Satellites to observe the Ocean

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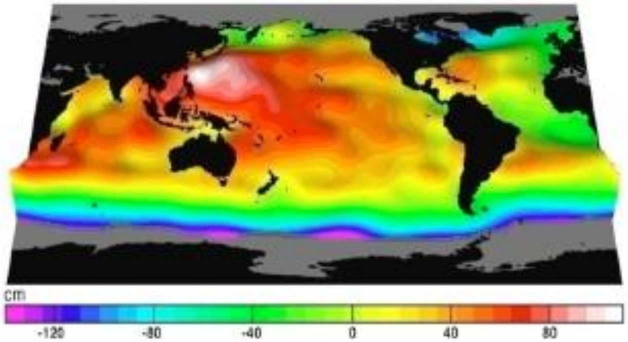
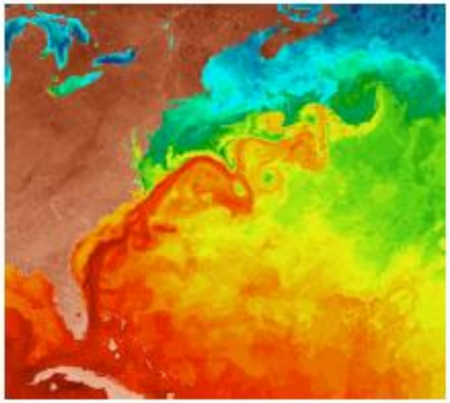
Parameters from the Ocean

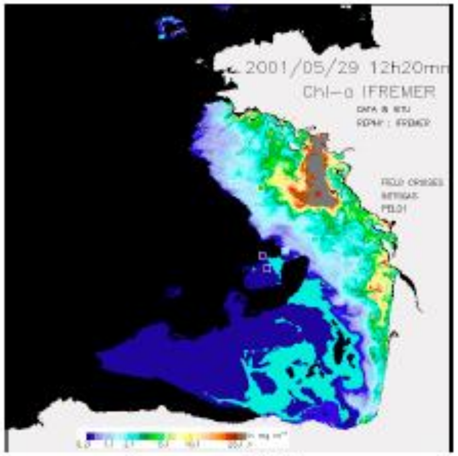
Key Ocean Paramters : Sea level and ocean currents, sea surface temperature, ocean colour, sea ice, winds, waves, sea surface salinity



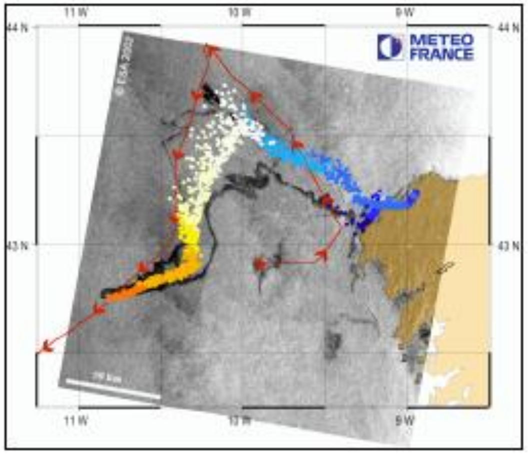
Altimetry and gravimetry
(sea level and ocean currents)



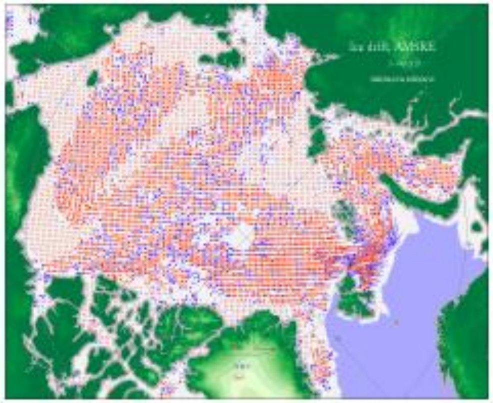
Sea Surface Temperature



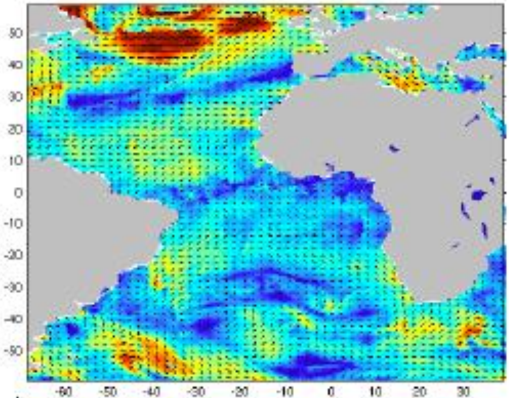
Ocean Colour
(Chl-a, SPM)



Surface roughness from SAR
(e.g. waves, winds, oil slicks)

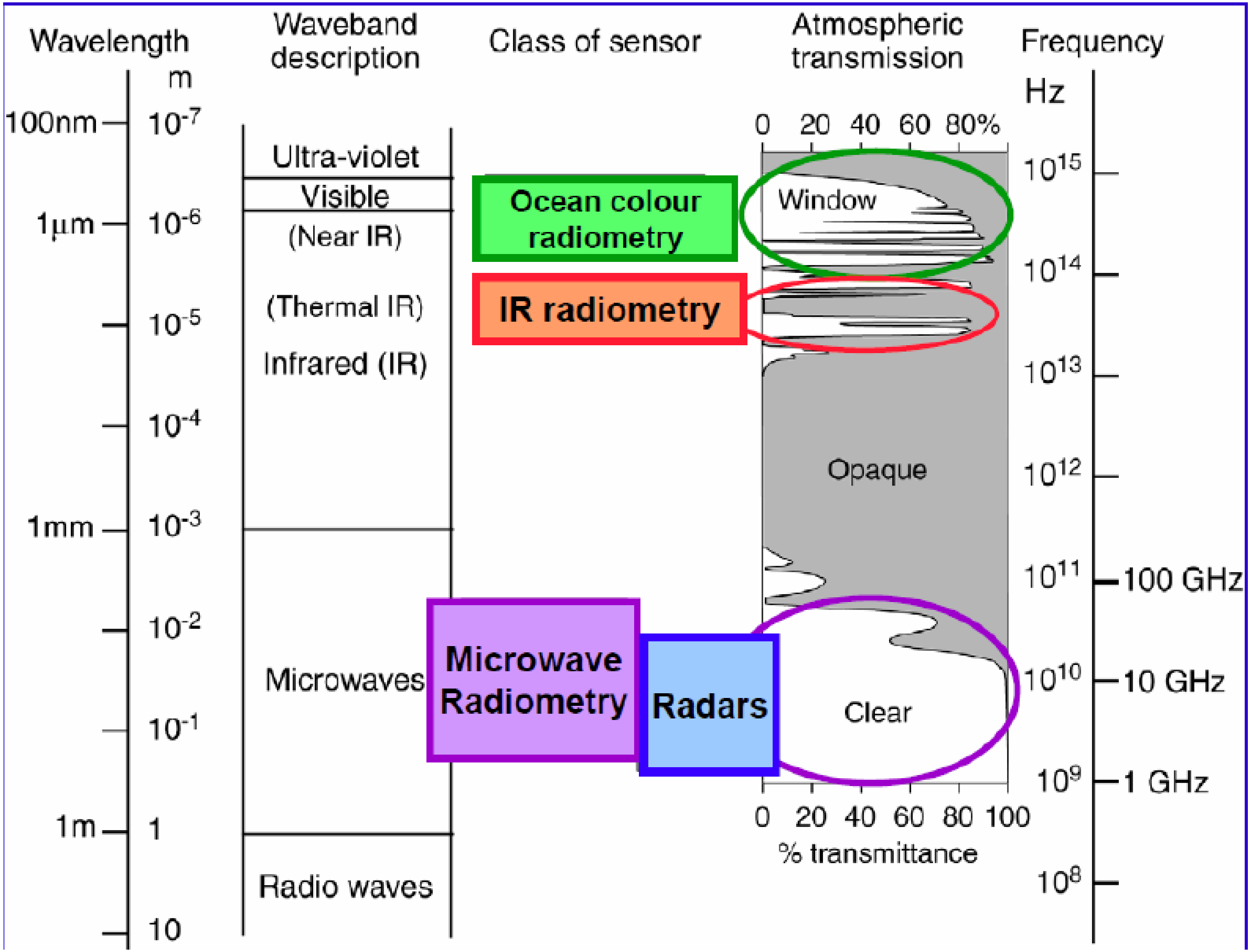


Sea Ice (concentration, drift, thickness)



Winds
(speed and direction)

The electromagnetic spectrum



Satellite Oceanography technique

Passive sensors	Wavelength or frequency	Information
Visible wavelength radiometers	400 nm - 1 μm	Solar radiation reflected by the sea surface : ocean colour
Infrared (IR) radiometers	about 10 μm	Thermal emission of the sea : SST
Microwave radiometers	1.5 – 1 m	Thermal emission of the sea : SST, sea ice, SSS, wind
Active sensors or radars	**Wavelength or frequency**	**Information**
Altimeters	3 - 30 GHz	Sea surface topography: (geoid, sea level, currents), wind, waves
Scatterometers	3 - 30 GHz	Sea surface roughness: Wind, sea ice
Synthetic Aperture Radars	3 - 30 GHz	Sea surface roughness: Winds, Wave, Oil, Currents

Parameters and Satellites for Ocean

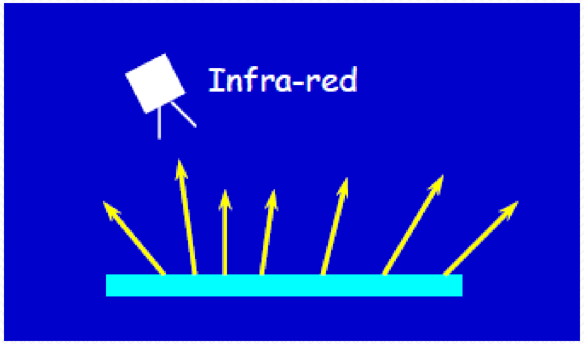
- **IR and MW SSTs (AVHRR, MODIS, TMI, AMSR-E, WindSAT, …)**
- **Diffuse atten. & Chl-A (SEAWIFS, MODIS, OCEANSAT,..)**
- **10-m wind speed (SSM/Is, TMI, AMSR-E)**
- **10-m wind vectors (QuikSCAT, WindSATE and MetOp ASCAT, OCEANSAT)**
- **SSH (Jason-1 & 2,T/P, ERS-2)**

Remote sensing - satellites

- Passive Sensors
  - Solar radiation
  - Emitted radiation
- Active sensors
  - Radar Pulse

Passive – solar radiation

- Use visible and Near IR wavelength
- Multispectral (detect color)
- Scanning (generate images)



  - Obstructed by clouds
  - Atmospheric disturbances

- Measure light reflected at the surface
- Measure water properties (color)
- Ex: Seawifs, MODIS, OCM/Oceansat-2…

Passive – Emitted radiation

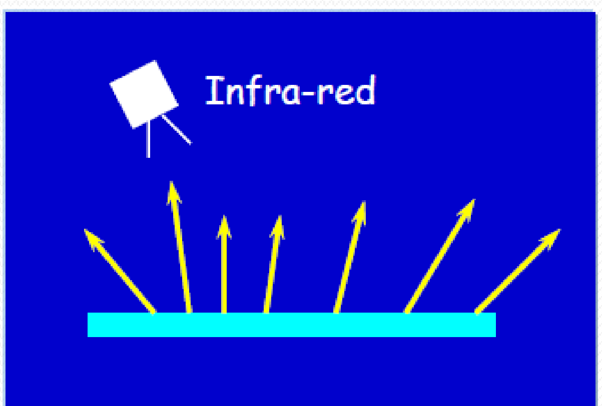
- Use **thermal infrared**
  - Multiple wavebands
  - Obstructed by clouds
  - Require Atmospheric correction

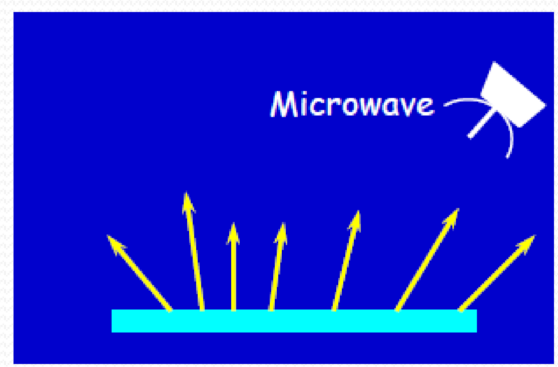
- Measure Sea surface temperature
- Ex: NOAA AVHRR

- Use **microwave**
  - Multiple frequency bands
  - See through clouds
  - Independent of atmosphere

  – Low resolution

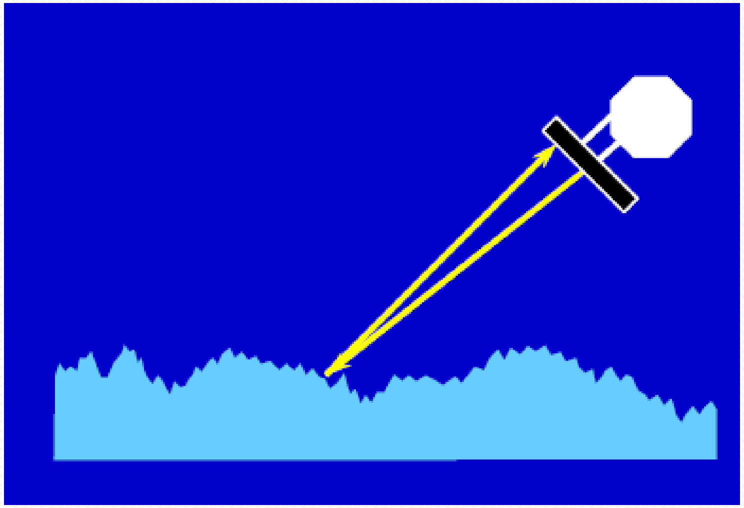
- Measure Sea surface temperature
- Measure sea surface roughness
- Sea surface salinity (SMOS)
- Ex: TMI/TRMM



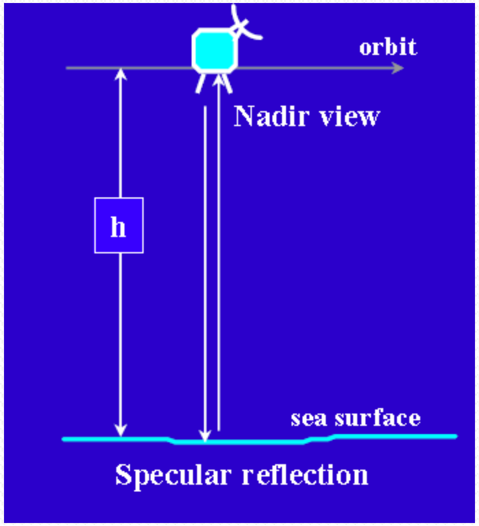


Active sensors

- Emit radar pulse Obliquely
  - To measure wind speed and direction (coarse resolution) - scatterometer
  - Imaging Radar – SAR (fine resolution) – detect surface roughness

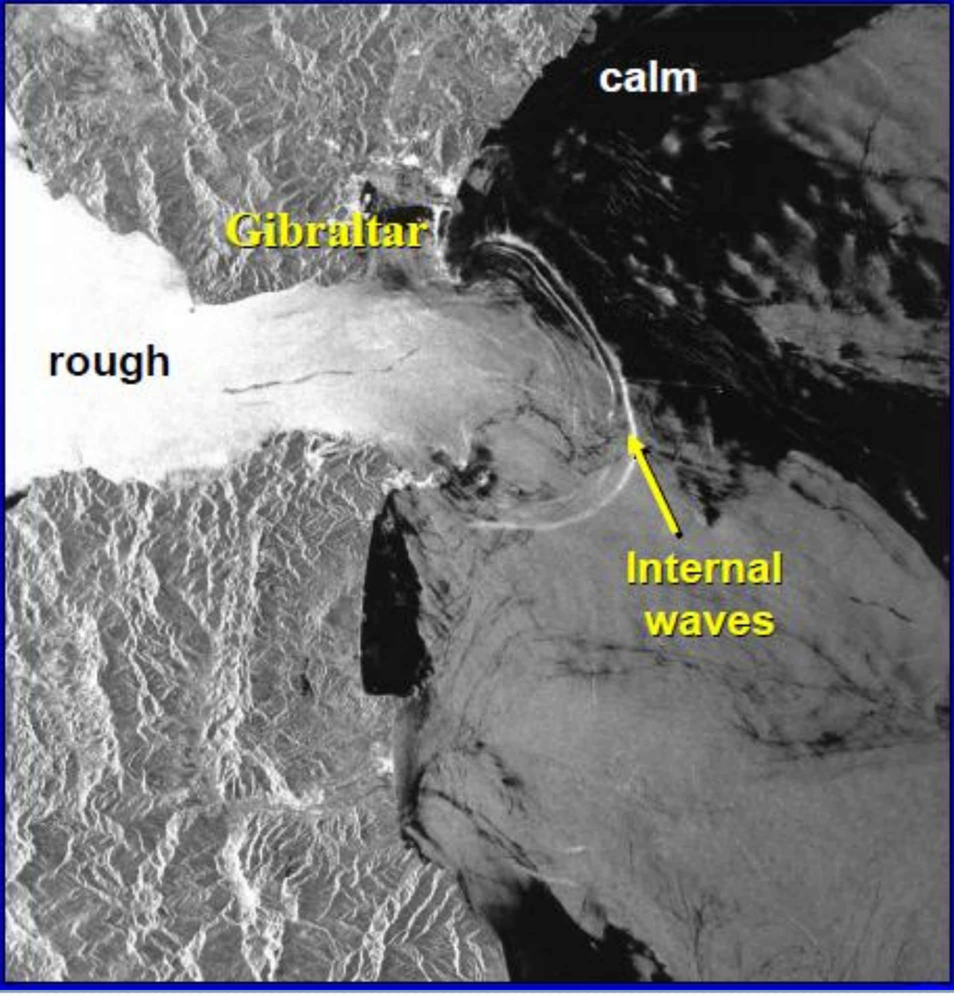


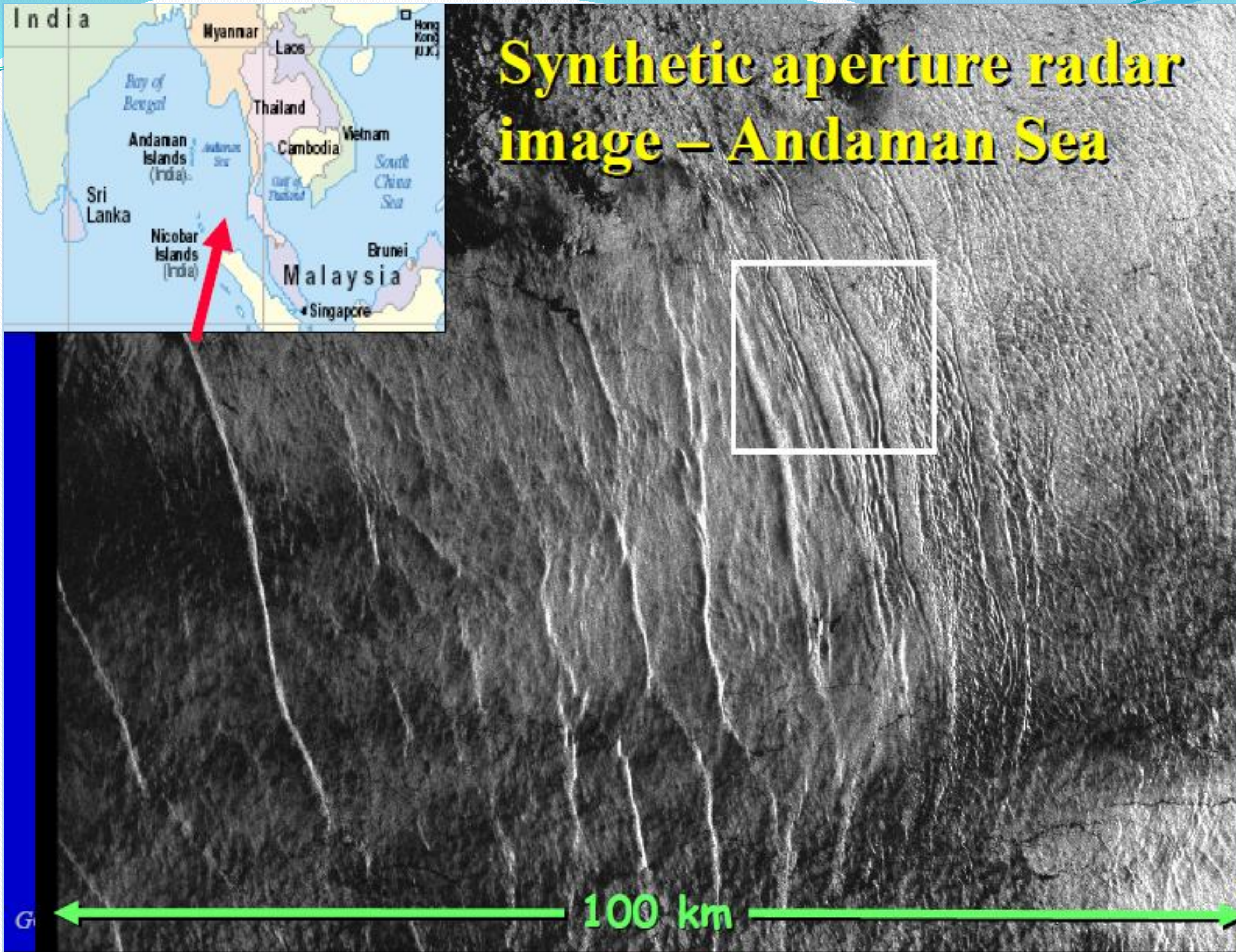
- Emit radar pulse vertically
- To measure timing, shape and strength of return pulse
- Altimeter
- Detect distance to surface
- Parameter: sea surface height anomaly, wave height and wind



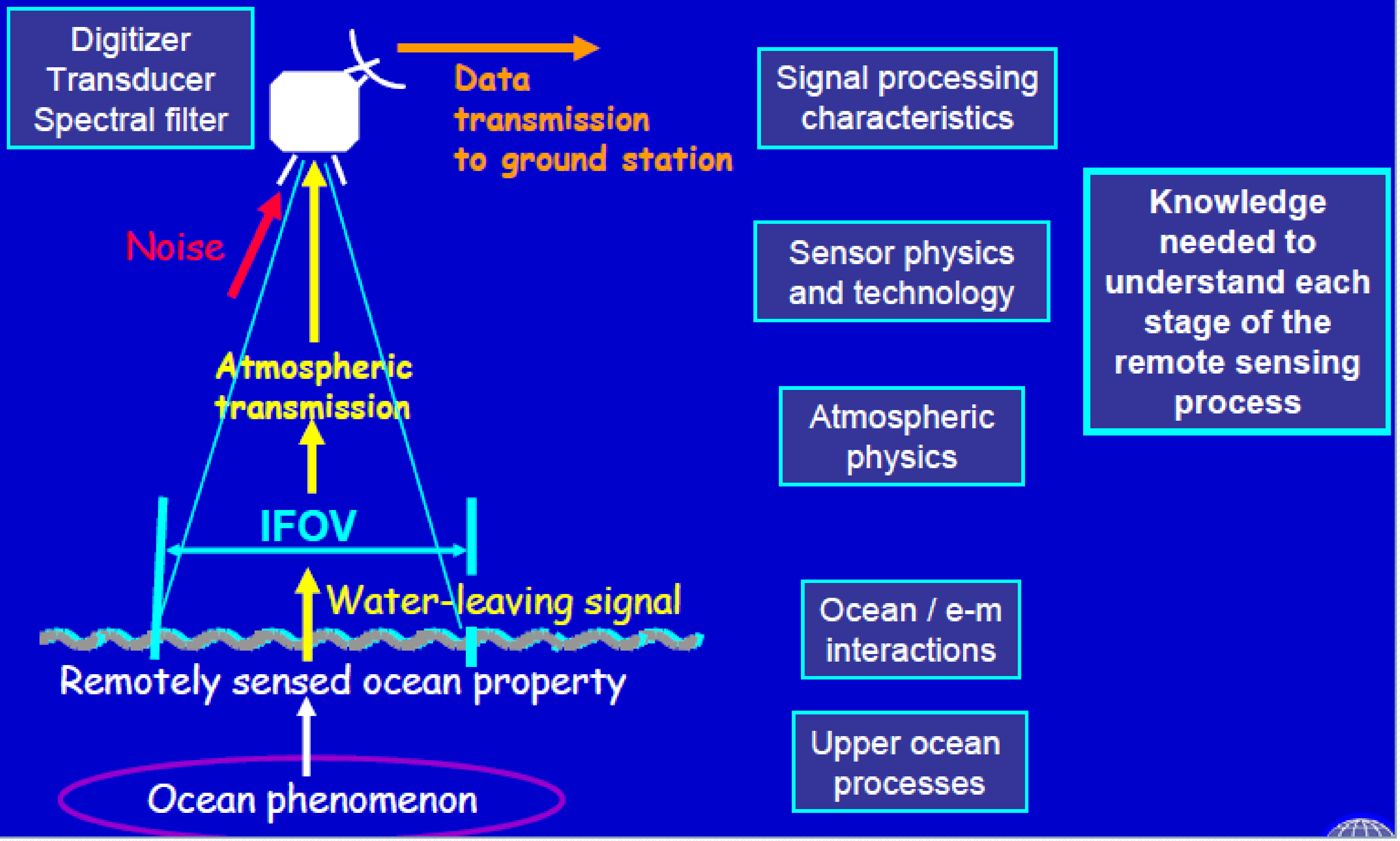
Synthetic Aperture Radar Data

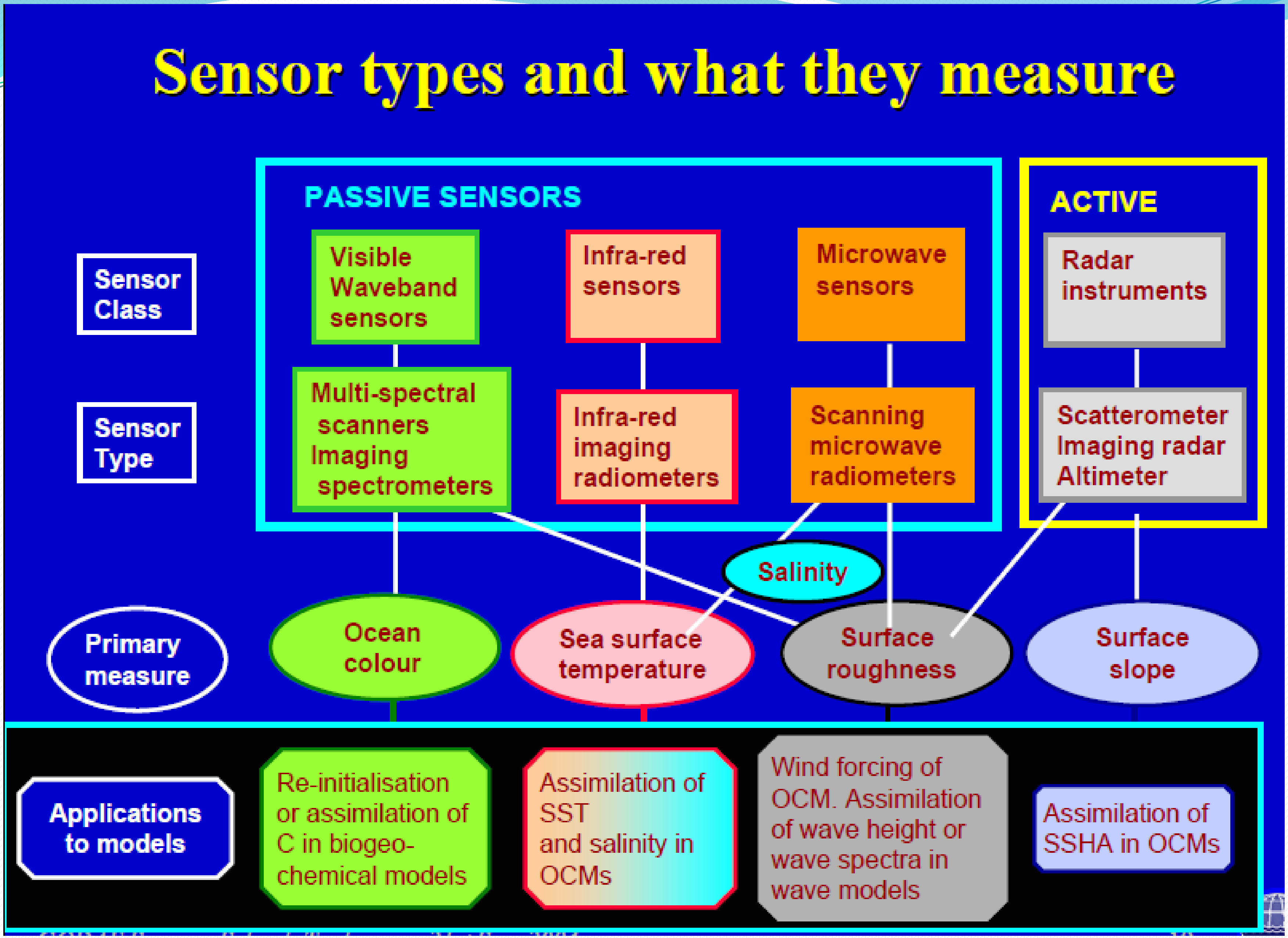
- SAR images: a unique view of the Ocean
  - Measure short scale (5-50 cm) roughness of the sea
  - Bright = rough
  - Dark = smooth
- Capable of observing a variety of ocean phenomena
  - Anything can be imaged that modulates surface roughness
  - Even subsurface phenomena
  - Wind conditions must be right




Synthetic aperture radar image – Andaman Sea
India
Myanmar
Laos
Bay of Bengal
Thailand
Vietnam
Andaman Islands (India)
Cambodia
South China Sea
Sri Lanka
Nicobar Islands (India)
Brunei
Malaysia
Singapore
100 km

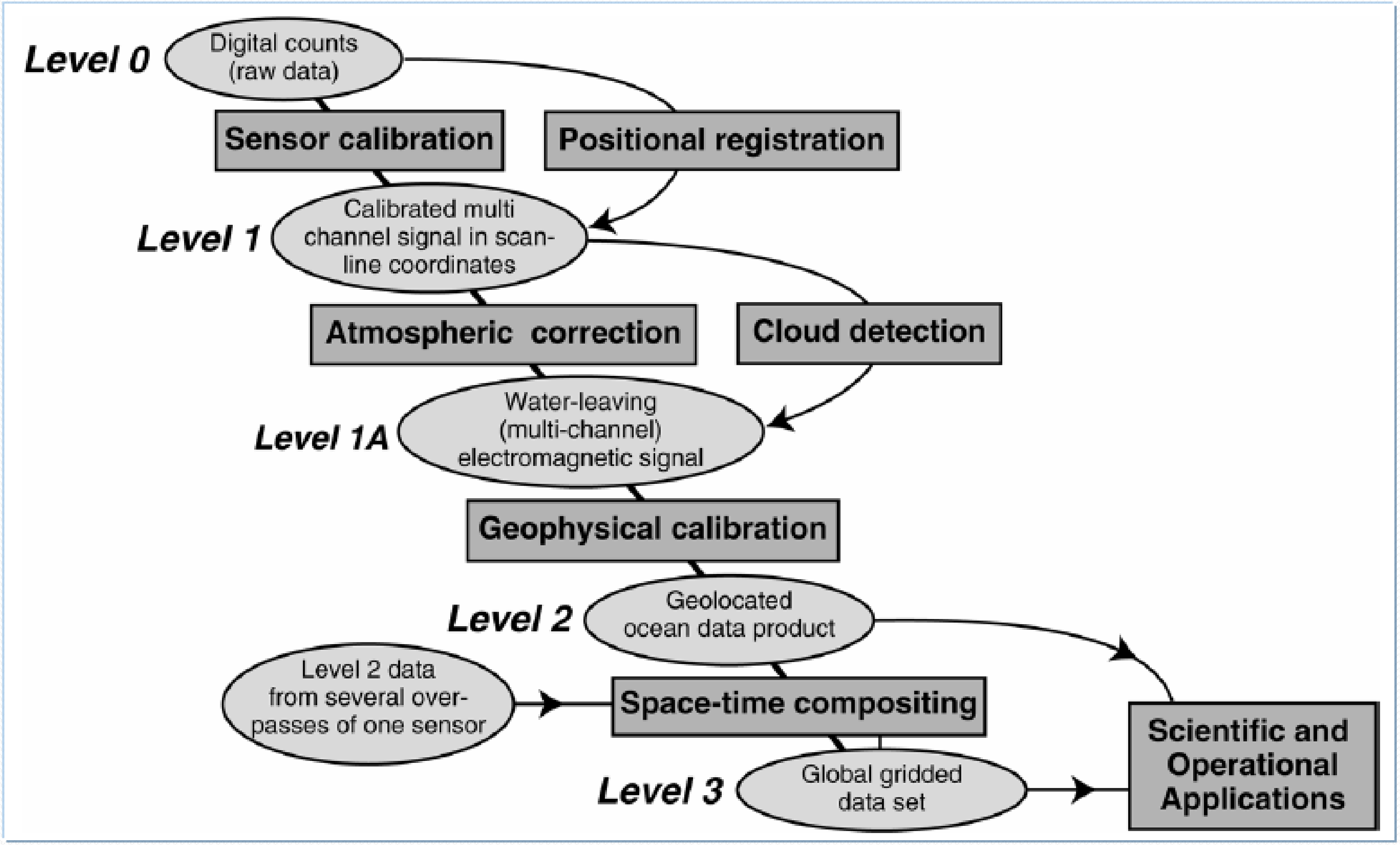
Information Flow in a R-S System





Source: I. Robinson

Satellite data processing – Level 1,2,3 products

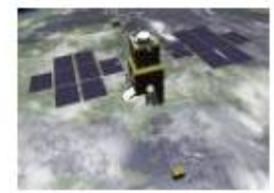


Source: I. Robinson

Altimeter

- **One of the most important satellite technique for physical oceanography. Unique capabilities for ocean forecasting. It provides measurements of sea surface topography (sea level) which is an integral of the ocean interior => Strong constraint for the 4D ocean circulation estimation.**
- **Very mature technique (> 20 years) : GEOS-3 (1975), SEASAT (1978), GEOSAT (1985-1989), ERS-1 (1991-1996), ERS-2 (1995- 2002), GFO (1998 - 2008), TOPEX/POSEIDON (1992-2006), Jason-1 (2001 - ?), ENVISAT (2002 - ?), Jason-2 (2008 - ?).**
- **but also one of the most challenging in terms of accuracy.**
- **Major advances in sensor and processing algorithm performances over the last 20 years. Only possible through a continuous dialogue between engineers and scientists.**
- **As a result, accuracy evolved from several meters to a few cm only**

Ocean Missions: Ocean Surface Topography



Topex/Poseidon, Jason1

RA (ERS), RA2 (Envisat)

GEOSAT

Jason2, Jason3, Jason-CS

SRAL (Sentinel 3A, 3B, 3C, 3D ..)

SARAL

GFO, GFO2

HY-2A, HY-2B, HY-2C, HY-2D

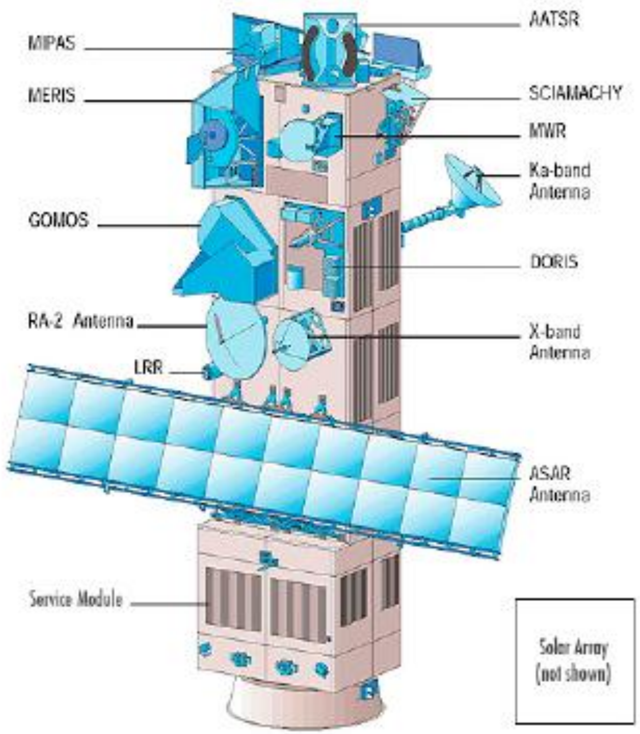
SWOT

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)

Jason-1

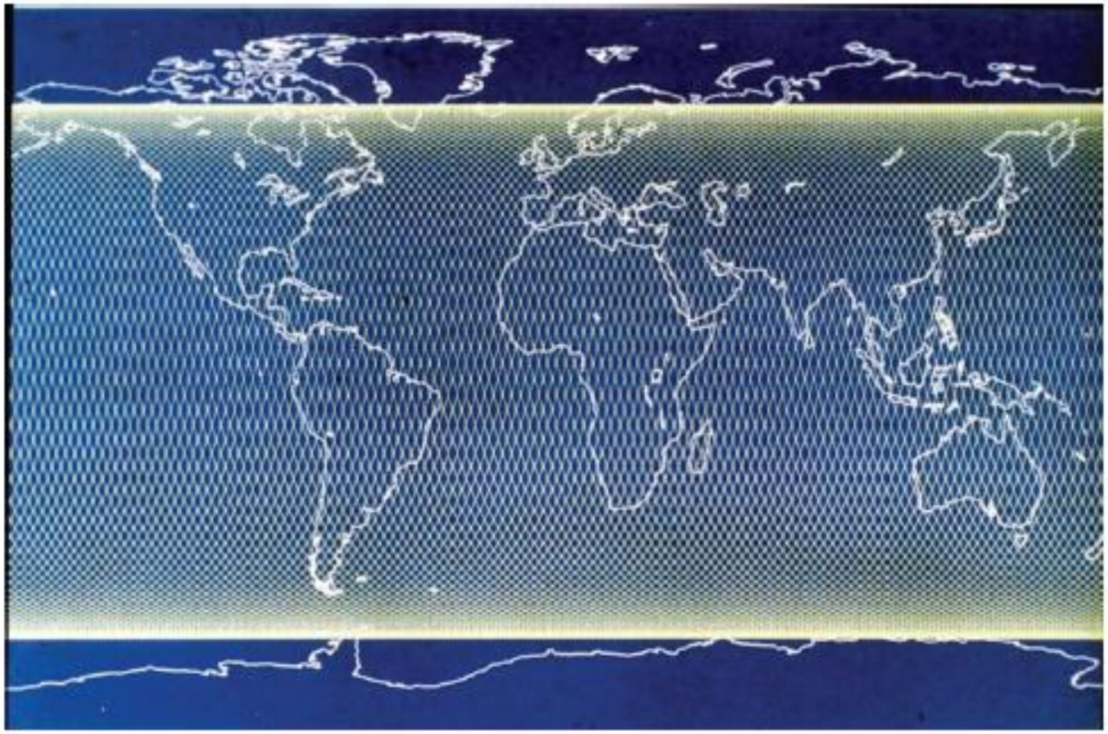
ENVISAT



Altimeter - coverage

Exact repeat orbits (to within 1 km)

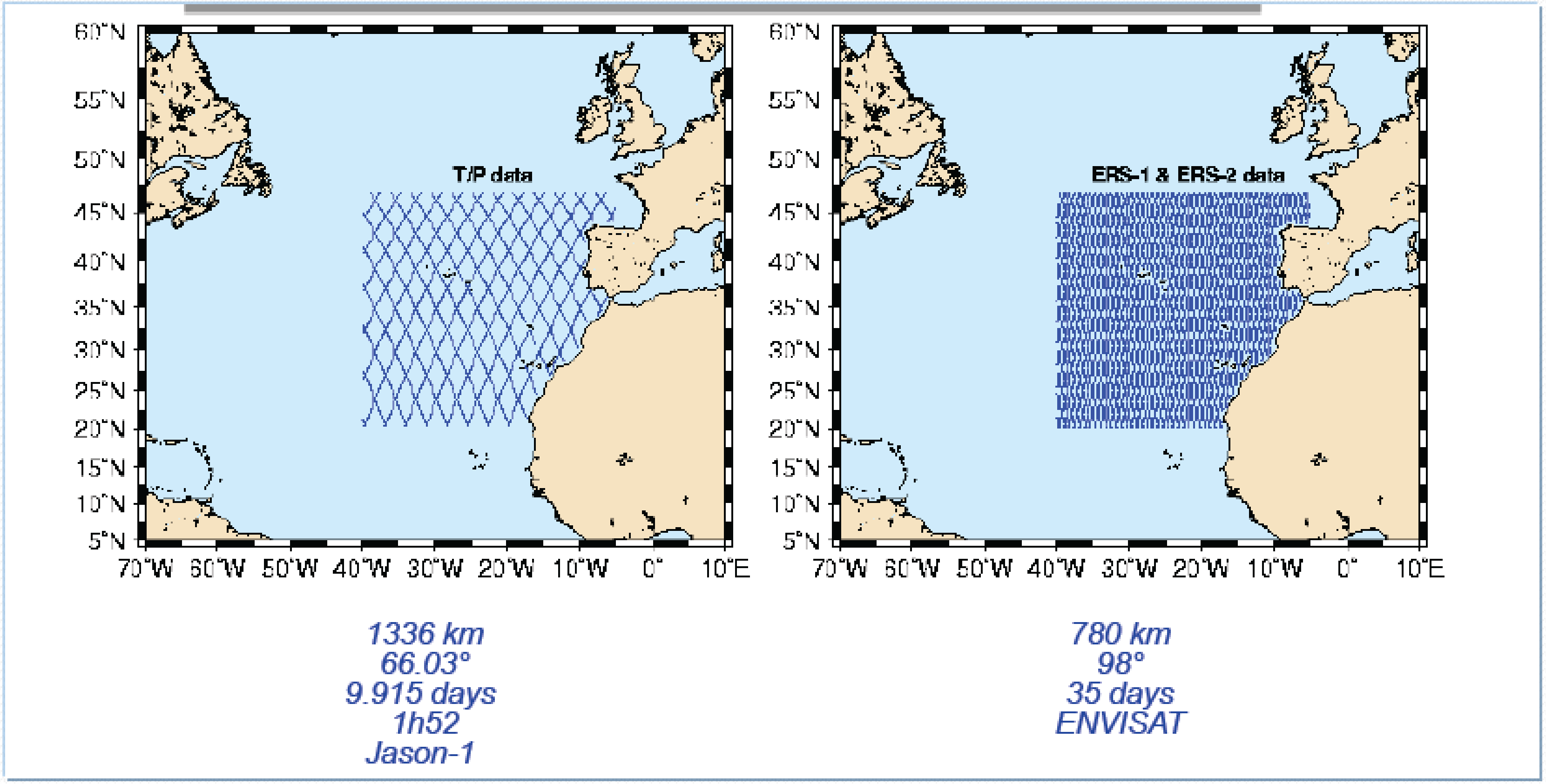
- Spatial coverage :
  - global
  - homogeneous
  - Nadir (not swath)
- Temporal coverage :
  - repeat period
    10 days, T/P-Jason-1
    35 days ERS/
    ENVISAT



TOPEX/Poseidon Sampling

1 measure/1 s (every 7 km)
all weather (radar)

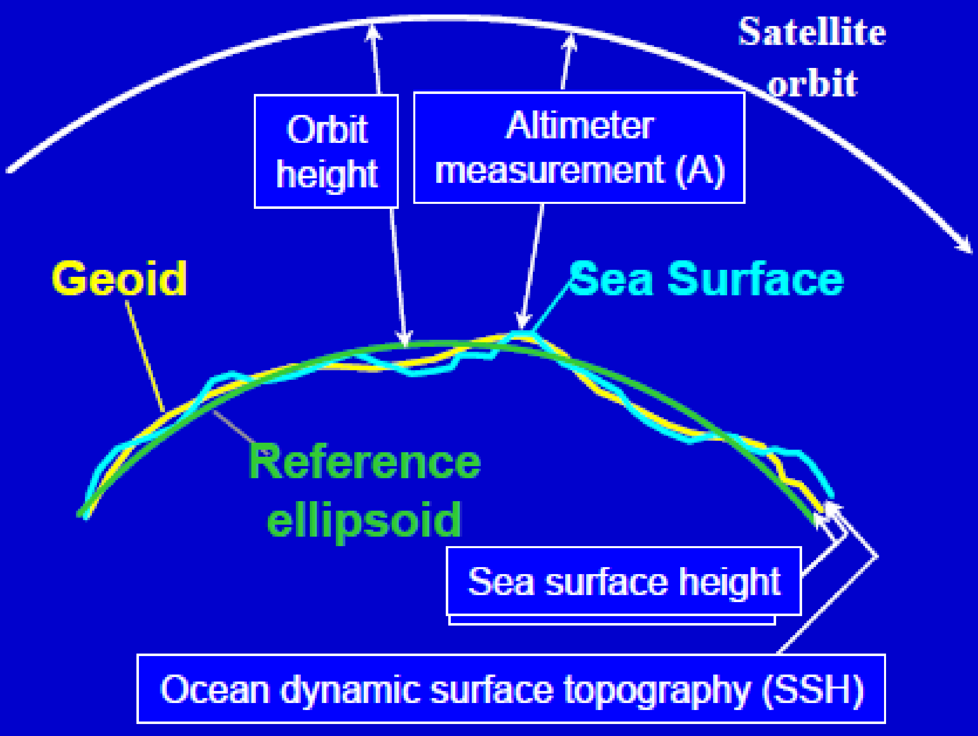
Repeat period and ground track



SARAL/ALTIKA

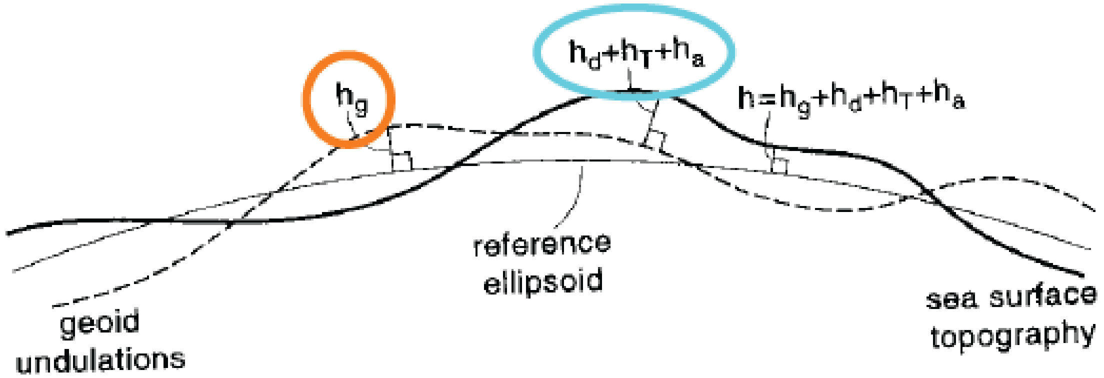
Principles of altimetry

- Measure distance between satellite and sea
- Determine position of satellite
- Hence determine height of sea surface
- Oceanographers require height relative to geoid



SSH = Orbit - A - Geoid

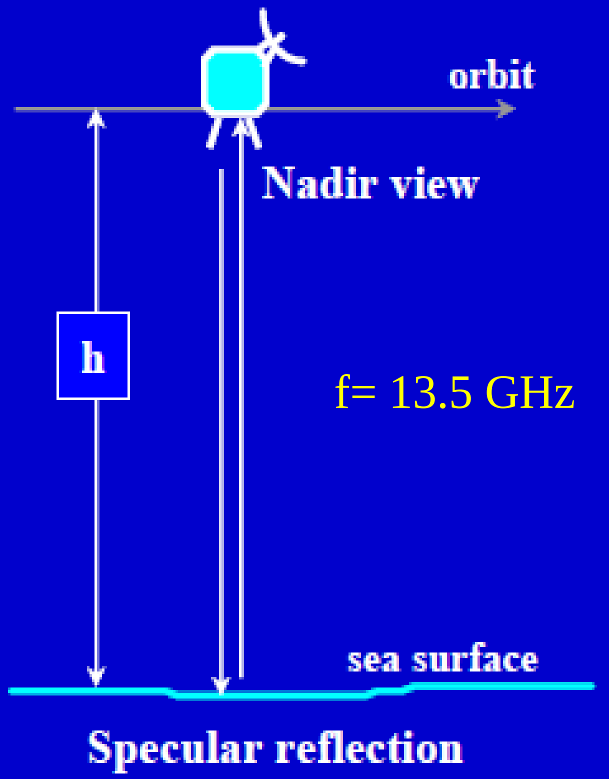
SSH=Geoid+dyn.topo+<noise>



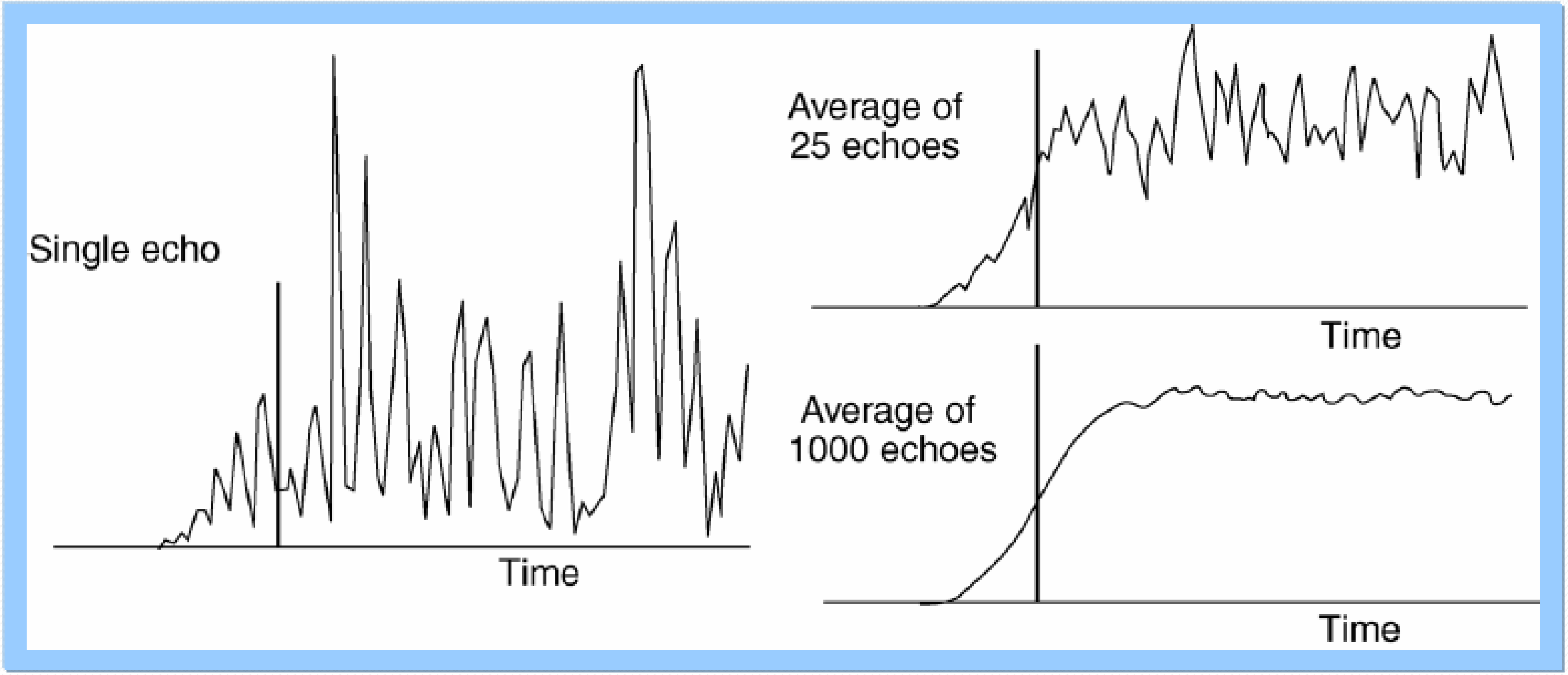
• h_g : geoid	100 m
• h_d : dynamic topography	2 m
• h_T : tides	1-20 m
• h_a : inverse barometer	1 cm/mbar

Measuring the distance with radar

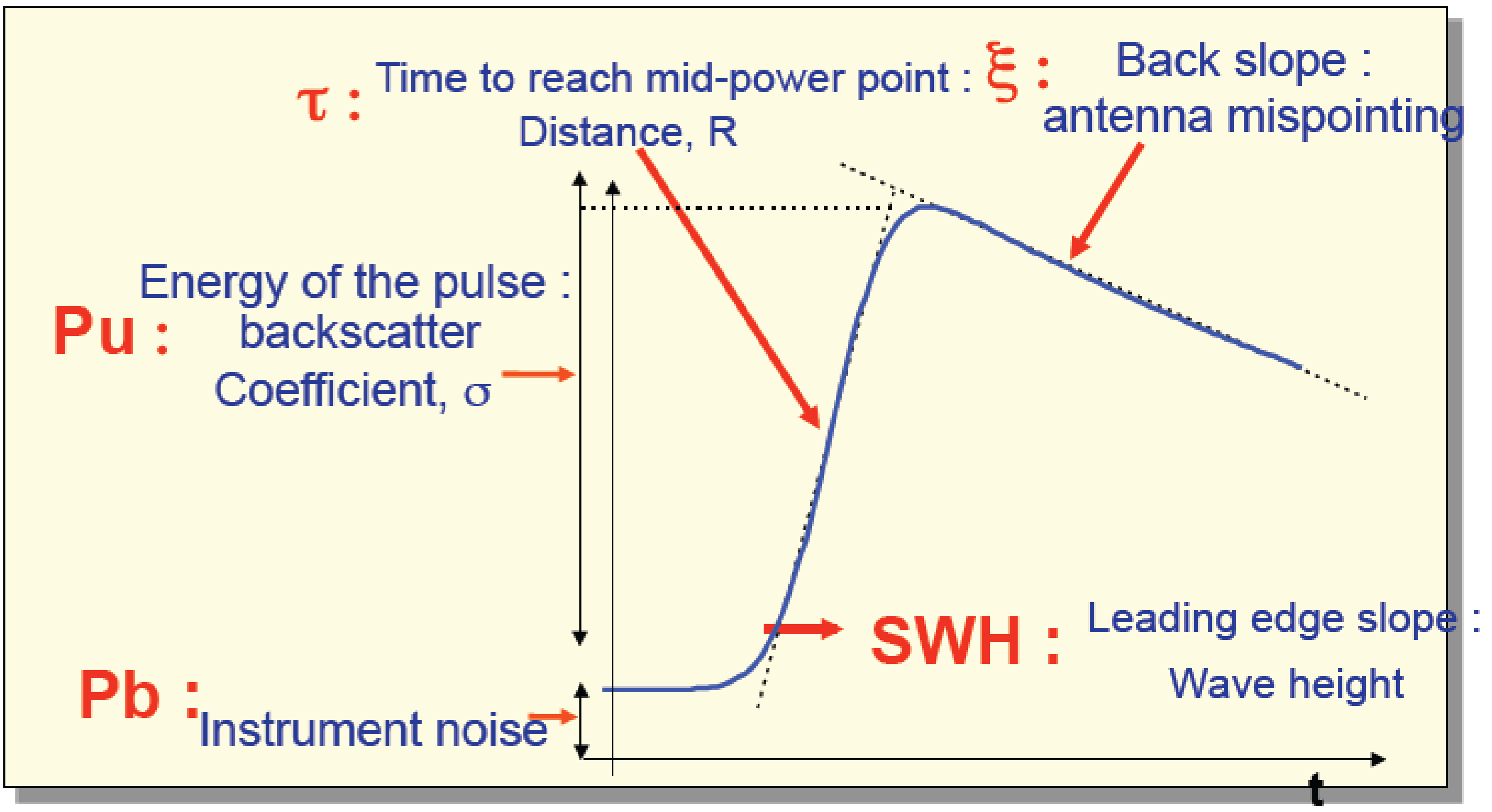
- Measure pulse travel time, 2T, from emit to return
- h = T/c ($c = 3 \times 10^8$ m/s)
- Resolution to 1cm needs a timing precision of 3×10^{-11}s (30 picoseconds)
- Requires using chirp pulses and compression
- Average ~1000 pulses
- Apply corrections for reduced c in atmosphere / ionosphere, and surface reflection delays



Typical radar pulse reflections



Typical parameters from the waveform



Parameters from altimeter

- Sea Surface Height (ocean)
- Significant wave height
- Wind speed
- Ice/land/lakes characteristics,…

Altimetry and Oceanography

- **Satellite altimetry is (one of) the most essential observing technique required to monitor, understand and forecast the state of the ocean**
- **Global, real time, all-weather measurements with high space/time resolution**
- **Sea level is directly related to ocean circulation (geostrophy)**
- **Sea level is also an integral of the ocean interior => strong constraint to infer the 4D ocean circulation through data assimilation.**
- **Only altimetry can constrain the mesoscale circulation in ocean models.**
- **Required for most applications.**

Dynamic topography (sea level relative to Geoid)

Geostrophy

u,v zonal and meridional currents

P pressure, f = Coriolis parameter

$$\begin{cases} f\,v = \dfrac{1}{\rho_0}\dfrac{\partial P}{\partial x} & (1) \\ -f\,u = \dfrac{1}{\rho_0}\dfrac{\partial P}{\partial y} & (2) \end{cases}$$

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

Hydrostatic balance

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

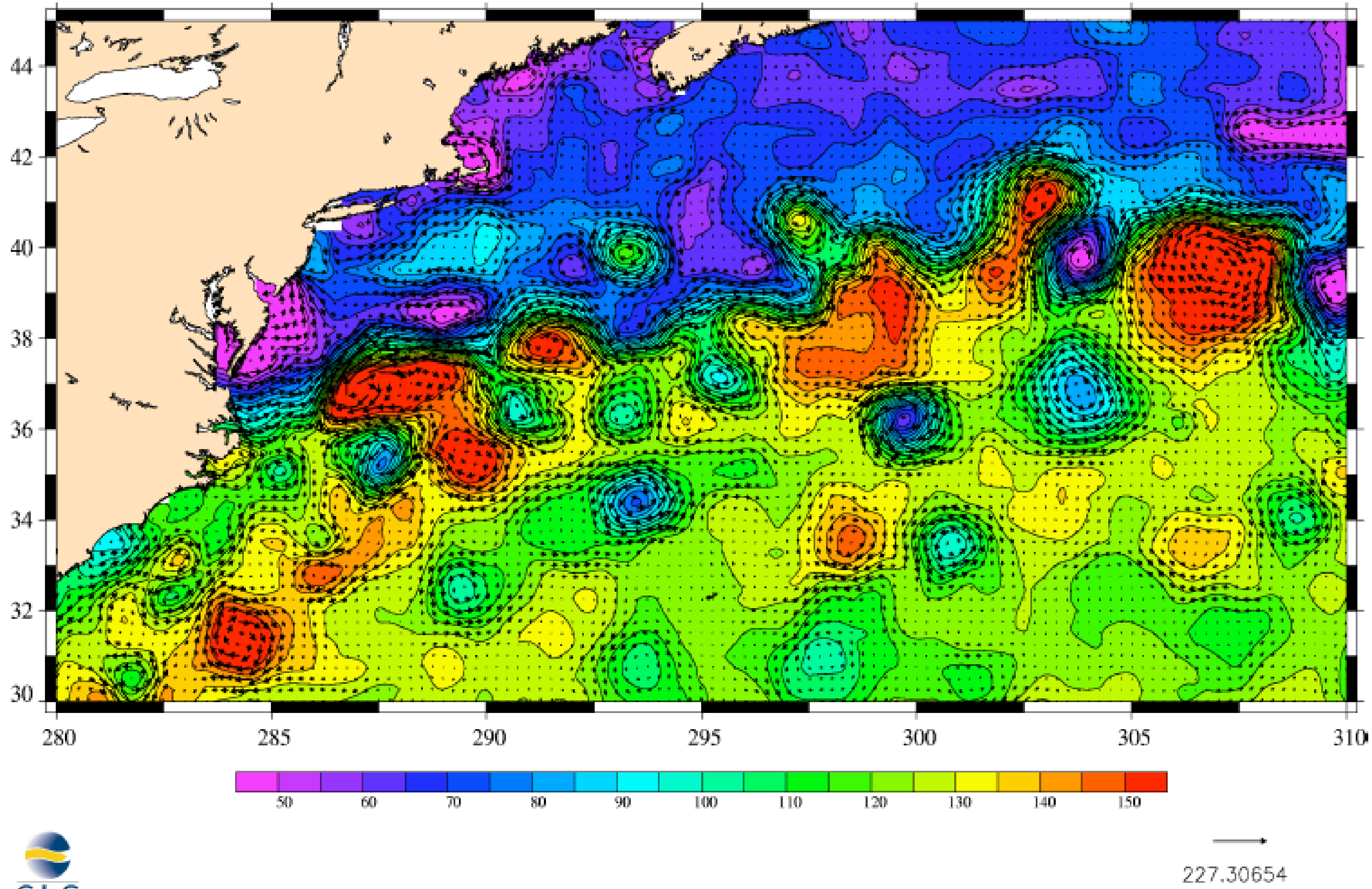
Sea surface topography and geostrophy

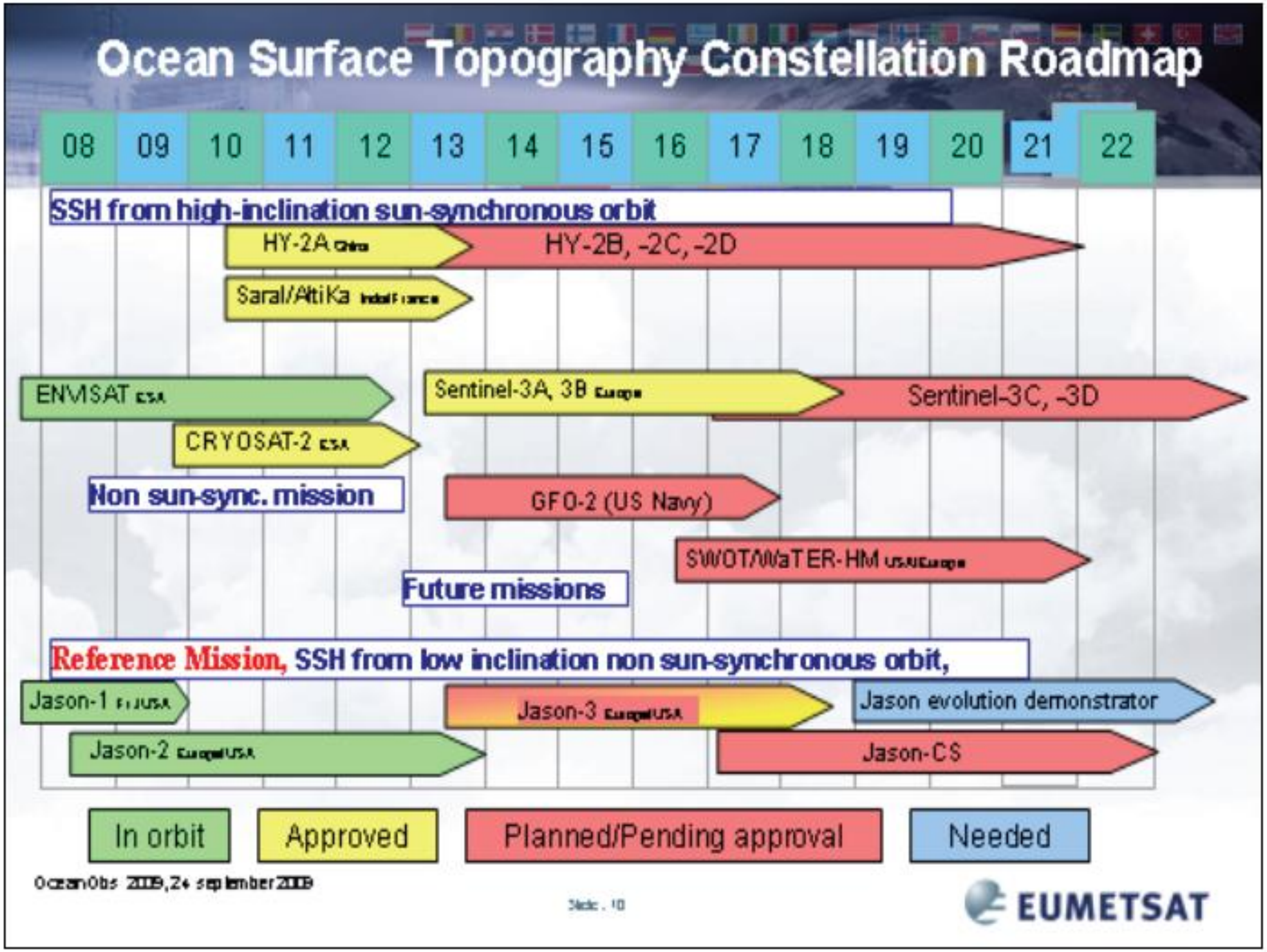
At the surface P = ρ g η (η = sea surface topography relative to the geoid - z local vertical) =>

$$\begin{cases} f\,v = g\dfrac{\partial \eta}{\partial x} \\ -f\,u = g\dfrac{\partial \eta}{\partial y} \end{cases} \qquad (4)$$

η ⇔ surface geostrophic ocean circulation
(atmosphere : atmospheric pressure ⇔ winds)

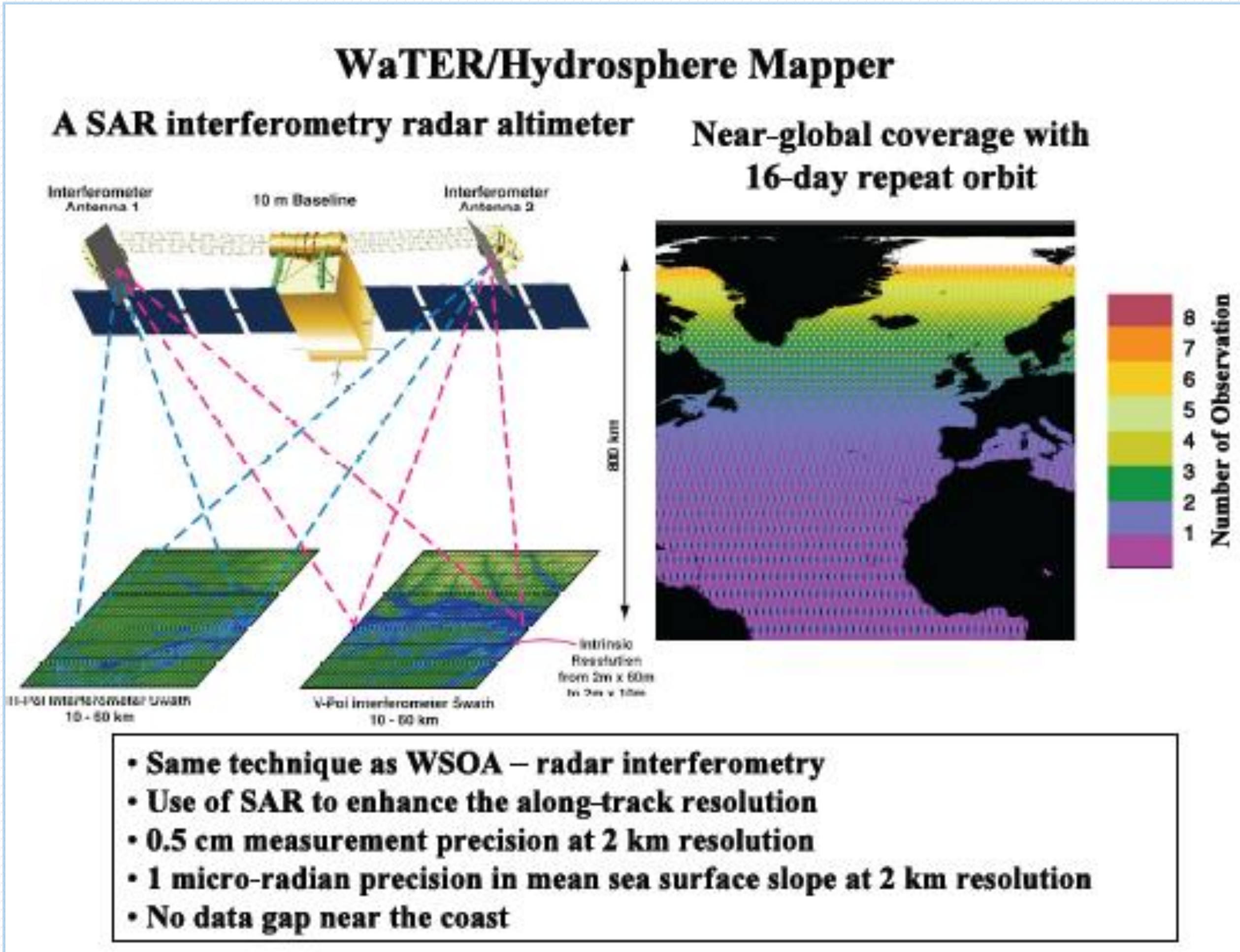
Gulf Stream and its meanders/eddies from T/P and ERS



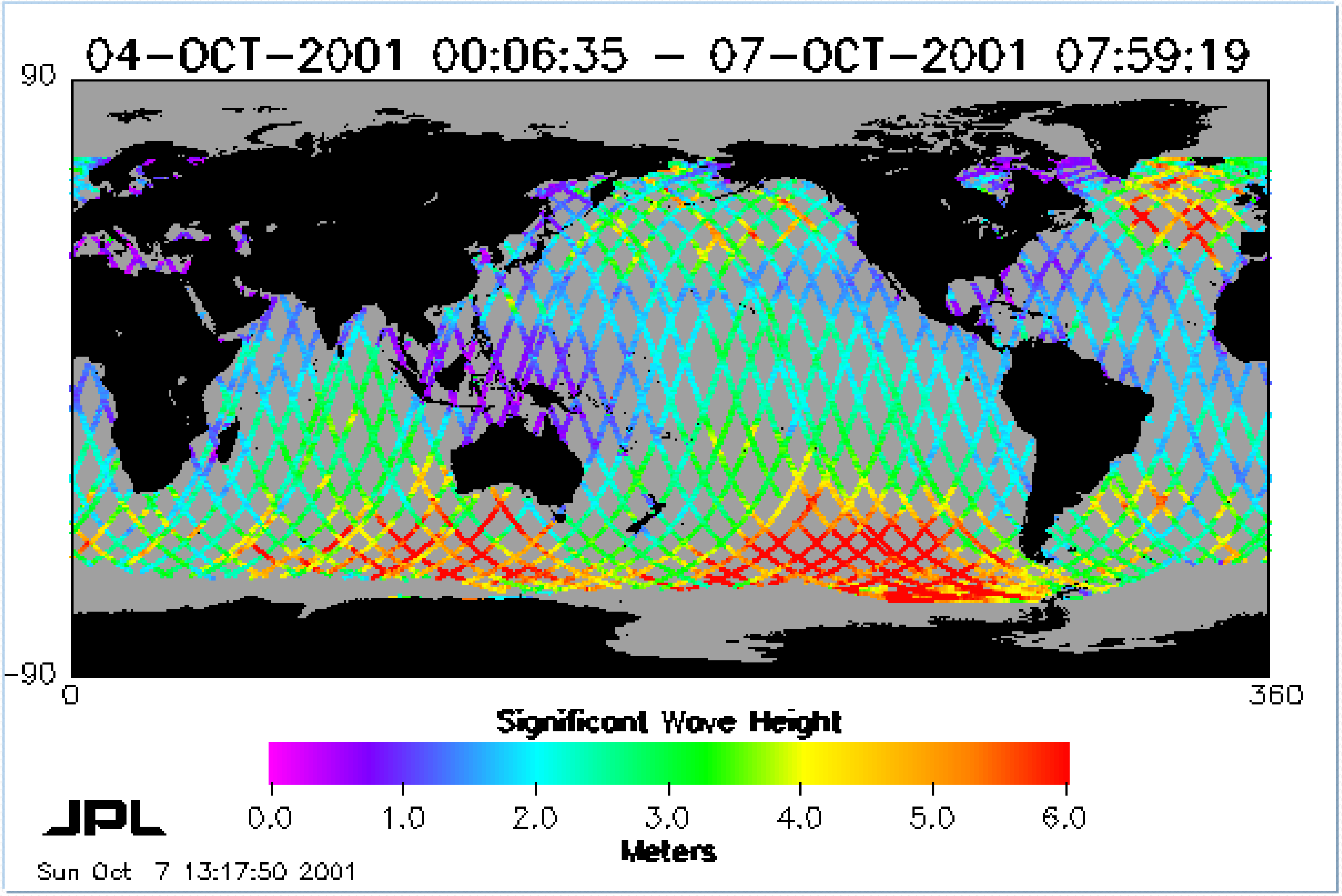


Ocean Surface Topography Constellation Roadmap
08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
SSH from high-inclination sun-synchronous orbit
HY-2A
HY-2B, -2C, -2D
Saral/AltiKa
ENVISAT
Sentinel-3A, 3B
Sentinel-3C, -3D
CRYOSAT-2
Non sun-sync. mission
GFO-2 (US Navy)
SWOT/WaTER-HM
Future missions
Reference Mission, SSH from low inclination non sun-synchronous orbit,
Jason-1
Jason-3
Jason evolution demonstrator
Jason-2
Jason-CS
In orbit
Approved
Planned/Pending approval
Needed
OceanObs 2009, 24 september 2009
EUMETSAT

New altimeter mission concept based on interferometry



Significant Wave height



Altimeter- Applications

- Geodesy and geophysics
  - Bathymetery, shape and size of Earth…
- Ocean
  - Large scale and mesoscale circulation, tides, MSL
- Ice
  - Dynamics and mass balance of ice sheets..
- Climate
  - Ocean's influence upon the atmosphere, seasonal, decadal..
- Atmosphere, wind and waves
  - Waves, wind, improved weather forecasting
- Hydrology and land
  - Lakes and enclosed seas, rivers
- Coastal applications

http://www.aviso.oceanobs.com/en/data/data-access-services/index.html

Limitations of Altimeter

- Measures only along the precise orbit repeat track with accuracy of 2-3 cm
- Detects only the variable signal
  - Long term mean SSH lost in the geoid
  - Mean ocean currents cannot be detected
  - An independent measure of gravity is needed
- SSH unreliable in shelf seas
  - Tidal signal cannot be accurately predicted
- Currents cannot be recovered in equatorial waters

Scatterometer

Science Objectives

•Acquire all-weather, high-resolution measurements of near-surface winds over global oceans.

•Determine atmospheric forcing, ocean response, and air-sea interaction mechanisms on various spatial and temporal scales.

•Combine wind data with measurements from scientific instruments in other disciplines to help us better understand the mechanisms of global climate change and weather patterns.

•Study both annual and semi-annual rain forest vegetation changes.

•Study daily/seasonal sea ice edge movement and Arctic/Antarctic ice pack changes

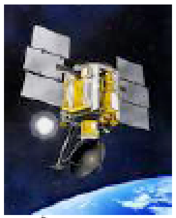
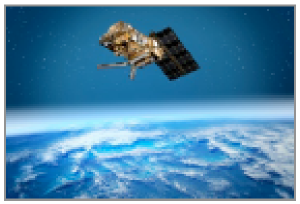
Operational Objectives

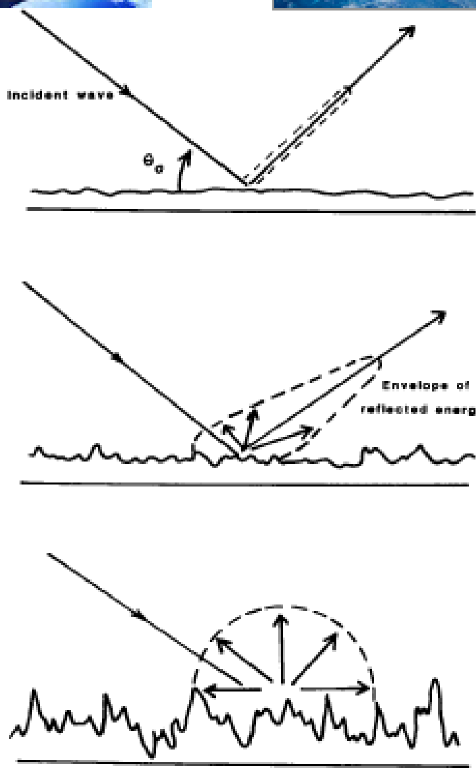
Improve weather forecasts near coastlines by using wind data in numerical weather- and wave-prediction models.

Improve storm warning and monitoring.

Scatterometer

Seawinds/Quickscat, ASCAT/MetOp



Microwave scatterometer (C and Ku bands) is based on the principle of the resonant Bragg scattering.

For a smooth surface, oblique viewing of the surface with active radar yields virtually no return.

Rough surface ⇨ signal ↑

+ : day/night measurements, under clouds
- : no measurements near the coast, sensible to heavy rain (Ku band)

Ocean parameters measured :

- Wind (speed and direction)
- Sea ice roughness…

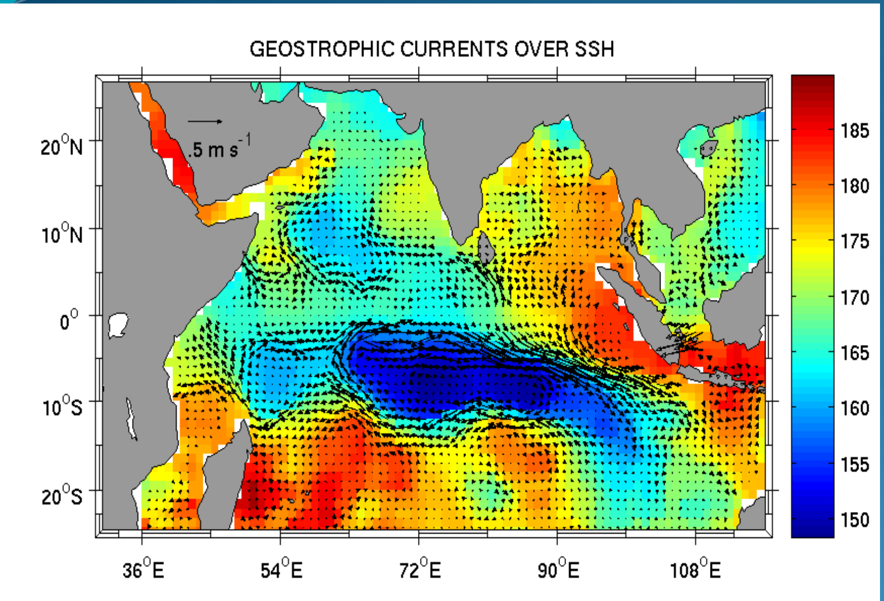
Scatterometer

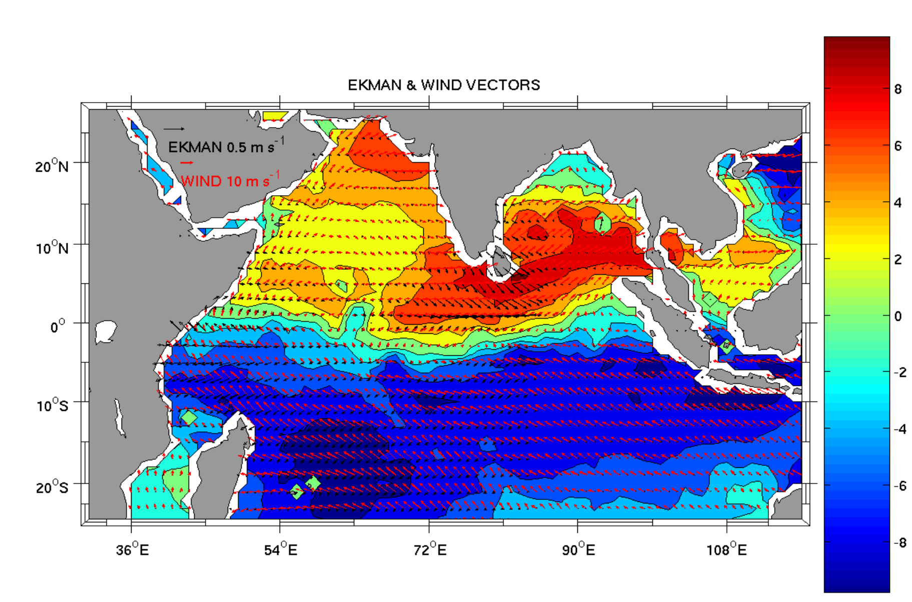
- NSCAT / QuikSCAT / ADEOS-II
- QuikSCAT:
  - 13.4 GHz
  - 90-percent coverage of Earth's oceans every day.
  - Wind-speed measurements of 3 to 20 meters/second, with an accuracy of 2 meters/second; direction, with an accuracy of 20 degrees
  - Spatial resolution of 25 kilometers
  - Data available from 1999 to 2009

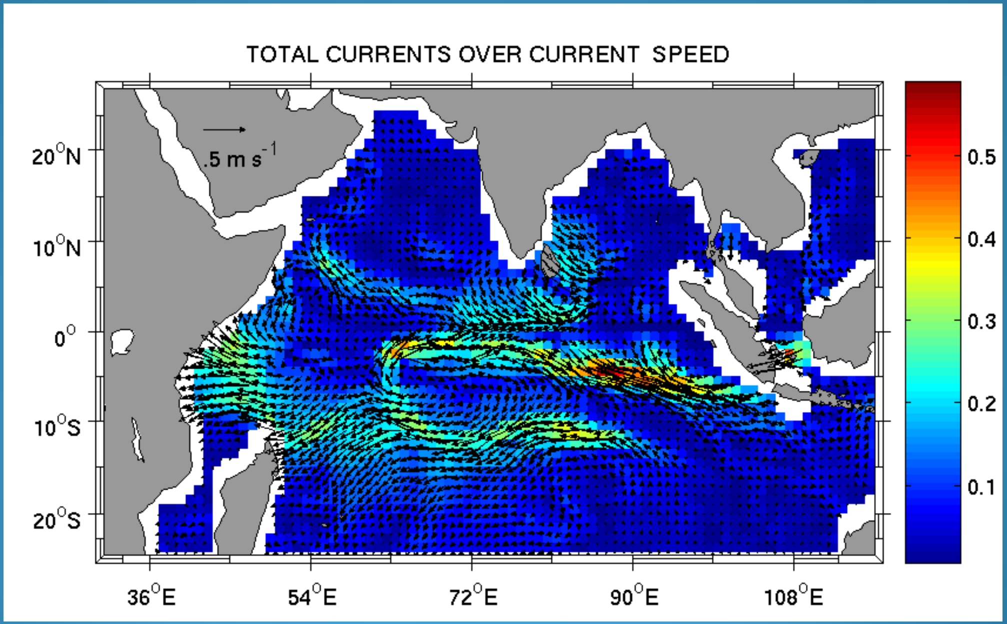
http://podaac.jpl.nasa.gov/DATA_CATALOG/quikscatinfo.html

- **Advantages**
  - Large measurement swath
  - Incidence angle is constant across the swath
- **Disadvantages**
  - Wind retrievals more sensitive to rain
  - Retrieval performance varies across measurement swath
  - At the edge of the swath only two instead of four looks are possible

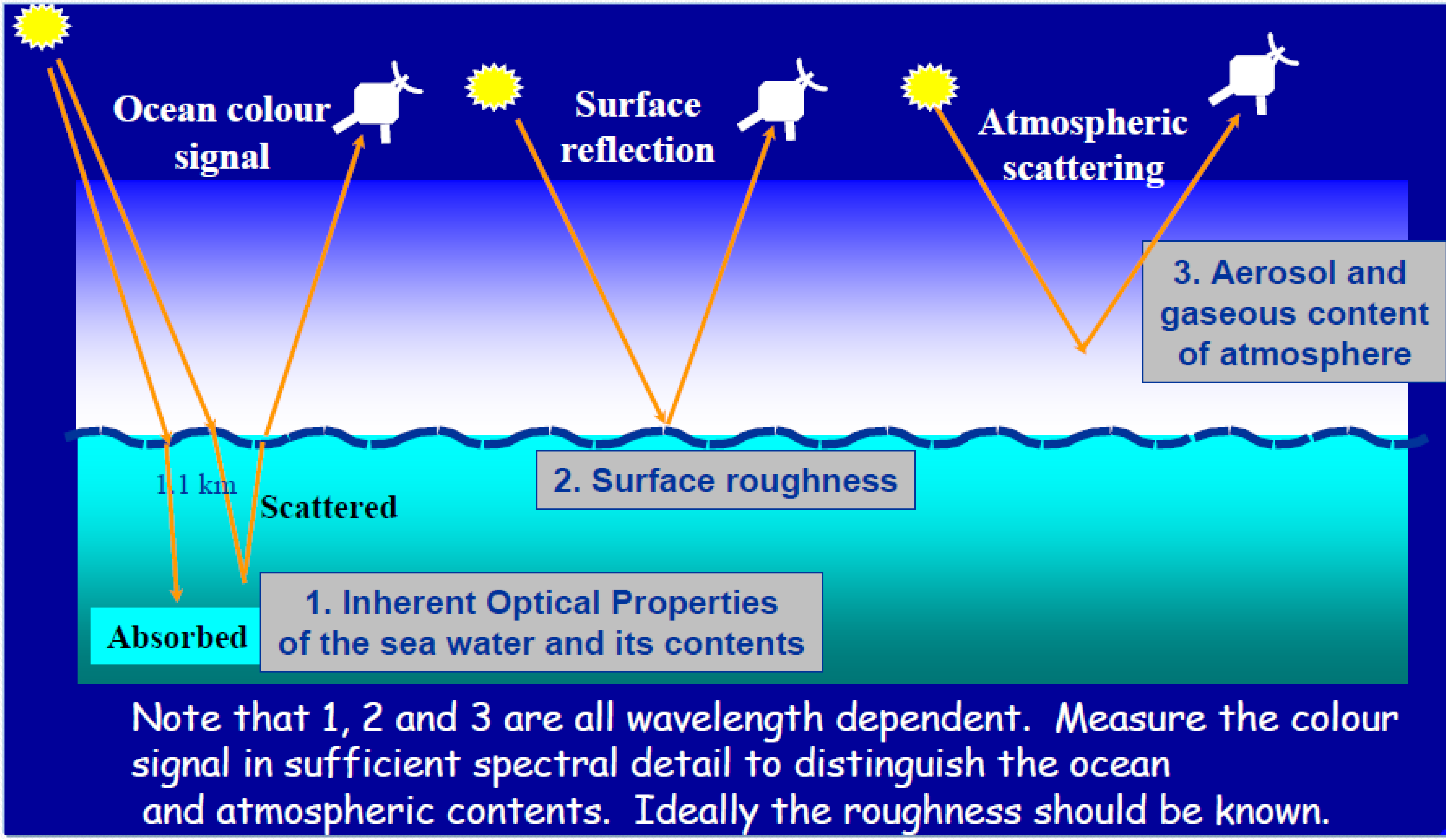
Surface currents





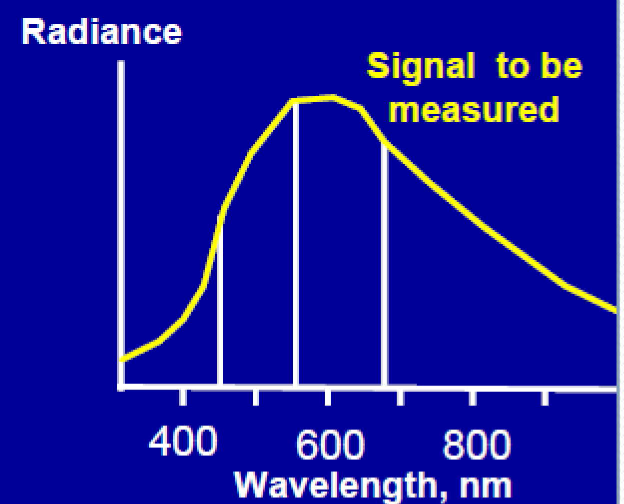


Ocean color : Principle

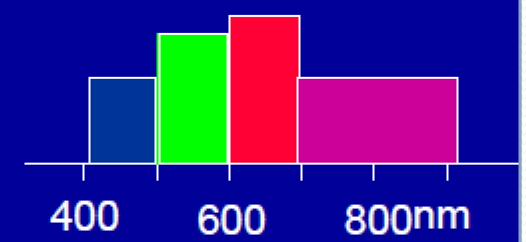


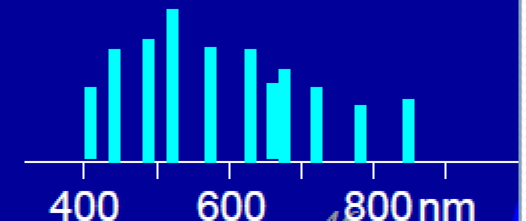
Using color to carry information

- **What is colour?**
  - The spectral distribution of visible light
  - The spectrum is typically a continuum

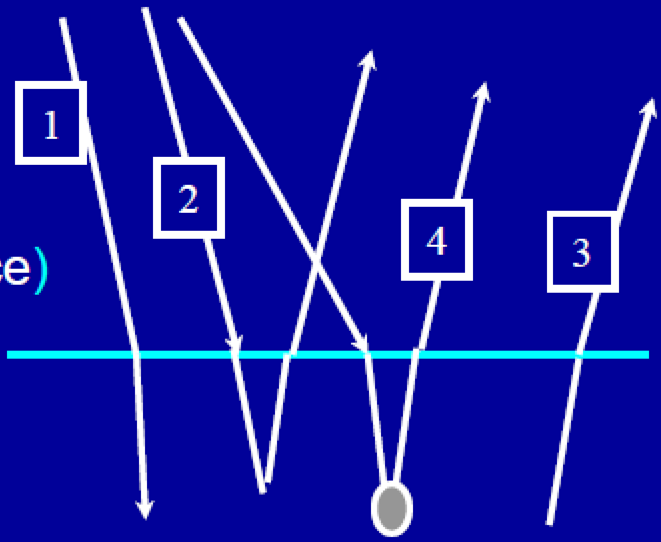


- **How is it measured?**
  - A detector samples discrete wavebands
  - The eye detects the response in three bands defined by three spectral functions
  - The “colour” is simply the set of values measured in the different wavebands or “channels” .
  - May be a few broad bands or many narrow bands





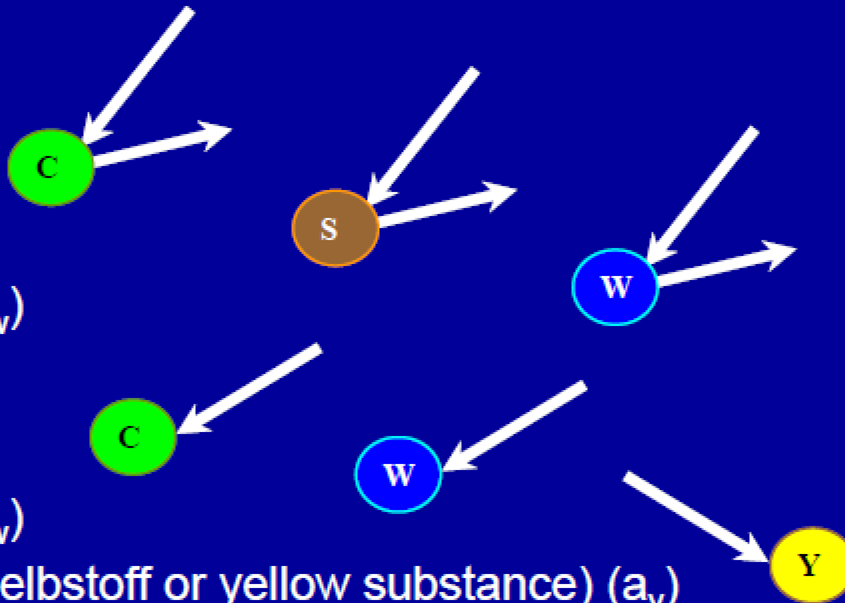
What affect light in the Sea ?



- **Light entering the sea:**
  - Comes from the sun
  - often scattered by the atmosphere or clouds (75%-95% of TOA radiance)
- **Light in the sea**
  - is absorbed (1)
  - is scattered (2)
  - may be emitted by fluorescence (3)
  - may be frequency shifted (Raman scattering) (4)
- **Light leaving the sea**
  - consists of photons which have been scattered into a direction which brings them back to the surface
  - wavelength distribution (colour) is altered by the sea compared with those that enter the sea.

What affect color of the Sea?

- Spectral makeup determined by absorption (a) and scattering (b)
- Reflectance is roughly 0.33 (b/a).
- Backscattering (b) is caused by:
  - Phytoplankton (b_c)
  - Suspended particulate matter (b_s)
  - The water molecules themselves (b_w)
- Absorption (a) is caused by:
  - Phytoplankton (a_c)
  - The water molecules themselves (a_w)
  - Dissolved organic material (DOM, Gelbstoff or yellow substance) (a_y)



- Each a_x and b_x has its particular spectral form
- Therefore the colour depends on the concentrations of those water constituents which interact with the light.

Ocean color

In principle

• Colour can tell us about relative and absolute concentrations of those water constituents which interact with the light.

• Hence we measure chlorophyll (phytoplankton biomass), yellow substance and sediment load

In practice

Difficult to distinguish independently varying water constituents

CASE 1waters are where the phytoplankton population dominates the optical properties (typically open sea)

CASE 2waters are where other factors (terrigenous DOM, suspended or river borne sediments) are also present.

Most success with CASE 1 waters so far, using green/blue ratio algorithms for chlorophyll, of the form: **C = A(R550/R490)B**

Accuracy for C of ~ ±30% is achievable in open ocean

Data from CASE 2 waters are harder to analyse.

Measurement of subsurface reflectance >> Phytoplankton and its pigments, dissolved organic material and suspended particulate matter

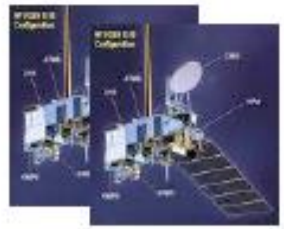
Applications Ocean color

- **Measurement of Chlorophyll**
  - Global distribution of chlorophyll
  - Estimates of primary production
  - Detection of plankton blooms
- **Measure Optical diffuse atténuation coefficient**
- **Measurement of suspended sediment**
- **Measurement of dissolved organic material**
- **As a tracer of dynamical processes**
- **Monitoring pollution**
- **Contribution to climate monitoring**

- Physical oceanography
- Ecosystem assessment
- Fisheries oceanography
- Biogeochemistry
- Coastal management

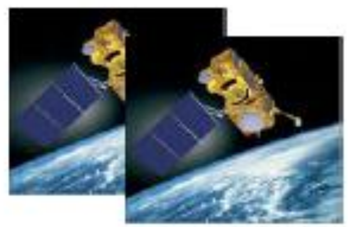
Ocean color - Missions

SeaWifs, MODIS



VIIRS (NPP, NPOESS-C1)

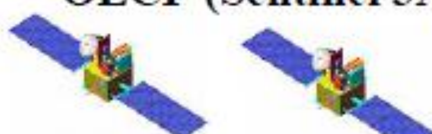
MERIS (Envisat)



OLCI (Sentinel 3A, 3B, …)

GOCI (geostationary)

OCM on IRS-P4



OCM on OceanSat 2,3

Radiometers

- Infrared radiometers – 3.7, 10.5 and 11.5 micro m (AVHRR)
  - Resolution (1 km spatial, global coverage)
  - Accuracy – 0.4 to 0.5 K
  - Problem in measuring SST below cloud
  - Geostationary satellite – AVHRR – 3-5 km resolution, higher temporal sampling
- Microwave sensors – 7 and/or 11 GHz for SST
  - TMI/AMSR-E
  - Course resolution (~ 25 km)
  - Accuracy – 0.6-0.7 K
  - Penetrate cloud

Ocean Missions: Sea surface temperature

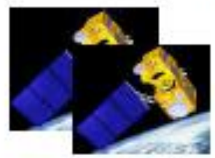
AVHRR on TIROS-N, AHRR/ 2 on NOAA-7

ATSR (ERS), AATSR (ENVISAT)

AMSR-E on Aqua

AVHRR/3 on METOP and NOAA series (IJPS)

and follow-on's as part of JPS

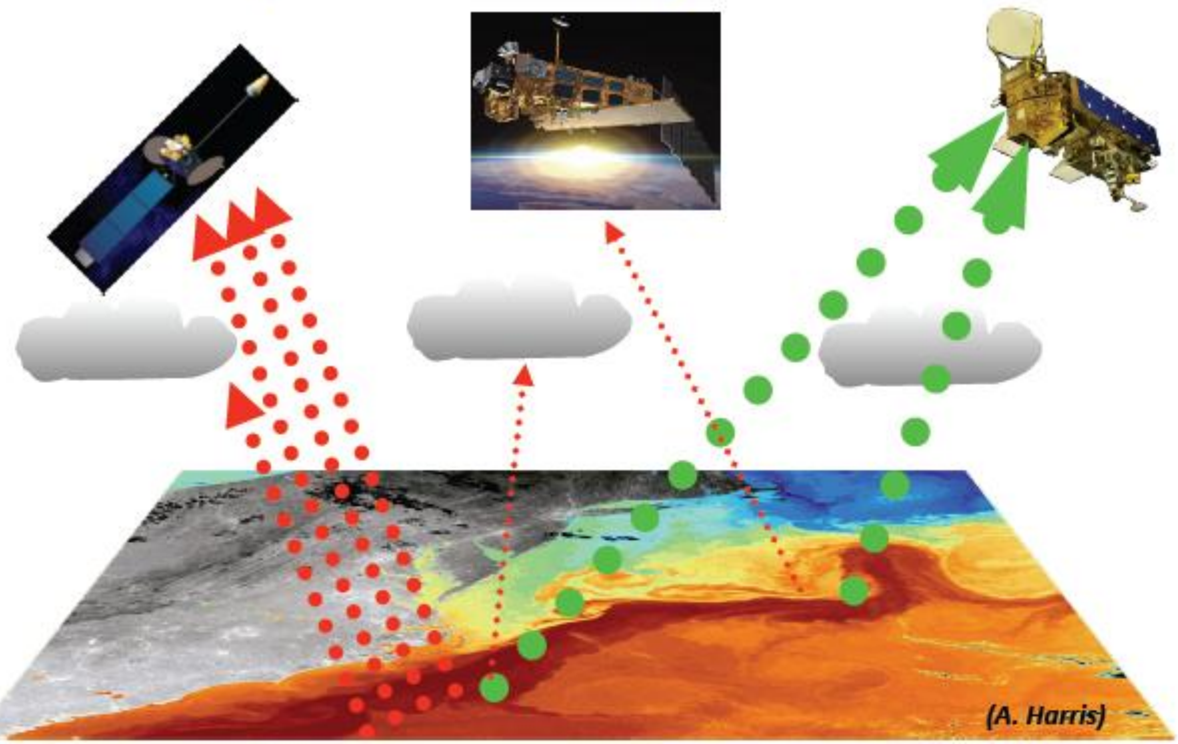


SLTSR (Sentinel 3A, 3B, 3C, 3D ..)

AMSR-2 on GCOM-W 1, 2 and 3

Geostationary missions (MSG, GOES)

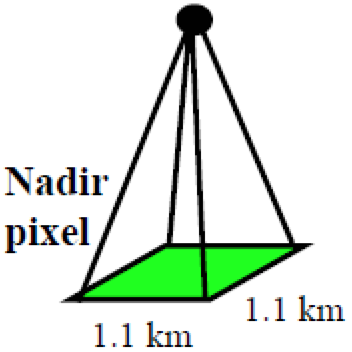
Complementary Measurements



- Polar Orbiting infrared has ***high accuracy & spatial resolution***
- Geostationary infrared has ***high temporal resolution***
- Microwave Polar orbiting has ***all-weather capability***

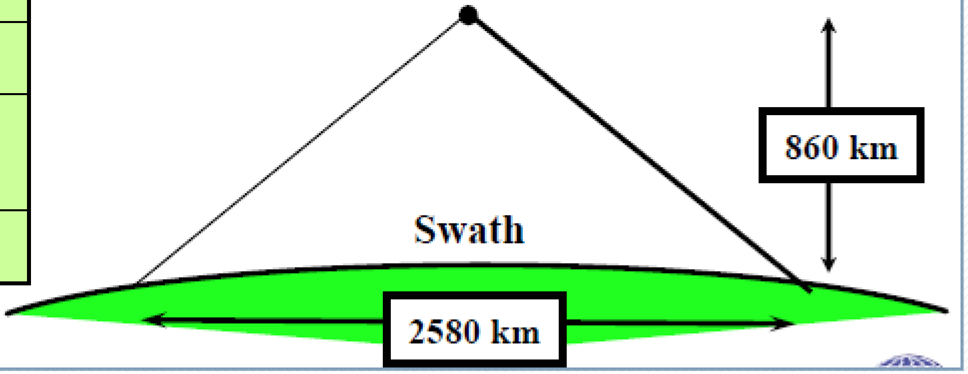
Infra-red sensor - AVHRR

- **Advanced Very-High Resolution Radiometer**
- **Since 1982 the AVHRR/2 has been deployed on NOAA-7, -9,-etc**
- **Specification**

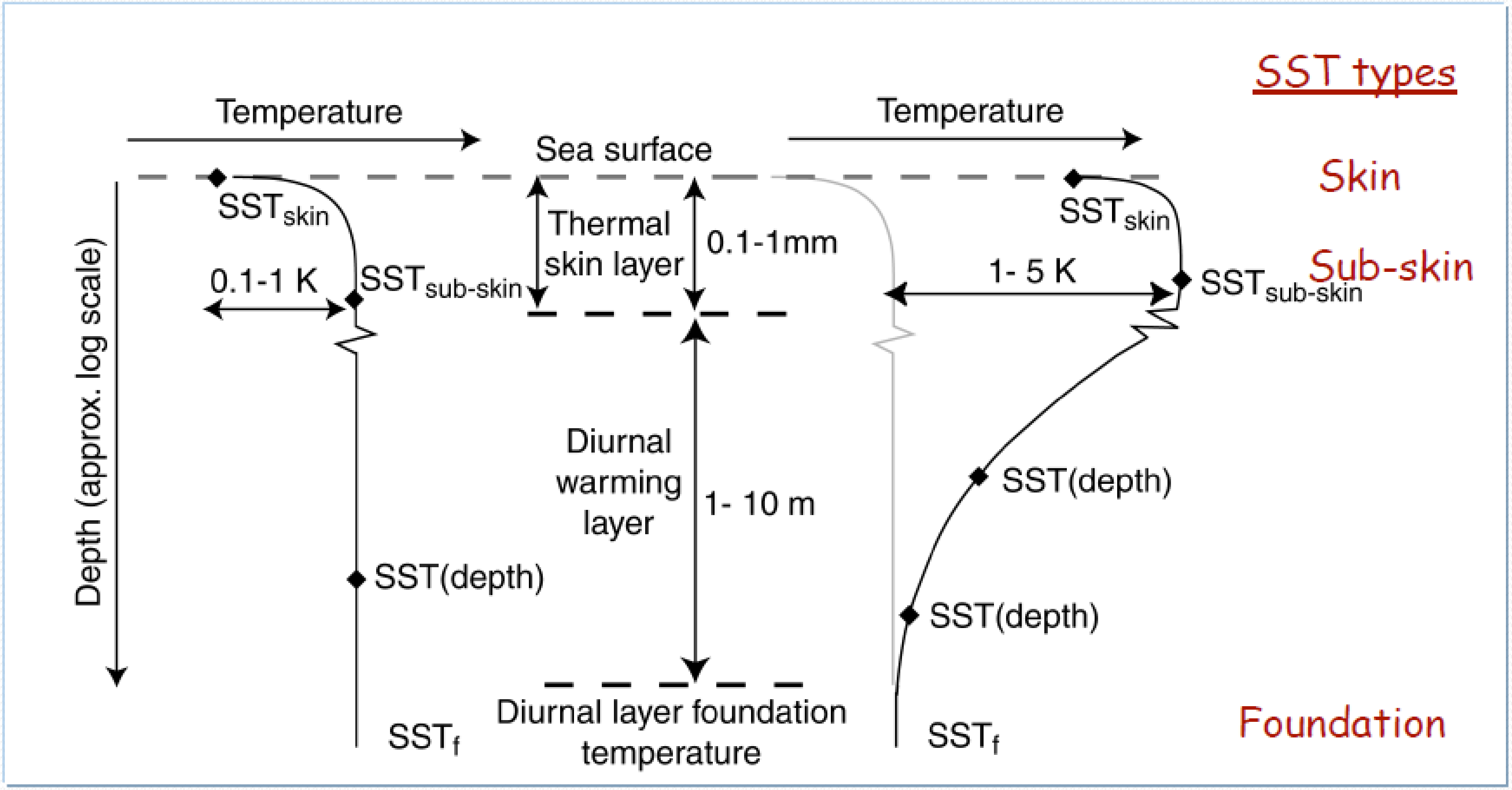


Channel	AVHRR/2 wave-bands (microns)	Description	Application
1	0.58 - 0.68	Visible	water turbidity
2	0.725 - 1.10	Near infra-red	coastline, clouds
3	3.55 - 3.93	Thermal I-R (night only)	SST
4	10.3 - 11.3	Thermal I-R	SST
5	11.5 - 12.5	Thermal I-R	SST

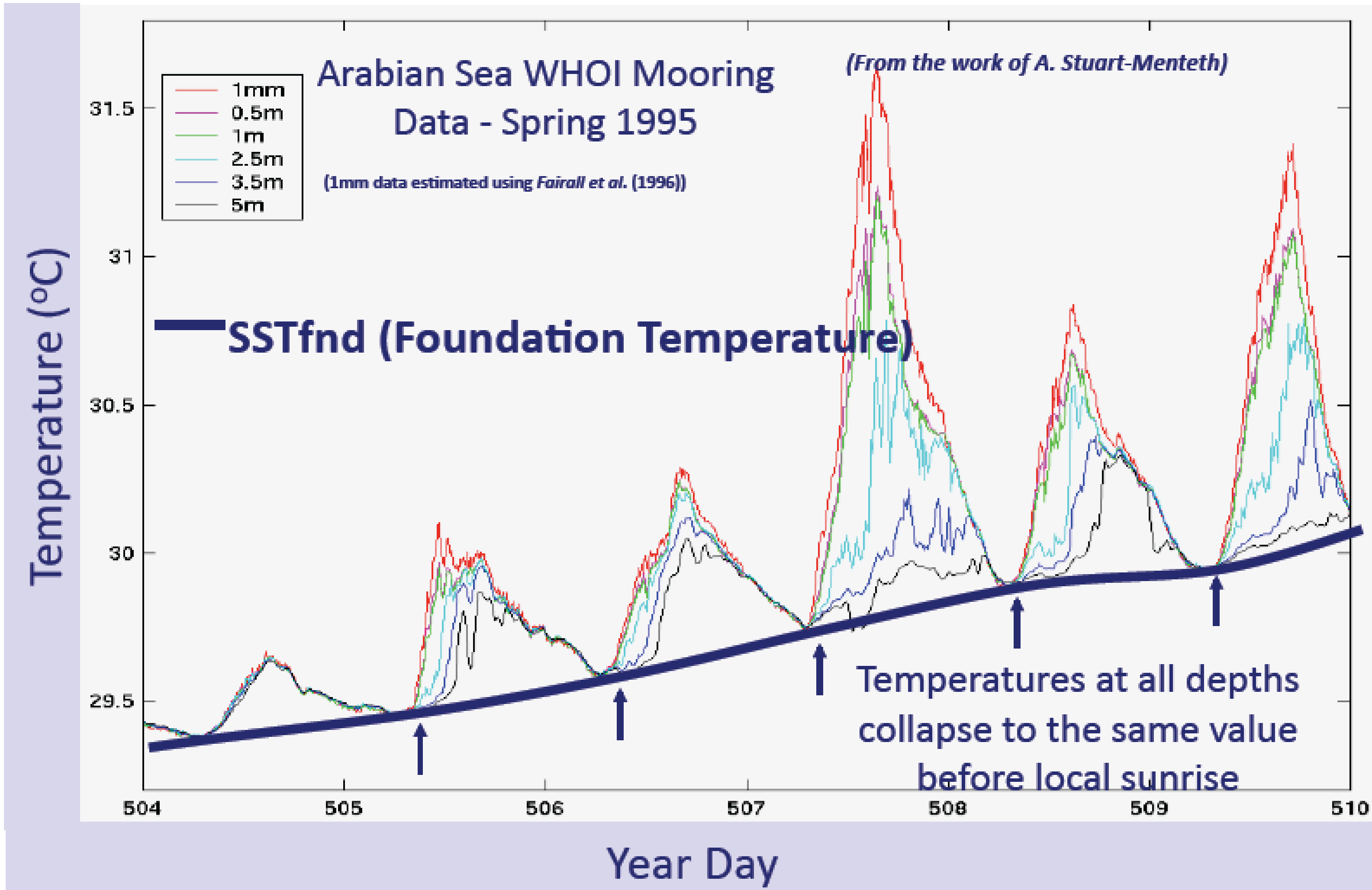
Sensitivity of thermal channels (NEΔT)	0.12 K at 300K
Number of digitisation levels	1024 (10-bit)
Ground field of view, Square Pixels	1.1 km at nadir
Swath width	2580 km



Defining Sea "Surface" temperature

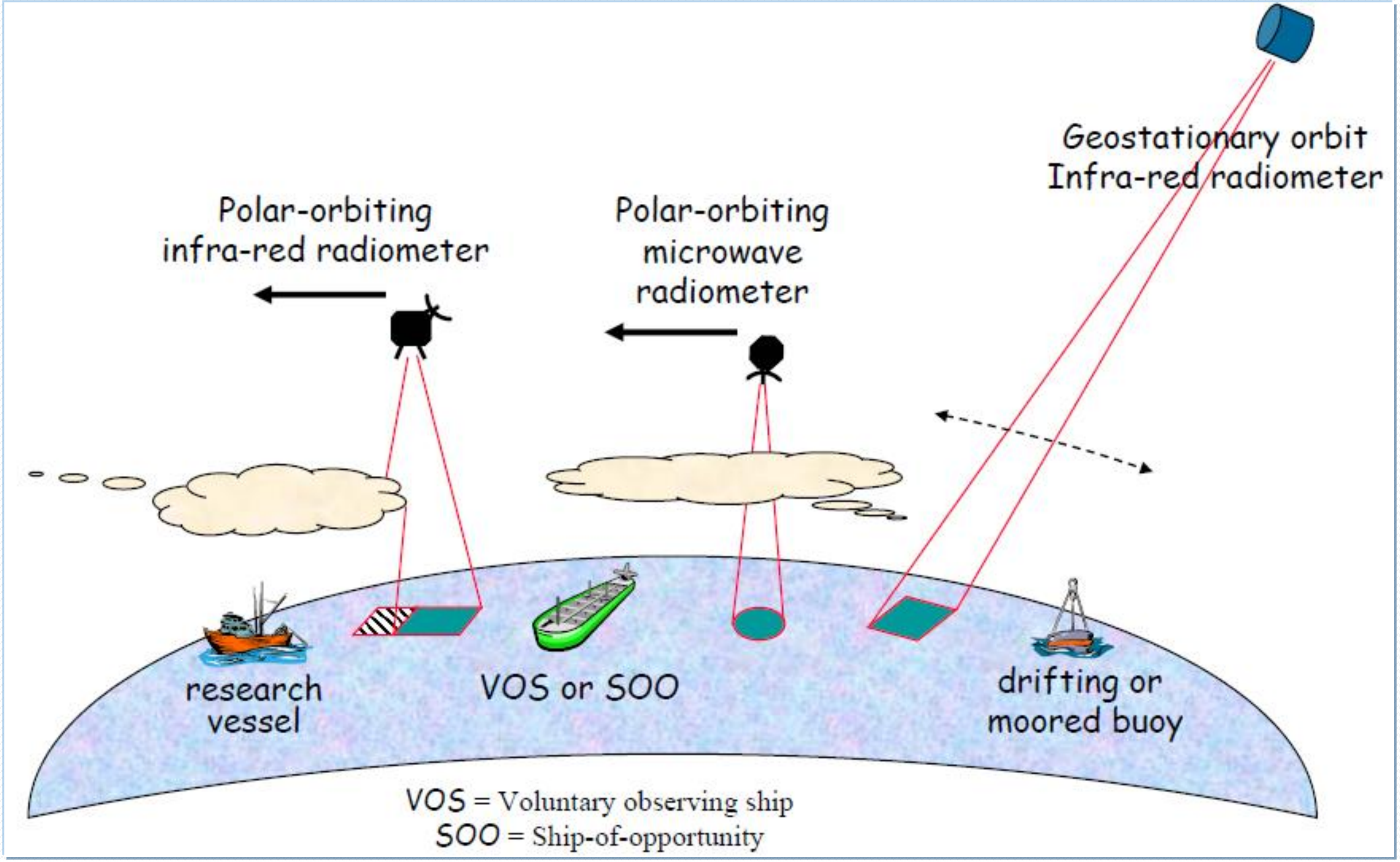


Foundation temperature



Donlon, 2008

Platforms to measure SST



Other satellites

- SAR
- GRACE
- SMOS/Aquairius
- Resourcesat
- ....

Other satellite derived products

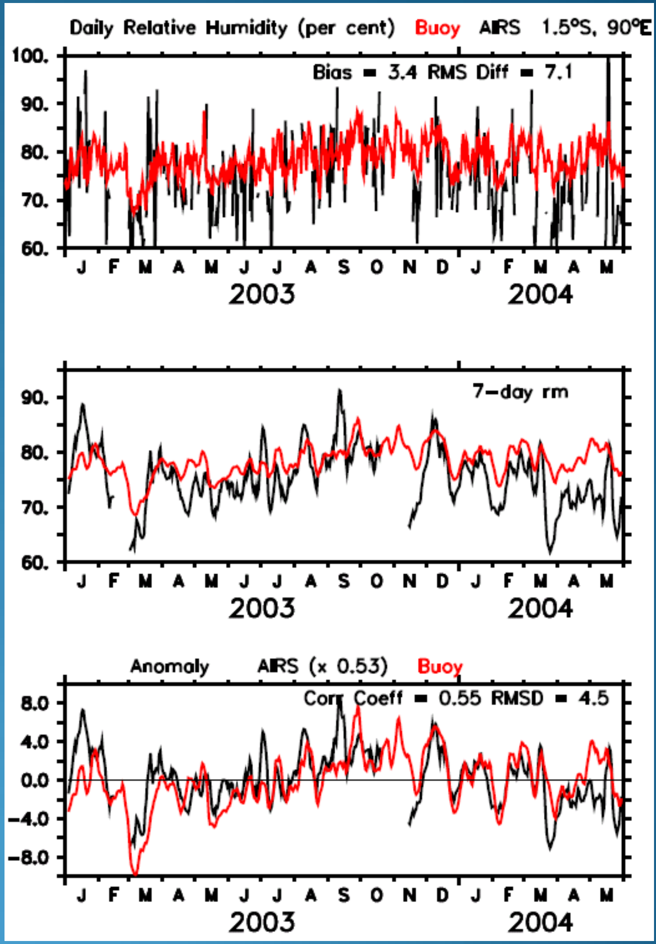
▪**Surface Air temperature**
(AQUA/AIRS)

▪**Surface Humidity**
(AQUA/AIRS)

▪**Short wave radiation**
(ISCCP)

▪**Rainfall**
(TRMM 3B42,IMD,GPCP &CMAP)

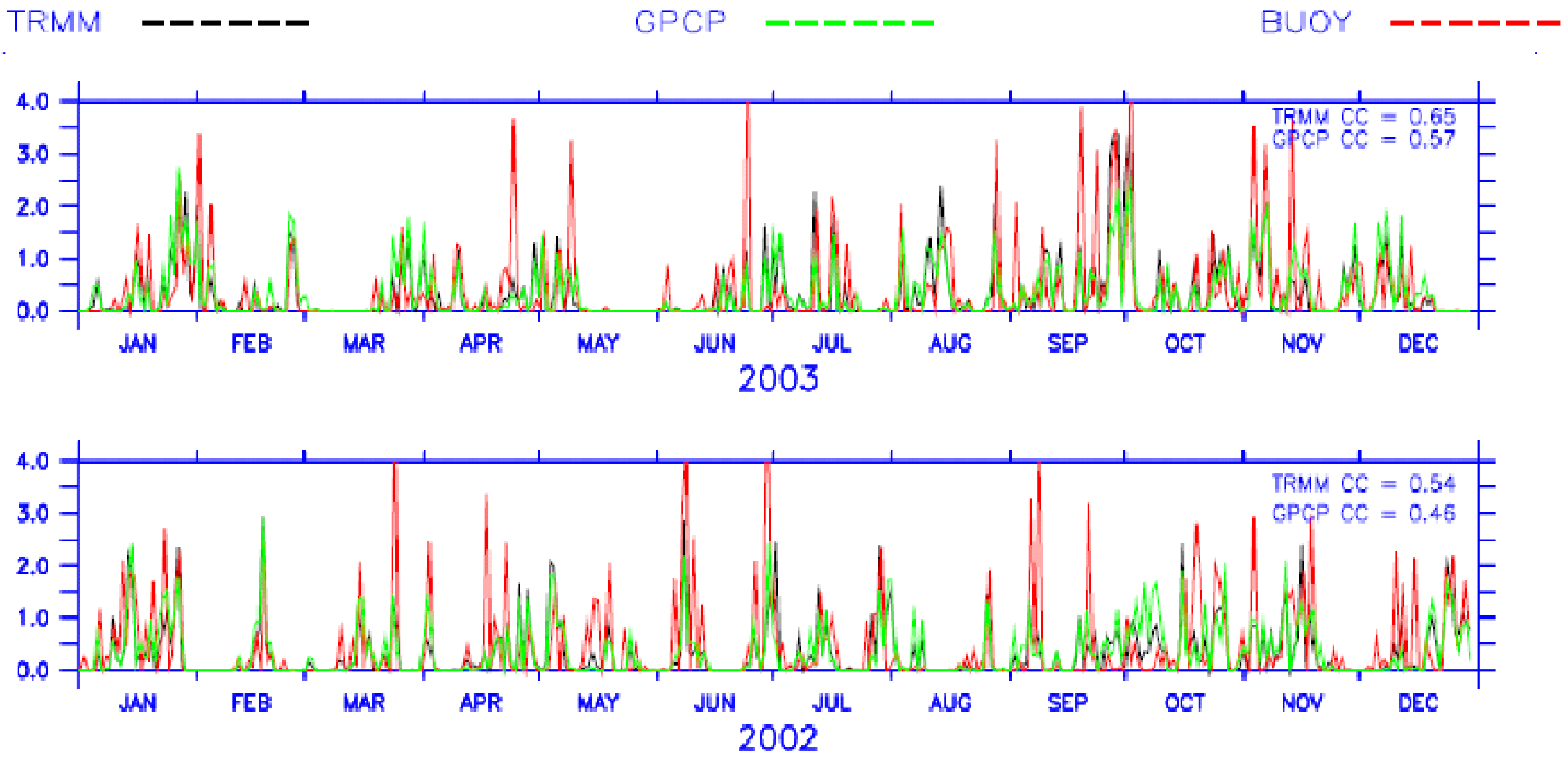
Relative humidity



Ongoing work on improving surface fluxes with the help of new daily and sub-daily satellite data

… guided by RAMA and ARGO

Daily precipitation comparison at 90 E 1.5 S



Useful books

- Fu, L.L., and A. Cazenave (2001). Satellite altimetry and Earth sciences, Academic Press.

- Robinson, I. (2004). Measuring the Oceans from Space: The principles and methods of satellite oceanography, Springer.

- Martin S. (2004). An introduction to ocean remote sensing, Cambridge University Press.