National Aeronautics and
Space Administration

Partner

Satellite Data and Other NASA Resources for Air Quality Applications

Carl Malings

Assistant Research Scientist at Morgan State University (MSU)
working under the GESTAR II Cooperative Agreement
in the Global Modelling and Assimilation Office (GMAO)
part of the Earth Sciences Division (ESD)
at the NASA Goddard Space Flight Center (GSFC)

Outline for the presentation

NASA's role in providing air quality data

- Airborne Data
- Global Models
- Satellite Remote Sensing

Strengths & Weaknesses of Satellite Data for Air Quality Applications

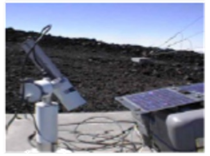
New & Upcoming Satellite Missions Relevant to Air Quality

- TROPOMI
- TEMPO
- MAIA
- PACE

Data Access, Visualization, and Training Resources

Sources of air quality information

traditional monitors



low-cost sensors

Ground Measurements

atmospheric observations

NASA contributions

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

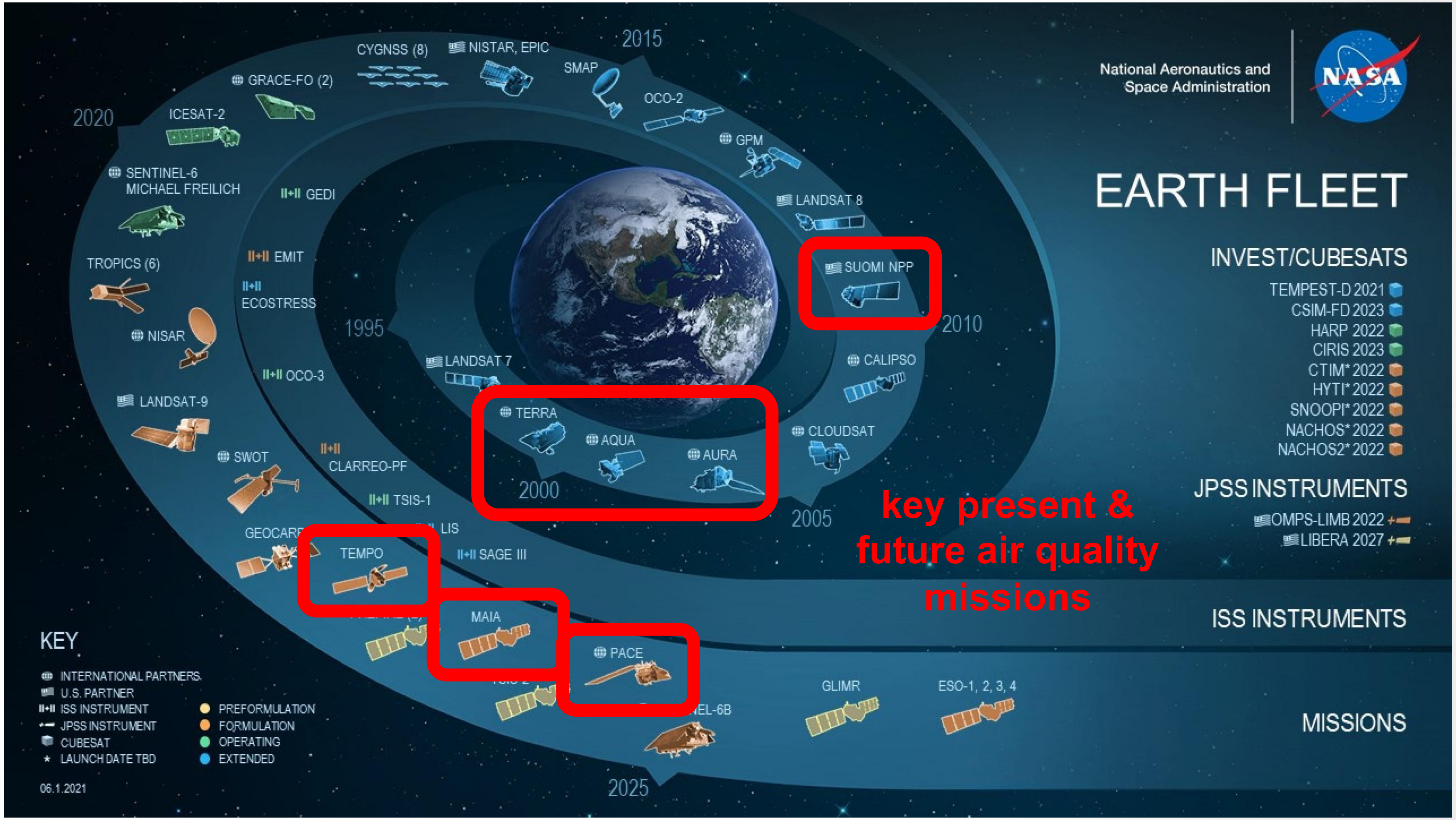
Satellite instruments and retrievals

Geophysical Parameters
(useful data product)

Retrieval Algorithm
(data processing)

Radiative Transfer Theory
(physics)

Spectral Radiance
(instrument)



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

Ground-based atmospheric column observations

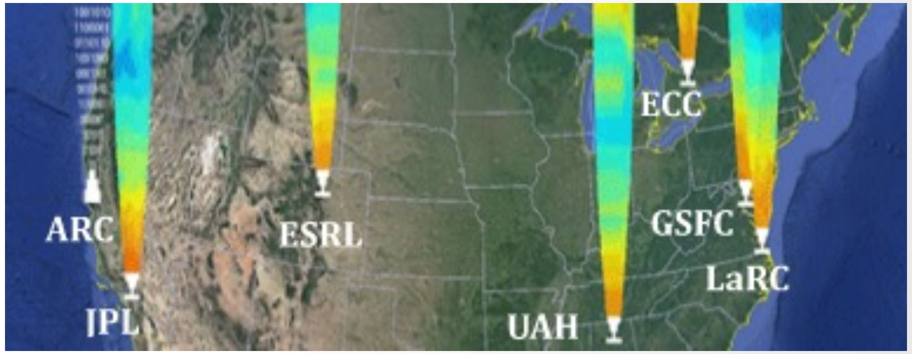
AERONET
aerosol optical depth
(relevant to PM)

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

Source: https://pandora.gsfc.nasa.gov/

PANDORA
atmospheric gases
(NO_2, Ozone)

TOLNET
LIDAR measurements
of Ozone profiles



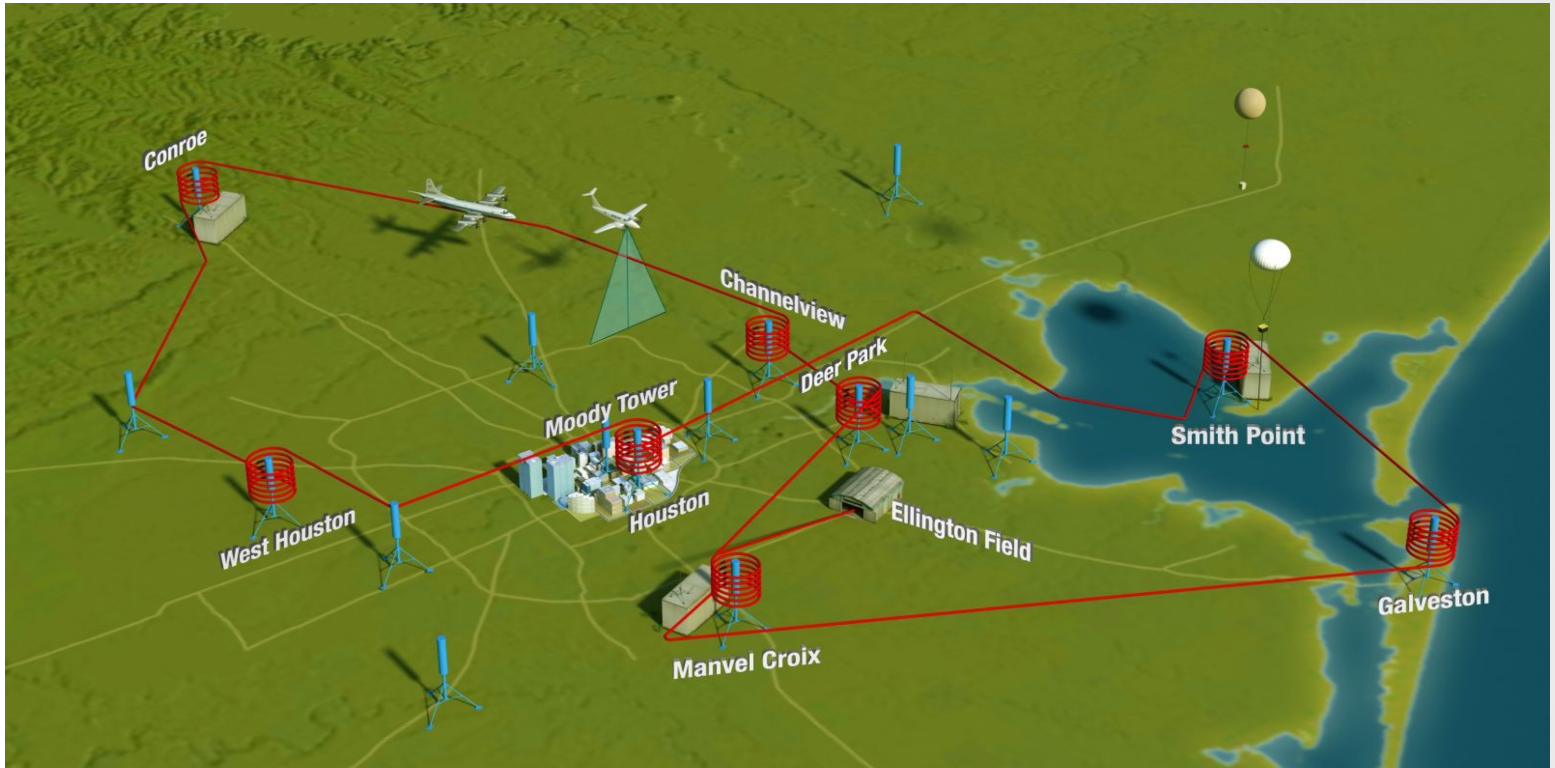
Source: https://www-air.larc.nasa.gov/missions/TOLNet/index.html

Airborne air quality campaigns

Typically, these campaigns gather data to improve satellite retrieval algorithms and models.

Instruments aboard NASA DC-8 Aircraft (photo credit: Pedro Campuzano-Jost)

Source: https://espo.nasa.gov/firex-aq/content/FIREX-AQ

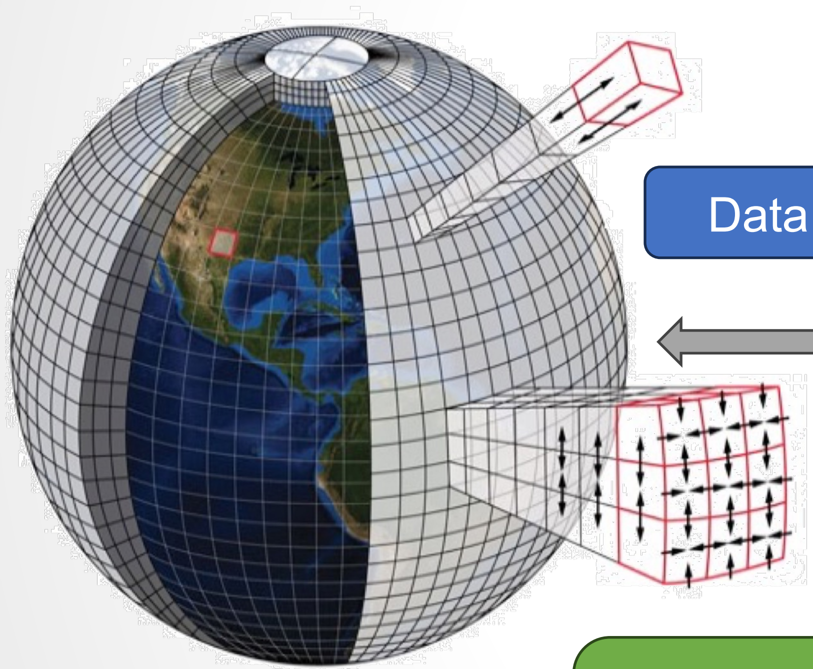


Flight patterns over Houston during DISCOVER-AQ 2013

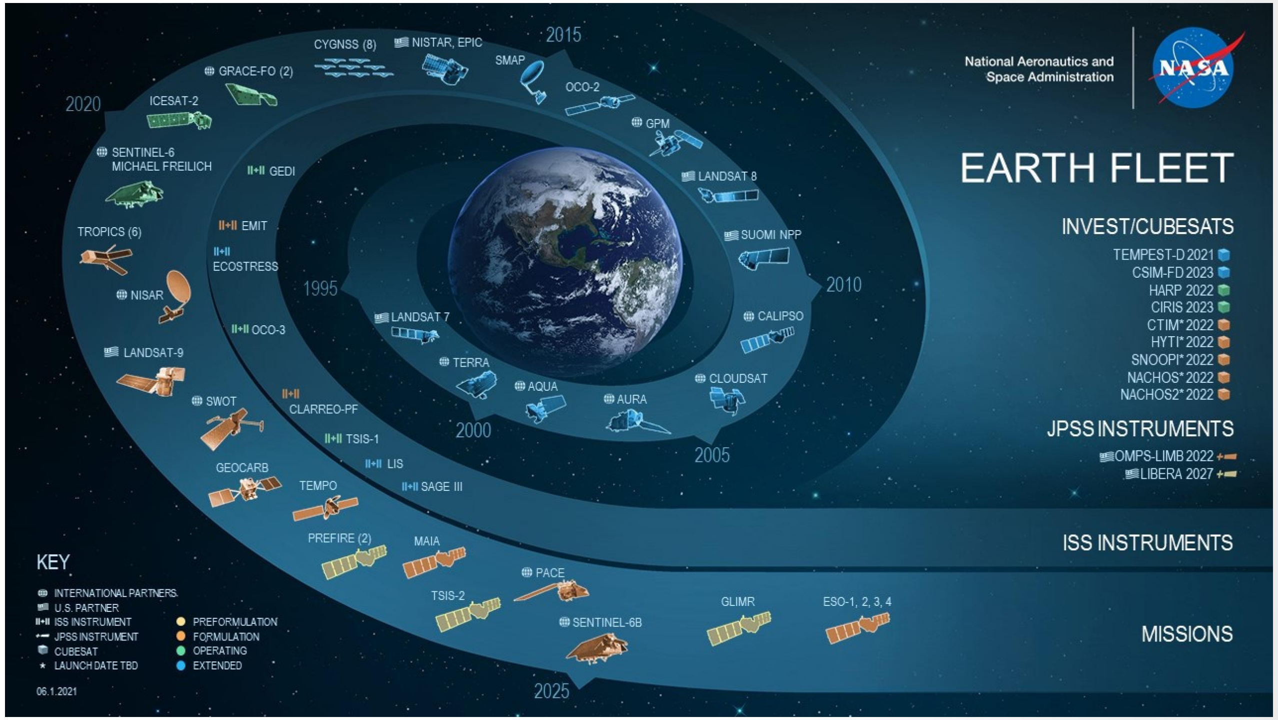
Source: NASA LARC DISCOVER-AQ campaign webpage
https://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html

NASA Global Modeling & Assimilation Office (GMAO)

The **GMAO** uses **computer models** and **data assimilation** to enhance NASA's program of **Earth Observations**.

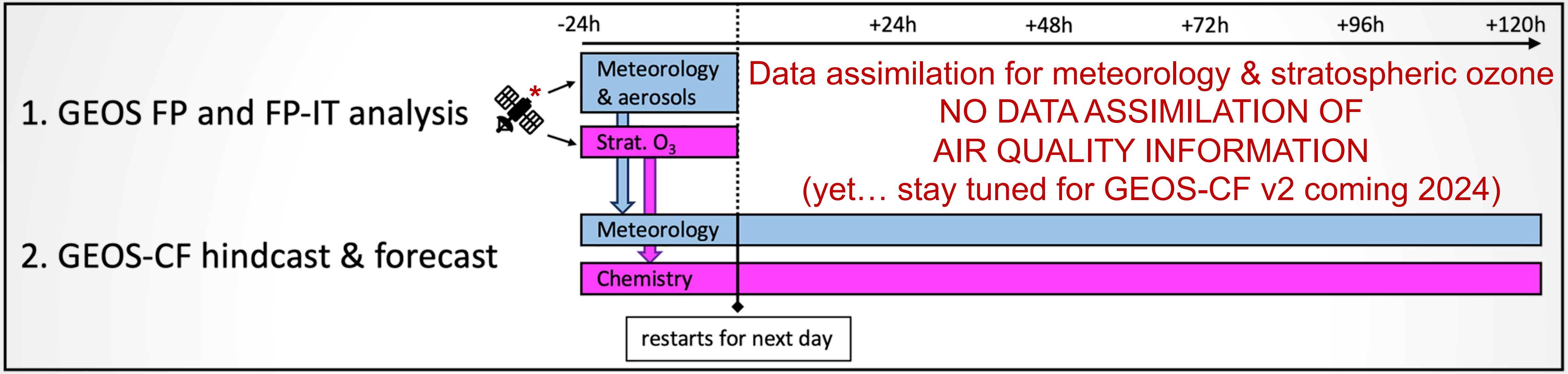


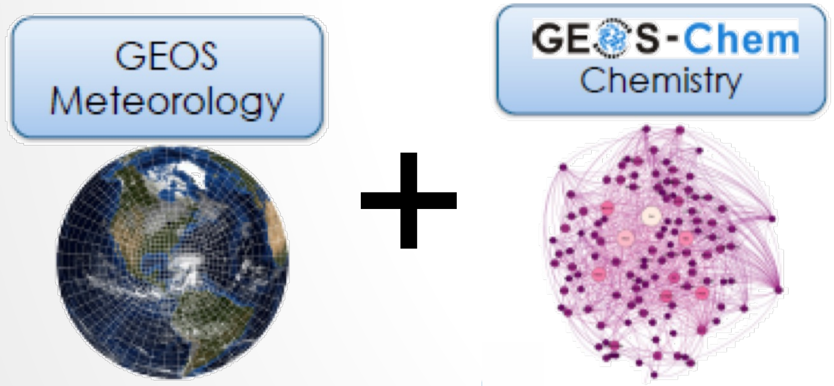
Data Assimilation



Mission Support
Retrieval Algorithms
OSSE

GEOS-CF: NASA global air quality forecast model

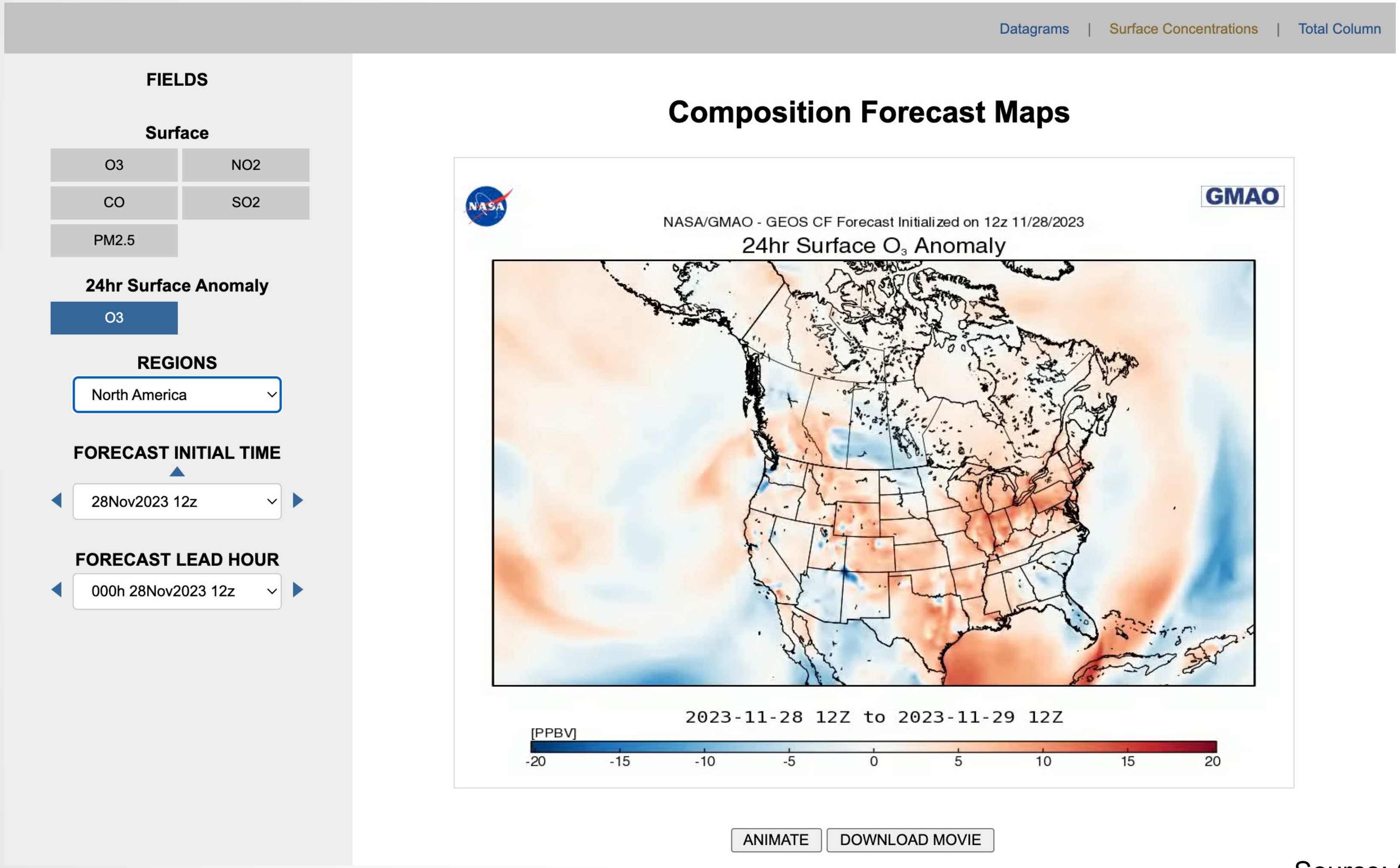




- Combine GEOS meteorology with GEOS-Chem chemistry
- 250 chemical species
- Hourly temporal resolution
- 0.25 degree (25 km) spatial resolution
- Global coverage
- Daily 1-day replay and 5-day forecast

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

Visualizing GEOS-CF forecasts in GMAO FLUID



The GMAO FLUID website provides access to visualizations of GMAO data products, including

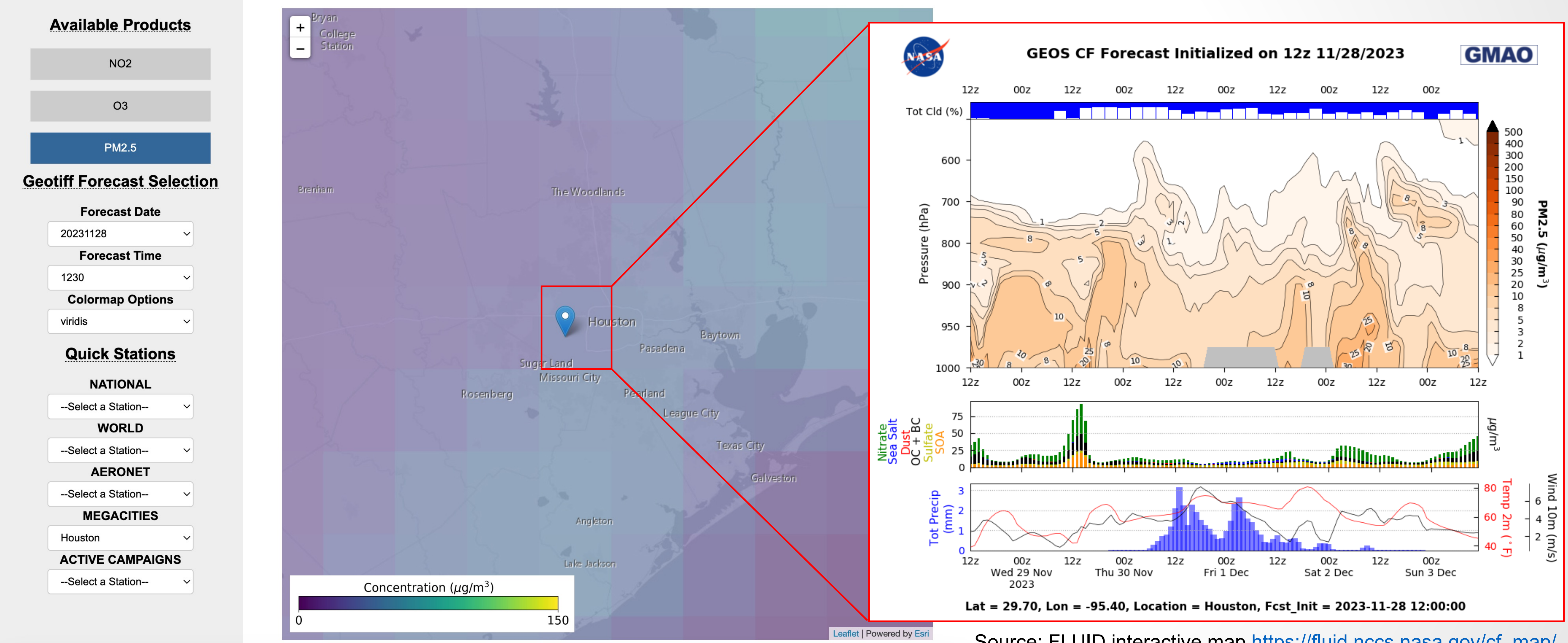
GEOS-CF replay and forecast surface concentration maps and animations are available globally and for regions.

Pre-generated “datagrams” for US and world cities depict the forecast time series and details.

Custom interfaces are often developed to support NASA airborne campaigns.

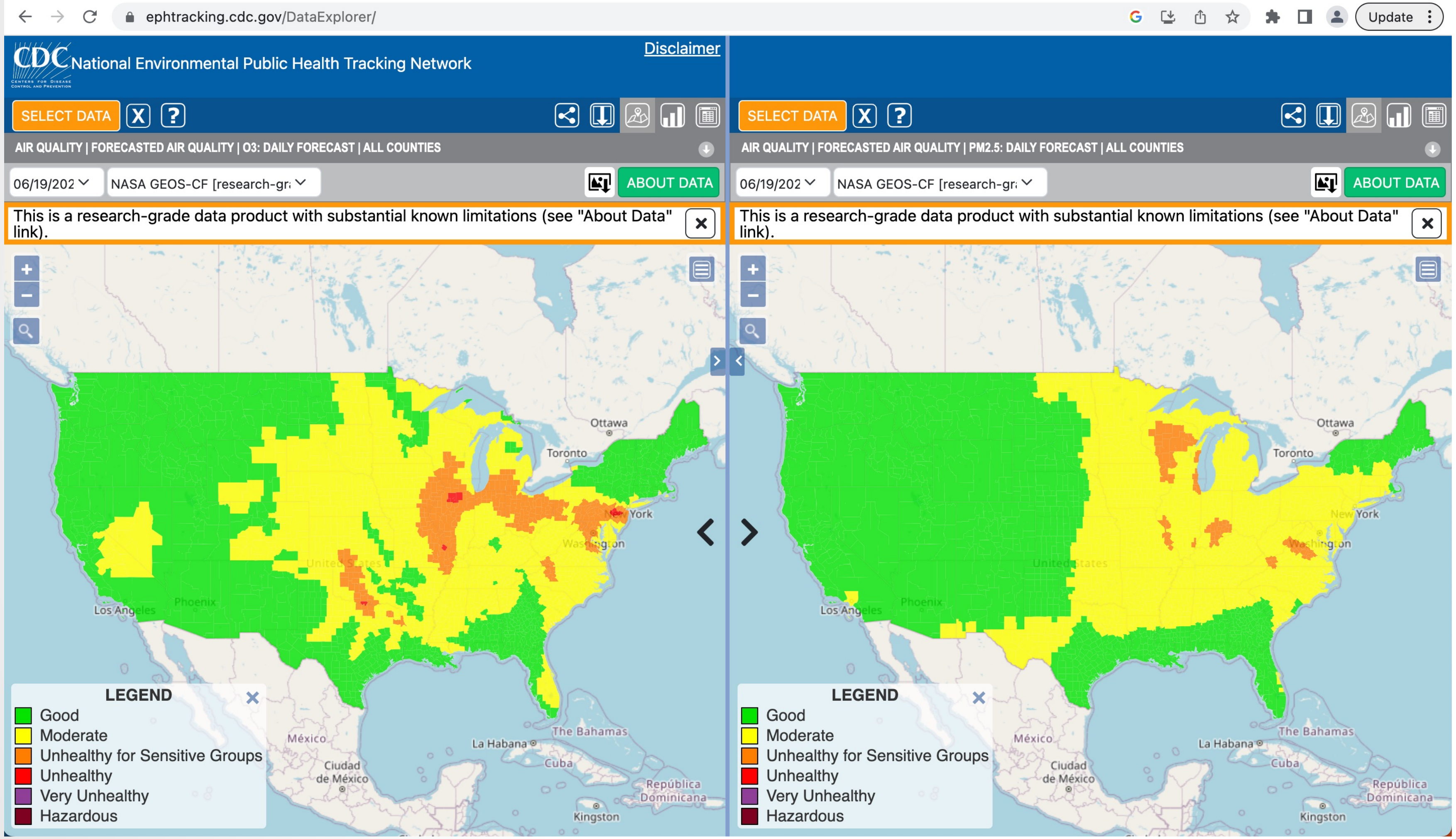
Source: GMAO FLUID for GEOS-CF https://fluid.nccs.nasa.gov/cf/

GEOS-CF interactive map and forecast datagrams



Source: FLUID interactive map https://fluid.nccs.nasa.gov/cf_map/

GEOS-CF derived AQI forecasts in CDC Tracker



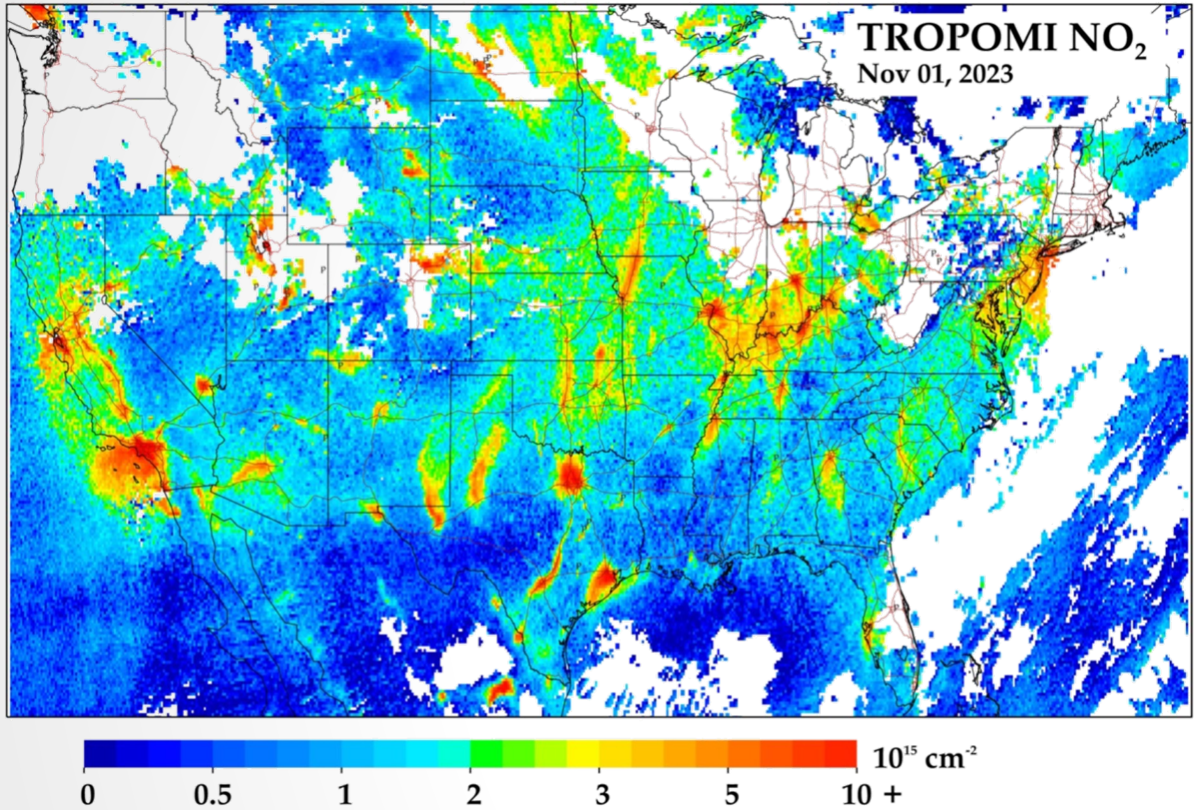
CDC tracker derives county-level daily US AQI values from gridded hourly GEOS-CF replay and forecasts over the USA.

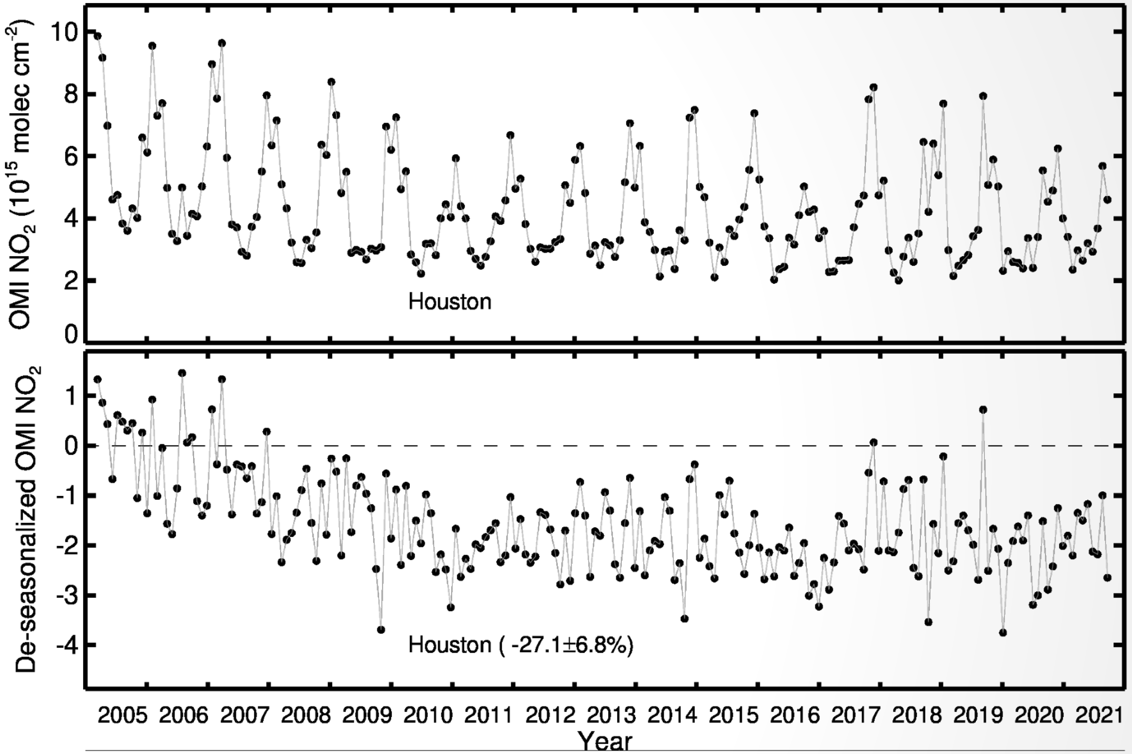
Can complement other information, such as EPA AirNow and AirData, for health impact studies and early warning of potentially hazardous air quality.

Source: https://ephtracking.cdc.gov/DataExplorer/

Satellites Data for Air Quality Benefits & Limitations

What satellite data CAN do for air quality

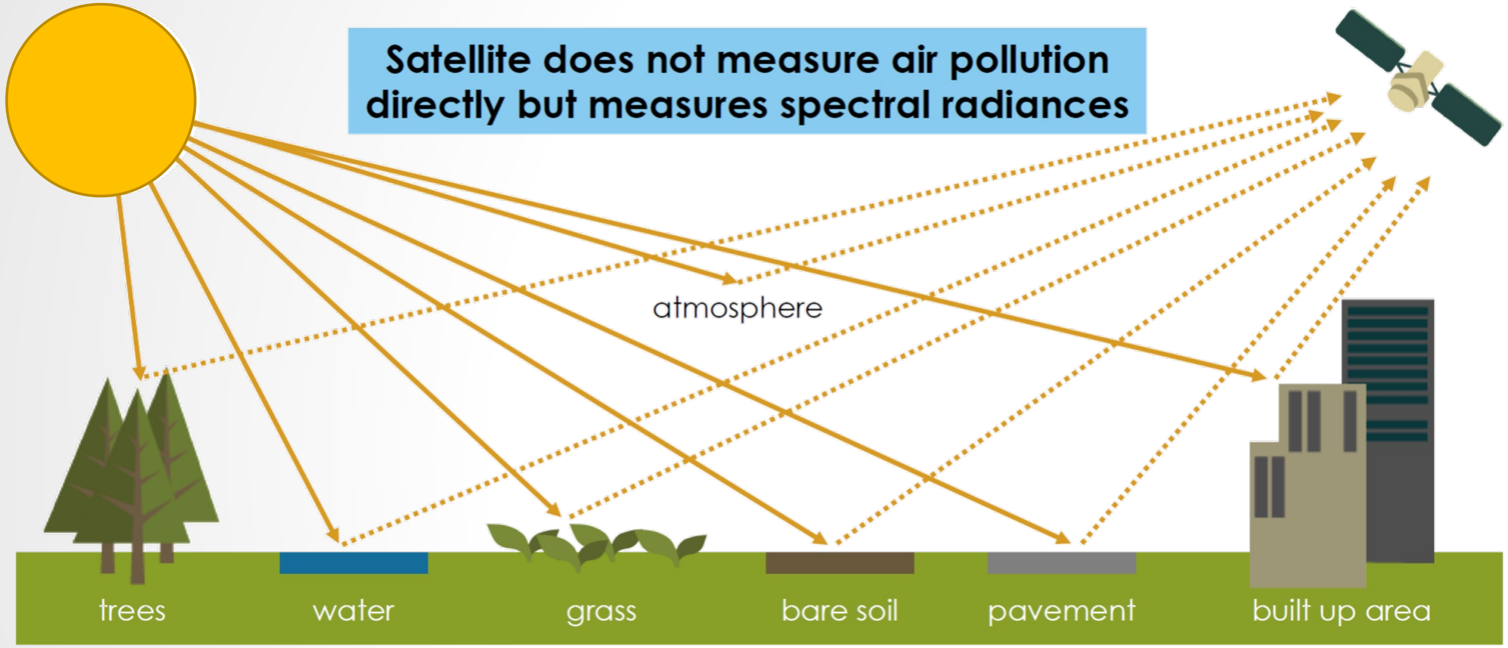


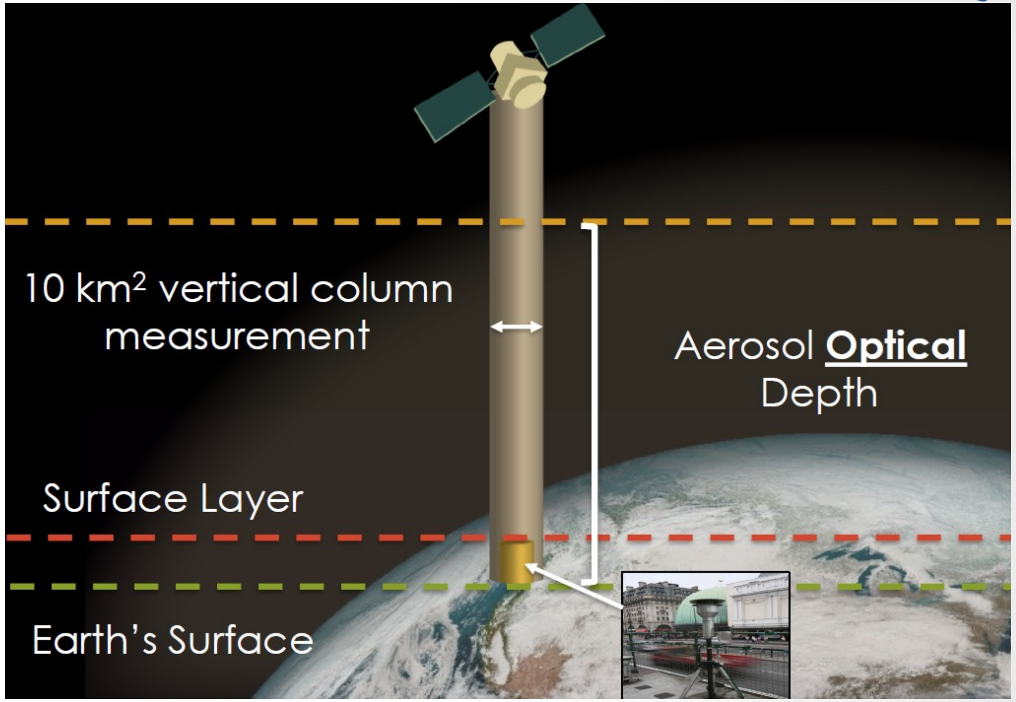


- **Examine a large area**: where are the hotspots? how is long-range transport happening?
- **Track changes over time:** how much has the average concentration over an area changed over time?
- **A picture is worth a million datapoints:** Anyone can understand a satellite photo of a smoke plume.

Sources: George Washington University "TROPOMI NO2 USA" website https://tropomino2.us/
NASA GSFC Nitrogen Dioxide Trends for World Cities https://airquality.gsfc.nasa.gov/no2/world

What satellite data CANNOT do for air quality

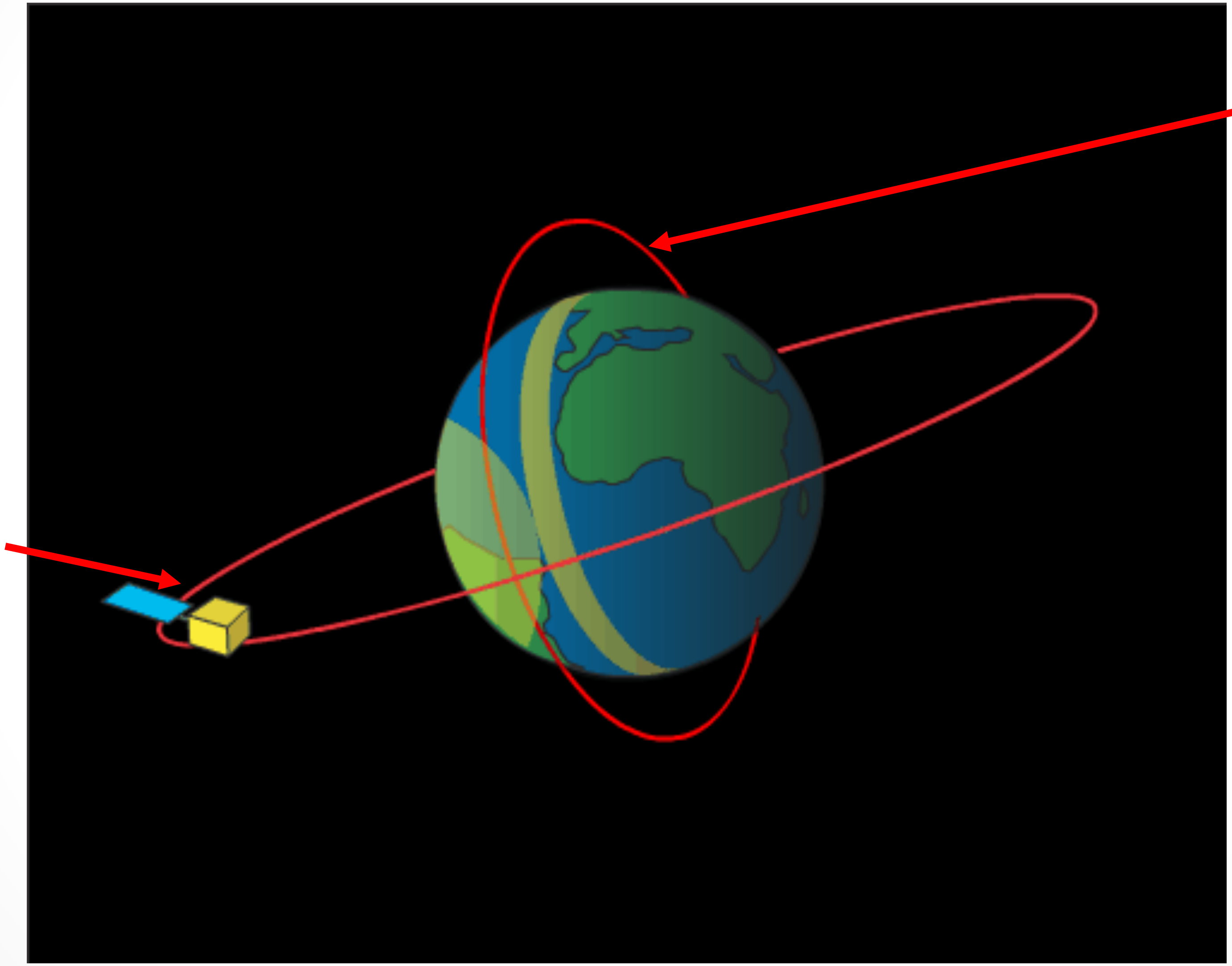




- **See at night:** satellites measure the properties of reflected sunlight passing through the atmosphere.
- **See through clouds:** most satellite measurements are blocked by cloud cover.
- **See what is happening at "nose level":** satellites measure quantities in the whole atmosphere.
- **See at 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

Common types of orbits for air quality satellites



Polar Orbit

Observes a location about once a day (weather permitting)

Observes at about the same time of day (sun-synchronous)

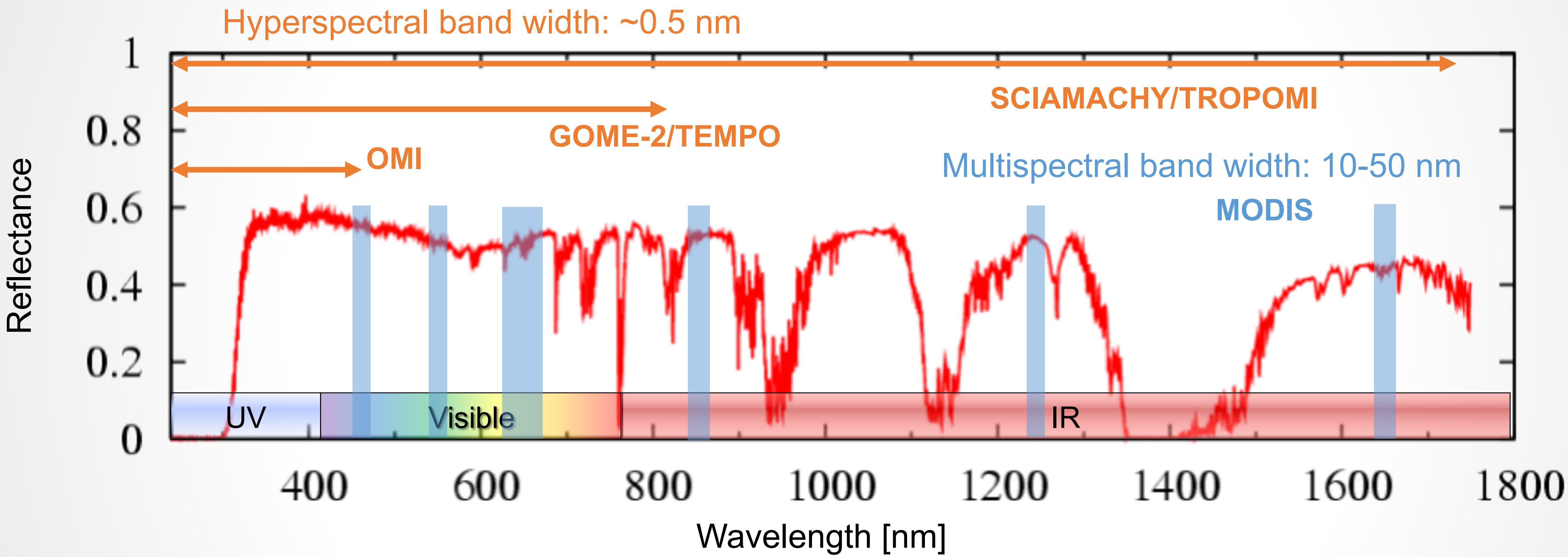
Geostationary Orbit

Observes the same area all the time

Observes throughout the day (weather and light permitting)

source: NOAA
https://scijinks.gov/orbit/

Spectral resolution & what satellites can remotely measure



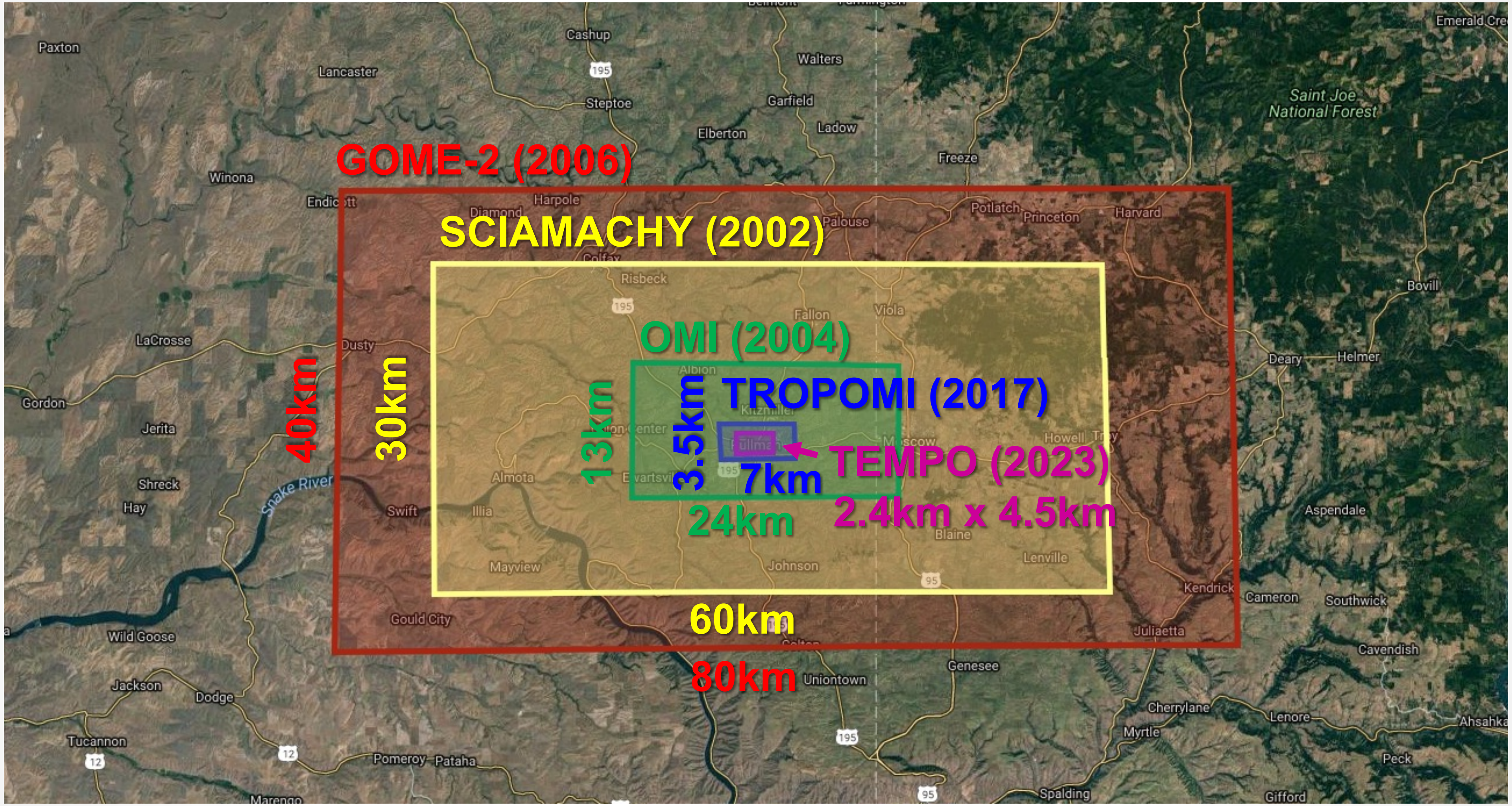
UV & vis. multispectral data → aerosol information
Aerosol Optical Depth (AOD) @ 550nm

UV & vis. hyperspectral data → NO_2, SO_2, O_3*, HCHO
IR hyperspectral data → CO, CO_2, CH_4

*high O_3 concentrations in the stratosphere make near-surface measurements difficult

Source: Gupta, Follette-Cook, Strode, Malings (2023). [ARSET - NASA Air Quality-Focused Remote Sensing for EPA Applications](#) *NASA ARSET*.

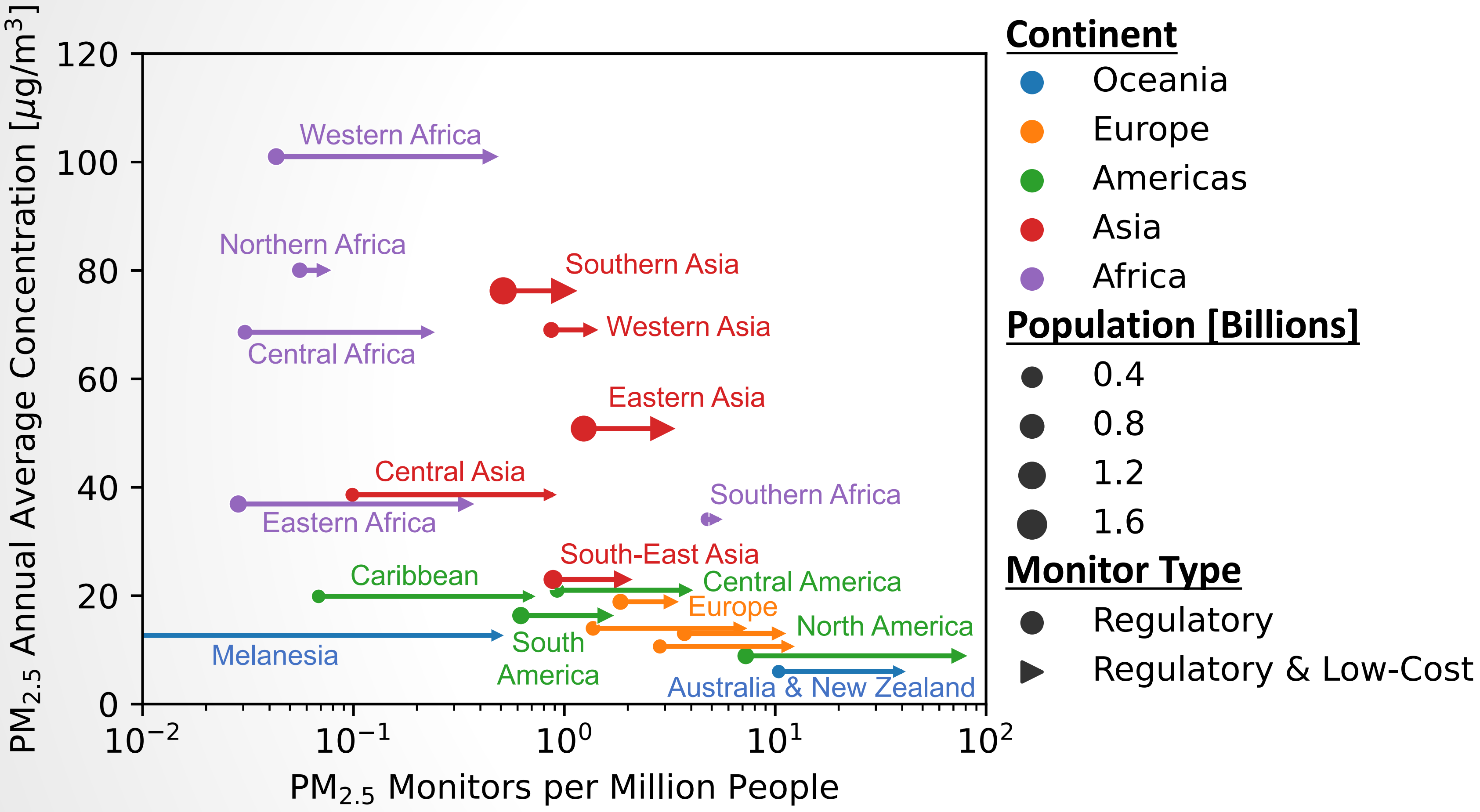
Spatial resolution has been improving over time



Source: Gupta, Follette-Cook, Strode, Malings (2023). [ARSET - NASA Air Quality-Focused Remote Sensing for EPA Applications](). *NASA ARSET*.

Filling Air Quality Data Gaps with Satellites

Surface air quality data gaps in the US and globally



Most regions have fewer than 10 regulatory air quality monitors per million people for $PM_{2.5}$ (and generally fewer for other pollutants).

Only about a third of US counties have regulatory air quality monitors.

Only 60% of census urban areas have regulatory air quality monitors.

Low-cost sensors increase monitor density by up to ten times in some regions.

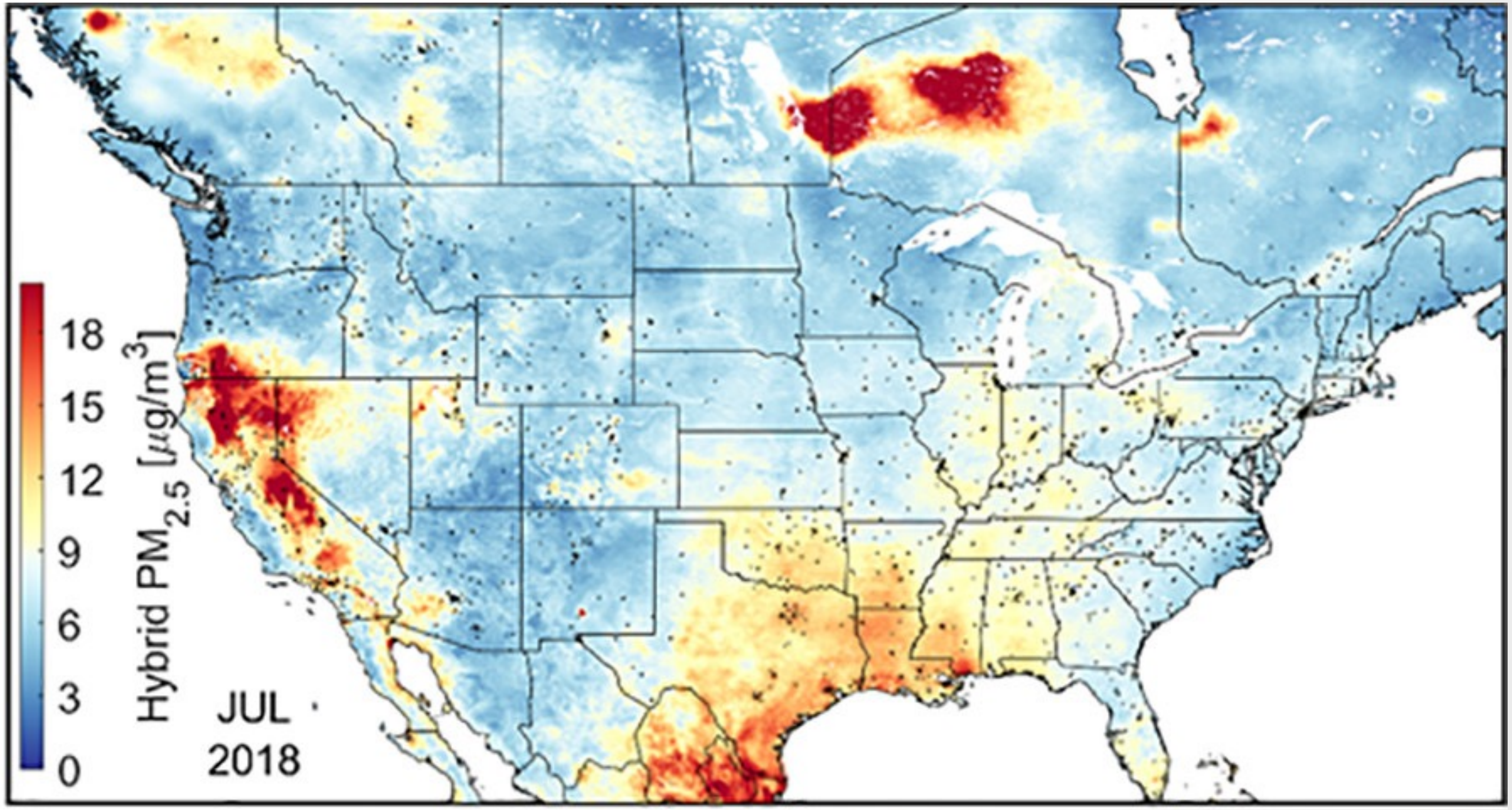
Sources: Do you have outdoor air monitoring data for all counties in the U.S.? *US Environmental Protection Agency*.
Malings et al. (2022) Forecasting with the GEOS-CF System and Other NASA Resources to Support Air Quality Management. Proceedings of the International Conference on Air Quality in Africa.

Surface concentrations from satellite data

Combine satellite data with other information (models, surface monitors) to derive high spatial resolution maps of surface concentrations (especially $PM_{2.5}$) globally and regionally.

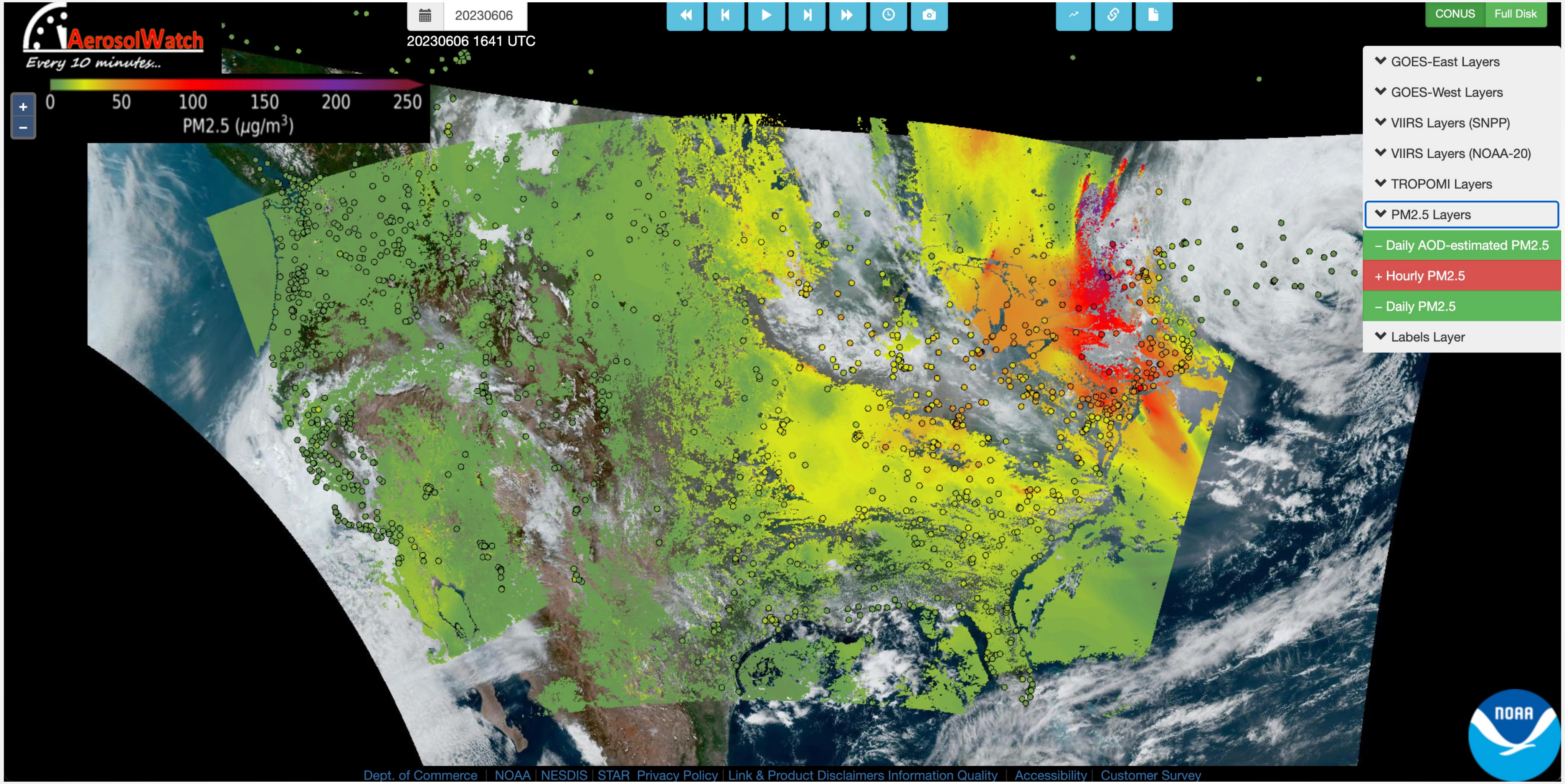
Many datasets available through [NASA Socioeconomic Data and Applications Center (SEDAC)]().

Datasets may lag significantly behind real-time.



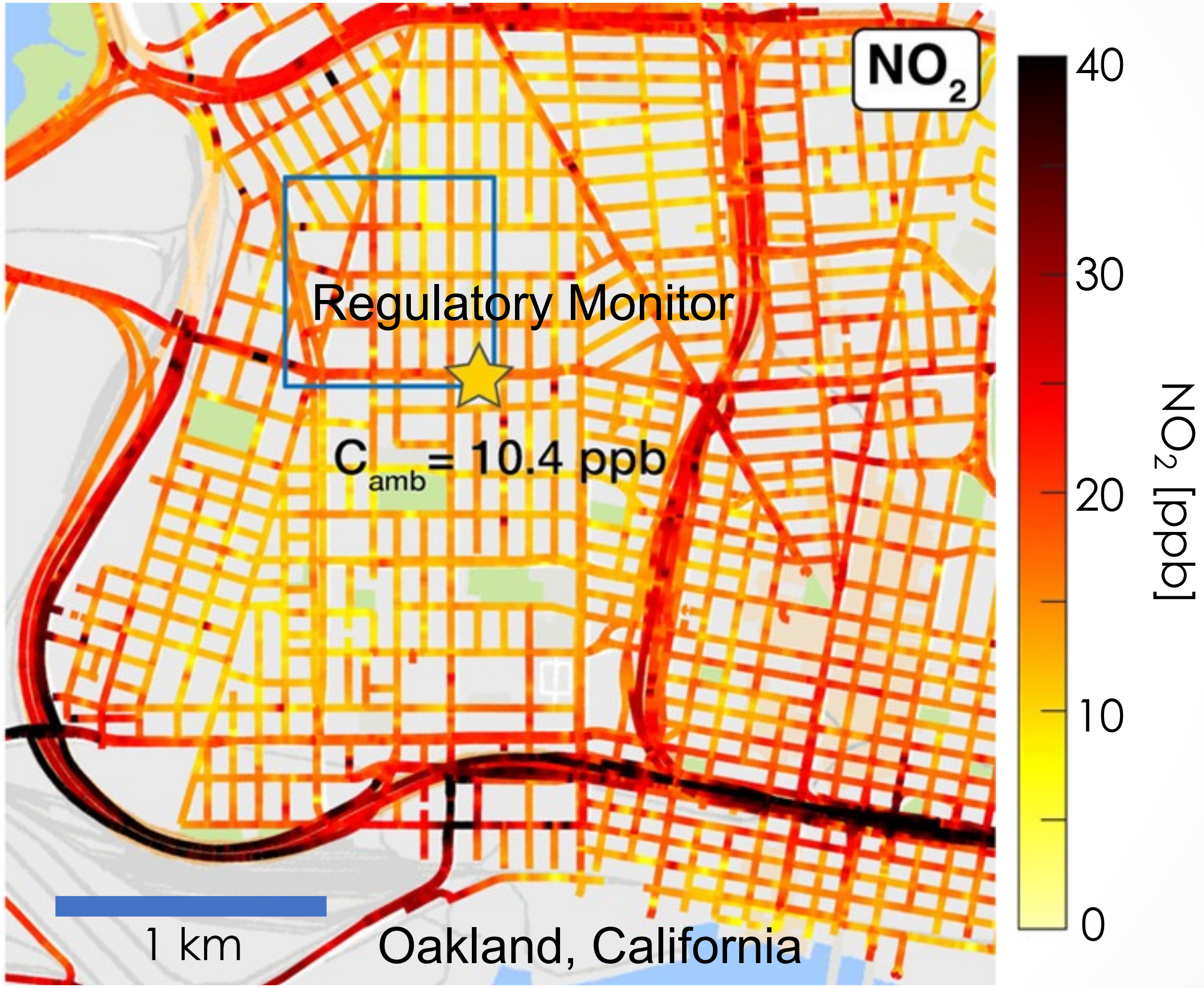
Sources: Di et al. (2019) An ensemble-based model of $PM_{2.5}$ concentration across the contiguous US … . *Environmental International*.
van Donkelaar et al. (2021) Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. *Env. Sci. & Tech*.

Surface $PM_{2.5}$ estimation with geostationary AOD



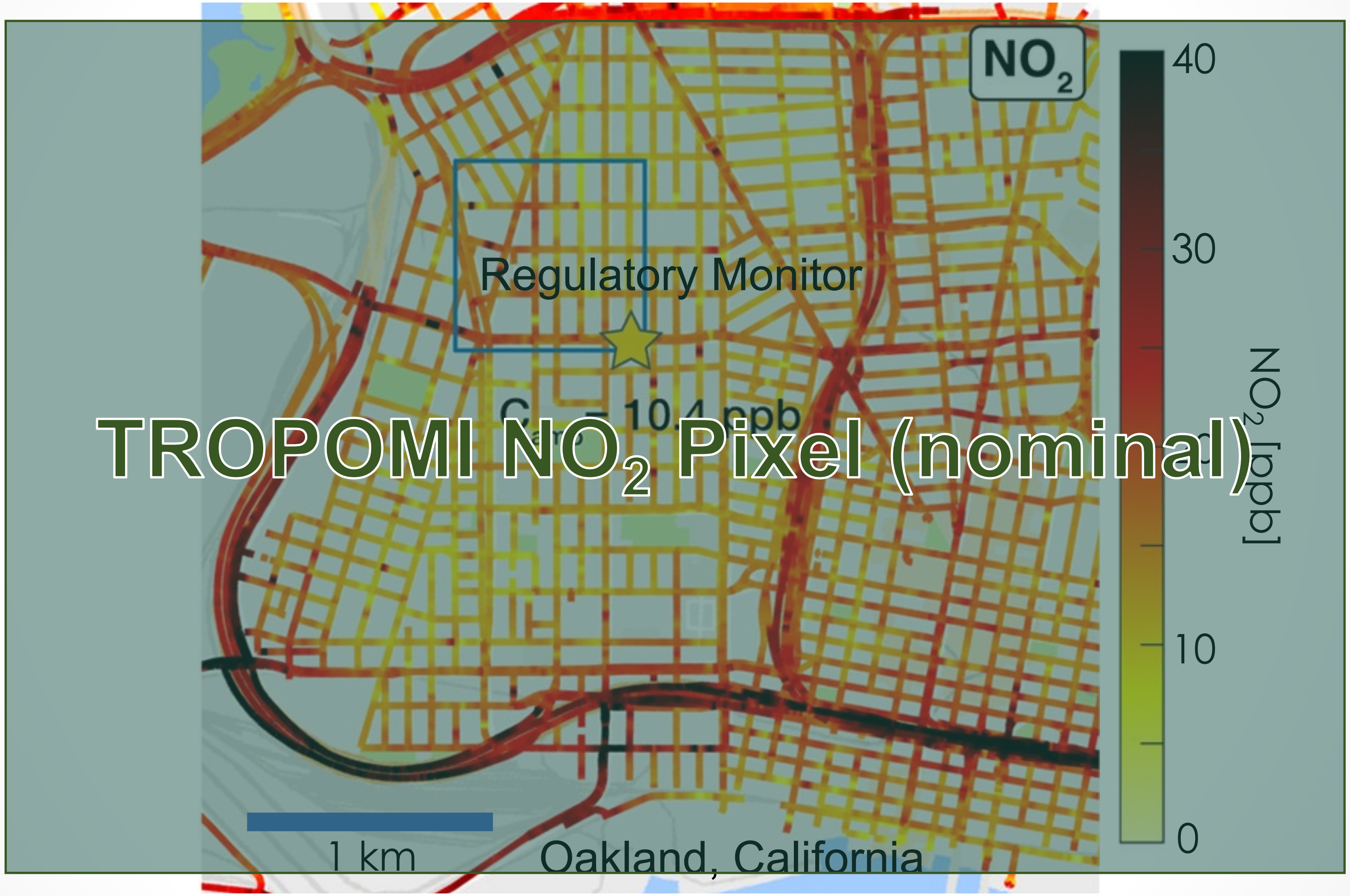
Sources: NOAA Aerosol Watch Website https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/
Zhang & Kondragunta (2021) Daily and Hourly Surface $PM_{2.5}$ Estimation from Satellite AOD. Earth and Space Science.

Hyper-local variability is still beyond current capabilities



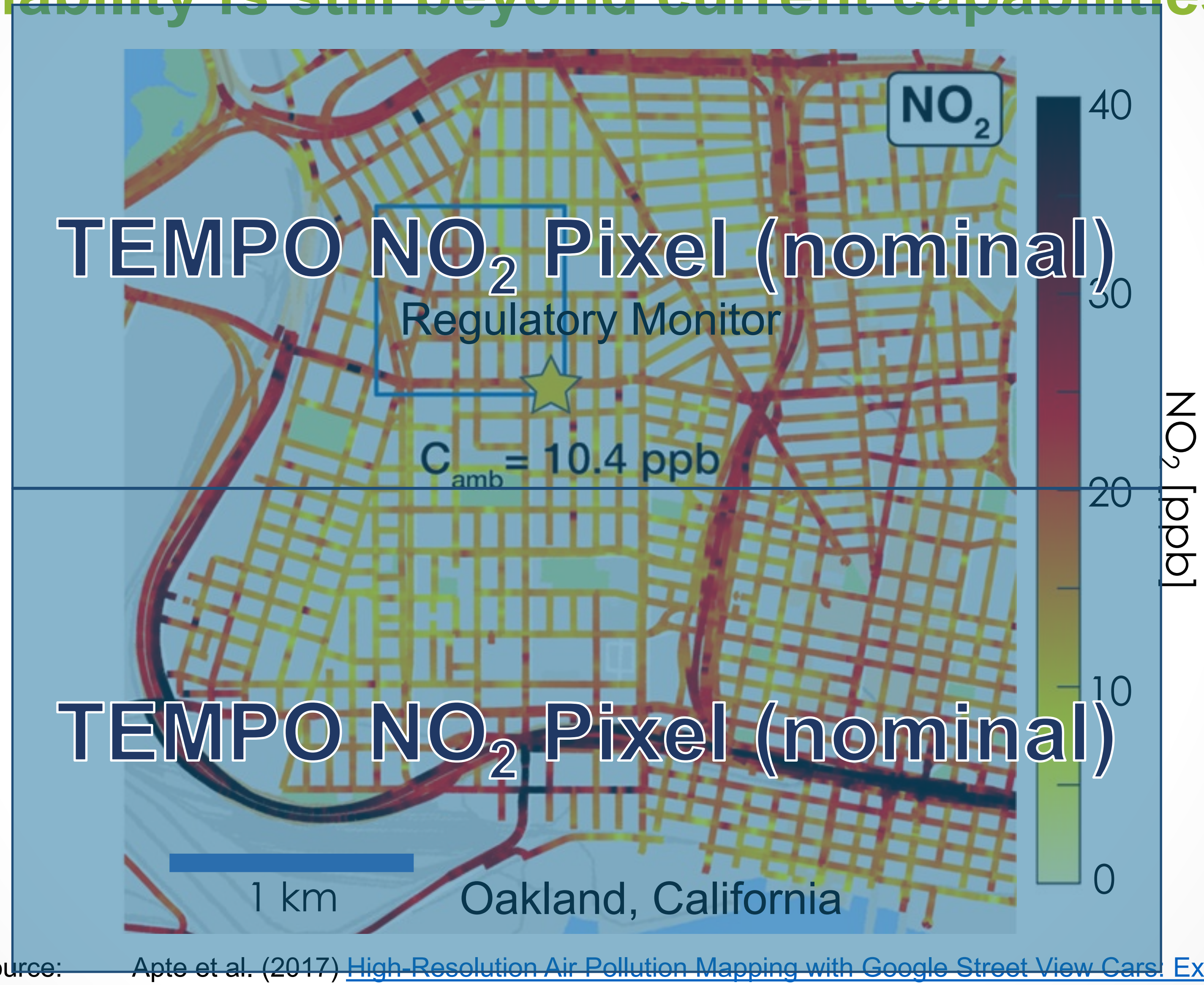
Source: Apte et al. (2017) [High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data](). *Env. Sci. & Tech.*

Hyper-local variability is still beyond current capabilities



Source: Apte et al. (2017) High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data. *Env. Sci. & Tech.*

Hyper-local variability is still beyond current capabilities

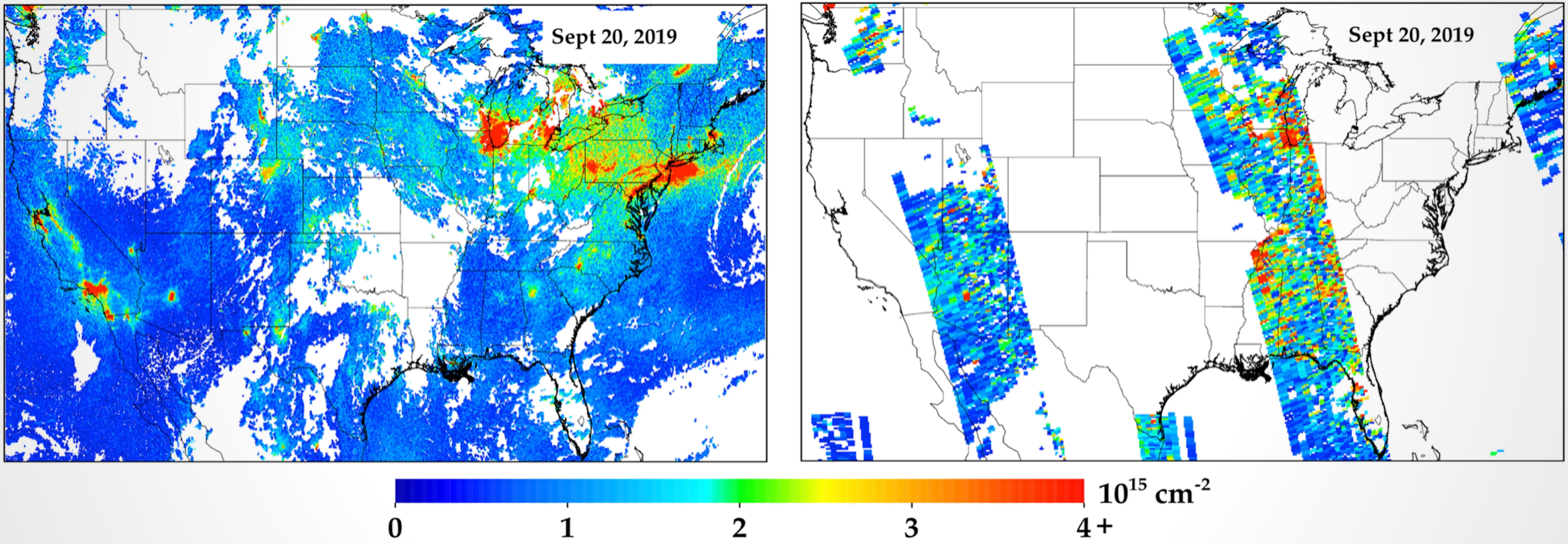


Source: Apte et al. (2017) High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data. *Env. Sci. & Tech.*

New & Upcoming Missions

TROPOspheric Monitoring Instrument (TROPOMI)

TROPOMI Tropospheric NO_2 (Launched 2017) OMI Tropospheric NO_2 (Launched 2004)



Source: Goldberg, Anenberg, Kerr, Mohegh, Lu, Streets (2021) TROPOMI NO_2 in the United States…. *Earth's Future*.

Tropospheric Emissions: Monitoring of POllution (TEMPO)

Launched April 2023, first light images August 2023.

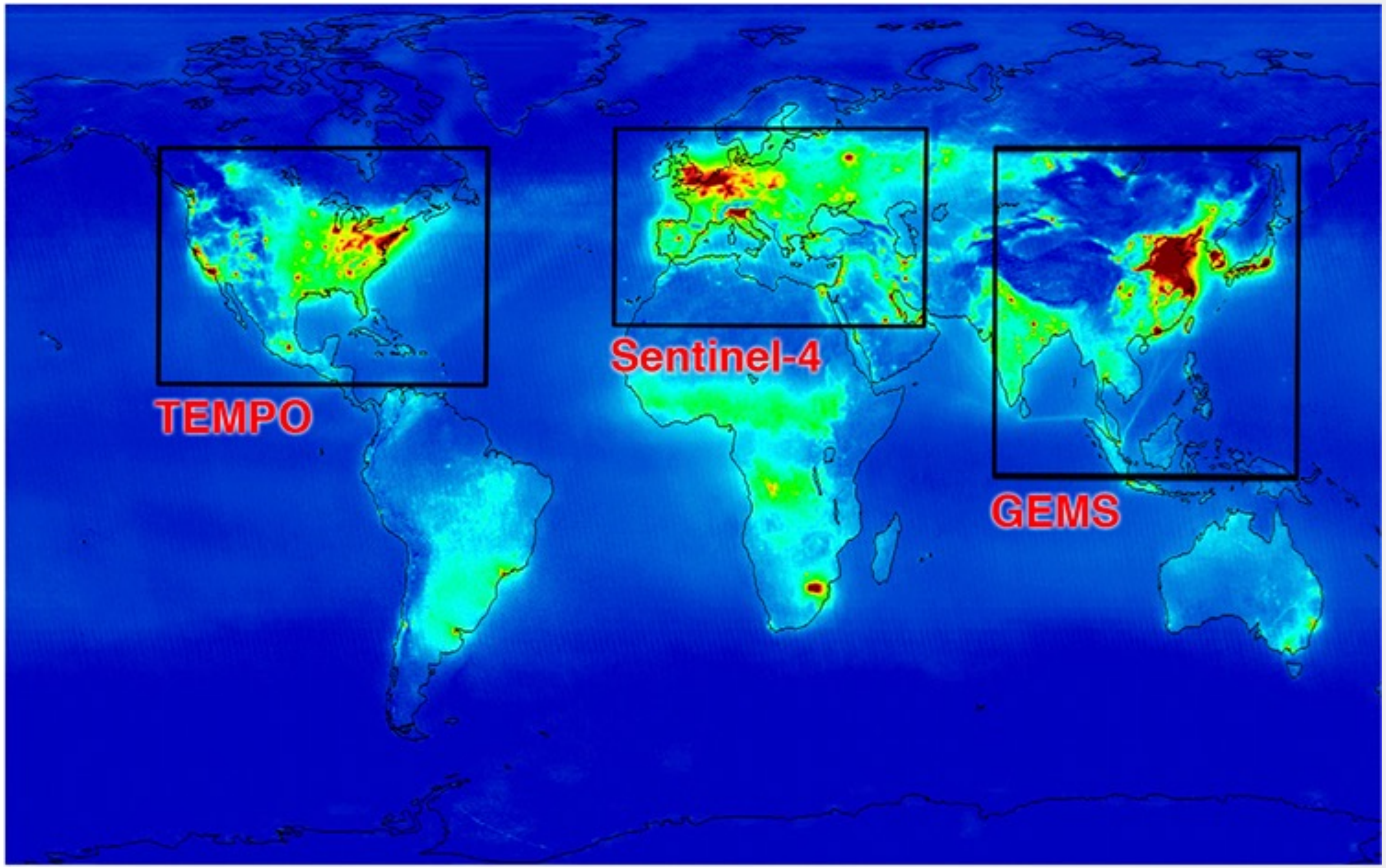
First geostationary hyperspectral instrument for North America.

Part of a constellation of similar instruments with GEMS (launched 2020) and Sentinel-4 (anticipated 2024).

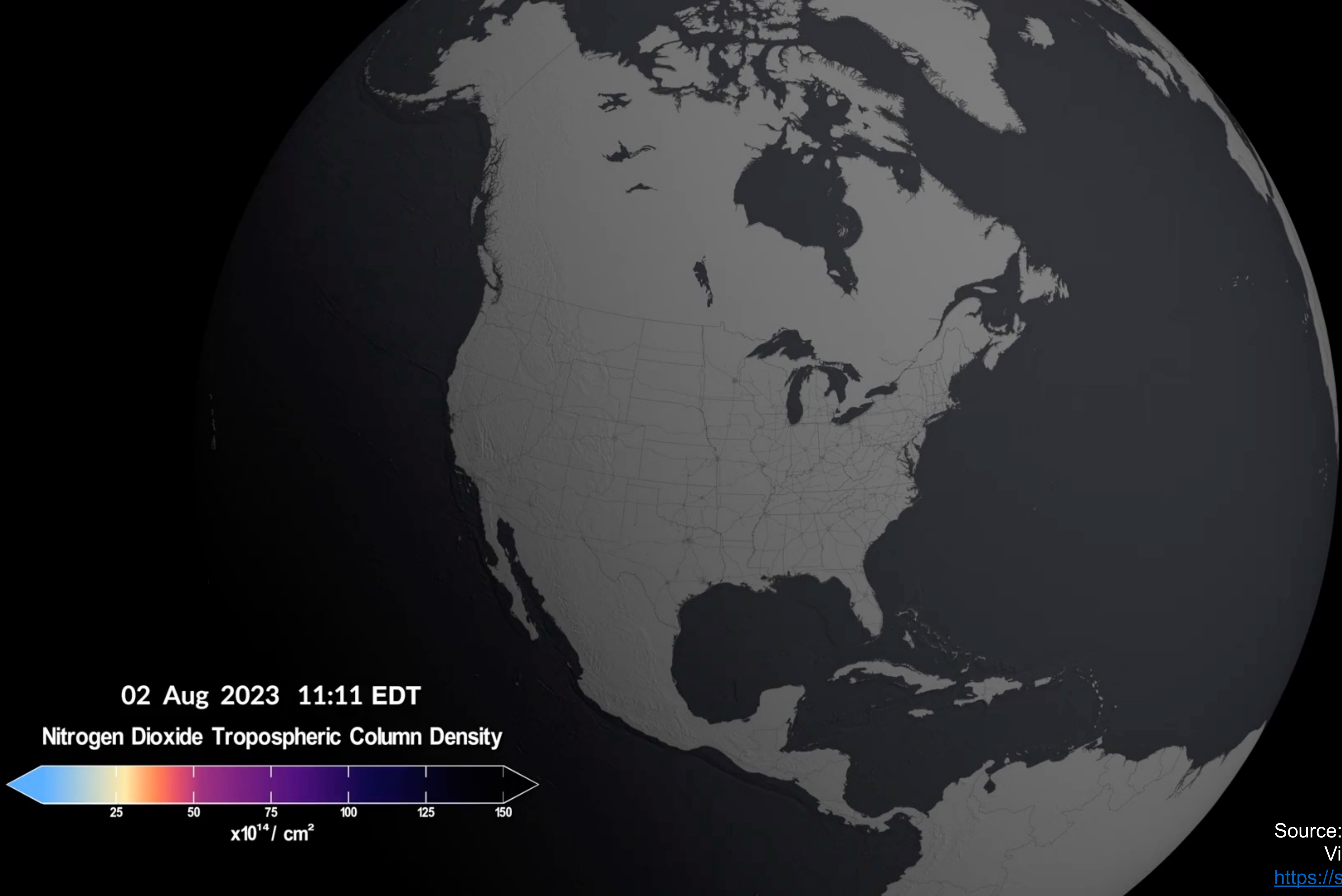
Hourly temporal resolution.
2 x 4.75 km spatial resolution.

Anticipated primary data products:

- NO_2
- HCHO
- NEW 0-2 km O_3 product!



Sources: NASA & Smithsonian TEMPO Website https://tempo.si.edu/index.html
TEMPO Early Adopters Program https://weather.msfc.nasa.gov/tempo/



Source: NASA GSFC Scientific Visualization Studio
https://svs.gsfc.nasa.gov/5142/

Multi-Angle Imager for Aerosols (MAIA)

Sources: NASA JPL MAIA Website https://maia.jpl.nasa.gov/
MAIA Early Adopters Program https://maia.jpl.nasa.gov/resources/data-and-applications/

Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE)

Anticipated launch January 2024.

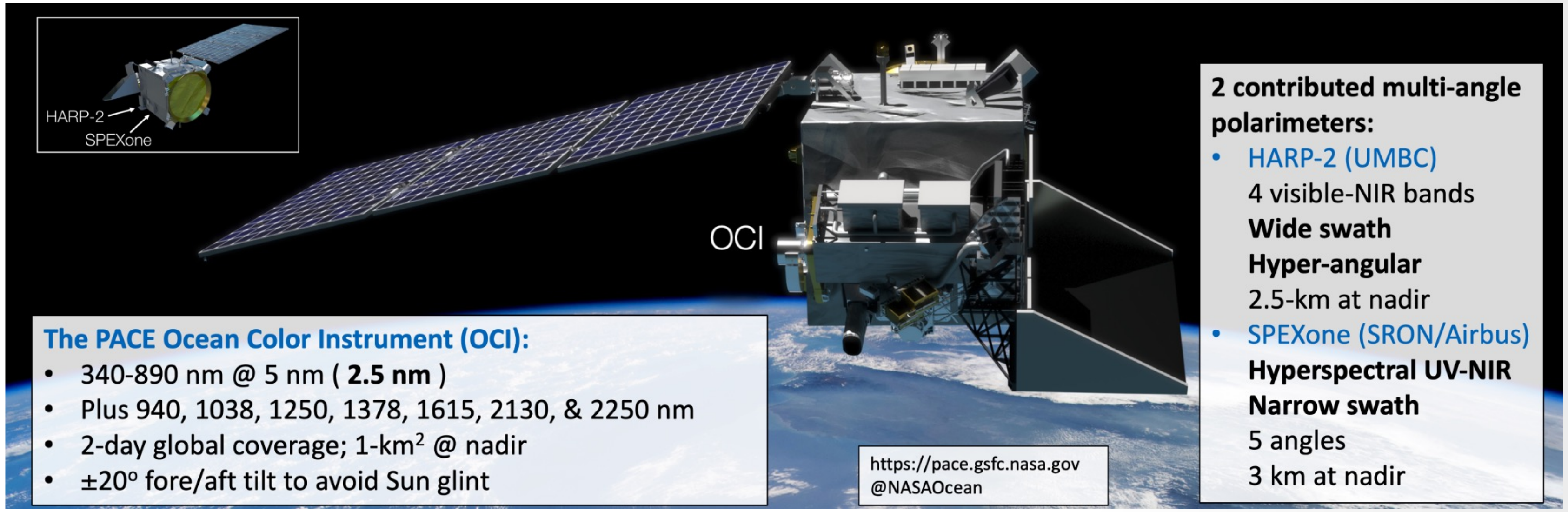
Polar-orbiting hyperspectral imager and 2 multi-angle polarimeters.

Supports applications in ocean biogeochemistry, aerosols and air quality, and clouds.

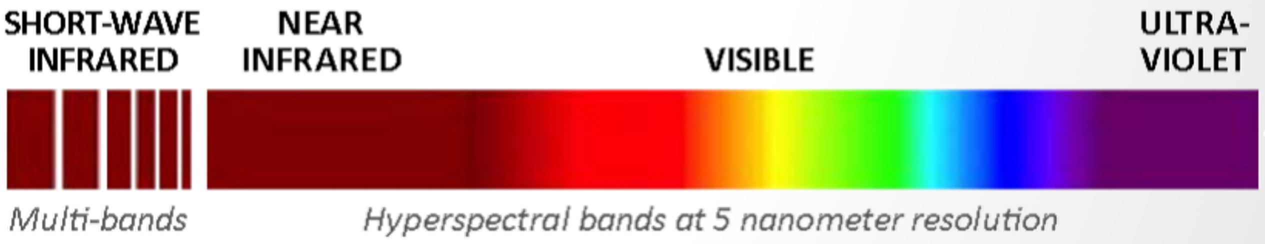
2 day global coverage.
1 km^2 spatial resolution for most data.

Anticipated air quality data products:

- Many Aerosol parameters, i.e., optical depth, size distribution, layer height, type, absorption
- NO_2
- O_3 (column)



PACE

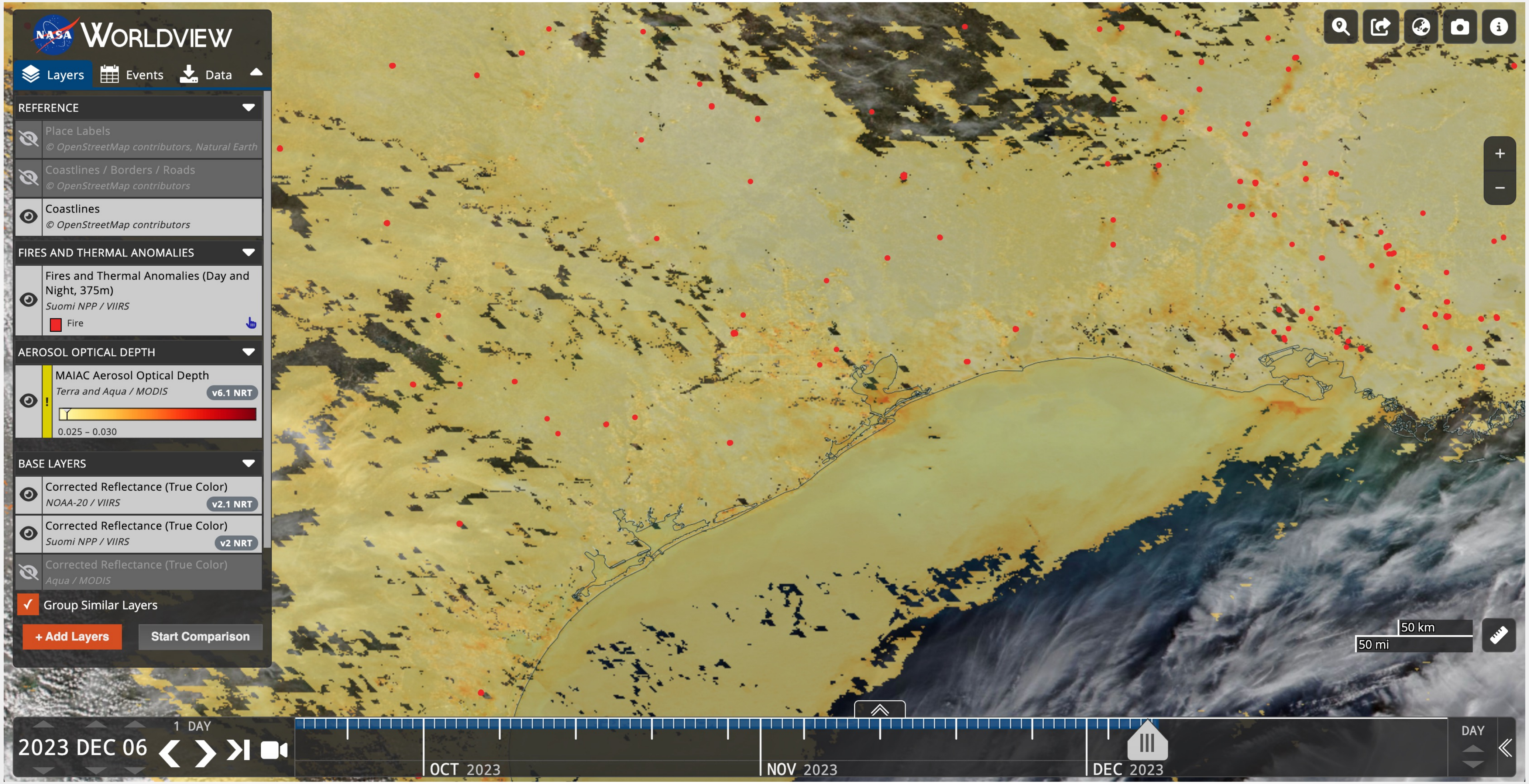


Sources: NASA GSFC PACE Website https://pace.gsfc.nasa.gov/
PACE Early Adopters Program https://pace.oceansciences.org/app_adopters.htm

Satellite Data Resources

NASA Worldview

https://worldview.earthdata.nasa.gov

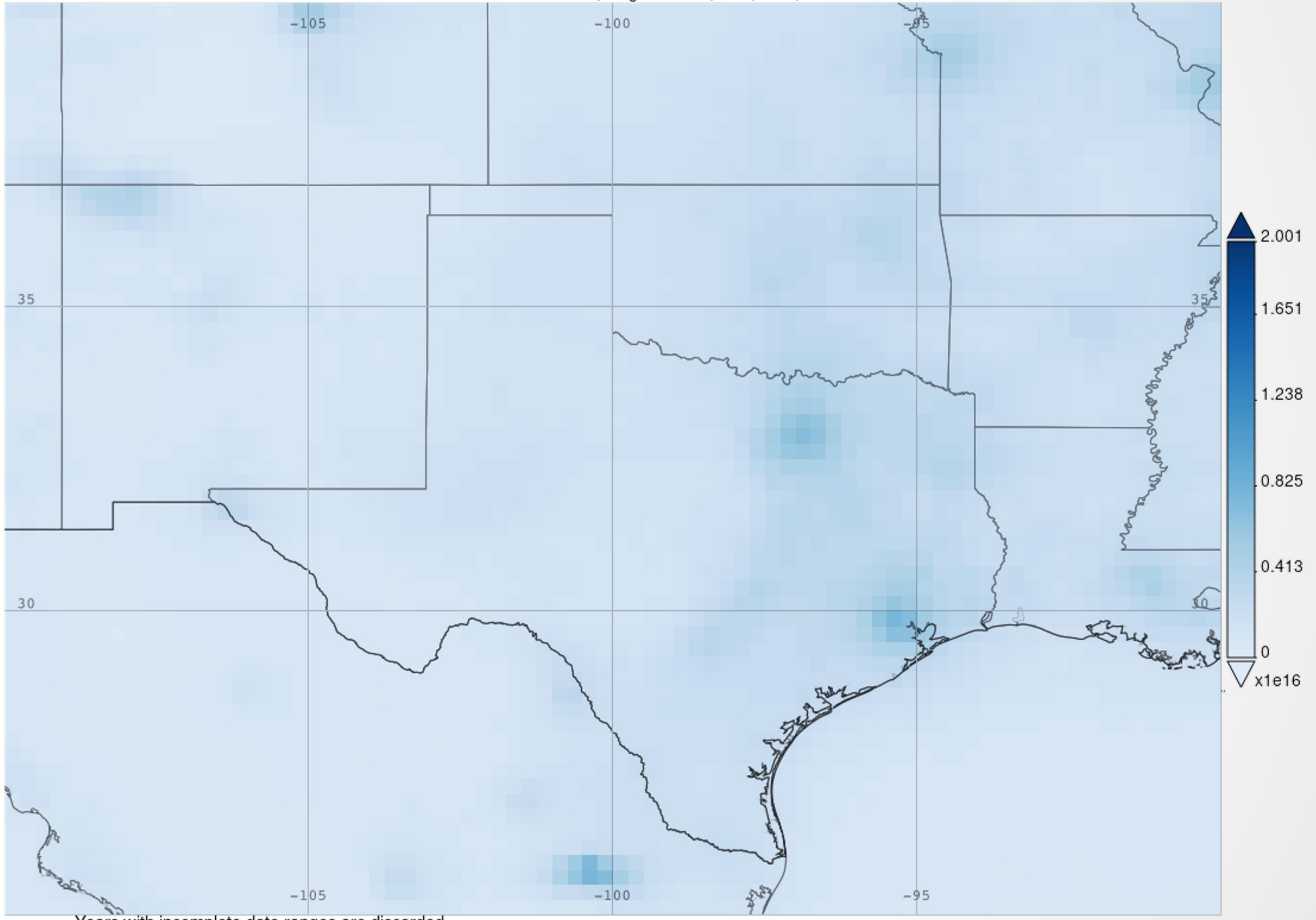


NASA Giovanni

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

- Work online with many gridded NASA data products (satellite & model)
- Perform simple analysis
  - spatial & temporal averaging
  - recurring/periodic averages
  - differences
- Plot results
  - area colormaps
  - time series
  - scatterplots
  - correlation plots
  - histograms
- Download data subsets
  - NetCDF
  - GeoTIFF
  - KMZ

Days from Dec 1 - Dec 31 (2005-12-01 - 2020-12-31)
Average NO2 Tropospheric Column (30% Cloud Screened) daily 0.25 deg. [OMI OMNO2d v003] molecules/cm^2 for days from Dec 1 - Dec 31 2005-12-01 - 2020-12-31, Region 110W, 25N, 90W, 40N



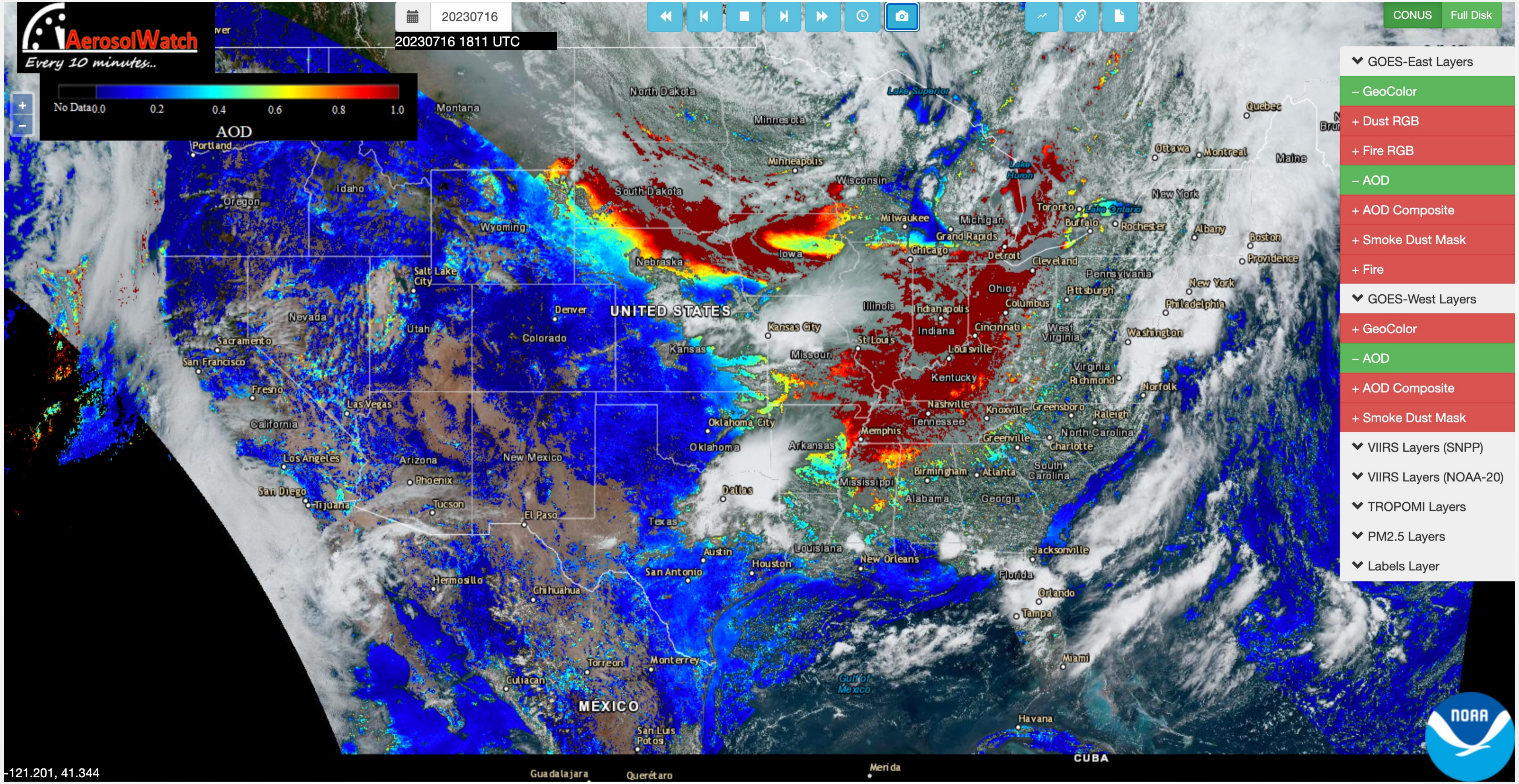
- Years with incomplete date ranges are discarded.

National Aeronautics and
Space Administration

Partner

NOAA AerosolWatch

https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch



NASA Applied Remote Sensing Training (ARSET)

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 offers trainings for:

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

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 (HAQAST)

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."

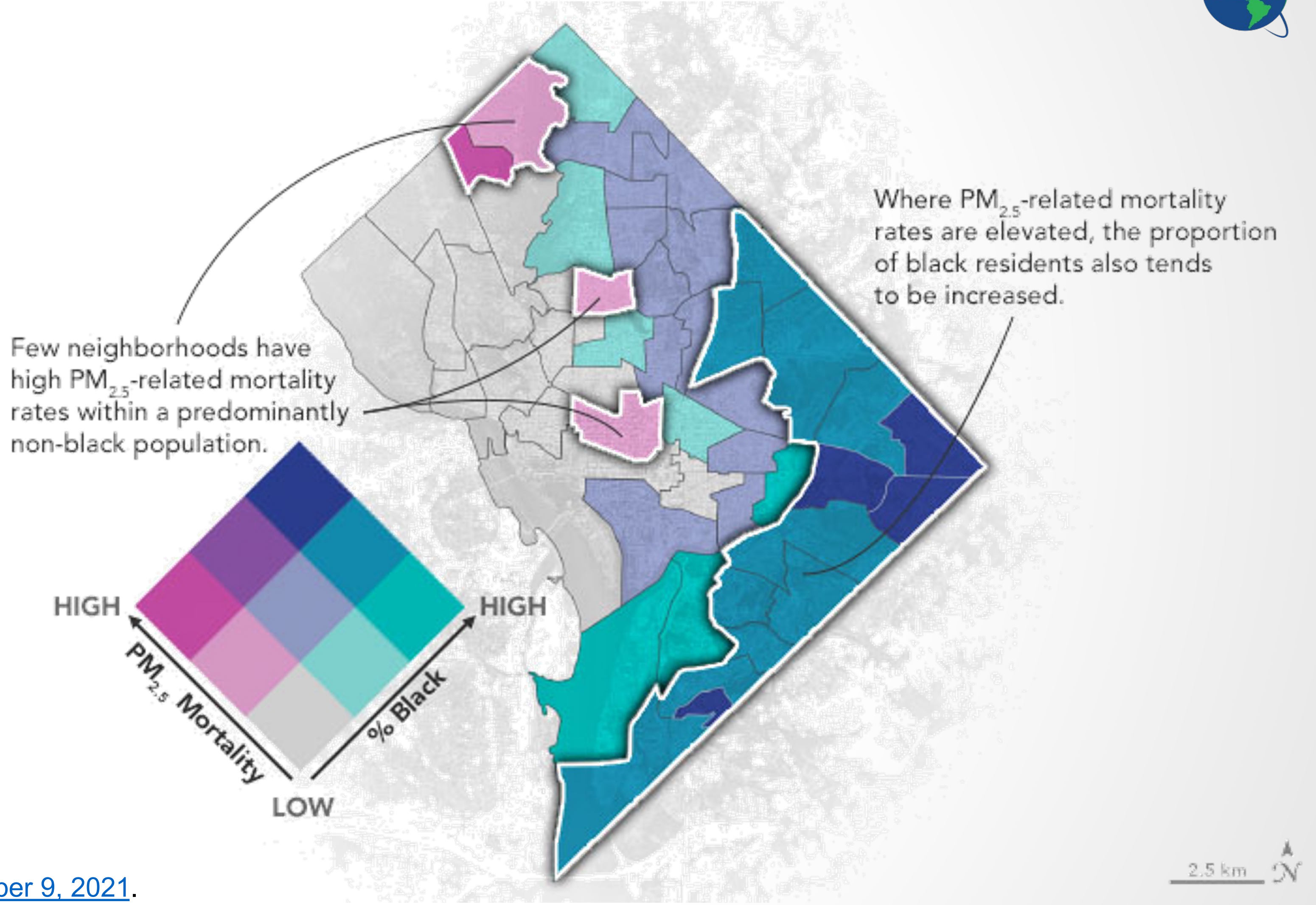
- Use NASA satellite & other data to help solve real-world public health and air quality problems.
- Work around the world on diverse issues related to health and air quality.
- Collaborate with public stakeholders to help guide long-term research.
- "Tiger Teams" pursue short-term, high-impact projects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

HAQAST

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

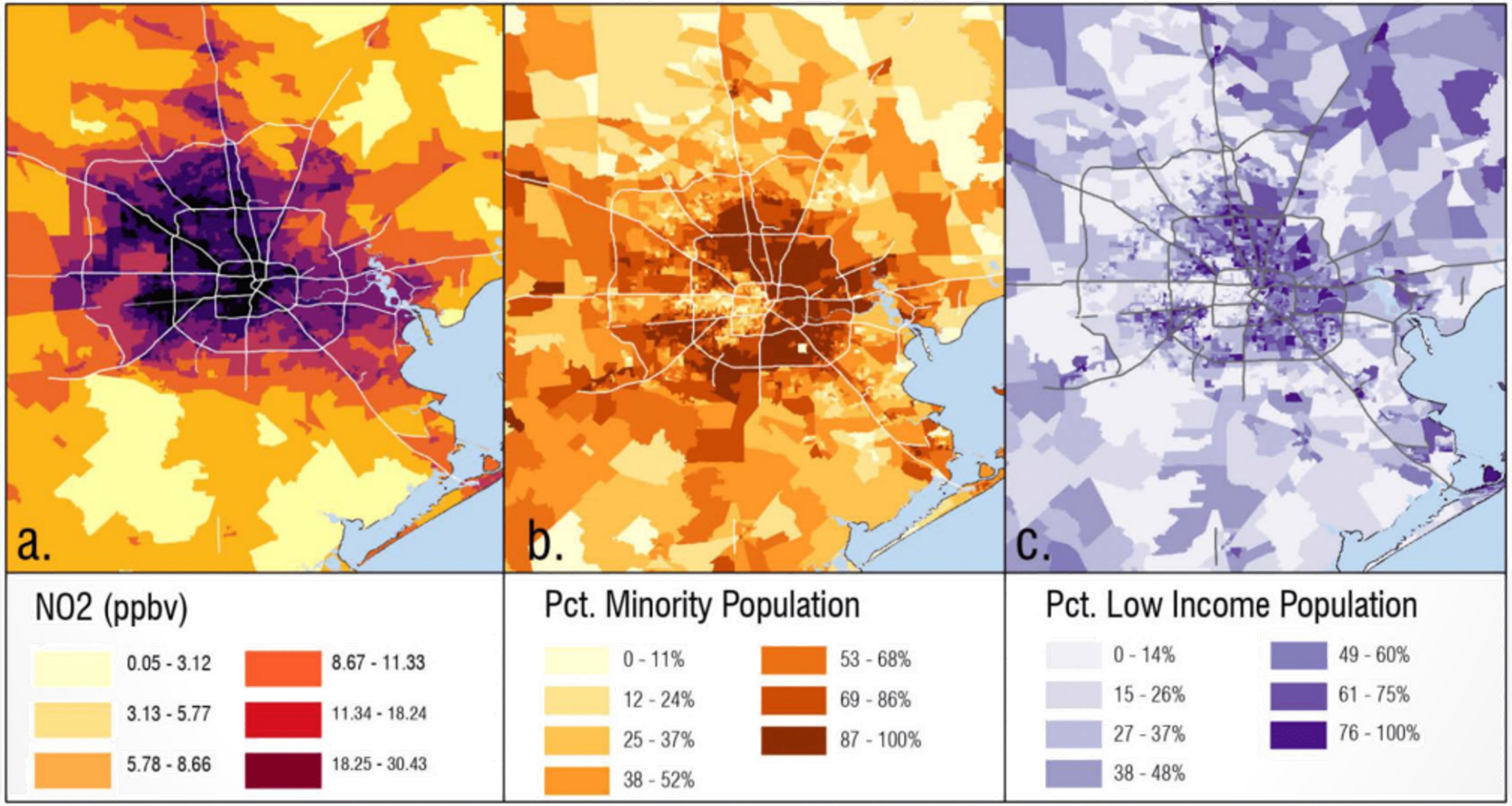
Satellite Data for Environmental Justice & Equity

- Minoritized and marginalized populations often experience disproportionate exposure to a range of environmental hazards
- Satellite remote sensing data can supplement on-the-ground efforts to investigate such disparities in risk exposure from global to local scales
- Satellite Data for Environmental Justice (SD4EJ) is a NASA HAQAST Tiger Team whose goal is to integrate satellite data EJ screening and mapping tools.
- NASA ARSET recently delivered a training focusing on this topic with support from the SD4EJ team



Sources: [NASA Earth Observatory Image of the Day, November 9, 2021]. [NASA ARSET - Satellite Data for Air Quality Environmental Justice and Equity Applications] (2023).

Viewing satellite-derived surface NO_2 in EPA EJScreen



Source: NASA HAQAST Satellite Data for Environmental Justice Tiger Team website, https://haqast.org/ej/.

Thank You!