Satellite Oceanography and Applications 1: Introduction, SST, Ocean color

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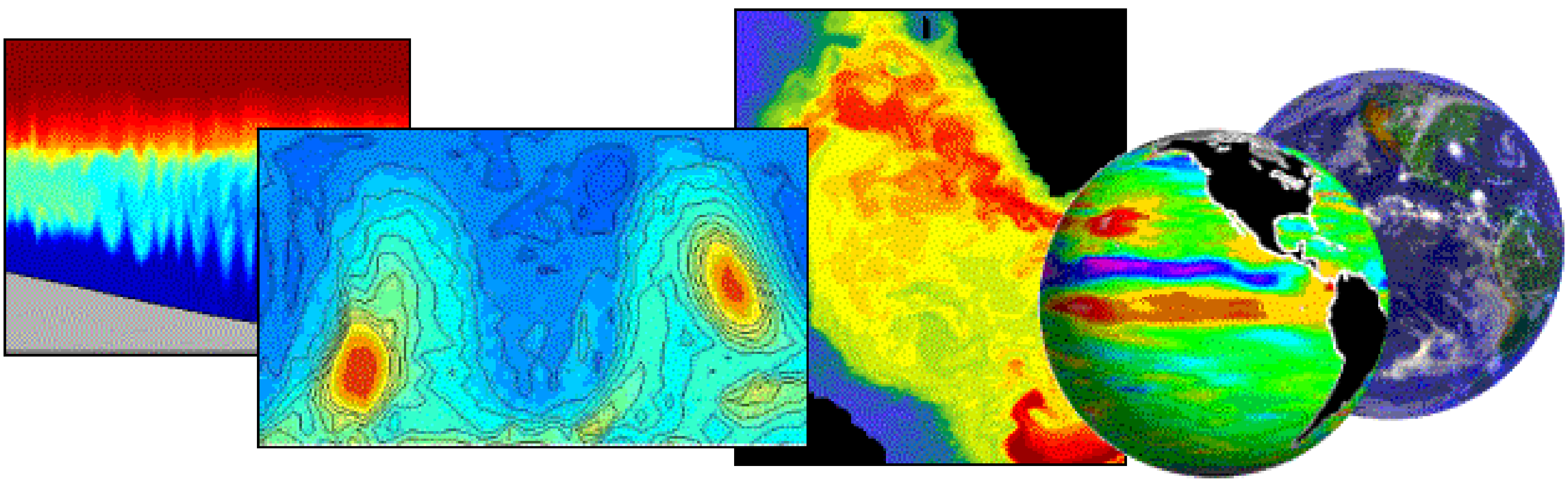
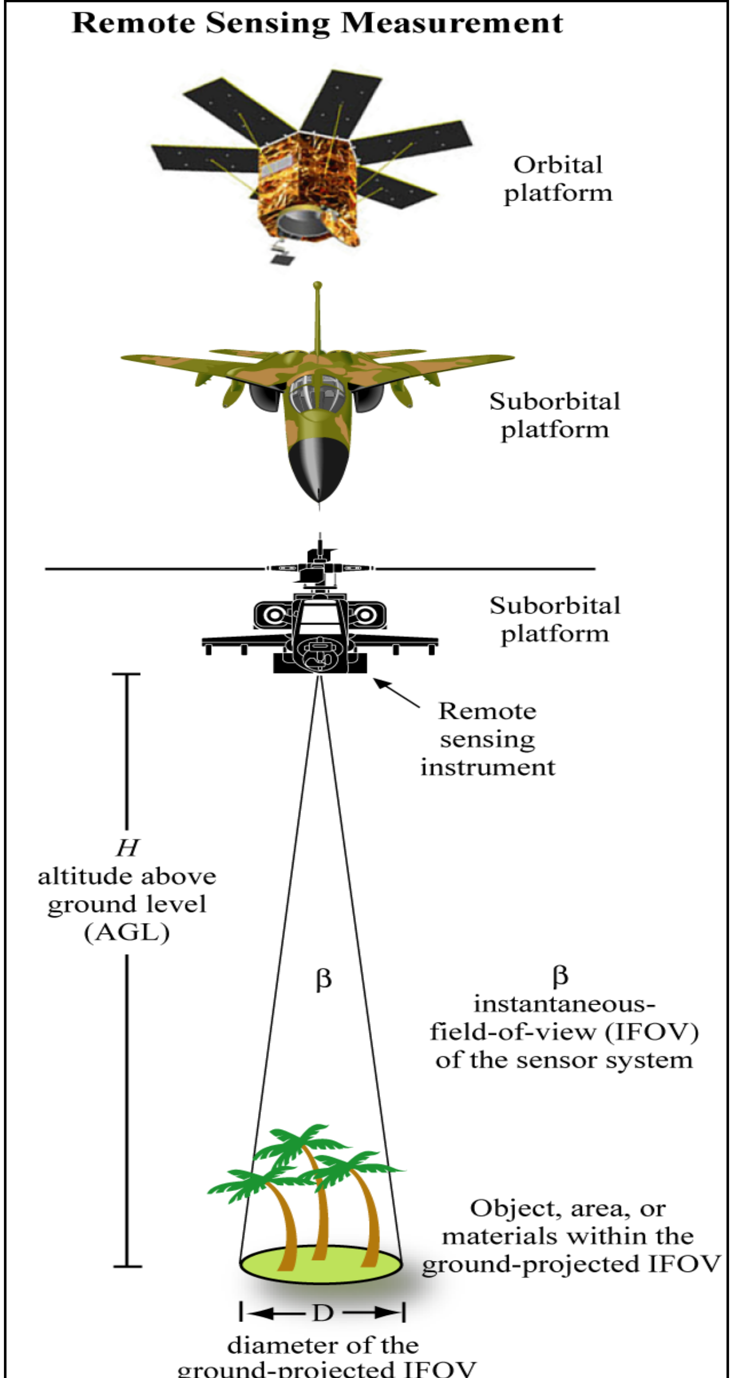


RMU Summer Program (AUGUST 24-28, 2015)

Objectives/Goals

- ✓ To know the basic **methods** of ocean remote sensing (ORS)
- ✓ To explain the generic **mechanisms** of ORS
- ✓ To appreciate the **limitations** of ORS
- ✓ To understand the **processes** which enable ocean parameters to be derived from satellite image data.
- ✓ To display, enhance and **interpret** image data
- ✓ To identify and describe **oceanographic observations** which are best made by remote sensing methods.
- ✓ To appreciate the **synergy** from combining remote sensing and conventional *in situ* observations.

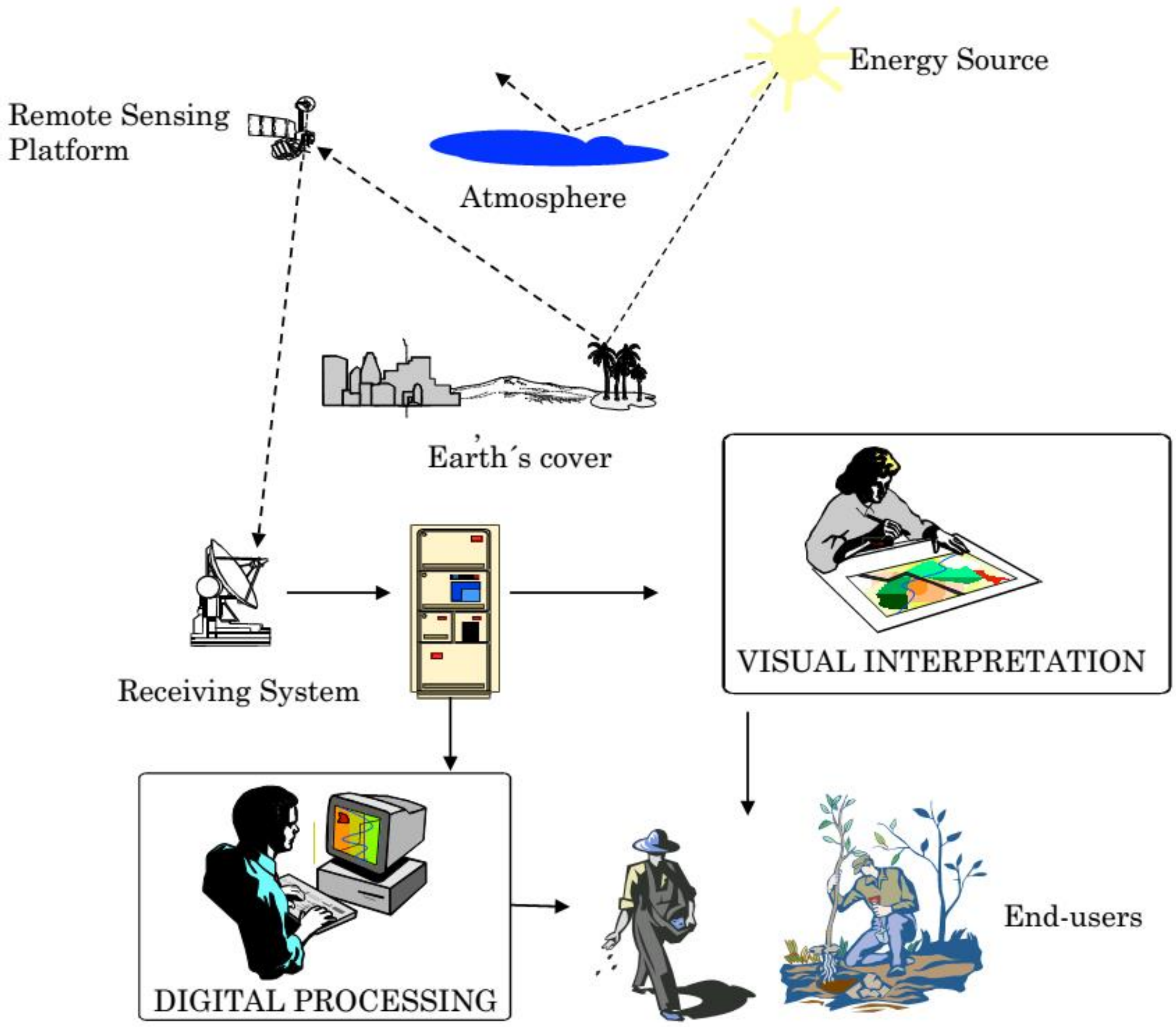


Jensen, 2009

A remote sensing instrument collects information about an object or phenomenon within the instantaneous-field-of-view (IFOV) of the sensor system **without being in direct physical contact** with it.

The sensor is located on a suborbital or satellite platform

Remote Sensing: Primary components



A. Energy Source
B. Radiation and Atmosphere
C. Interaction with target
D. Energy recorded by sensor
E. Transmission, reception, processing
F. Interpretation and analysis
G. Application of information

Satellites and Sensors: A brief history

Remote Sensing: A brief history

Hot-air Balloons Invented by the Montgolfier Brothers in 1783

A cartoon by the artis

Gaspard Felix Tournachon (Nadar)

1858 Gaspard Felix Tournachon (Nadar) takes first aerial photograph near Paris, using a captive balloon and a collodion plate. Unfortunately, this first aerial photograph did not survive.

Remote Sensing: A brief history

In 1903, Julius Neubronner patented a breast-mounted camera for carrier pigeons that weighed only 70 grams.

A squadron of pigeons is equipped with light-weight 70-mm aerial cameras.

Satellites and Sensors: A brief history

1957 – Soviet Union launches first satellite *Sputnik*

1978 – NASA launches three ocean-observing satellites:

TIROS-N (Television and InfraRed Operational Satellites) on NOAA 6-7 Satellite with AVHRR (Advanced very high Resolution Radiometer) radiometer measuring SST

Seasat Satellite with radar-altimeter measuring sea surface height; microwave scatterometer and synthetic aperture radar (SAR). both measuring ocean roughness;

Nimbus-7 Satellite with ocean color sensor -Costal Zone Color Scanner (CZCS).

Importance of satellite oceanography

- Observes the distribution of certain ocean surface properties in exquisite spatial detail: allows the true spatial structure to be examine

- Captures a "snapshot" of the spatial distribution. "Freezes" the continually changing ocean

- Offers a repeated view: consistent measurements by a single sensor

- Observes part of the ocean other methods miss
  - Shipping routes are concentrated in certain zones
  - Ships tend to avoid poor weather hazardous regions
  - Drifting buoys tend to avoid regions of divergent currents

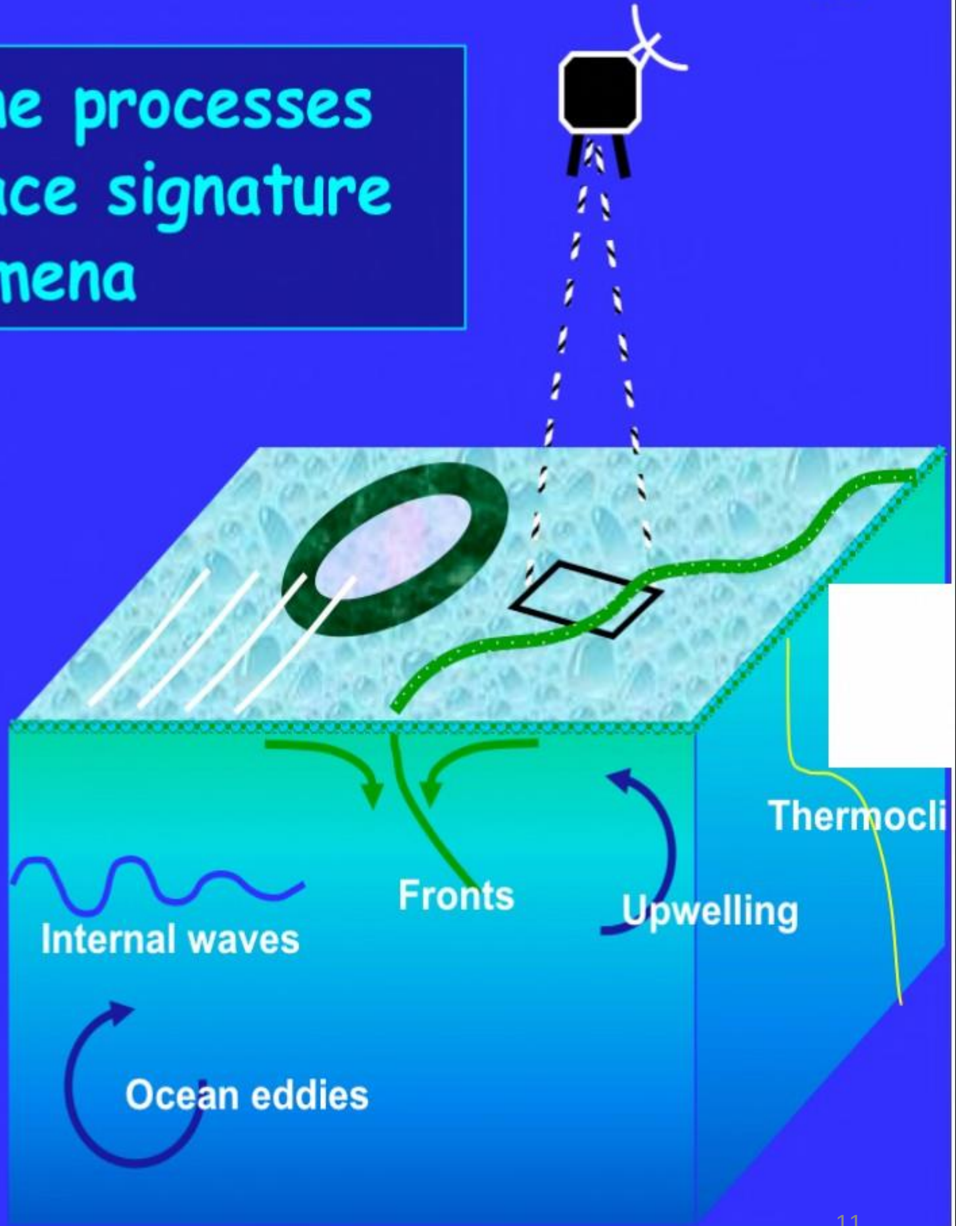
Limitations of satellite oceanography

- Can observe only some of the ocean's properties and variables
- Measures the ocean only at or near the surface
  -- Although the surface is the most critical place to measure
- Ocean measurements may be corrupted by the atmosphere
- Some satellites/methods cannot see through clouds at all
- Can make measurements only when the satellite is in the right place at the right time
- All measurements require calibration and validation using in situ data

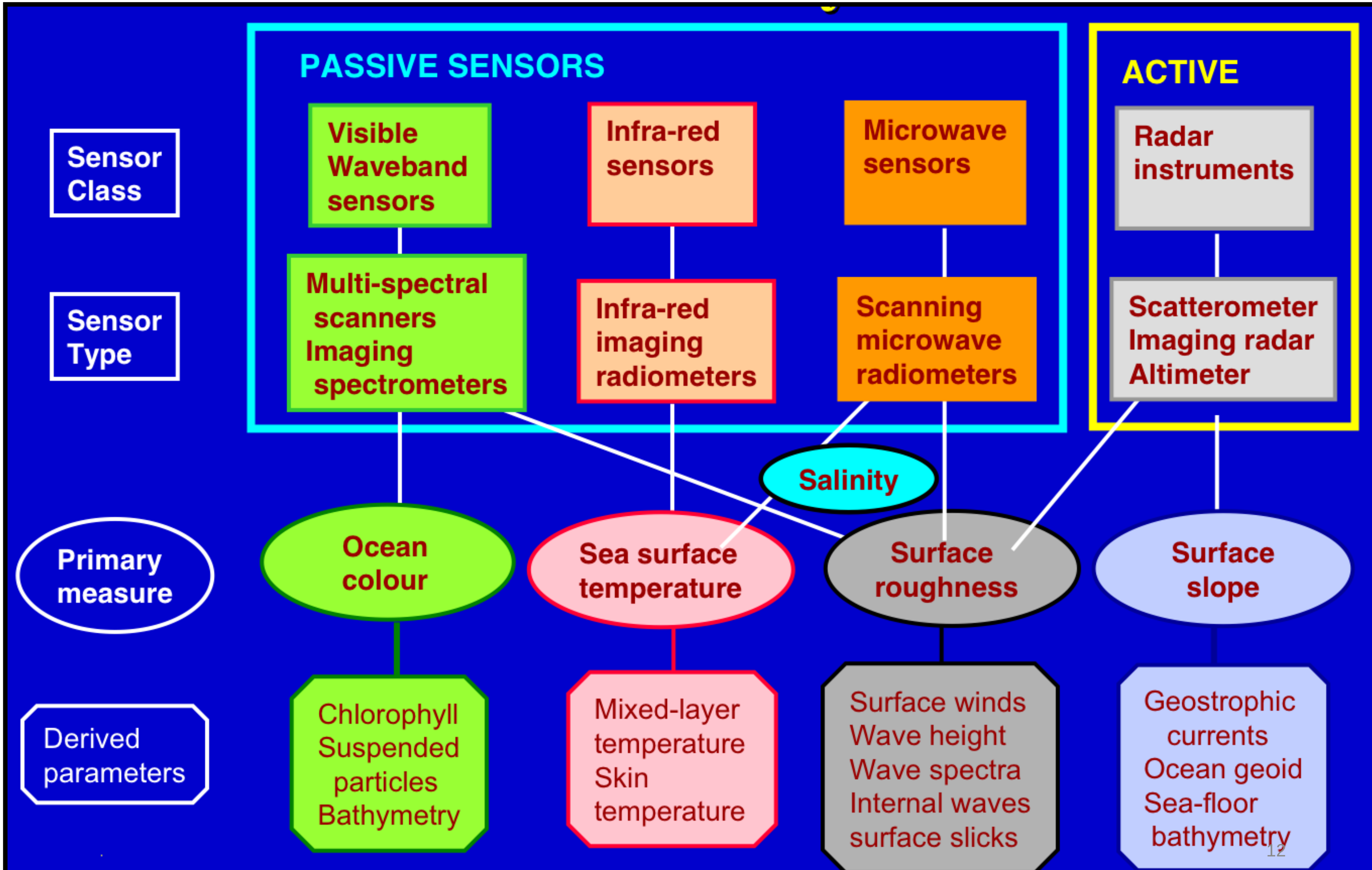
An obvious limitation of remote sensing

<u>Challenge</u>: Understand the processes which produce a surface signature for subsurface phenomena

- Remote sensors observe the sea SURFACE
- **We often want to observe processes INSIDE the sea**
- **Subsurface processes can only be detected if they have a *surface signature***



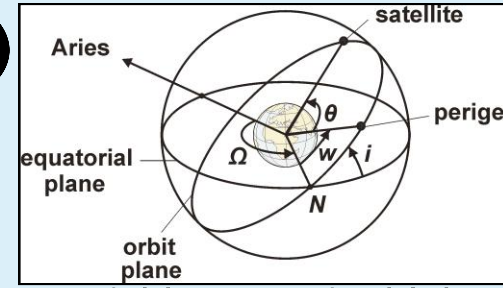
A summary of sensor types & what they measure



Basic physics and principles

Satellite orbital dynamics

Geostationary orbit (Geosynchronous)

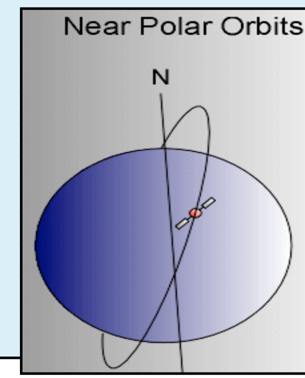


These satellites are used for weather obs.

The satellite orbits in the same direction

as the Earth with a period of one day. The disadvantage of this type of orbit is that since these satellites are very far away, they have poor resolution. Also, have trouble monitoring activities near the poles.

Polar orbit (Sun-Synchronous)



These satellites are good for Chl, SST.

Scans from north to south over one face, and

Reverse in other face. A period of 1-2 hours.

Nearly polar sun- synchronous orbit

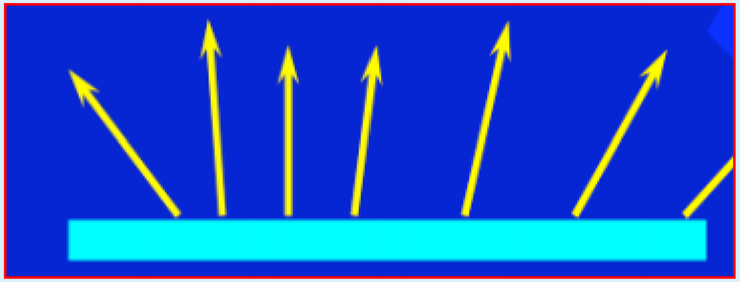
These satellites are used for TRMM.

Near Equatorial low inclination orbit. This orbit covers half of the globe.

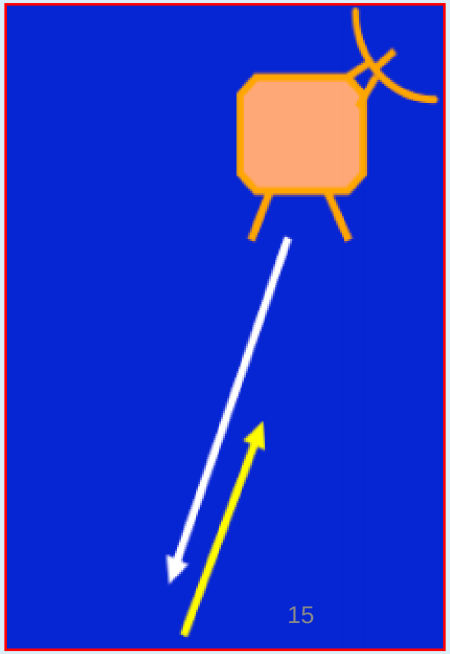
Sources of energy for remote sensing

- The Sun
  - --- Visible waveband
  - --- Near Infra red waveband

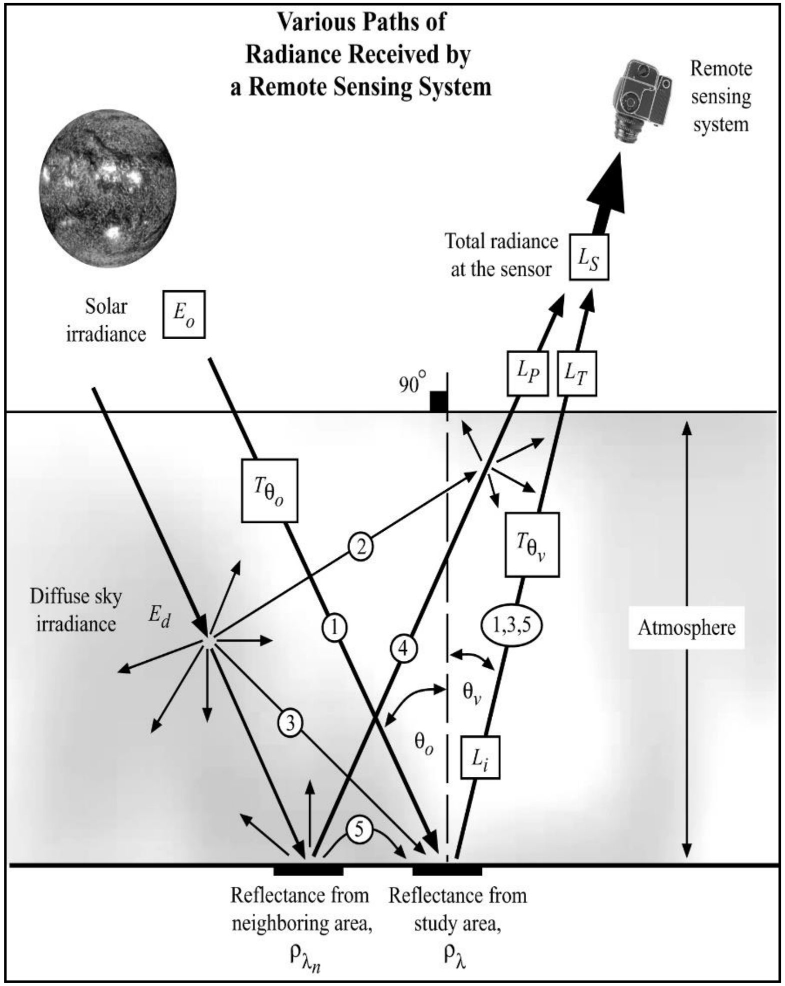
- Thermal emission by the ocean surface
  - --- Thermal infra red
  - --- Microwaves



- Energy source on the satellite
  - --- Microwaves (Radar)
  - --- Visible (Lidar)



Electromagnetic Energy Interactions



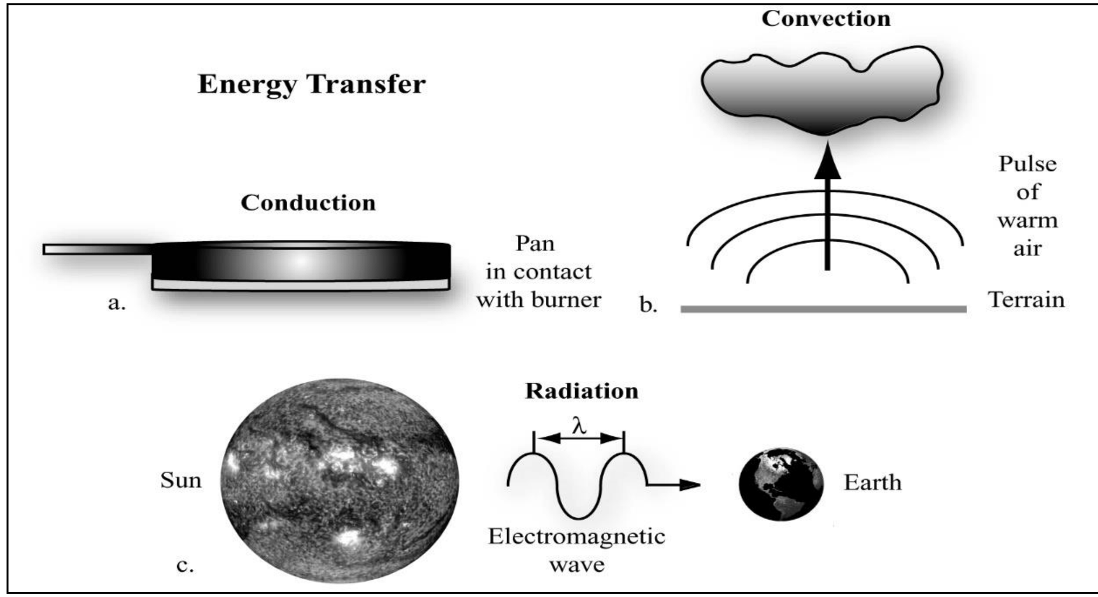
Energy-matter interactions in the atmosphere, at the study area, and at the remote sensor detector

Energy recorded by remote sensing systems undergoes fundamental *interactions*:

Eg., if the energy being remotely sensed comes from the Sun, the energy:

- is radiated by atomic particles at the source (the Sun),
- propagates through the vacuum of space at the speed of light,
- interacts with the Earth's atmosphere,
- interacts with the Earth's surface,
- interacts with the Earth's atmosphere once again, and
- finally reaches the remote sensor where it interacts with various optical systems, filters, or detectors.

How is Energy Transferred?



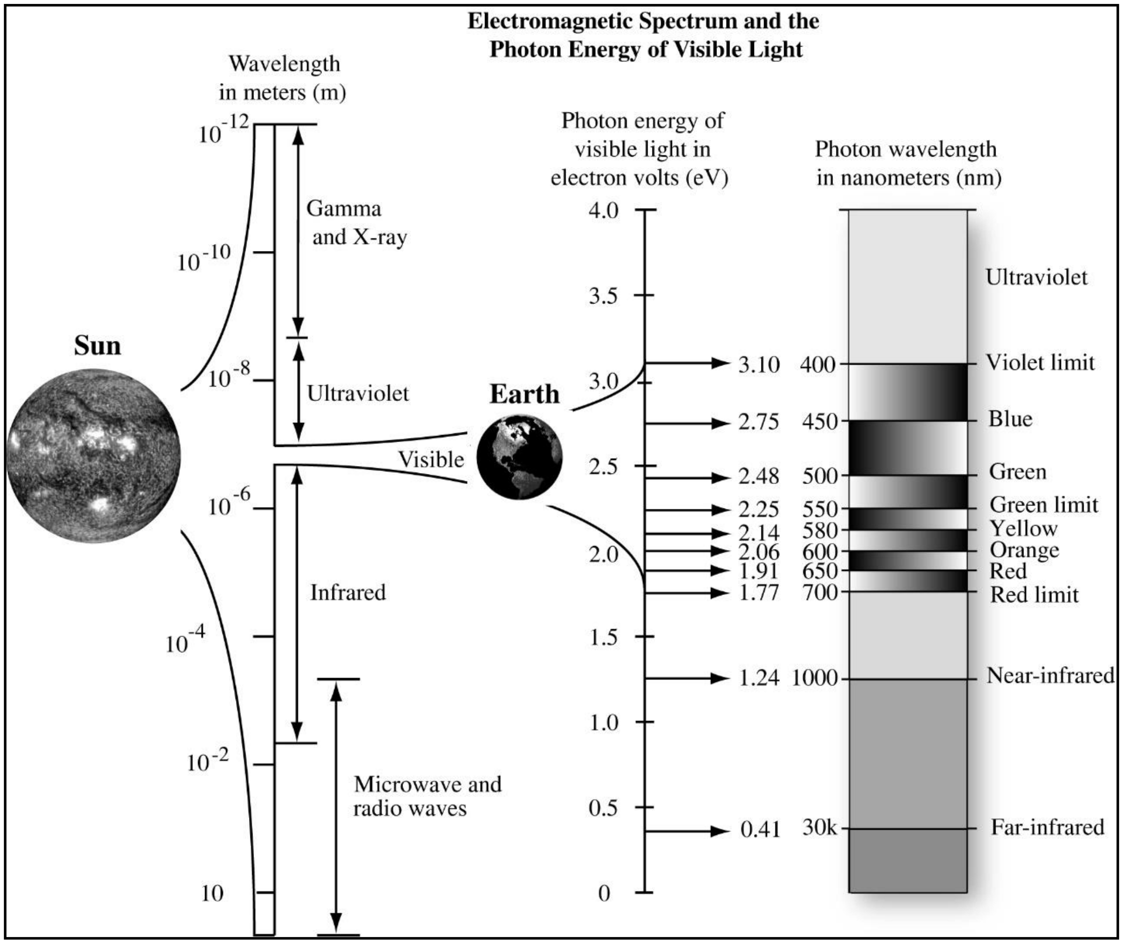
Energy may be transferred 3 ways: *conduction*, *convection*, and *radiation*:

(a) conduction: one body (molecule or atom) transfers its kinetic energy to another by colliding with it (direct contact).

(b) ***convection****:* the KE of a body is transferred from one place to another by physically moving the bodies. E.g. the convectional heating of air in the atmosphere in the early afternoon

(c) Electromagnetic energy in the form of *electromagnetic* waves (***radiation***) transmitted through the vacuum of space from the Sun to the Earth.

Electromagnetic Spectrum

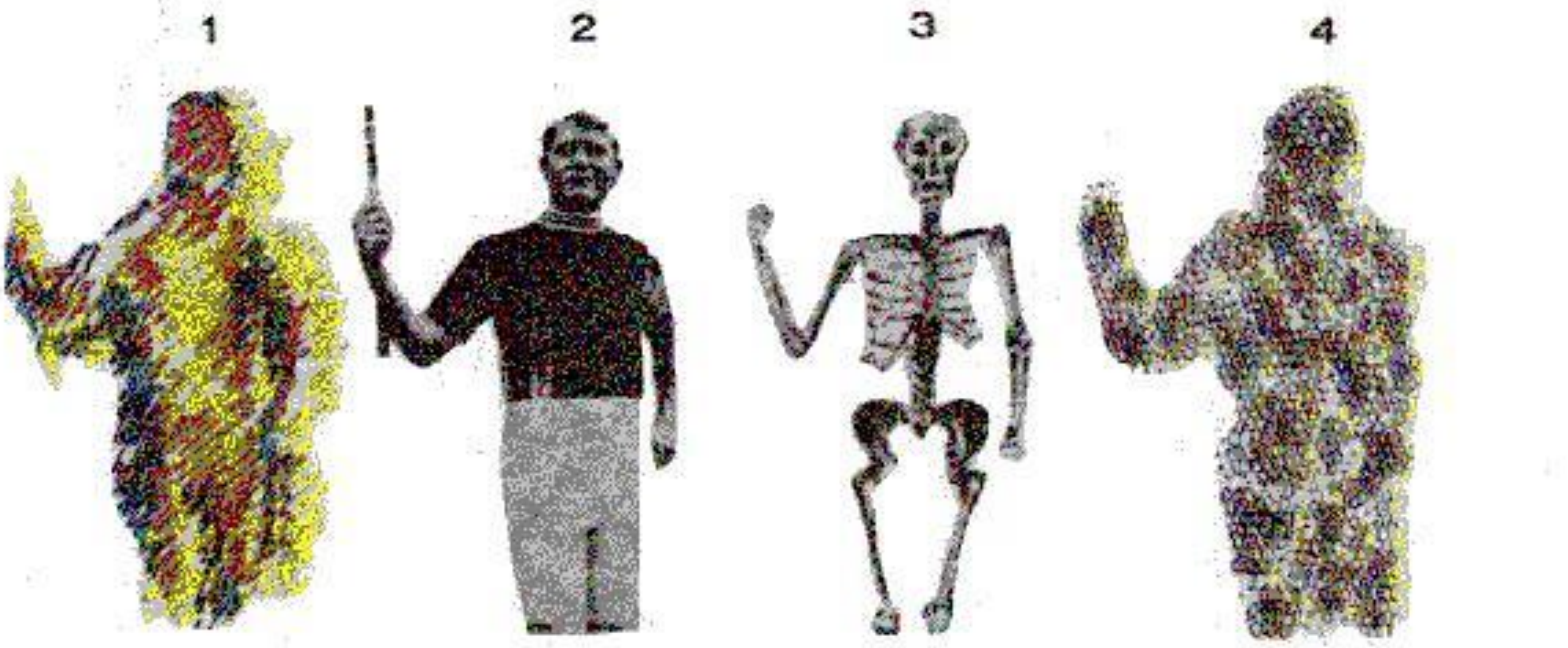


The Sun produces a *continuous spectrum* of energy from gamma rays to radio waves that continually bathe the Earth in energy.

The visible portion of the spectrum may be measured using wavelength (micrometers or nanometers) or electron volts (eV).

All units are interchangeable.

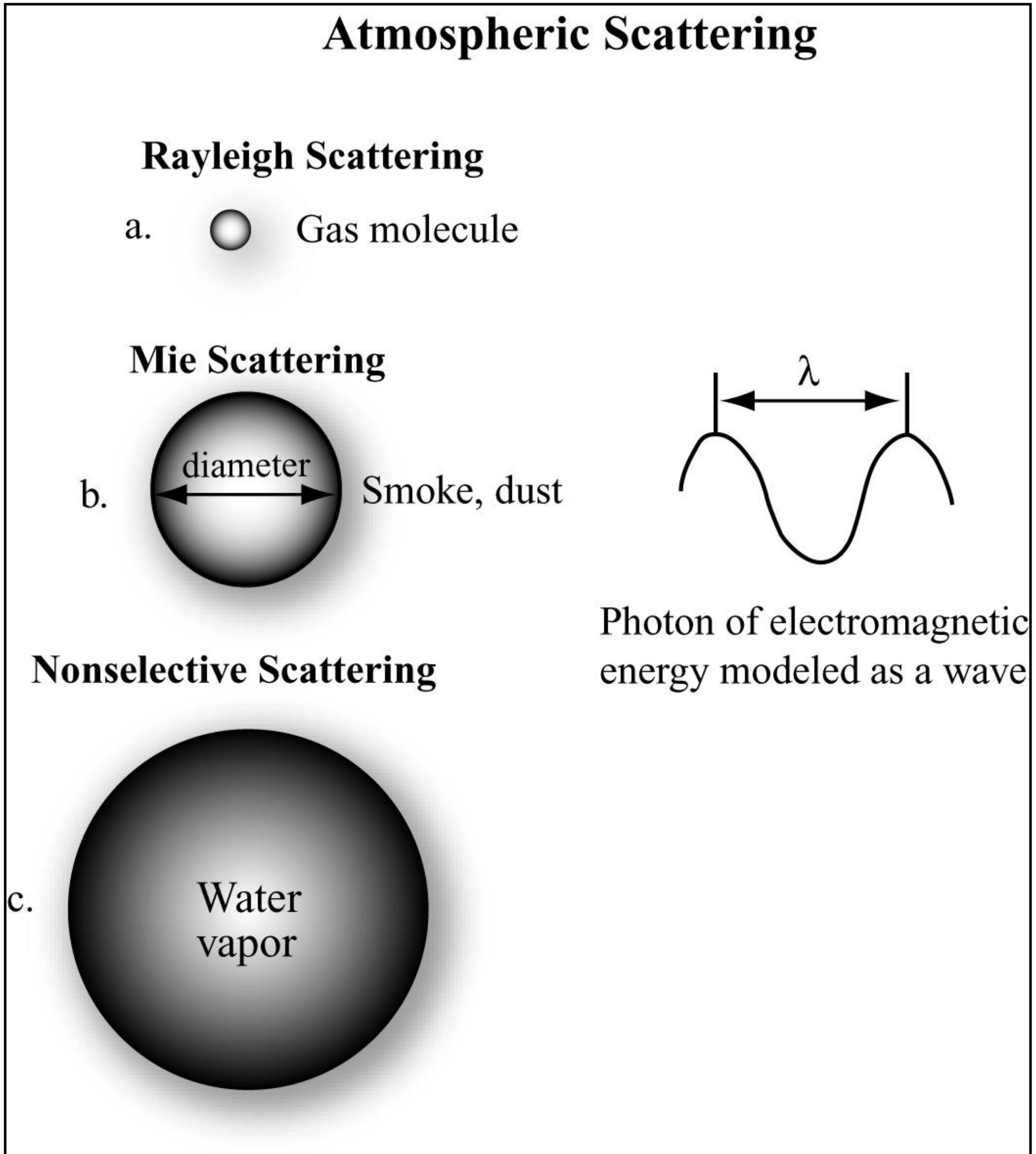
Electromagnetic Spectrum



IR device Bare eyes X-ray Microscope

A man detected by different instruments

Scattering



Once electromagnetic radiation is generated, it is propagated through the earth's atmosphere almost at the speed of light in a vacuum.

- Unlike a vacuum in which nothing happens, however, the atmosphere may affect not only the speed of radiation but also its wavelength, intensity, spectral distribution, and/or direction.

Absorption

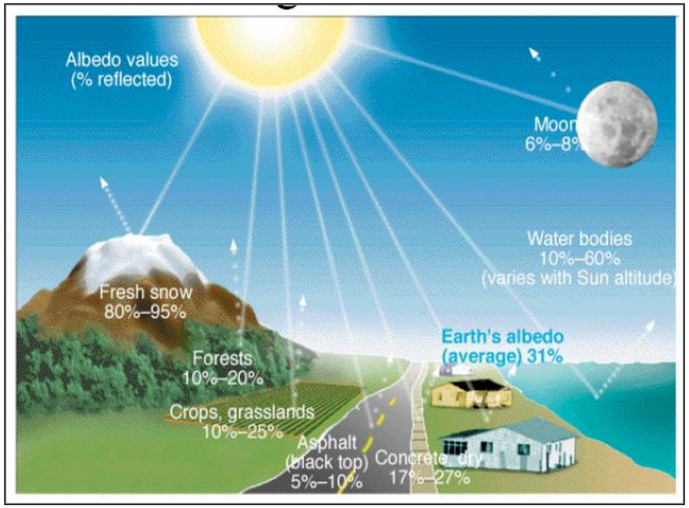
• *Absorption* is the process by which radiant energy is absorbed and converted into other forms of energy.

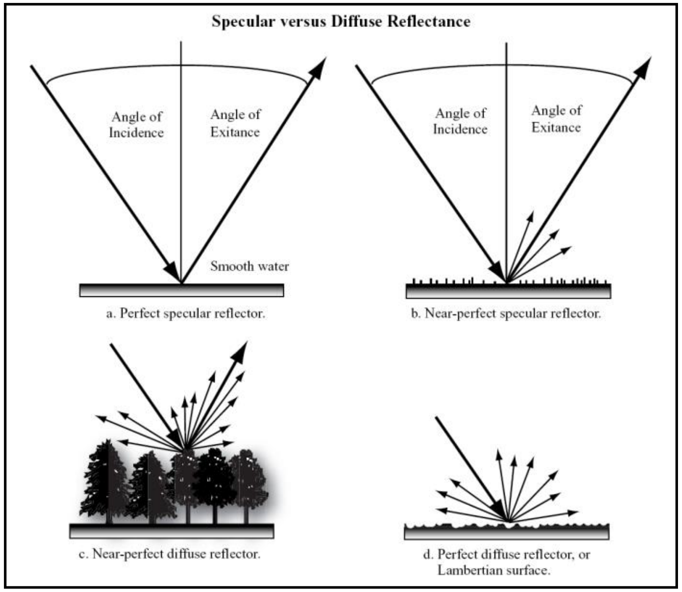
• An *absorption band* is a range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by substances such as water (H_2O), carbon dioxide (CO_2), oxygen (O_2), ozone (O_3), and nitrous oxide (N_2O).

• The cumulative effect of the absorption by the various constituents can cause the atmosphere to *close down* in certain regions of the spectrum. This is bad for remote sensing because no energy is available to be sensed.

~ 40% of sunlight is reflected by clouds
~ 20% of sunlight is absorbed by the atmosphere
~ 40% of sunlight is absorbed by the Earth's surface

Reflectance





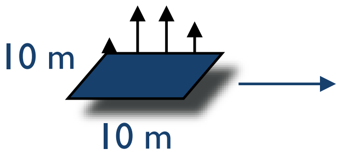
Reflectance: radiation "bounces off" an object like a cloud or the terrain.

• Reflection exhibits fundamental characteristics that are important in remote sensing:

(a) First, the incident radiation, the reflected radiation, and a vertical to the surface from which the angles of incidence and reflection are measured all lie in the same plane.

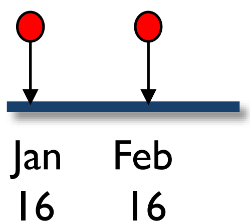
(b) Second, the angle of incidence and the angle of reflection are equal.

Remote Sensor Resolution Considerations

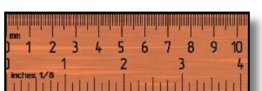


- Spatial - the size of the field-of-view, e.g. 10 × 10 m.

- Spectral - the *number* and *size* of spectral regions (or frequencies) the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared.



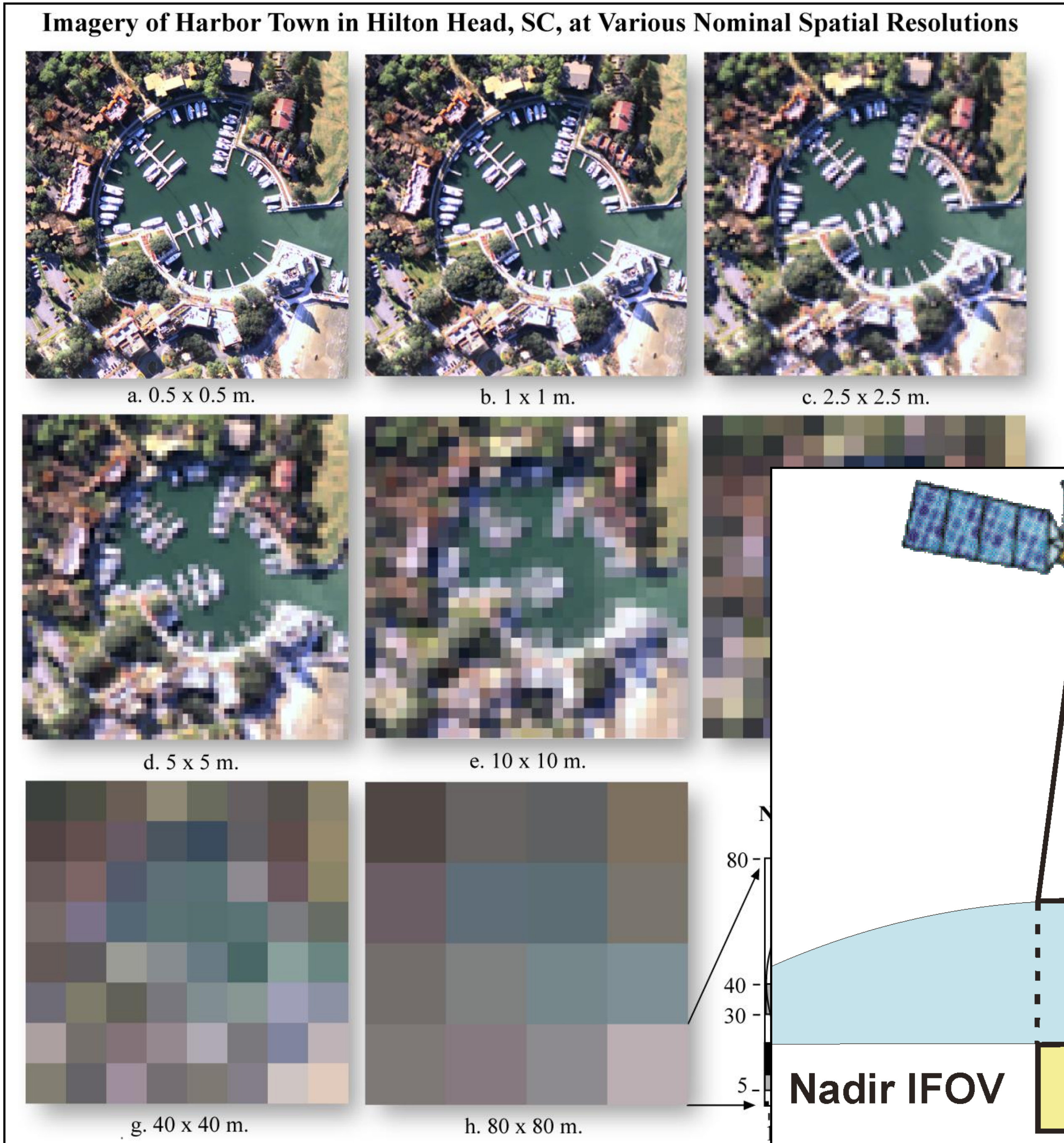
- Temporal - how often the sensor acquires data, e.g., every 30 days.

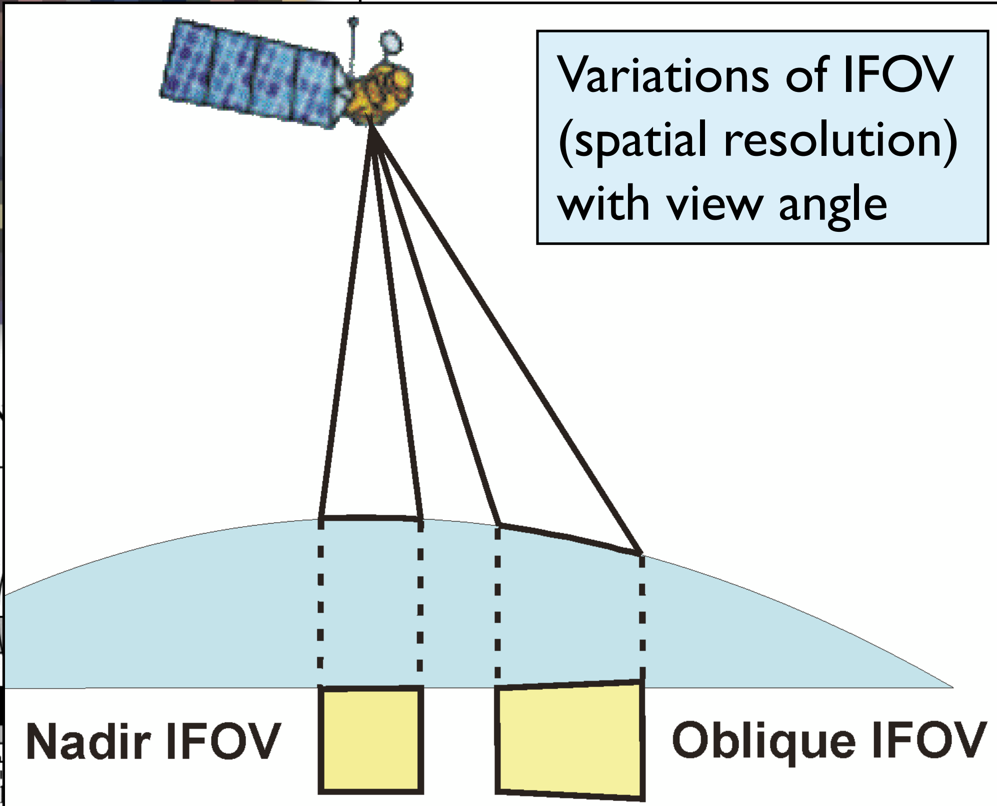


8-bit
(0 - 255)
10-bit
(0 - 1023)

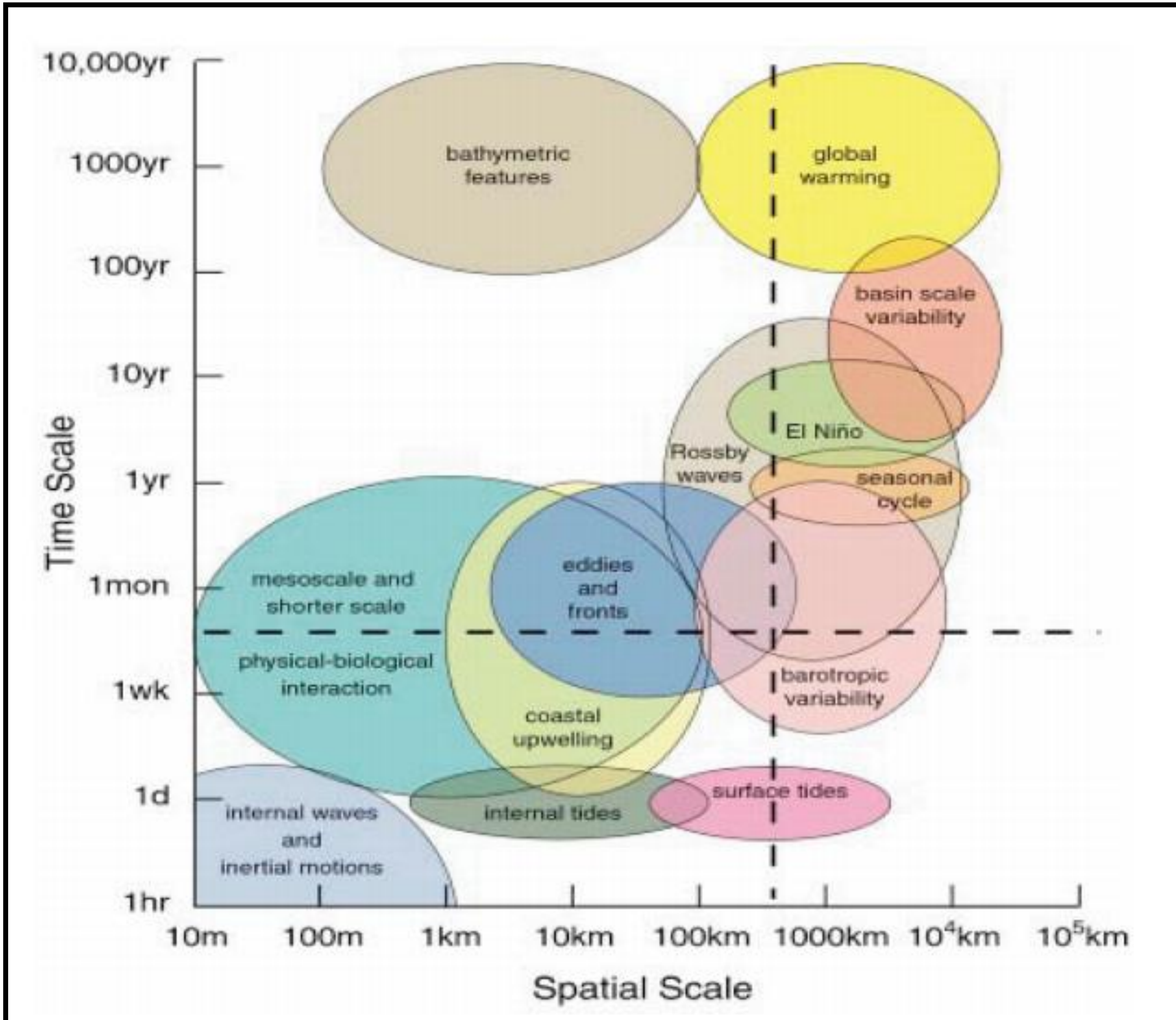
- Radiometric - sensitivity of detectors to small difference in electromagnetic energy.

Spatial Resolution



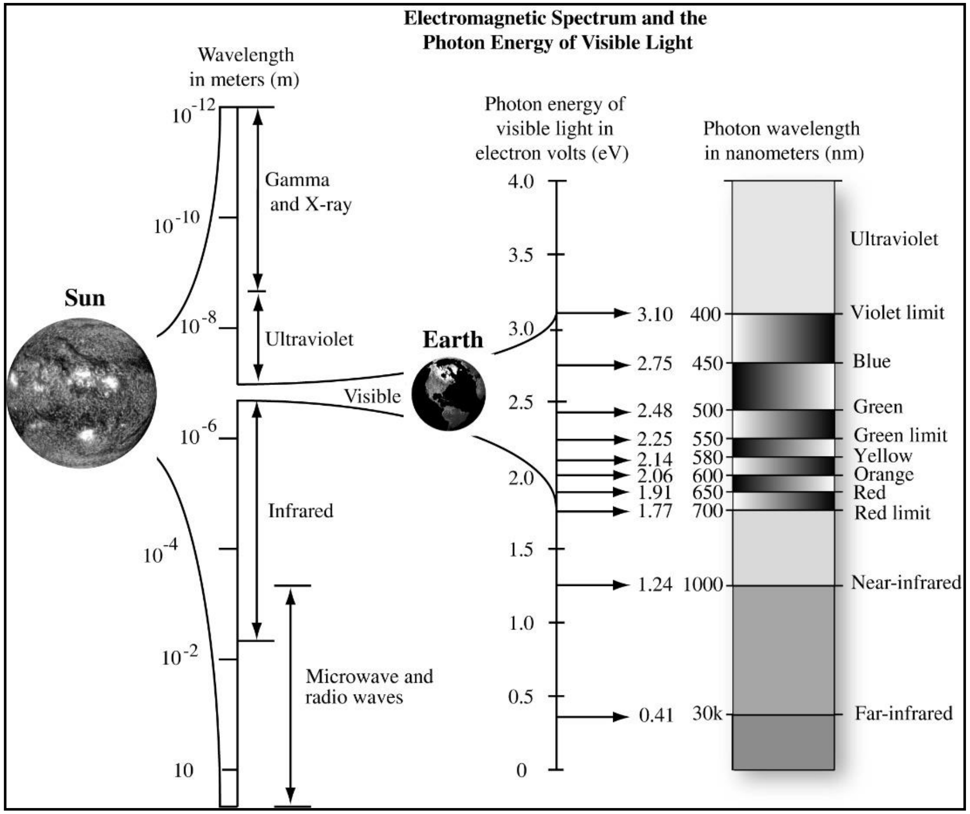


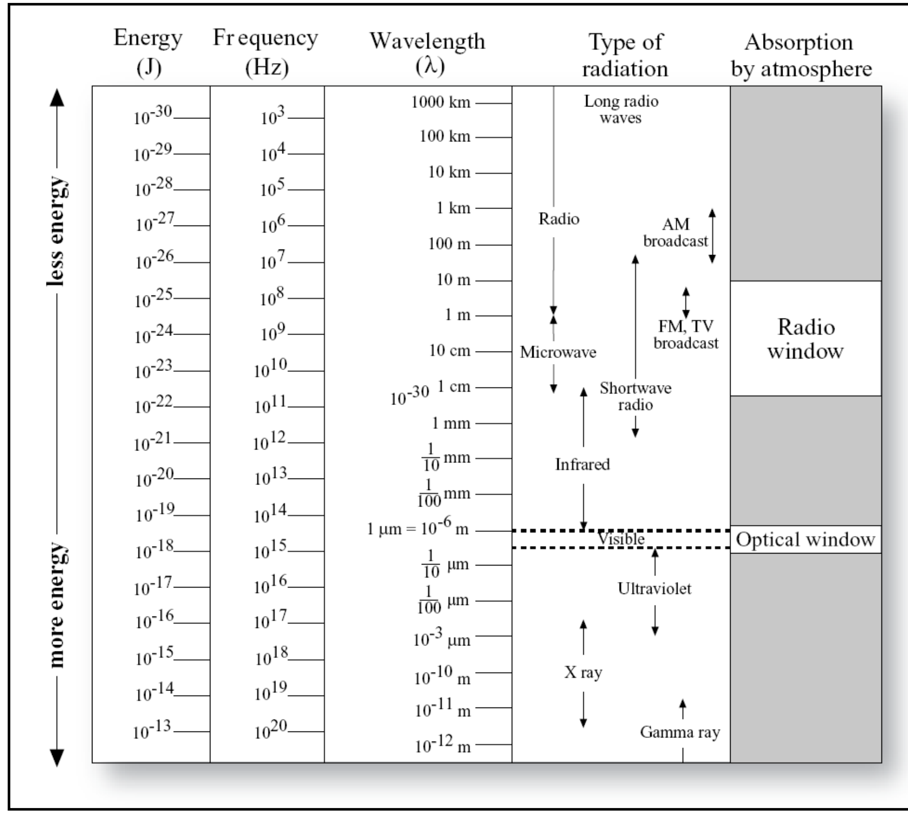
Ocean scale



Time Scale
10,000yr
1000yr
100yr
10yr
1yr
1mon
1wk
1d
1hr
bathymetric features
global warming
basin scale variability
El Niño
Rossby waves
seasonal cycle
mesoscale and shorter scale
eddies and fronts
physical-biological interaction
coastal upwelling
barotropic variability
surface tides
internal tides
internal waves and inertial motions
10m
100m
1km
10km
100km
1000km
10^4km
10^5km
Spatial Scale

Radiometry: Infrared

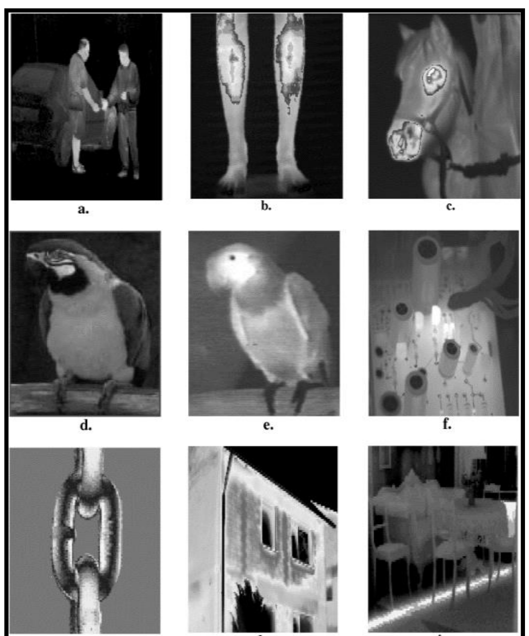


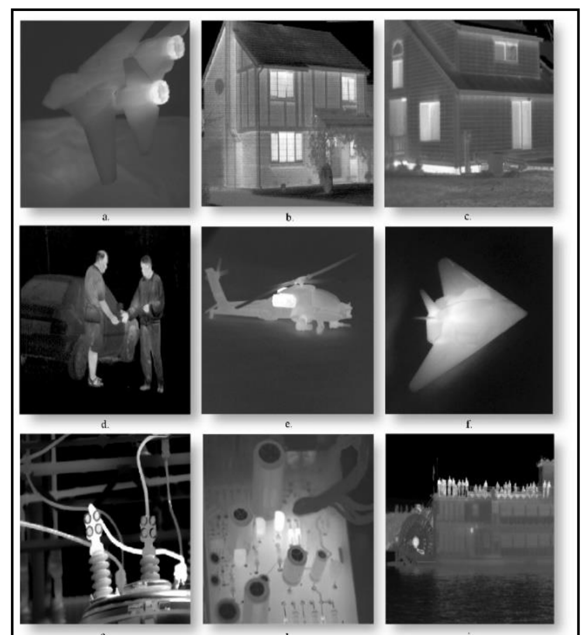


Thermal Infrared Remote Sensing

Thermal infrared energy is emitted from all objects that have a temperature greater than absolute zero. ***Radiometry*** is the techniques of measuring electromagnetic radiation.

Humans sense thermal energy primarily through the sense of touch. Our eyes cannot detect differences in thermal infrared energy because they are primarily sensitive to short wavelength visible light from 0.4 μm to 0.7 μm. Our eyes are not sensitive to the reflective infrared (0.7 - 3.0 μm) or thermal infrared energy (3.0 - 14 μm).

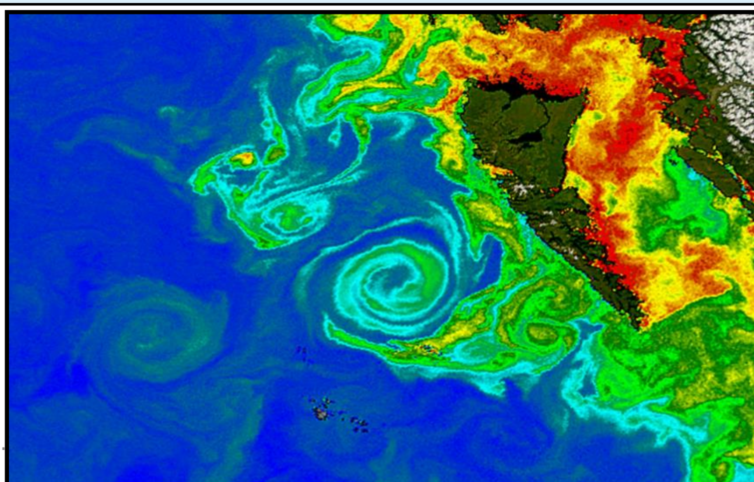


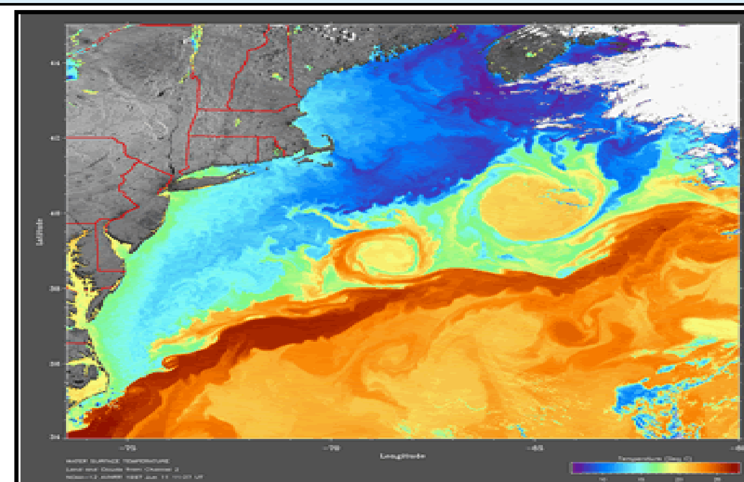


Why SST from space?

- From satellite SST we can identify and monitor surface disturbances that cross entire ocean basins, track ocean eddies and map ocean fronts

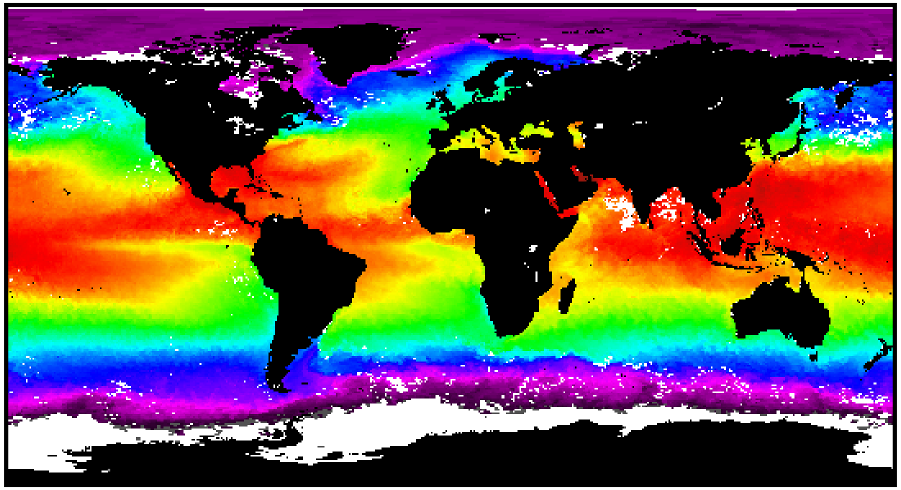
- It can also reveal striking features such as ‘storms’ in the upper ocean, known as eddies.
  - These are typically ~100 km wide and carry large amounts of energy around the globe. They play an important role in ocean circulation and climate.

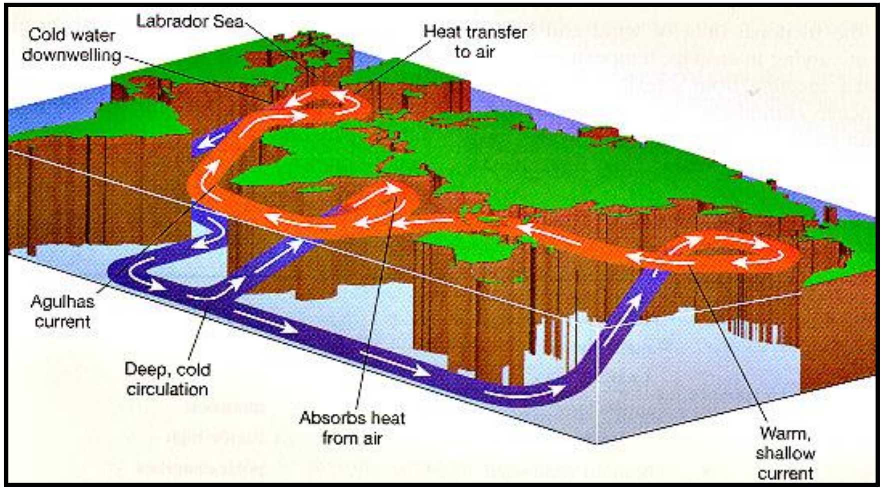




Why SST from space?

- Space-borne IR sensors estimate SST by measuring heat radiation from the ocean surface.
  - This gives the temperature of the surface 'skin', the top mm or so, rather than the bulk of the water.
  - The skin temperature is critical. It controls the exchange of heat and moisture between the ocean and atmosphere.





IR: basics and SST

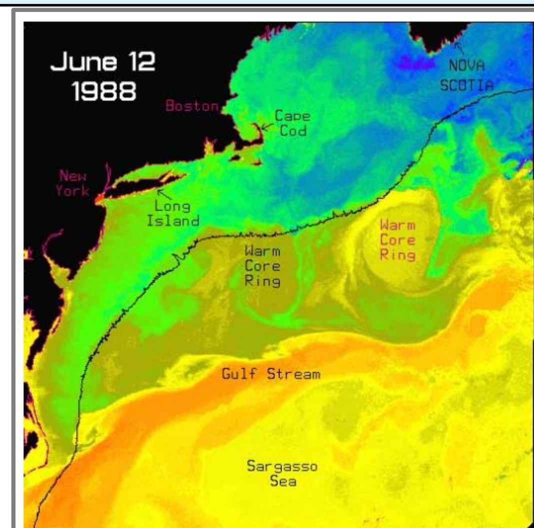
- SST is measured using a radiometer (like "night vision goggle")
  - Infrared (mainly)
  - microwave

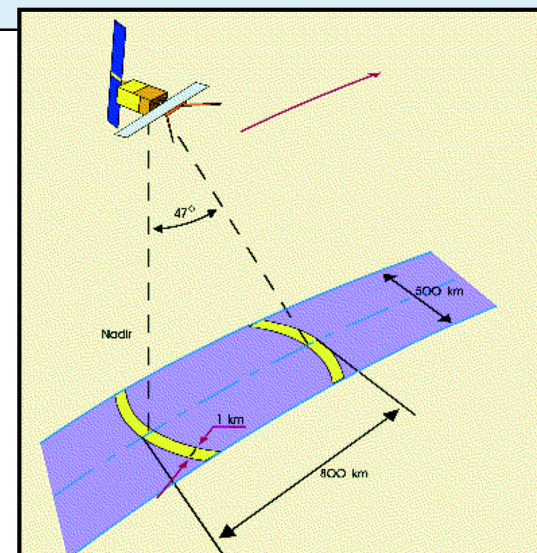
- Spectral bands used are near the peak of surface emission – the peak ones aren't used due to atmospheric effects

- It is measured by:
  - taking the intensity of radiation at top of atmosphere
  - removing the atmospheric contribution
  - results in the brightness temperature (T_B) at the surface. **T_B is approximately equal to the SST**

IR: basics and SST

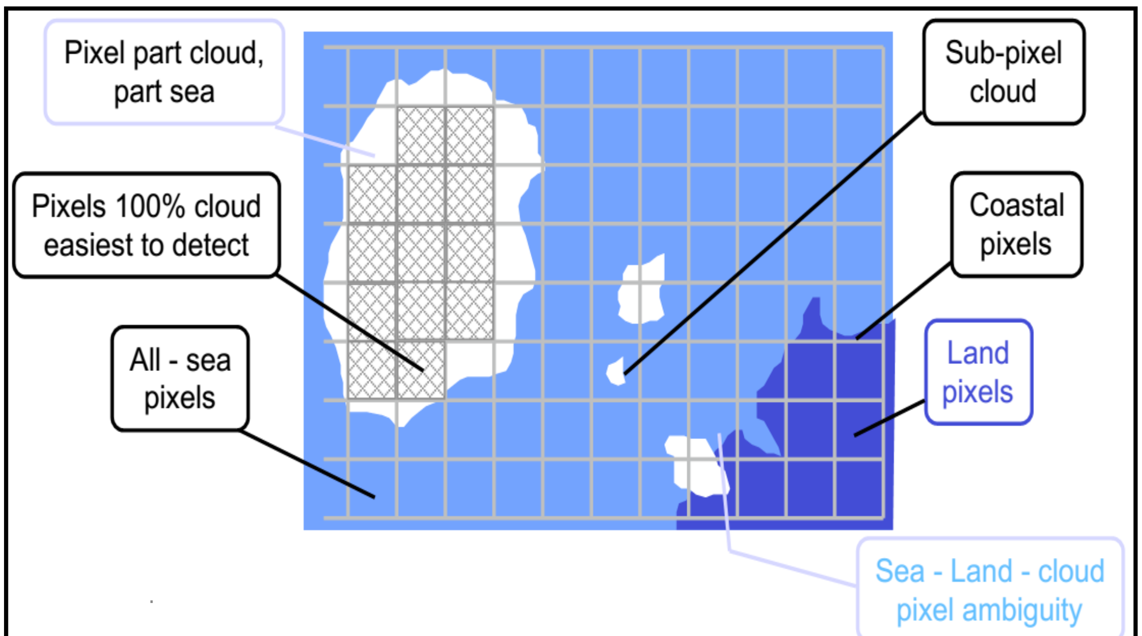
- Popular SST products:
  - NOAA Multi-channel (MC)/Pathfinder SST global. AVHRR sensor has been available since 1978
  - ATSR ASST (Along-Track Scanning Radiometer Average Sea Surface Temperature Products) on ERS-1& ERS-2
  - TRMM (Tropical Rainfall Measuring Mission) TMI (TRMM Microwave Imager) SST





Cloud detection

- Temperature thresholds
- Visible waveband threshold (daytime only)
  - various things in image - land sea cloud have different spectral characteristics - different intensities in different spectral bands

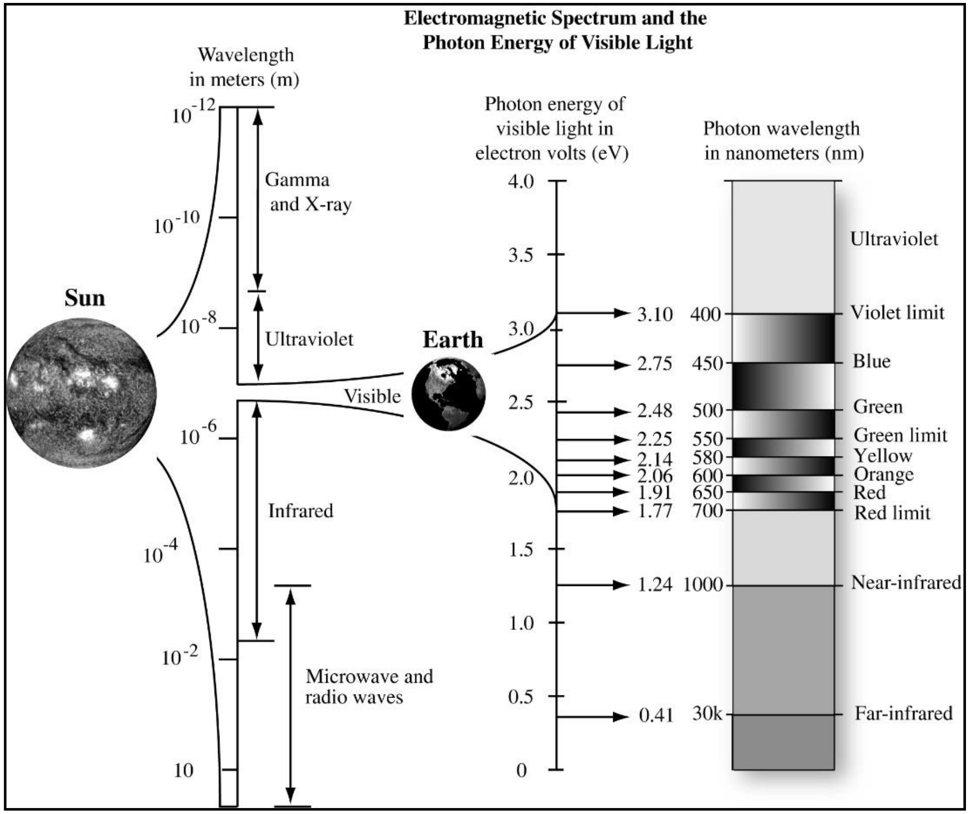


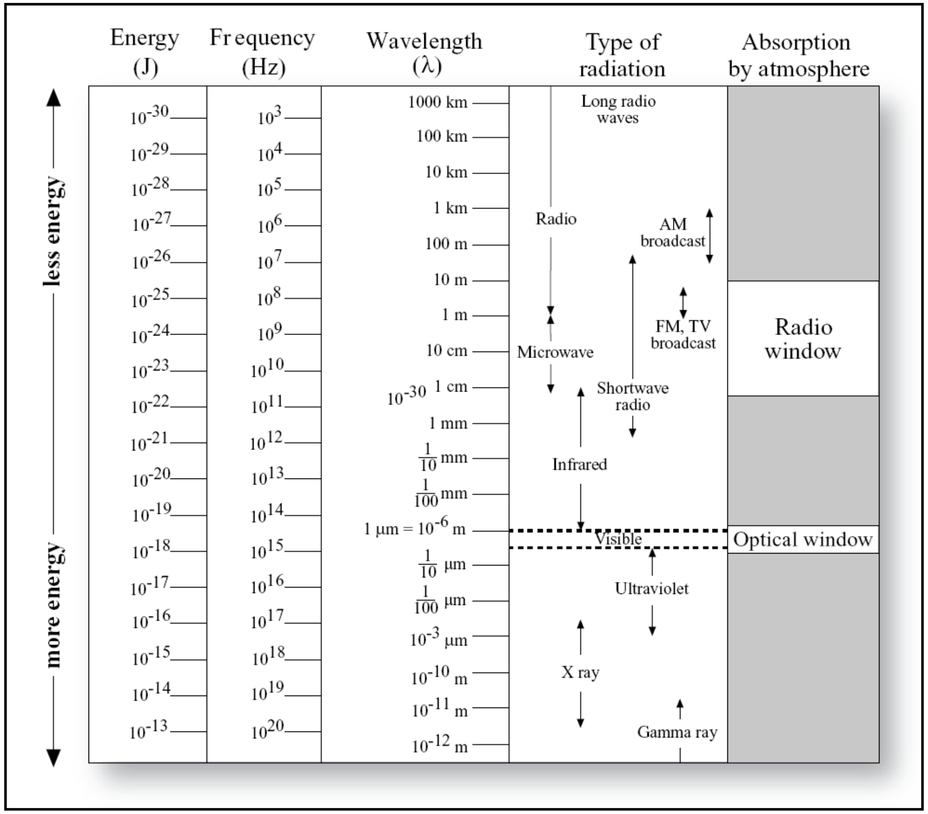
- spatial coherency testing
- multi-spectral tests
- problems with sub-pixel clouds

Applications of satellite-measured SST

Application	Area covered	Spatial resolution (km)	Time span of data	Sampling Interval	Sensitivity °C	Accuracy K
Climatological database	Global	50	30 years	5-10 days		0.2
Global SST for CO_2 monitoring	Global	200	> 5 years	15 days		0.05
Weather forecasting	Global	10		2-5 days		0.5
Ocean heat flux	Ocean basin	50	5 years	2 days		0.2
Deep convection	Regional (500-1000km)	5	10-60 days in late winter	1 day	0.1	0.1
Dynamical processes:						
Equatorial long waves	Ocean basin	50	1 year	1-5 days	0.3	1
Mesoscale eddies	Regional	5	1 year	1 day	0.2	1
Fronts	Regional	1	10-100 days	1 day	0.2	1
Upwelling	Regional	1	10-100 days	1 day	0.1	1
Coastal discharges and pollution	Local (200-500km)	0.3-1	10 days	hours	0.1	1

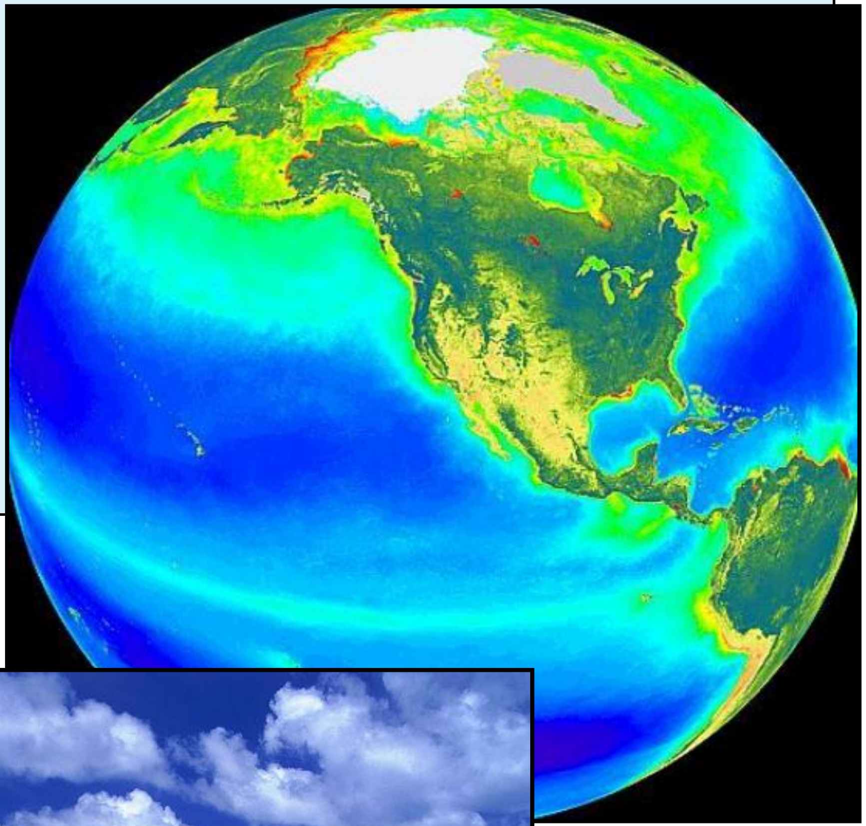
Visible waveband: Ocean color





What is the color of the ocean?

- The color of the ocean appears BLUE in clear water.
- But it changes due to :
  -- Phytoplankton patchiness
  -- Inorganic/Organic matter



What is the color of the ocean?

• Clean ocean water absorbs red light, i.e., sun radiation of long wavelength and transmits and scatters the light of short wavelength. That is why ocean surface looks blue.

• Phytoplankton cells contain chlorophyll that absorbs other wavelengths and contributes green color to ocean water.

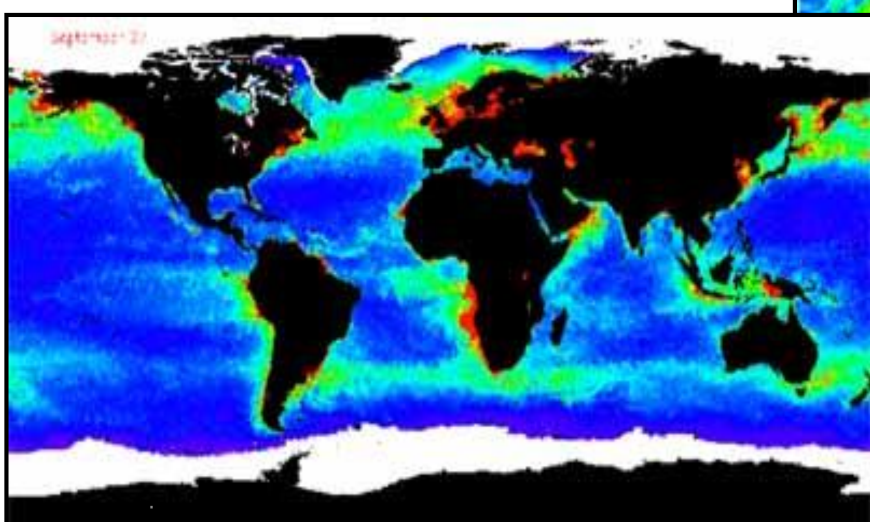
• In coastal areas suspended inorganic matter backscatters sunlight, contributing green, yellow and brown to water color.

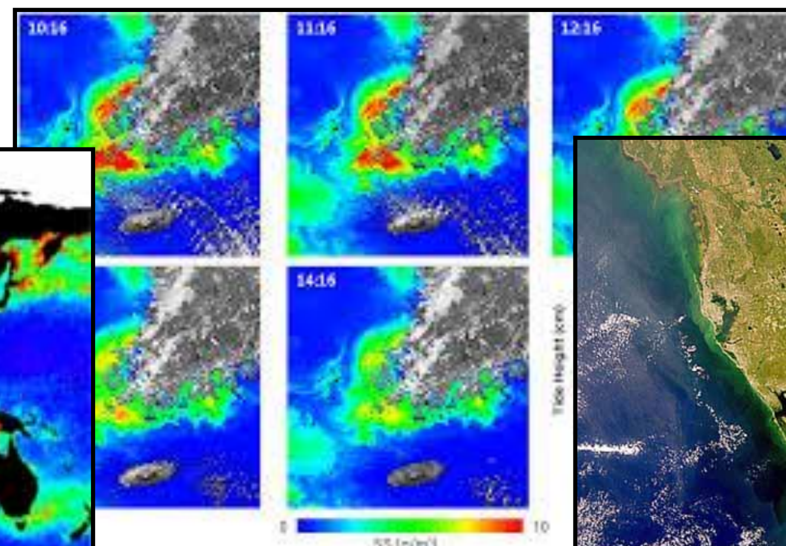
Why ocean color from space?

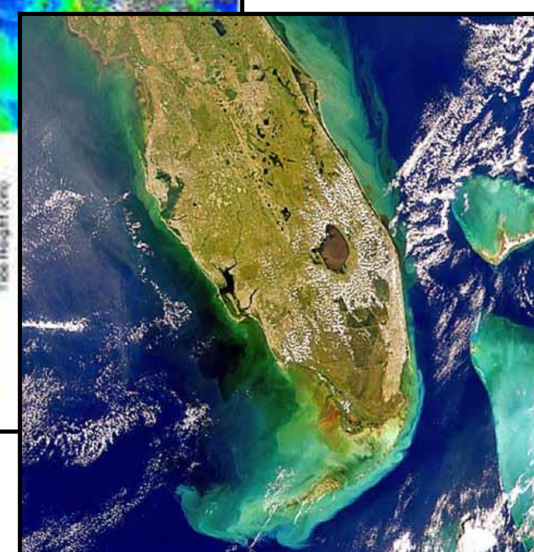
- ☐ Locates and enables monitoring of regions of high and low bio-activity. Synoptic Scales of Pigments
- ☐ Food–primary production (phytoplankton linked with chl); marine fisheries
- ☐ Climate (phytoplankton, possible CO_2 sink-carbon budget)
- ☐ Seasonal influences; phytoplankton blooms; upwelling
- ☐ River and Estuary plumes and influences
- ☐ Boundary currents. Reveals current structure & behavior.
- ☐ Reveals Anthropogenic influences (pollution); oil spills
- ☐ Remote sensing reveals large and small scale structures that are very difficult to observe from the surface.

Major Ocean Color Data Products

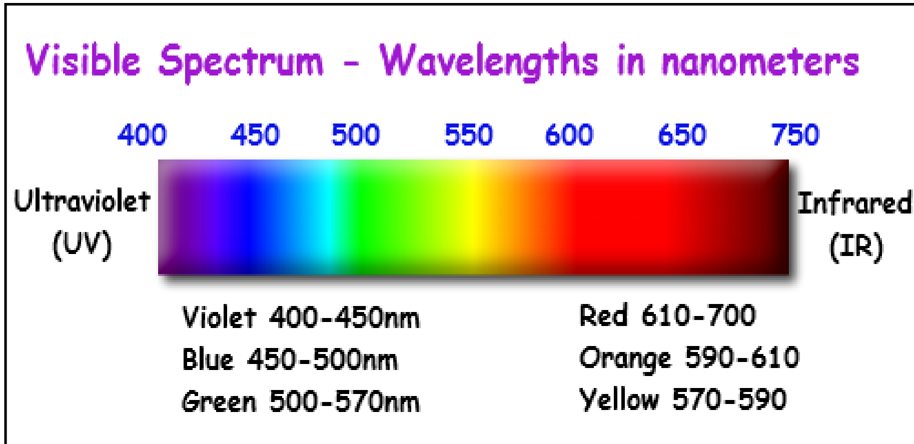
- ✓ Chlorophyll
- ✓ Suspended Sediments
- ✓ Yellow Substances
- ✓ Aerosol

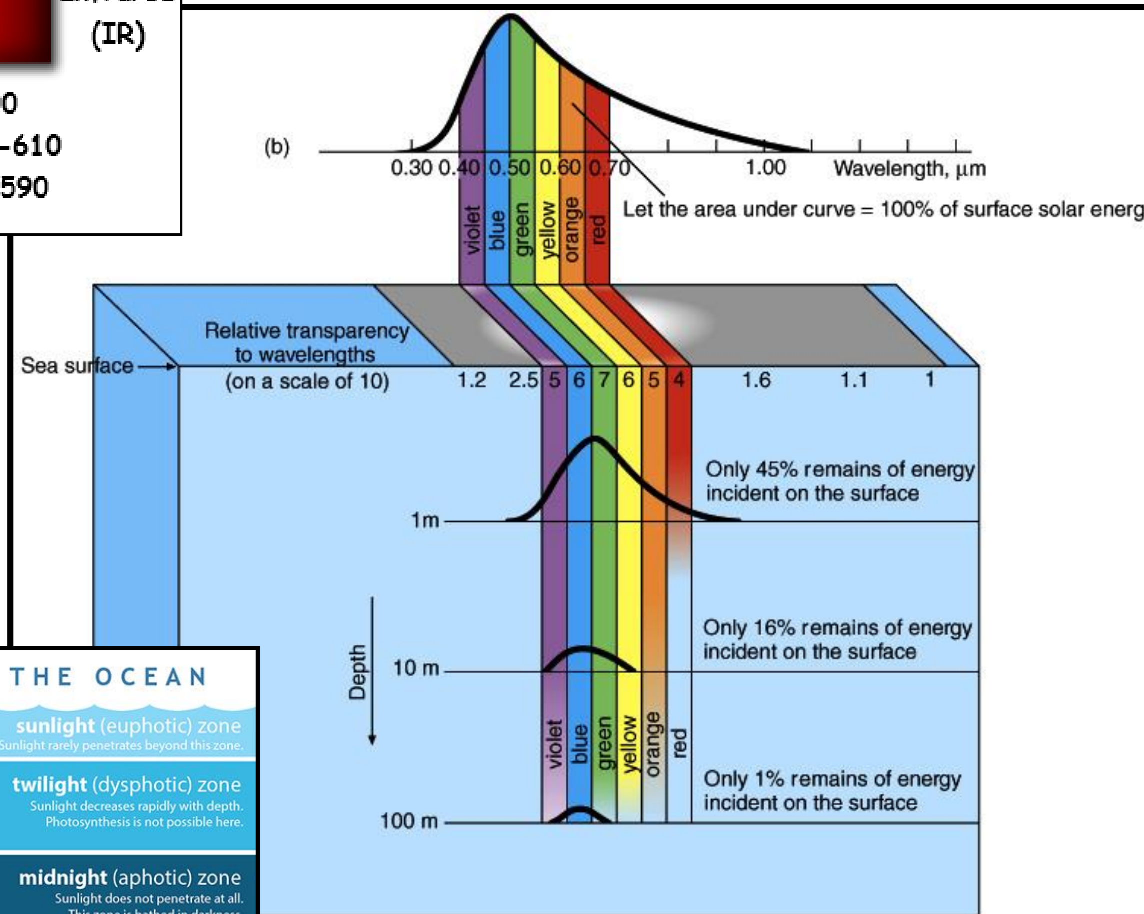


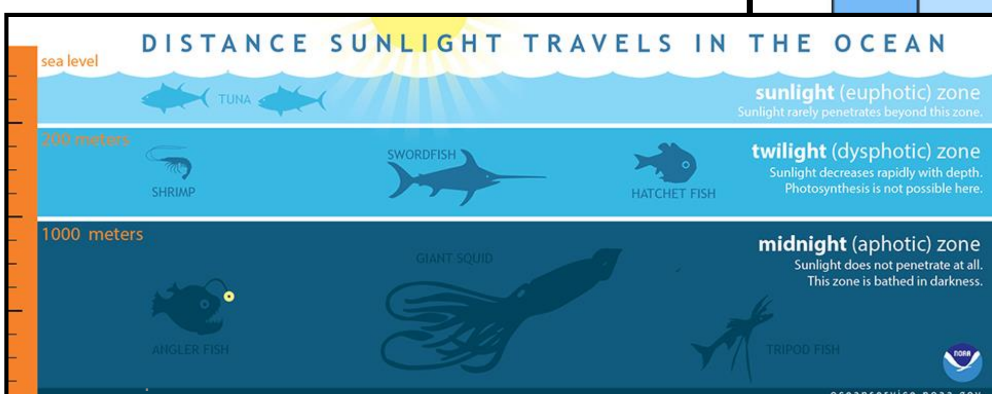




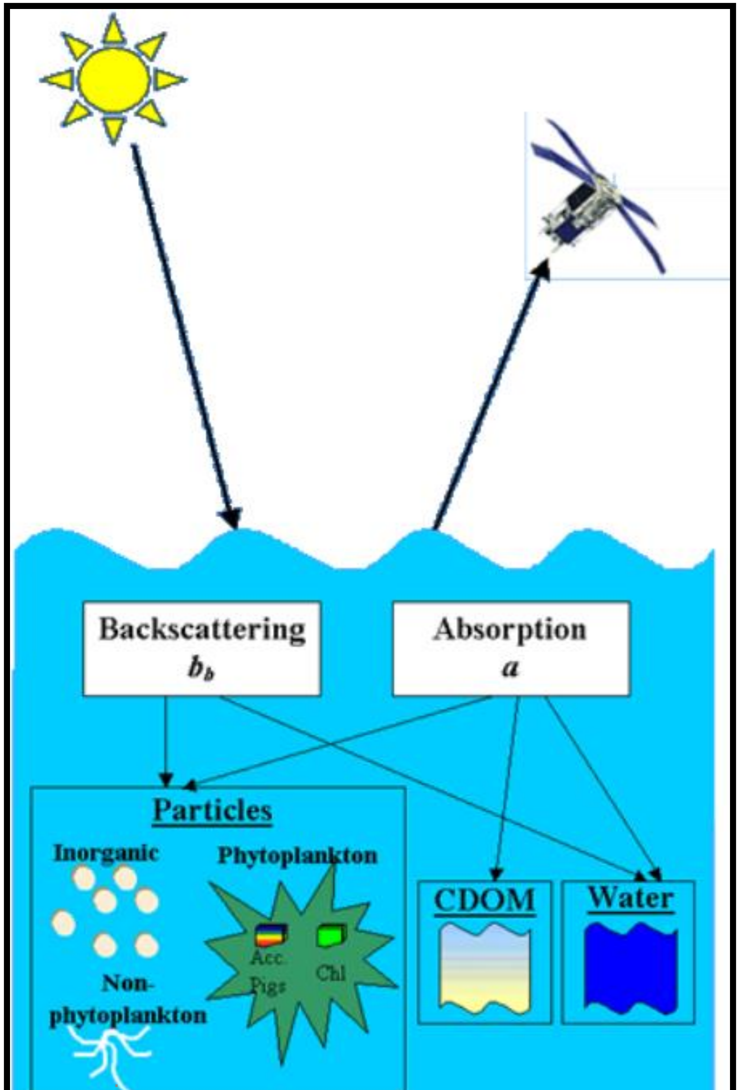
Principles of satellite measurements of ocean color

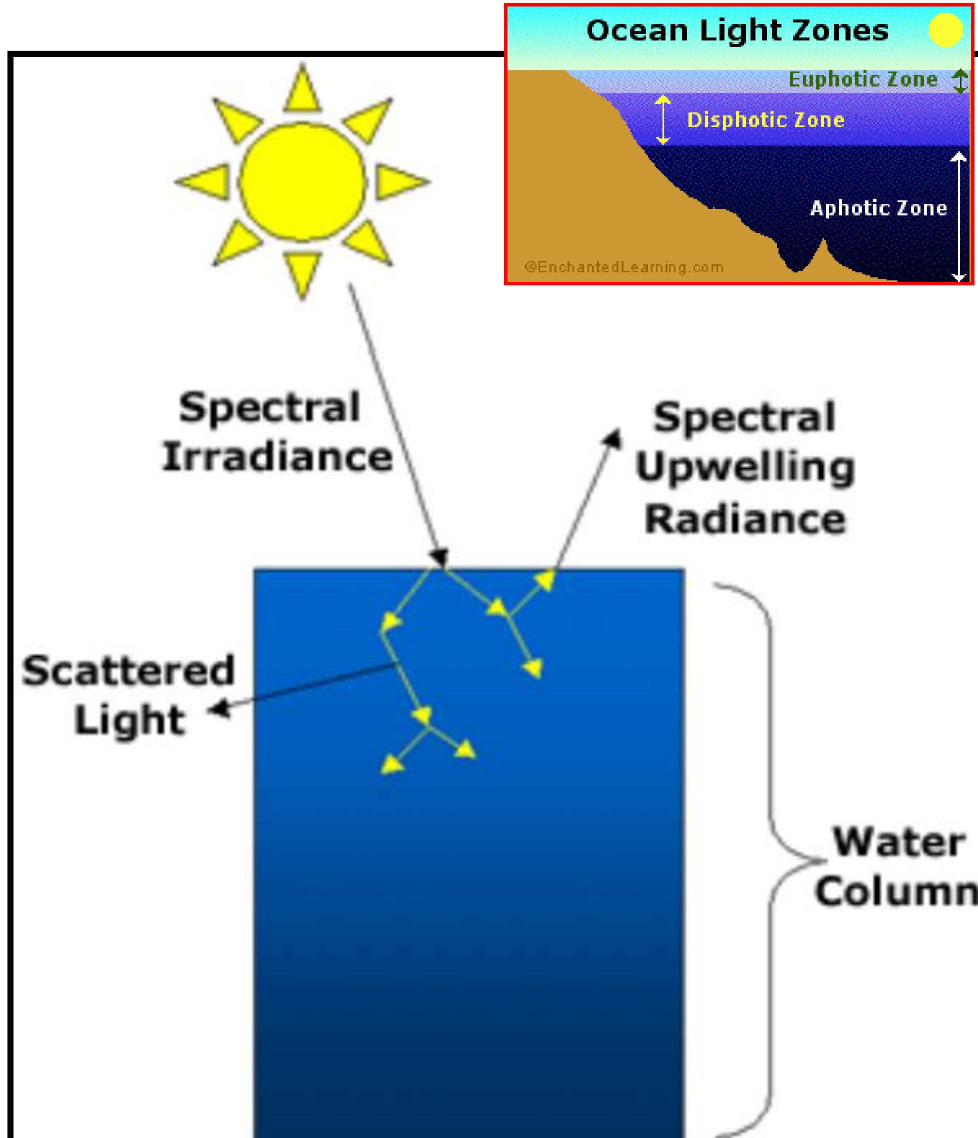




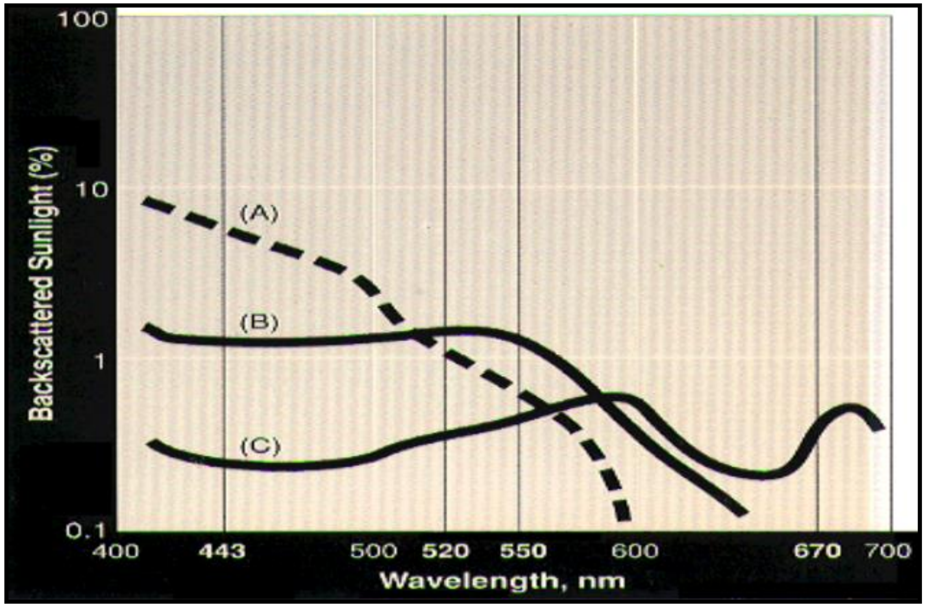


Basic principles of satellite measurements of ocean color





Principles of satellite measurements of ocean color



Ocean color can be measured on the basis of the spectrum of visible light emitted from the study object.

Clean ocean water (A) has maximum in short (blue) wavelength and almost zero in yellow and red.

Higher is phytoplankton (i.e., chlorophyll and other plant pigments) concentration, more is contribution of green color (B).

In coastal zones with high concentration of dead organic and inorganic matter light spectrum has maximum in red (C).

Sources of ocean color change

- Phytoplankton and its pigments

- Dissolved organic material

  -- Colored Dissolved Organic Material (CDOM, or yellow matter, or gelbstoff) from decaying vegetable matter (land) and phytoplankton degraded by grazing of photolysis.

- Suspended particulate matter

  -- The organic particulates (detritus) consist of phytoplankton and zooplankton cell fragments and zooplankton fecal pellets.

  -- The inorganic particulates consist of sand and dust created by erosion of land-based rocks and soils. These enter the ocean through:

  -- River runoff.

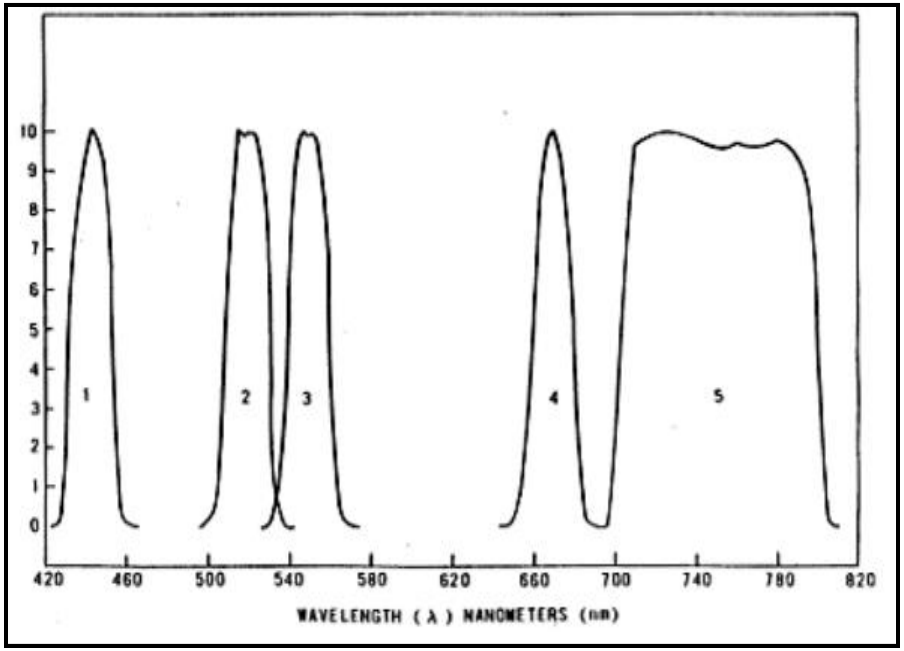
  -- Deposition of wind-blown dust.

  -- Wave or current suspension of bottom sediments.

Current ocean color sensors

SENSOR	AGENCY	SATELLITE	OPERATING DATES	SWATH (km)	RESOLUTION (m)	NO. OF BANDS	SPECTRAL COVERAGE (nm)
MOS Moderate Opto - elecrical Scanner	DLR (Germany)	IRS –P 3 (India)	21-Mar-1996	200	500	18	408-1600
SeaWiFS	NASA (USA)	OrbView –2 (USA)	1-Aug-1997	2806	1100	8	402-885
OCI	NEC (Japan)	ROCSAT –1 (Taiwan)	Jan 1999	690	825	6	433-12500
OCM	ISRO (India)	IRS – P4 (India)	26-May-1999	1420	350	8	402-885
MODIS-TERRA	NASA (USA)	EOS – Terra (USA)	18-Dec-1999	2330	1000	36	405-14385
MISR	NASA (USA)	EOS – Terra (USA)	18-Dec-1999	360	250	4	446-867
OSMI	KARI (Korea)	KOMPSAT (Korea)	20-Dec-1999	800	850	6	400-900
MERIS	ESA (Europe)	ENVISAT –1 (Europe)	1-Mar-2002	1150	300/1200	15	412-1050
MODIS-AQUA	NASA (USA)	EOS –Aqua (USA)	4-May-2002	2330	1000	36	403-14385
OCTS	CNSA (China)	Hai Yang –1 (China)	15-May-2002	1400	1100	10	402-12500

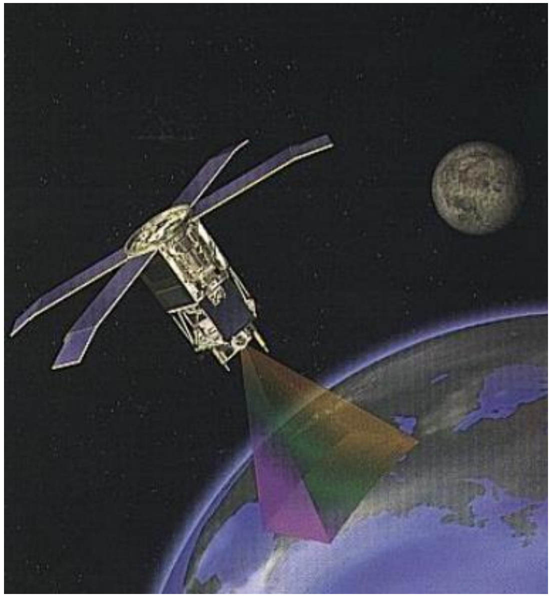
CZCS -- Coastal Zone Color Scanner (1978 - 1986)



- was a multispectral line scanner developed by NASA to measure ocean color.
- Sun-synchronous, near polar
- CZCS was launched aboard Nimbus-7 satellite platform in October 1978

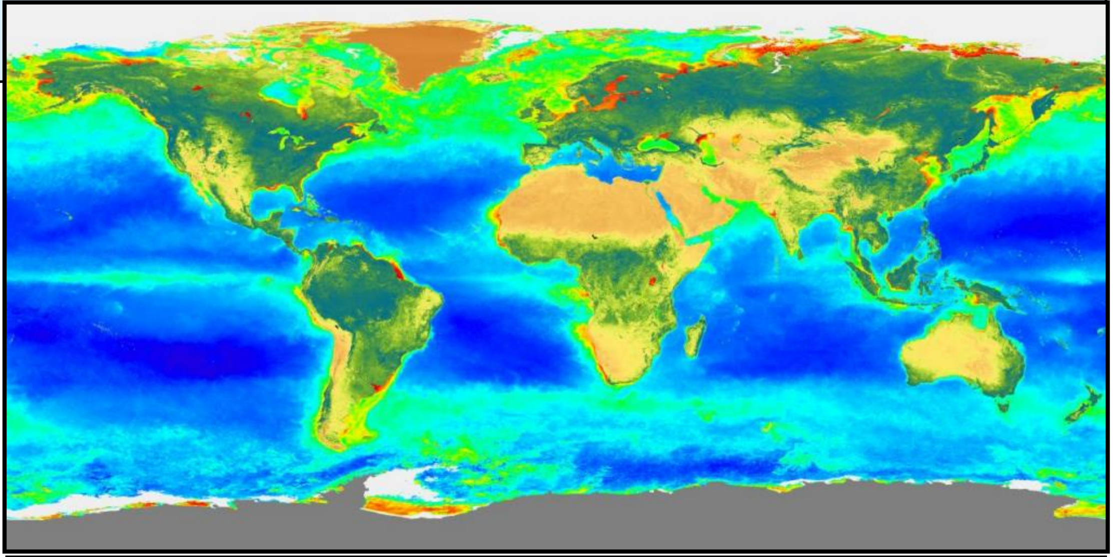
1	433-453 nm (blue)	chlorophyll absorption
2	510-530 nm (green)	chlorophyll concentration
3	540-560 nm (yellow)	Gelbstoffe concentration
4	660-680 nm (red)	aerosol absorption
5	700-800 nm (far red)	land and cloud detection

SeaWiFS-- Sea-viewing Wide Field-of-view Sensor (since 1997)



- The SeaWiFS program was started in 1980s, immediately after the end of the CZCS mission.
- Sun Synchronous orbit
- launched on August 1, 1997 by SeaStar Space Craft.

Band	Wavelength
1	402-422 nm
2	433-453 nm
3	480-500 nm
4	500-520 nm
5	545-565 nm
6	660-680 nm
7	745-785 nm
8	845-885 nm



Ocean Chl and Normalized Digital Vegetation Index (NDVI) computed from SeaWiFS

MODIS--Moderate Resolution Imaging Spectroradiometer

- Two MODIS sensors:
  -- **Terra** satellite launched December 18th, 1999

  -- **Aqua** satellite launched May 4th, 2002.

- Both have sun-synchronous near-polar orbit.

- Terra's orbit around the Earth is timed so that it passes from N to S across the equator in the morning (10:30 a.m., descending node)

- Aqua passes S to N over the equator in the afternoon (1:30 p.m., ascending node).