Remote Sensing for Resource Management

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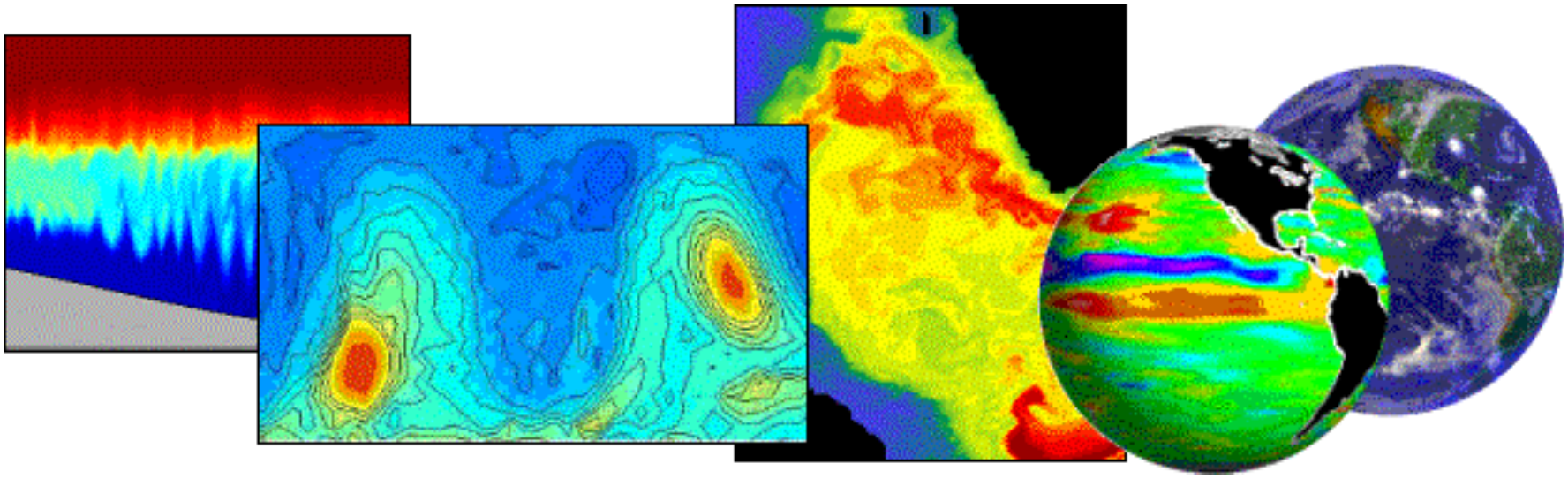

RMU Summer Program (July 31-AUG 4, 2017)

Motivation


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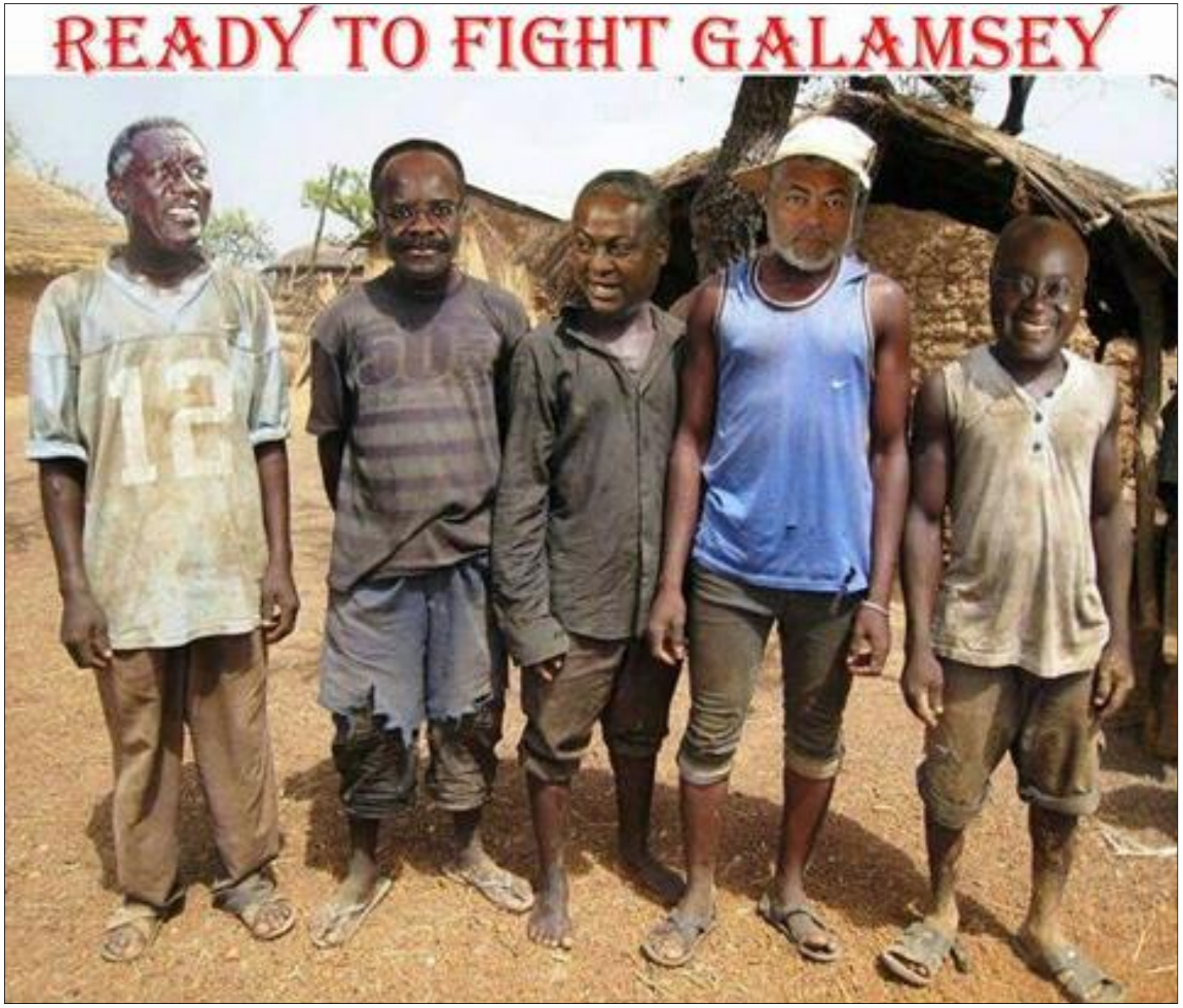

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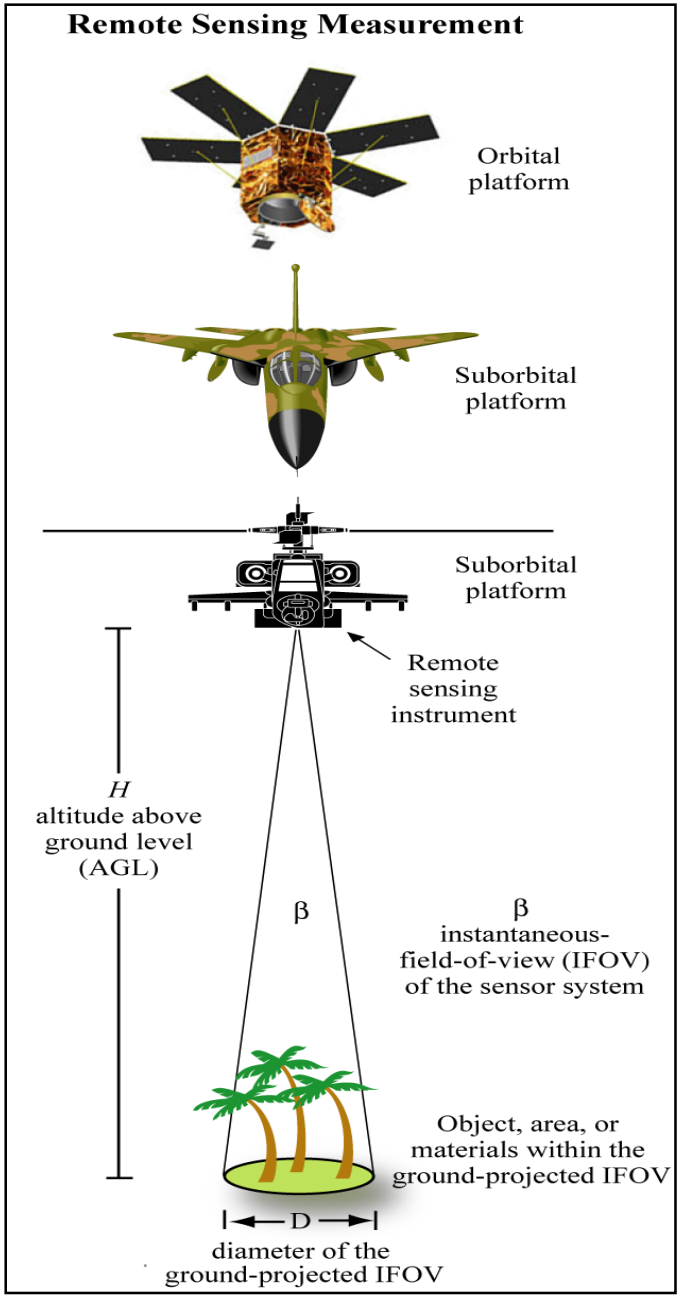
Introduction

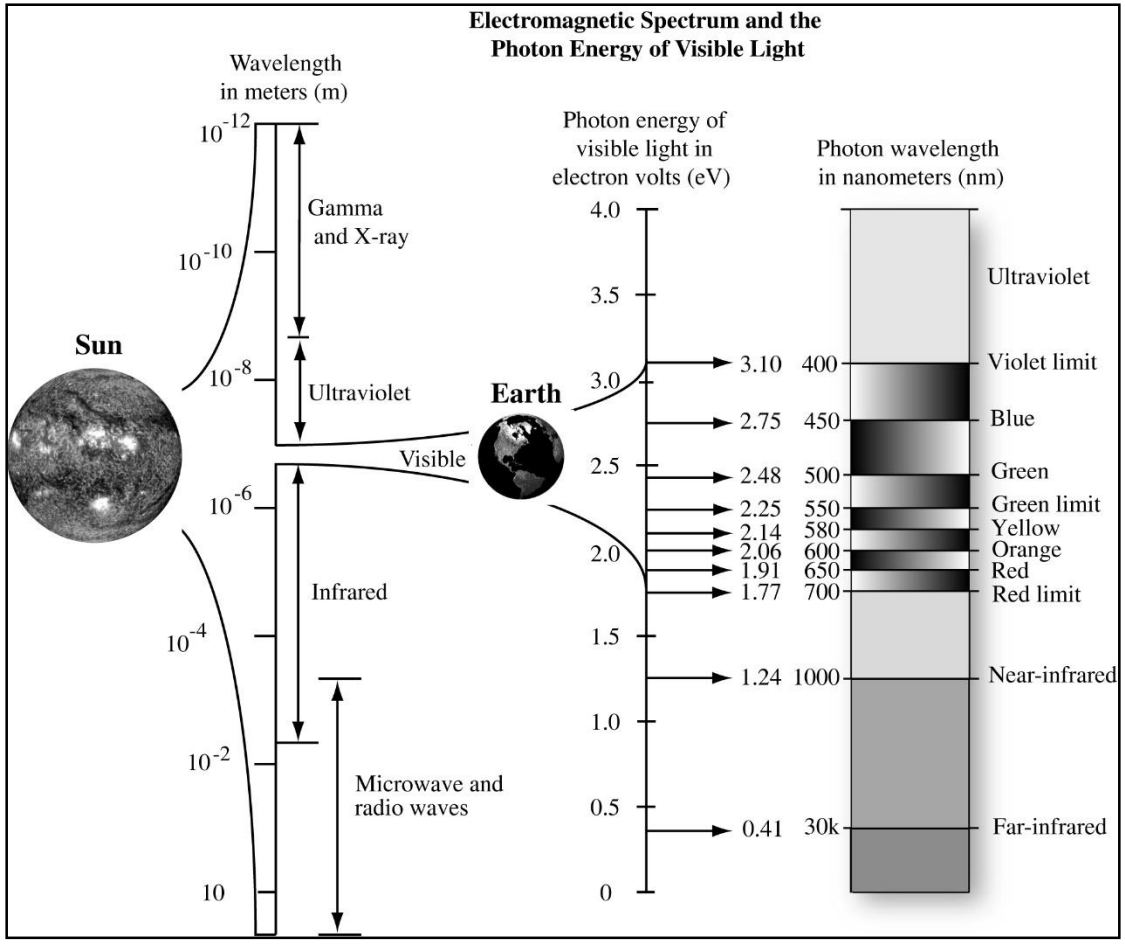


Remote Sensing:

"the *art*, *science*, and *technology* of obtaining reliable information about the properties of an object *without coming into physical contact* with the object

- Sample Electromagnetic Radiation
- Acquire geospatial data
- Convert energy into image
- Extract info about features

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.

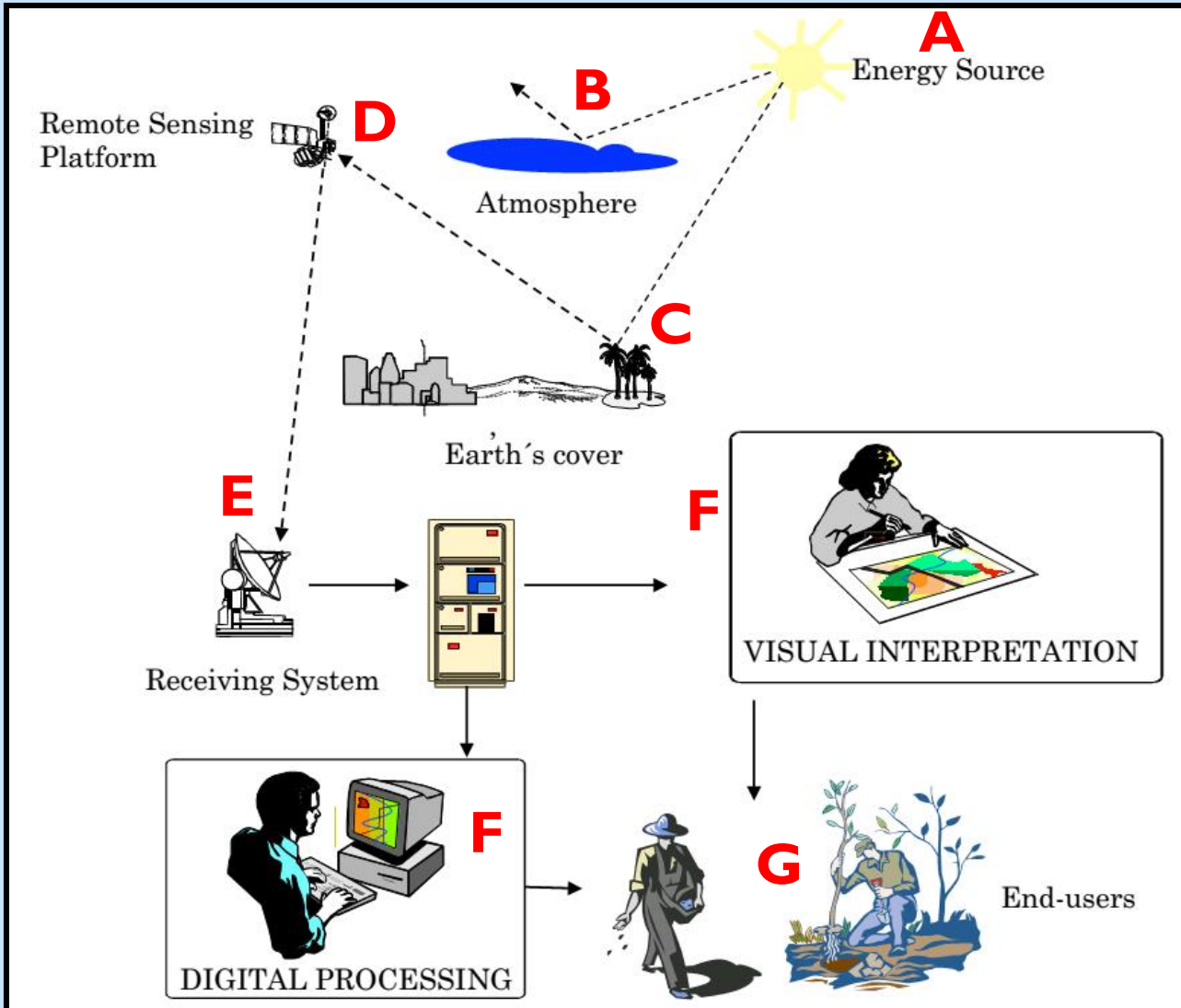
Importance of satellite oceanography

- Observes the distribution of certain ocean surface properties in exquisite **spatial detail**: large area coverage
- Captures a "snapshot" of the spatial distribution. "Freezes" the continually changing ocean
- Offers a repeated view: consistent measurements by a single sensor – **repetitive**
- Some sensors are all season, all weather
- 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

Elements of the remote sensing process



A. Energy Source

B. Radiation and Atmosphere

C. Interaction with target

D. Energy recorded by sensor

E. Transmission, reception, processing

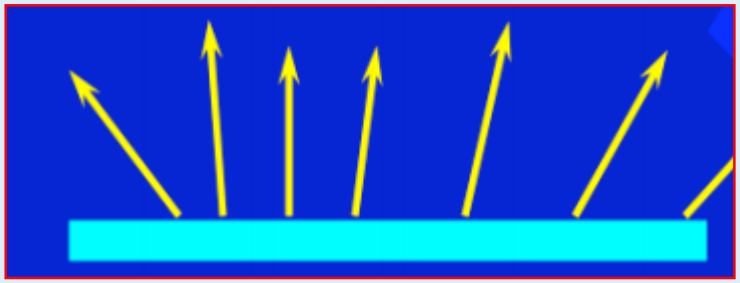
F. Interpretation and analysis

G. Application of information

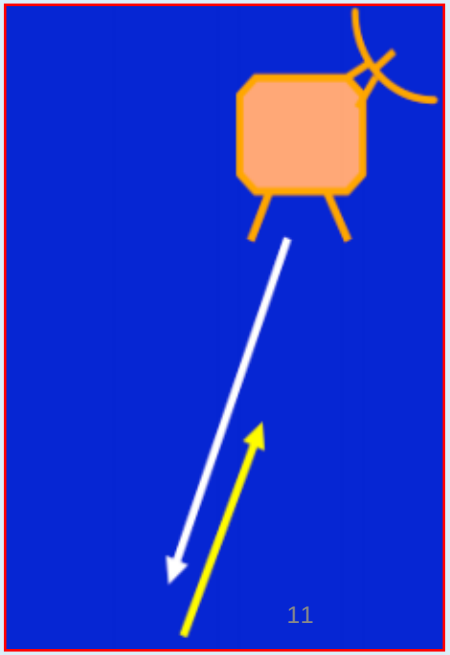
Sources of energy for remote sensing

- 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)



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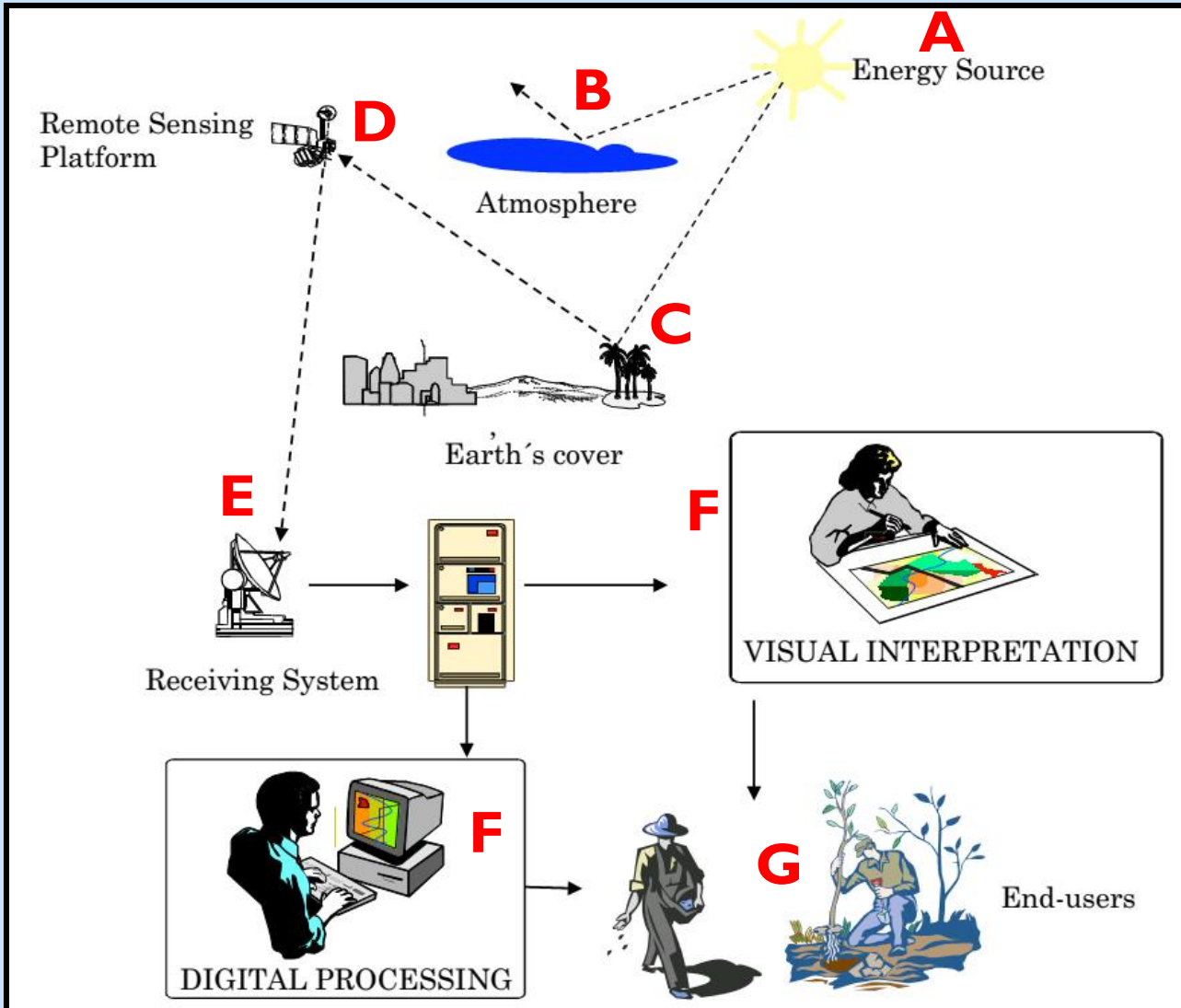

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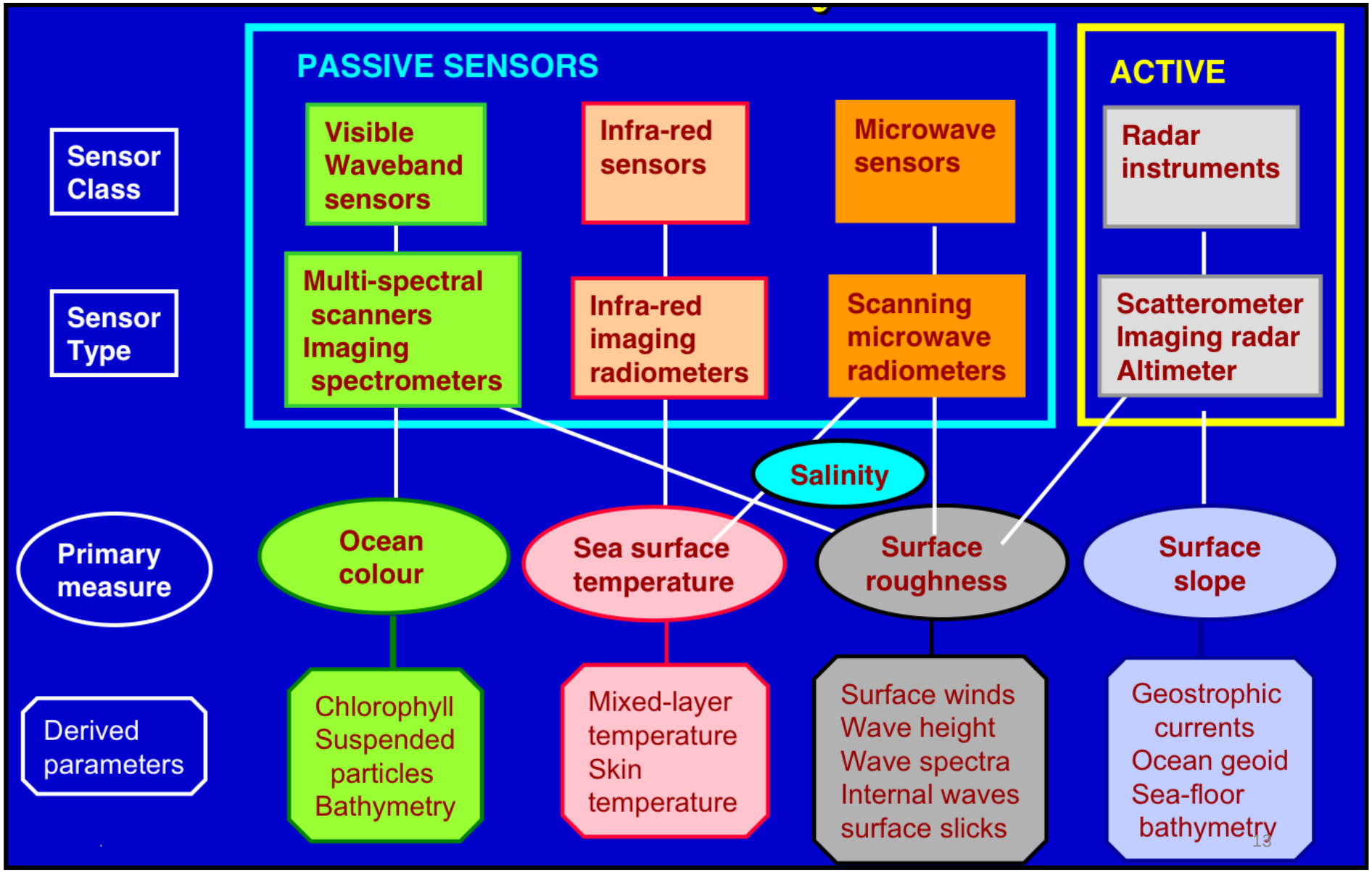
A summary of sensor types & what they measure



RECAP: Satellite data sources

- **Radiometers:** sea surface temperature

-- Envisat (AATSR) -- NOAA (AVHRR)

- **Spectral sensors:** ocean color and water quality

-- Envisat (MERIS) -- Aqua (MODIS) -- Quickbird

- **Altimeters:** SSH, SWH, surface wind speed, ocean currents

-- Envisat -- Jason-1 -- Jason-2 -- GFO-- ERS-2

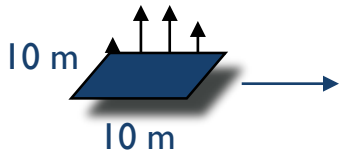
- **Scatterometers:** surface wind speed and direction.

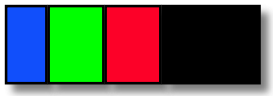
-- QuikSCAT -- ASCAT -- ERS-2

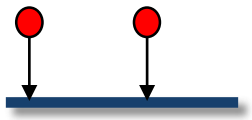
- **Synthetic Aperture Radars** (SAR): winds, waves, currents, oil slicks and ship detection.

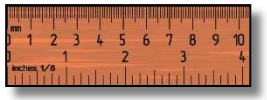
-- Envisat (ASAR) -- Radarsat -- TerraSAR-X

Remote Sensor Resolution Considerations









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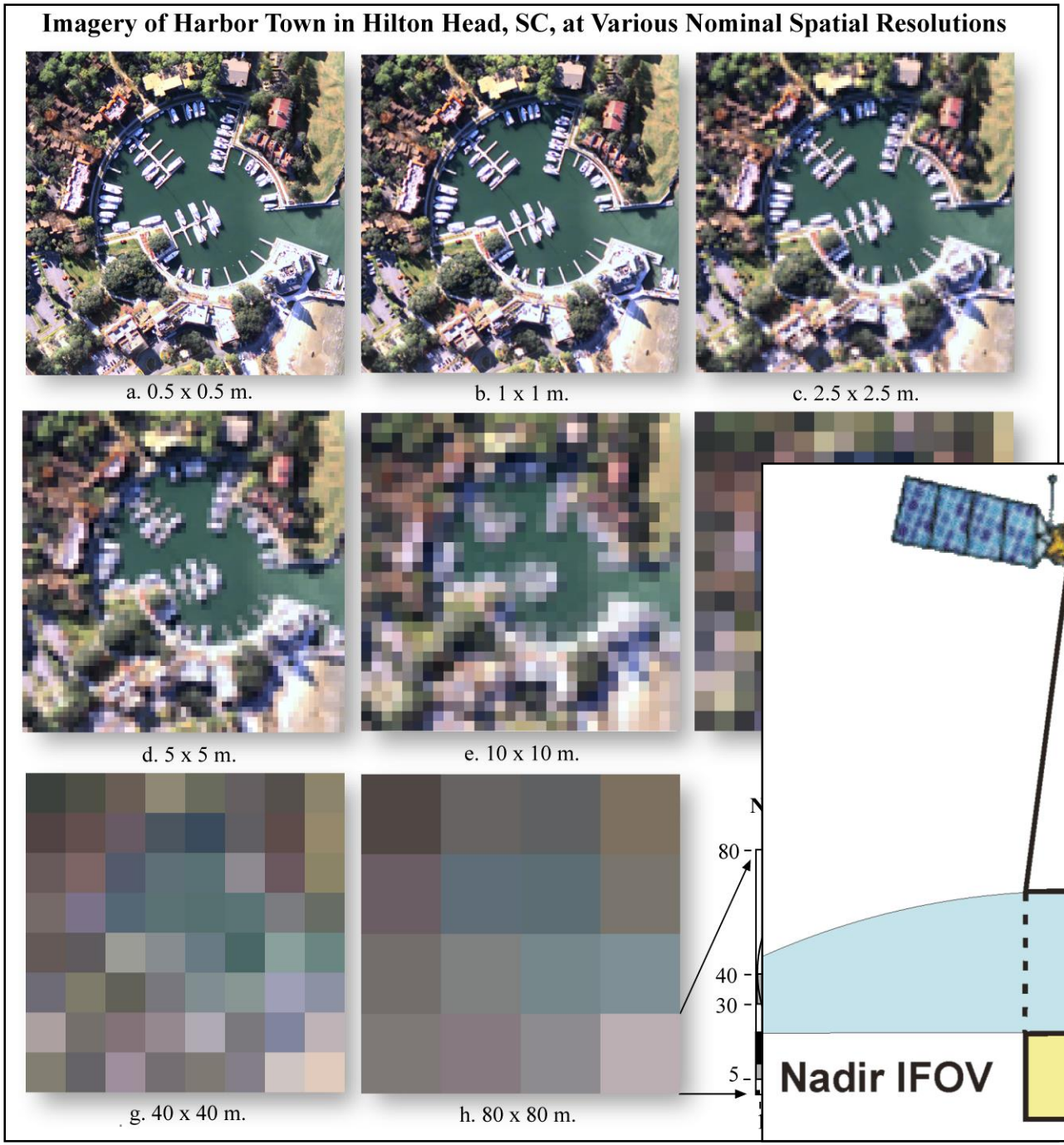
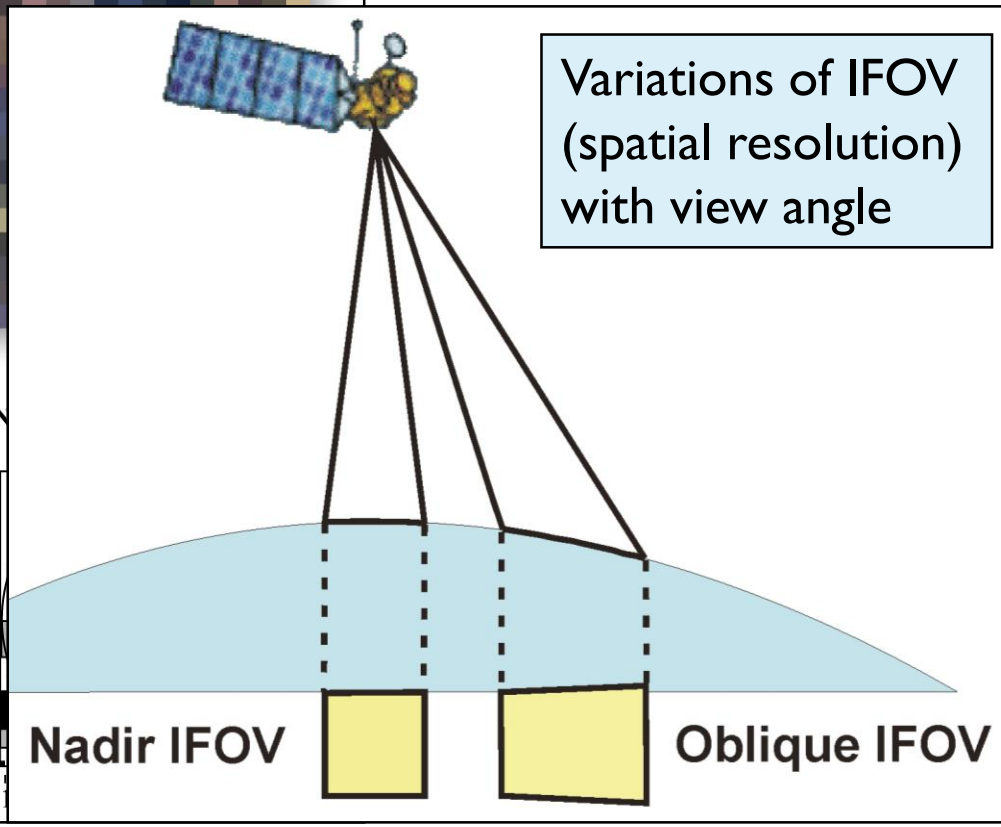
(0 - 255)
10-bit
(0 - 1023)

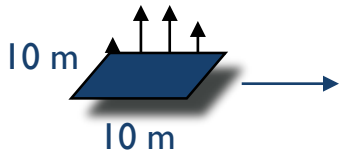
- Spatial - the size of the field-of-view, e.g. 10 × 10 m.
- Spectral - the *number* and *size* of spectral regions (or frequencies) the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared.
- Temporal - how often the sensor acquires data, e.g., every 30 days.
- Radiometric - sensitivity of detectors to small difference in electromagnetic energy.

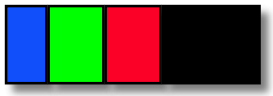
Spatial Resolution

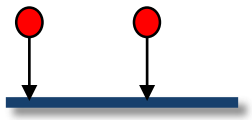


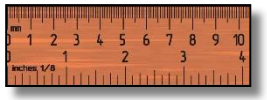


Remote Sensor Resolution Considerations









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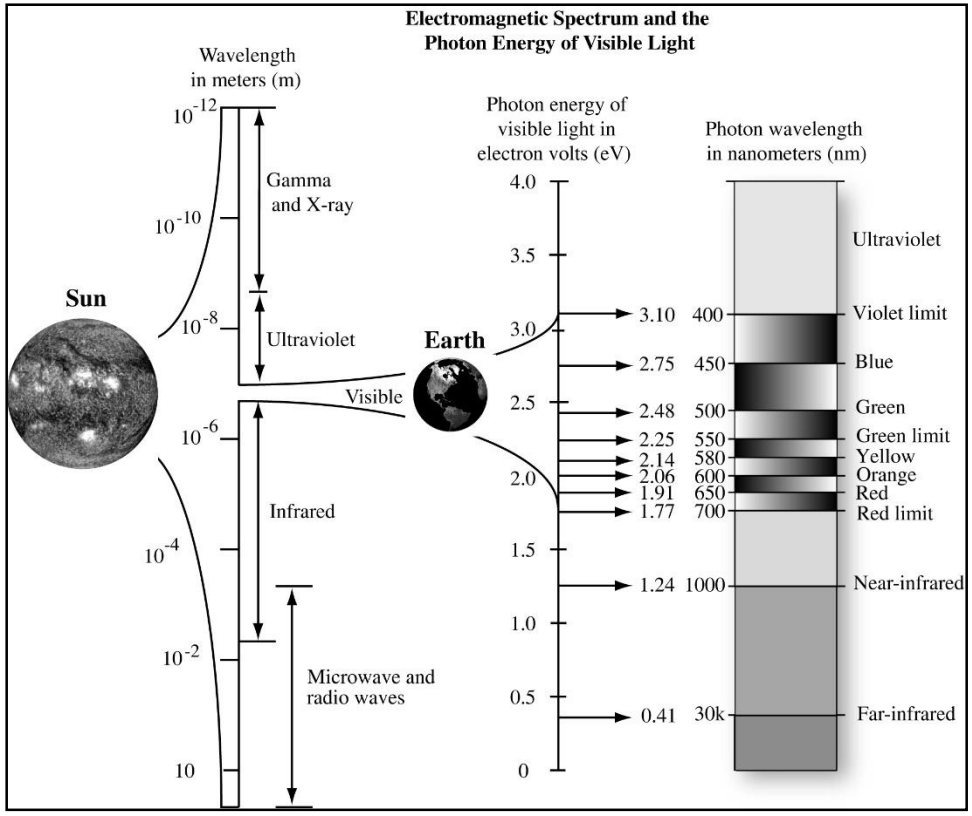
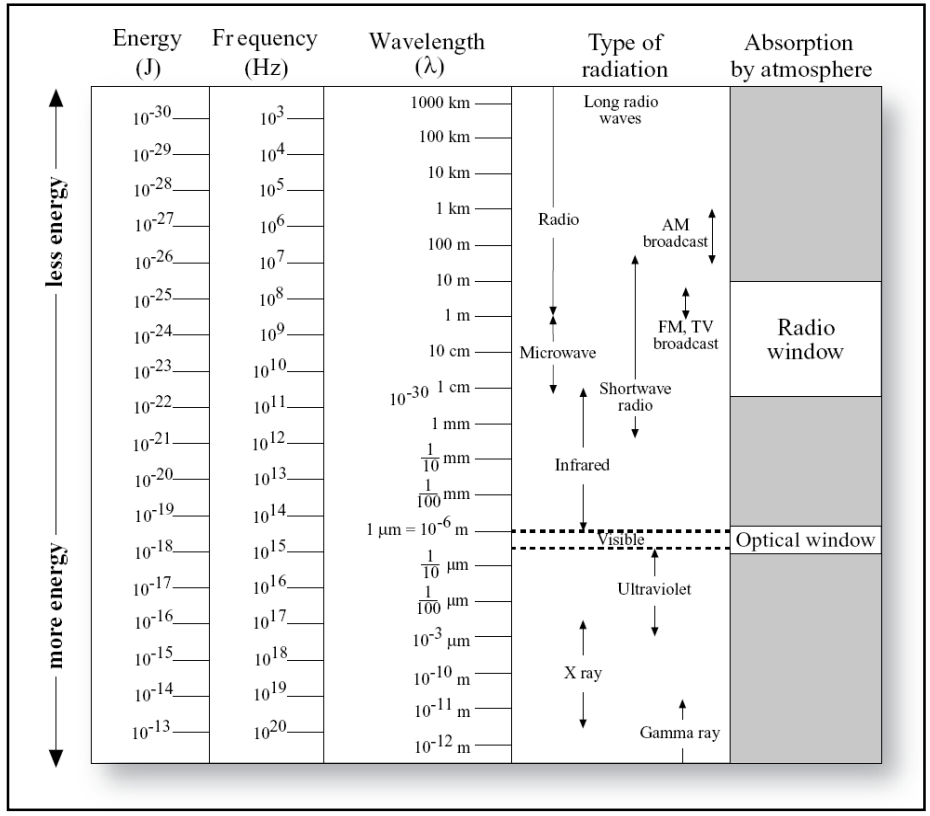
Applications of Remote sensing

- Agriculture: precision farming, crop health analysis, land cover
- Town planning: wetland delineation, transport engineering
- Natural resource mgt: EIA, limnology, geomorphology, habitat mapping, hydrology, water quality, change detection
- National security: disaster mapping and monitoring (NADMO), narcotic crop surveillance (NACOB), crowd control, weapons tracking
- Meteorological application: weather forecasting, aviation, farming

Radiometry: Infrared

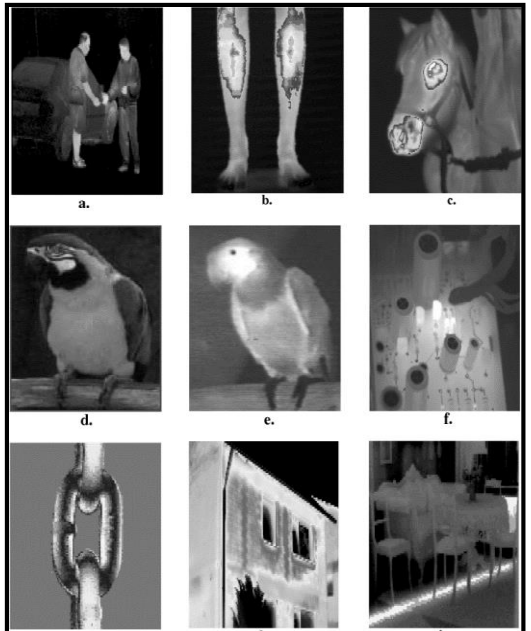




Thermal Infrared Remote Sensing

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

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).



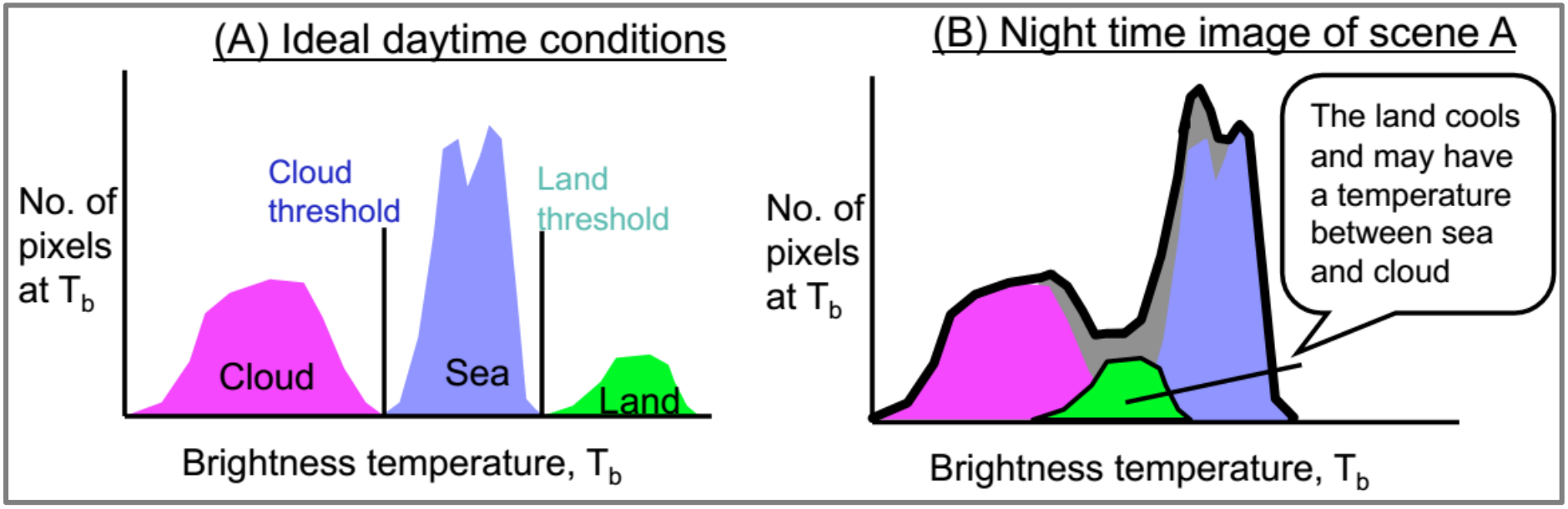
IR: basics and SST

- 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**

Ideal and typical image histograms - thermal



- In an ideal world cloud, sea and land are separated
- Unfortunately at night land cools and shifts to lower temperatures
- However masks can overcome this for land

Which spatial resolution?

- Coarse spatial resolution SST required for monitoring global climate variables. E.g. ATSR has a spatial resolution of about 50km.

- Higher resolution data enables the variability of SST to be detected. Need a resolution of 5 km

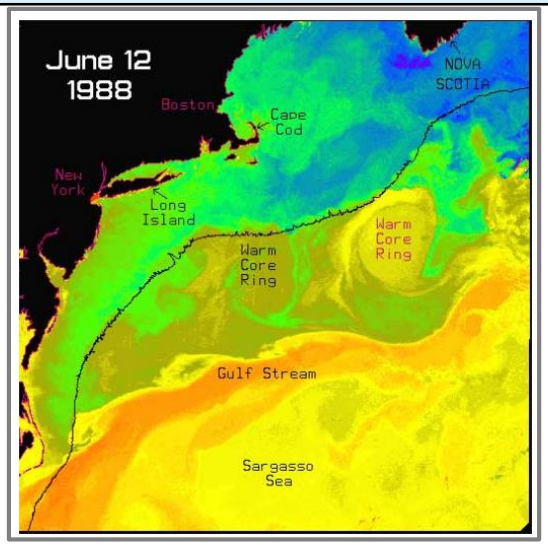
  --for the meanders and variability of major ocean currents e.g. the Gulf Stream and the Kuroshio.

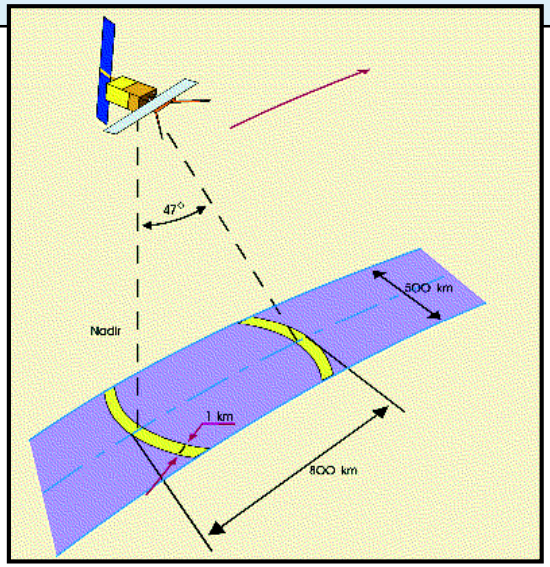
  --for looking at heat transport through the ocean: the position of fronts, the movement of mesoscale eddies

- Highest resolution data (1-2 km) can monitor the thermal structure of coastal waters, identifying river outfall plumes, thermal pollution etc.

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



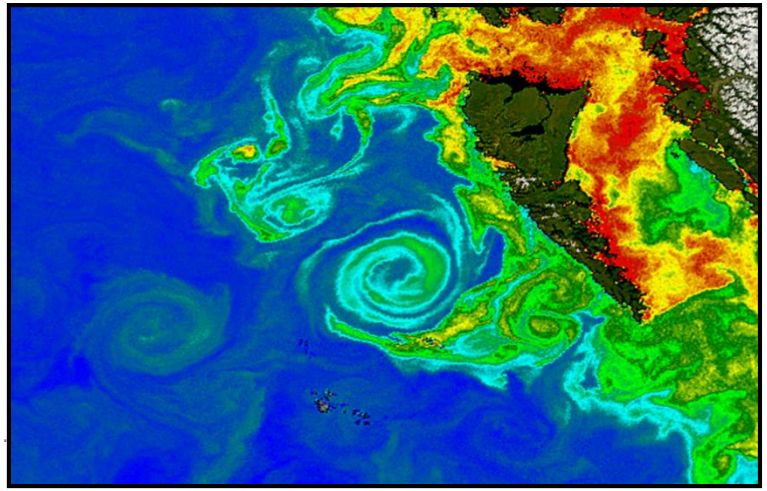


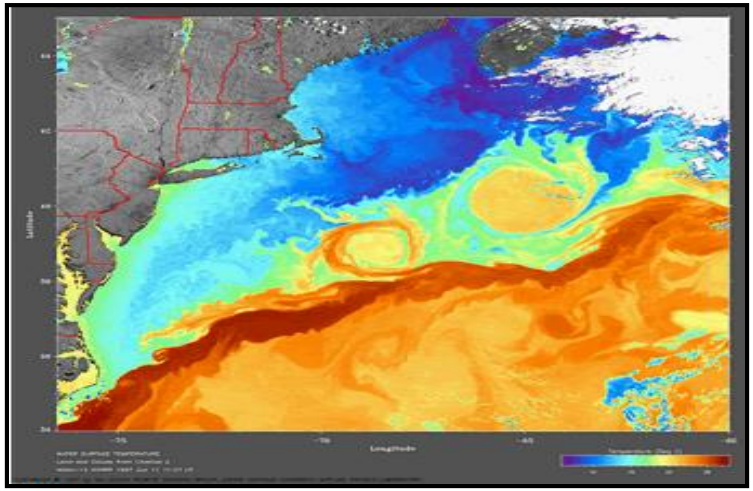
Interpretation of SST measured from space

- The measured SST is the surface skin temperature
- Conventional measurements give bulk SST (ships buoys etc.)
- Typical difference is 0.2 to 0.5 ˚C
- Difference depends on mixing wind etc.
- Some oceanographic problems need skin temperature
  - e.g. Ocean-Atmosphere interactions
- In others bulk temp is used (partly for historical reasons)

Why SST from space?

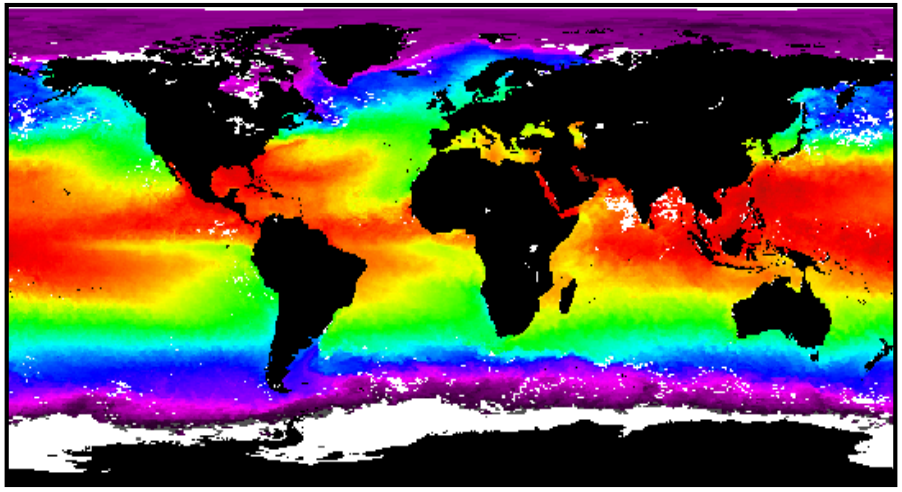
- From satellite SST we can identify and monitor surface disturbances that cross entire ocean basins, track ocean eddies and map ocean fronts
- It can also reveal striking features such as 'storms' in the upper ocean, known as eddies.
  - These are typically ~100 km wide and carry large amounts of energy around the globe. They play an important role in ocean circulation and climate.

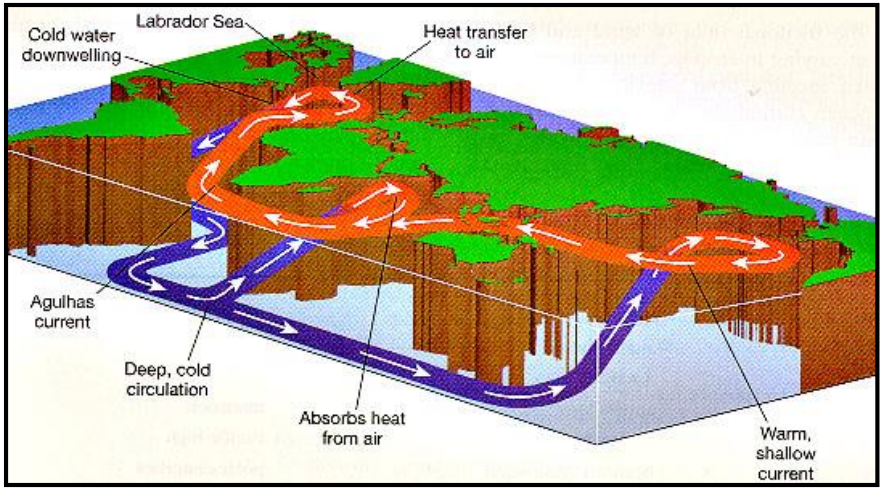




Why SST from space?

- 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.

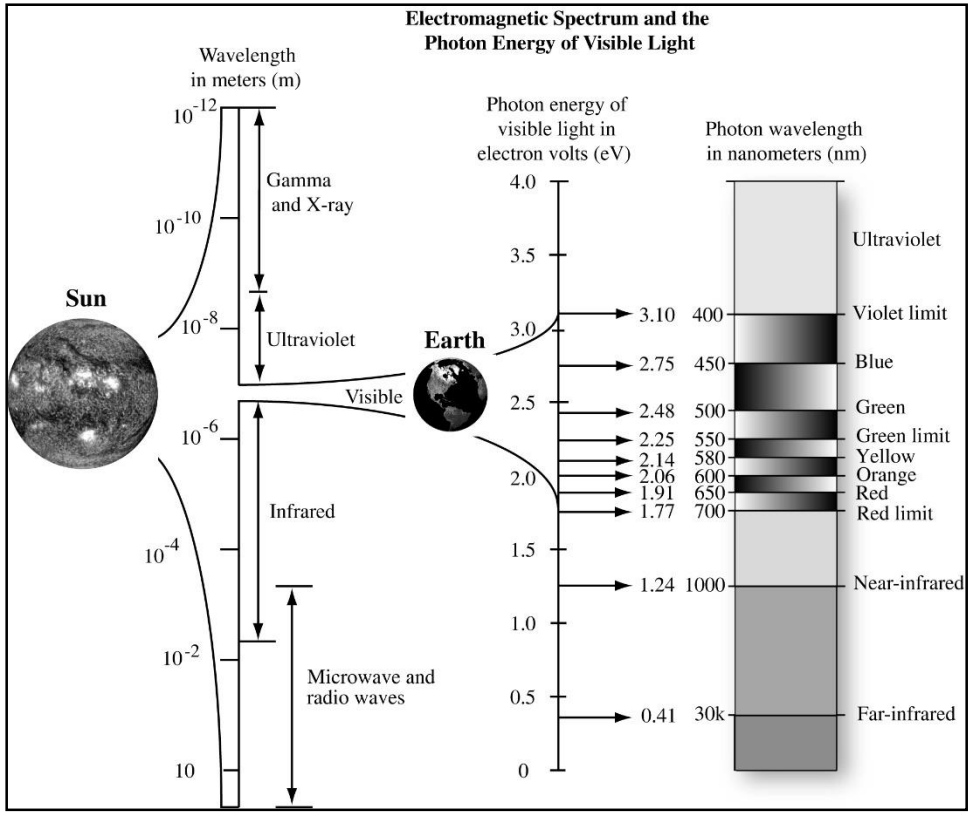


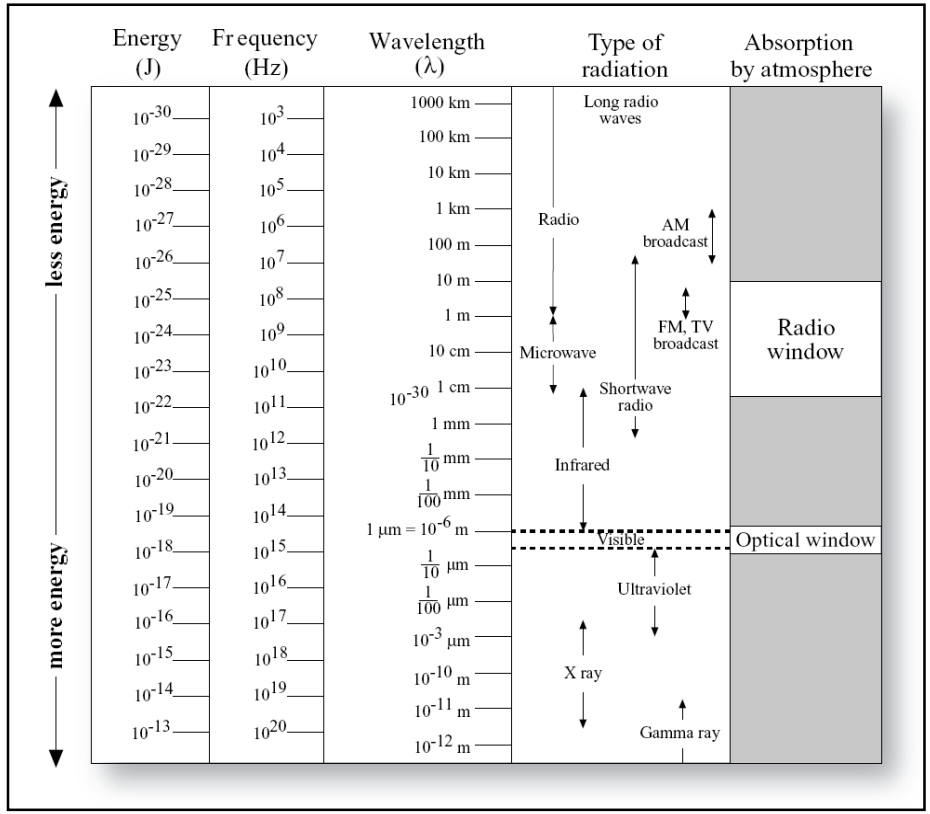


Applications of satellite-measured SST

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

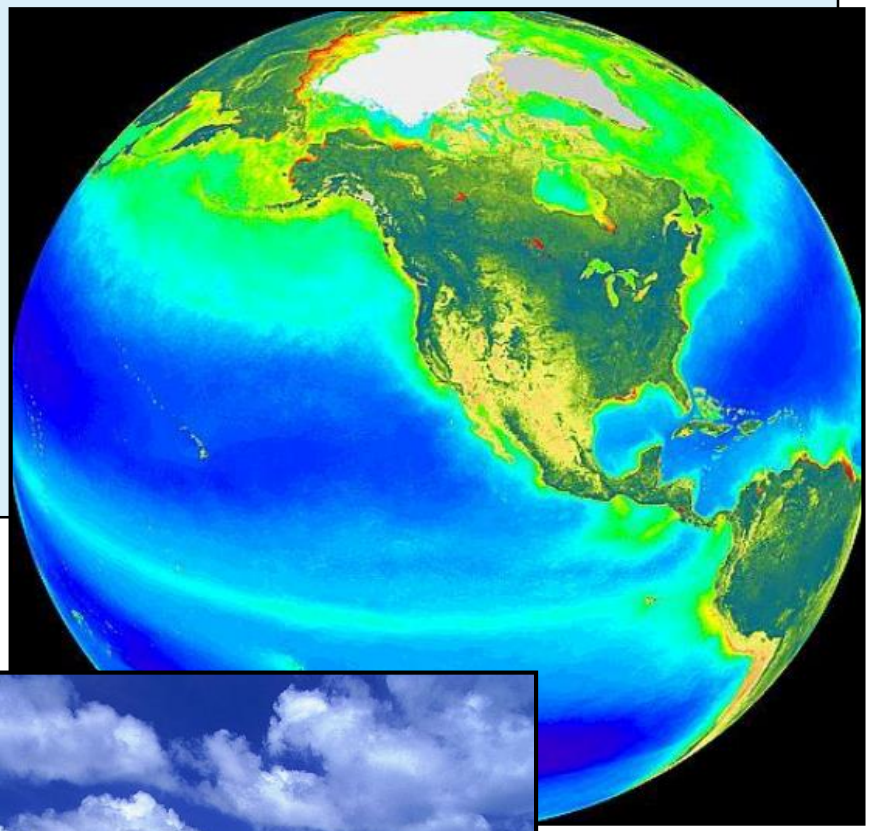
Visible waveband: Ocean color

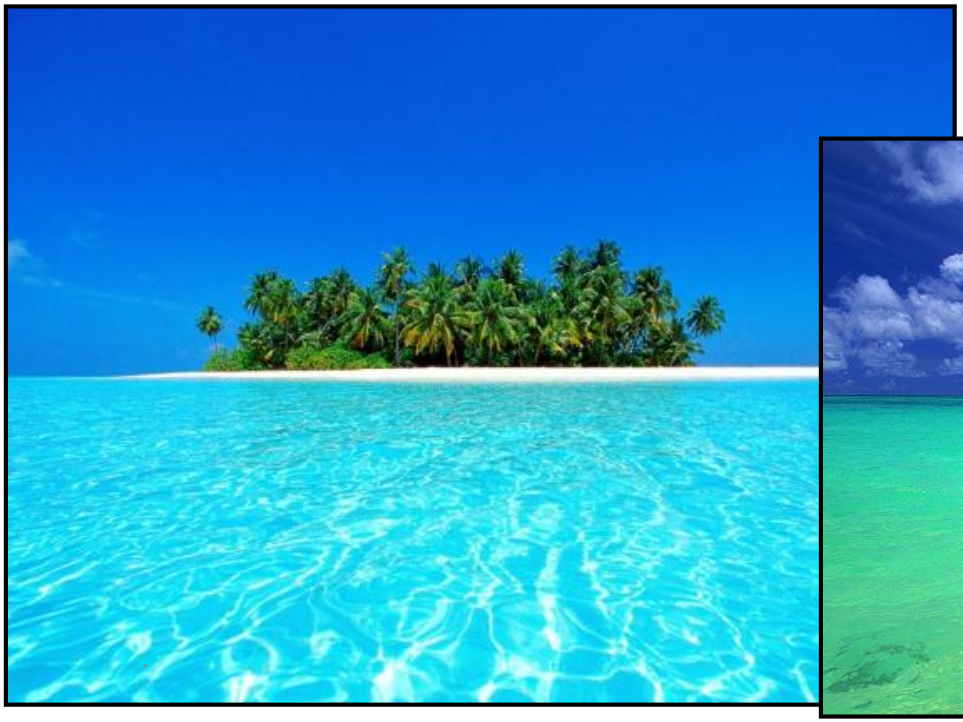


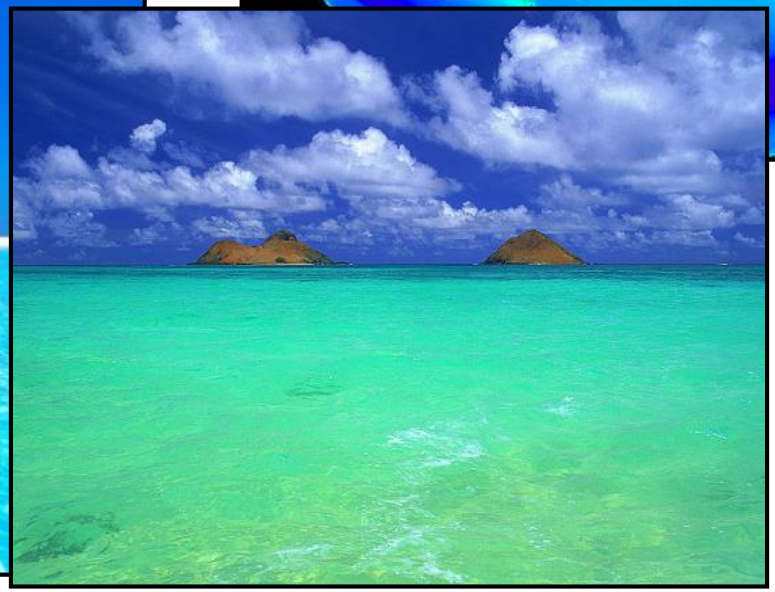


What is the color of the ocean?

- 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?

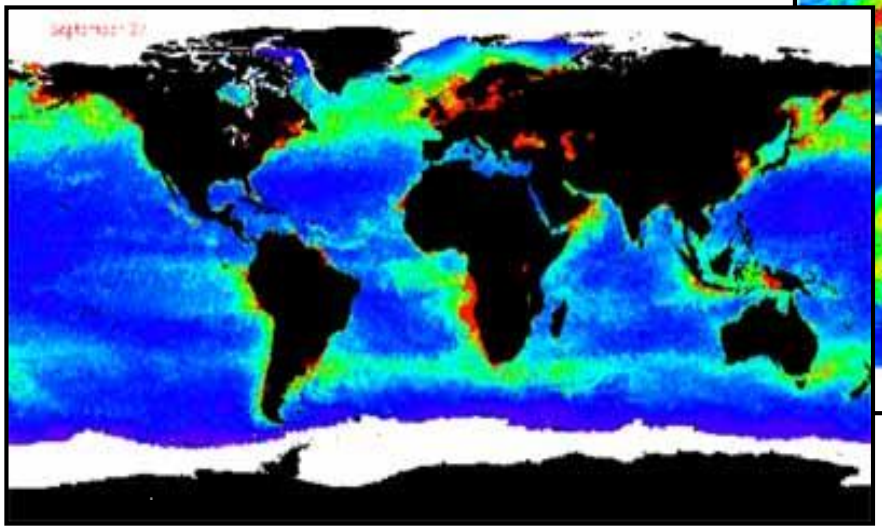
- Clean ocean water absorbs red light, i.e., sun radiation of long wavelength and transmits and scatters the light of short wavelength. That is why ocean surface looks blue.
- Phytoplankton cells contain chlorophyll that absorbs other wavelengths and contributes green color to ocean water.
- In coastal areas suspended inorganic matter backscatters sunlight, contributing green, yellow and brown to water color.

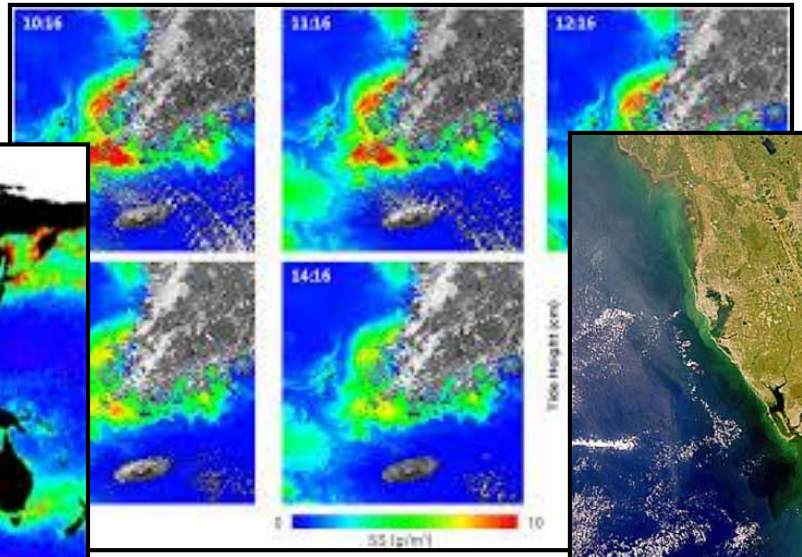
Why ocean color from space?

- 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





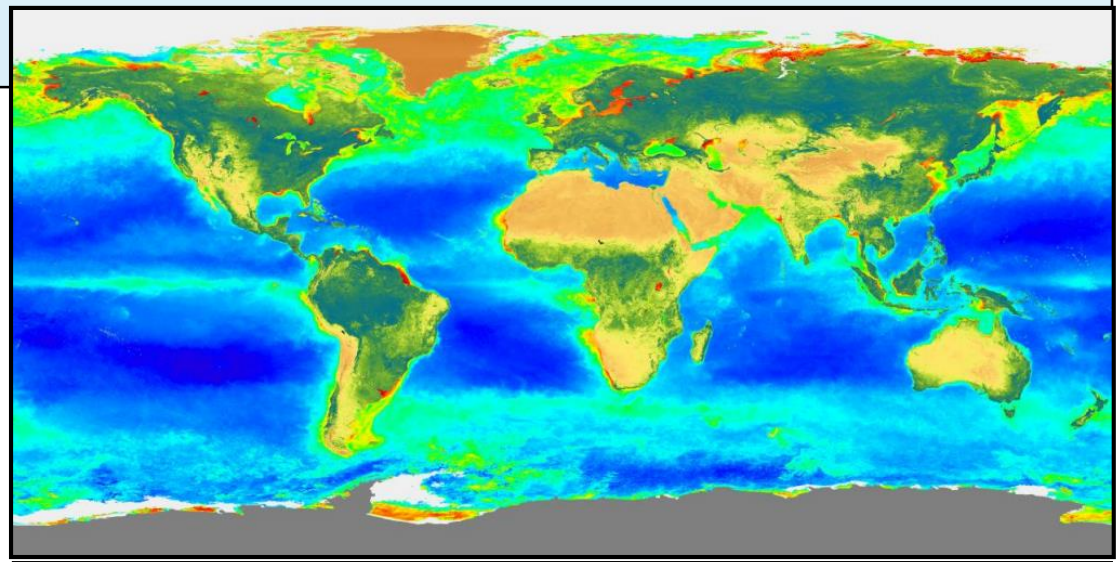
Current ocean color sensors

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

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



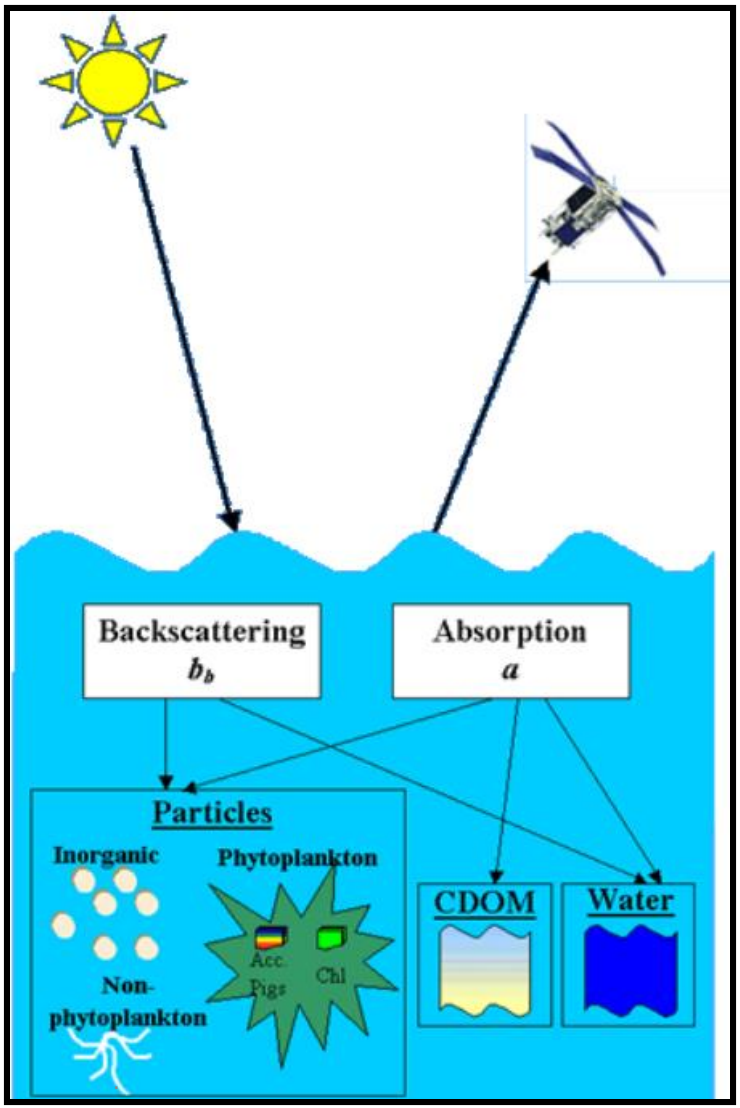
Ocean Chl and Normalized Digital Vegetation Index (NDVI) computed from SeaWiFS

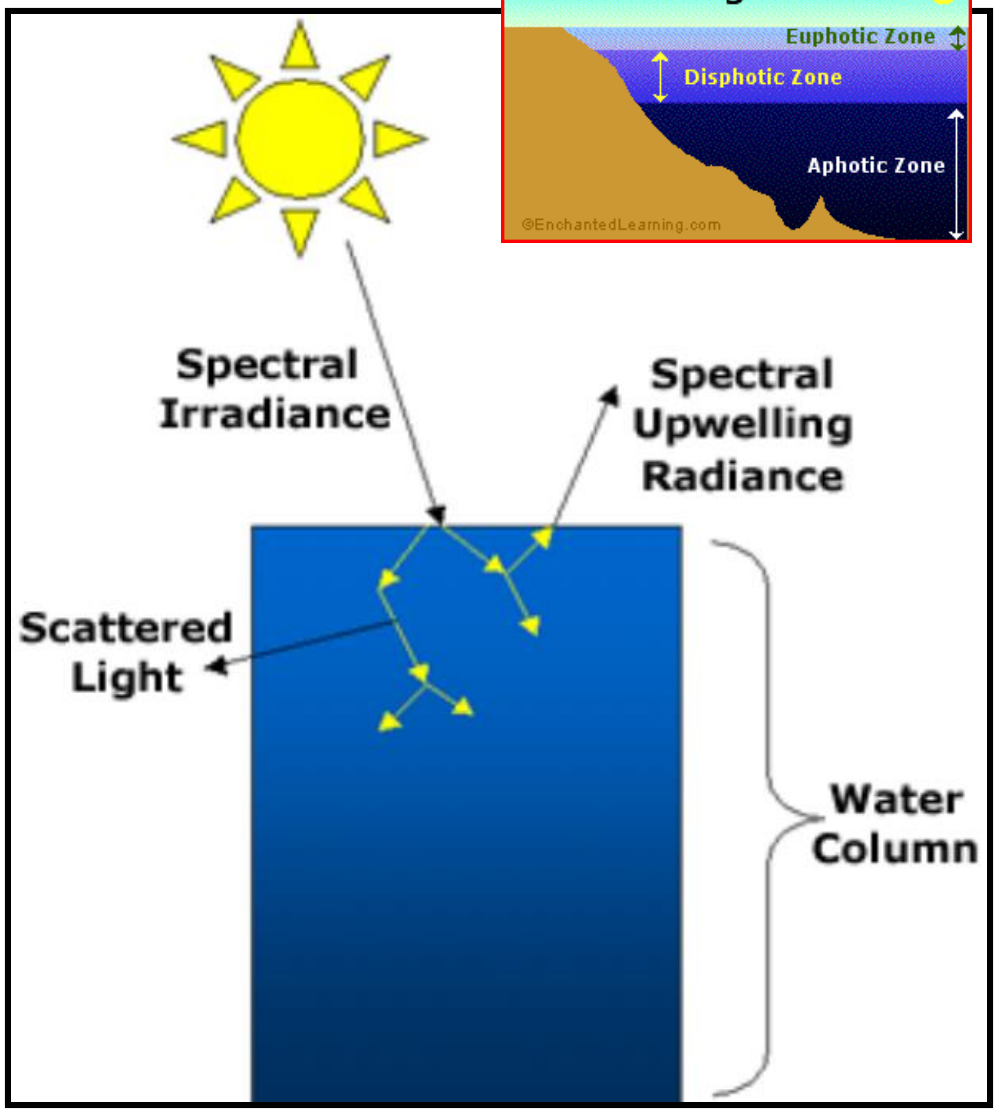
MODIS--Moderate Resolution Imaging Spectroradiometer

- Two MODIS sensors:
  - -- **Terra** satellite launched December 18th, 1999
  - -- **Aqua** satellite launched May 4th, 2002.
- Both have sun-synchronous near-polar orbit.

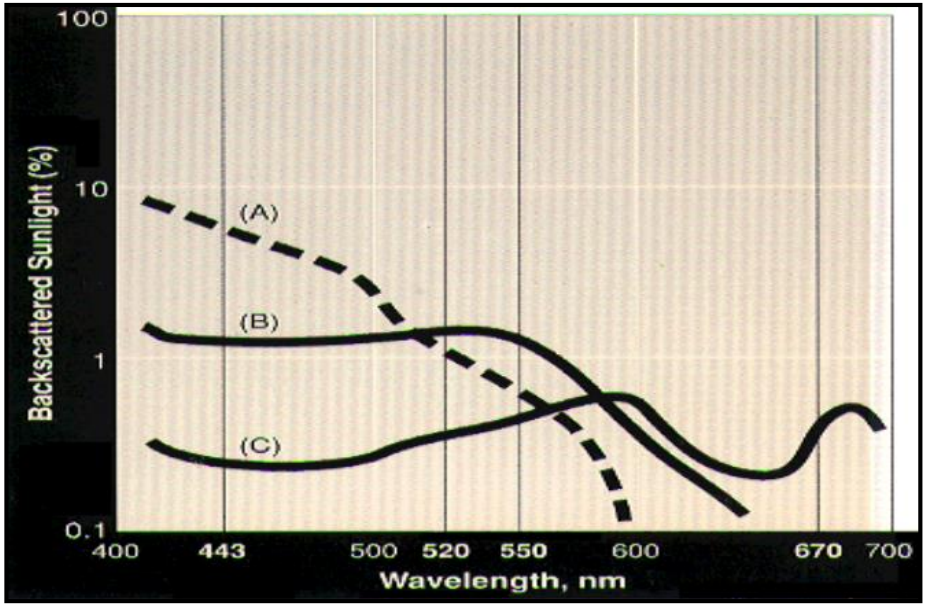
- Terra's orbit around the Earth is timed so that it passes from N to S across the equator in the morning (10:30 a.m., descending node)
- Aqua passes S to N over the equator in the afternoon (1:30 p.m., ascending node).

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.

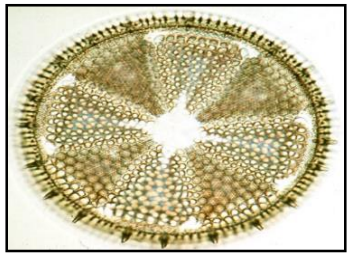
Clean ocean water (A) has maximum in short (blue) wavelength and almost zero in yellow and red.

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

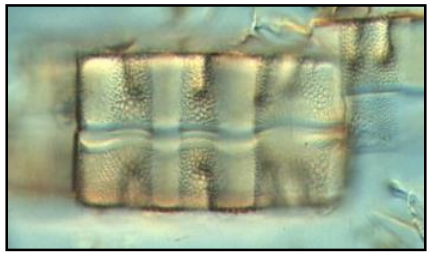
In coastal zones with high concentration of dead organic and inorganic matter light spectrum has maximum in red (C).

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.



Case Waters



Based on the density of dissolved and suspended material, Morel and Prieur (1977) divide the ocean into **case 1** and **case 2** waters.

Case 1 waters: phytoplankton pigments and their co-varying detrital pigments dominate the seawater optical properties.

Case 2 waters: other substances that do not co-vary with Chl-a (such as suspended sediments, organic particles, and CDOM) are dominant.

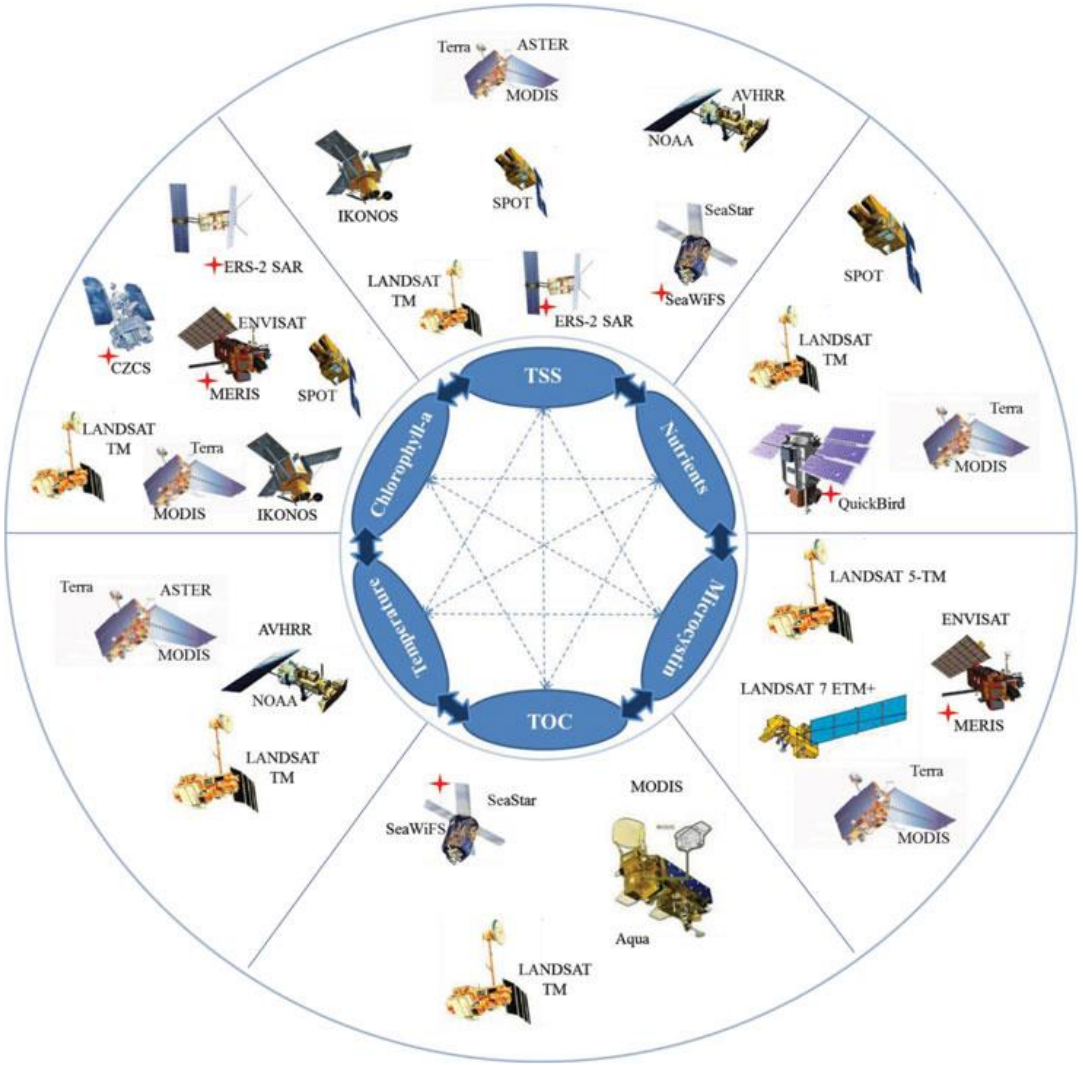
Even though case 2 waters occupy a smaller area of the world ocean than case 1 waters, because they occur in coastal regions with large river runoff and high densities of human activities such as fisheries, recreation and shipping, they are equally important.

Applications

Remote sensing techniques can be used to monitor water quality parameters:

- suspended sediments (turbidity)
- chlorophyll, and temperature.

Applications



Assessment metrics and associated satellites for monitoring differing water quality constituents. Note: Red crosses indicate satellites no longer in use. Chang et al. 2015

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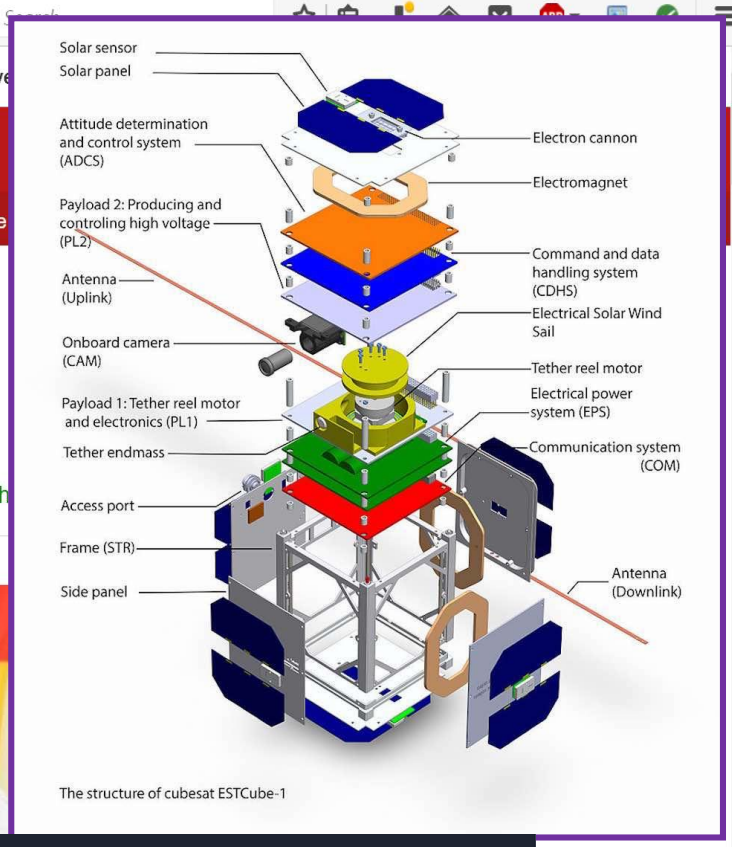
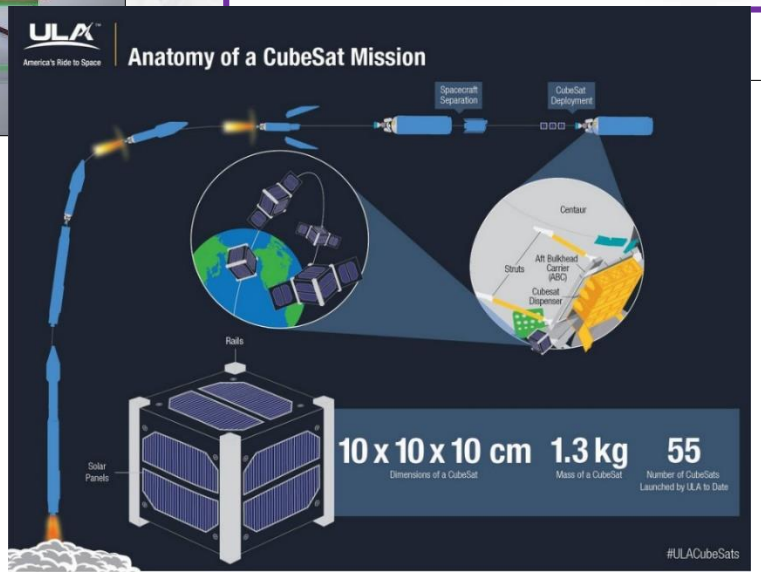
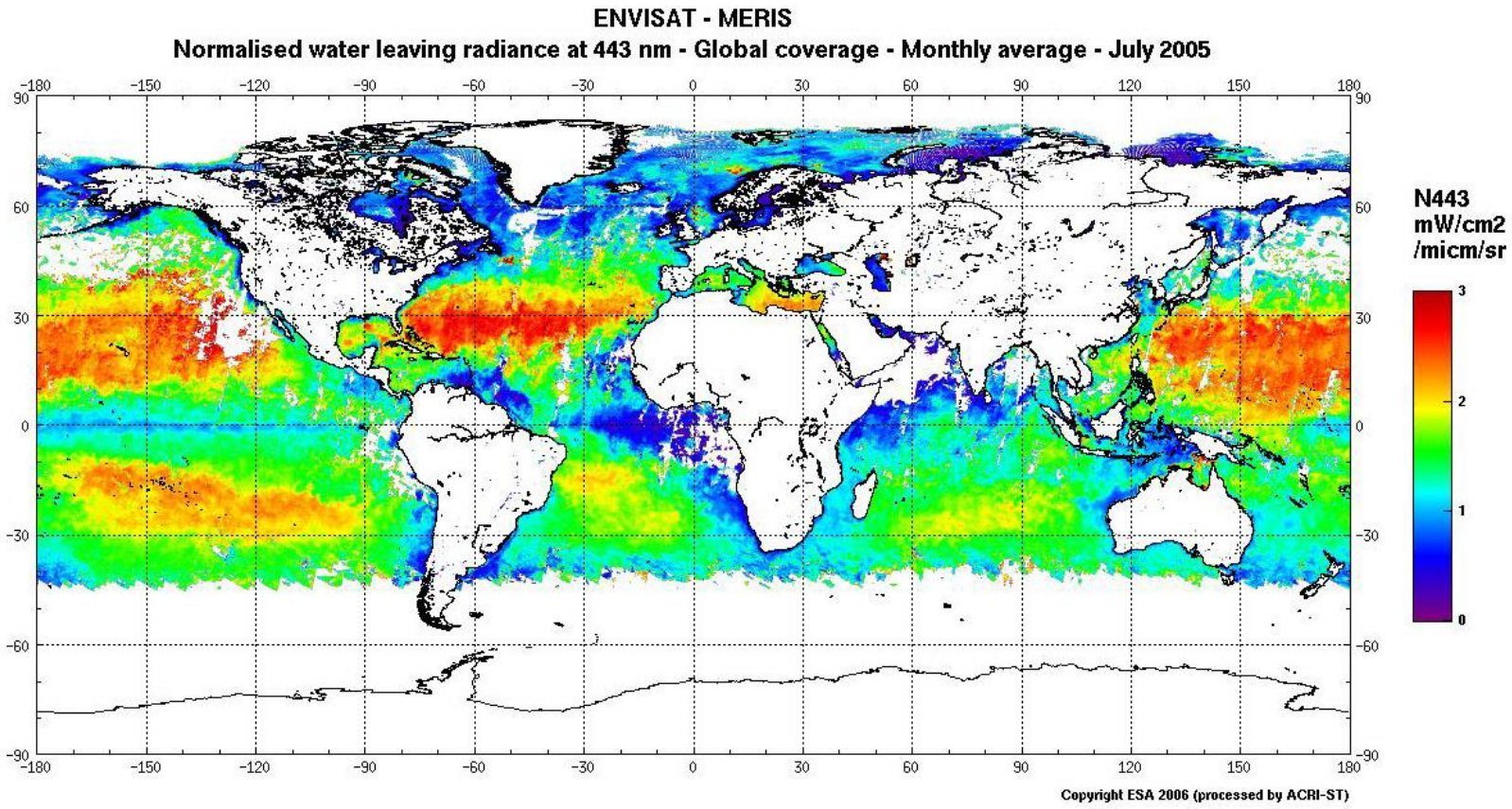


The structure of cubesat ESTCube-1

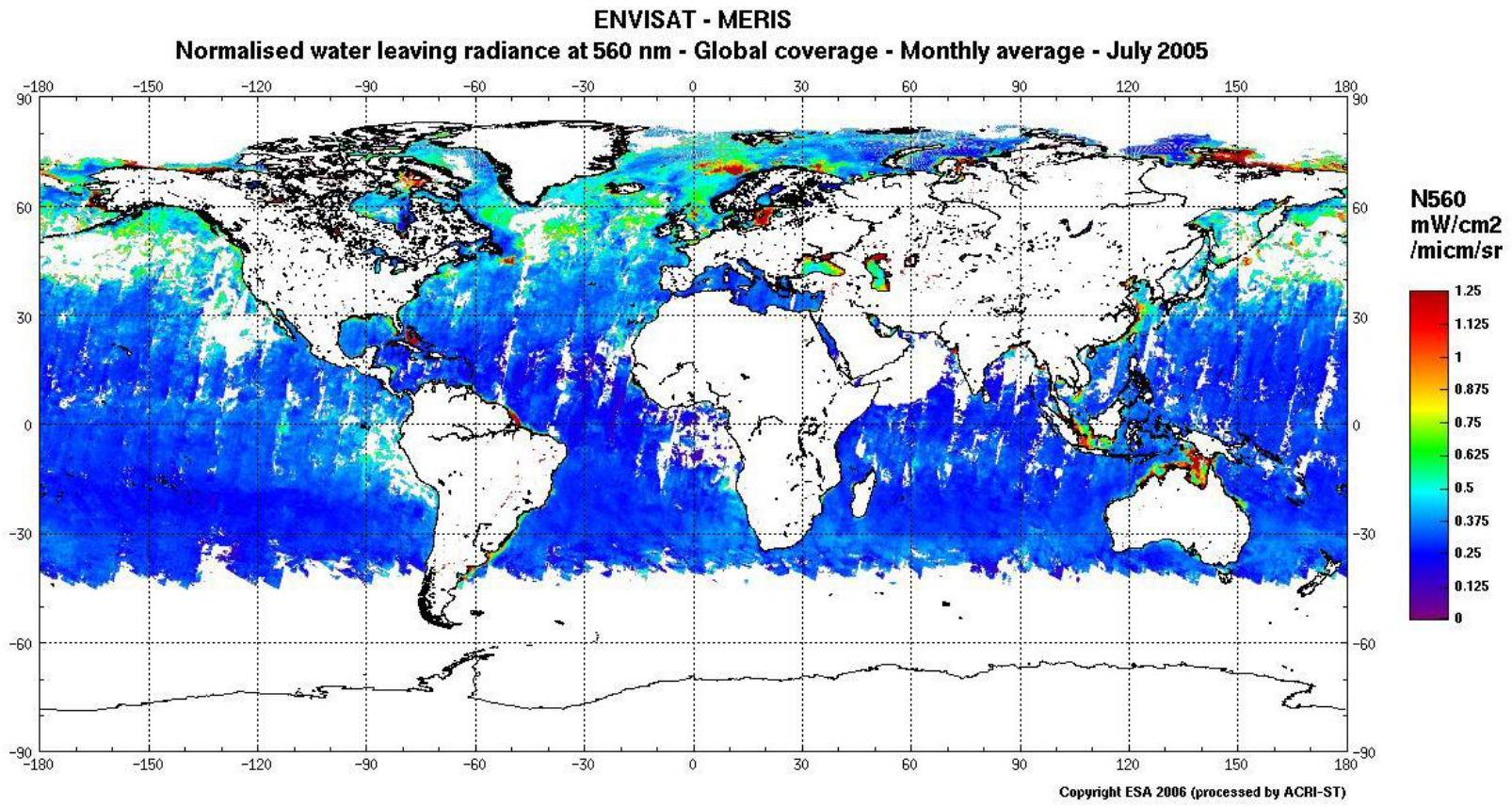


Ocean color: MERIS/ENVISAT, 443 nm



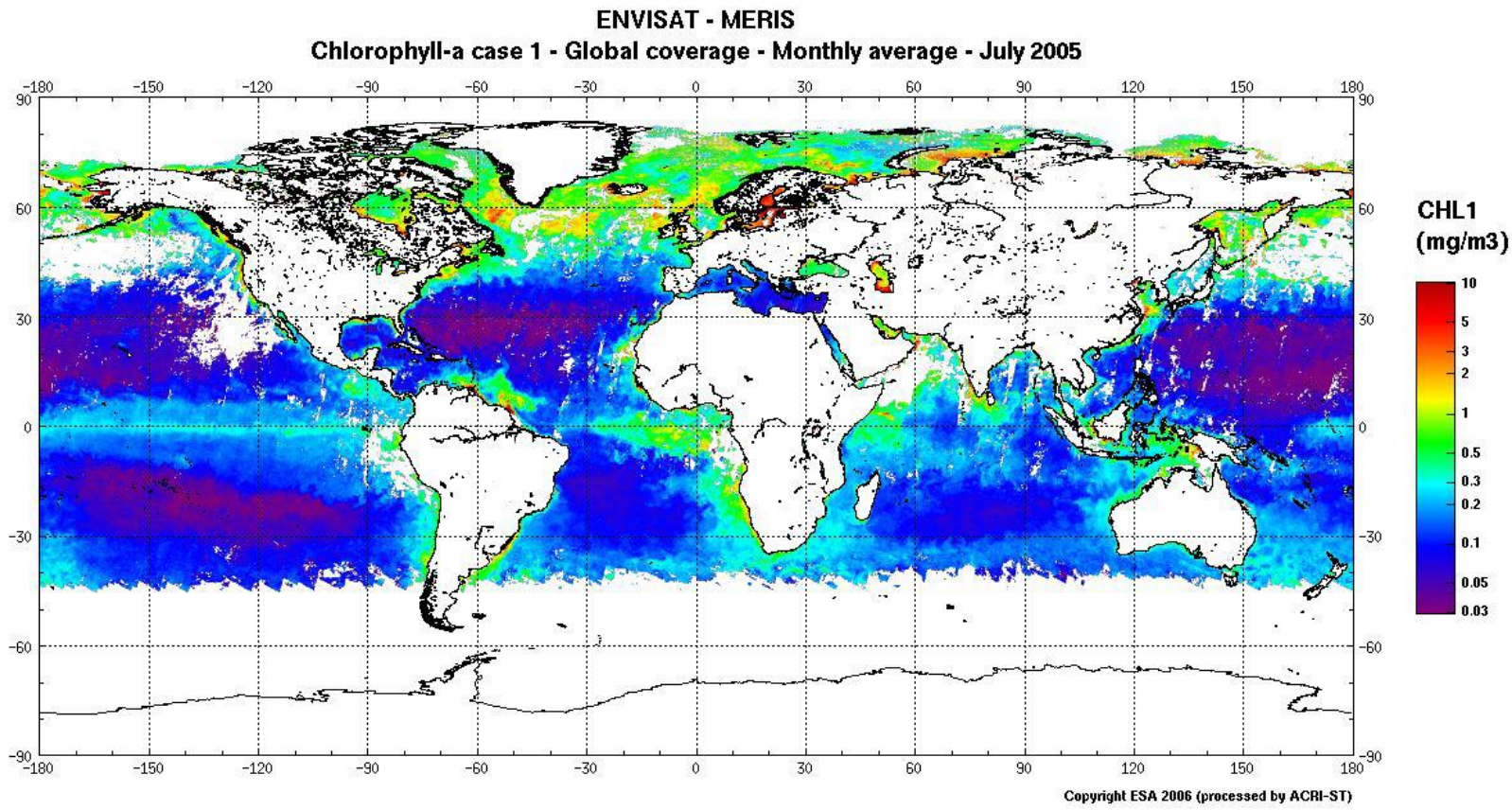
Normalized water leaving radiance at 443 nm

Ocean color: MERIS/ENVISAT, 560 nm



Normalized water leaving radiance at 560 nm

Ocean color: MERIS/ENVISAT, chlorophyll



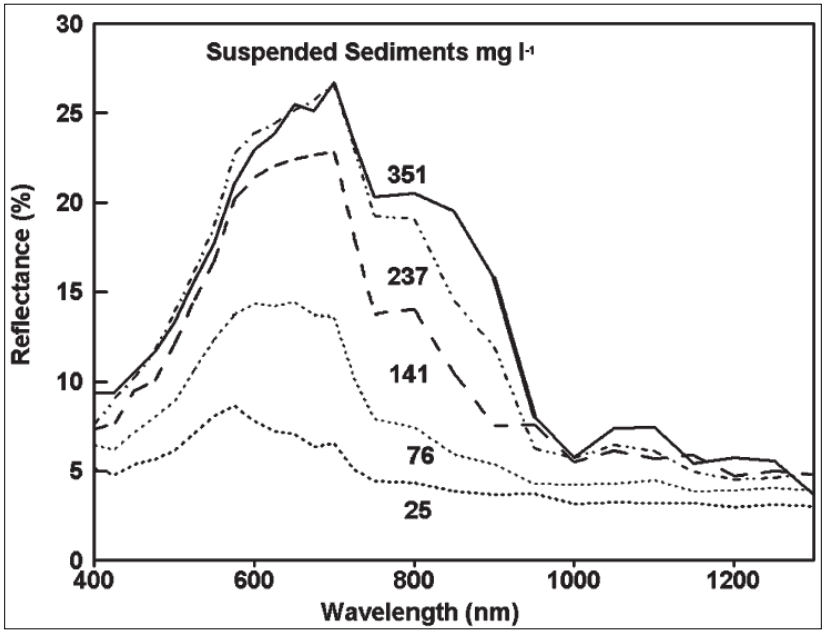
Chl-a case 1

Water quality: basis for using RS

Particles in water change backscattering characteristics of water

Optimal wavelength for measuring water quality depends on

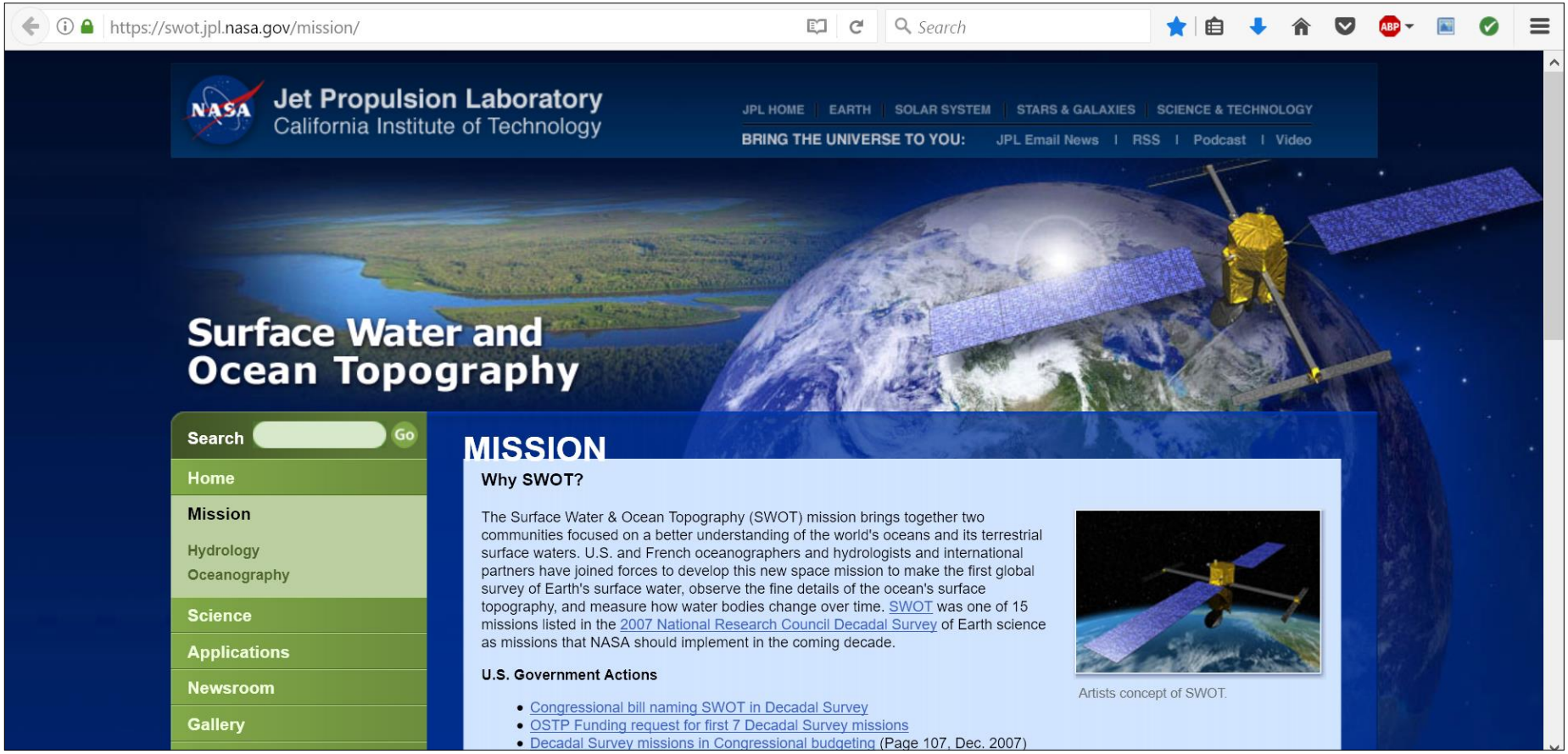
- the substance being measured
- its concentration
- sensor characteristics.



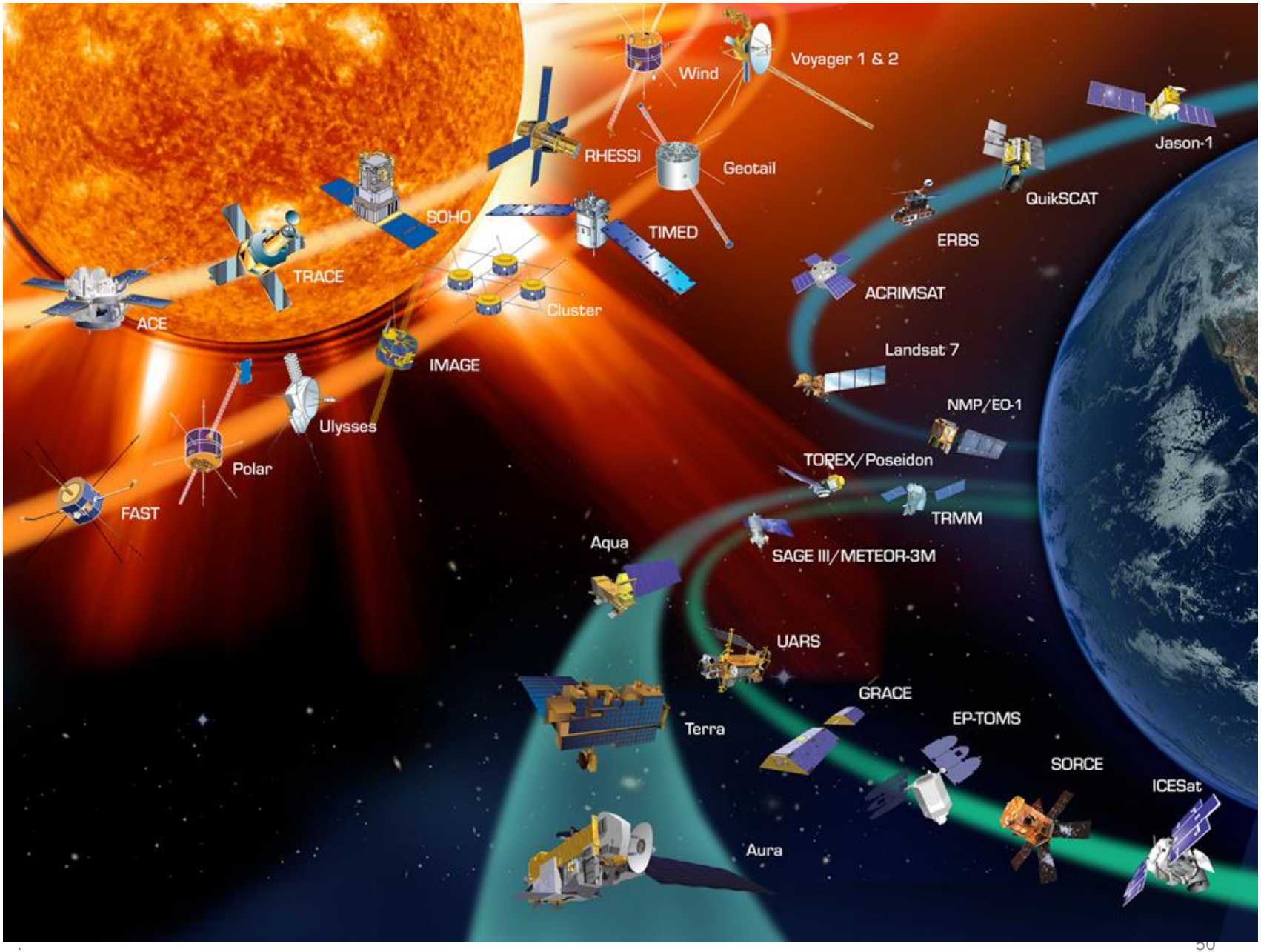
Suspended sediments increase the radiance from surface waters in the visible and near-infrared portion of the EM spectrum

Wavelengths between 700 and 800 nm best for determining suspended sediments

Future satellites



Launch planned for April 2021


Wind
Voyager 1 & 2
RHESSI
Geotail
Jason-1
QuikSCAT
SOHO
TIMED
ERBS
TRACE
ACRIMSAT
ACE
Cluster
IMAGE
Landsat 7
NMP/EO-1
Ulysses
TOREX/Poseidon
Polar
TRMM
FAST
SAGE III/METEOR-3M
Aqua
UARS
GRACE
Terra
EP-TOMS
SORCE
ICESat
Aura