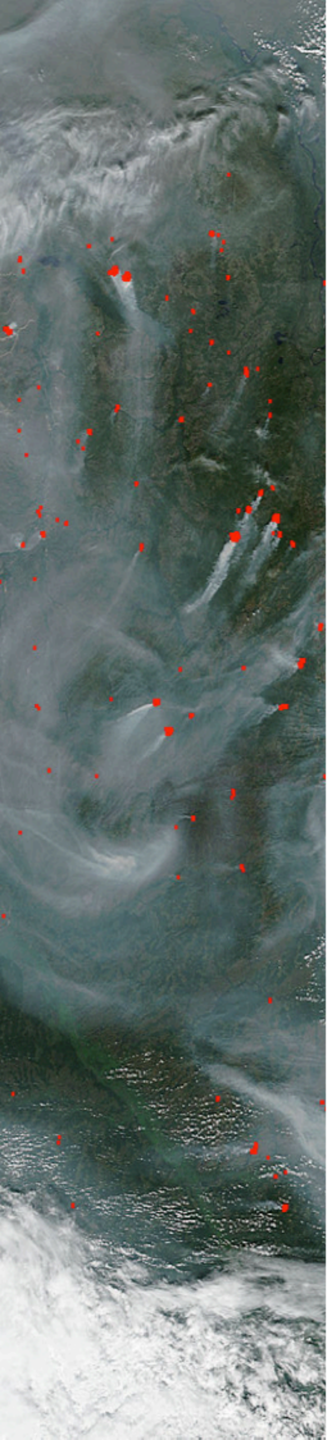


National Aeronautics and
Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
@NASAARSET

Current and Future Satellite Capabilities for Air Quality Monitoring: An Overview

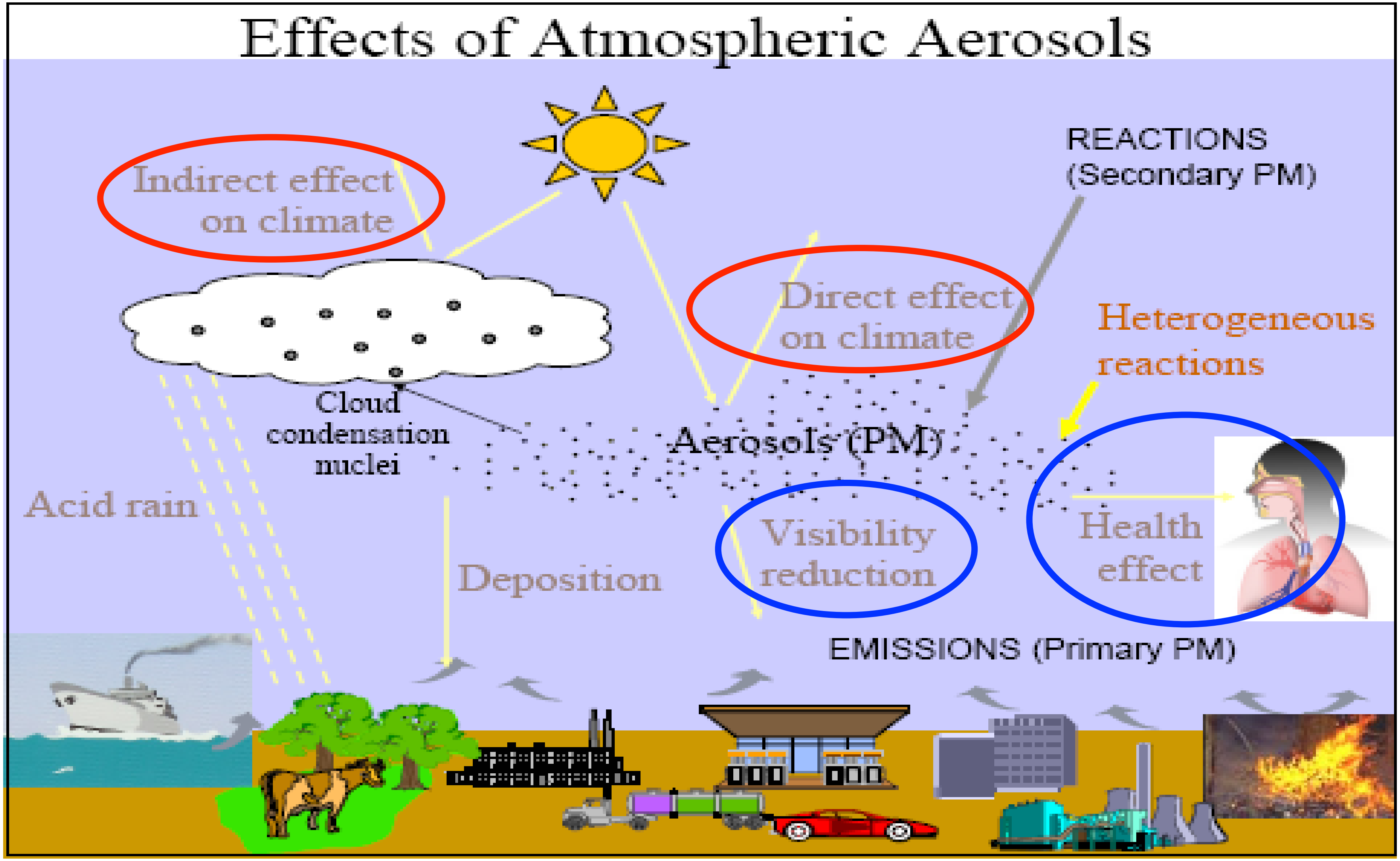
NASA ARSET Workshop: NASA Earth Observations, Data and Tools for Air Quality Applications

Sunday, August 28, 2016 to Monday, August 29, 2016
17th IUAPPA World Clean Air Congress and 9th CAA Better Air Quality (BAQ) Conference
Pusan National University, Busan, South Korea

Objectives

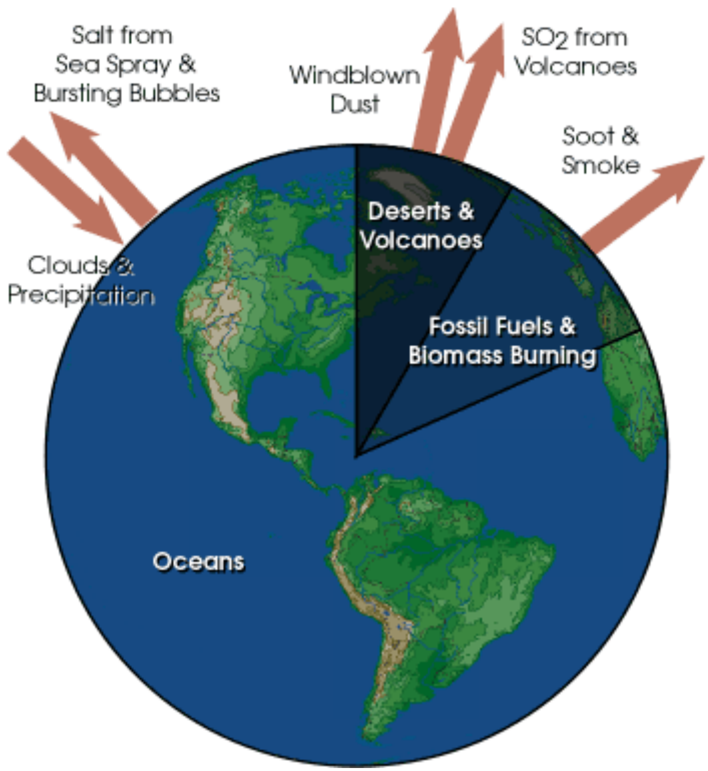
- Provide an overview of existing satellite capabilities for air quality monitoring around the world
- Provide example applications of satellite data sets for air quality research and management
- Provide an overview of upcoming and future satellite missions for air quality monitoring
- A brief tutorial on the fundamentals of satellite remote sensing

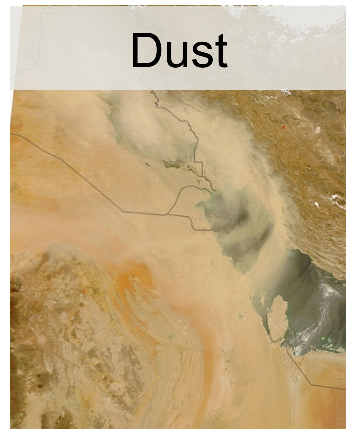
Motivation – Tiny but Potent



Pollution Sources

Atmospheric aerosols are highly variable in space and time

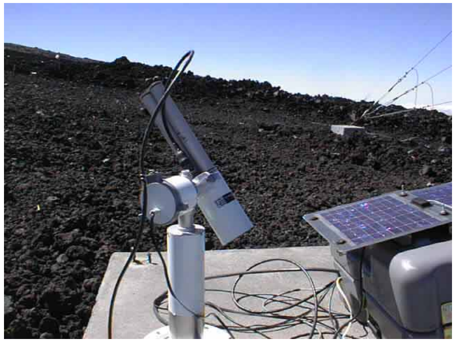




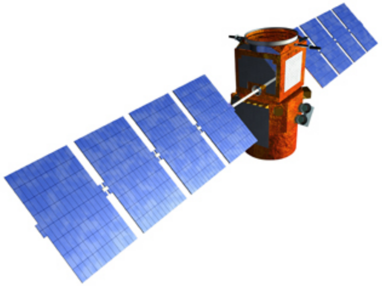
Air Pollution Monitoring

TEOM

CIMEL



Satellites

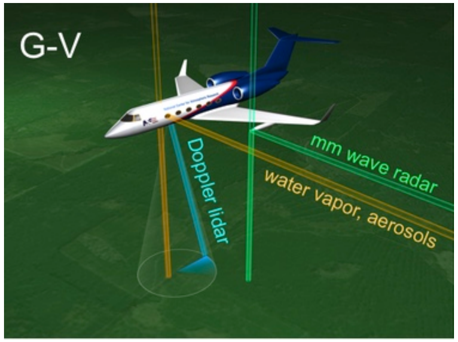


Models

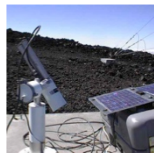
Sampler

Lidar

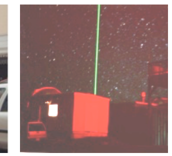
Aircraft



Air Pollution Monitoring

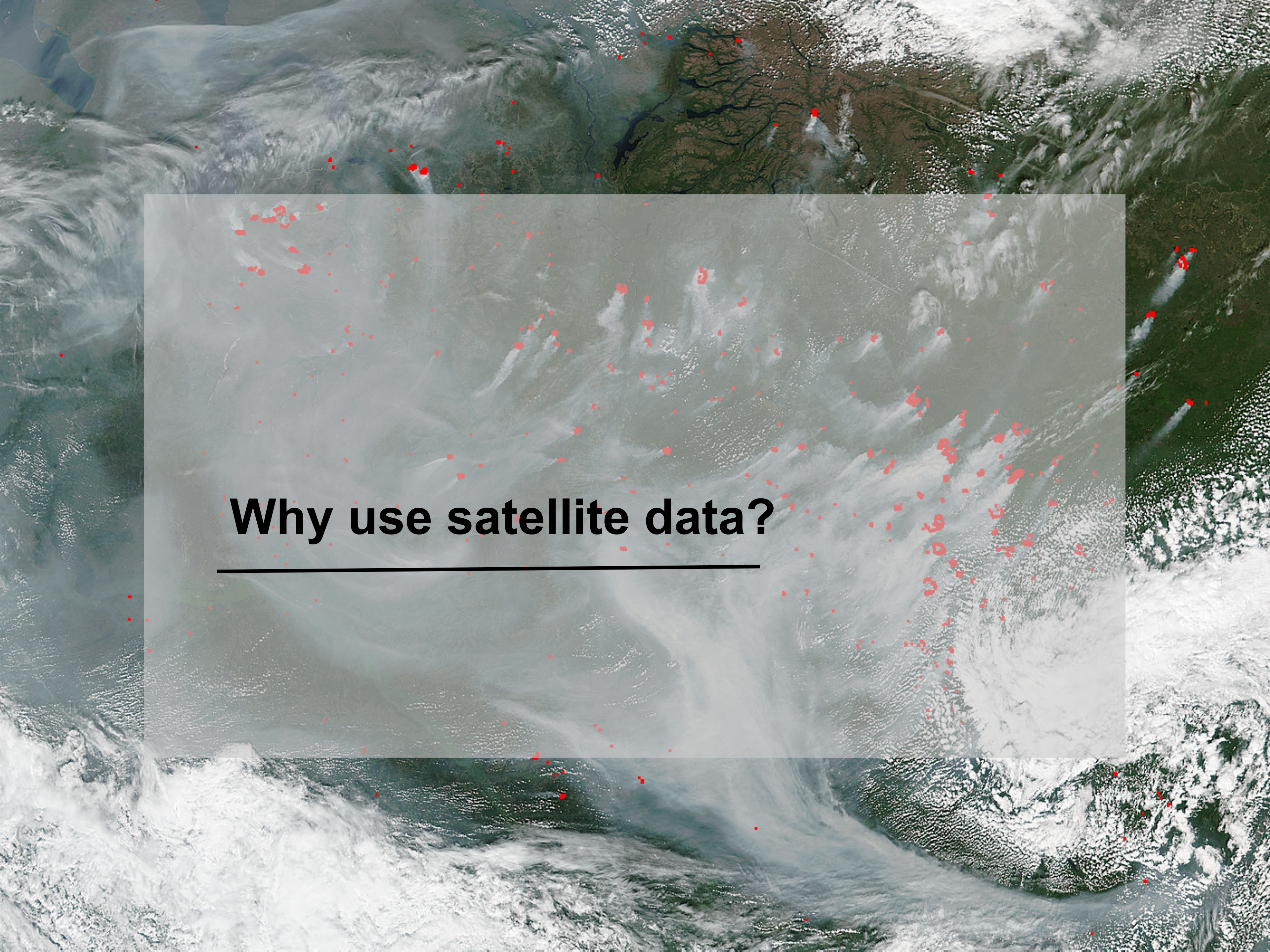



Ground Measurements

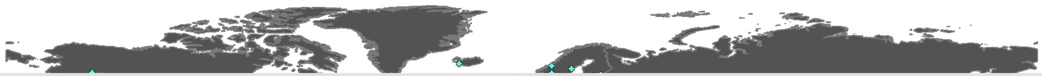
Air & Space Observations

Models

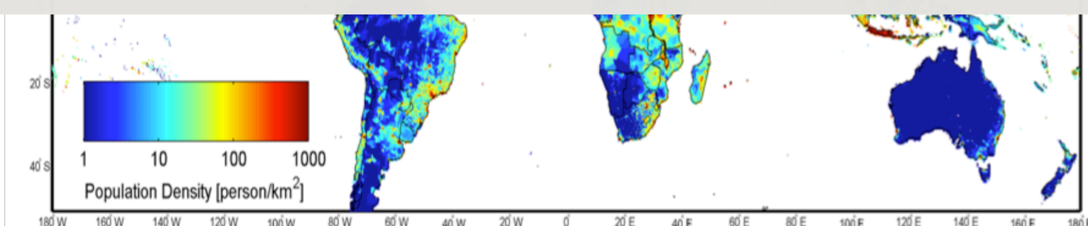



Why use satellite data?

Global Status of PM2.5 Monitoring



- Many countries do not have PM2.5 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 in the county
- Surface measurements are not cost effective
- How about using remote sensing satellite?

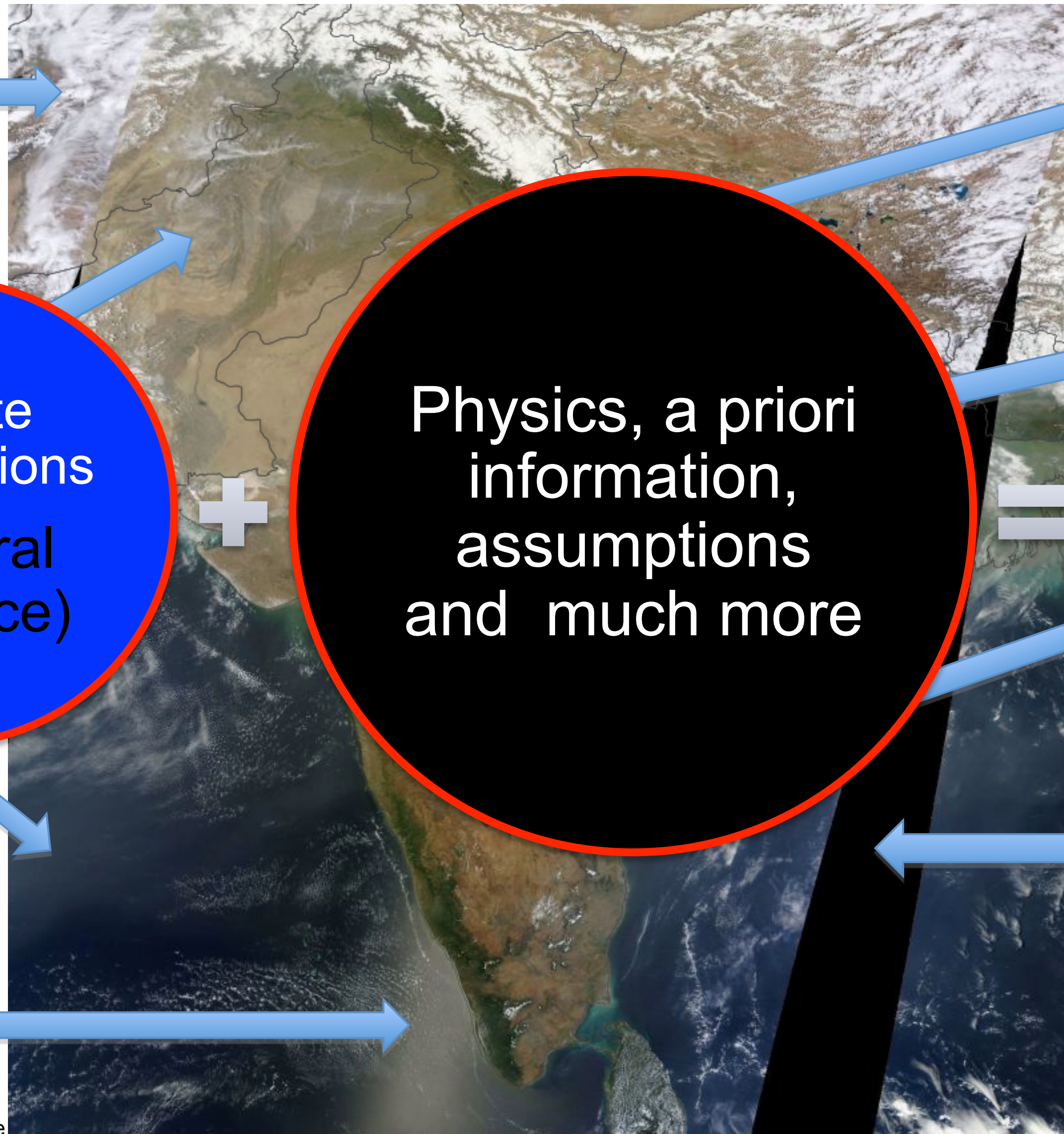


NASA Earth Science

Current and Upcoming Missions

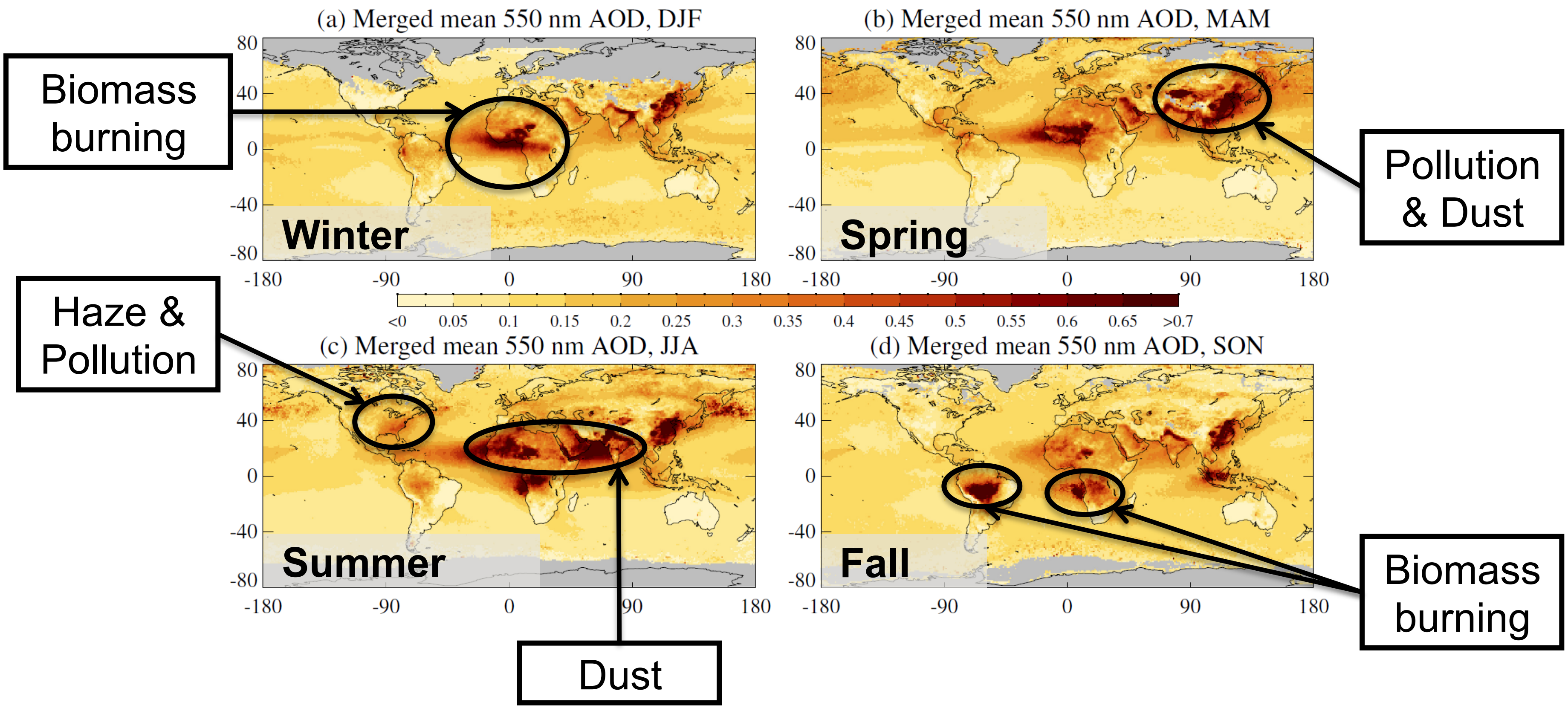
What can we learn from true color imagery?

MODIS Terra Image from April 19 2013



Aerosols from Satellites

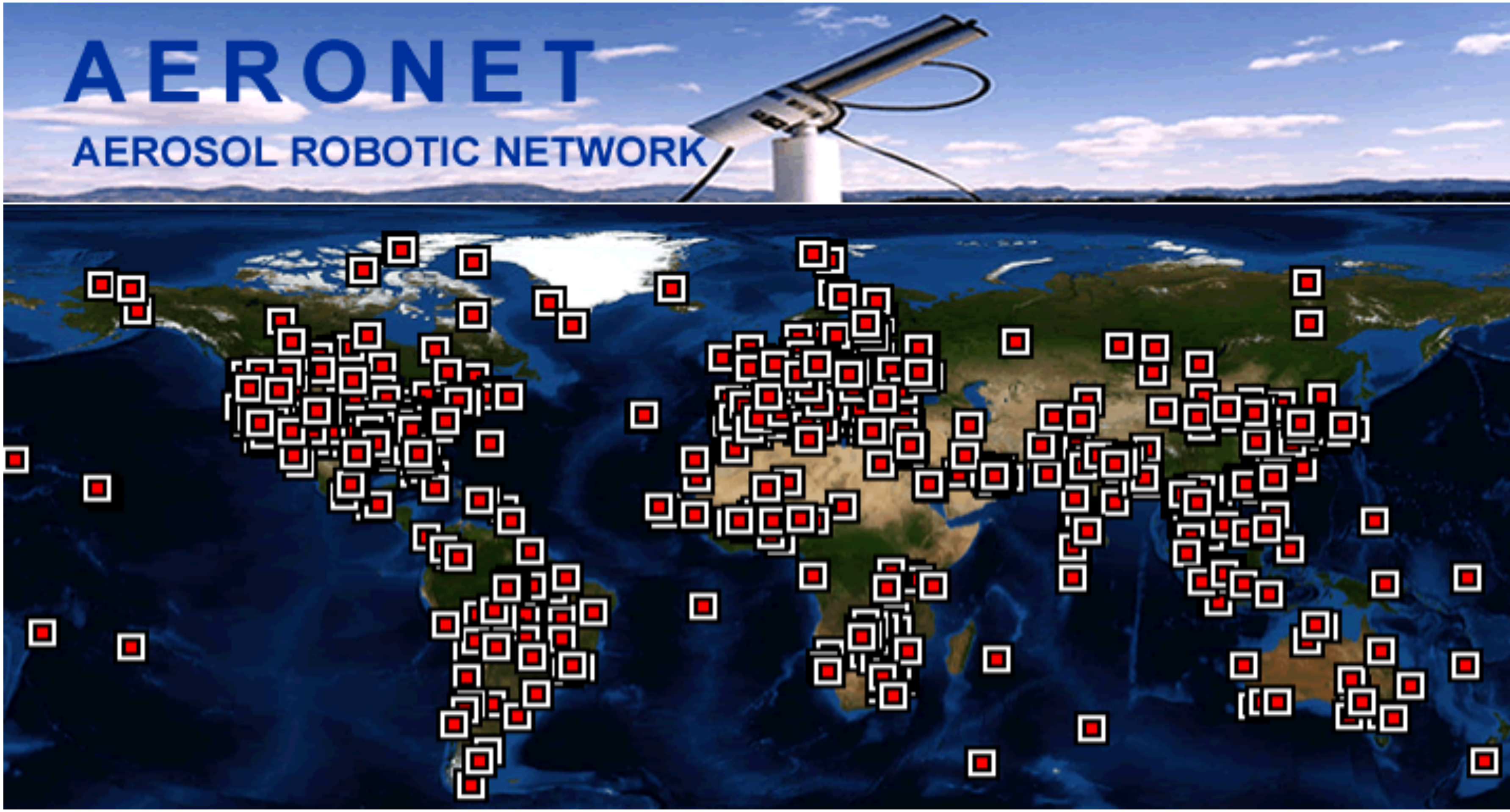
Aerosol Optical Thickness (MODIS Aqua)



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

AERONET

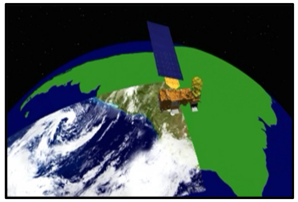
http://aeronet.gsfc.nasa.gov/



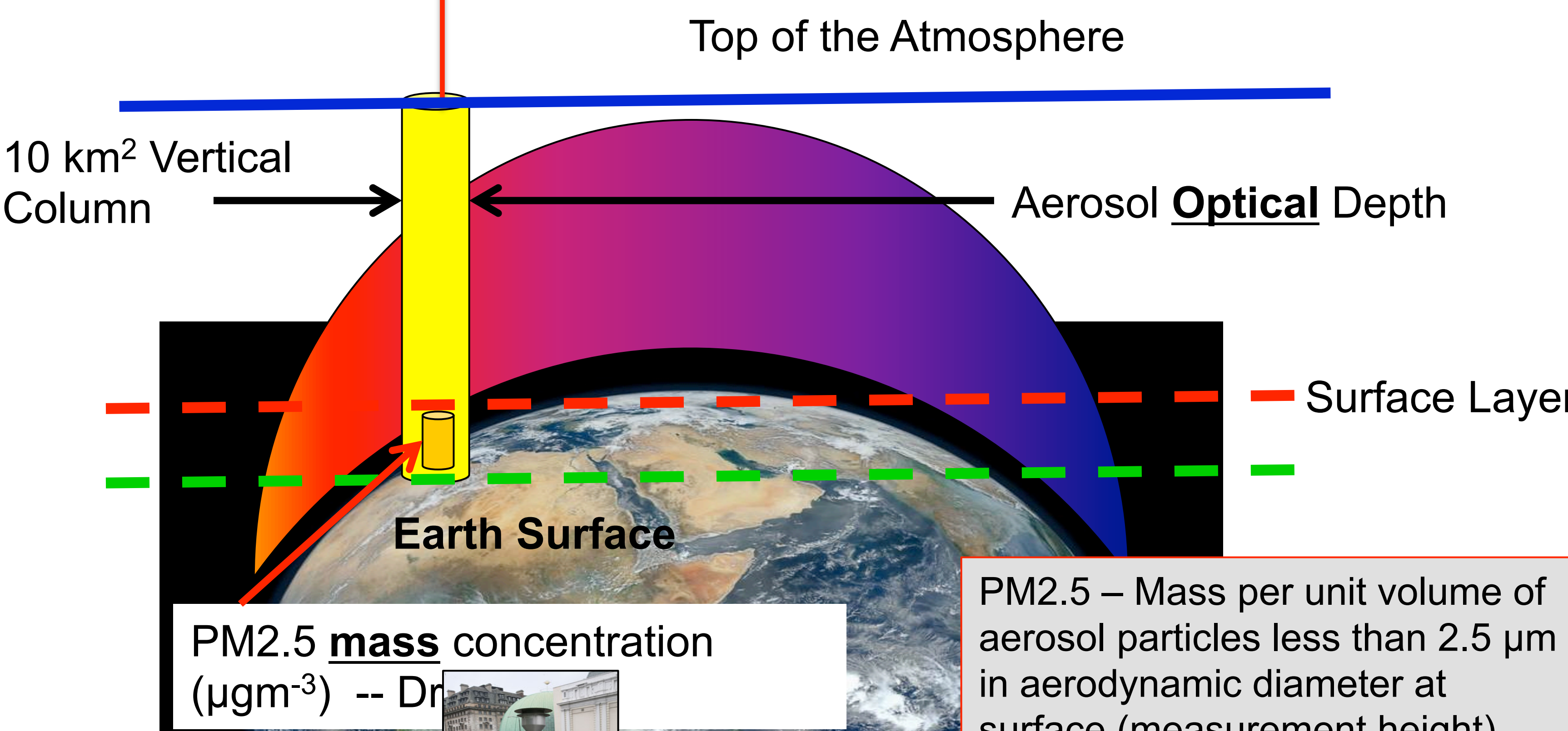
AERONET measurements of Aerosol Optical Depth are considered ground truth and used to validate satellite aerosol retrievals

Applications

Satellite vs Ground Observation

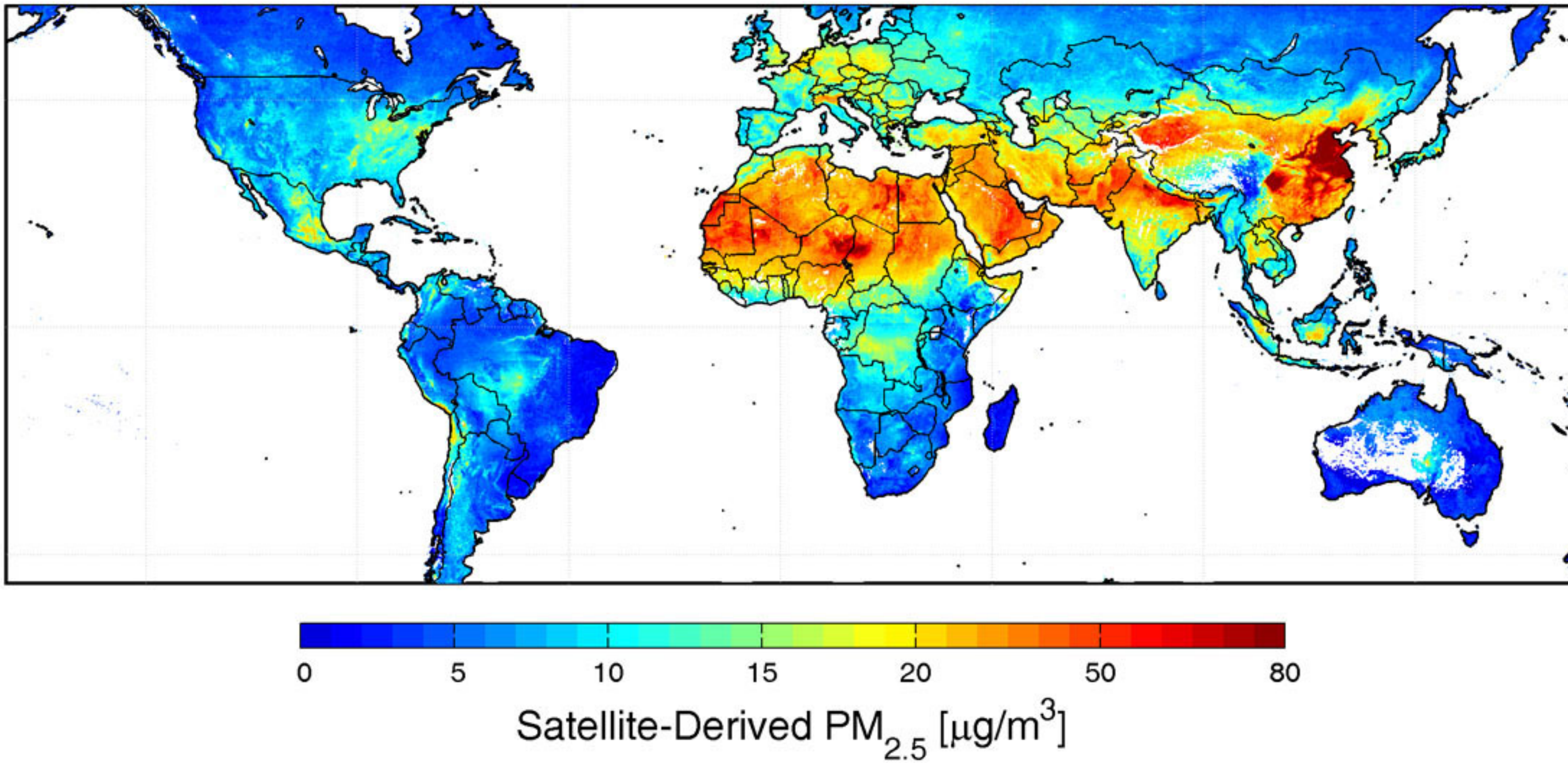


AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unitless. AOD is function of shape, size, type and number concentration of aerosols



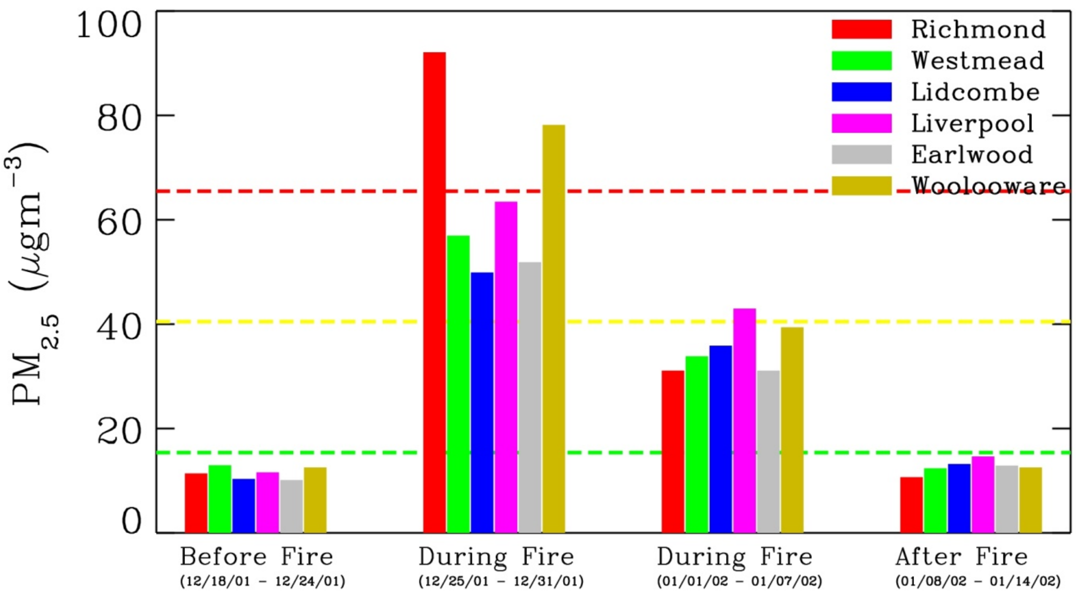
PM2.5 – Mass per unit volume of aerosol particles less than 2.5 µm in aerodynamic diameter at surface (measurement height) level

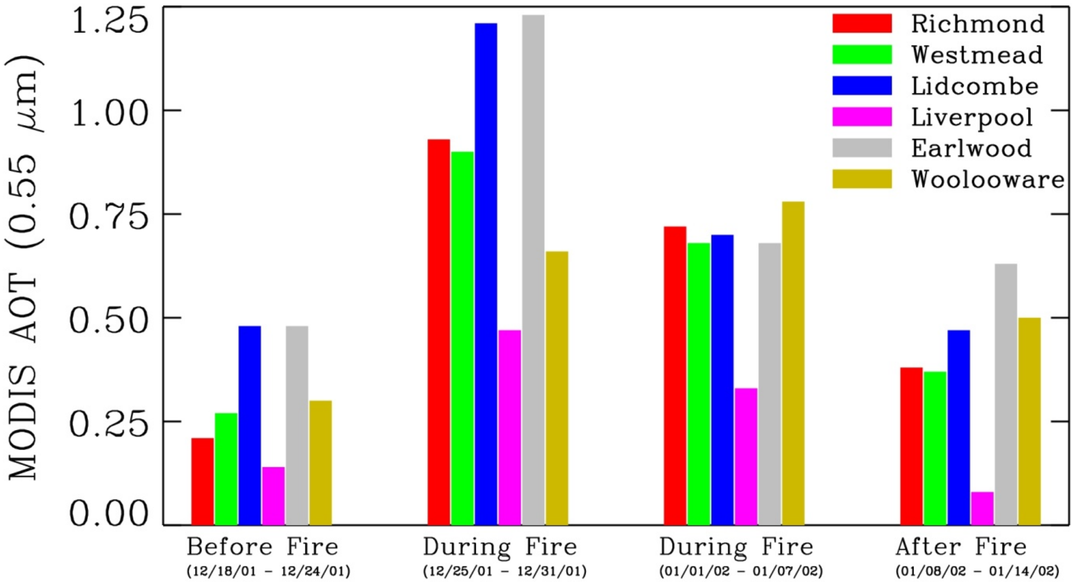
Annual Mean PM2.5 from Satellite Observations



Source: van Donkelaar et al., 2006, 2009

Application of Satellite Observations: Bushfires in Sydney, Australia

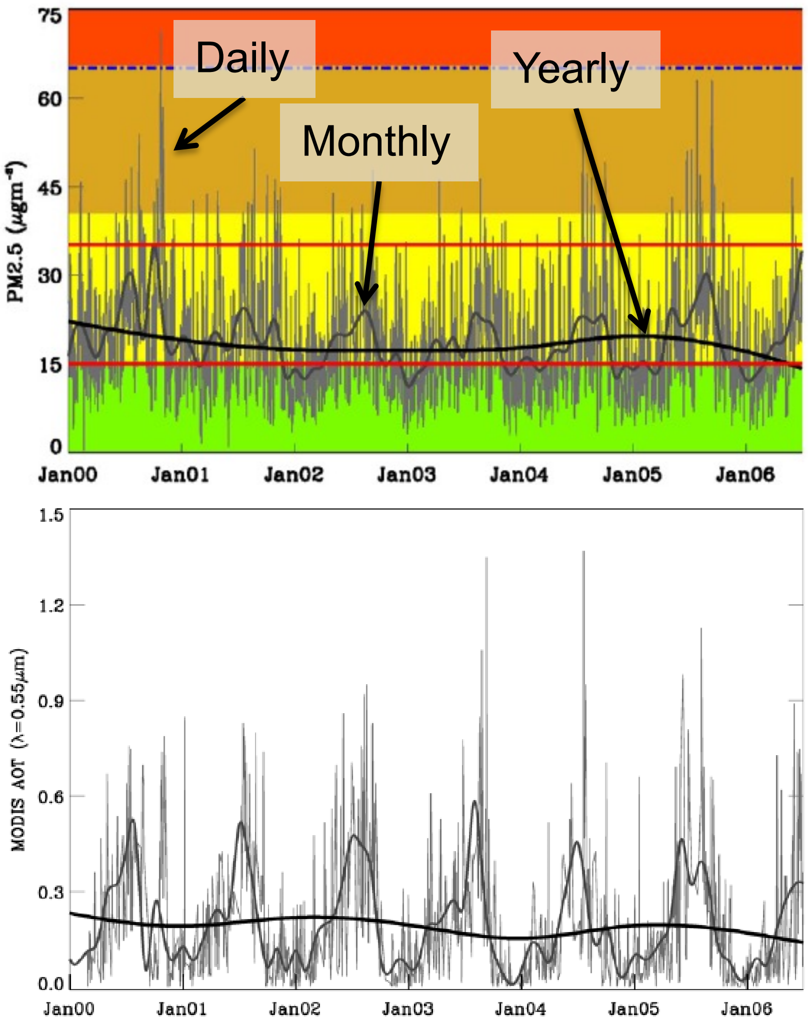




Credit: Gupta and Christopher, 2007

Air Quality Trends

Birmingham, AL

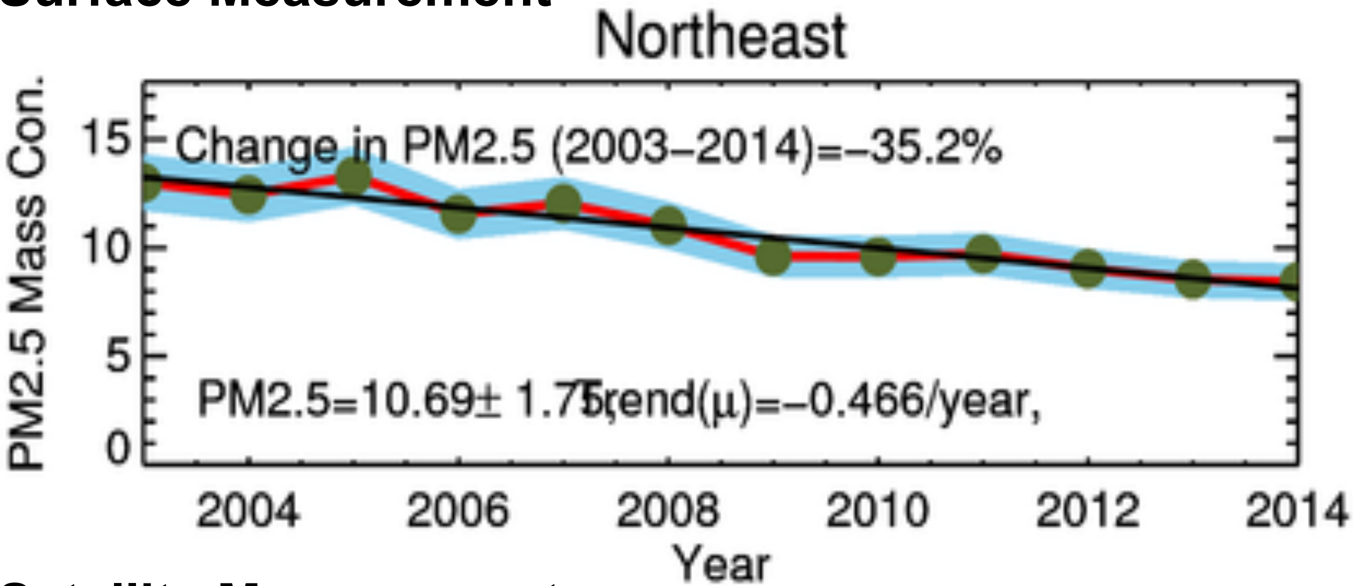


A decreasing trend in annual PM2.5 was noted with the almost 22% reduction in PM2.5 mass concentration observed in 2006 compared to 2002

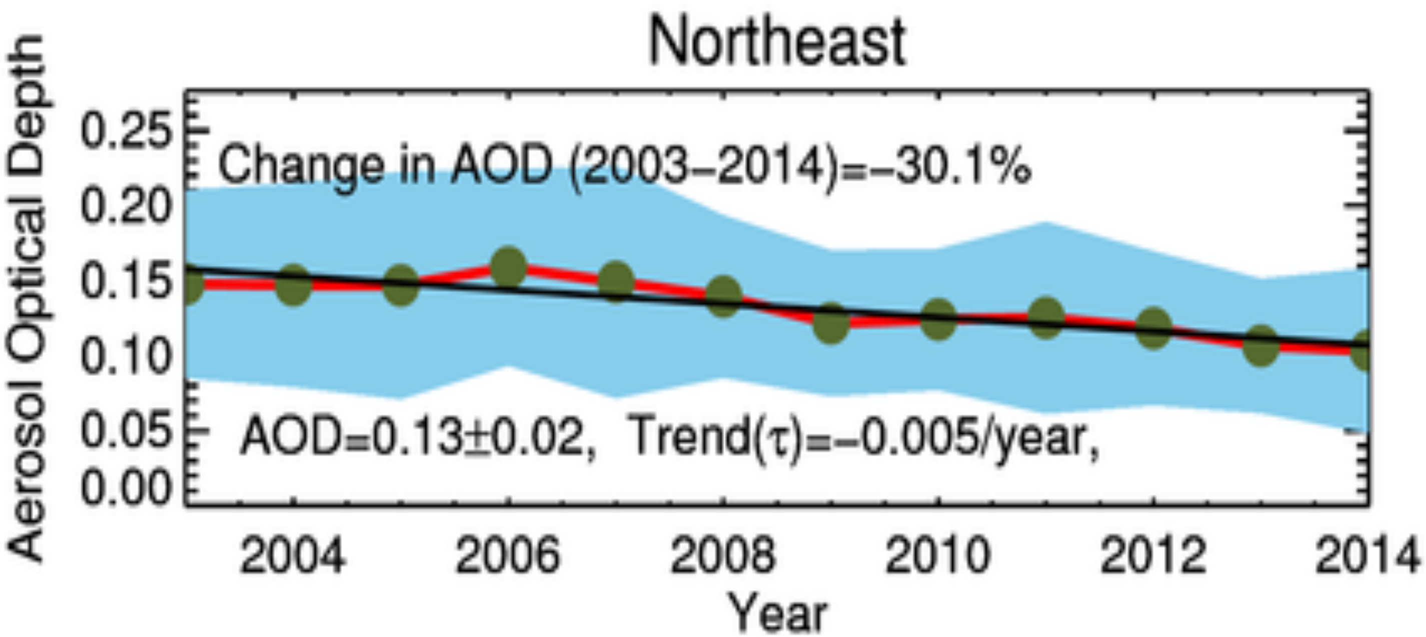
MODIS-Terra Collection 5, Level 2, $10km^2$ AOTs for 2000-2006

Source: Gupta and Christopher, 2007

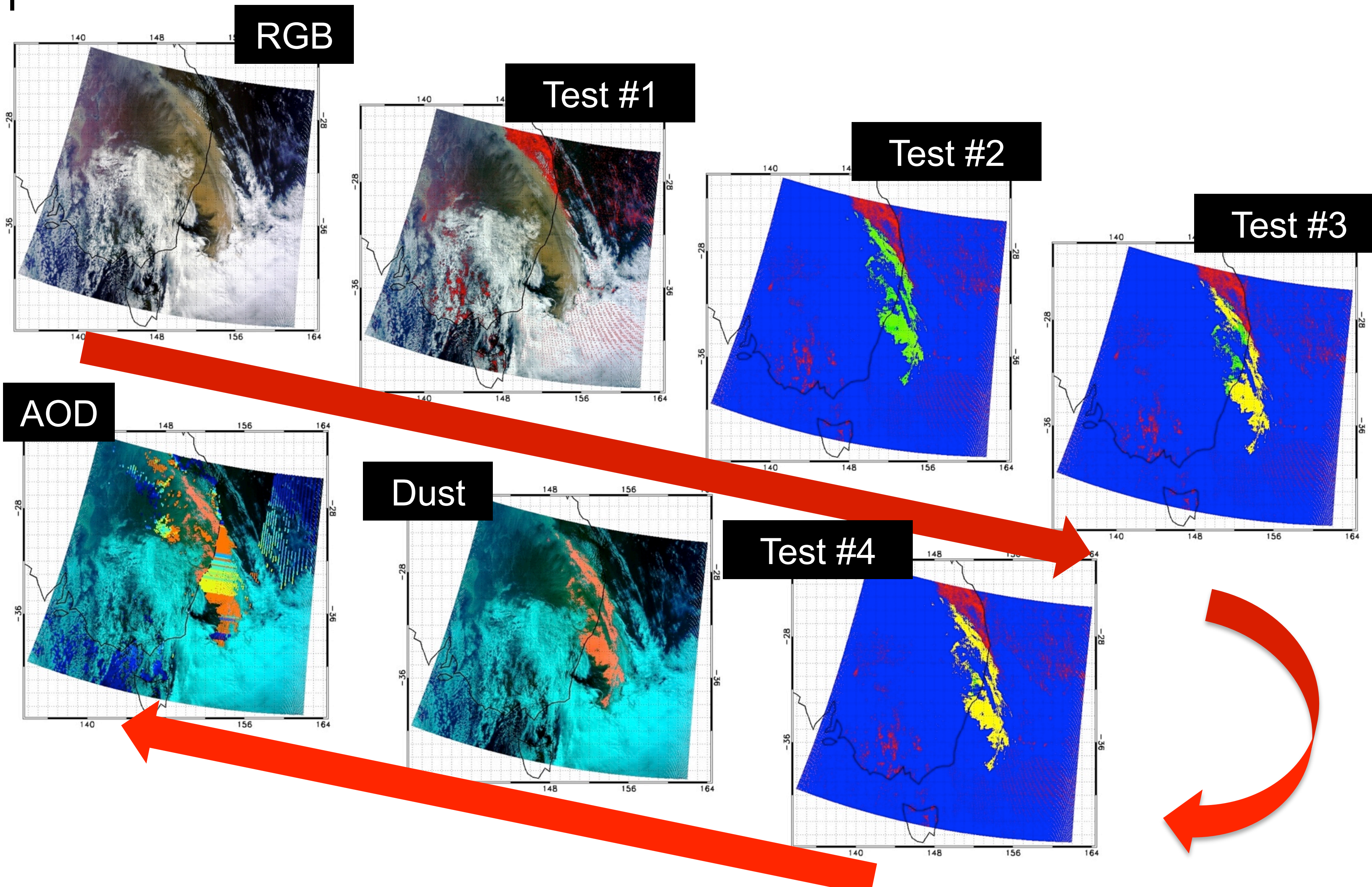
Surface Measurement



Satellite Measurement

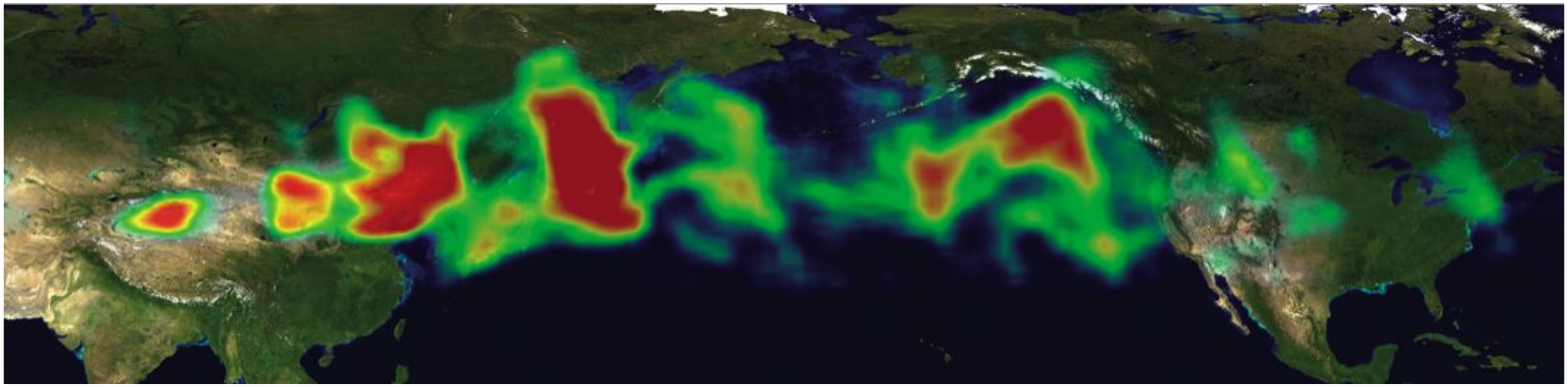


Dust & Smoke Monitoring

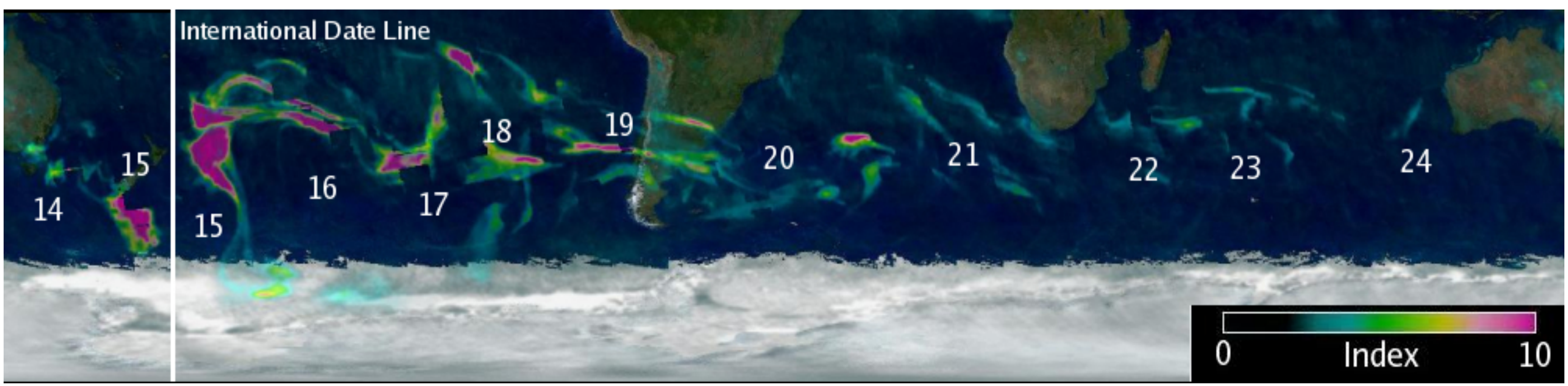


Long Range Transport

Dust from Mongolian Deserts Reaches the U.S.

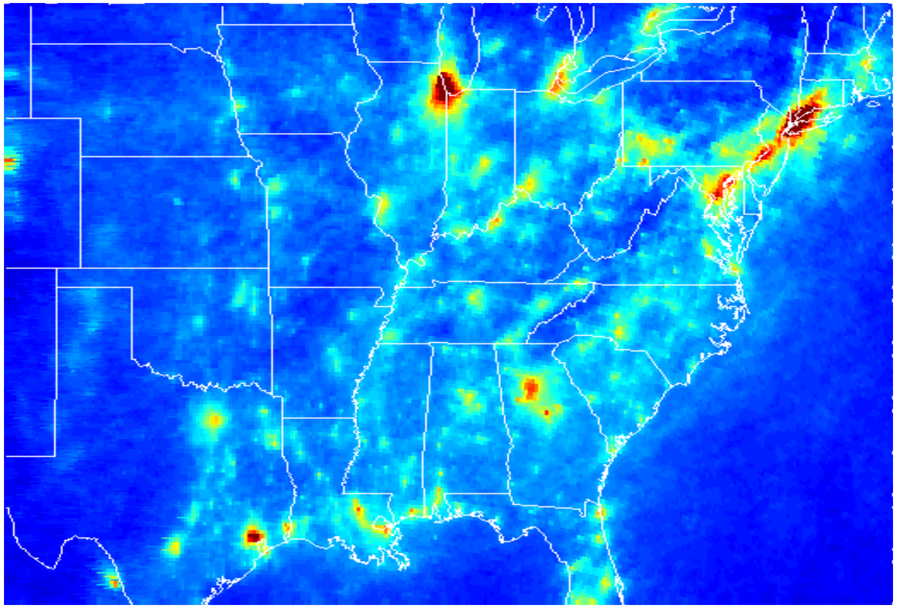


Smoke Travels Around the World in 11 Days

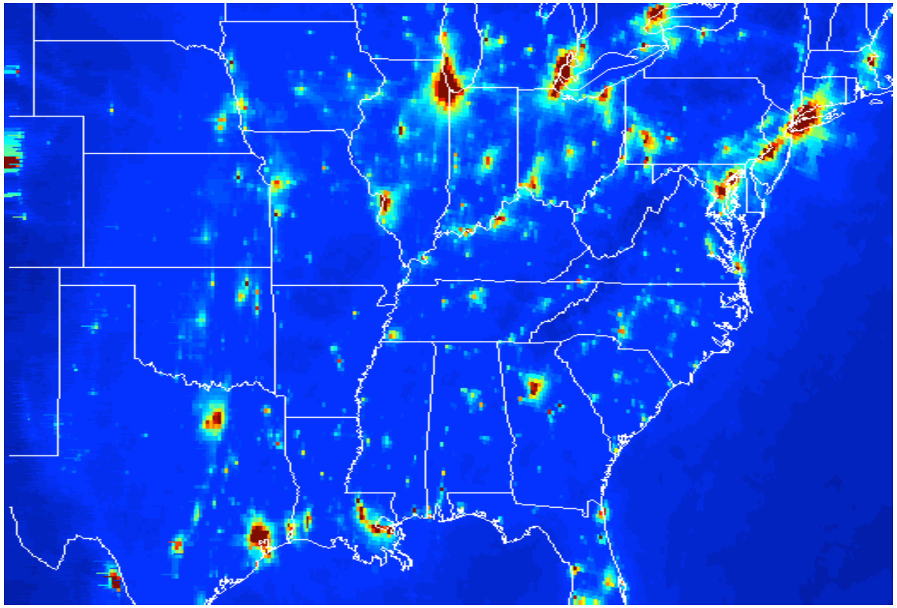


Model-Satellite Inter-Comparison

CMAQ Model NO_2

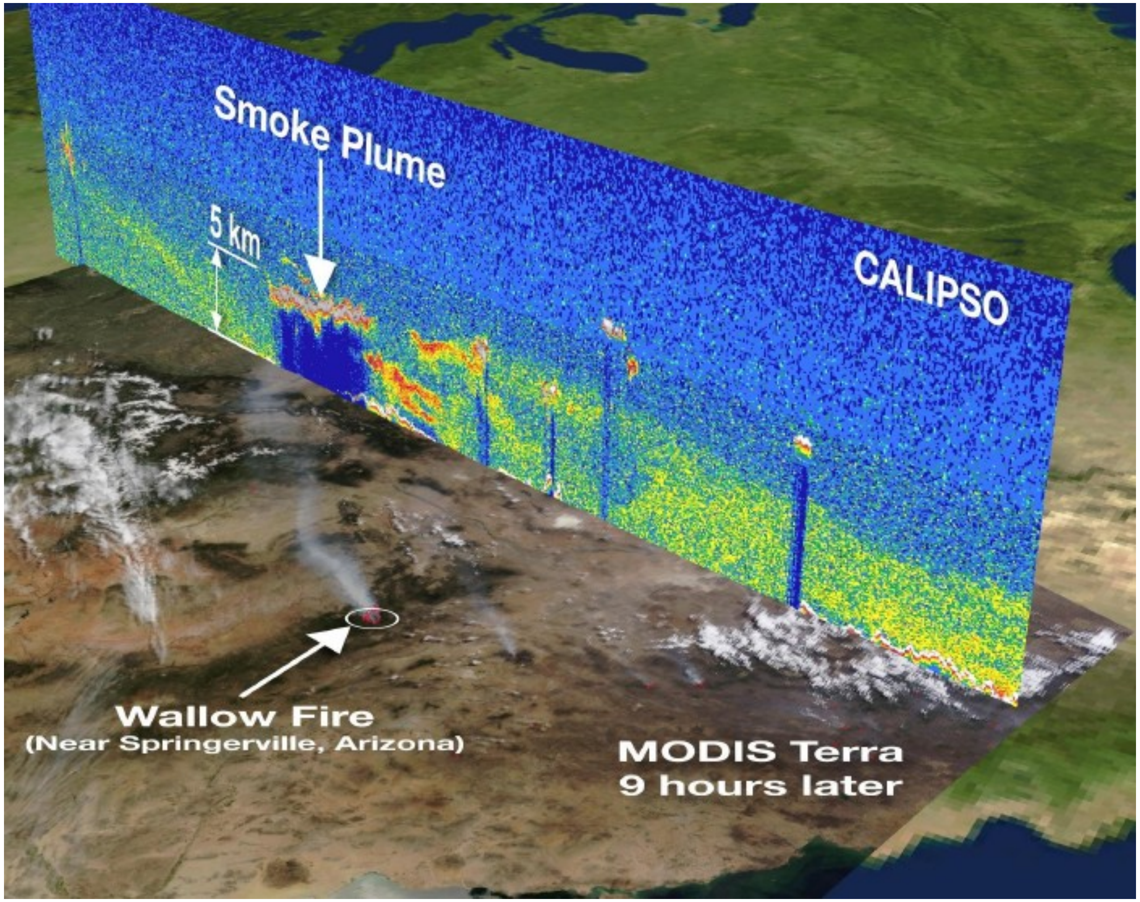


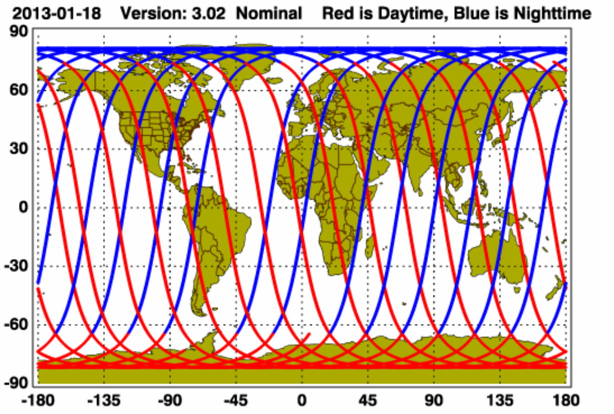
OMI NO_2



Vertical Profiles of Aerosols

CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

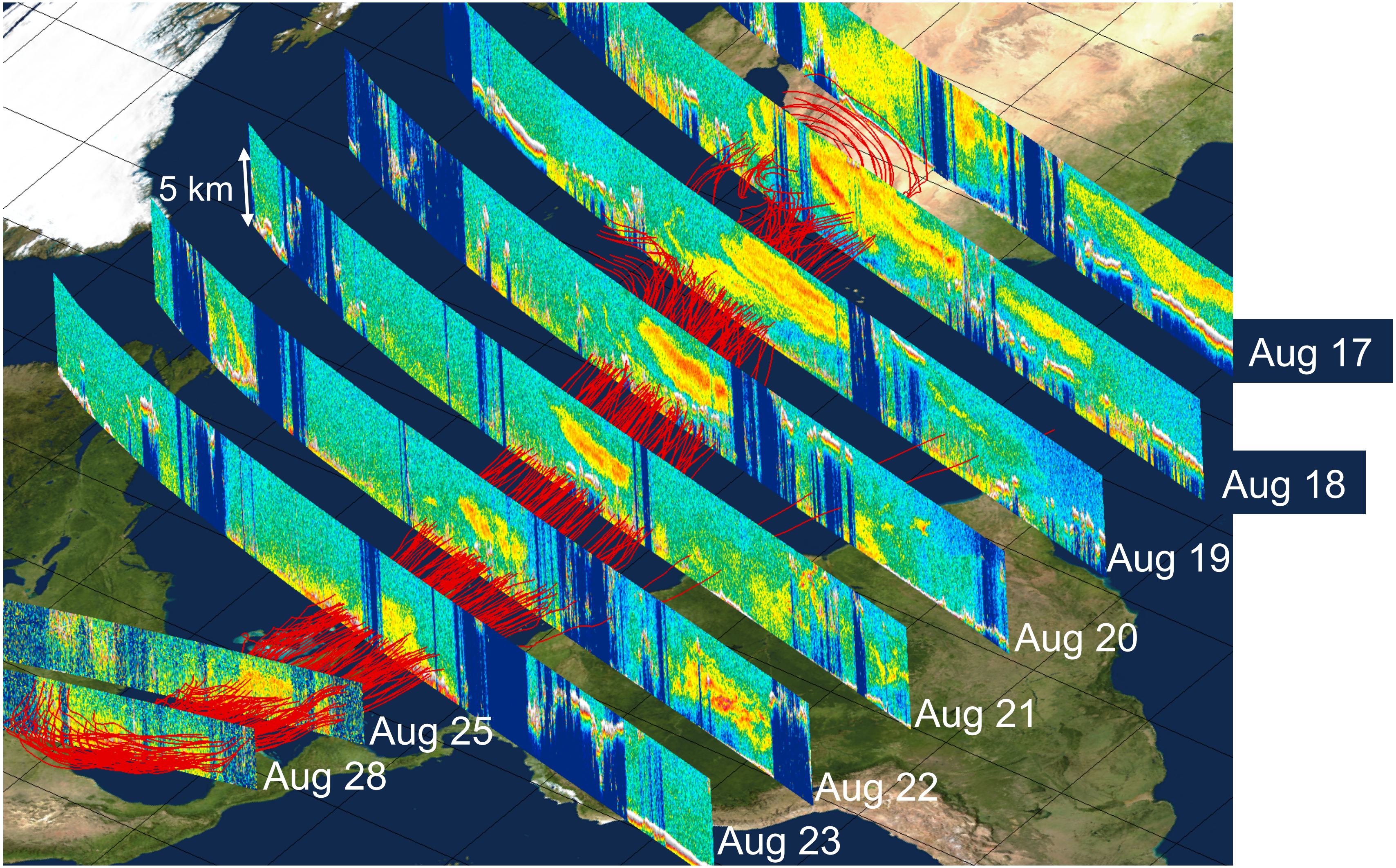




CALIPSO Browse Images
http://www-calipso.larc.nasa.gov/products/lidar/browse_images/production/

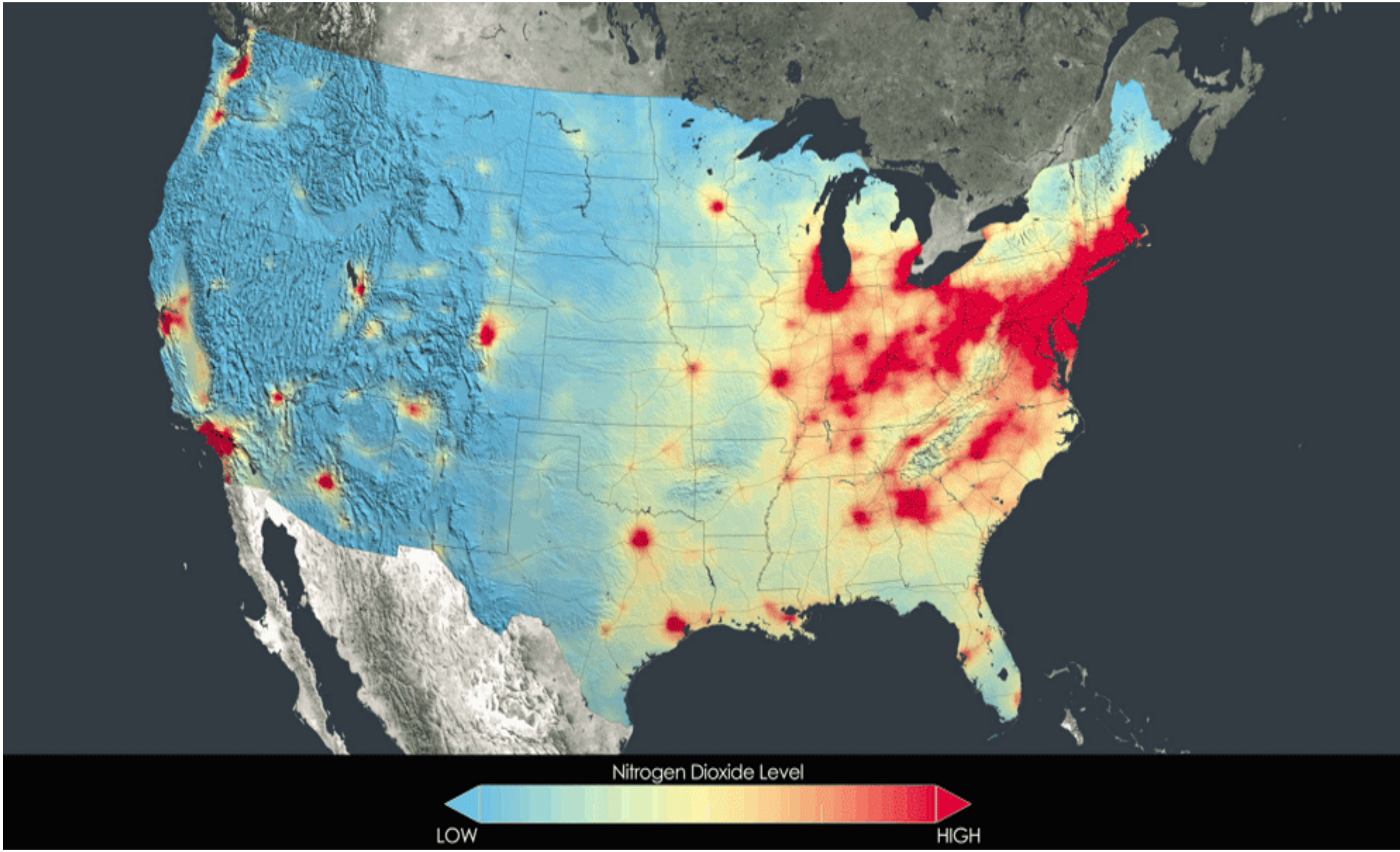
Example of CALIPSO Data

Major Saharan Dust Transport Event: Aug 17-28



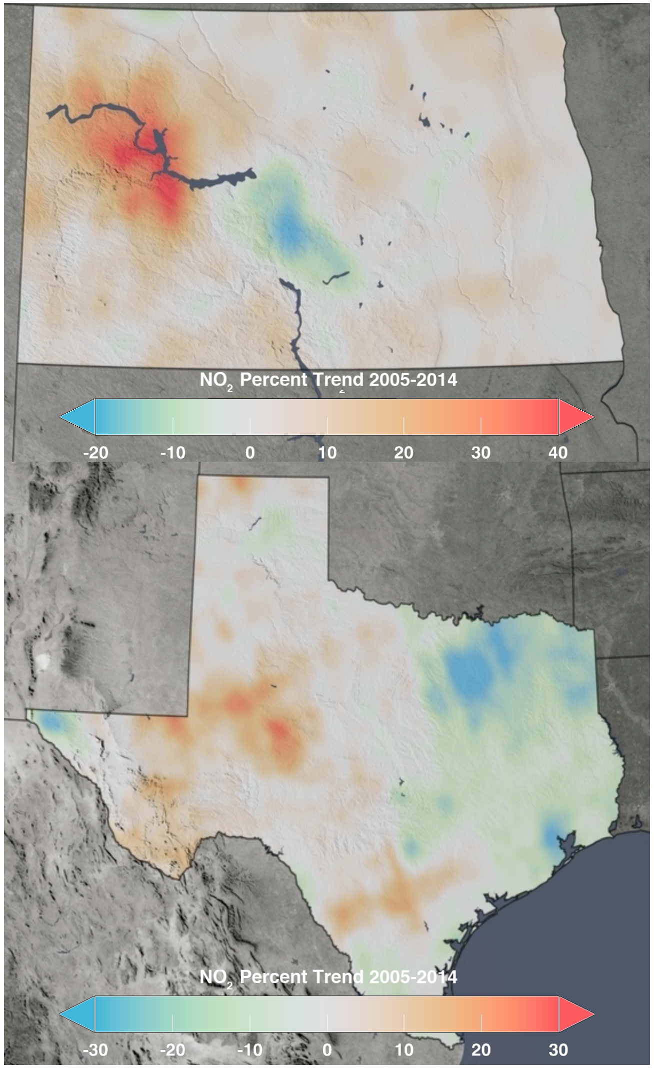
Courtesy of: Dave Winker, P.I. CALIPSO

NO_2 Trends Over the United States



OMI Detects NO_2 Increases from ONG Activities

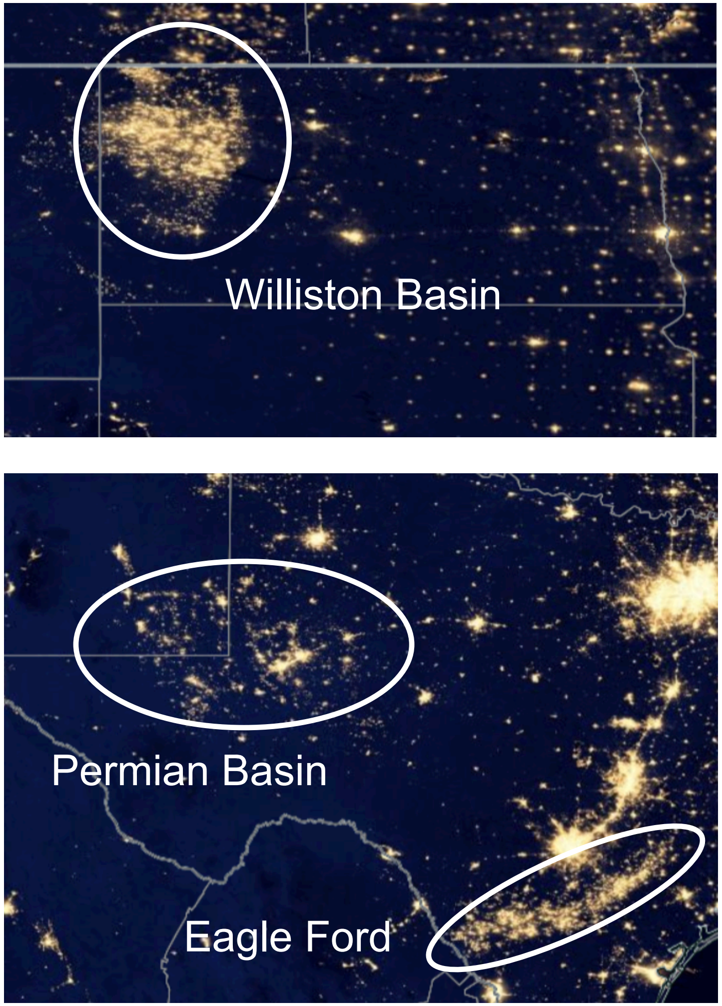
2005-2014



Suomi NPP VIIRS Lights at Night

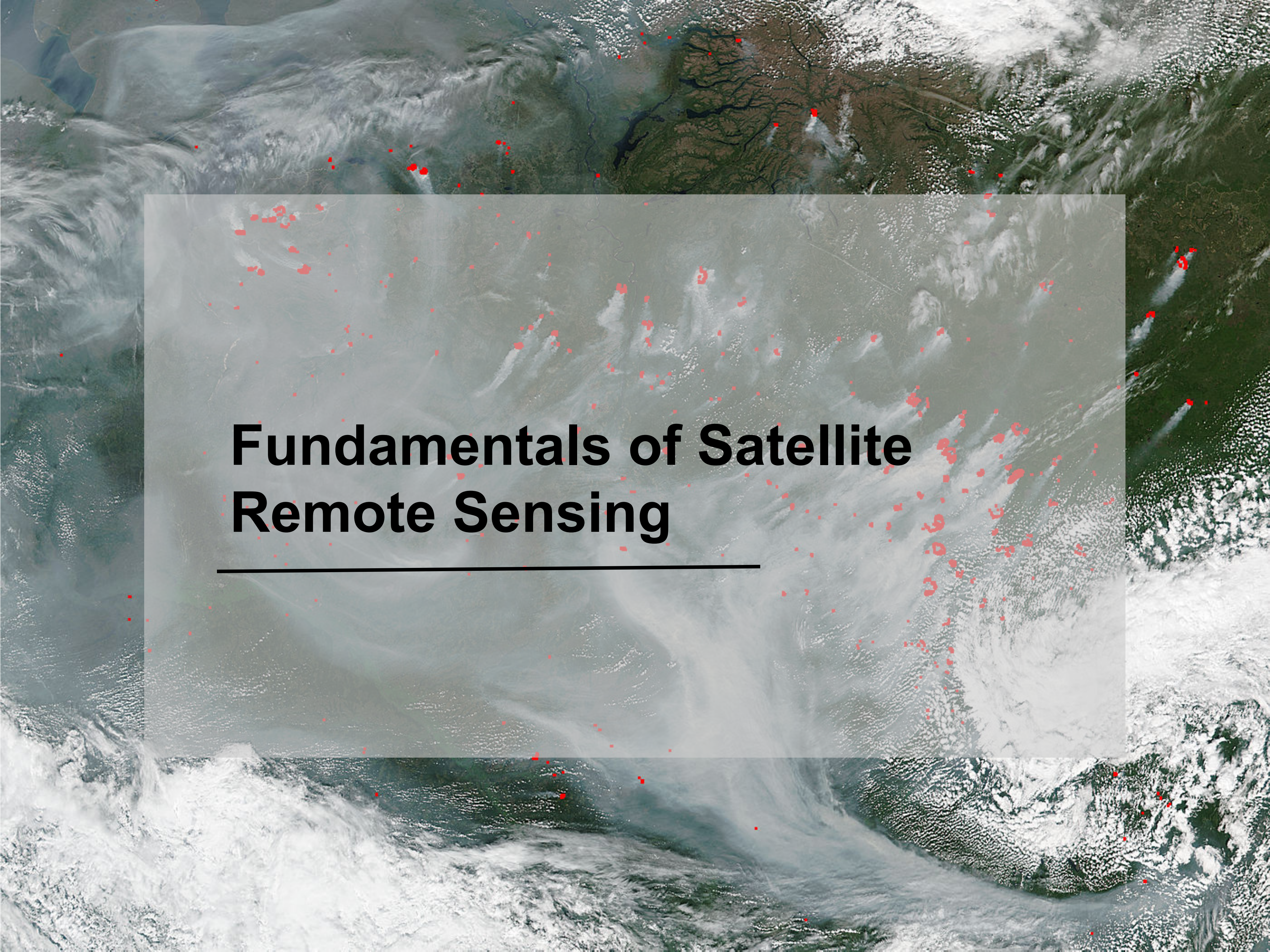
North Dakota

Texas

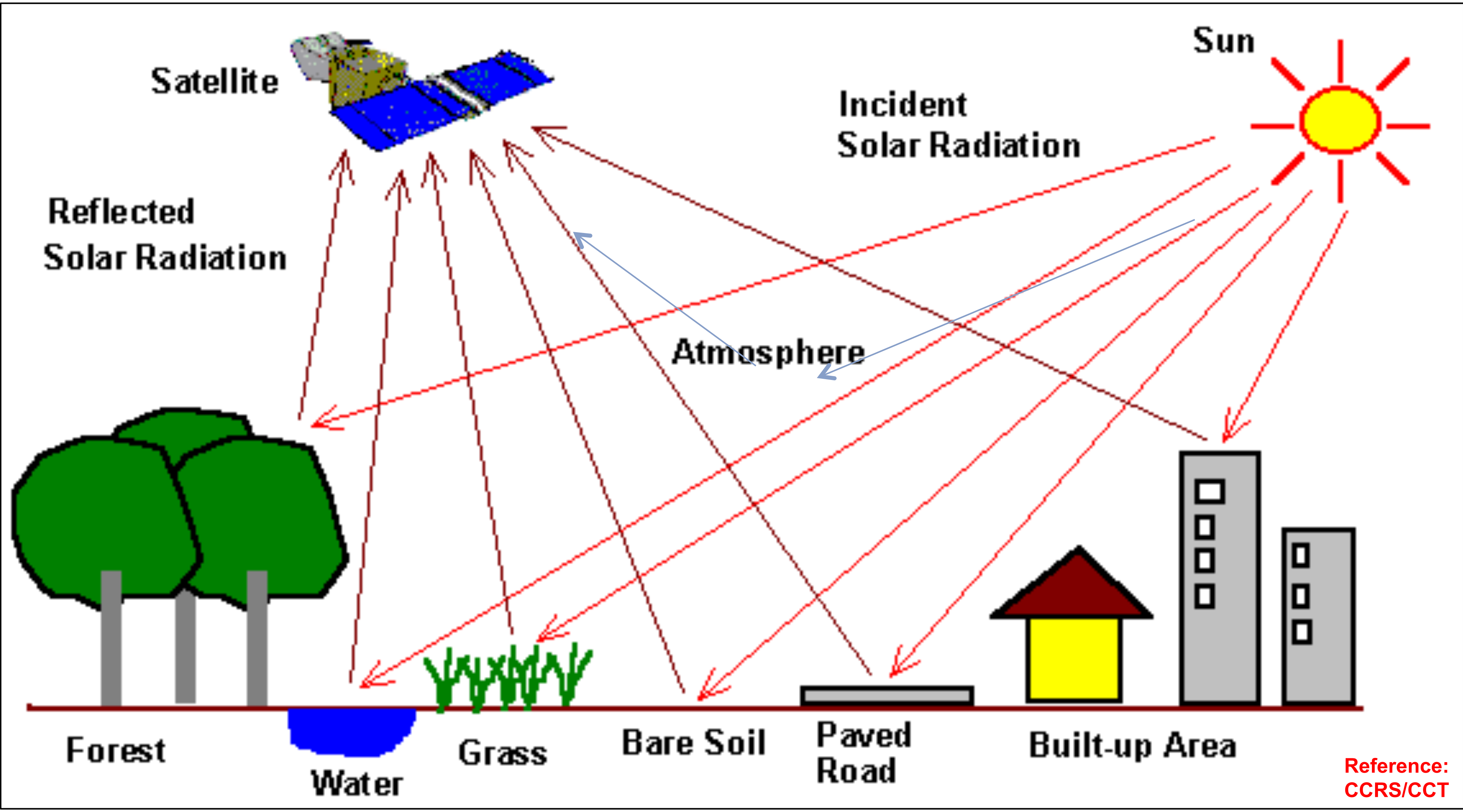


Courtesy of: Bryan Duncan

Fundamentals of Satellite Remote Sensing



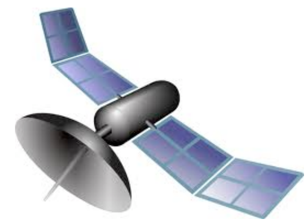
What do satellites measure ?

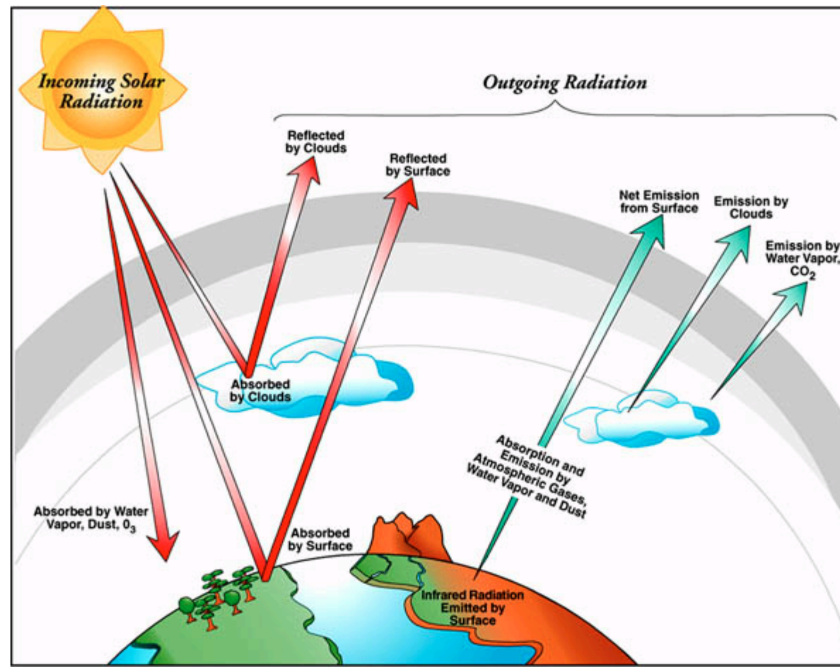


Reference:
CCRS/CCT

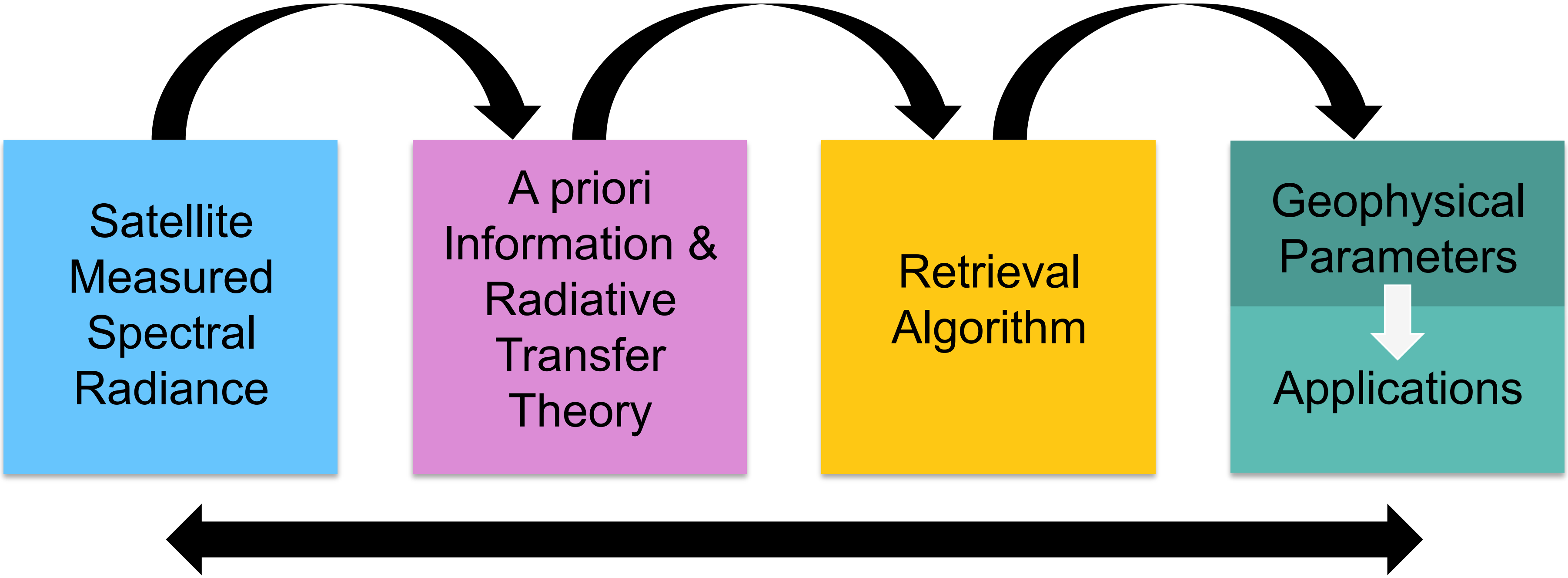
Measuring Properties of the Earth-Atmosphere System from Space

- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions
- Thus, satellite measurements contain information about the surface and atmospheric conditions





The Remote Sensing Process

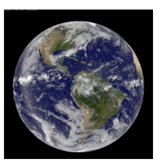


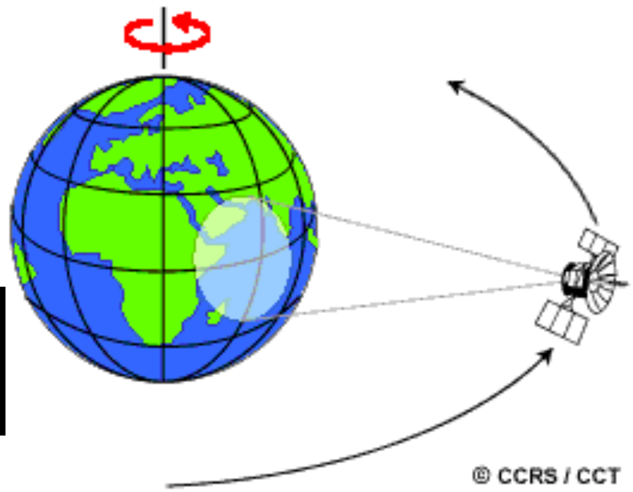
Characterizing Satellites and Sensors

- Orbits
  - polar vs. geostationary
- Energy Source
  - passive vs. active…
- Solar and Terrestrial Spectra
  - visible, UV, IR, Microwave…
- Measurement Technique
  - scanning, non-scanning, imager, sounders…
- Resolution (Spatial, Temporal, Spectral, Radiometric)
  - low vs. high
- Applications
  - Weather, Ocean Colors, Land Mapping, Atmospheric Physics, Atmospheric Chemistry, Air Quality, Radiation Budget, Water Cycle, Coastal Management, ...

Common Types of Orbits

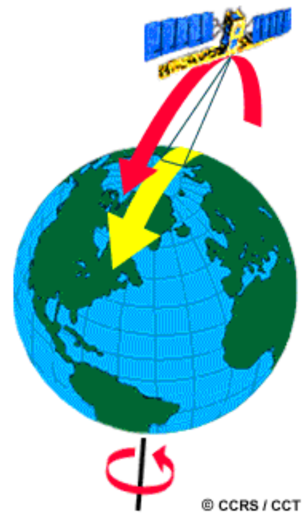
Geostationary Orbit

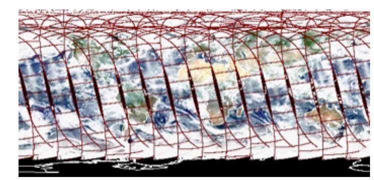




- Same rotational period as Earth
- Appears 'fixed' above Earth
- Over equator at ~36,000 km

Polar Orbit



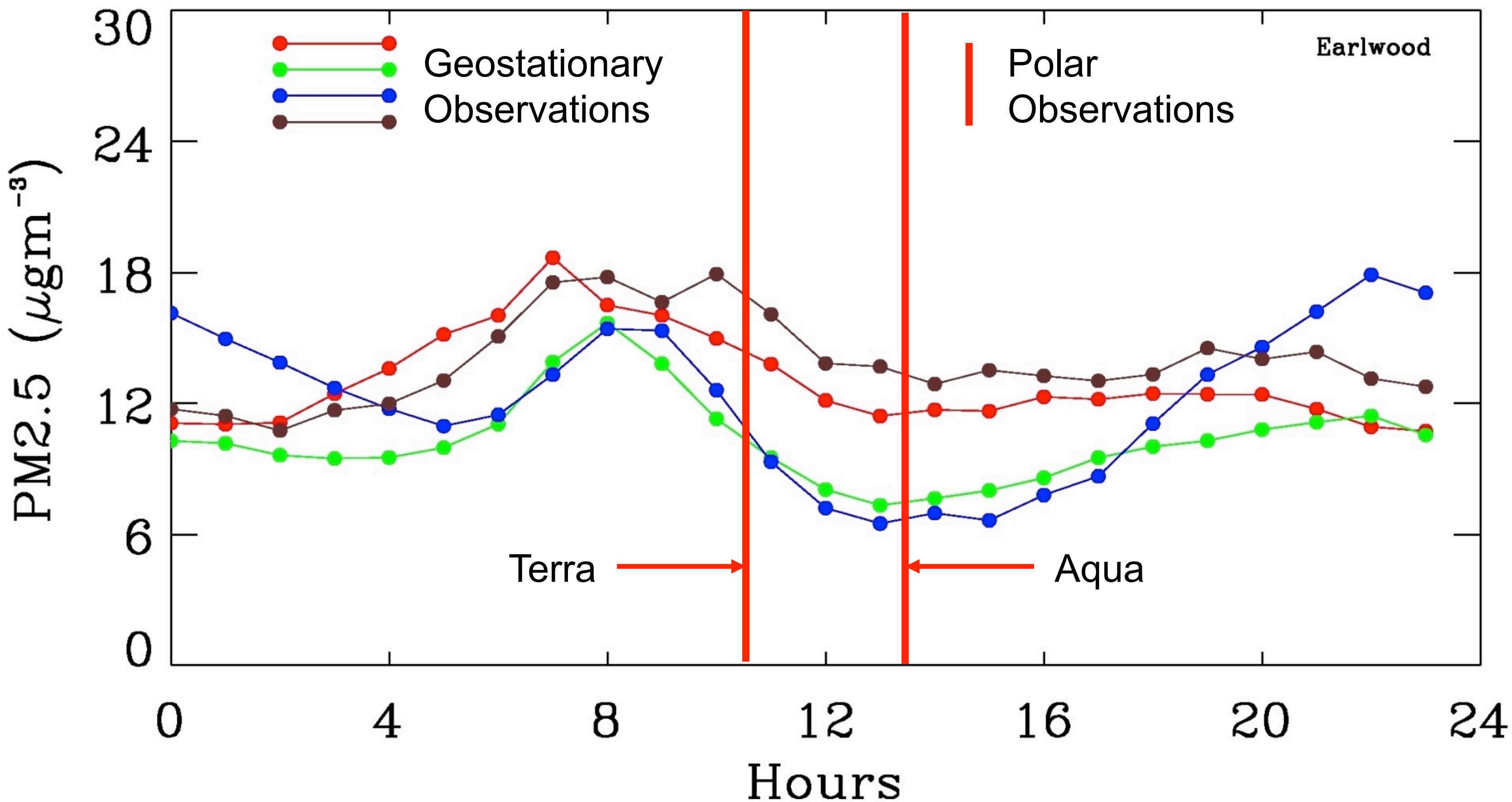


- Fixed, circular orbit above Earth
- ~600-1,000 km
- Sun-synchronous orbit with orbital pass at about the same **local solar time** each day

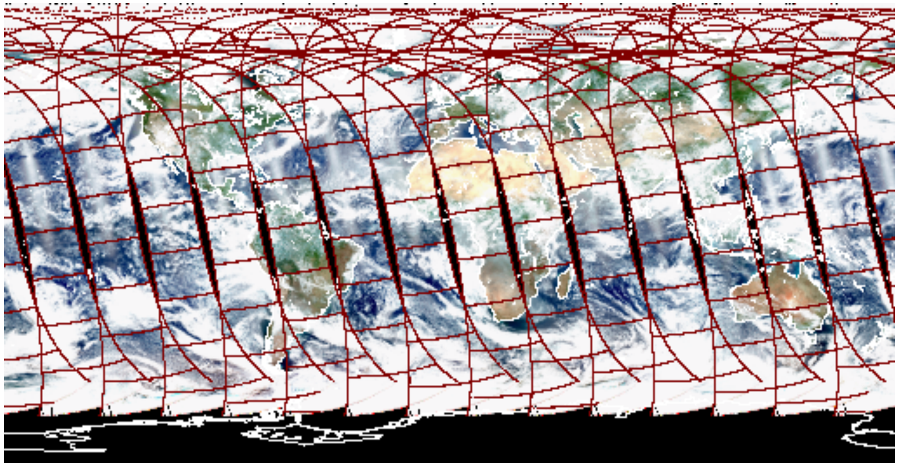
Observation Frequency

- Polar Orbiting Satellites:
  - 1-2 observations, per day, per sensor

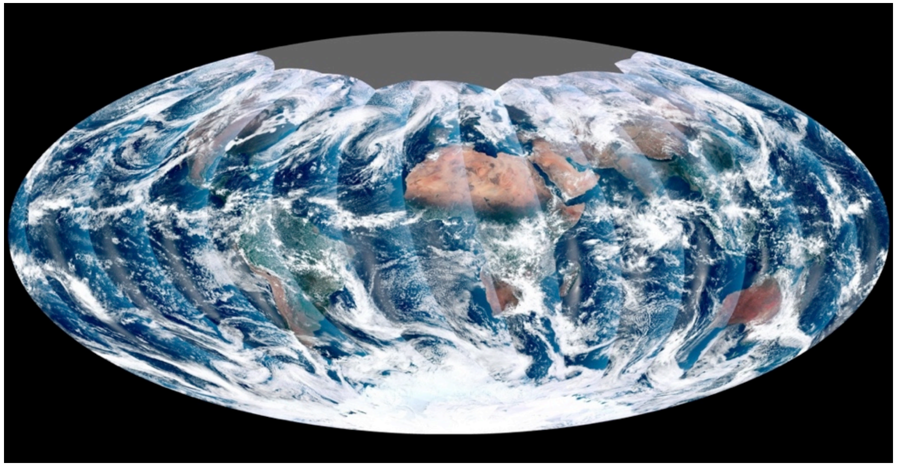
Future Geostationary Satellites
TEMPO, GEMS, Sentinel-4



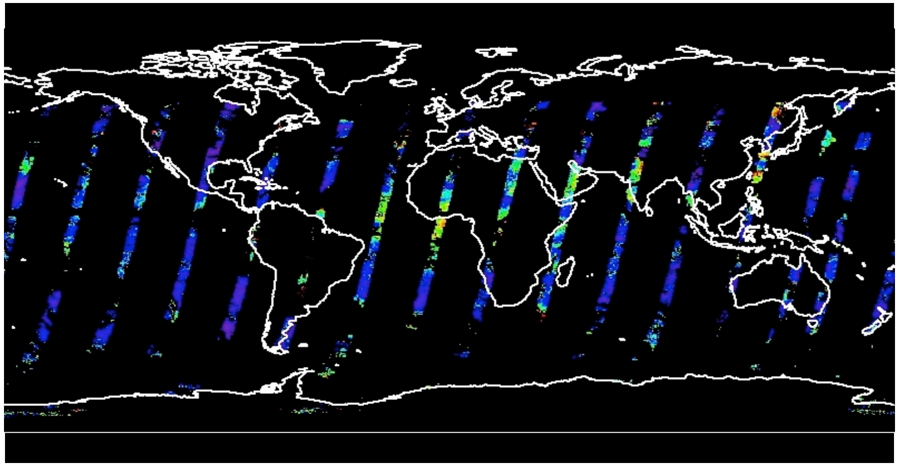
Satellite Coverage



MODIS



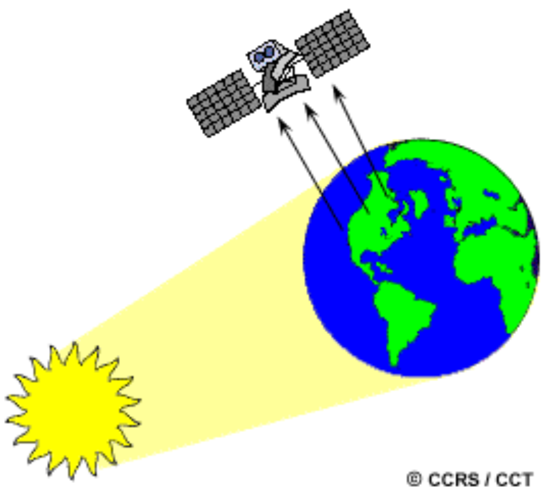
VIIRS



MISR

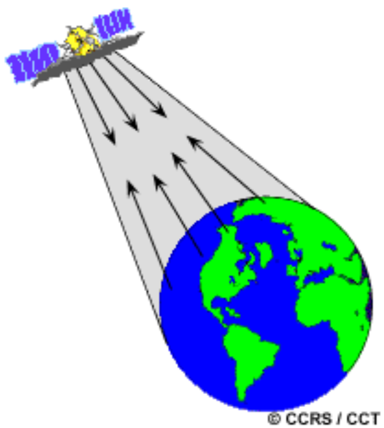
Active & Passive Sensors

Passive Sensors



- Remote sensing systems that measure naturally available energy are called passive sensors
- MODIS, MISR, OMI, VIIRS

Active Sensors



- The sensor emits radiation directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor.*
- CALIPSO

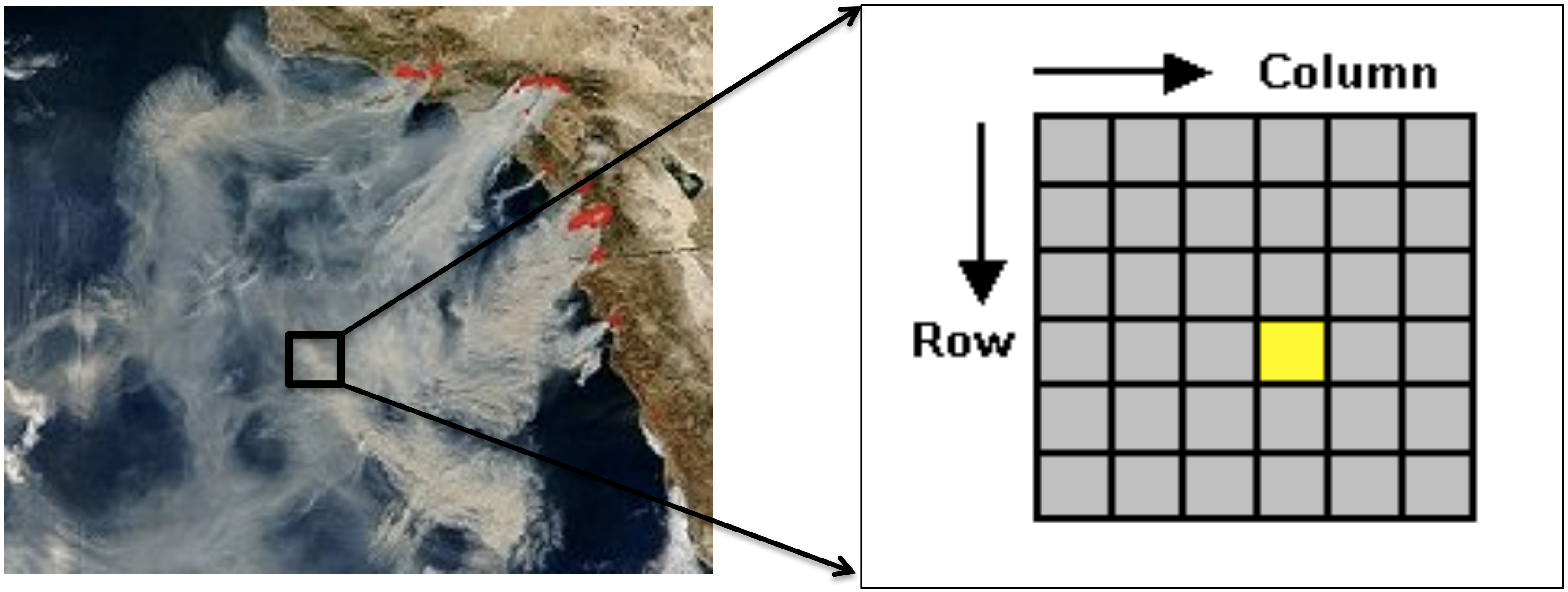
*Text Source: Natural Resources Canada

Remote Sensing – Types of Resolution

- Spatial Resolution
  - The smallest spatial measurement
- Temporal Resolution
  - Frequency of measurement
- Spectral Resolution
  - The number of independent channels
- Radiometric Resolution
  - The sensitivity of the detectors

- Depends on the satellite orbit configuration and sensor design
- Resolutions are different for different sensors

Pixel – the Smallest Unit of an Image



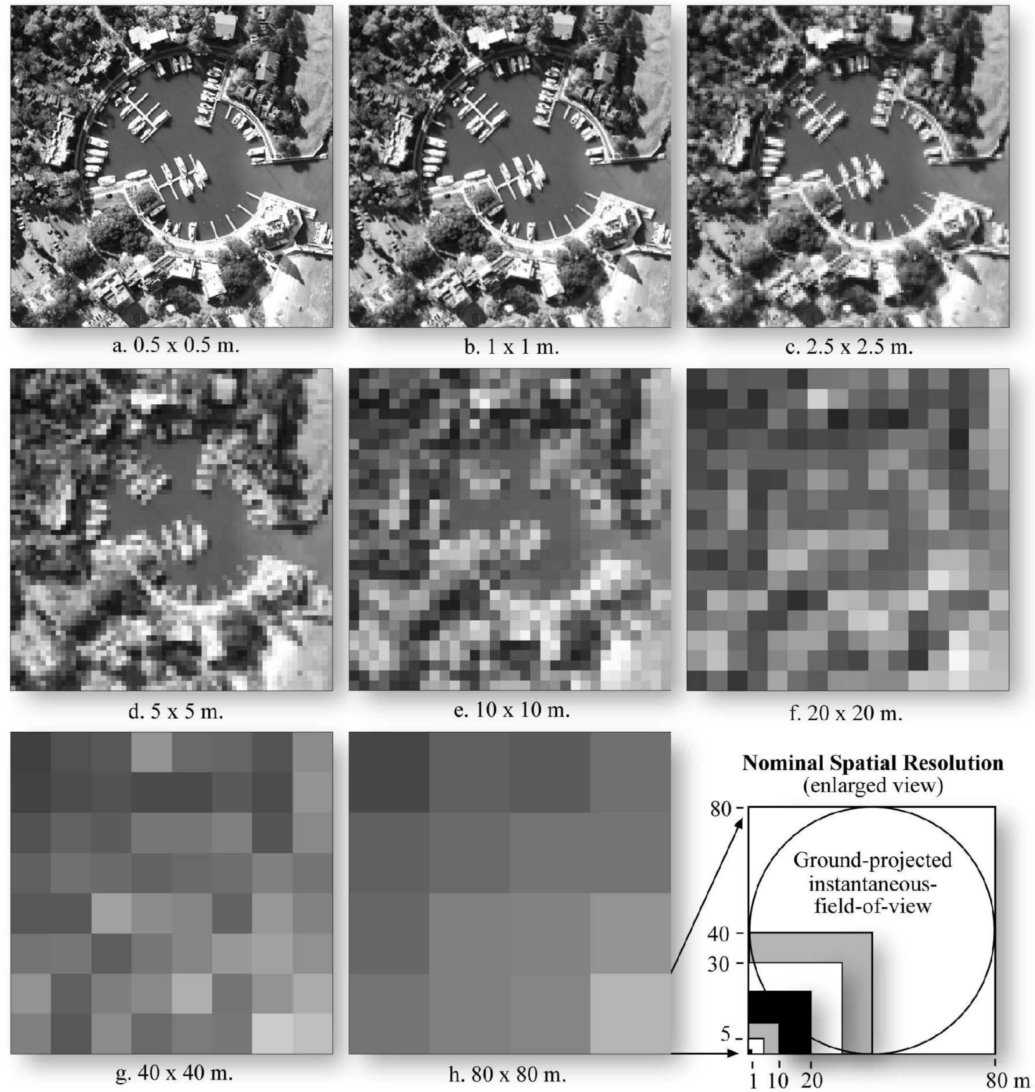
- A digital image is comprised of a two dimensional array of individual picture elements – called pixels – arranged in columns in rows
- Each pixel represents an area on the Earth's surface
- A pixel has an intensity value and a location address in the 2D image
- Spatial resolution is defined by the size of a pixel

*Text Source: Center for Remote Imaging, Sensing & Processing

Why is spatial resolution important?

- **MODIS**
  - 250 m – 1 km
- **MISR**
  - 275 m – 1.1 km
- **OMI**
  - 13x24 km
- **VIIRS**
  - 375 m

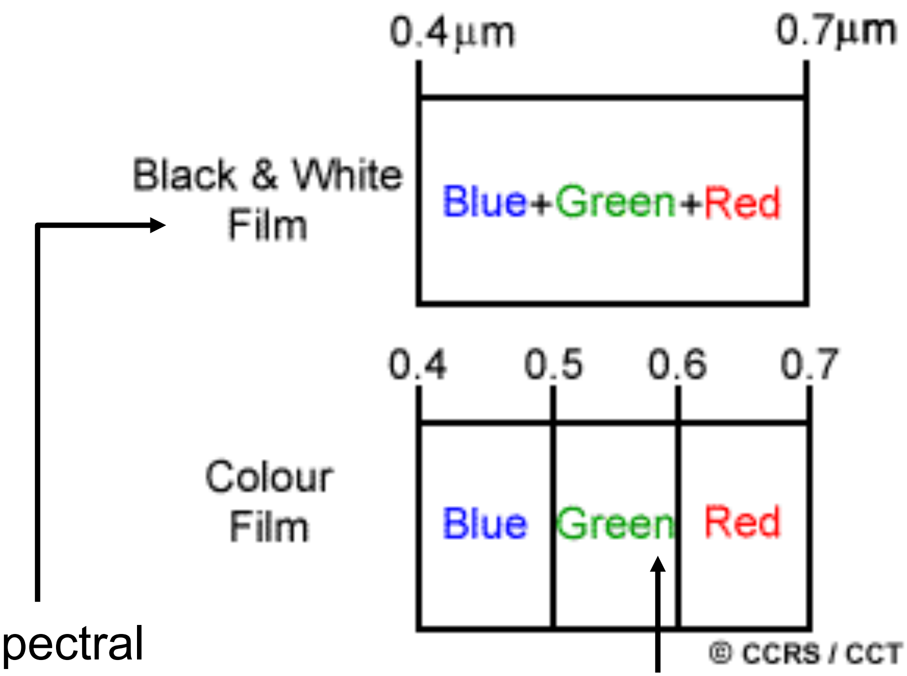
Imagery of Harbor Town in Hilton Head, SC, at Various Nominal Spatial Resolutions



Source: Introductory Digital Image Processing, 3rd edition, Jensen, 2004

Spectral Resolution

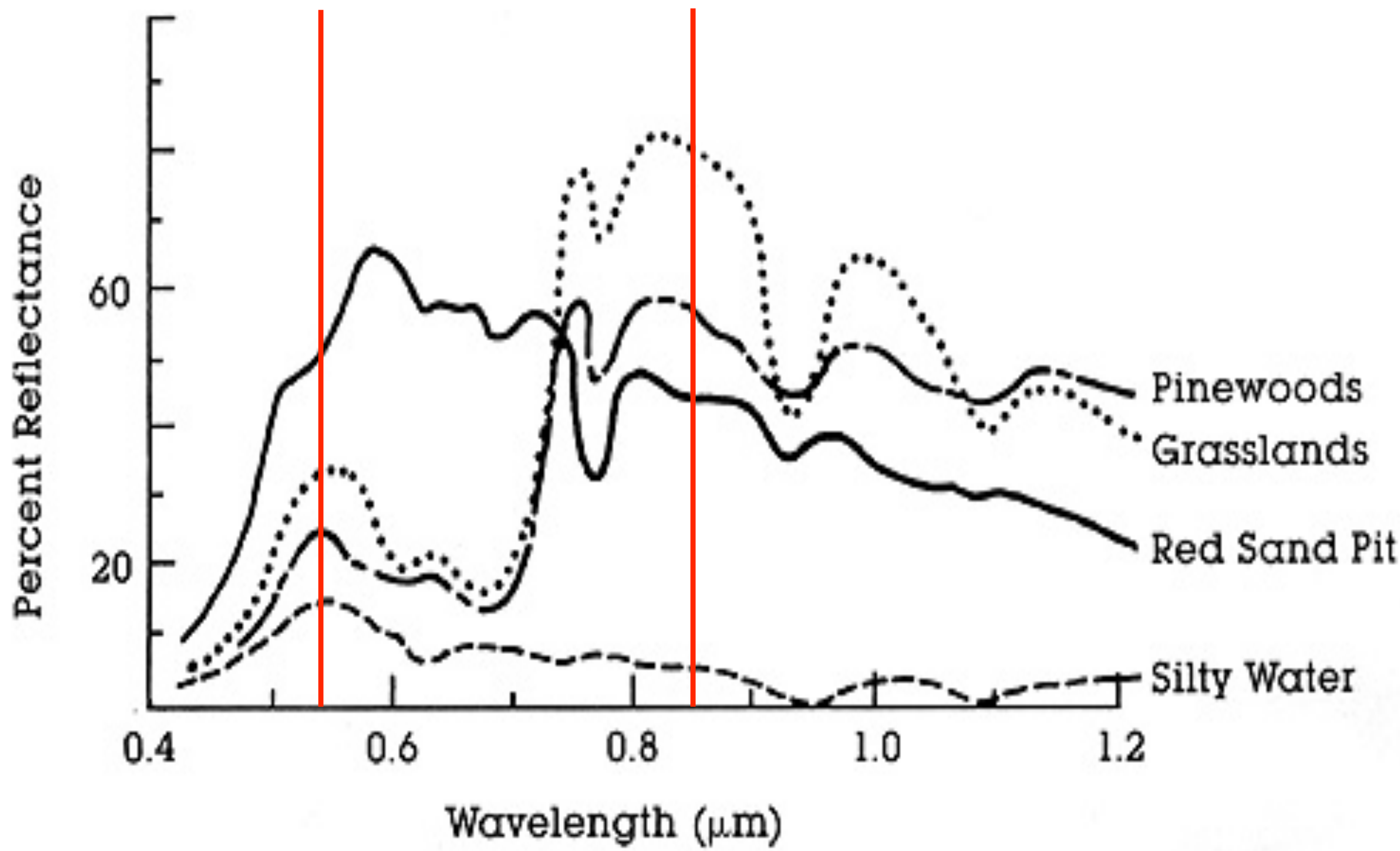
- Spectral resolution describes a sensor's ability to define fine wavelength intervals
- The finer the spectral resolution, the narrower the wavelength range for a particular channel or band
- **Multispectral Sensors**
  - MODIS
  - Low spectral resolution
- **Hyperspectral Sensors**
  - OMI, AIRS
  - High spectral resolution



Low spectral resolution

High spectral resolution

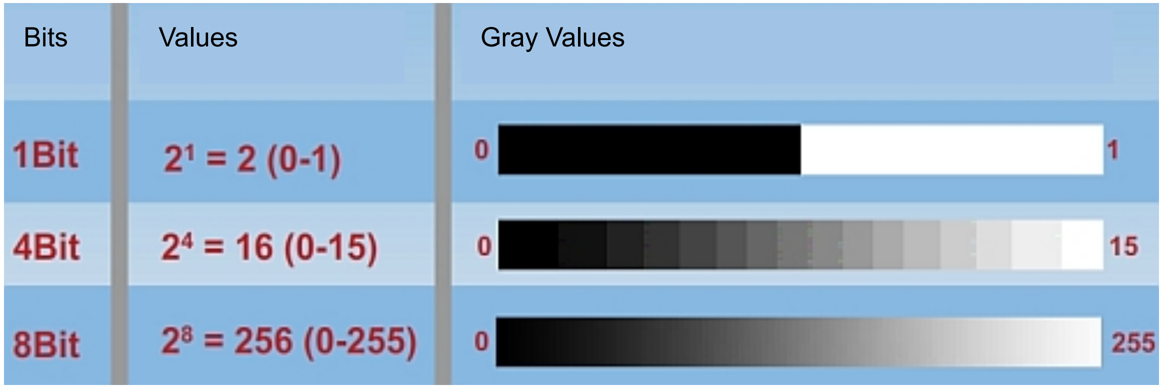
Why is spectral resolution important?



Radiometric Resolution

- Imagery data are represented by positive digital numbers that vary from 0 to (one less than) a selected power of 2
- The maximum number of brightness levels available depends on the number of bits (**represents radiometric resolution**) used in representing the energy recorded
- The larger this number, the higher the radiometric resolution

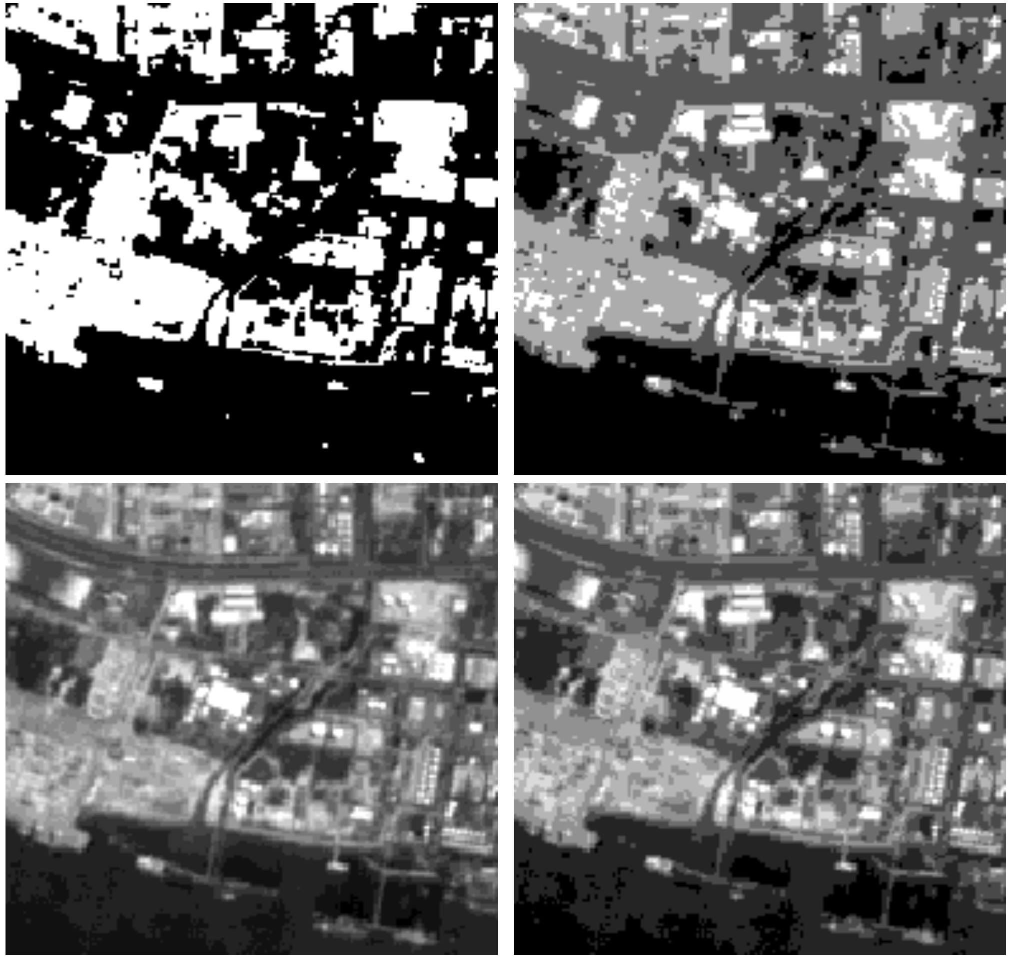
- 12 bit sensor (MODIS, MISR)
  – 2^{12} or 4,096 levels
- 10 bit sensor (AVHRR)
  – 2^{10} or 1,024 levels
- 8 bit sensor (Landsat 7 TM)
  – 2^{8} or 256 levels



Source: FIS

*Text Source: Natural Resources Canada

Radiometric Resolution



2 - levels

4 - levels

8 - levels

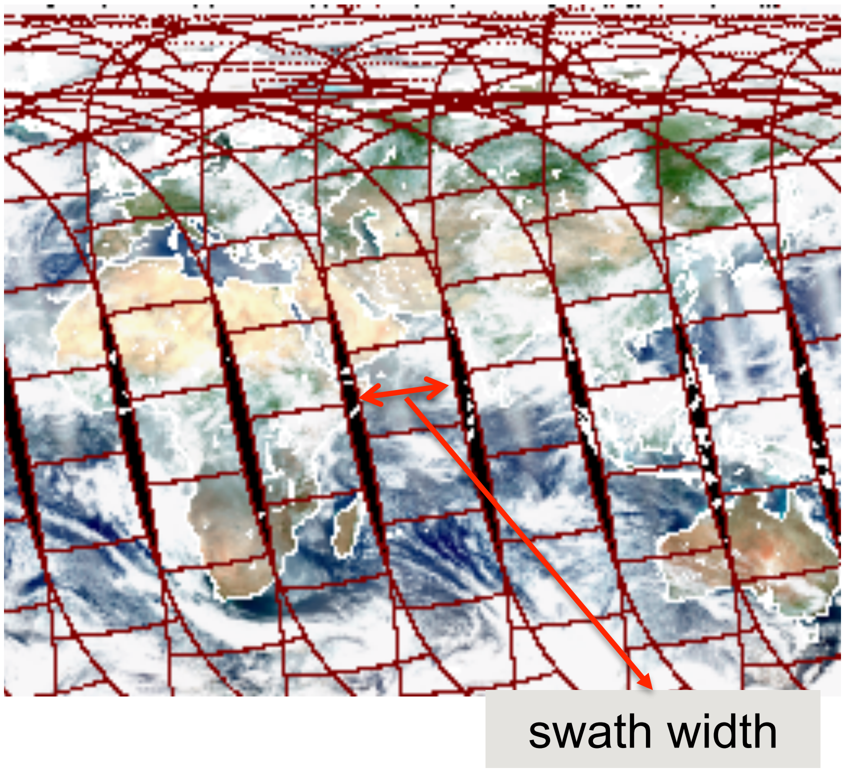
16 - levels

(MODIS 4096 levels)

In classifying a scene, different classes are more precisely identified if radiometric resolution is high

Temporal Resolution

- How frequently a satellite can provide observations of the same area on the Earth
- It mostly depends on the swath width of the satellite – the larger the swath, the higher the temporal resolution



- MODIS
  - 1-2 days
- OMI
  - 1-2 days
- MISR
  - 6-8 days
- VIIRS
  - 1 day
- Geostationary
  - 10 min – 1 hr

Remote Sensing Tradeoff

It is very difficult to obtain extremely high spectral, spatial, temporal, **AND** radiometric resolutions all at the same time

Future Satellite Capabilities for Air Quality Applications

GOES-R

- Expected Launch: November 2016
- Advanced Baseline Imager (ABI): 16 Spectral Bands
- Very High Temperature Resolution: 15 min – 30 seconds

GOES-R

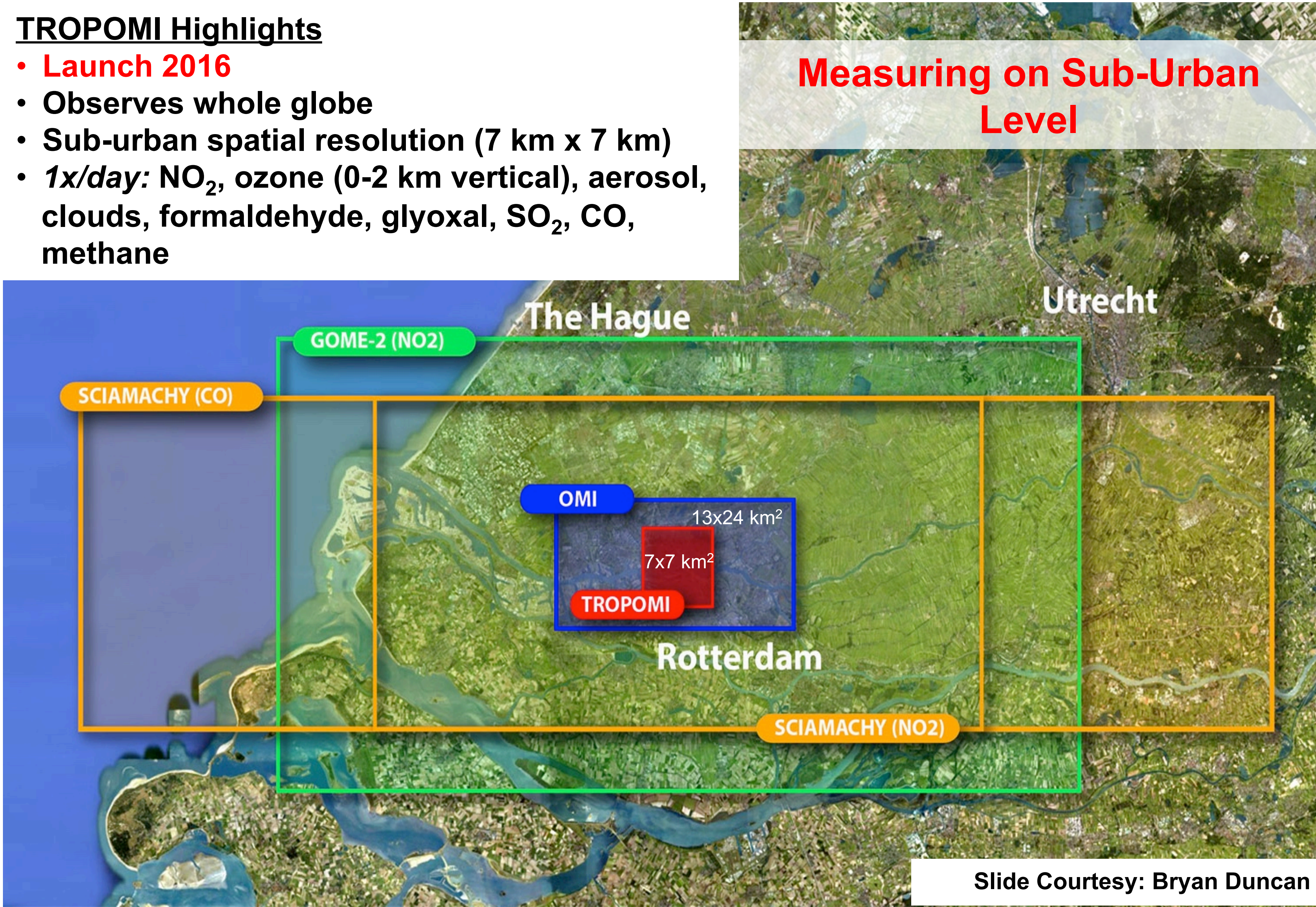
	ABI	Current GOES Imager
Spectral Coverage	16 bands	5 bands
Spatial Resolution		
0.64 µm Visible	0.5 km	~ 1 km
Other visible/near-IR	1.0 km	n/a
Bands (>2 µm)	2 km	~ 4 km
Spatial Coverage		
Full Disk	4 per hour	Scheduled (3 hrly)
CONUS	12 per hour	~4 per hour
Mesoscale	Every 30 sec	n/a
Visible (reflective bands)		
On-orbit calibration	Yes	No

Upcoming Instruments

European Space Agency TROPOMI

TROPOMI Highlights

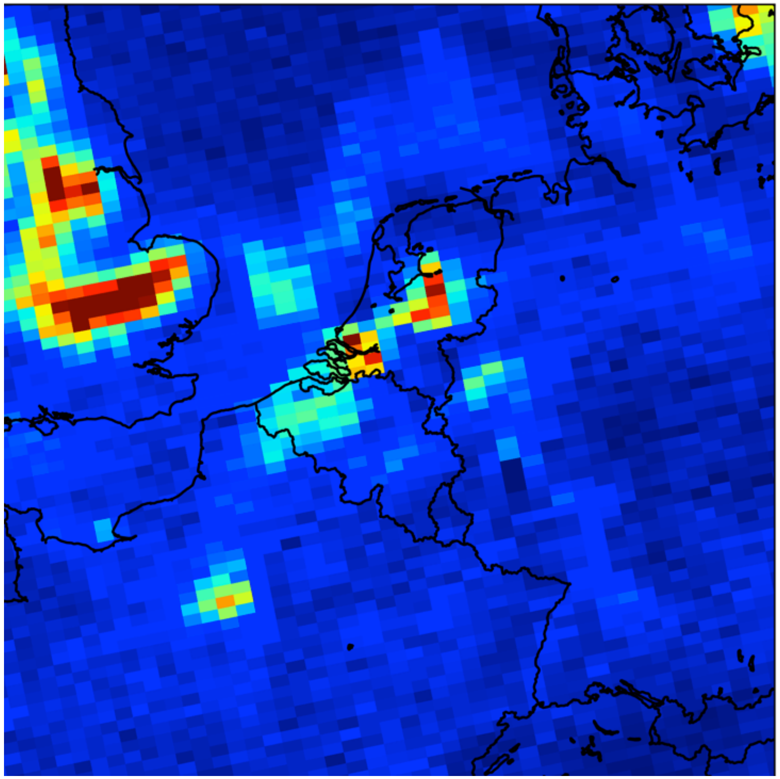
- **Launch 2016**
- **Observes whole globe**
- **Sub-urban spatial resolution (7 km x 7 km)**
- ***1x/day:* NO_2, ozone (0-2 km vertical), aerosol, clouds, formaldehyde, glyoxal, SO_2, CO, methane**



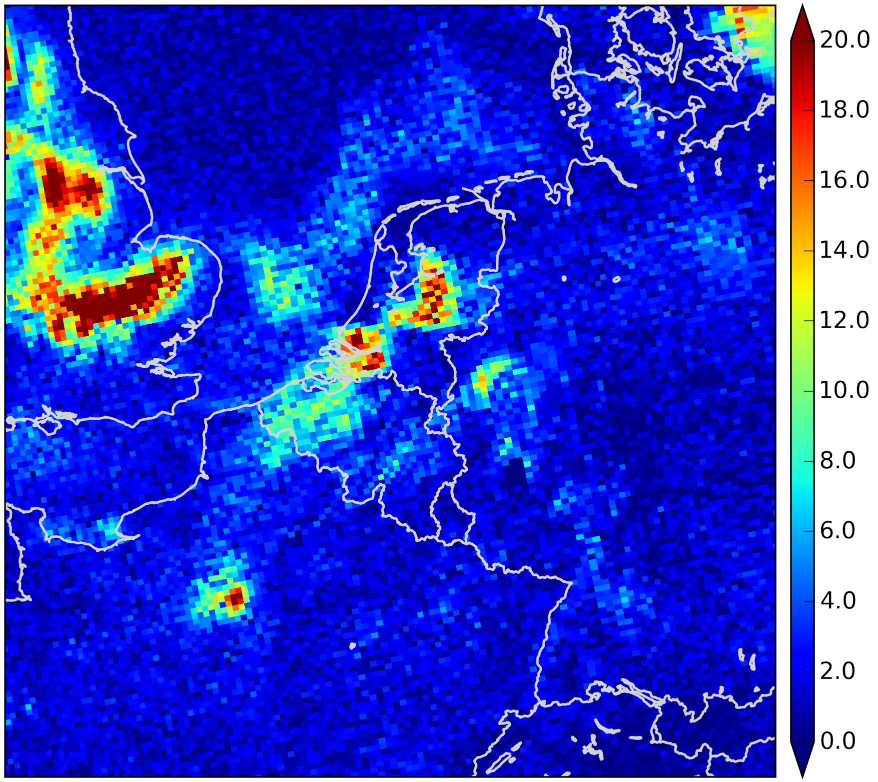
Slide Courtesy: Bryan Duncan

TROPOMI: Impact of Resolution

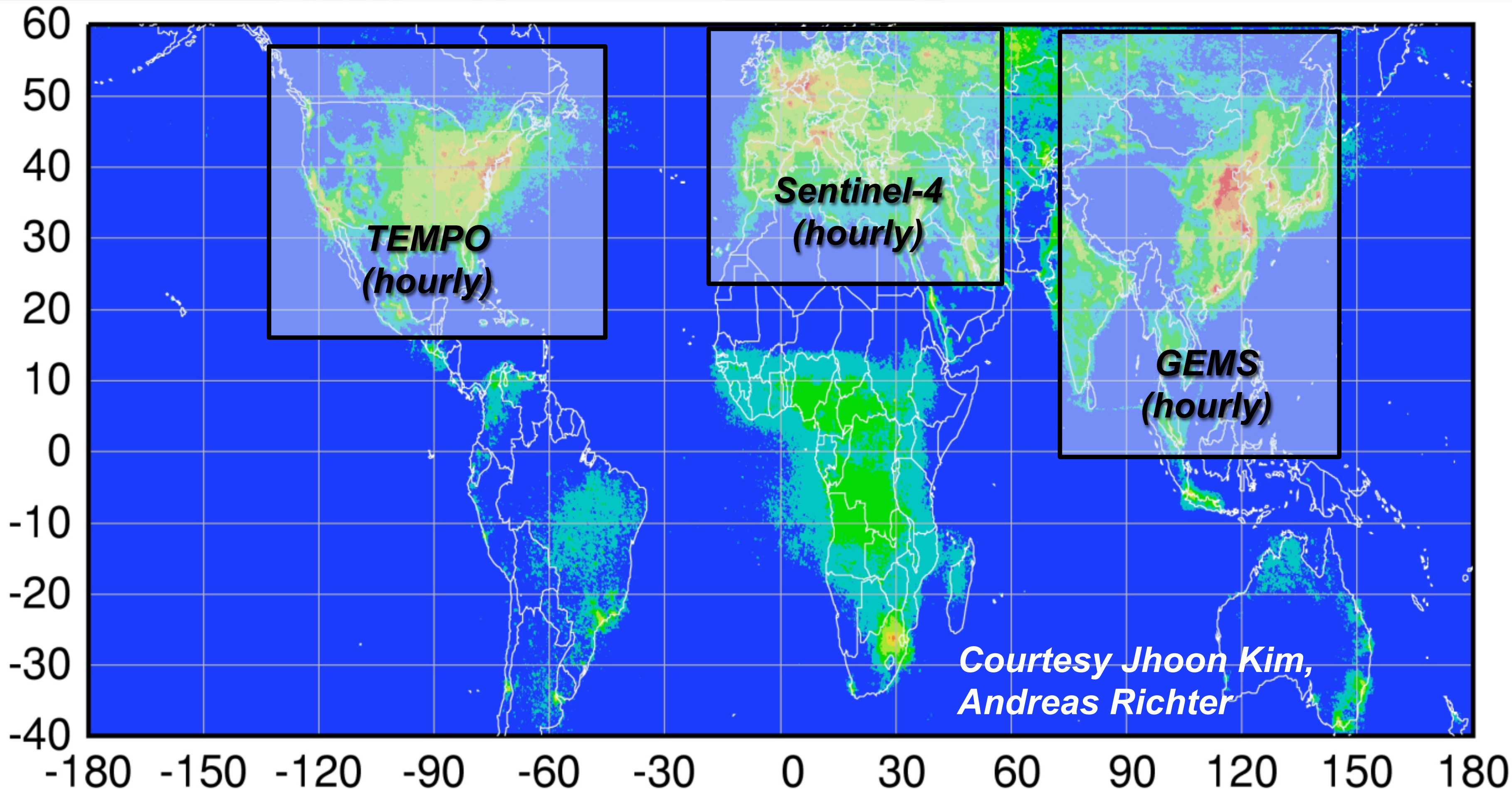
OMI (now)



TROMPOMI (launch 2016)



Global pollution monitoring constellation (2018-2020)



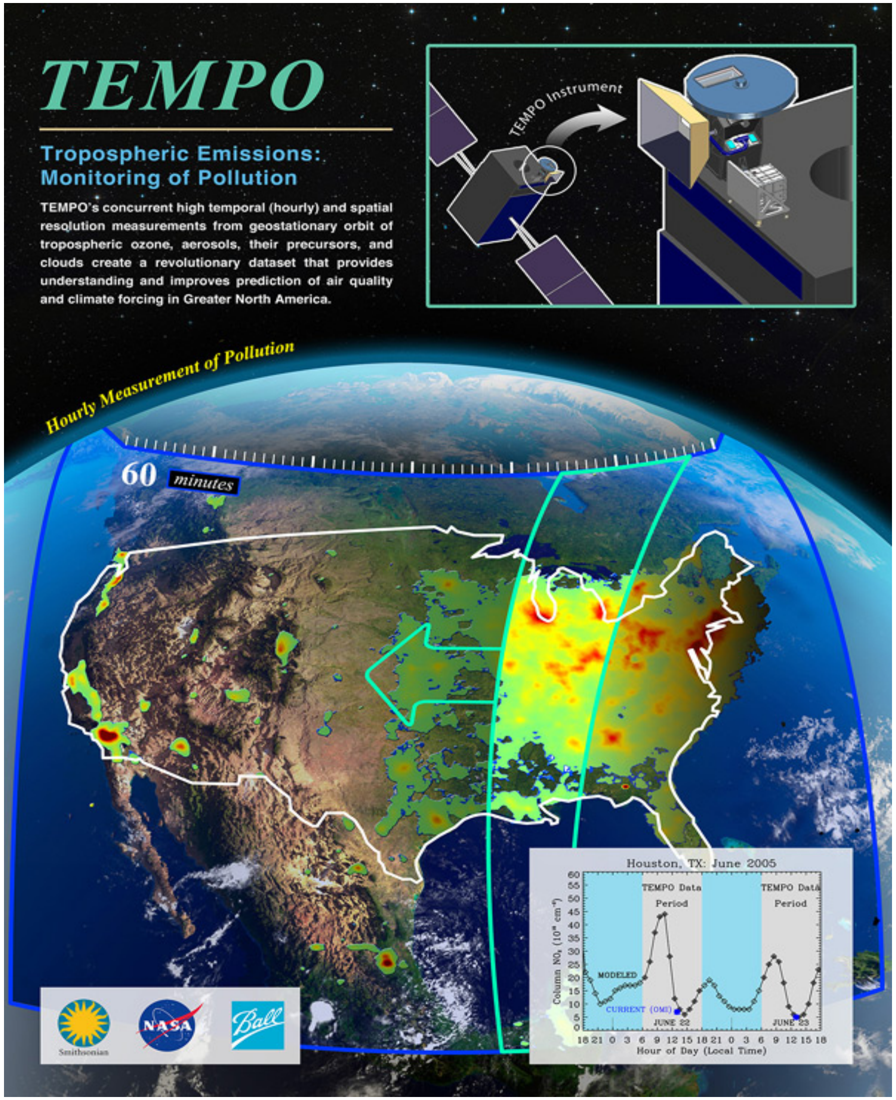
Policy-relevant science and environmental services enabled by common observations

- 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

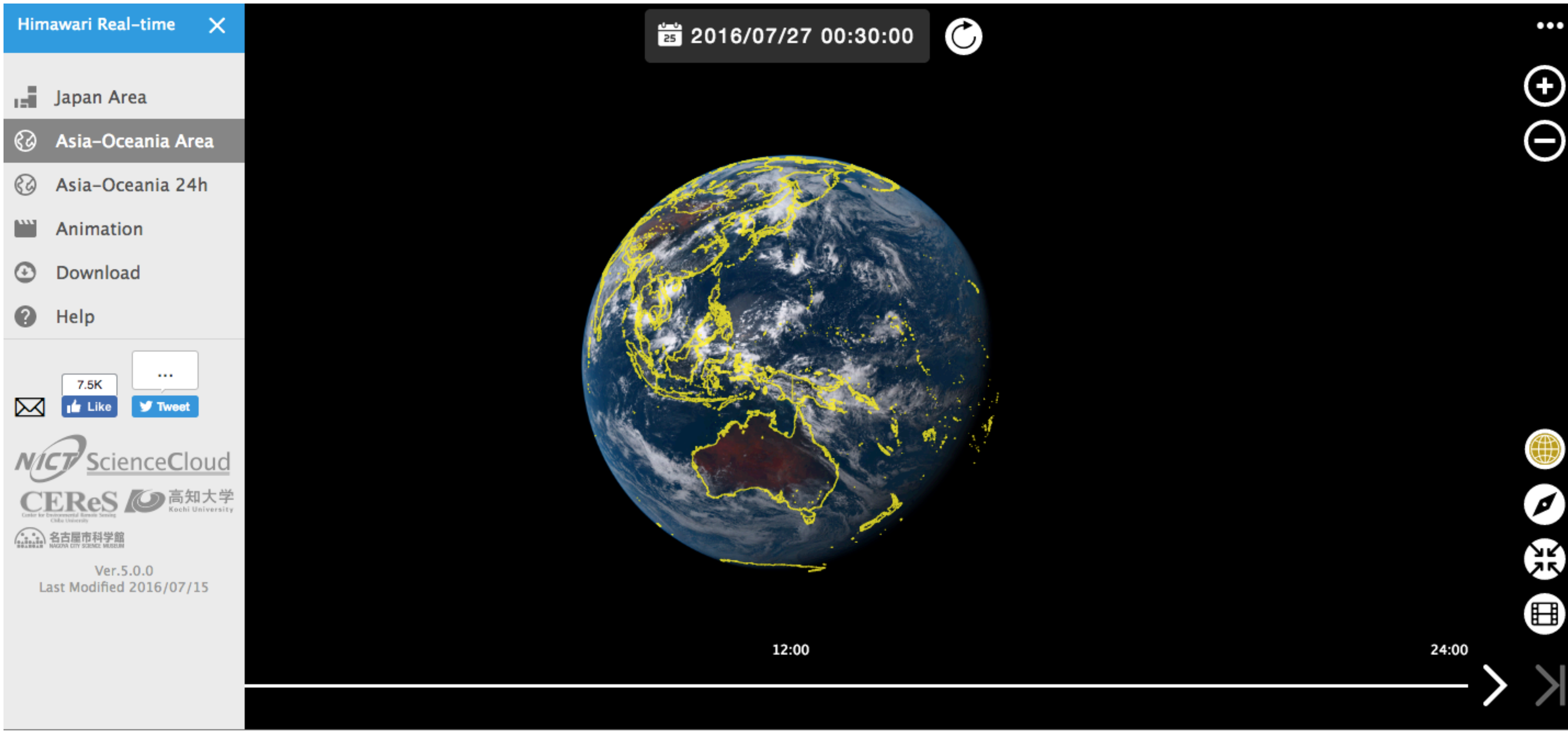
- Geostationary over North America
- High Temporal Resolution
  - 1 hr
- High Spatial Resolution
  - 2.2 x 4.7 km
- Spectral Range
  - 290-740nm
- Data Products:
  - O_3, NO_2, SO_2, H_2CO, $C_2H_2O_2$, aerosols, cloud parameters, & UVB radiation
- Expected Launch: 2020



Himarawi 8

http://himarawi8.nict.go.jp/

- Japan Meteorological Agency
- Launch date: October 7, 2014



Questions & Discussion

- Can satellites help fill some of the data gaps?
- What are advantages of polar orbiting satellites as compared to geostationary satellites?
- What are remote sensing tradeoffs ?
- List the sources of uncertainties in satellite observations for air quality application?

Questions?