



Satellite Remote Sensing of Air Quality – An Overview

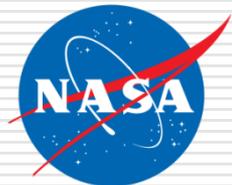
Pawan Gupta

NASA ARSET- AQ – GEPD & SESARM, Atlanta, GA
September 1-3, 2015

ARSET - AQ

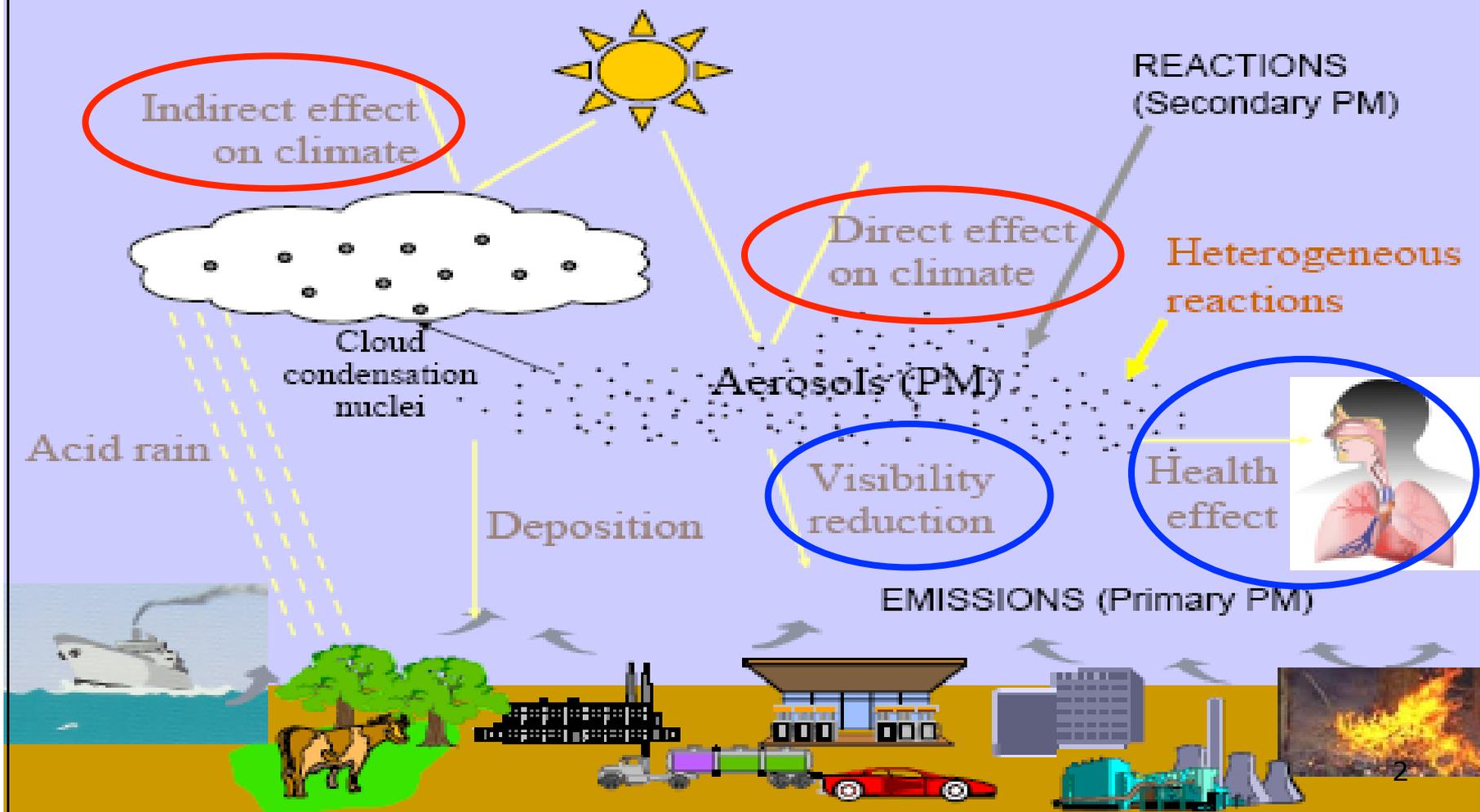
Applied Remote Sensing and Training – Air Quality

A project of NASA Applied Sciences

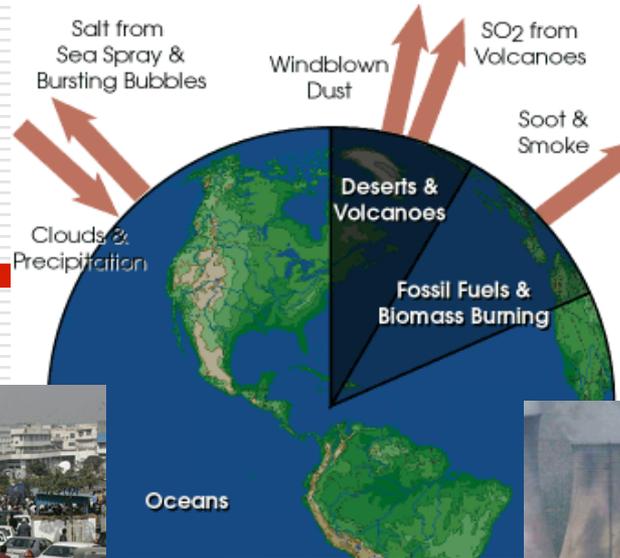


Motivation – tiny but Potent

Effects of Atmospheric Aerosols

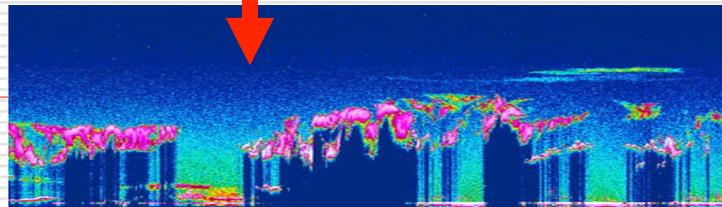
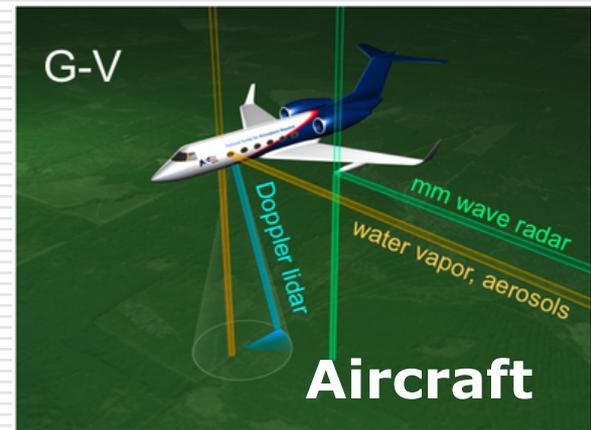
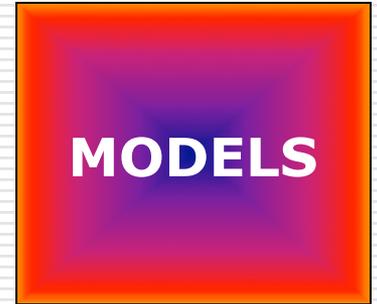
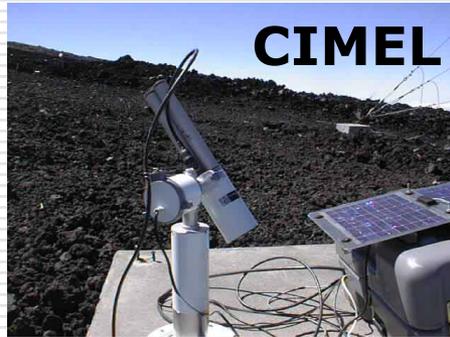


Pollution Sources



Atmospheric aerosols are highly variable in space and time

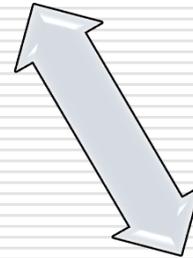
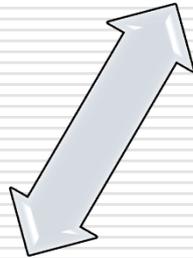
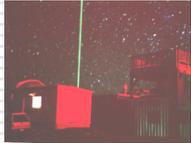
Air Pollution Monitoring



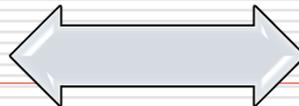
Air Pollution Monitoring



**Ground
Measurements**



**Air and 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

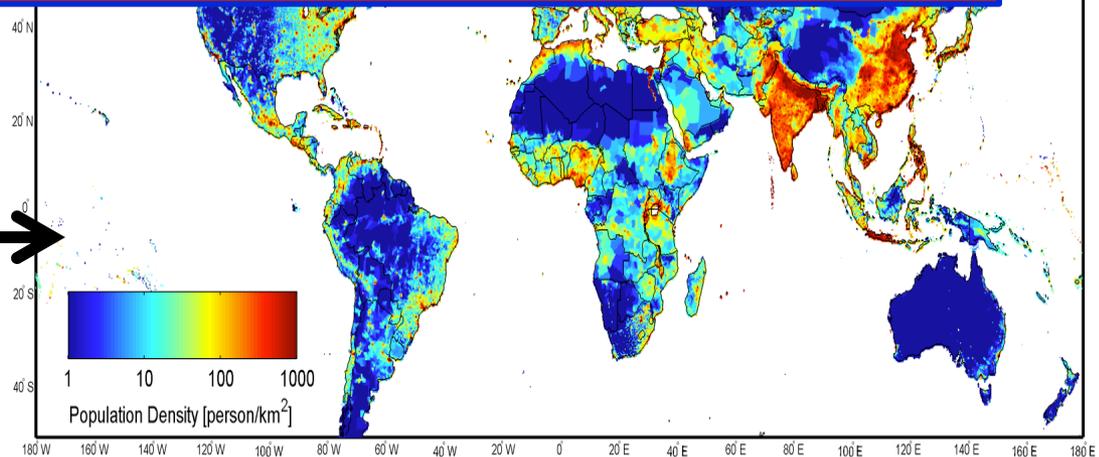
★ Surface measurements are not cost effective

★ How about using remote sensing satellites?

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

Ground
Sensor
network

Population
Density

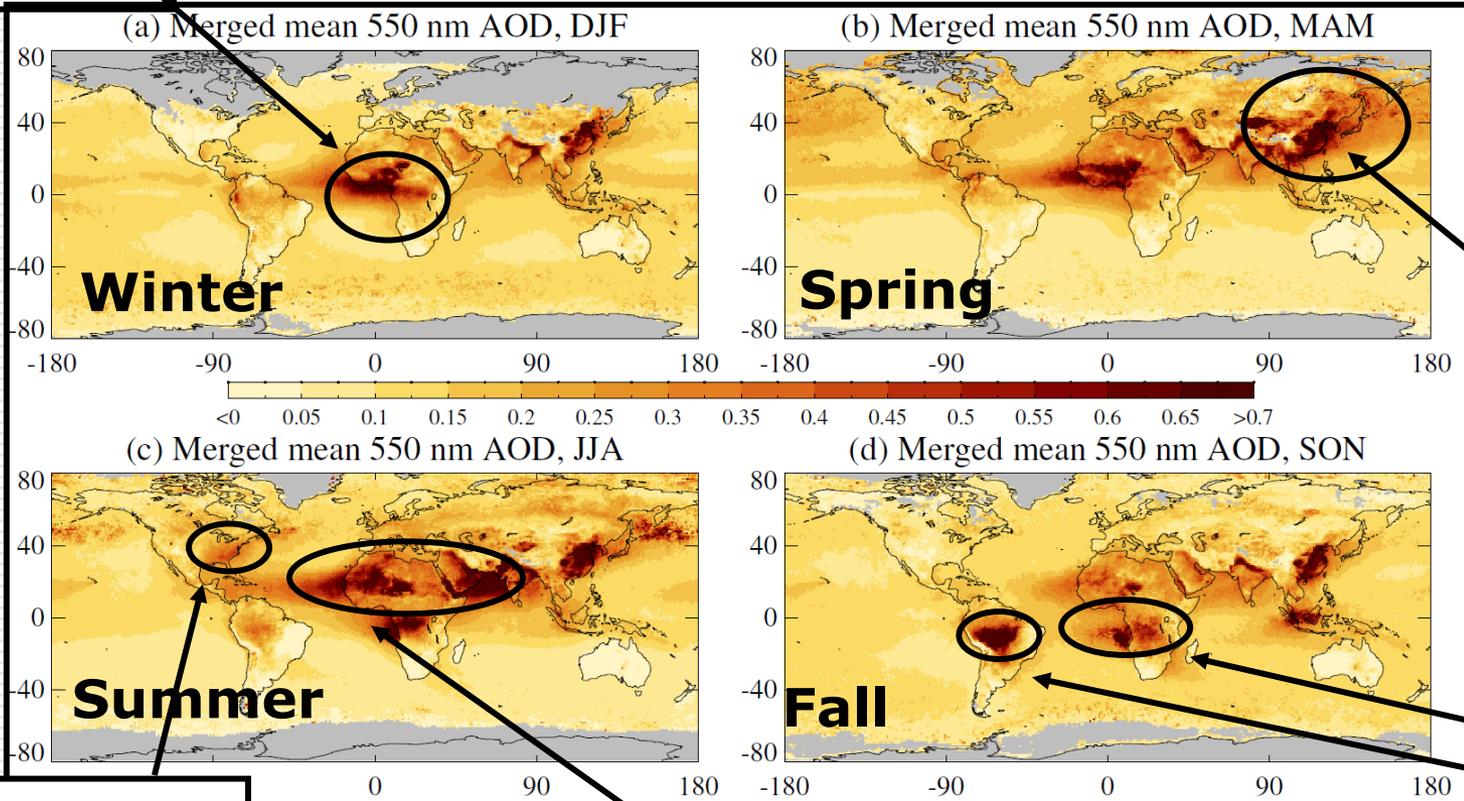


Brauer M, Ammann M, Burnett R et al.
GBD 2010 Outdoor Air Pollution Expert Group
2011 Submitted –under review

Aerosols from satellites

Aerosol Optical Thickness MODIS AQUA

**Biomass
Burning**



**Pollution &
dust**

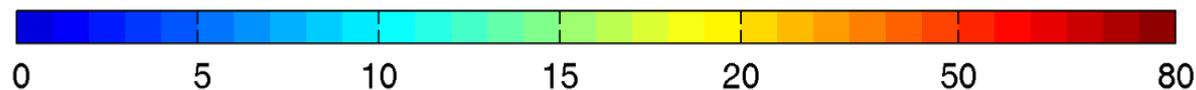
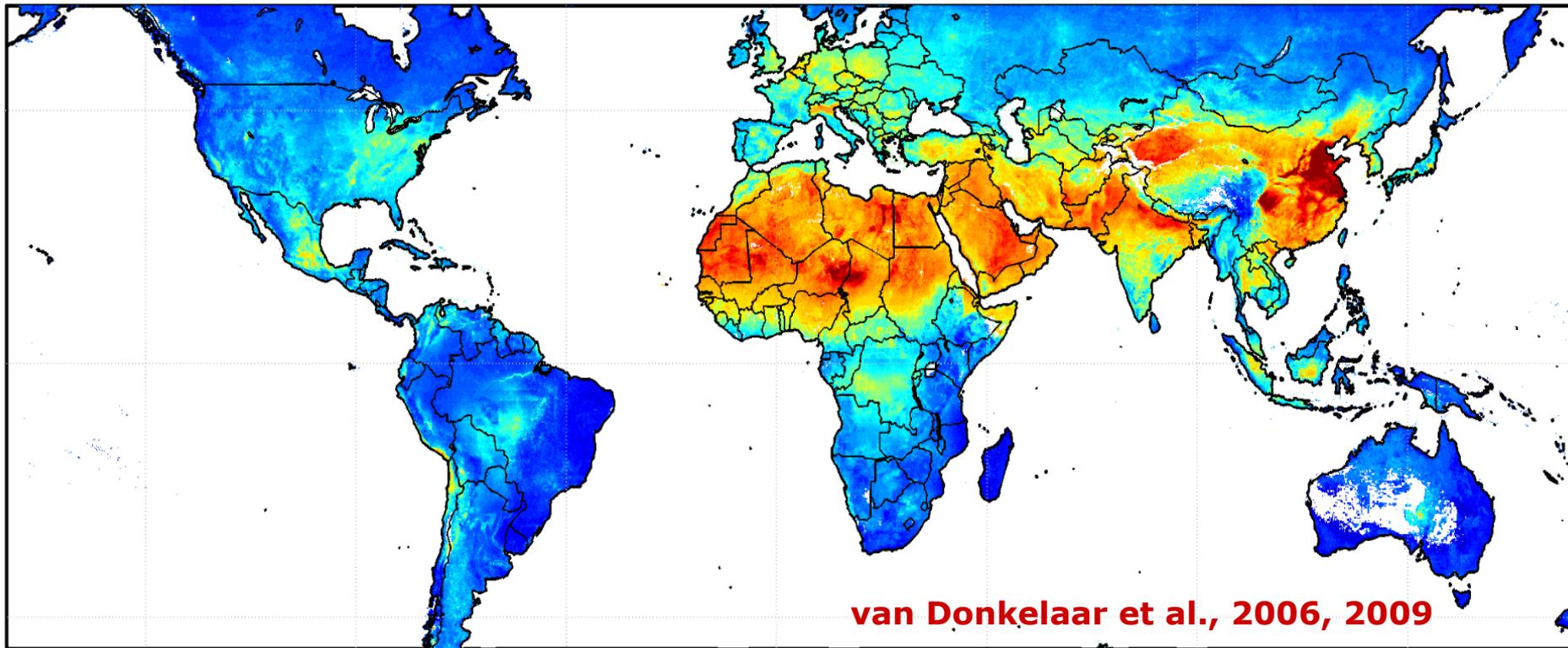
**Haze &
Pollution**

Dust

**Biomass
Burning**

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

Annual Mean PM_{2.5} from Satellite Observations



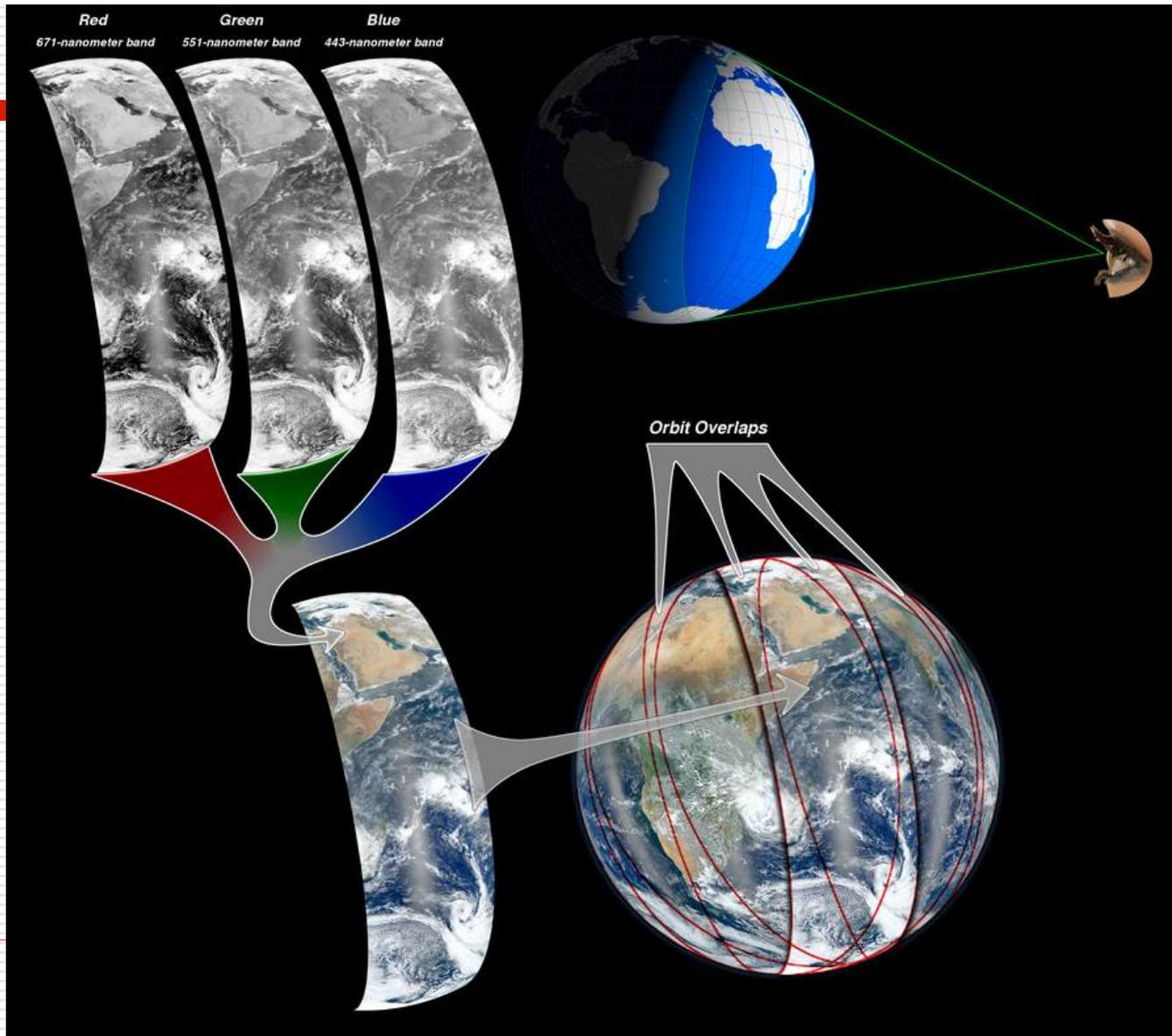
Satellite-Derived PM_{2.5} [$\mu\text{g}/\text{m}^3$]

Earth Observing Systems

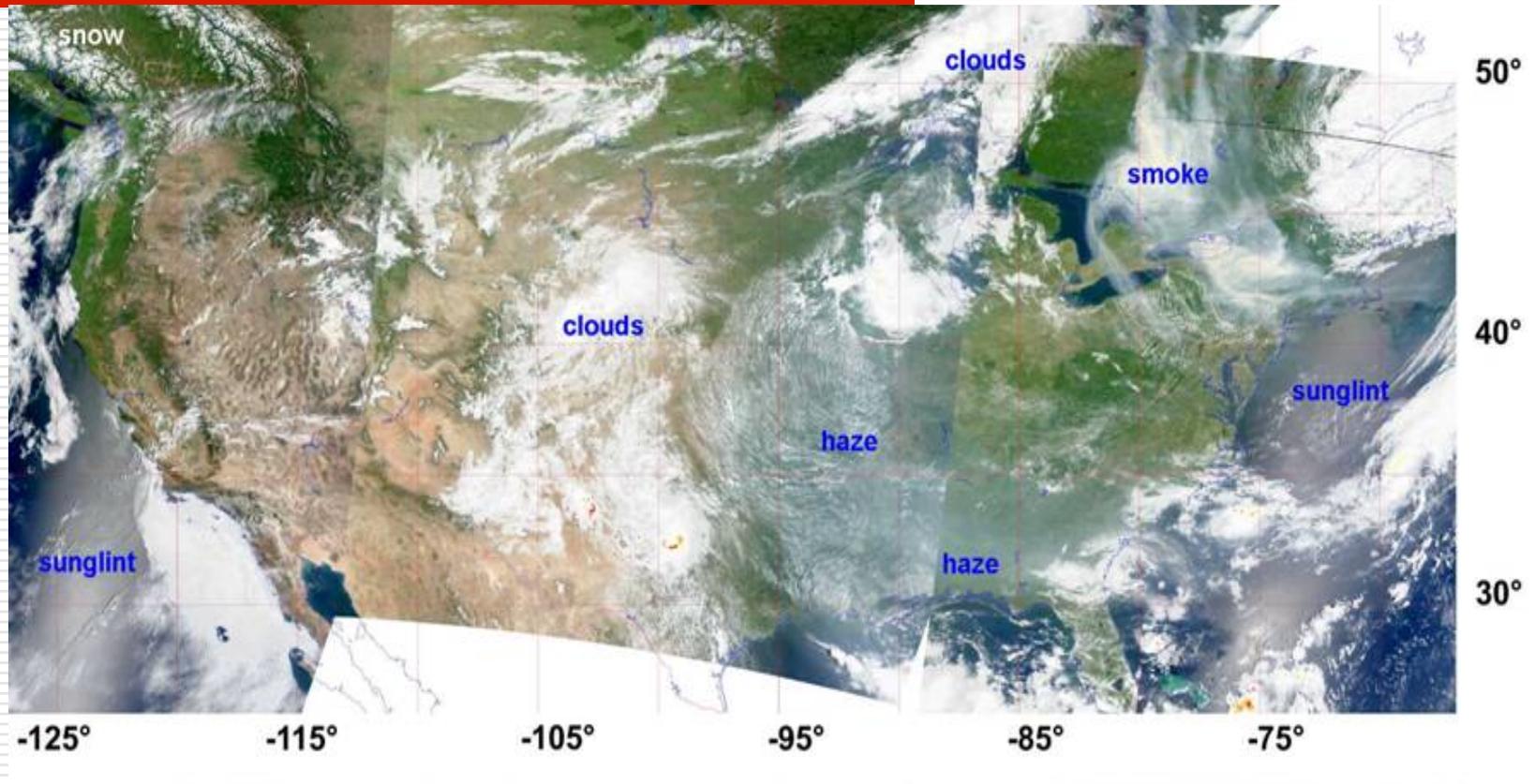


What do satellites measure and
how are they useful?

True Color Image – Radiance/Reflectance Measurements



What can we learn from true color imagery?



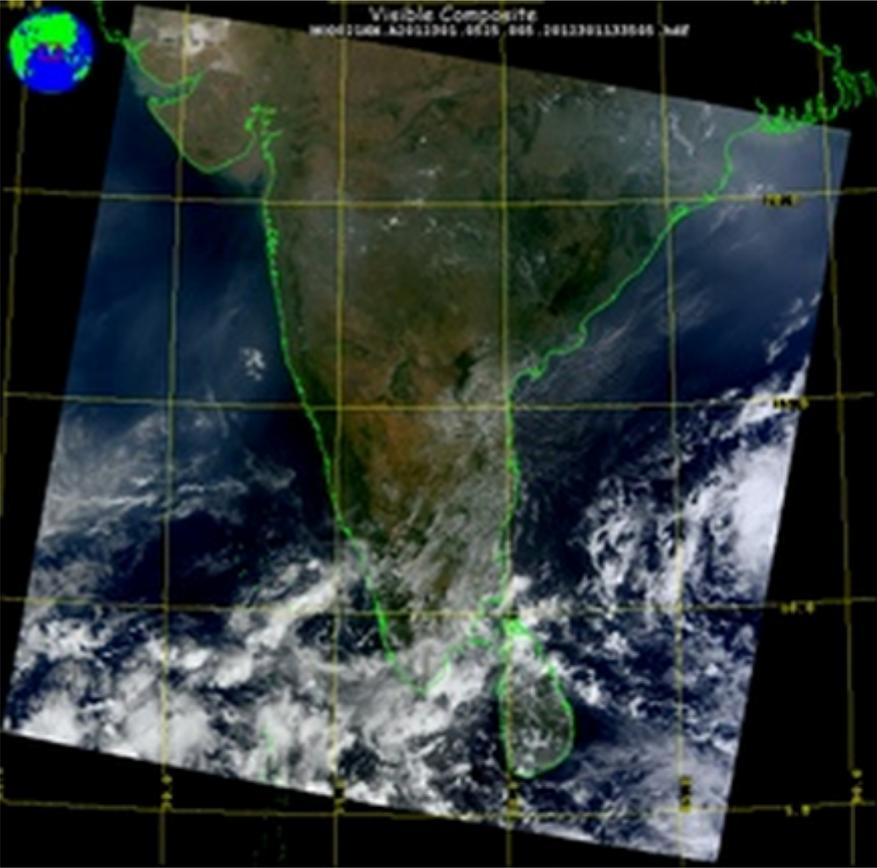
(Possible) Identification of land, ocean and atmosphere features

Satellite Algorithms

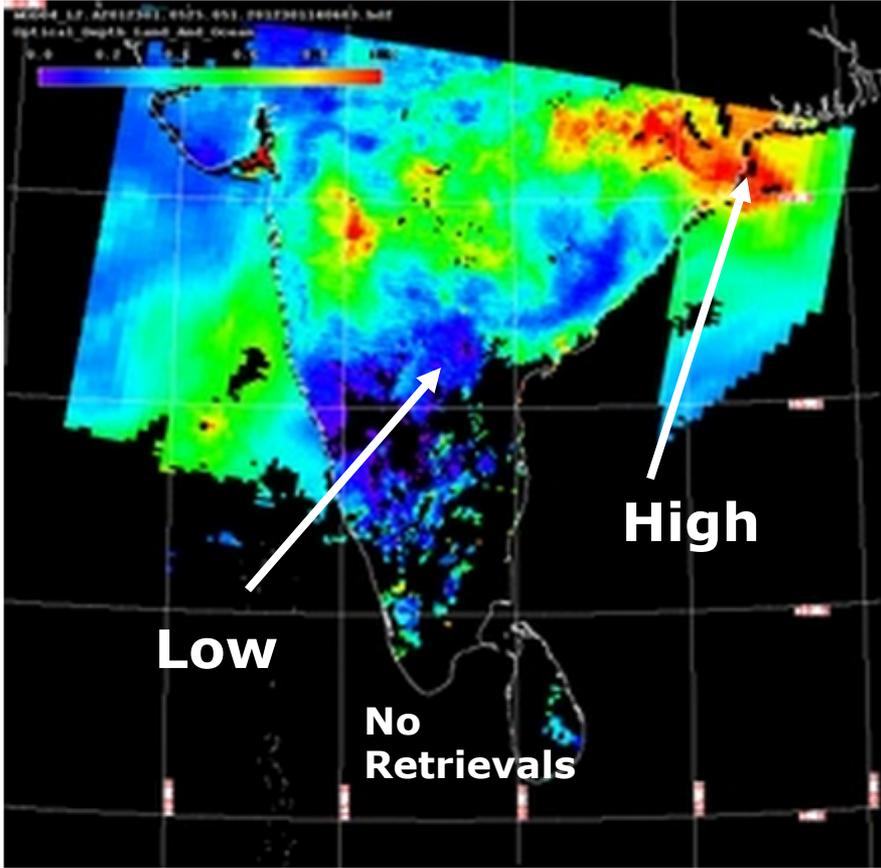
Radiance -to- Aerosol Products



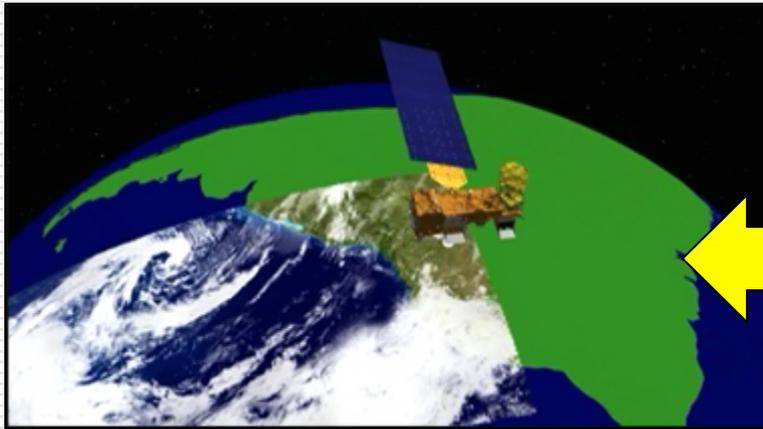
RGB



Aerosol Optical Depth



Thus Monitoring...



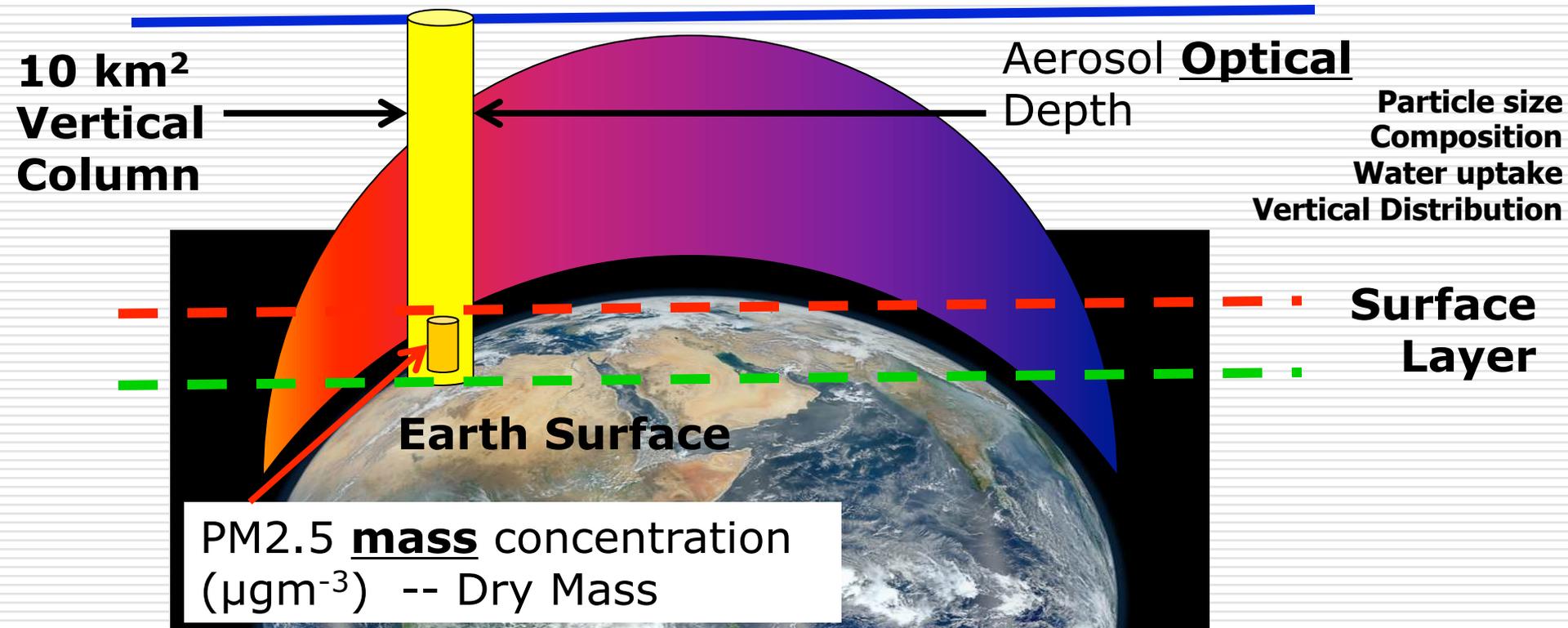
From Space



From Surface

Satellite vs Ground Observation

To of the Atmosphere



Empirical Ways to Estimate PM_{2.5}

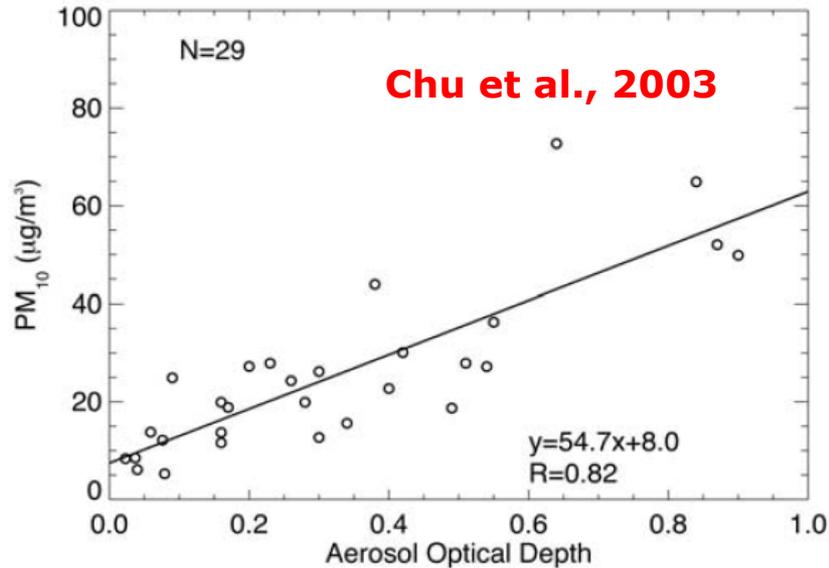


Figure 14. Relationship between 24-hour PM₁₀ concentrations and daily averaged AERONET τ_a measurements from August to October 2000 in northern Italy.

Intercomparison between satellite-derived AOT and PM_{2.5} mass: Implications for air quality

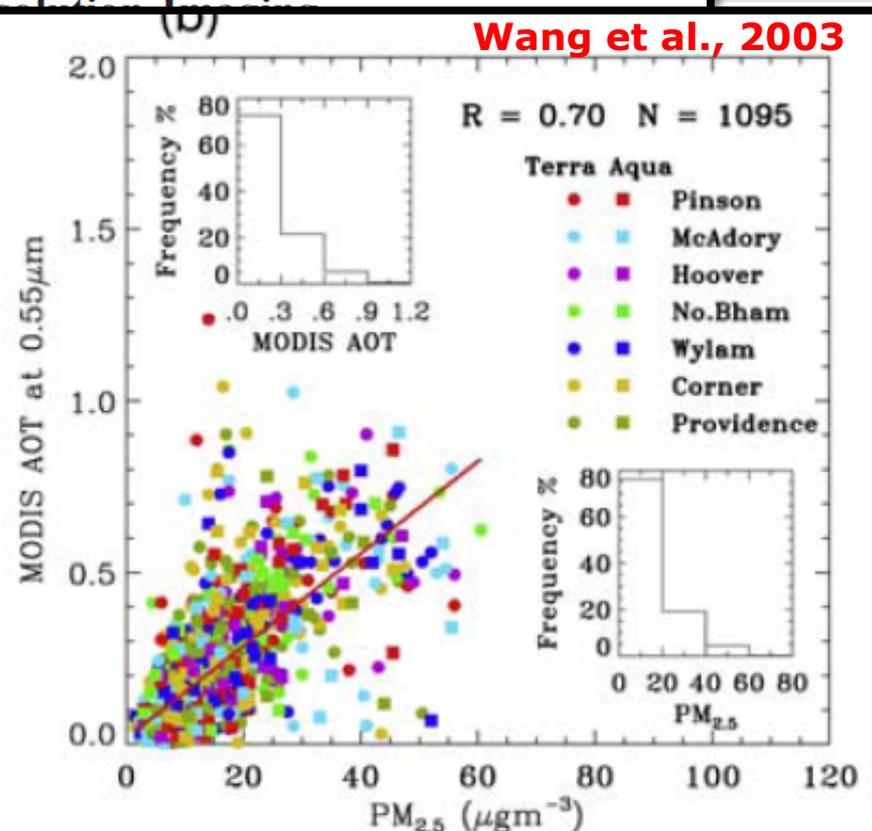
Jun Wang and Sundar A. Christopher

Department of Atmospheric Sciences, University of Alabama in Huntsville

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

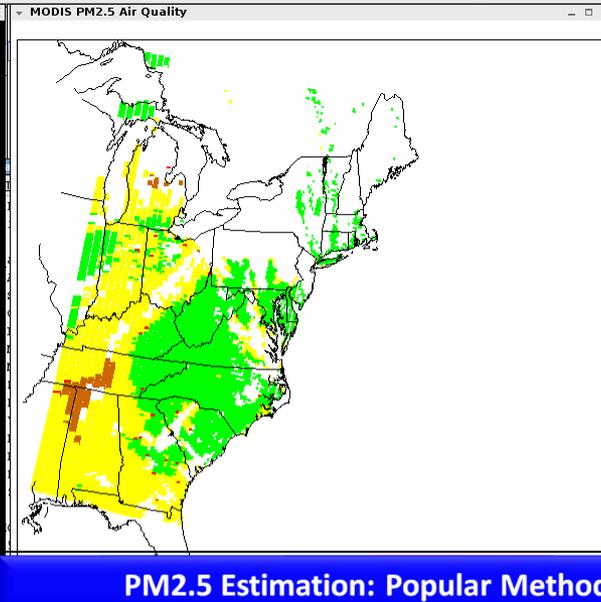
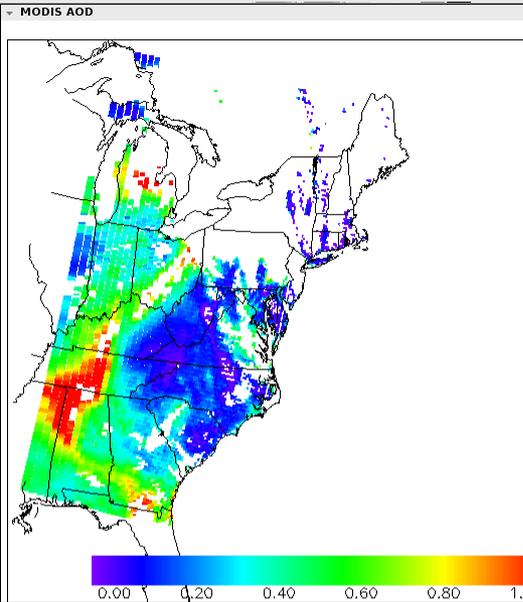
J. Geophys. Res., Vol. 108, NO. D21, 4661, doi:10.1029/2002JD003179, 2003

Over land from the Earth



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
22	0.17	14	15.1	Good	Good
23	0.16	16	14.6	Moderate	Good
24	0.04	5	9.0	Good	Good
25	0.08	5	10.9	Good	Good
26	0.11	18	12.3	Moderate	Good
27	0.02	12	8.1	Good	Good
28	0.52	32	31.4	Moderate	Moderate
29	0.56	32	33.3	Moderate	Moderate
30	0.46	21	28.6	Moderate	Moderate
31	0.43	25	27.2	Moderate	Moderate
32	0.32	12	22.1	Good	Moderate
33	0.48	18	29.6	Moderate	Moderate
34	0.11	7	12.3	Good	Good
35	0.11	7	12.3	Good	Good
36	0.56	26	33.3	Moderate	Moderate
37	0.84	41	46.4	Unhealthy for S	Unhealthy for

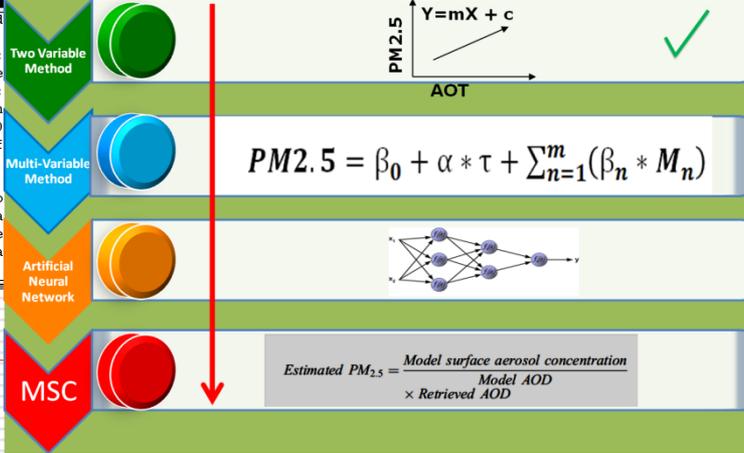
PM_{2.5} Estimation: Popular Methods

```

x1=0.01; xstart+i*nxsteps
lab=ticks(i)
% Compiled module:
% Aerosol Optical Depth
xyouts, xl, yl, string(lab, format='tickfor
endfor
; xyouts, xstart+(barlength)/3.3, positio
end

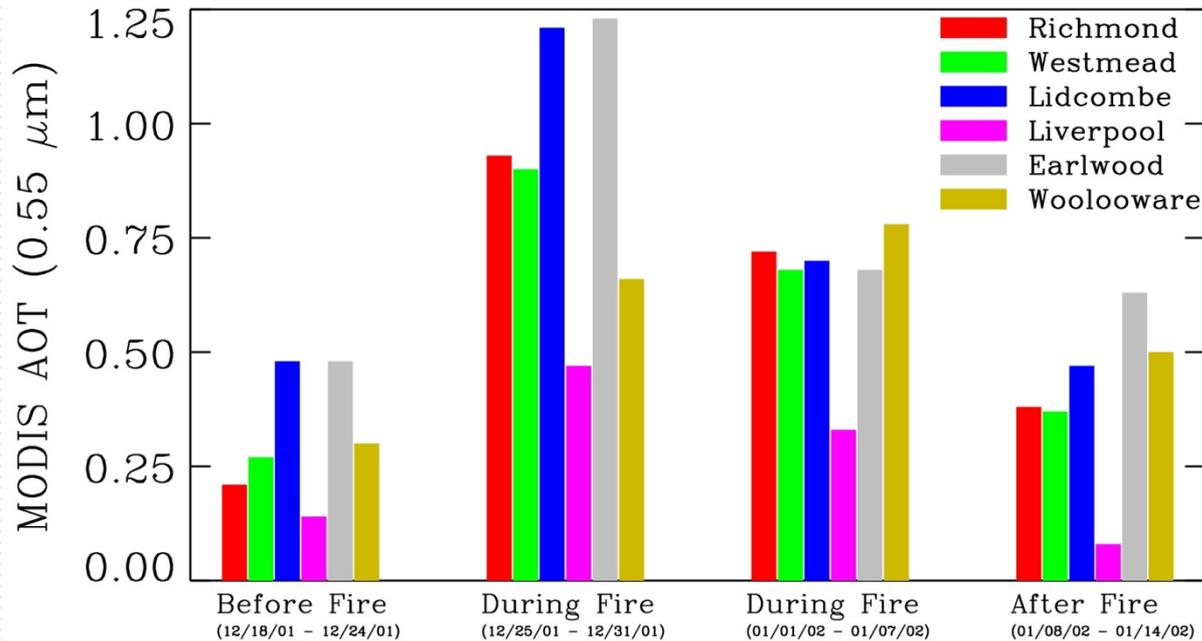
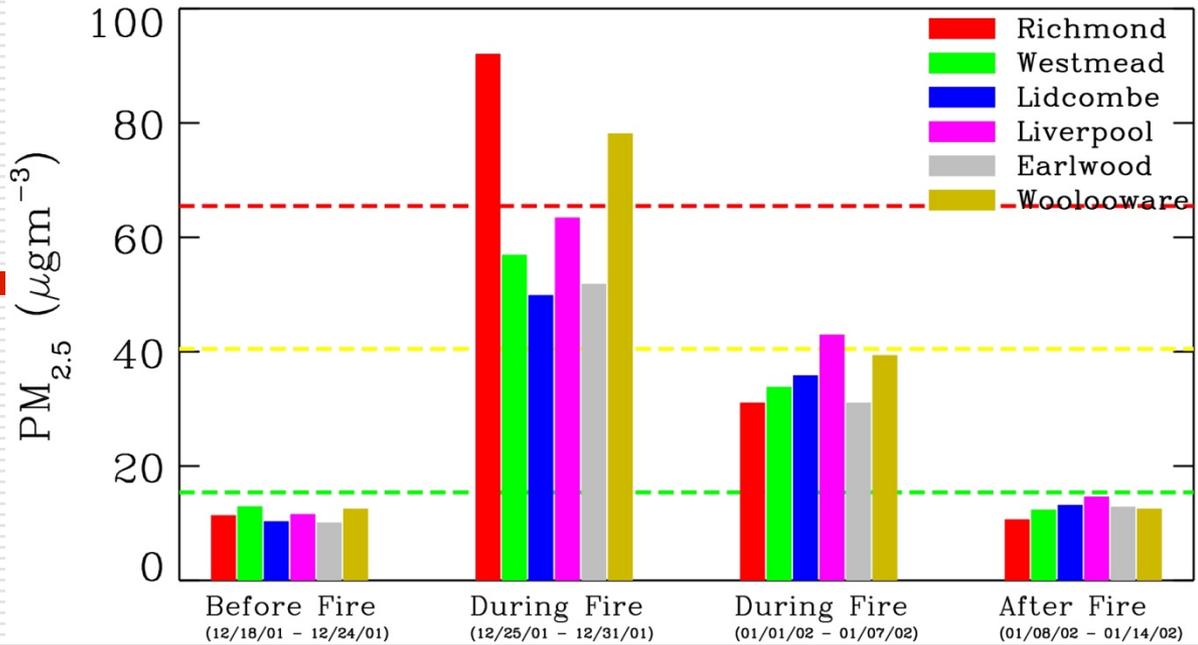
pro loadyellowtored
loadct, 34, ncolors=200, bottom=0, /silent
tv1ct, r, g, b, /get
;aqc 205 to 209
r(201:209)=[000,255,000,255,000,255,204,255,2
g(201:209)=[000,255,000,000,255,255,102,000,0
"read_modis_aerosol_at_PM_station.pro" 387L,
    
```

Enter the Longitude
There are
% Compiled module
% Aerosol Optical Depth
For Nearest Pixel
Distance between
Averaged AOD for
Number of Pixels
Do you have slope
: y
Air Quality Category
Enter Intercept Value
NO valid AOD value
% Program caused a
IDL>

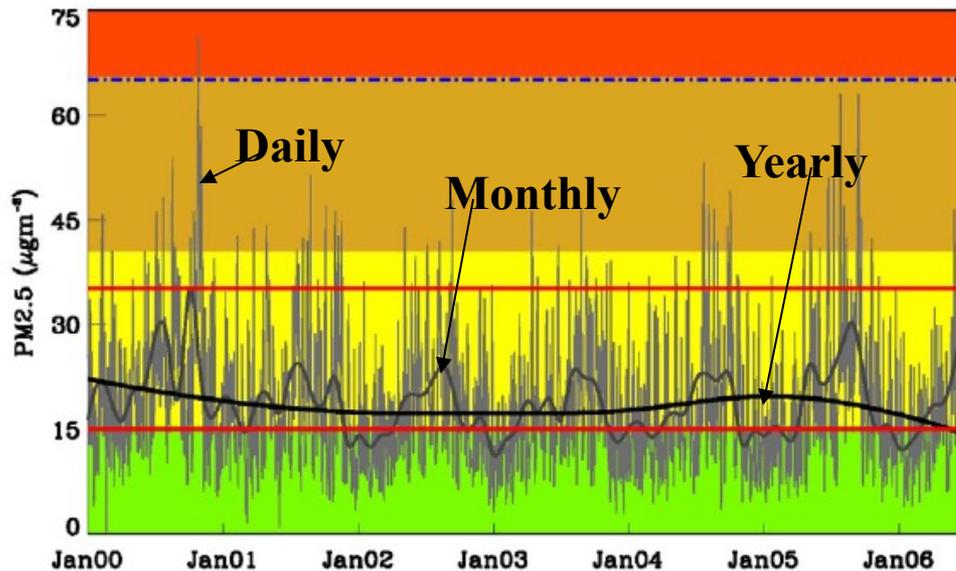


and Empirical Methods, Data Assimilation etc. are under utilized

Application of Satellite Observations during bushfires in Sydney, Australia

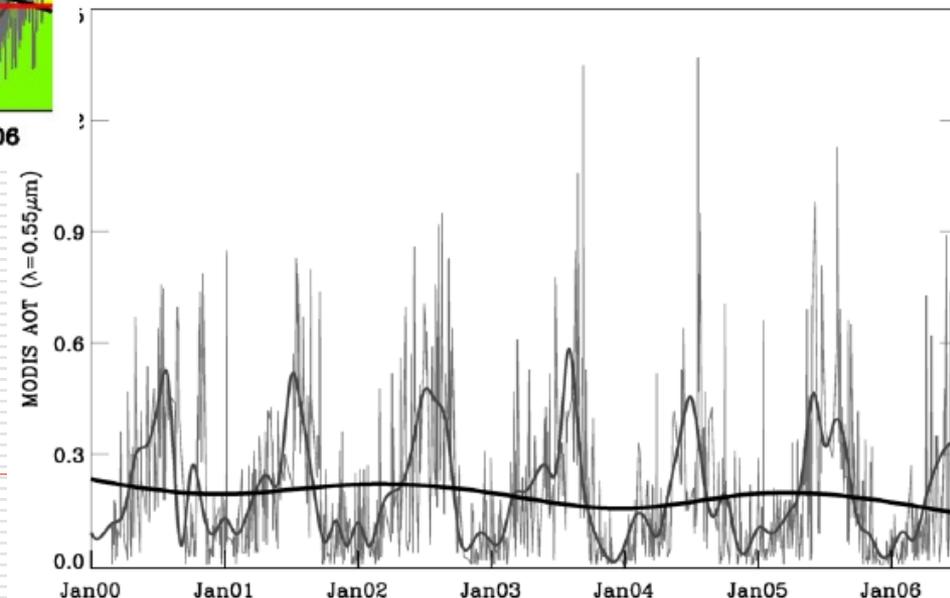


Air Quality Trends: Birmingham, AL

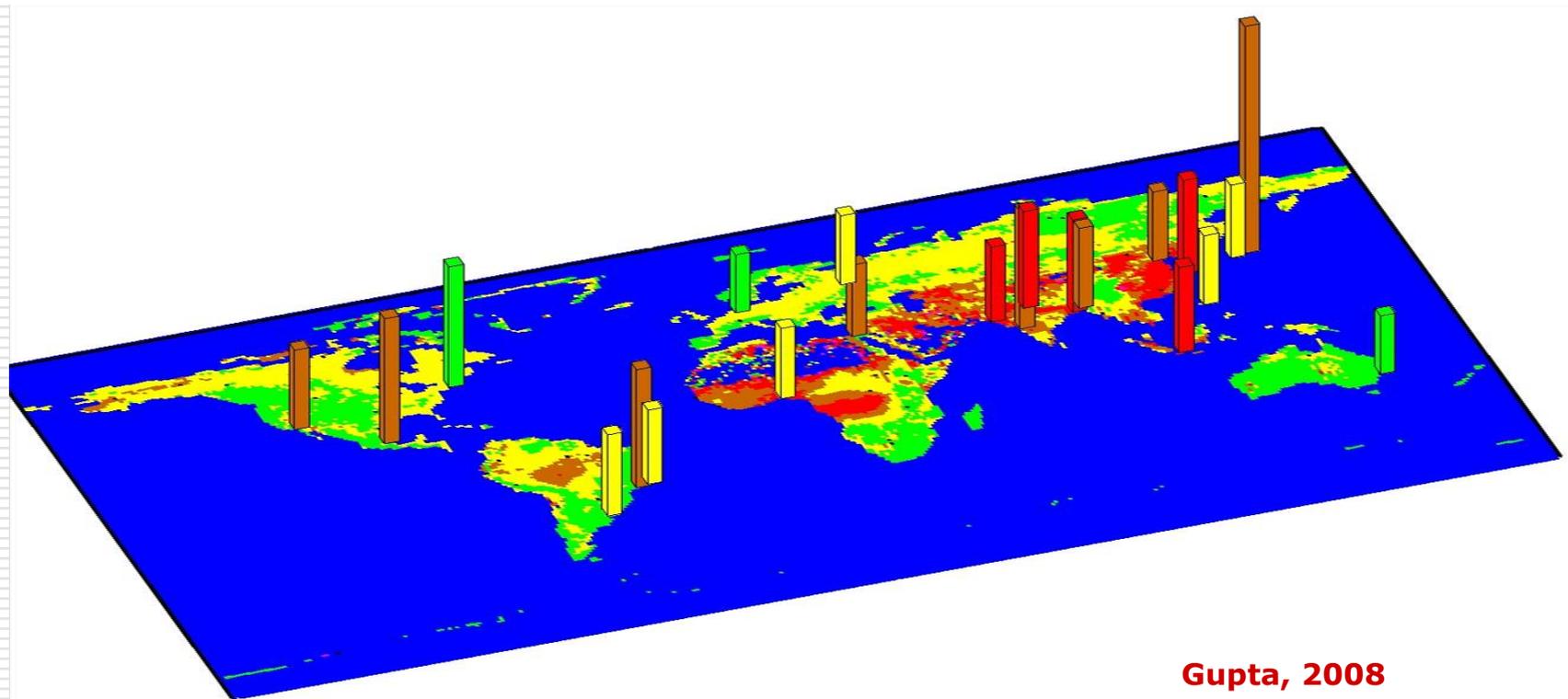


A decreasing trend in annual PM_{2.5} was noted with the almost 22% reduction in PM_{2.5} mass concentration was observed in 2006 compared to 2002.

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

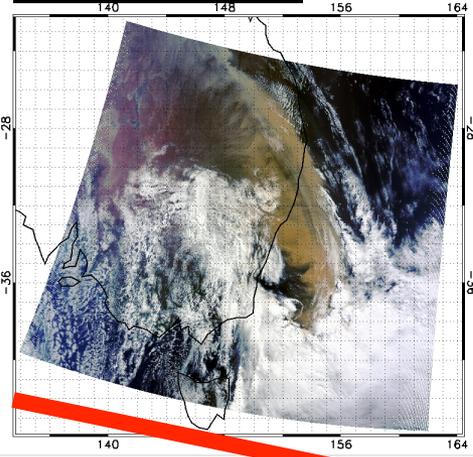


Another view of air quality over global regions

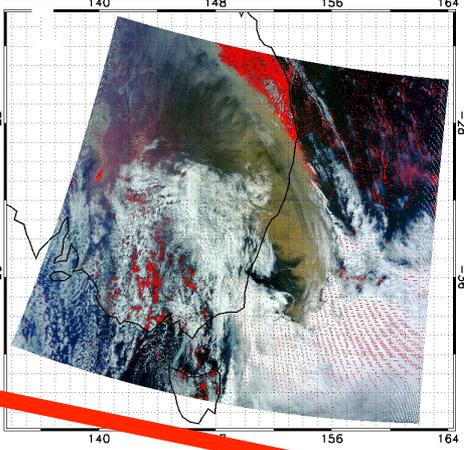


Satellite derived air quality conditions are poor in almost all of the global mega cities with population more than 10 million

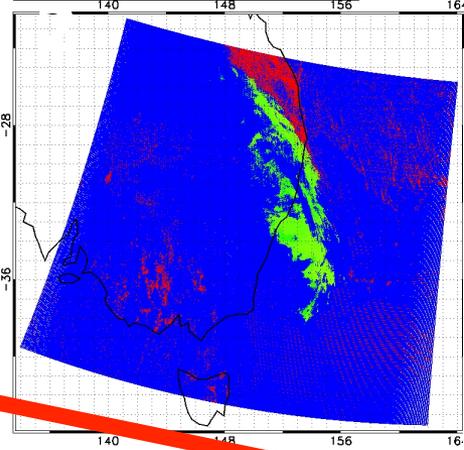
RGB



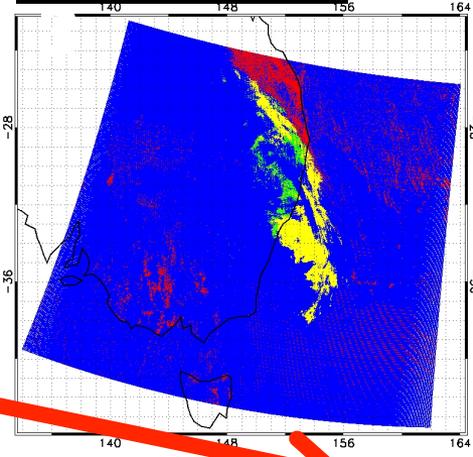
TEST #



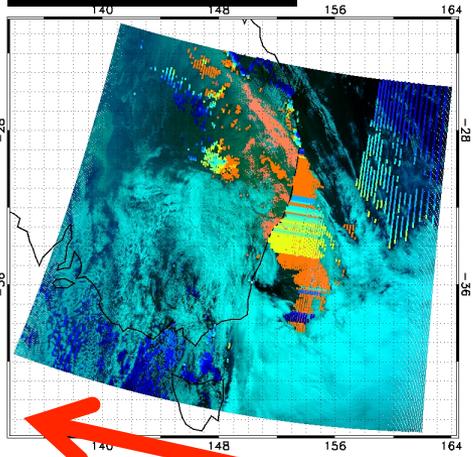
TEST #



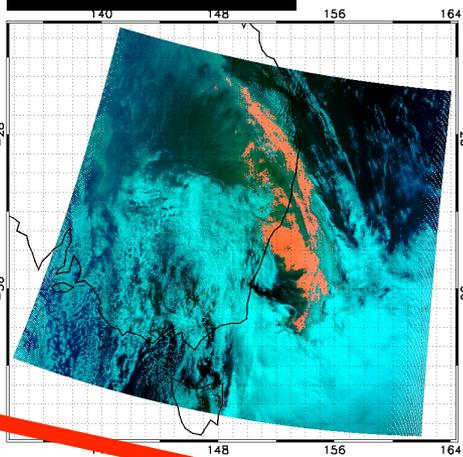
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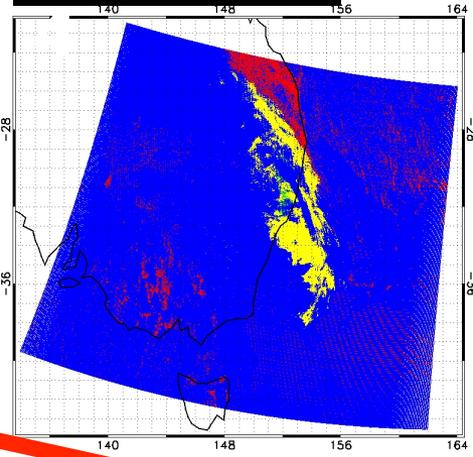
AOD



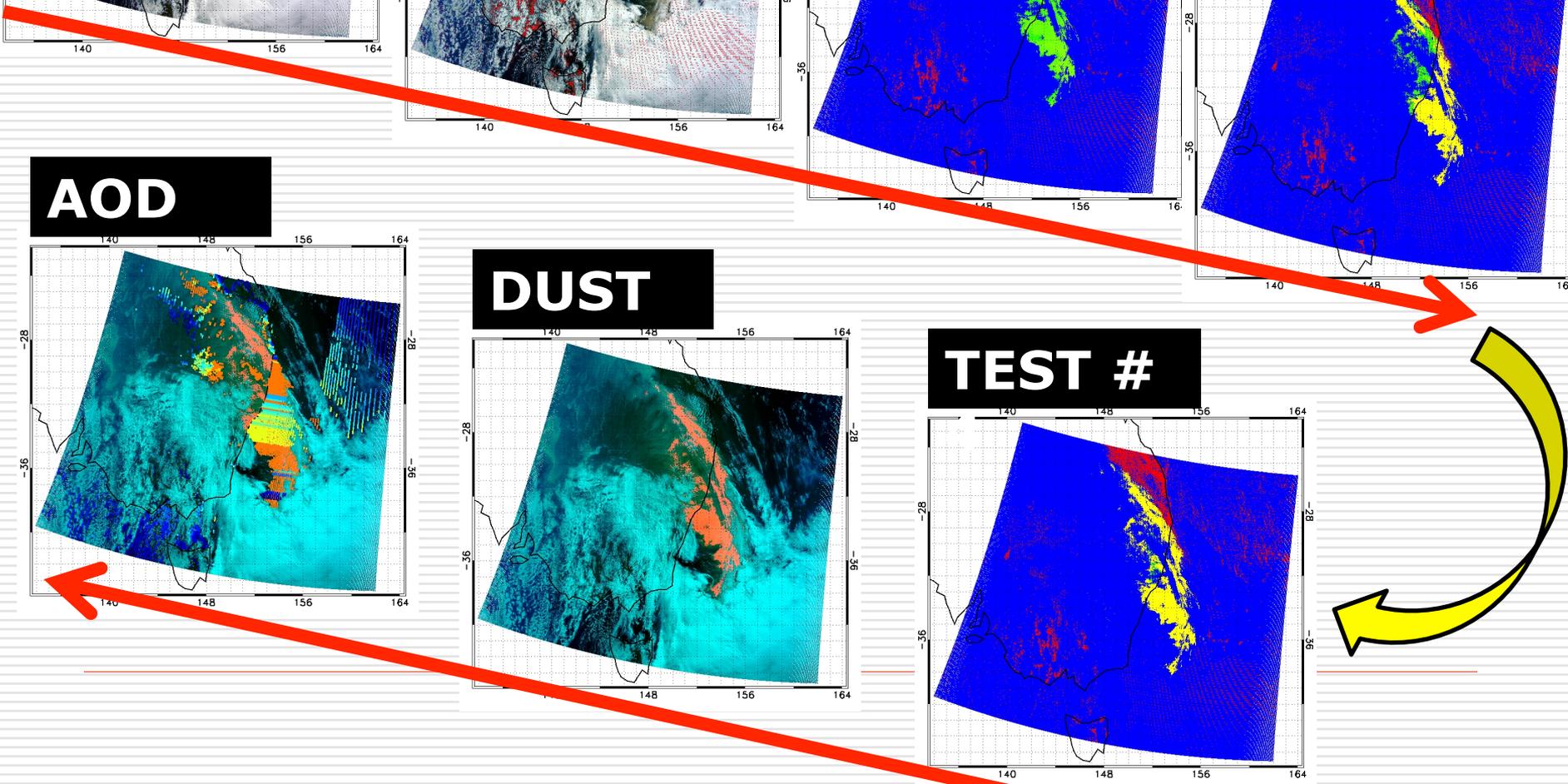
DUST



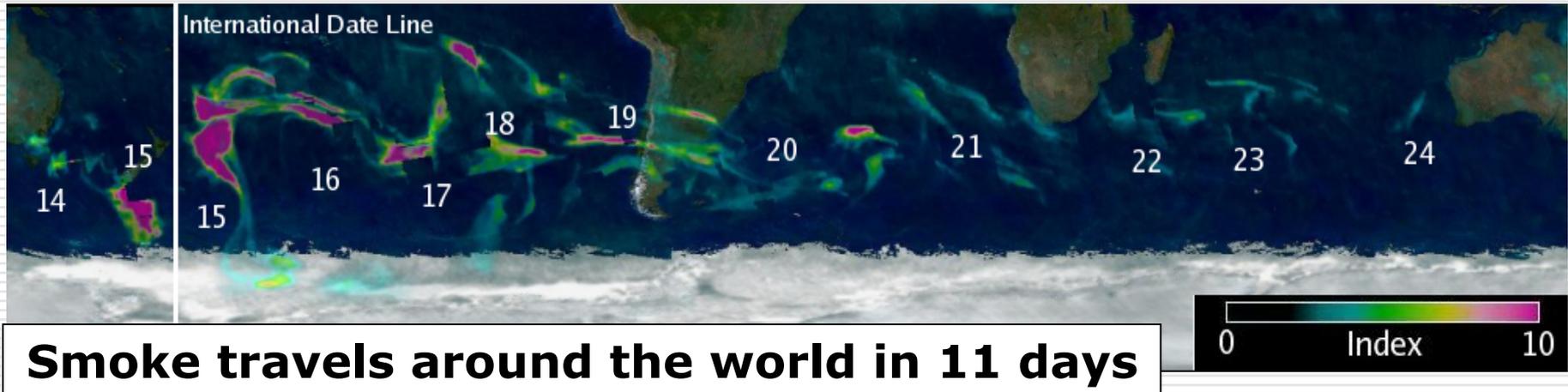
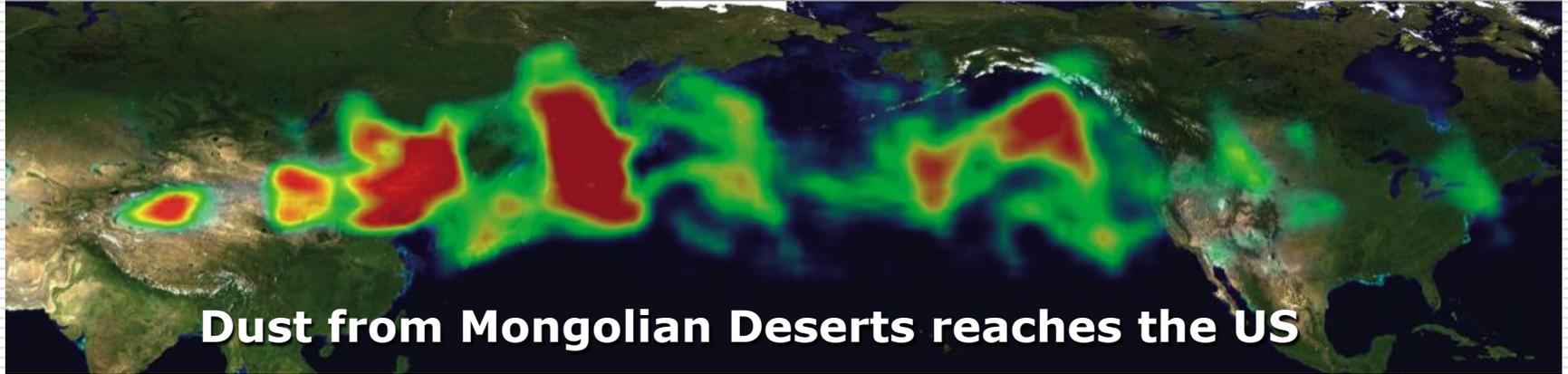
TEST #



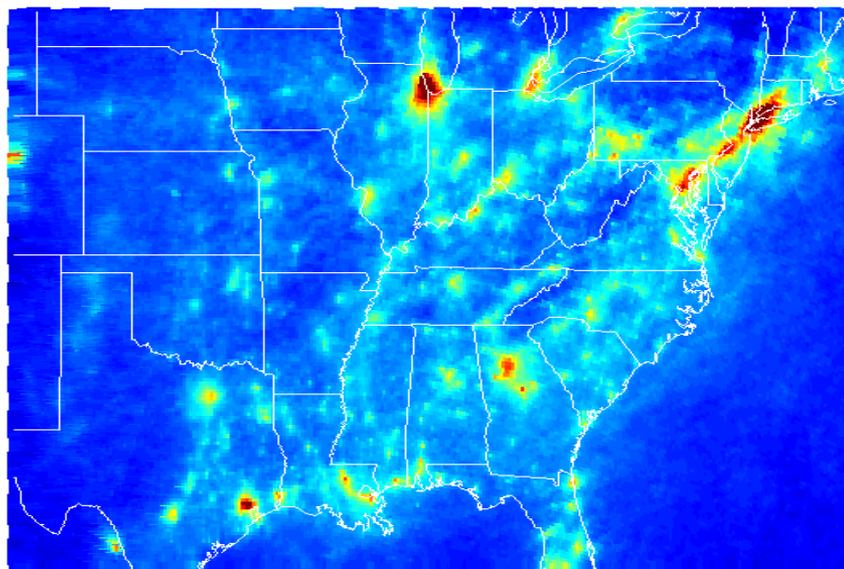
Dust & Smoke Monitoring



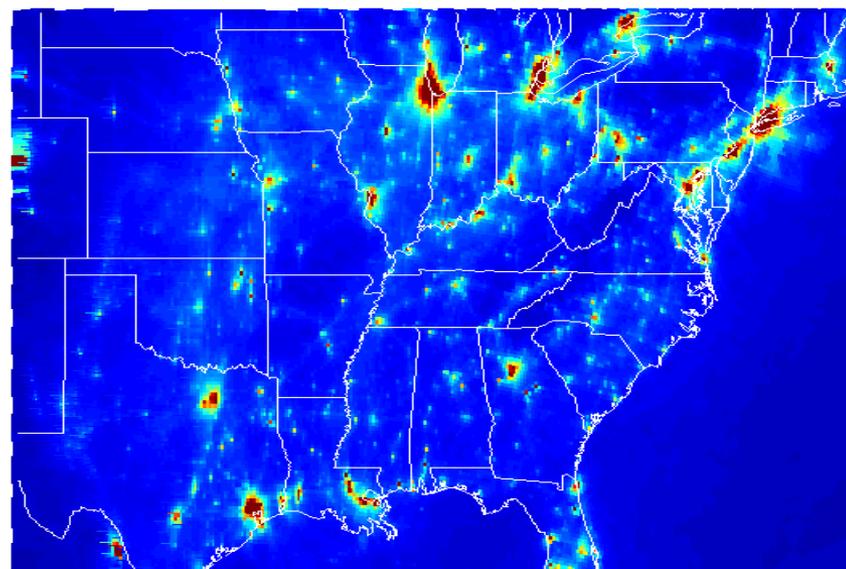
Long Range Transport



Model-Satellite Inter-comparison

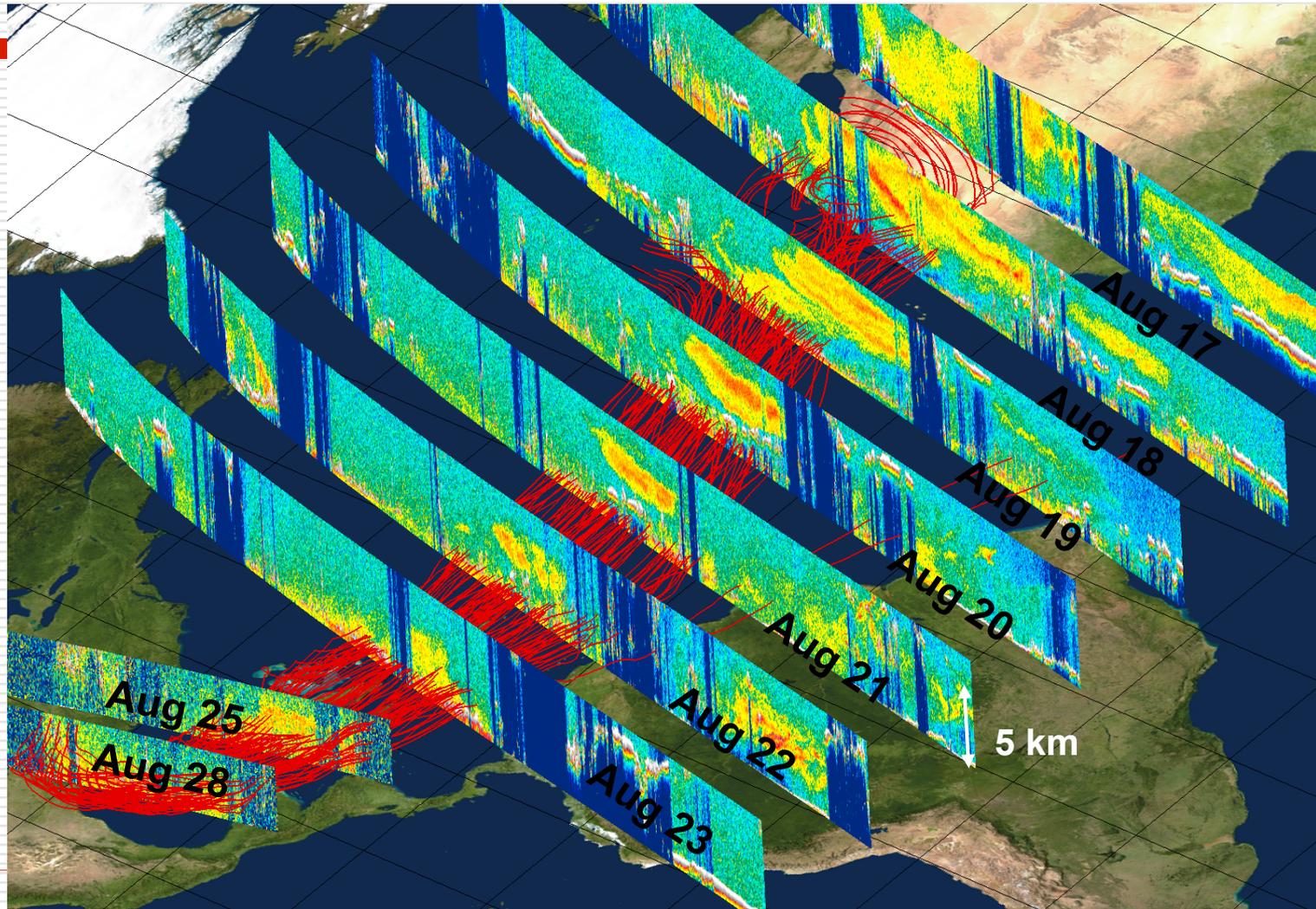


CMAQ Model NO₂



OMI NO₂

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



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

Vertical Profiles of Aerosols

CALIPSO

Cloud-Aerosol Lidar and Infrared
Pathfinder Satellite Observations

Smoke Plume

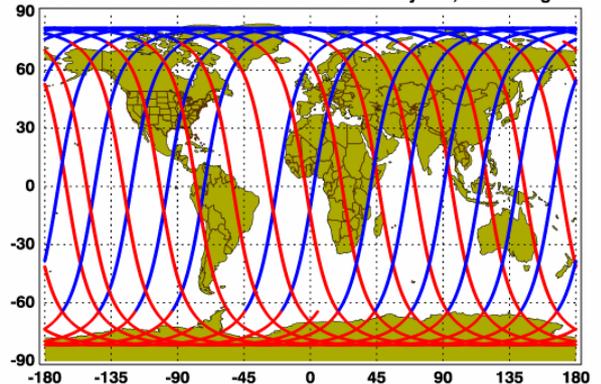
5 km

CALIPSO

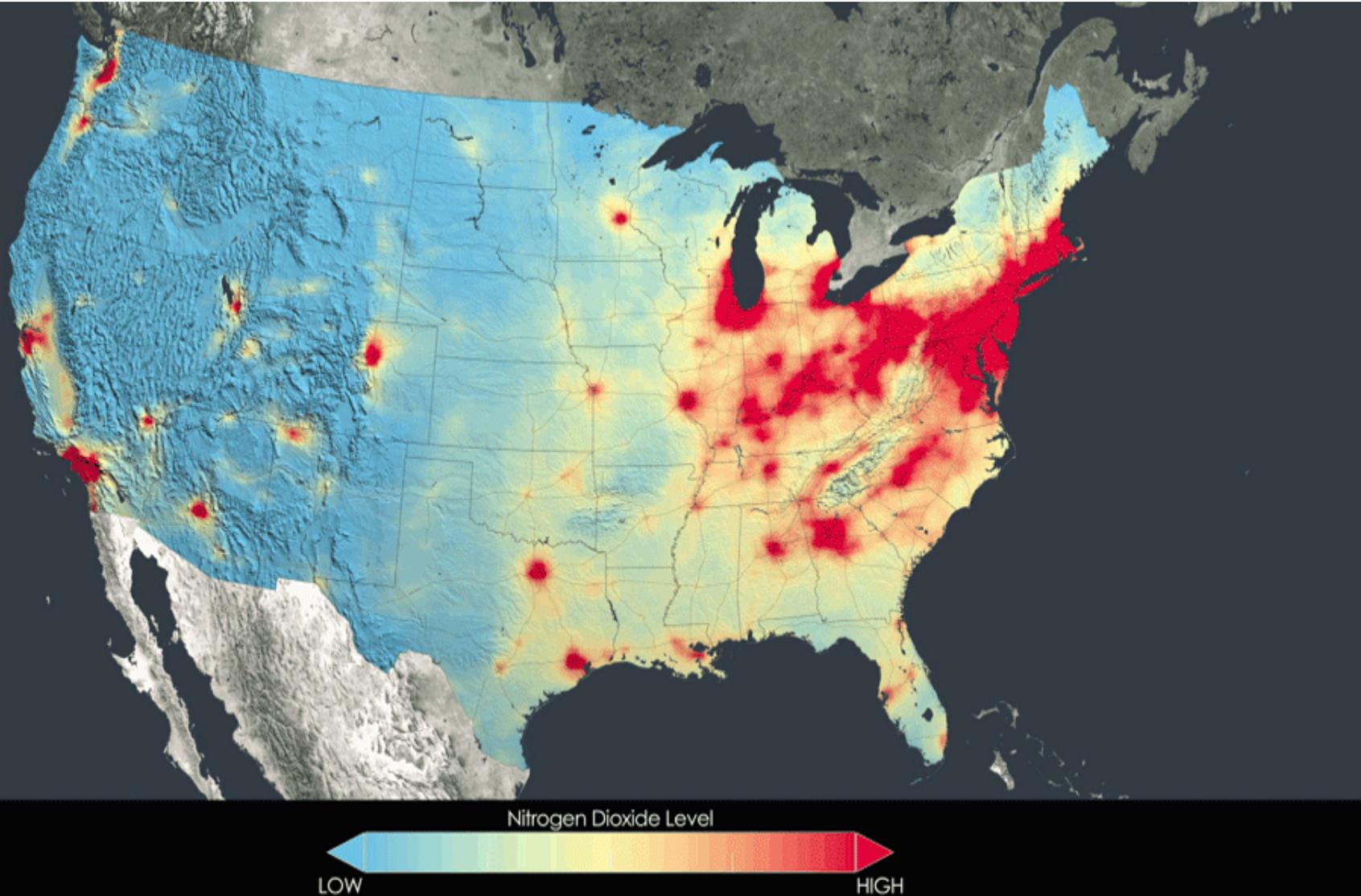
Wallow Fire
(Near Springerville, Arizona)

MODIS
9 hours

2013-01-18 Version: 3.02 Nominal Red is Daytime, Blue is Nighttime

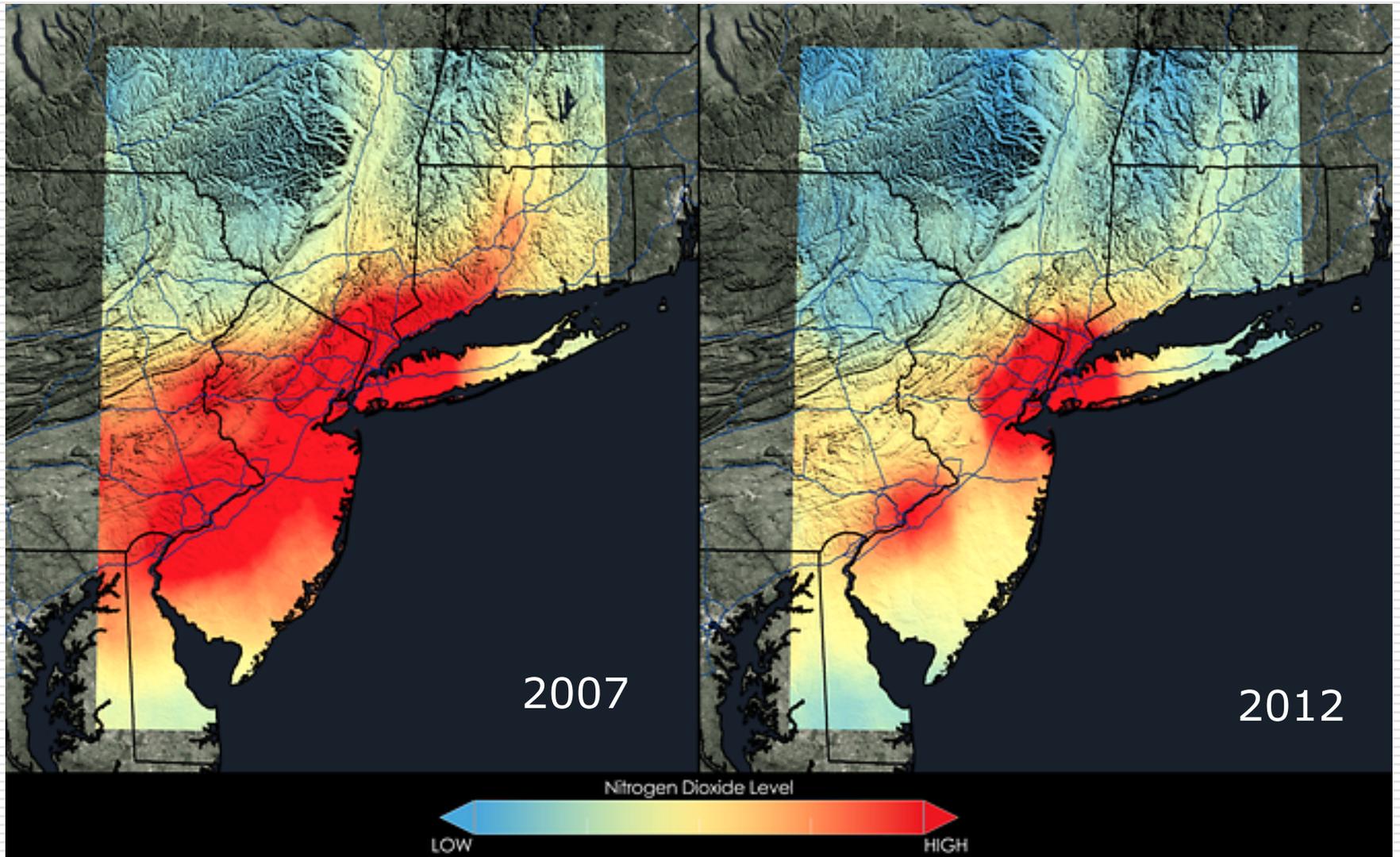


NO2 Trends over United States

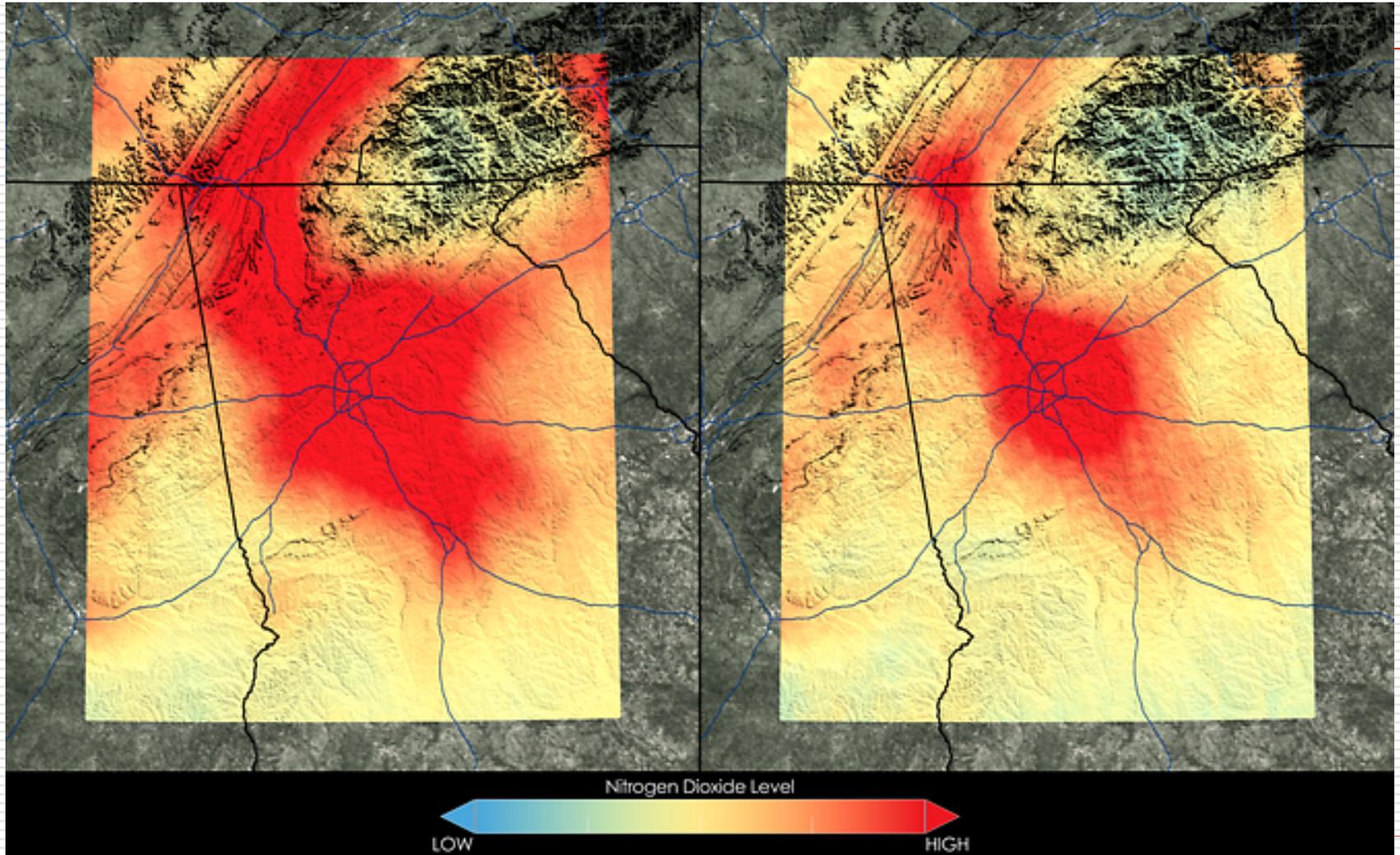


http://www.nasa.gov/content/goddard/new-nasa-images-highlight-us-air-quality-improvement/#.VBmon_IdWS0

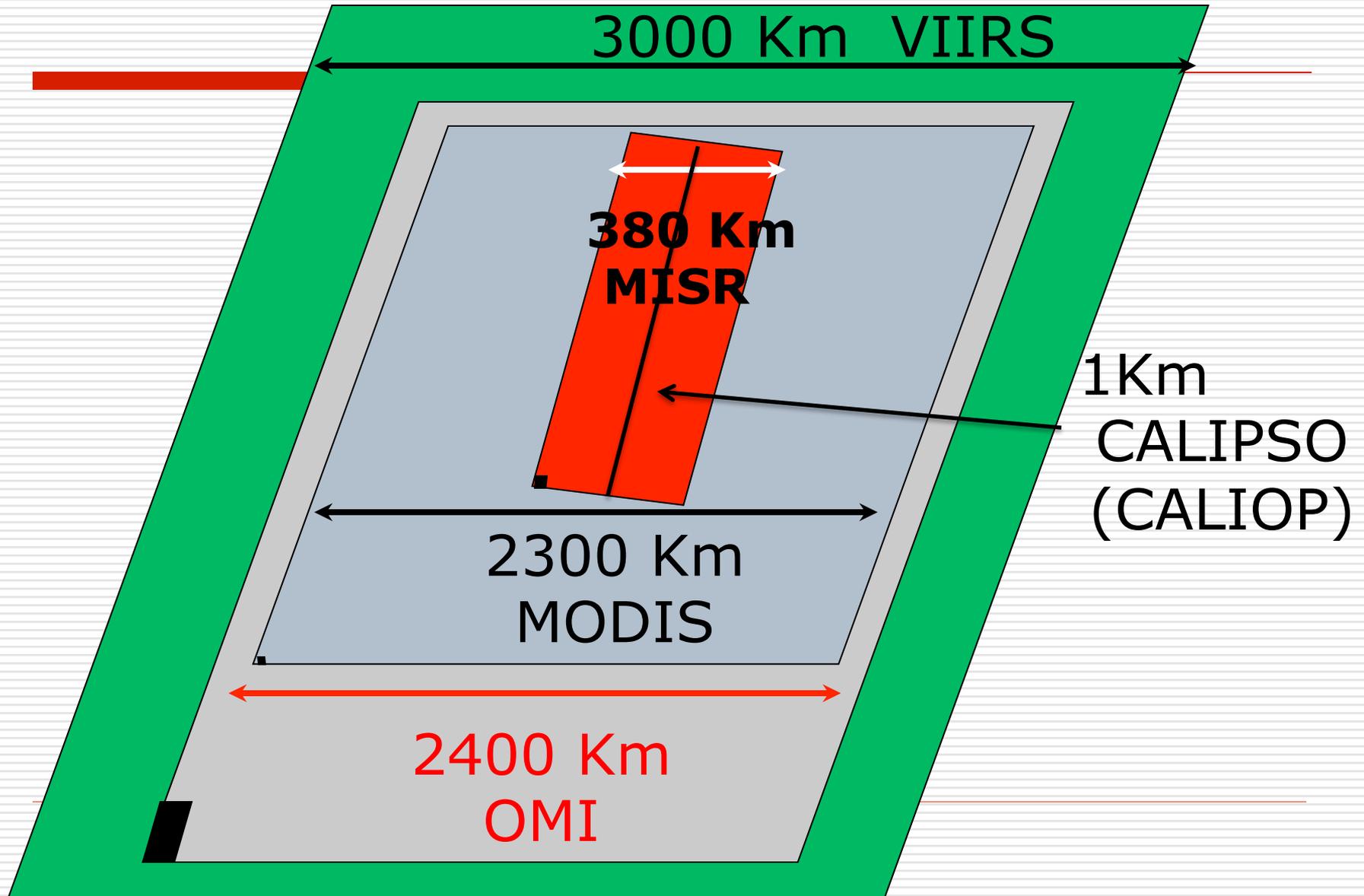
NO2 Trends over New York City



NO2 Trends over Atlanta



Principal Satellites for Air Quality Remote Sensing



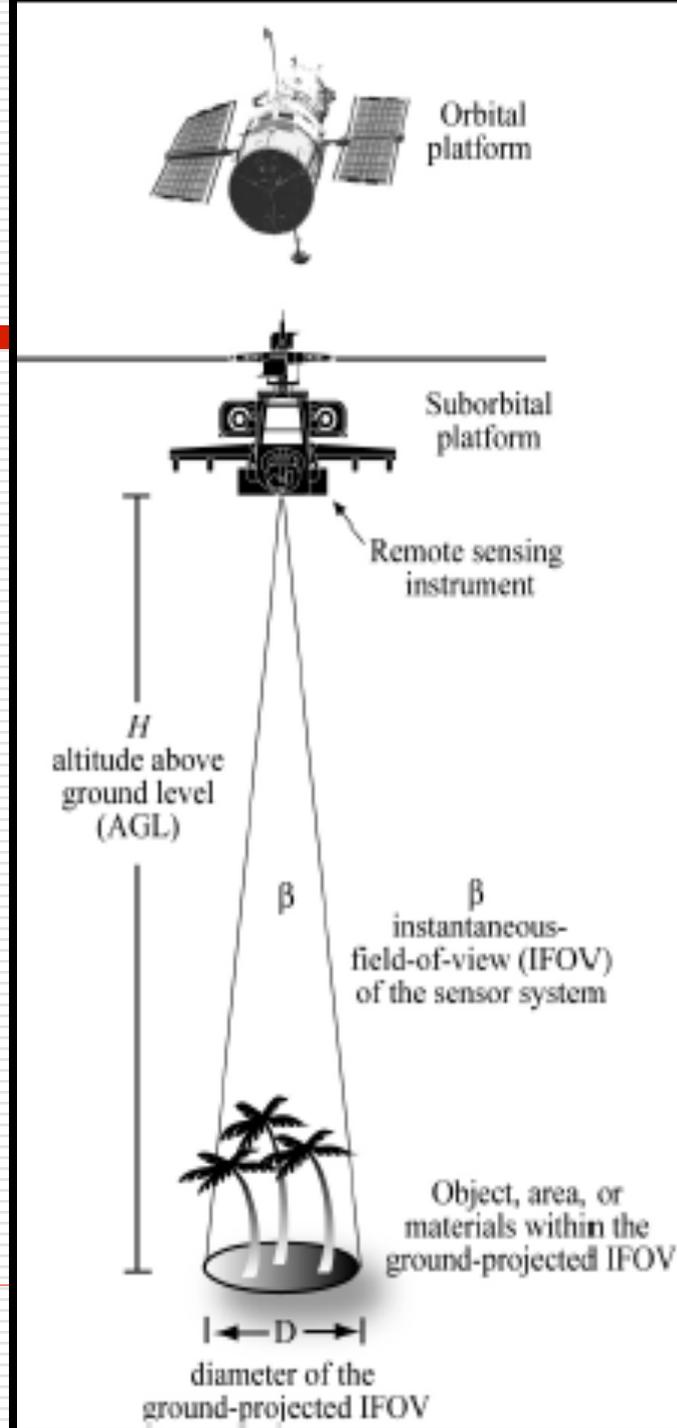
Some Remote Sensing Concepts

Remote Sensing

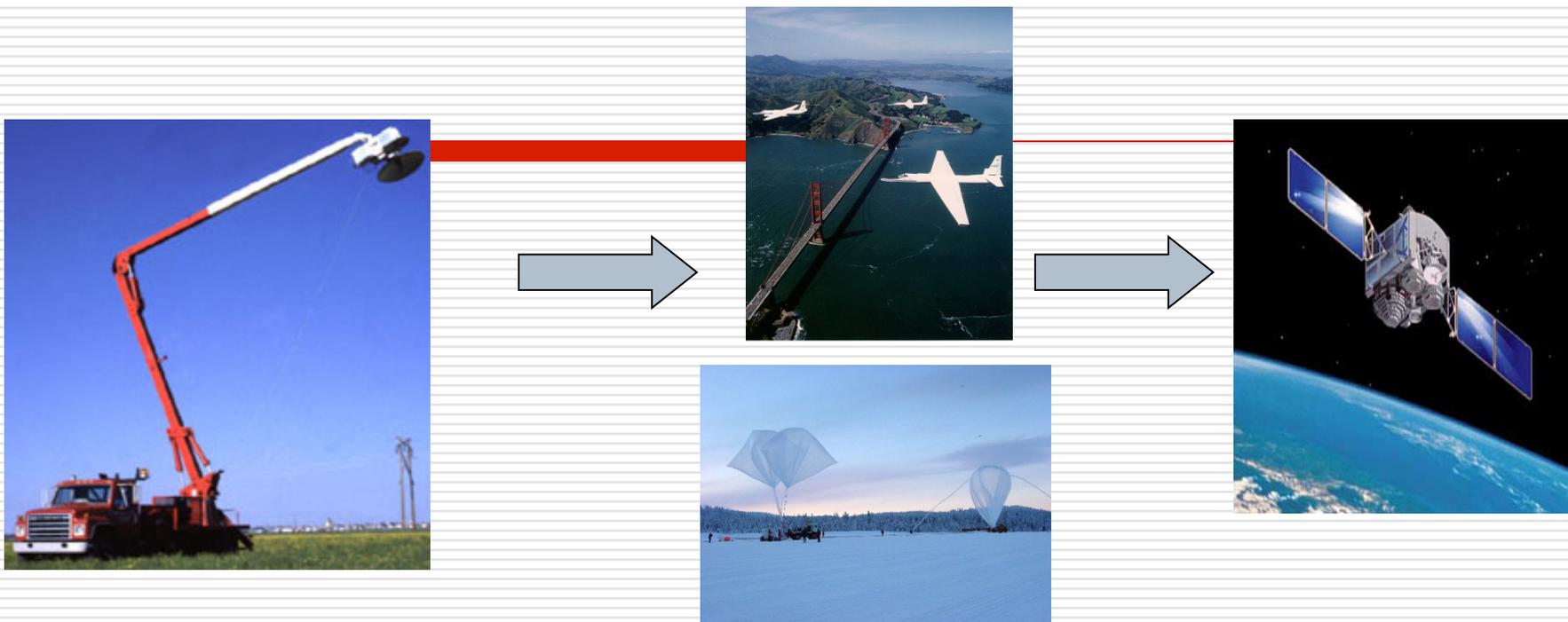
Collecting information about an object without being in direct physical contact with it.



Remote Sensing ...



Remote Sensing: Platforms



• **Platform depends on the application**

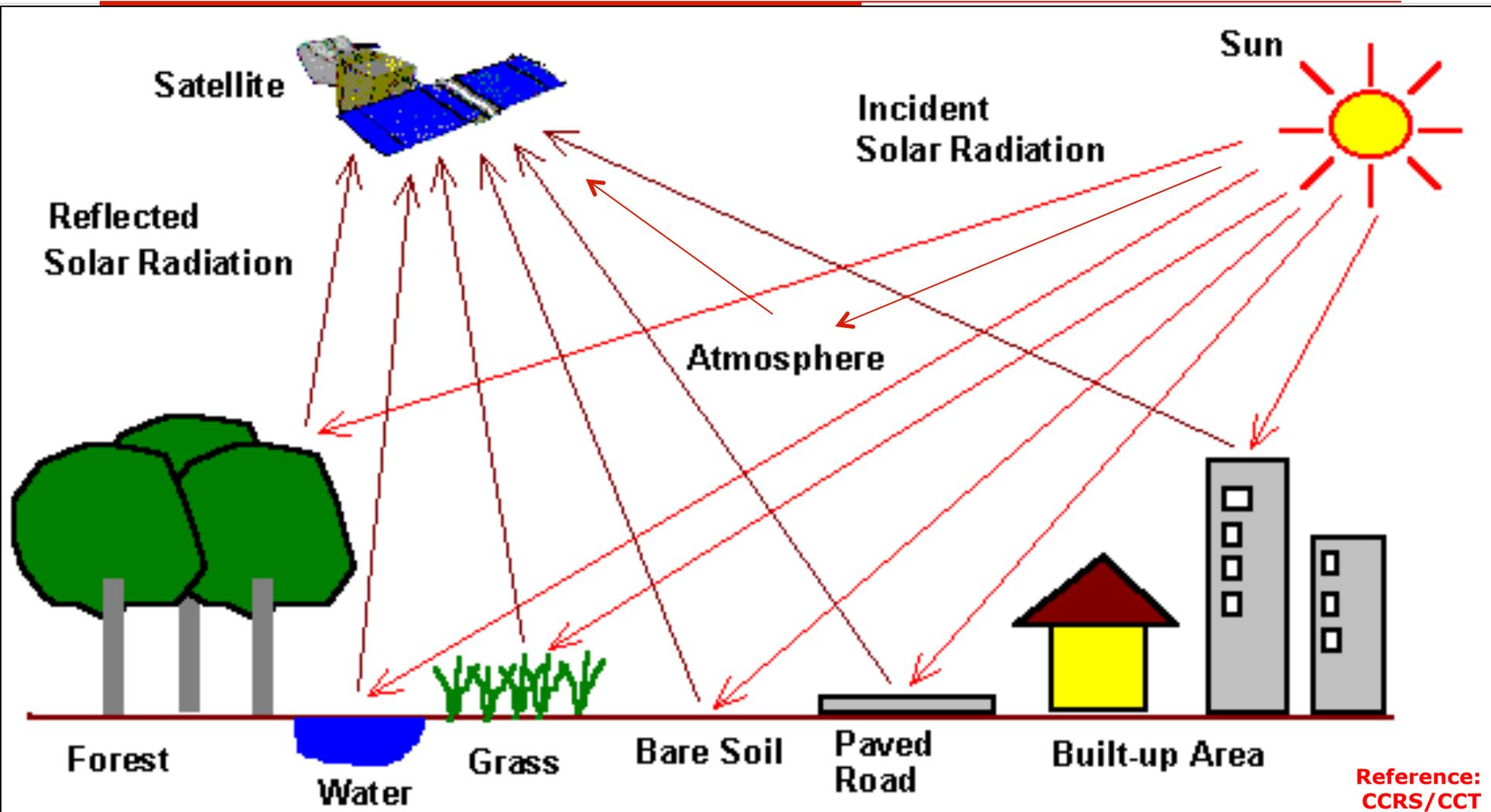
• **What information do we want?**

• **How much detail?**

• **What type of detail?**

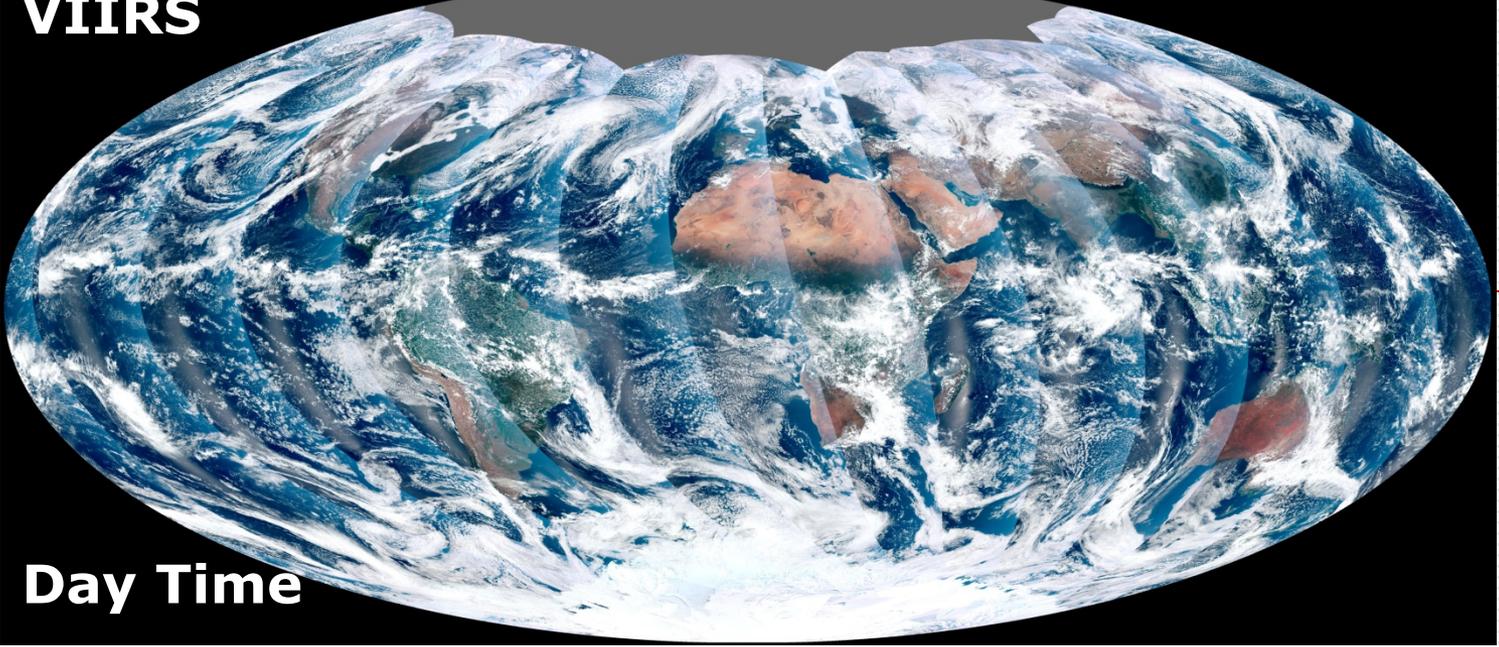
• **How frequent?**

What does a satellite measure?

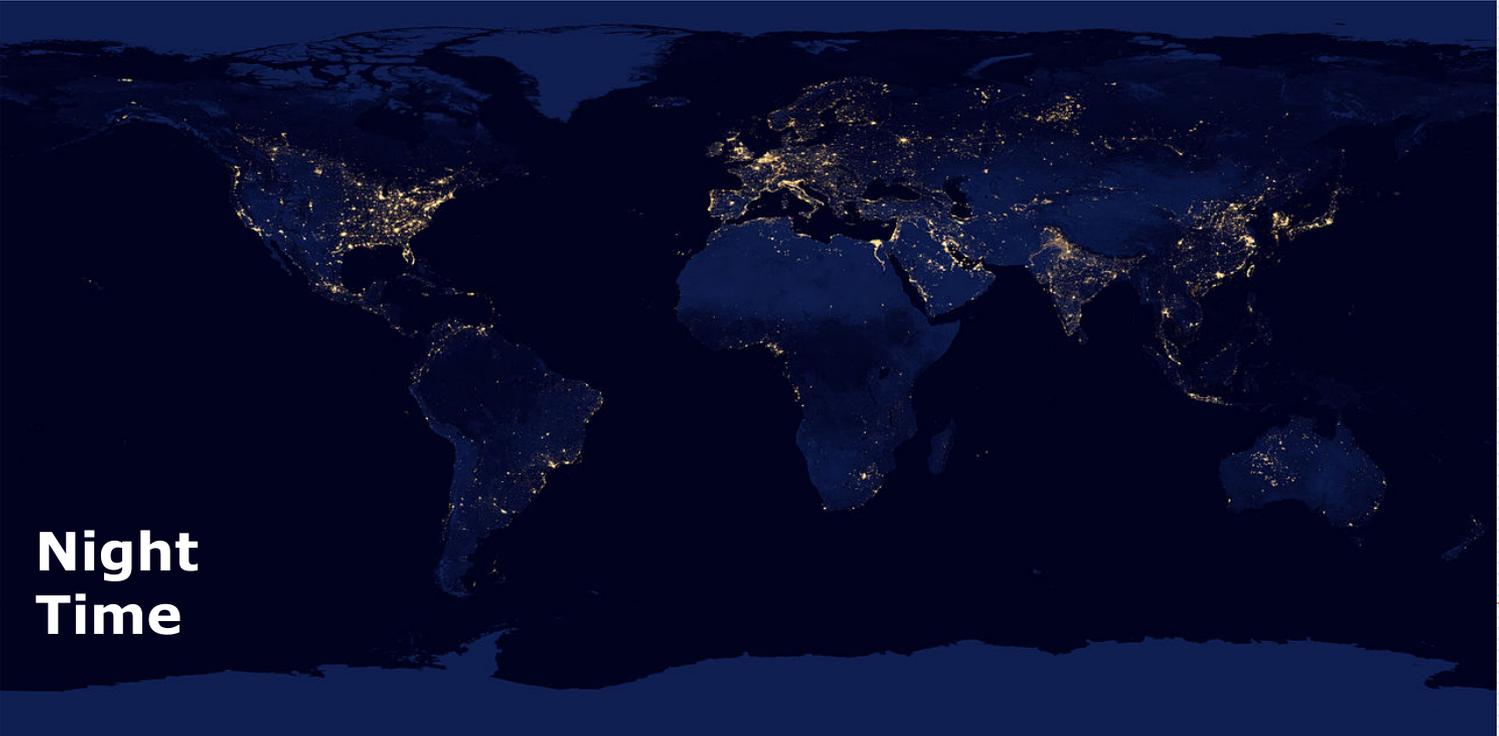


**What you get from
satellite ?**

VIIRS

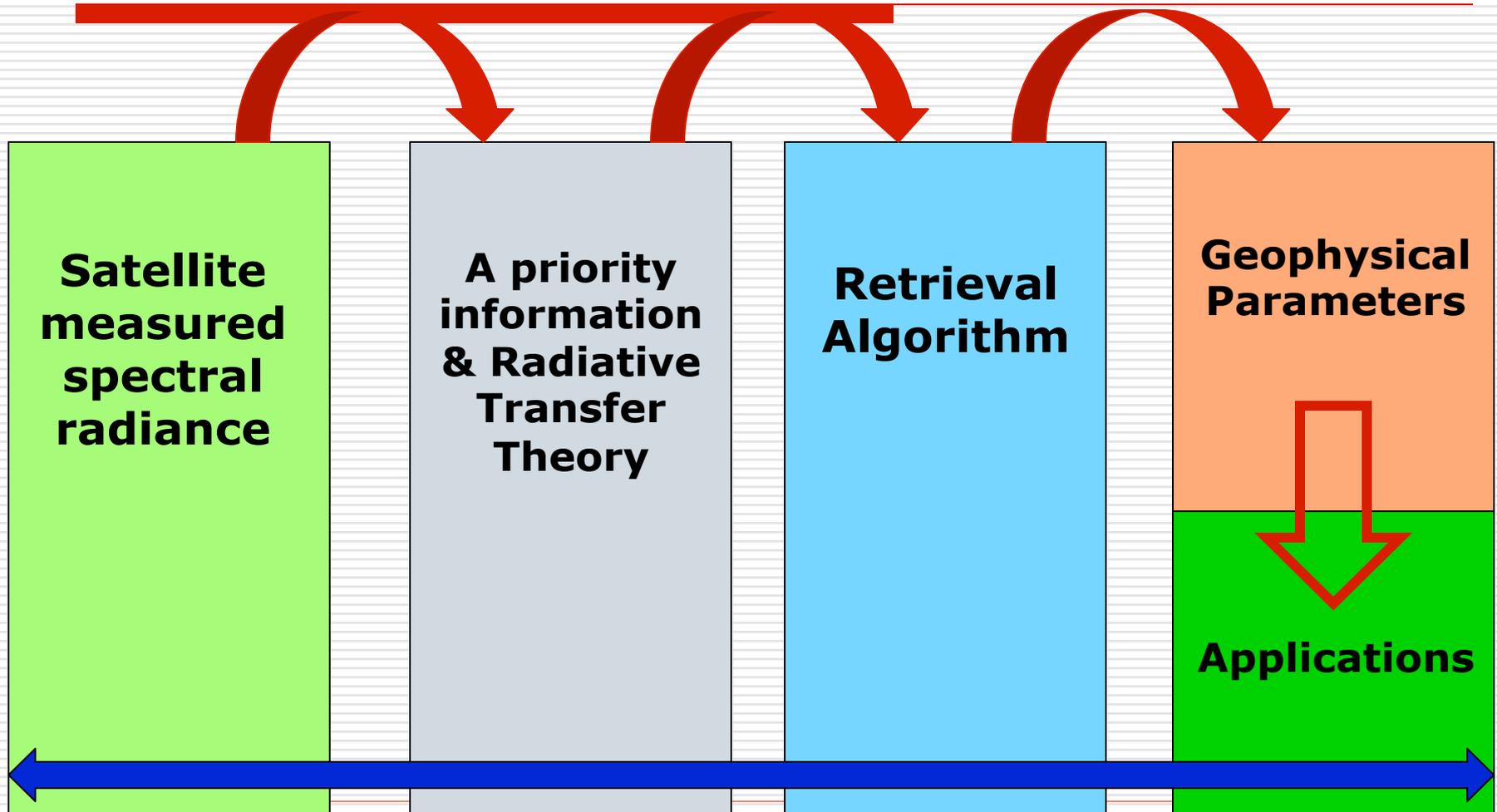


Day Time



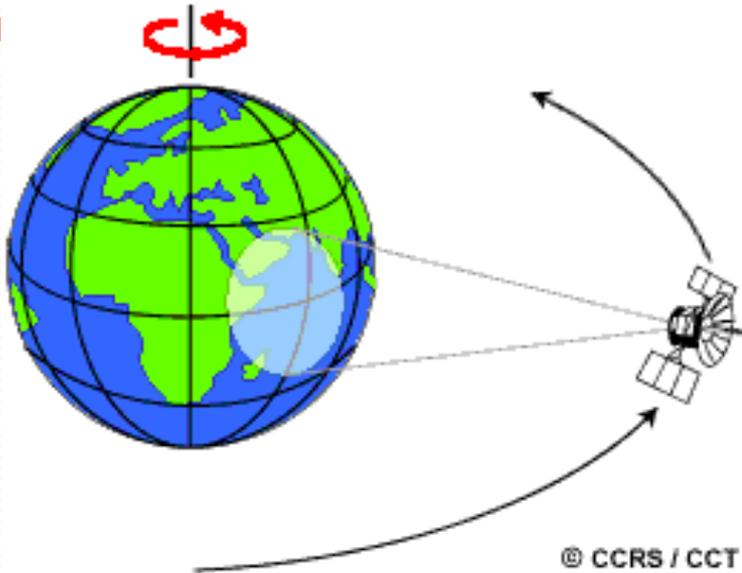
**Night
Time**

Remote Sensing Cont...



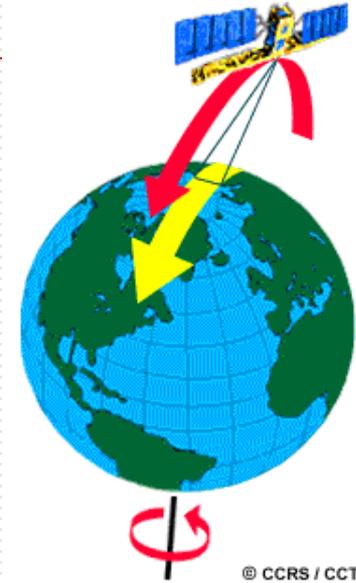
Common types of orbits

Geostationary



Geostationary orbit
An orbit that has the same
Earth's rotational period
Appears 'fixed' above earth
Satellite on equator at
~36,000km

Polar



Polar orbiting orbit
fixed circular orbit
above the earth,
~600-1000km in sun
synchronous orbit with
orbital pass at about
same **local solar time**
each day

Remote Sensing – Resolutions

- **Spatial resolution**

The smallest spatial measurement.

- **Temporal resolution**

Frequency of the measurement.

- **Spectral resolution**

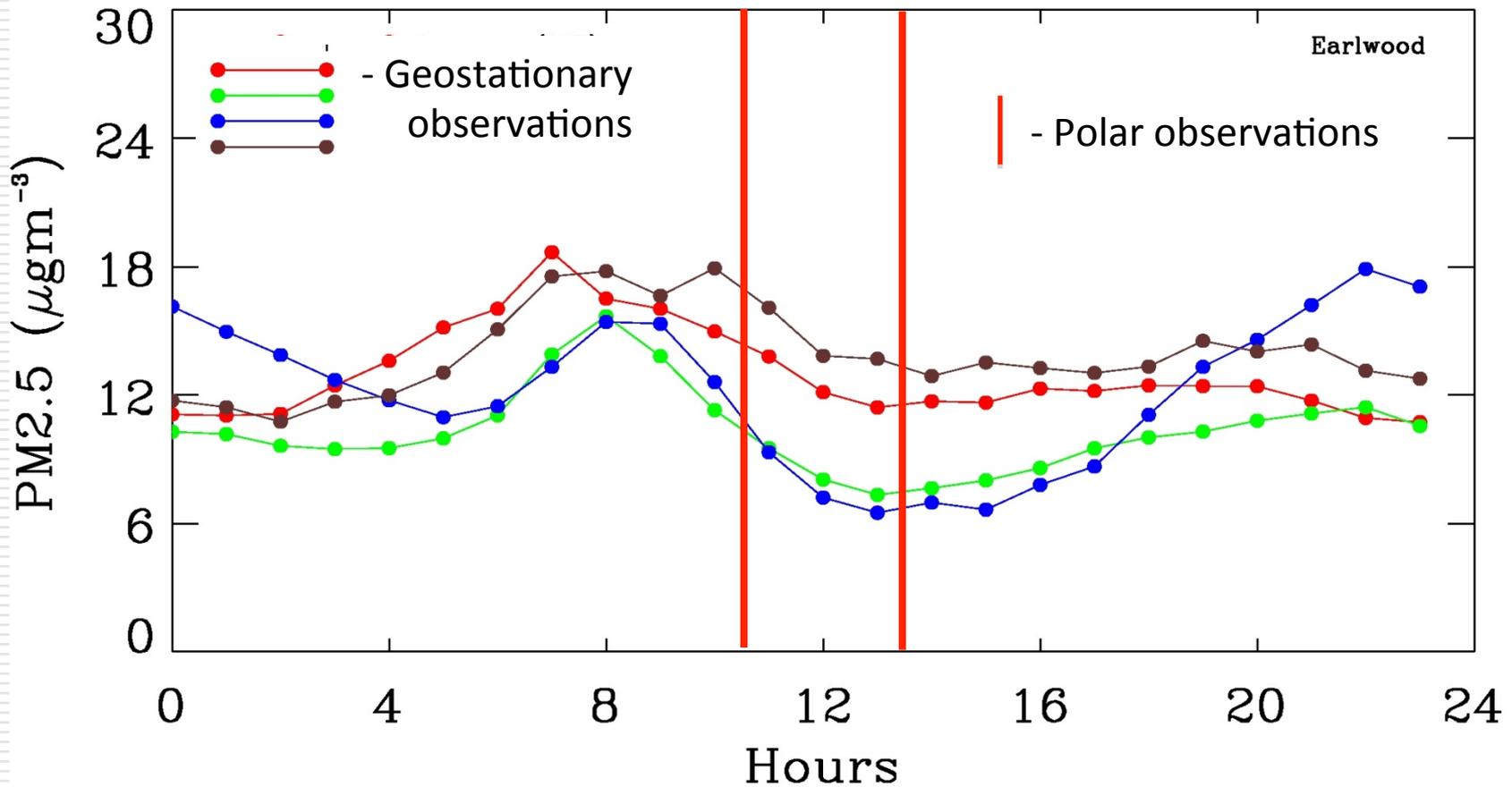
The number of independent channels.

- **Radiometric resolution**

The sensitivity of the detectors.

Temporal Resolution

Polar orbiting satellites – 1 - 2 observations per day per sensor



Geostationary satellites – Future satellites - TEMPO, GEMS, Sentinel-4

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

Why is spatial resolution important?



a. 0.5 x 0.5 m.



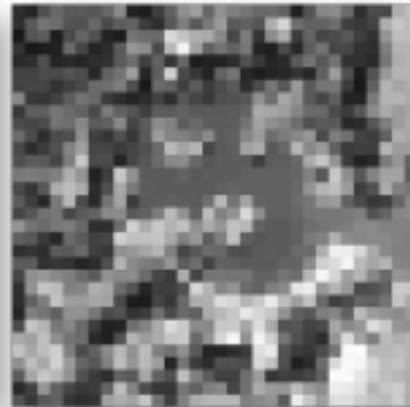
b. 1 x 1 m.



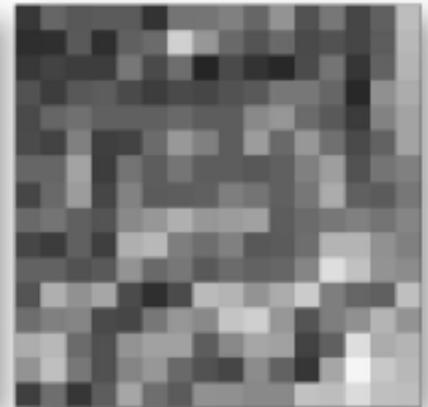
c. 2.5 x 2.5 m.



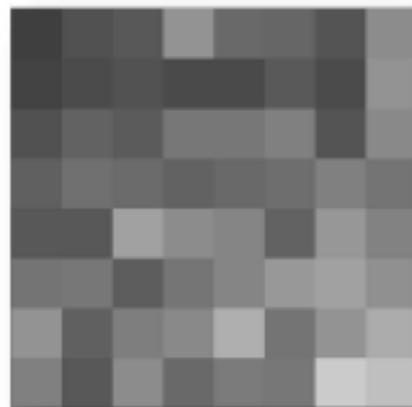
d. 5 x 5 m.



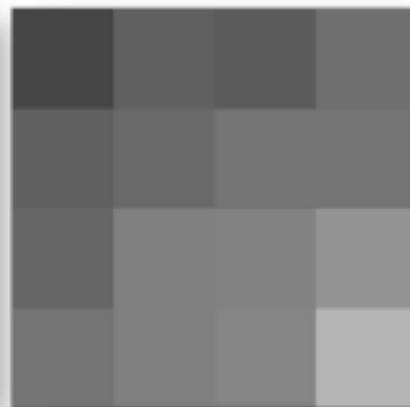
e. 10 x 10 m.



f. 20 x 20 m.

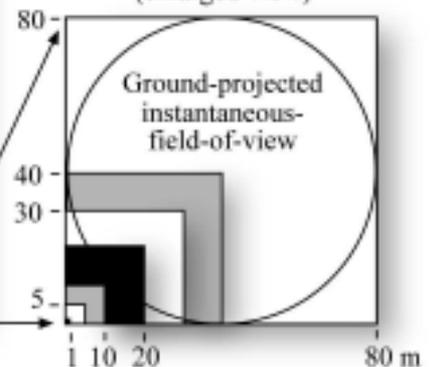


g. 40 x 40 m.



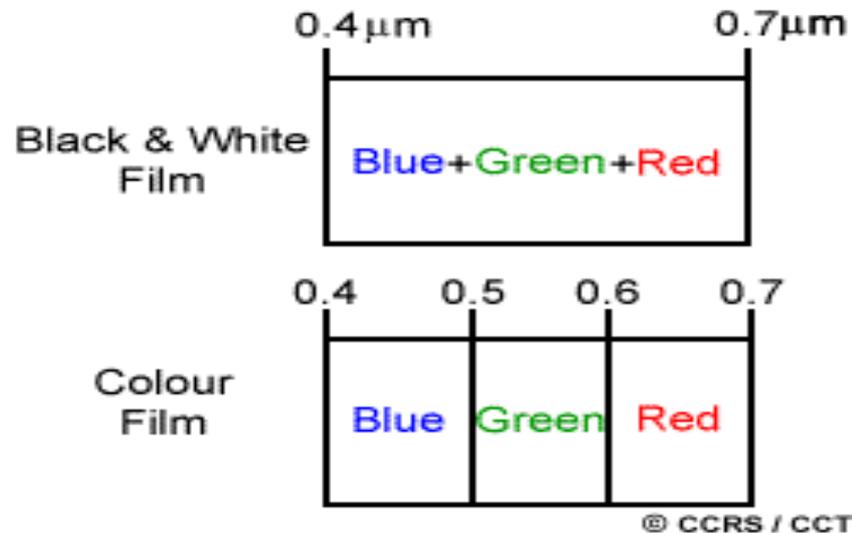
h. 80 x 80 m.

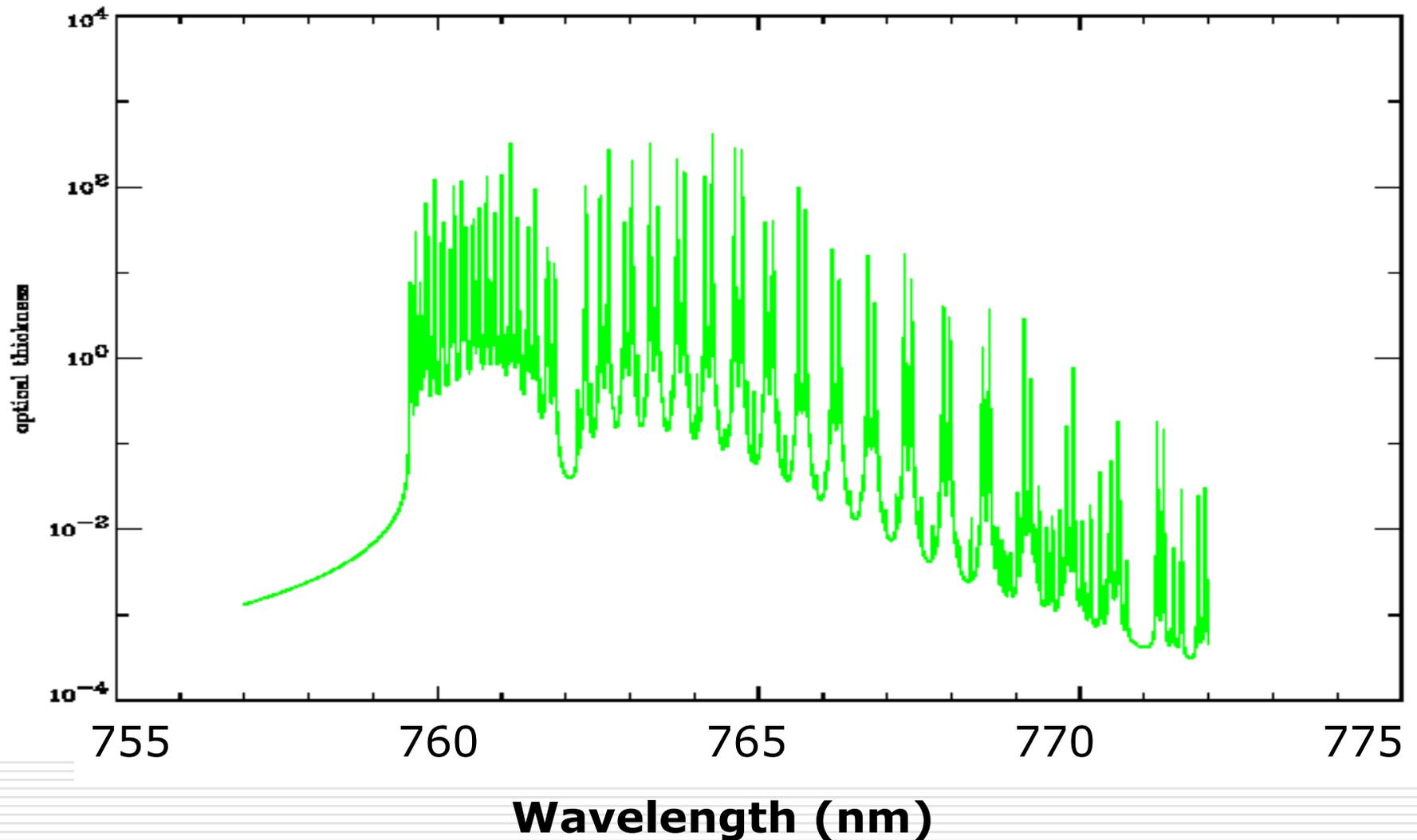
Nominal Spatial Resolution
(enlarged view)



Spectral Resolution

- Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.
- **multi-spectral sensors - MODIS**
- **hyper spectral sensors - OMI, AIRS**





In order to capture information contained in a narrow spectral region – hyper spectral instruments such as OMI, or AIRS are required

Radiometric Resolution

- Imagery data are represented by positive digital numbers which 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 used in representing the energy recorded.

- 12 bit sensor (MODIS, MISR) – 2^{12} or 4096 levels**

- 10 bit sensor (AVHRR) – 2^{10} or 1024 levels**

- 8 bit sensor (Landsat TM) – 2^8 or 256 levels (0-255)**

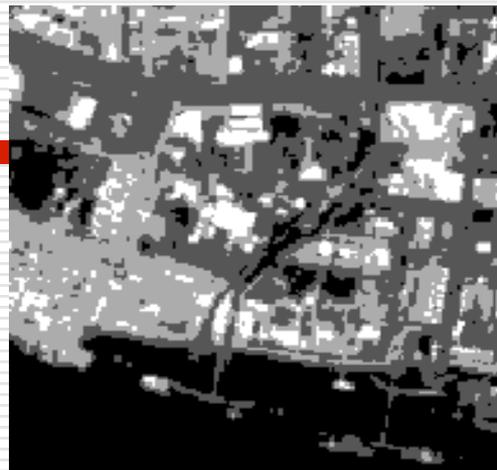
- 6 bit sensor (Landsat MSS) – 2^6 or 64 levels (0-63)**

Radiometric Resolution

2 - levels



4 - levels



8 - levels



16 - levels



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

Data User Guide

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