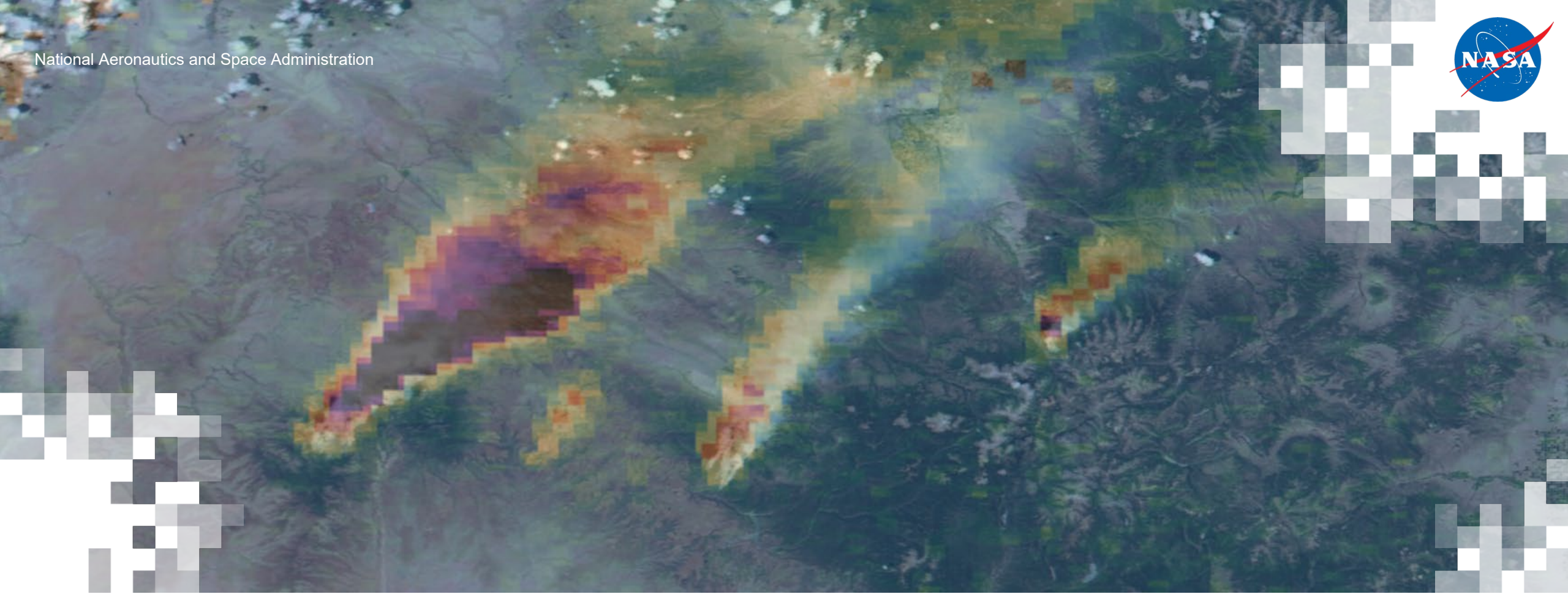




Key Remotely Sensed Parameters for Aerosol and Trace Gas Monitoring

Carl Malings (Morgan State University & NASA GSFC)

August 10, 2026

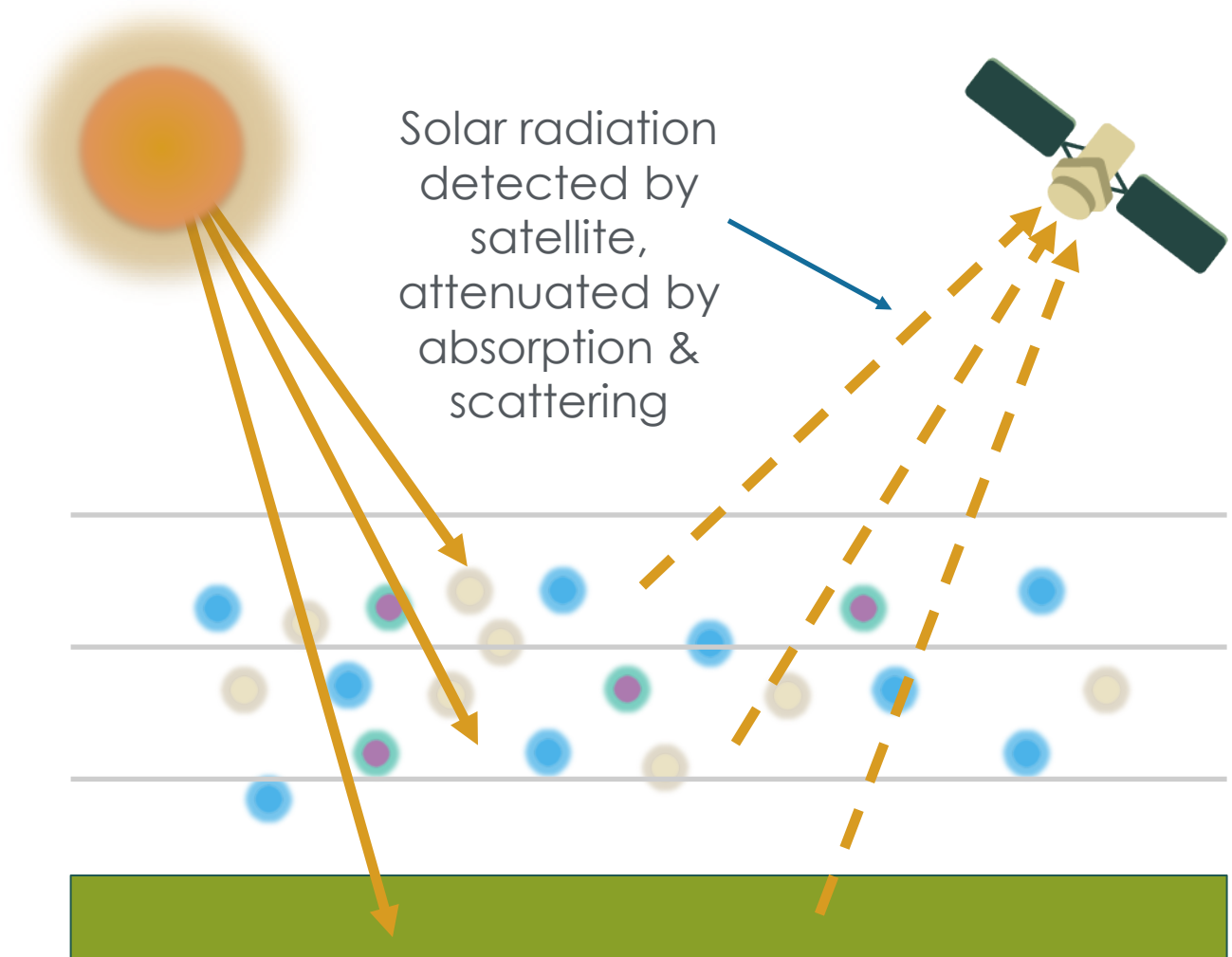
Objectives

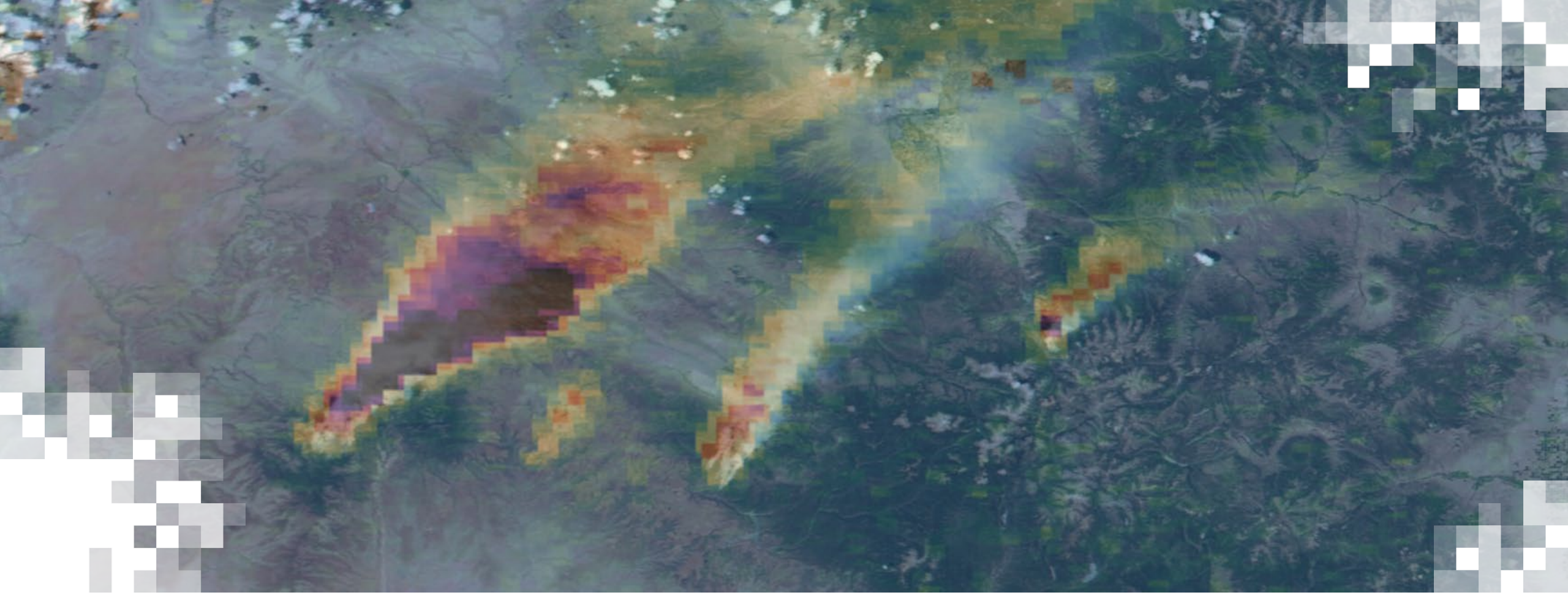
- Describe the basic capabilities and limitations of satellite data for assessing aerosol and trace gas air pollutants.
- Identify satellite sensors and data products most applicable for detecting the presence and amount of key aerosol and trace gas pollutants over the US.



Remote Sensing of the Atmosphere

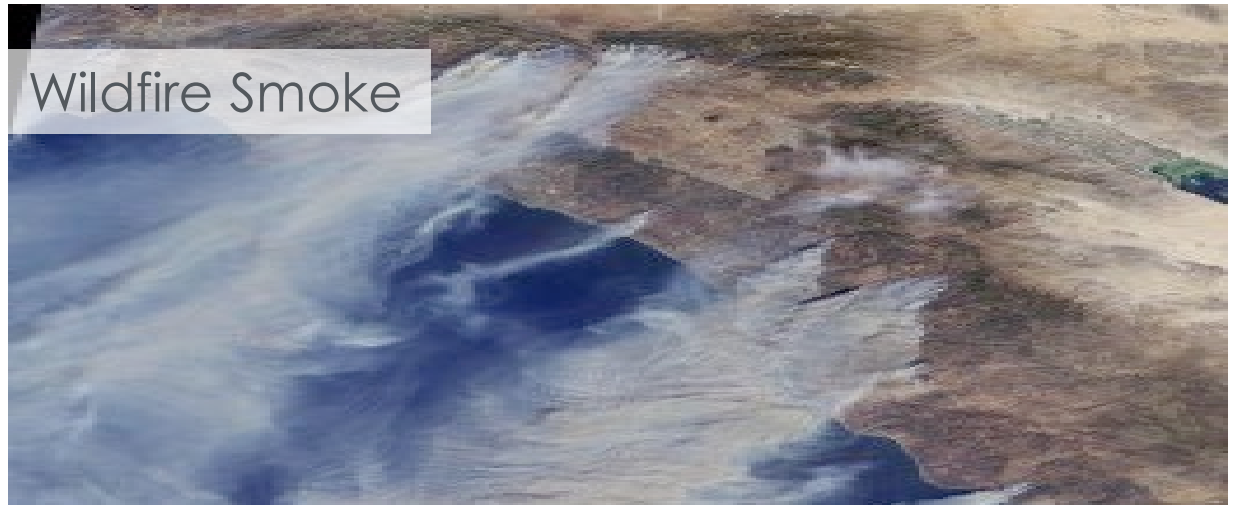
- Satellites measure backscattered **UV**, **visible**, and **IR** radiation from the Earth's surface and atmosphere.
- Trace gases and particles in the atmosphere have **spectral signatures** relating to how they reflect, scatter, absorb, and re-emit radiation.
- **Retrieval algorithms** use radiation measurements and physics-informed models to infer **geophysical quantities** such as optical depth, particle number density, or partial pressure.





Remote Sensing of Aerosols

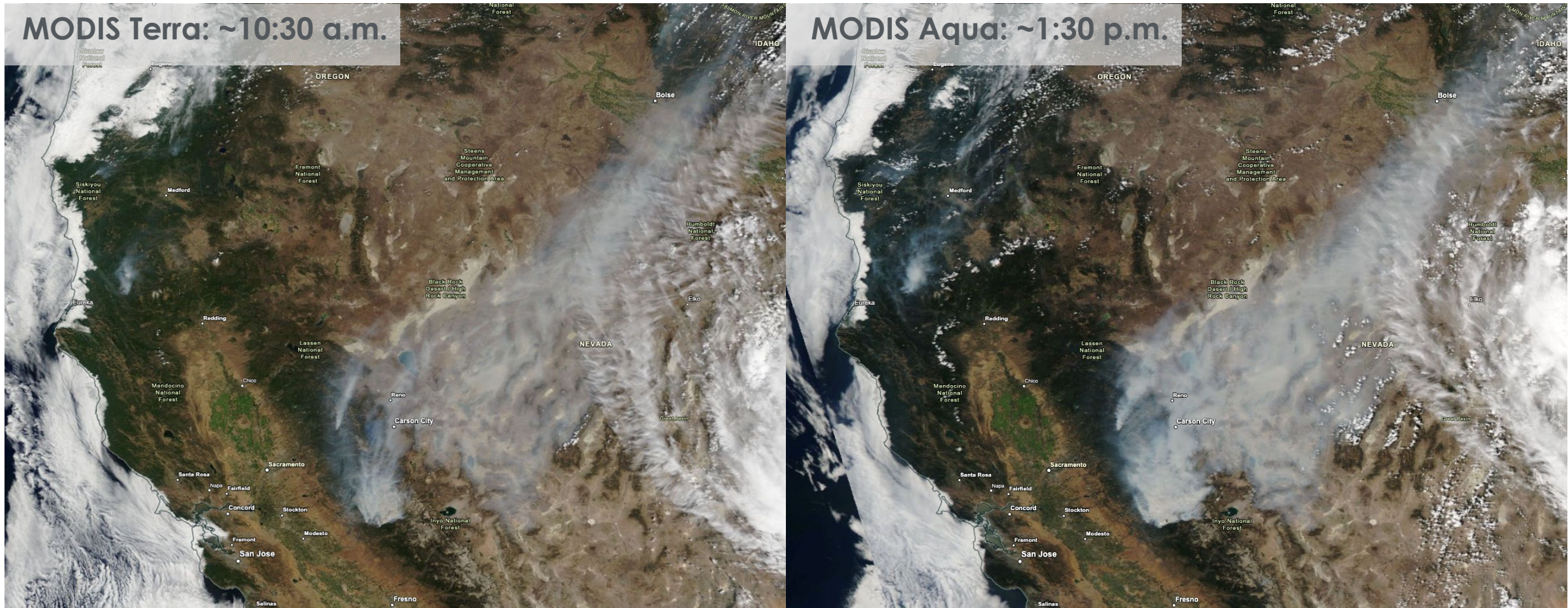
Visible Imagery of Aerosols



Source: [NASA Earth Observatory](https://earthobservatory.nasa.gov/)



Visible Imagery of Aerosols



August 23, 2013

Source: [NASA Worldview](https://worldview.nasa.gov/)

NASA ARSET – NASA Satellite Observations and Tools for Air Quality Management

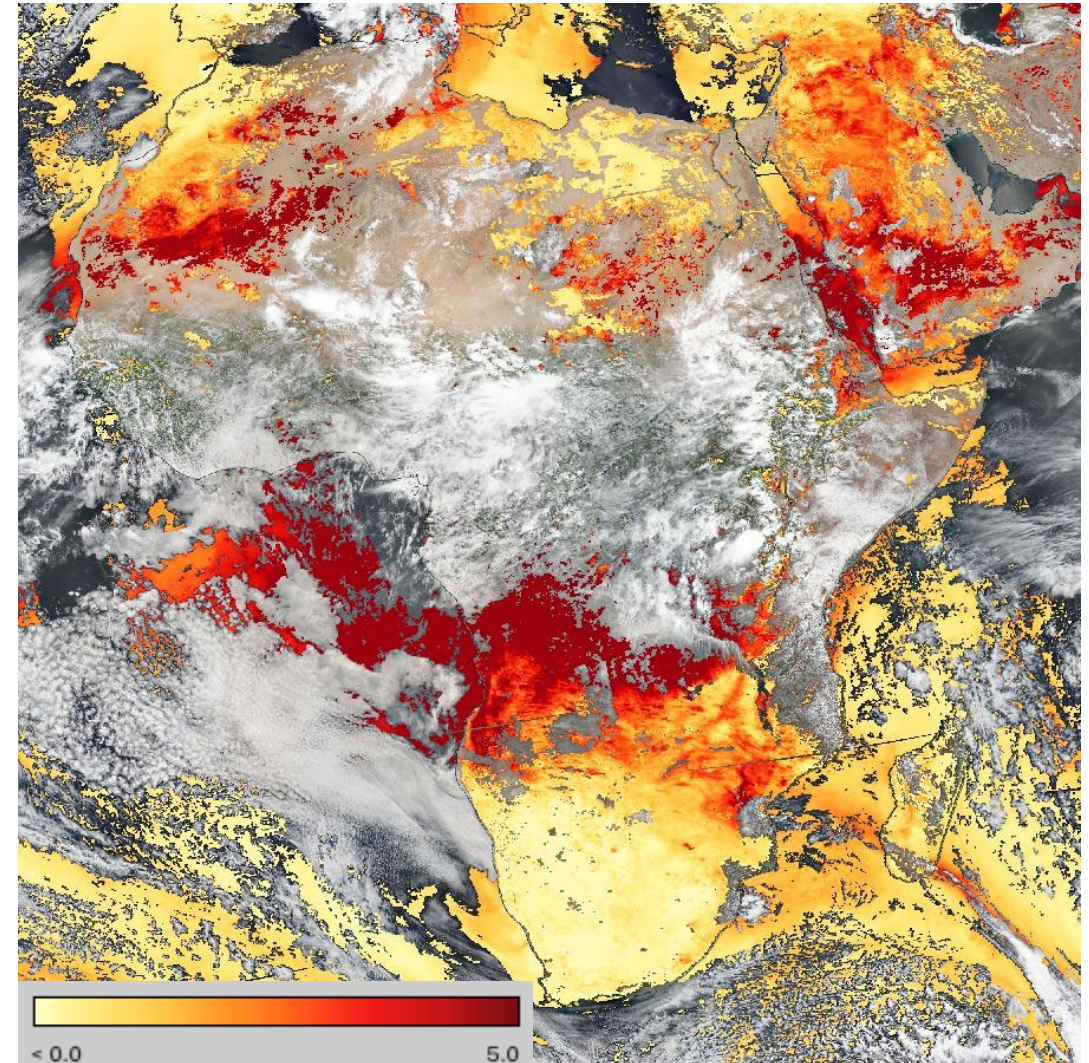
Visible Imagery of Aerosols



Source: [NASA Scientific Visualization Studio, "Godzilla Dust Storm"](#)

Aerosol Optical Depth

- AOD, or Aerosol Optical Thickness (AOT)
- Measures the quantity of light removed by scattering and absorption by aerosols along an atmospheric path.
- Unitless
- AOD is wavelength-dependent.
- AOD measured at mid-visible wavelengths (500-550nm) is reasonably representative of total aerosol concentration.
- Dense clouds, smoke, and dust interfere with AOD retrieval.

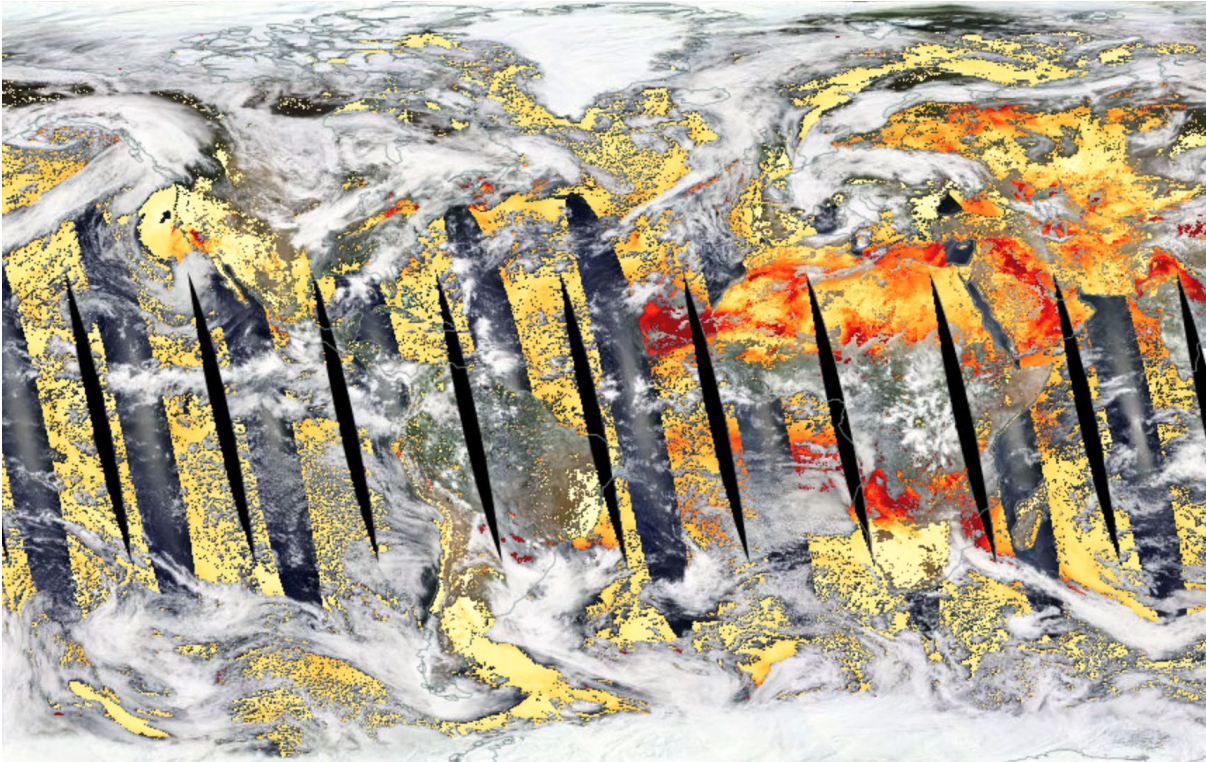


Source: [NASA Worldview](#)



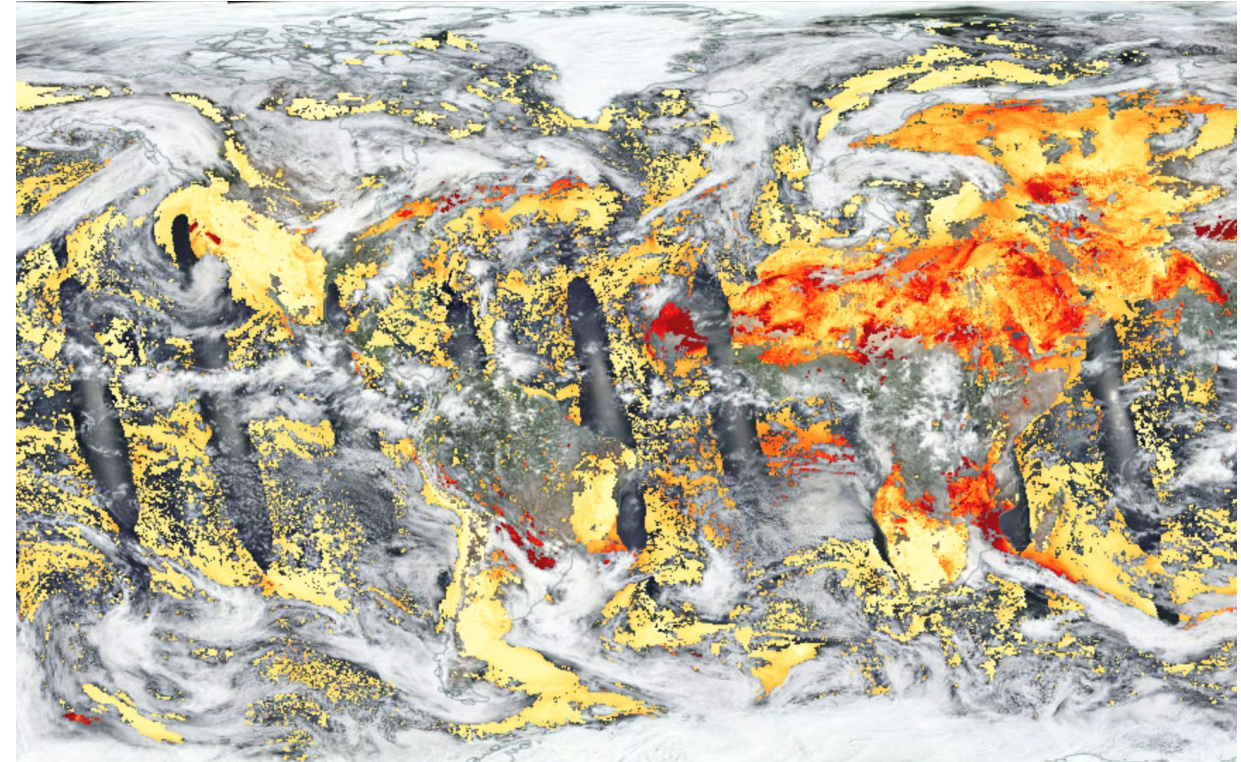
MODIS & VIIRS

MODIS Aqua Deep Blue AOD (Launched 1999)



2 Satellites (Aqua, Terra)
1 km high-resolution AOD ([MAIAC](#))

VIIRS SNPP Deep Blue AOD (Launched 2011)



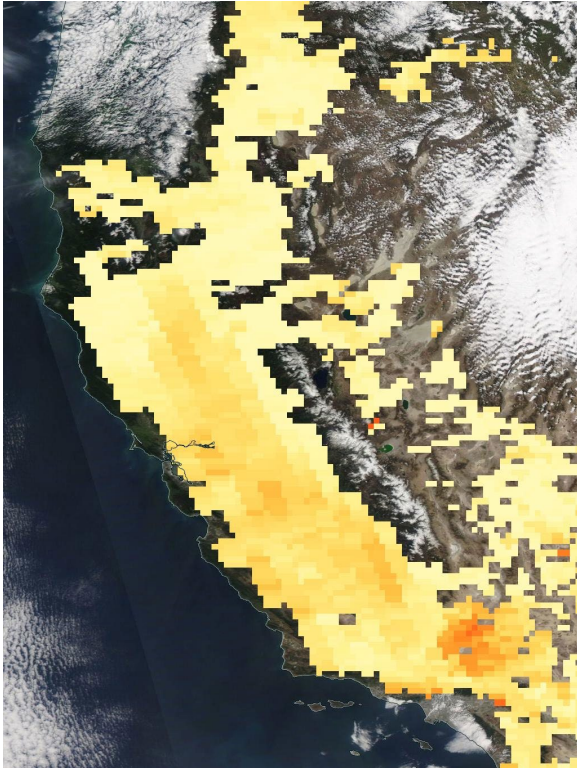
3 Satellites (SNPP, NOAA-20, NOAA-21)
0.75 km high-resolution AOD ([MAIAC](#))

Source: [NASA Worldview](#)



Aerosol Optical Depth Retrieval Algorithms

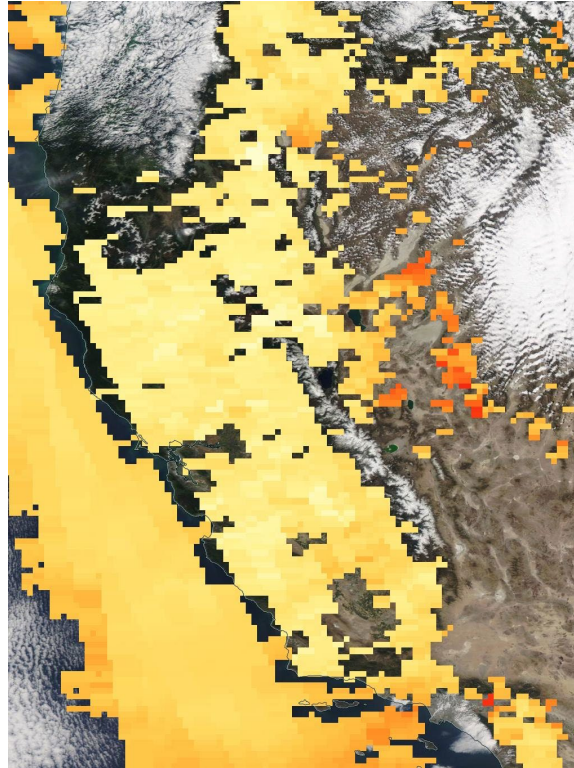
Deep Blue (10km)
MOD/MYD04_L2



Land Only,
Best for Bright Surfaces

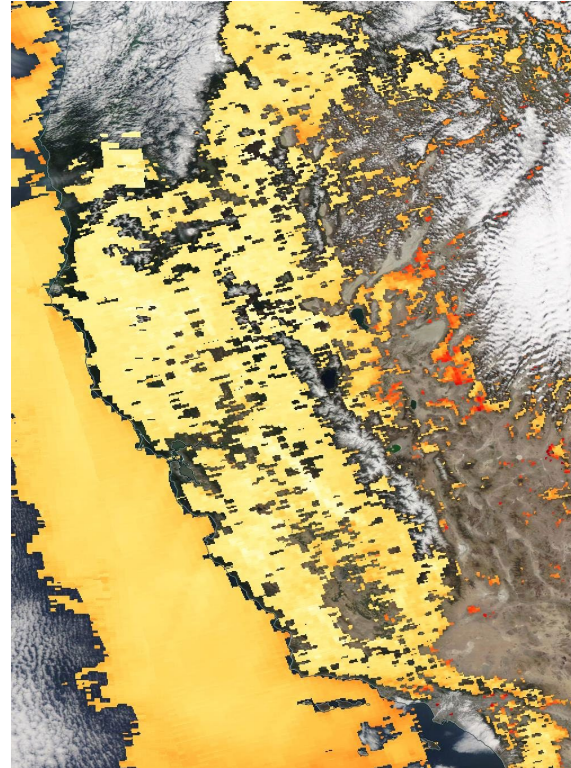
Source: [NASA Worldview](#)

Dark Target (10km)
MOD/MYD04_L2



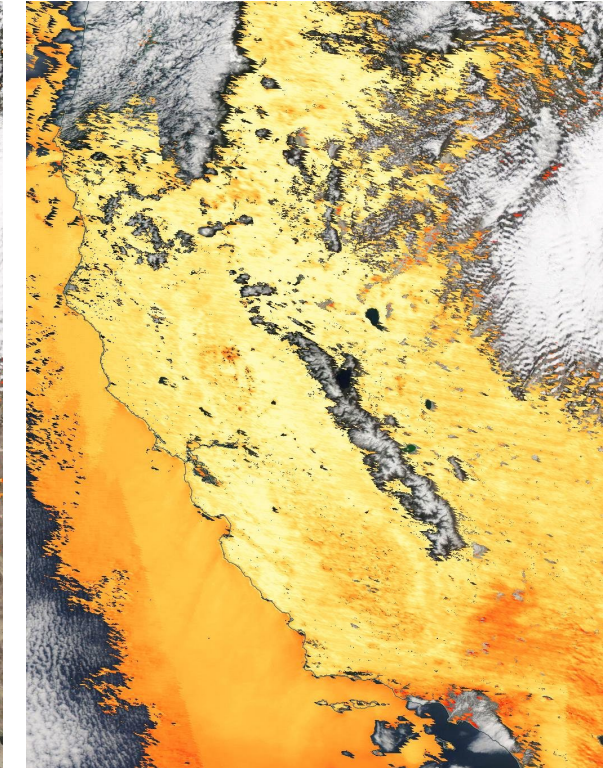
Land & Water,
Best for Dark Surfaces

Dark Target (3km)
MOD/MYD04_3K



Higher Resolution,
Issues in Urban Areas

MAIAC (1km)
MCD19A2

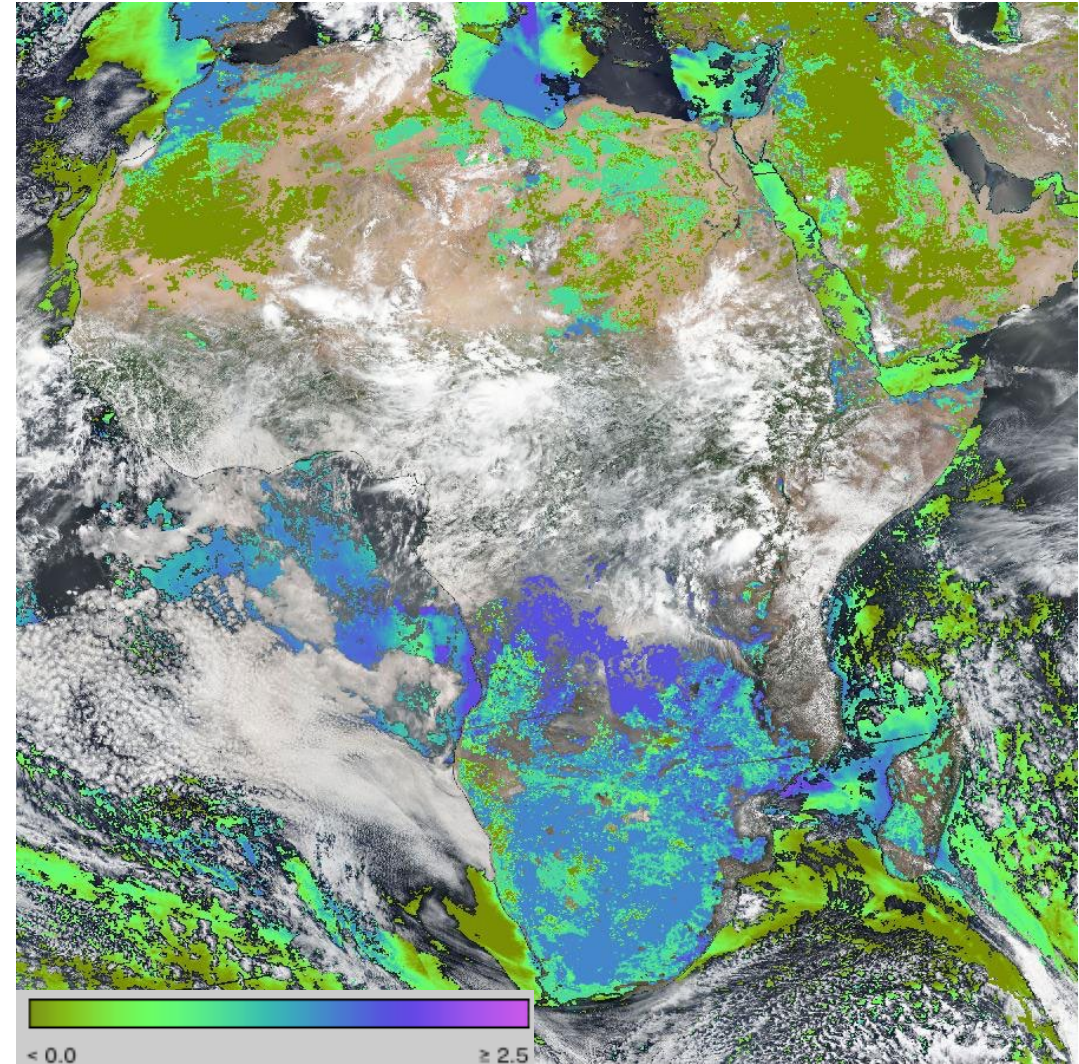


Highest Resolution,
Combine Aqua &
Terra



Angstrom Exponent

- Angstrom Parameter or Angstrom Exponent measures how AOD varies with wavelength.
- Typically estimated between 440nm and 870nm.
- Unitless
- Greater than 2 indicates smaller aerosols (e.g., smoke).
- Less than 0.5 indicates larger aerosols (e.g., dust).

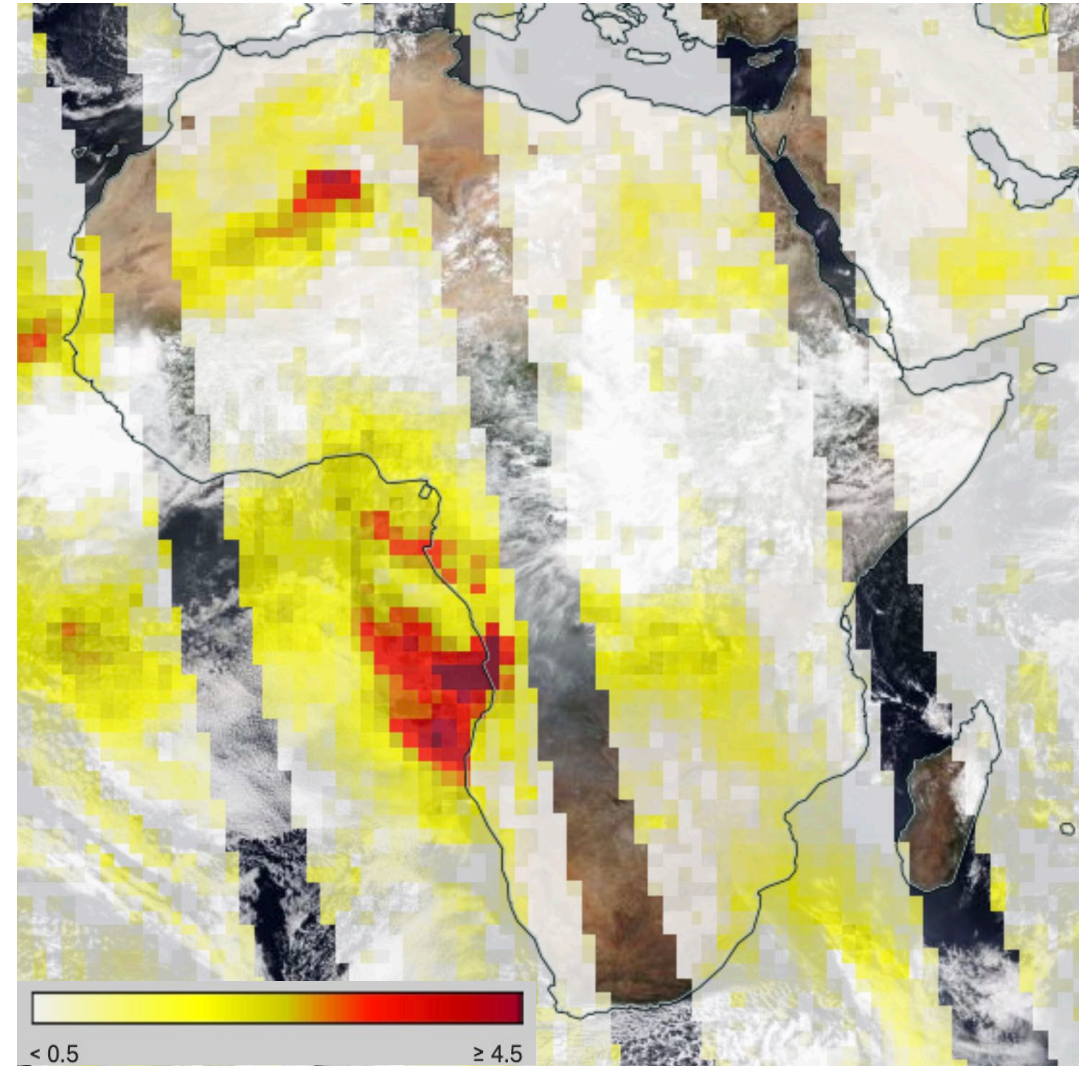


Source: [NASA Worldview](#)



UV Aerosol Index

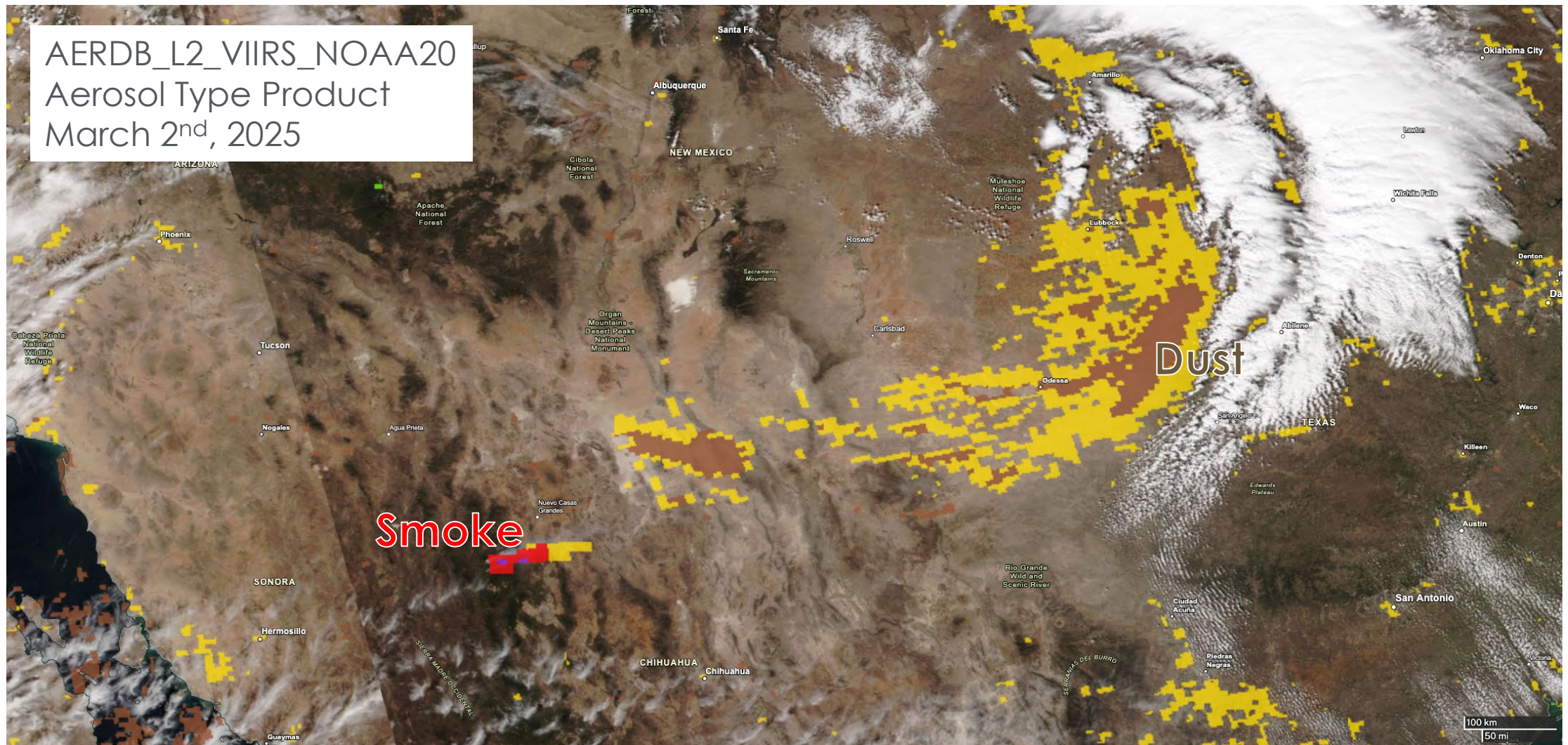
- Measures UV absorption at different wavelengths.
- Unitless
- Large positive values generally represent absorbing aerosols.
 - Dust
 - Smoke
- Small or negative values represent non-absorbing (scattering) aerosols.
 - Clouds



Source: [NASA Worldview](#)



Aerosol Type Products



Source: [NASA Worldview](#)



Geostationary Aerosol Imagery from GOES ABI

Geostationary Operational Environmental Satellite series

- GOES-East (GOES-19)
- GOES-West (GOES-18)

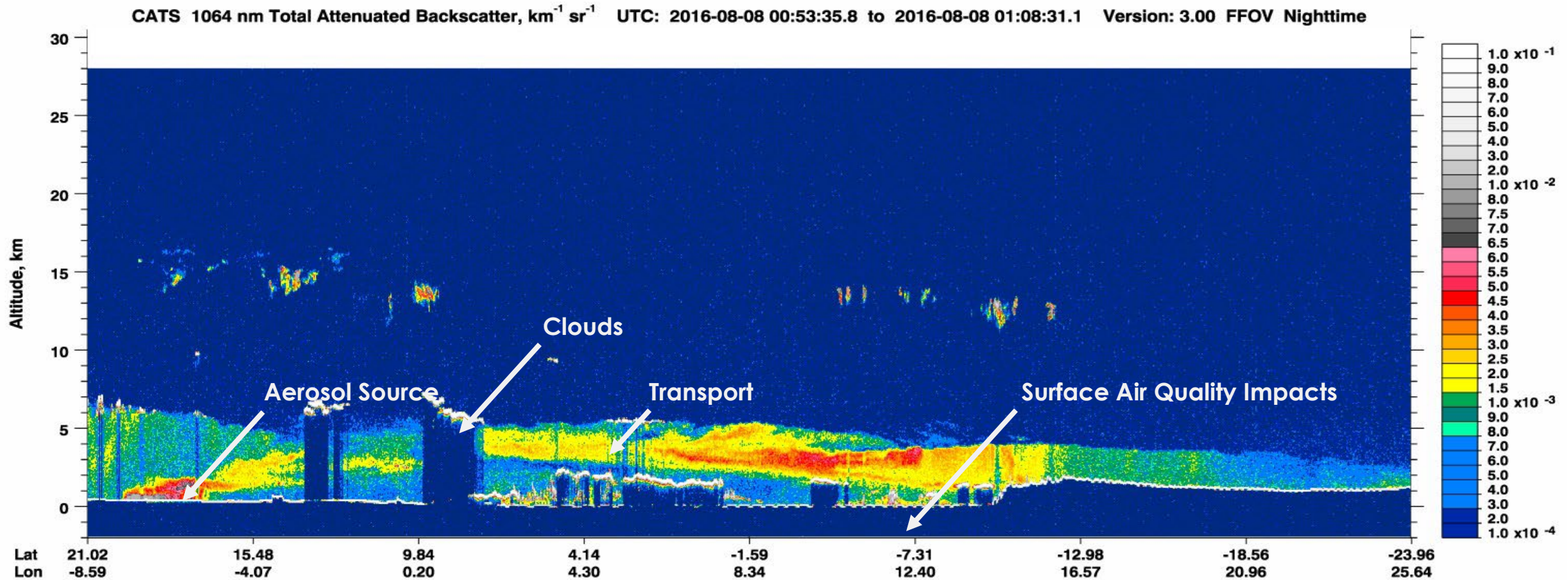
Advanced Baseline Imager (ABI)

- Geostationary multispectral instruments covering the Americas
- 10-minute temporal resolution
- 2 x 2 km spatial resolution
- AOD data products
- False color smoke and dust identification
- Fire detection

Source: [NOAA Aerosol Watch](#)



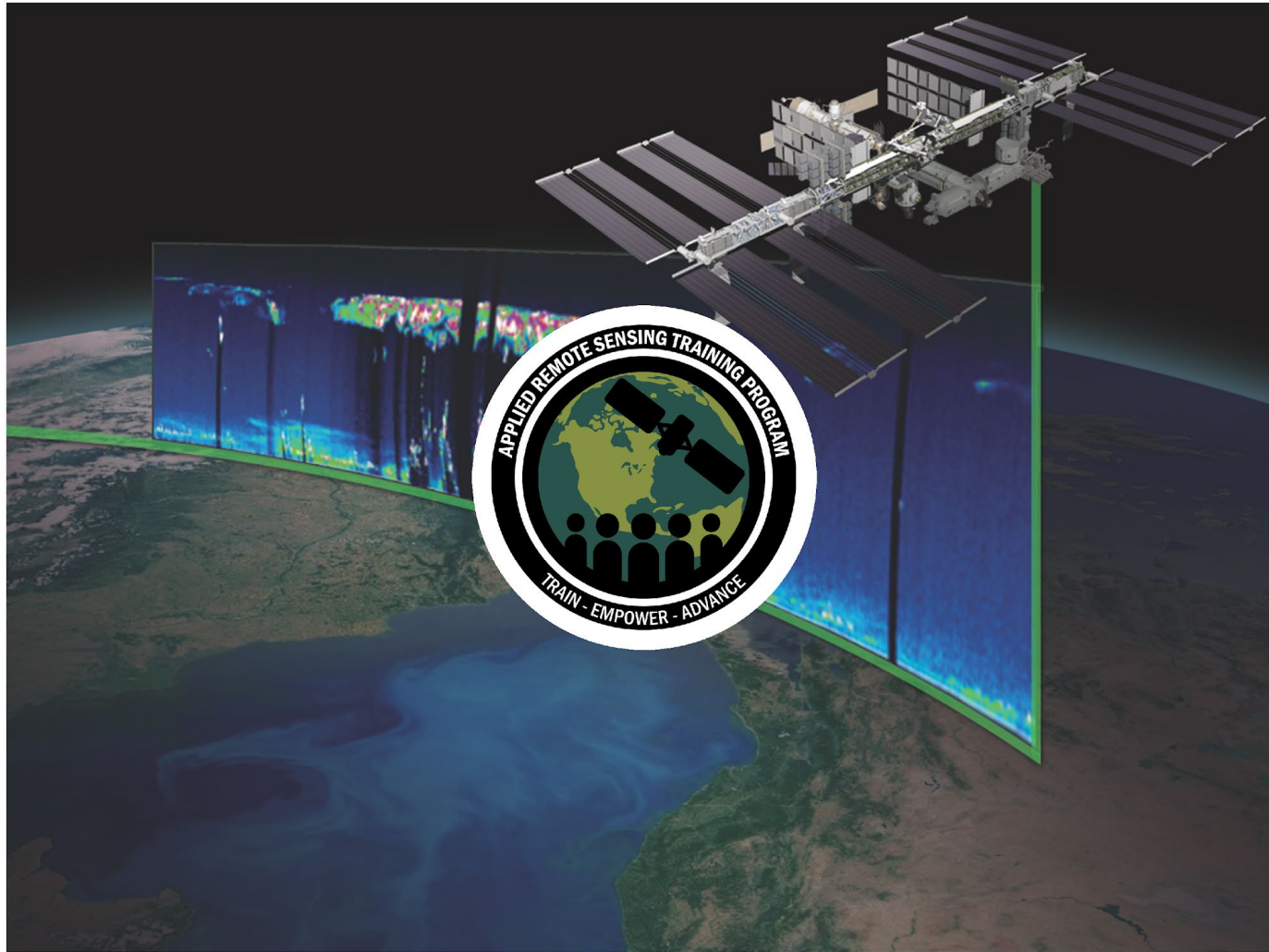
Active Remote Sensing of Aerosols from Space



CATS Lidar on International Space Station



LiDAR Profiling Satellite Observations for Air Quality Applications



Online, Instructor-Led

Level: Introductory

2 Parts

June 4, 2025 – June 11, 2025

[Link to Training](#)



Fire Detection

- IR remote sensing useful to detect thermal anomalies (usually fires)
- Provides data on:
 - Hotspot Location
 - Fire Radiative Power [W/m²]
- Available from multiple multispectral satellites (MODIS, VIIRS, GOES ABI)



Source: [NASA Scientific Visualization Studio, "Active Fires as Observed by VIIRS, January-September 2021"](#)



Introduction to NASA Earth Observations & Tools for Wildfire Monitoring & Management



Online, Instructor-Led

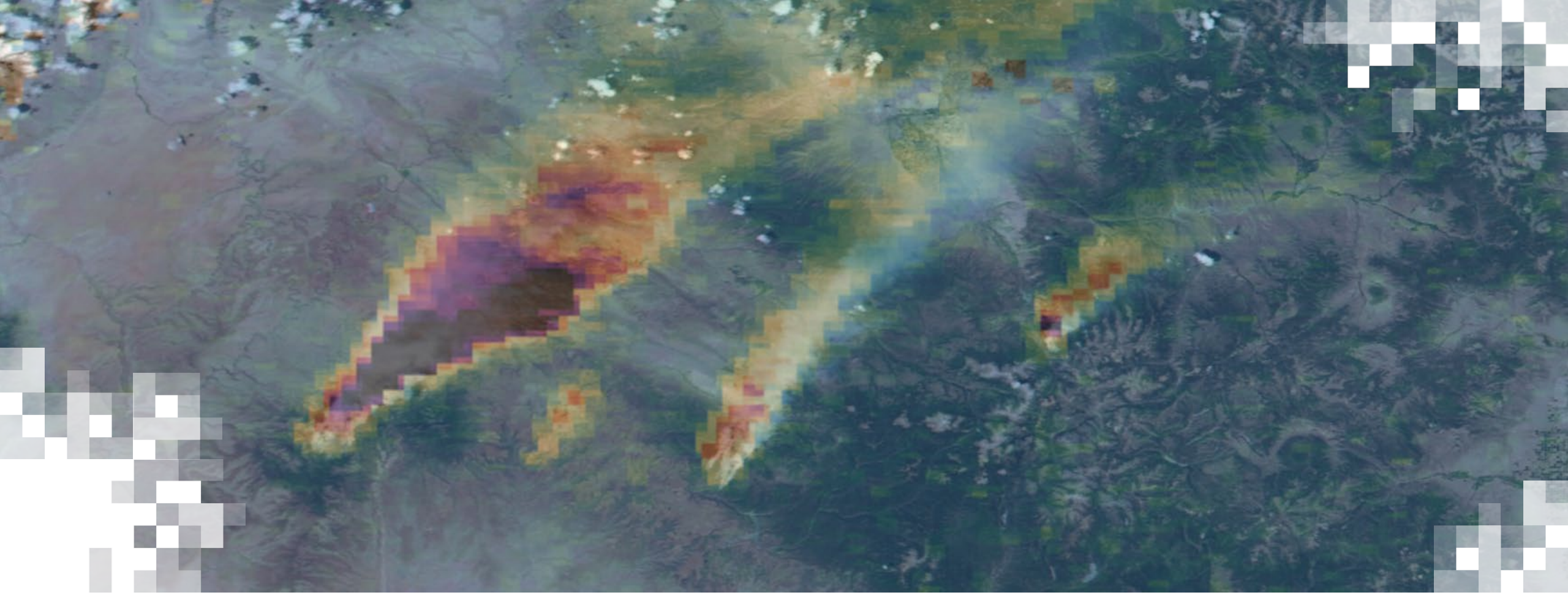
Level: Introductory

3 Parts

April 16, 2025 –
April 30, 2025

[Link to Training](#)

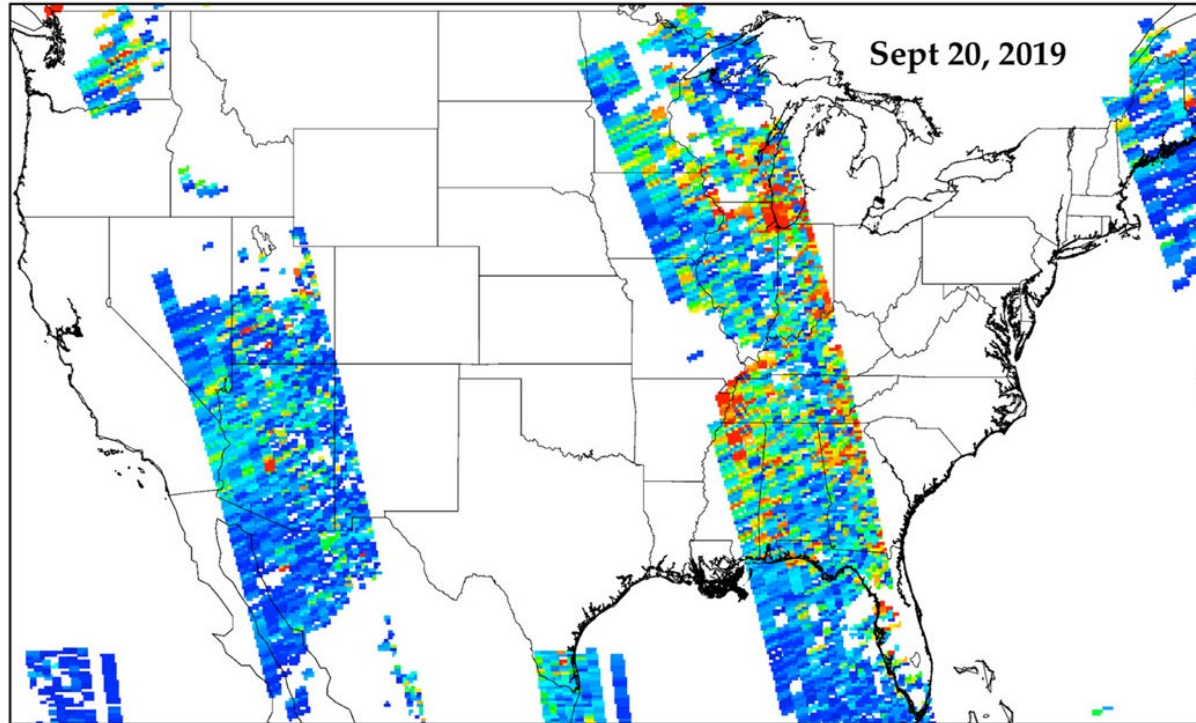




Remote Sensing of Trace Gases

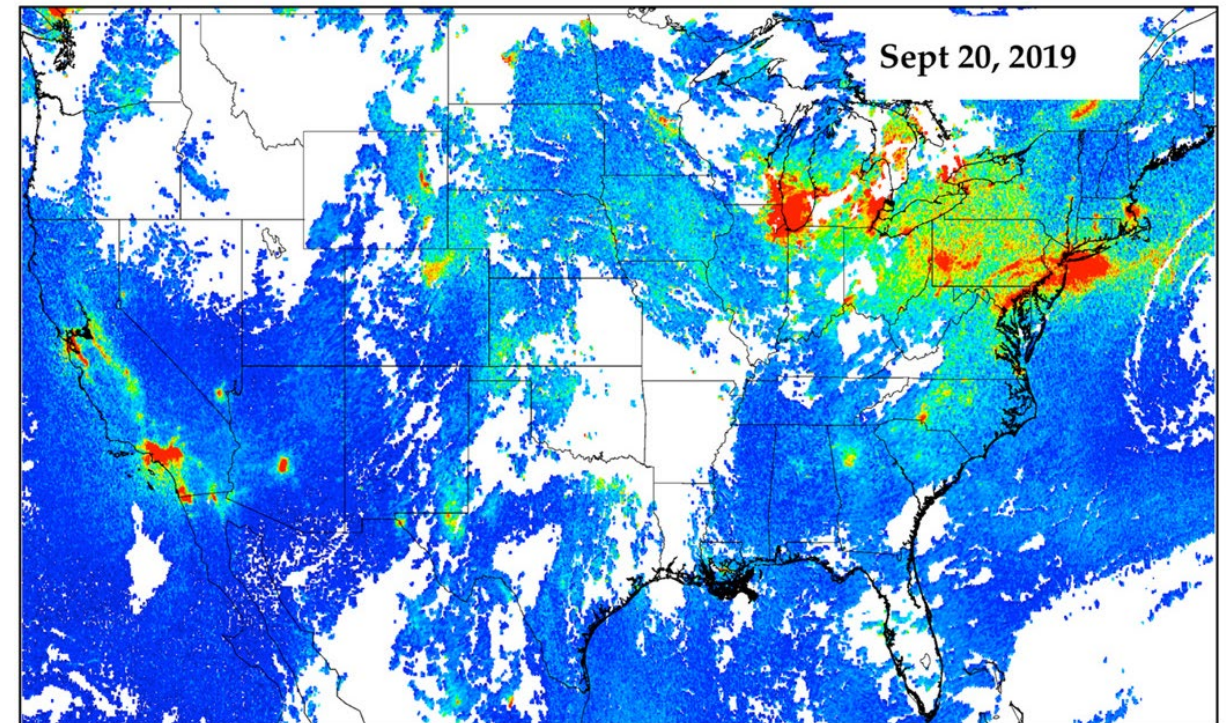
OMI & TROPOMI

OMI Tropospheric NO₂



1 Satellite: Aura (2004-Present)
13 x 24 km² Spatial Resolution
UV & Visible Hyperspectral Resolution
Sun-Synchronous LEO

TROPOMI Tropospheric NO₂



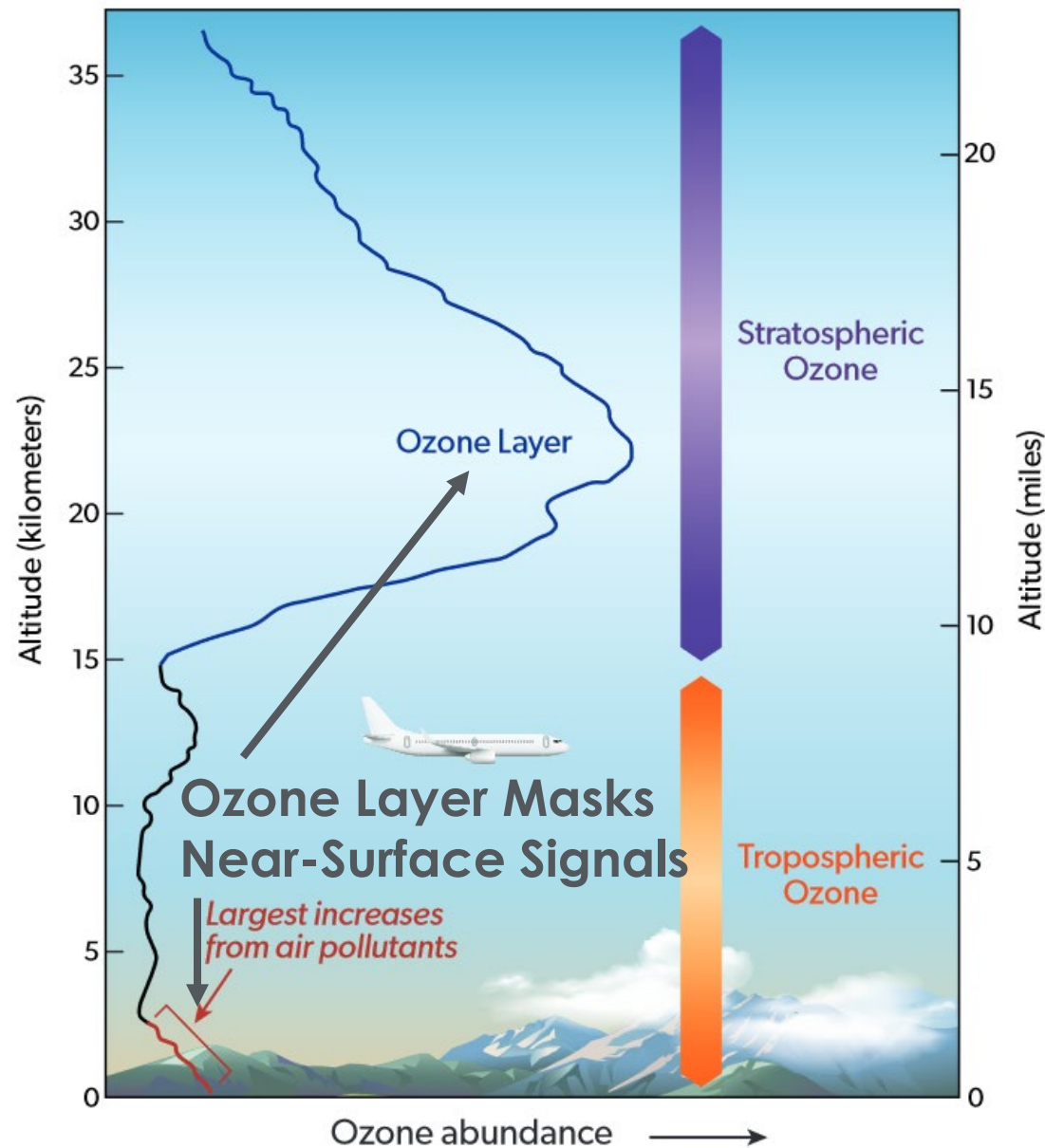
1 Satellite: ESA Sentinel 5 Precursor (2017-Present)
3.5 x 5.5 km² Spatial Resolution
UV & Visible & NIR & SWIR Hyperspectral Resolution
Sun-Synchronous LEO

Source: Goldberg, Anenberg, Kerr, Moheg, Lu, Streets (2021) [TROPOMI NO₂ in the United States: A Detailed Look at the Annual Averages, Weekly Cycles, Effects of Temperature, and Correlation With Surface NO₂ Concentrations](#). *Earth's Future*.



Ozone

- High Stratospheric Concentrations (Ozone Layer)
- Total Column Ozone is well-measured by satellites
- Tropospheric and Near-Surface Ozone is extremely difficult to estimate using satellites
 - New TEMPO ozone profile products aim to overcome this challenge; see Aaron's talk later
- Typical Unit: Dobson Units

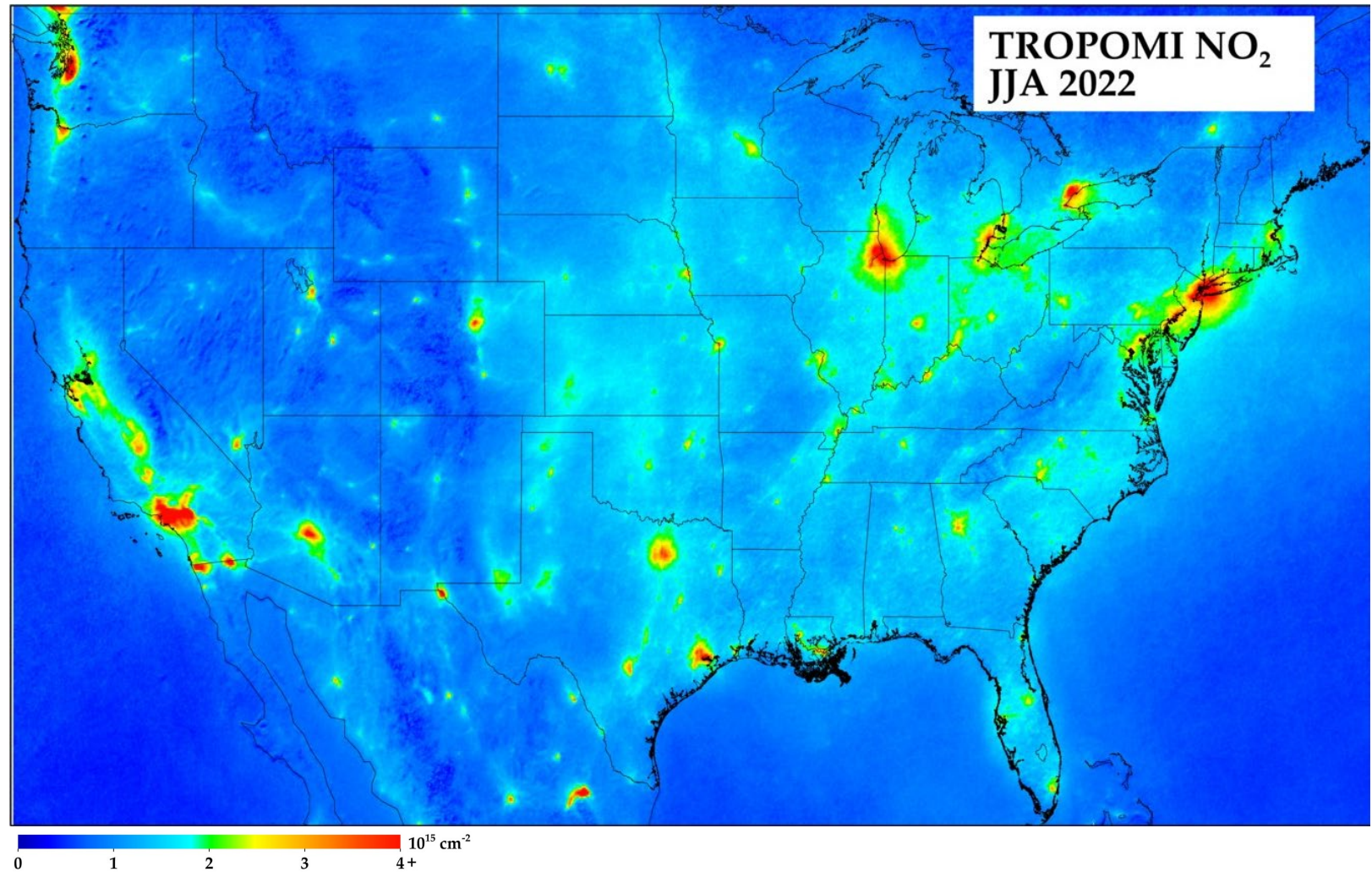


Source: [Scientific Assessment of Ozone Depletion, 2022](#)



Nitrogen Dioxide

- Short atmospheric lifetime concentrates NO_2 near its sources.
- Satellite NO_2 tends to be well-correlated to surface NO_2 .
- Useful for identifying sources and assessing spatial distributions and exposures in urban areas.
- Typical Unit: Mol. per cm^2



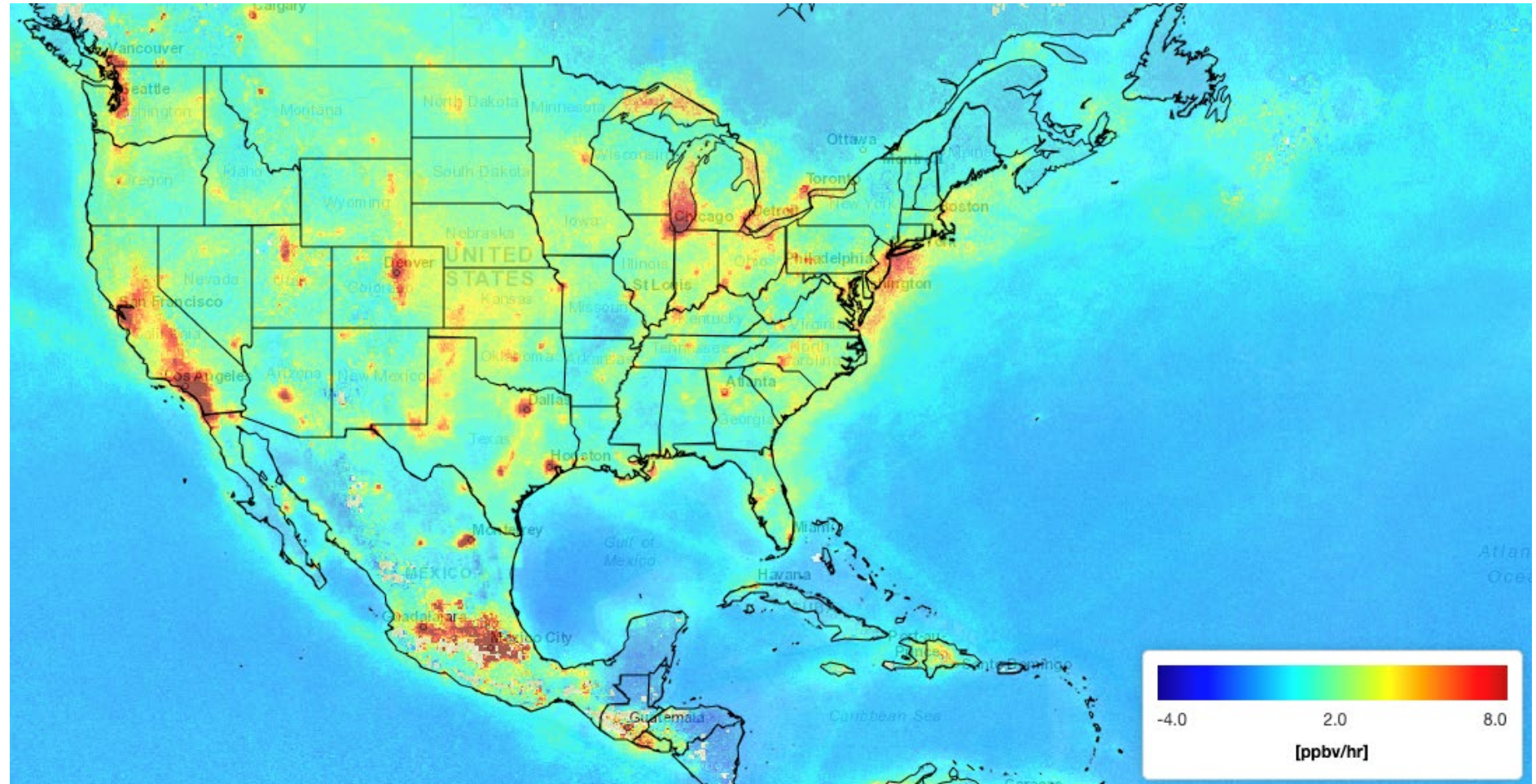
Source: George Washington University "TROPOMI NO_2 USA" Website: <https://tropomino2.us/>



Formaldehyde

August 2023 Net Ozone Production Rate (PO3) Estimated from a Combination of TROPOMI NO₂ and HCHO Data

- Measurable with satellites
- Generally high uncertainties
- Proxy for other VOCs
- HCHO and NO₂ together provide insights into Ozone formation potential

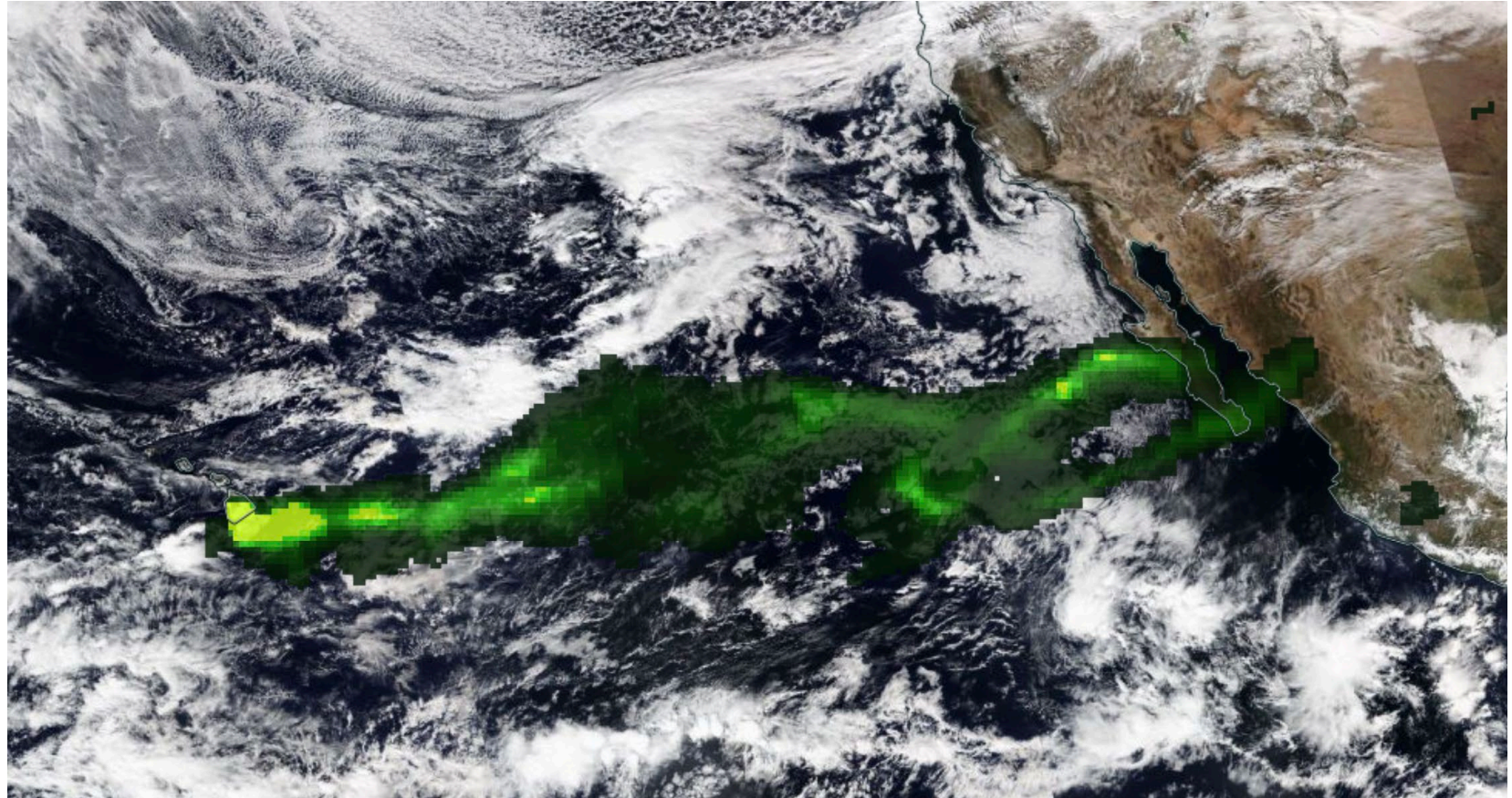


Source: [Ozonrates](https://ozonrates.nasa.gov/), a NASA-Funded Tool by Dr. Amir Souri and Collaborators



Sulfur Dioxide

- Measurable with satellites
- Generally sensitive to high concentrations only
- Estimates depend on assumed injection height
- Satellites are better suited to assessing large sources: volcanoes, coal power plants, heavy industry, ore smelting



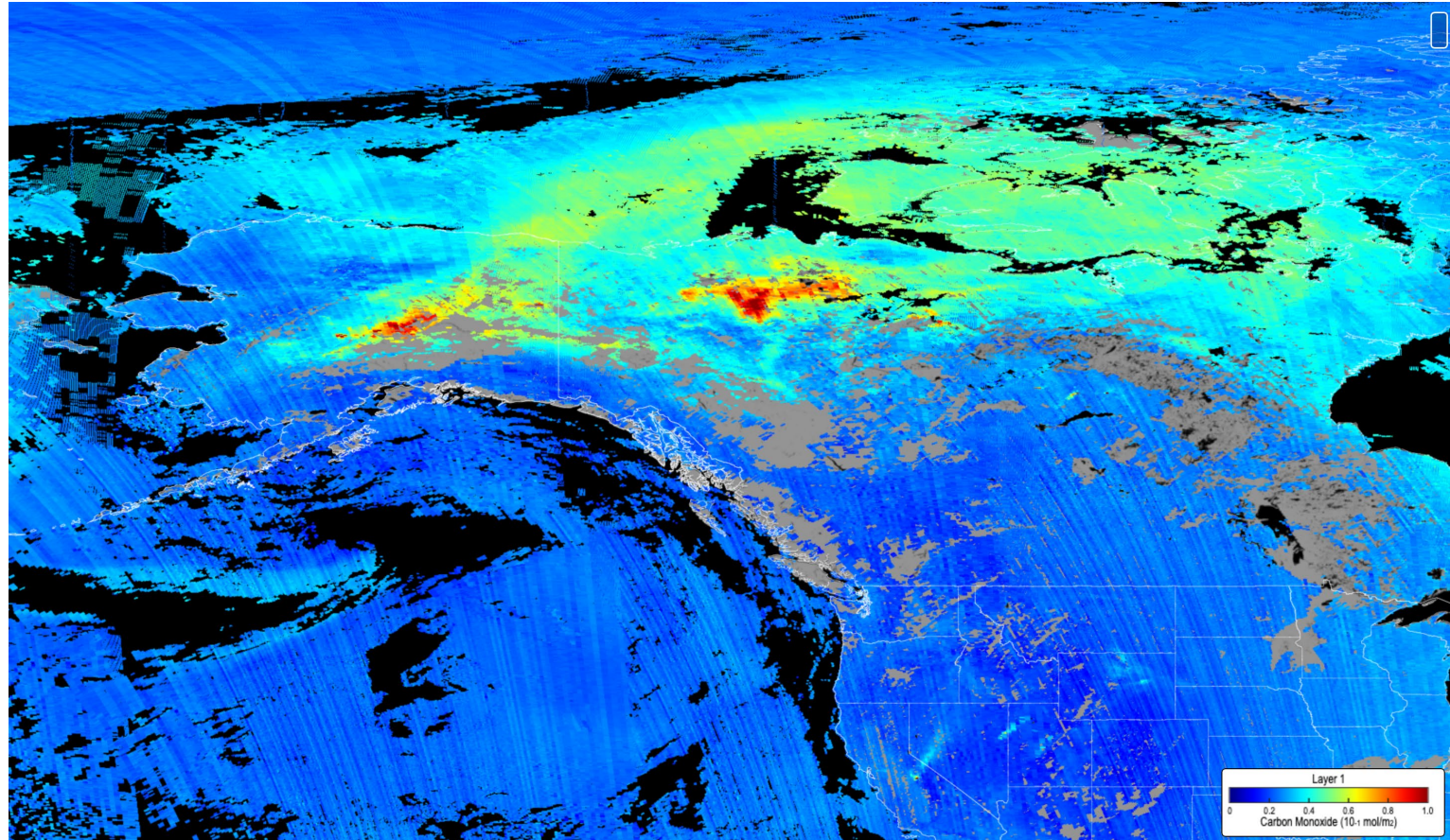
TROPOMI SO₂ Plume (Lower Troposphere) from Mauna Loa Eruption, November 30, 2022

Source: [NASA Worldview](#)



Methane and Carbon Monoxide

- TROPOMI sensitivity in NIR and SWIR allows measurement of CO and CH₄
- CO useful as marker of long-range pollutant transport, especially smoke
- Other missions provide more dedicated GHG observations (CH₄, CO₂)

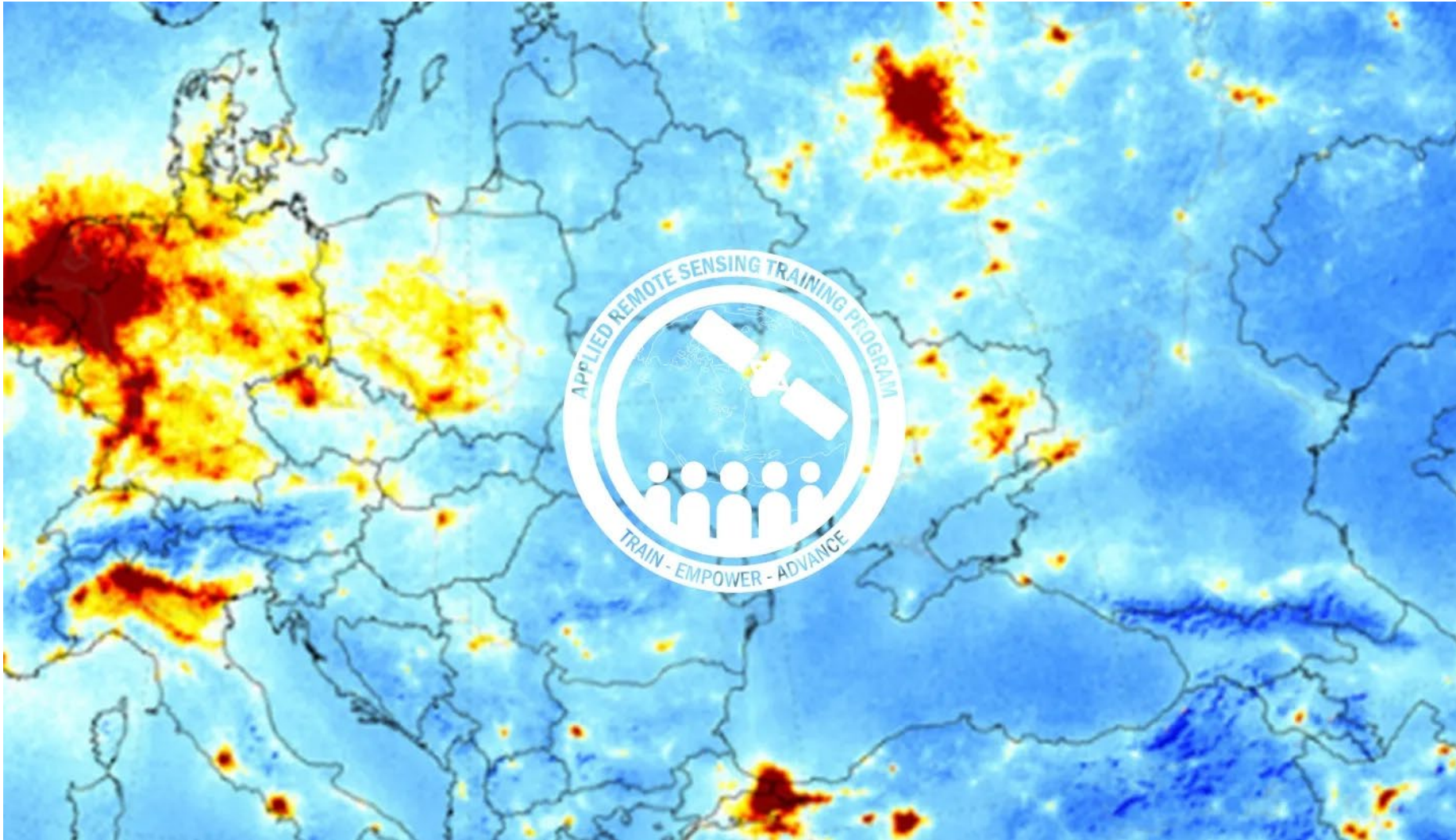


TROPOMI CO from Various Wildfires, July 9, 2022

Source: [NOAA JSTAR Mapper](#)



High Resolution NO₂ Monitoring From Space with TROPOMI



Online, Instructor-Led

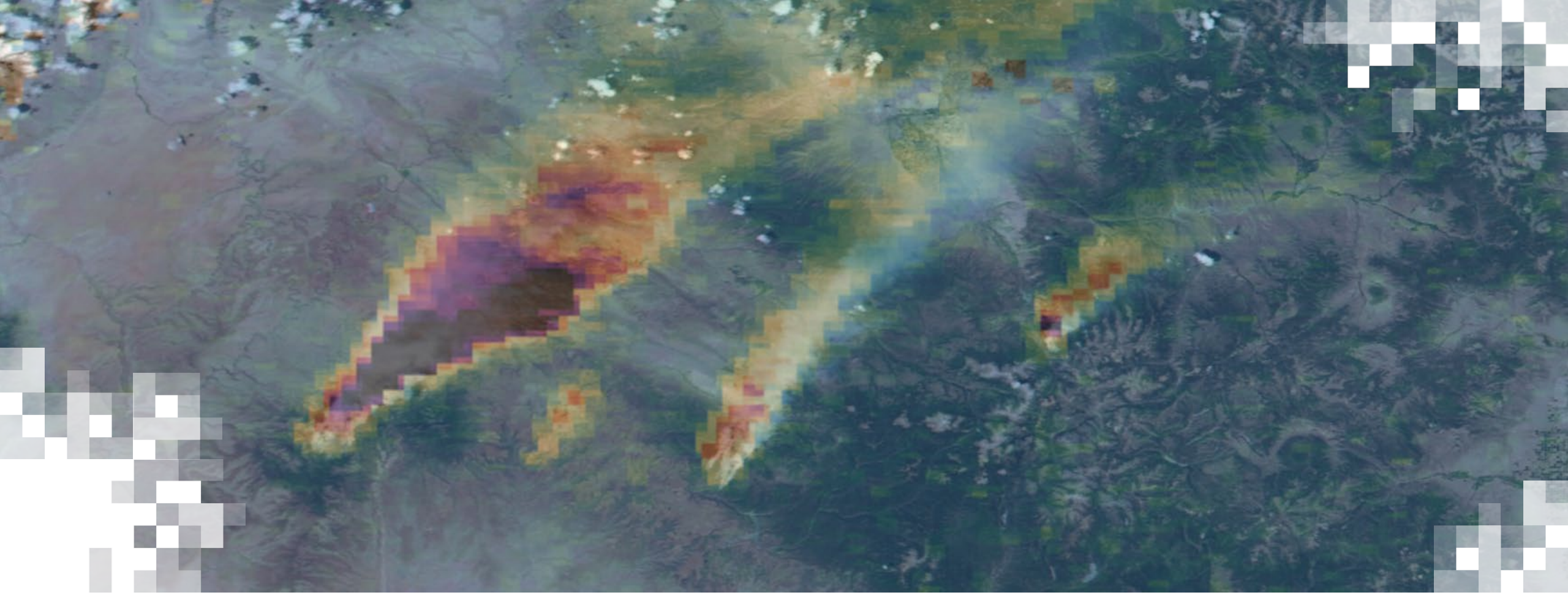
Level: Advanced

3 Parts

May 28, 2019 –
June 3, 2019

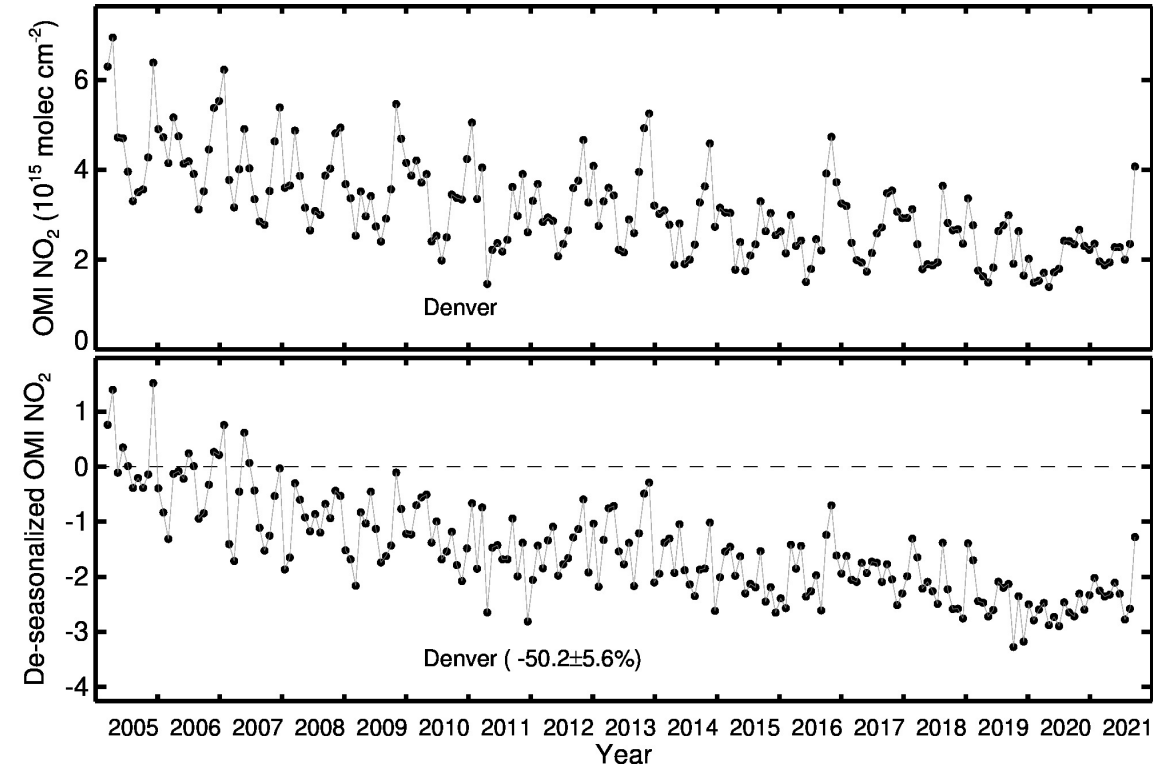
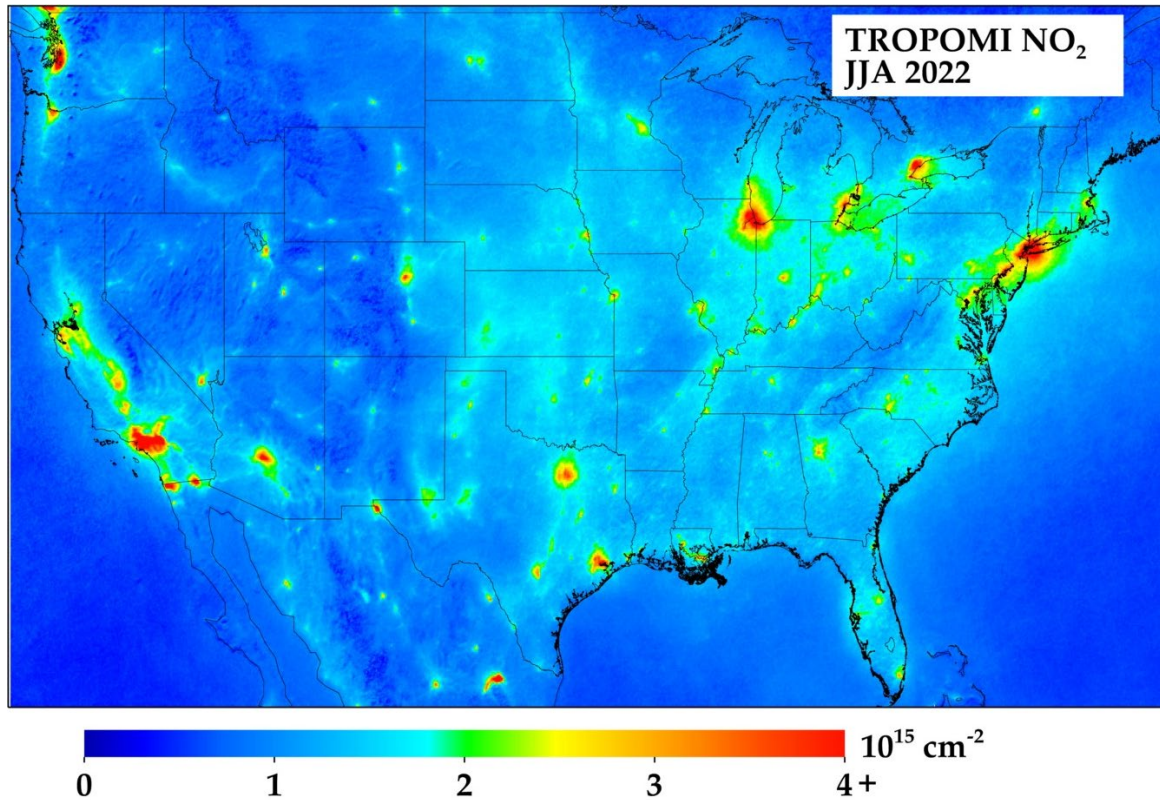
[Link to Training](#)





Common Benefits and Limitations of Remote Sensing for Air Quality

What Satellites CAN Do for Air Quality



Examine a Large Area: Where are the hotspots? How is long-range transport happening?

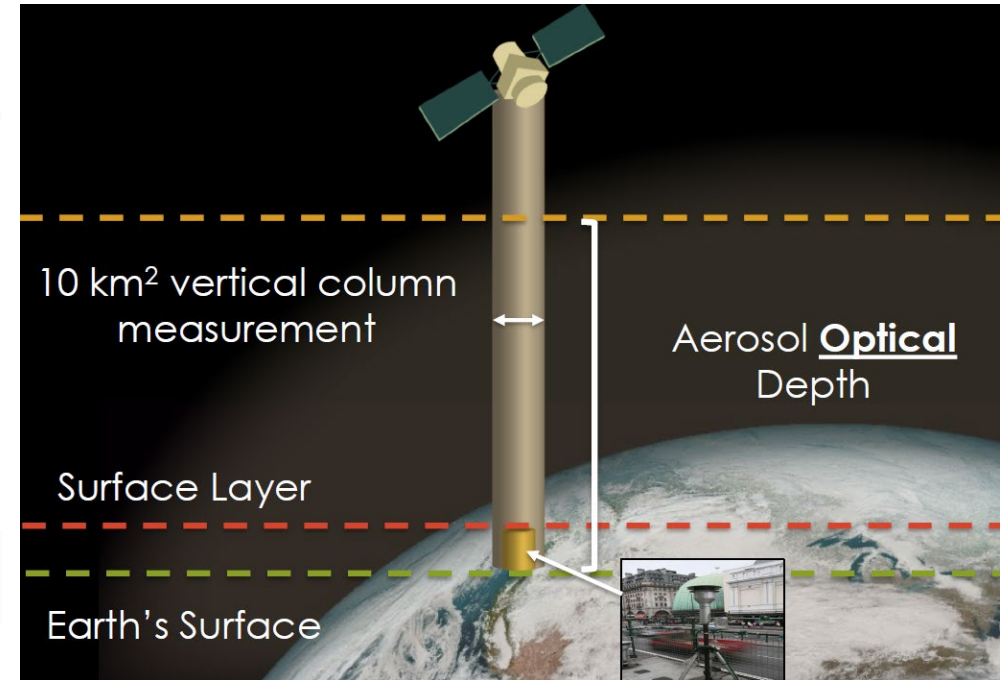
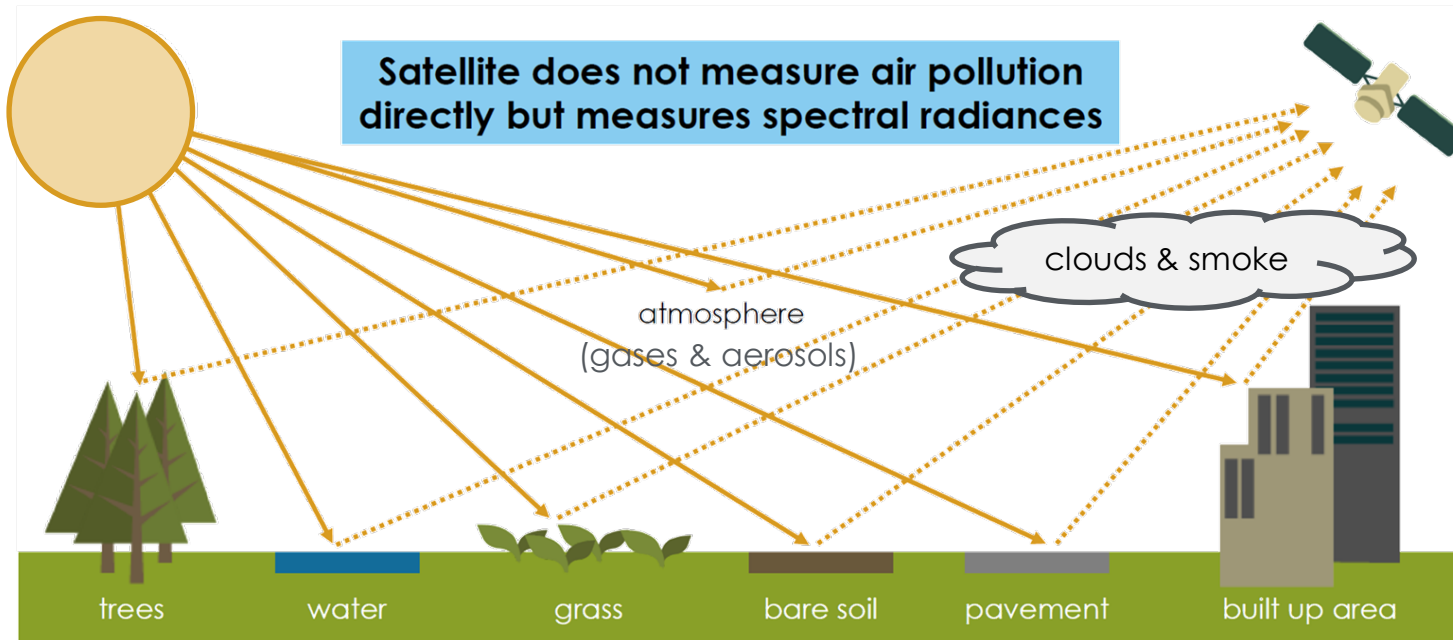
Cover Remote Areas: What is happening at locations far away from surface monitors?

Track Changes Over Time: How much has the average concentration over an area changed over time?

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 Satellites CAN NOT Do for Air Quality



Can't see at night: passive sensors measure reflected sunlight passing through the atmosphere

Can't see through clouds: most satellite aerosol & trace gas measurements are blocked by cloud cover

Can't see what is happening at "nose level": satellites measure quantities in the whole atmosphere

Can't see all times of day: polar-orbiting satellites will observe a location once (maybe twice) per day
geostationary satellites provide more frequent (daytime) data



Key Remotely Sensed Parameters for Aerosol and Trace Gas Monitoring

Aerosols

True-Color Imagery	Situational awareness of aerosol type, sources, transport
Aerosol Optical Depth (AOD)	Total aerosols in the atmospheric column (<i>no info on type, size, height</i>)
Angstrom Exponent (AE)	Dominant size: high AE → more fine particles
UV Aerosol Index	Distinguish absorbing and scattering aerosols
Aerosol Type	Classify aerosols (e.g., dust, smoke, sea salt)

Trace Gases

NO ₂	Good spatial correlation with surface concentrations & sources, indicator of urban pollution
O ₃	High concentrations in Ozone layer; <i>little signal at surface, but measures total column</i>
HCHO	Useful proxy for overall volatile organic compounds and ozone precursors, <i>but noisy signal</i>
CO	Useful tracer for long-range pollutant transport, biomass burning
SO ₂	Only large industrial sources and volcanic emissions are reliably detected



Relevant ARSET Trainings

- [Fundamentals of Remote Sensing](#)
- [An Inside Look at How NASA Measures Air Pollution](#)
- [Accessing and Analyzing Air Quality Data from Geostationary Satellites](#)
- [LiDAR Profiling Satellite Observations for Air Quality Applications](#)
- [Tools for Analyzing NASA Air Quality Model Output](#)
- [Introduction and Access to Global Air Quality Forecasting Data and Tools](#)
- [Satellite Observations and Tools for Fire Risk, Detection, and Analysis](#)
- [MODIS to VIIRS Transition for Air Quality Applications](#)
- [High Resolution NO₂ Monitoring From Space with TROPOMI](#)
- [NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications](#)





Thank You!

