Введение в спутниковую океанографию - 2

Introduction to Satellite Oceanography, part 2

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IFREMER / ЛСО РГГМУ

Objective of today's lecture:

Continue introduction to RS techniques and observations with topics on:

- Satellite orbit types
- Advantages of satellite RS + unique applications
- Main sensors types with examples
- Fundamental limitations of RS

Satellite Orbit

Determined by Kepler's Laws

- Perturbed by gravitational, irregularities, friction, solar pressure, etc.
- Ranging and repositioning is required for satellite to maintain their orbit

- The orbital period is the time it takes for the satellite to circle the earth
- Easy to compute if assume the earth is a sphere but earth is an oblate ellipsoid

Launch and Maneuver of Satellites

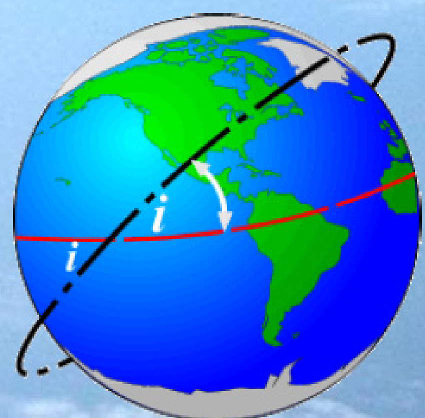
Velocity of a satellite in low-earth orbit: 7 km/s

- A rocket capable of reaching this orbit consists of 97% fuel
- Single-stage rockets only capable of placing small satellites into orbit
- Multiple-stage rockets can put a few tons into orbit
- The space shuttle can place 30 tons into 400 km orbit or 6 tons into a geostationary orbit.

Orbit Geometry

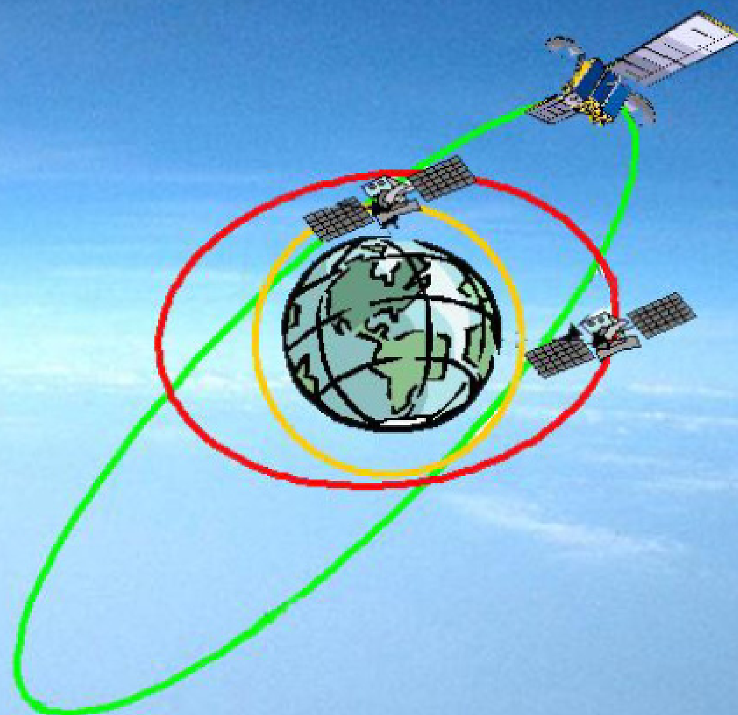
- Ascending (Descending) pass
  - Path followed by the satellite as it moves from south to north (north to south) in its orbital trajectory

- Inclination
  - Angle made by the ground track of the satellite in relation to the Equator on its ascending pass
  - Less than 90 degrees is a prograde orbit (in direction of rotational motion)
  - Greater than 90 degrees is a retrograde orbit (opposite rotational motion)



Types of Orbits

- Geostationary
- Geosynchronous
- Sun Synchronous
- Altimetric
- Molniya

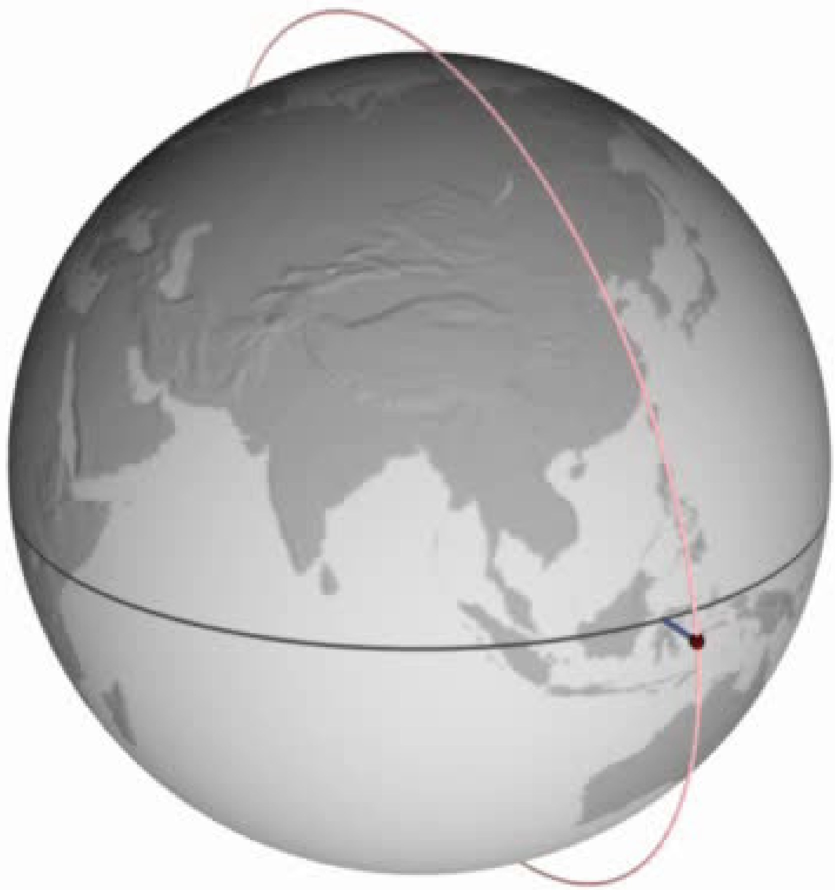


Types of Orbits

Sun Synchronous

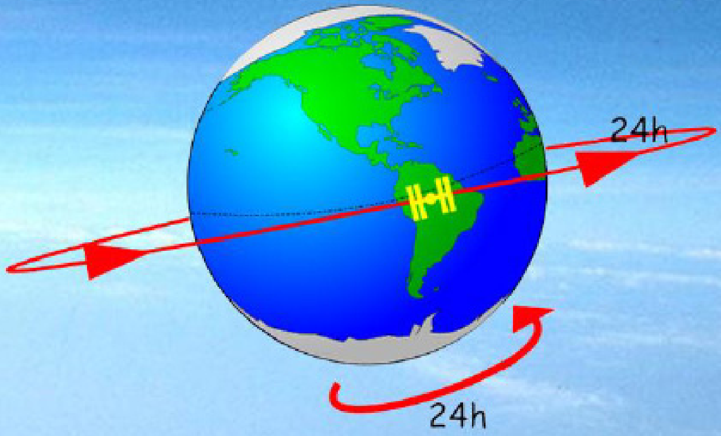
- The satellite crosses a given latitude at the same solar time every day
- The orbital plane rotates about the polar axis
- Orbital height about 1000 km
- Orbital inclination is greater than 96°
- Landsat, SPOT, NOAA, DMSP, RADARSAT, ERS-1/2

Sun-synchronous orbit



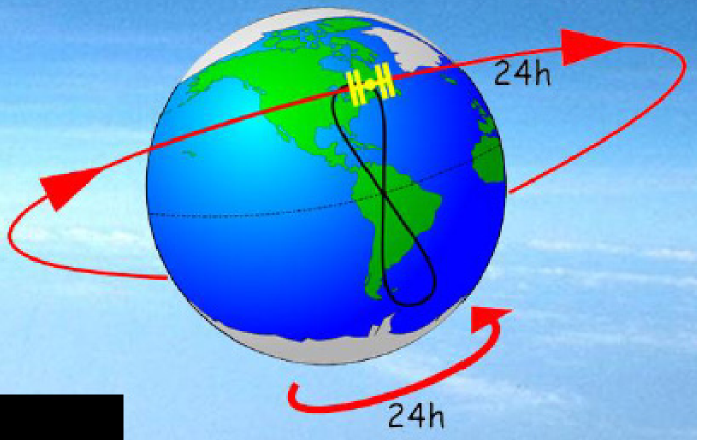
Types of Orbits

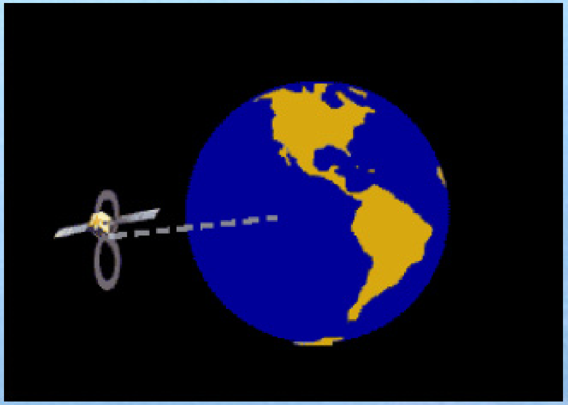
- **Geostationary**
  - Orbit is stationary with respect to a location on the earth
  - Circular orbit around the equator (orbital inclination = zero)
  - The orbital period id equal to the earth rotation (for a sidereal day, rotation with respect to star) = 23 hrs 56 min. 4 sec.
  - Orbit altitude is 35,800 km (about 36,000 km) above the equator



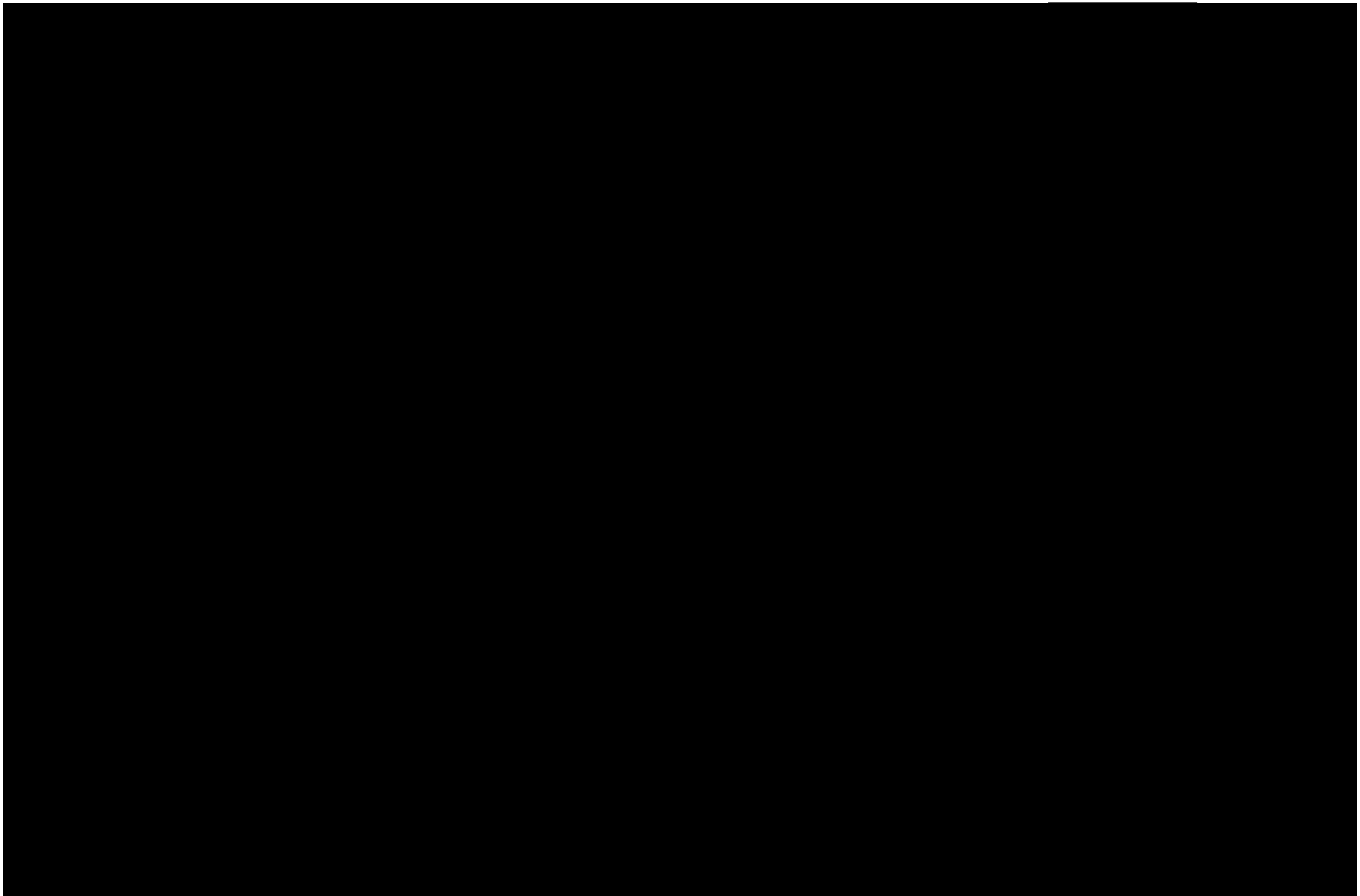
Types of Orbits

- Geosyncronous
  - Orbital period = earth's rotation = 24 hrs
  - Orbital inclination ≠ zero
  - Traces a figure-eight on the surface of the Earth
  - Half the time, the orbit is above (below) where it need to be





Different satellite orbits



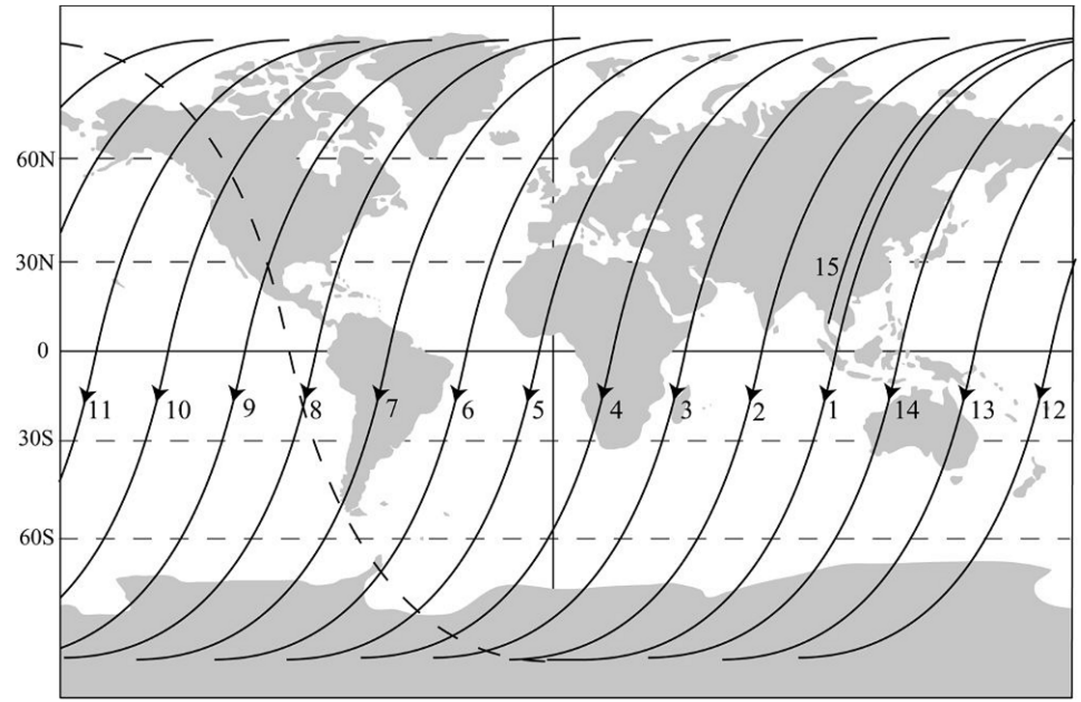
Satellite orbits

In a **near-polar** orbit the satellite completes 14/15 orbits a day.
The tracks are distributed evenly around the globe.

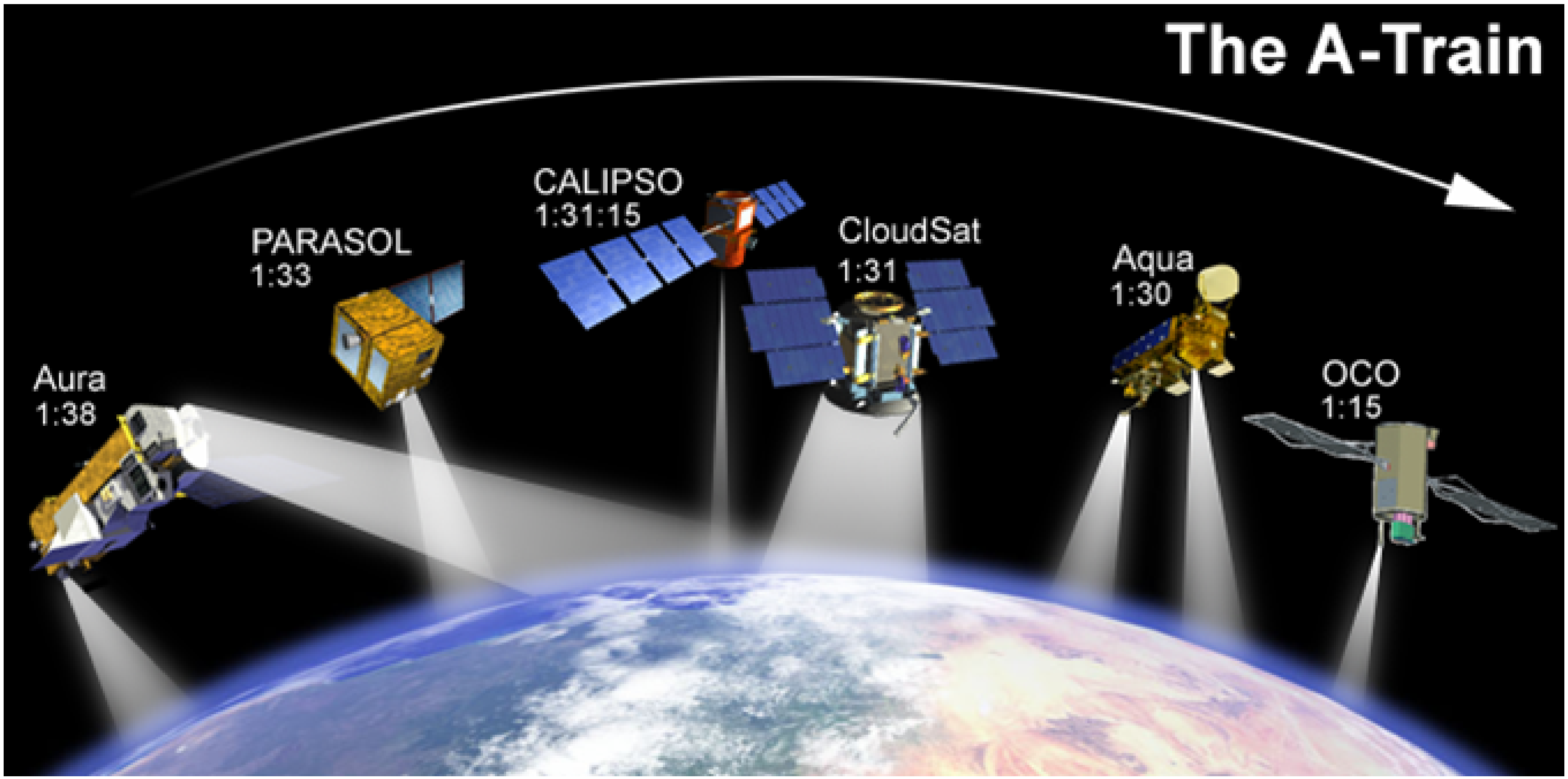
•Geostationary sensors typically offer a revisit interval of less than 30 min and spatial resolution of 3 to 5 km.

•The polar orbiting sensor cover the whole Earth in a single day if it is the swath at least 2700 km.

• Each point on the Earth surface is viewed once from descending track and once from ascending track.



Ground track of a typical near-polar, low-Earth orbit, showing all the descending passes for one day and one ascending pass (dashed).

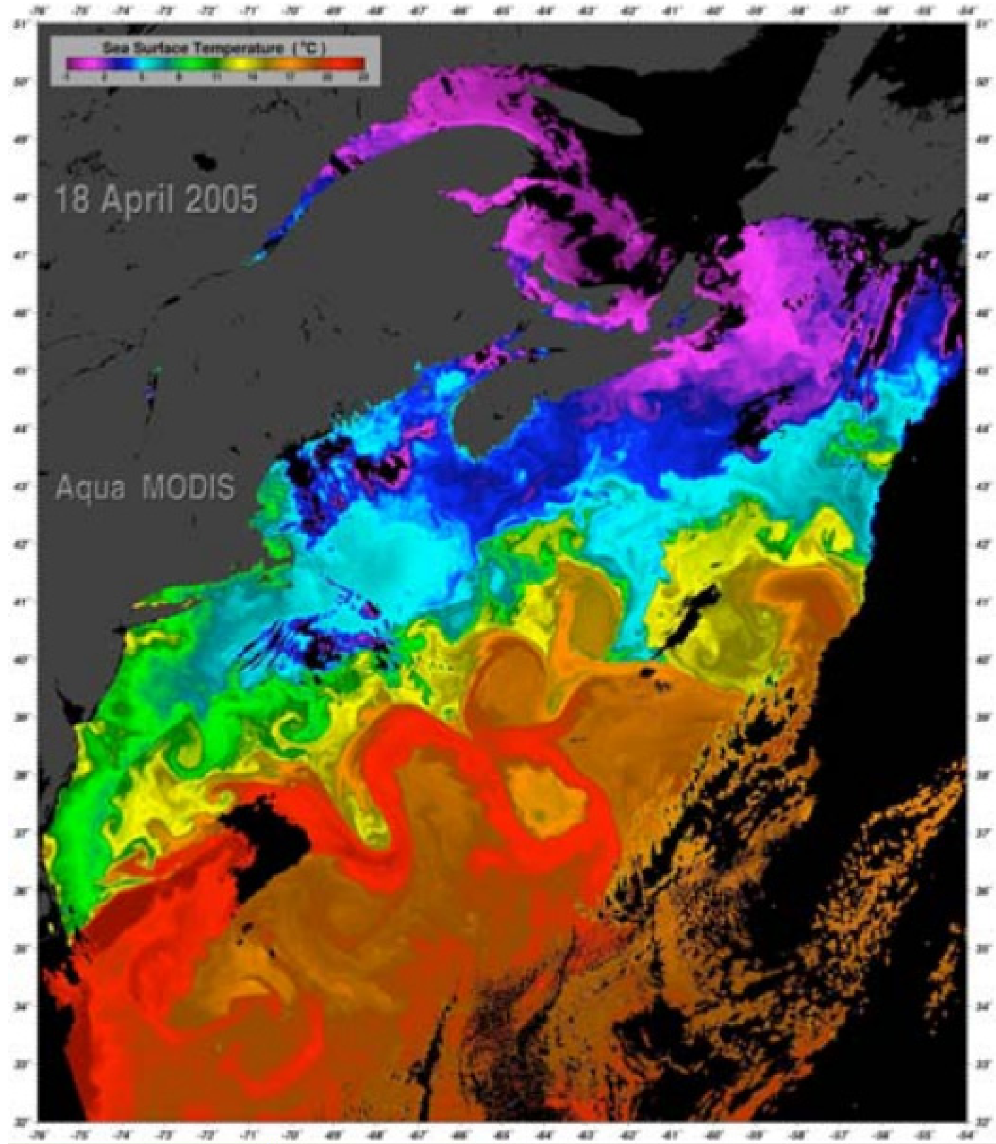

The A-Train
Aura
1:38
PARASOL
1:33
CALIPSO
1:31:15
CloudSat
1:31
Aqua
1:30
OCO
1:15

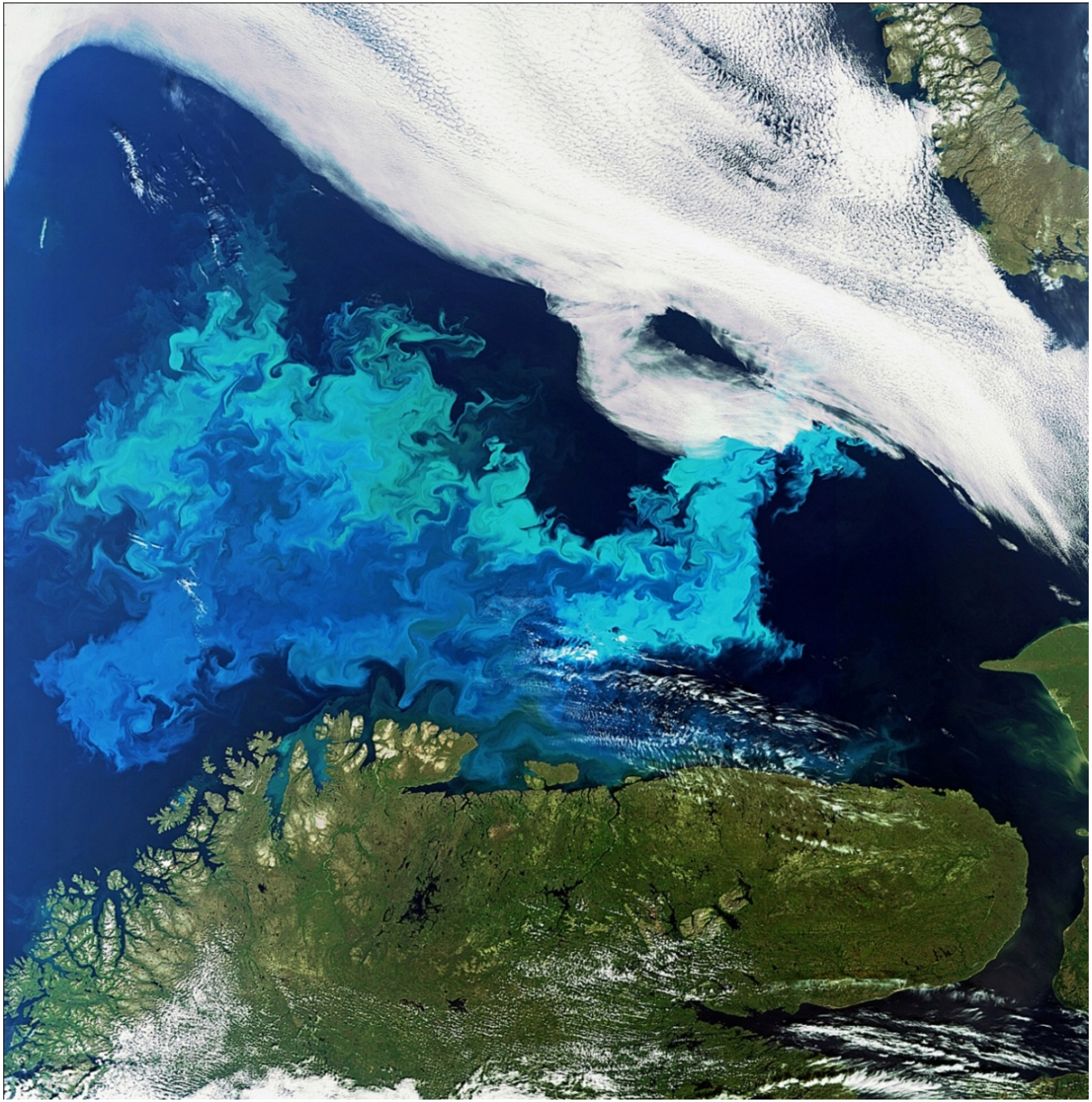
Ocean remote sensing: a privileged view

- Spatially detailed
  - Spatial resolution from meters to Kms
  - A synoptic picture that is 100 km - 10 000 km wide
- Regularly repeated
  - Revisit intervals between 30 min. and 35 days
  - Continuously repeated over years to decades
- Global coverage
  - Satellites see the parts where ships rarely go
  - Single-sensor consistency - no intercalibration uncertainties
- Measures parameters that cannot be observed in situ
  - Surface roughness at short length scales (2-50 cm)
  - Surface slope (a few cm over 100s of kilometres)

Spatially detailed overview of mesoscale ocean processes

North Atlantic Sea Surface temperature showing the Gulf Stream meandering





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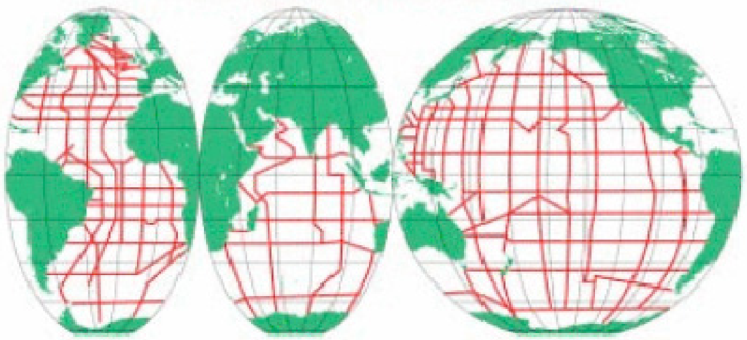
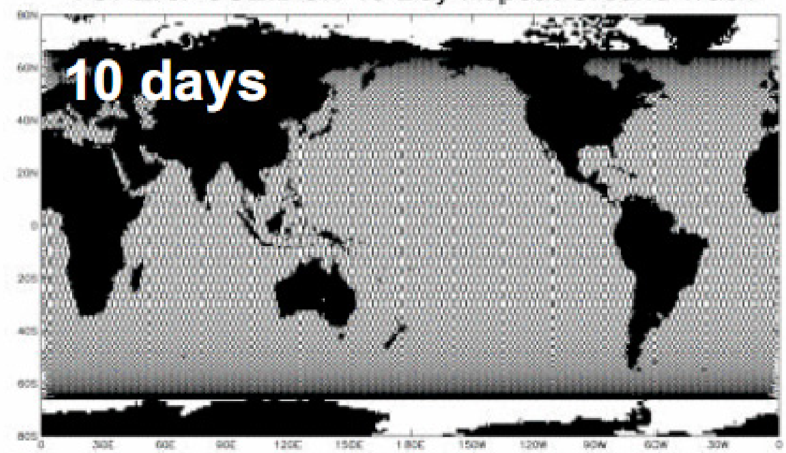
10 years

WOCE Hydrographic Survey Lines

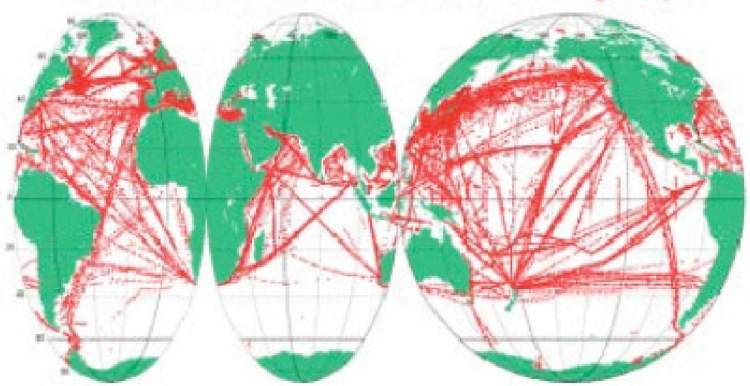


TOPEX/POSEIDON 10-Day Repeat Ground Track

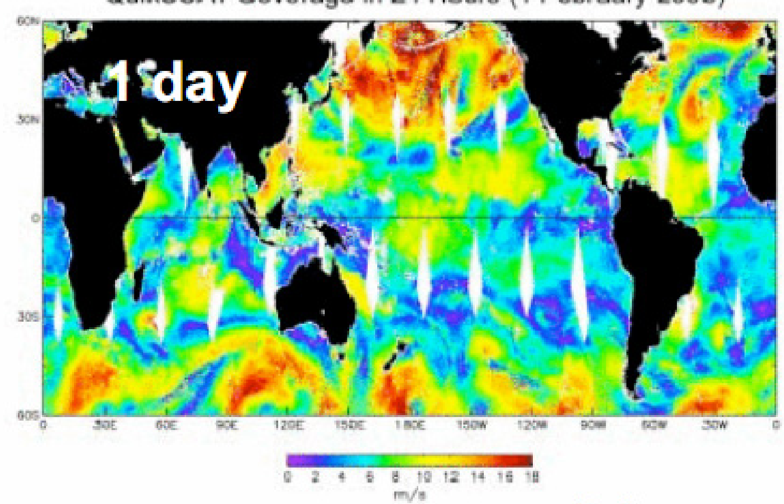


10 years

Observations from Volunteer Observing Ships



QuikSCAT Coverage in 24 Hours (1 February 2000)



D. Stammer

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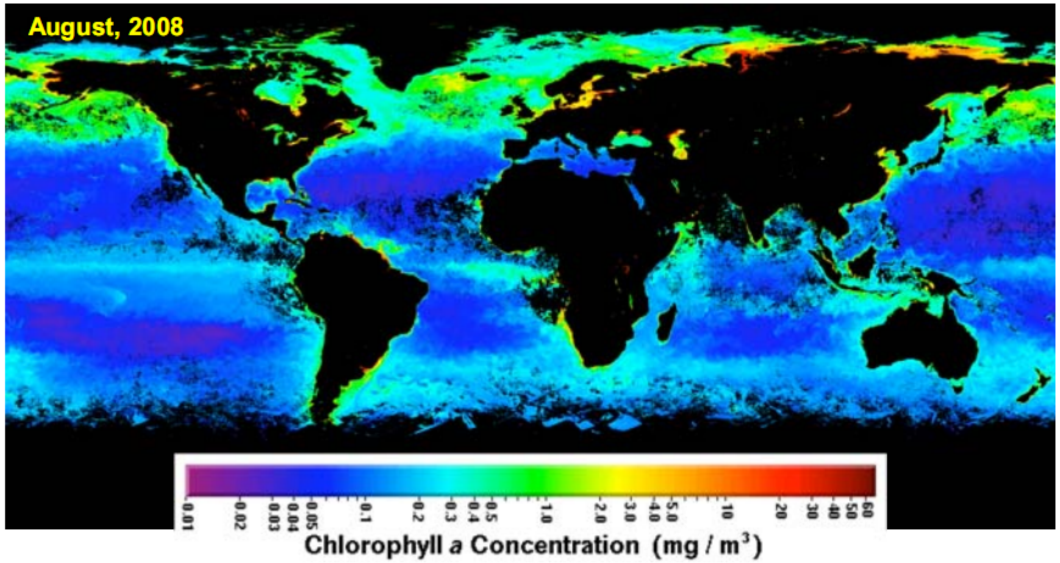
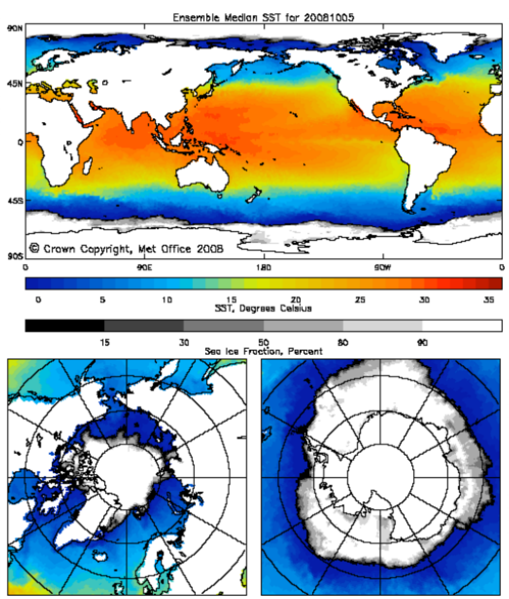
Global measurements for global science

The distribution of ocean chlorophyll measured from MODIS

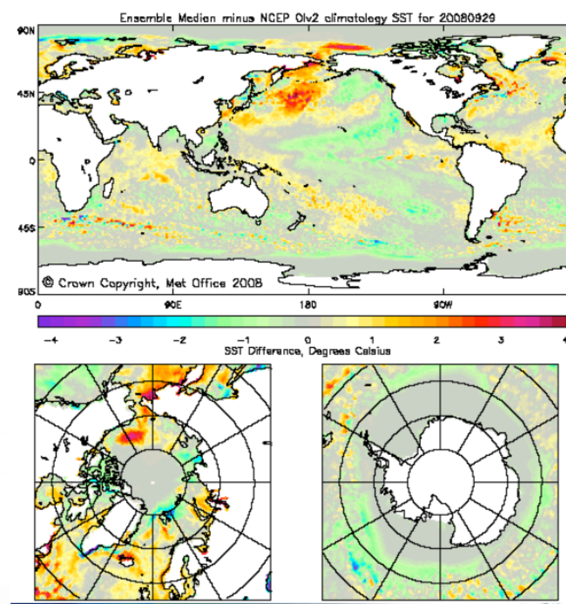


Global sea surface temperature

Ensemble of SST analyses derived from satellite data from several sensors, for 5 Oct 2008

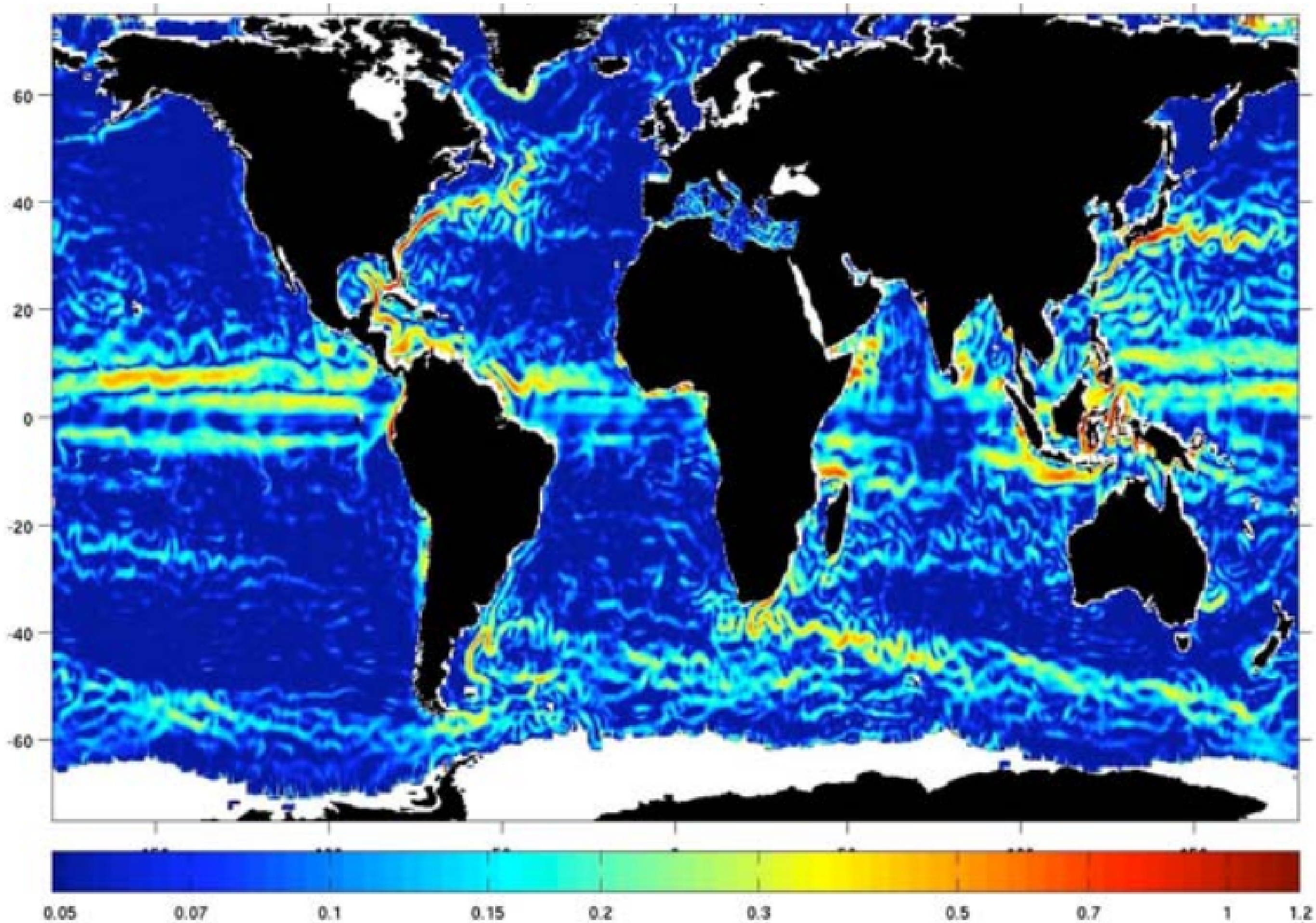


SST anomaly changes over 7 days



Source:- http://www.ghrsst-pp.org/Todays-global-SST.html

Global currents from Envisat



Computed from Envisat cycle 50 SSHA + Rio05 Mean Dynamic Topography

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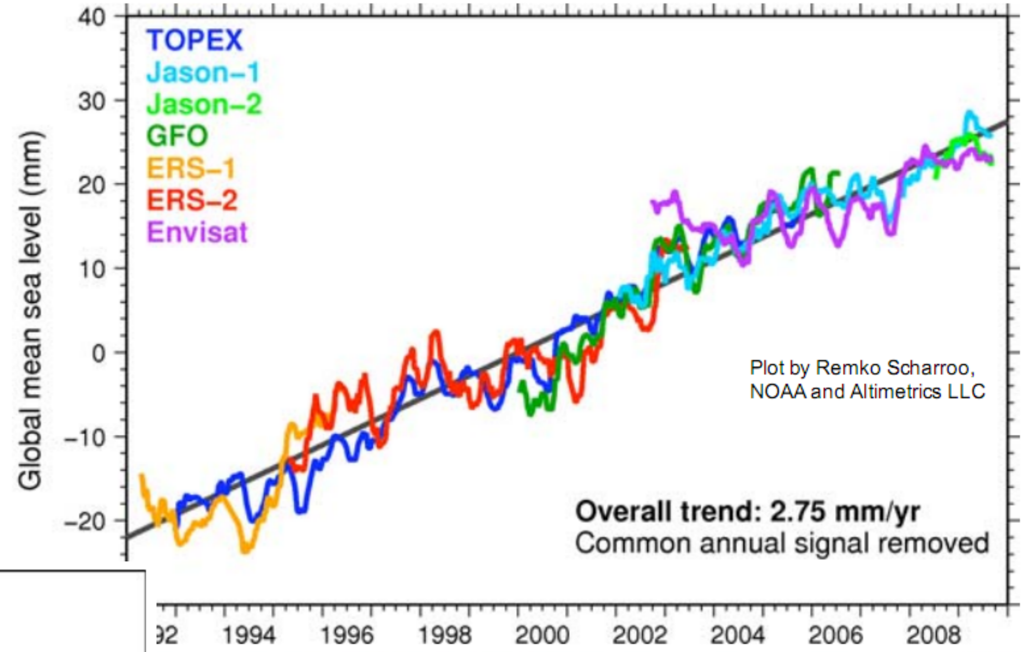
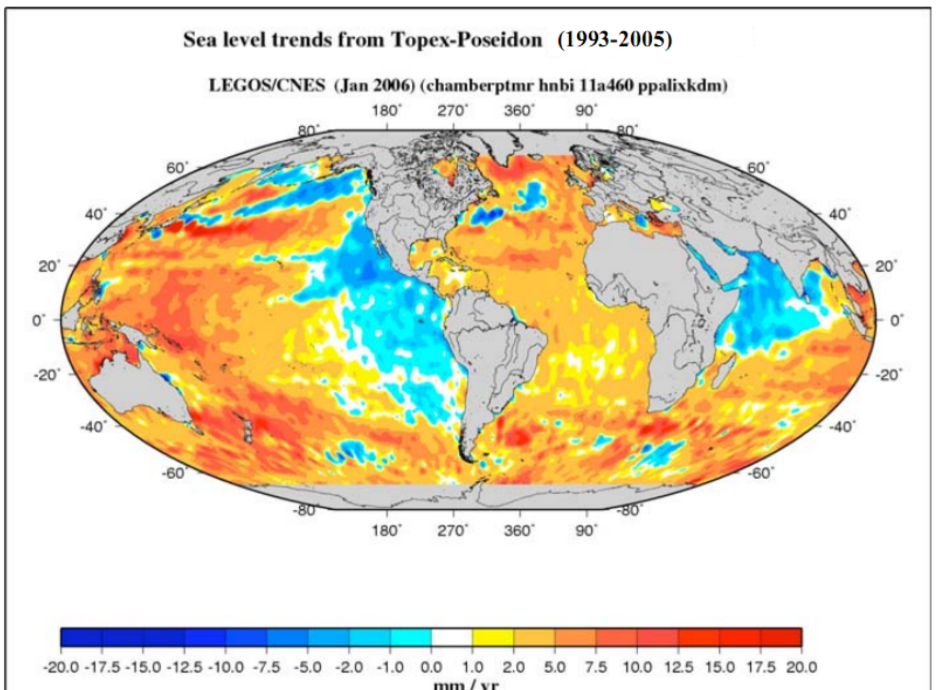
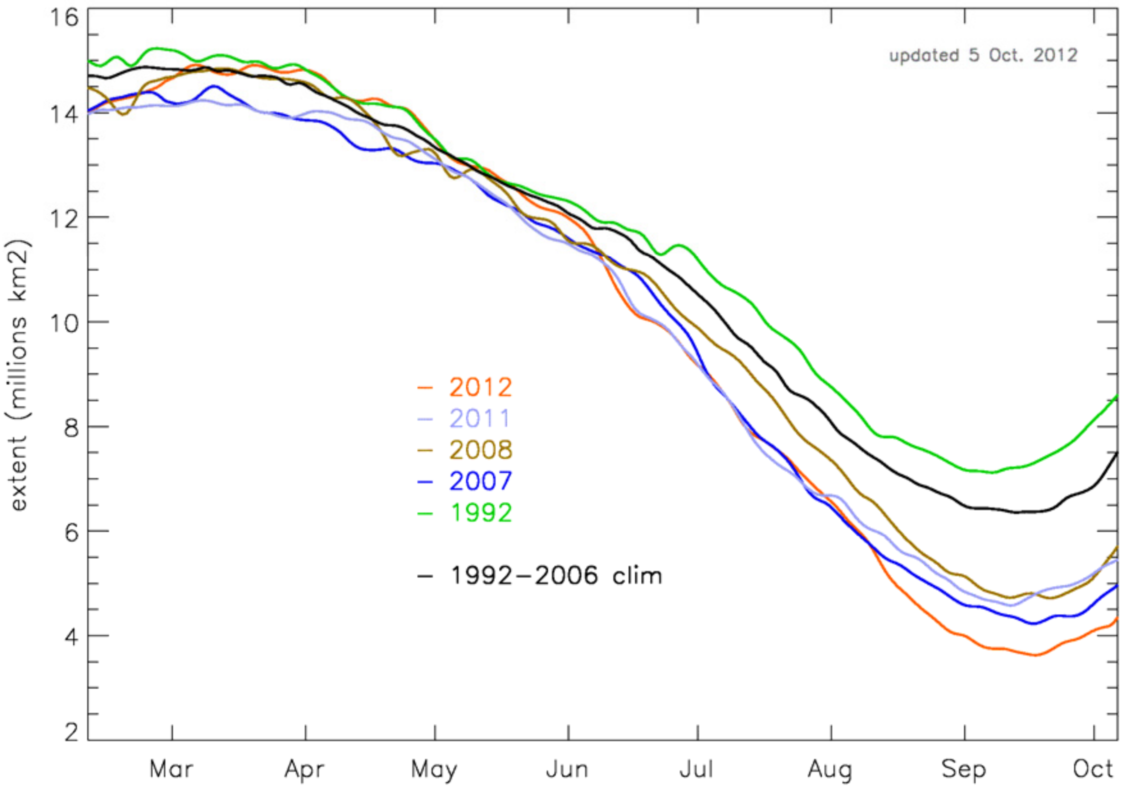
Sea Level Rise





Sea ice in the Arctic



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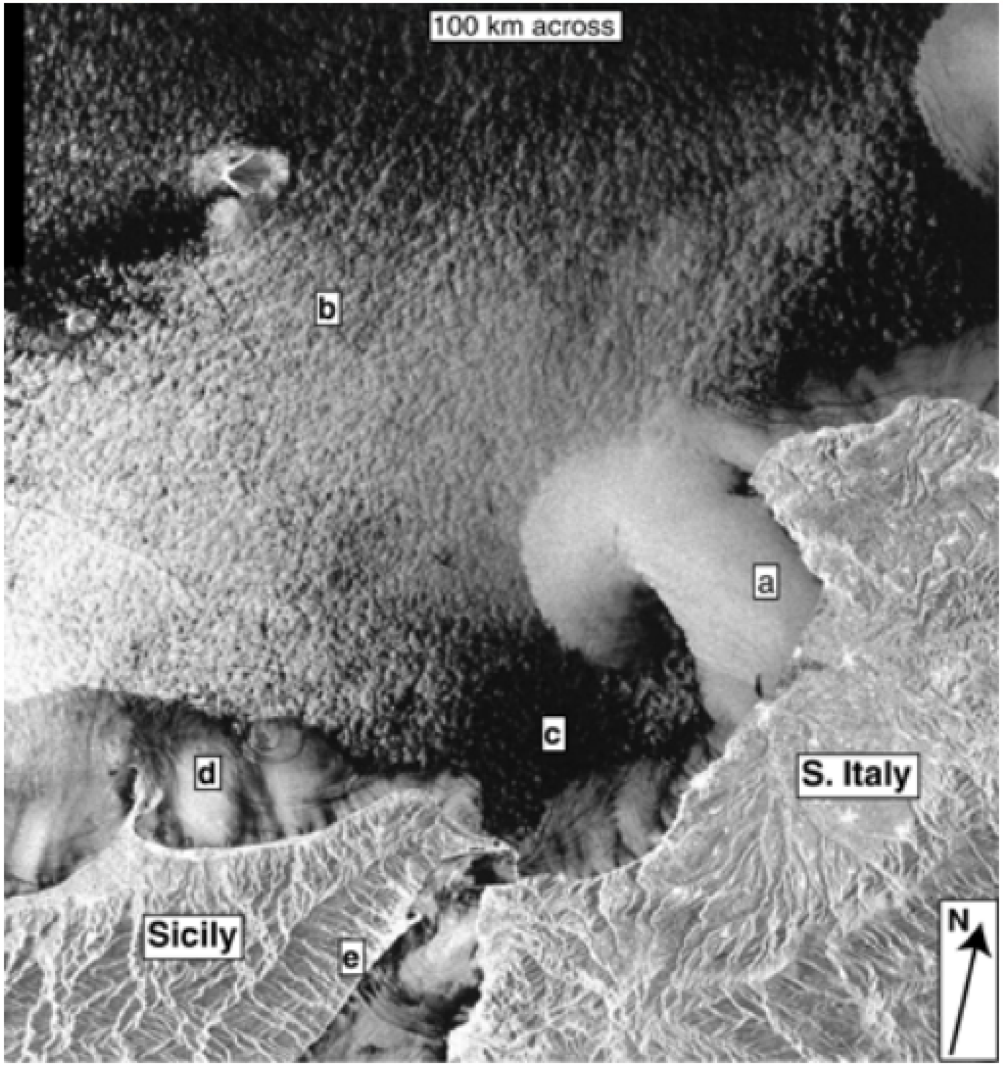
SAR images of sea surf. roughness

A possible oil seepage slick observed on ERS SAR imagery.



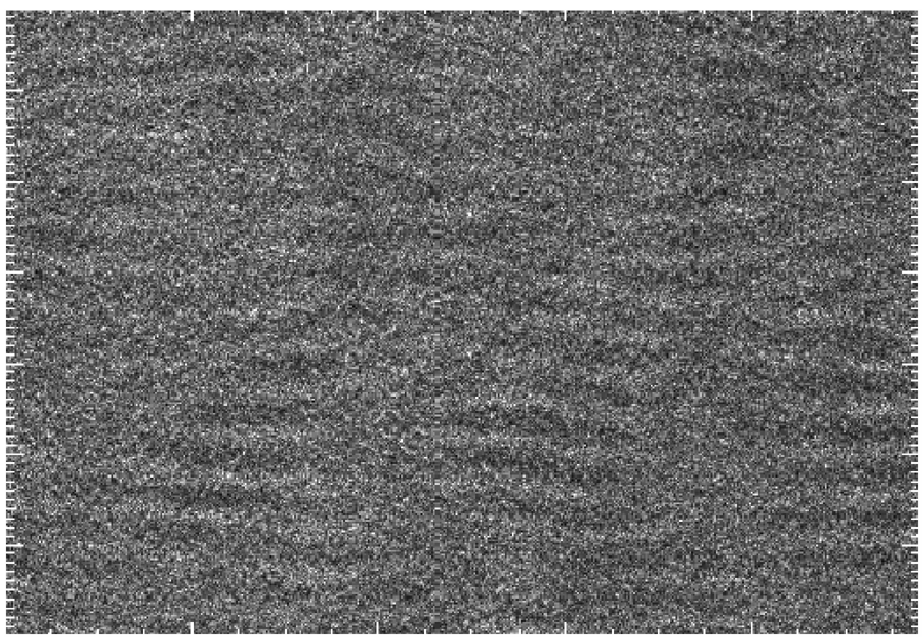
Mediterranean ERS SAR image shows signatures of (a) katabatic winds, (b) convective atmospheric cells, (c) low winds, (d) ocean eddies and (e) internal waves.

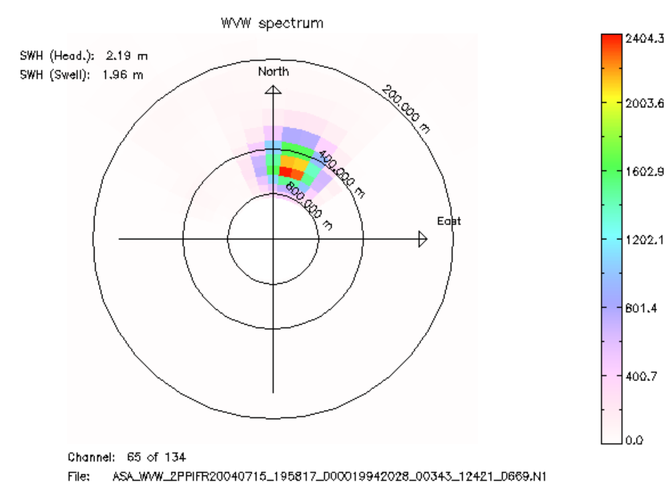
Waves across the Pacific revisited

« A comparison with meteorological events in the Southern Ocean would be far more meaningful if such Observations could be made at a time when a weather satellite is in suitable orbit » (Munk et al. 1963)

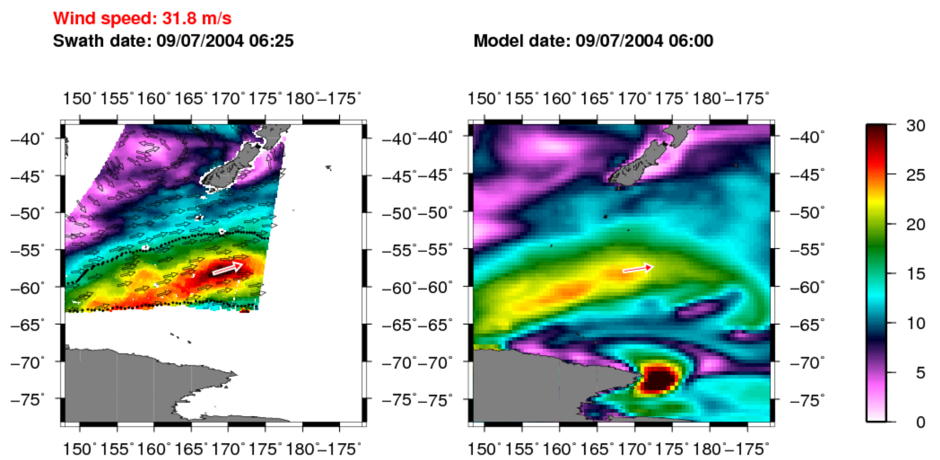
Data sources:
NDBC buoys
ENVISAT ASAR
Altimeters
(+propagation models)

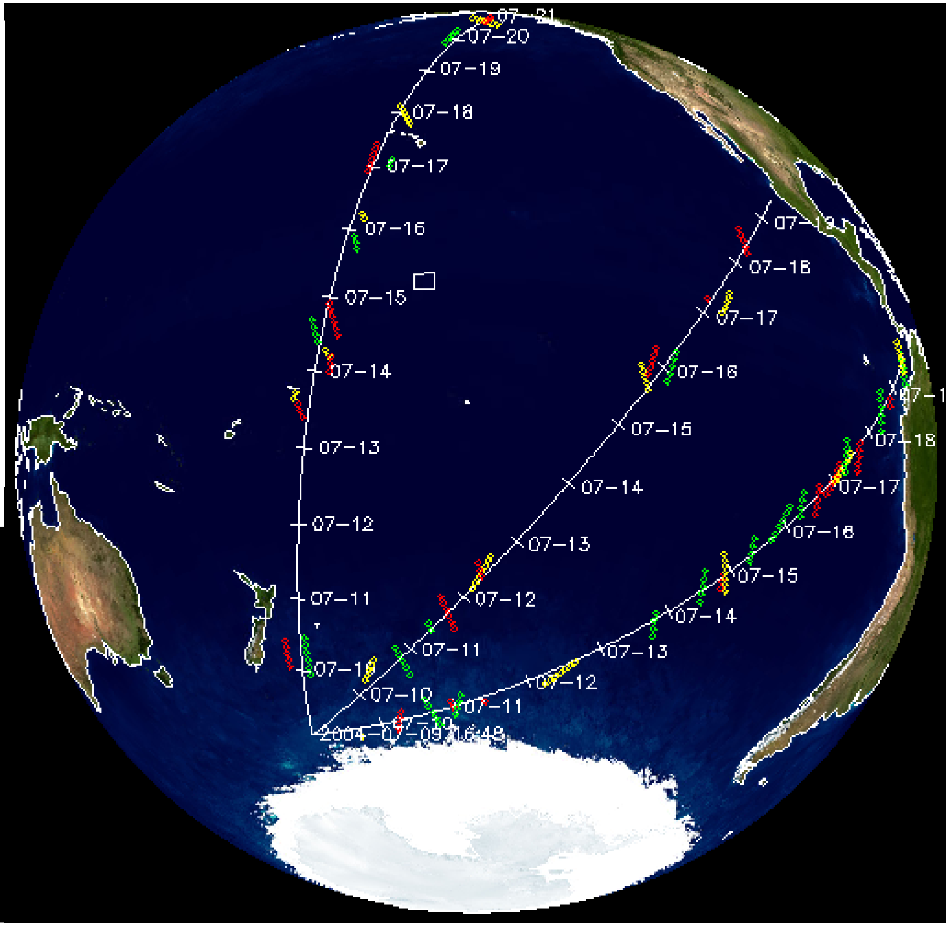
SAR is *the* swell instrument
-ERS and ENVISAT wave mode products





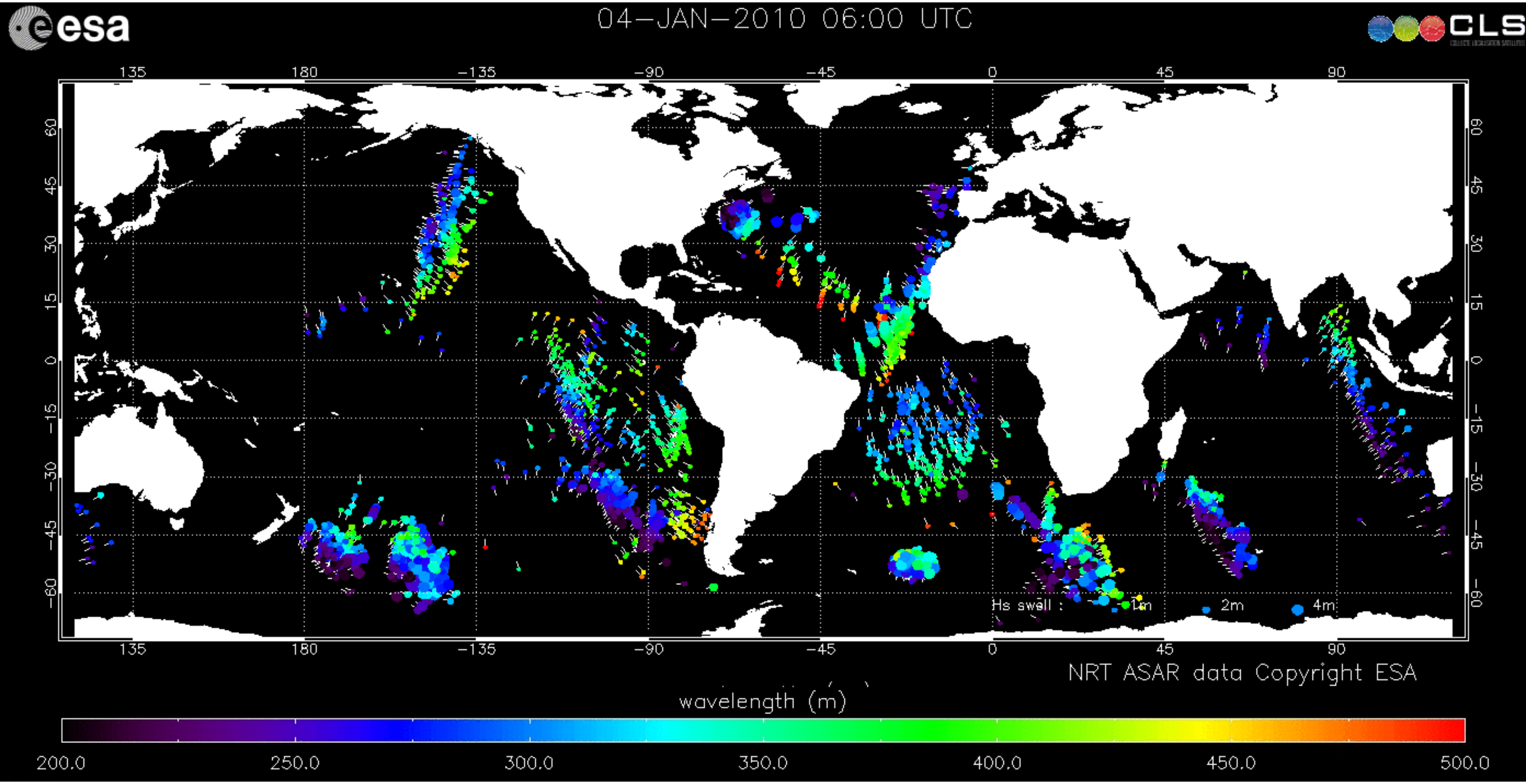
Stormwatch + wavetracker



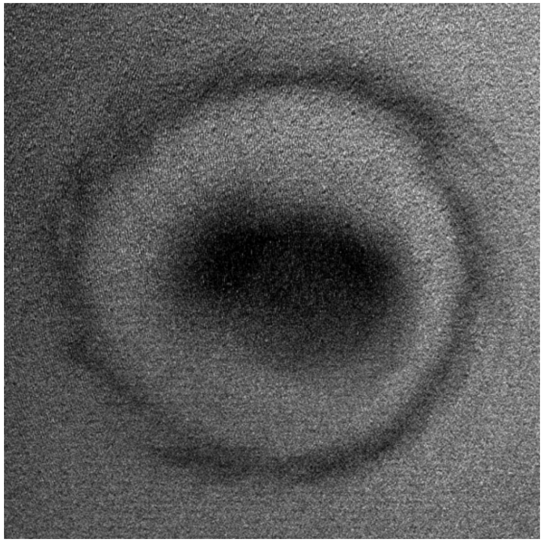


RED : ENVISAT ASAR
GREEN : ENVISAT RA2
YELLOW : JASON ALTIMETER

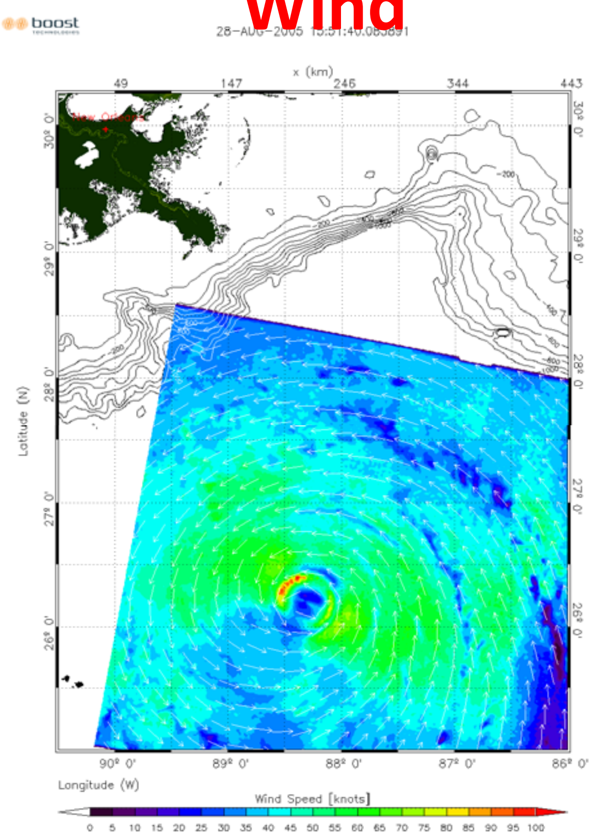
Global firework animation during 3 weeks (with significant wave height)



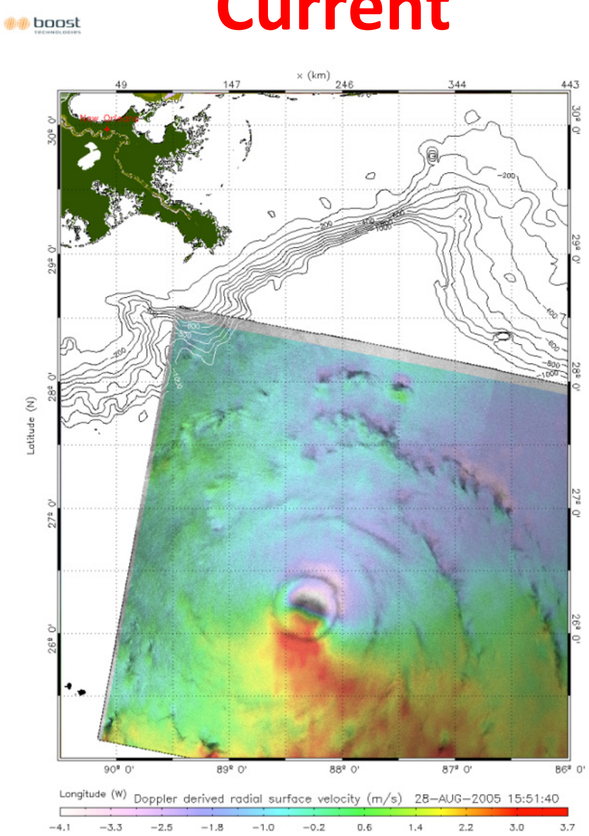
Inside Extremes:
Example of hurricane Katrine



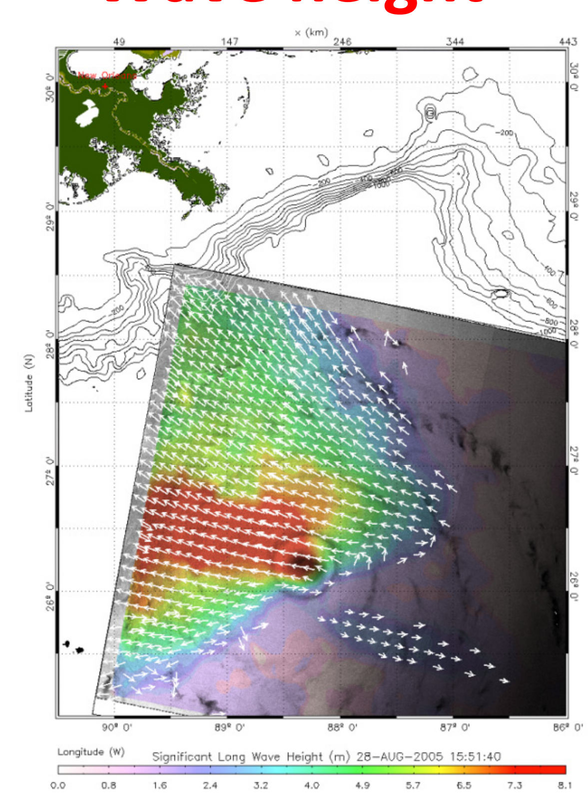
Wind

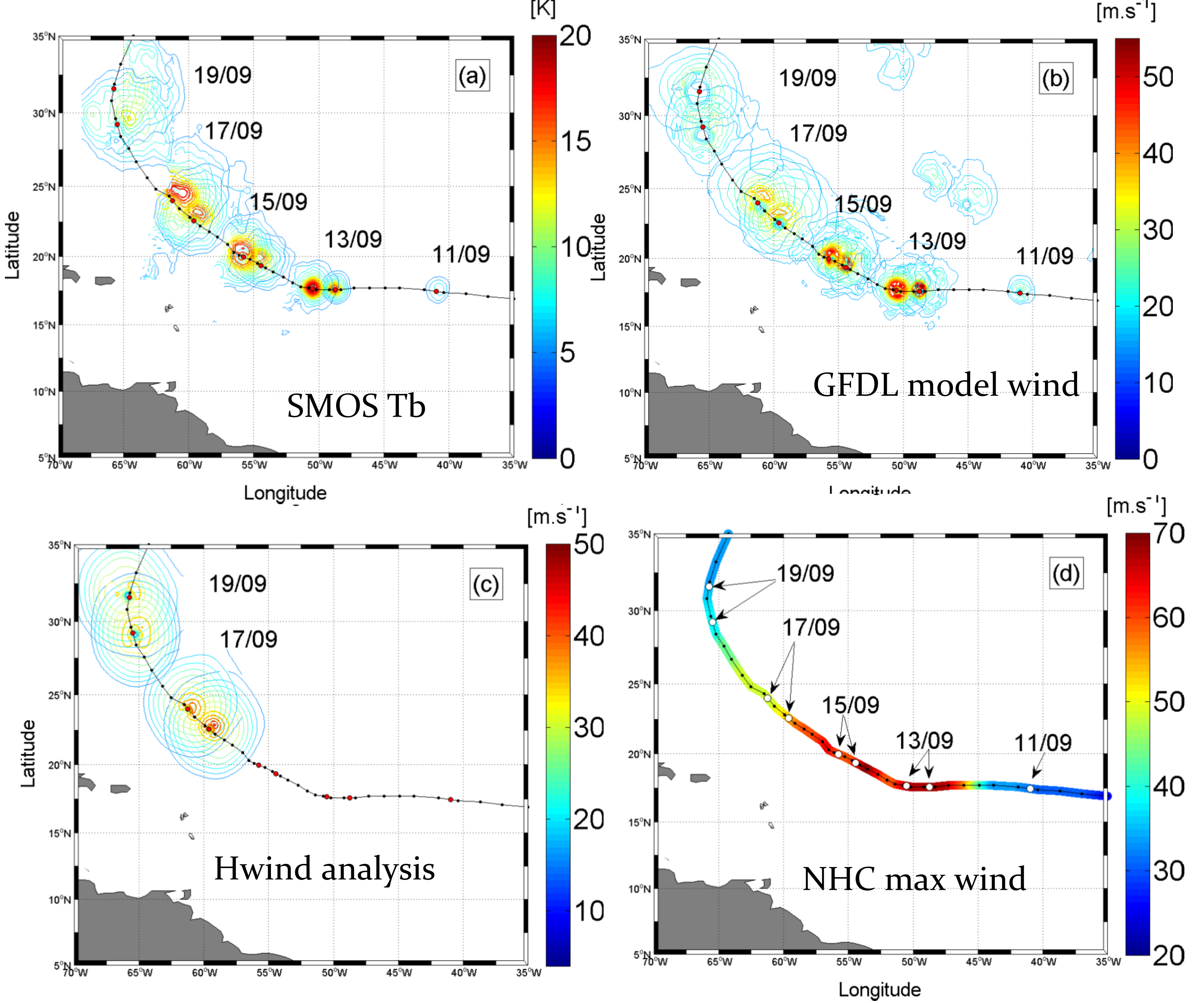


Current

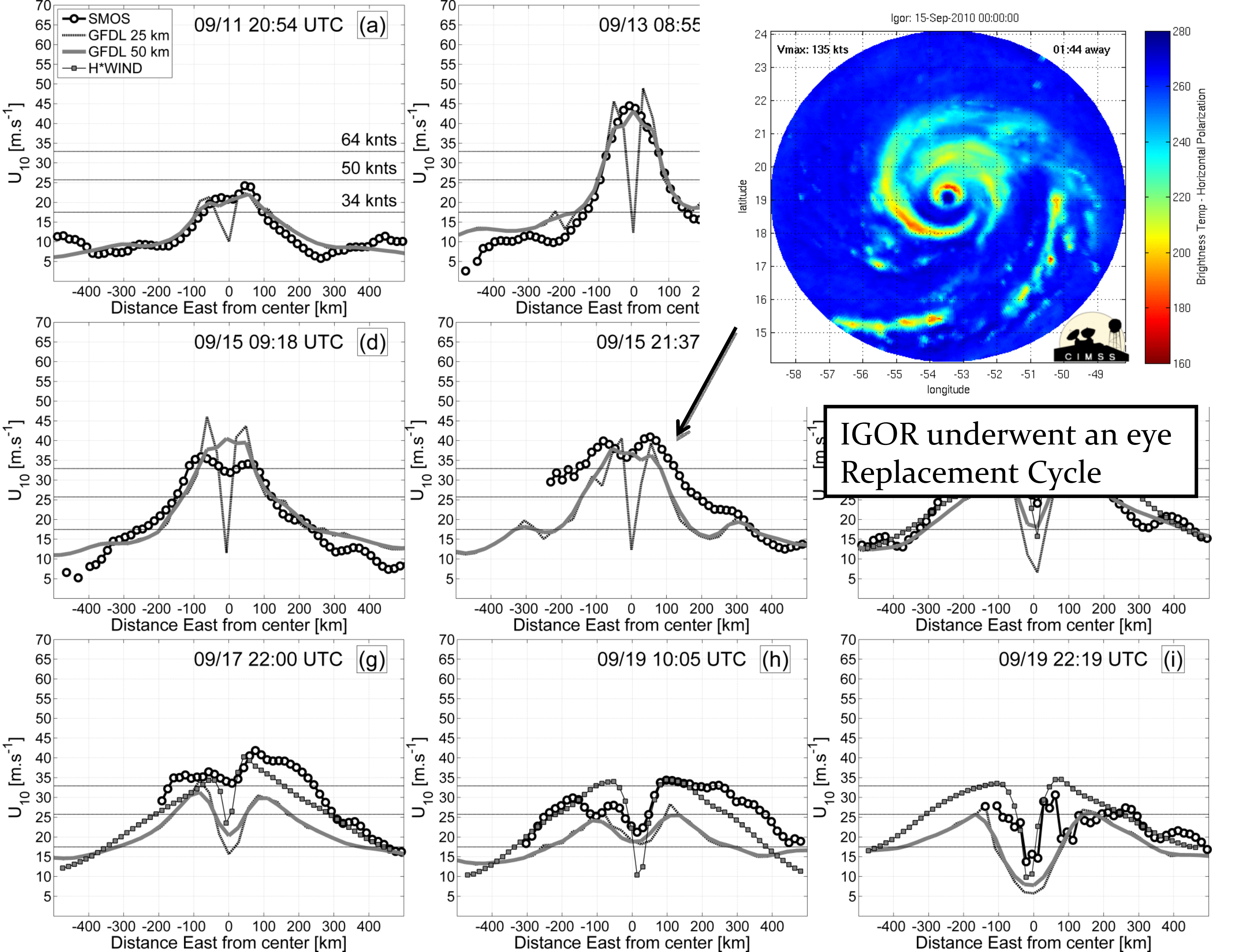


Wave height



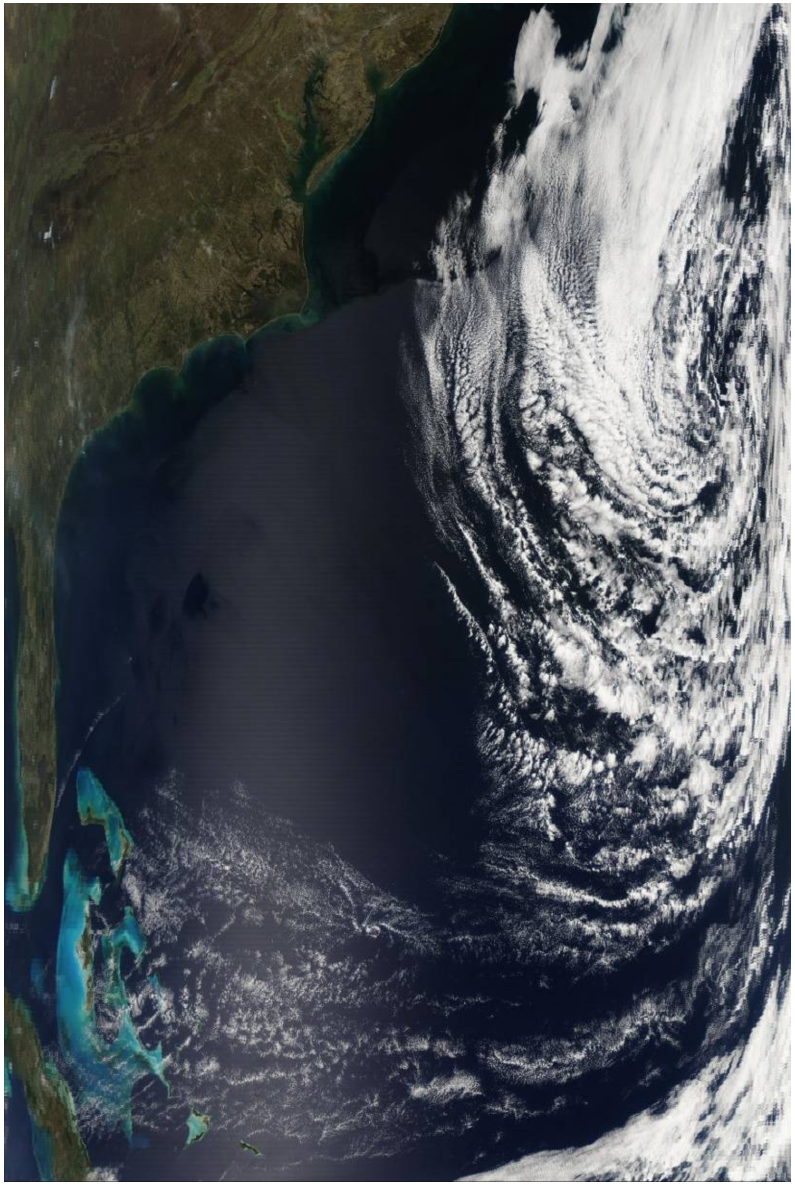


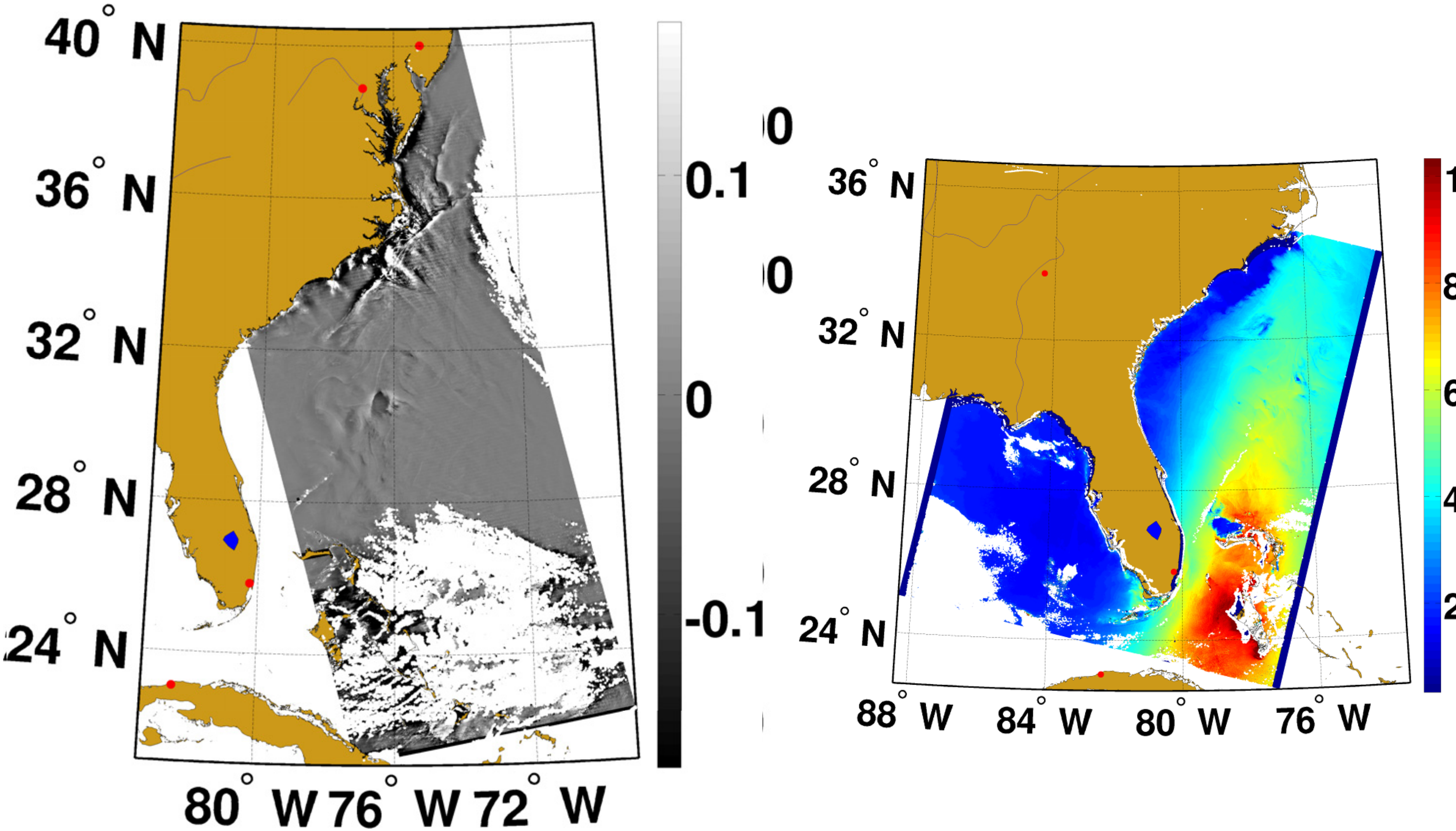
(a)
SMOS Tb
[K]
19/09
17/09
15/09
13/09
11/09
Latitude
Longitude
(b)
GFDL model wind
[m.s-1]
19/09
17/09
15/09
13/09
11/09
Latitude
(c)
Hwind analysis
[m.s-1]
19/09
17/09
Latitude
(d)
NHC max wind
[m.s-1]
19/09
17/09
15/09
13/09
11/09
Longitude


SMOS
GFDL 25 km
GFDL 50 km
H*WIND
09/11 20:54 UTC
(a)
64 knts
50 knts
34 knts
09/13 08:55
09/15 09:18 UTC
(d)
09/15 21:37
09/17 22:00 UTC
(g)
09/19 10:05 UTC
(h)
09/19 22:19 UTC
(i)
U10 [m.s-1]
Distance East from center [km]
Igor: 15-Sep-2010 00:00:00
Vmax: 135 kts
01:44 away
latitude
longitude
Brightness Temp - Horizontal Polarization
CIMSS
IGOR underwent an eye Replacement Cycle

Sea surface observations during tropical storms

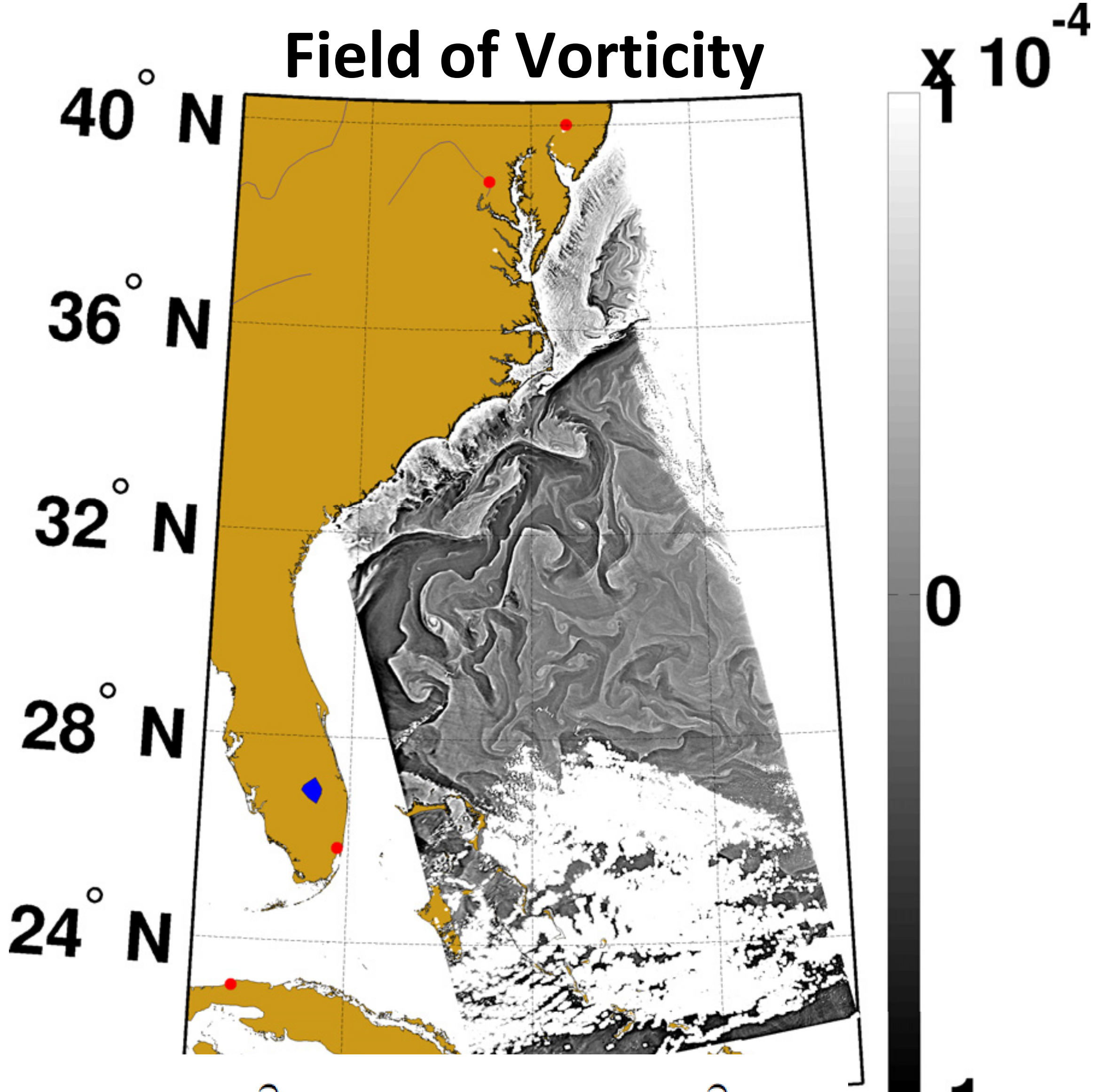
Dynamic Earth



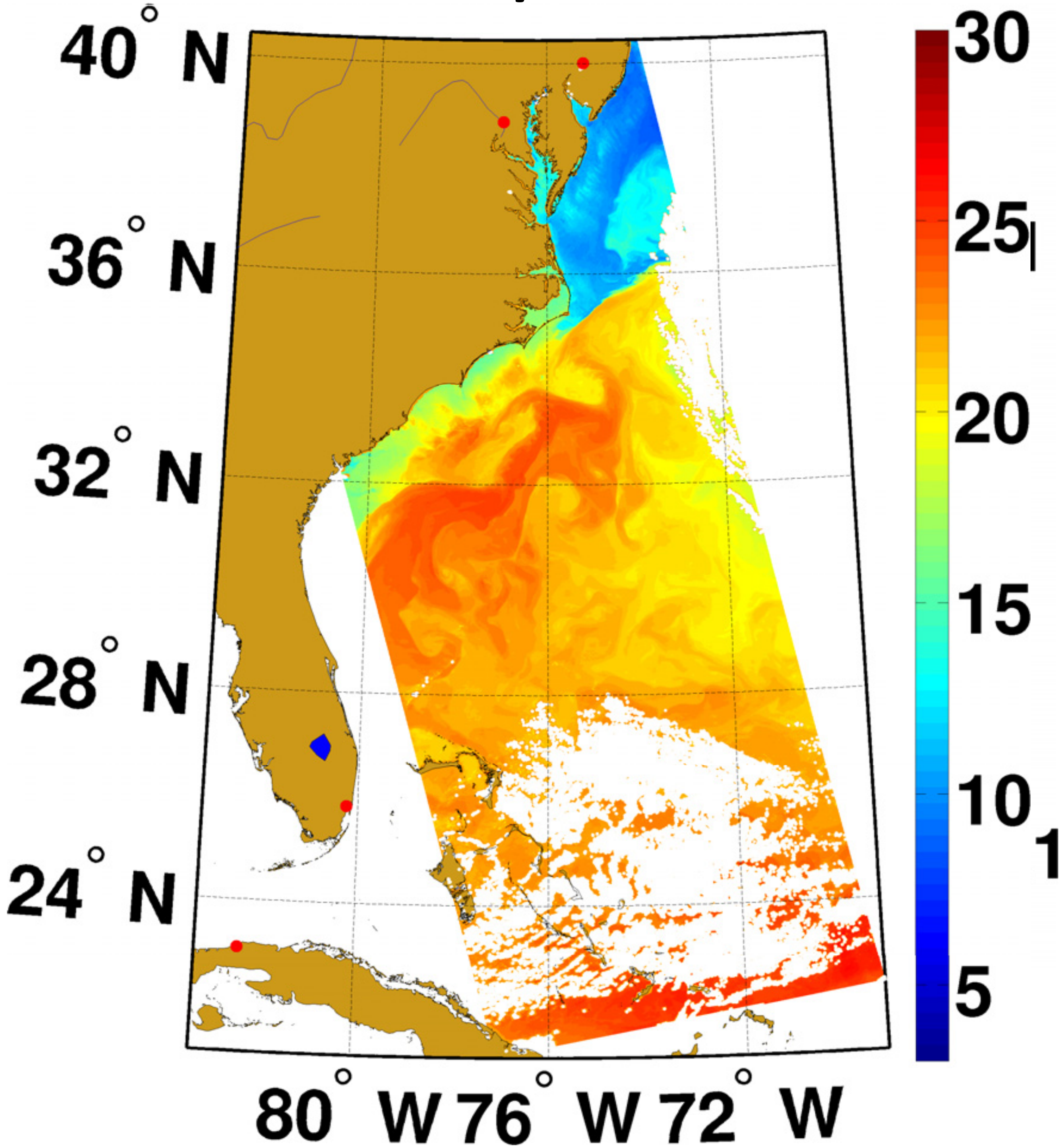
40° N
36° N
32° N
28° N
24° N
80° W
76° W
72° W
0.1
0
-0.1
36° N
32° N
28° N
24° N
88° W
84° W
80° W
76° W

Field of Vorticity

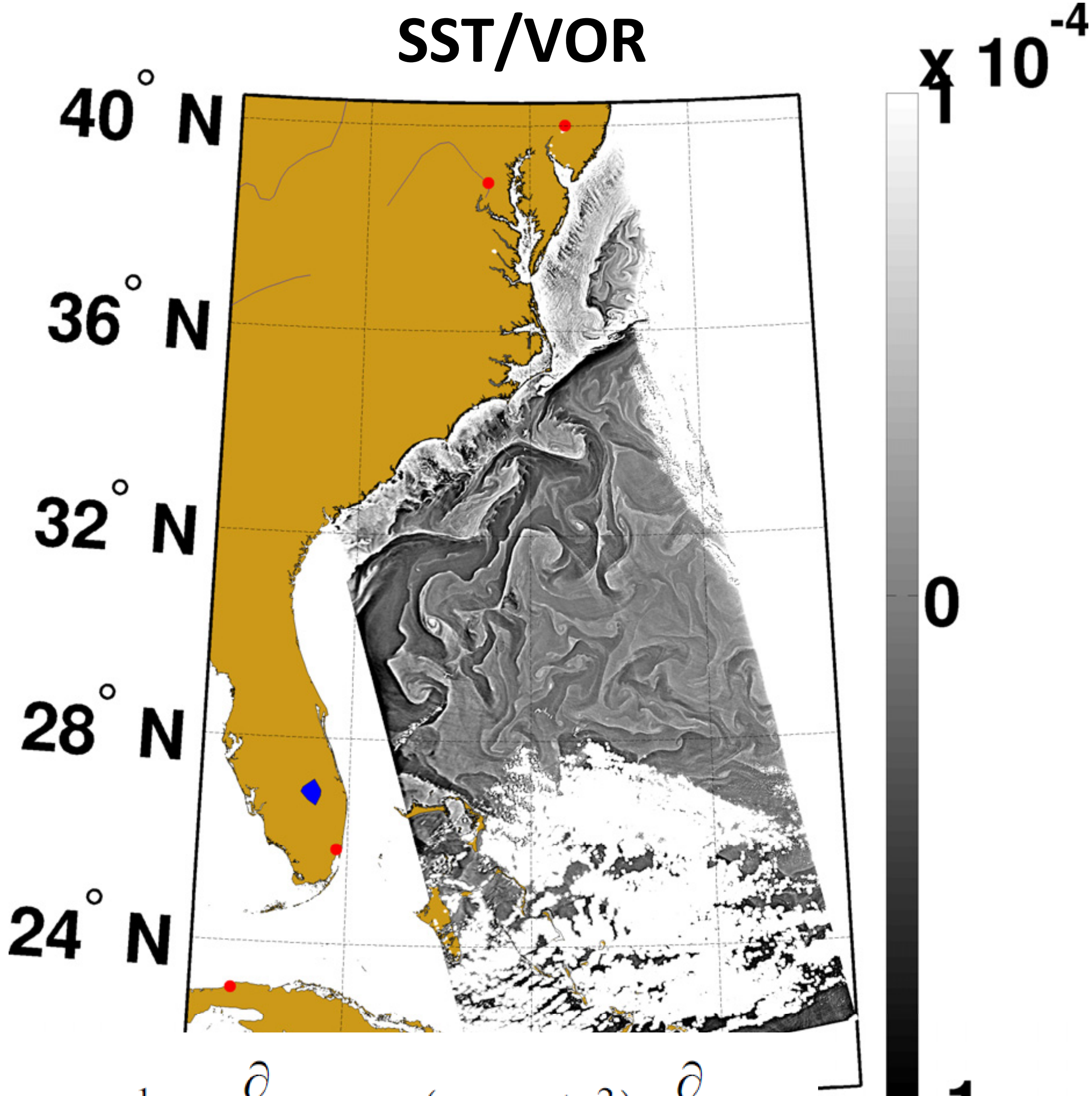


$$\nabla \cdot \boldsymbol{u} = -f^{-1} u_\beta^e \frac{\partial}{\partial x_\beta} \Omega + \left(\nu_t g \alpha / f^2\right) \frac{\partial}{\partial x_3} \Delta T$$

MSS/SST

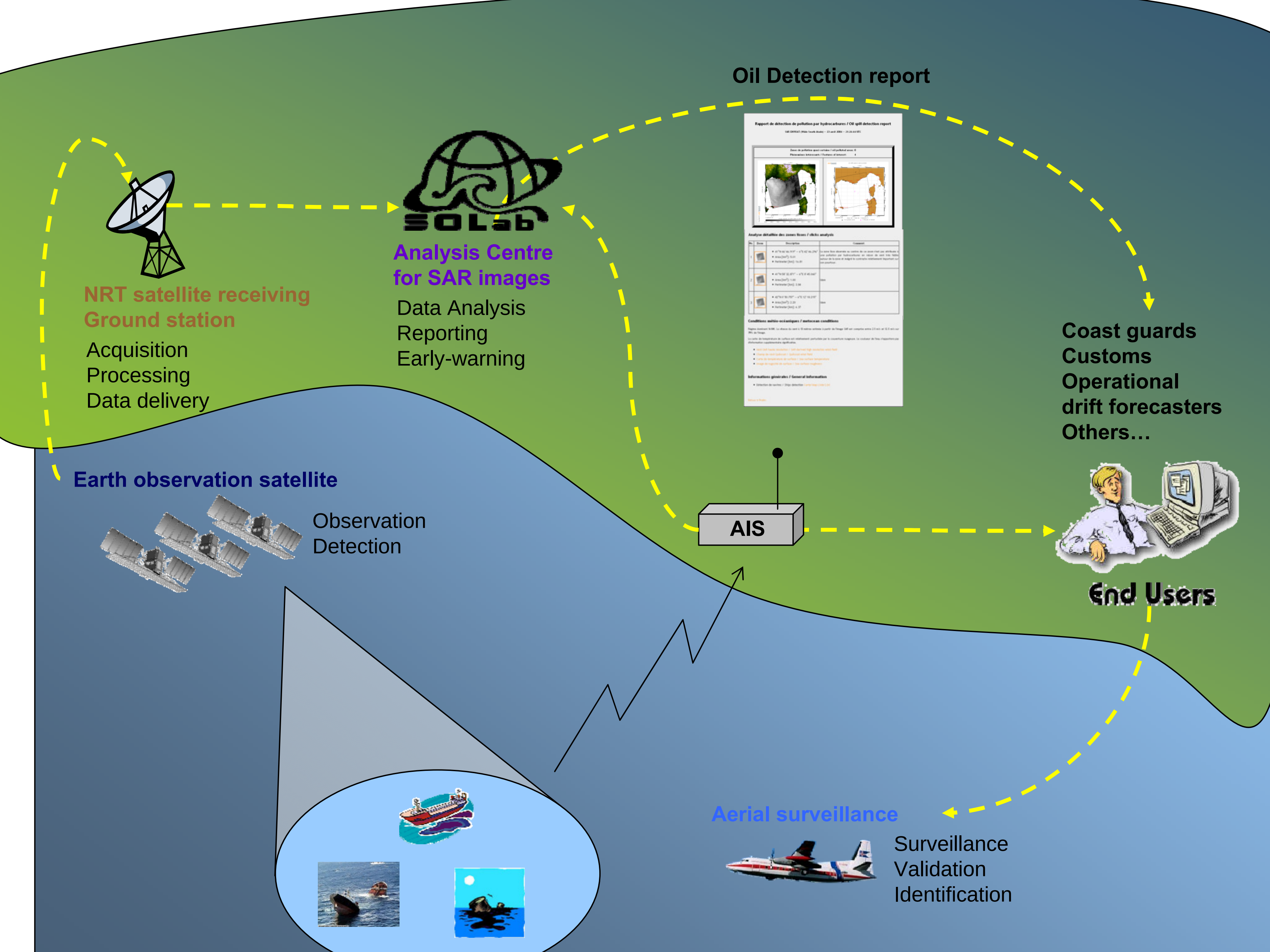


SST/VOR



$$\nabla \cdot \boldsymbol{u} = -f^{-1} u_{\beta}^{e} \frac{\partial}{\partial x_{\beta}} \Omega + \left(\nu_t g \alpha / f^2 \right) \frac{\partial}{\partial x_3} \Delta T$$

Application to Oil Spills Detection

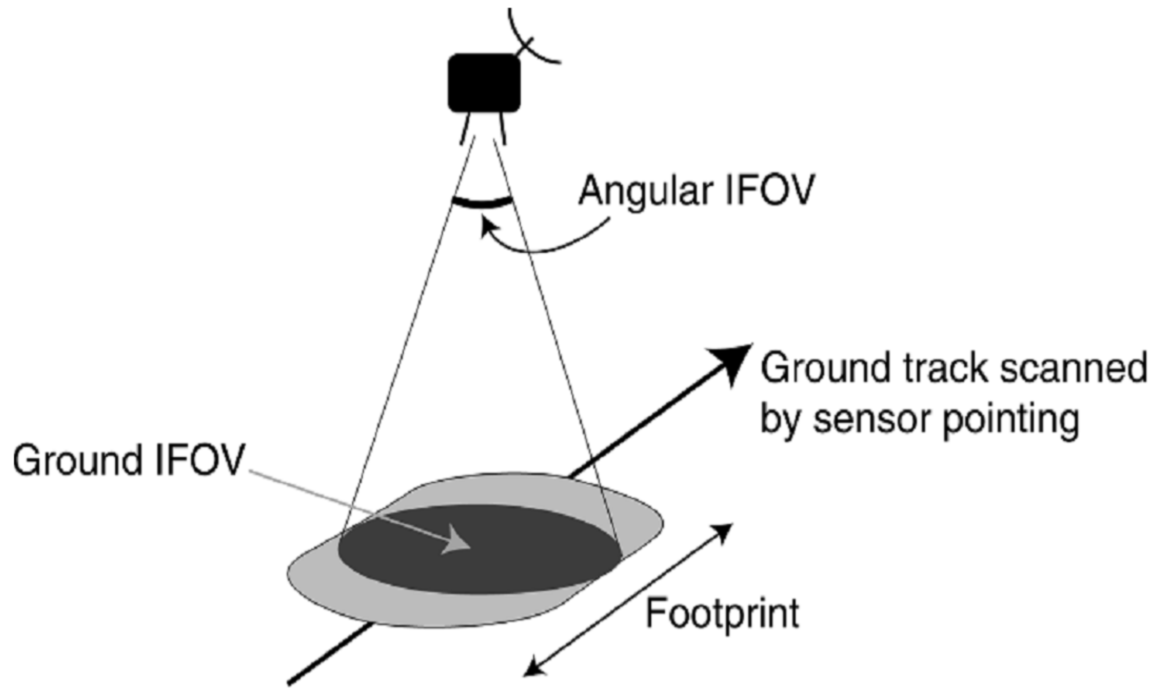

Oil Detection report
NRT satellite receiving
Ground station
Acquisition
Processing
Data delivery
Analysis Centre
for SAR images
Data Analysis
Reporting
Early-warning
Coast guards
Customs
Operational
drift forecasters
Others…
Earth observation satellite
Observation
Detection
AIS
End Users
Aerial surveillance
Surveillance
Validation
Identification

Sampling capabilities of sensors on satellites

The sampling characteristics of different satellite oceanography methods depends on the sensor-platform combination.

Creation of image-like data from point samples

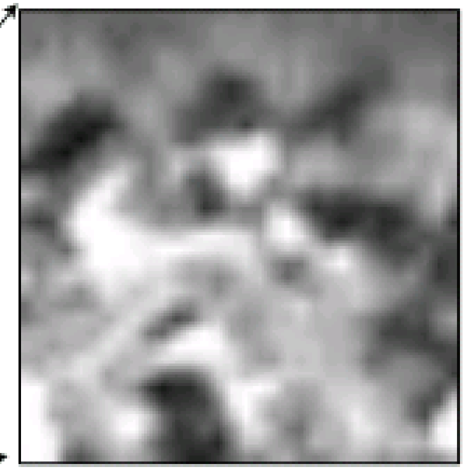
- Remotely sensed image consist of millions of individual scientific measurements.
- The footprint defines the spatial resolution of the sensor.
- Remote Sensor integrates the incoming radiation over the IFOV and the estimates of ocean properties correspond to averages over the footprint.



Sketch showing how the instantaneous field of view (IFOV) defines the measurement footprint during the sample integration time.

What is digital image?

(a)

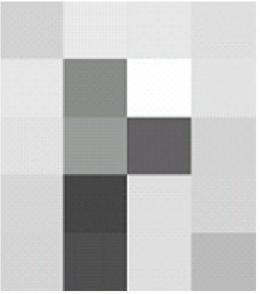


(b)

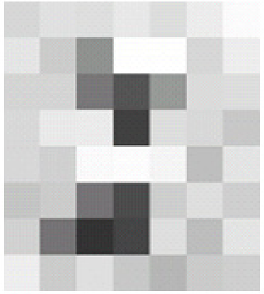
95	96	94	88	89	88	86	84	80	85	87	87
95	97	107	111	108	106	101	90	97	101	88	100
89	98	87	82	82	70	81	77	99	97	103	96
98	98	80	83	77	83	78	86	97	106	118	119
119	118	107	94	104	100	94	96	90	99	84	87
82	79	79	76	95	94	122	98	119	110	80	70
82	93	97	98	96	111	124	124	126	122	112	109
116	110	102	91	88	89	85	89	90	88	82	83
107	118	126	123	120	123	108	84	94	102	133	120
113	116	117	127	132	124	129	122	125	117	103	93
83	76	79	94	104	100	99	90	136	145	143	128
131	139	115	100	92	101	128	136	124	101	86	98
112	126	143	118	139	116	106	91	75	70	69	94
112	113	112	95	152	157	157	147	128	127	120	112
111	115	126	138	122	85	53	40	58	97	133	117

(c)

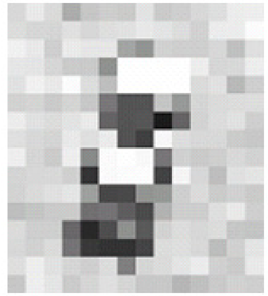
SPATIAL (GEOMETRIC) RESOLUTION



1.6 m resolution

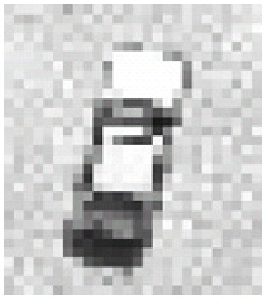


0.8 m

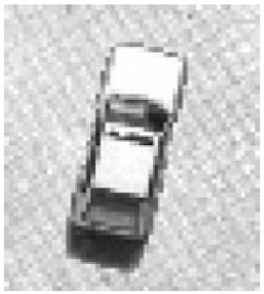


0.4 m

Geometric resolution =
pixel size



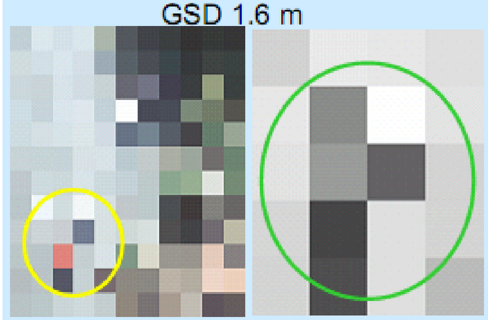
0.2 m



0.1 m

0.05 m

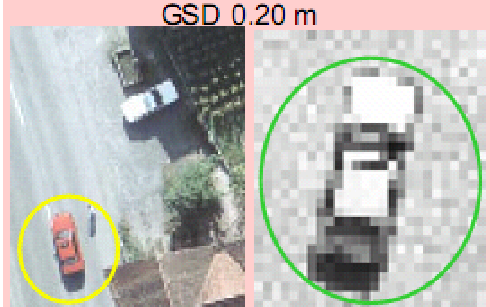
GSD 1.6 m



Size of *detectable* object
GSD x 3

Car size ~ 4.5m - 5m
GSD 1.6 m x 3 = 4.8 m

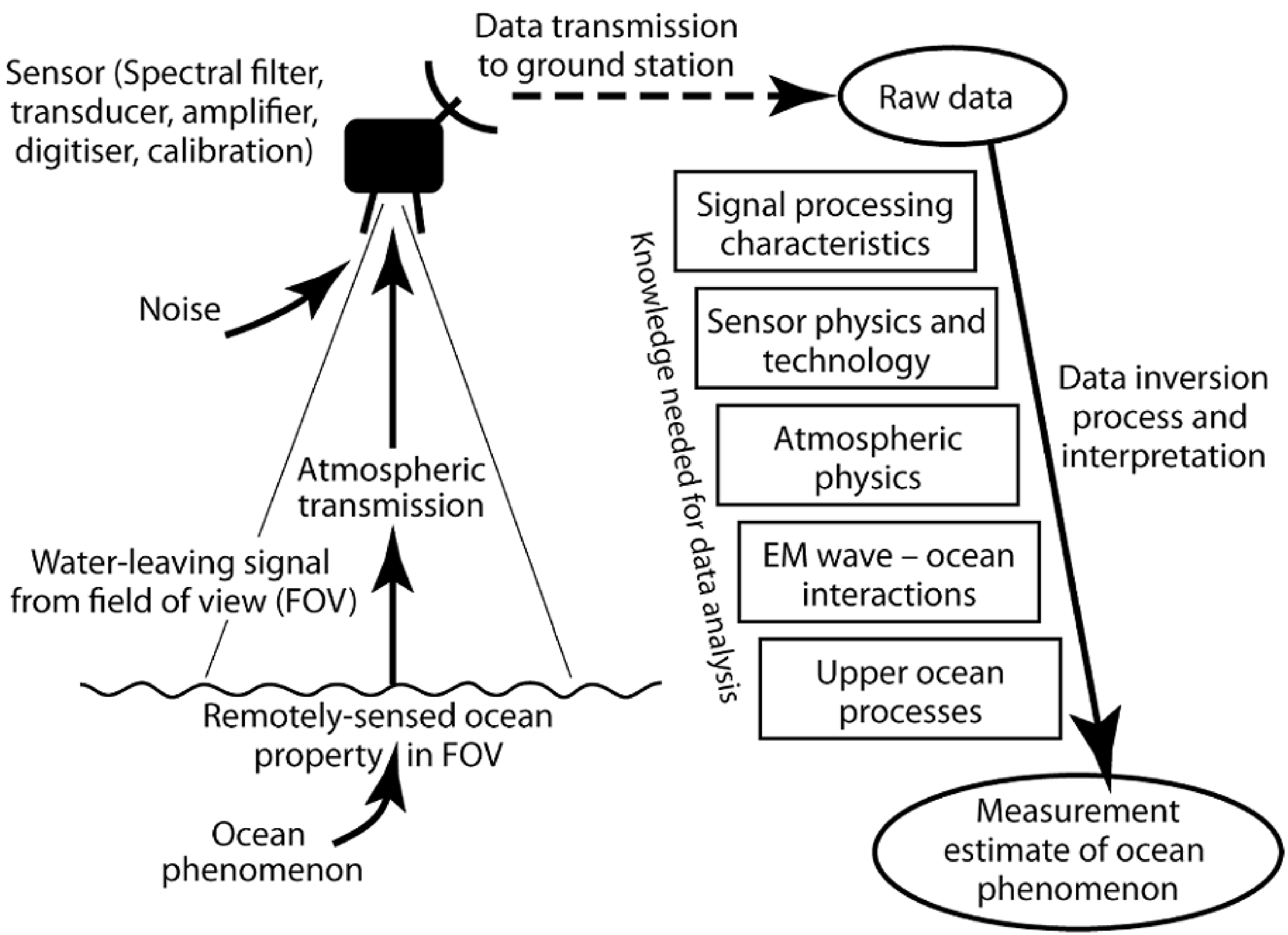
GSD 0.20 m



Size of *interpretable* object
GSD x 24

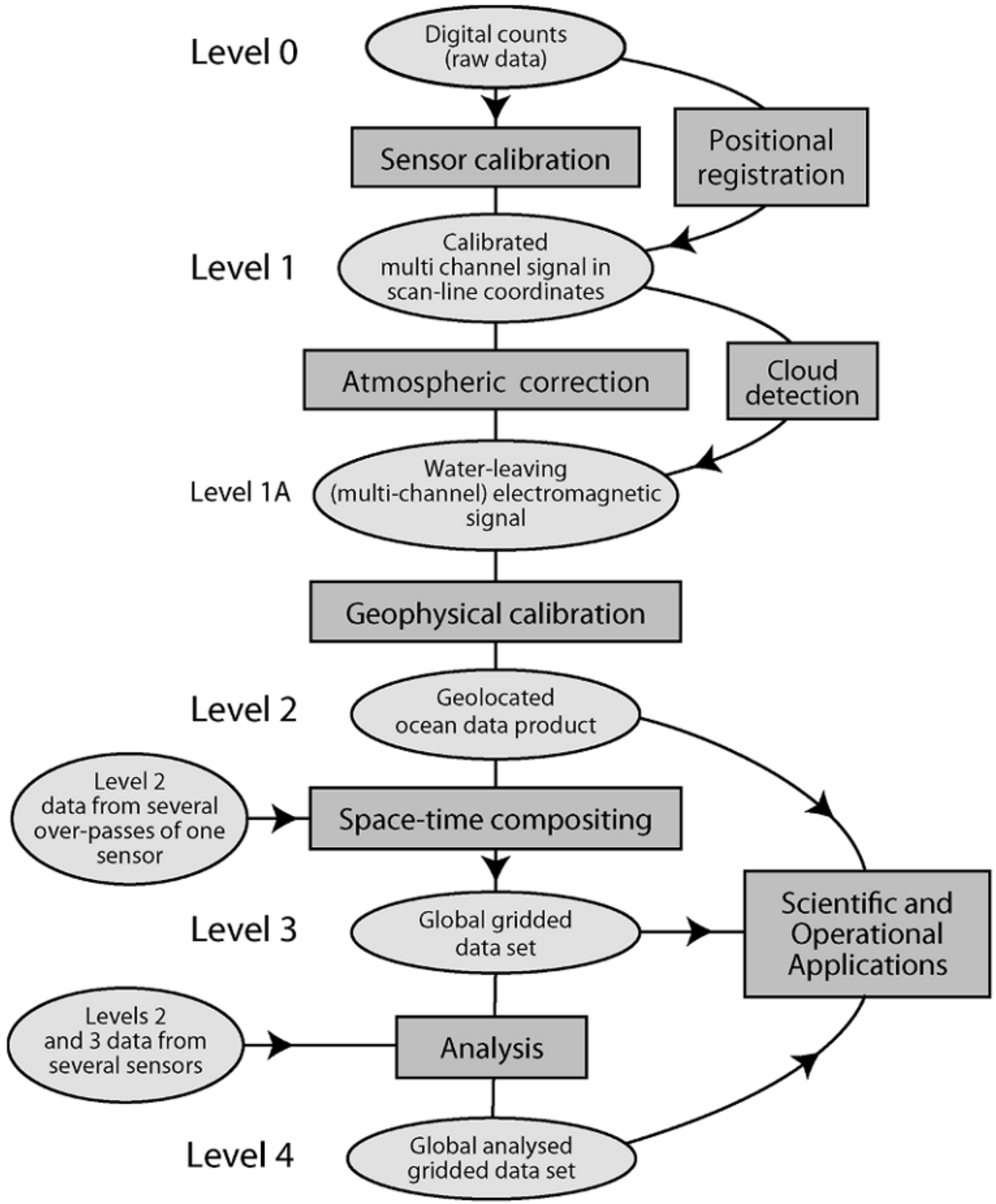
Car size ~ 4.5 - 5m
GSD 0.2 m x 24 = 4.8 m

Schematic of information flow in ocean remote sensing



Main steps of satellite data processing

Data-processing tasks to convert raw satellite data into ocean products



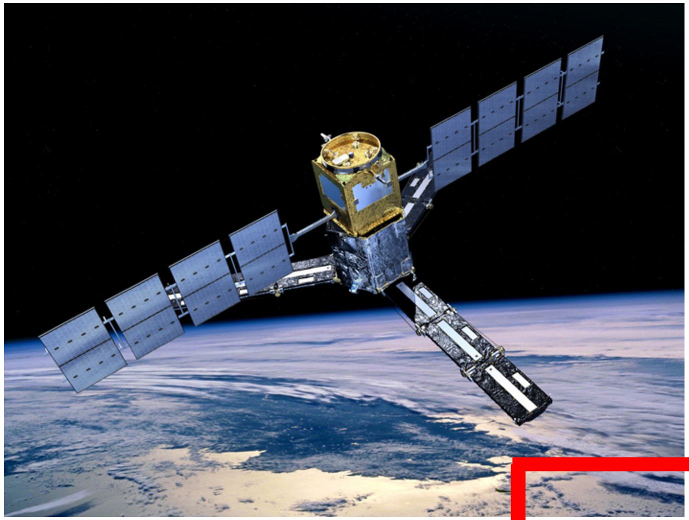
Levels of satellite data products

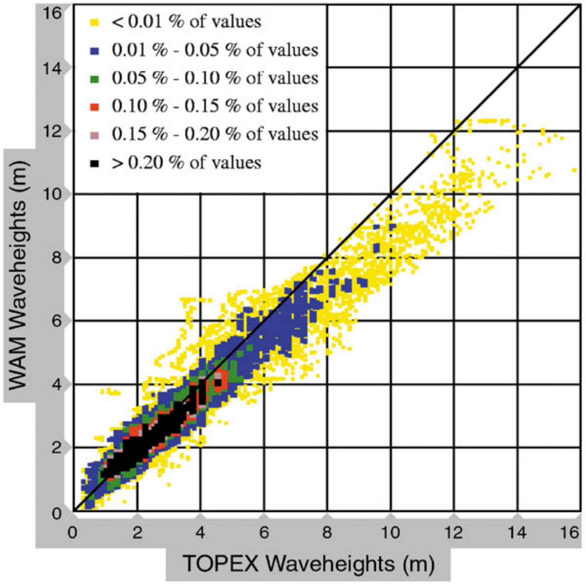
Level	*Description of product*
0	Raw data received from the satellite, in standard binary form.
1	Image data in sensor co-ordinates. Individual calibrated channels, of measurements made at the satellite.
1.5 (or 1a)	In special cases, level 1 data with atmospheric correction applied.
2	Atmospherically corrected and calibrated image dataset of water-leaving radiance or derived oceanic variable. Geolocated, but normally presented in image co-ordinates.
3	Composite images of derived ocean variable resampled onto standard map base. Averaged in space and time from several overpasses of level 2 data. Derived from a single sensor. May contain gaps.
4	Image representing an ocean variable averaged within each cell of a space-time grid, for which gaps at level 3 have been filled by data analysis including interpolation. The analysis may merge several level 2 and/or level 3 datasets from a number of sensors and may also use *in situ* observations or model output.

Sensor calibration

- RS instruments need to be calibrated if their measurements are to lead to reliable quantitative estimates of geophysical parameters
- Various levels – from relative to absolute
- Last demanding – to calibrate within specific overpass or image
- More demanding – to establish the consistency of measurements by particular sensor throughout its lifetime.
- Absolute – enables measurements of one instrument to be compared with data from another sensor measuring the same parameter
- Most satellite systems are calibrated before the launch
- Specifically important is to identify change in sensor performance when it is working/ operating simultaneously or nearby to other sensors on satellite platform
- The ultimate purpose of calibration is also to attach the error estimates to the quantification of geophysical parameters measured from space
- Post launch calibration – use of calibrated targets on the ground to test the algorithm performance, geolocation accuracy,…

Validation





< 0.01 % of values
0.01 % - 0.05 % of values
0.05 % - 0.10 % of values
0.10 % - 0.15 % of values
0.15 % - 0.20 % of values
> 0.20 % of values
WAM Waveheights (m)
TOPEX Waveheights (m)
0 2 4 6 8 10 12 14 16

Cloud detection

•Sensors using the visible and IR parts of the spectrum cannot view the sea surface through cloud.

•Next task after applying the sensor calibration is to detect which pixels are obscured by cloud and which are clear.

•The purpose of cloud detection is to flag pixels as cloudy (1) or cloud-free (0). Sometimes more complex flagging is used – 0-3.

•**Flagging a pixel as cloudy is equivalent to stating that it contains no useful information.**

•Simplest CD – to define a threshold or range indicating cloud.

•Problem – pixels partly covered by clouds.

•If multiple channels are available – we can use e.g. optical channel to flag the clouds for the thermal channel.

•Another option – to use spatial structure of the image to indicate the cloud.

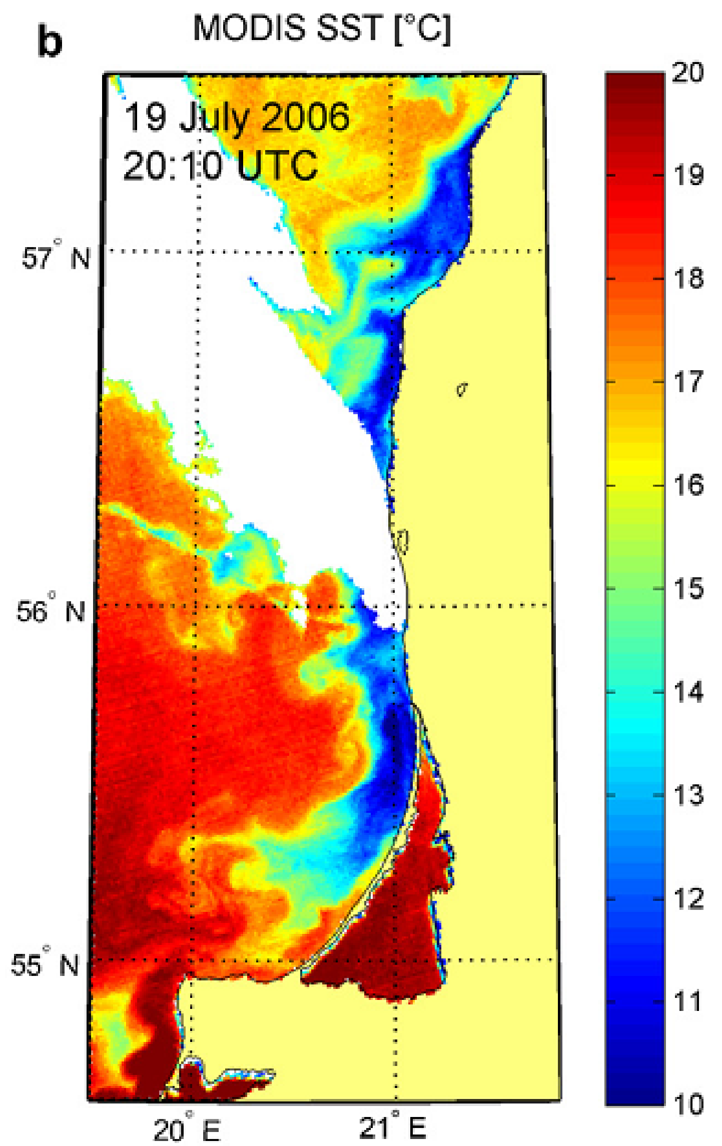


Image file formats

File type	File name extension	Bits per pixel	Compression	Other information
Simple binary (flat file)	dat bin out	Undefined	None	
Bitmap	bmp	8, 16, 24	None	The simplest format for Microsoft Windows systems.
Graphics interchange format	gif	8	~50%	Loss-less compression. Its use is now restricted by licensing issues.
Tagged image file format	tiff or tif	8, 16, 24	None or ~10%	Loss-less, good choice for master copies.
Portable network graphics	png	8, 16, 24	Up to 35%	Loss-less in original form, intended replacement for gif and tiff.
Joint picture expert group	jpg or jpeg	Variable; less than original	Up to 97%	Very lossy. Creates an approximation of an image based on what the human eye perceives.
Hierarchical data format Network common data format	hdf cdf	These are flexible formats that may contain many images in a single large file. They consist of metadata (defining the number type, size, variable name, text description of the data records etc.) followed by the data records.		

Image file formats and their handling

•Most file formats contain at the beginning some ***metadata*** – the information needed to unpack the images from the numbers stored in the file.

•Sometimes metadata has some additional info on the location and acquisition time of the image, the level of processing (L0-L4), or the scaling factor.

•Important to distinguish image file formats with **fundamental quantitative data** from those formats used to transmit information purely as **pictures** (JPEG, etc).

E.g. when the multiple channel data are displayed as colour composite – the picture format simply codes for the resulting colour at each pixel and loses the discrete info contained in three individual spectral channels.

•Special software is needed to extract such information and access to the numbers: ERDAS (commercial), UNESCO Win BILKO (open source), …

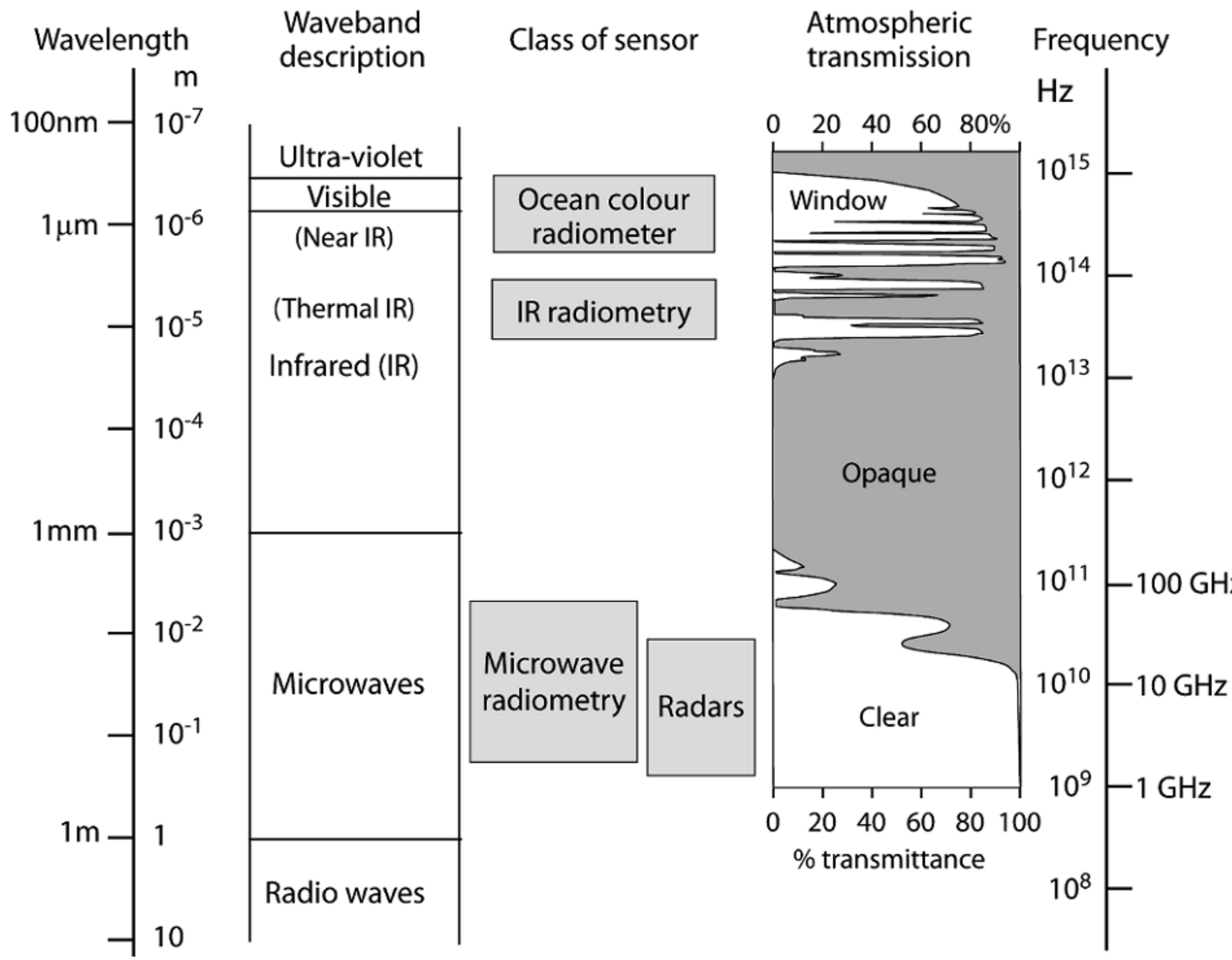
If you need to apply some algorithms with utilizing some mathematical functions and repeatedly for many images – programming languages such as Fortran, C, or matrix-based software as IDL, Matlab, etc.

Main parameters measured from Space:

- Color
- Radiant temperature
- Roughness
- Height

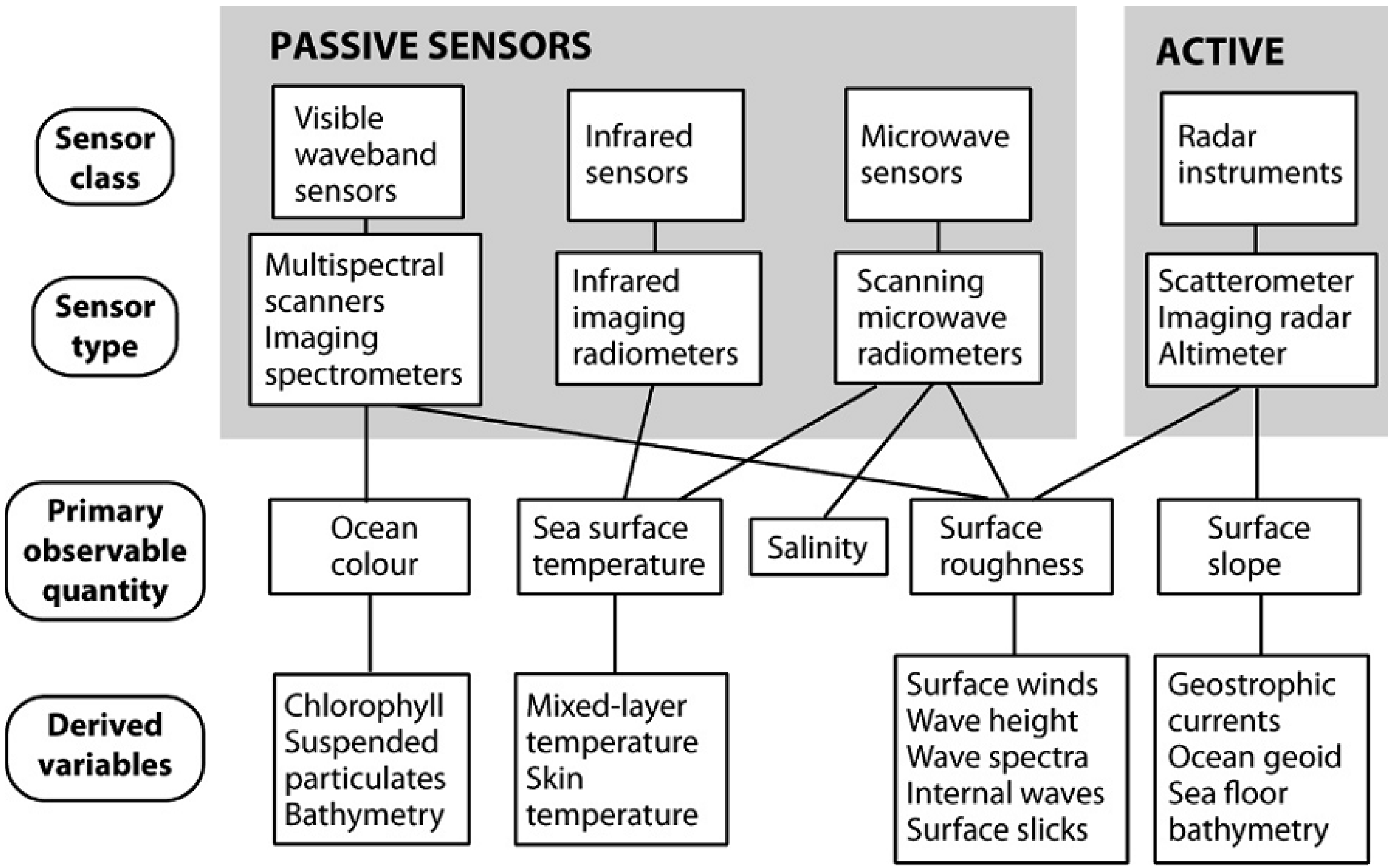
Main sensor types used in remote sensing

- All sensors employed on ocean-observing satellites use electromagnetic (EM) radiation to view the sea.
- The capability of each sensor to measure particular ocean parameter depends on which part of EM spectrum they use



The electromagnetic spectrum, showing the regions exploited by typical remote sensing instruments

Main sensor types used in remote sensing



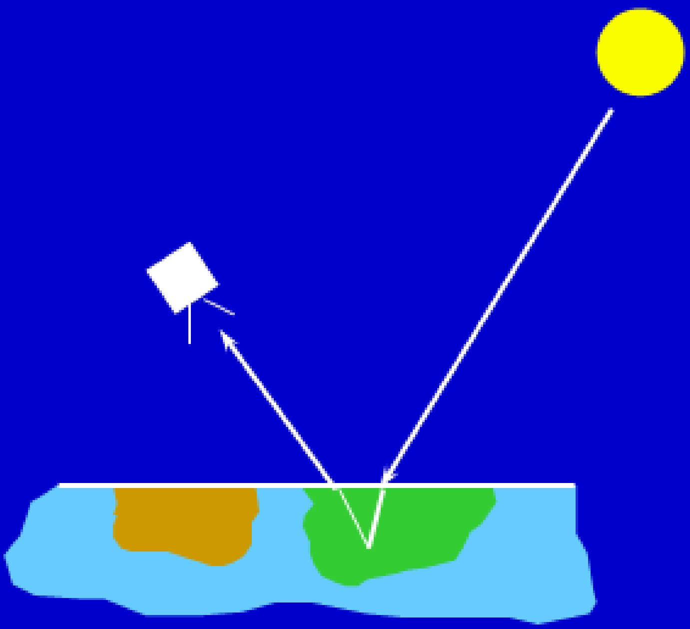
Schematic illustrating the different remote-sensing methods and classes of sensors used in satellite oceanography, along with their applications (from Robinson, 2004).

Sensor Types: 1
Passive Sensors - solar radiation

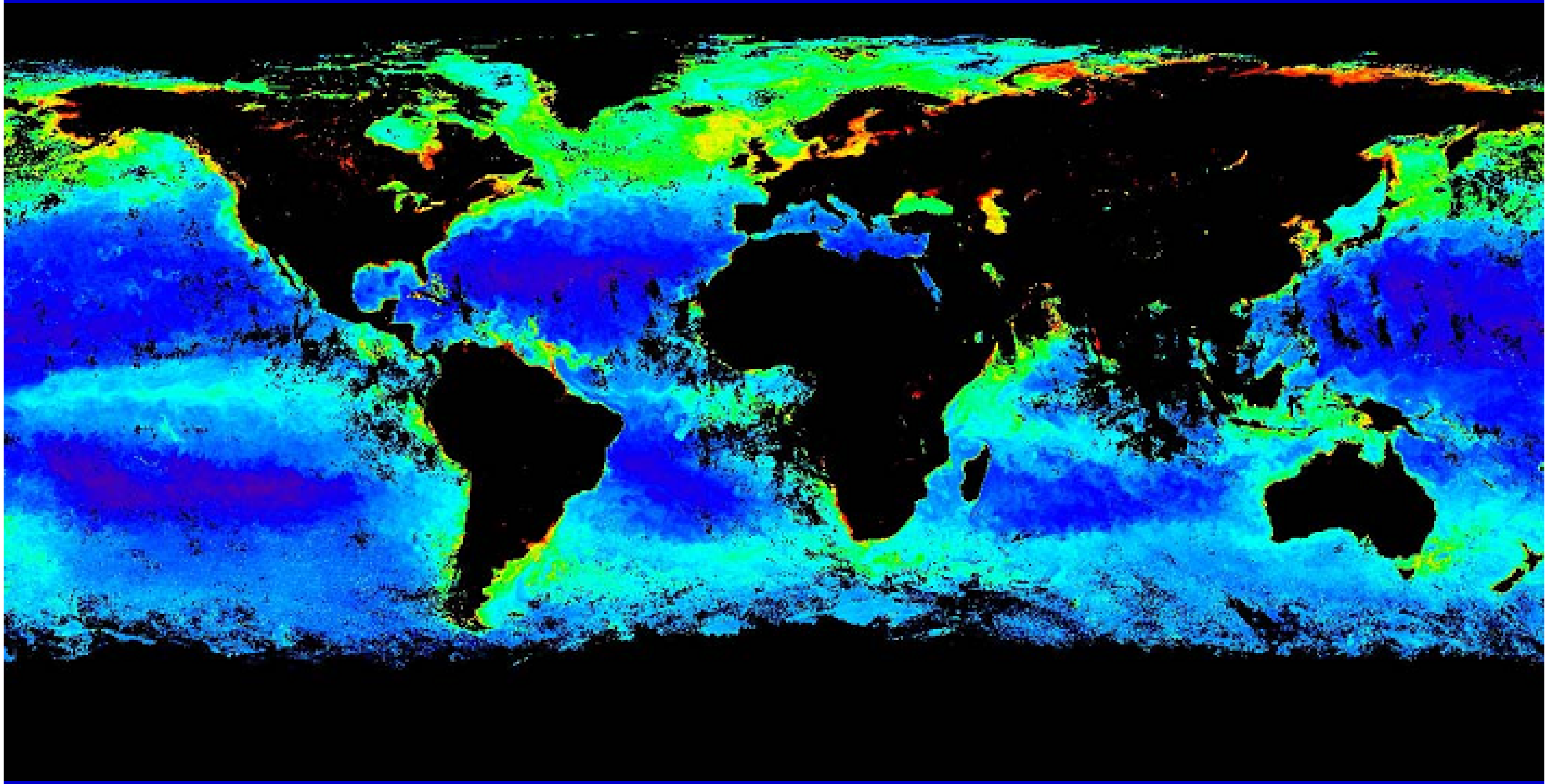
- Use visible and near infra-red wavelengths
- Multispectral (detects colour)
- Scanning (generates images)

- Obstructed by clouds
- Corrupted by the atmosphere

- Measures water properties which colour the sea
- Also measures light reflected at the surface
- Near infra-red light does not penetrate the sea



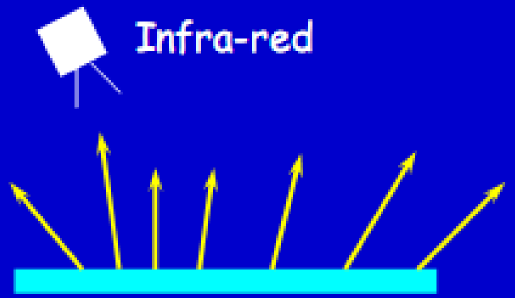
Satellite ocean datasets, 1: from ocean colour



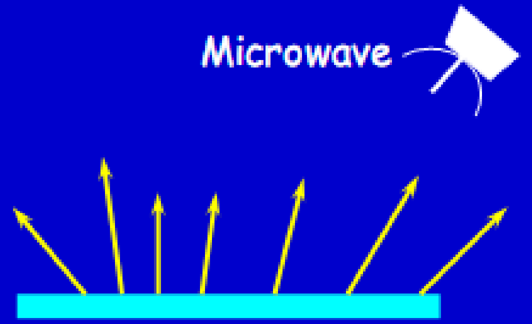
Global distribution of surface chlorophyll concentration derived from the SeaWiFS sensor during 28th August to 4th September 2004

Sensor Types: 2
Passive sensors - emitted radiation

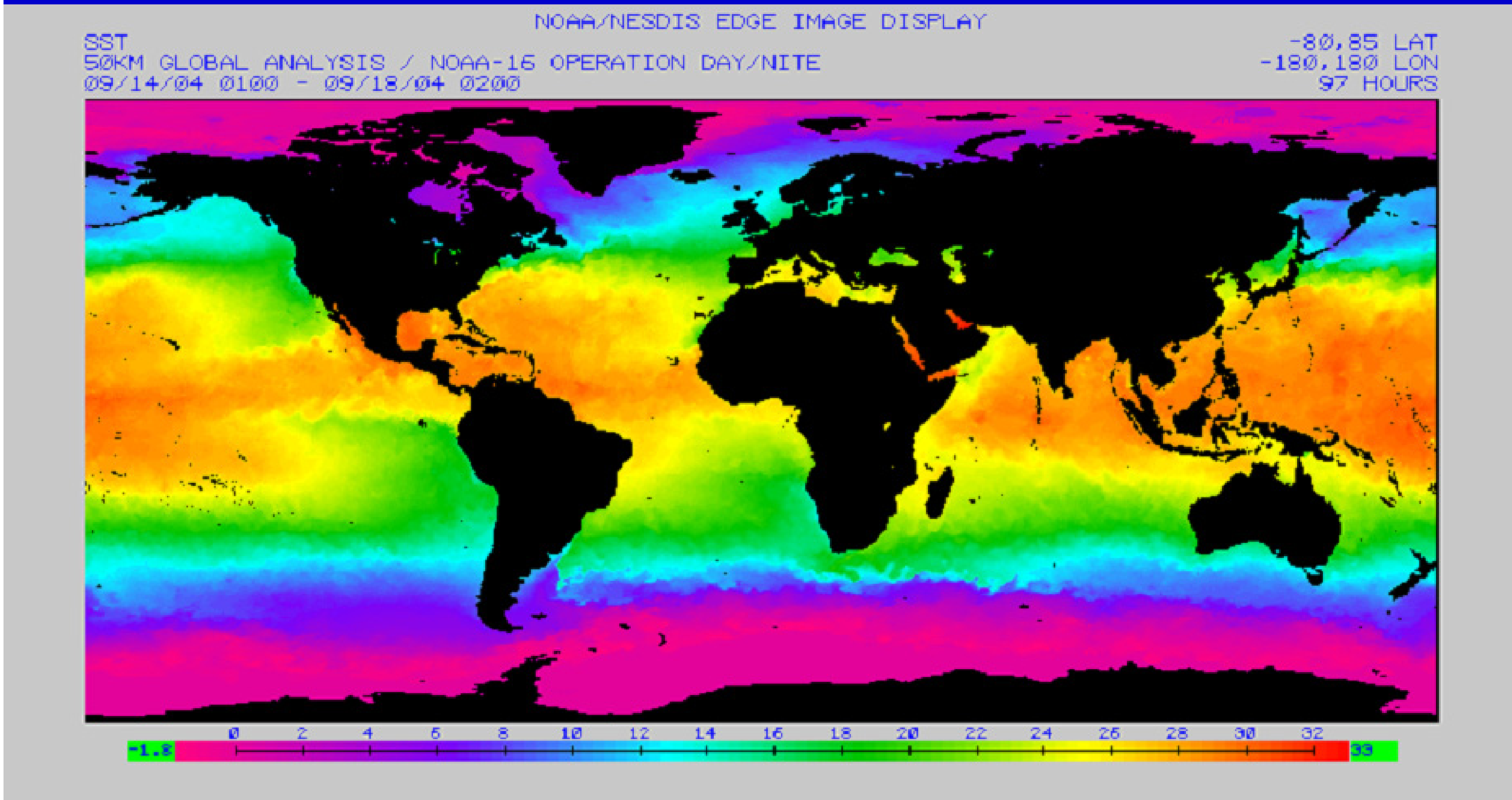
- Thermal Infra-red radiometers
- Multiple wavebands
- Obstructed by clouds
- Requires atmospheric correction
- Measure sea surface temperature



- Microwave radiometers
- Multiple frequency bands
- See through clouds
- Almost independent of atmosphere
- Measure sea surface temperature
- Measure surface roughness
- Measure salinity ?

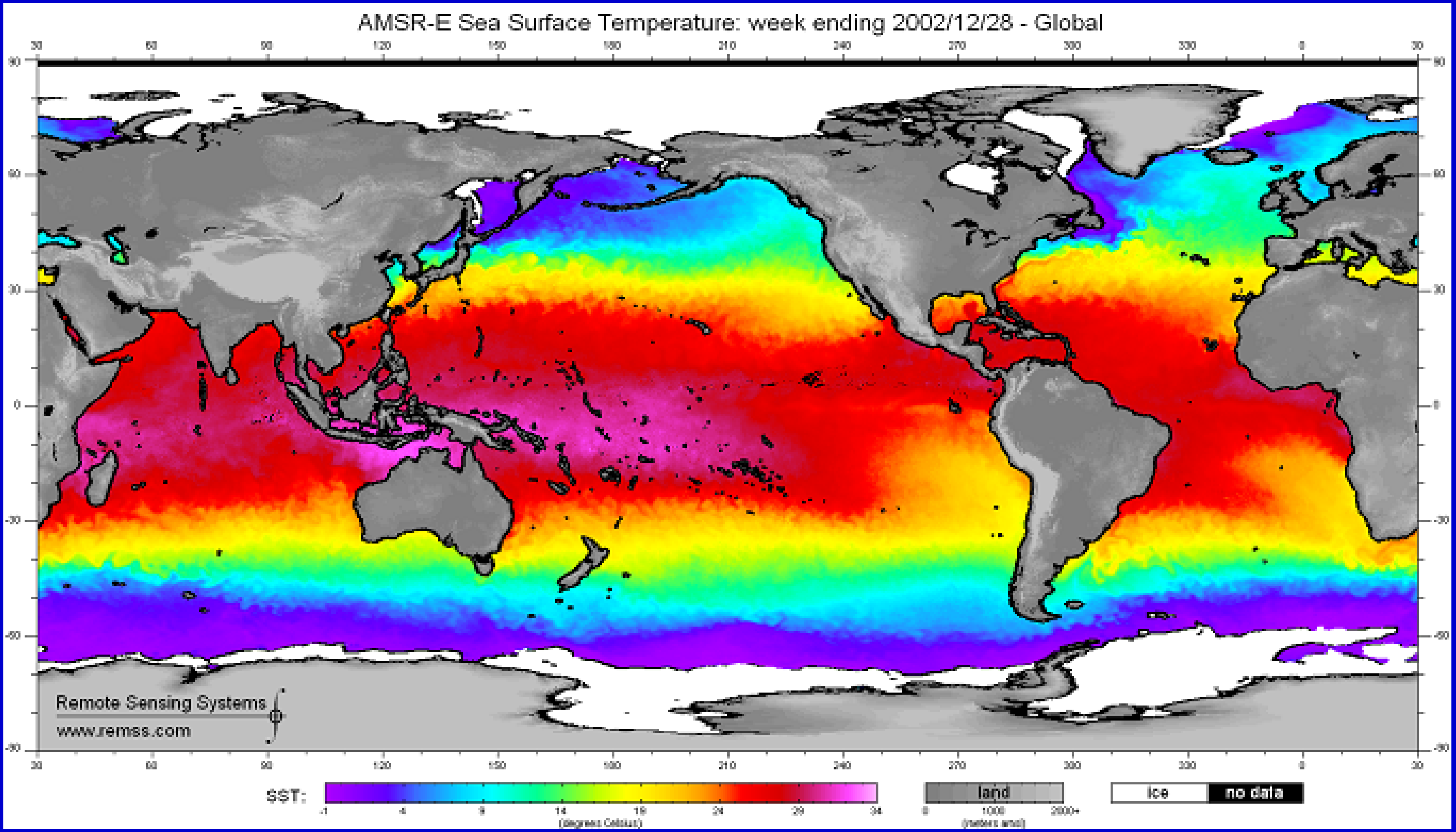


Satellite ocean datasets, 2: from infrared sensors



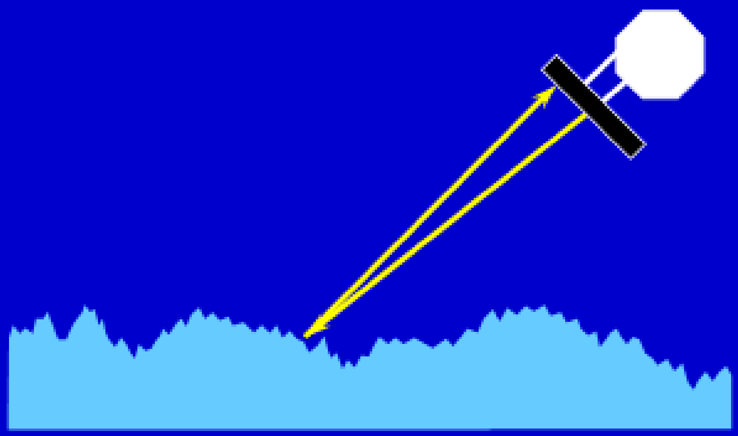
Global Sea Surface Temperature (SST) distribution derived from the NOAA AVHRR sensors during 14th to 18th September 2004

Satellite ocean datasets, 3: from microwave radiometers



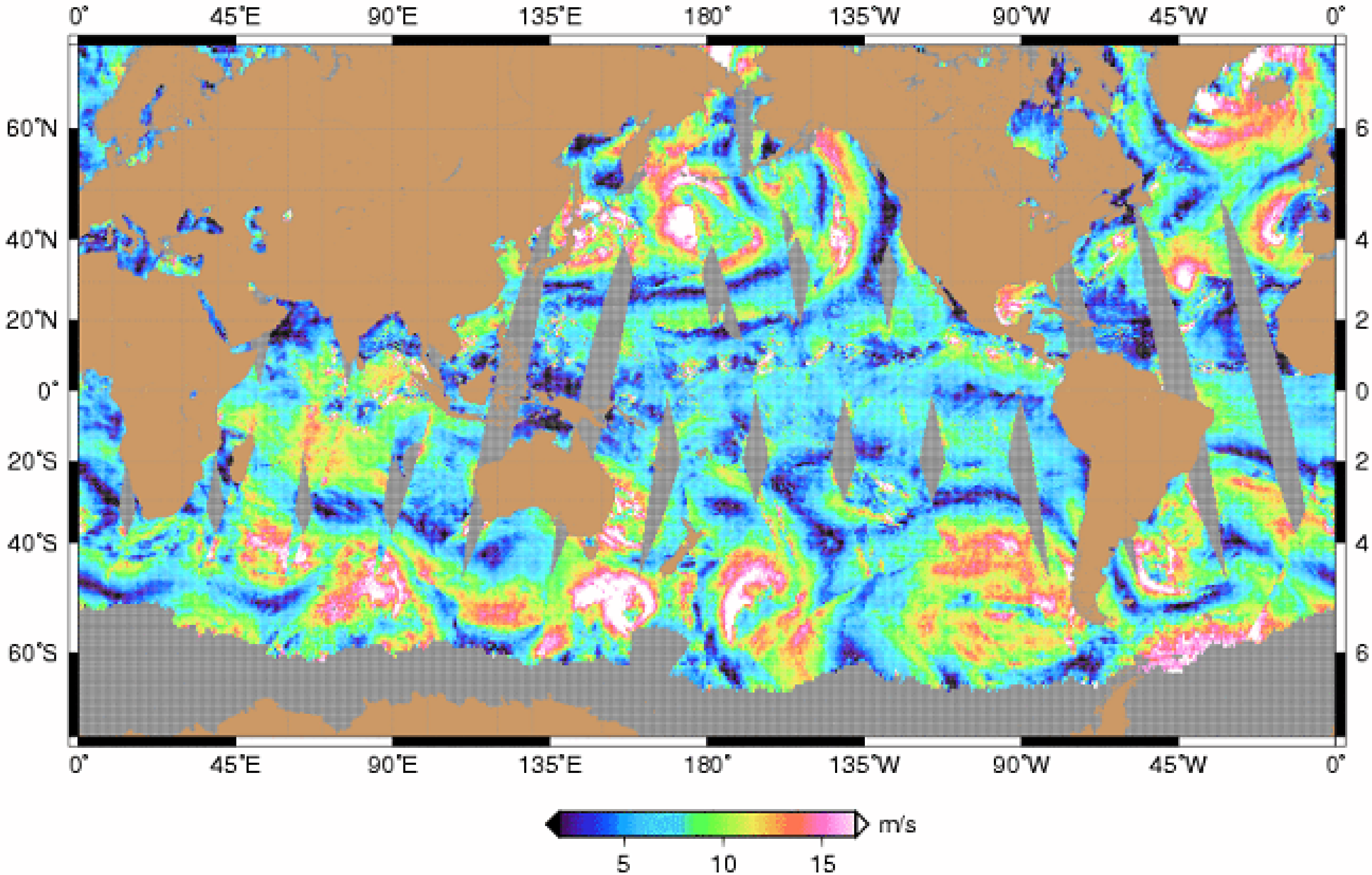
Sensor Types: 3. Active Sensors

- Emit radar pulse obliquely
- Scatterometer (course resolution)
- Measure wind speed and direction
- Imaging radar – SAR (fine resolution)
- Detect surface roughness patterns



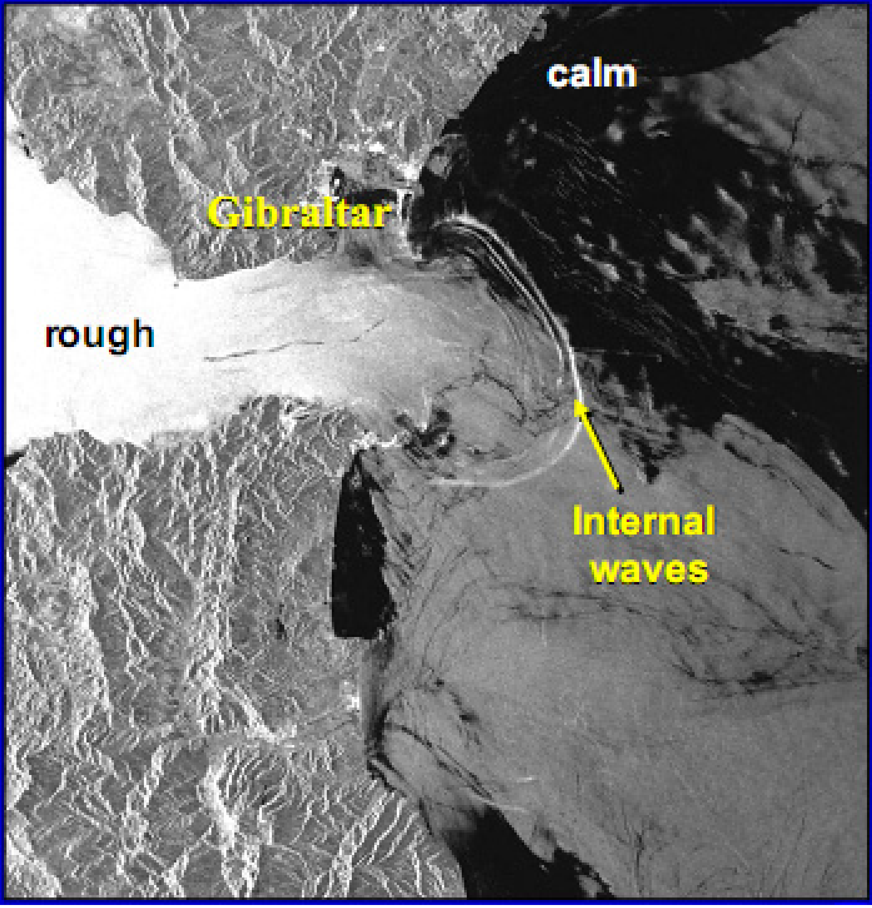
Ocean Surface Wind Speed

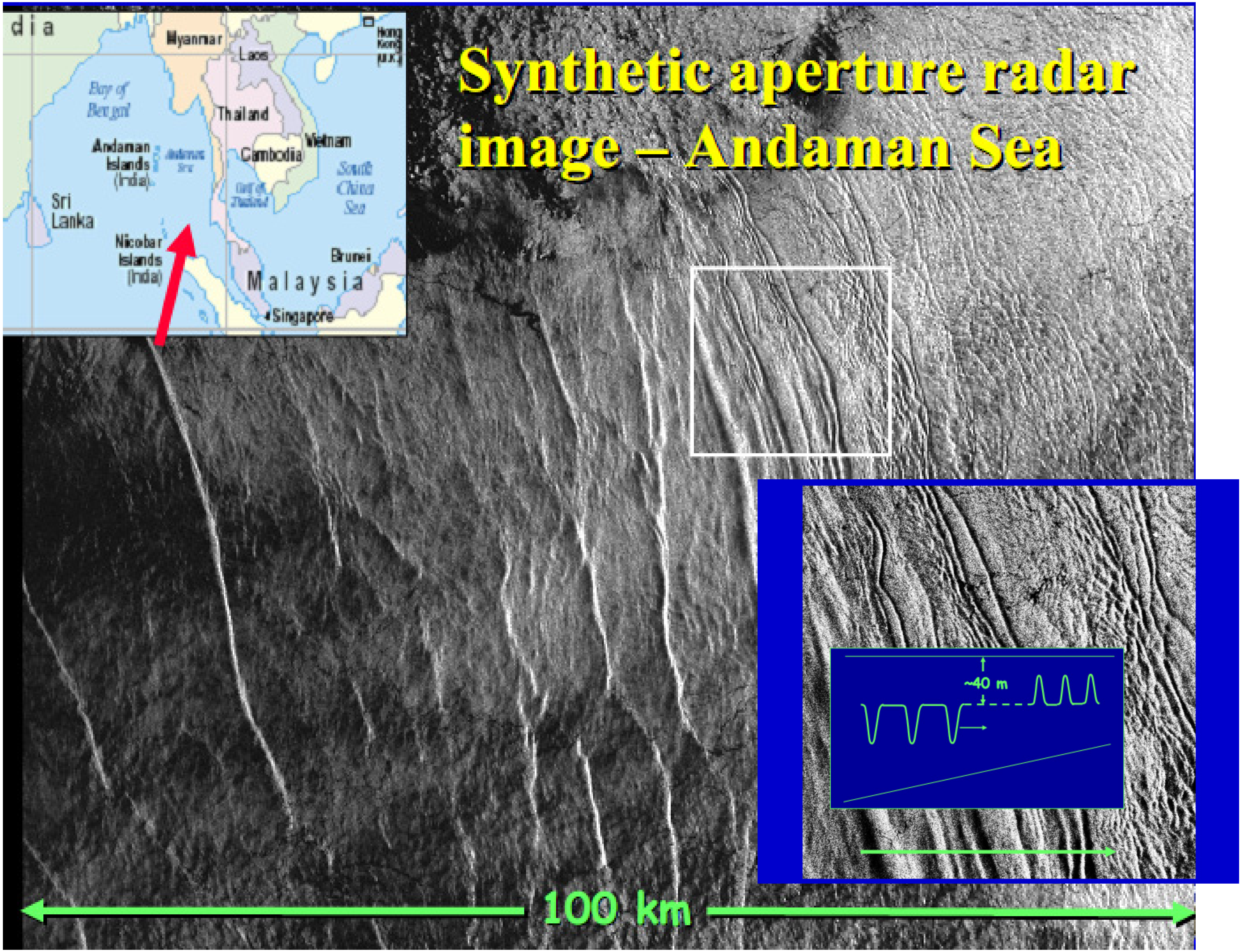
QuikScat: Wed Oct 1 23:31:03 2003 to Thu Oct 2 18:25:26 2003 (GMT)



Synthetic Aperture Radar Data

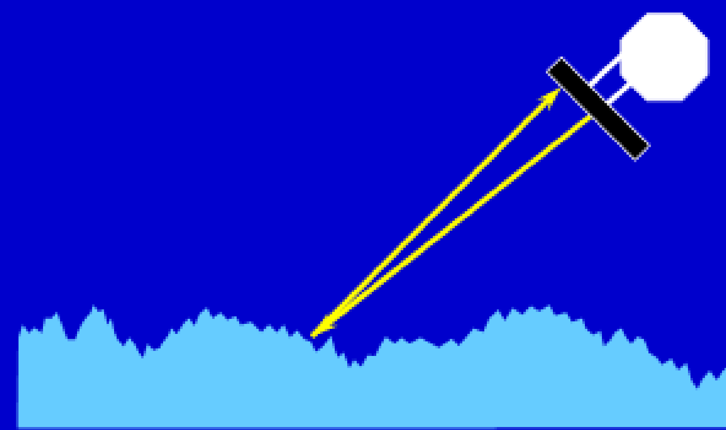
- SAR images: a unique view of the Ocean
  - Measure short scale (5-50 cm) roughness of the sea
  - Bright = rough
  - Dark = smooth
- Capable of observing a variety of ocean phenomena
  - Anything can be imaged that modulates surface roughness
  - Even subsurface phenomena
  - Wind conditions must be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



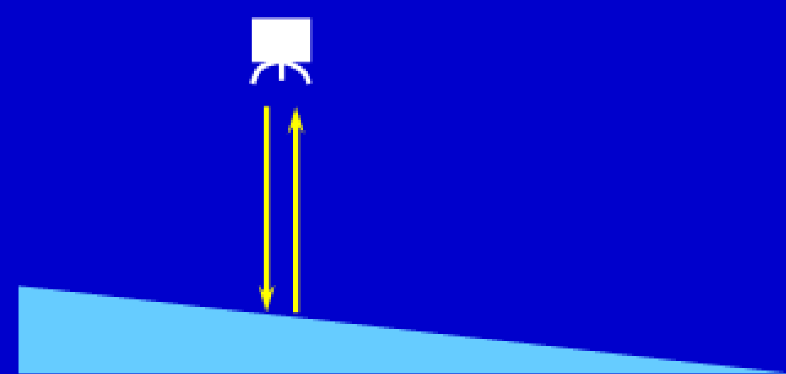

Synthetic aperture radar image – Andaman Sea
dia
Myanmar
Laos
Bay of Bengal
Thailand
Vietnam
Andaman Islands (India)
Cambodia
South China Sea
Sri Lanka
Nicobar Islands (India)
Brunei
Malaysia
Singapore
~40 m
100 km

Sensor Types: 3. Active Sensors

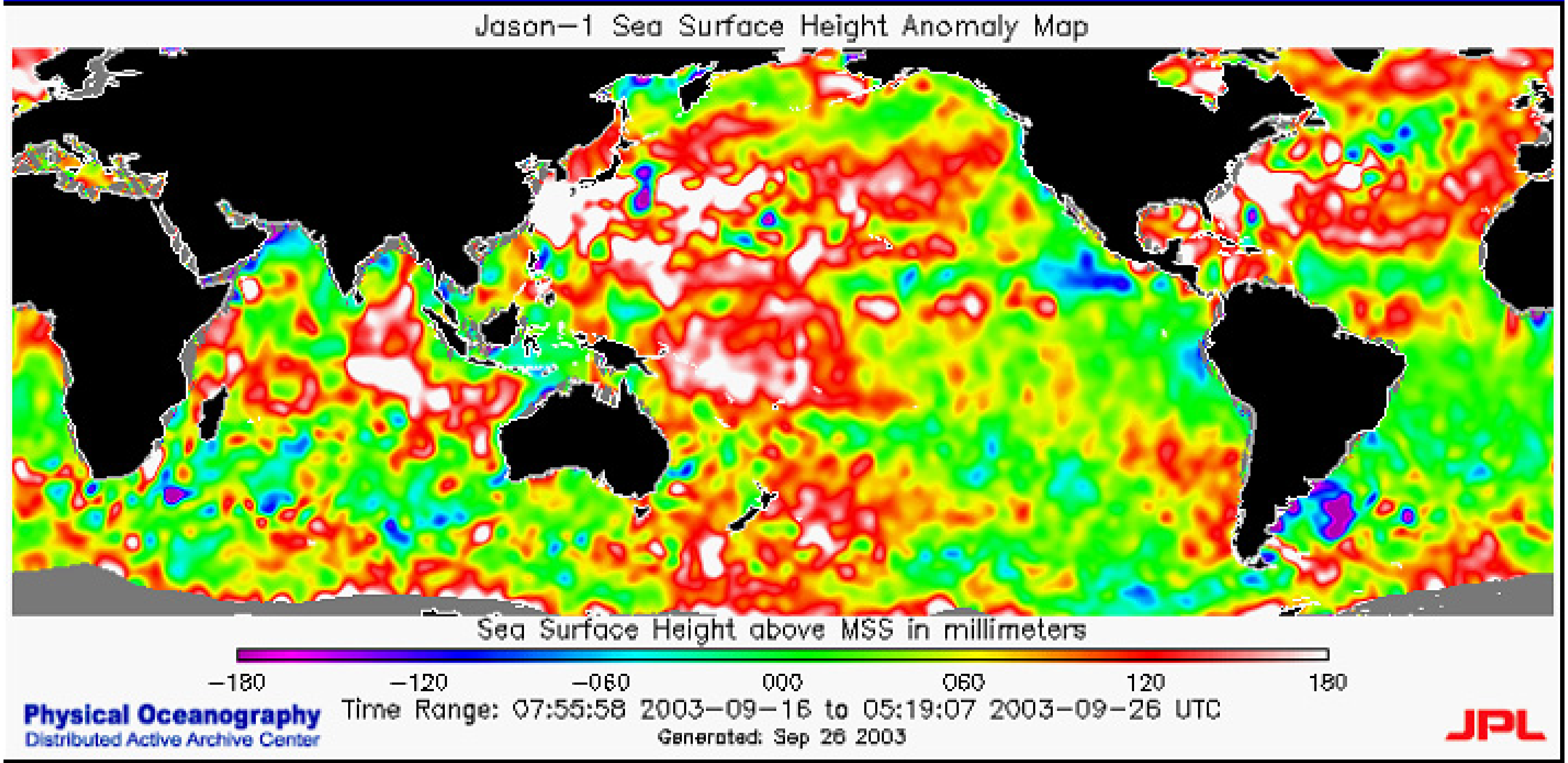
- Emit radar pulse obliquely
- Scatterometer (course resolution)
- Measure wind speed and direction
- Imaging radar – SAR (fine resolution)
- Detect surface roughness patterns



- Emit radar pulse vertically
- Altimeter
- Measure timing of return
- Detect distance to surface
- Measure shape and strength of return pulse
- Detect wave height & wind

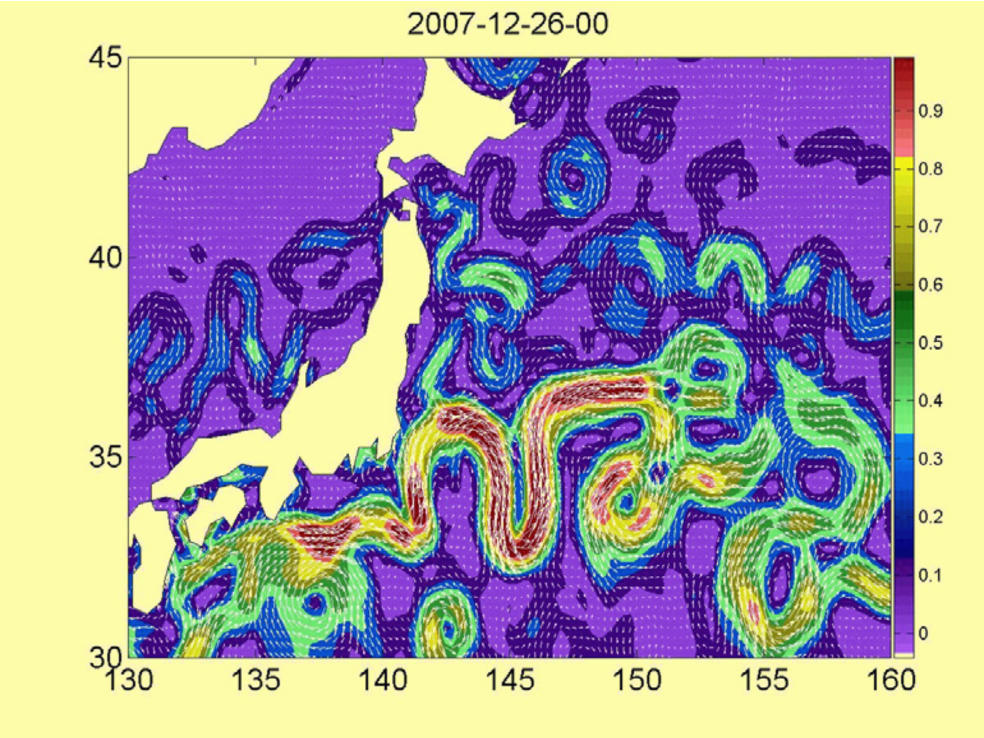


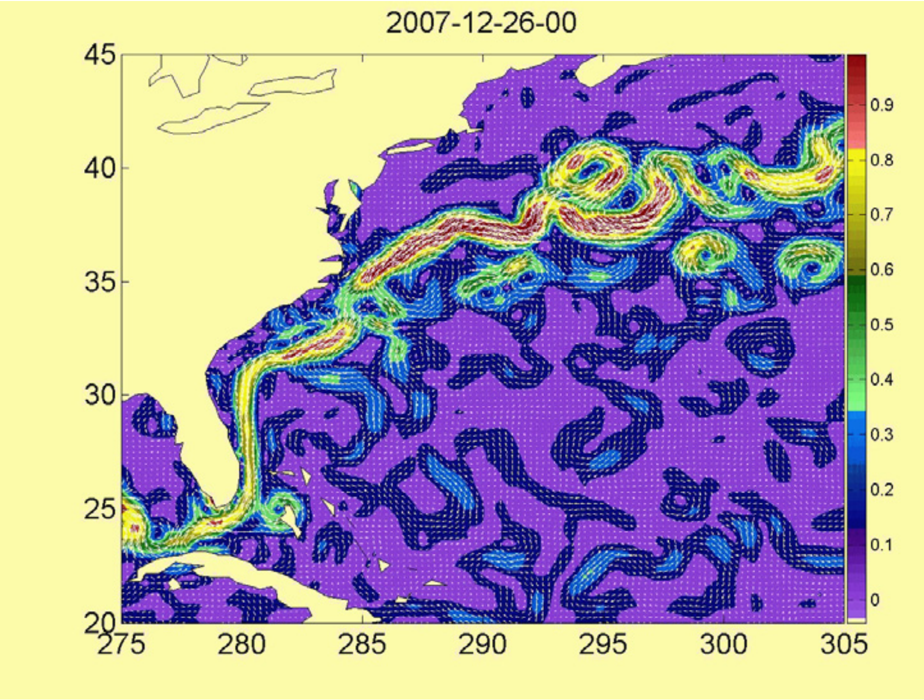
Satellite ocean datasets, 4: from altimetry



SS Height Anomaly (from Altimeter)
Height 16-26 Sep, 2003 - mean height over several years

The Altimetry example





Fundamental limitations of satellite ocean remote sensing

- 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 methods cannot see through clouds at all
- Measurements can be made only when the satellite is in the right place
- All measurements require calibration and validation using *in situ* data

Main references:

- Robinson I. S. 2004. Measuring the Oceans from Space, The principles and methods of satellite oceanography, Springer, p. 655.

Next lecture / Следующая лекция:

21& 22 November/Ноября 2012 (следующие среда и четверг)

15.15 room/ ауд. 318

IR measurements of SST

Определение температуры морской поверхности на основе спутниковых ИК-данных

by Dr. Sergey Stanichny (MHI NANU, Sevastopol)

д.ф.-м.н., Сергей Станичный (МГИ НАНУ, Севастополь)

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