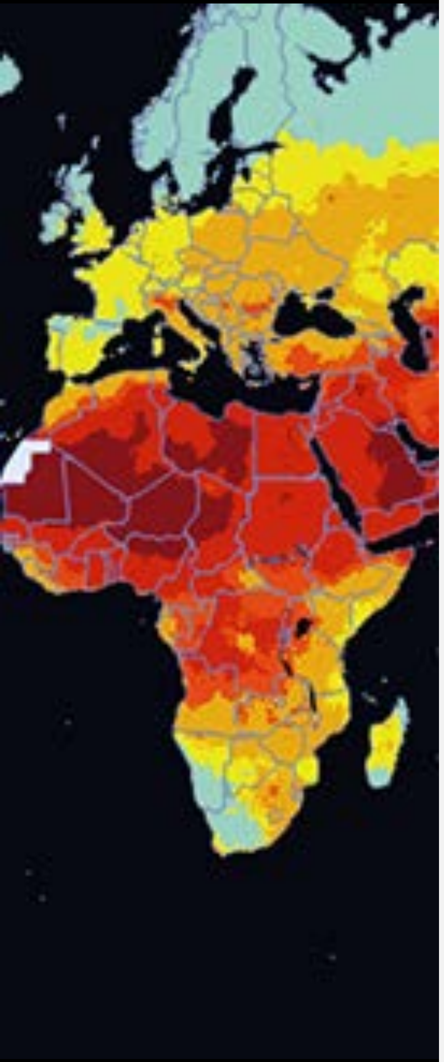


National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Satellite Derived Annual PM2.5 Data Sets in Support of United Nations Sustainable Development Goals

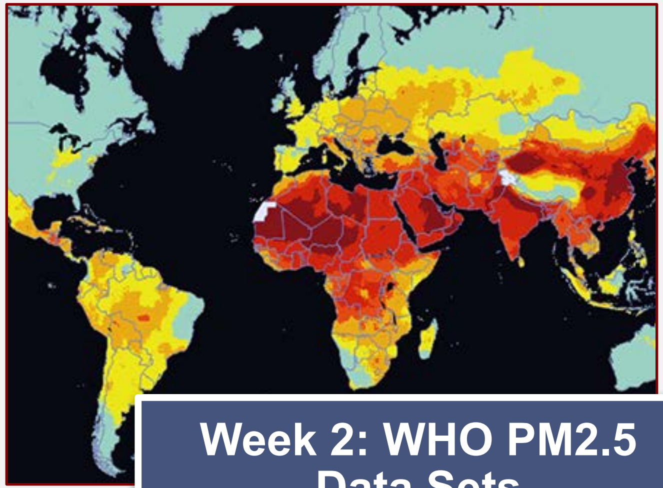
March 15-29, 2017

Pawan Gupta, and Melanie Follette-Cook

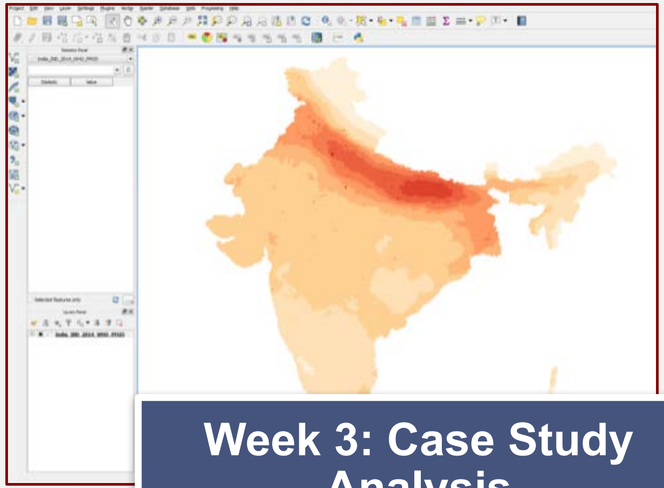
Agenda

3 week webinar series

Week 1: ARSET, Remote Sensing and SDGs



Week 2: WHO PM2.5 Data Sets



Week 3: Case Study Analysis

Learning Objectives

- Become familiar with the UN Sustainable Development Goals, as well as the satellite observations of air quality that are used to calculate indicators 3.9.1 and 11.6.2
- Learn about PM2.5 estimates made using satellite, surface, and model data sets
- Understand how to use the 2014 WHO data set and access the indicator data for a city or country

Session 1: Outline

1. Brief Introduction to ARSET Program
2. Introduction to SDGs
3. Fundamentals of Satellite Remote Sensing

Today's Instructor: Pawan Gupta, Ph. D.
GESTAR/USRA, Code 614
NASA Goddard Space Flight Center
Greenbelt, MD 20771, USA
pawan.gupta@nasa.gov
http://arset.gsfc.nasa.gov/people/pawan-gupta-0

Applied Remote Sensing Training Program (ARSET)

NASA's Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/

- Empowering the global community through remote sensing training
- Part of NASA's Applied Sciences Capacity Building Program
- Goal: increase the use of Earth Science in decision-making through training for:
  - policy makers
  - environmental managers
  - other professionals in the public and private sector
- Trainings offered focusing on applications in:

Disasters | Ecoforecasting | Health & Air Quality | Water Resources

ARSET Training Levels

Fundamentals, Level 0

- Online only
- Assumes no prior knowledge of remote sensing

Basic Training, Level 1

- Online and in-person
- Requires level 0 training or equivalent knowledge
- Specific applications

Advanced Training, Level 2

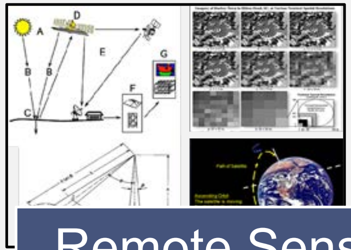
- Online and in-person
- Requires level 1 training or equivalent knowledge
- More in-depth or focused topics

Fundamentals of Remote Sensing: Fundamentals of Remote Sensing

Basic Training: Introduction to Remote Sensing for Air Quality Applications for the Indian Subcontinent and Surrounding Regions

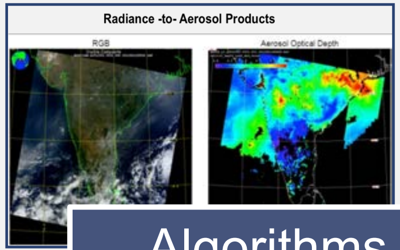
Advanced Training: Advanced Webinar: Satellite Remote Sensing of Particulate Matter Air Quality

ARSET Air Quality Trainings

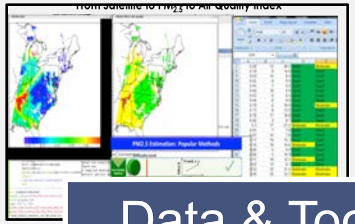

Remote Sensing

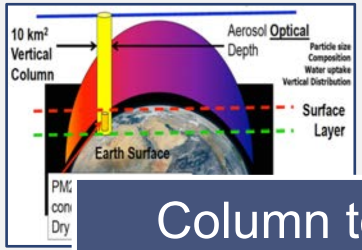

Satellites


Images



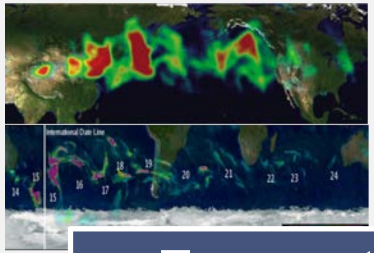
Algorithms

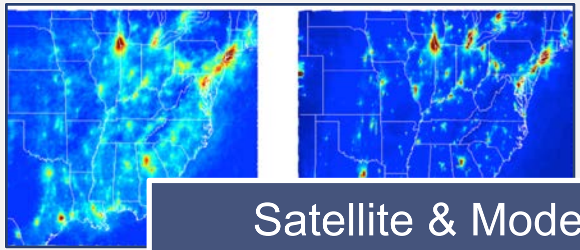

Data & Tools

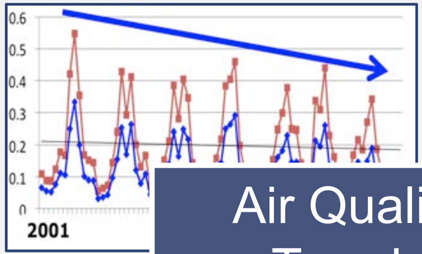


Column to Surface

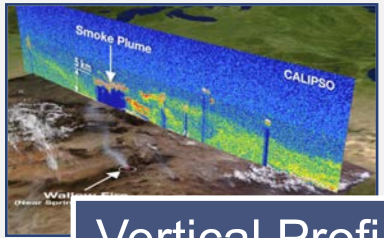

Dust and Smoke


Transport


Satellite & Model Comparison



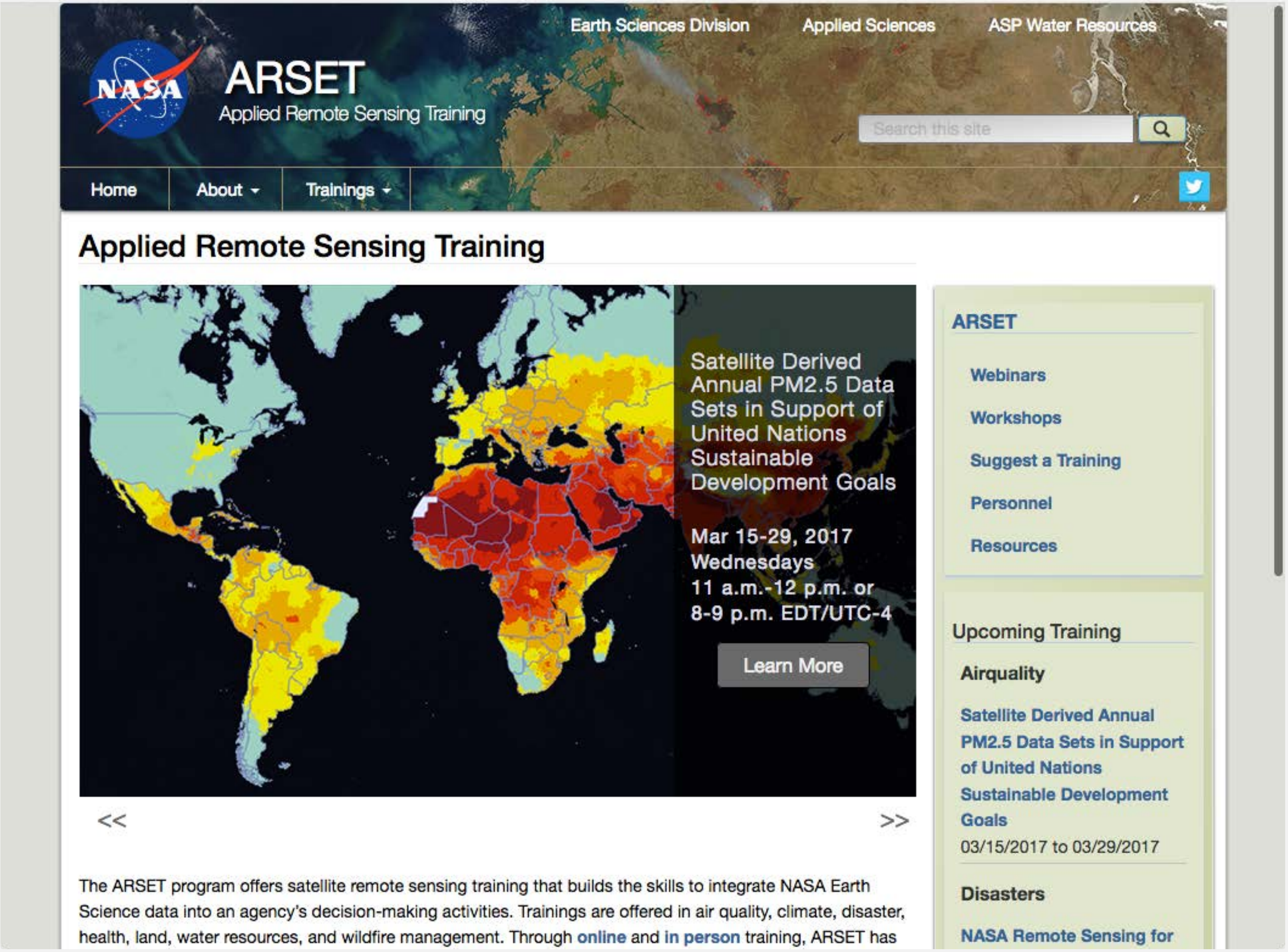
Air Quality Trends



Vertical Profiles

ARSET Website

http://arset.gsfc.nasa.gov/



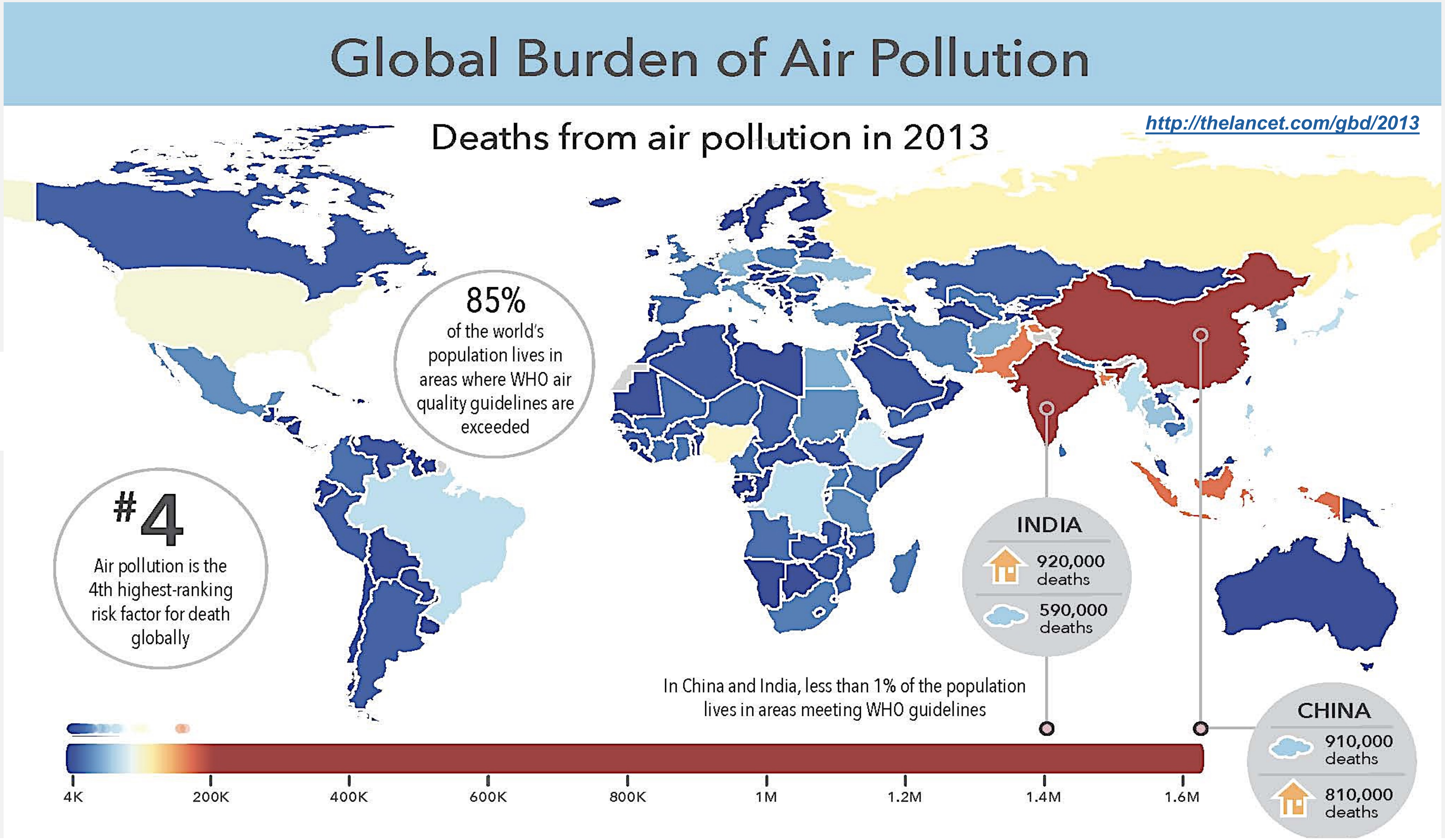
UN Sustainable Development Goals (SDGs)

UN Sustainable Development Goals (SDGs)

Transforming Our World: The 2030 Agenda for Sustainable Development

- A plan of action for people, planet and prosperity
- All countries and all stakeholders, acting in collaborative partnership, will implement this plan
- 17 SDGs and 169 targets under this agenda
- Balance the three dimensions of sustainable development:
  - economic, social, and **environmental**
- In this webinar series, our focus will be particle air pollution

Text adapted from "Transforming our world: the 2030 Agenda for Sustainable Development"



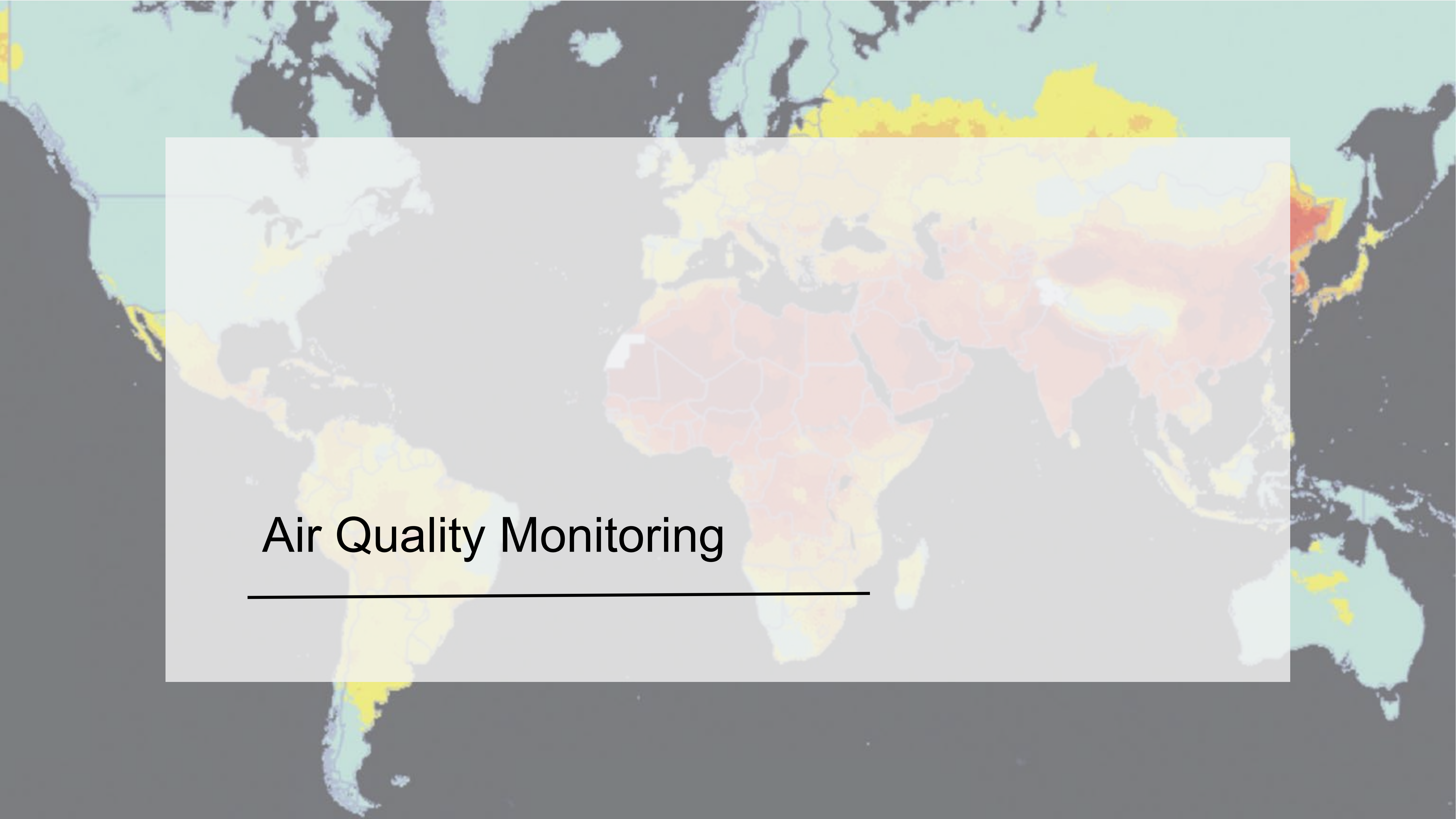
- Air pollution was responsible for 5.5 million deaths in 2013
- Satellite data can help quantify the impact on human health

United Nations Sustainable Development Goals

- **Goal 11, Target 11.6, Indicator 11.6.2**
  - **Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable**
    - Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
      - Indicator 11.6.2: ***Annual mean levels of fine particulate matter*** (e.g. PM2.5 and PM10) in cities (population weighted)
      - Meta data (http://unstats.un.org/sdgs/metadata/files/Metadata-11-06-02.pdf)

- **Goal 3, Target 3.9, Indicator 3.9.1**
  - **Goal 3: Ensure healthy lives and promote well-being for all at all ages**
    - Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination
      - Indicator 3.9.1: Mortality rate attributed to household and ***ambient air pollution***
      - Meta data (http://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf)

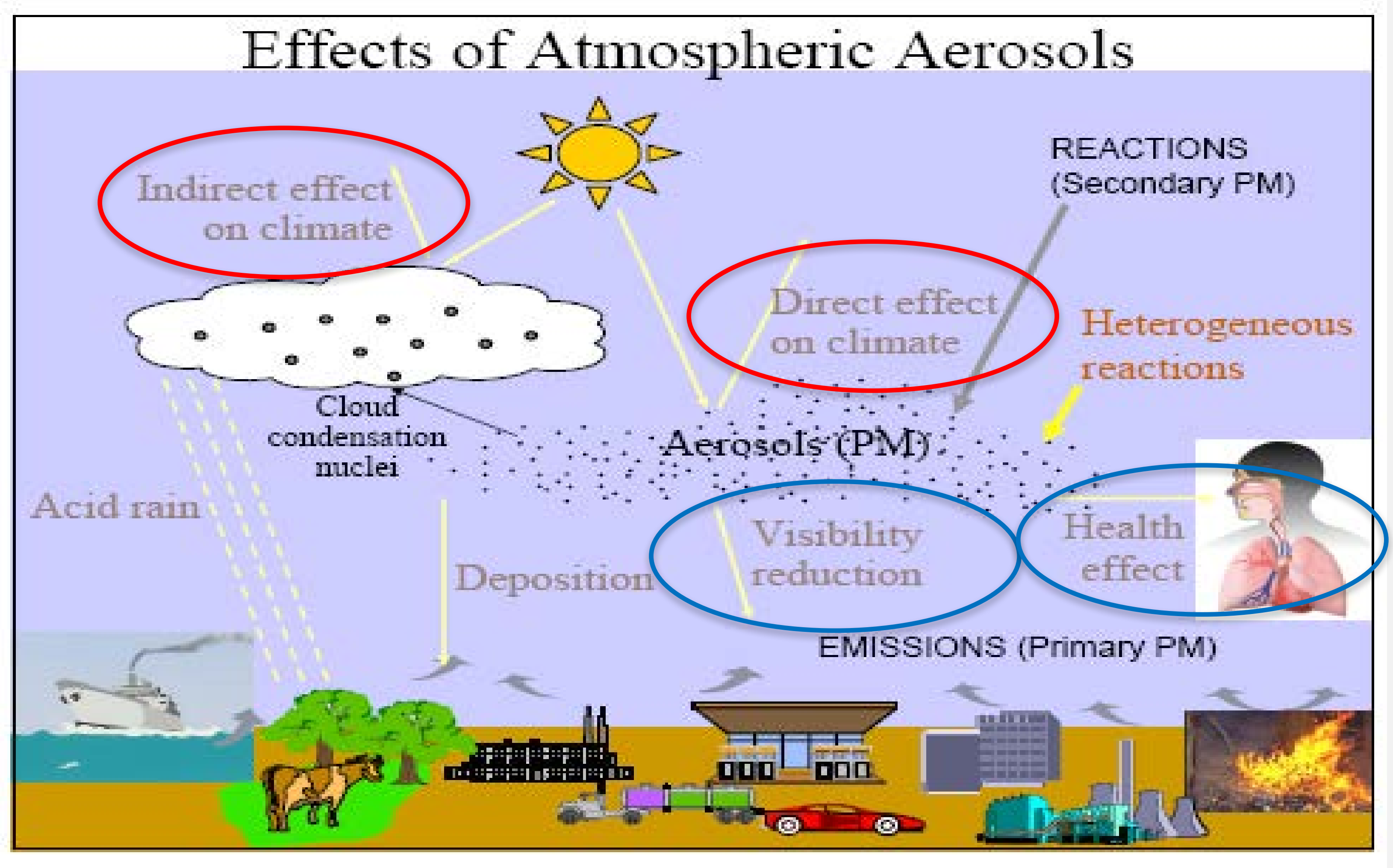
Air Quality Monitoring



Common Terminology

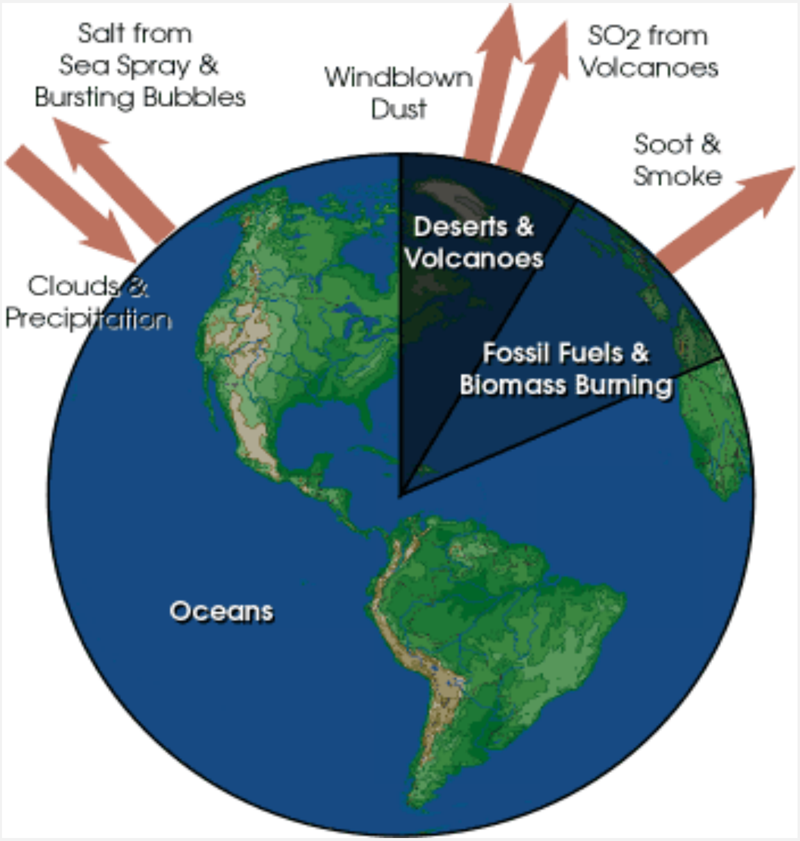
- Aerosols
- Particulate Matter
- Atmospheric Aerosols
- Particles

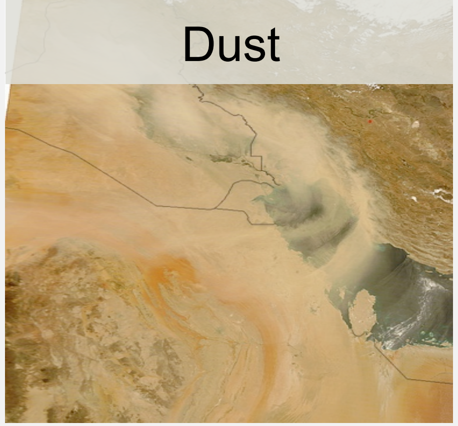
Motivation: Tiny but Potent



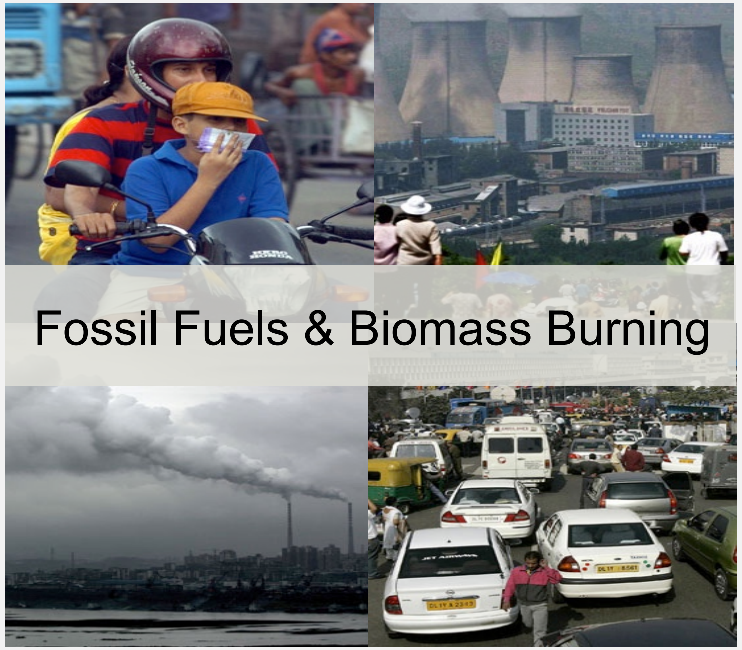
Pollution Sources

Atmospheric aerosols are highly variable in space and time




Dust


Volcanoes

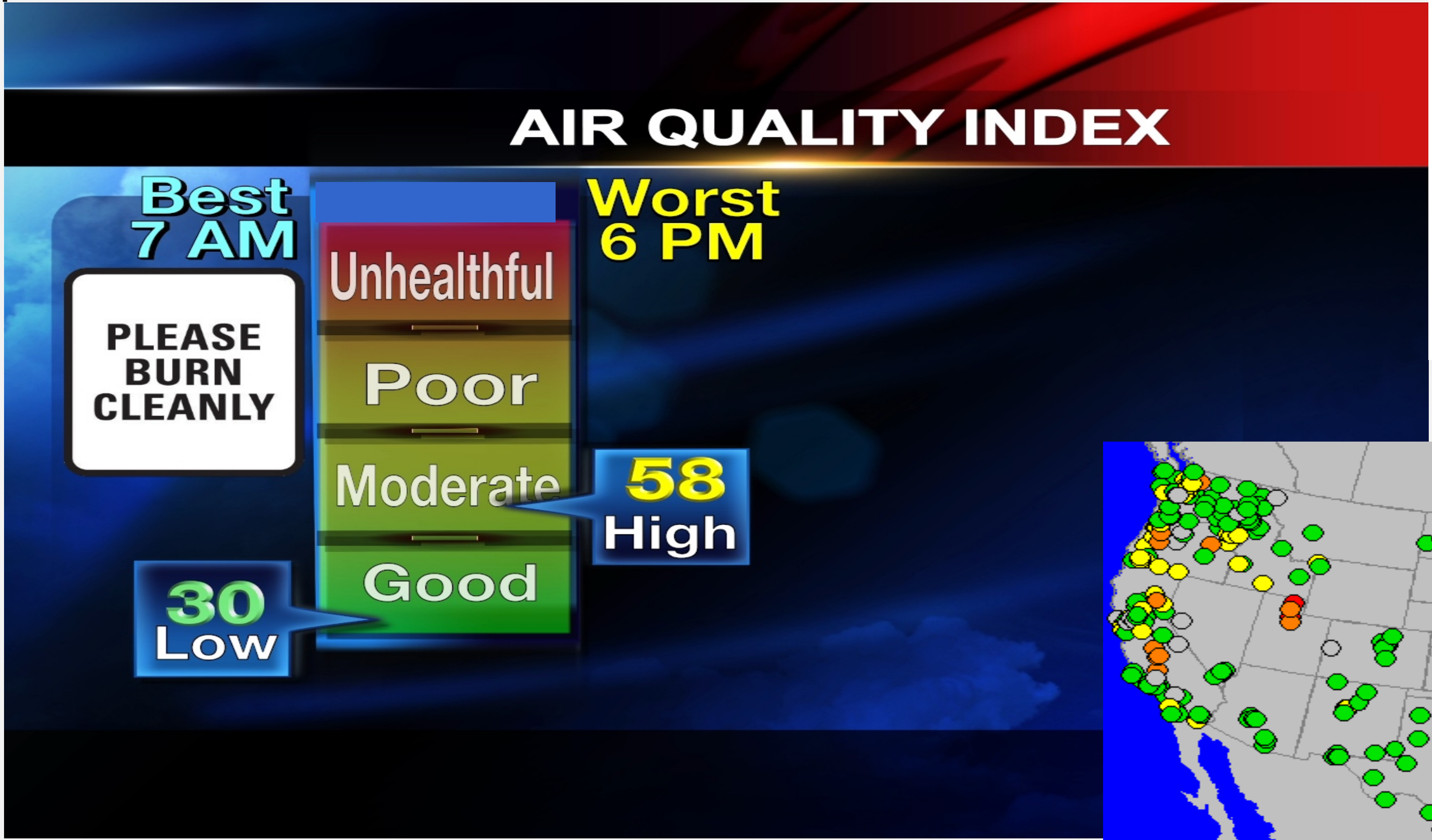

Fossil Fuels & Biomass Burning


Soot & Smoke

Traditional Air Quality Monitoring

Images from: http://aqicn.org/products/monitoring-stations/

Air Quality Monitoring and Reporting



AIR QUALITY INDEX

Air Quality Index (AQI) Values	Levels of Health Concern
0 to 50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 to 500	Hazardous

Spatial Gaps

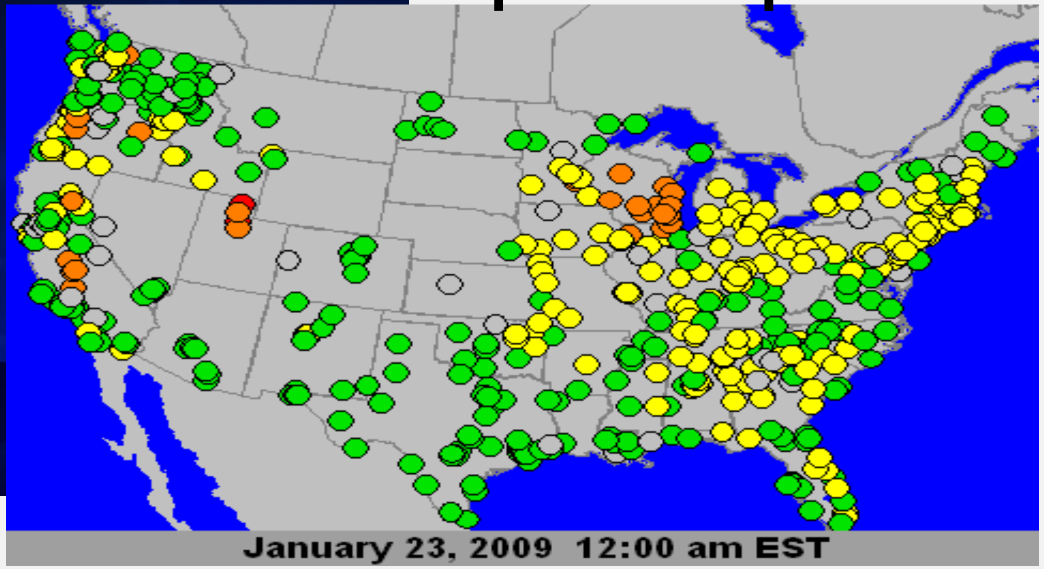
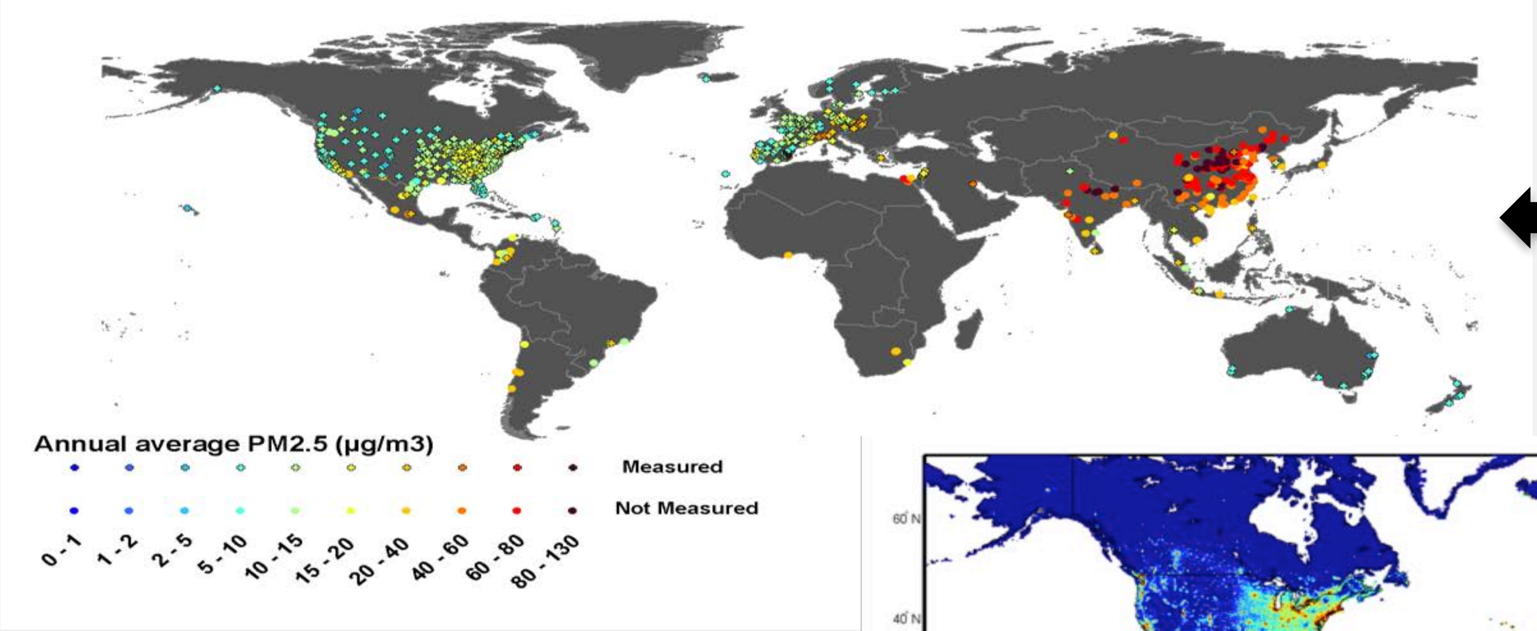
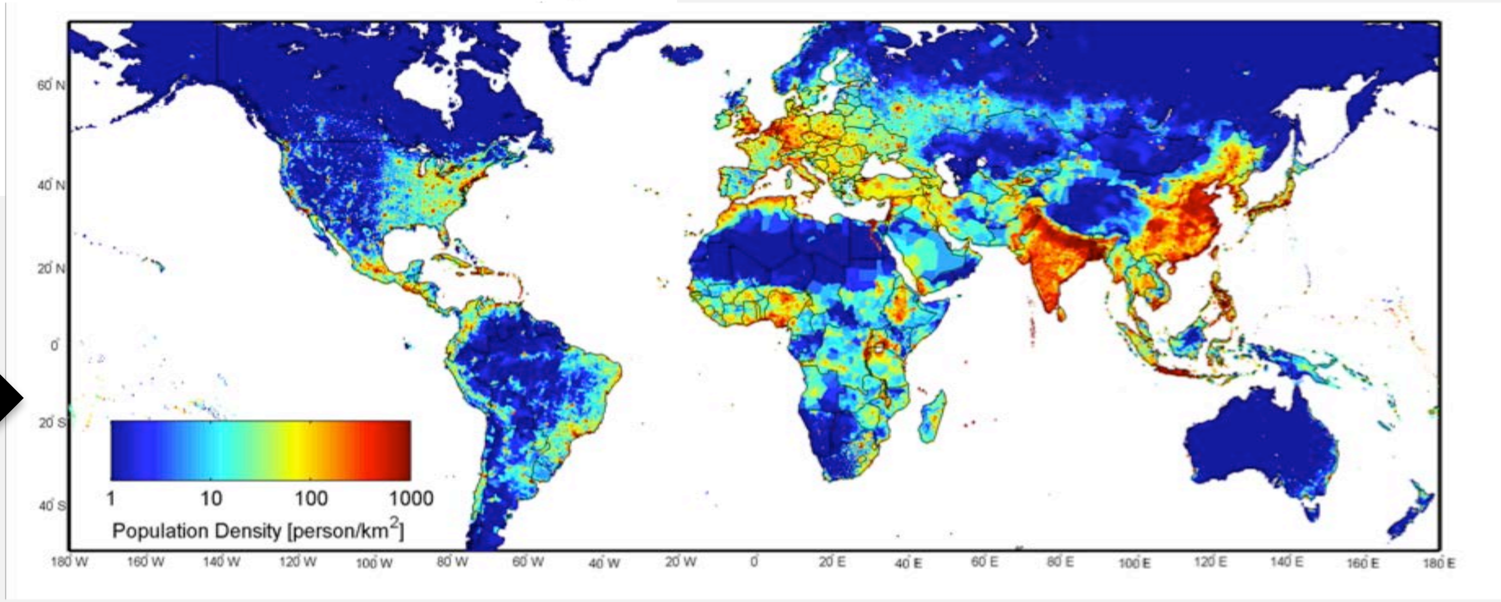


Image Credit: AirNow map, USEPA. http://www.airnow.gov

Global Status of PM2.5 Monitoring



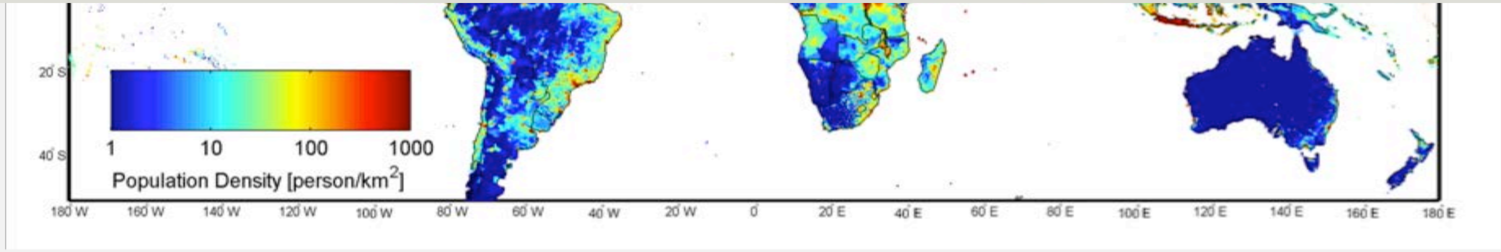
Ground Sensor Network



Population Density

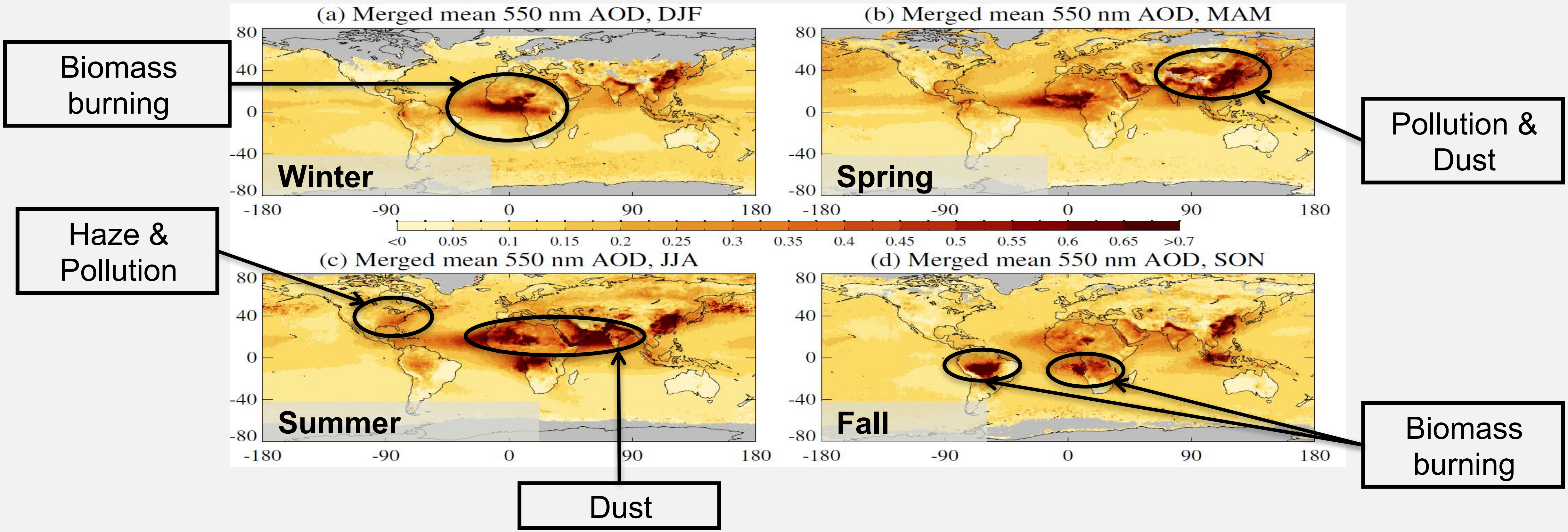
Global Status of PM2.5 Monitoring

- Many countries do not have PM2.5 mass measurements
- Spatial distribution of the existing ground network does not support the high population density
- Surface measurements are not cost effective
- How about using remote sensing satellite observations?



Aerosols from Satellites

Aerosol Optical Thickness (MODIS Aqua)



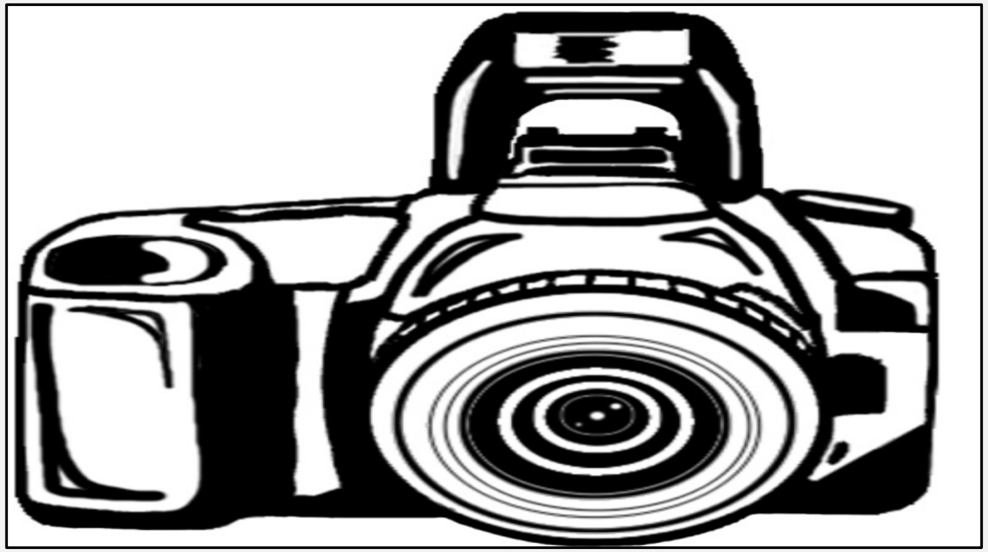
Several satellites provide state-of-the-art aerosol measurements globally, on a daily basis

NASA's Current and Upcoming Missions

Fundamentals of Satellite Remote Sensing

What is remote sensing?

- Collecting information about an object without being in direct physical contact with it

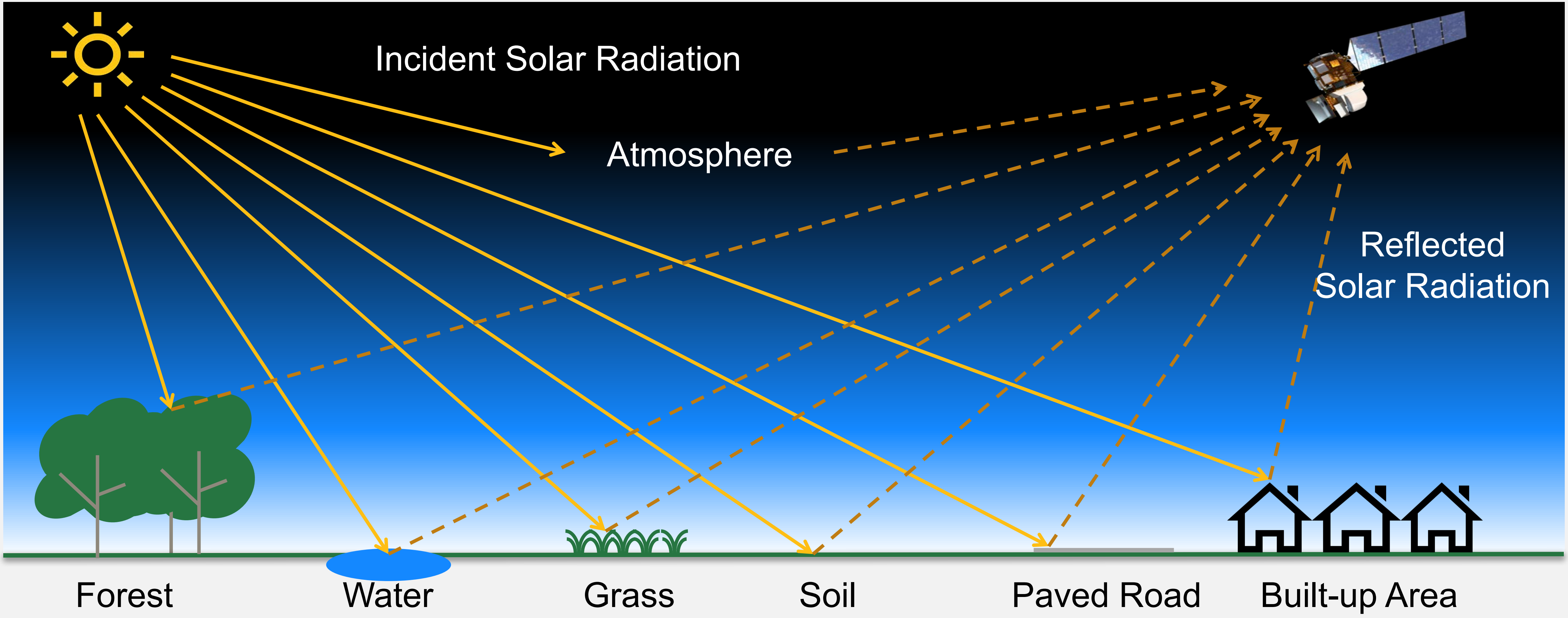


Remote Sensing: Platforms



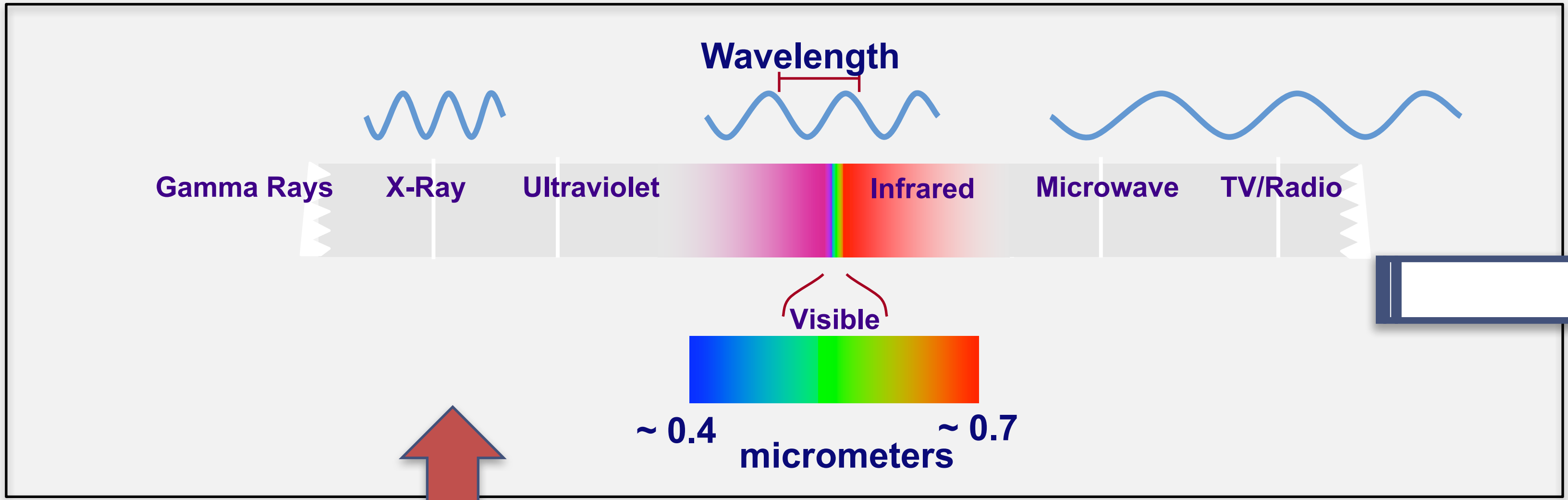

- The platform depends on the application
- What information do you want?
- How much detail do you need?
- What type of detail?
- How frequently do you need the data?

What Does a Satellite Measure ?

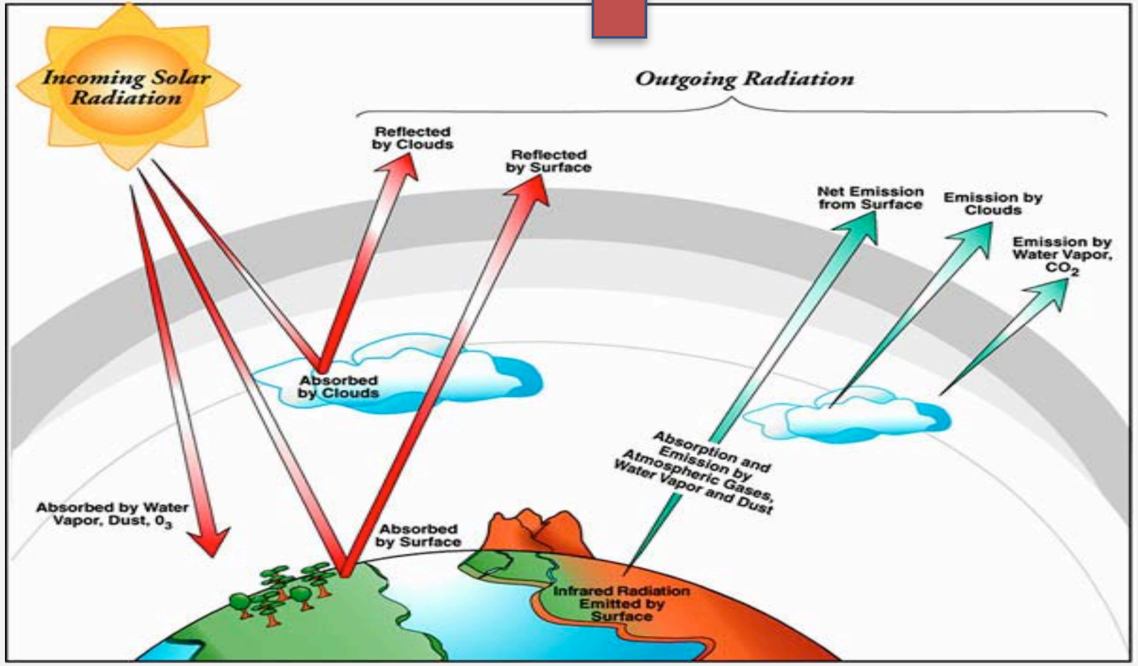


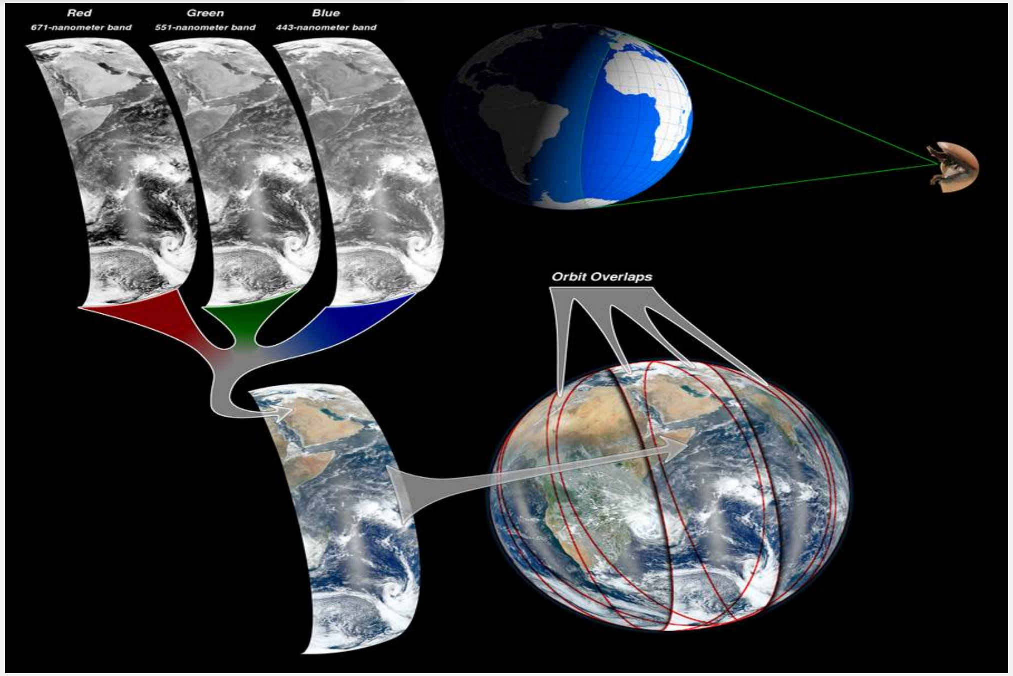
Adapted from Peterson (2007) http://maps.unomaha.edu/Peterson/gis/notes/RS2.htm

Measurements to Visual: True Color Images



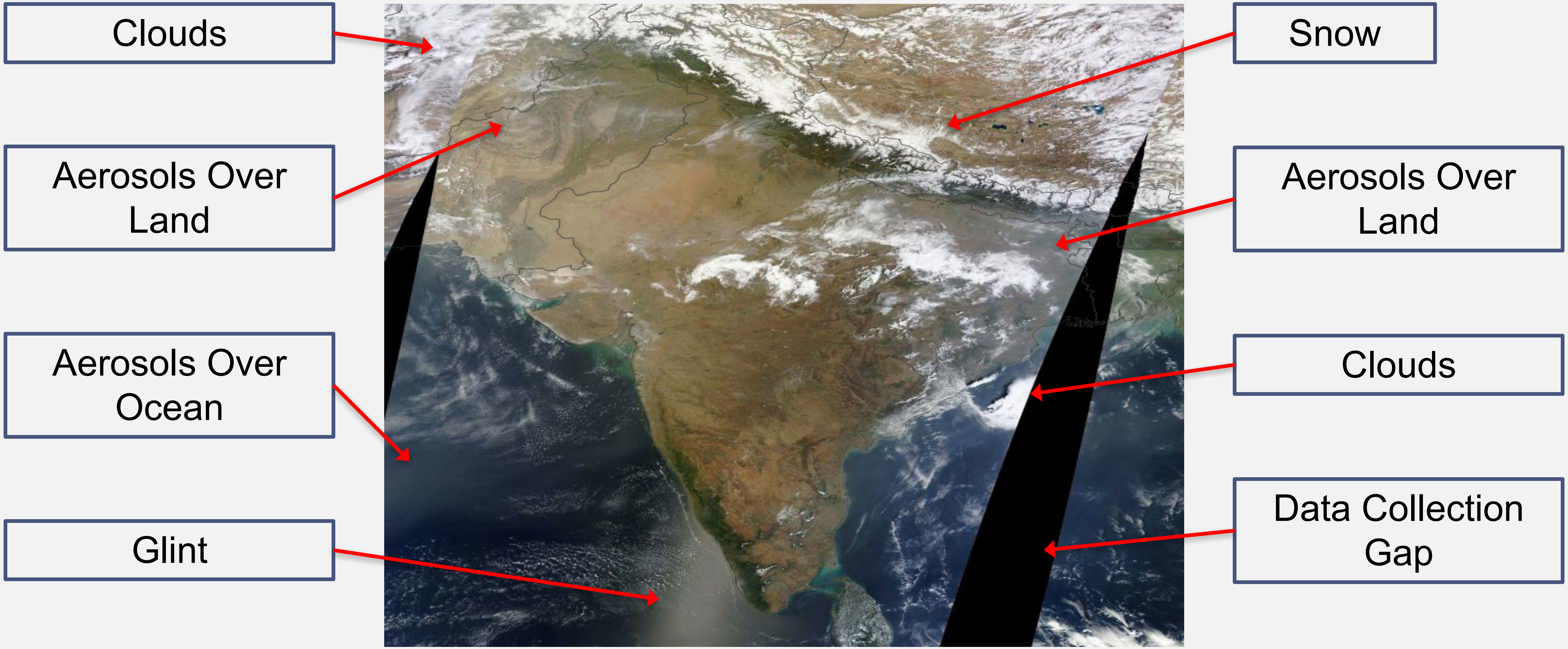
Satellite





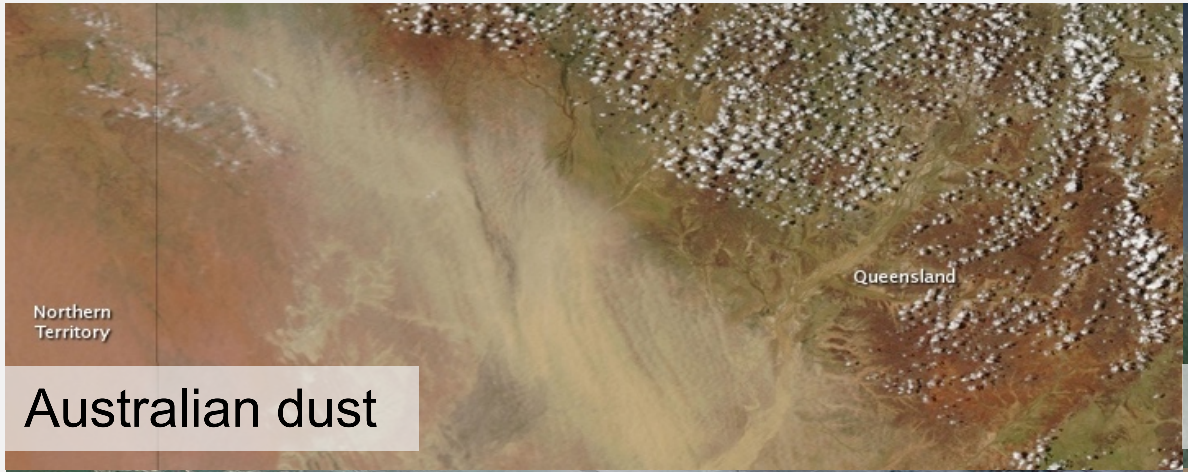
What can we learn from true color imagery?

MODIS Terra Image, April 19, 2013



How do we identify aerosols in true color images?

More reliable when a clear source is in the image



Australian dust

Sangeang Api, Indonesia eruption

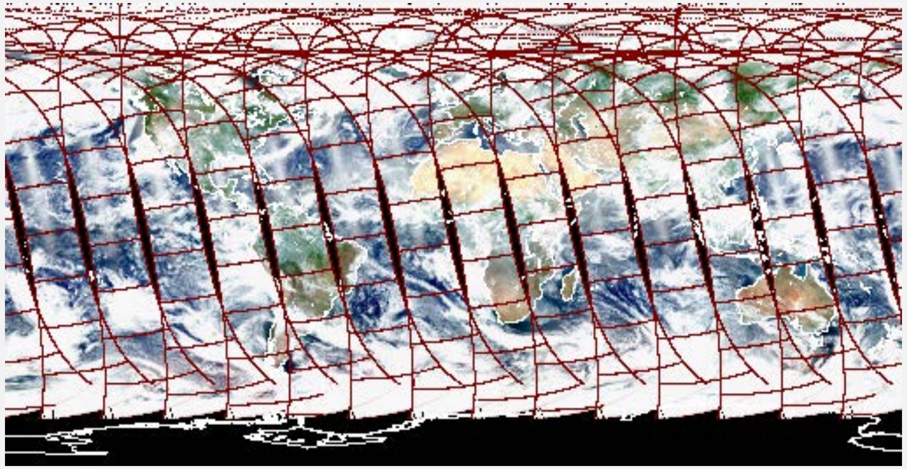
Urban: industrial or smoke pollution?


Indian oil fires

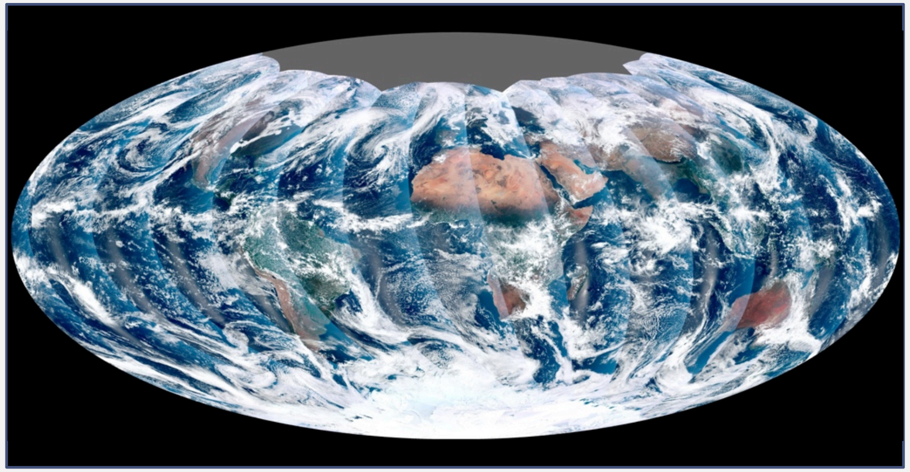
How do we identify aerosols in true color images?

More reliable when a clear source is in the image

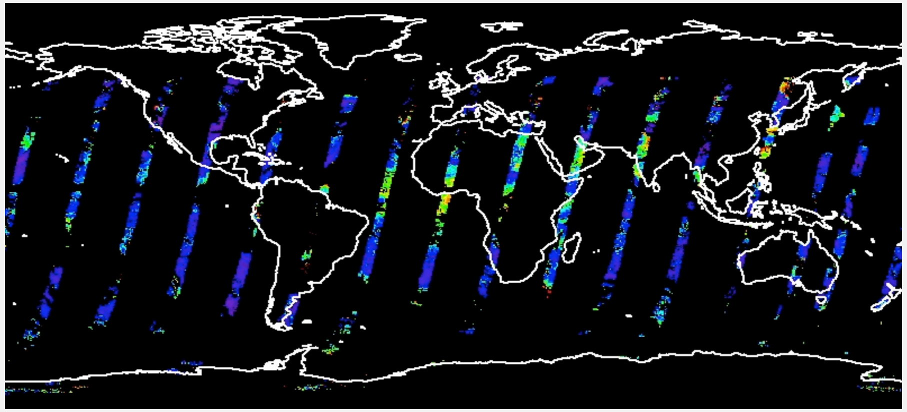
Daily Satellite Coverage



MODIS

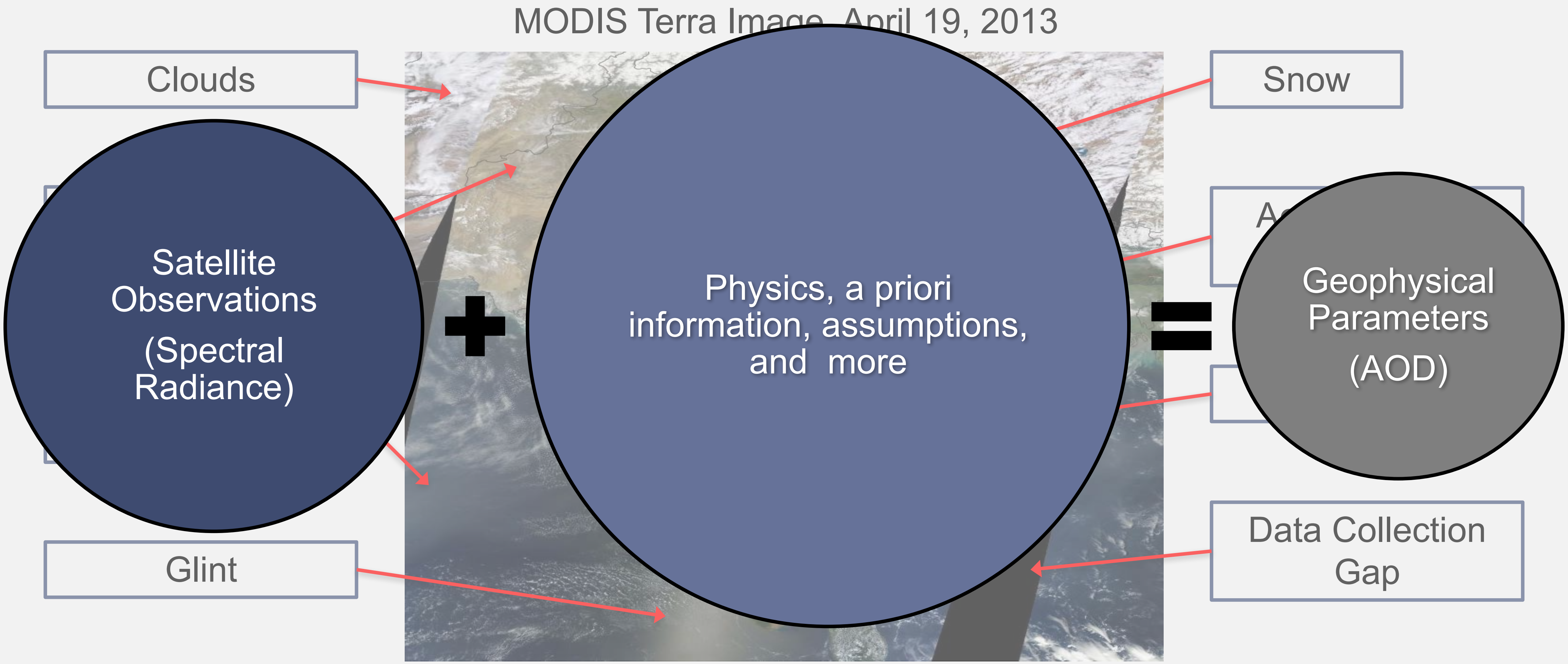


VIIRS



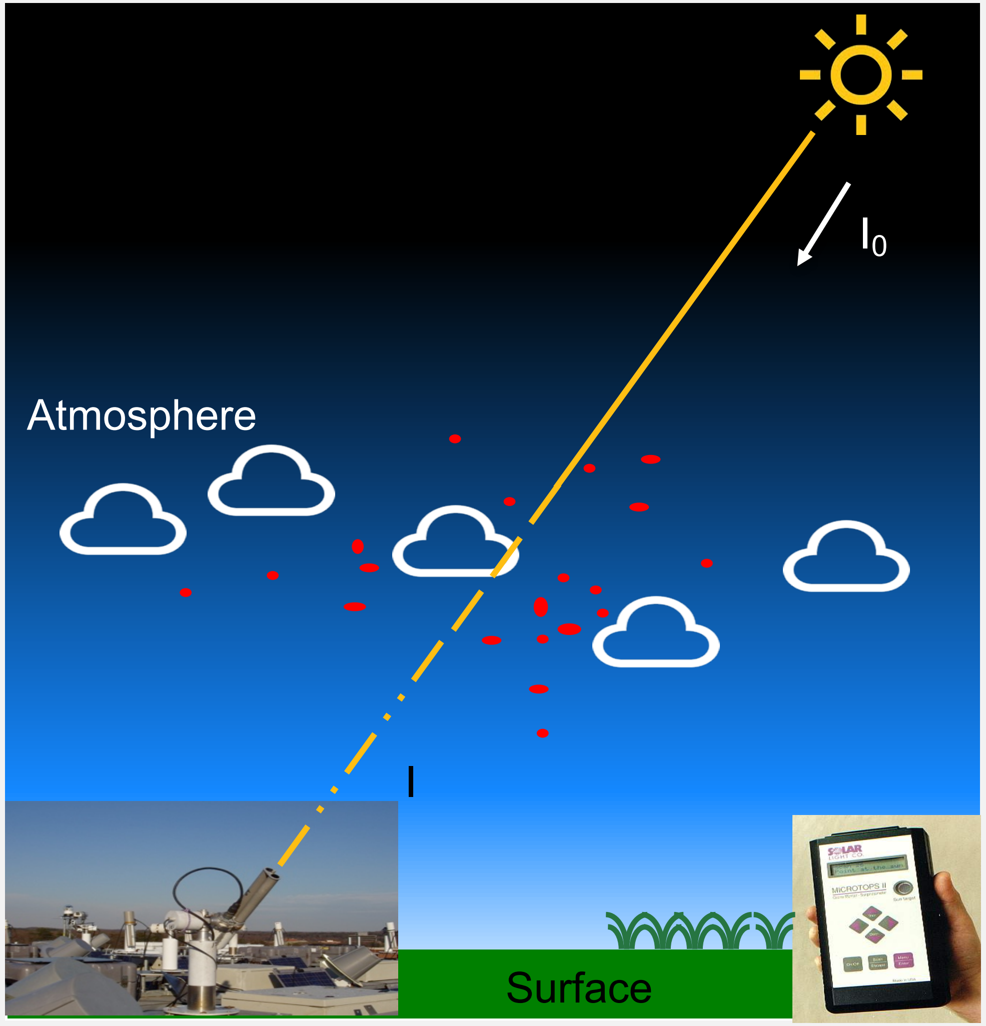
MISR

What can we learn from true color imagery?



Aerosol Optical Depth (AOD)
or
Aerosol Optical Thickness (AOT)

Optical Depth



The optical depth expresses the quantity of light removed from a beam by **scattering** or **absorption** during its path through a **medium**

Optical depth τ as

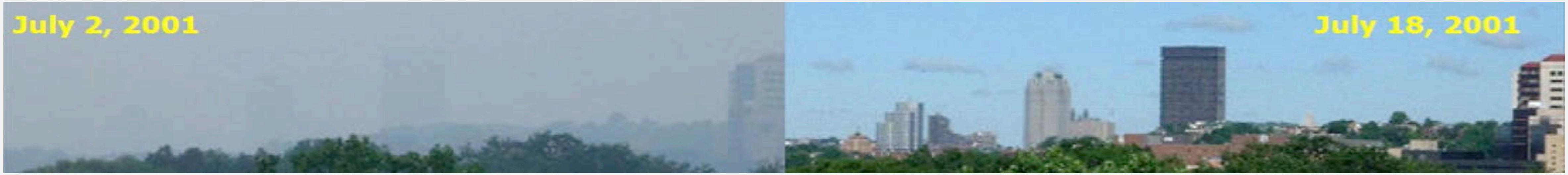
$$I = I_o e^{-m\tau}$$
$$m = \sec\theta_o$$
$$\tau = \tau_{Rayl} + \tau_{aer} + \tau_{gas}$$

Optical depth due to aerosols in the atmospheric column is called **aerosol optical depth**

Inferring AOD and PM2.5 from Visuals

Pittsburgh

$PM_{2.5}$ = 45 μgm^{-3} $PM_{2.5}$ = 4 μgm^{-3}



Pictures are taken from the same location, at the same time of day, on two different days

AOD = ~0.8

AOD = ~0.1

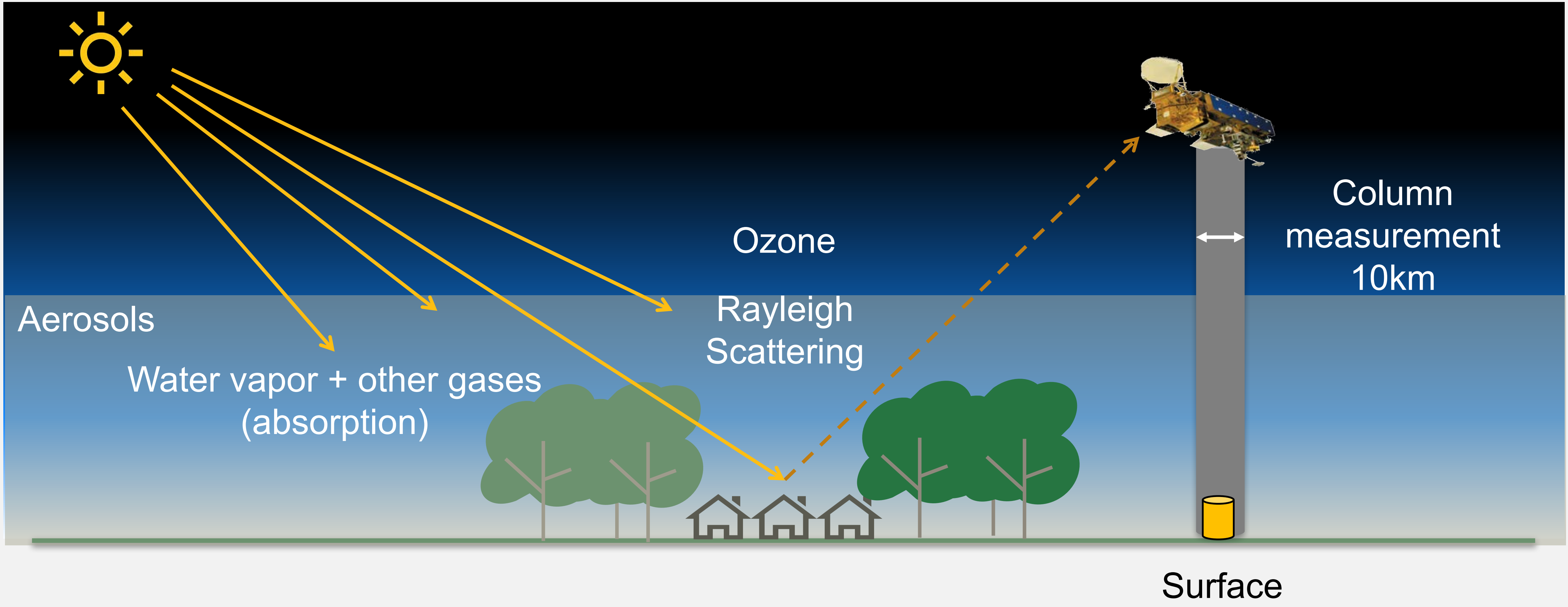
Image Credit: Learning with CLEAR: Introduction to Aerosols - What Are Aerosols? http://caice.ucsd.edu/index.php/education/clear/learning-with-clear/introduction-to-aerosols/

Inferring AOD and PM2.5 from Visuals

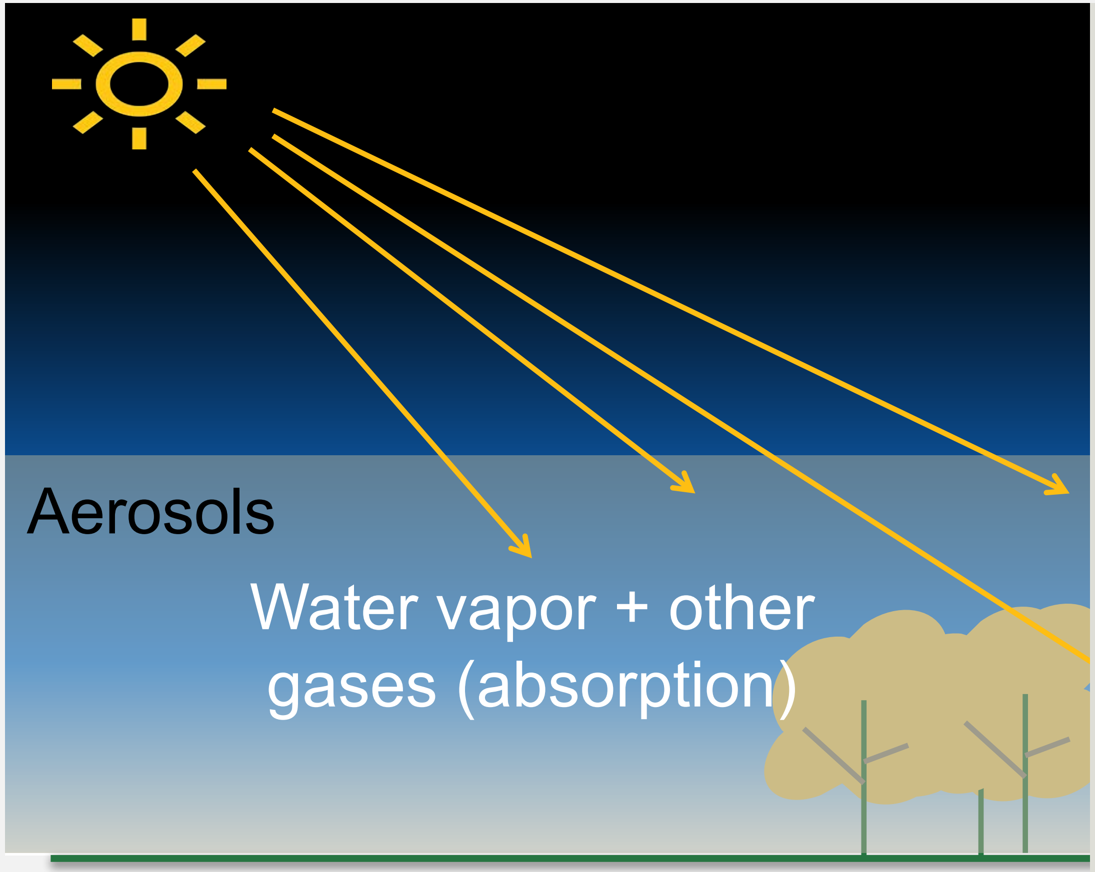
Singapore

Image Credit: Roslan Rahman/AFP/Getty Images

Aerosol Optical Depth from Satellites



Aerosol Optical Depth from Satellites

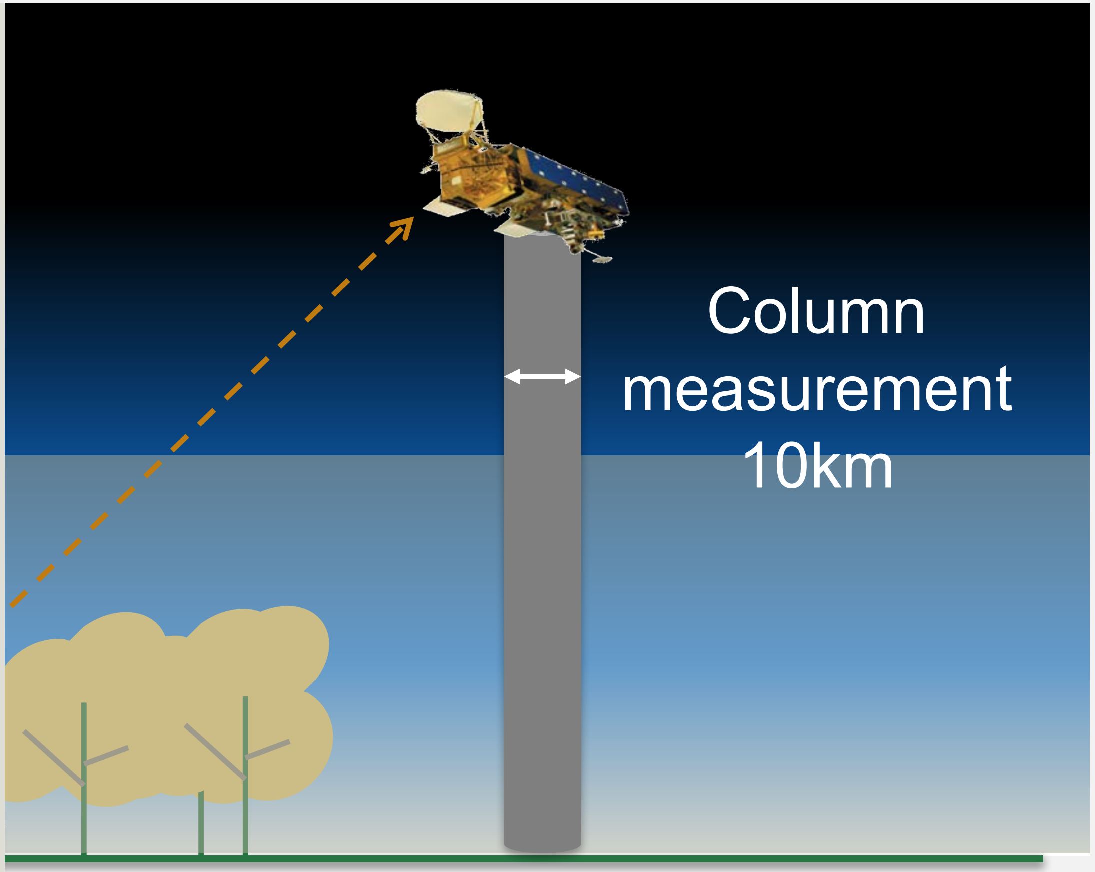


- AOT(τ)= $\int \beta_{ext}\, dz$
  - particle size
  - composition
  - water update
  - vertical distribution

- There are satellite retrieval issues: inversion (e.g. aerosol model, background)

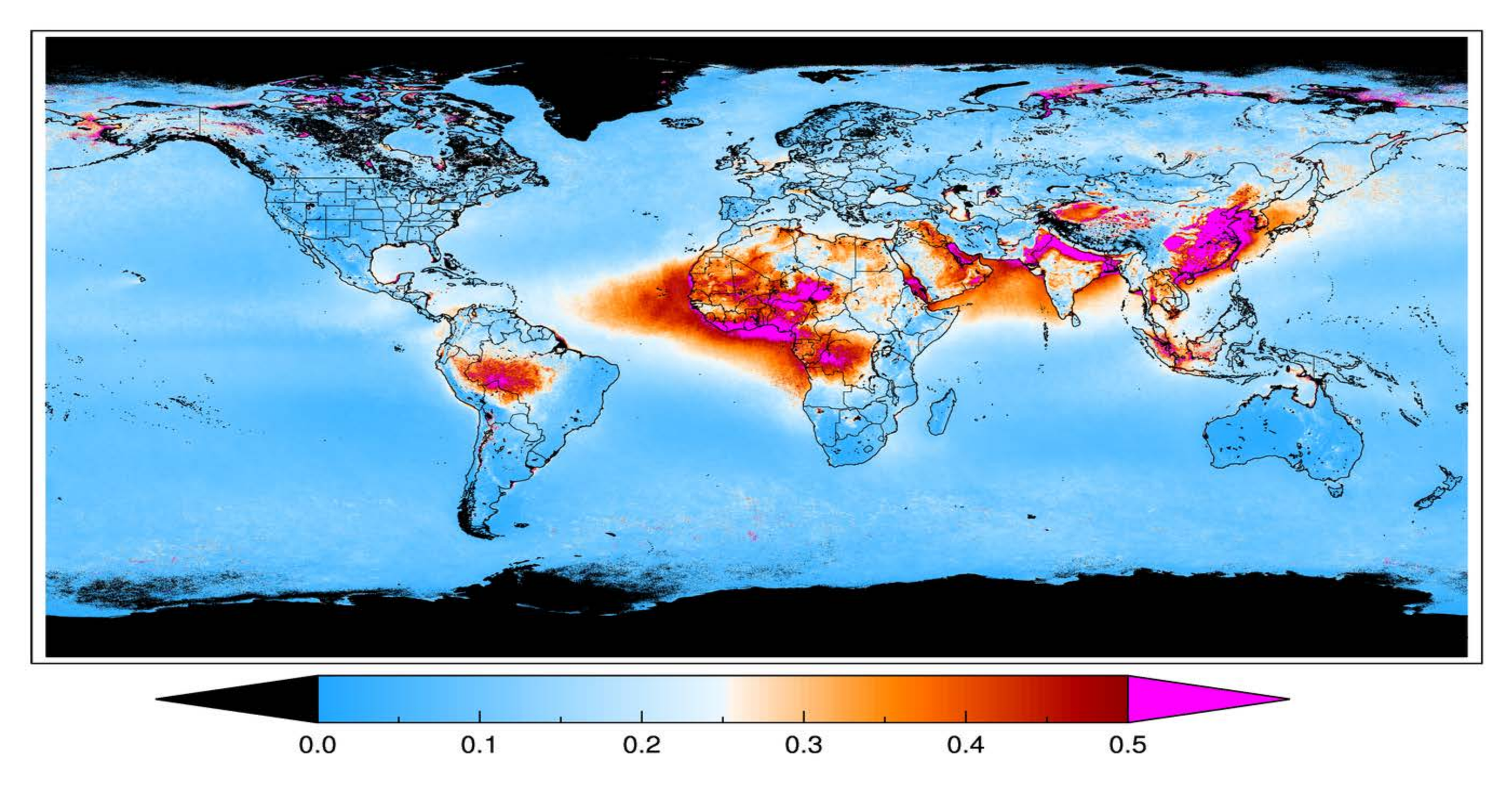
Aerosol Optical Depth from Satellites

- Seven MODIS bands are utilized to derive aerosol properties
  - **0.47 µm**
  - 0.55 µm
  - **0.65 µm**
  - 0.86 µm
  - 1.24 µm
  - 1.64 µm
  - **2.13 µm**
- 10x10 km^2 resolution
- 3x3 km^2 resolution

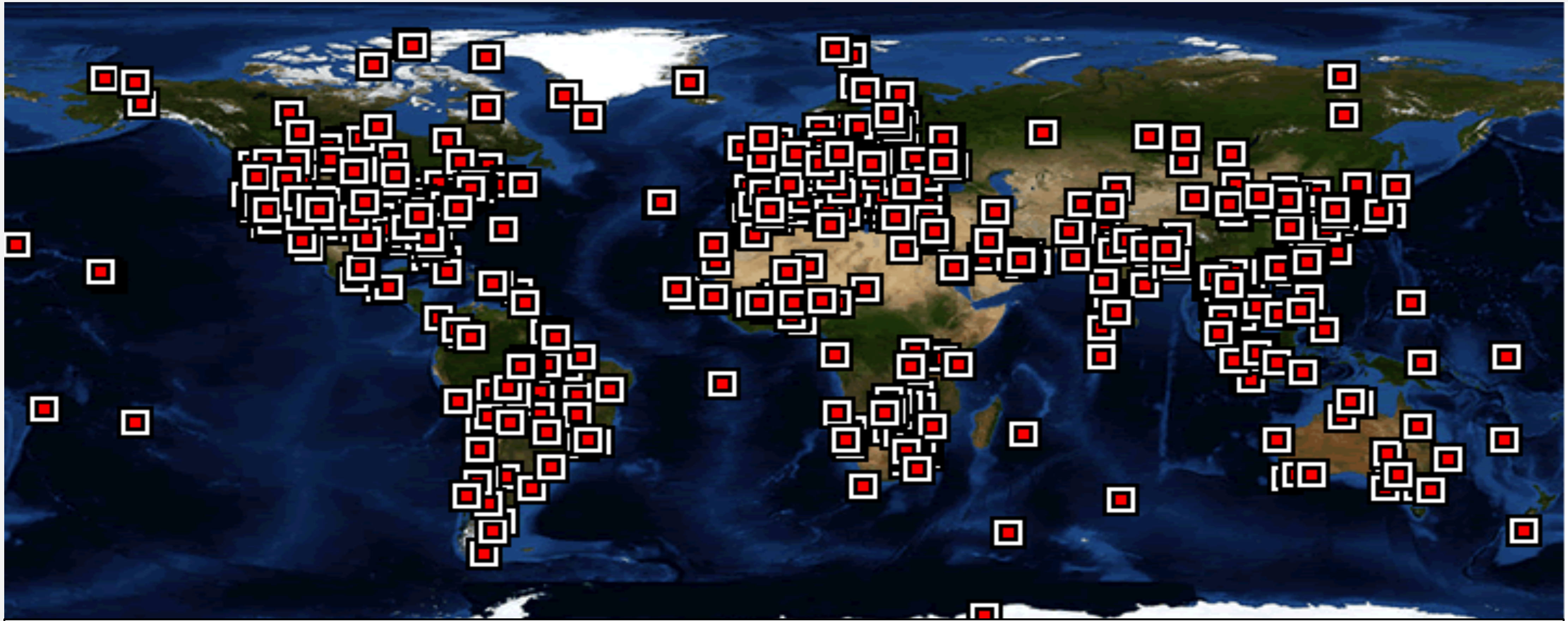


Satellites Provide Global View of Particles

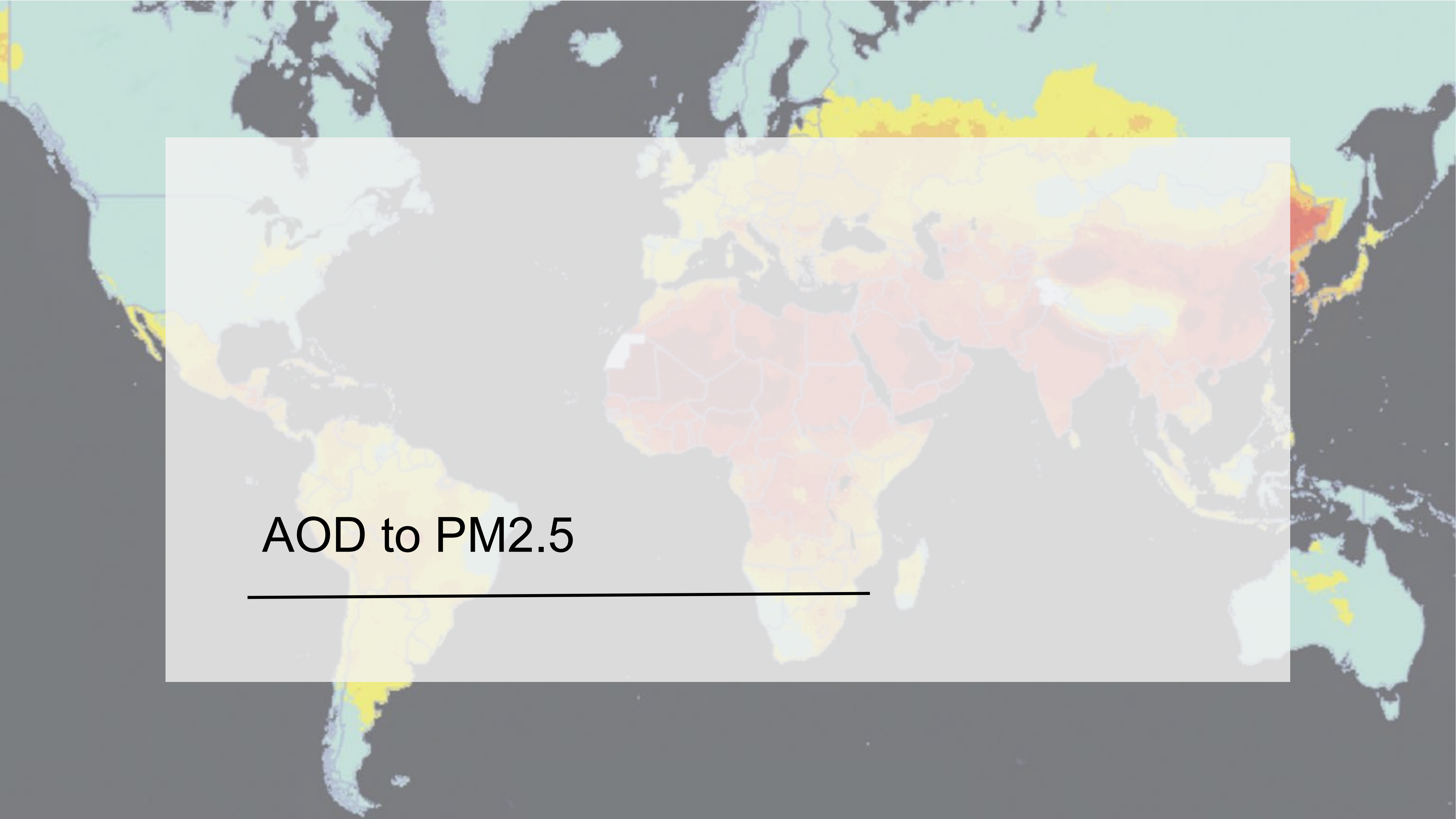
Aerosol Optical Depth at 550nm
(Mean of 2003 to 2008)



- **AOD:**
  - column integrated value (top of the atmosphere to surface)
  - optical measurement of aerosol loading
  - Unitless
  - a function of shape, size, type number concentration of aerosols, and wavelength of measurement

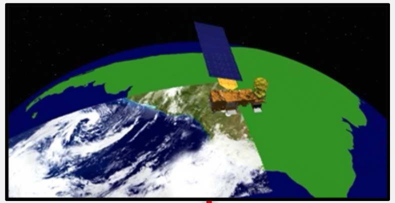


AERONET measurements of aerosol optical depth are considered ground truth and are used to validate satellite aerosol retrievals

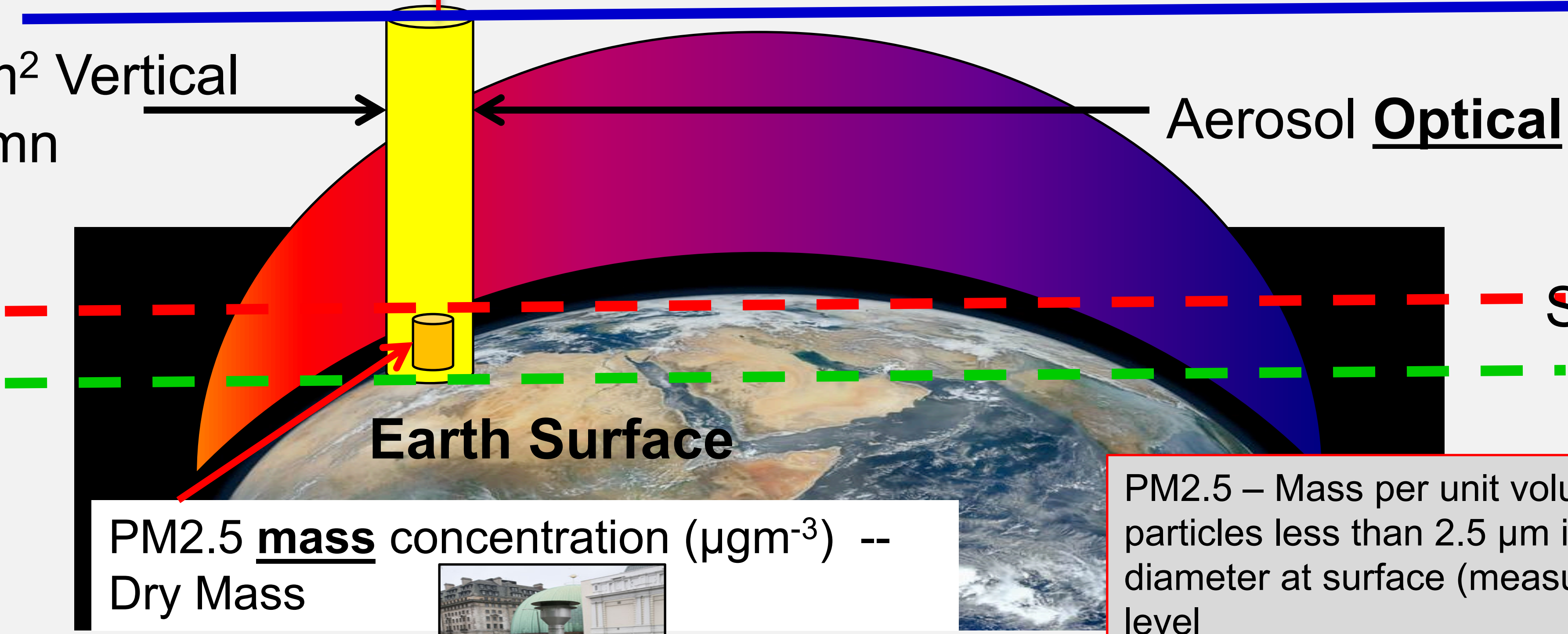


AOD to PM2.5

Satellite vs. Ground Observation



AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unitless. AOD is function of shape, size, type and number concentration of aerosols



PM2.5 **mass** concentration (μgm^{-3}) -- Dry Mass

PM2.5 – Mass per unit volume of aerosol particles less than 2.5 μm in aerodynamic diameter at surface (measurement height) level

AOD – PM2.5 Relationship

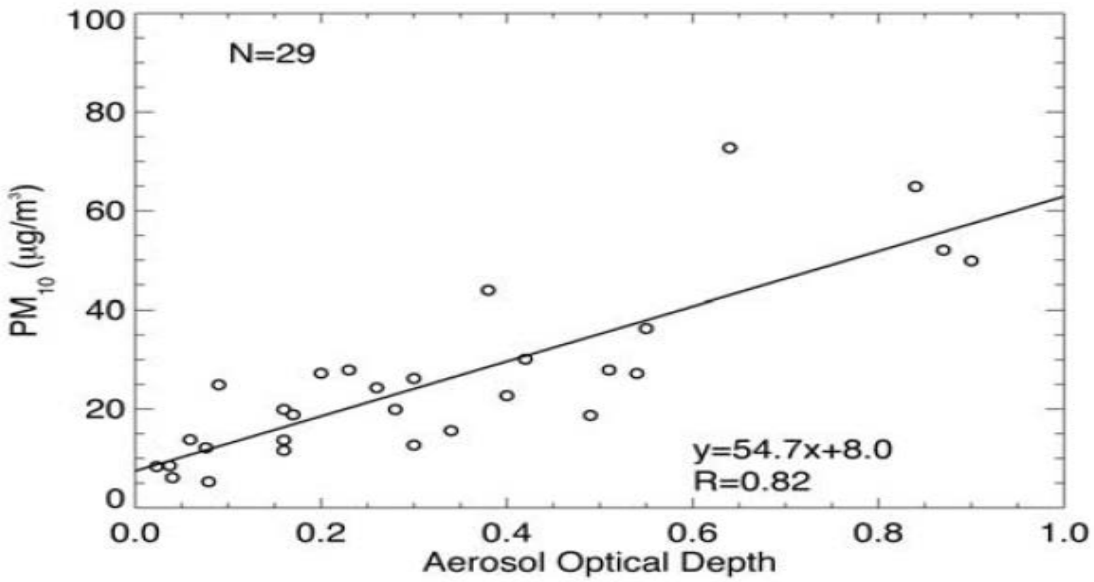
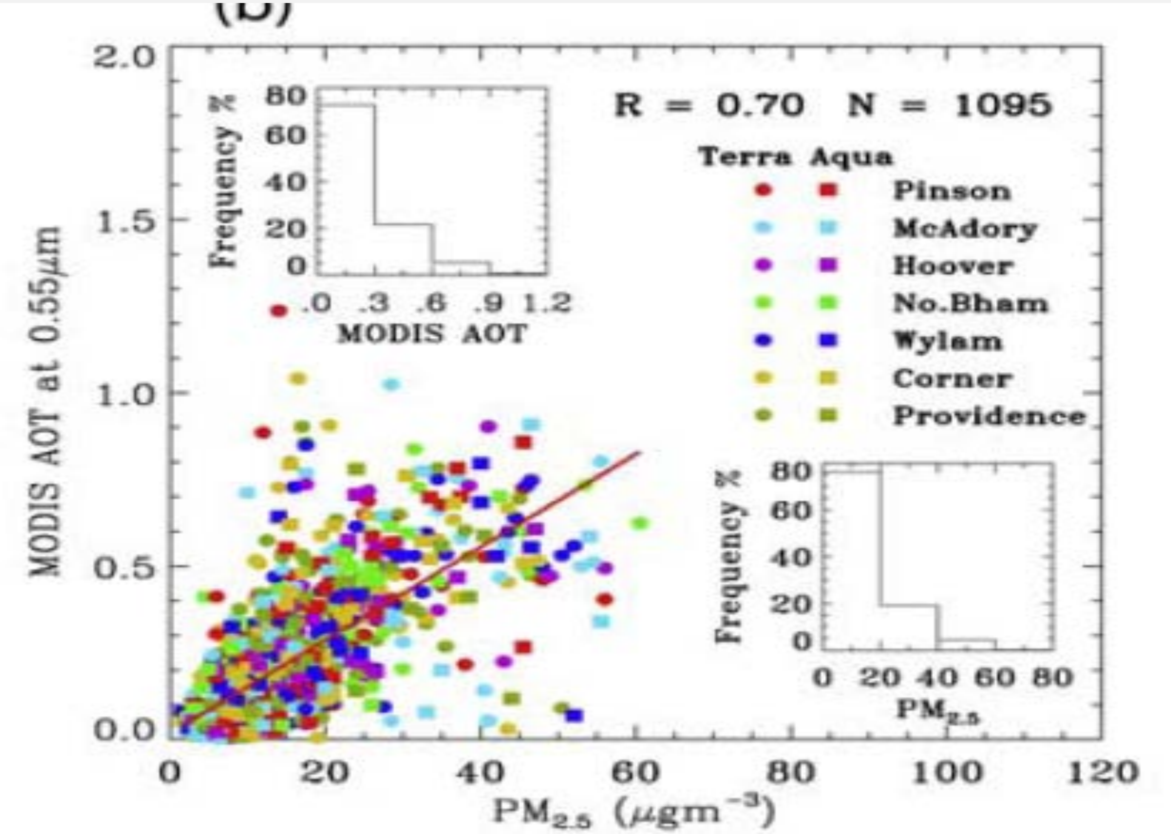


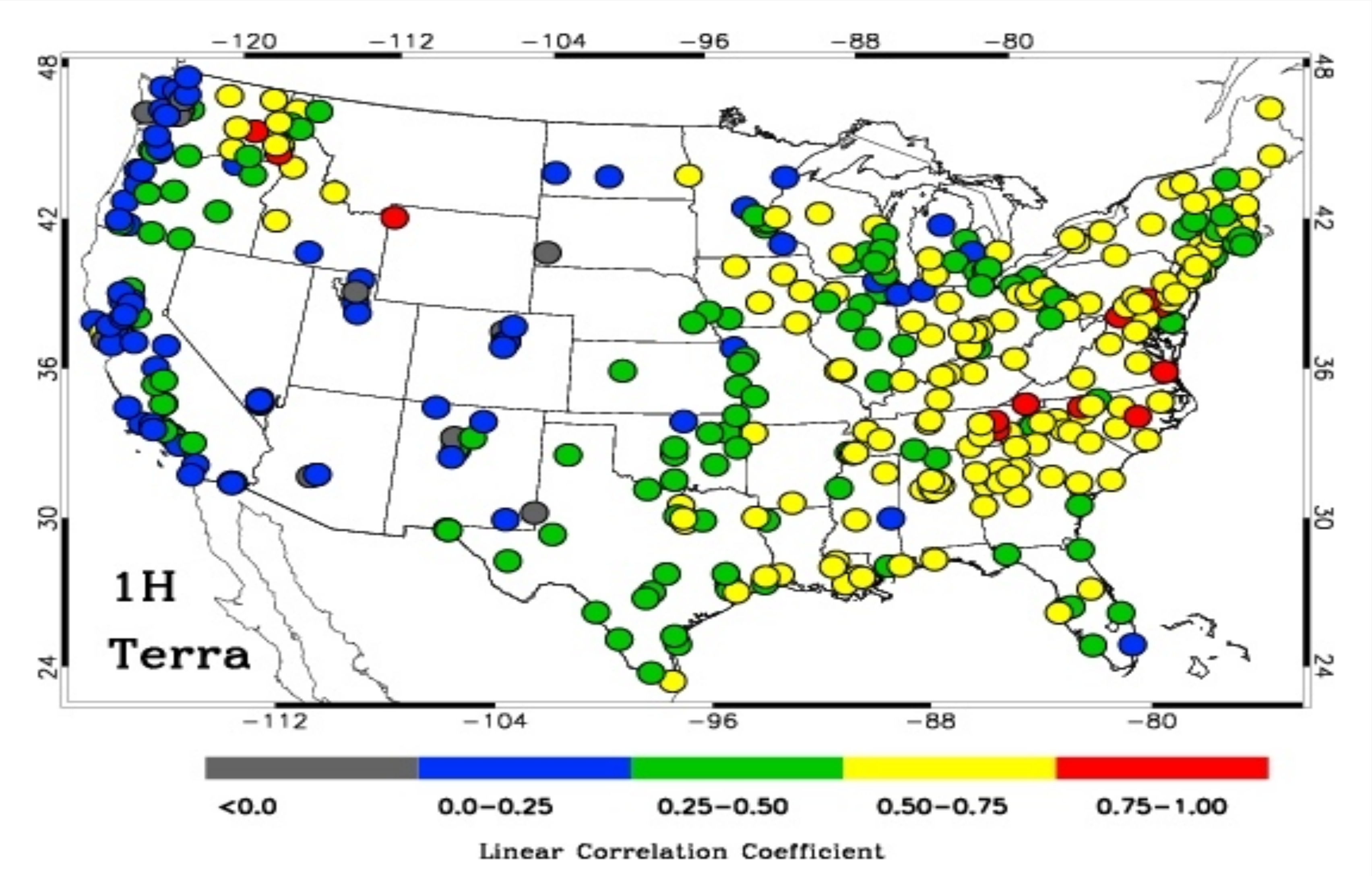
Figure 14. Relationship between 24-hour PM_{10} concentrations and daily averaged AERONET τ_a measurements from August to October 2000 in northern Italy.



Chu et al., 2003

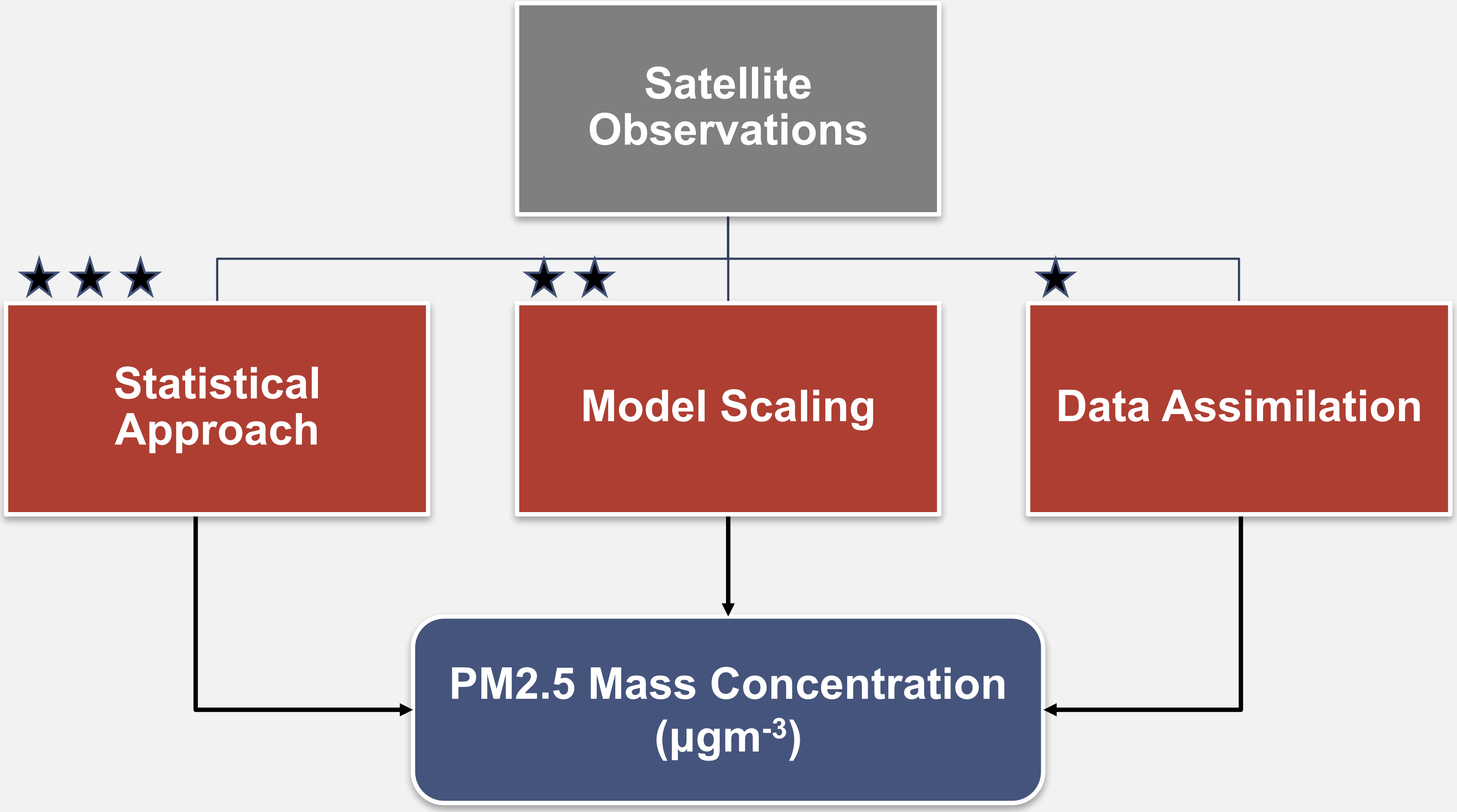
Wang et al., 2003

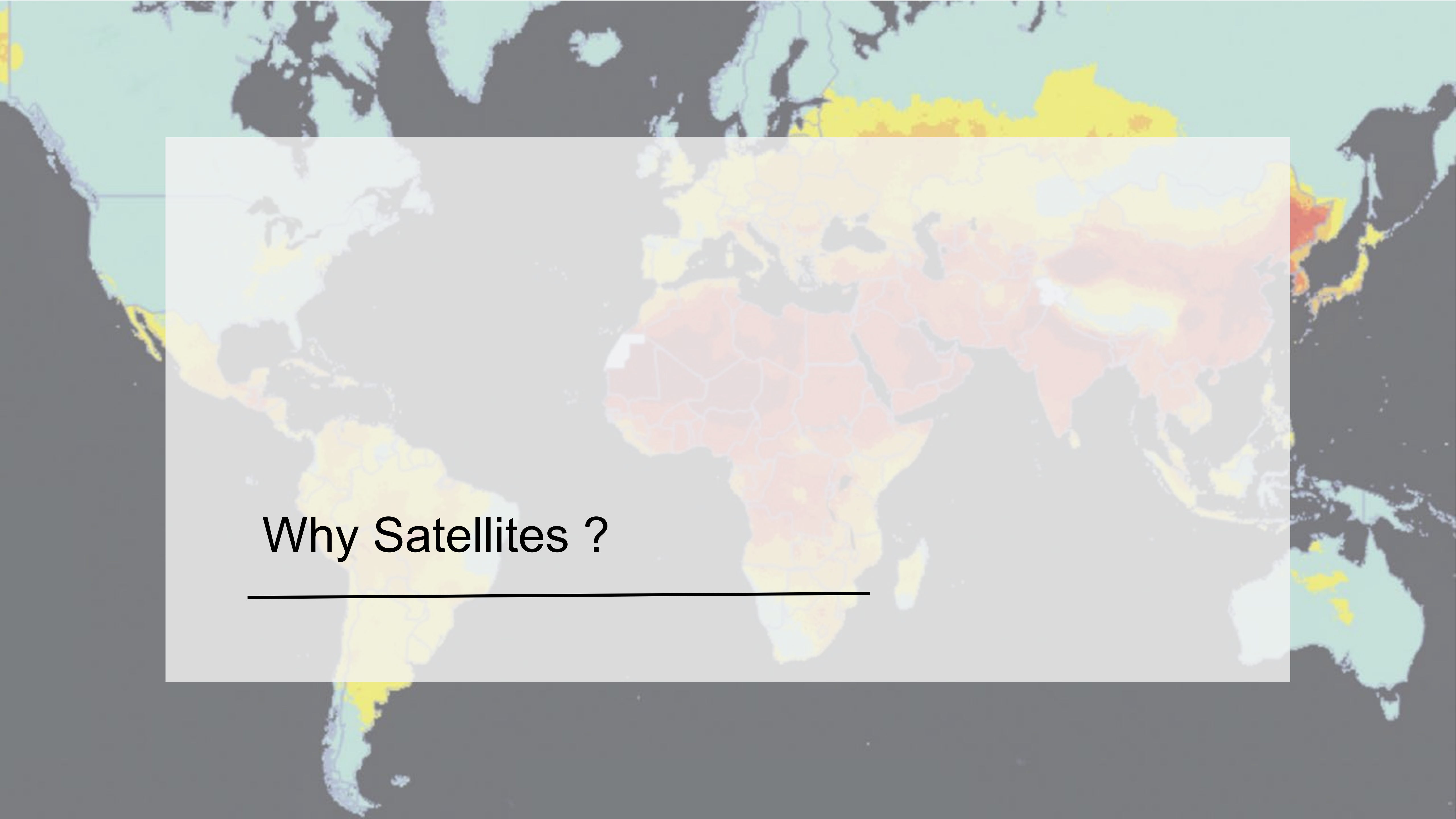
Spatial Patterns in AOD– PM2.5 Relationship



Gupta 2008

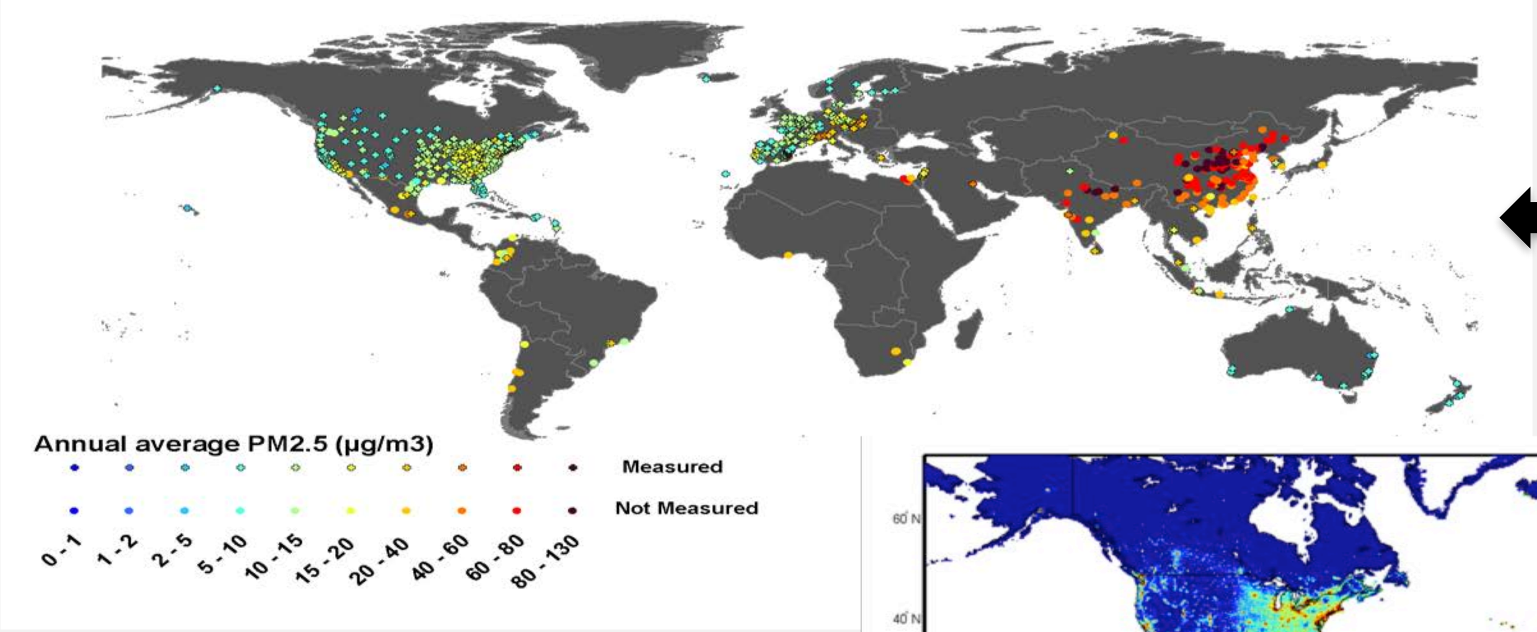
Satellite Remote Sensing of PM2.5: Summary



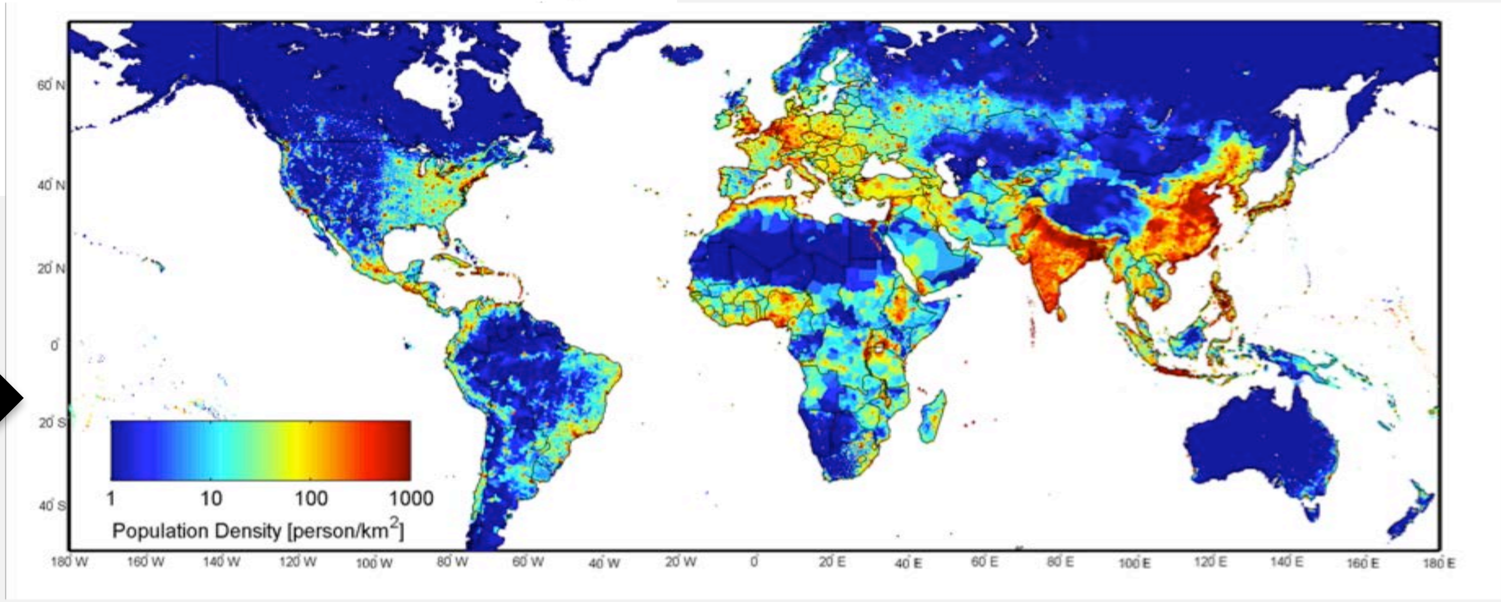


Why Satellites ?

Global Status of PM2.5 Monitoring

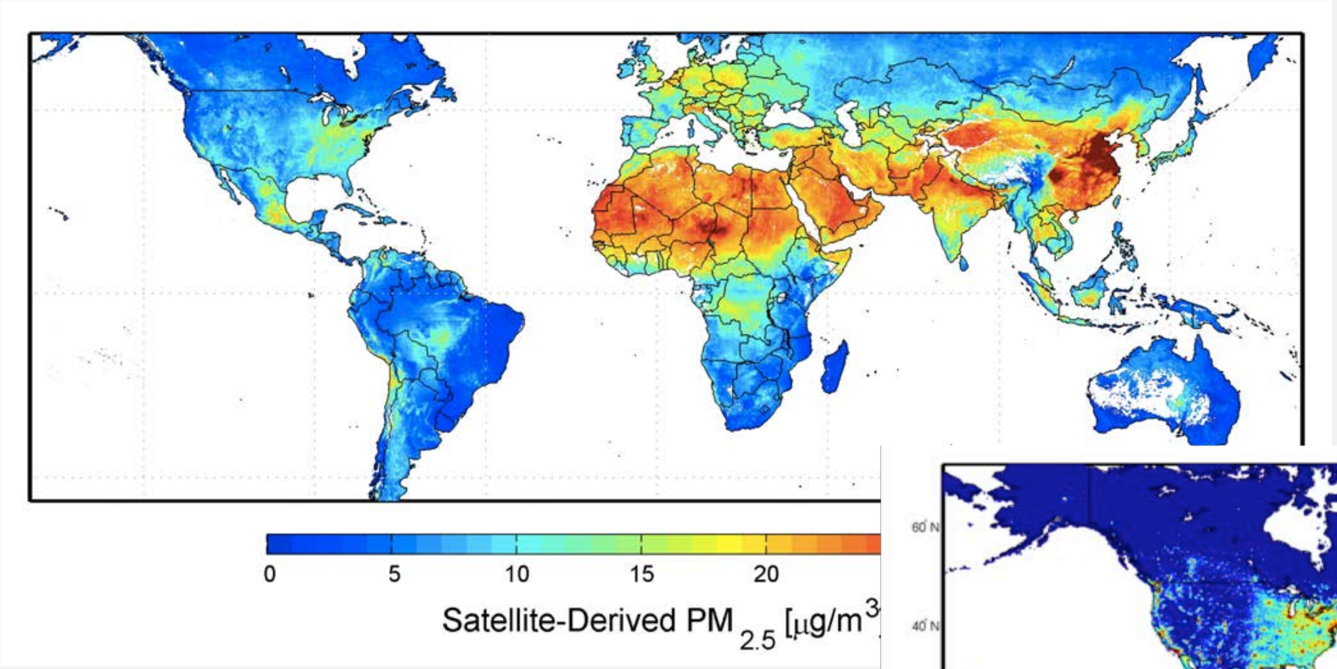


Ground Sensor Network



Population Density

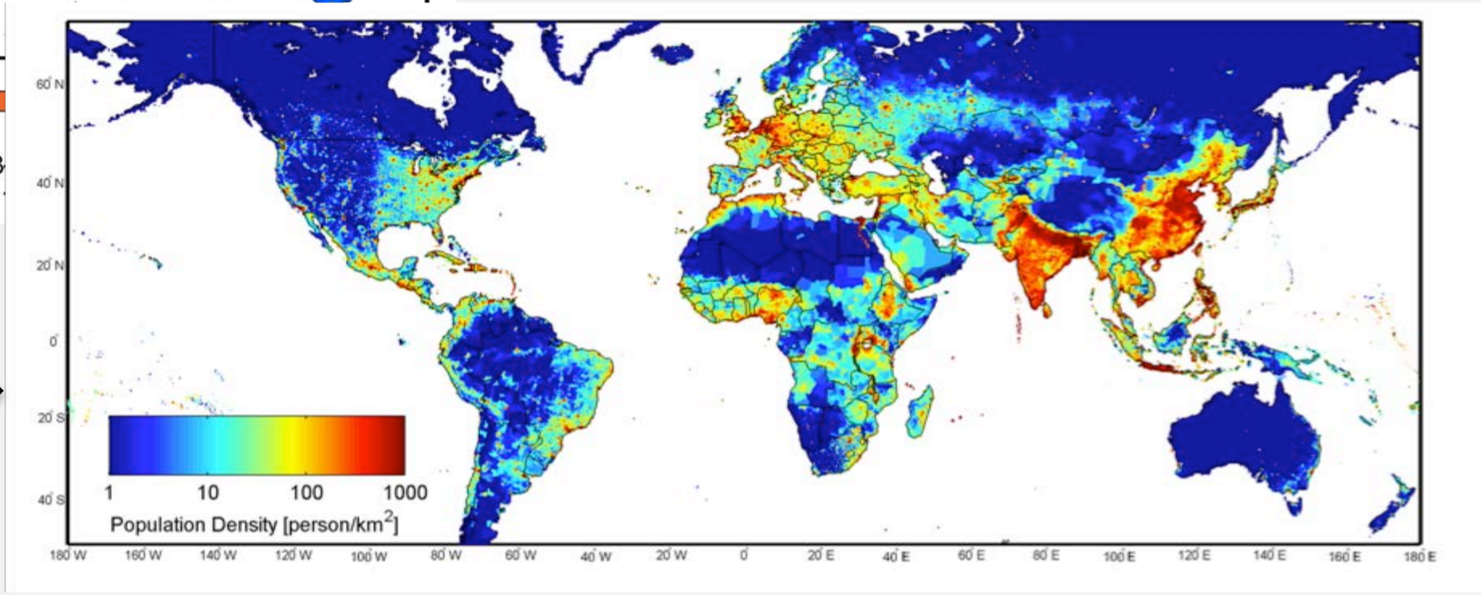
Global Status of PM2.5 Monitoring: Future View



van Donkelaar et al., 2010

Satellite Estimated PM2.5

Population Density



Suggested References

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Suggested Reading

http://www.nsstc.uah.edu/sundar/papers/2009/AWMA-proof.pdf

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R.M. Hoff


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Remote Sensing of Particulate Pollution from Space: Have We Reached the Promised Land?

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IMPLICATIONS

Satellite measurements are going to be an integral part of the Global Earth Observing System of Systems. Satellite measurements by themselves have a role in air quality studies but cannot stand alone as an observing system. Data assimilation of satellite and ground-based measurements into forecast models has synergy that aids all of these air quality tools.

the "but for" provision in the rule makes the use of satellite data possible in significant exceedances only. Applications such as event identification, transport, and atmospheric composition determination are strengths of satellite measurements. Where high precision is required (compliance monitoring, the "but for" test, and quantitative measurement of visibility effects on Class I areas), satellite data are presently of limited utility.

The use of the AOD as a measure for mass concentration has skill in some regions but less in others and does not provide a uniform way to measure aerosols across the United States. We discussed in Table 4 the range of mea-

In 2007, the A&WMA Critical Review by Bachmann discussed the history of the National Ambient Air Quality Standards (NAAQS).[142] The 39-yr history of those standards parallels the time period that satellite meteorology and observations have developed and yet, to date, no satellite measurements have been used to quantitatively address the NAAQS. From the review conducted here, only one congres-

EPA has taken a satellite observations role for itself in the Exceptional Events Rule.[144] If a region can show conclusively that they are being impacted by an event (a fire, a dust storm, etc.) that is outside of their jurisdiction to regulate, the event can be flagged as a nonexceedance event. This provides a significant motivation for regional

Although the desire for the use of satellite data for air quality purposes is widely stated, the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring AOD is

Homework: Due March 21, 2017

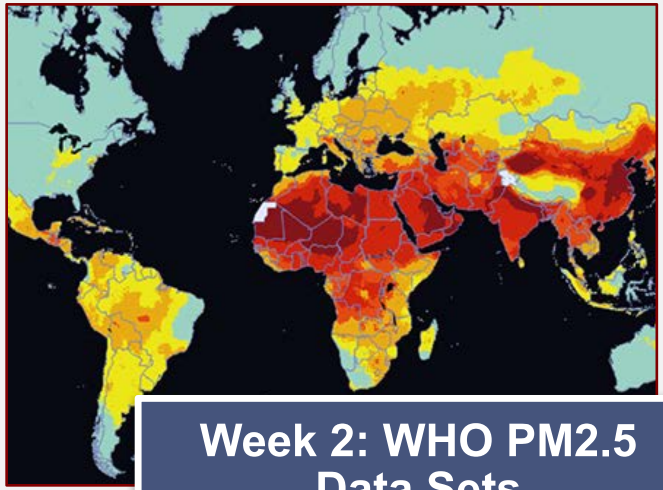
- Available at: https://goo.gl/forms/z6ORwSeewzsFANPX2

- All training materials (slides, recordings, and homework assignments) are available at: http://arset.gsfc.nasa.gov/airquality/webinars/AQ-SDG-17

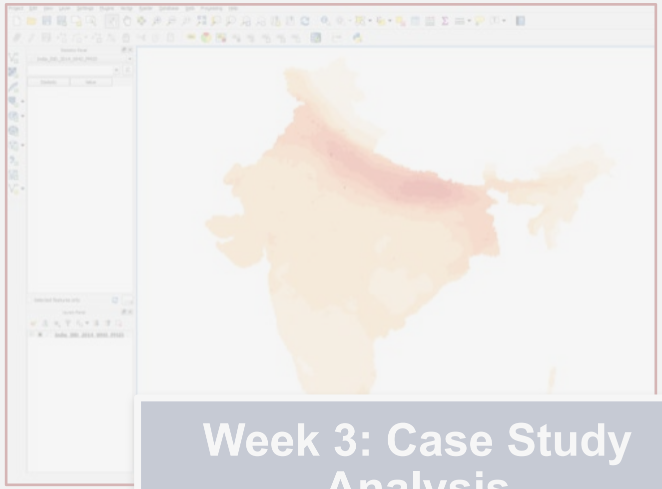
Next Week

WHO Resources for Global Air Quality Assessment

Week 1: ARSET, Remote Sensing and SDGs



Week 2: WHO PM2.5 Data Sets



Week 3: Case Study Analysis