Satellite Oceanography

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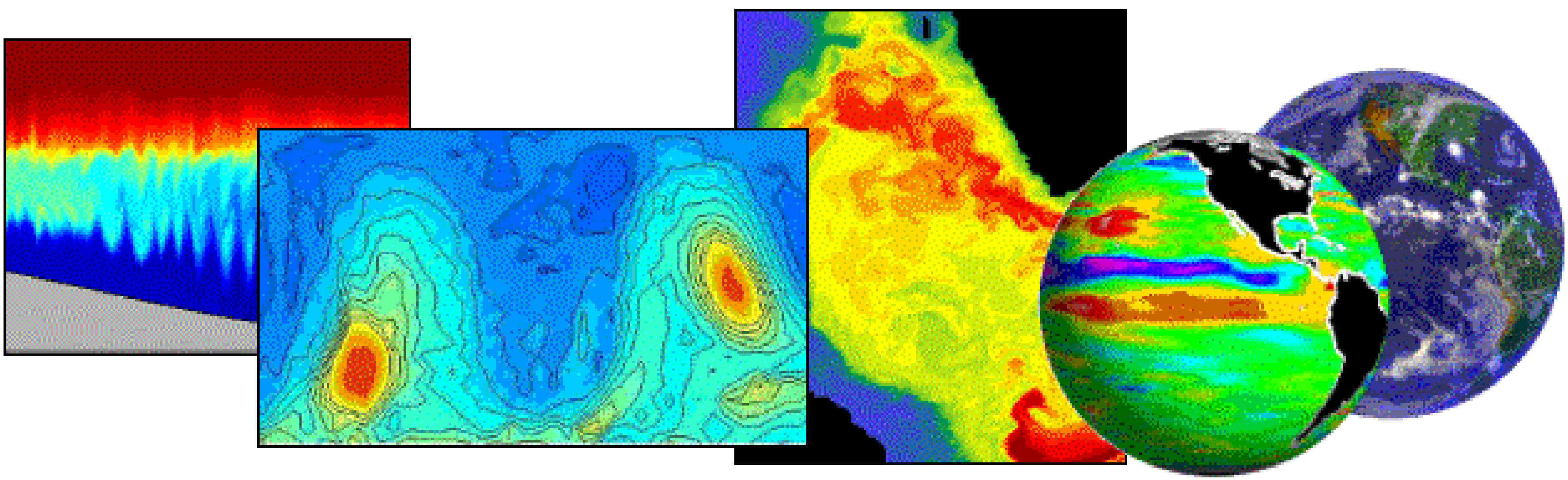


UG-DMFS Summer School (July 30-August 3, 2018)

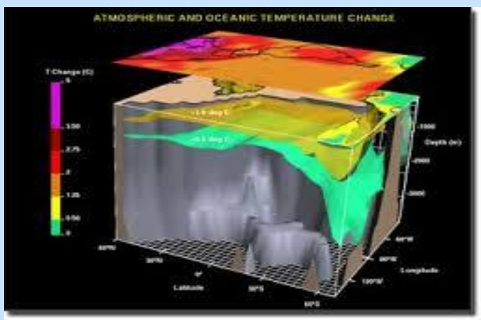
Outline:

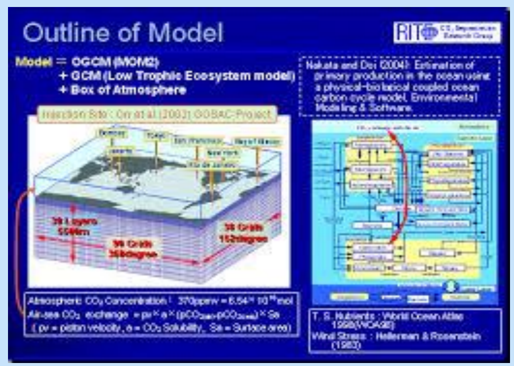
- Remote Sensing: Intro
- Altimetry
- Scatterometry

Background: Oceanographic Data Sources

In-situ data:

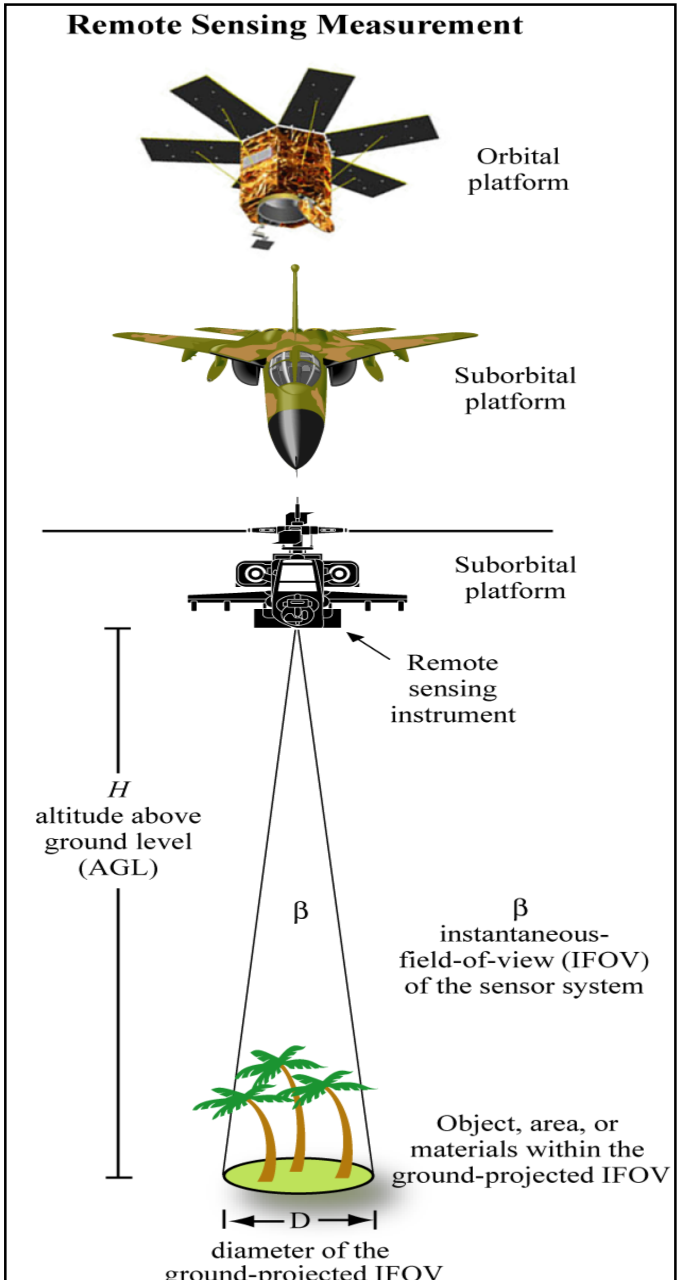
Modeling outputs:





Satellite data:

Introduction



What is remote sensing:

the art, science and technology of

- acquiring,
- processing, and
- interpreting

images and related data that are obtained from **ground-based, air-or space-borne instruments** that record the interaction between matter (target) and electromagnetic radiation

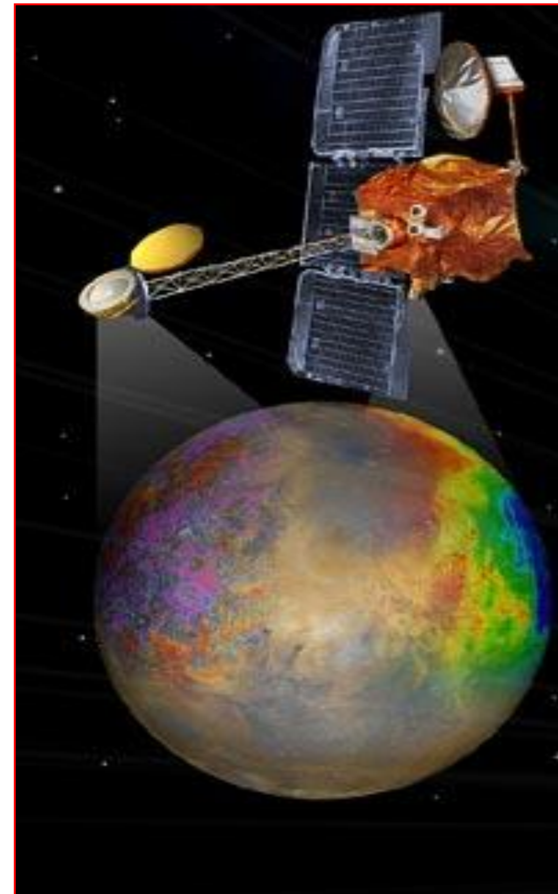
Energy patterns derived from **noncontact sensor systems**

Remote Sensing: using electromagnetic spectrum to image the **land, ocean,** and **atmosphere**.

Remote sensing platforms

Ground-based

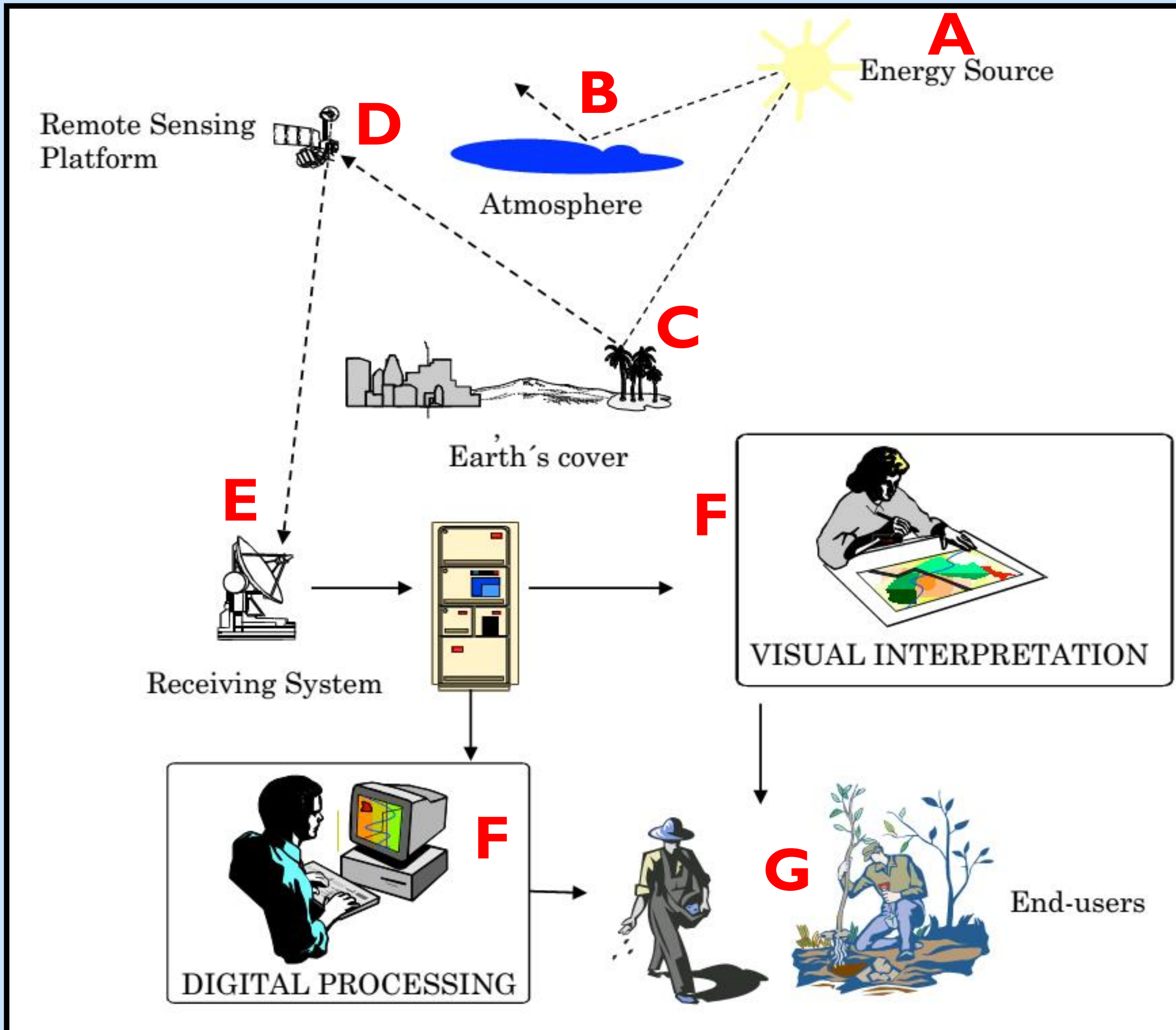
Airplane-based



Satellite-based

Remote Sensing: Primary components

- Energy- radiation
- Sensor
- Object



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

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.

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

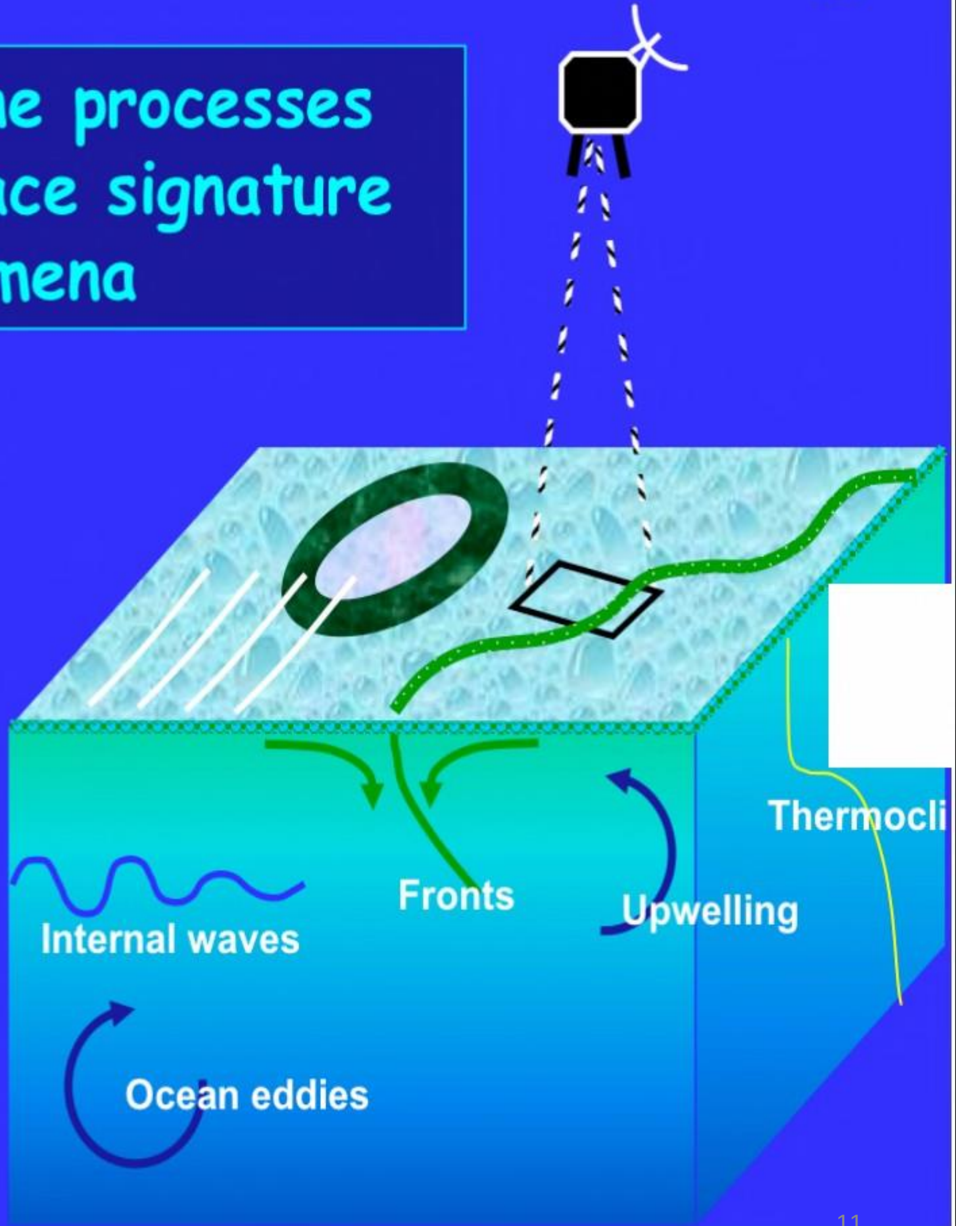
Limitations of satellite oceanography

- 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

Challenge: 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***



Applications of Remote Sensing

Carbon Management

Public Health

Energy Management

Aviation

Water Management

Homeland Security

Coastal Management

Disaster Management

Agricultural Efficiency

Invasive Species

Ecological Forecasting

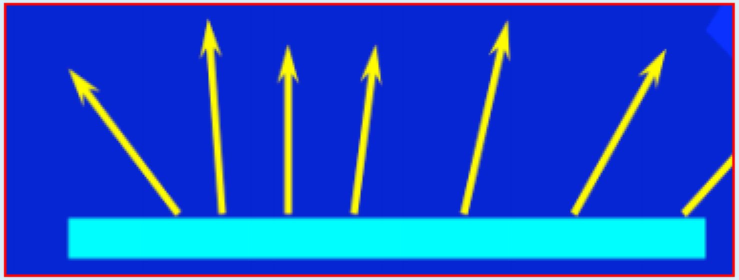
Air Quality

Basic physics and principles

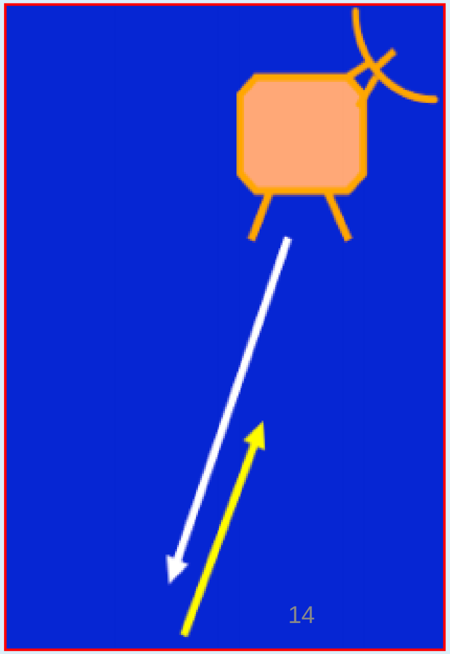
Sources of energy for remote sensing

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

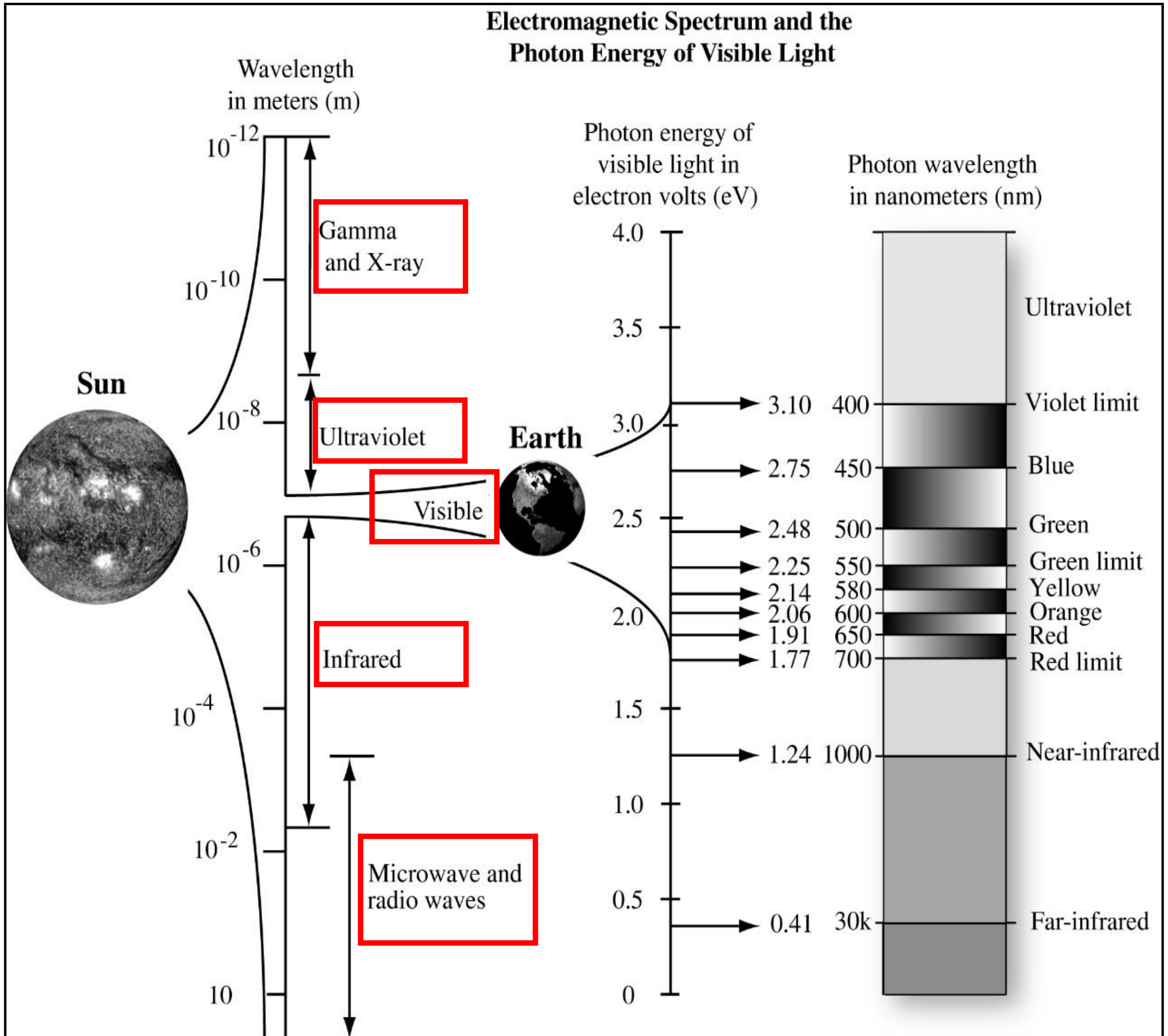
- Thermal emission by the ocean surface
  - --- Thermal infra red
  - --- Microwaves



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

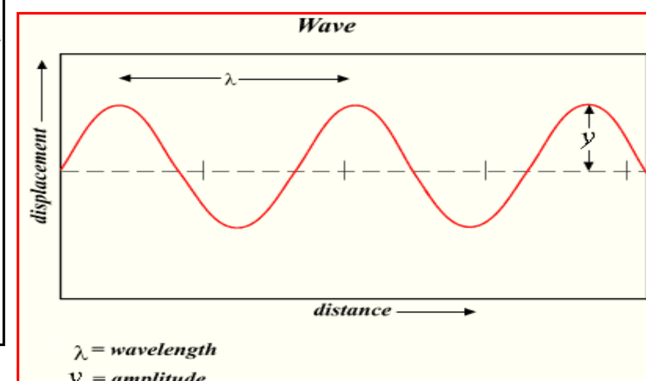


Electromagnetic Spectrum



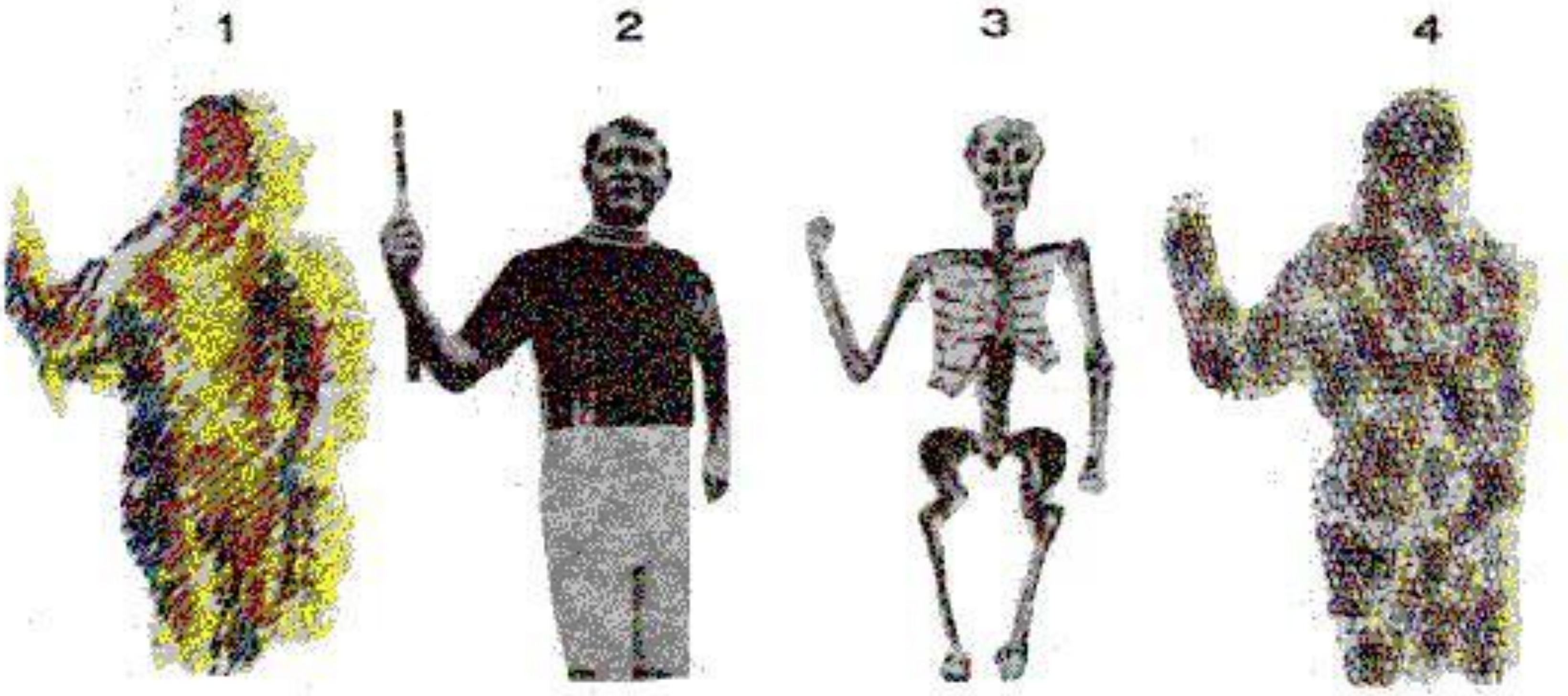
The Sun produces a *continuous spectrum* of energy that continually bathe the Earth in energy.

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



Electromagnetic radiation behaves in most circumstances as waves and can thus be characterized as waves.

Electromagnetic Spectrum



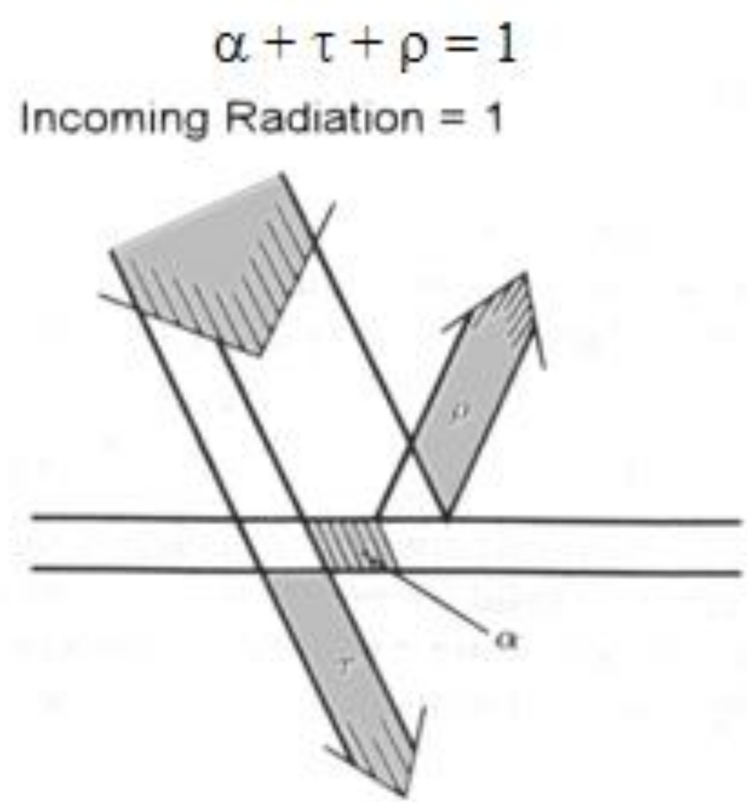
A man detected by different instruments

Thermal radiation

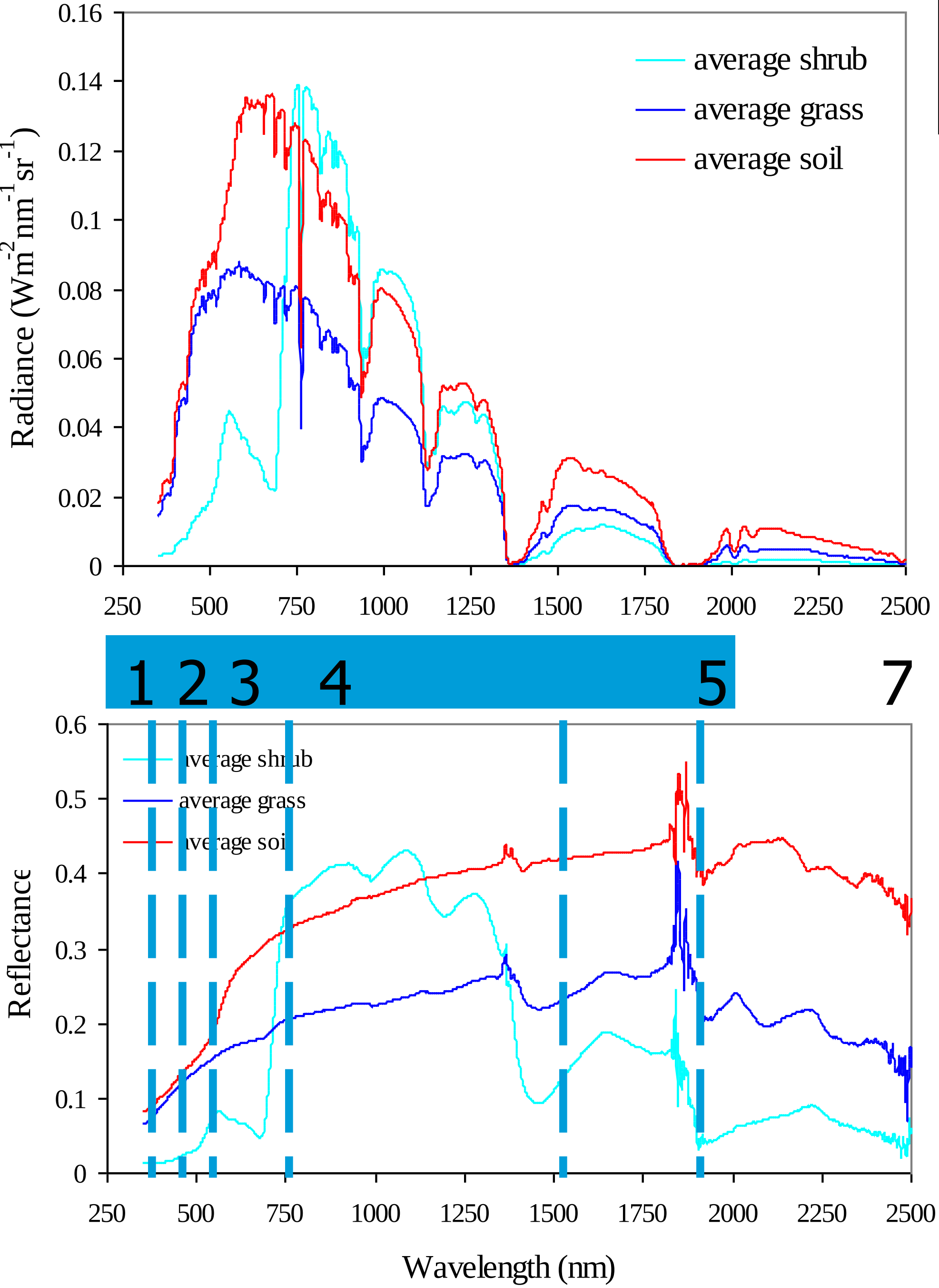
- All matter above absolute zero (0 Kelvin = -273°C = -459.4°F) emits radiant energy in form of electromagnetic waves.

3 key additional properties of surfaces which control the radiation heat transfer of a surface:

- absorptivity α,
- transmissivity *T* and
- reflectivity ρ.

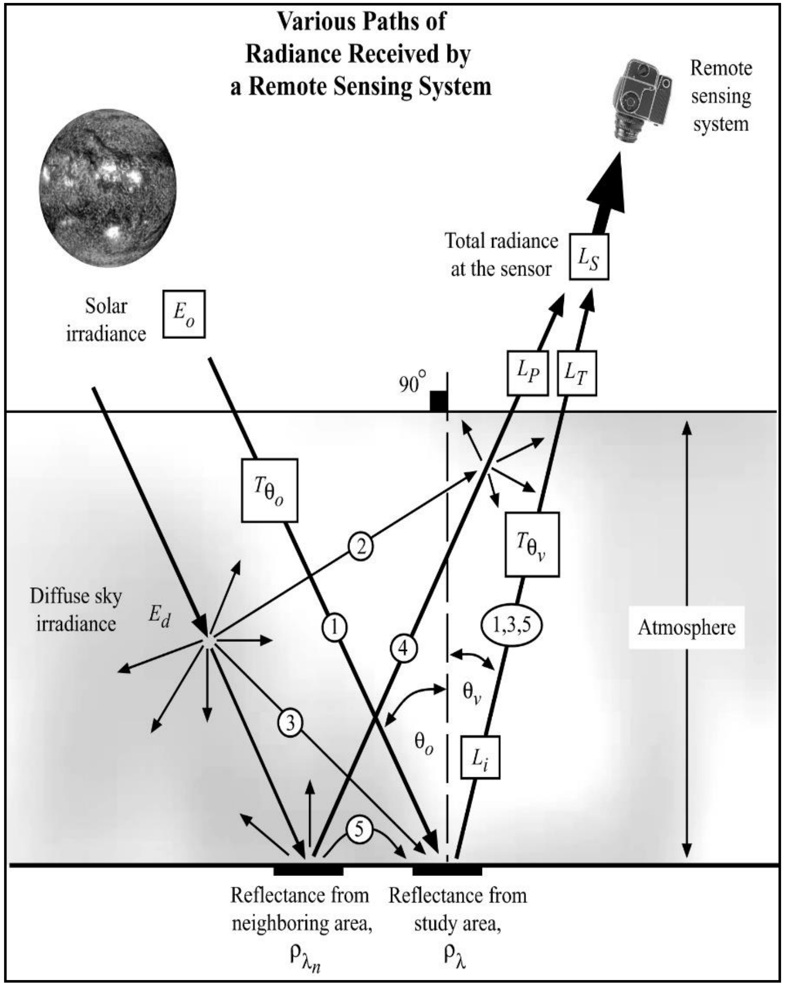


What we measure in remote sensing?



- Temperature
- Soil moisture
- Mineral and rock types
- Rainfall
- Snow cover, snow depth or snow water equivalent
- Vegetation type and biomass
- Sea ice properties (concentration, thickness, extent, area)
- Elevation and change
- Aerosol, gas types and concentration

Electromagnetic Energy Interactions



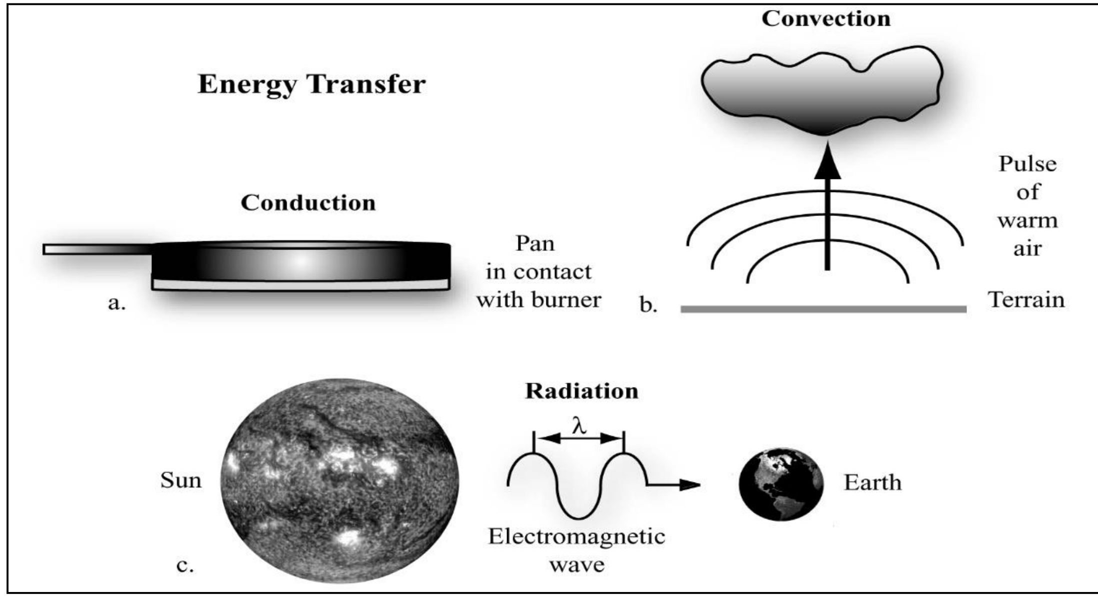
Energy-matter interactions in the atmosphere, at the study area, and at the remote sensor detector

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?



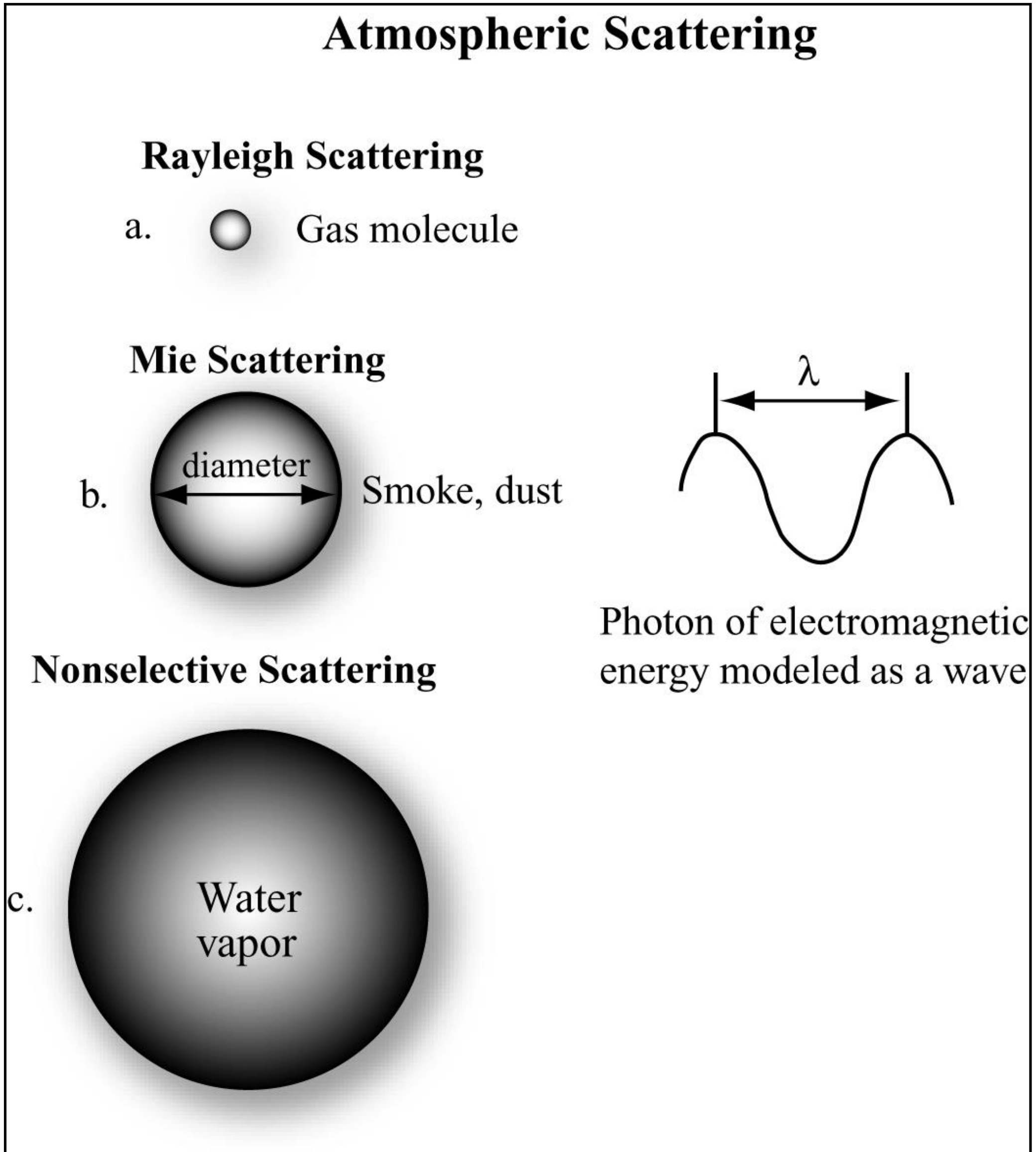
Energy may be transferred 3 ways: *conduction*, *convection*, and *radiation*:

(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.

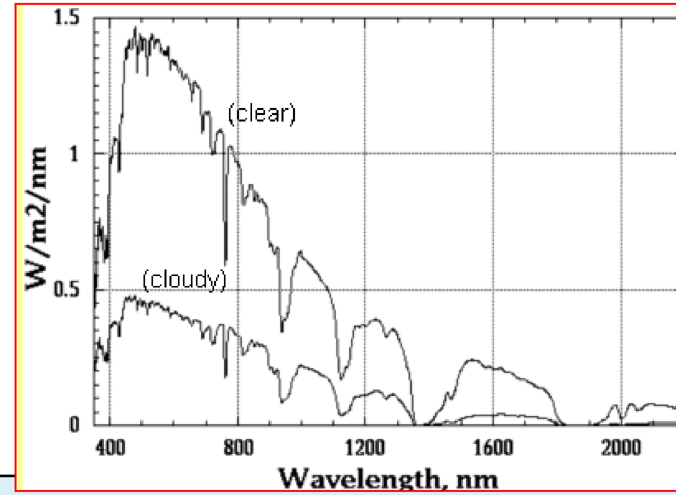
Scattering



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



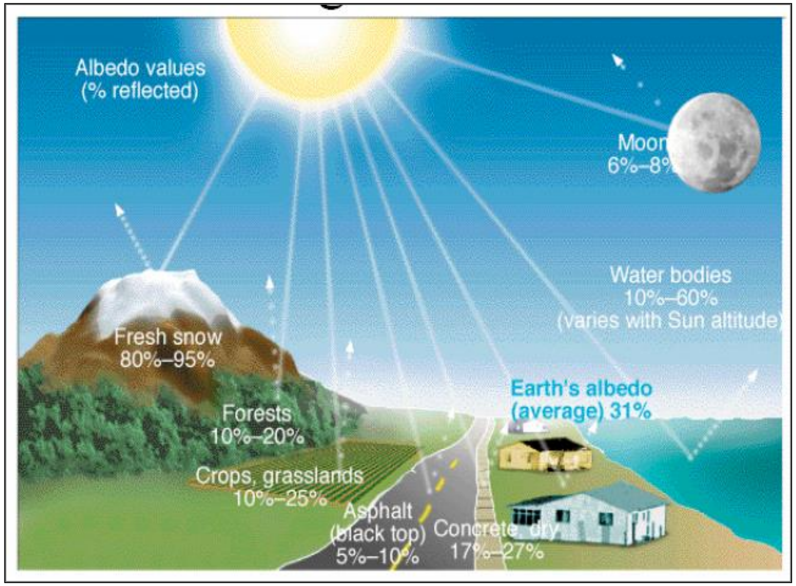
• *Absorption*: radiant energy is absorbed and converted into other forms of energy.

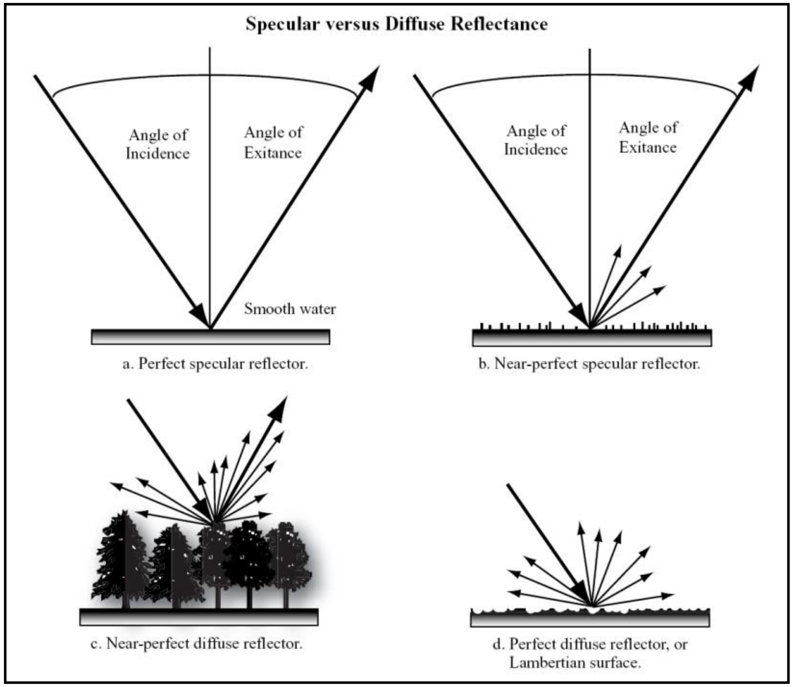
• An *absorption band*: a range of wavelengths (or frequencies) in the EM spectrum within which radiant energy is absorbed by substances such as H_2O, CO_2, O_2, O_3, & nitrous oxide (N_2O).

• The cumulative effect of the absorption can cause the atmosphere to ***close down*** in certain regions of the spectrum. Bad for remote sensing as 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





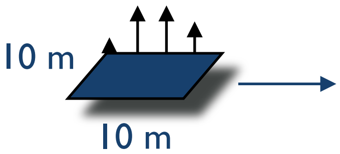
Reflectance: radiation "bounces off" an object like a cloud or the terrain.

• 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.

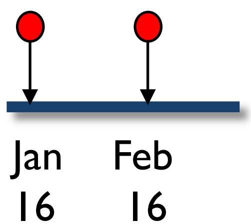
(b) Second, the angle of incidence and the angle of reflection are equal.

Remote Sensor Resolution Considerations

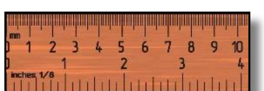


- Spatial - the size of the field-of-view, e.g. 10 × 10 m.

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



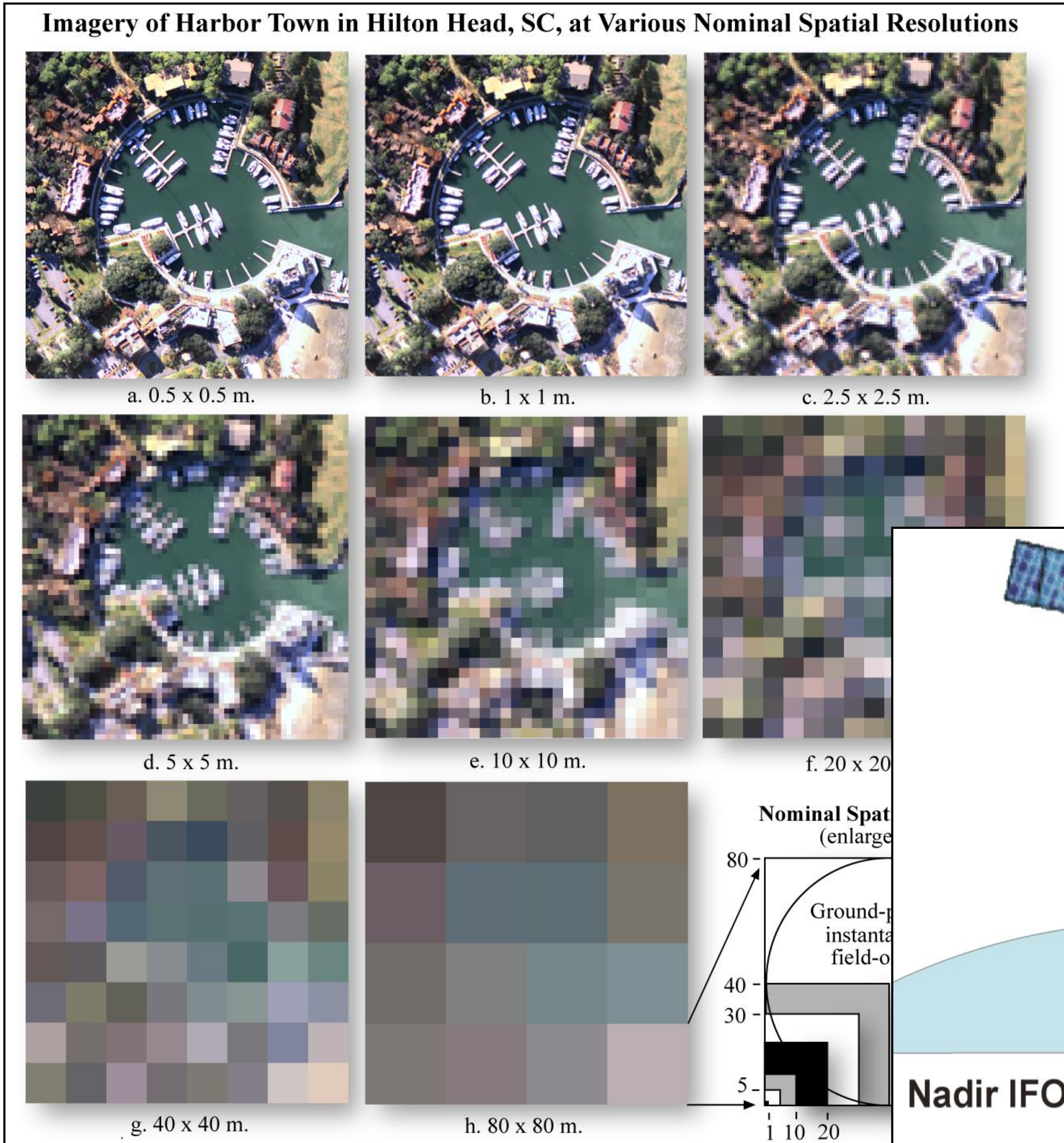
- Temporal - how often the sensor acquires data, e.g., every 30 days.

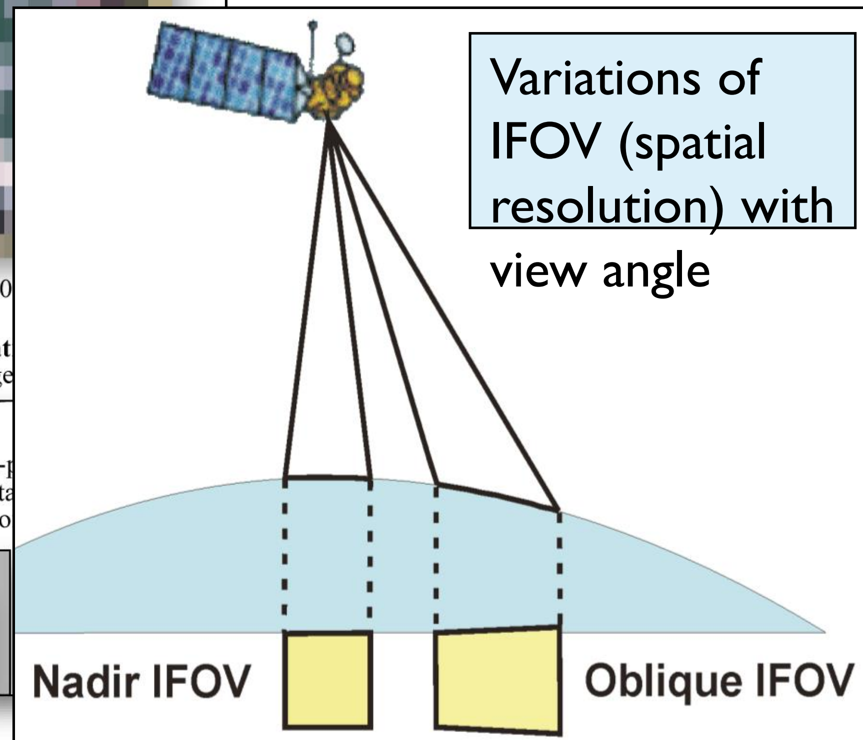


8-bit
(0 - 255)
10-bit
(0 - 1023)

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

Spatial Resolution



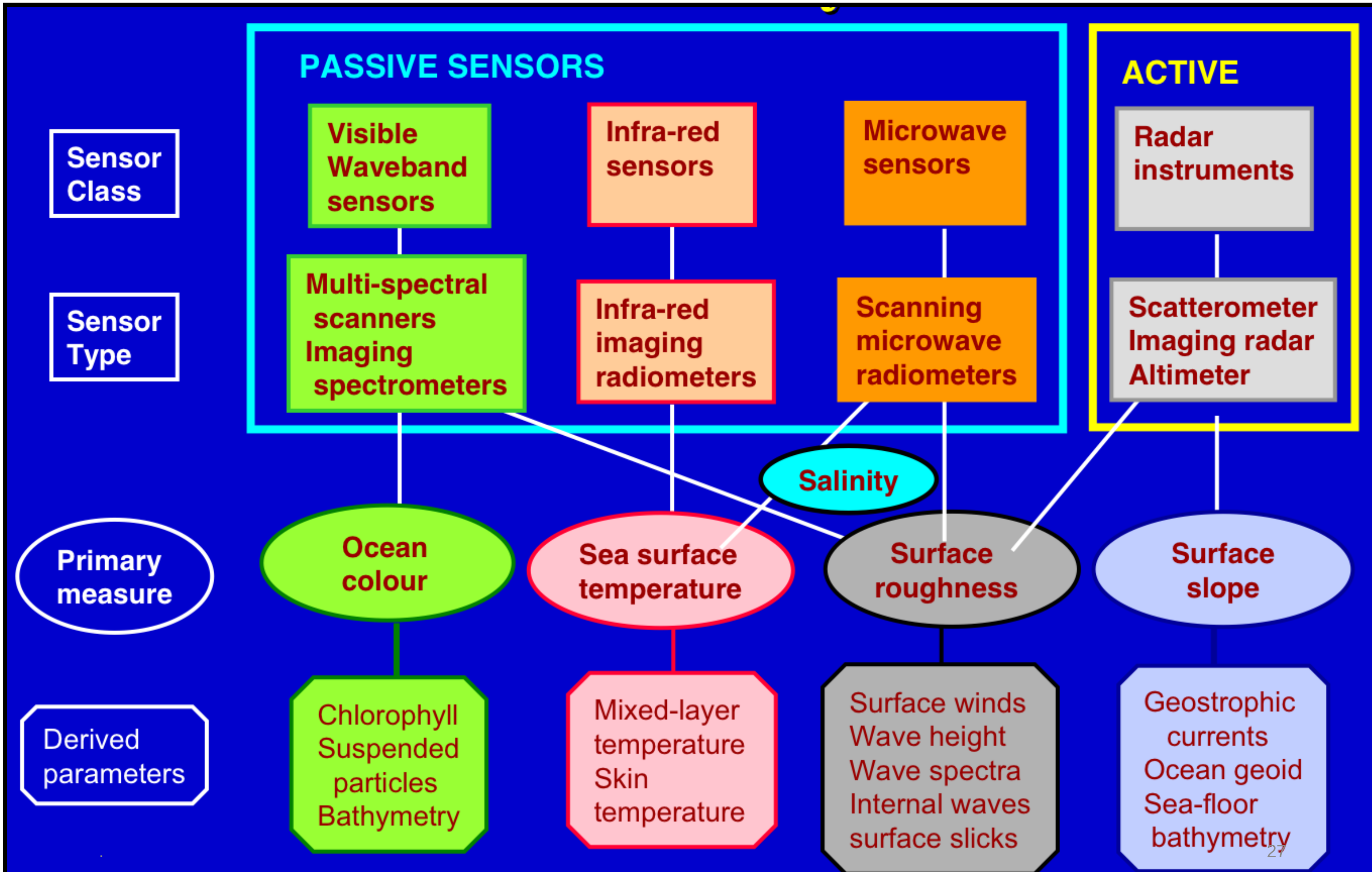


Active and passive sensors

Active sensors (microwave) create their own radiation with which to illuminate the target, and then observe the nature of the reflected signal, in contrast to **passive** (sun, IR and visible wavelength) sensors which rely on naturally occurring radiation.

Passive sensors	**Wavelength**	**Information**
Visible wavelength radiometers	400 nm - 1 μm	Solar radiation reflected by Earth surface
Infrared (IR) radiometers	about 10 μm	Thermal emission of the Earth
Microwave radiometers	1.5 - 300 mm	Thermal emission of the Earth in the microwave
Active devices		
Altimeters	3 - 30 GHz	Earth surface topography
Scatterometers	3 - 30 GHz	Sea surface roughness
Synthetic aperture radars	3 - 30 GHz	Sea surface roughness and movement

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

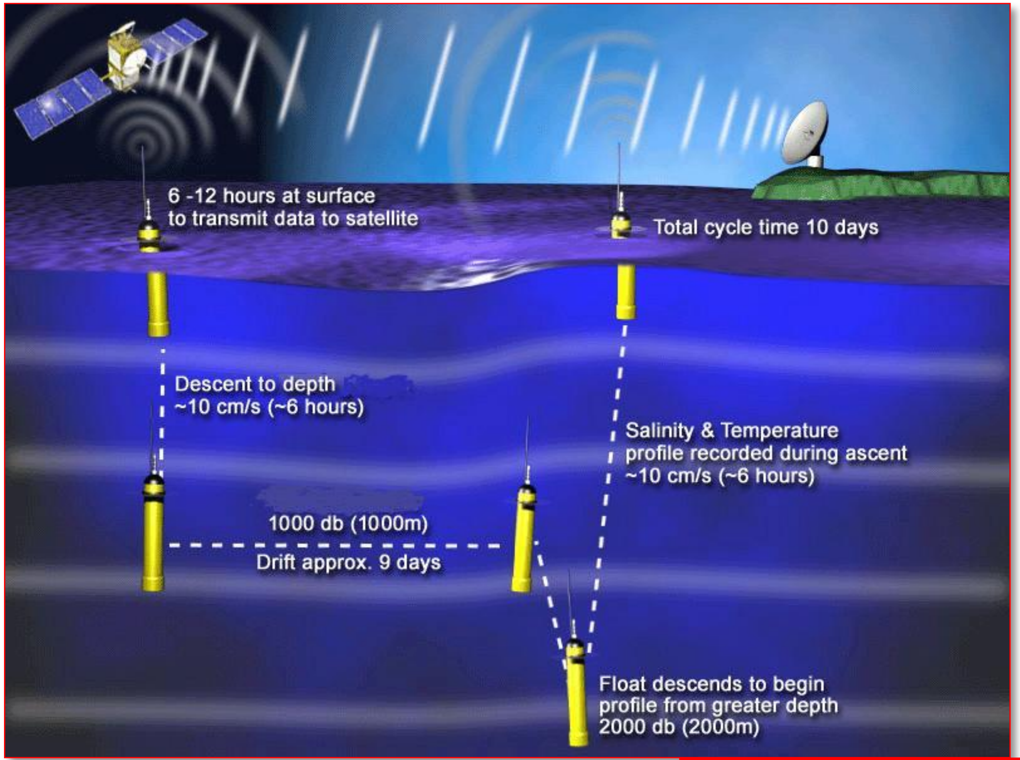
- **Scatterometers:** surface wind speed and direction.

-- QuikSCAT -- ASCAT -- ERS-2

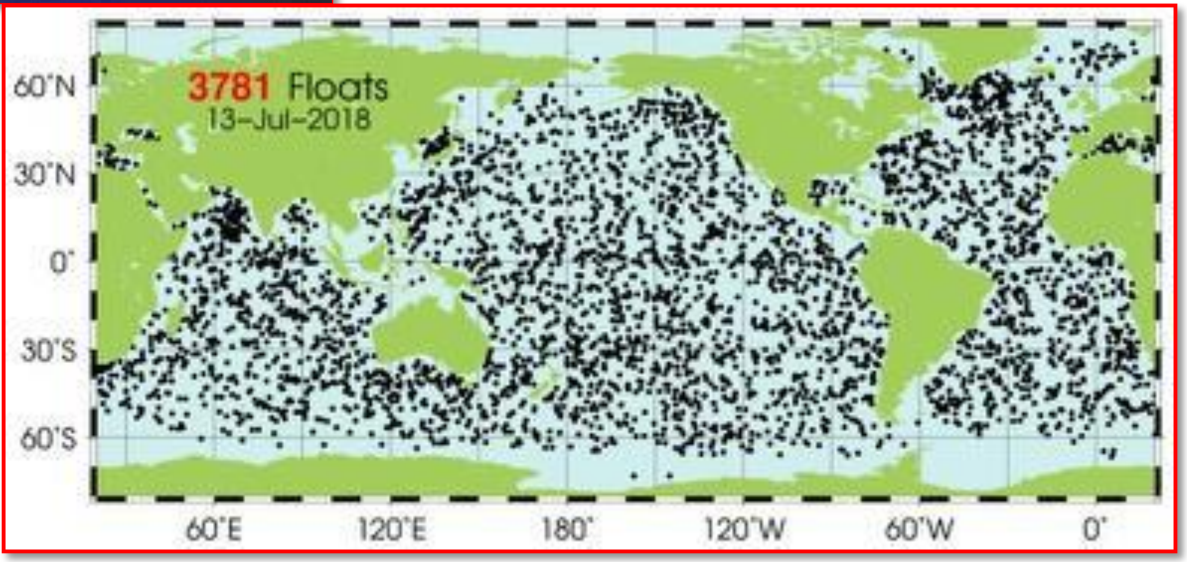
- **Synthetic Aperture Radars** (SAR): winds, waves, currents, oil slicks and ship detection.

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

Satellite data validation - Argo float data



Argo is a global array of more than 3,700 free-drifting profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean.



Altimetry

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

  -- Envisat -- Jason-1 -- Jason-2

  -- GFO -- ERS-2

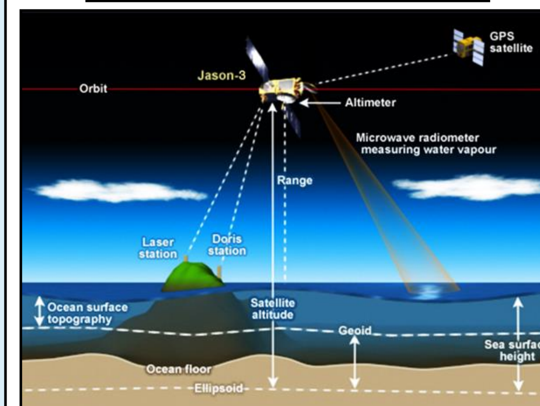
Basic principles of satellite altimetry

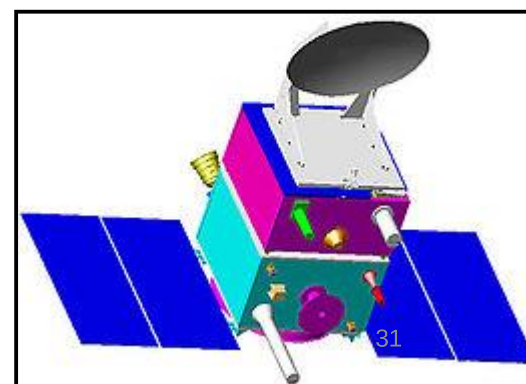
✓ Altimetry: the measurements of altitude/height/elevation above a fixed reference level

-- ***altus*** *(Latin) - height*

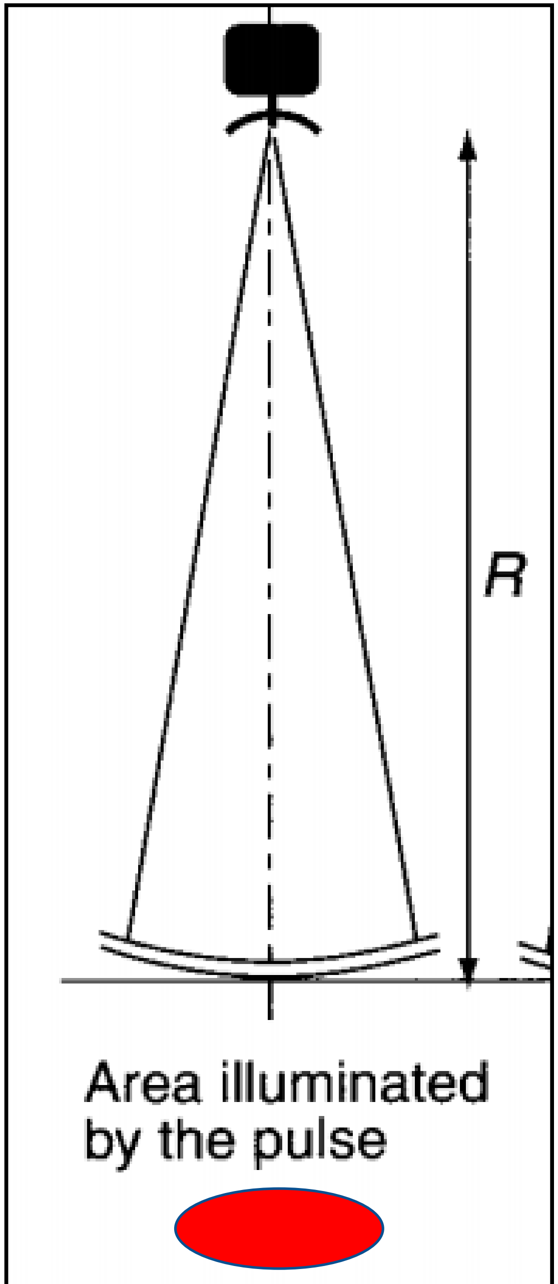
-- ***metron*** *(Greek) - to measure*

- Skylab, GEOS-3, Seasat: 1975-1980
- TOPEX/Poseidon: US & France.
  August 10, 1992 – December, 2005
- Jason-1: a follow on to TOPEX/Poseidon.
  December 7, 2001- July 3, 2013
- Jason-2: June 20, 2008-present
- Jason-3: January 17, 2016-present
- SARAL/Altika: India & France. Feb 25, 2013 - present





Basic principles of satellite altimetry



• Altimetry satellites basically determine the distance from the satellite to a target surface by measuring the satellite-to-surface round-trip time of a radar pulse.

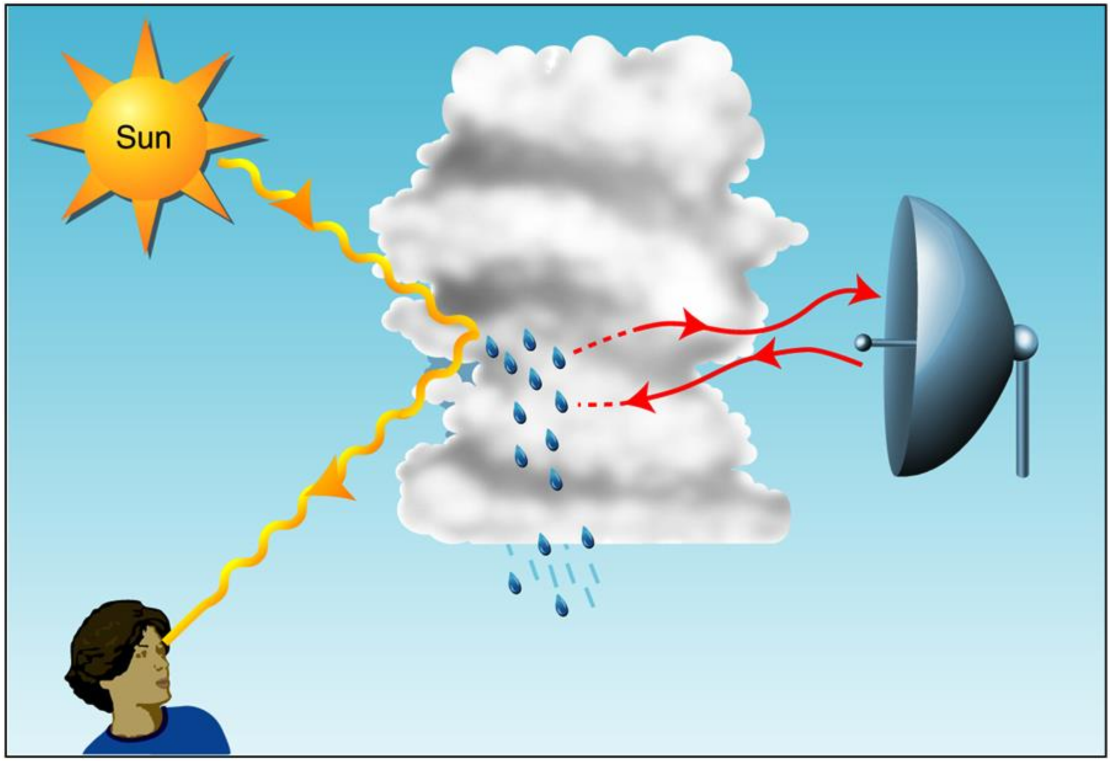
• Radar altimeters on board the satellite transmit signals at high frequency (e.g. Topex/Poseidon - over 1700 pulses per sec) to Earth

• The altimeter receives back echo from the sea surface

Time after pulse emission:

$$t = 2R/c$$

Doppler Radar Schematic



- Short wave lengths (e.g. visible) light are reflected from clouds.
- Longer wavelengths interact with drops.

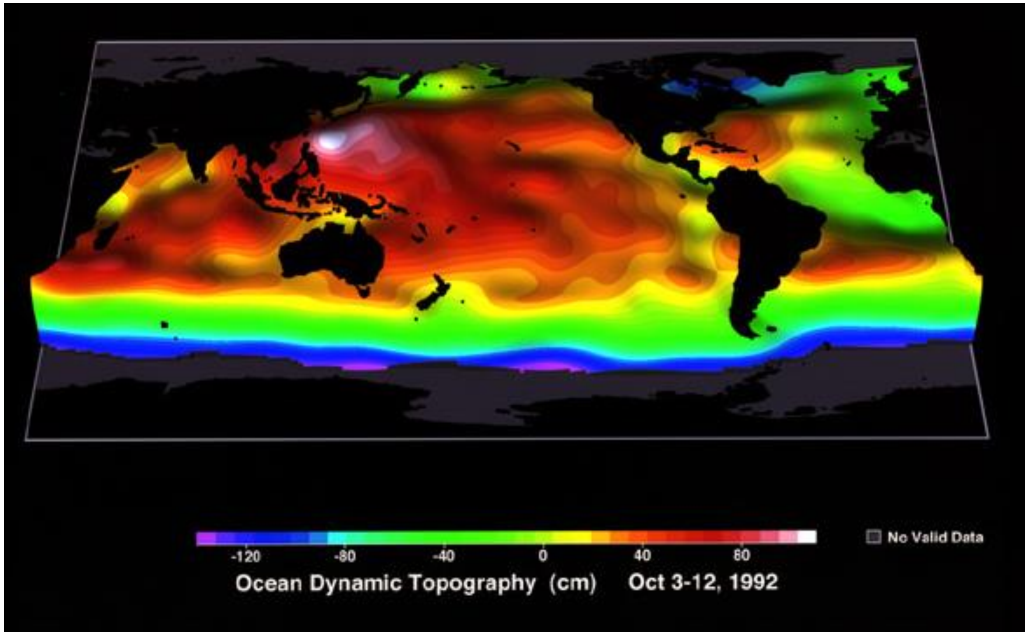
Other key concepts:

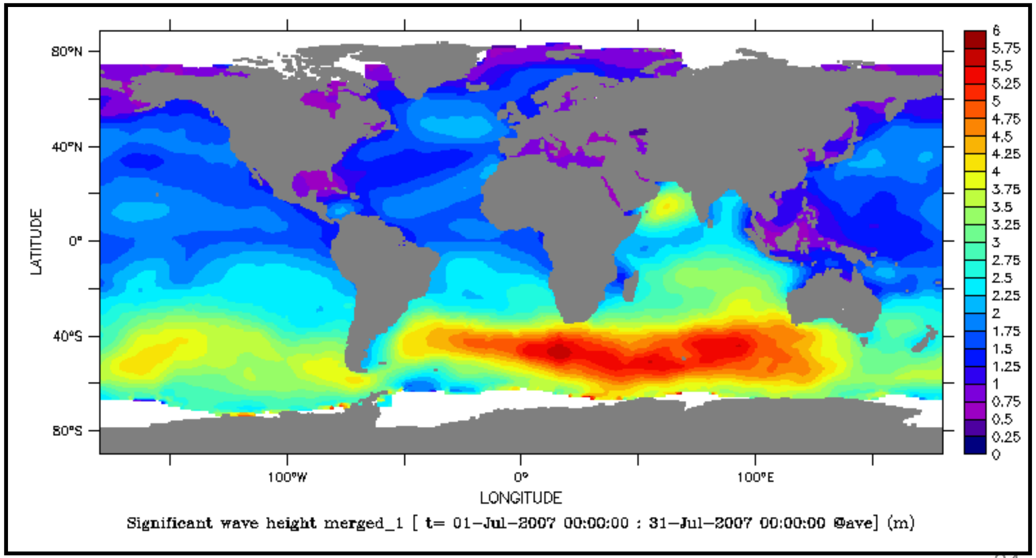
-- Radar emits the signal and receives the fraction that is scattered back (*an active system*).

-- The human eye only receives (*a passive system*).

Main parameters measured by an altimeter

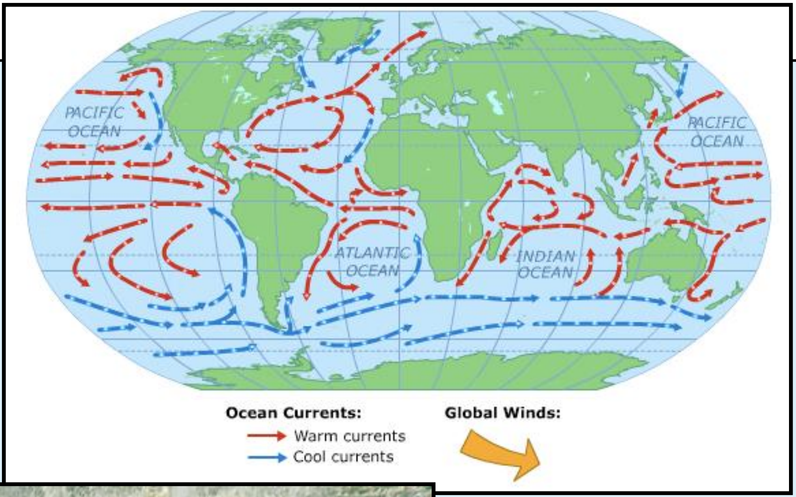
1. Sea Surface Height (SSH)
2. Significant Wave Height (SWH)
3. Wind speed
4. Ice/land/lakes characteristics





Importance of satellite altimetry data

- Ocean variability
- Ocean circulation
- Sea level change
- Planetary waves
- Ocean tides
- Ocean models
- Hydrography
- Ship navigation



Radar or Laser?

Radar altimetry

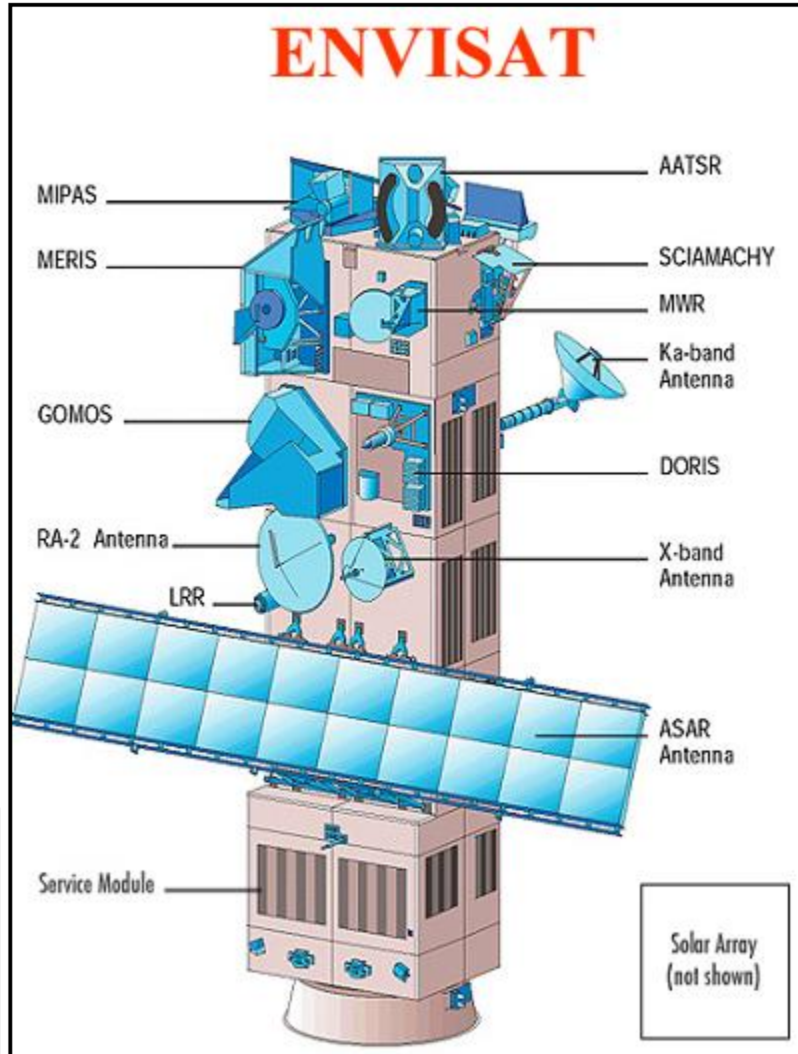
- footprint 2-20 km
- vertical accuracy < 5cm
- weather independent
- robust
- long history, 18 years
- operates on most altimetry missions - works over water and ice

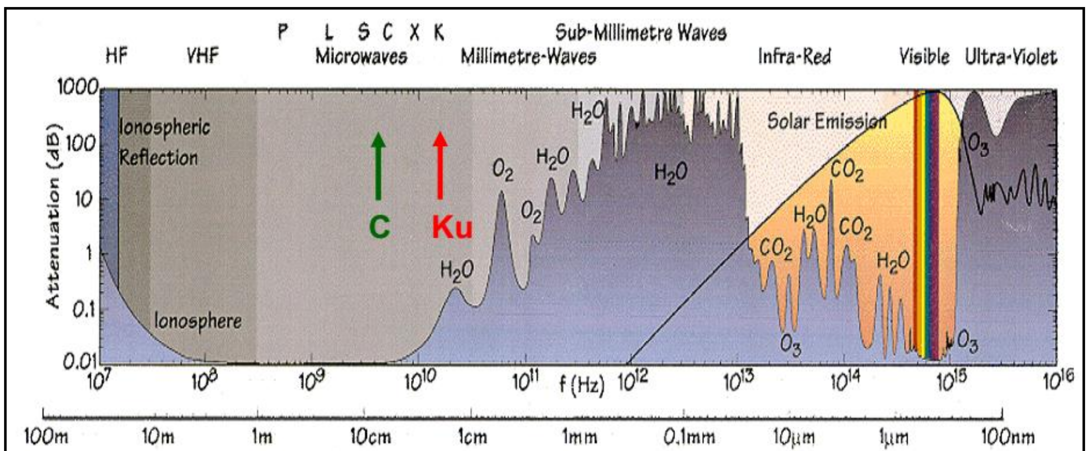
Laser altimetry

- footprint 40-70 meters
- vertical accuracy < 10cm
- weather dependent, clouds
- energy consuming, not robust
- short missions only
- operates on ICESat, MGS and SELENE - works over water, ice and land

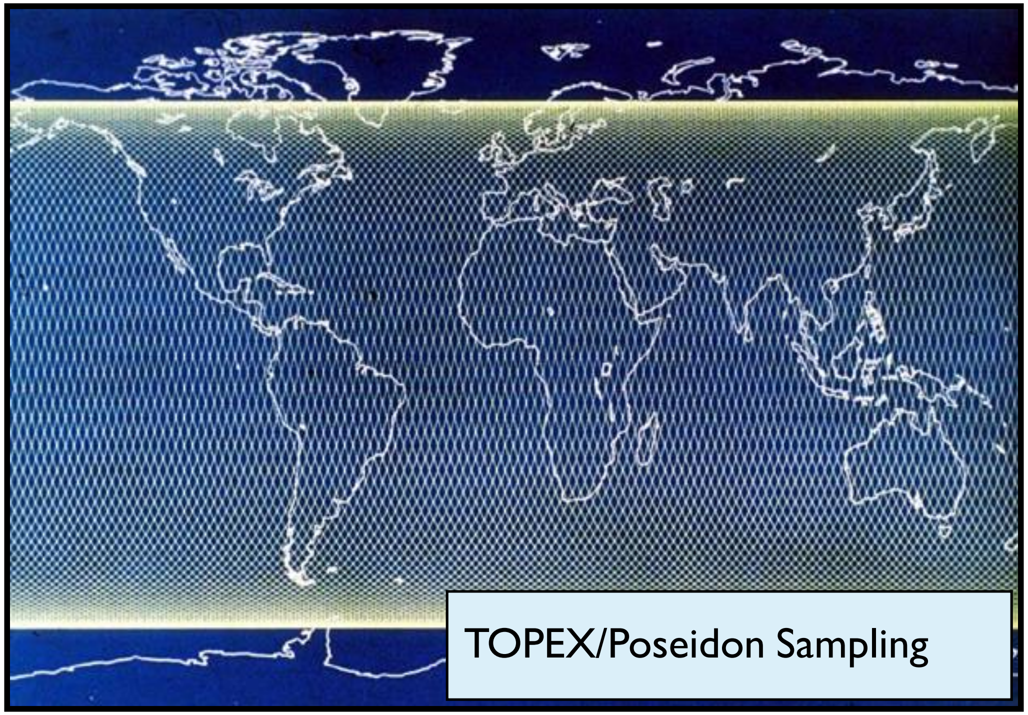
Anatomy of an Altimeter mission

1. Radar altimeter – Ku band (13.5 GHZ).
2. C or S band for ionospheric correction.
3. Microwave radiometer for atmospheric corrections.
4. Tracking system for precise orbit determination (DORIS, LRA, GPS)





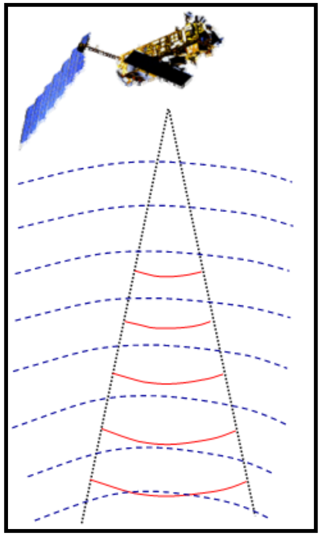
Satellite altimetry coverage



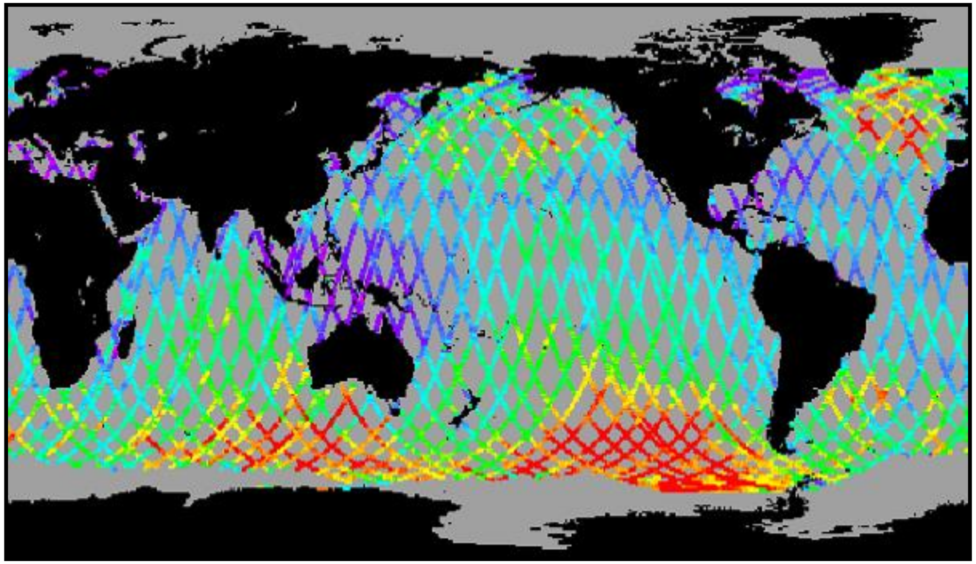
TOPEX/Poseidon Sampling

- Spatial coverage :
  - global
  - homogeneous
  - Nadir (not swath)
- Temporal coverage :
  - repeat period
  - 10 days, T/P-Jason-1
  - 35 days, ERS/ENVISAT

	Geosat	ERS	TOPEX	Poseidon-1	Poseidon-2	ENVISAT
Altitude	785 km	800 km	1336 km	1336 km	1347 km	800 km
Inclination	108 °	98.5 °	66 °	66 °	66 °	98.55°
Trajectory	Retrograde	Retrograde	Prograde	Prograde	Prograde	Retrograde
Repeat Period	17 days	35 days	10 days	10 days	10 days	35 days
Track Spacing Equator	163 km	77 km	315 km	315 km	315 km	77 km



Wave height and wind estimations



- SSH depends on:
  - -- Geoid
  - -- Ocean Tides
  - -- Atmospheric pressure
  - -- Geostrophic circulation
  - -- Ocean waves

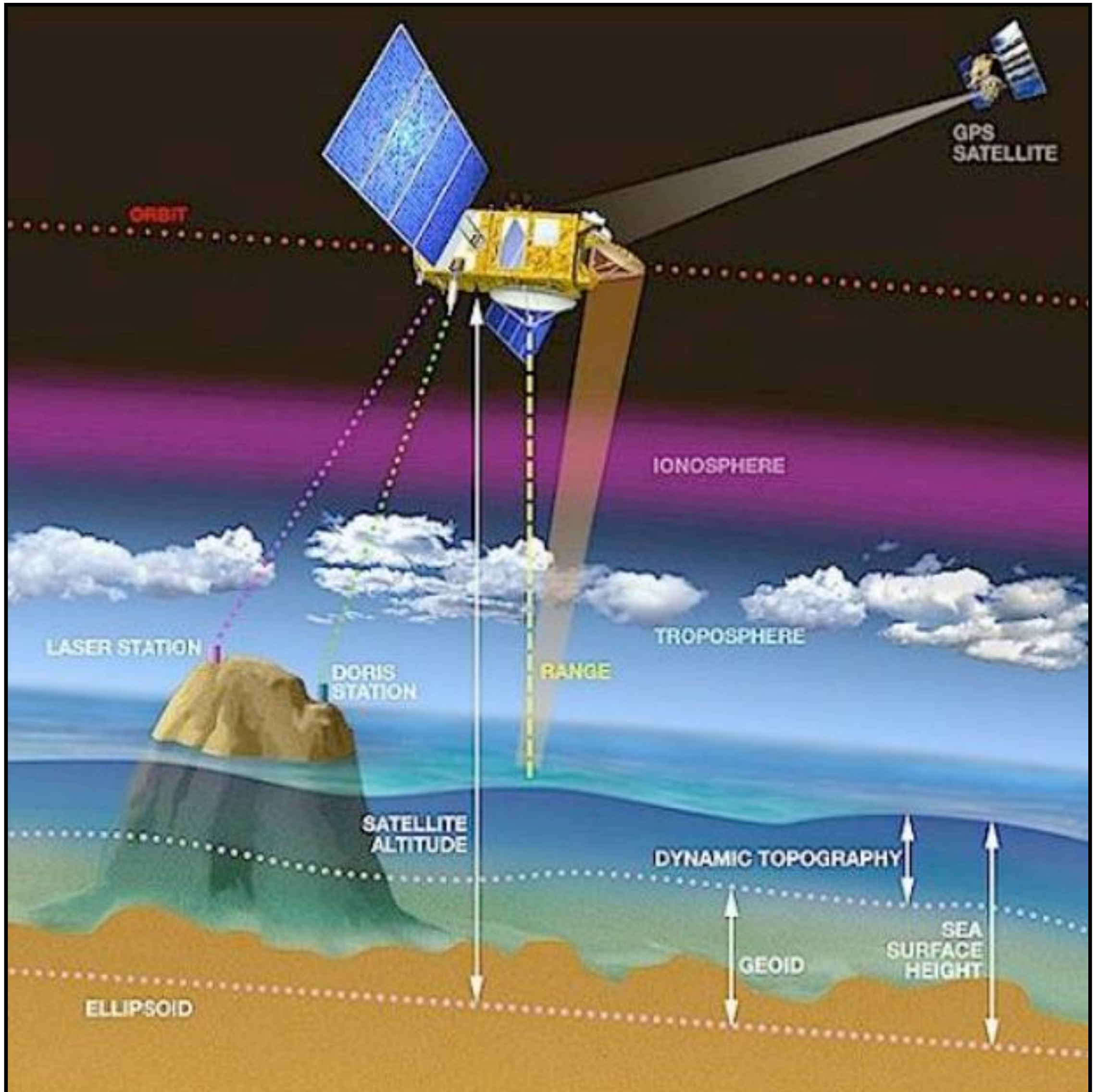
- Significant Wave Height is estimated from the change in slope of the wave form's leading edge.

- The power of the return signal is related to the wind-induced roughness of the sea-surface.

- Wind Speed is then estimated from empirical formulae. Wind direction cannot be resolved.

SSH measurement

SSH (relative to an earth ellipsoid) = Orbit height – Range – Σ Corr



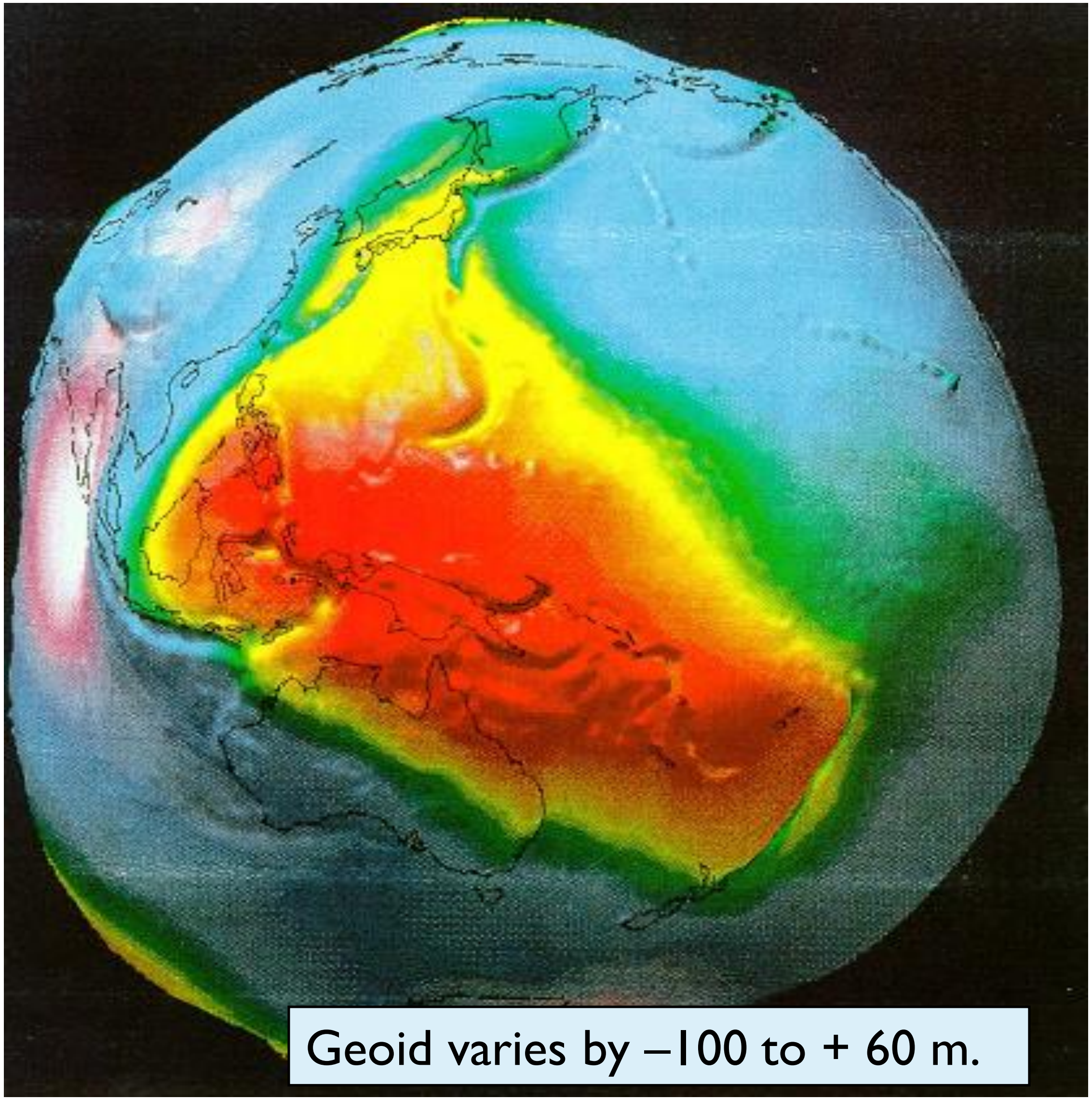
SSH = Geiod + Dynamic topography (η)

Geoid: is that equipotential surface of the Earth gravity field, that most closely approximates the mean sea surface height.

The earth is not a perfect ellipsoid due to uneven distribution of mass

SSH measurement

SSH (relative to an earth ellipsoid) = Orbit height – Range – Σ Corr



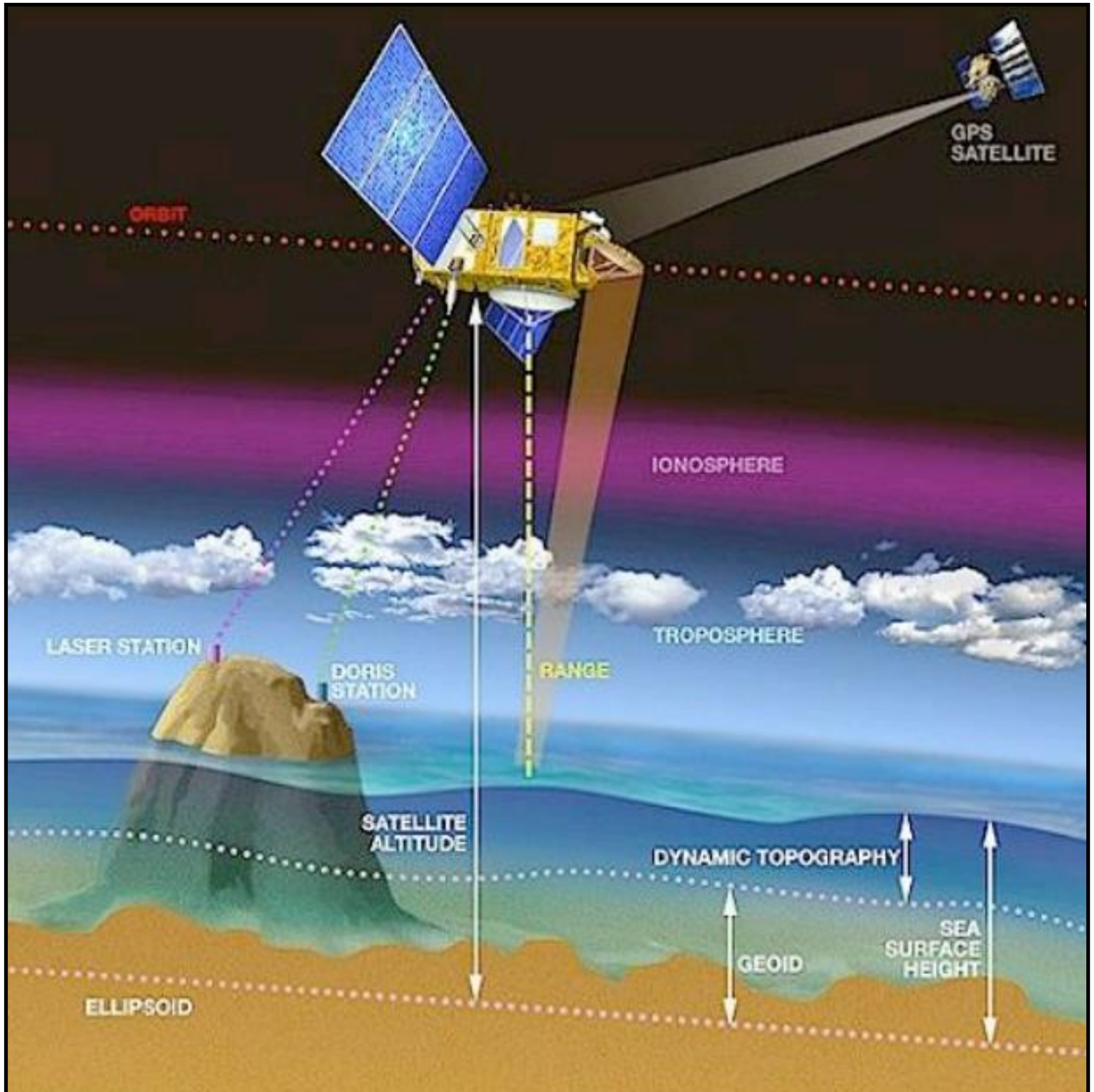
Geoid varies by –100 to + 60 m.

The earth has large bumps and troughs due to variations in the ocean bottom topography and inhomogeneous density distributions in the earth's interior.

These density variations create a **bumpy geoid**. If the ocean were at rest, the sea surface would exactly follow the geoid.

SSH measurement

SSH (relative to an earth ellipsoid) = Orbit height – Range – Σ Corr

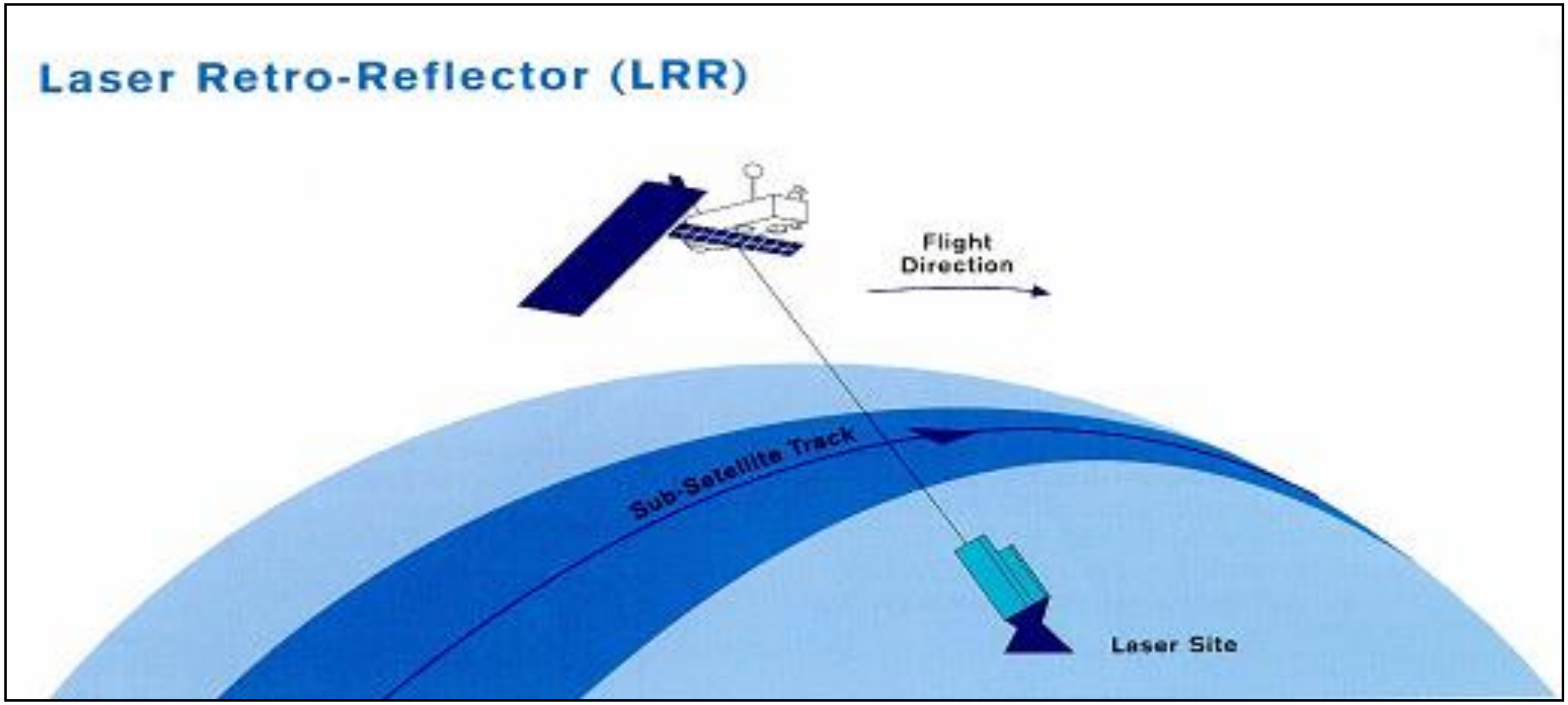


Precision of the SSH:

- Orbit error
- Errors on the range
  - - instrumental noise
  - - various instrument errors
  - - various geophysical errors (e.g., atmospheric attenuation, tides, inverse barometer effects, …)

Satellite Tracking Systems … Laser Tracking and GPS

Satellite tracking is also made using complementary systems : Laser tracking, DORIS and GPS



Satellite Laser Ranging (SLR):

A network of laser ground stations make direct, precise measurements of the distance between the satellite and the laser ground station

Satellite Tracking Systems … Laser Tracking and GPS

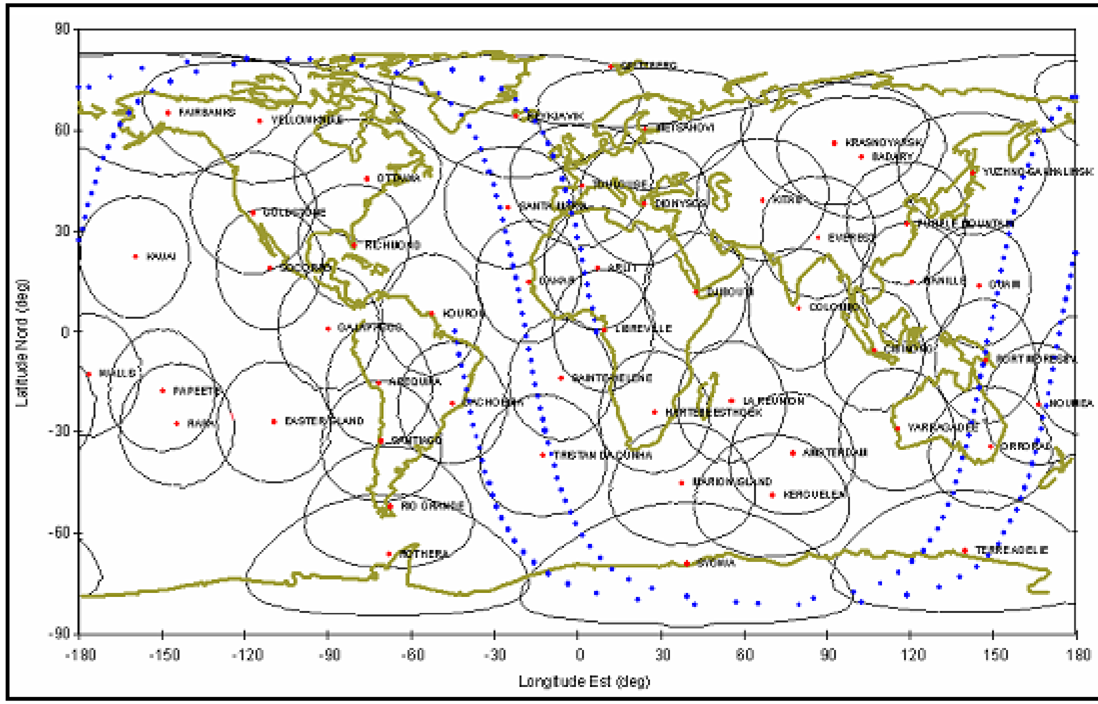
Satellite tracking is also made using complementary systems : Laser tracking, DORIS and GPS

Global Positioning System (GPS):

• An onboard GPS receiver provides precise, continuous tracking of the satellite by monitoring range and timing signals from up to 6 GPS satellites at the same time.

Satellite Tracking Systems … Laser Tracking and GPS

Satellite tracking is also made using complementary systems : Laser tracking, DORIS and GPS



DORIS: a Doppler tracking system. A network of DORIS beacons emit 2 signals at different frequencies. An onboard captor measures the Doppler shift between the signals to determine the distance between the satellite and the ground beacon.

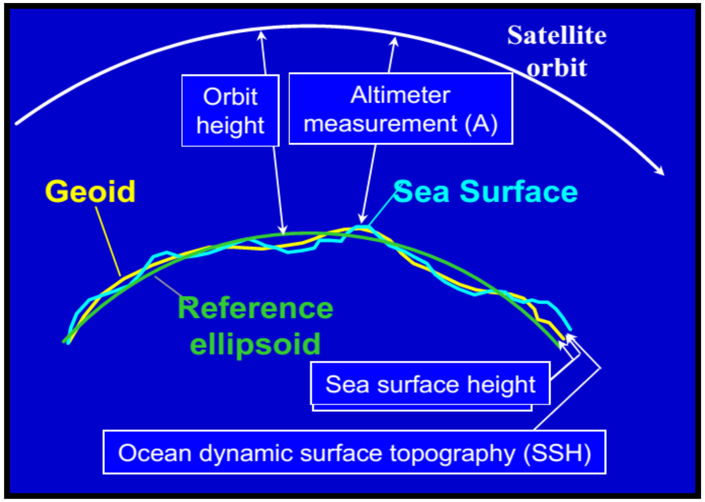
Altimeter data processing

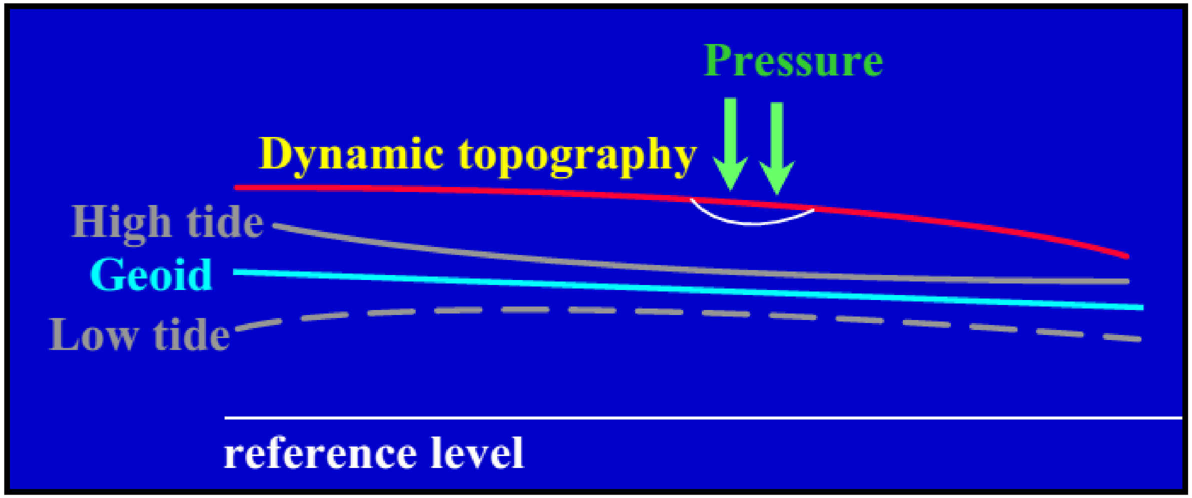
- ***Orbit error correction:***
  - - caused by imperfect knowledge of the spacecraft position in the radial direction.
  - - It is the largest error on altimetric measurements of sea surface topography.
  - - It is also more important for real time applications.

- ***Repeat Track analysis***
  - - used to correct geiod errors at small time scales
  - - CHAMP, GRACE, & GOCE missions expected to provide better geiod data

- ***Mapping and multiple altimeter data merging:*** using optimal interpolation methods to construct map (and error) of the SLA on regular space/time grid

Interpreting the Ocean Surface Topography





- Geiod (~100 m)

-- Time invariant
-- Needs to be independently measured (gravity survey)
-- GRACE (~200 km resolution)
-- GOCE (~80 km resolution)

- Atmospheric pressure (~0.5 m)

-- Apply inverse barometer correction (1mbar ~ 1 cm)

- Tides (~1-2 m)

-- Apply a tidal prediction
-- New tidal models derived from altimetry
-- Special orbits needed to avoid tidal aliasing

- Dynamic topography (~1 m)

-- The intended measurement

Limitations of Satellite Altimetry

- Measures SSHA to an accuracy of 2-3 cm

☐ Measures only along the precise orbit repeat track

- Detects only the variable signal

☐ Long term mean SSH lost in the geoid
☐ Mean ocean currents cannot be detected
☐ Needs longer time series to measure lower frequencies
☐ An independent measure of gravity is needed

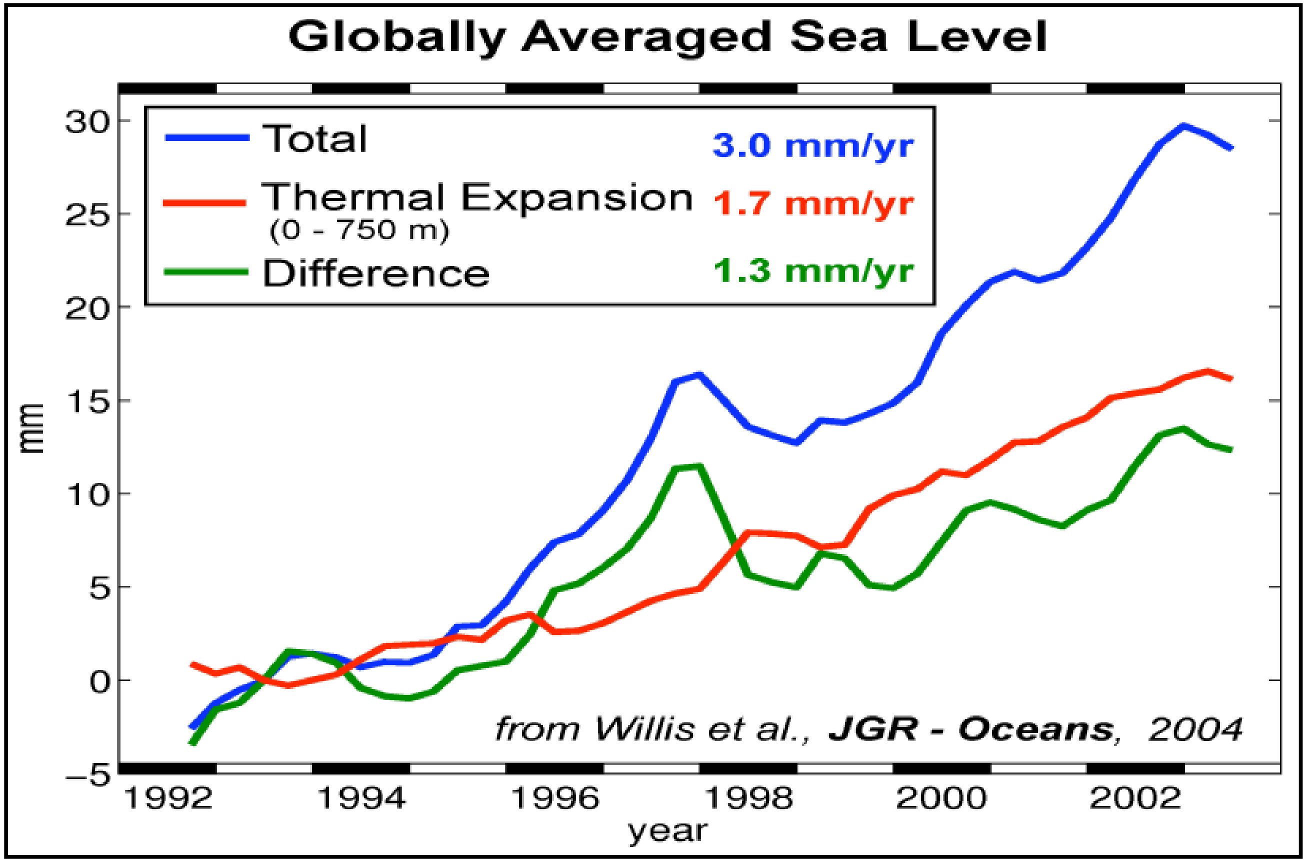
- SSH unreliable in shelf seas

☐ The tidal signal cannot be accurately predicted
☐ Other ageostrophic motions are likely

- Currents cannot be recovered in equatorial waters

☐ Geostrophy not valid

Global Mean Sea Level Trends



- Recent rate of ice discharge from Greenland ~ 0.5 mm/year
- Over 10 years, the heat absorbed by the ocean is enough to do

--- heat the entire atmosphere by 5 degrees,

--- melt all of the world's sea ice (3 times over),

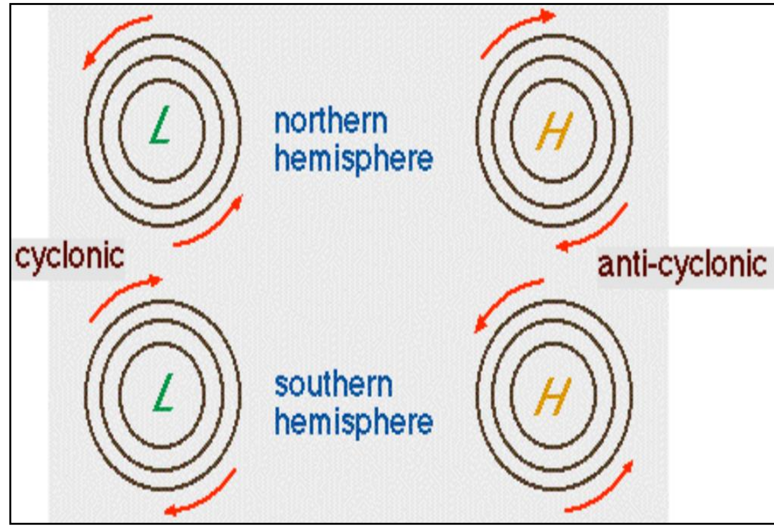
--- melt enough land-bound ice to raise sea level by 24 cm

Consequences of sea level rise

• Over 10 years, the heat absorbed by the ocean is enough to do
--- heat the entire atmosphere by 5 degrees,
--- melt all of the world's sea ice (3 times over),
--- melt enough land-bound ice to raise sea level by 24 cm

Observing ocean currents using satellite altimetry

- Geostrophic currents: current in which the horizontal pressure gradient is balanced by Coriolis force.
- May occur when conditions are barotrophic (homogeneous) or baroclinic (variations in density)



Geostrophy

u,v zonal and meridional currents

P pressure, f = Coriolis parameter

$$\begin{cases} fv = \dfrac{1}{\rho_0}\dfrac{\partial P}{\partial x} & (1) \\ -fu = \dfrac{1}{\rho_0}\dfrac{\partial P}{\partial y} & (2) \end{cases}$$

$$f = 2\Omega \sin\theta$$

Hydrostatic balance

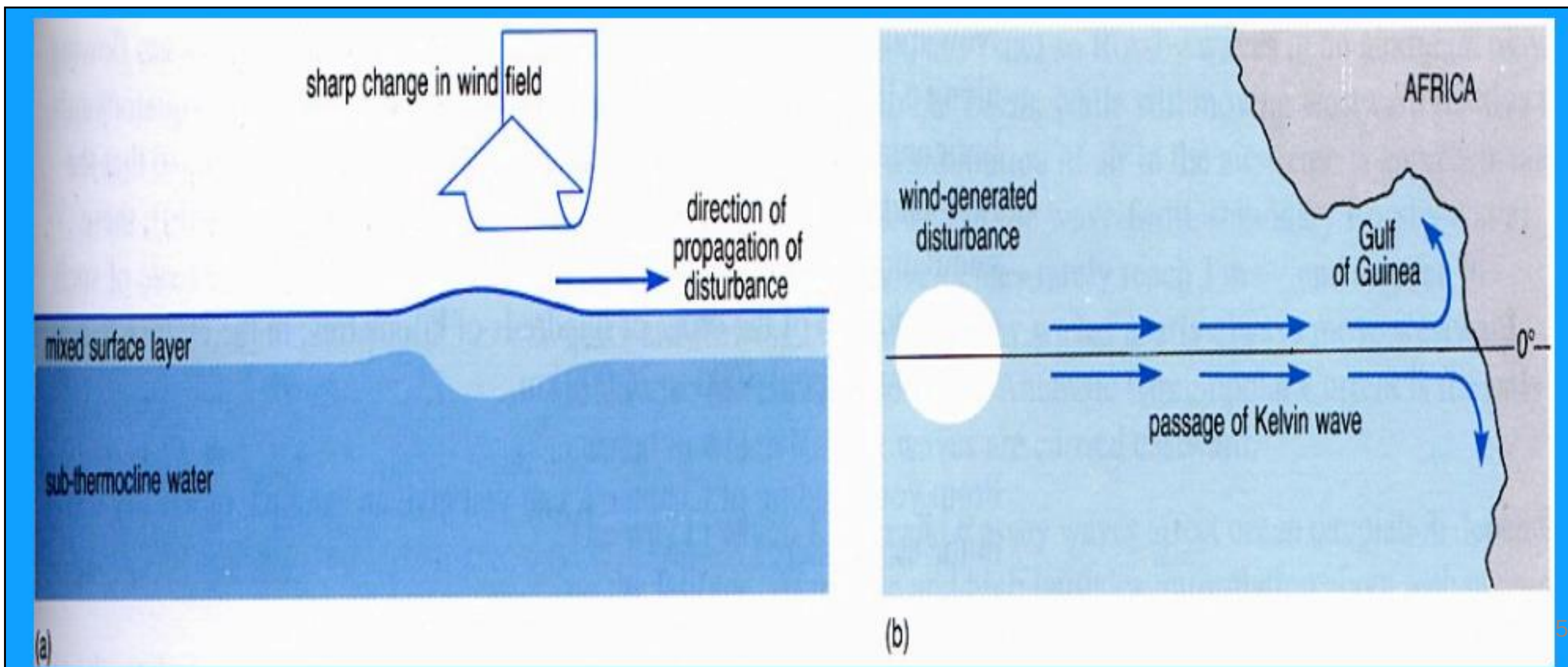
$$\left\{ \frac{\partial p}{\partial z} = -\rho g \qquad (3) \right.$$

- At the surface P = ρg η(η= sea surface topography relative to the geoid - z local vertical) =>

$$\begin{cases} fv = g\dfrac{\partial \eta}{\partial x} \\ -fu = g\dfrac{\partial \eta}{\partial y} \end{cases} \qquad (4)$$

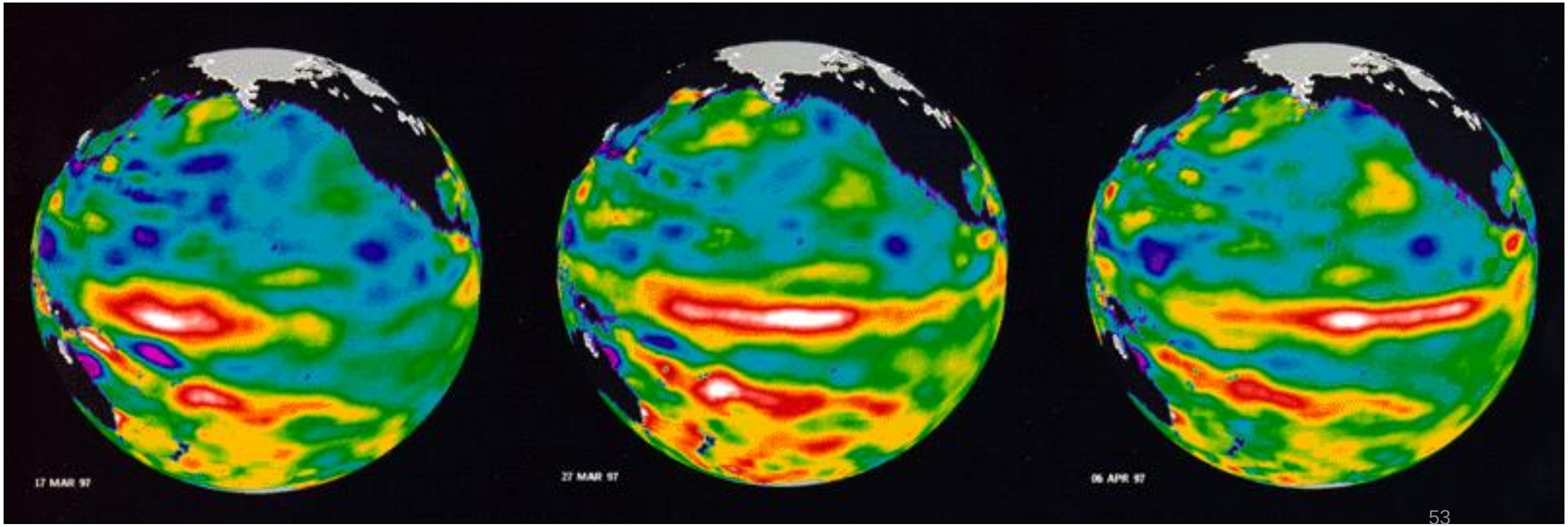
Kelvin Waves

- Kelvin waves are similar to surface wind waves in that the principal maintaining force is gravity.
- The necessary condition for propagating Kelvin waves is that the horizontal pressure gradient force and Coriolis force act in opposite direction.
- Along the equator f=0 , hence equator serve as a wave guide.



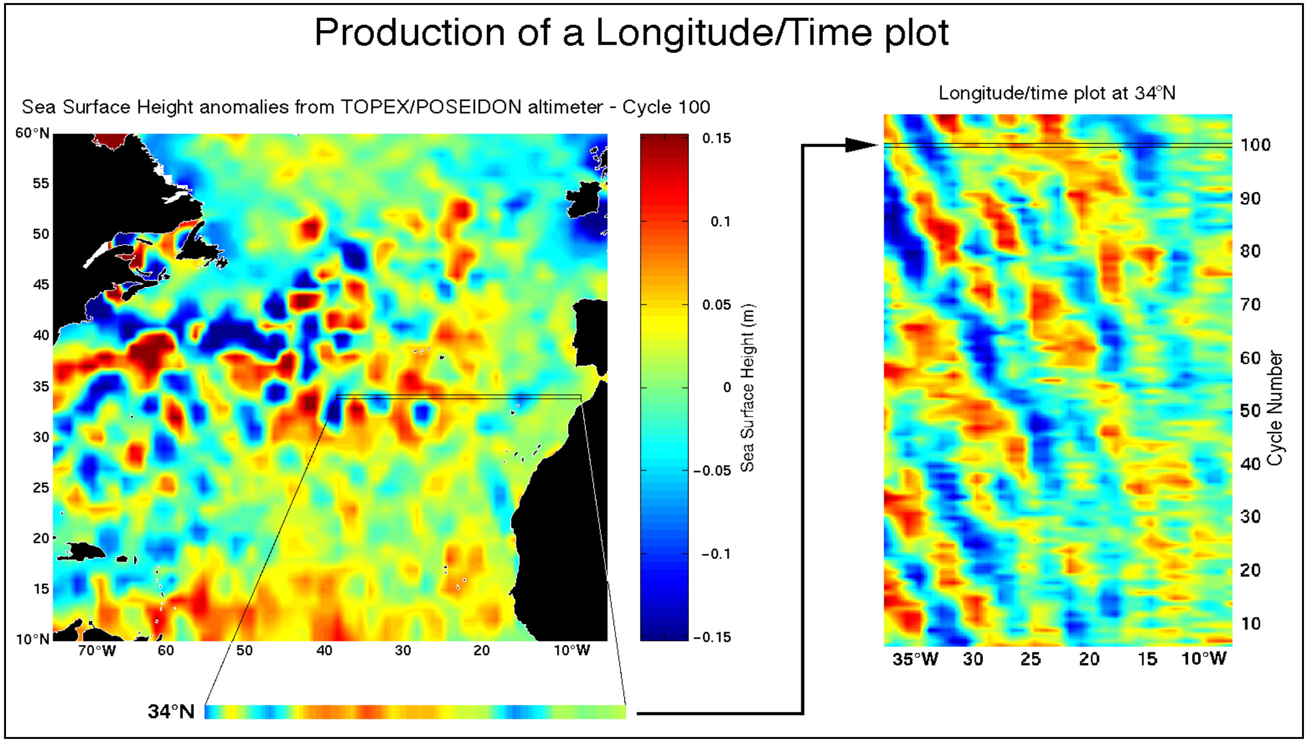
Equatorial Kelvin Waves

- Satellite altimetry from TOPEX/Poseidon
- Scenes are 10 days apart

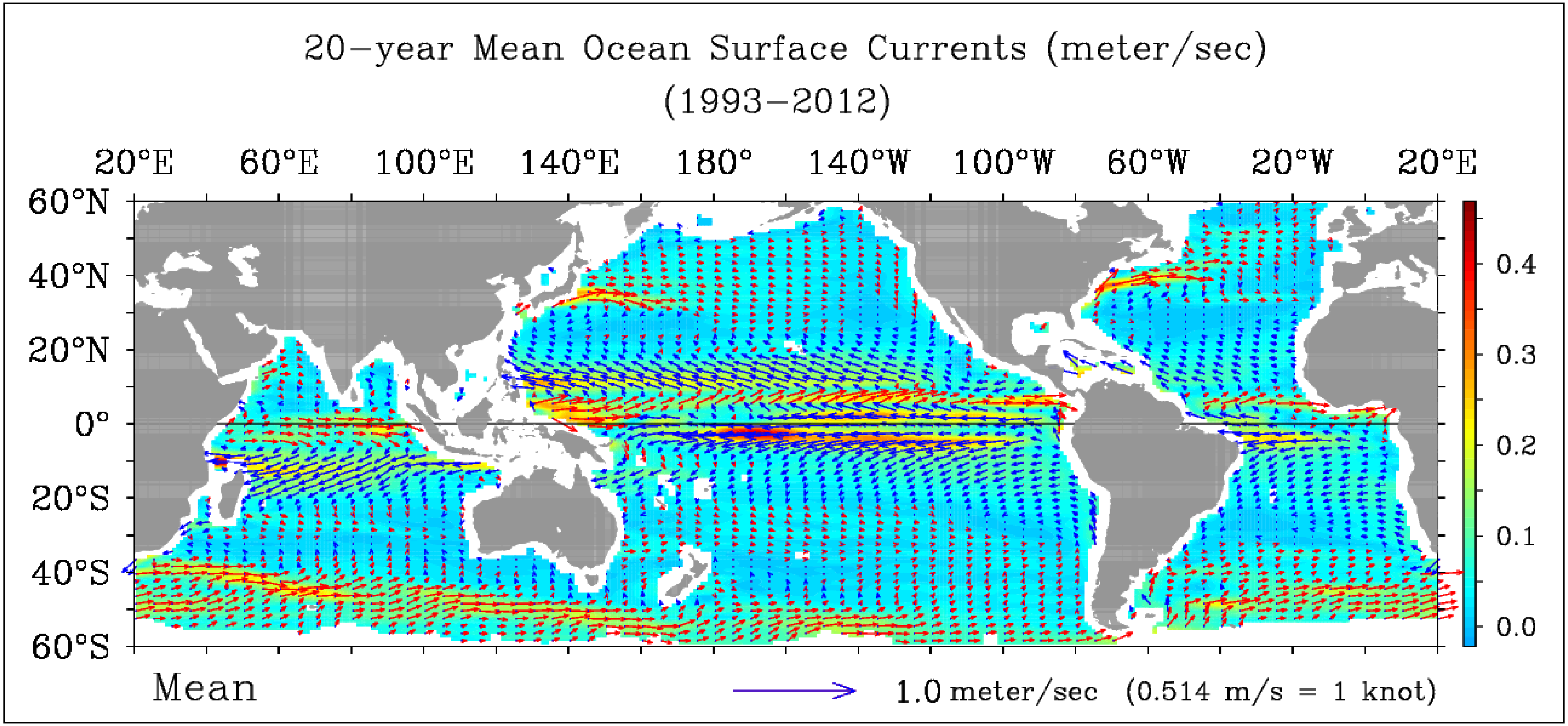


Rossby waves

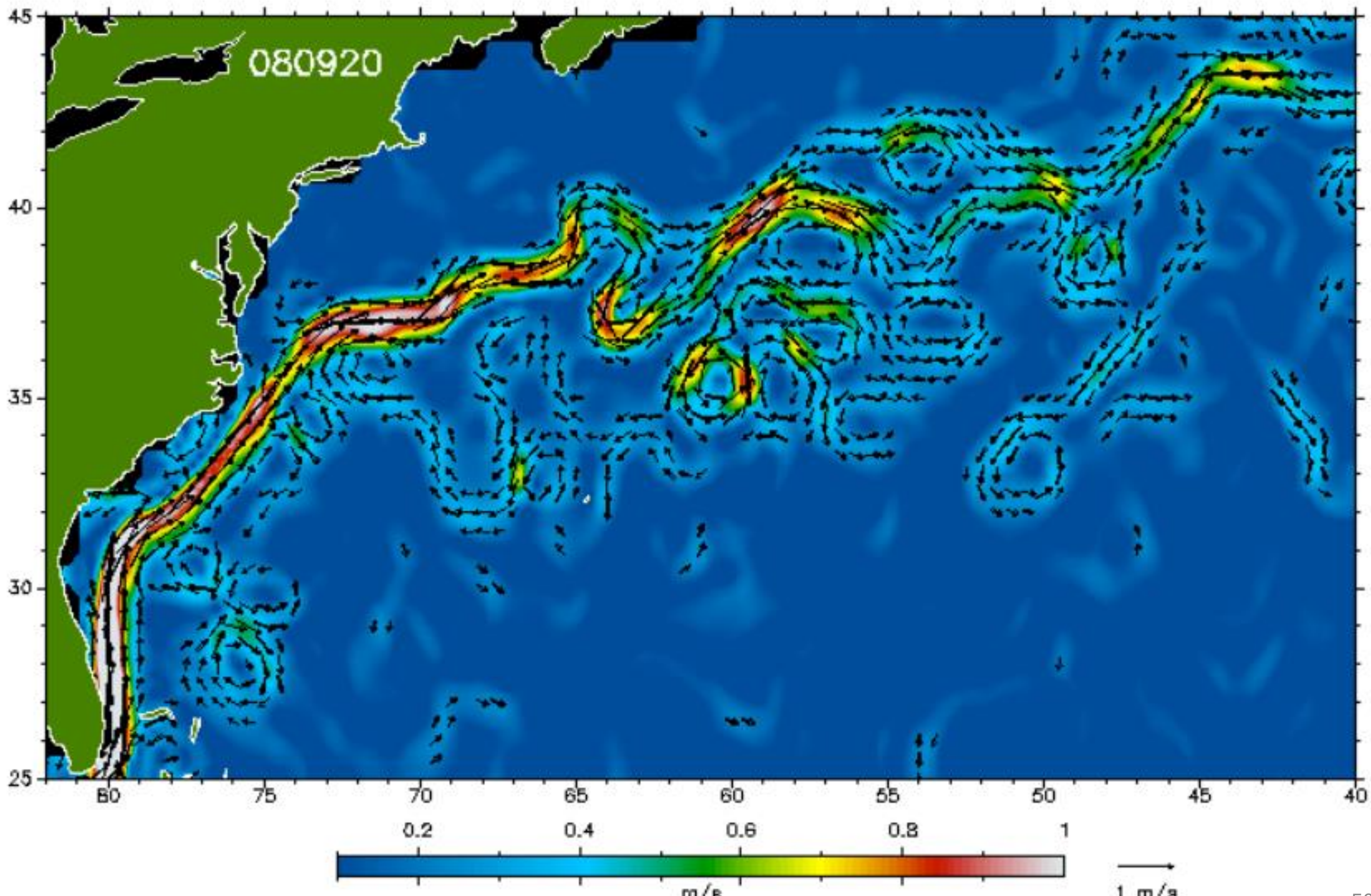
- Rossby waves, or planetary waves are a special class of large-scale waves which occur in both the atmosphere and the ocean.
- They arise because of the latitudinal variation of the Coriolis parameter.
- Long wavelength (100s-1000s of Km). Wave amplitude < 10 cm



Surface currents from satellites



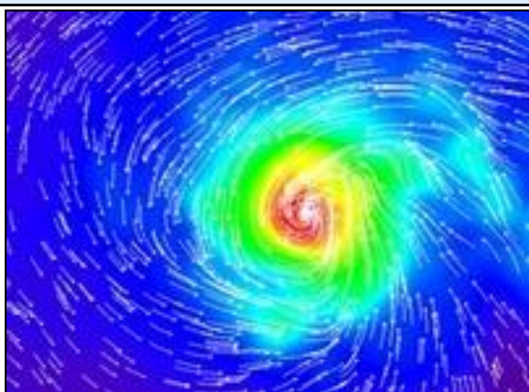
Gulf Stream position from altimetry



Scatterometry

Scatterometry - Observing ocean winds

- Scatterometers measure the power of backscattering reflected from the surface of objects.
- The sensor is an **active microwave radar** sensor that measures the two dimensional velocity vectors of the sea wind
- The **wind speed** can be determined from the strength of the backscatter signal.
- The **wind direction** is found by determining the angle that is most likely to be consistent with the backscatter observed from multiple angles.

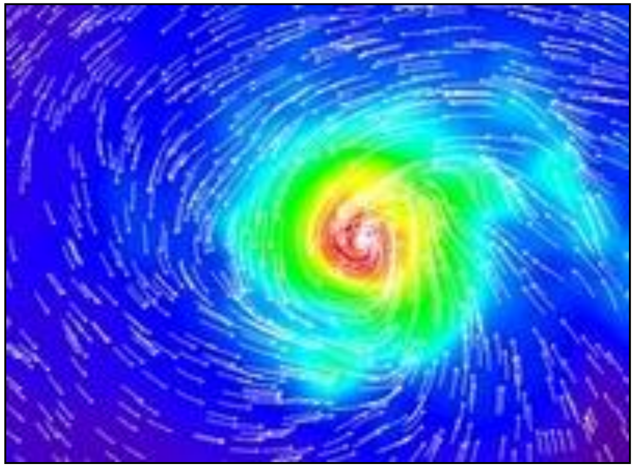


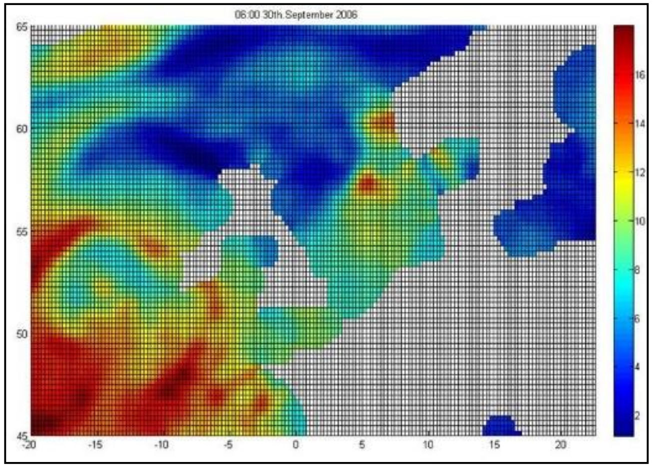
Applications/importance of Scatterometry

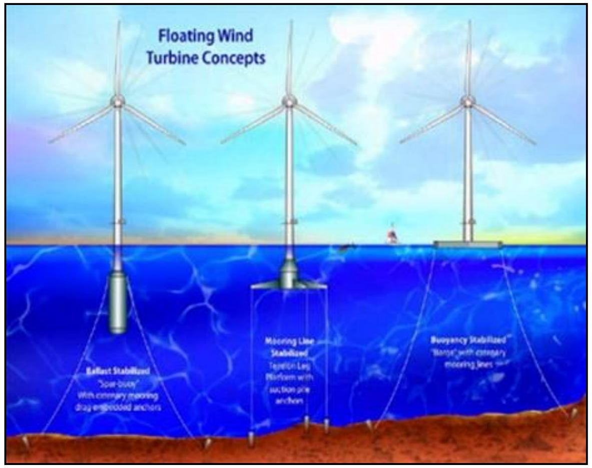
- **Weather forecasting**: provides an all-weather, high-resolution measurements of near- surface winds over global oceans.

- **Oceanography:** helps understand atmospheric forcing, ocean response, and air-sea interaction on various spatio-temporal scales.

- **Climate variability**: helps us better understand the mechanisms of global climate change and weather patterns. Tropical Cyclones

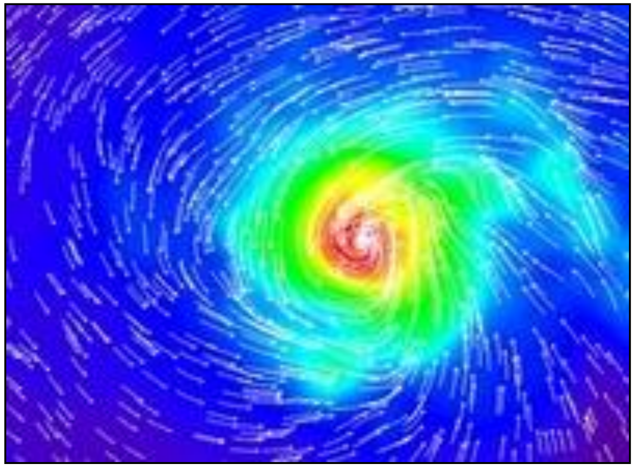


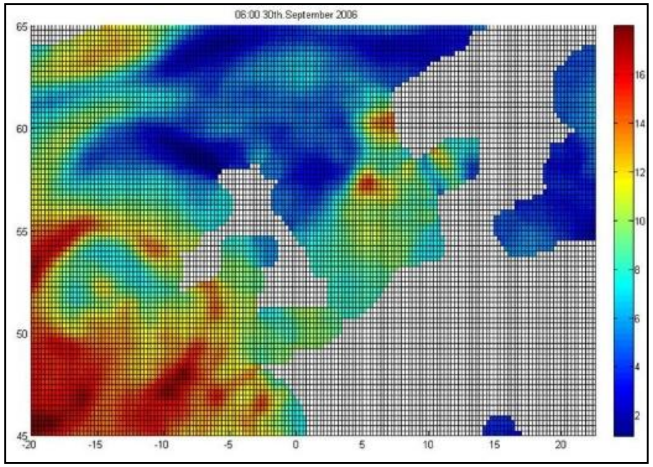


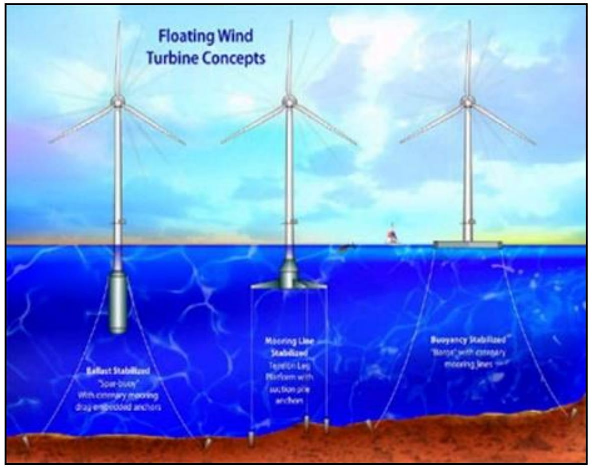


Applications/importance of Scatterometry

- **Land and Sea Ice**: study daily/seasonal sea ice edge movement and Arctic/Antarctic ice pack changes.
- **Wind Energy**: emerging offshore wind energy industry.
- **Marine Safety** (NRT): monitor severe weather, fronts, storms





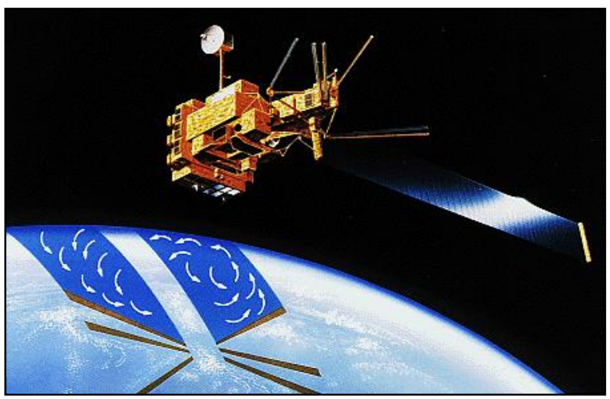


History of Scatterometry

Sensor/Satellite	Period in Service	Spatial Resolution	Operational Frequency
SeaSat	1978/7/7 - 1978/10/10	50 km with 100 km spacing	Ku band (14.6 GHz)
ERS-1	1991/7 - 1997/5/21	50 km	C band (5.3 GHz)
ERS-2	1997/5/21 - 2011/7	50 km	C band (5.3 GHz)
NSCAT	1996/9/15 - 1997/6/30	25 km and 50 km	Ku band (13.995 GHz)
SeaWinds on QuikSCAT	1999/7/19 - 2009/11/23	25 km	Ku band (13.4 GHz)
SeaWinds on ADEOS II	2002/12 - 2003/10	25 x 6 km	Ku band (13.4 GHz)
ASCAT	2006/10 - Present	50km	C band (5.255 GHz)
OCEANSAT2	2009/9/23 – Present	25km	Ku band (13.5 GHz)
HY-2A	2011/8 - Present	25km	Ku band (13.256 GHz)

History of Scatterometry

- **SeaSat**: first Earth-orbiting satellite designed for remote sensing of the Earth's oceans
- Carried on board the first spaceborne SAR
- Operated by NASA/JPL. Lasted 105 days (1978/7/7 -1978/10/10)



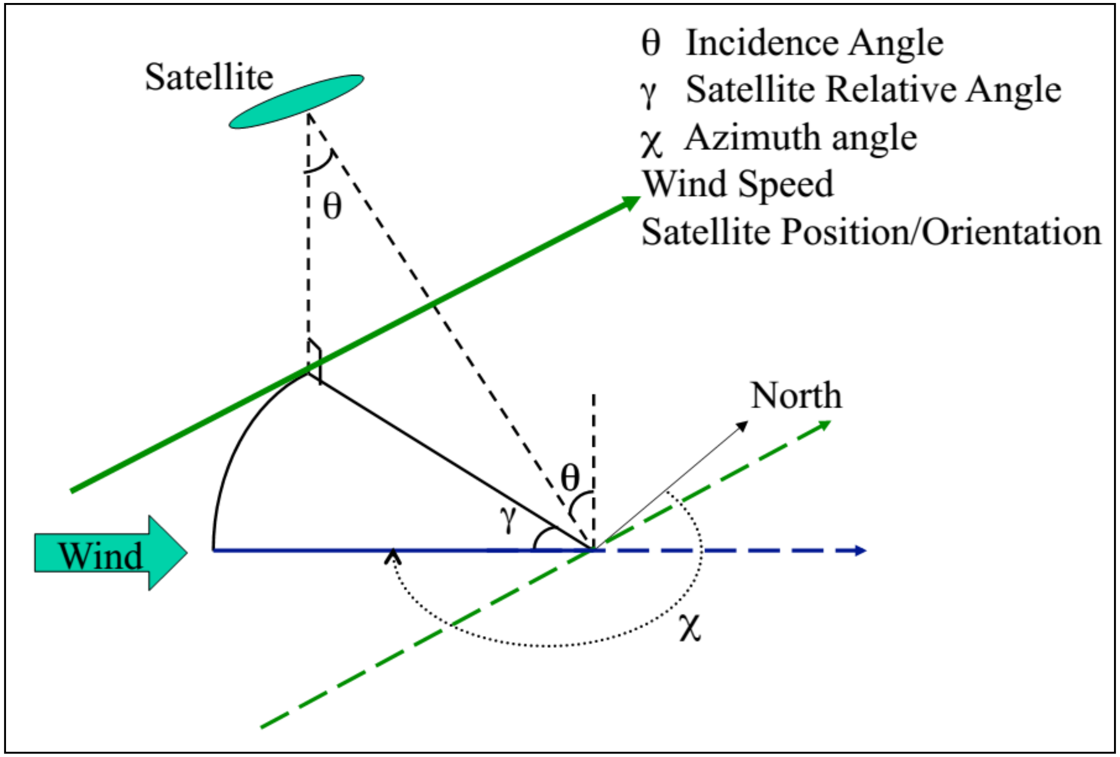
- **NSCAT**: aboard the Advanced Earth Observing Satellite (ADEOS)- Japan Space Agency
- Lasted 9 months, due to a solar panel failure

- **ASCAT**: Advanced SCATterometer (ASCAT) is a real aperture radar operating at 5.255 GHz (C-band)
- Operated by the European Space Agency (ESA)

History of Scatterometry: QuikSCAT

- a "*quick recovery*" mission after the loss of NSCAT in 1997.
- Expected to last 3 years; did 10 years! –1999 - 2009
- ***Satellite:***
  -- The QuikSCAT satellite
  -- Polar orbiting satellite
  -- Orbital height ~ 803 km
  -- One orbit in ~ 100 minutes
- ***Sensor:***
  -- SeaWinds scatterometer
  -- Active microwave sensor
  -- Responds to short water waves which respond very rapidly to changes in vector wind

Basic principles of Scatterometry



- ***Sensor:*** Active microwave sensor
- ***What is being sensed:***
  -- Microwaves Bragg scatter off of short water waves.

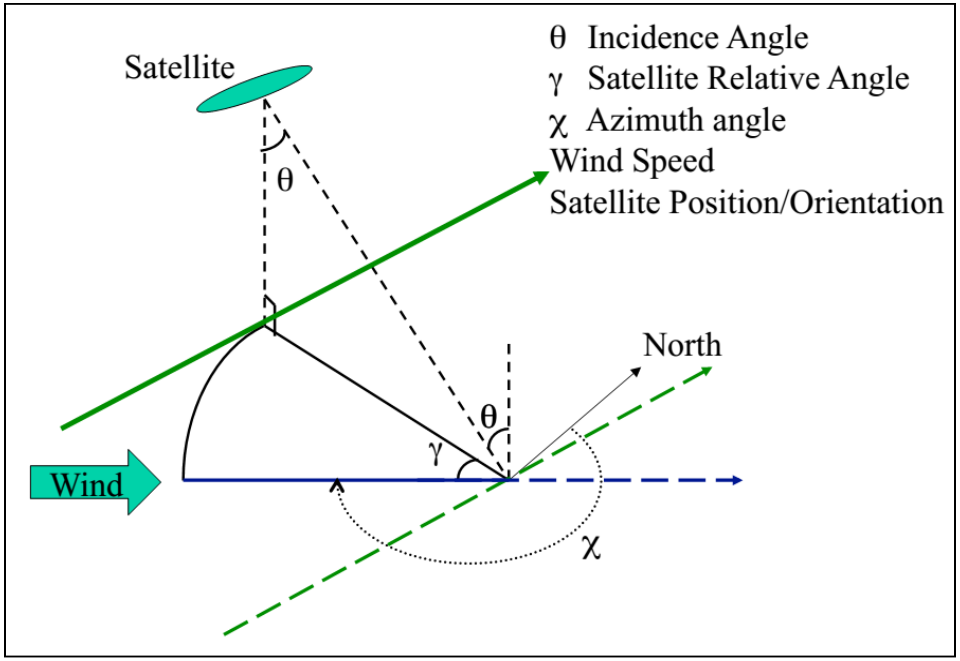
  -- 1 to 100 cm wavelengths, depending on microwave frequency

- Bragg scattering is a function of the
  -- incident angle

  -- azimuth angle (relative to the mean wind/wave direction)

  -- and wave characteristics such as amplitude and wavelength, over a band of wavelengths.

Basic principles of Scatterometry



- ***What is being sensed:***
  - -- The fraction of signal that returns to the satellite is recorded.
  - -- 2 beams can provide a reasonable estimate of wind speed.
  - -- 3 or more beams are preferred to determine wind direction.
  - -- As the satellite moves in its orbit, different beams scan the same areas.

ERS-1 and ERS-2 Scatterometers

- Single swath
- Thee antennas
- C-band (5.3 GHz)

NASA and SeaSat Scatterometers

- Duo swath
- Three antennas
- Ku-band (13.995 GHz)

SeaWinds Scatterometer

- Single wide swath
- Two rotating antennas
- Ku-band (13.4 GHz)

Validation of Scatterometer Winds

- Scatterometer winds have been compared to winds from many sources:

-- *In-situ*: research vessels, volunteer observing ships (VOS), moored buoys, and drifting buoys.

-- *Remotely sensed*: ERS-2 scatterometer, T/P altimetry, SSM/I.

-- *Modeled*: ECMWF, GEOS, and NCEP.

- Validation with High-Quality Research Vessel Observations

-- Automated Wind Observations

-- High temporal resolution

-- Observed winds are corrected for ship motion.

Outstanding Problems

- Lack of angular diversity near nadir and near swath edges

-- Near nadir the directions are parallel to the satellite track
-- Near the edge they are perpendicular to the track
-- Results in poor ambiguity selection in these regions

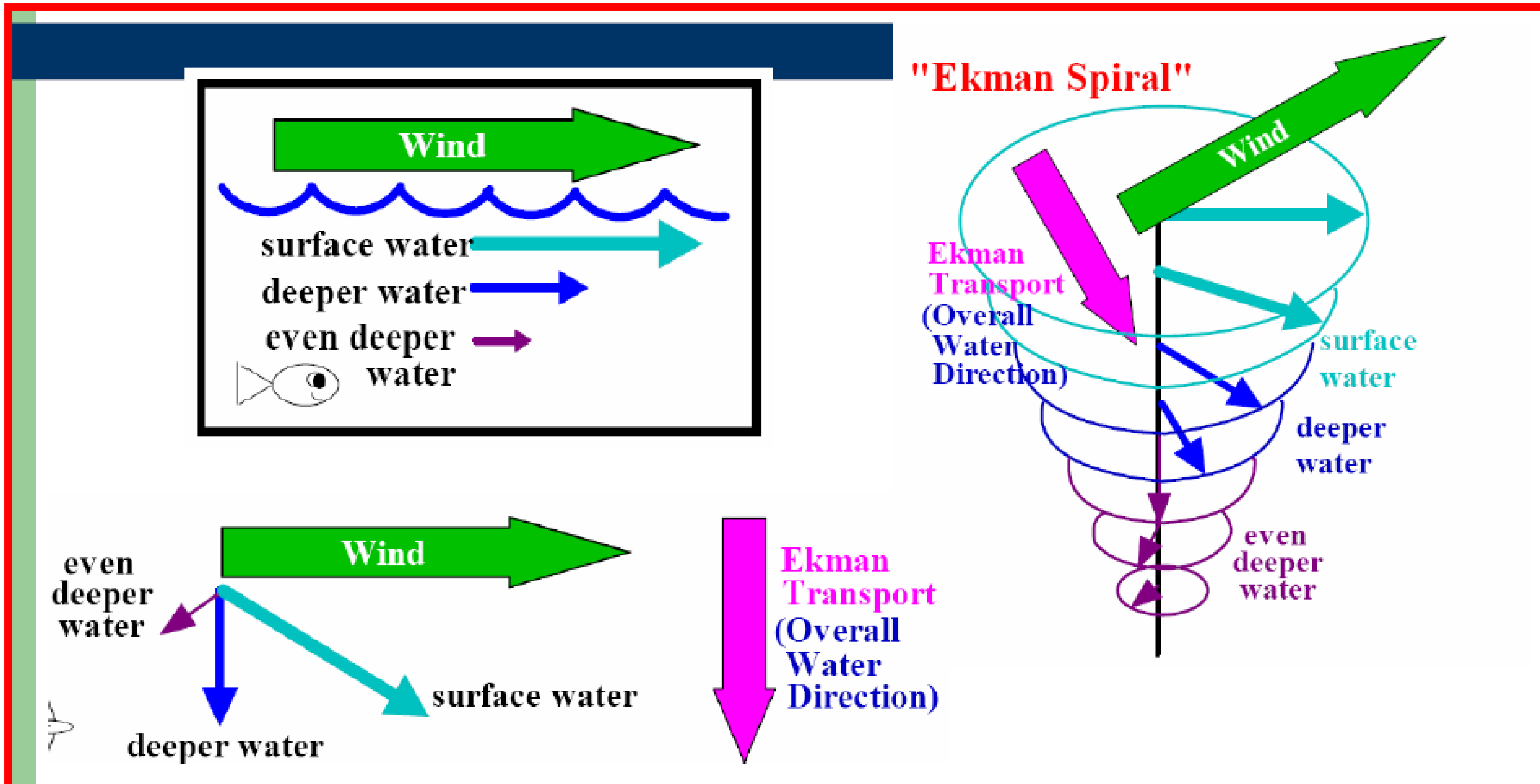
- Rain Contamination

-- Rain influences the retrieved signal through thee mechanisms
-- -- Attenuation of signal
-- -- Backscatter from rain
-- -- Modification of the water surface
-- Flags for rain are inadequate

- Coverage

-- Need one more satellite to resolve diurnal cycle

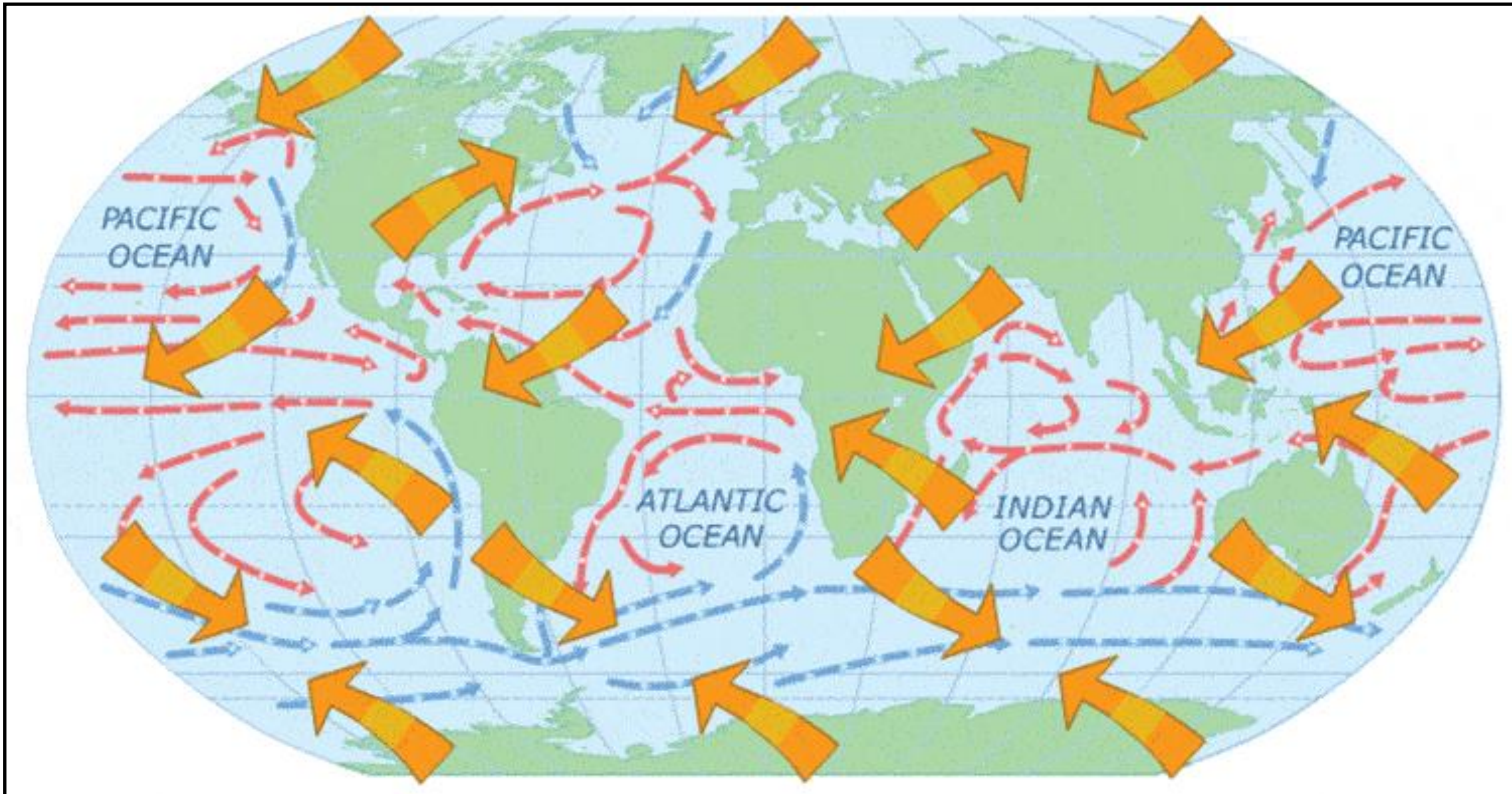
Global wind & current patterns: What causes ocean currents?



- Winds drive the ocean surface circulation

Ocean currents can be created in several different ways, but most ocean currents at the surface of the ocean are created by the ***wind*** pushing the surface of the water

Global wind & current patterns

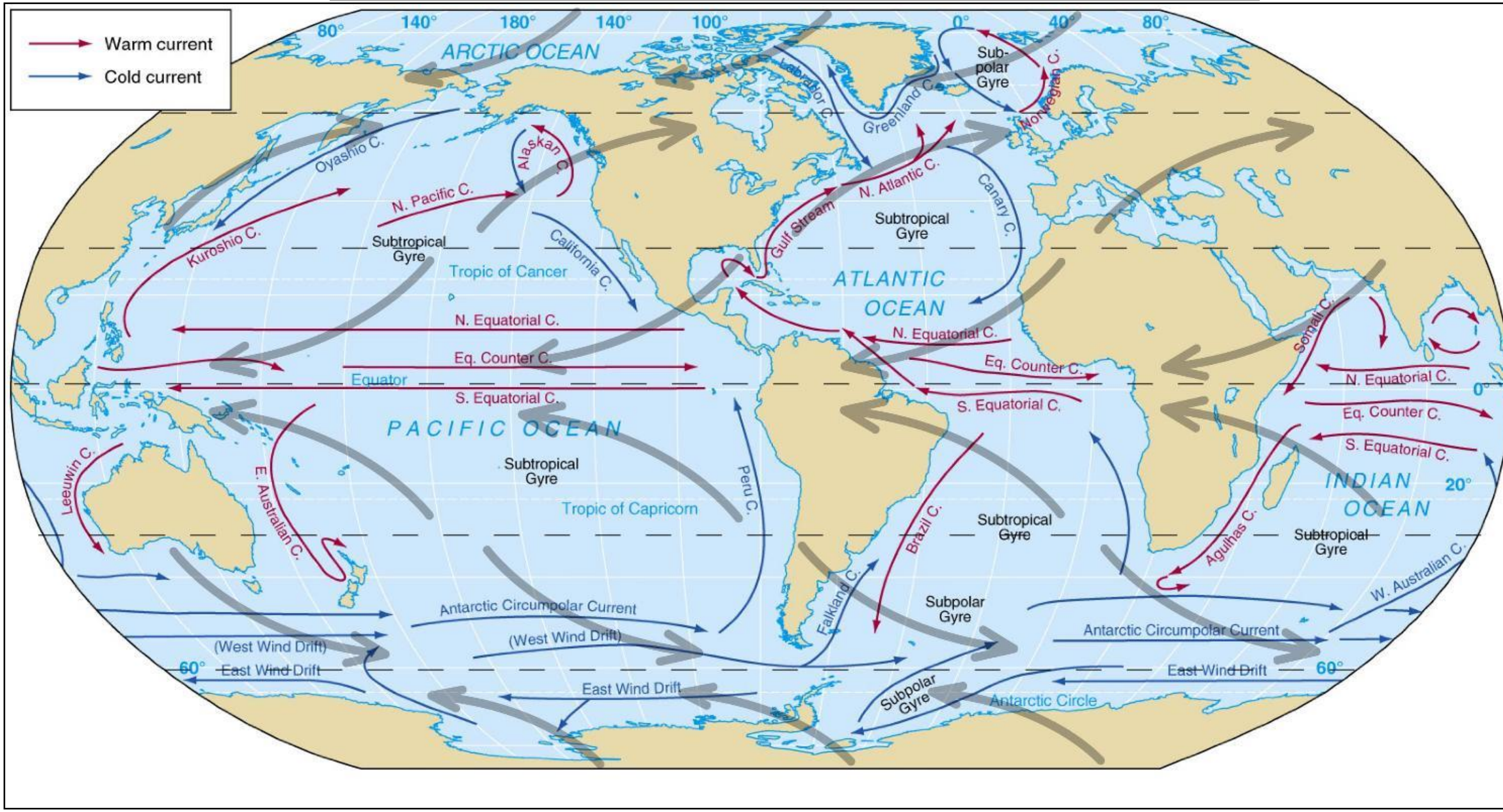


- Winds drive the ocean surface circulation

-- winds are described in terms of where they are ***blowing from***

-- currents are described in terms of where they are ***flowing towards***

Global wind & current patterns



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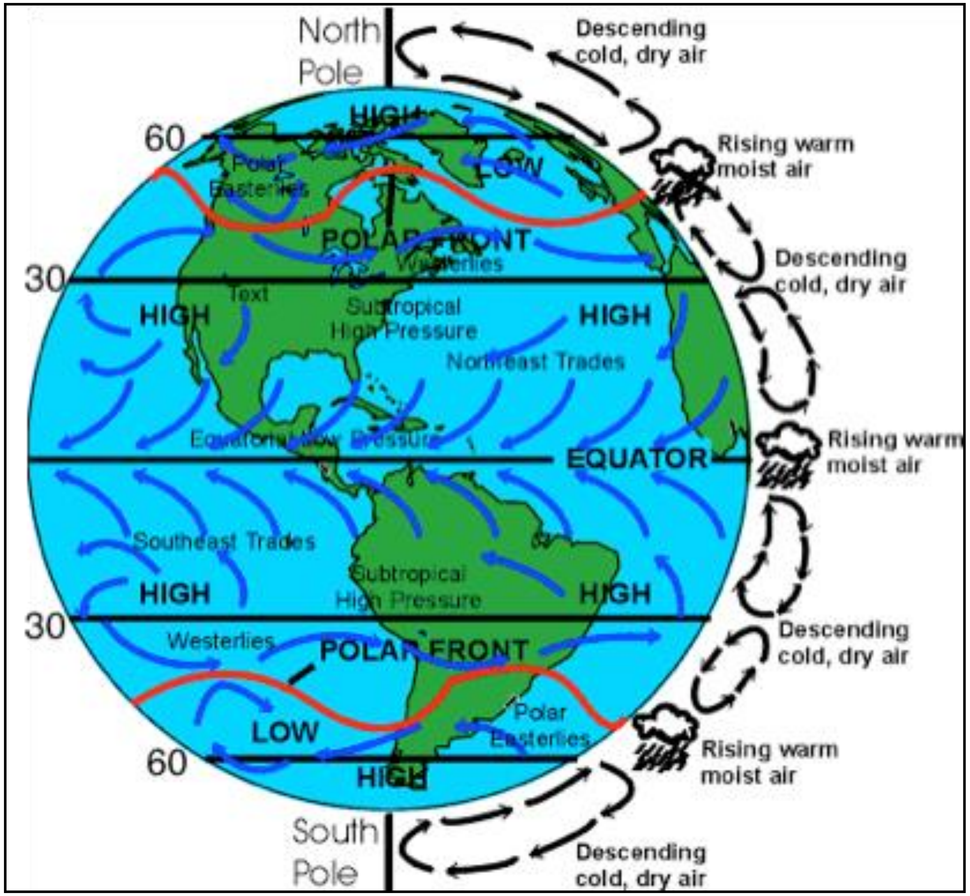
Global wind patterns



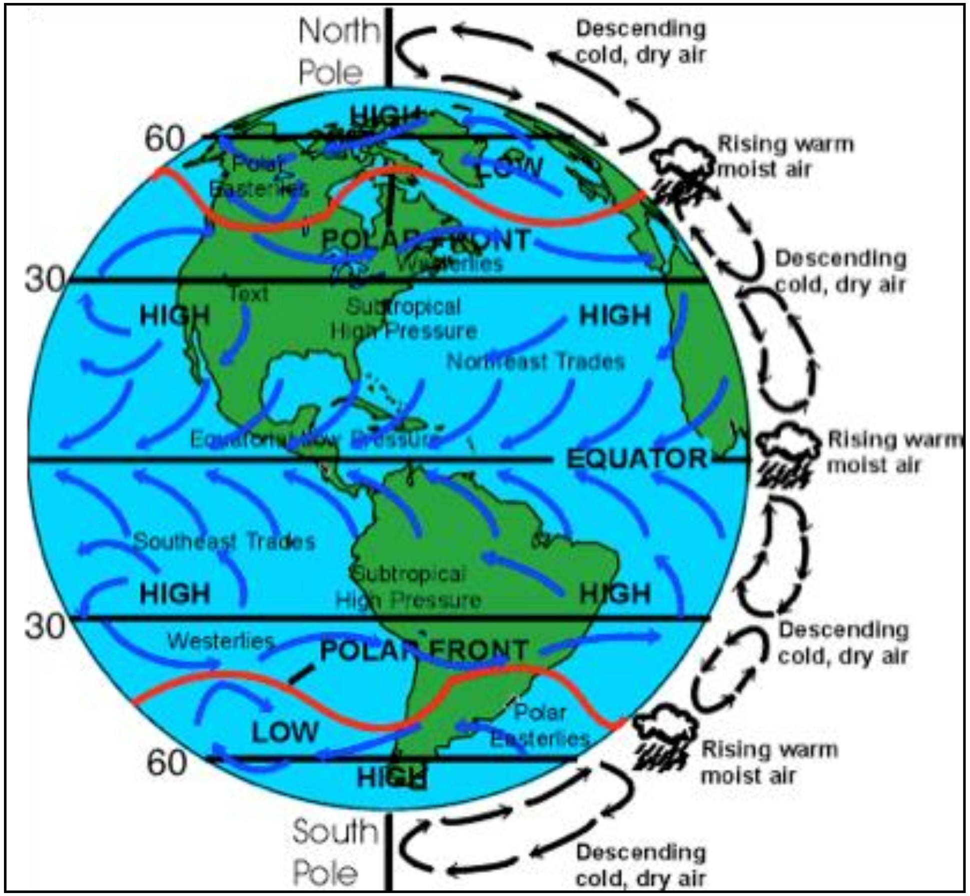
- Each hemisphere has 3 main zonal winds bands
- These are driven by the vertical circulation of the atmosphere:

-- ***easterlies*** close to the poles

-- ***westerlies*** at subpolar latitudes

-- ***trade winds*** at subtropical latitudes

Global wind patterns



- The trades are NE in the NH and SE in the SH.
- At the equator (just north) is the ITCZ where winds are light
- Seasonality: winds are stronger during winter than summer.
- In the NIO and NWP winds change direction due to the Asian monsoon.