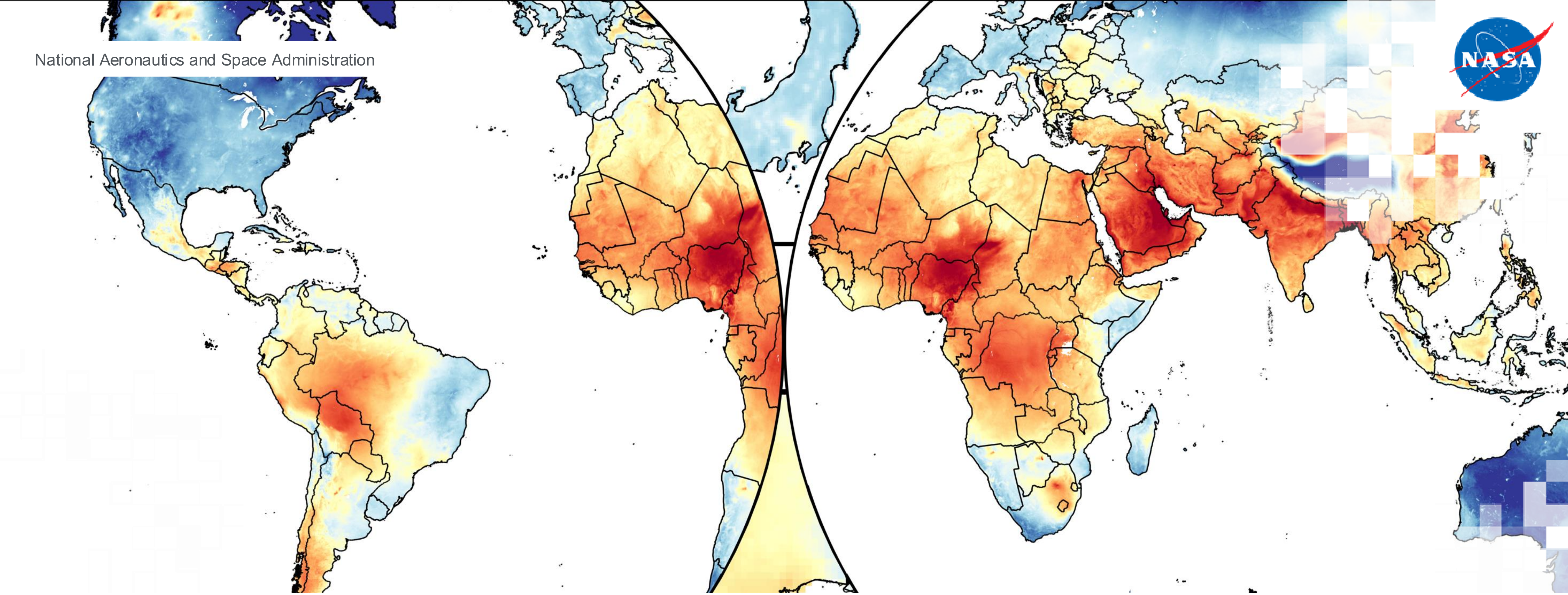
National Aeronautics and Space Administration

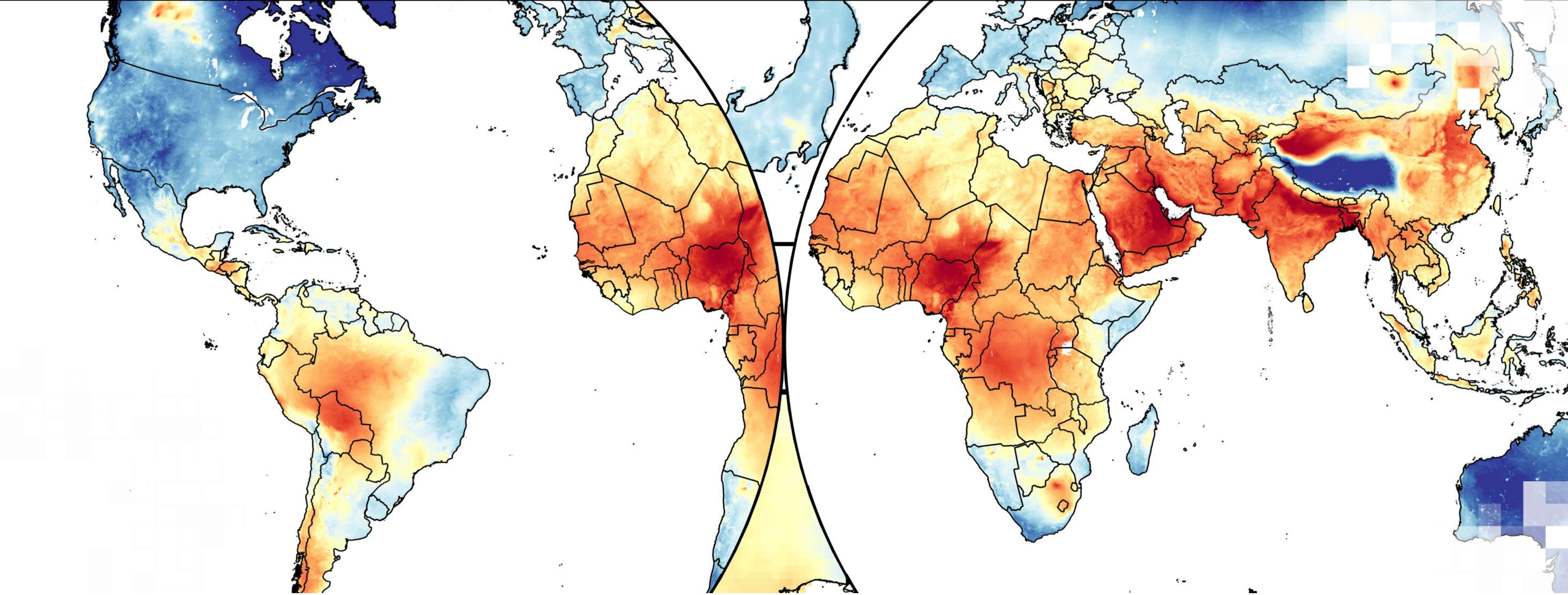


Estimating Surface $PM_{2.5}$ using Satellite Data and Other Information Sources

Part 1: AOD Versus $PM_{2.5}$ - When They Are and Are Not Related

Carl Malings (Morgan State University, MSU), Pawan Gupta (NASA GSFC), Aaron van Donkelaar (Washington University in St. Louis), Junhyeon Seo (MSU), Sebastián Diez (Universidad del Desarrollo), & Ana Prados (University of Maryland Baltimore County)

July 8, 2026



About ARSET

About ARSET

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

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

DISASTERS

ECOLOGICAL CONSERVATION

HEALTH & AIR QUALITY

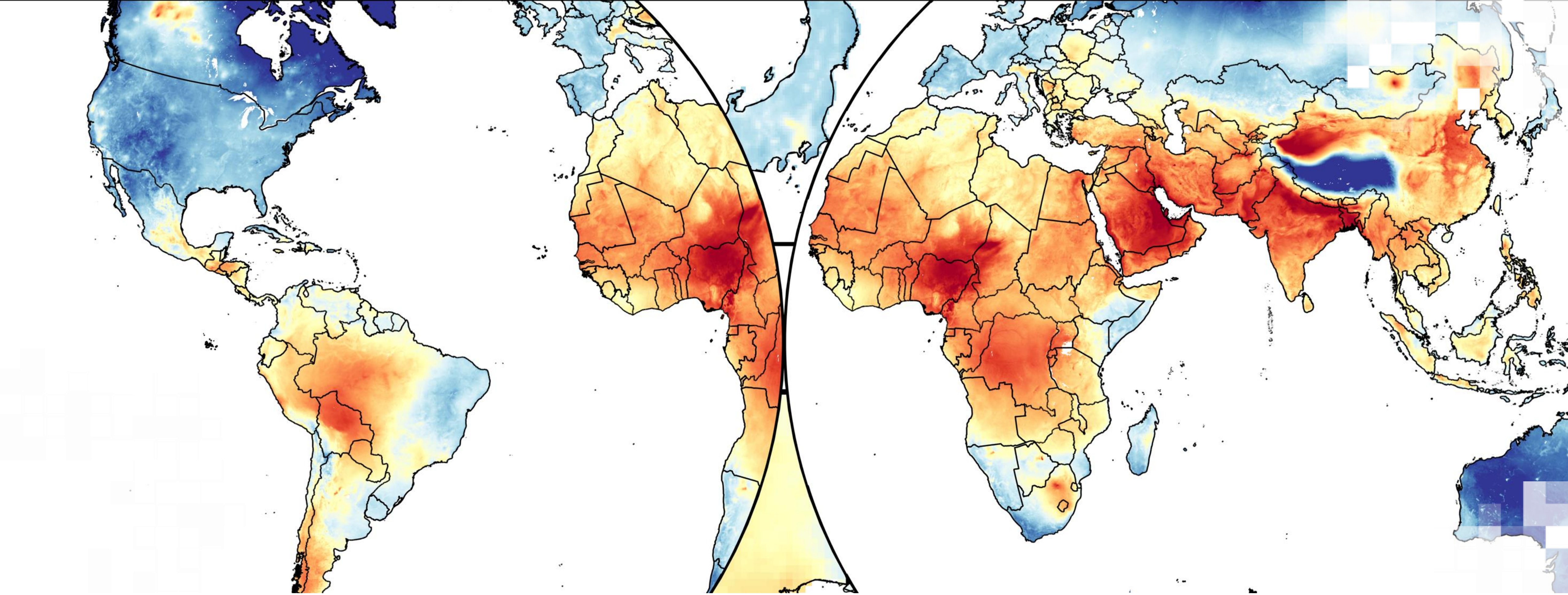
WATER RESOURCES

WILDLAND FIRES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.

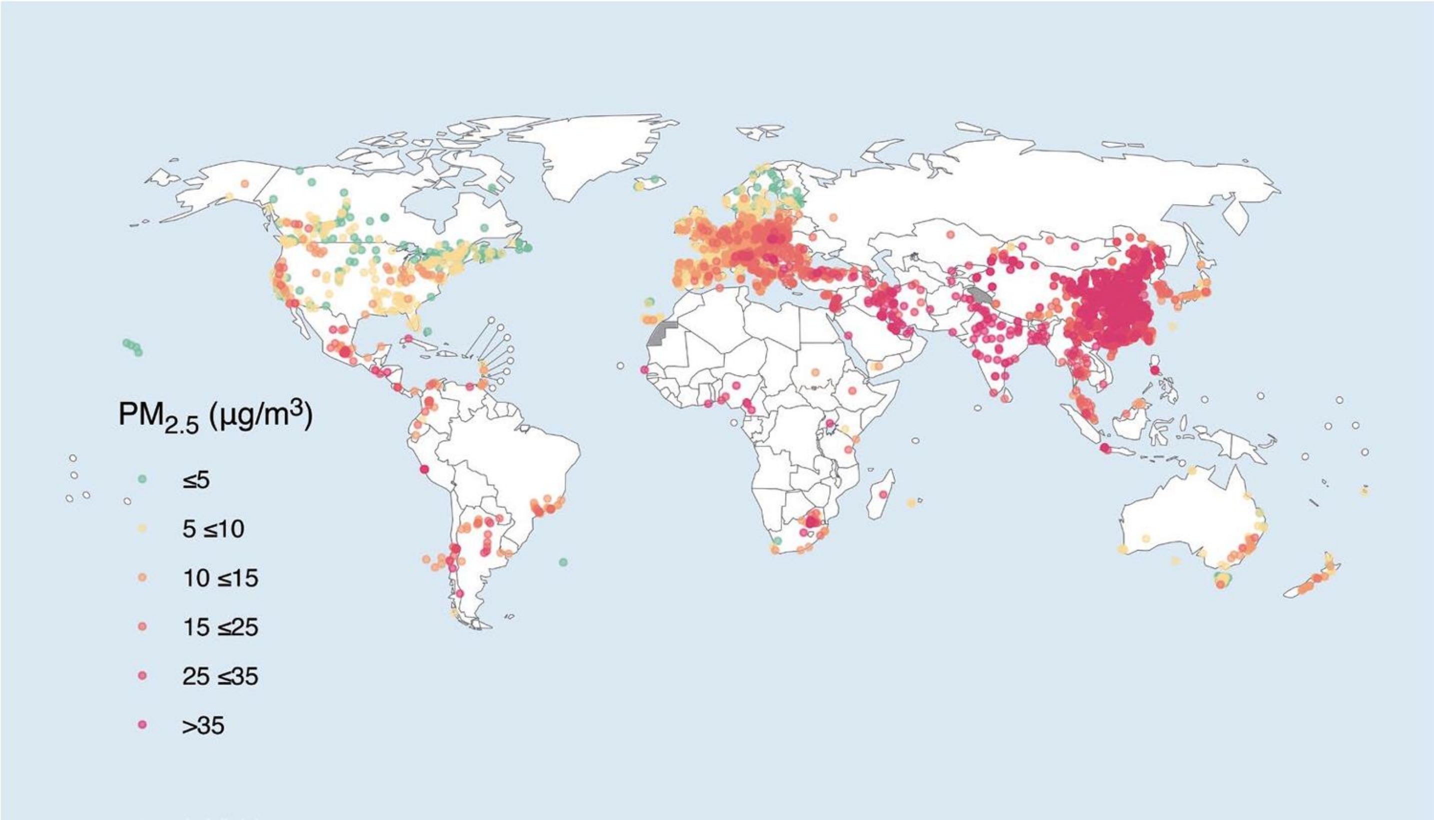


Estimating Surface $PM_{2.5}$ Using Satellite Data and Other Information Sources
Overview

Fine Particulate Matter ($PM_{2.5}$) is a key, but under-monitored, air pollutant.

- The 2023 Global Burden of Disease Study found that **"ambient $PM_{2.5}$ remains the leading global environmental risk factor"** for premature mortality.
- PM is the most widely used indicator for assessing the health effects of exposure to air pollution.
- Only 117 of 194 countries (60%) and only 6,743 of more than 12,000 urban settlements worldwide (<56%) reported $PM_{2.5}$ data to WHO by 2022.

Global $PM_{2.5}$ from WHO Ambient Air Quality Database 2010-2019



Sources: Hay S, Ong K, Santomauro D et al. (2025), World Health Organization (2023)

Training Learning Objectives

By the end of this training, participants will be able to:

- Explain the basic methods of inferring surface $PM_{2.5}$ from satellite AOD, their required inputs, and their complexities.
- Differentiate between available data products for surface $PM_{2.5}$ from NASA and Washington University in St. Louis based on their methodologies, strengths, and weaknesses.
- Use NASA Earthdata and the SatPM website to access these surface $PM_{2.5}$ data products for a location and time period of interest.
- Compare these satellite-derived $PM_{2.5}$ estimates to in-situ measurements using appropriate co-location strategies and evaluation metrics.

Prerequisites

- Fundamentals of Remote Sensing
- An Inside Look at How NASA Measures Air Pollution

Training Outline

Part 1

AOD Versus $PM_{2.5}$ – Their Relationship and its Limits

July 8, 2026

10:00–12:00 EDT

Part 2

Estimation of $PM_{2.5}$ from AOD – Methodologies and Available Datasets

July 15, 2026

10:00–12:00 EDT

Part 3

Case Study – Comparing Available Satellite-Derived $PM_{2.5}$ Products to In-Situ Measurements

July 22, 2026

10:00–12:00 EDT

Homework

Opens July 22 – Due August 5 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

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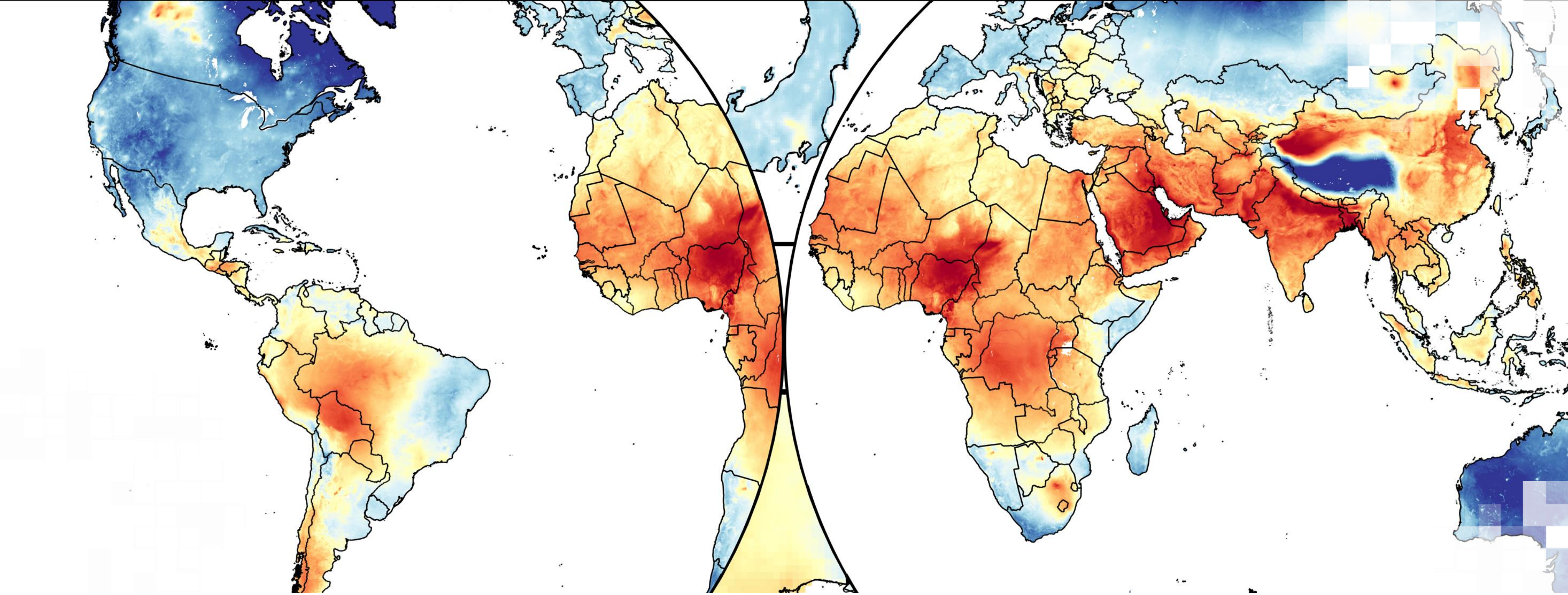


Estimating Surface $PM_{2.5}$ Using Satellite Data and Other Information Sources

Part 1: AOD Versus $PM_{2.5}$ – When They Are and Are Not Related

Part 1 – Trainers

Carl Malings

Assistant Research Scientist

Morgan State University

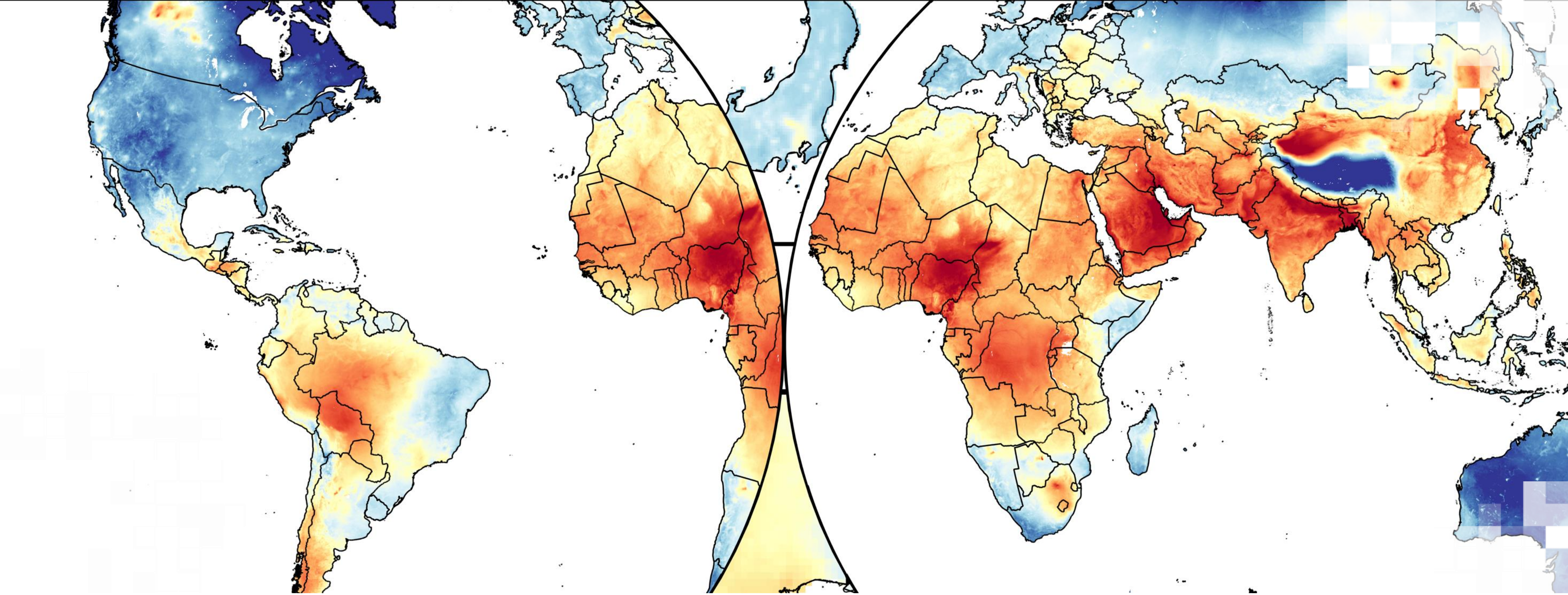
Part 1 Objectives

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

- Identify the inputs used by different methods of inferring surface $PM_{2.5}$ from satellite AOD.
- Explain simple regression methods of inferring surface $PM_{2.5}$ from satellite AOD.

How to Ask Questions

- To ensure we see your question, please locate the three dots ... to the bottom right of your training window.
- You will see a Slido/Q&A option. You may also see a standalone Slido tab or app.
- Please place all questions there and we will answer them during the Q&A session.
- We will try to get to all of the questions during the Q&A session after the webinar. The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

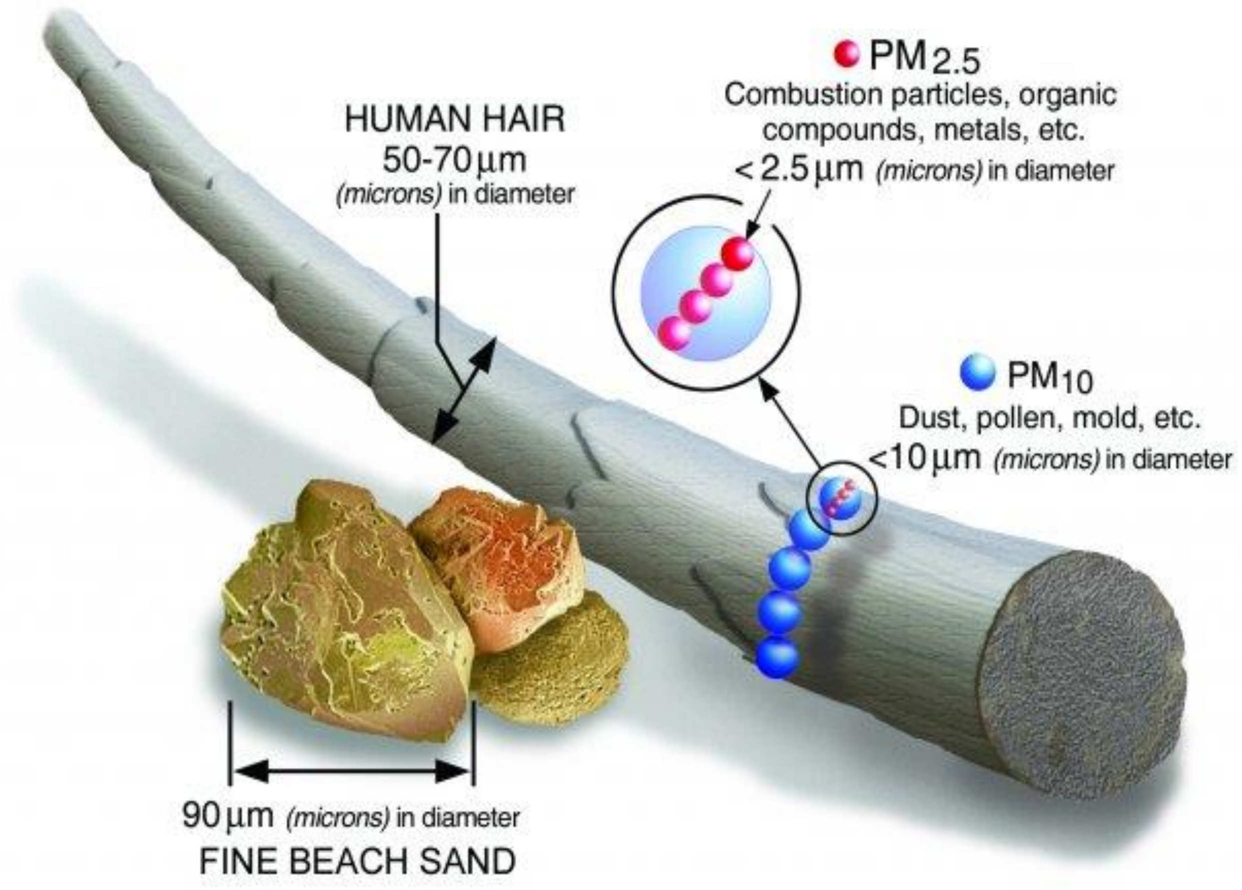


Part 1:

The Pieces – Ground-Based Measurements, AOD, and CTM

Particulate Matter and its Size Fractions

- Particulate Matter (PM) or aerosol refers to solid and liquid particles suspended in the air.
- Commonly categorized by size – **smaller particles cause more severe health impacts**:
  - **PM_{10}** (Coarse PM, ≤ 10 microns in diameter)
    - Irritate nose, throat, and lungs
  - **$PM_{2.5}$** (Fine PM, ≤ 2.5 microns in diameter)
    - Pass from lungs into bloodstream
    - Impact heart, arteries, and brain
  - **PM_1** (Ultrafine PM, ≤ 1 micron in diameter)
    - Reach the deepest parts of the lungs and internal organs
- Can also be categorized by composition, shape, source, etc.



Source: US Environmental Protection Agency, "Particulate Matter Basics"

$PM_{2.5}$ is directly measured with ground-based instruments.

- **Reference Monitors:**
  - e.g., US Federal Reference Method
  - Filter Sampling, e.g., 24-hour averages
- **Continuous Monitors:**
  - e.g., US Federal Equivalent Methods
    - Beta Attenuation Monitors
    - Tapered Element Oscillating Microbalances
    - Optical Techniques (Aethalometer, Nephelometer)
  - Typically provide more real-time information (e.g., hourly)
  - Typically ±10% of reference
- **Reference monitors provide "gold standard" PM mass measurements**

Source: US Environmental Protection Agency, "Ambient Monitoring Technology Information Center"

Air sensors can supplement $PM_{2.5}$ monitoring at lower unit cost.

- Reference and Continuous monitors are expensive to deploy and operate.
  - High purchase costs
  - Ongoing operation costs (e.g., calibration)
- **Low-Cost Air Sensors:**
  - Employ lower-cost techniques (usually optical methods)
  - Typically lack special inlets and humidity control
  - Data quality varies with sensor model and conditions; ±30% is typically the goal
- **Different measurement technologies have varying accuracy compared to the reference method, but can have other benefits (e.g., higher time resolution, lower cost).**

Source: US Environmental Protection Agency, "Air Sensor Toolbox"

Siting and quality control impact how representative $PM_{2.5}$ data are.

- **Siting impacts how representative data are of typical regional conditions.**
  - Background monitors capture regional conditions.
  - Near-source monitors capture local conditions.
  - Many low-cost sensors do not meet siting criteria.
- **Quality Control Requirements:**
  - Regular calibration and maintenance
  - Performance audits
  - Removal of inaccurate data from summaries

Rooftop Monitor to Represent Regional Urban Conditions

Roadside Monitor to Represent Local Urban Conditions

Source: Photographs provided by Carl Malings

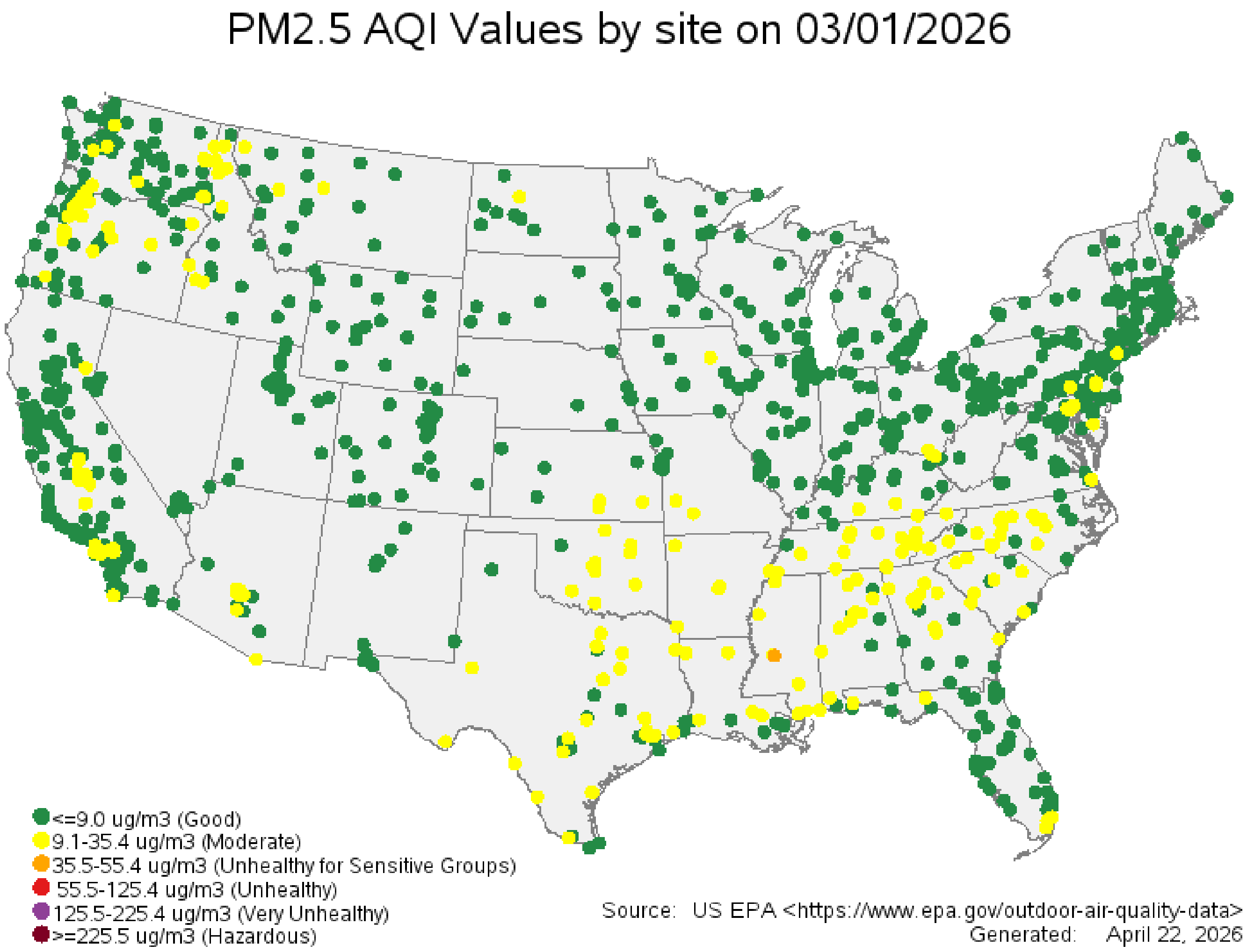
National Ambient Air Quality Monitoring Network Data

National environmental agencies are often the best source for reference-quality $PM_{2.5}$ data.

Example:

US Environmental Protection Agency (EPA)

- Establishes measurement, siting & quality control guidelines
- Collects data from US States, Territories, and local agencies
- Archives data and provides free public access
- Uses data to assess compliance with air quality regulations and develop policies to improve air quality



Source: US Environmental Protection Agency, "[AirData: Air Quality Data Collected at Outdoor Monitors Across the US]"

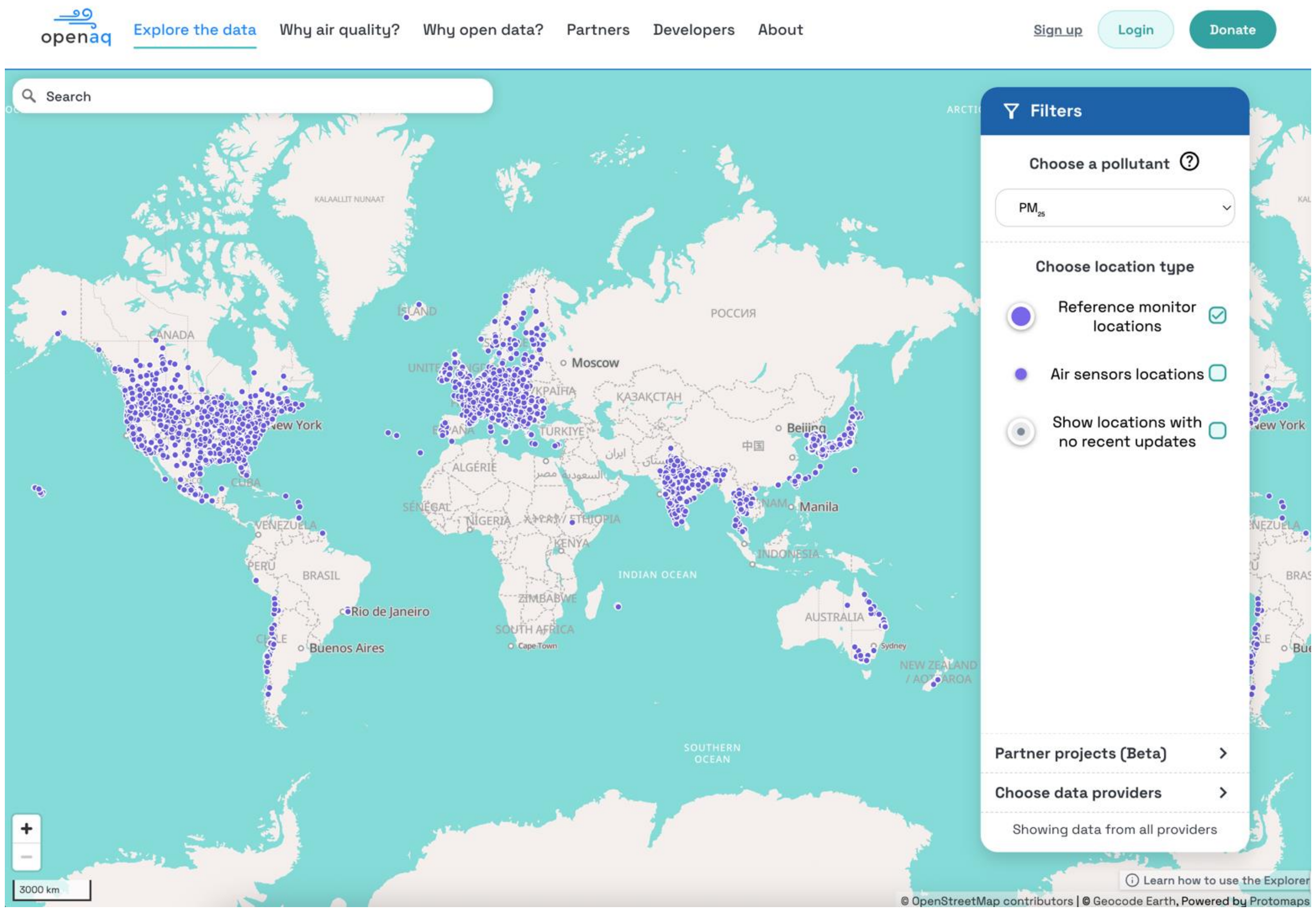
Global air quality data aggregators help integrate diverse datasets.

Data aggregators (private companies, nonprofits, international organizations) collect $PM_{2.5}$ measurements from other sources.

Example:

OpenAQ

- Harmonize data standards across different data providers
- Collect metadata on siting and measurement methods
- Facilitate data findability & accessibility (e.g., website, application programming interface)
- **Do not perform quality control, calibration, or siting verification**
- Can only access public data



Source: OpenAQ, "Explore the Data"

Strengths and Limitations of Ground-Based Monitoring

Strengths:

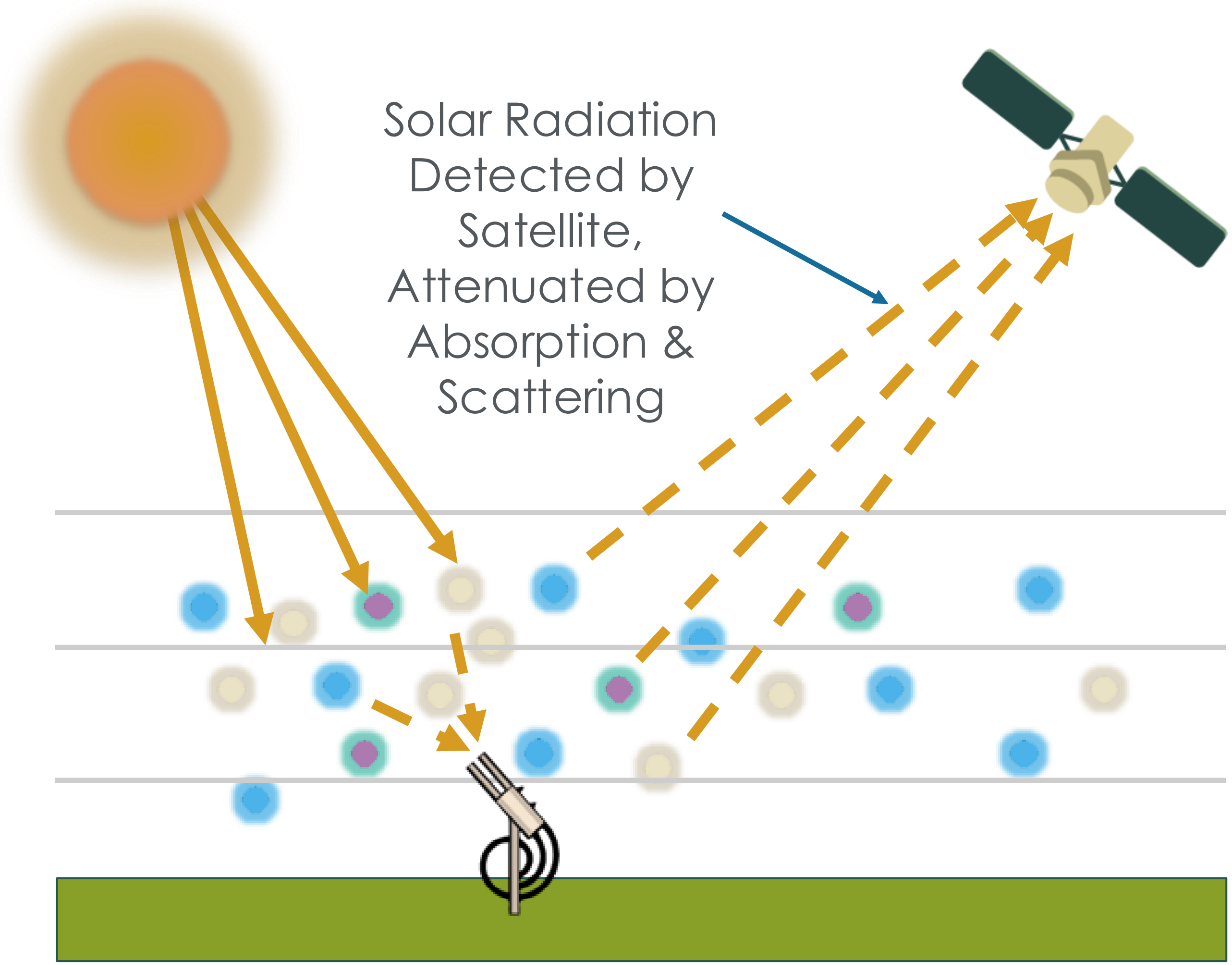
- **Ground-based monitors provide the most direct and accurate data on $PM_{2.5}$ concentration where people live and breathe.**
- Reference monitors provide basic information for research and policy.
- Reference monitors are required for enforcement of air quality regulations in many countries.
  - Other data sources are not legally acceptable.

Limitations:

- Reference monitors are expensive to purchase and operate.
  - Low-cost sensors trade better affordability and more instruments for lower accuracy.
- Limited availability worldwide
  - Some countries lack any reference monitors
- Measurements at one location may not fully capture exposure.
  - Siting does not always follow best practices, especially for low-cost sensors.
- Quality control standards and requirements for open reporting vary by country.

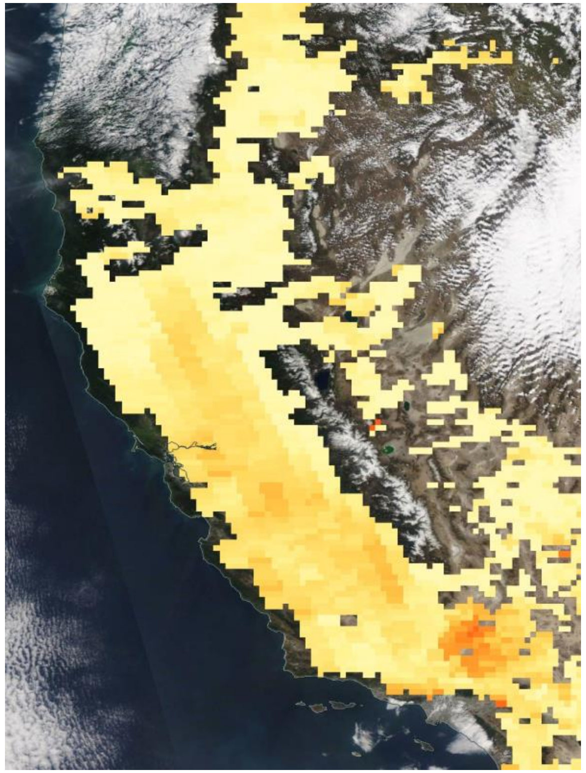
Aerosol Optical Depth (AOD)

- Also called Aerosol Optical Thickness (AOT)
- Indicates the quantity of light **scattered** and/or **absorbed** by aerosols as the light travels through the atmosphere
- Indicative of the entire column of the observed atmosphere (not just at the surface or near the instrument)
- Measured at certain wavelengths, most often including 550 nm (green)
- Can be measured from the ground, by aircraft, or by satellites
- Satellite retrieval algorithms calculate AOD using measured light intensity combined with information about the atmosphere, the sensor's viewing angle, and Earth's reflectivity.



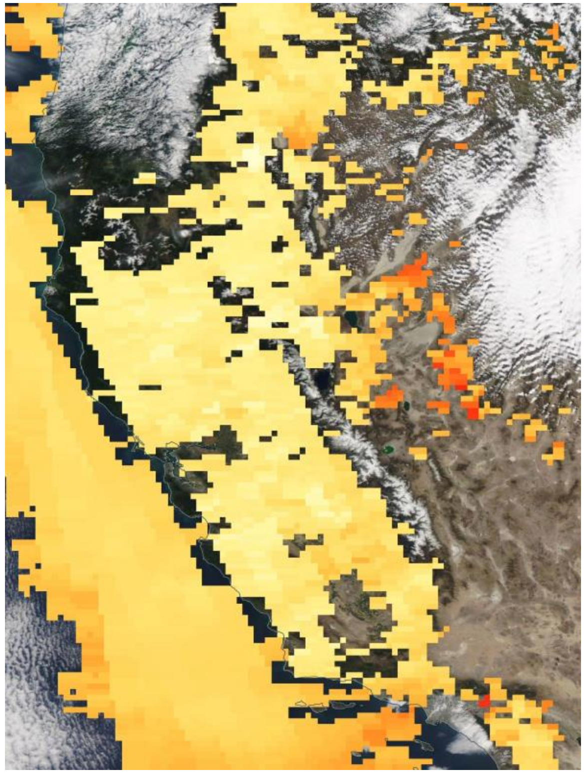
There are different AOD retrieval methods from the same instrument.

Deep Blue (10km)



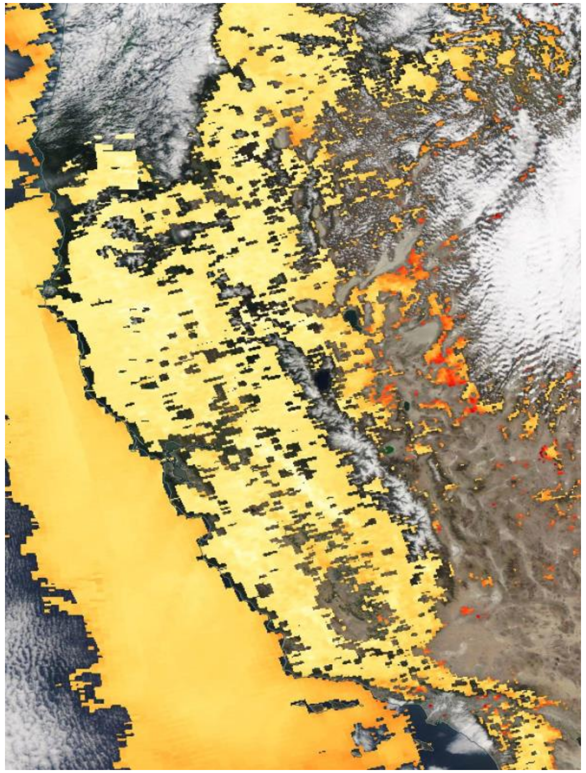
Land Only,
Best for Bright Surfaces

Dark Target (10km)



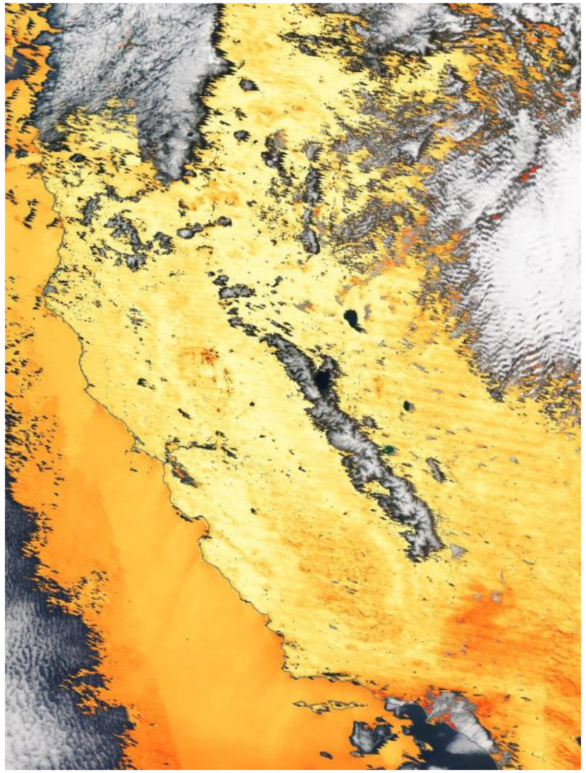
Land & Water,
Best for Dark Surfaces

Dark Target (3km)



Higher Resolution,
Issues in Urban Areas

MAIAC (1km)

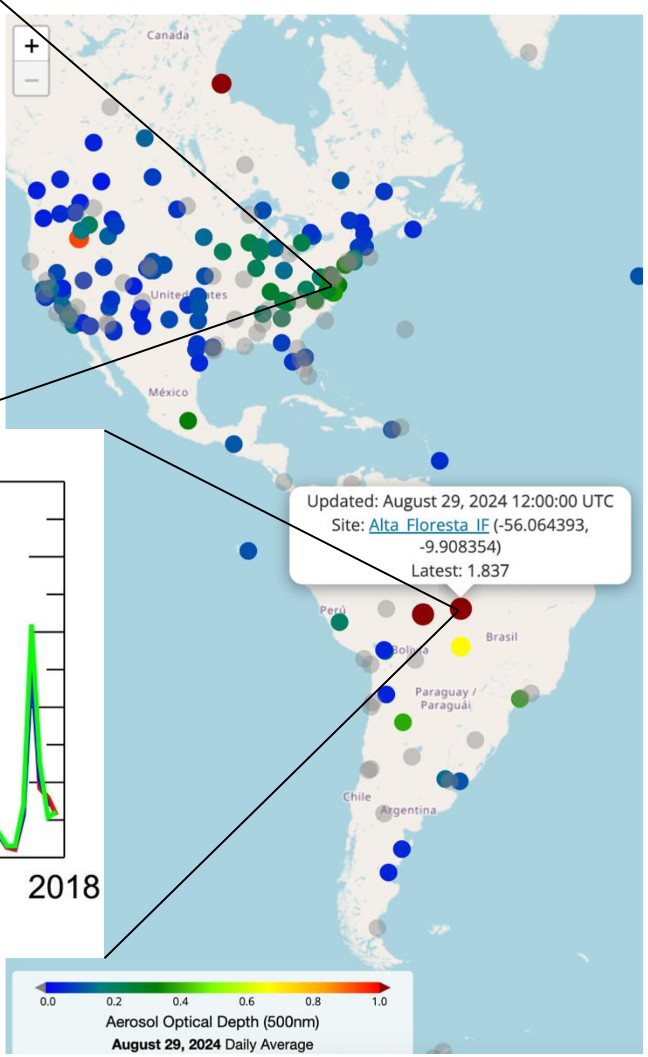


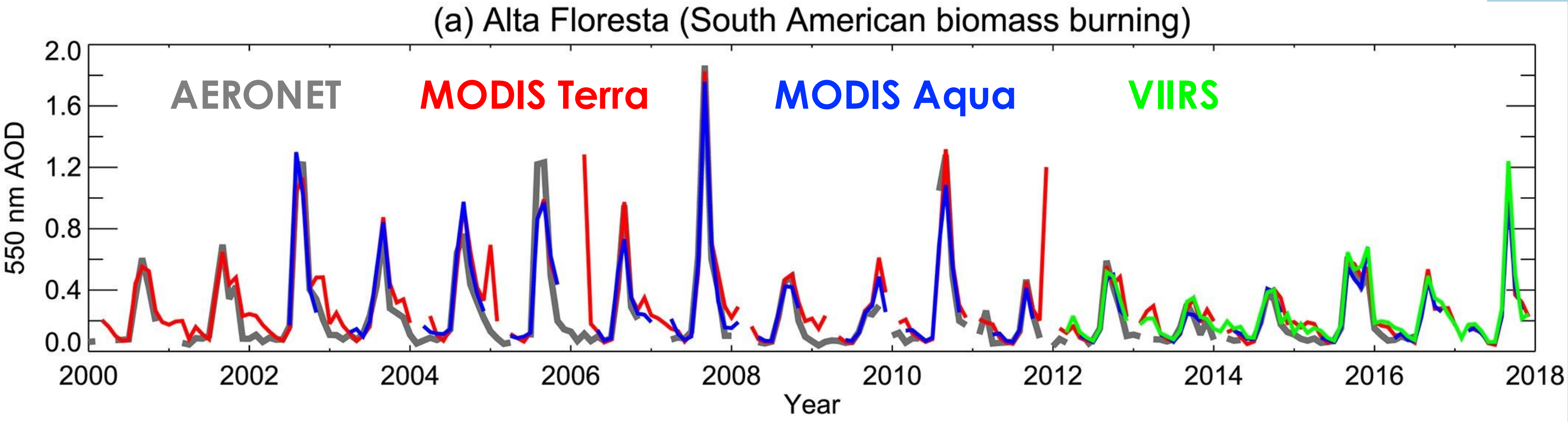
Highest Resolution,
Best for Urban Areas

Source: [NASA Worldview]

AOD Validation with Ground-Based Networks such as AERONET

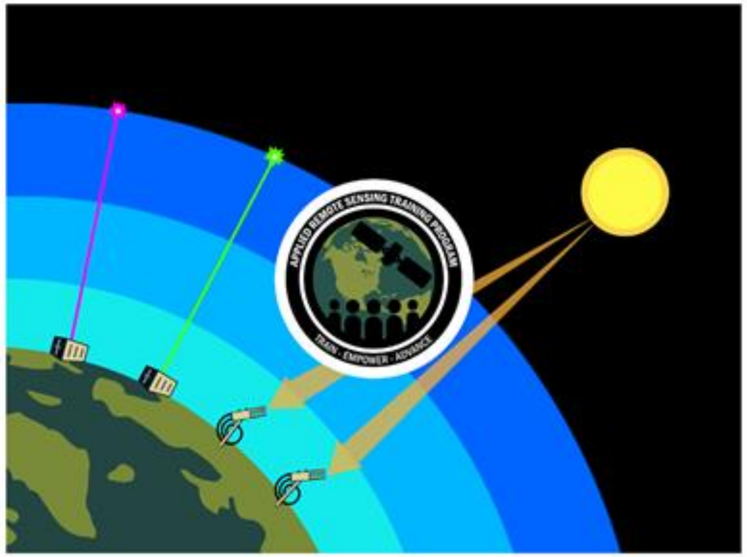
- Aerosol Robotic Network (AERONET) ground-based sun photometers provide bottom-up measurements of AOD.
- The data is used for validation and continuity of satellite AOD data products.





Source: NASA GSFC AERONET Website
Hsu et al. (2019)

NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications



This five-part training introduced participants to four NASA ground-based networks: the Aerosol Robotic Network (AERONET), Pandora and the Pandonia Global Network (PGN), the Tropospheric Ozone Lidar Network (TOLNet), and the Micro-Pulse Lidar Network (MPLNET). These networks provide data relevant to aerosol and trace gas column concentrations and vertical structure, supporting applications in air quality and climate. **More information can be found on the training webpage.**

Instructors

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Guest Instructor

Bryan Place
SciGlob/PGN
Guest Instructor

John Sullivan
NASA GSFC/TOLNet
Guest Instructor

Judd Welton
NASA GSFC/MPLNET
Guest Instructor

Common Satellite AOD Data Products Providing Global Coverage

Instrument	MODIS	VIIRS
Resolution	1, 3, 10 km	6, 0.75 km
Availability	From 2000	From 2012
Revisit Time	1-2 Days	Daily
Satellites	Terra (Launched in 1999) Aqua (Launched in 2002)	SNPP (Launched in 2011) NOAA-20 (Launched in 2017) NOAA-21 (Launched in 2022)
Overpass [Local Time]	Aqua ~1:30 PM Terra ~10:30 AM	~1:30 PM
Algorithms & Products	Deep Blue & Dark Target (10 km): MOD04_L2/MYD04_L2 Dark Target (3 km): MOD04_3K/MYD04_3K MAIAC (1 km): MCD19A2	Deep Blue (6 km): AERDB_L2_VIIRS_SNPP/NOAA20 Dark Target (6 km): AERDT_L2_VIIRS_SNPP/NOAA20/NOAA21 MAIAC (0.75 km): VNP19A2/VJ119A2

MODIS to VIIRS Transition for Air Quality Applications

With the end of the Moderate Resolution Imaging Spectroradiometer (MODIS) data record approaching, it is important that current MODIS users transition to Visible Infrared Imaging Radiometer Suite (VIIRS) data and visualization tools. This training teaches participants how to access VIIRS data products, the differences involved in using VIIRS as opposed to MODIS, and how to apply VIIRS aerosol optical depth observations for air quality applications. **More information can be found on the training webpage.**

Instructors

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ARSET Instructor

Additional Satellite AOD Data Products Providing Global Coverage

Instrument	SeaWiFS	MISR
Resolution	13.5 km	17.6, 4.4 km
Availability	1997 to 2010	From 2000
Revisit Time	Daily	2-9 Days
Satellites	OrbView-2 (Launched in 1997)	Terra (Launched in 1999)
Overpass [Local Time]	~12:00 PM	~10:30 AM
Algorithms & Products	Deep Blue (13.5 km): SWDB_L2	MISRv22 (17.6 km): MIL3MAEN_004 MISRv23 (4.4 km): MIL2ASAE_003

Strengths and Limitations of Satellite AOD

Strengths:

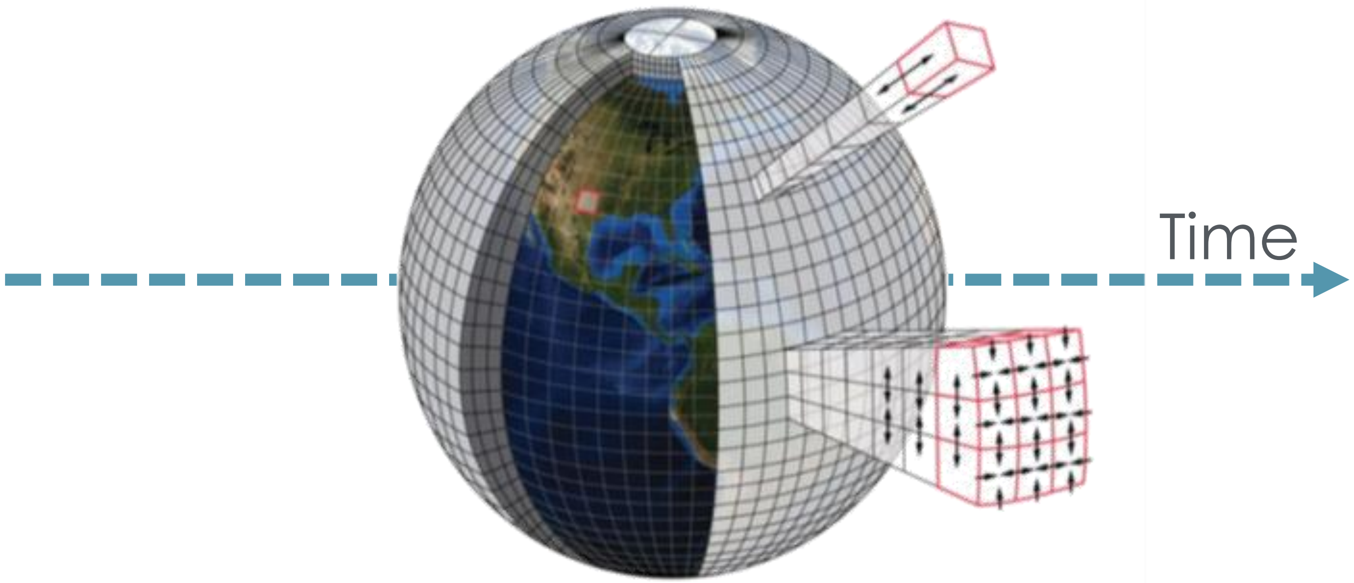
- **Global coverage with polar-orbiting satellites**
- Long data records, consistent across instruments & satellites

Limitations:

- Daytime-only measurements
- Missing data due to clouds, dense smoke, & reflective surfaces
  - Factors such as cloud cover can be seasonally dependent, leading to systematic biases in long-term datasets.
- Column-integrated, not surface-level
- Not size-specific to $PM_{2.5}$
- Multiple algorithms suitable to different conditions

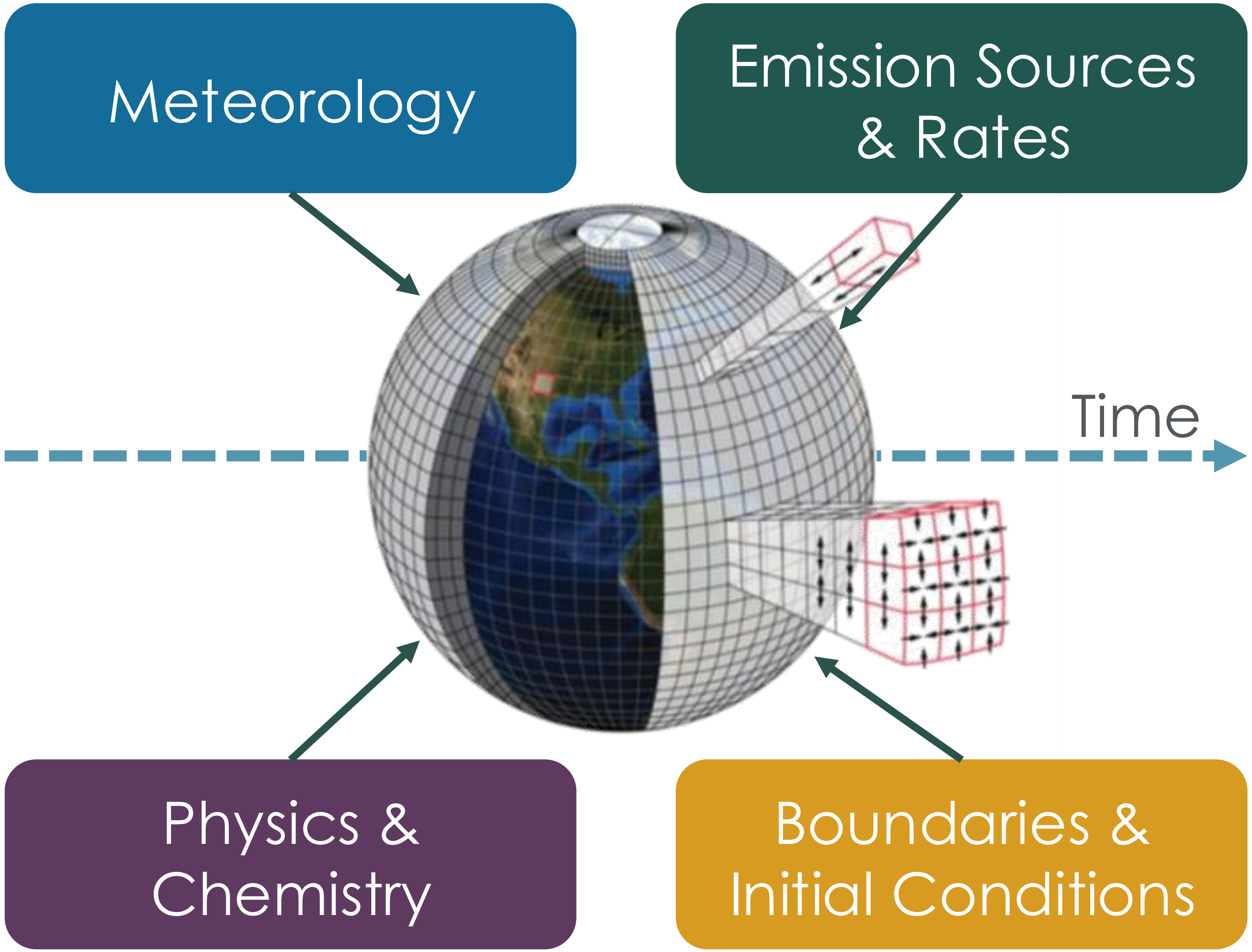
Chemical Transport Model (CTM)

- Mathematical model of the atmosphere and its constituents
- Represents physical & chemical processes impacting air quality
  - Emission
  - Production & Transformation
  - Transport
  - Deposition & Removal
- Operates on a 4D grid
  - Horizontal Resolution
  - Vertical Resolution
  - Temporal Resolution
- Different operating modes
  - Historical Simulation
  - Forecasting
  - Counterfactual



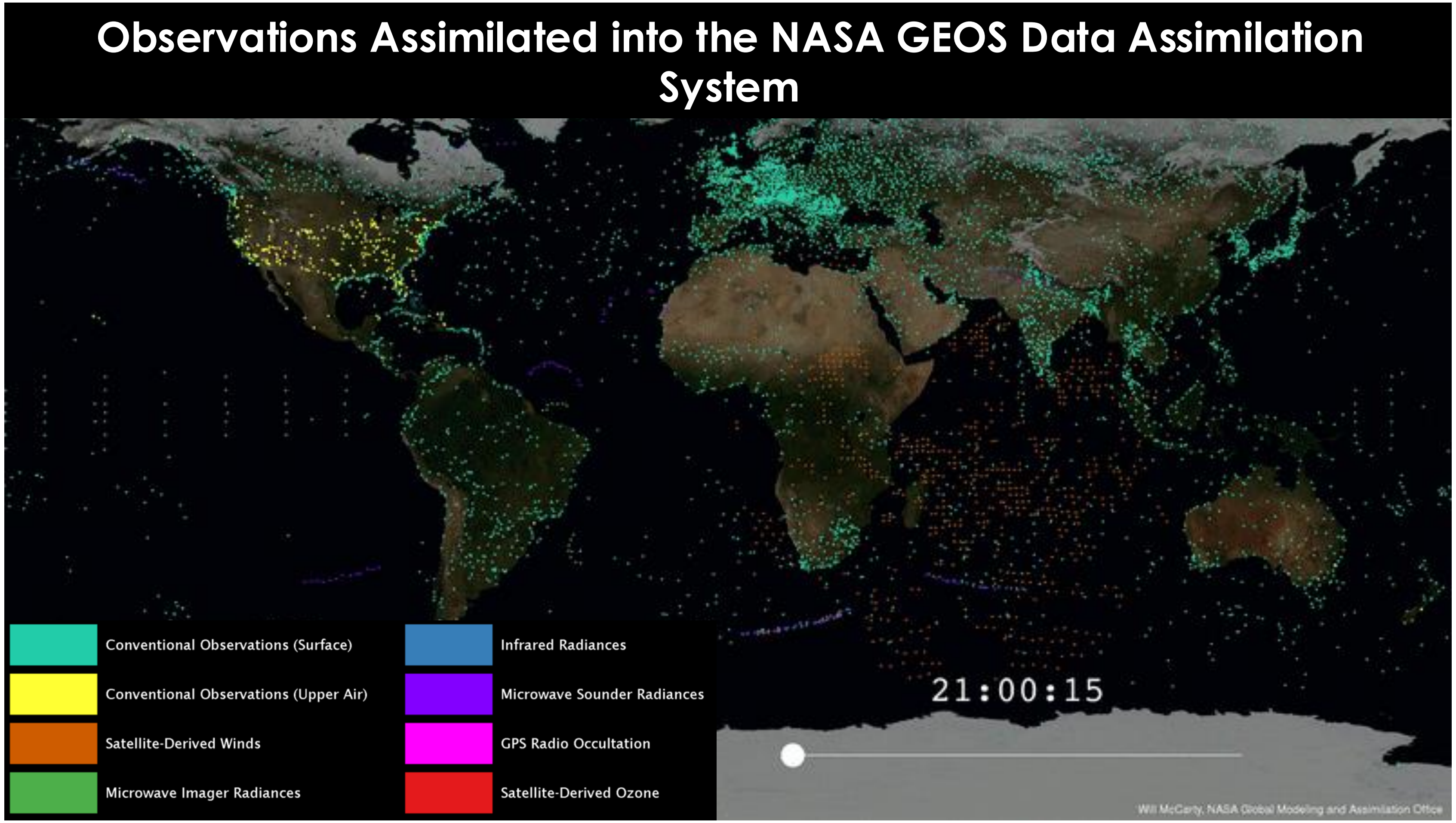
Ingredients of a CTM

- Required Input Data
  - Meteorology (if not simulated)
  - Emission inventories & projections
  - Initial and/or boundary conditions
- Digital Infrastructure – Software/Code
  - Atmospheric general circulation model (to simulate meteorology)
  - Physical and chemical mechanisms (e.g., aerosol module)
  - Coupling of meteorology & chemistry
- Physical Infrastructure – Hardware
  - High-performance computing clusters
  - High-capacity data input/output/storage



Data Assimilation and Reanalysis

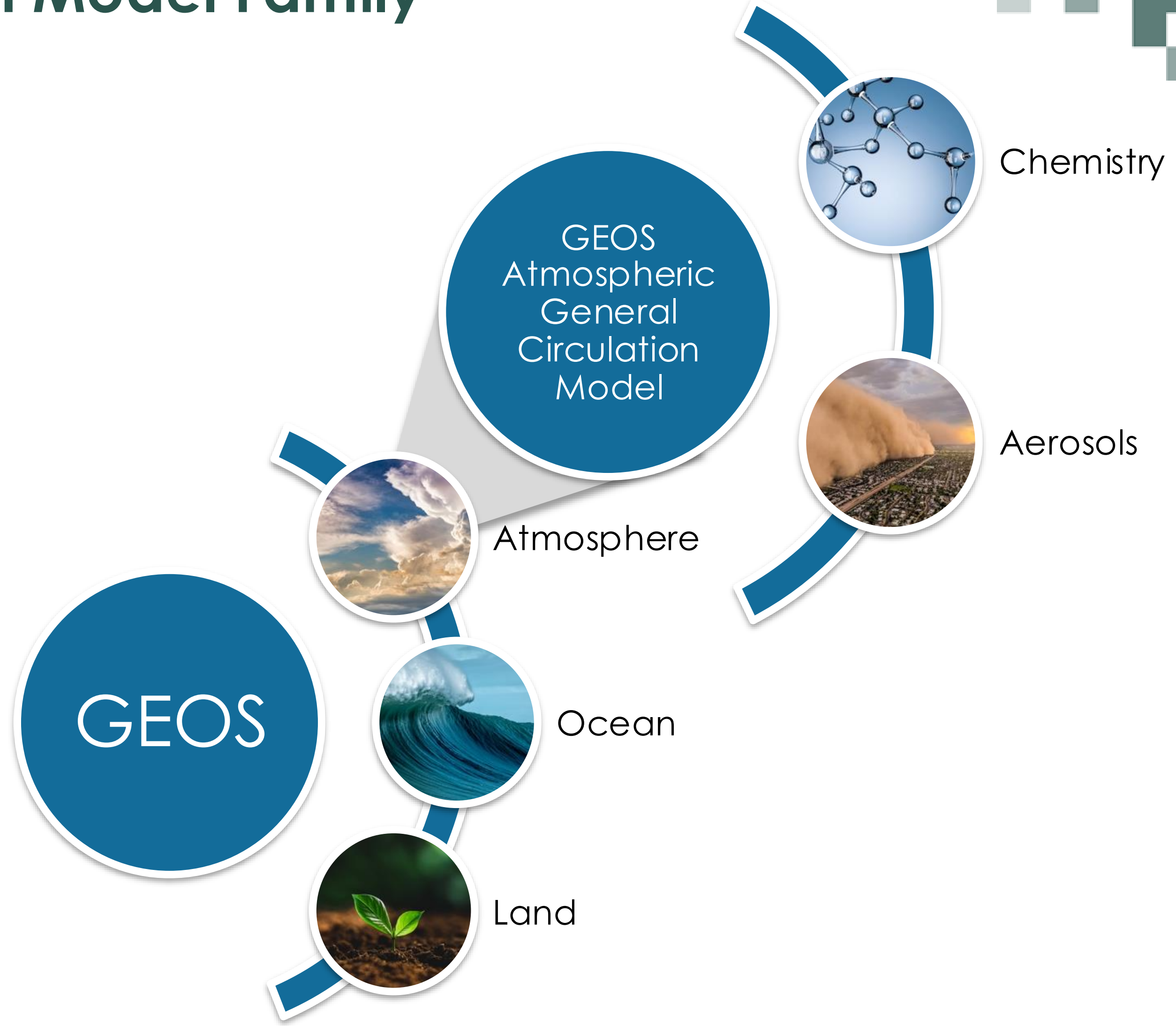
- **Data assimilation** describes the process of assimilating, or incorporating, observations into a model state to produce the best estimate of the atmosphere, land, and ocean conditions.
- A **background** is the model's "first guess" state.
- An **analysis** is the updated model state, better matching observations.
- A **reanalysis** blends observations with model simulations of the past using a consistent model version.



Source: NASA Scientific Visualization Studio (SVS)

NASA Goddard Earth Observing System Model Family

- **The Goddard Earth Observing System (GEOS)** is an Earth System Model, representing:
  - Land
  - Ocean
  - Atmosphere
- GEOS uses a Hybrid 4D-Ensemble Variational (Hyb-4DEnVar) data assimilation system.
  - Analyses are created every 6 hours using over 5 million observations.
  - GEOS assimilates AOD from MODIS.
- Model is run in multiple modes, including:
  - GEOS FP: Forward Processing (meteorological & aerosol forecast)
  - GEOS-CF: Composition Forecast
  - MERRA-2: Modern Era Reanalysis for Research and Applications Version 2



Source: NASA Global Modeling & Assimilation Office (GMAO)

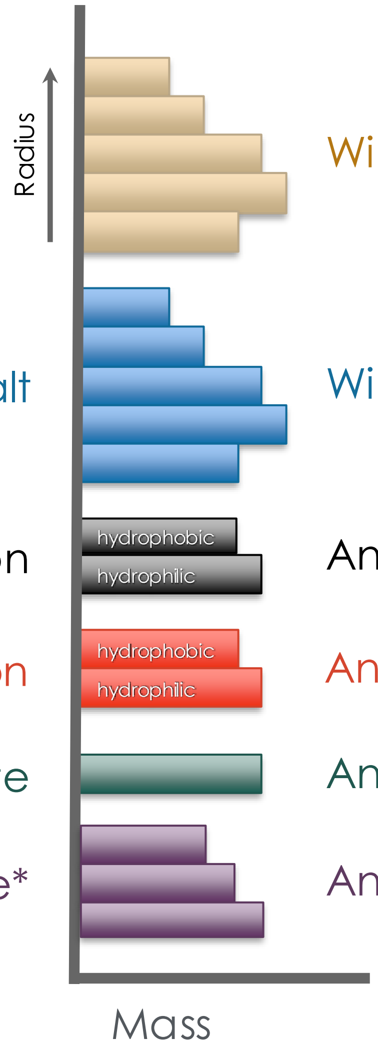
NASA GEOS Products Relevant to $PM_{2.5}$

	GEOS FP	GEOS-CF	MERRA-2
Mode	Analysis + Forecast	Analysis + Forecast	Reanalysis
Spatial Resolution	Simulation: ~12 km **Output: ~25 km (0.25°x0.312°)**	**~25 km (0.25°x0.312°)**	**~50km (0.5°x0.625°)**
Temporal Resolution	2-D Data: Hourly 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	**Last ~20 days**	**Last ~14 days**	**1980-Present**
Initialization	Daily 10-day Forecast at 00Z Daily 5-day Forecast at 12Z	Daily 5-day Forecast at 12Z	~3 weeks behind real time
AOD Assimilation	**MODIS, VIIRS***	**N/A**	**MODIS**

* In testing

Aerosol Mechanism in NASA GEOS (FP, MERRA-2)

Goddard Chemistry, Aerosol, Radiation and Transport (GOCART) Model



Dust — Wind and Topographic Sources, 5 Mass Bins

Sea Salt — Wind-Driven Source, 5 Mass Bins

Black Carbon — Anthropogenic and Wildfire Sources, Mass Hydrophobic & Hydrophilic

Organic Carbon — Anthropogenic and Wildfire Sources, Mass Hydrophobic & Hydrophilic

Sulfate — Anthropogenic, Wildfire, and Volcanic

Nitrate* — Anthropogenic and Wildfire Sources , 3 mass bins

- GOCART simulates aerosols in the discrete categories shown here.
- MODIS AOD is assimilated in MERRA-2, updating total aerosol loading (but not changing distribution between categories).
- When there are no observations, MERRA-2 draws towards the GOCART simulation.

*There are no nitrate aerosols in MERRA-2.

Sources: Chin et al. 2002, Colarco et al. 2010, Randles et al. 2017

Tools for Analyzing NASA Air Quality Model Output

This training builds capacity to apply Python codes and other online tools to read, map, and analyze datasets from NASA's Goddard Earth Observing System (GEOS) air quality forecasts as well as products from the second Modern-Era Retrospective analysis for Research and Application (MERRA-2) reanalysis. The training sessions include lectures and hands-on activities, including exercises, interacting with web-based and offline python tools, and time to perform analyses. **More information can be found on the [training webpage.]**

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Guest Instructor

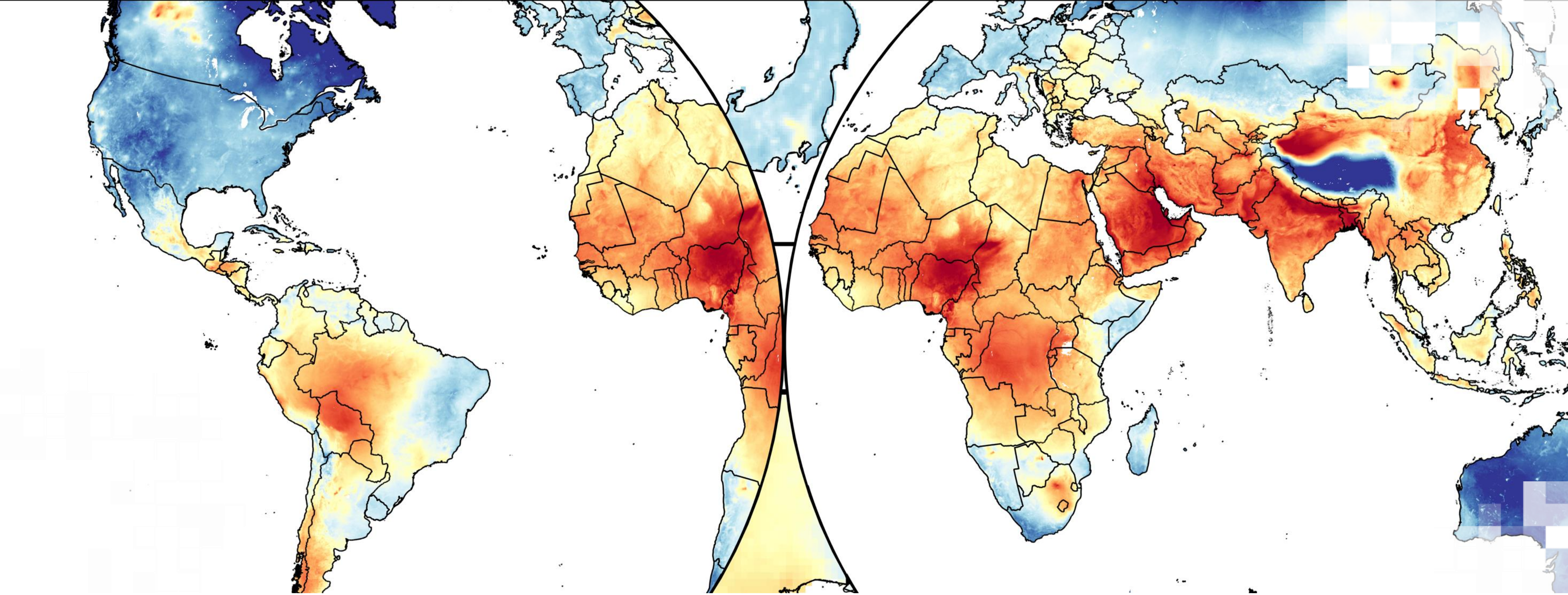
Strengths and Limitations of CTMs & Reanalysis

Strengths:

- **Provide information about regions and pollutants with limited ground and/or satellite observations.**
- Provide gridded, spatially and temporally consistent datasets, simplifying analysis.
- Provide details which may not be available from observations (e.g., aerosol source, composition, size distribution).

Limitations:

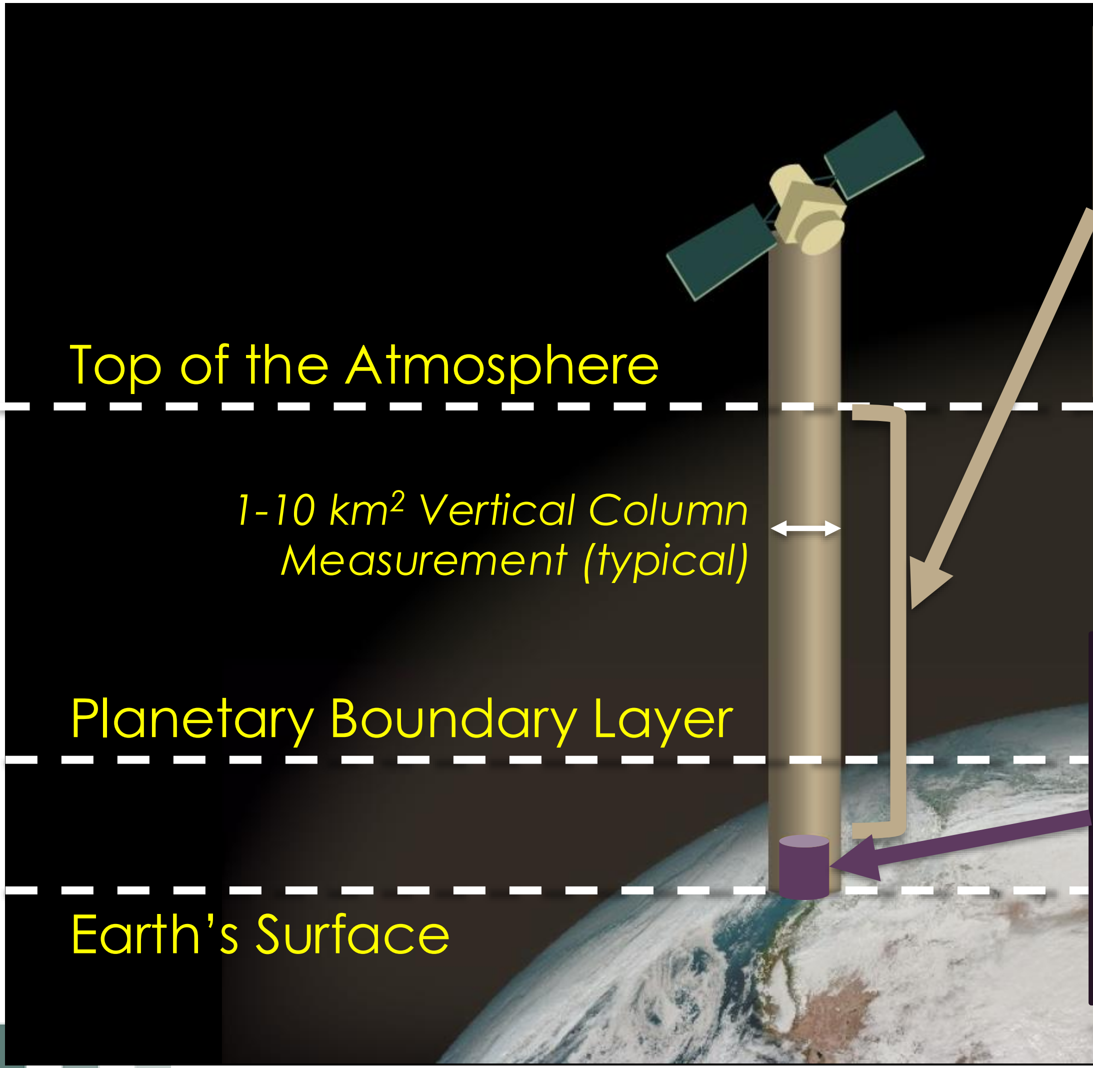
- **Model outputs will only be as good as their algorithms & inputs, and…**
  - Emissions
  - Meteorology
  - Chemical & Physical Mechanisms
  - Observations & Data Assimilation
- Model resolution may be relatively coarse compared to rapid spatial & temporal changes in $PM_{2.5}$ concentration.
- Models are technically & computationally intensive to run.
  - Publicly available outputs of global models may be suitable for some applications.



Part 1:

Why (or When) is AOD related to $PM_{2.5}$?

$PM_{2.5}$ and AOD are not directly comparable quantities.



Aerosol **Optical** Depth:

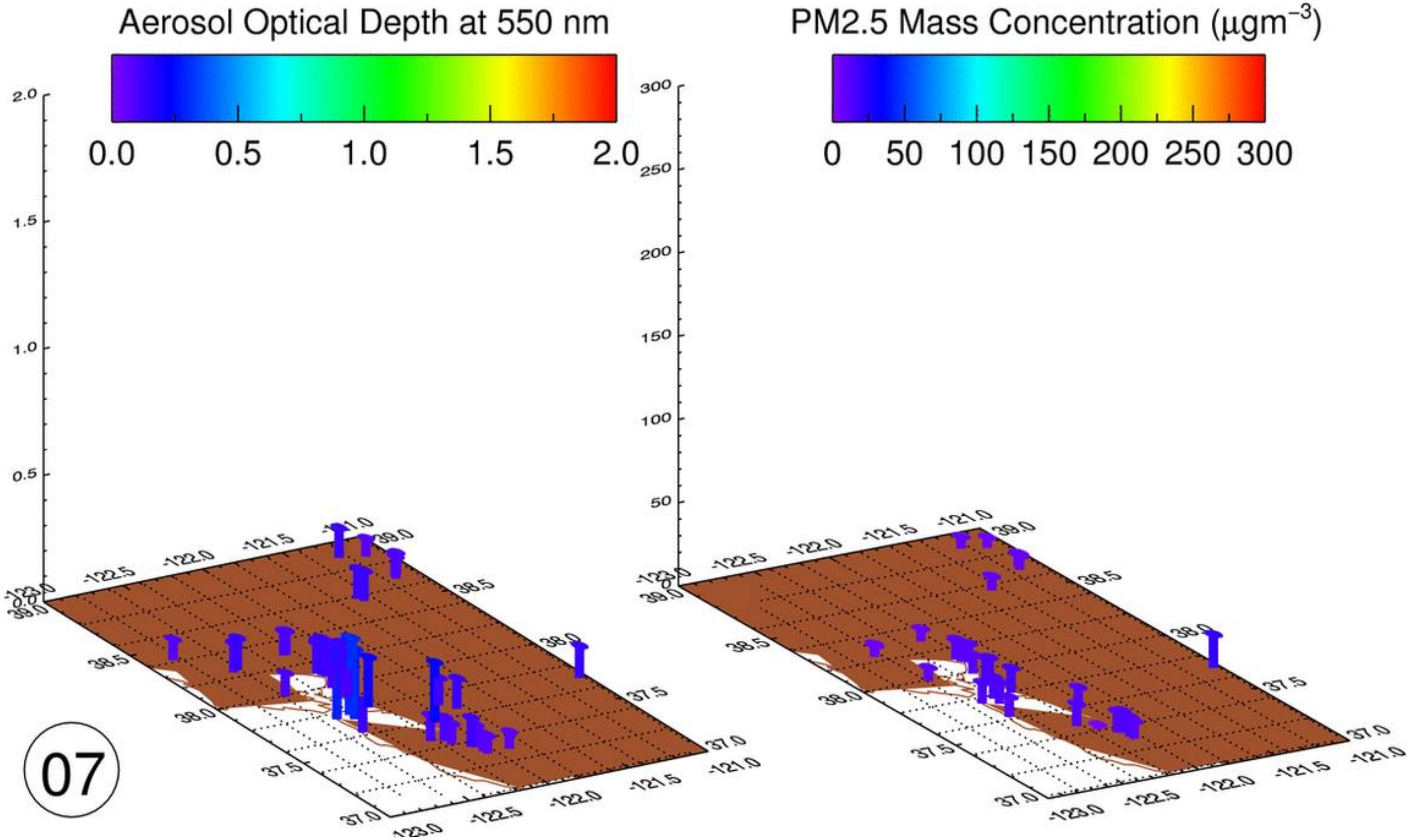
- Column-integrated value (top of atmosphere to surface)
- Unitless, optical measure of aerosol loading
- A function of shape, size, type, and number concentration of aerosols

$PM_{2.5}$ **Mass** Concentration:

- Near-surface value
- Dry mass per unit volume
- Mass concentration units ($\mu g\ m^{-3}$)
- Considers only particles less than 2.5 μm in diameter

However, AOD and $PM_{2.5}$ can be correlated.

- Fires in Bay Area, CA, USA, October 2017
- Vertical bars show the location of ground-based sensors, color coded with MODIS AOD and $PM_{2.5}$ values.
- The animation shows the impact of smoke from fires on local air quality and AOD.
- Both the column values (i.e., AOD) and surface values (i.e., $PM_{2.5}$) show similar response patterns to the fires.



Source: [Gupta et al. (2018)]

The Idealized Relationship Between AOD and $PM_{2.5}$

Assuming cloud-free skies, a well mixed boundary layer with no overhead aerosols, and aerosols that have similar optical properties, AOD and $PM_{2.5}$ can be related by this equation:

$$\mathrm{AOD}_{550\,nm} = \mathrm{PM}_{2.5}\ \mathrm{H}\ \ \mathrm{f}(RH)\,\frac{3\,Q_{ext,dry}}{4\,\rho\,r_{eff}}$$

$$\mathrm{PM}_{2.5} = \eta \times \mathrm{AOD}_{550\,nm}$$

- H: Mixing (boundary layer) height
- f(RH): How aerosol scattering changes with changing relative humidity

- $Q_{ext,dry}$: Extinction coefficient for dry aerosols
- ρ: Aerosol dry mass density
- r_{eff}: Particle effective radius

Source: Hoff & Christopher, 2009

AOD to $PM_{2.5}$ Relationship Factors: Vertical Profile of Aerosols

AOD and $PM_{2.5}$ are **well correlated** if:

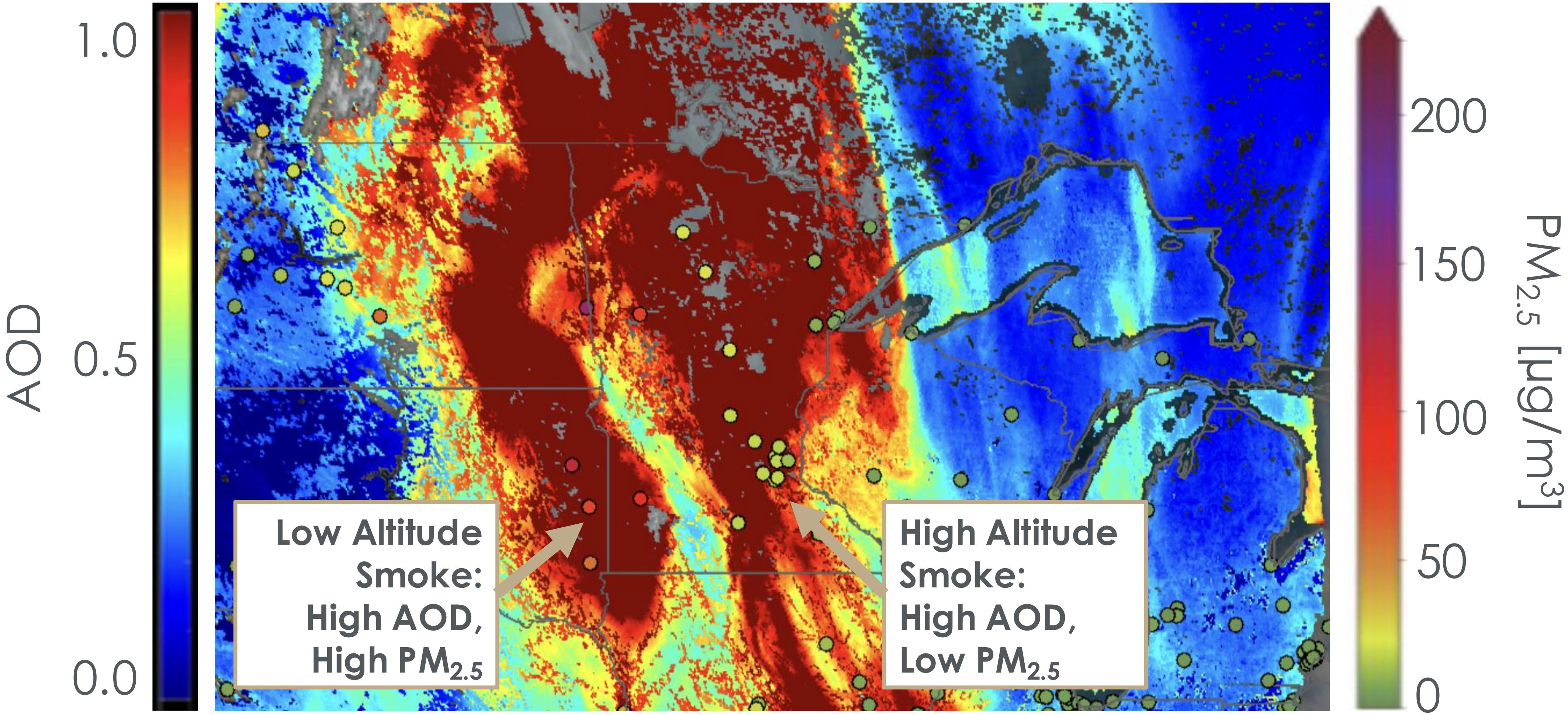
Aerosols concentrated near surface

⟵ Vertical Distribution of Aerosols ⟶

AOD and $PM_{2.5}$ are **poorly correlated** if:

Aerosols lofted above surface

Examples of Aerosol Vertical Profile Impacting AOD to $PM_{2.5}$ Relationship

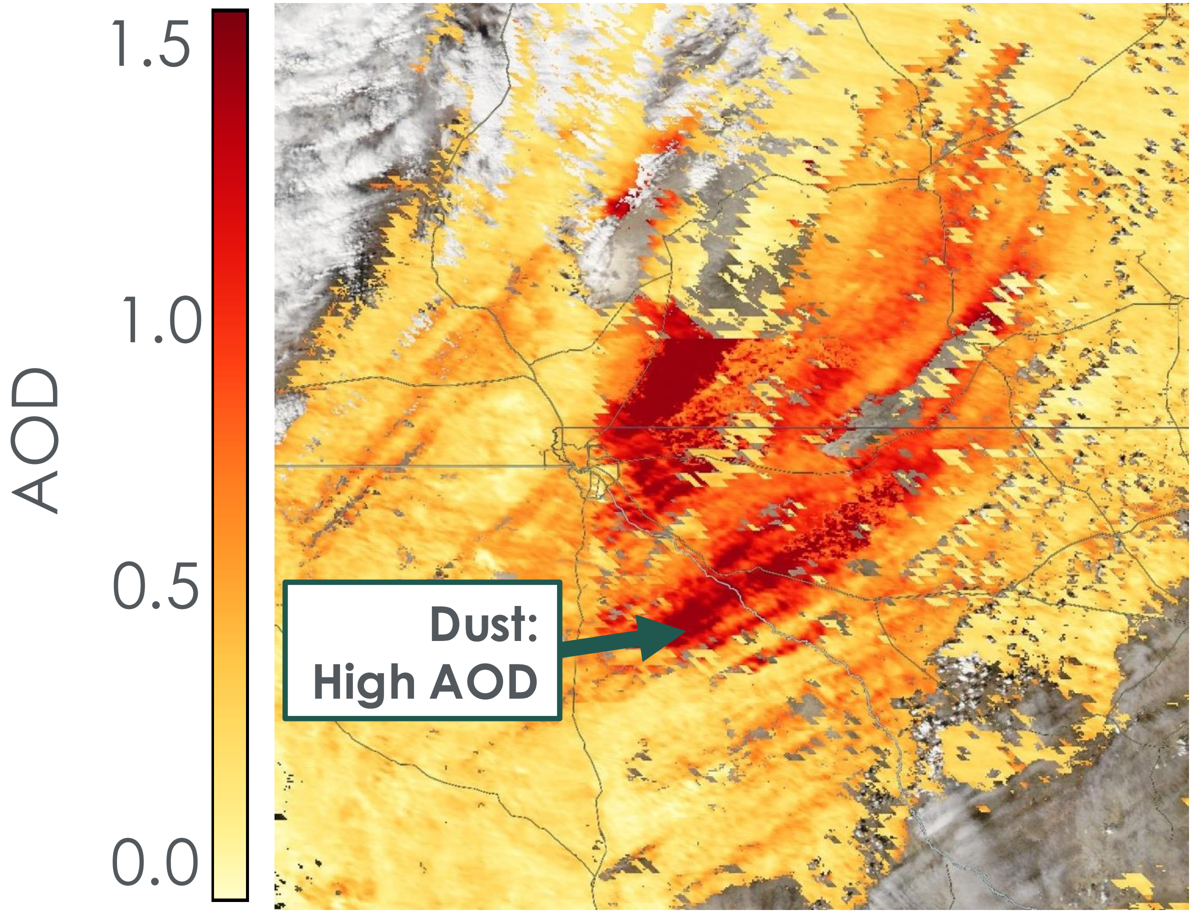


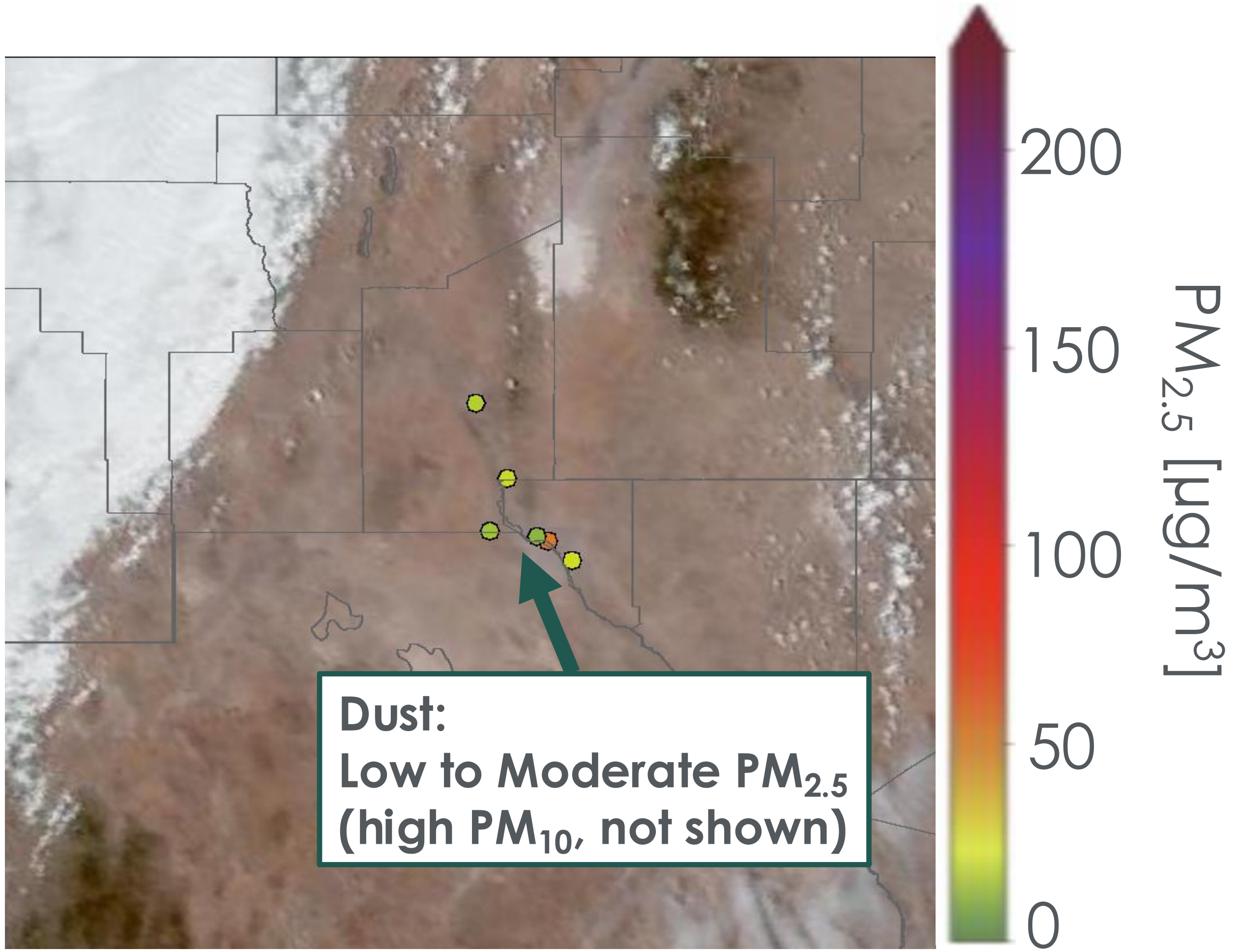
Source: NOAA AerosolWatch, June 1, 2025

AOD to $PM_{2.5}$ Relationship Factors: Aerosol Size Distribution

AOD and $PM_{2.5}$ are **well correlated** if:		AOD and $PM_{2.5}$ are **poorly correlated** if:
Aerosols concentrated near surface	⟵ Vertical Distribution of Aerosols ⟶	Aerosols lofted above surface
Fine aerosols are dominant	⟵ **Aerosol Size Distribution** ⟶	**Coarse aerosols are dominant**

Example of Aerosol Size Distribution Impacting AOD to $PM_{2.5}$ Relationship



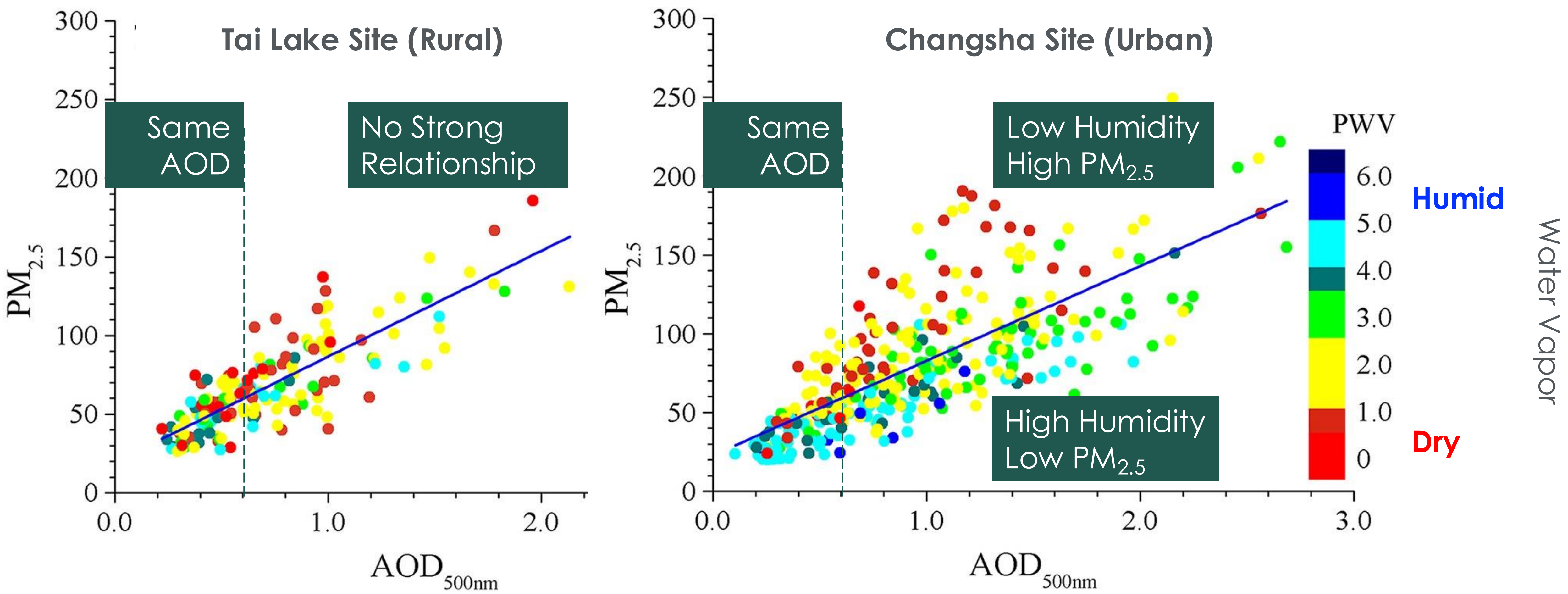


Sources: NOAA AerosolWatch, February 26, 2023; NASA Worldview, MAIAC AOD

AOD to $PM_{2.5}$ Relationship Factors: Aerosol Hygroscopic Properties

AOD and $PM_{2.5}$ are **well correlated** if:		AOD and $PM_{2.5}$ are **poorly correlated** if:
Aerosols concentrated near surface	← Vertical Distribution of Aerosols →	Aerosols lofted above surface
Fine aerosols are dominant	← Aerosol Size Distribution →	Coarse aerosols are dominant
Hydrophobic, steady humidity	← **Aerosol Hygroscopicity** →	**Hydrophilic, variable humidity**

Example of Aerosol Hygroscopicity Impacting AOD to $PM_{2.5}$ Relationship

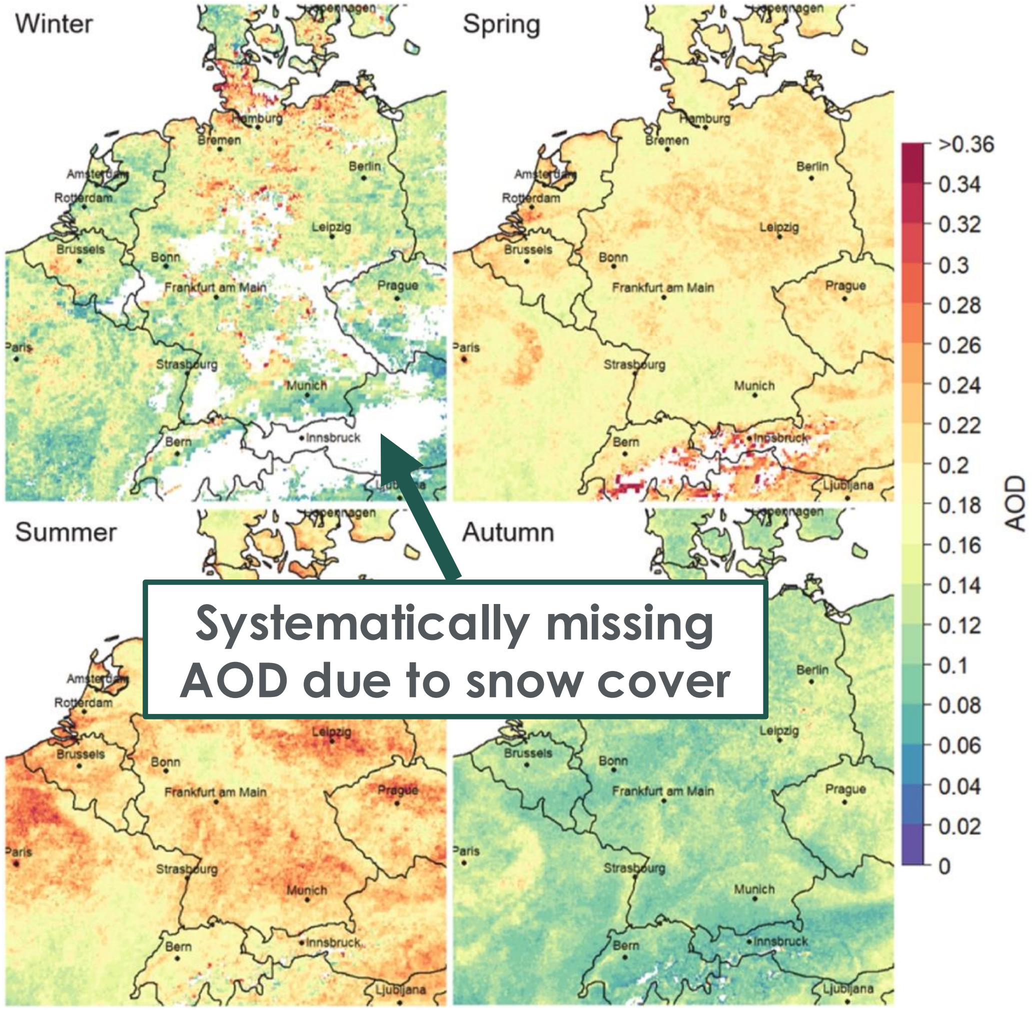


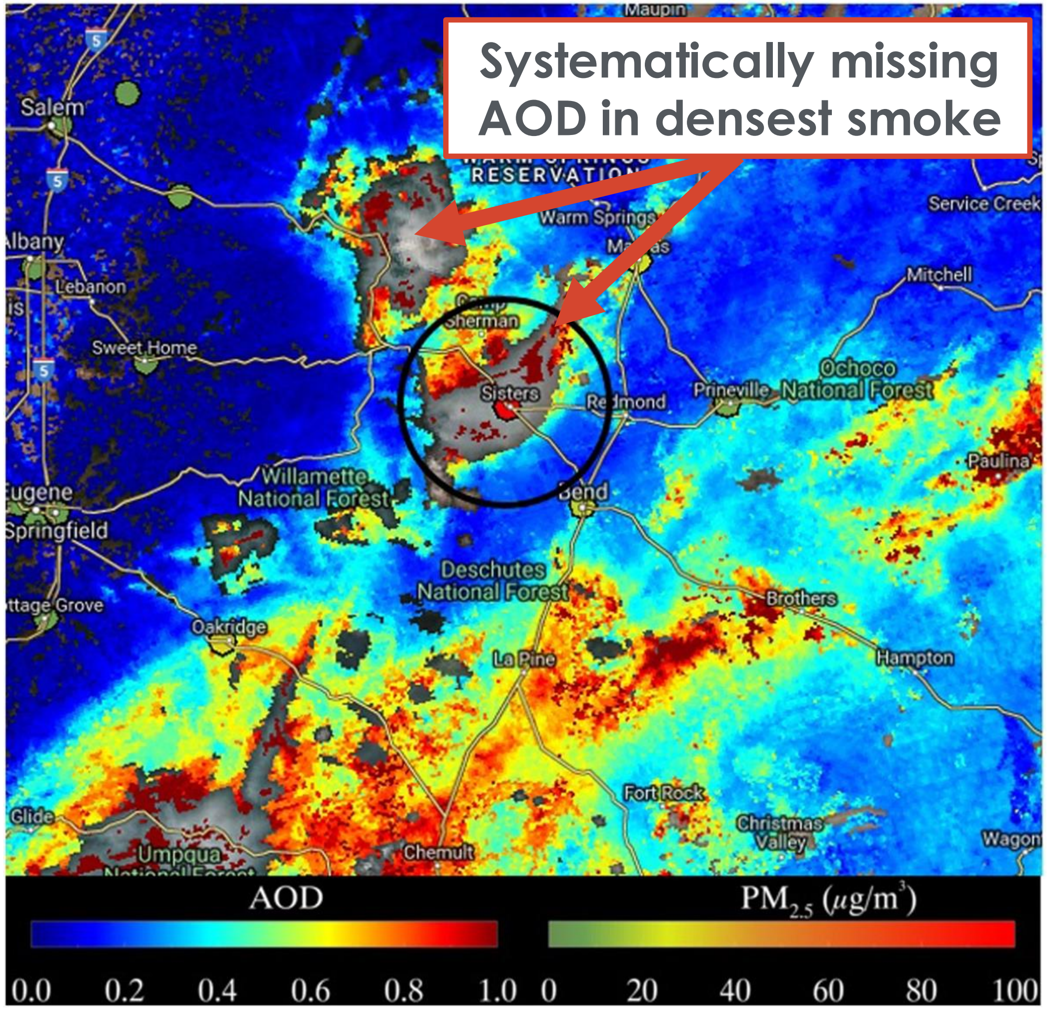
Source: Xin et al. 2016

AOD to $PM_{2.5}$ Relationship Factors: Systematic Reasons for Missing AOD

AOD and $PM_{2.5}$ are **well correlated** if:		AOD and $PM_{2.5}$ are **poorly correlated** if:
Aerosols concentrated near surface	⟵ Vertical Distribution of Aerosols ⟶	Aerosols lofted above surface
Fine aerosols are dominant	⟵ Aerosol Size Distribution ⟶	Coarse aerosols are dominant
Hydrophobic, steady humidity	⟵ Aerosol Hygroscopicity ⟶	Hydrophilic, variable humidity
Clear-sky conditions	⟵ **AOD Coverage** ⟶	**Cloud cover, dense smoke, reflective surfaces**

Examples of AOD Coverage Impacting AOD to $PM_{2.5}$ Relationship





Sources: Bi et al. 2019, Zhang & Kondragunta 2021, Handschuh et al. 2022

AOD to $PM_{2.5}$ Relationship Factors: Spatial Variability of $PM_{2.5}$ vs. AOD

AOD and $PM_{2.5}$ are **well correlated** if:		AOD and $PM_{2.5}$ are **poorly correlated** if:
Aerosols concentrated near surface	⟵ Vertical Distribution of Aerosols ⟶	Aerosols lofted above surface
Fine aerosols are dominant	⟵ Aerosol Size Distribution ⟶	Coarse aerosols are dominant
Hydrophobic, steady humidity	⟵ Aerosol Hygroscopicity ⟶	Hydrophilic, variable humidity
Clear-sky conditions	⟵ AOD Coverage ⟶	Cloud cover, dense smoke, reflective surfaces
Low spatial variability (similar concentrations 1-10 km)	⟵ **Spatial Resolution & Variability** ⟶	**High spatial variability (different concentrations <1km)**

Example of AOD Spatial Resolution Compared to $PM_{2.5}$ Spatial Variability

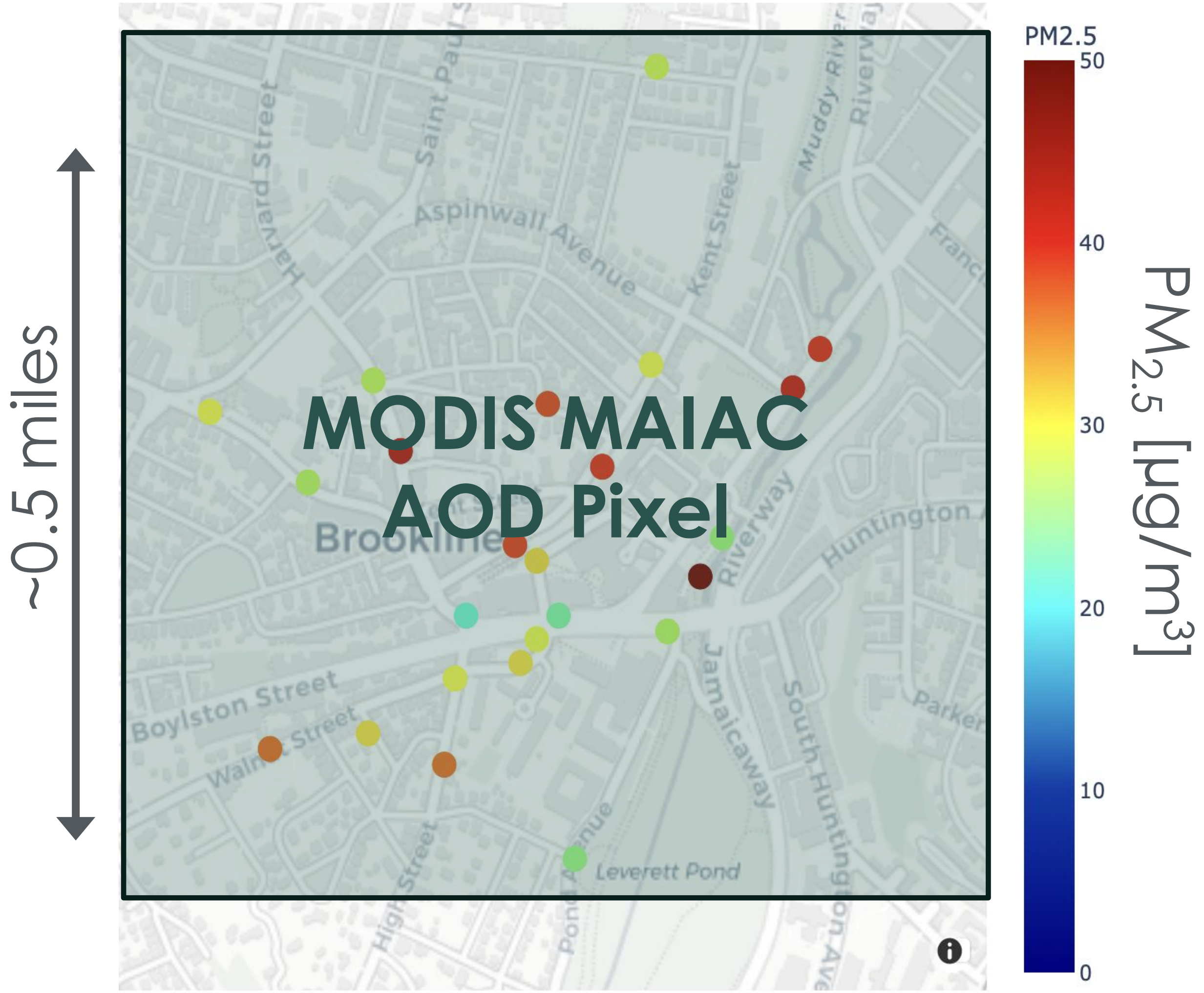


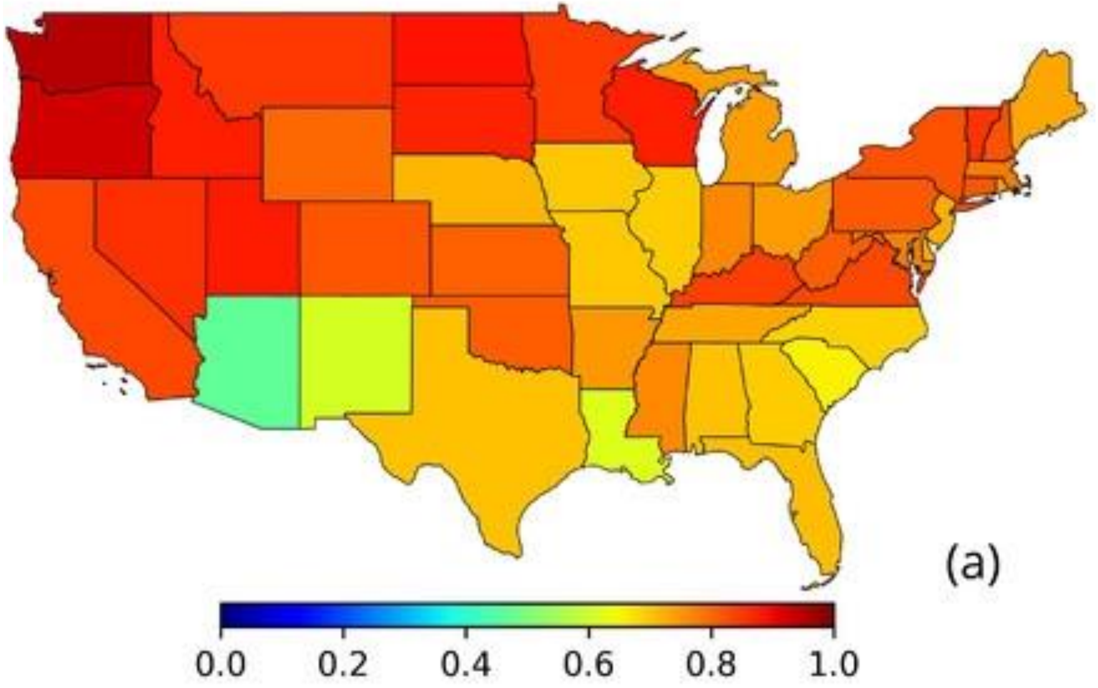
Figure provided by Matthew Elia and Amy Mueller, Northeastern University iSUPER Impact Engine, https://isuper.sites.northeastern.edu/ (Unpublished as of May 2026).

AOD to $PM_{2.5}$ Relationship Factors: Temporal Alignment of Satellite Passes

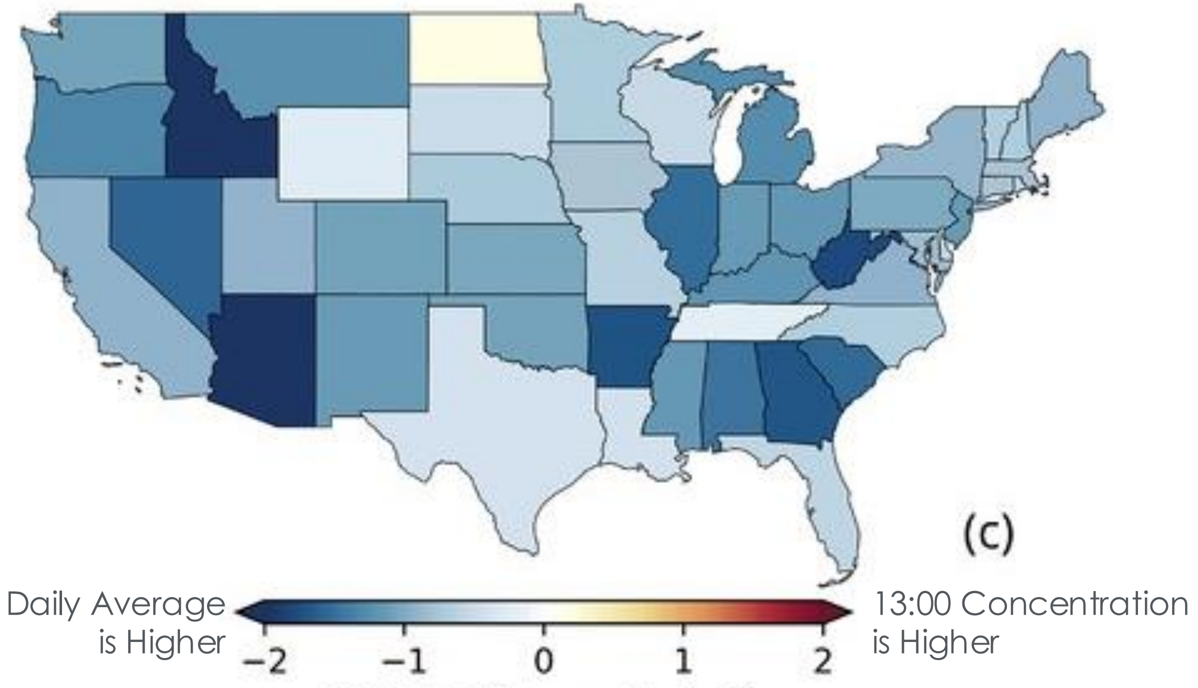
AOD and $PM_{2.5}$ are **well correlated** if:		AOD and $PM_{2.5}$ are **poorly correlated** if:
Aerosols concentrated near surface	← Vertical Distribution of Aerosols →	Aerosols lofted above surface
Fine aerosols are dominant	← Aerosol Size Distribution →	Coarse aerosols are dominant
Hydrophobic, steady humidity	← Aerosol Hygroscopicity →	Hydrophilic, variable humidity
Clear-sky conditions	← AOD Coverage →	Cloud cover, dense smoke, reflective surfaces
Low spatial variability (similar concentrations 1-10 km)	← Spatial Resolution & Variability →	High spatial variability (different concentrations <1km)
Measurements at overpass time	← **Temporal Alignment** →	**Measurements at other times**

Example of Temporal Alignment Impacting AOD to $PM_{2.5}$ Relationship

$PM_{2.5}$ at 13:30 Local Time (VIIRS Overpass) Compared to Daily Average

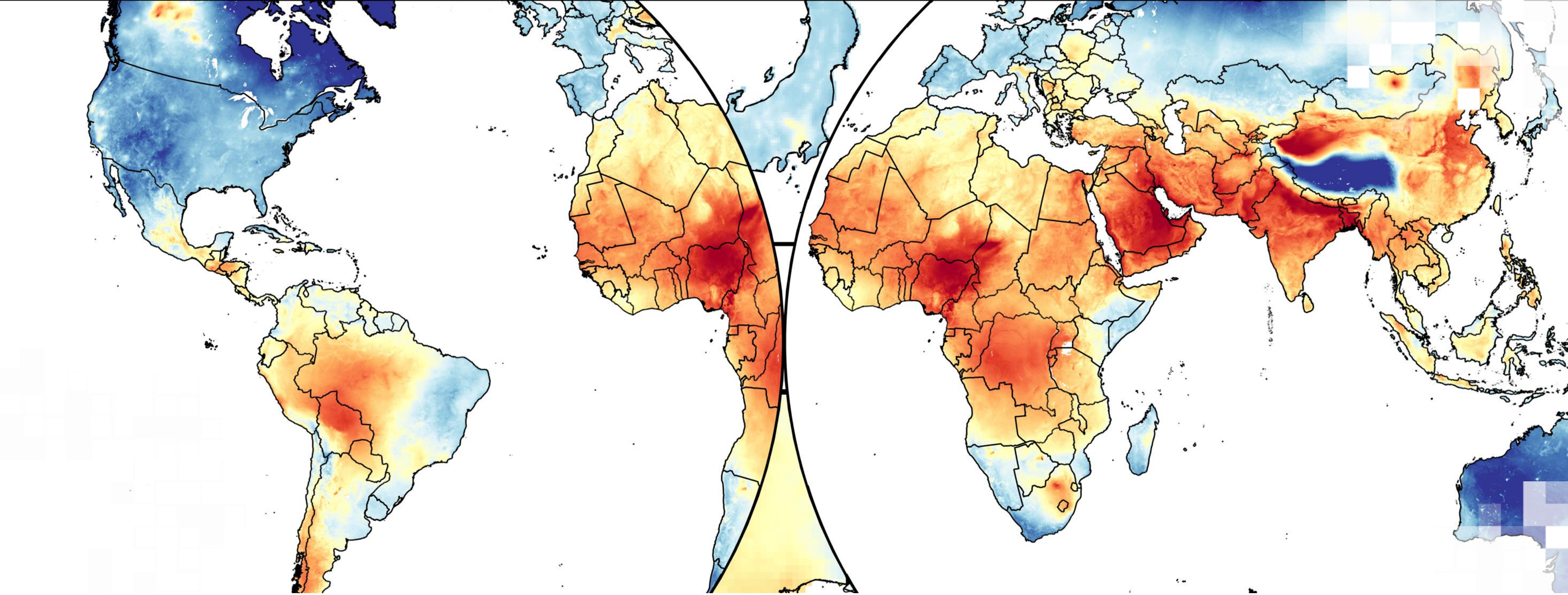


Correlation Coefficient



$PM_{2.5}$ Difference [μg/m^3]

Source: [Zhang et al. 2022]

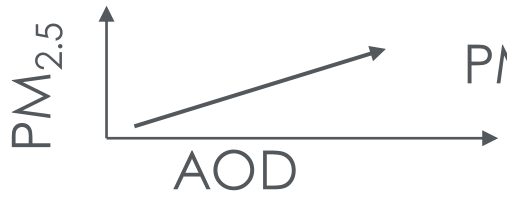


Part 1:

Simple Relations of AOD to $PM_{2.5}$

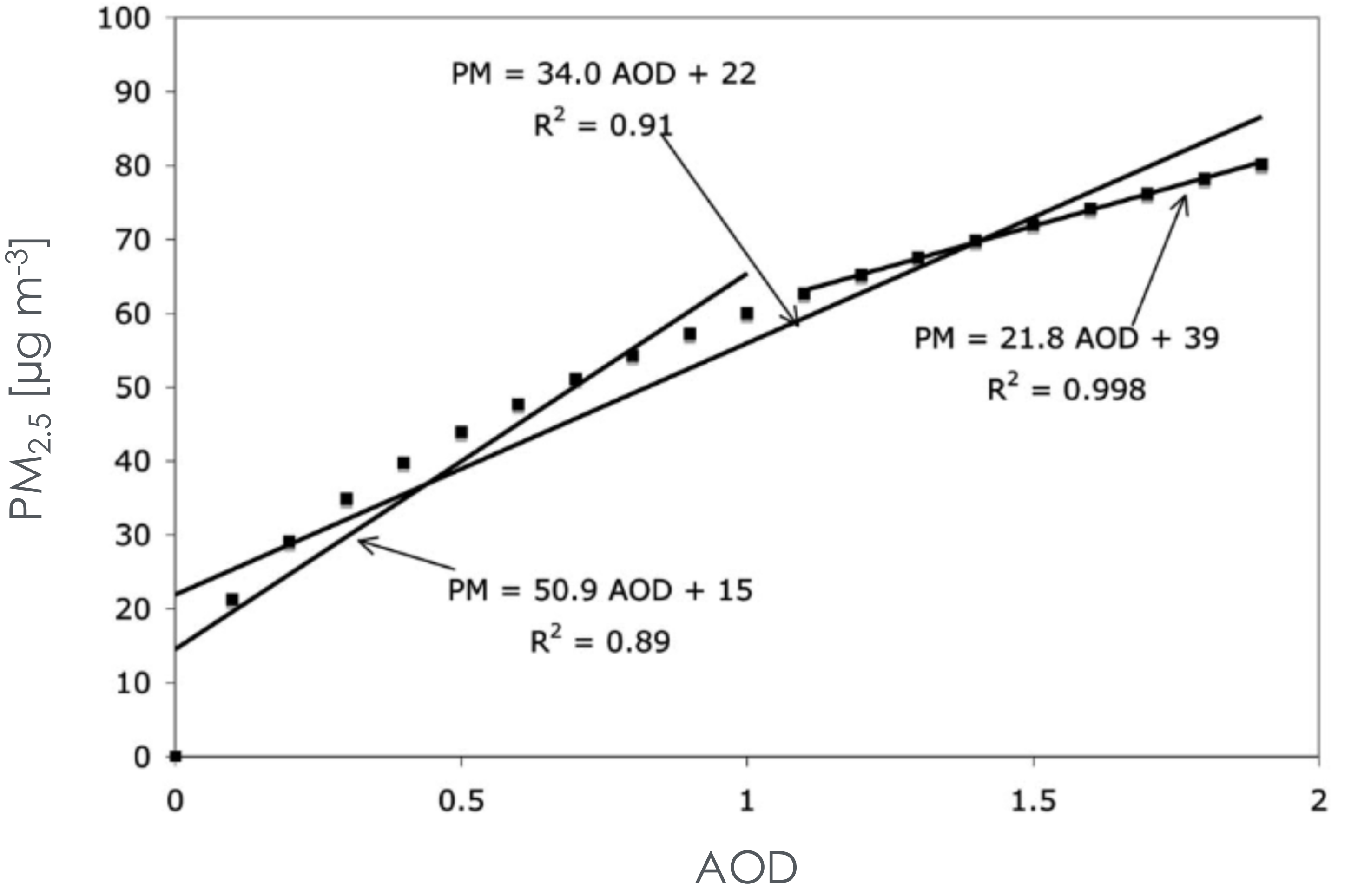
When AOD and $PM_{2.5}$ are well correlated, linear regression can suffice.

Two-Variable Linear Regression



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

Example of an Idealized Linear Relationship



Source: [Hoff & Christopher, 2009]

AOD and $PM_{2.5}$ are Rarely Well-Correlated

Linear regression varied by:

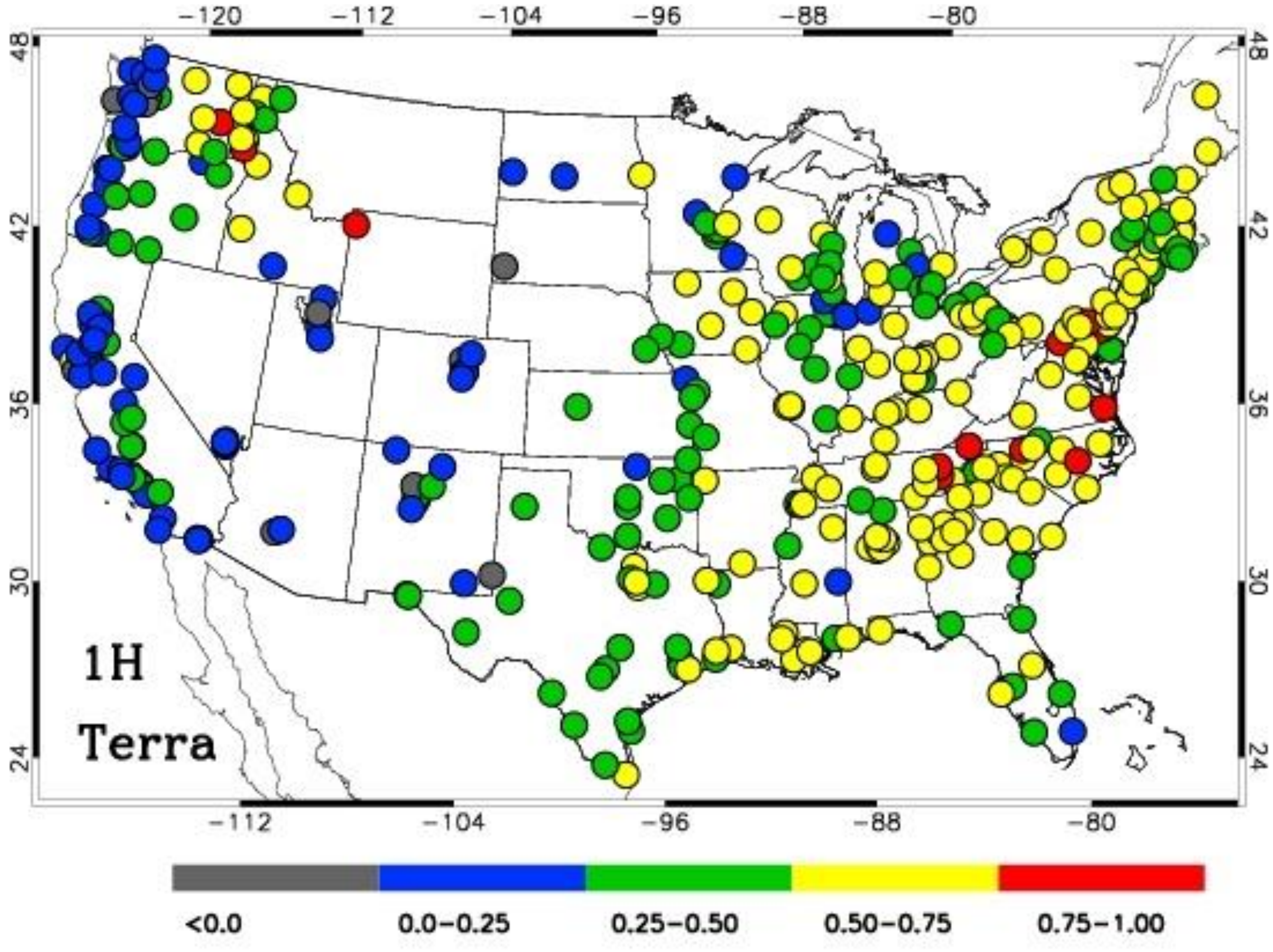
- Location
- Season

Similar results might be expected for:

- A small spatial domain (e.g., a city)
- A season with similar meteorology

However, even so, **there will be a lot of variability**, especially if there are major air pollution episodes (e.g., fires).

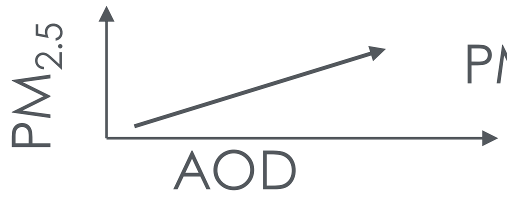
Linear Correlation (r)



Source: Gupta, 2008

Multivariable linear regression can account for confounding factors.

Two-Variable Linear Regression



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

Multivariable Linear Regression

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

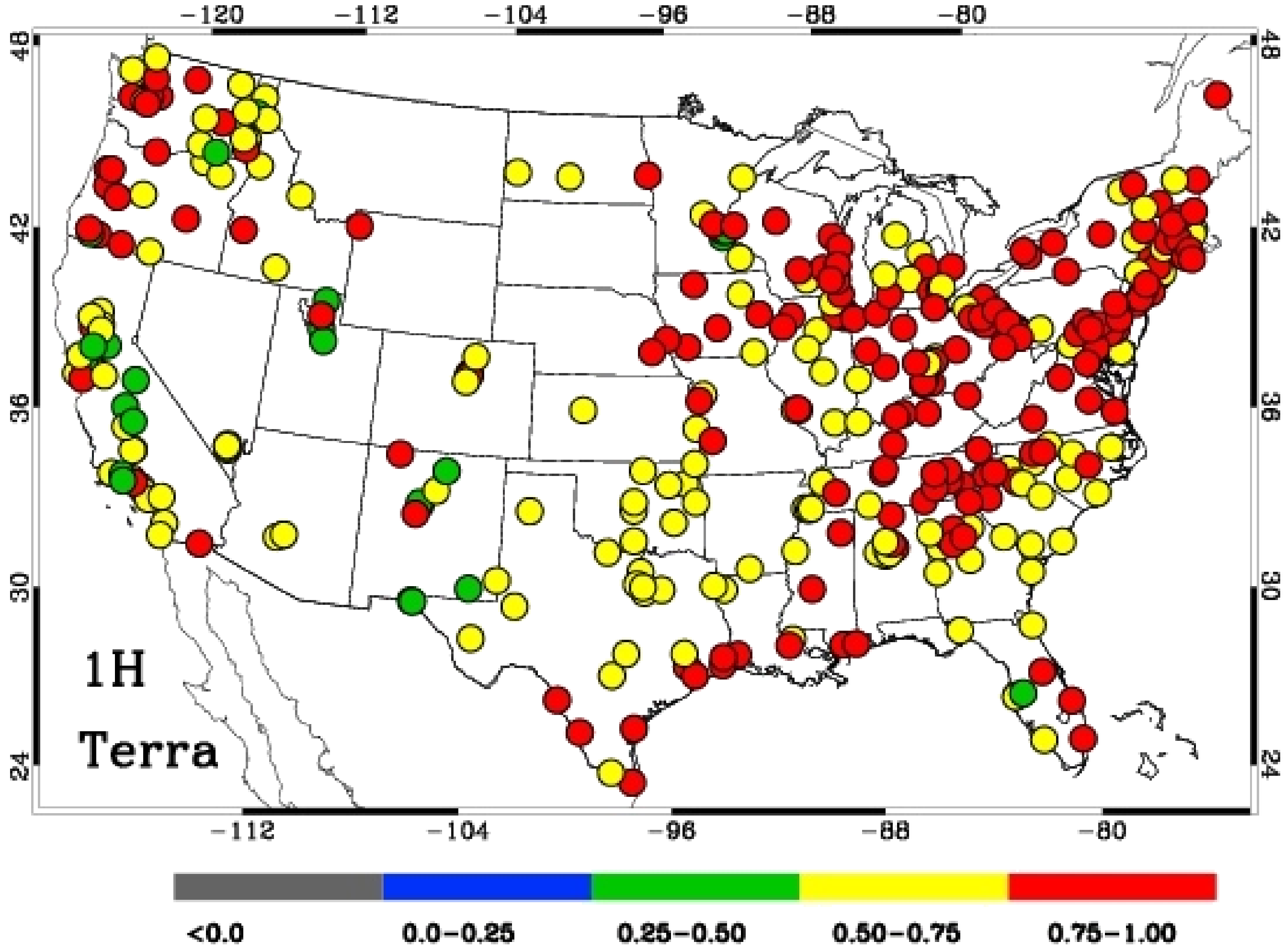
Accounting for known confounding factors can improve regressions.

Additional explanatory variables included for the multivariable regression:

- Temperature
- Relative Humidity
- Height of Planetary Boundary Layer
- Wind Speed
- Cloud Fraction

Overall correlation and accuracy are improved, but there remains **considerable variability across regions and seasons**.

Linear Correlation (r)



Source: Gupta, 2008

More sophisticated approaches may be needed (coming up in Part 2)

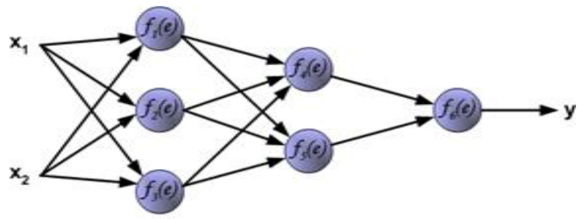
Two-Variable Linear Regression

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

Multivariable Linear Regression

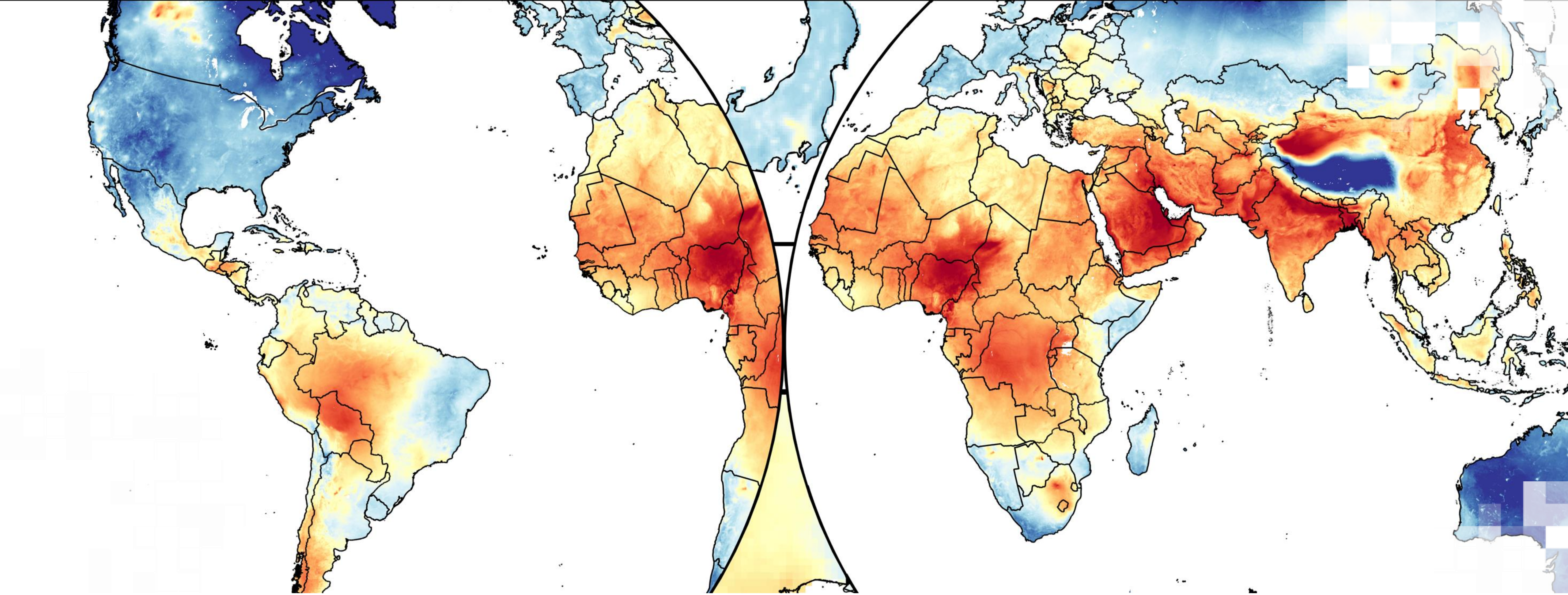
$$PM_{2.5} = \beta_0 + a \times AOD + \sum_{n=1}^{m}(\beta_n \times M_n)$$

Machine Learning



Geophysical Methods

$$\text{Estimated } PM_{2.5} = \frac{\text{Model Surface Area Concentration}}{\text{Model AOD}} \text{ x Satellite AOD}$$



Part 1:
Summary

Summary

In Part 1, we learned about the "pieces" used to estimate $PM_{2.5}$ from satellite AOD:

- Official measurements of $PM_{2.5}$ (e.g., for regulatory enforcement) come from in-situ monitors, measuring particle mass concentration near ground level under controlled conditions.
- Certain satellite remote sensing instruments can measure AOD, representing the quantity of light removed by aerosols during its path through the atmosphere.
- CTMs can simulate both $PM_{2.5}$ and AOD, but have limited resolution and require inputs about emissions and meteorology.

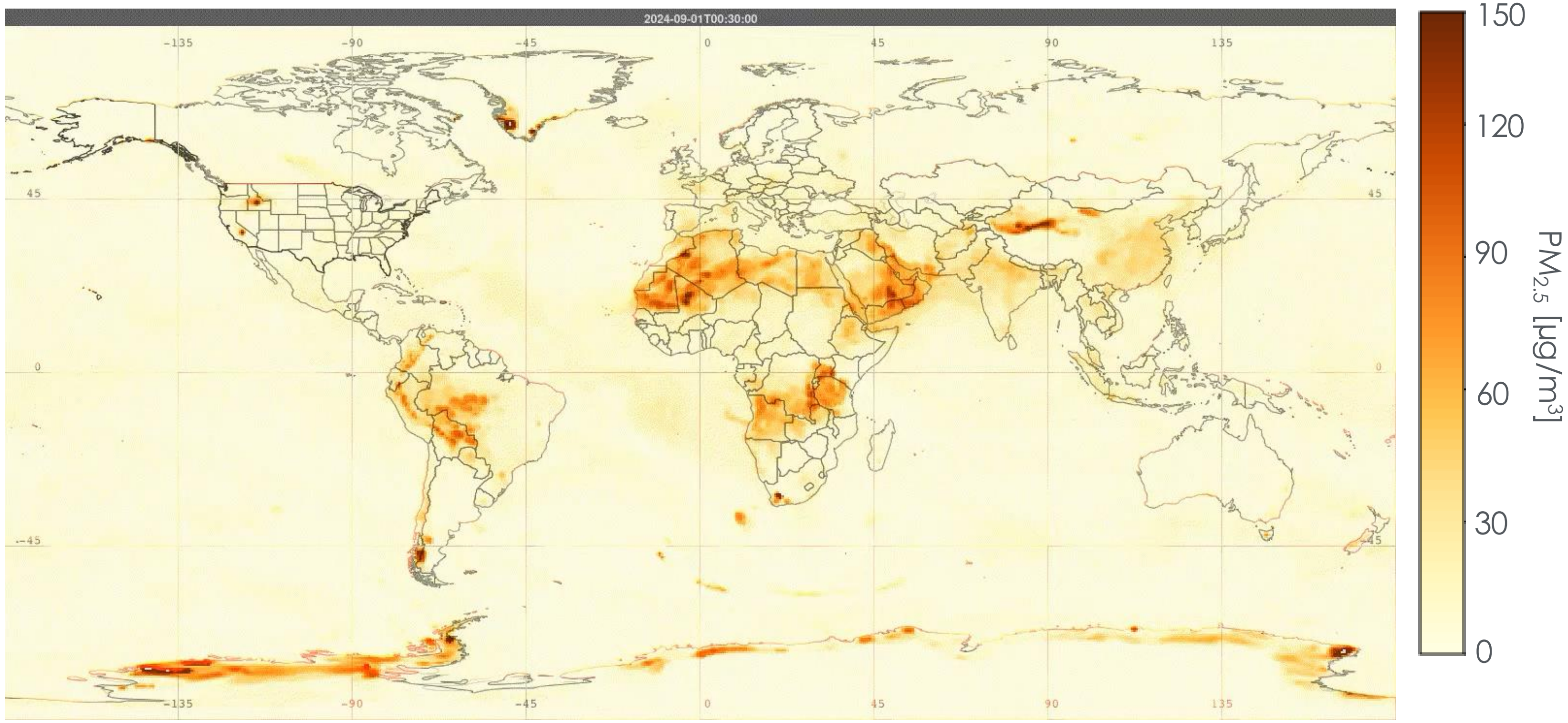
We also learned why a simple linear relationship between AOD and $PM_{2.5}$ may not apply:

- Aerosols may be suspended about ground level.
- Aerosols may be dominated by coarser particles.
- Aerosols can grow and block more light under humid conditions.
- Systematic gaps in AOD data coverage from satellites can bias our comparisons.
- Spatial resolution of AOD data may not represent local variations in $PM_{2.5}$.

Looking Ahead to Part 2

- In Part 2, we will learn about how the “pieces” we discussed in Part 1 can be combined to estimate surface $PM_{2.5}$ in locations without ground-based monitors.
- We will also learn about two common datasets for global surface $PM_{2.5}$ estimation:
  - Washington University St. in Louis SatPM Dataset
  - NASA MERRA-2 CNN HAQAST $PM_{2.5}$ Dataset

Global $PM_{2.5}$ from MERRA2_CNN_HAQAST_PM25
September 1-15, 2024



Source: [NASA Giovanni]

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on July 22, 2026
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by August 5, 2026**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

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Caterina Mogno

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- ARSET YouTube

For questions, comments, or to share how you have applied our trainings to your work or studies, email nasa.arset@gmail.com.

Join our quarterly newsletter to stay up-to-date on our latest trainings:

1. Send an email with no subject line to arset-join@lists.nasa.gov.
2. Follow the instructions sent in response.

Resources

- US Environmental Protection Agency, "Particulate Matter Basics"
- US Environmental Protection Agency, "AirData: Air Quality Data Collected at Outdoor Monitors Across the US"
- OpenAQ, "Explore the Data"
- NASA ARSET Trainings
  - Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications
  - MODIS to VIIRS Transition for Air Quality Applications
  - Tools for Analyzing NASA Air Quality Model Output

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Thank You!