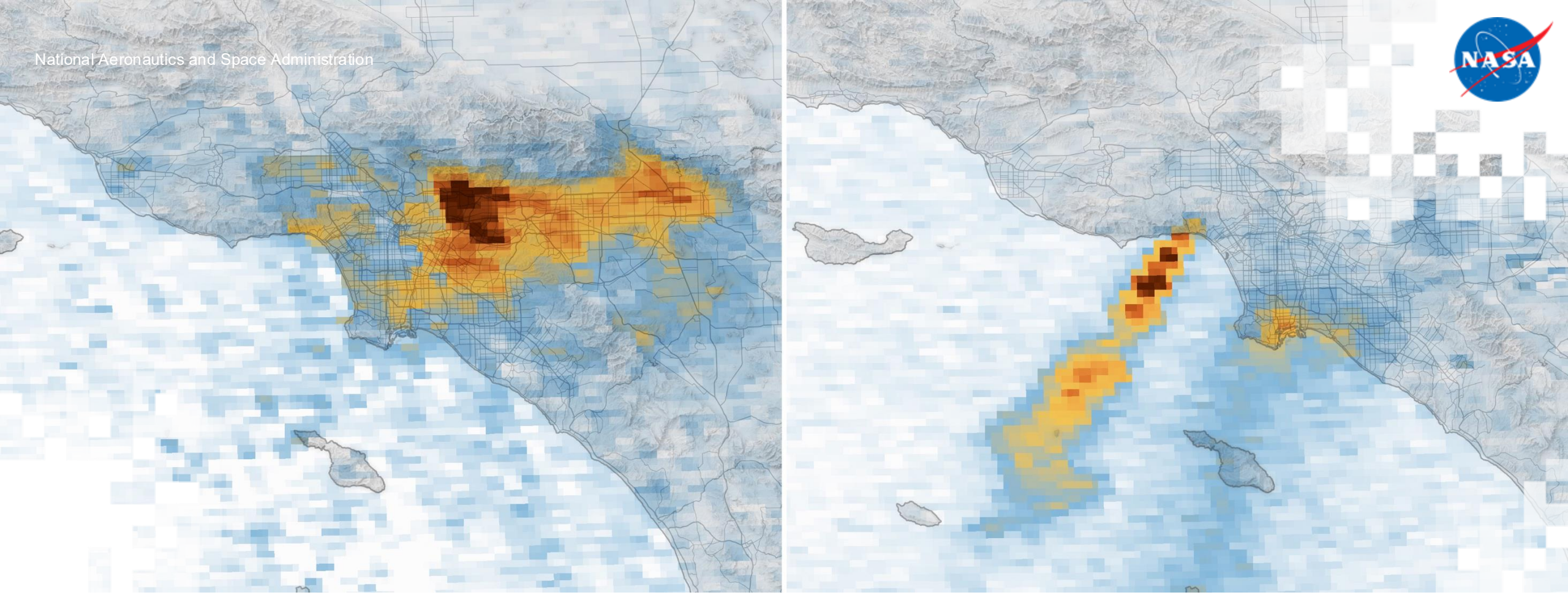


Introduction to Geostationary Observations for Air Quality Applications in the Western US

Day 2, Part 2: Satellite Resources for Air Quality

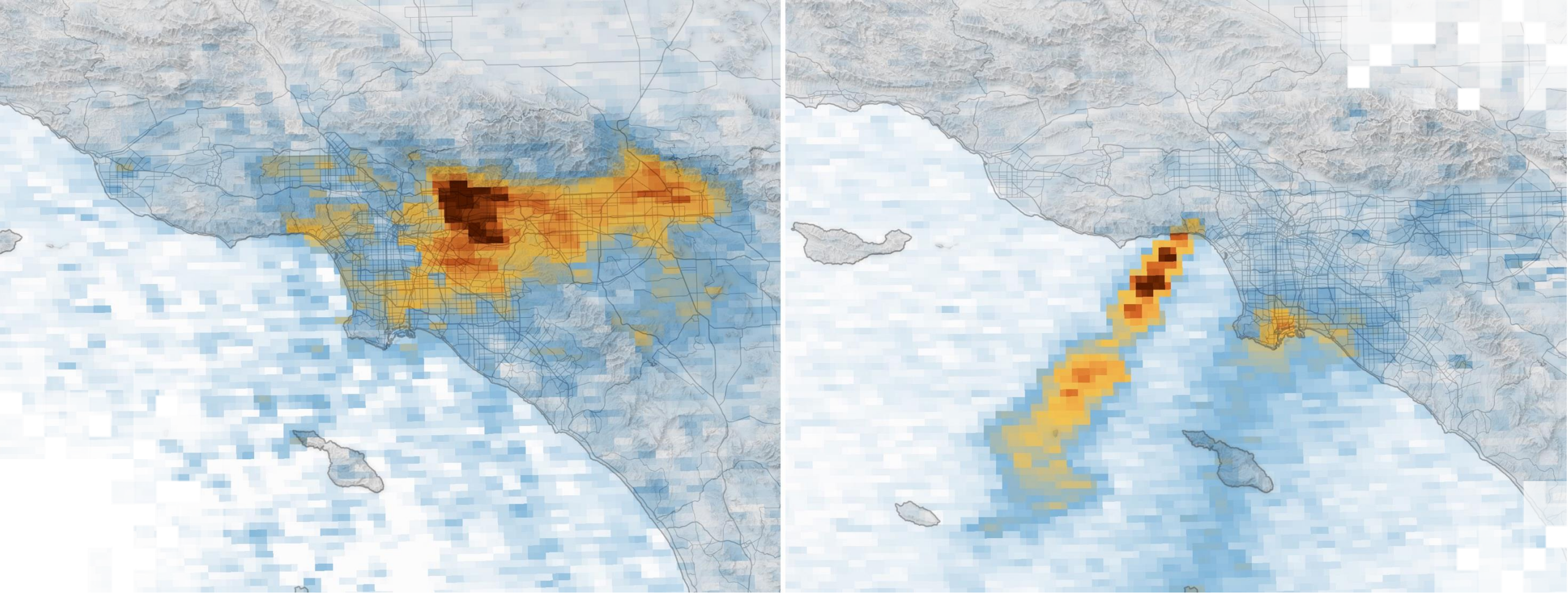
Carl Malings (ARSET)

August 05, 2025

Day 1, Part 2 Objectives

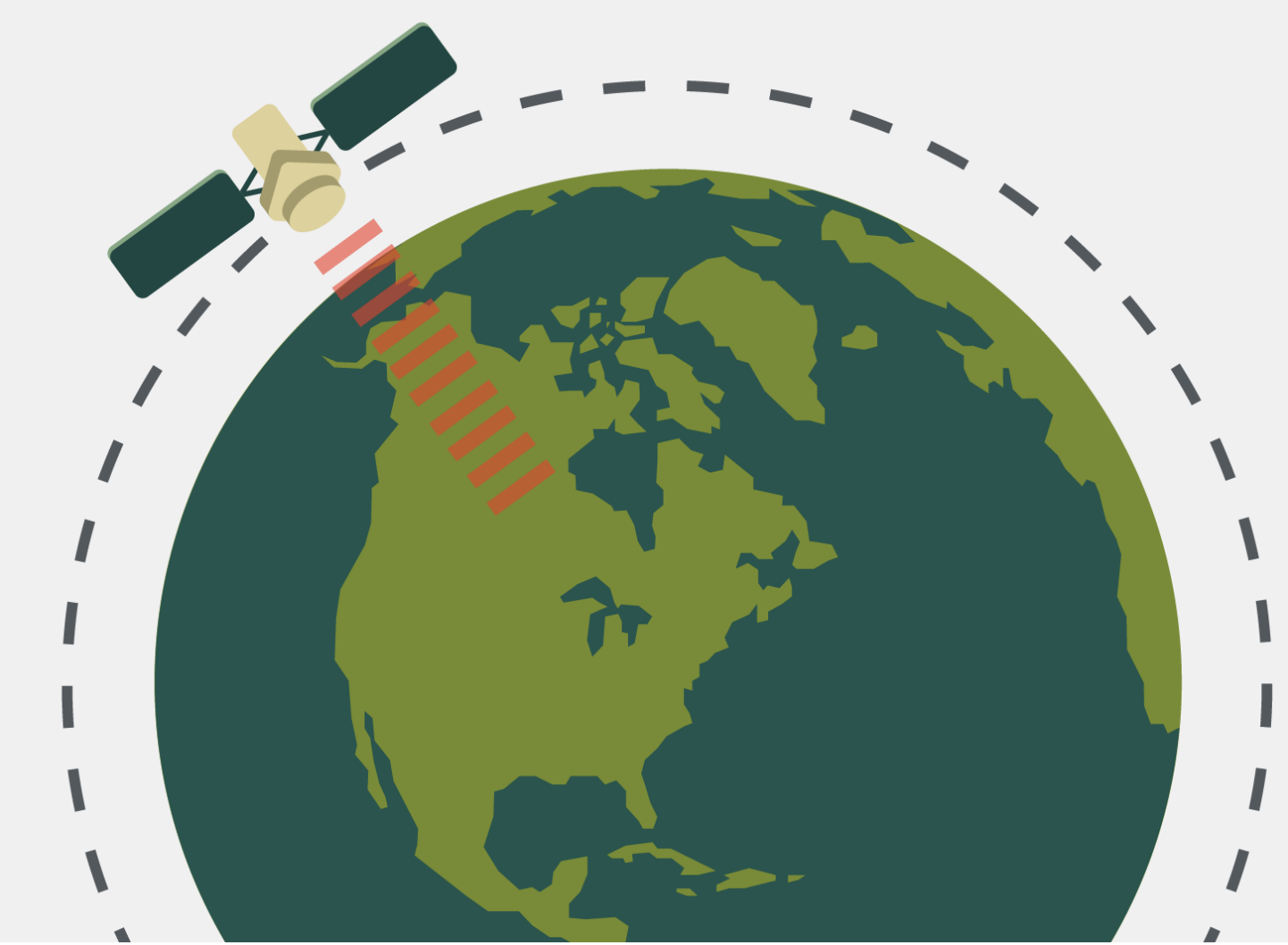
By the end of Day 1, Part 2, participants will be able to:

- Recall terms and concepts from the Fundamentals of Remote Sensing.
- Recognize common remotely sensed parameters relevant for air quality.
- Compare the capabilities of several common remote sensing missions used to study air quality.
- Explain the typical benefits and limitations of using remote sensing to study air quality.
- Identify prior ARSET trainings which cover concepts and datasets outside the scope of this workshop.



Fundamentals of Remote Sensing

Fundamentals of Remote Sensing



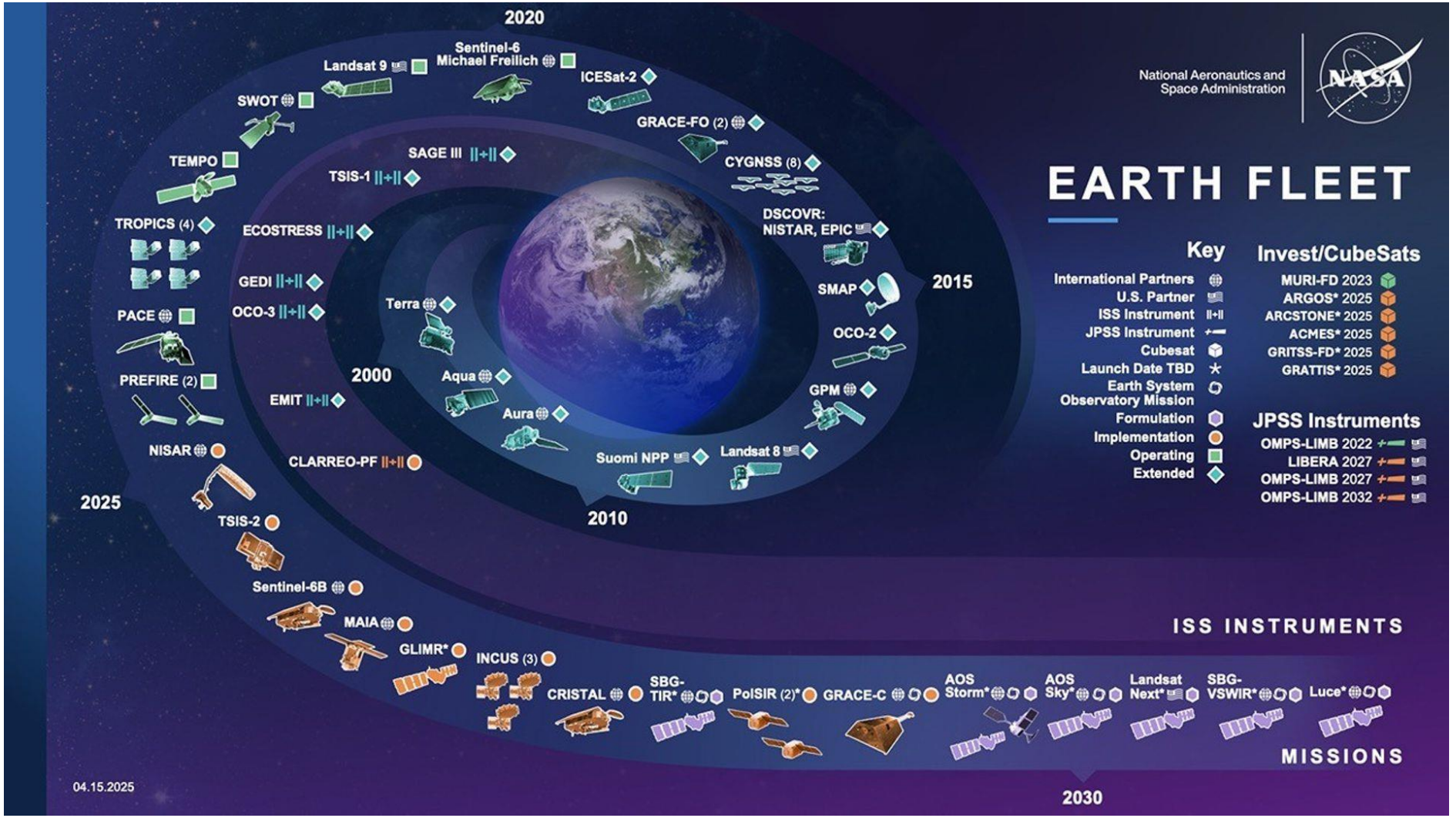
Online, Self-Paced

5 Modules

go.nasa.gov/3EVfr9T

Link to Fundamentals Training

NASA's Earth Science Fleet

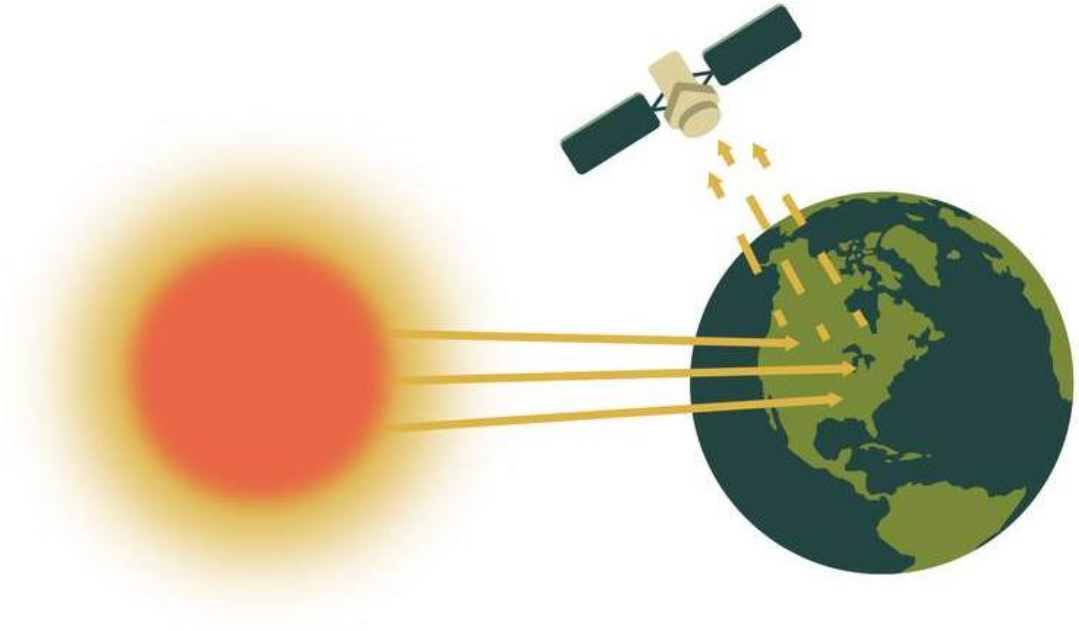


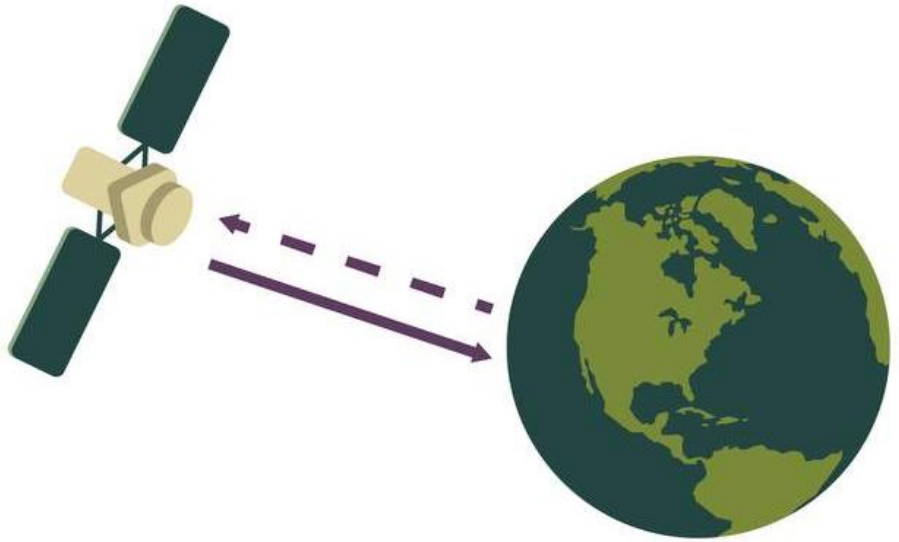
Source: [NASA Earth Science Missions]

Terminology

- Satellite
- Instrument or Sensor

Active & Passive Sensors





Passive

Rely on sunlight or emitted energy

Lower power requirements, typically wider swath width

Active

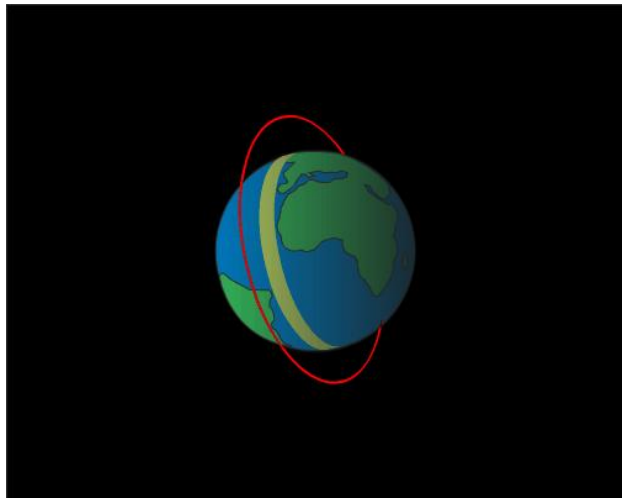
Provide their own source of energy (e.g., laser, microwave, radar)

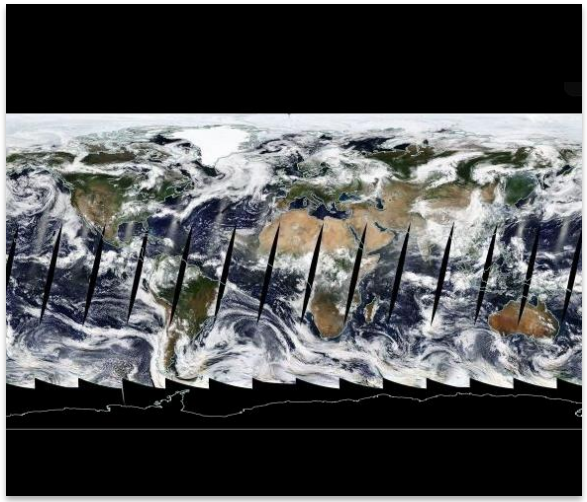
Higher power requirements, typically narrower swath width

Terminology

- Satellite
- Instrument or Sensor
- Active and Passive Sensors

Orbits

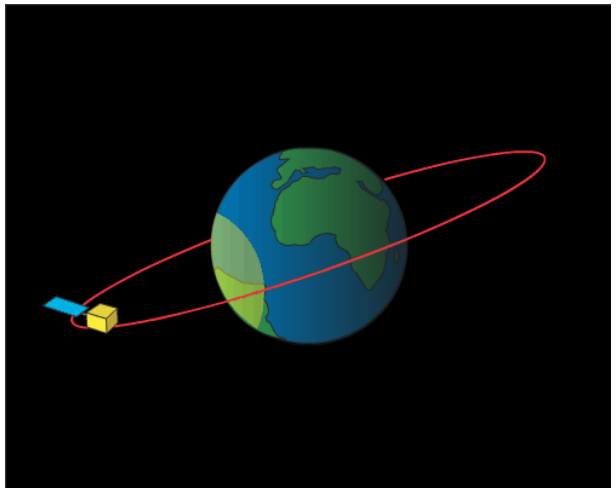


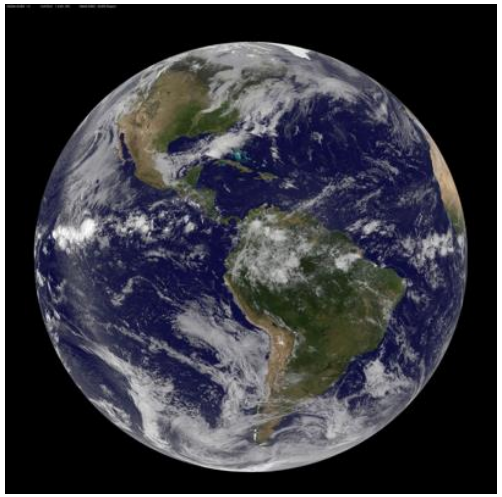


Polar Orbit (LEO)

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 instruments achieve **full global coverage** every 1-2 days





Geostationary Orbit (GEO)

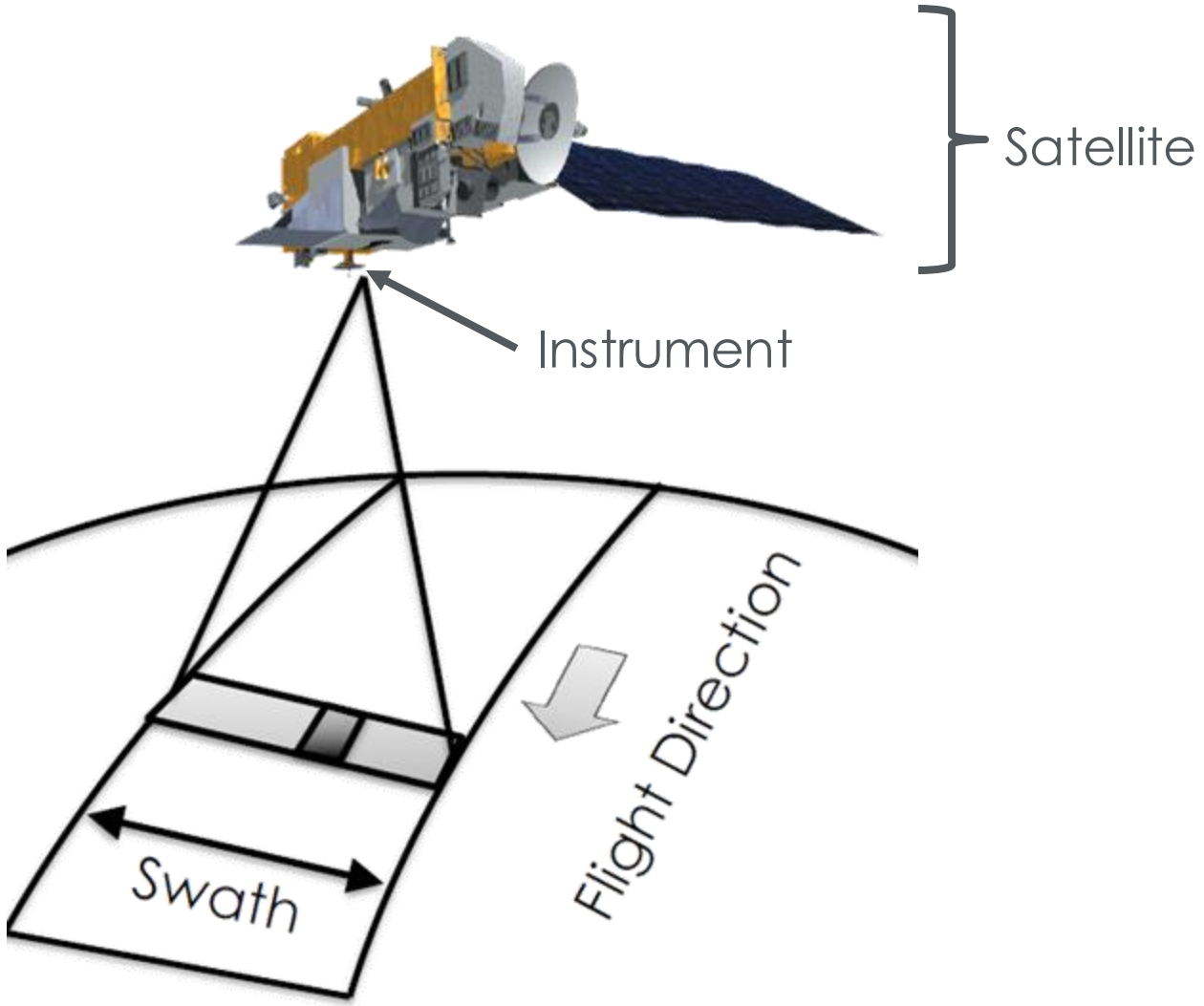
Orbit ~36,000 km above the Equator with the same rotational period as Earth

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

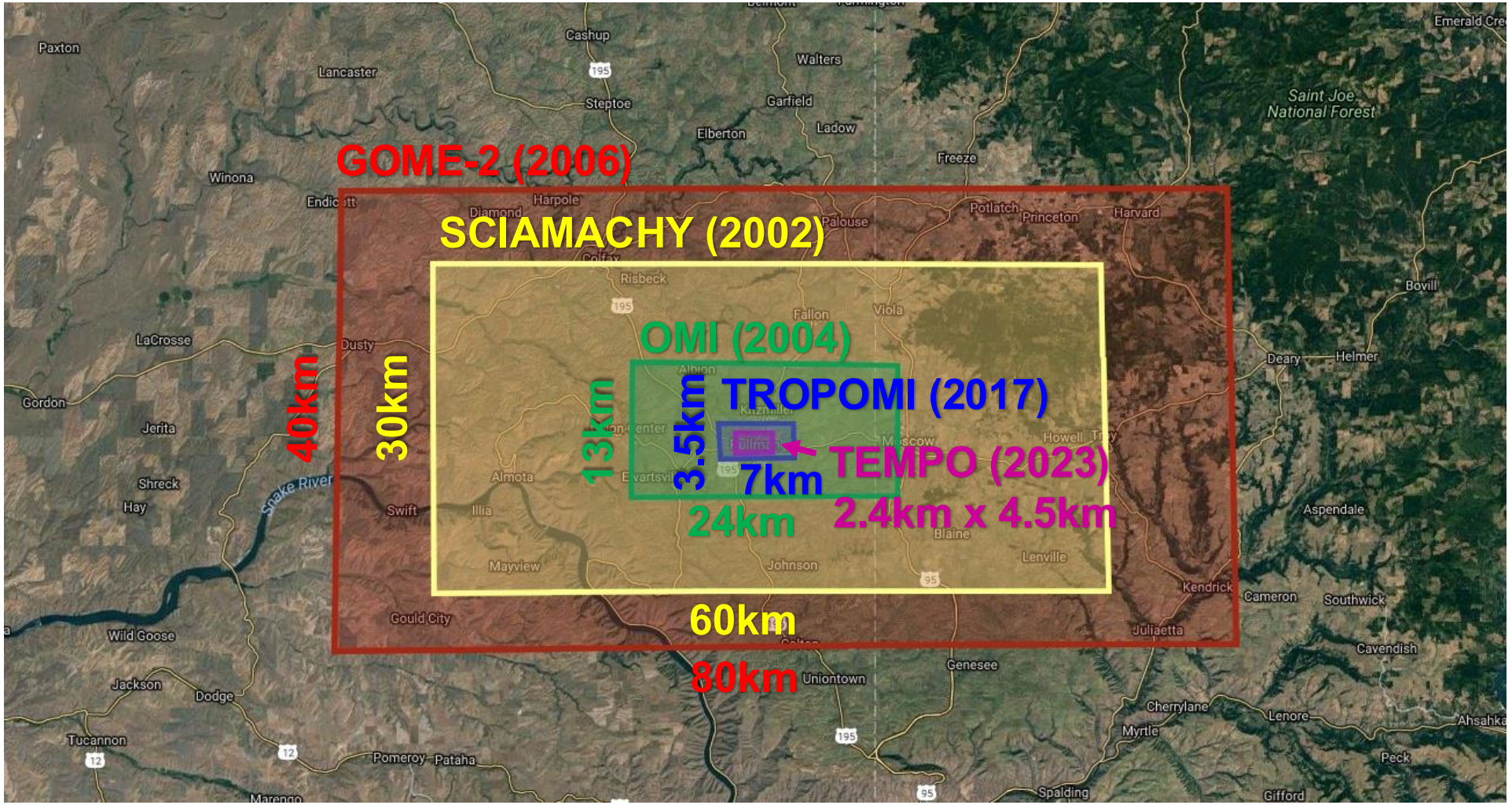
Always covers the same hemisphere

Terminology

- Satellite
- Instrument or Sensor
- Active and Passive Sensors
- Orbit
- Swath or Field of Regard
- Overpass Time (Local Solar Time)
- Equator Crossing Time
- Ascending/Descending

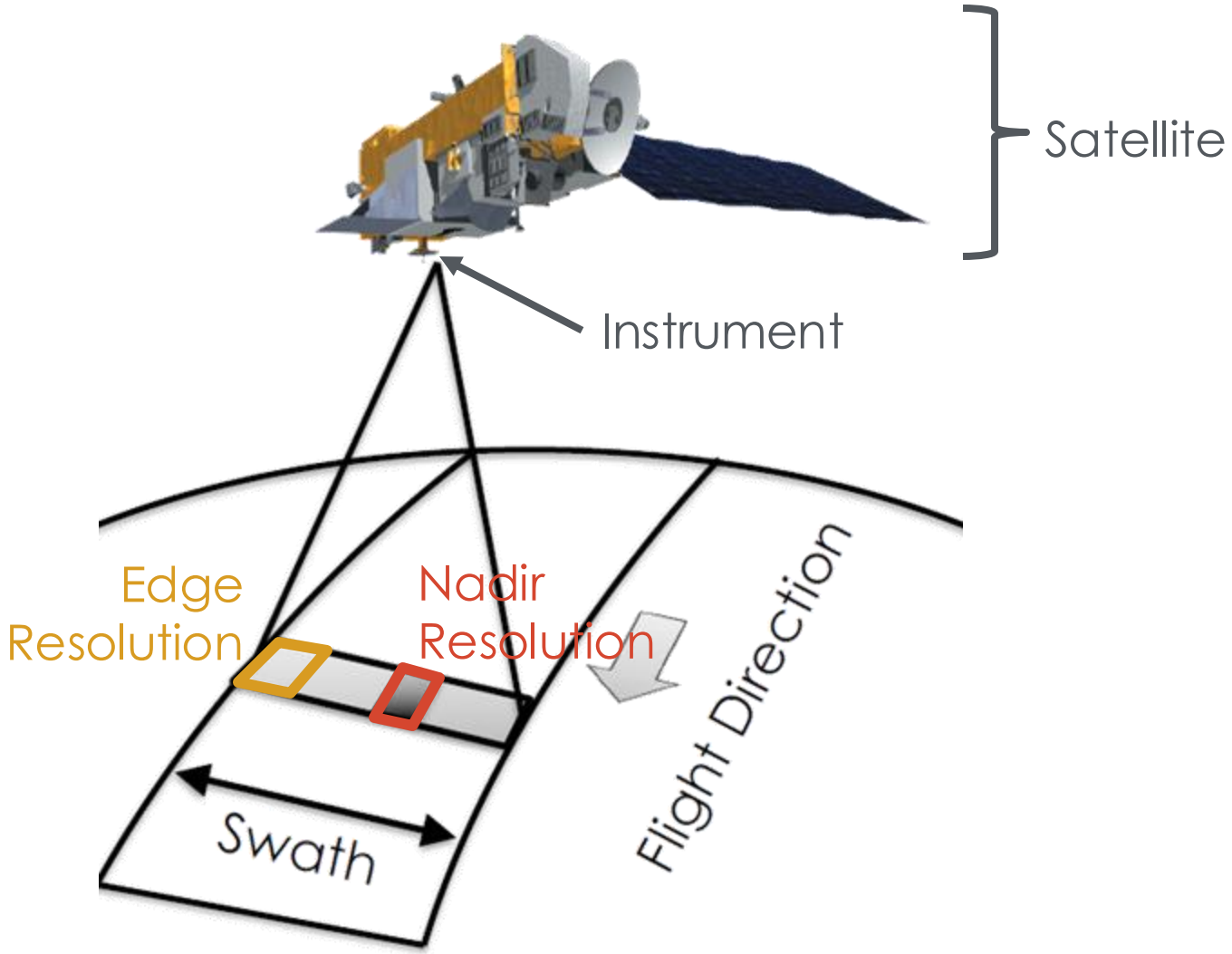


Spatial Resolution



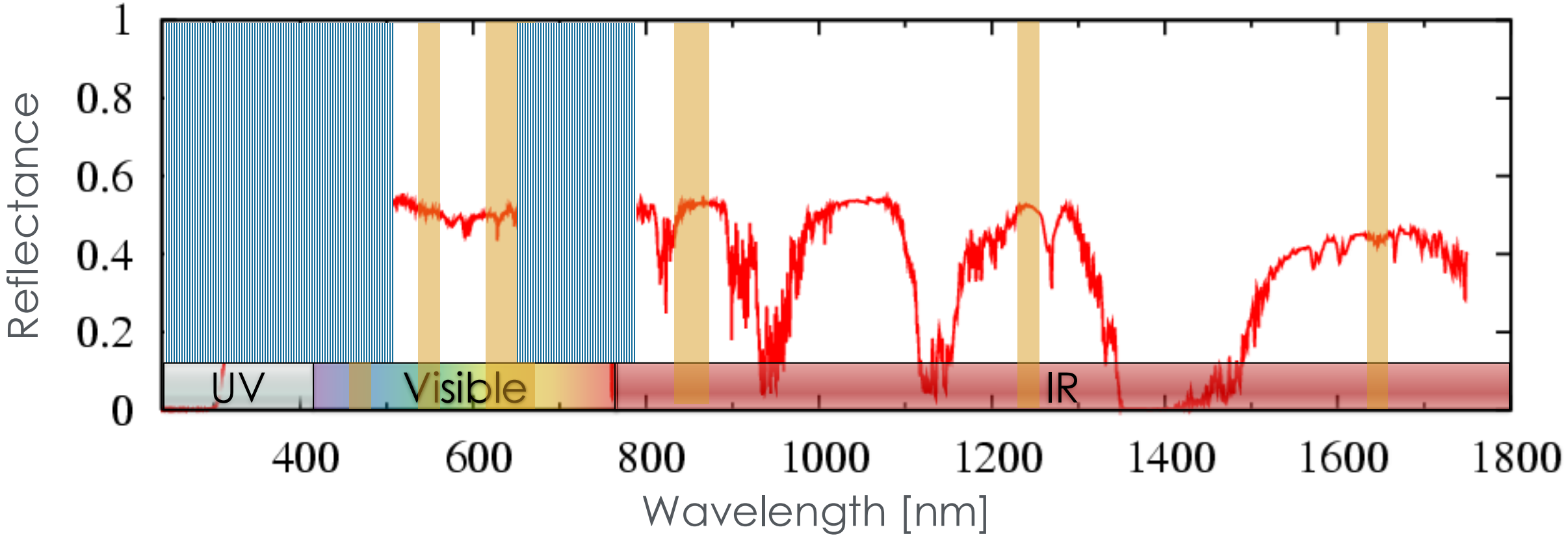
Terminology

- Satellite
- Instrument or Sensor
- Active and Passive Sensors
- Orbit
- Swath or Field of Regard
- Overpass Time (Local Solar Time)
- Equator Crossing Time
- Ascending/Descending
- Spatial Resolution (Nadir vs. Edge)



Spectral Range & Resolution

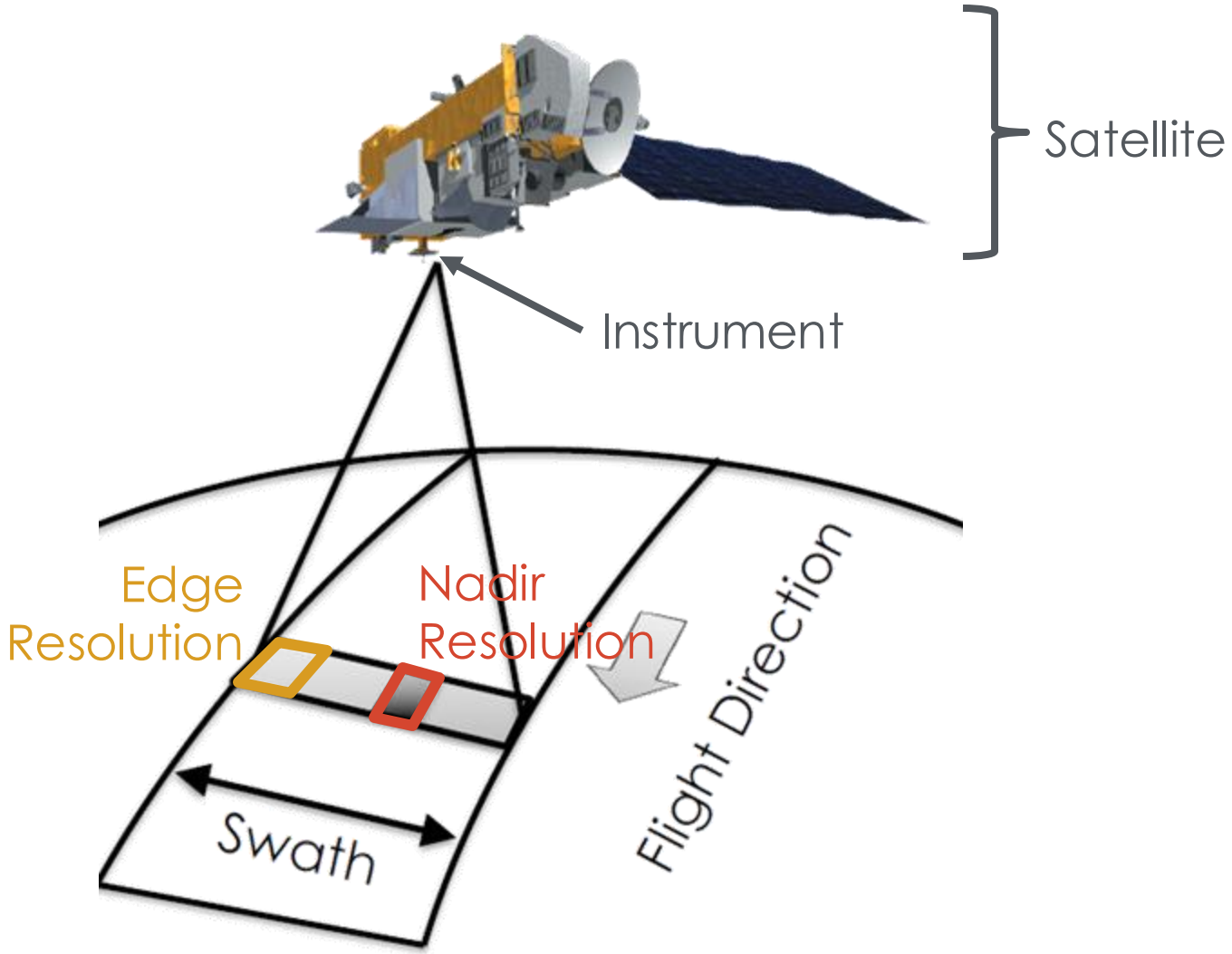
TROPOMI Hyperspectral Band Width: ~0.5 nm (2600 channels)



MODIS Multispectral Band Width: 10-50 nm (19 channels)

Terminology

- Satellite
- Instrument or Sensor
- Active and Passive Sensors
- Orbit
- Swath or Field of Regard
- Overpass Time (Local Solar Time)
- Equator Crossing Time
- Ascending/Descending
- Spatial Resolution (Nadir vs. Edge)
- Spectral Resolution and Range



Satellite Data Processing Levels

- **Level 0:**
- **Level 1:**
- **Level 2:**
- **Level 3:**
- **Level 4:**

Source: Data Processing Levels. *NASA EarthData.*

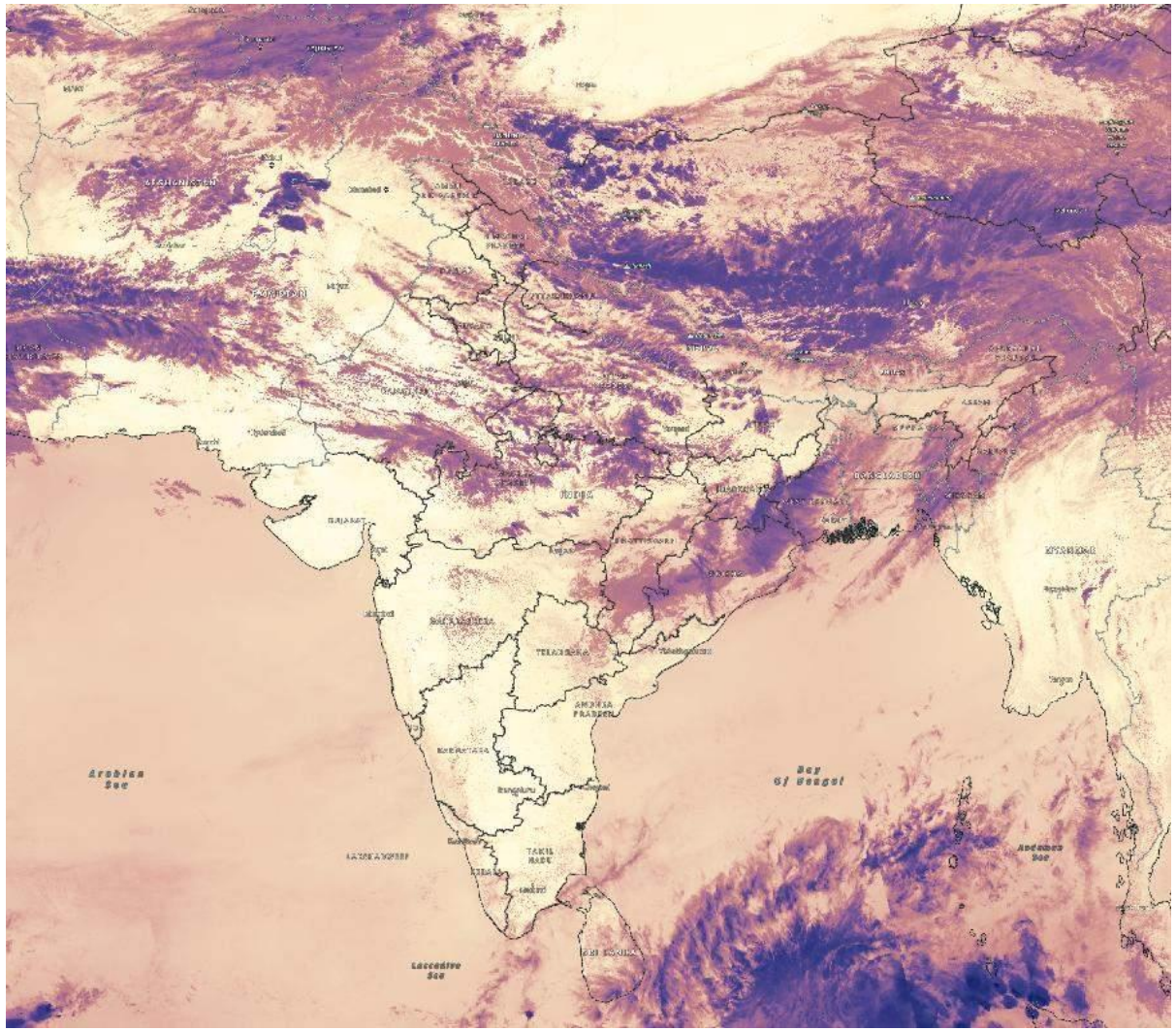
Satellite Data Processing Levels

- **Level 0:** Raw data
- **Level 1:**
- **Level 2:**
- **Level 3:**
- **Level 4:**

Source: Data Processing Levels. *NASA EarthData.*

Satellite Data Processing Levels

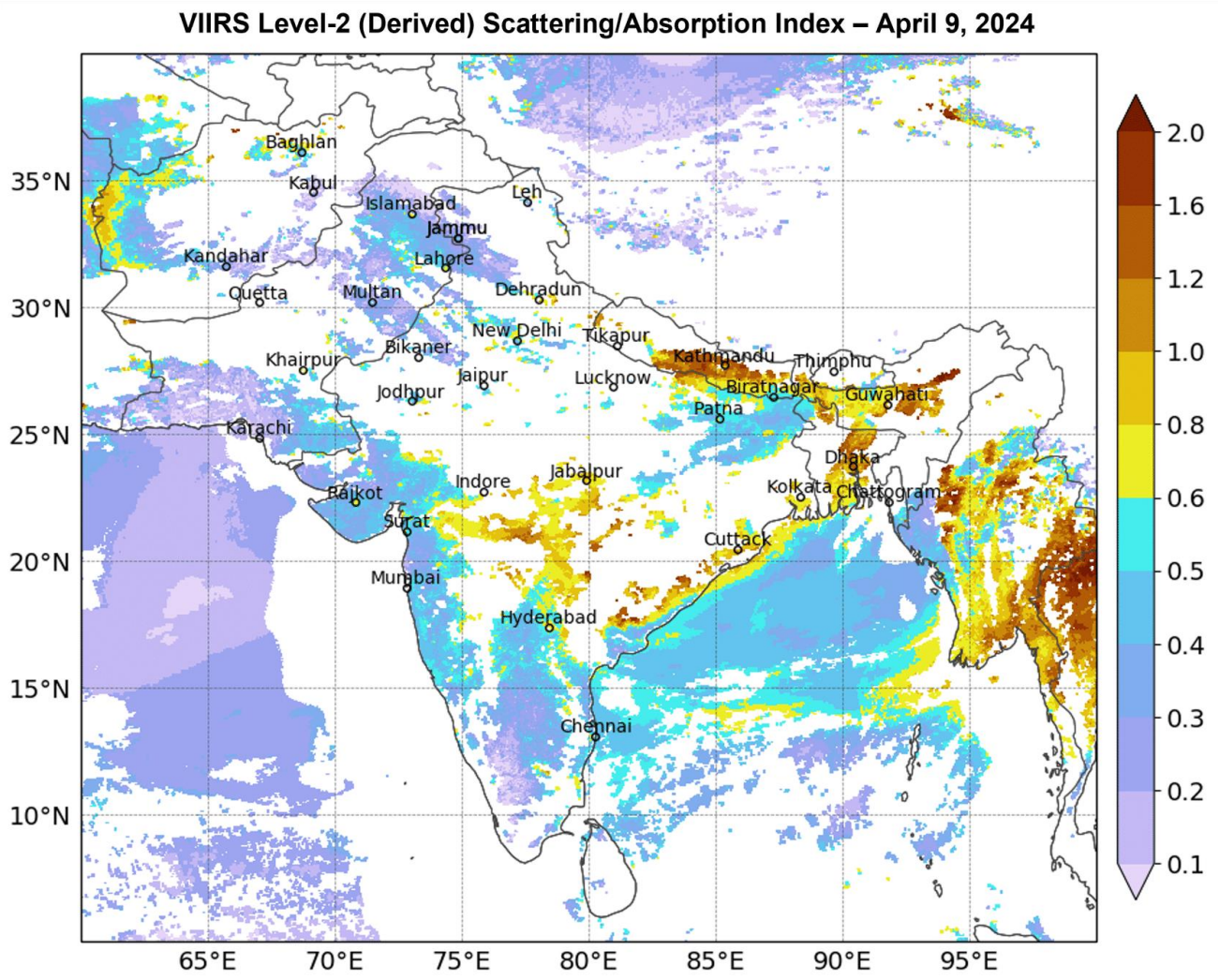
- **Level 0:** Raw data
- **Level 1:** Geo-referenced raw data
- **Level 2:**
- **Level 3:**
- **Level 4:**



Source: Data Processing Levels. *NASA EarthData.*

Satellite Data Processing Levels

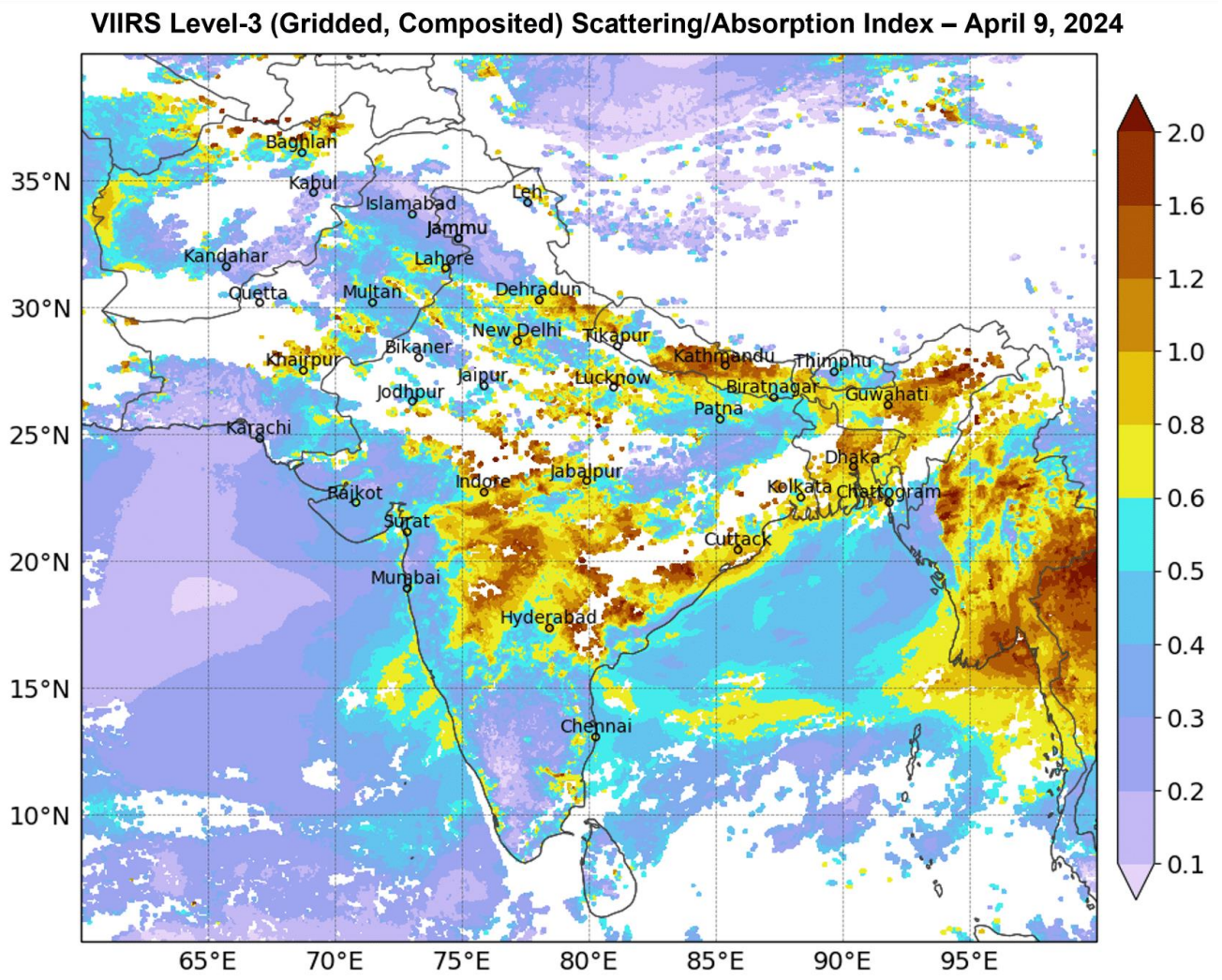
- **Level 0:** Raw data
- **Level 1:** Geo-referenced raw data
- **Level 2:** Derived geophysical variables (e.g., column concentrations)
- **Level 3:**
- **Level 4:**



Source: Data Processing Levels. *NASA EarthData.*

Satellite Data Processing Levels

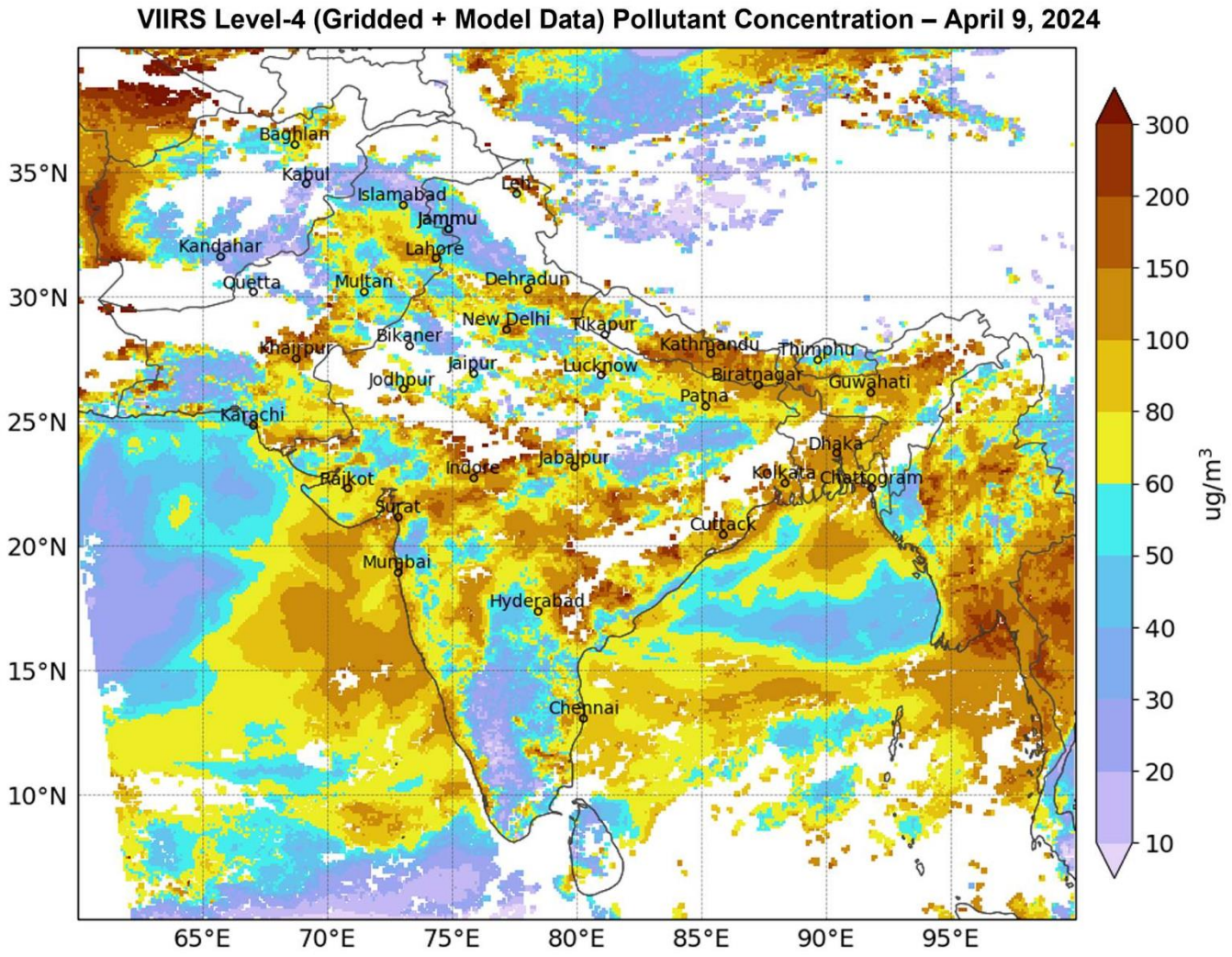
- **Level 0:** Raw data
- **Level 1:** Geo-referenced raw data
- **Level 2:** Derived geophysical variables (e.g., column concentrations)
- **Level 3:** Data re-mapped to uniform space & time grids (usually with recommended quality controls)
- **Level 4:**



Source: Data Processing Levels. *NASA EarthData.*

Satellite Data Processing Levels

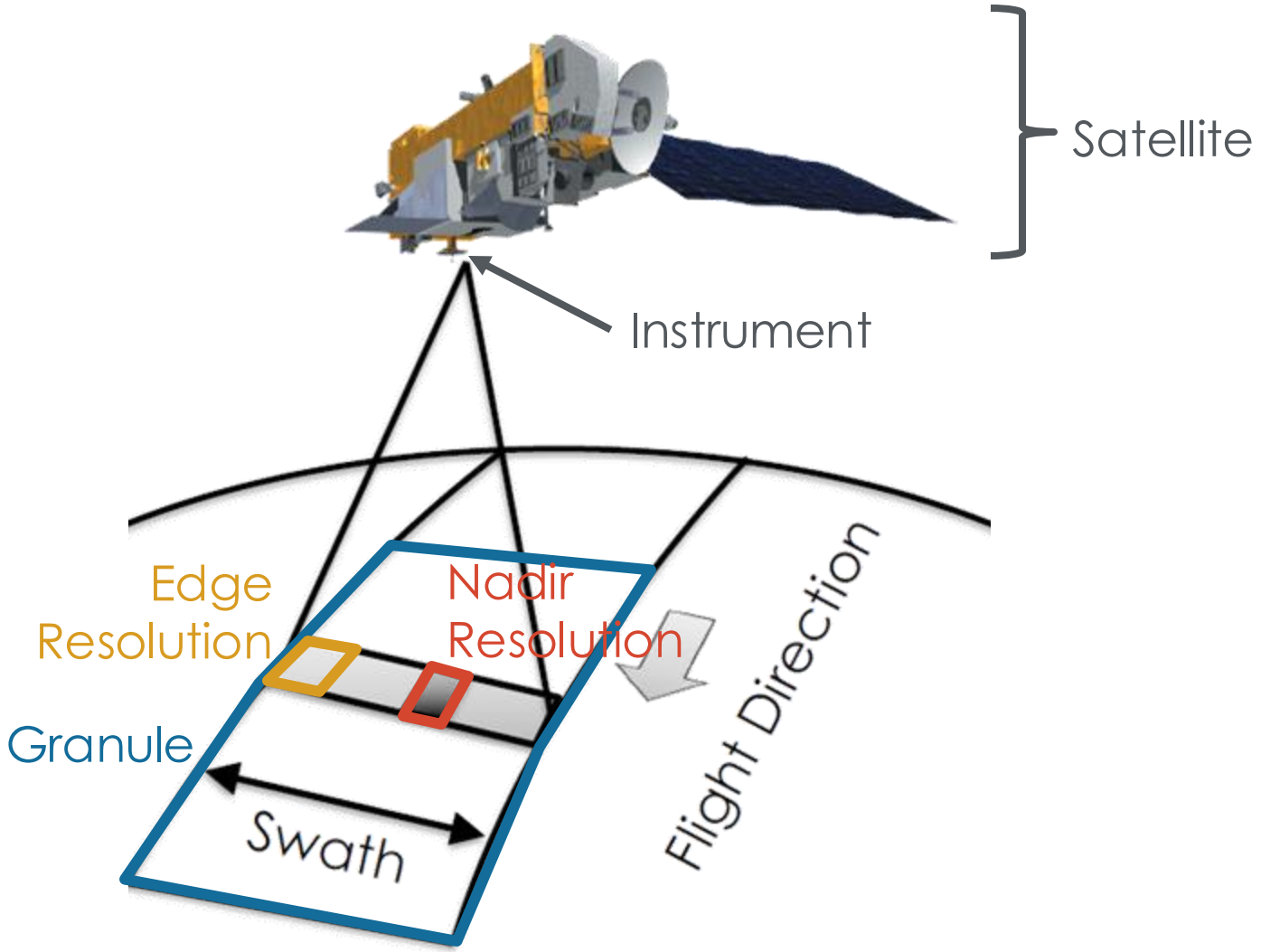
- **Level 0:** Raw data
- **Level 1:** Geo-referenced raw data
- **Level 2:** Derived geophysical variables (e.g., column concentrations)
- **Level 3:** Data re-mapped to uniform space & time grids (usually with recommended quality controls)
- **Level 4:** Data from multiple sources combined together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

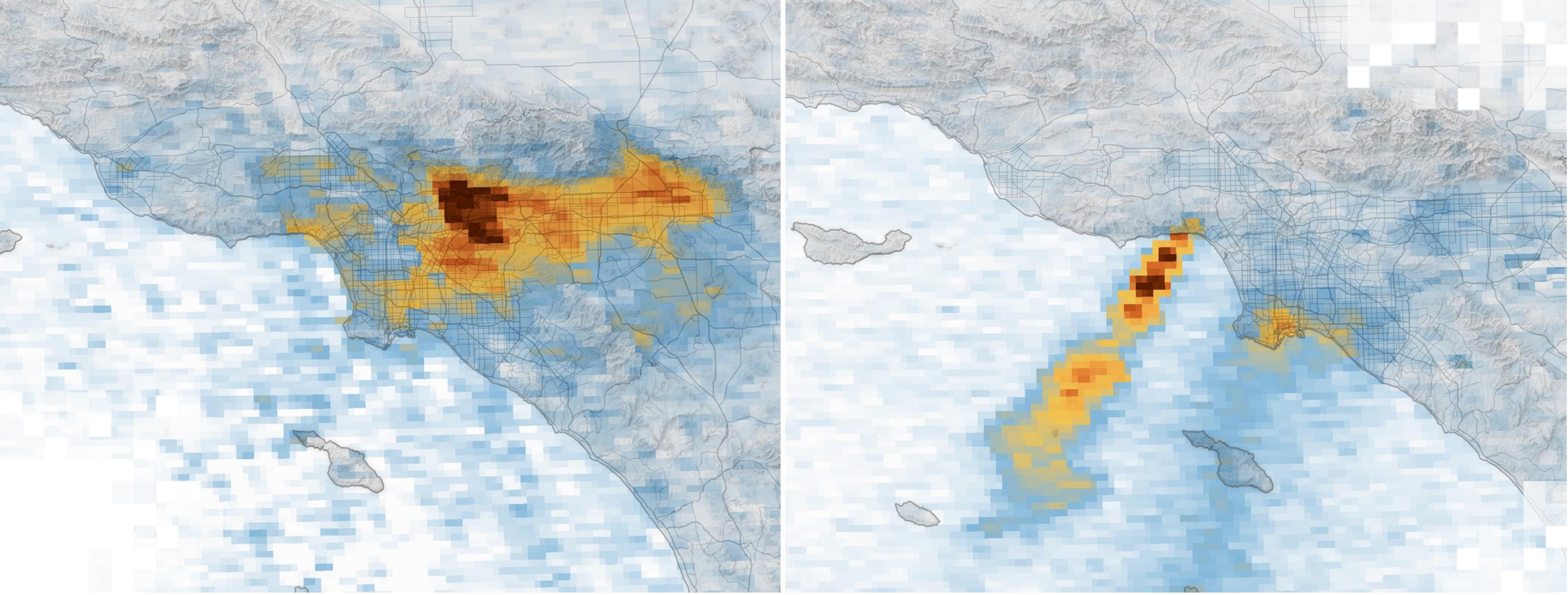


Source: Data Processing Levels. *NASA EarthData.*

Terminology

- Satellite
- Instrument or Sensor
- Active and Passive Sensors
- Orbit
- Swath or Field of Regard
- Overpass Time (Local Solar Time)
- Equator Crossing Time
- Ascending/Descending
- Spatial Resolution (Nadir vs. Edge)
- Spectral Resolution and Range
- Data Product
- Processing Level
- Granule

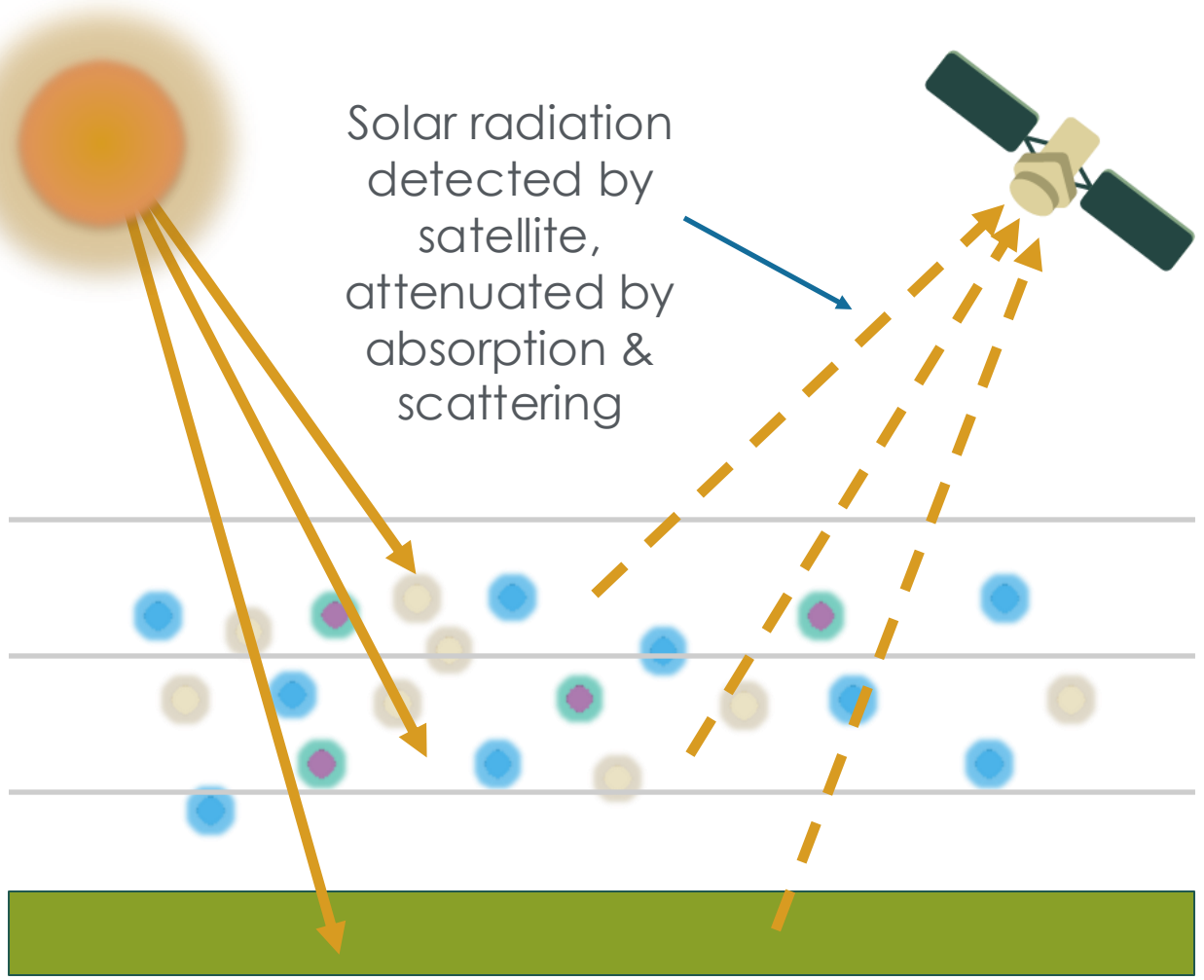




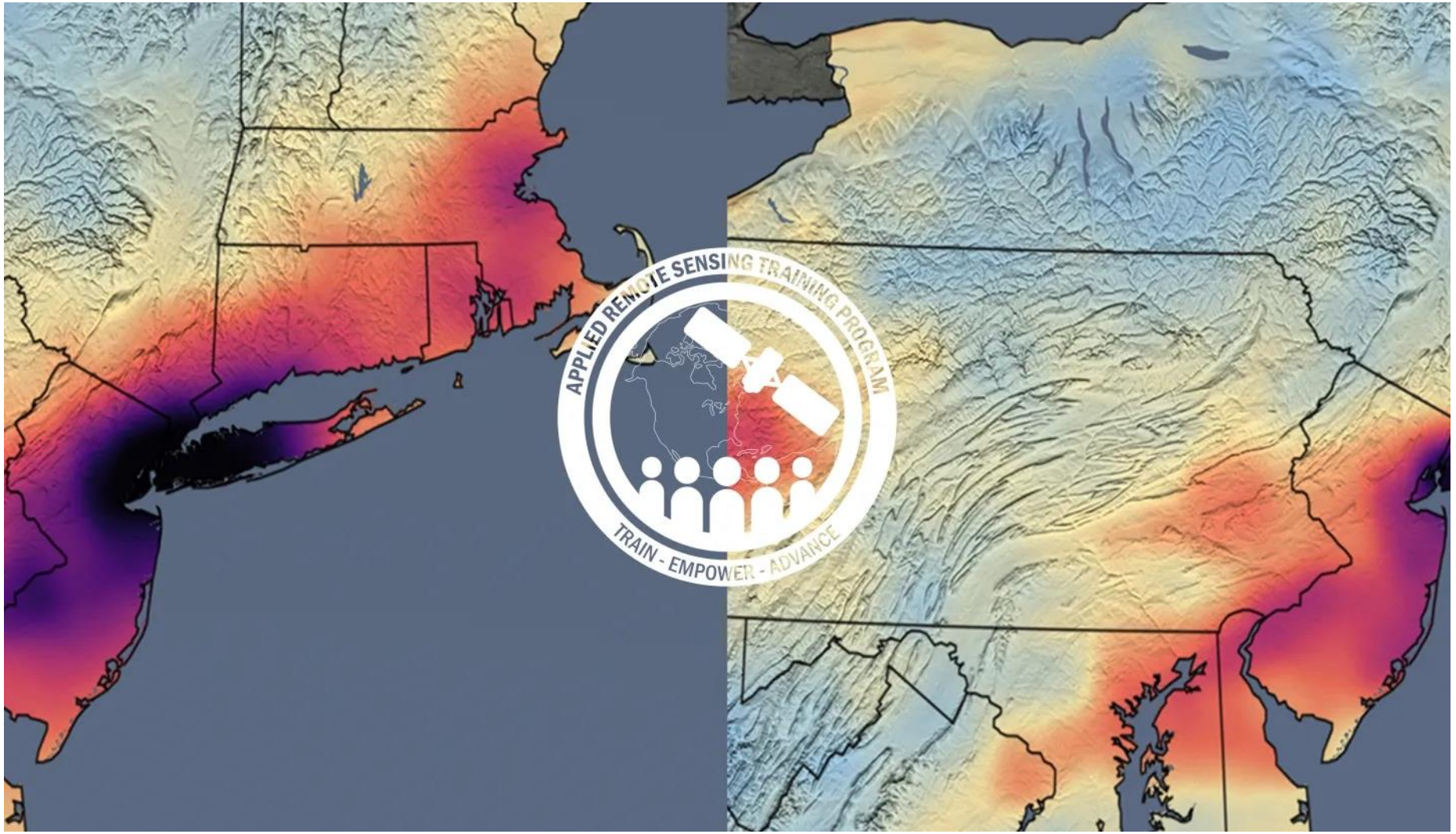
Remote Sensing for Air Quality Applications

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.



An Inside Look at How NASA Measures Air Pollution



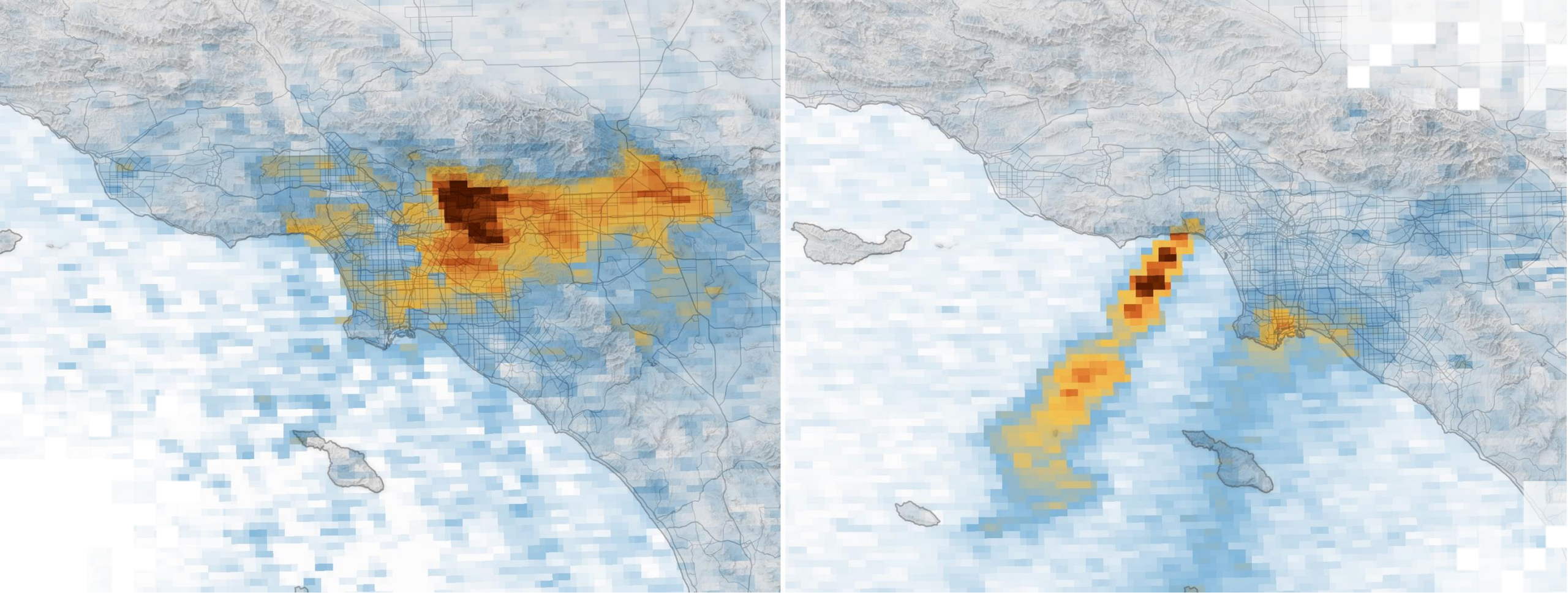
Online, Instructor-Led

Level: Introductory

2 Parts

May 26, 2020 –
May 28, 2020

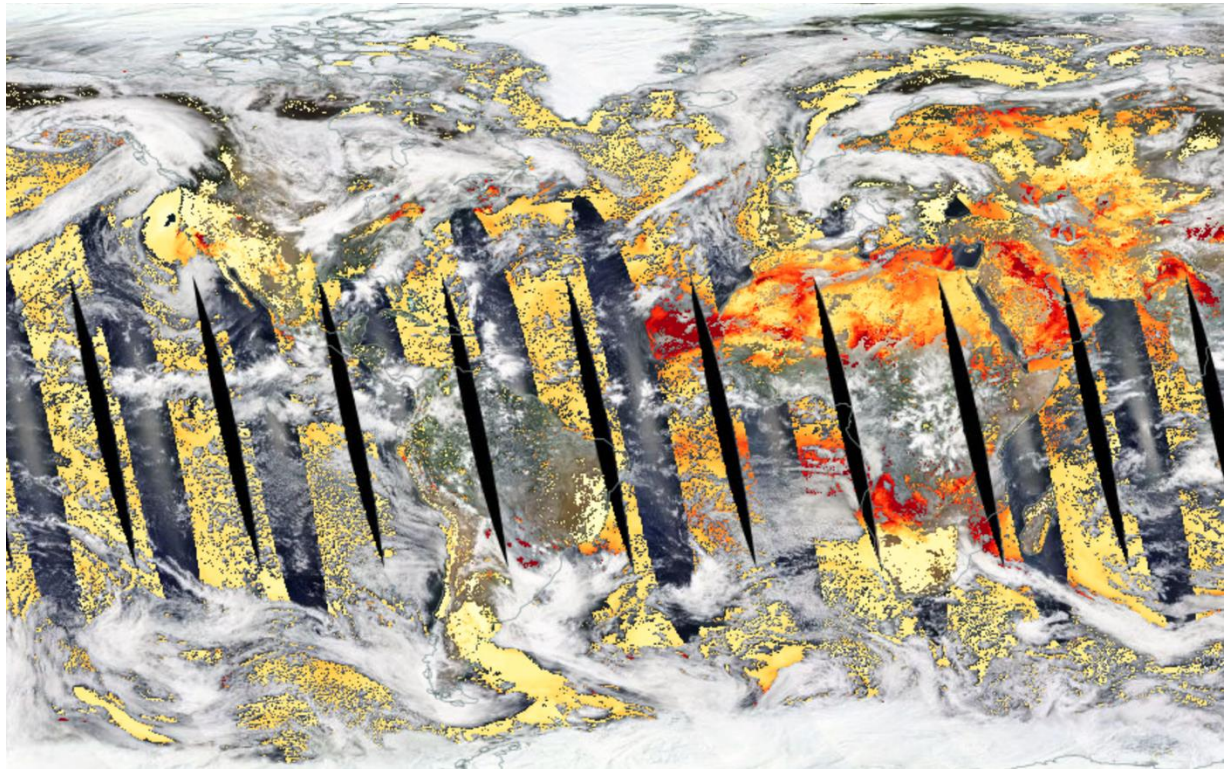
Link to Training



Remote Sensing of Aerosols

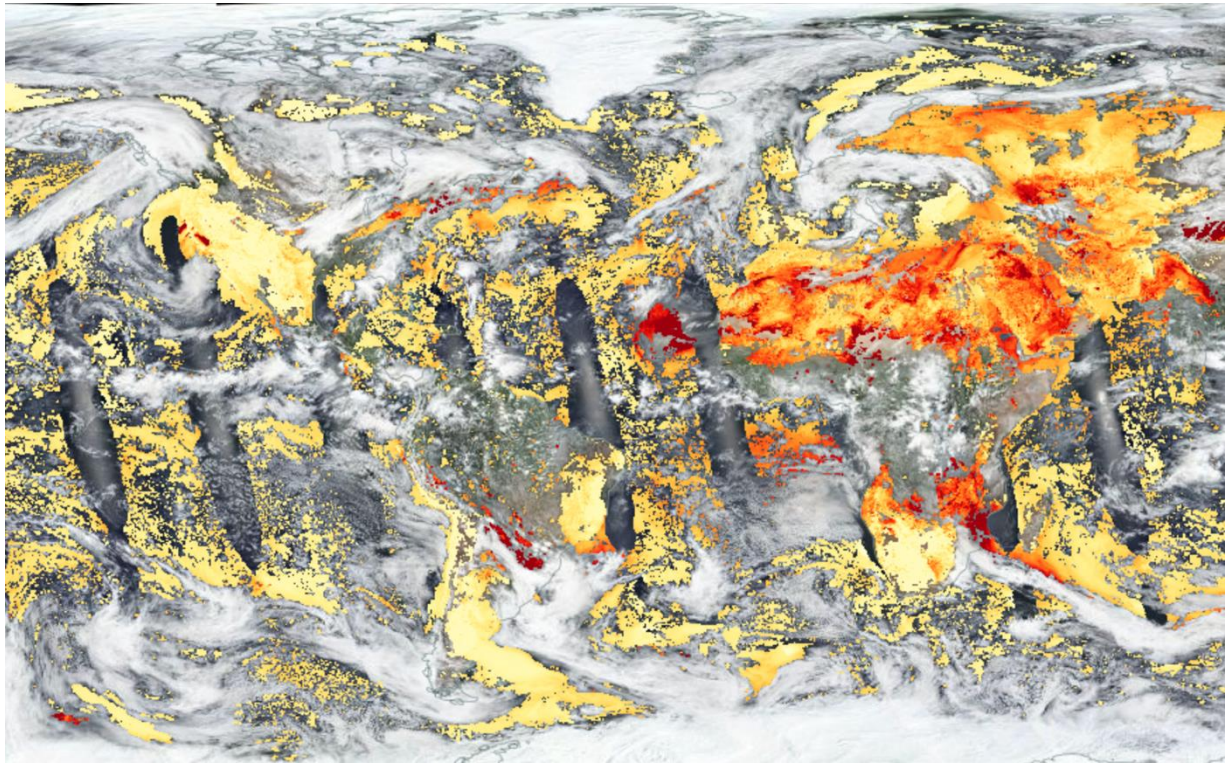
MODIS & VIIRS

MODIS-Aqua



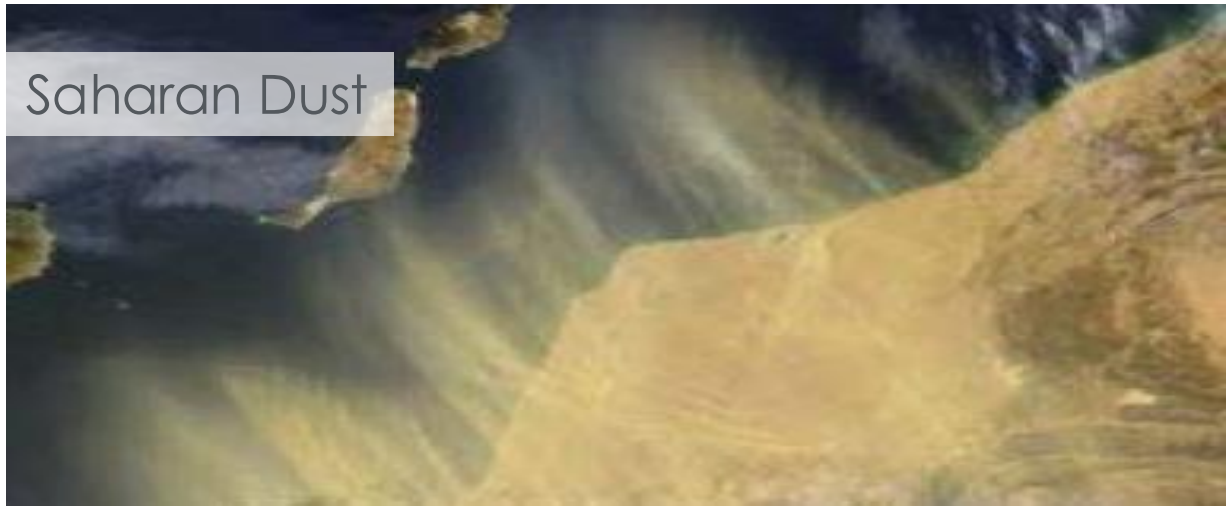
2 Satellites: Terra, Aqua (1999-Present)
0.5 – 2.0 km Spatial Resolution
36 Spectral Channels
Sun-Synchronous LEO

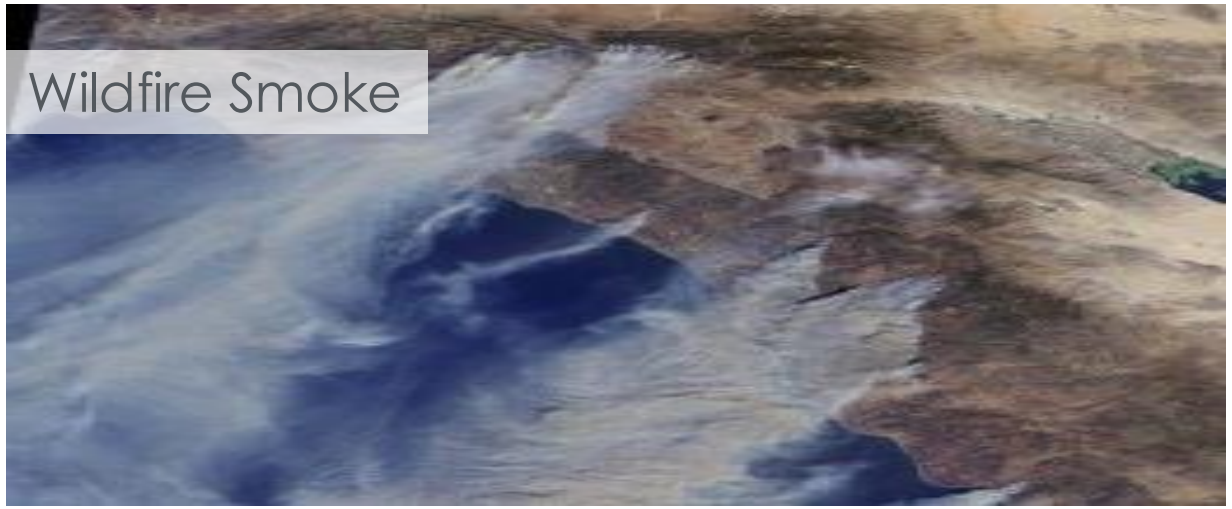
VIIRS-SNPP



3 Satellites: SNPP, NOAA-20, NOAA-21 (2011-Present)
0.75 – 1.5 km Spatial Resolution
22 Spectral Channels
Sun-Synchronous LEO

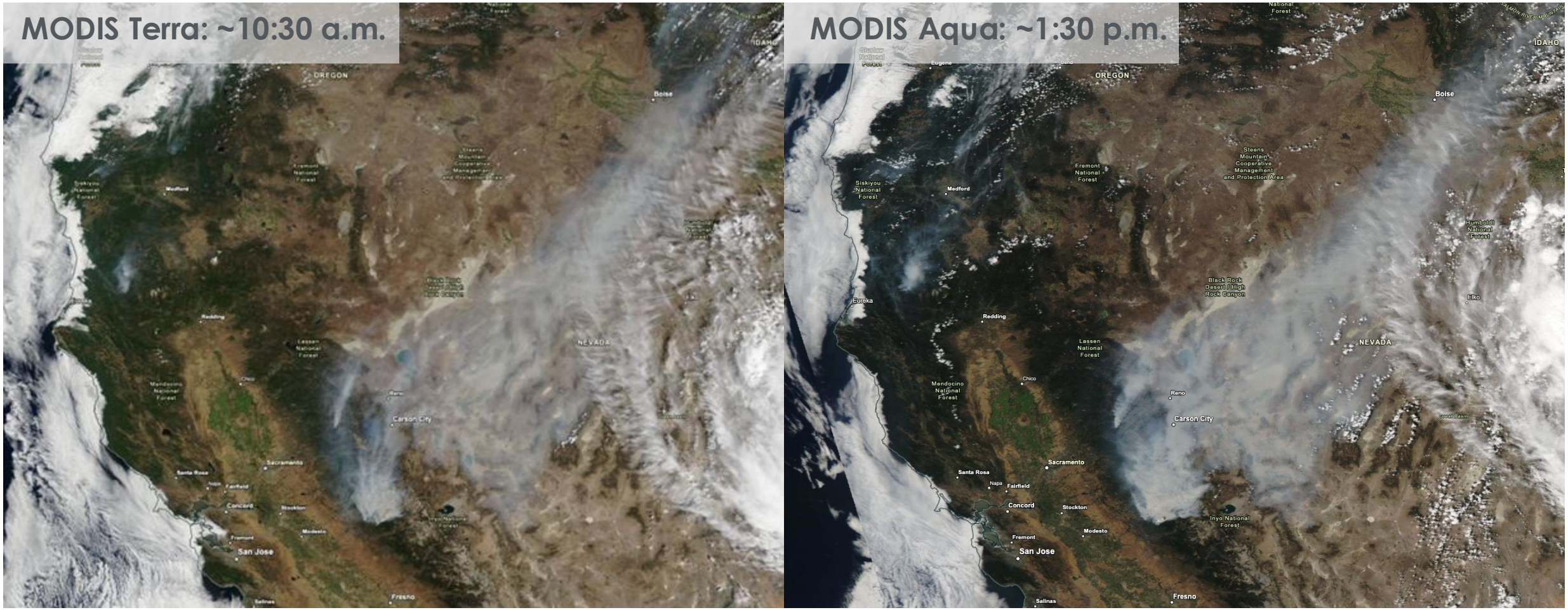
Visible Imagery of Aerosols





Source: NASA Earth Observatory

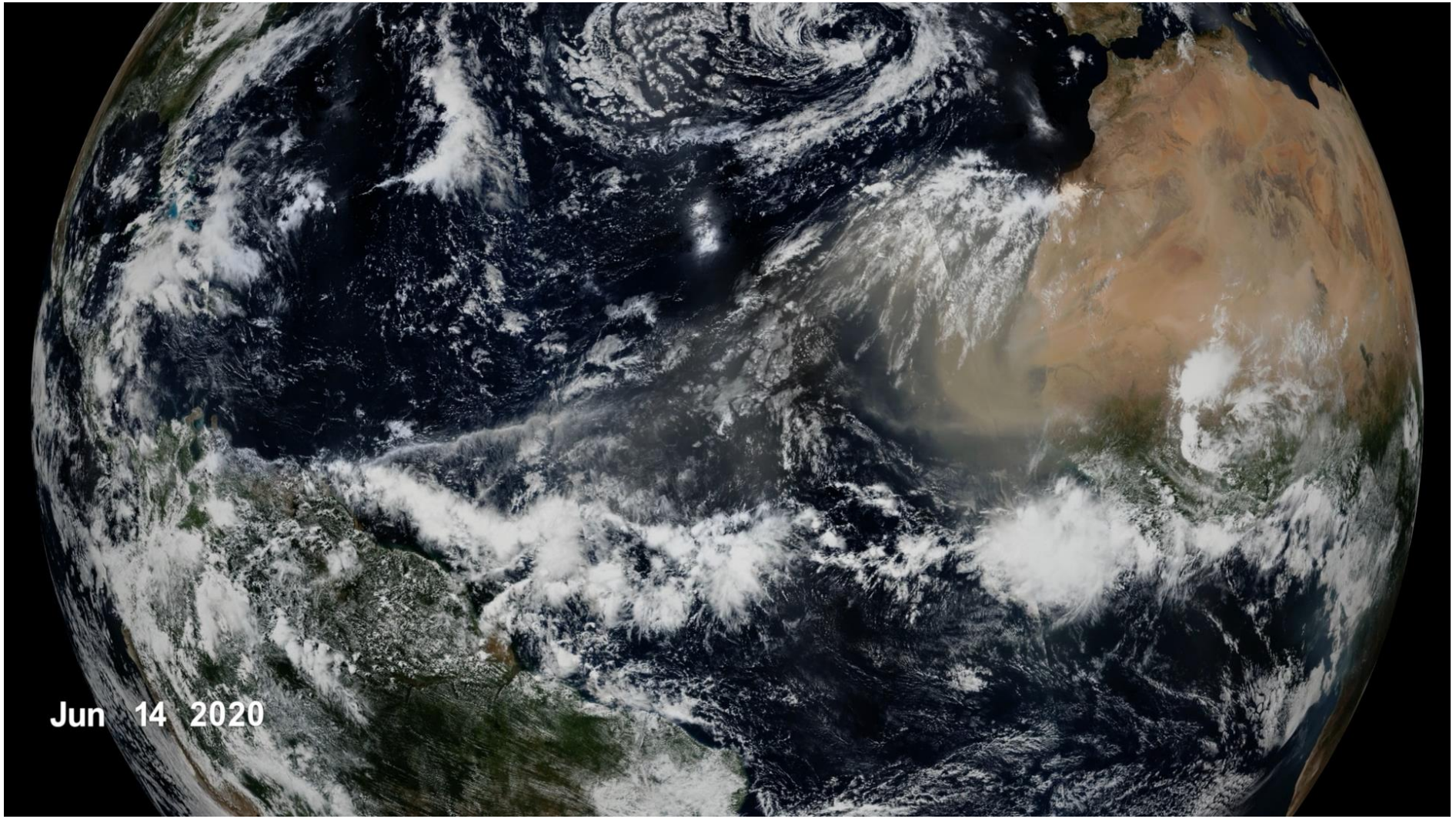
Visible Imagery of Aerosols



August 23, 2013

Source: NASA Worldview

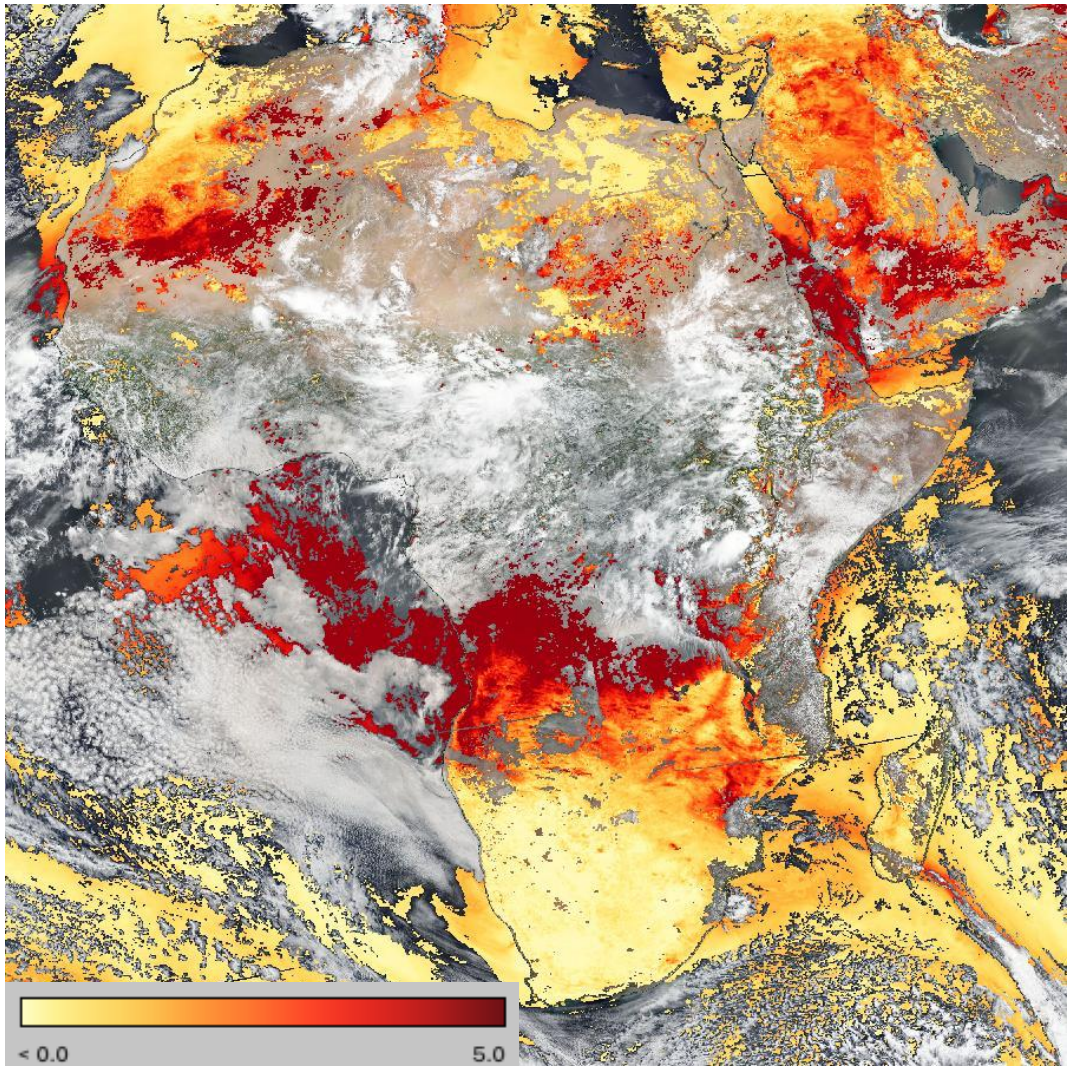
Visible Imagery of Aerosols



Source: NASA Scientific Visualization Studio, "Godzilla Dust Storm"

Aerosol Optical Depth

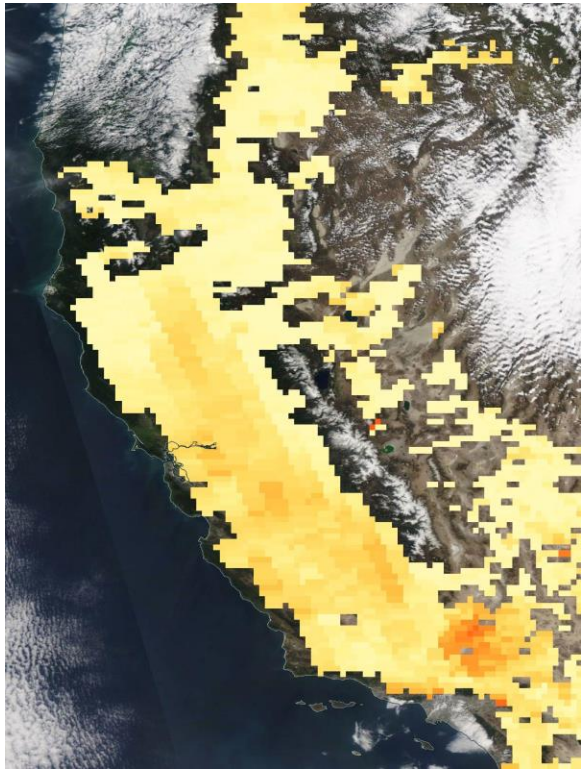
- AOD, or Aerosol Optical Thickness (AOT)
- Measures the quantity of light removed by scattering and absorption by aerosols along an atmospheric path.
- Unitless
- AOD is wavelength-dependent.
- AOD measured at mid-visible wavelengths (500-550nm) is reasonably representative of total aerosol concentration.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



Source: NASA Worldview

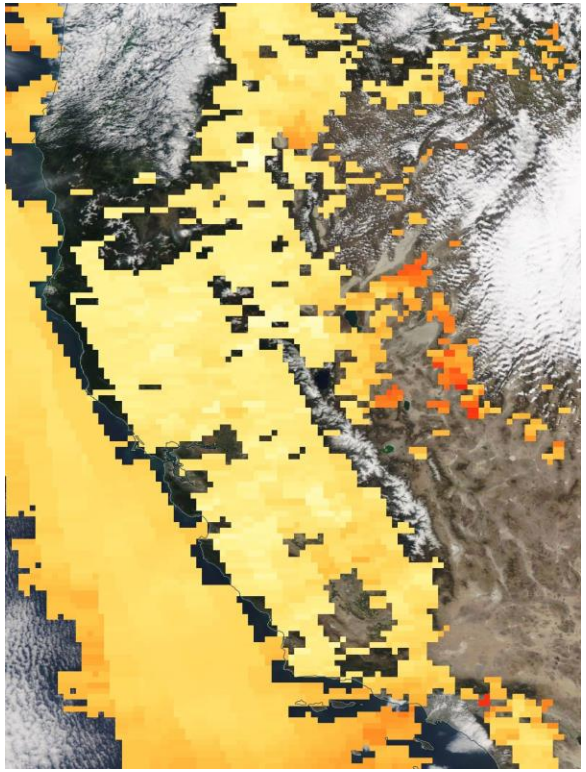
Aerosol Optical Depth Retrieval Algorithms

Deep Blue (10km)
MOD/MYD04_L2



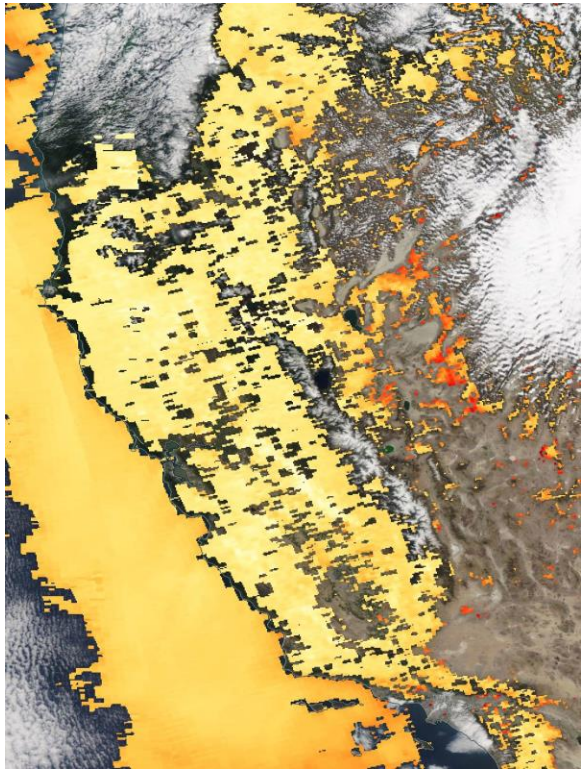
Land Only,
Best for Bright Surfaces

Dark Target (10km)
MOD/MYD04_L2



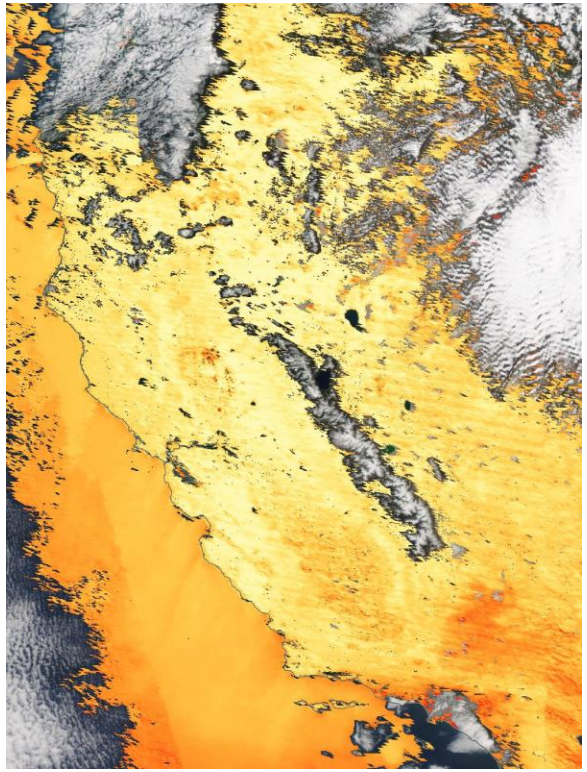
Land & Water,
Best for Dark Surfaces

Dark Target (3km)
MOD/MYD04_3K



Higher Resolution,
Issues in Urban Areas

MAIAC (1km)
MCD19A2

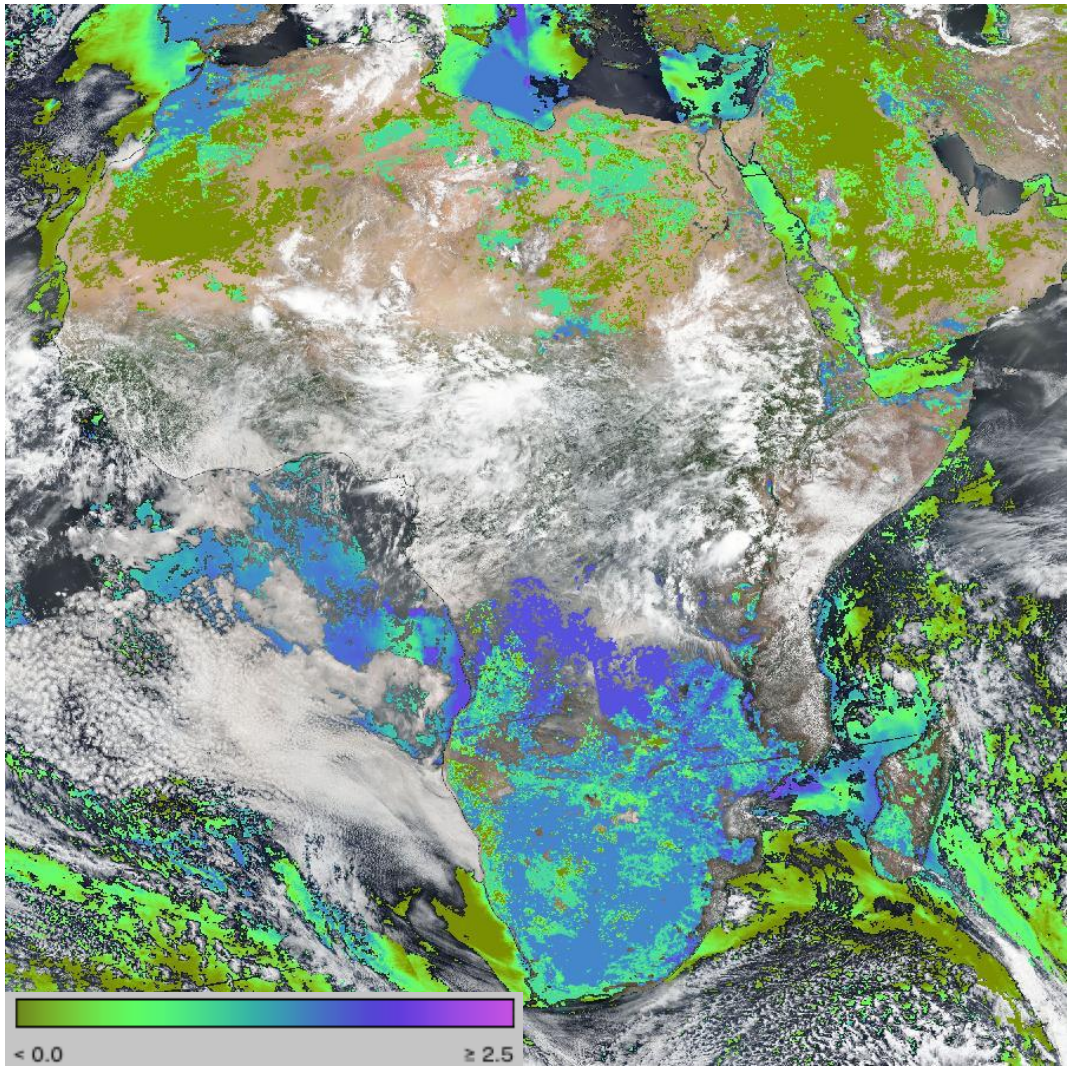


Highest Resolution,
Combine Aqua &
Terra

Source: NASA Worldview

Angstrom Exponent

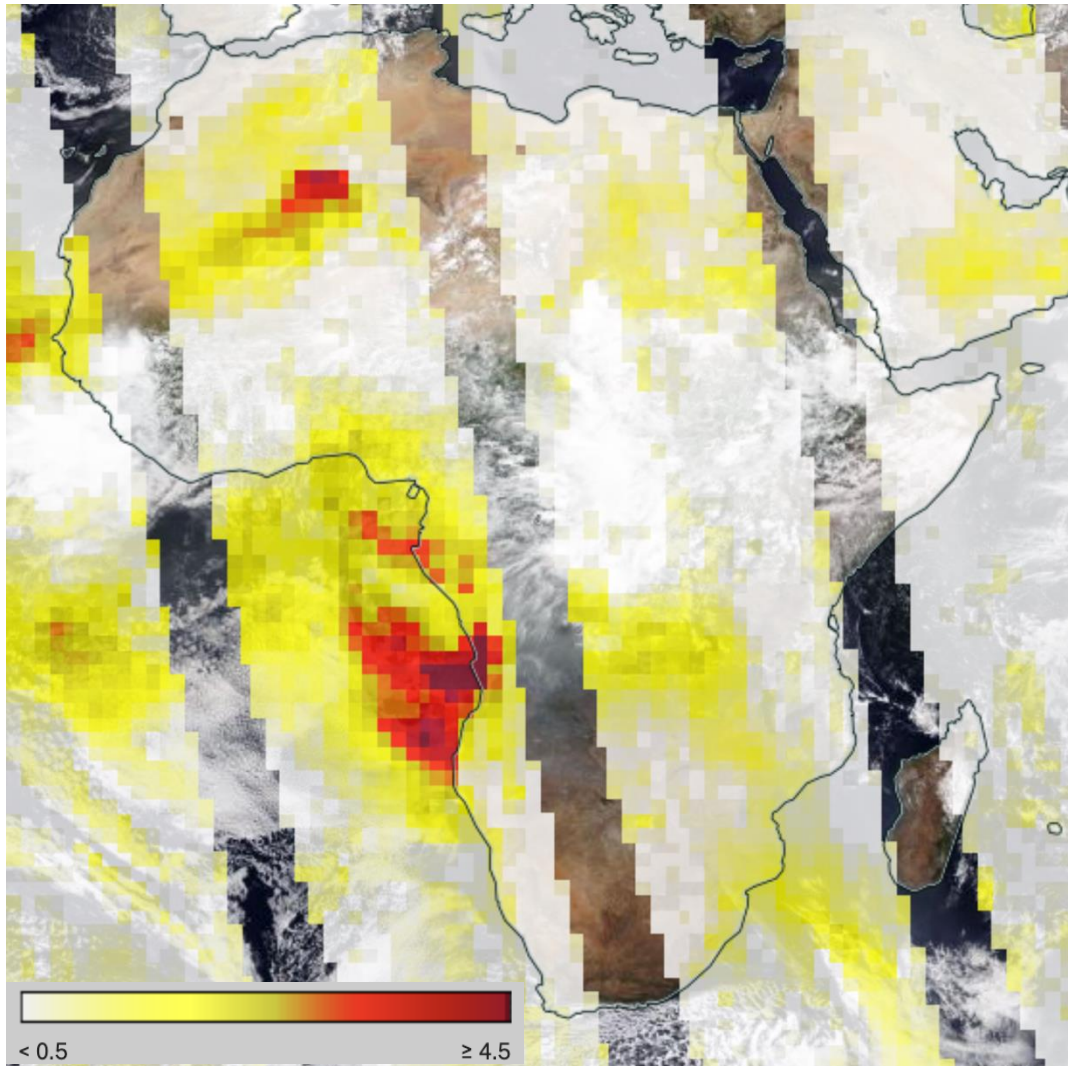
- Angstrom Parameter or Angstrom Exponent measures how AOD varies with wavelength.
- Typically estimated between 440nm and 870nm.
- Unitless
- Greater than 2 indicates smaller aerosols (e.g., smoke).
- Less than 0.5 indicates larger aerosols (e.g., dust).



Source: NASA Worldview

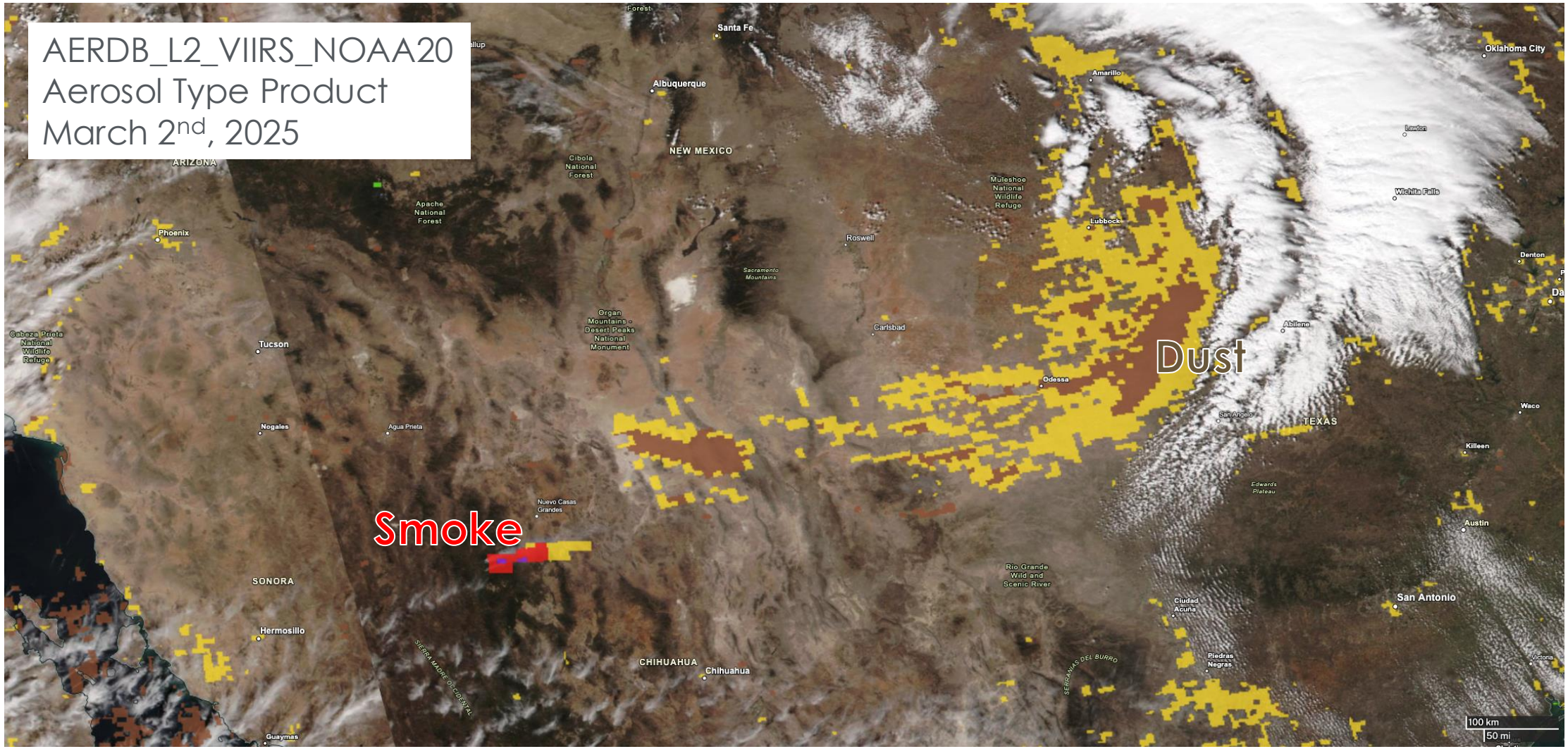
UV Aerosol Index

- 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]

MODIS to VIIRS Transition for Air Quality Applications

Online, Instructor-Led

Level: Advanced

1 Part

October 22, 2020

Link to Training

Fire Detection

- IR remote sensing useful to detect thermal anomalies (usually fires)
- Provides data on:
  - Hotspot Location
  - Fire Radiative Power [W/m^2]
- 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

Satellite Observations and Tools for Fire Risk, Detection, and Analysis

Online, Instructor-Led

Level: Intermediate

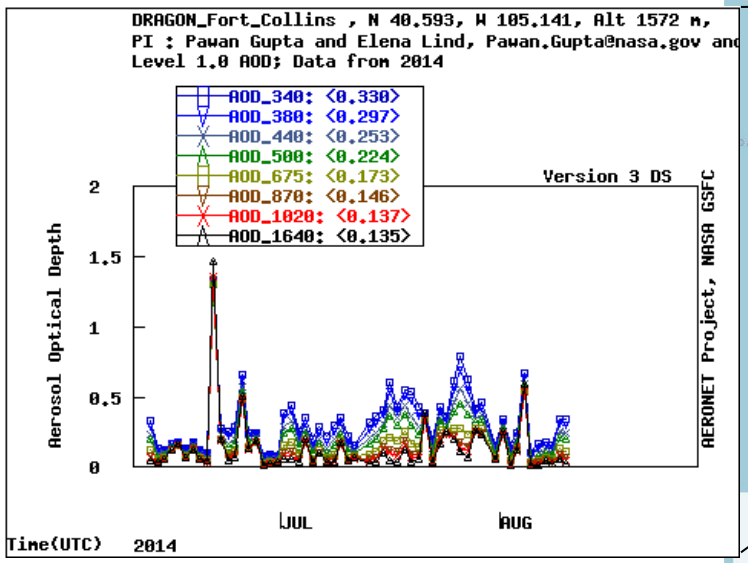
6 Parts

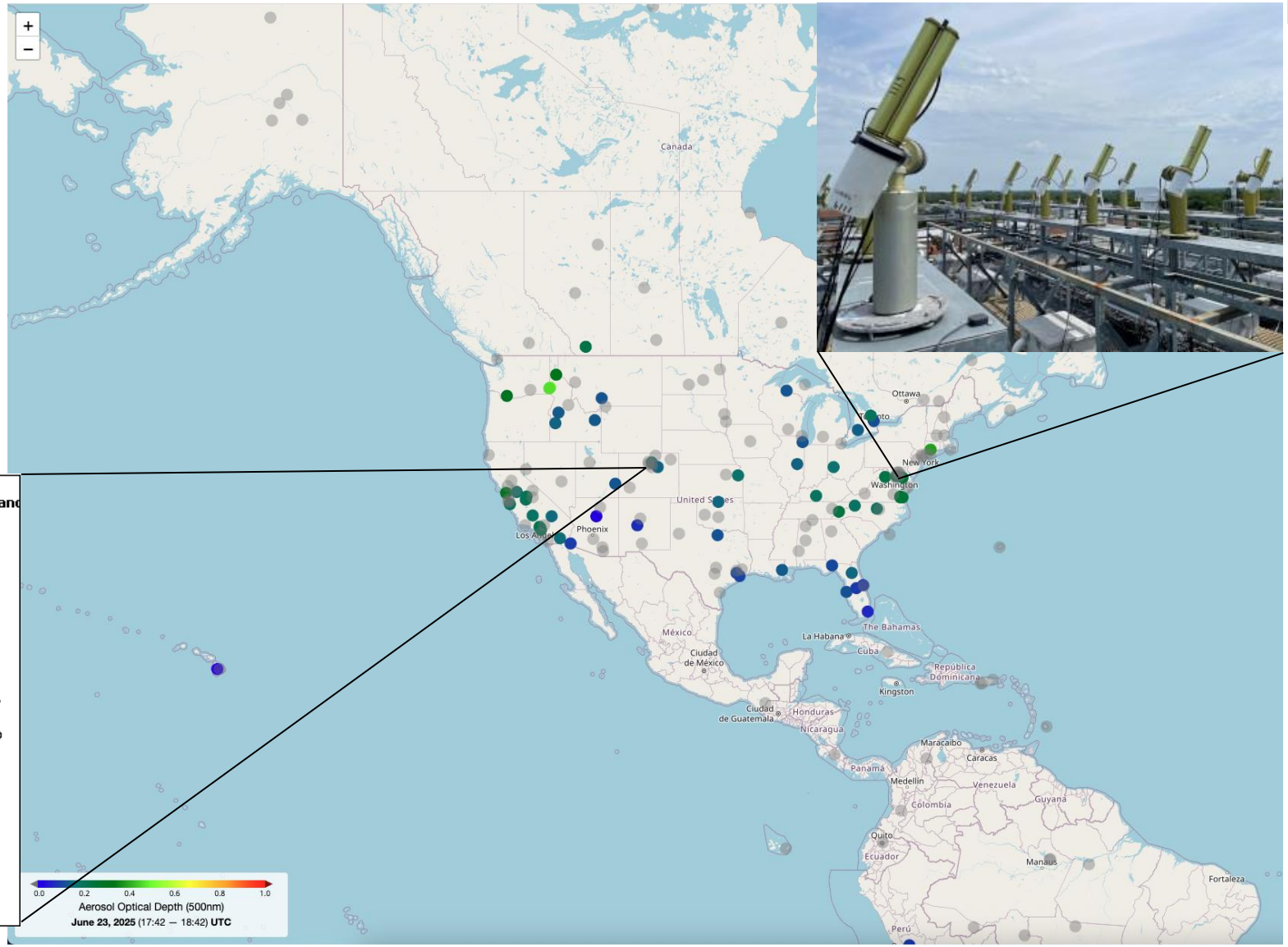
May 11, 2021 –
May 27, 2021

Link to Training

AERONET

- Aerosol Robotic Network
- Global Network, 100+ Sites
- Multispectral AOD
- Satellite Validation, Research
- Relating Satellite AOD to Near-Surface $PM_{2.5}$

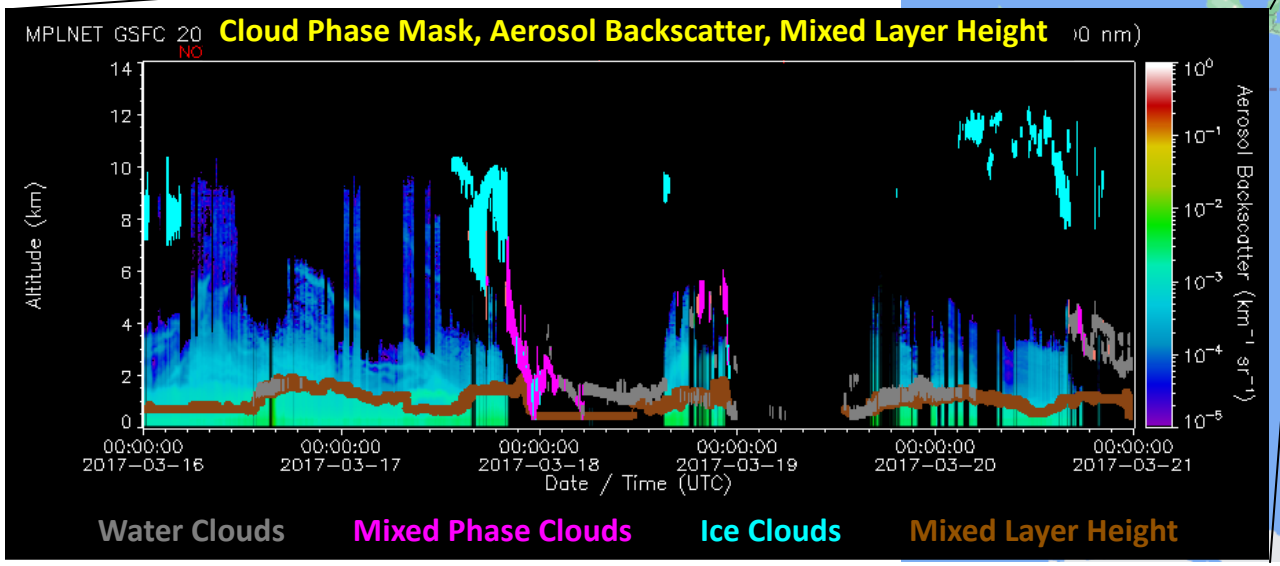


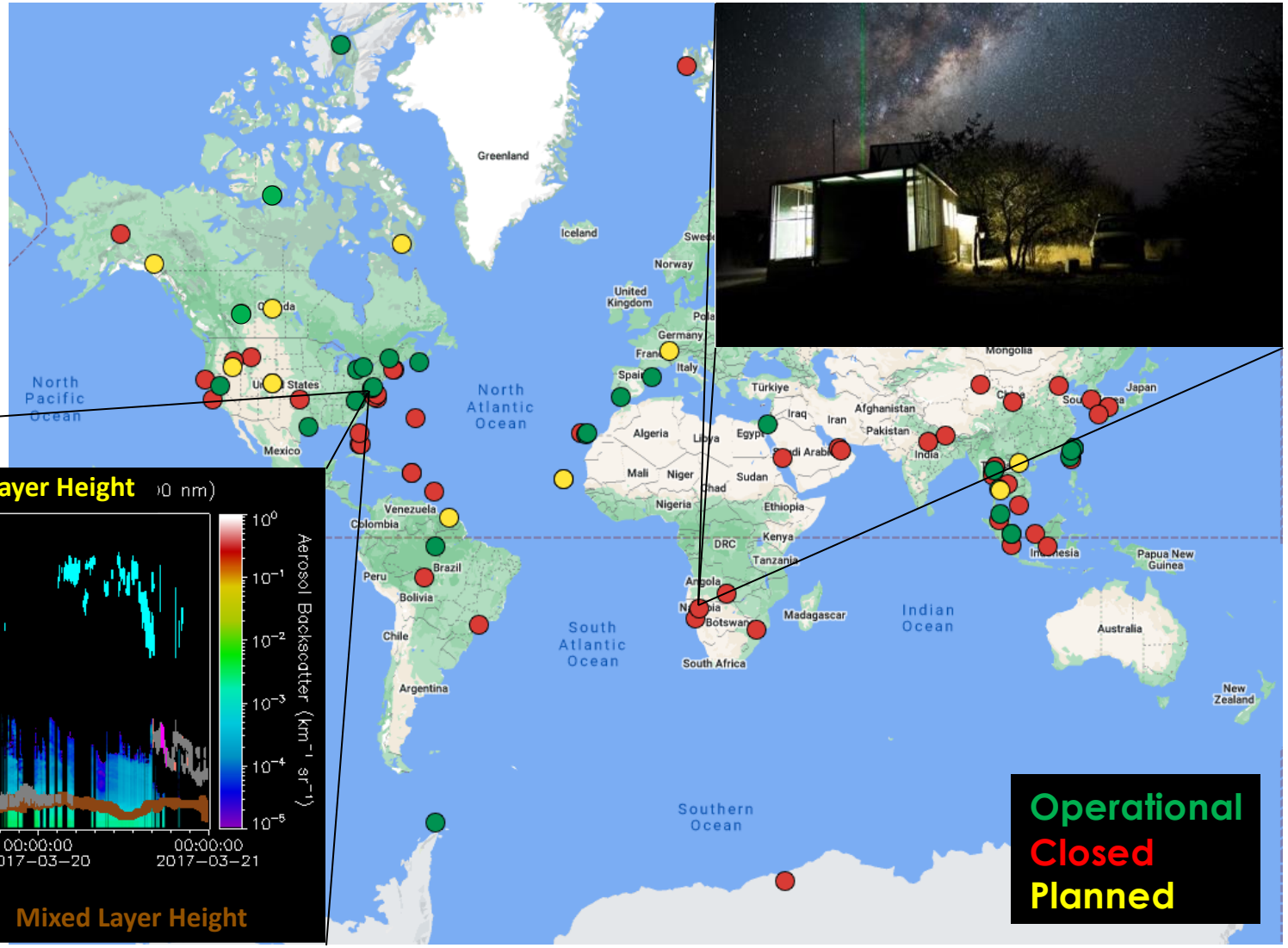


Source: AERONET Website

MPLNET

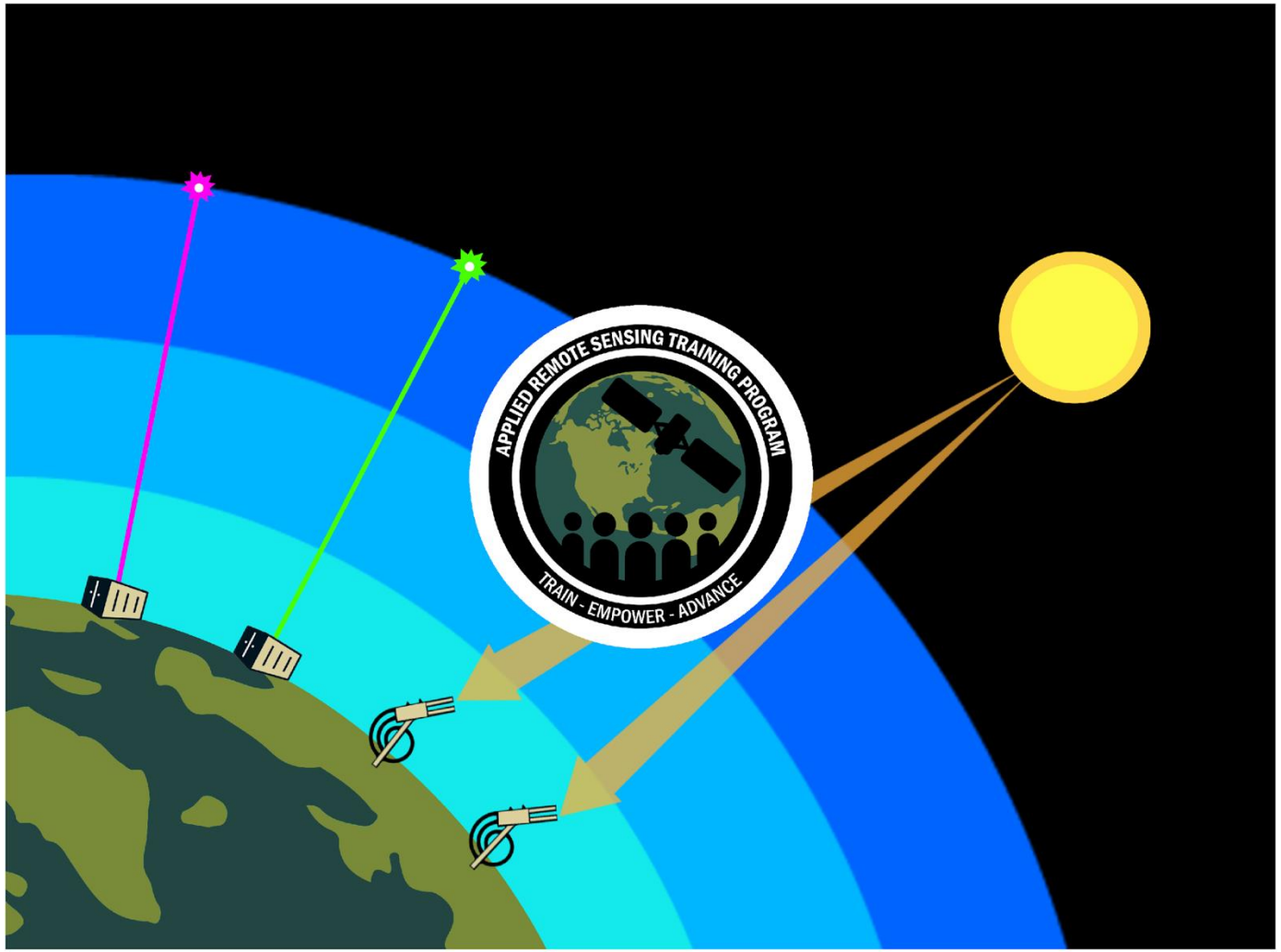
- Micro-Pulse Lidar Network
- Global Network, 85 Sites
- Active Remote Sensing for Aerosols
- Satellite Validation, Research
- Aerosol, Cloud, PBL Vertical Profiles





Source: MPLNET Website

NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications



Online, Instructor-Led

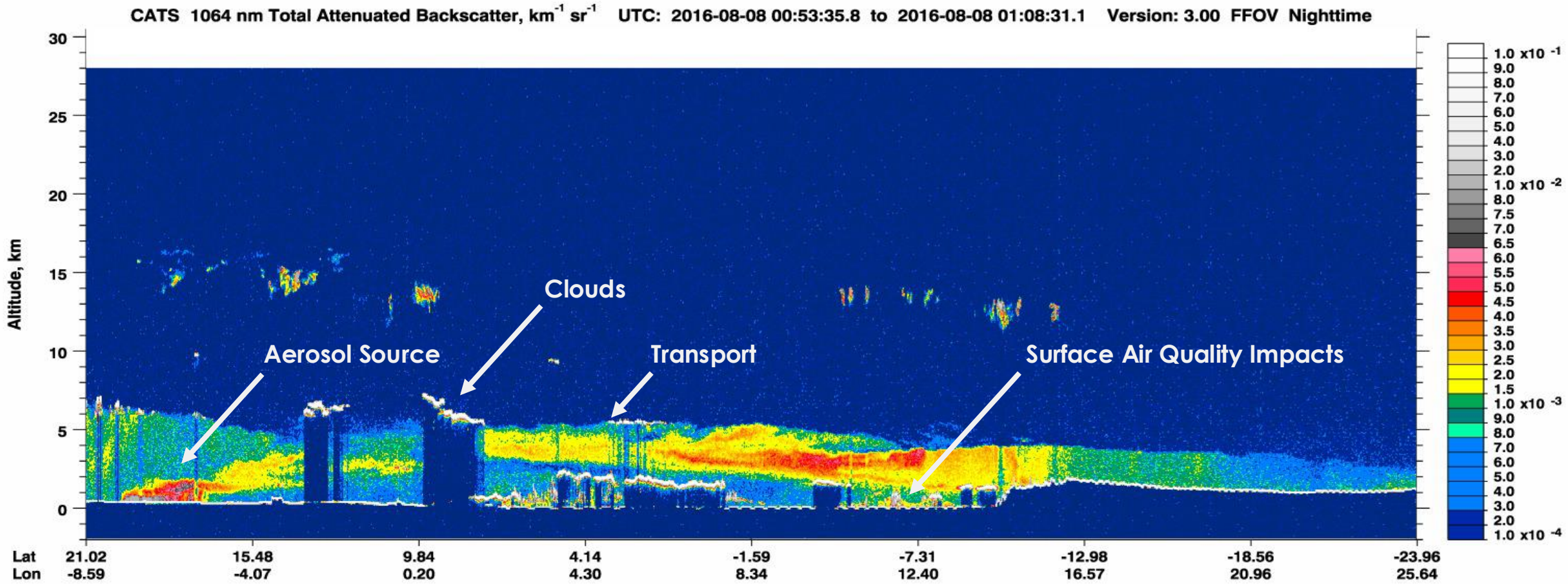
Level: Intermediate

5 Parts

August 8, 2024 - August 22, 2024

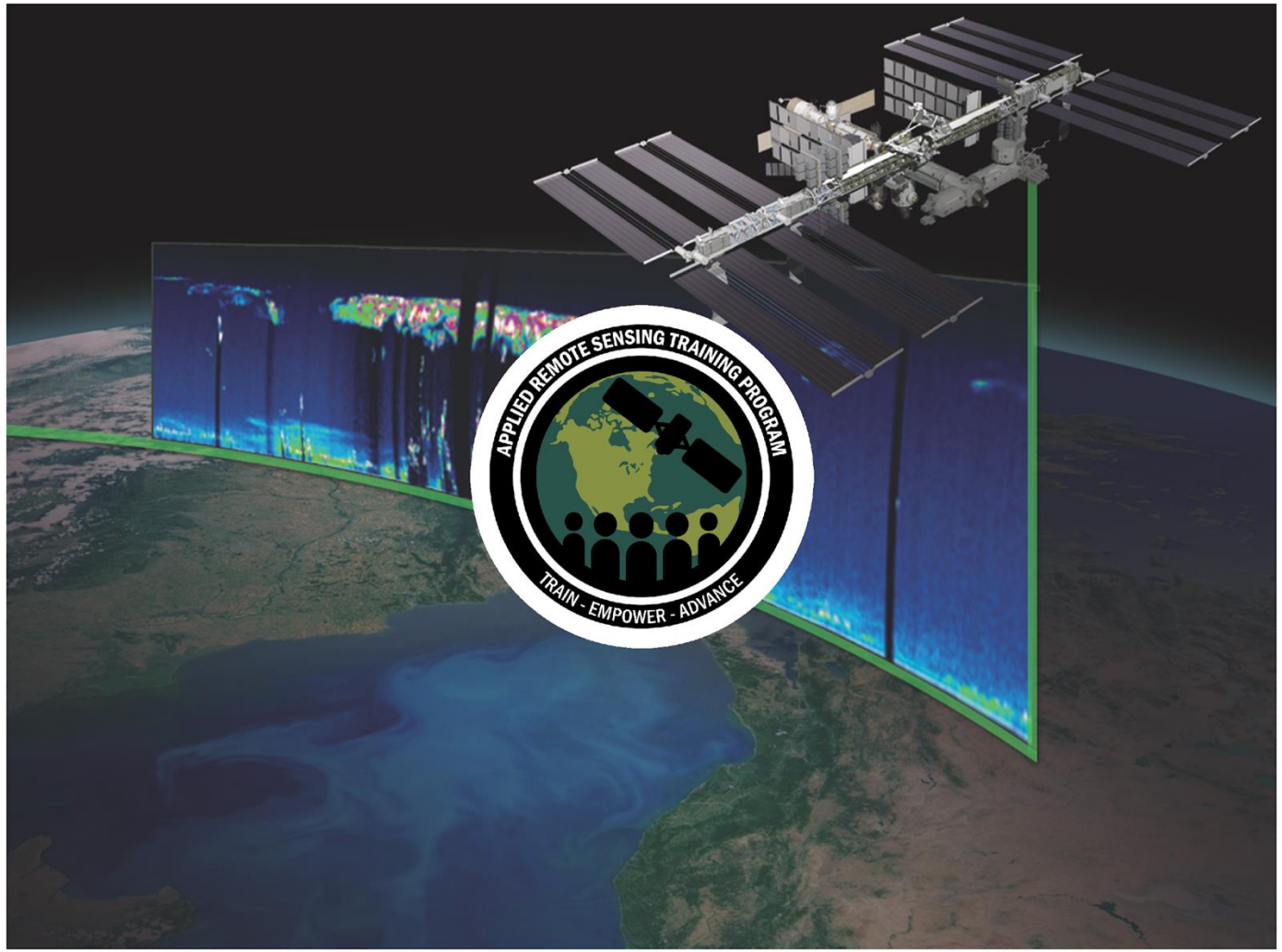
Link to Training

Active Remote Sensing of Aerosols from Space



CATS Lidar on International Space Station

LiDAR Profiling Satellite Observations for Air Quality Applications



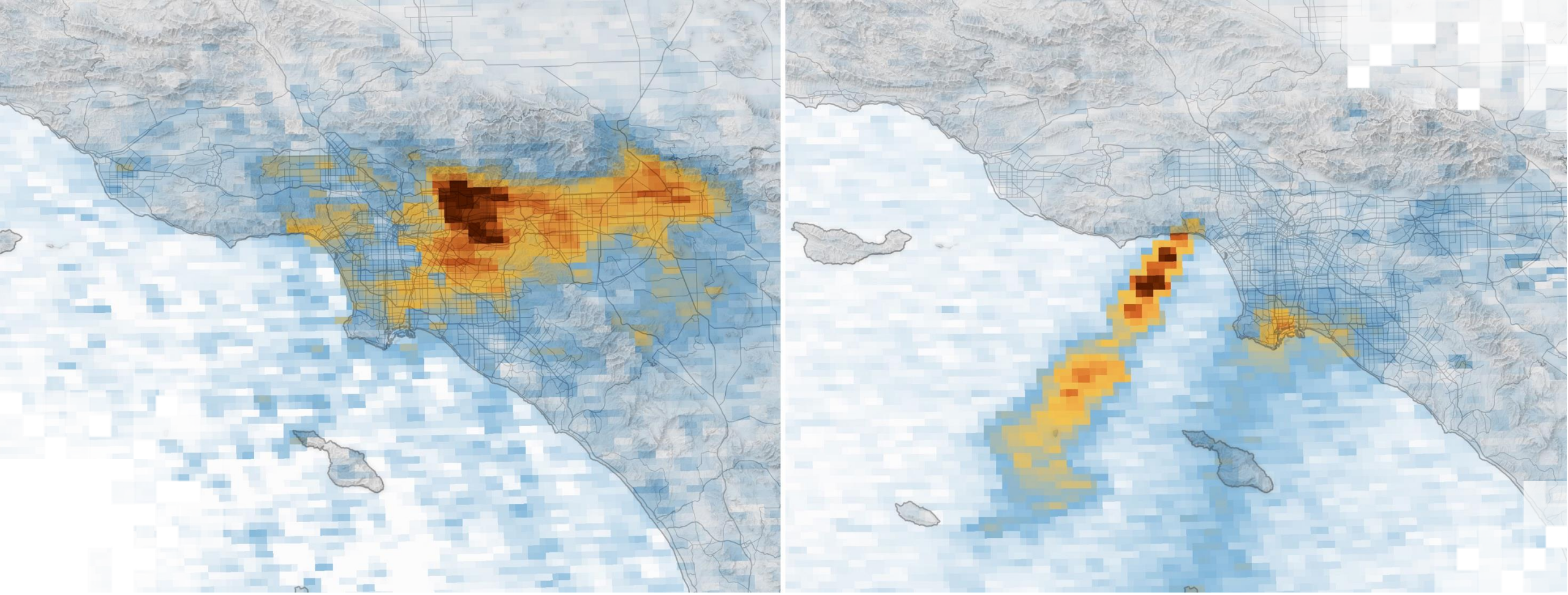
Online, Instructor-Led

Level: Introductory

2 Parts

June 4, 2025 - June11, 2025

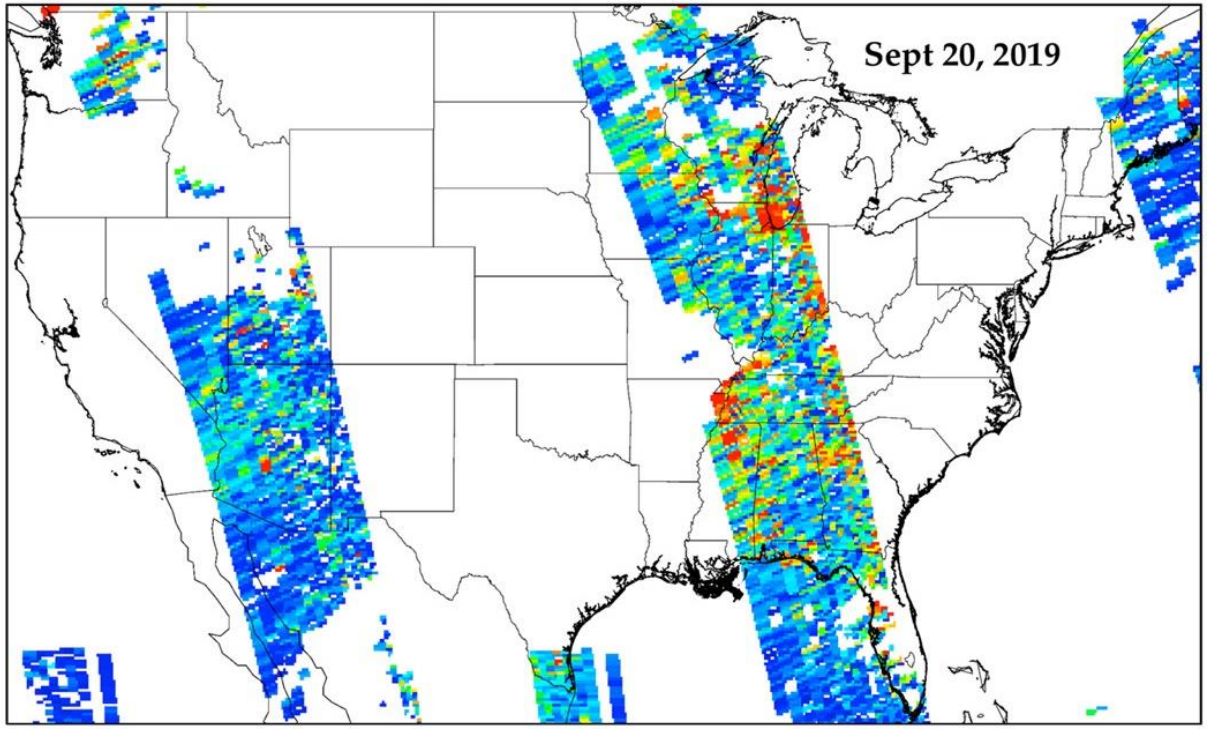
Link to Training



Remote Sensing of Trace Gases

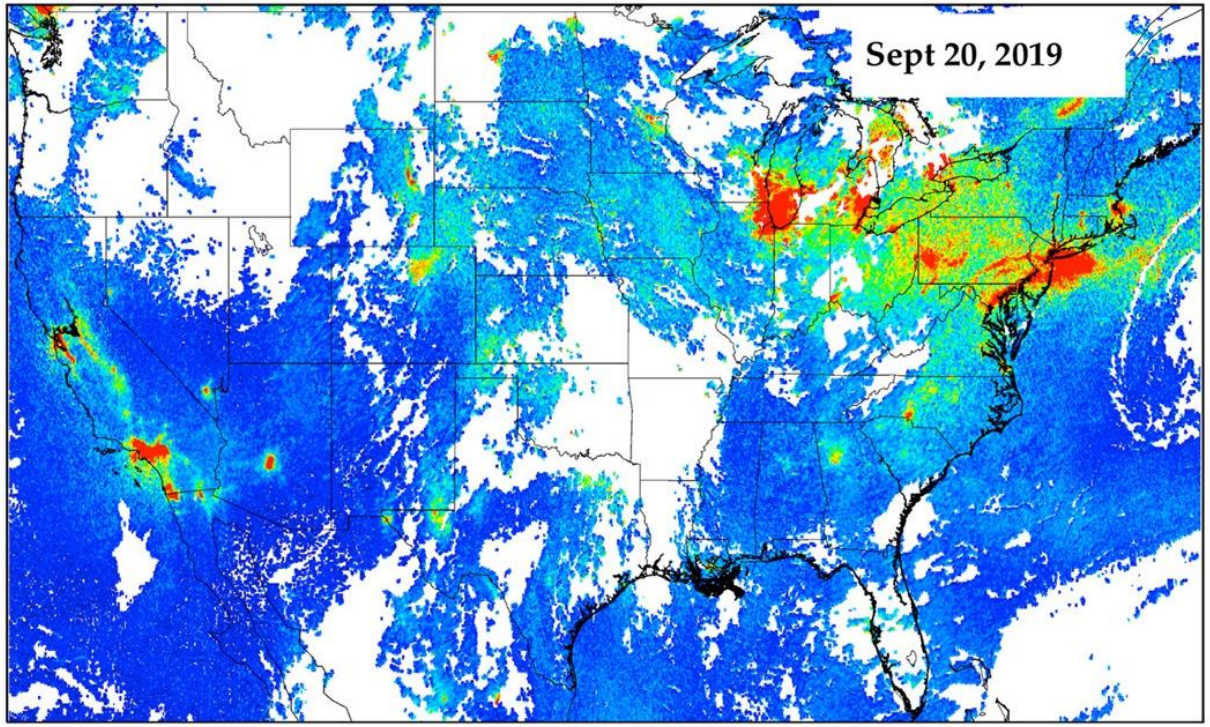
OMI & TROPOMI

OMI Tropospheric NO_2



1 Satellite: Aura (2004-Present)
13 x 24 km^2 Spatial Resolution
UV & Visible Hyperspectral Resolution
Sun-Synchronous LEO

TROPOMI Tropospheric NO_2

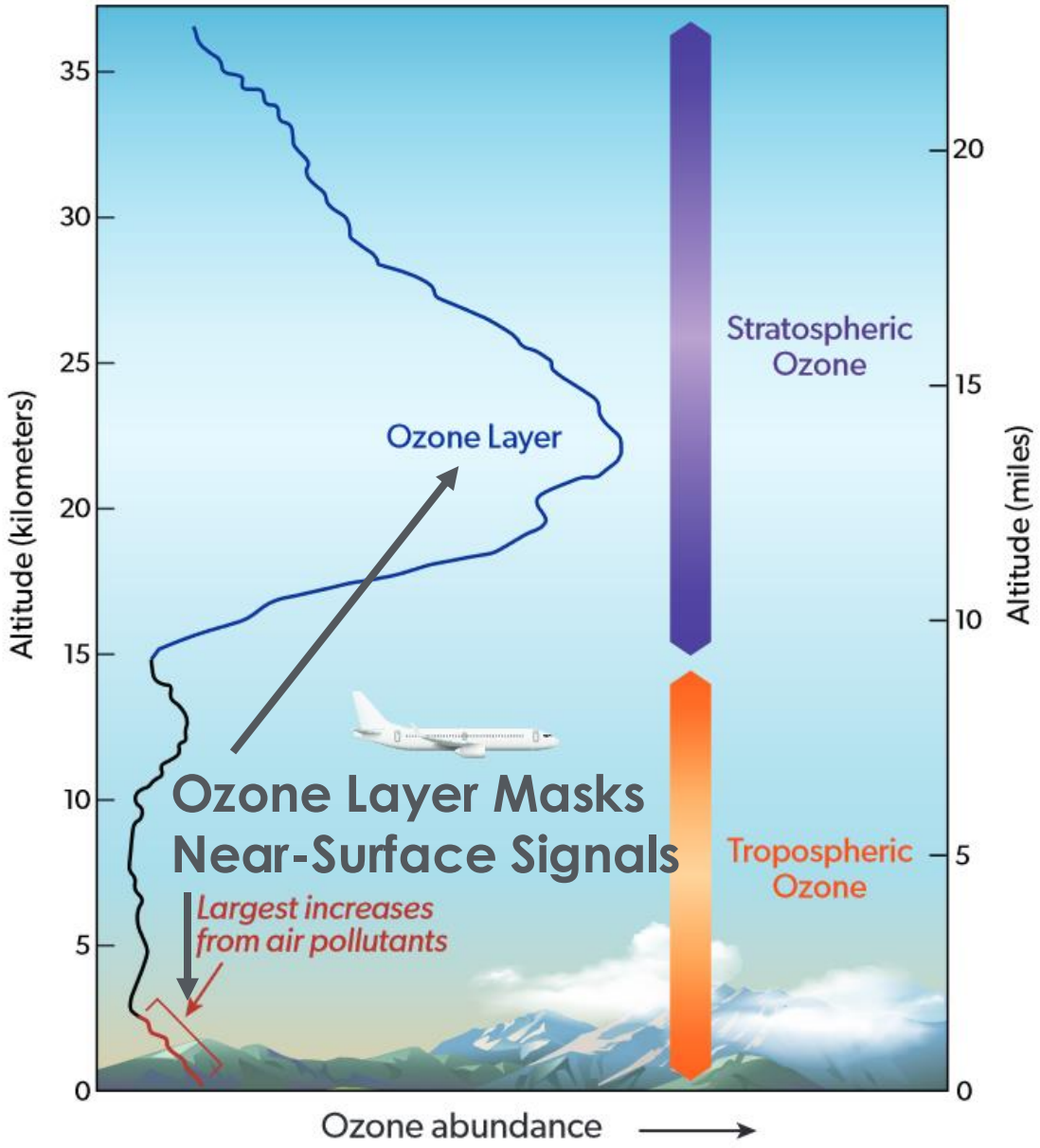


1 Satellite: ESA Sentinel 5 Precursor (2017-Present)
3.5 x 5.5 km^2 Spatial Resolution
UV & Visible & NIR & SWIR Hyperspectral Resolution
Sun-Synchronous LEO

Source: Goldberg, Anenberg, Kerr, Mohegh, Lu, Streets (2021) TROPOMI NO_2 in the United States: A Detailed Look at the Annual Averages, Weekly Cycles, Effects of Temperature, and Correlation With Surface NO_2 Concentrations. *Earth's Future*.

Ozone

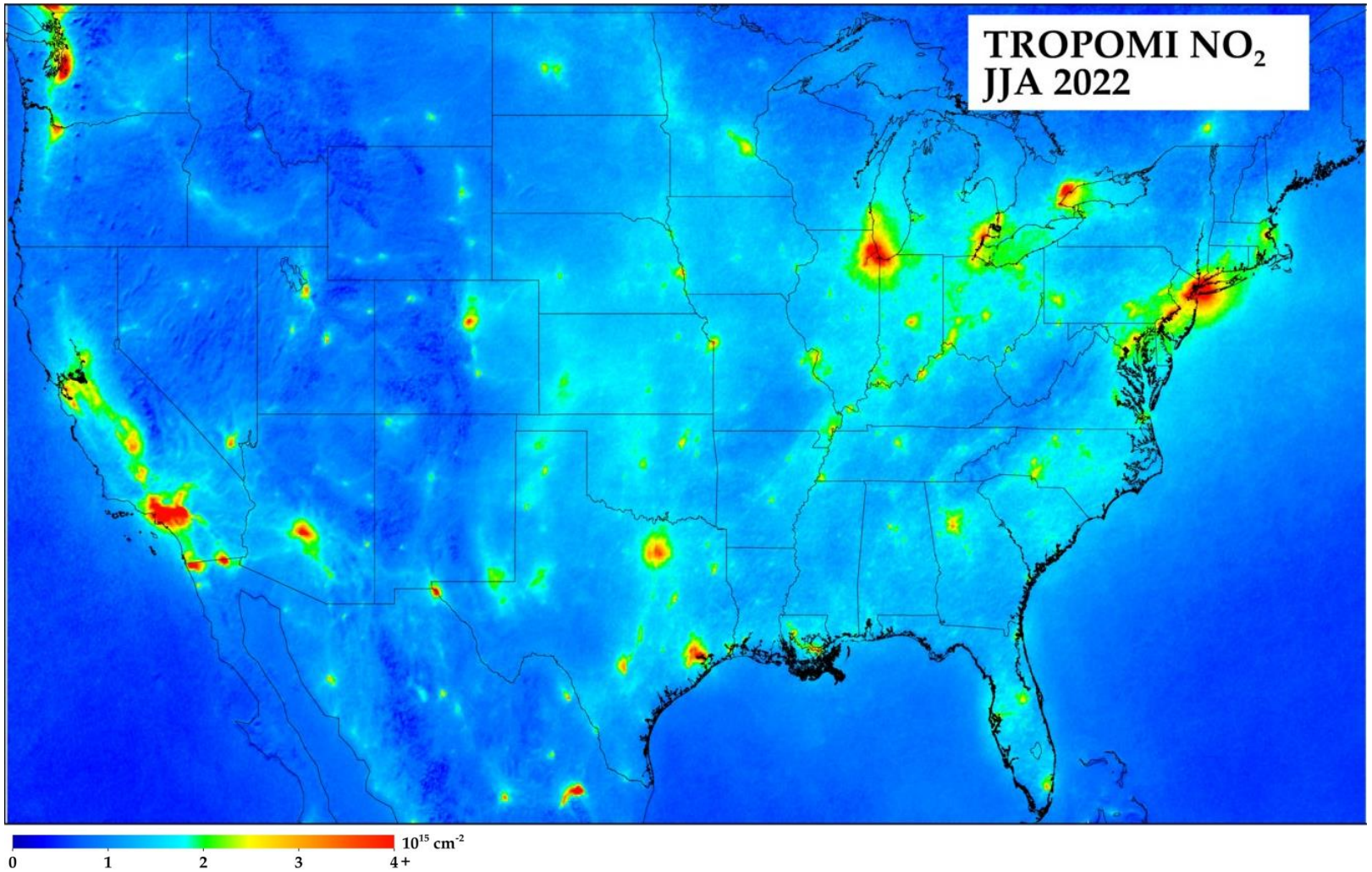
- OMI: Ozone Monitoring Instrument
- High Stratospheric Concentrations (Ozone Layer)
- Total Column Ozone is well-measured by satellites
- Tropospheric and Near-Surface Ozone is extremely difficult to estimate using satellites
- Typical Unit: Dobson Units



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

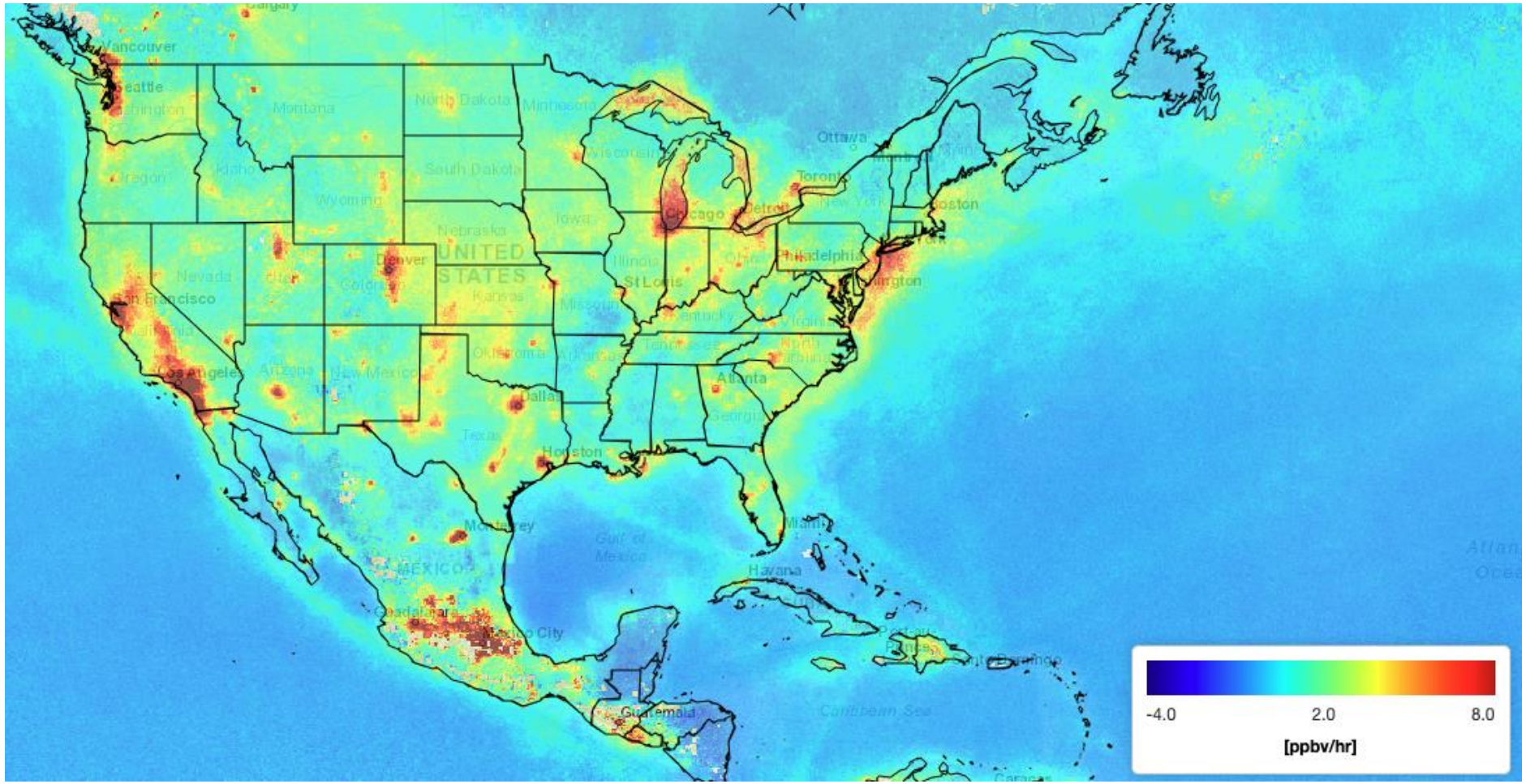


Source: George Washington University "TROPOMI NO_2 USA" Website: https://tropomino2.us/

Formaldehyde

- Measurable with satellites
- Generally high uncertainties
- Proxy for other VOCs
- HCHO and NO_2 together provide insights into Ozone formation potential

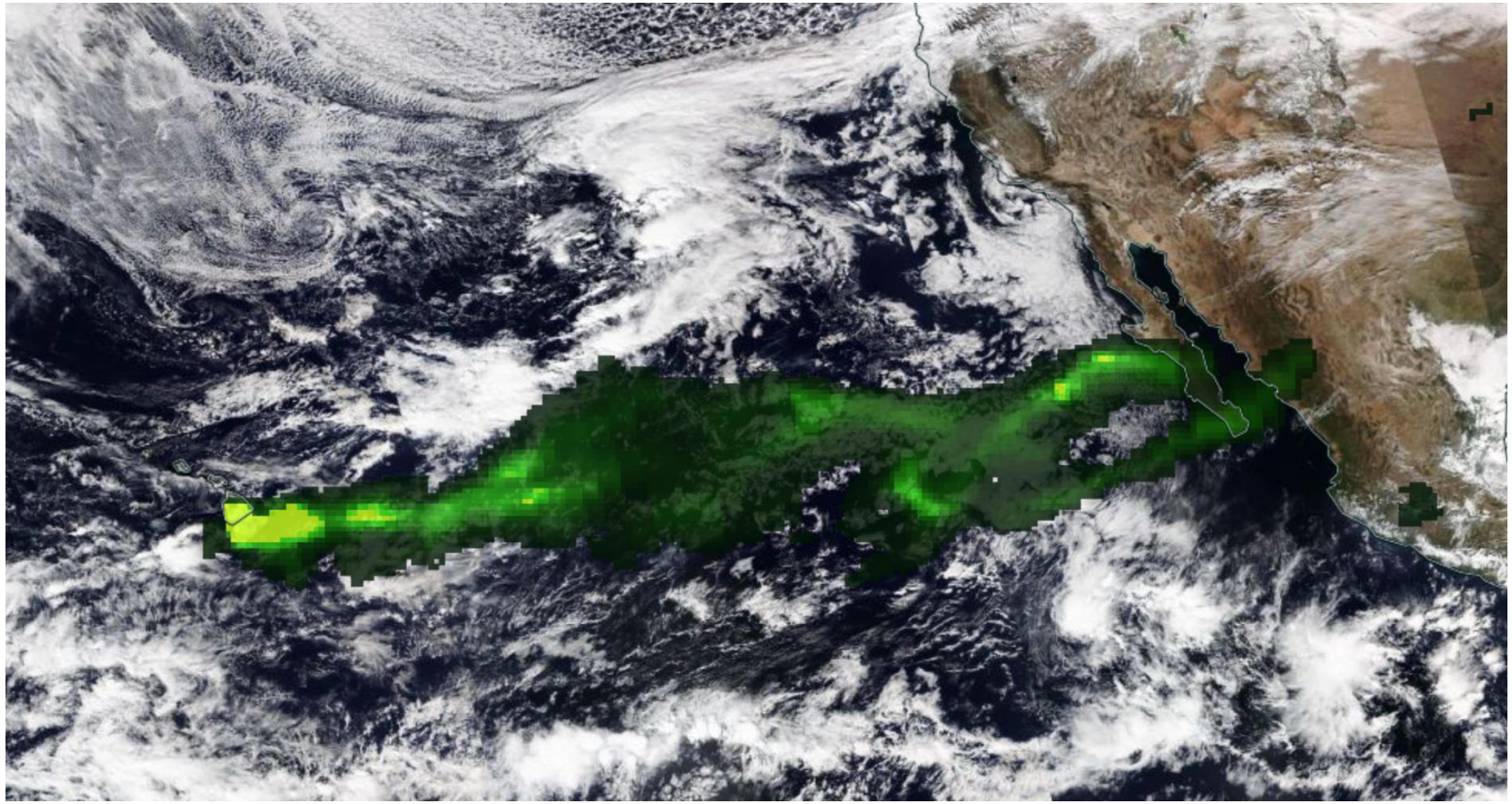
August 2023 Net Ozone Production Rate (PO3)
Estimated from a Combination of TROPOMI NO_2 and HCHO Data



Source: Ozonerates, 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

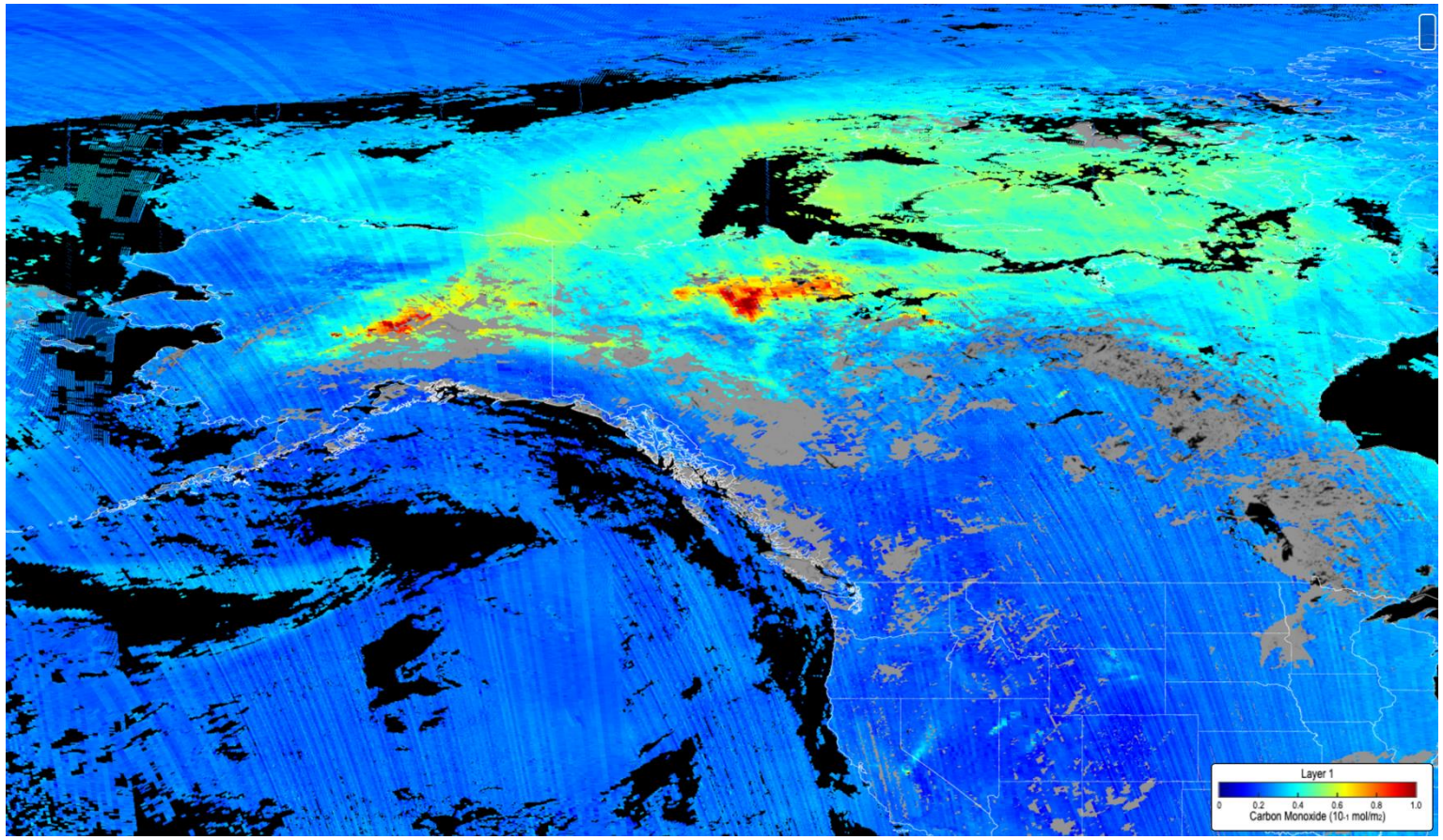


TROPOMI SO_2 Plume (Lower Troposphere) from Mauna Loa Eruption, November 30, 2022

Source: NASA Worldview

Methane and Carbon Monoxide

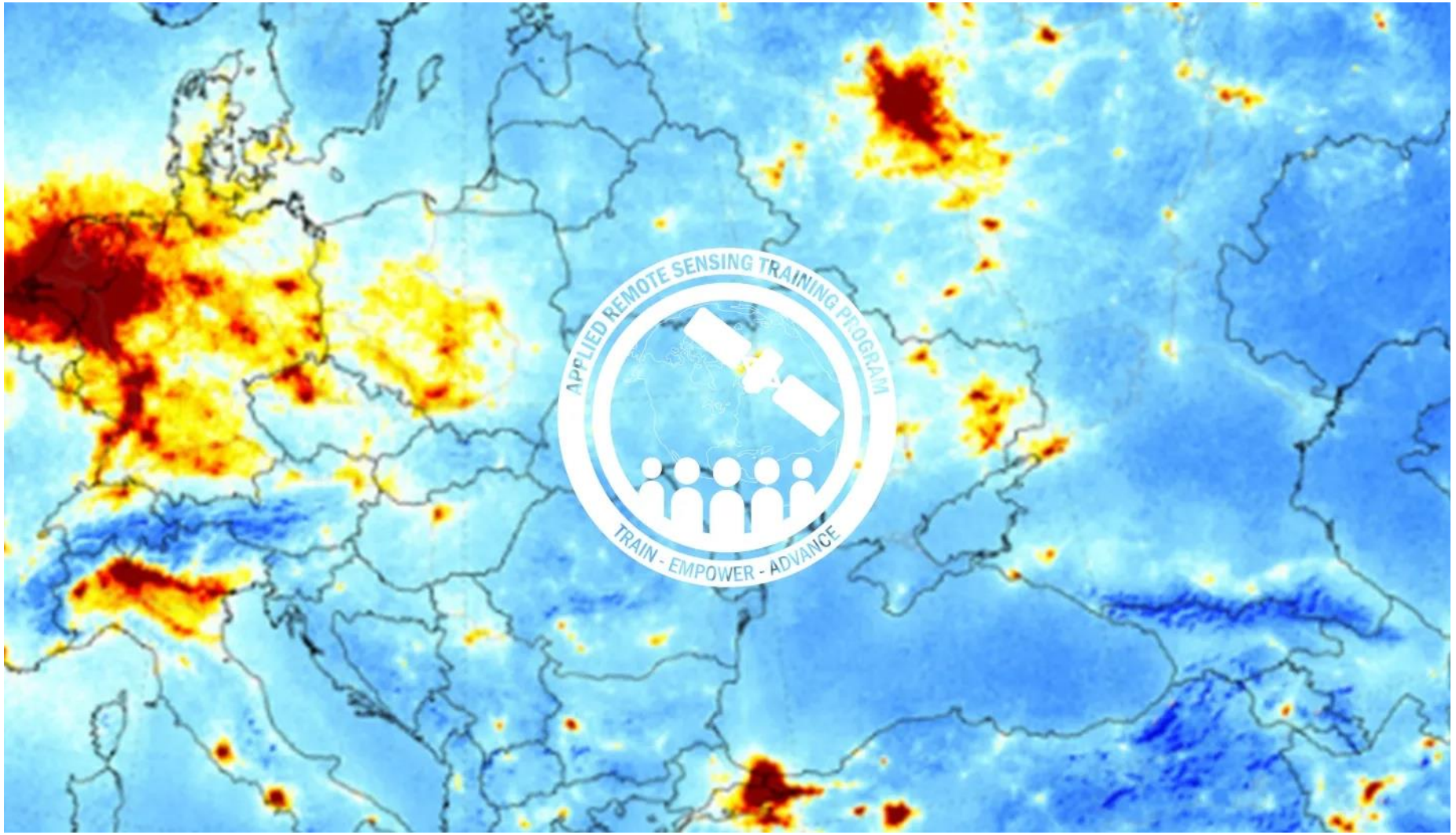
- TROPOMI sensitivity in NIR and SWIR allows measurement of CO and CH_4
- CO useful as marker of long-range pollutant transport, especially smoke
- Other missions provide more dedicated GHG observations (CH_4, CO_2)



TROPOMI CO from Various Wildfires, July 9, 2022

Source: NOAA JSTAR Mapper

High Resolution NO_2 Monitoring From Space with TROPOMI



Online, Instructor-Led

Level: Advanced

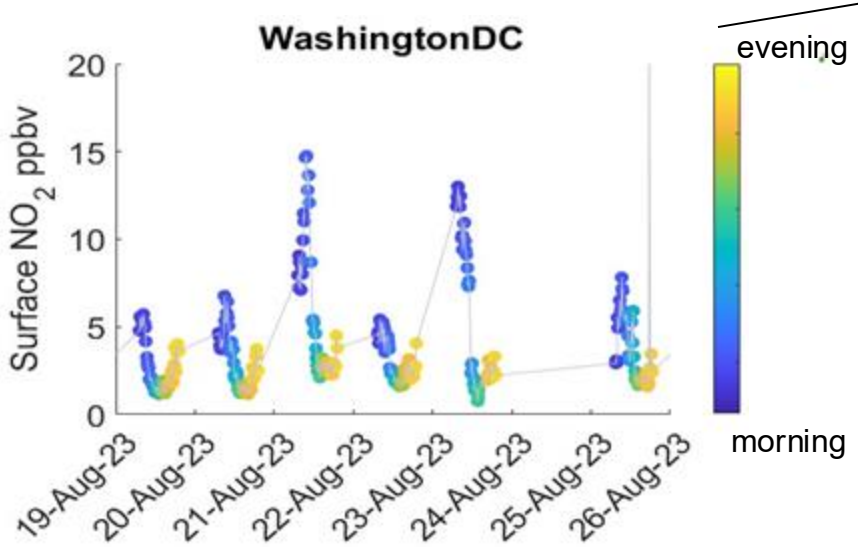
3 Parts

May 28, 2019 – June 3, 2019

Link to Training

Pandora

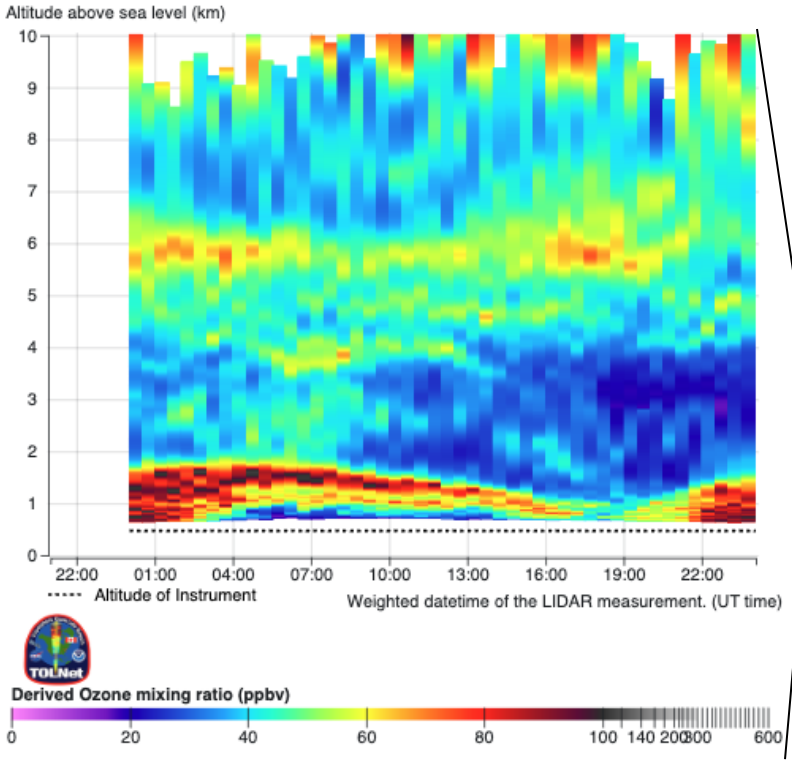
- Global Network, 100+ Sites
- Passive Remote Sensing for Trace Gases
- Satellite Validation, Research
- O_3, NO_2, HCHO, & SO_2 Products
- Direct Sun and Sky-Scanning (MAX-DOAS) Modes

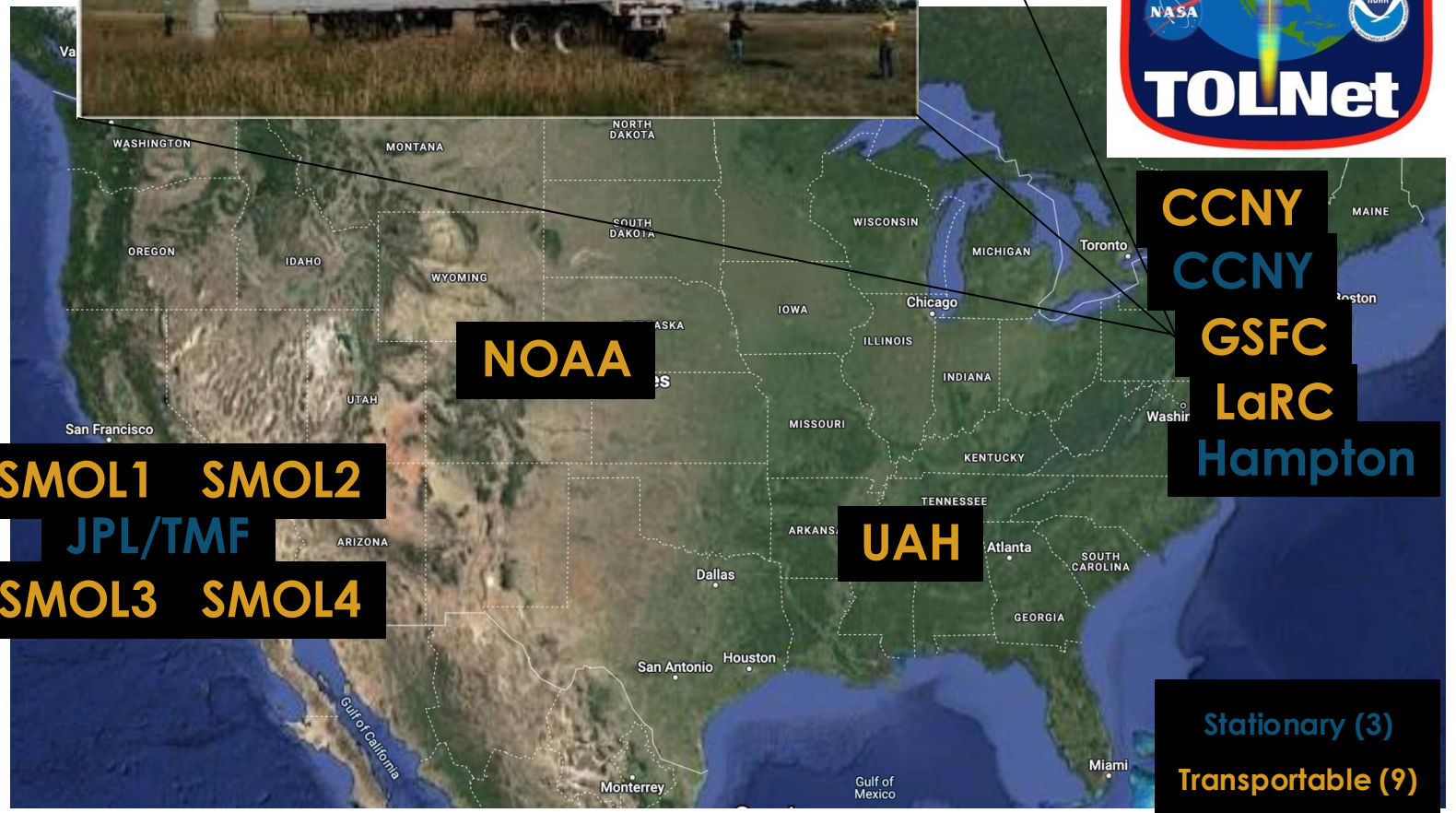


Source: Pandora Website

TOLNet

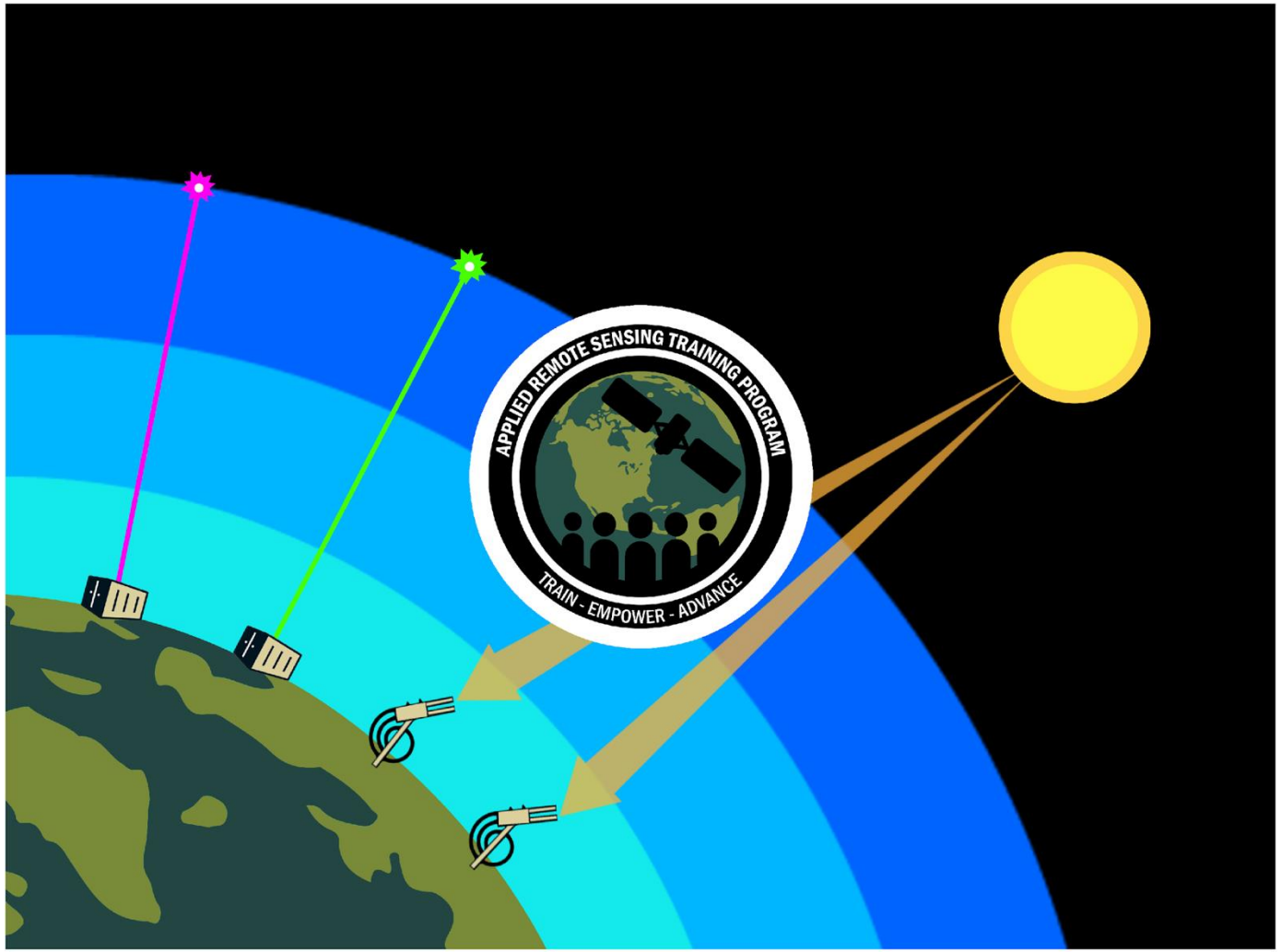
- Tropospheric Ozone Lidar Network
- 3 Stationary Sites, 9 Transportable
- Active Remote Sensing for Ozone





Source: [TOLNet Website]

NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications



Online, Instructor-Led

Level: Intermediate

5 Parts

August 8, 2024 - August 22, 2024

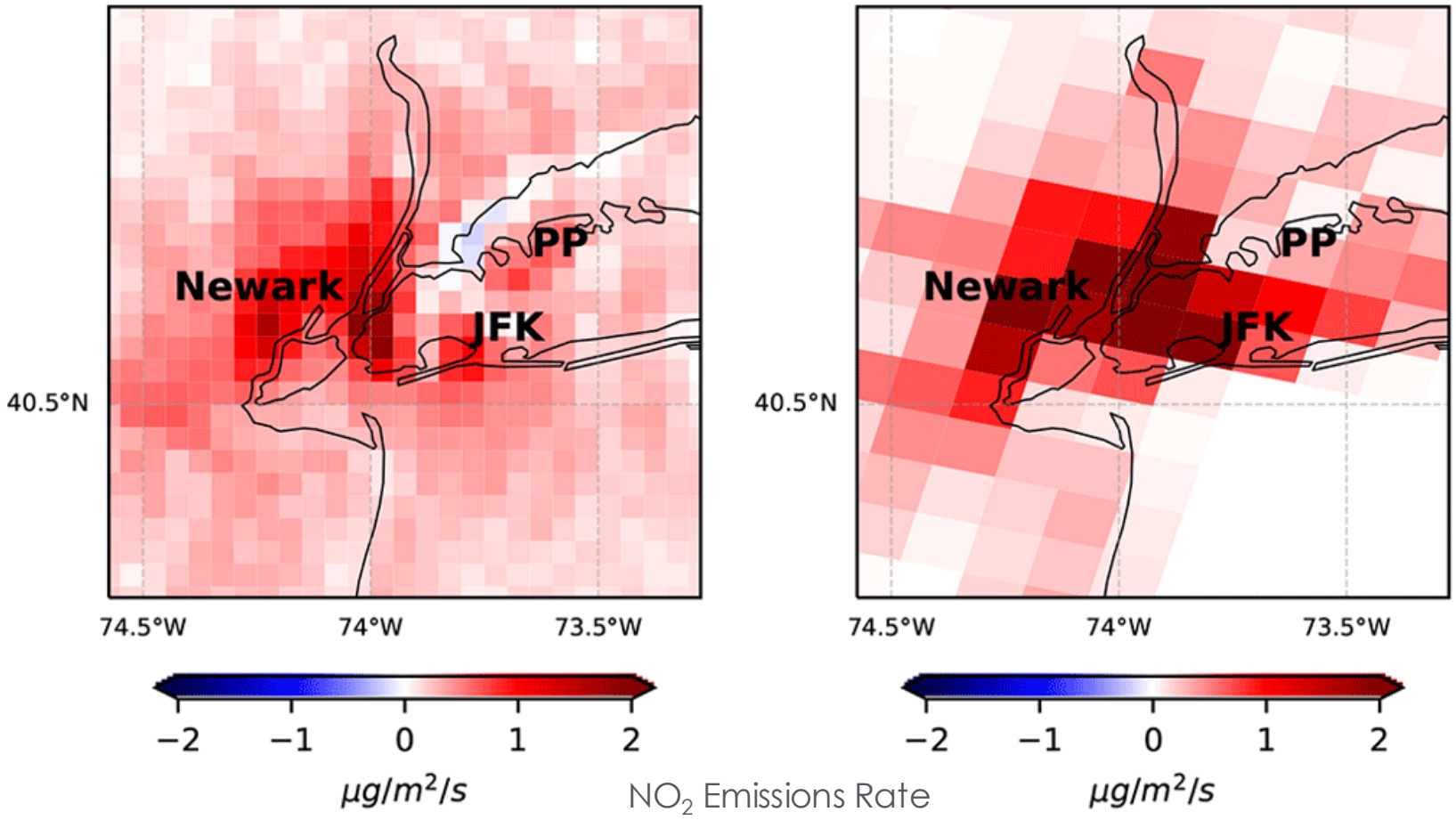
Link to Training

Emissions from Satellites

- Satellite data and model information can help calculate emission rates of pollutants.
- Create "top-down" inventories, for comparison with "bottom-up" methods.
- Most viable for sources with distinct "plumes", or high contrast with background concentrations.

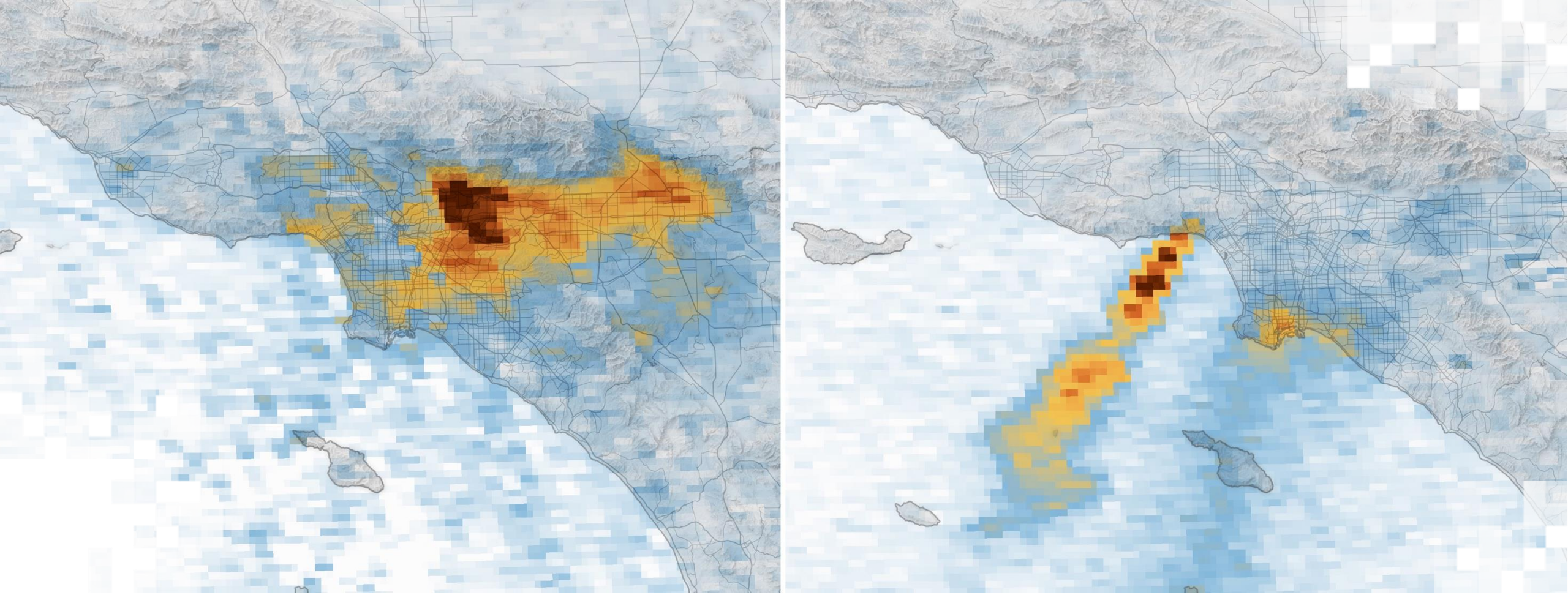
"Top-Down" Inventory
Using TROPOMI

"Bottom-Up" Inventory
US NEI



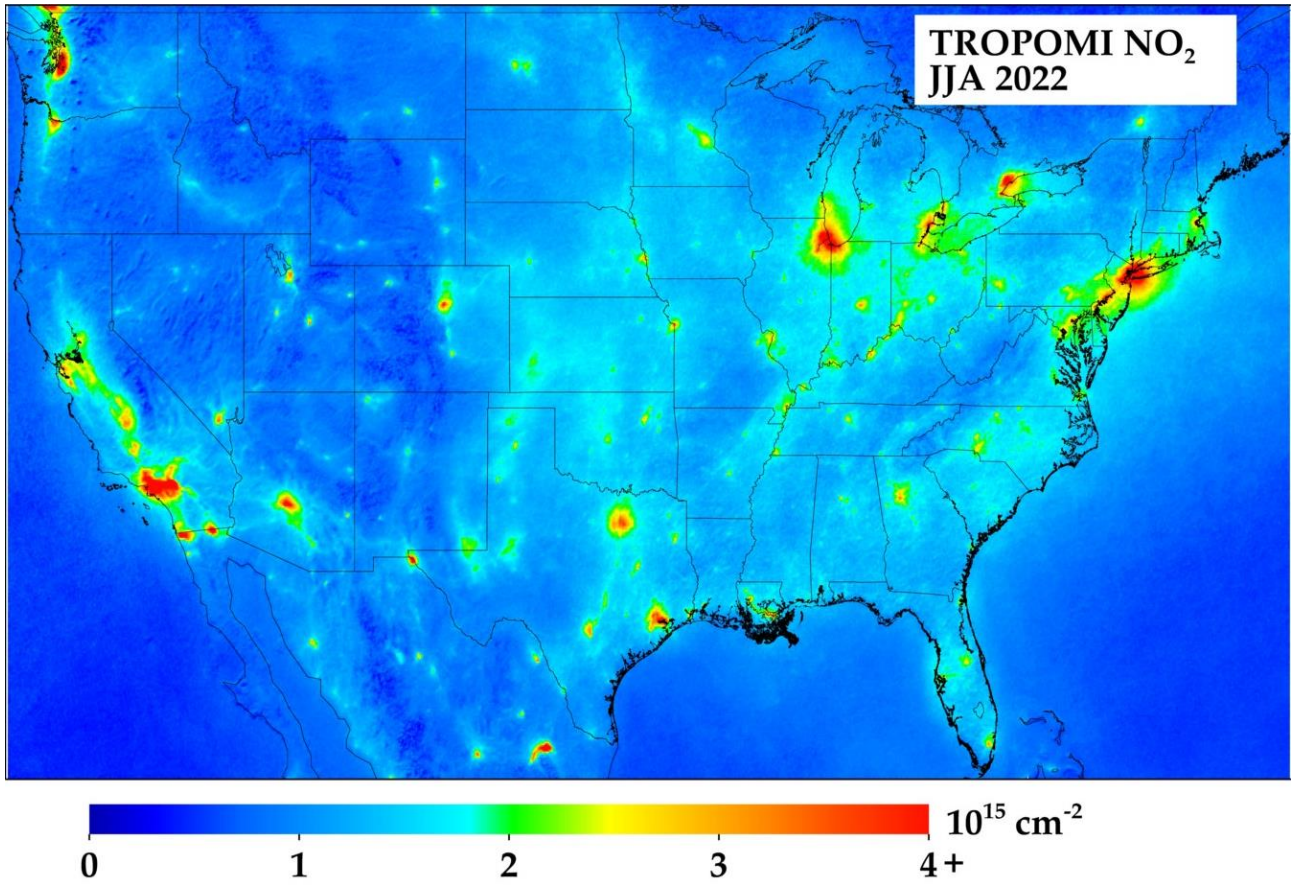
NO_2 Emissions Rate

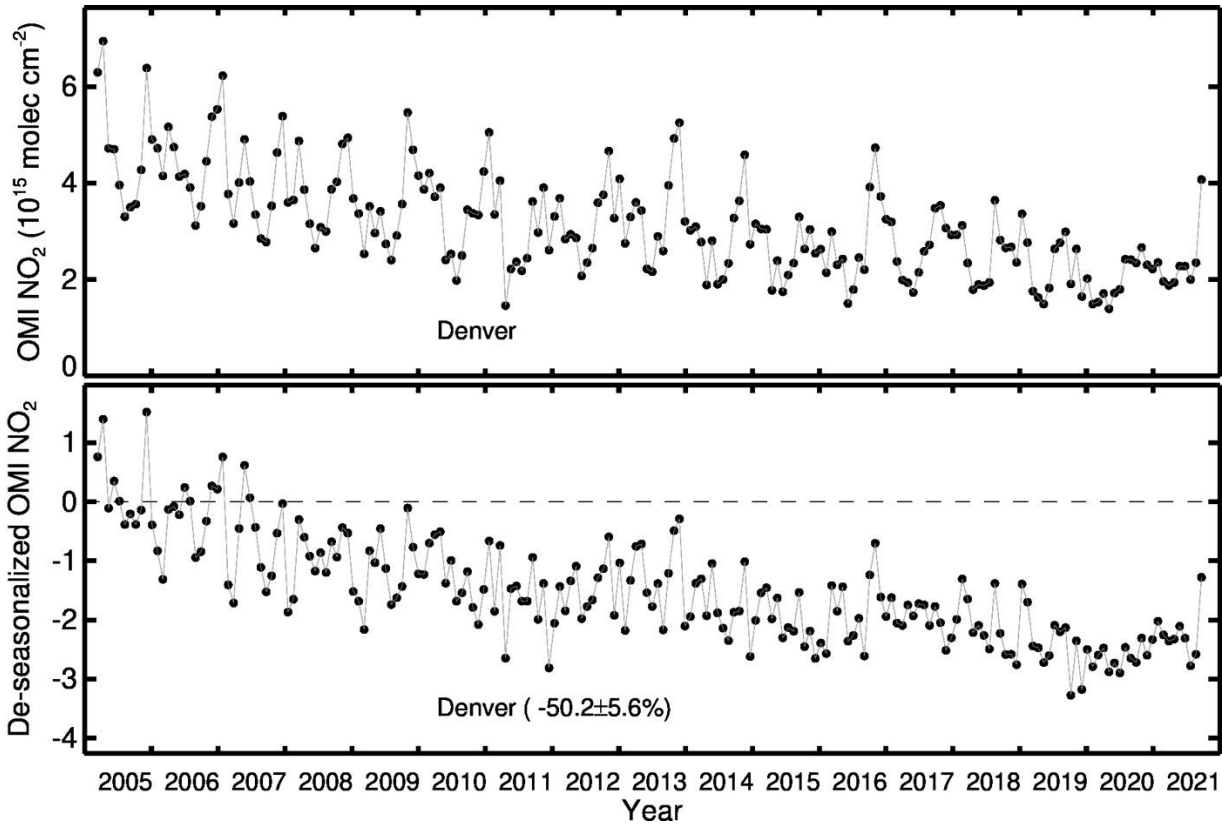
Source: Liu et al. (2024) High-resolution mapping of nitrogen oxide emissions in large US cities from TROPOMI retrievals of tropospheric nitrogen dioxide columns. *Atmospheric Chemistry and Physics*.



Common Benefits and Limitations of Remote Sensing for Air Quality

What Satellites CAN Do for Air Quality

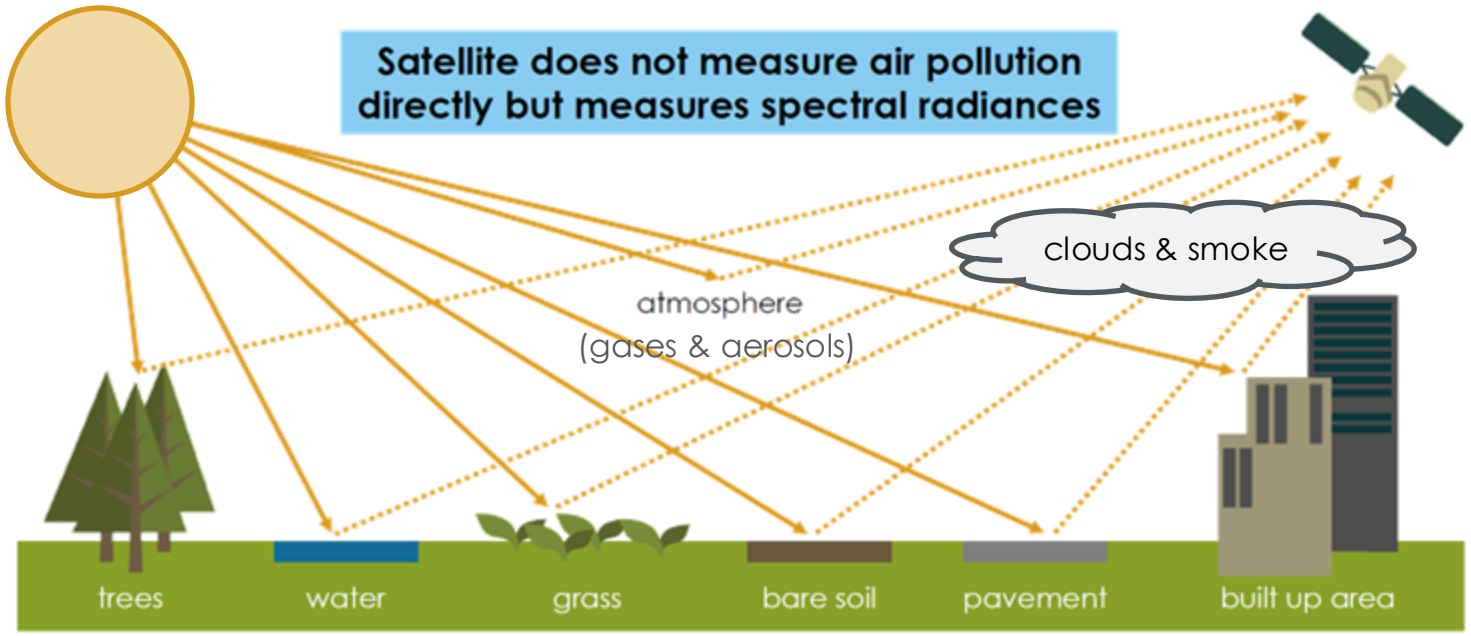


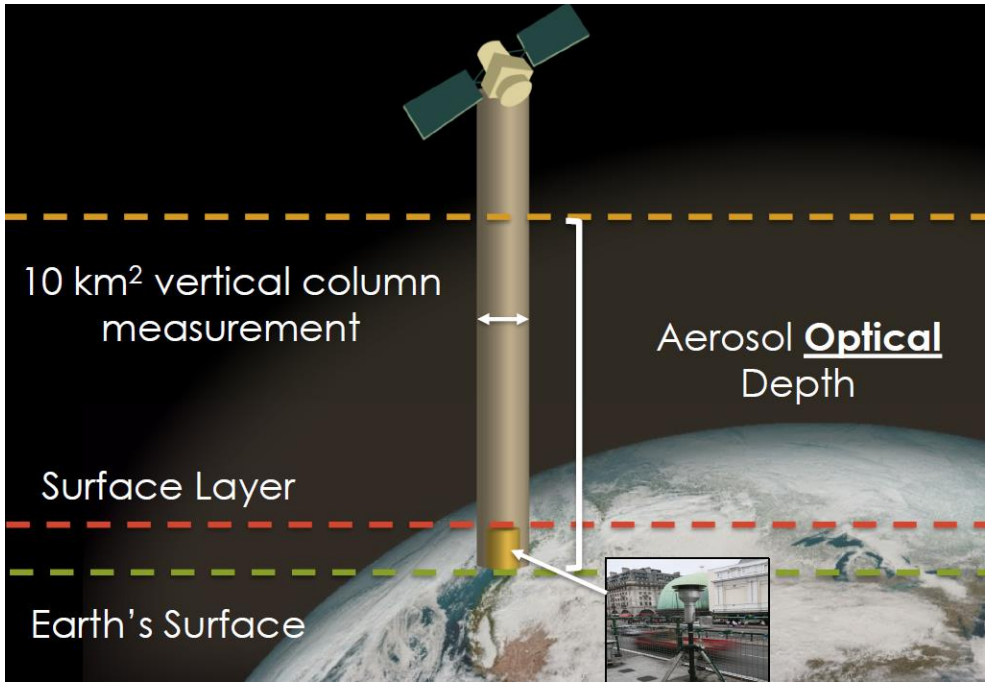


Examine a Large Area: Where are the hotspots? How is long-range transport happening?
Cover Remote Areas: What is happening at locations far away from surface monitors?
Track Changes Over Time: How much has the average concentration over an area changed over time?

Sources: George Washington University "TROPOMI NO_2 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 like TEMPO provide more frequent (daytime) data

Resources

- 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 NO_2 Monitoring From Space with TROPOMI
- NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!