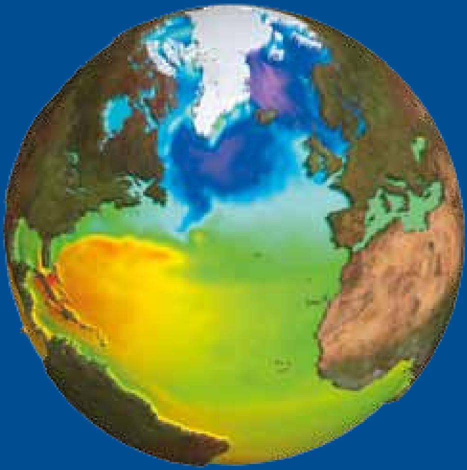
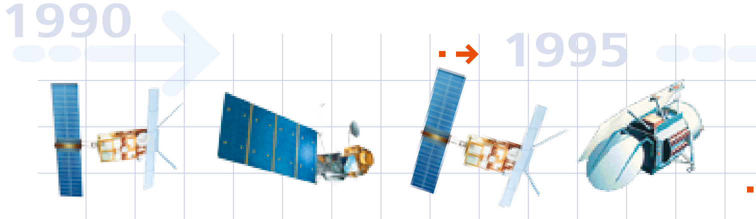


The ocean covers 70% of the Earth's surface, contains 96% of all its liquid water, and can absorb a thousand times more heat than the atmosphere, yet we are only just beginning to uncover its secrets. Satellites are vital to learning more, as they enable the ocean to be observed continuously, anywhere, even over the roughest of seas.

Among the various satellite techniques used for observing the oceans, altimetry is particularly important. Altimetry measurements of sea-surface height reflect what is happening from the ocean bottom to its surface: ocean currents, temperature and salinity variations, tides, etc. They also enable wave height and wind speed to be determined. In addition, altimetry applications broadened their reach beyond the oceans, to include lakes, rivers, ice and even land surfaces.

CNES contributes a great deal to ocean observation activities either by developing remote sensing systems (satellites, instruments) or by making data available to scientists. As far as altimetry is concerned, station keeping operations, data quality assurance, product development and distribution are handled by the CNES Altimetry and Precise Location Department (the "Service d'Altimétrie et de Localisation Précise" or SALP)

Altimetry



ERS-1, ESA
1991-1996

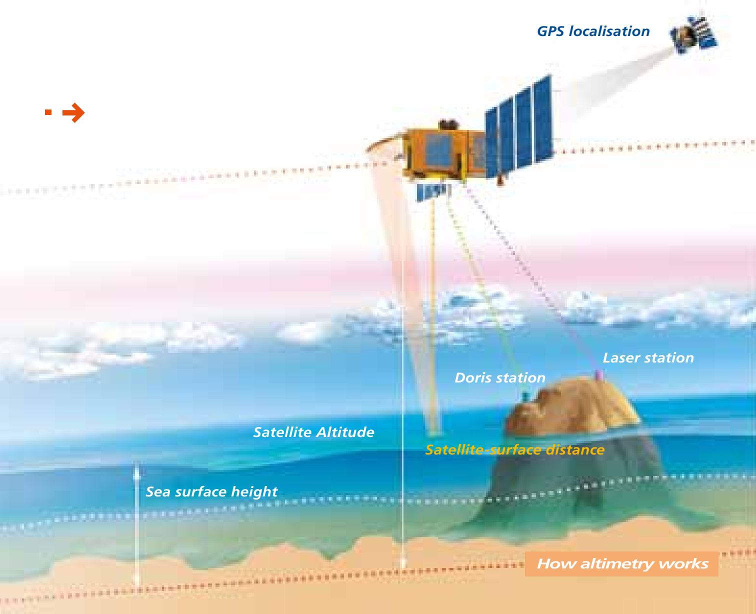
Topex/Poséidon, NASA/CNES, 1992-2006

ERS-2, ESA
1995-2011

GFO, US NAVY/ **NOAA** 1998-2008

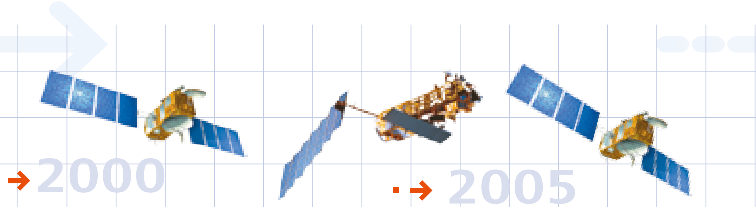
Satellite altimetry is a technique for observing the Earth and its oceans from Space. The principle is to precisely measure a satellite's altitude and then the distance between the satellite and the target surface. By calculating the difference between the two, 'sea-surface height' is obtained. This sea-surface height, and in particular any variations, can be used to deduce a vast amount of information about the ocean and its movements. With systems such as Doris and GPS, which measure the satellite's position extremely accurately, sea-surface height can be calculated to within just a few centimetres.

Altimetry can also determine wave height and wind speed on the ocean, as well as surface height for lakes and rivers, information about the Earth's gravity field, sea ice and polar ice cap topography.



How altimetry works

Doris

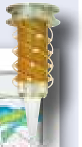


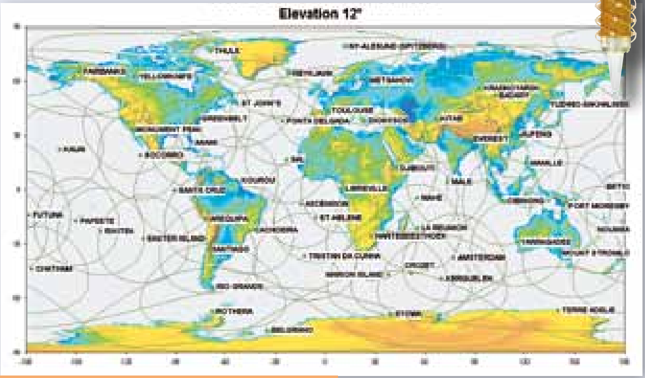
Jason-1, CNES/NASA 2001-

Envisat, ESA 2002-

Jason-2, CNES/EUMETSAT/NASA/NOAA, 2008-

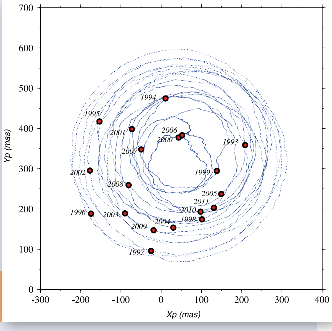
Doris is the leading system for calculating the altitude of altimetry satellites to within a few centimetres. It is also a terrestrial positioning system which can be used to rapidly determine the position (longitude, latitude and altitude) of any point on the Earth's surface, to within a few centimetres. This lends itself to numerous geodesy and geophysics applications, such as studies of the movements of tectonic plates or the Earth's poles.



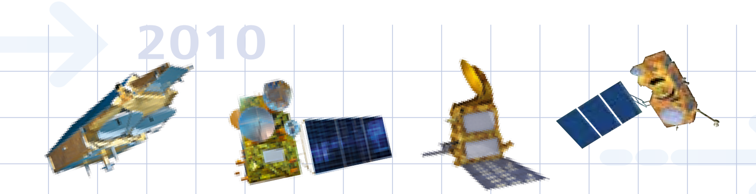


The network of Doris ground stations.

The Doris system was designed and developed by CNES, the IGN (the French National Geographical Institute) and the GRGS (the Space Geodesy Research Group). Its instruments are flying on the Spot 4 and 5 satellites and will also be carried by their successors, the Pleiades satellites. Since the Topex/Poseidon mission ended, Doris has been a central component of current and future altimetry missions, with the Jason-1 to 3, Envisat, Cryosat-2, HY-2A, Saral, Sentinel-3, SWOT and Jason-CS satellites.



Movements of the pole tracked by Doris.



Cryosat-2, ESA
2010-

HY-2A, CNSA
2011

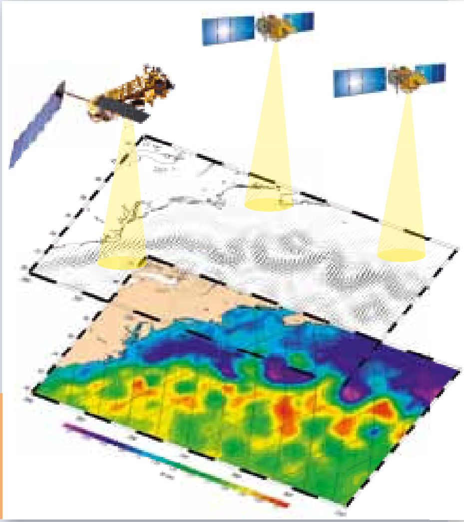
Saral, CNES/
ISRO, 2012

Sentinel 3A & 3B,
ESA, 2013-2015

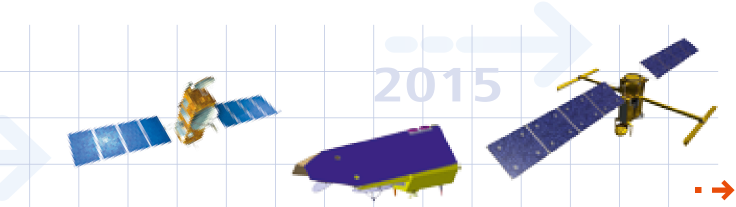
Since 1992, a series of high-precision altimetry satellites have been in continuous operation: first Topex/Poseidon, and then Jason-1, followed by Jason-2. This continuity has made it possible to observe phenomena occurring over fairly long periods, such as the rise in mean sea level, or recurring events such as El Niño. This coverage was, is or will be complemented by ERS-1 & 2 then Envisat, GFO, Cryosat-2, Saral... The fact that there are several altimetry satellites in operation (the barest minimum being two) means that we can see more details, at more frequent intervals.

Because data from altimetry satellites can be made available very rapidly, it can be used in ocean, meteorological or climate forecast models, which, in order to be as reliable as possible, require a large quantity of frequently-updated measurements.

However, altimetry satellites are not the only tools used to observe the oceans. Other techniques provide complementary perspectives: these include other satellite measurements (such as temperature, water colour, surface wind speeds and salinity) and in situ observations (sometimes relayed by satellites, using systems such as Argos).



The combined use of measurements obtained from several satellites improves monitoring of currents such as the Gulf Stream



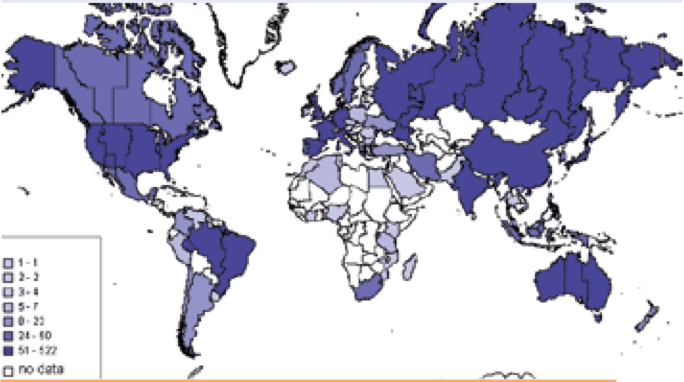
Jason-3, CNES/EUMETSAT/ **NASA/NOAA,** 2014

Jason-CS, ESA/NOAA/ EUMETSAT/CNES?, 2017

Swot, NASA/CNES 2019

Designing, manufacturing and launching satellites requires highly advanced skills and resources. The French Space agency (CNES) has been involved in altimetry since the early 1980s. It participated or participates to the Topex/Poseidon, Jason-1 to 3 and Swot altimetry mission designs. It designed the Doris system, the Poseidon (carried on Topex/Poseidon, Jason-1, -2 and -3) and AltiKa altimeter. CNES expertise is also called upon by ESA for the Envisat, Sentinel-3 or Jason-CS missions.

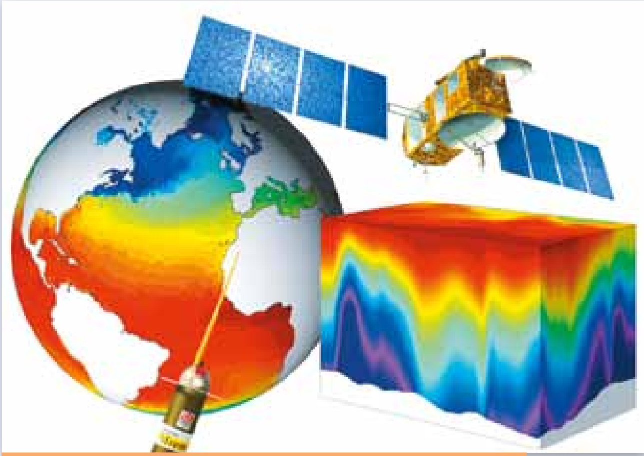
Once a satellite has been launched, it is still only the beginning of the story. Measurements must be retrieved and then complemented with others, to develop complete, practical data products. Their quality must be ascertained. Finally, they have to be disseminated, and must meet user requirements. Once again, CNES expertise is called upon, through its altimetry and precise location service (SALP), supported by its subsidiary CLS, for the preparation, integration, validation, distribution, archival, and full exploitation of the data. More than two thousand teams throughout the world now receive and use altimetry data for an ever-widening range of applications.



More than two thousand teams across the world use altimetry data produced by CNES

Mercator, forecasting the ocean

Mercator Ocean was created to achieve an ambitious objective of describing and forecasting the global ocean in real time and at any moment, both on the surface and at depth. Achieving this requires scientific know-how, observations (from satellites, of course, but also in situ), and immensely powerful models and computers. Thanks to the combined forces of five French agencies (CNRS, IFREMER, IRD, Meteo France and SHOM), this project is now operating at the European level, and has become the heart of a European operational oceanography centre.



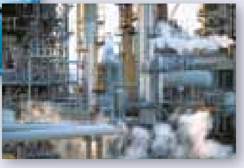
Ocean models, such as Mercator, integrate altimetry data and other measurements, in particular those obtained in situ

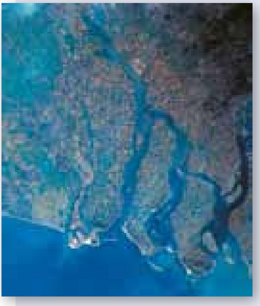
Since many centres and organisations are now integrating the forecasts in their projects, new applications for the ocean forecasts generated by Mercator Ocean are being developed all the time. They include protection of the environment, planning shipping routes, safety at sea, climate forecasts, and sustainable exploitation and stewardship of ocean resources, particularly those near the coast.

Mercator Ocean is a key participant in every international, operational oceanography project or programme, such as GODAE (Global Ocean Data Assimilation Experiment), an international experiment which is unifying and validating all the existing ocean forecasting projects to enable them to be compared. Not to be outdone, in the context of the GMES programme (Global Monitoring for Environment and Security), Europe is setting up an oceanography service with the MyOcean project.

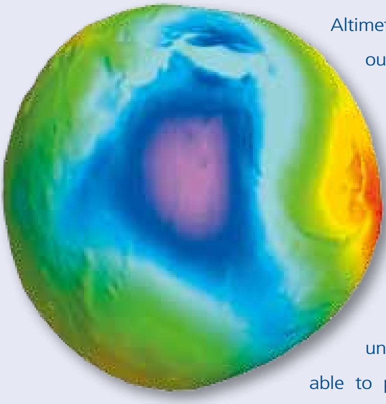
An ocean of applications

From waves to major currents, from changes occurring over a week to those over a decade, over ocean, ice or lakes, from an amplitude of just one millimetre to hundreds of metres . . . the phenomena observed by altimetry satellites are anything but uniform! Being able to observe such a diversity of events is one of altimetry's greatest strengths, enabling a large number of applications, whether related to global ocean circulation, phenomena such as El Niño in which the ocean and the atmosphere influence each other, or to eddies and tides.





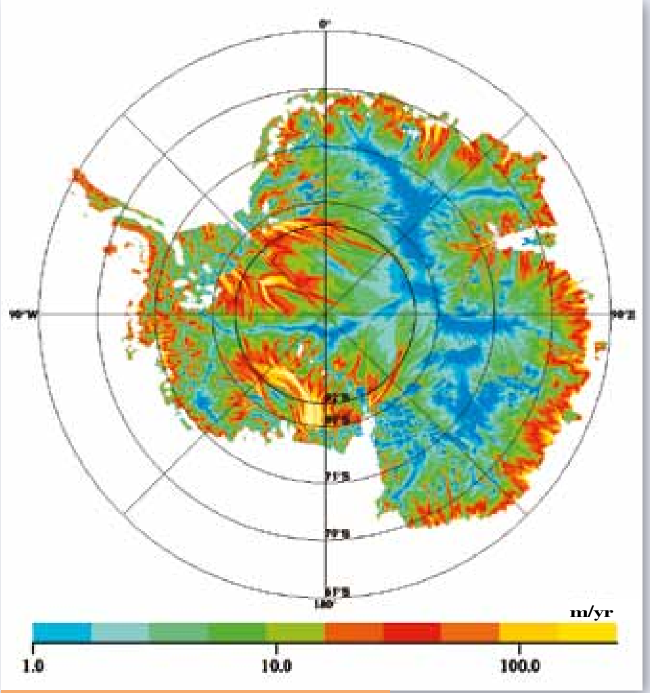
Research



Altimetry is primarily used to improve our knowledge of the Earth, and its oceans in particular. All applications are based on this fundamental research, and all benefit from advances made in this field.

Whether for learning more about the major currents, understanding the climate, being able to precisely measure the Earth's gravity field, understanding turbulent phenomena in the oceans, or determining the amplitude of tides in the middle of the sea, altimetry satellites can provide essential information on all of these subjects.

Studies of polar ice caps have also benefited from altimetry measurements. The Cryosat-2 satellite was specially designed for this purpose,



Ice flow rates in the Antarctic, determined from ERS-1 topography measurements.

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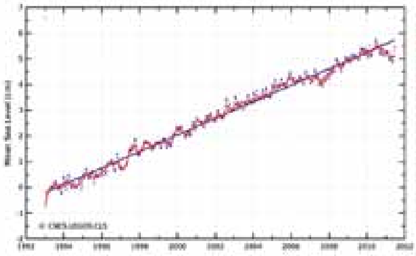
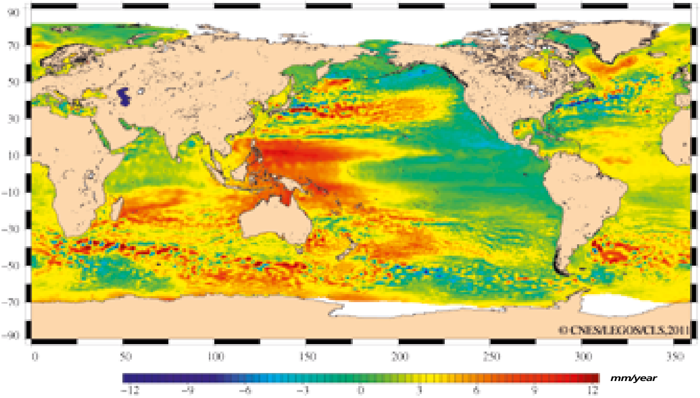
The level is rising

The indicators are proof that for at least the last hundred years the mean global level of the oceans has been rising. This increase in water level is now threatening coastal areas, home to a significant proportion of the Earth's population.


Mean sea level determined by altimeters: it is increasing by around 3 mm per year.

Beginning with a few isolated measurements around 1900, we have progressed to global coverage with altimetry satellites, which now provide us with a precise estimate of this rise. With nearly twenty years' worth of measurements, we are even able to confirm the trend and anticipate the consequences.

There are several possible 'suspects' which may be responsible for the mean rise in sea level: an increase in the temperature of the water, which dilates as it warms, the thawing of mountain glaciers and polar ice caps in Greenland and Antarctica, as well as melting permafrost. Changes to the amount of rainfall and evaporation also play a part, as well as runoff and inland water reserves, mainly owing to human activity such as dam construction and irrigation.

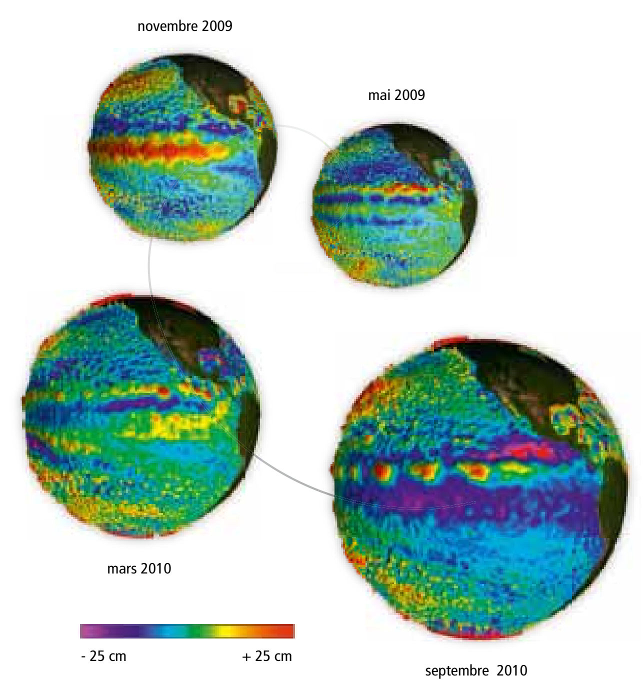


Variations in sea level since 1992. The increase in sea level is uneven, in some places it may rise by as much as 1 cm per year.

Climate, an exchange between air and water

What will the weather be like next summer? Although we will probably never be able to answer this question precisely, we can at least hope to have an idea of whether it will be warmer or cooler, dryer or wetter than usual, provided that we take the ocean and also the atmosphere into account.

The ocean is an enormous heat reservoir which has a major influence on the climate. Altimetry, which enables ocean circulation and its variations to be observed, is vital to climate forecasting.



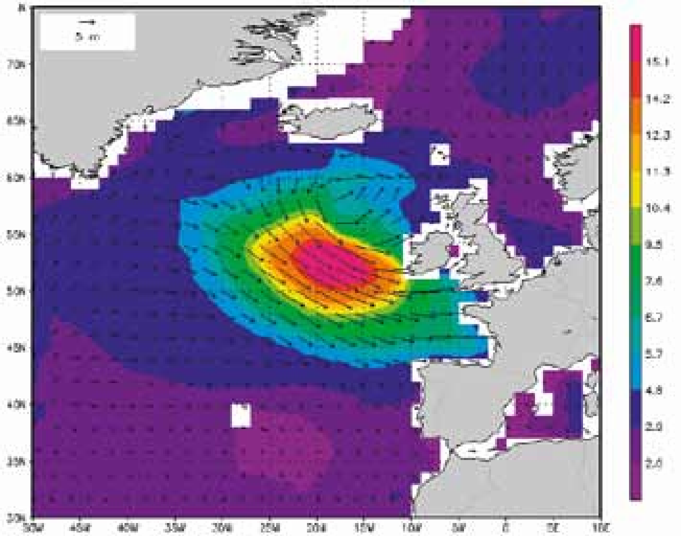
El Niño, a catastrophic climate phenomenon, and its reverse phase, La Niña were monitored in 2009-2010 using altimetry satellites among others.

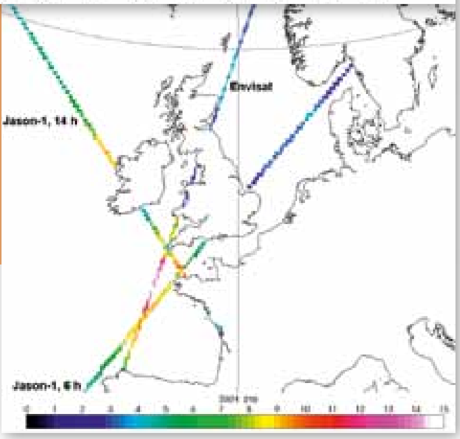
Information about ocean movements, provided by altimetry satellites, can be used by meteorological agencies to forecast the prevailing climate of coming seasons six months in advance. As a result, the planting of certain crops can be encouraged, consolidation or irrigation works can be undertaken, etc. Extreme phenomena such as El Niño (particularly in 1997-98), or more regular events such as the monsoons, make this measure especially important for the countries affected.

Winds and waves

For seafarers, as well as anyone planning coastal installations or living along the coastline, very high waves are a potential danger that cannot be ignored. Altimetry can be used to determine trends and estimate maximum wave heights. It can also measure wave height in the open sea, data which can be integrated rapidly in wave-height forecasting models used by Meteo France and ECMWF*.

These wave height forecasts are also broadcast to sailors, either to ensure their safety, or during search and rescue operations.





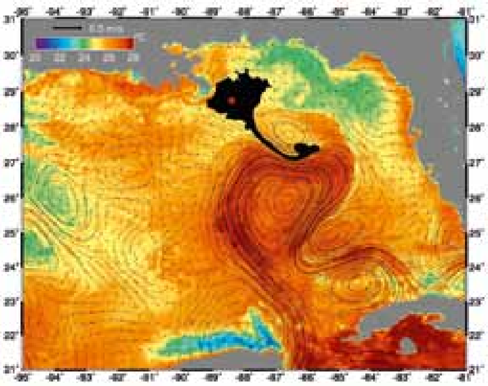
In December 2007, a strong storm hit North-East Atlantic coasts, especially Ireland, Great Britain and Brittany. Meteo France wave model forecasted it accurately (2007/12/09 at 12h00). Several altimetry satellites also measured the very high waves (about 18 m).

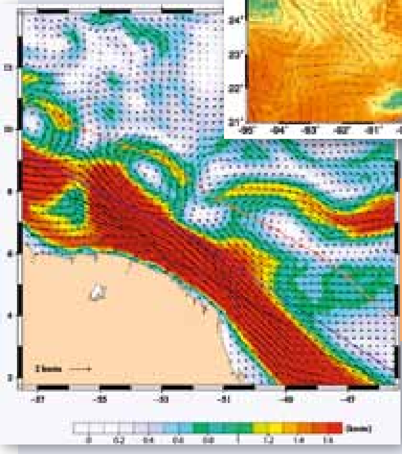
**ECMWF: European Centre for Medium-Range Weather Forecasts*

The environment and safety at sea

The sea is a hostile environment at times, frequented by a host of different people and cargoes, some with the potential to cause pollution. Information provided by satellites, either routinely or in the event of a disaster, can help protect both seafarers and the environment. For example, it can enable authorities to sound an alert, to make decisions and to take preventive measures.

Oil slick from the Deep Horizon platform (in black) and ocean currents computed from altimetry over the Gulf of Mexico.





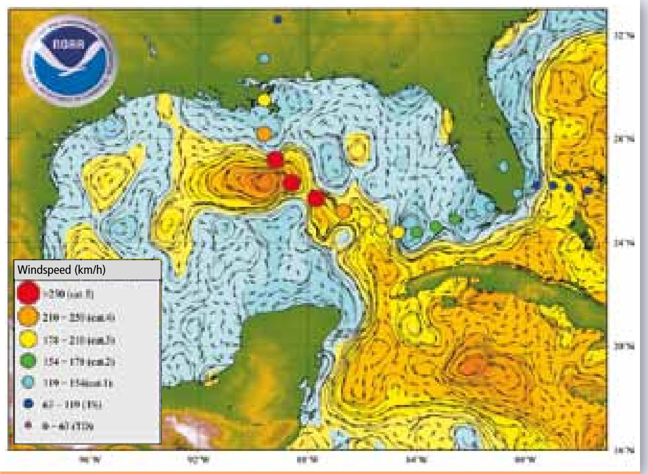
Using ocean models like Mercator, best routes (in blue) are proposed to shipping companies and their captains. Fuel saving can go up to 8% from the a priori route (in black)

When integrated in the models, sea-surface height measurements obtained with altimetry can help predict which way pollutants are likely to drift or whether toxic algae are likely to proliferate. Moreover, the use of ocean current forecasts to plan shipping routes can enable ships to save valuable time and fuel. Furthermore, in off-shore exploration and production, a knowledge of the currents is important when designing platform structures or undertaking operations at sea, as forecasts are needed to decide whether or not to carry out certain production or maintenance activities. Oceanographers also find this information valuable when undertaking in situ measurement campaigns.

Cyclones

Cyclones are among the most frequently occurring natural disasters in warm seas. Every year they cause considerable devastation.

They are essentially marine monsters, requiring a large expanse of warm water at least 26°C in temperature and 50 m in depth, before they can develop. Over land they lose their strength and peter out, but not before causing some damage. Such phenomena must be monitored closely in order to be able to alert the populations involved. Nothing is better-suited to this than satellites, with their birds-eye view. Wind speed at the sea surface, clouds, wave height, precipitation and ocean surface temperature, can all be measured by their instruments.

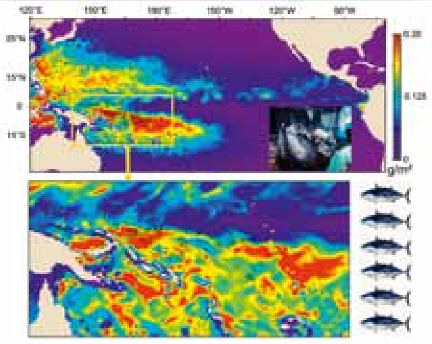


Trajectory and intensity of Hurricane Katrina (August 2005) and sea-surface heights as measured by altimetry: the hurricane increased in strength when it passed over the warm current found in the Gulf of Mexico.

Because heat in the ocean plays a major role in the formation and intensification of cyclones, eddies and warm and cold currents may modify a cyclone's trajectory and intensity. Altimetry contributes to cyclone forecasting as it improves our understanding of ocean circulation. Moreover, altimetry data on wave heights and wind speeds are used in wave forecasting models.

Biology and currents

Life in the ocean is fundamental to life on Earth. Phytoplankton in particular are major oxygen generators for the planet, much more so than the forests. Despite this, marine biodiversity is still largely unknown.

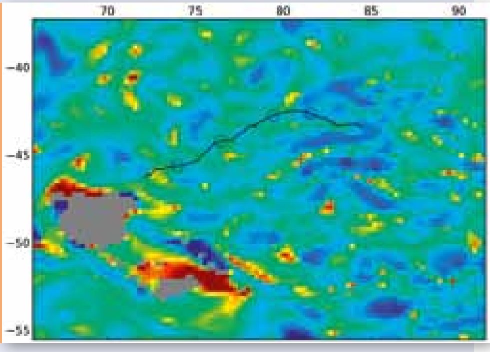


Simulation of the skipjack tuna biomass in the Pacific, used to estimate fishing (black circles, proportionate to captures) and environment impact. The model is based on ocean forecasting (Mercator Ocean), which uses satellite data.

The movements of the ocean, its temperature and salinity, etc, affect the life it harbours. From the smallest plant organisms (phytoplankton) to the largest whales, not forgetting animals such as fish and marine turtles, all are affected by the physical conditions of their environment.

Although measuring 'ocean colour' by satellite is the best technique for determining the quantity of phytoplankton, sea-surface height and surface temperature measurements complement and validate these data. They are also essential for predicting sudden proliferations of such plankton, and thus estimating the movements of the fauna which feed upon them, either directly or indirectly.

Marine ecosystem models with the available biological and physical information as input, help us better understand marine biology, marine animal behaviour and therefore manage ocean resources and biodiversity.

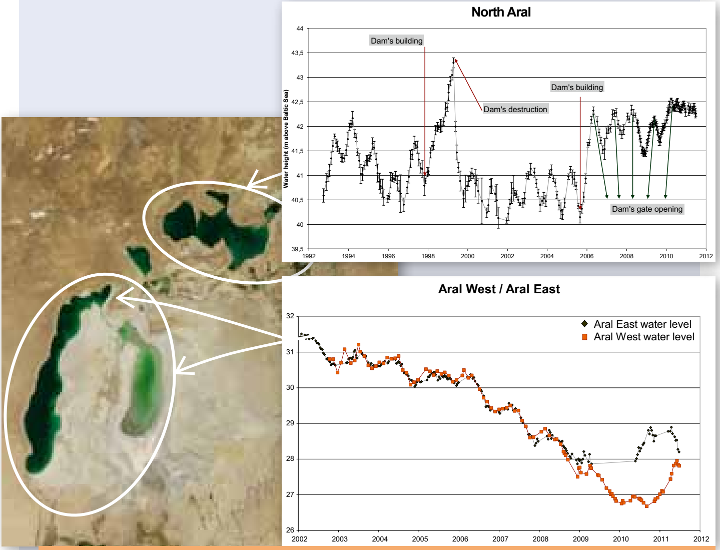


Tracking of an elephant seal. After leaving Kerguelen Island (Indian Ocean), it dives between 400 and 800 m depth (black circles) to hunt for its prey, plentiful there. Biomass of these preys is simulated by a model using satellite data (ocean color) and ocean forecasts by Mercator Ocean.

Lakes, rivers and landlocked seas

Water is one of the Earth's most vital resources. A knowledge of the level of lakes and reservoirs is therefore essential, in order to optimise their use. However, the necessary monitoring cannot always be performed in situ, for reasons such as a lack of resources or inaccessibility.

Initially designed to be used for the oceans, satellite altimetry was also found to be effective for measuring height variations on smaller surfaces such as lakes and even rivers. A large number of inland water bodies and rivers are therefore possible to monitor, like the great African and American lakes, the Aral Sea, the Amazon and the Ganges rivers. High mountain lakes which are fed by glacier runoff in the Andes or the Himalayas are also monitored, to mitigate consequences downstream of any overflow.

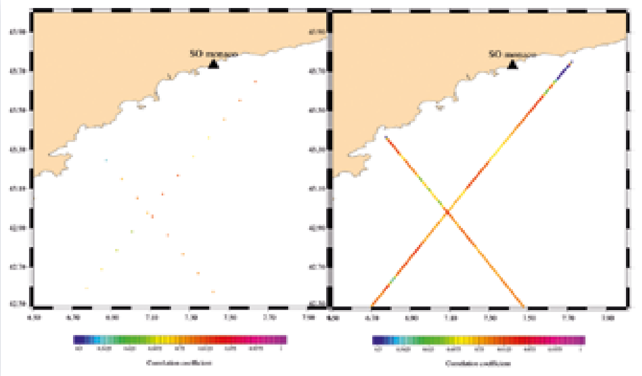


The level of the Aral Sea has been falling since the 1960s, as water from the rivers feeding it has been diverted for irrigation. It divided into two basins, then four. The North Aral Sea has since stabilised due to the construction of a dam. The South-East basin, being very shallow, can fill up when it is raining.

In addition, the occurrence of diseases such as malaria is linked to the presence of flooded areas. Altimetry data for such wetlands can be integrated into systems for monitoring epidemiological conditions in developing countries.

The future SWOT (Surface Water and Ocean Topography) altimetry mission will enable global observation at high resolution of these continental waters.

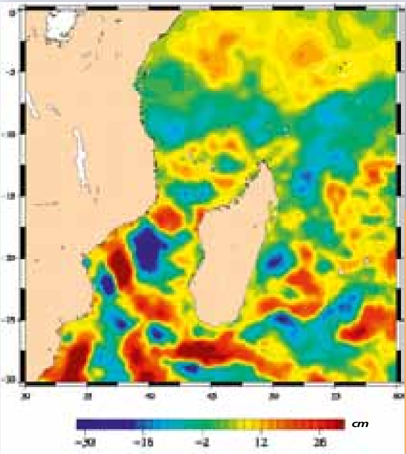
Closer to the shoreline



New datasets enable to have more data (right) with respect to classical, open-ocean datasets (left). They also match better the tide gauge measurements (red/purple is the better match)

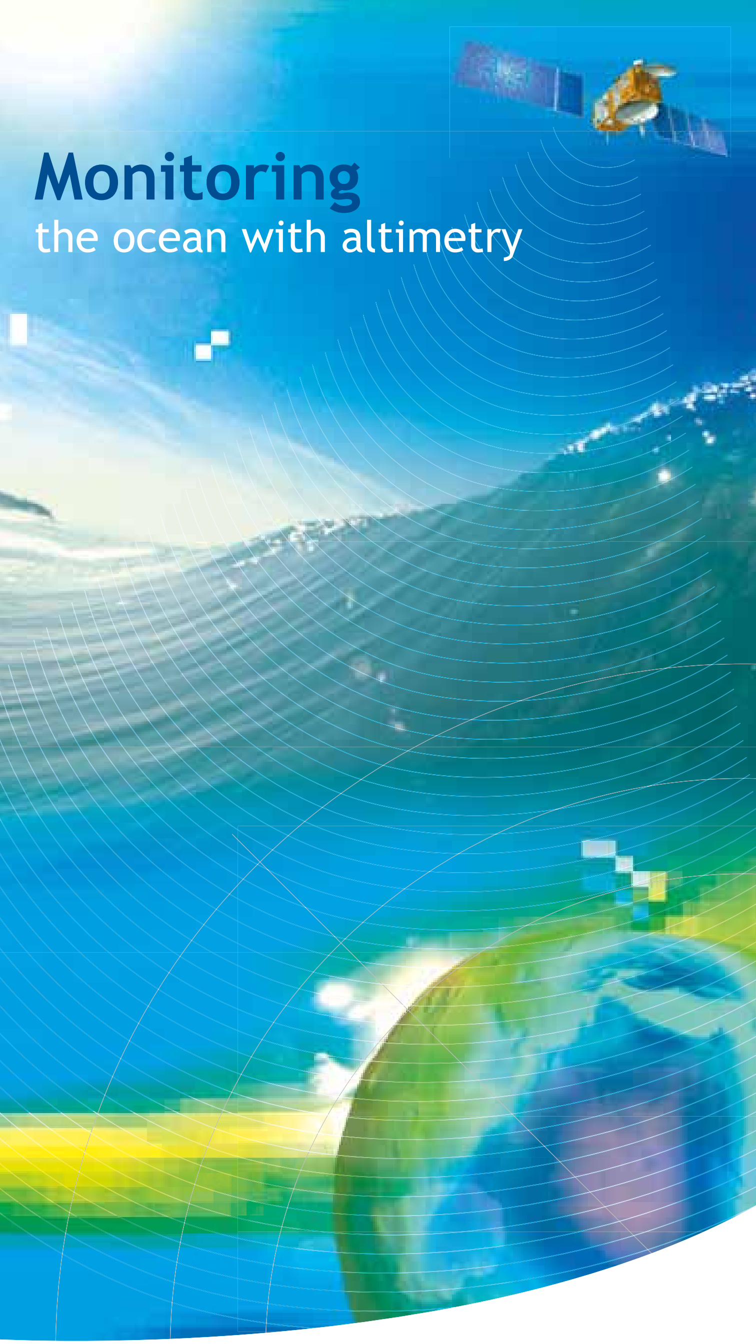
Most people's interest in the sea only extends to the beach (especially in summer) or the water close to the shore. Individual regions or seas are also of interest. The Mediterranean in particular has a very irregular coastline and comprises numerous smaller seas. It is especially busy, with heavily populated shores and a fragile ecosystem. The Black Sea and the Gulf of Mexico are also being closely studied.

Aquaculture, infrastructure planning (ports, dykes, etc) and protection of the shoreline can all benefit from coastal ocean models. These models require measurement data in order to make them more representative. Altimetry supplies these data for the open ocean, while the altimetry payload carried by Jason-2 is able to scrutinize conditions closer to the coasts.



The Mozambique Channel, between Africa and Madagascar Island, is one of the key area in the ocean circulation. To have a finer view on these currents, a new altimetry dataset was designed Studies to improve altimetry data in both resolution and coastal areas are ongoing.

Monitoring
the ocean with altimetry



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