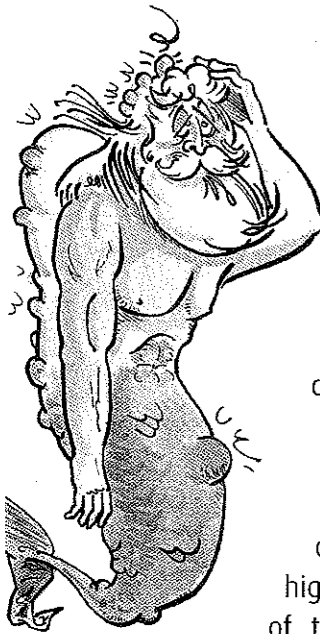
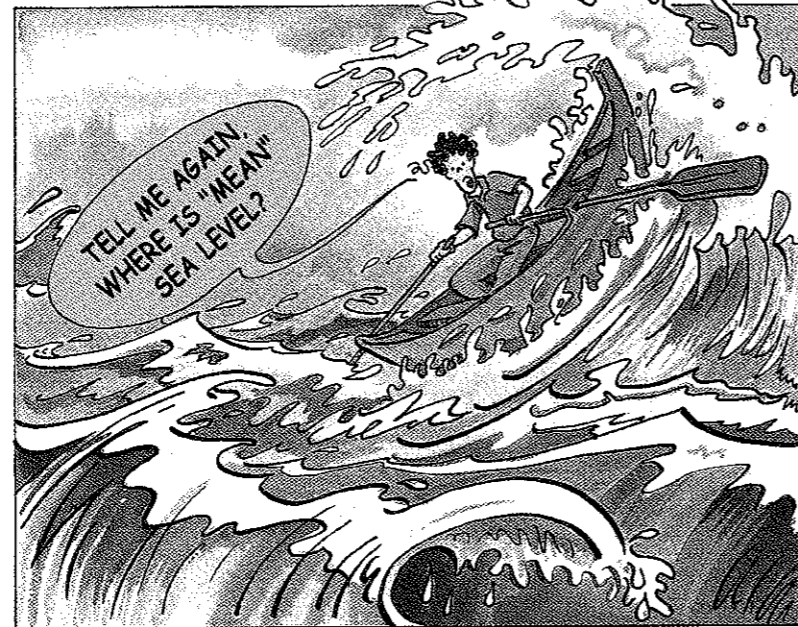


The surface of the oceans is bumpy!



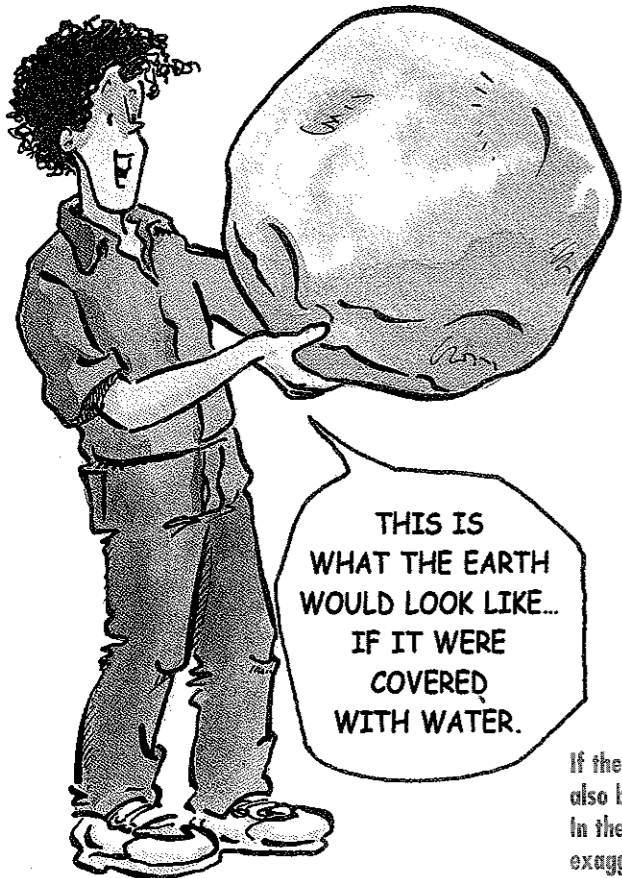
• The Earth is not a perfect sphere. Among other things, it's a little flatter at the poles and a little fatter at the equator.

• Moreover, the Earth's crust (whether it's on dry land or under water) is not smooth. It is made up of mountains and valleys that can be several kilometers high or deep. The composition of the subsoil is not uniform, either. In some places the material is denser, and in others there are deep gorges. That means that gravity varies from one region to another.



On the face of it, it might seem impossible to take very accurate measurements of levels in an environment as stormy as the ocean.

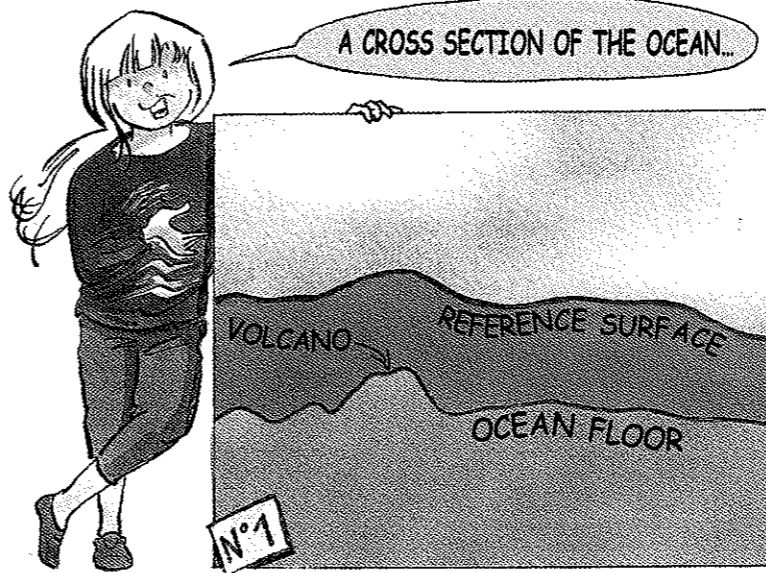
However, scientists have been able to map the surface of the ocean, to define stable reference levels (see pages 17 and 30) and to monitor their variations over time.



Thus we can observe that on a small scale, between 10 and 500 kilometers, the surface of the ocean "copies" the mountains and valleys of the ocean floor, although it smoothes them out to some extent. The surface of the water has a large dome above an underwater volcano (where the excess of matter causes an increase in the gravity) and depressions above large underwater gorges (where the absence of material creates a decrease in the gravity).

Under these conditions, the surface of the oceans cannot be smooth like the surface of a mirror. The ocean is bumpy, covered with bumps and depressions that can reach heights – or depths – of up to 100 meters over a distance of several thousand kilometers.

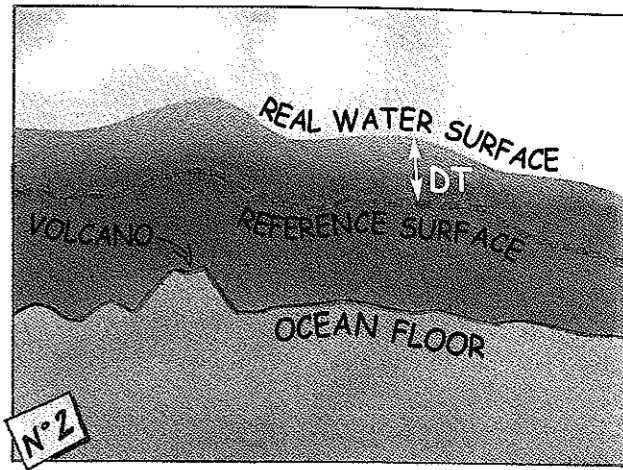
If the surface of the ocean is "bumpy", it's because the Earth's crust is also bumpy. In the drawing, the size of the bumps and depressions has been deliberately exaggerated.



... on an imaginary Earth that does not rotate around its polar axis.

The ocean would be at rest. The surface, which would be shaped only by the Earth's gravity – which varies from one area to another –, would be irregular but still. It could therefore be used as a reference to monitor the variations in the real level of the oceans.

Take a close look at the scale of the drawings. It has been estimated that an underwater volcano 1,000 meters high creates a bump only about 1 meter high on the surface. But because the "bump" is spread over several hundred kilometers, sailors can't see it.



... on the real Earth that rotates around its axis.

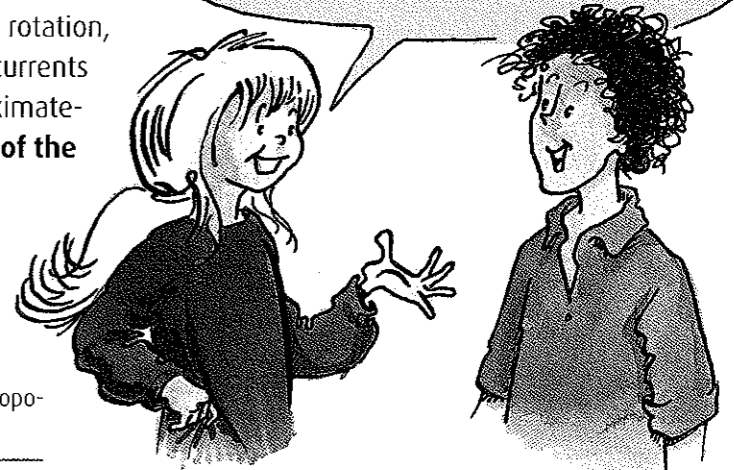
Obviously, the oceans are in motion. They circulate, driven by currents, whirlpools, tides and other forces. The water level is therefore not the same as the (still) surface illustrated in the first drawing. It is a series of wide domes and wide depressions above and below the reference surface.

The difference between the two, called *dynamic topography* (DT in the drawing), is variable but remains on the order of 1 meter.

• If the Earth did not rotate on its axis, if the atmosphere stopped moving, if the tides and the currents came to a standstill – hypothetically of course, because none of that is ever going to happen –, the surface of the oceans would still be bumpy, but it could be used as a reference surface because it would have stopped moving.

But the Earth rotates around its axis, and this rotation, along with the tides, the whirlpools and the ocean currents change this reference level by a small amount (approximately 1 meter), which is called **the dynamic topography* of the oceans.**

IT'S THIS LAYER OF SURFACE WATER, THE DYNAMIC TOPOGRAPHY, THAT THE TOPEX/POSEIDON SATELLITE MEASURES



* The adjective "dynamic" indicates that this uneven surface (or topography) is caused by the movement of the Earth, water and air.

TOPEX/Poseidon in action

The job of the *TOPEX/Poseidon* satellite is to take measurements and transmit them to the ground, where they are analyzed to **determine distances very accurately**.

An unusual orbit

The satellite has been placed in a rather unusual circular orbit 1,336 kilometers above the Earth and inclined at 66° above the equator. This choice is a compromise among various considerations: the performance of the instruments, the accuracy of the orbital calculation, the area to be observed (90% of the oceans), the rhythm of the tides, an orbit that regularly takes it over two sites (one in Italy and the other in the United States) that are used to calibrate the instruments at the beginning of the mission, etc.

Every ten days (every 9 days and 22 hours to be exact), after circling the Earth 127 times, the satellite passes over the same points (to within one kilometer), thereby describing a regular grid of tracks above the ground (see page 23) along which it travels. And then the cycle begins all over again.

The on-board instruments

To do its job, the satellite carries various instruments. In particular, as in the imaginary experiment described on page 15, several of these instruments measure the two distances required (**A** and **B** in the diagram on page 21).

– Three instruments, each independent of the others, indicate **the exact location of the satellite** when it took this or that measurement. There is a laser reflector (which measures a distance with reference to the ground stations), a GPS receiver (which measures a distance with reference to satellites) and a Doris receiver (which indicates the speed at which the satellite is moving toward or away from the ground stations).

By combining their results, **we get the exact position of the satellite** to within 3 centimeters, even though it is more than 1,300 kilometers above the Earth. (That corresponds to its distance from the reference ellipsoid, or the equivalent of **B** in the drawing.)

– **Two altimeters measure the distance between the satellite and the surface of the water (A in the diagram)**. These altimeters function like radar systems. They emit radio waves that are reflected by the water surface and return to the satellite. A very complex device measures the time it takes the signal to travel out and back, which gives us the distance we are looking for (because the speed of propagation of the signal is known, i.e. the speed of light, almost 300,000 kilometers per second). After numerous corrections (see sidebar), **the instantaneous accuracy of the distance measurement is 3 centimeters!**

The first altimeter, *TOPEX*, is American and operates 90% of the time. The second altimeter, *Poseidon*, is French. *Poseidon* was installed experimentally and operates the remaining 10% of the time (actually ten days in a row every one hundred days).

Since the satellite was launched, **one of these two altimeters has been in operation 24 hours a day**. The raw measurements are first stored on board and then transmitted to the ground by satellites. The data are then sent to two processing centers, one in Pasadena, California (USA), and the other in Toulouse (France).

After processing and formatting, all the data are distributed to a number of different users (see page 24).

Essential corrections

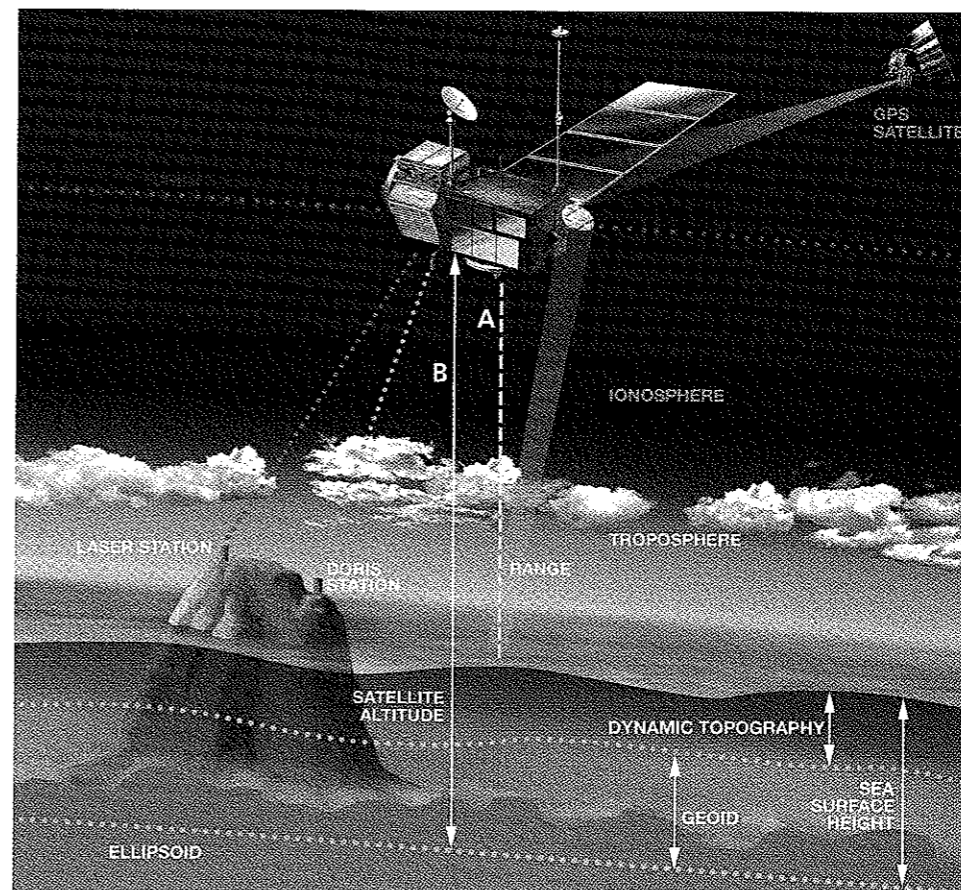
The radio waves emitted and then received by the instruments travel through a medium that is not a vacuum. For example, the moisture in the atmosphere slows them down and distorts the distance measurements.

Considering **the extreme accuracy required**, all potential forms of interference must be identified to evaluate their influence and to make the appropriate corrections. Some of these types of interference are:

- **the electrons** present in the upper atmosphere (the ionized part of which is called the ionosphere) in large quantities at altitudes of approximately 400 kilometers. They cause an error of 2 to 40 centimeters in the measurement of the distance between the ocean and the satellite;

- **the dry air of the atmosphere** – meteorologists measure the atmospheric pressure every day, which makes it possible to correct for this effect, which cause measurements to vary by as much as 2 meters;

- **the water vapor** in the atmosphere, the concentration of which is systematically measured by a radiometer specially installed on the satellite for this task. The correction varies from 5 to 40 centimeters.



The *TOPEX/Poseidon* satellite measures the height of the oceans compared to a reference surface or the center of the Earth.

The altimeter gives the distance **A** and the orbitography system gives the distance **B**. The difference between these two distances gives us the height we are looking for.

Mapping ocean currents

The measurements made by TOPEX/Poseidon are accurate enough that they can be used to draw maps of the ocean currents for the entire globe. But why are such maps useful and even necessary?

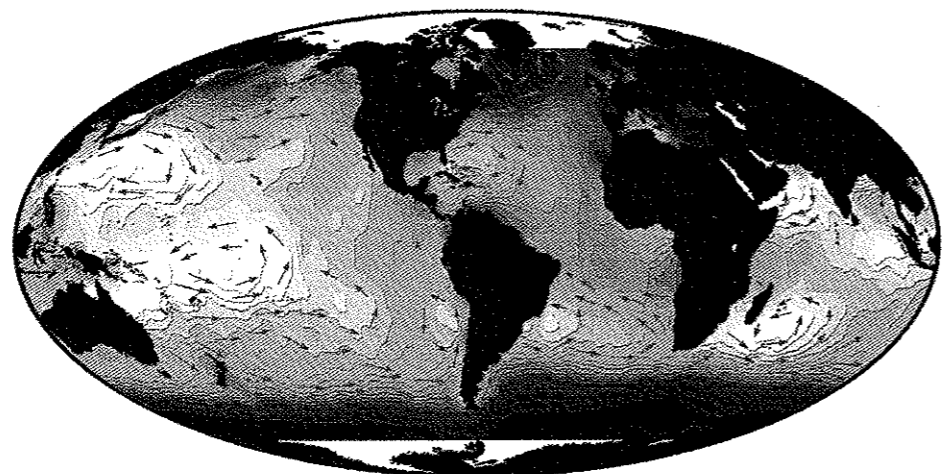
On one hand, they answer scientists's questions. They help us to understand the Earth's climate and environment.

On the other hand, they help us protect economic activity. Fifty percent of the world's population lives fewer than 100 kilometers from a coast, fishing supplies 10 to 15% of the world's protein requirements and 98% of world trade is by sea.

Thanks to satellites, we can map the major currents (and monitor their seasonal variations) such as the Gulf Stream, the Kuroshio current and the Antarctic Circumpolar Current, the most powerful in the world, which was previously practically impossible to observe.

Sailors also need to have forecasts of conditions at sea and currents, for fishing, navigation and naval operations.

Ocean currents do not flow like long, peaceful rivers in the oceans. We have detected innumerable instabilities, meanders and whirlpools. These whirlpools, which can be as wide as 100 or 200 kilometers in diameter, can "survive" for several weeks or even months. They are to the oceans what thunderstorms are to the atmosphere. Scientists have discovered their importance in the dissipation of energy in the currents, in the vertical mixing of ocean water and in the dispersion of dissolved substances.



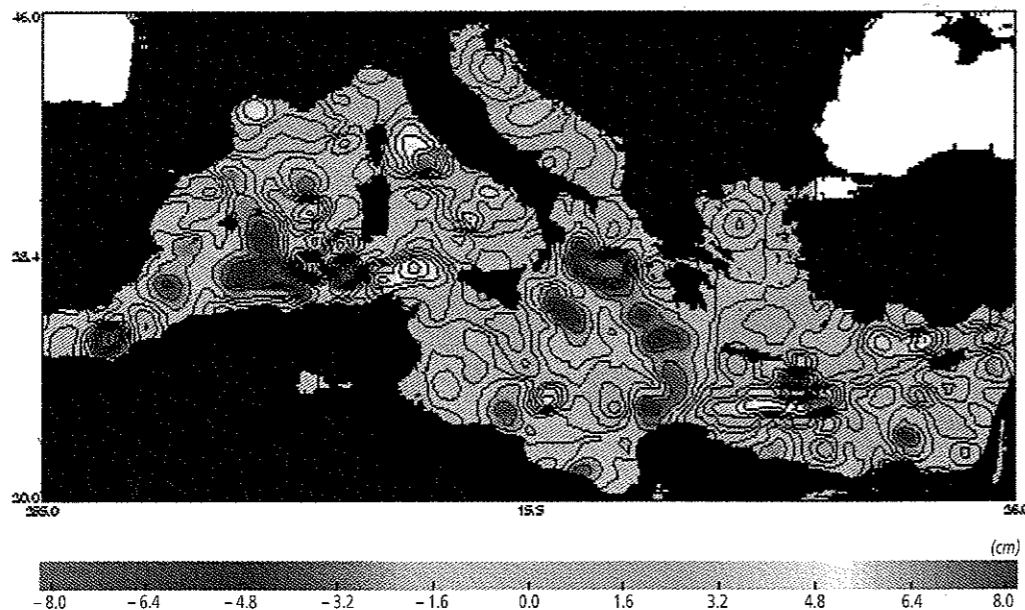
-110.00 -90.00 -70.00 -50.00 -30.00 -10.00 10.00 30.00 50.00 70.00 90.00 110.00 (cm)

World ocean-relief map drawn on the basis of measurements made by TOPEX/Poseidon between October 1992 and July 1993.

The map shows most of the permanent circulation.

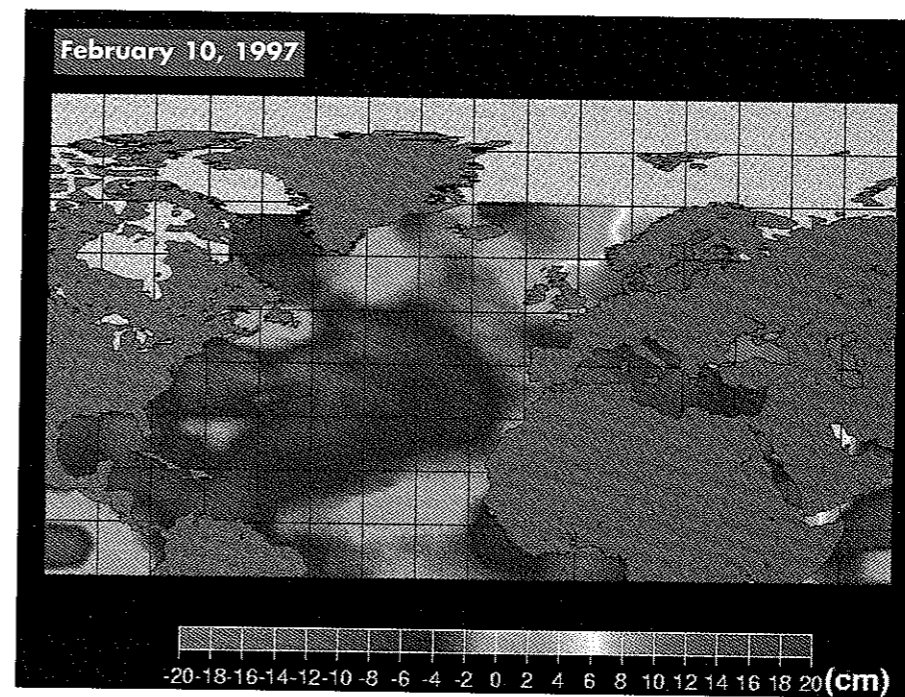
The scale is indicated in centimeters. Dark colors correspond to "depressions" in the surface of the ocean and lighter colors to "bumps". Note in particular the relatively high spot (about 1 meter higher than average) in the Western Pacific. This phenomenon results from the accumulation of warm water driven by the trade winds.

The red arrows show the principal currents. In the Northern Hemisphere, they circulate clockwise around the bumps and in the opposite direction around the depressions. The directions are reversed in the Southern Hemisphere.



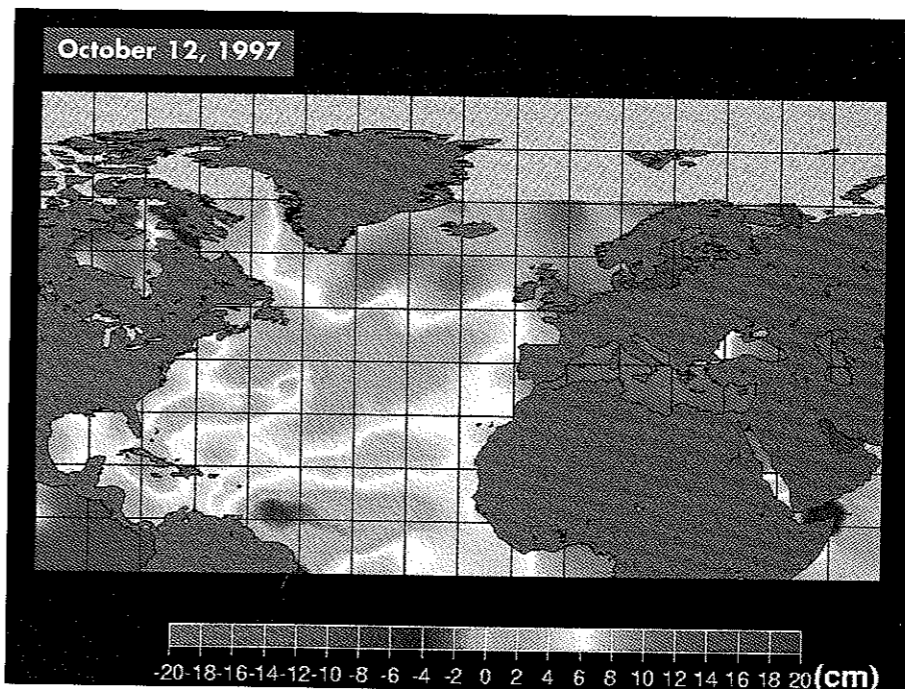
Map of anomalies in the level of the Mediterranean sea in the summer of 1996 over a period of 3 months, based on measurements from TOPEX/Poseidon and the European satellite ERS-2.

Studying the oceanic seasons



February 10, 1997

-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 (cm)



October 12, 1997

-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 (cm)

There are seasons in the ocean, just like there are seasons in the atmosphere.

In the Northern Hemisphere, for example, the ocean receives more heat from the Sun in the summer, which causes it to expand. But because it takes about two months for the heat to diffuse down through the top thousand meters of water, the height of the ocean reaches its maximum, which is about 5 centimeters above its average level, only in the autumn.

And for the same reason, the ocean reaches its lowest level in the spring, about two months after it begins to cool in winter.

TOPEX/Poseidon has made it possible for us to determine the actual amplitude of these variations, which were previously thought to be no more than one or two centimeters.

These seasonal variations can be detected and measured* by instruments on the satellite. Knowledge of these variations is very useful to climatologists to improve their models and their ability to predict climate trends.

The contraction (top) and expansion (bottom) of the North Atlantic as a function of the season, as "seen" by TOPEX/Poseidon.

Each color represents a difference from the average level. The scale runs from -20 cm (light purple) to +20 cm (orange).

The scale runs from -8 cm to +8 cm. Compared to the average level, the areas in yellow or red are higher and the areas in blue or purple are lower. Note the abundance of small whirlpools (several tens of kilometers in diameter).

* Thanks to TOPEX/Poseidon and to the European ERS satellites, we can also observe, for the first time - using altimetry - the circulation and seasonal variations in the Mediterranean (see page 26).

MAT Les dérèglements climatiques dus au phénomène naturel El Niño ont provoqué une impressionnante série de catastrophes en chaîne : sécheresses, inondations et tempêtes - d'un bout à l'autre de la planète. L'épisode 1997-1998 passera sans doute pour l'une des plus grandes calamités naturelles du siècle. ● AU PÉROU ET EN ÉQUATEUR, éboulements et inondations sont quotidiens. La capitale péruvienne, Lima, a été touchée pour la première fois par des torrents de boue venus des contreforts des Andes. En Équateur, 18 des 21 provinces que compte le pays sont touchées. Une catastrophe qui oblige les deux pays andins à réviser à la baisse leurs prévisions de croissance. ● LA COMMUNAUTÉ SCIENTIFIQUE a lancé en 1985 un programme d'observation et a étudié pendant dix ans ce phénomène, pour comprendre les effets du balancier climatique que provoque El Niño.

El Niño a provoqué une des plus grandes catastrophes naturelles du siècle

Le déplacement périodique de cette masse d'eau chaude de la taille des États-Unis, située habituellement dans le Pacifique ouest, est à l'origine des dérèglements climatiques - sécheresses, inondations et tempêtes - survenus d'un bout à l'autre de la planète



Article from *Le Monde* dated March 7, 1998.

Detecting and forecasting repetitive climatic anomalies such as El Niño

Some years, an unexplained and very intense climatic event occurs in the Pacific off the coast of Peru. Over the course of several months, the normally "cold" water (18 to 22°C) is replaced by warmer water (up to 25°C or even 29°C). For fishermen - and there are lots of them who make their living in this region, which is the world's largest fishing ground - it is a catastrophe. For example, fish such as anchovies, which are ordinarily abundant, disappear because the plankton* they feed on thrives only in cold waters that are rich in nutrients. At its peak, the phenomenon extends over more than 10,000 kilometers and covers an area larger than the United States. Before the era of satellites, no one even suspected it covered such a wide area.

This climatic anomaly, which is still not fully understood, originates with the weakening of the trade winds** which normally keep the warm water to the west of this basin, closer to the Philippines.

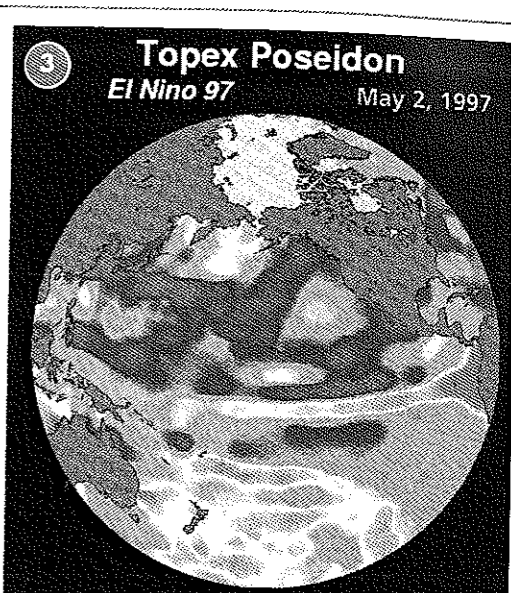
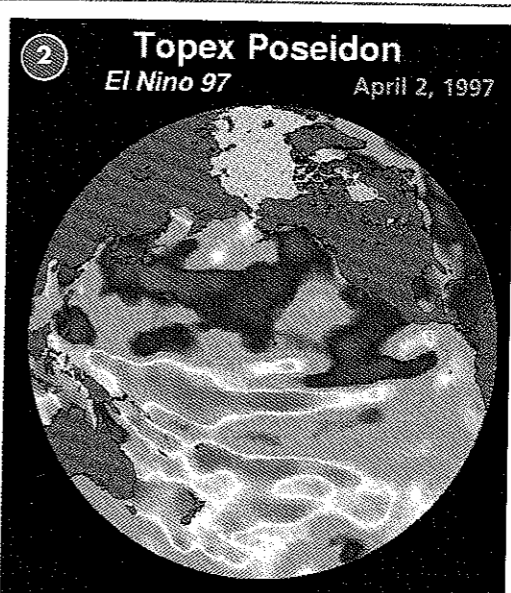
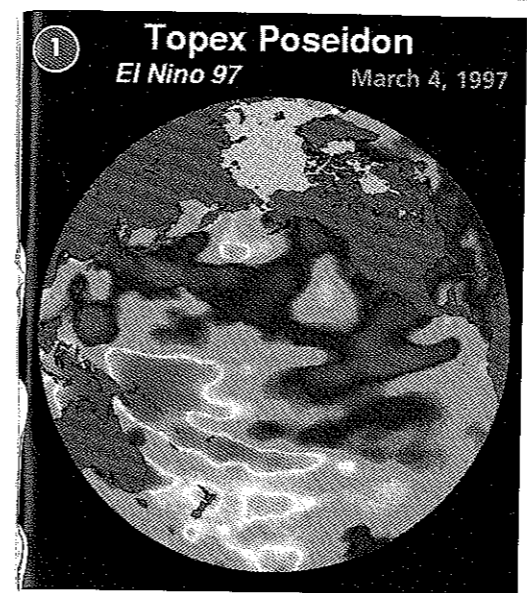
The phenomenon itself has been known for thousands of years, and it occurs at irregular intervals of two to seven years. It normally peaks in December, which is why it is called El Niño which, in Spanish, refers to the Baby Jesus whose birth is celebrated on December 25. Its effects continue for more than a year.

But its consequences are not limited to fishing. The climate of the entire planet is affected. Droughts, floods, storms and tornadoes are observed all over the world. Areas that are usually arid (such as Eastern Africa)

become wet, and conversely rainy regions (Australia and Indonesia, among others) experience drought and forest fires.

Because of its size, the 1997-1998 El Niño was one of the most devastating of the 20th century. It caused the death of thousands of people and damage estimated in the billions of dollars.

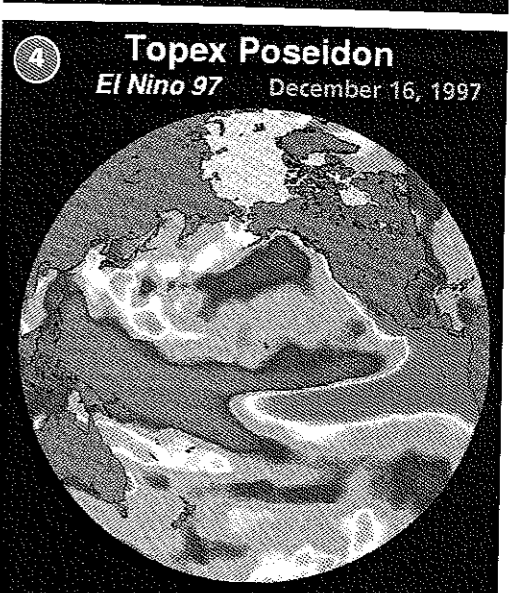
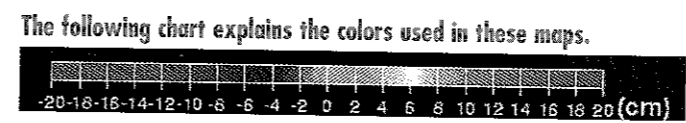
Beginning in March 1997, TOPEX/Poseidon "saw" the early evidence of the phenomenon. It observed the propagation of a "dome" of warm water (20 to 30 centimeters higher than the rest of the ocean) crossing the Pacific from west to east. Scientists hope that - thanks to satellite altimetry and modeling - they will soon be able to predict its appearances a year in advance.



Thanks to the TOPEX/Poseidon satellite, it is now possible - for the first time - to monitor the evolution of the El Niño phenomenon continuously and comprehensively.

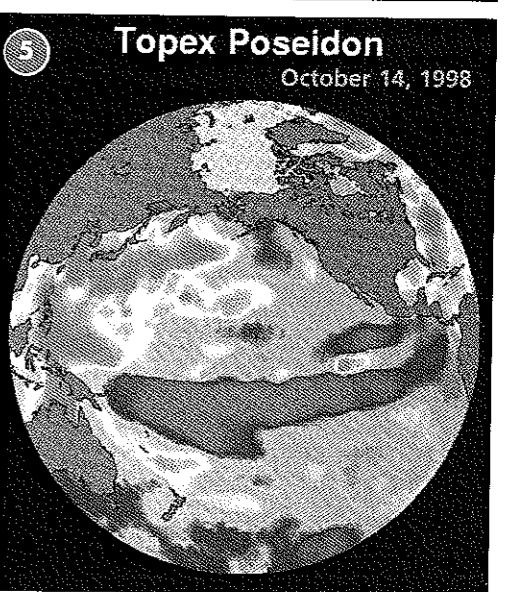
On these maps, the anomaly takes the form of the expansion towards South America of a red zone which is more than 20 centimeters higher than the rest of the Pacific.

The map from October 1998 shows a drop (in other words, a cooling) of the water at the surface of the Eastern Pacific. This phenomenon, which is called La Niña, seems to be the reverse of El Niño. It seems to accentuate certain meteorological events such as the monsoons, for example.

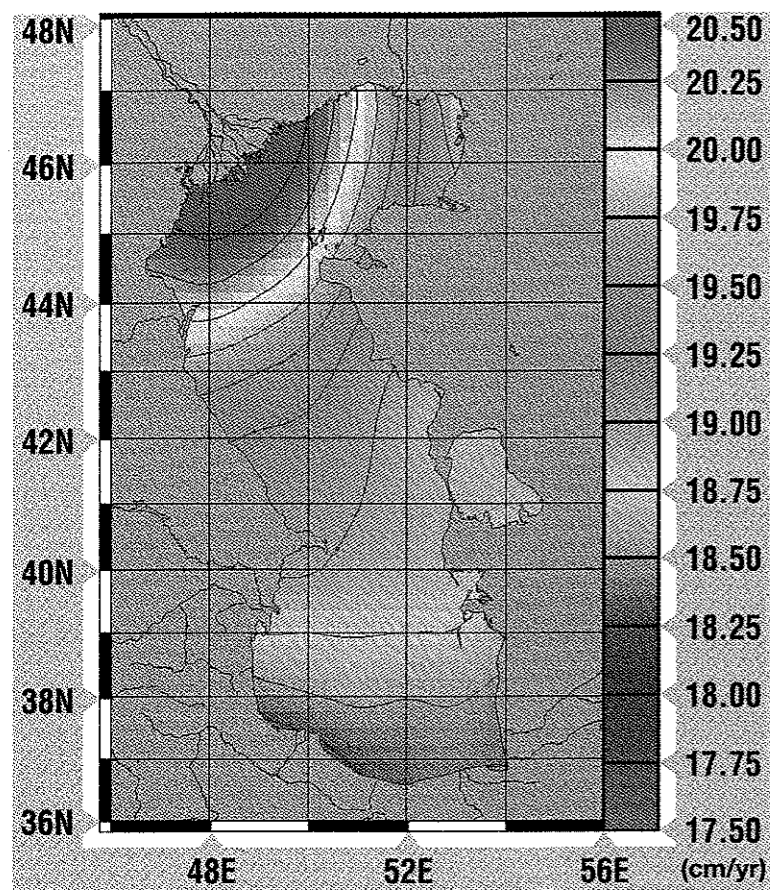


But, you will say, what good is predicting such anomalies when we can't do anything about them? The answer is that it would then be possible to limit their impact by informing the population in time so that preparations could be made to confront a natural disaster. Dikes and levees could be constructed, drainage ditches and sewer systems could be cleaned and repaired, houses could be rebuilt, food and clothing stored, and a host of other precautions could be taken.

The ability to predict such phenomena would also have major political, social and economic consequences. Stockpiles of food could be increased, harvests could be timed more efficiently and cultivation could be selected on the basis of the weather. Measures could also be taken to prevent the development and spread of certain illnesses or epidemics, among other things.



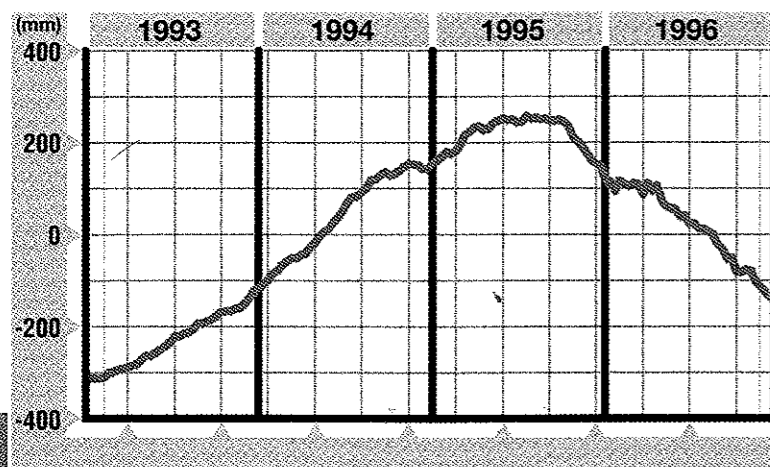
* **Plankton** : A group of microscopic organisms that live in the ocean, including animal plankton (zooplankton) and plant plankton (phytoplankton).
 ** **Trade winds** : Regular east winds that blow in tropical areas.



The Caspian Sea is a landlocked sea almost as large as France and is located north of Iran. Depending on variations in the local climate and the flow of the Volga River which feeds it, its level varies a great deal.

Between January 1993 and July 1995, measurements by TOPEX/Poseidon showed an average rise of approximately 19 cm/year.

But since 1995, the trend has been reversed (see graph below). The level is currently dropping by about 25 cm/year, which risks creating major economic problems in the area.



Monitoring the average level of the oceans

The measurements made by tide recorders seem to indicate that the level of the oceans has risen by about fifteen centimeters since the beginning of the 20th century, which means an average rise of 1.5 to 2 millimeters a year.

This rise in sea level, the cause of which is not fully understood, could be explained by the warming of the planet which is accompanied by an expansion of the liquid mass of the ocean, by the melting of mountain glaciers and by variations in the weight and volume of the polar icecaps.

The TOPEX/Poseidon satellite can measure these variations in level over the entire planet and can repeat its measurements at regular intervals. One of its most remarkable achievements is the measurement of variations (called interannual variations) in the level of the sea, from one year to the another, with an accuracy of better than 1 mm/year.

Satellite altimetry not only gives us a single number for the variation of the water level on a planetary scale, it also lets us determine this variation on a regional scale, something that was previously impossible.

Thus we find that the greatest rise in ocean levels occurred in the tropical Pacific, on account of the expansion due to the 1997-1998 El Niño. On the other hand, the average effect in the Indian Ocean, and in the North and South Atlantic, was only 1.4 mm/year.

But only by continuing these series of satellite measurements for many years in a row and comparing the measurements will we be able to have total confidence in the results.

Learning more about the tides

Contrary to what you might think, we don't really know a lot about the tides. We know what causes them (the attraction of the Moon and the Sun), but we don't know the precise scope of their effects.

Off, the average height of the tide is approximately 50 centimeters, but on certain coasts, the tide frequently reaches heights of several meters. These variations in the water level are accompanied by major currents (called tidal currents). It is essential to be able to predict, to within a few centimeters, the height to which the tide will raise or lower the surface of the water if we want to study geophysical and oceanographic phenomena such as ocean currents in detail.

This forecasting ability is also necessary to protect access to ports and coastal navigation (sometimes the hull of a ship clears the bottom by no more than thirty centimeters) as well as for the construction of major civil engineering and infrastructure projects near the water's edge.

Up to now, these periodic variations have been measured by tide recorders, instruments that are installed along the coasts. But the geographic distribution of these

tide recorders is not sufficient at all to reflect the complexity of the ocean tide over the entire planet, and it tells us nothing about the height of the tides in the open ocean. This complexity is due, among other things, to the fluidity of the ocean, the irregular shape of the coasts, the variable depth of the water and the deformation of the sea floor under the variable weight of the ocean.

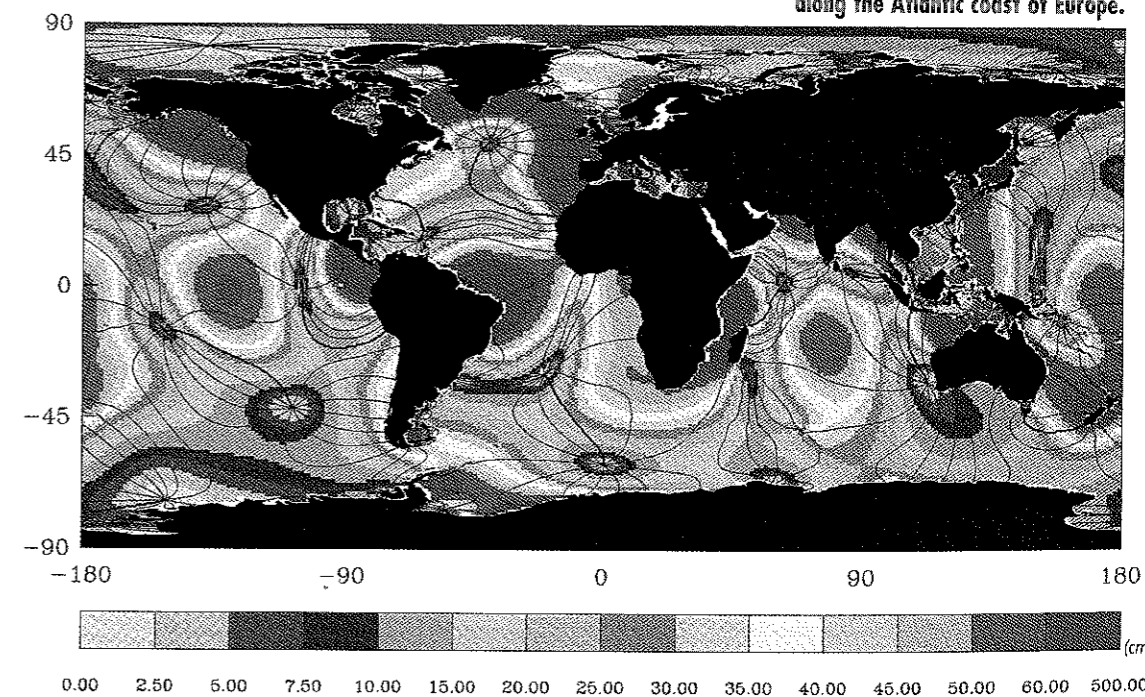
Of course, mathematical models have been developed, but the quality of their predictions is still inconsistent. A satellite as accurate as TOPEX/Poseidon is equivalent to thousands of tide recorders distributed almost uniformly over all the oceans and seas of the world. Thanks to its measurements, we have improved the numerical models used to

predict the height of the tides to within 2 or 3 centimeters for the deep ocean (more than 1,000 meters deep).

Research is under way to attempt to adapt these models to coastal regions, where predictions are not yet as accurate as necessary.

This model can be used to predict the height (in centimeters) of ocean tides for the whole Earth. It takes into consideration some of the observations made by TOPEX/Poseidon. The quality of its predictions has been verified using data from tide recorders located at 80 locations around the world. Predictions are accurate to within 2 to 3 centimeters.

Note the very strong tides (shown in red) along the Atlantic coast of Europe.



GLOSSARY

Altimetry: Radar system used to measure the distance between the satellite that carries it and the surface of the ocean.

Coriolis (Gaspard Gustave de): French engineer and mathematician (1792-1843) who was the first to demonstrate (and describe mathematically) the deviation experienced by any object that moves on the surface of the Earth on account of the Earth's rotation.

DORIS (acronym for Détermination d'Orbite et Radiopositionnement Intégrés par Satellite - in English, Doppler Orbitography and Radiopositioning Integrated by Satellite): French system that makes it possible to determine the position of a satellite in Earth orbit to within a few centimeters.

Dynamic topography: Elevation by several centimeters to several decimeters of the level of the oceans under the action of oceanic circulation. This effect is superimposed on the static effect of the marine geoid (from several decimeters to several meters).

The actual sea level is the combination of these two effects (see diagram on page 21).

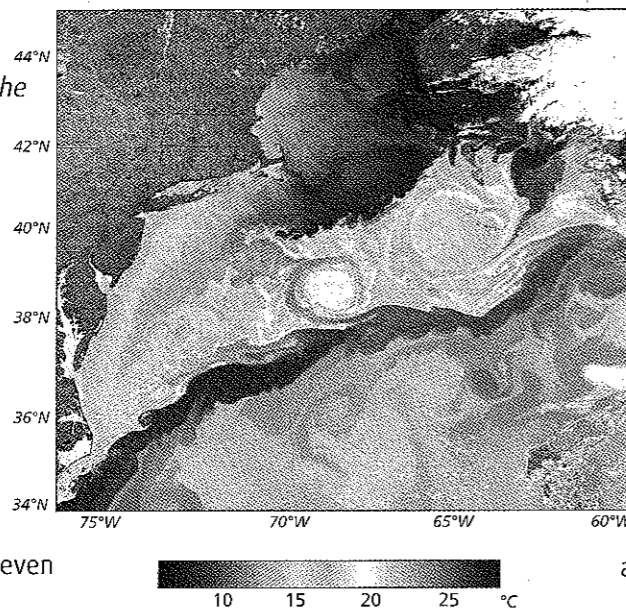
El Niño (from the Spanish for "the Baby Jesus". Christians celebrate the birth of Jesus at Christmas, which is generally when the phenomenon reaches its maximum intensity): A climatic phenomenon observed in the Pacific Ocean. It consists of an unusual warming of the surface water along the American coastline by 4 to 6°C. This phenomenon, which affects the ocean and the atmosphere, can last more than one year. It is repeated with variable intensity at irregular intervals of from two to seven



Since 1777, maps of the Gulf Stream have been available to make it easier to cross the Atlantic.

On its way, the temperatures of the Gulf Stream drops from 25°C to 2°C, heating the water and the atmosphere as it passes and giving up moisture to the atmosphere. This warm current, like the Kuroshio (its equivalent in the Pacific), is a western boundary current formed by the East winds. It includes strong turbulence and very strong variations of direction, speed and temperature.

Thermal map of the Gulf Stream, near the US East Coast.



years. The most recent El Niño events occurred in 1976, 1982-83, 1991-92, 1994 and 1997-98. The causes of the phenomenon remain uncertain.

Greenhouse effect: The warming of a planet's atmosphere when it absorbs more energy than it loses. The greenhouse effect is due to the behavior of the gases in the atmosphere.

On Earth, for example, these gases are primarily water vapor, carbon dioxide and methane - although in very low concentrations - which cause this rise in temperature. Without them, there would be no greenhouse effect, and the temperature on the surface of the Earth would be 33°C colder.

The greenhouse effect varies from planet to planet: +6°C on Mars, +500°C on Venus, etc.

Heat engine: The term used for a system that "transports" energy, for example one that "absorbs" heat in one location and gives it up in another location.

The ocean, which transports heat from the equatorial regions toward the poles, can be considered a heat engine.

La Niña: Climatic phenomenon observed in the Pacific Ocean after certain El Niño events, with reverse manifestations: a drop in ocean levels and cooling of the surface water.

Mercator (from the name of a 16th century Flemish geographer and mathematician): French project to promote the establishment on a worldwide level of operational oceanography which will consist of rapidly providing users with a three-dimensional description of the ocean (past and present) - sea conditions, currents, whirlpools, etc. - as well as its predicted evolution for one month in advance.

Model: In the modern world, a model is an object (or a person) we want to imitate or reproduce.

Scientists also use models - called mathematical or numerical models - that are created to represent, in mathematical language, the principal characteristics of a particular phenomenon: weather trends in a region, the exchange of energy between the atmosphere and the oceans, oceanic circulation, etc.

Ocean current: Movement of a mass of water within a large expanse of water (ocean or sea). Ocean currents can be cold or warm, and can flow on the surface or beneath the surface.

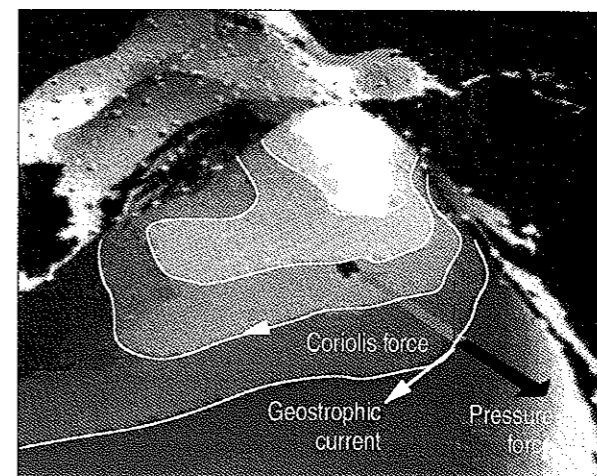
The major surface currents are very turbulent and consist of meanders and whirlpools. They are comparable to gigantic rivers several tens of kilometers wide, the influence of which extends several hundred meters and sometimes several kilometers deep.

For example, the Gulf Stream - a warm current which circulates at a speed of 100 km/day from Central America to Europe - moves up to 100 million cubic meters of water per second, or the equivalent of 300 (!) times the flow of the Amazon, the mightiest river in the world.

Oceanic circulation: A system of large-scale movements on a planetary scale that affect the oceans and seas. The ocean is set in motion by the action of the wind and the distribution of the sun's heat, which varies from one region to another.

The rotation of the Earth also affects this worldwide circulation, which occurs both on the surface and underwater.

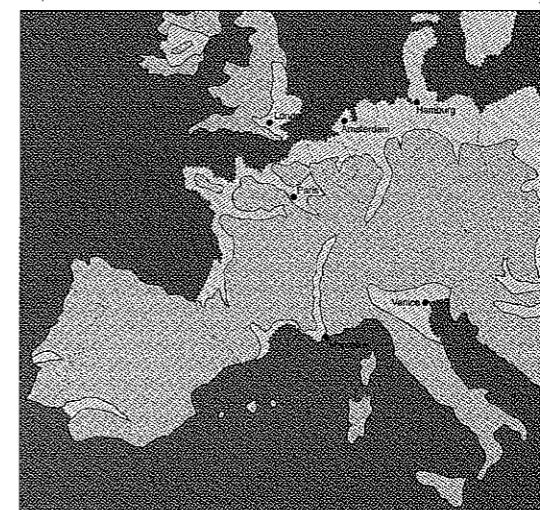
Orbitography: Technique that consists of determining the orbit of a satellite.



The Coriolis force affects the movement of air masses in the atmosphere and the movement of ocean currents. It causes them to turn toward the right of the wind in the Northern Hemisphere and toward the left in the Southern Hemisphere. The intensity of the Coriolis force is zero at the equator and increases the closer we get to the poles.

The European coastline if all the continental ice melted and the water level rose by 80 meters.

A warmer climate has an effect on the ocean by raising the water level (as a result of the melting of glaciers and the fact that water expands as it becomes warmer). Such a rise in ocean levels would have catastrophic consequences for a large part of the world's population (50% of which lives less than 100 km from the coast), in particular in Pacific atolls or in Bangladesh, which are only slightly higher than the current level of the oceans.



Satellite altimetry: Technique measure and map, to an accuracy of a few centimeters, the topography of the surface of the oceans. It also provides information on wave height and wind speed at the surface.

Sverdrup (Harald Ulrik): Norwegian meteorologist and oceanographer (1888-1957). His name has been used to designate the unit of measurement of water transport in the ocean. A sverdrup (abbreviation Sv) equals one million cubic meters per second. A current 100 km wide and

500 m thick moving at 50 cm/s transports 20 Sv.

A few examples: All of the rivers of the world carry a flow of 1 Sv. Along the coast of Florida, the Gulf Stream carries 80 Sv. The Antarctic Circumpolar Current - the most powerful in the world - transports an average of 130 Sv south of Tierra del Fuego. The flow of water on the surface of the Atlantic Ocean toward the Mediterranean sea is 1 Sv, etc.

Tide: Continuous oscillating movement of the surface of the oceans. This periodic rise and fall are due to the attraction of this mass of fluid by the Moon and the Sun. The height of this daily oscillation averages about 50 centimeters, but it can reach up to 10 m on certain coasts (Canada, among others) as a result of resonance effects.

We know much less about earth tides than about the ocean tides. The cause of Earth tides is the same, but the effects are not as spectacular. For example, at the level of Europe, the ground rises and falls by about 30 cm daily.