National Aeronautics and Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
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Current and Future Satellite Capabilities for Air Quality Monitoring: An Overview

Pawan Gupta and Melanie Follette-Cook

Satellite Remote Sensing of Air Quality

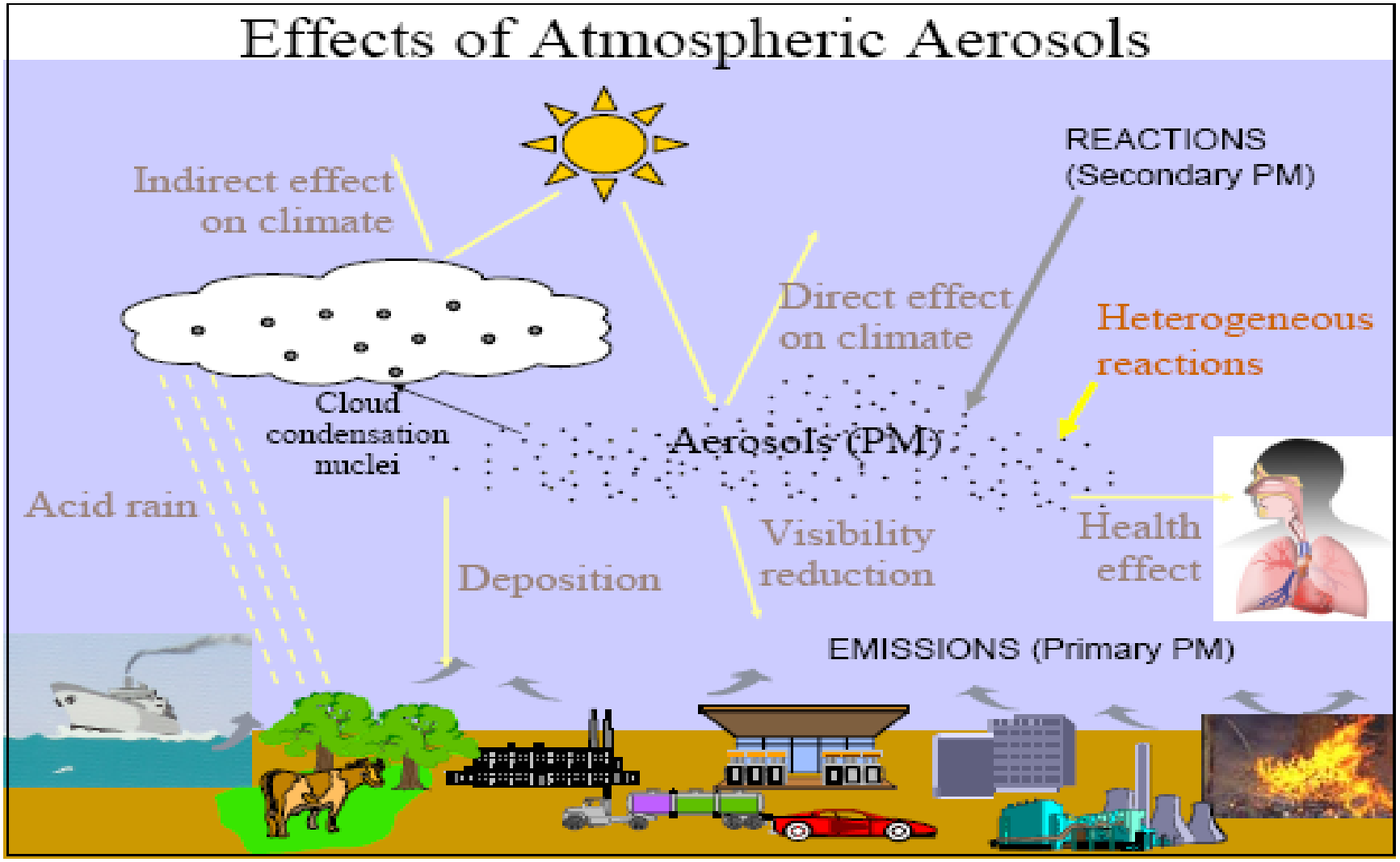
September 19-21, 2017
University of California, Riverside

Learning Objectives

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

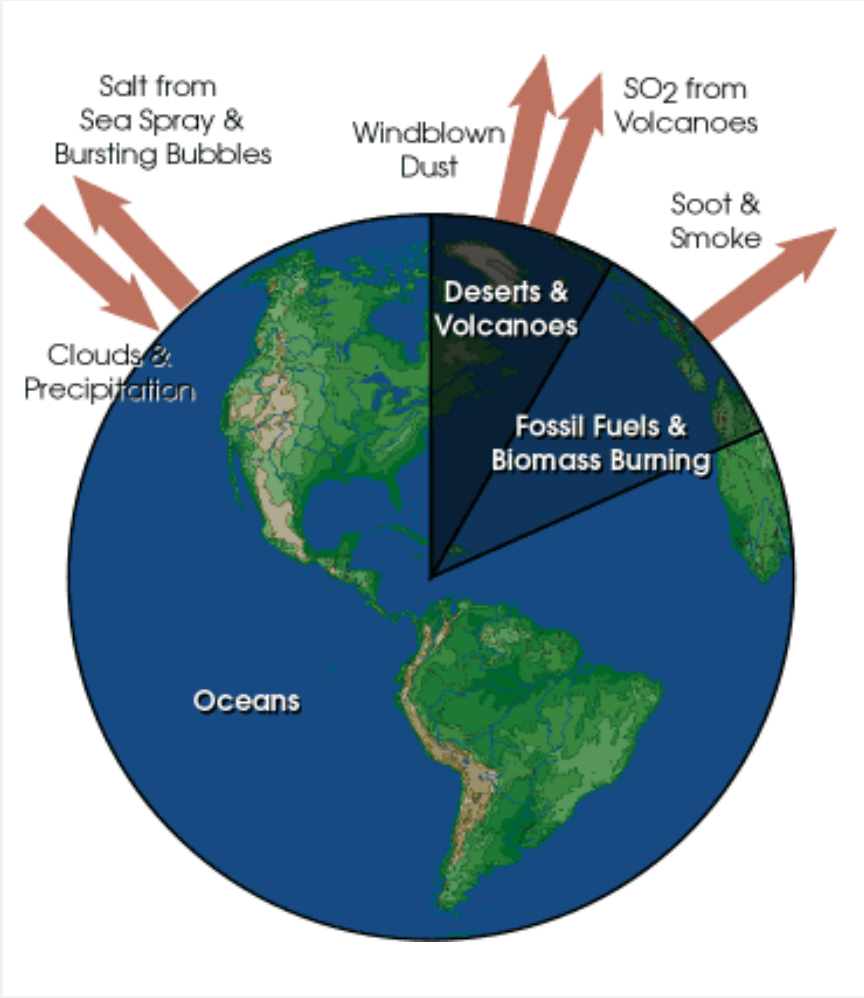
- Describe existing satellite capabilities for global air quality monitoring
- Identify upcoming and future satellite missions for air quality monitoring

Motivation: Tiny, but Potent

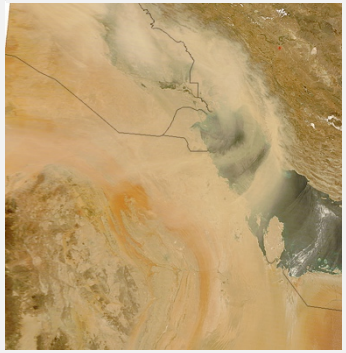


Pollution Sources

Atmospheric aerosols are highly variable in space and time



Dust

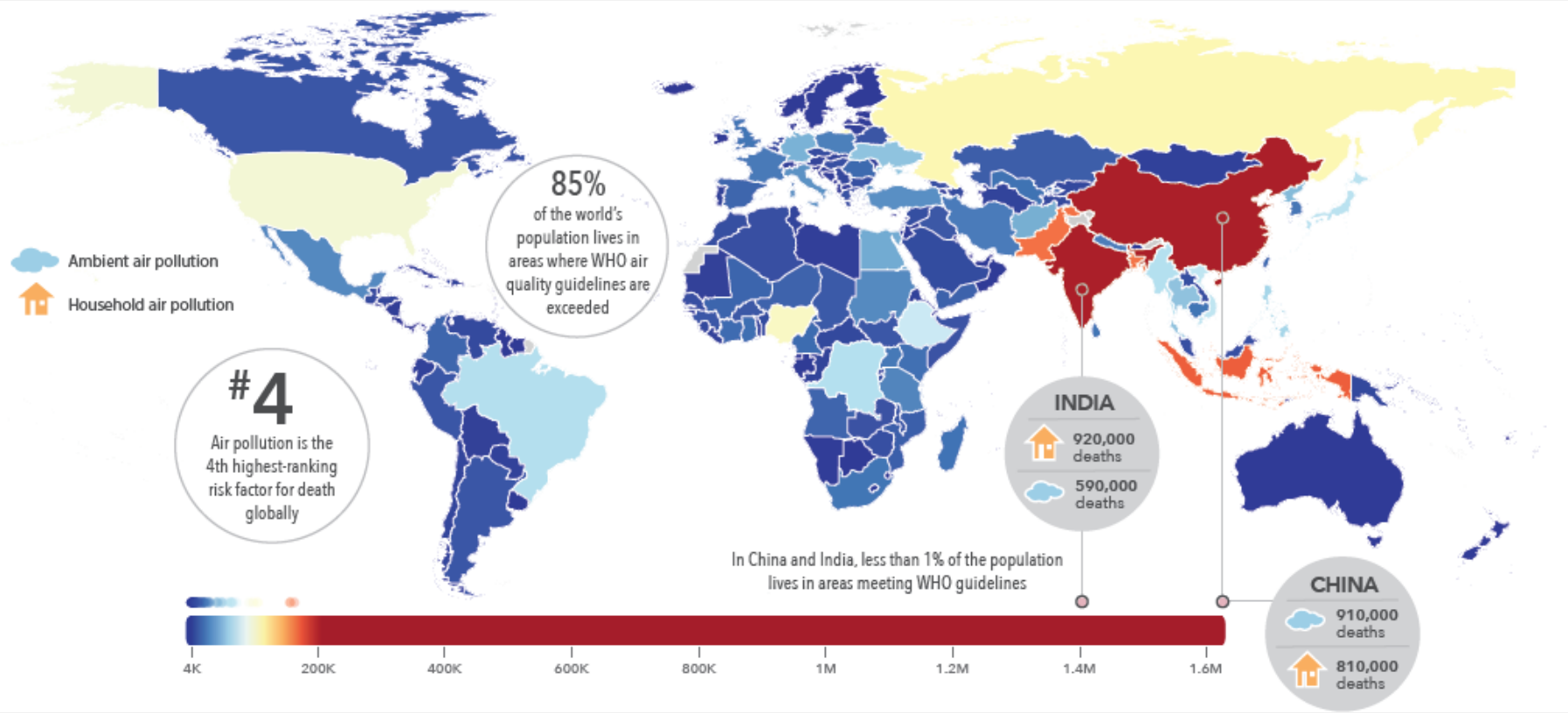


Volcanoes

Fossil Fuels & Biomass Burning

Soot & Smoke

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

Image Credit: http://thelancet.com/gbd/2013

UN Sustainable Development Goals (SDGs)

Transforming Our World: The 2030 Agenda for Sustainable Development

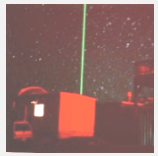
- A plan of action for people, planet, and prosperity
- All countries and all stakeholders, acting in collaborative partnership, will implement this plan
- 17 SDGs and 169 targets under this agenda
- Balance the three dimensions of sustainable development:
  - economic, social, and environmental

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

Traditional Air Quality Monitoring

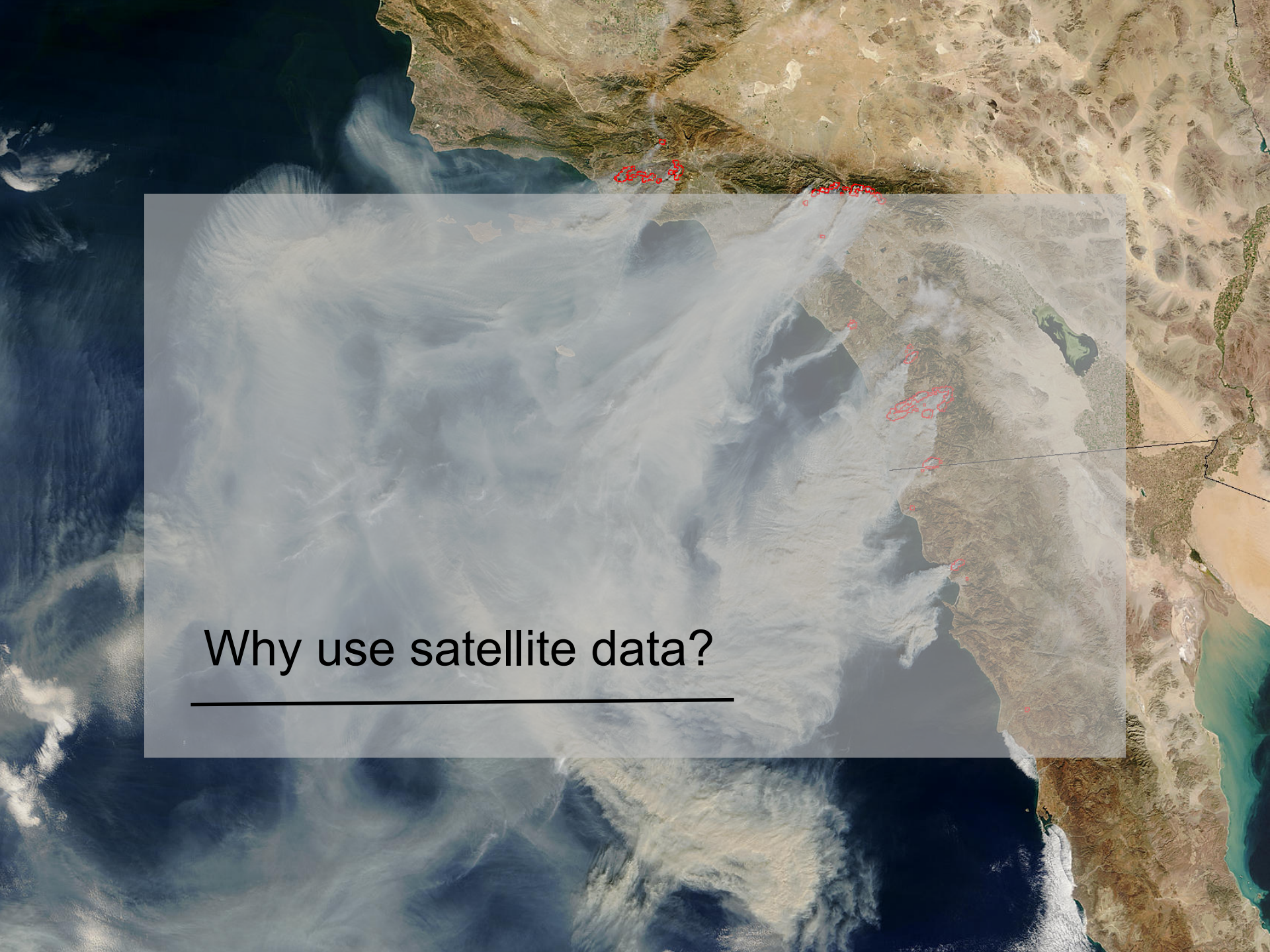
Air Pollution Monitoring

Ground Measurements



Air & Space Observations

Models

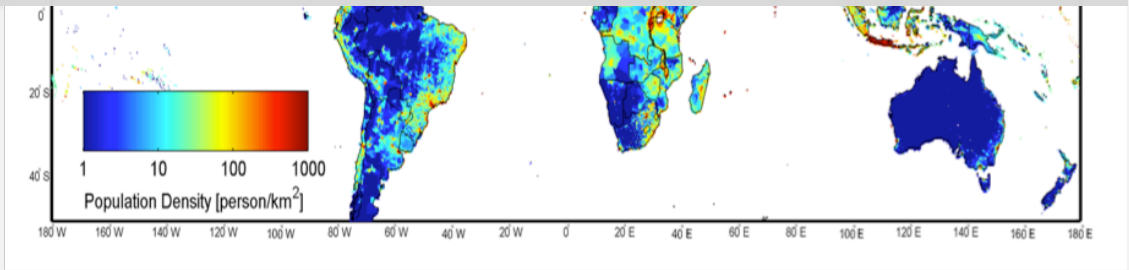


Why use satellite data?

Global Status of $PM_{2.5}$ Monitoring

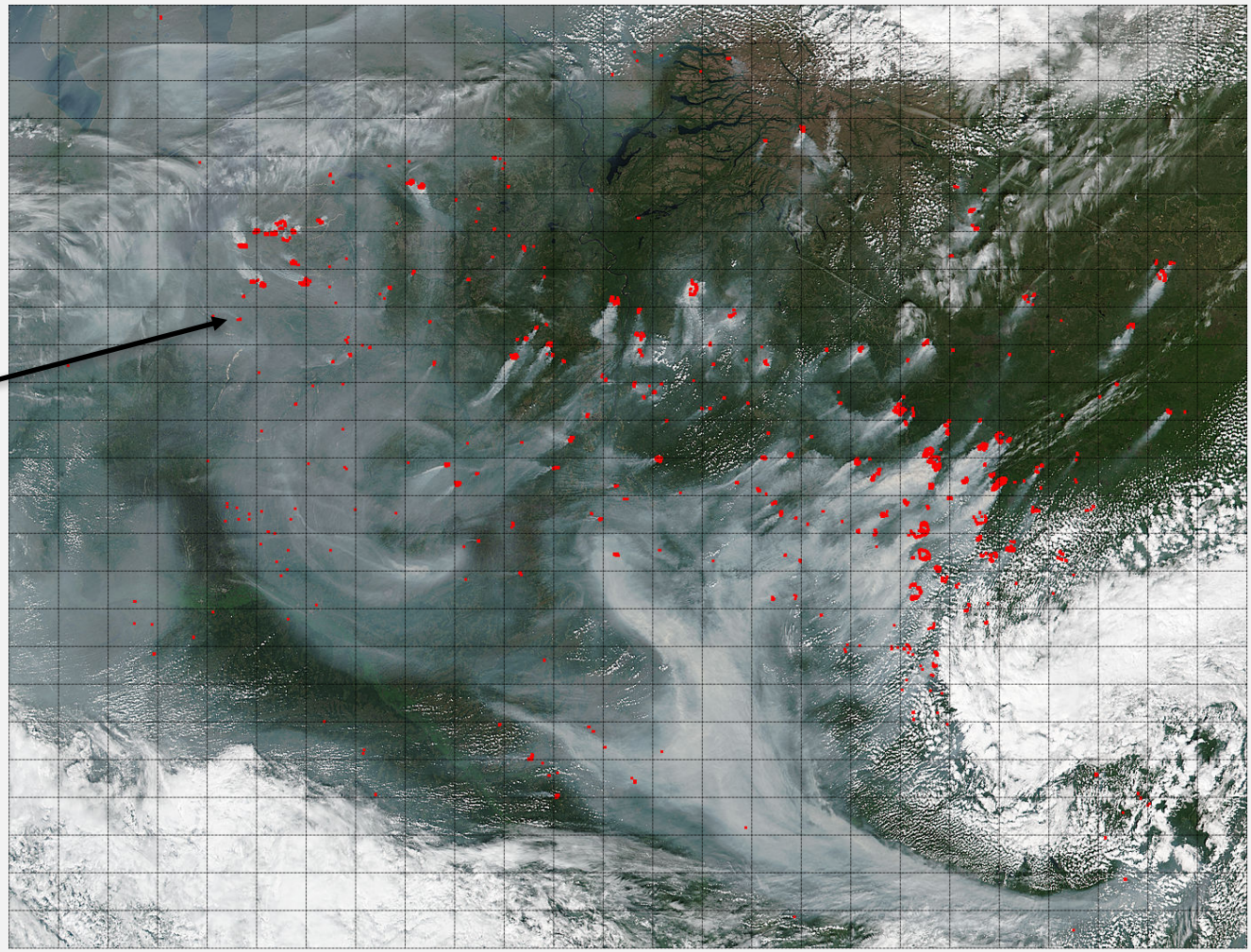
- Many countries do not have $PM_{2.5}$ mass measurements
- Spatial distribution of air pollution from existing ground network does not support high population density
- 2,400 out of 3,100 counties in the U.S. (31% of the total population) have no PM monitoring
- Surface measurements are not cost effective
- Can satellite measurements be used to fill these gaps?

Density



“A Picture is Worth a Thousand Words”

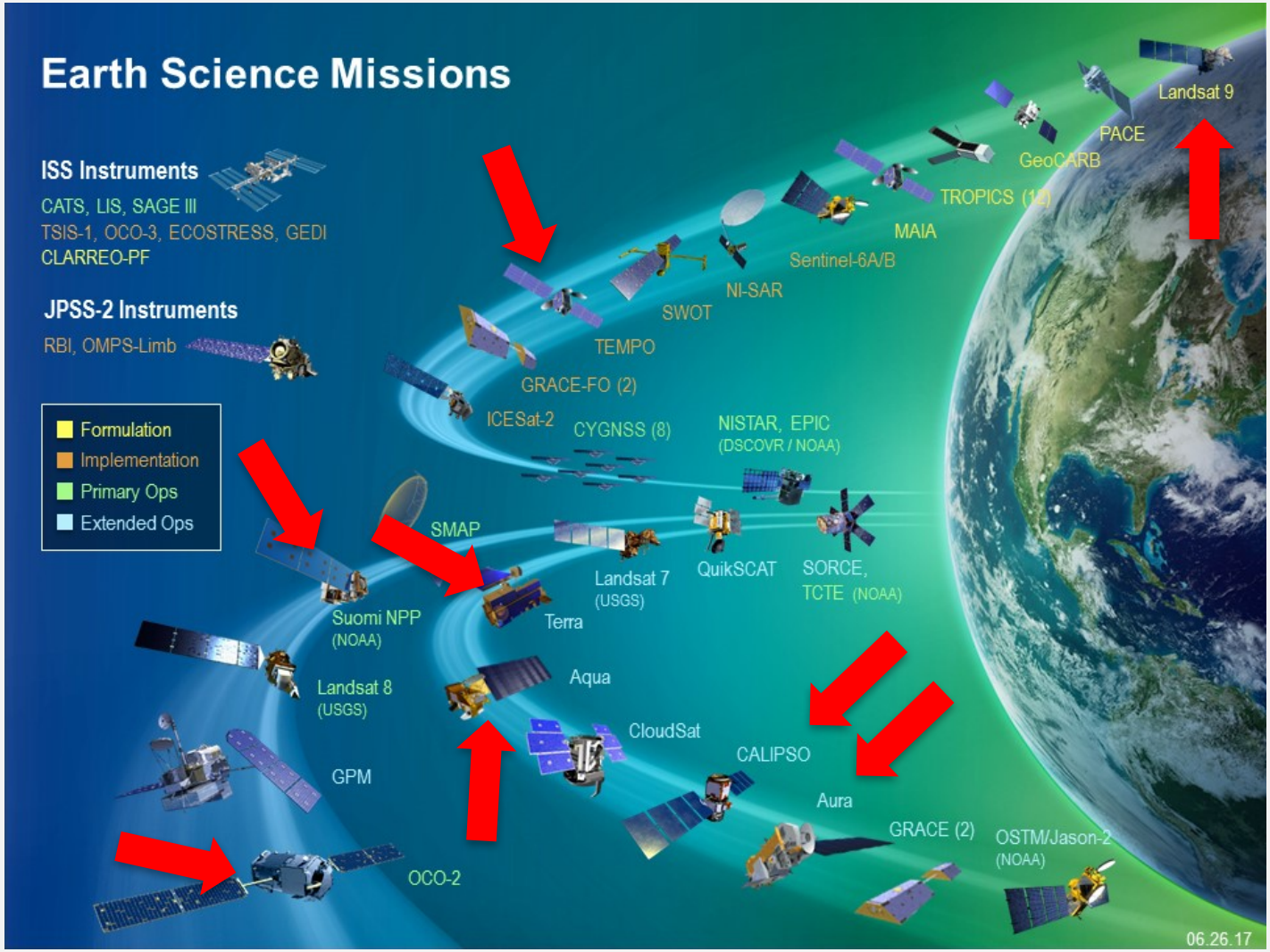
A satellite picture is worth ~~a~~ **millions of data points**



A geo-physical number

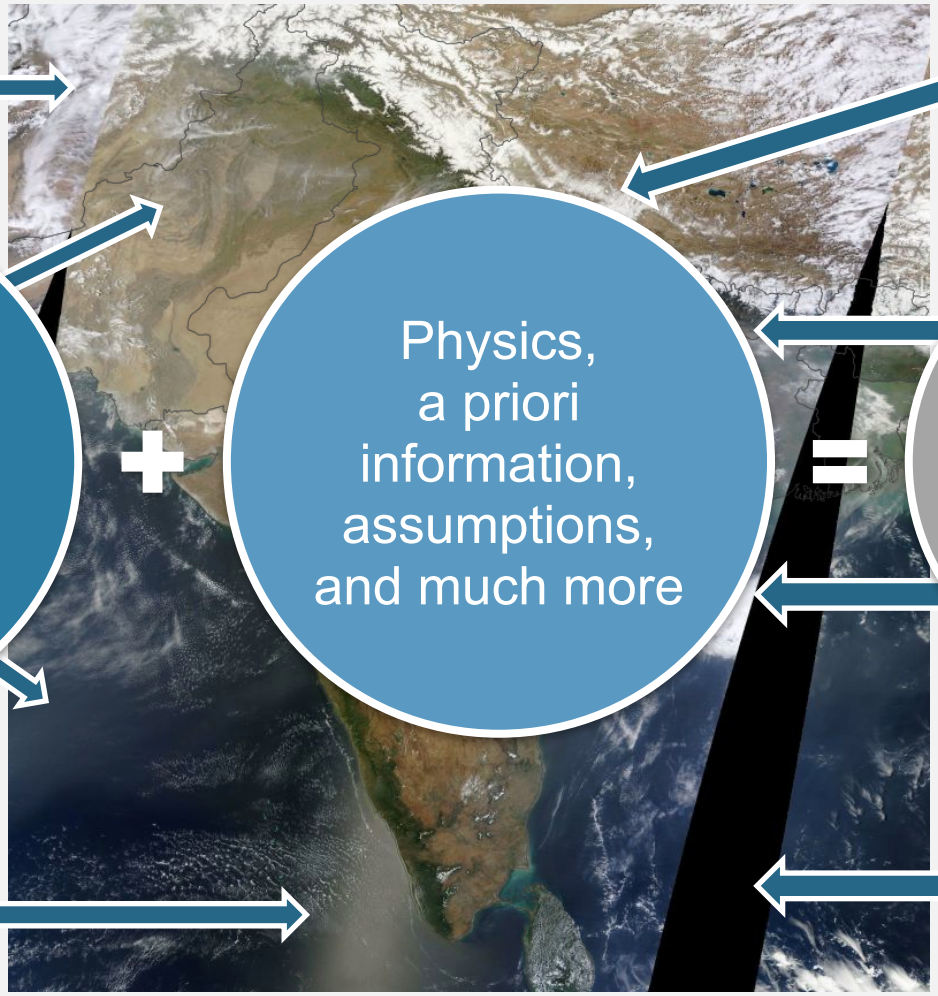
NASA Earth Science

Current and Upcoming Missions



What can we learn from true color imagery?

MODIS Terra Image, April 19, 2013



Clouds

Snow

Satellite Observations (Spectral Radiance)

+

Physics, a priori information, assumptions, and much more

=

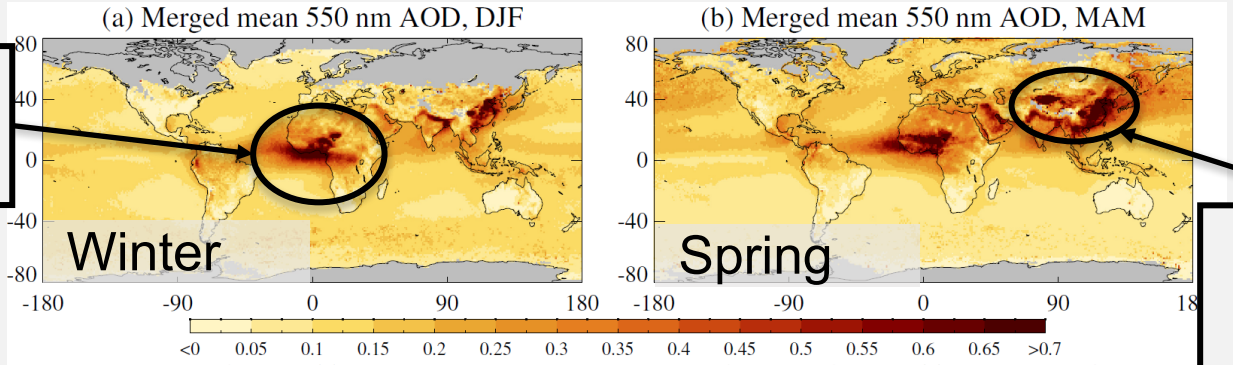
Geophysical Parameters (e.g. AOD)

Glint

Data collection gap

Aerosols from Satellites

Aerosol Optical Thickness (MODIS Aqua)



Biomass burning

Pollution & Dust

Haze & Pollution

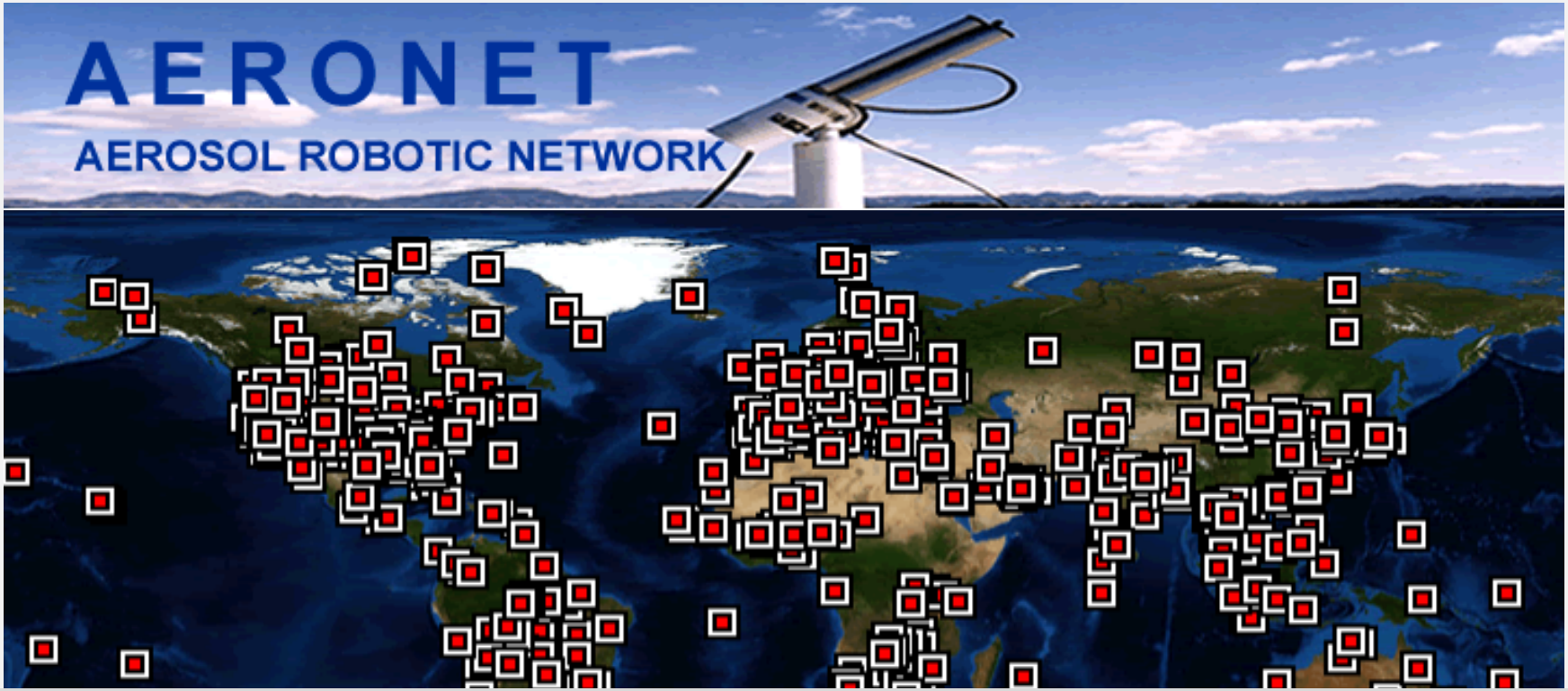
Dust

Biomass burning

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

AERONET

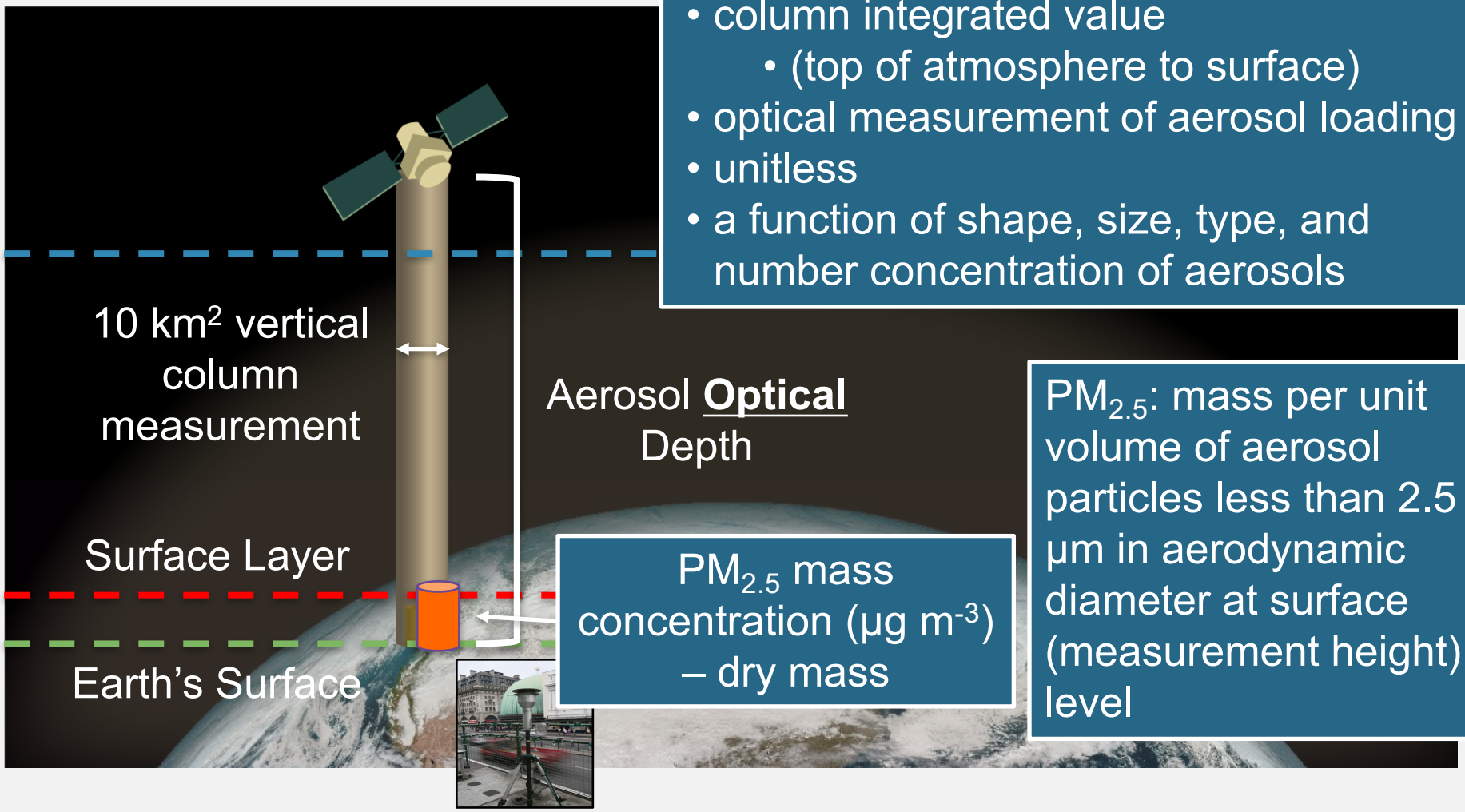
http://aeronet.gsfc.nasa.gov/



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

Applications

Satellite vs. Ground Observation

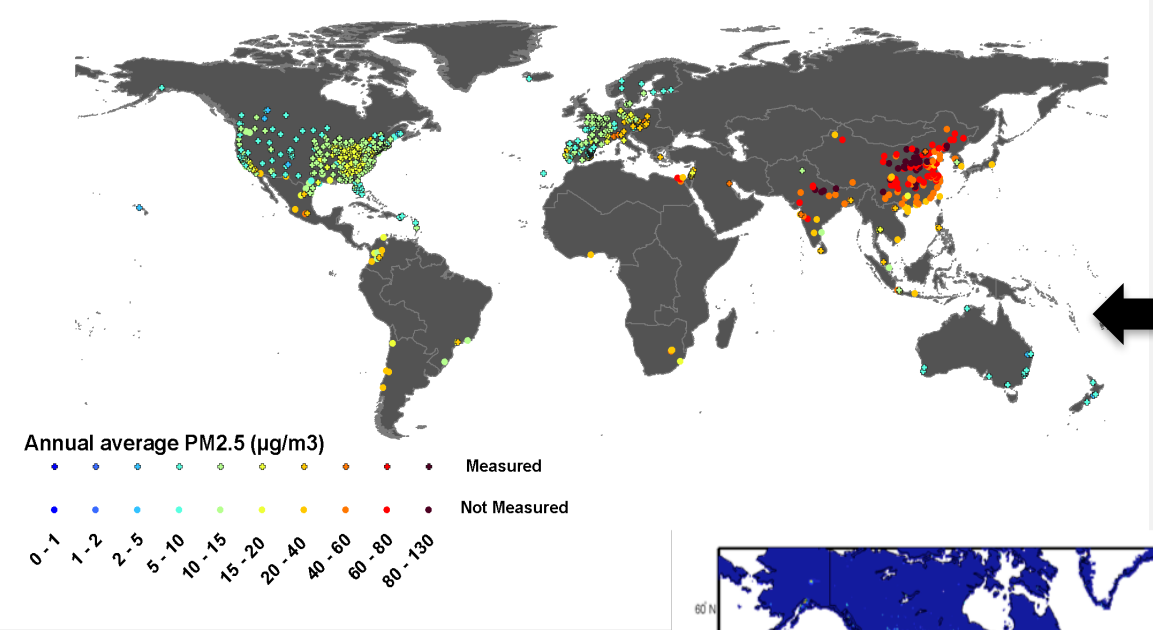


AOD:
- column integrated value
  - (top of atmosphere to surface)
- optical measurement of aerosol loading
- unitless
- a function of shape, size, type, and number concentration of aerosols

$PM_{2.5}$: mass per unit volume of aerosol particles less than 2.5 µm in aerodynamic diameter at surface (measurement height) level

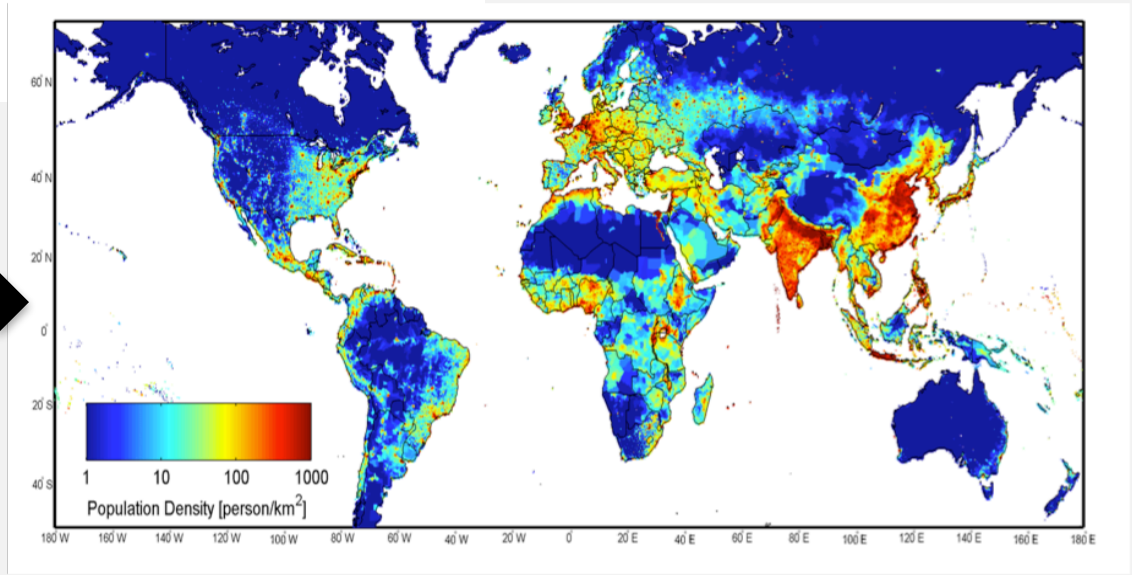
Satellite vs. Ground Observation

Global Status of $PM_{2.5}$ Monitoring

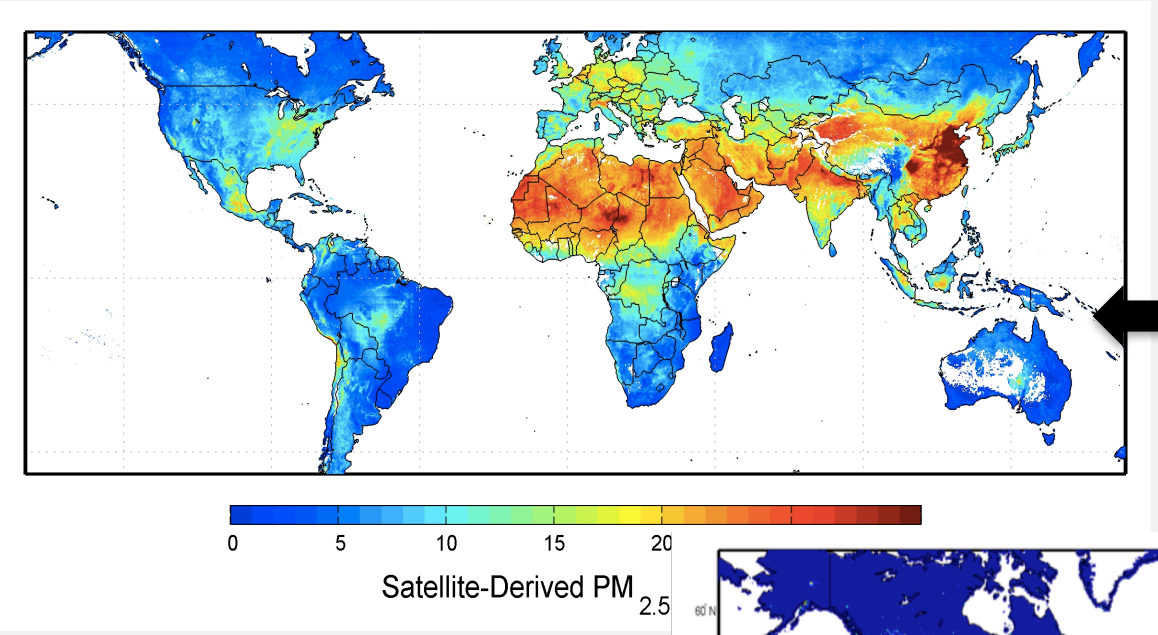


Ground Sensor Network

Population Density



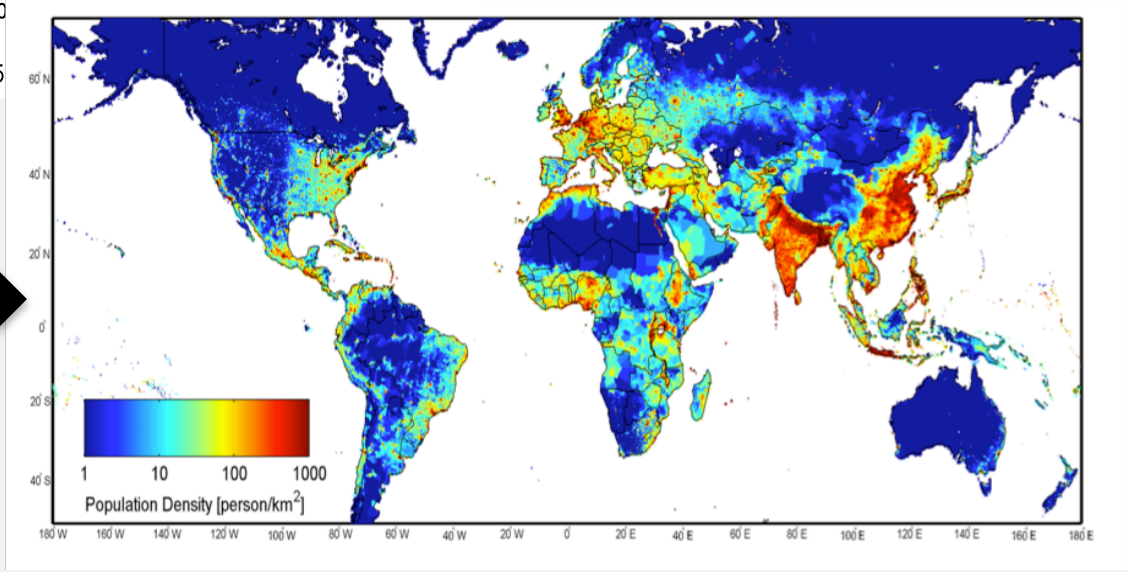
Global Status of $PM_{2.5}$ Monitoring: Future View



Satellite Estimated $PM_{2.5}$

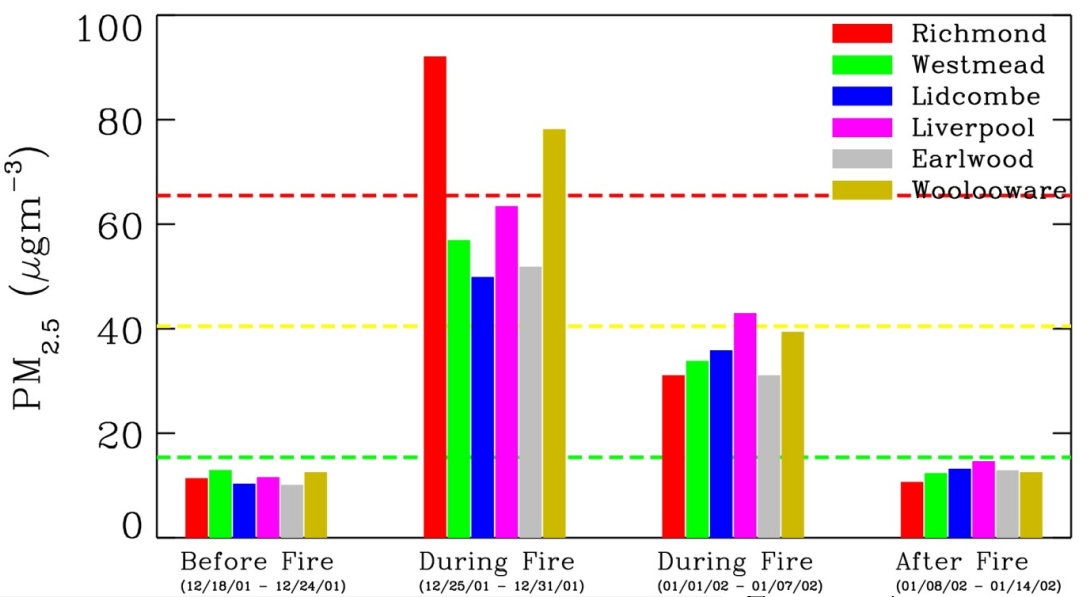
van Donkelaar et al., 2010

Population Density



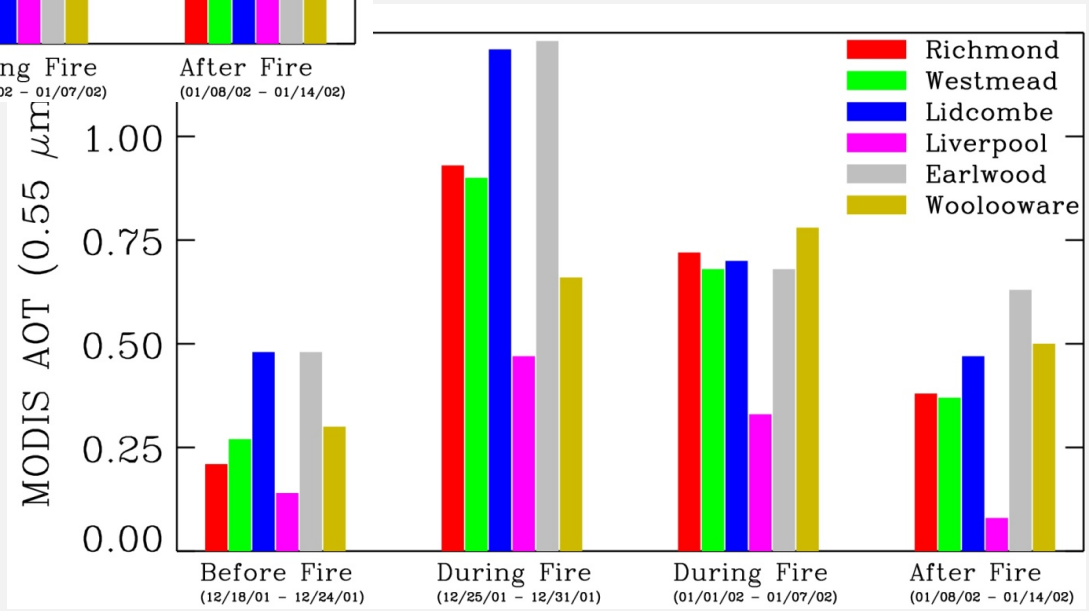
Application of Satellite Observations

Bushfires in Sydney, Australia



Surface $PM_{2.5}$

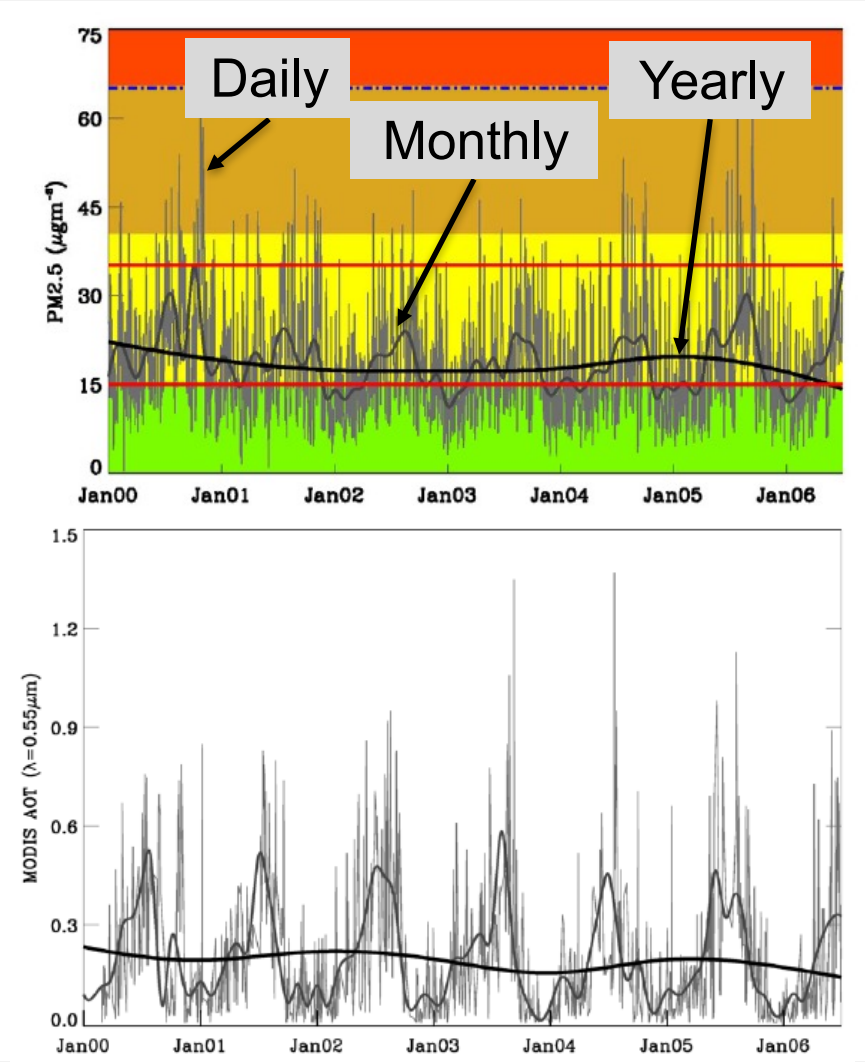
AOD from satellite



Credit: Gupta and Christopher, 2007

Air Quality Trends

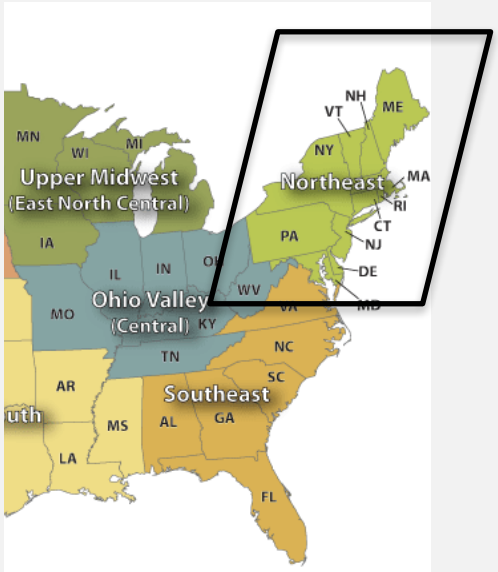
Birmingham, Alabama

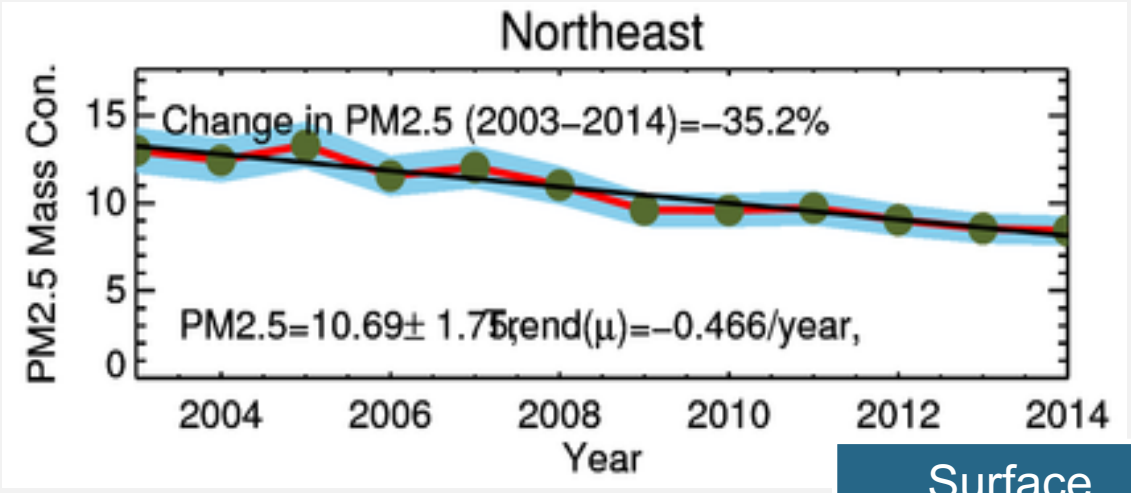


- Decreasing trend in annual $PM_{2.5}$, 22% from 2002 to 2006
- MODIS-Terra Collection 5, Level 2, 10 km^2 AOTs for 2000-2006

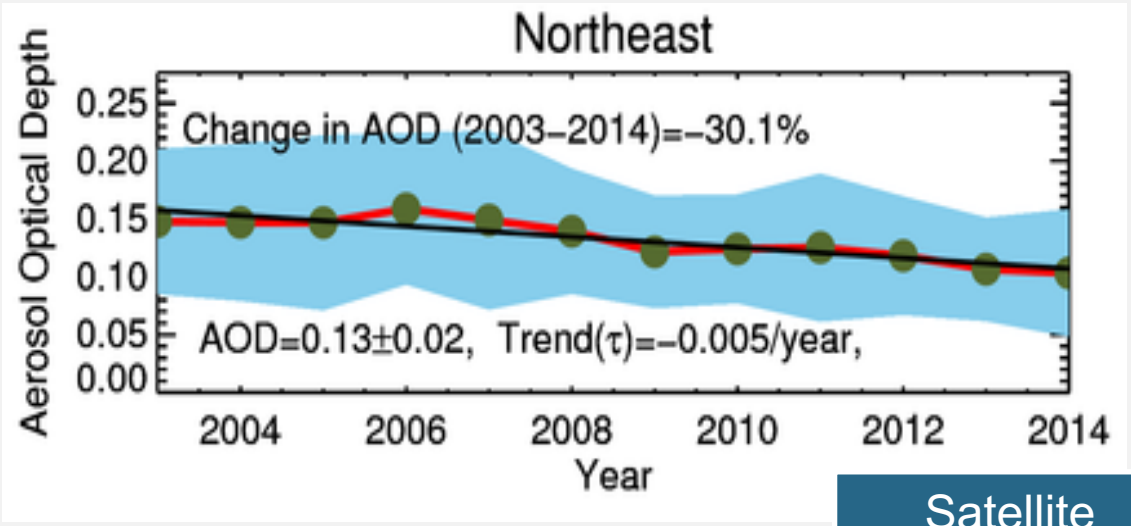
Source: Gupta and Christopher, 2007

Measurements: Surface vs. Satellite



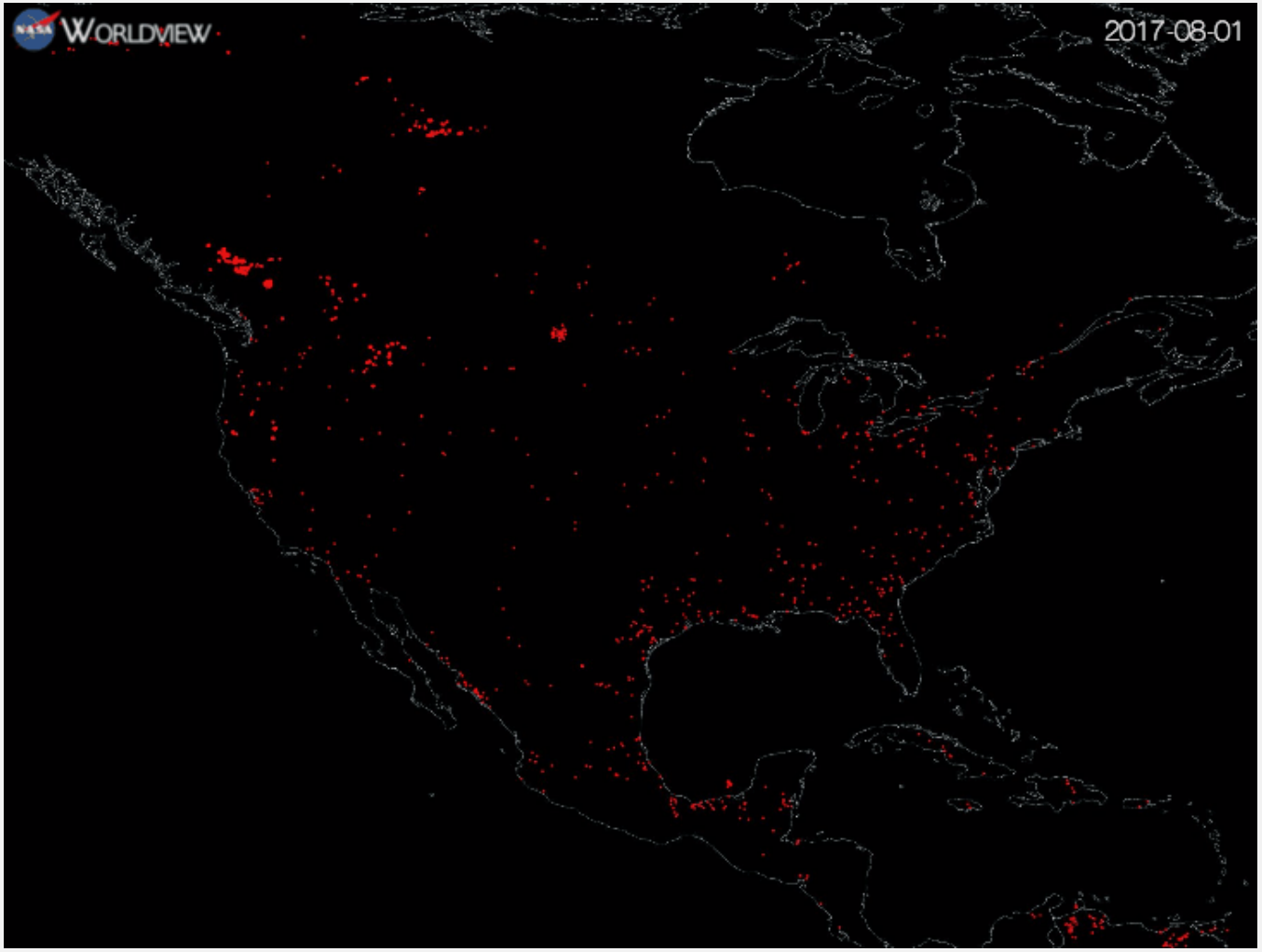


Surface



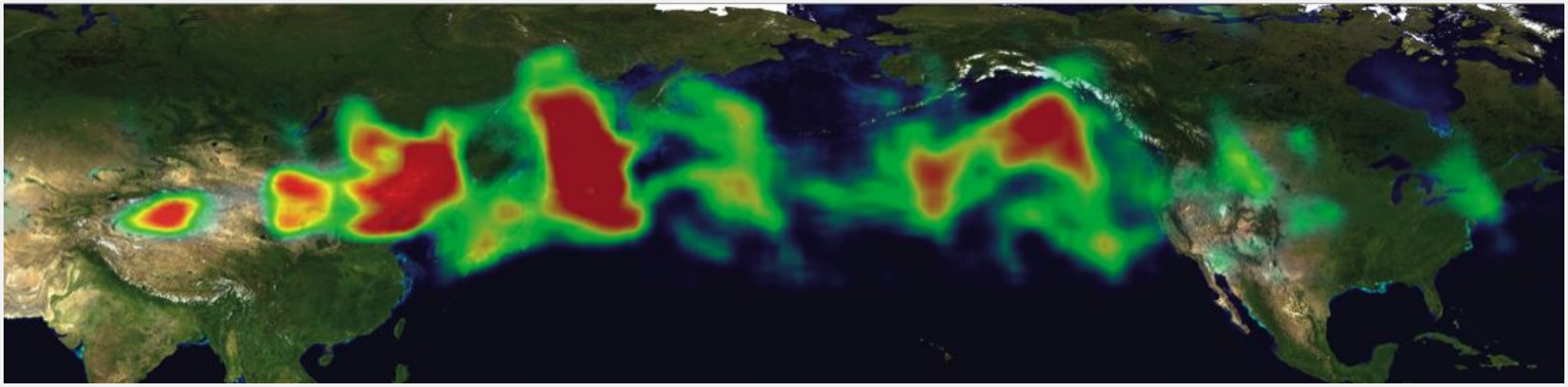
Satellite

Fire Detection and Monitoring

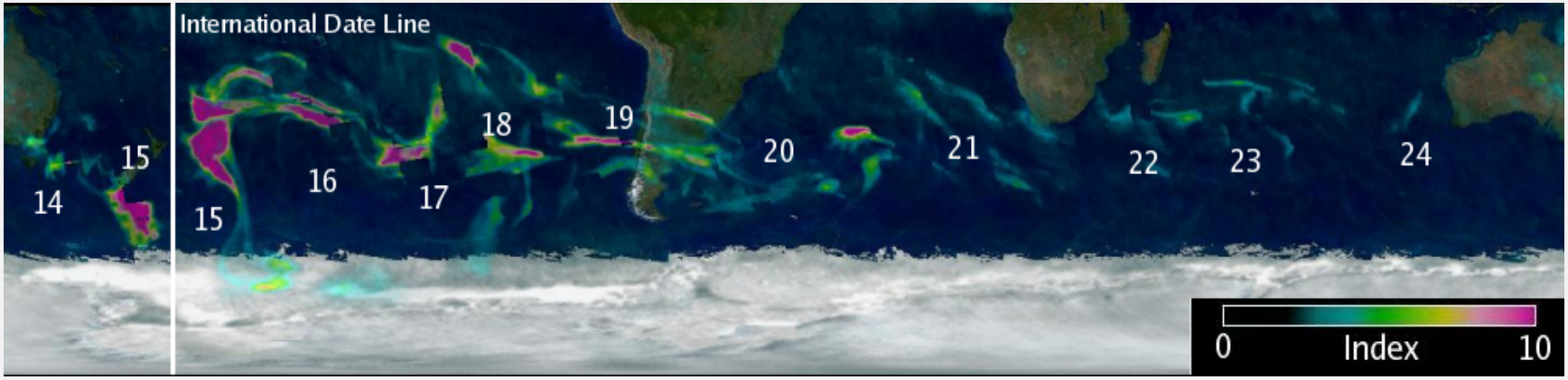


Long Range Transport

Dust from Mongolian Deserts Reaches the U.S.

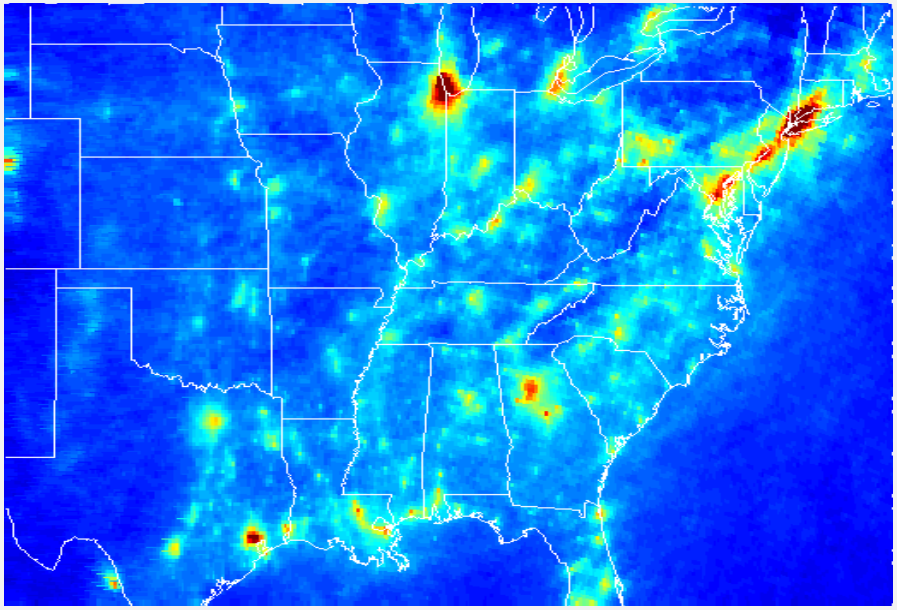


Smoke Travels Around the World in 11 Days

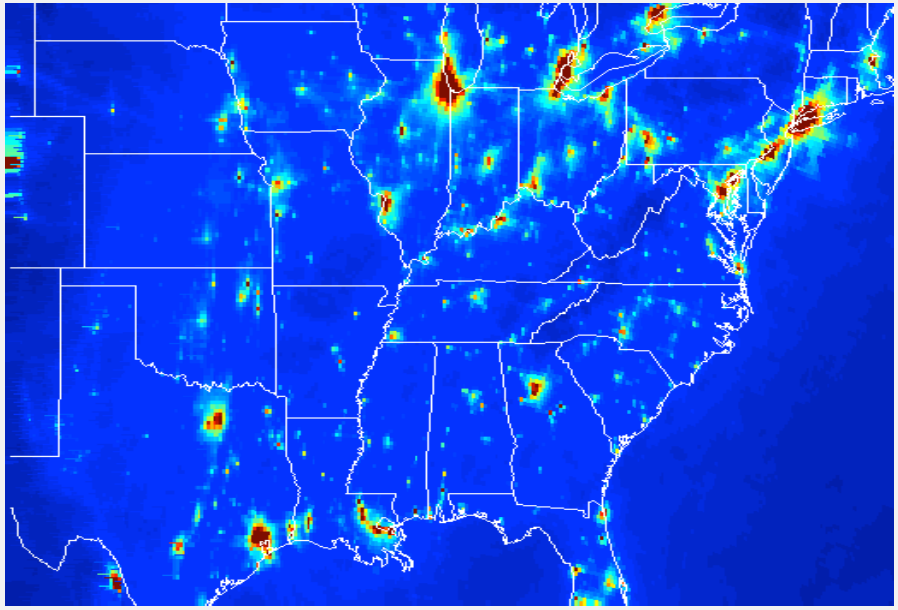


Model-Satellite Inter-comparison

CMAQ Model NO_2

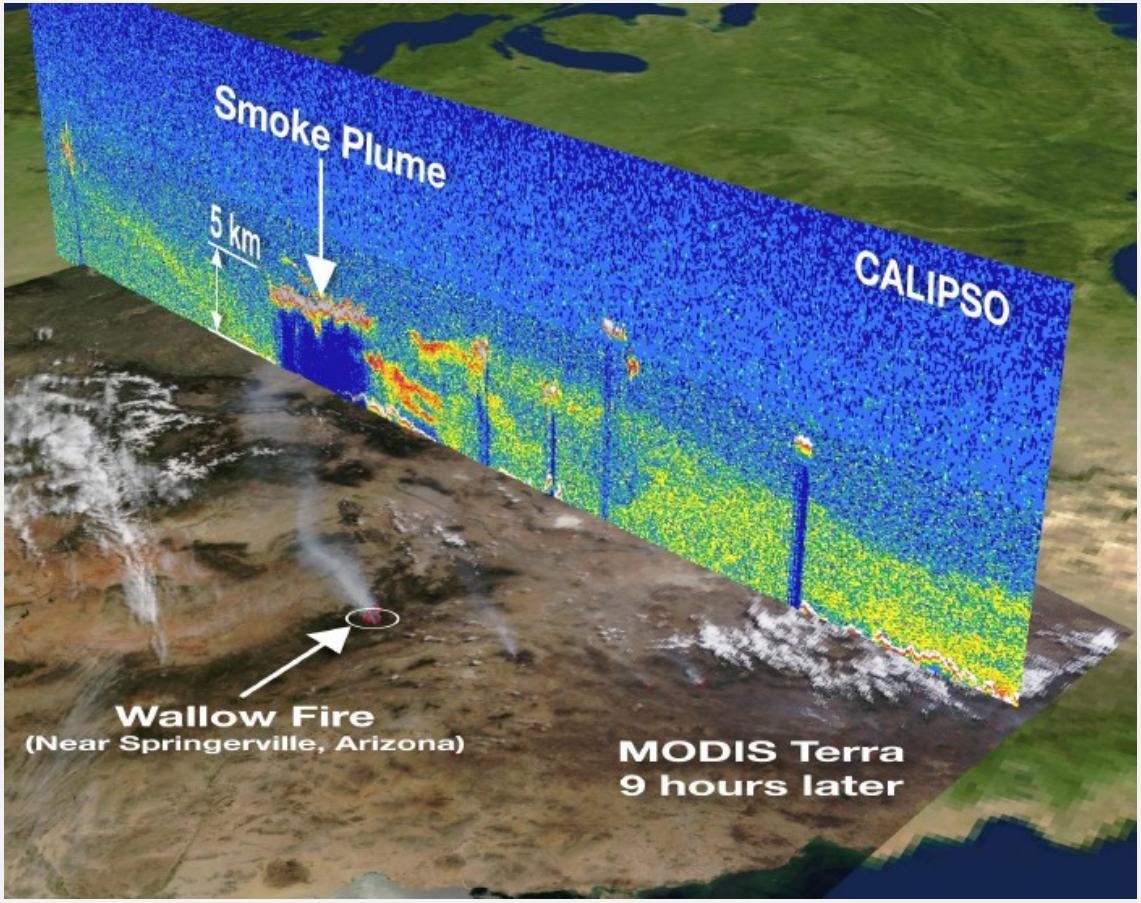


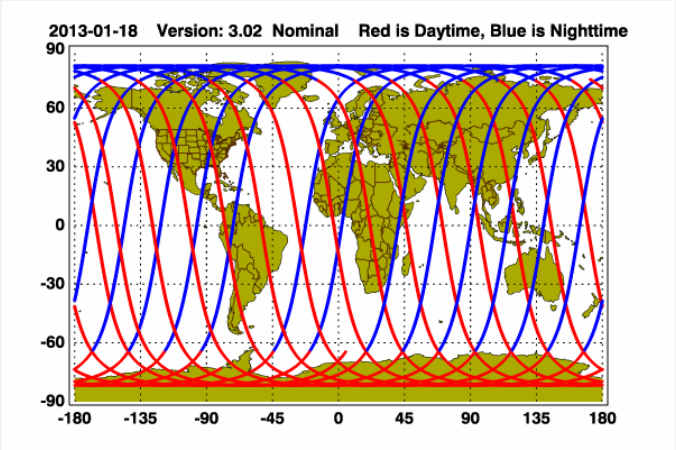
OMI NO_2



Vertical Profiles of Aerosols

CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

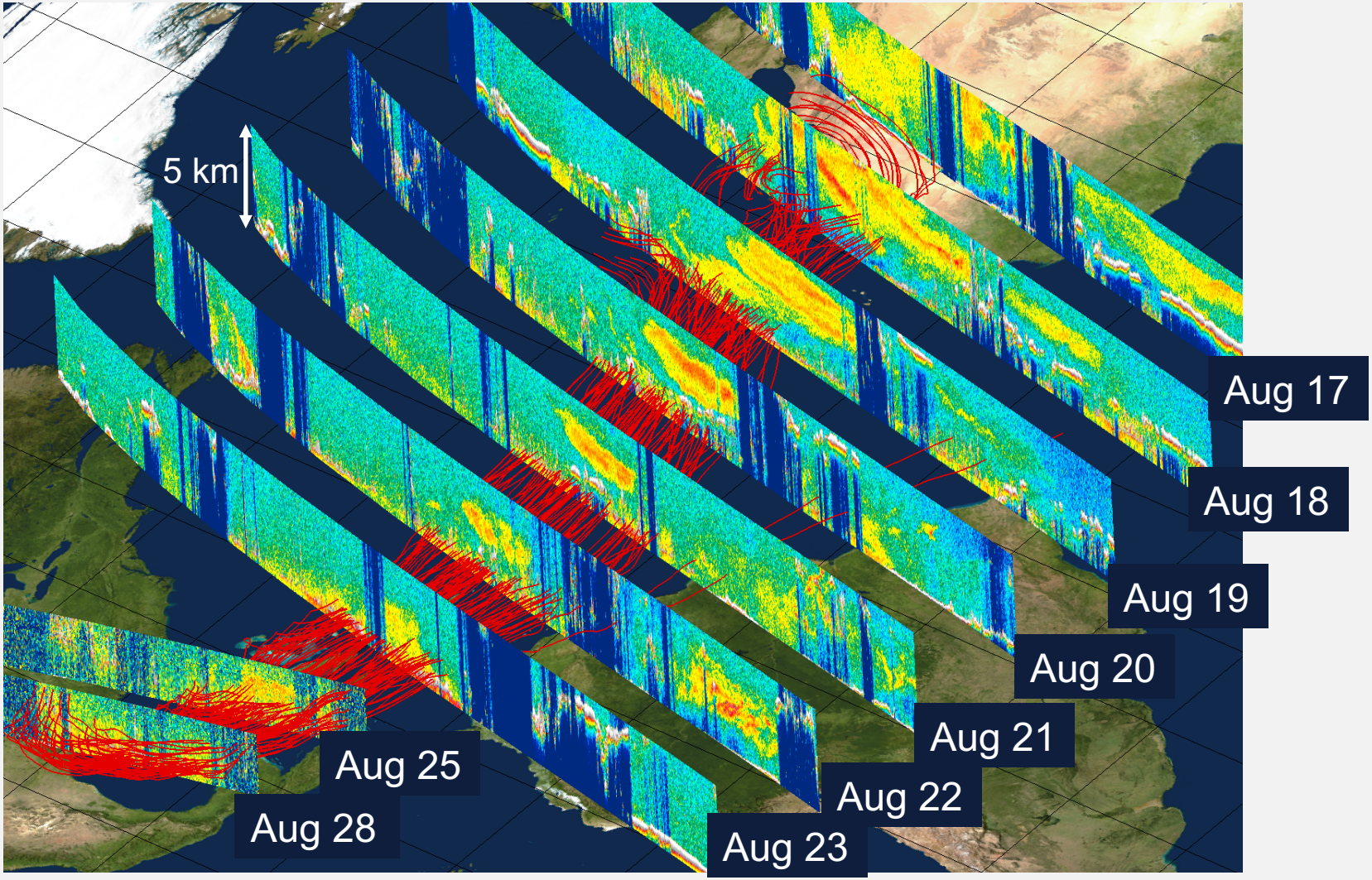




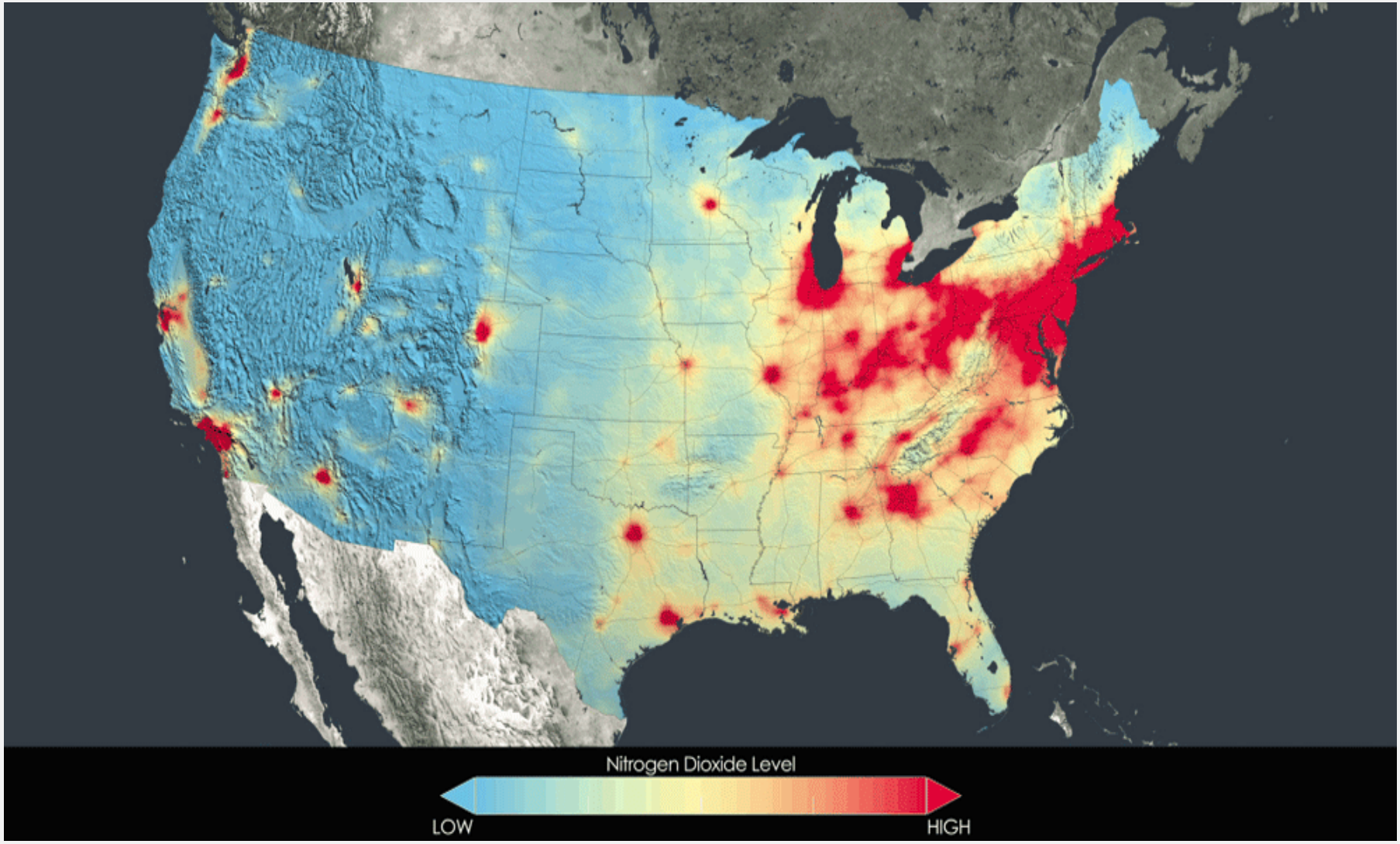
CALIPSO Browse Images
http://www-calipso.larc.nasa.gov/products/lidar/browse_images/production/

Example of CALIPSO Data

Major Saharan Dust Transport Event: Aug 17-28

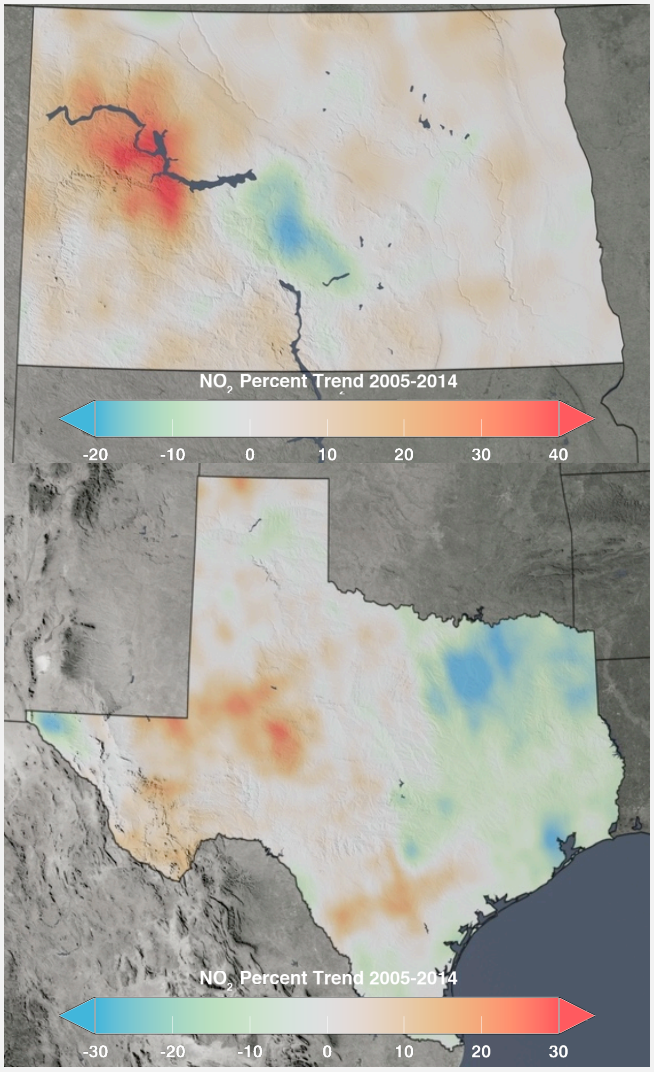


NO_2 Trends Over the United States



OMI Detects NO_2 Increases from ONG Activities

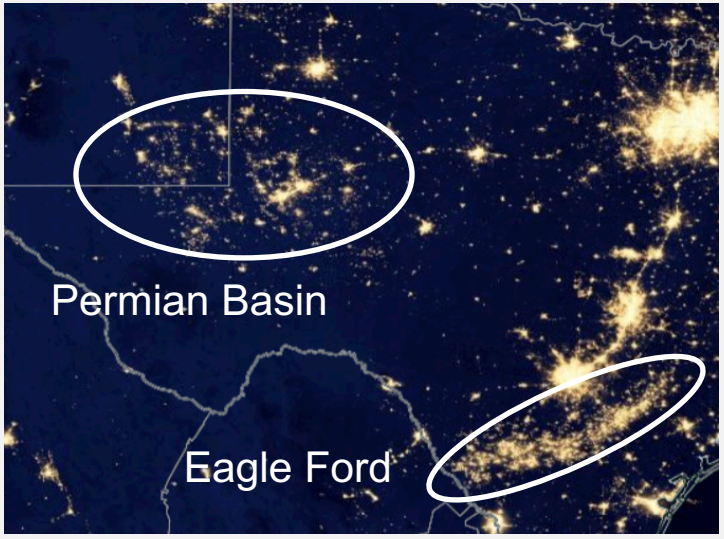
2005-2014



North Dakota

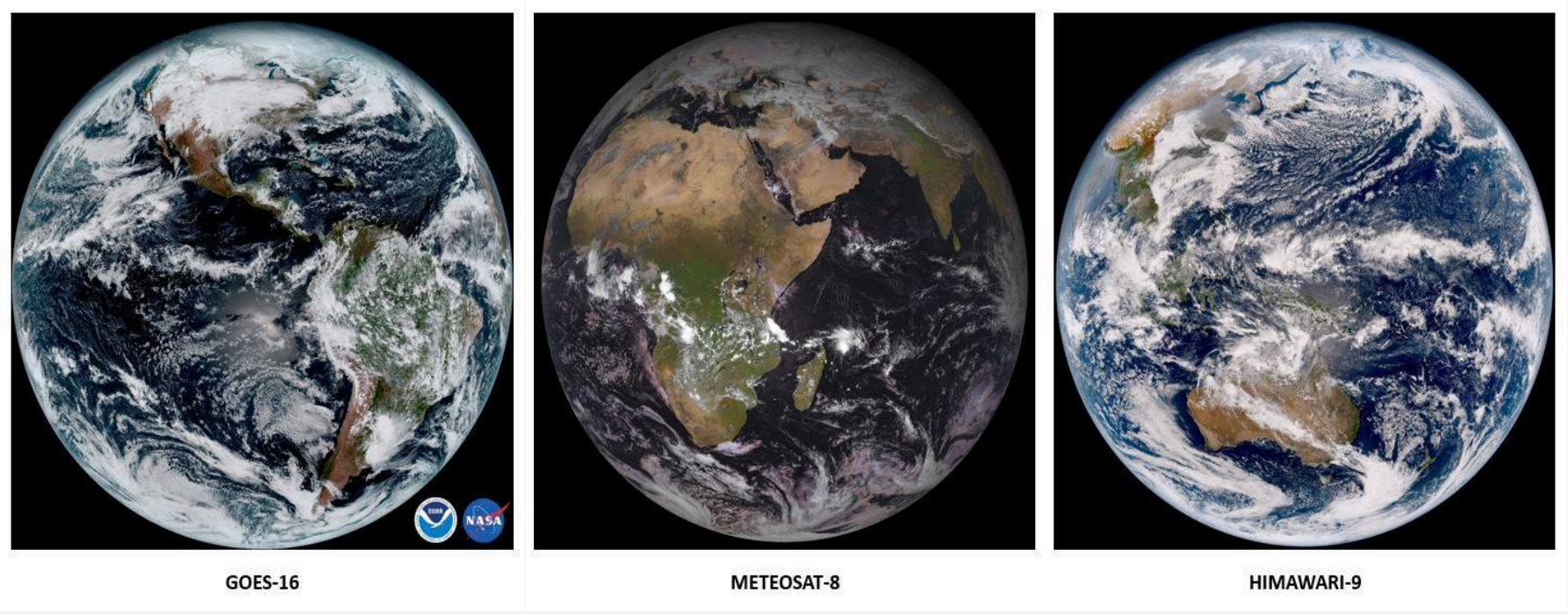
Suomi NPP VIIRS Lights at Night

Texas



Breaking the Temporal Barrier

The beginning of a new era in satellite remote sensing of air quality



Source: NOAA NESDIS

GOES-R

- Launched: November, 2016
- Advance Baseline Imager (ABI): 16 Spectral Bands
- Very High Temporal Resolution: 15 min – 30 seconds

GOES-16 Loop: Smoke Over the Southeast U.S.

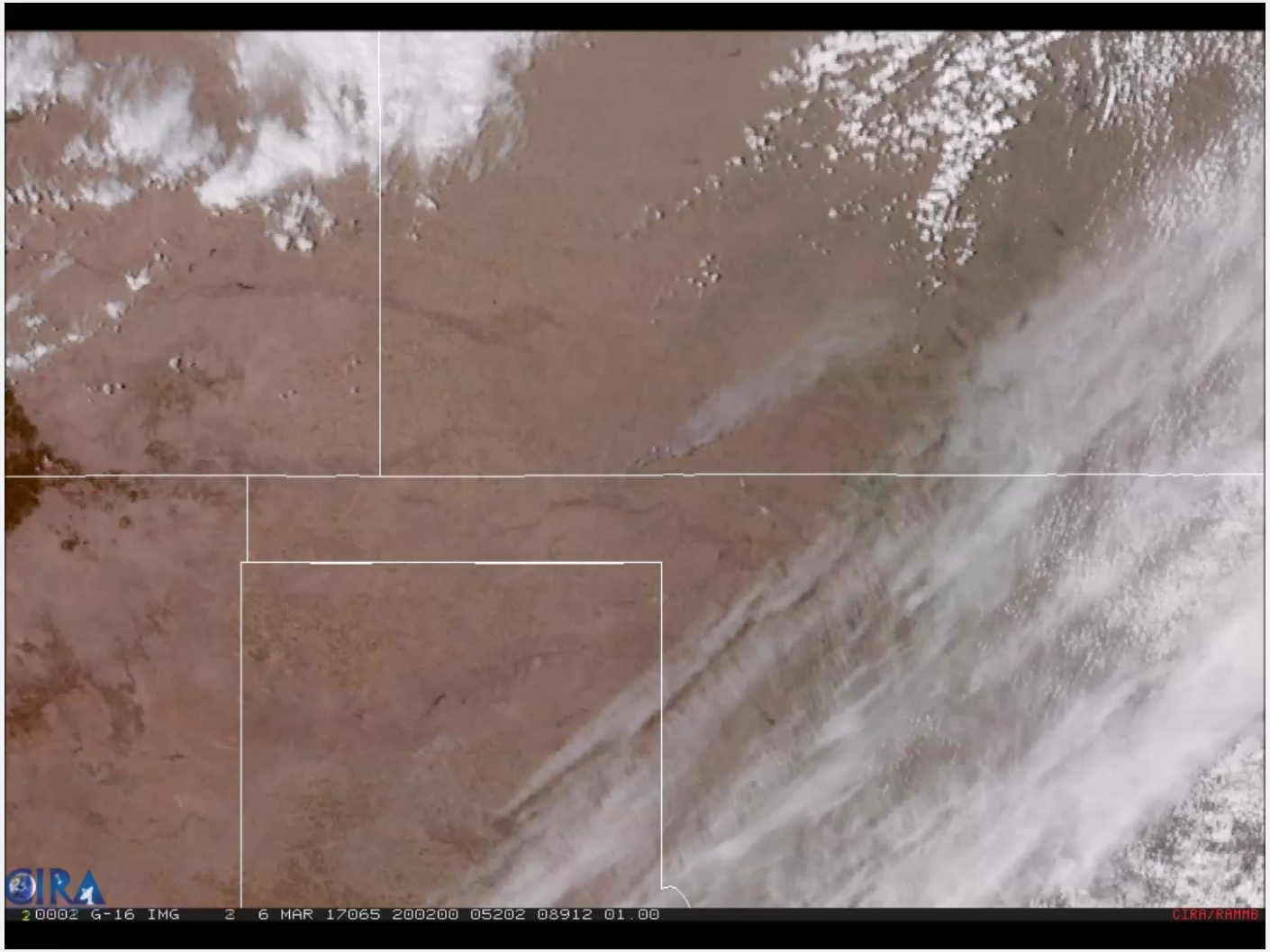
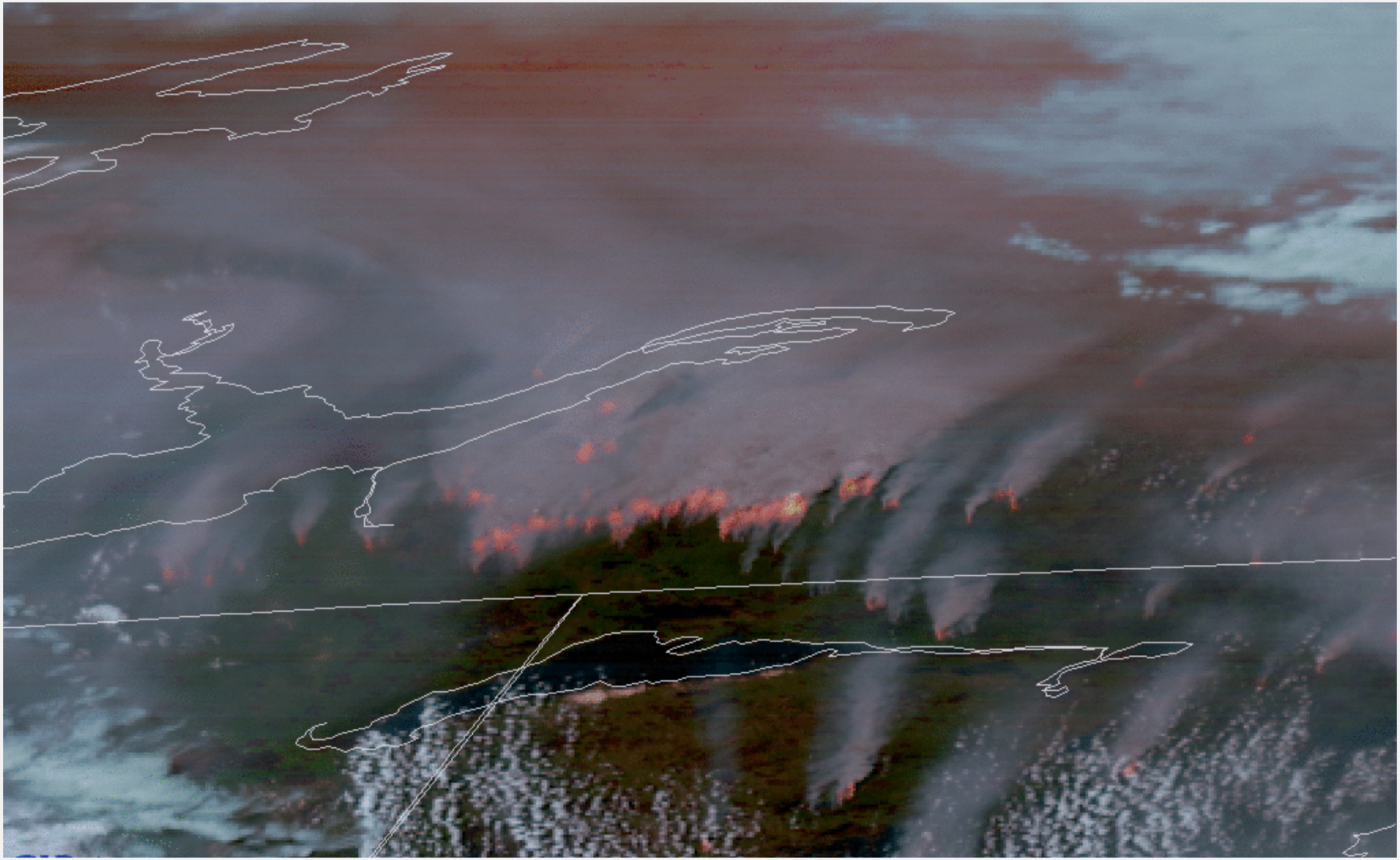
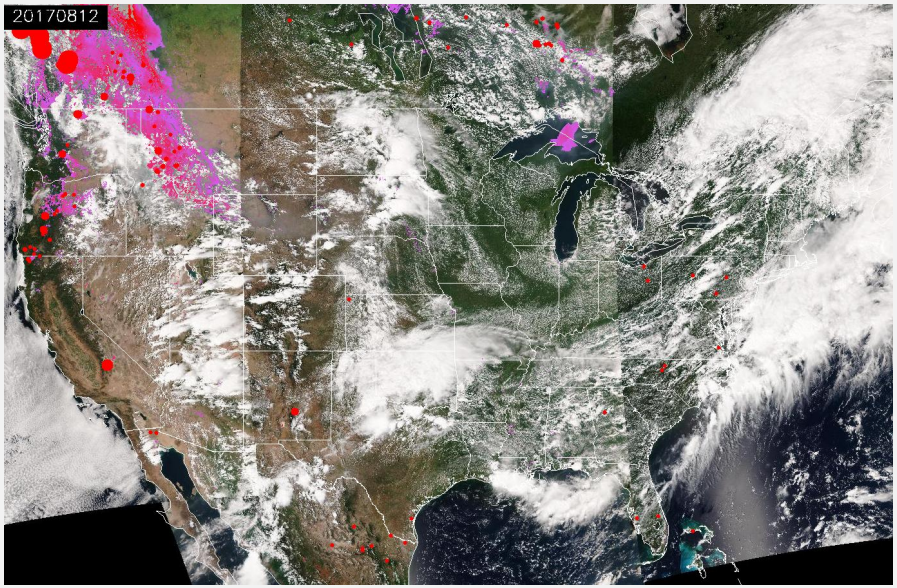


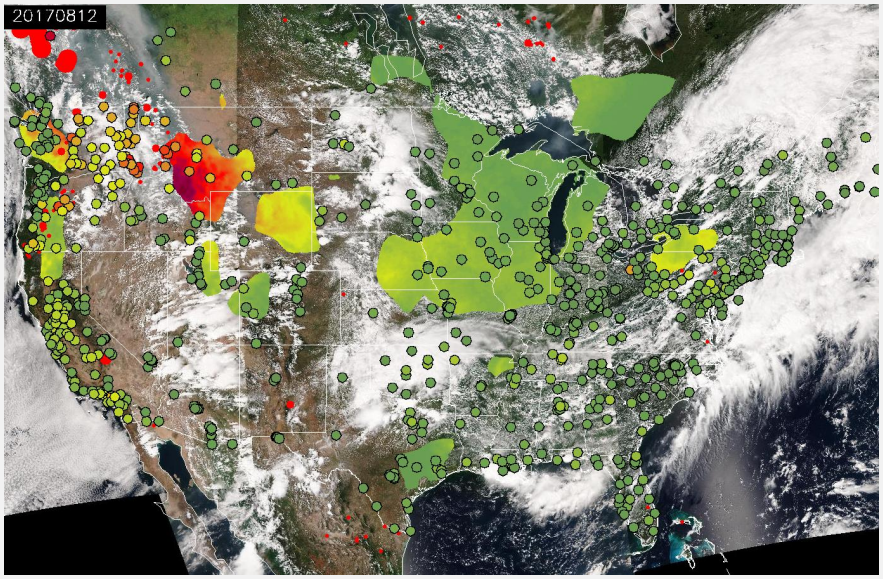
Image: NOAA CoRP, STAR: http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

GOES-16 Loop: Fires and Smoke over Canada



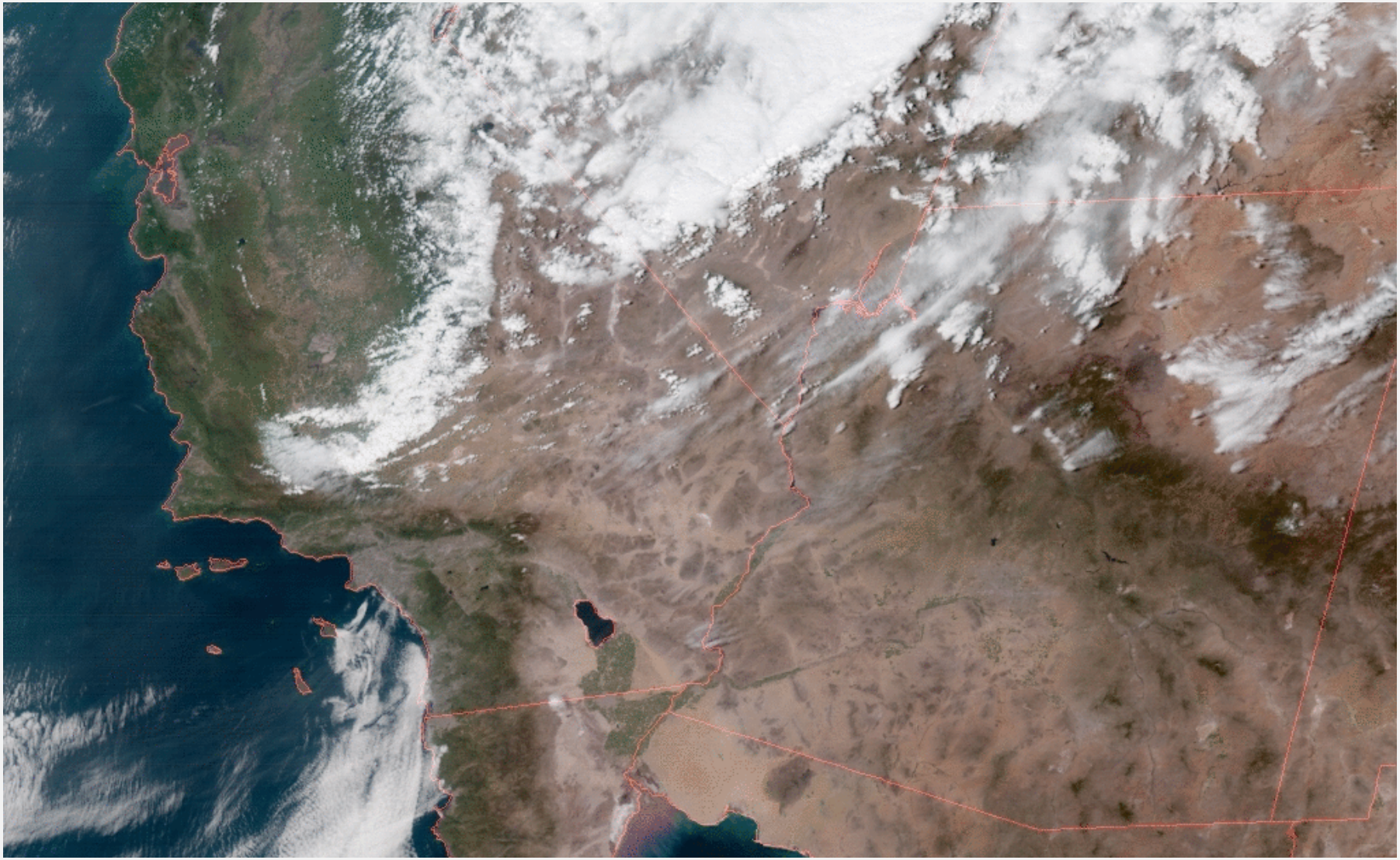
Smoke and Surface Air Quality – August 12, 2017



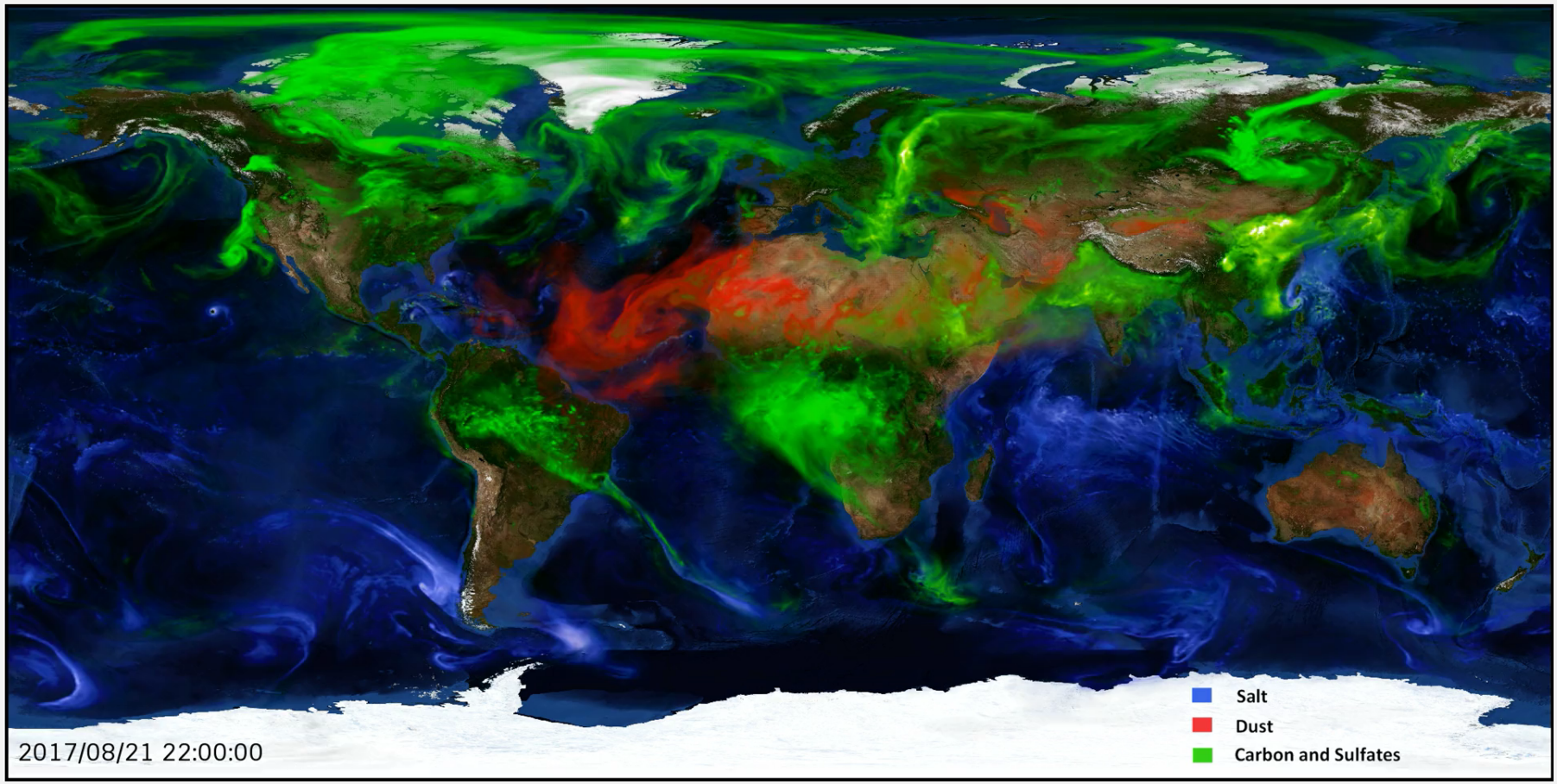


https://www.star.nesdis.noaa.gov/smcd/spb/aq/eidea/index.php?plot_sel=3&goto_date=20170814

GOES-16 Loop: Dust Storm in Southern California



GEOS Aerosol Forecast

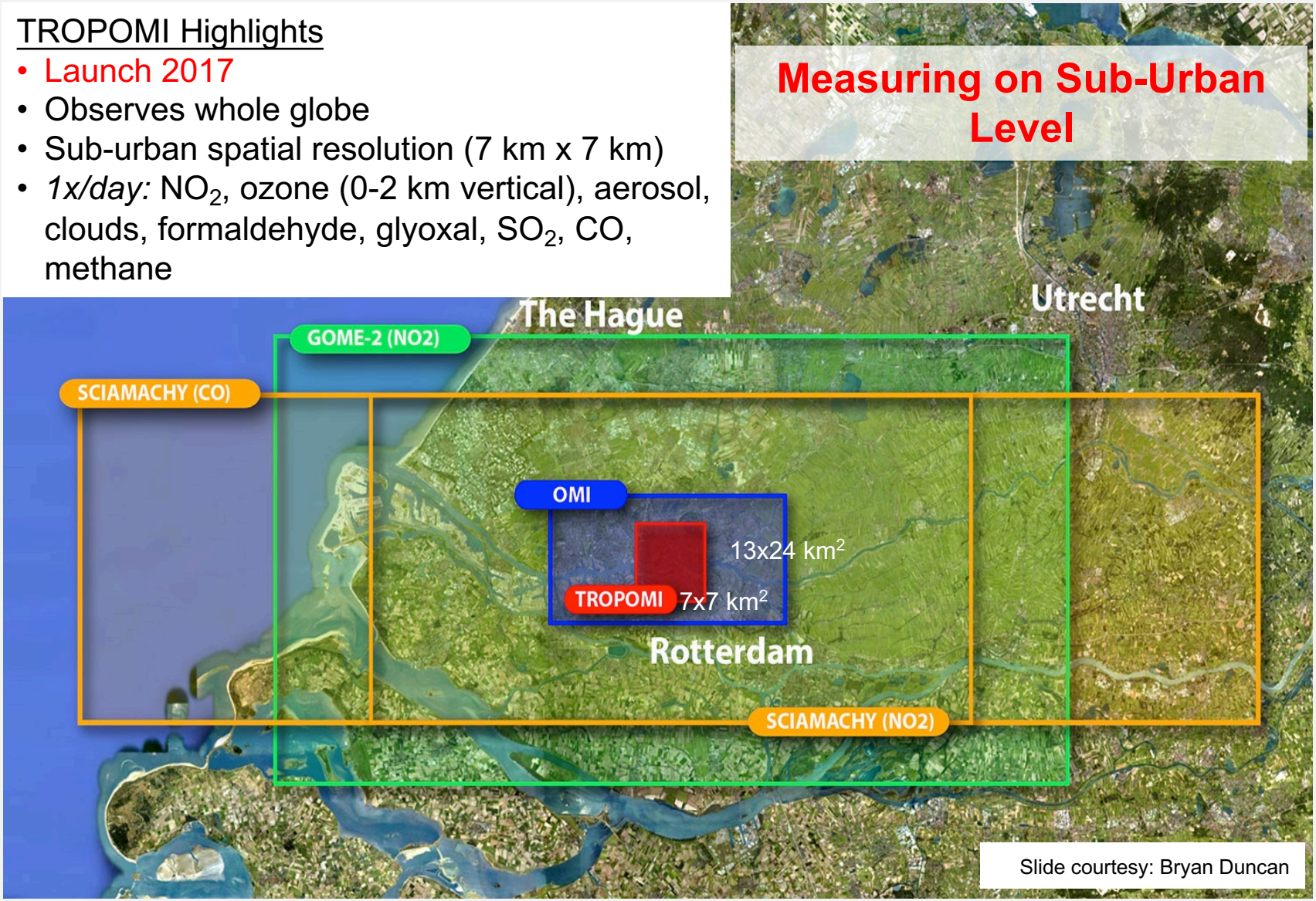


Future Satellite Capabilities for Air Quality Applications

European Space Agency TROPOMI

TROPOMI Highlights

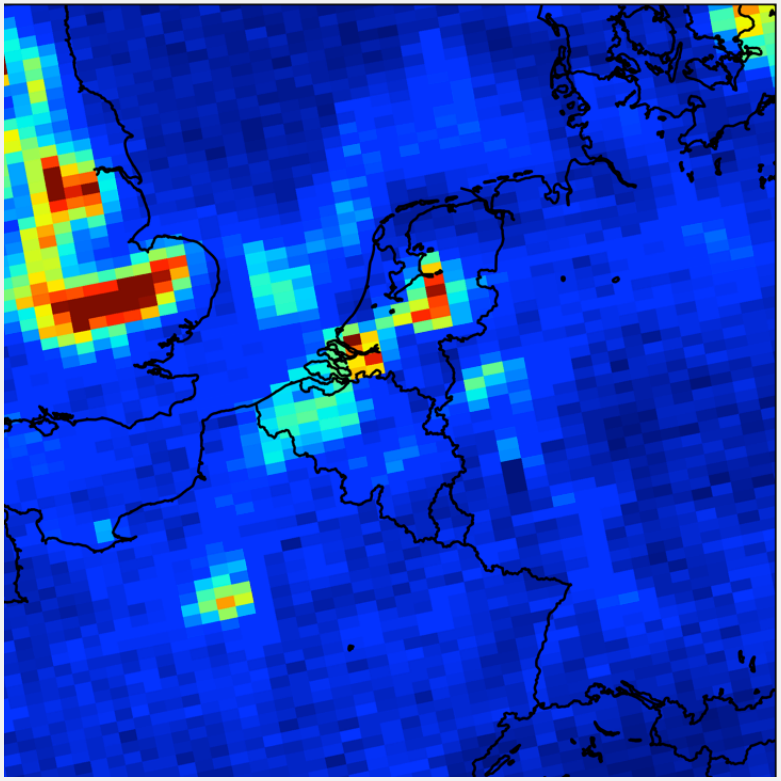
- Launch 2017
- Observes whole globe
- Sub-urban spatial resolution (7 km x 7 km)
- *1x/day:* NO_2, ozone (0-2 km vertical), aerosol, clouds, formaldehyde, glyoxal, SO_2, CO, methane



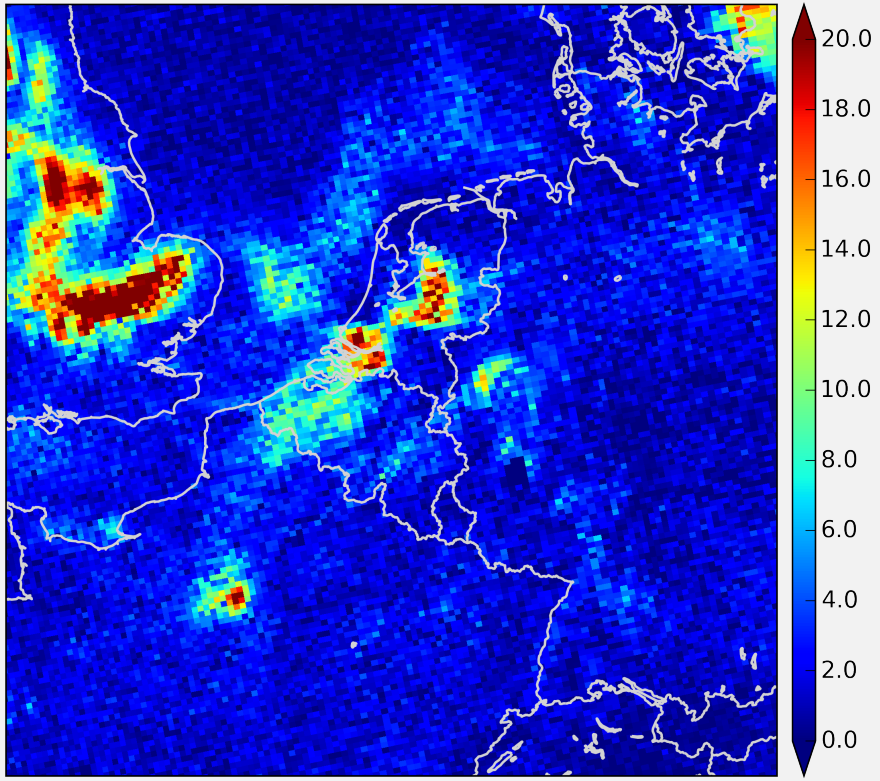
Slide courtesy: Bryan Duncan

TROPOMI: Impact of Resolution

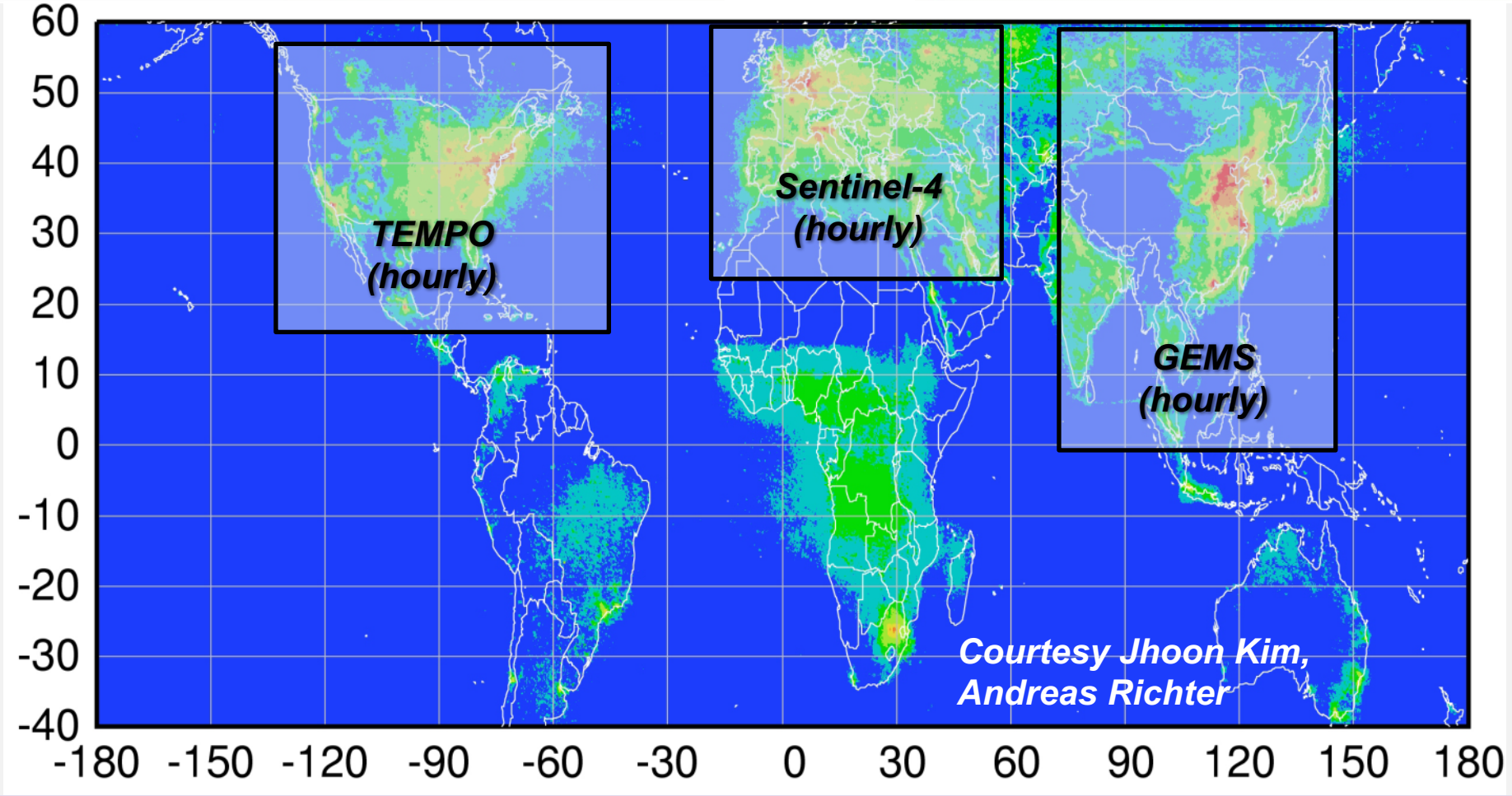
OMI (now)



TROMPOMI (Simulated data)



Global pollution monitoring constellation (2018-2020)



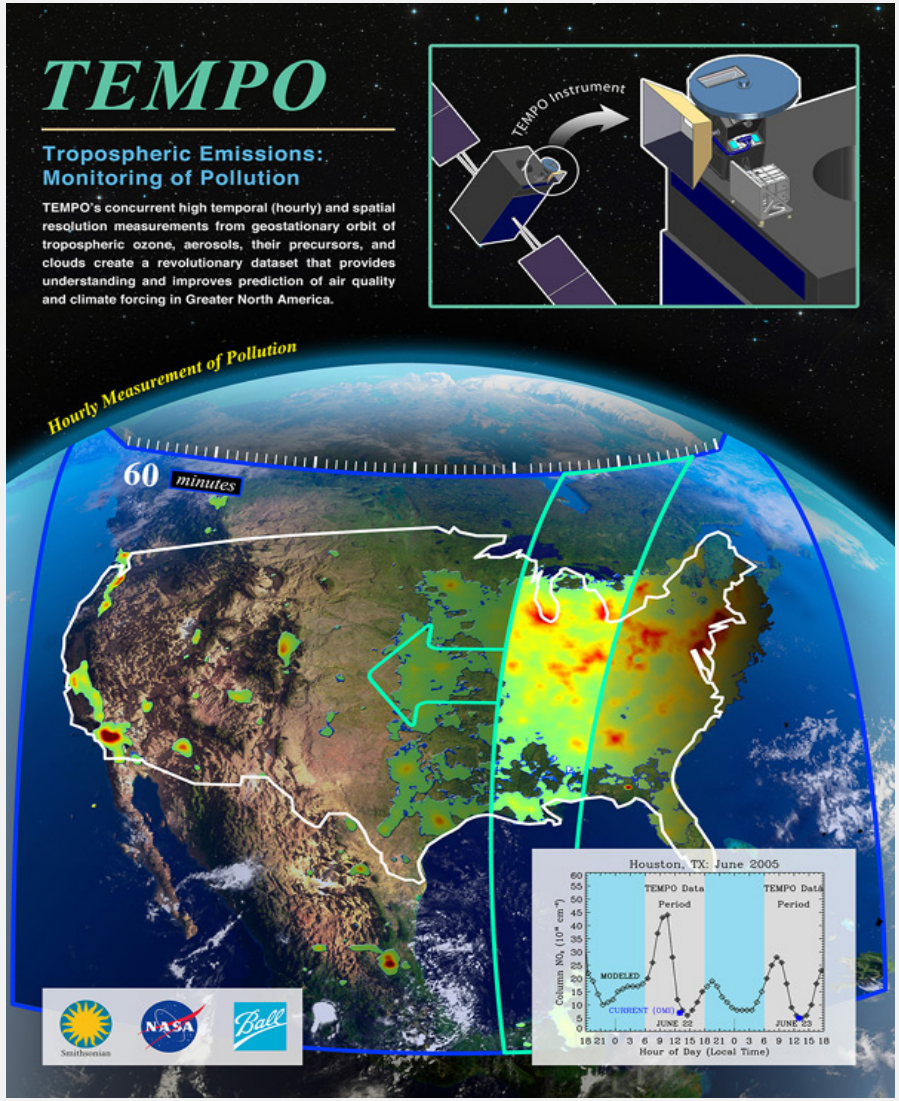
Policy-relevant science and environmental services enabled by common observations

- Improved emissions, at common confidence levels, over industrialized Northern Hemisphere
- Improved air quality forecasts and assimilation systems
- Improved assessment, e.g., observations to support United Nations Convention on Long Range Transboundary Air Pollution

Slide from KChance

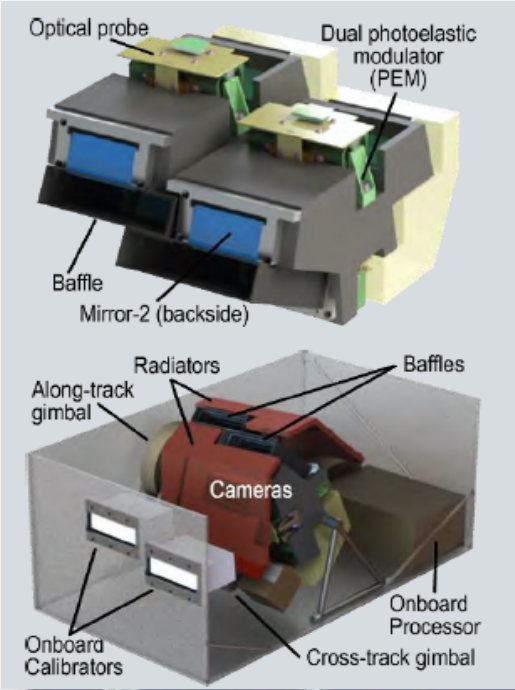
TEMPO

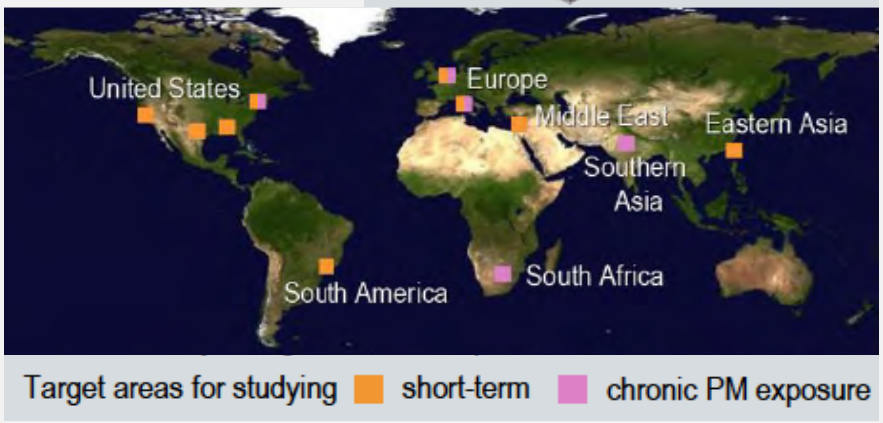
- Geostationary over North America
- High Temporal Resolution
  - 1 hr
- High Spatial Resolution
  - 2.2 x 4.7 km
- Spectral Range
  - 290-740nm
- Data Products:
  - O_3, NO_2, $C_2H_2O_2$, aerosols, cloud parameters, & UVB radiation
- Expected Launch: 2021

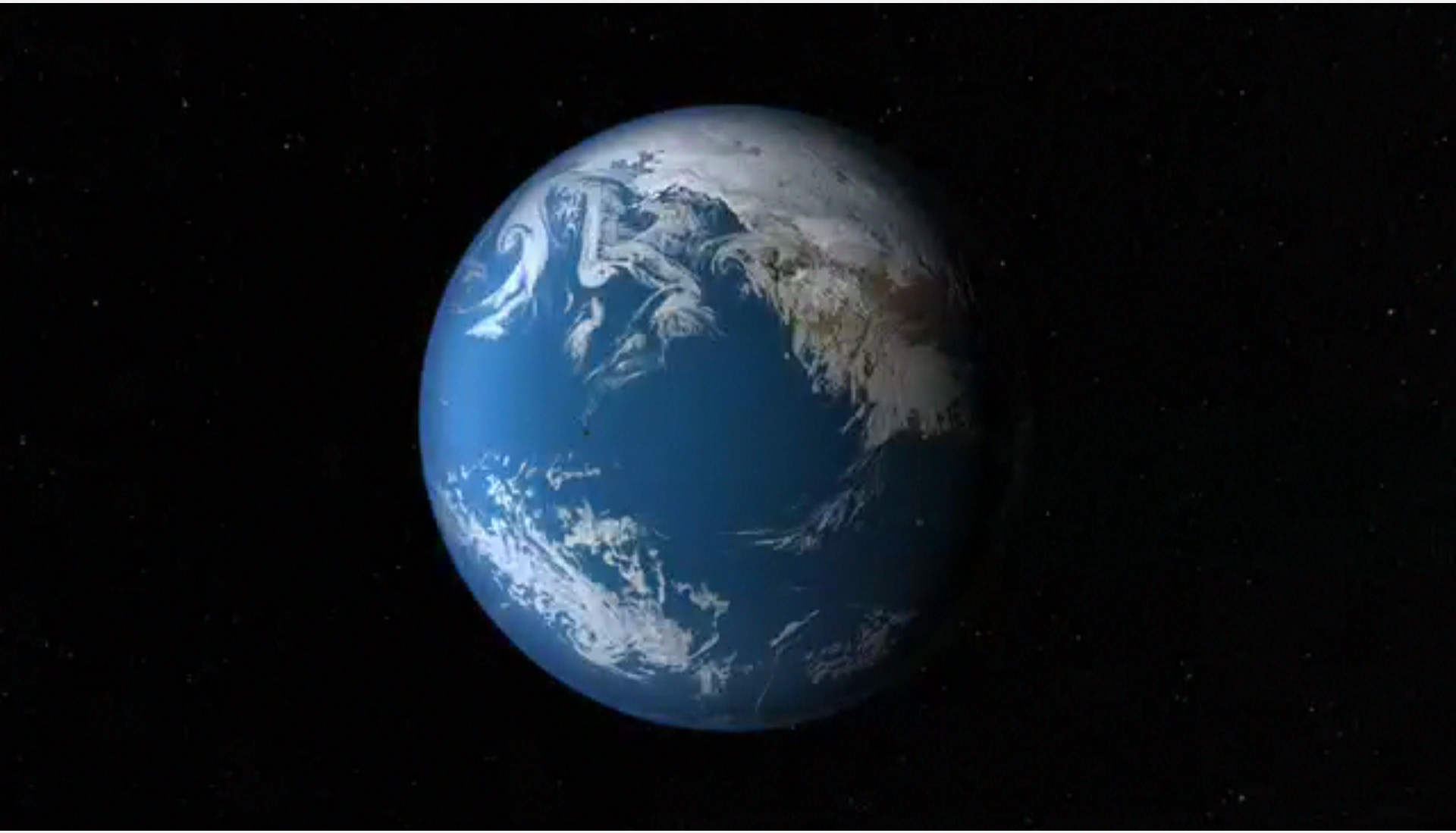


Multi-Angle Imager for Aerosols (MAIA)

- Mission Goal: Assess linkages between different airborne particulate matter types and adverse birth outcomes, cardiovascular and respiratory disease, and premature deaths
- Sun synchronous orbit
- Spatial Resolution: 230 m
- Large Swath Width: 600 km
- Expected Launch: 2021







Can satellites help fill some of the data gaps?

What are advantages of polar orbiting satellites as compared to geostationary satellites and vice-versa?