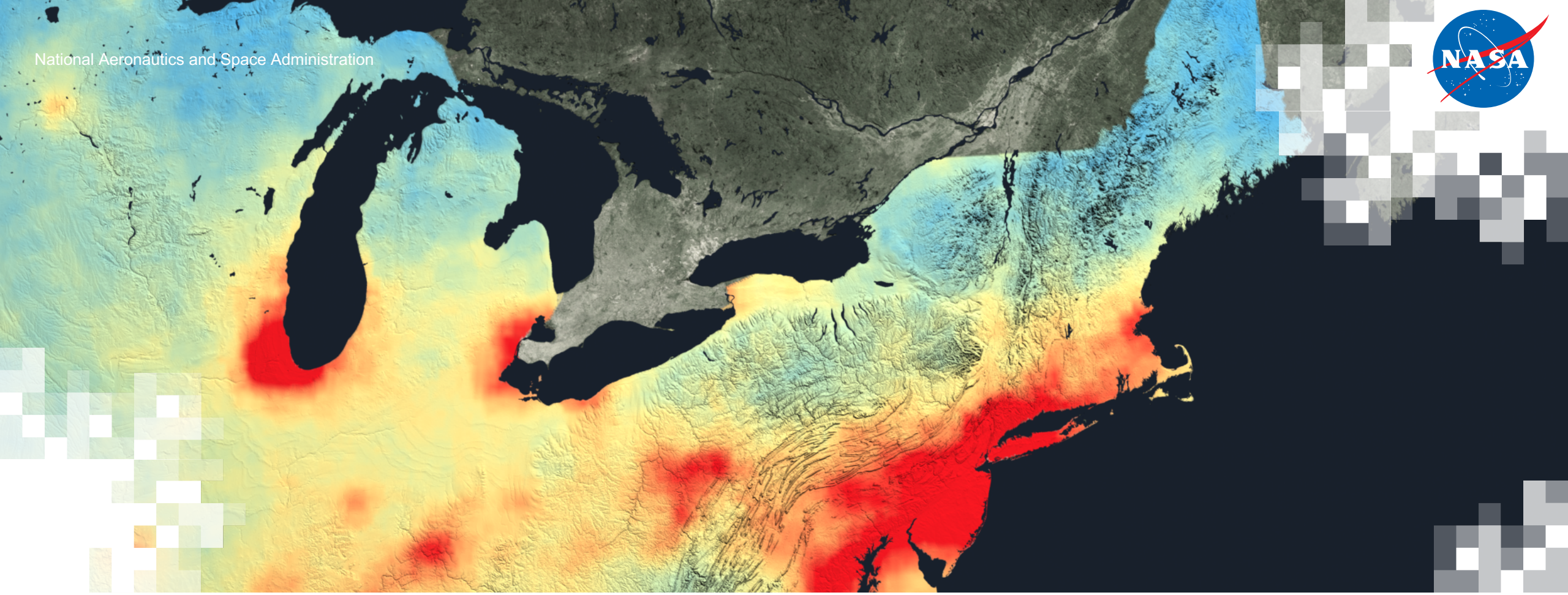
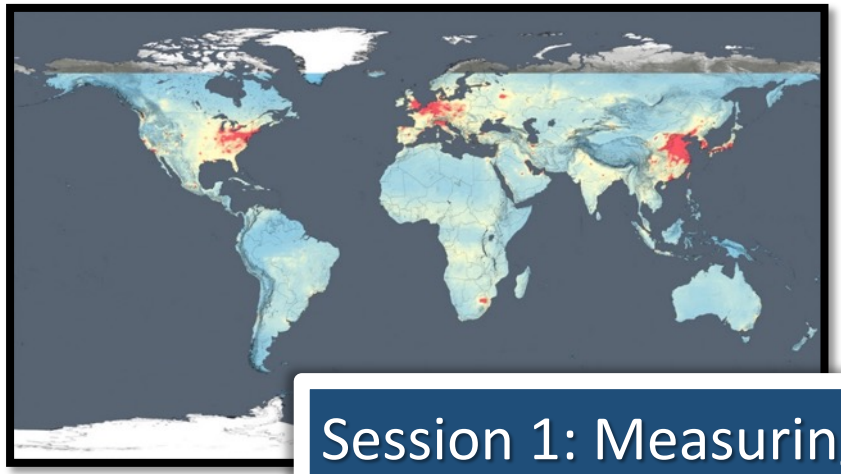


Measuring Aerosols and Fires from Space

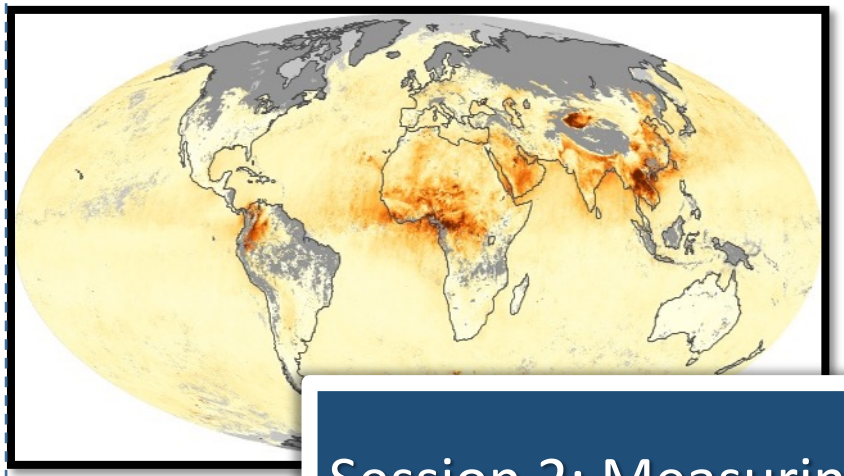
Pawan Gupta, Ana Prados, and Melanie Follette-Cook

An Inside Look at how NASA Measures Air Pollution, May 26-28, 2020

Webinar Agenda



Session 1: Measuring Nitrogen Dioxide from Space



Session 2: Measuring Aerosols from Space

Melanie Follette-Cook

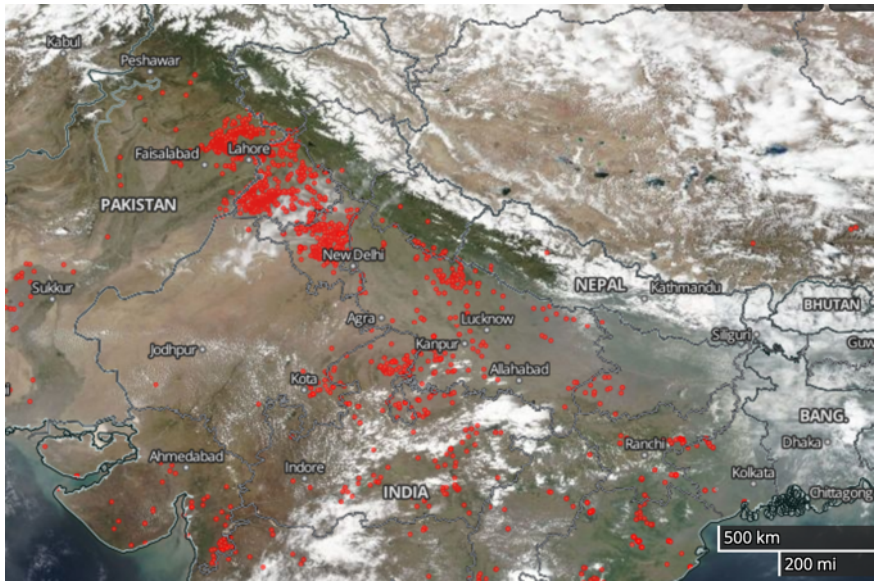
Ana Prados

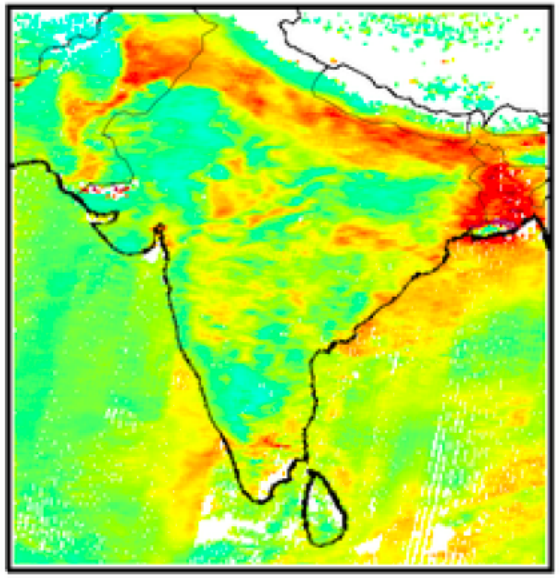
Pawan Gupta

Learning Objectives

By the end of this presentation, you will be able to:

- Explain what images & maps like these are showing
- Describe the capabilities and limitations of satellite aerosol observations
- Find and download true color, aerosol, and fire detection satellite imagery





Space-Based Observations Relevant for Air Quality

Gases

- Ozone (O_3)
- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO_2)
- Sulfur Dioxide (SO_2)
- Greenhouse Gases (CO_2, Methane)

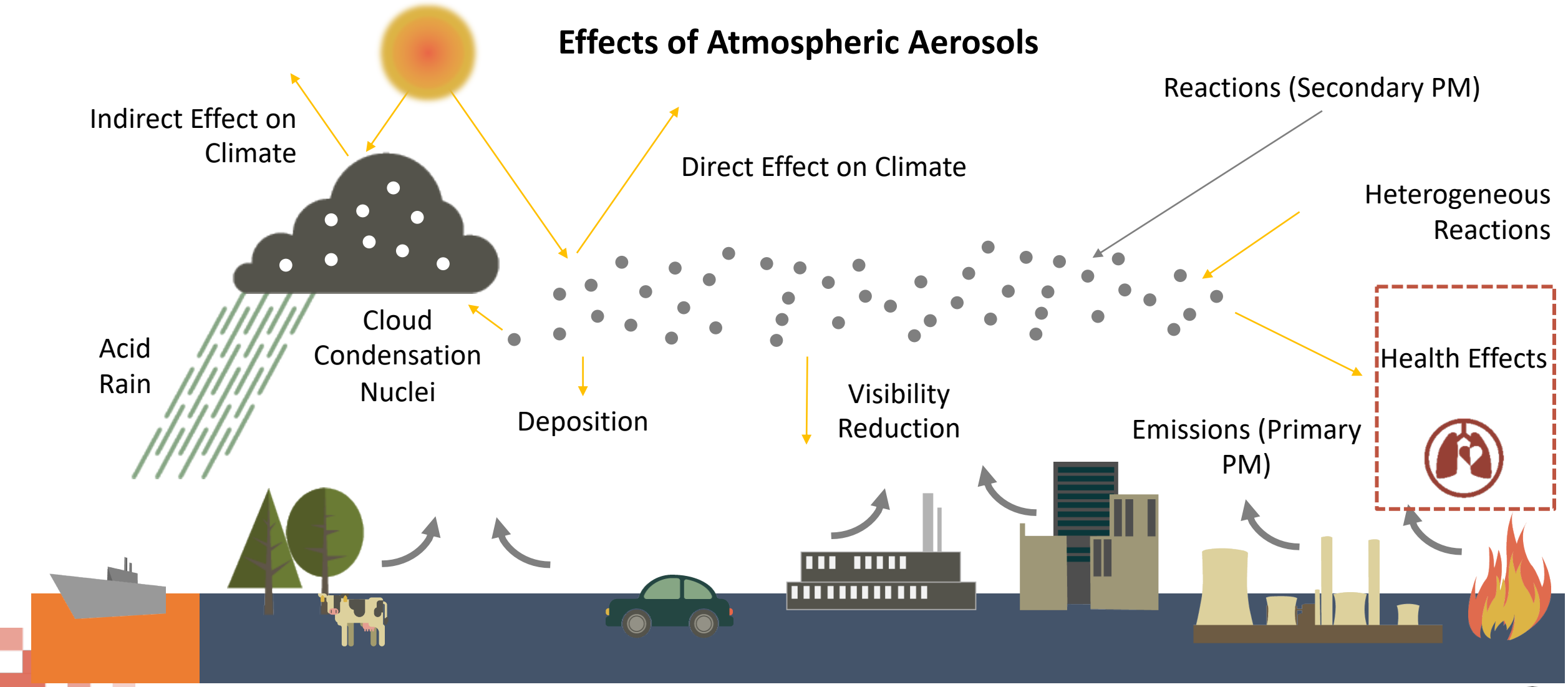
Particles

- True Color Imagery
- Aerosol Optical Depth Imagery

Fire Location

Today's presentation focuses on **Particle Pollution**

Motivation: Tiny, but Potent



Why Does NASA Measure Aerosols?

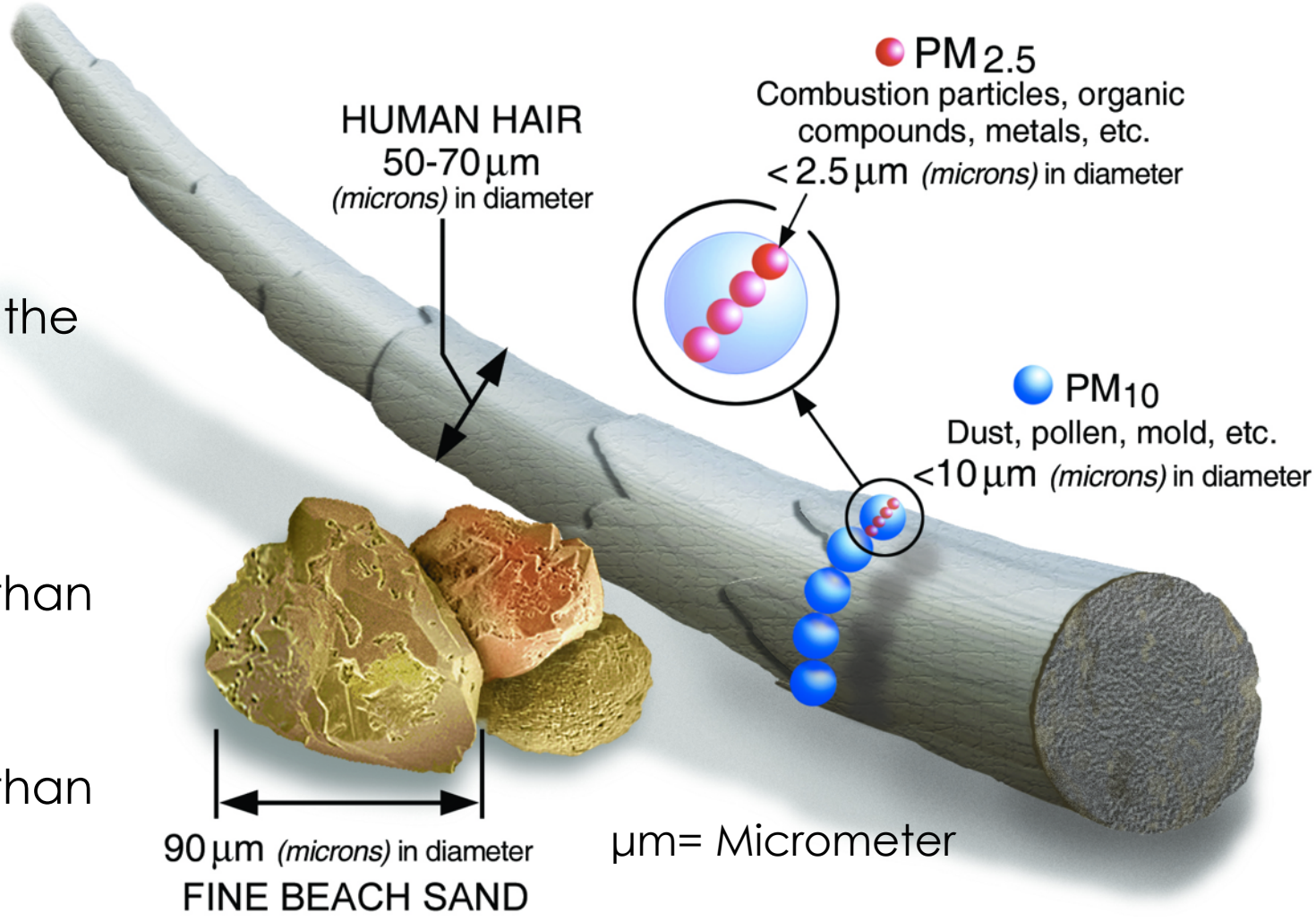
- Small particles (and $PM_{2.5}$ in particular) can get deep into the lungs where they have been linked to respiratory problems (decreased lung function, asthma), cardiovascular problems, and premature mortality.
- Alteration of nutrient balance from particles that contain nitrogen, in lakes and streams
- Damage to forests and crops from acid rain
- Visibility impairment
- Particles affect the climate, either cooling or heating it, depending on the particle type.

What are Aerosols (Particulate Matter)?

- Aerosols are tiny particles suspended in the earth's atmosphere.
- Two types of small particles are criteria pollutants regulated by the U.S EPA (and in many other countries):

  $PM_{2.5}$ "fine particles" with aerodynamic diameters less than or equal to 2.5µm

  PM_{10} "Coarse particles" with aerodynamic diameters less than or equal to 10µm.



µm= Micrometer

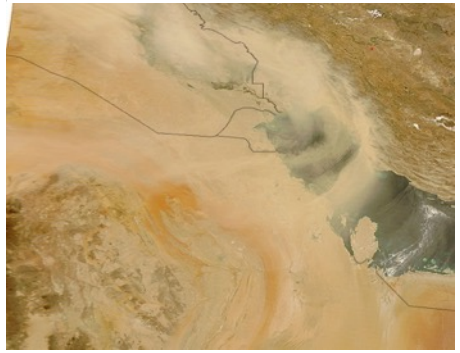
Mass Concentration Units - µg/m^3

Image Credit: U.S. EPA

What are aerosols and where do they come from?

- Directly emitted: e.g. a diesel engine
- Or produced indirectly from other compounds: e.g. sulfate aerosols are produced from direct emissions of SO_2
- Sources: Fossil fuels such as gasoline, diesel, coal, domestic cooking; and oceans, volcanoes, fires, and dust
- Chemical composition varies with region and time of the year: sulfates, nitrates, organic compounds, and metals
- Size Varies: Nanometer to millimeter
- Shape Varies: Spherical to non-regular
- Lifetime: Hours, days, or weeks

Dust

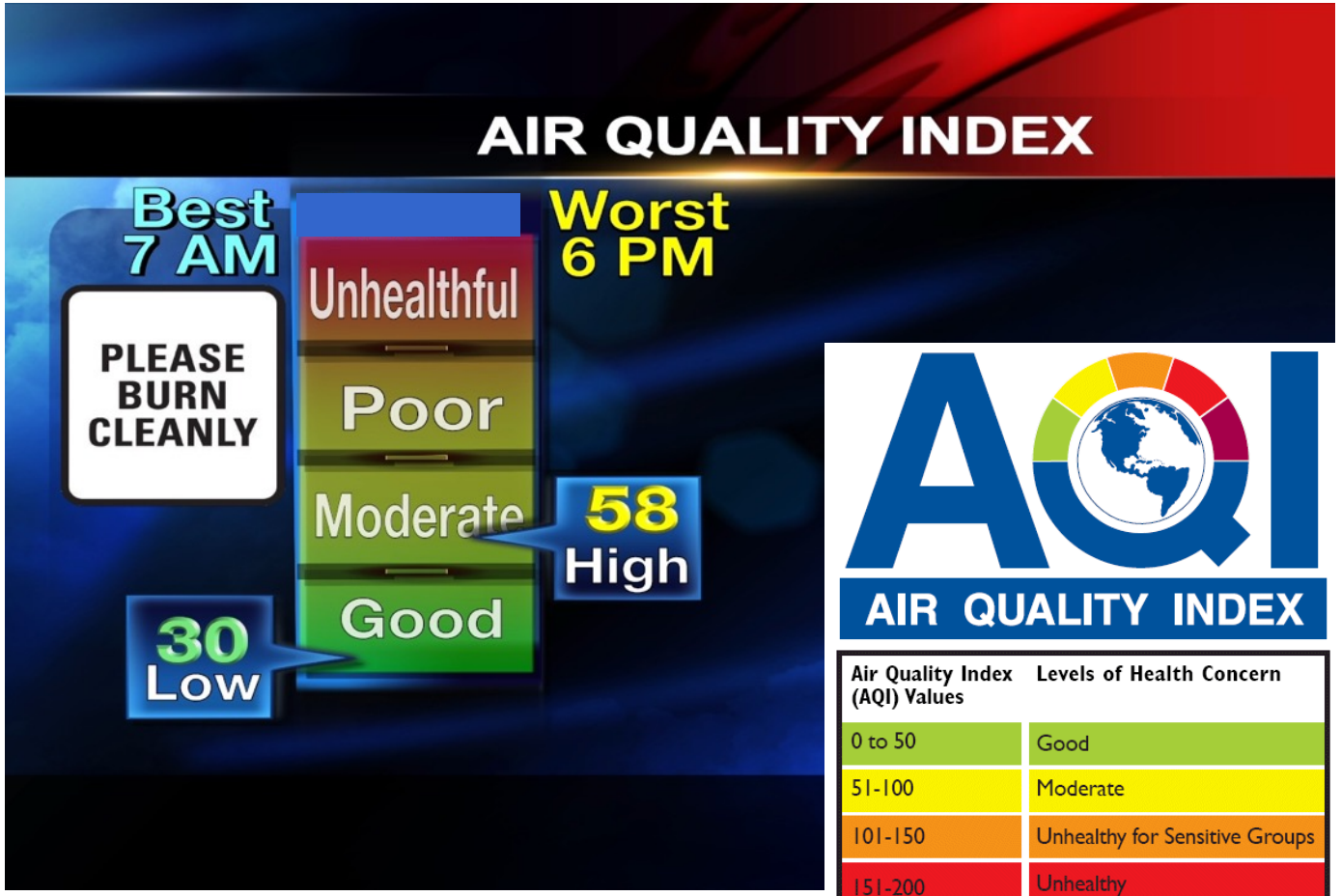


Volcanoes

Fossil Fuels & Biomass Burning

Soot & Smoke

Air Quality Monitoring and Reporting



AQI

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

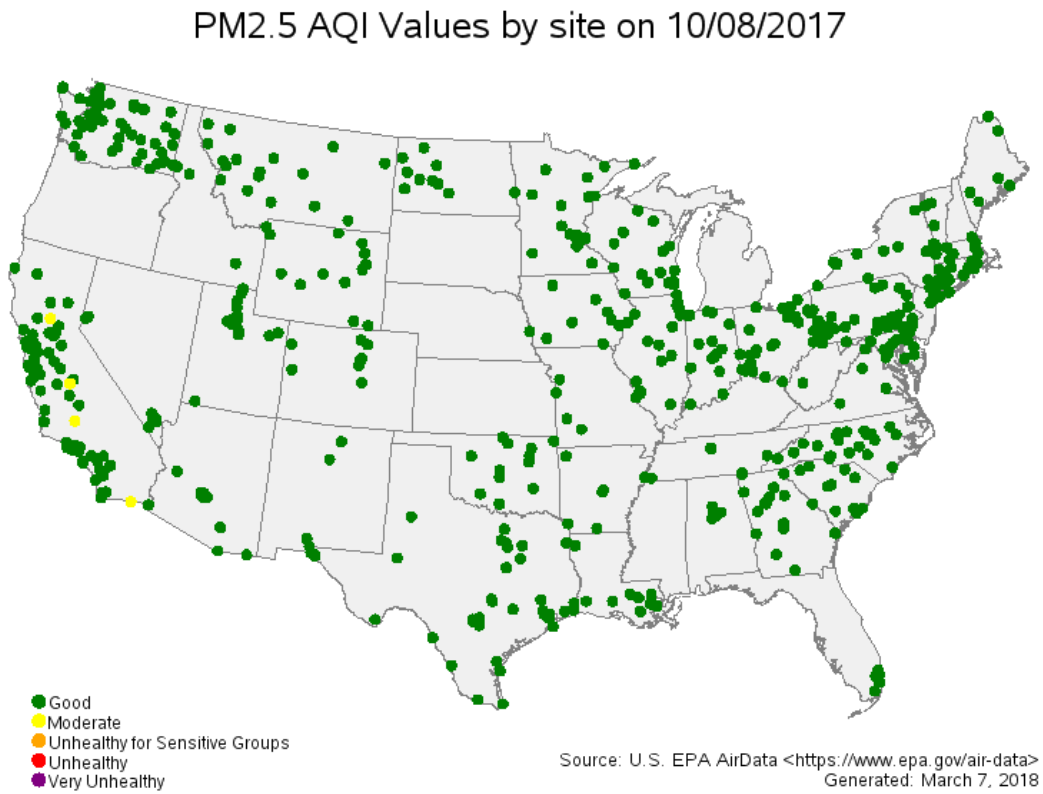


Image Credit: AirNow map, USEPA. http://www.airnow.gov

Traditional Air Quality Monitoring

Standard Monitors (Expensive)

Low-cost Monitors

Image Credits: http://aqicn.org

$PM_{2.5}$ and the Air Quality Index (AQI)

- $PM_{2.5}$ is measured at the surface with a monitor. Values are used to derive an Air Quality Index (AQI).
- U.S. EPA defines AQI as (varies by country):

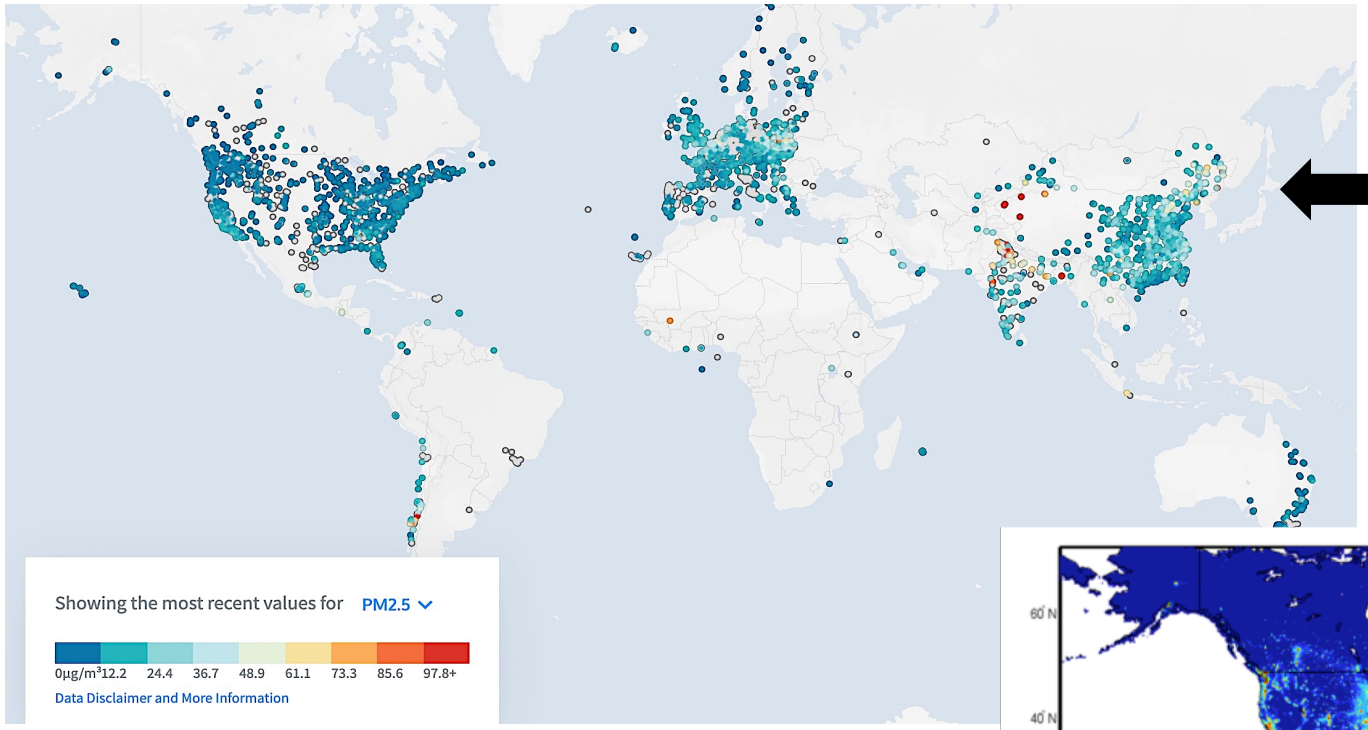
  "....a yardstick that runs from 0 to 500. The higher the AQI value, the greater the level of **air pollution** and the greater the health concern. For example, an AQI value of 50 or below represents good **air quality**, while an AQI value over 300 represents hazardous **air quality**."

$PM_{2.5}$ AQI

AQI Category	Index Values	Revised Breakpoints ($\mu g/m^3$, 24hr Average)
Good	0-50	0.0-12.0
Moderate	51-100	12.1-35.4
Unhealthy for Sensitive Groups	101-150	35.5-55.4
Unhealthy	151-200	55.5-150.4
Very Unhealthy	201-300	150.5-250.4
Hazardous	301-400	250.5-350.4
Hazardous	401-500	350.5-500

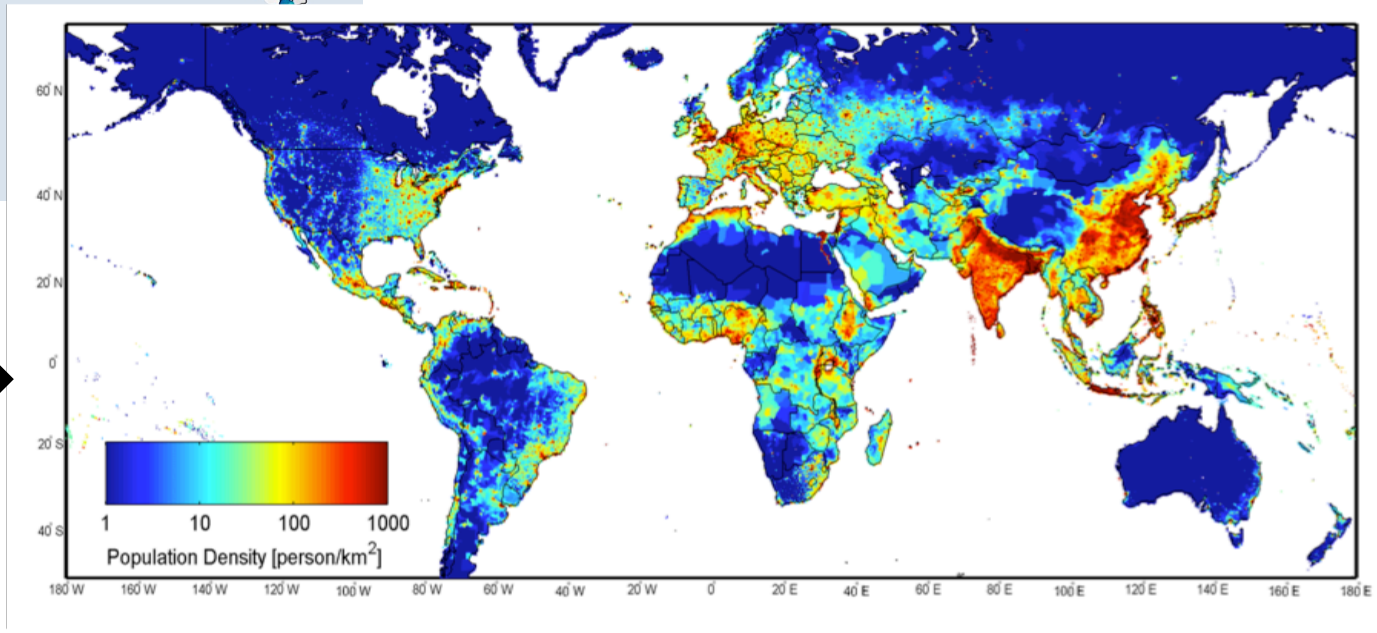
There is a separate (and combined) AQI for each criteria pollutant based on its individual level of concern.

$PM_{2.5}$ Monitoring around the World



Ground Sensor Network (Publicly Available) Many areas with high population density have almost no monitors.

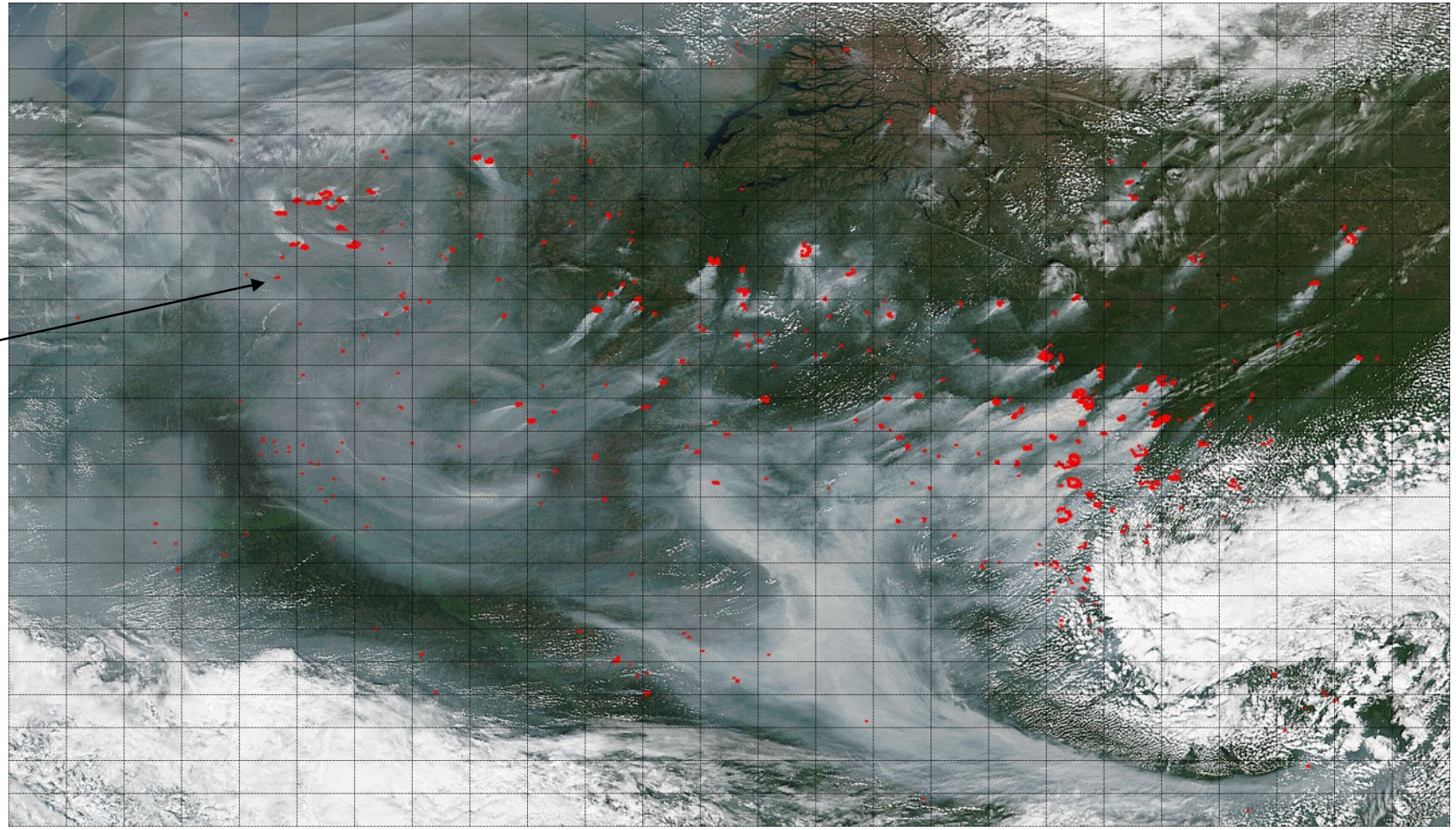
Population Density



Source: openaq.org

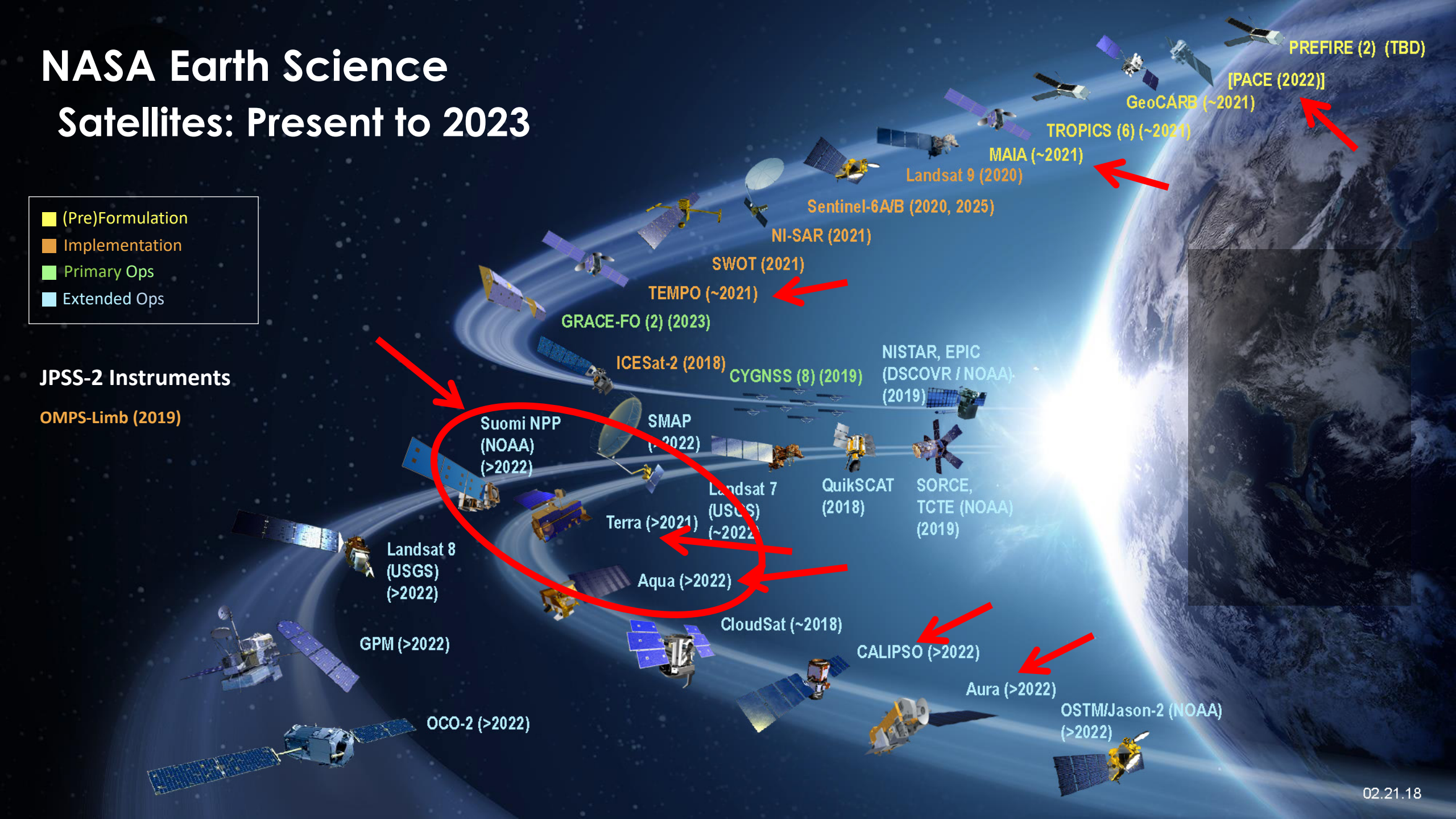
“A Picture is Worth a Thousand Words”

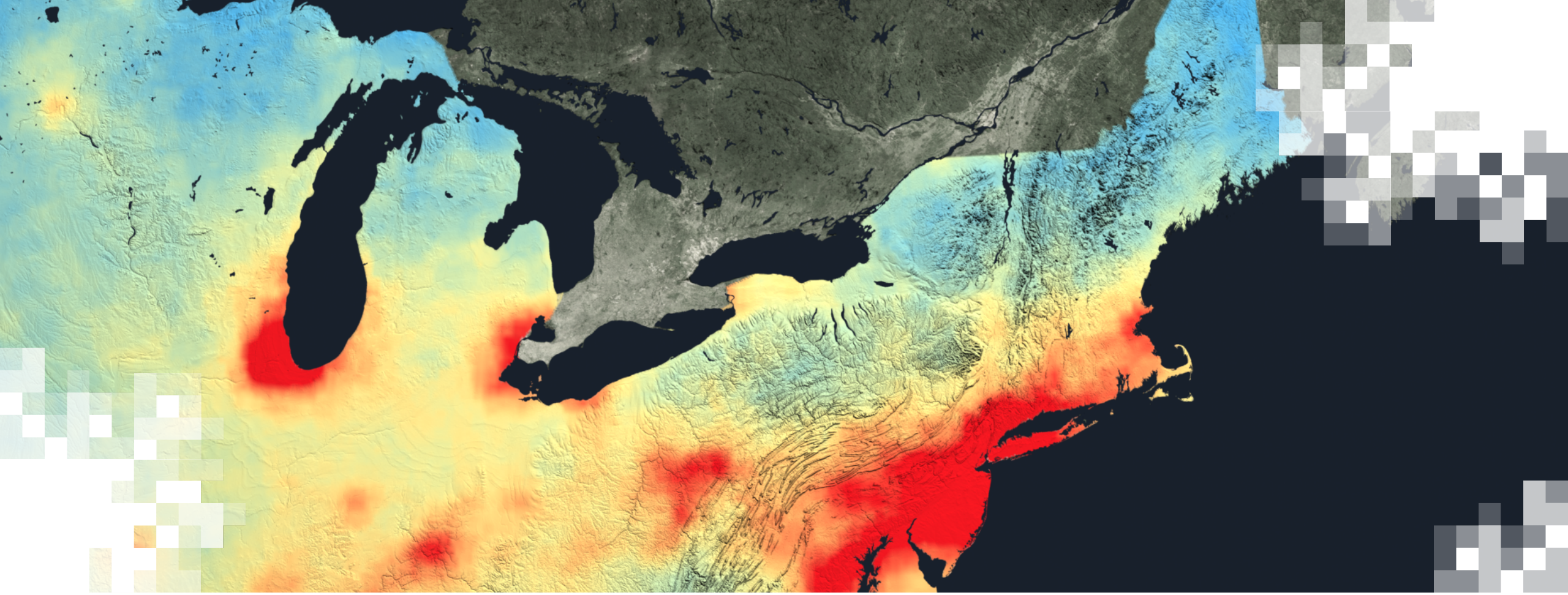
A satellite picture is worth ~~a~~ **millions of data points**.



A geo-physical number

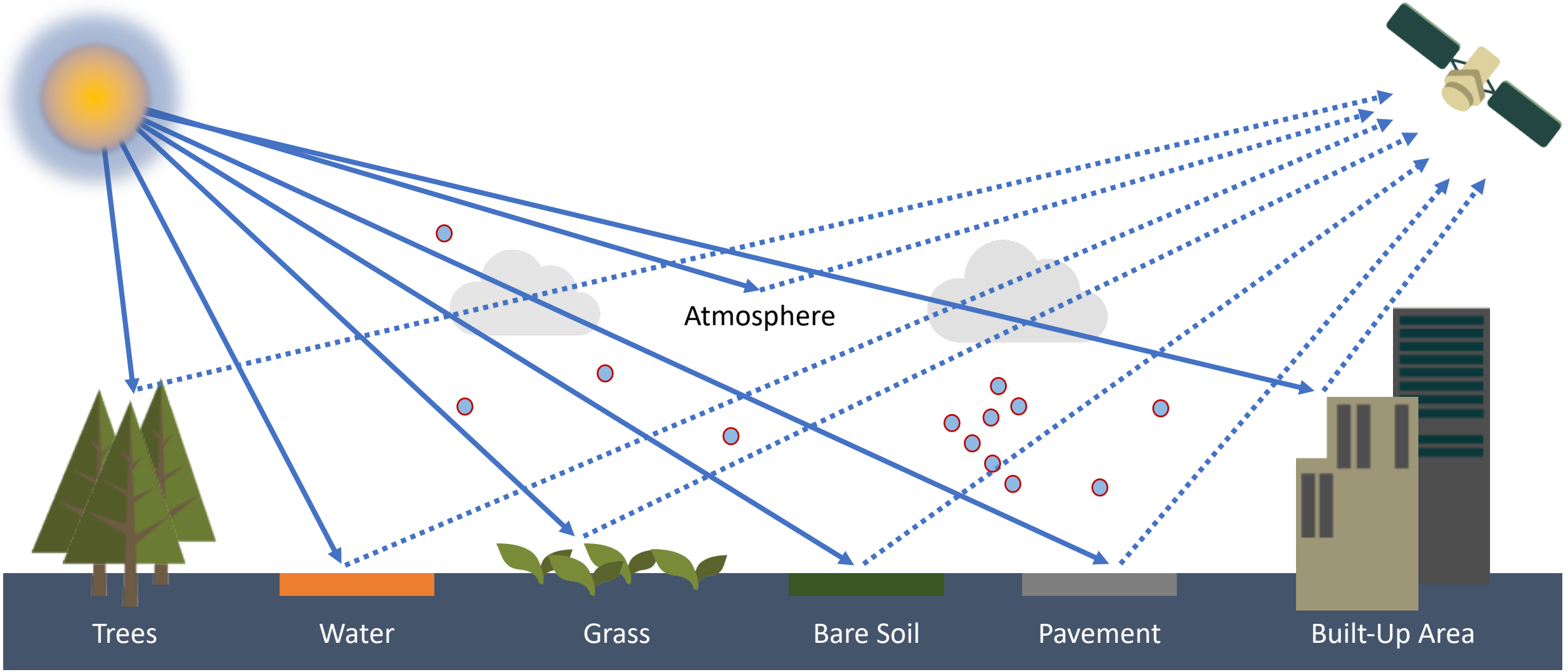
NASA Earth Science Satellites: Present to 2023



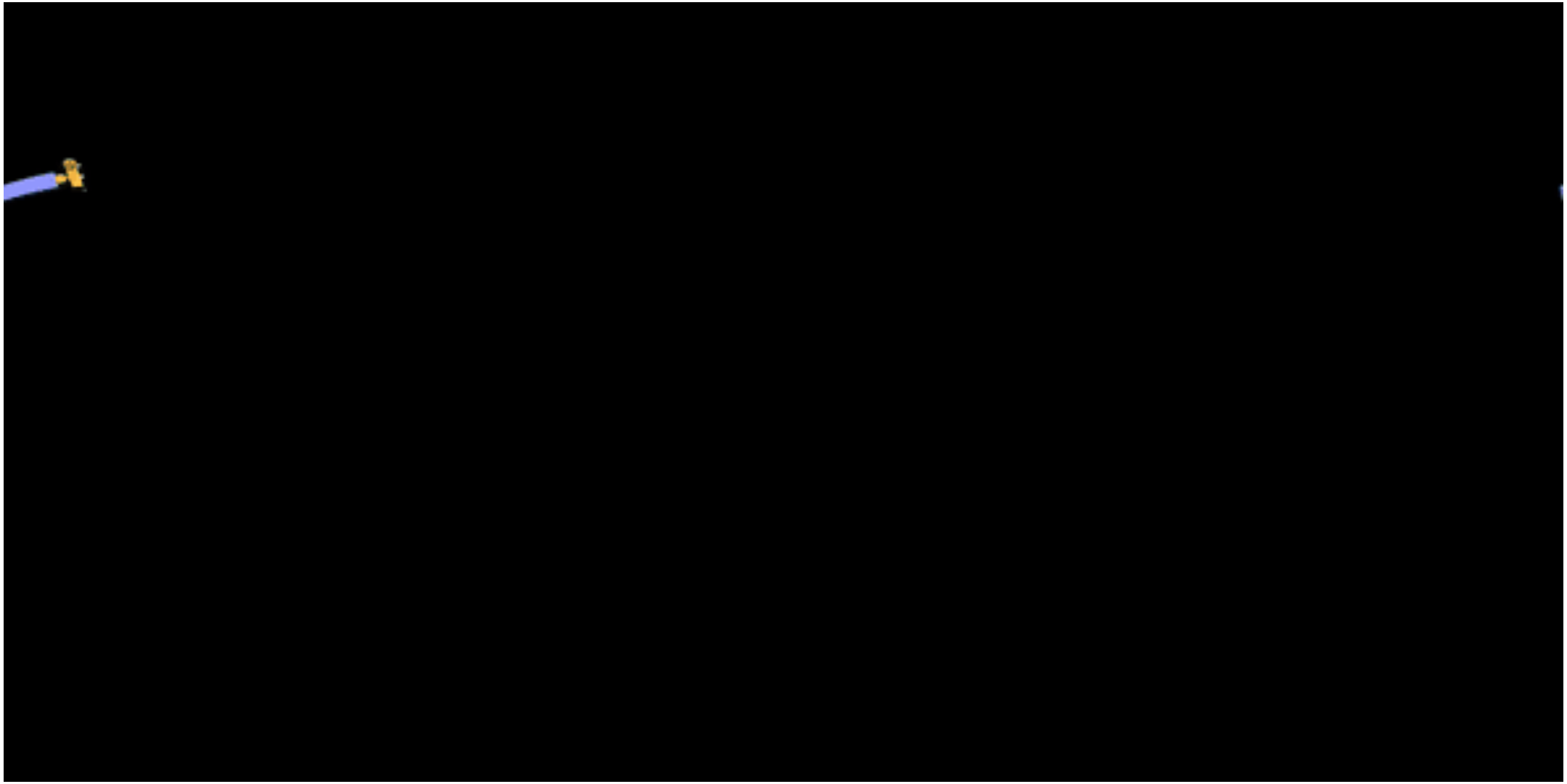


Remote Sensing Basics: Review

What do satellites measure?

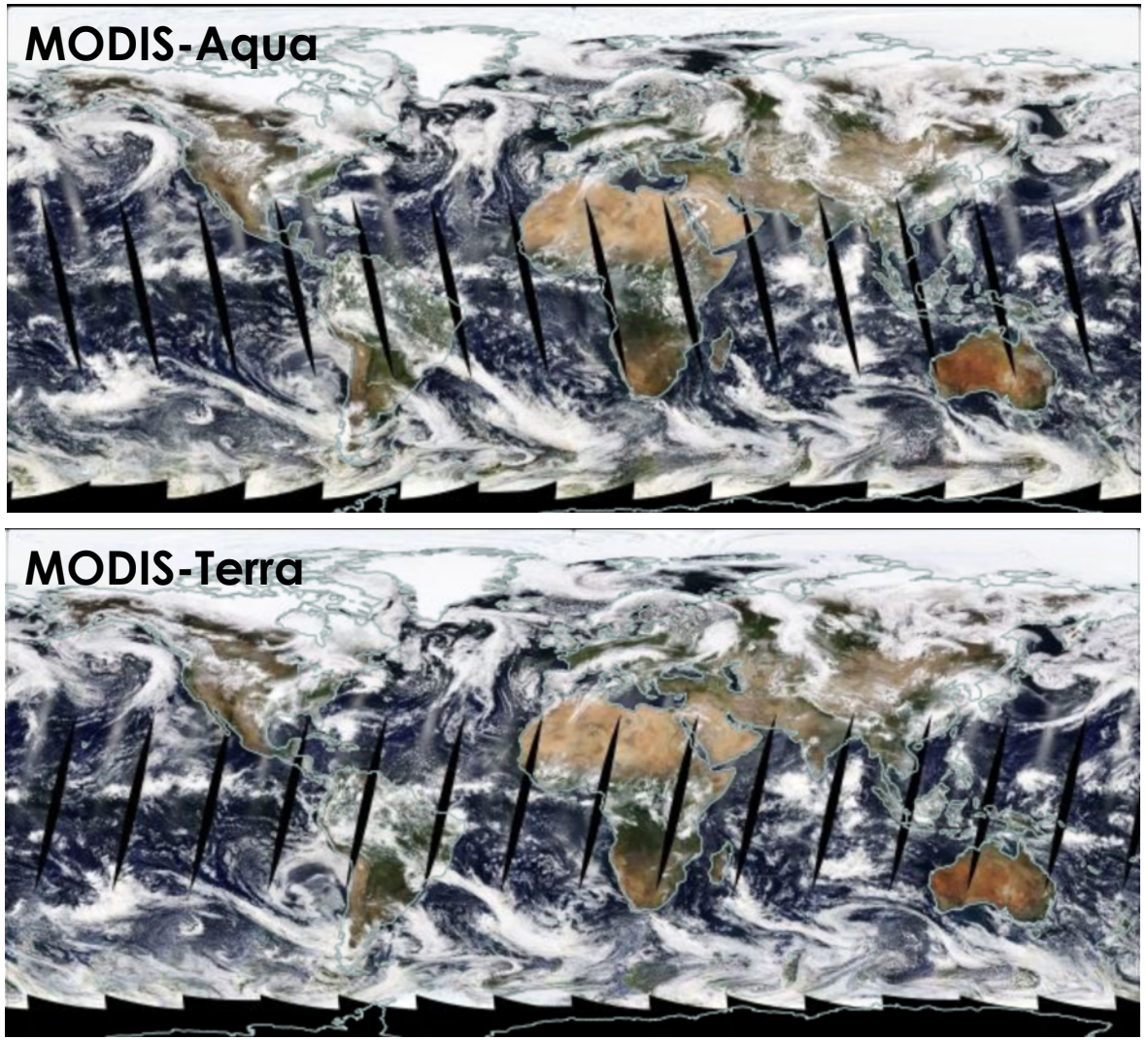


Aqua Satellite Orbiting the Earth



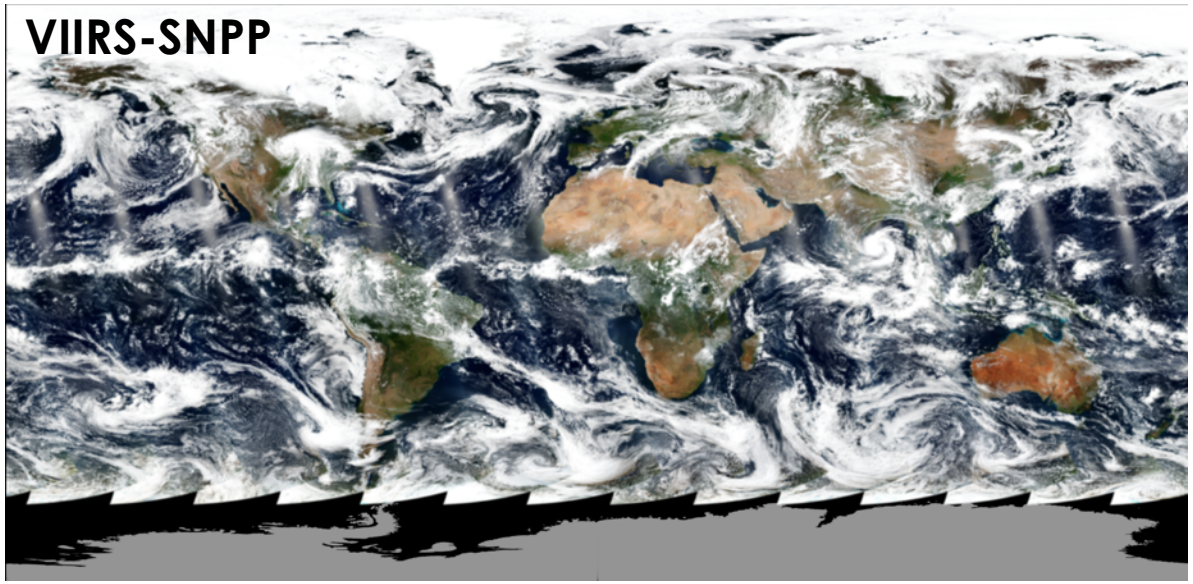
Moderate Resolution Imaging Spectroradiometer (MODIS)

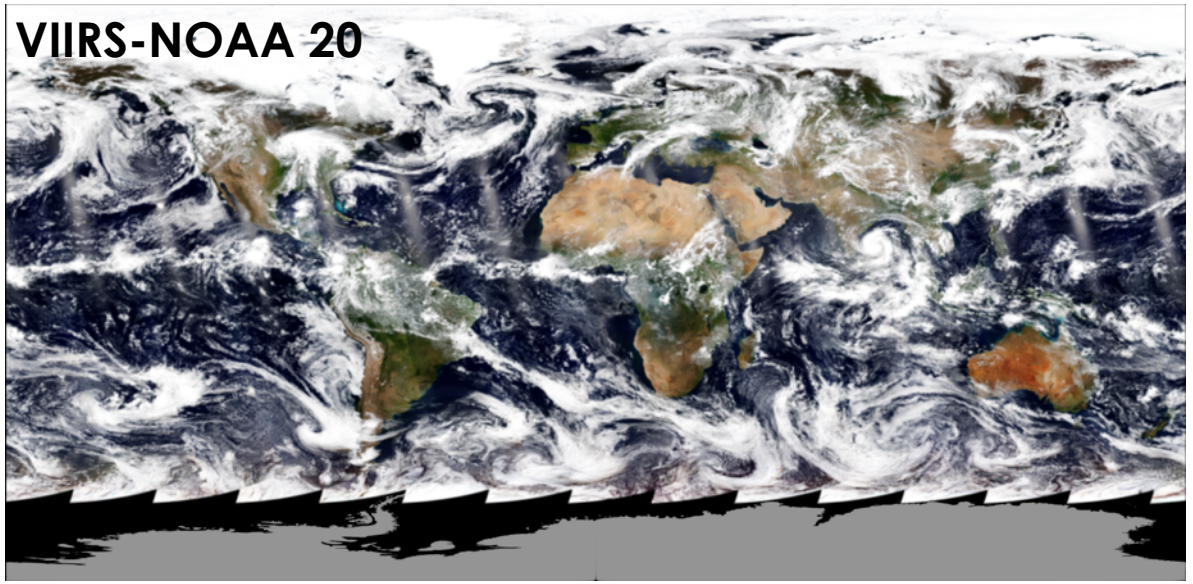
- Spatial Resolution:
  - 250 m, 500 m, 1 km
- Platform:
  - Terra (morning satellite) & Aqua (afternoon satellite)
- Temporal Resolution:
  - 2000 – Present
  - Daily, 8-day, 16-day, monthly, yearly
- Spectral Coverage:
  - 36 bands (major bands include red, blue, IR, NIR, MIR)
- Provide measurements on land, water, and atmosphere



Visible Infrared Imaging Radiometer Suite (VIIRS)

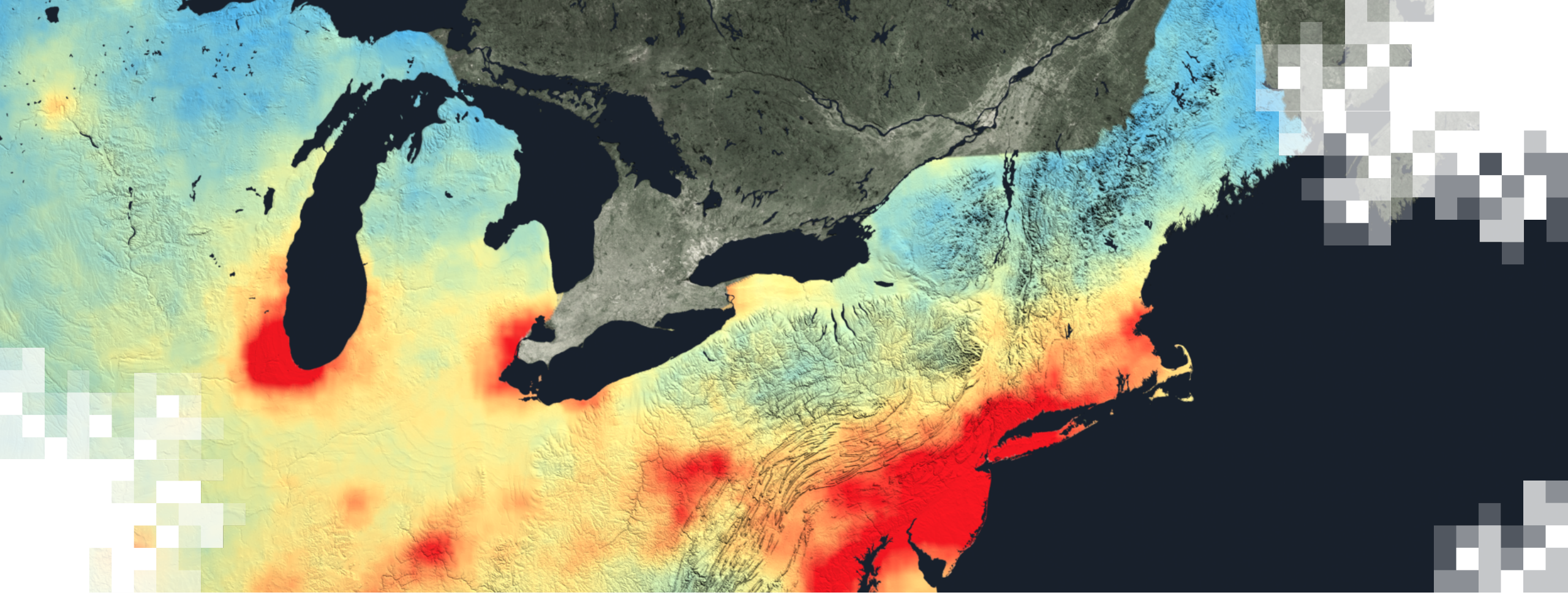
- Spatial Resolution:
  - 375 m, 750 m
- Platform:
  - SNPP, NOAA20 (JPSS1) - Current
  - JPSS2, JPSS3 - Future
- Temporal Resolution:
  - 2011 – Present
  - Daily, 8-day, 16-day, monthly, yearly
- Spectral Coverage:
  - 22 bands (major bands include red, blue, IR, NIR, MIR)
- Provide measurements on land, water, and atmosphere





Spaced Based Monitoring of Particles and Fires

- True Color Imagery
- Aerosol Optical Depth Imagery (a proxy for $PM_{2.5}$)
- Fire Detection/Location Images
- In this presentation, we focus on measurements from the Moderate Resolution Imaging Spectroradiometer (MODIS) and VIIRS.

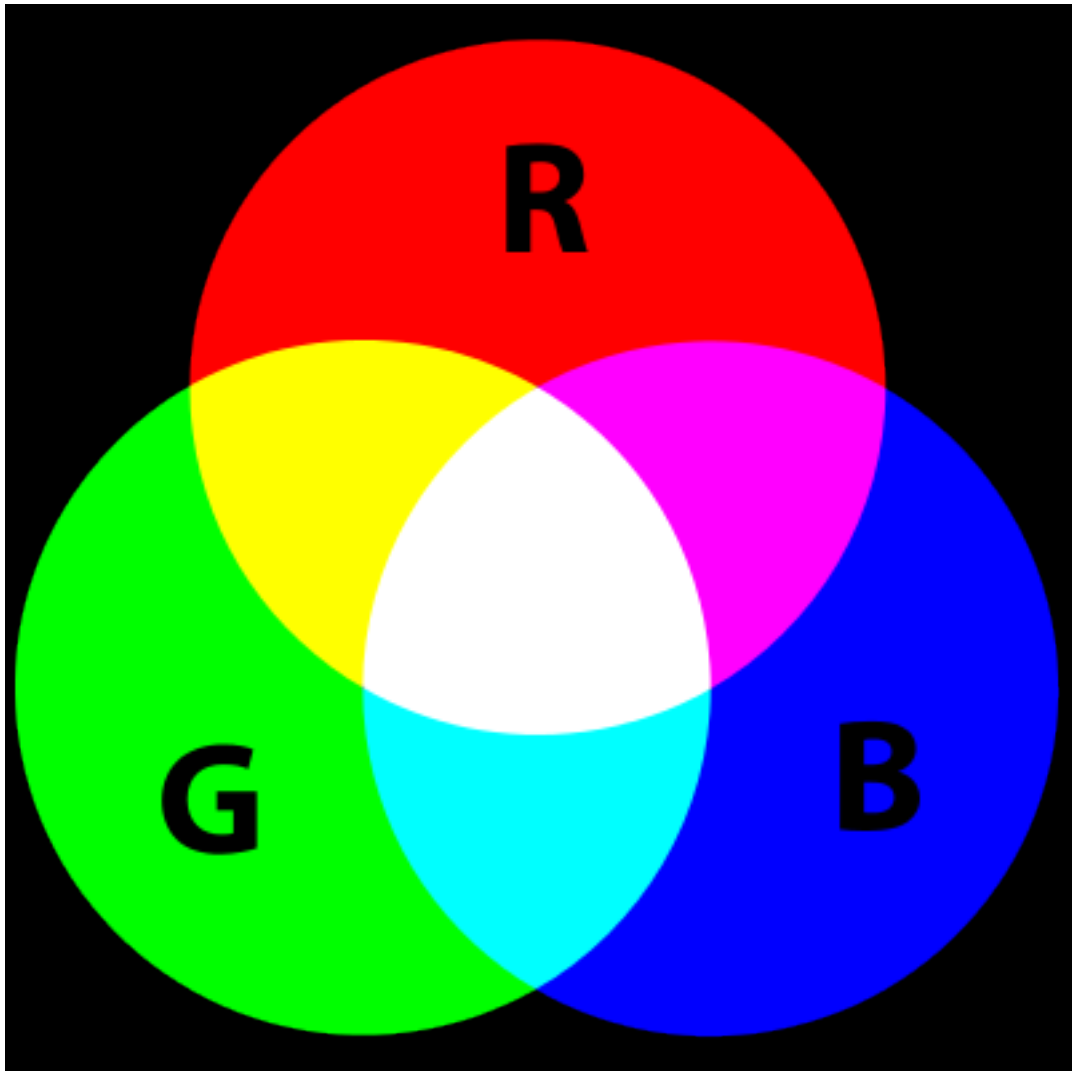


True Color Imagery

True Color or RGB Imagery

- Satellite sensors (cameras) collect the Sun's energy reflected by the Earth.
- True color images are essentially photographs created using energy measured in three bands (channels) red, green, and blue.
- Images simulate what the human eye sees.

RGB = **Red** + **Green** + **Blue**



True Color Image (or RGB)

A MODIS "true color image" uses visible wavelength bands 1, 4, 3

R = 0.66 µm

G = 0.55 µm

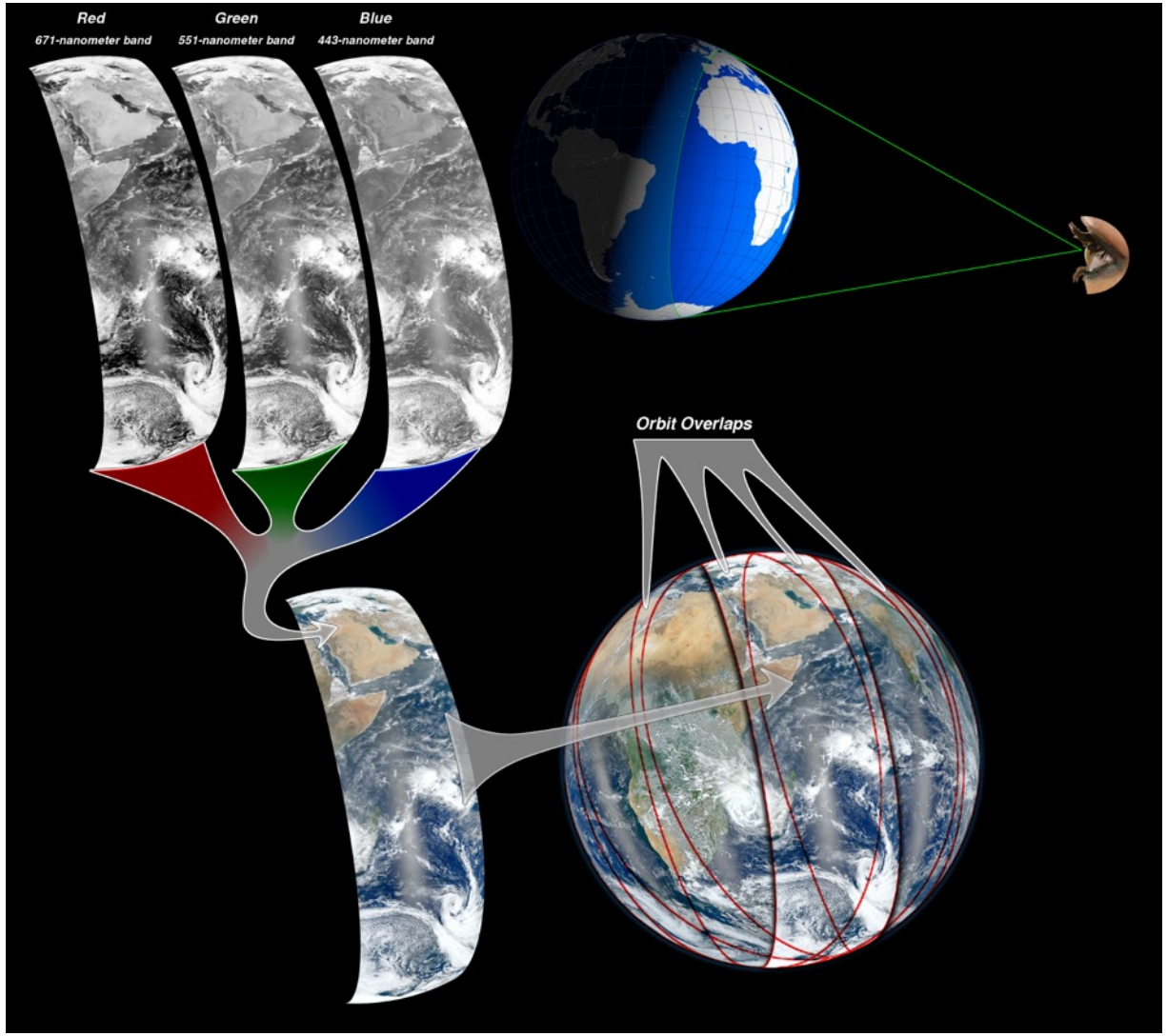
B = 0.47 µm

A VIIRS "true color image" uses visible wavelength bands I1, M4, M3

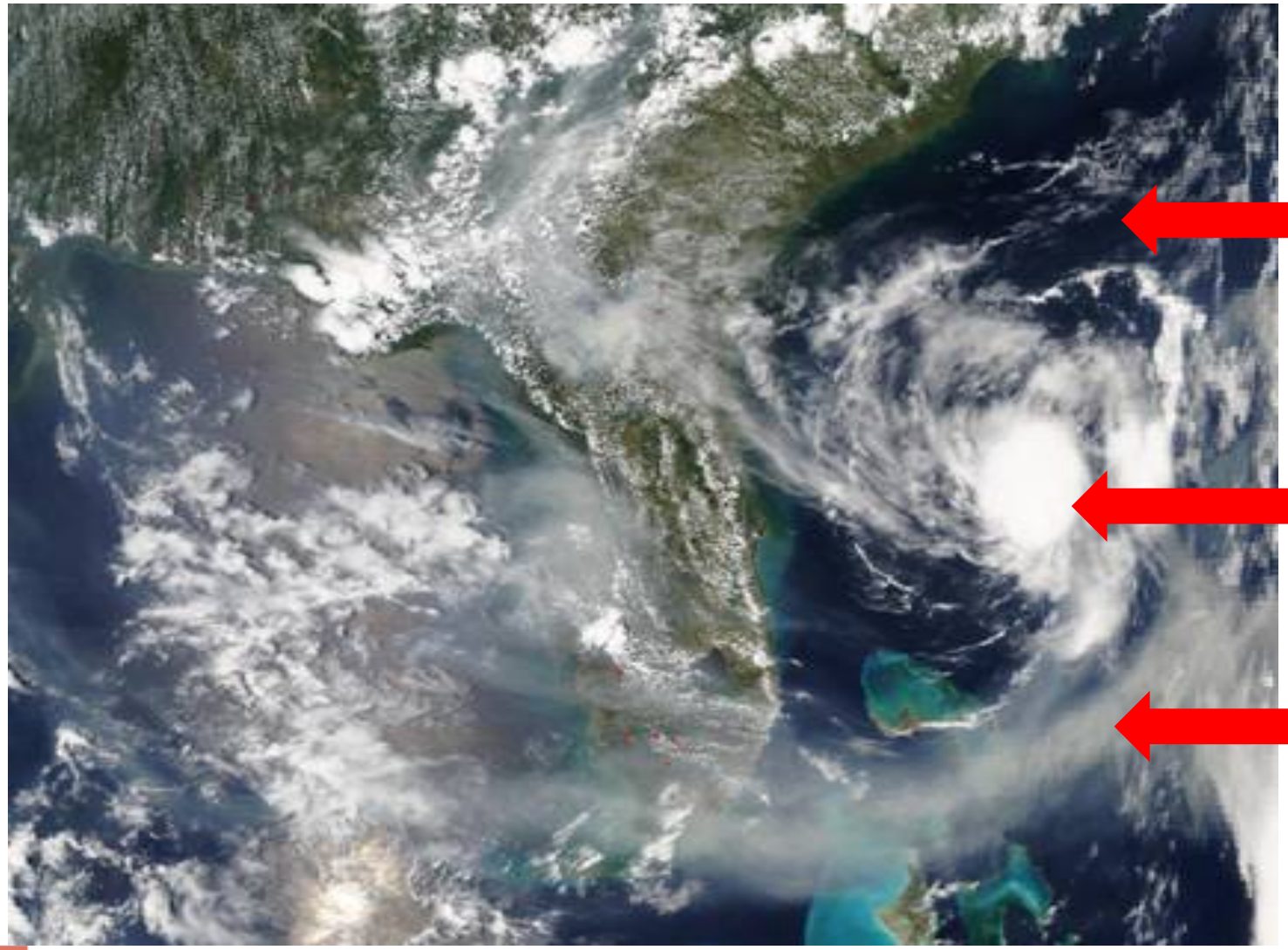
R = 0.640 µm

G = 0.555 µm

B = 0.488 µm



Interpreting True Color Images



Water is dark in visible imagery because it absorbs most of the energy.

Clouds are white because they reflect most incoming energy.

Pollution is hazy depending on its absorption properties.

True Color Image Interpretation

How do aerosols appear in true color images?

Agricultural Fires - India

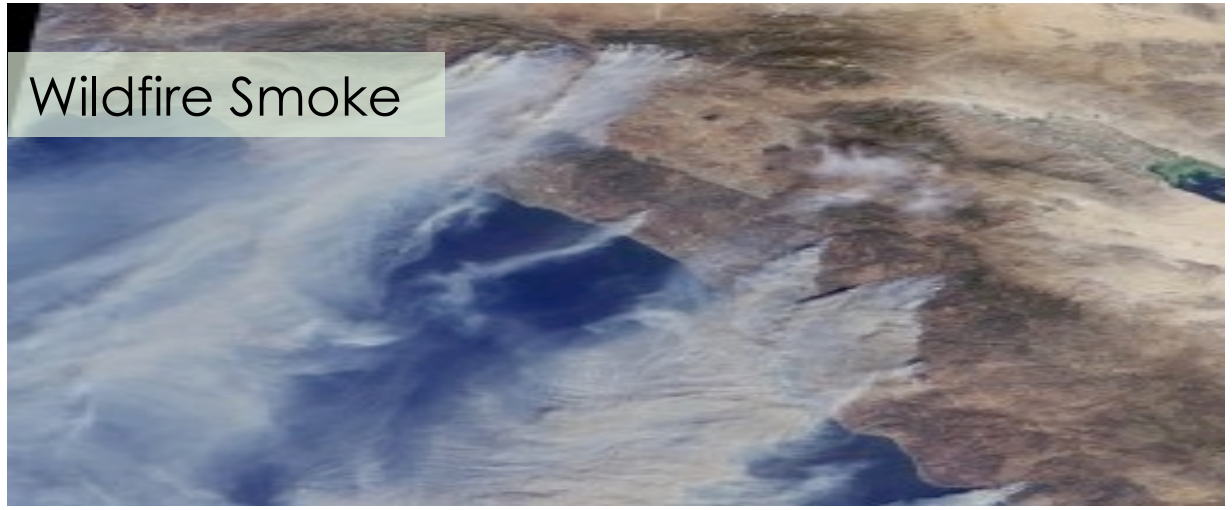
Sangeang Api, Indonesia

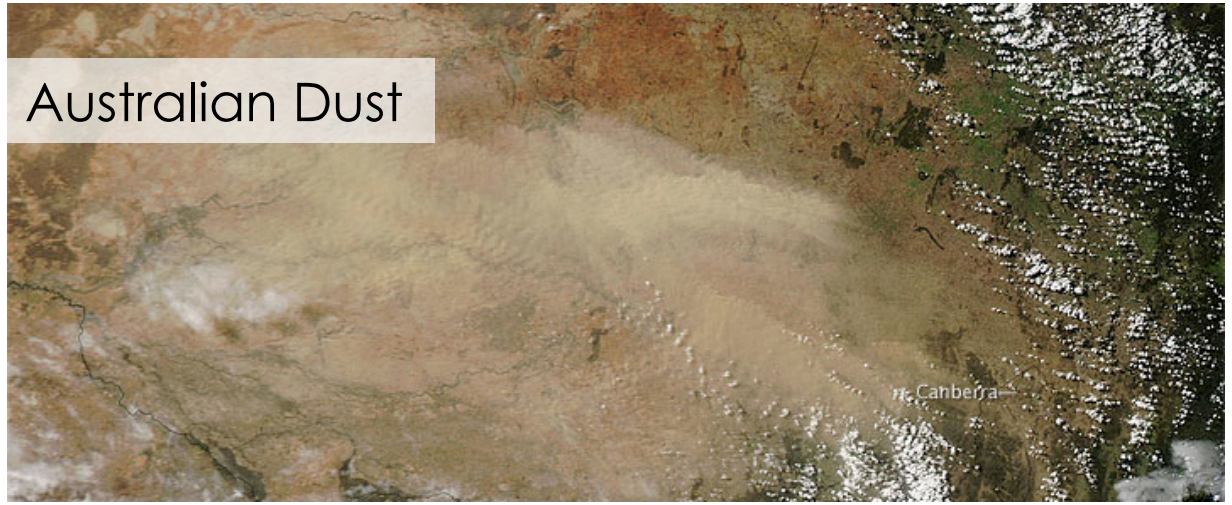
Urban-industrial/smoke pollution?

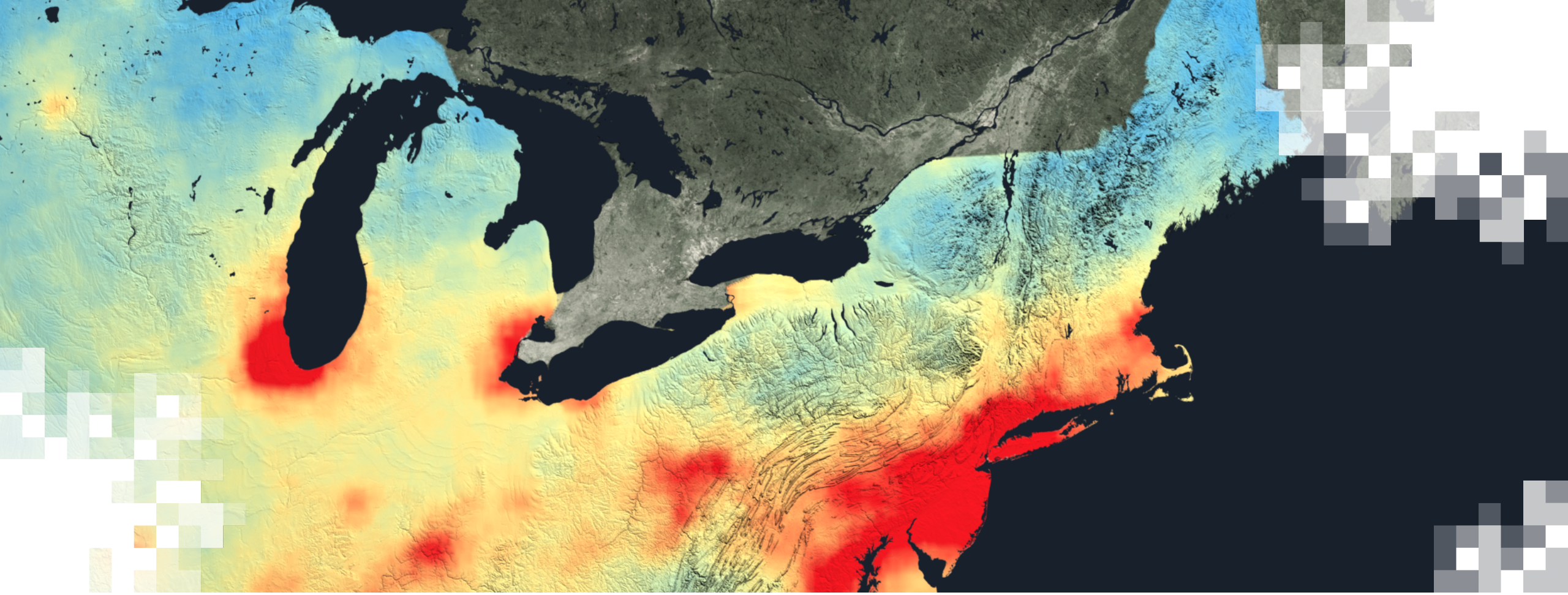
Urban-industrial/smoke pollution?

True Color Image Interpretation

How do aerosols appear in true color images?



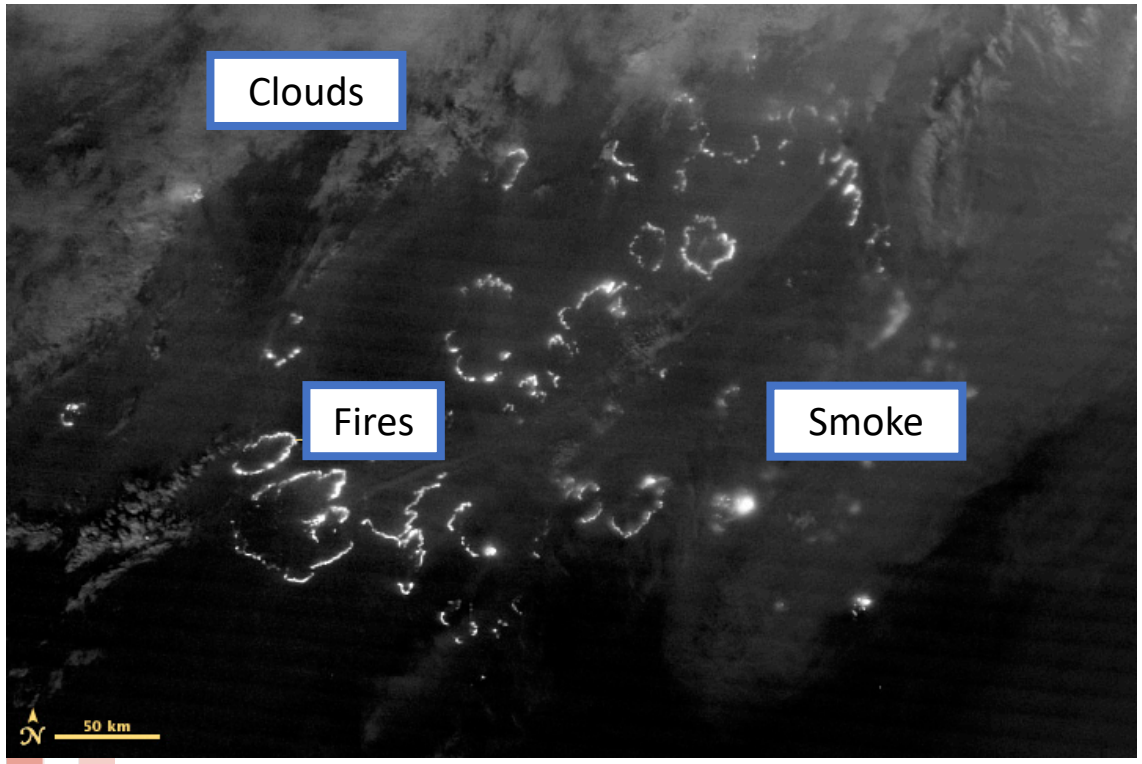


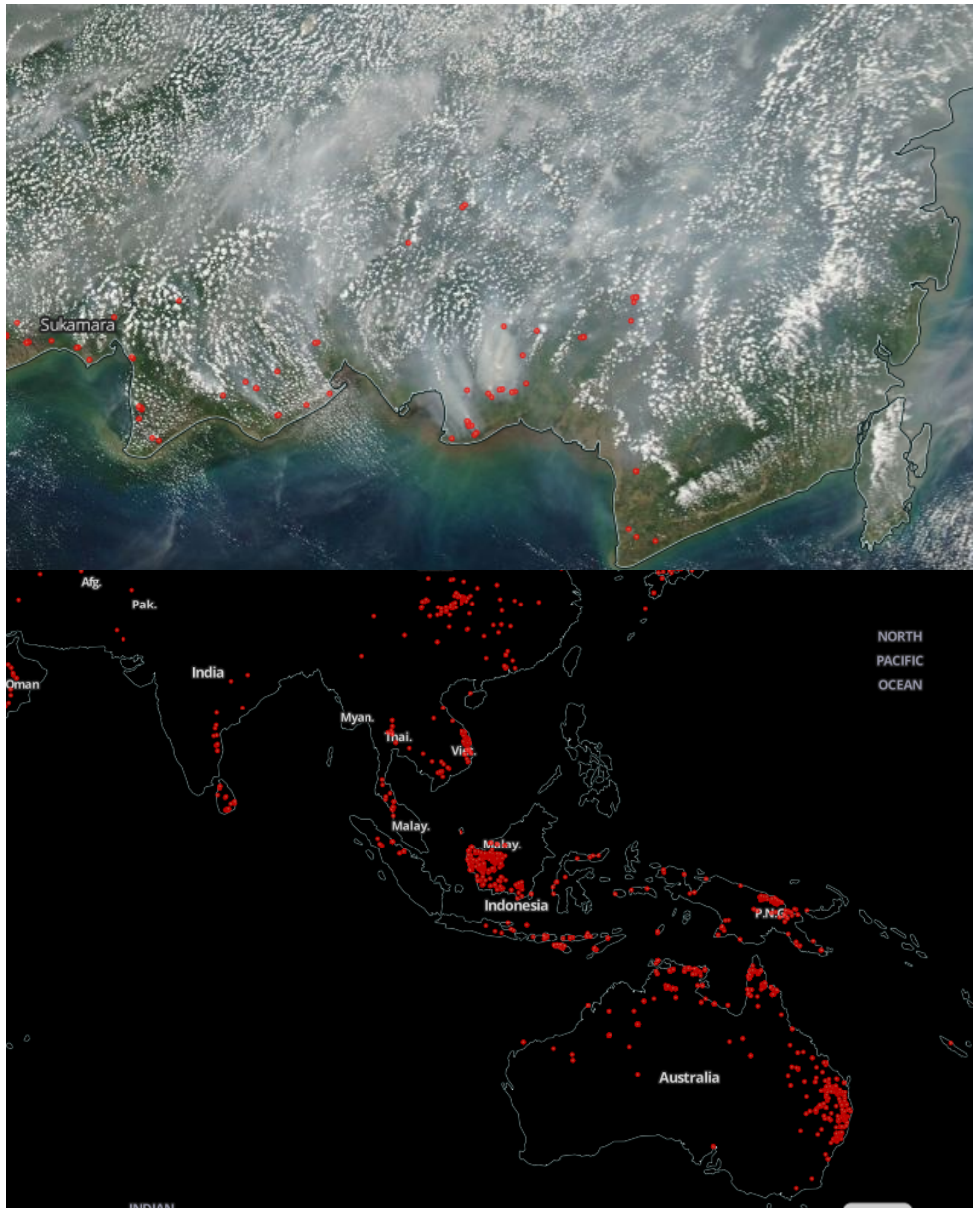


Fire Detection

Fire Detection from Satellites

- By detecting smoke
- By detecting temperature anomalies
- By detecting light

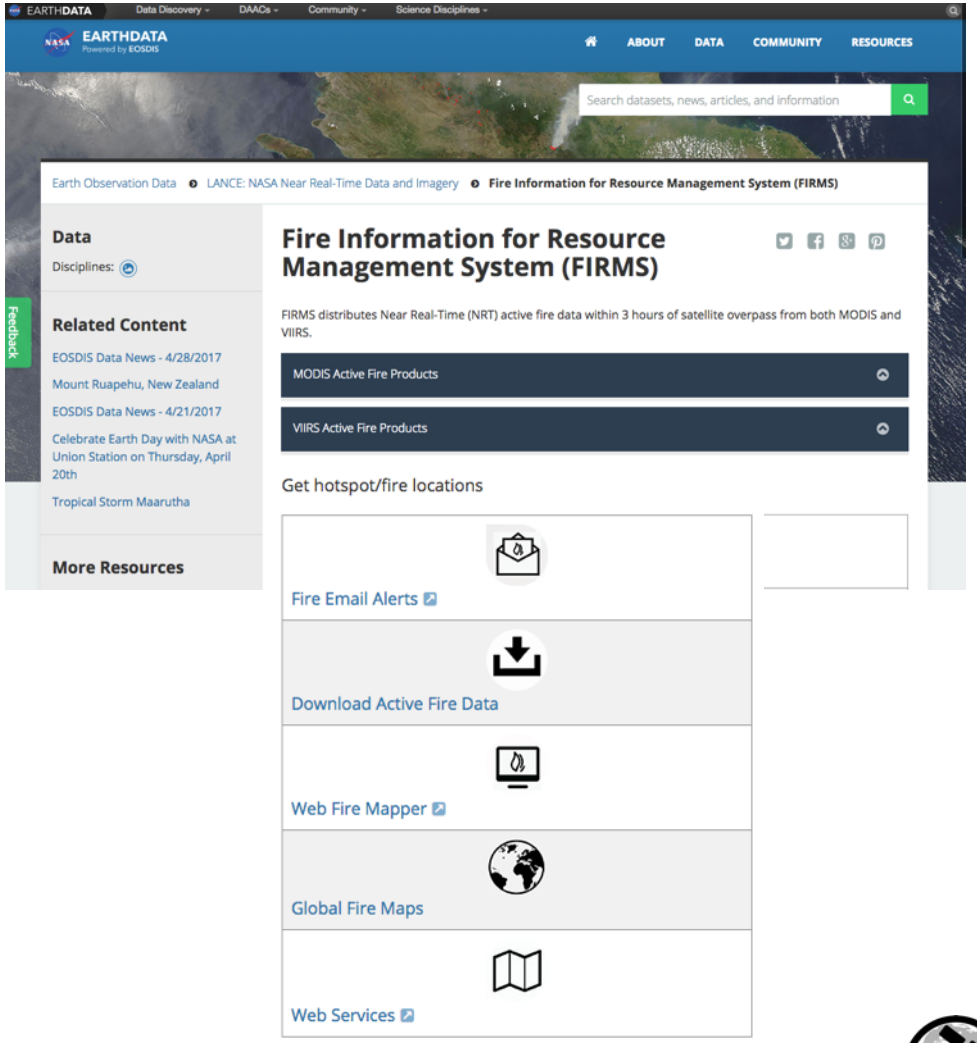




Fire Information for Resource Management System (FIRMS)

https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms

- Near real-time (NRT) active fire data within 3 hours of satellite overpass
- Global MODIS and VIIRS fire locations
- Historical data available
- Available in:
  - Email alerts
  - Download shapefile, WMS, KML, or txt
  - Visualization in Web Fire Mapper or Worldview
- FIRMS Webinar:
  - https://www.youtube.com/watch?v=0fPVmnY6pBs&feature=youtu.be



Where to Obtain MODIS Fire Products

Archived Data

Land Process Distributed Active Archive (LPDAAC): http://lpdaac.usgs.gov/

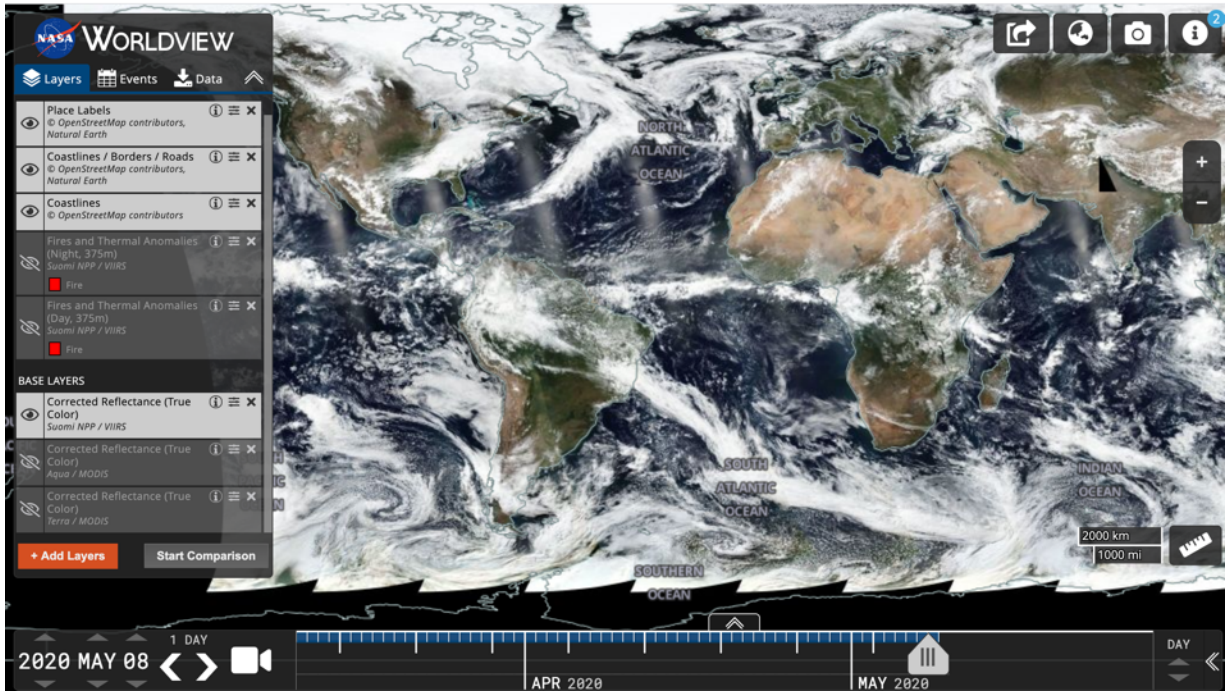
NASA Earthdata: https://earthdata.nasa.gov/

Near Real Time (NRT)

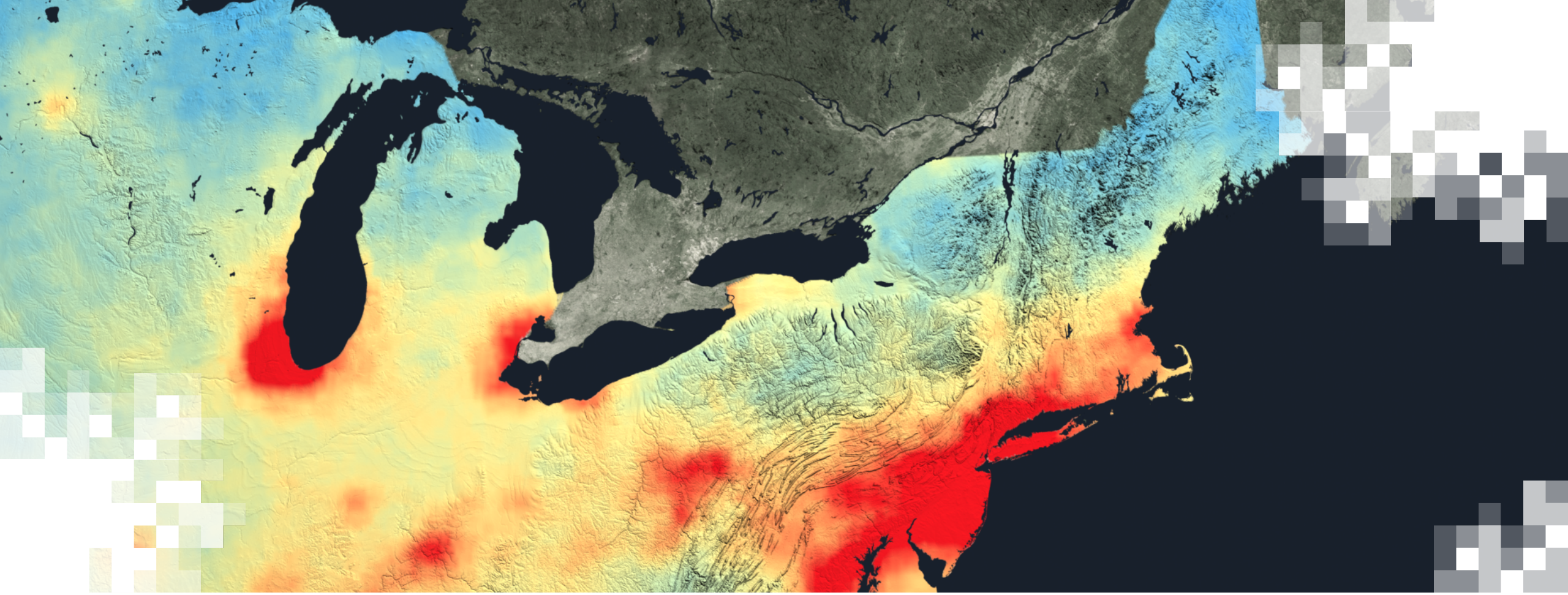
Worldview: http://worldview.earthdata.nasa.gov

NASA Worldview

https://worldview.earthdata.nasa.gov



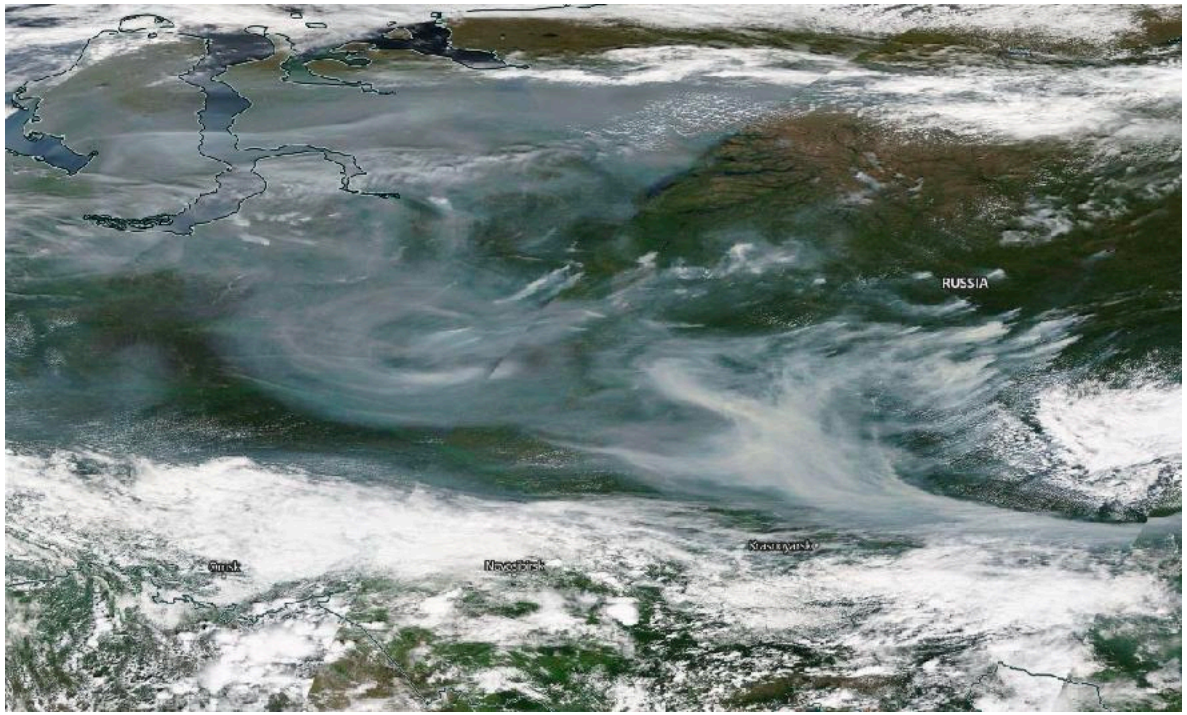
https://www.youtube.com/watch?v=nW8JZJ-5g_0&feature=youtu.be

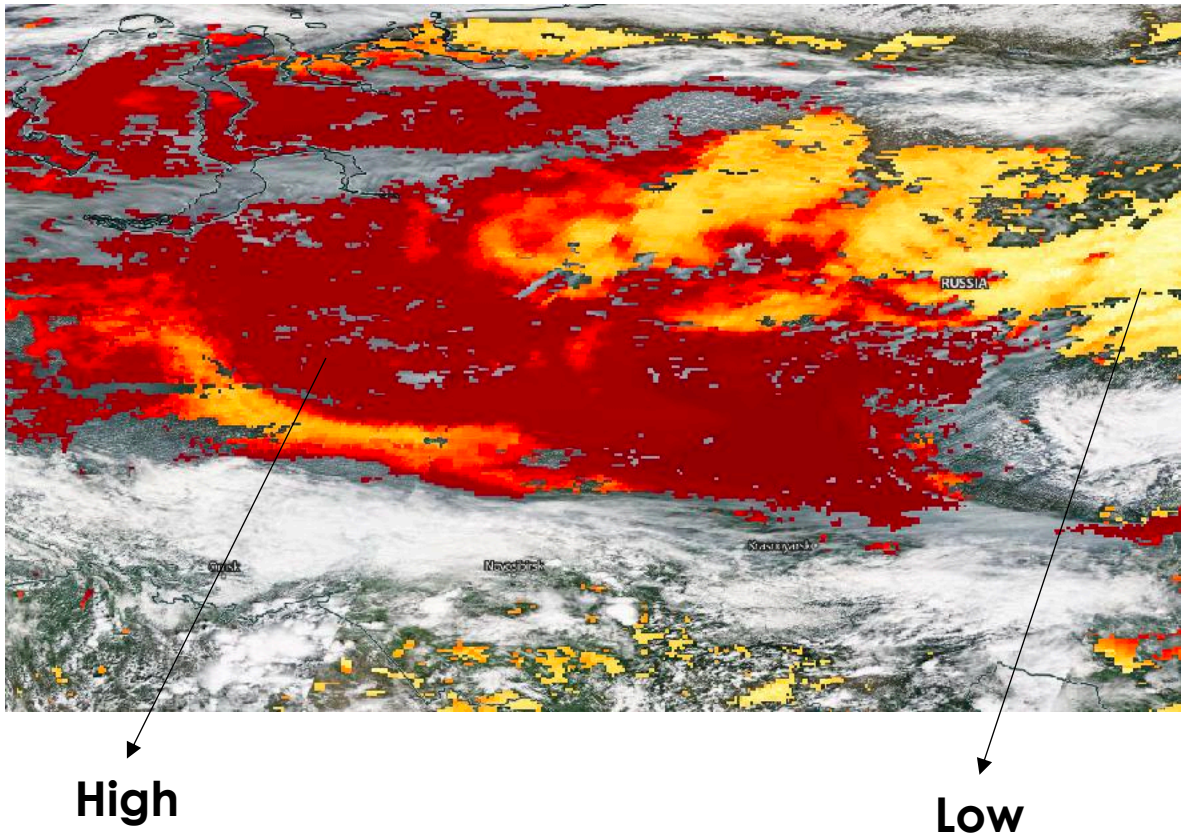


Aerosol Optical Depth Basics and Image Interpretation

From Pretty Pictures to Numbers

Spectral Measurements → Pollution Maps

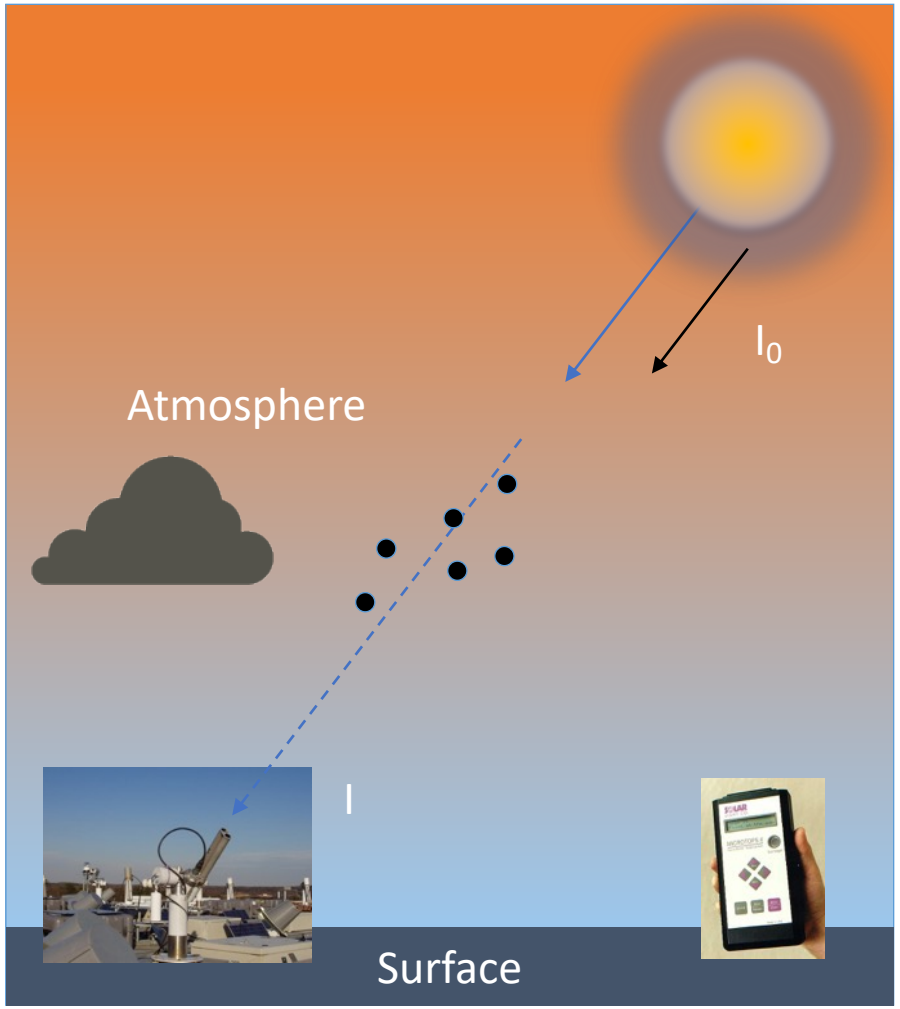




Aerosol Optical Depth (AOD)

- Also called Aerosol **Optical** Thickness (AOT)
- Unitless quantity
- **Optical measurements** represent how solar light intensity changes as it interacts with particles in the atmosphere.

Optical Depth



- ✓ The optical depth expresses the quantity of light removed from a beam by **scattering** and/or **absorption** during its path through a medium.
- ✓ The aerosol optical depth represents the loading of particles in the entire column of the atmosphere (from surface to the top of the atmosphere).
- ✓ Always represented at a certain wavelength (most often at 550 nm)
- ✓ Value depends on particle concentration, shape, size, chemical composition, location in the atmosphere, and wavelength of measurement.
- ✓ Can be measured from the ground and space

Visibility, AOD, and PM2.5

Pittsburgh

$PM_{2.5}$ = 45 μgm^{-3}

AOD = ~0.8

$PM_{2.5}$ = 4 μgm^{-3}

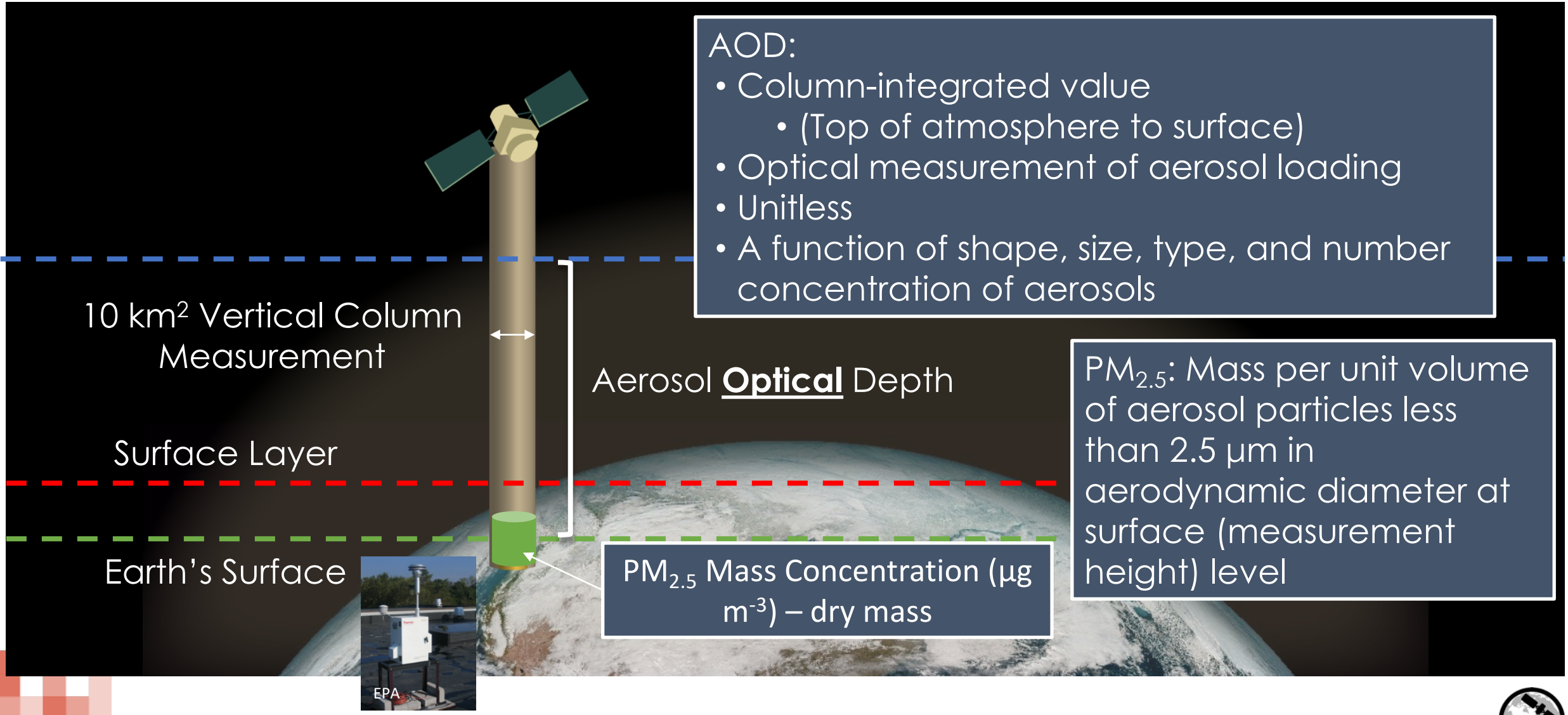
AOD = ~0.1

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

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/

Column vs. Surface Concentration



Surface vs. Satellite Measurements

- Fires in Bay Area, CA, U.S.A.
- October 2017
- Individual vertical bars show the location of ground monitors, color coded with MODIS AOD and $PM_{2.5}$ values.
- The animation shows the impact of smoke from fires on local air quality (i.e. $PM_{2.5}$), and the AOD.
- Both the column values (i.e. AODs) and surface values (i.e. $PM_{2.5}$) show similar responses to the fires.
- There are simple to advanced methods developed over the last two decades to convert AOD to $PM_{2.5}$.

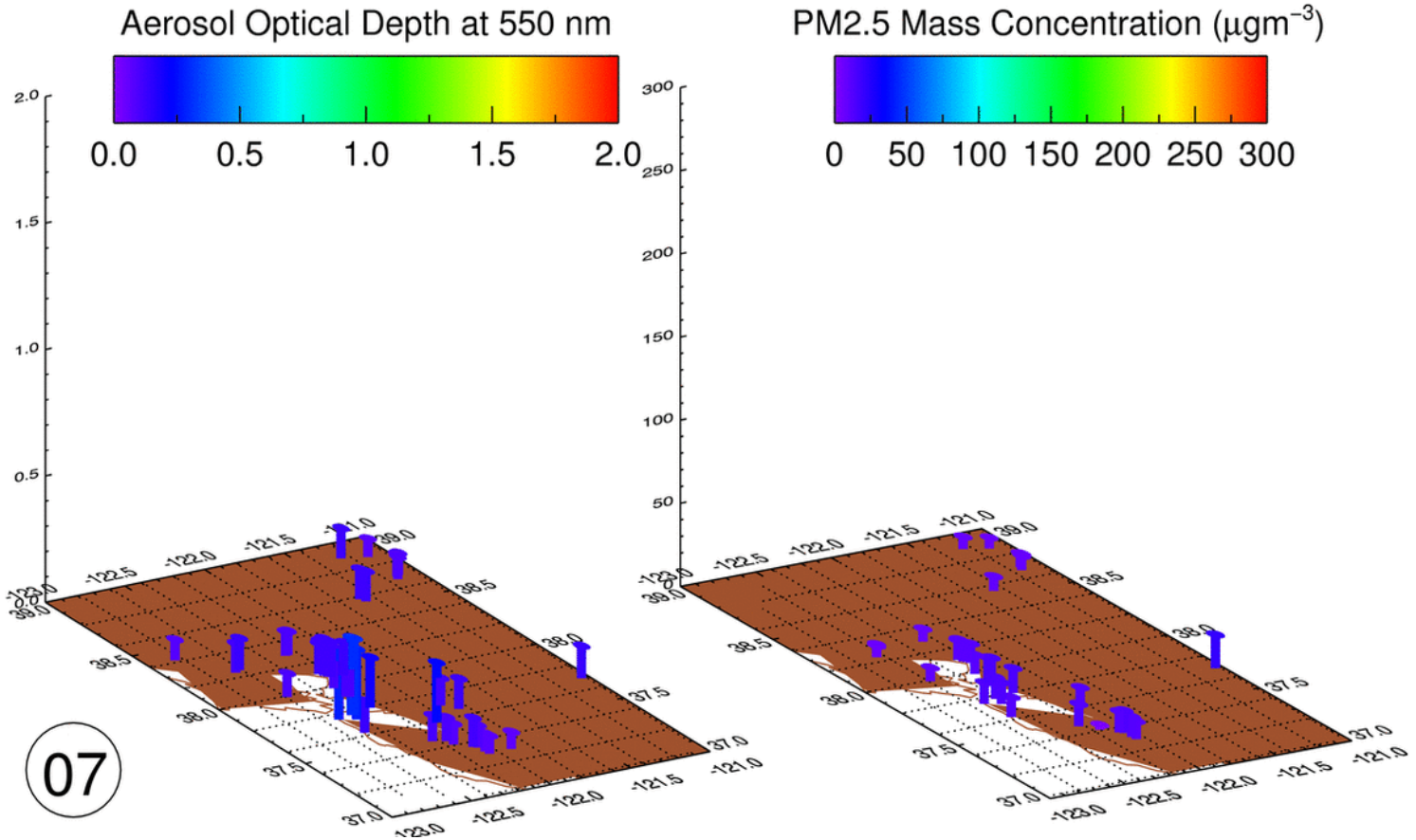
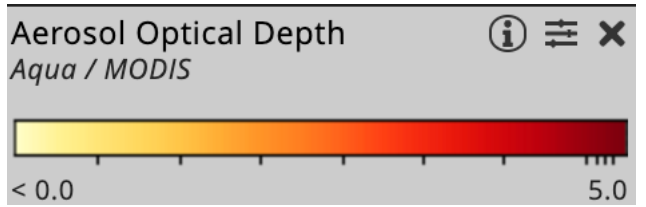


Image Credit: Gupta et al., 2018

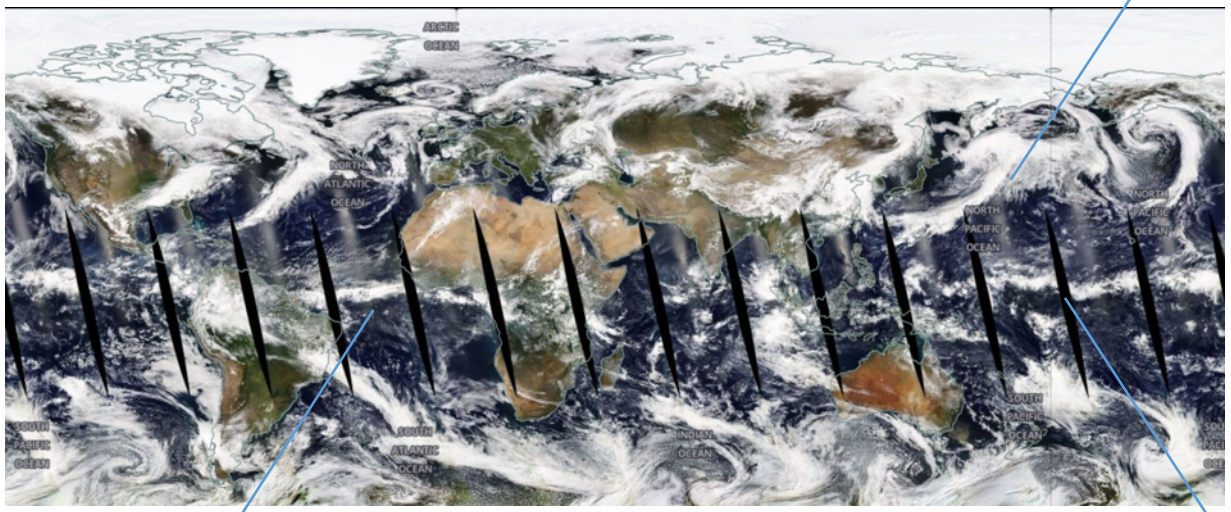
Global Observations – ONE DAY COVERAGE

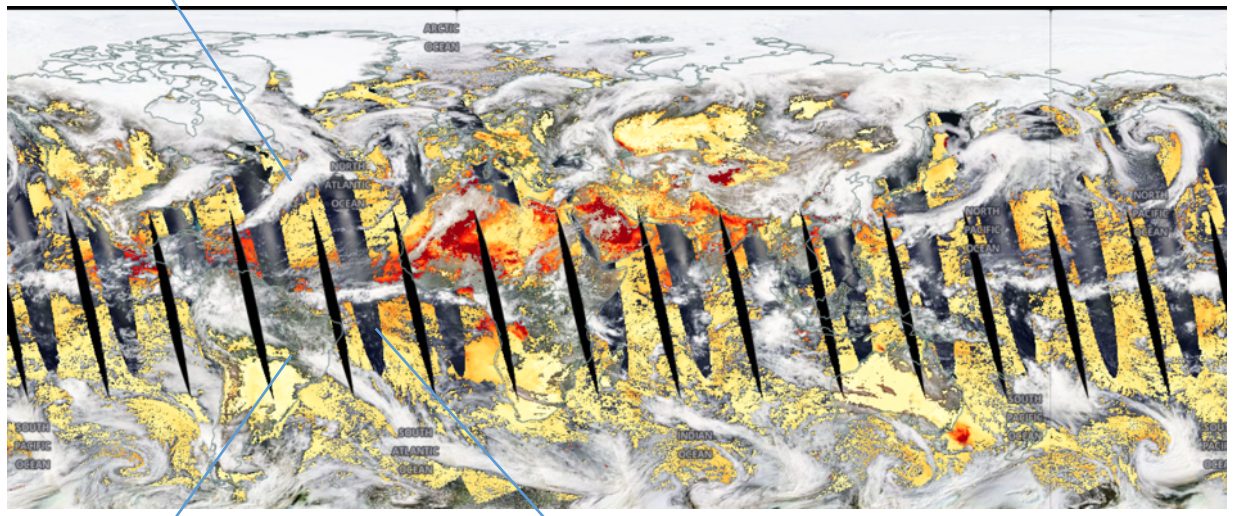
MODIS-Aqua - May 8, 2020 - https://go.nasa.gov/35NGMFw



Clouds

True Color Image



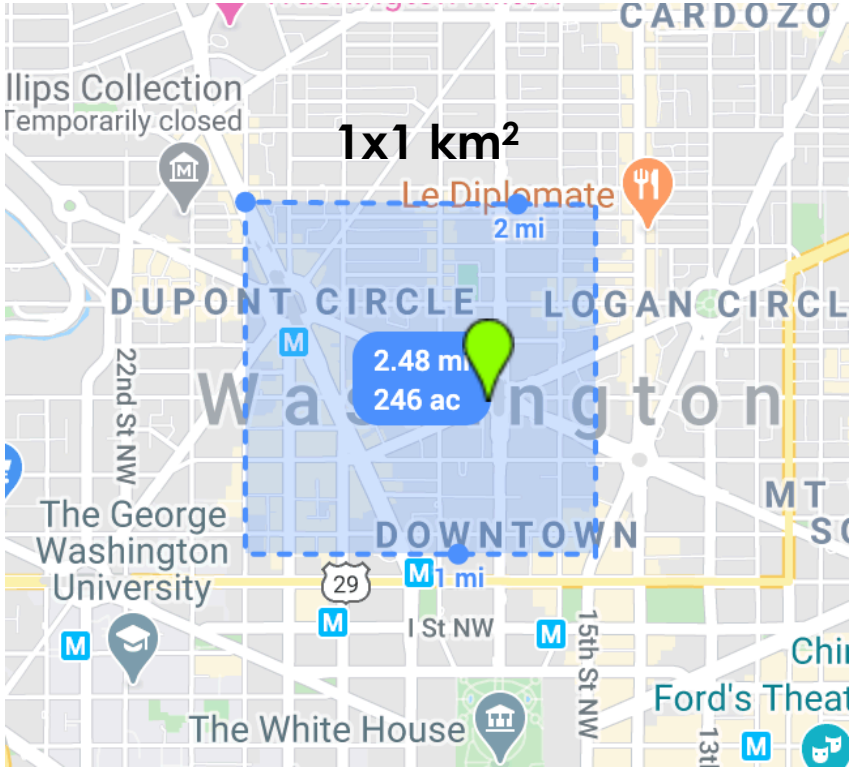


Sun Glint

Orbital Gaps

Sun Glint

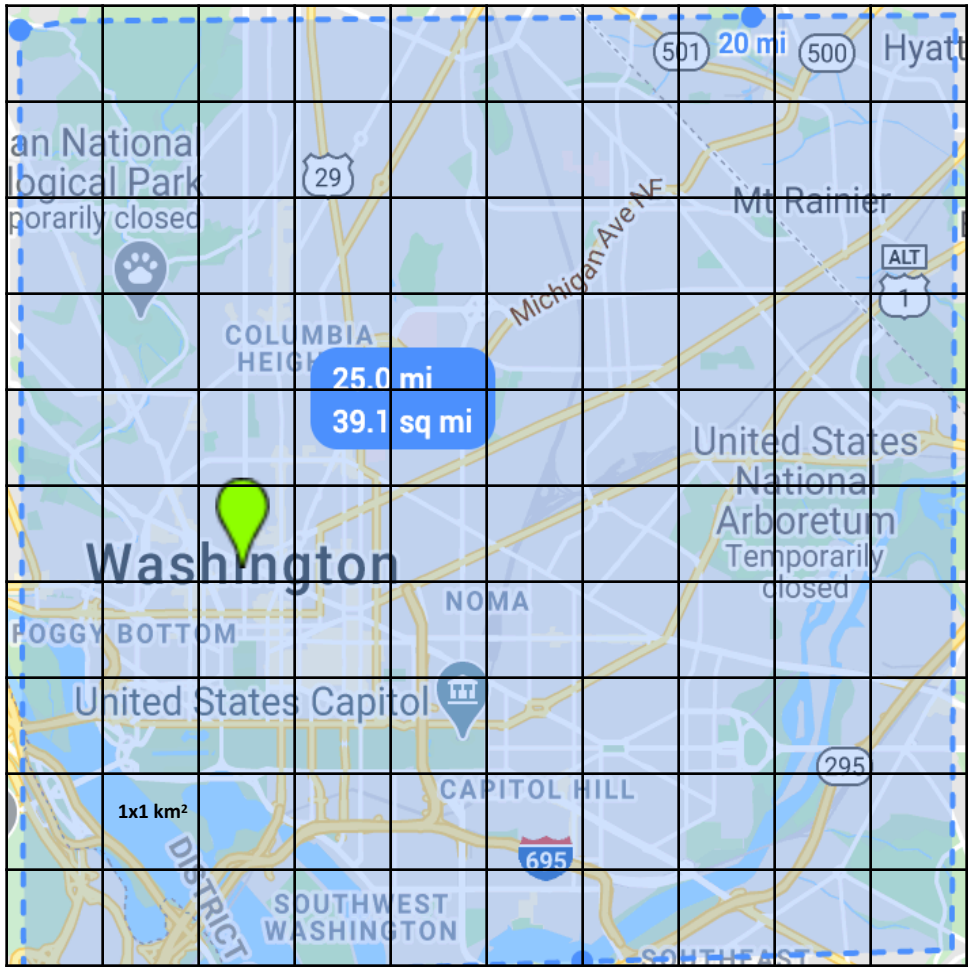
How much area is covered by each AOD measurement?



AOD data are available in 1 km, 3 km, 6 km, 10 km, and 1degree (~110 km).

10x10 km²

10 km



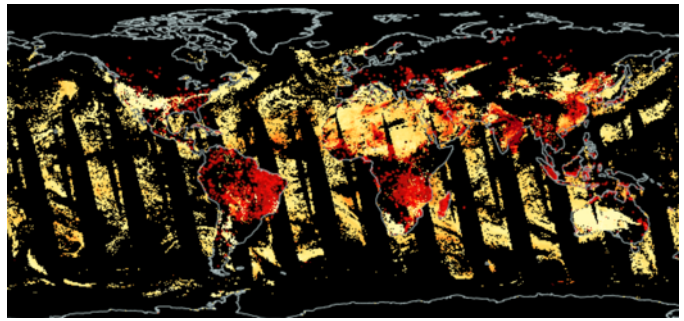
10 km

MODIS Data:

- MODIS Aerosol Optical Depth data are available at Level 2 in these resolutions:
  - 1 km
  - 3 km, 10 km

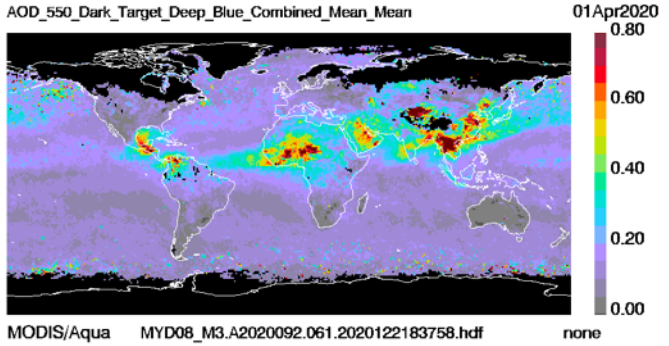
- Level 3 (gridded) data are available in 1 degree (~110 km) resolution
  - averaged for daily, weekly, and monthly time periods.

MOD04_L2, Level 2
(10 km), 5 -minutes



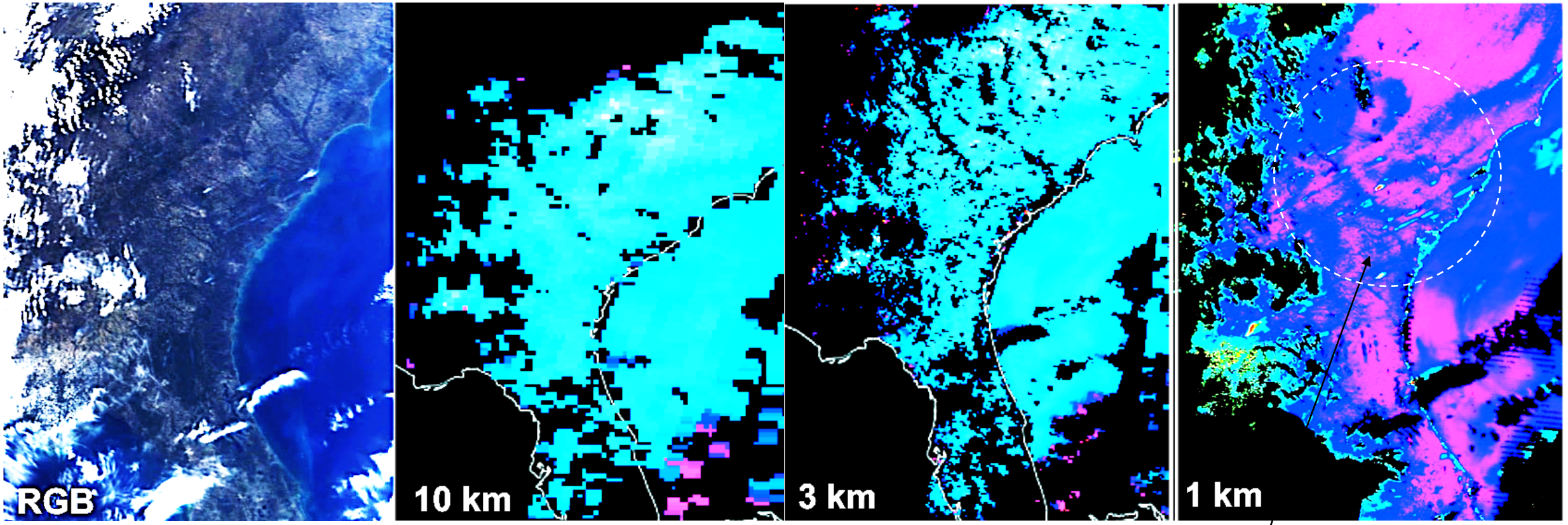
https://landweb.modaps.eosdis.nasa.gov/cgi-bin/ATM/ATMbrowse.cgi

MODO8_M3 Level 3 Gridded
(1° x 1°)
Daily, Weekly, Monthly

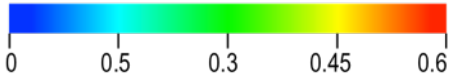


https://atmosphere-imager.gsfc.nasa.gov/images/l3/monthly

RGB and Three High Resolution MODIS AOD Images

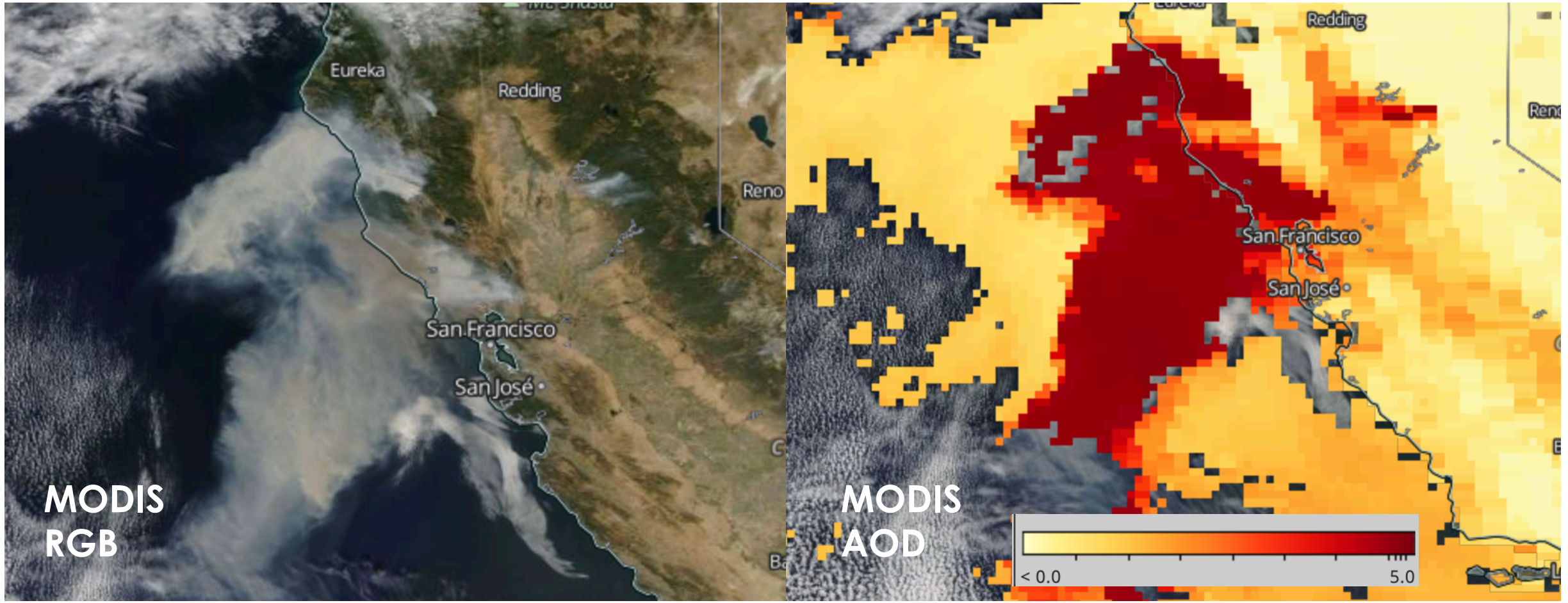


High resolution data helps identify small-scale features.



Smoke plumes from prescribed burning are visible in 1 km data.

High Resolution MODIS AOD (10x10 km^2) - October 9, 2017

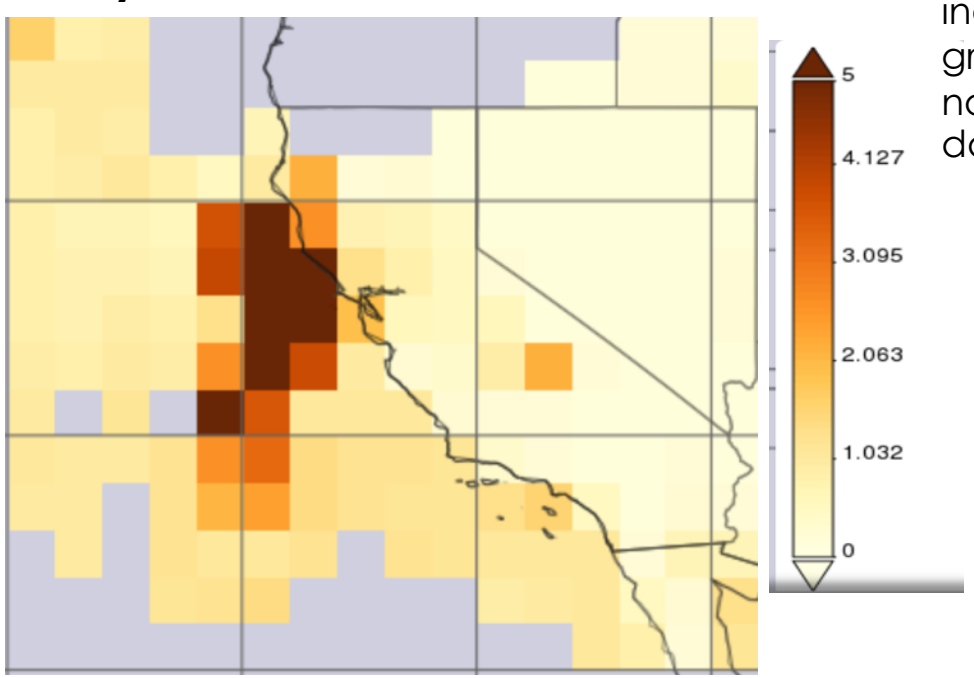


https://go.nasa.gov/2ZezR6K

Interpreting Coarser-Resolution Gridded Products

Daily MODIS AOD (~110x110 km^2) - October 9, 2017

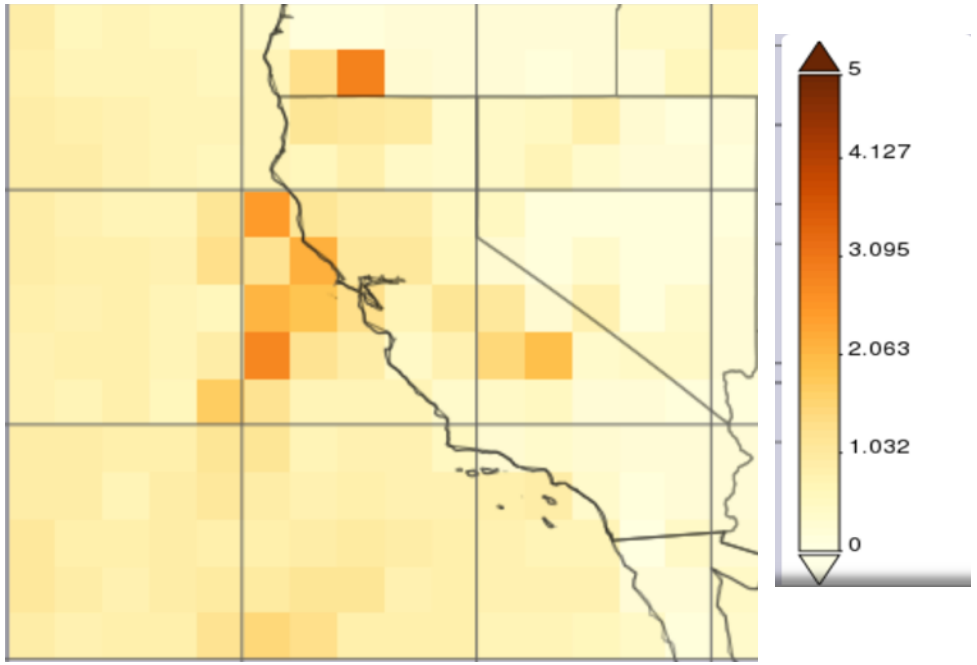
Daily Data at 1°x1° Resolution



Grey color indicates grids with no AOD data.

Level 2 (10 km) data are binned and averaged to generate a ~110 km daily grid (level 3). There are high AOD values near the fires, but the fine scale details are missed due to the spatial averaging.

Weekly Data at 1°x1° Resolution



Level 2 (10 km) data are binned and averaged to generate a ~110x110 km grid (level 3) averaged over 1 week. Since there are more data points available, all grids have values, but the AOD is lower due to the temporal averaging.

So what can we see from this image?

What quantity are we looking at?

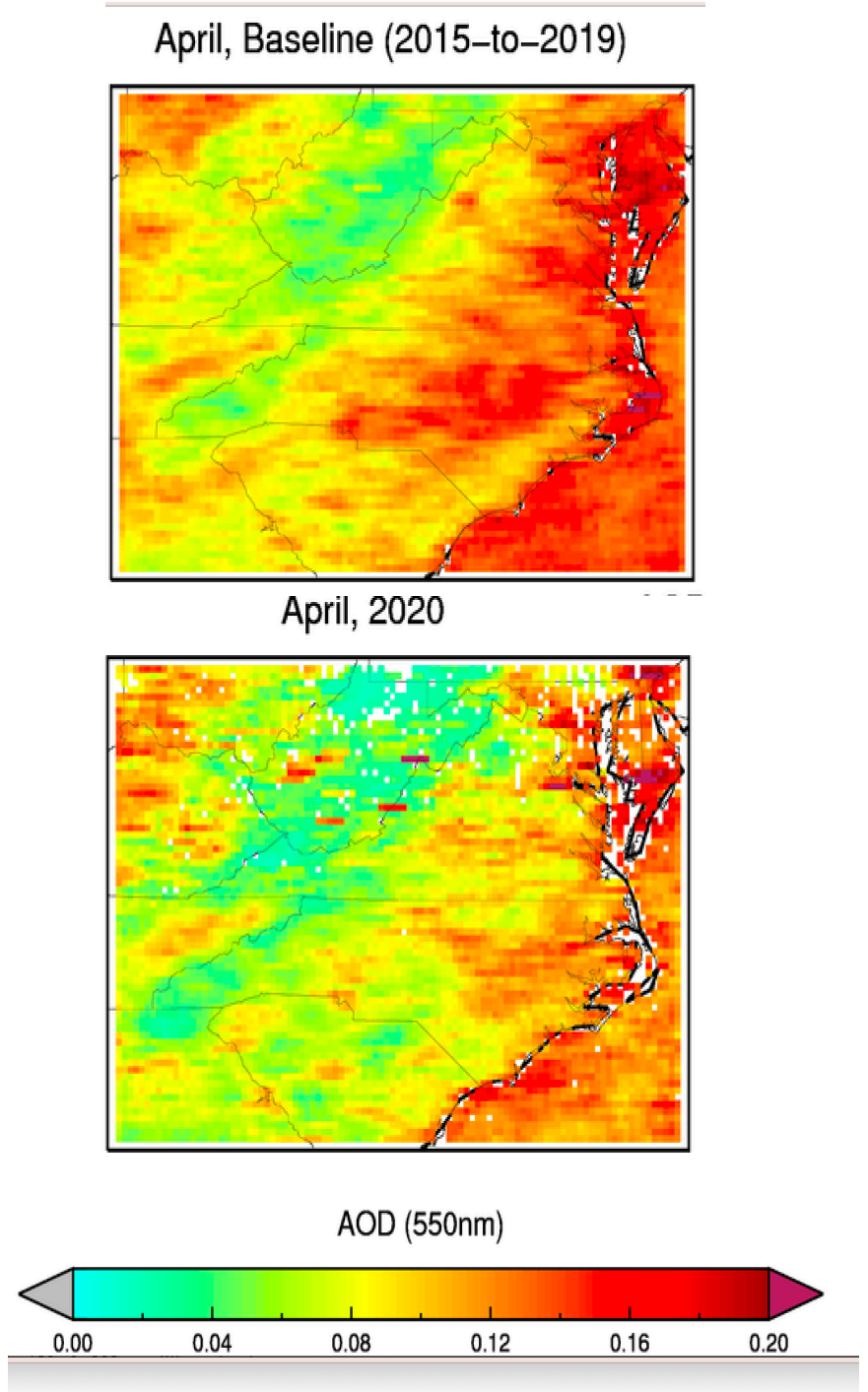
Aerosol Optical Depth at 550 nm

Is this image for one day?

No. These images show averages of daily data over a month.

Is this data gridded? Or at the native resolution of the satellite?

This image was made using gridded data. This data is produced by NASA and involves carefully averaging and filtering the native resolution data from the satellite.



So what can we see from this image?

Is this a map of PM2.5 at the surface, where people breathe?

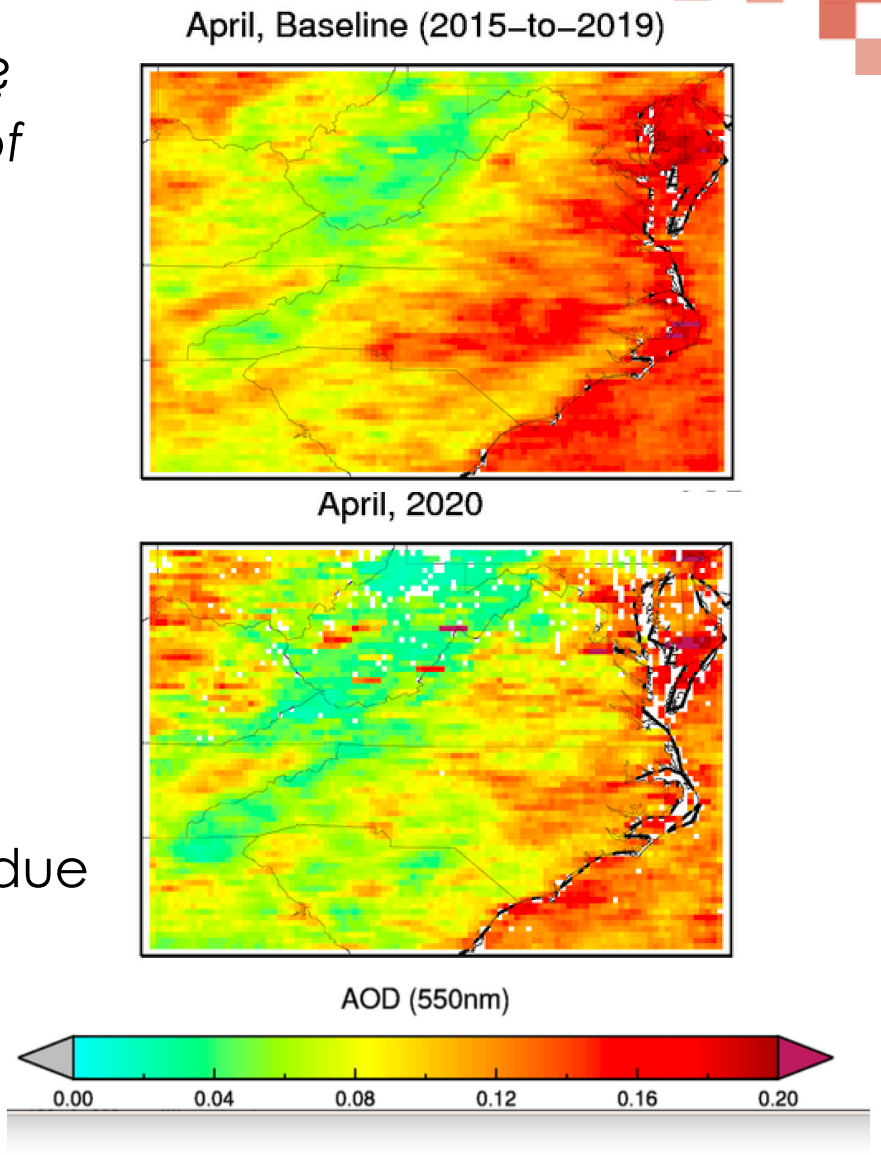
No. This is a map of AOD, which represents all types of aerosols in the entire column of atmosphere from surface to top-of-the-atmosphere.

Can changes in the entire column tell me information about changes at the surface?

Mostly yes. Sources of aerosols are primarily at the surface, leading to high values near sources, but there can be multiple layers of aerosol in the atmosphere and in those cases change in the column may not represent change at the surface.

Are all of the changes between the top and bottom image due to the lockdown in response to COVID-19?

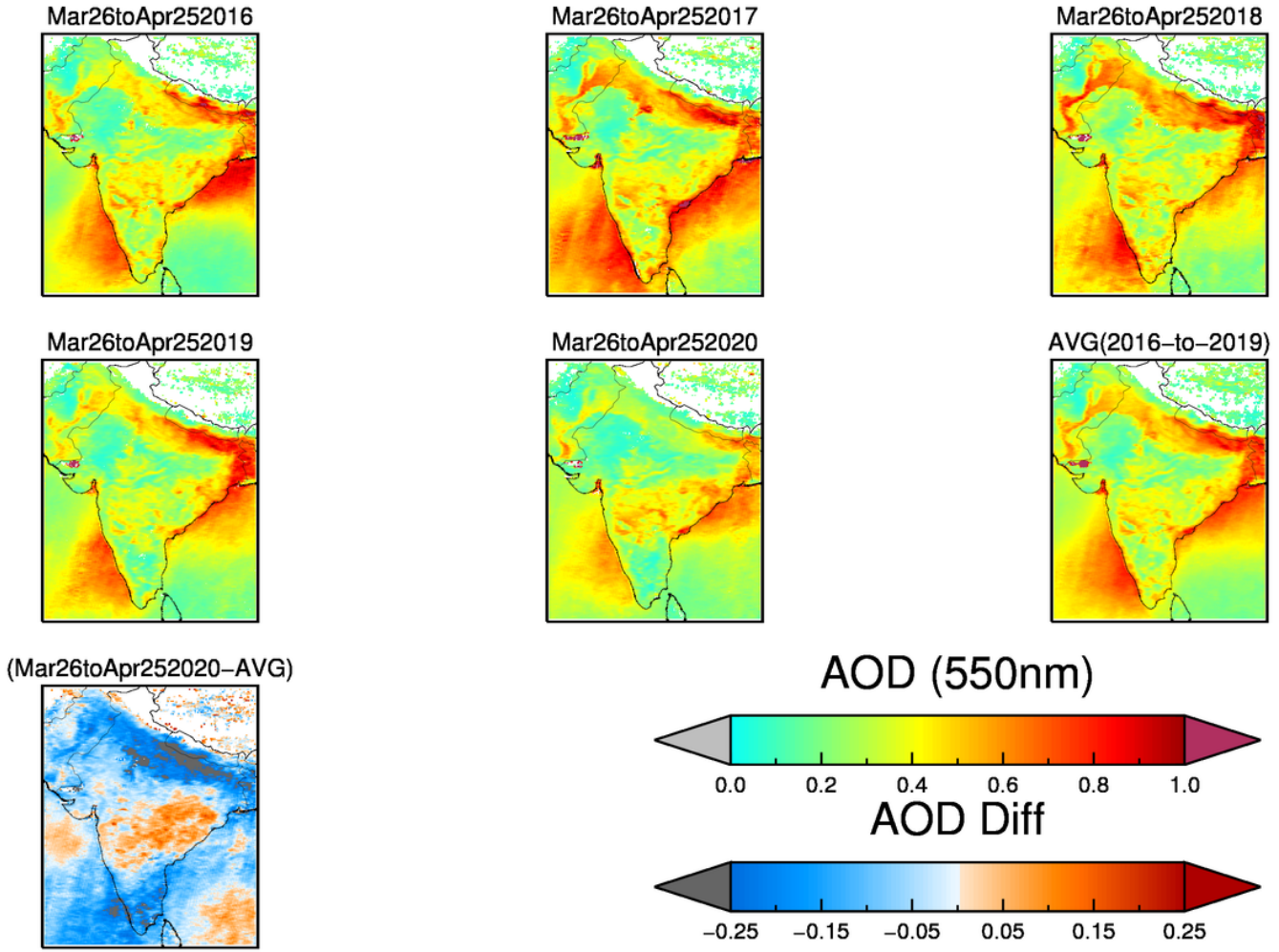
No. The amount of AOD depends on emissions + chemistry + weather. Calculating the change in AOD from the lockdown requires careful and rigorous scientific analysis.



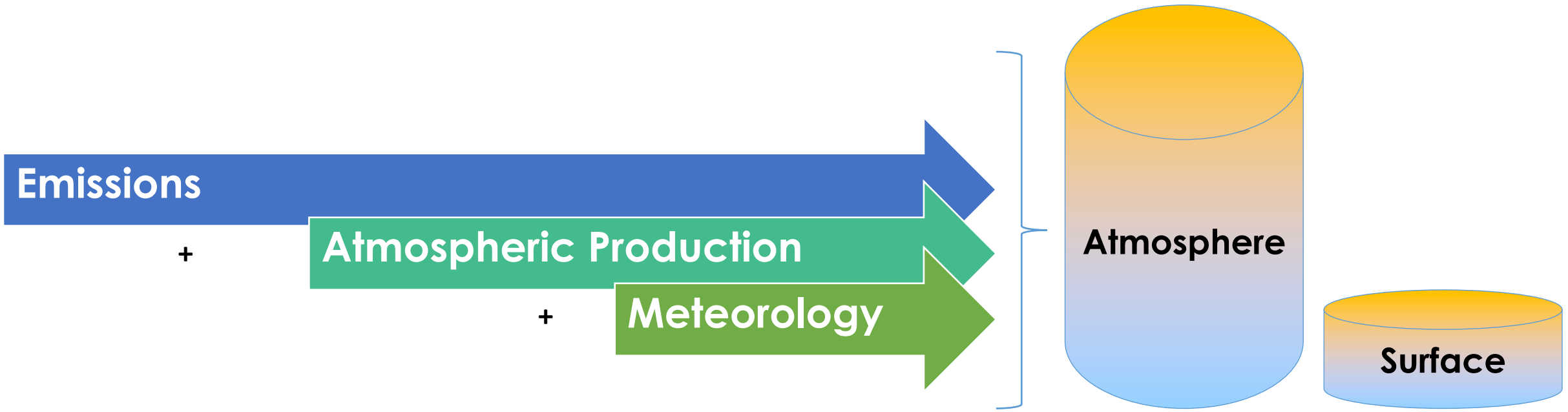
Aerosols over the Indian Sub-Continent

https://earthobservatory.nasa.gov/images/146596/airborne-particle-levels-plummet-in-northern-india

- MODIS AOD at 10 km
- 30-day average from March 26 to April 25
- To look at year-to-year variability, years 2016 to 2020 were examined separately.
- This simple analysis only shows the deviation in the aerosol loading from the climatological mean to the year 2020.
- To understand this year to year variability, more in-depth analysis is required to examine contributing factors such as meteorology.



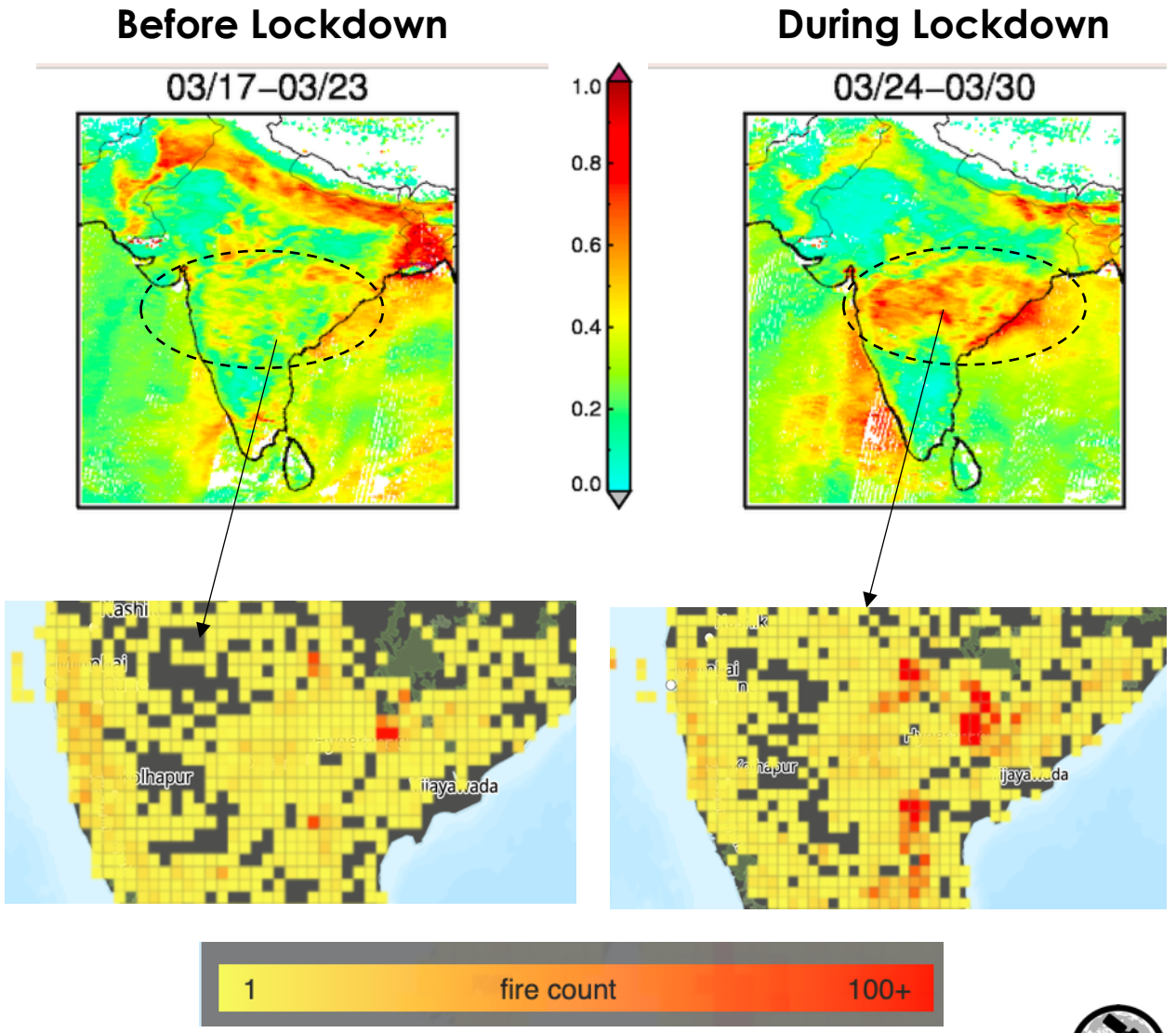
What determines ambient aerosol concentrations?



Changes in emissions of PM2.5 do not necessarily translate into changes in PM2.5 pollution at the surface due to other factors such as atmospheric production and meteorology

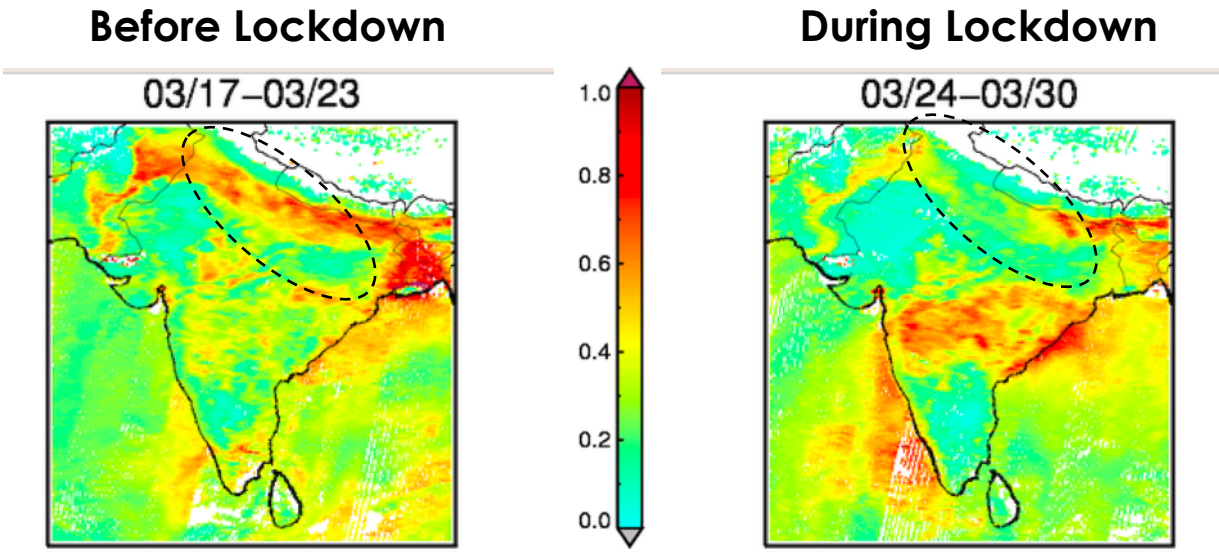
Changes in AOD over India Before and After the Lockdown

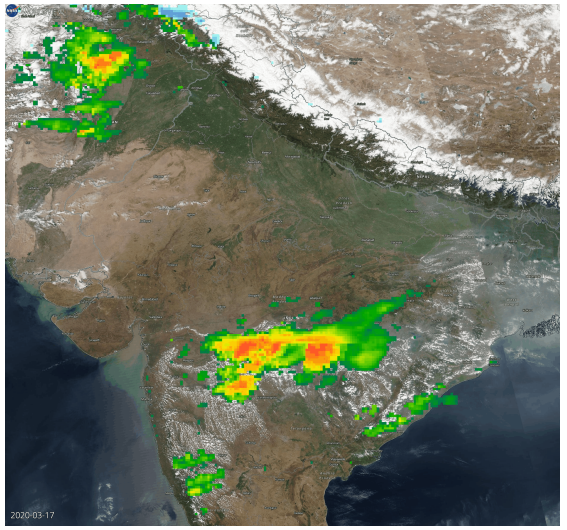
- The two top images represent the weekly average AOD before and after the lockdown.
- Many emissions sources (vehicle, industry, power plants) were reduced or shut down, resulting in lower pollution levels.
- The AOD decreased in some regions but increased in others.
- VIIRS fire count data show an increase in fires in south-central India during the first week of the lockdown.
- We can't always measure aerosols or fires when there is cloud cover. This leads to less data points in certain regions and time periods, and potentially creates artificial biases in the average AOD.

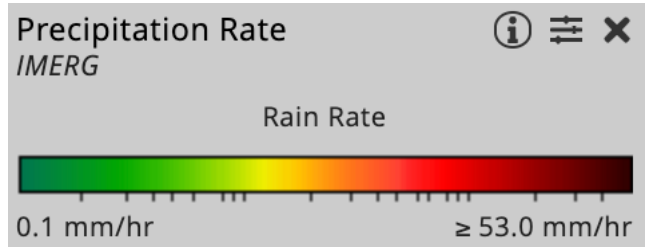


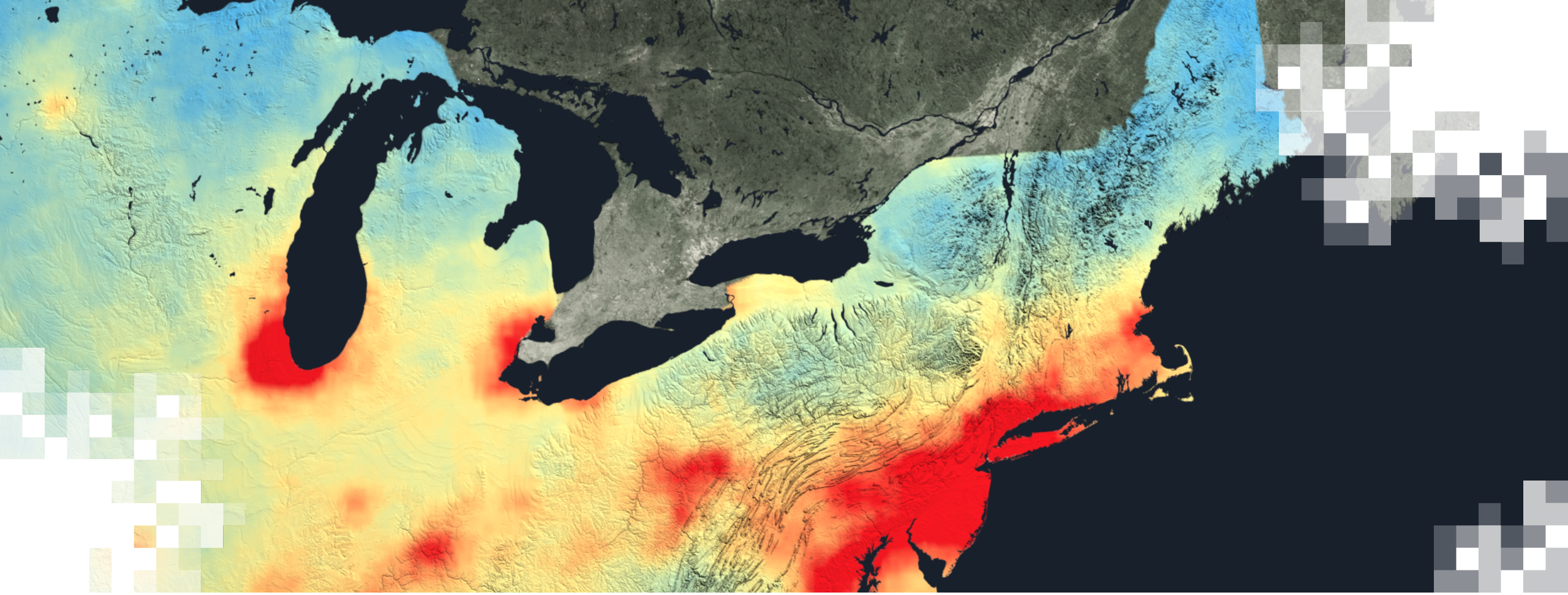
Impact of Meteorology On Aerosol Pollution

- During the first week of lockdown, AOD values over the Indo Gangetic Plain (IGP) were lower than the previous week.
- IGP has the highest population density. More human activity -> more emissions.
- Precipitation data from satellites suggests heavy rainfall in northern India during the first week of lockdown -> rain washes out the aerosols from atmosphere -> lower AOD values.
- Therefore, lower AOD values over the IGP could be the combined effect of lockdown and meteorology during the first week of lockdown.
- And what is causing the increases in AOD after the lockdown? -> Potentially new local sources such as fires.









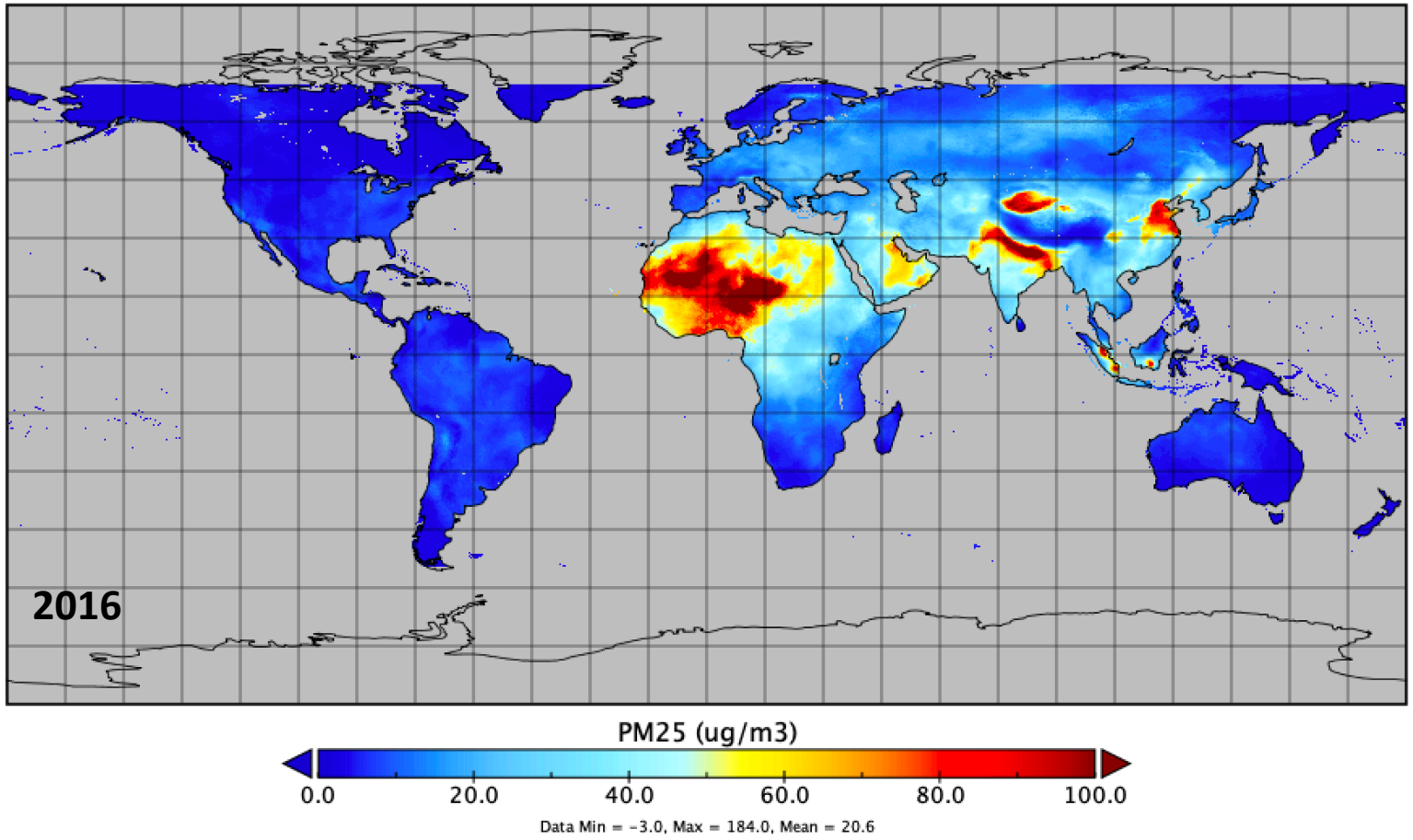
Practical Uses of Aerosol Satellite Images and Data

Practical Uses of Aerosol Satellite Images and Data

- Health Applications:
  - Estimation of ground-level aerosol pollution from satellite AOD
  - Health Exposure Studies: Global Burden of Disease
- Improving air quality forecasts
- Understanding short- & long-term changes in pollution level due to policy interventions
- Estimation of emissions from dust and fires
- Assimilation into Global Models

Global Annual Average $PM_{2.5}$

- Multiple satellites, model simulations, and ground measurements are used to derive annual mean $PM_{2.5}$ for the entire globe.
- Long-term data records (1998 – current) can help understand population exposure and health impacts from aerosols.
- These maps help identify polluted areas at ground level, where people live and breathe.
- They also help identify major pollution sources.



Source: van Donkelaar et al., 2016,
http://fizz.phys.dal.ca/~atmos/datasets/EST2016/GlobalGWRnoGWRcwUni_PM25_GL_201601_201612-RH35_Median.nc

Satellite Estimated $PM_{2.5}$

- MODIS AOD data have been used to derive weekly $PM_{2.5}$ maps to assess the impact of fire smoke on local air quality.
- Air quality impacts at the local to regional scale can be assessed more effectively using regional models and high-resolution satellite data.

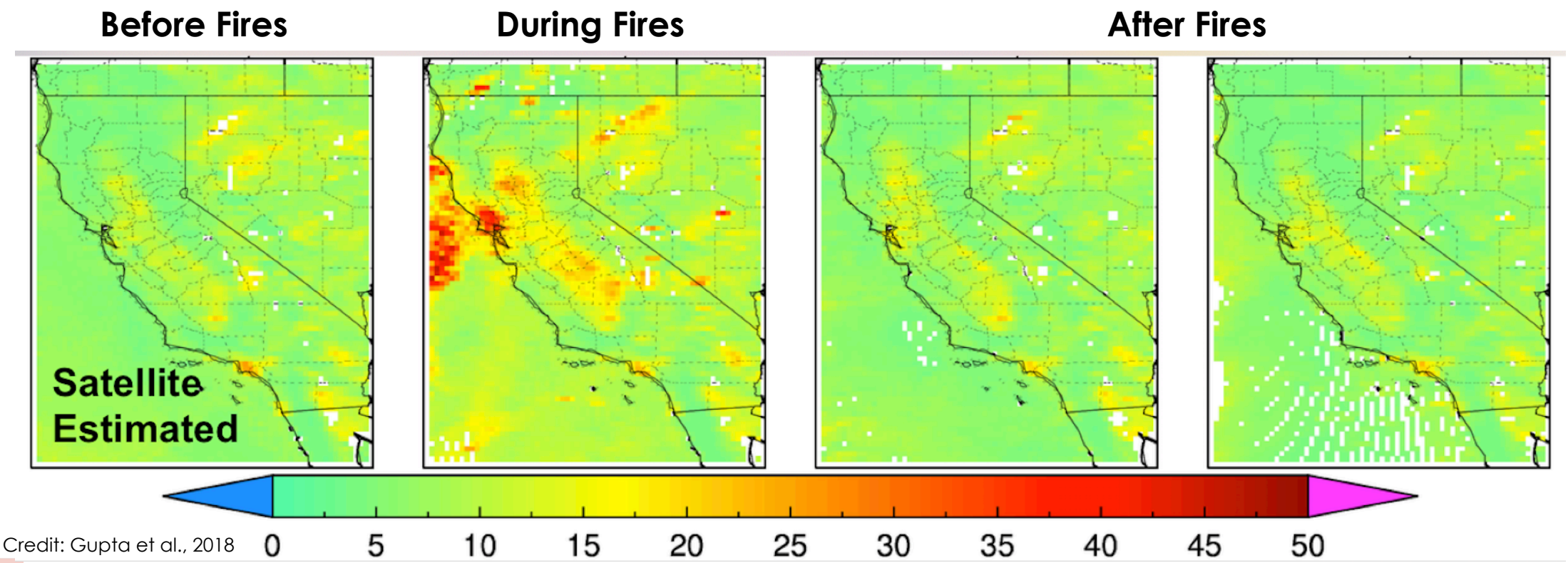
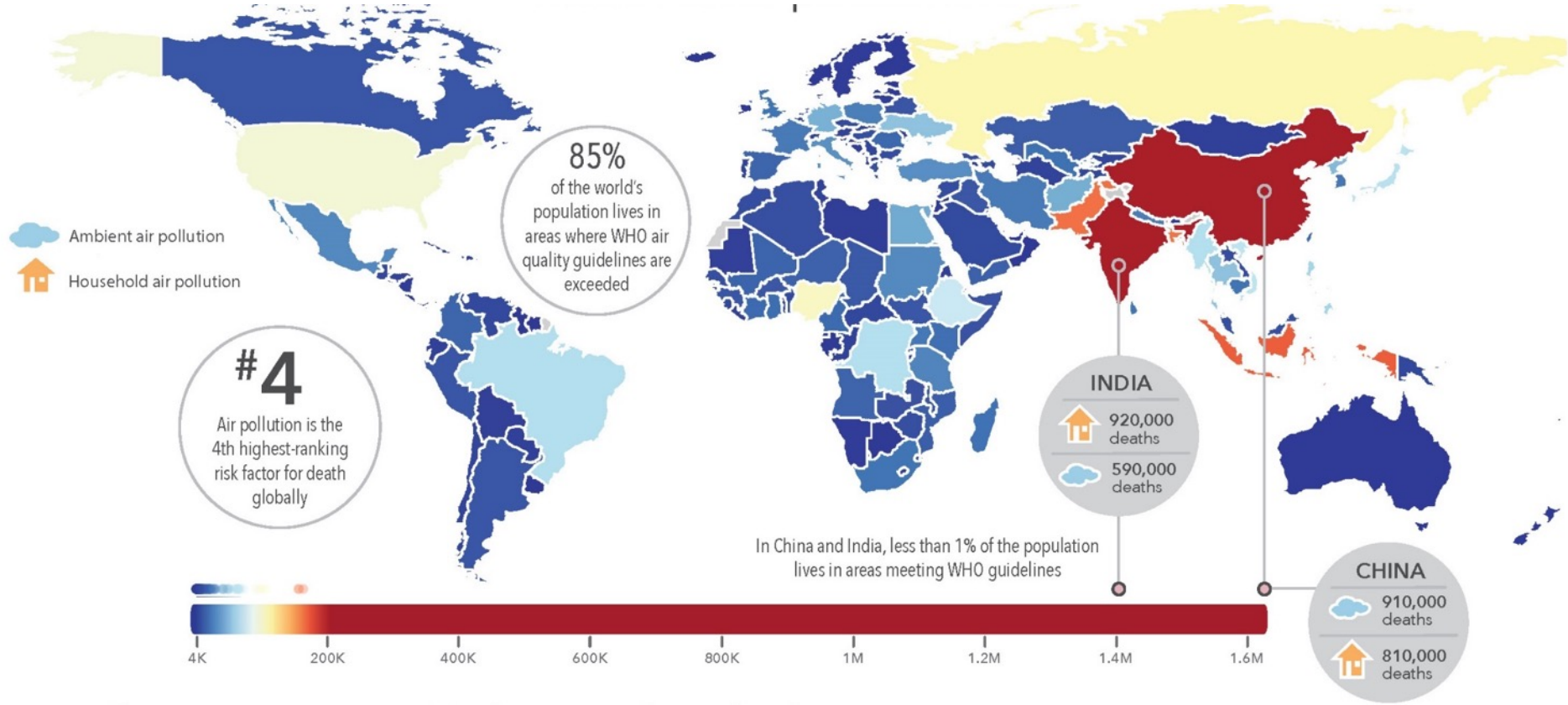


Image Credit: Gupta et al., 2018

Global Burden of Air Pollution



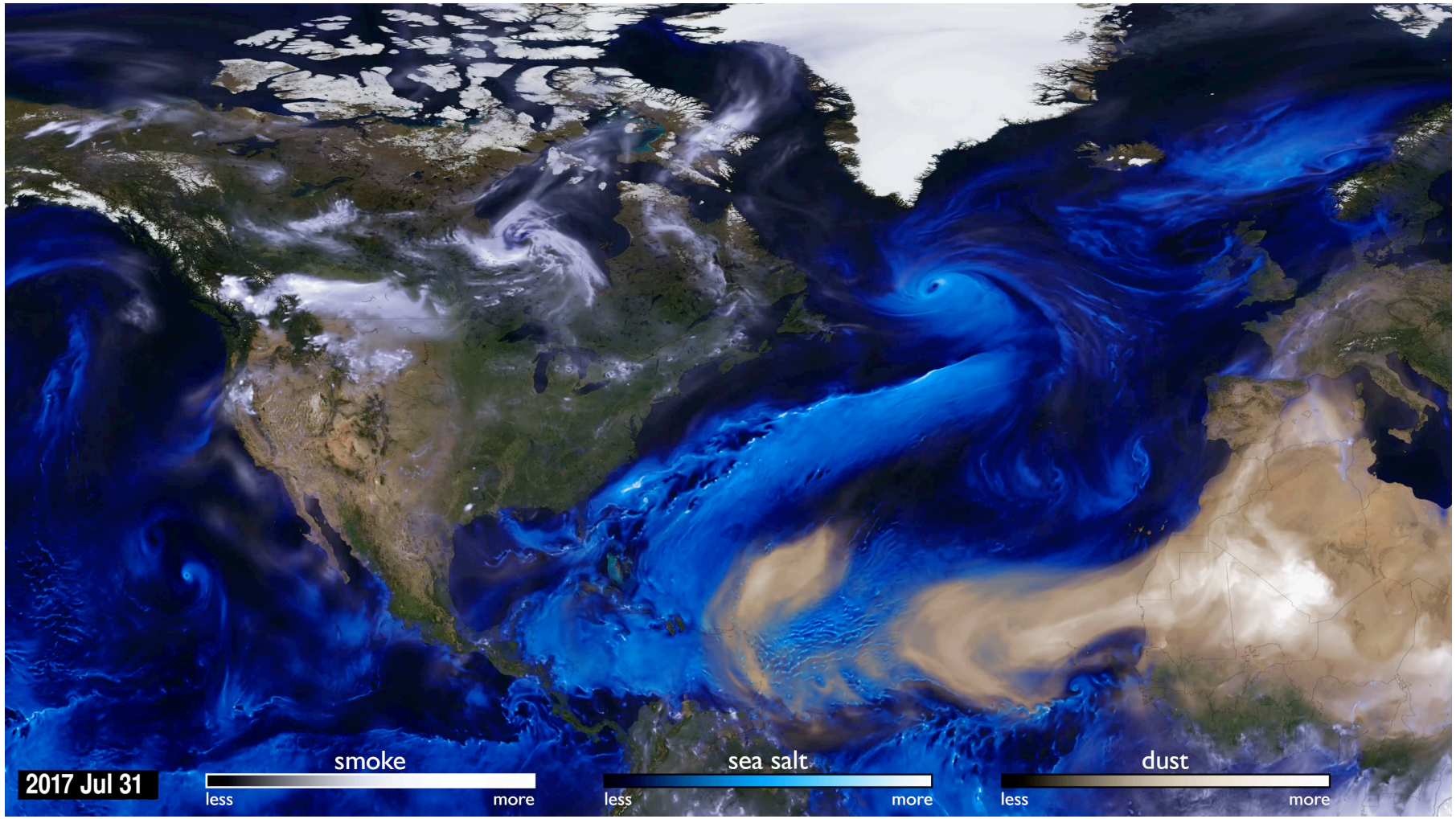
- Air pollution was responsible for 5.5 million deaths in 2013.
- Satellite data can help quantify the impact of aerosols on human health.

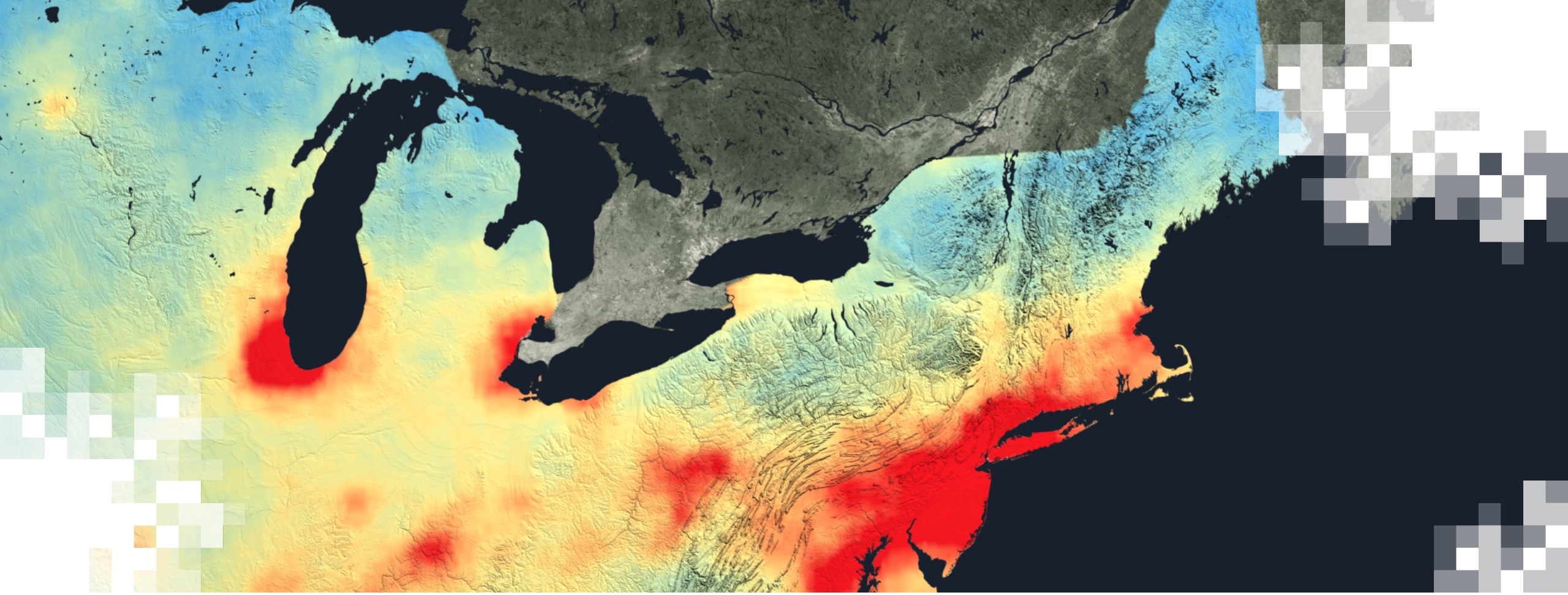
Image Credit: The Lancet

Assimilation of Satellite AOD into NASA Global Models

https://fluid.nccs.nasa.gov/weather/

- Satellite data can help identify fire locations and emissions, and total aerosol loading.
- Adding satellite data to models improves their forecasting accuracy.



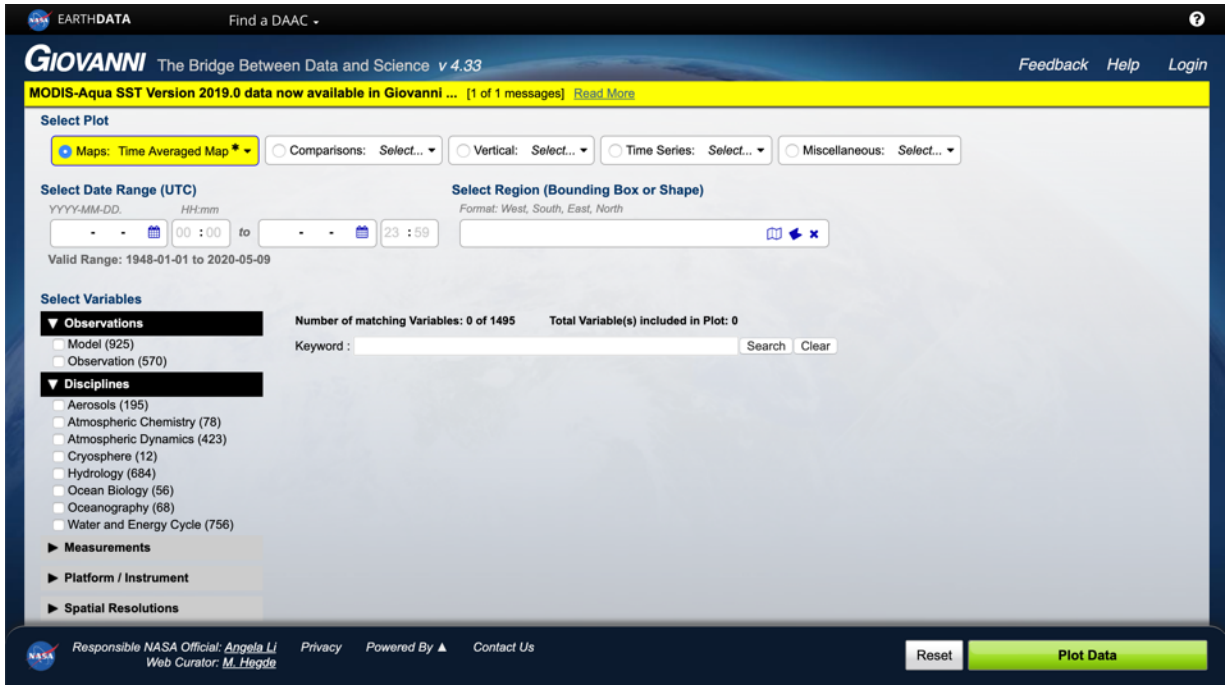


Data Access

Coarse Resolution Data Access, Visualization and Analysis

https://giovanni.gsfc.nasa.gov/giovanni/

- Level 3 data are gridded at equal latitude x longitude grid boxes.
- MODIS level 3 aerosol data are gridded at 1°x1° resolution (~110x110 km).
- Each level 3 aerosol file has data for either one day, eight days, or one month for the entire world.
- Level 3 data can be accessed, visualized, and analyzed using GIOVANNI.



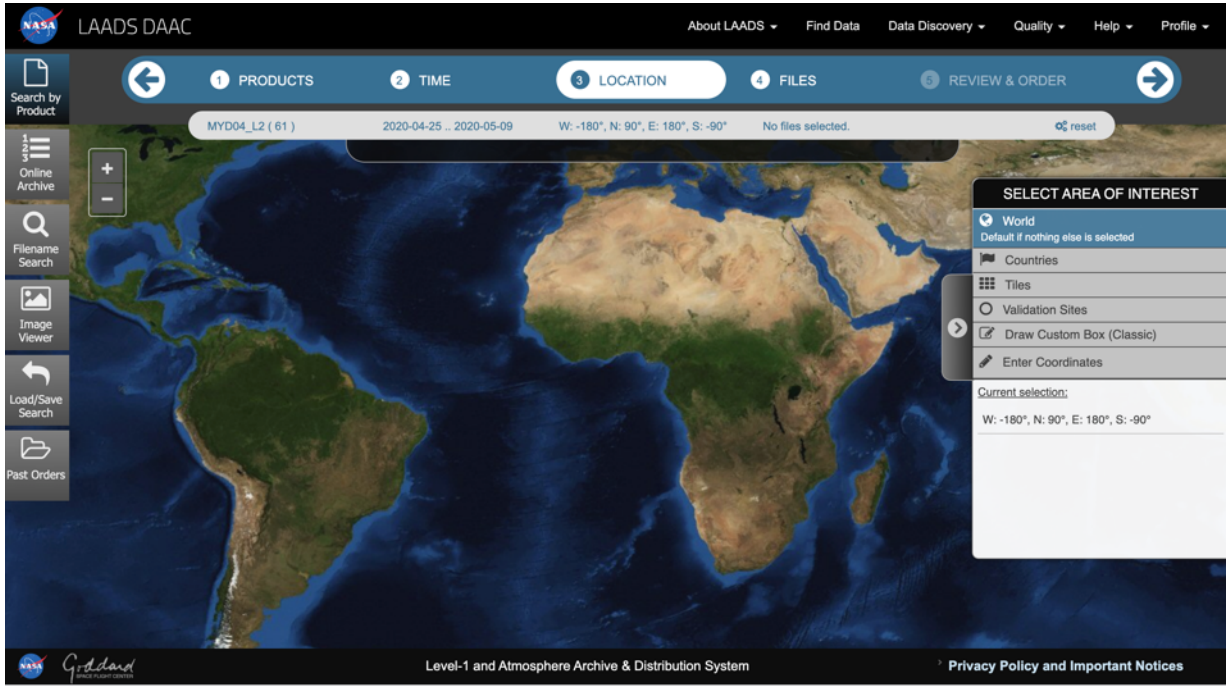
Step by Step Instructions for Using GIOVANNI

https://arset.gsfc.nasa.gov/sites/default/files/airquality/workshops/19-TEMPO/D1P5E_GiovanniAerosols_final.pdf

High Resolution Data Access

https://ladsweb.modaps.eosdis.nasa.gov/

- There are two MODIS sensors. One makes measurements in the morning (Terra) and one in afternoon (Aqua).
- Each level 2 aerosol file has data for 5 minutes of observation time.
- AOD data resolution is 10x10 km and 3 km.
- MODIS only provides day-time aerosol observations under cloud-free regions.
- Data comes in .hdf format, see sample python routine and tutorial.
- Panoply is open source software to visualize and map data from .hdf files.



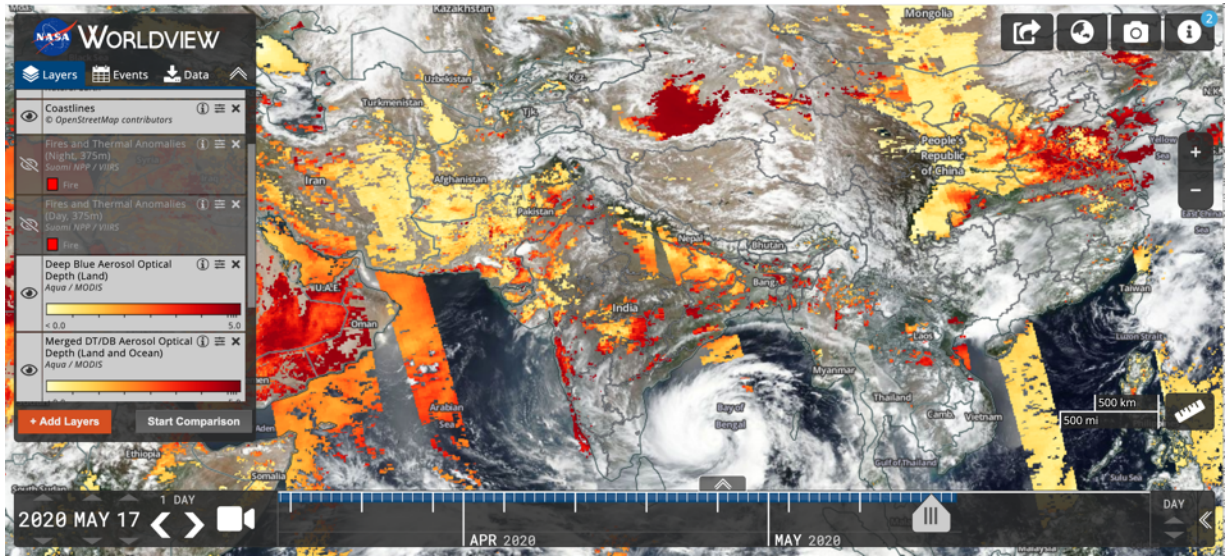
Step by Step Instructions to Download the Data
https://arset.gsfc.nasa.gov/sites/default/files/airquality/webinars/18-hires/s1e-final.pdf

High Resolution MODIS AOD Data Usage

- The MODIS Aerosol Product name is 'MYD04_L2/MOD04_L2' – This will help identify the files and satellite – MYD -> MODIS-Aqua data, and MOD-> MODIS-Terra Data
- There are many variables (SDS) in each .hdf file, including multiple AODs, sun-satellite viewing geometry, geographical locations, observation time, and other parameters for research and analysis.
- Each AOD value is also associated with quality flags, and only high-quality data should be used for quantitative analysis.
- The recommended parameter for data analysis is:
  - "Dark_Target_Deep_Blue_Optical_Depth_550_Combined"
  - It is Deep Blue & Dark Target Algorithm Merged Product – 10 km only
  - The product is already quality controlled, no additional QAF filtering is required.
- For more details on data sets and python scripts to read & extract data, refer to this online tutorial: PPT, Recording

NASA Worldview

https://worldview.earthdata.nasa.gov



https://www.youtube.com/watch?v=nW8JZJ-5g_0&feature=youtu.be

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