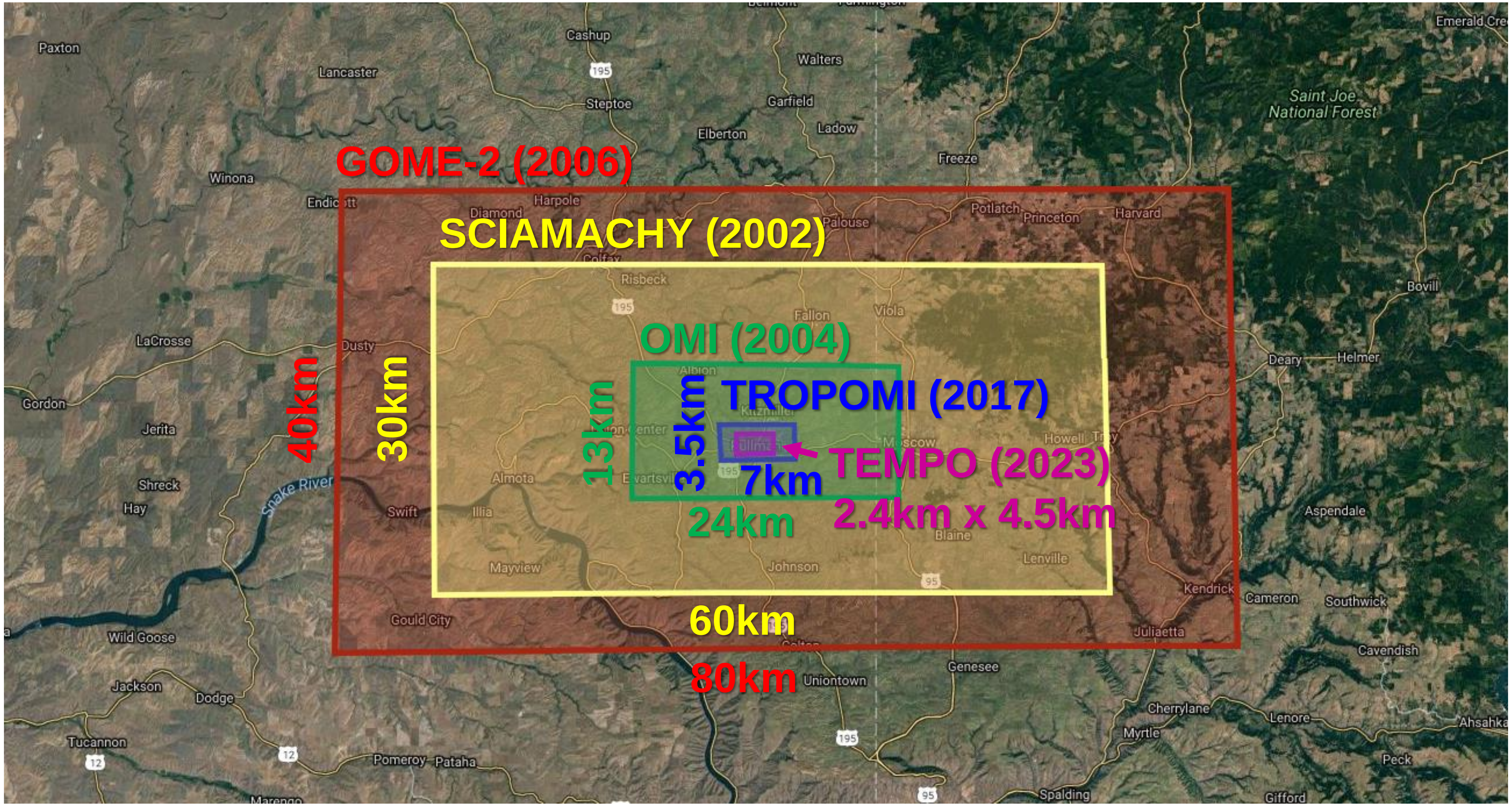
Improving Spatial Resolution



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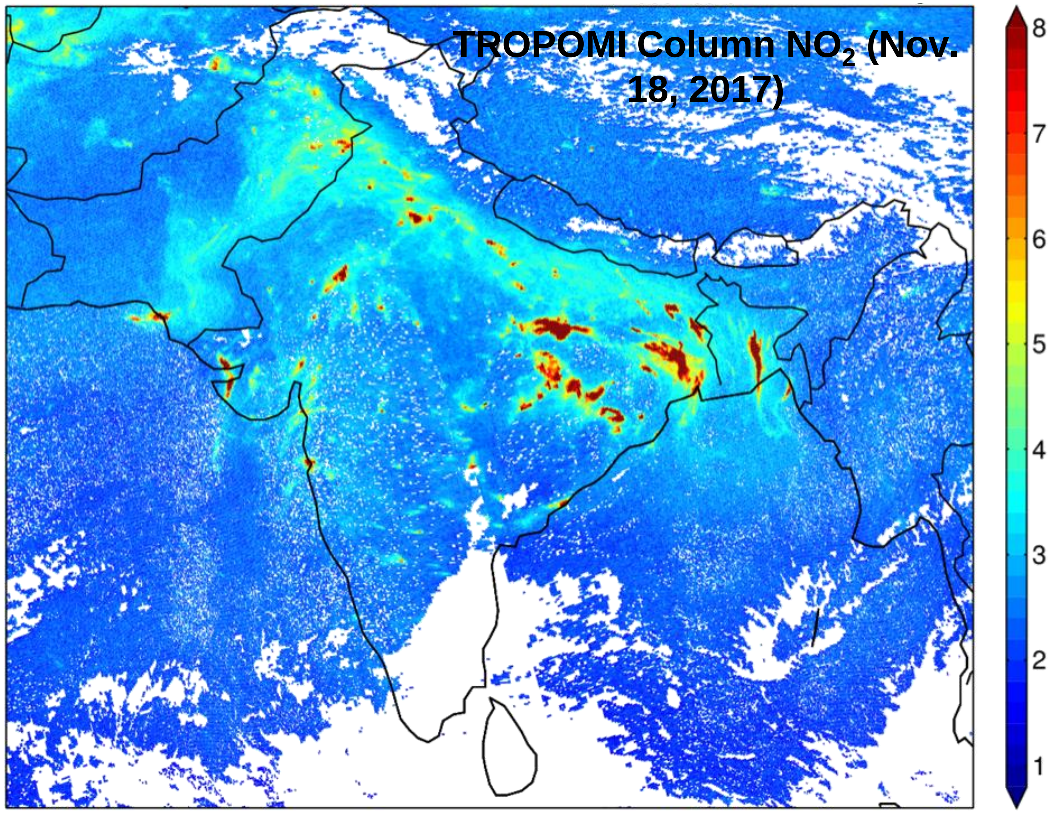
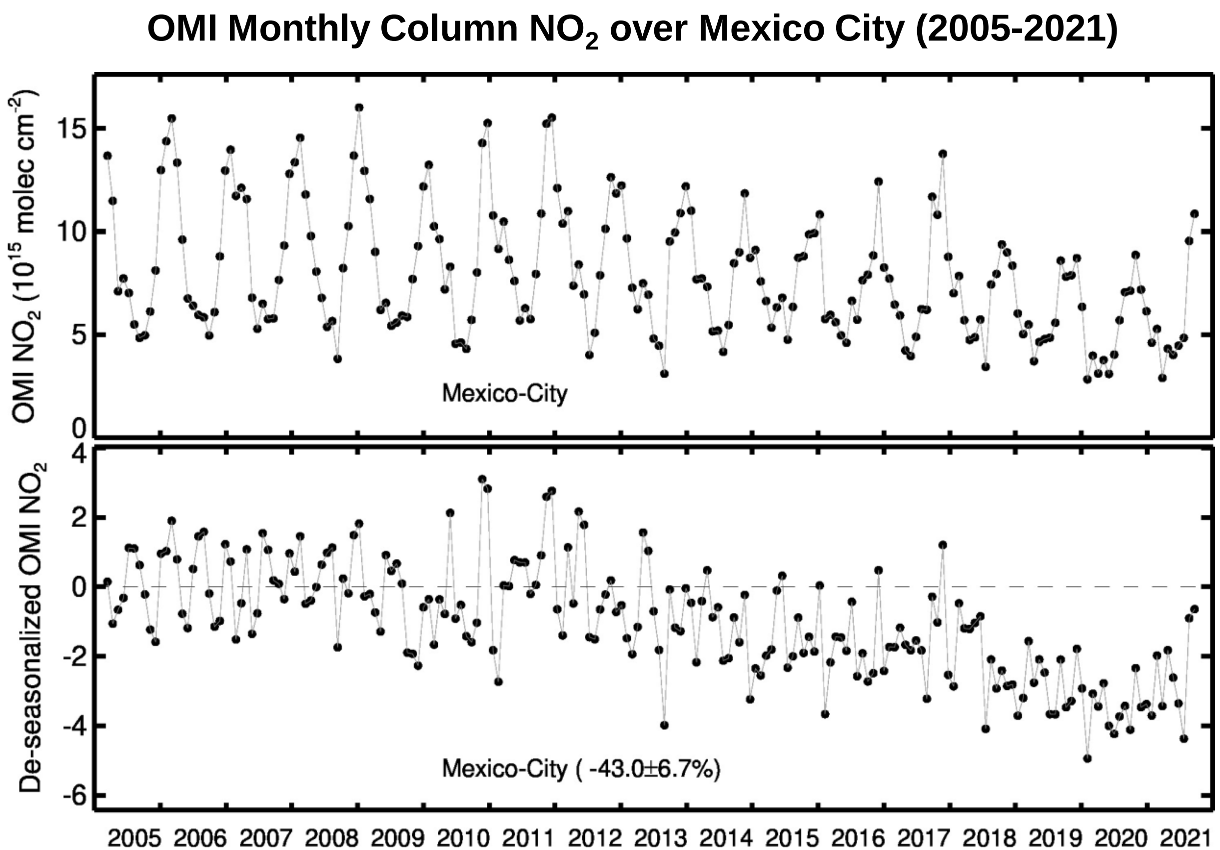
Pros for Air Quality Applications





- **Examine a large area**: where are the hotspots? how is long-range transport happening?
- **Track changes over time:** how much has the average concentration over an area changed over time?

Sources: Gupta, P.; Follette-Cook, M. (2018). Satellite Remote Sensing of Air Quality. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-remote-sensing-air-quality

NASA GSFC Nitrogen Dioxide Trends for World Cities: https://airquality.gsfc.nasa.gov/no2/world

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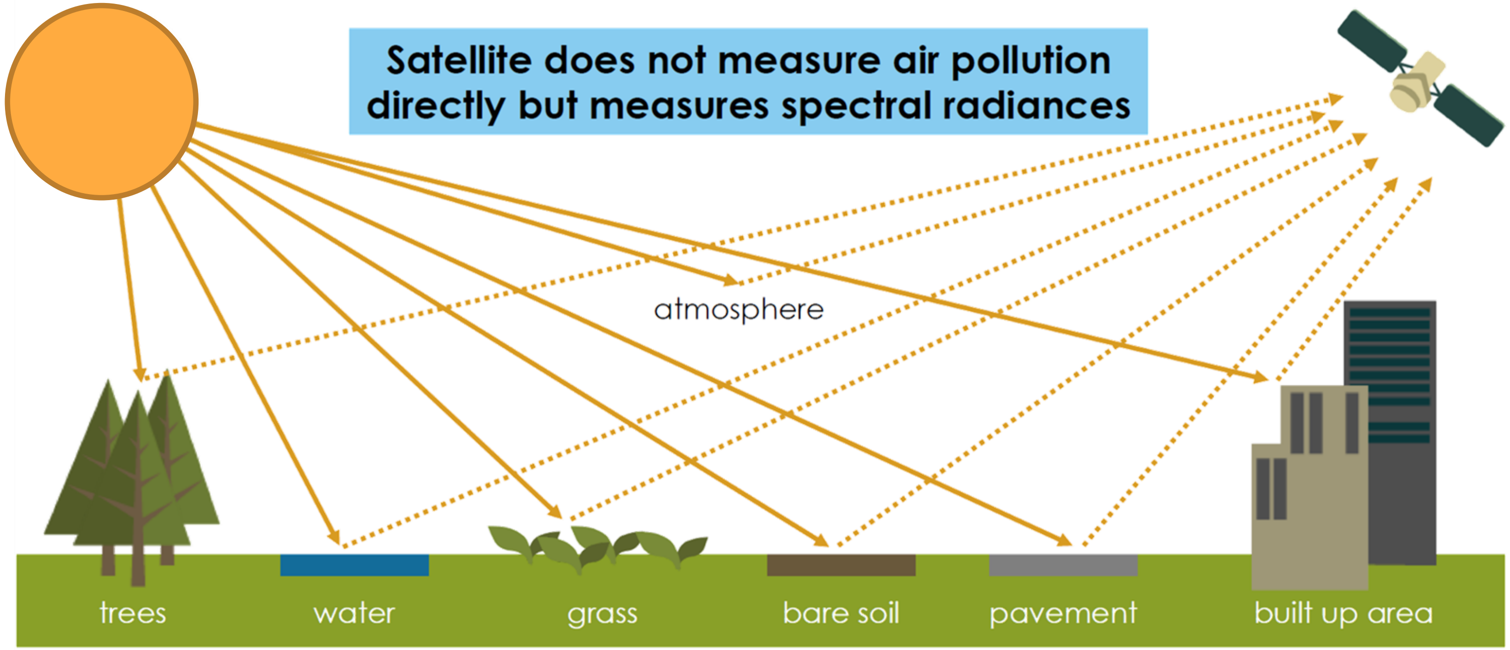
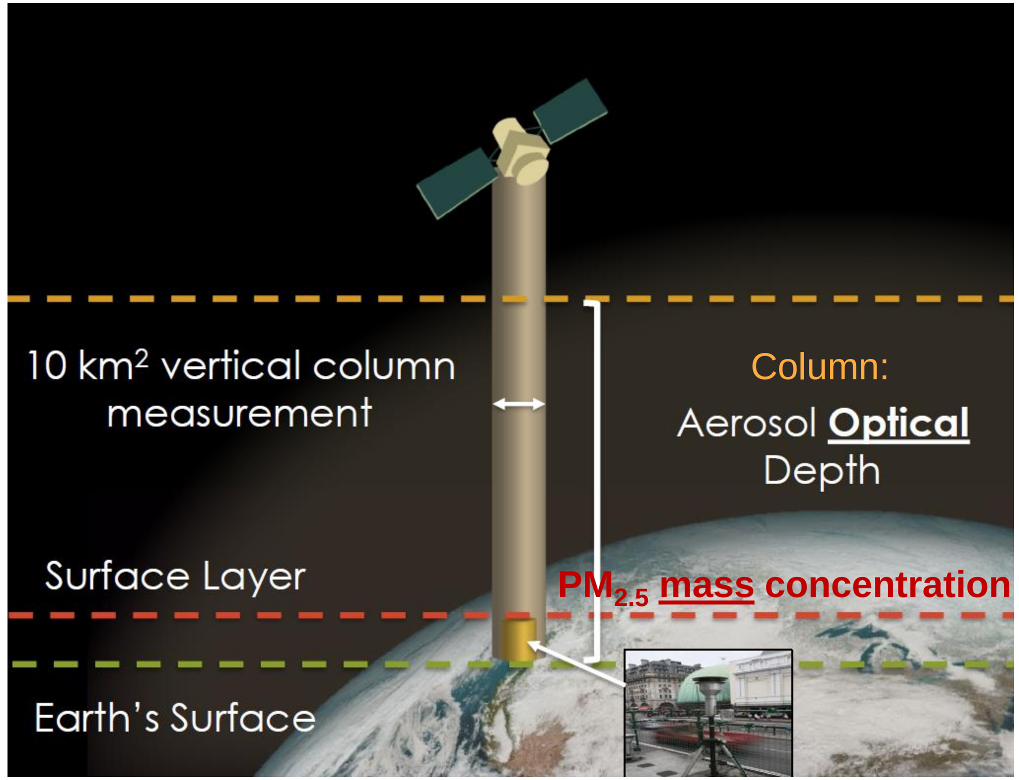
Cons for Air Quality Applications





- **Night:** most satellites require sunlight to make their retrievals.
- **Clouds & Smoke:** most satellite measurements are blocked by clouds and dense smoke.
- **"Nose Level" Data:** most satellites measure the whole atmosphere, not just the surface.
- **Overpass Times:** polar-orbiting satellites observe a location about once per day at similar local times. Geostationary satellites observe at more times, but still only during the day.

Source: Gupta, P.; Follette-Cook, M. (2018). Satellite Remote Sensing of Air Quality. NASA Applied Remote Sensing Training Program (ARSET).
https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-remote-sensing-air-quality

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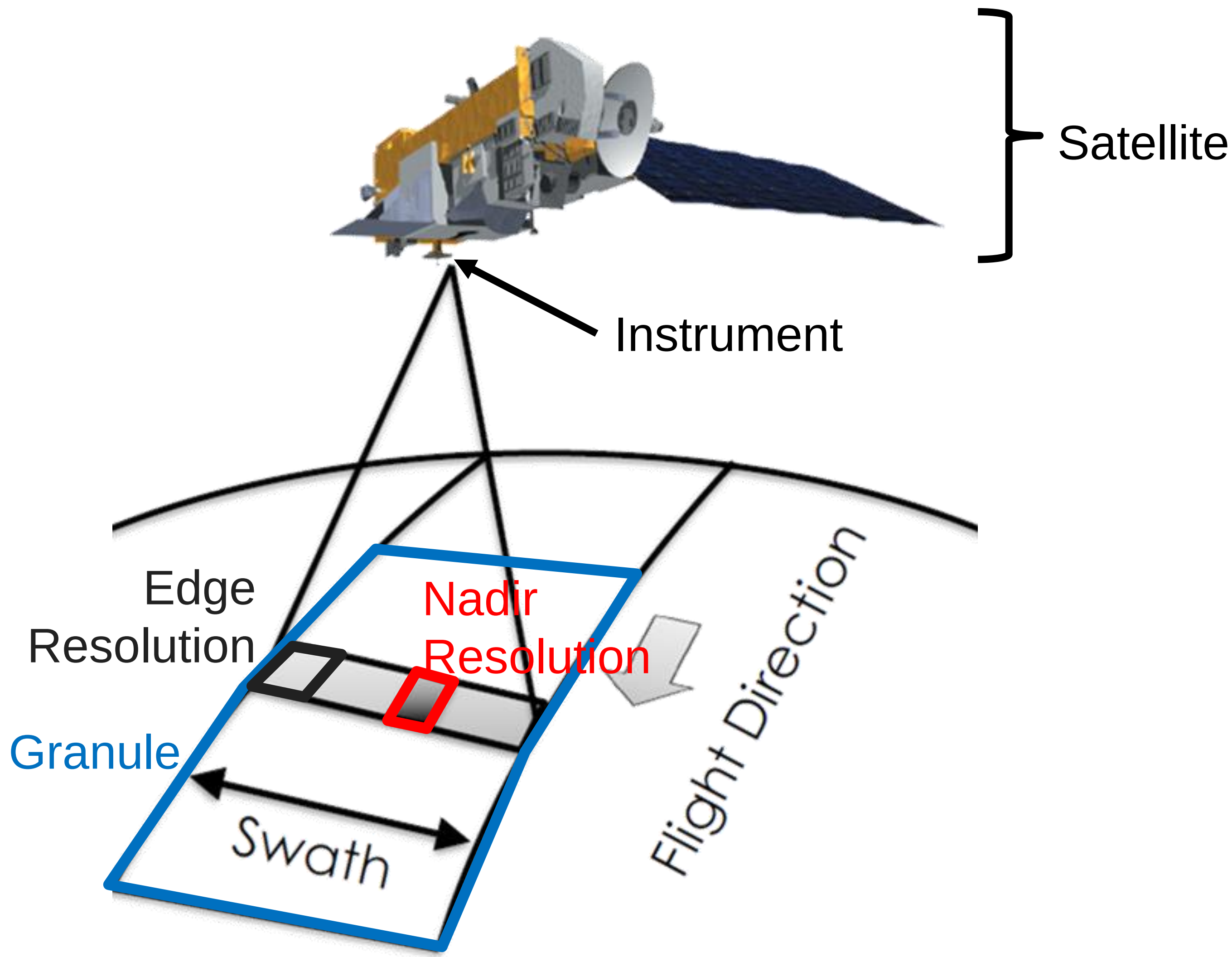
Common Satellite Data Terms

- Satellite v. Instrument
- Swath or Field of Regard
- Overpass time (local solar time)
- Equator crossing time
- Ascending/Descending
- Temporal Resolution/Return period
- Spatial Resolution (nadir v. edge)
- Spectral Resolution
- Data product
- Granule
- Quality flags and masks
- Column concentration
- Aerosol Optical Depth/Thickness
- Processing level



Source: Follette-Cook, M.; Prados, A.; Gupta, P. (2020). An Inside Look at How NASA Measures Air Pollution. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/join-mission/training/english/arset-inside-look-how-nasa-measures-air-pollution

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Satellite Data Processing Levels

- **Level 0:** Raw data
- **Level 1:** Geo-referenced raw data
- **Level 2:** Derived geophysical variables (e.g., column concentrations)
- **Level 3:** Data re-mapped to uniform space & time grids
- **Level 4:** Data combined together from multiple sources (e.g., satellite and model data)

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Source: NASA EarthData https://earthdata.nasa.gov/collaborate/open-data-services-and-software/data-information-policy/data-levels

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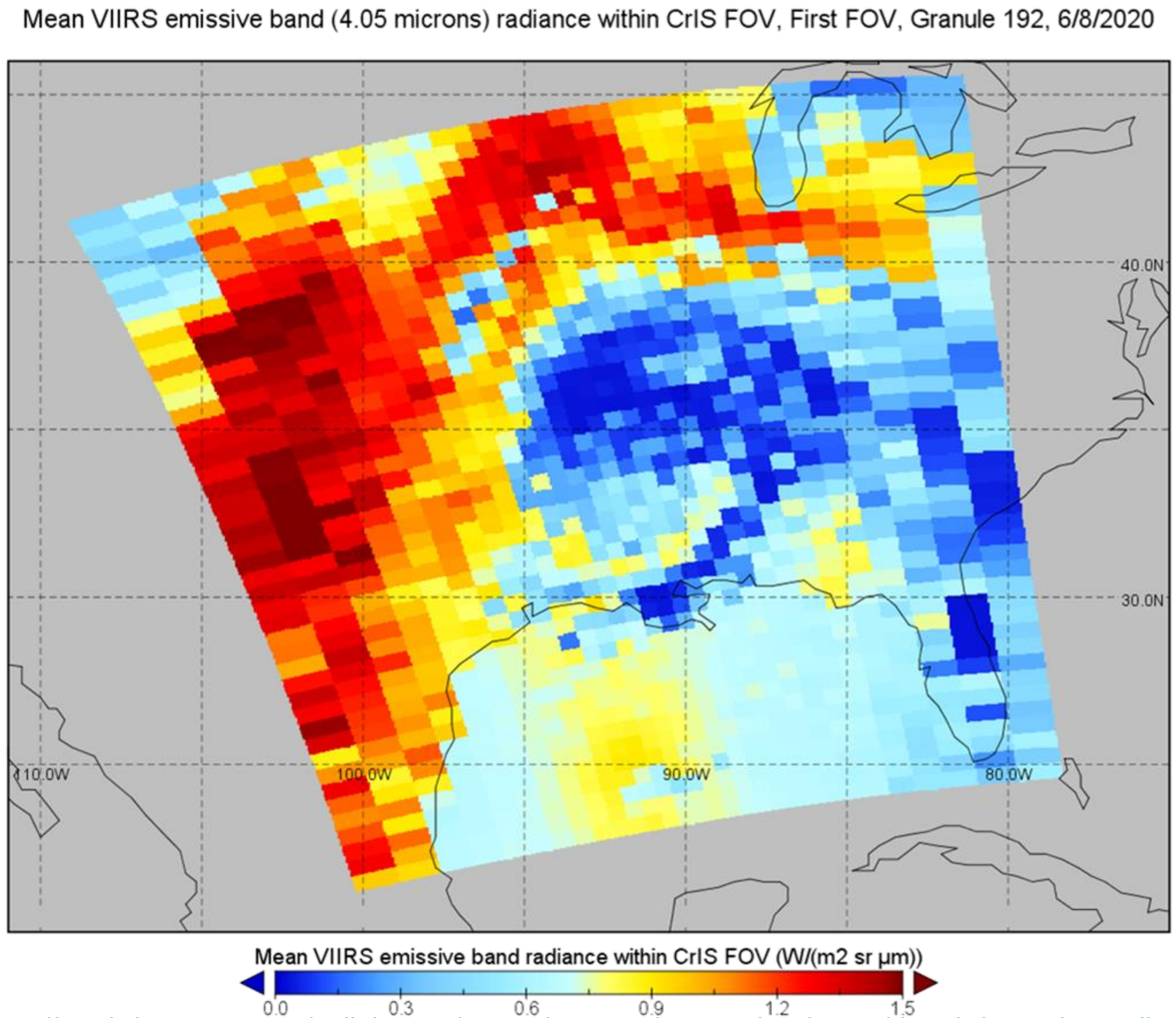

Source: NASA EarthData https://earthdata.nasa.gov/collaborate/open-data-services-and-software/data-information-policy/data-levels
NASA GES DISC https://disc.gsfc.nasa.gov/datasets/SNDRSNCrISL1BIMG_2/summary

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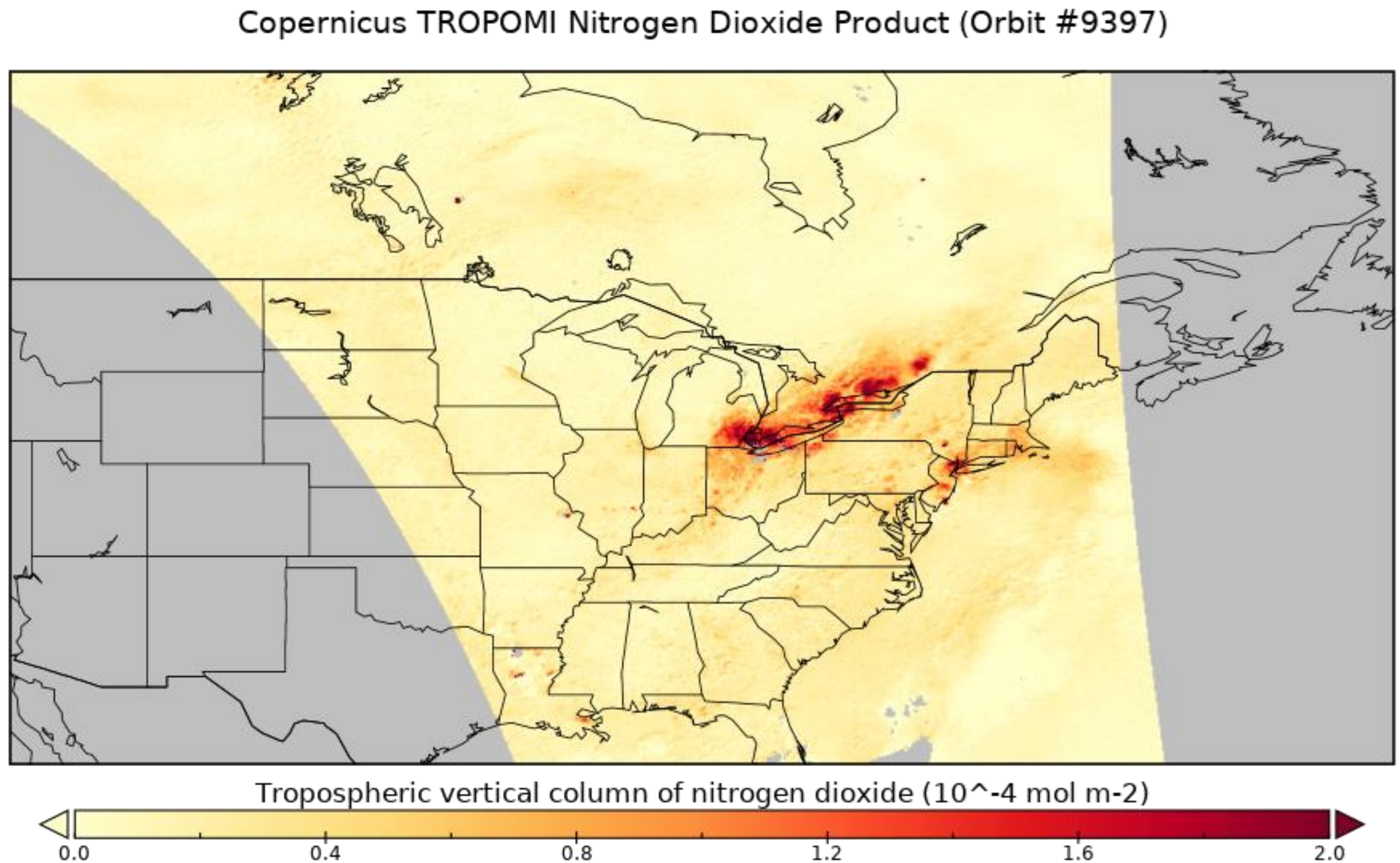

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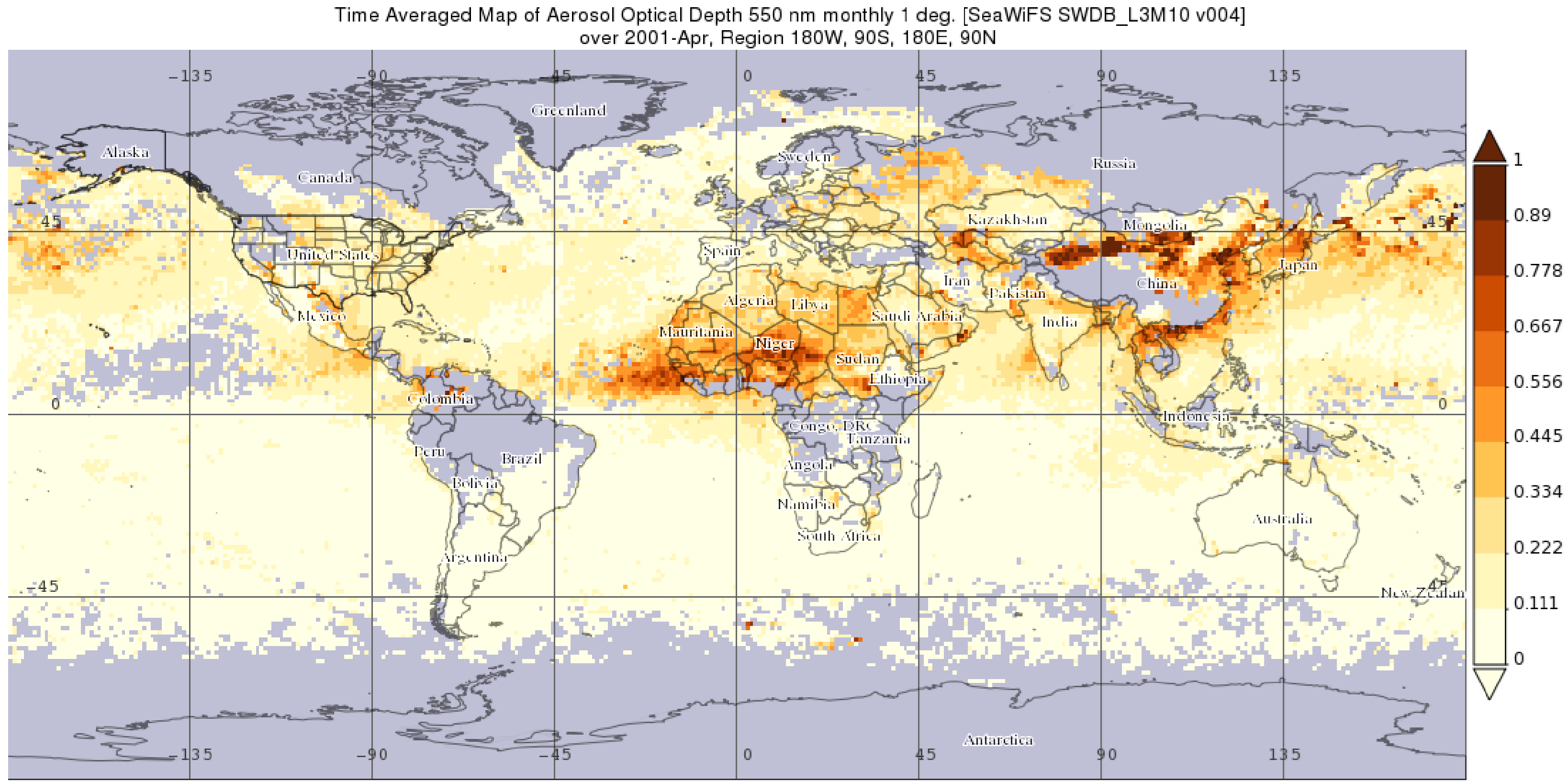

Source: NASA EarthData https://earthdata.nasa.gov/collaborate/open-data-services-and-software/data-information-policy/data-levels
NASA GES DISC https://disc.gsfc.nasa.gov/datasets/SWDB_L3M10_004/summary

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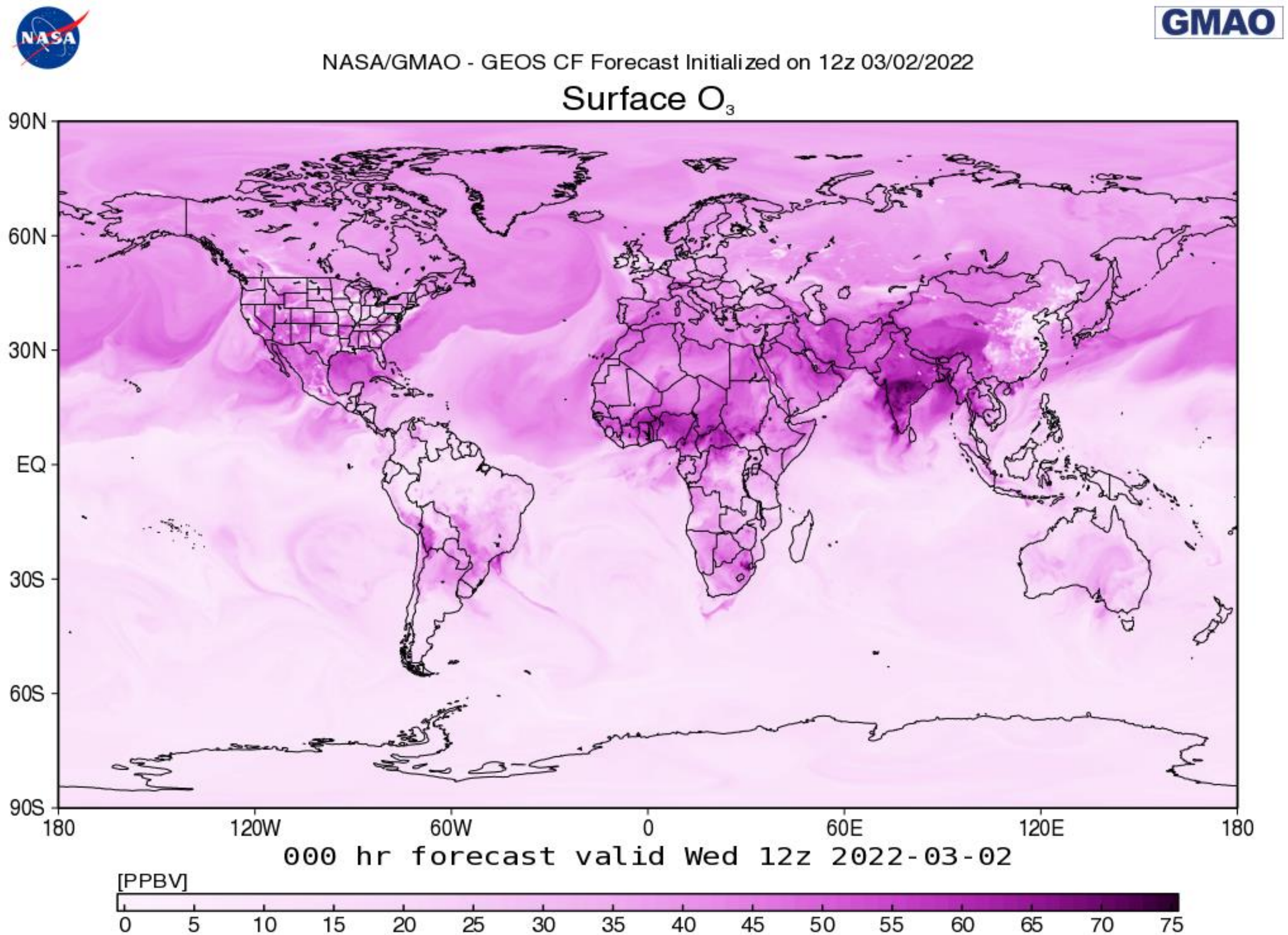

Source: NASA EarthData https://earthdata.nasa.gov/collaborate/open-data-services-and-software/data-information-policy/data-levels
NASA GMAO FLUID Tool https://fluid.nccs.nasa.gov/cf/classic_geos_cf/?one_click=1&tau=000&stream=GEOSCFFC&level=0&region=global&fcst=20220302T120000&field=o3sfc

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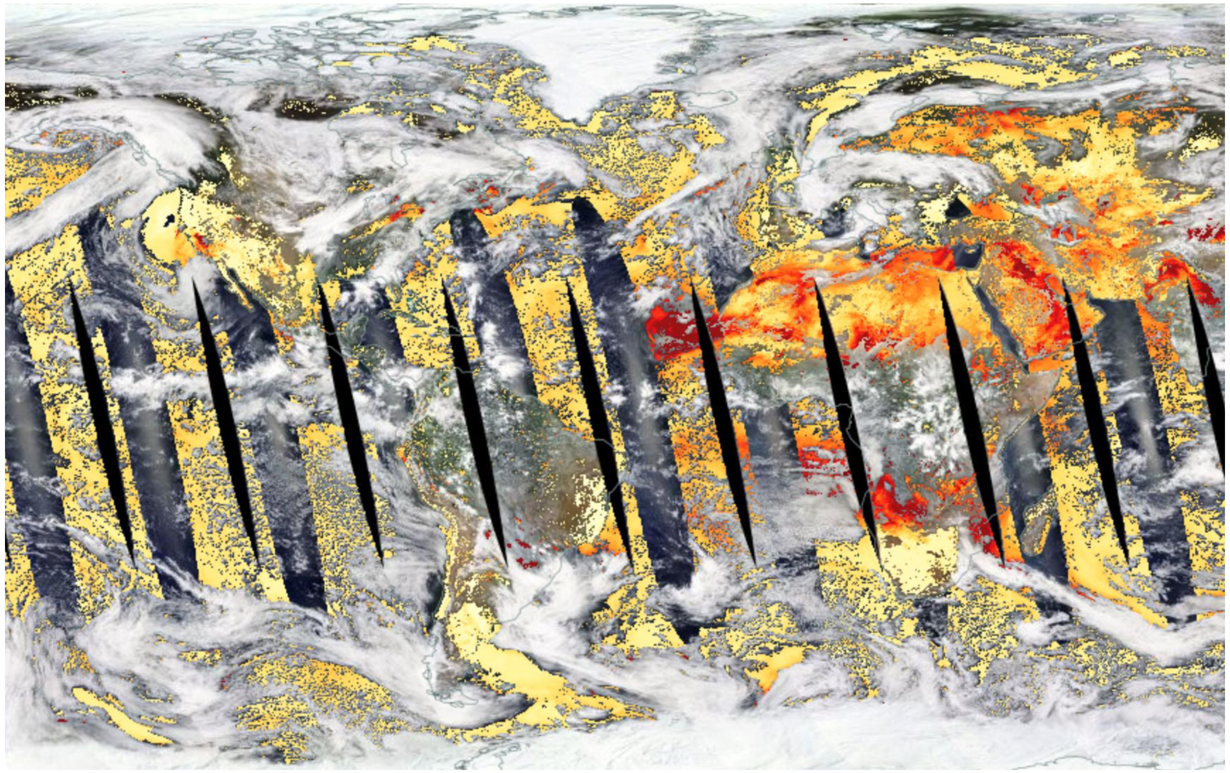
MODIS and VIIRS

MODIS		VIIRS
Aqua, Terra	Satellites	SNPP, NOAA-20, NOAA-21
1999, 2002	Launched	2011, 2017, 2022
Moderate Resolution Imaging Spectroradiometer	Instrument	Visible Infrared Imaging Radiometer Suite
405 - 14385 nm (IR, Visible)	Spectral Range	412 - 12100 nm (IR, Visible)
36	Spectral Bands	22
0.5 – 2 km pixel edge	Spatial Resolution	0.75 – 1.5 km pixel edge
1-2 Days	Global Coverage	Daily
~ 10:30, 13:30 LST	Local Overpass Time	~ 12:30, 13:30 LST

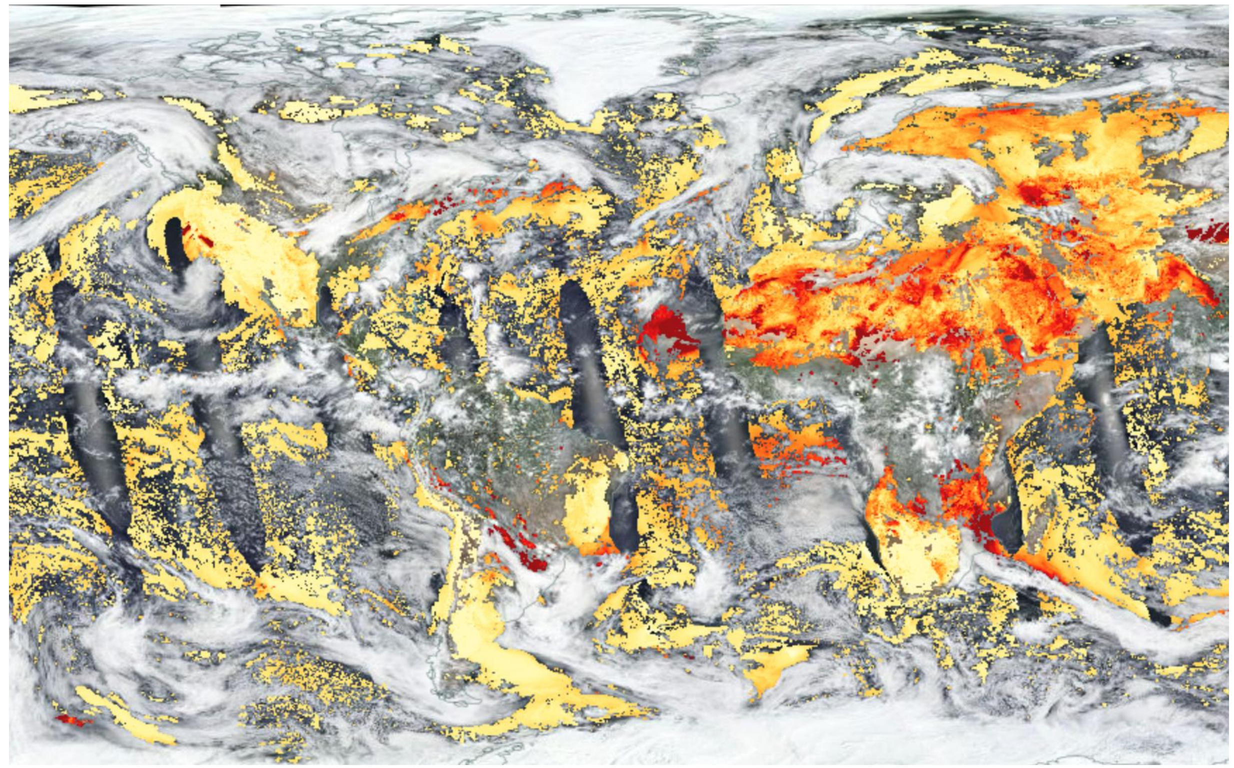
MODIS and VIIRS: Air Quality

MODIS		VIIRS	
True Color Image	-	True Color Image	-
Aerosol Optical Depth	MOD/MYD04_L2 (10km) MOD/MYD04_3K (3km) MCD19A2 (1km) Gridded (1°)	Aerosol Optical Depth	AERDB_L2_VIIRS (6km) AERDT_L2_VIIRS (6km) JRR-AOD_v2r3 (0.75km) Gridded (1°)
Fire Detection	MOD/MYD04A1 (1km)	Fire Detection	VNP12IMGTDL_NRT VJ114IMGTDL_NDT (0.375km)
		Smoke Detection	-
		Dust Detection	-

Aerosol Optical Depth



MODIS-Aqua (DB)



VIIRS-SNPP (DB)

Source: Gupta, P.; Follette-Cook, M.; Strode, S.; Malings, C. (2023). ARSET - NASA Air Quality-Focused Remote Sensing for EPA Applications. NASA Applied Remote Sensing Training Program (ARSET). http://appliedsciences.nasa.gov/join-mission/training/english/arset-nasa-air-quality-focused-remote-sensing-epa-applications

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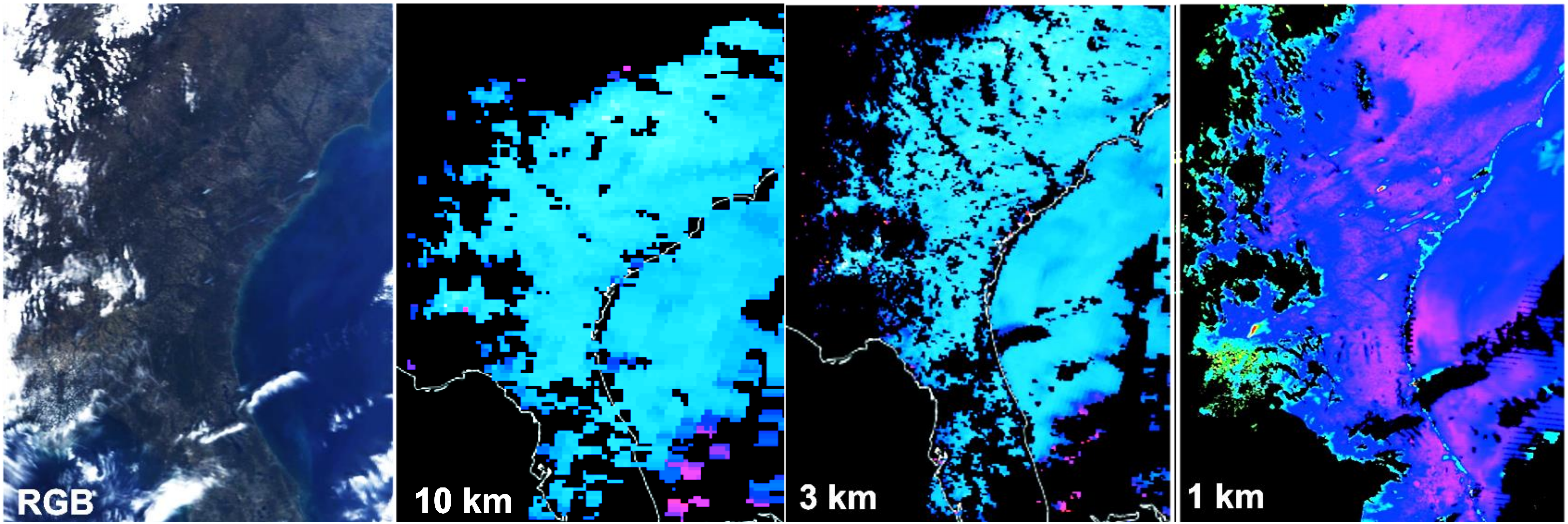
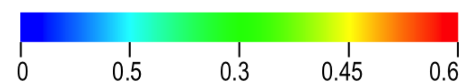
Different Retrieval Algorithms

Deep Blue / Dark Target | **Dark Target** | **MAIAC**



Deep Blue: land only, best for bright surfaces

Dark Target: land & water, best for dark surfaces



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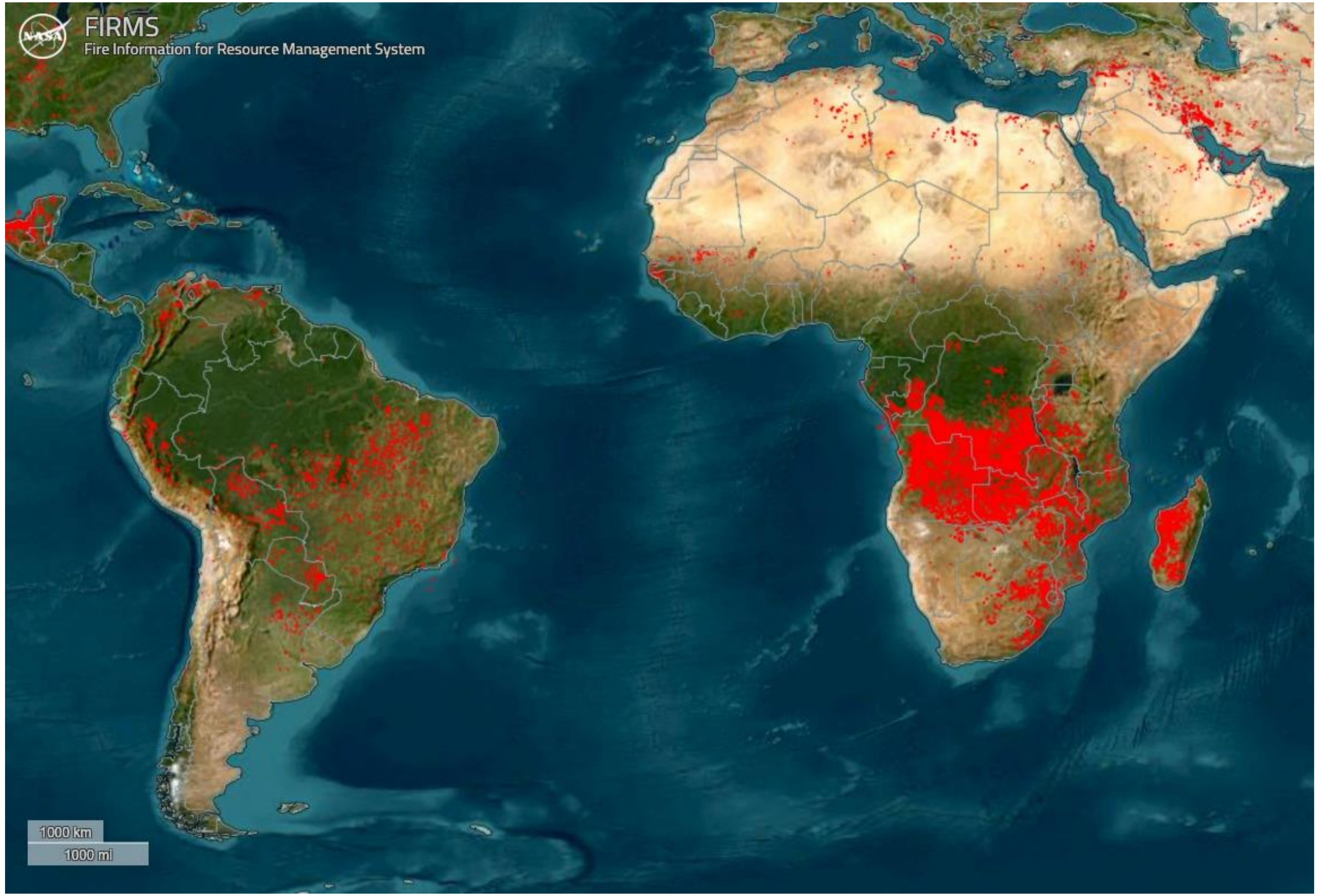
Fire Detection

- **Thermal Anomalies**
  - Detection of extreme temperatures
  - Indicative of active burning
  - Thick smoke can block signal
  - May miss small fires
- **Fire Radiative Power (FRP)**
  - Rate of emitted radiative energy by a fire
- **Fire Radiative Energy (FRE)**
  - Time integrated FRP
  - Correlation between FRE and fire emissions



Source: NASA FIRMS https://https://firms.modaps.eosdis.nasa.gov/

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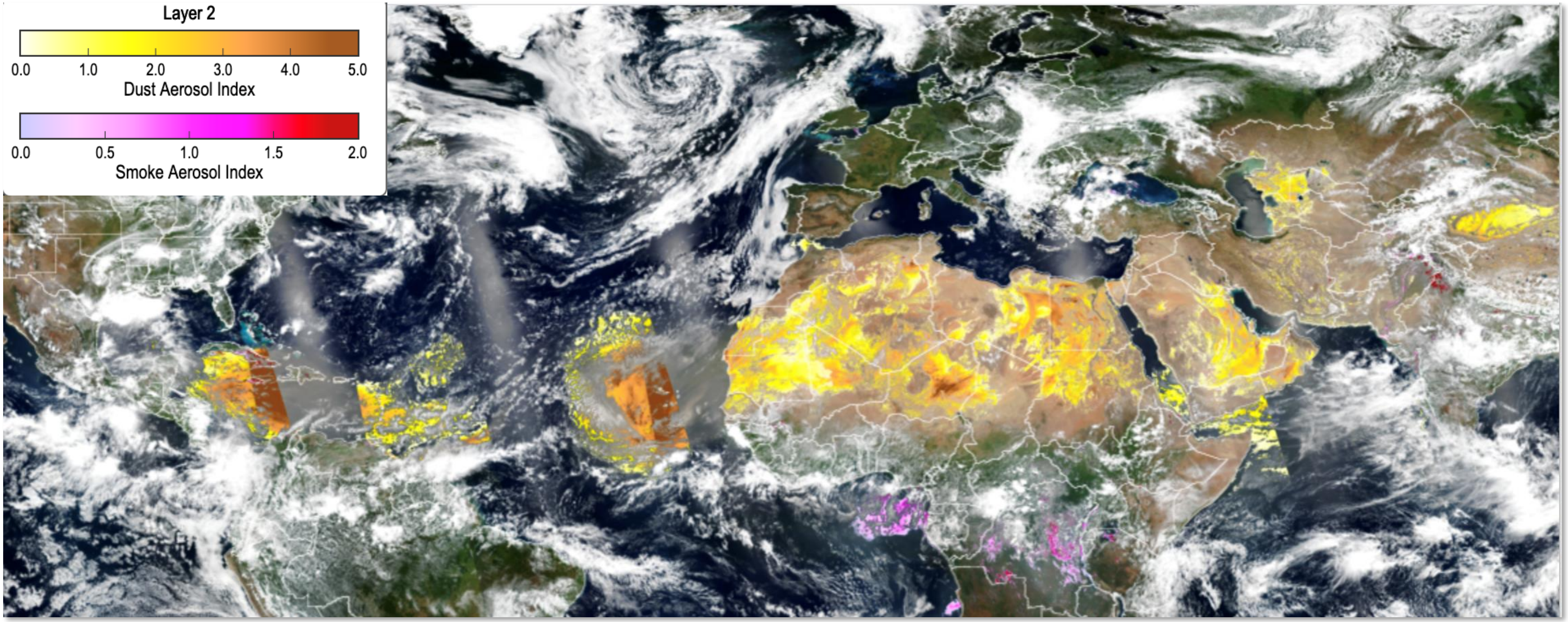
VIIRS Smoke and Dust Index



Source: NOAA JSTAR Mapper https://www.star.nesdis.noaa.gov/jpss/mapper

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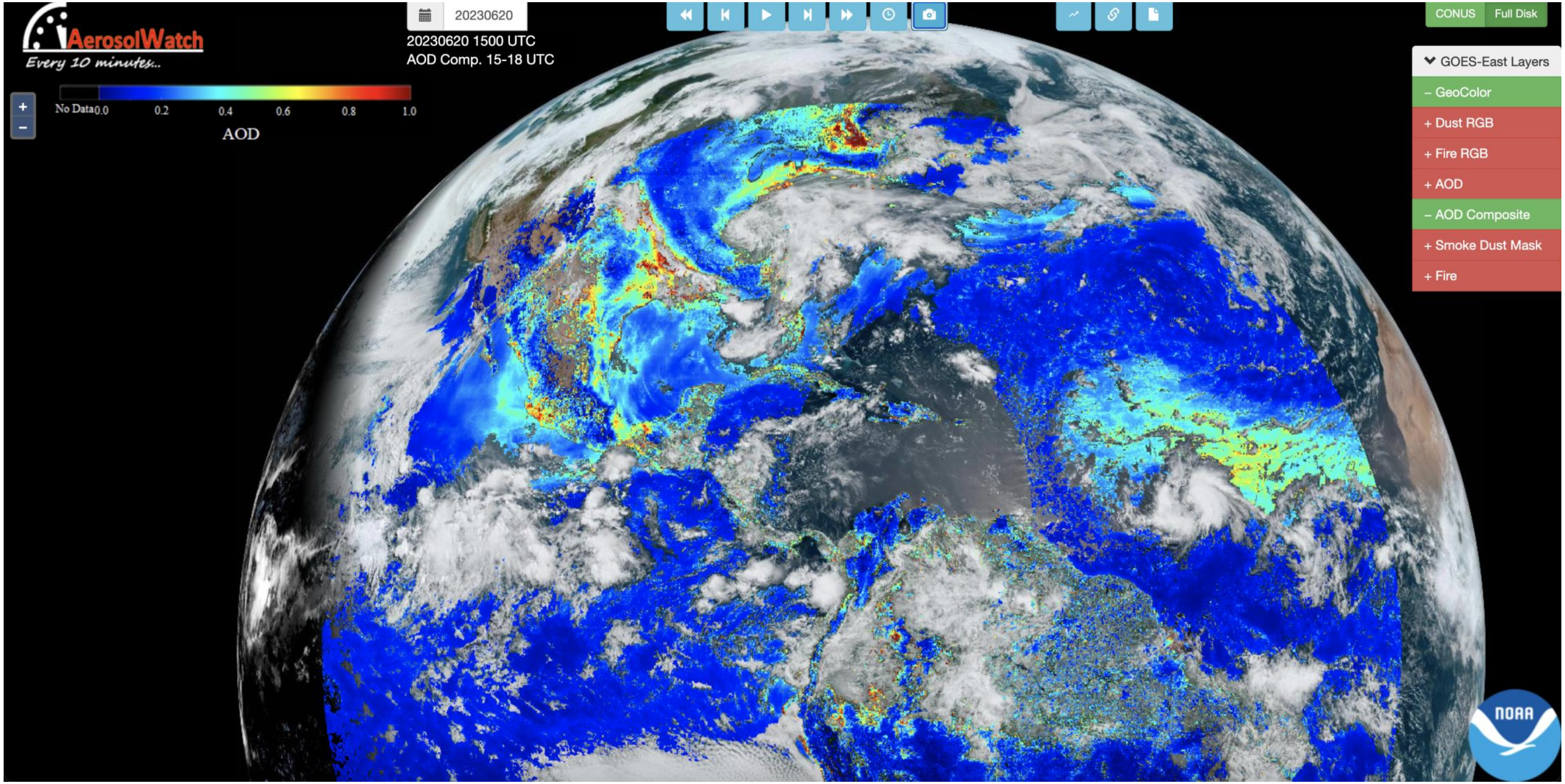
Geostationary AOD

GOES-East



Source: NOAA Aerosol Watch https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch

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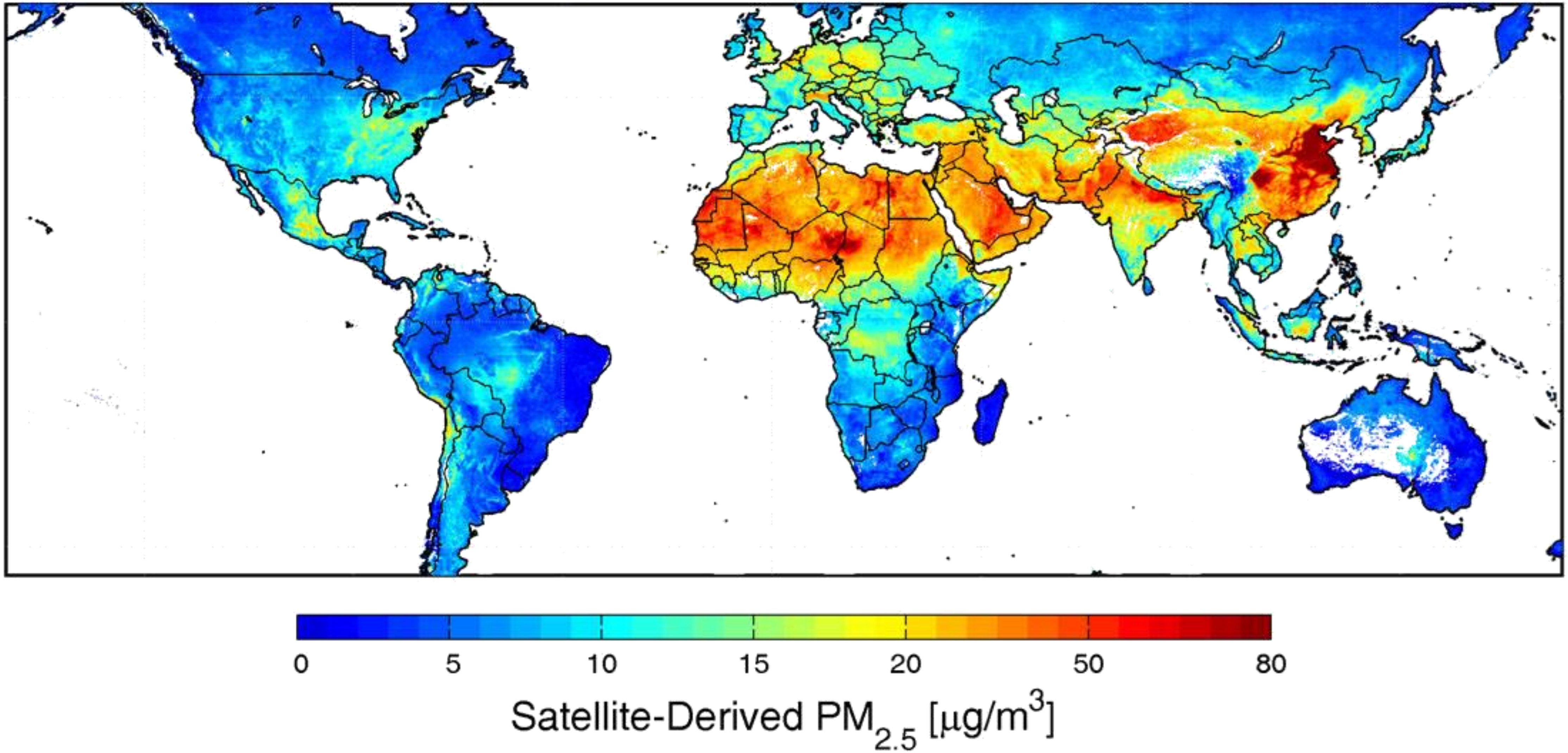
Satellite-Derived Surface $PM_{2.5}$



Source: van Donkelaar et al. (2010). Global Estimates of Ambient Fine Particulate Matter Concentrations from Satellite-Based Aerosol Optical Depth: Development & Application. Environmental Health Perspectives ,118(6). https://doi.org/10.1289/ehp.0901623

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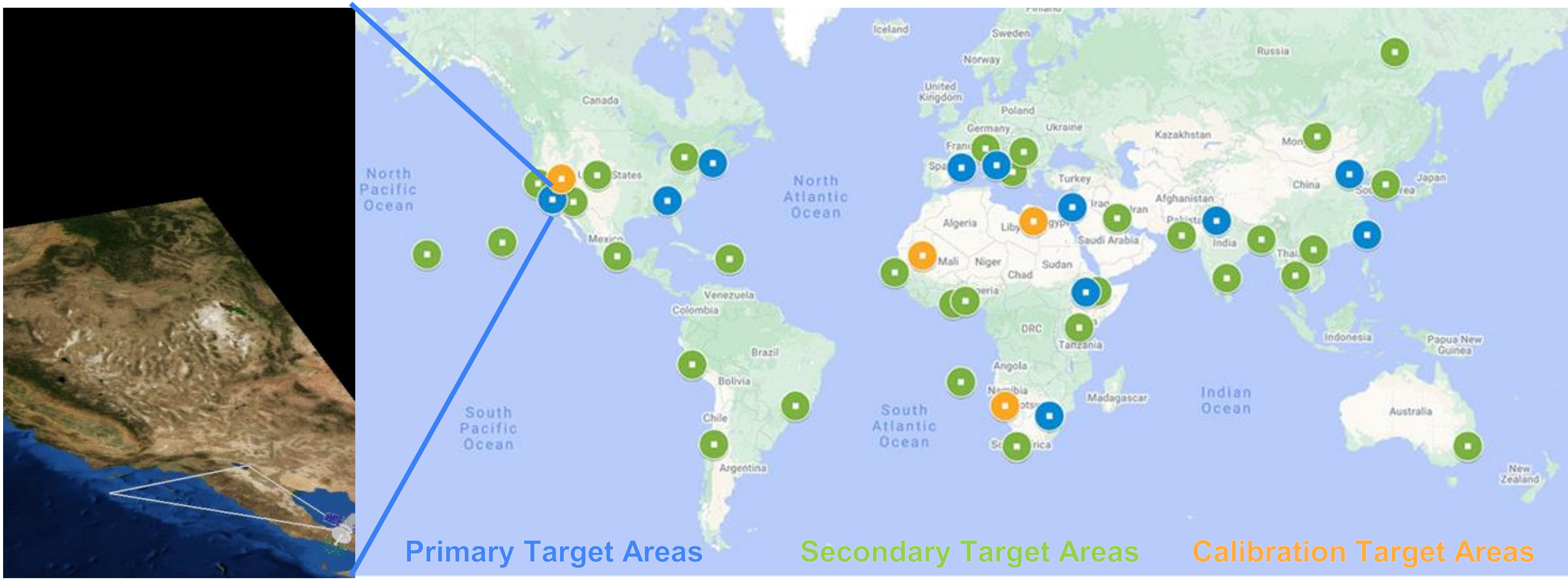
MAIA



- **Multi-Angle Imager for Aerosols**: targeted aerosol mission, assessing type and size distributions
- Satellite mission coordinated with surface PM measurements and health studies
- Anticipated launch 2024

Source: MAIA website https://maia.jpl.nasa.gov/

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OMI and TROPOMI

OMI		TROPOMI
Aura	Satellite	Sentinel-5P
July 2004	Launched	Oct 2017
Nadir-Viewing Imaging Spectrometer	Instrument	Nadir-Viewing Imaging Spectrometer
264 – 504 nm (UV/VIS)	Spectral Range	270 nm – 2.3 μm (UV/VIS/NIR/SWIR)
0.42 – 0.63 nm	Spectral Resolution	0.55 nm
13x24 km^2 at Nadir	Spatial Resolution	5.5 x 3.5 km^2 at Nadir 7 x 28 km^2 (UV1 Band) 7 x 7 km^2 (SWIR Bands)
Daily	Global Coverage	Daily
~ 13:45 LST	Local Overpass Time	~ 13:30 LST*

*synchronized within 5 minutes of SNPP

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OMI and TROPOMI: Trace Gases

OMI		TROPOMI	
Tropospheric and Total Column NO_2	Swath, Gridded (0.25° and 0.1°)	Tropospheric and Total Column NO_2	Swath (5.5 km x 3.5km)
Total Column SO_2	Swath, Gridded (0.25°)	Total Column SO_2	Swath (5.5 x 3.5 km)
Total Column HCHO	Swath, Gridded (0.1°)	Tropospheric Column HCHO	Swath (5.5 x 3.5 km)
Tropospheric and Total Column O_3	Gridded (0.25°)	Tropospheric, Total Column O_3, Profiles	Swath (5.5 x 3.5 km)
		Carbon Monoxide (CO)	Swath (7 km x 5.5 km)
		Methane (CH_4)	Swath (7 km x 5.5 km)

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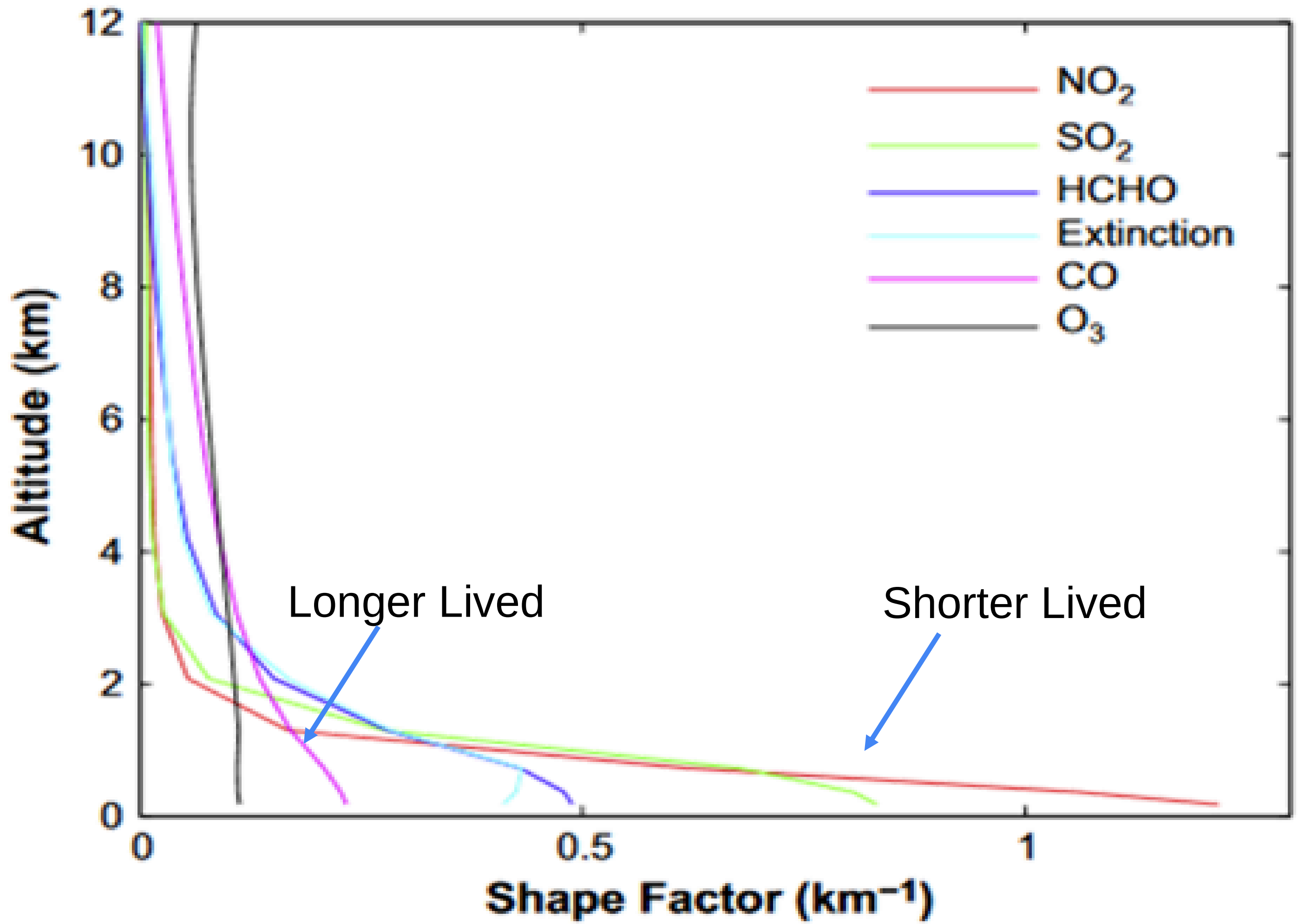
Ozone

- **Why measure O_3?**
  - Negative health impacts for humans, crops, and ecosystems
  - Important to tropospheric chemistry
- **Limitations of Satellite O_3 Data**
  - High stratospheric concentrations mask more air-quality-relevant tropospheric concentrations
  - Use of satellite Ozone is **NOT RECOMMENDED** for air quality



Source: Martin, R.V., Satellite remote sensing of surface air quality, Atmos. Environ., 42, 7823-7843, 2008.

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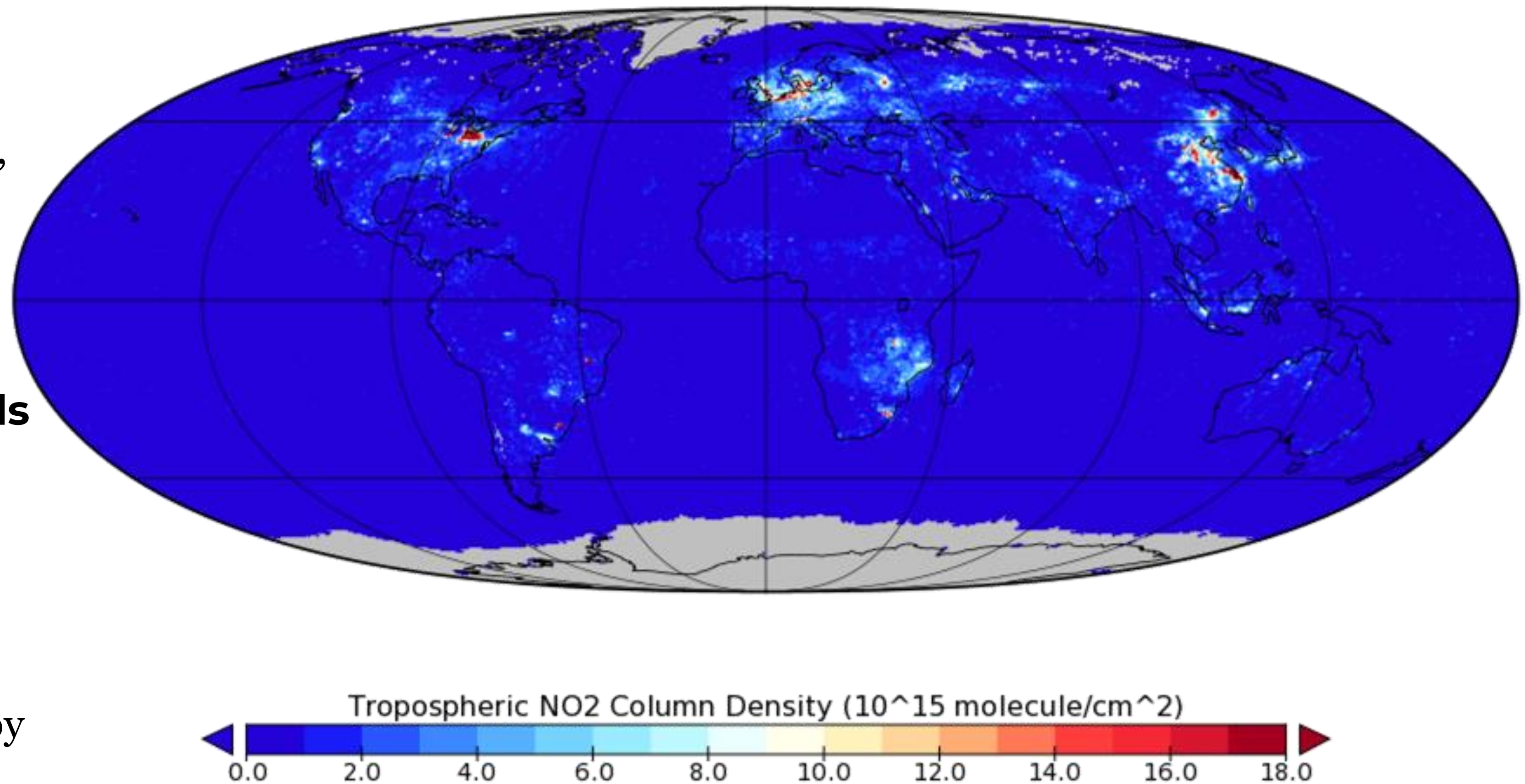
Nitrogen Dioxide

- **Why measure NO_2?**
  - health irritant
  - ozone precursor
  - Surface sources: fire, agricultural burning, transportation, industry, power generation
  - High concentrations in the planetary boundary layer (PBL)

- **OMI: long data record for trends**
  - OMNO2 standard level 2 product
  - OMNO2g gridded products

- **TROPOMI: high resolution**
  - S5P_L2__NO2____HiR
  - Available from NASA Earthdata by agreement with ESA

OMNO2d Level 3 Gridded (0.25° x 0.25°) Daily Product



Source: NASA GES DISC https://disc.gsfc.nasa.gov/

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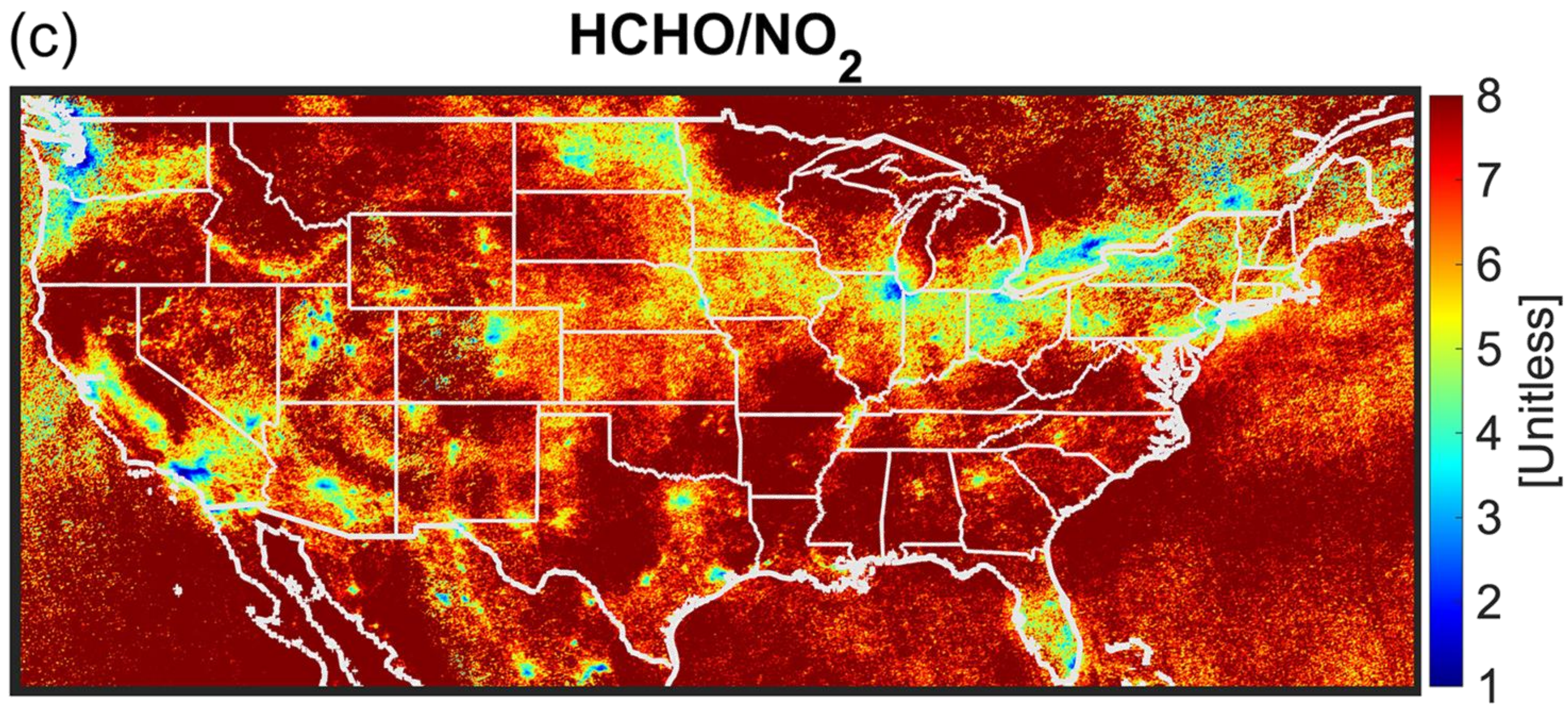
Formaldehyde

- **Why measure HCHO?**
  - Major precursor for O_3
  - proxy for total VOC chemical reactivity and isoprene emissions
- **Using $HCHO/NO_2$ Ratios**
  - $HCHO/NO_2 < 1$: VOC-Limited
  - $HCHO/NO_2 > 2\text{-}4$: NO_X-Limited
- **OMI: long data record for trends**
  - OMHCHO level 2 product
  - OMHCHOG gridded products
- **TROPOMI: high resolution**
  - S5P_L2__HCHO___HiR_2
  - Available from NASA Earthdata by agreement with ESA

Comparing HCHO and NO_2 from TROPOMI to determine Ozone Formation Potential over the US



Source: Souri et al. 2023, Characterization of errors in satellite-based HCHO/NO2 tropospheric column ratios with respect to chemistry, column-to-PBL translation, spatial representation, and retrieval uncertainties. https://doi.org/10.5194/acp-23-1963-2023

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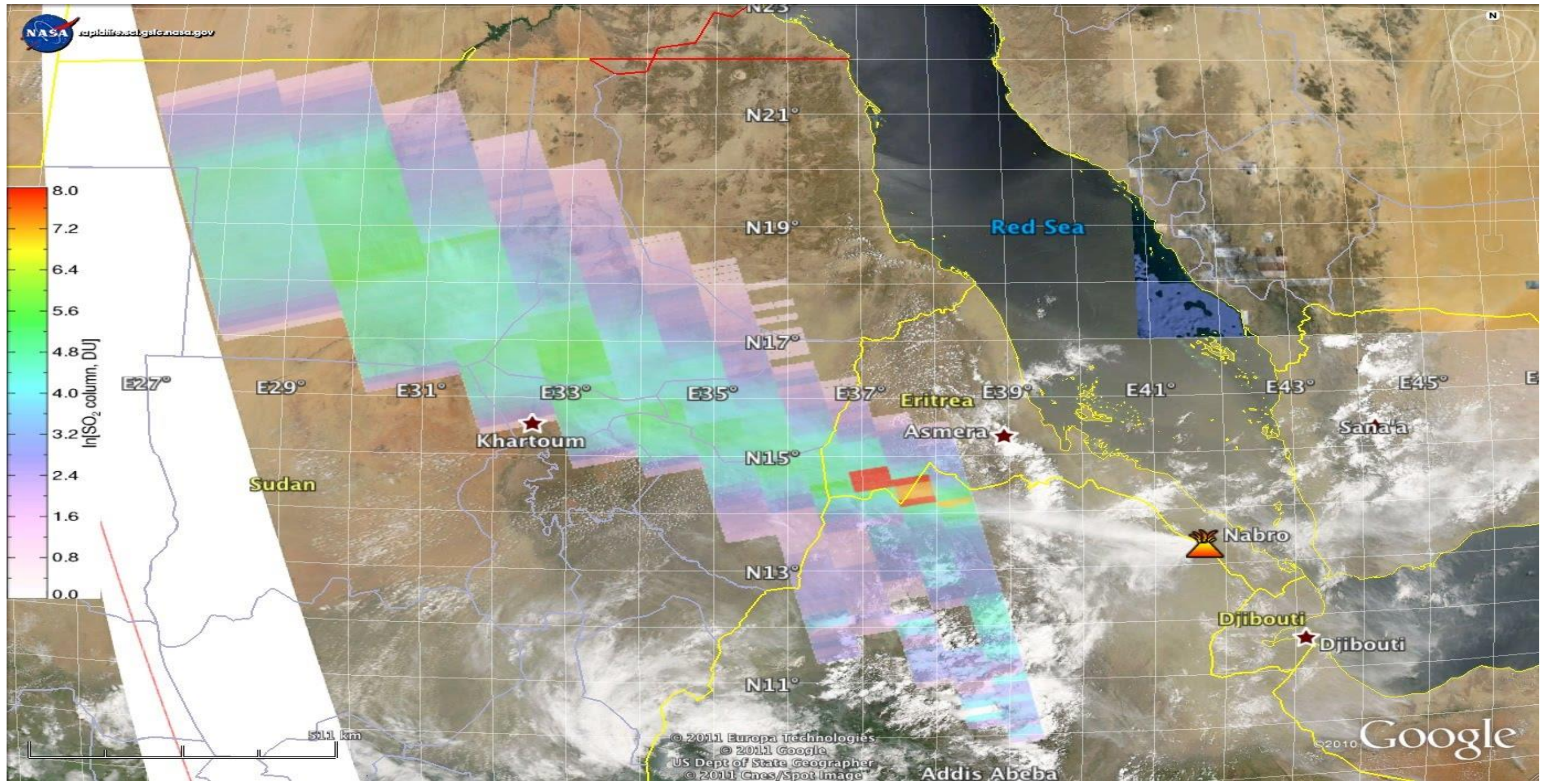
Sulfur Dioxide

- **Why measure SO_2?**
  - SO2 has also been linked to adverse respiratory effects.
  - Contributes to acid deposition
  - Sources: Volcanoes, coal and oil burning
- **OMI: long data record for trends**
  - OMSO2 standard level 2 product
  - OMSO2e gridded data product, assumes near-surface emissions (most relevant to air quality)
- **TROPOMI: high resolution**
  - S5P_L2__SO2____HiR
  - Available from NASA Earthdata by agreement with ESA



Aqua MODIS visible image of the Nabro (Eritrea) eruption on June 13, 2011, with the OMI SO_2 plume overlaid.

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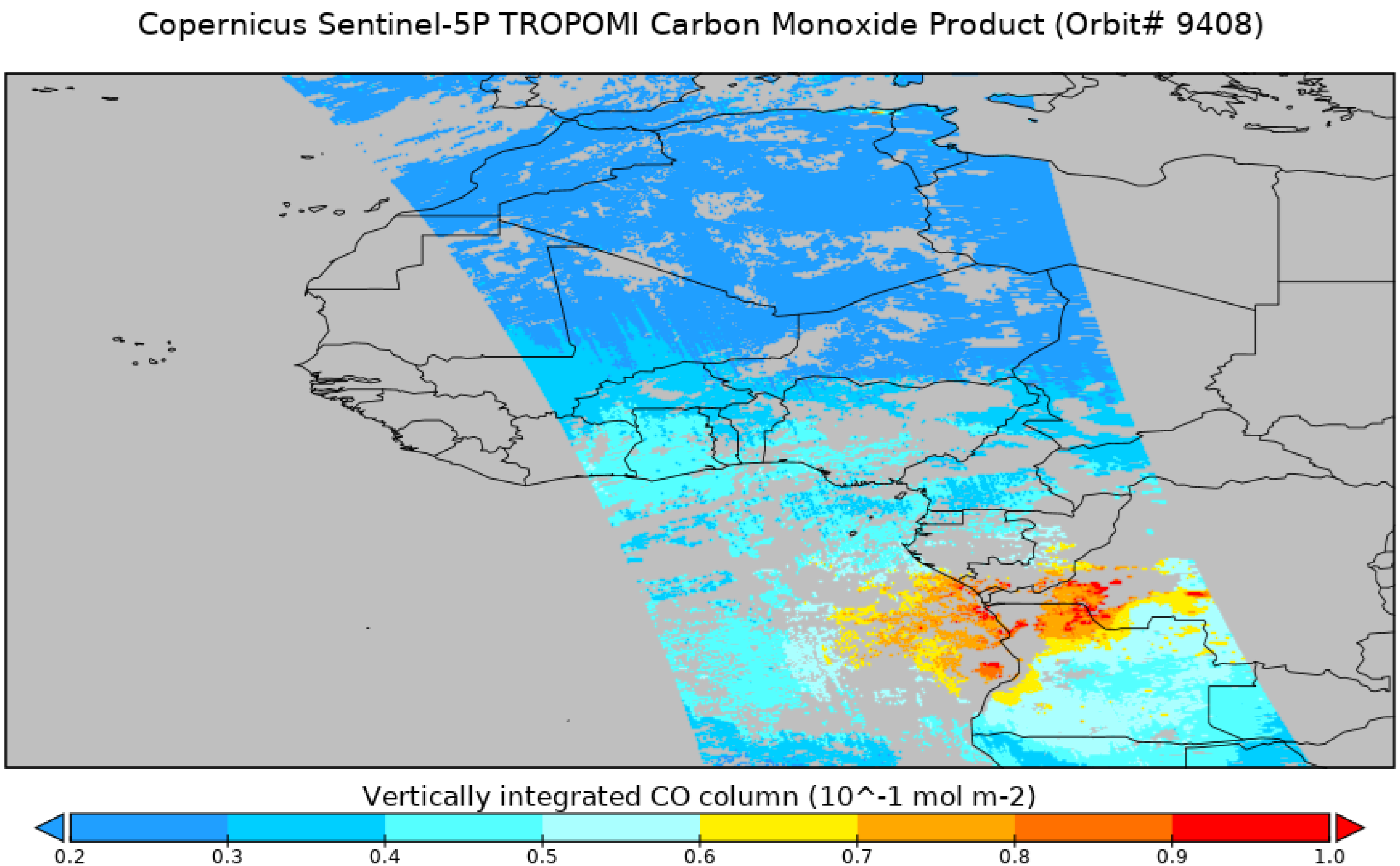
Carbon Monoxide and Methane

- **Why measure CO?**
  - Major precursor for O_3
  - Relatively long lifetime (~1-2 months) makes it a useful tracer
- **Why measure CH4?**
  - Potent greenhouse gas
  - “Super-emitter” point sources (natural gas leaks)
  - Distributed sources (agriculture) hard to quantify from ground
- **TROPOMI: high resolution**
  - S5P_L2__CO_____HiR
  - S5P_L2__CH4____HiR
  - Available from NASA Earthdata by agreement with ESA



Source: NASA GES DISC https://disc.gsfc.nasa.gov/

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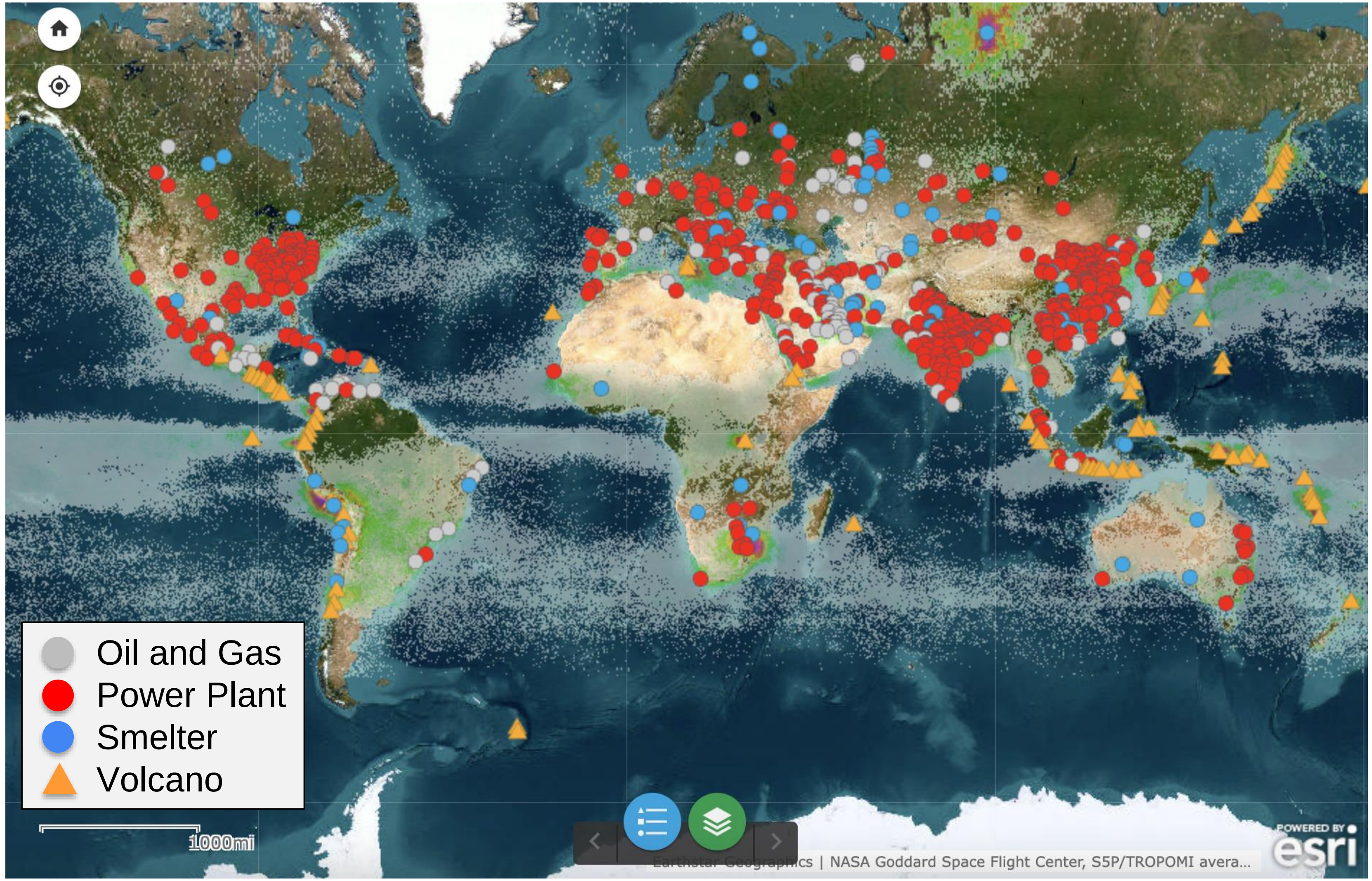
Emissions from Satellites

- Developing a bottom-up emission inventory requires extensive data collection from many sources
  - Costly
  - Time-consuming
  - May be incomplete
- Satellites can estimate top-down emissions inventories
  - Can keep pace with changing emissions
  - May detect missing sources
  - Many uncertainties in deriving emissions from satellite data



Source: NASA Global Sulfur Dioxide Monitoring Home Page https://so2.gsfc.nasa.gov/

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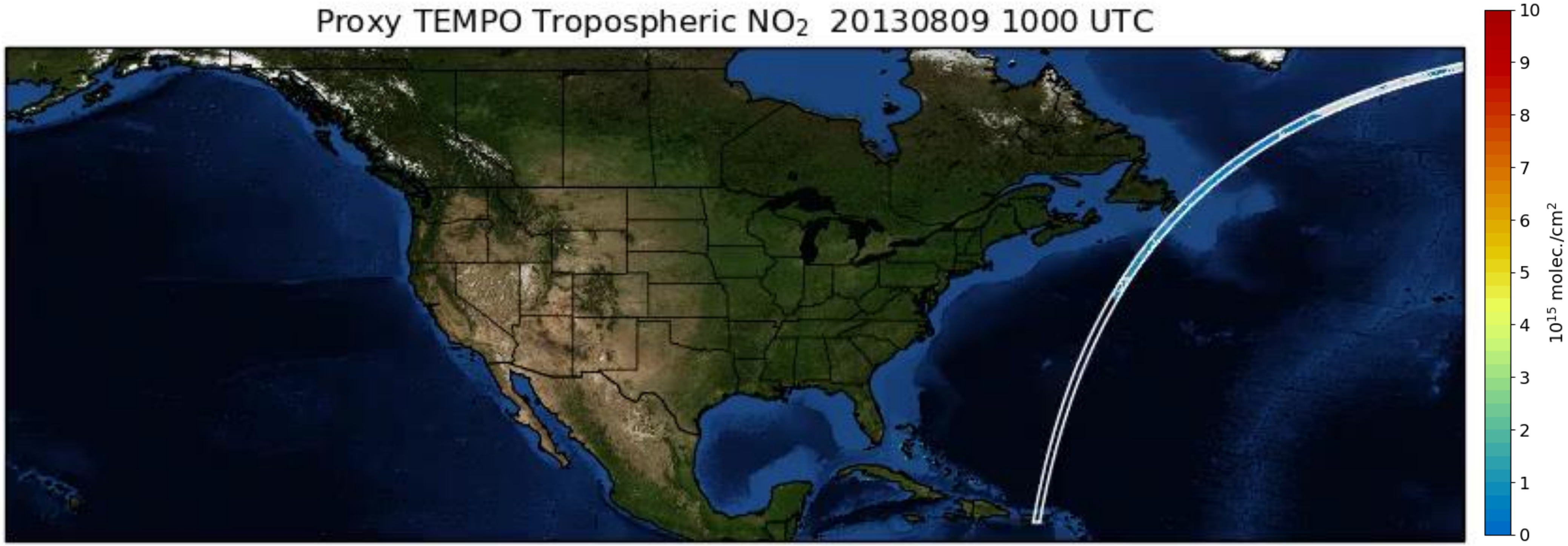
TEMPO



- **Tropospheric Emissions: Monitoring of Pollution**
- Geostationary satellite (Intelsat IS40e) providing **hourly daytime information** over North America
- Nominal spatial resolution: **~ 2.5 km x 5 km** (with higher resolution towards the south)
- Key Products: **NO_2**, **Formaldehyde**, **Ozone** (including near-surface retrievals)
- Launched **April 7, 2023**
- Level 2 & 3 data products expected **April 2024**

Source: Aaron Naeger, TEMPO applications & early adopter program
https://weather.ndc.nasa.gov/tempo/

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OUTLINE

- Basics of Remote Sensing
- Satellite Aerosol Products
- Satellite Trace Gas Products
- Accessing NASA Data
  - BREAK
- GEOS-CF Air Quality Forecasts
- Bias-Corrected Forecasts

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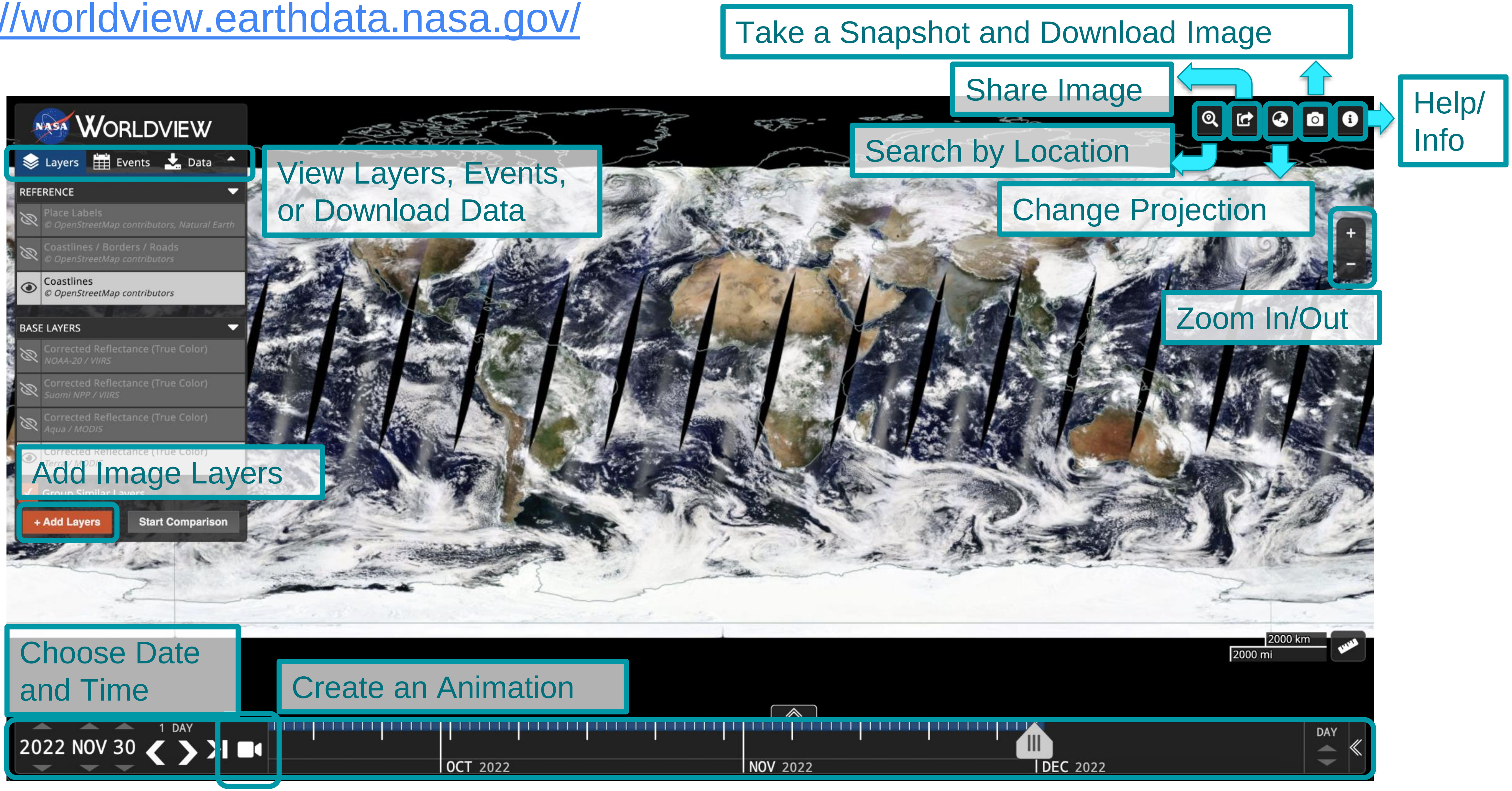
NASA Worldview

https://worldview.earthdata.nasa.gov/



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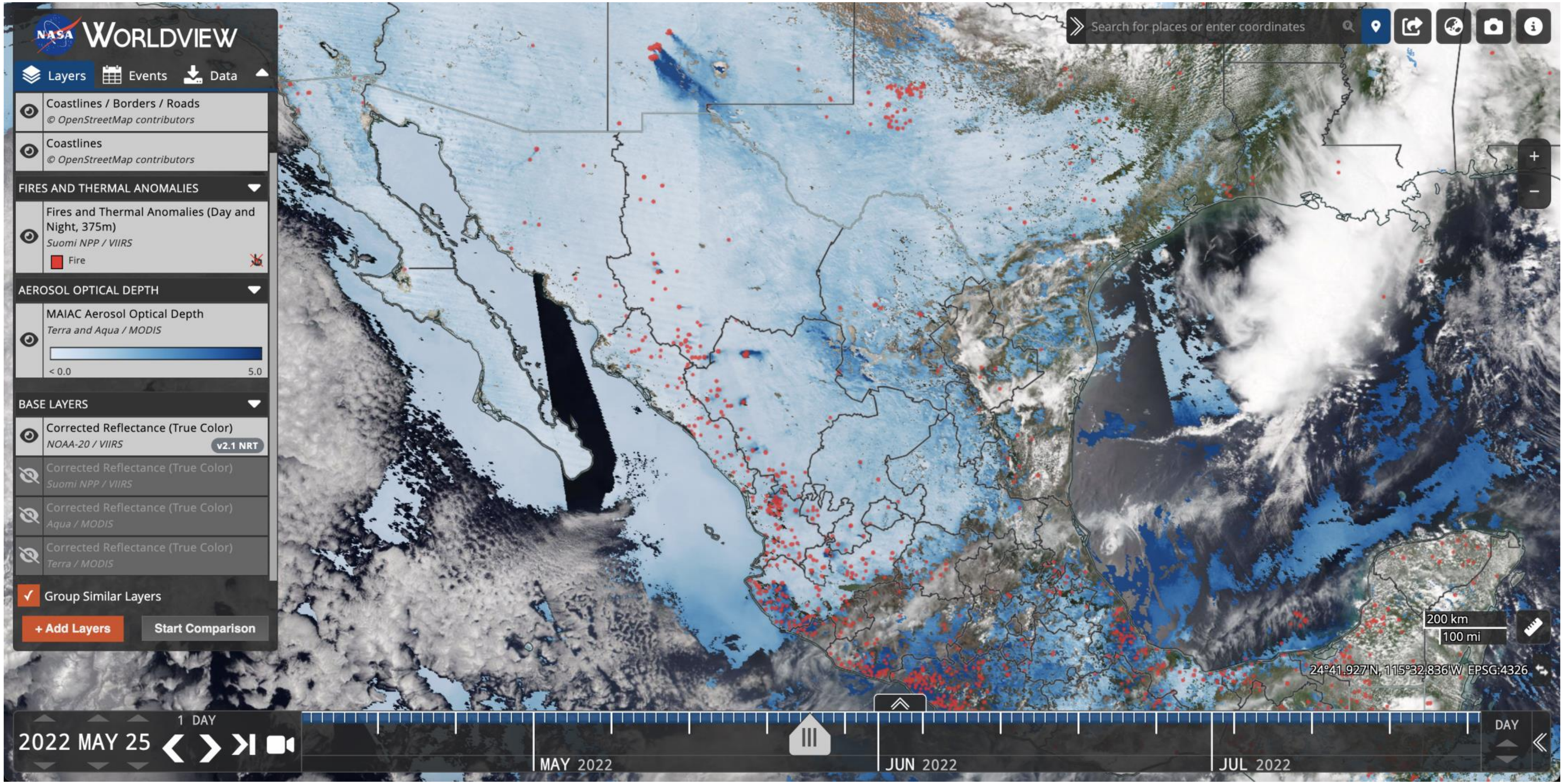
NASA Worldview

https://worldview.earthdata.nasa.gov/

MODIS MAIAC AOD **VIIRS Fire Detections**



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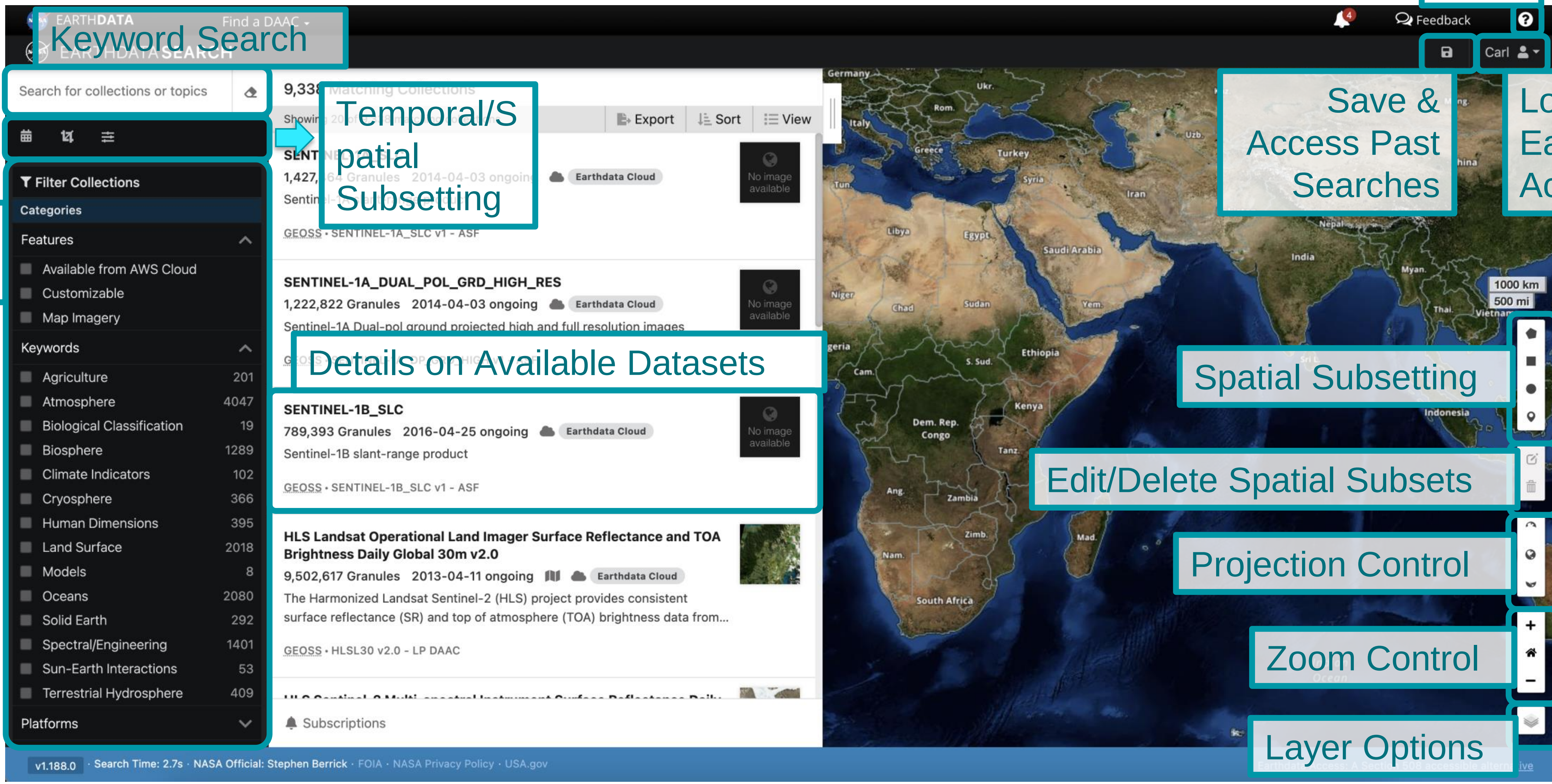
NASA Earthdata Search

https://search.earthdata.nasa.gov/search



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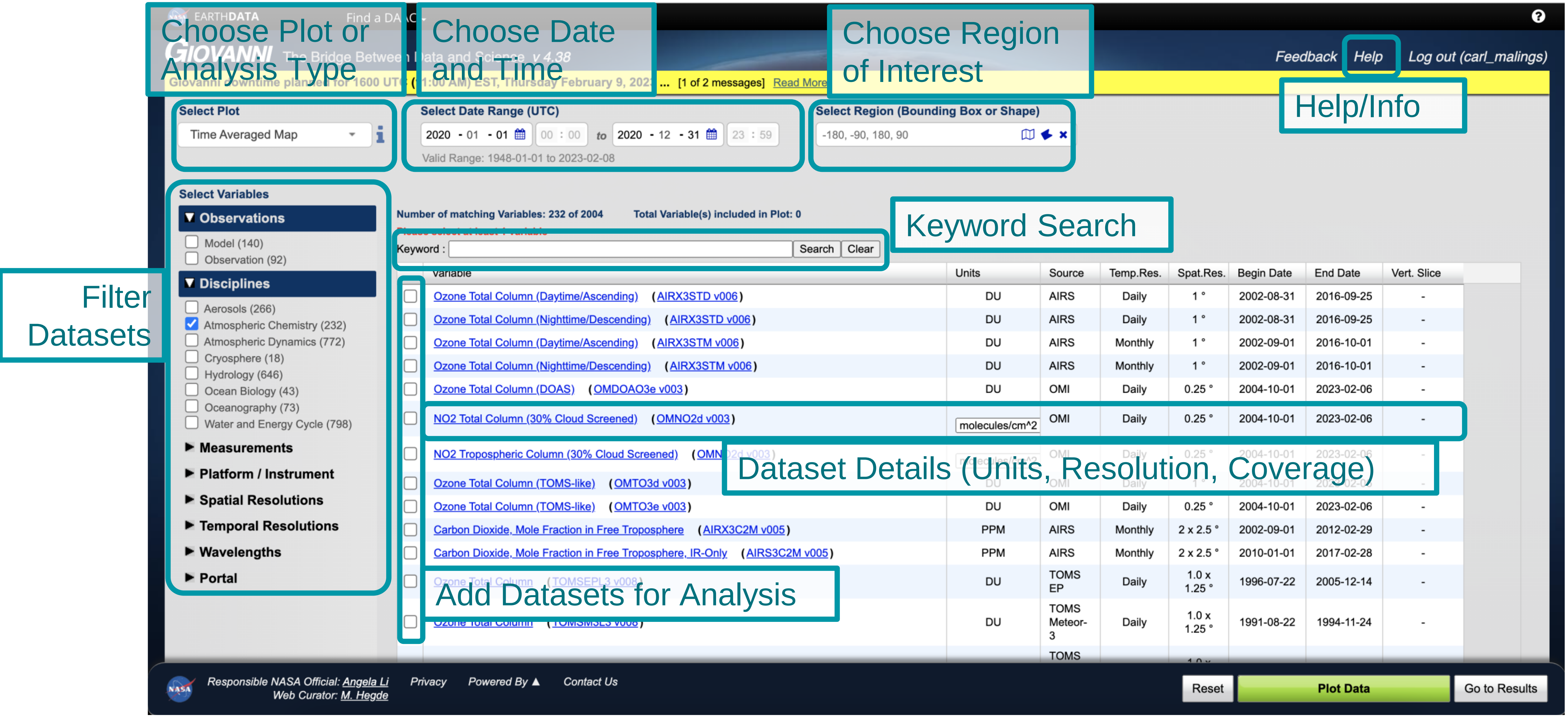
NASA Giovanni

https://giovanni.gsfc.nasa.gov/giovanni/



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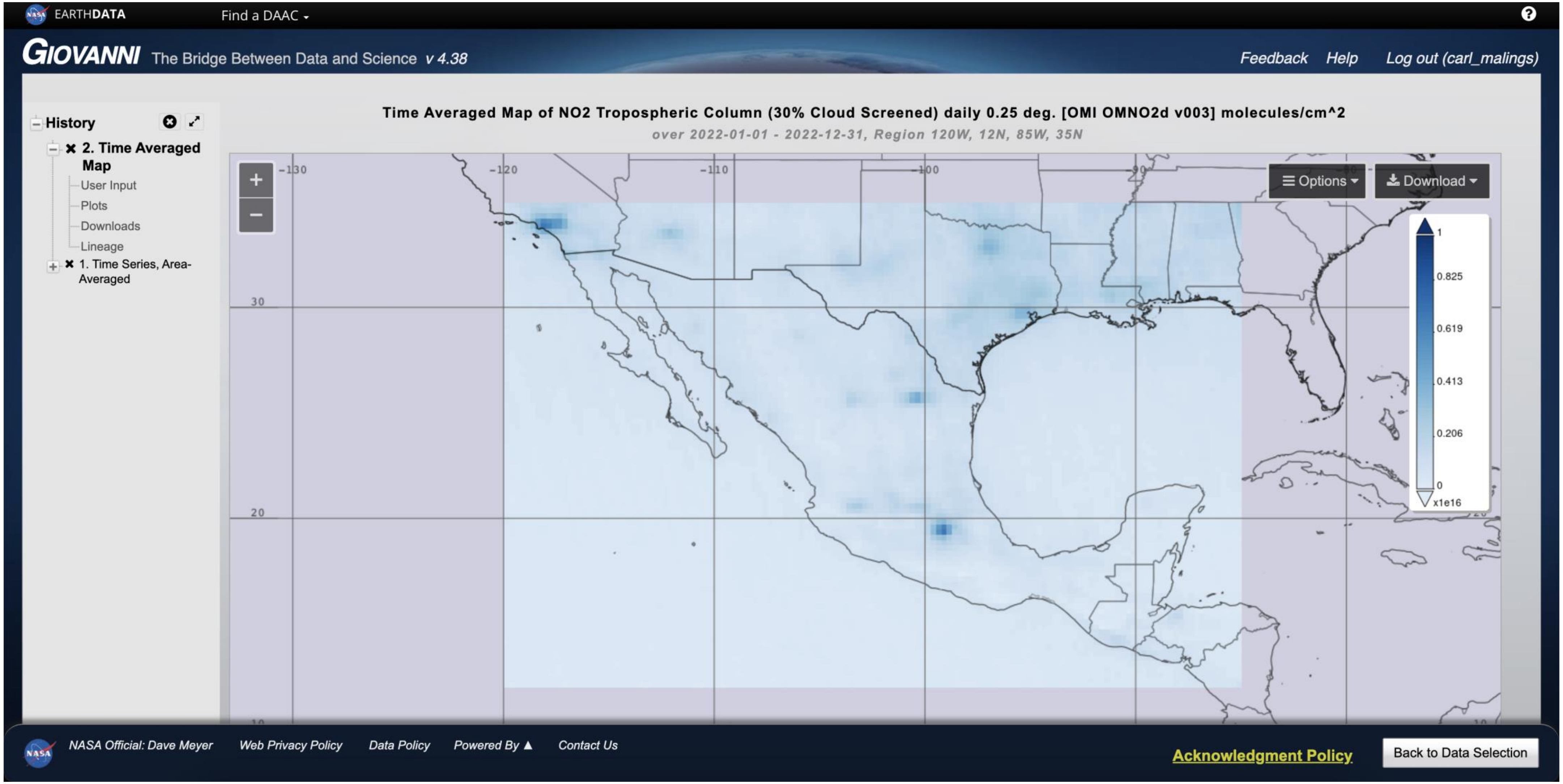
NASA Giovanni

https://giovanni.gsfc.nasa.gov/giovanni/

Time-averaged Map (2022 OMI Tropospheric NO_2)



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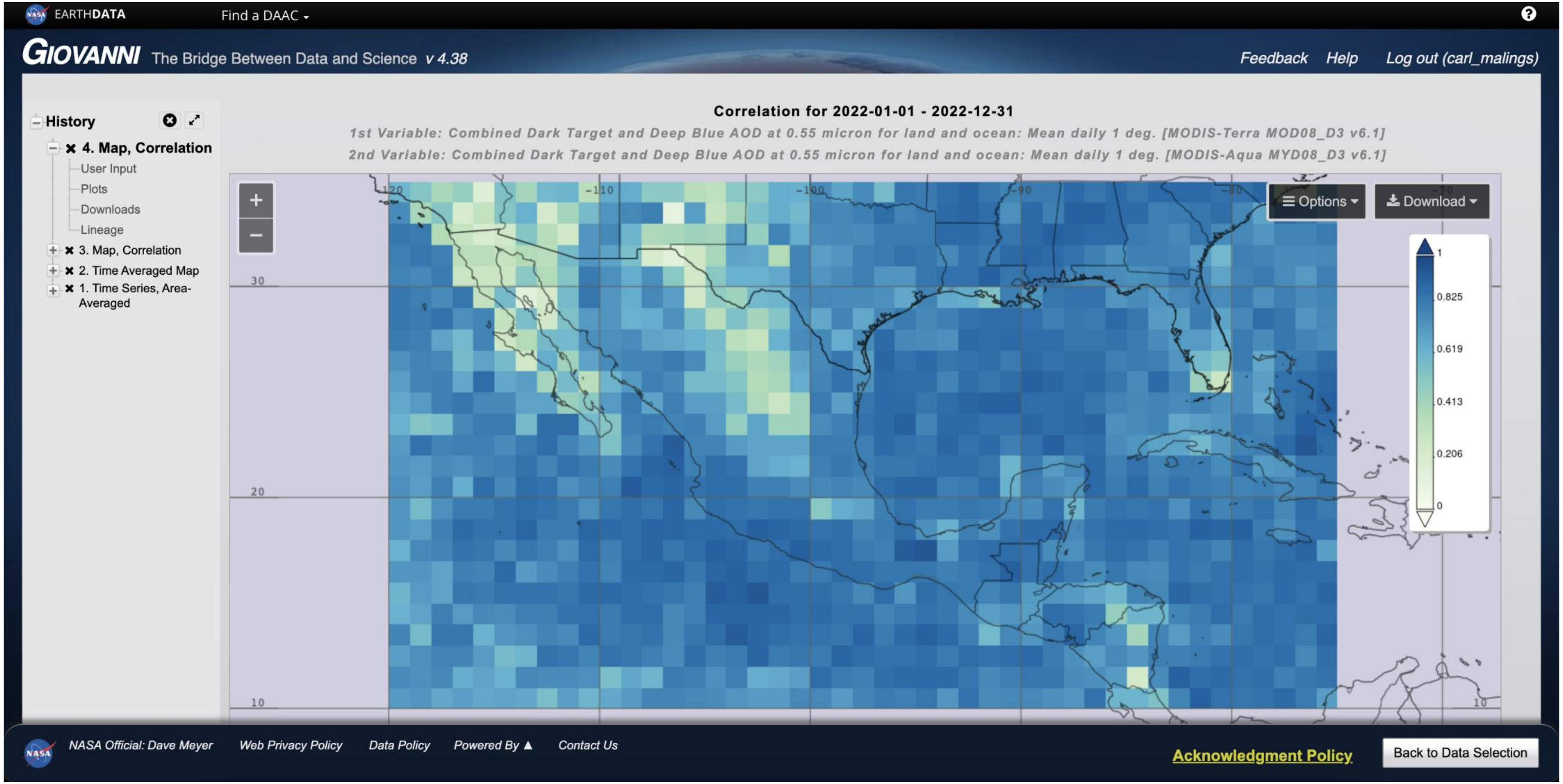
NASA Giovanni

https://giovanni.gsfc.nasa.gov/giovanni/

Correlation Map (2022 AOD, MODIS Aqua & Terra)



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Applied Remote Sensing Training (ARSET)

ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.

Our trainings are:

- Online and in-person
- Open to everyone
- Live, instructor-led, or self-guided
- Provided at no cost, with materials and recordings available from our website
- Often multi-lingual
- Tailored to those with a range of experience in remote sensing, from **introductory** to **advanced**

https://appliedsciences.nasa.gov/arset

ARSET offers trainings for:

- Disasters
- Health & Air Quality
- Land Management
- Water Resources
- Climate

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Health and Air Quality Applied Science Team (HAQAST)

"Our goal is to use NASA's data and satellites to pursue cutting edge applied research in order to keep you healthy and safe."

- Use NASA satellite & other data to help solve real-world public health and air quality problems.
- Work around the world on diverse issues related to health and air quality.
- Collaborate with public stakeholders to help guide long-term research.
- "Tiger Teams" pursue short-term, high-impact projects in small groups.

HAQAST

Getting started with NASA satellite data for health and air quality:
https://haqast.org/getting-started/

https://haqast.org/

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GRACIAS

THANK YOU!

TERIMA KASIH