Satellite Remote Sensing of Air Quality – An Overview

Pawan Gupta
NASA ARSET- AQ – EPA Training
September 29, 2014

ARSET - AQ

Applied Remote SEnsing and Training – Air Quality

A project of NASA Applied Sciences

ARSET

NASA Applied Sciences and Capacity Building

National and international activities to engage and train users applying NASA Earth Science satellites and modeling data in their decision making activities

NASA Applied Science : Capacity Building Program

Applied Remote SEnsing Training, ARSET (GSFC)

On-line and hands on basic/advanced trainings tailored to end-uses organizations

DEVELOP (LaRC national office)

Dual student/local government capacity building using collaborative projects

SERVIR Coordination Office (MSFC)

Building international capacity with hubs in

- East Africa
- Hindu Kush - Himalaya
- Mesoamerica

Gulf of Mexico Initiative, GOMI (SSC)

Building Gulf region's capacity for local environmental management

NASA Earth Science
Applied Sciences Program

Applications to Decision Making: Thematic Areas

Agricultural Efficiency

Air Quality

Climate

Disaster Management

Ecological Forecasting

Public Health

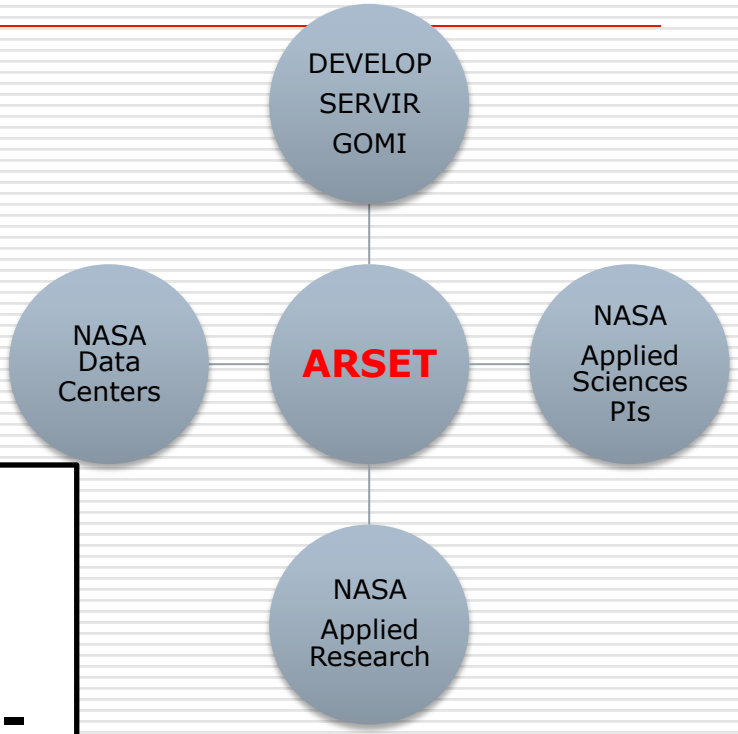
Water Resources

Weather

Applied Remote Sensing Training (ARSET)

GOAL:

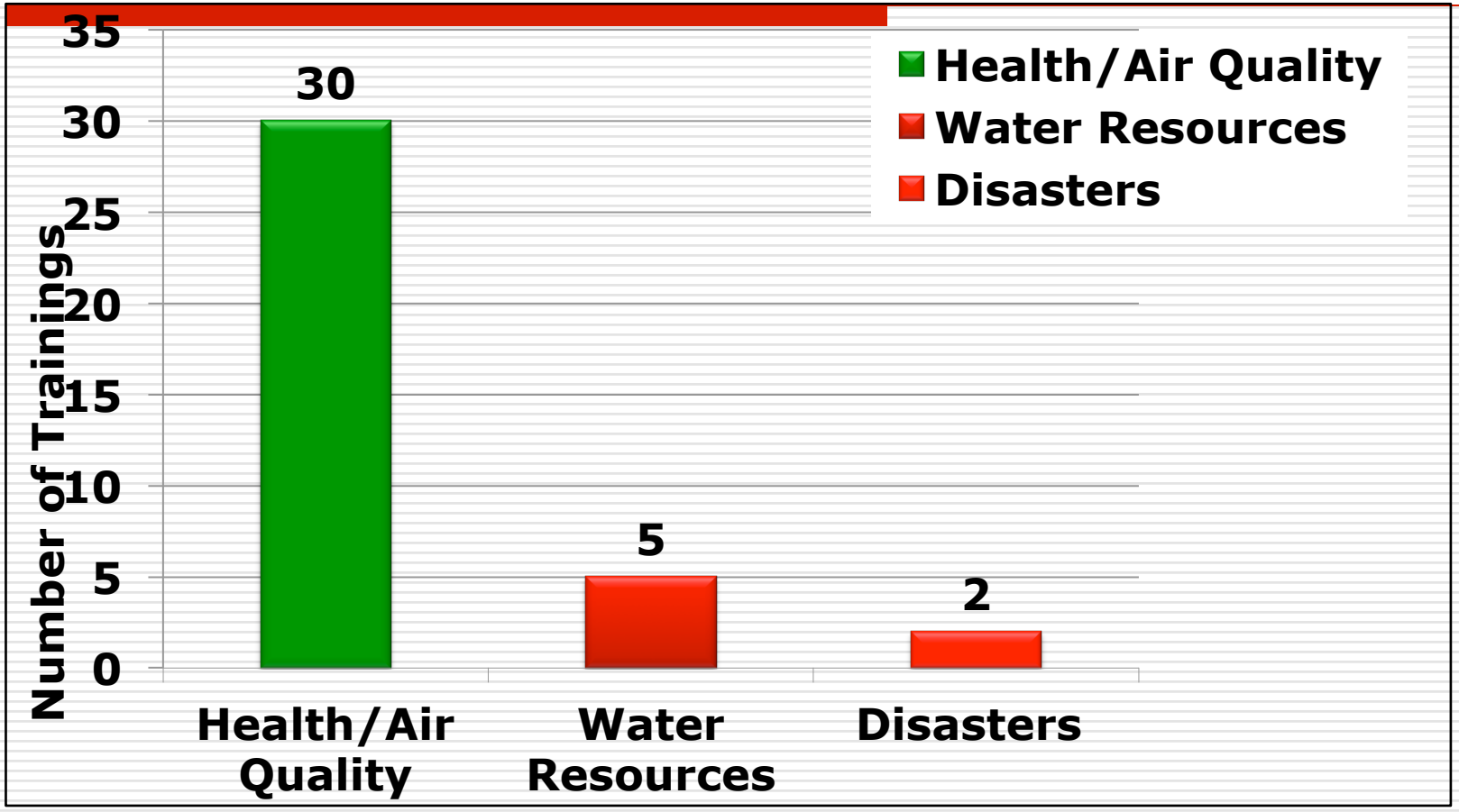
Increase utilization of NASA observational and model data for decision-support



Objectives:

- Provide end-user communities and institutions with **professional hands-on technical workshops**
- Build long term partnerships with end-user communities and institutions in the public and private sectors

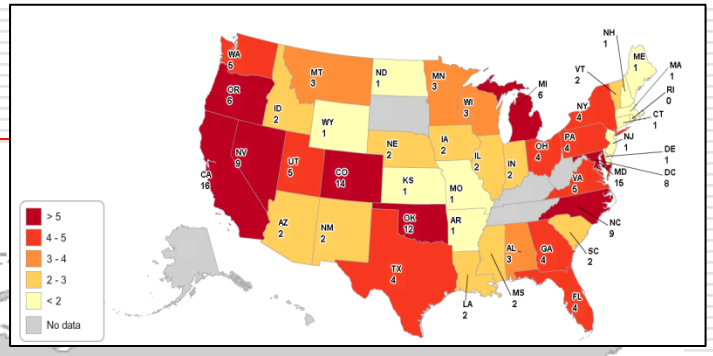
ARSET Trainings by Societal Benefit Area

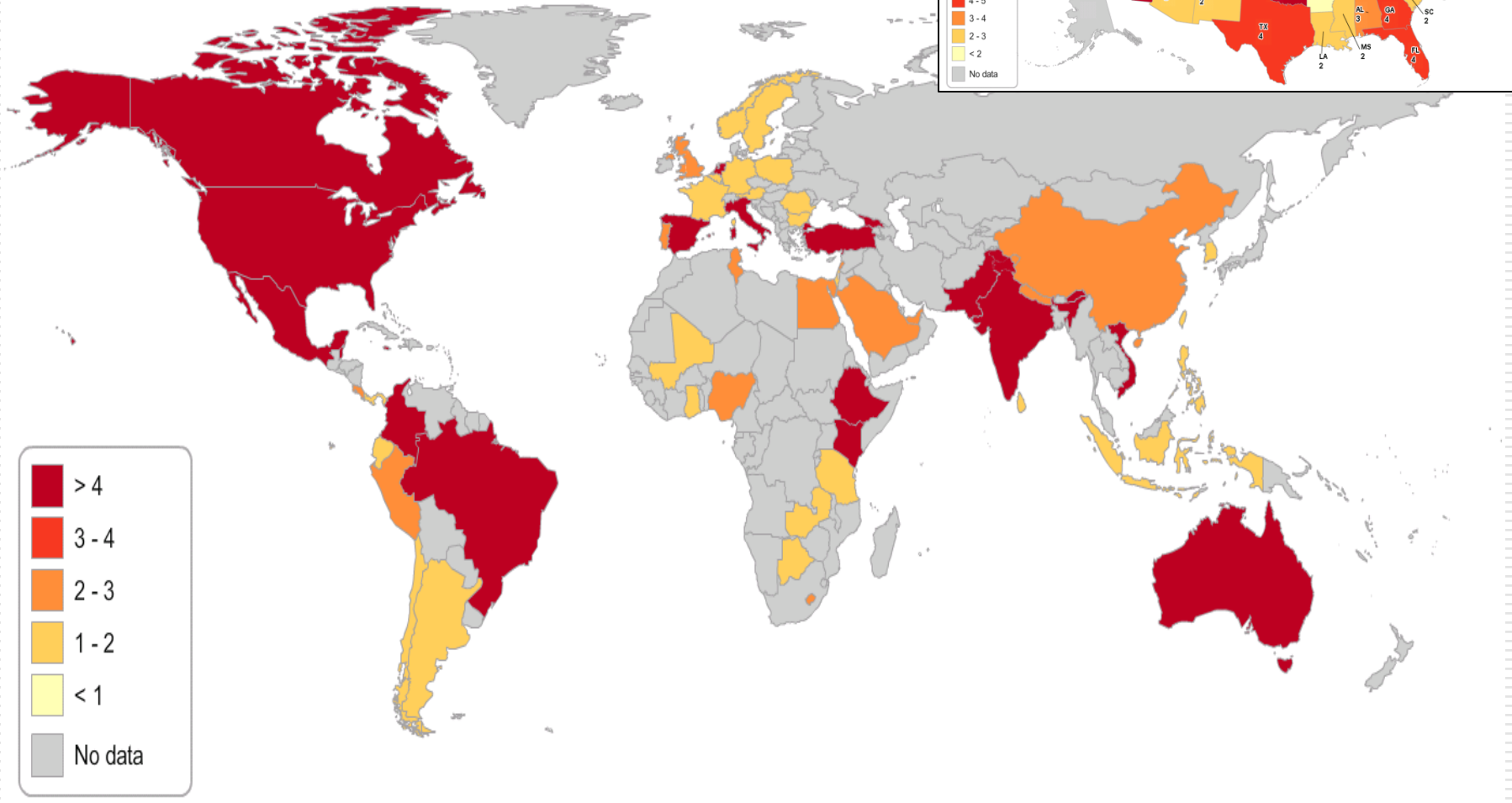


2008 – 2014: + 1600 End-users
: + 400 organization

ARSET: 2008 – 2014
+1600 End-users Reached

Number of participating organizations per country: Air Quality, Water Resources, Flood Monitoring.





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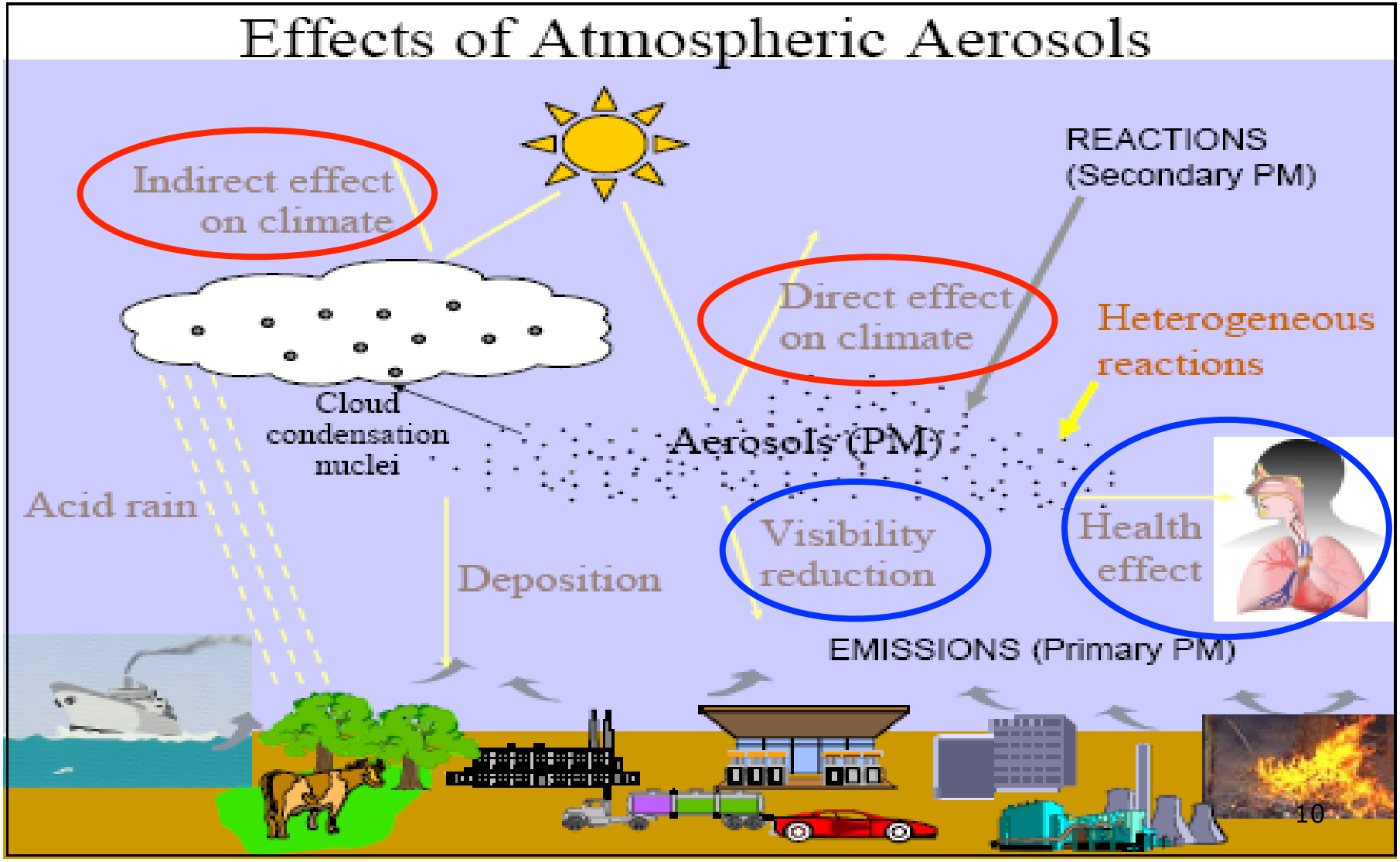
Satellite Remote Sensing of Air Quality

Motivation – tiny but Potent



Pollution and Breathing

News Focus

Particle air pollution clearly causes substantial deaths and illness, but what makes fine particles so toxic—the size, the chemical compound, or both?

Mounting Evidence Indicts Fine-Particle Pollution

At risk. Studies with elderly volunteers have shown that slight changes in outdoor particle levels can change heart rate variability.

Industrial Air Pollution: Possible Effect on Lung Cancer

Abstract. *Higher lung cancer mortality rates occurred in males living in certain heavily industrialized areas of Los Angeles County, California. These areas were characterized by elevated concentrations of benzo*[a]*pyrene and other polynuclear aromatic hydrocarbons of primarily industrial origin in the soil and air.*

Industrial pollution linked to lung cancer

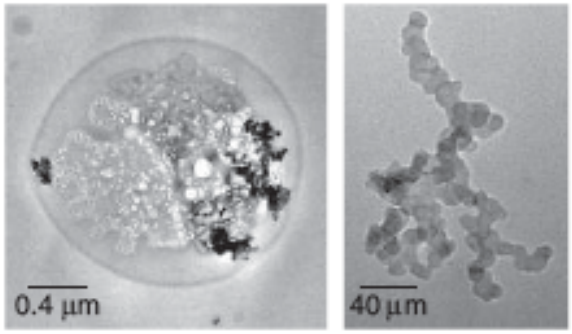
Pollution and Health

Air Pollution–Related Illness Effects of Particles

André Nel

Worldwide epidemiological studies show a consistent increase in cardiac and respiratory morbidity and mortality from exposure to particulate matter (PM) (*1*–*3*). PM is a key ingredient of polluted air and is estimated to kill more than 500,000 people each year (*4*).

Enhanced online at www.sciencemag.org/cgi/content/full/308/5723/804



Dangerous dirt. (**Left**) Electron micrograph of a fine mode particle collected by an impactor from air outside an engineering laboratory at the University of California, Los Angeles. A halo surrounds residues of what are probably inorganic salts and polar organic compounds dissolved in the original aqueous droplet. Sootlike particles are also present. (**Right**) Aggregates of ultrafine particles collected on the last stage of an eight-stage impactor. These are soot particles emitted from diesel engine sources such as buses. More volatile particles may have evaporated in the electron microscope.

Increase in cardiac and respiratory illnesses

Pollution Suppresses Rain

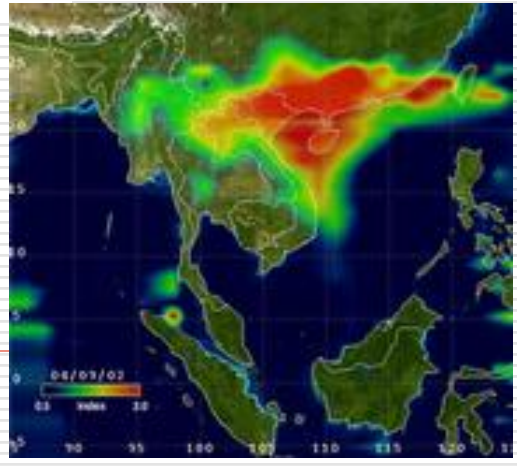
Suppression of Rain and Snow by Urban and Industrial Air Pollution

Daniel Rosenfeld

Direct evidence demonstrates that urban and industrial air pollution can completely shut off precipitation from clouds that have temperatures at their tops of about −10°C over large areas. Satellite data reveal plumes of reduced cloud particle size and suppressed precipitation originating from major urban areas and from industrial facilities such as power plants. Measurements obtained by the Tropical Rainfall Measuring Mission satellite reveal that both cloud droplet coalescence and ice precipitation formation are inhibited in polluted clouds.

Pollution reduces size of cloud droplets

Shuts off rain processes

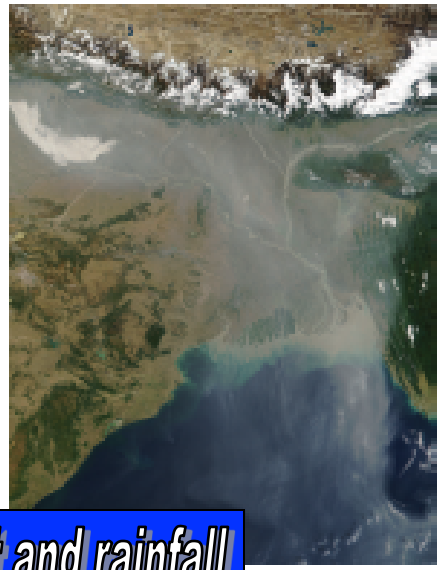


Pollution affects rice harvest

Air pollution and climate change both reduce Indian rice harvests

Wolfgang Cramer*
Department of Global Change and Natural Systems, Potsdam Institute for Climate Impact Re
D-14412 Potsdam, Germany

An ever-changing mix of anthropogenic pollutants alters the chemical and physical properties of the atmosphere and thereby causes potentially negative impacts on human society. To establish a robust cause-and-effect chain, all the way from a particular kind of emission to its economic and/or social impacts, remains a transdisciplinary tour de force with several risks of failure along the way. The first major link along such a chain, that between increased aerosol loads ("atmospheric brown clouds," or ABC) over the Indian subcontinent, globally increasing greenhouse gas (GHG) concentrations, and regional changes in temperature, rainfall, and surface-near radiation, requires consideration of chemical and physical



ham India and Bang-
Terra satellite's MODIS
2001 (image courtesy
http://visibleearth.

Despite remaining open questions, the basic mechanisms linking regional climatic conditions in South Asia to ABC are known from a combination of measurement campaigns and model simulations (7). First, the radiation budget is strongly affected by the presence of haze (Fig. 1), which reduces direct radiation at the surface (land or ocean, approximately -10 to -15 W m^{-2}, during the 1990s) and warms the troposphere by approximately the same amount of energy. On average, the net solar forcing at the top of the atmosphere changes by <1 W m^{-2}, but much higher values may occur between January and May. Particularly during this period, substantial dimming of solar radia-

Pollution reduces sunlight and rainfall

11% drop in yields

No boundaries for pollution

Global Air Pollution Crossroads over the Mediterranean

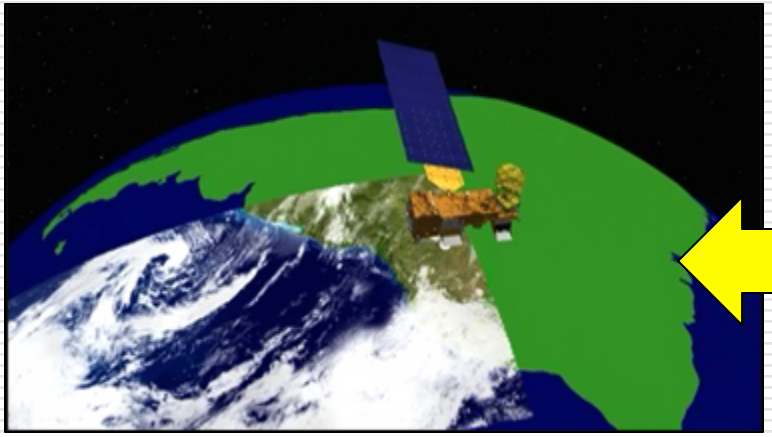
J. Lelieveld,[1*] H. Berresheim,[2] S. Borrmann,[1,3] P. J. Crutzen,[1,4] F. J. Dentener,[5] H. Fischer,[1] J. Feichter,[6] P. J. Flatau,[4,7] J. Heland,[8] R. Holzinger,[1] R. Korrmann,[1] M. G. Lawrence,[1] Z. Levin,[9] K. M. Markowicz,[4,10] N. Mihalopoulos,[11] A. Minikin,[8] V. Ramanathan,[4] M. de Reus,[1] G. J. Roelofs,[12] H. A. Scheeren,[12] J. Sciare,[13] H. Schlager,[8] M. Schultz,[6] P. Siegmund,[14] B. Steil,[1] E. G. Stephanou,[11] P. Stier,[6] M. Traub,[1] C. Warneke,[15] J. Williams,[1] H. Ziereis[8]

The Mediterranean Intensive Oxidant Study, performed in the summer of 2001, uncovered air pollution layers from the surface to an altitude of 15 kilometers. In the boundary layer, air pollution standards are exceeded throughout the region, caused by West and East European pollution from the north. Aerosol particles also reduce solar radiation penetration to the surface, which can suppress precipitation. In the middle troposphere, Asian and to a lesser extent North American pollution is transported from the west. Additional Asian pollution from the east, transported from the monsoon in the upper troposphere, crosses the Mediterranean tropopause, which pollutes the lower stratosphere at middle latitudes.

Intercontinental transport

Air pollution standard exceeded

Thus Monitoring…

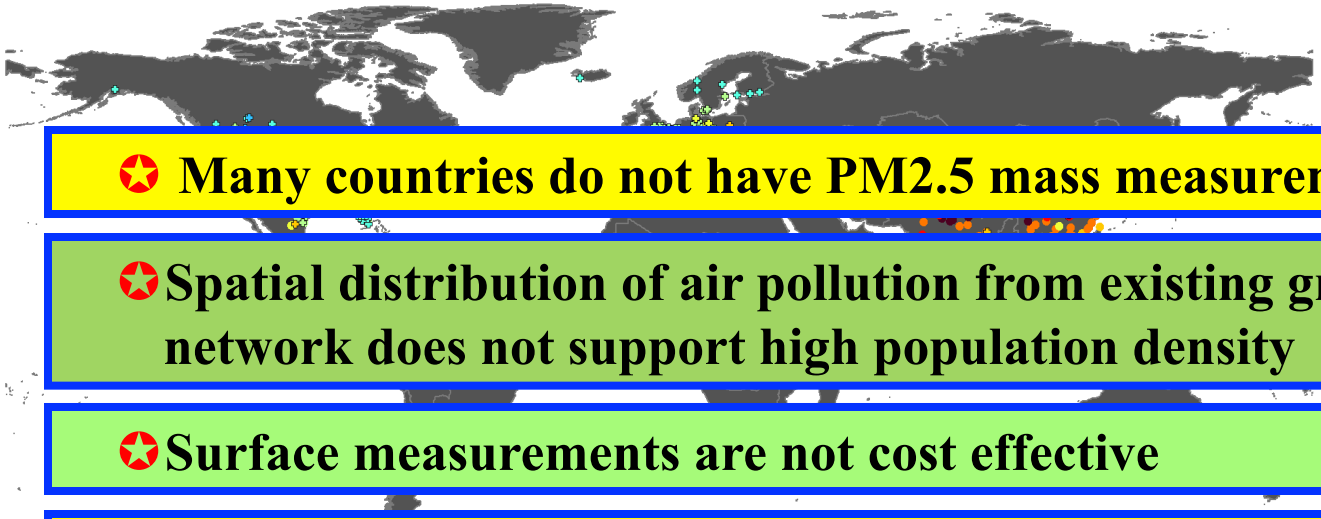


From Space

From Surface

Why Satellite ?

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
- ✪ Surface measurements are not cost effective
- ✪ How about using remote sensing satellites?

Ground Sensor Network

Annual a

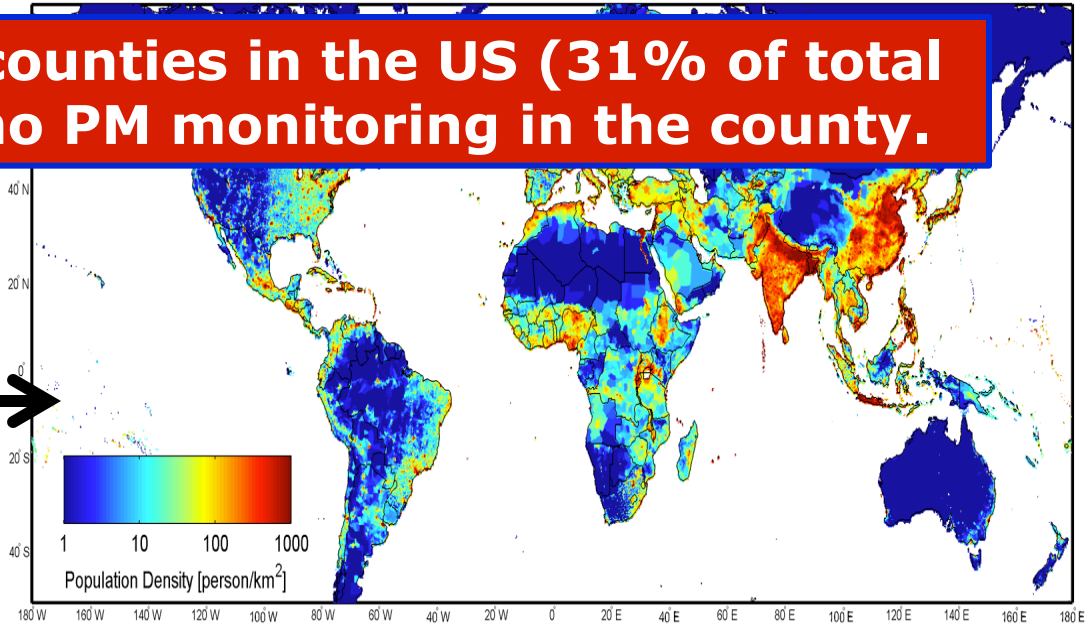
Not Measured

0-1

- 2400 out of 3100 counties in the US (31% of total population) have no PM monitoring in the county.

Brauer M, Ammann M, Burnett R et al.
GBD 2010 Outdoor Air Pollution Expert Group
2011 Submitted –under review

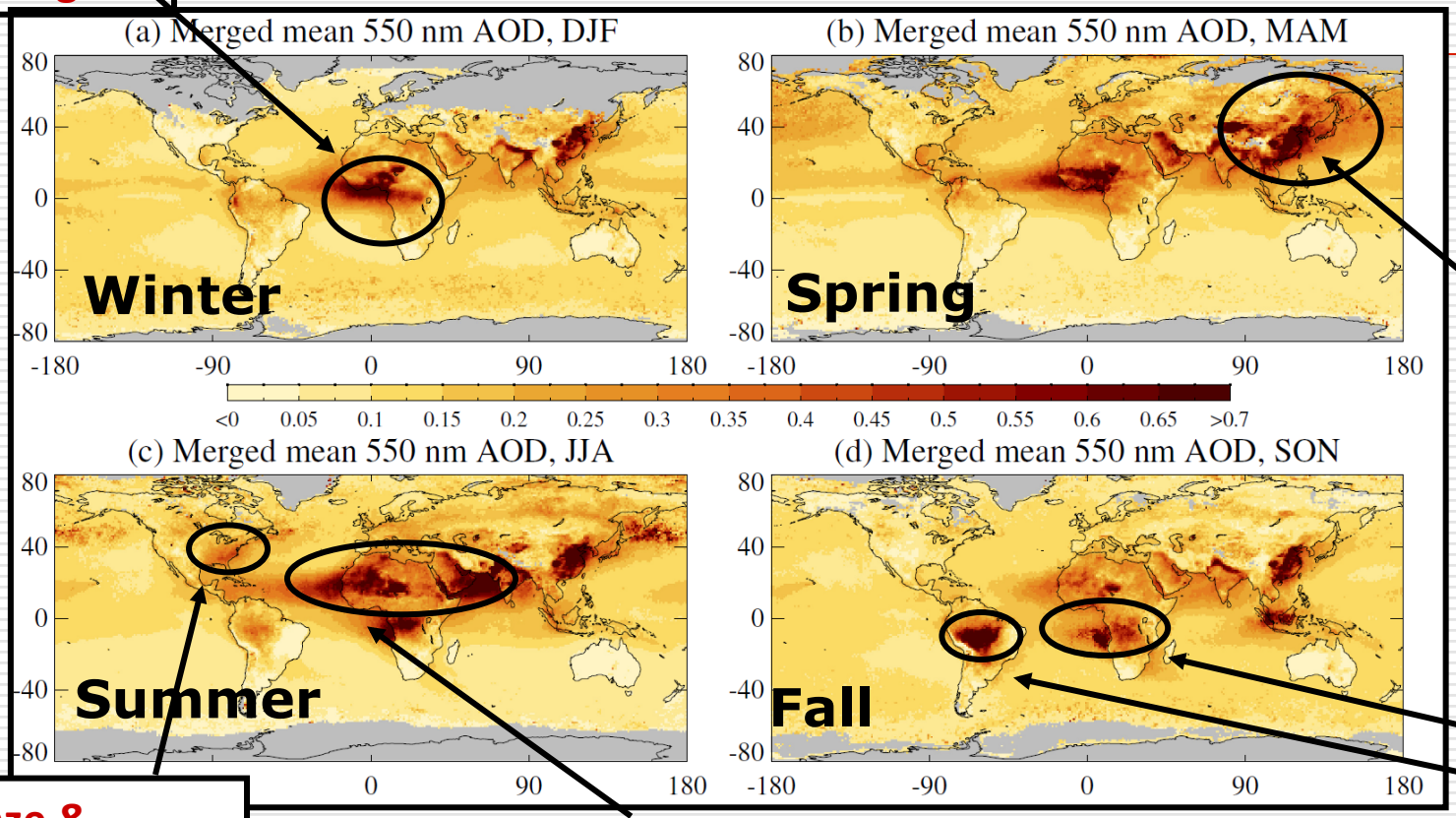
Population Density



Aerosols from satellite

Biomass Burning

Aerosol Optical Thickness MODIS AQUA



Pollution & dust

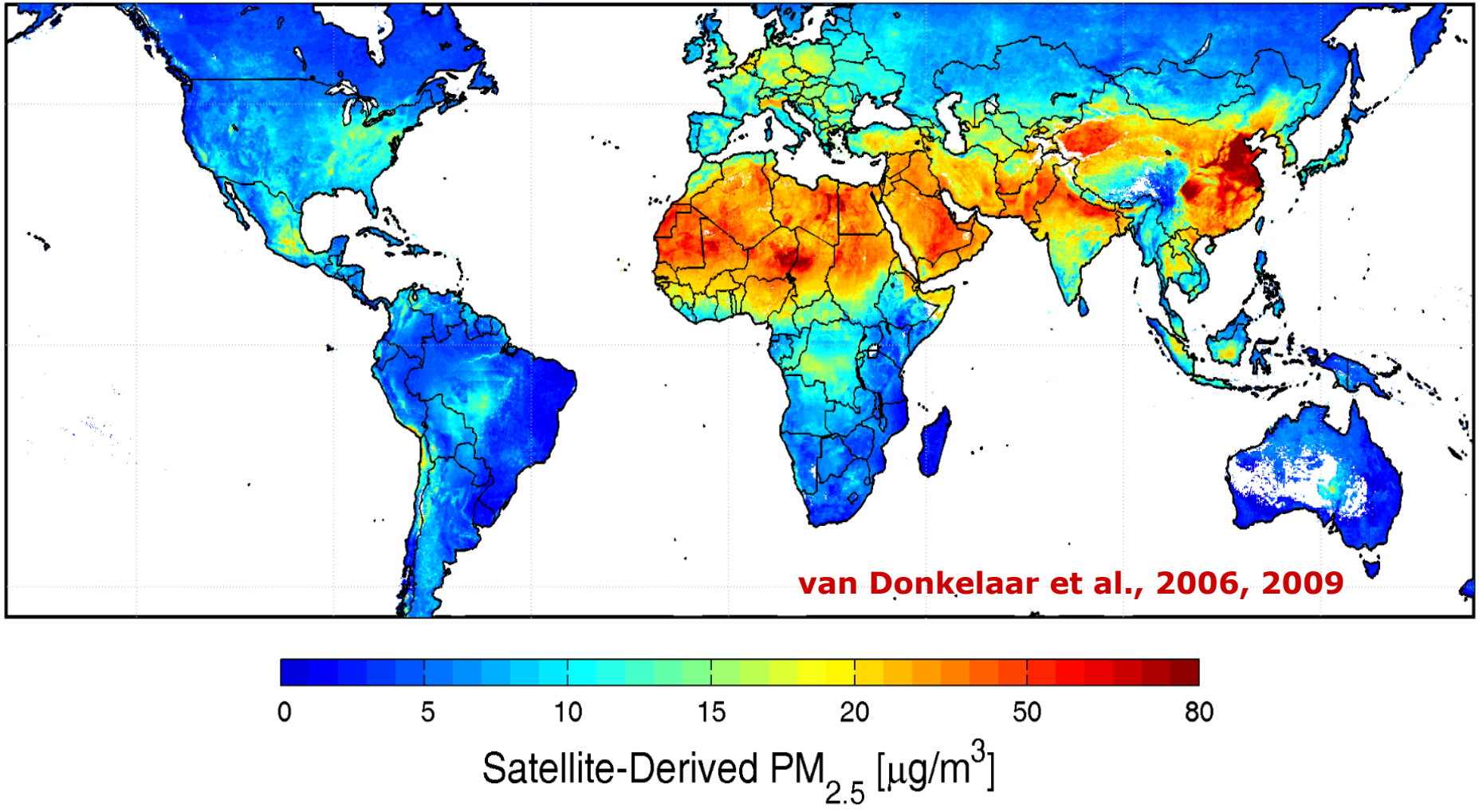
Haze & Pollution

Dust

Biomass Burning

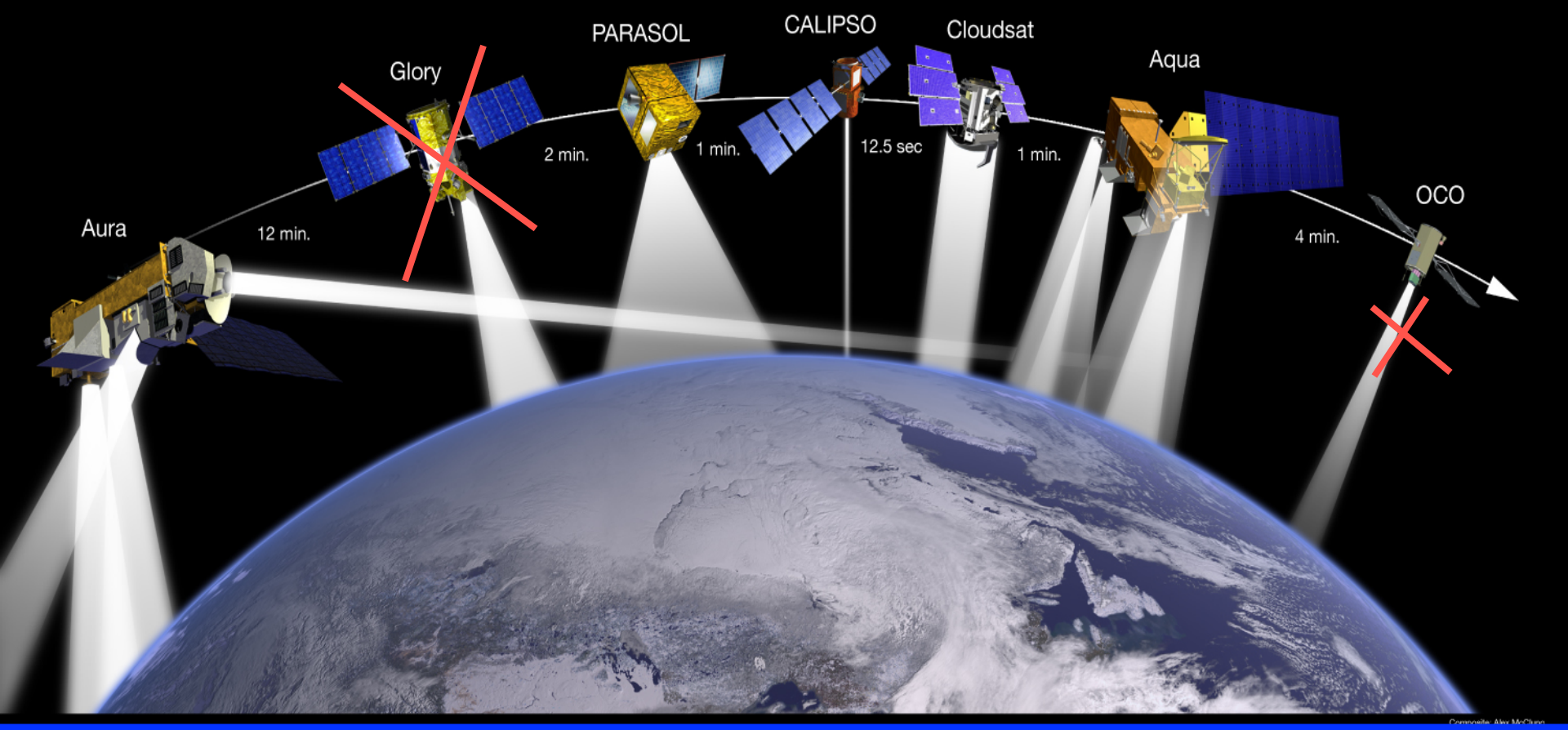
Several satellites provide state-of-art aerosol measurements over global region on daily basis

Annual Mean PM2.5 from Satellite Observations



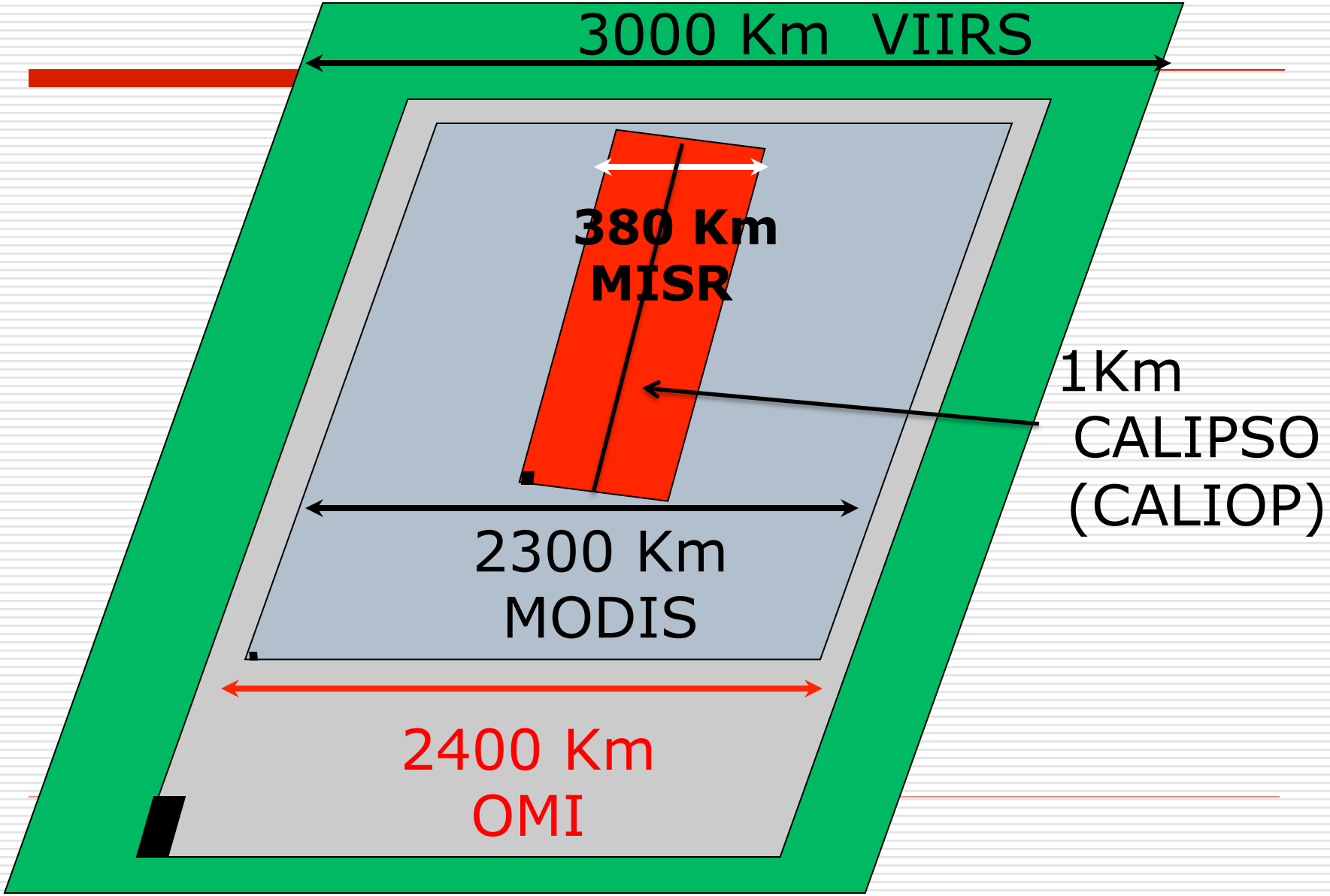
National Aeronautics and Space Administration

The Afternoon Constellation "A-Train"

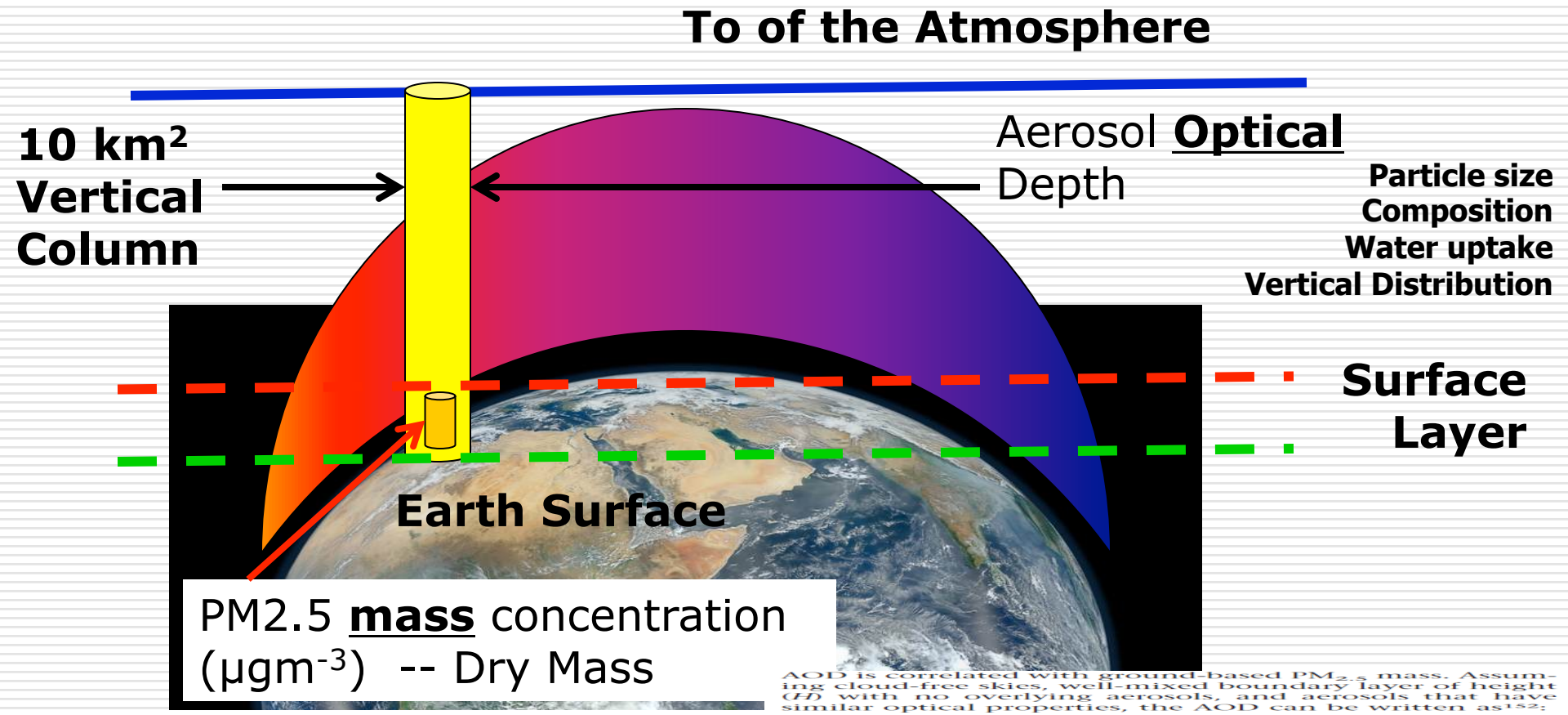


Number of Earth Observing Satellites Provides Measurements of Atmosphere, Land and Ocean

Principal Satellites in Air Quality Remote Sensing



What is our interest and what we get from satellite?

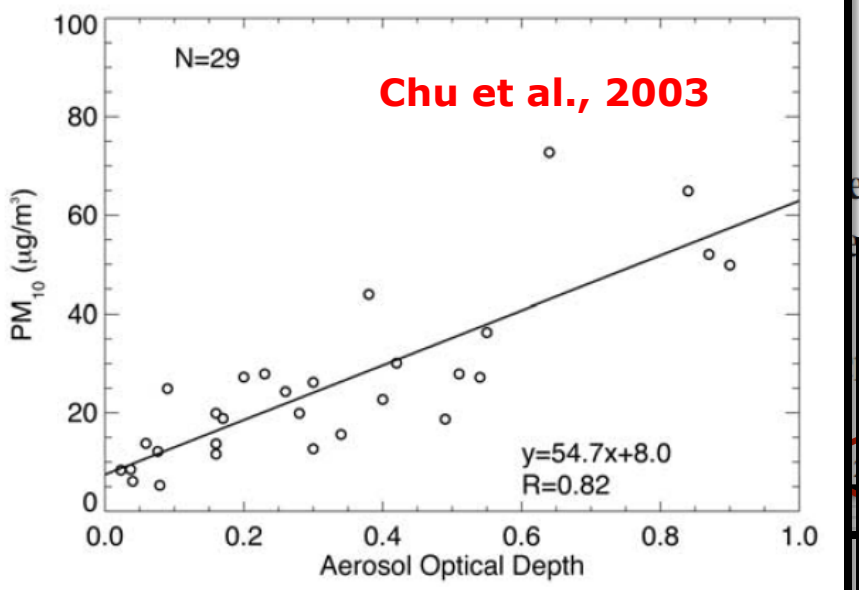


AOD is correlated with ground-based $PM_{2.5}$ mass. Assuming cloud-free skies, well-mixed boundary layer of height (H) with no overlying aerosols, and aerosols that have similar optical properties, the AOD can be written as[152]:

$$AOD = PM_{2.5}\, H\, f(RH)\, \frac{3 Q_{ext,dry}}{4 \rho\, r_{eff}} = PM_{2.5}\, H\, S \qquad (10)$$

where $f(RH)$ is the ratio of ambient and dry extinction coefficients, ρ is the aerosol mass density ($g \cdot m^{-3}$), $Q_{ext,dry}$ is the Mie extinction efficiency, and r_{eff} is the particle effective radius (the ratio of the third to second moments of the size distribution). S is the specific extinction efficiency ($m^2 \cdot g^{-1}$) of the aerosol at ambient relative humidity (RH).

Empirical Ways to Estimate PM2.5



Chu et al., 2003

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

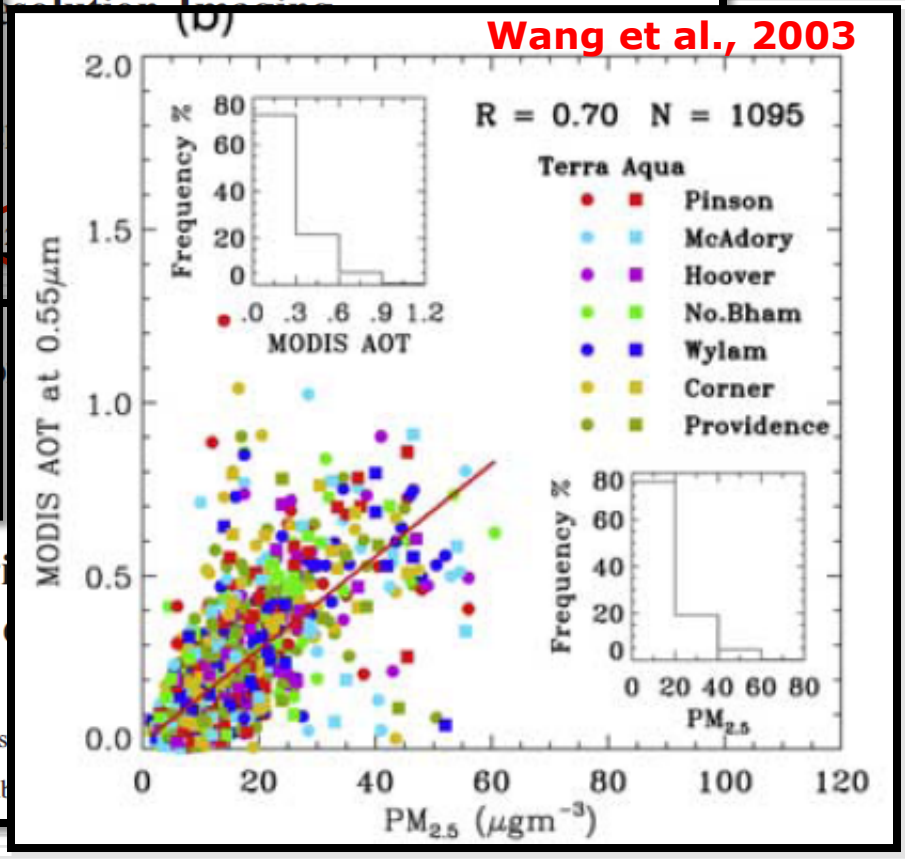
OL. 108, NO. D21, 4661, doi:10.1029/2002JD003179, 2003

er land from the Earth

Intercomparison between satellite-deri and $PM_{2.5}$ mass: Implications for air

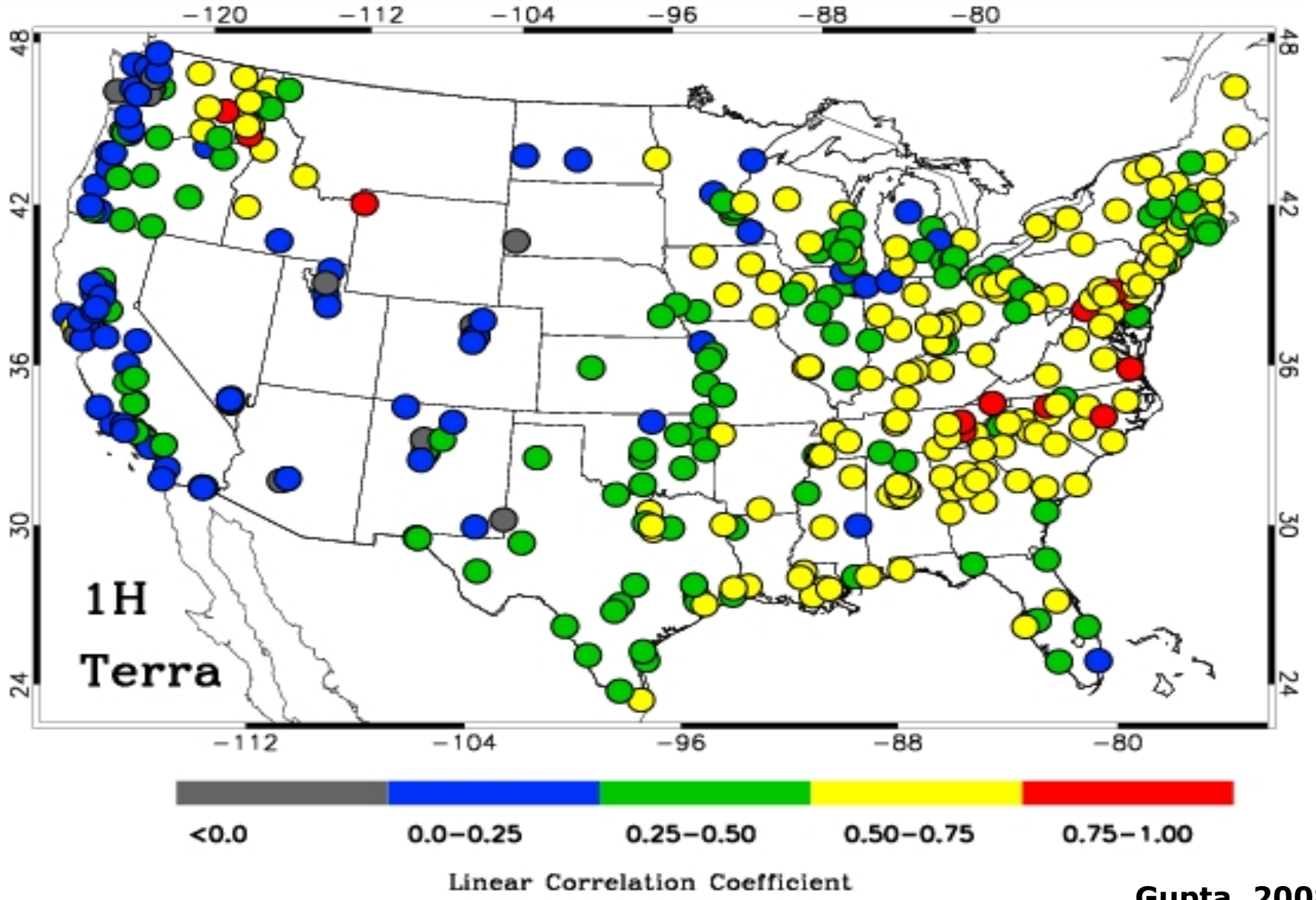
Jun Wang and Sundar A. Christopher
Department of Atmospheric Sciences, University of Alabama in Hunts

Received 14 July 2003; revised 13 August 2003; accepted 10 Septemb



Wang et al., 2003

AOT-PM2.5 Relationship

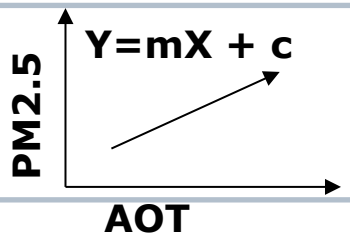


Gupta, 2008

PM2.5 Estimation: Popular Methods

Difficulty Level

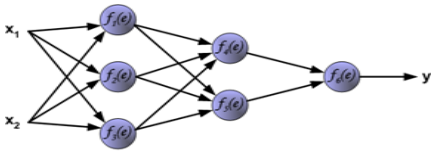
Two Variable Method



Multi-Variable Method

$$PM2.5 = \beta_0 + \alpha * \tau + \sum_{n=1}^{m} (\beta_n * M_n)$$

Artificial Neural Network

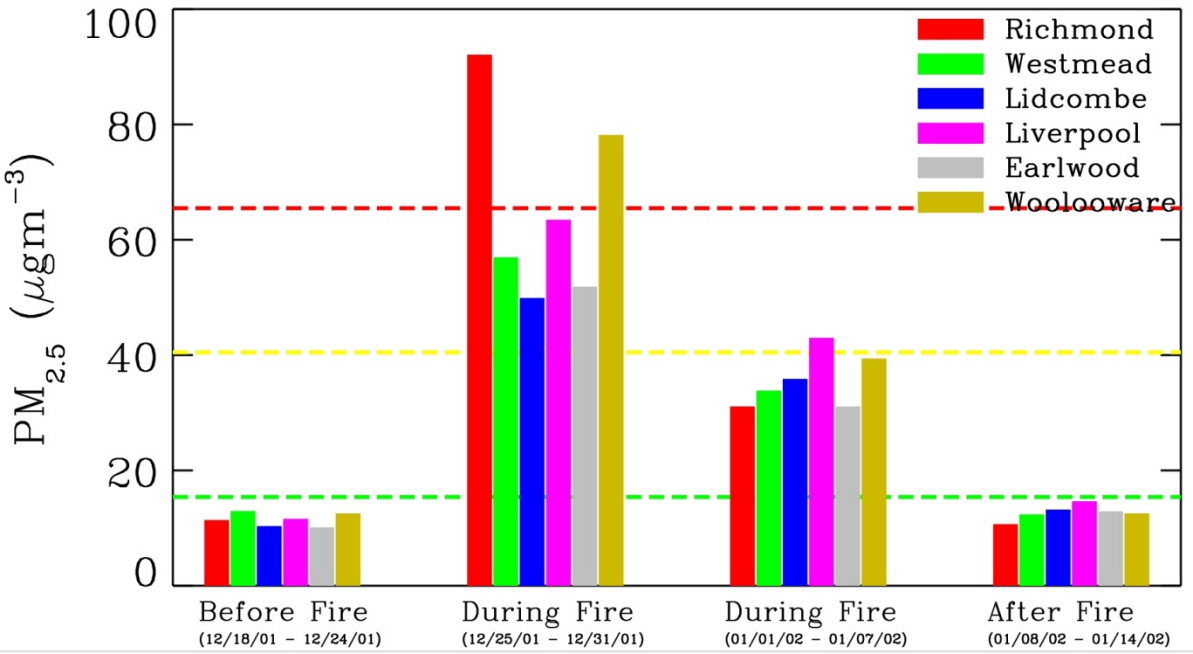


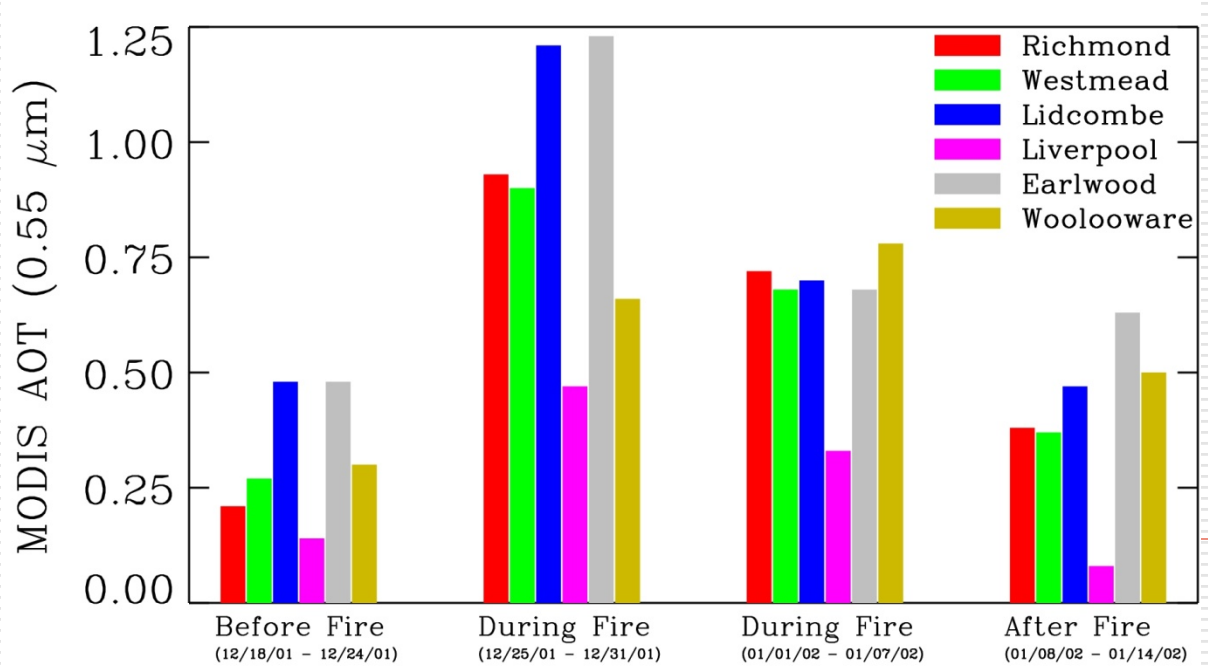
MSC

$$Estimated\ PM_{2.5} = \frac{Model\ surface\ aerosol\ concentration}{Model\ AOD} \times Retrieved\ AOD$$

and Empirical Methods, Data Assimilation etc. are under utilized

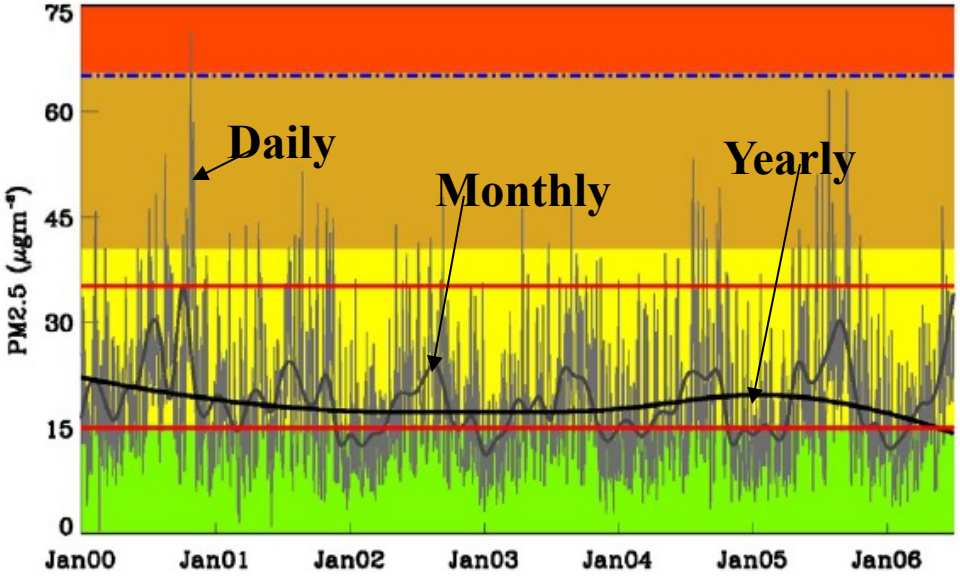
Application of Satellite Observations during bushfires in Sydney, Australia





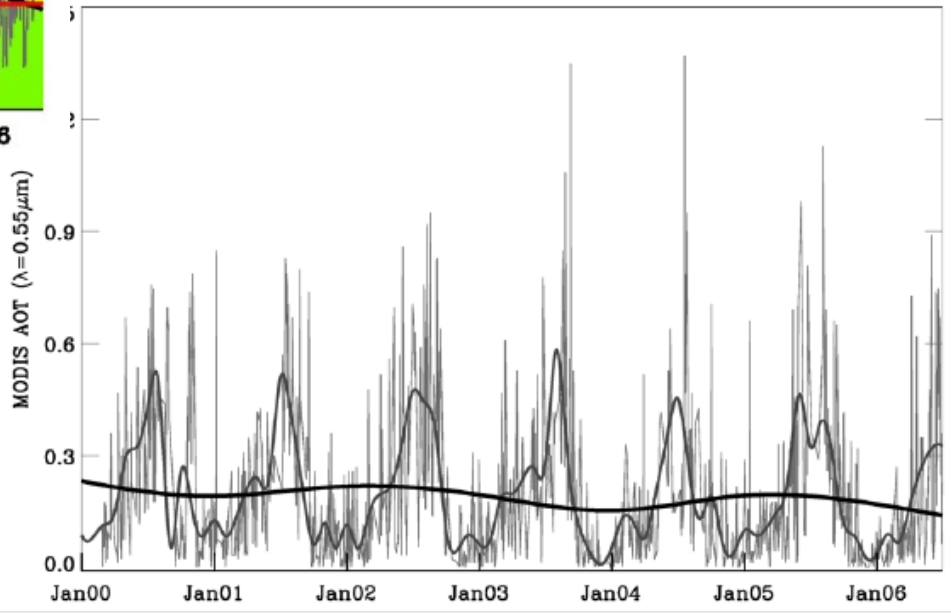
Gupta and Christopher, 2007

Air Quality Trends: Birmingham, AL



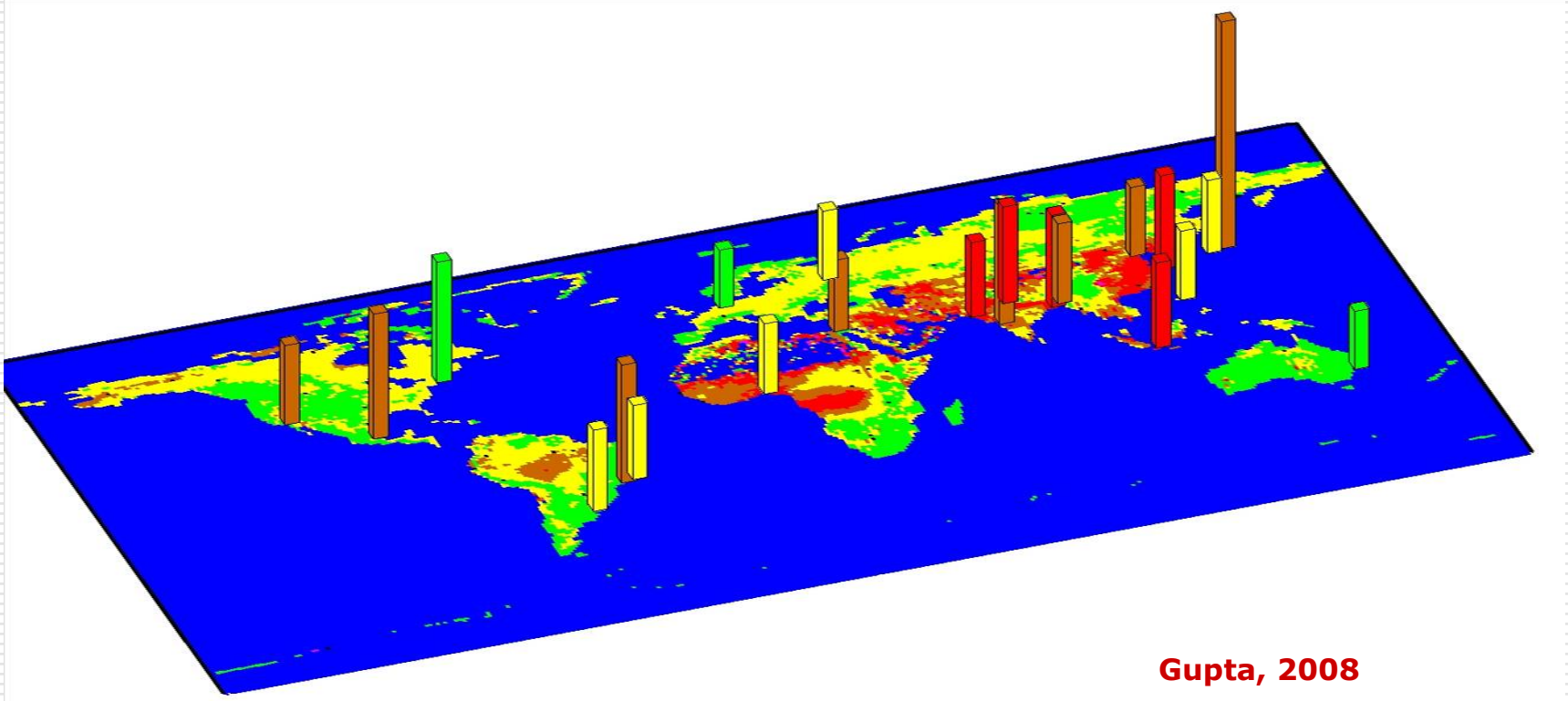
A decreasing trend in annual PM2.5 was noted with the almost 22% reduction in PM2.5 mass concentration was observed in 2006 compared to 2002.

MODIS-Terra Collection 5, Level 2, 10 km² AOTs for 2000-2006



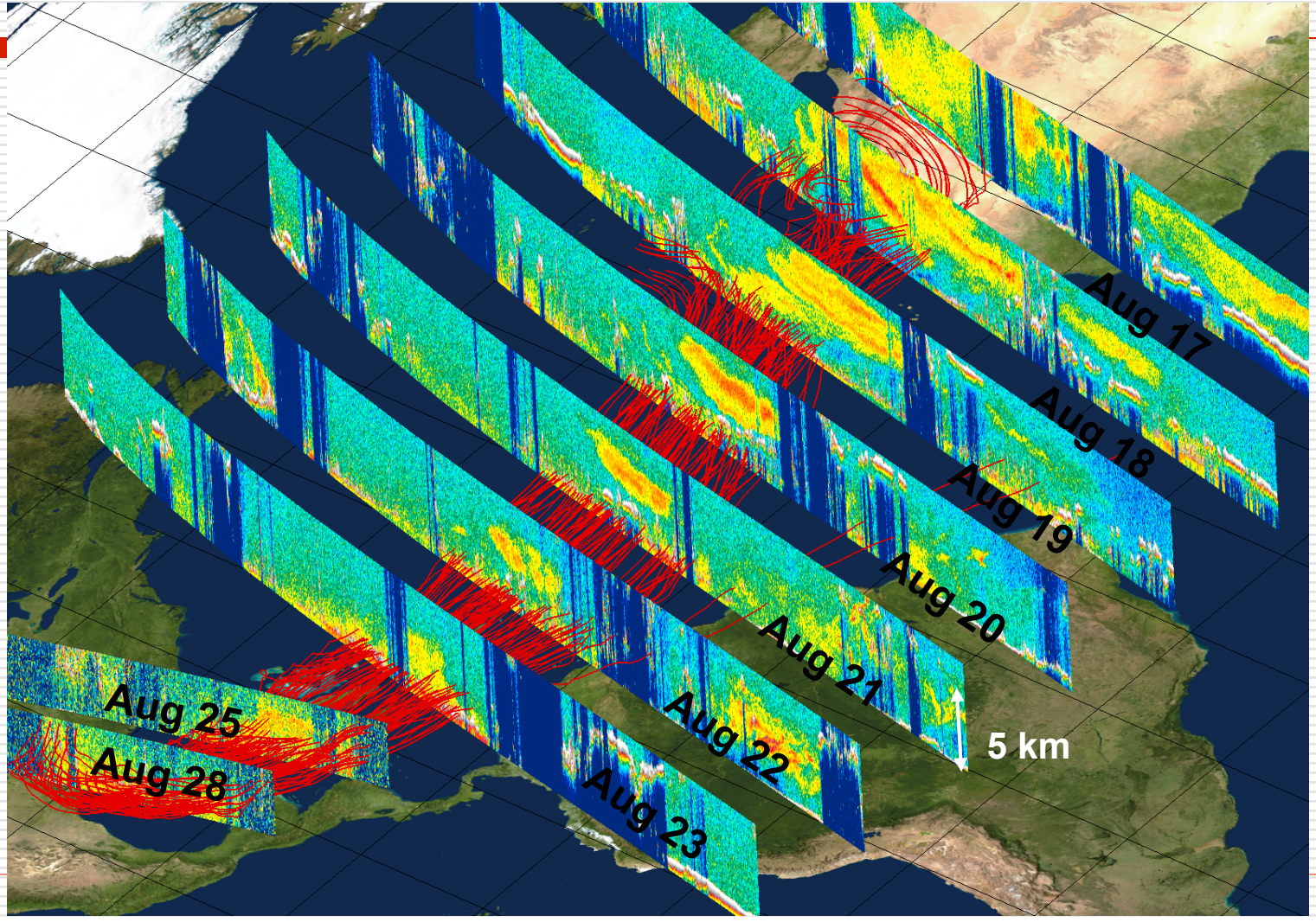
Gupta and Christopher, 2008

Another view of air quality over global regions



Satellite derived air quality conditions are poor in almost all of the global mega cities with population more than 10 million

Example of CALIPSO Data: Major Saharan Dust Transport Event: Aug 17-28



(courtesy of Dave Winker, P.I. CALIPSO)

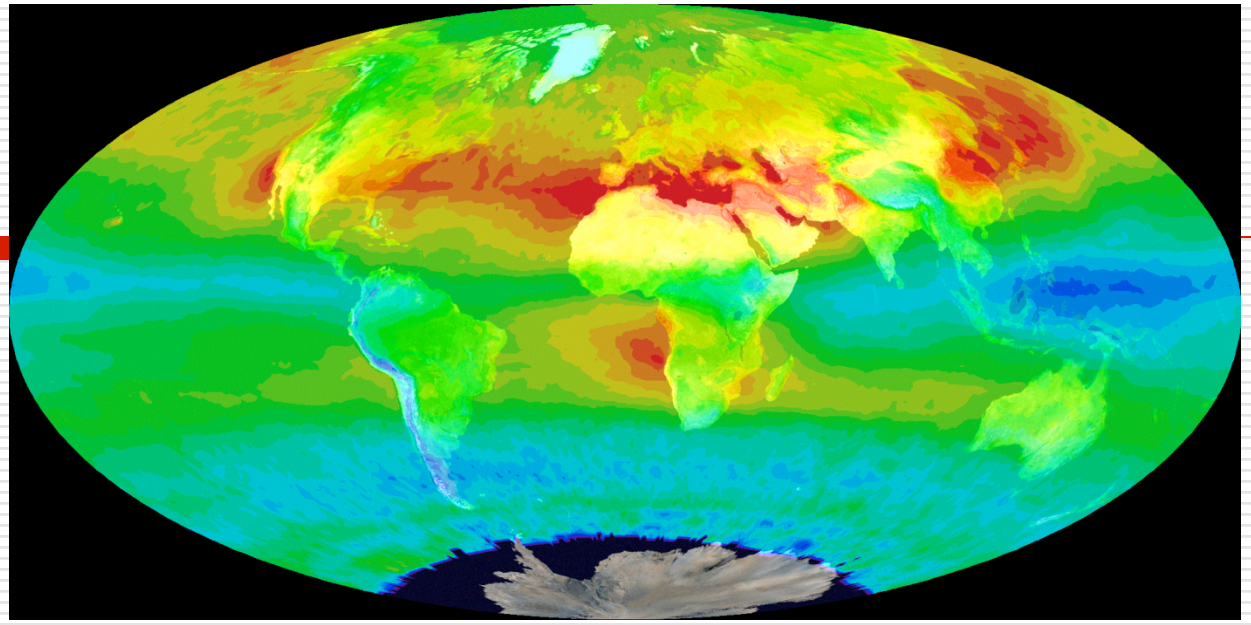
Aerosols - Particulate Matter (PM10, PM2.5)

- MODIS
- MISR
- OMI
- VIIRS
- POLDER
- CALIPSO
- GOES
  - GOES-R
  - TEMPO
  - PACE
  - GEO-CAPE

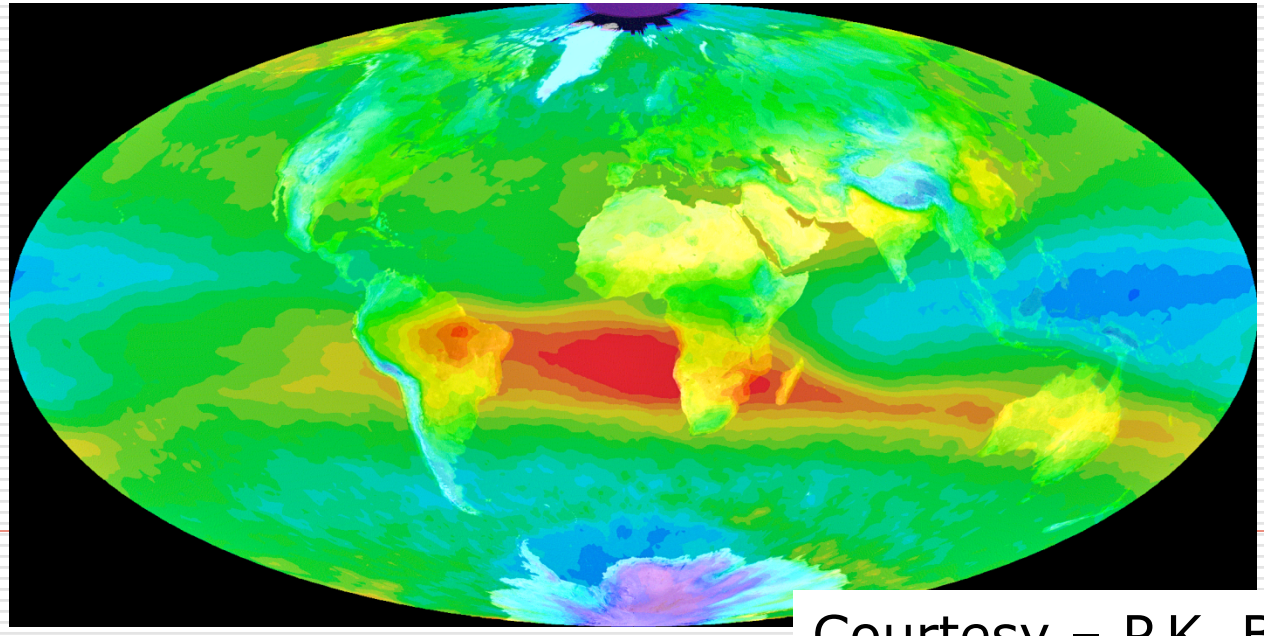
Trace Gases

Ozone below 10 km from a NASA satellite

June-Aug 2006

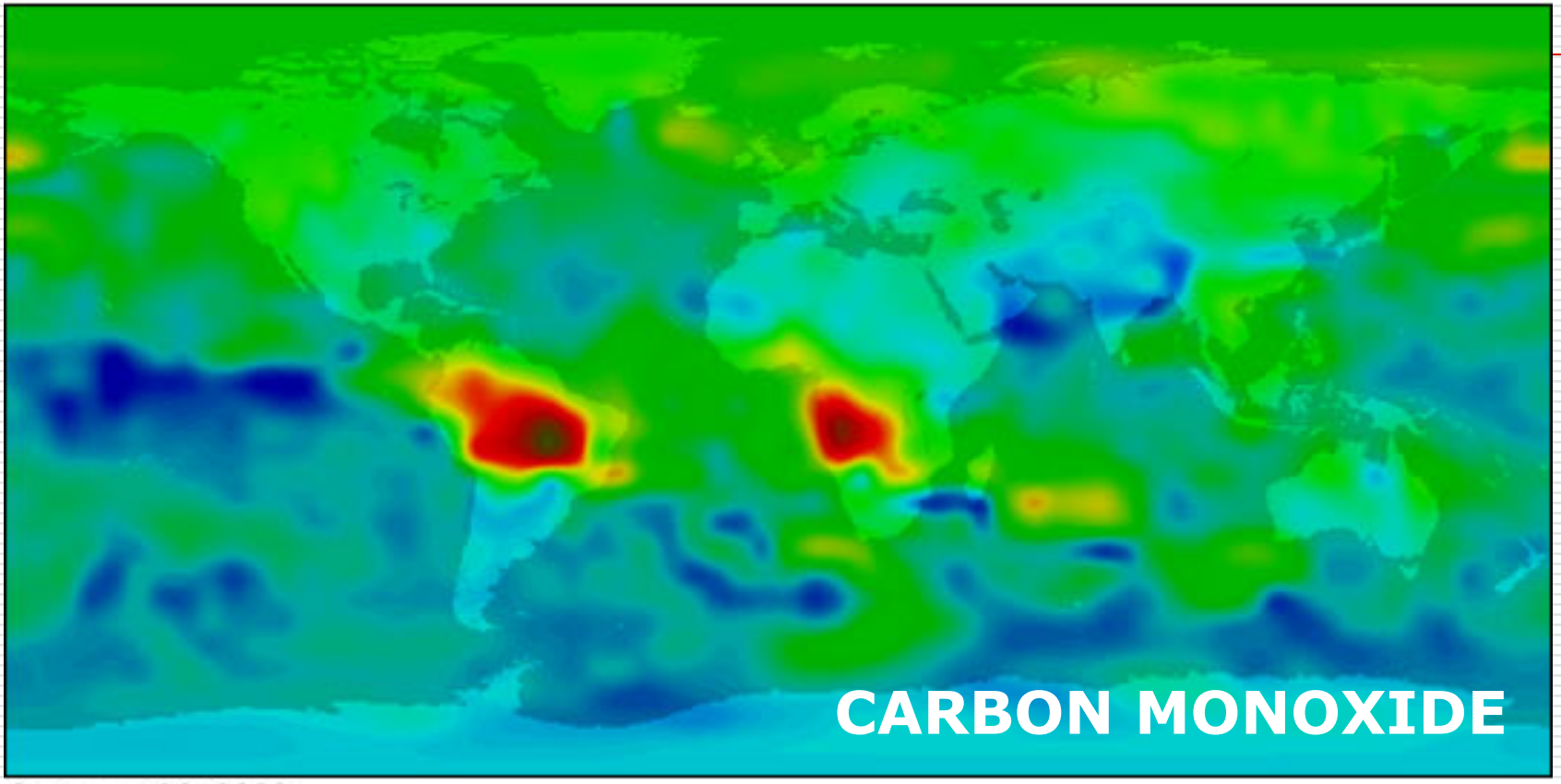


Sept-Nov 2006



Courtesy – P.K. Bhartia

Pollution Gas - MOPITT



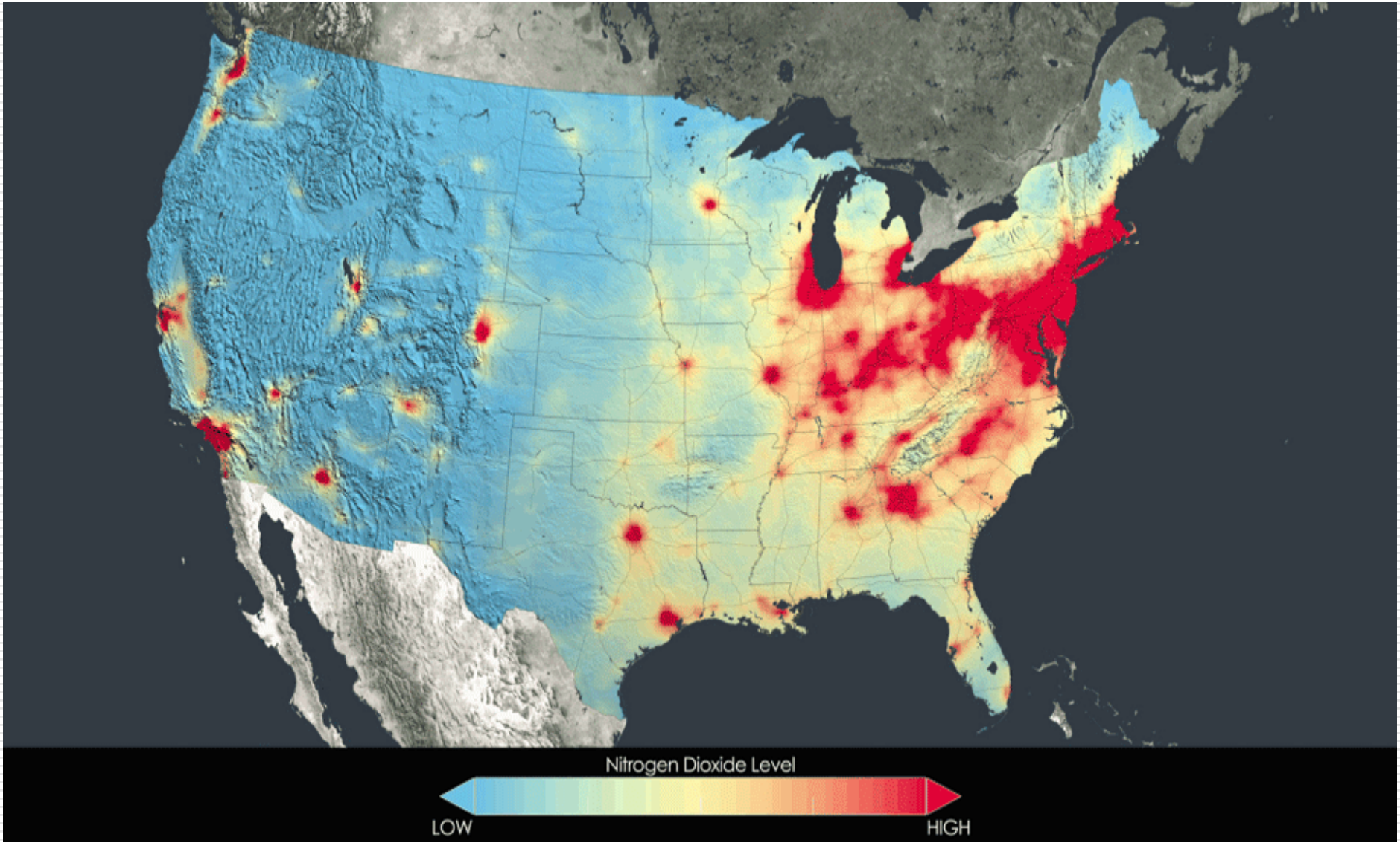
October 30, 2000

Carbon Monoxide Concentration (parts per billion)

50 220 390

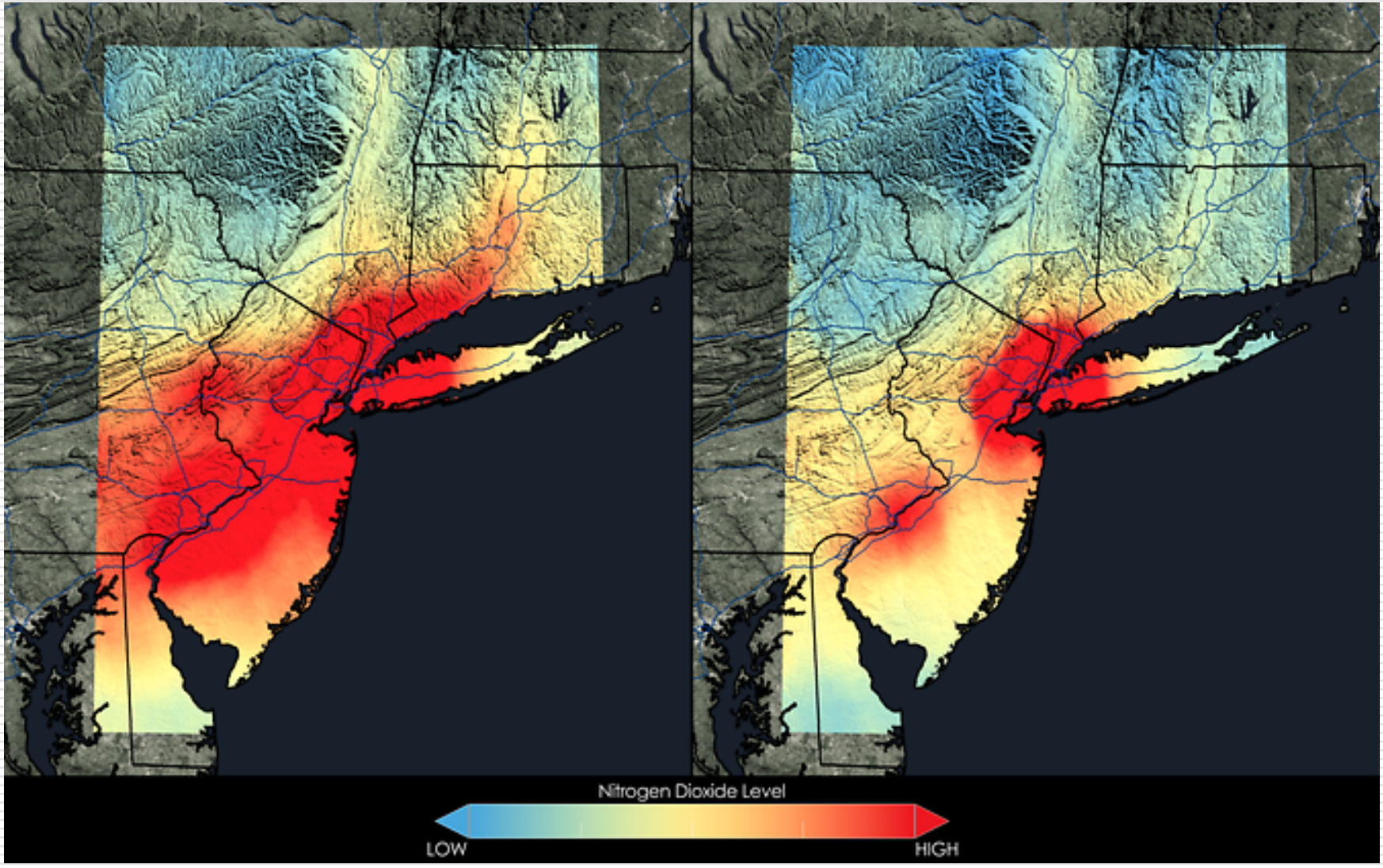
Courtesy – P.K. Bhartia

NO2 Trends over United States

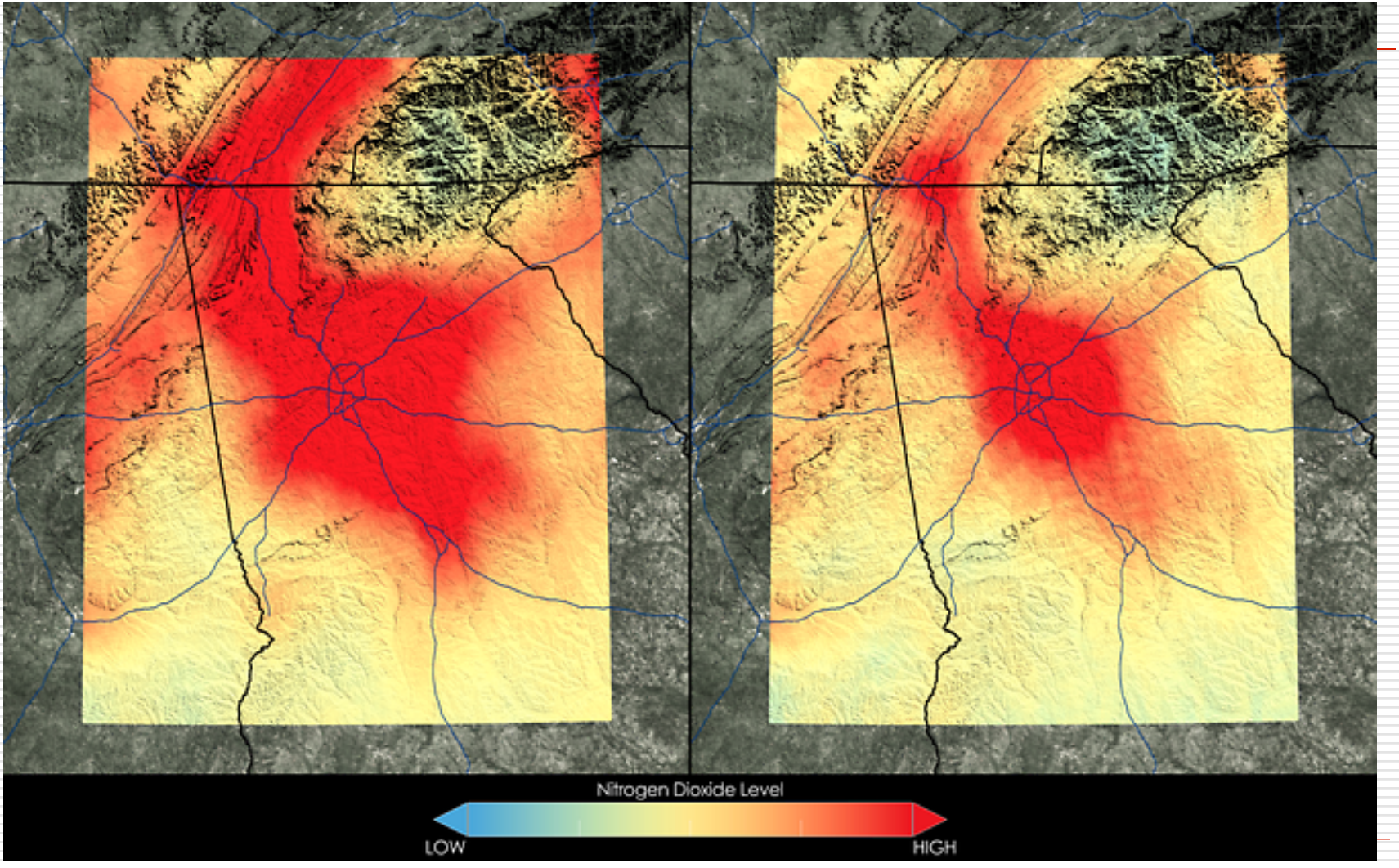


http://www.nasa.gov/content/goddard/new-nasa-images-highlight-us-air-quality-improvement/#.VBmon_ldWSo

NO2 Trends over New York City

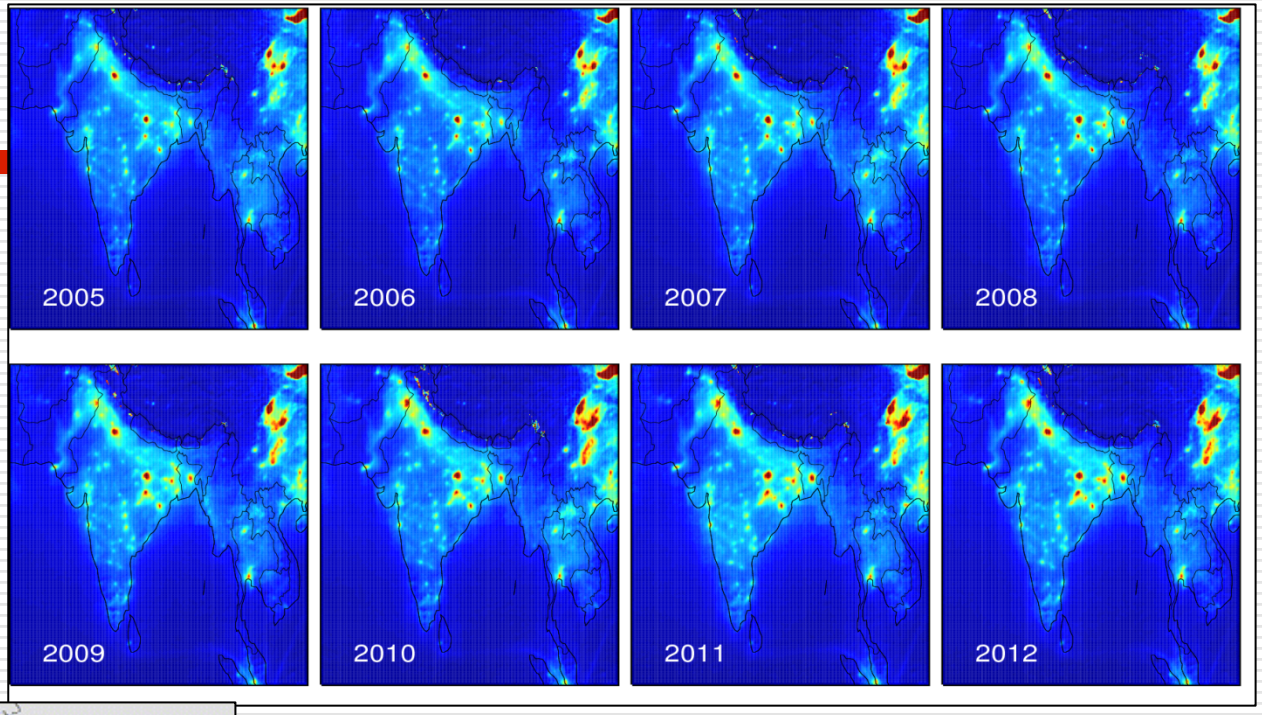


NO2 Trends over Atlanta

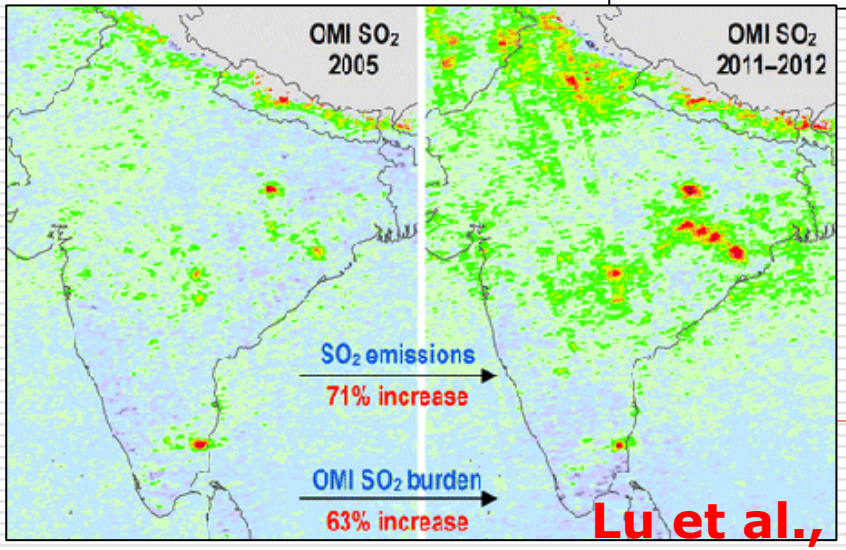


NO_2 & SO_2 from OMI

OMI NO_2 Trends



courtesy: Lok Lamsal



Lu et al., 2013

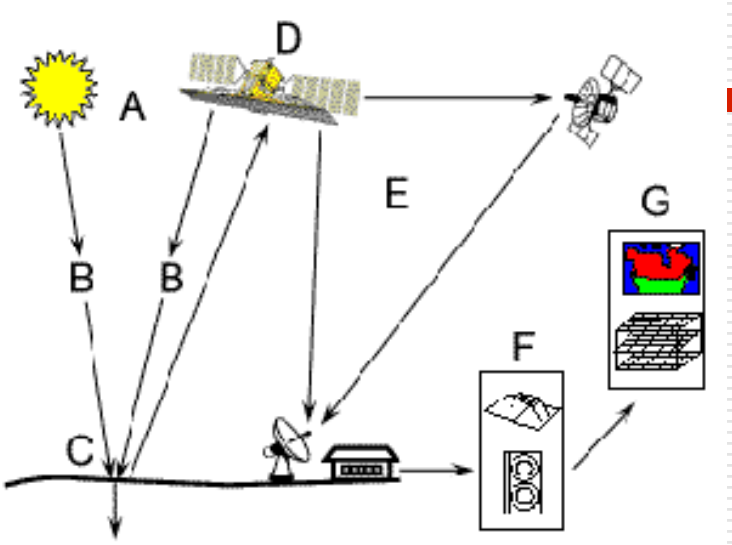
OMI SO_2 Trends

What you get to learn at a typical ARSET training?

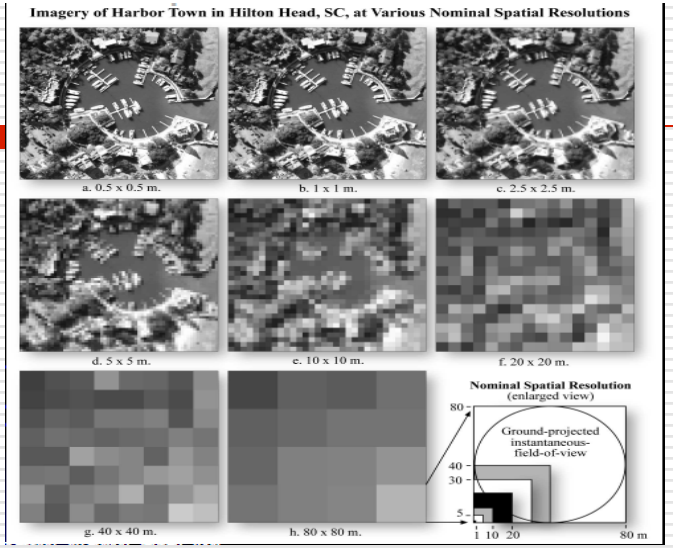
Or

How ARSET can help?

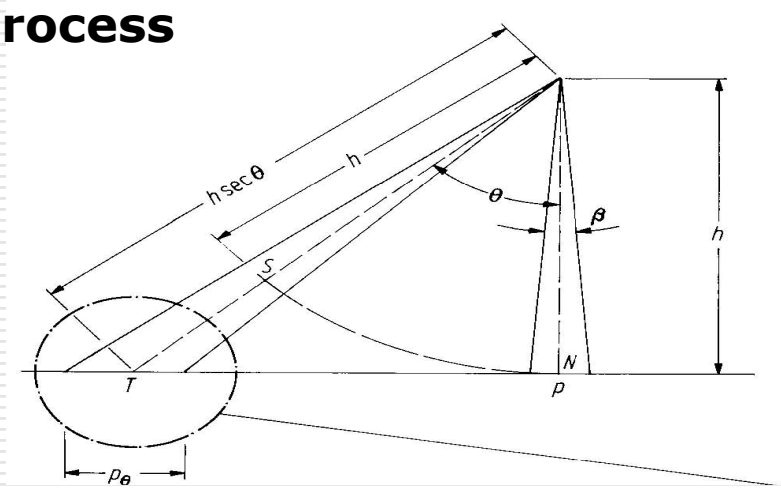
Fundamental of Satellite Remote Sensing



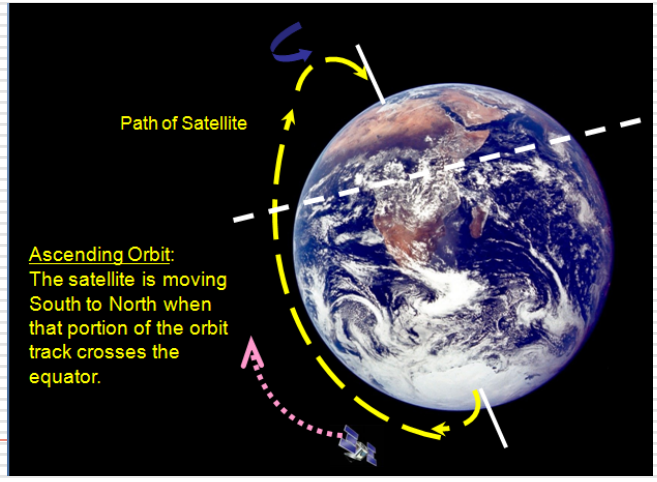
Remote Sensing Process



Resolutions

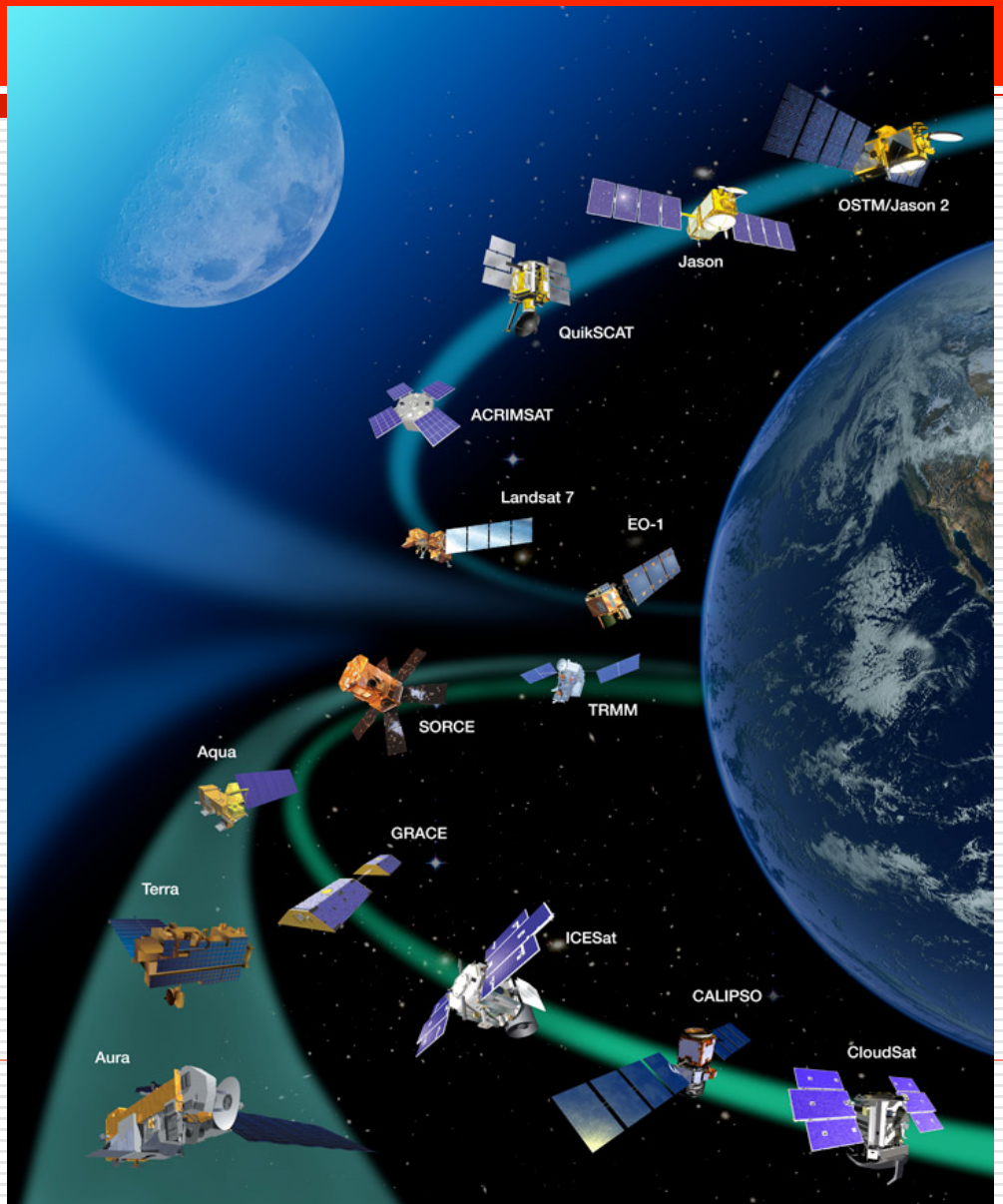


Observation Geometry

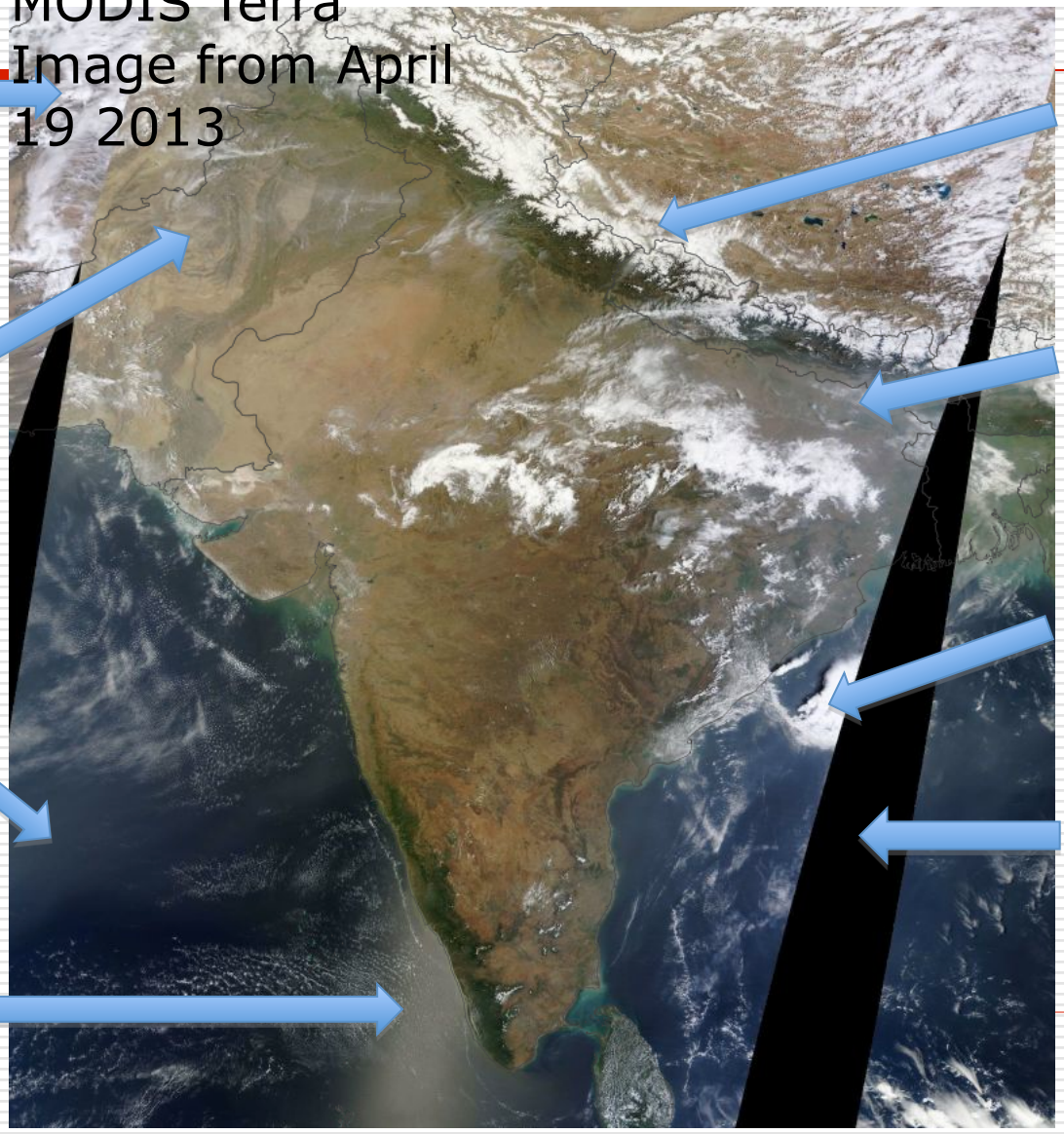


Orbits

Earth Observing Systems



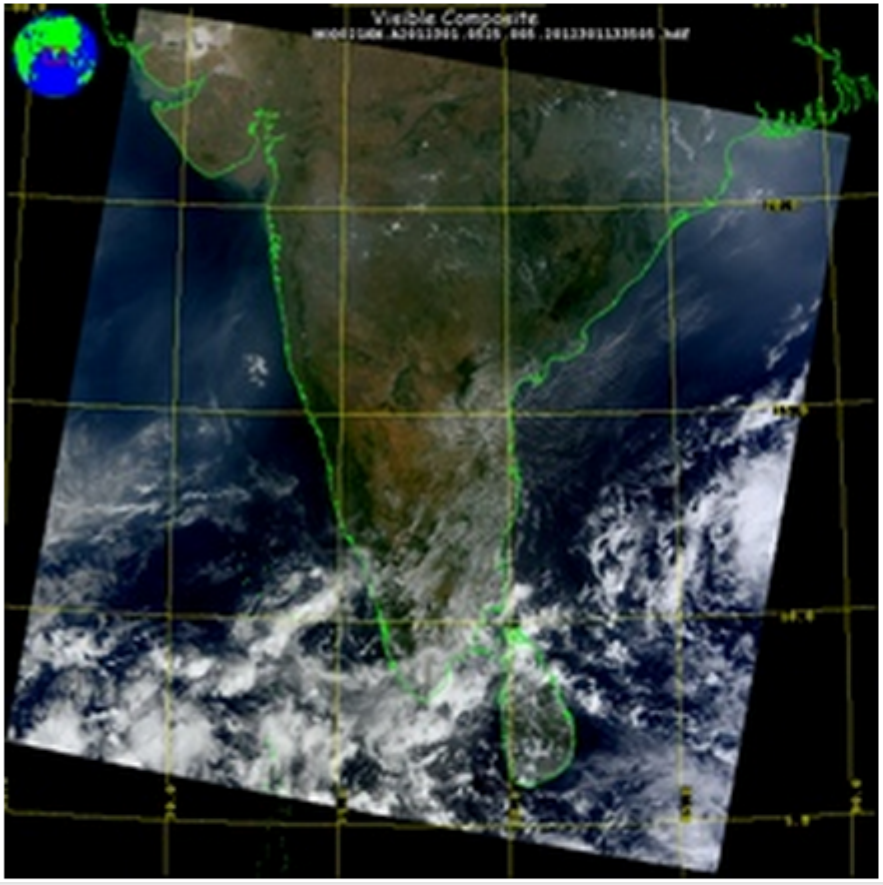
What can we learn from true color imagery? Access & Interpretation



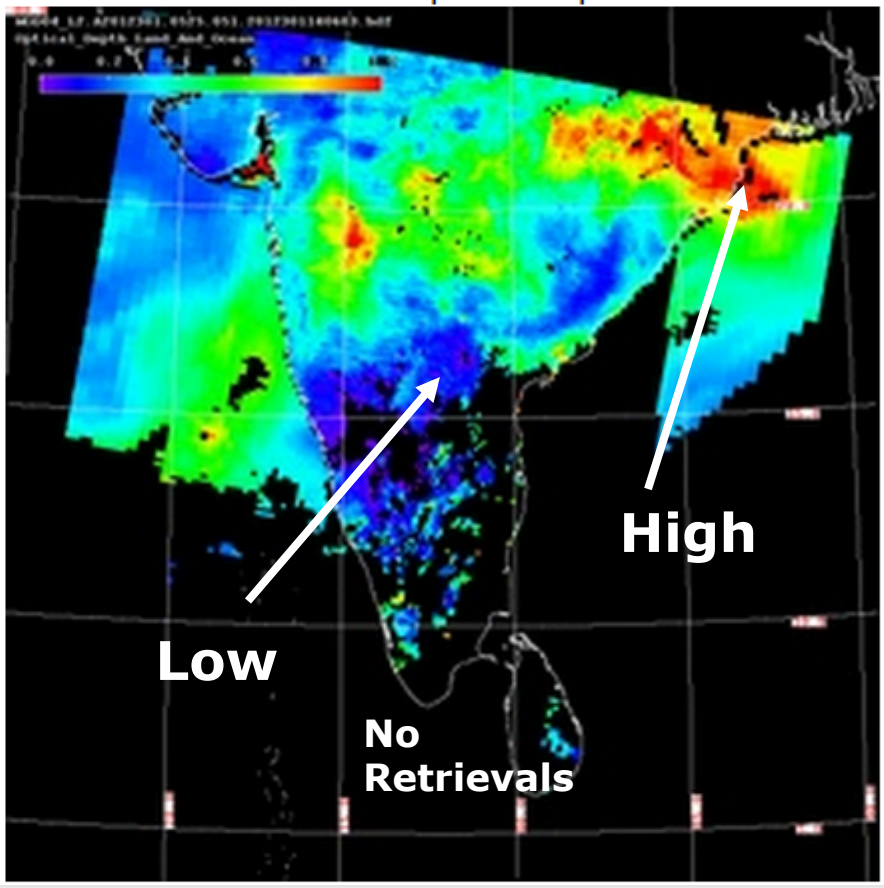
Satellite Algorithms

Radiance -to- Aerosol Products

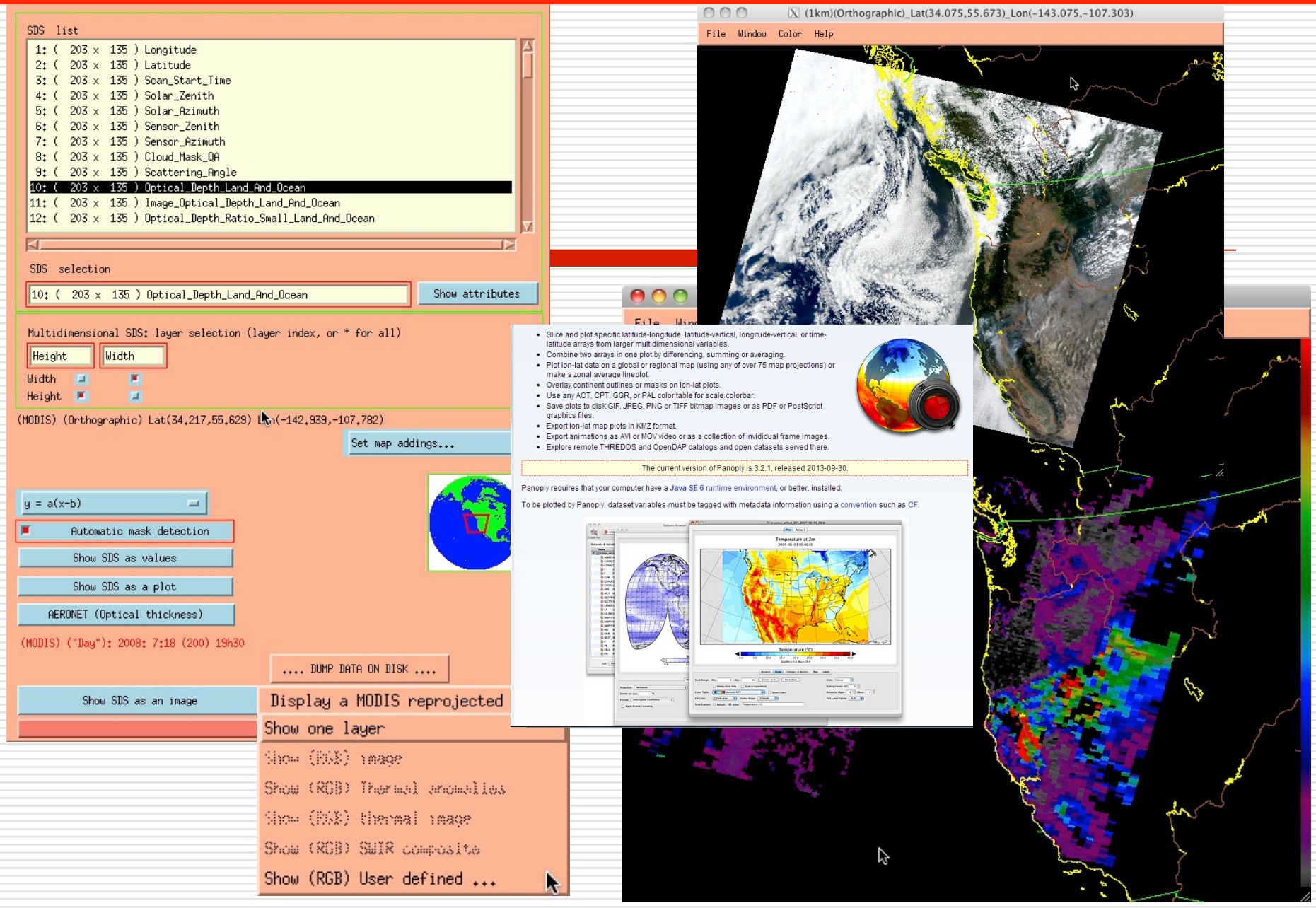
RGB



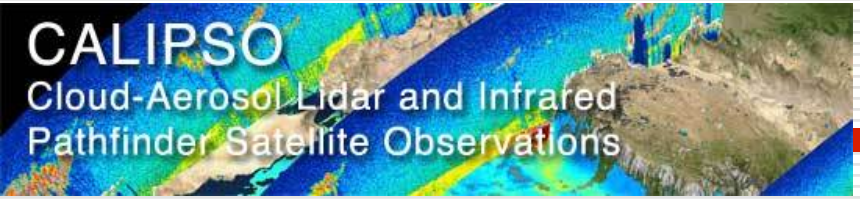
Aerosol Optical Depth

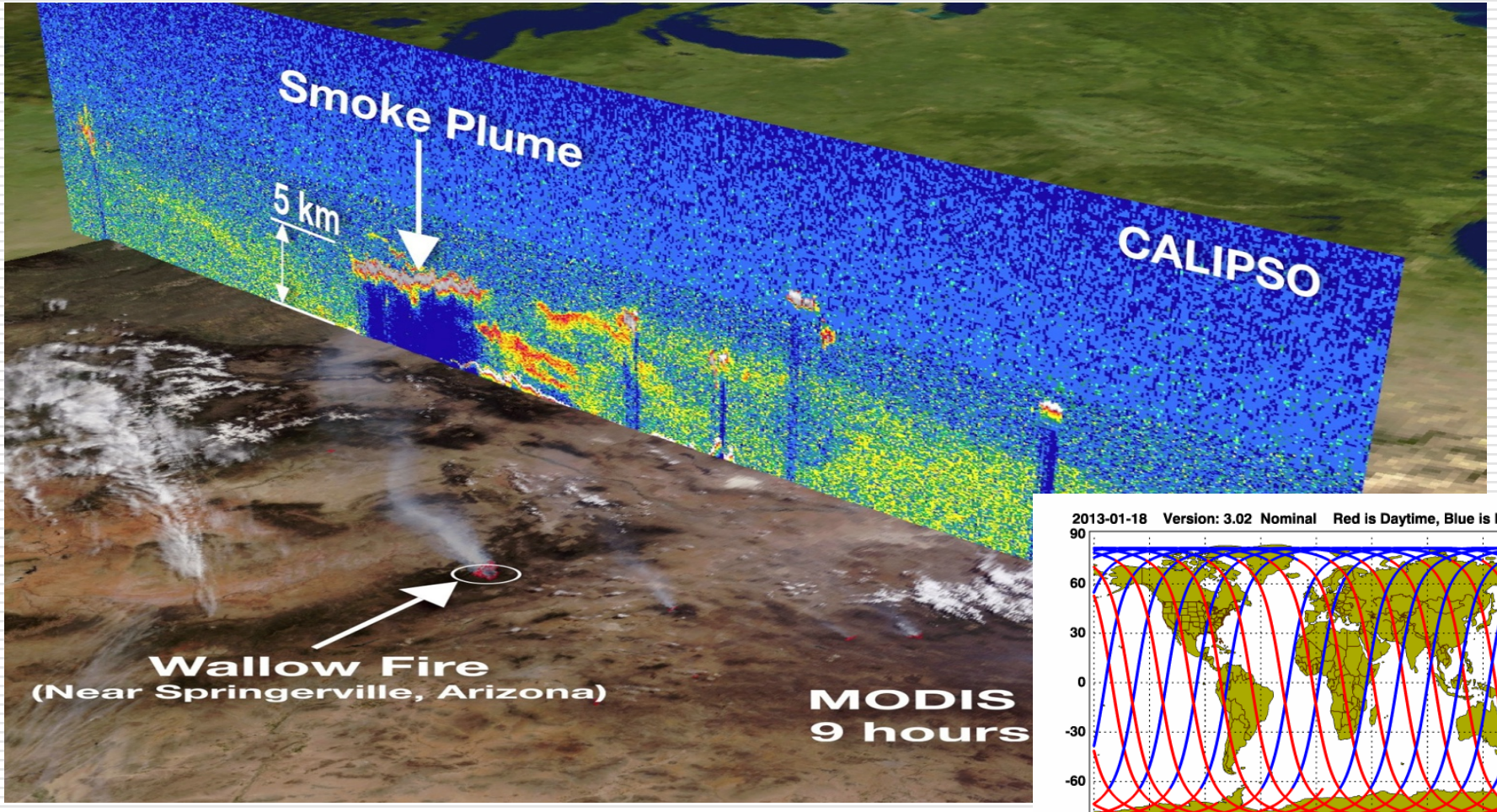


Data Formats, Reading, Understanding & Visualization



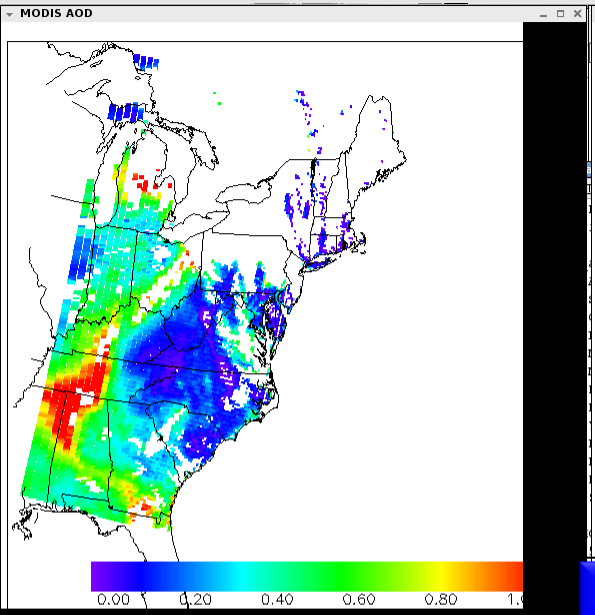
Vertical Profiles of Aerosols

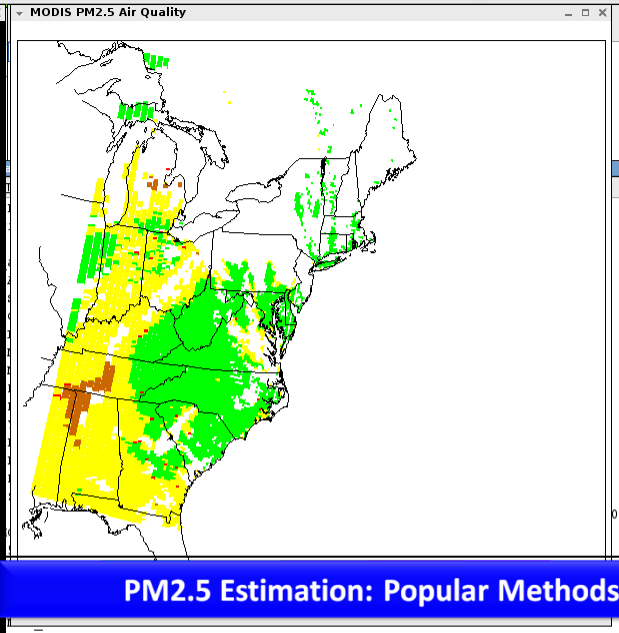


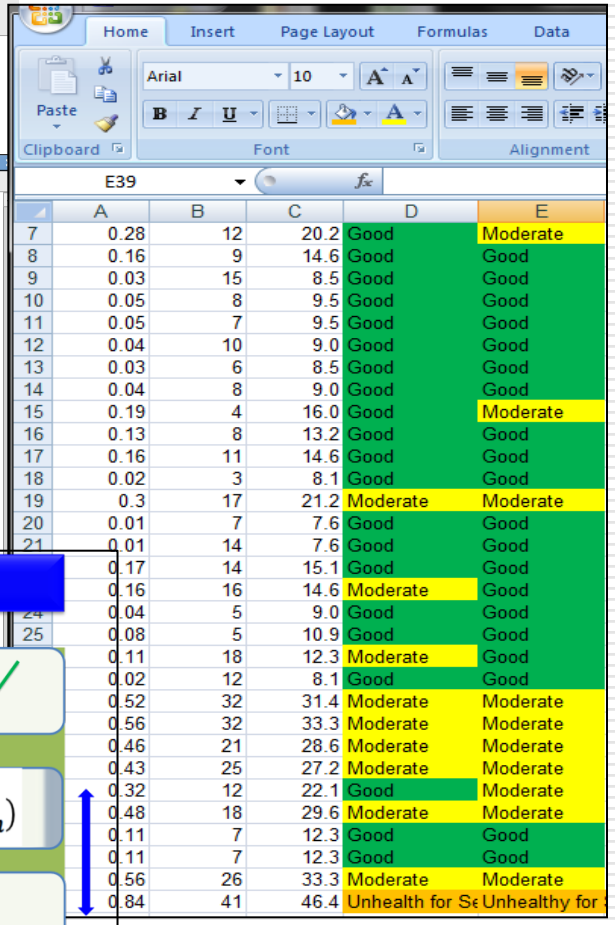


Particulate Matter Air Quality from Space

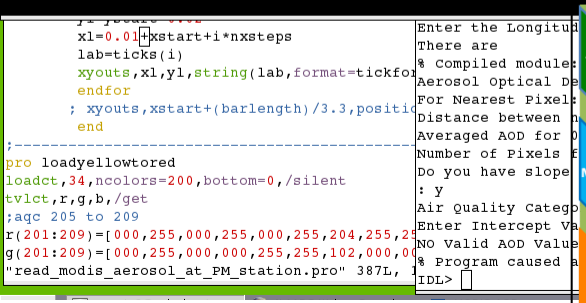
From Satellite to $PM_{2.5}$ to Air Quality Index







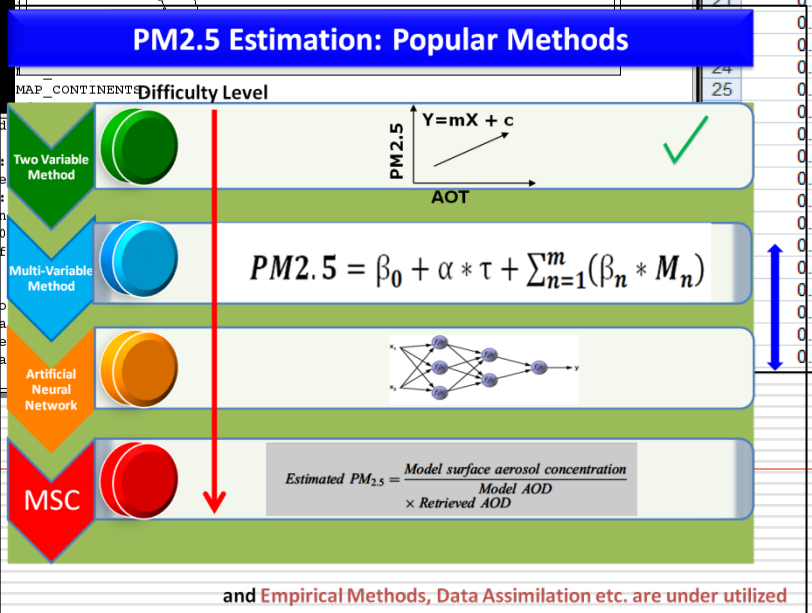
	A	B	C	D	E
7	0.28	12	20.2	Good	Moderate
8	0.16	9	14.6	Good	Good
9	0.03	15	8.5	Good	Good
10	0.05	8	9.5	Good	Good
11	0.05	7	9.5	Good	Good
12	0.04	10	9.0	Good	Good
13	0.03	6	8.5	Good	Good
14	0.04	8	9.0	Good	Good
15	0.19	4	16.0	Good	Moderate
16	0.13	8	13.2	Good	Good
17	0.16	11	14.6	Good	Good
18	0.02	3	8.1	Good	Good
19	0.3	17	21.2	Moderate	Moderate
20	0.01	7	7.6	Good	Good
21	0.01	14	7.6	Good	Good
	0.17	14	15.1	Good	Good
	0.16	16	14.6	Moderate	Good
24	0.04	5	9.0	Good	Good
25	0.08	5	10.9	Good	Good
	0.11	18	12.3	Moderate	Good
	0.02	12	8.1	Good	Good
	0.52	32	31.4	Moderate	Moderate
	0.56	32	33.3	Moderate	Moderate
	0.46	21	28.6	Moderate	Moderate
	0.43	25	27.2	Moderate	Moderate
	0.32	12	22.1	Good	Moderate
	0.48	18	29.6	Moderate	Moderate
	0.11	7	12.3	Good	Good
	0.11	7	12.3	Good	Good
	0.56	26	33.3	Moderate	Moderate
	0.84	41	46.4	Unhealth for Se	Unhealthy for



```
xl=0.01+xstart+i*nxsteps
lab=ticks(i)
xyouts,xl,yl,string(lab,format=tickfo
endfor
; xyouts,xstart+(barlength)/3.3,positi
end

pro loadyellowtored
loadct,34,ncolors=200,bottom=0,/silent
tvlct,r,g,b,/get
;aqc 205 to 209
r(201:209)=[000,255,000,255,000,255,204,255,2
g(201:209)=[000,255,000,000,255,255,102,000,0
"read_modis_aerosol_at_PM_station.pro" 387L,
```

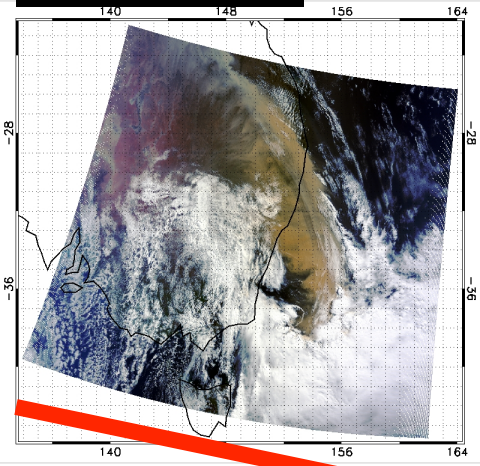
```
Enter the Longitud
There are
% Compiled module:
Aerosol Optical De
For Nearest Pixel:
Distance between
Averaged AOD for
Number of Pixels
Do you have slope
: y
Air Quality Categ
Enter Intercept Va
NO Valid AOD Value
% Program caused a
IDL>
```



and Empirical Methods, Data Assimilation etc. are under utilized

Dust & Smoke Monitoring

RGB



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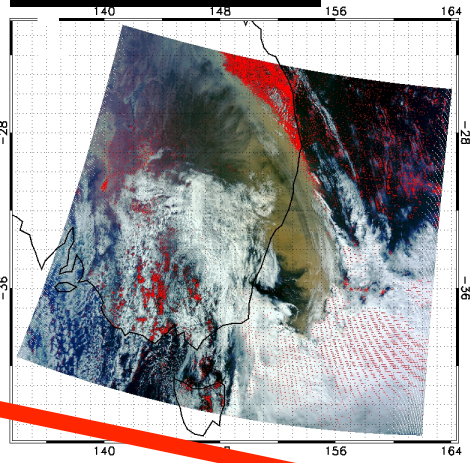

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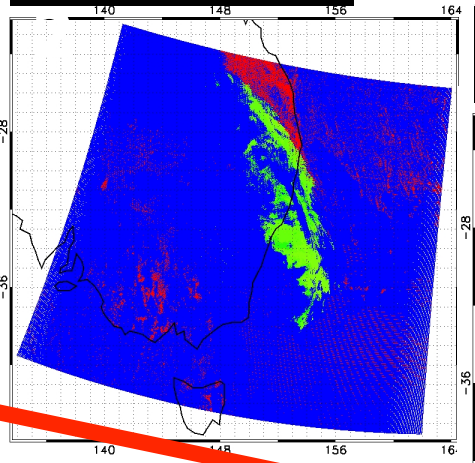

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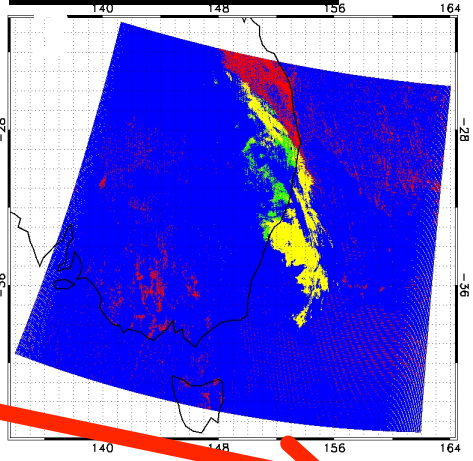
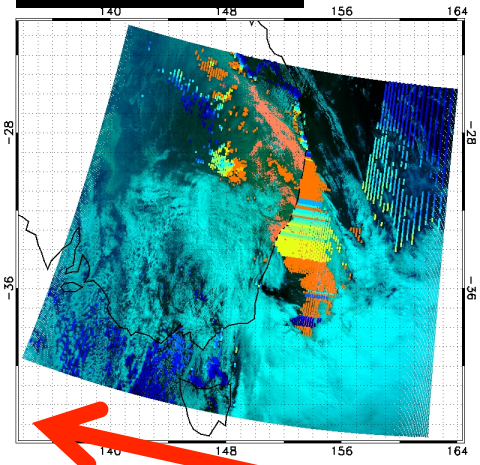
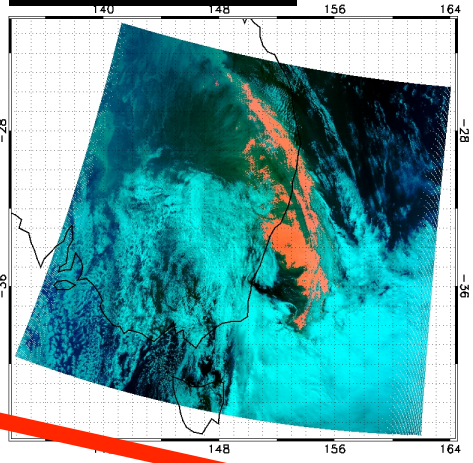


AOD



DUST



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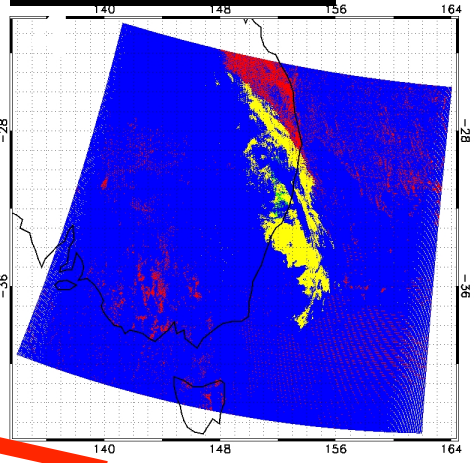
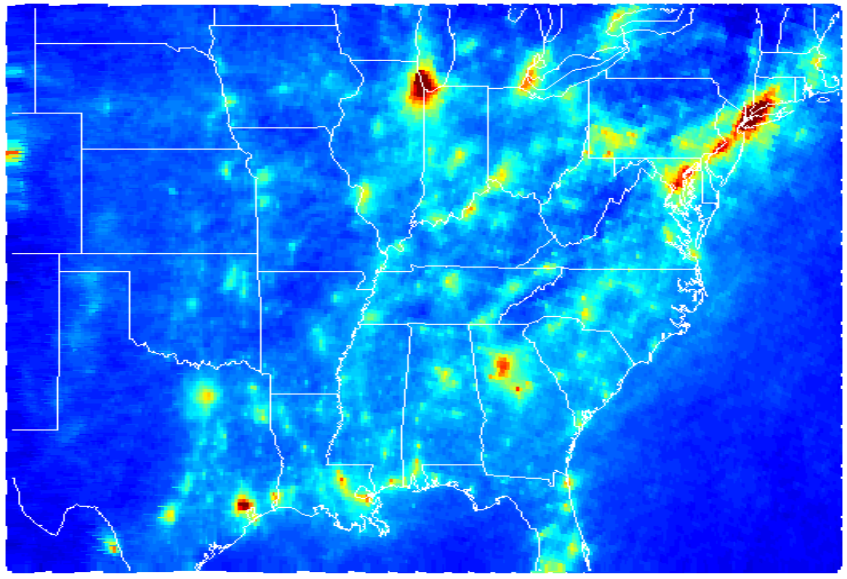
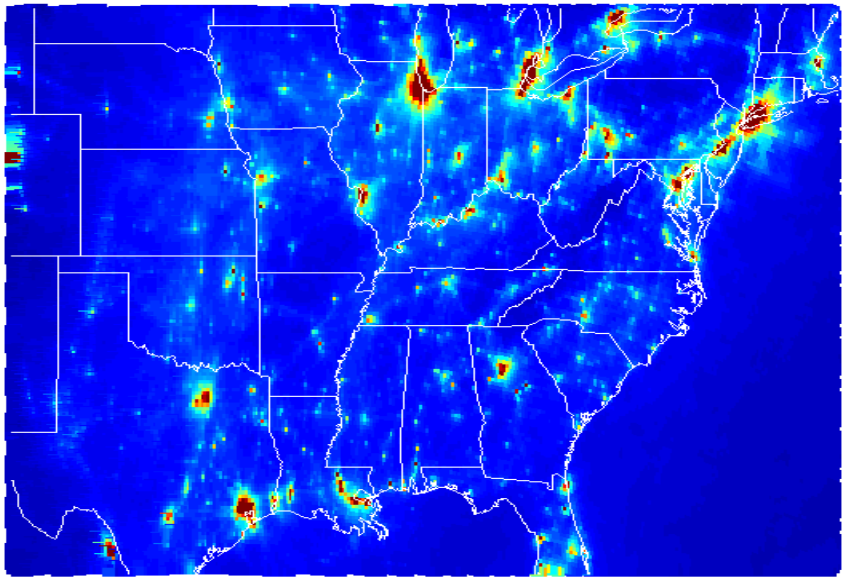


Model-Satellite Inter-comparison

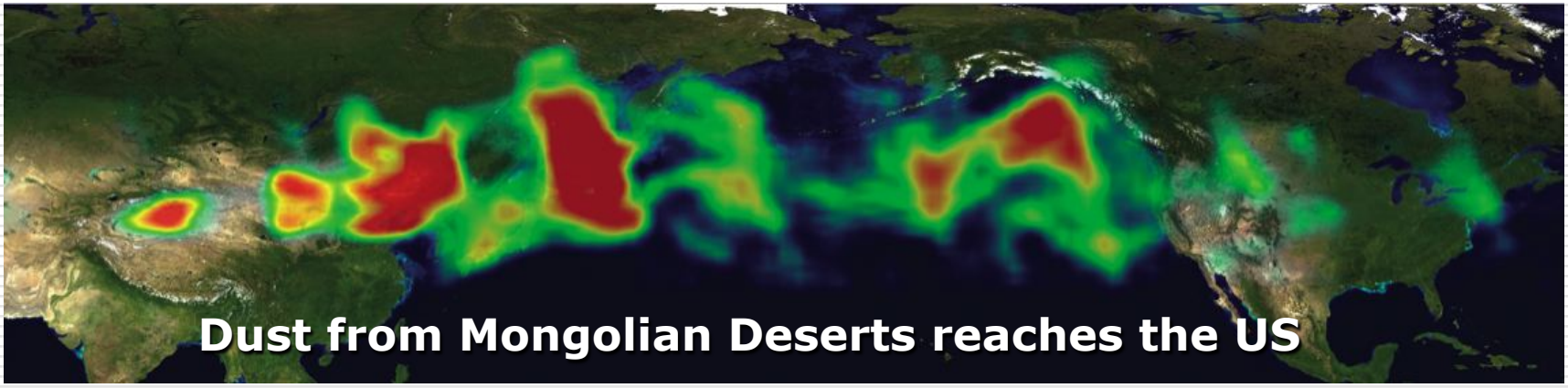


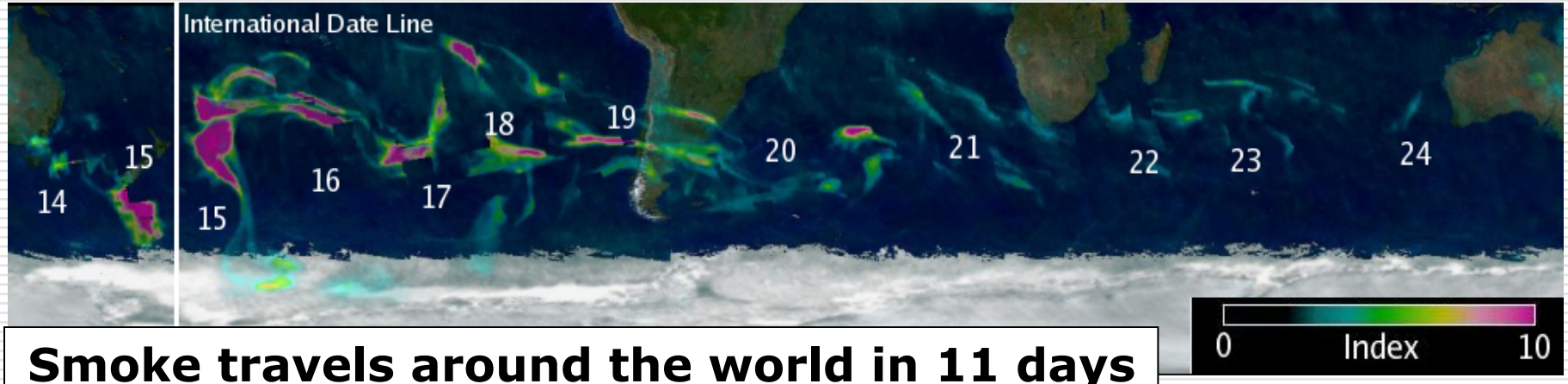
CMAQ Model NO_2



OMI NO_2

Long Range Transport

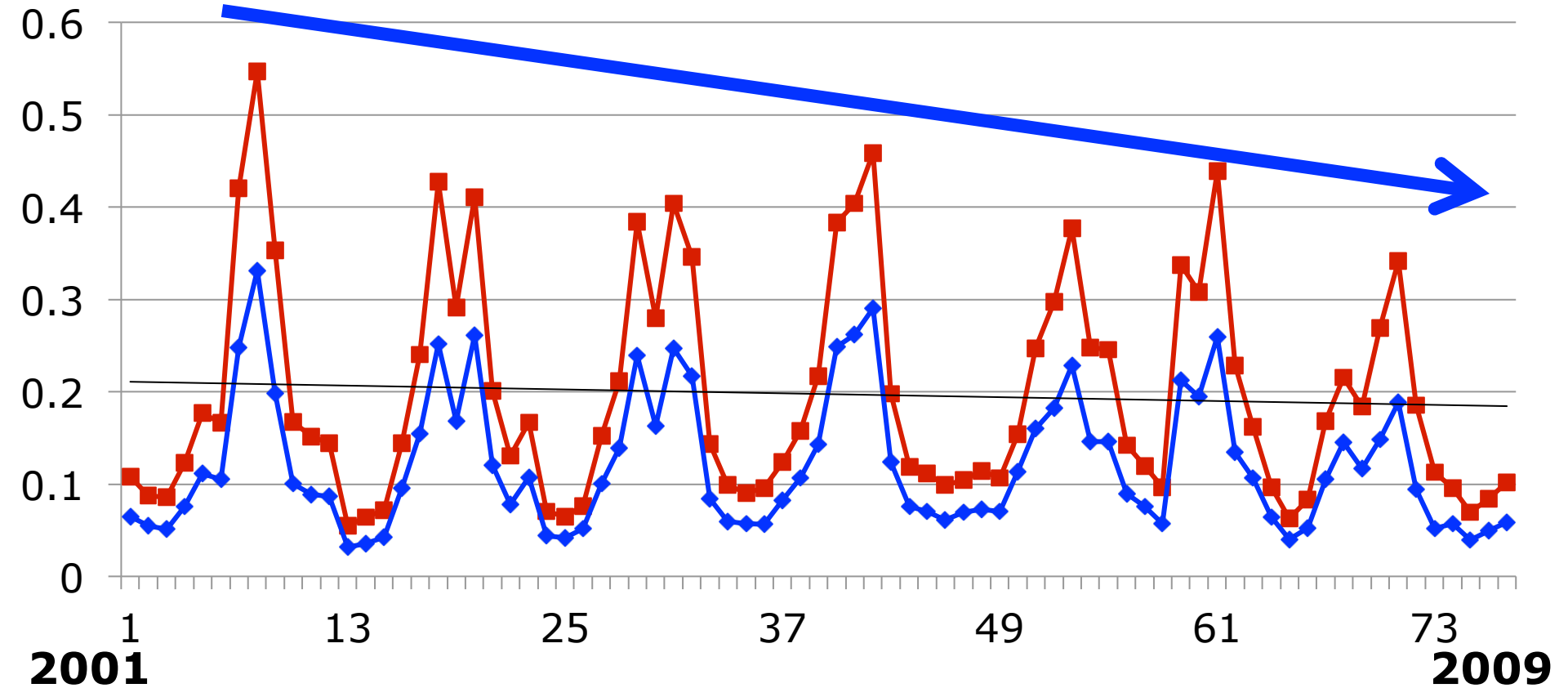




Smoke travels around the world in 11 days

Air Quality Trends

AERONET over CCNY



Data User Guide

Bryan N. Duncan, Ana I. Prados, Lok N. Lamsal, Yang Liu, David G. Streets, **Pawan Gupta**, Ernest Hilsenrath, Ralph A. Kahn, J. Eric Nielsen, Andreas J. Beyersdorf, Sharon P. Burton, Arlene M. Fiore, Jack Fishman, Daven K. Henze, Chris A. Hostetler, Nickolay A. Krotkov, Pius Lee, Meiyun Lin, Steven Pawson, Gabriele Pfister, Kenneth E. Pickering, R. Bradley Pierce, Yasuko Yoshida, Luke D. Ziemba, **Satellite data of atmospheric pollution for U.S. air quality applications: Examples of applications, summary of data end-user resources, answers to FAQs, and common mistakes to avoid**, Atmospheric Environment, Volume 94, September 2014, Pages 647-662, ISSN 1352-2310, http://dx.doi.org/10.1016/j.atmosenv.2014.05.061.

(http://www.sciencedirect.com/science/article/pii/S1352231014004270)

An ARSET/AQAST Collaboration