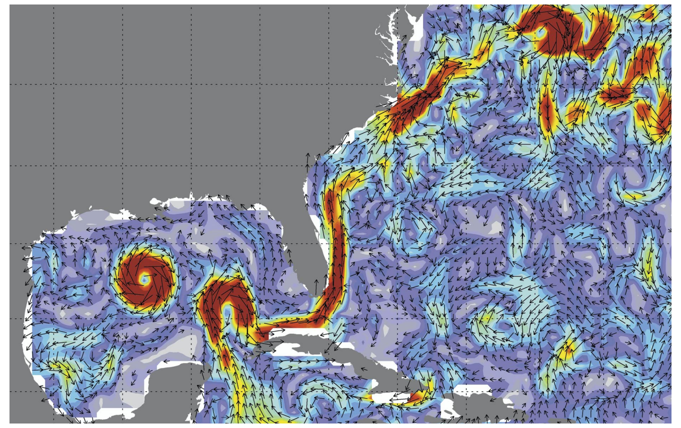
Ocean currents and eddies

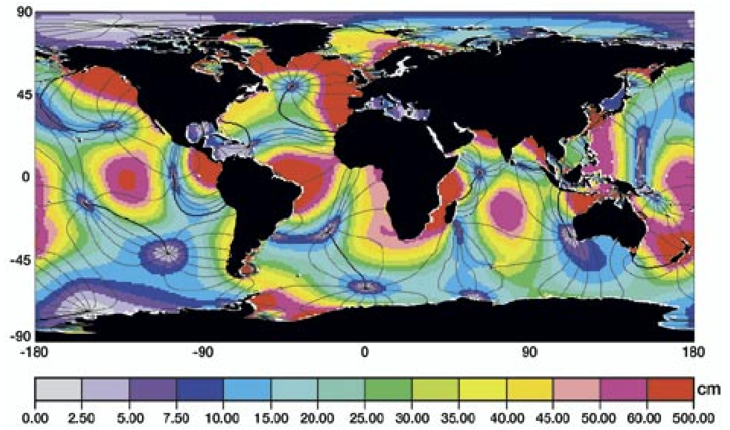
Satellite altimetry provides detailed and quantitative information on the location, velocity and movement of ocean currents and eddies. As a complement to other types of observation it offers a useful constraint on high resolution ocean circulation models.
The laboratory has developed sophisticated data assimilation methods for this purpose. Several projects in which LEGOS participates, including the operational oceanography project MERCATOR, use altimetry and in situ data to constrain ocean models and provide estimates and short-term forecasts of ocean variables. The main underlying scientific objective is the predictability of ocean processes. There are numerous applications: nesting of coastal models, initializing climate models, biogeochemistry and fisheries research.



Trajectory of the Gulf Stream and the Loop Current in the Gulf of Mexico in a MERCATOR forecast.

The tides and their dissipation

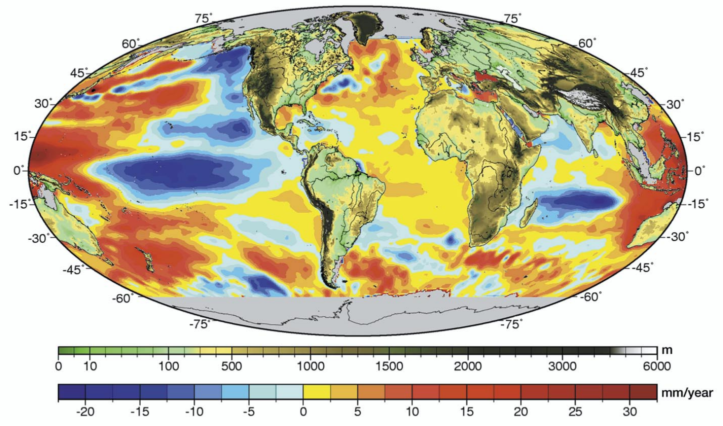
Ocean tides have an amplitude of the order of one metre in the open ocean but can reach about ten metres along coastlines. In the past, tides were observed only along continental and island coastlines. Altimetry has contributed the equivalent of thousands of tide gauges installed along satellite ground tracks. These measurements have improved tidal mapping on a global scale. It is now possible to predict tides to within one centimetre in the open ocean and to within ten centimetres along coastlines. Current studies have brought into question the accepted concepts on the dissipation of tidal energy and the importance of internal waves. These waves, excited by the interaction of tidal currents with seamounts, contribute to mixing of water masses and help maintain the deep ocean circulation. Tides thus play an unexpected role in the Earth's climate.



Amplitude of the lunar tide in cm. The tide wave turns around points with zero amplitude in 12h25 minutes.

The mean level of the seas

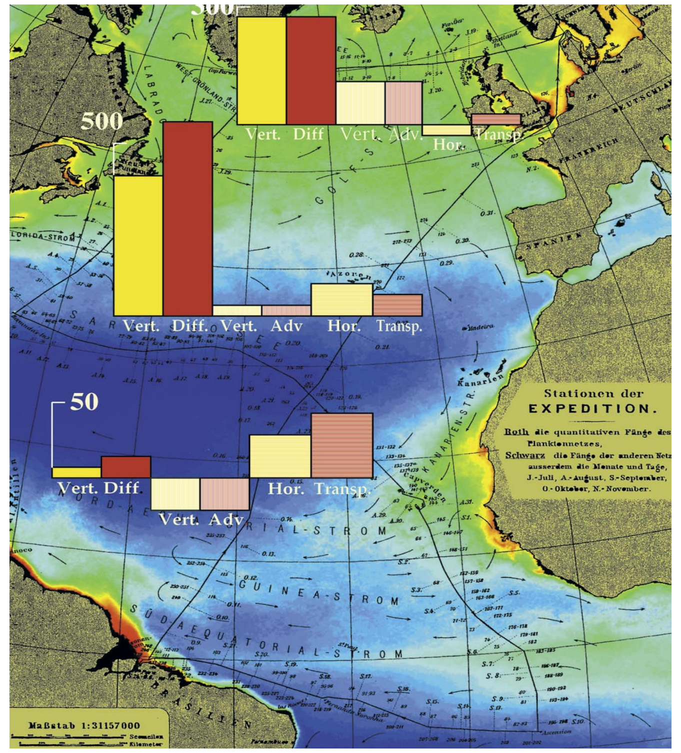
Since the beginning of the 1990s, satellite altimetry, in particular TOPEX/POSEIDON, has continually monitored the variations in sea level in relation to a reference tied to the centre of the Earth, with global coverage and outstanding accuracy of a few tenths of a millimetre per year. Satellite altimetry now allows us to monitor sea level change globally, as opposed to tide gauge networks which are limited to continental coastlines and ocean islands. The TOPEX/POSEIDON observations indicate that since the beginning of 1993, the global mean sea level has risen by about 2.5 mm/year. However this is only a mean value: while in certain regions the sea has indeed risen (up to 20-30 cm in places) it has, on the contrary, dropped in other regions. There are two categories of phenomena behind the variations of the mean sea level: changes in volume, of thermal origin (expansion or contraction of ocean waters in response to variations in temperature) and changes in water content due to exchanges with other surface reservoirs (atmosphere, continental water reservoirs, polar ice-caps). Recent work at LEGOS shows that the mean sea level rise recorded by TOPEX/POSEIDON over the last decade is almost entirely due to the heating of oceanic waters.



Regional variations in the change in sea level between 1993 and 2000. The yellow and red colours represent a rise in sea level whereas blue represents a drop.

Biogeochemistry and ocean circulation

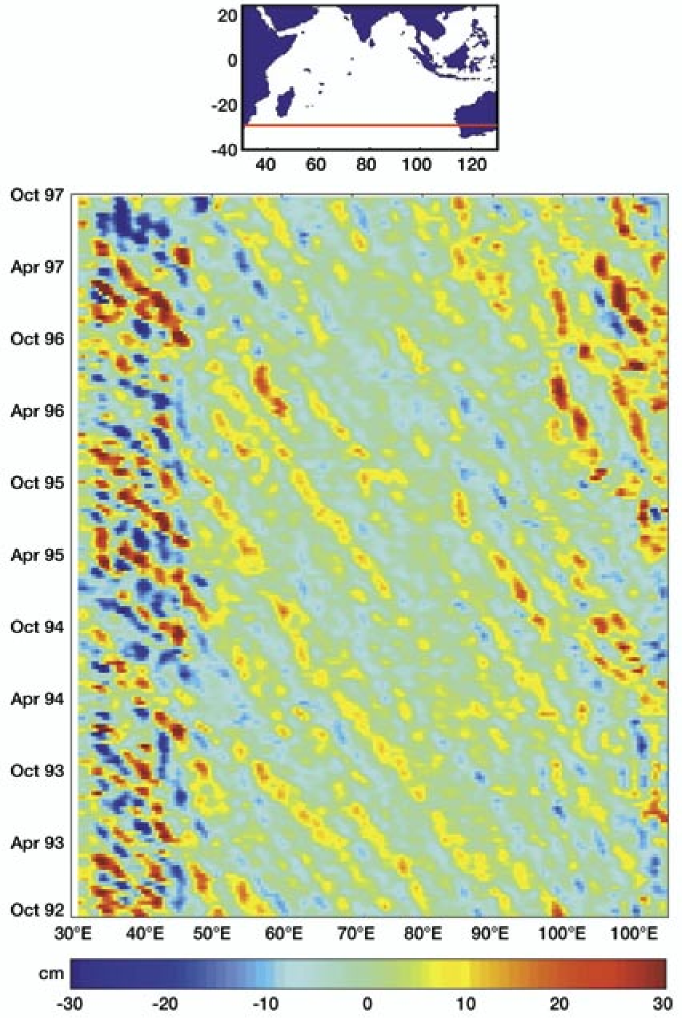
The oceanic mesoscale circulation and its eddies play a major role in plankton dynamics.



This role is illustrated in the different biogeochemical regions of the North Atlantic ocean by means of a three-dimensional, coupled physical/biogeochemical model which resolves the mesoscale. The horizontal transport supplying nutrients to the euphotic layer is dominant in the subtropical gyre, while vertical transport plays a major role in other regions. The red colour (yellow) indicates model simulations with (without) assimilation of altimetric data. Unit: mmol $NO_3/m^2/year$.

Ocean waves

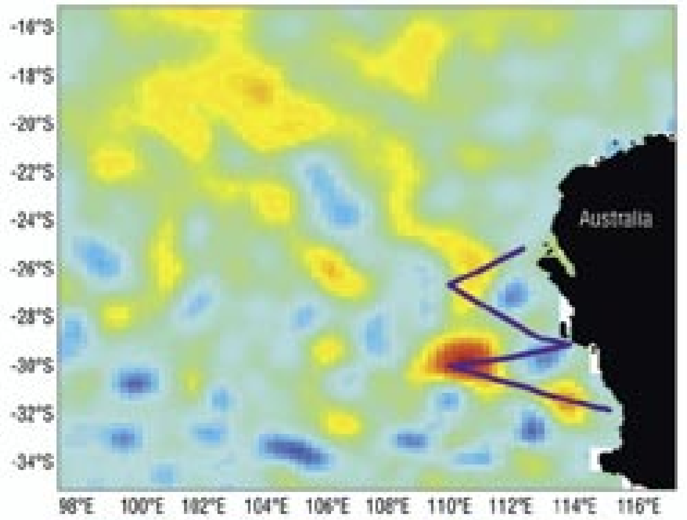
A change in forcing of the ocean's surface may create planetary waves. These waves have a very long wavelength (500 to 1000 km). Kelvin waves are long gravitational waves guided by the coastlines or by the equator. Rossby waves propagate in the deep ocean, always towards the west. They may take 5 to 10 years to cross the ocean at mid latitudes. While they were already well-known in theory, observations made by the TOPEX/POSEIDON satellite have recorded the actual characteristics of these waves. We therefore now know that the ocean has a very long memory of perturbations generated at the surface, which is important for understanding their role in climate variability.



Propagation of Rossby waves seen by the TOPEX/POSEIDON satellite. The figure shows the temporal evolution of sea level along 29°S in the Indian ocean. The X-axis (longitude) is given in degrees, from the coast of Australia (130°E) to the coast of Africa (30°E); the Y-axis is given in years, from October 1992 to October 1997; the colours mark the rise in sea level, from –30 cm (in blue) to +30 cm (in red). These waves, which are generated on the eastern boundary, propagate freely towards the west until they interact with the current meanders and eddies off the eastern coast of Madagascar at about 55° East.

Altimetry, geochemistry and circulation

A variation in sea level, observed by altimetry may reveal a change in mass or internal density: for example warm water with a low salt content may cause the sea level to rise. When the water mass is no

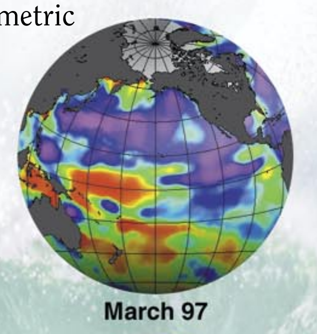


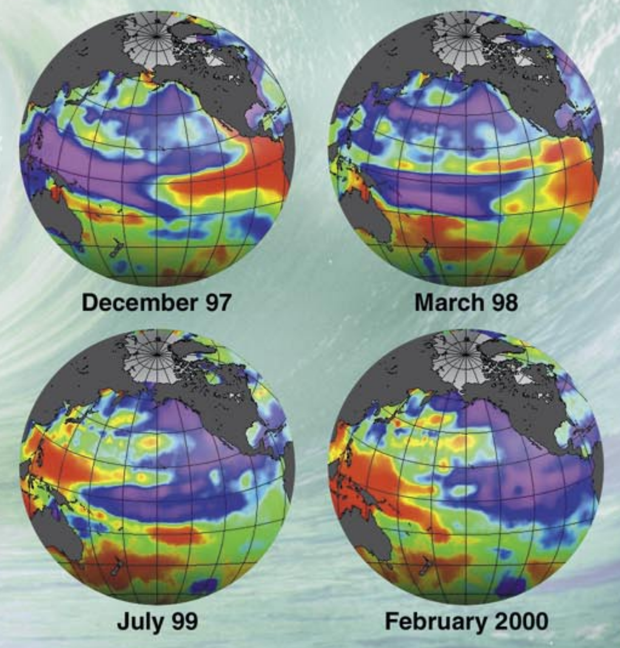
The sea level in the eastern Indian ocean as revealed by the TOPEX/POSEIDON and ERS-2 altimeters during the TIP 2000 campaign in September 2000. The colours show the rise in sea level, from -30 cm (in blue) to +30 cm (in red); the solid line shows the track of the R/V ship, Marion Dufresne.

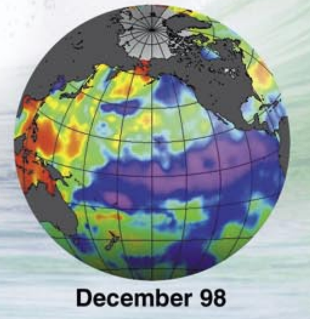
longer in contact with the atmosphere, its temperature and salinity remain constant, except in regions of mixing. The stability of these two parameters, as well as the distribution of other trace elements (nutrients salts, freons, tritium, thorium or neodymium) enable us to reconstruct the trajectory, history and age of water masses. Coupling altimetry with chemical tracers is a powerful tool for understanding the circulation of an ocean region. We adopted this strategy for the TIP 2000 cruise to understand the origin of altimetric sea level anomalies in the eastern Indian Ocean. The first results show that the positive sea level anomalies are related to water masses coming from Indonesia.

El Niño and climate

On seasonal to interannual time scales, it is now accepted that disturbances of our planet's climate are mainly due to interactions between the tropical oceans and the global atmosphere, and more particularly to the El Niño-Southern Oscillation phenomenon (ENSO) in the tropical Pacific ocean. Given the high thermal inertia of sea water as compared to the atmosphere, the tropical Pacific ocean is the memory of the ENSO system, which can thus be predicted six months to a year in advance. Intensive use of satellite altimetry has allowed a breakthrough in monitoring and understanding ENSO. The "El Niño of the Century" in 1997-98 and its transition to the cold phase La Niña were detected perfectly by TOPEX/POSEIDON. In the future, the series of Jason satellites will ensure a continued supply of altimetric measurements, which will increase our understanding of ENSO and improve its forecast. Humankind will thus be better able to anticipate and reduce the impact of climatic disturbances related to ENSO.







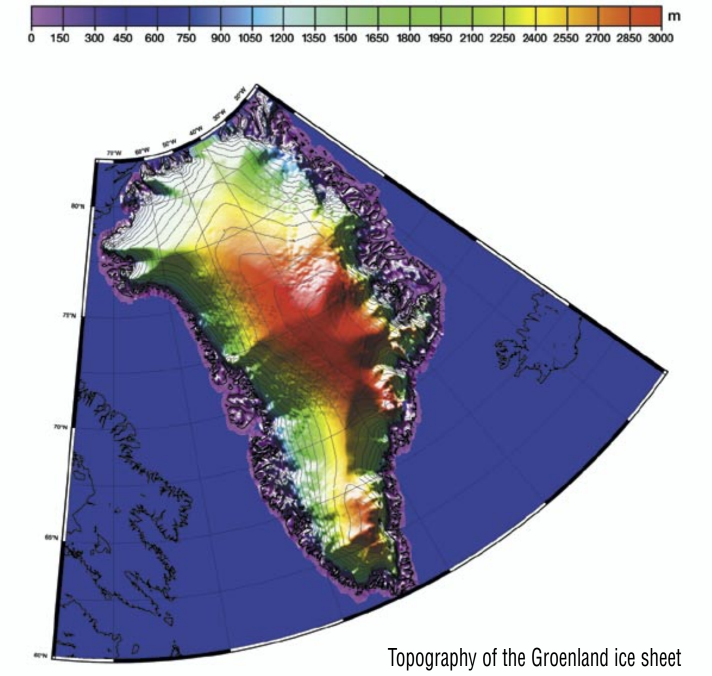
El Niño and La Niña seen by TOPEX/POSEIDON

Understanding the cryosphere

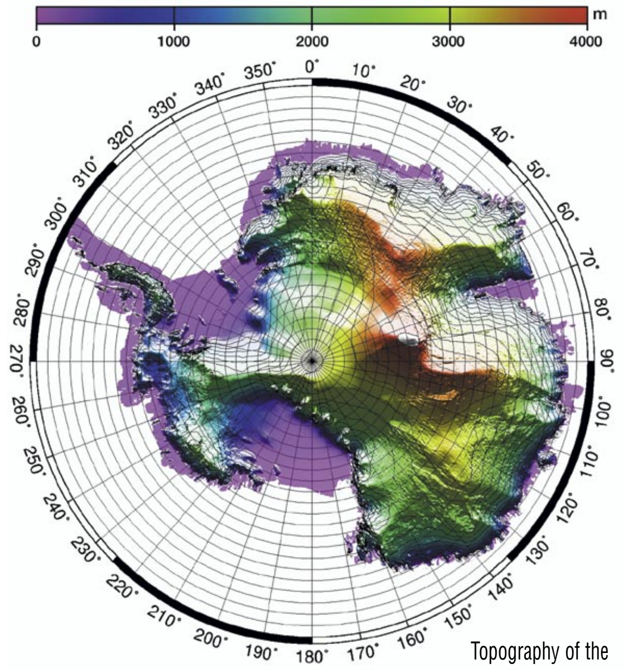
The cryosphere

Altimetry has enabled an unprecedented breakthrough in mapping of the topography of the Antarctic and Greenland ice-caps. The accuracy of height measurements of these regions has decreased from within 100 metres to less than 1 metre.

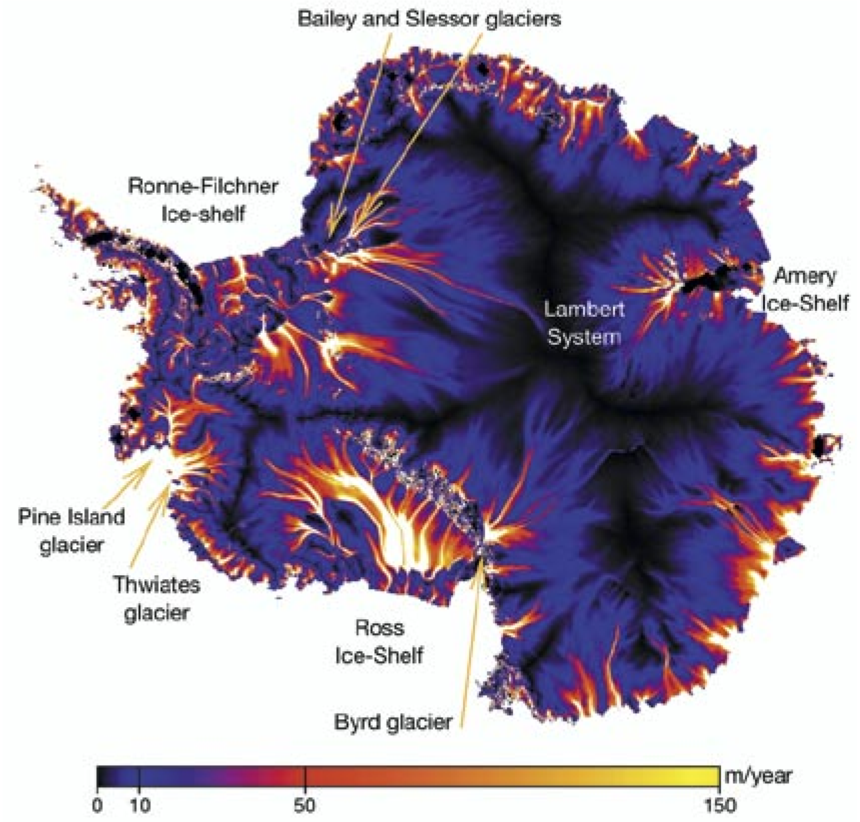
The topography thus identified has revealed numerous details, among others the flow structure shown in the figure below, in which we can see a network of ice rivers supplying glaciers on the edge of the polar ice-cap. In the long term, repeated monitoring of the topography by ERS-1, ERS-2 and ENVISAT will make it possible to evaluate the contribution of polar ice-caps to variations in the global mean sea level.



Topography of the Greenland ice sheet



Topography of the Antarctica ice sheet

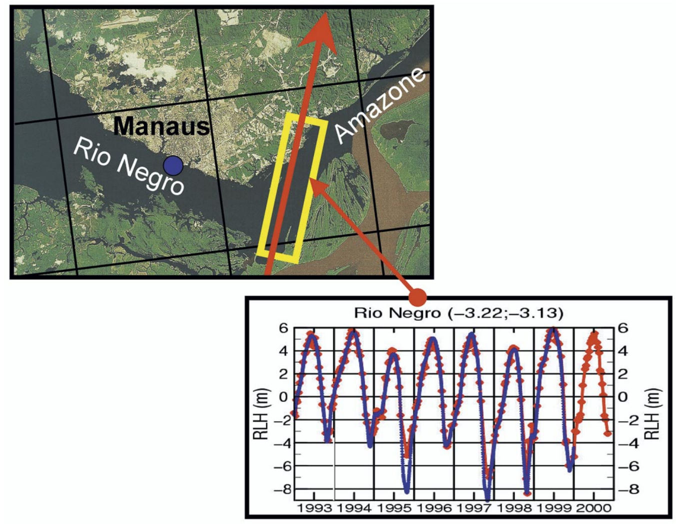


Speed of flow of ice in Antarctica

Understanding rivers and lakes

Rivers and lakes

A new application of satellite altimetry has turned out to be quite promising. It consists of measuring the temporal fluctuations of free water reservoirs on the continents (lakes, inland seas, rivers, flood plains). Such fluctuations are caused by regional variations in the hydrological cycle (rainfall, evaporation, ground run-off, construction of dams, etc.) which are either due to changes in the climate or are caused by human beings. Satellite data from TOPEX/POSEIDON, ERS-1 and ERS-2 enable us to monitor fluctuations in the level of the Caspian and Aral seas and large continental lakes. In the world's largest river basins it is possible to detect temporary and permanent flood plains and to measure variations in the level of rivers and their tributaries.
In addition to the possibilities offered by radar altimetry for rivers and lakes, it will soon be possible to measure fluctuations in water content in the soil and underground aquifers, as well as snow thickness, as part of the future space gravimetry missions (GRACE and GOCE). The study of continental water resources and their temporal evolution in response to climatic variability has now become an important application of space observation.



An example of this application used for the Amazon basin. The left hand side of the figure shows the flight track of TOPEX/POSEIDON over the Amazon River (red line) near to the city of Manaus. On the right hand side we see the temporal evolution in water levels measured by TOPEX/POSEIDON (in red). As a comparison, the water levels given by in situ hydrographic measurements taken nearby are given in blue.

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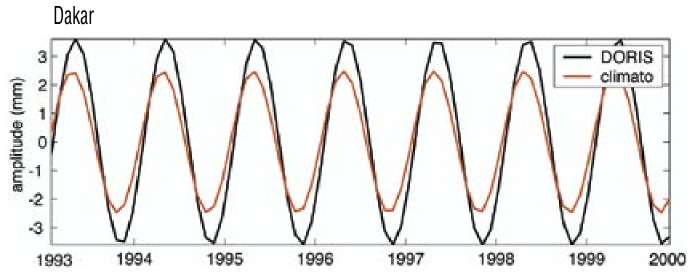
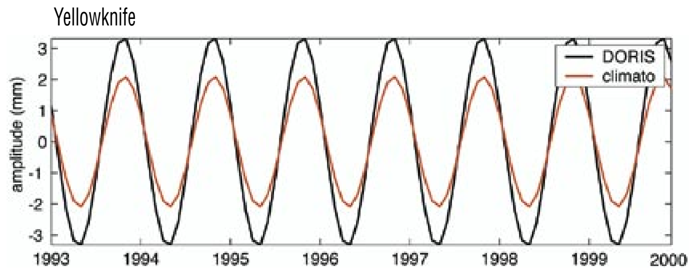
Understanding the deformations in the Earth's crust

Doris measures the weight of the seasons

The Earth can be considered as an elastic body which reacts to pressure applied on its surface by changing its shape. These radial deformations, of the order of a few millimetres, are due to the weight of the atmosphere, of the snow pack, soil moisture and ocean water masses. These deformations can be detected either by analysing air and water pressure fields expressed in terms of vertical deformations of the Earth's crust or directly measured by space geodesy. The DORIS system is currently being used for this purpose. It is one of the three orbit determination systems on board TOPEX/POSEIDON and will soon be carried by Jason-1 and Envisat as well. It has also been installed on the Spot-2, Spot-3 and Spot-4 Earth observation satellites and will soon be installed on Spot 5. Recent analysis has shown that there is a good match between the seasonal vertical deformations deduced from air and water pressure fields and the vertical movements of the DORIS beacons. The very high accuracy of the system will, in the future, make it possible to investigate deformations at other time scales than the seasonal and should help to improve models of continental hydrology.





Amplitude of vertical deformations of the Earth's crust due to variations in atmospheric pressure, snow cover, soil humidity and the distribution of ocean water masses, deduced from models and observations of each of these parameters.
Comparison between vertical deformations of the crust given by cumulated observation/modelling data (in red) and direct observations obtained by the DORIS system (in black) near two DORIS stations (Dakar, Senegal and Yellowknife, Canada).

For more information:
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