

## ARSET

Applied Remote Sensing Training

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

 @NASAARSET

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


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March 15-29, 2017

Pawan Gupta, and Melanie Follette-Cook

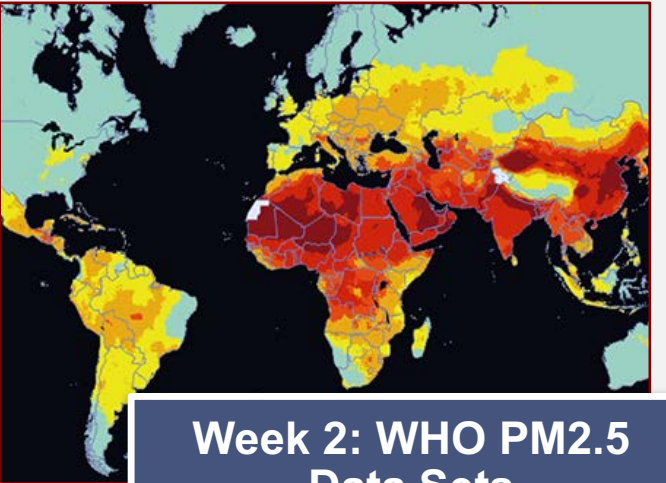
# Agenda

3 week webinar series



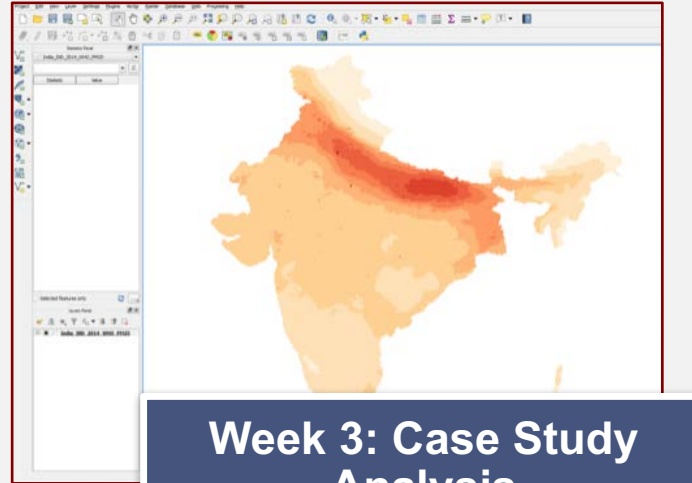
The image shows the 17 Sustainable Development Goals (SDGs) arranged in a grid. Each goal is represented by a colored square with a number, an icon, and a brief description. The goals are: 1. No Poverty, 2. Zero Hunger, 3. Good Health and Well-being, 4. Quality Education, 5. Gender Equality, 6. Clean Water and Sanitation, 7. Affordable and Clean Energy, 8. Decent Work and Economic Growth, 9. Industry, Innovation and Infrastructure, 10. Reduced Inequalities, 11. Sustainable Cities and Communities, 12. Responsible Consumption and Production, 13. Climate Action, 14. Life Below Water, 15. Life on Land, 16. Peace, Justice and Strong Institutions, and 17. Partnerships for the Goals.

**Week 1: ARSET, Remote Sensing and SDGs**



A world map showing the distribution of WHO PM2.5 data sets. The map uses a color scale from yellow to red to indicate the concentration of data sets, with higher concentrations (red) visible in Europe, Africa, and parts of Asia.

**Week 2: WHO PM2.5 Data Sets**



A screenshot of a GIS application window. The main map area displays a map of India, colored in shades of orange and red, indicating a specific data set or analysis. The application interface includes various toolbars and a legend.

**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](mailto:pawan.gupta@nasa.gov)  
<http://arset.gsfc.nasa.gov/people/pawan-gupta-0>

A world map with a semi-transparent white rectangular box overlaid on the center. The map uses a color scale from light blue to red to represent different data points. The white box contains the text 'Applied Remote Sensing Training Program (ARSET)' in black, with a horizontal line underneath.

# Applied Remote Sensing Training Program (ARSET)

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# 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



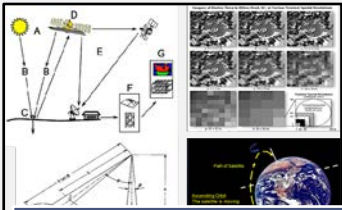
**Fundamentals of Remote Sensing:** Fundamentals of Remote Sensing

**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



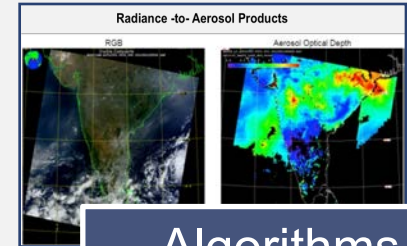
Remote Sensing



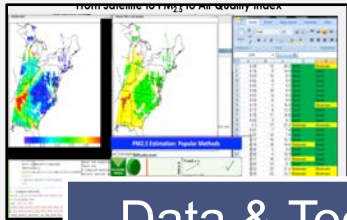
Satellites



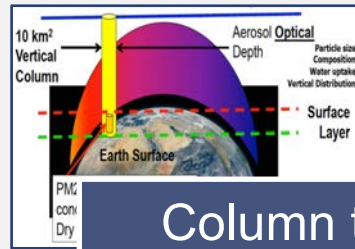
Images



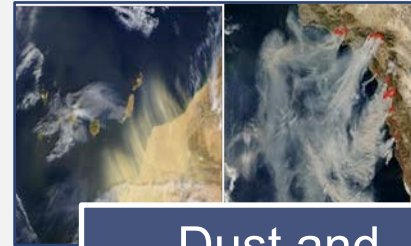
Algorithms



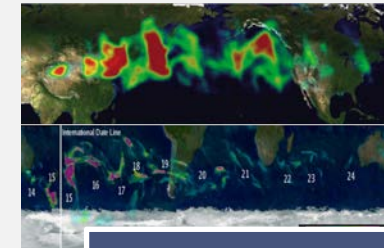
Data & Tools



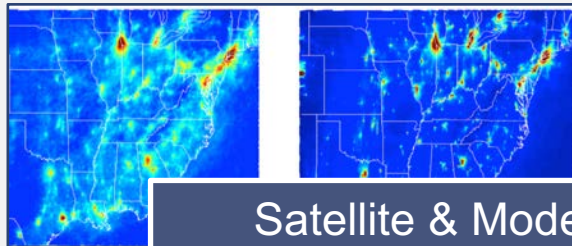
Column to Surface



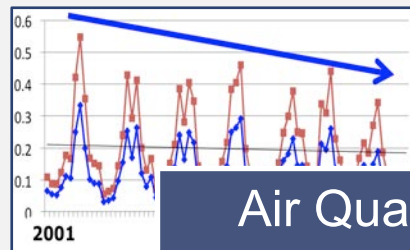
Dust and Smoke



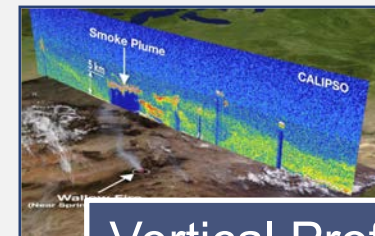
Transport



Satellite & Model Comparison



Air Quality Trends



Vertical Profiles



# ARSET Website

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

Earth Sciences Division Applied Sciences ASP Water Resources

**NASA** **ARSET**  
Applied Remote Sensing Training

Search this site

Home About ▾ Trainings ▾

## Applied Remote Sensing Training

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

Mar 15-29, 2017  
Wednesdays  
11 a.m.-12 p.m. or  
8-9 p.m. EDT/UTC-4

Learn More

ARSET

- Webinars
- Workshops
- Suggest a Training
- Personnel
- Resources

Upcoming Training

**Airquality**

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

03/15/2017 to 03/29/2017

**Disasters**

NASA Remote Sensing for

<< >>

The ARSET program offers satellite remote sensing training that builds the skills to integrate NASA Earth Science data into an agency's decision-making activities. Trainings are offered in air quality, climate, disaster, health, land, water resources, and wildfire management. Through [online](#) and [in person](#) training, ARSET has

A world map is shown in the background, with a semi-transparent white rectangular box overlaid in the center. The map uses a color gradient from light yellow to dark red to represent different levels of development or progress. The white box contains the text 'UN Sustainable Development Goals (SDGs)' in a bold, black, sans-serif font. A thin black horizontal line is positioned below the text.

# UN Sustainable Development Goals (SDGs)

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# UN Sustainable Development Goals (SDGs)

## Transforming Our World: The 2030 Agenda for Sustainable Development

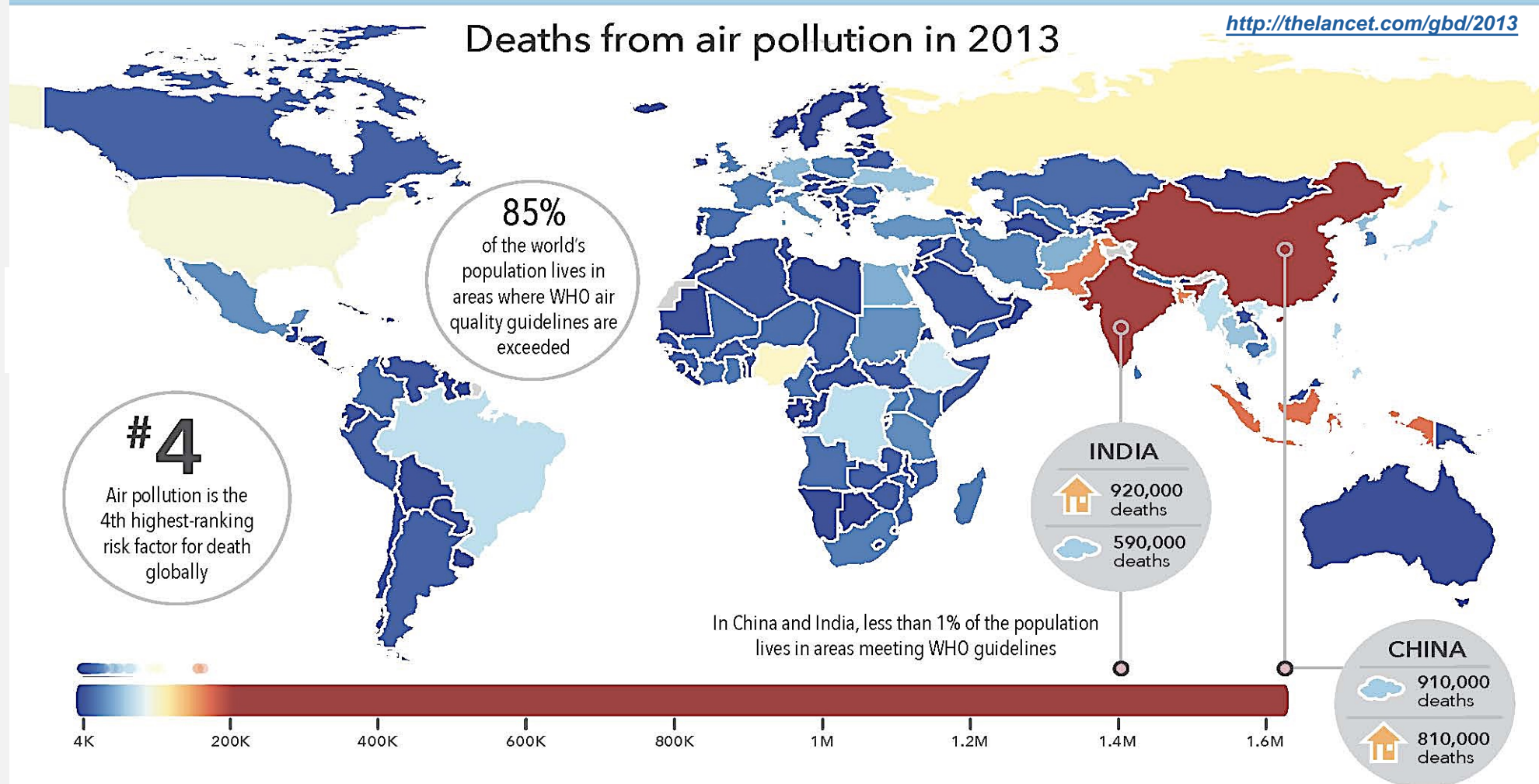
- A plan of action for people, planet and prosperity
- All countries and all stakeholders, acting in collaborative partnership, will implement this plan
- 17 SDGs and 169 targets under this agenda
- Balance the three dimensions of sustainable development:
  - economic, social, and **environmental**
-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



Text adapted from [“Transforming our world: the 2030 Agenda for Sustainable Development”](#)



# Global Burden of Air Pollution



- 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>)

A world map with a color-coded overlay representing air quality monitoring data. The overlay uses a color scale from light yellow to dark red, with the highest concentrations (red) appearing in East Asia and parts of South Asia. A semi-transparent white rectangular box is overlaid on the map, containing the text 'Air Quality Monitoring' and a horizontal line below it.

# Air Quality Monitoring

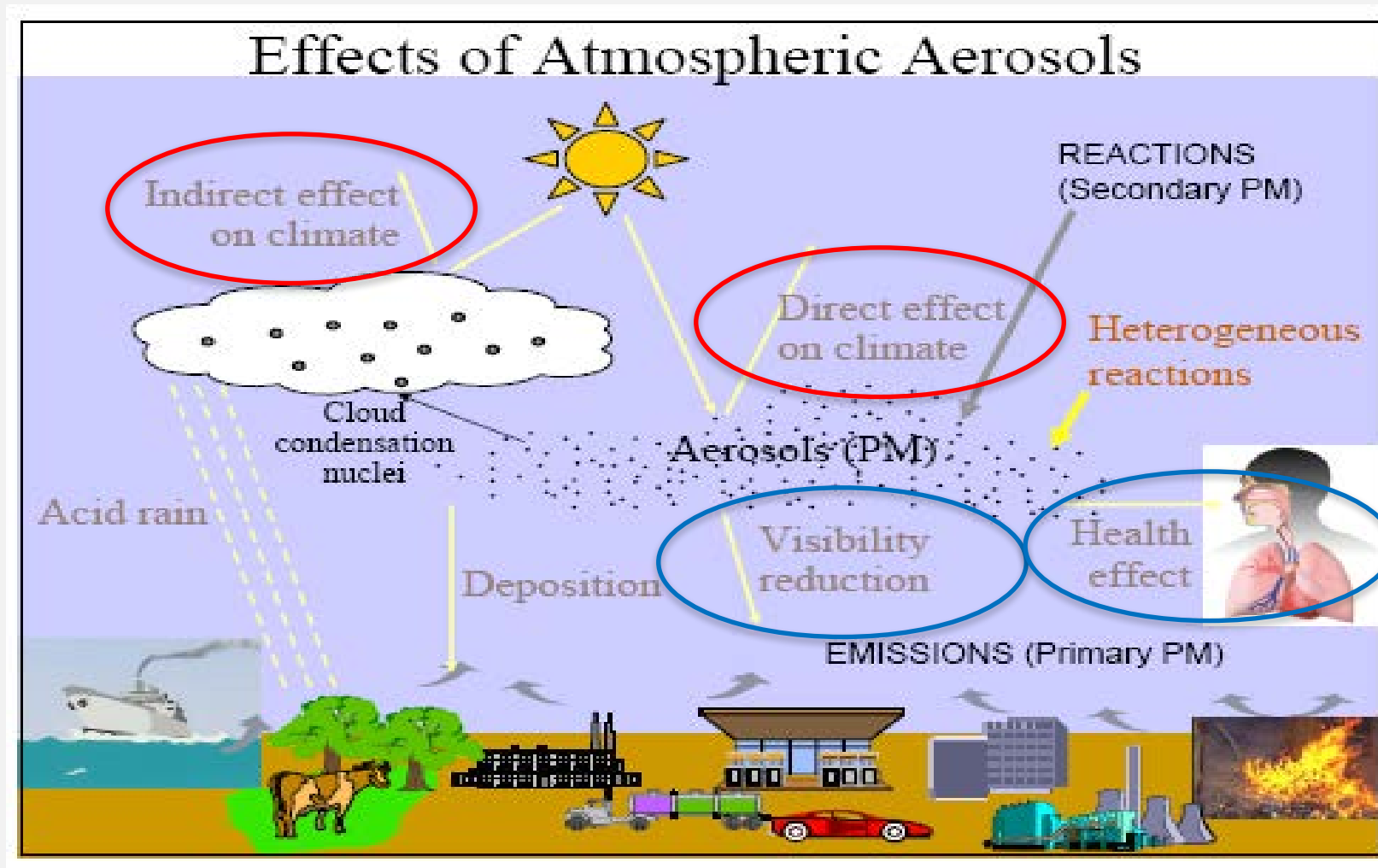
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# Common Terminology

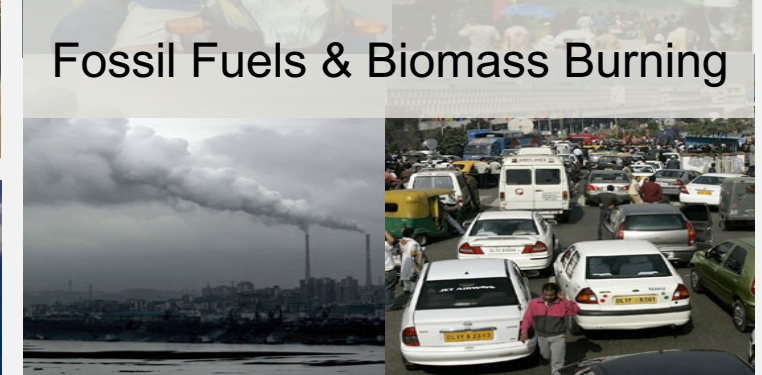
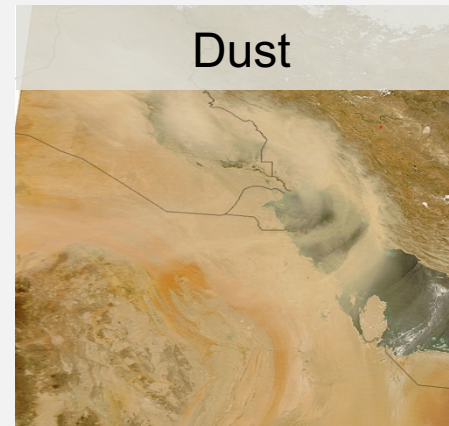
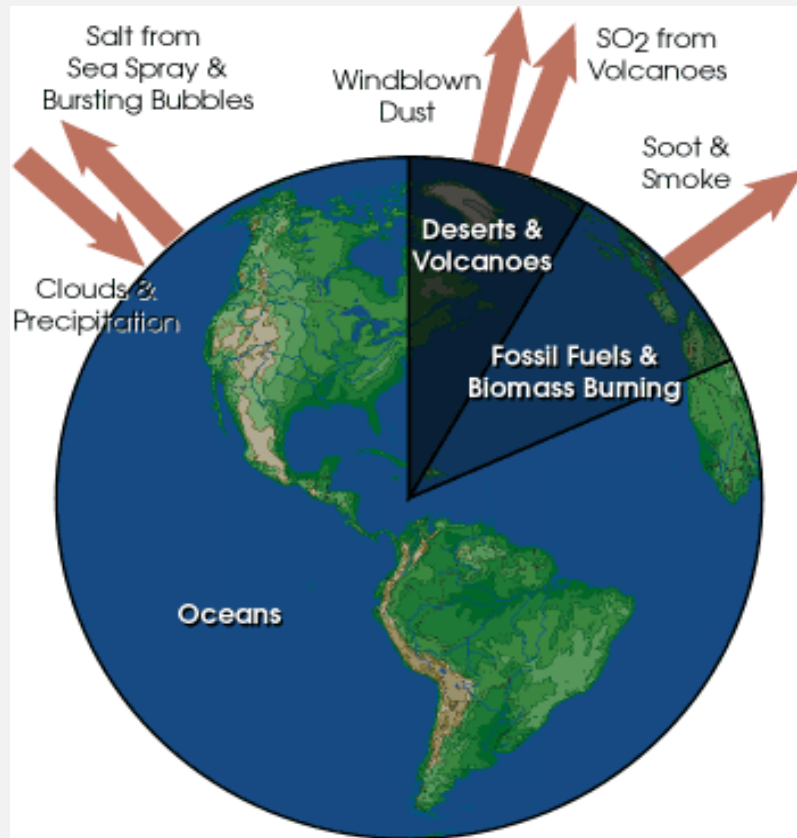
- Aerosols
- Particulate Matter
- Atmospheric Aerosols
- Particles

# Motivation: Tiny but Potent



# Pollution Sources

Atmospheric aerosols are highly variable in space and time



# 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

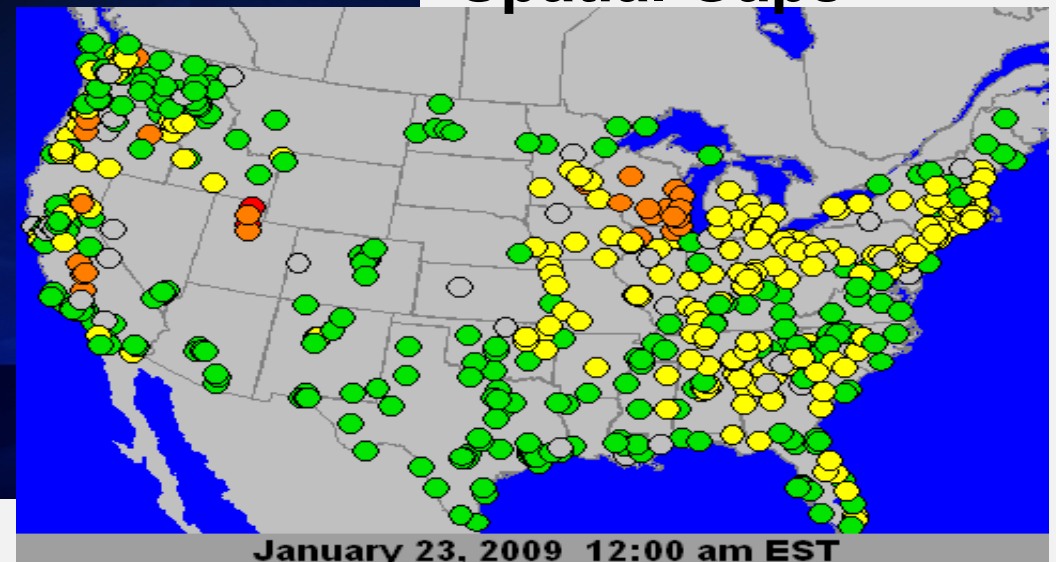
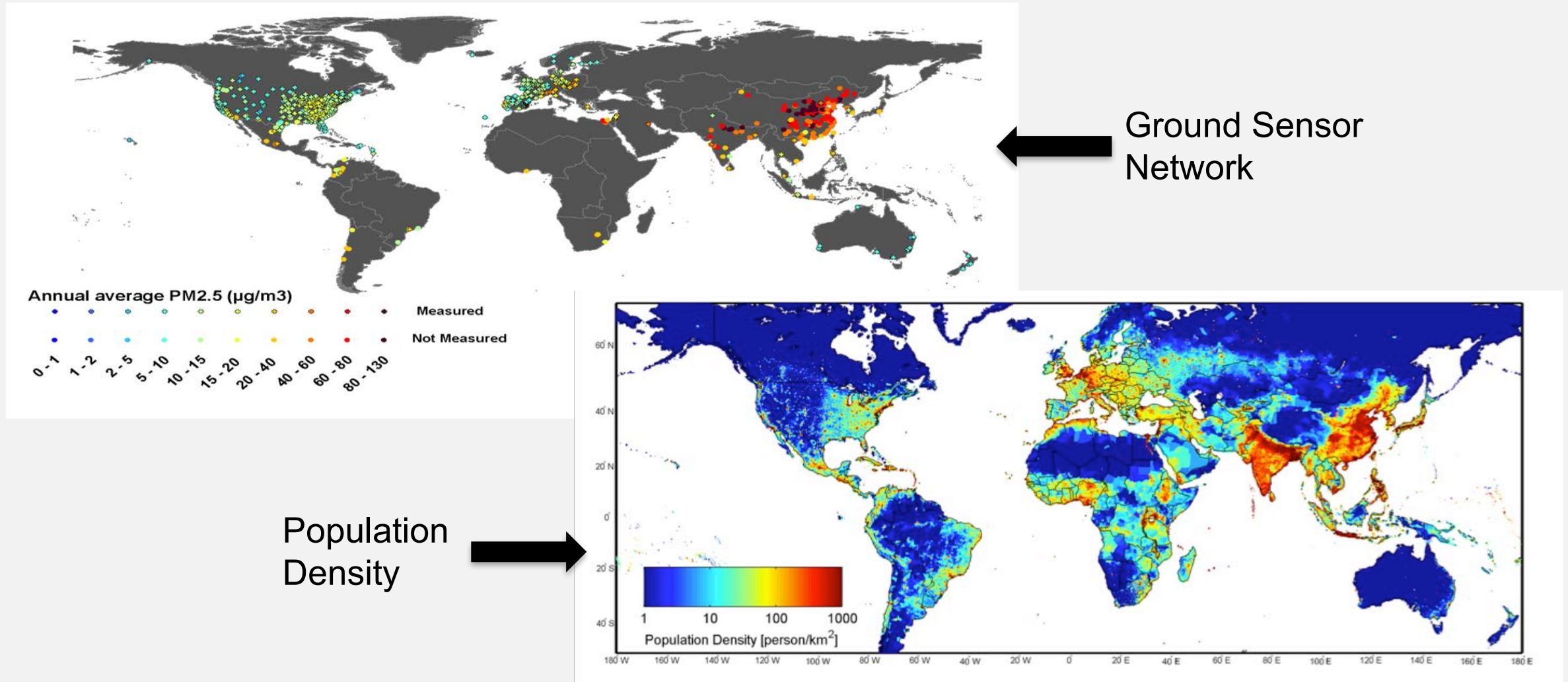


Image Credit: AirNow map, USEPA. <http://www.airnow.gov>

# Global Status of PM2.5 Monitoring



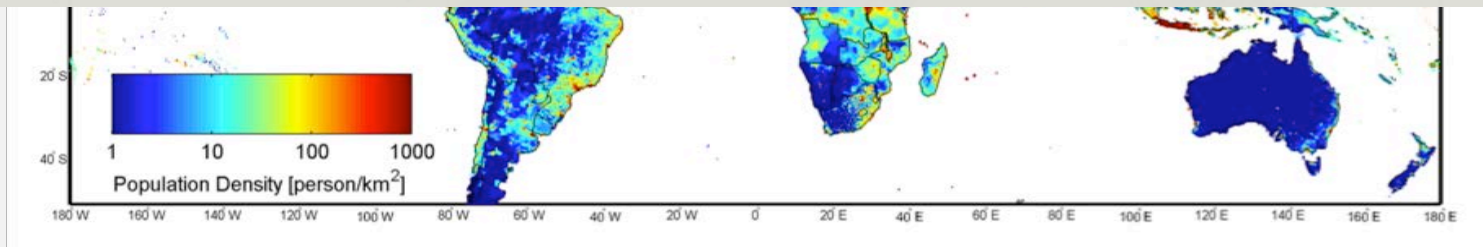


# Global Status of PM<sub>2.5</sub> Monitoring



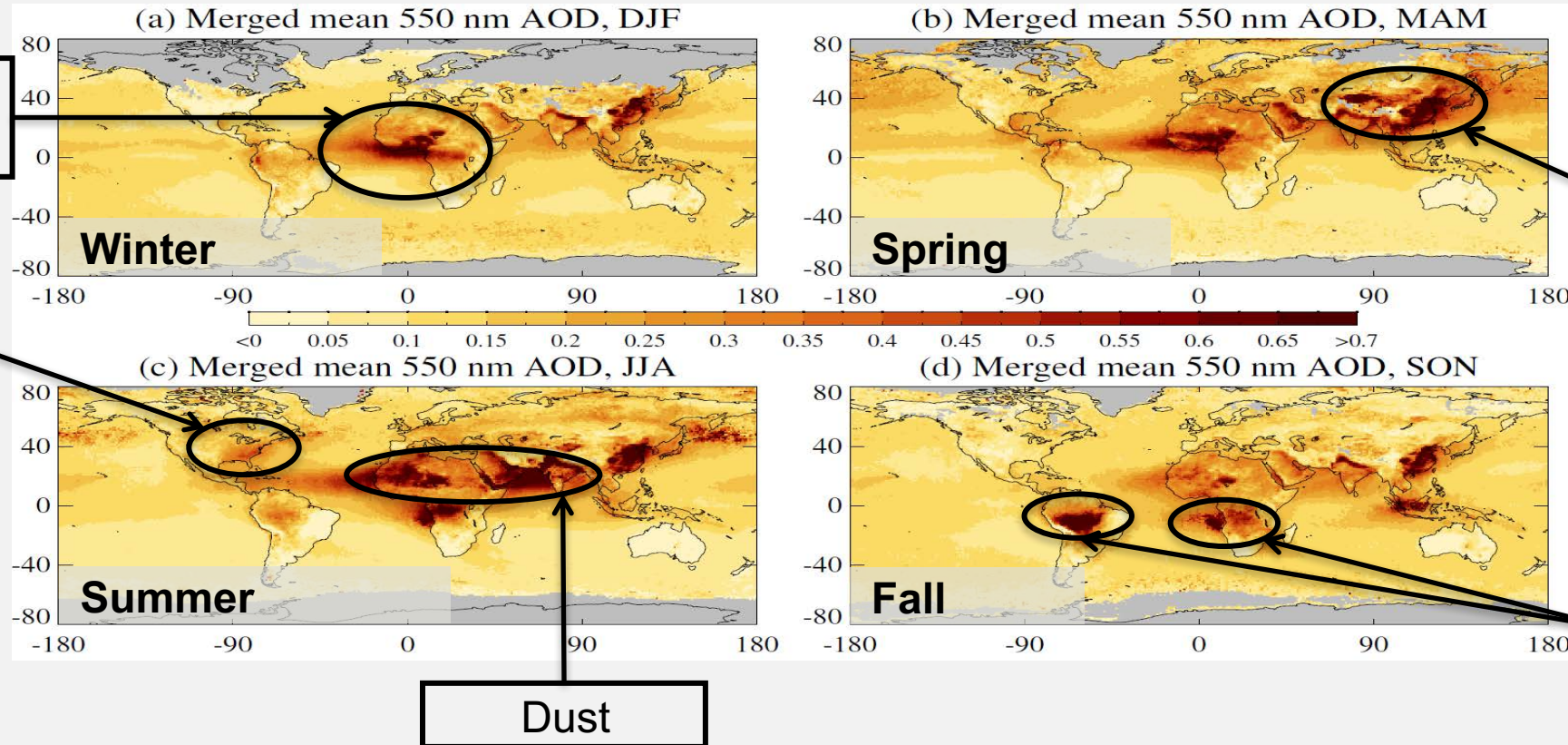
- Many countries do not have PM<sub>2.5</sub> mass measurements
- Spatial distribution of the existing ground network does not support the high population density
- Surface measurements are not cost effective
- How about using remote sensing satellite observations?

Population  
Density



# 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





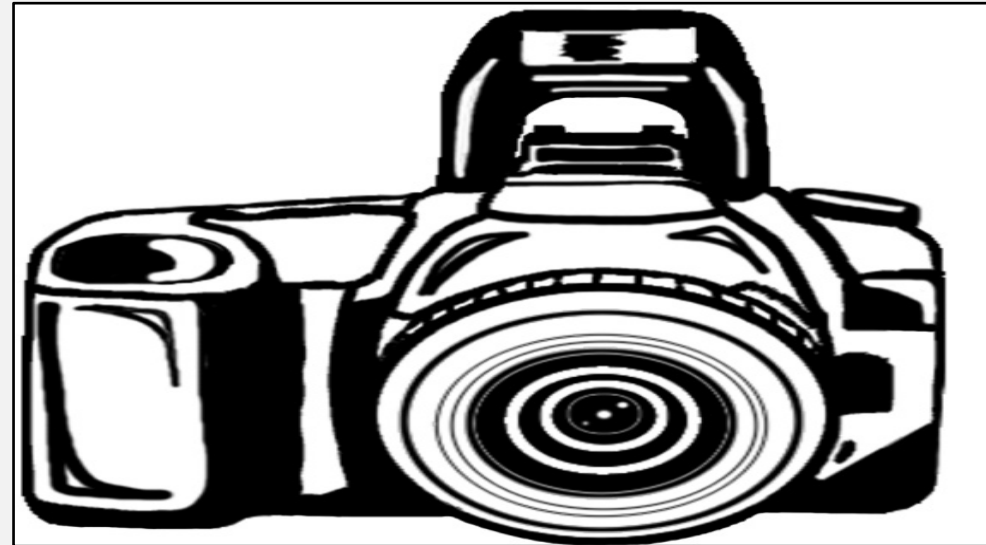
A world map with a color-coded overlay representing satellite remote sensing data. The colors range from light yellow to dark red, indicating different levels of data intensity or temperature. The map is centered on the Atlantic Ocean, showing the Americas on the left and Europe, Africa, and Asia on the right. A semi-transparent white box is overlaid on the map, containing the title text.

# Fundamentals of Satellite Remote Sensing

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# What is remote sensing?

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



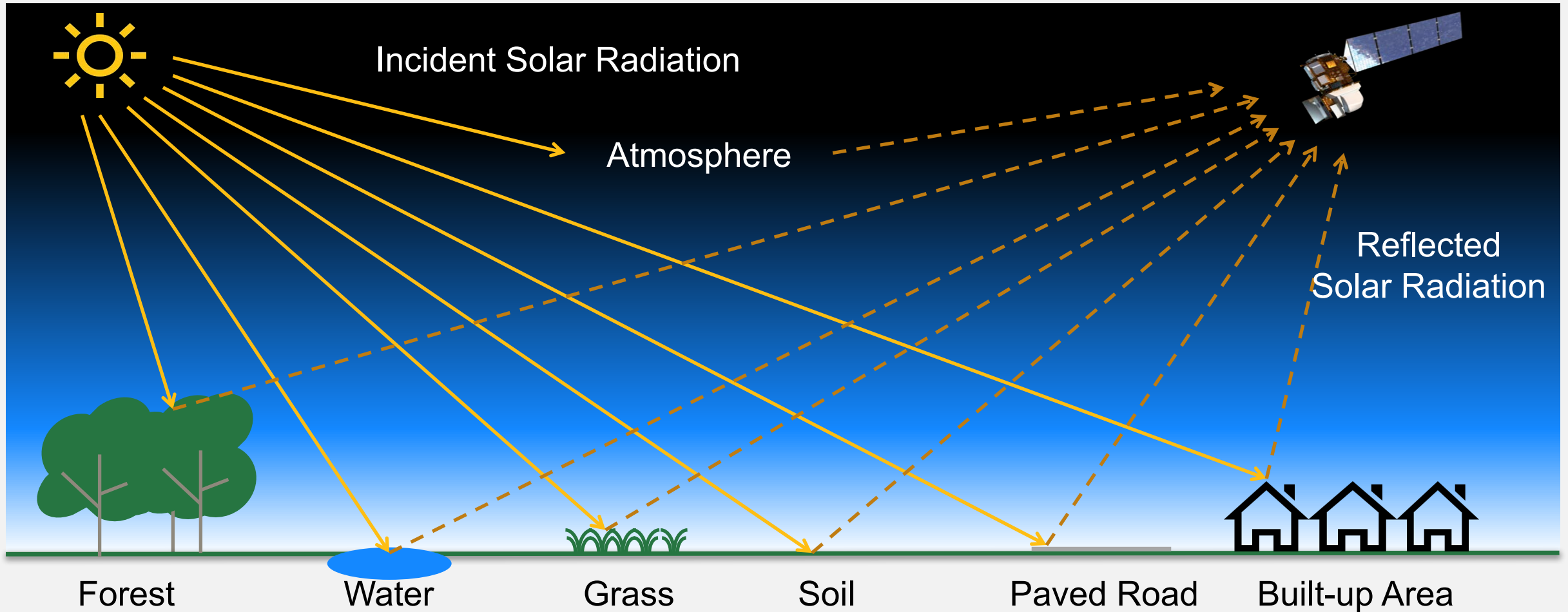
# Remote Sensing: Platforms



- 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?

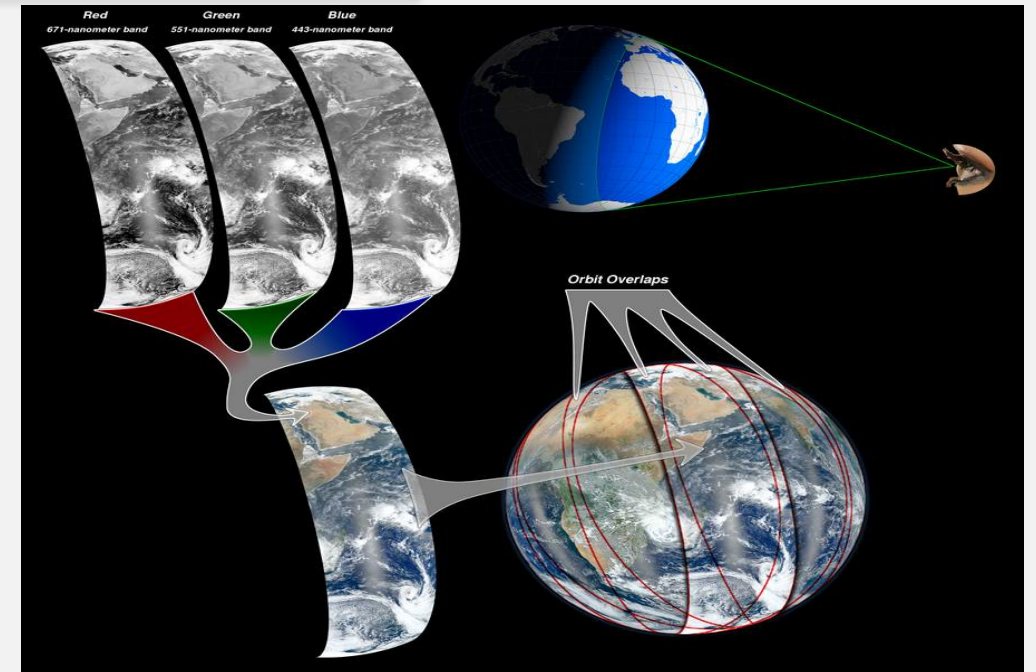
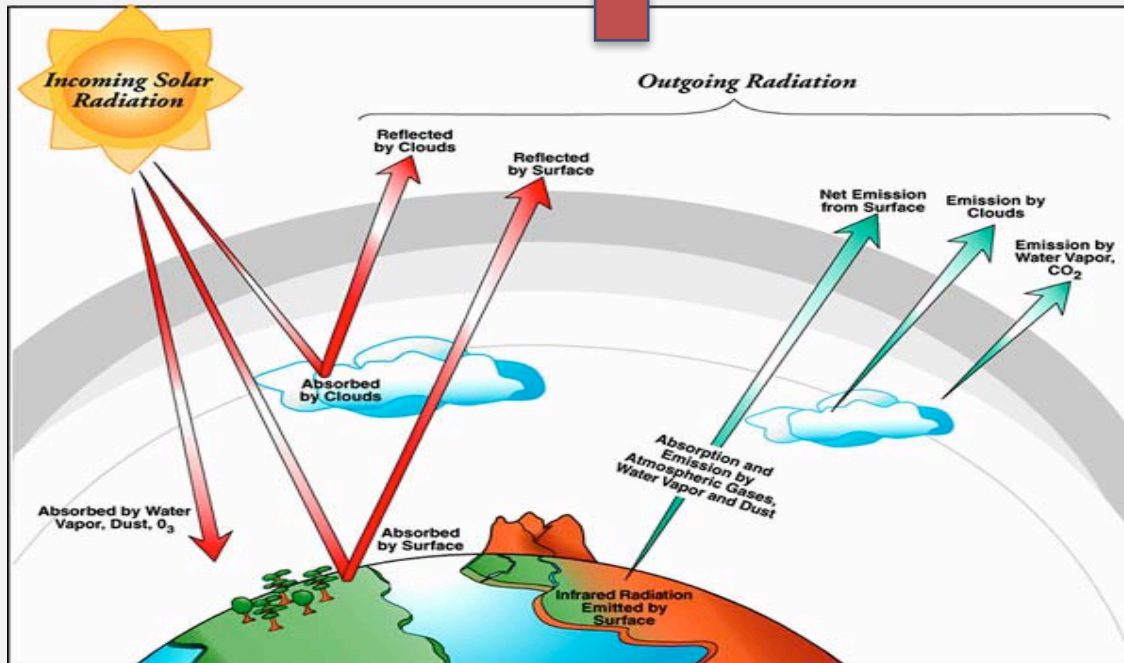
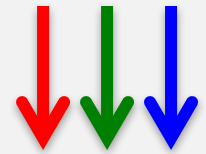
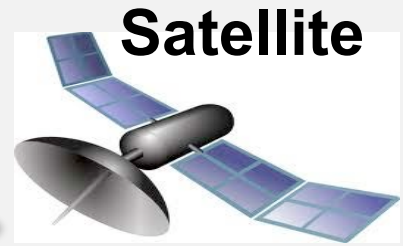
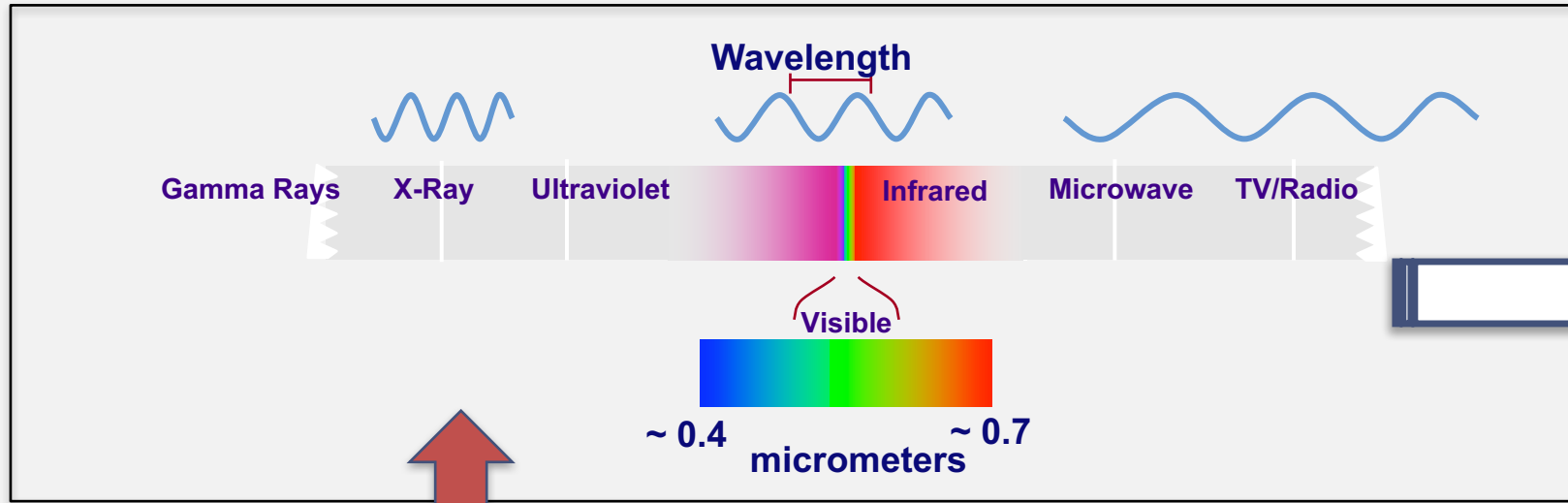


# What Does a Satellite Measure ?



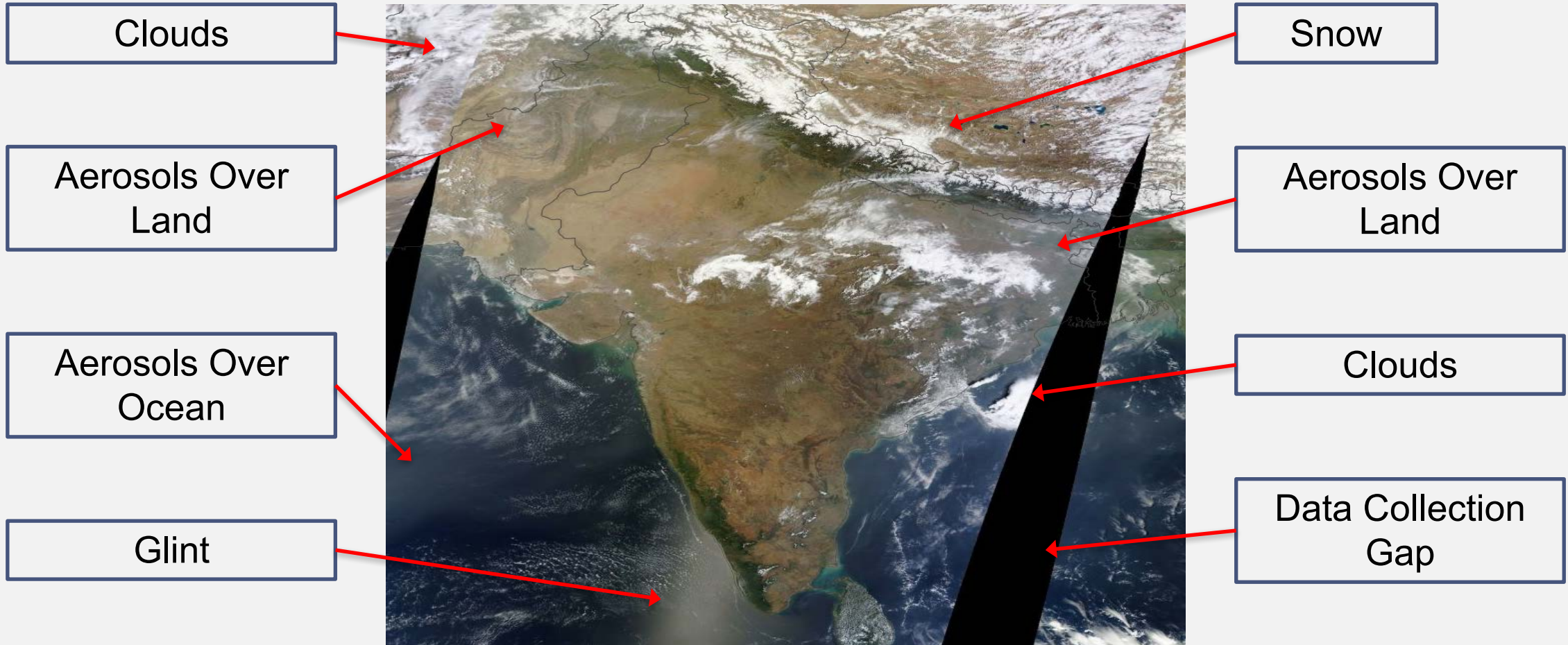
Adapted from Peterson (2007) <http://maps.unomaha.edu/Peterson/gis/notes/RS2.htm>

# Measurements to Visual: True Color Images



# What can we learn from true color imagery?

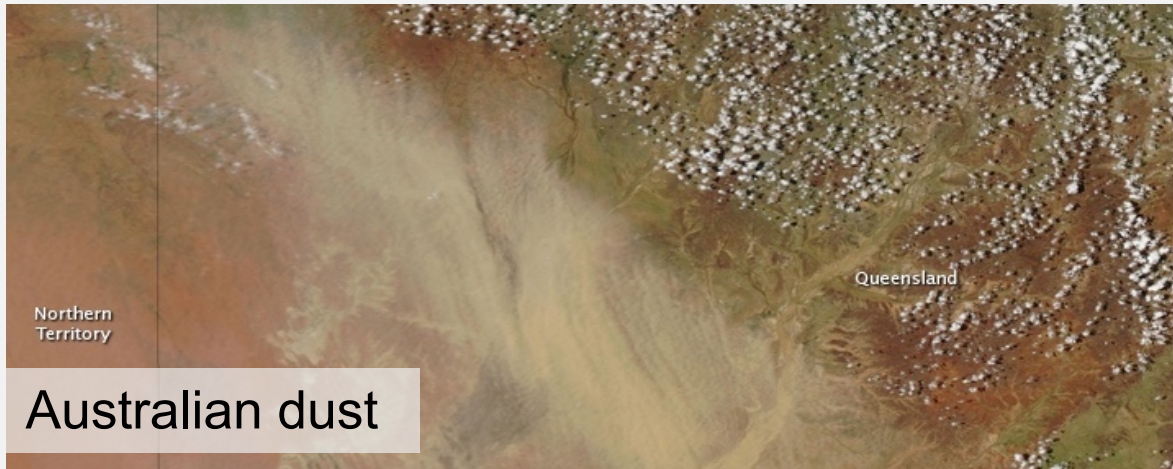
MODIS Terra Image, April 19, 2013





# How do we identify aerosols in true color images?

More reliable when a clear source is in the image





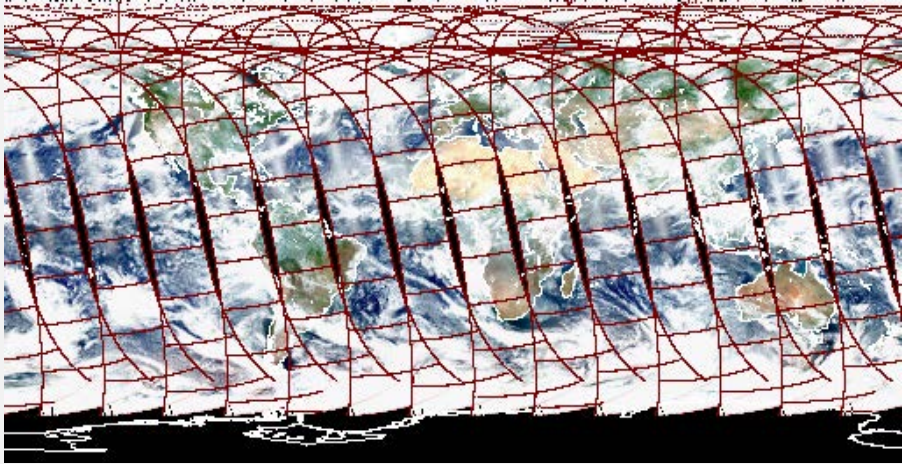
# How do we identify aerosols in true color images?

More reliable when a clear source is in the image

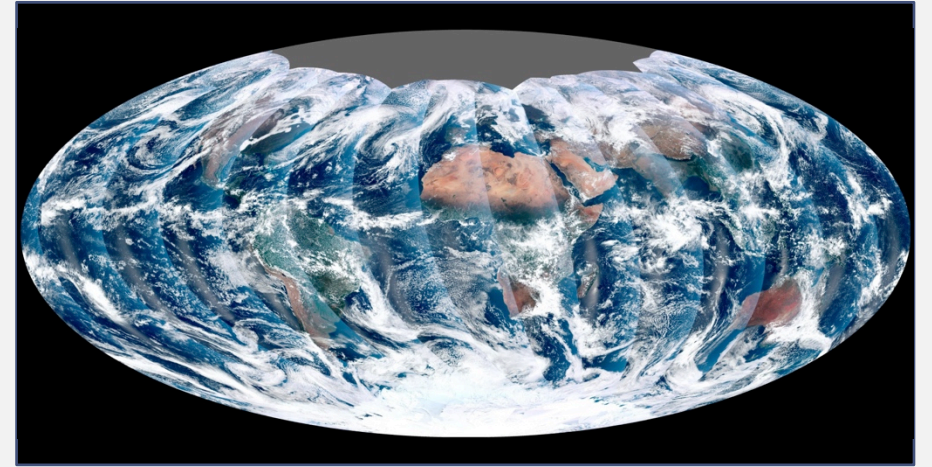




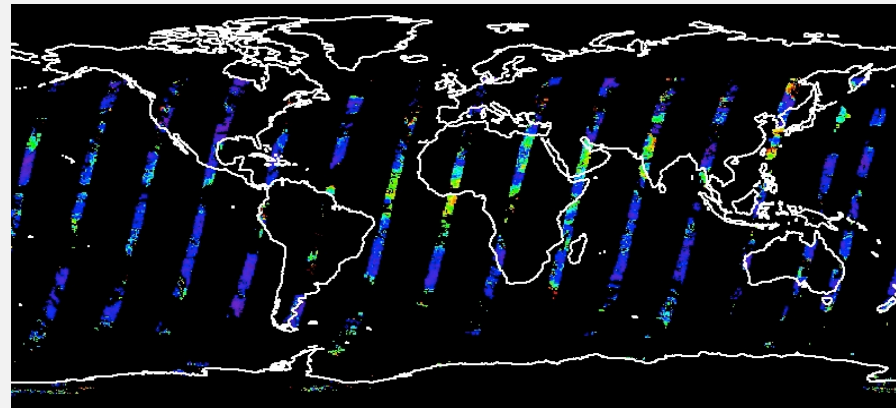
# Daily Satellite Coverage



MODIS

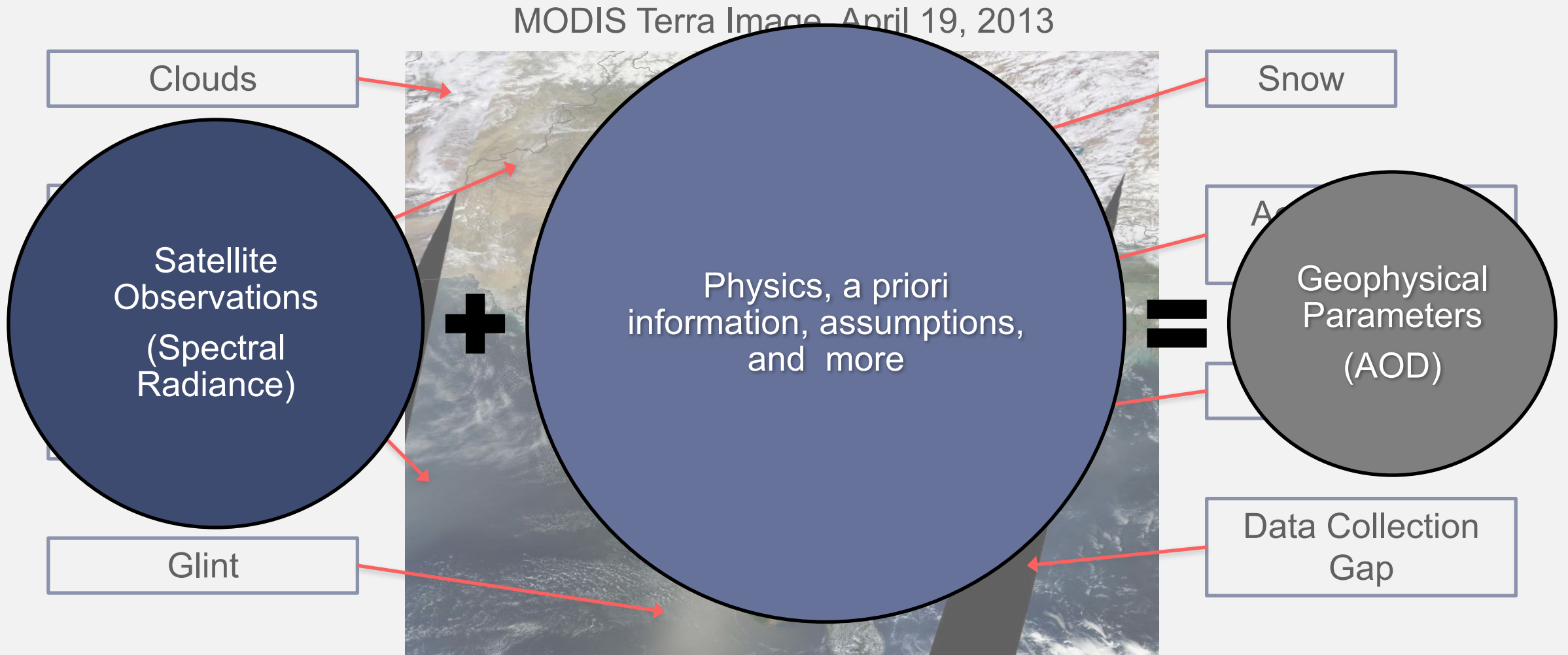


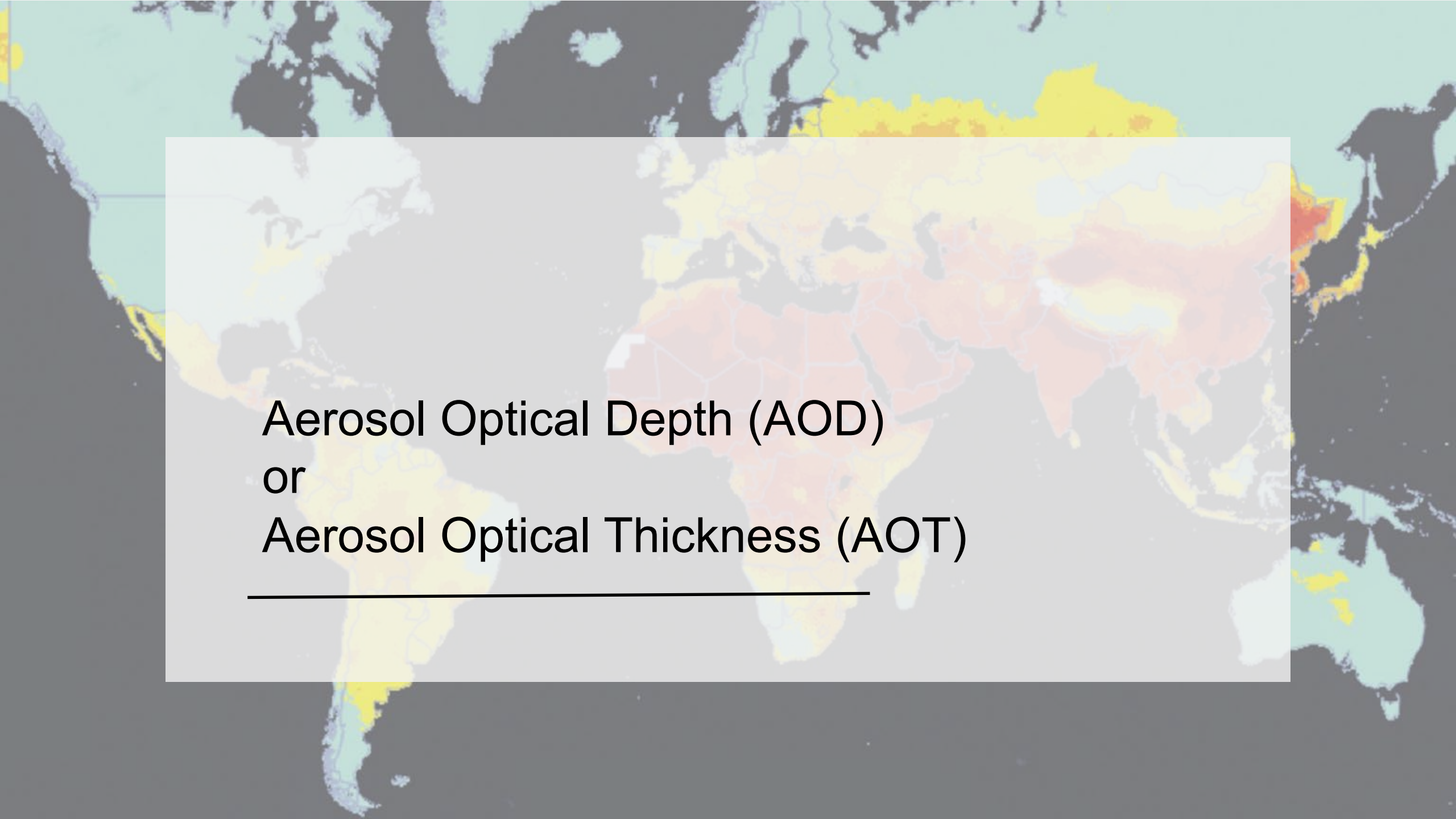
VIIRS



MISR

# What can we learn from true color imagery?



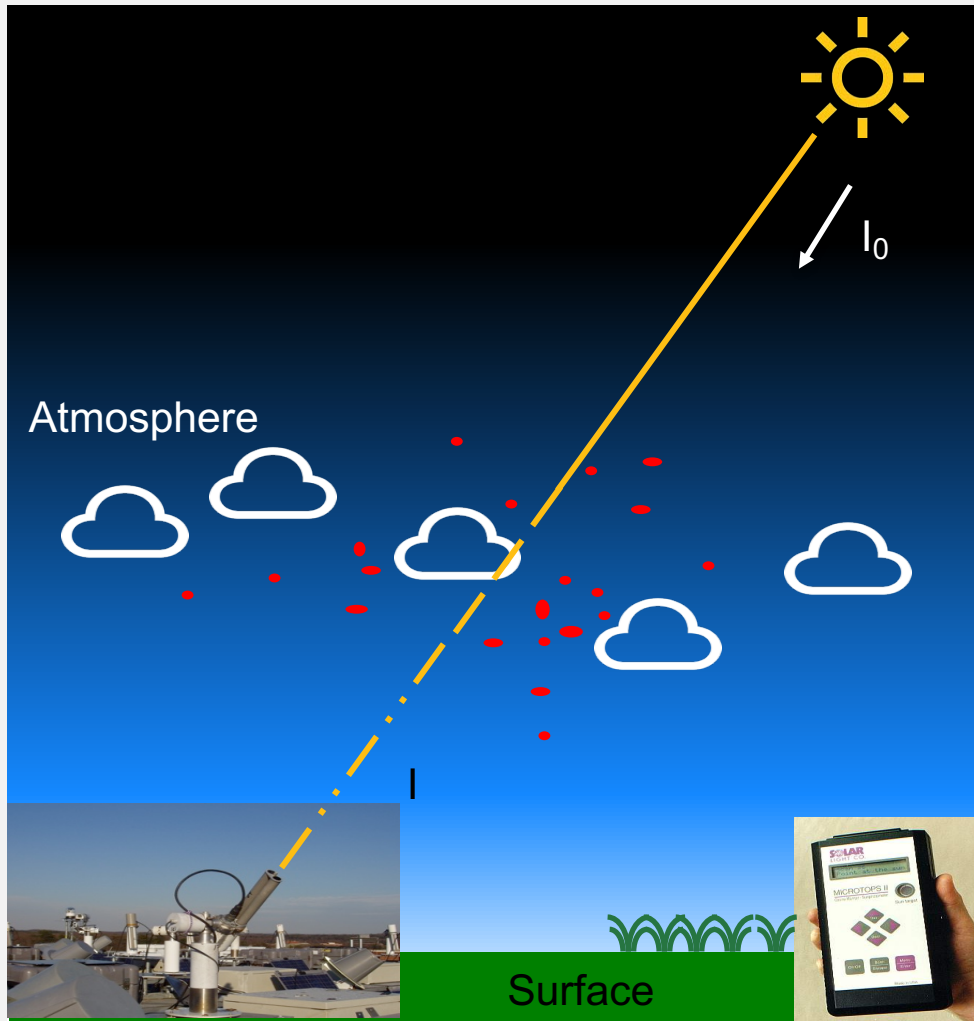


Aerosol Optical Depth (AOD)  
or  
Aerosol Optical Thickness (AOT)

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# 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  $\tau$  as

$$I = I_0 e^{-m\tau}$$

$$m = \sec\theta_0$$

$$\tau = \tau_{Rayl} + \tau_{aer} + \tau_{gas}$$

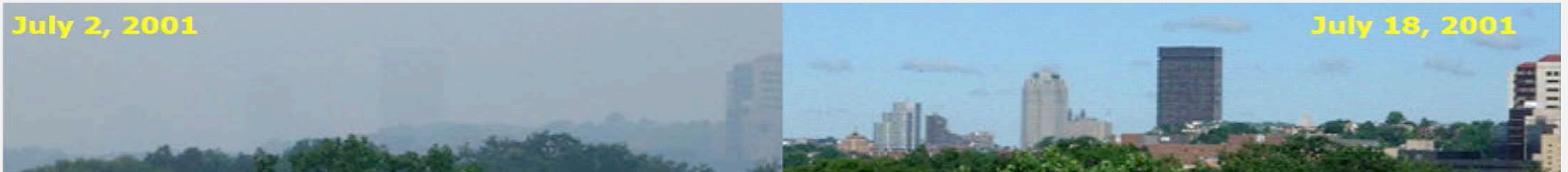
Optical depth due to aerosols in the atmospheric column is called **aerosol optical depth**

# Inferring AOD and PM<sub>2.5</sub> from Visuals

## Pittsburgh

PM<sub>2.5</sub> = 45 μgm<sup>-3</sup>

PM<sub>2.5</sub> = 4 μgm<sup>-3</sup>



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/>

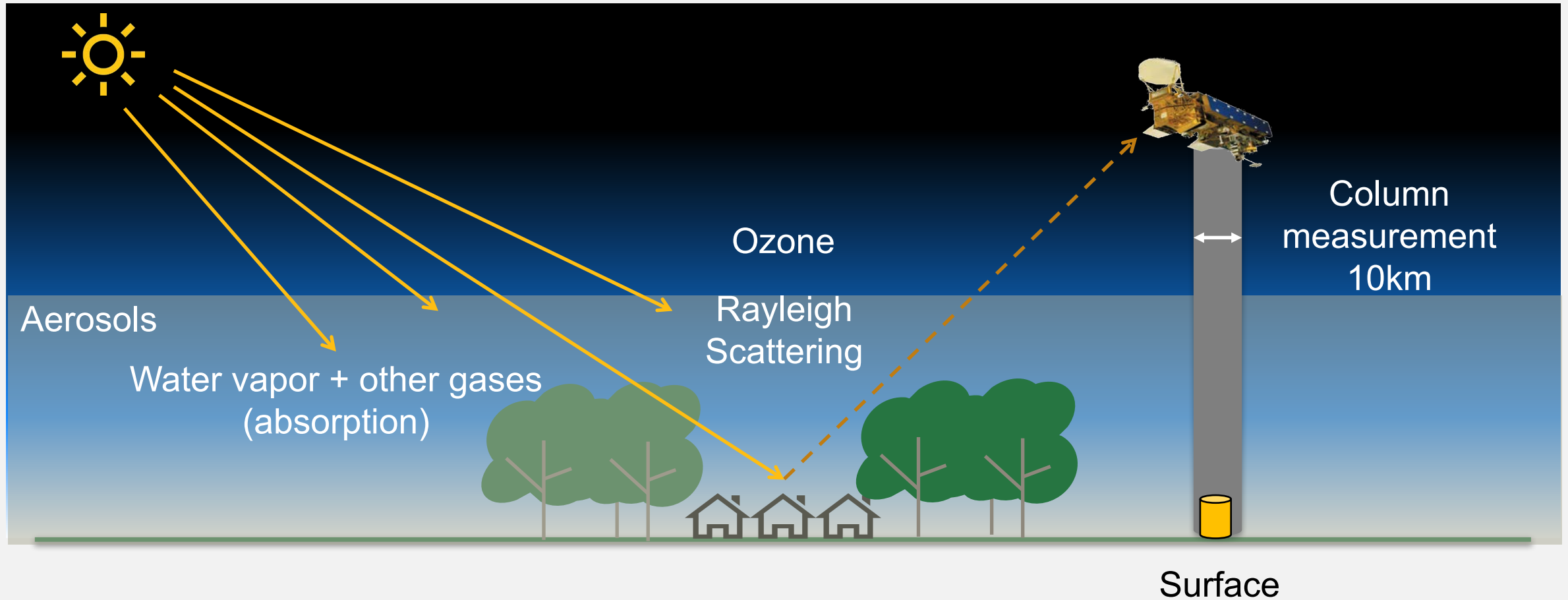
# Inferring AOD and PM2.5 from Visuals

## Singapore



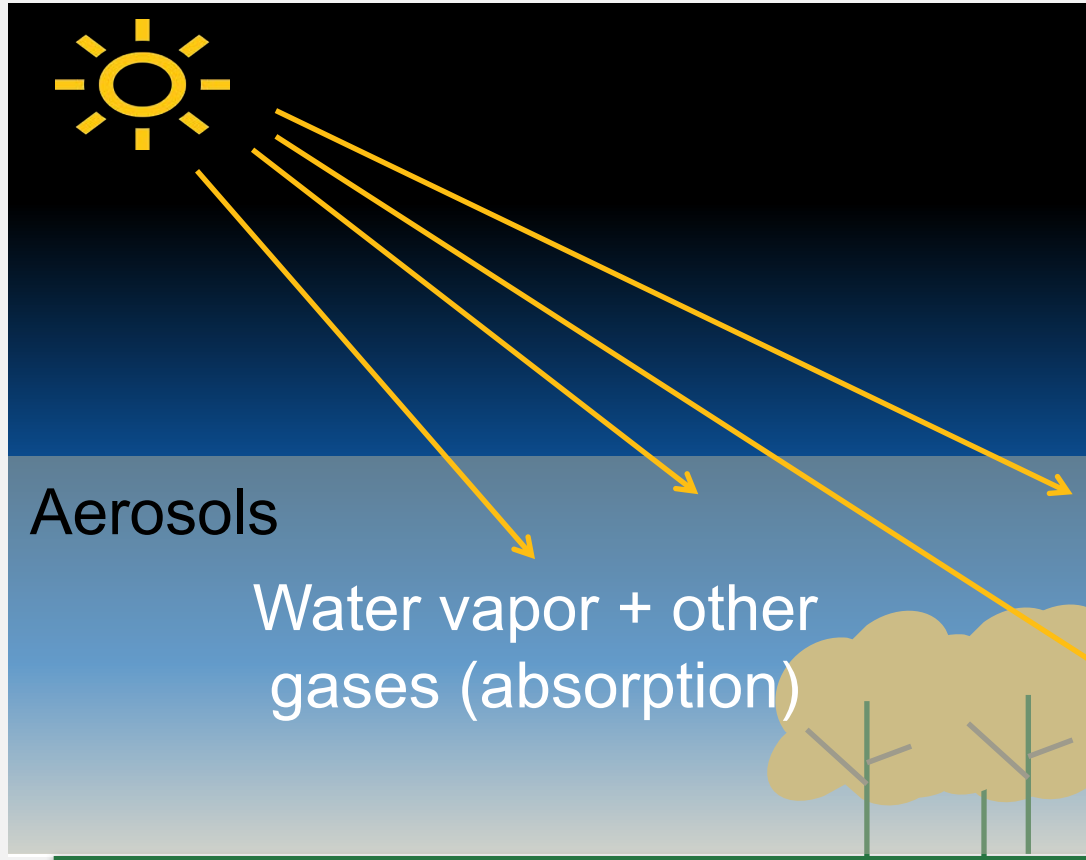
*Image Credit: Roslan Rahman/AFP/Getty Images*

# Aerosol Optical Depth from Satellites





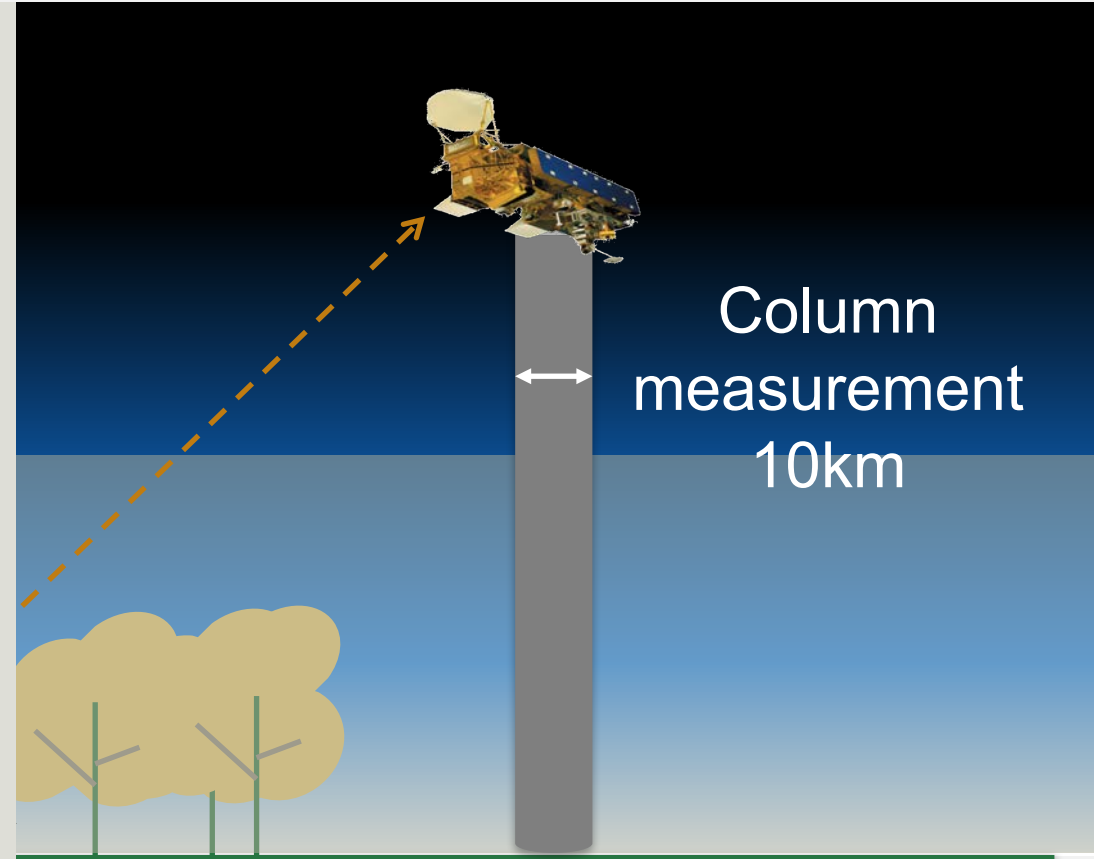
# Aerosol Optical Depth from Satellites



- $AOT(\tau) = \int \beta_{ext} dz$ 
  - particle size
  - composition
  - water uptake
  - vertical distribution
- There are satellite retrieval issues: inversion (e.g. aerosol model, background)

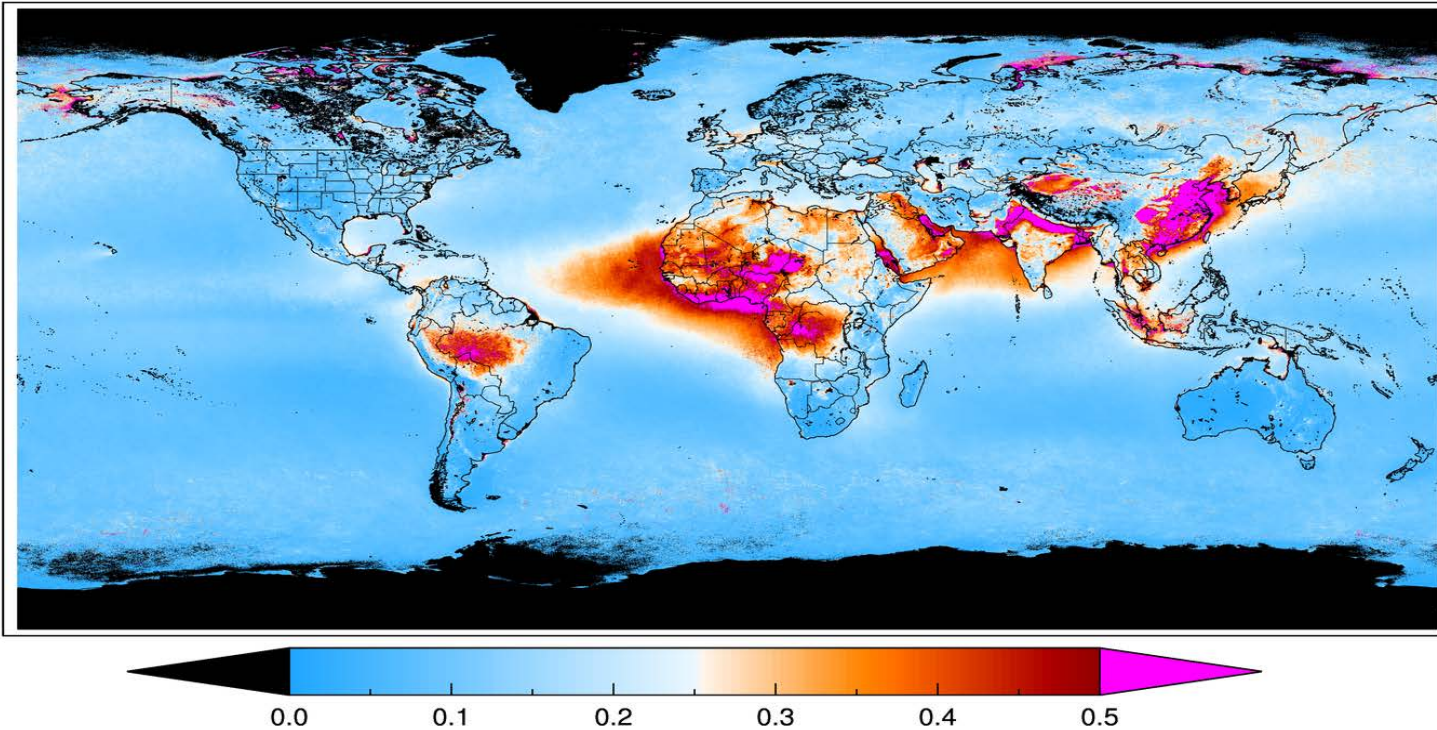
# Aerosol Optical Depth from Satellites

- Seven MODIS bands are utilized to derive aerosol properties
  - **0.47  $\mu\text{m}$**
  - 0.55  $\mu\text{m}$
  - **0.65  $\mu\text{m}$**
  - 0.86  $\mu\text{m}$
  - 1.24  $\mu\text{m}$
  - 1.64  $\mu\text{m}$
  - **2.13  $\mu\text{m}$**
- 10x10 km<sup>2</sup> resolution
- 3x3 km<sup>2</sup> resolution



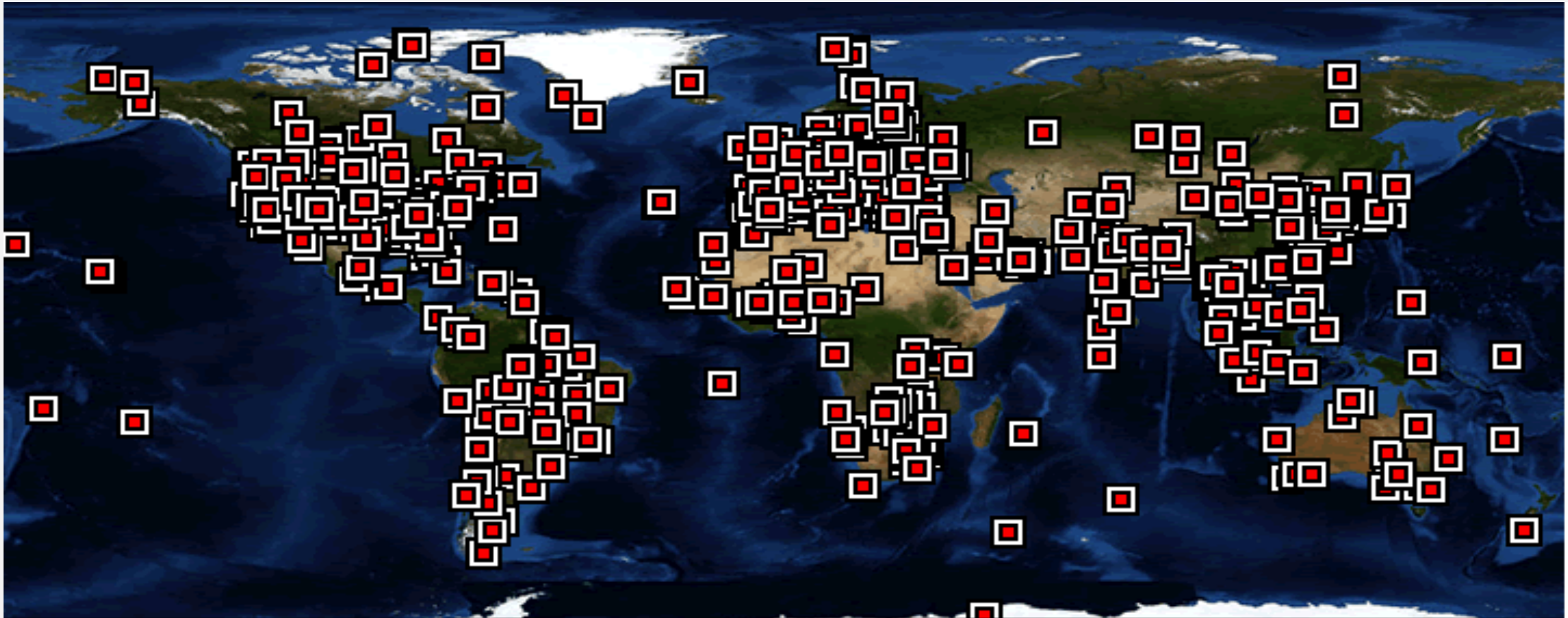
# Satellites Provide Global View of Particles

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**

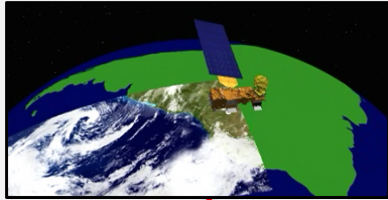


A world map with a color scale from light yellow to dark red, representing the conversion of Aerosol Optical Depth (AOD) to PM2.5. The map shows high concentrations of PM2.5 in East Asia, South Asia, and parts of Africa and South America. A semi-transparent white box is overlaid on the map, containing the text 'AOD to PM2.5' and a horizontal line.

**AOD to PM2.5**

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# 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

Top of the Atmosphere

10 km<sup>2</sup> Vertical Column

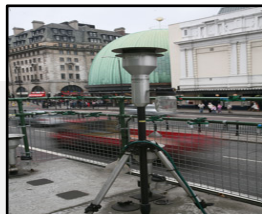
Aerosol **Optical** Depth

Surface Layer

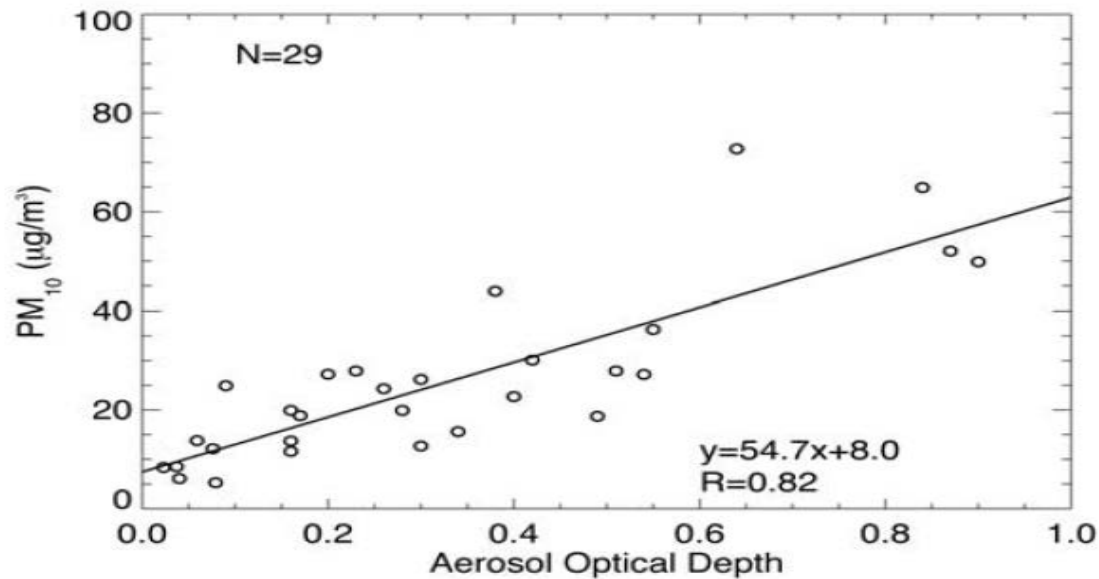
Earth Surface

PM2.5 **mass** concentration ( $\mu\text{g}\cdot\text{m}^{-3}$ ) -- Dry Mass

PM2.5 – Mass per unit volume of aerosol particles less than 2.5  $\mu\text{m}$  in aerodynamic diameter at surface (measurement height) level

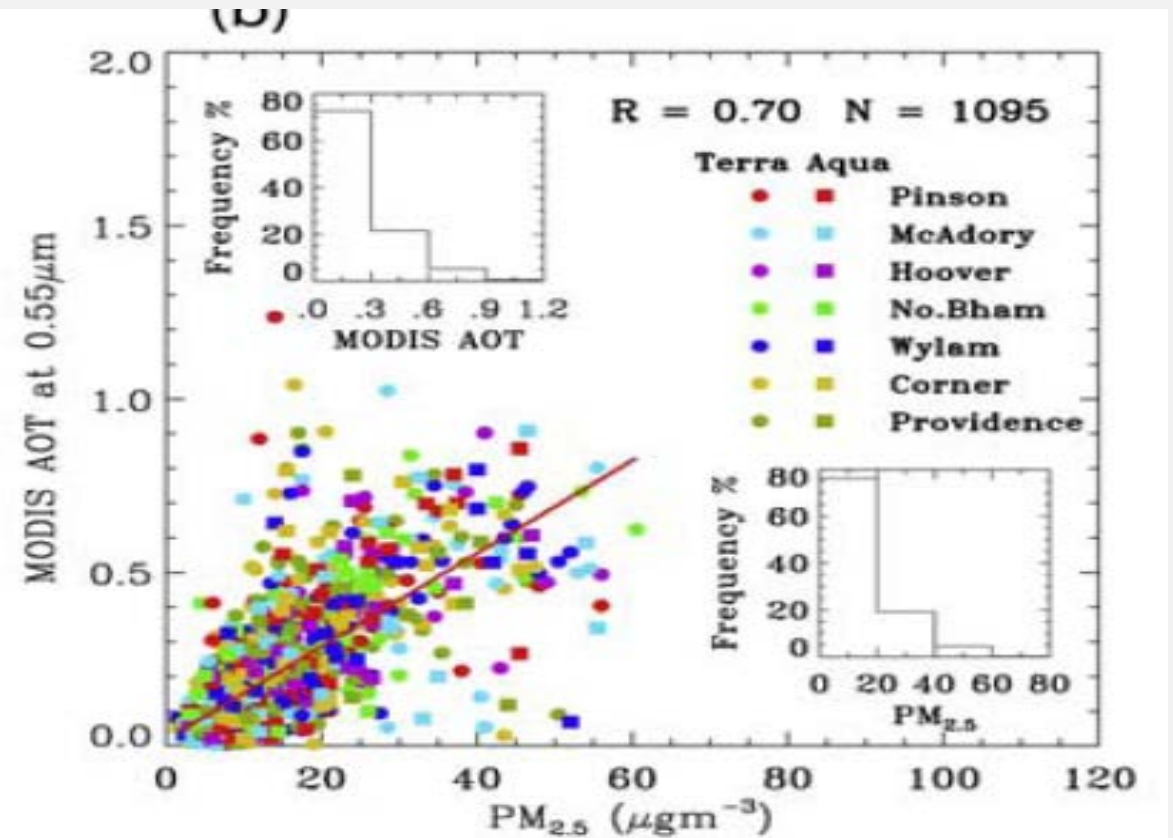


# AOD – PM2.5 Relationship



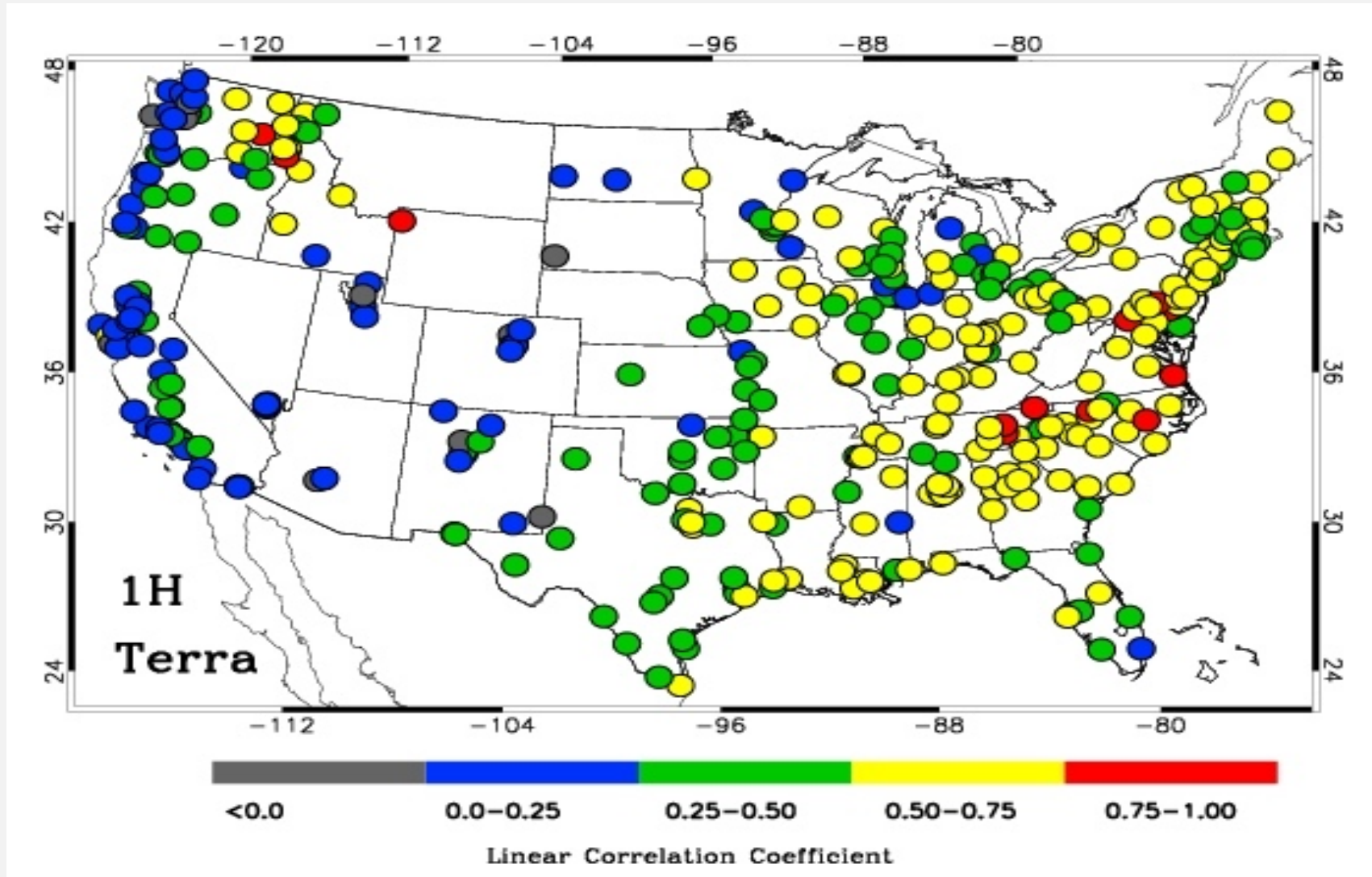
**Figure 14.** Relationship between 24-hour PM<sub>10</sub> concentrations and daily averaged AERONET  $\tau_a$  measurements from August to October 2000 in northern Italy.

Chu et al., 2003



Wang et al., 2003

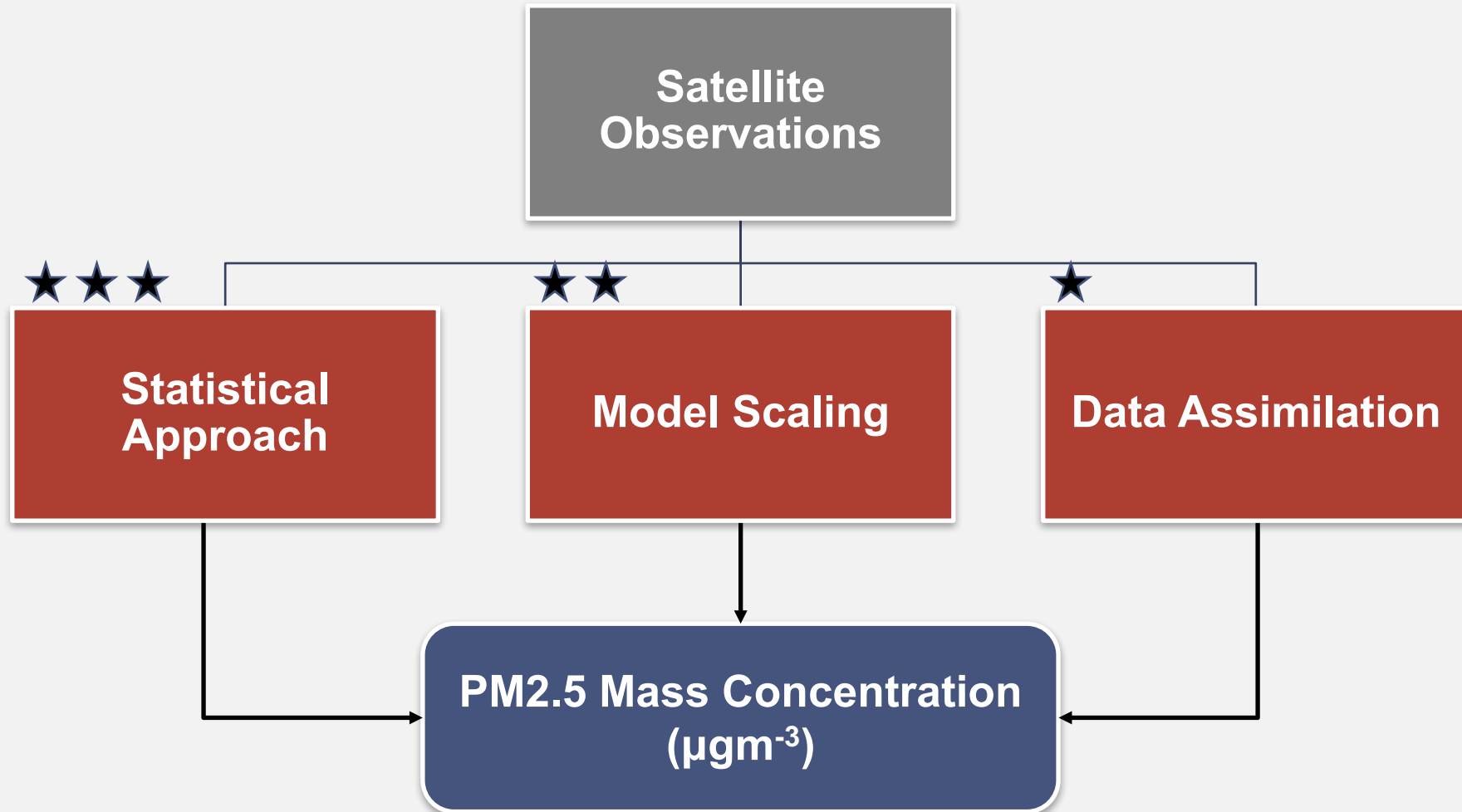
# Spatial Patterns in AOD– PM2.5 Relationship



Gupta 2008



# Satellite Remote Sensing of PM2.5: Summary

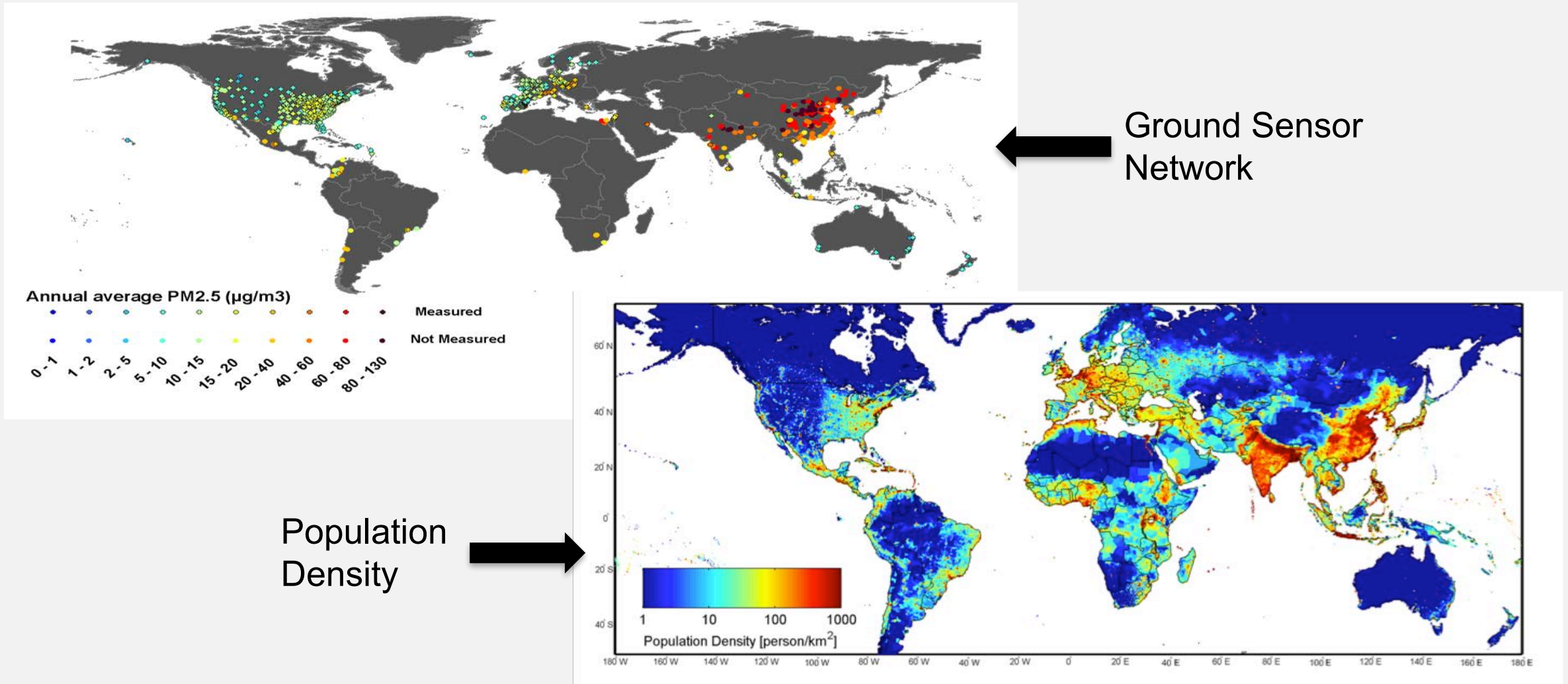


A world map is shown in the background, with a semi-transparent white rectangular box overlaid on the center. Inside the box, the text "Why Satellites ?" is written in a bold, black, sans-serif font. Below the text is a solid black horizontal line. The map behind the box shows various colors representing different regions or data points, with a grid of latitude and longitude lines visible.

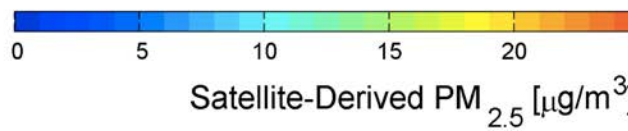
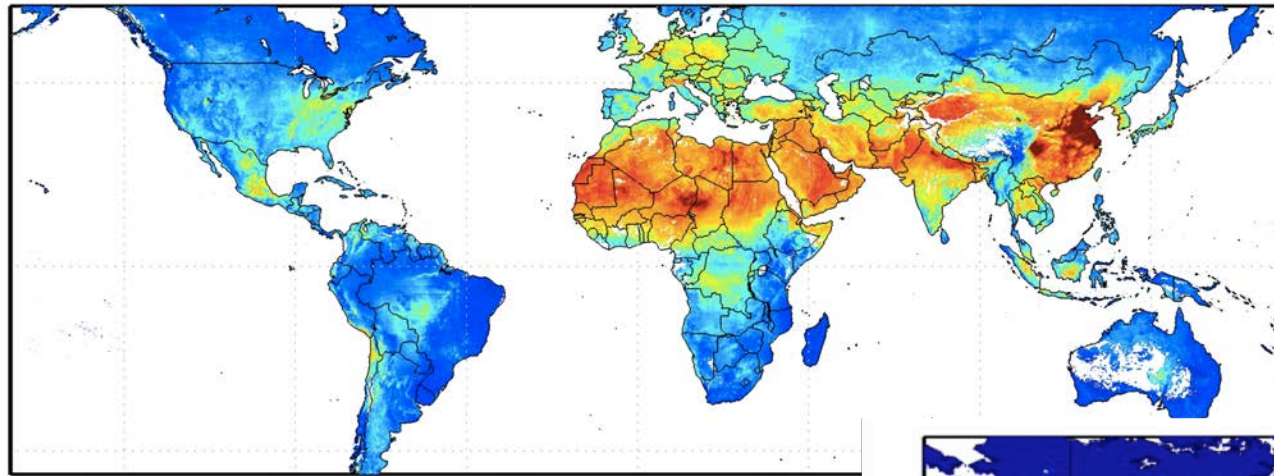
**Why Satellites ?**

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# Global Status of PM2.5 Monitoring

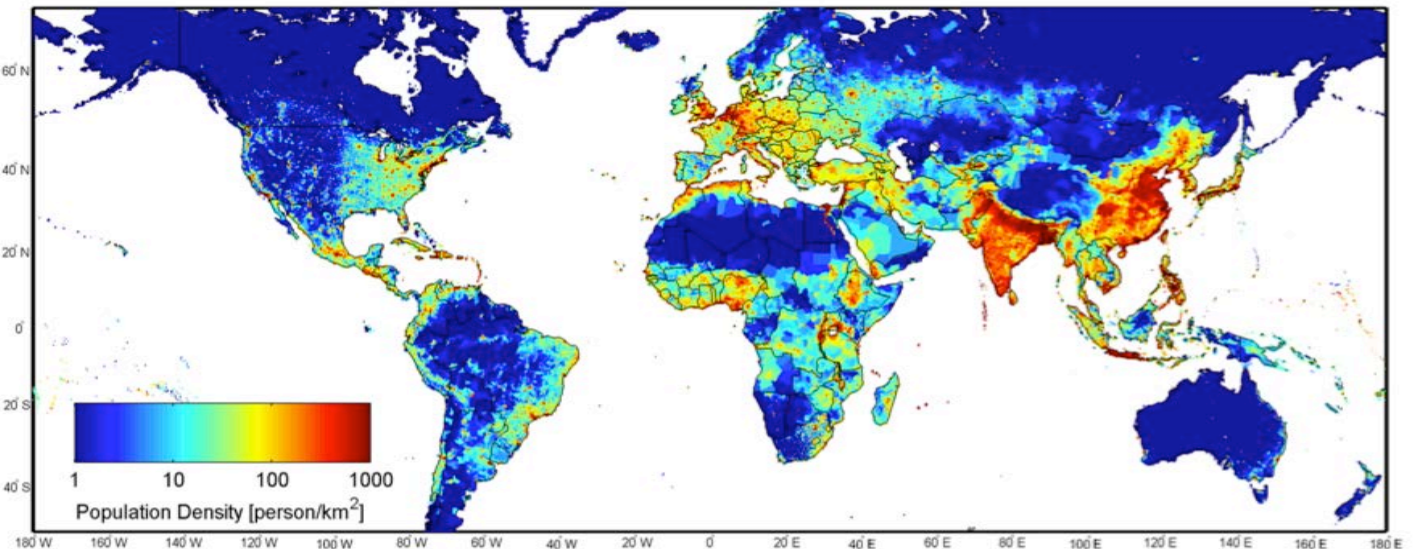


# Global Status of PM2.5 Monitoring: Future View



van Donkelaar et al., 2010

Population  
Density



← Satellite Estimated  
PM<sub>2.5</sub>



# Suggested References

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- van Donkelaar, A., R. V. Martin, M. Brauer and B. L. Boys, Use of Satellite Observations for Long-Term Exposure Assessment of Global Concentrations of Fine Particulate Matter, *Environmental Health Perspectives*, 123, 135-143, do:10.1289/ehp.1408646, 2015.

# Suggested Reading

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

## 2009 CRITICAL REVIEW

ISSN:1047-3289 J. Air & Waste Manage. Assoc. 59:645-675  
DOI:10.3155/1047-3289.59.6.645  
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R.M. Hoff



S.A. Christopher

## 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).<sup>142</sup> 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 congress-

EPA has taken a satellite observations role for itself in the Exceptional Events Rule.<sup>144</sup> 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

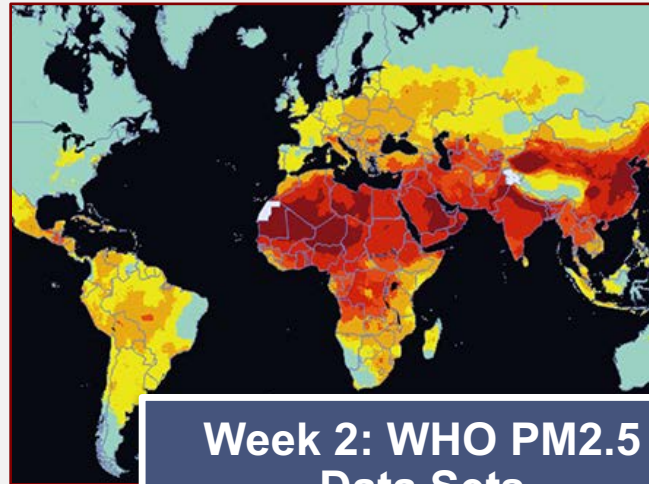
- Available at: <https://goo.gl/forms/z6ORwSeewzsFANPX2>
- All training materials (slides, recordings, and homework assignments) are available at: <http://arset.gsfc.nasa.gov/airquality/webinars/AQ-SDG-17>

# Next Week

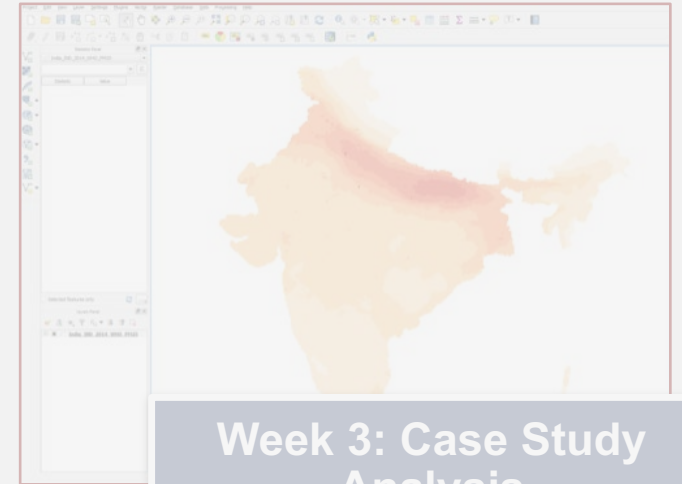
## WHO Resources for Global Air Quality Assessment



**Week 1: ARSET, Remote Sensing and SDGs**



**Week 2: WHO PM2.5 Data Sets**



**Week 3: Case Study Analysis**