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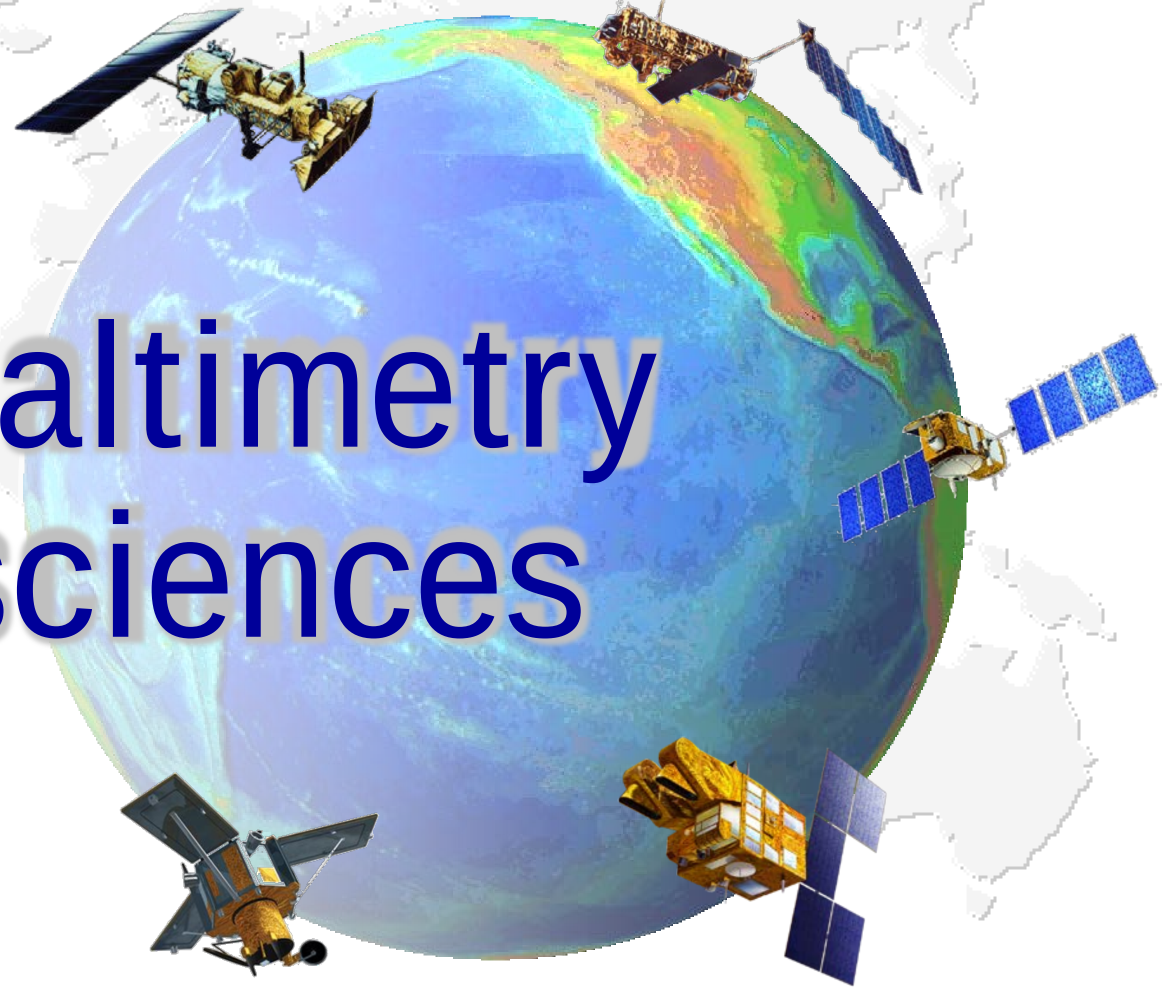

Satellite altimetry in Earth sciences

Joint COSPAR and WMO Capacity Building Workshop
«Satellite remote sensing, water cycle and climate change»

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20 July — 1 August 2014,
Tver, Russian Federation
Tver State University.

Satellite Altimetry in Earth Sciences

- **Geodesy & geophysics**
- **Ocean**
- **Ice**
- **Climate**
- **Atmosphere, wind & waves**
- **Hydrology & land**
- **Coastal**

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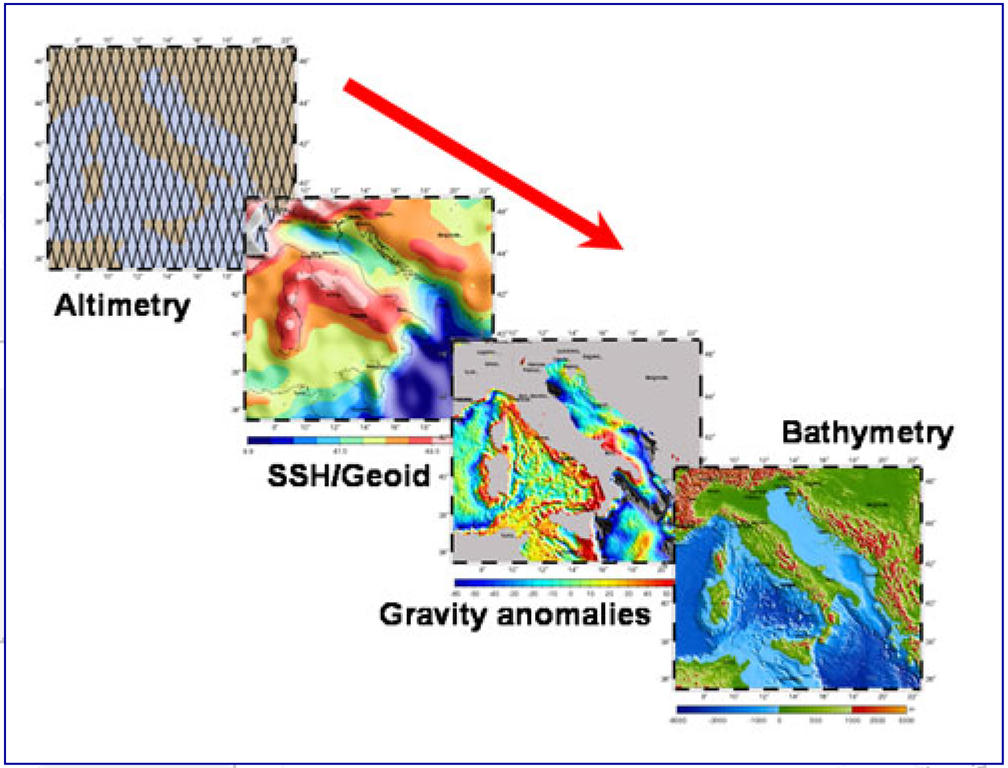
Geodesy & geophysics

Geophysics is the study of the substances that make up the Earth and the physical processes occurring on, in and above it. Information derived from altimetry data can be used to study the Earth's shape and size, gravity anomalies (geodesy), seafloor relief (bathymetry), tectonic plate motion and rifts (geophysics), etc.



Although often linked to plate tectonics, tsunamis are very different, transient phenomena. However, their impact on the sea surface can be seen by altimeters in some cases, thus helping the study of their propagation.

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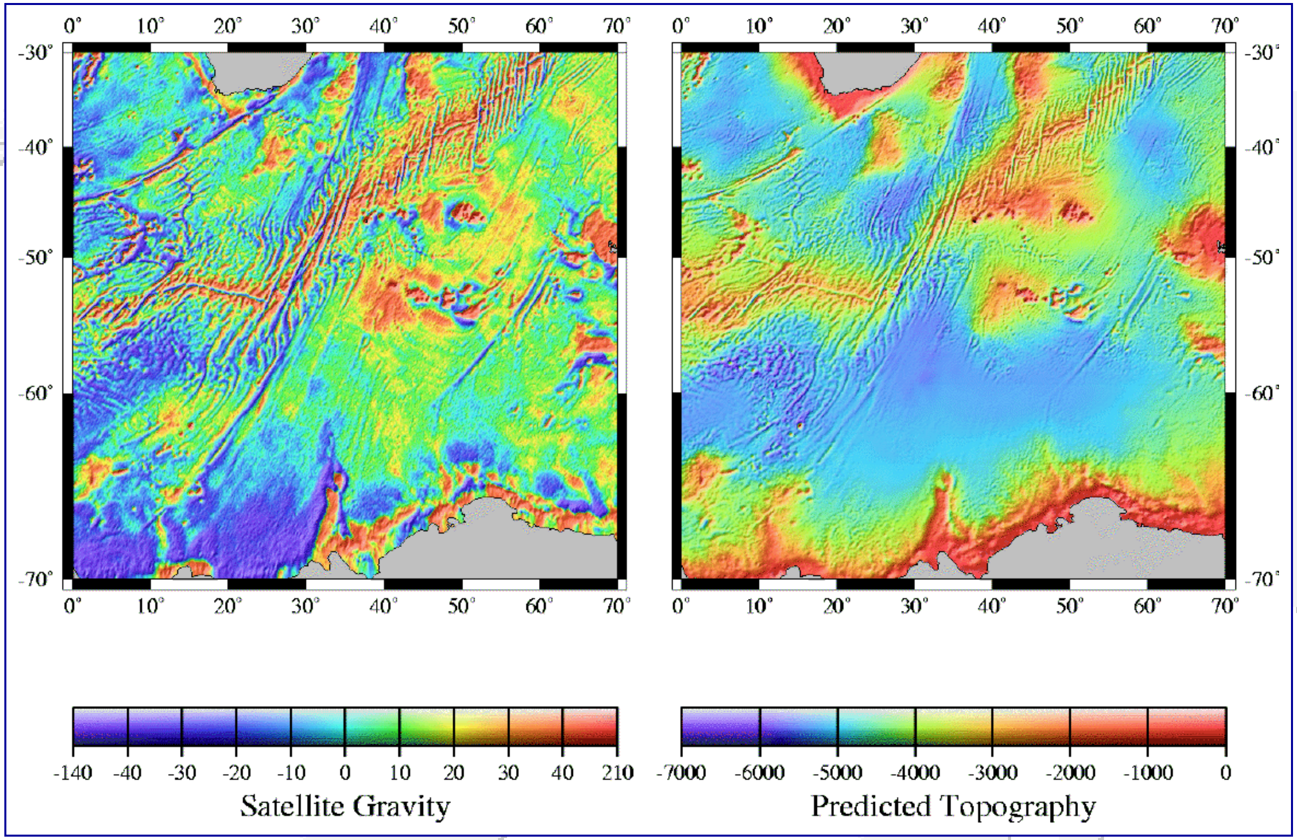
Bathymetry Estimate from Altimetry



Gravity anomalies (left), computed from altimetry, and predicted topography (right) deduced from these gravity anomalies plus in situ measurements.

The conceptual approach uses the sparse depth soundings to constrain the long-wavelength depth while the shorter-wavelength topography is predicted from the downward-continued satellite gravity measurements.

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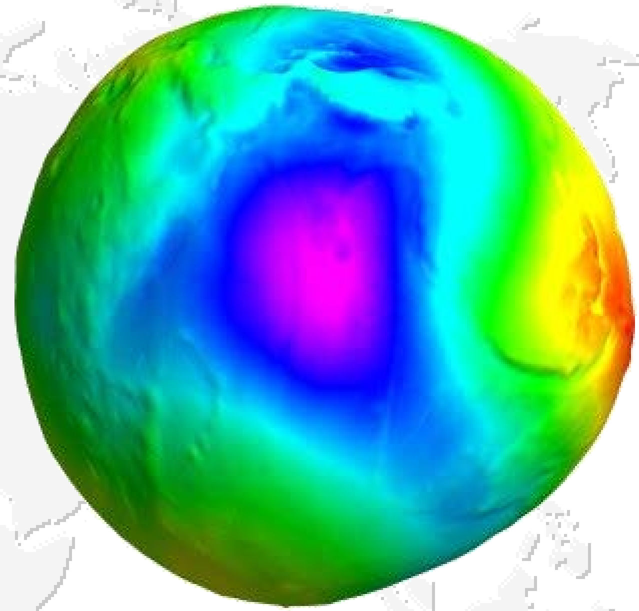
Geodesy

Geodesy is the science of the Earth's shape and size. Altimetry makes it possible to compute Mean Sea Surface; such a surface includes the geoid, i.e. the shape of the sea surface, assuming a complete absence of any perturbing forces (tides, winds, currents, etc.). The geoid reflects the Earth's gravitational field. It varies in height by as much as 100 metres over distances of several thousand kilometres due to uneven mass distribution within the planet's crust, mantle and core. Other less pronounced irregularities are also visible over smaller distances. These mostly reflect the ocean bottom topography.



Long-wavelength geoid (heights are exaggerated with respect to the Earth's diameter).

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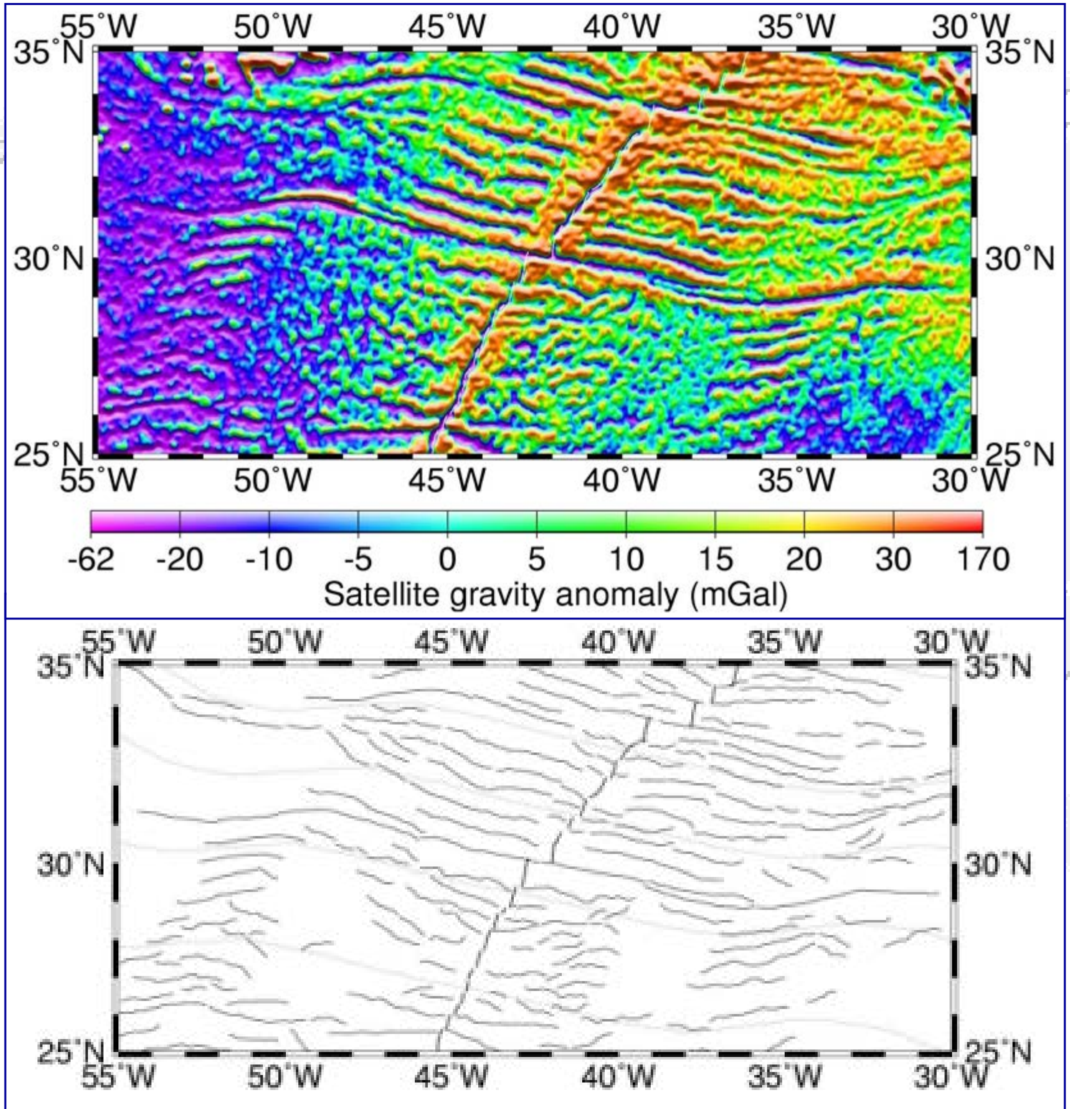
Plate Tectonics



Gravity anomalies (top) in the North Atlantic measured in milligals (1 mGal = 10-5 m/s^2). Since gravity depends on distribution and density of material, features such as the Mid-Atlantic Ridge and fracture zones show up clearly.

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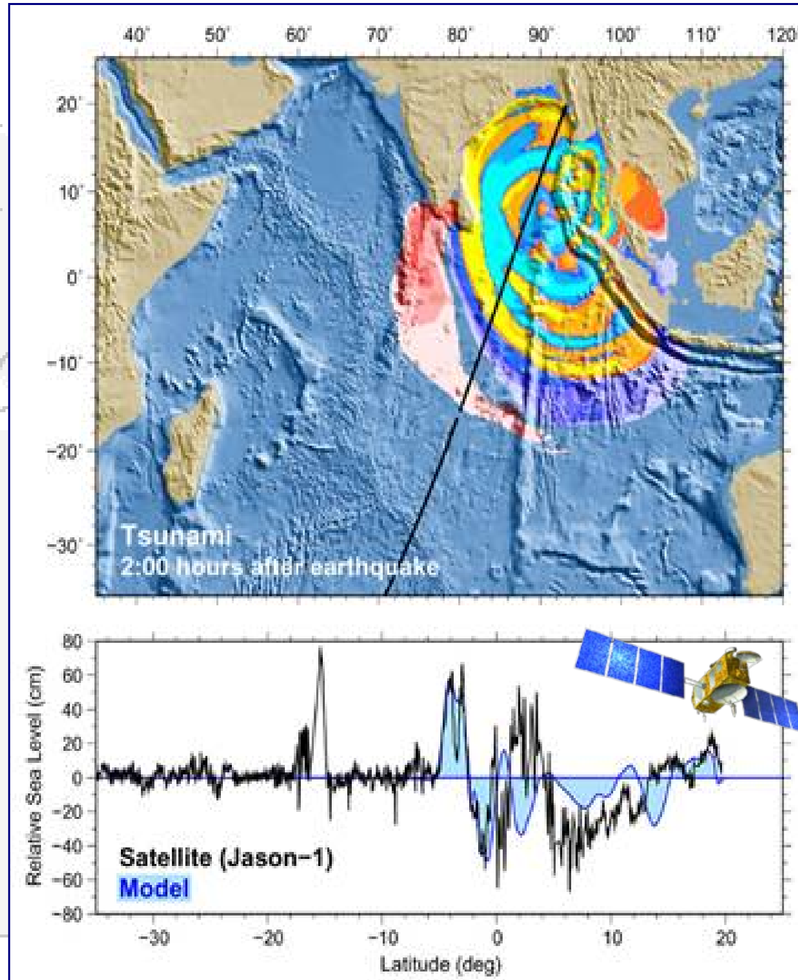
Tsunamis

Tsunamis are waves triggered by the vertical deformation of the ocean bottom, caused by submarine earthquakes or landslides. They lead to waves crossing the oceans at high speed (around 800 km/h), and a potentially enormous quantity of water flooding the coasts when these waves come to shore. Theoretically, sea level anomalies observed by altimetry should reflect these waves. However, observation is difficult, since the additional height is one of the signals of ocean variability.



Ground track for Jason-1 overlaid by the CEA wave propagation simulation at the time of the satellite's passage (top). The area corresponding to the tsunami's front is circled 26 December 2004. Sea level anomalies measured by Jason-1 compared to the CEA simulation (bottom).

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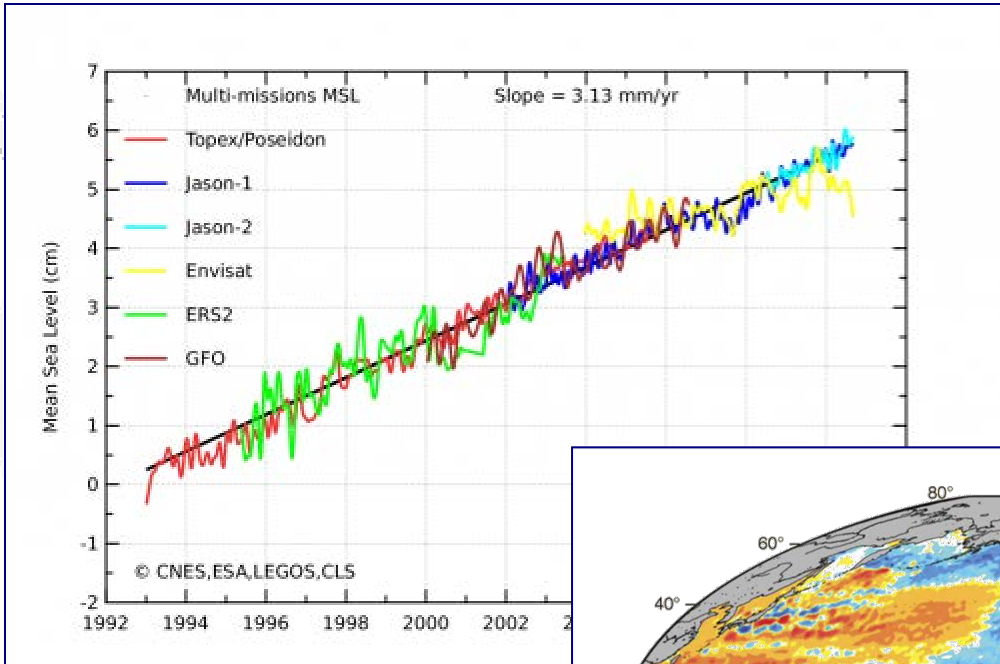
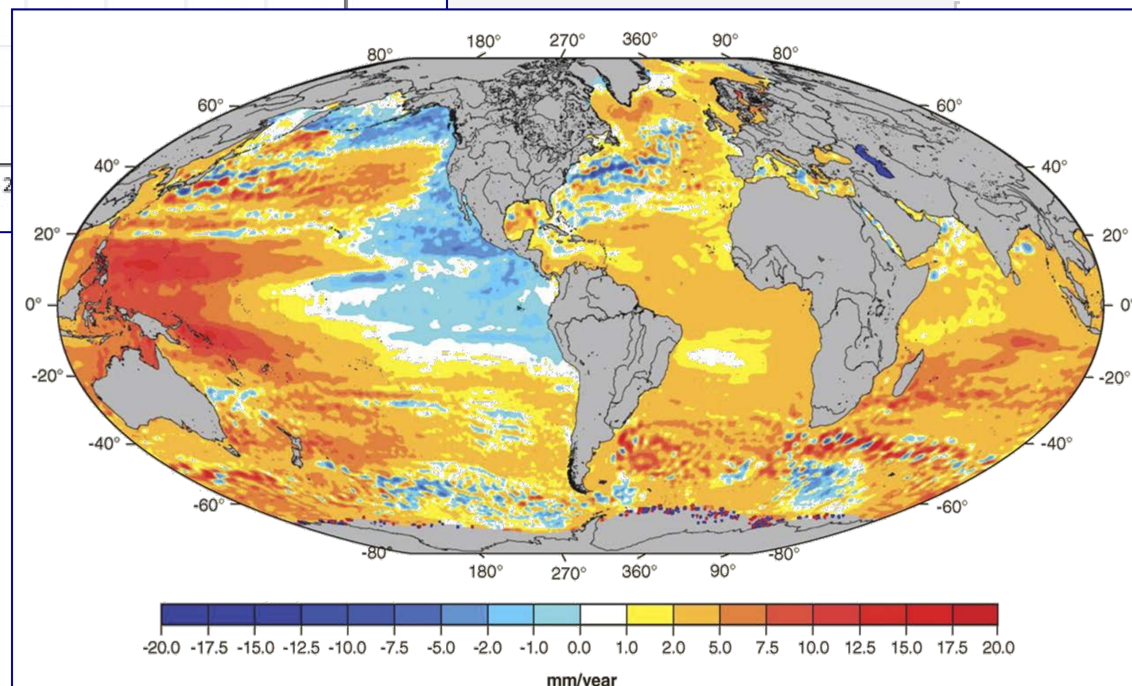
Sea Level Rise



Mean Sea Level variation computed from altimetry 1993–2011



Mean Sea Level trends computed from altimetry, from January 1993 to 2005. Regional variations were sometimes more than ten times the average (West Pacific, Indian Ocean), whereas in other regions sea level actually decreased.

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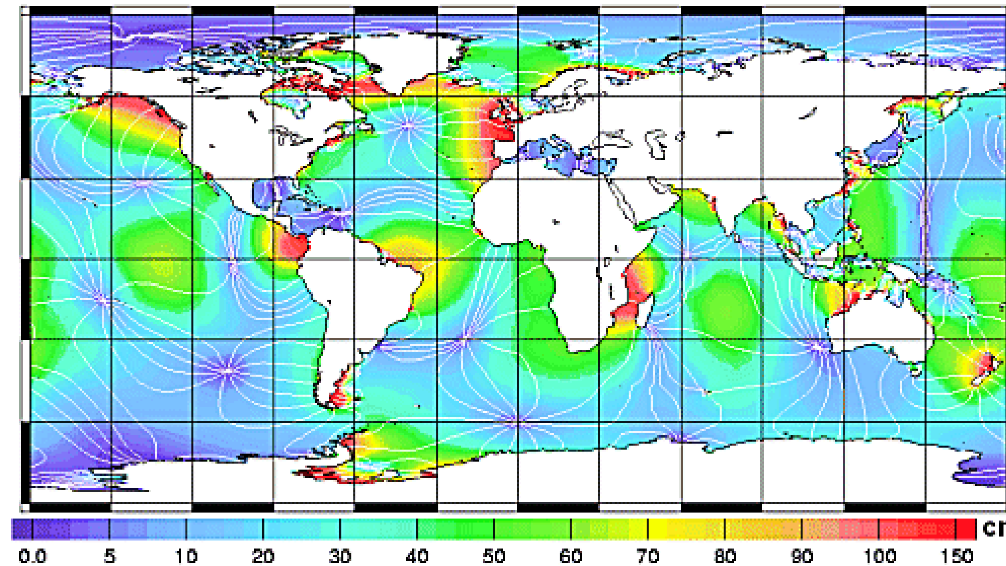
Tides

Tides have been studied for longer than most other ocean phenomena; however, for most of this time, the only measurements possible were those made by tide gauges on the coasts, mostly in harbours, which were thus subject to local factors, the geometry of the coasts and, in particular, the bathymetry. Now, satellite altimetry provides measurements of sea surface heights in the open ocean accurate to 2-3 centimetres that are assimilated into mathematical tide prediction models.



Amplitude of the M_2 tidal constituent (in centimeters) derived from the FES2008 model. Cotidal lines indicating the phase every 30 degrees originate at amphidromic points where the tidal range is zero.

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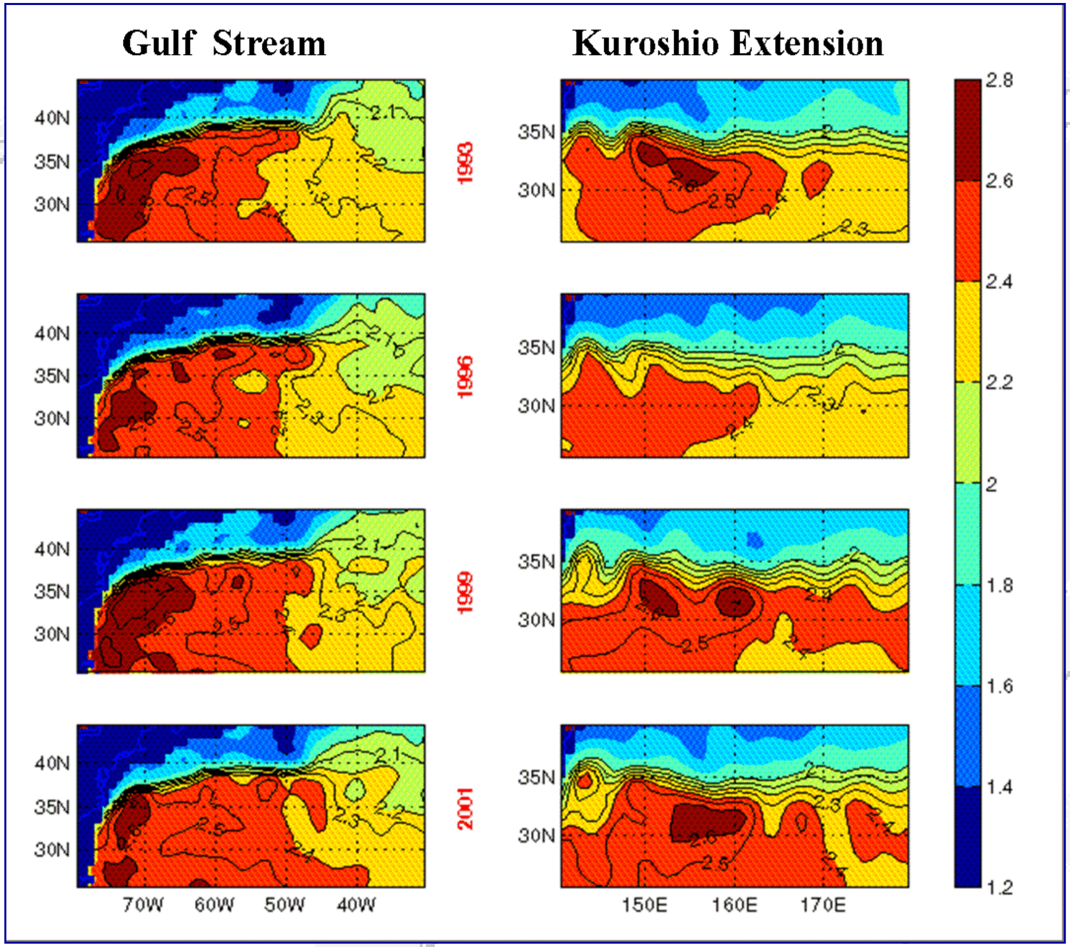
Large-scale ocean circulation



Changes in the extent of the Gulf Stream and the Kuroshio, as seen by Topex/Poseidon. The currents were 'elongated' in 1993 and 1999, and contracted in 1996 and 2001.

A view of the global ocean circulation shows currents swirling around the hills and valleys at the sea surface. In the Northern Hemisphere, currents flow around hills in a clockwise direction and in an anticlockwise direction (the opposite occurs in the Southern Hemisphere) around valleys. These currents form gyres on either side of the equator. Planetary waves are other large-scale phenomena that are less easy to see on an instantaneous map, but nonetheless they too have a global impact.

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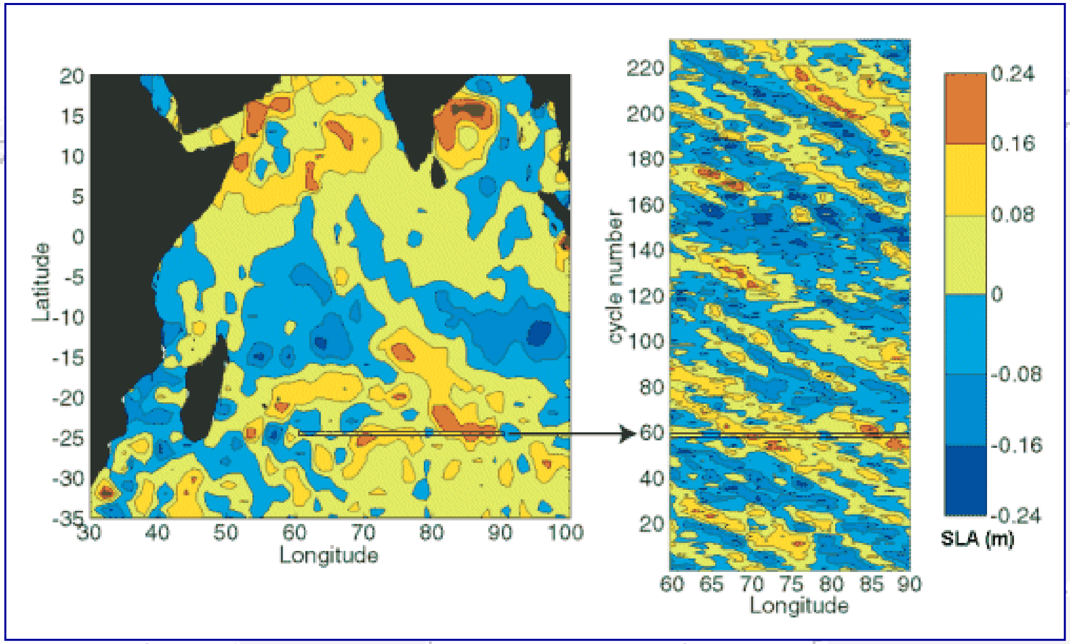
Planetary Waves



Map of sea level anomalies, on the left, and longitude-time diagram on the right (the time is indicated in Topex/Poseidon cycles). Diagrams like these bring out the variations of sea level over time along a particular parallel. The elevation at 90°E in cycle 20 (in yellow) can be found about 3 months (10 cycles) later at 85°E, 6 months later at 80°E, and so on. The westward motion of this elevation can be seen on the diagram as a sloped line. Another elevation follows the same path with a 3 month offset, creating a parallel trace. (Credits Southampton Oceanography Center, NOCS).

Though the large currents are very important, the ocean and climate are also influenced by phenomena that are harder to see. "Planetary" waves cross the oceans along parallels and interact with general oceanic circulation. These are either Rossby waves, which go from East to West or Kelvin waves which move in the opposite direction. These waves and their reflections play a key role, in particular in the *El Niño* and *La Niña* phenomenons.

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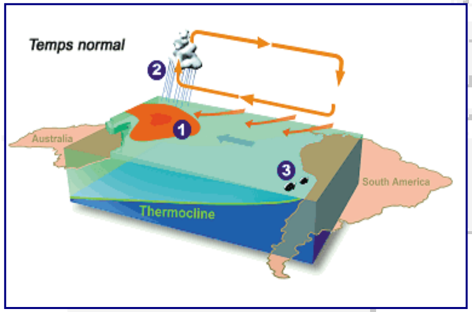
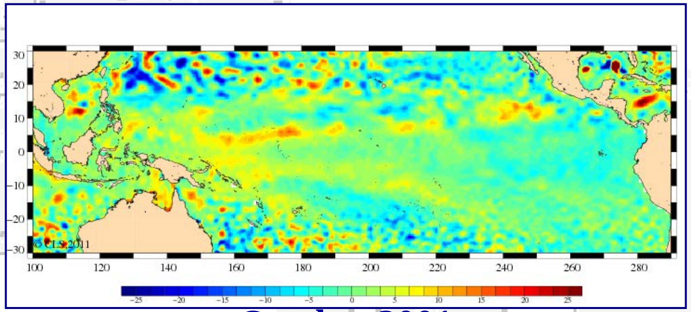
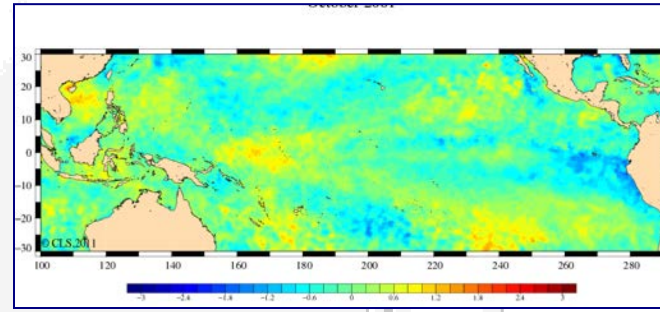
El Niño - La Niña

Sea level anomaly | **Sea surface temperature**

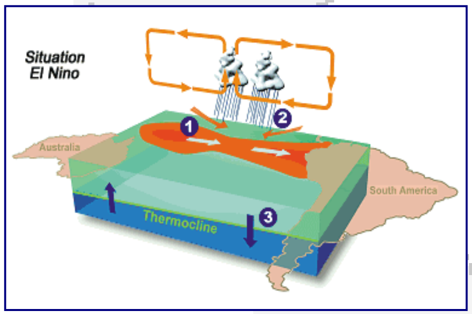


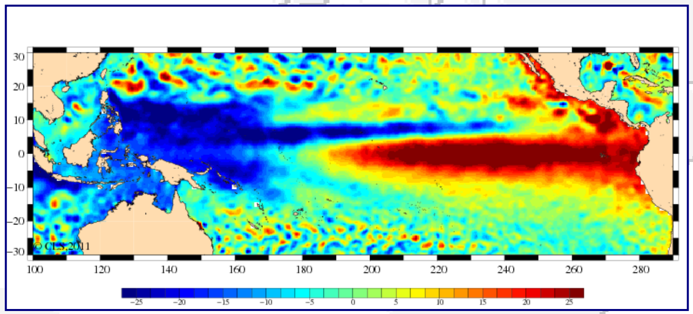


October 2001

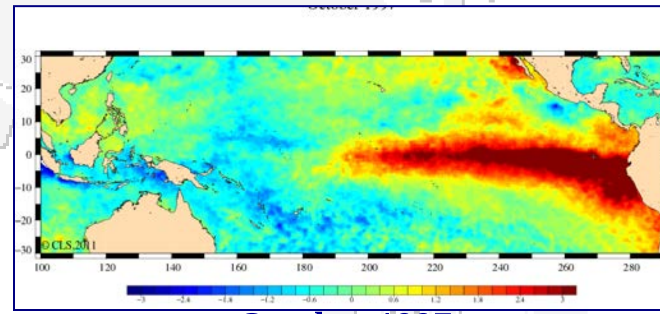


October 2001

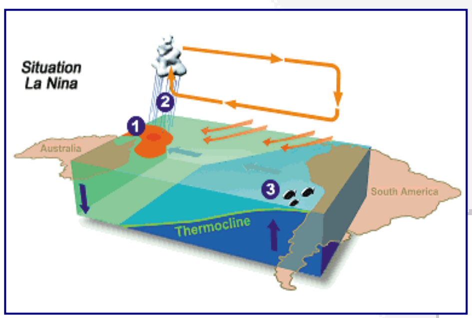


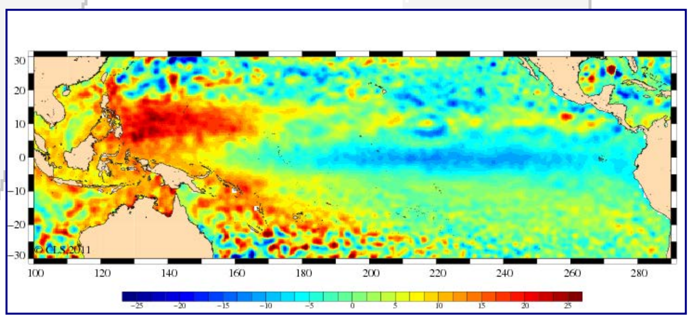


October 1997

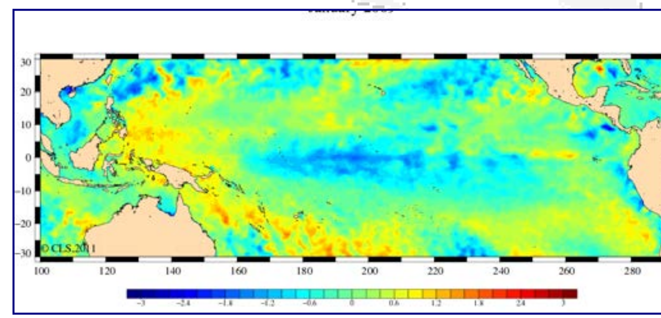


October 1997





December 2008



December 2008

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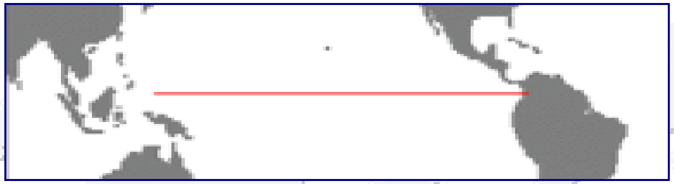
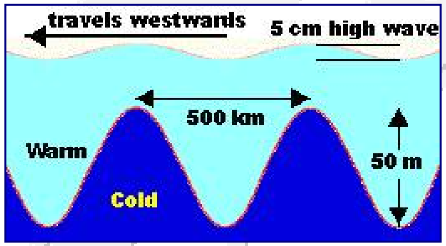
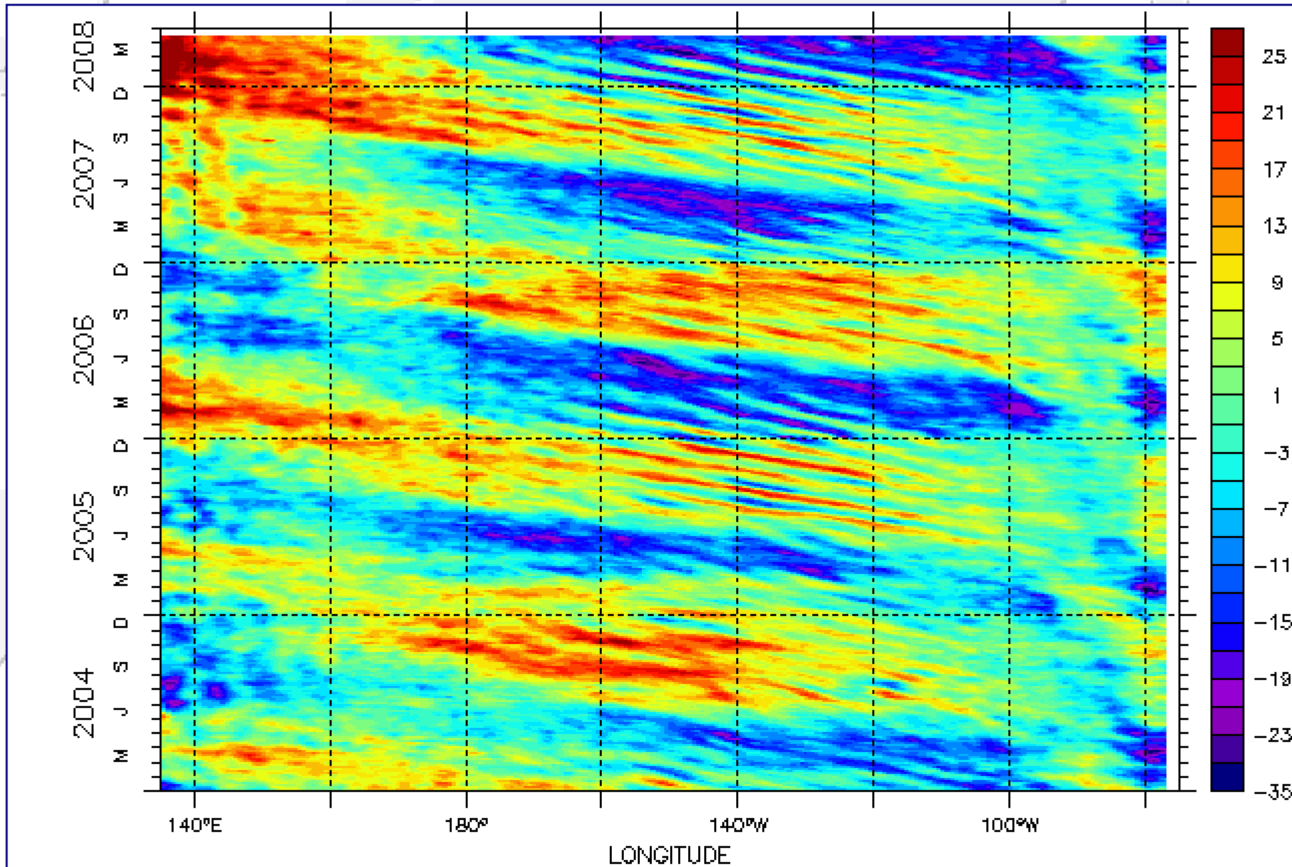
Kelvin Waves







Sea level anomalies calculated according to altimetry satellites TOPEX/Poseidon and Jason-1 along the equator

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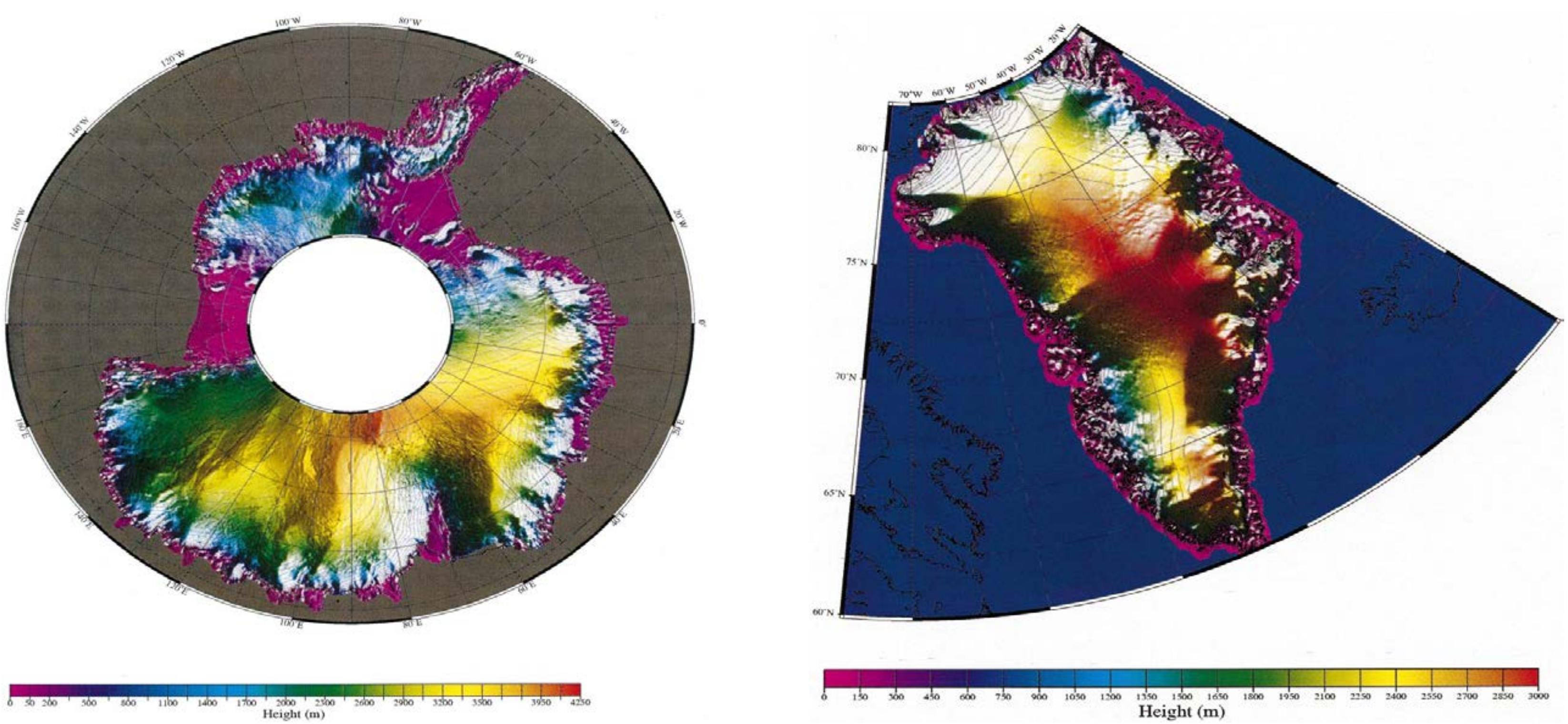
Ice Sheets



Map of Antarctic ice sheet (left) and Greenland (right) with a resolution of 2 "according to the geodesic program ERS-1 satellite

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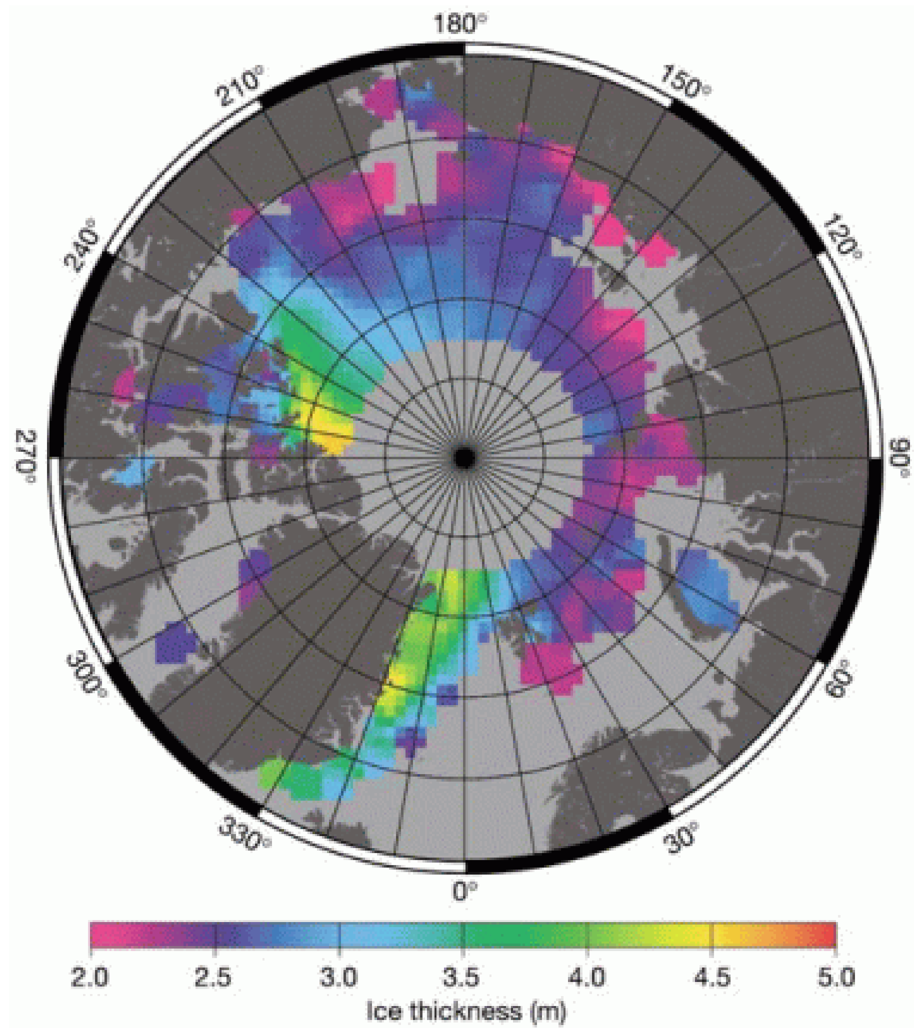
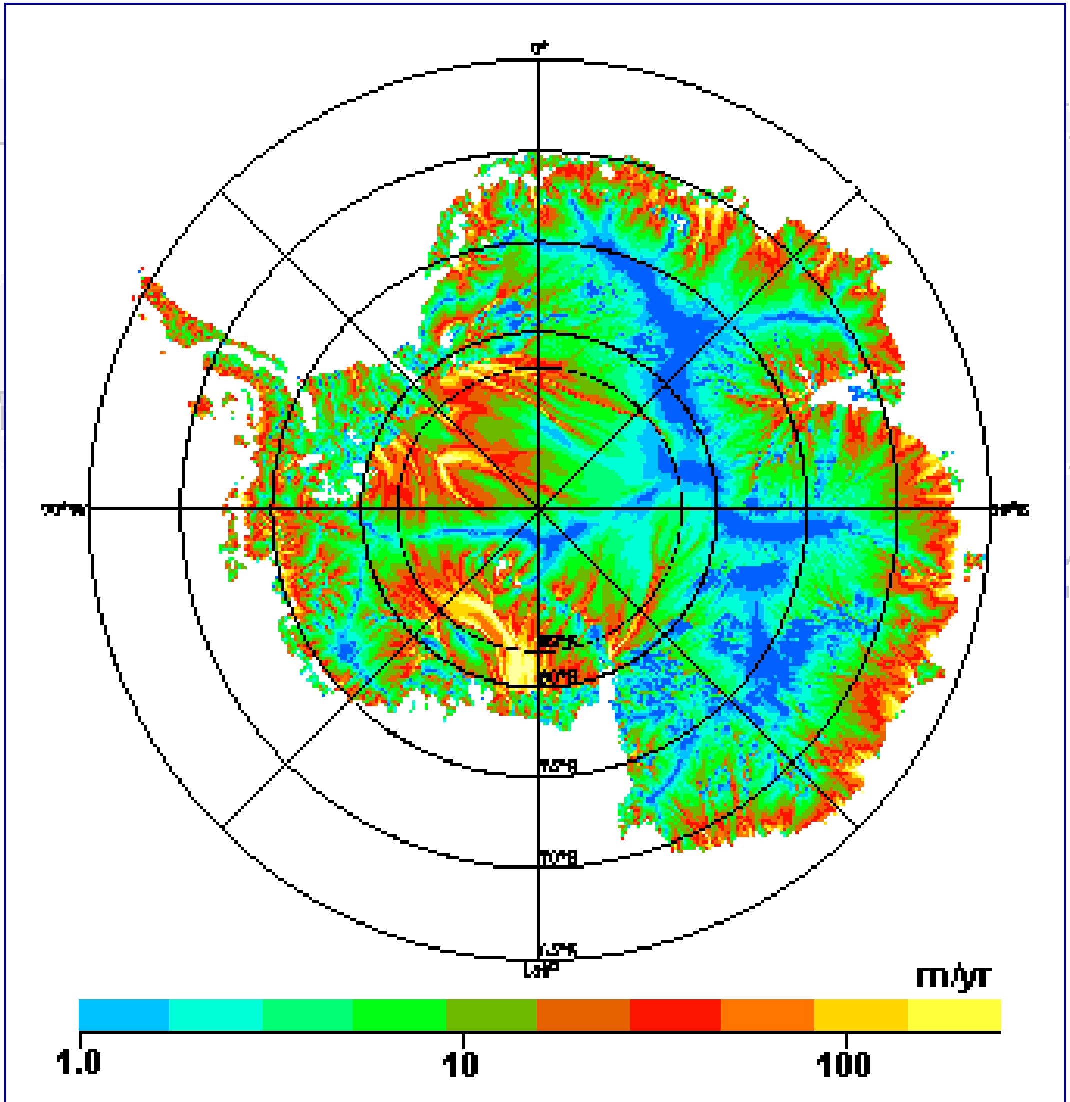
Sea Ice

Sea ice is one of the least-known parameters needed for climate modelling. While its extent and age can be measured by other sensors, altimetry is the only one providing sea ice thickness.



Average winter (October to March) Arctic sea ice thicknesses from October 1993 to March 2001 from satellite altimeter measurements of ice freeboard. Data are not available for the marginal ice zone, or above the ERS latitudinal limit of 81.58°N.

Ice Sheets



Speed of ice flow in Antarctica, derived from ERS-1 topography measurements (geodetic phase)

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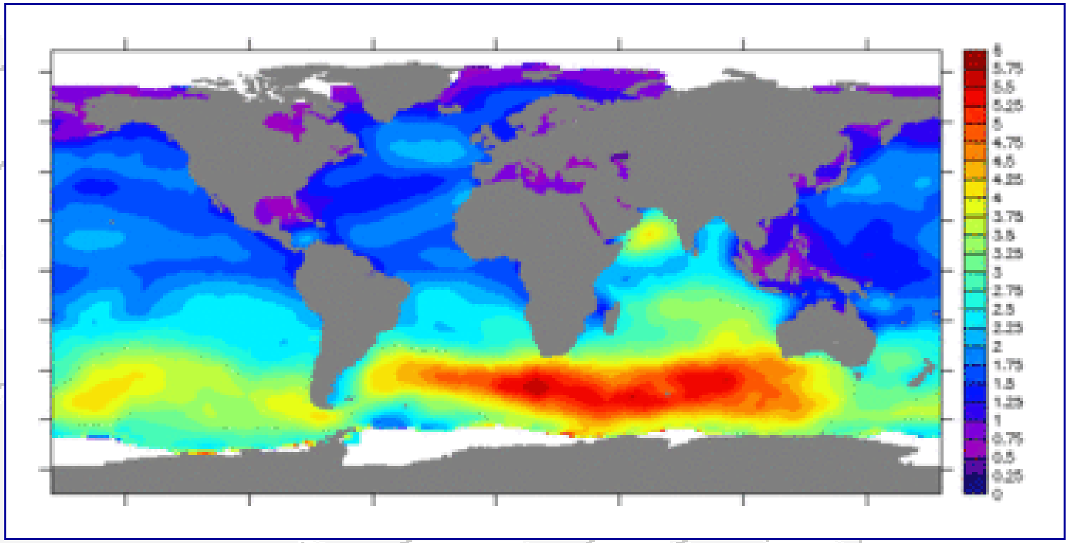
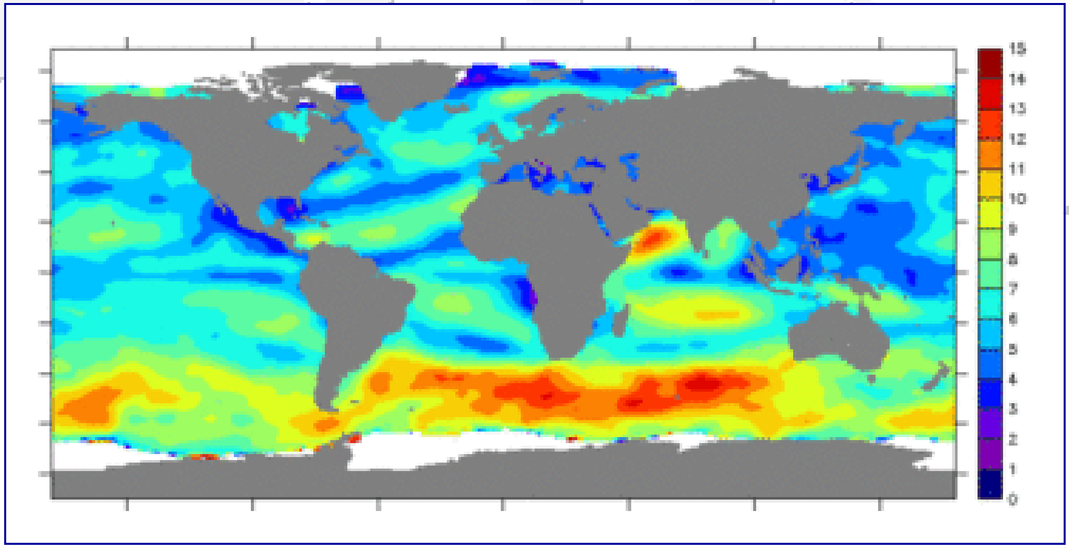
Wind and Waves

Spaceborne altimeters measure sea surface height first and foremost, but we can also obtain other physical parameters using satellite altimetry techniques. One such example is wave height, which is of prime importance to marine weather forecasters and ships at sea. Wave height can be derived by looking at how the sea surface reflects the radar signal.





Significant wave height (m) (top) wind speed (m/s) (bottom) and in July 2007.

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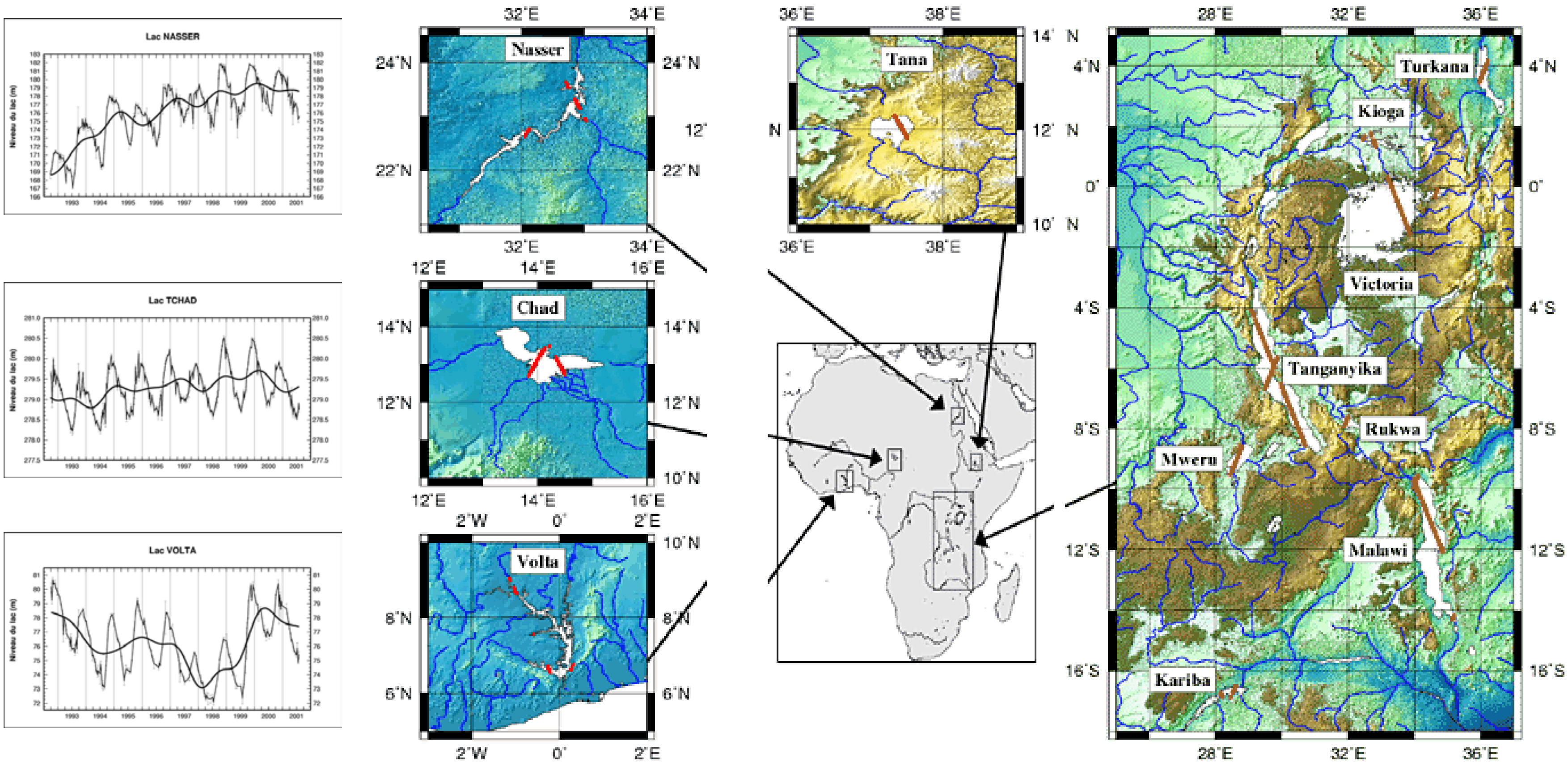
Lake and Enclosed Sea



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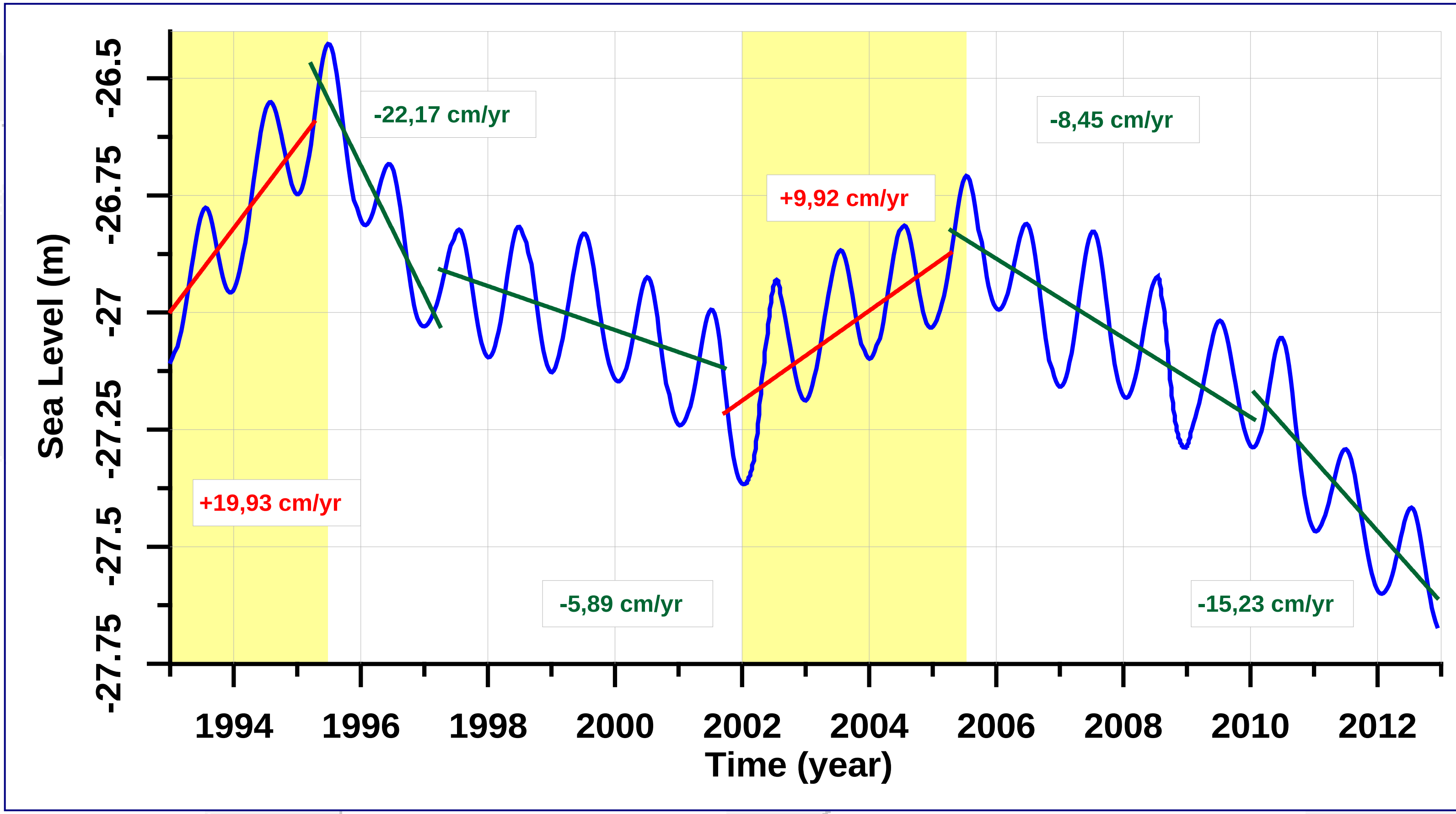
The Caspian Sea Level



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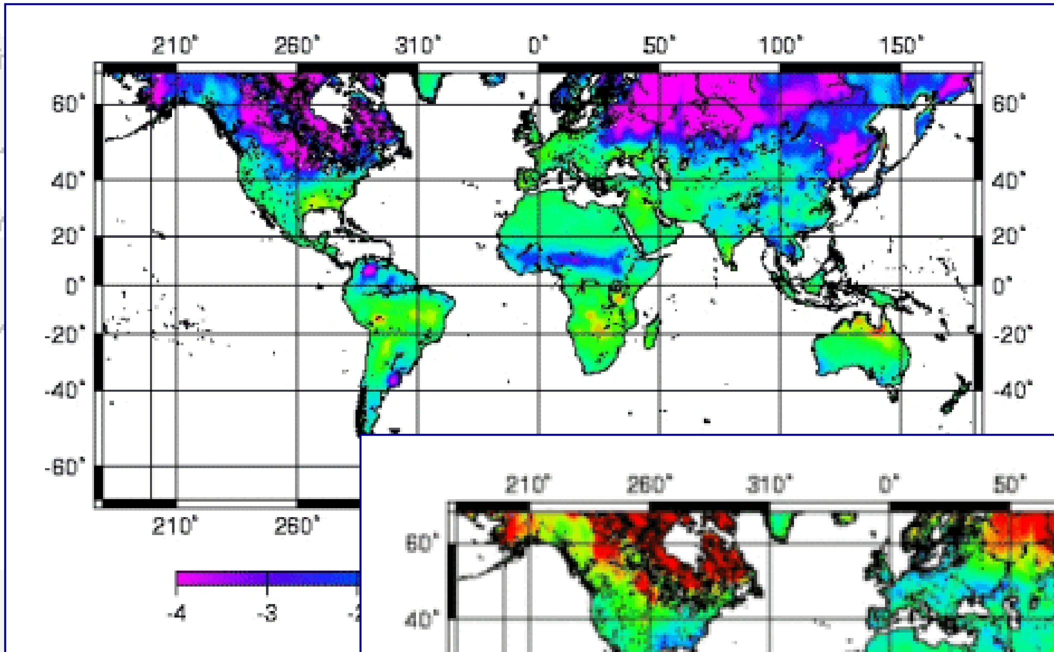
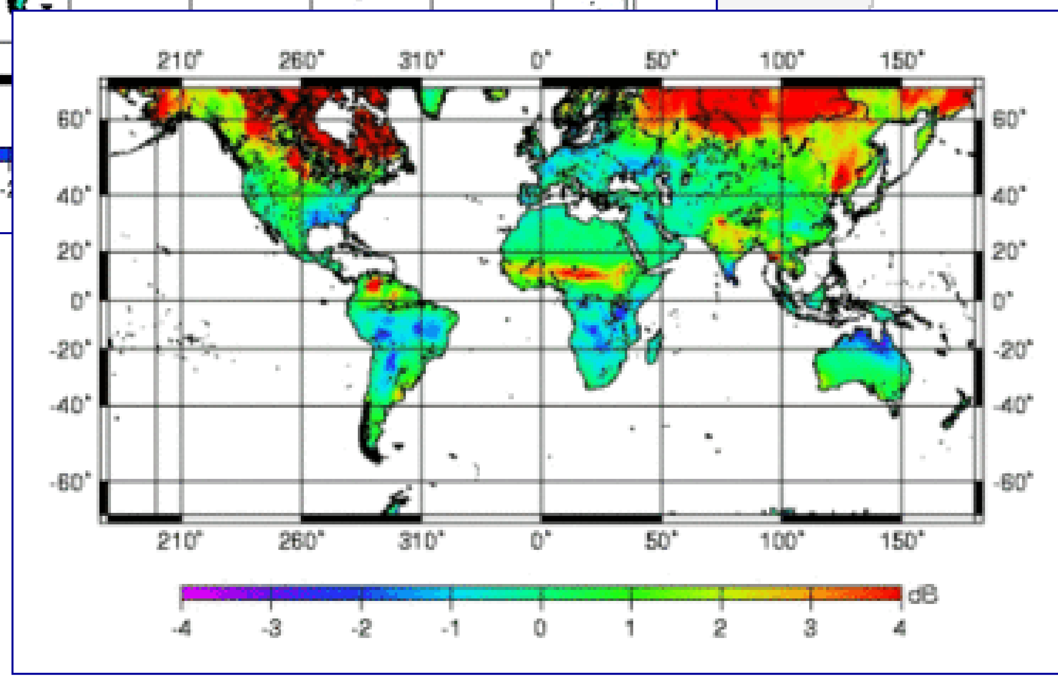
Altimetry over Land





Seasonal anomalies of the backscatter coefficient for Topex in Ku band, in winter (top) and summer (bottom) for the first ten years of measurements. Strong variations can be seen, especially for regions which are covered by snow in winter (higher than 55°N), or which have a marked rainy season (equator, India).

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Спасибо за внимание

Thank you for your attention