ADVANCED TRAINING COURSE ON
OCEAN REMOTE SENSING
Methods, Tools and Applications
University of Hamburg • 25 > 29 September 2006

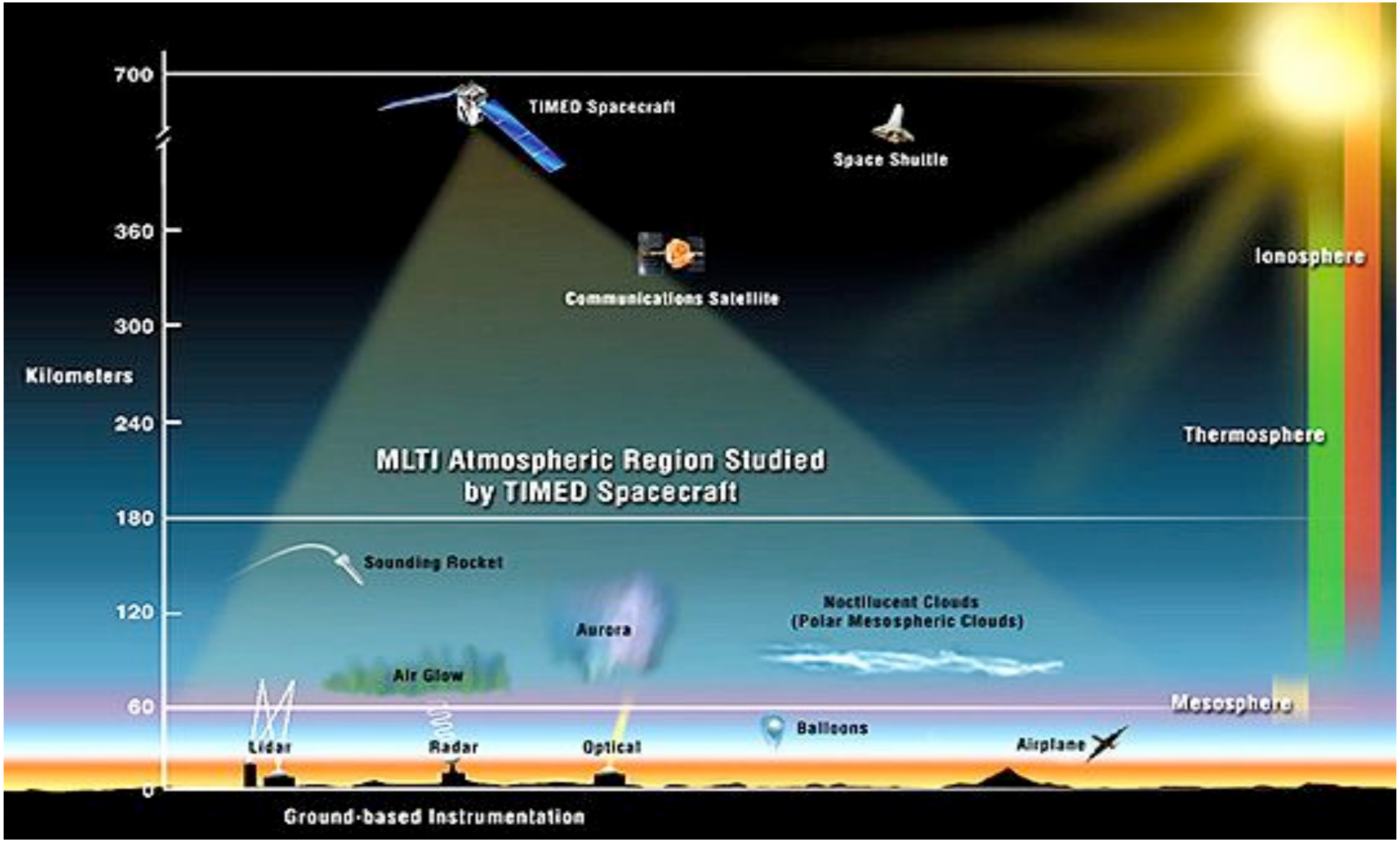
esa

Oceanography from Space,

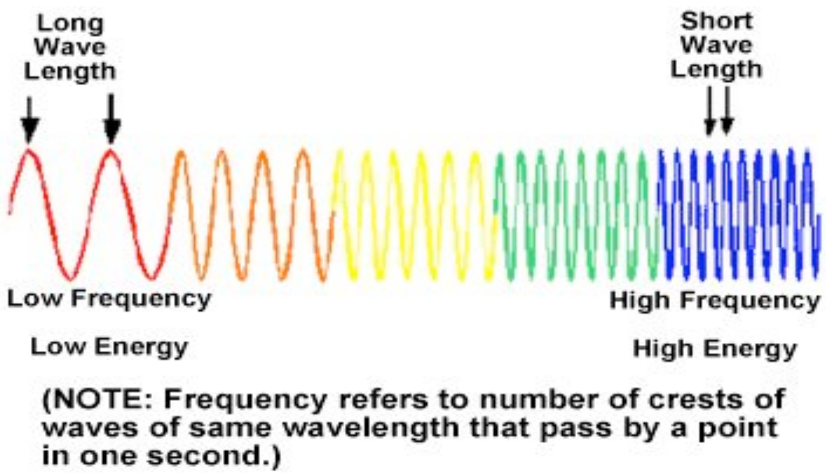
D. Stammer, IfM

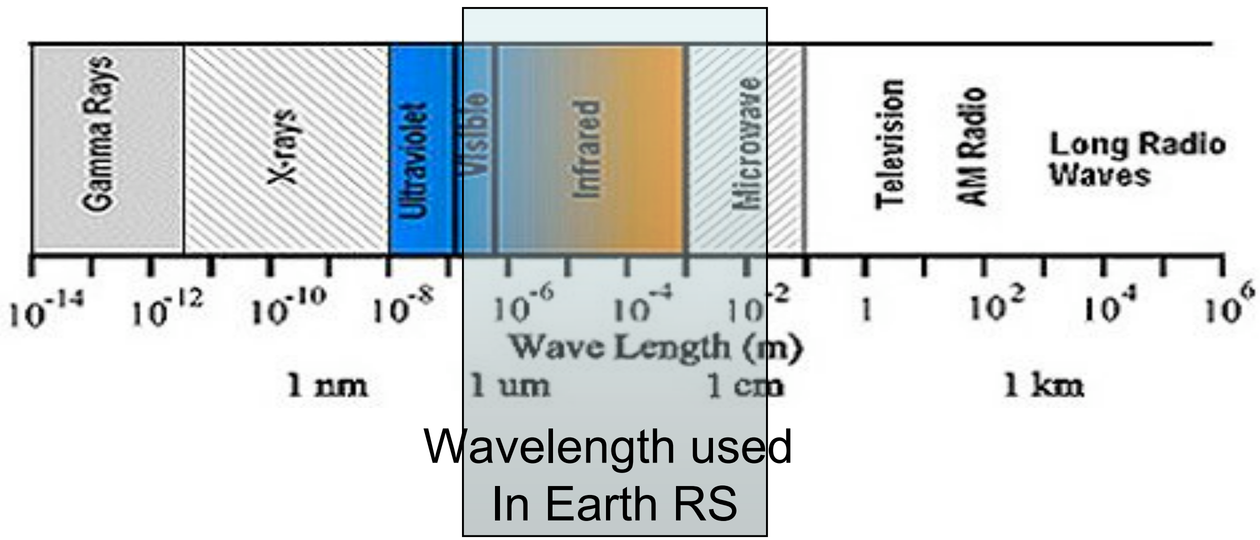
ENVISAT
CARING FOR THE EARTH

Earth Observing Satellites

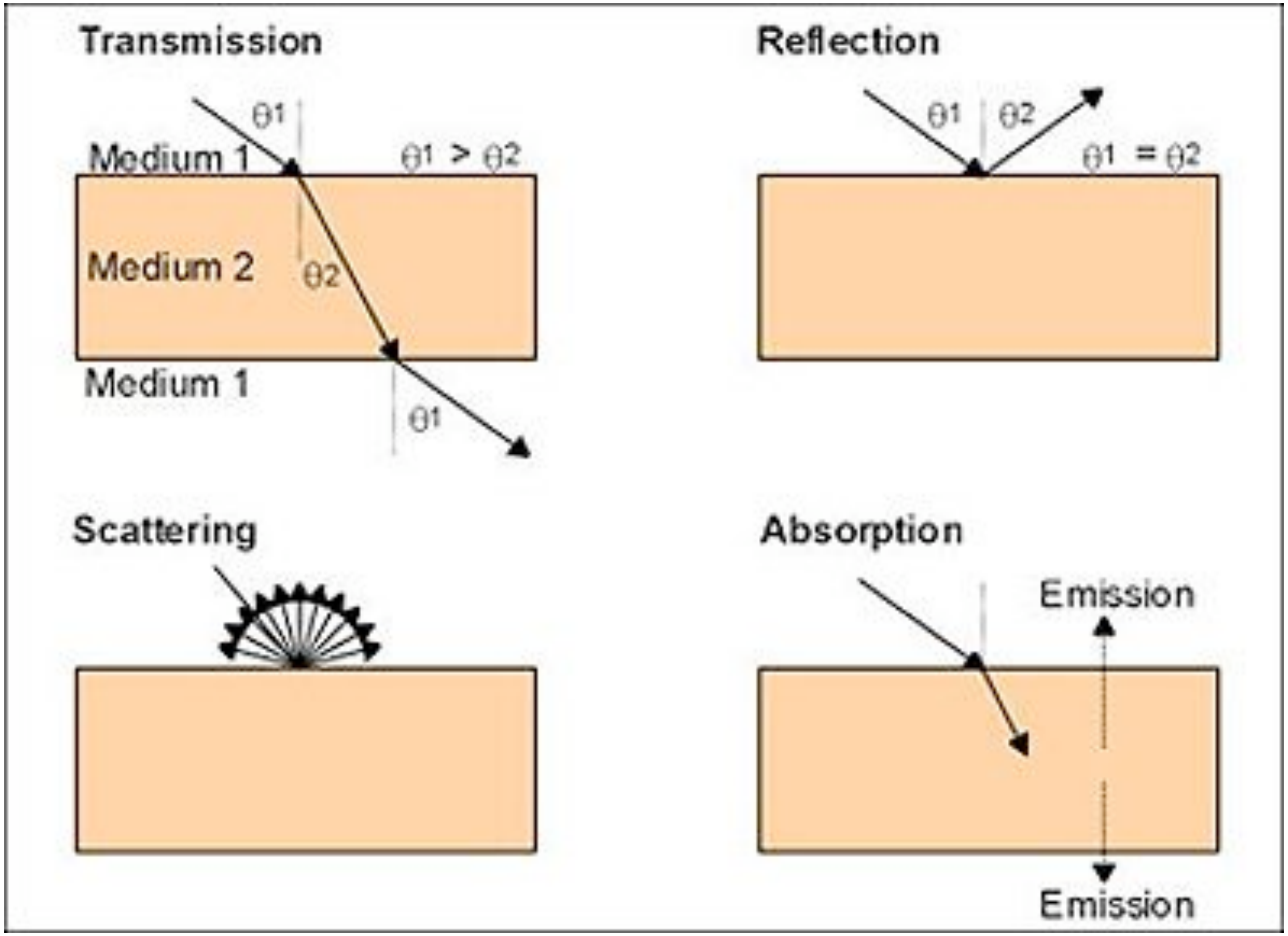


Electromagnetic Waves

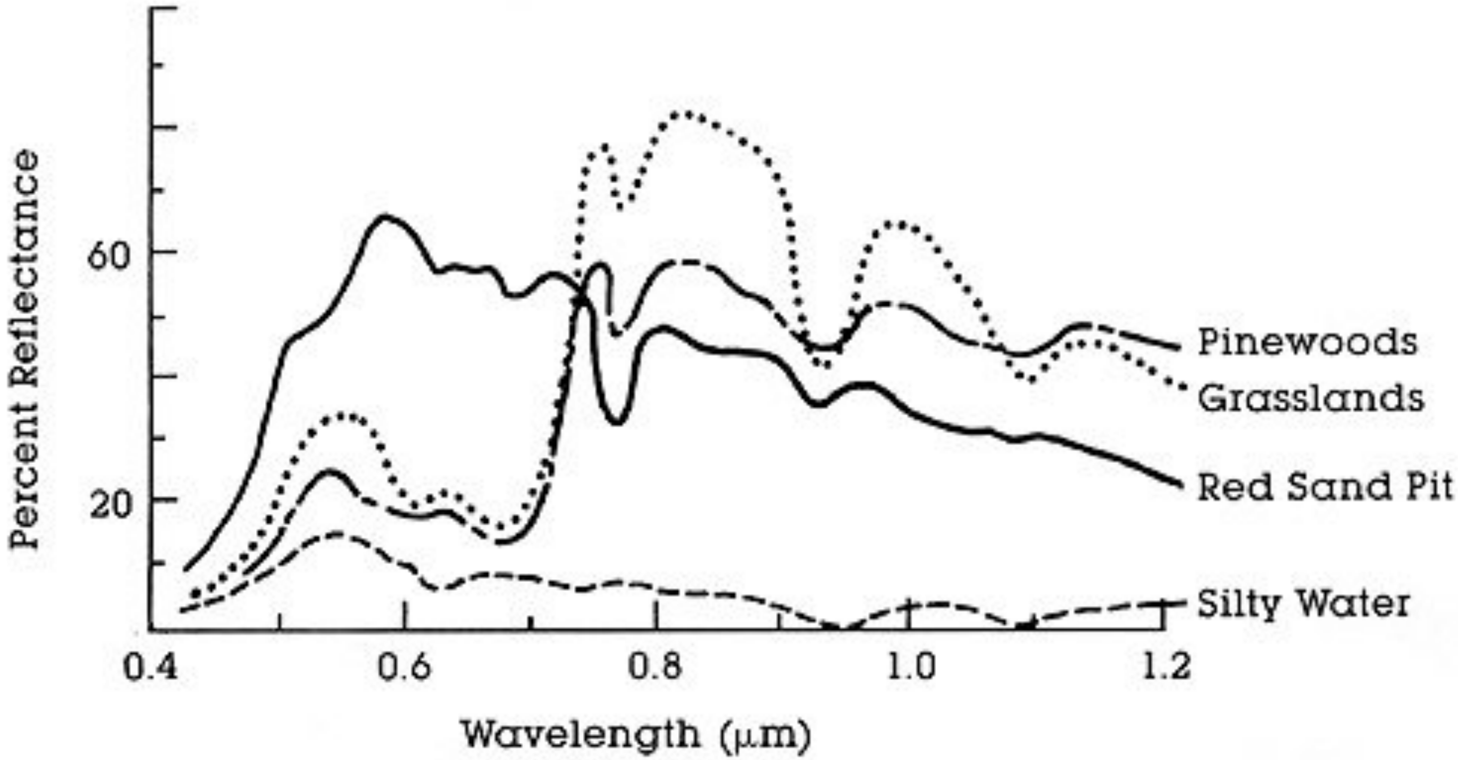




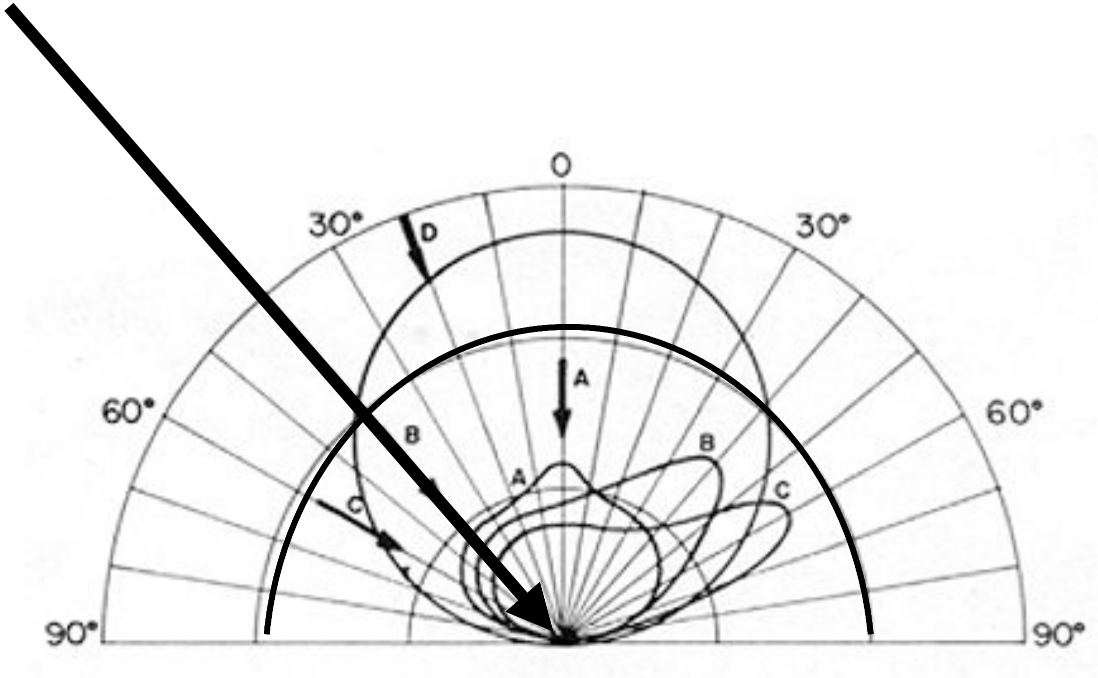
Remote Sensing Principles



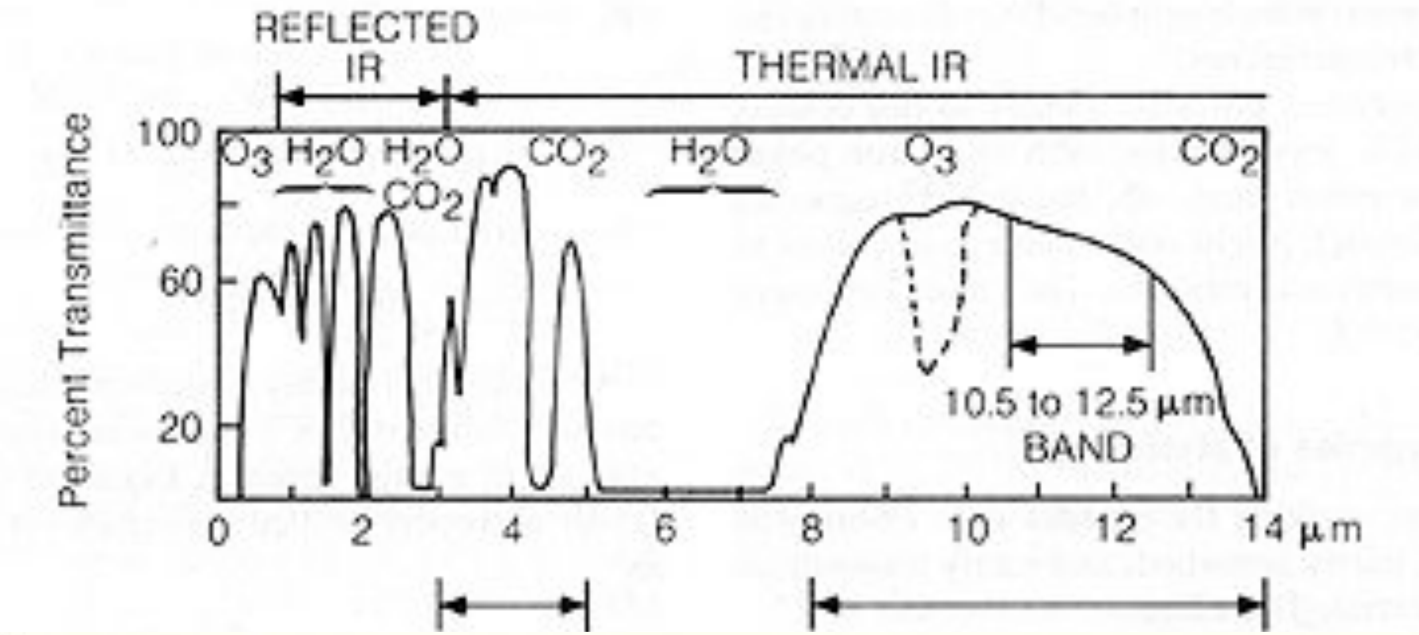
Reflectance

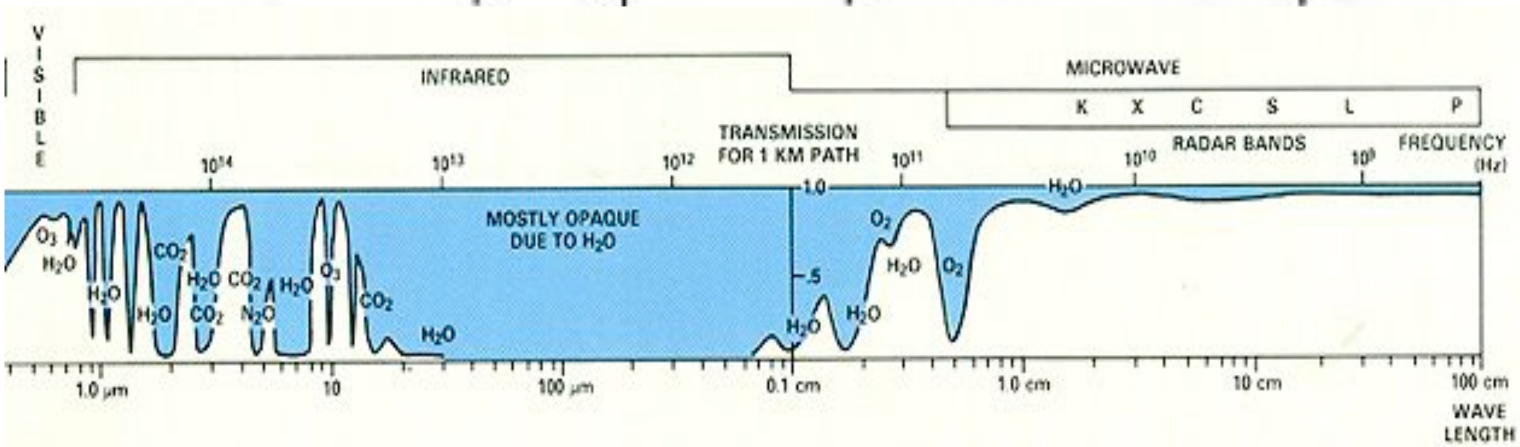


Scattering

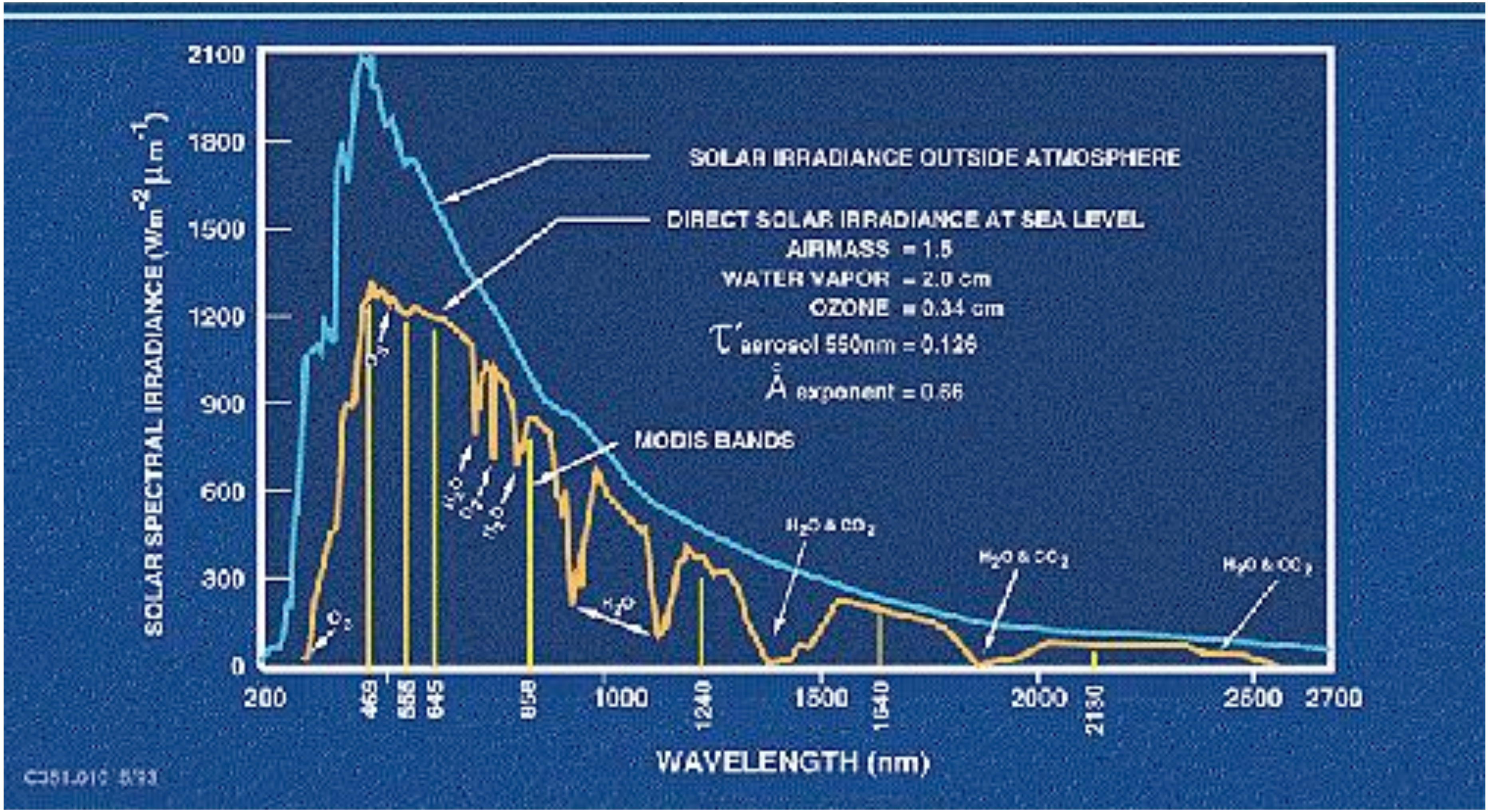


Transmittance

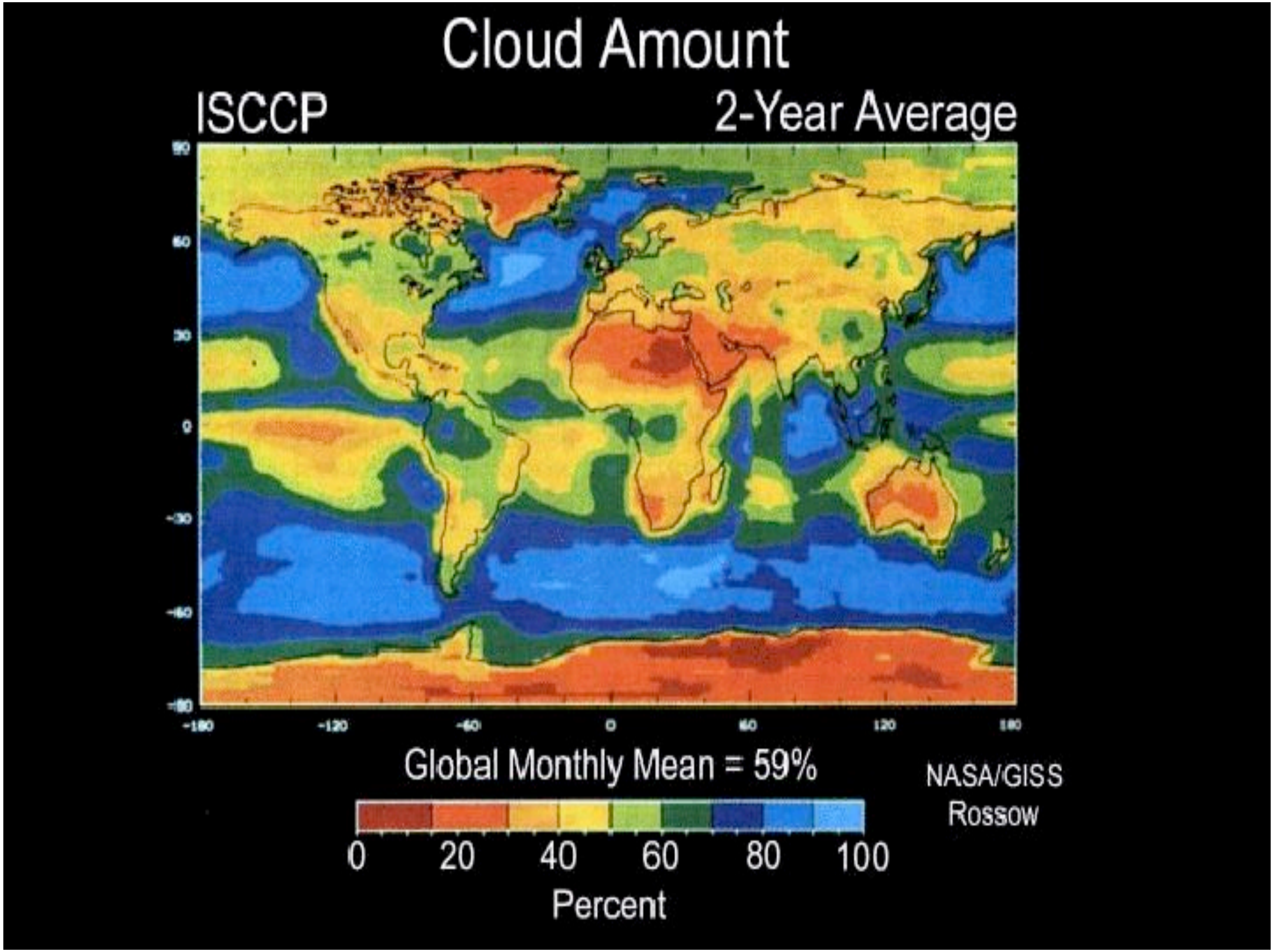




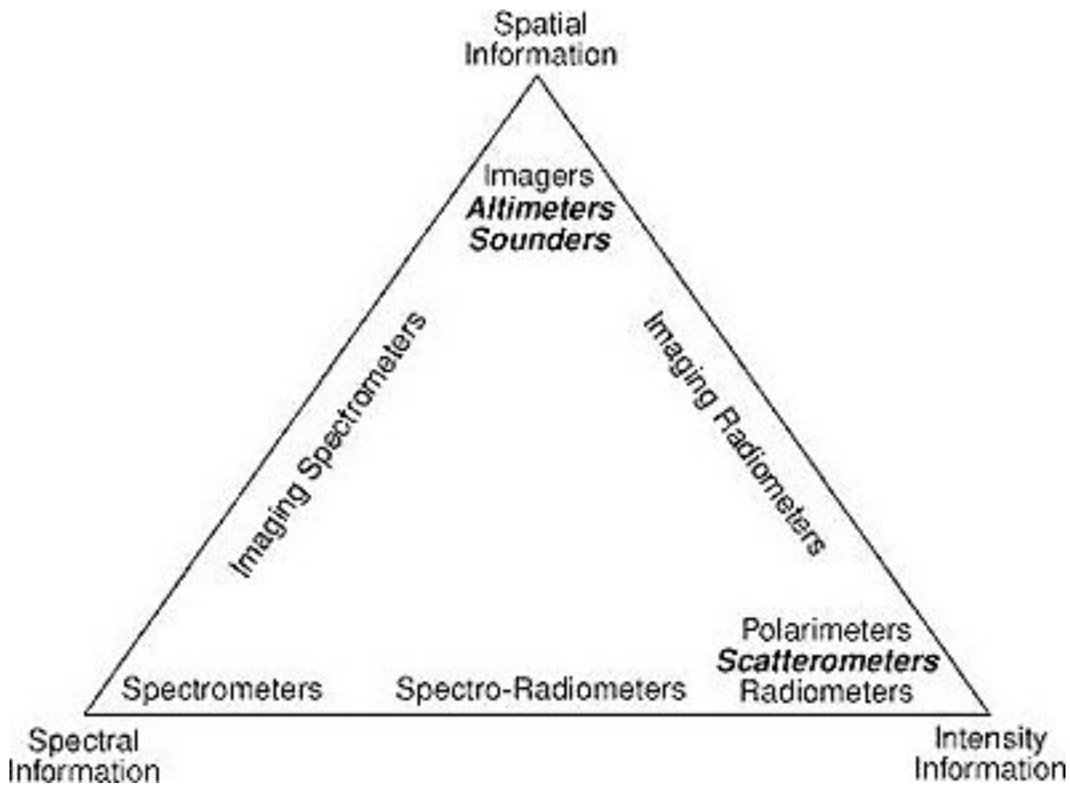
Solar Radiation

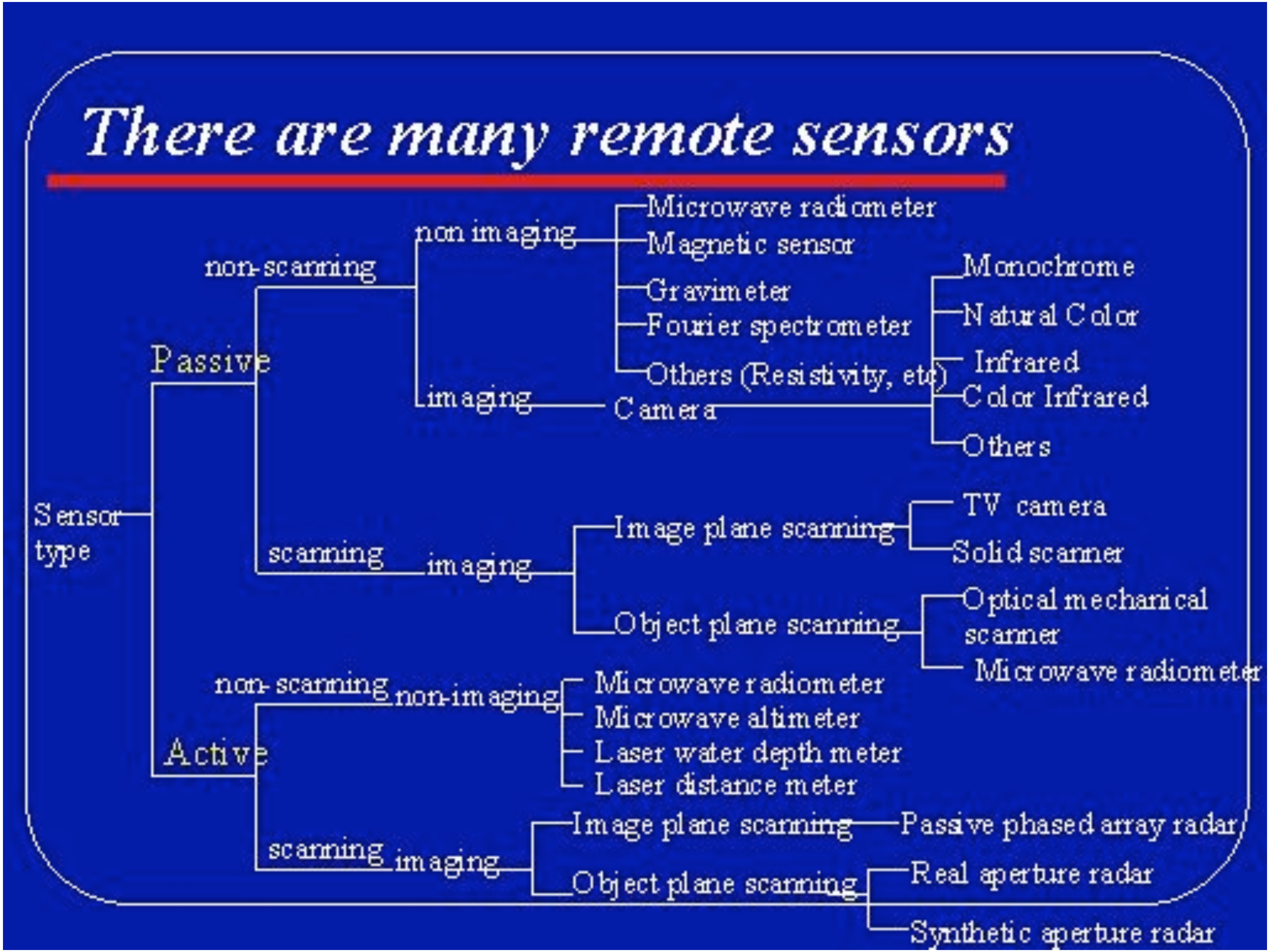


The atmosphere is not transparent

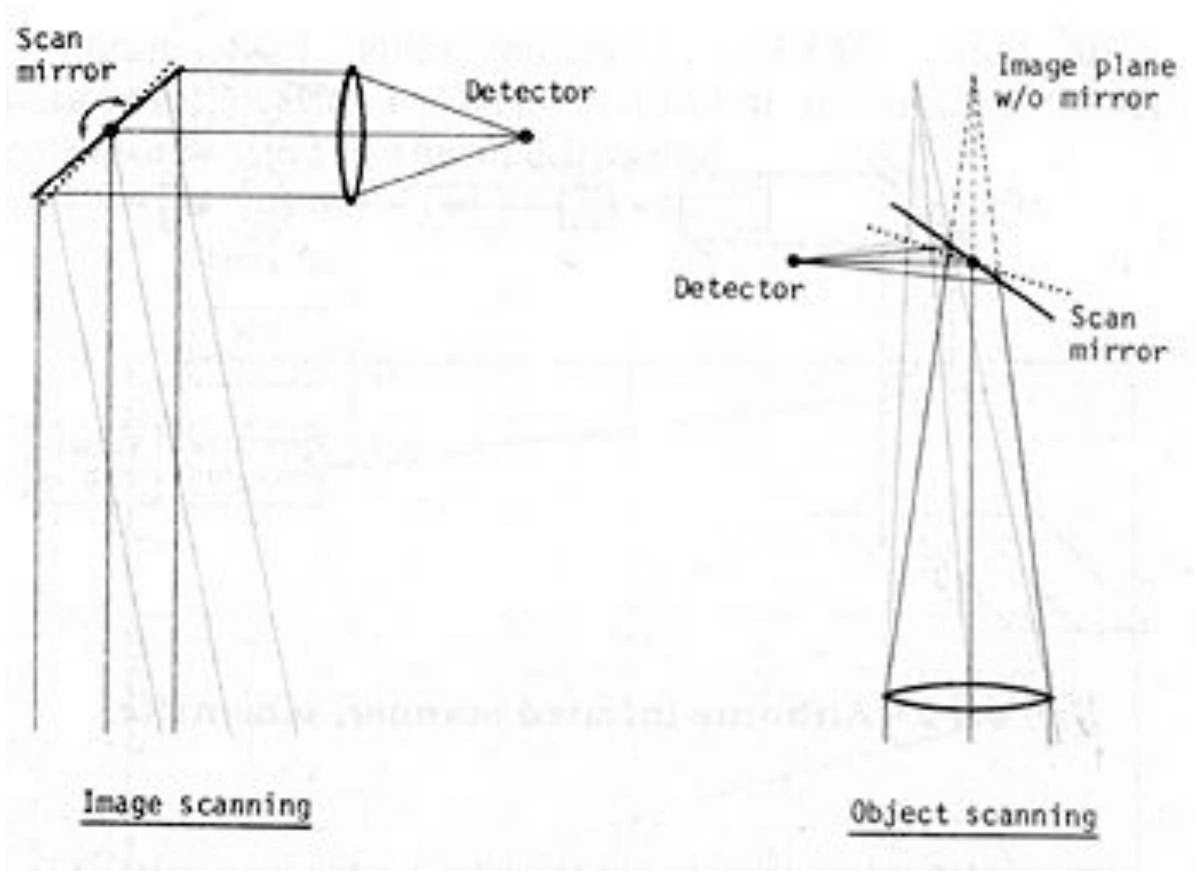

Cloud Amount
ISCCP
2-Year Average
Global Monthly Mean = 59%
0
20
40
60
80
100
Percent
NASA/GISS
Rossow

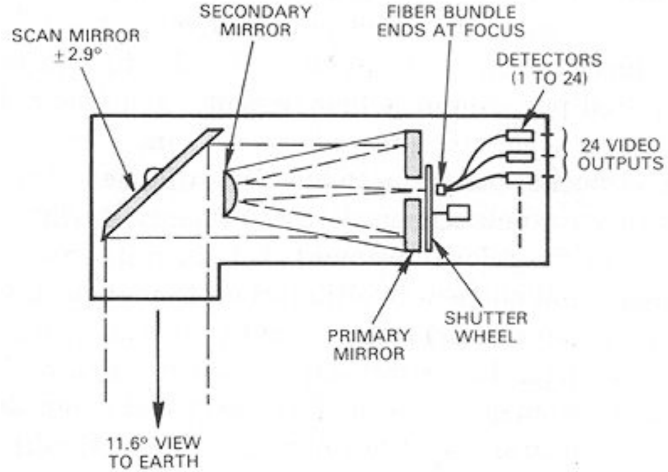
Remote Sensing Approaches

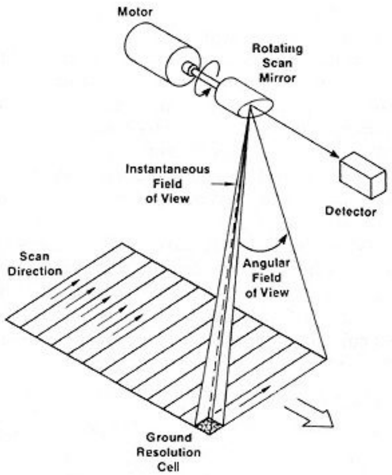


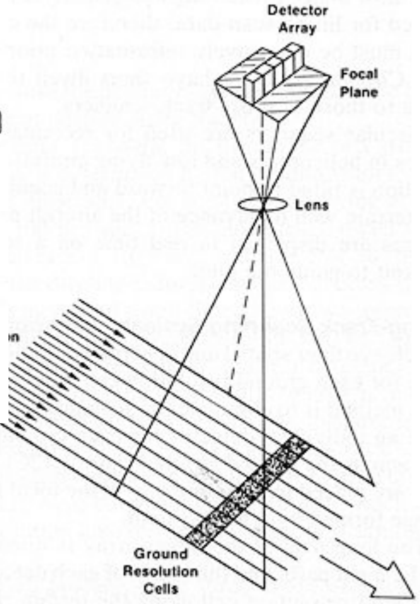

There are many remote sensors
Sensor type
Passive
non-scanning
non imaging
Microwave radiometer
Magnetic sensor
Gravimeter
Fourier spectrometer
Others (Resistivity, etc)
imaging
Camera
Monochrome
Natural Color
Infrared
Color Infrared
Others
scanning
imaging
Image plane scanning
TV camera
Solid scanner
Object plane scanning
Optical mechanical scanner
Microwave radiometer
Active
non-scanning
non-imaging
Microwave radiometer
Microwave altimeter
Laser water depth meter
Laser distance meter
scanning
imaging
Image plane scanning
Passive phased array radar
Object plane scanning
Real aperture radar
Synthetic aperture radar

Instruments

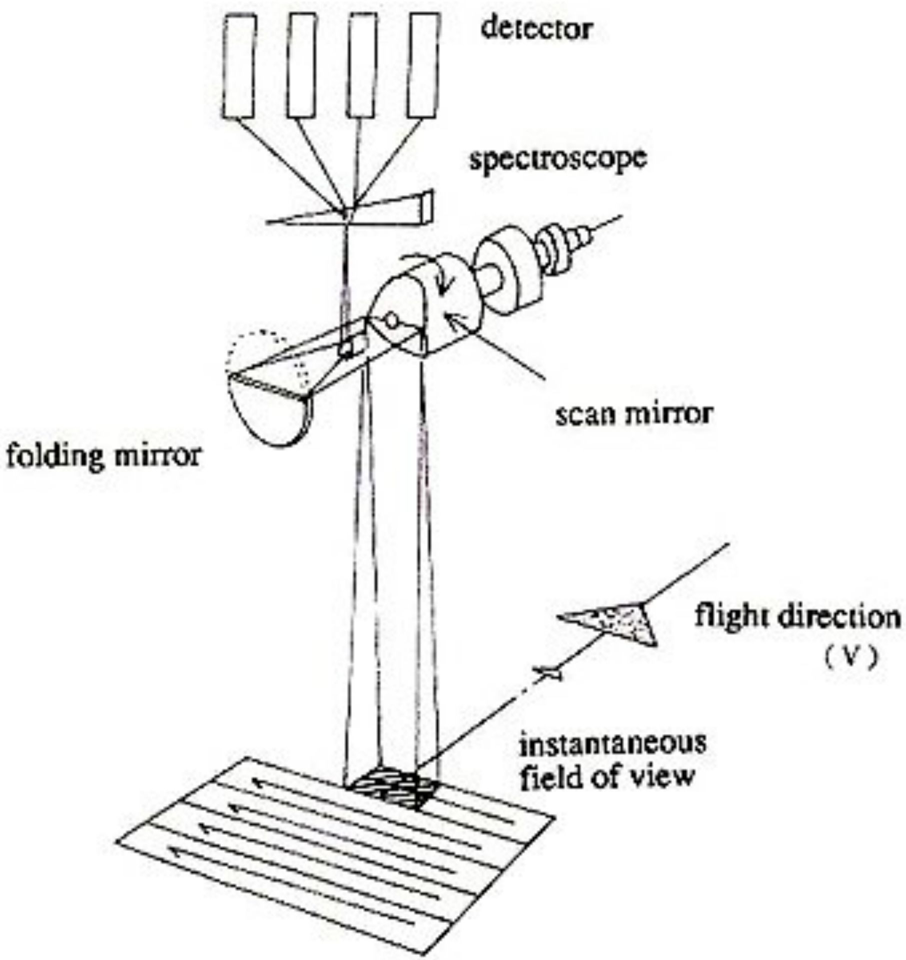








C. ALONG-TRACK SCANNER.



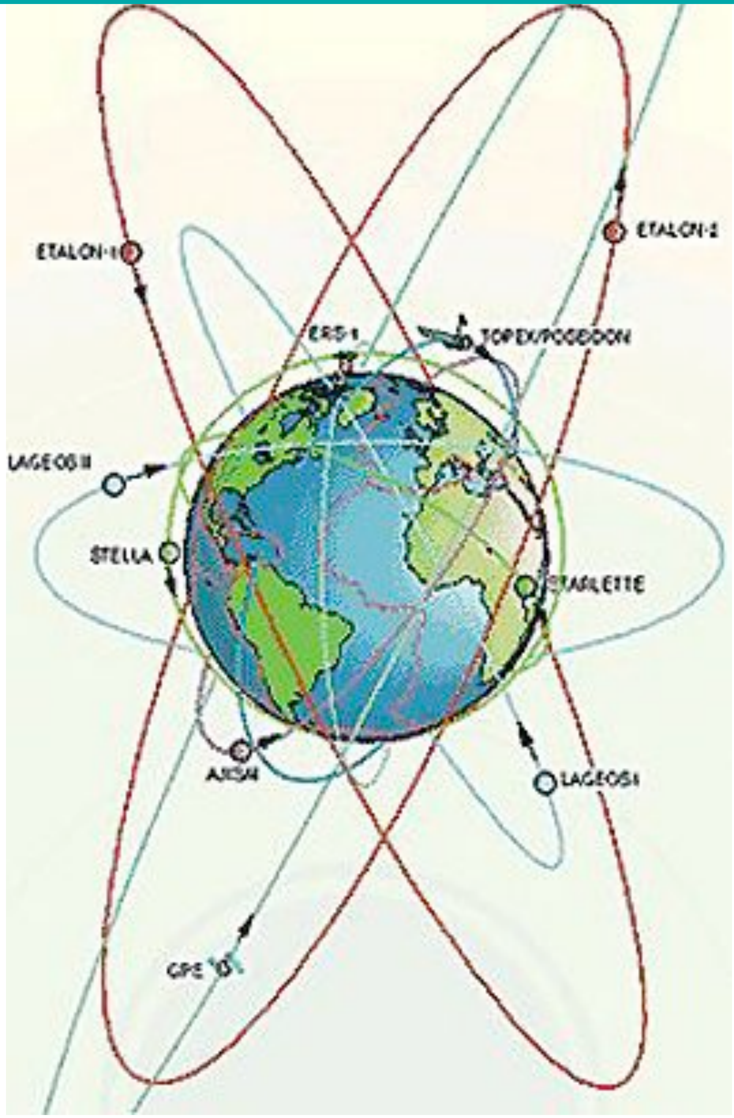
Orbits

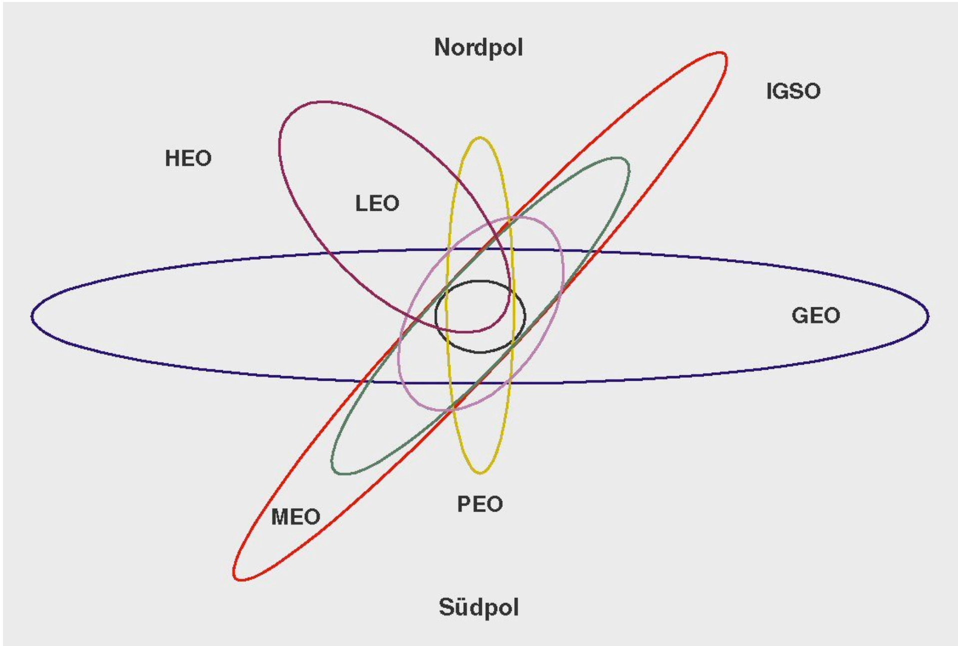
Orbits determine:

- Where do I see the Earth
- How often
- Resolution in space
- What space-time pattern

Important parameters: inclination, height, repeat period, swath width.

Orbits


ETALON-1
ETALON-2
ERS-1
TOPEX/POSEIDON
LAGEOS II
STELLA
STARLETTE
LAGEOS I


Nordpol
IGSO
HEO
LEO
GEO
MEO
PEO
Südpol

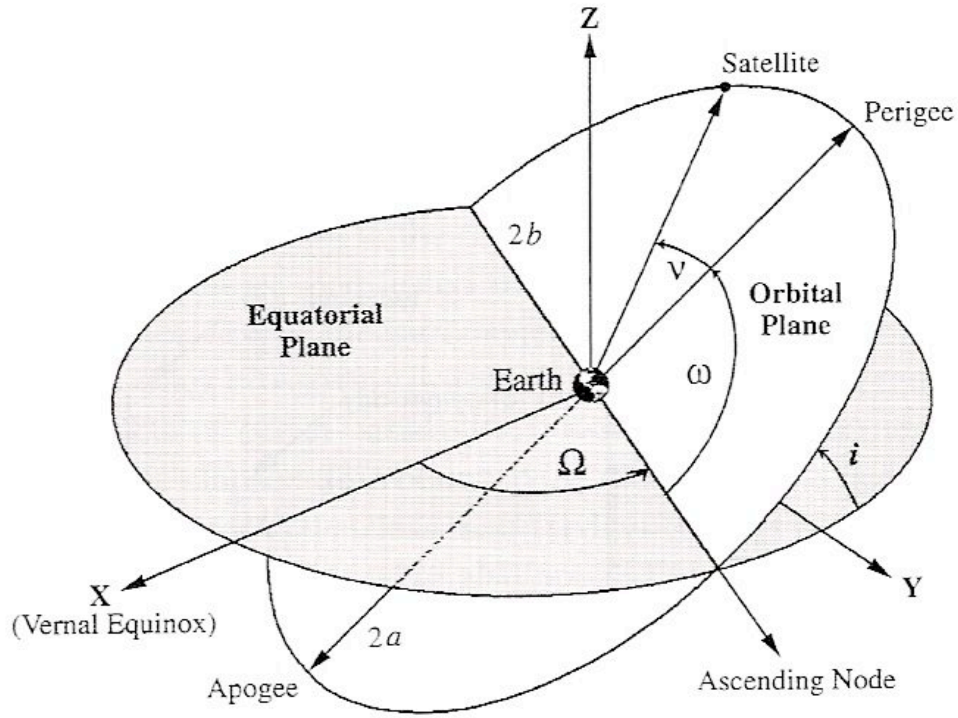


FIGURE 38 The elements of an elliptical orbit: semimajor axis a, inclination i, longitude (or right ascension) of the ascending node Ω, argument of perigee ω, and true anomaly ν. The eccentricity e relates the semimajor axis a to the semiminor axis b through the expression $e^2 = (a^2 - b^2)/a^2$.

The Earth System

Theory
Observations
Lab Experiments
Instruments

Biology
Chemistry
Geology
Physics

Continents
Atmosphere
Cryosphere
Ocean

Predictions

Recommendations

The Earth System

Atmosphere

Pedosphere

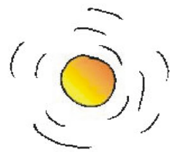
Cryosphere

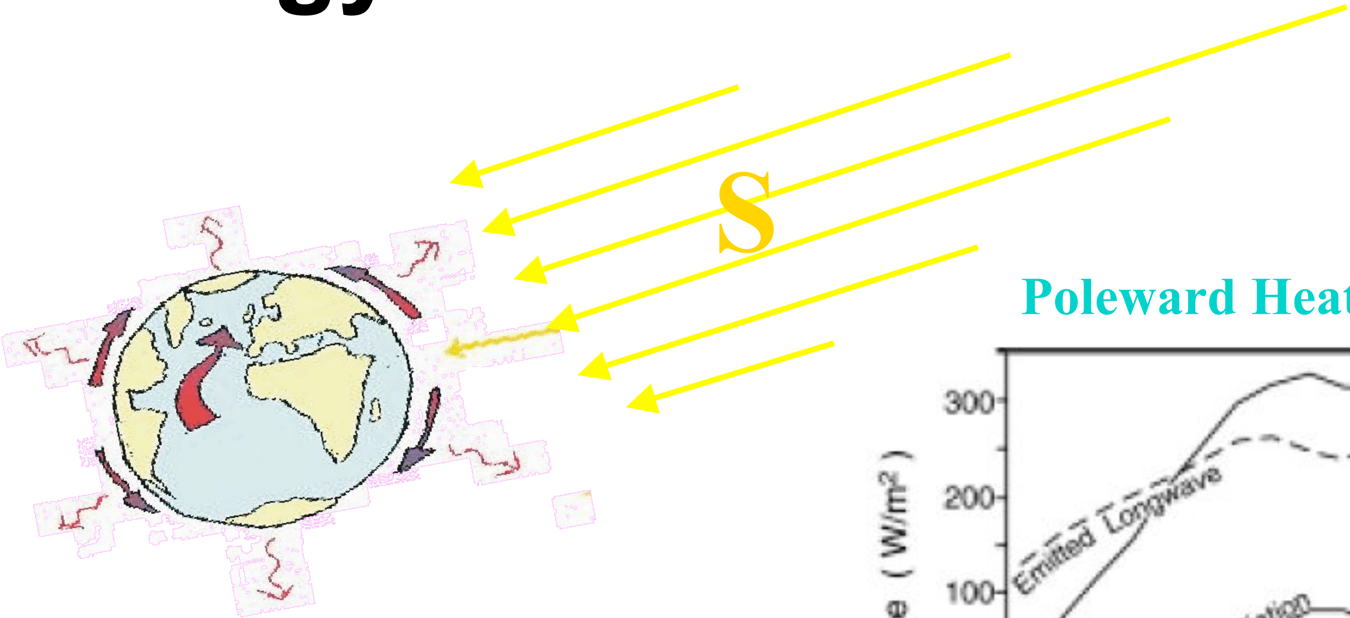
Solid earth

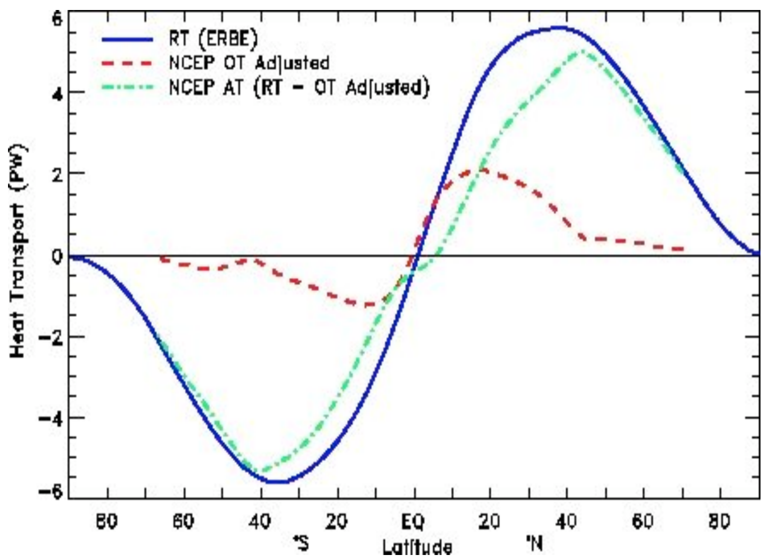
Ocean

Here we will deal only with the ocean !!!

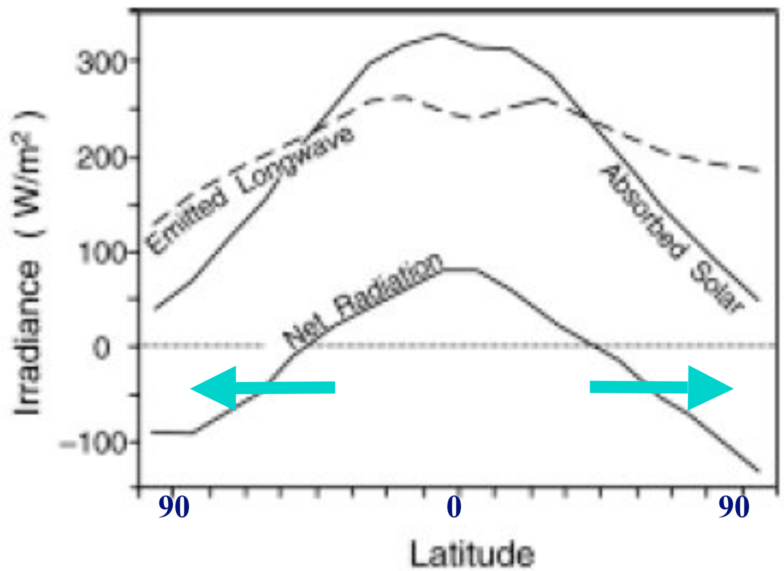
Energy Balance - Climate





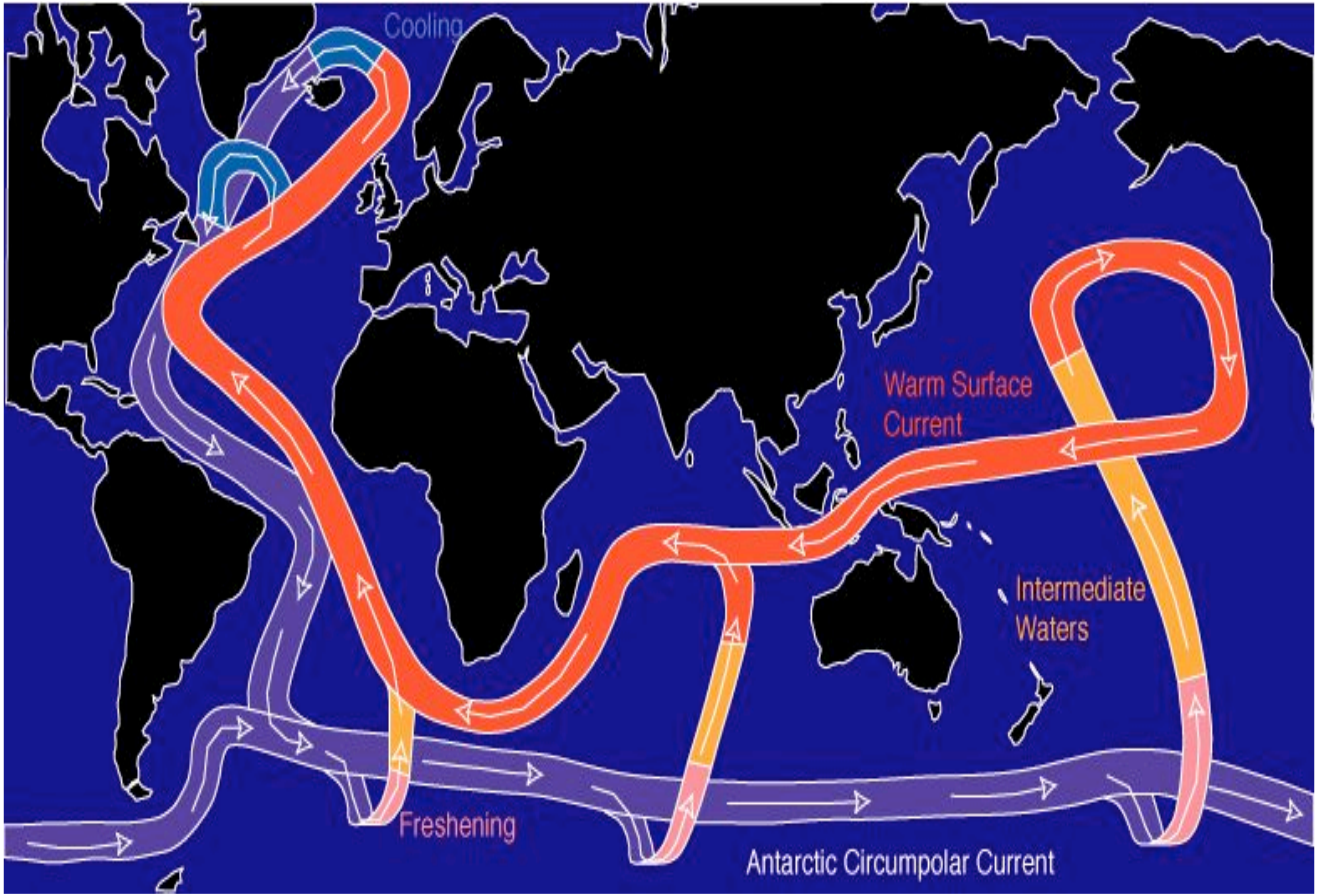


Poleward Heat Transport



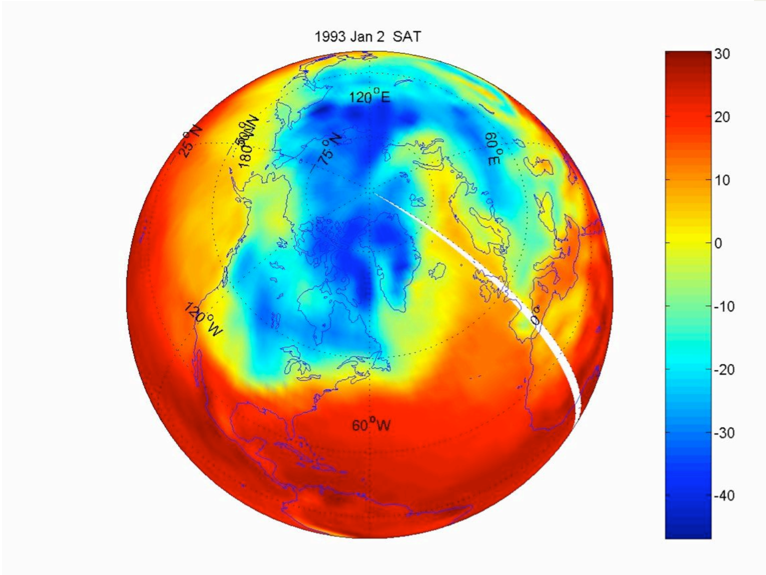
Heat transports in the ocean and atmosphere balance radiation budget of Earth system between low and high latitudes.

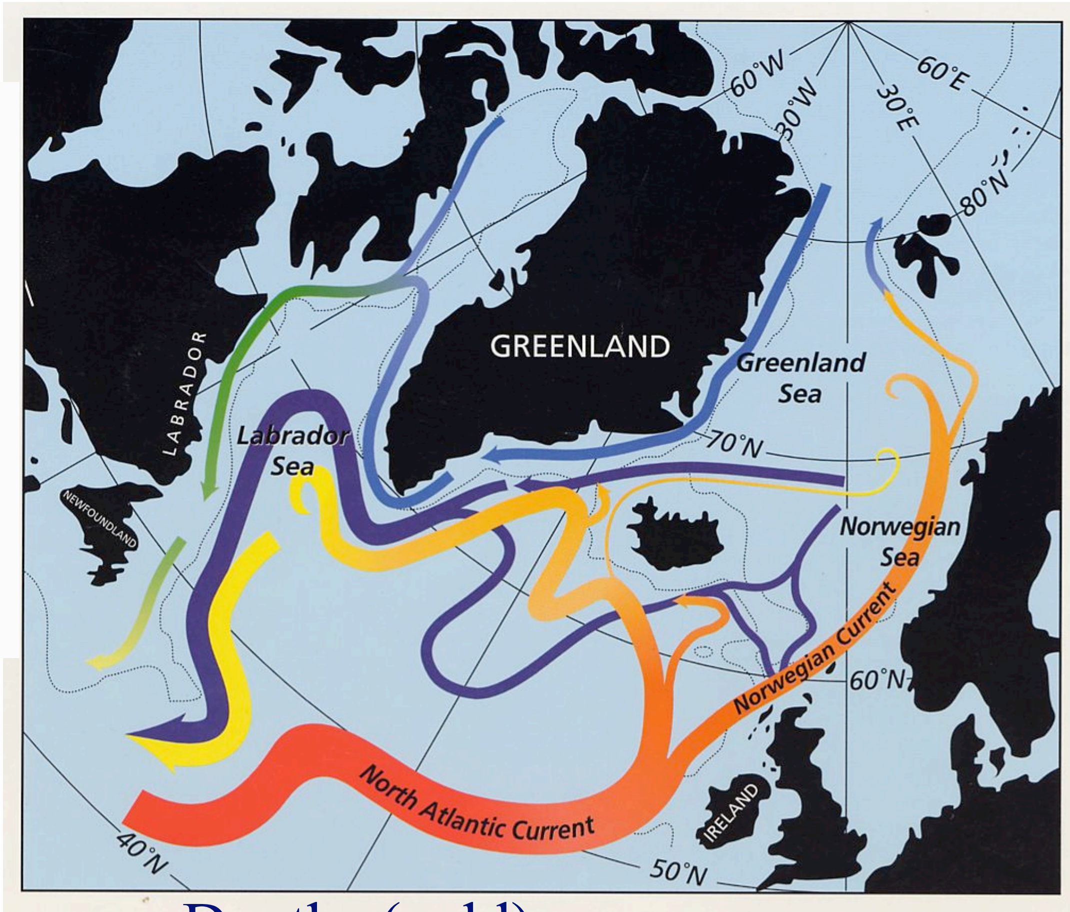
The Meridional Overturning Circulation



… determines the clima in Europa

Air temperature January



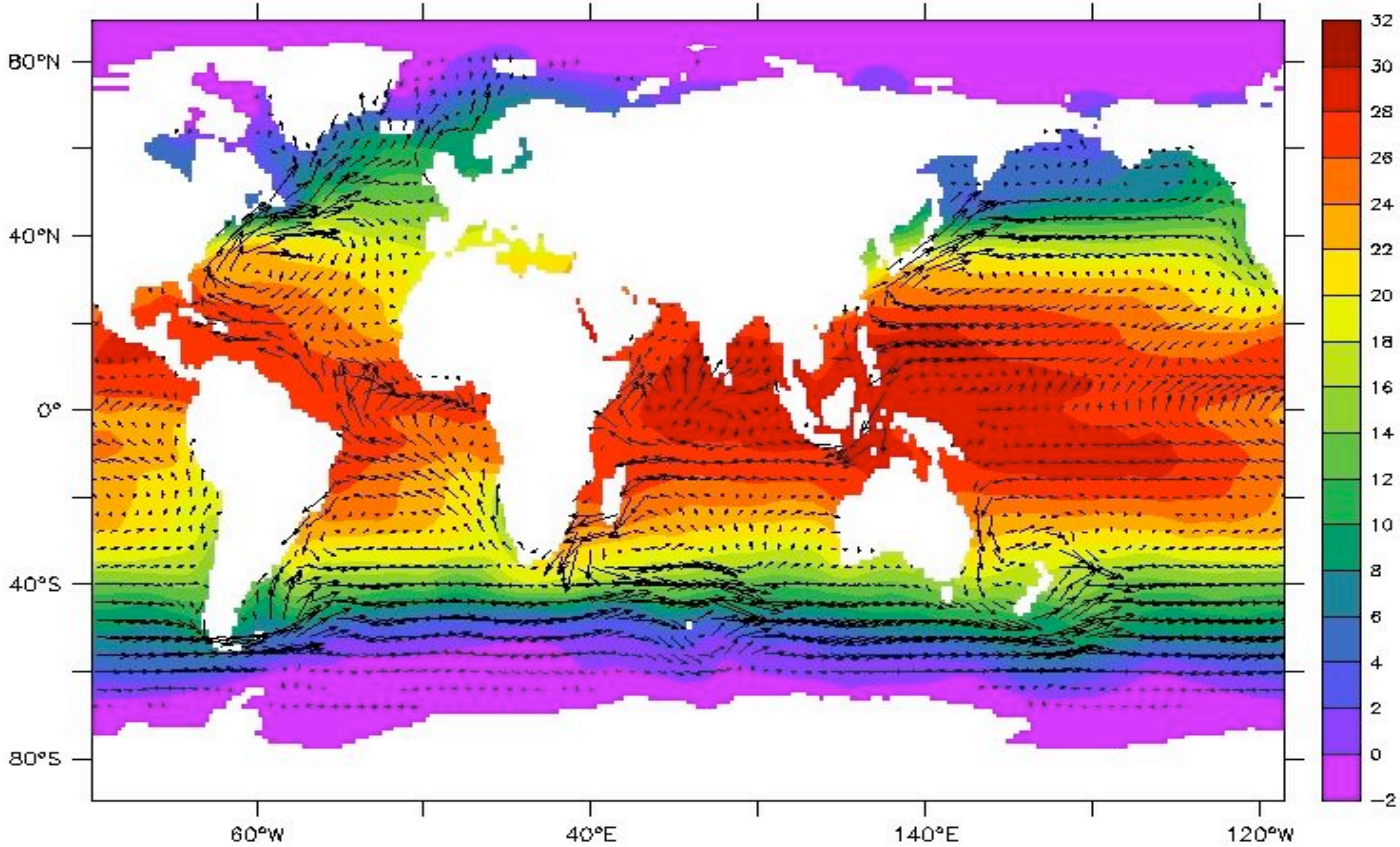


Ocean currents

Surface (warm)

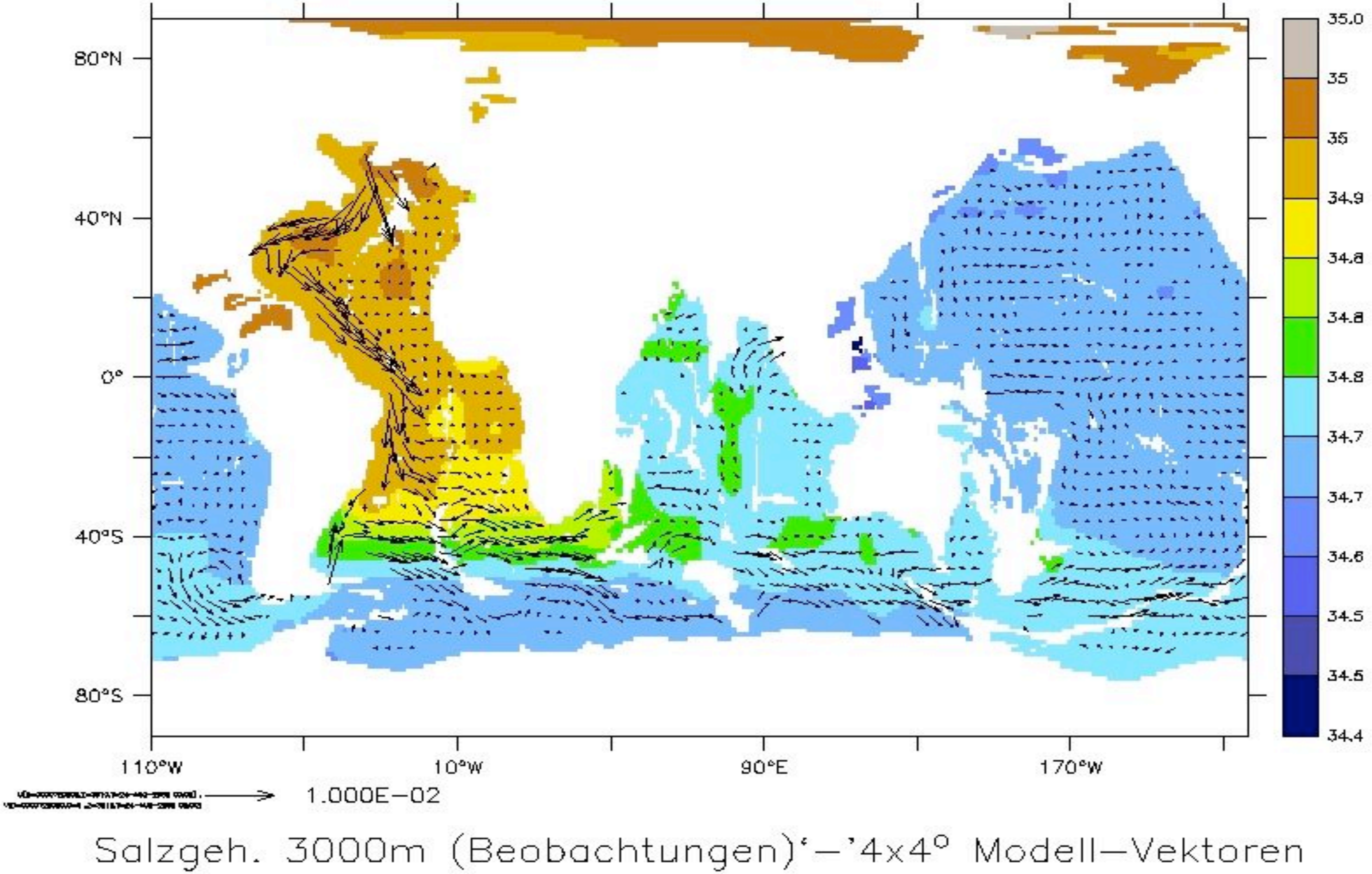
Depths (cold)

Near-surface Circulation of the global Ocean:
Continents are responsible for meridional component of mean circulation.
Asymmetry in temperature and currents western <---> eastern sides

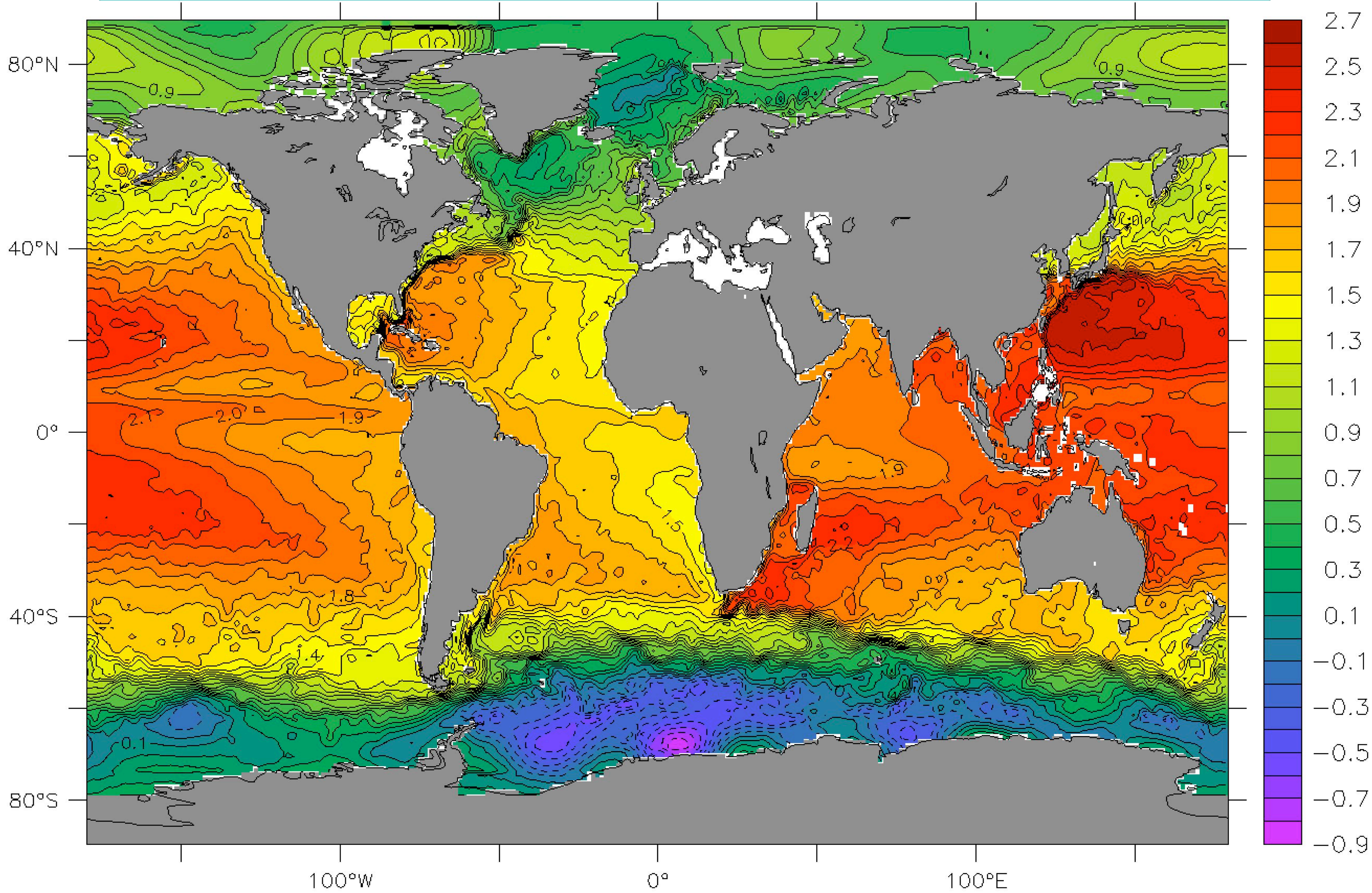


surface temp. (°C), 100m velocity 4x4° model simulation

Deep circulation brings Atlantic surface water into Pacific.

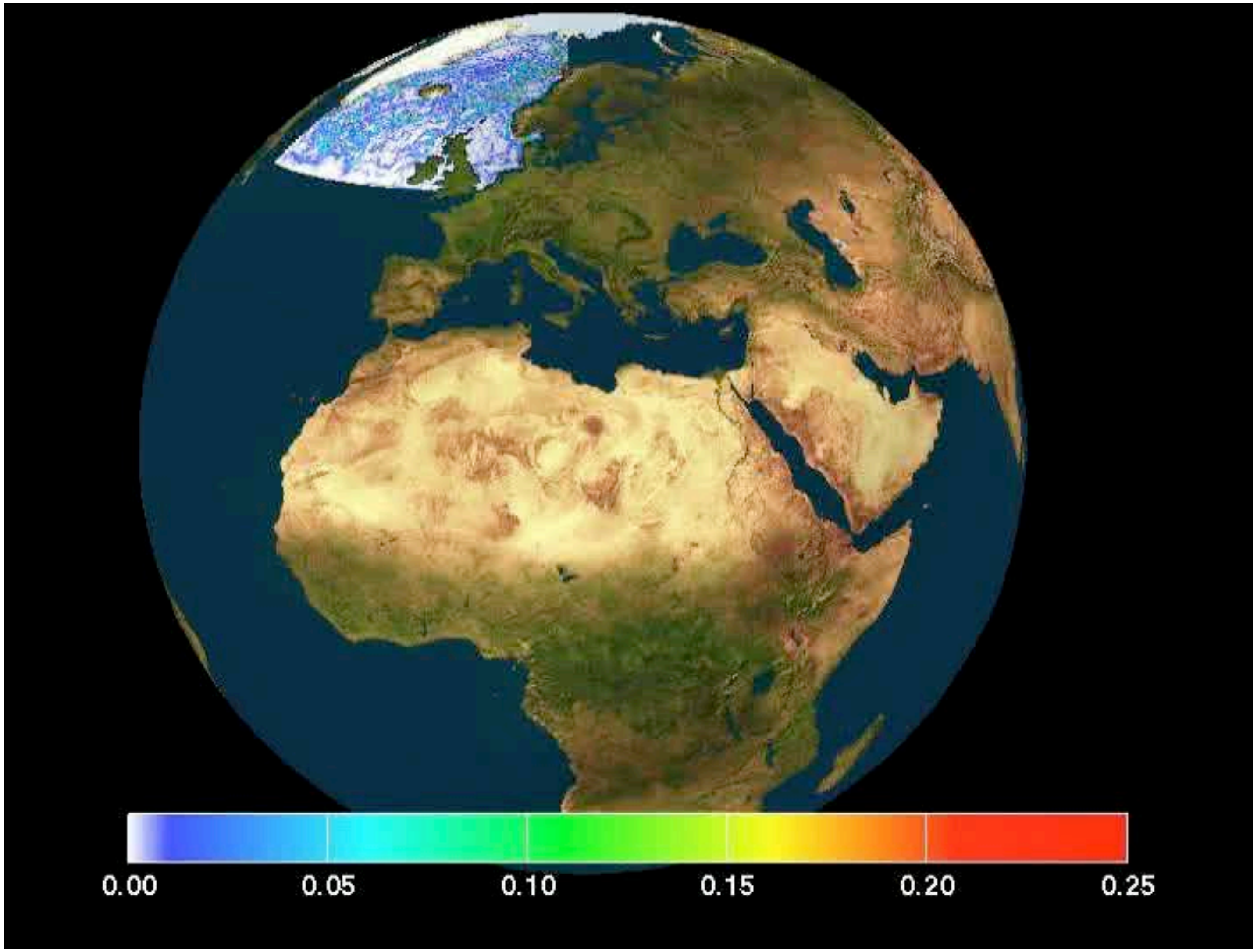


Sea Surface Height is good proxy for near surface circulation.

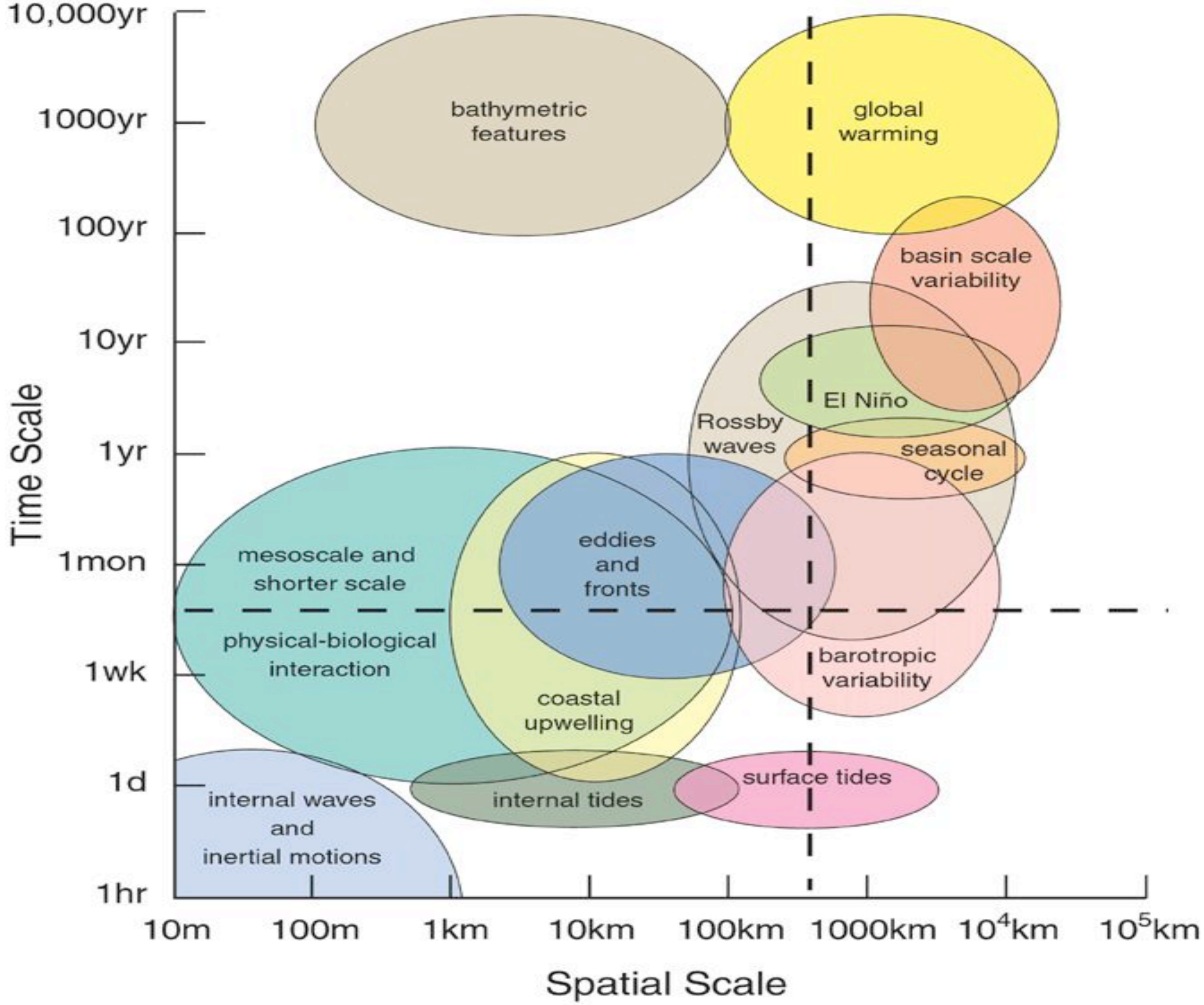


Rio & Hernandez (2004)

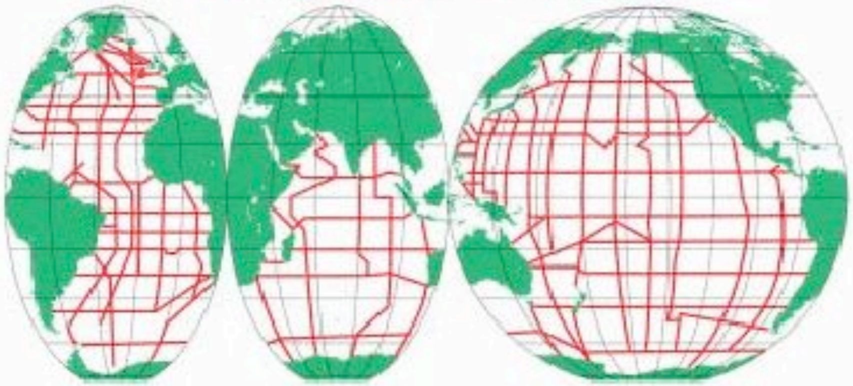
But the ocean is a turbulent fluid!



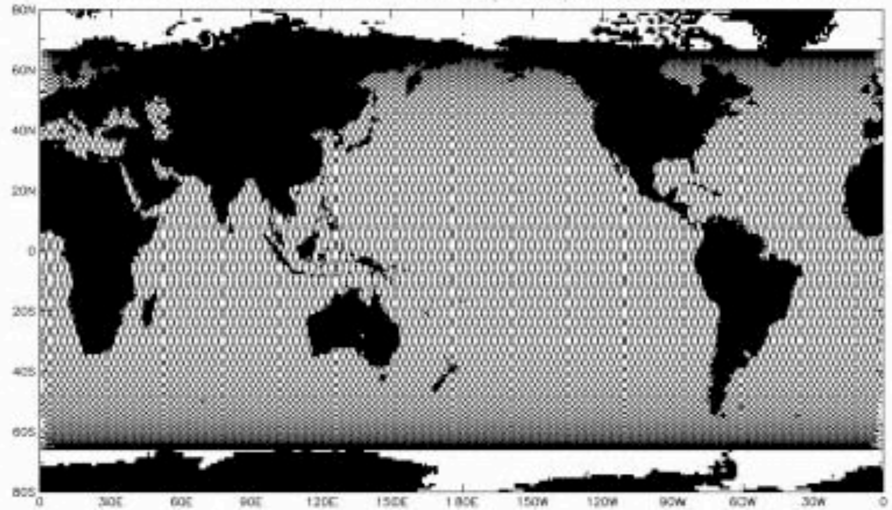
There are many important processes in the ocean with many space and time scales



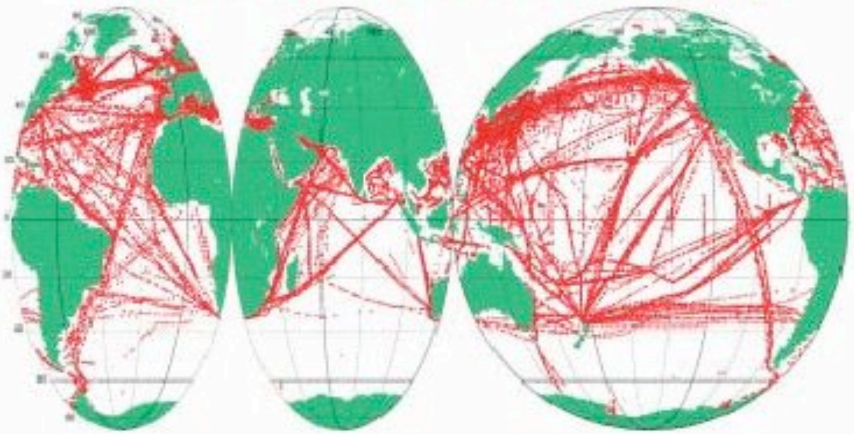
WOCE Hydrographic Survey Lines



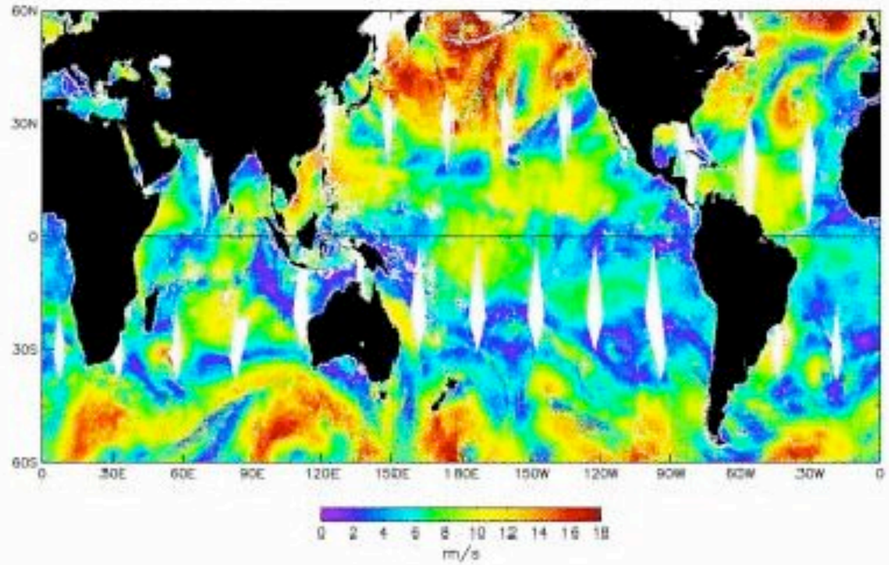
TOPEX/POSEIDON 10-Day Repeat Ground Track



Observations from Volunteer Observing Ships

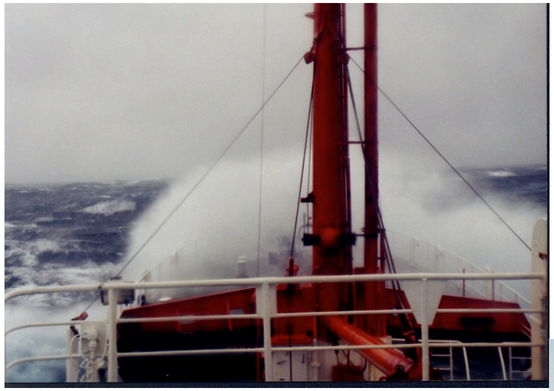


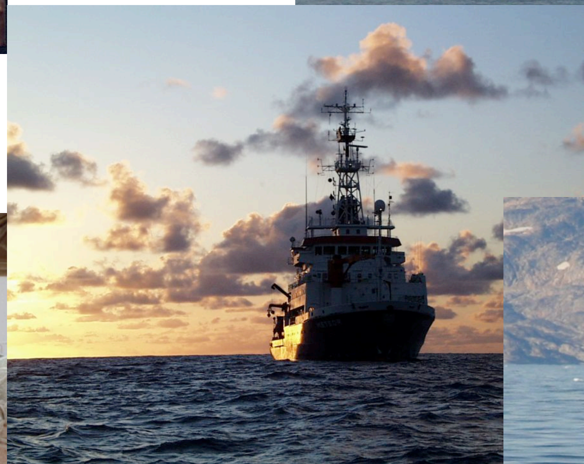
QuikSCAT Coverage in 24 Hours (1 February 2000)



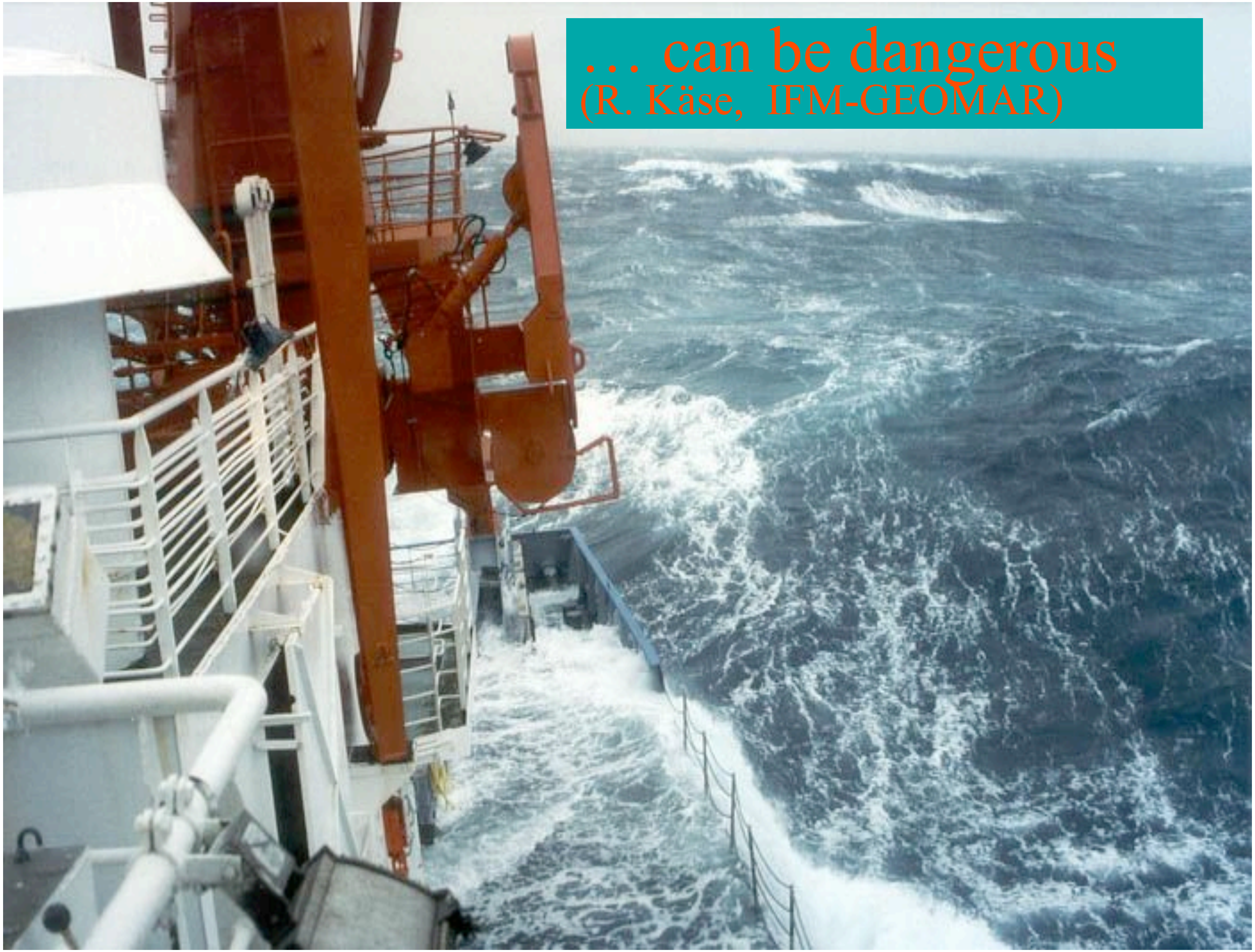
The alternative to Earth observations from satellites

The use of Research Vessels …

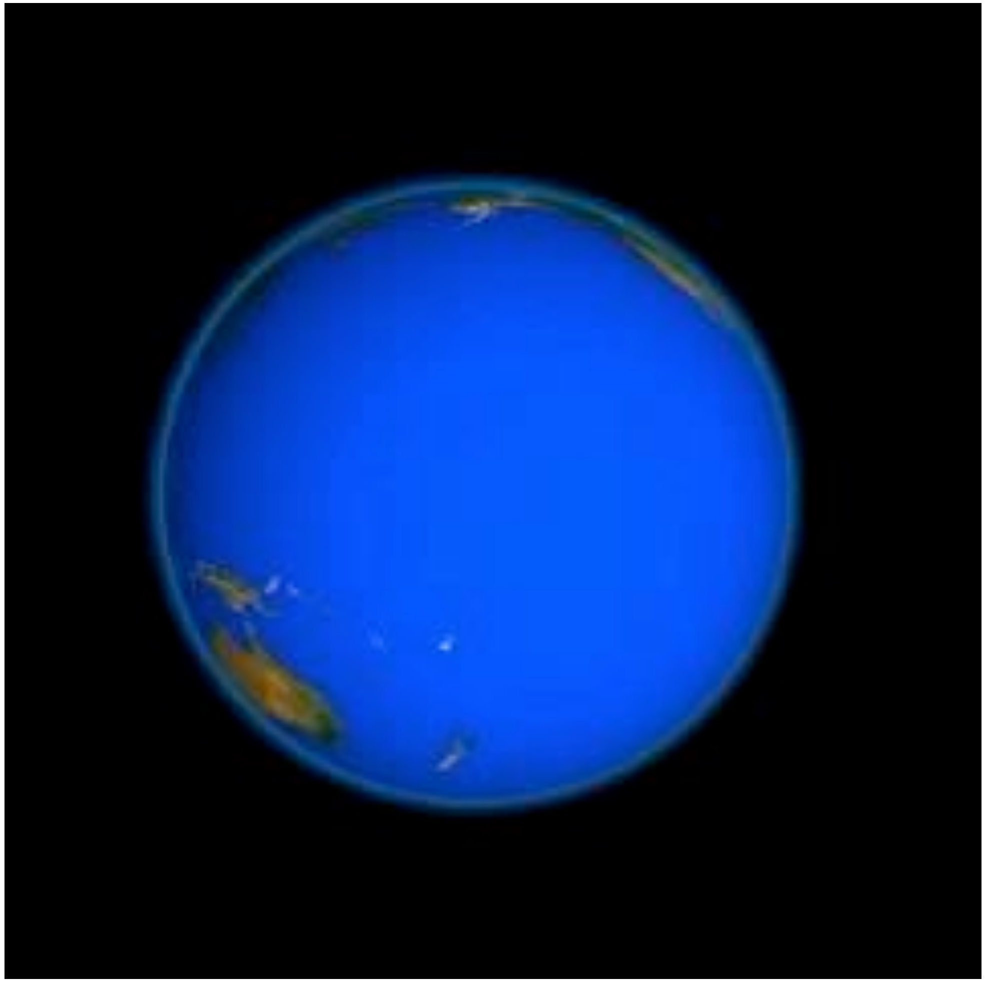




(D. Quadfasel, IfM)


… can be dangerous
(R. Käse, IFM-GEOMAR)

Earth observing Satellites are an important ellement of the Earth observing system



The offer the possibility to observe the Earth globally with a space-time resolution required for quantitative monitoring over the ocean, land, Ice and in the atmosphere.

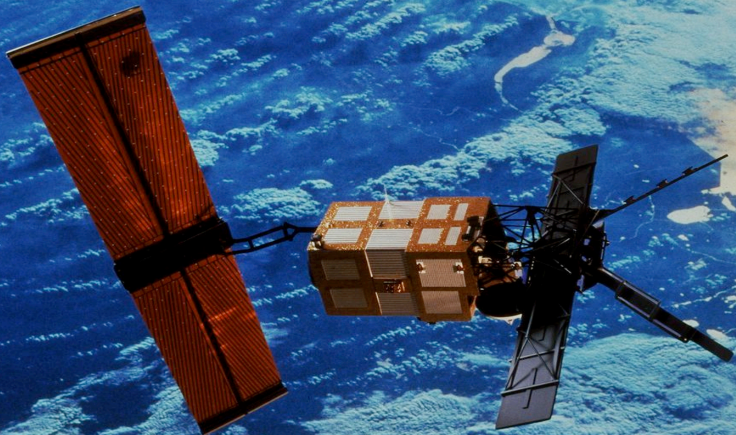
esa

ERS-1 first ESA Earth observing Satellite. Launched in 1991. Continued by ERS-2 in 1995.

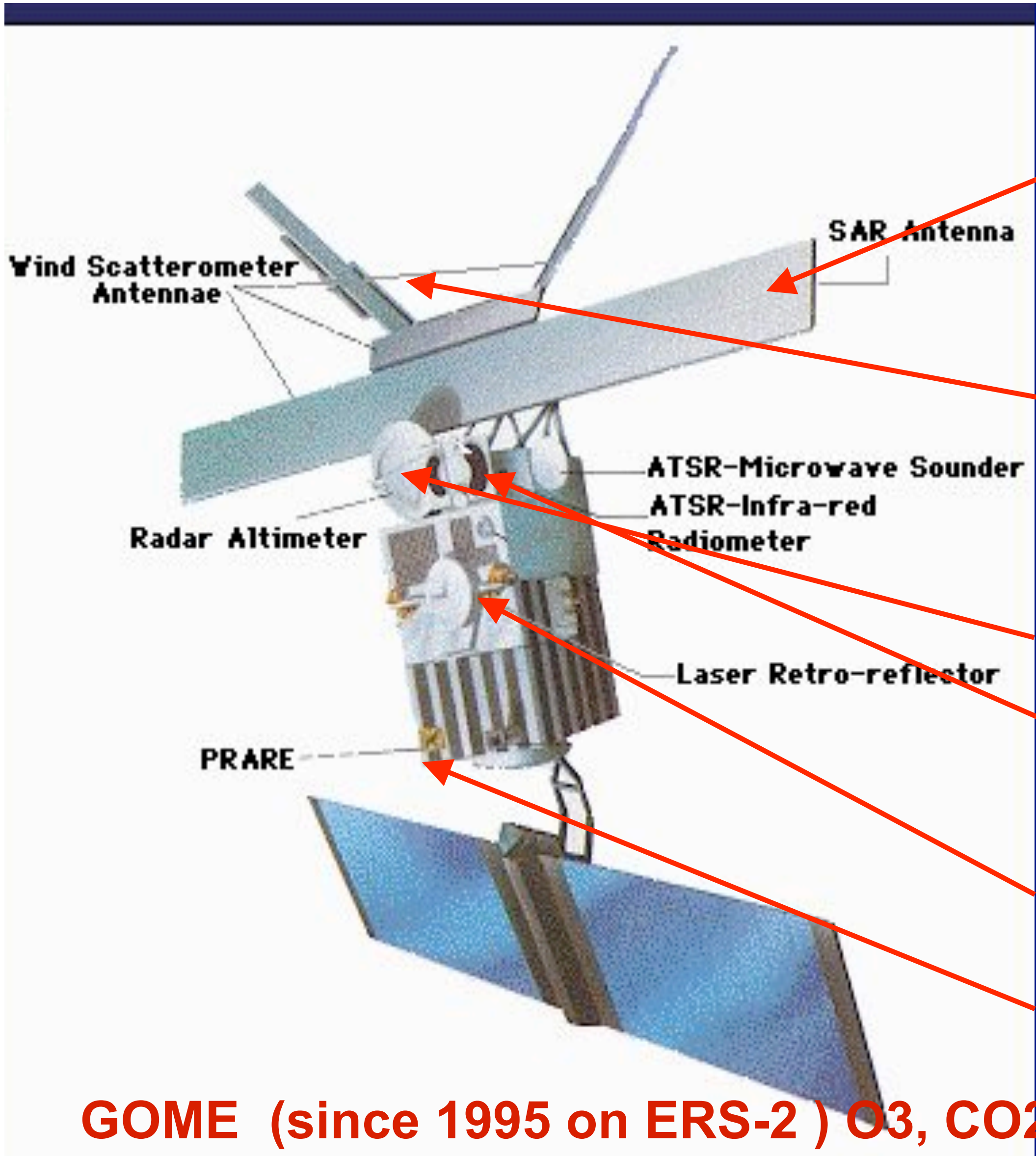
http://www.esa.int

http://earth.esa.int

http://envisat.esa.int



ERS-1/2 Payload



AMI (C-Band, 5.3 GHz)

- **all weather, day and night**

SAR image mode (High rate)

SAR wave mode (Low Rate)

Wind Scatterometer (Low rate)

- **all weather; compared to Ku-band scatterometers no rain contamination**

Radar Altimeter (Microwave sounder)

ATSR (ATSR-2 ERS2) Along Track Scanning Radiometer

- **SST measurement precision: 0.1 K**

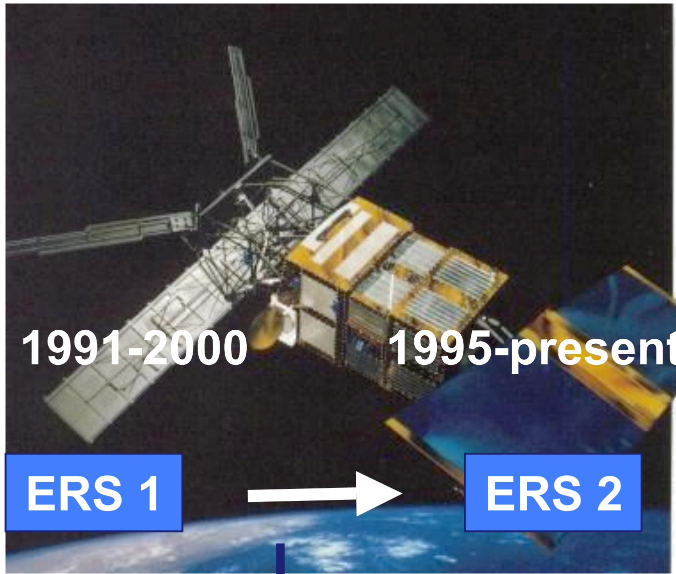
Laser Retro-reflector

PRARE (Precise Range and Rate Equipment)

GOME (since 1995 on ERS-2) O3, CO2, SO2

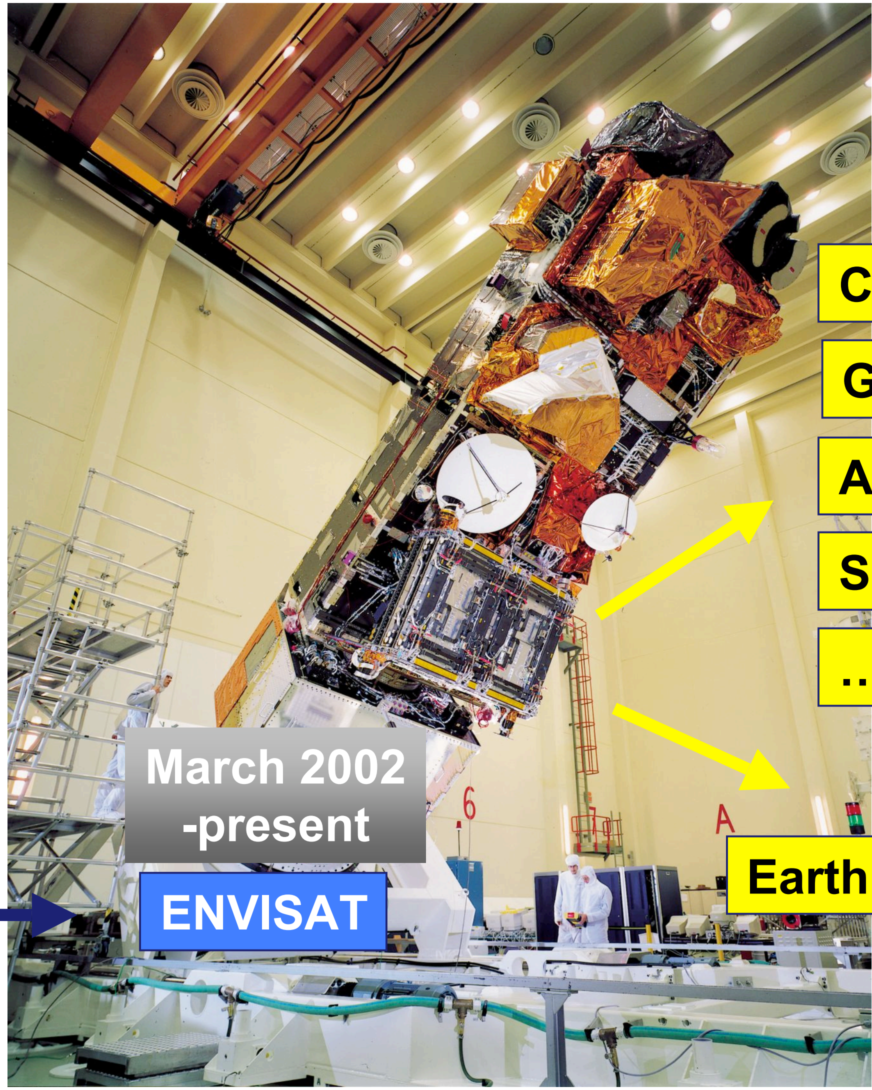
Europe's expanding EO Capability

Continuity & Evolution



Oceans
Sea Ice
Cryosphere
Land Surface

+ Global Ozone
+ enhanced ATSR
(3 visible channels)



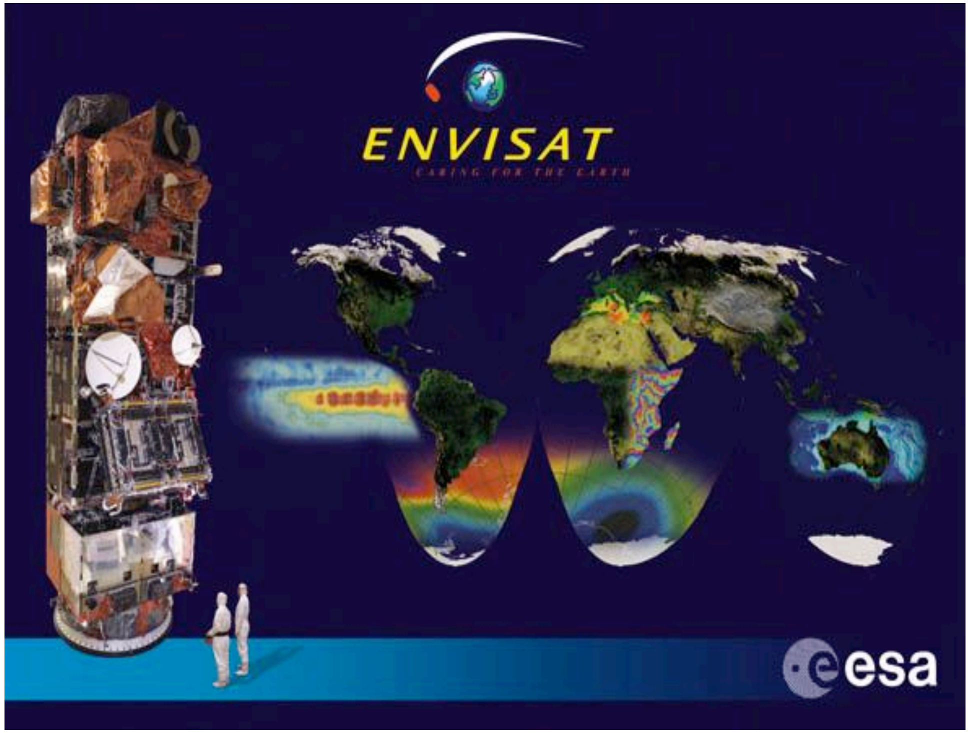
CryoSat
GOCE
ADM
SMOS
…more

Earth Watch

+ Ocean Colour
+ Atmospheric Constituents

ENVISAT: Mission Objectives

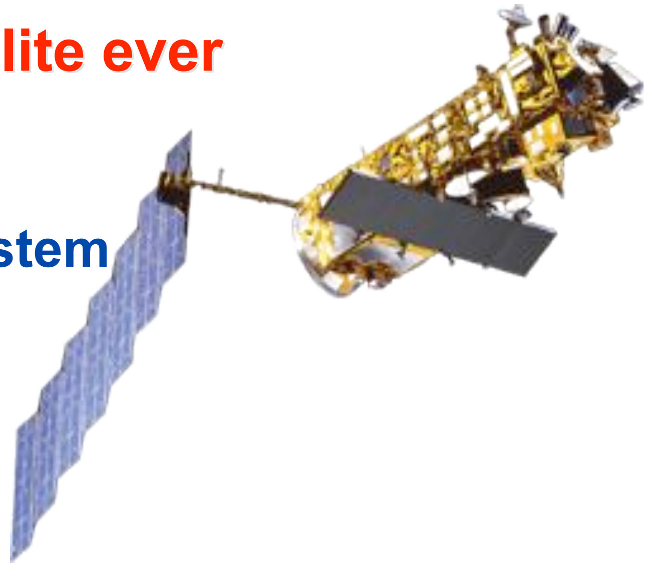
- to provide for continuity of the observations started with the ERS satellites, including those obtained from radar-based observations,

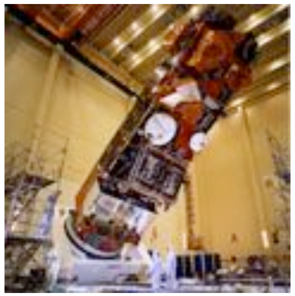


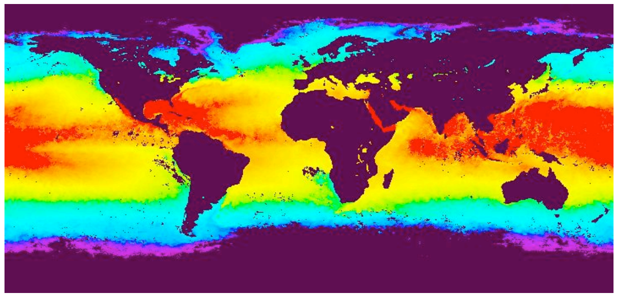
- to provide for enhancement of the ERS missions, notably the ocean and ice mission,
- to extend the range of parameters observed, to meet the need to increase knowledge of the factors determining the environment,
- to make a significant contribution to environmental studies, notably in the areas of atmospheric chemistry and ocean studies (including marine biology).

ENVISAT

- ♣ Largest Earth Observation satellite ever
- ♣ Flagship of ESA Earth Observation
- ♣ 10 sensors to monitor the Earth system
- ♣ 77 types of data products
- ♣ 140 GB data generated per day
- ♣ Launched 1st March, 2002







- ¬Launch by ARIANE 5 on 1st March 2002

- ¬Injection on perfect orbit

- ¬Launch configuration
  - ♣length 10.5 m
  - ♣envelope diameter 4.6 m

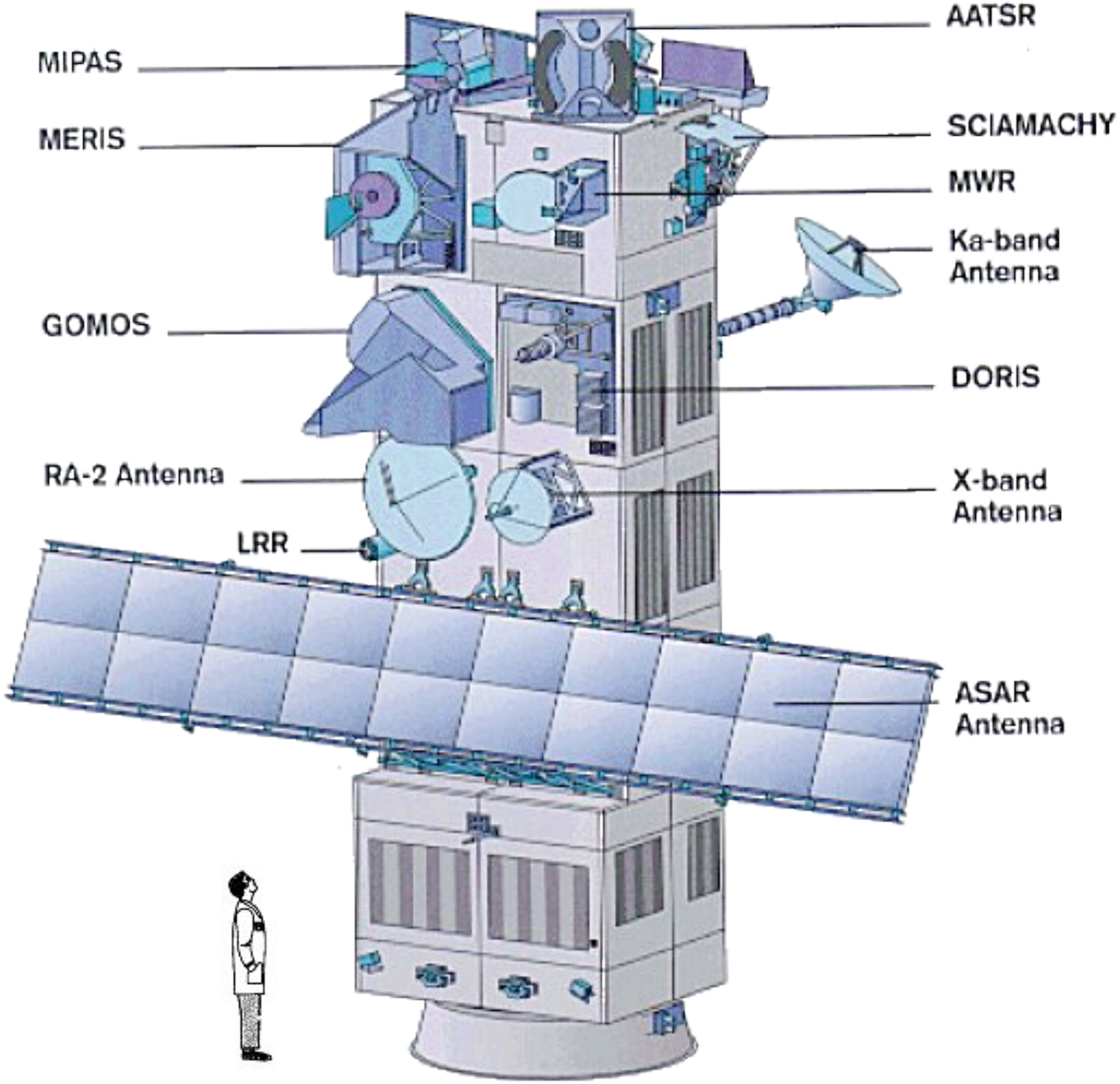
- ¬In-Orbit configuration
  - ♣**26m x 10m x 5m**

- ¬ **Mass**
  - ♣Total satellite **8140 Kg** (ERS1 2384 kg)
  - ♣Payload 2050 Kg

- ¬Solar array power
  - ♣6.5 kW (EOL)

- ¬Orbit
  - ♣sun synchronous, 800 km as ERS, 10:00, i.e. 30 minutes before ERS-2
  - ♣14 11/35 orbits per day
  - ♣repeat cycle of 35 days (501 orbits)

ENVISAT: powerful tool for monitoring the state of our planet



- ***Dimensions***
  - Launch configuration:
    - length 10.5 m
    - envelope diameter 4.6 m
  - In-Orbit configuration:
    - **26m x 10m x 5m**

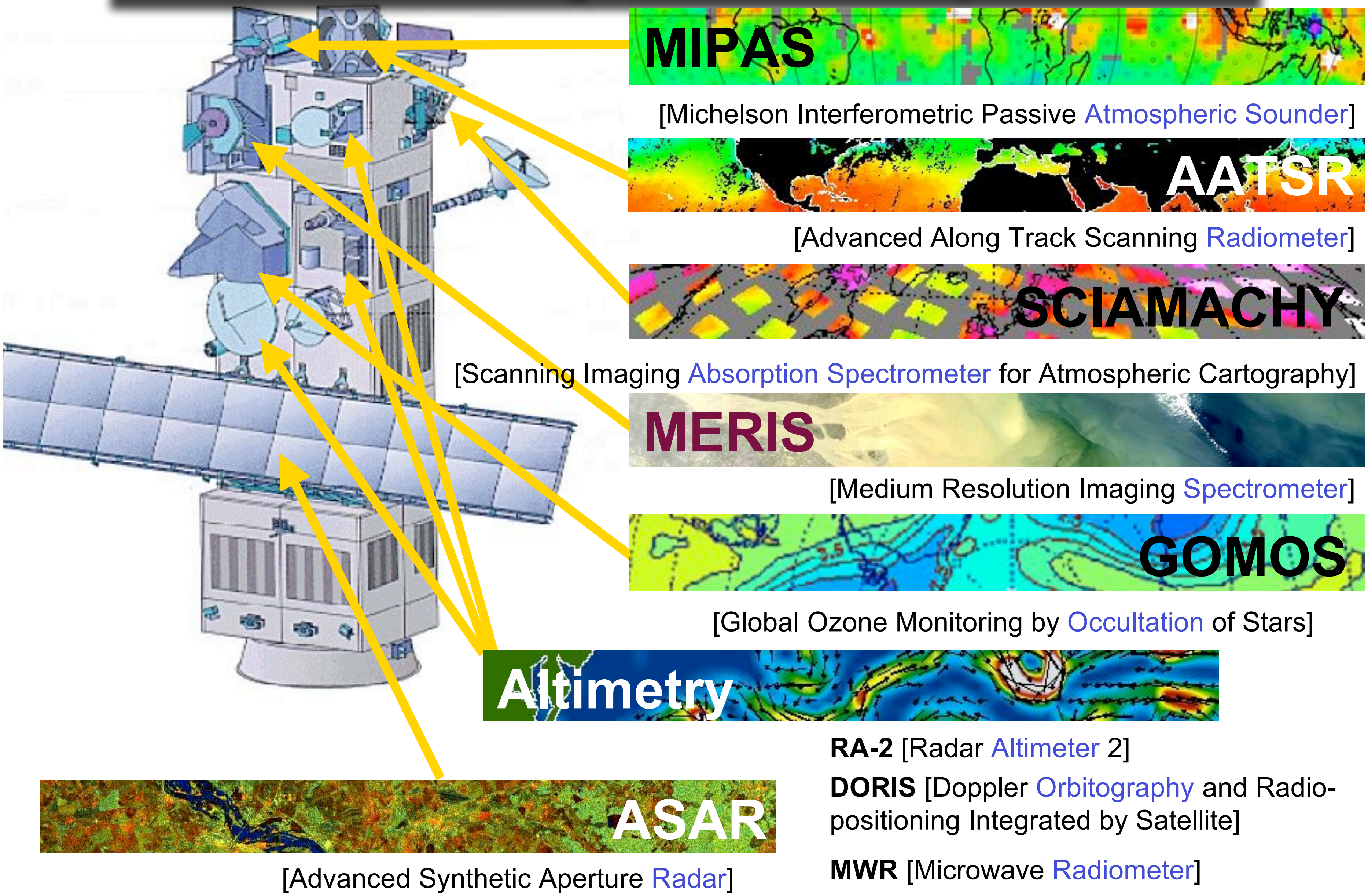
- ***Mass***
  - Total satellite **8140 Kg**
  - Payload 2050 Kg

- ***Power***
  - Solar array power*:*
    - 6.5 kW (EOL)
  - Average power demand*:*

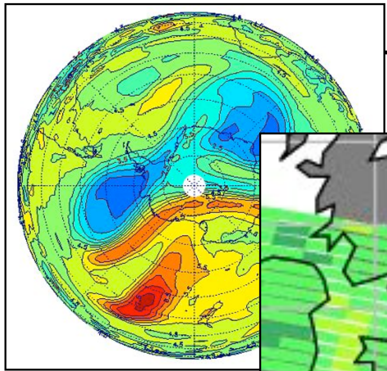
	Sun (watts)	Eclipse (watts)
Payload	1700	1750
Satellite	3275	2870

- ***Orbit***
  - **800 km** as ERS, sun synchronous 10:00, i.e. 30 minutes before ERS-2

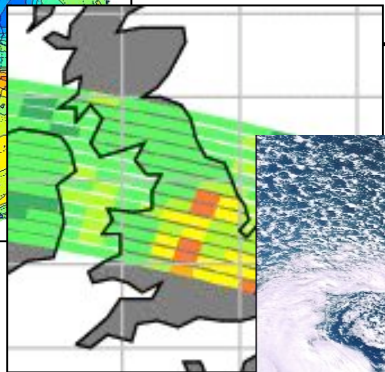
ENVISAT: powerful tool for monitoring the state of our planet



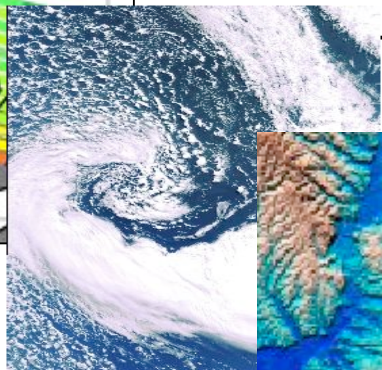
Synergy between ENVISAT instruments: what ENVISAT can see when it looks down at you?



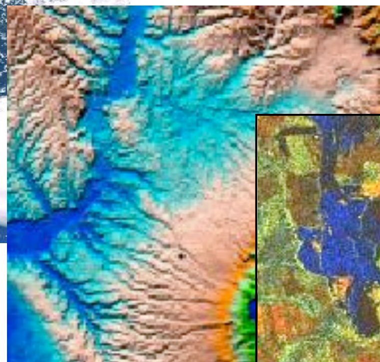
Altitude 0 to 100 km: GOMOS, MIPAS and SCIAMACHY are building a three-dimensional profile of ozone concentrations in the atmosphere.



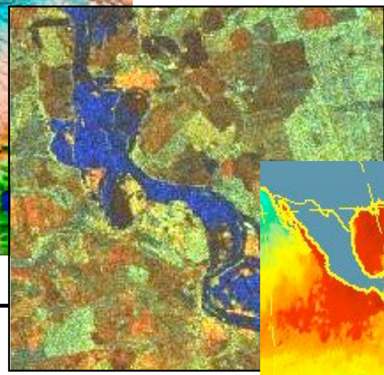
Altitude 0 to 20 km: MIPAS and SCIAMACHY are detecting low levels of gases from industry, power generation and agriculture.



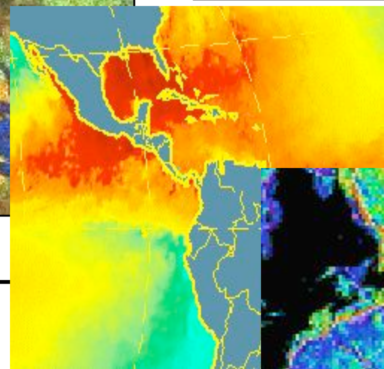
Altitude 0 to 10 km: MERIS obtains an image in which the clouds you see are but a part of a complex map of the concentration of water vapour.



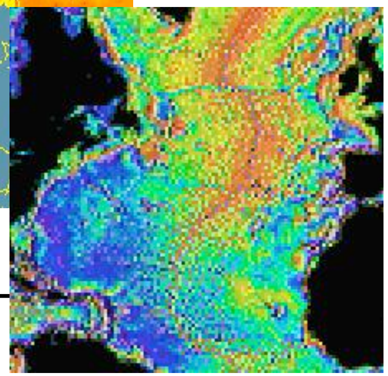
Altitude 0 to 4 km : ASAR and RA-2 create an accurate digital map of your surroundings, with height contours as accurate as 10 m.



Ground level: ASAR, AATSR and MERIS map the vegetation and land use around you.

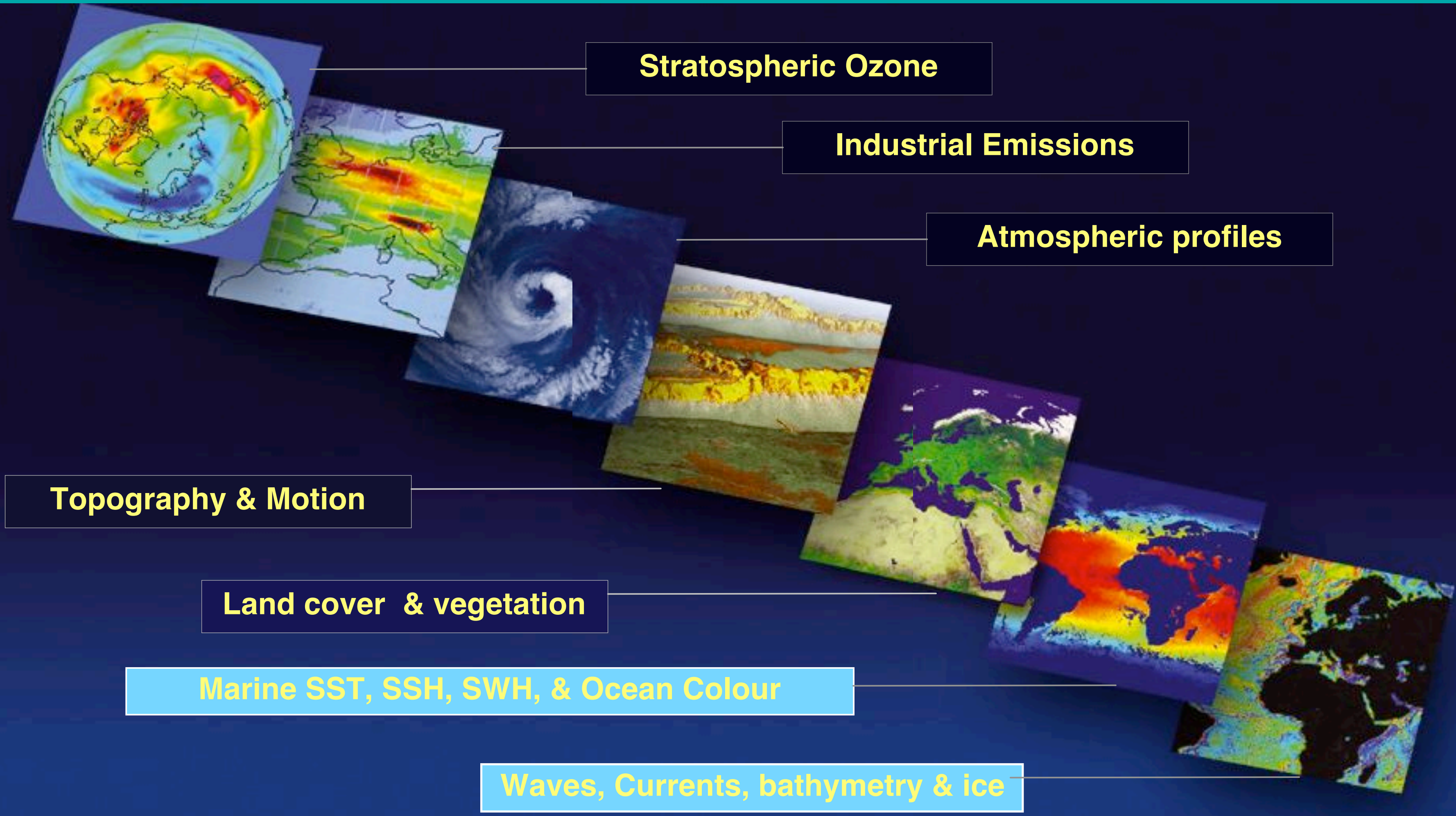


Sea level: AATSR measures sea surface temperature to 0.3 °C accuracy. MERIS precisely maps ocean colour, plankton and chlorophyll distributions. ASAR and RA-2 measure ocean currents, average wave-heights and wind velocities.

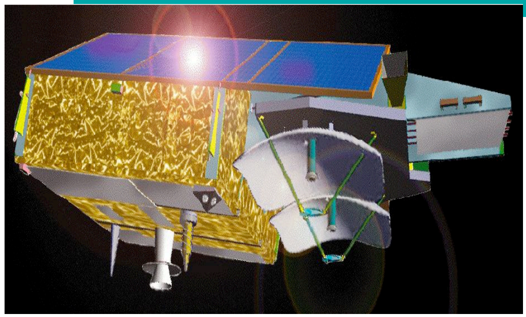


Underwater: RA-2 and DORIS combine to produce a detailed map of local gravitational strength, detecting the distribution of denser and less dense rock in the Earth crust beneath the oceans.

Environmental Information from Envisat



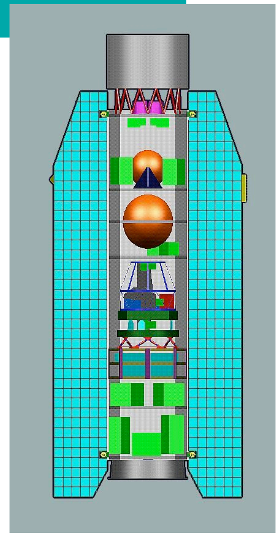
Earth Explorer Missions



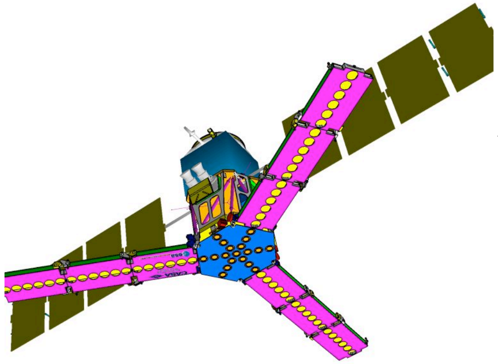
Ice elevation, ice thickness
Launch 2004

CryoSAT-II

Gravity field and geoid
Launch 2006



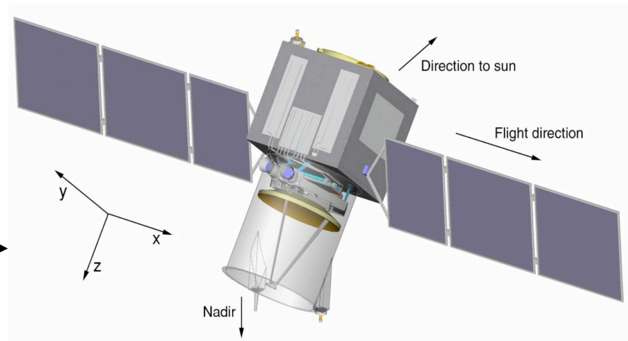
GOCE



Soil moisture and ocean salinity
Launch 2007

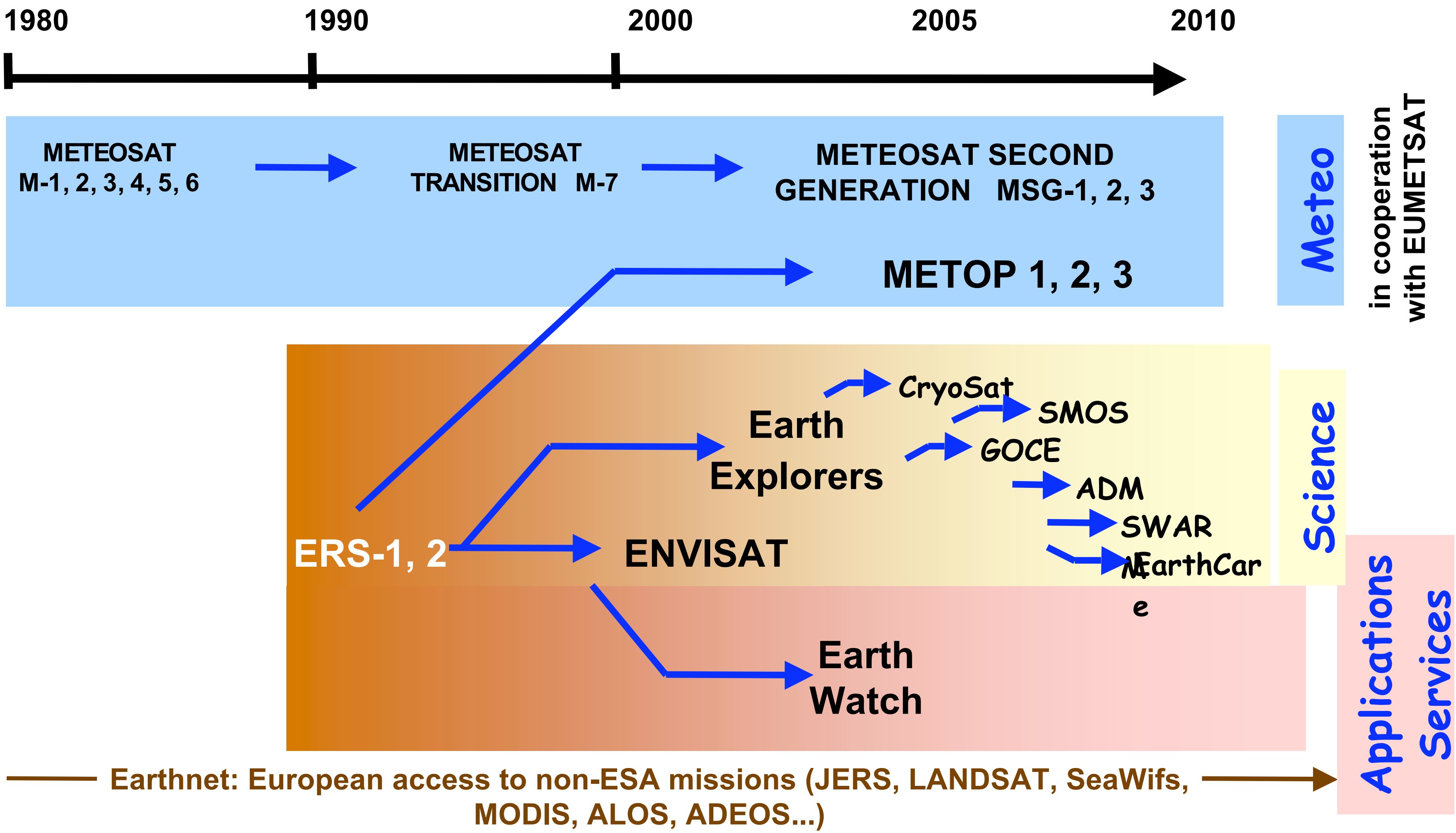
SMOS

Wind speed vectors
Launch 2008



ADM-Aeolus

ESA's E.O. programme



Elements of Ocean Remote Sensing

Variables:

SSH, SST, Color, Eis, Wind, SWH.

Systems:

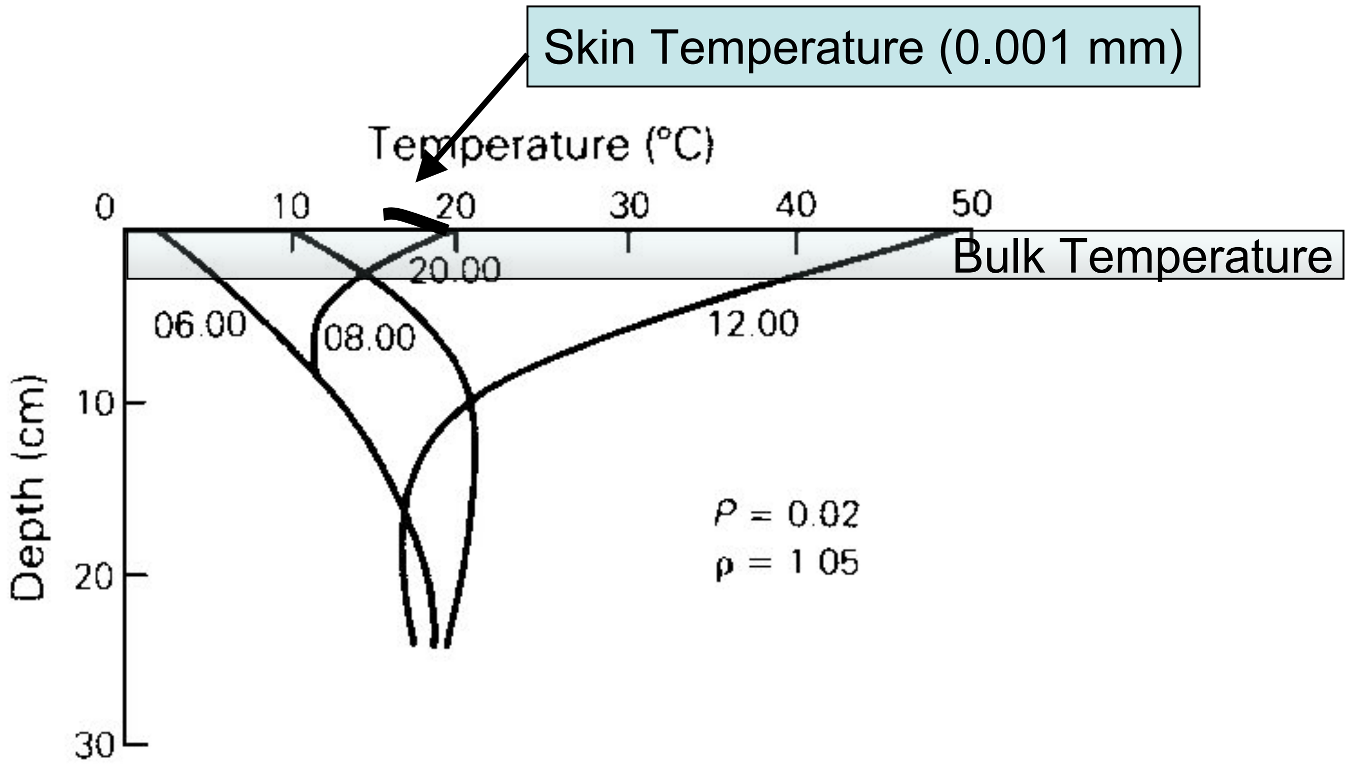
Passive: VIS, IR, MW.

Aktiv: ALT, SCAT, SAR, Laser

Remote sensing of the ocean is hampered by atmosphere, but less so in MW band.

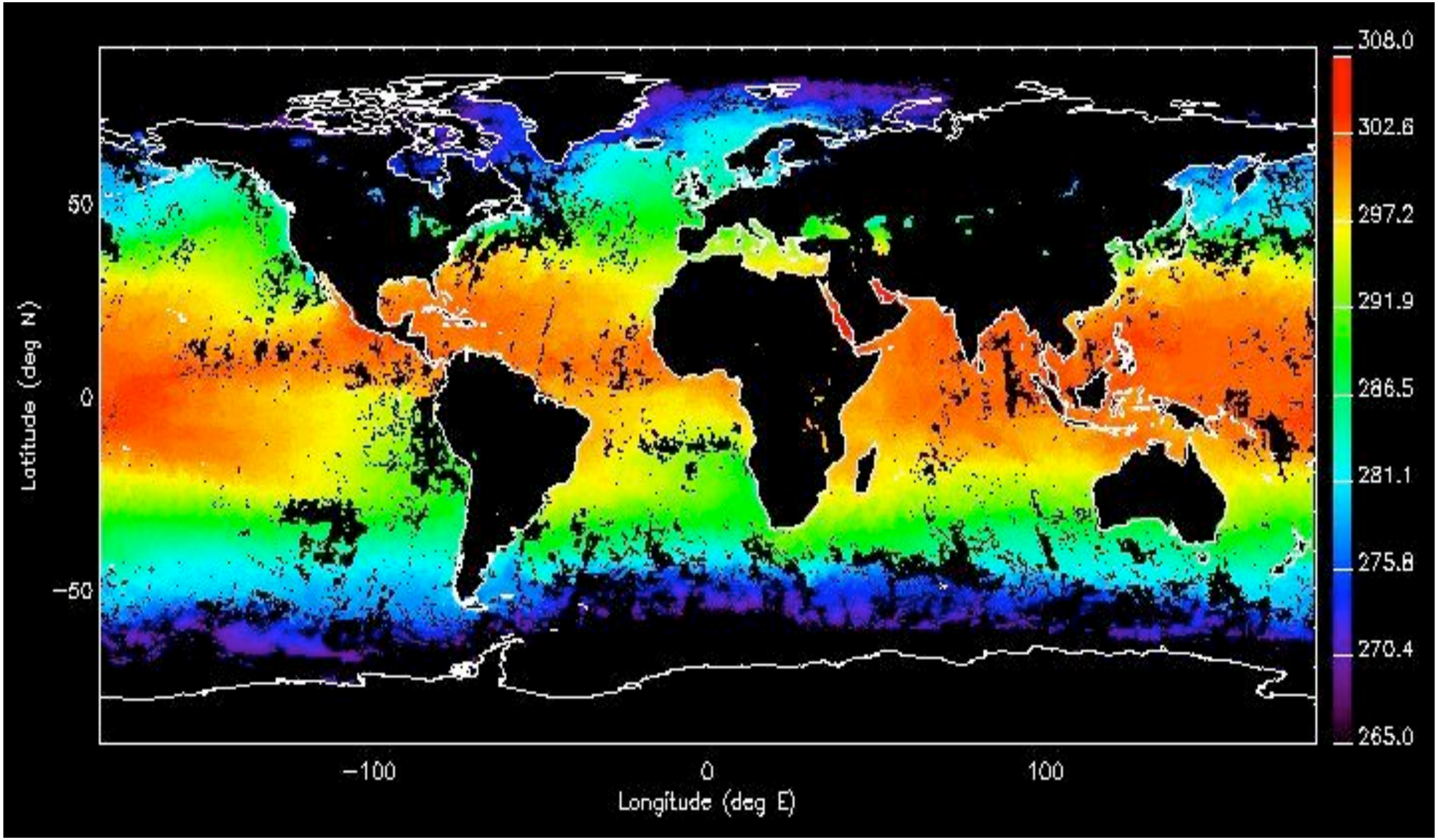
Data assimilation is important element of remote sensing.

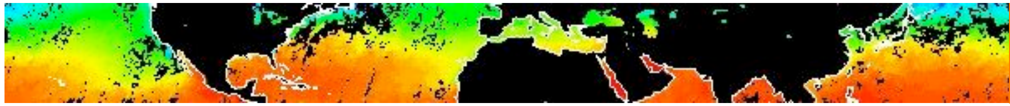
Sea Surface Temperature



Sea Surface Temperature

(October 2002)

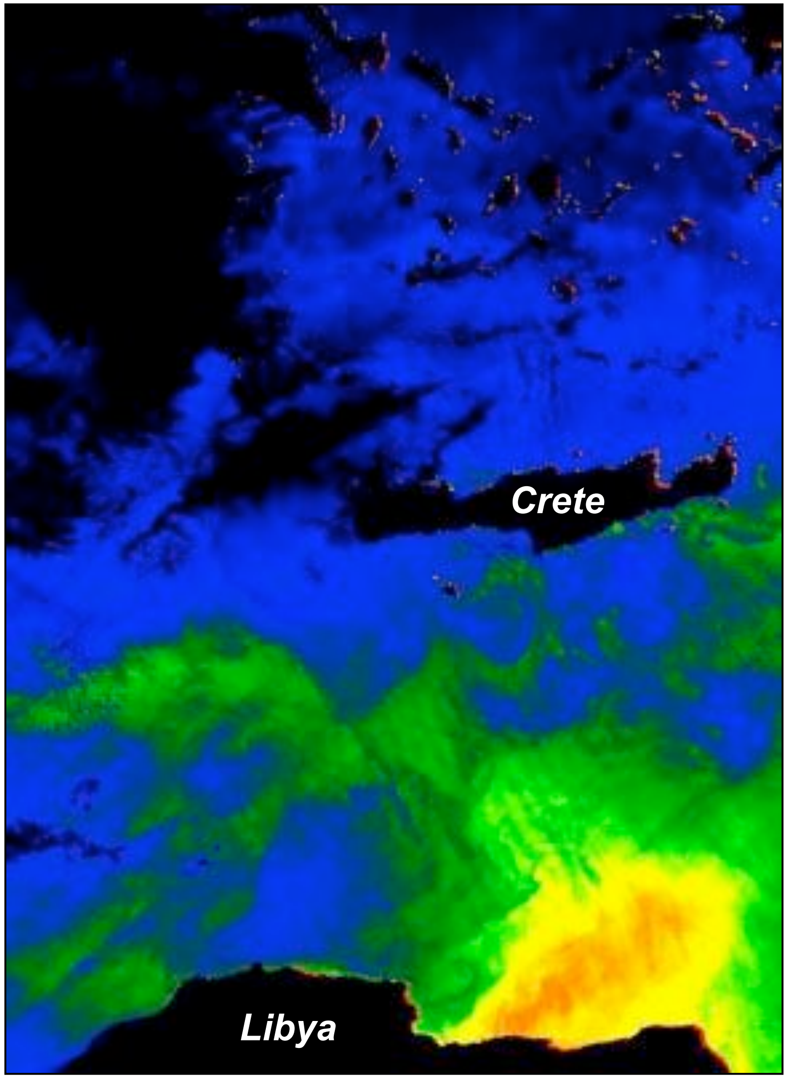




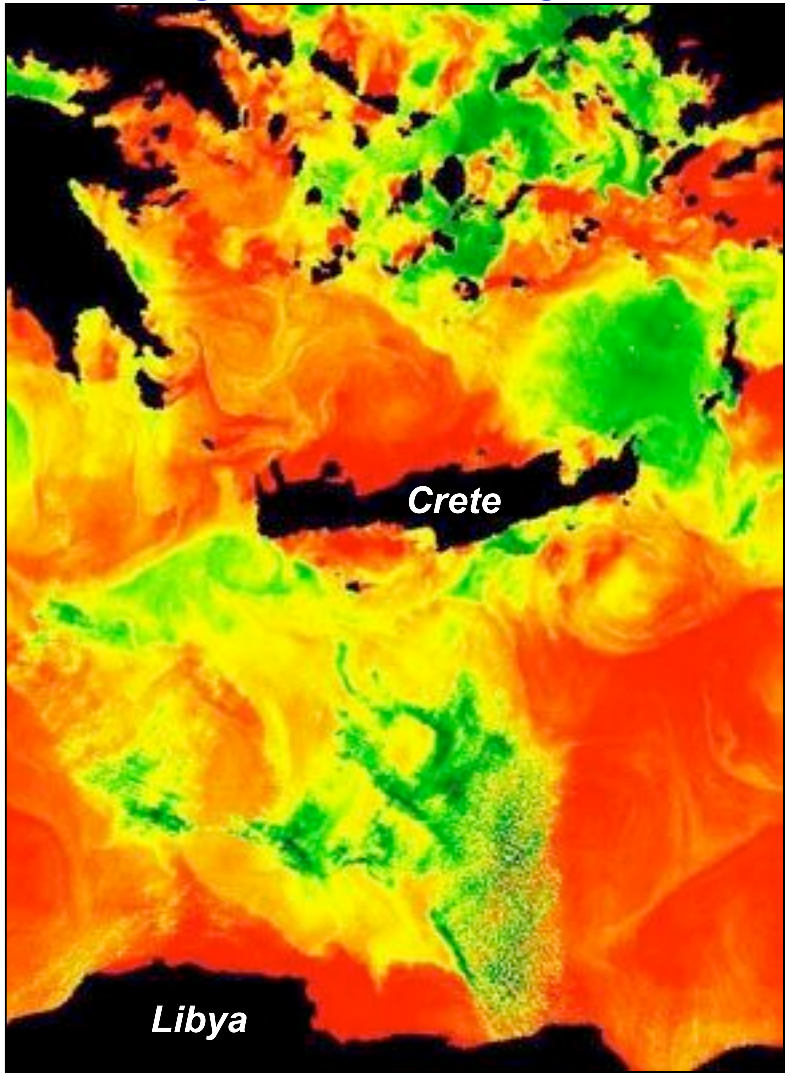
AATSR

Sea Surface Temperature

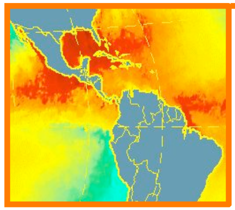
End August 2002



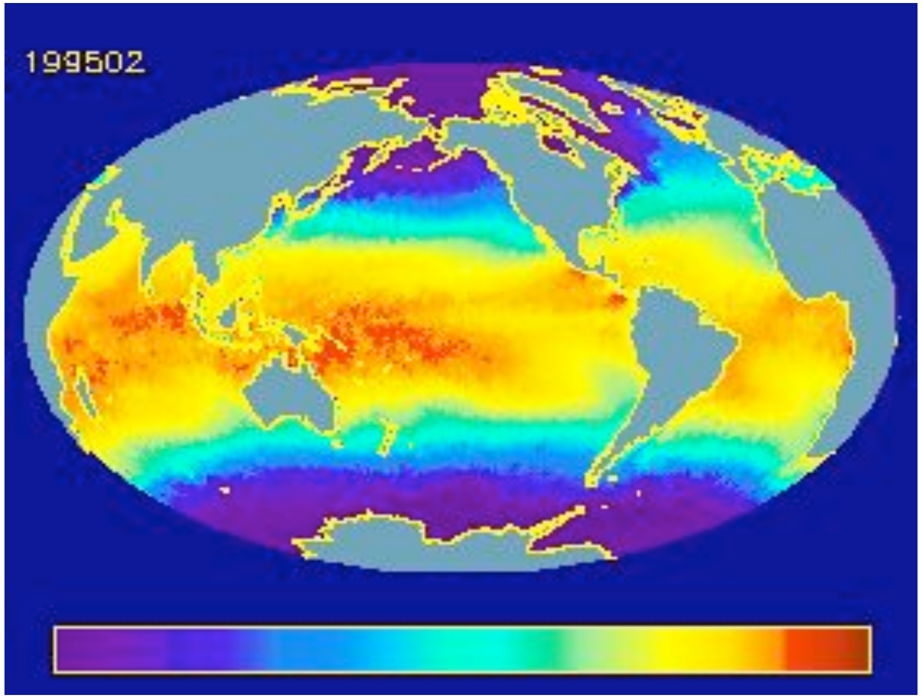
End August 2003: *3 degrees warmer*



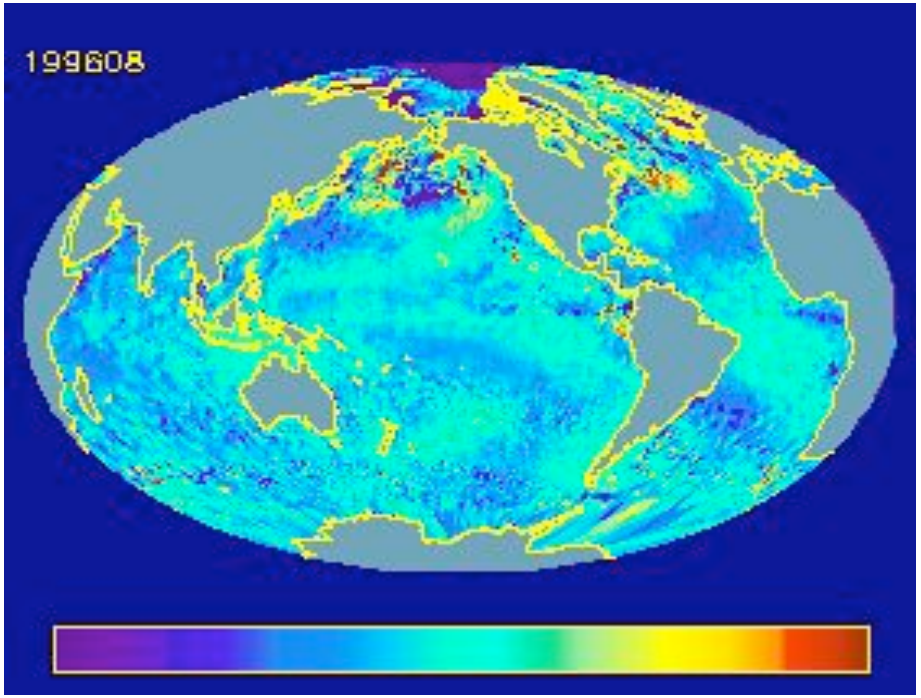
Long Term monitoring of SST



Sea level: AATSR measures sea surface <u>temperature</u> to 0.3 °C accuracy (with < 0.1 K / decade drift)

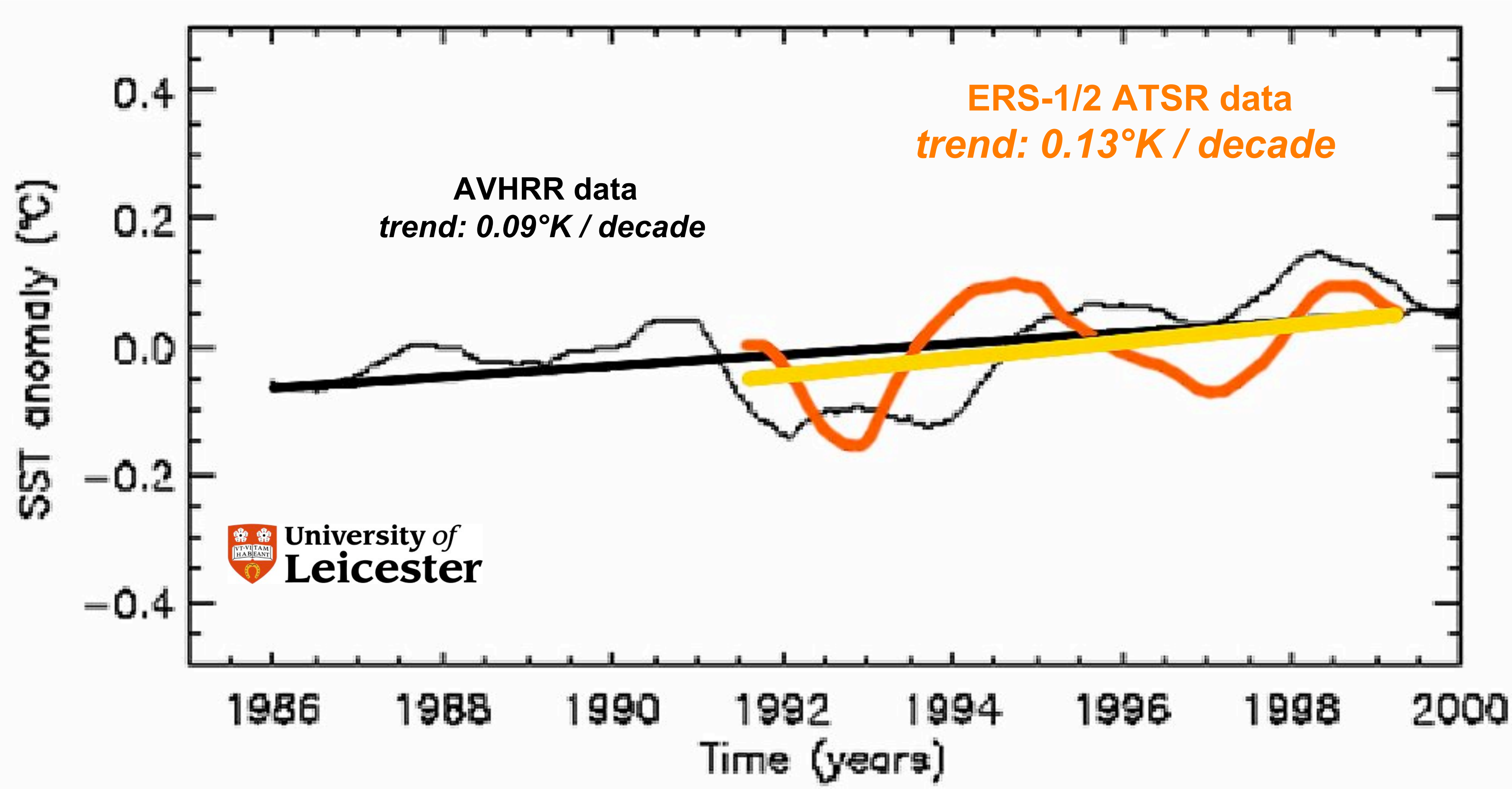


Mean Sea Surface Temperature

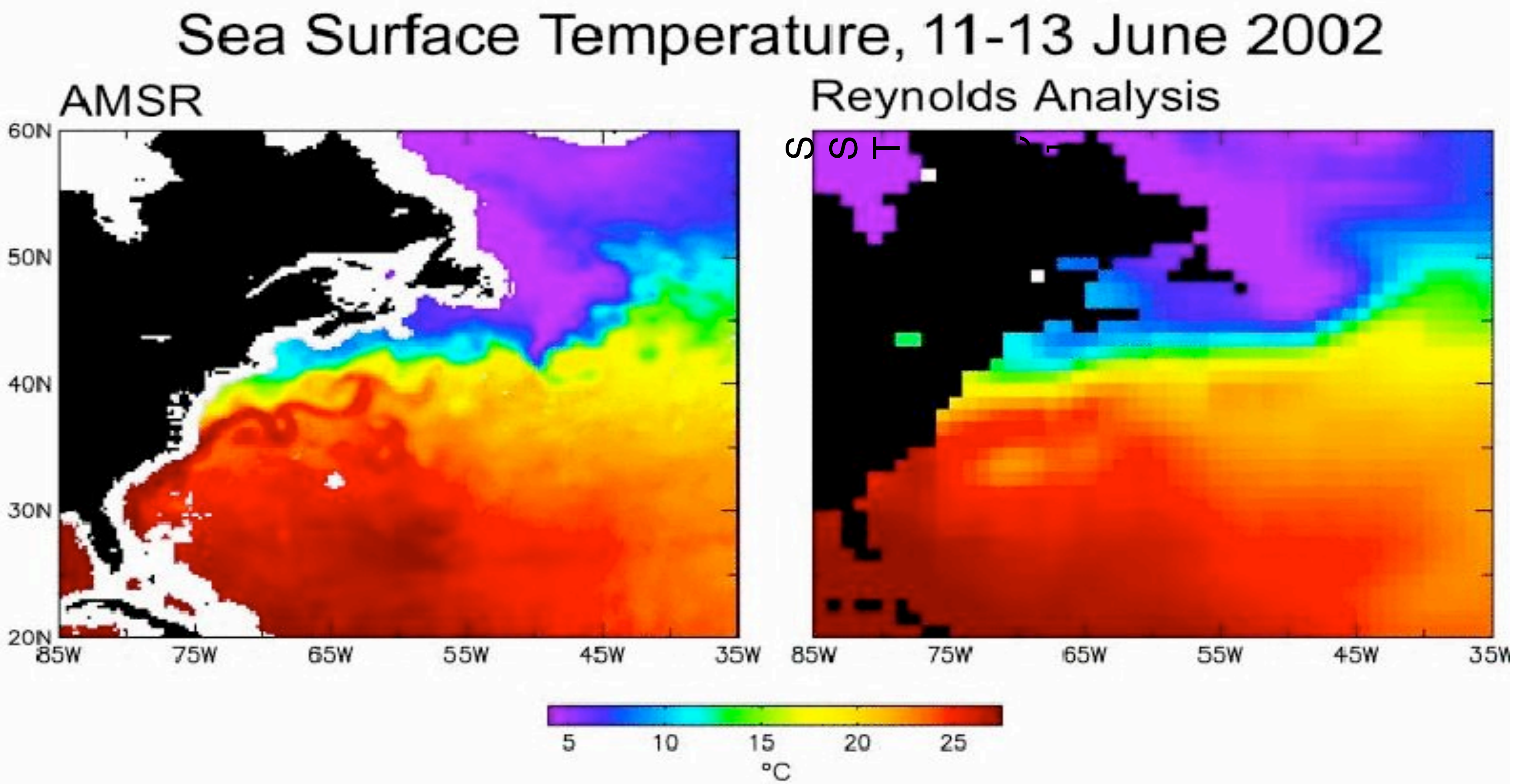


Sea Surface Temperature Anomaly

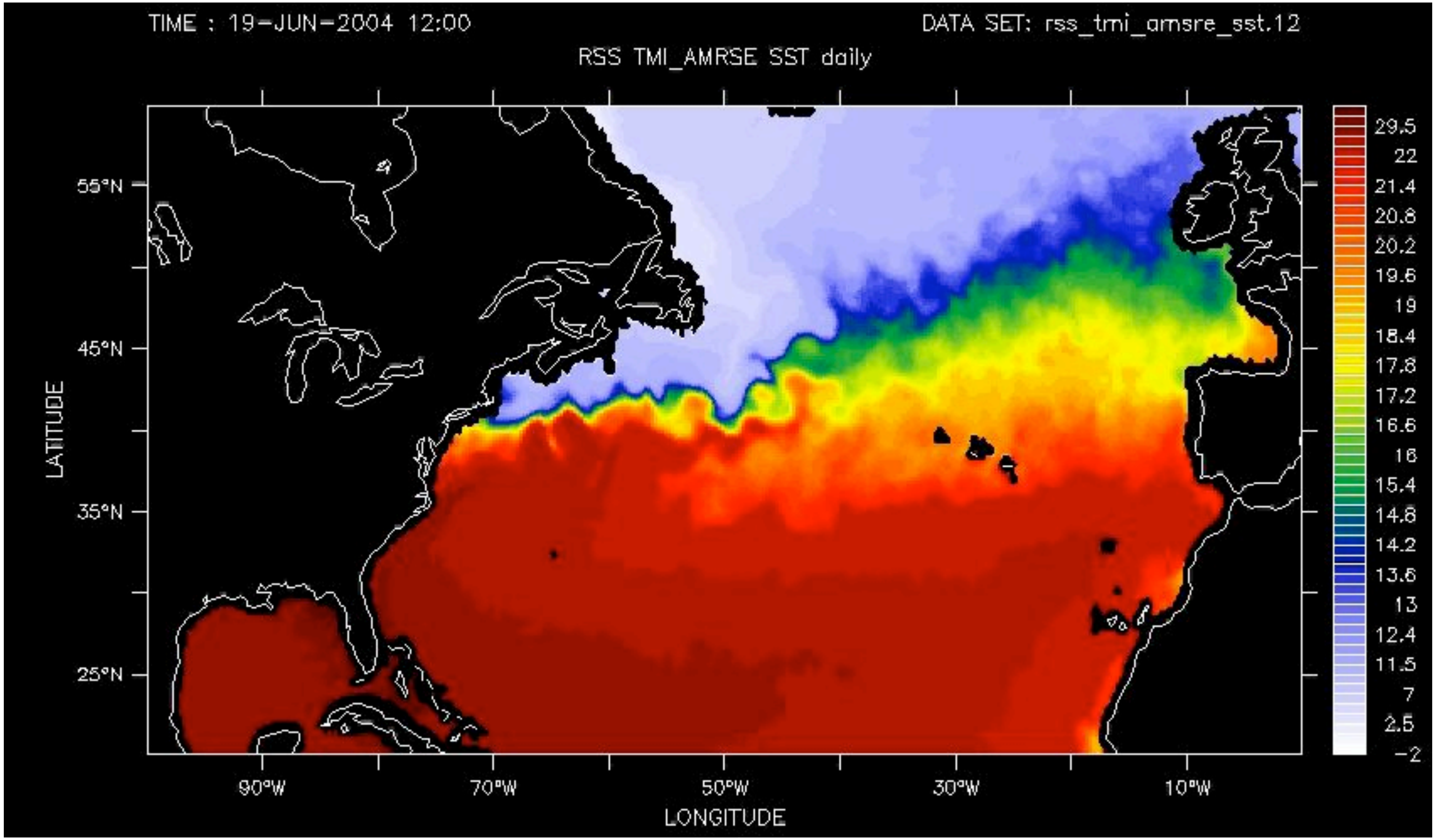
Estimate of Residual Trends in Global Sea Surface Temperature



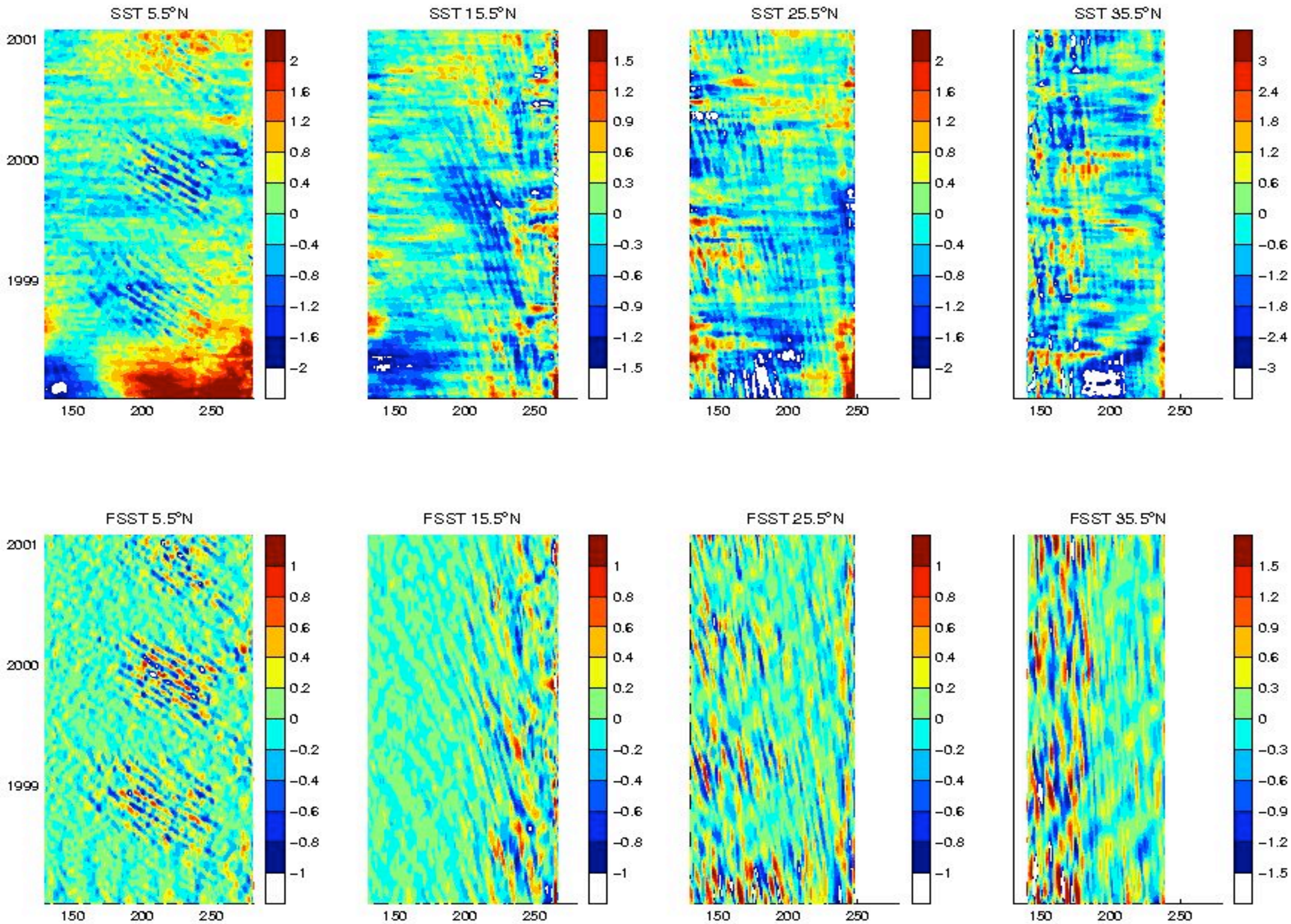
Measuring SST using Microwave Technology:



MW SST from AMSR-E



SST anomalies reveal ocean Rossby waves.



MW data lead to improved estimates

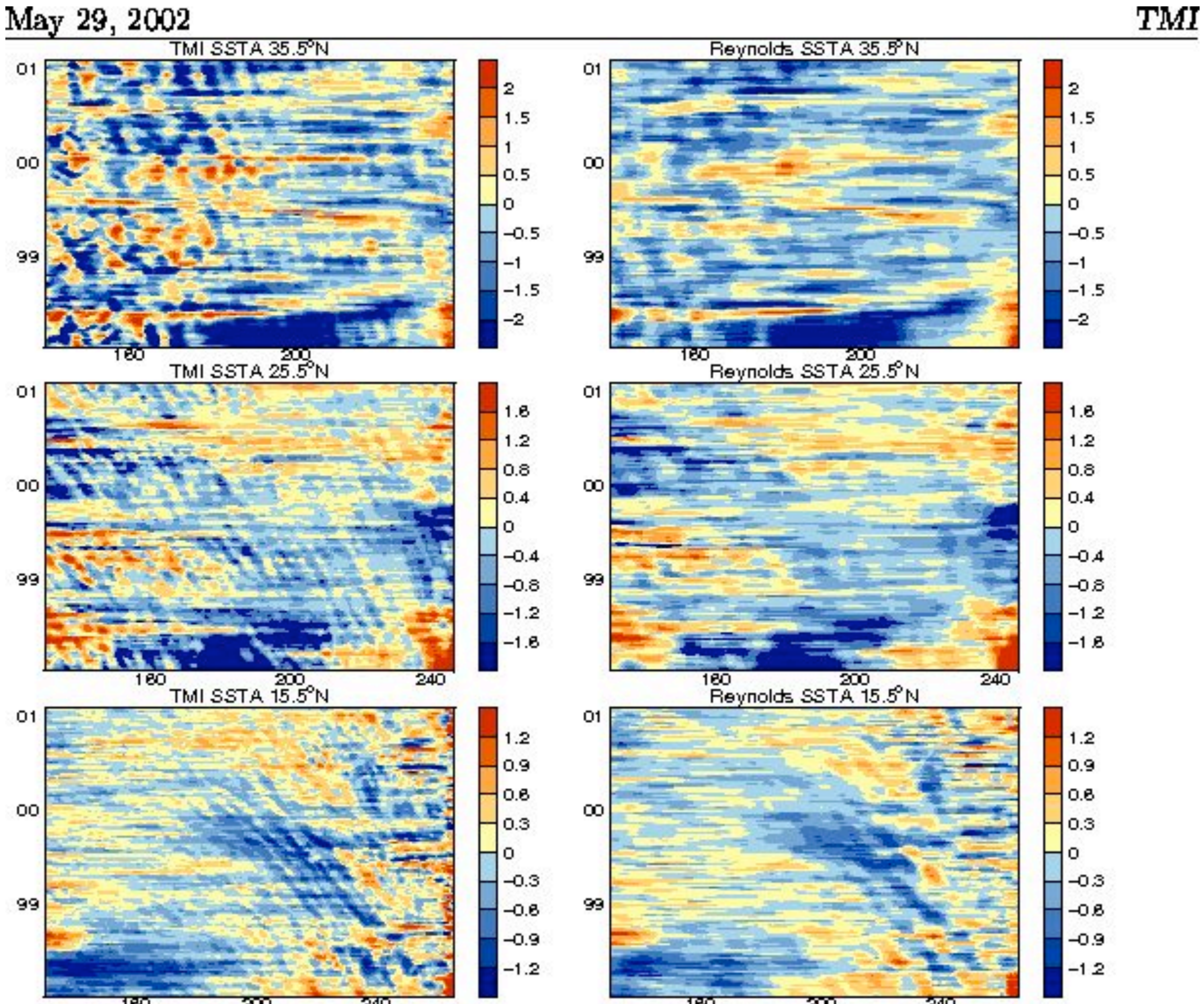
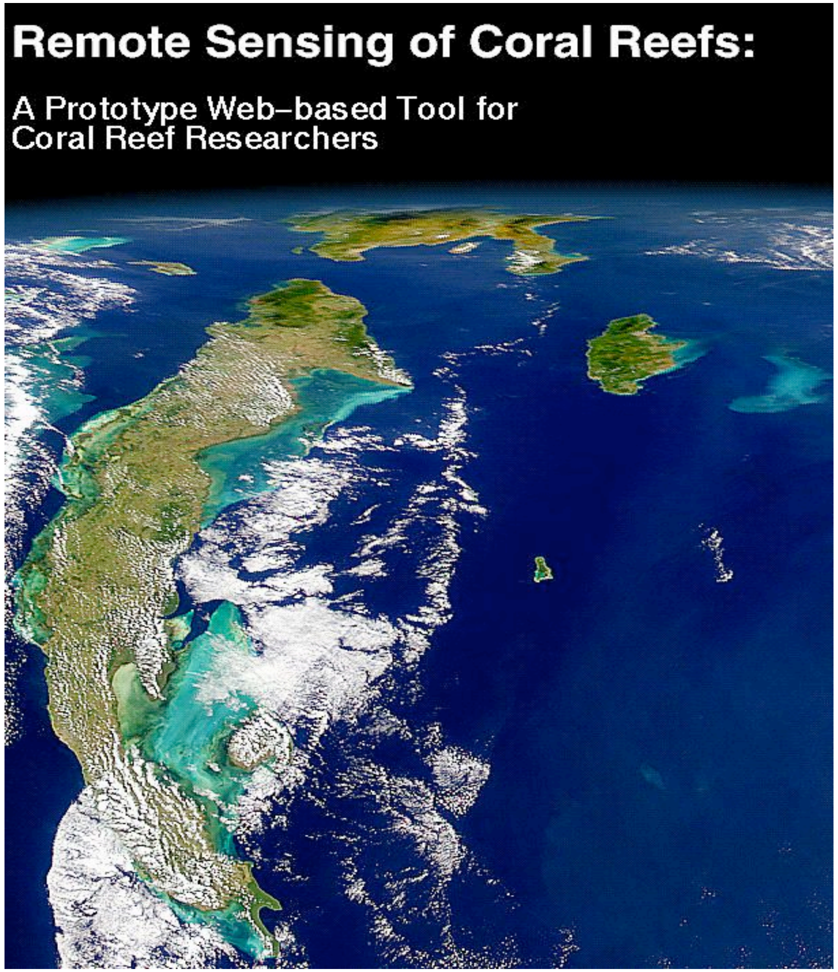
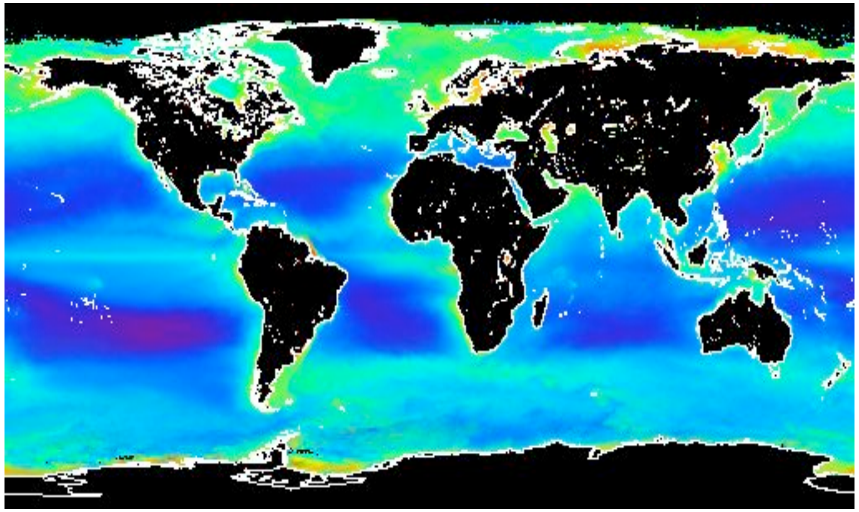


Figure 7:
24

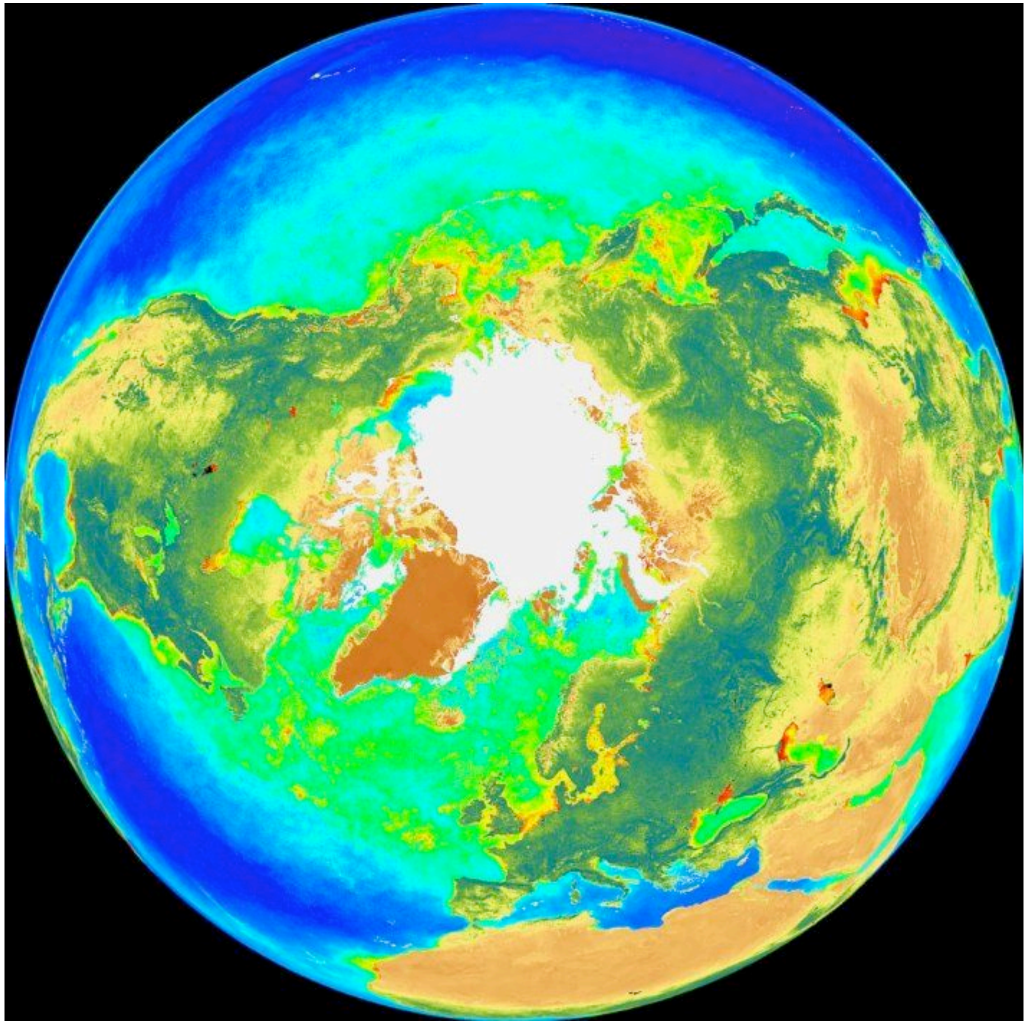
COLOR: Visible Observations of life and suspended matter.



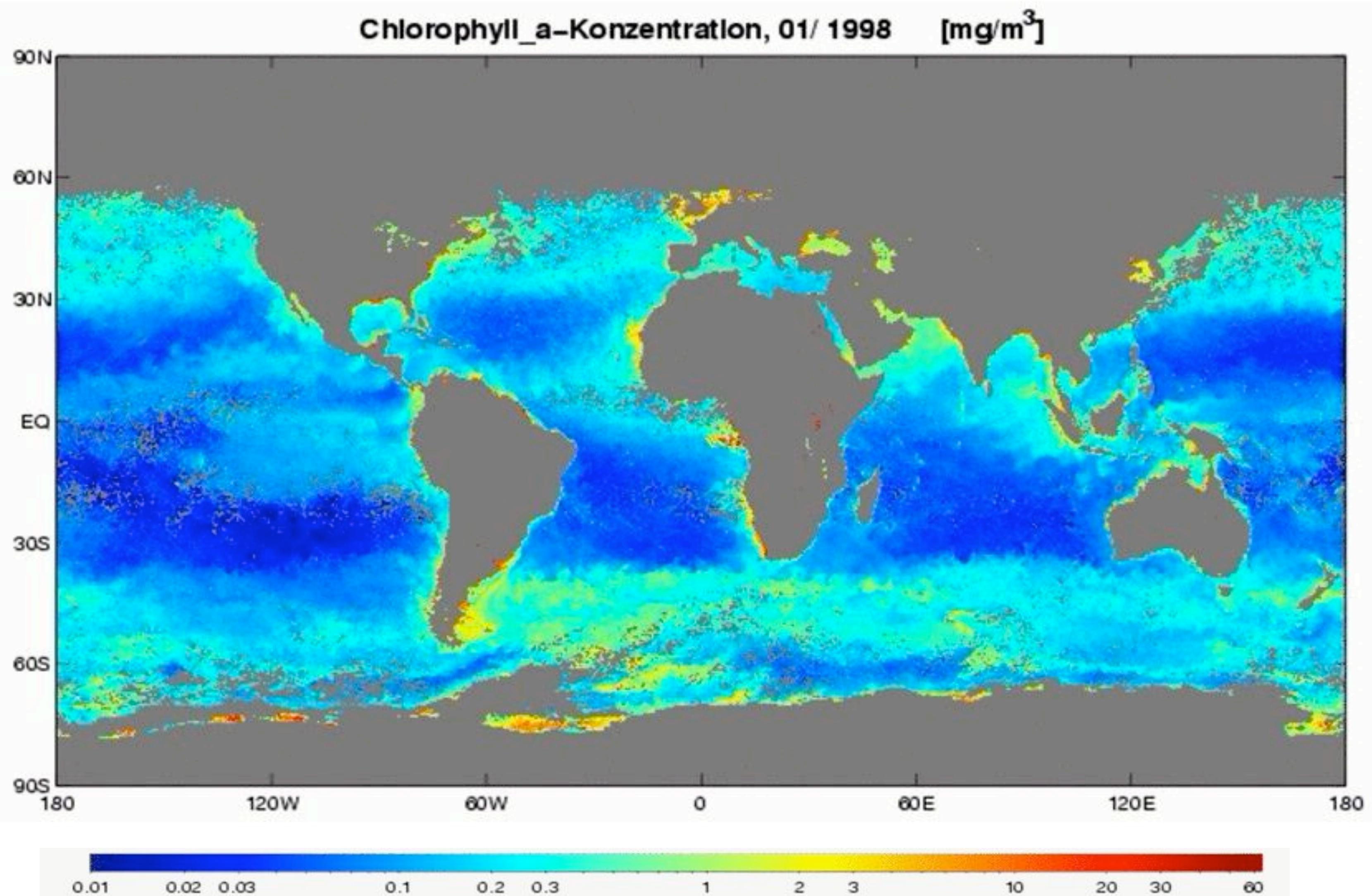
Primärproduktion, Absorption



Chl_a concentration and Ice

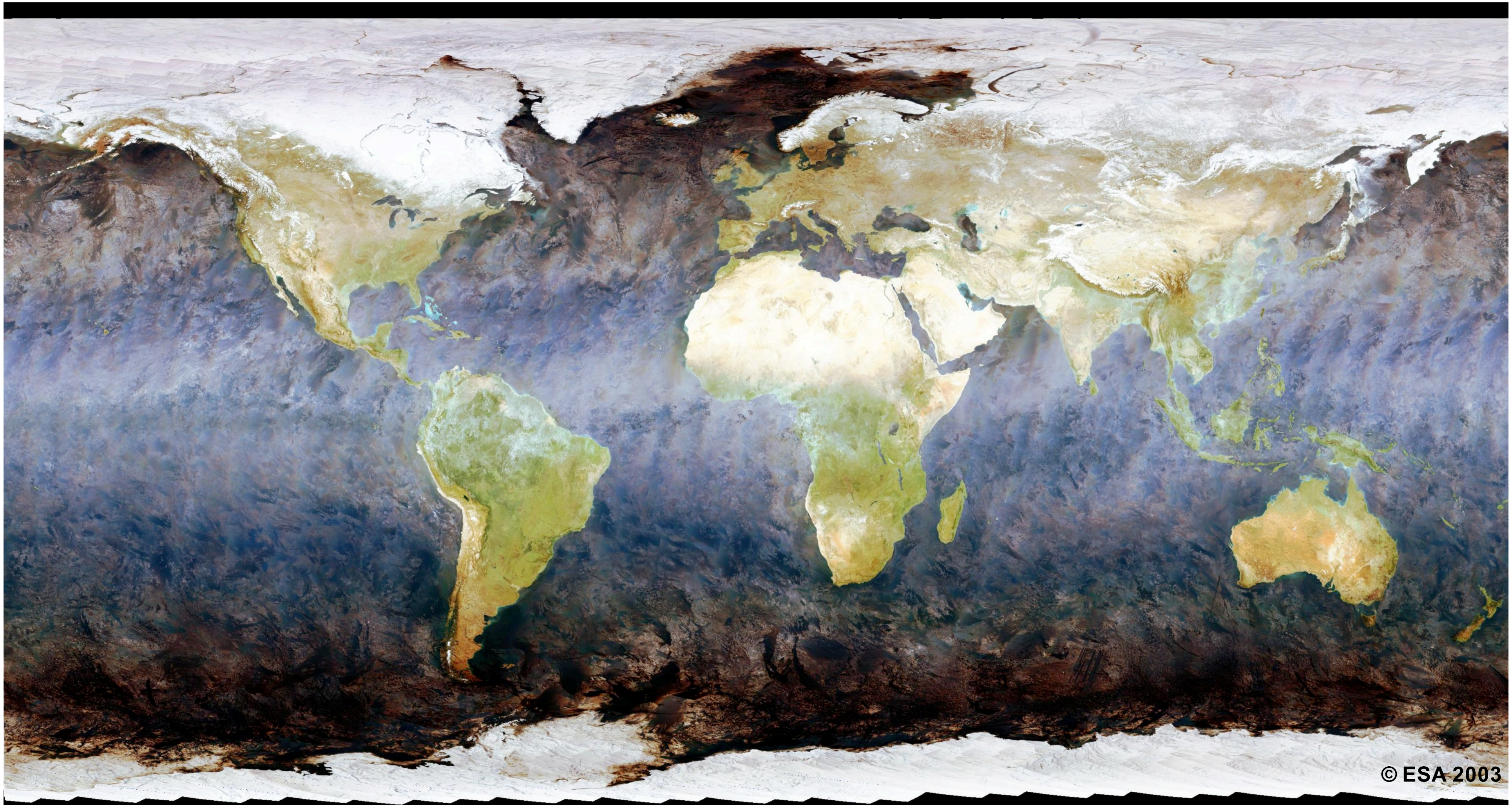


Animation Chl_a from SeaWIFS



(K. Anderssen, IfM)

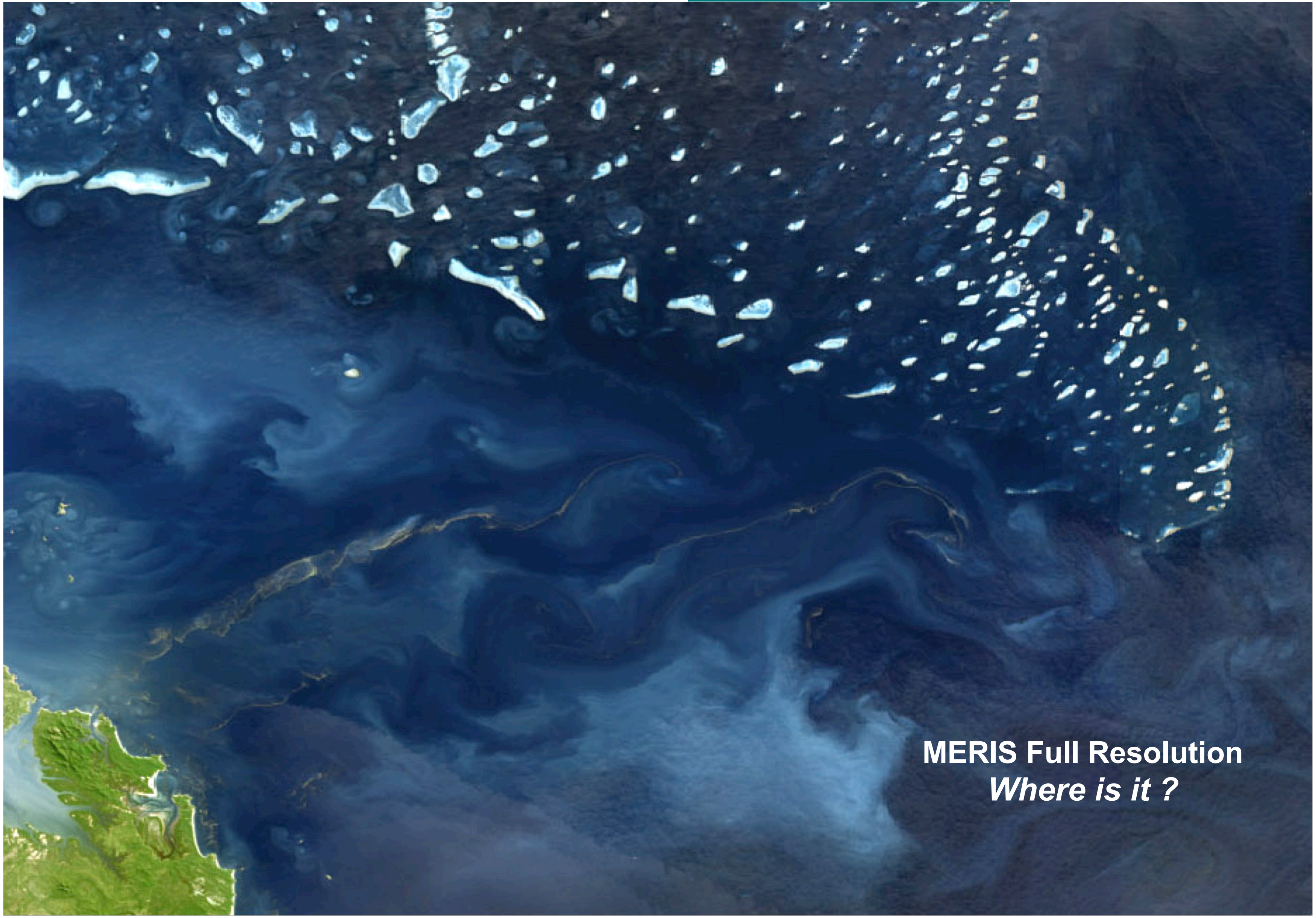

MERIS: high revisit capability
MERIS imaging the world
15 to 30 April 2003
GAEL
Consultant



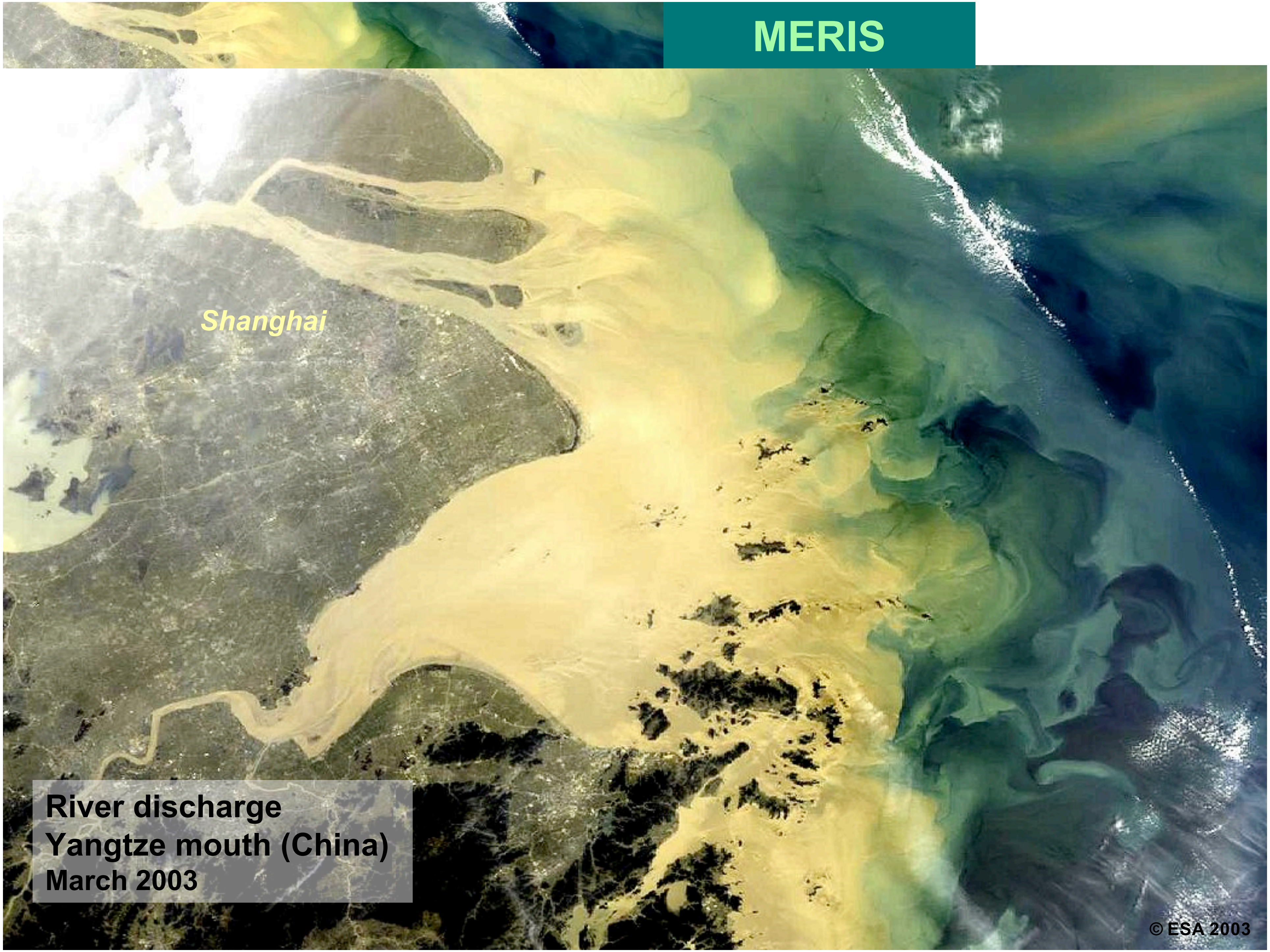
MERIS image of the world
March & April 2003

MERIS

MERIS

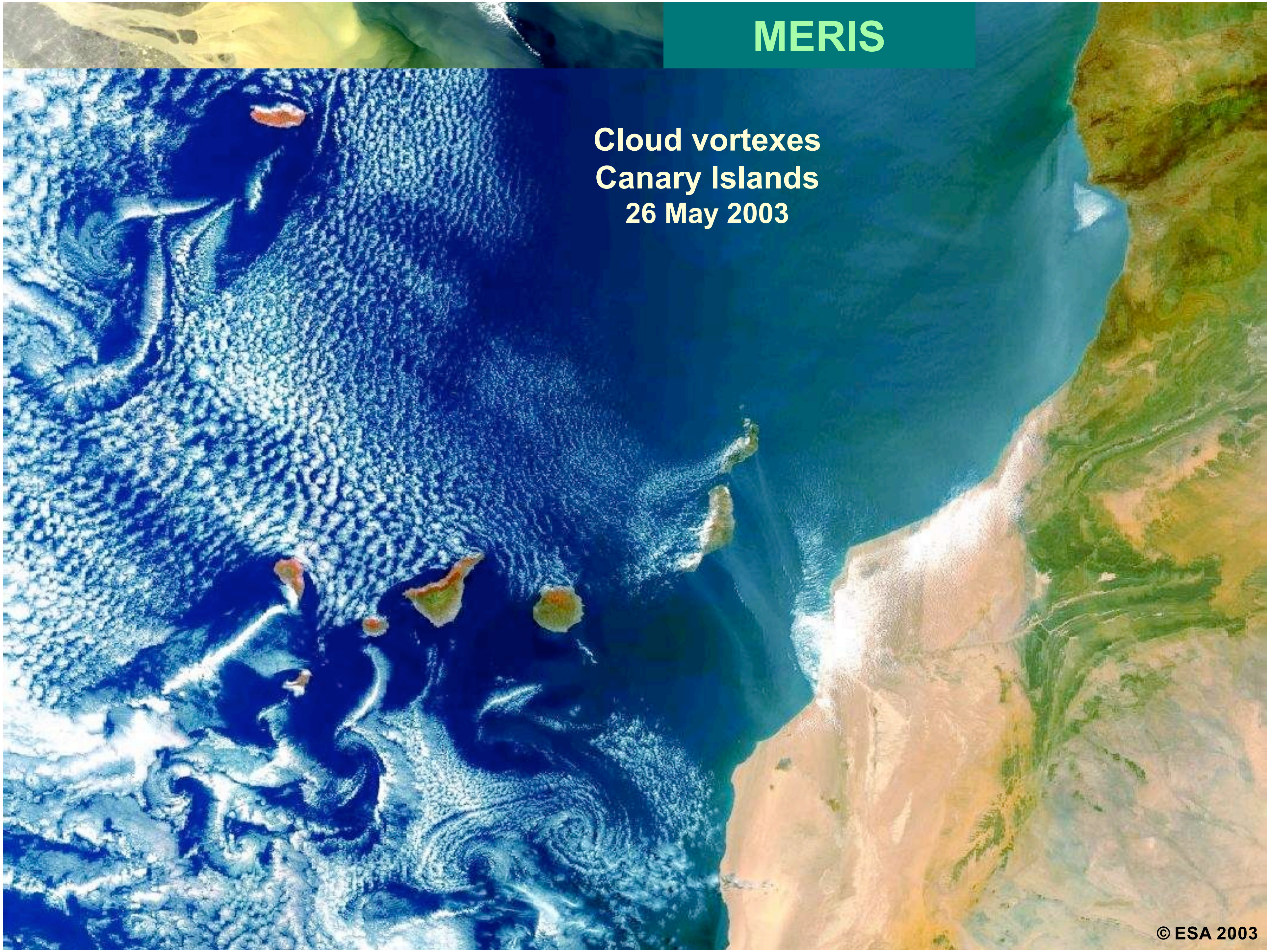


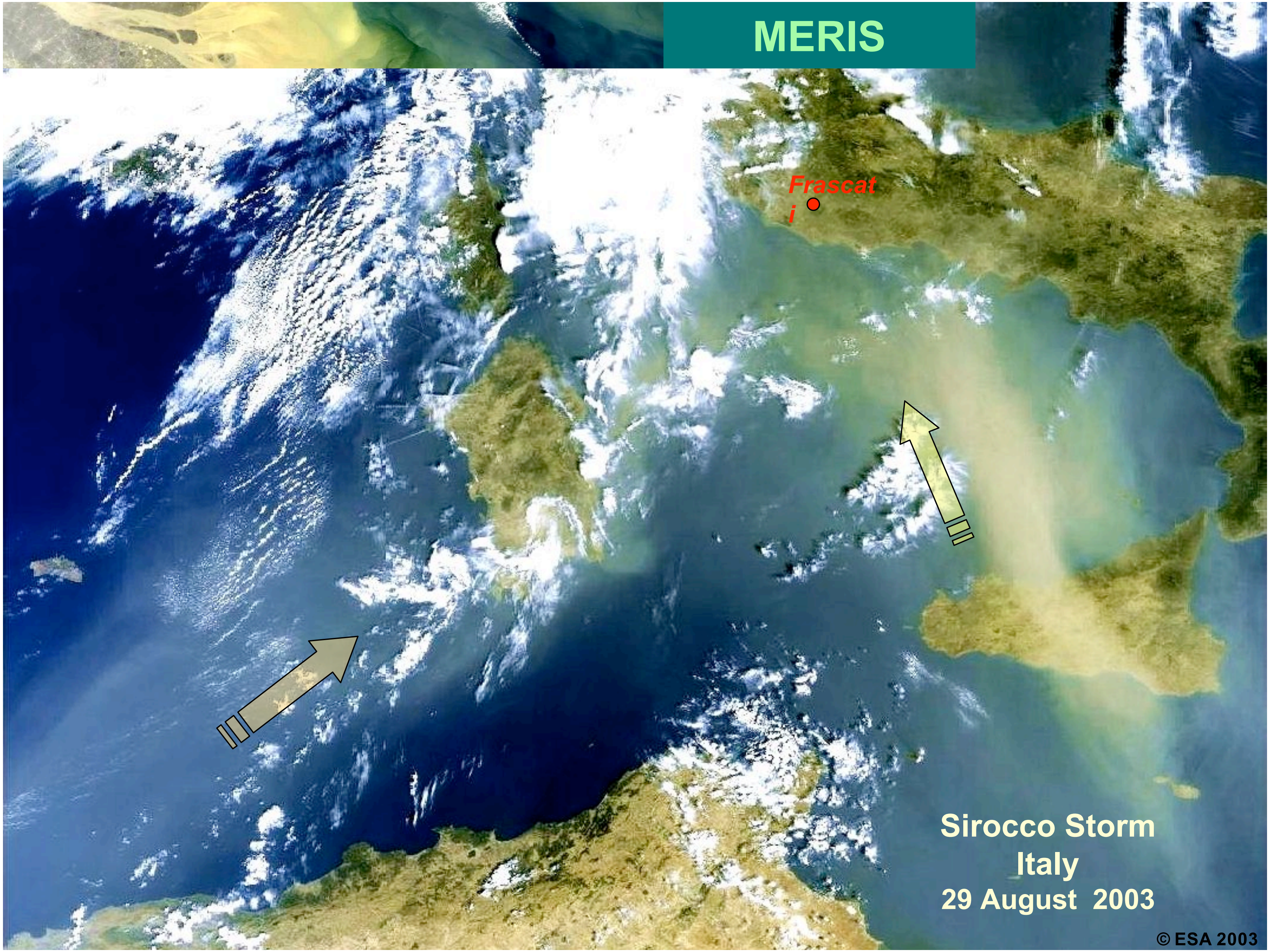
MERIS



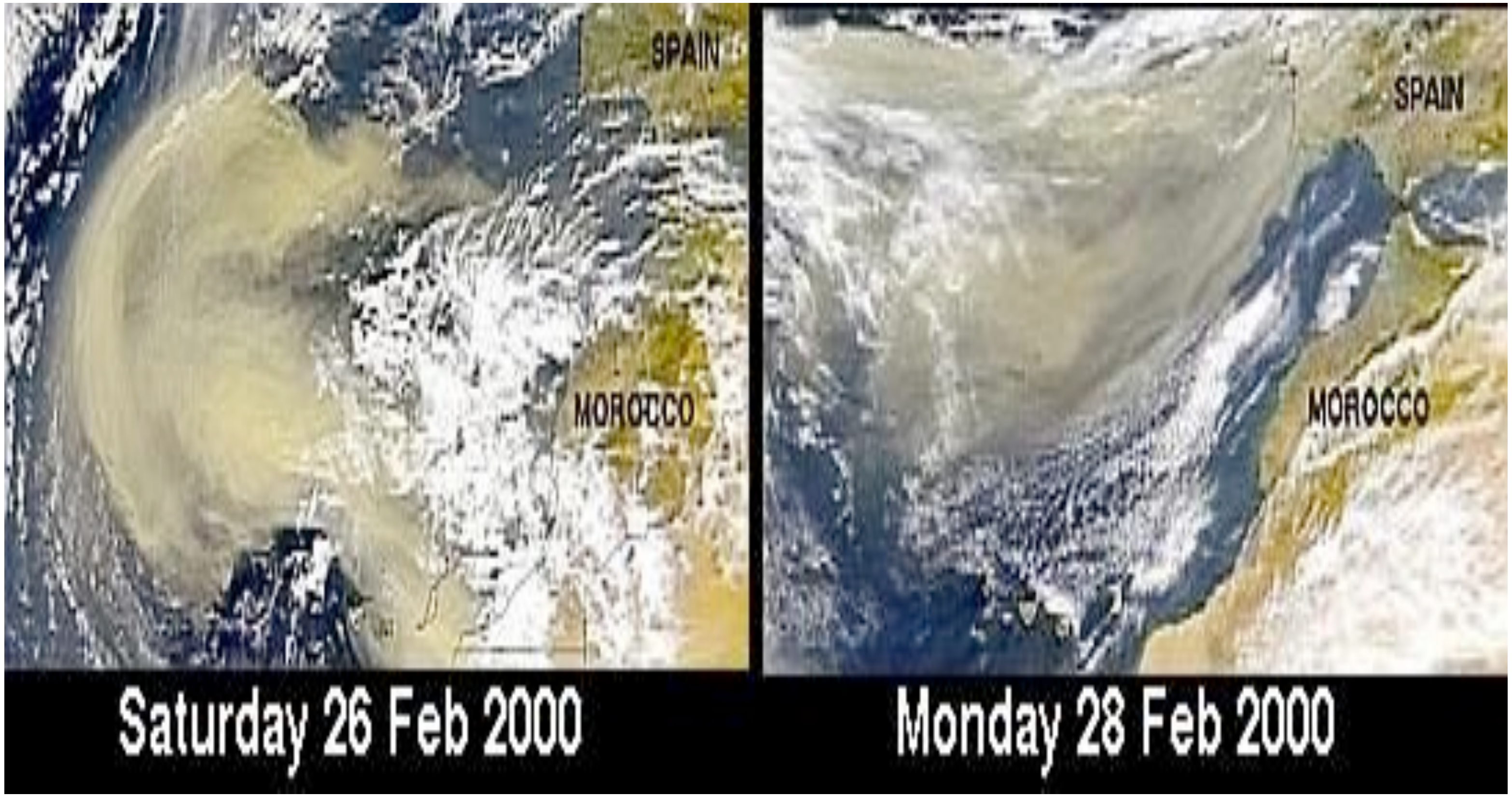
River discharge
Yangtze mouth (China)
March 2003

MERIS


MERIS
Cloud vortexes
Canary Islands
26 May 2003
© ESA 2003


MERIS
Frascat
i
Sirocco Storm
Italy
29 August 2003
© ESA 2003

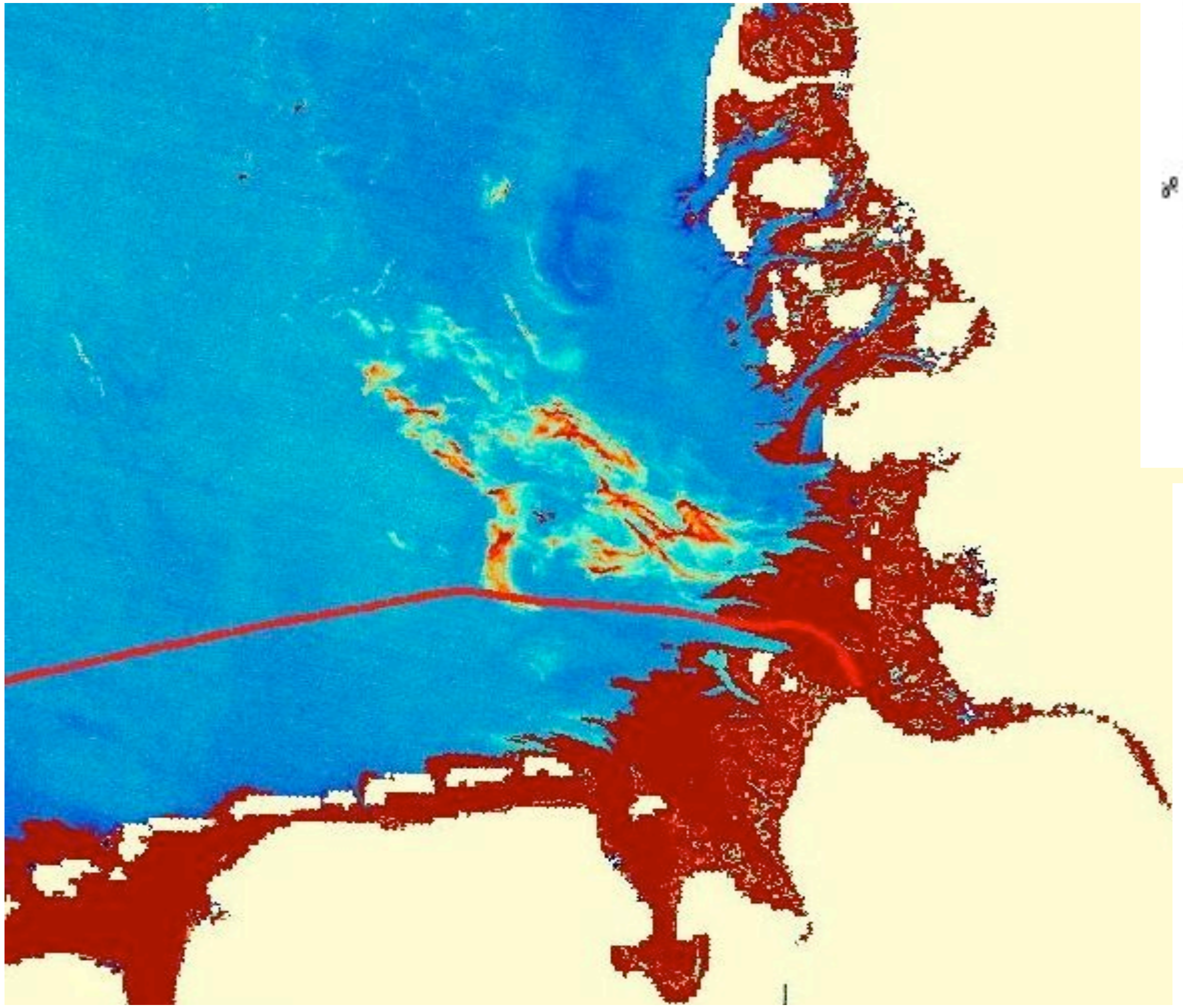
Atmospheric dust, ocean fertilisation and ocean dimming.

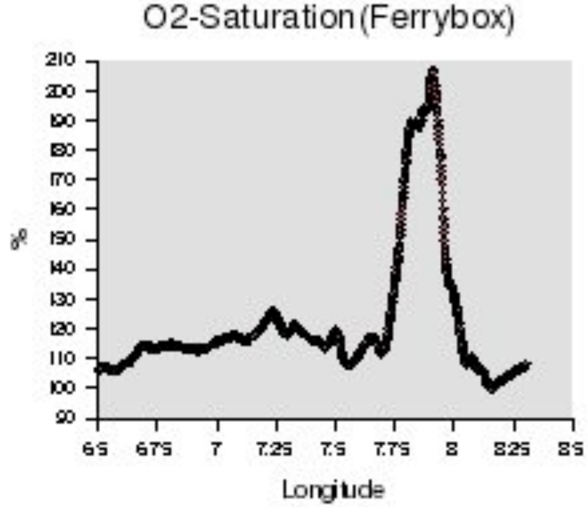


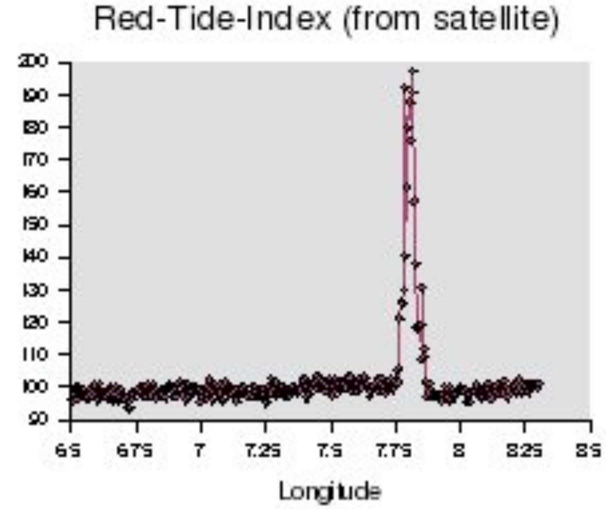
Red Tide in the German Bight

source: GKSS

MERIS Red Tide Index 3.8.2004



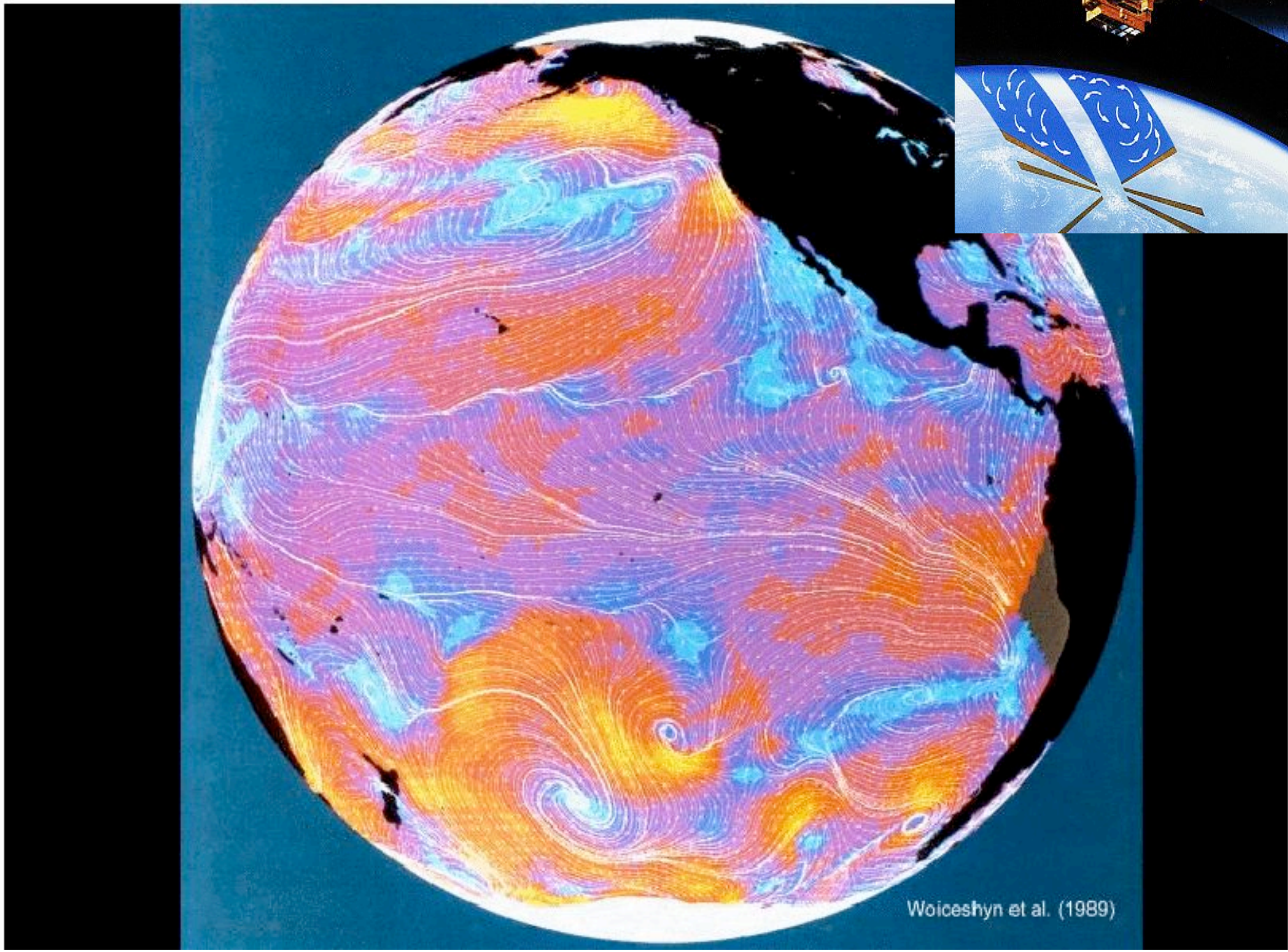


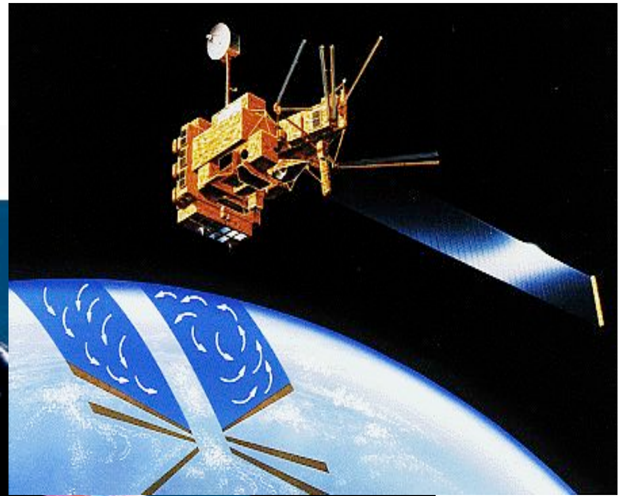


Wind stress measurements

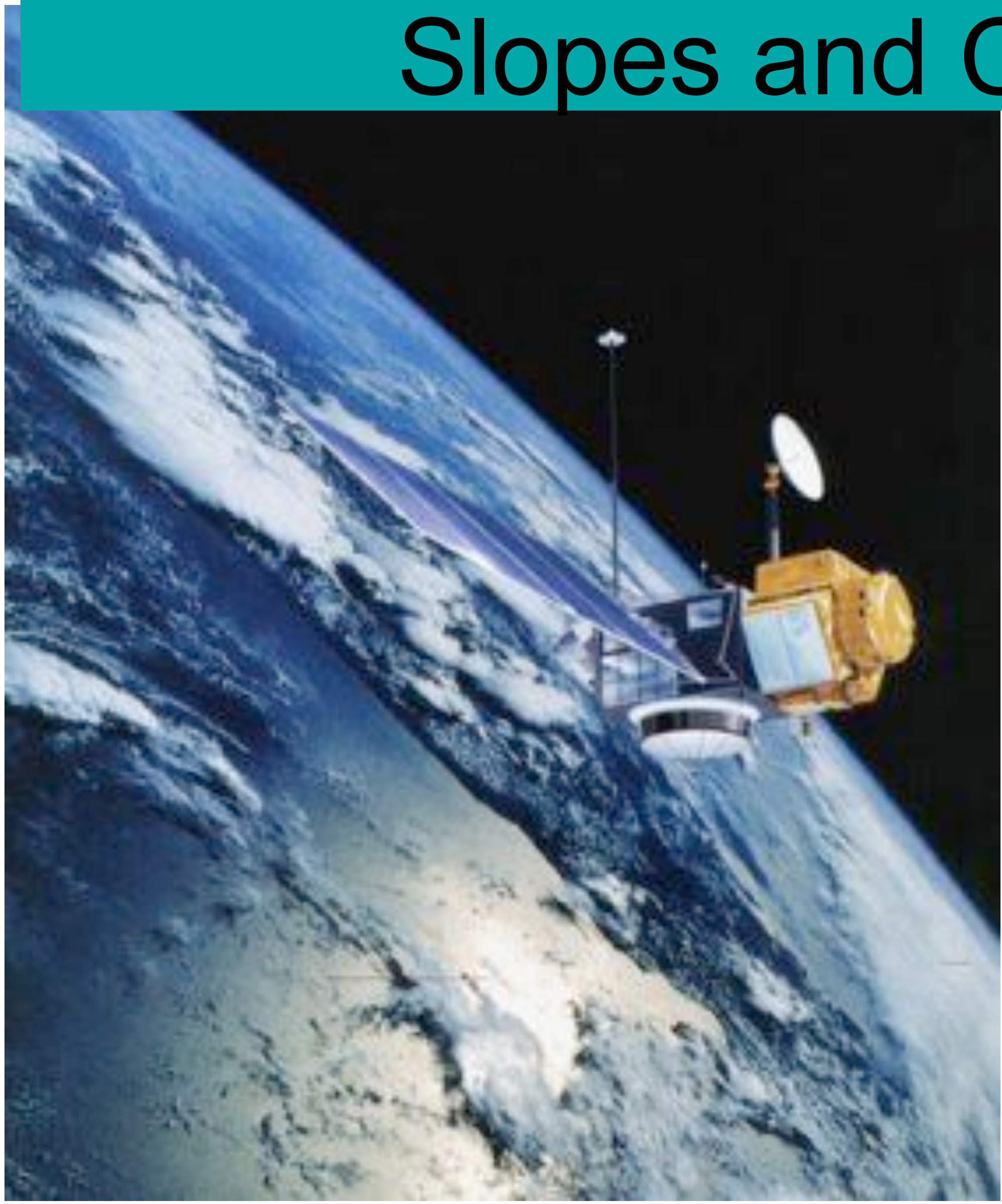
A scatterometer measures the surface roughness in several directions relative to the wind. The dependence of this parameter on the wind stress allows to infer the wind speed and direction from satellites with spatial resolution of about 25 km.

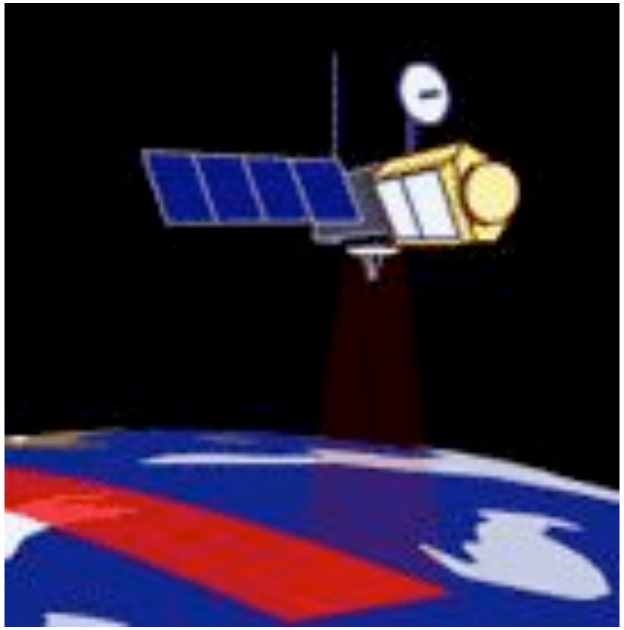
NSCAT Wind Stress Measurements

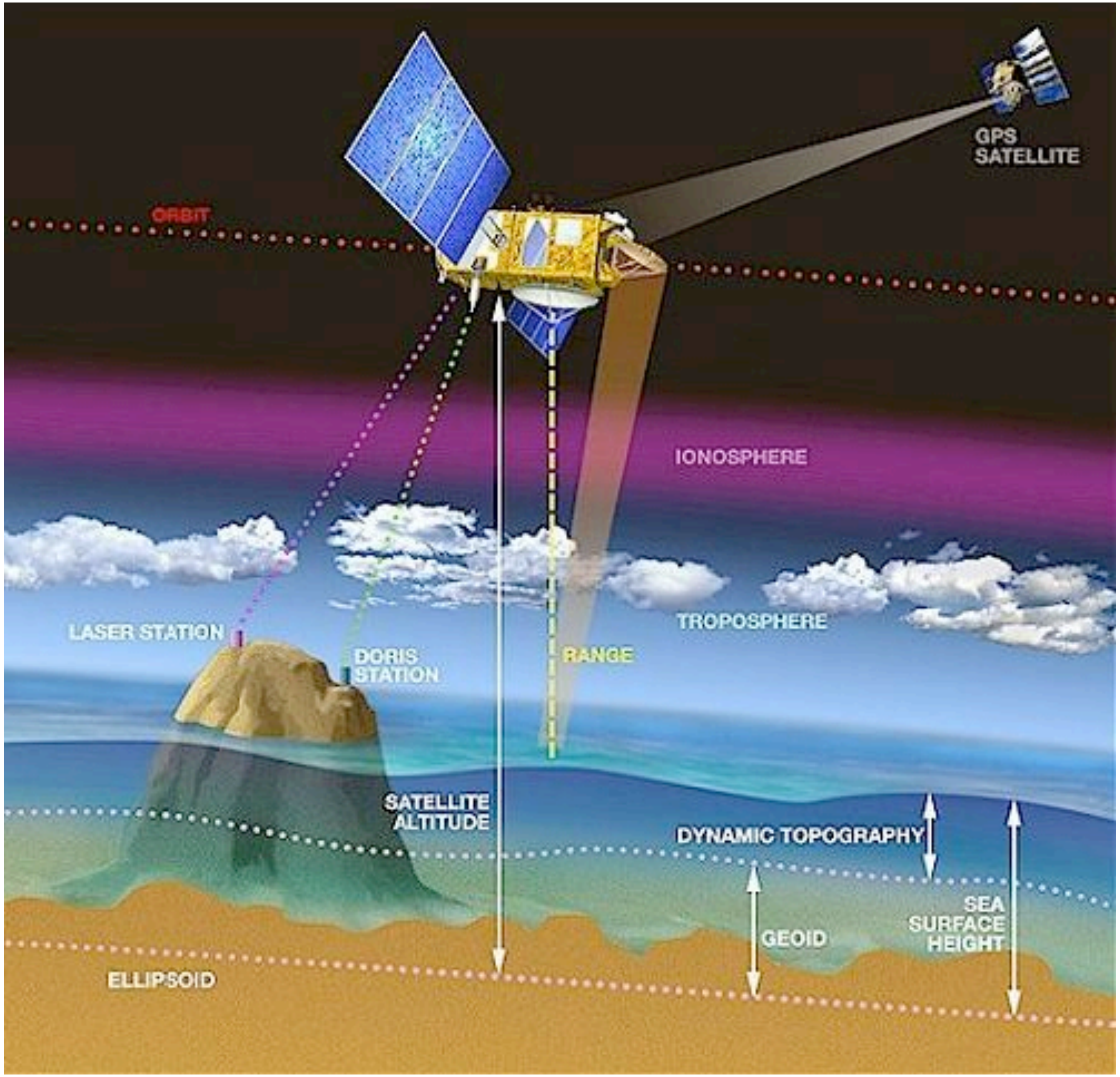


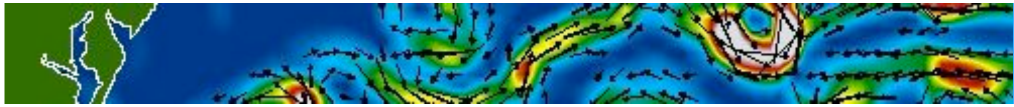


Altimetry Measures Sea Surface Slopes and Currents



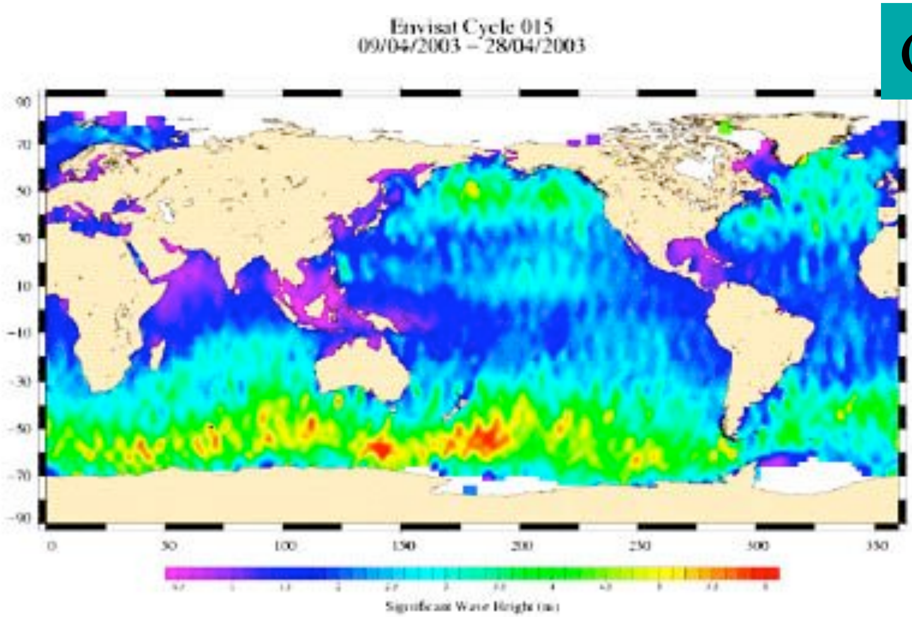


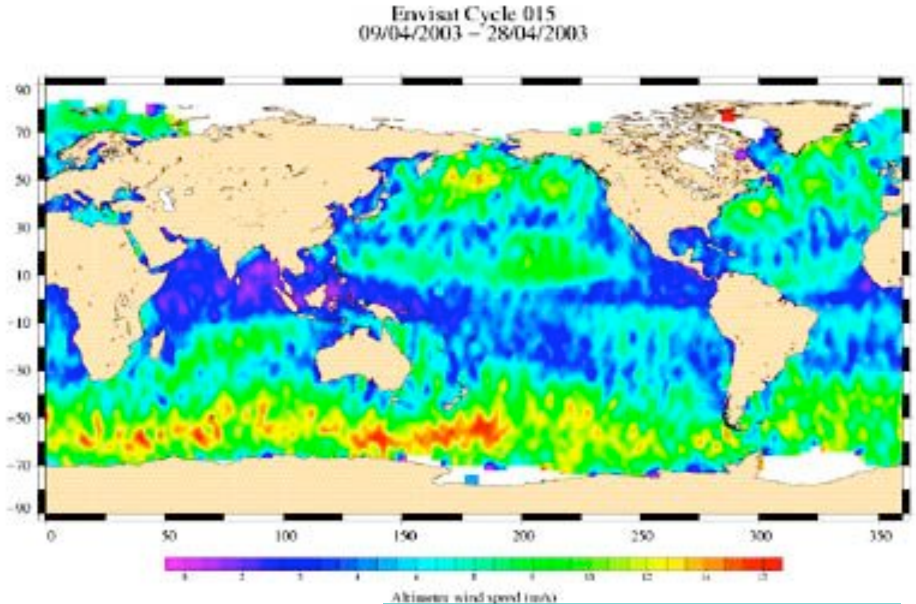

GPS SATELLITE
ORBIT
IONOSPHERE
TROPOSPHERE
LASER STATION
DORIS STATION
RANGE
SATELLITE ALTITUDE
DYNAMIC TOPOGRAPHY
SEA SURFACE HEIGHT
GEOID
ELLIPSOID



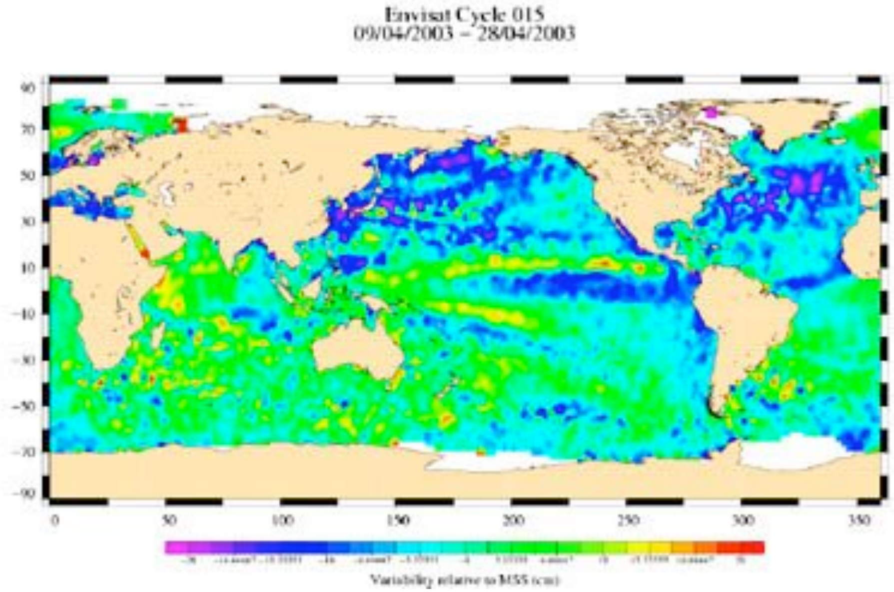
Altimetry

Global wave height



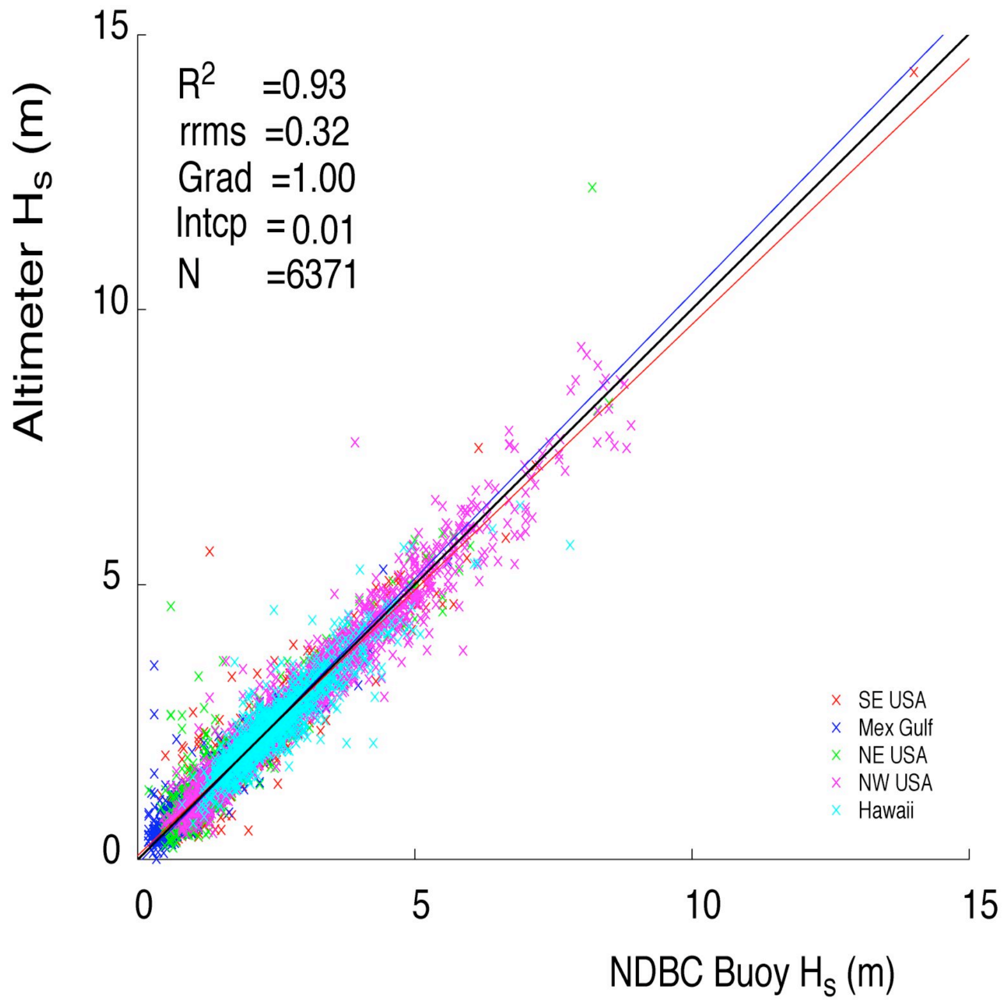


Global wind speed



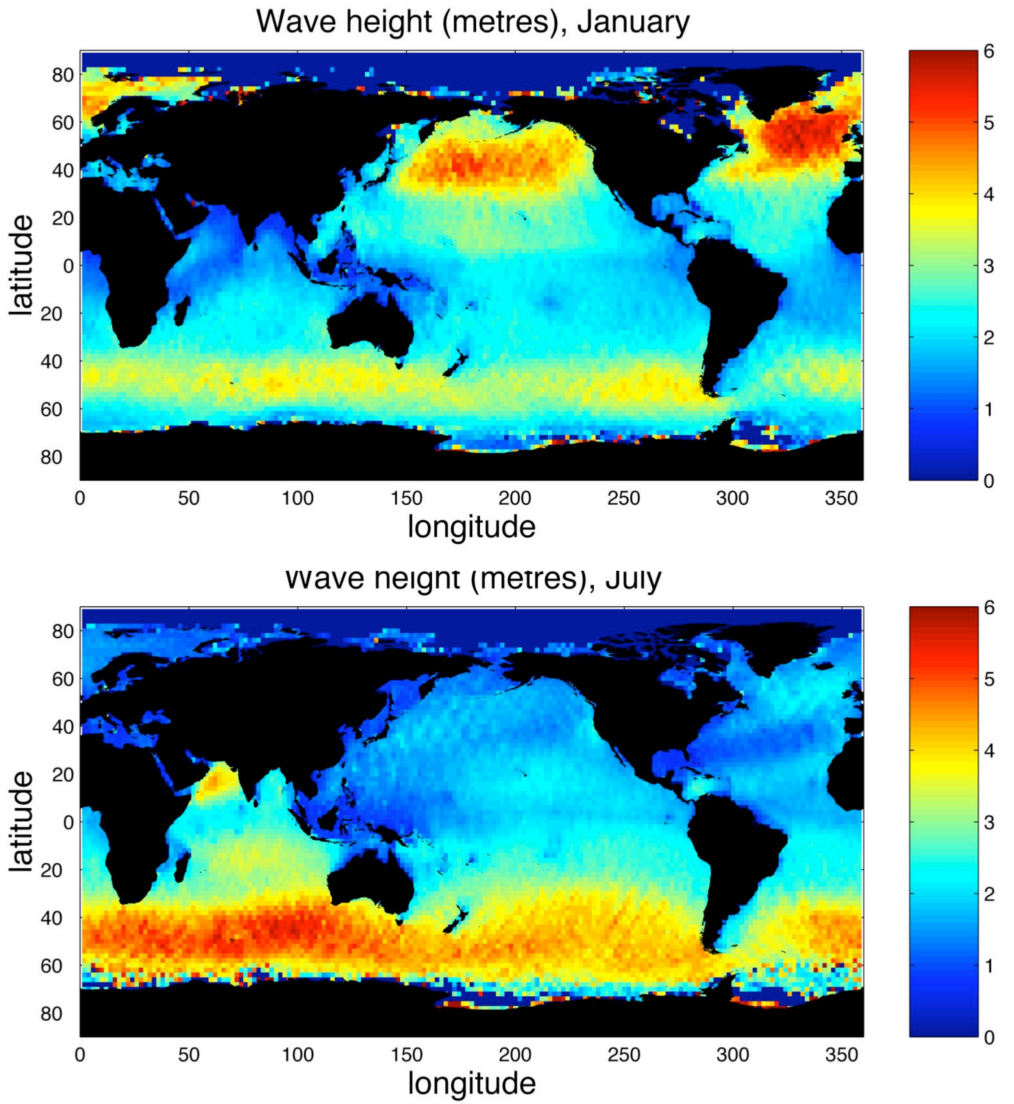
Sea Level anomaly

SWH Information agrees well with Buoy Data



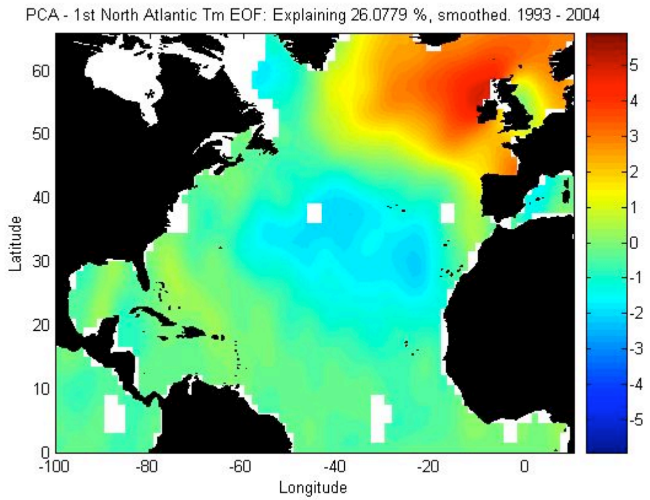
The wave climate

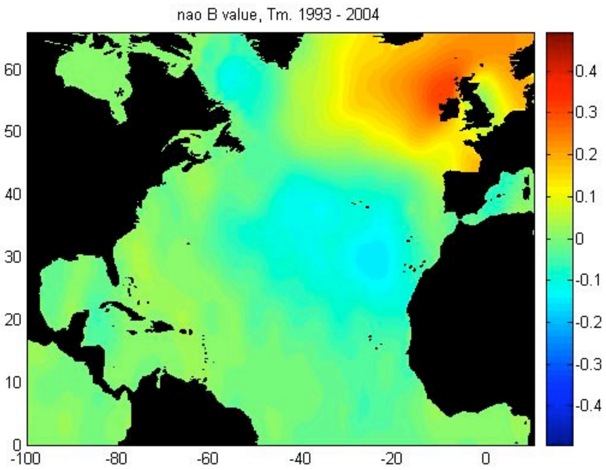
- The biggest signal in the wave climate is of course seasonal.



Wave Period and the NAO

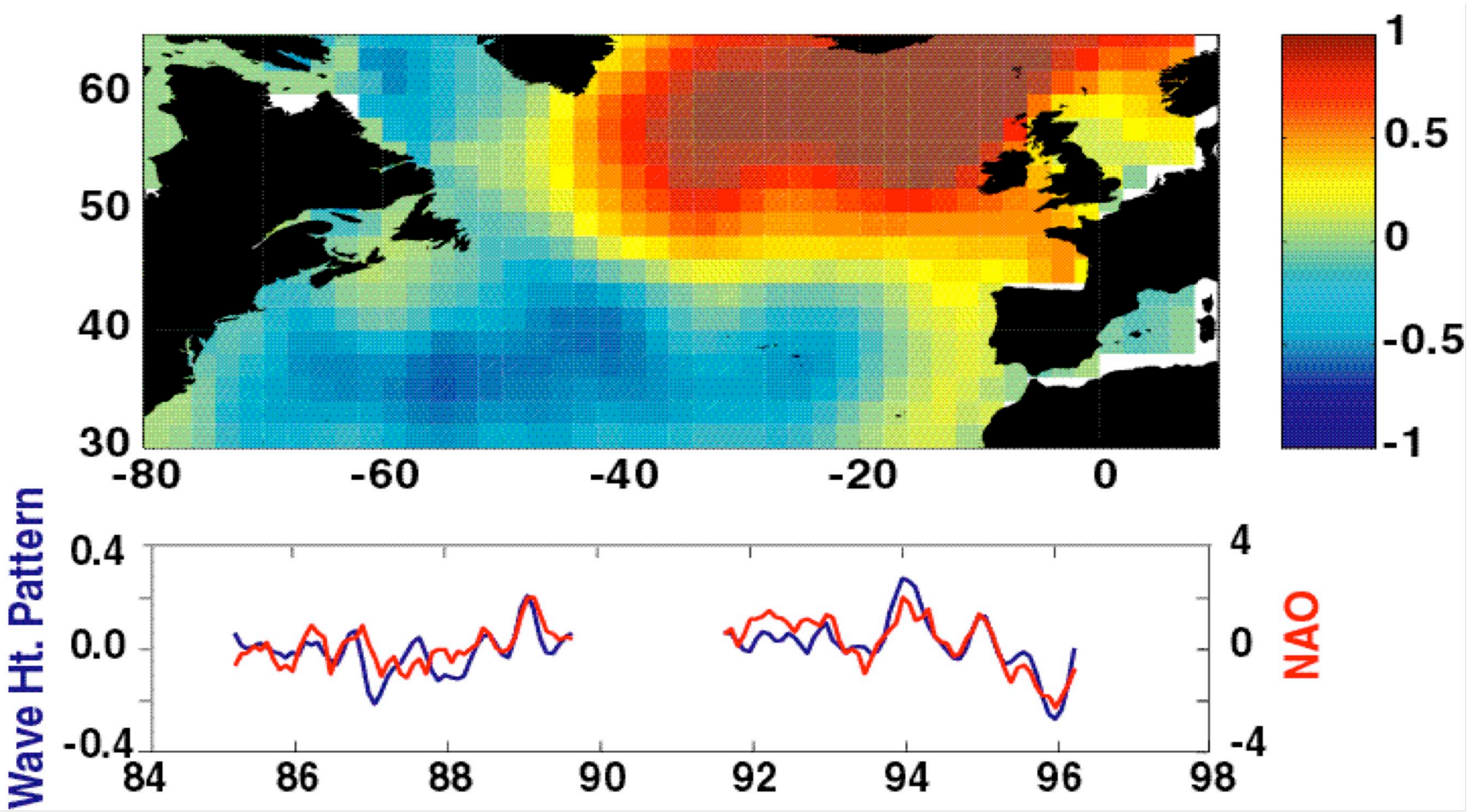
- In a similar way to wave height wave period relates to the NAO





The above shows the first EOF of period. On the left we have a regression of Tm on the NAO

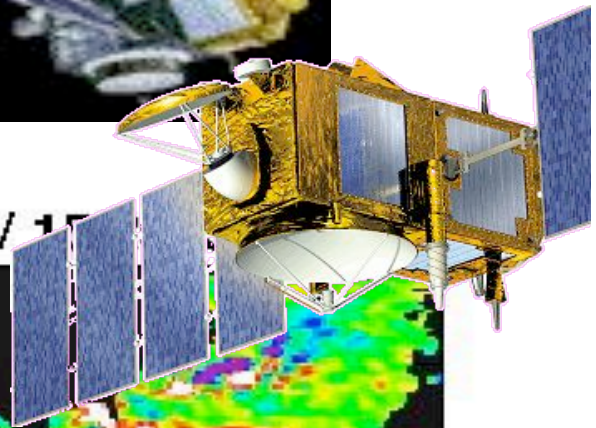
EOF 80's-90's

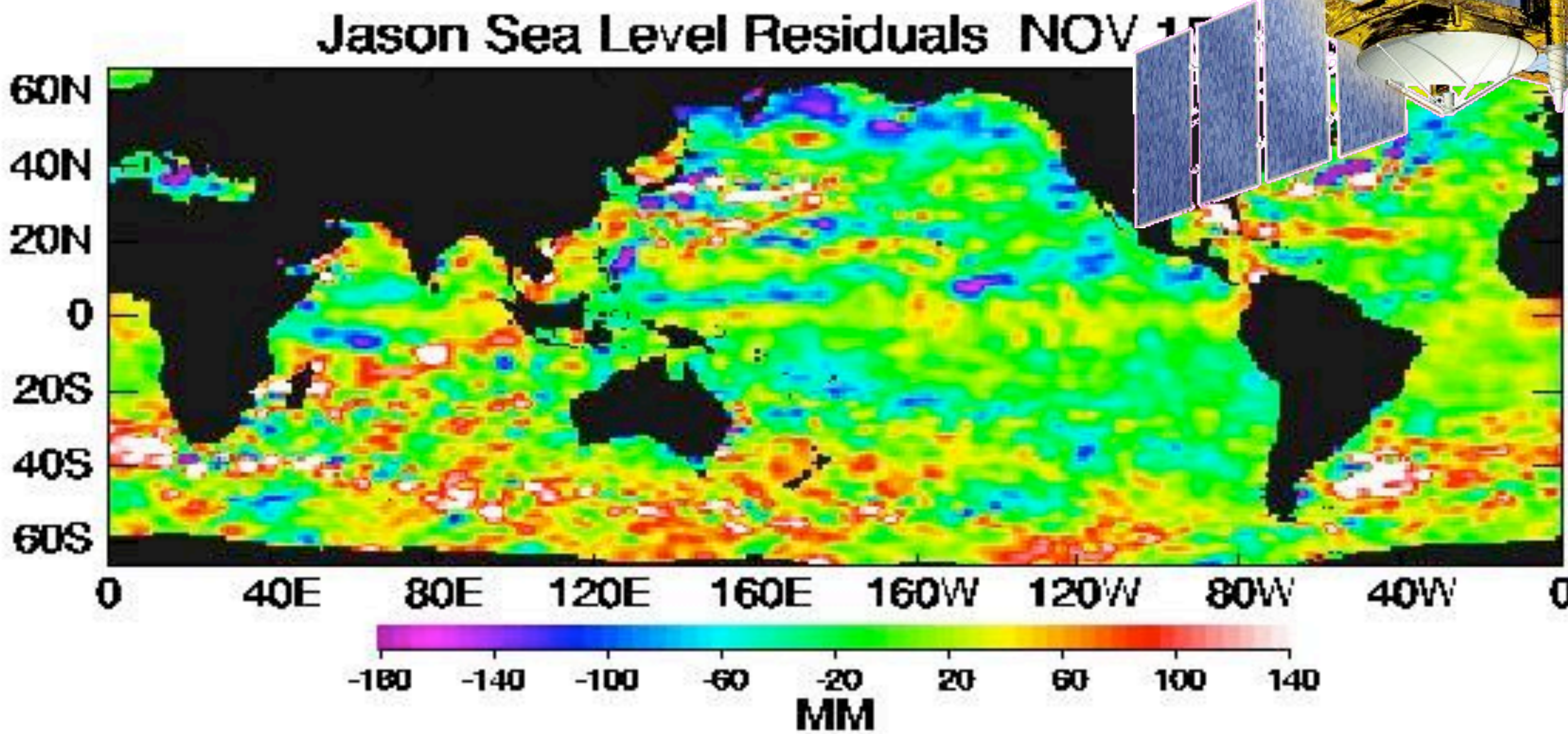


60
50
40
30
-80
-60
-40
-20
0
1
0.5
0
-0.5
-1
Wave Ht. Pattern
0.4
0.0
-0.4
84
86
88
90
92
94
96
98
4
0
-4
NAO

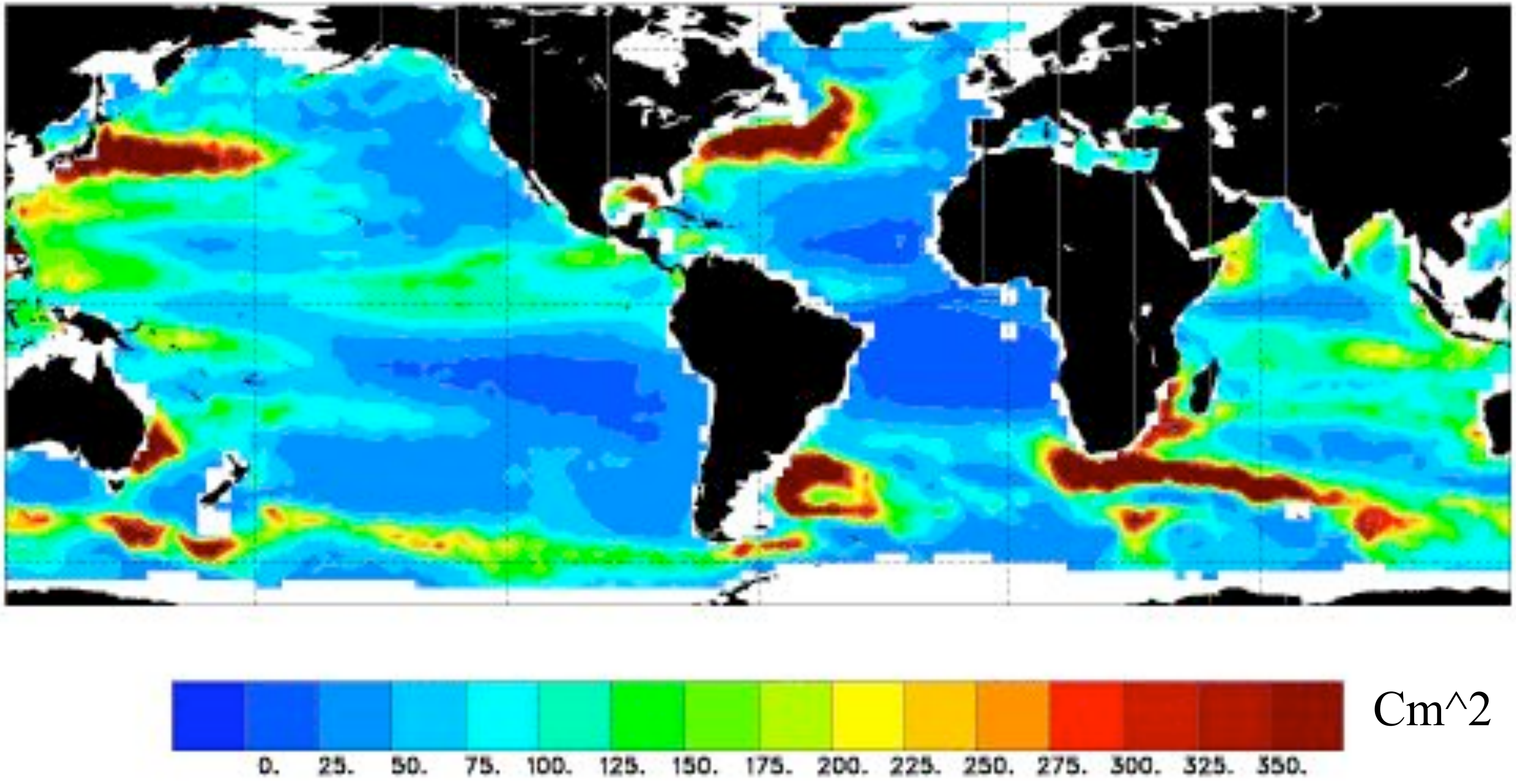
SSH Measurements

(Von TOPEX mehr als 1800 Art.)



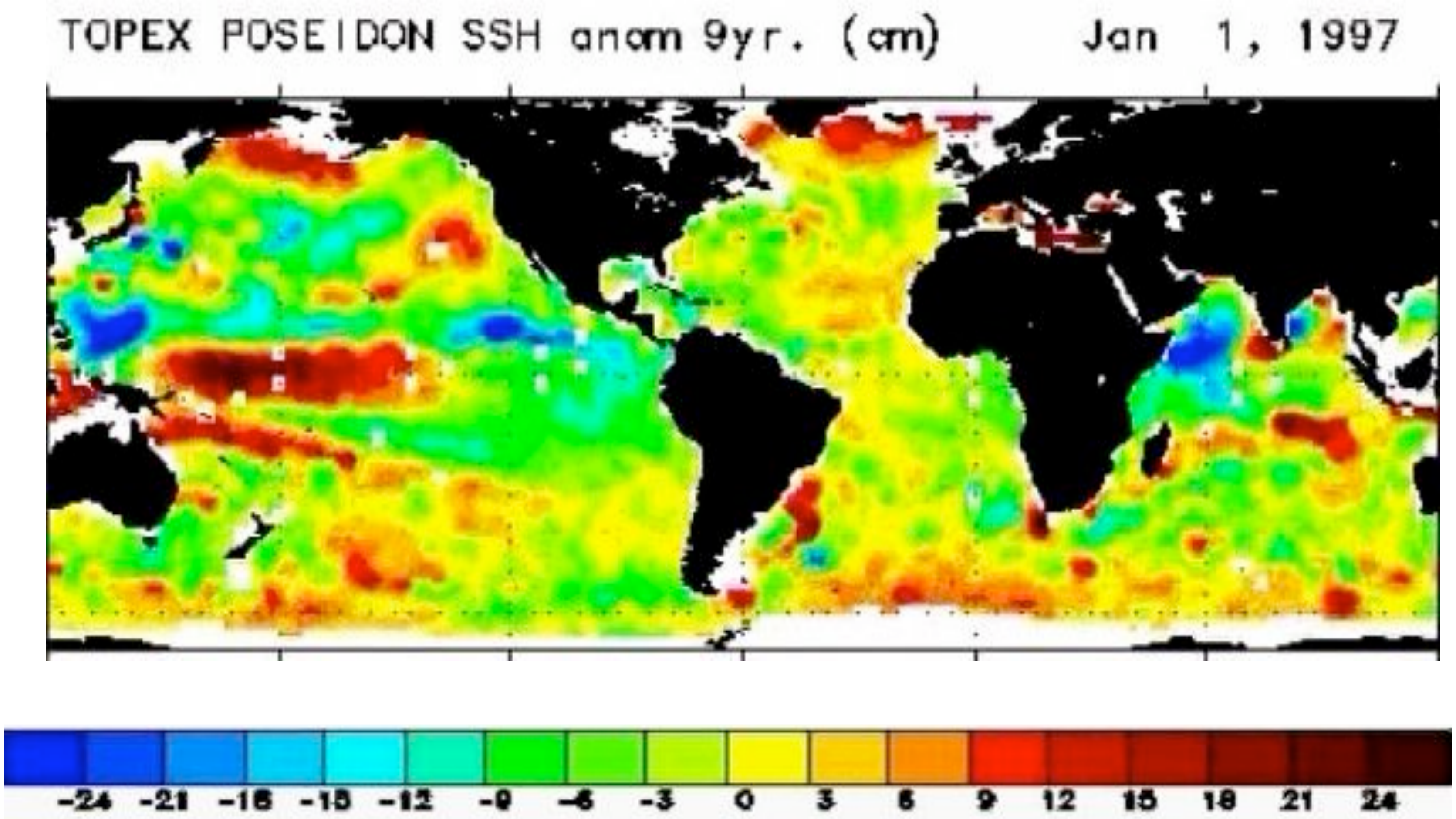


T/P 1993-2001 ssh var



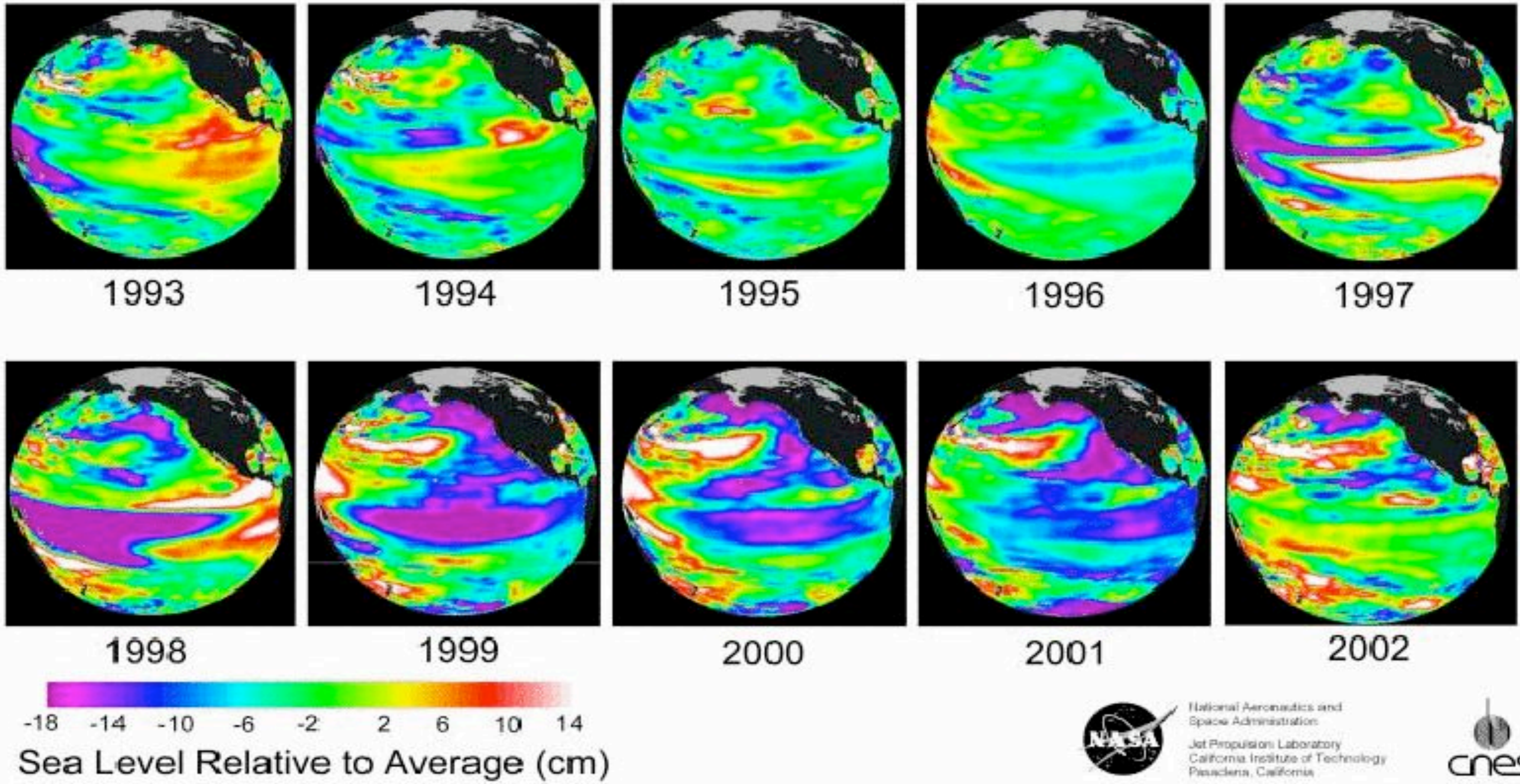
TP 93-01var

Observations of SSH Anomalies



Annual Averages of SSH from 10 Years of TOPEX/POSEIDON Data

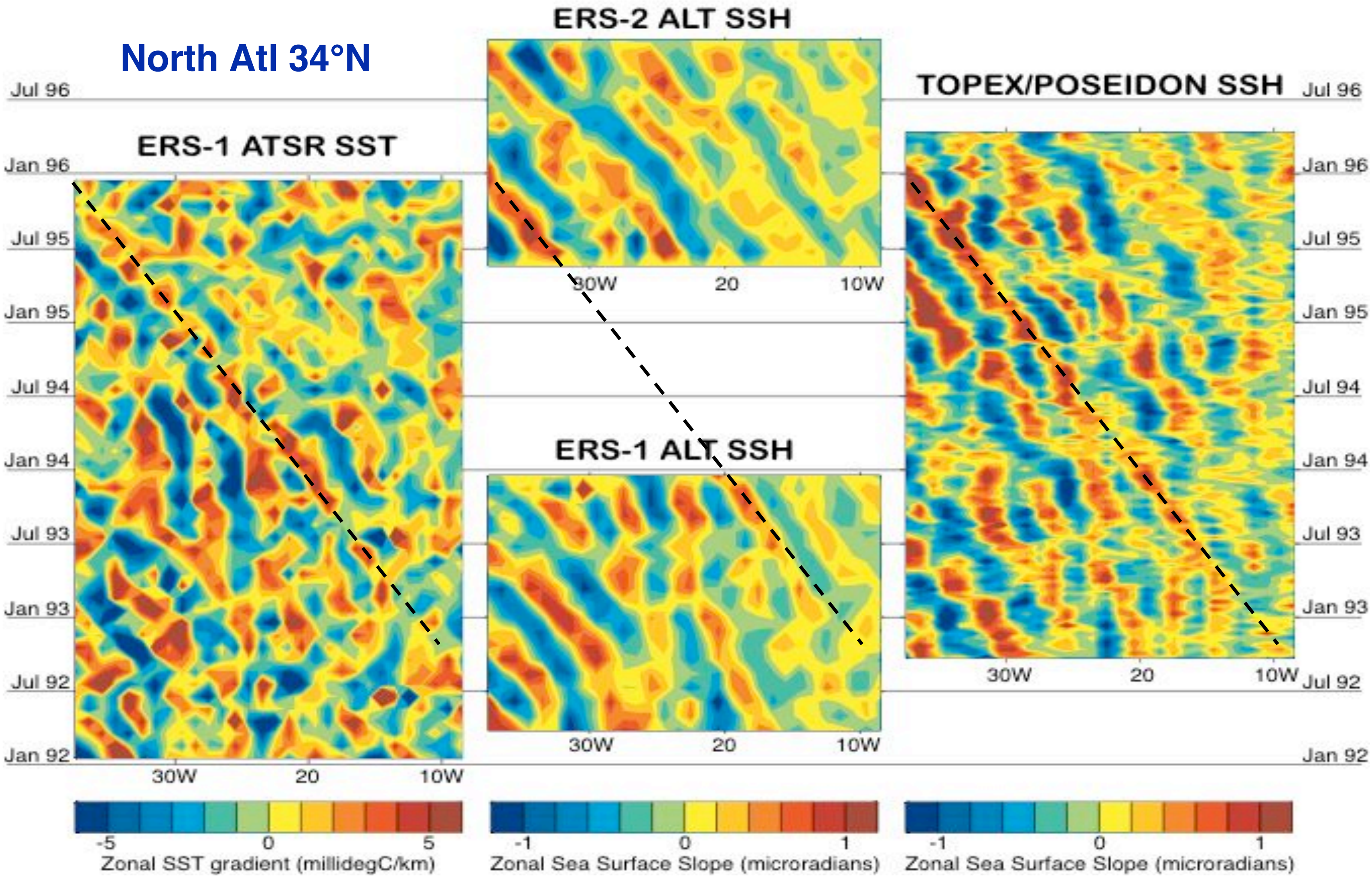
(Courtesy of L.-L. Fu)



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

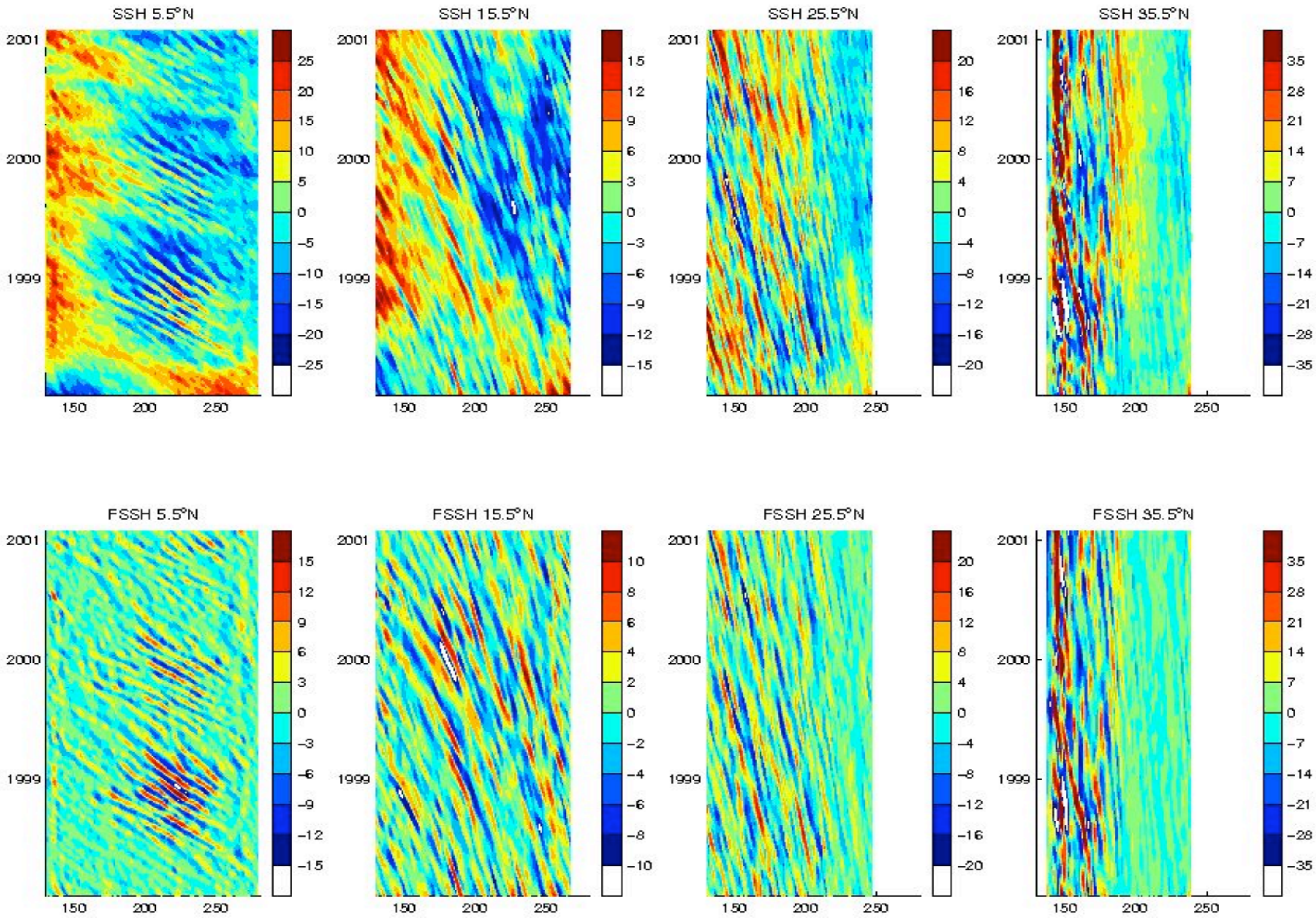
cnes

ERS-based observations



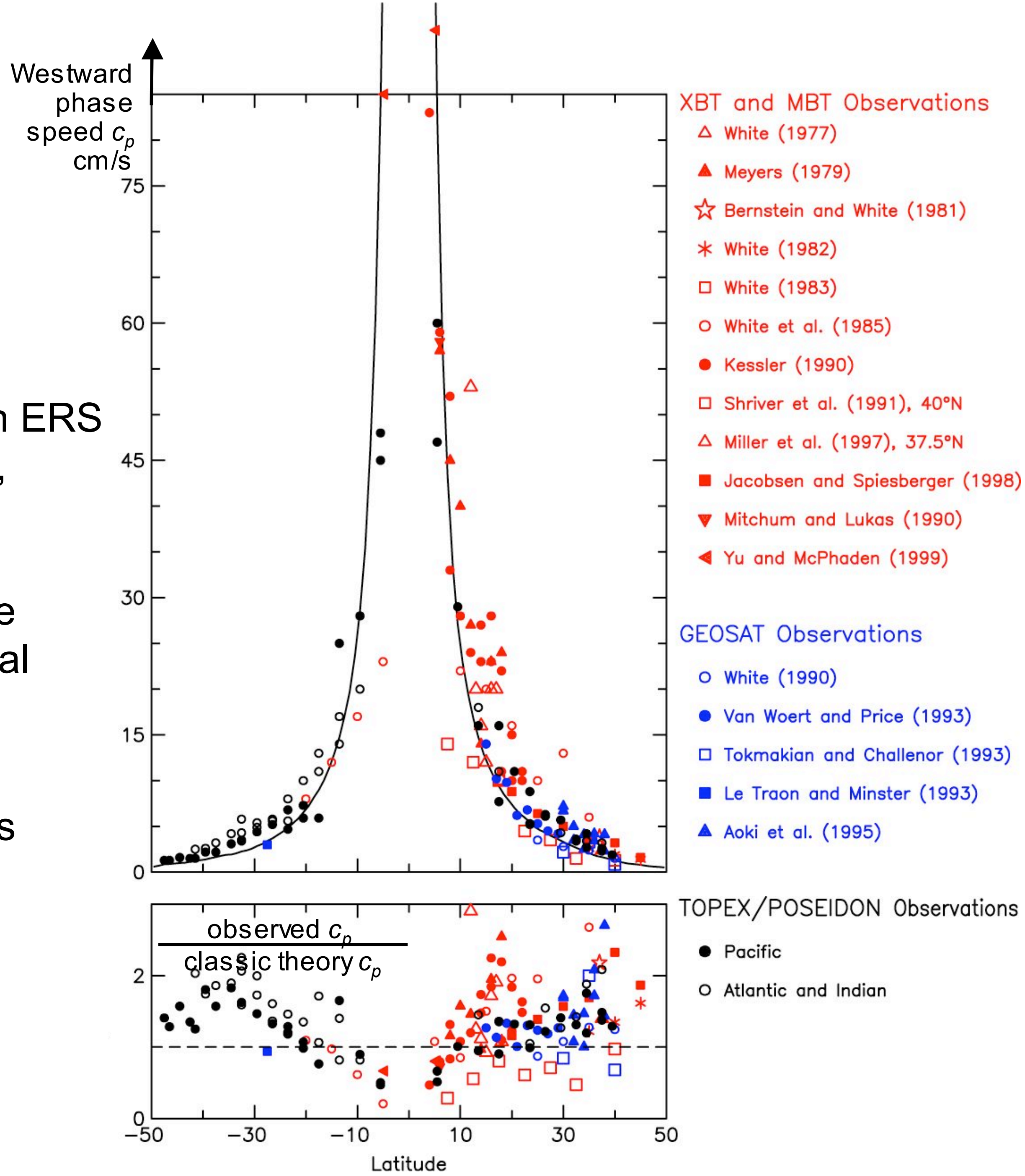
Cipollini et al 1997 (North Atlantic): Hughes et al 1998 (Southern Ocean)

SSH Anomalies from T/P



Merged T/P+ERS

- Chelton et al 2006
- Made possible by both remarkable improvement in ERS orbits (Scharroo et al 1998, 2000), and careful intercalibration + optimal interpolation techniques (Le Traon et al 1998, Ducet et al 2000)
- Good example of synergy between different altimeters



West- and eastward traveling waves.

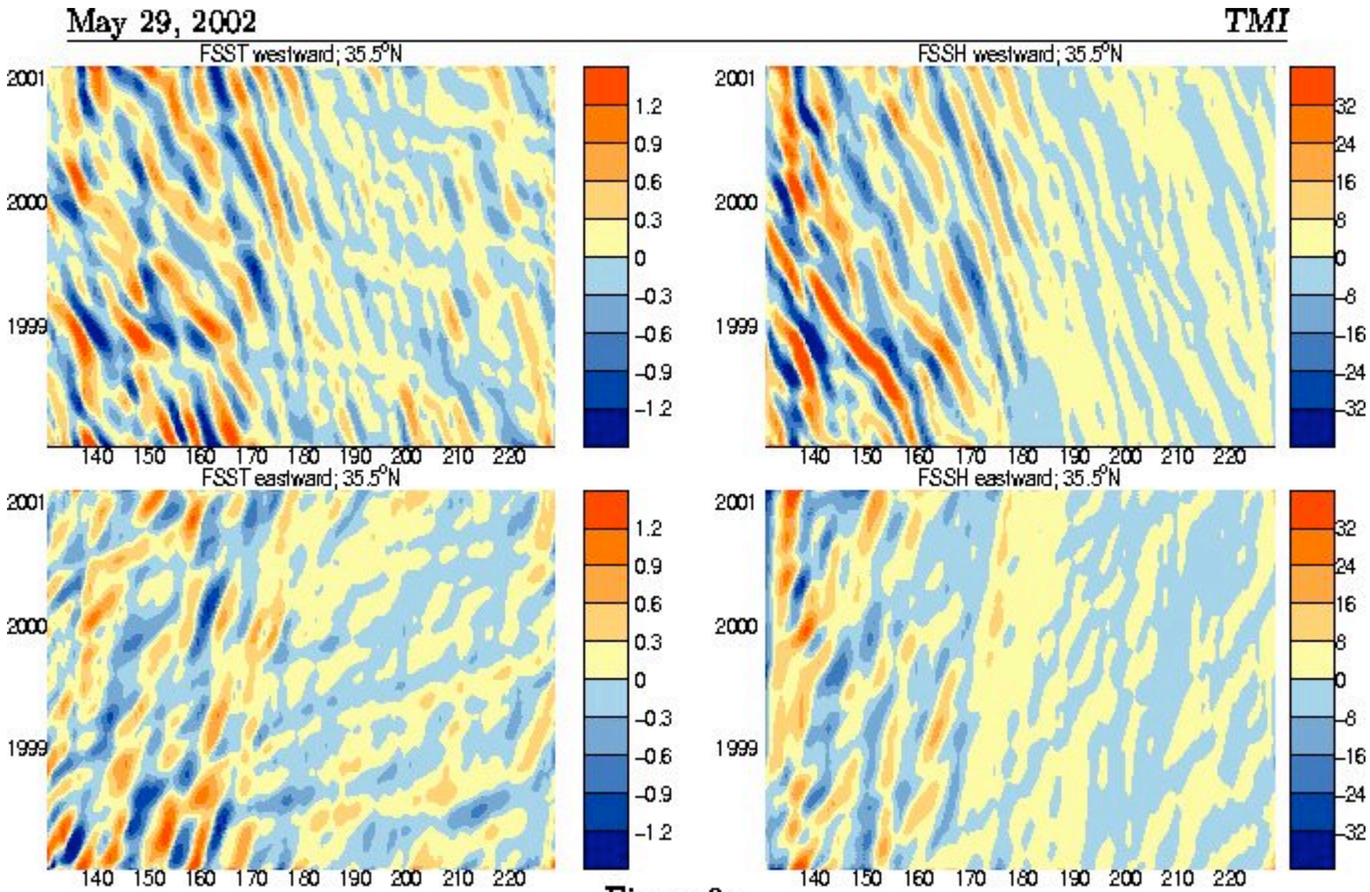
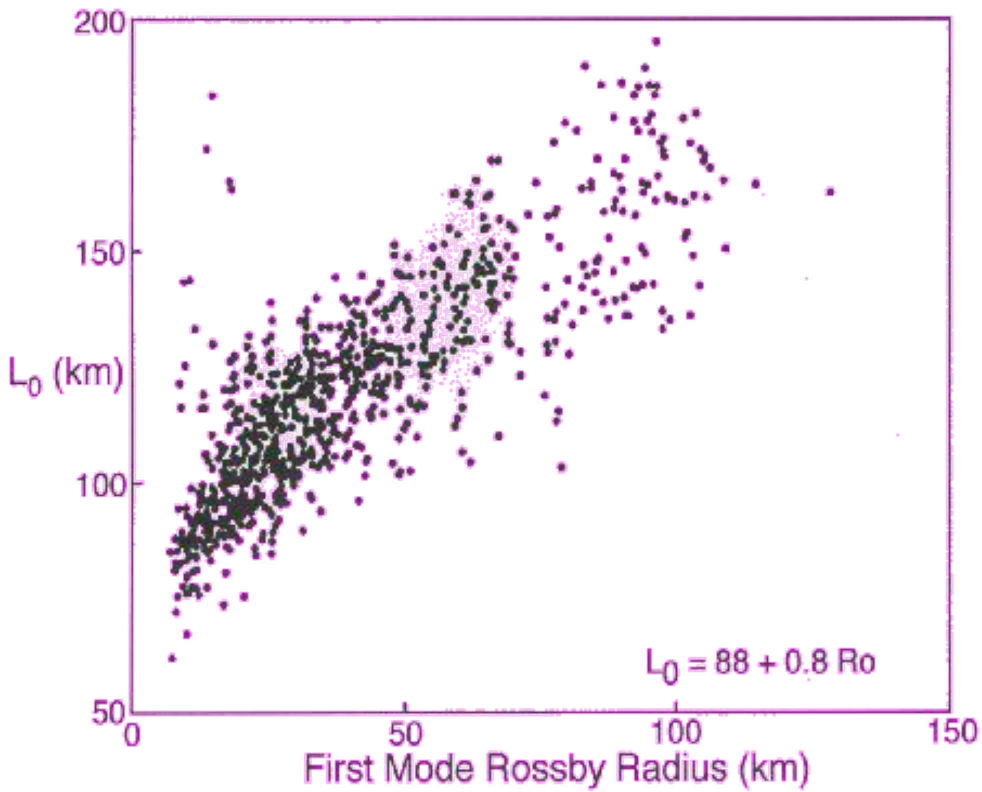
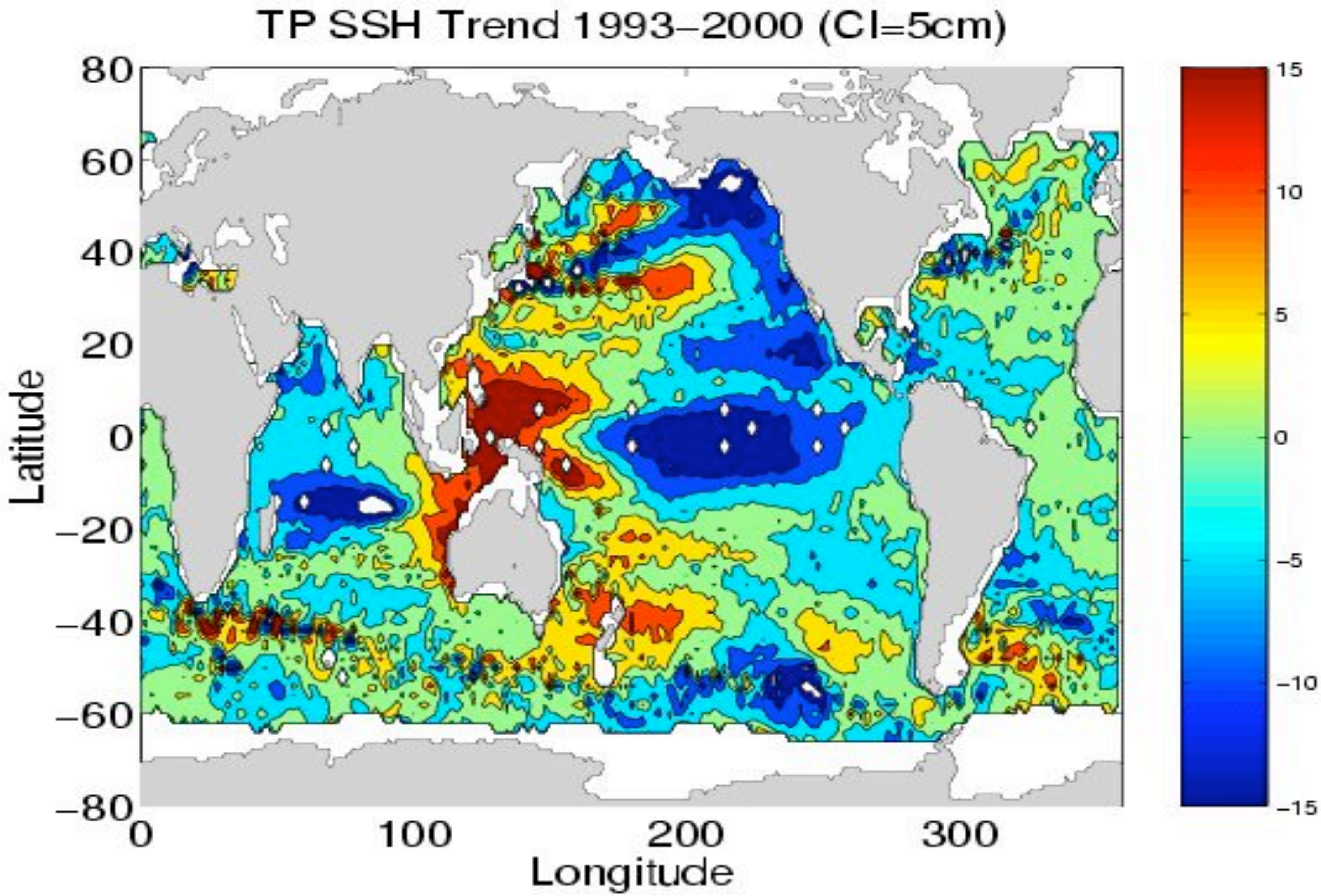


Figure 9:
26

Example of SSH eddy statistics from along-track data: Relation eddy scale to Ro.

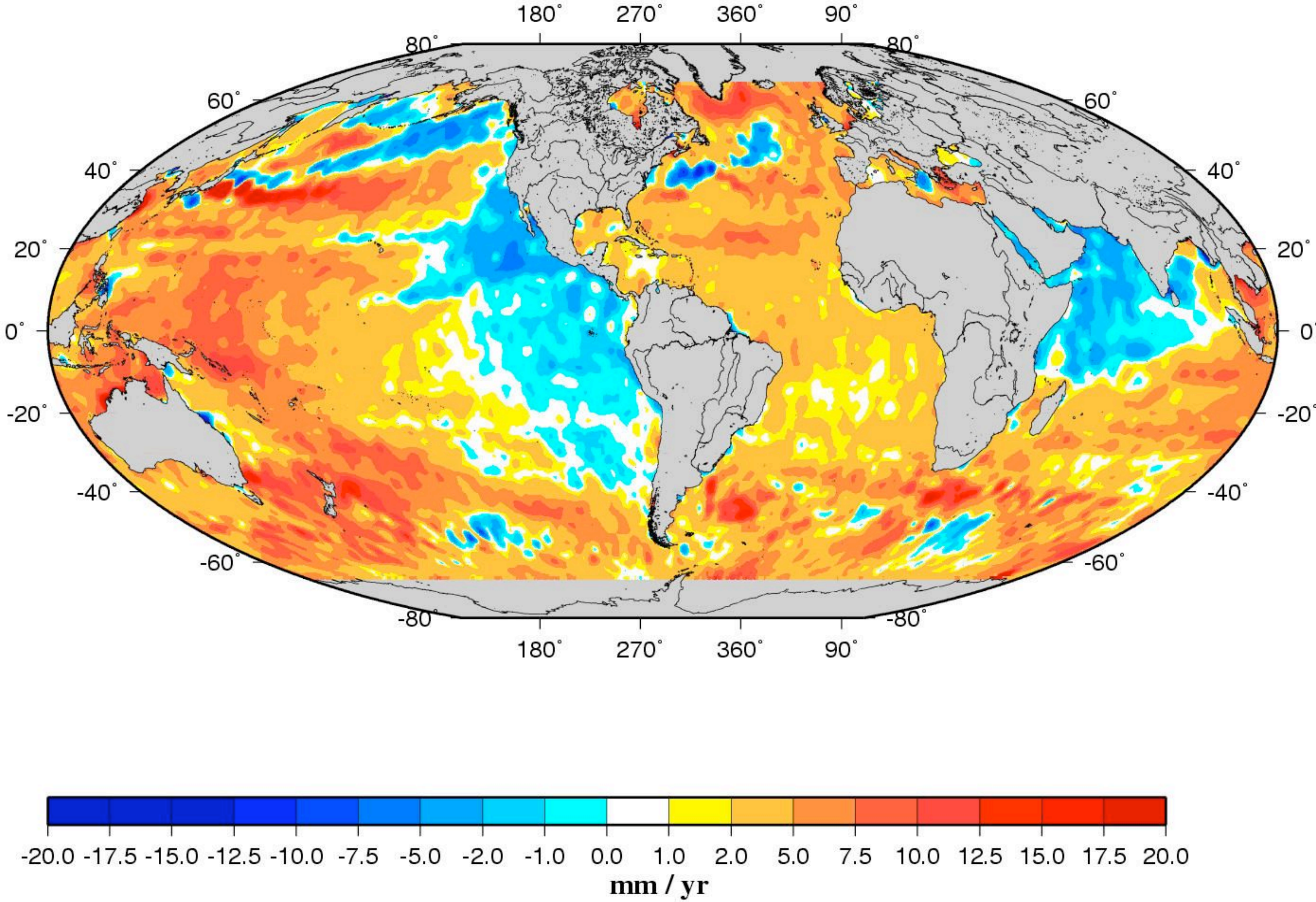


SSH Drift 1993 – 2002



Sea level trends from Topex-Poseidon (1993-2005)

LEGOS/CNES (Jan 2006) (chamberptmr hnbi 11a460 ppalixkdm)



Processes causing sea level change:

- **Change in** sea water density

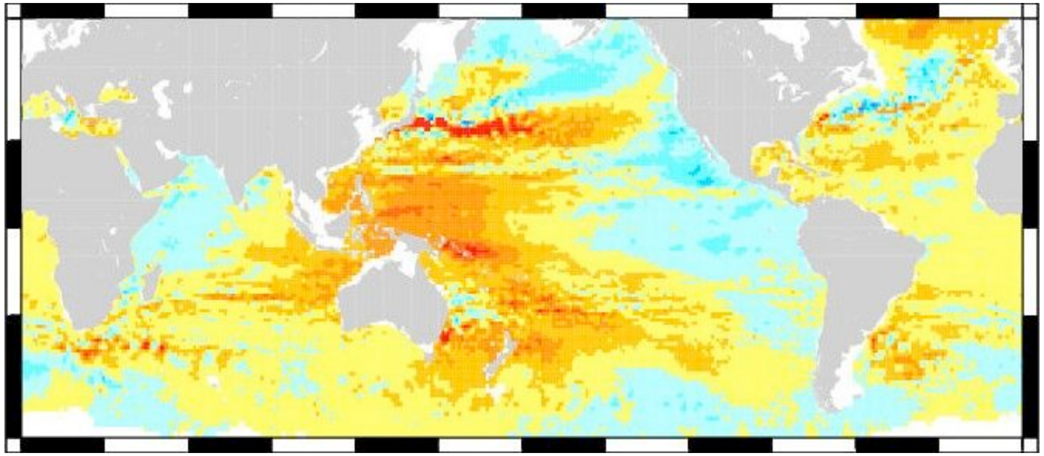
  Temperature **Salinity**

- **Change in** ocean mass

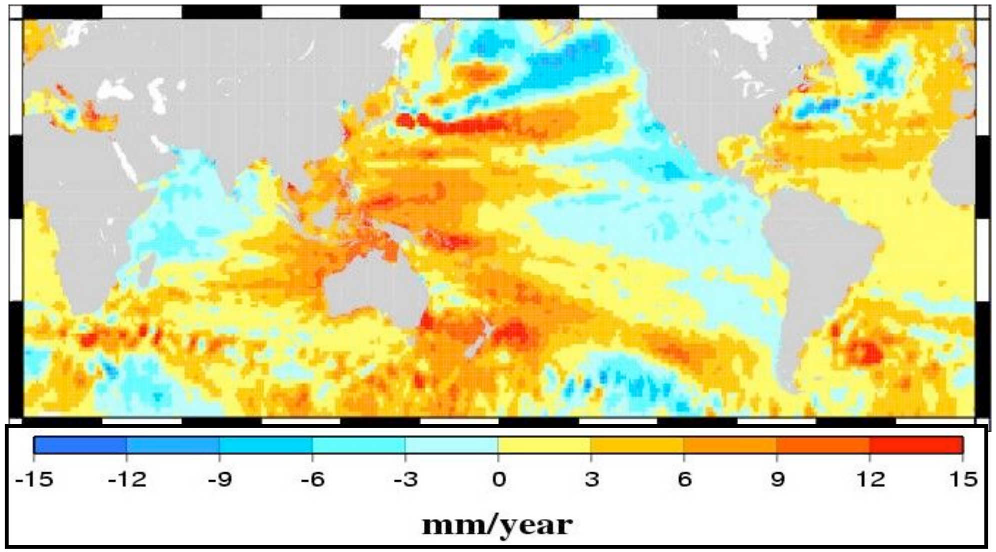
  Water mass exchange with terrestrial reservoirs, mountain glaciers and ice sheets

Maps of steric sea level trends and Topex/Poseidon trends (1993-2003)

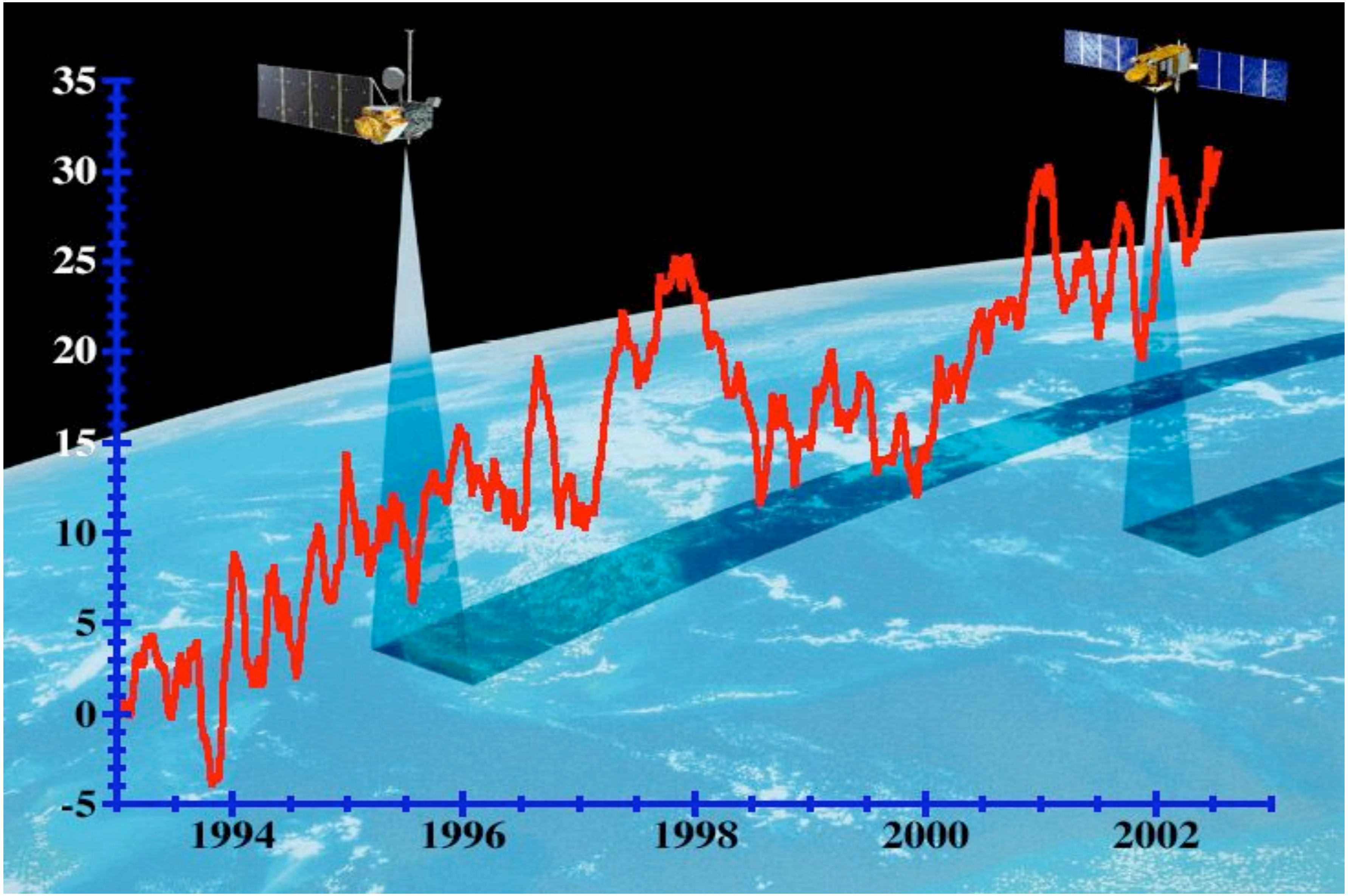
Steric sea level



Topex/Poseidon



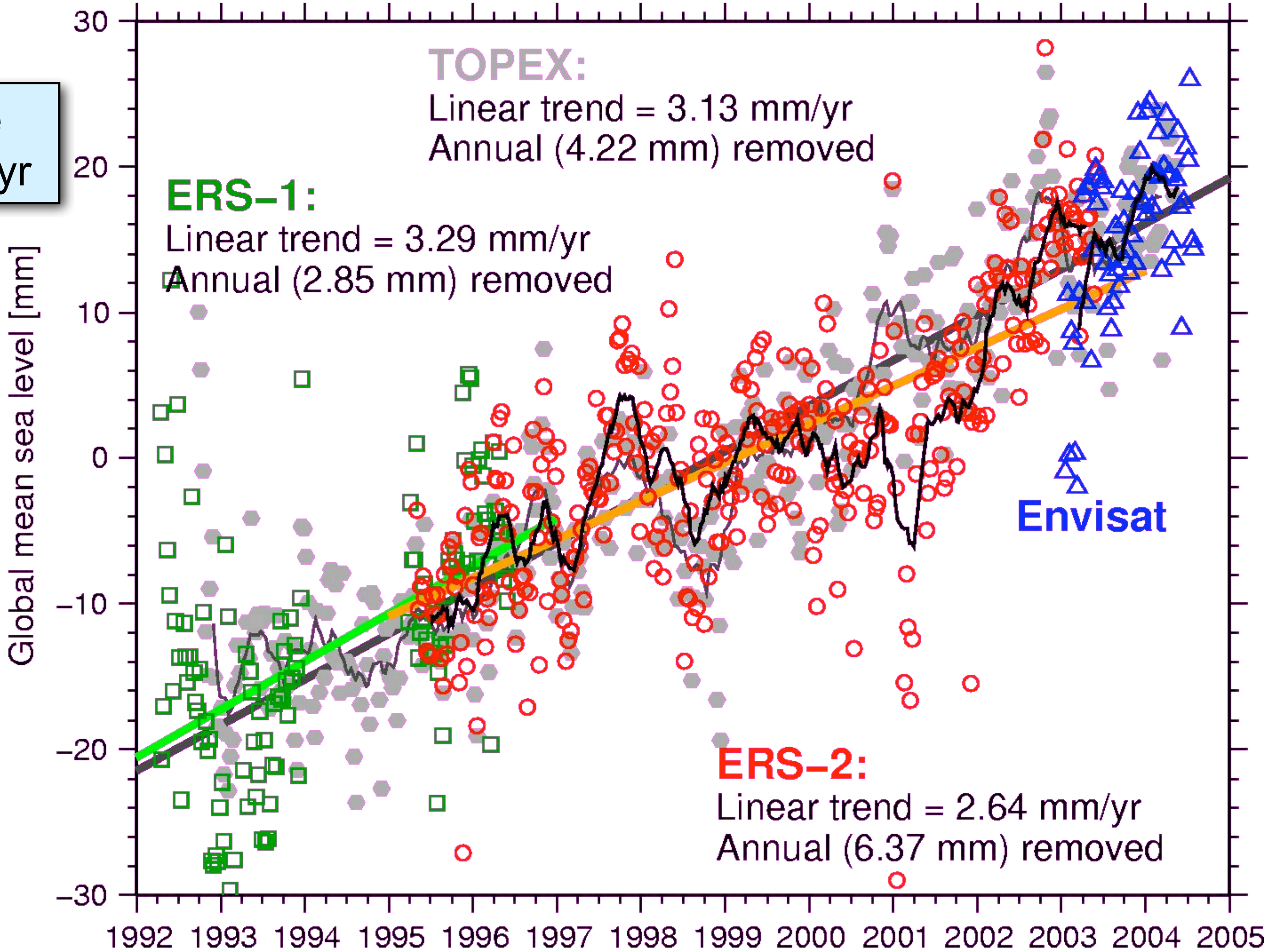
Global Sea Level Rise:



Sea Surface Height (Altimeter)

altimeter measurements initiated in the early 1990

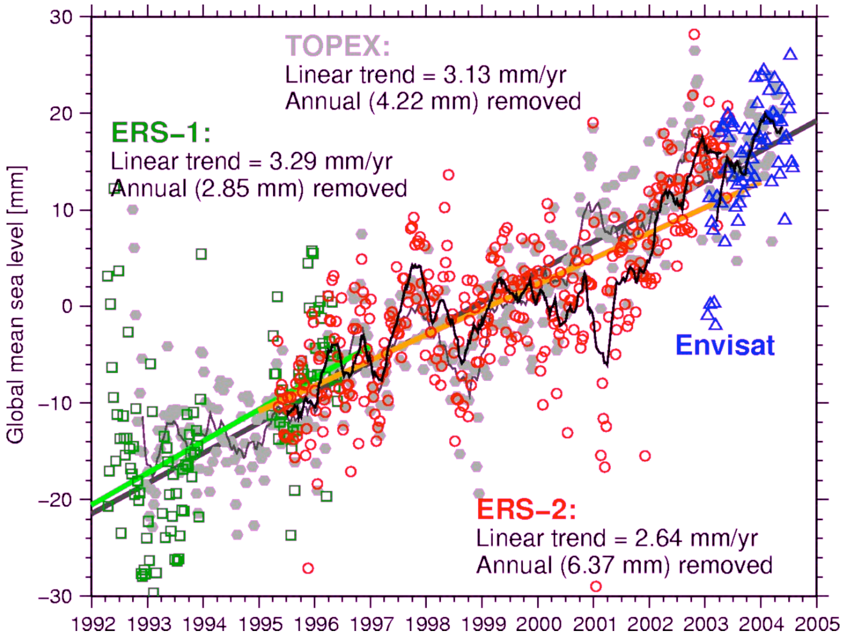
Sea level rise
Trend: +3 mm/yr

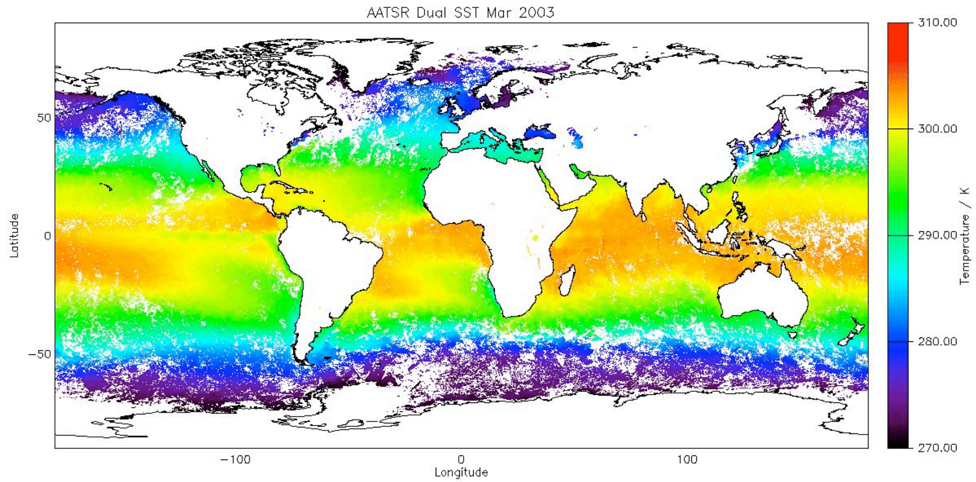


Courtesy of Remko Scharroo, NOAA,US

Sea Level rise

Sea Surface temperature rise





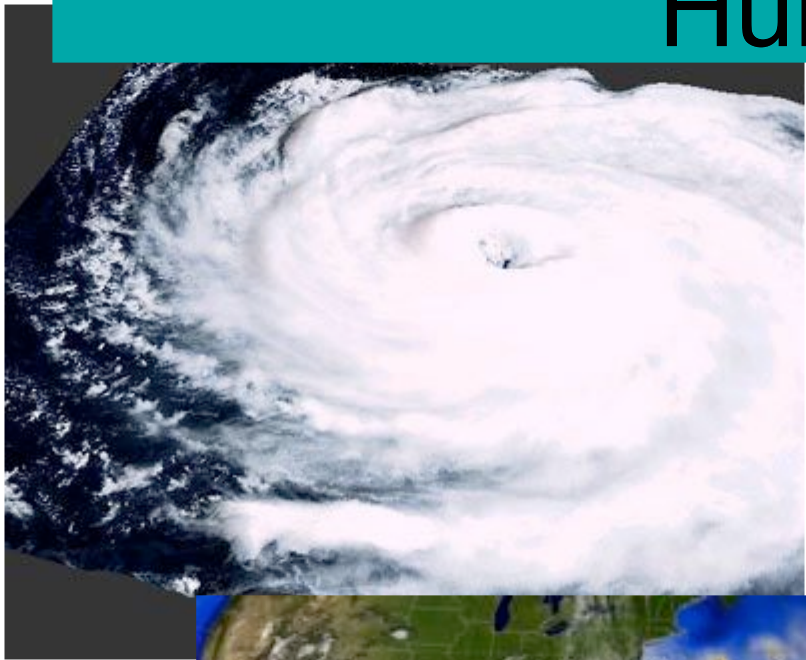
Altimetry measurements
Trend +3 mm/yr

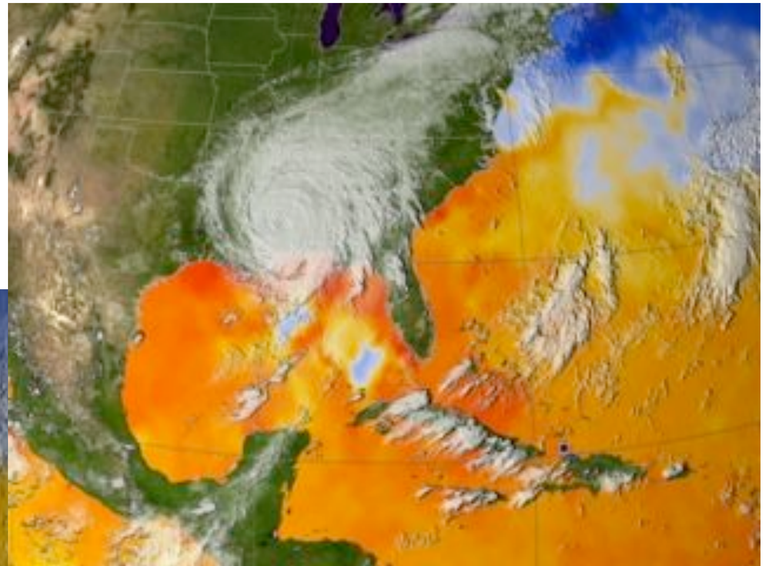
ATSR/AATSR measurements
Trend 0.13±0.03°C/decade

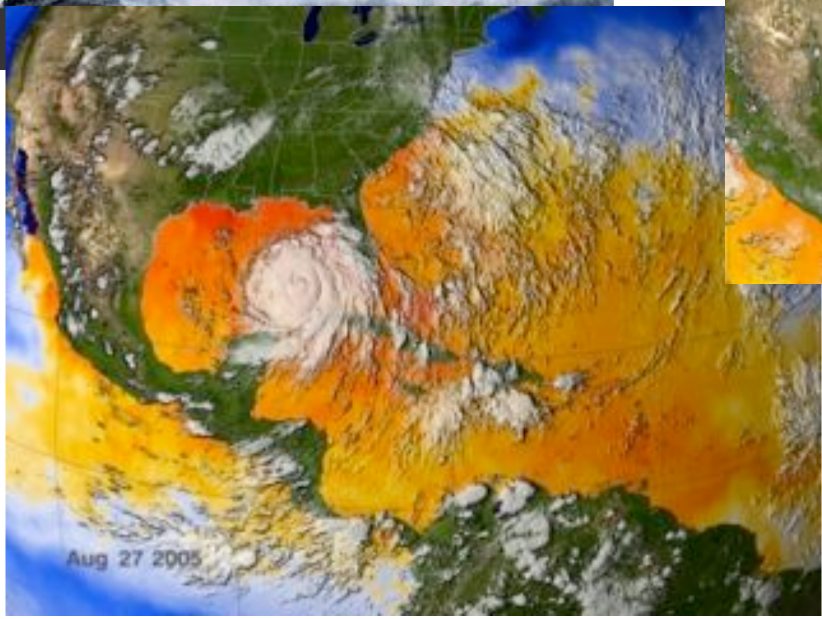
Courtesy of Remko Scharroo, NOAA,US

Courtesy of David Llewellyn Jones, Univ. Leicester, UK

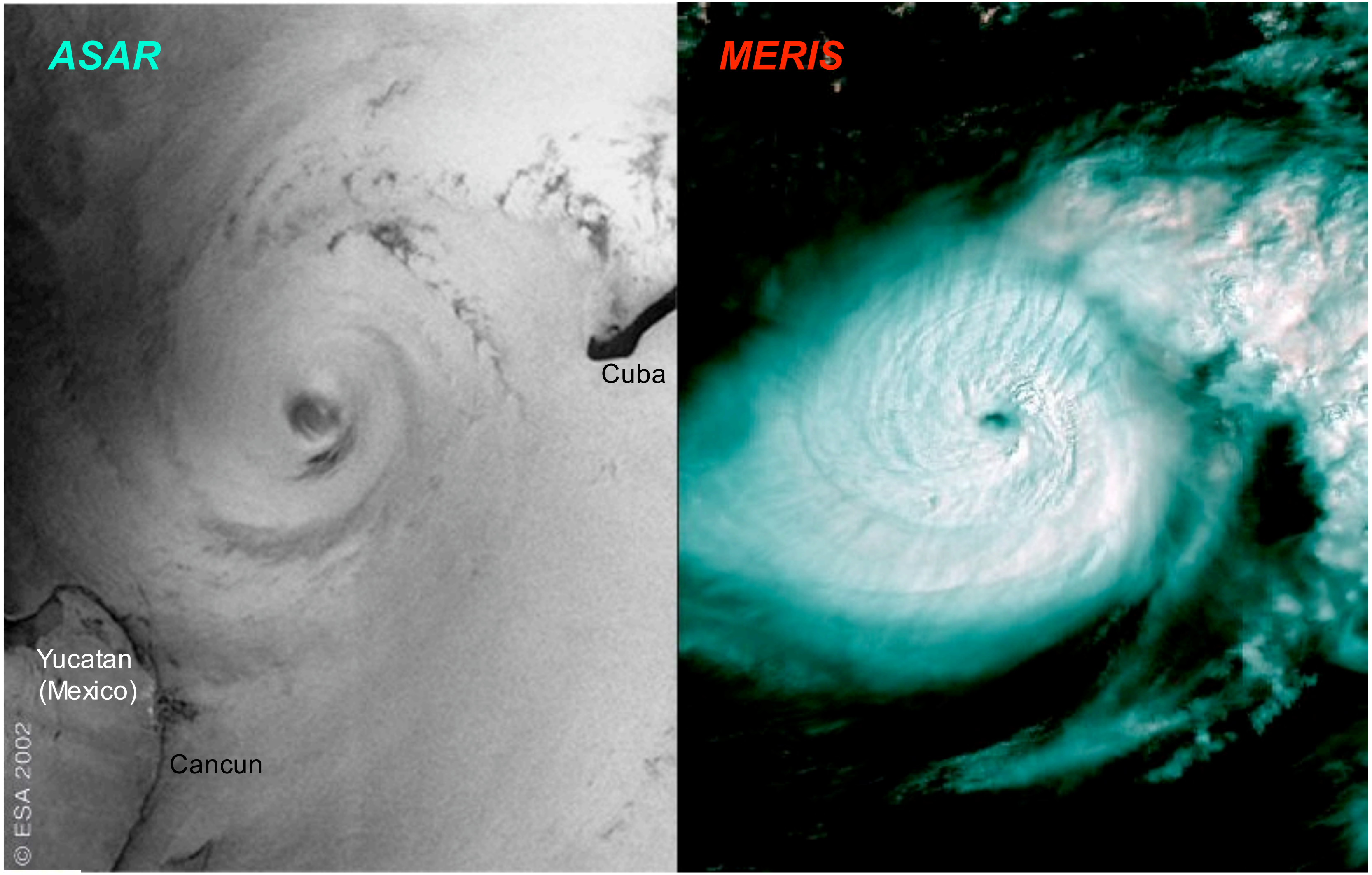
Satellite Observations of Hurricanes







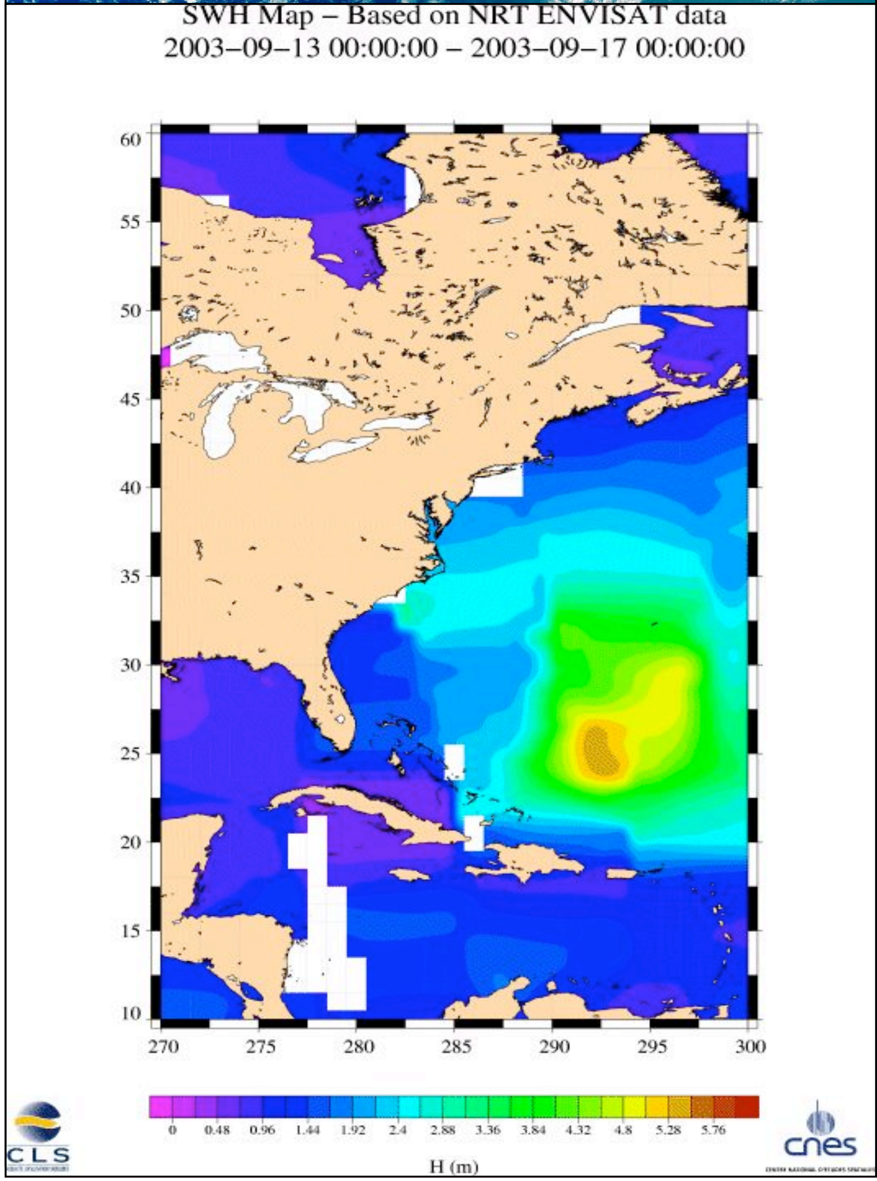
Hurricane Isidore (September 2002)

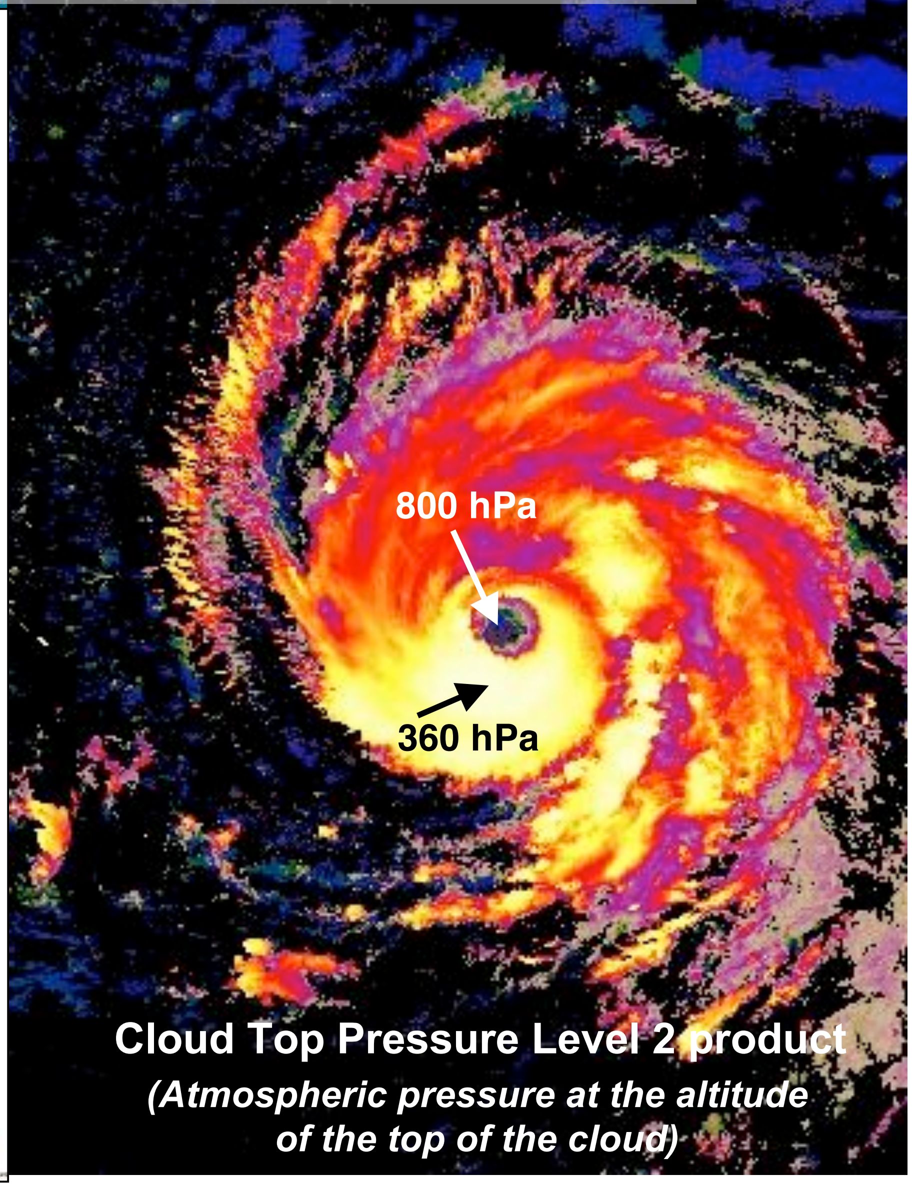


MERIS

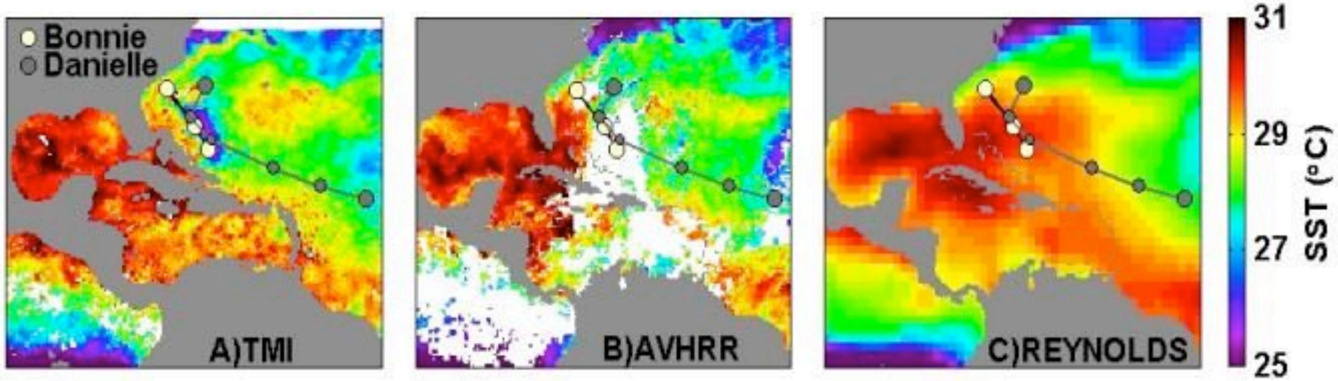
Altimetry

Hurricane Isabel – 8 September 2003 – Category 3 Hurricane



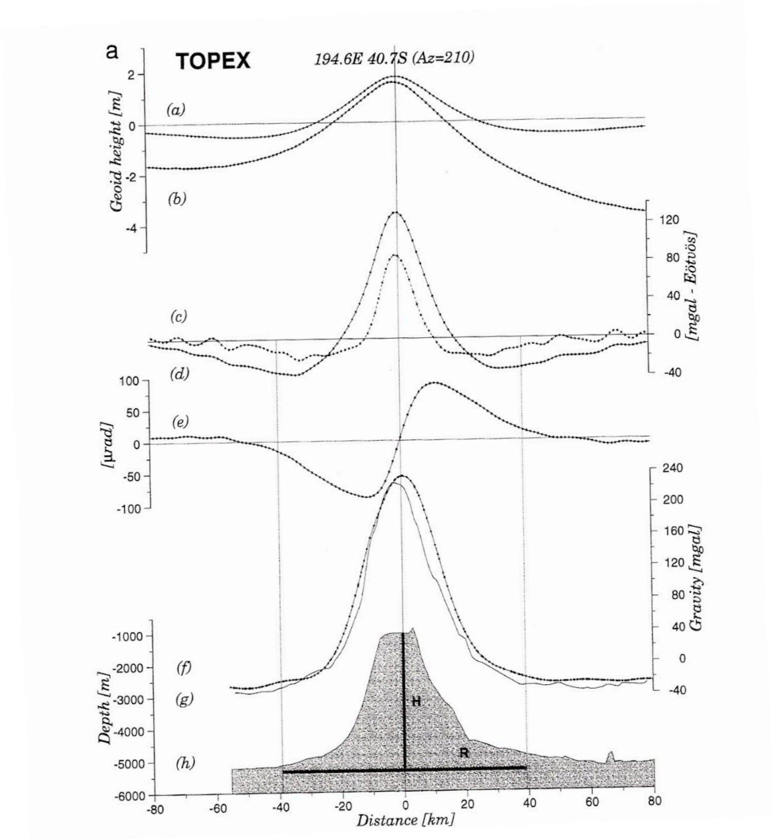


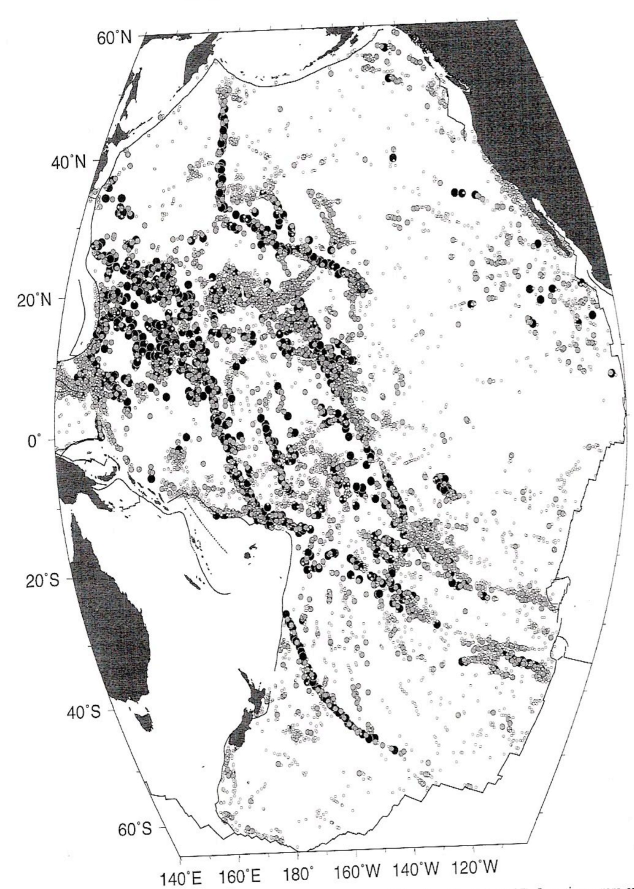
SST during Hurricane Danielle



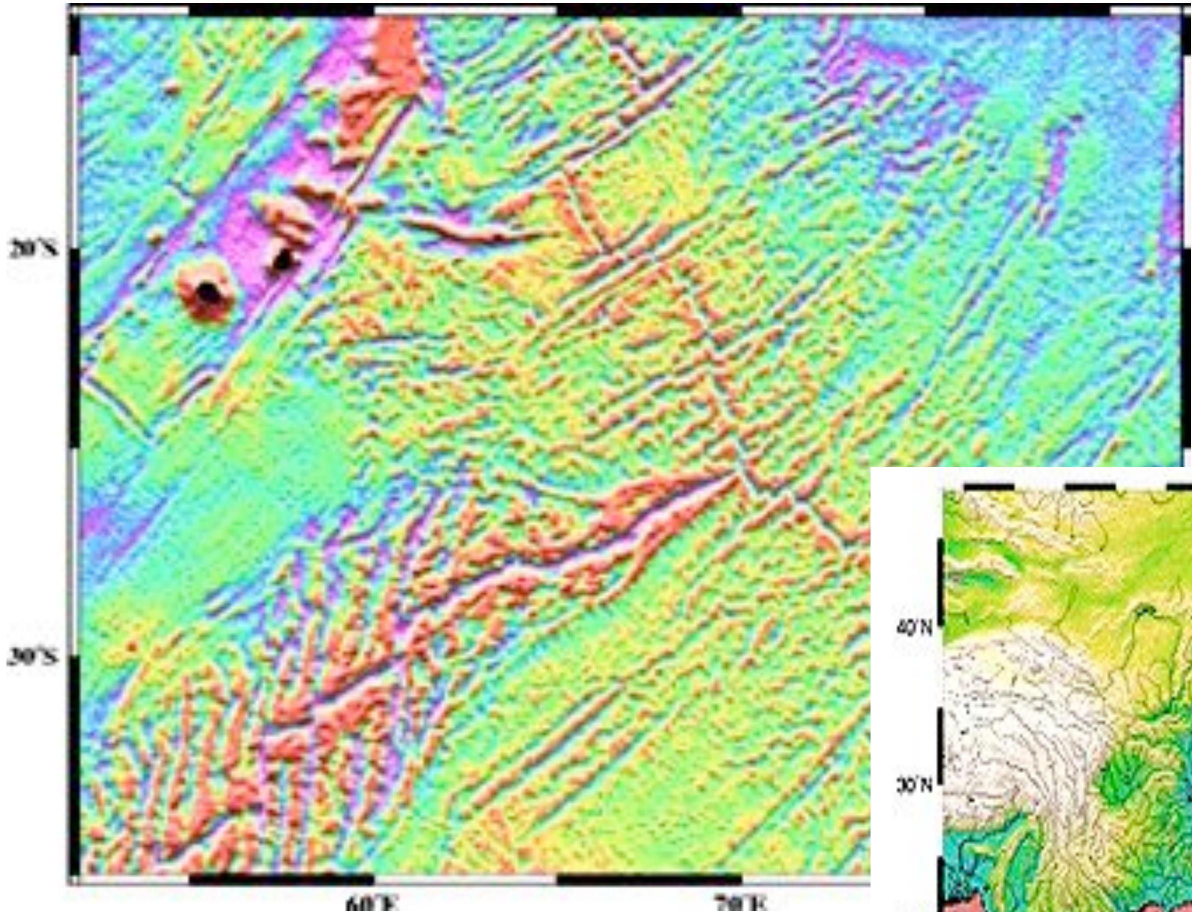
- TMI views cold wake from Hurricane Bonnie
- AVHRR misses it due to cloud cover
- Reynolds (weekly SST) lacks temporal resolution

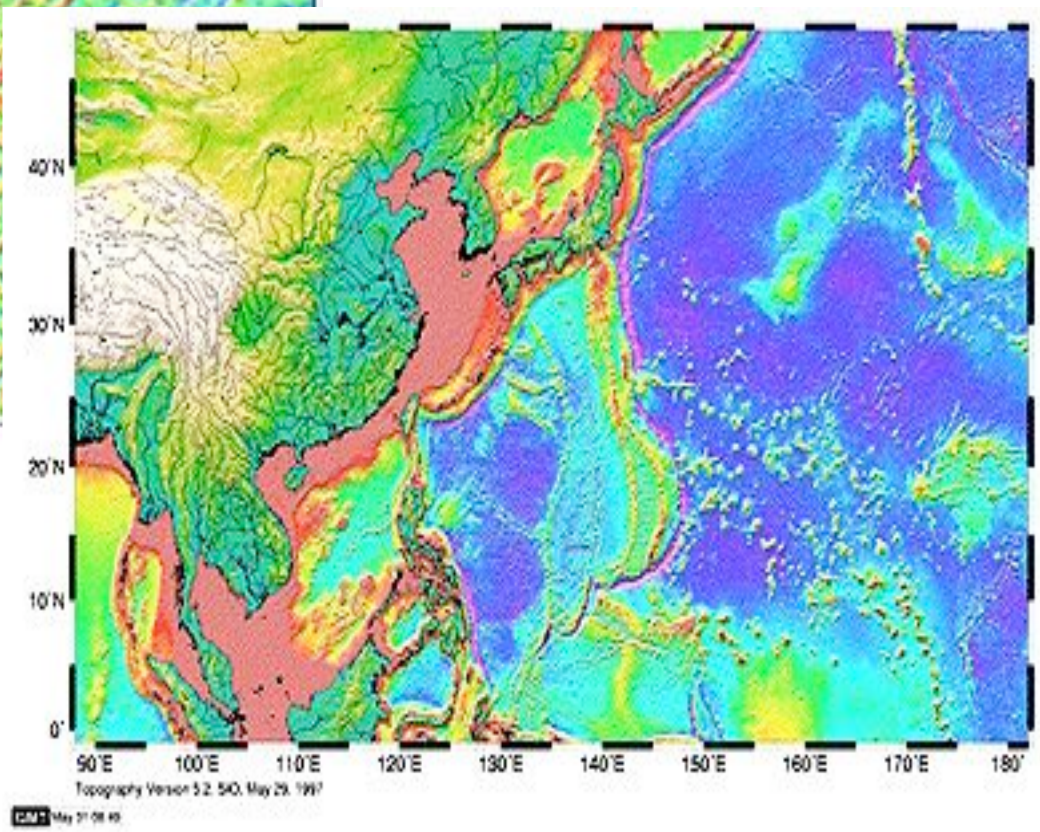
Altimetry and Bathymetry



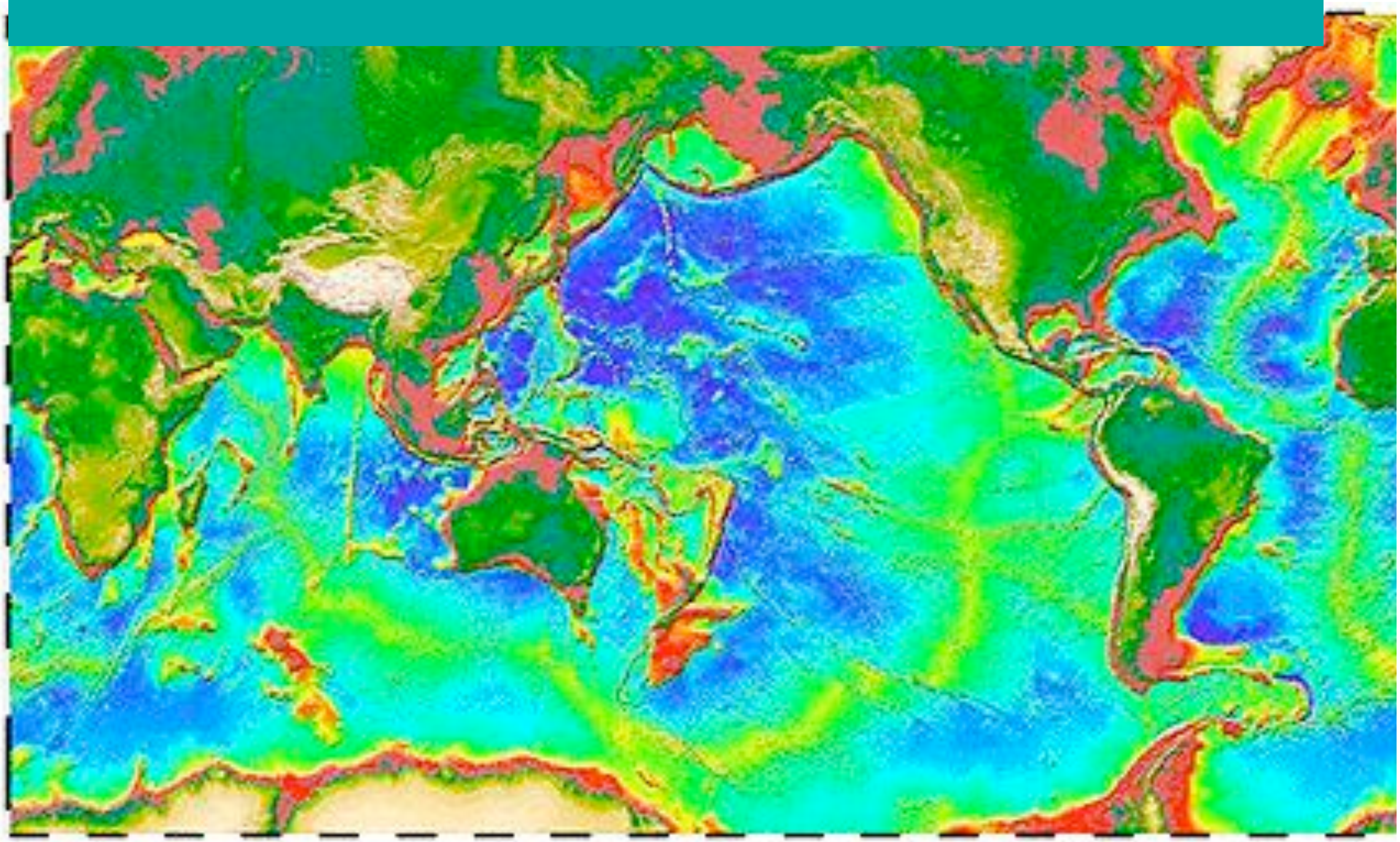


Wessel and Lyons (1997). Locations were ex-

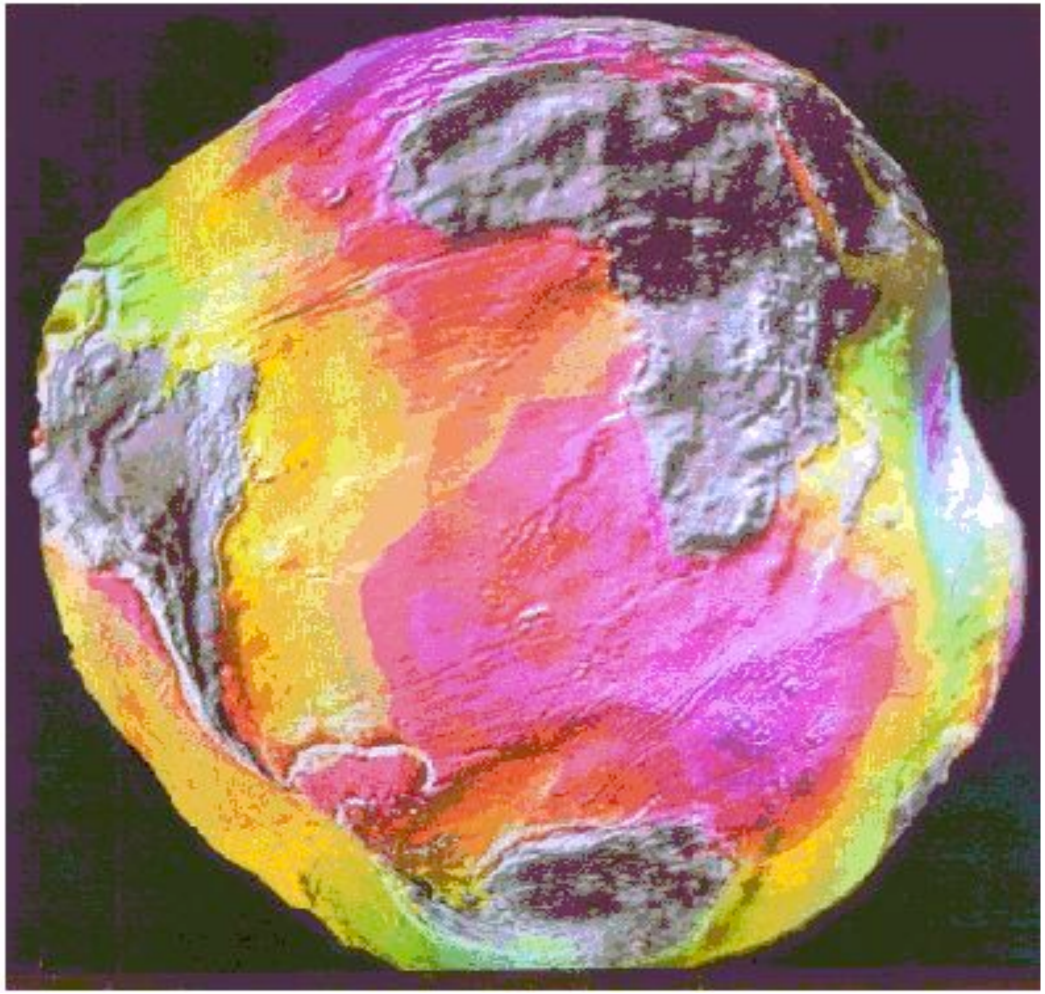

20°S
30°S
60°E
70°E


40°N
30°N
20°N
10°N
0°
90°E
100°E
110°E
120°E
130°E
140°E
150°E
160°E
170°E
180°
Topography Version 5.2. SIO, May 29, 1997

The Sandwell and Smith Topography

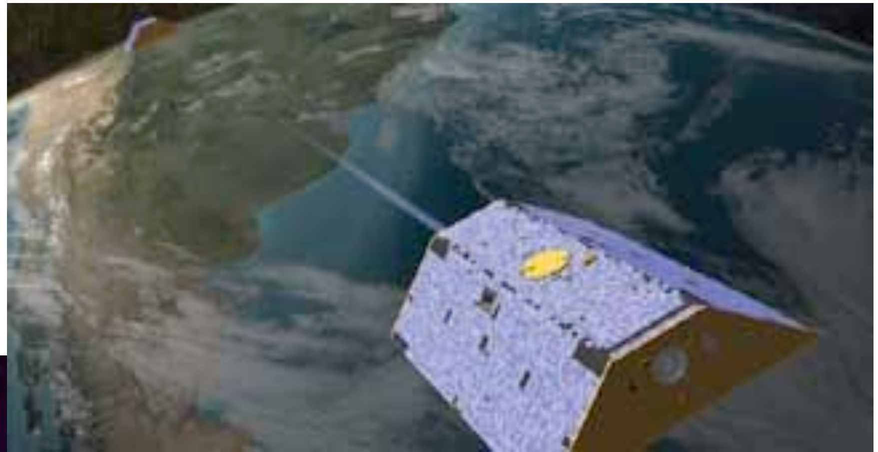


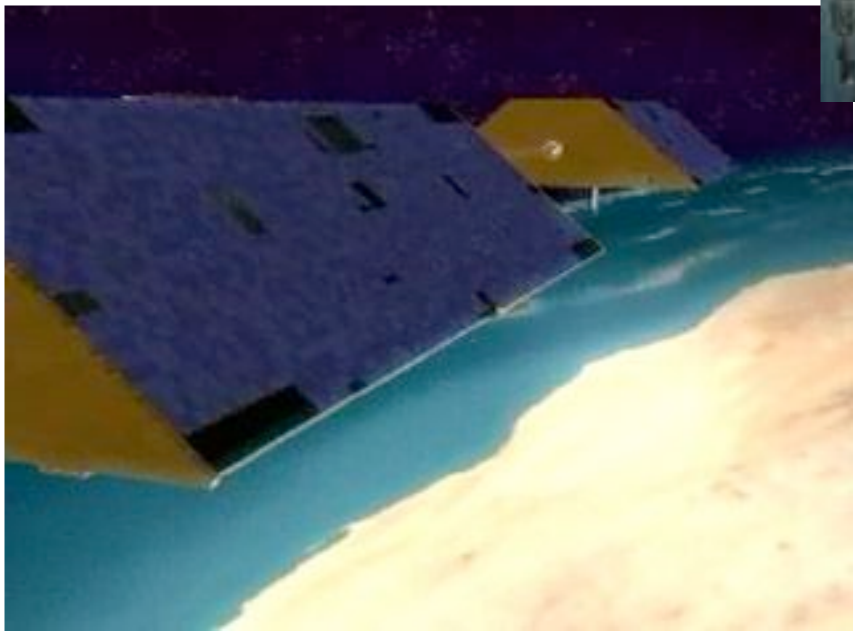
The Marine

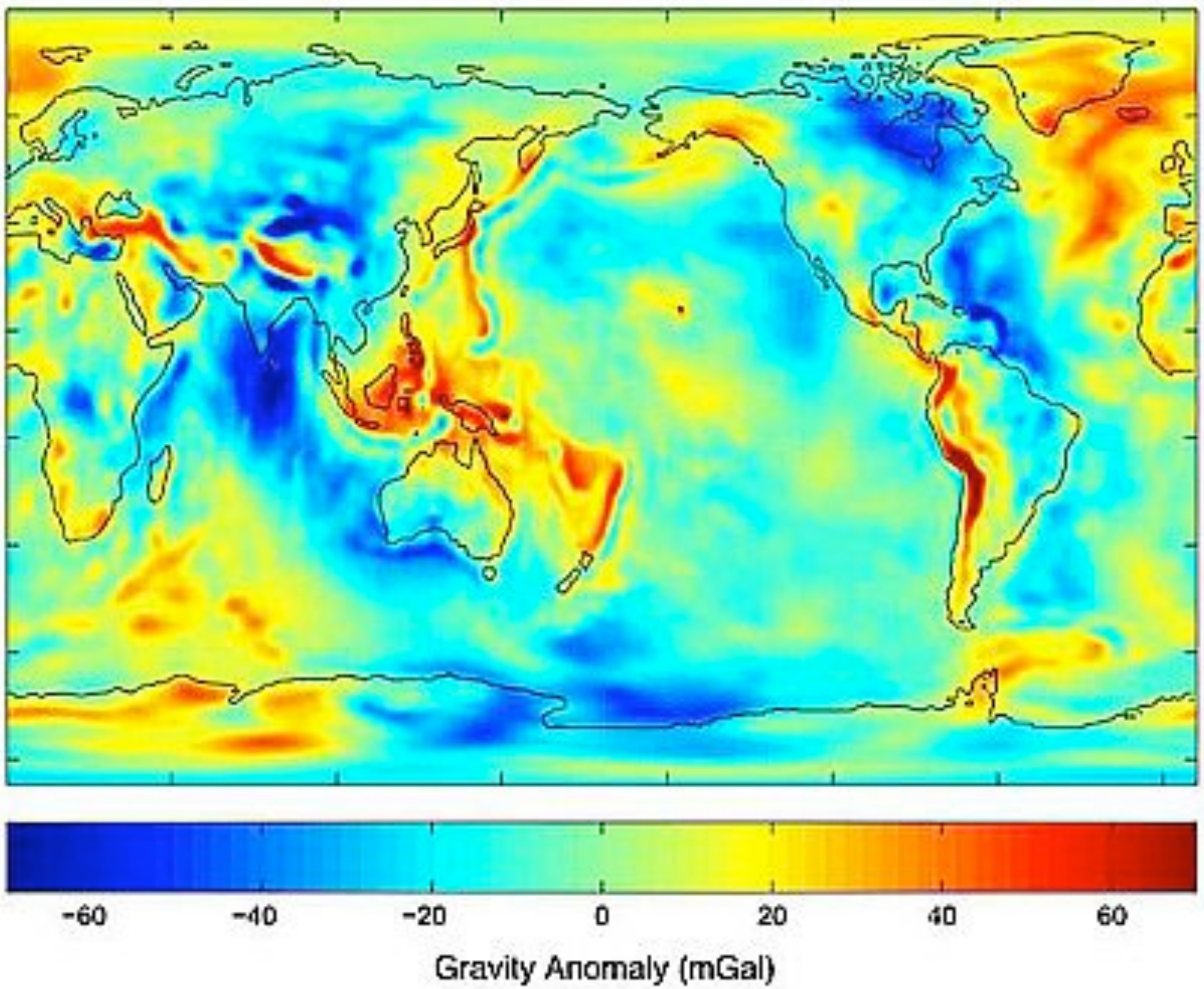


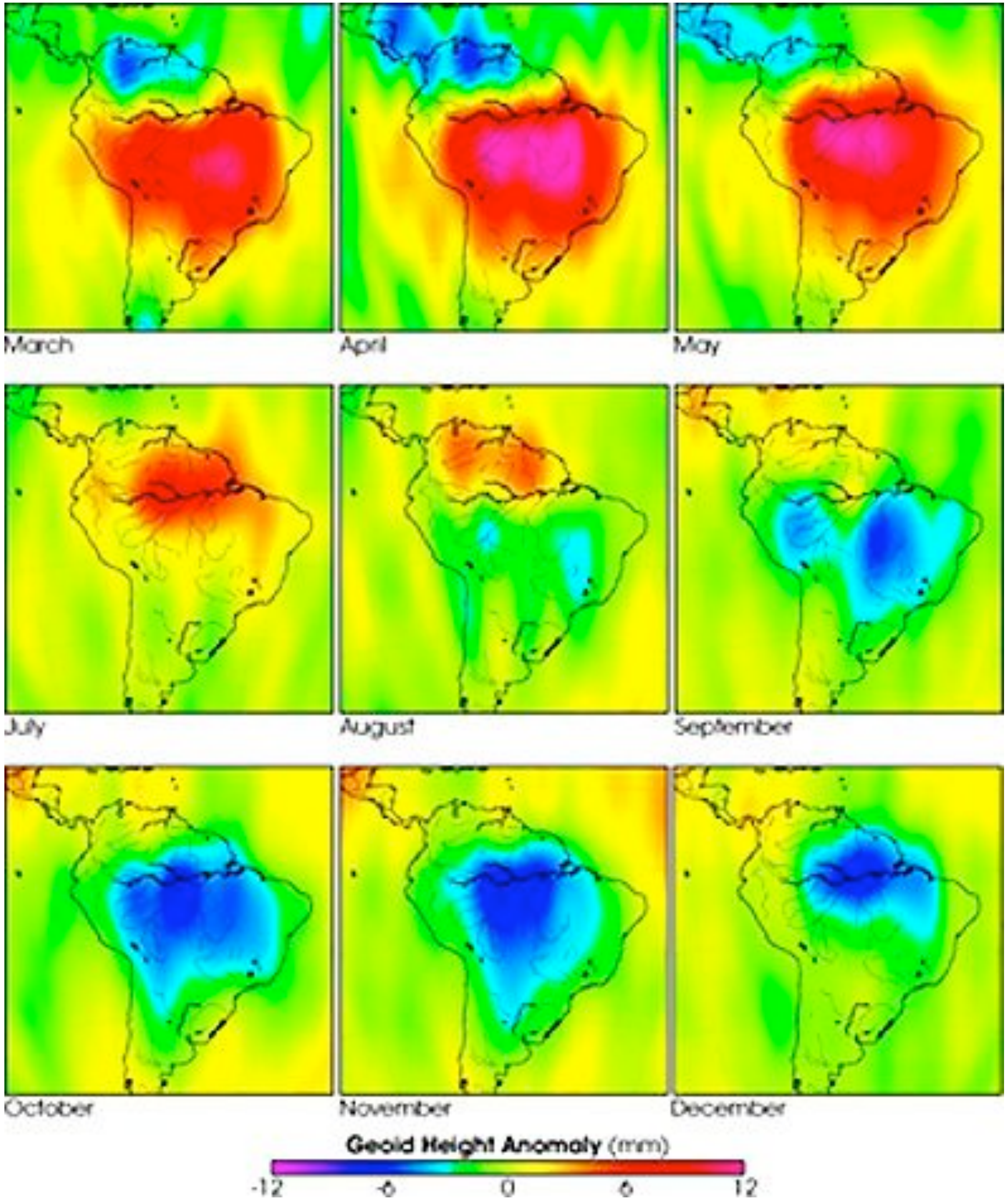
Temporal variation
Are being cause
Through changes in
Ground water and
Ocean mass.

The GRACE Mission





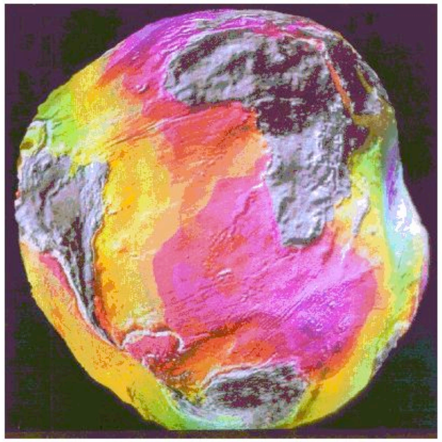

-60
-40
-20
0
20
40
60
Gravity Anomaly (mGal)

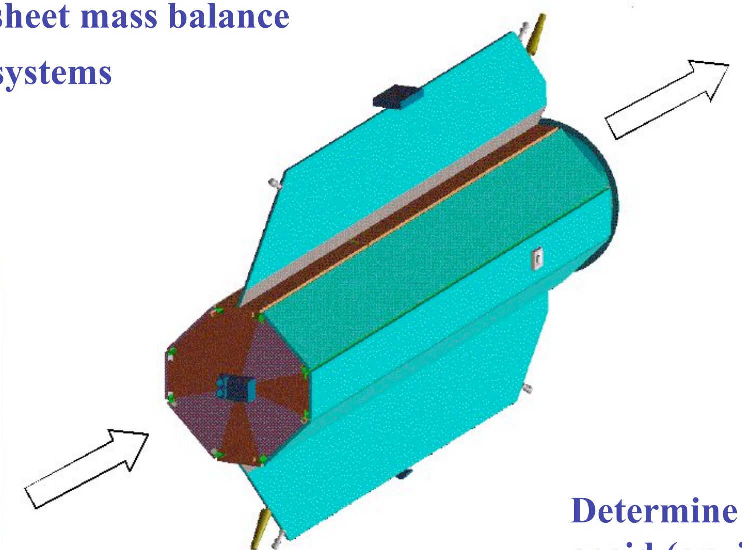

March
April
May
July
August
September
October
November
December
Geoid Height Anomaly (mm)
-12
-6
0
6
12

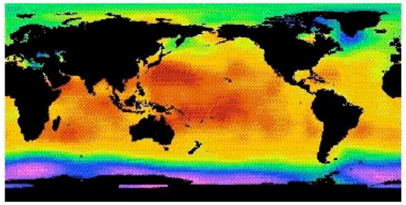
GOCE and the Geoid

Studies in:

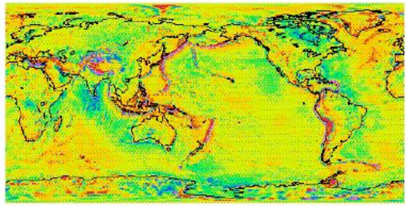
- **Solid Earth Physics - anomalous density structure of lithosphere and upper mantle**
- **Oceanography - dynamic ocean topography and absolute ocean circulation**
- **Ice Sheet Dynamics - ice sheet mass balance**
- **Geodesy - unified height systems**
- **Sea Level change**







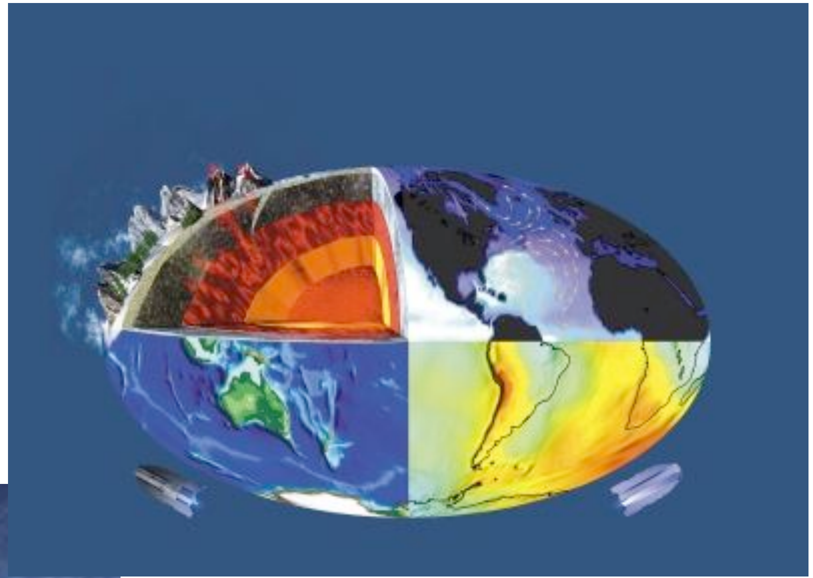
Geoid

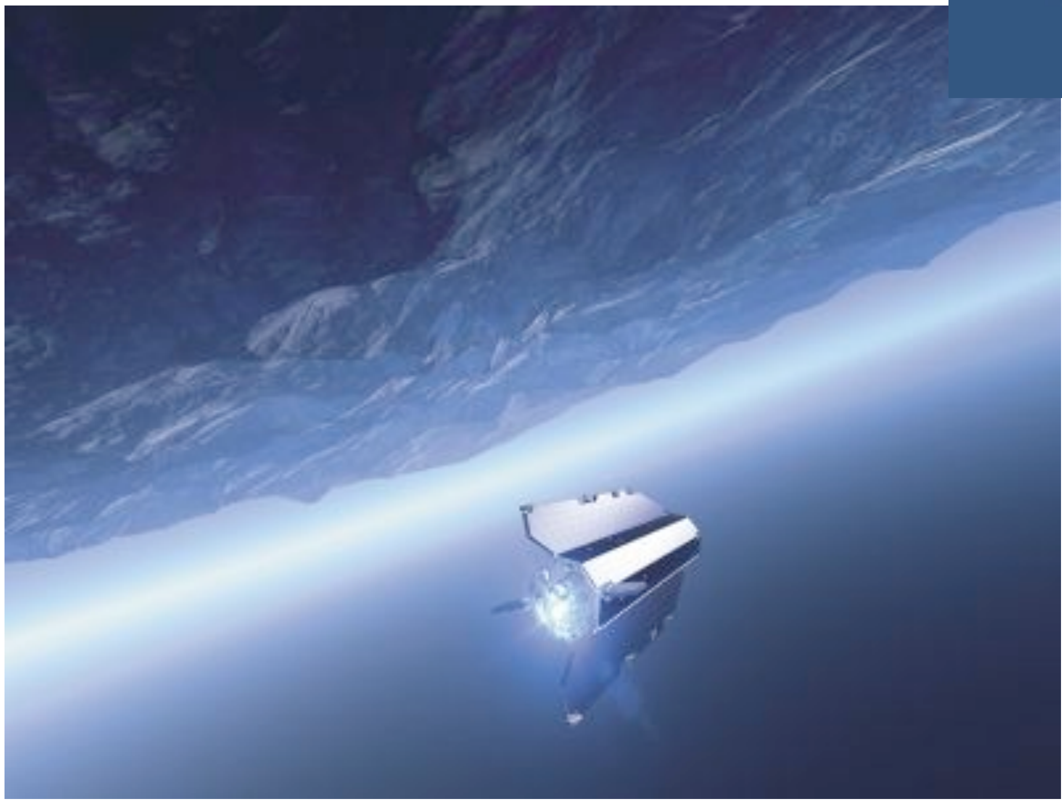


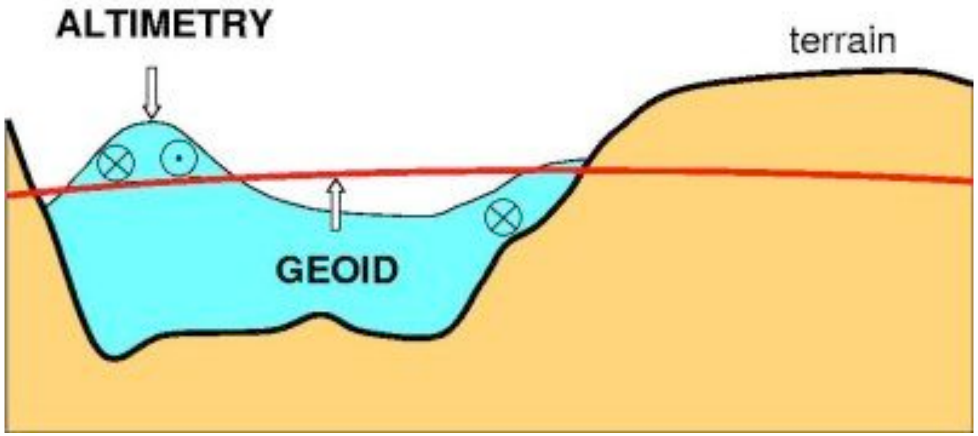
Gravity Anomalies

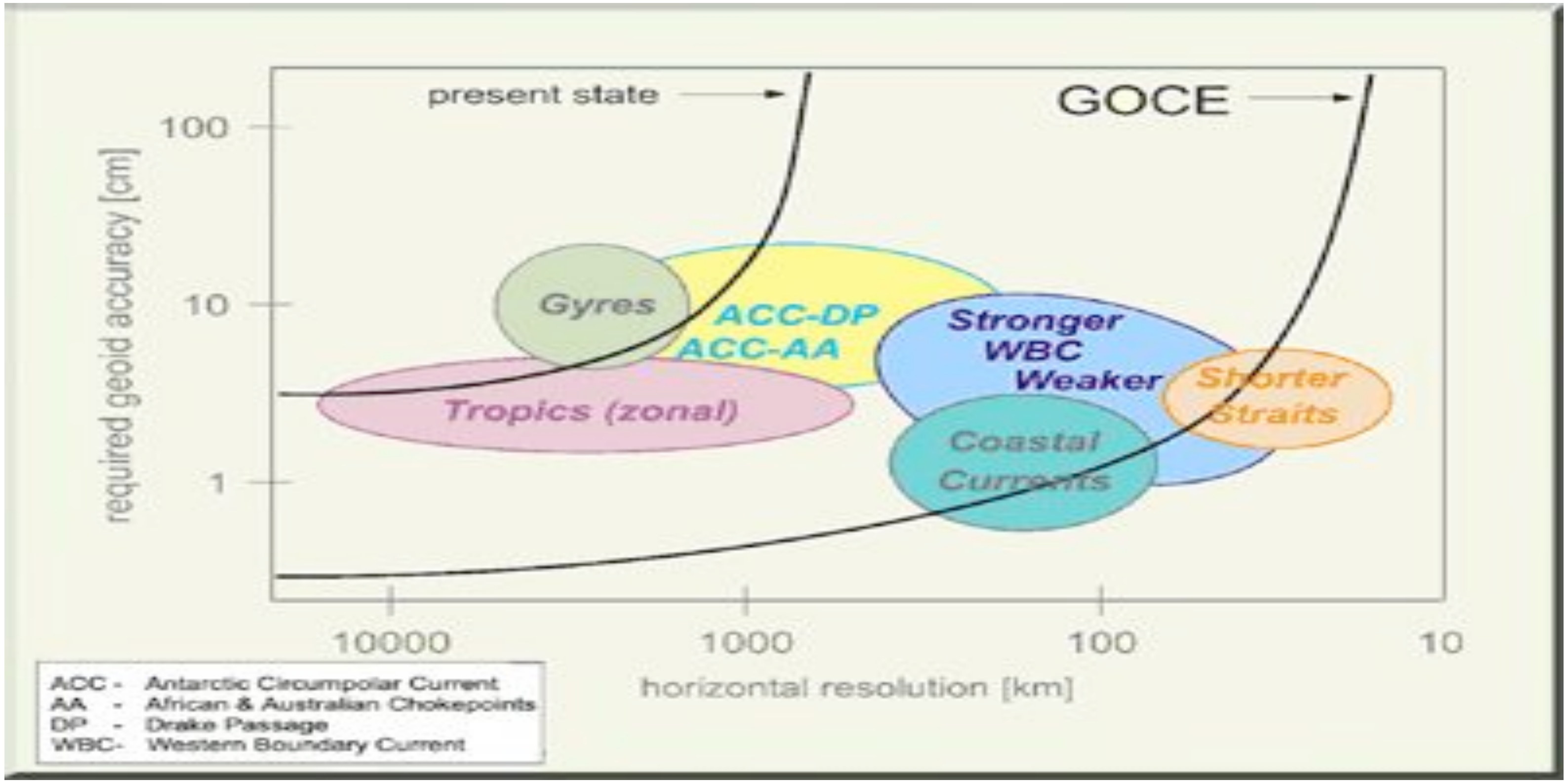
Determine Earth's gravity field and its geoid (equipotential surface for a hypothetical ocean at rest):

- **high accuracy (1 mgal and 1 cm)**
- **fine spatial resolution (~ 100 km)**

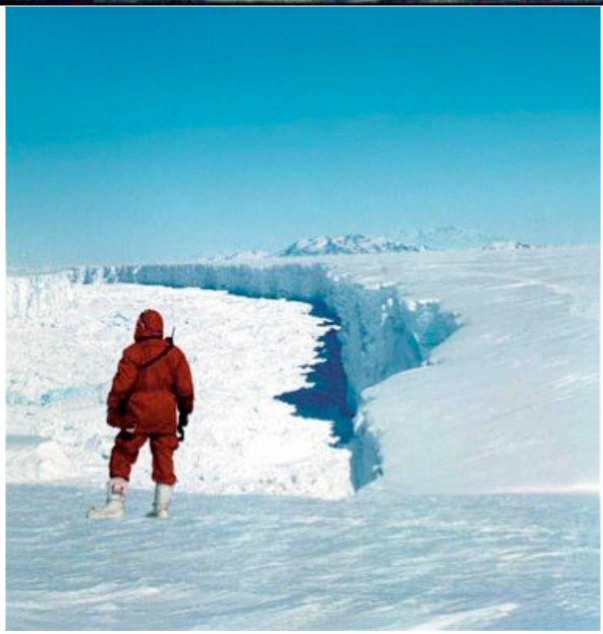




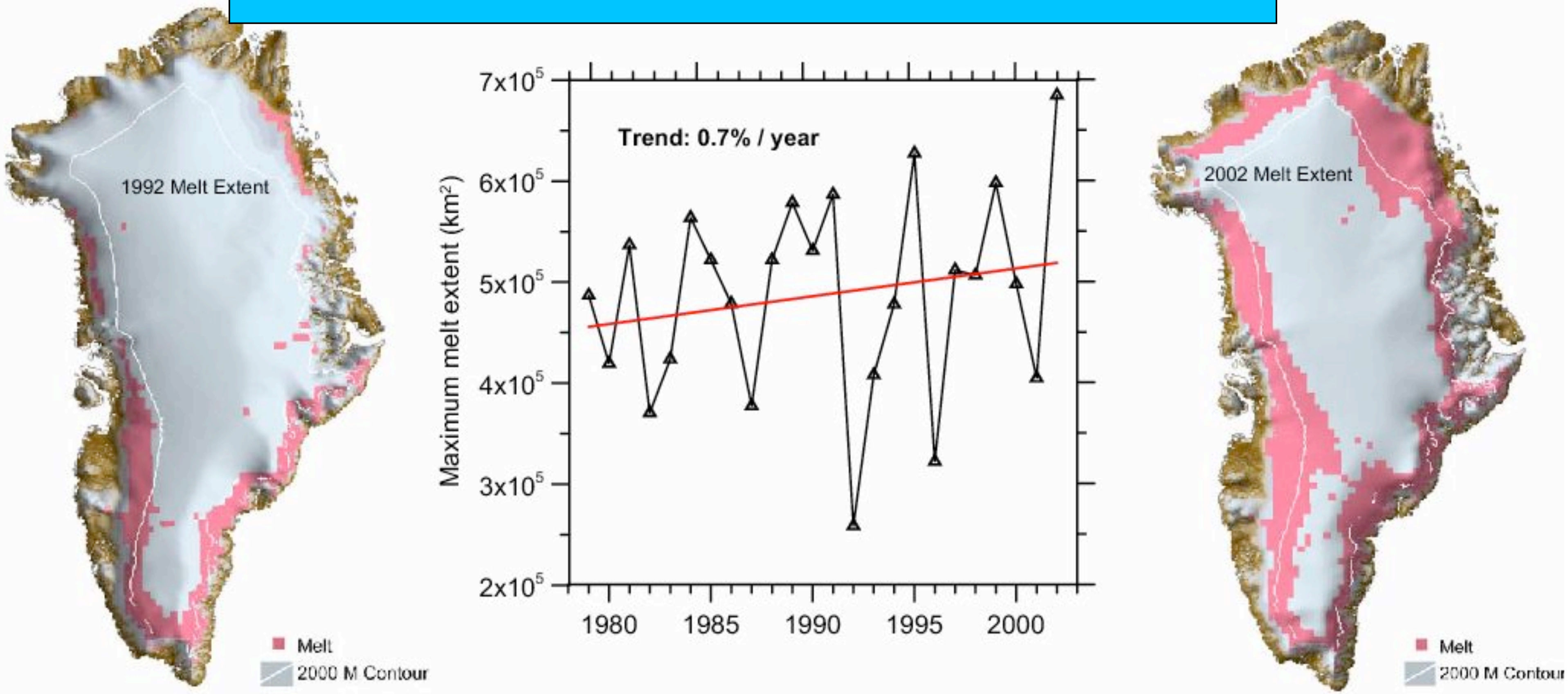

ALTIMETRY
terrain
GEOID


present state
GOCE
100
10
1
required geoid accuracy [cm]
Gyres
ACC-DP
ACC-AA
Tropics (zonal)
Stronger
WBC
Weaker
Shorter
Straits
Coastal
Currents
10000
1000
100
10
horizontal resolution [km]
ACC - Antarctic Circumpolar Current
AA - African & Australian Chokepoints
DP - Drake Passage
WBC- Western Boundary Current






Reaktion des Grönlandeises auf globale Erwärmung



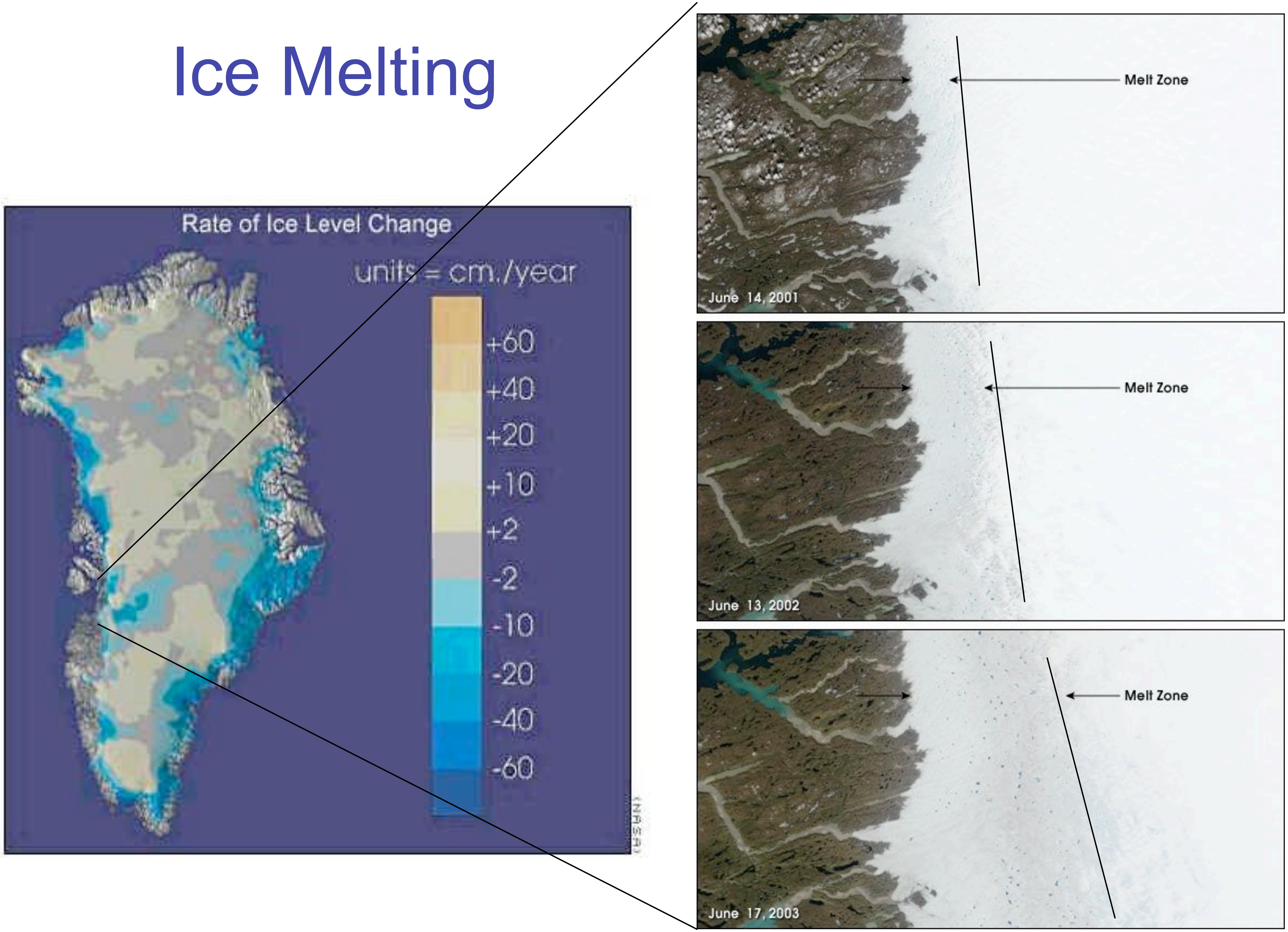
Greenland ice sheet melt area increased on average by 16% from 1979 to 2002.
The smallest melt extent was observed after the Mt. Pinatubo eruption in 1992

University of Colorado

CIRES

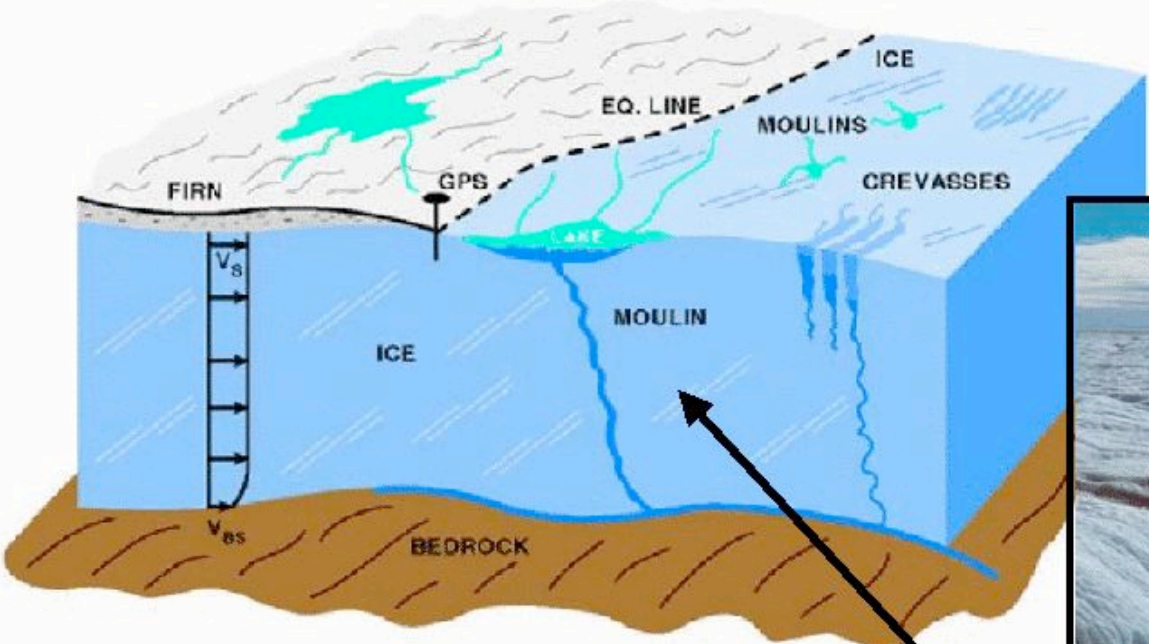
Konrad Steffen and Russell Huff, University of Colorado at Boulder

Ice Melting



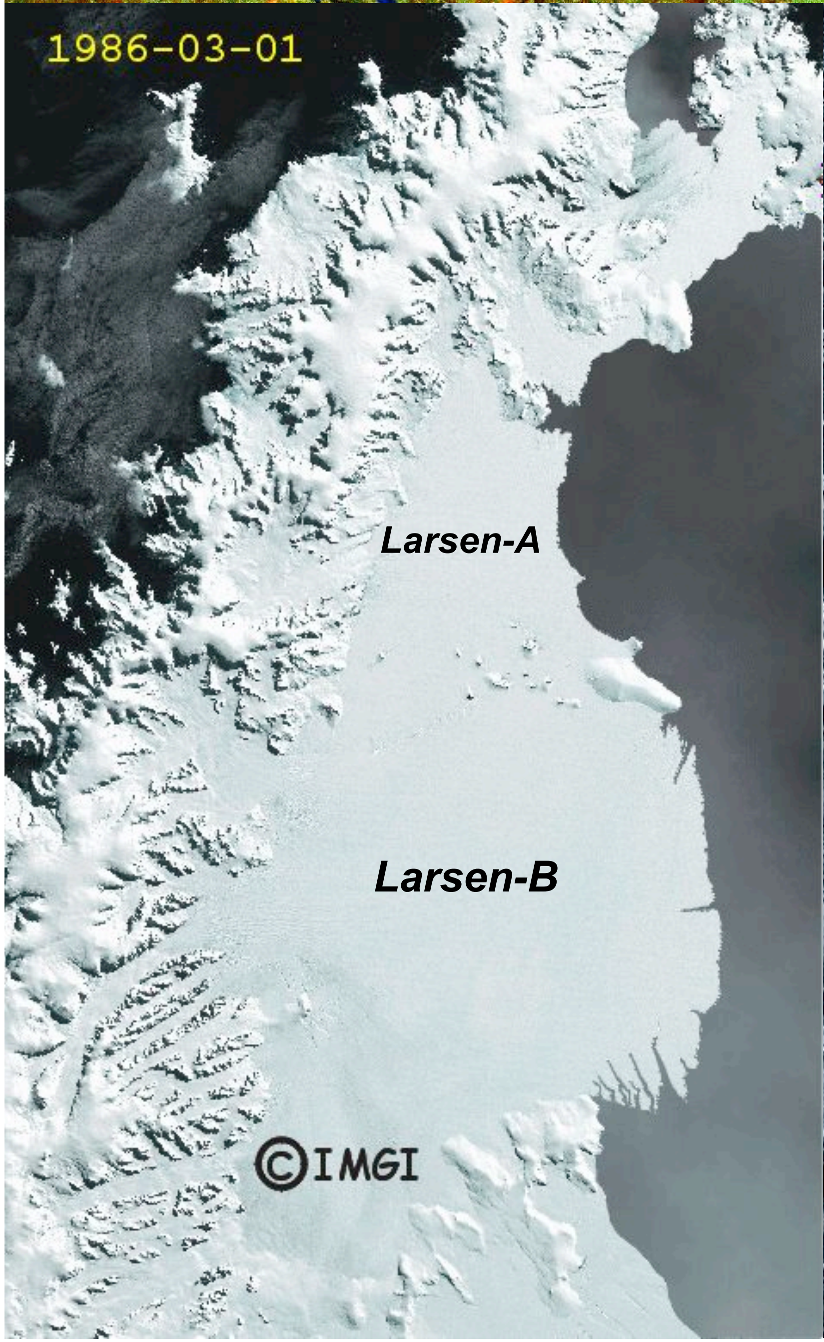
Rate of Ice Level Change
units = cm./year
+60
+40
+20
+10
+2
-2
-10
-20
-40
-60
Melt Zone
June 14, 2001
Melt Zone
June 13, 2002
Melt Zone
June 17, 2003

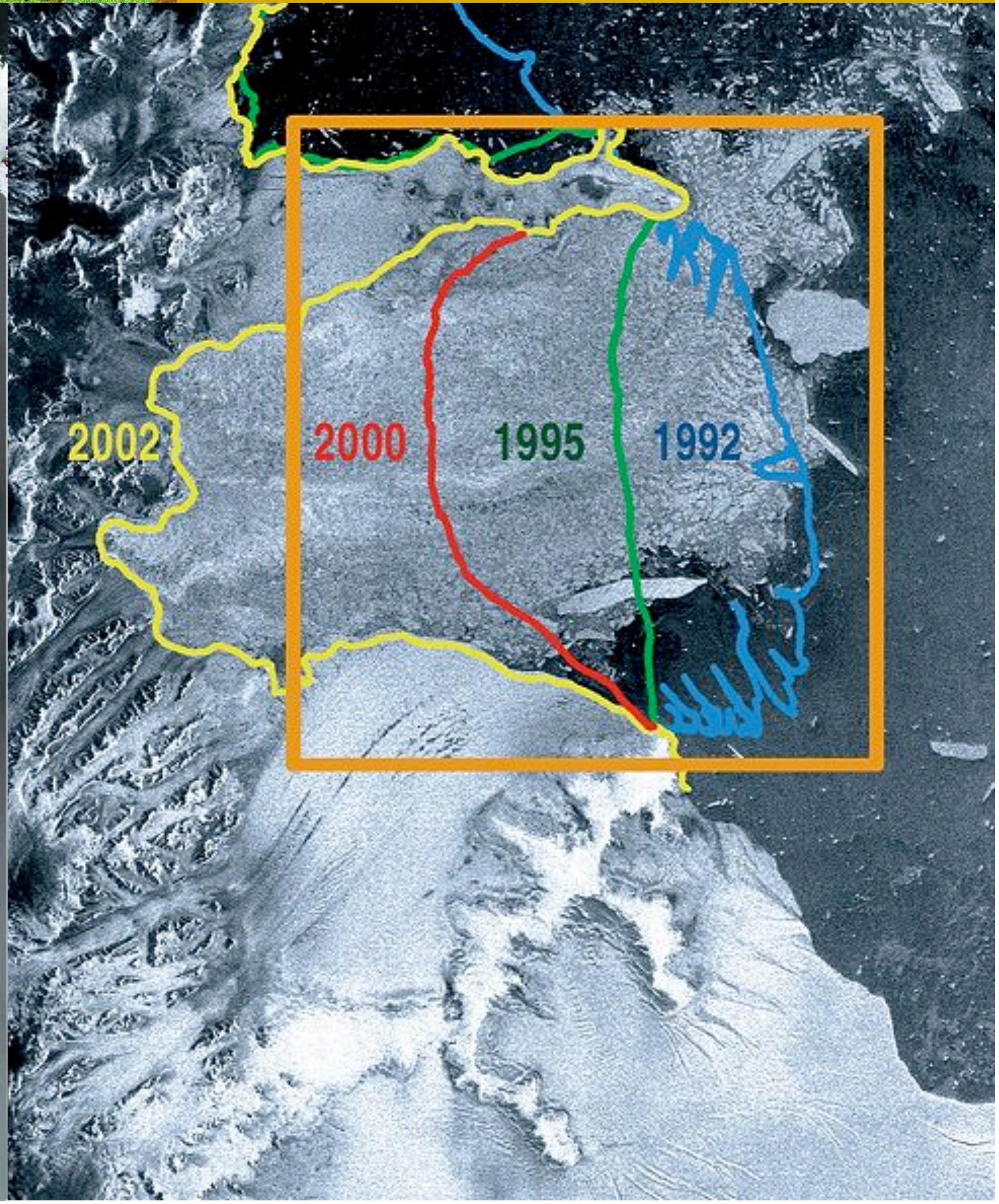
New mechanisms of increased ice shield sensitivity to global warming



Zwally et al., (2002) *Science*
Parizek and Alley (2004) submitted

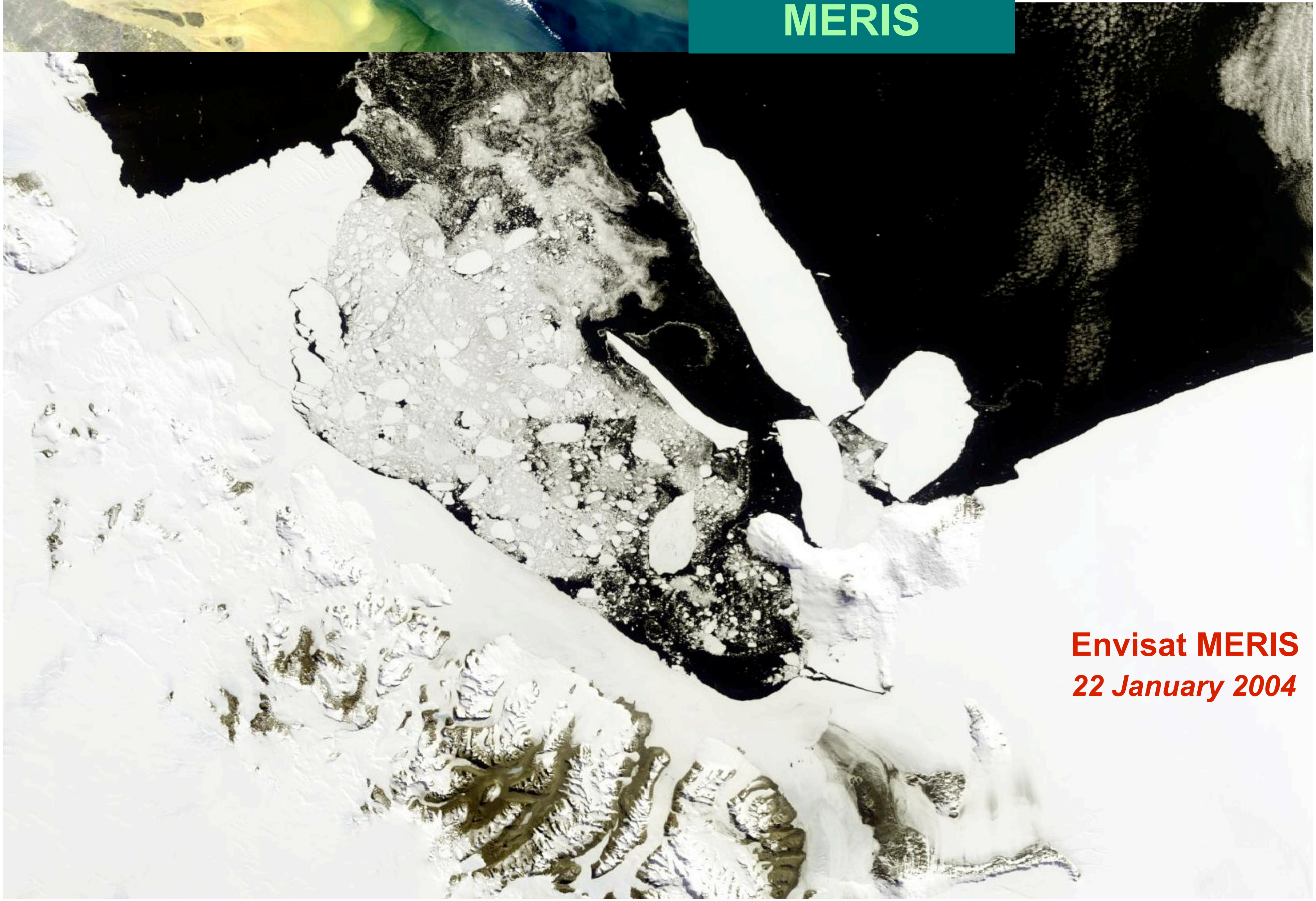
ERS / Envisat SAR



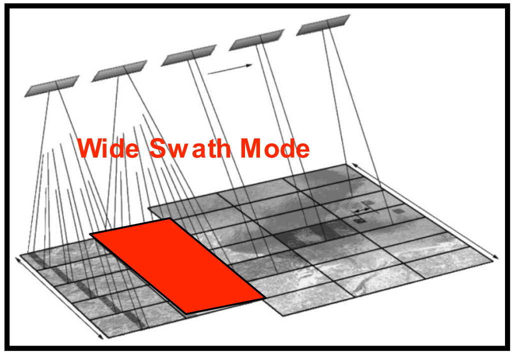


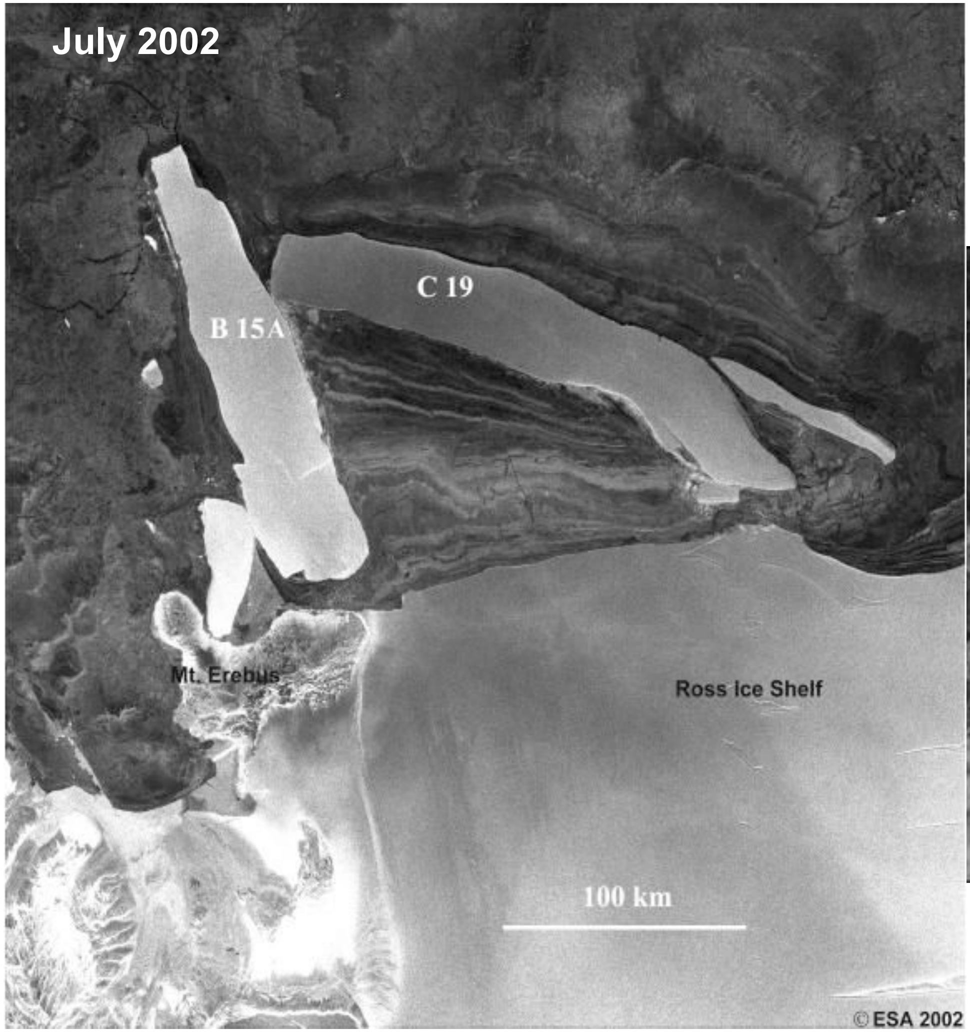
ASAR

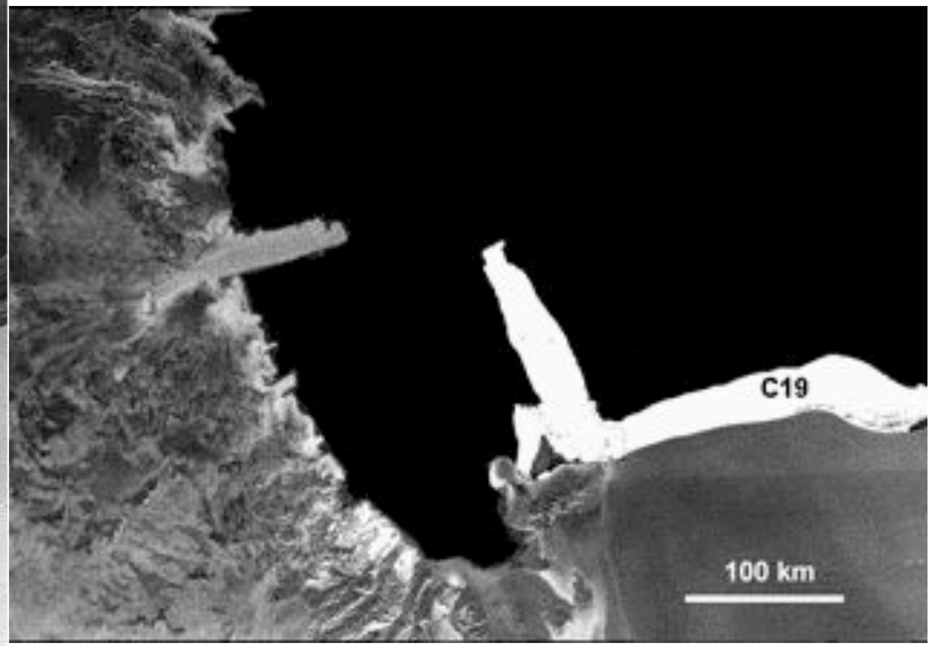
MERIS



C-19 iceberg monitoring in Antarctica
(from May to October 2002)

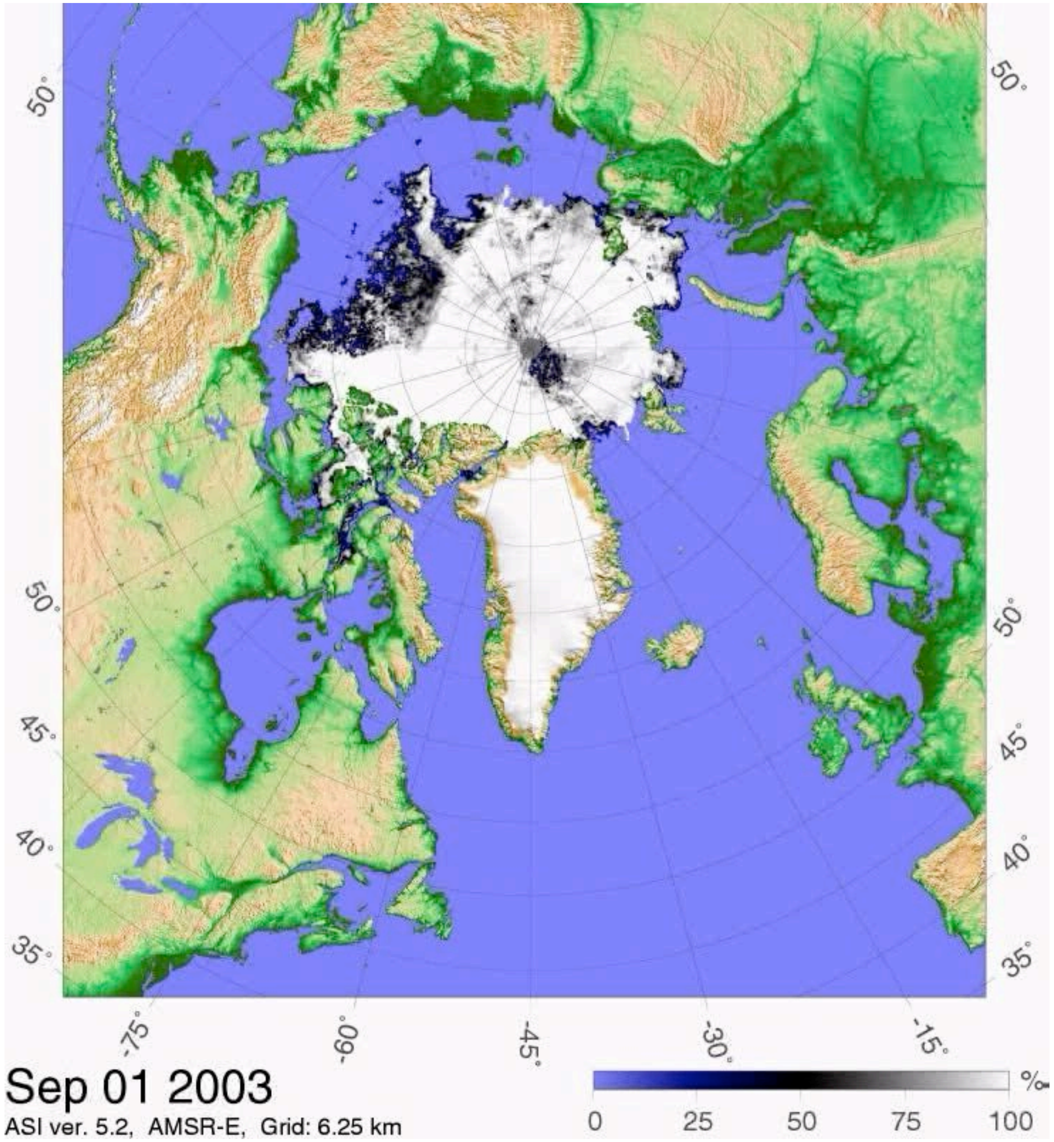






Generated using browse images

Arctic Sea Ice Monitoring

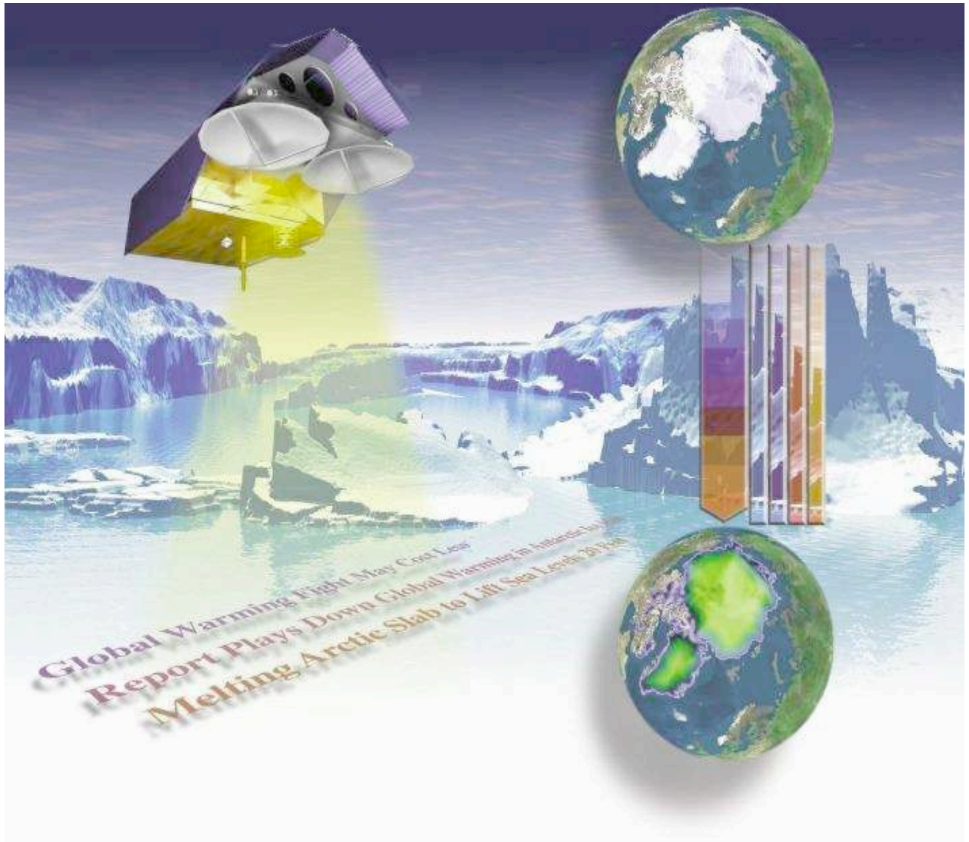


Daily ice concentration maps using passive microwave sensors show strong seasonal and interannual variations in sea ice extent between 1.9. 2003 and 31. 8. 2005.

(S. Kern und G. Spreen, IFM)

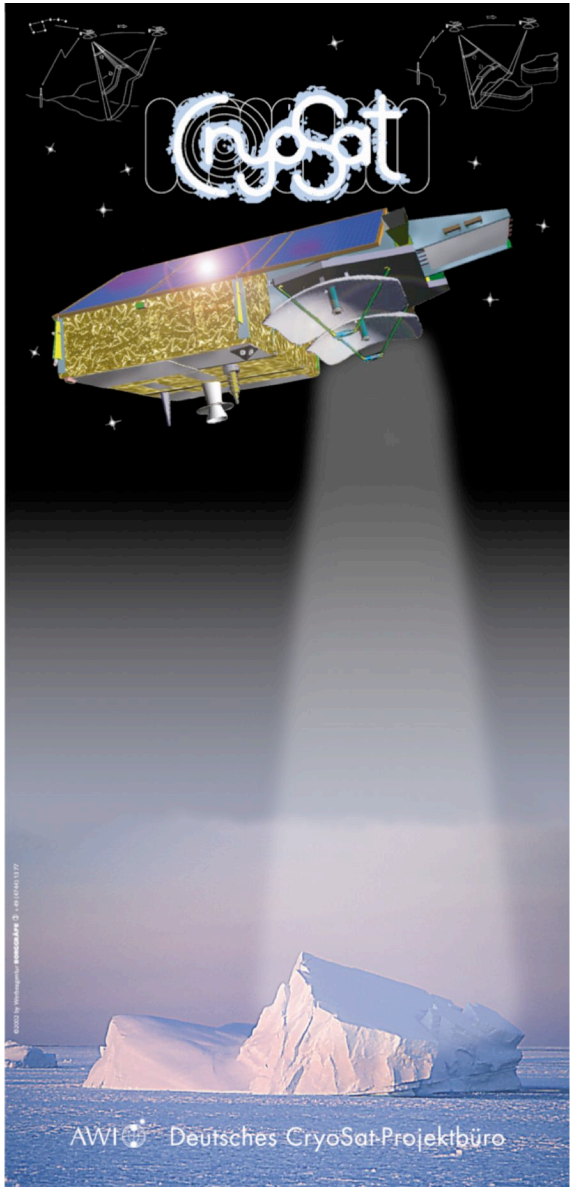
ESA's CryoSat-II Mission

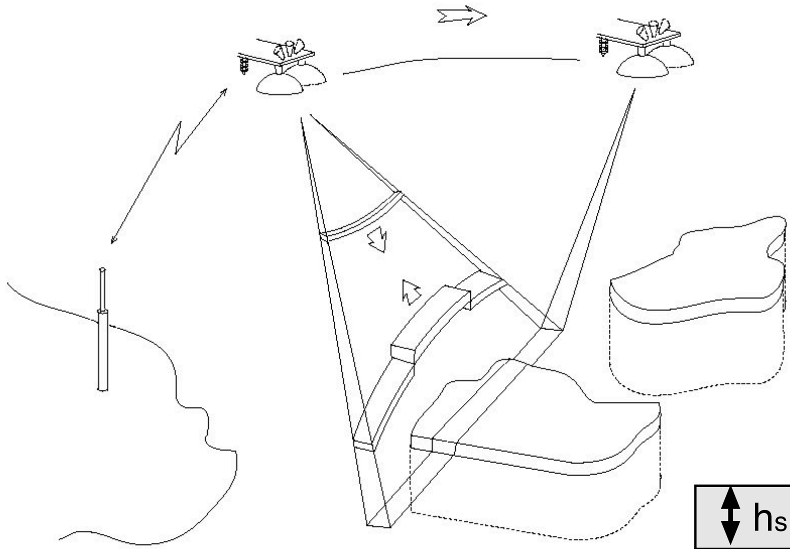
- Research goals:
  - Study of mass imbalances of Antarctic and Greenland ice sheets
  - Investigate the influence of the Cryosphere on global sea level rise
  - Use of sea ice thickness information for advances in Arctic and global climate studies
- Measures variations in the thickness of the polar ice sheets and thickness of floating sea ice

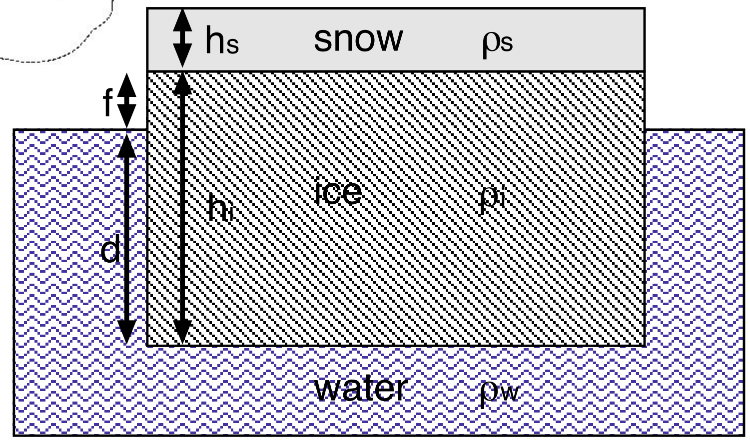


Payload: SIRAL altimeter, conventional pulse limited operation, synthetic aperture along track, interferometer across track

CryoSat: First observations of regional, seasonal, and interannnual sea ice variability

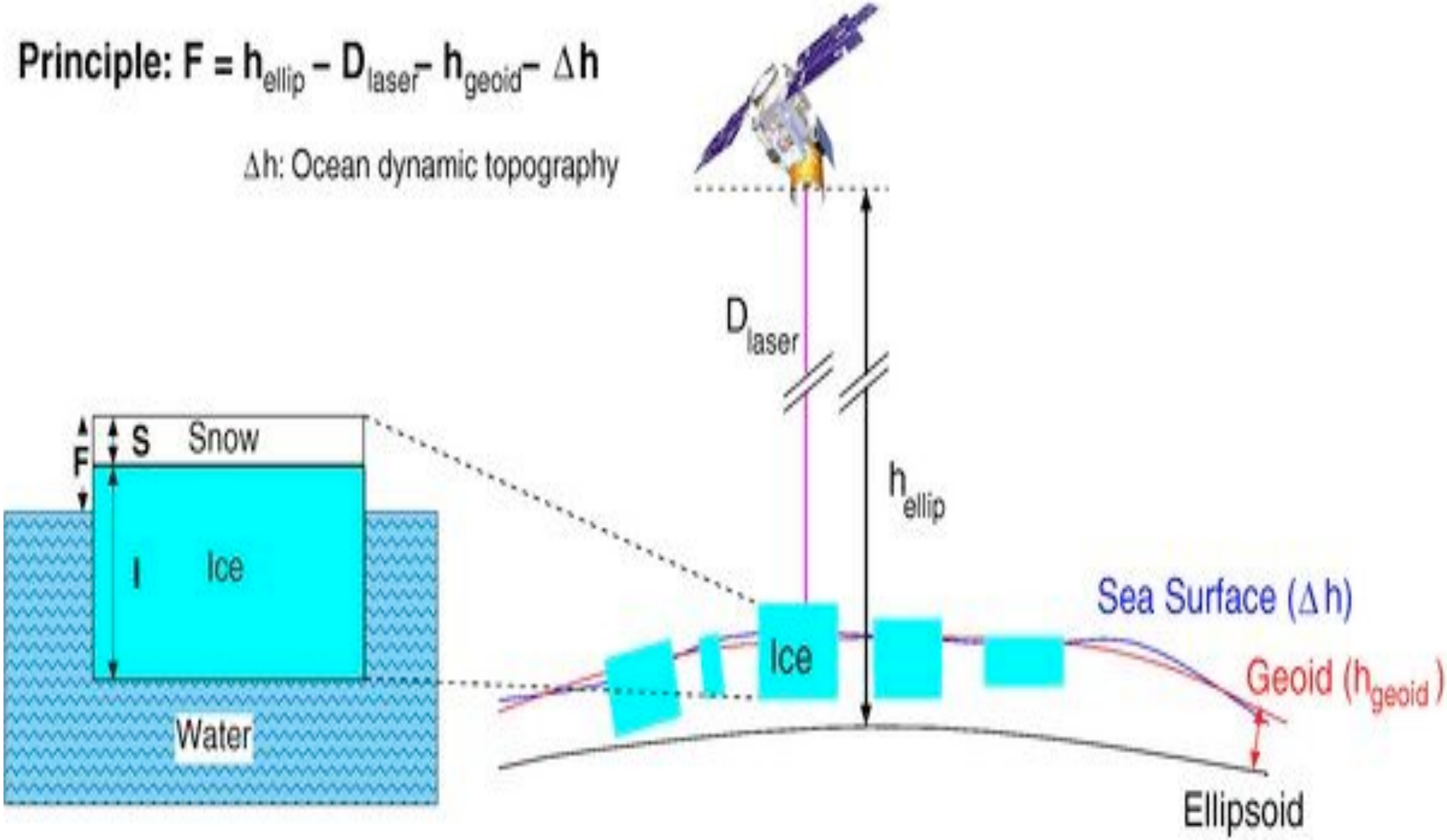






$$h_i = f \frac{\rho_w}{(\rho_w - \rho_i)} + \frac{h_s \rho_s}{(\rho_w - \rho_i)}$$

IceSat

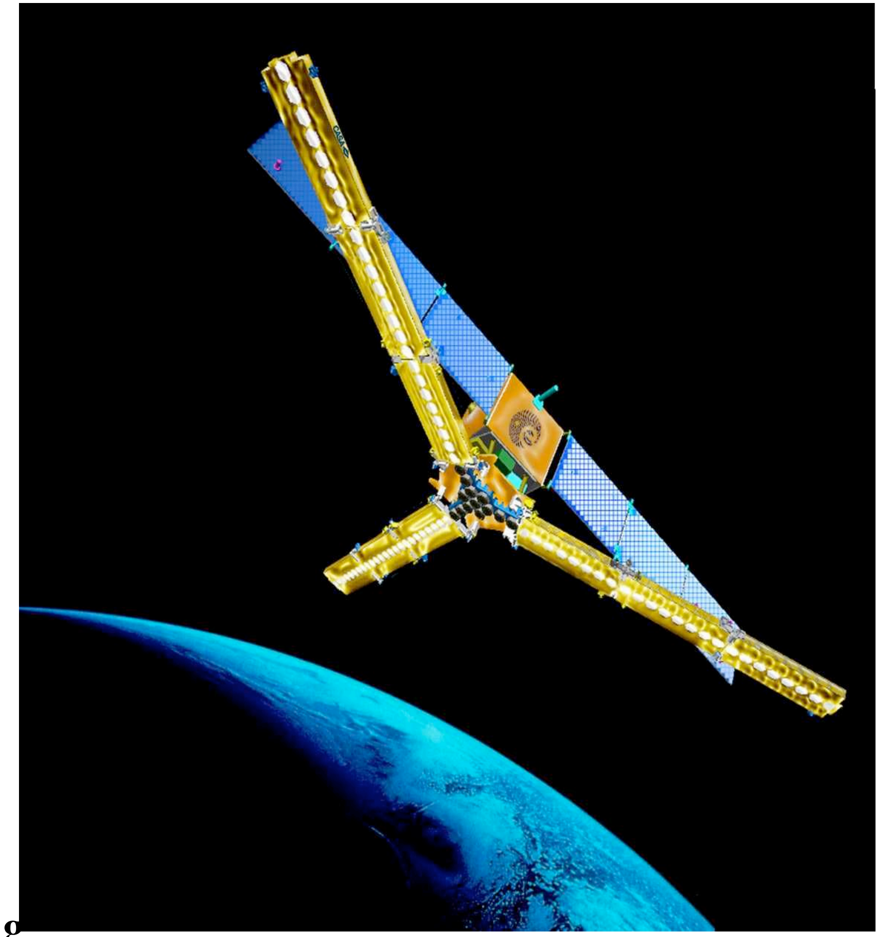


Principle: F = h_ellip – D_laser – h_geoid – Δh
Δh: Ocean dynamic topography
D_laser
h_ellip
F
S
Snow
I
Ice
Water
Ice
Sea Surface (Δh)
Geoid (h_geoid)
Ellipsoid

ESA's SMOS Mission

- To demonstrate the use of L-band 2-D interferometry to observe:
  - *salinity over oceans,*
  - *soil moisture over land*
  - *ice characteristics*

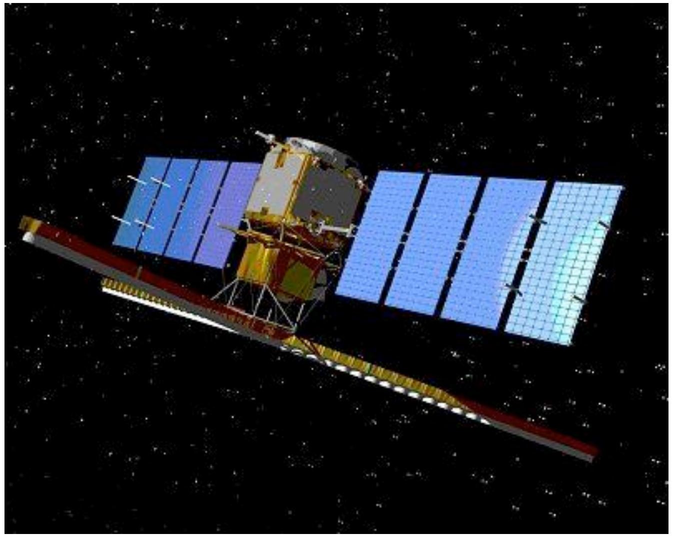
- To advance the development of climatological, hydrological and meteorological models.

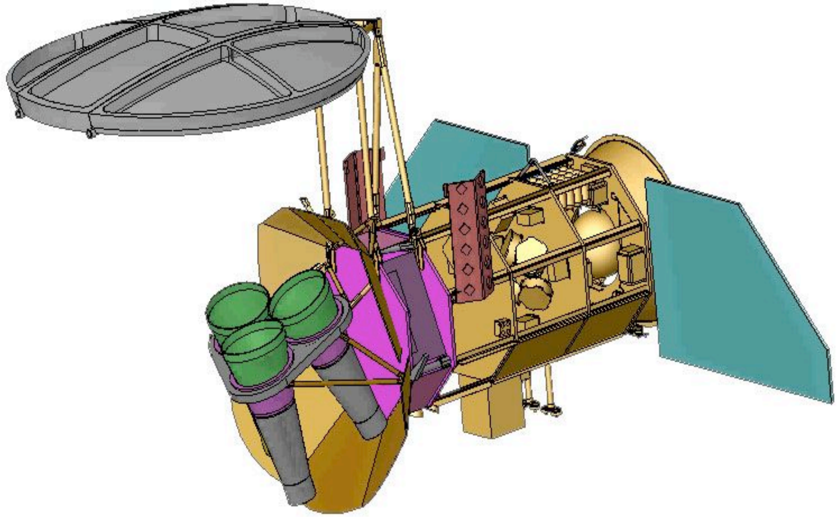


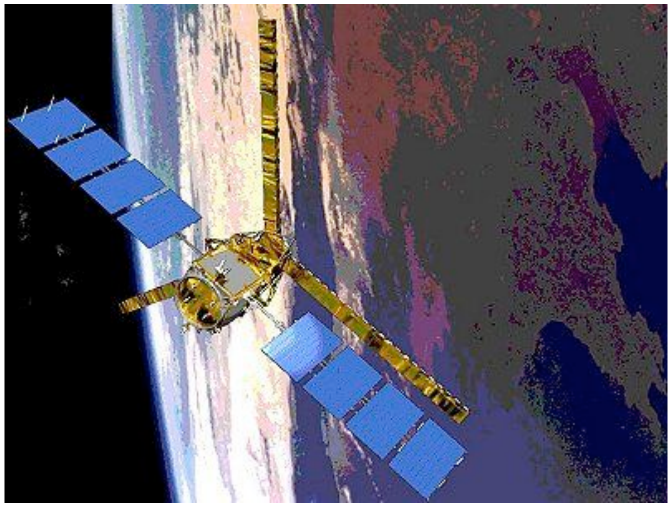
Payload:

L-band radiometer, synthetic aperture, exploiting interferometry, multi-polarisation, varying incidence angle

SMOS und AQUARIUS

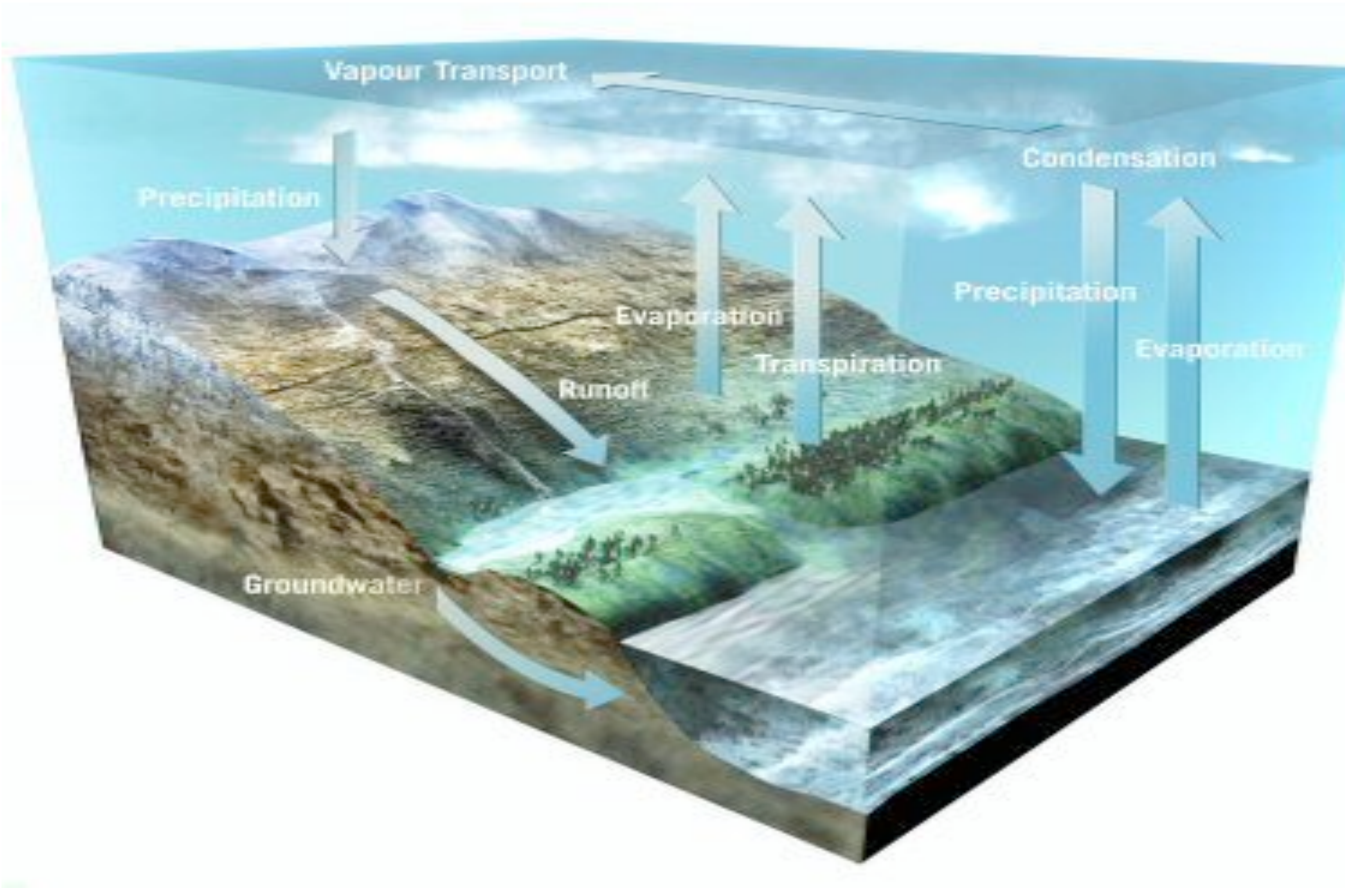






Both measure soil moisture and
Surface salinity.

SMOS helps observing the water cycle



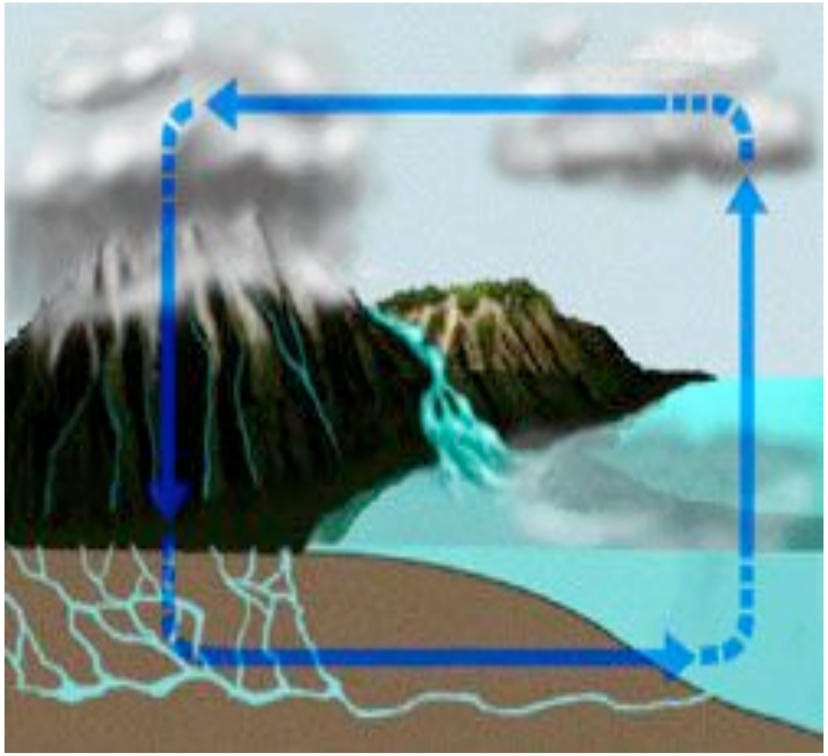
The Global Water

Atmosphere:

Atmospheric Water Vapour Transport

Land:

Precipitation;
snow, ice;
soil moisture.



Ocean:

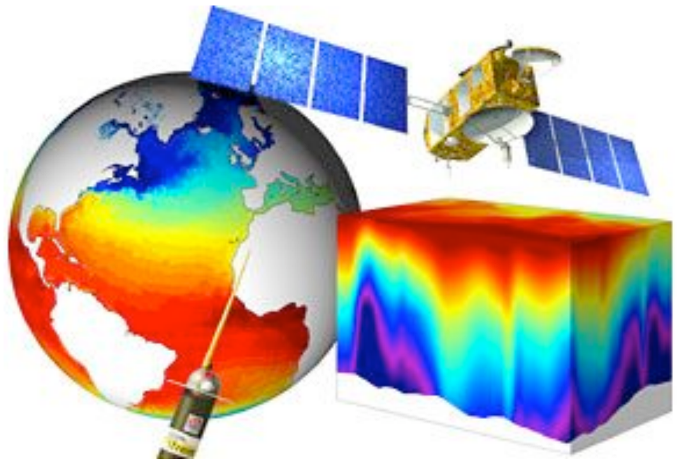
Net evaporation;
surface salinity
fresh water/sea ice
transports

Ground water, run-off

The future integrated oceanography

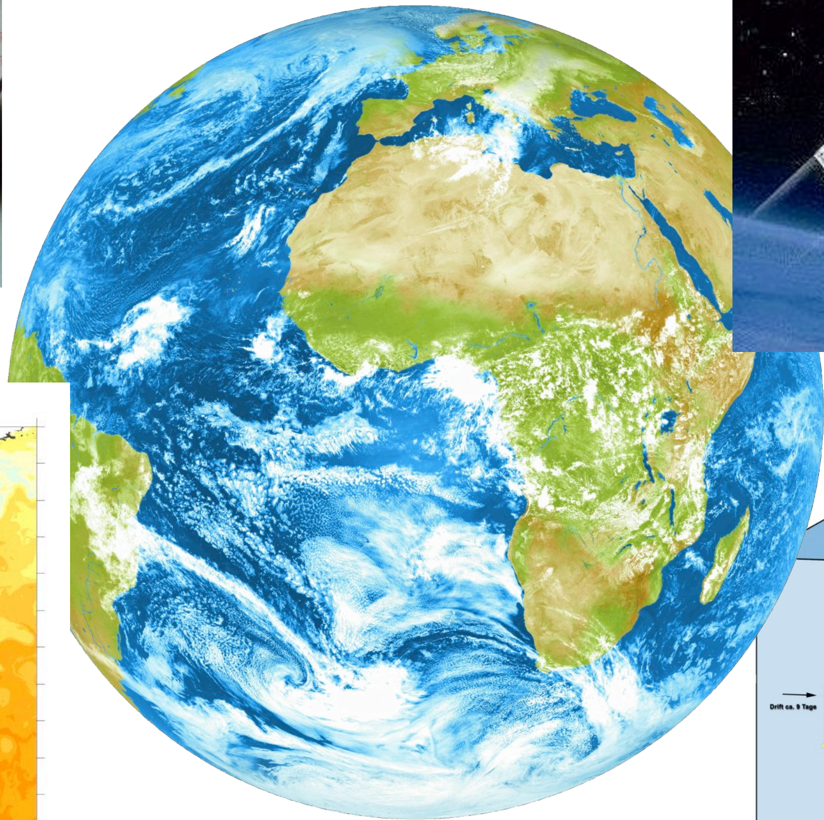
- **Use remote sensing data, in-situ data and models for an improved description and forecast of the ocean state.**

- **Required for operational oceanography applications and to develop an improved understanding of ocean circulation.**

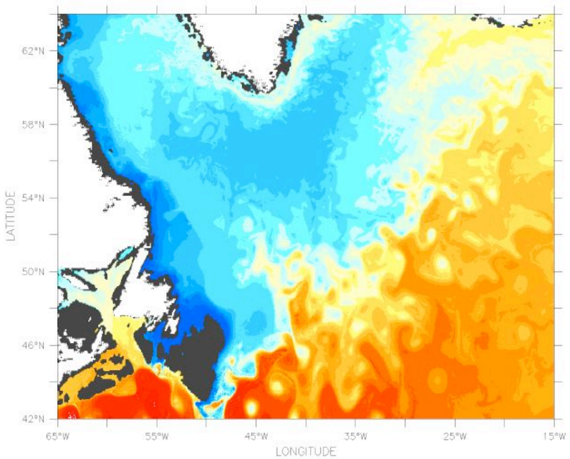


Infrastructure Required for Operational Oceanography

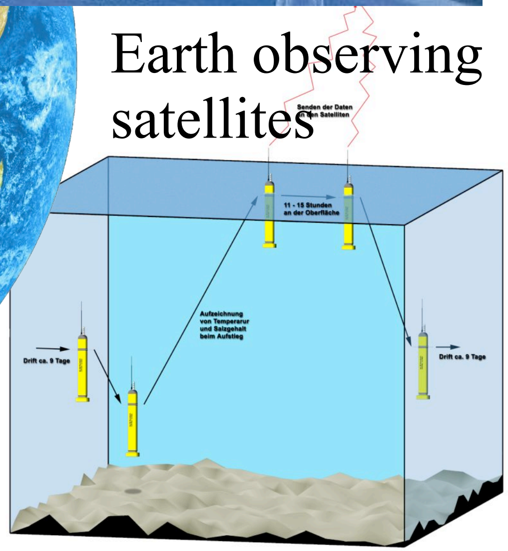
Research Platforms



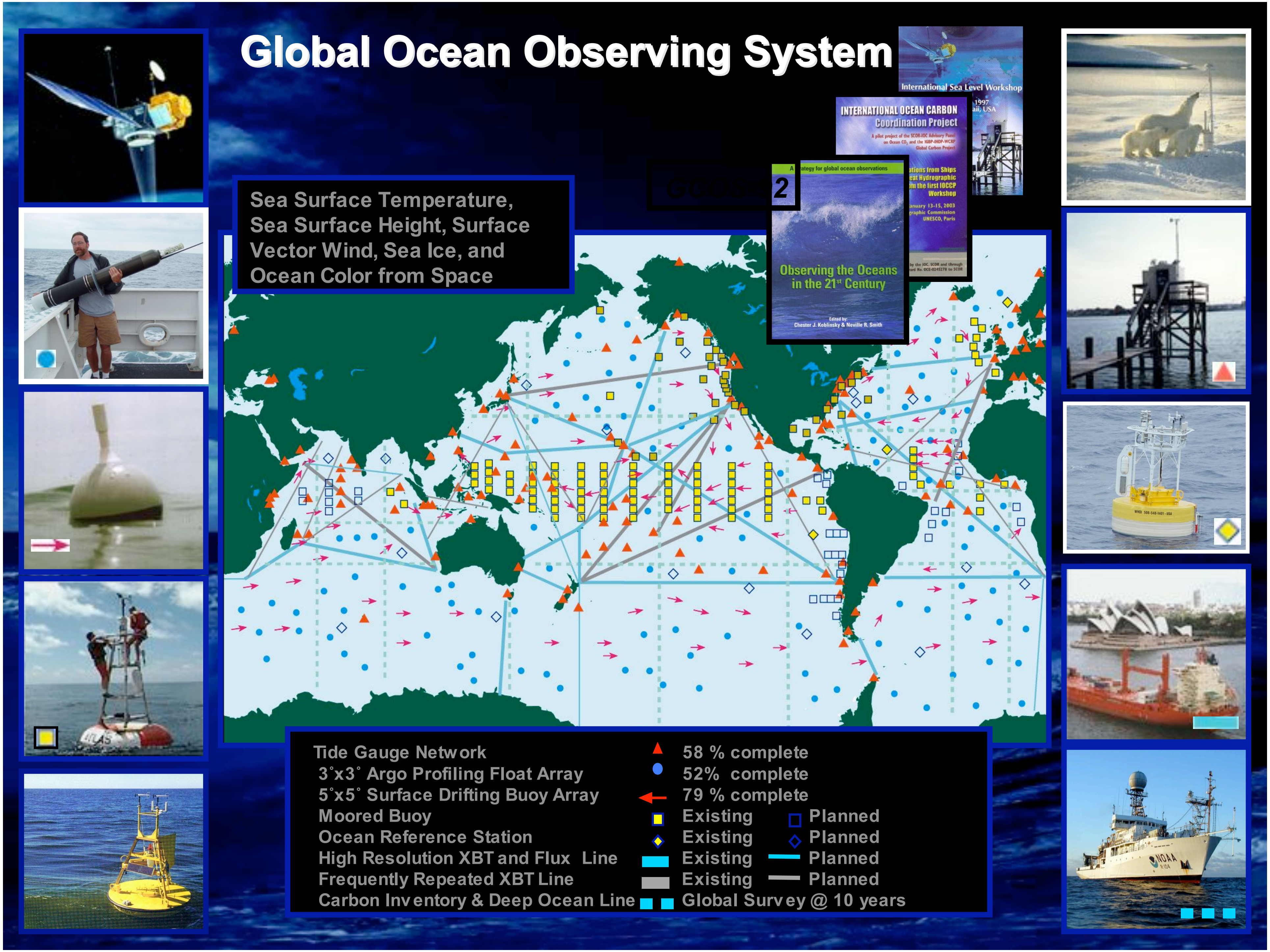
Earth observing satellites



Model simulations and assimilation on super computers



Autonomous in situ observing systems



Global Ocean Observing System
Sea Surface Temperature, Sea Surface Height, Surface Vector Wind, Sea Ice, and Ocean Color from Space
International Sea Level Workshop
INTERNATIONAL OCEAN CARBON Coordination Project
Observing the Oceans in the 21st Century
Tide Gauge Network — 58 % complete
3°x3° Argo Profiling Float Array — 52% complete
5°x5° Surface Drifting Buoy Array — 79 % complete
Moored Buoy — Existing — Planned
Ocean Reference Station — Existing — Planned
High Resolution XBT and Flux Line — Existing — Planned
Frequently Repeated XBT Line — Existing — Planned
Carbon Inventory & Deep Ocean Line — Global Survey @ 10 years

Data assimilation

Method:

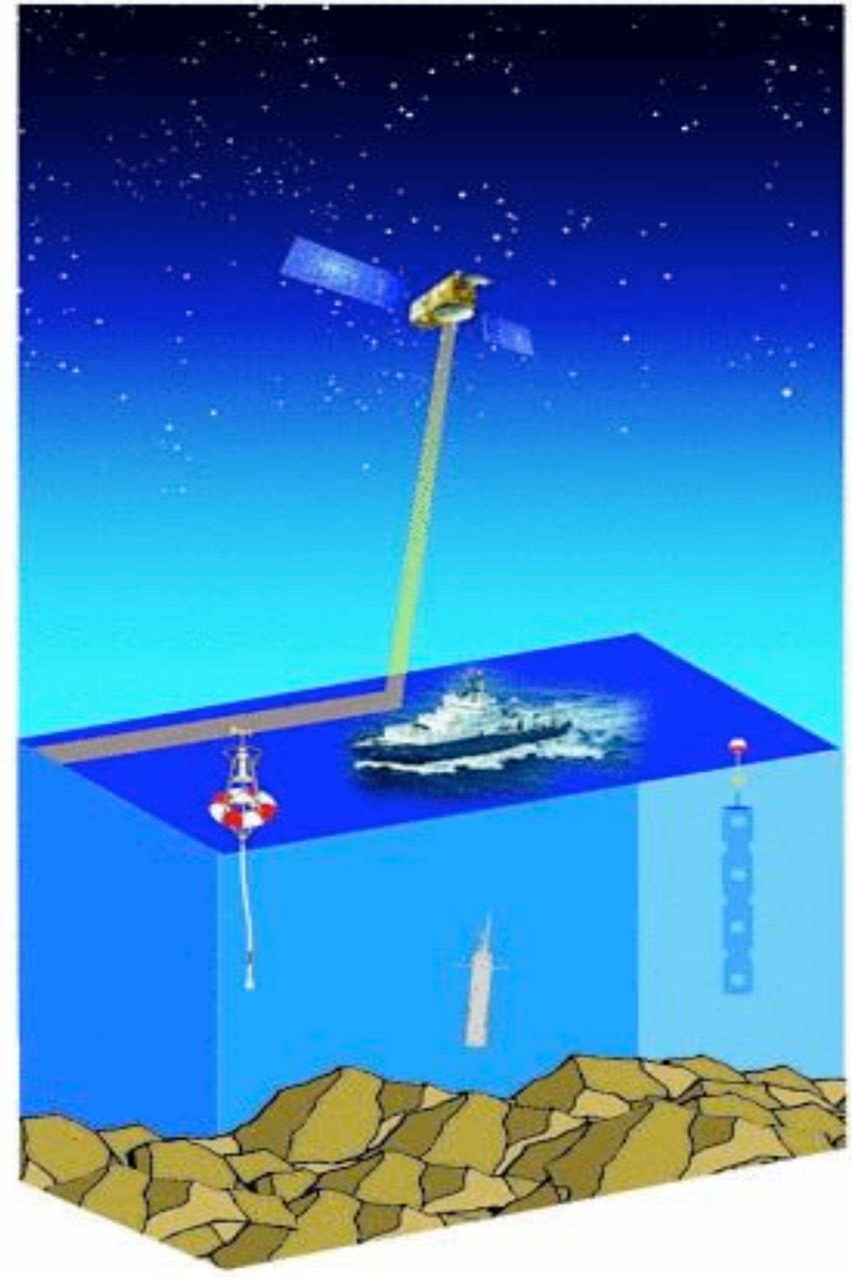
Synthesis of all available

Observations to obtain dynamically consitent description of ocean circulation. Used to

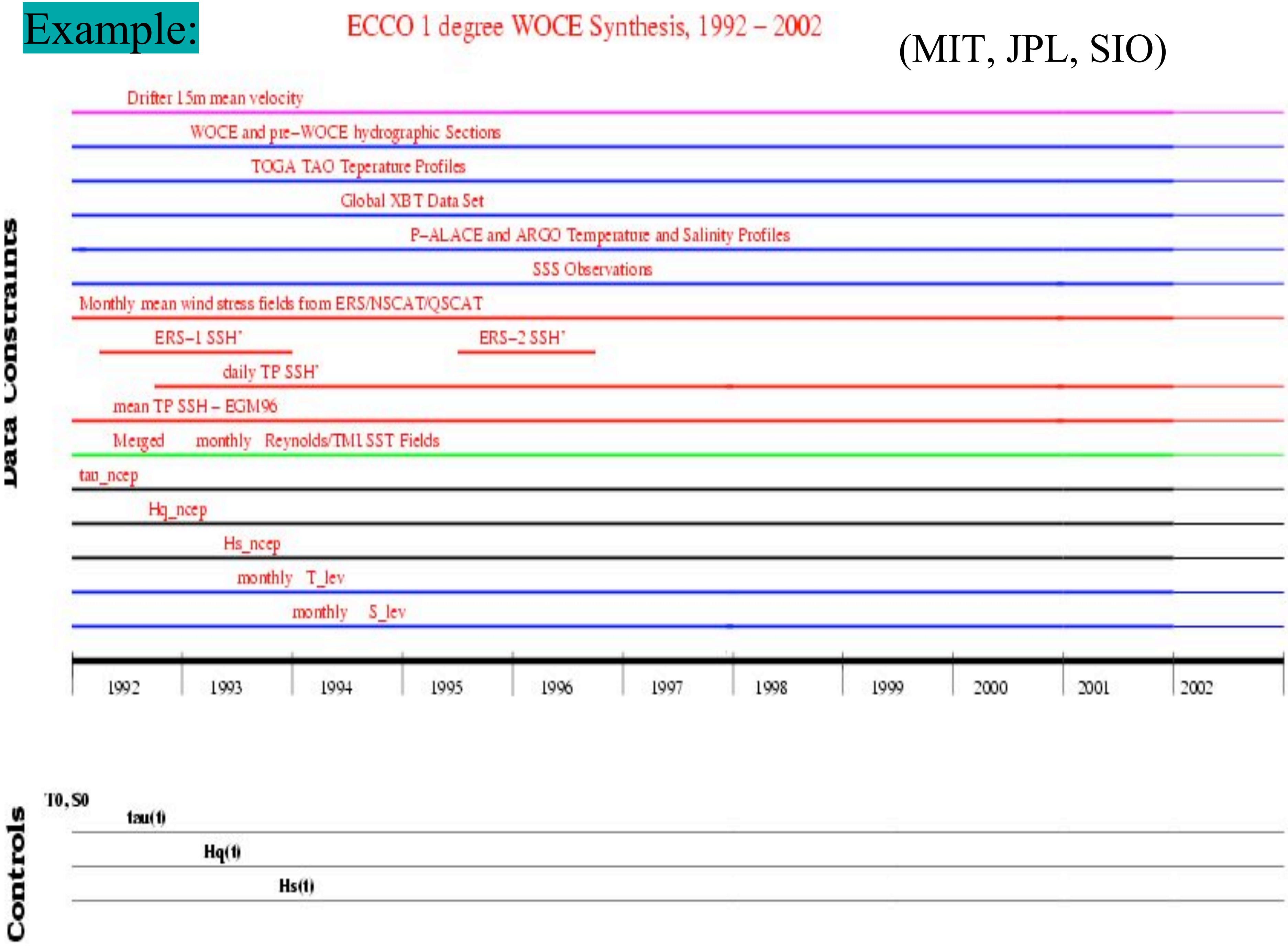
estimate climate change;

estimate oceans uptake of CO2; initialize coupled models; now-casting of

Ocean currents.



Example:



(MIT, JPL, SIO)

What are the requirements for operational oceanography: a GOOS perspective

- Safety and efficiency of marine operations
- Control and mitigate the effects of natural hazards
- Detect and predict the effects of climate change
- Reduce public health risks
- Protect and restore healthy ecosystems
- Restore and sustain living marine resources

Operational Oceanography Applications

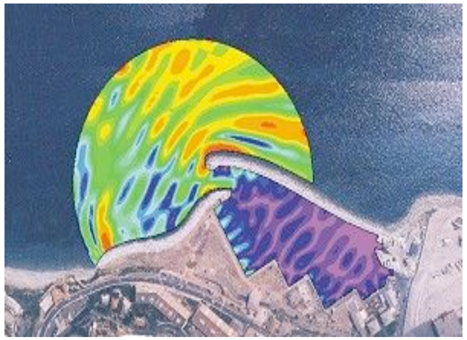
Global warming, climate and seasonal forecasting, weather

Fisheries and fishery management

Offshore Industry

Maritime security

Navies



Coastal applications

Ocean and ecosystem research

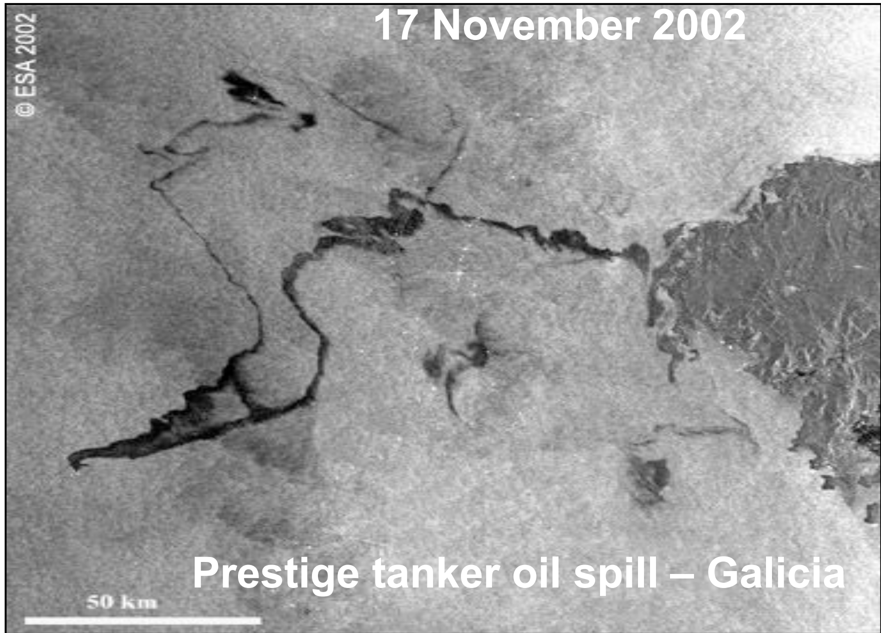
others…

ASAR

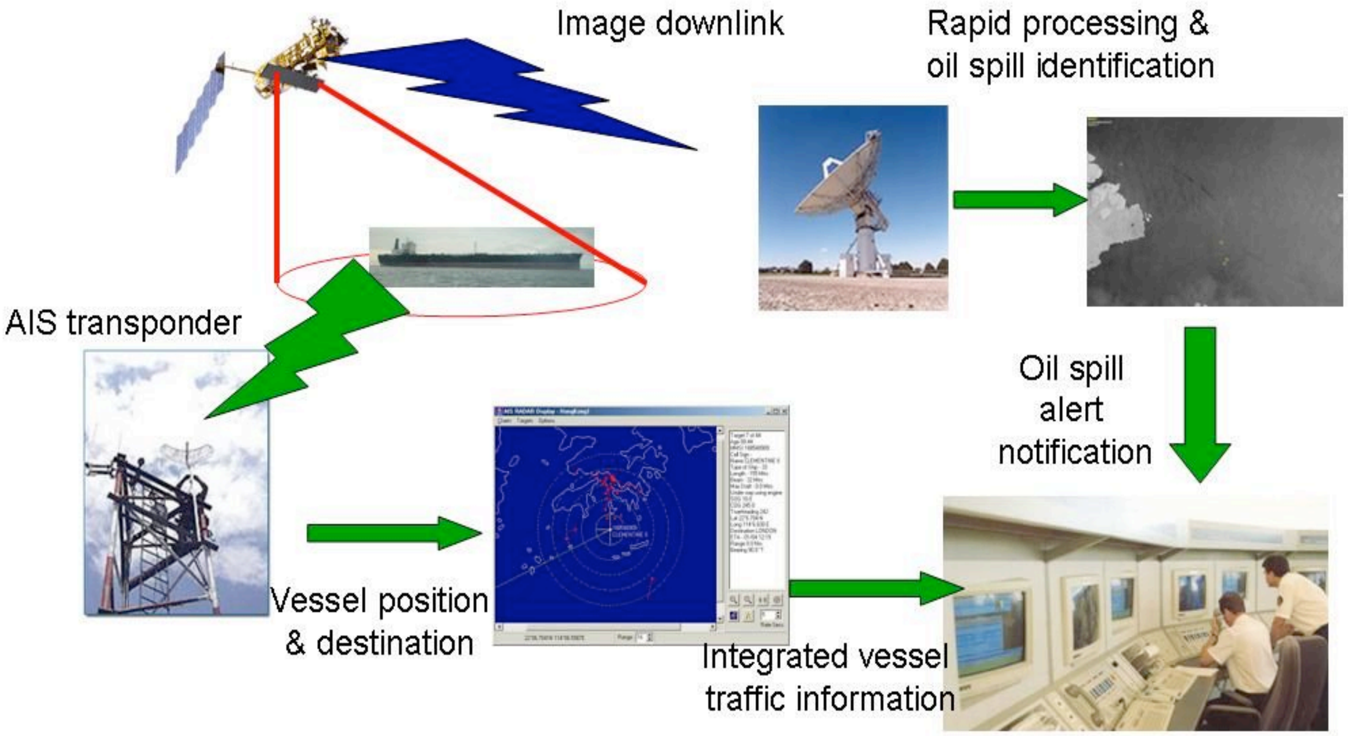

(AP PHOTO)


(AP PHOTO)

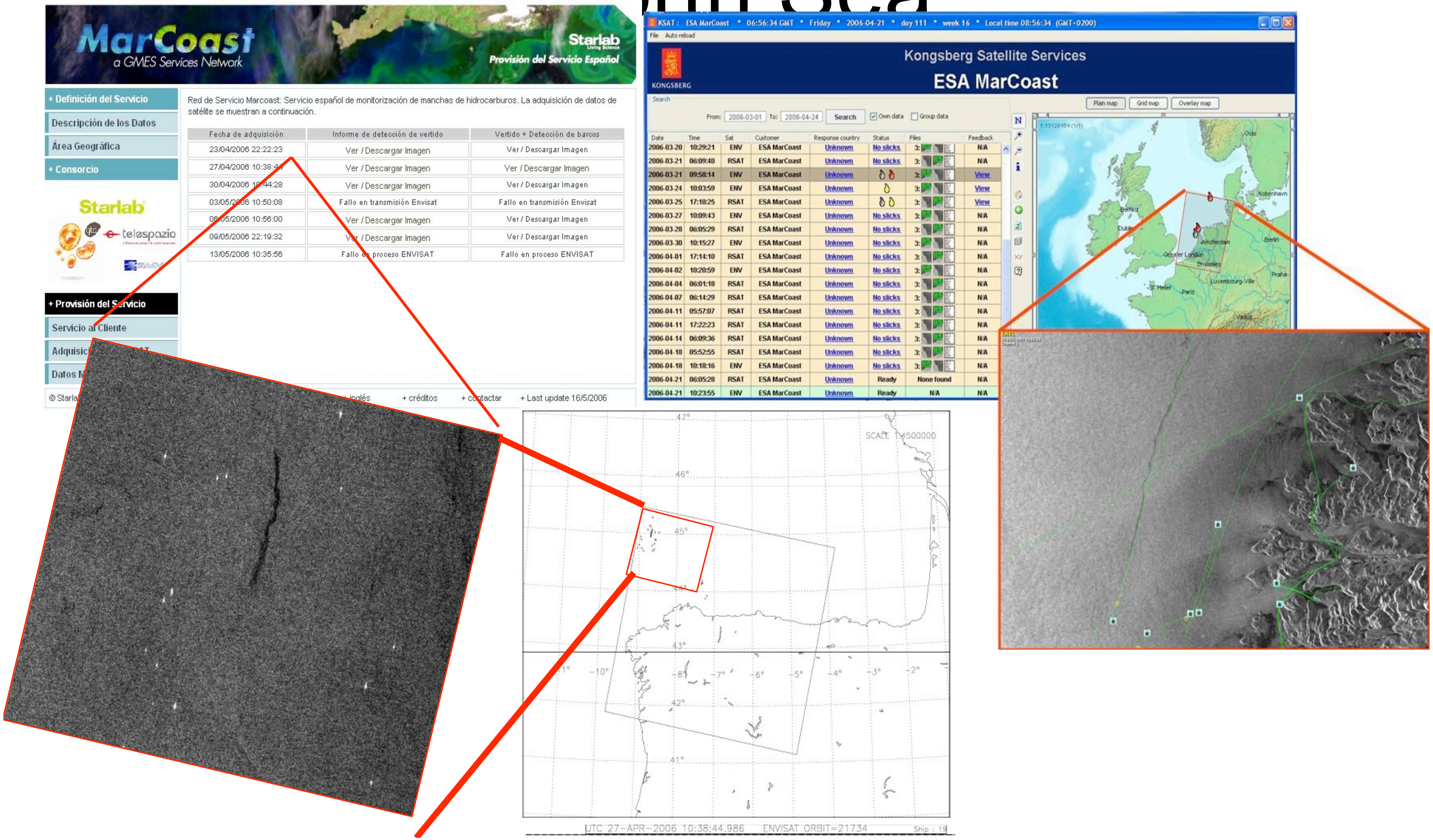

(AP PHOTO)


17 November 2002
© ESA 2002
50 km
Prestige tanker oil spill – Galicia

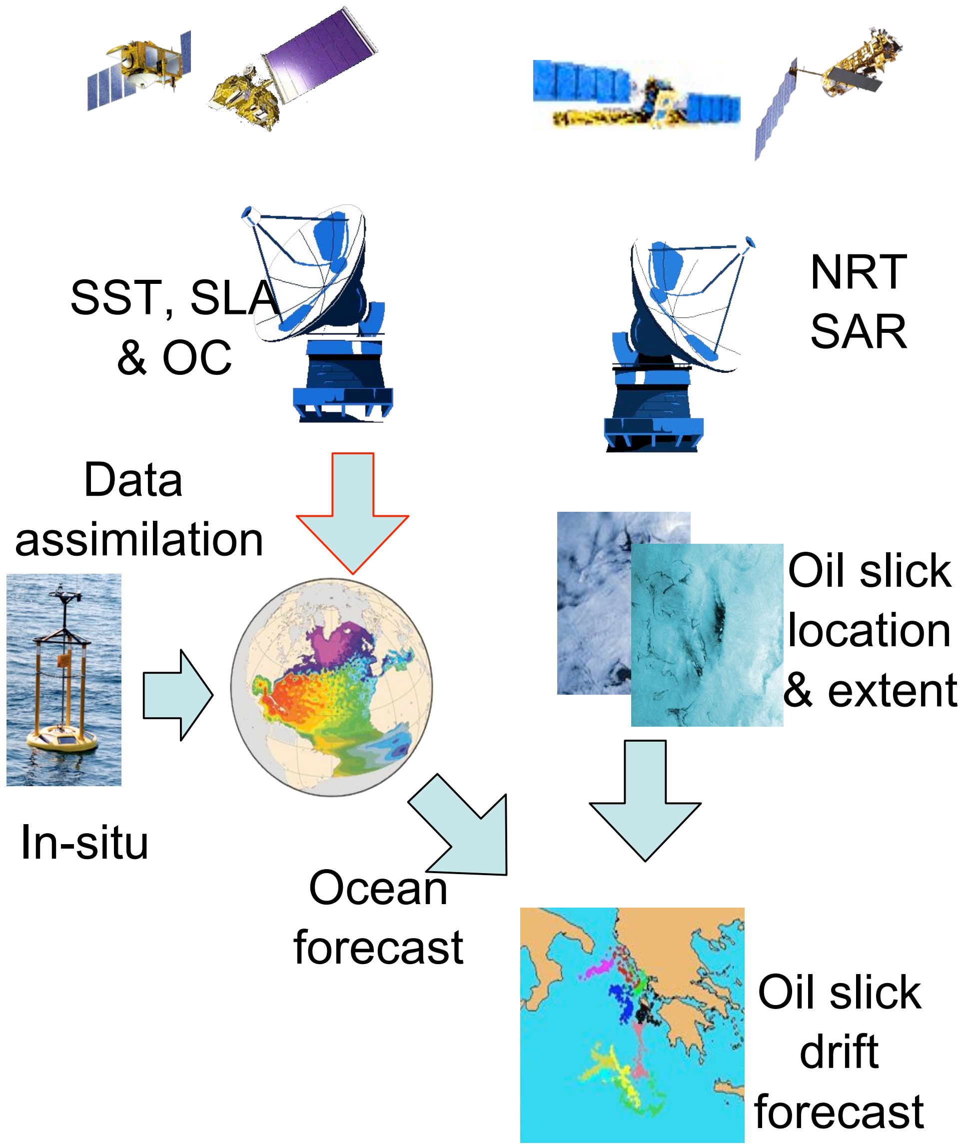
Oil Spill detection

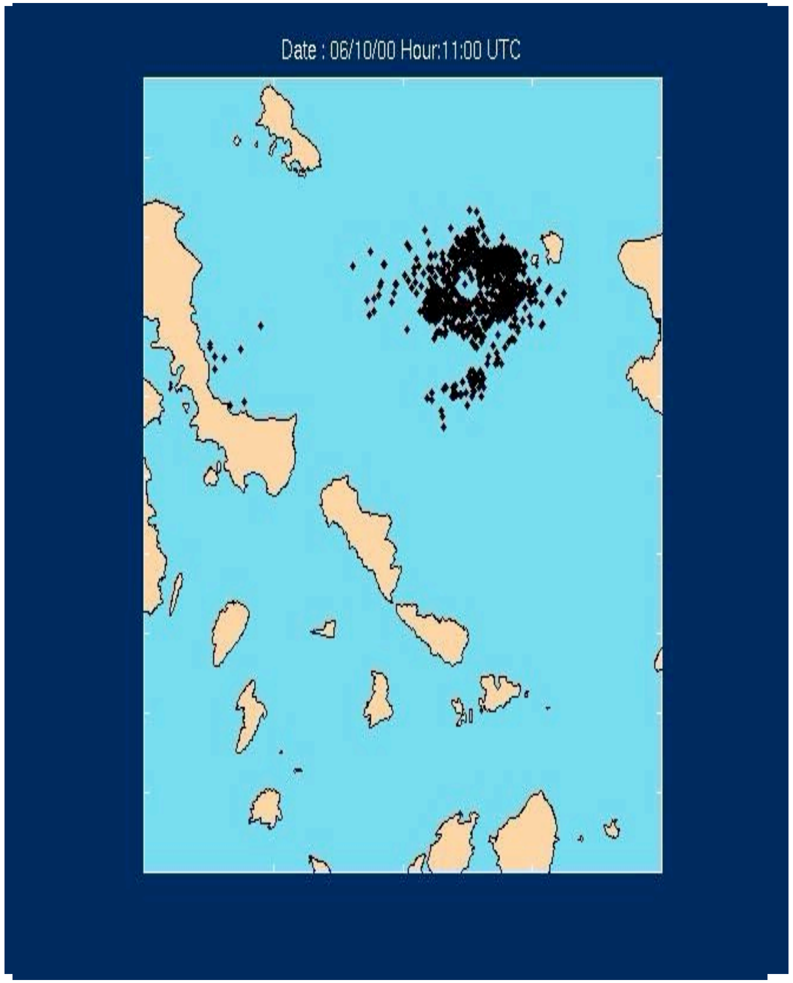


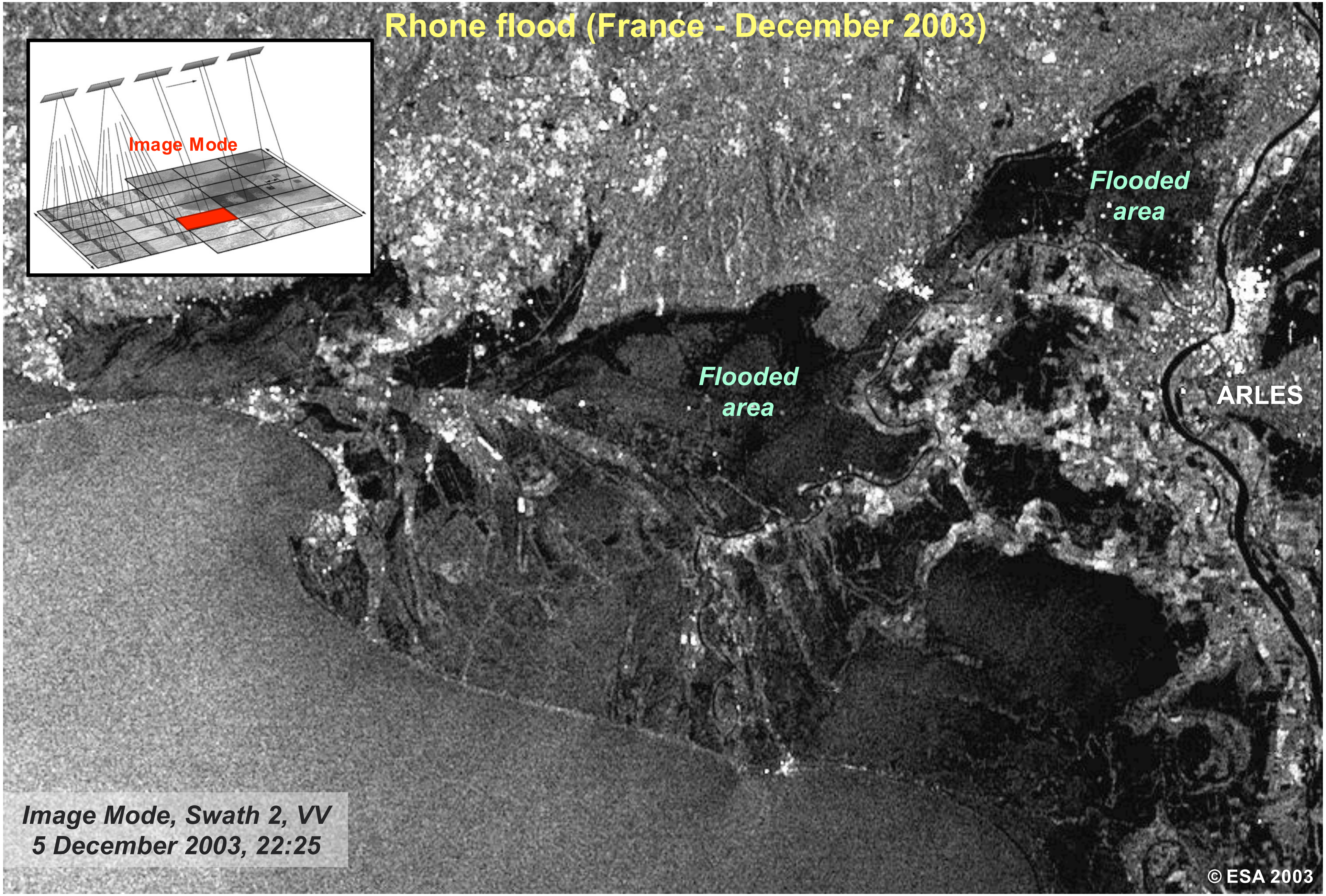
Service Examples: Spain & North Sea



MarCoast Drift Forecasting





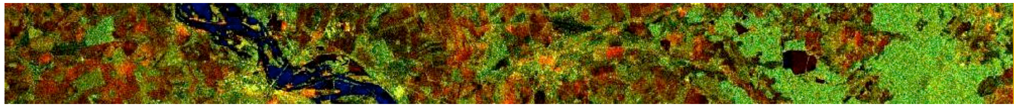

Rhone flood (France - December 2003)
Image Mode
Flooded area
Flooded area
ARLES
Image Mode, Swath 2, VV
5 December 2003, 22:25
© ESA 2003

SAR Sea Floor Immage

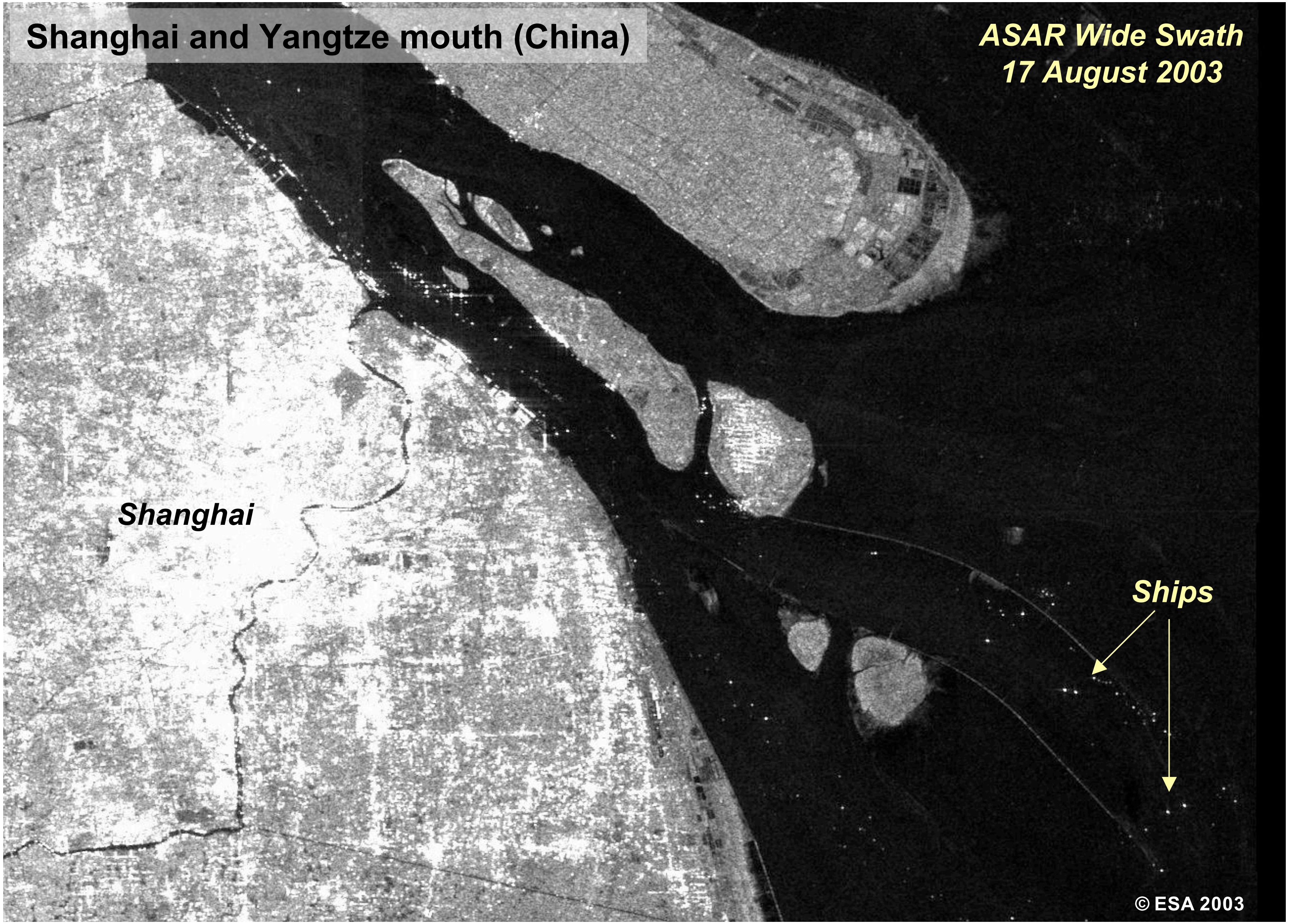
Structure of the sea flor can be detected in SAR immages due to their inpact on the surface roughness

SAR immages can be used to monitor changes in the sediements.

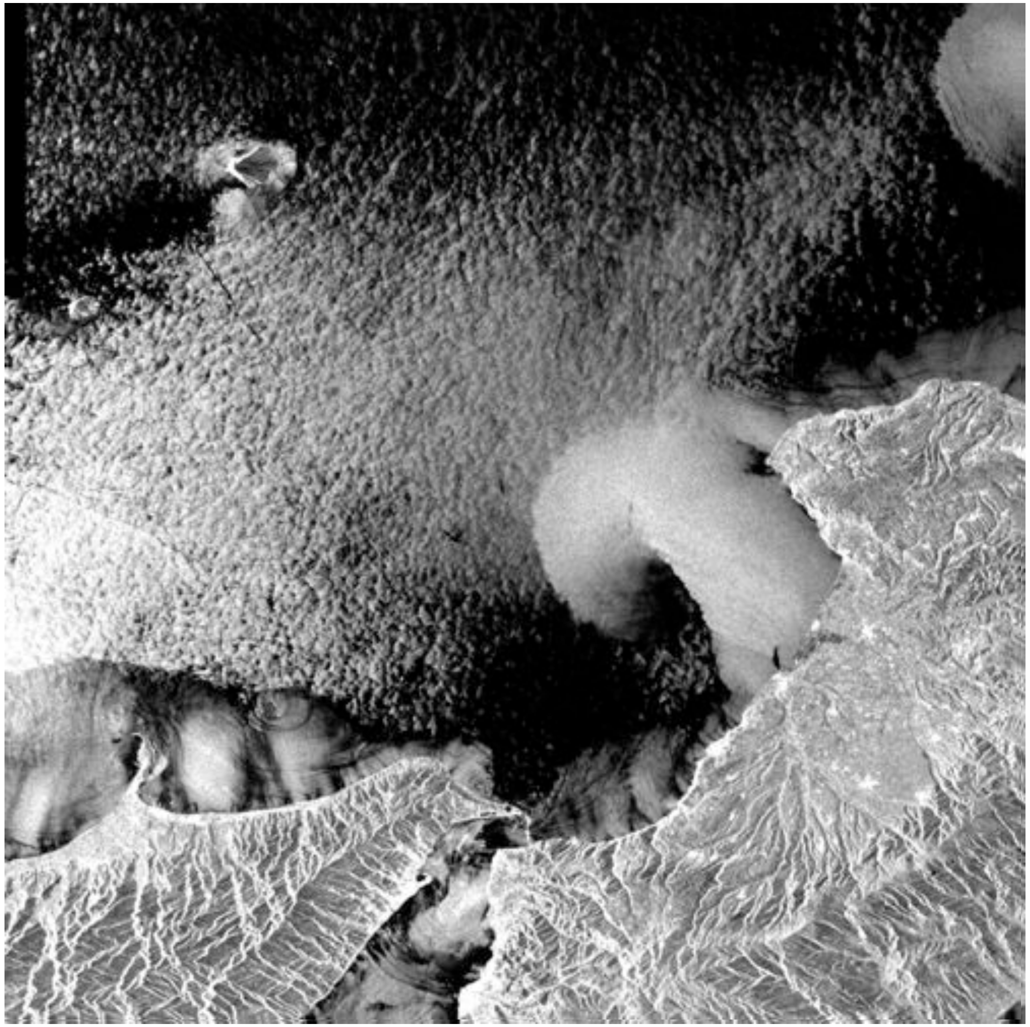
ERS-1 SAR Immage,
100 km × 100 km,
Chinese Coast Line.



ASAR

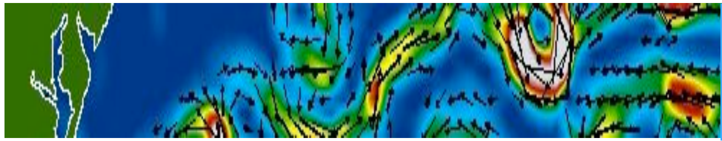

Shanghai and Yangtze mouth (China)
ASAR Wide Swath
17 August 2003
Shanghai
Ships
© ESA 2003

Eample: wind phenomena:

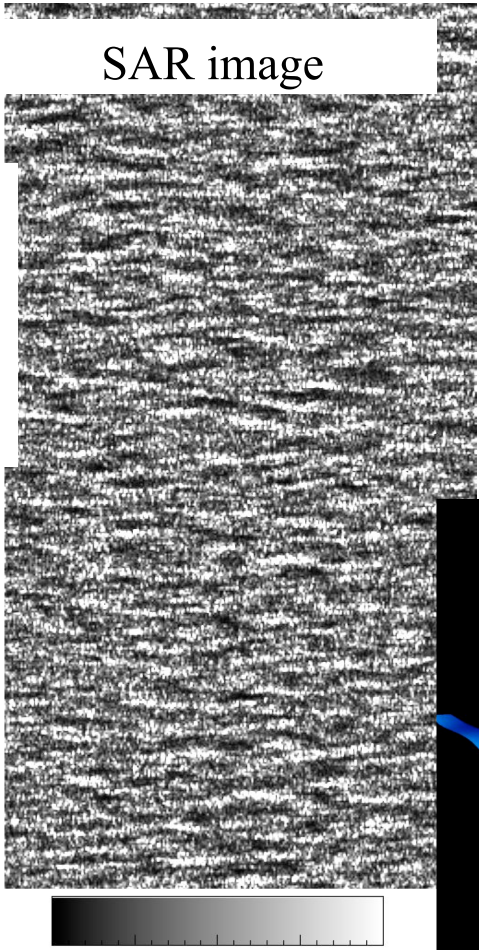


}Atmospheric convection cellsoriginating from land-sea breze.

ERS-1 SAR immage
100 km × 100 km,
Messina (Italy)

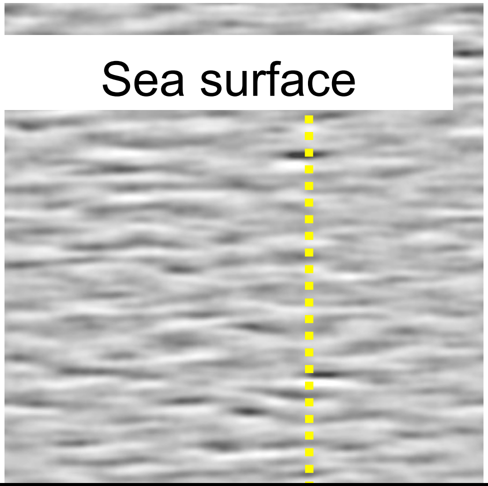


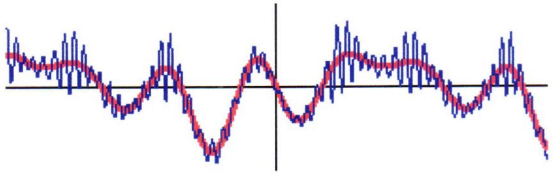
Sea Surface (SAR Wave Mode)



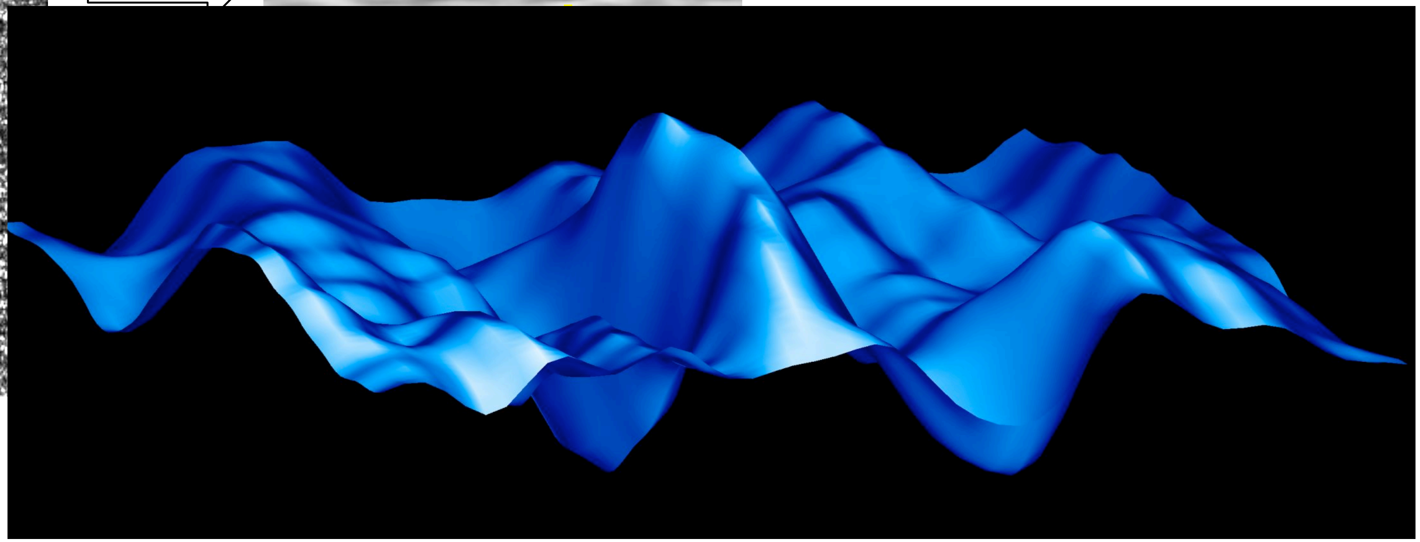
8 km

Inversion



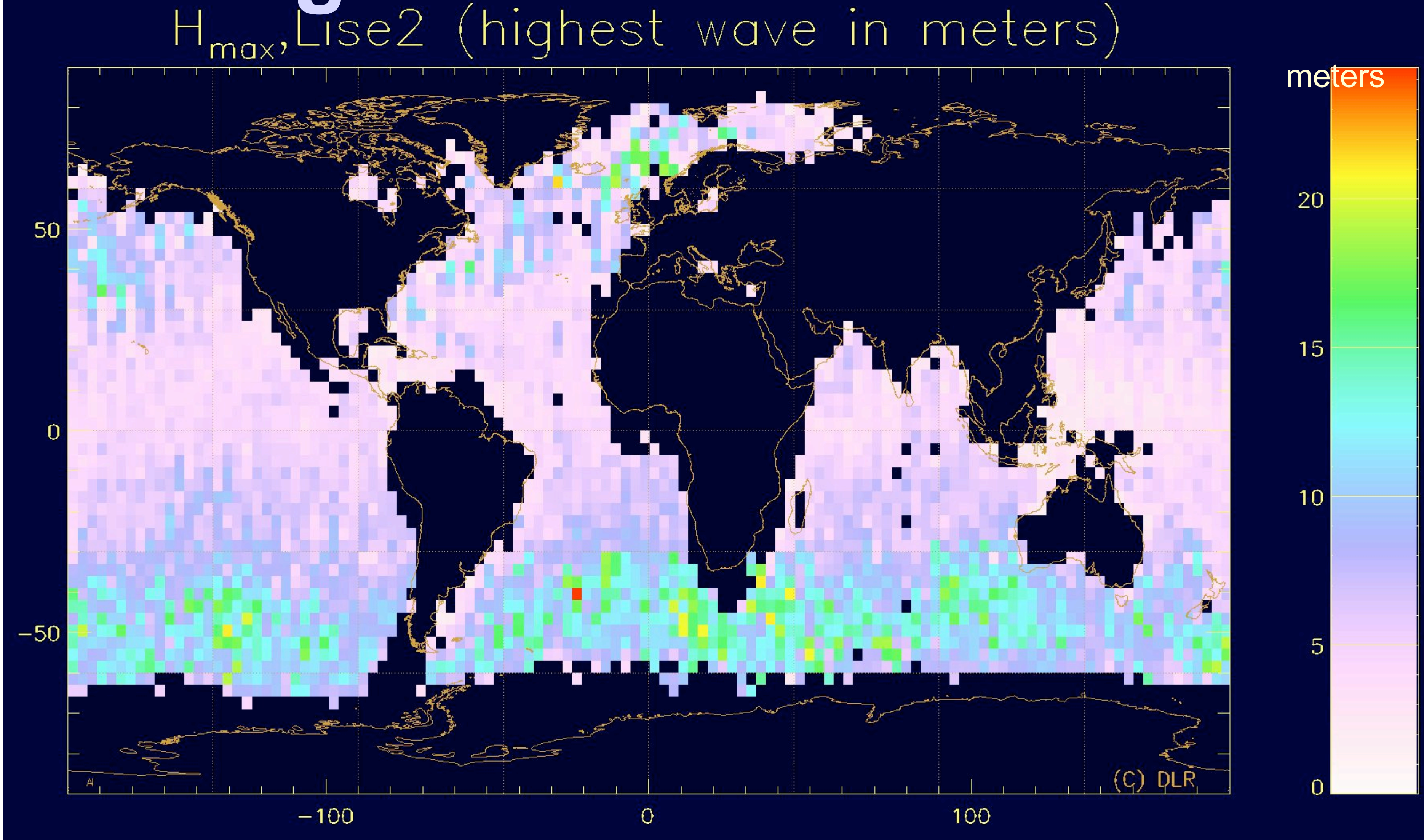


23 m high Wave



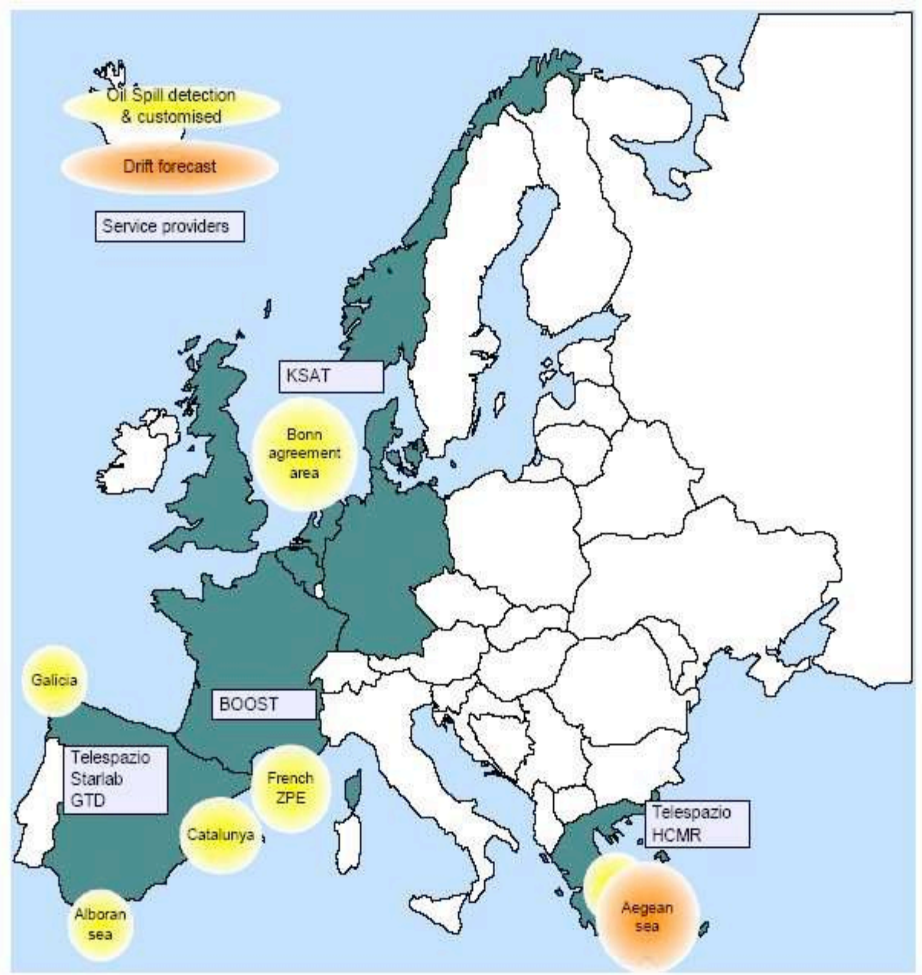
200 m

Highest waves in dataset

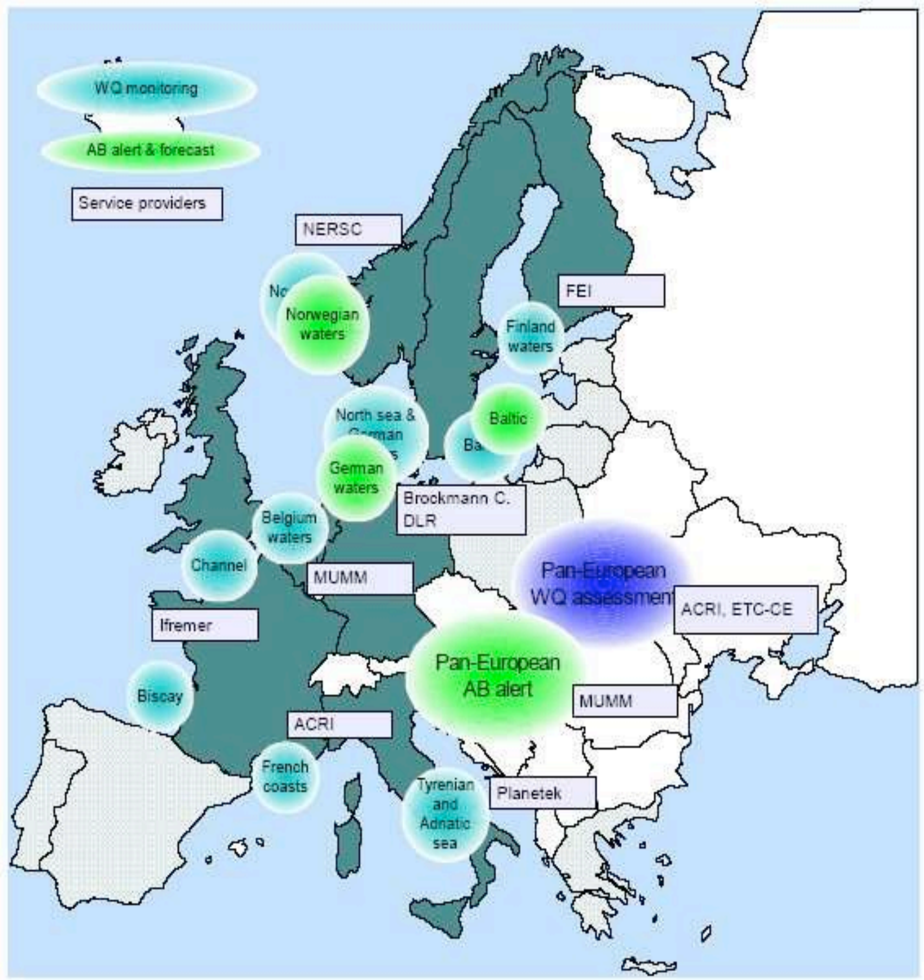


Geographic coverage – baseline service

Oil pollution

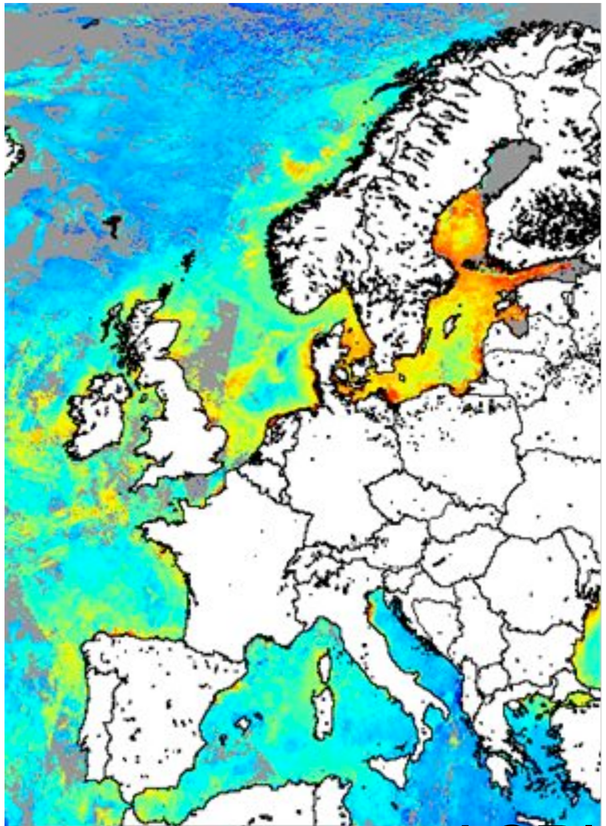


Water Quality & Algal Bloom

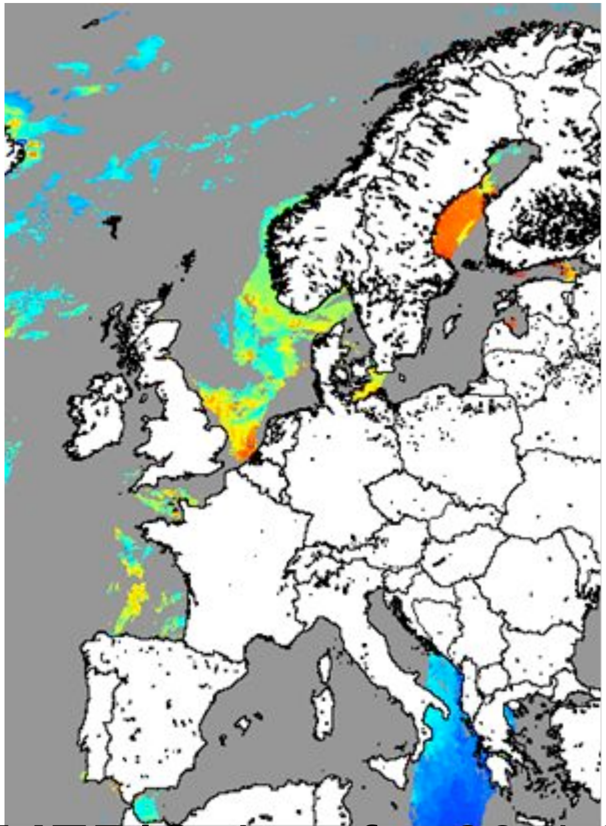


Pan-European alert (MUMM)

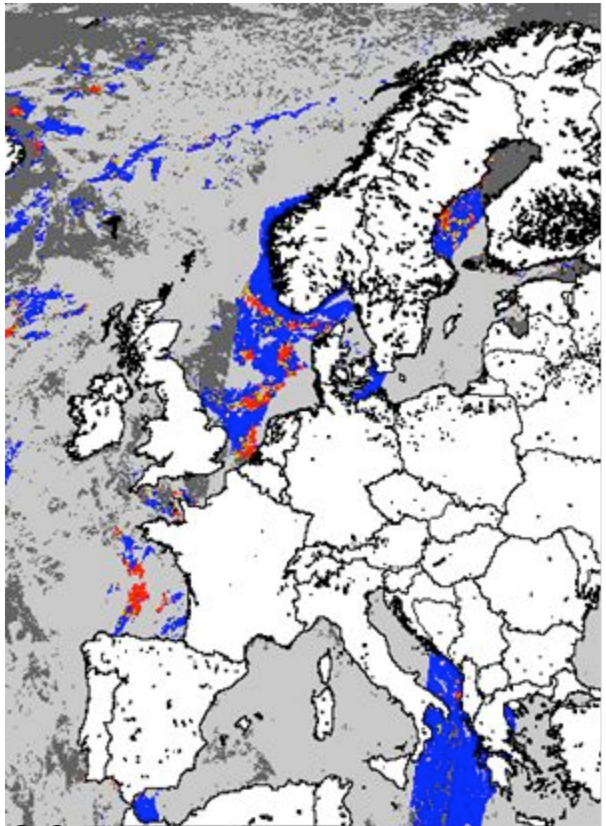
Ref. CHL



Daily CHL

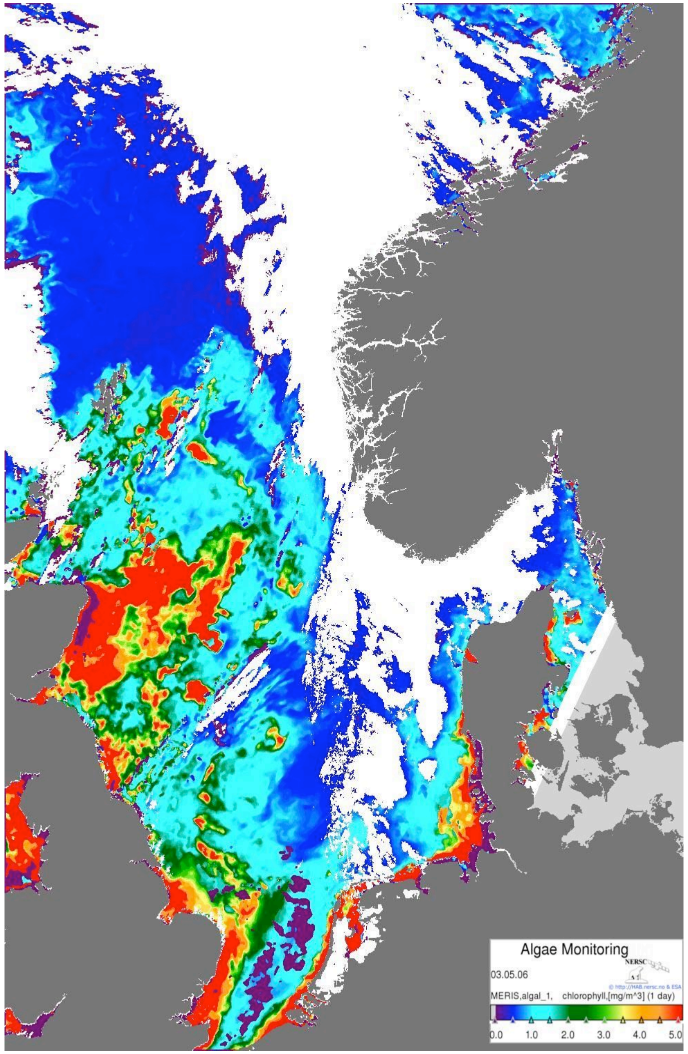


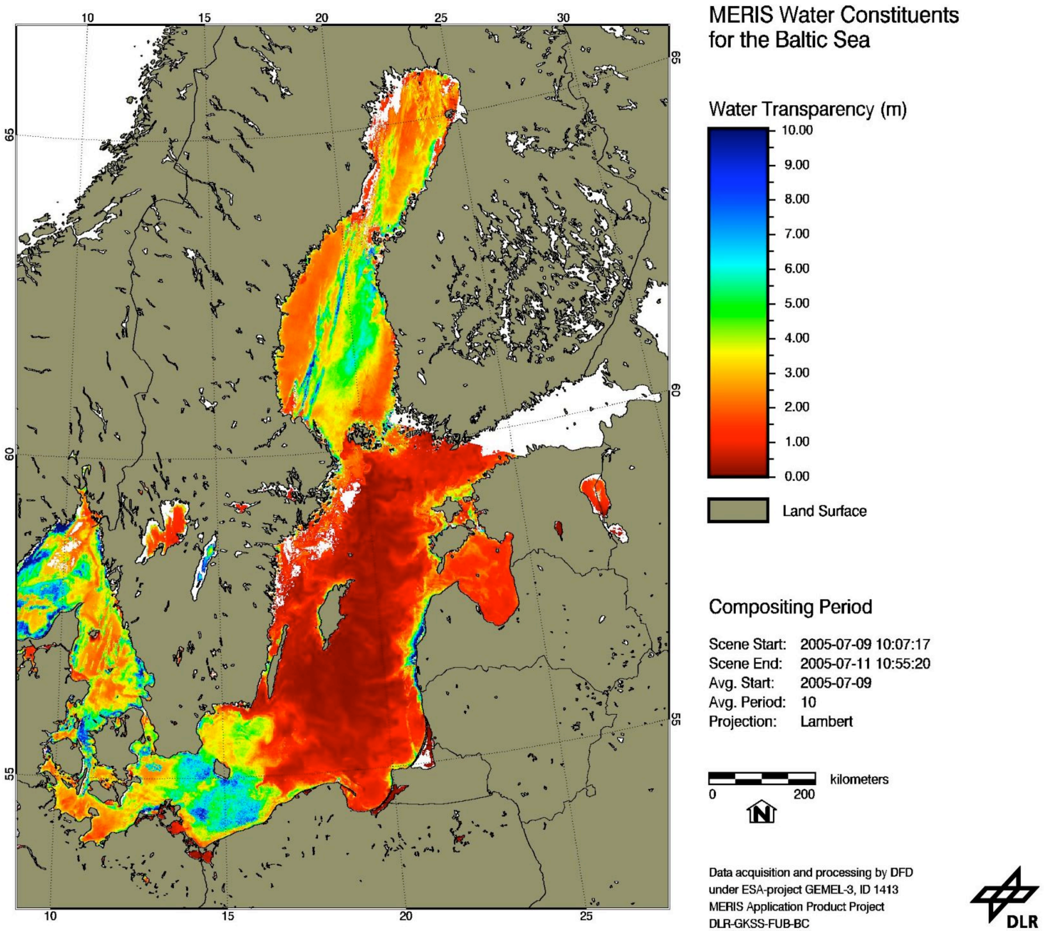
Algae Bloom (red)



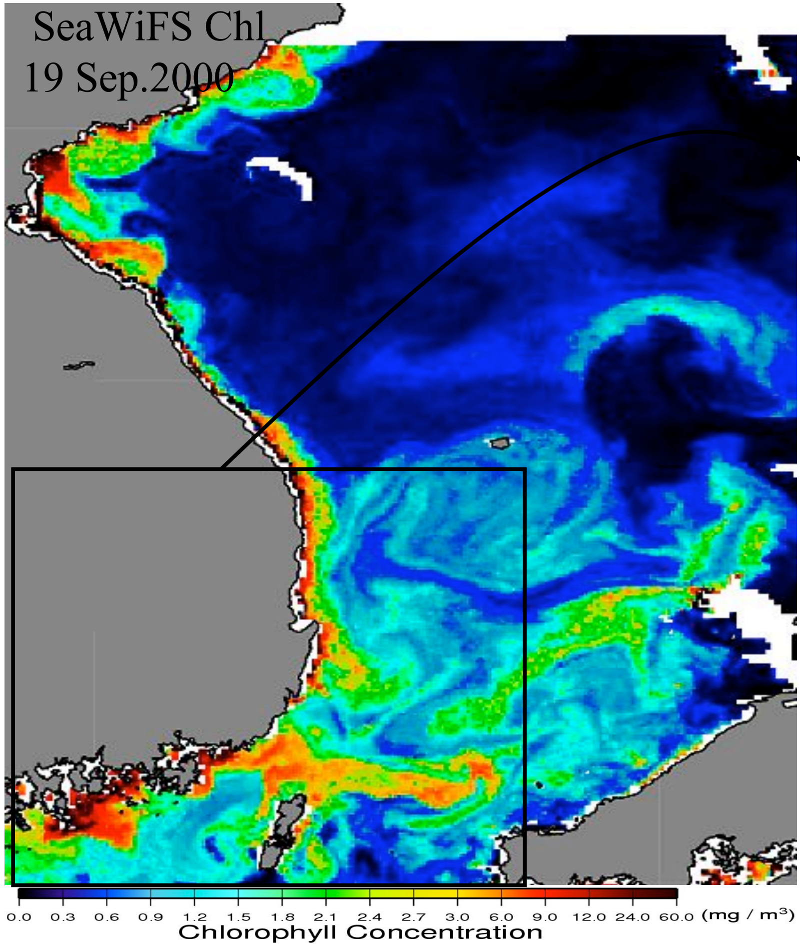
e.g. ACRI-MERIS data for 23.4.2005

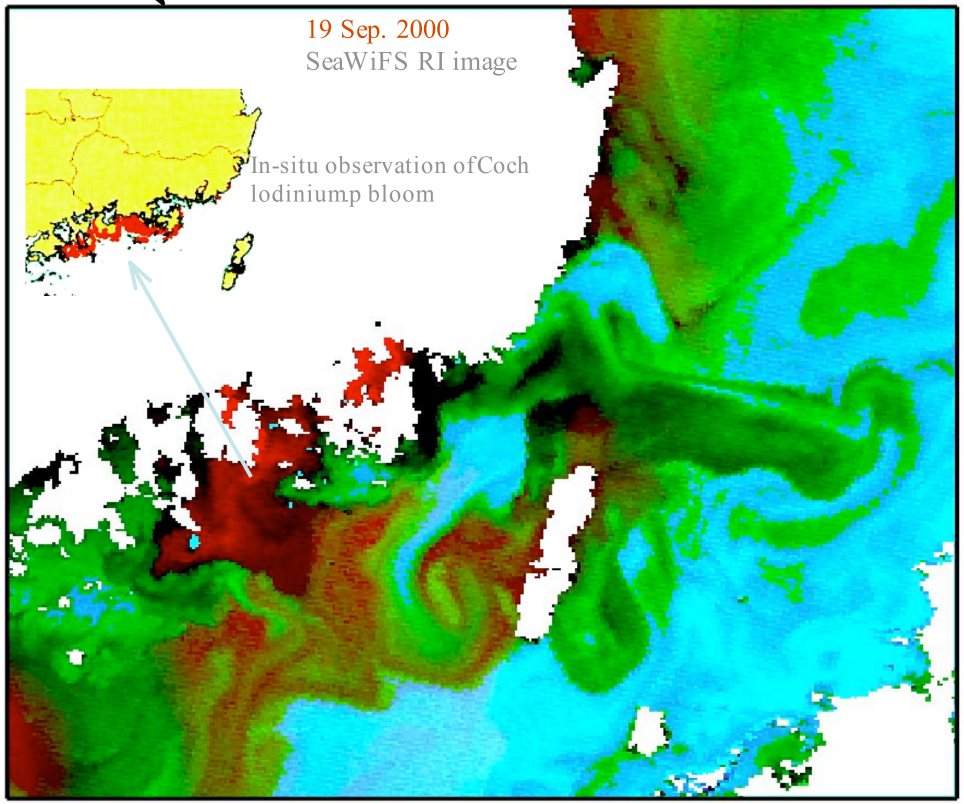
Algal Bloom Services





Ocean Environmental Monitoring

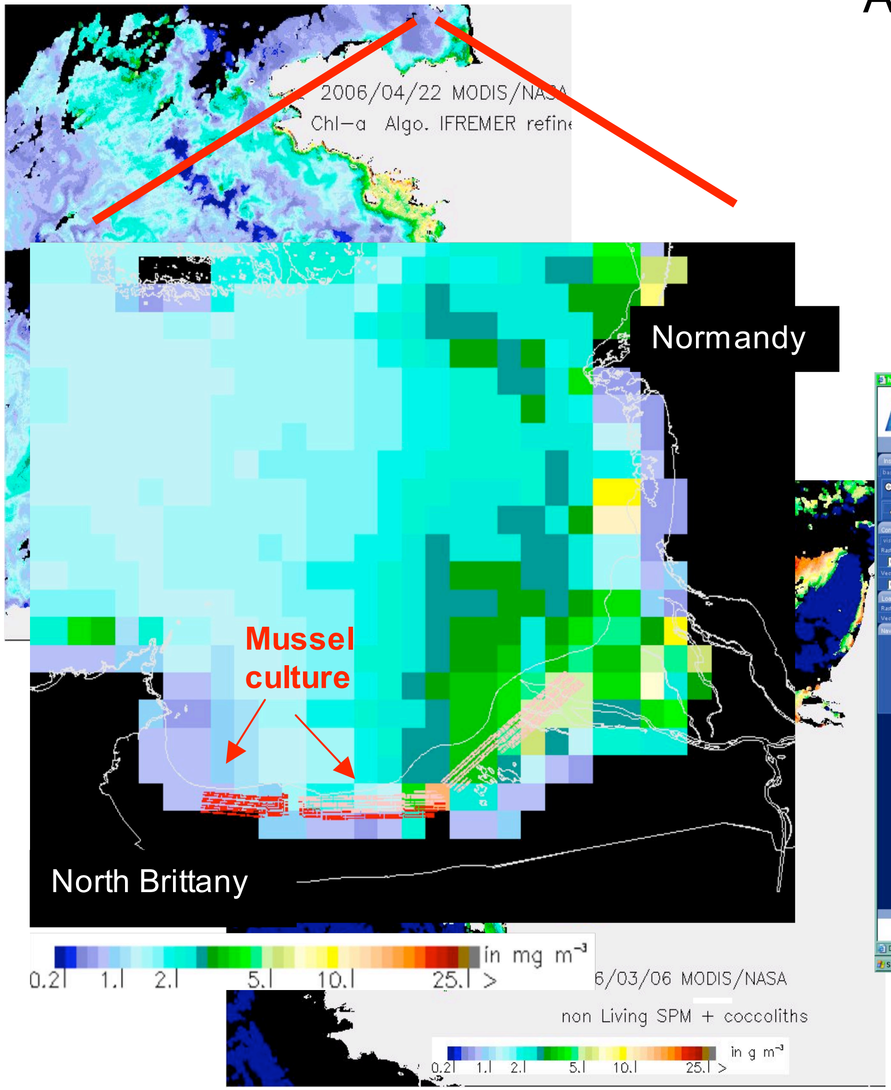




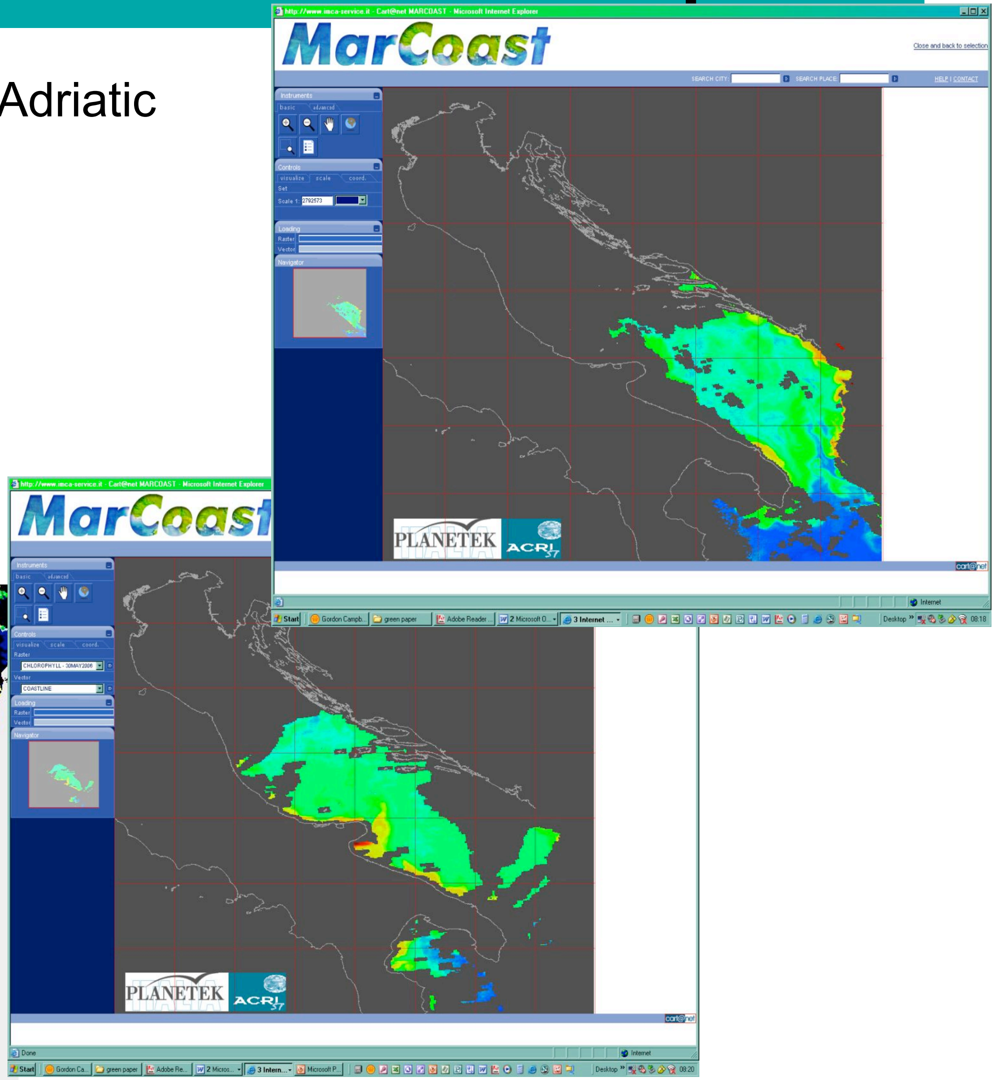
Detecting and monitoring red tide algal blooms around Korean and neighboring waters

Water Quality Service examples

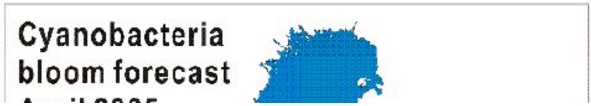
Bay of Biscay/ English Channel

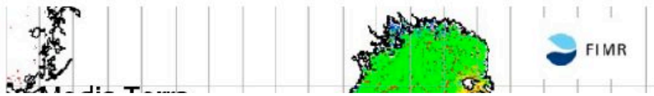


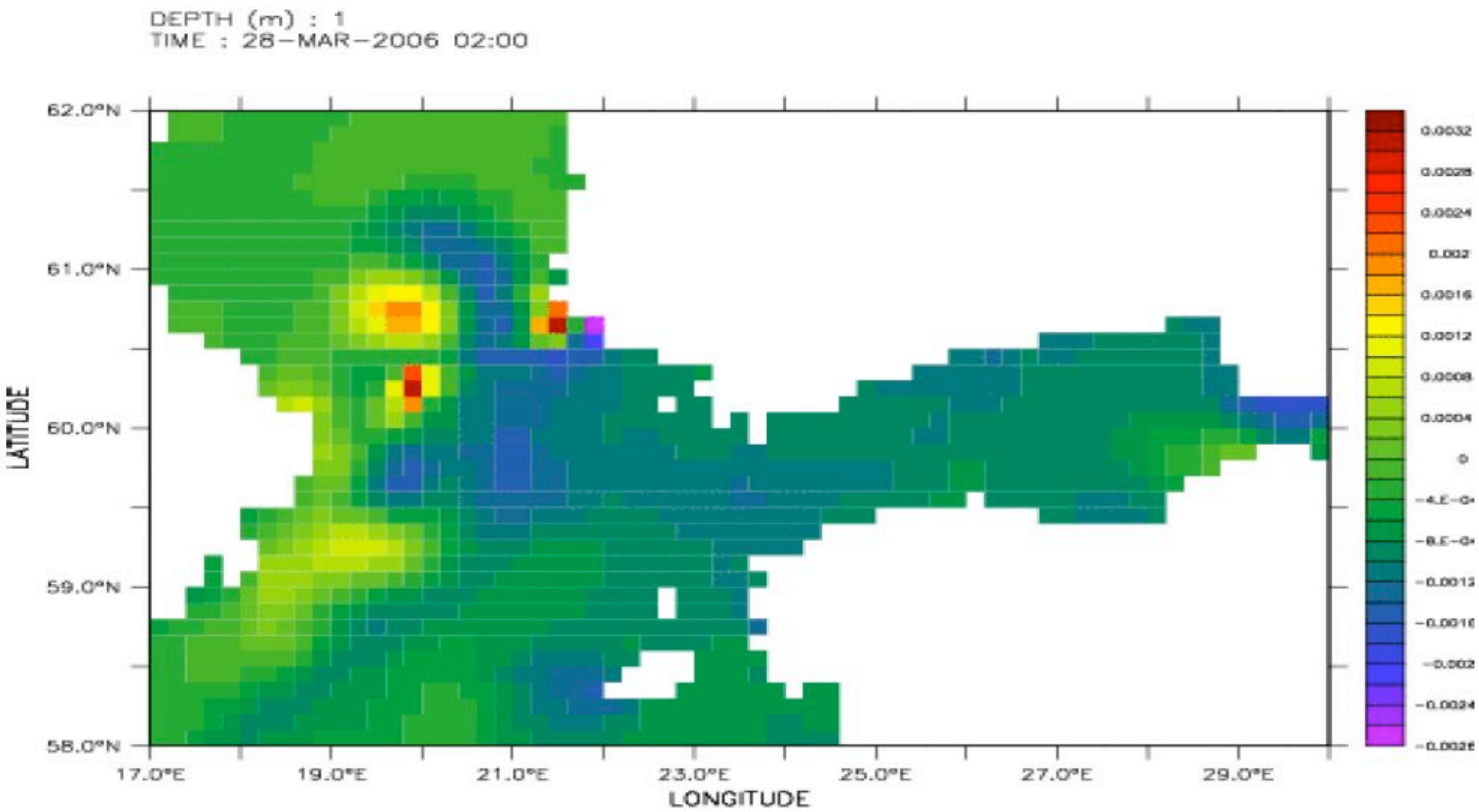
Adriatic



Cynaobacteria monitoring & forecasting

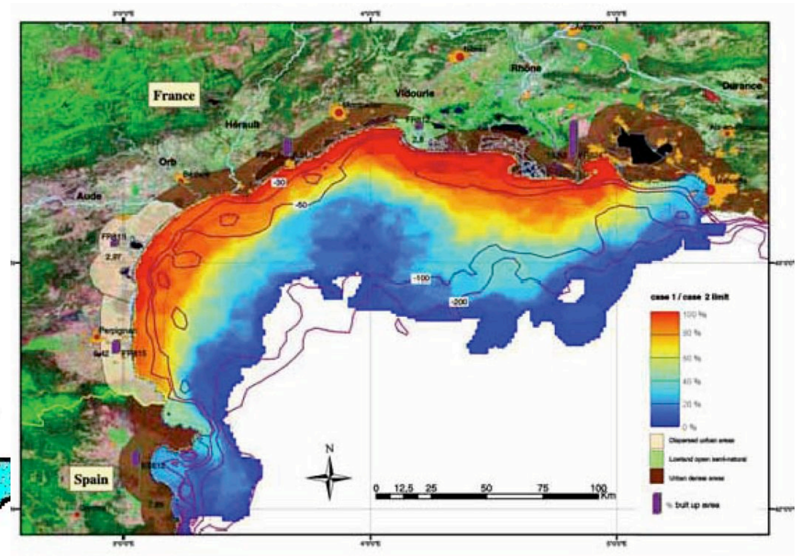


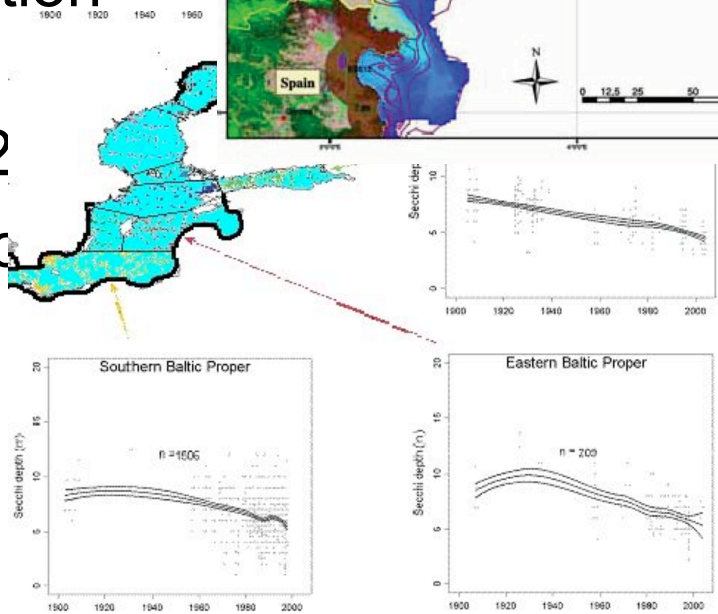




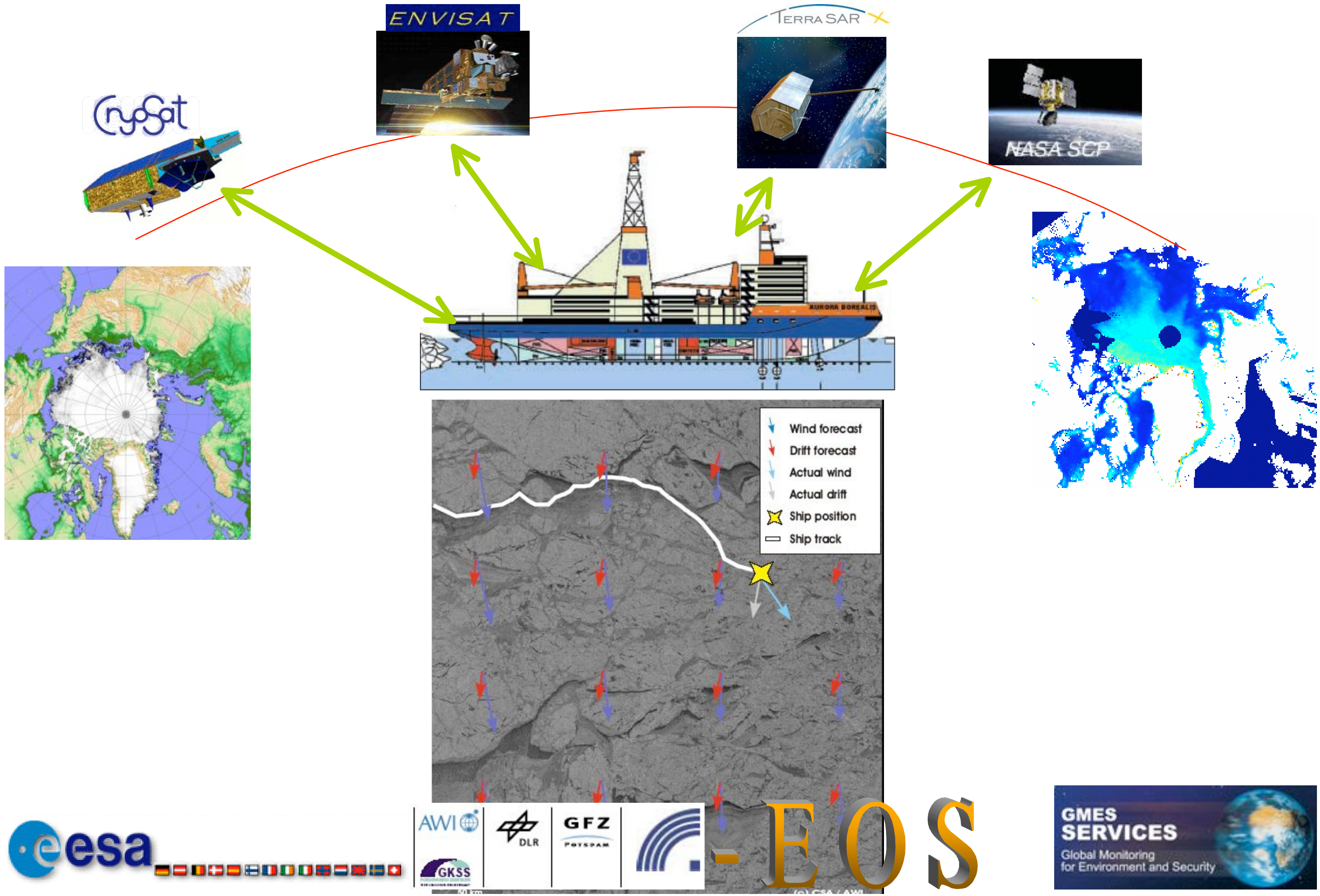
Water Quality Indictors for EEA

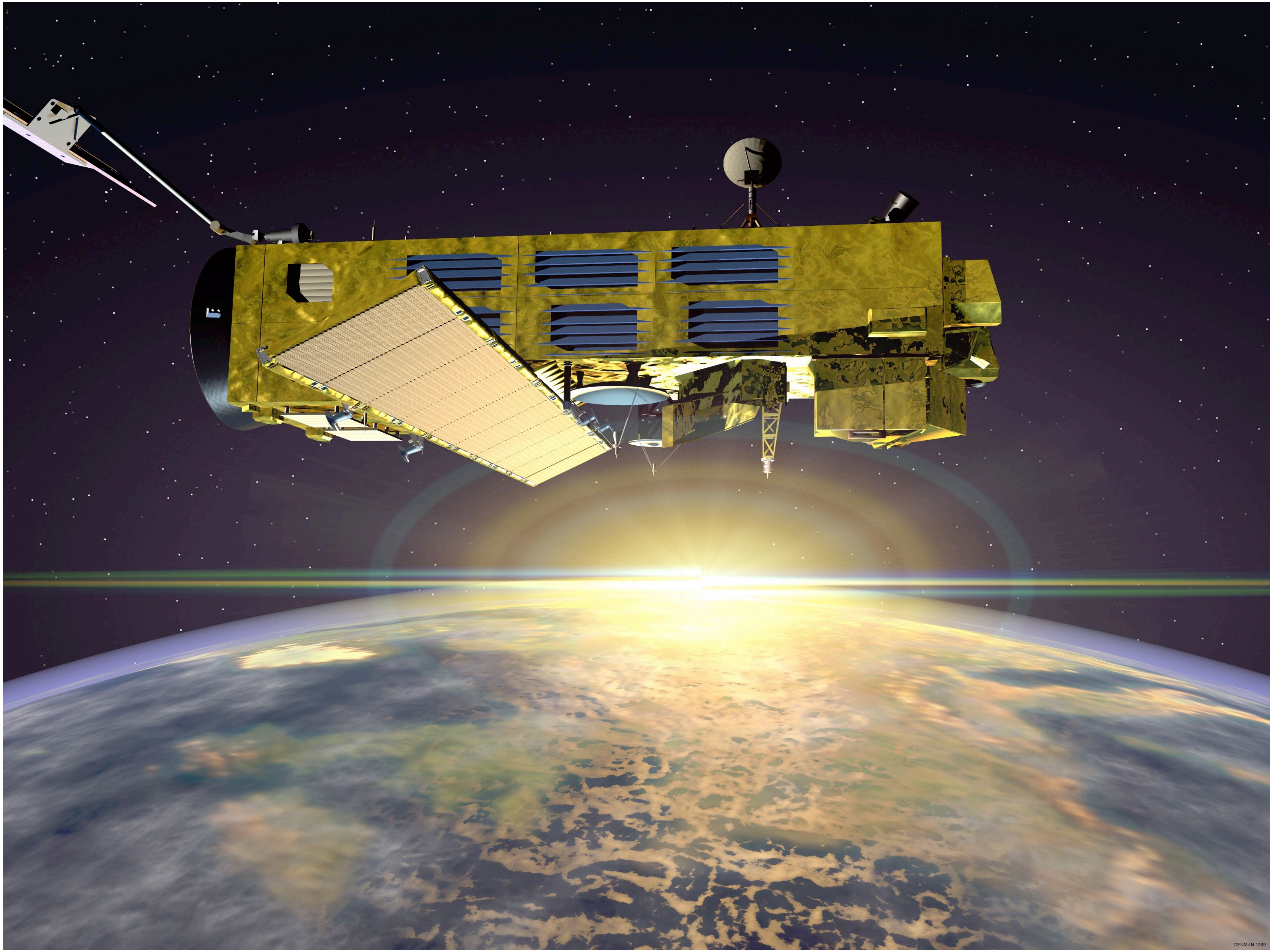
- Service content (bi annual)
  - Water Quality Indicators:
    - Chlorophyll concentration (2km)
    - Water transparency (2
    - Algal Bloom occurrenc climatology
      - Number & location
      - Indication of type and harmfulness
  - Water Quality Trends Assessment





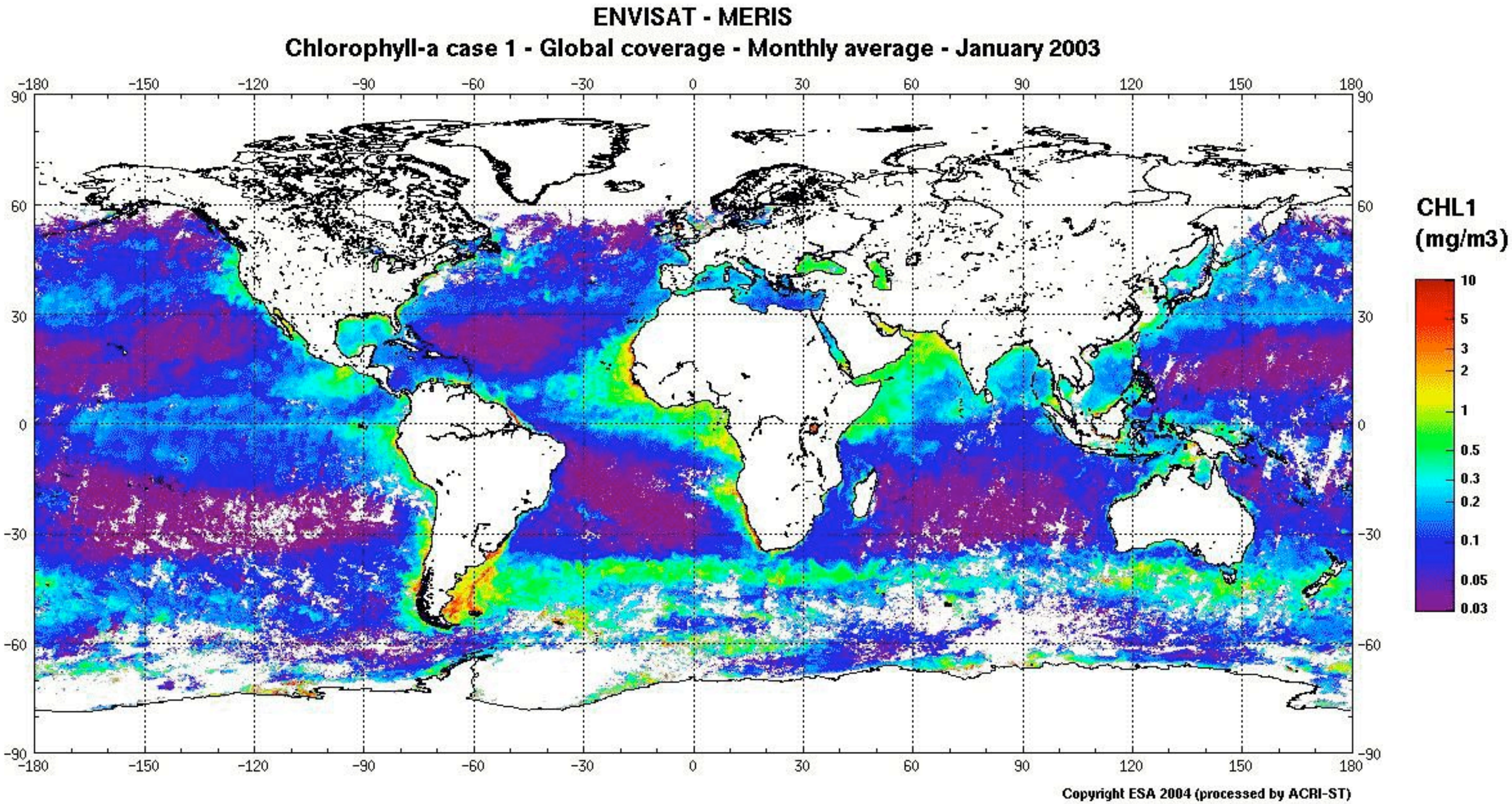
Ice monitoring and forecast system




DENMAN 1999

Envisat measures global Chlorophyll concentration

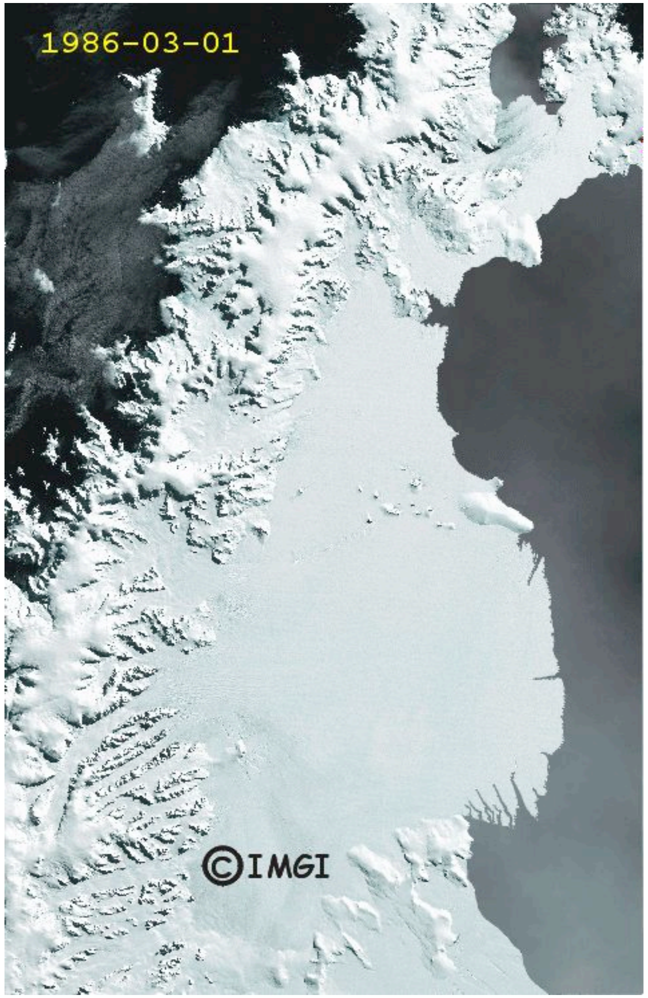
Chlorophyll concentration is a measure of abundance of phytoplankton biomass, which has an important role in fixing CO_2 through photosynthesis.



Courtesy of ACRI, F

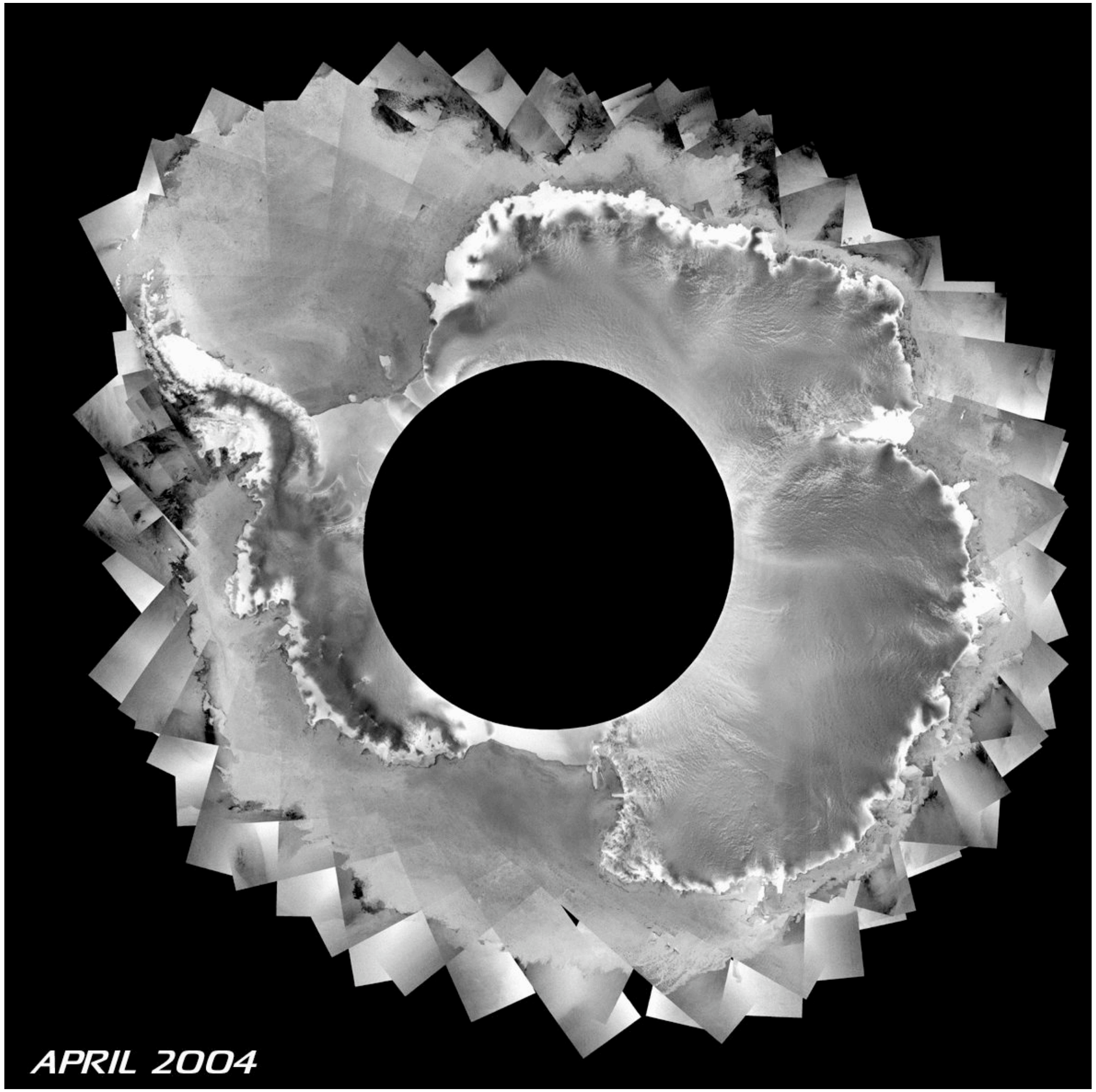
Envisat monitors Ice-Sea Ice in Antarctica

LARSEN B collapse observed in 2002 by ERS /Envisat



Courtesy of H.Rott, Univ Innsbruck, AU

Envisat Radar monitoring Antarctica Ice and Sea-Ice extent (April-to June 2004)



SST Anomalies

Hill et al, 2000; Leeuwenburgh & Stammer, 2001