Overview of Earth Observations : Principles of Satellite Remote Sensing and Applications to Particulate Matter Air Quality

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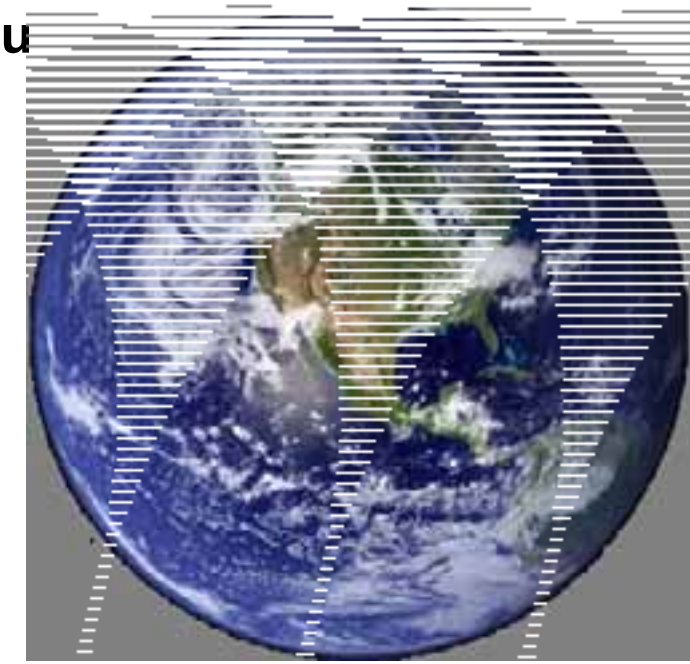
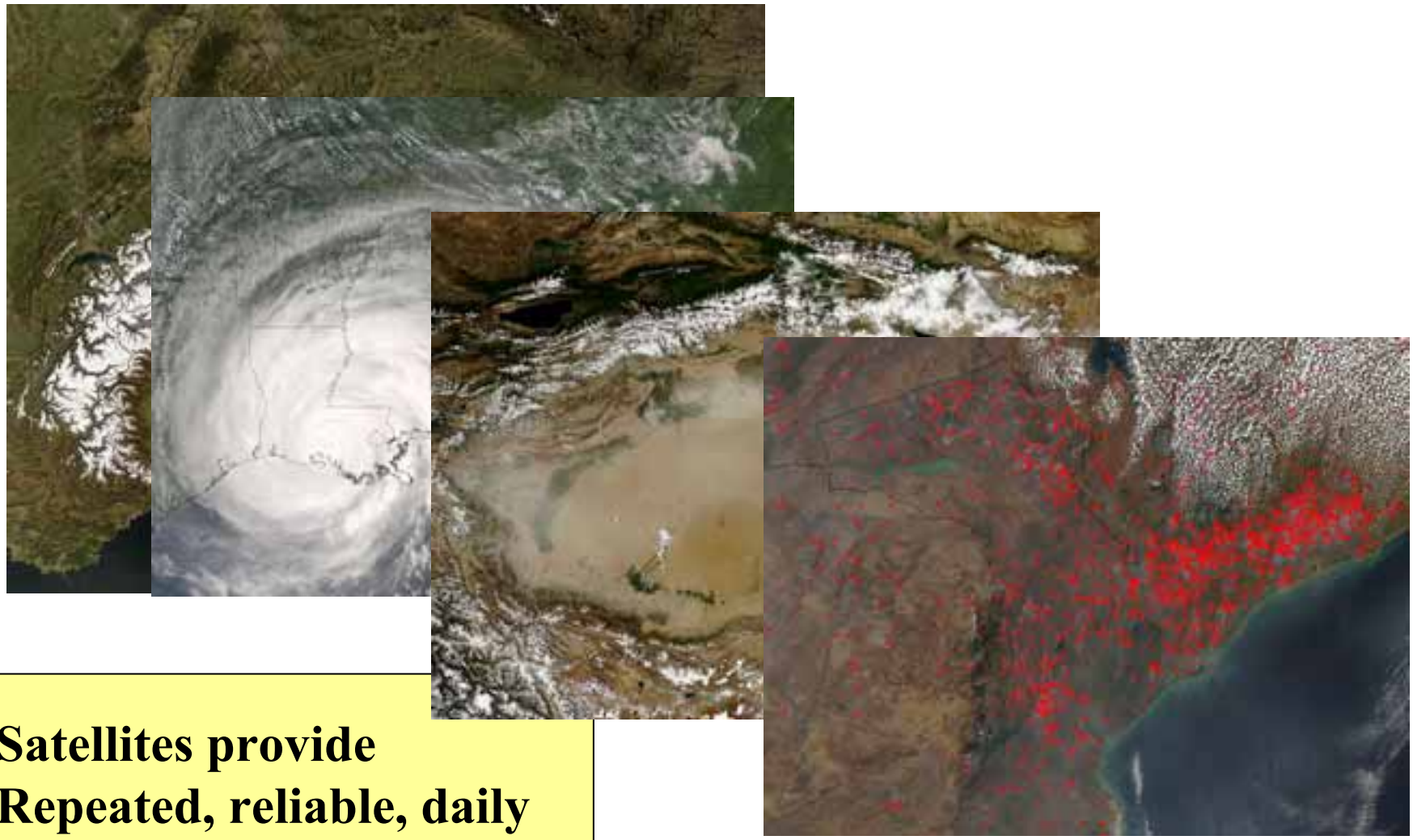


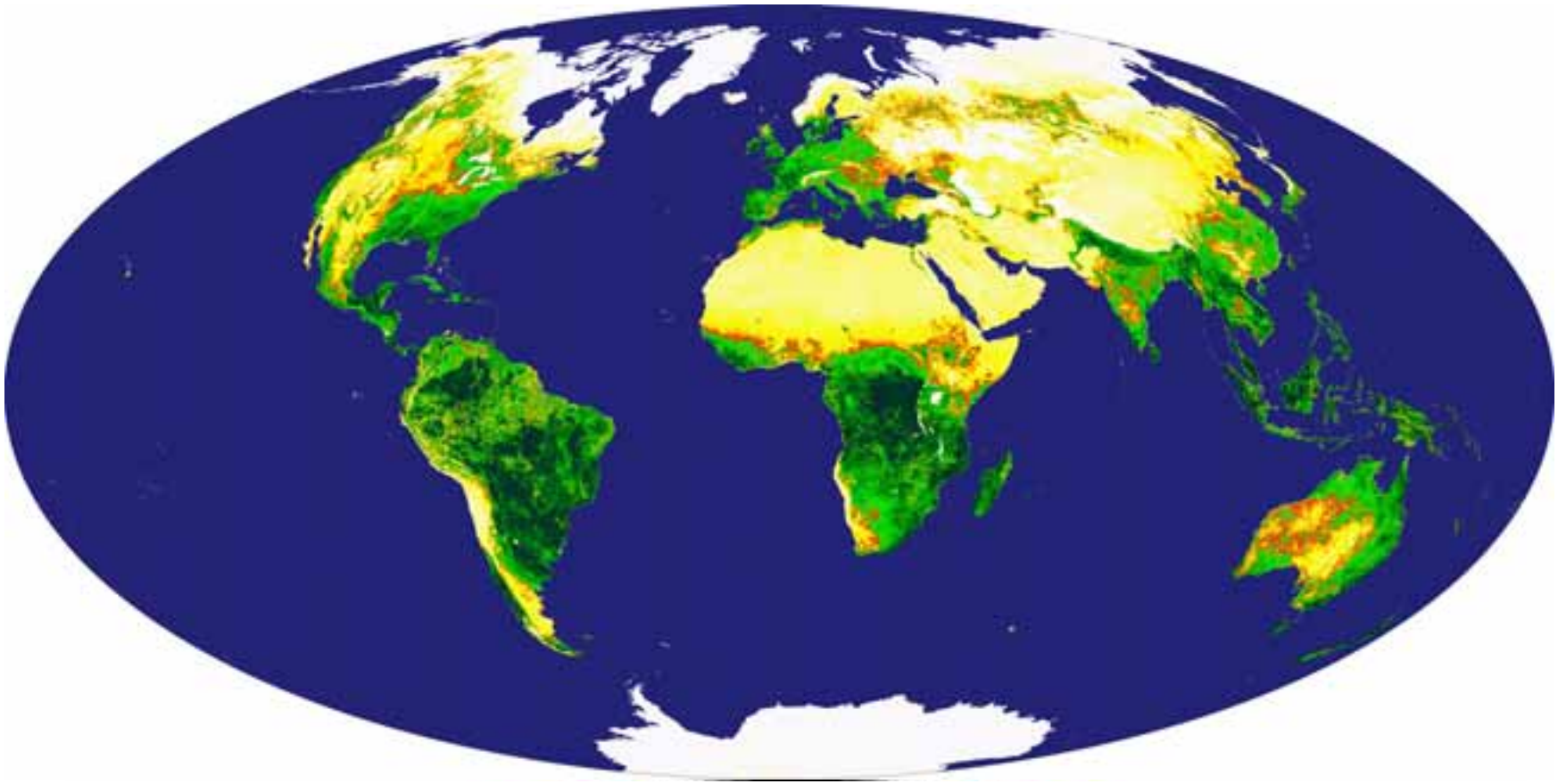
Graz, Austria, September 2008

Examples of Satellite Remote Sensing Imagery



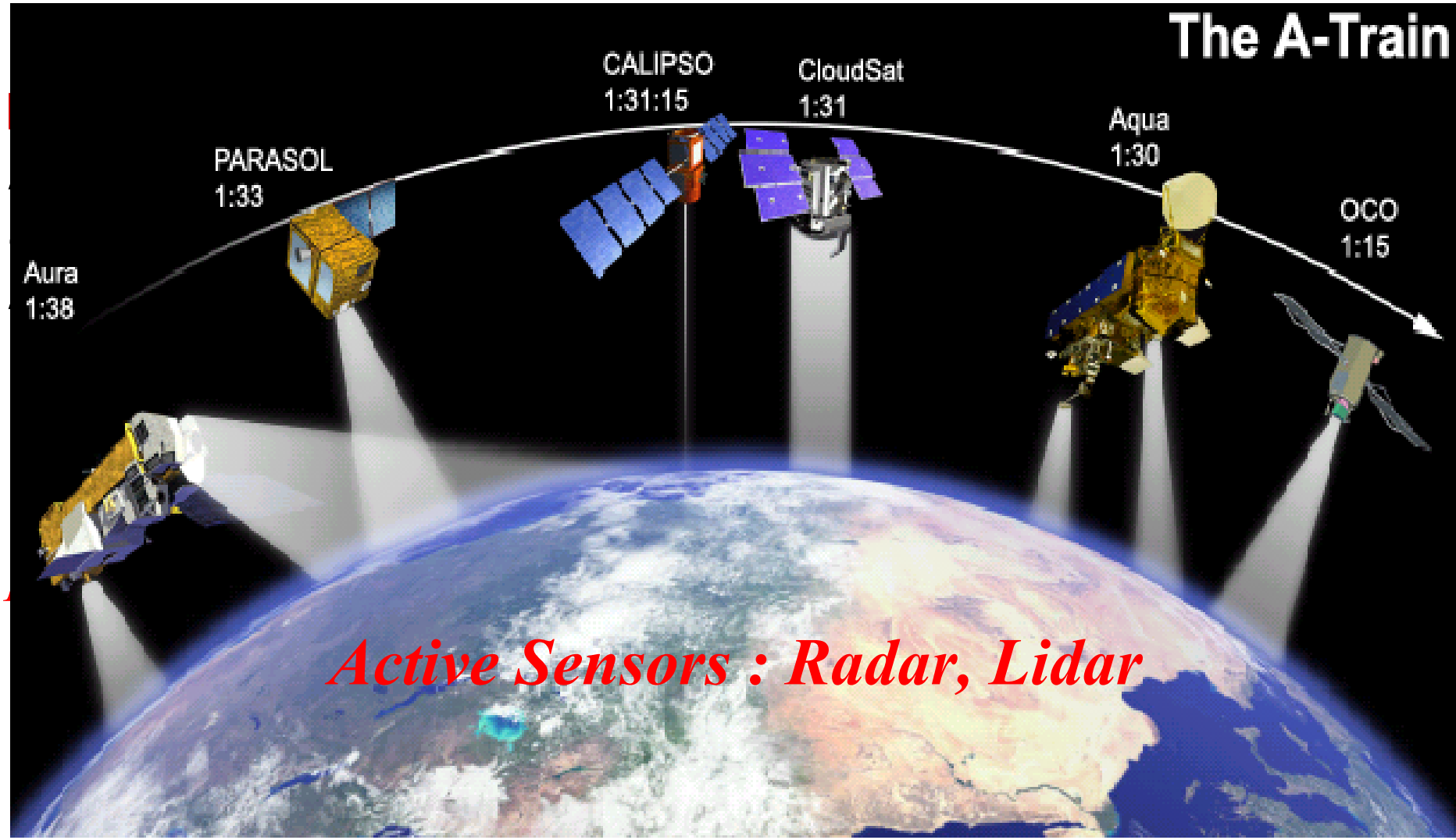
Satellites provide Repeated, reliable, daily global coverage

Global View



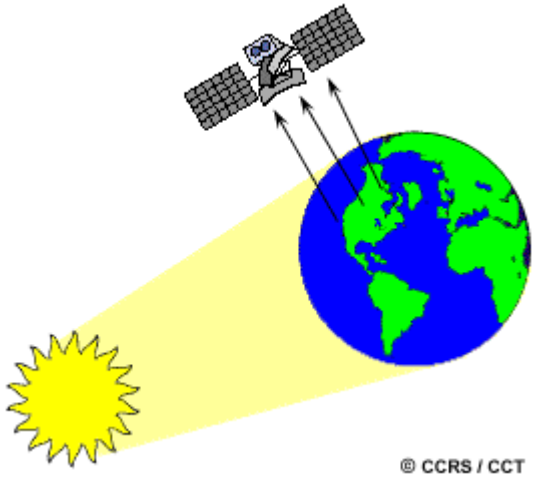
Satellite data used for assessing global weather, climate, environment and for understanding the earth-atmosphere system

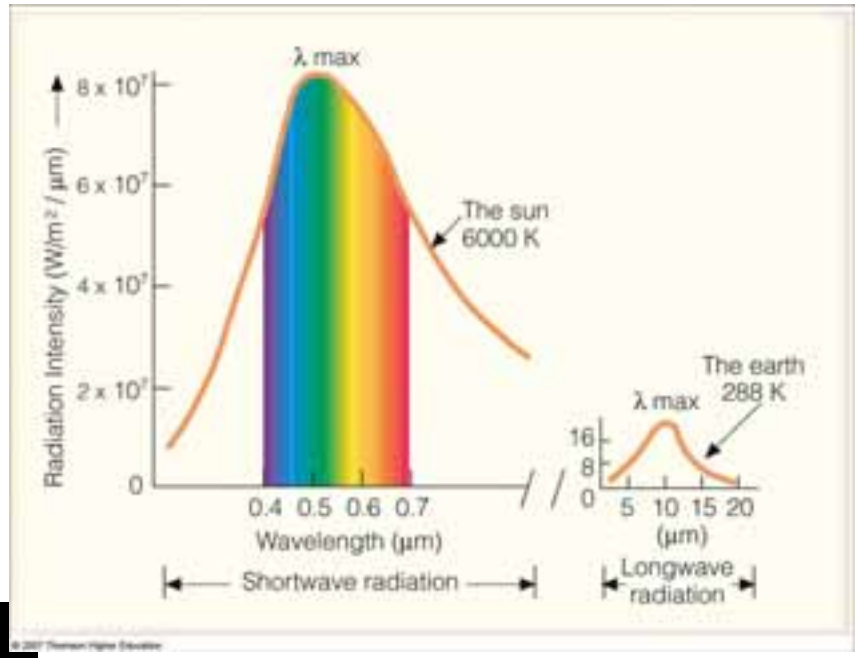
Satellite Remote Sensing – Definition and methods

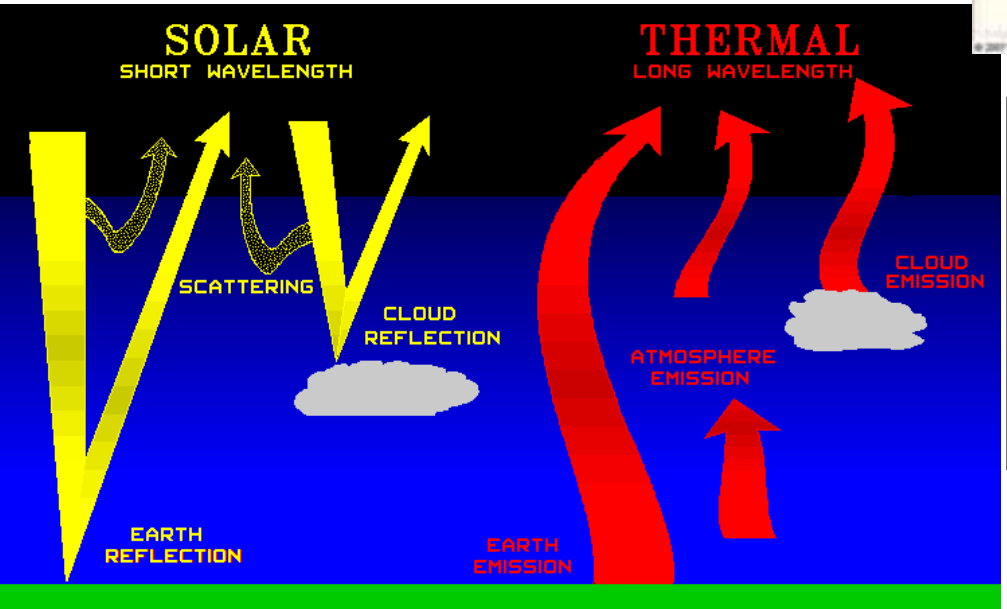


Principles of Remote Sensing

Reflected and Emitted Radiation

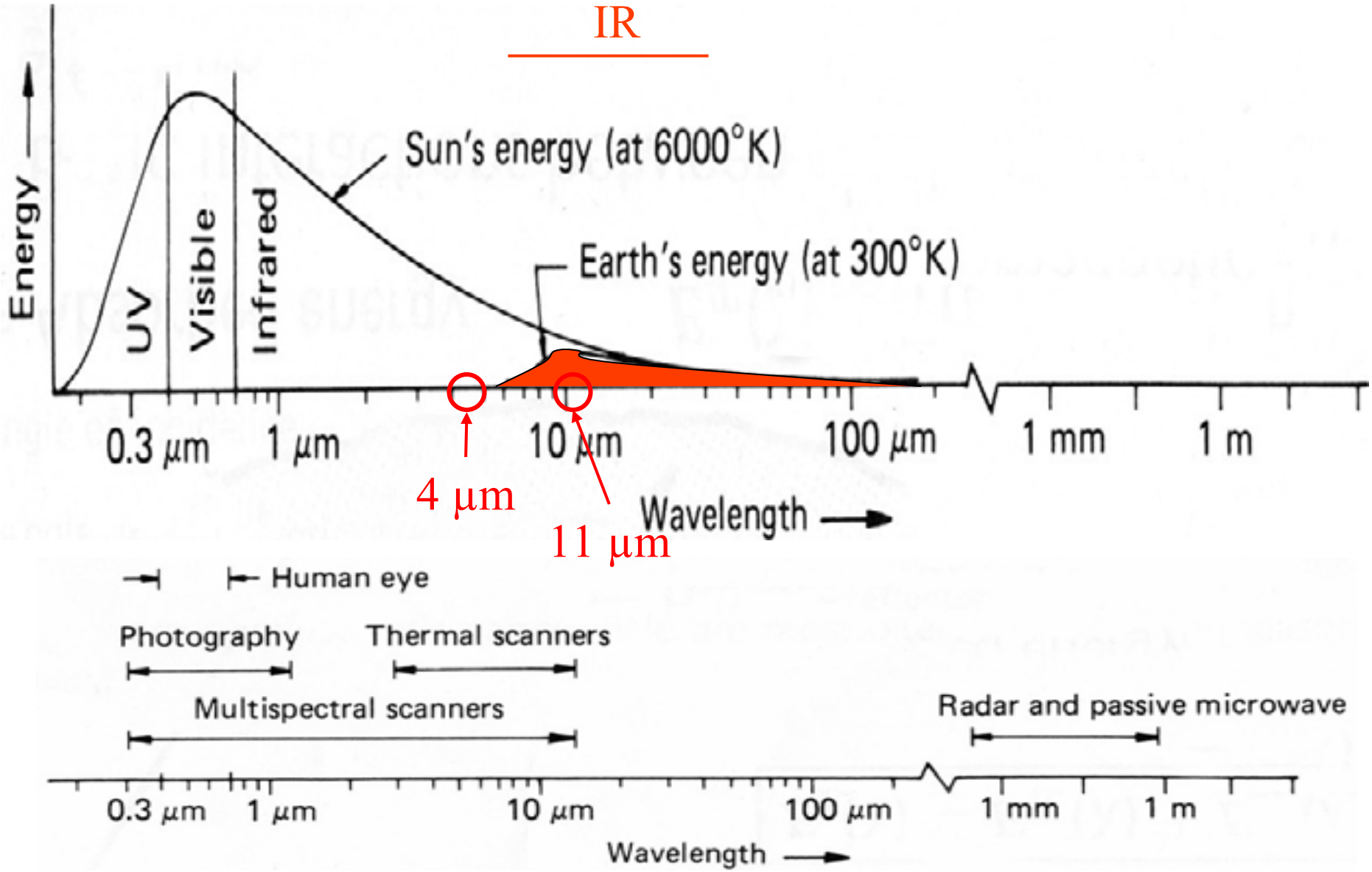






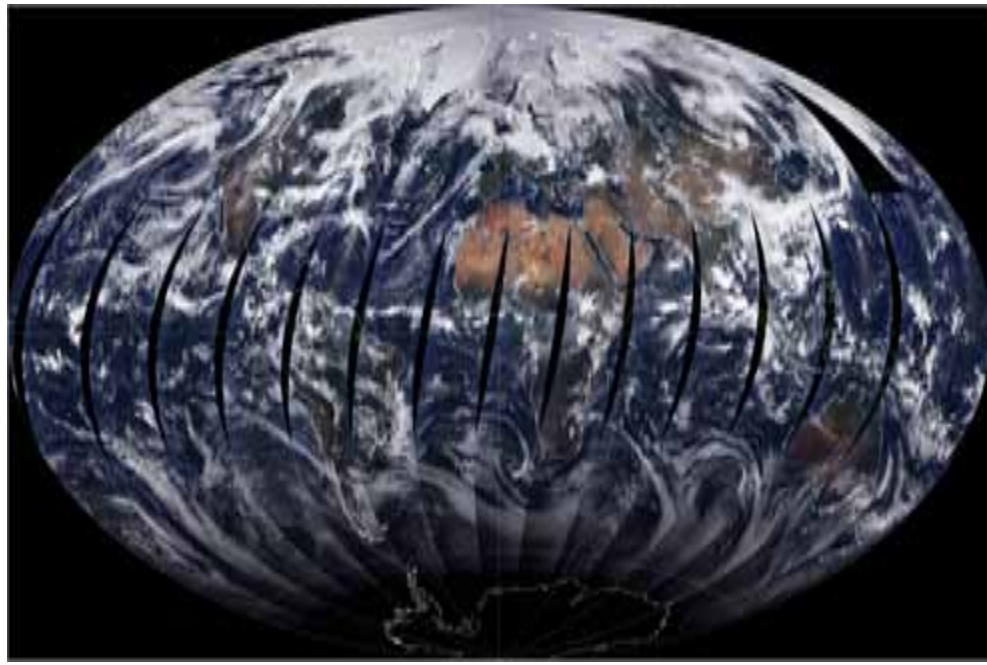
Passive Satellite Remote Sensing Can be broadly classified into Solar Reflected and thermal Emissive components

Spectral Characteristics



MODerate-resolution Imaging Spectroradiometer (MODIS)

- Sensor Characteristics
  - 36 spectral bands ranging from 0.41 to 14.385 μm
  - cross-track scan mirror with 2330 km swath width
  - Spatial resolutions:
    - 250 m (bands 1 - 2)
    - 500 m (bands 3 - 7)
    - 1000 m (bands 8 - 36)
- NASA, Terra & Aqua
  - launched 1999, 2002
  - 705 km polar orbits, descending (10:30 a.m.) & ascending (1:30 p.m.)



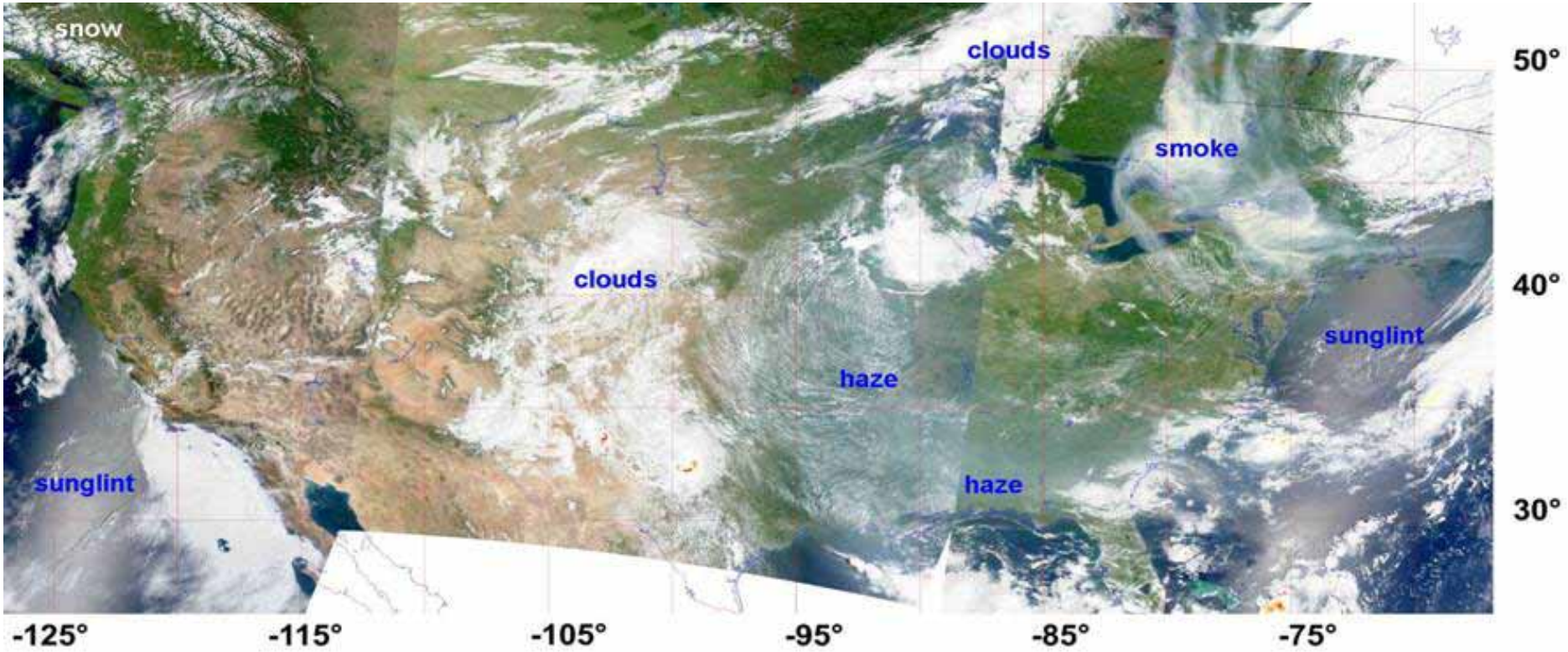
MODIS - Bands

Primary Use	*Band*	*Bandwidth (nm)*[1]	*Spectral Radiance*[2] *(W/(m² μm- sr))*	*Required SNR*[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

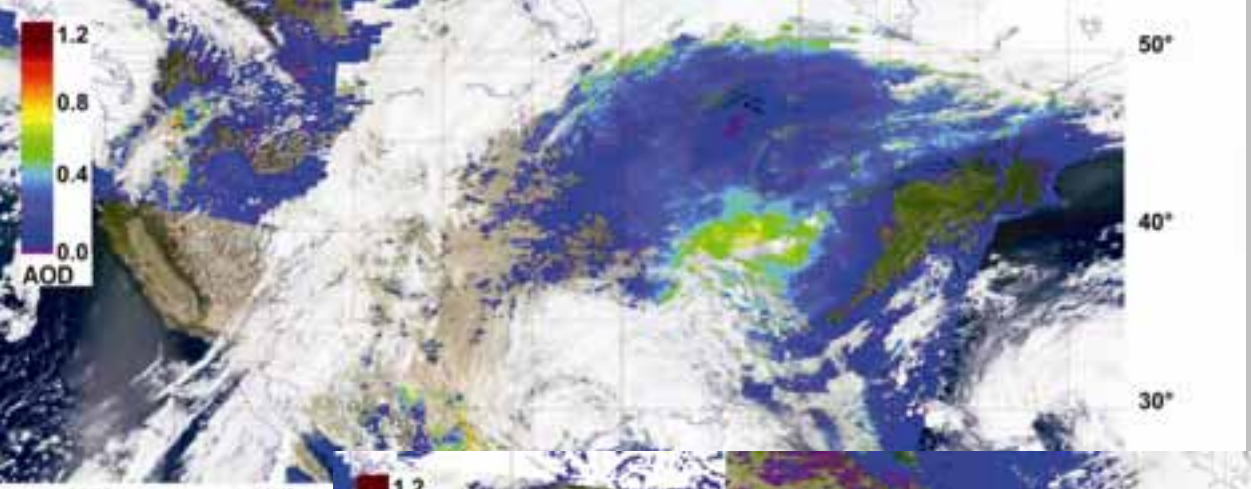
MODIS – Bands (contd…)

Primary Use	*Band*	*Bandwidth (μm)[1]*	*Spectral Radiance (W/(m² μm- sr))[2]*	*Required NE[delta]T(K)[4]*
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	*26*	*1.360 - 1.390*	*6.00*	*150(SNR)*
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

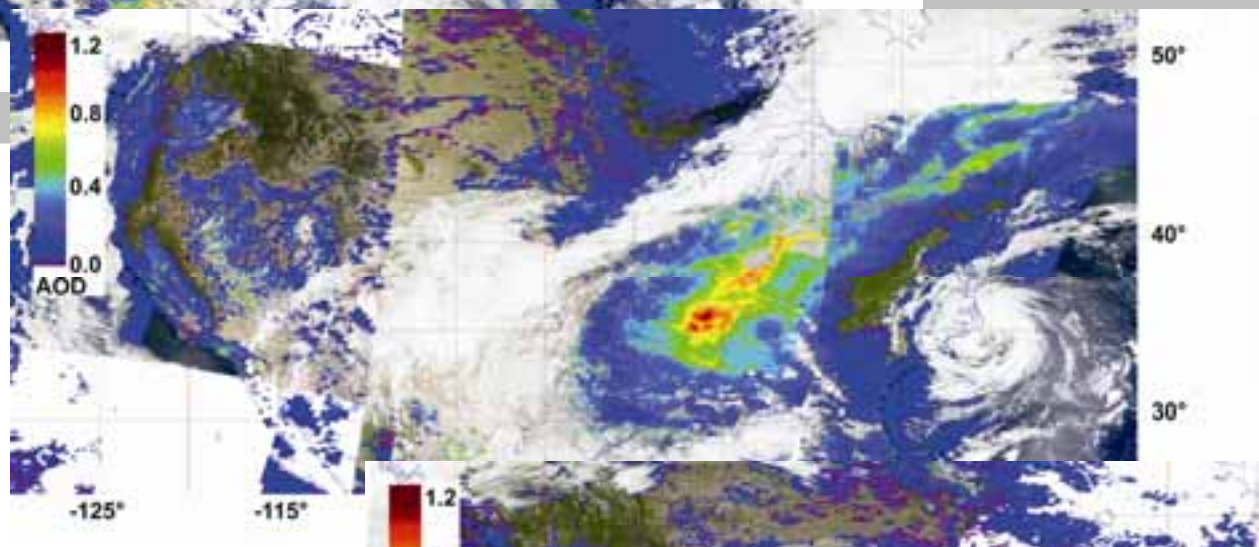
Visible imagery - Interpretation



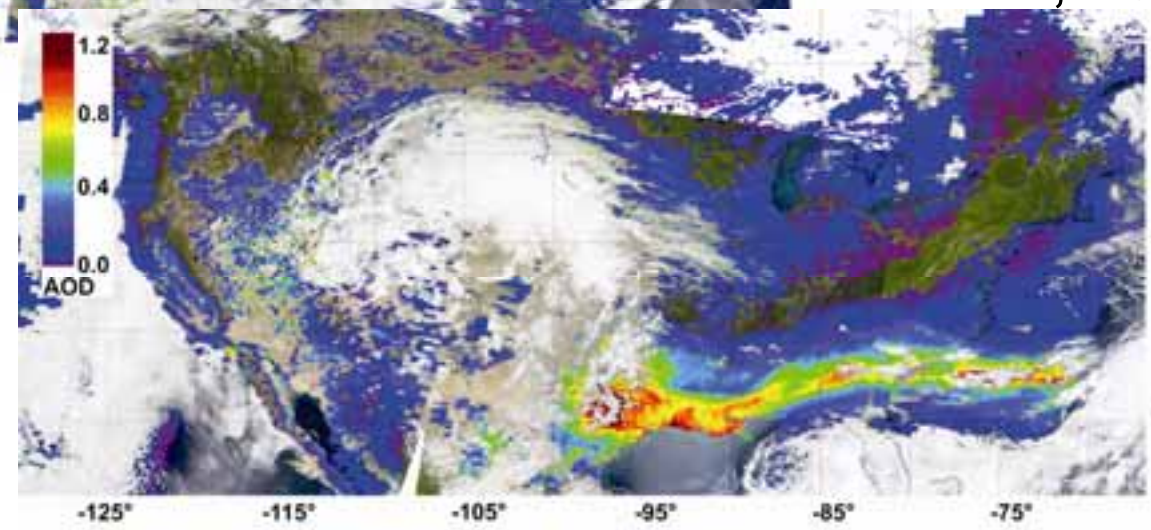
Satellites provide large-scale snapshots of earth-atmosphere system



September 8, 2002



September 10, 2002

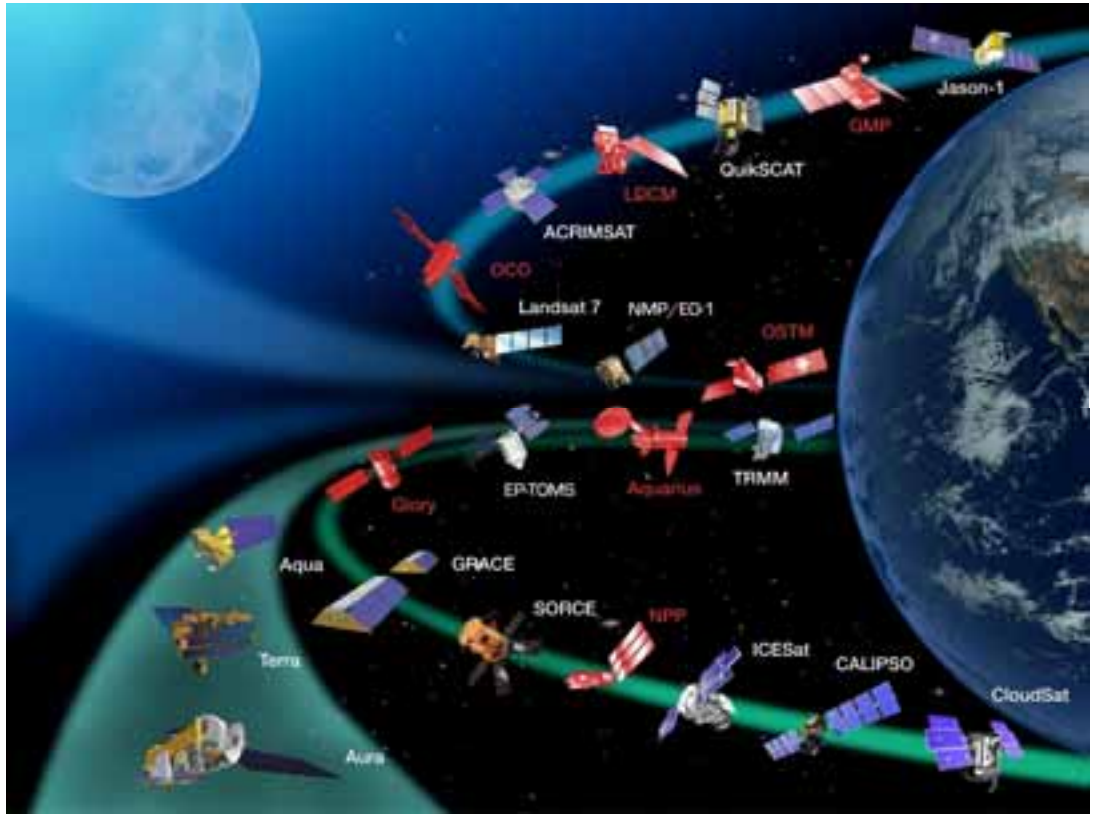


September 12, 2002

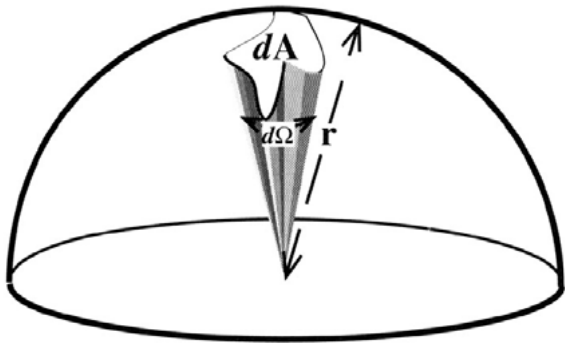
Pollution Transport from satellites

Satellite Remote Sensing

- Advantages: *Repeated reliable measurements*
- Challenges: *Expensive and need expertise to convert measurements to geophysical values such as temperature.*

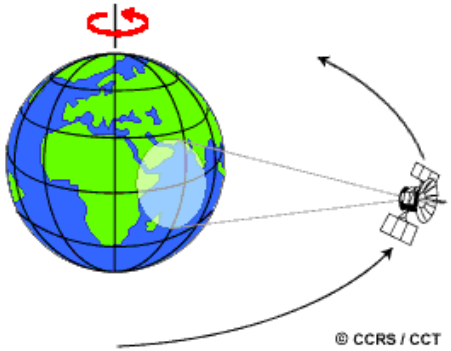


I **= flux per unit area per unit solid angle normal to the direction of propagation [$Wm^{-2}sr^{-1}$]**



$$B_\lambda(T)d\lambda = \frac{2hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}}-1\right)}d\lambda$$

Selected Satellite Orbits

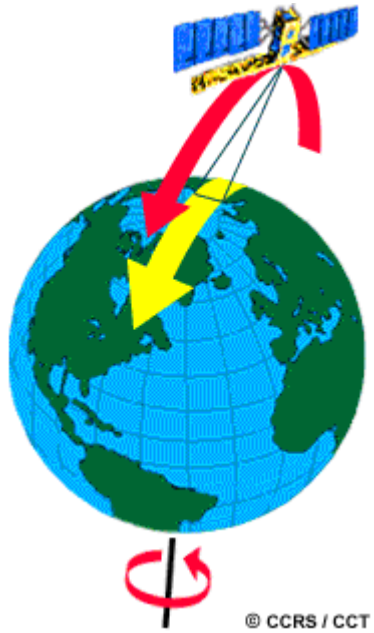


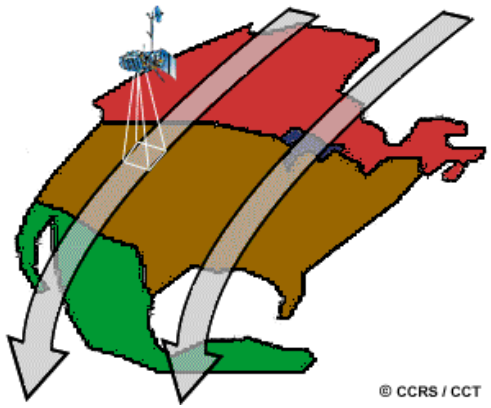
Geostationary

High Temporal Resolution

Polar Orbiting

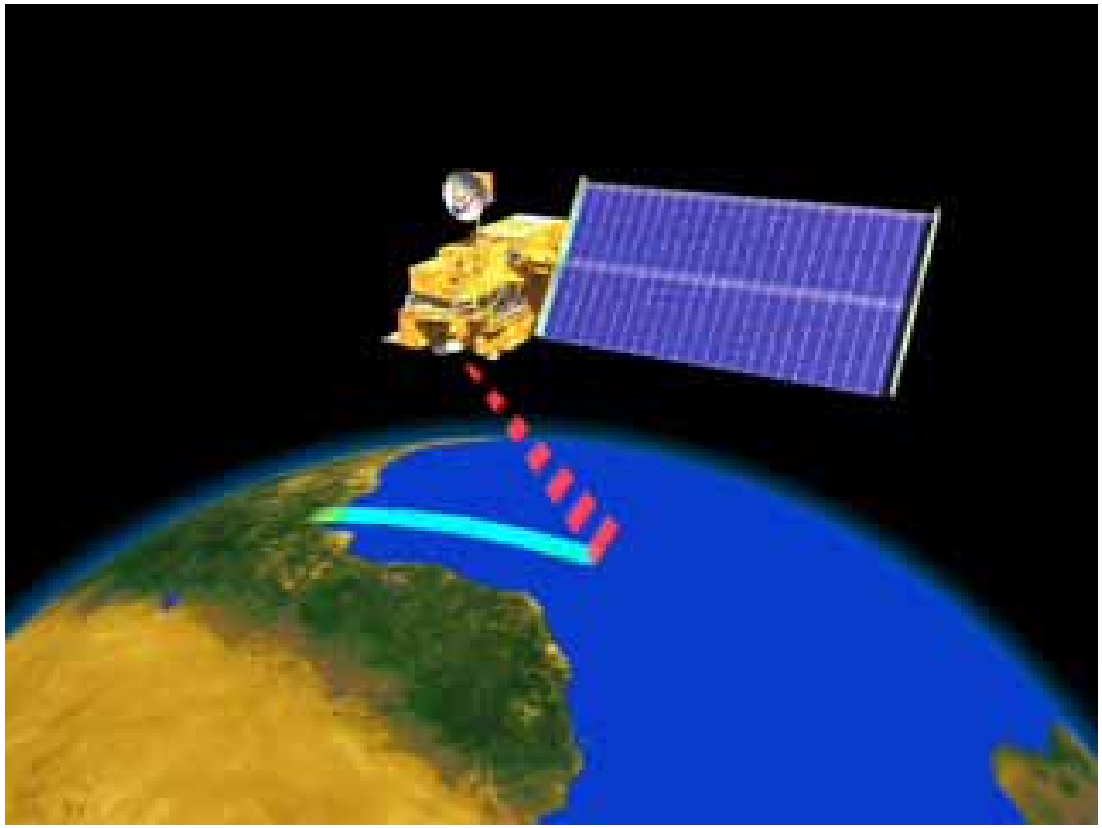
Global Coverage





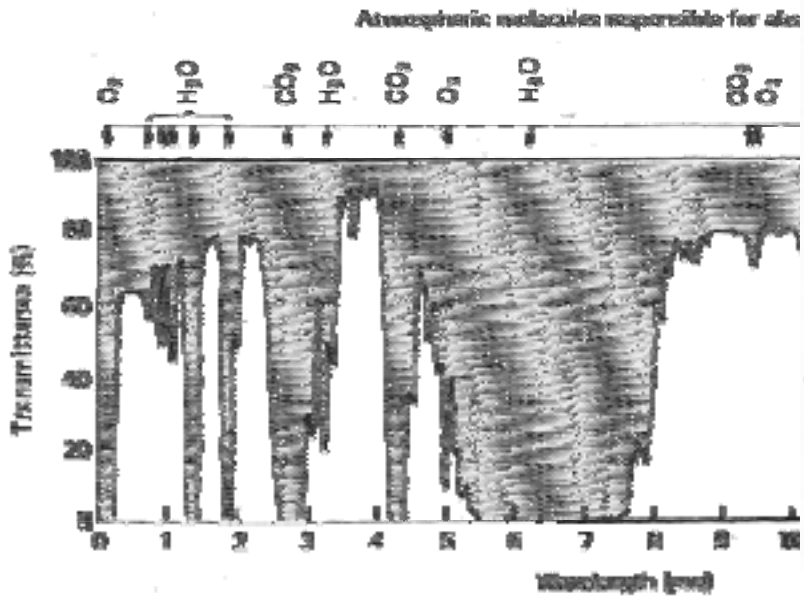
Polar Orbiting orbit

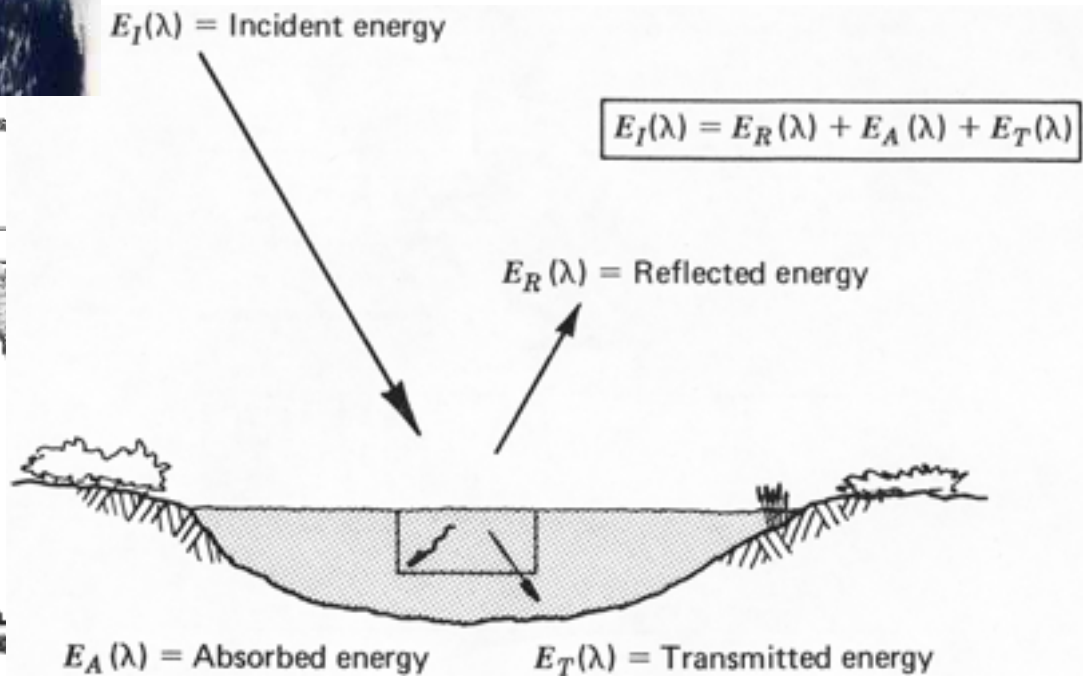
Sun synchronous



Scattering, Absorption and emission

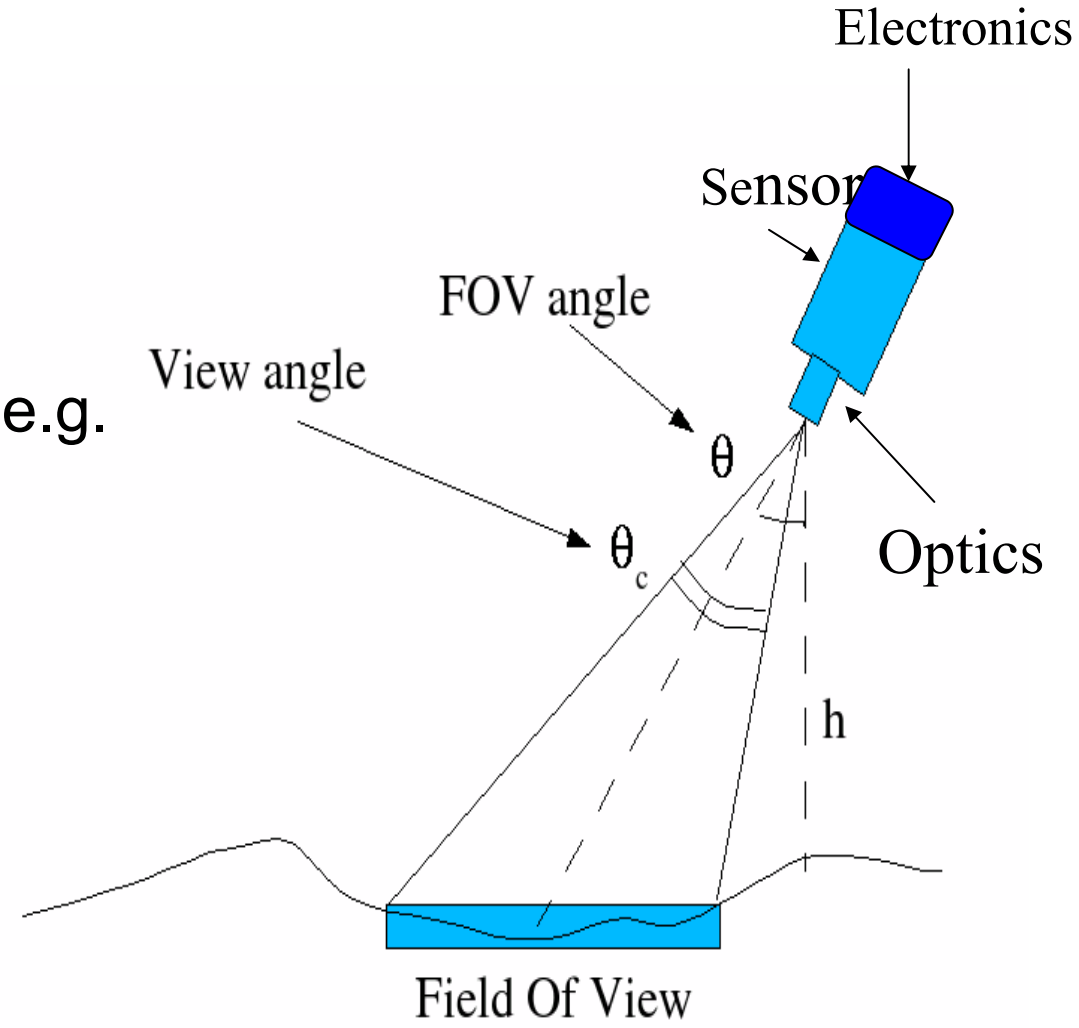
Atmospheric Windows for Remote Sensing

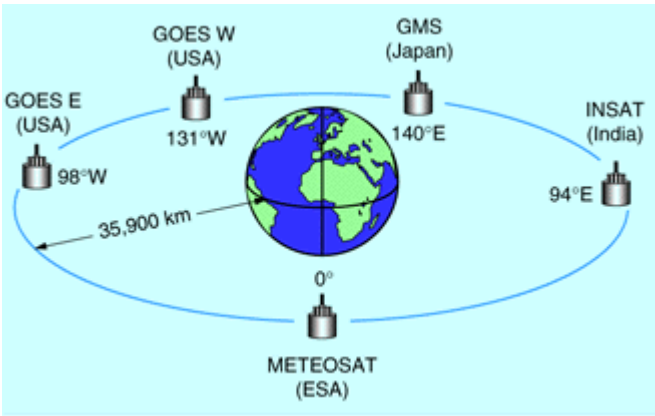


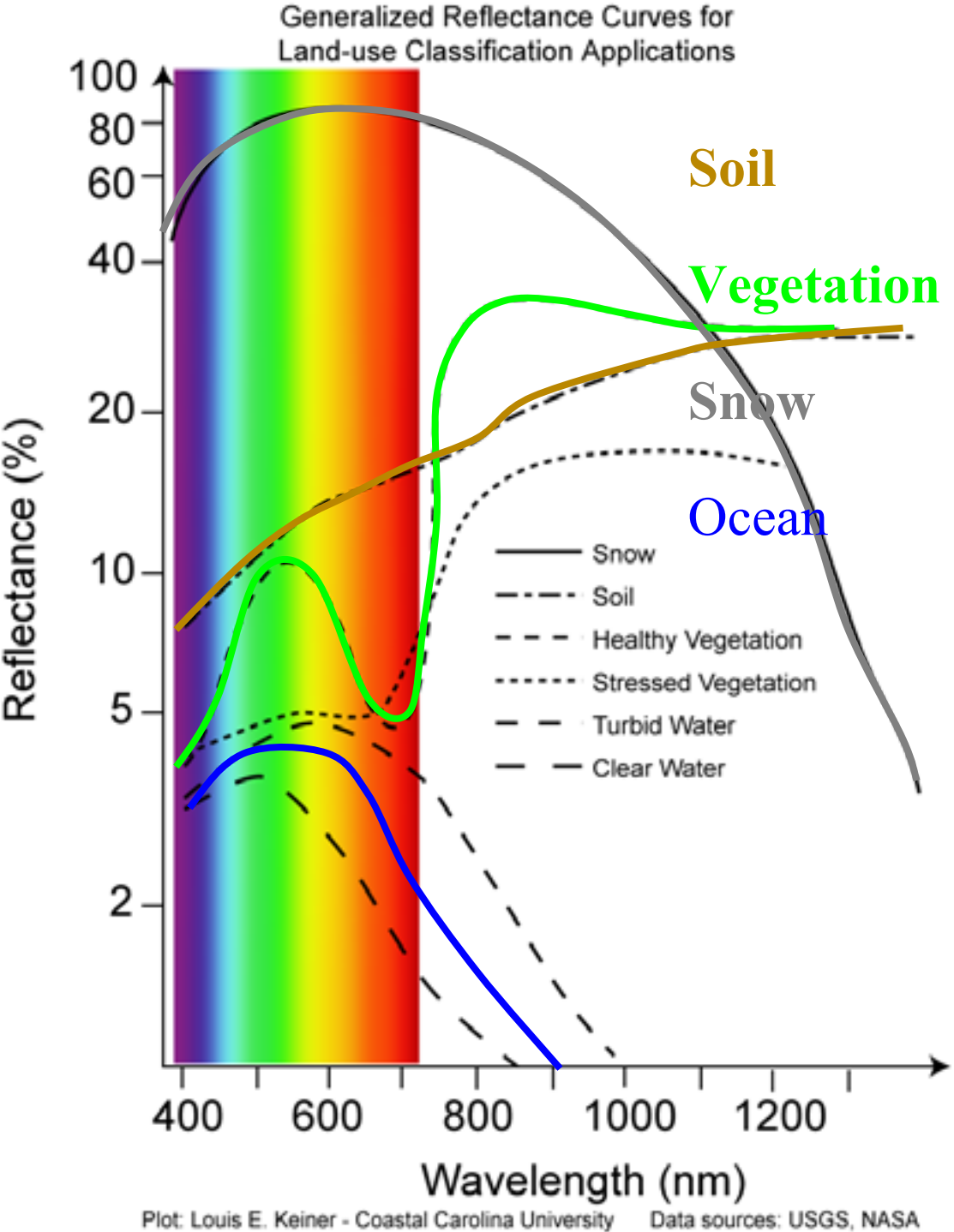


Remote Sensing - Resolutions

- *4 major resolutions*
  - Spatial resolution
  - Temporal resolution
  - Spectral resolution
  - Radiometric resolution (e.g. 8bit)





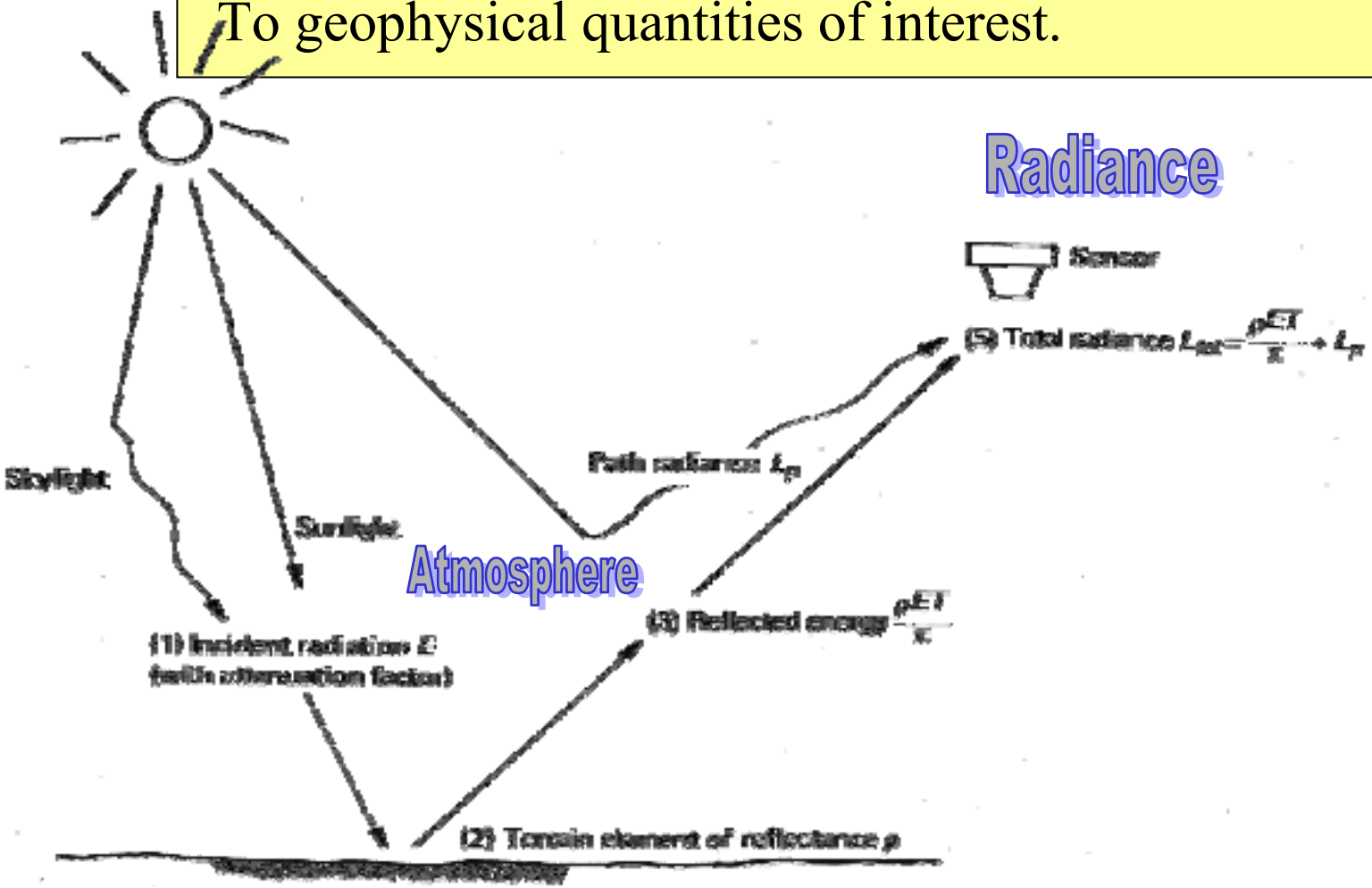


Spectral Resolution And Spectral Signatures

Features such as Soil, vegetation, Snow, and ocean Appear different in Different parts Of the EM spectrum That is used in Remote Sensing

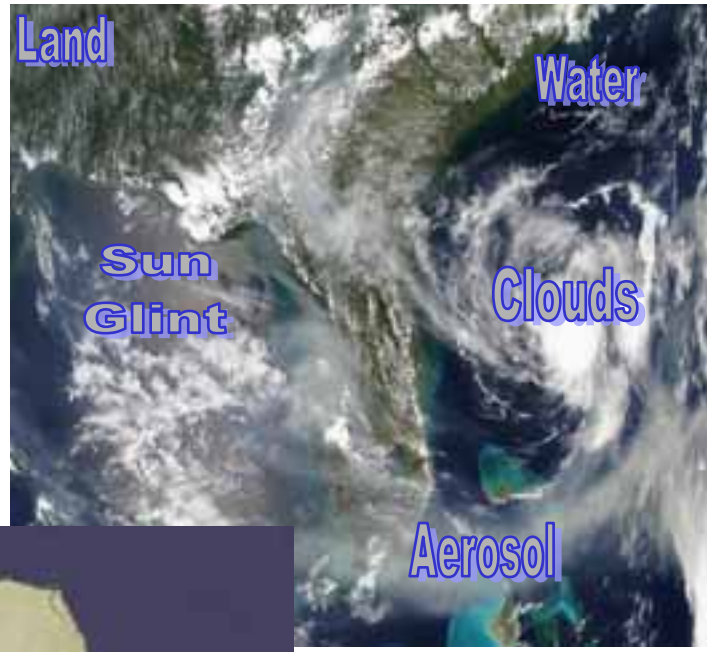
What does satellite “see”

Satellites do not measure temperature or pollution Concentrations. The measured radiances must be converted To geophysical quantities of interest.

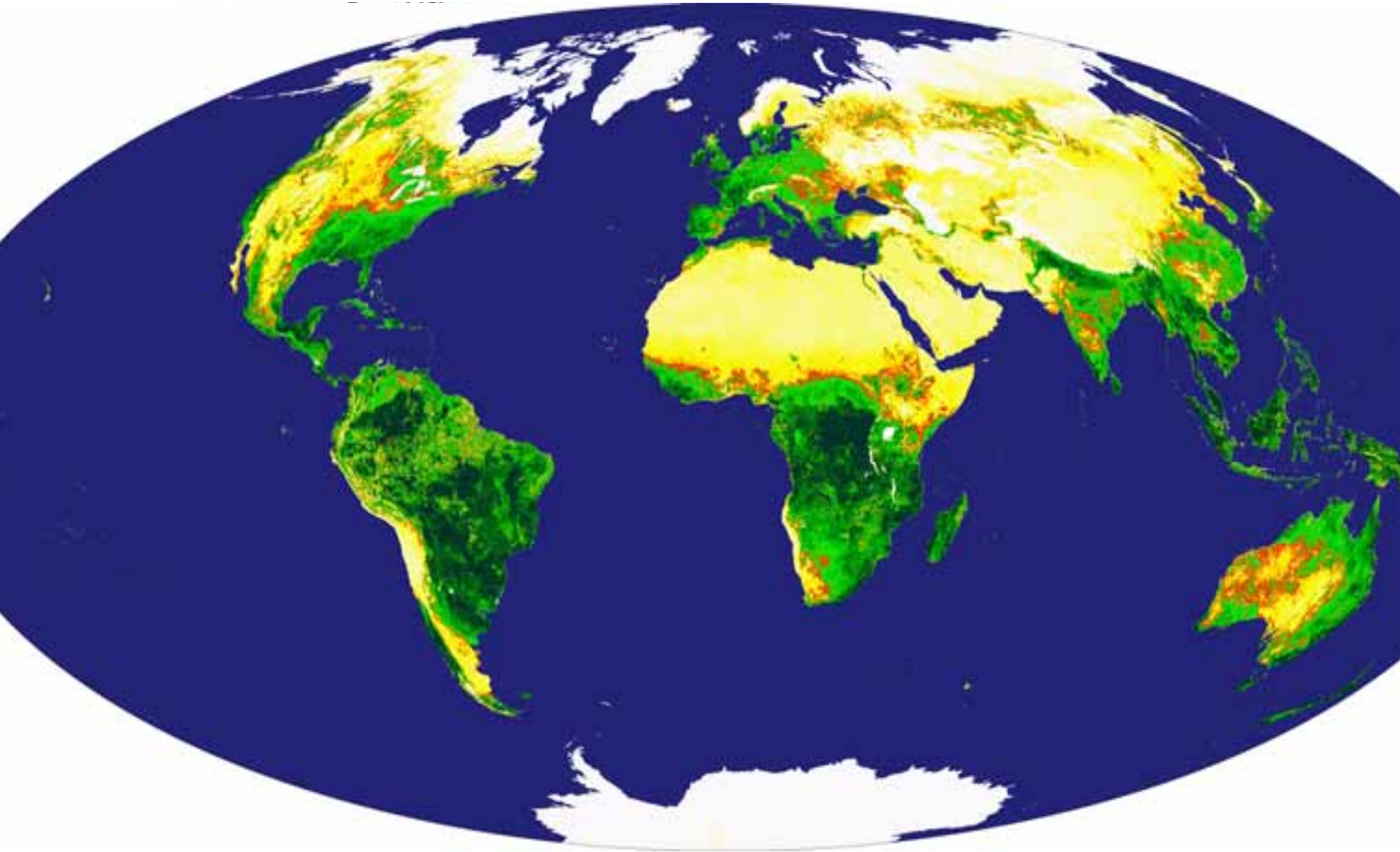


From pretty pictures to numbers

- Radiance is converted to reflectance and temperature
- Multi-spectral Image must be separated into various features (clouds, aerosols, ocean, land etc.)
- This must now be converted to geophysical parameter
- Examples include : AOD, Temperature

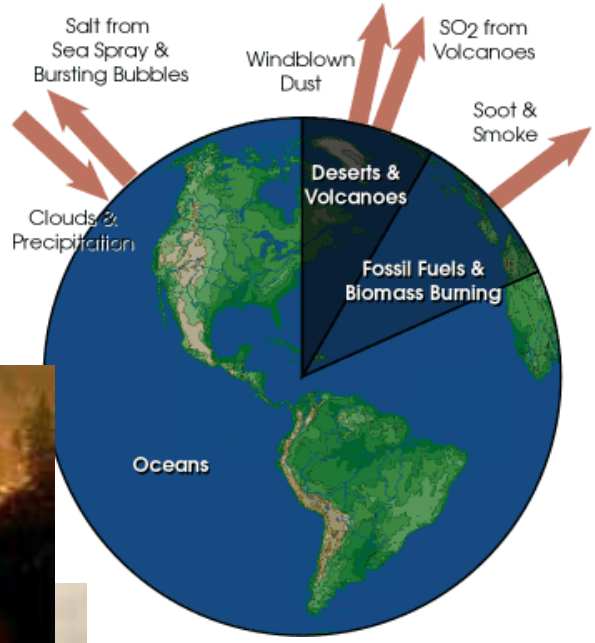


Land Remote Sensing

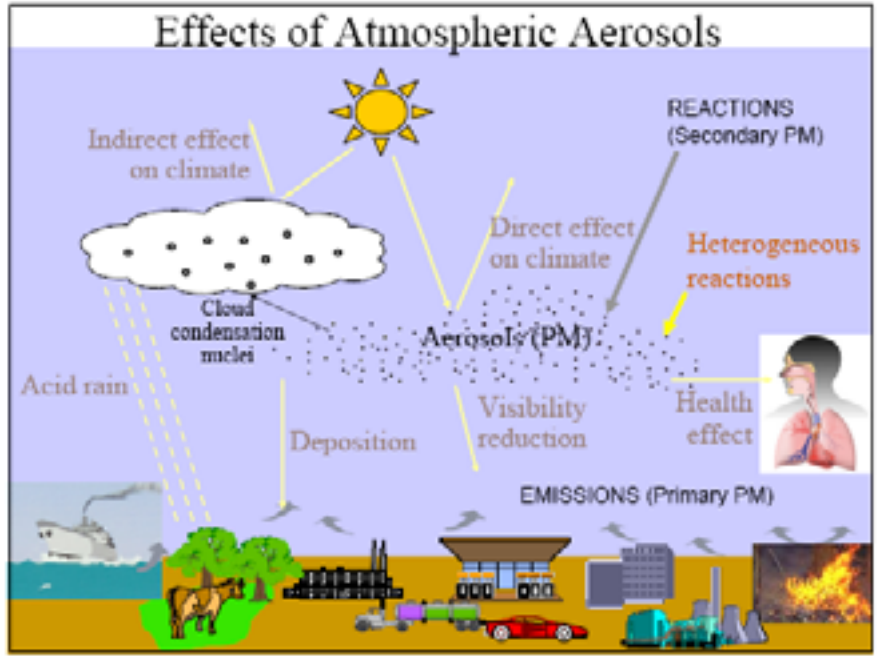


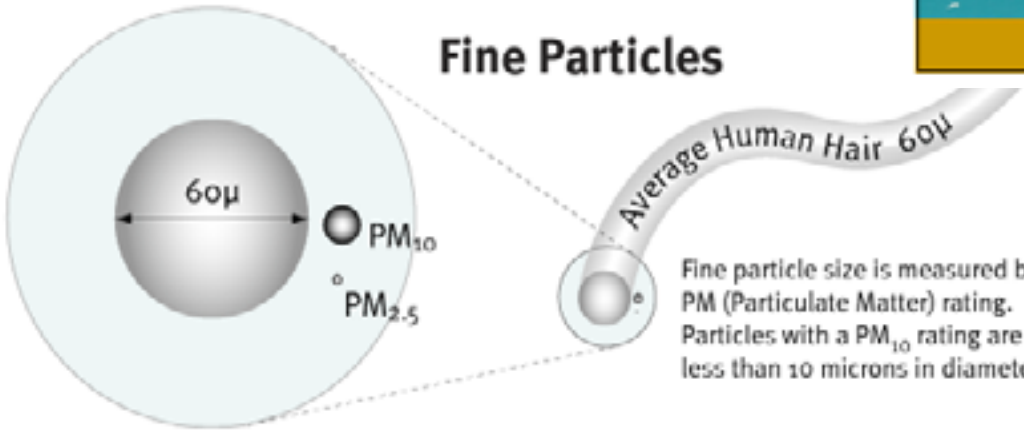
Aerosols/Particulate Matter

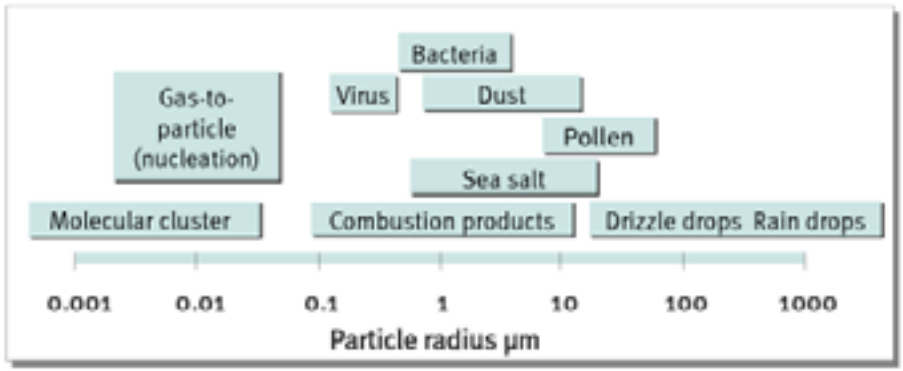
- Climate
- Visibility
- Health
- Hydrology
- Nutrient source



Tiny but potent







Queensland Government
Environmental Protection Agency

Pollution and Breathing

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

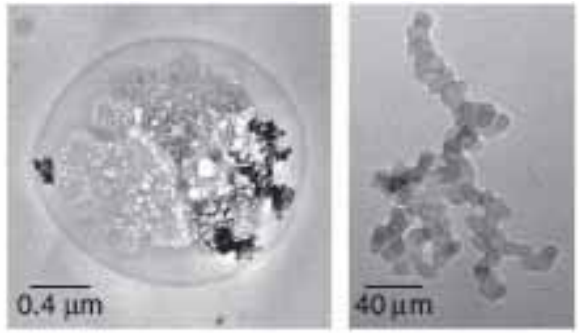
Pollution and Health

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

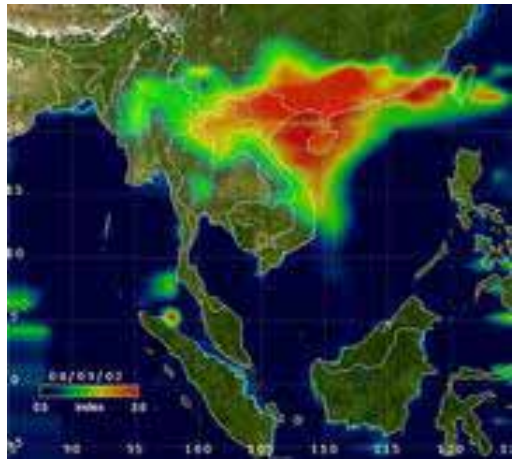
Suppression of Rain and Snow by Urban and Industrial Air Pollution

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.

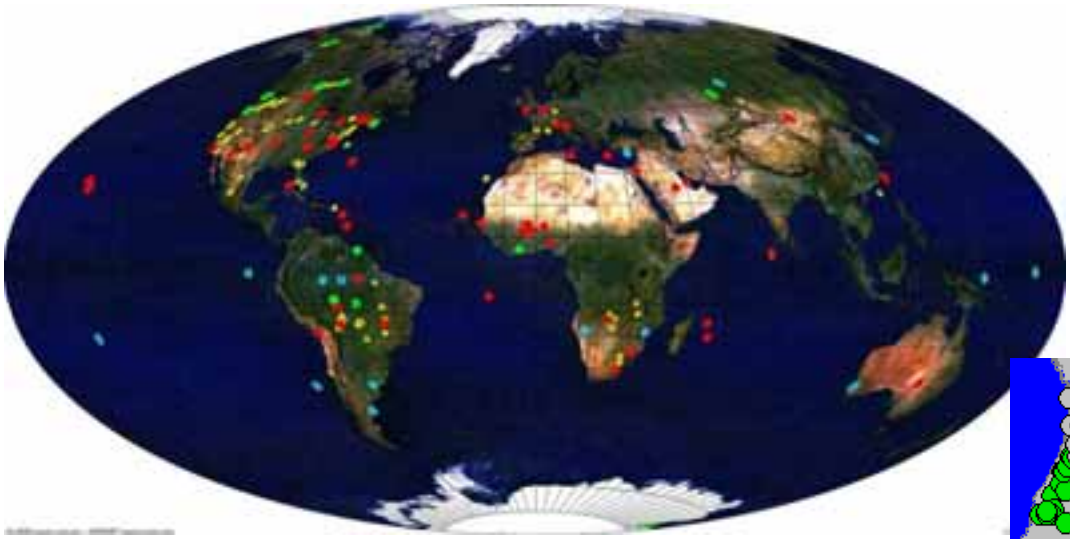
Pollution reduces size of cloud droplets

Shuts off rain processes

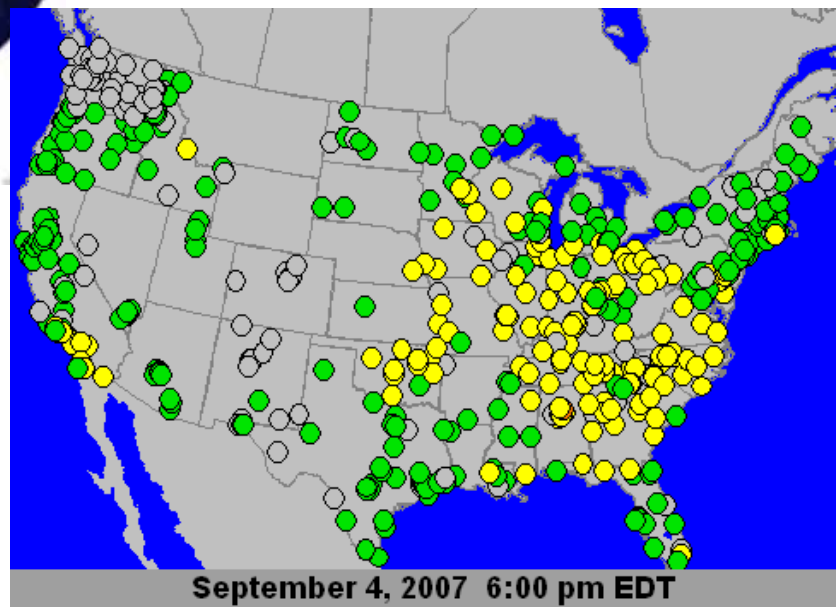


How do we measure pollution

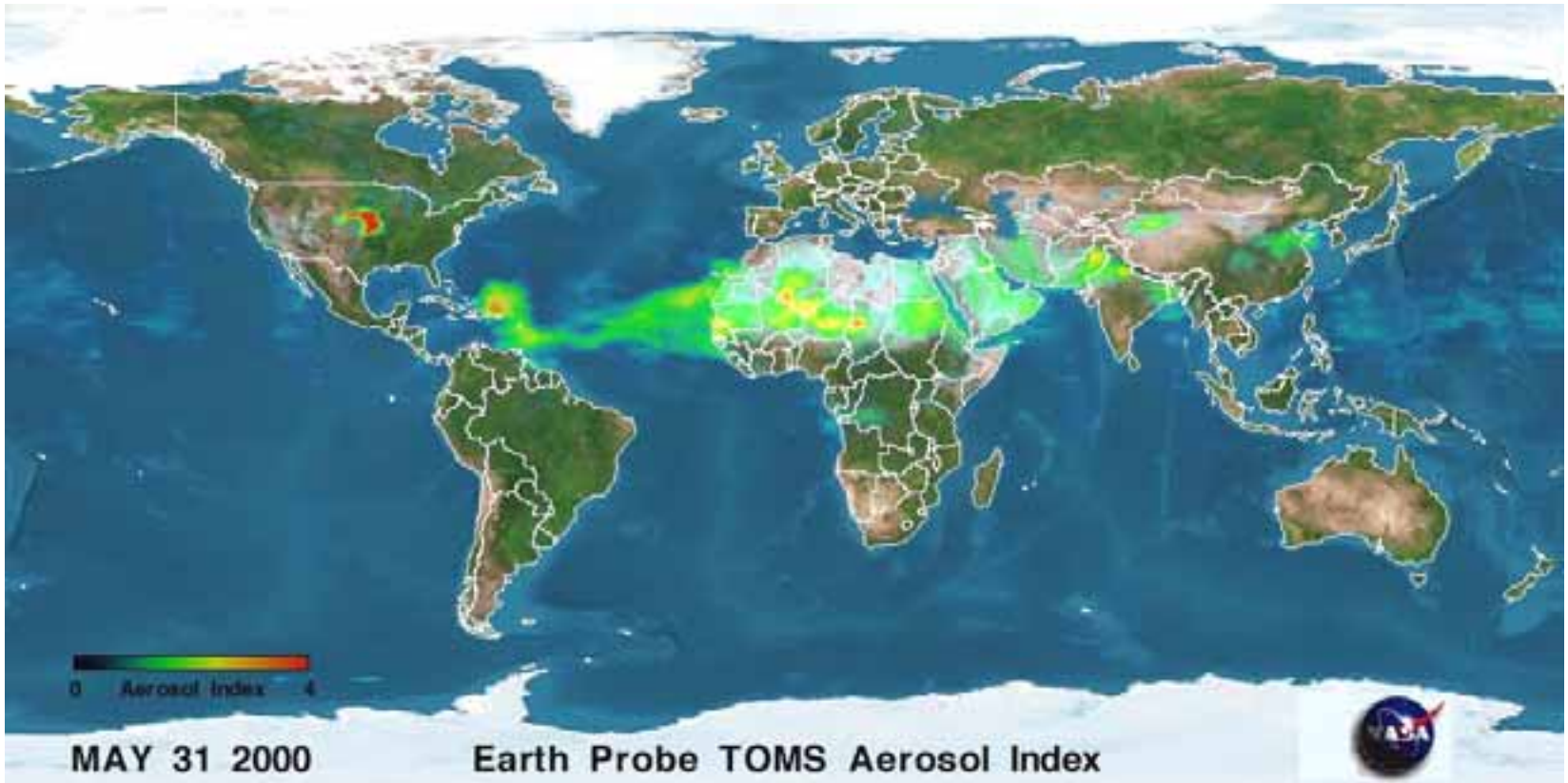
AERONET : Highly reliable but spatially limited
Column measurements



The air we breathe
Surface Particulate matter mass
Microgram per cubic meter
Not available in many countries



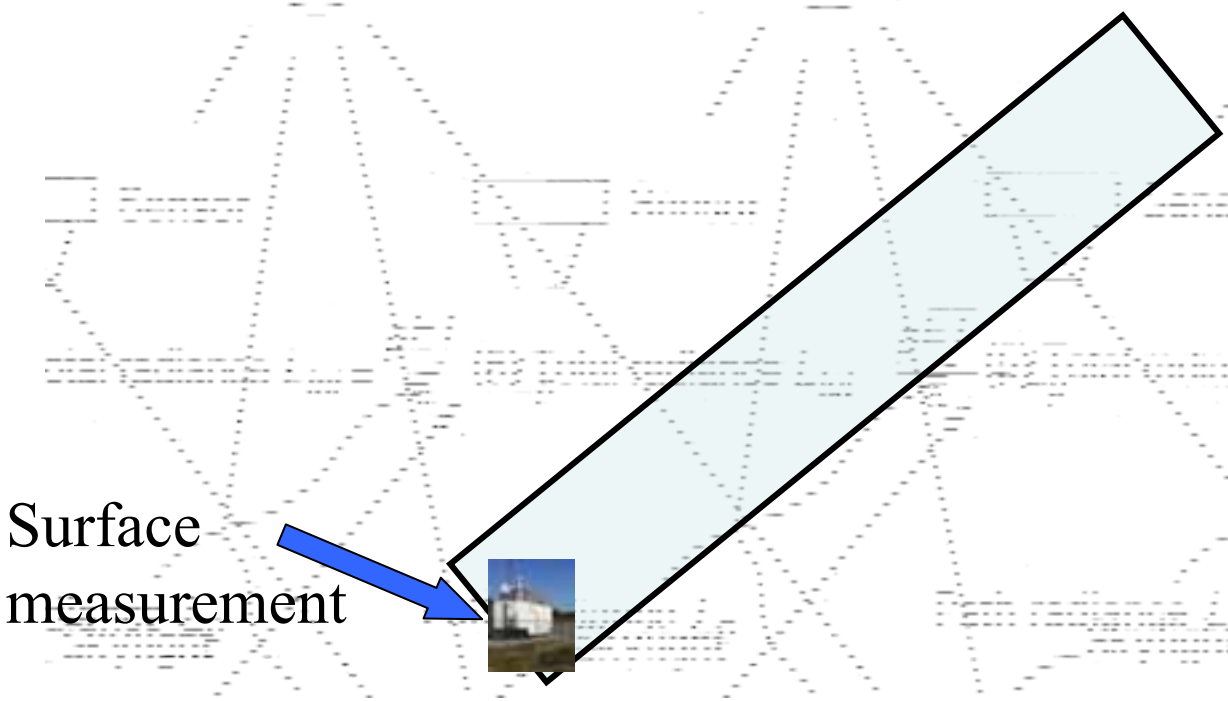
Aerosols from Space, Example



Satellites are the only viable method for monitoring global pollution

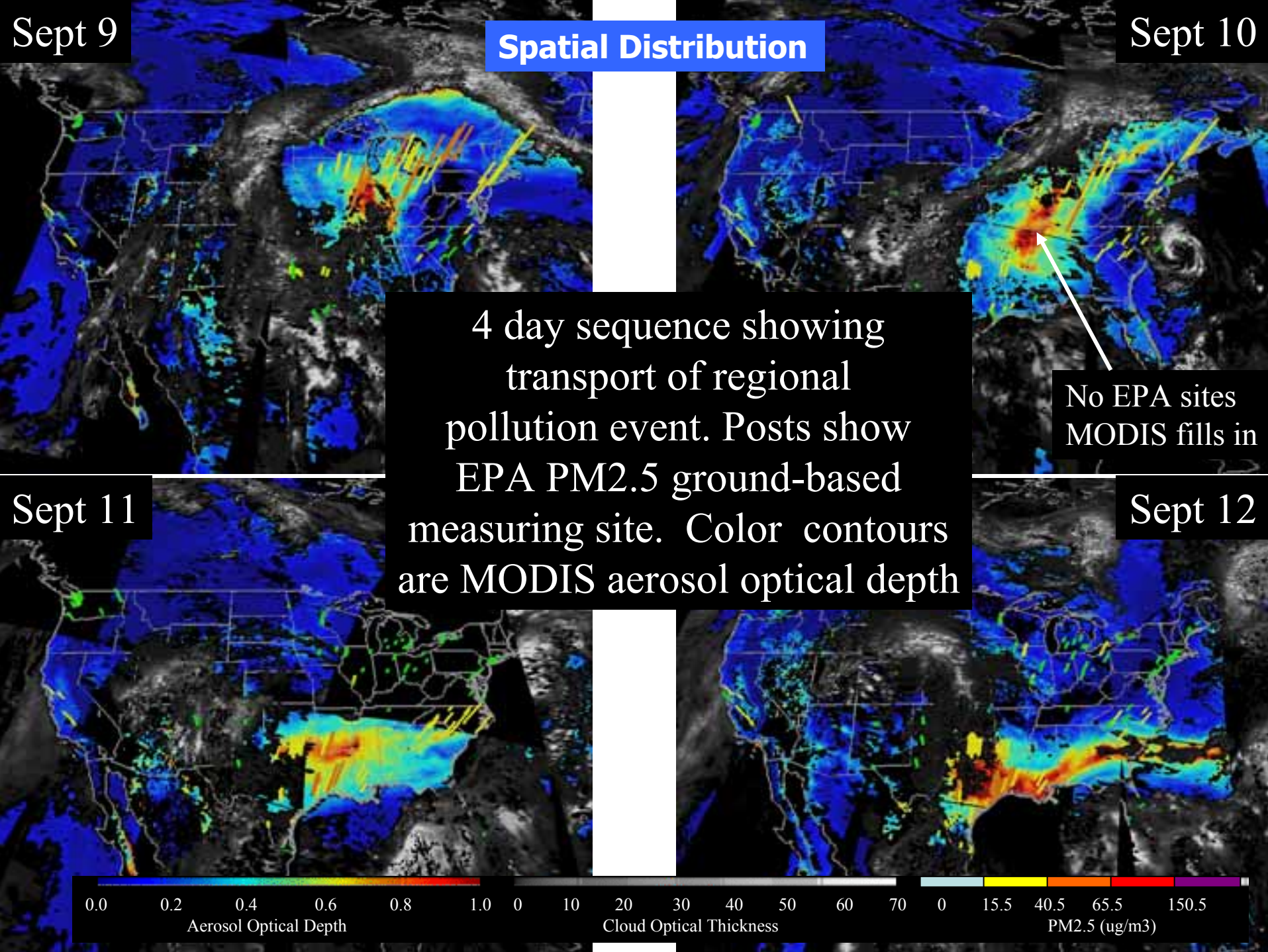
How do satellites measure pollution?

Multi-spectral satellite data



Satellite measured radiances are converted to columnar Aerosol Optical Thickness

$$AOT\ (\tau) = \int \beta_{ext}\, dz$$


Sept 9
Spatial Distribution
Sept 10
4 day sequence showing transport of regional pollution event. Posts show EPA PM2.5 ground-based measuring site. Color contours are MODIS aerosol optical depth
No EPA sites
MODIS fills in
Sept 11
Sept 12
0.0 0.2 0.4 0.6 0.8 1.0
Aerosol Optical Depth
0 10 20 30 40 50 60 70
Cloud Optical Thickness
0 15.5 40.5 65.5 150.5
PM2.5 (ug/m3)

The strength of satellite remote sensing

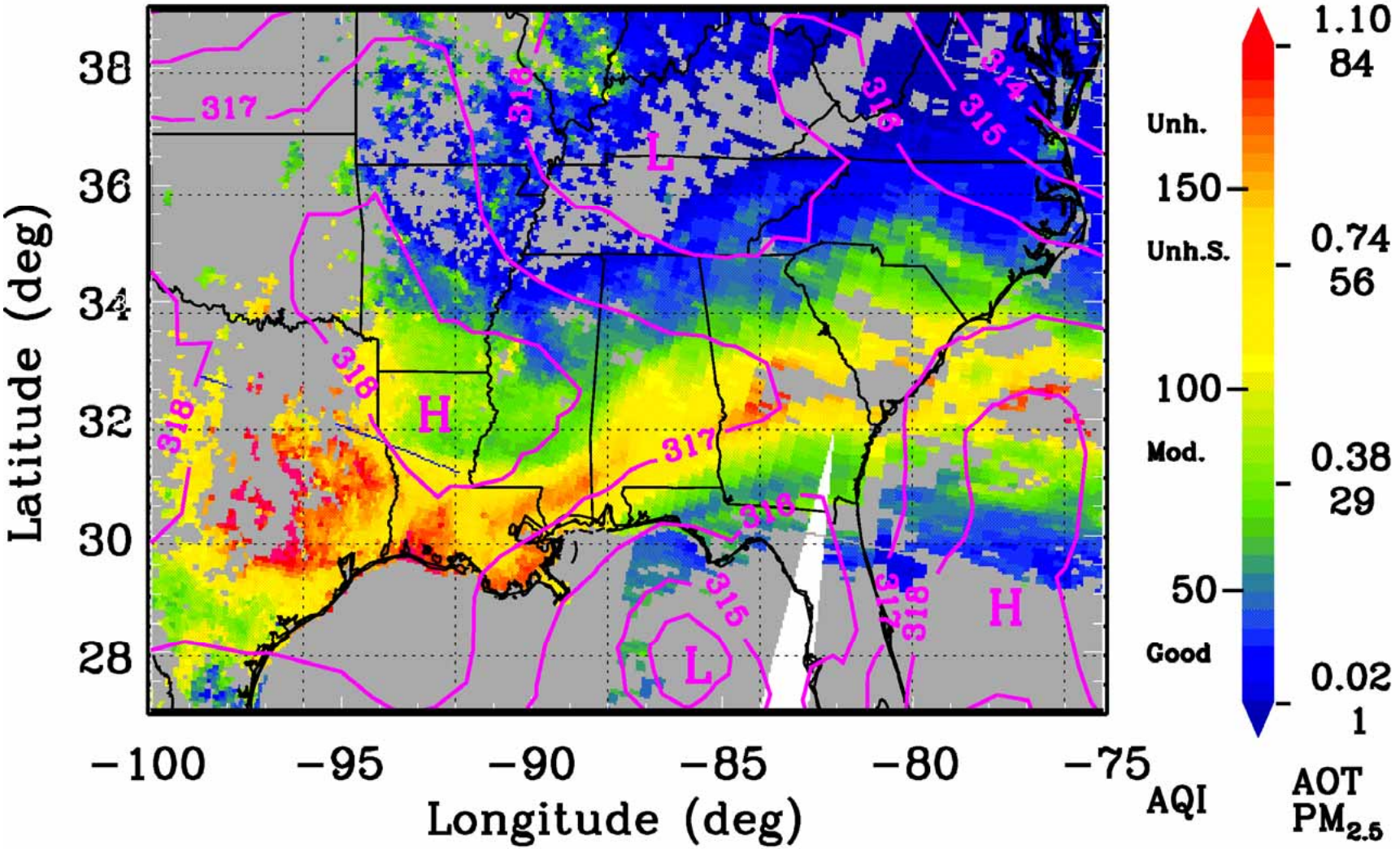
From AOT to air quality

- Using satellite AOT to assess air quality categories
- Air quality standards vary by country

Index Values	Category	Cautionary Statements	$PM_{2.5}$ (ug/m^3)	PM_{10} (ug/m^3)
0-50	Good	None	0-15.4	0-54
51-100	Moderate	Unusually sensitive people should consider reducing prolonged or heavy exertion	15.5-40.4	55-154
101-150	Unhealthy for Sensitive Groups	Sensitive groups should reduce prolonged or heavy exertion	40.5-65.4	155-254
151-200	Unhealthy	Sensitive groups should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion	65.5-150.4	255-354
201-300	Very Unhealthy	Sensitive groups should avoid all physical activity outdoors; everyone else should avoid prolonged or heavy exertion	150.5-250.4	355-424

AOT-PM2.5

Assess AOT-PM2.5
Assess Meteorology
Vertical Distribution of Aerosols



Summary – Section 1

- Satellite Remote Sensing is a powerful tool for studying the earth atmosphere system.
- Knowledge of Atmospheric Radiative transfer, meteorology, and image processing is necessary.
- Satellite sensors measures radiances and must be converted to geophysical values (e.g. Temperature).
- Since very few ground monitors are available, satellites are the only viable tools for monitoring air pollution from space.
- Satellite data sets are highly successful in studying weather, climate and other environmental issues.