

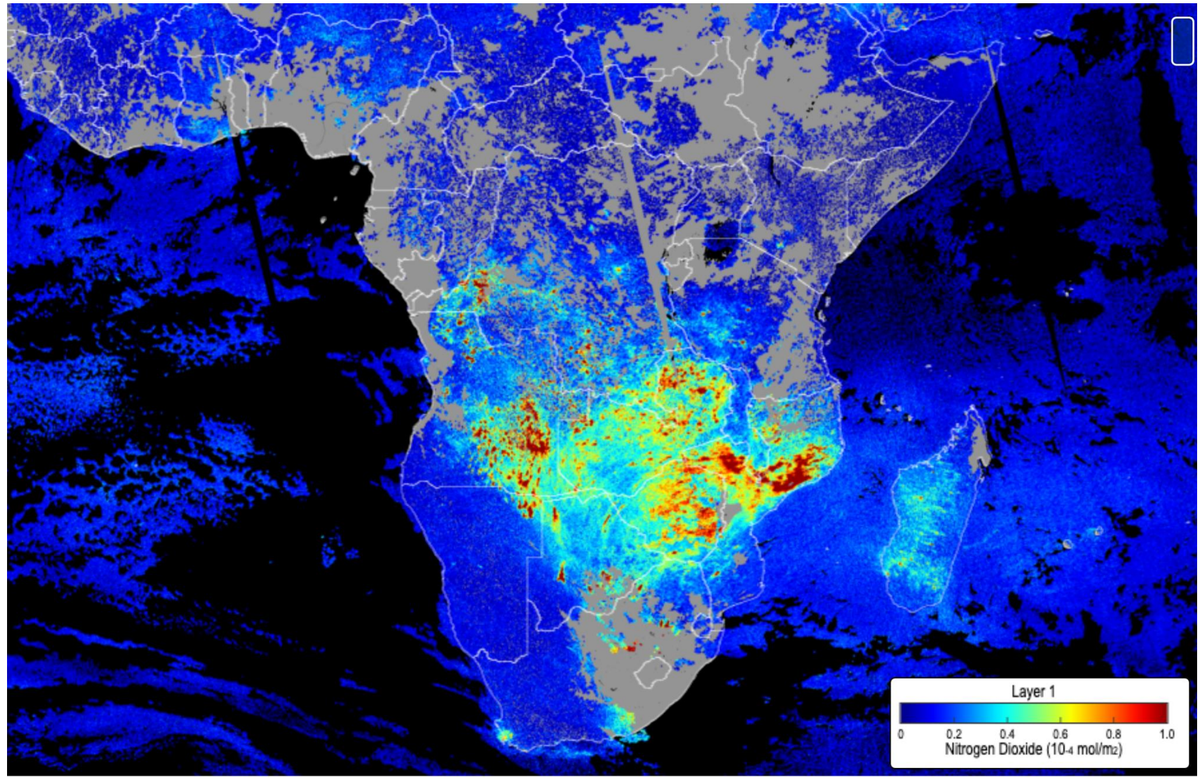
# Air Quality Remote Sensing Missions and Datasets

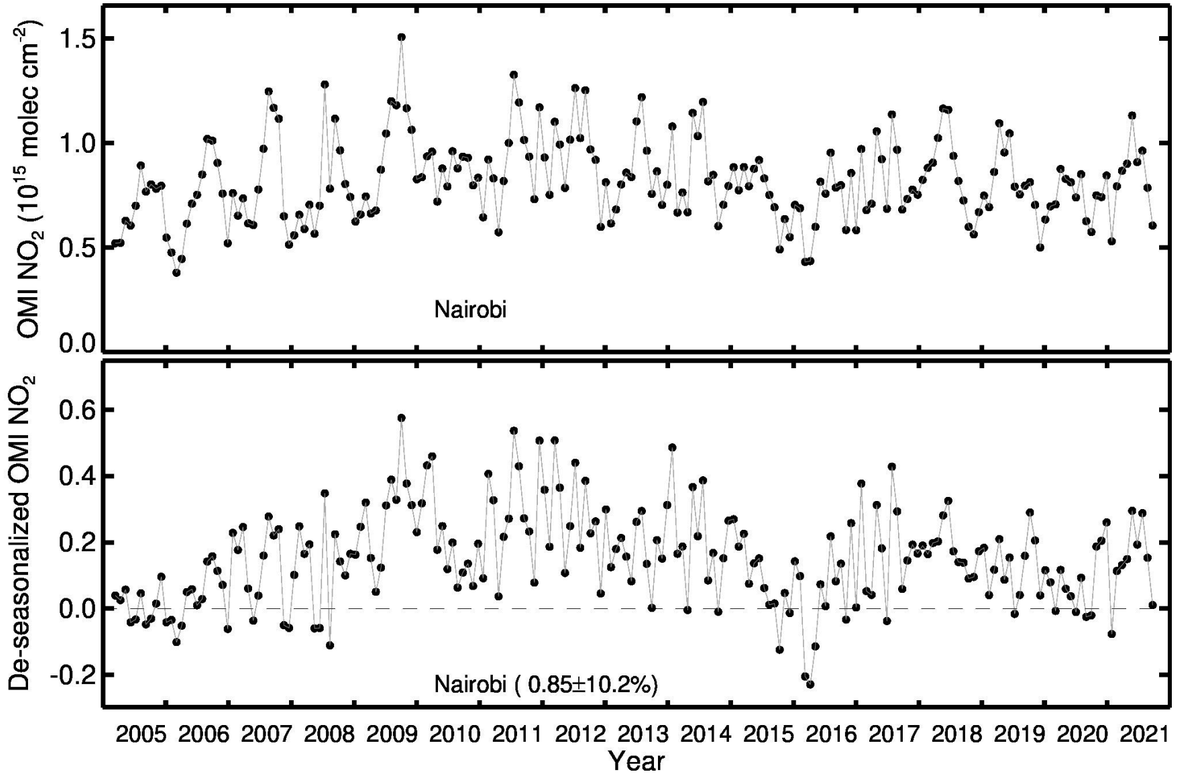
**Carl Malings**
Morgan State University & NASA Goddard Space Flight Center

# Agenda

- 14:15 - 15:15 Air Quality Remote Sensing Missions and Datasets
  - Recap: advantages and limitations of satellite data
  - Ground based remote sensing: AERONET, Pandora, MPLNET
  - Air quality models and data assimilation
  - Derived information and data fusion
  - Resources to learn more

# What Satellites CAN do for Air Quality

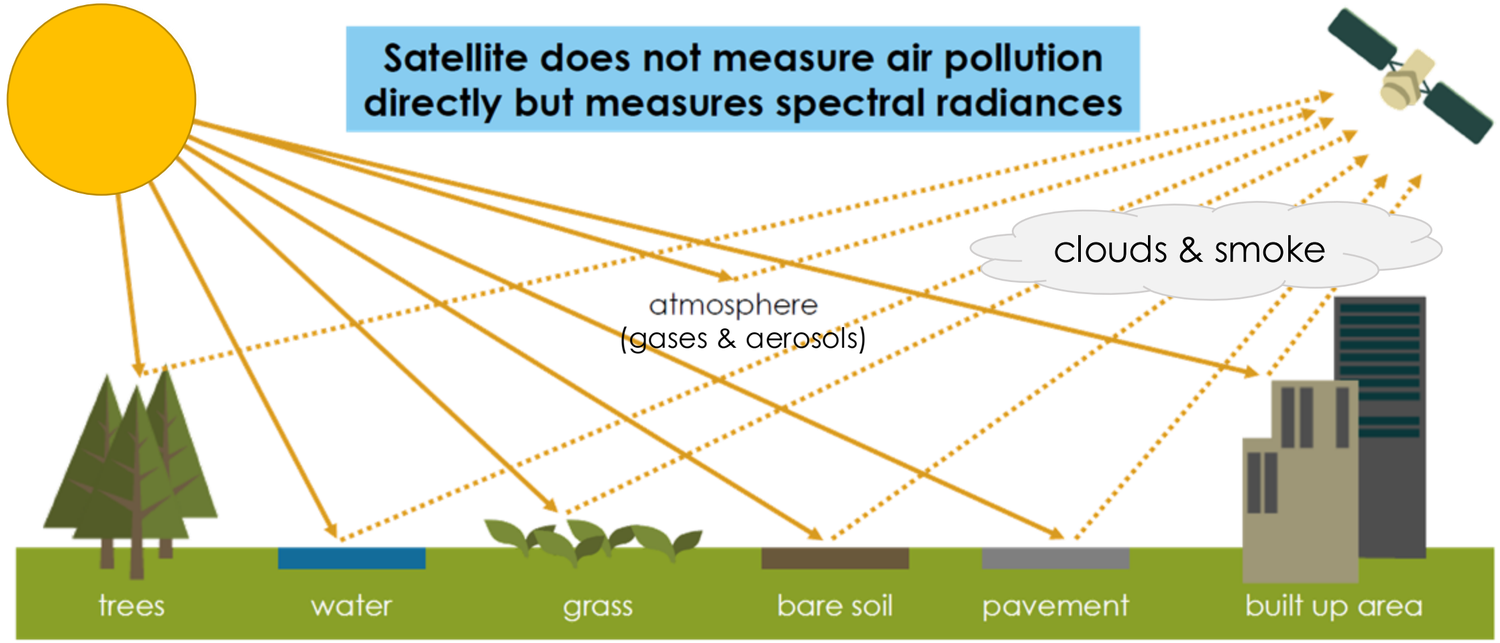


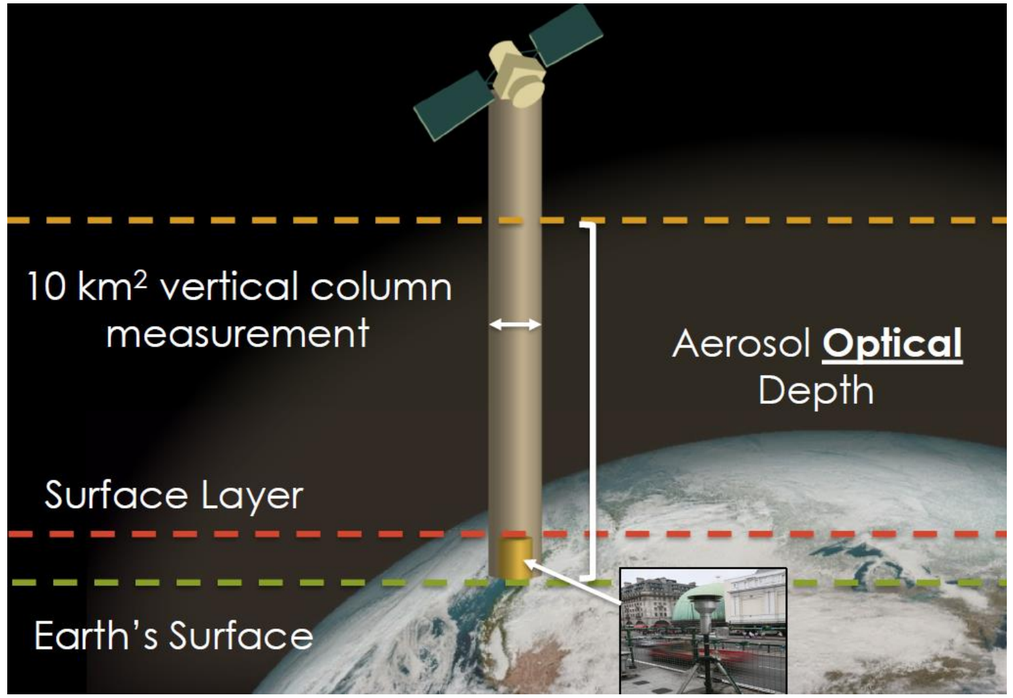




- **Examine a large area**: where are the hotspots? how is long-range transport happening?
- **Track changes over time:** how much has the average concentration over an area changed over time?
- **A picture is worth a million datapoints:** satellite photos can be clear and compelling in communications.

Sources: TROPOMI Nitrogen Dioxide, Sep. 17, 2024, viewed in NOAA JSTAR Mapper
NASA GSFC Nitrogen Dioxide Trends for World Cities https://airquality.gsfc.nasa.gov/no2/world

# What Satellites CAN'T do for Air Quality




- **See at night:** satellites measure the properties of reflected sunlight passing through the atmosphere.
- **See through clouds:** most satellite measurements are blocked by cloud cover.
- **See what is happening at "nose level":** satellites measure quantities in the whole atmosphere.
- **See at different times of day:** polar-orbiting satellites will observe a location once per 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

# Sources of Air Quality Information

traditional monitors



low-cost sensors

Ground Measurements



atmospheric observations

Air & Space Observations

Models

satellites





aircraft

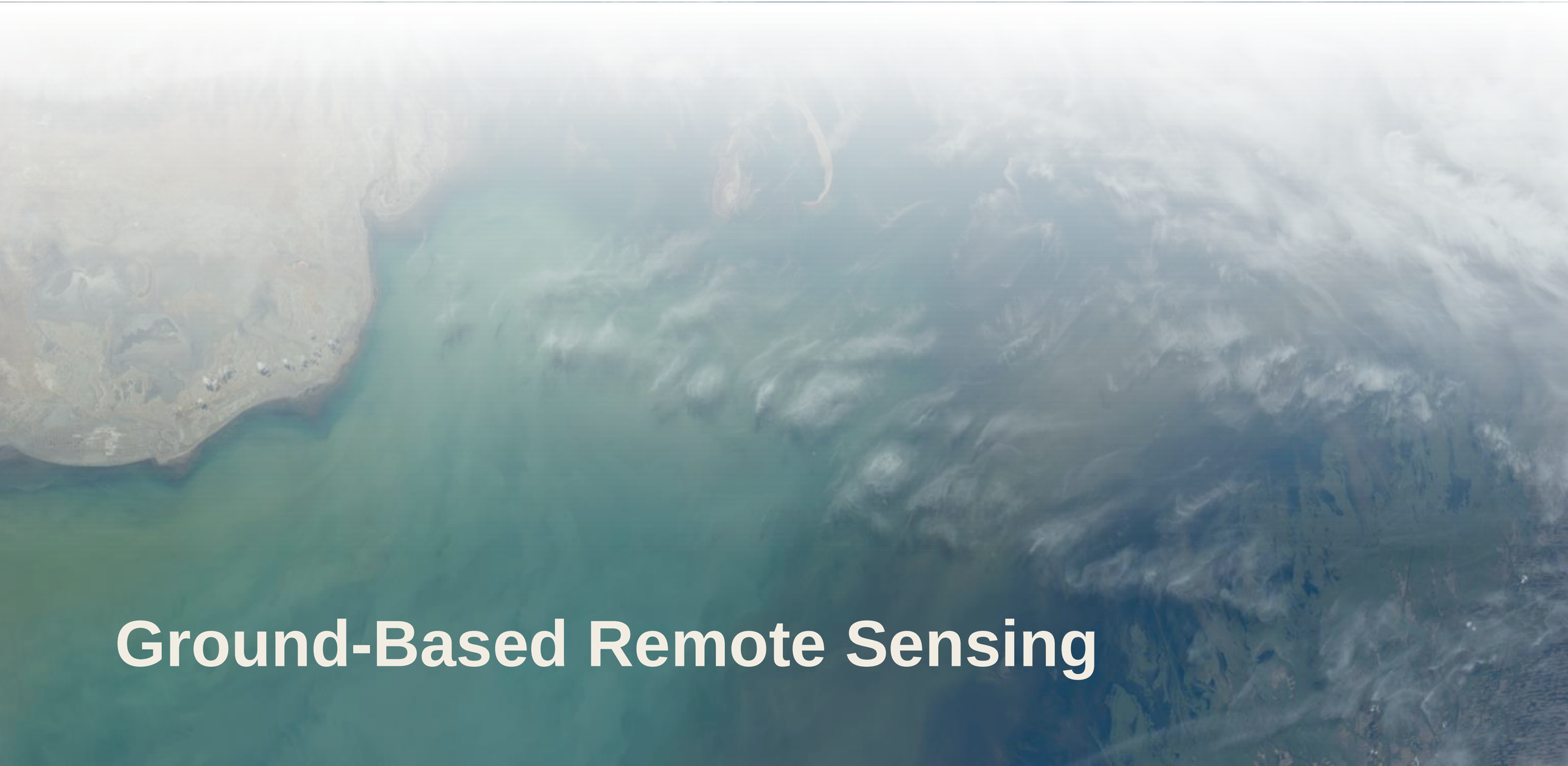
balloons




global models

regional models

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



# Ground-Based Remote Sensing

# NASA Atmospheric Composition Ground Networks

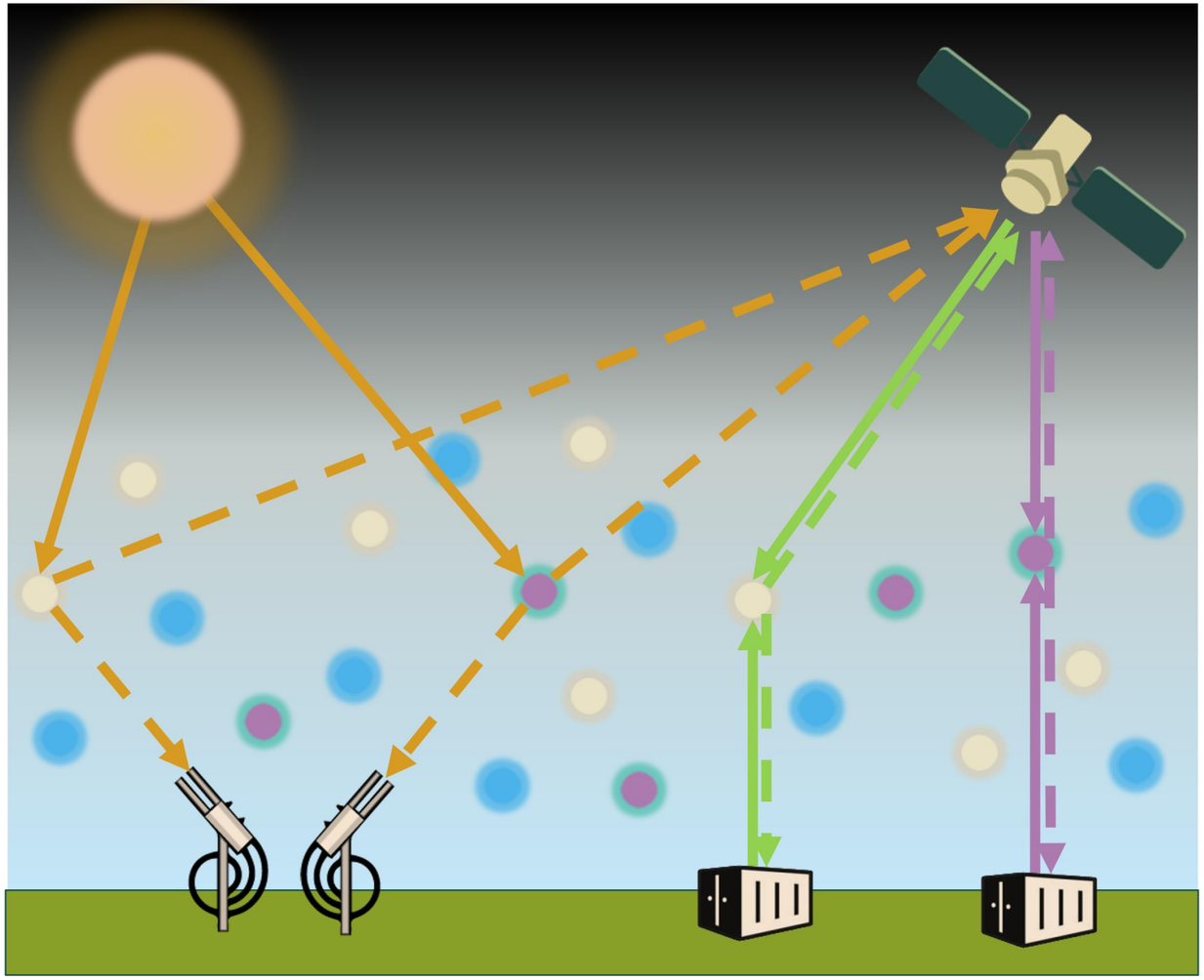
Ground networks offer a bottom-up view, complementing satellites' top-down view.

Together, these networks:

- Provide trace gas and aerosol column concentrations and vertical profiles
- Support air quality and climate applications
- Allow for continuity across satellite missions

NASA supports four atmospheric composition ground-based remote sensing networks:

**AERONET (global)**
**Pandora (global)**
**TOLNet (US & Canada)**
**MPLNET (global)**



Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# AERONET Surface AOD Monitors

**Aerosol Robotic Network (AERONET)**
NASA + others

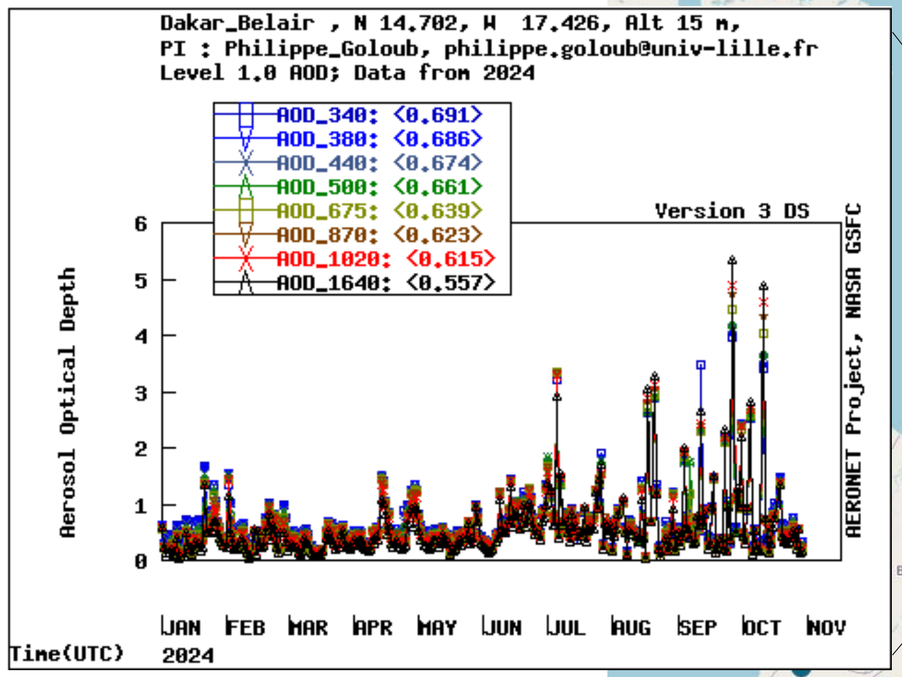
A global network of surface monitors measuring AOD from the ground up

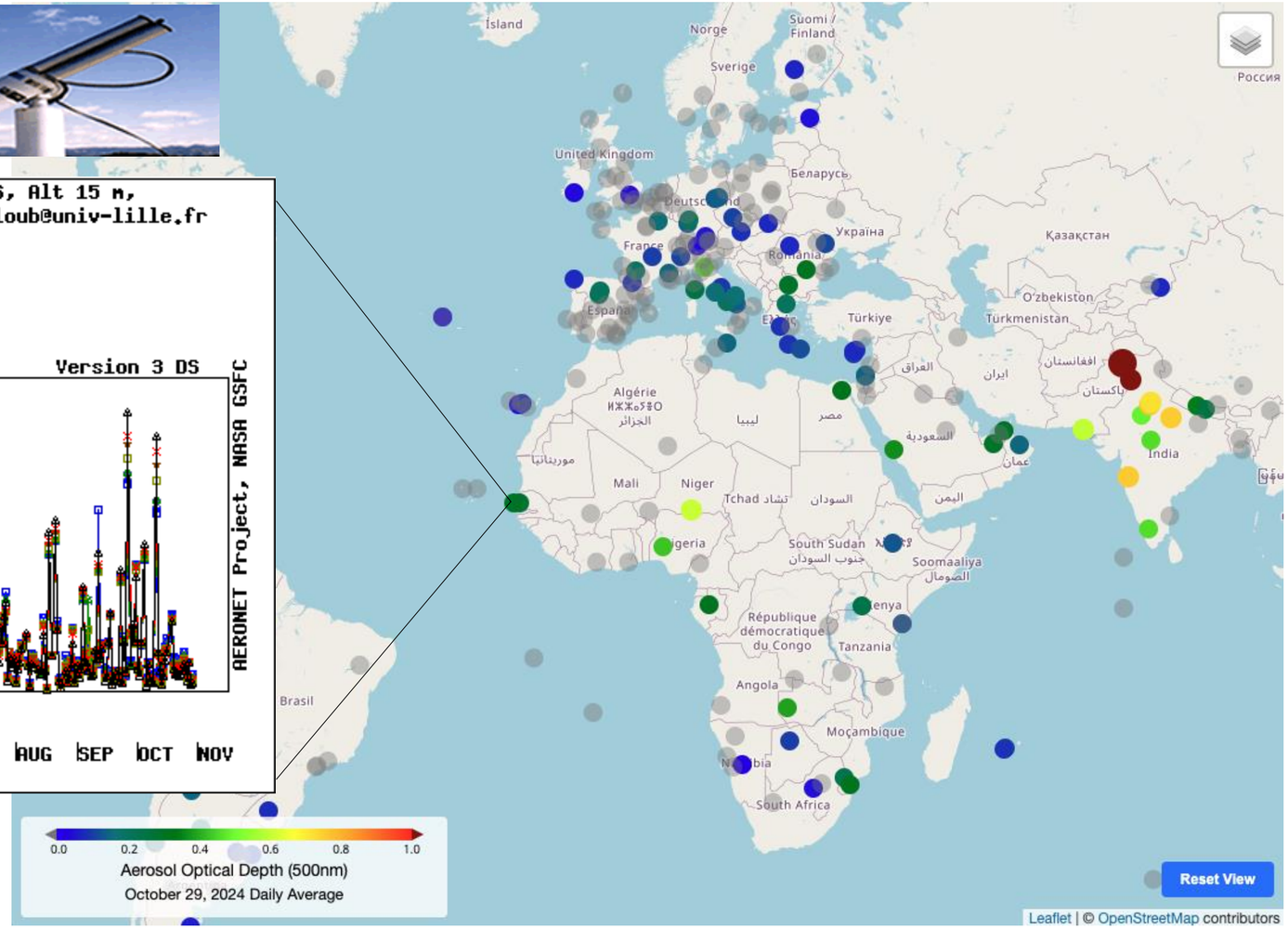
100+ sites

Helps to validate satellite data across missions

Can help to relate satellite AOD to surface PM concentrations



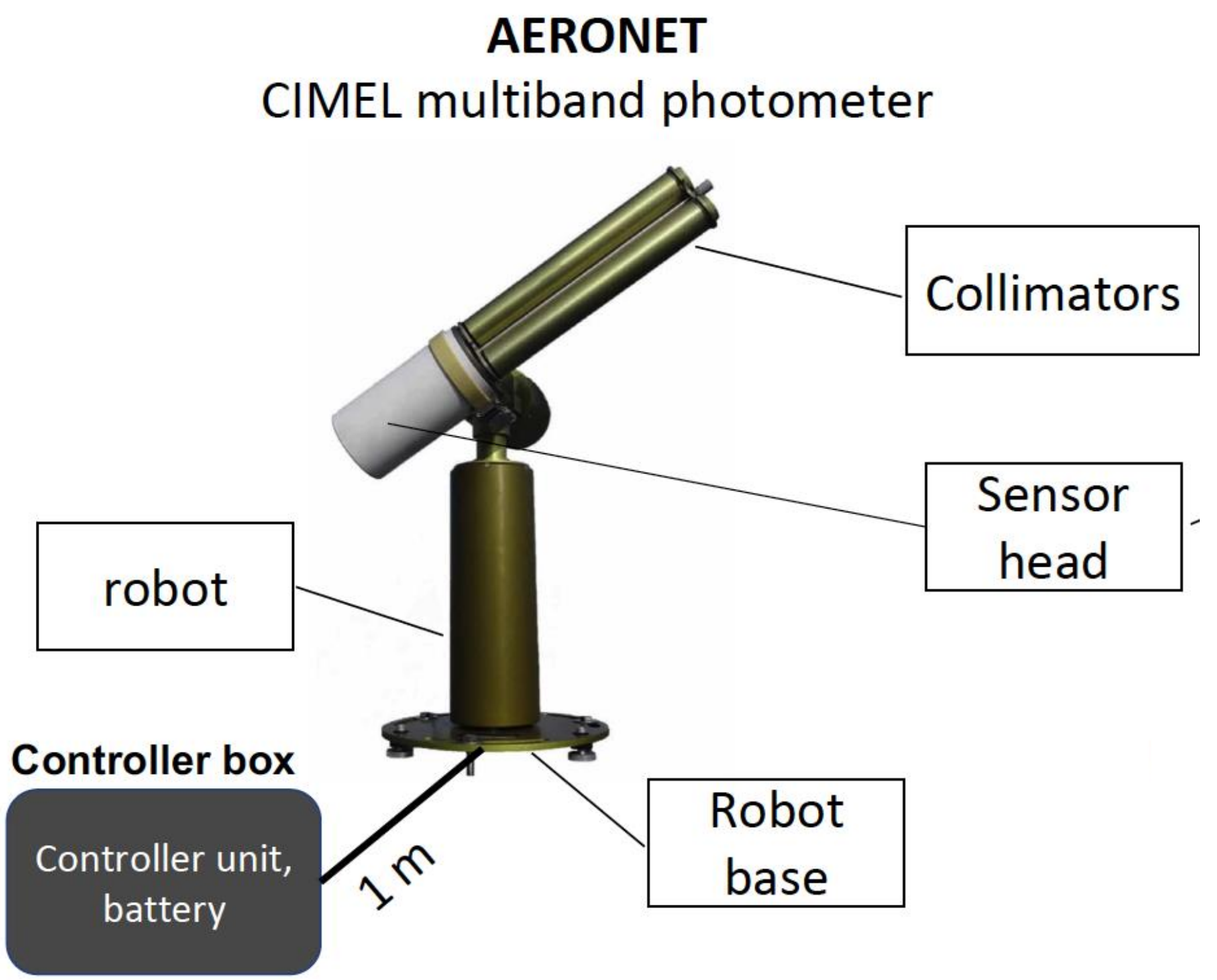




Source: AERONET website https://aeronet.gsfc.nasa.gov/

# AERONET Sun Photometers

- A sun photometer is a ‘light meter’ that measures the amount of sunlight within a narrow range of wavelengths.
- The instrument points at the sun or scans the sky, and light is collected through a small opening to detect direct or scattered light from specific directions.

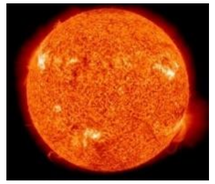





Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# Datasets Available from AERONET

## Sun and Moon Direct Irradiance




3 Sun and 3 Moon Obs. - Triplets

↓

**Beer-Lambert Law**

↓

Derived Parameters (Columnar)

- ✓**Aerosol Optical Depth (AOD)**
- ✓**Ångström Exponent**
- ✓**Water Vapor**

## Sky Radiance (θ,φ)



Almucantar, Principal Plane, and Hybrid

↓

**Inversion Procedure**

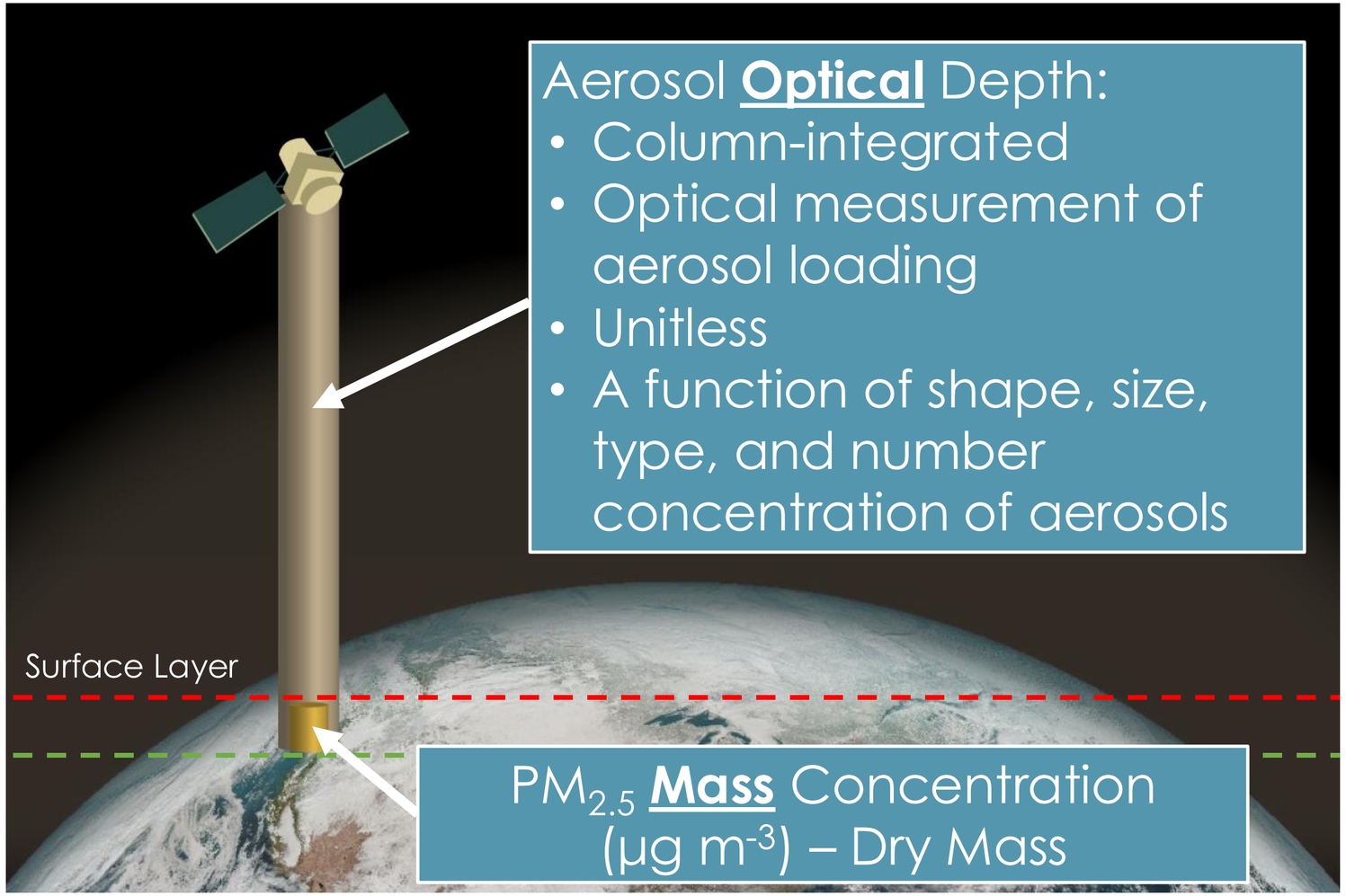
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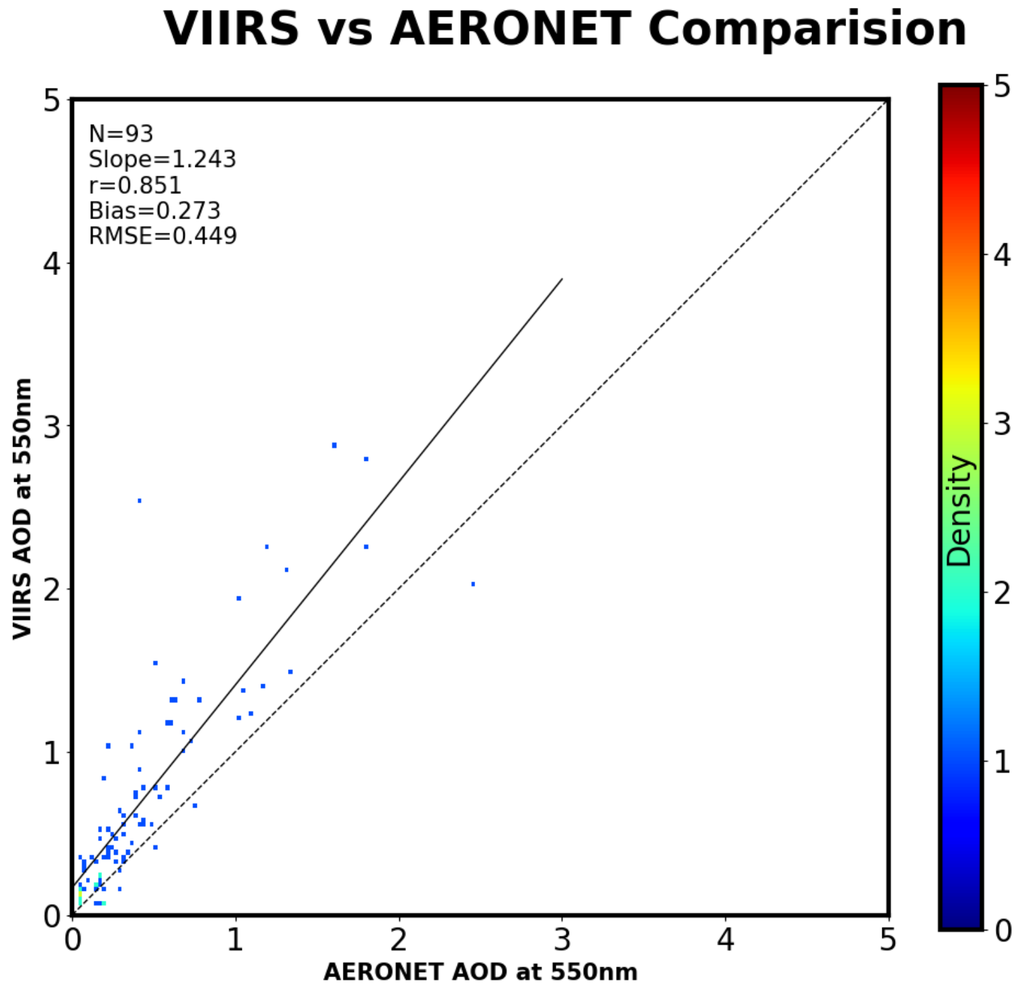
Derived Parameters (Columnar)

- ✓**Microphysical Properties** (e.g., size distribution, sphericity)
- ✓**Radiative Properties** (e.g. single scattering albedo, refractive index)

Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# Relating Column to Surface Aerosols




Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# Pandora & Pandonia Global Network

NASA + ESA + others

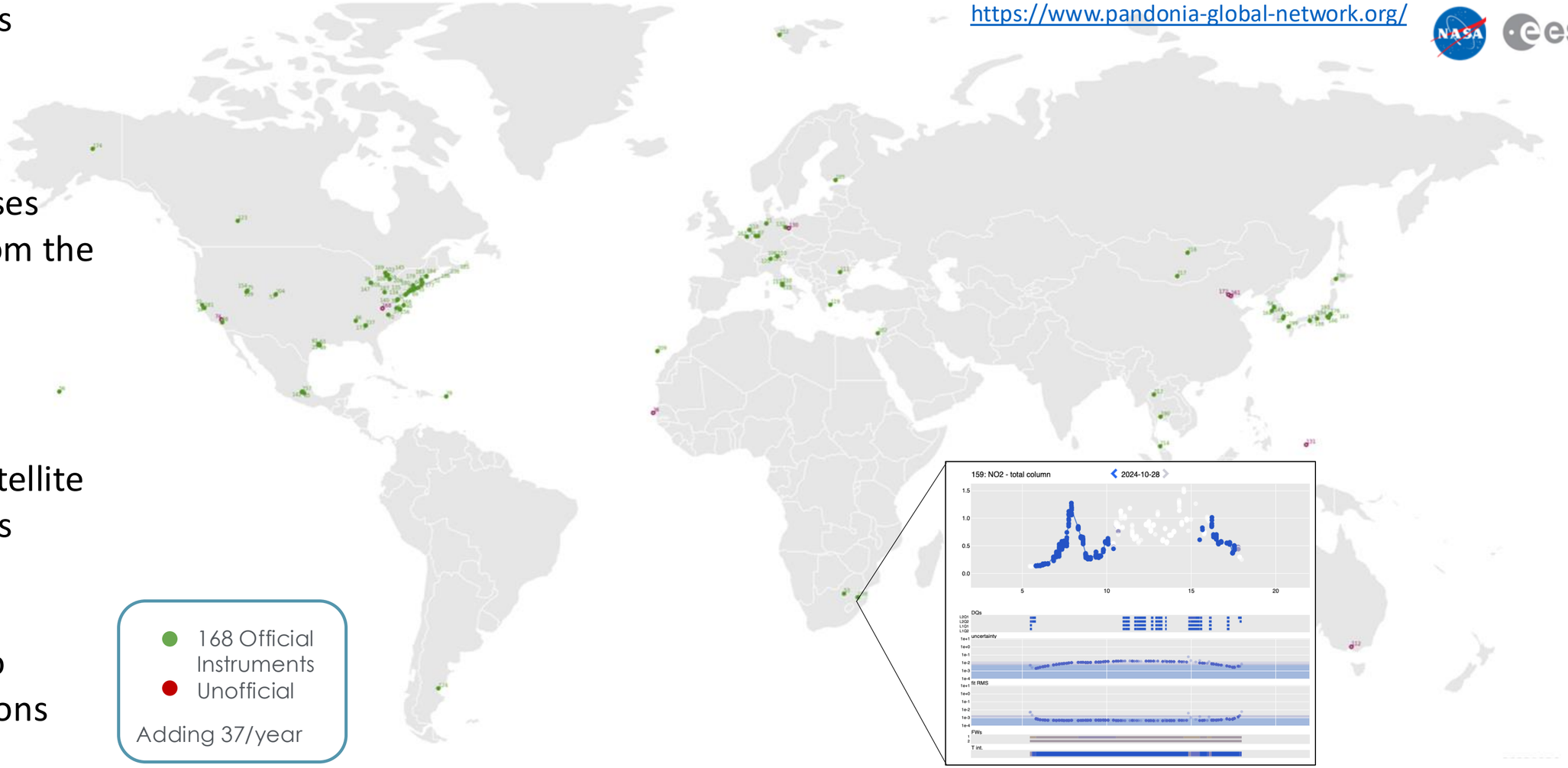
https://www.pandonia-global-network.org/

A global network of surface monitors measuring trace gases ($NO_2$, $O_3$, HCHO) from the ground up

100+ sites

Helps to validate satellite data across missions

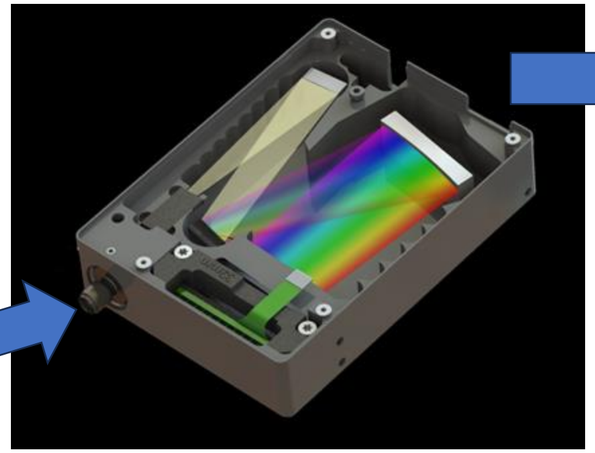
Can help to relate satellite trace gas to surface concentrations



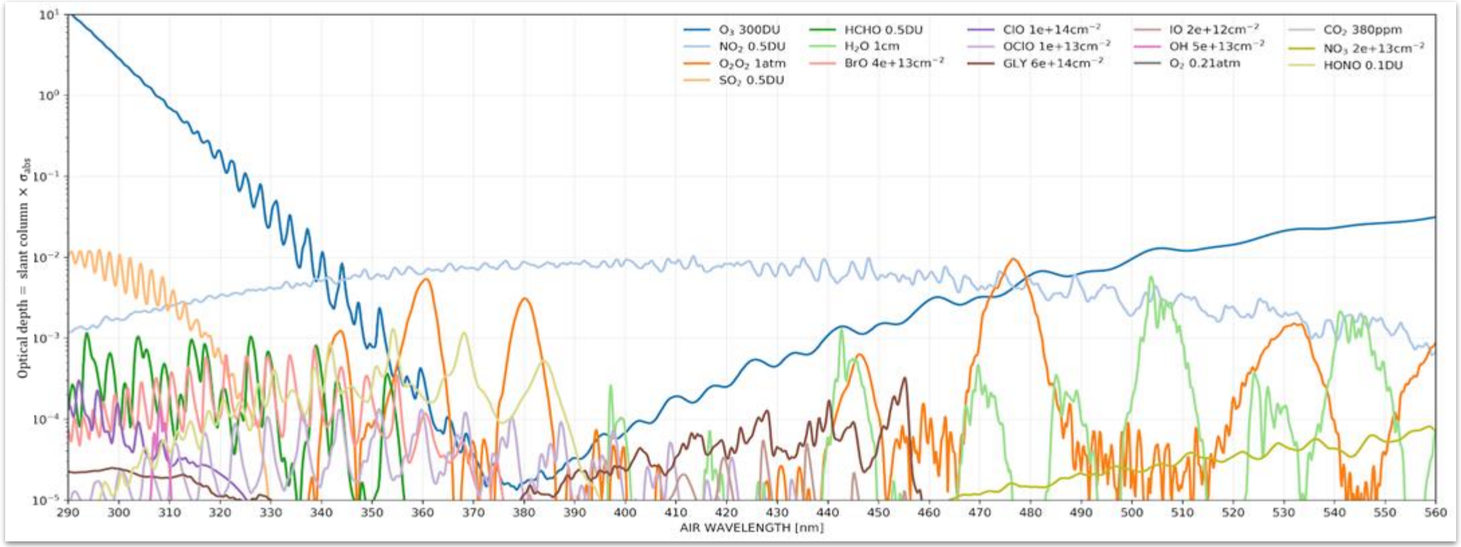

Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET).
https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# Pandora Hyperspectral Measurements



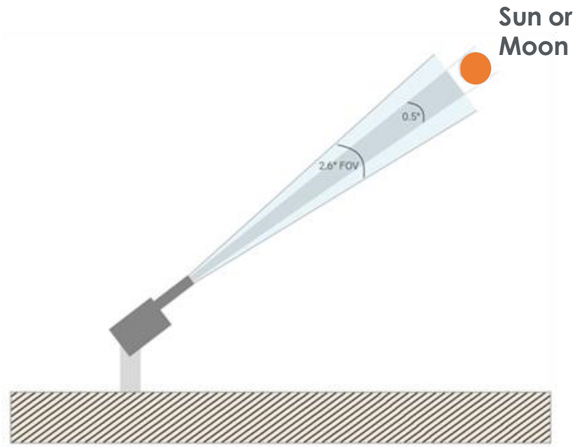


High spectral resolution data needed to distinguish spectral signatures of trace gases



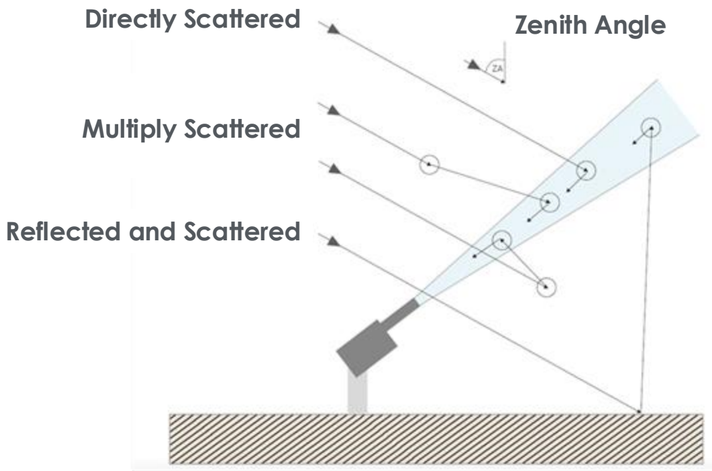

Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# Pandora Measurement Modes & Products




## Direct Sun or Moon

- Total absorption used to derive column abundance between instrument and top of atmosphere
- $H_2O$, $O_3$, $NO_2$, $SO_2$, HCHO




## MAX-DOAS

- Multi-Axis Differential Optical Absorption Spectroscopy
- Differential measurements used to derive abundance at multiple elevations (using 11-13 different angles)
- $NO_2$, HCHO

Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# MPLNET: Micro-Pulse Lidar Network

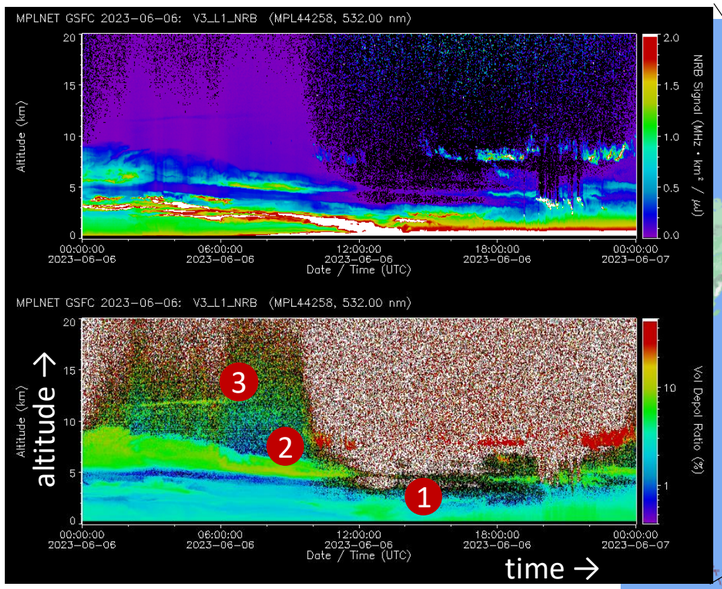
NASA + others contribute to GALION global network

active lidars measuring aerosol, cloud, and planetary boundary layer vertical profiles

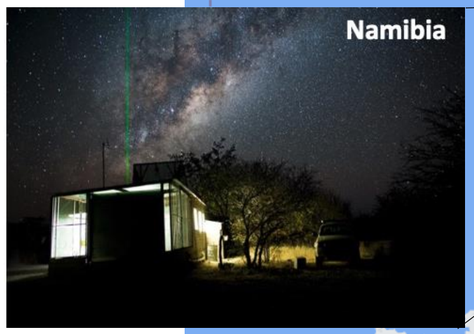
85+ sites

Improves understanding of aerosol and cloud behavior

Can help relate satellite aerosols to surface concentrations




**MPLNET distinguished smoke from 3 different fires passing over the same location**

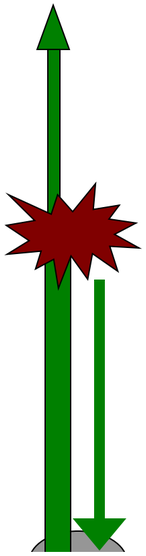






Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# Lidar Principles






**Backscatter Lidars** profile aerosols and thin clouds.

Visible (green) light is ideal for smaller particles like aerosols.

Lidars transmit short pulses of laser light into the atmosphere.

The light is attenuated as it travels up and back through the atmosphere by scattering and absorption, in total referred to as **extinction**.

A small portion of the light **backscatters** (180º) from particles in the atmosphere and is collected by a telescope and recorded using a detector and data system.

The backscatter and extinction parameters in the measured signals are the optical properties of the aerosol and clouds.

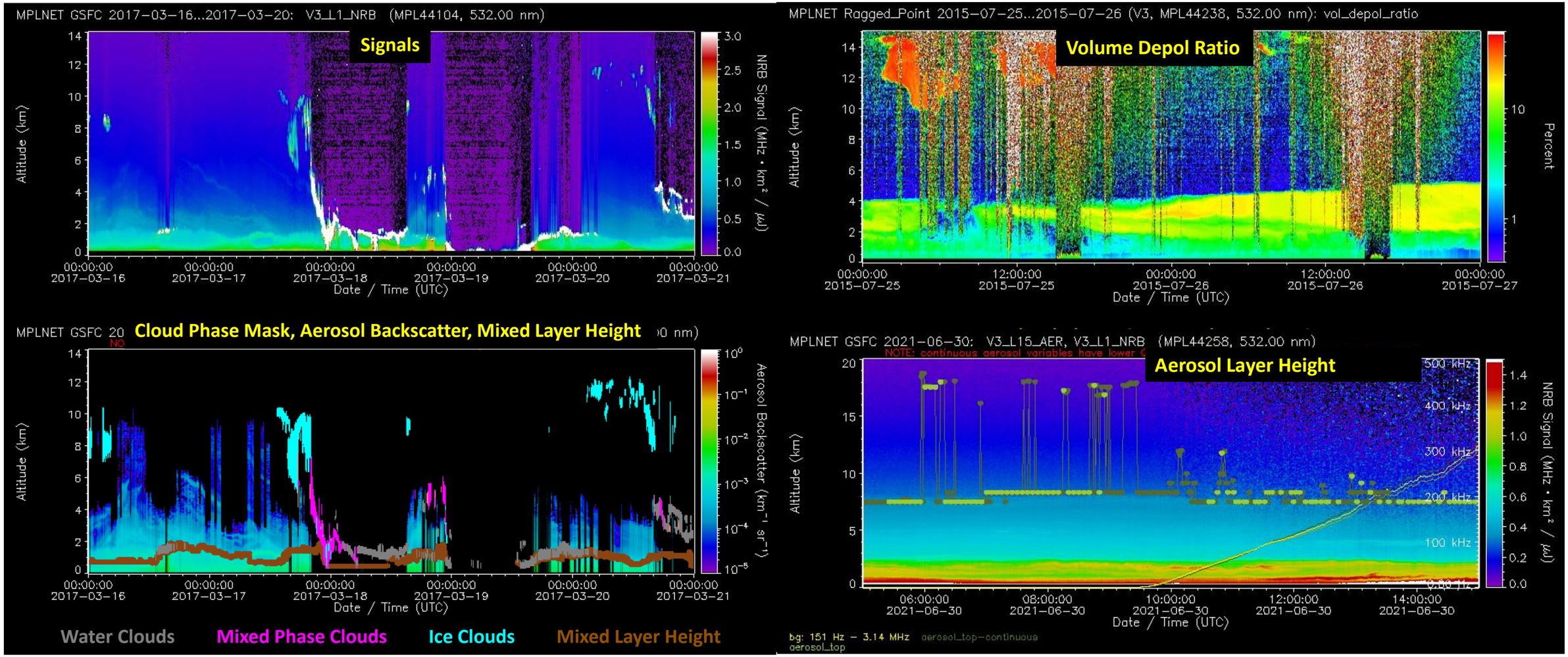
The altitude of the particle is determined from the time between pulse transmission and signal reception, using the speed of light.

Scattering from non-spherical particles (dust, ice clouds) depolarizes the laser. The **depolarization ratio** is proportional to the particle's non-sphericity.

The remote sensing data from the lidar provides **optical proxies** for vertical profiles of aerosol and cloud concentration, composition, and shape.

Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

# MPLNET Data Products




Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET).
https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air

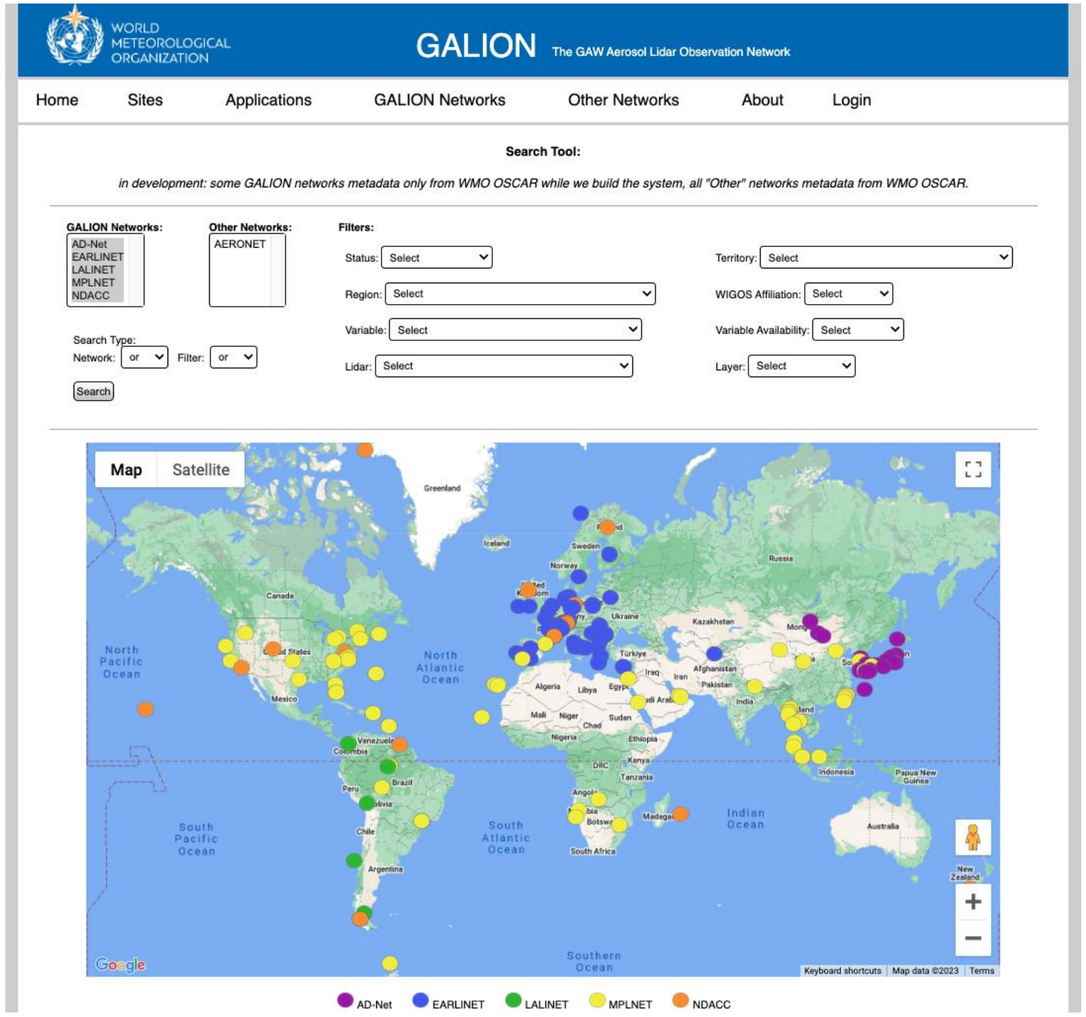
# GALION: GAW Aerosol Lidar Observation Network

**New Data Center and Website: [https://galion.world/](https://galion.world/)**

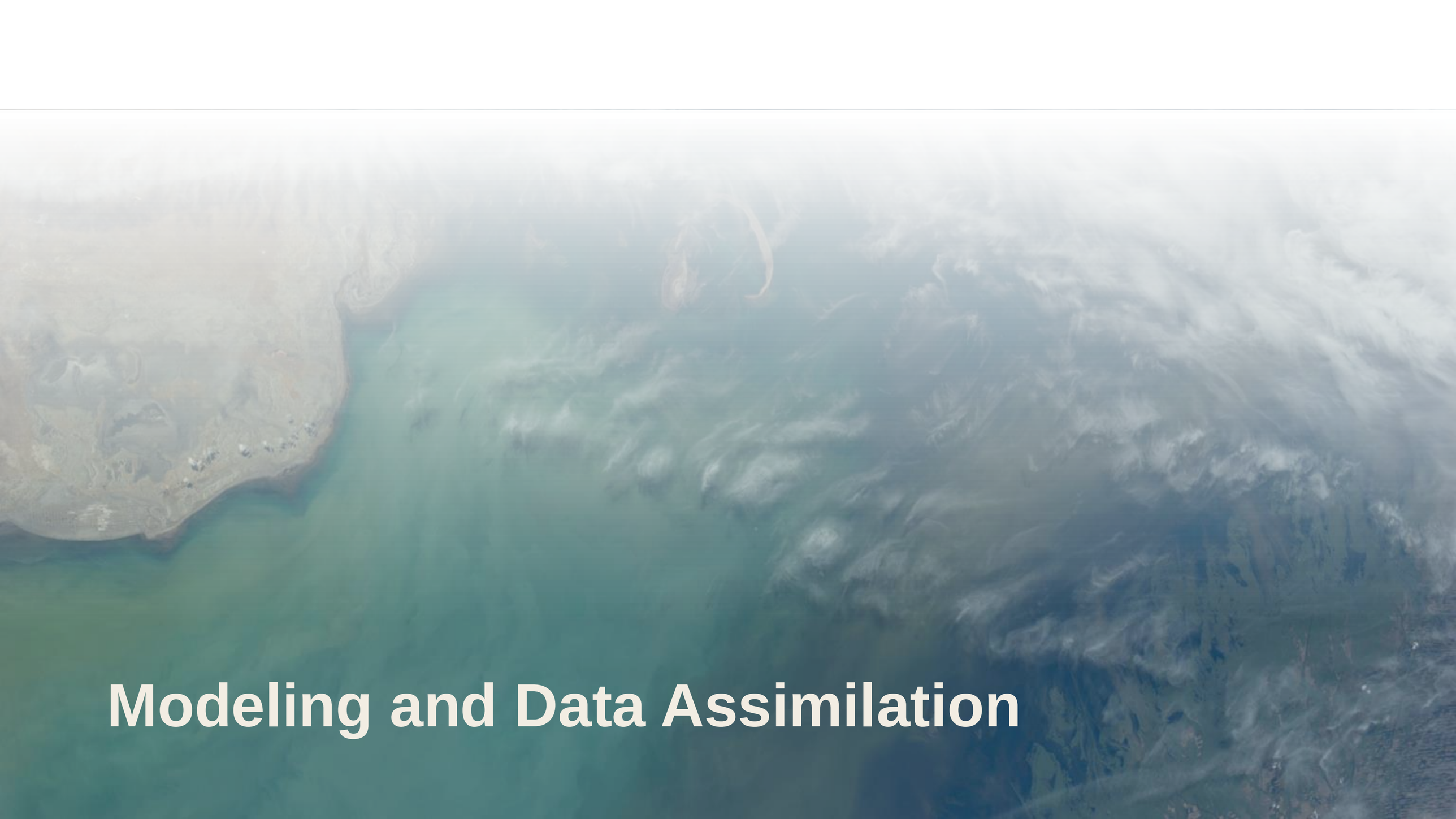
**Capabilities**

- GALION information and search and discovery
- Automated handshakes with WMO OSCAR database Metadata APIs
- Goal: One source to get aggregated lidar network information and data access

NOTE: we are still updating metadata from networks. The website is functional, but some portions will not be public until the metadata are complete. Mainly download of search results.



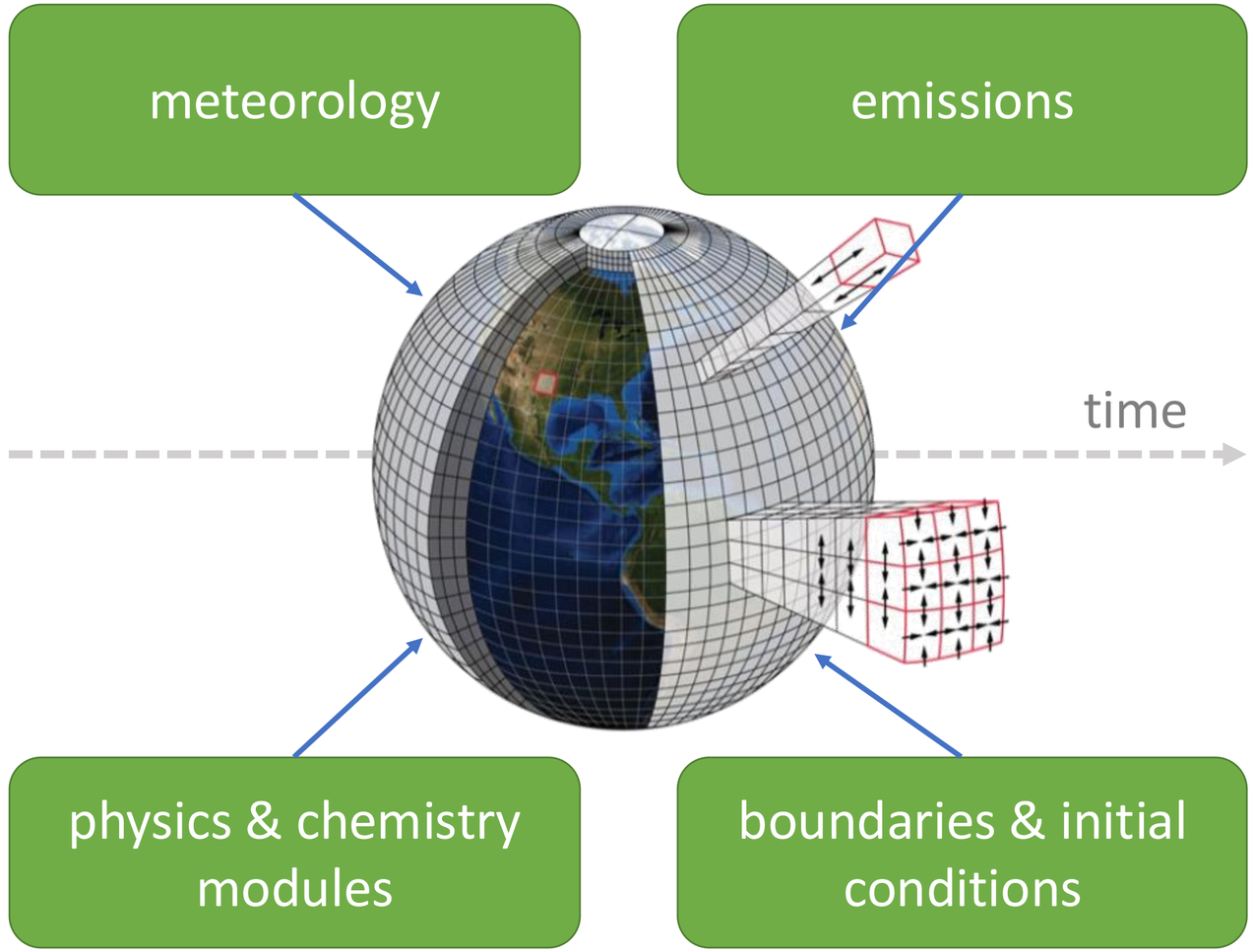

Source: ARSET - NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications. NASA Applied Remote Sensing Training Program (ARSET). https://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-atmospheric-composition-ground-networks-supporting-air



# Modeling and Data Assimilation

# Atmospheric Chemistry and Transport Models

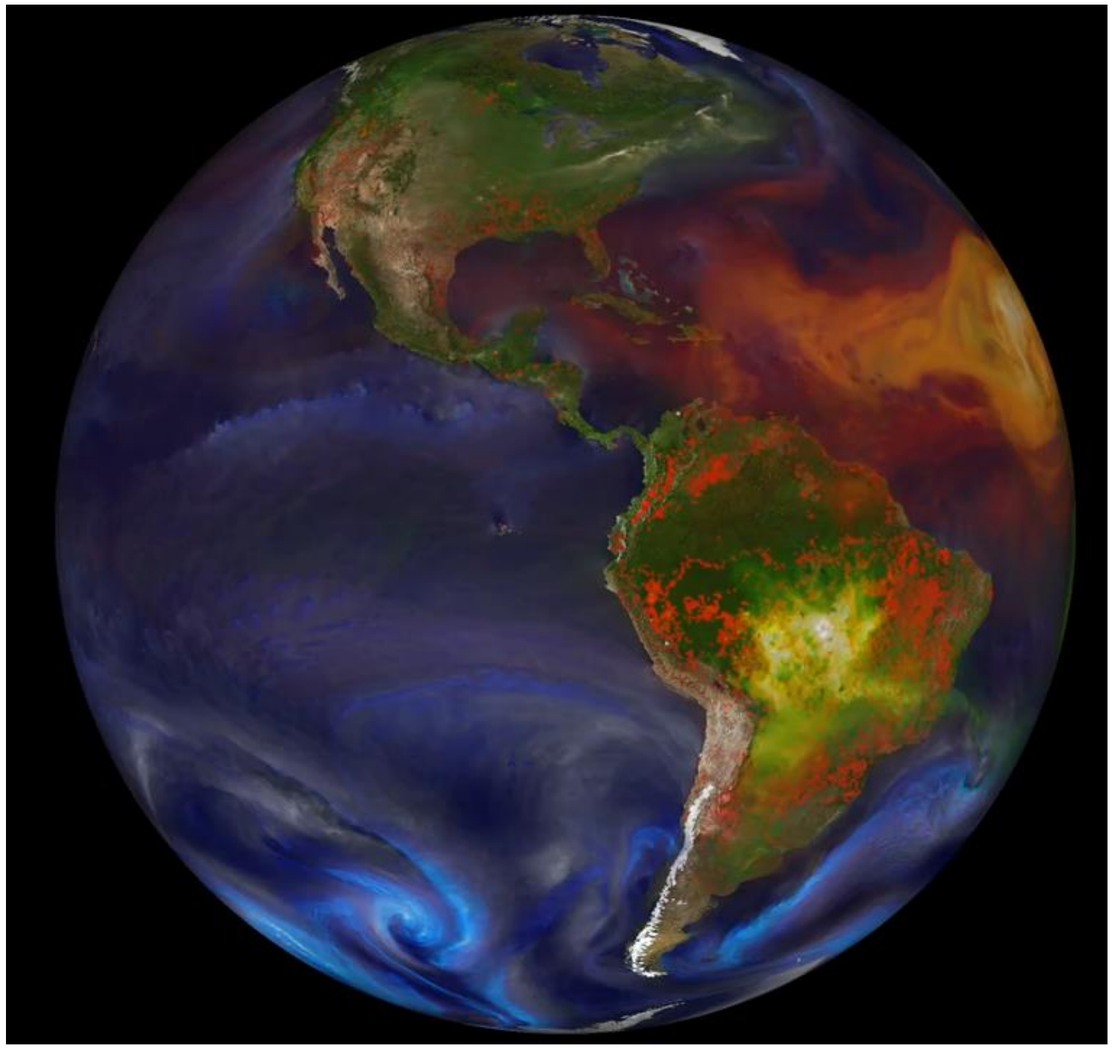
- **Mathematically represent the processes which influence air quality**
  - Emission
  - Transport
  - Diffusion
  - Chemical & physical transformation
  - Deposition & removal
- Provide a **complete and self-consistent** representation of the modelled system, with forecasting/hindcasting.
- Limited by **spatial and temporal resolution**, **representation of processes**, and **required input data**.




Source: Gupta, P.; Follette-Cook, M.; Parrington, M.; Stewart, C. (2021). *Introduction and Access to Global Air Quality Forecasting Data and Tools*. NASA ARSET. https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-and-access-global-air-quality-forecasting-data-and

# NASA Global Modeling and Assimilation Office

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



Source: NASA Scientific Visualization Studio https://svs.gsfc.nasa.gov/30017

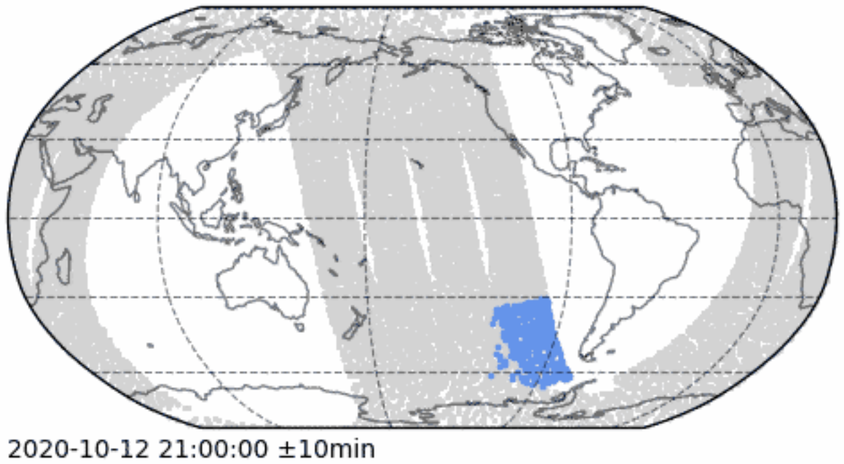
# Data Assimilation

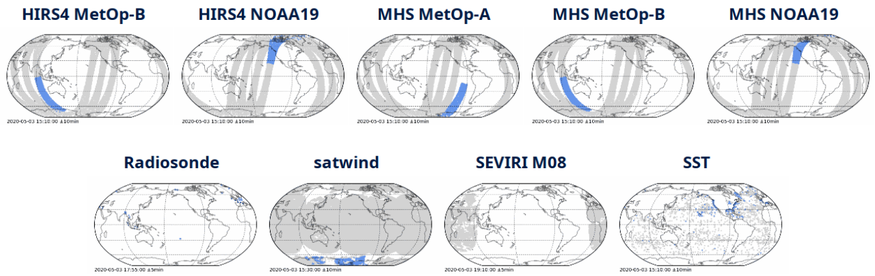
Observing System(s)

Observation Data

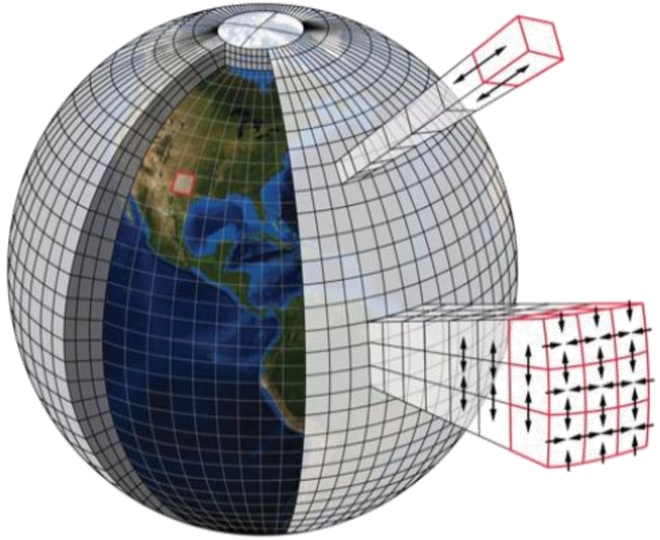
Observation Operator

Background (prior)




Data Assimilation System (3D-Var, 4D-Var, EnKF)



Innovation (update)

Analysis (posterior)

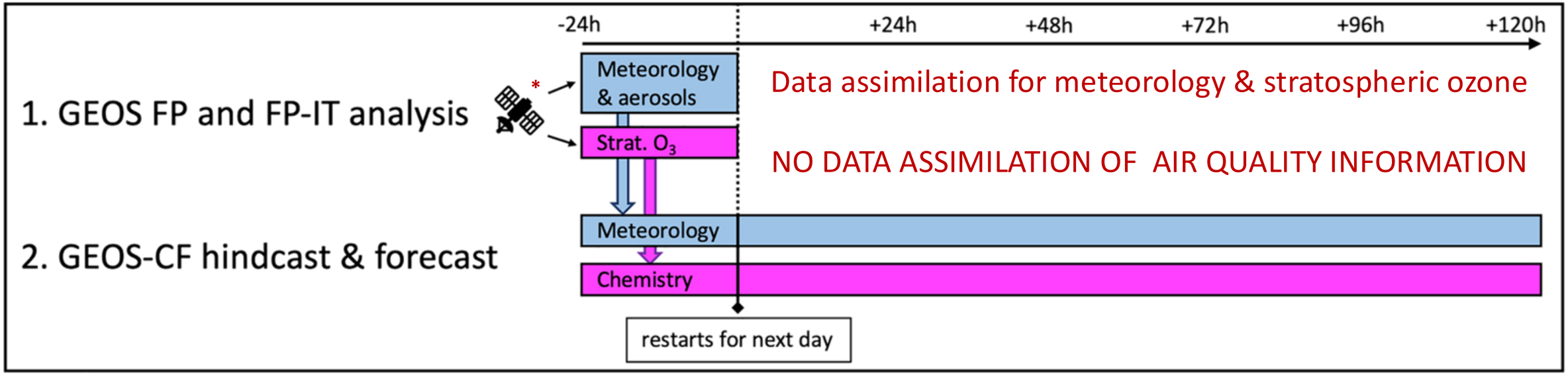
Source: Joint Center for Satellite Data Assimilation, https://www.jcsda.org/

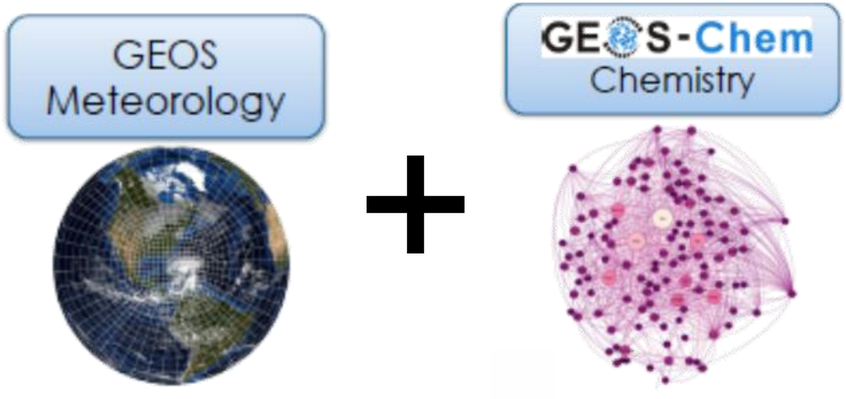
# NASA Global Earth Observing System (GEOS)

| | GEOS FP | GEOS-CF | MERRA-2 |
|---|---|---|---|
| Type | Analysis + Forecast | Replay + Forecast | Reanalysis |
| Domain | Global | Global | Global |
| Spatial Resolution | Simulation: ~12 km<br>Output: ~25 km (0.25°x0.312°) | ~25 km (0.25°x0.312°) | ~50km (0.5°x0.625°) |
| Temporal Resolution | 2-D data: Hourly<br>3-D data: Every 3 h | 15 min, Hourly | Hourly, Daily, Monthly |
| Vertical Levels | 72 (near surface-0.1 hPa) | 72 (near surface-0.1 hPa) | 72 (near surface-0.1 hPa) |
| Output available | Analysis: 2014 – Present<br>Forecast: ~20 days | Replay: 2018 – Present<br>Forecast: 2019 – Present (aqc collection)<br>~14 days (all collections) | 1980-Present |
| Initialization | Daily 10-day forecast at 00Z<br>Daily 5-day forecast at 12Z | Daily 5-day forecast at 12Z | ~1-2 months behind real time |
| Data Assimilation | Yes | No | Yes |
| File Specification Doc | https://gmao.gsfc.nasa.gov/pubs/docs/Lucchesi1203.pdf * | https://gmao.gsfc.nasa.gov/pubs/docs/Knowland1204.pdf * | https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich785.pdf * |

Source: Gupta, P.; Follette-Cook, M.; Parrington, M.; Stewart, C. (2021). *Introduction and Access to Global Air Quality Forecasting Data and Tools*. NASA ARSET. https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-and-access-global-air-quality-forecasting-data-and

# GEOS Composition Forecast (GEOS-CF)



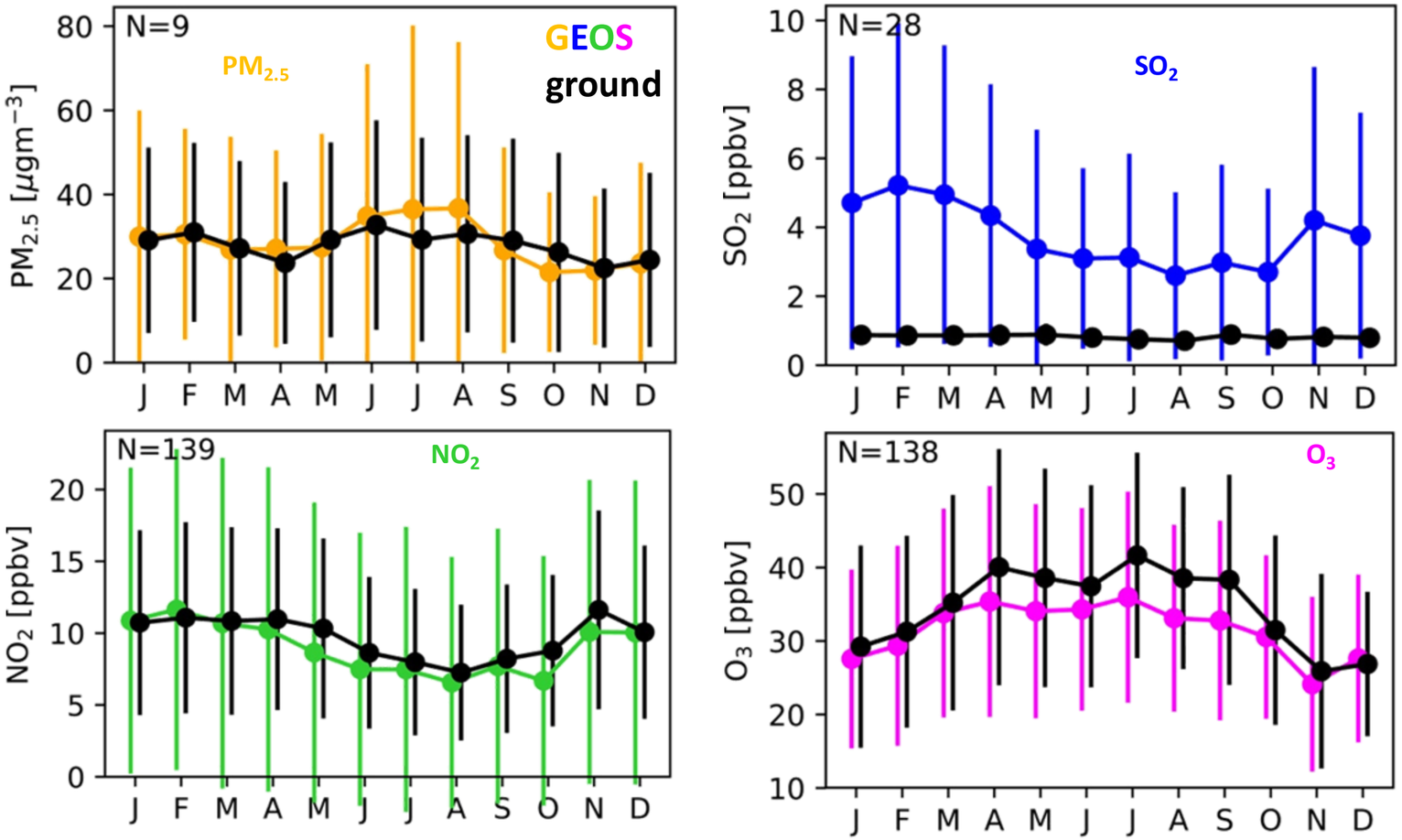

- Combine GEOS meteorology with GEOS-Chem chemistry
- 250 chemical species
- Hourly temporal resolution
- 0.25 degree (25 km) spatial resolution
- Global coverage
- Daily 1-day hindcast and 5-day forecast

Source: Keller, C., et al. (2021) "Description of the NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0". *Journal of Advances in Modeling Earth Systems*, 13:4. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020MS002413

# GEOS-CF Performance in Africa

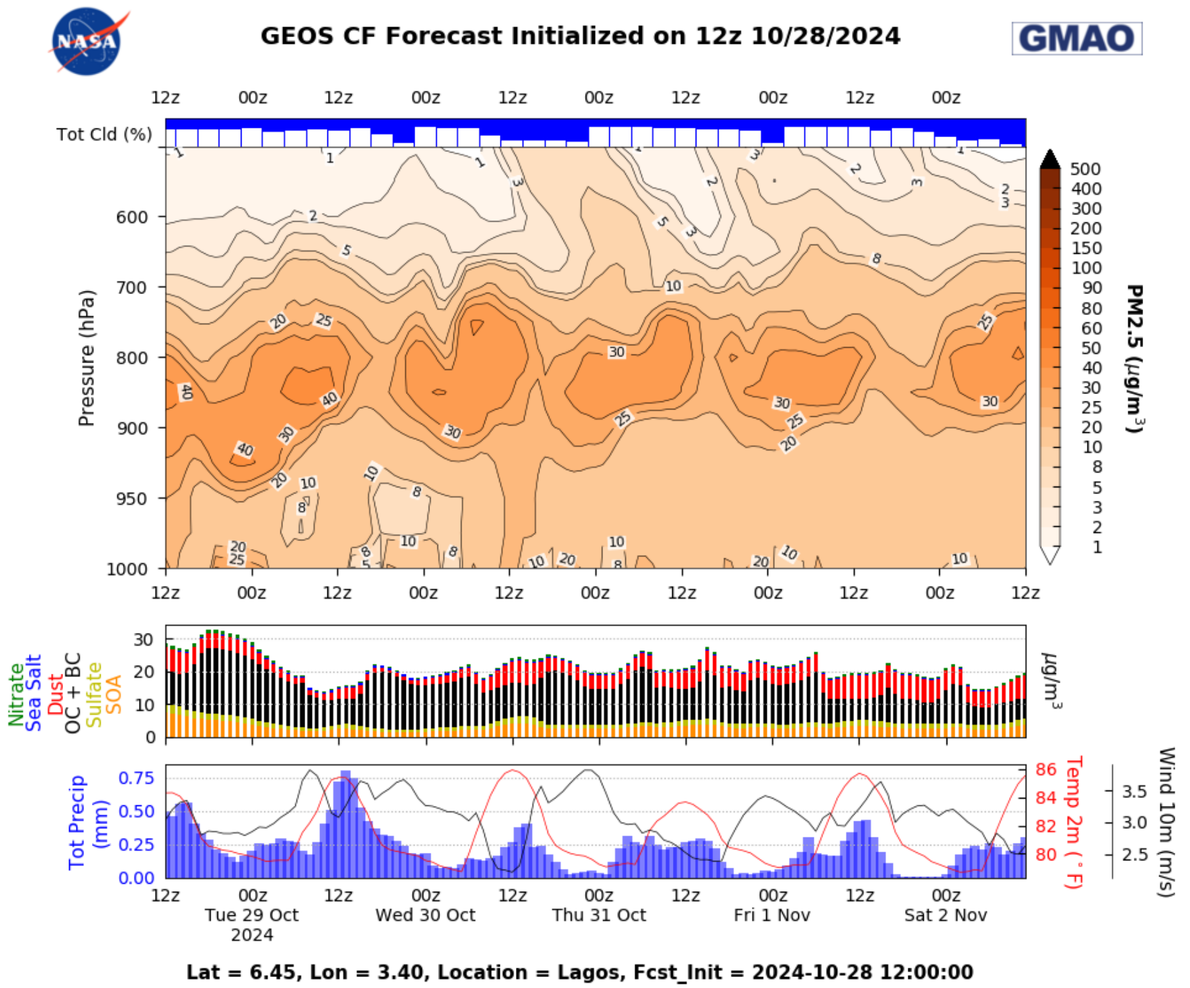
- Generally good capturing of $PM_{2.5}$, $NO_2$, $O_3$ trends
- $SO_2$ is biased high globally (data assimilation can improve this).
- Agreement can vary annually, seasonally and by region.
- There can be high bias at individual locations due to local impacts.
- **Limited ground data for verification**.

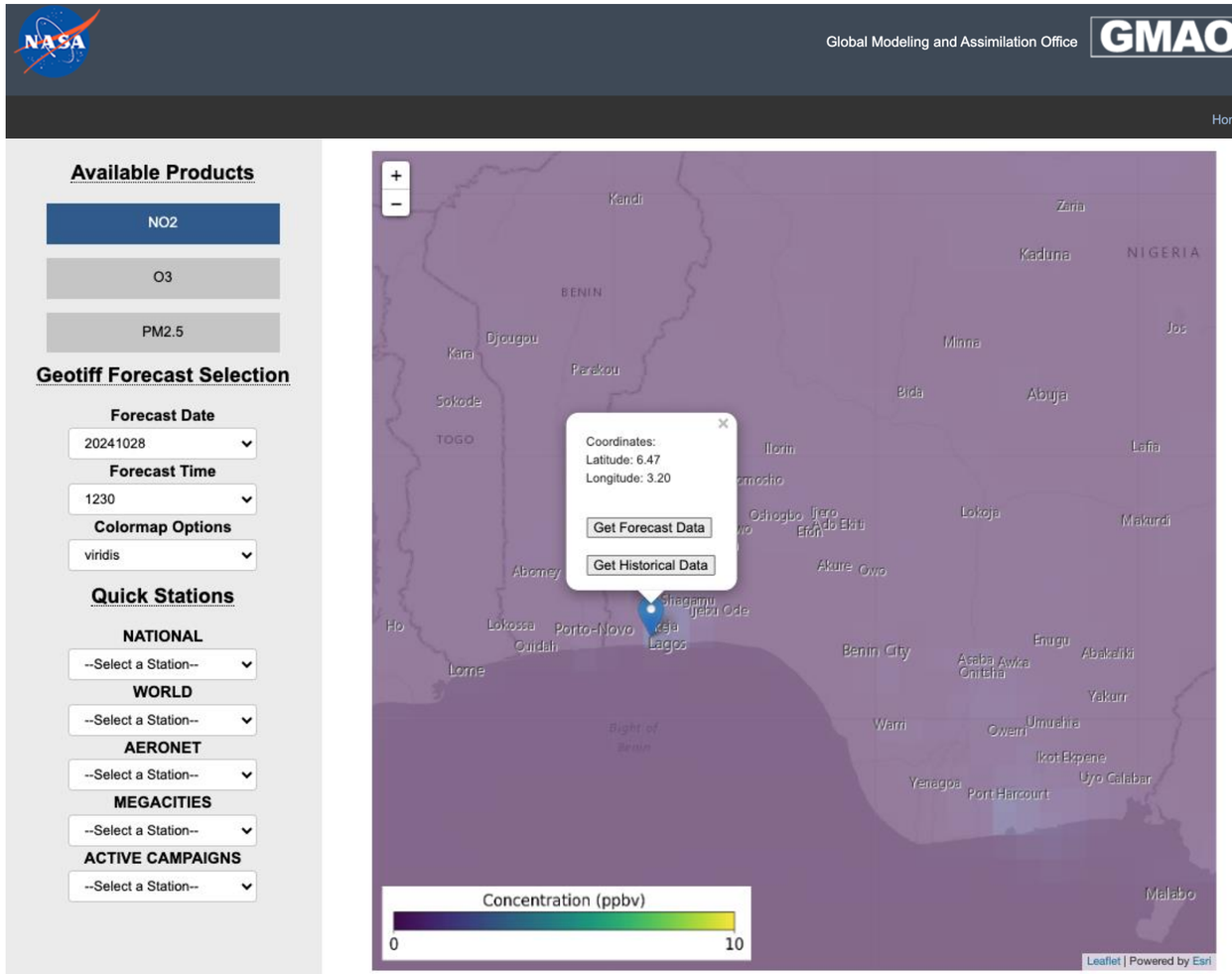
Monthly average concentrations at sites in Africa




Source: Keller, C., et al. (2021) "Description of the NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0". *Journal of Advances in Modeling Earth Systems*, 13:4. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020MS002413

# NASA FLUID webpage



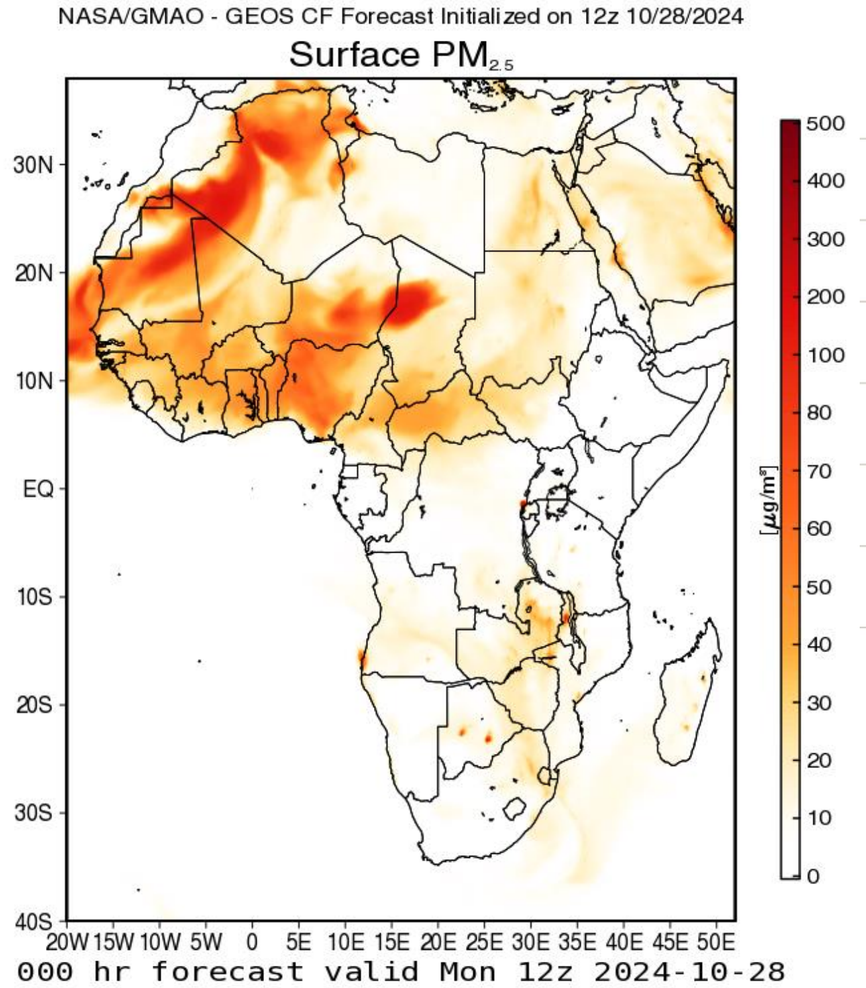



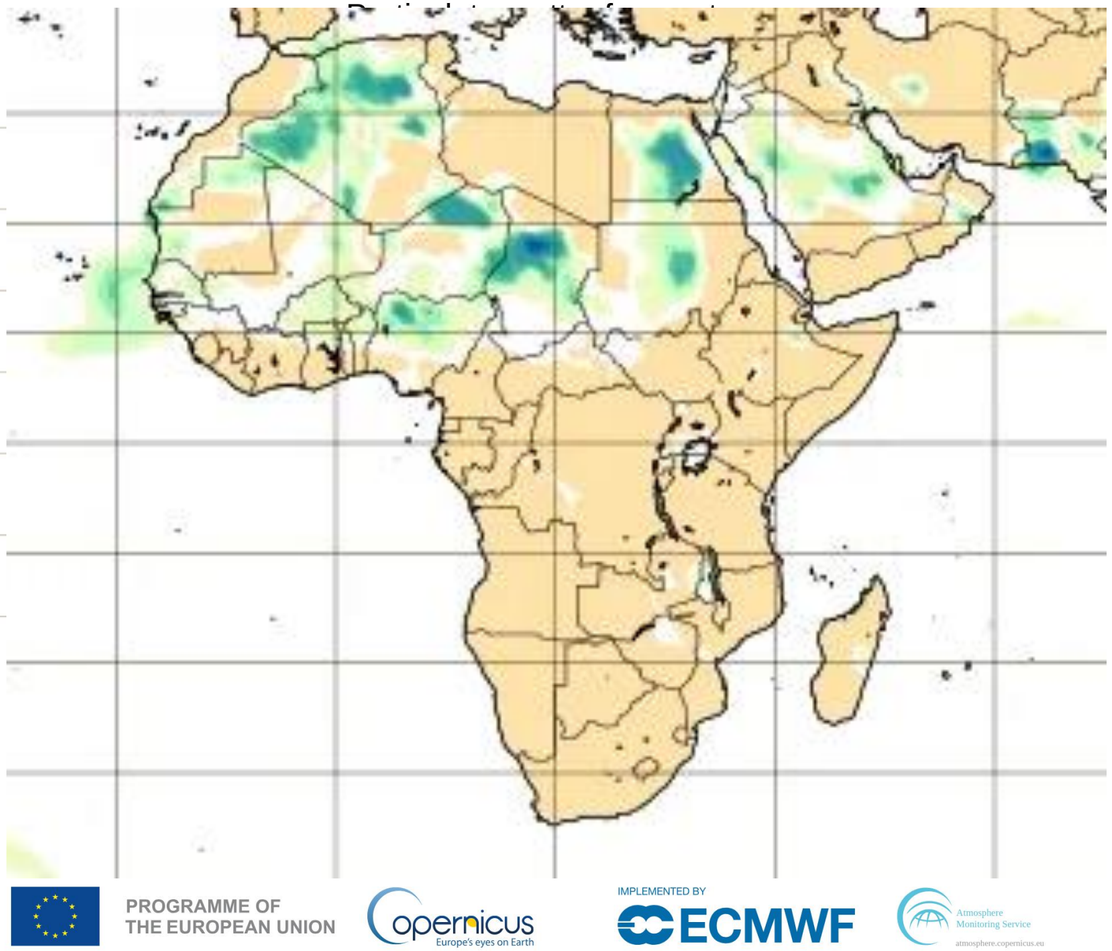

https://fluid.nccs.nasa.gov/cf/

# GEOS-CF & CAMS Forecasts

**GEOS-CF Composition Forecast**
NASA GMAO
Hourly, 5-day forecast
0.25º (~25km)

**CAMS Global Atmospheric Composition Forecast**
ECMWF
Hourly, 5-day forecast
0.35º (~40km)




Forecast key pollutants

- $NO_2$
- $SO_2$
- $PM_{2.5}$
- $O_3$
- CO

Sources: NASA GMAO GEOS-CF Fluid Visualization Tool https://fluid.nccs.nasa.gov/cf/
ECMWF CAMS Atmospheric Composition Charts https://charts.ecmwf.int/

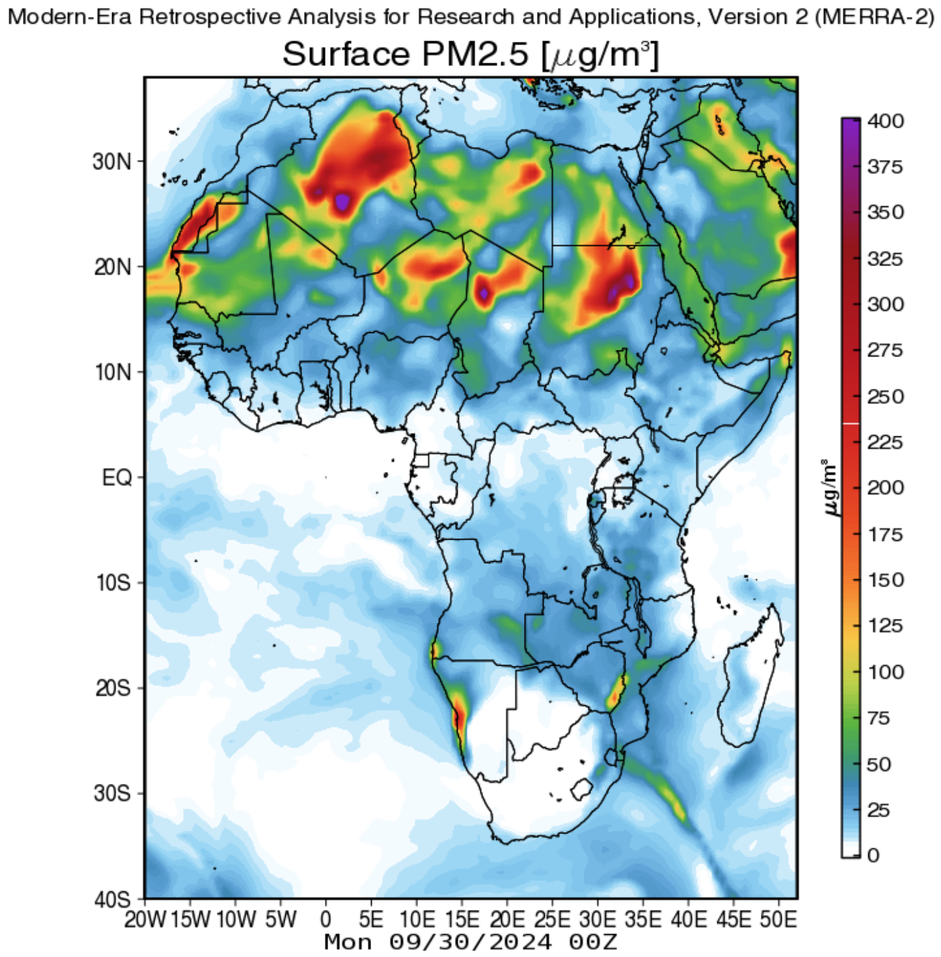
# MERRA-2 & CAMS Reanalysis

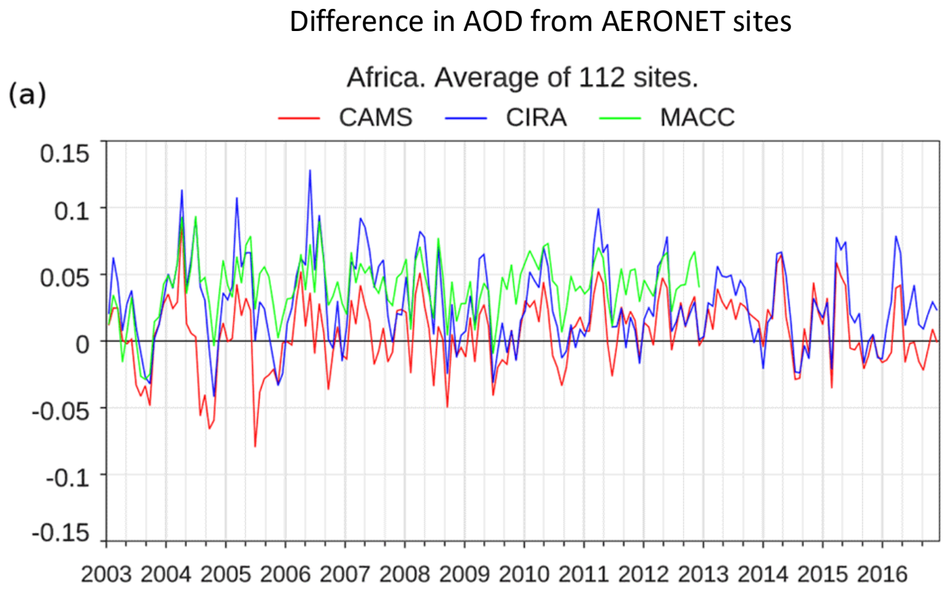
**Modern Era Retrospective Analysis for Research and Applications version 2**
NASA Global Modeling & Assimilation Office (GMAO)
0.5º (~50km)

**CAMS Global Reanalysis (EAC4)**
European Center for Midrange Weather Forecasting (ECMWF)
0.75º (~80km)

Analyze key pollutants

- $NO_2$
- $SO_2$
- $PM_{2.5}$
- $O_3$
- CO

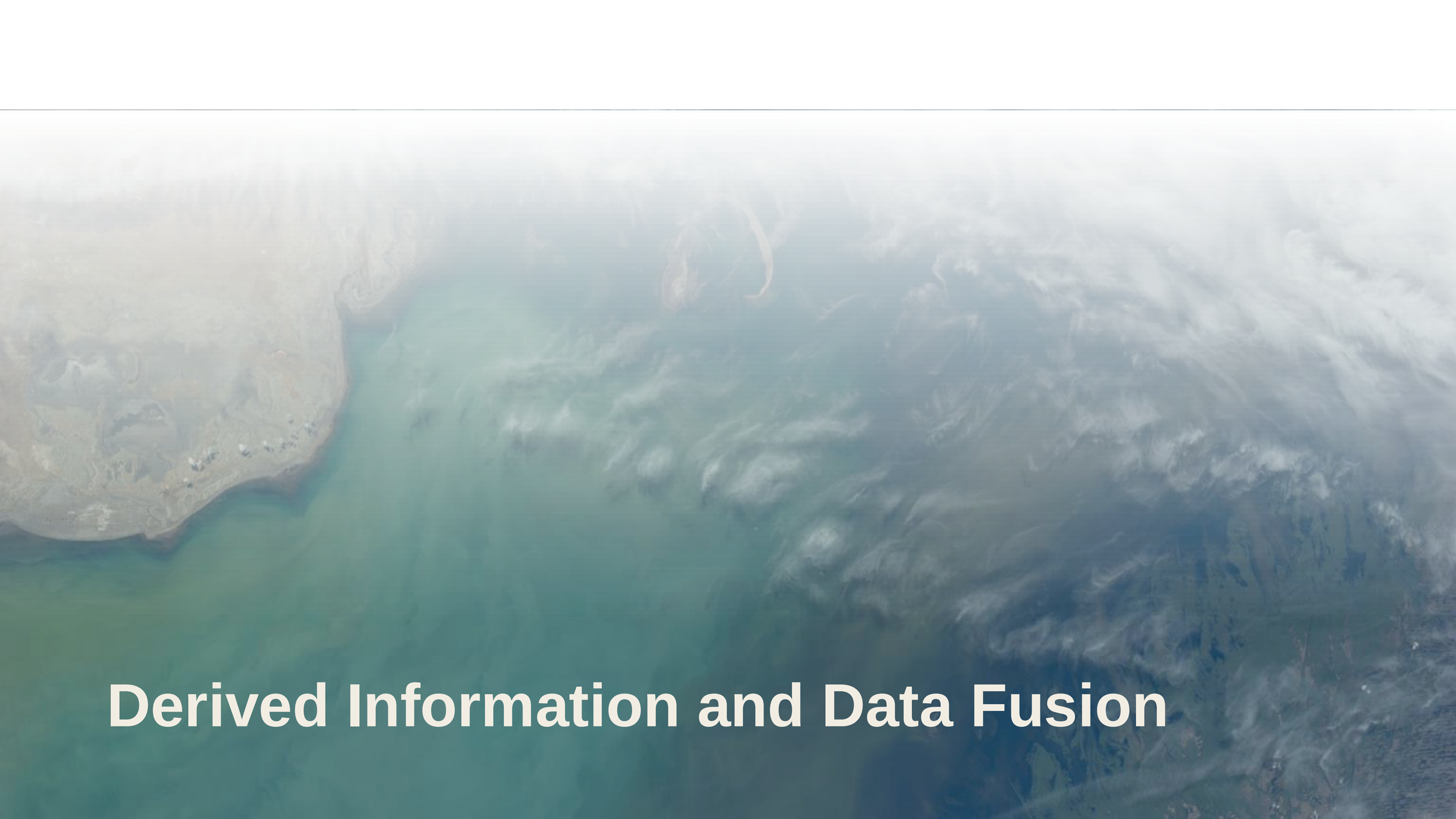



Sources: NASA GMAO MERRA-2 Fluid Visualization Tool https://fluid.nccs.nasa.gov/reanalysis/
Inness et al. (2019) The CAMS reanalysis of atmospheric composition. *Atmospheric Chemistry and Physics*.

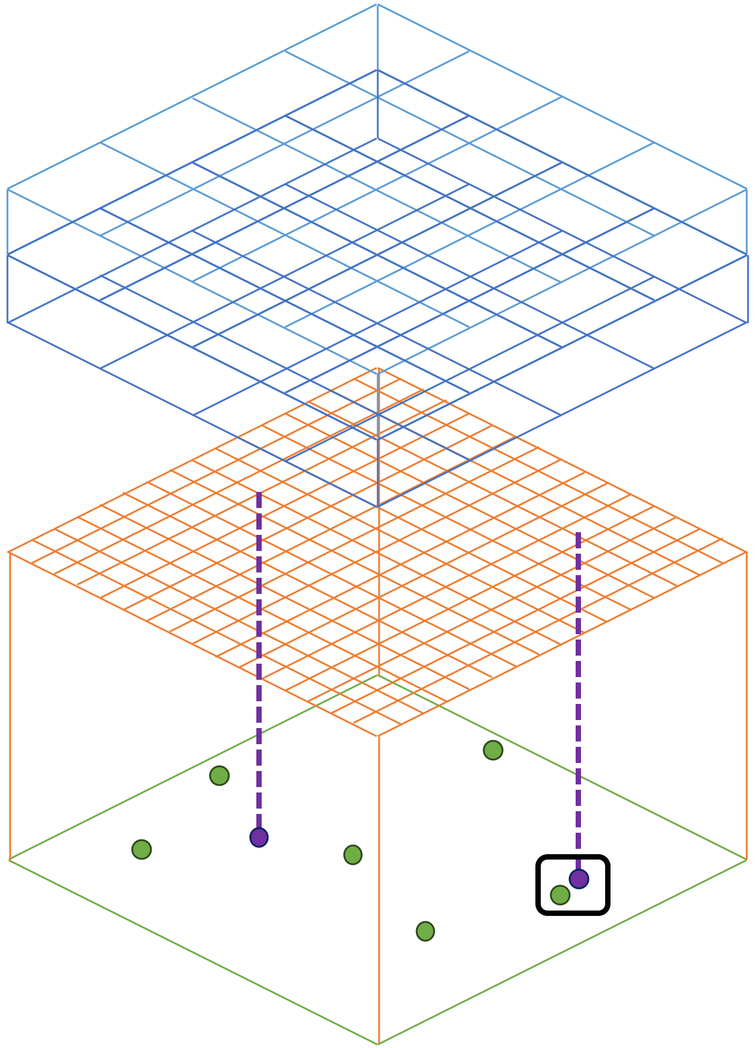
Partner

carl.a.malings@nasa.gov



# Derived Information and Data Fusion

# Combining Multiple Information Sources



Atmospheric Models (column & surface)

**Data Assimilation**

Satellite Remote Sensing (column)

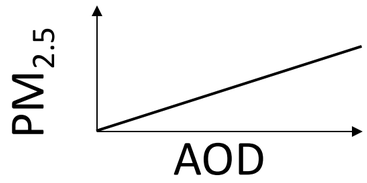
Ground-based Remote Sensing (column)

In-Situ Air Quality Measurements (surface)

**Data Fusion & Derived Information**

# Deriving Surface $PM_{2.5}$ from AOD

**Two-Variable Regression Method**




$$PM_{2.5} = \beta_0 + \alpha \times AOD$$

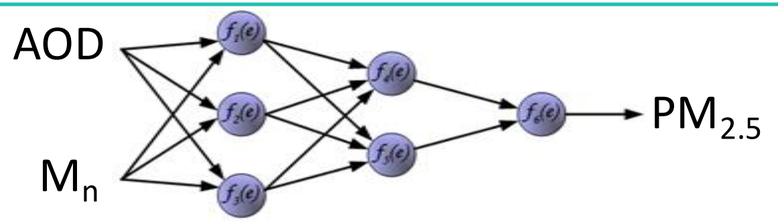
Inputs
- Ground Monitors
- Satellite AOD

**Multivariable Regression Method**

$$PM_{2.5} = \beta_0 + \alpha \times AOD + \sum_{n=1}^{m} (\beta_n \times M_n)$$

- Ground Monitors
- Satellite AOD
- Land use ?
- Meteorology ?

**Artificial Intelligence & Machine Learning**




- Ground Monitors
- Satellite AOD
- Land use ?
- Meteorology ?
- More ???

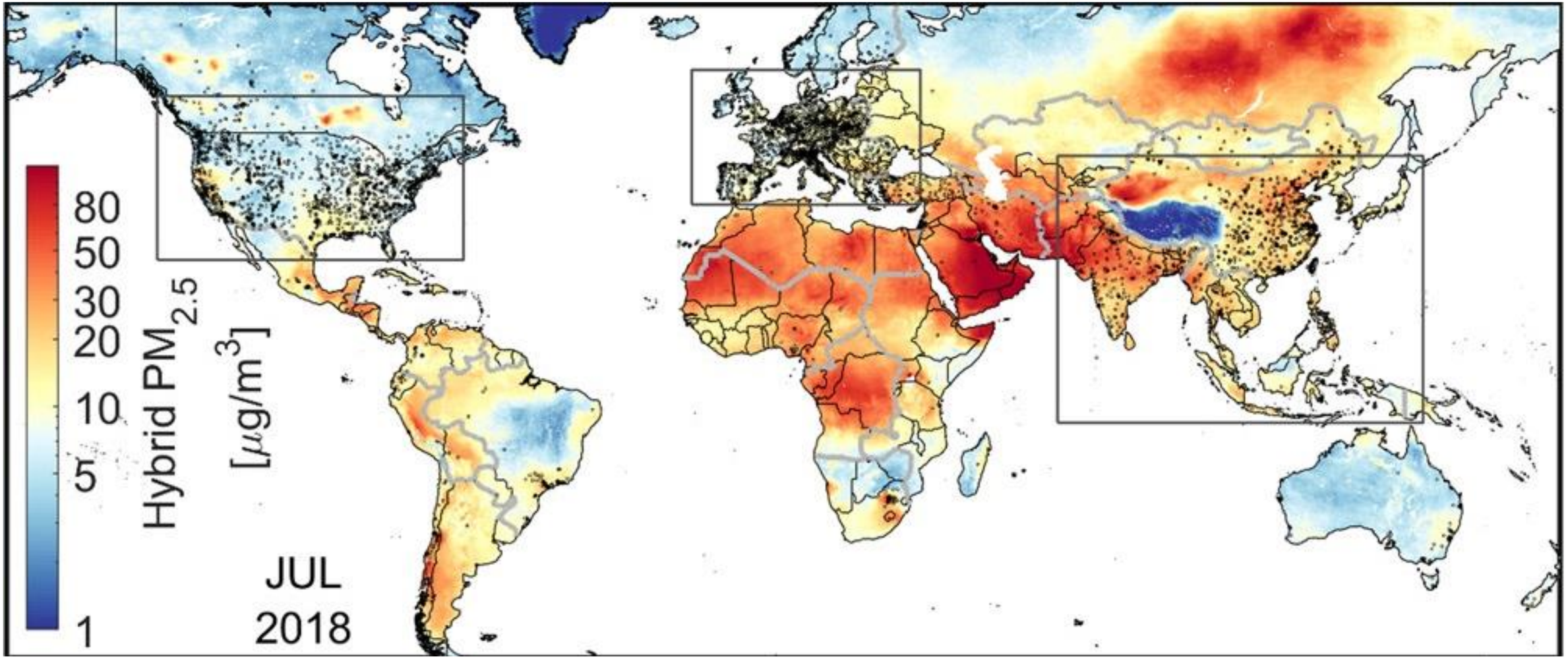
**Geophysical Methods using Atmospheric Models**

$$PM_{2.5} = \frac{\text{Model } PM_{2.5}}{\text{Model AOD}} \times \text{Satellite AOD}$$

- Atmospheric Model
- Satellite AOD
- Ground monitors (optional)
- Remote sensors (optional)

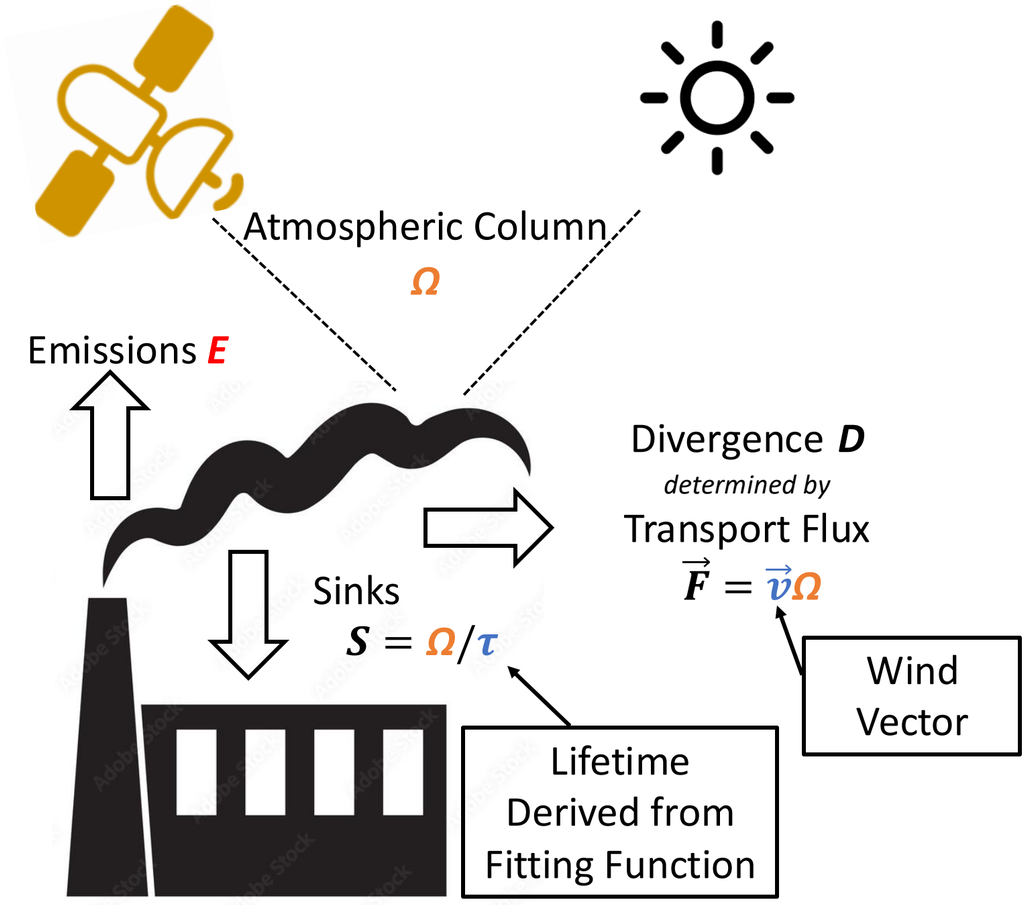
Source: ARSET - NASA Air Quality-Focused Remote Sensing for EPA Applications. NASA Applied Remote Sensing Training Program (ARSET). http://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-air-quality-focused-remote-sensing-epa-applications

# Deriving Surface $PM_{2.5}$ from AOD




Sources: van Donkelaar et al. (2021) Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. *Env. Sci. & Tech.* Atmospheric Composition Analysis Group (ACAG), NASA Socioeconomic Data and Applications Center (SEDAC).

# Emissions from Satellite Data




## Continuity Equation

$$\frac{\partial \Omega}{\partial t} = E - S - D$$

Assuming steady state:

$$0 = E - S - D$$

$$E = D + S = \nabla \cdot \vec{F} + S$$
$$= \nabla \cdot \vec{v}\Omega + \Omega/\tau$$

$$mean(E) = mean(D) + mean(S)$$
$$= \nabla \cdot mean(\vec{F}) + mean(S)$$
$$mean(E) = \nabla \cdot mean(\vec{v})\ mean(\Omega) + mean(\Omega)/\tau$$

Slide courtesy of Fei Liu

Source: ARSET - NASA Air Quality-Focused Remote Sensing for EPA Applications. NASA Applied Remote Sensing Training Program (ARSET). http://appliedsciences.nasa.gov/get-involved/training/english/arset-nasa-air-quality-focused-remote-sensing-epa-applications

# Emissions from Satellite Data

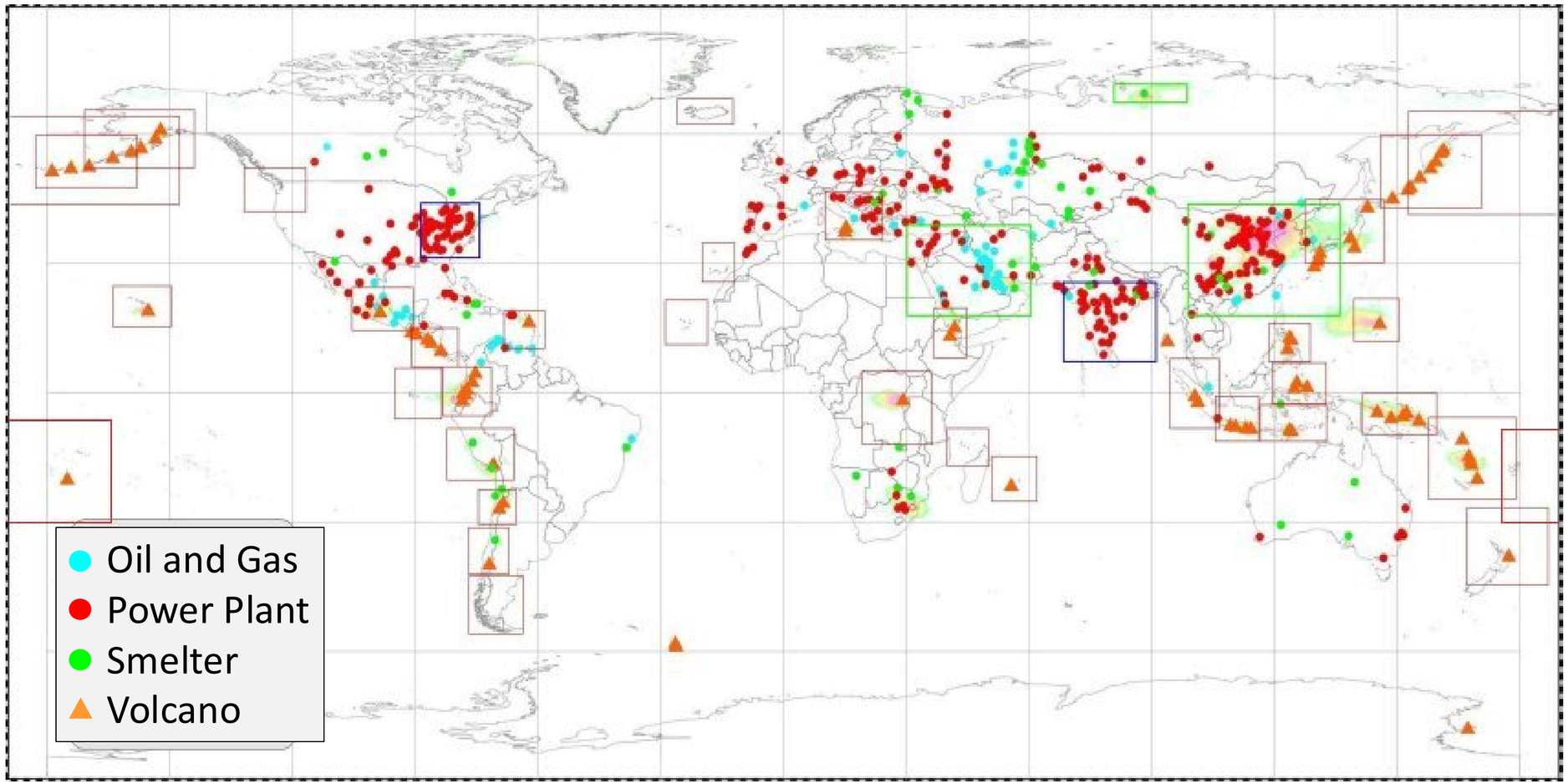
Developing a bottom-up emission inventory requires extensive data collection from many sources

- Costly
- Time-consuming
- May be incomplete

Satellites can estimate top-down emissions inventories

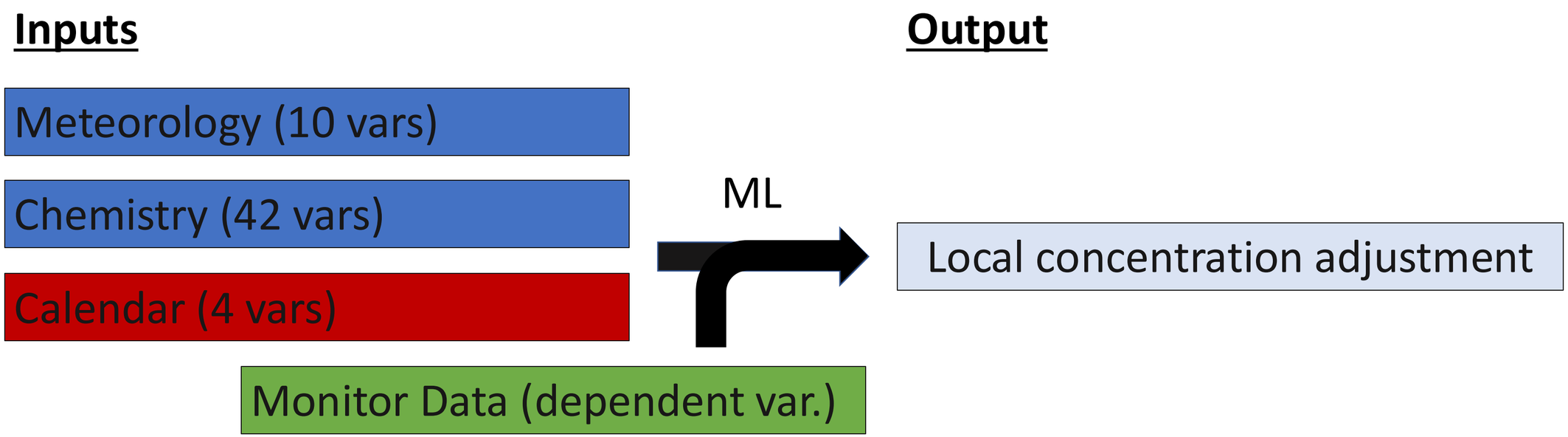
- Can keep pace with changing emissions
- May detect missing sources
- Many uncertainties in deriving emissions from satellite data

**Red** = daily volcanic regions, **green** = daily pollution regions, **blue** = long-term pollution images




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

# Machine Learning for Model Bias Correction

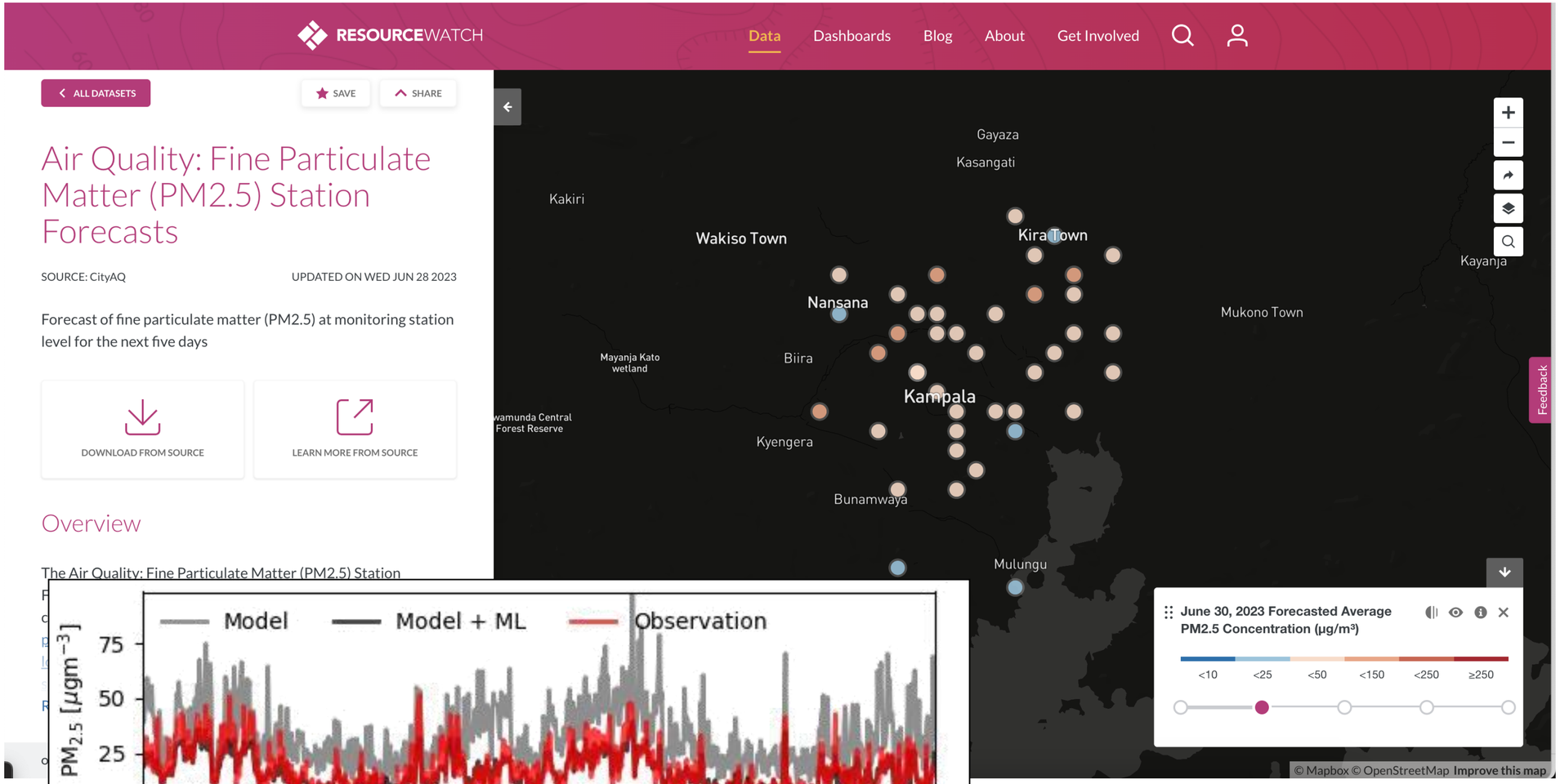



- Algorithm: gradient boosted decision trees (XGBoost)
- Train separate algorithm for each site

Slide Credit: K. Emma Knowland, NASA GMAO

Source: Keller, C., et al. (2021) "Global impact of COVID-19 restrictions on the surface concentrations of nitrogen dioxide and ozone". *Atmospheric Chemistry and Physics*, 21:5. https://acp.copernicus.org/articles/21/3555/2021/

# Machine Learning for Model Bias Correction







GEOS-CF global forecast

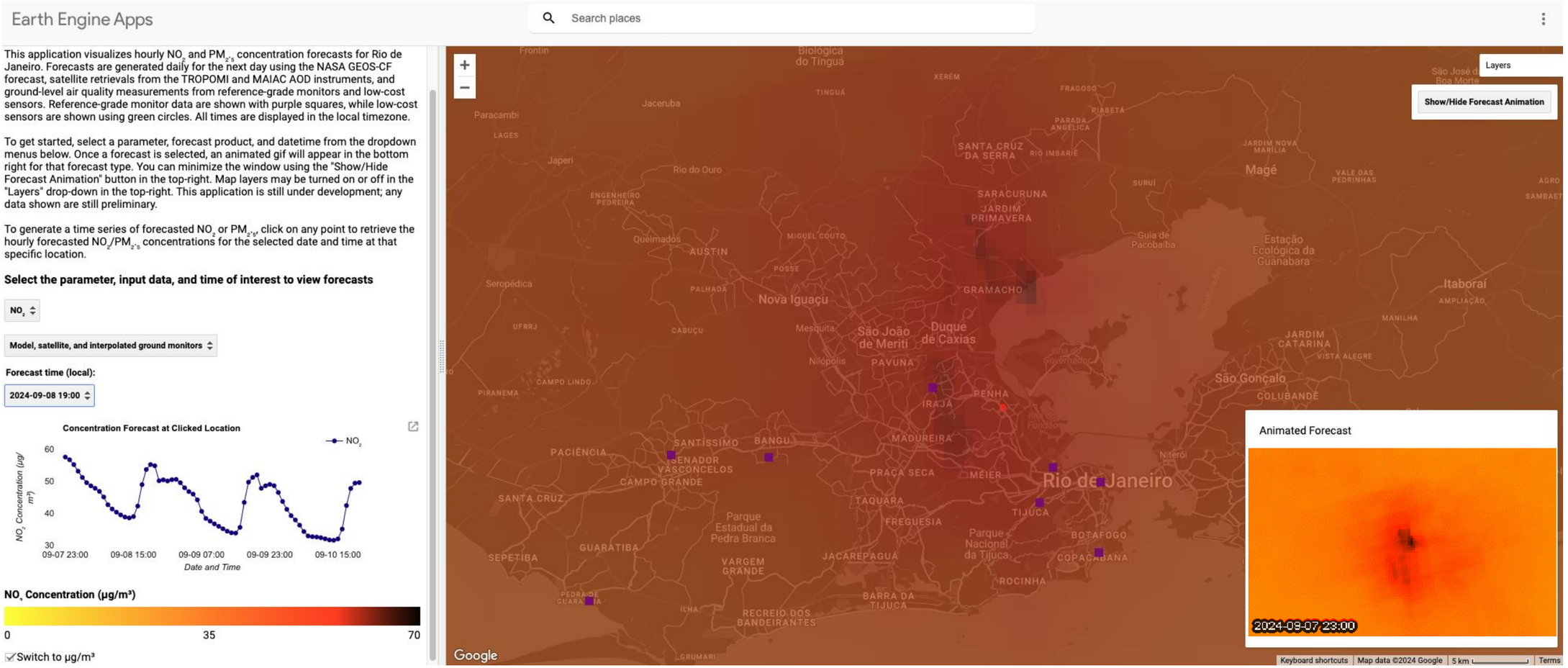
AirQo local measurements

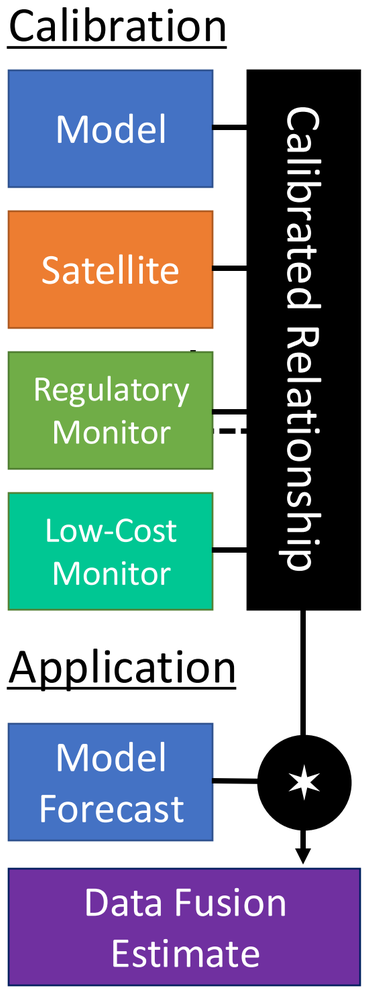
XGBoost Machine Learning Calibration (needs 1+ year of data)

local bias-corrected custom forecast for each monitor site

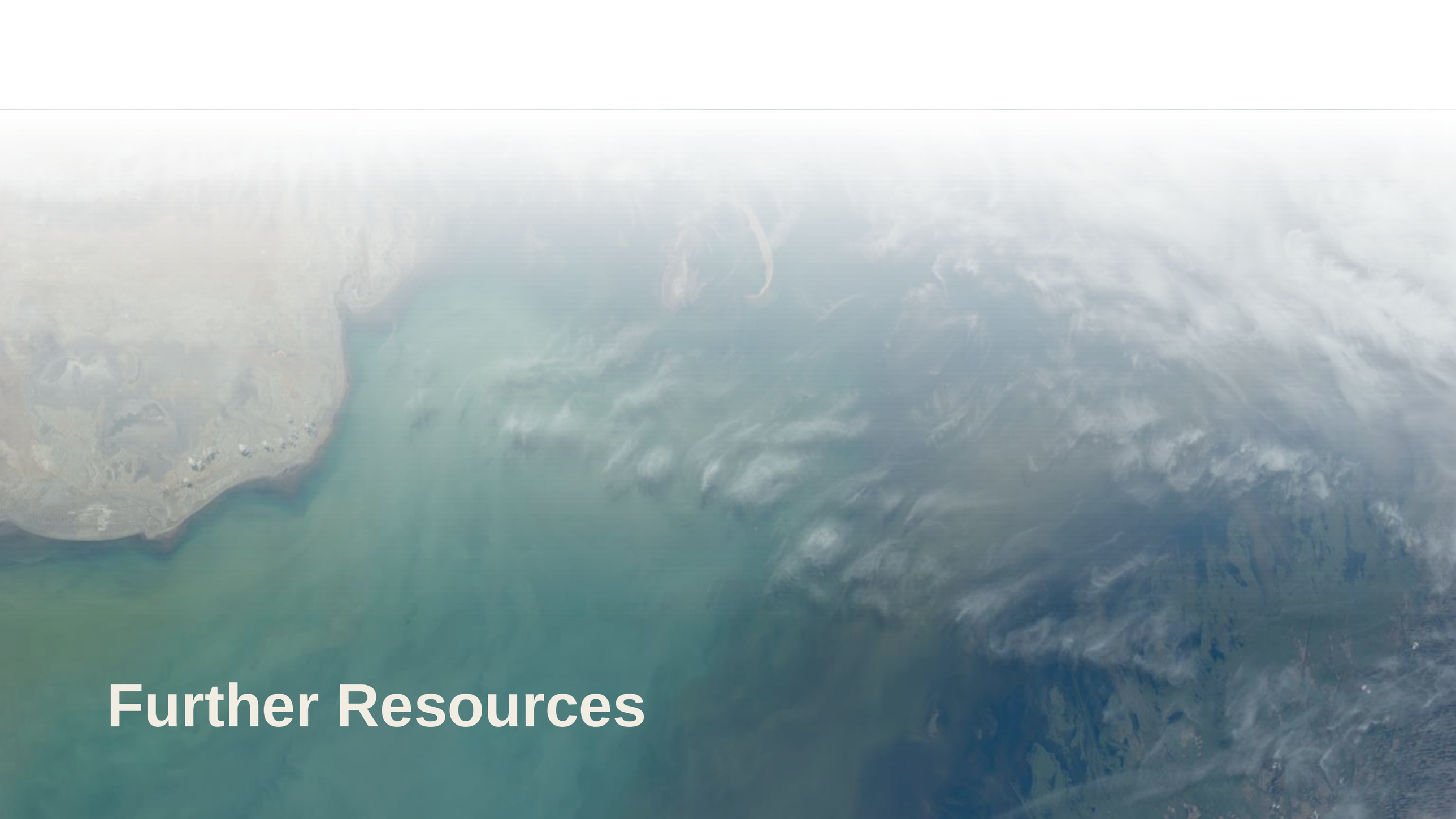
Source: World Resources Institute CanAIRy Alert https://www.wri.org/initiatives/canairy-alert

# Data Fusion for Air Quality Forecasting




Source: NASA GMAO Science Snapshot "Google Earth Engine Data Fusion Tool to support Air Quality Managers"



# Further Resources

# NASA Applied Remote Sensing Training

https://appliedsciences.nasa.gov/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**



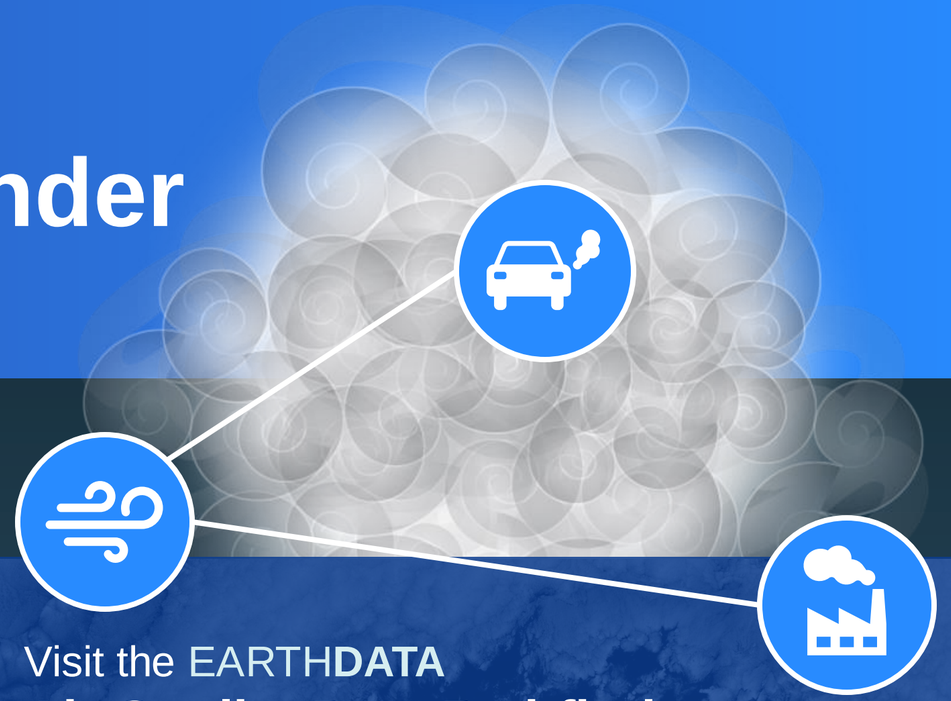

**ARSET Training Themes**

- AGRICULTURE
- CLIMATE & RESILIENCE
- DISASTERS
- ECOLOGICAL CONSERVATION
- HEALTH & AIR QUALITY
- WATER RESOURCES

EARTH**DATA** Offers

# The Air Quality Data Pathfinder

## for Your Research & Applications



*Air pollution is one of the largest global environmental and health threats. NASA provides data resources to better understand the movement of pollutants and the impact of events leading to poor air quality. This Pathfinder helps you access, and leverage data acquired from NASA's satellite, airborne, and ground-based missions and campaigns.*

Available Data Types:

- Aerosols
- Trace Gases (e.g., Nitrogen Dioxide, Sulfur Dioxide, Carbon Monoxide, etc.)
- Weather (e.g., Air Temperature, Clouds, Precipitation, etc.)
- Land Surface (e.g., Soil Moisture, Surface Reflectance, Topography, etc.)
- Human Dimensions

Data are from satellites, airborne and ground-based platforms, and models, including:

- AIRS
- AMSR2
- GPM
- MODIS
- OLI/TIRS
- OMI
- OMPS
- SMAP
- TROPOMI
- VIIRS
- GEOS
- MERRA-2



Visit the EARTH**DATA**

**Air Quality Data Pathfinder**

for more information**:**

- Commonly Used Datasets for Air Quality Research and Applications
- Tools for Using Data
- Resources for Applying and Connecting NASA Data
- GIS Resources
- Tips for Getting Help and Connecting with NASA experts
- Tutorials and more!

# Health and Air Quality Applied Science Team

https://haqast.org/

**"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.




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

# GEOHealth Community of Practice

geohealthcop.org

The GEO Health Community of Practice is a global network of governments, organizations, and observers. It seeks to use environmental observations to improve health decision-making at the international, regional, country, and district levels.

**The Air Quality Work Group hosts monthly virtual meetings**

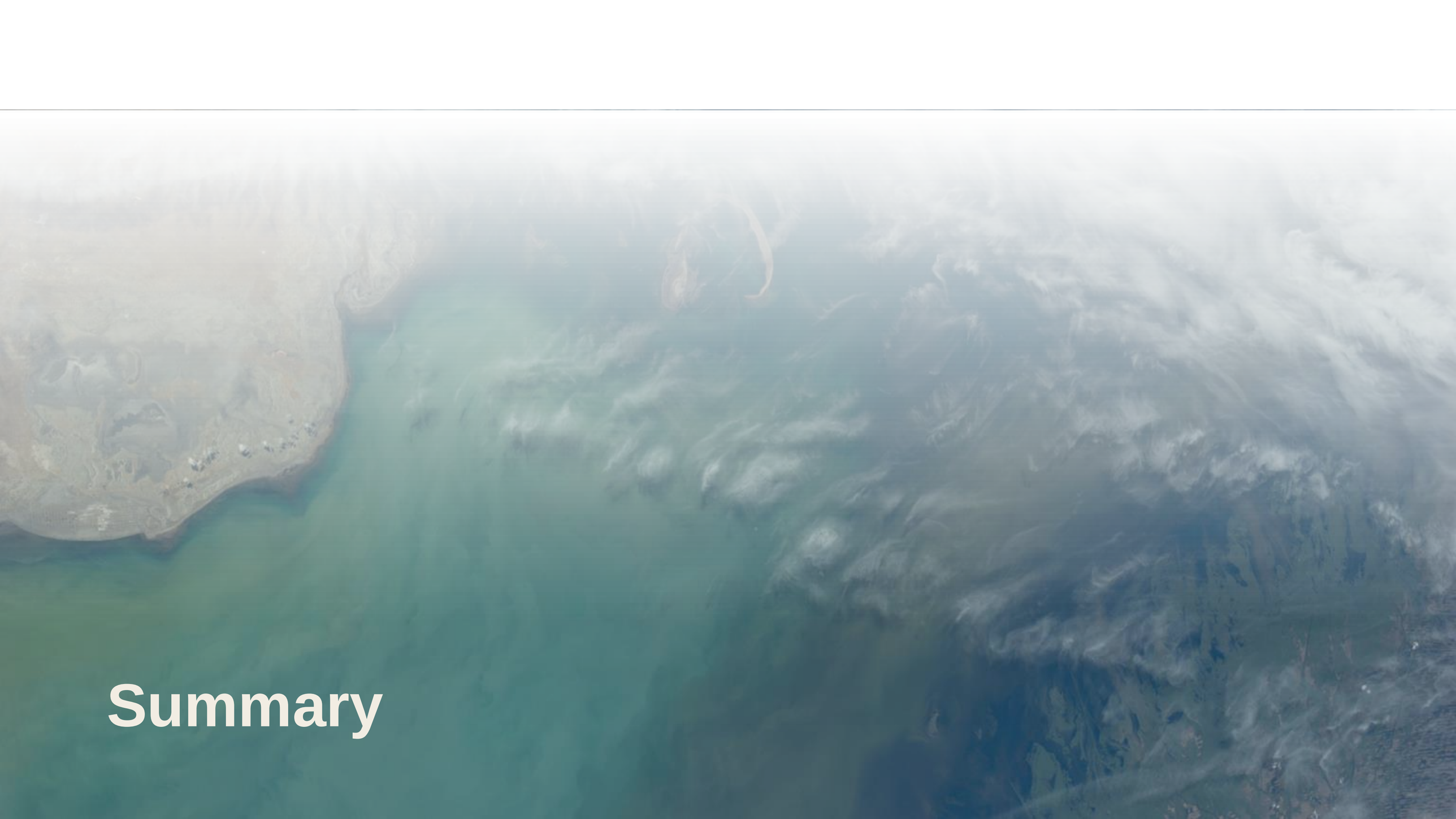
**To join our mailing list, please email Carl Malings and Nathan Pavlovic**

GEO HEALTH
COMMUNITY OF PRACTICE

Small Work Groups:

- Heat Work Group
- Infectious Diseases Work Group
- **Air Quality Work Group**
- Food Security and Safety Work Group
- Health Care Infrastructure Work Group
- Animal Health Work Group

NASA Partner GODDARD EARTH SCIENCES GESTAR II GMAO



# Summary

# Summary

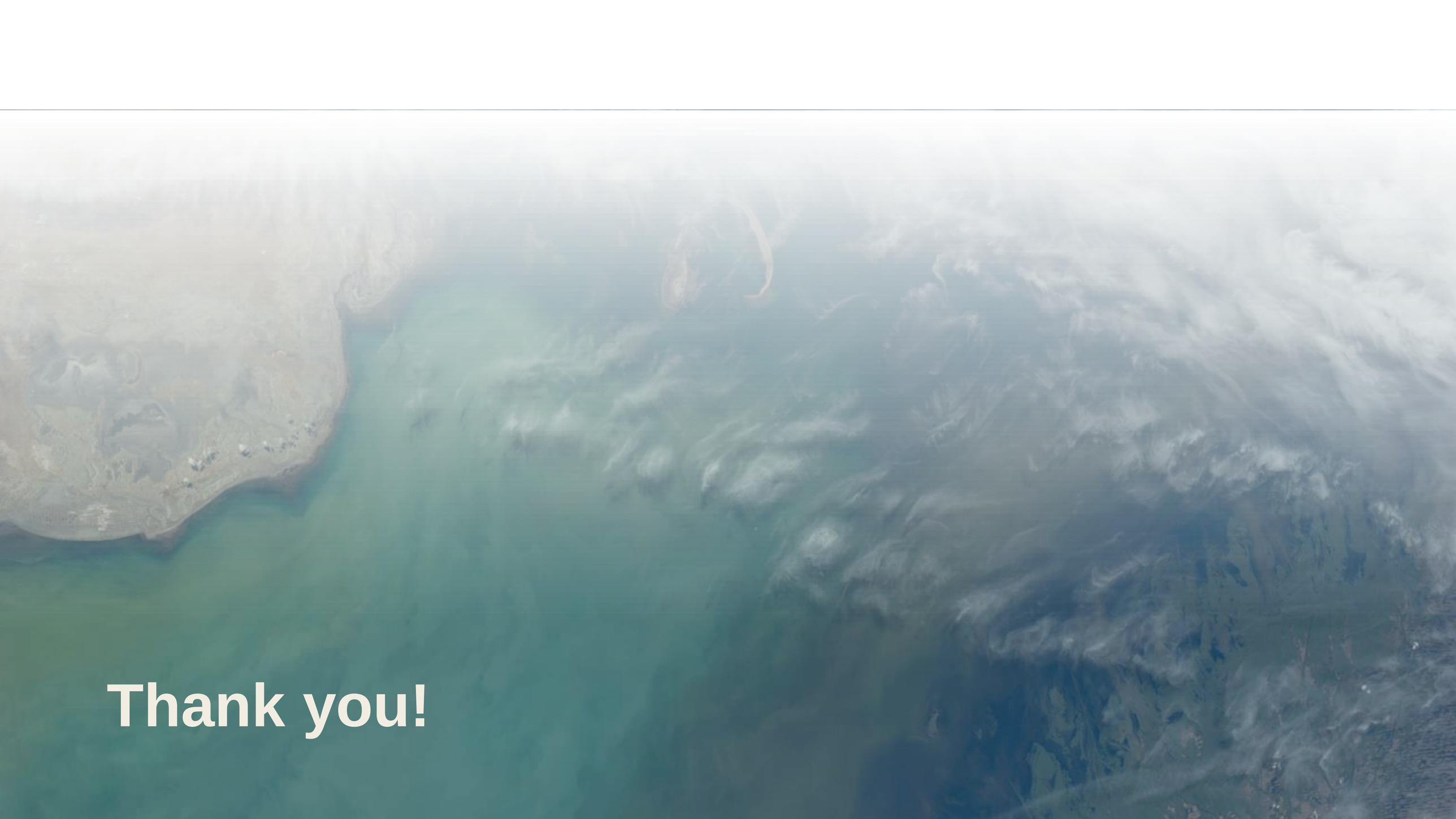
- Satellite data can fill global to local gaps in our understanding of air quality.
- Satellites do not directly measure air quality near the Earth's surface.
- Other sources of information, especially models and ground-based sensors, help to connect satellite information to surface air quality
- Combining these data can produce derived products including surface air quality and emissions estimates

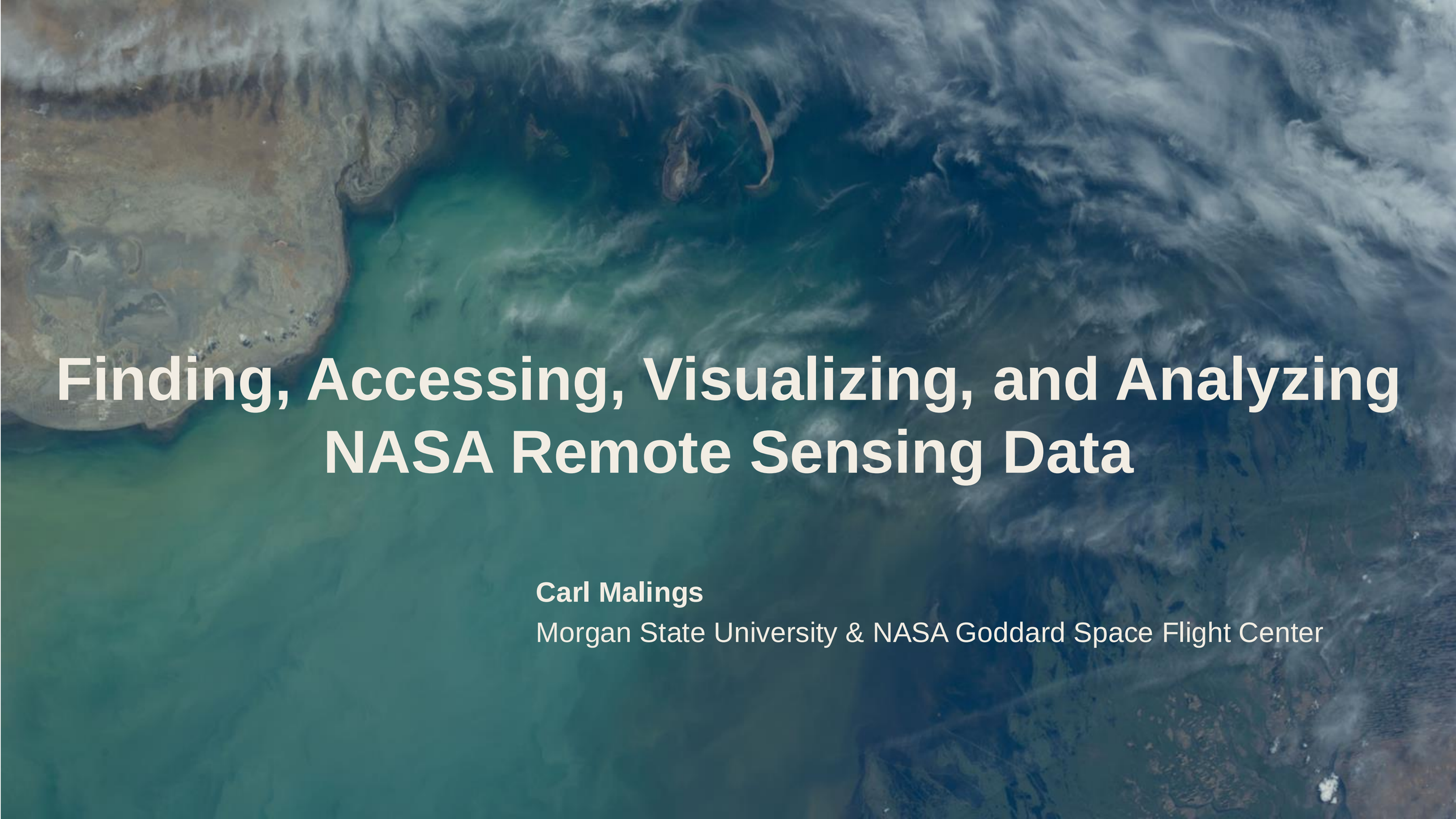
# Summary of Common Resources

| Instrument | Type | Spatial Resolution | Temporal Resolution | Key Measurements | Key Use Case |
|---|---|---|---|---|---|
| AERONET | Ground-based instruments | point | 5 to 15 minutes (day and bright moon) | AOD, aerosol type and size distribution | Validation of satellite aerosol information, improving relation to surface PM |
| Pandora/ Pandonia | Ground-based instruments | point | 5 to 10 minutes (daytime only) | Column $O_3$, $NO_2$, HCHO | Validation of satellite trace gas information, improving relation to surface concentrations |
| MPLNET | Ground-based instruments | point | 1 minute (day and night) | aerosol & cloud profiles, PBL height | Validation of satellite aerosol information, improved tracking of aerosols and clouds |

# Summary of Common Resources

| Dataset | Type | Spatial Resolution | Temporal Resolution | Key Measurements | Key Use Case |
|---|---|---|---|---|---|
| MERRA-2 | Historical Model | 0.5º ~ 50 km | Hourly (1980-2024) | $O_3$, $SO_2$, Aerosols ($PM_{2.5}$, $PM_{10}$) | Long-term regional exposure analysis |
| EAC4 | Historical Model | 0.75º ~ 80 km | 3-Hourly (2003-2023) | $O_3$, $NO_2$, $SO_2$, HCHO, CO, $CH_4$, Aerosols ($PM_1$, $PM_{2.5}$, $PM_{10}$) | Long-term regional exposure analysis |
| ACAG datasets | Historical Model | 0.01º ~ 1 km | Monthly (1998-2022) | $PM_{2.5}$, $NO_2$ | Long-term, high-resolution exposure analysis for key pollutants |
| GEOS-CF | Forecast Model | 0.25º ~ 25 km | Hourly (5-day forecast) | $O_3$, $NO_2$, $SO_2$, CO, $PM_{2.5}$ | Short-term forecasting of key pollutants |
| CAMS forecast | Forecast Model | 0.35º ~ 40 km | Hourly (5-day forecast) | $O_3$, $NO_2$, $SO_2$, HCHO, CO, $CH_4$, $PM_{2.5}$ | Short-term forecasting of key pollutants |


Thank you!

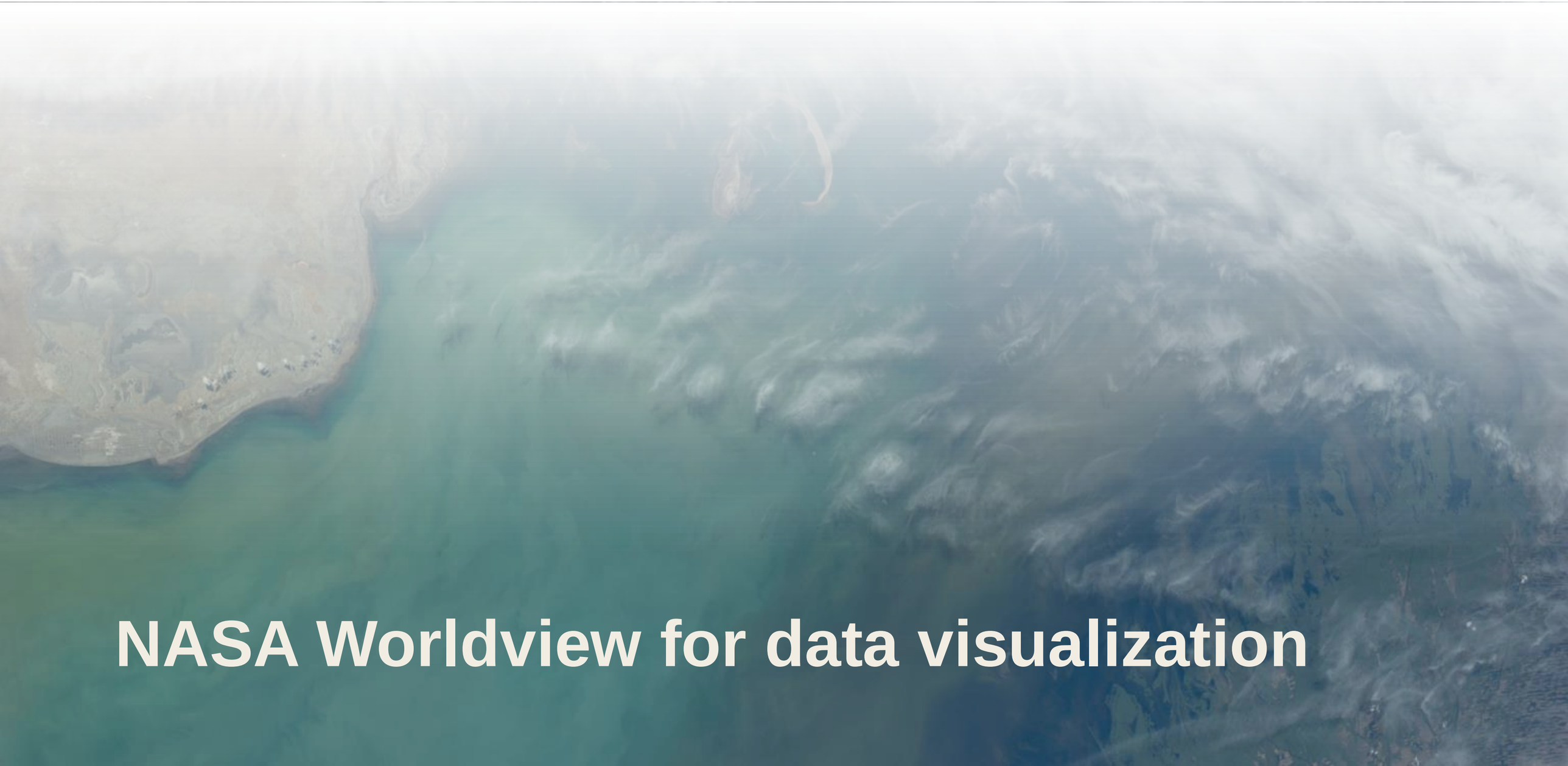


# Finding, Accessing, Visualizing, and Analyzing NASA Remote Sensing Data

**Carl Malings**
Morgan State University & NASA Goddard Space Flight Center

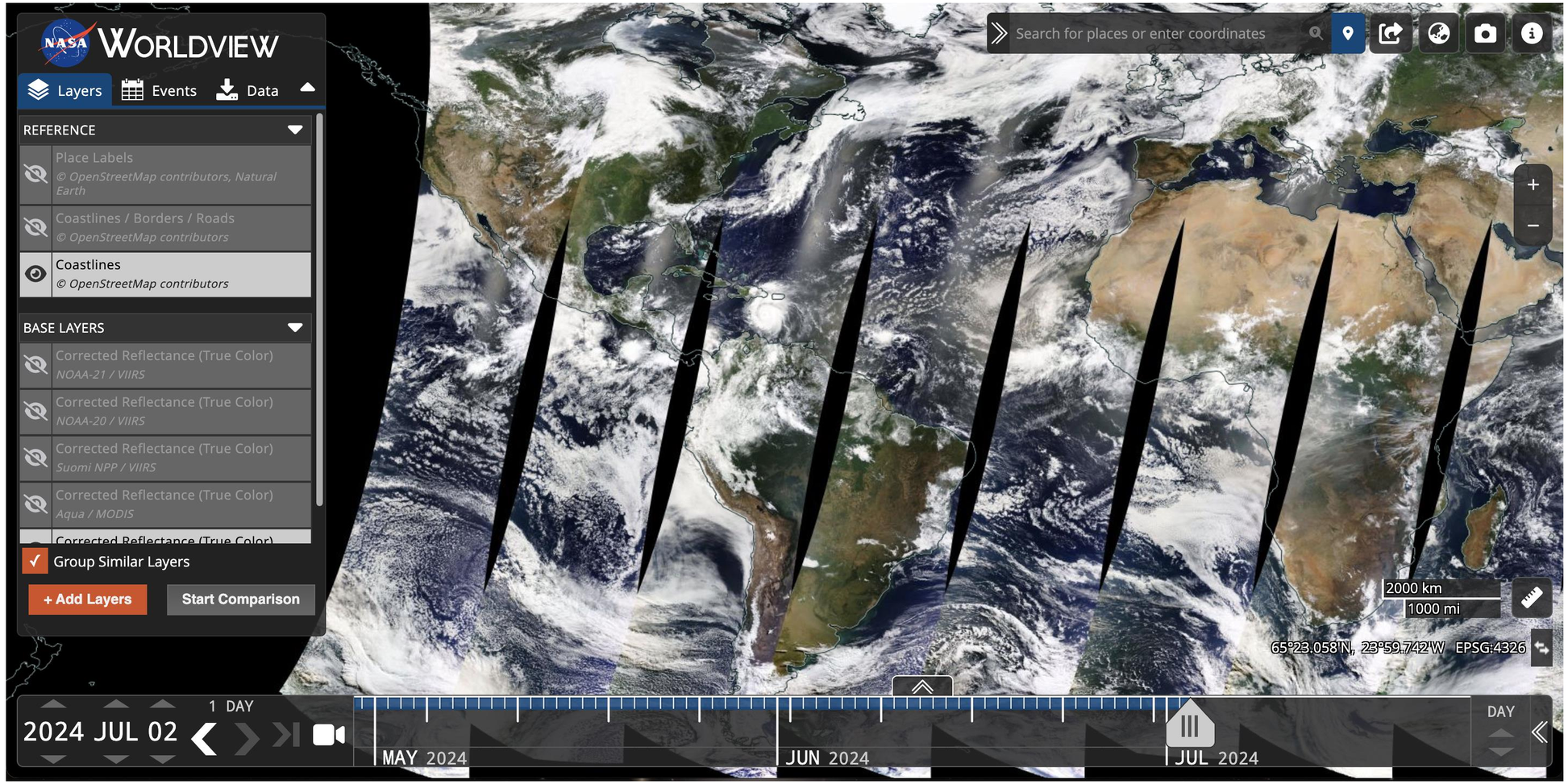
# Agenda

- 14:15 - 15:15 Finding, Accessing, Visualizing, and Analyzing Data
  - Worldview
  - Earthdata Search
  - Giovanni
  - GMAO FLUID



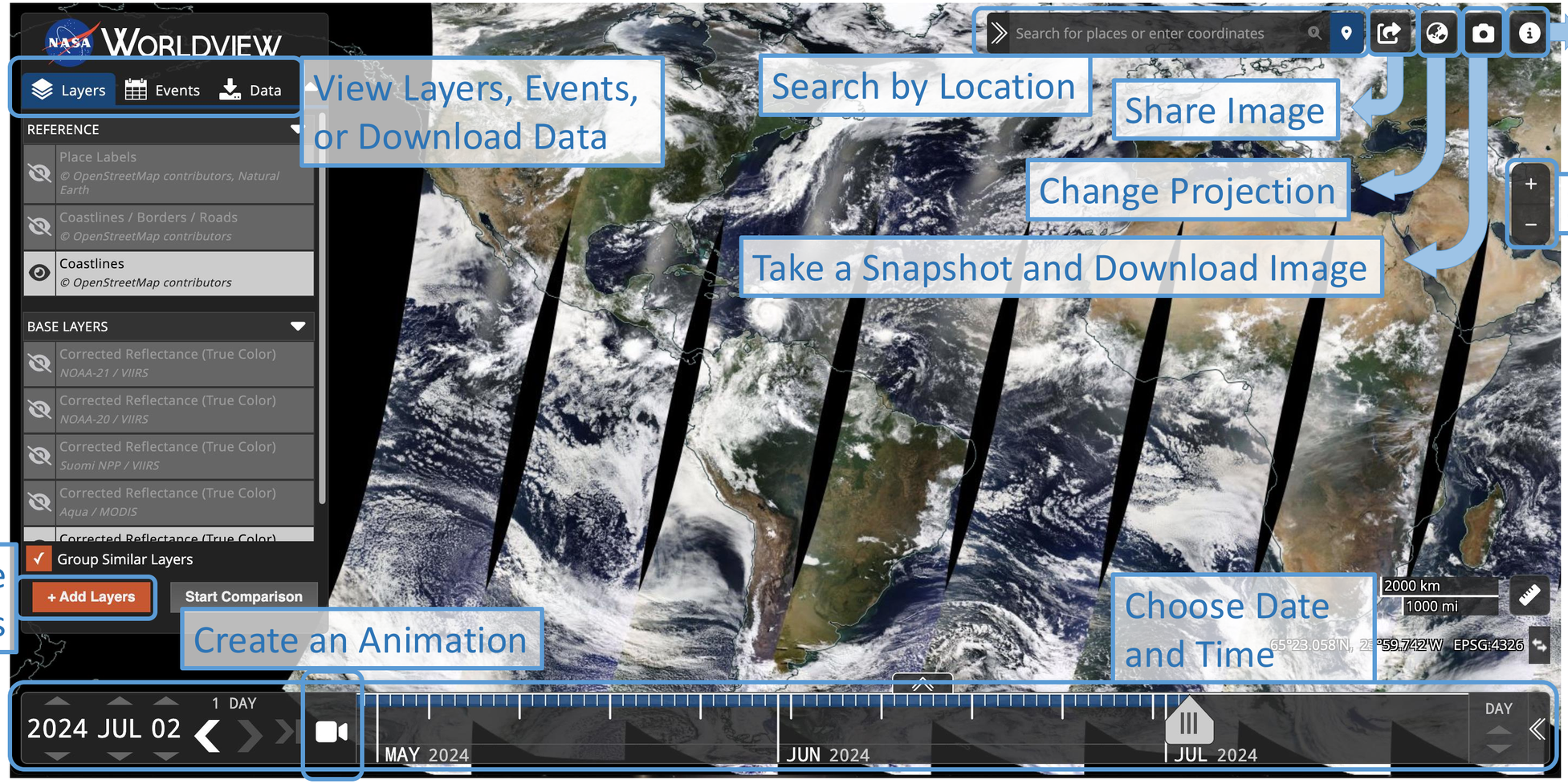
# NASA Worldview for data visualization

# NASA Worldview




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

# Worldview Controls




View Layers, Events, or Download Data

Search by Location

Share Image

Change Projection

Take a Snapshot and Download Image

Help/ Info

Zoom In/Out

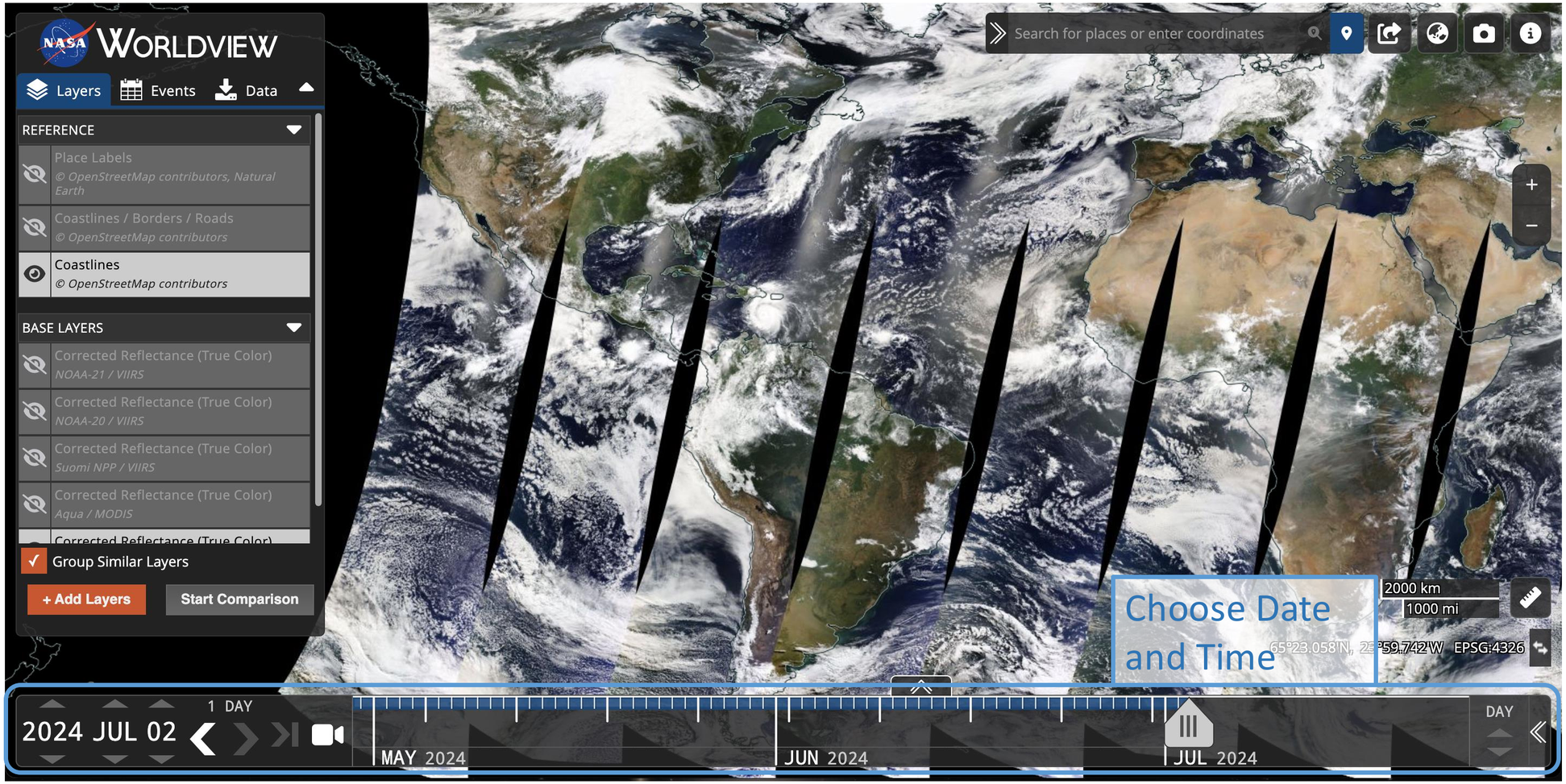
Add Image Layers

Create an Animation

Choose Date and Time

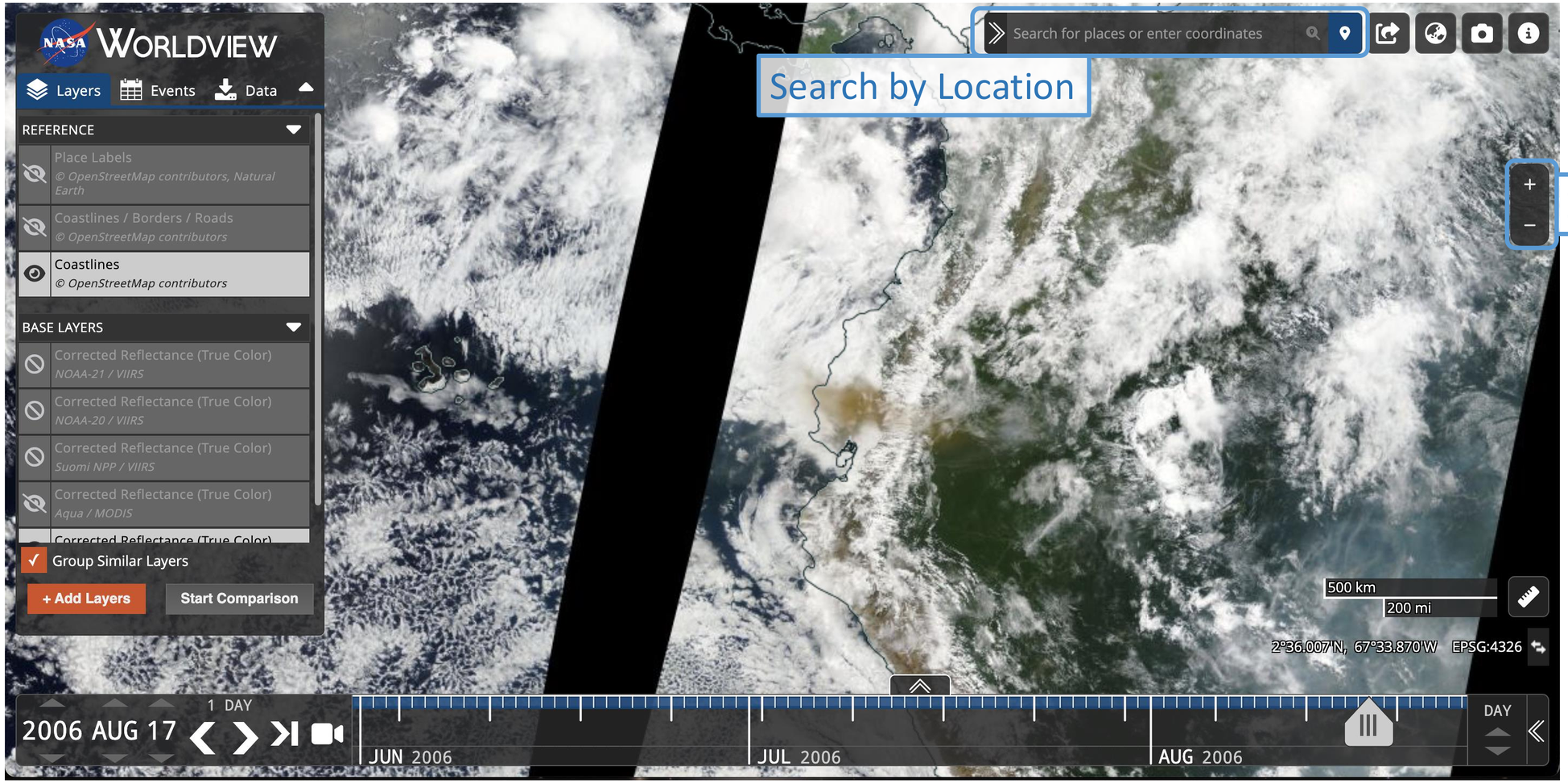
https://worldview.earthdata.nasa.gov/

# Select Date



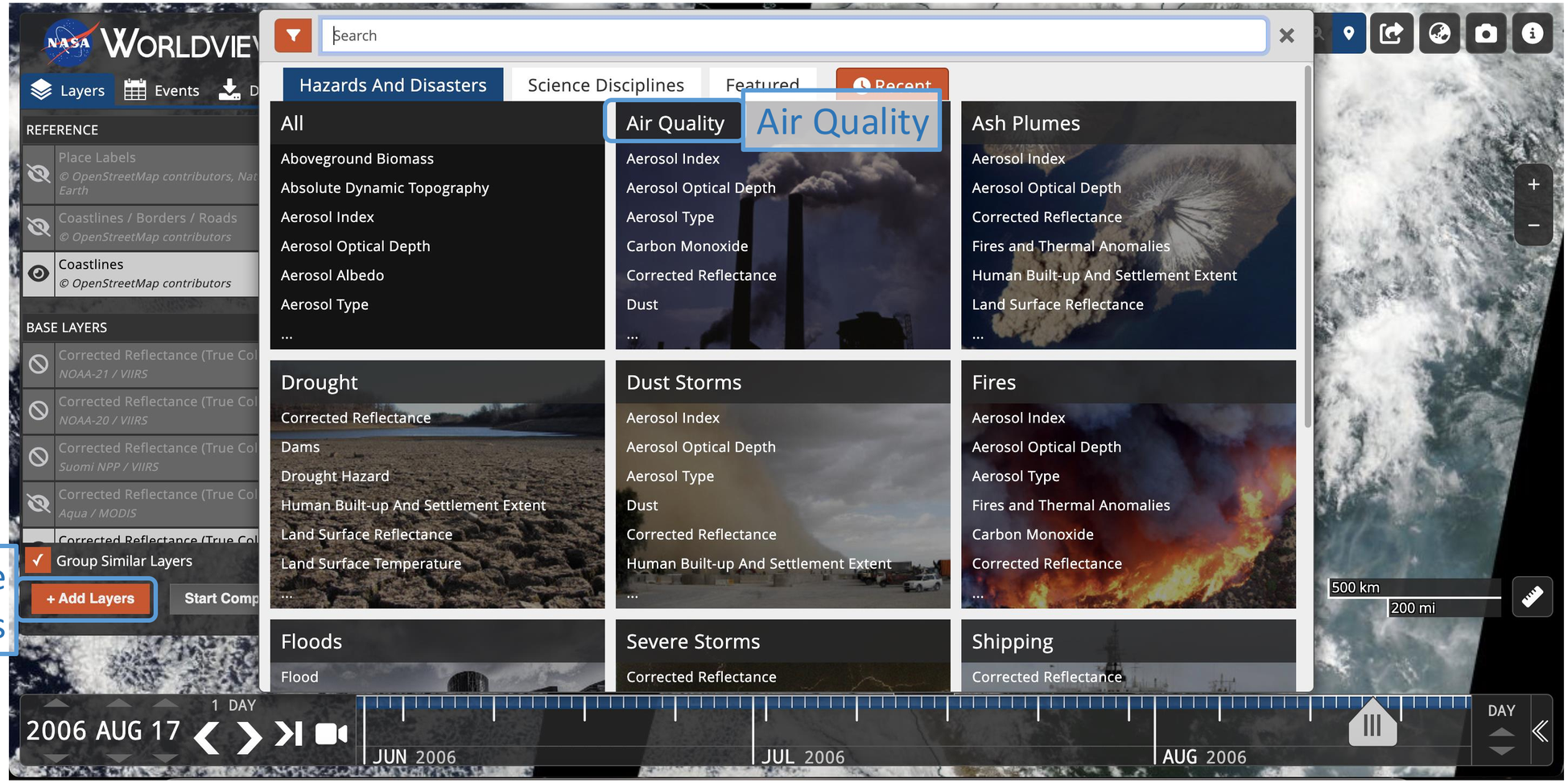

https://worldview.earthdata.nasa.gov/

# Zoom to Region of Interest




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

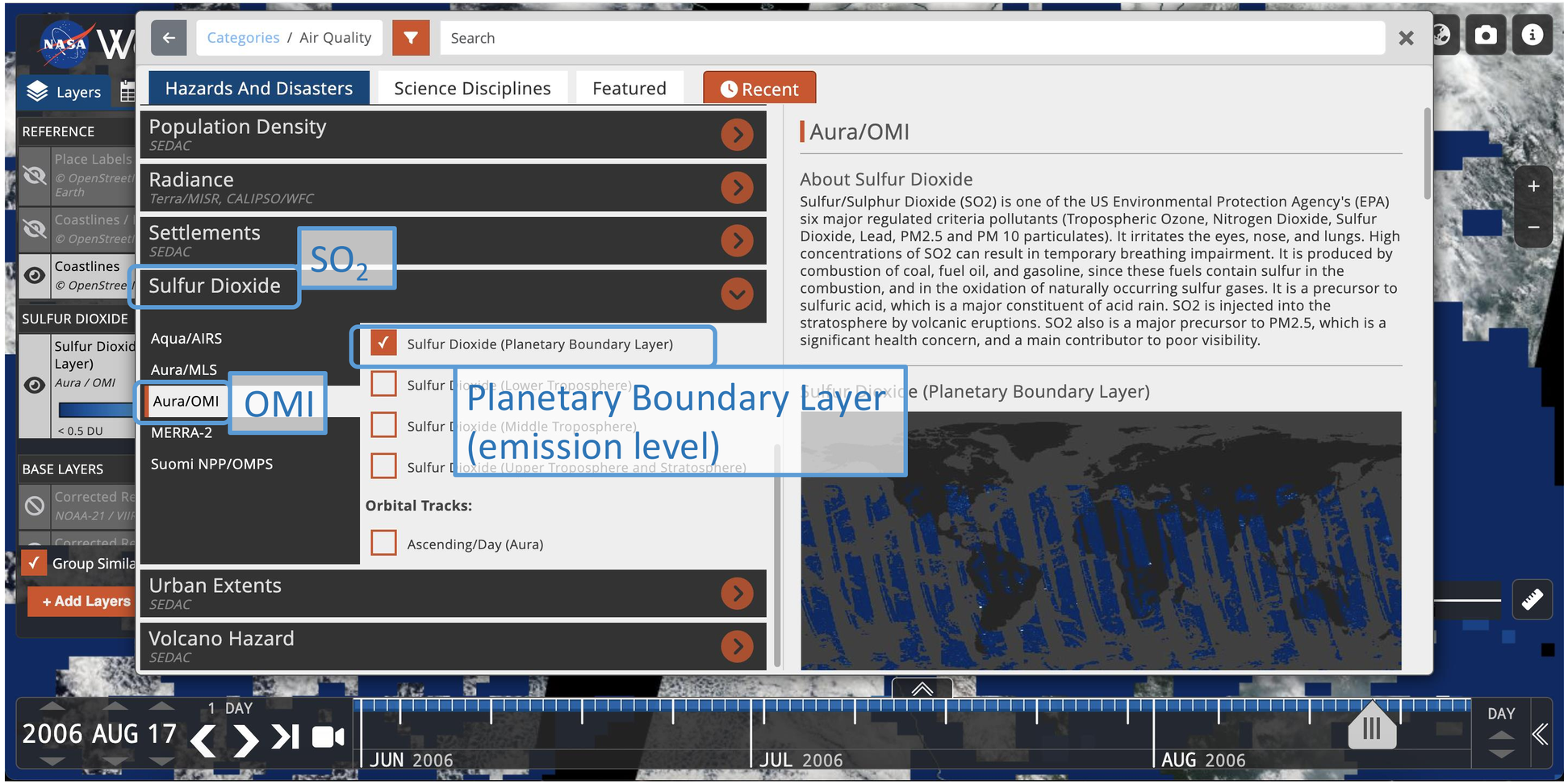
# Add a New Layer




Add Image Layers

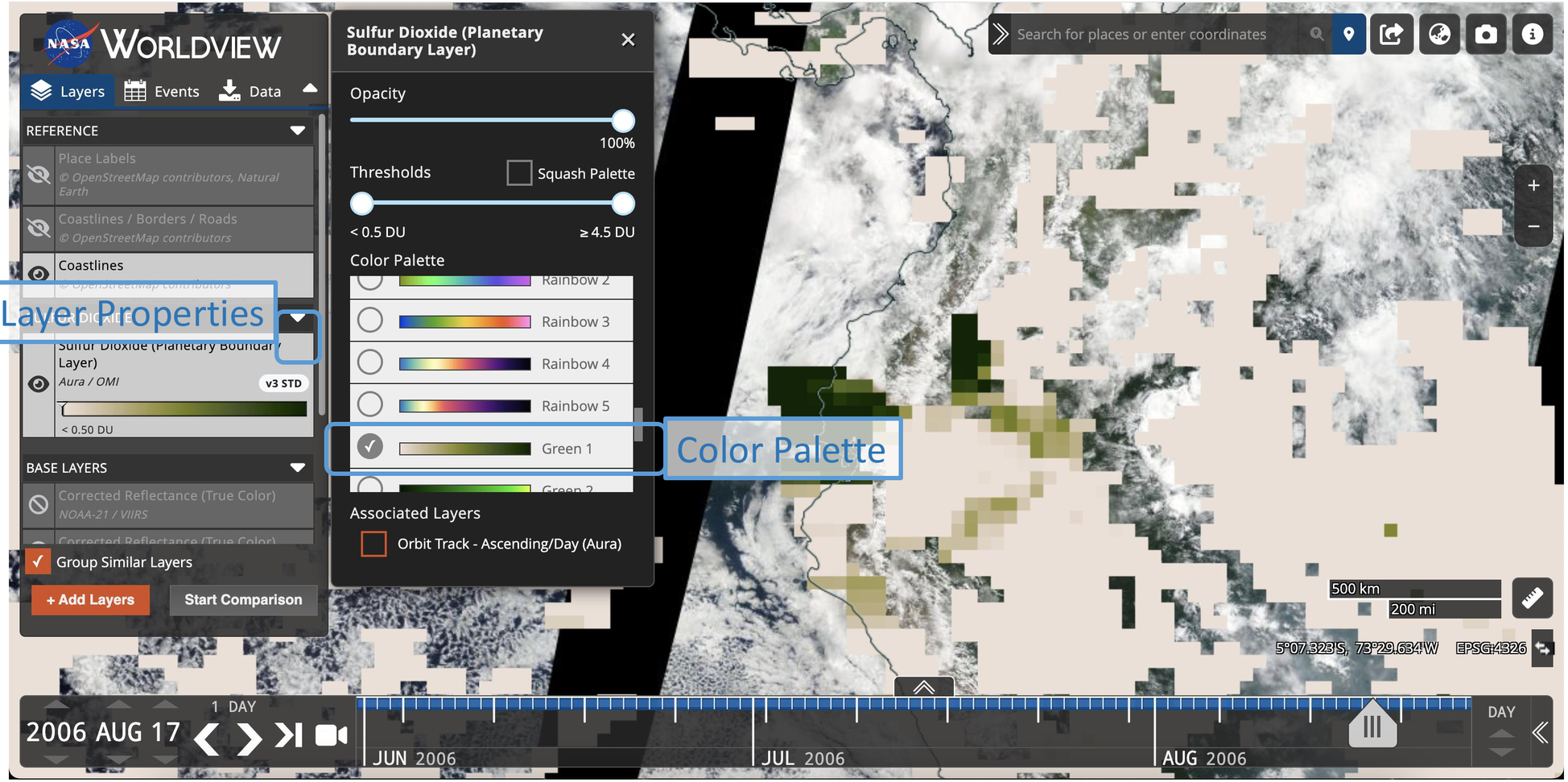
https://worldview.earthdata.nasa.gov/

# Add a New Layer




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

# Modify Color Scale

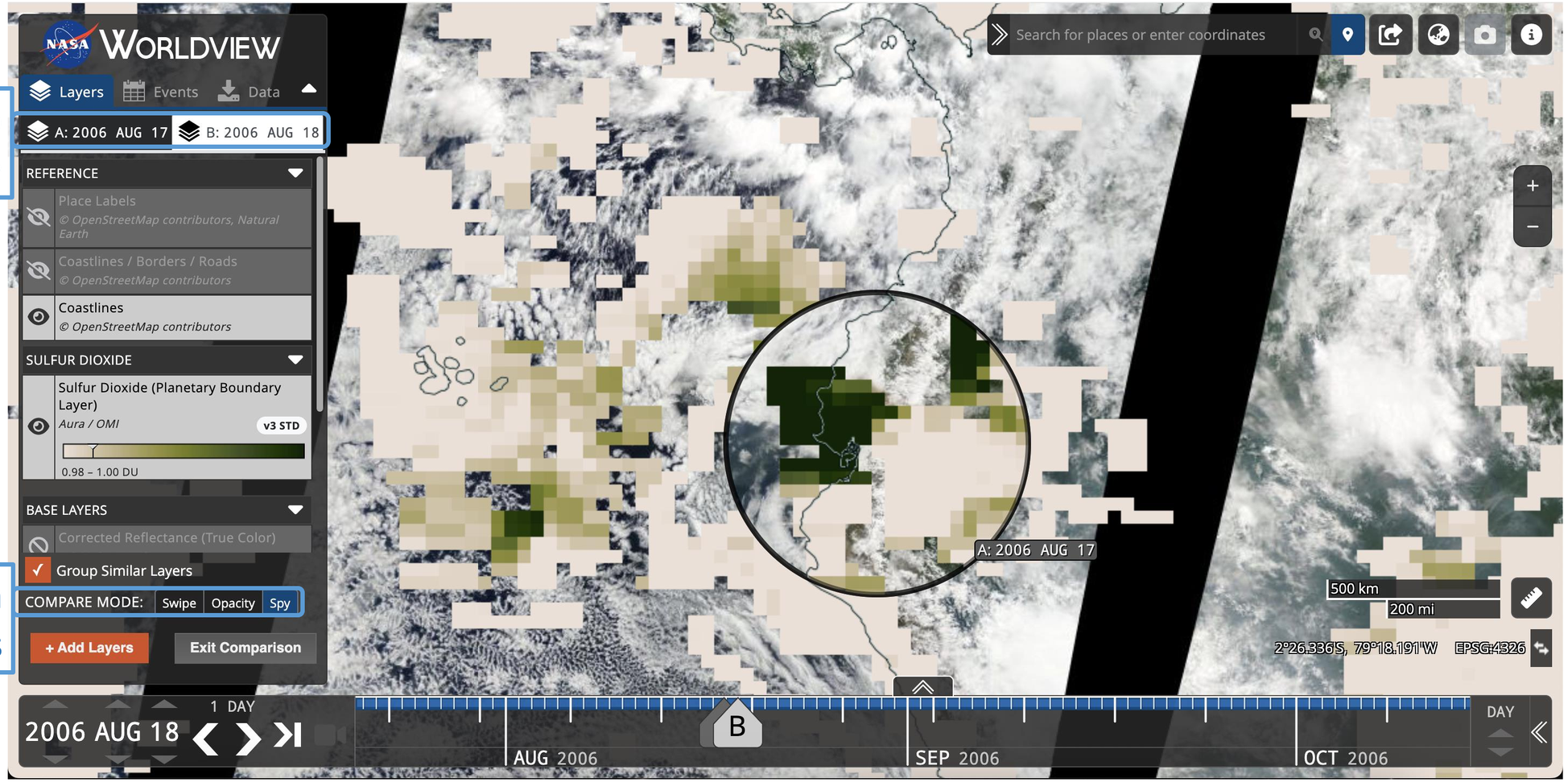



https://worldview.earthdata.nasa.gov/

# Compare Imagery

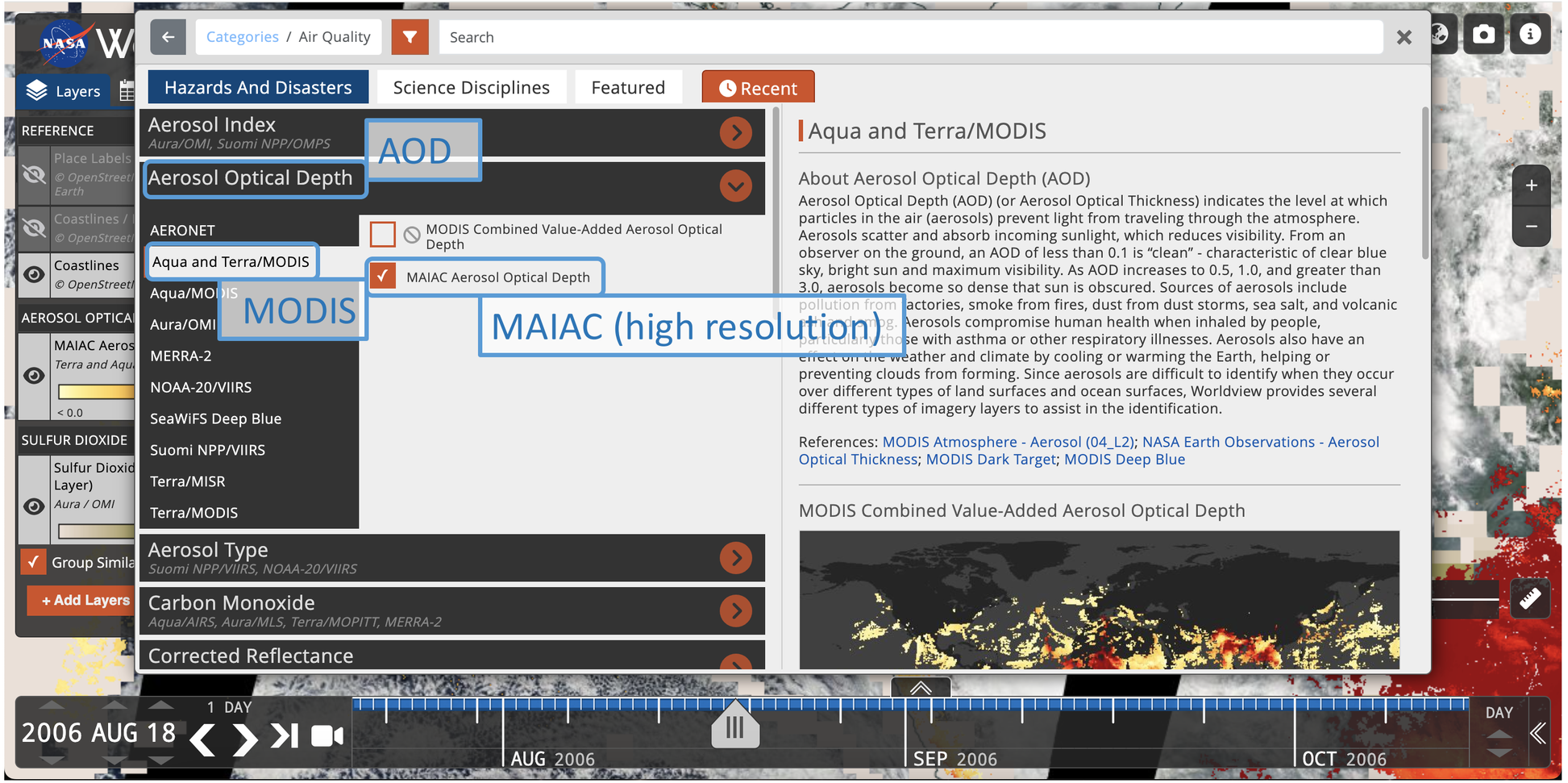
Dates to Compare

Comparison Modes



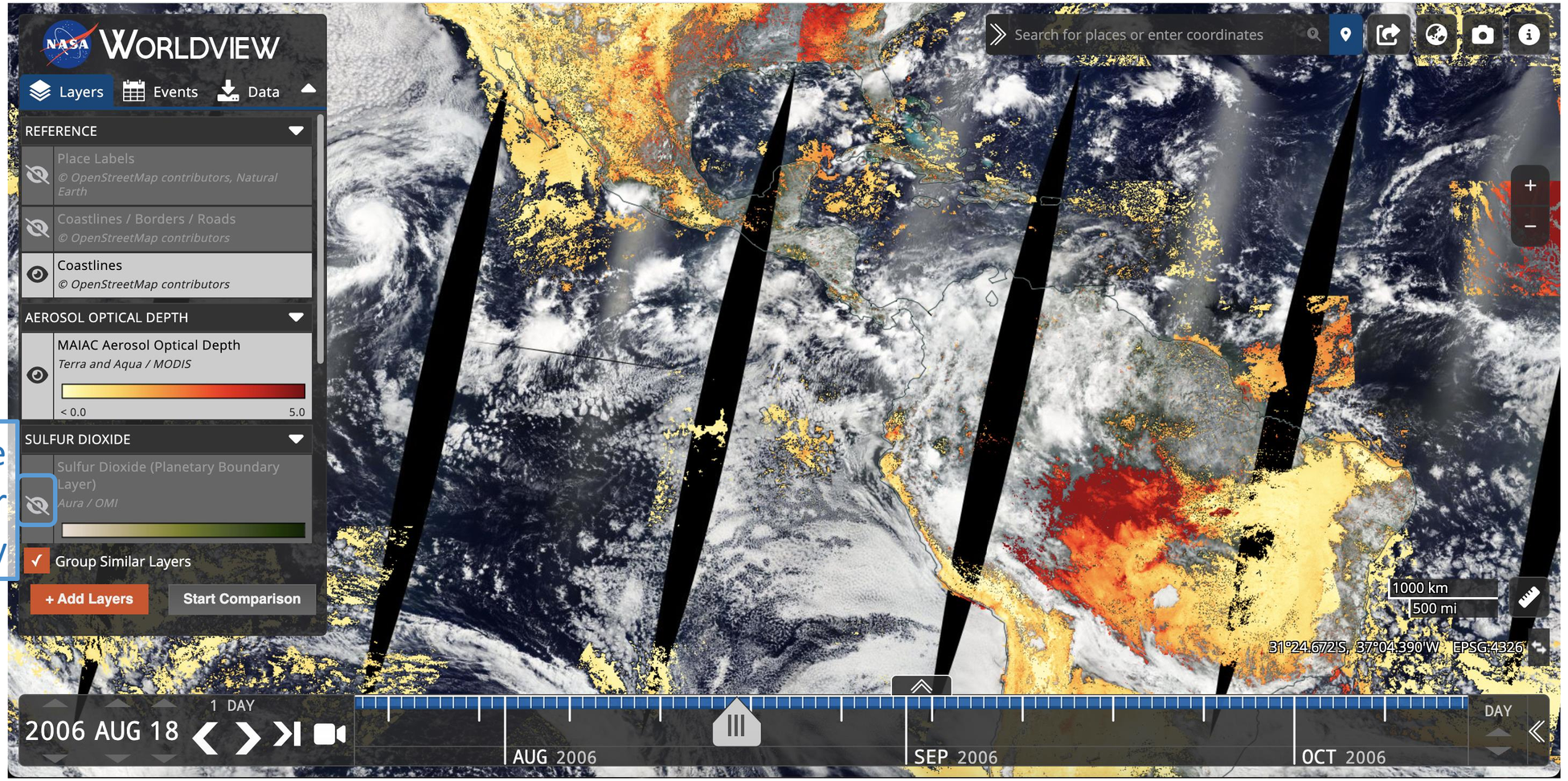

https://worldview.earthdata.nasa.gov/

# Add Another Layer




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

# Add Another Layer

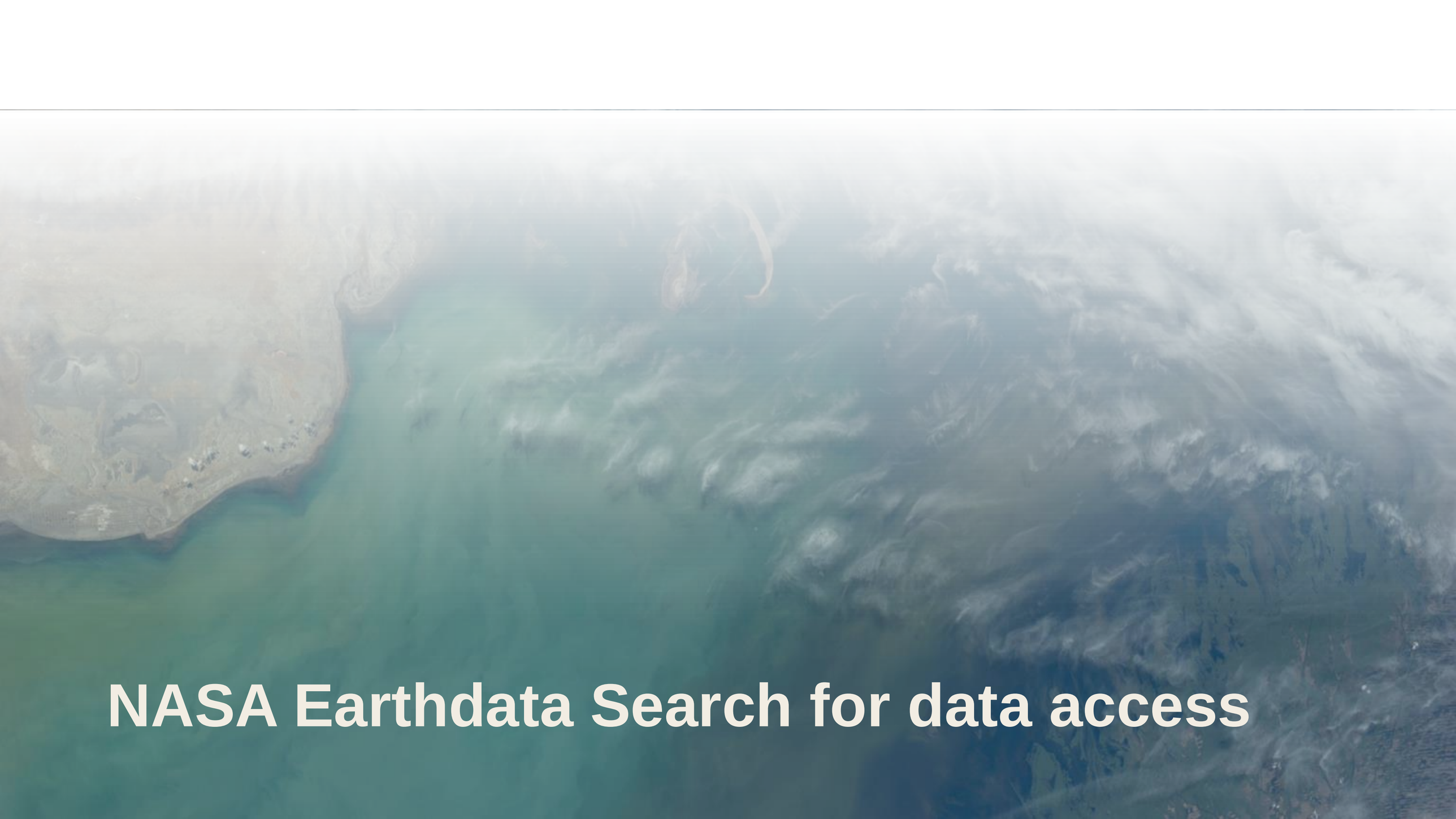



Toggle Layer Visibility

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

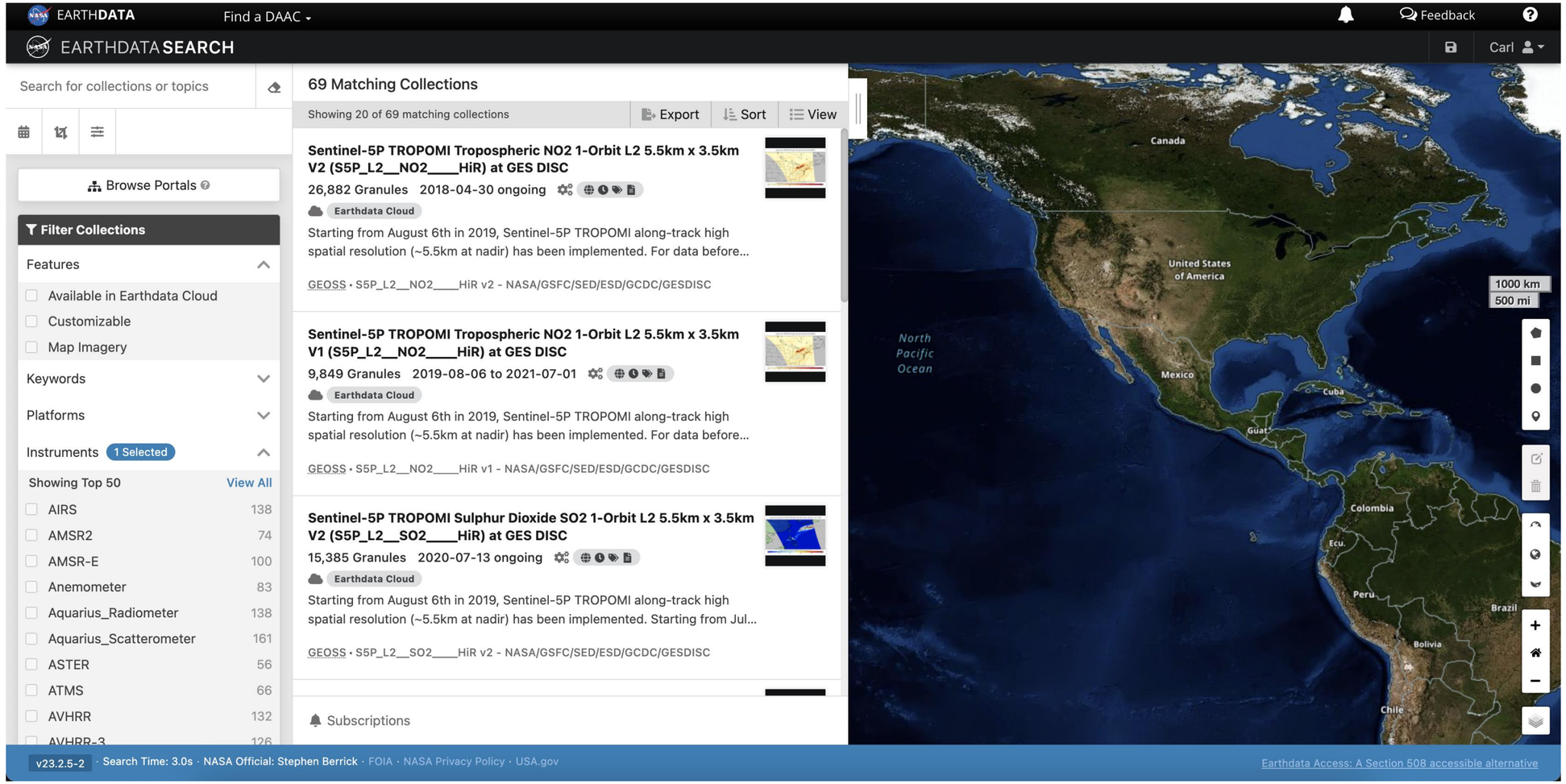
# Suggested Worldview Excercises

- Navigate to your location and visualize different types of imagery
- Add layers for key air quality datasets, e.g., OMI $NO_2$, MODIS MAIAC AOD
- Scroll back to an air quality event of interest and examine it using visual, aerosol, and trace gas datasets
- Walk through some of the demos available in the pop-up window when worldview starts, e.g., “Satellite Detections of Fire”
- AERONET data are available in worldview; find and activate the AERONET AOD overlay



# NASA Earthdata Search for data access

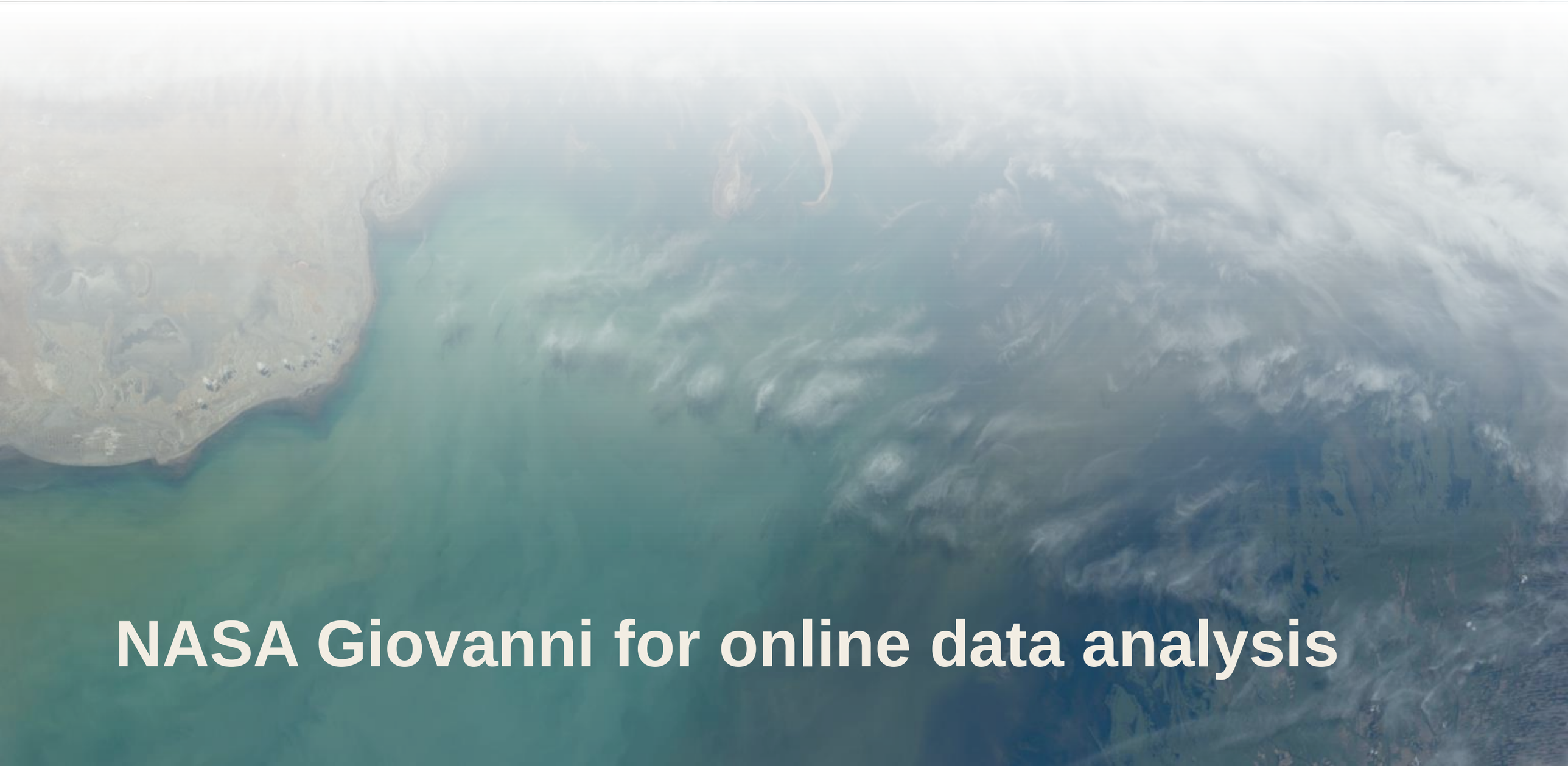
# NASA Earthdata Search




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

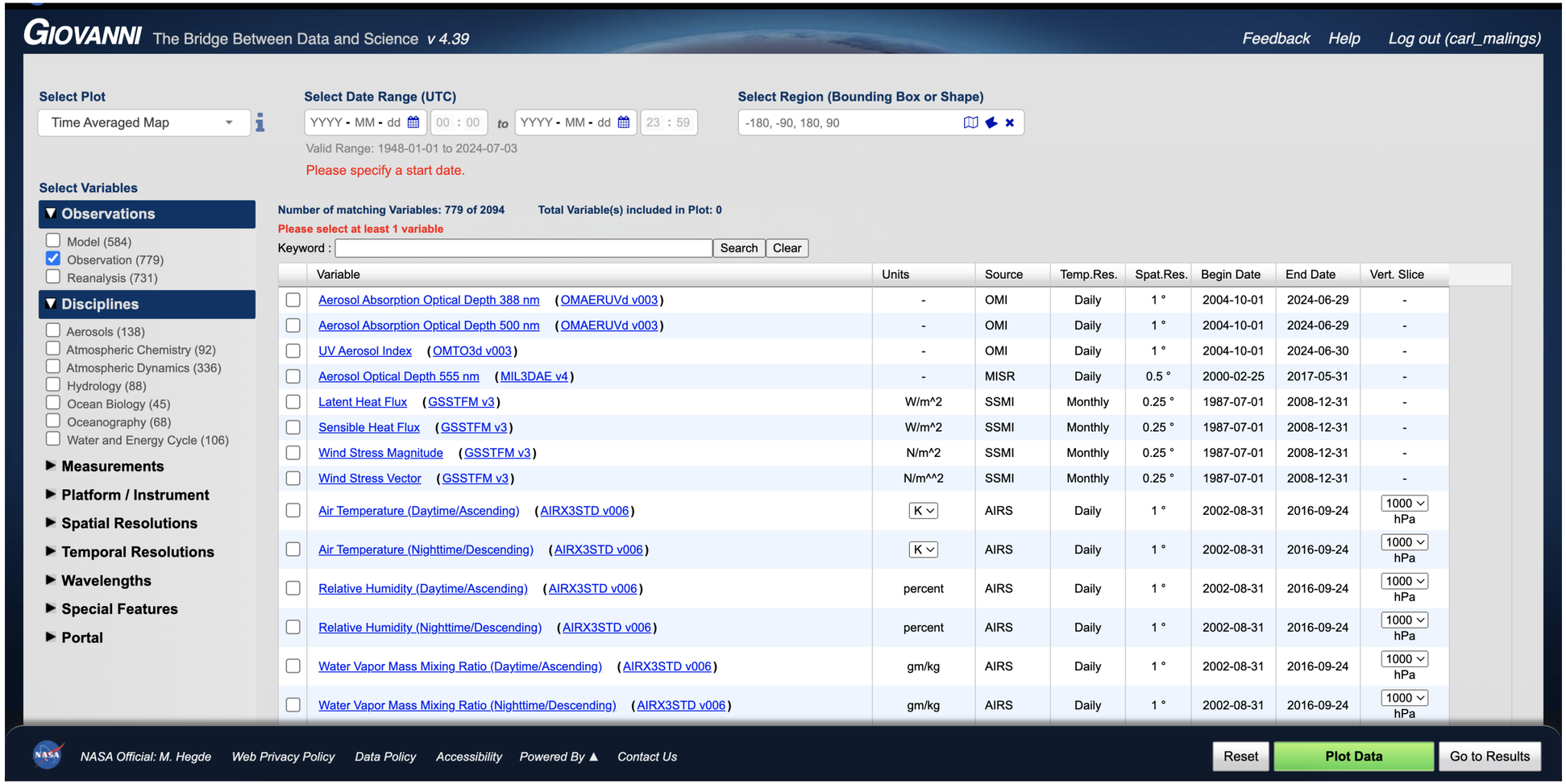
# Suggested Earthdata Search Exercises

- Practice finding some of the key datasets discussed today
  - MODIS MAIAC AOD
  - VIIRS Deep Blue AOD
  - OMI $NO_2$
  - TROPOMI $NO_2$ (available from NASA via agreement with ESA)
  - OMI $SO_2$
  - MERRA-2 $PM_{2.5}$
  - CALIPSO Aerosol Profiles
- Refine the search by space and time
- Examine the different data access options



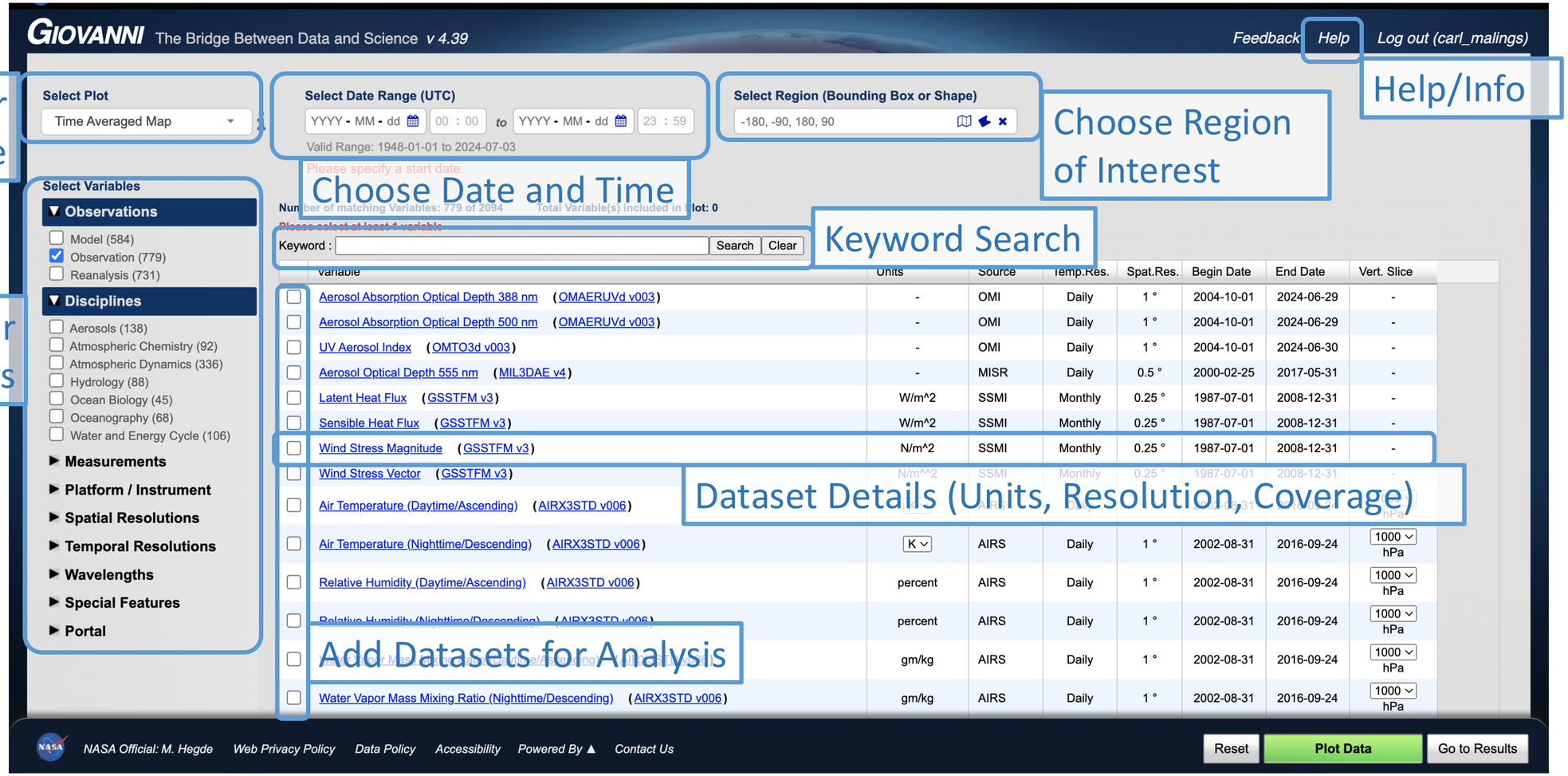
# NASA Giovanni for online data analysis

# NASA Giovanni




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

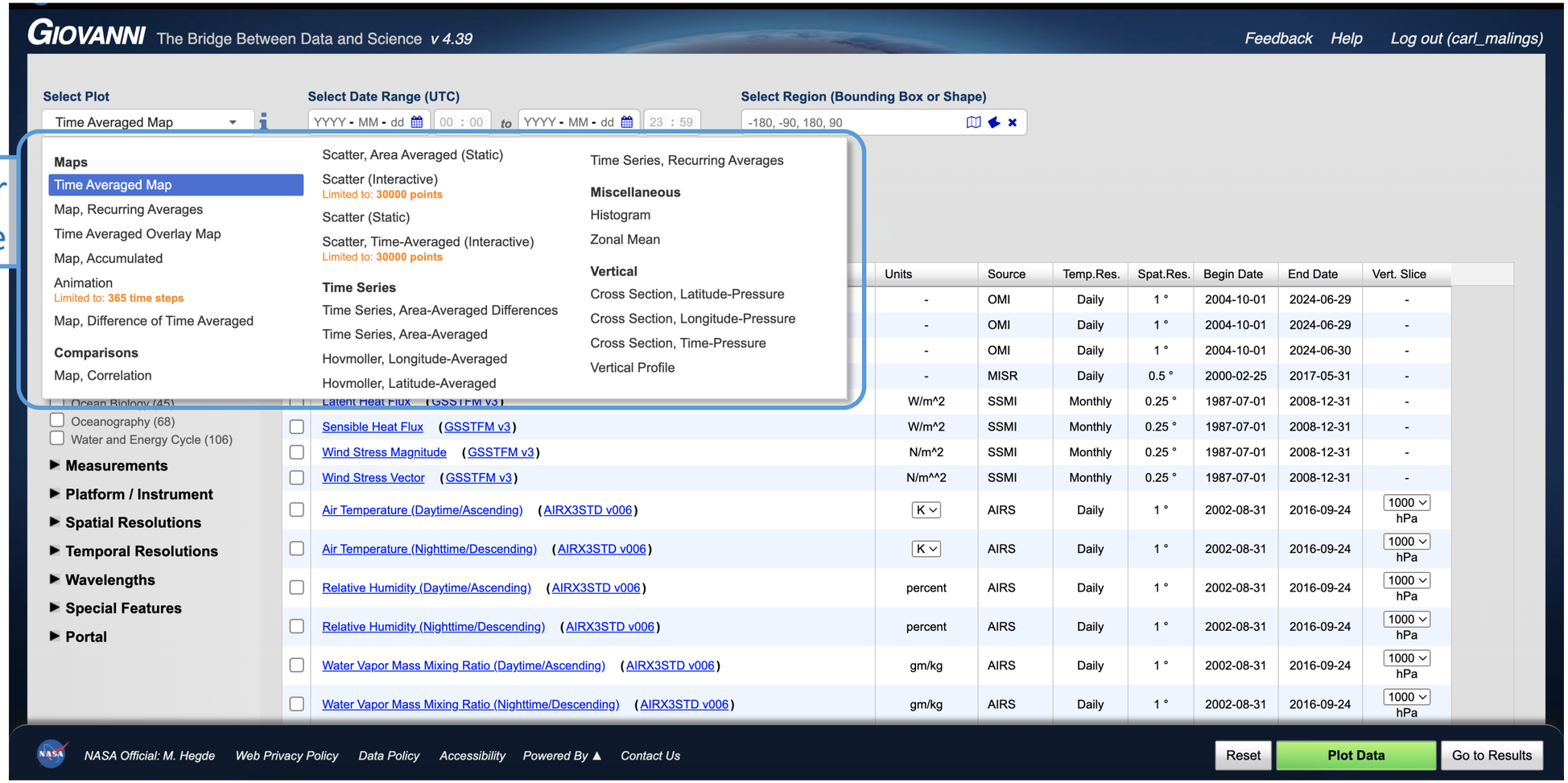
# Giovanni Controls




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

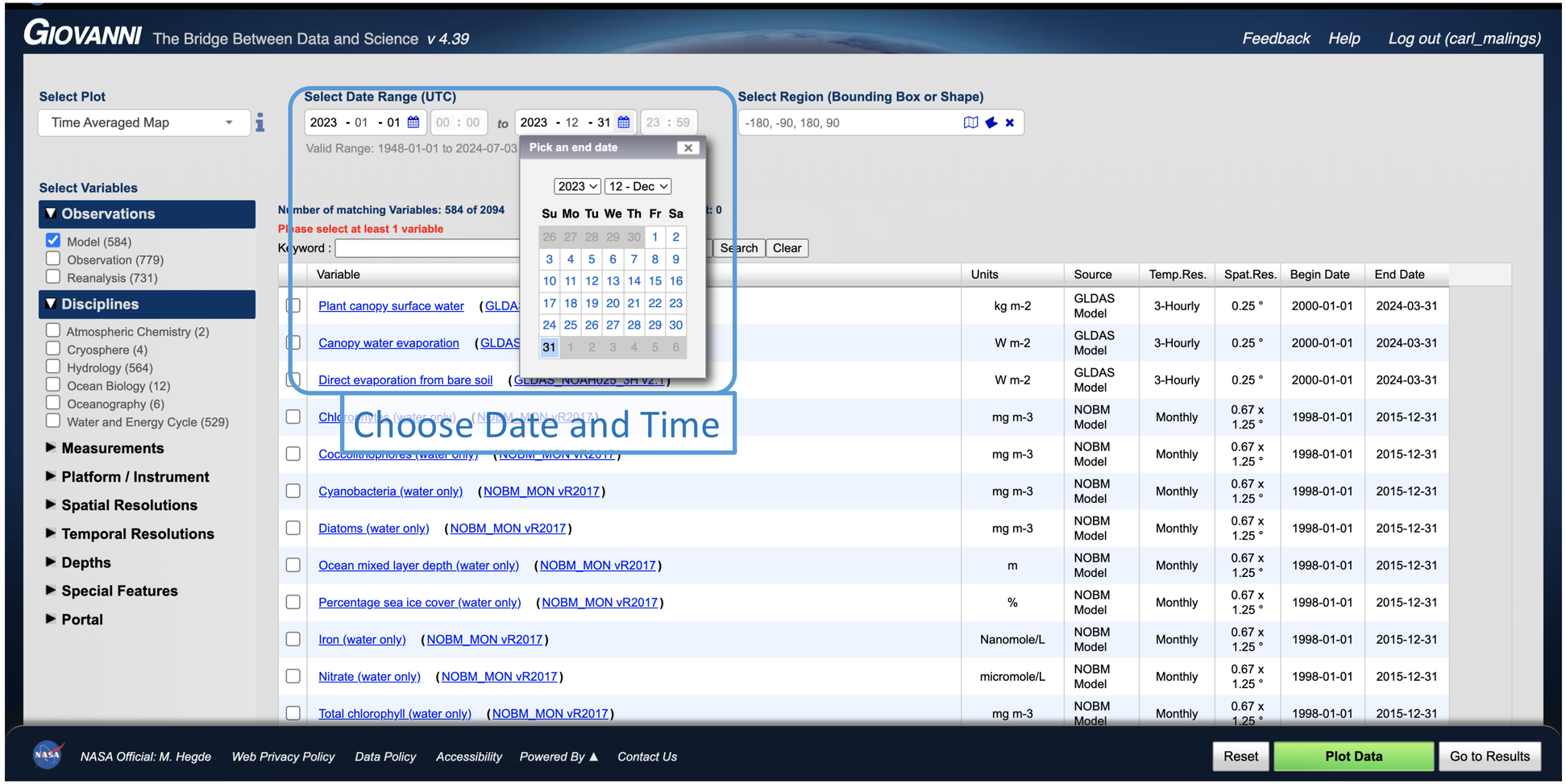
# Select Plot Type

Choose Plot or Analysis Type



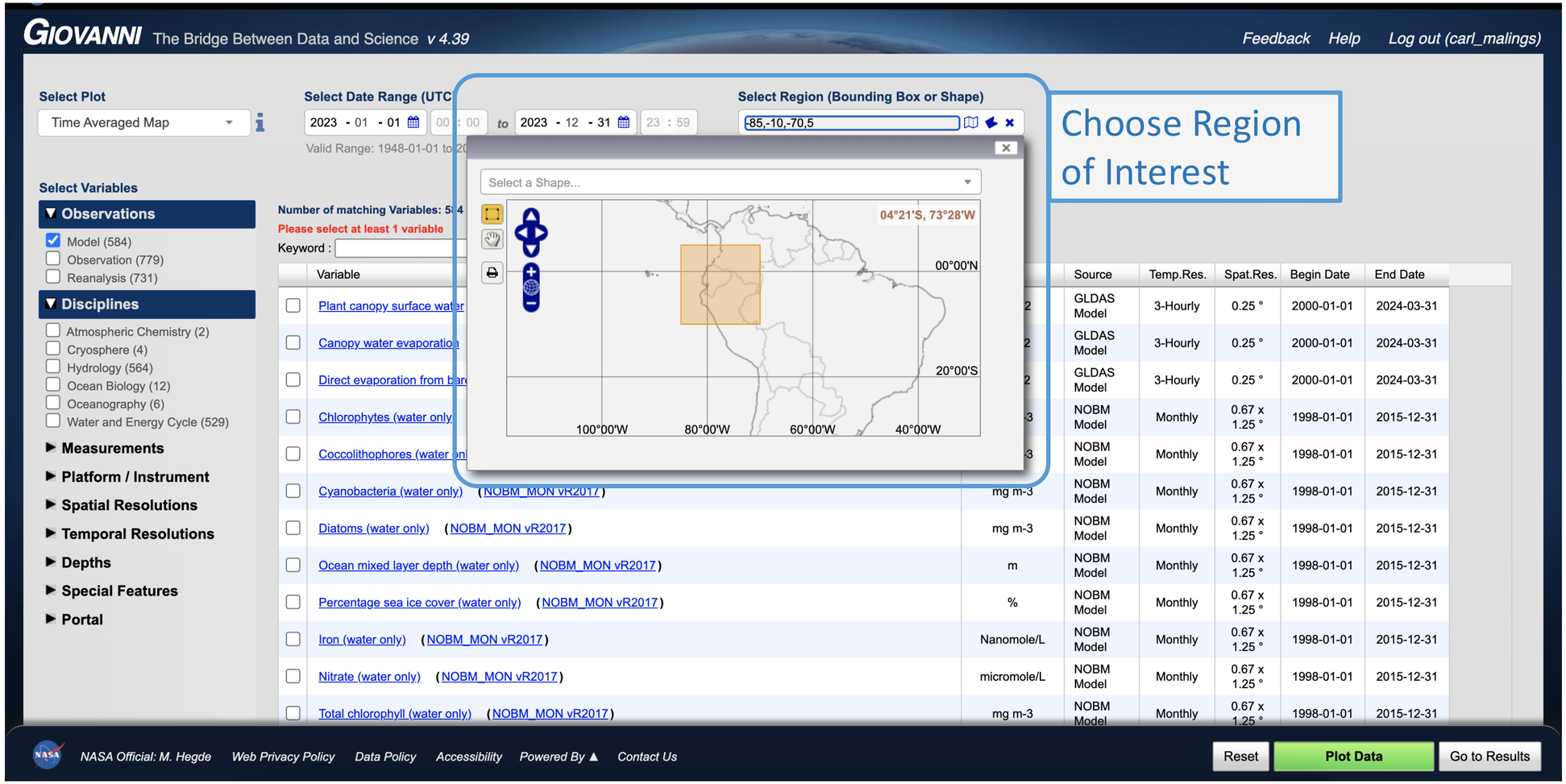

https://giovanni.gsfc.nasa.gov/giovanni/

# Select Date Range



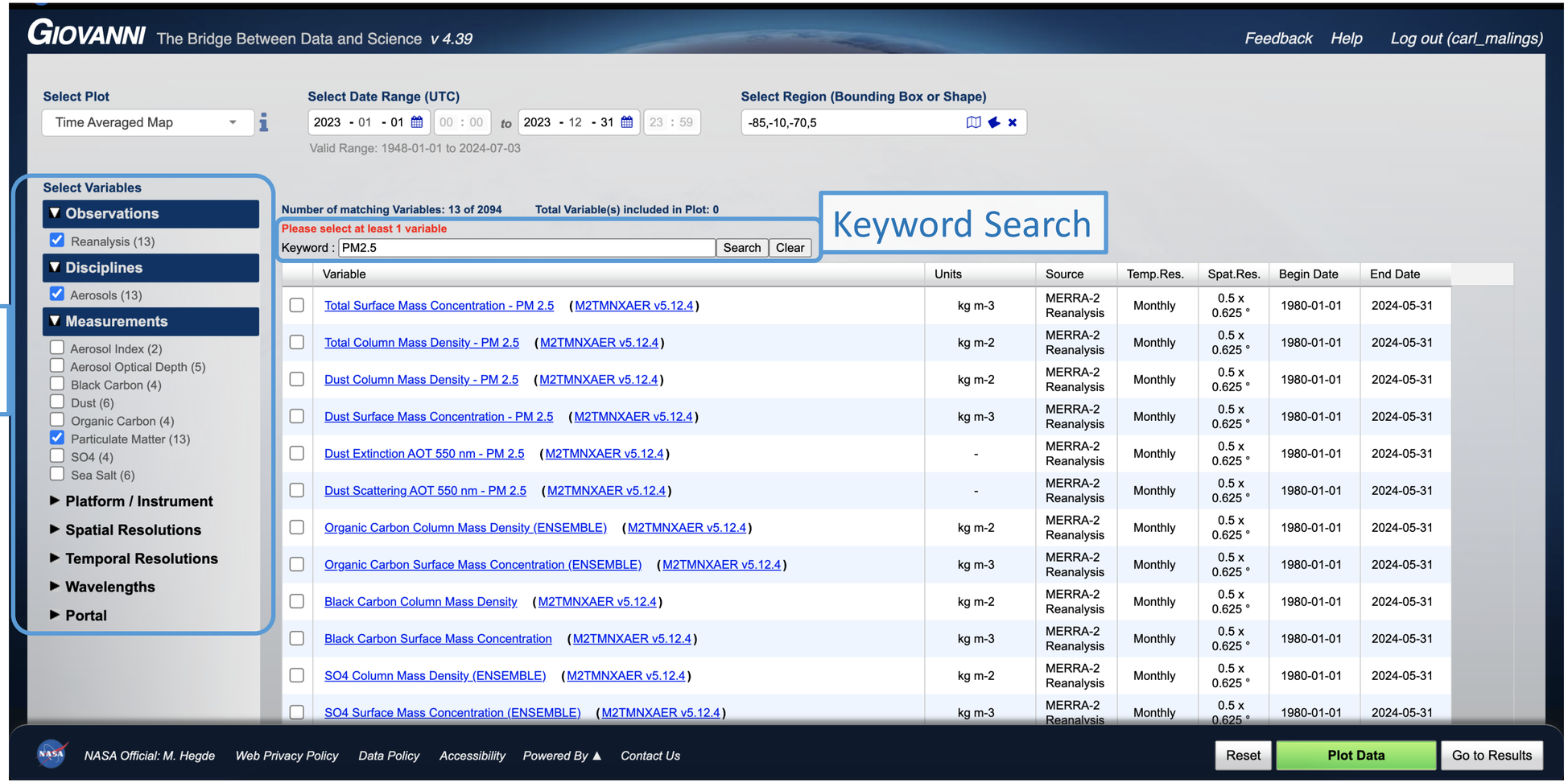

https://giovanni.gsfc.nasa.gov/giovanni/

# Select Region of Interest



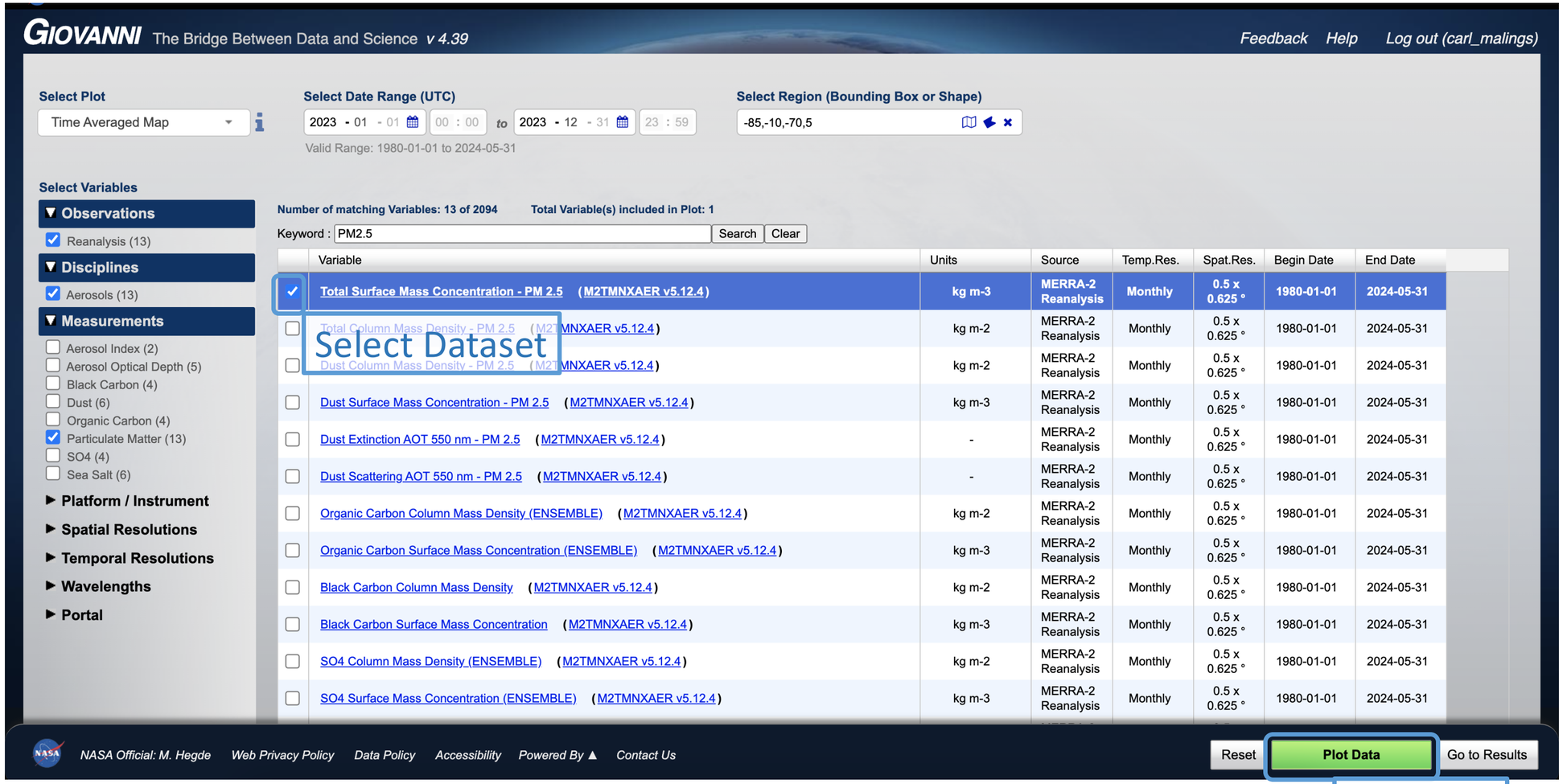

https://giovanni.gsfc.nasa.gov/giovanni/

# Refine Search



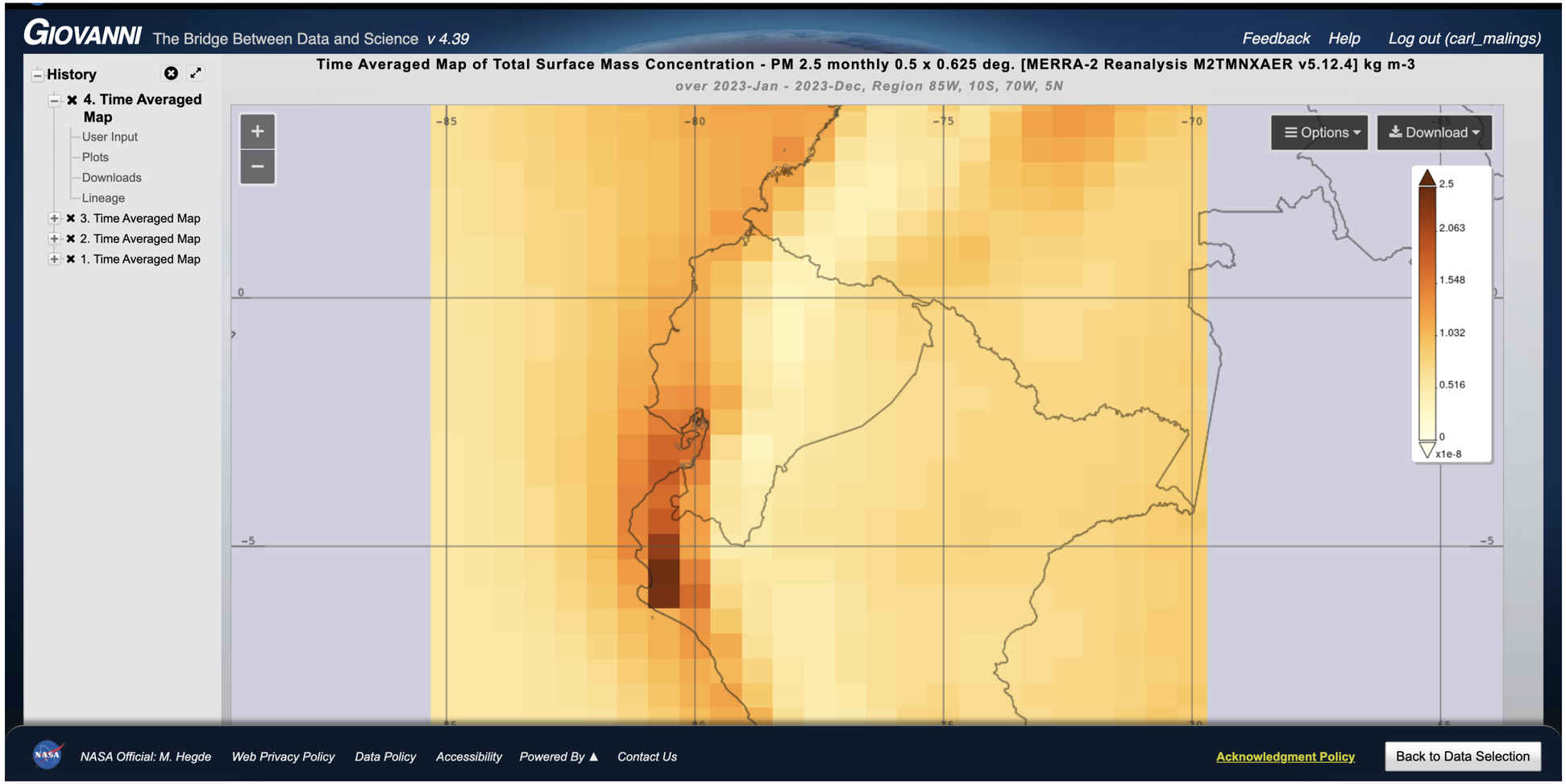

https://giovanni.gsfc.nasa.gov/giovanni/

# Select & Plot Data



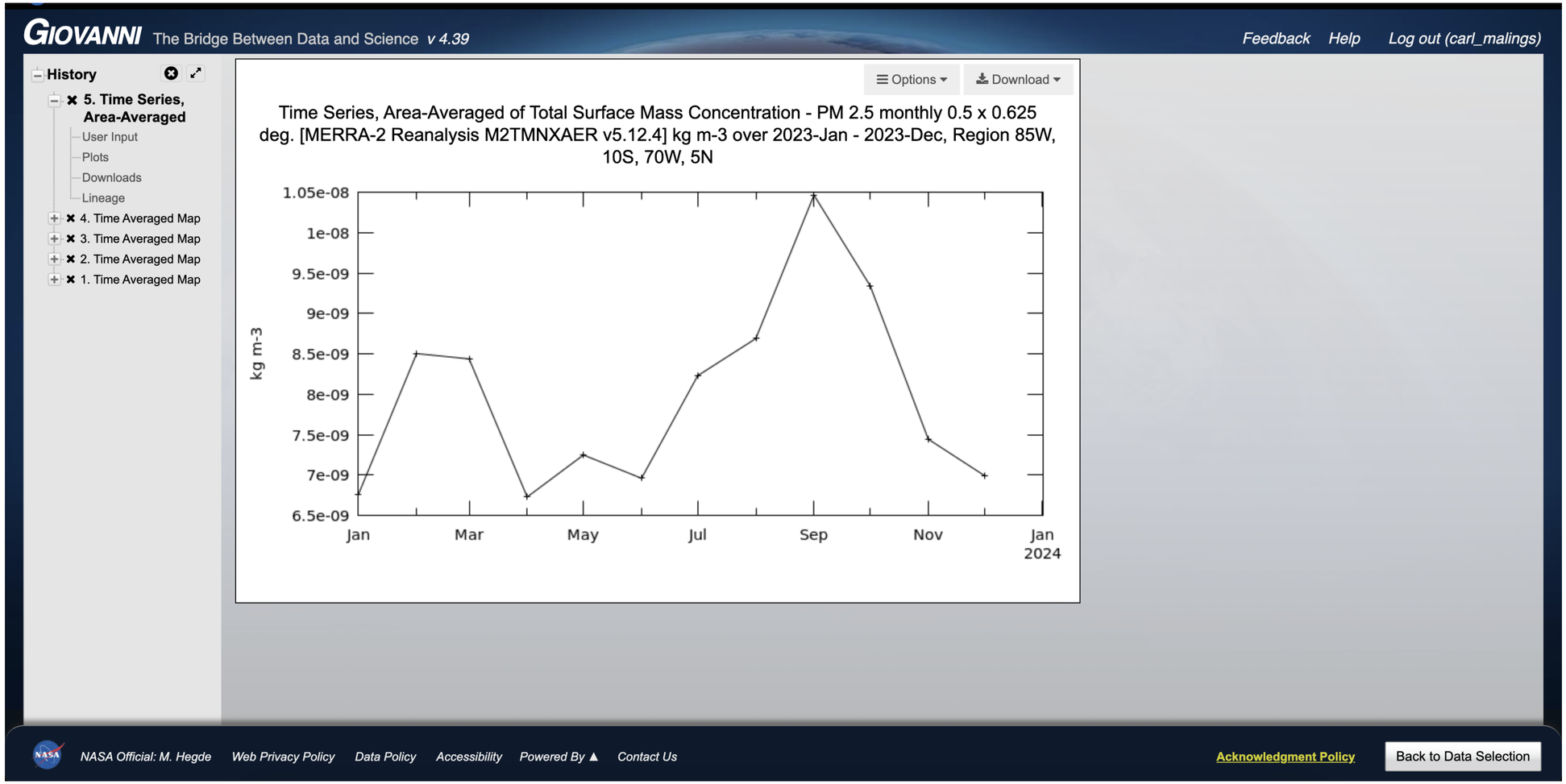

https://giovanni.gsfc.nasa.gov/giovanni/

# Time-Averaged Map




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

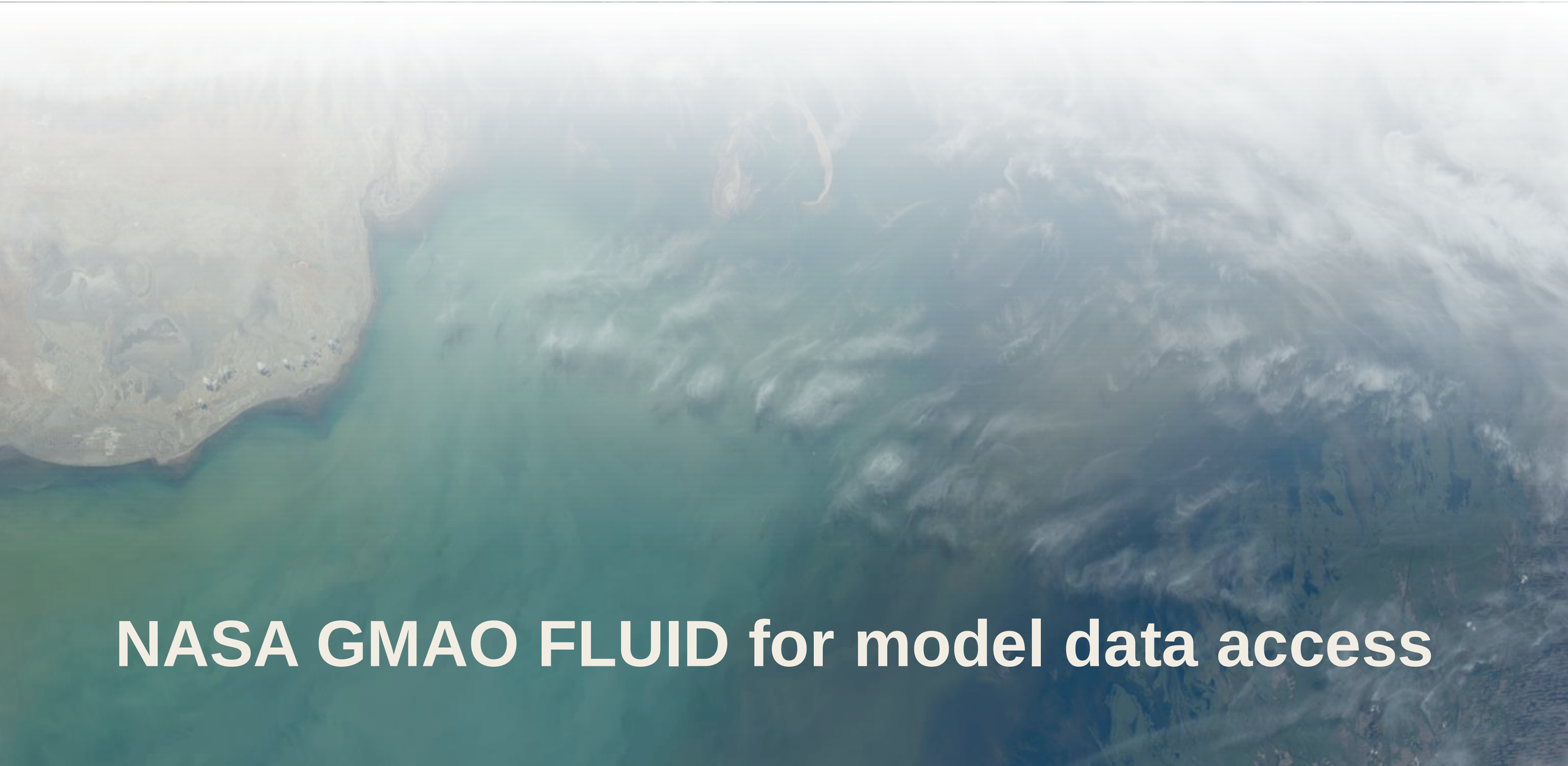
# Time Series Plot




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

# Suggested Giovanni Exercises

- Select a dataset (e.g., OMI $NO_2$) and produce an annual average map plot for a region of interest to you.
- Produce a monthly average time-series plot for the same region.
- Select two datasets representing the same quantity (e.g., MERRA-2 AOD and MODIS AOD) and create a correlation map plot to see the level of agreement between them.



# NASA GMAO FLUID for model data access

# NASA GMAO FLUID

Weather | Mission Support | CF | Reanalysis | Carbon

Datagrams | Surface Concentrations | Total Column

**Interactive CF Map Tool**

Click Here

**Data Access**

» HTTPS

Replay | Forecast

» OPeNDAP

Replay | Forecast

» Data Download Tool

Replay | Forecast

**Questions?**

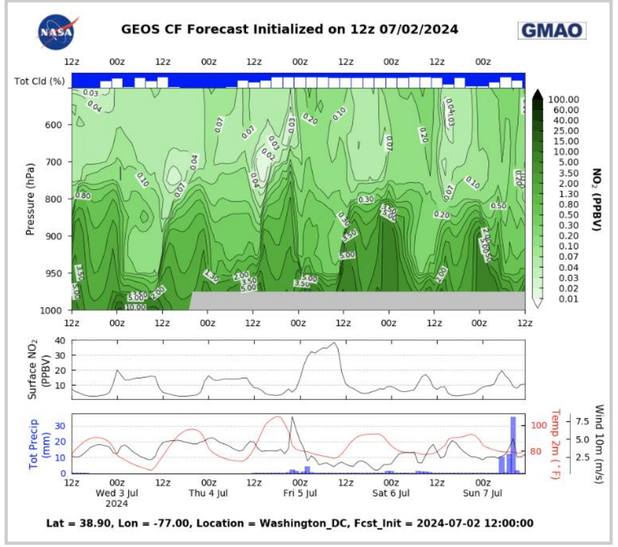
Find more information on CF forecasts and replay here.

Contact us at geos-cf@lists.nasa.gov

## Composition Forecast Products

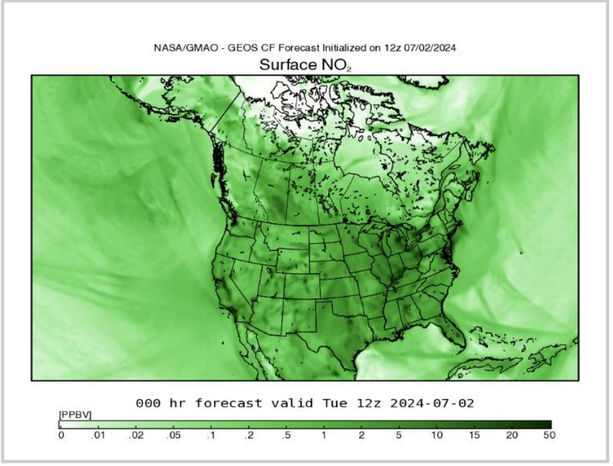
### Datagrams

Technical Description




### Surface Concentrations

Technical Description




https://fluid.nccs.nasa.gov/cf/

# FLUID Controls

Weather | Mission Support | CF | Reanalysis | Carbon

Datagrams | Surface Concentrations | Total Column

Choose Data Product (MERRA-2, GEOS-CF)

Interactive Map

**Interactive CF Map Tool**
Click Here

Data Access

**Data Access**

» HTTPS
Replay | Forecast

» OPeNDAP
Replay | Forecast

» Data Download Tool
Replay | Forecast

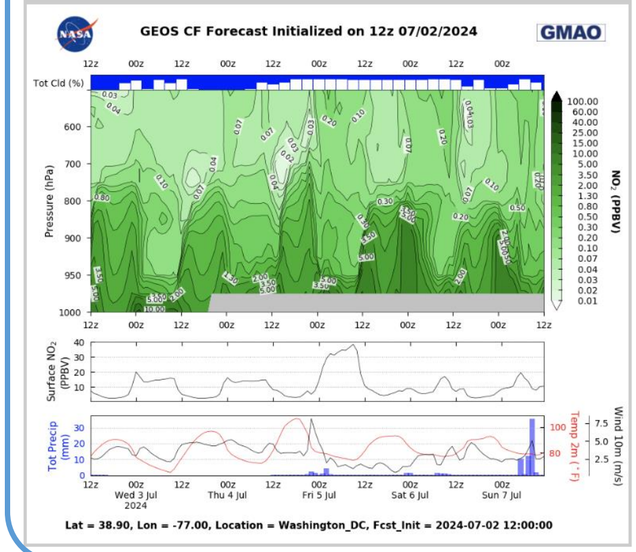
**Questions?**

Find more information on CF forecasts and replay here.

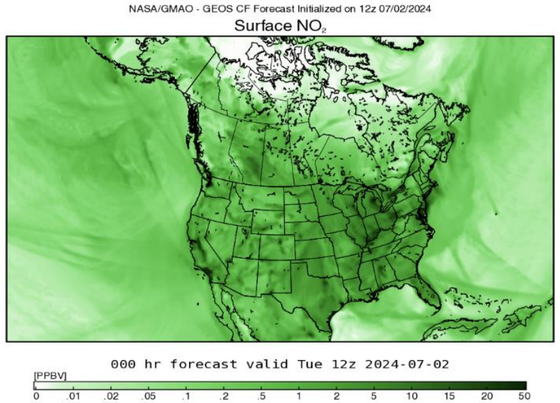
Contact us at geos-cf@lists.nasa.gov

## Composition Forecast Products

### Datagrams
Technical Description



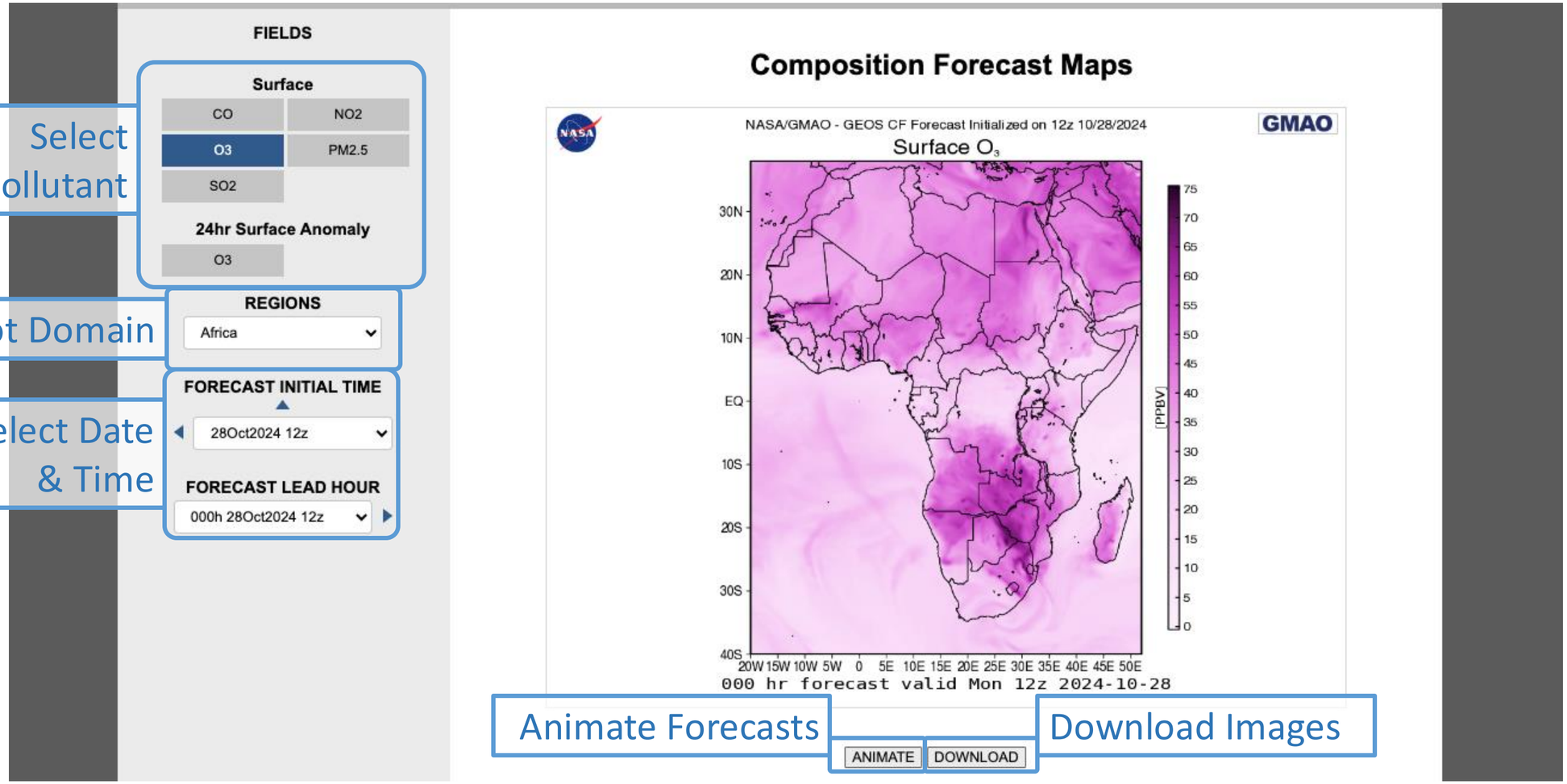

### Surface Concentrations
Technical Description




Plot Types

https://fluid.nccs.nasa.gov/cf/

# Surface Concentration Maps




Select Pollutant

Select Plot Domain

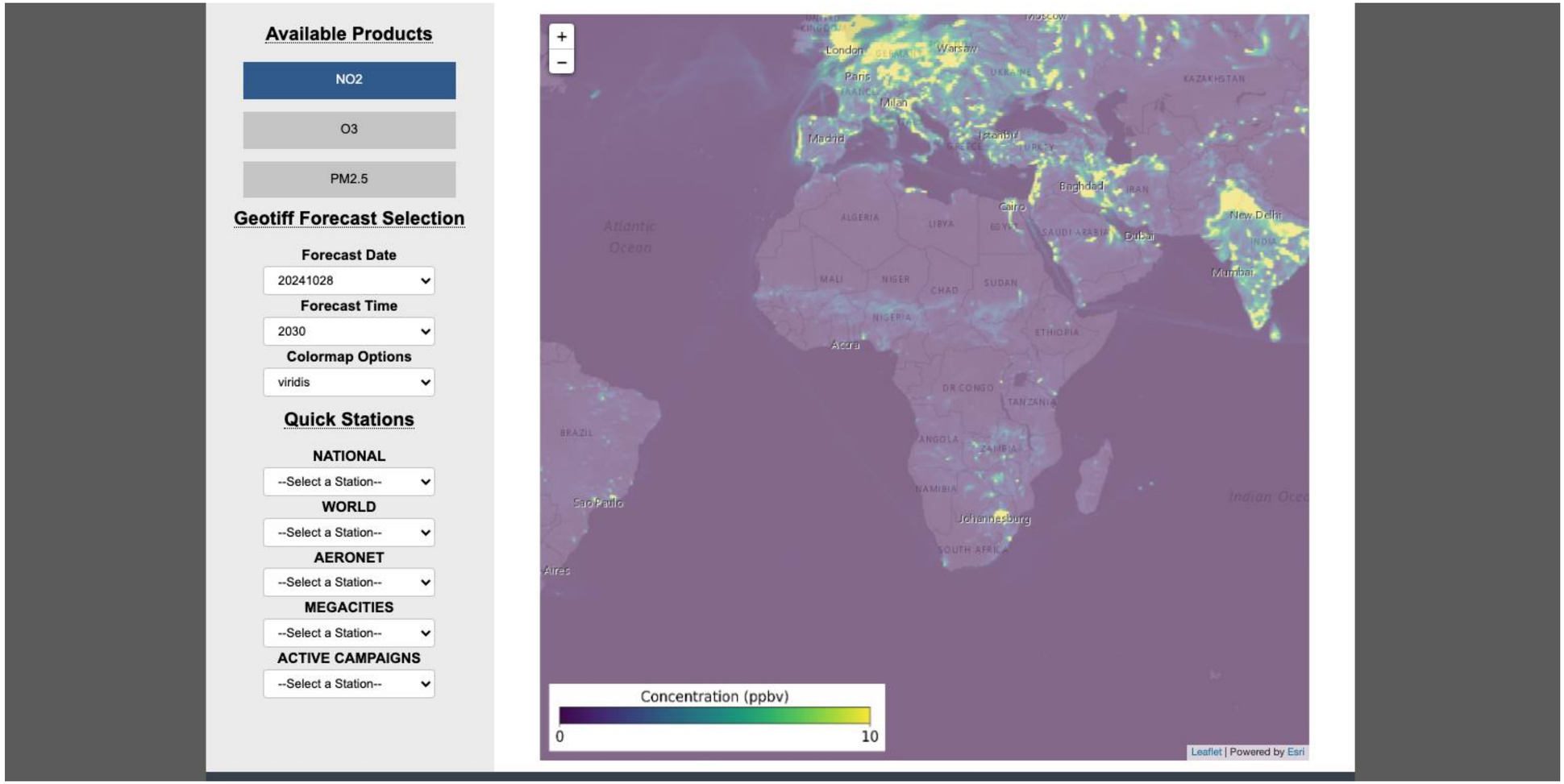
Select Date & Time

Animate Forecasts

Download Images

https://fluid.nccs.nasa.gov/cf/

# Interactive Map



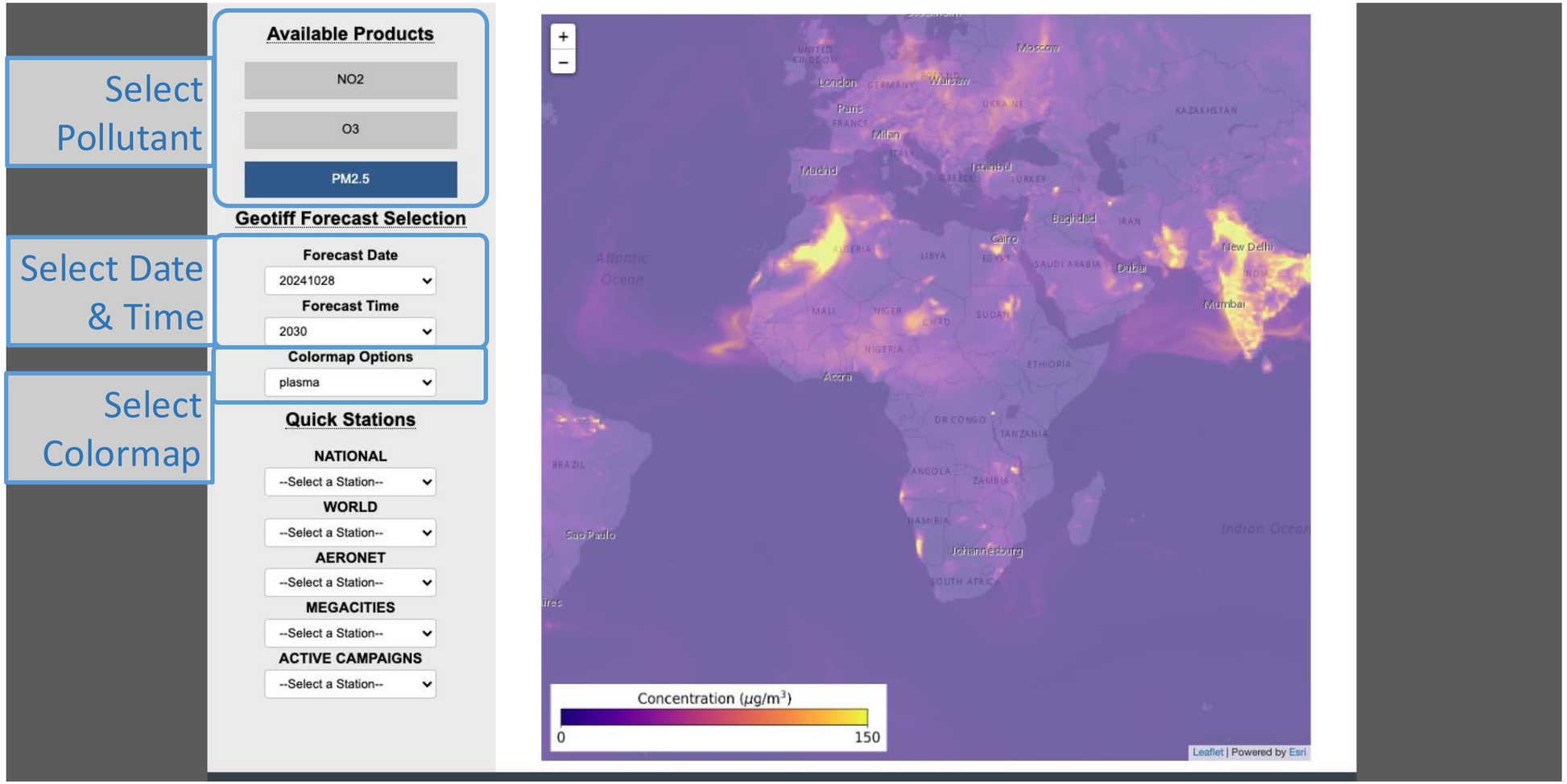

https://fluid.nccs.nasa.gov/cf/

# Change Pollutant Display

Select Pollutant

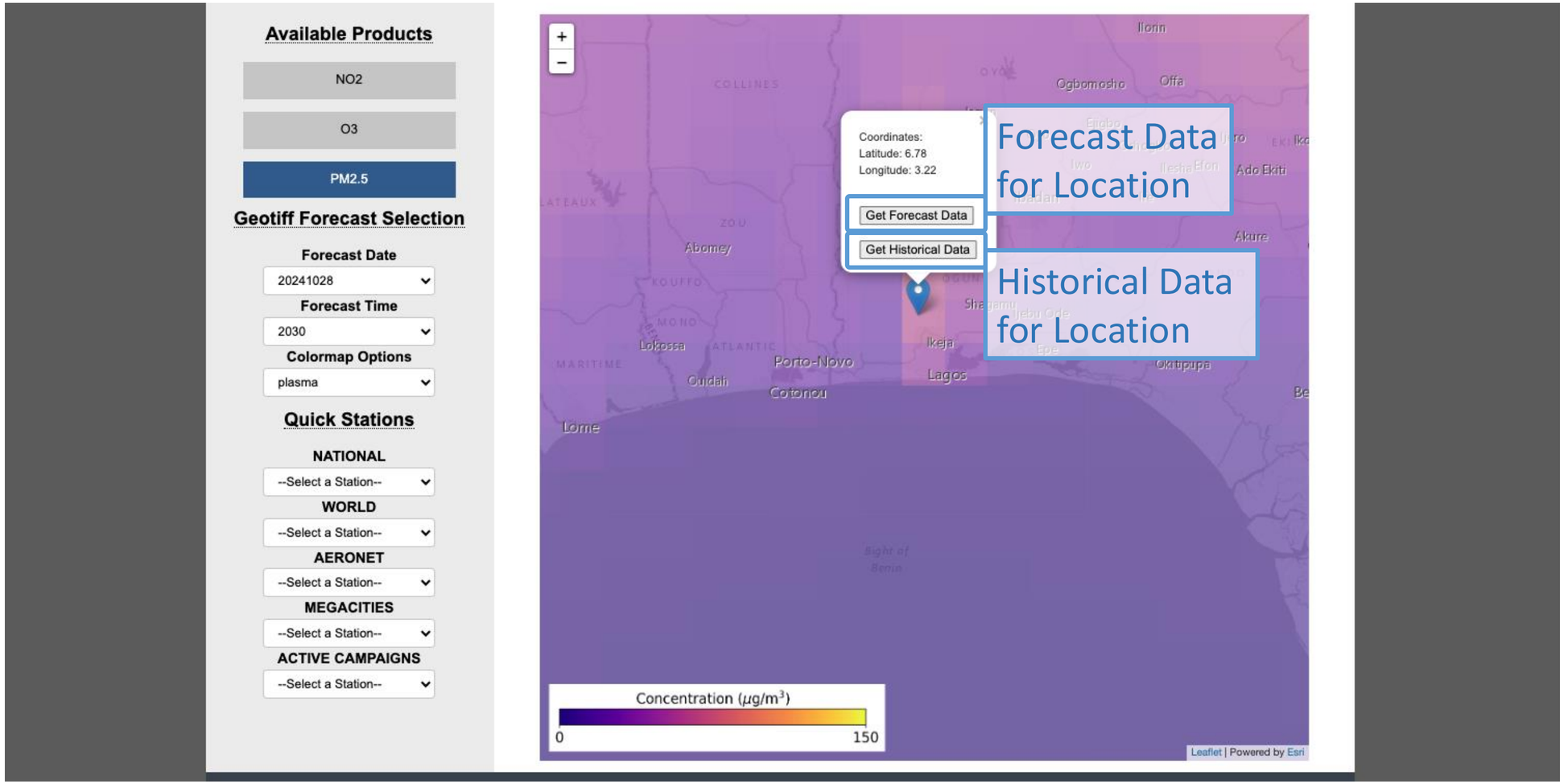
Select Date & Time

Select Colormap




https://fluid.nccs.nasa.gov/cf/

# Get Data for a Grid Cell




https://fluid.nccs.nasa.gov/cf/

# Forecast Datagrams

Download Data

**Downloadable Data**

**Chemistry Data**

☐ $NO_2$ ☐ $O_3$ ☐ PM2.5

--Select File Format--

--Select Dataset--

Download Chem Data

**Meteorology Data**

--Select File Format--

Download Met Data

**Other Data Sets**

Pressure Level Plot

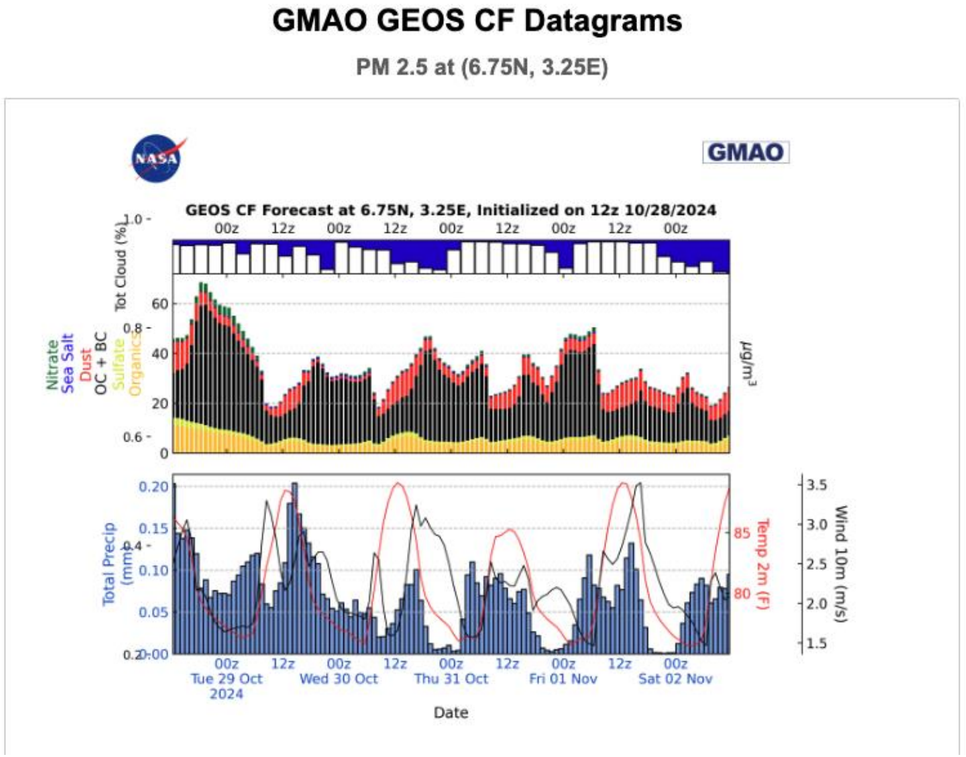
Historical CF Plot

NO2

O3

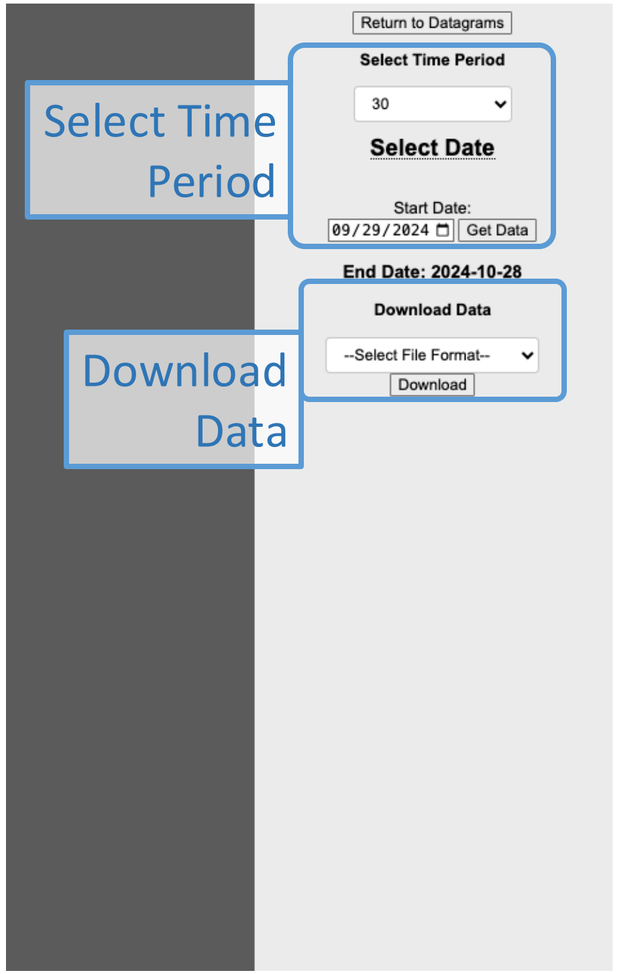
PM 2.5

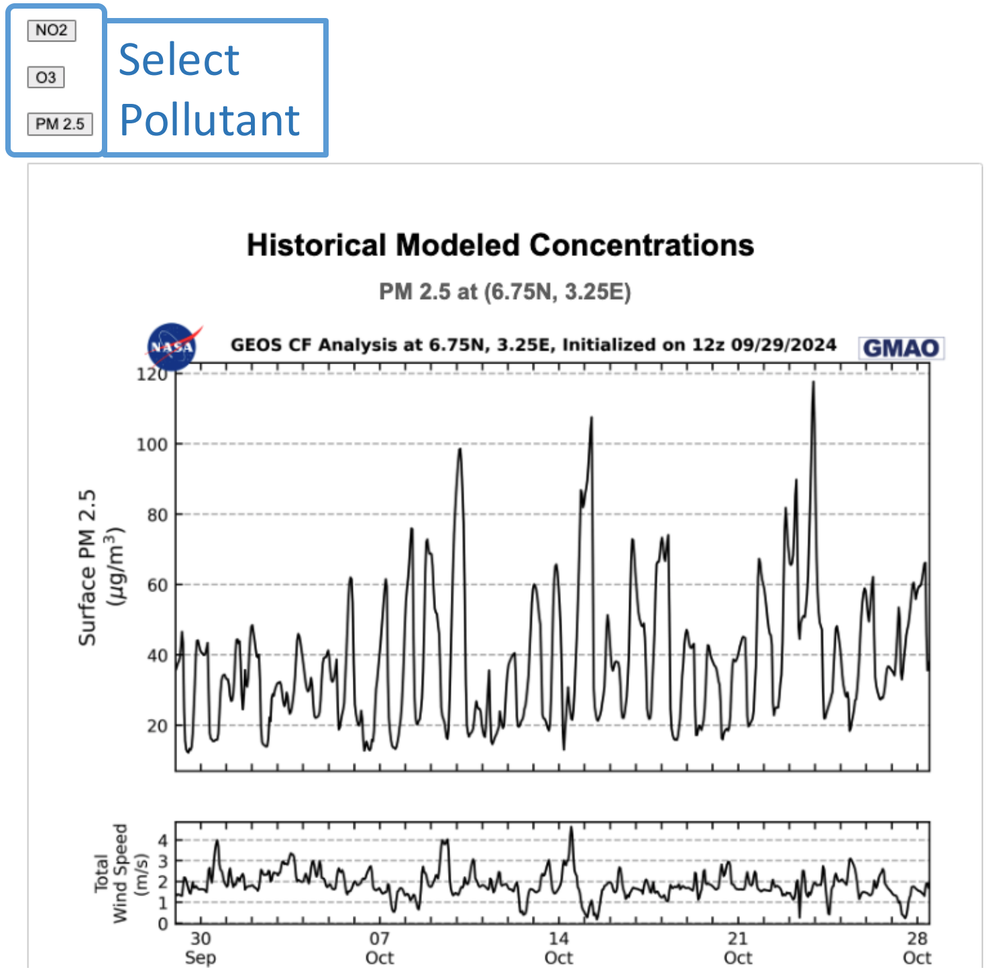
Select Pollutant




https://fluid.nccs.nasa.gov/cf/

# Historical Data



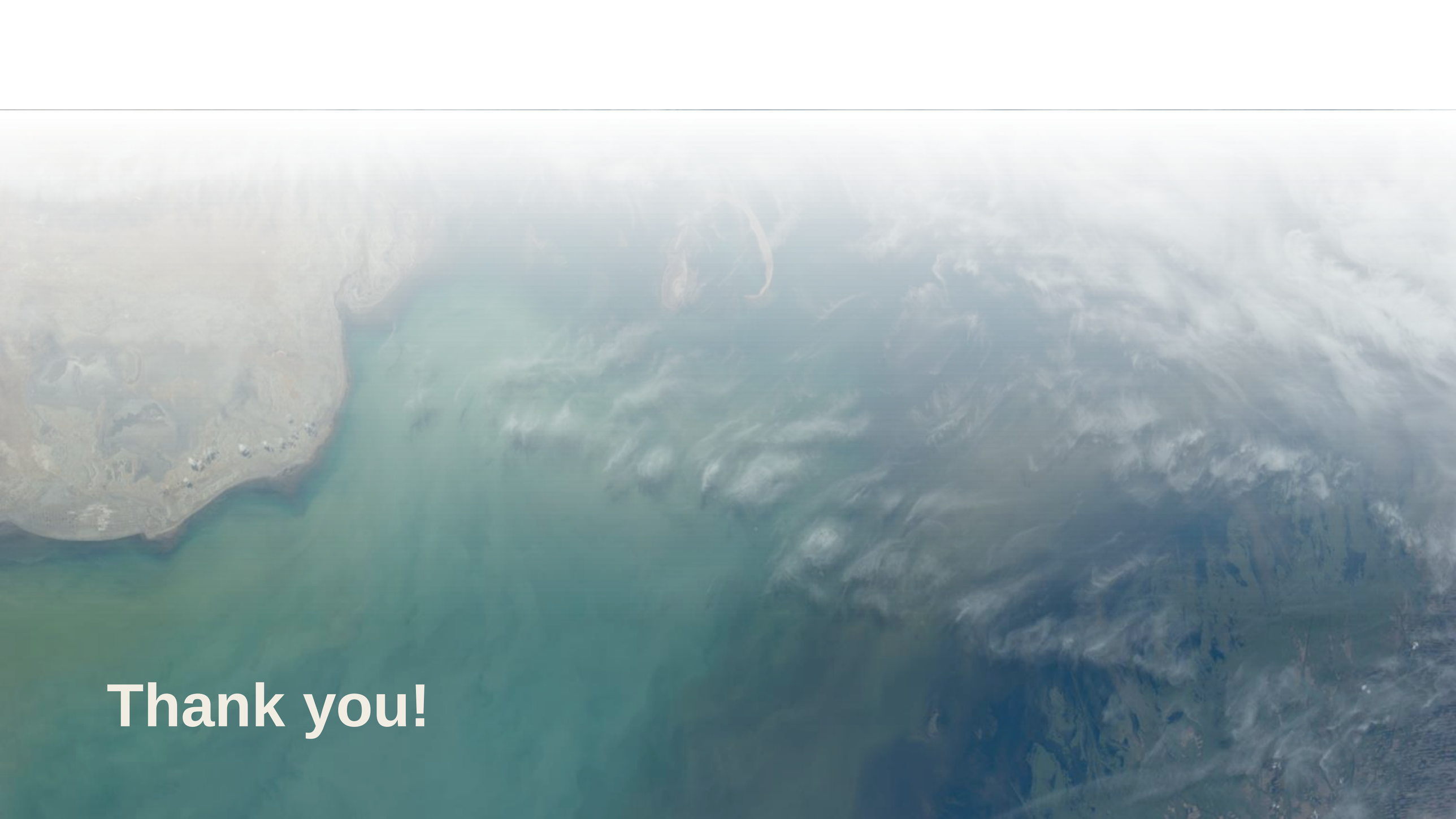

https://fluid.nccs.nasa.gov/cf/

# Suggested GMAO FLUID Exercises

- Bring up today's air quality forecast for your location.

# Summary of Common Tools

| Tool | Link | Available Datasets & Models | Primary Use |
|---|---|---|---|
| Worldview | https://worldview.earthdata.nasa.gov/ | MODIS, VIIRS, OMI, TEMPO, AERONET, MERRA-2 | Visualize satellite imagery in near-real-time |
| JSTAR Mapper | https://www.star.nesdis.noaa.gov/mapper/ | VIIRS, TROPOMI | Visualize satellite imagery |
| Giovanni | https://giovanni.gsfc.nasa.gov/giovanni/ | MODIS, OMI, MERRA-2 | Conduct simple analysis (maps, time-series plots, correlation) on gridded datasets |
| GMAO FLUID | https://fluid.nccs.nasa.gov/ | MERRA-2, GEOS-CF | Visualize model outputs and forecasts |
| CAMS Charts | https://atmosphere.copernicus.eu/charts/packages/cams/ | ECMWF CAMS forecast | Visualize forecasts |


Thank you!