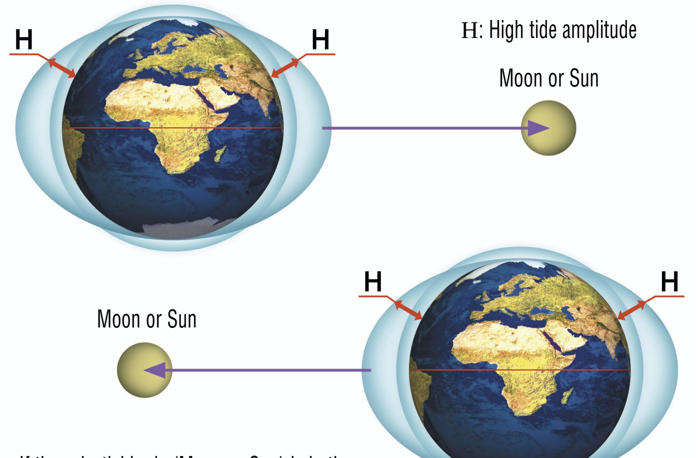
The Sun and the Moon have a date with the sea

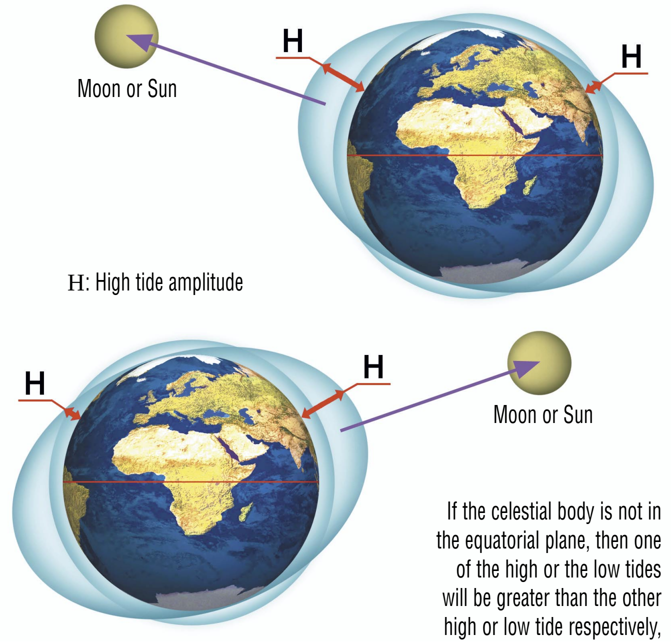
Tides account for some of the most significant variations in sea level. The combined attraction of the Moon and the Sun is behind this phenomenon and its variations.

The Moon, like the Sun, attracts the Earth and its oceans, which then change their shape. Water accumulates at the place of maximum attraction, in other words at that point on the globe which is the closest to the celestial body. In addition, due to the speed of the movement, an opposing centrifugal force keeps the Earth on its orbit. This centrifugal force pushes the water back and it then accumulates in the opposite direction to the celestial body.



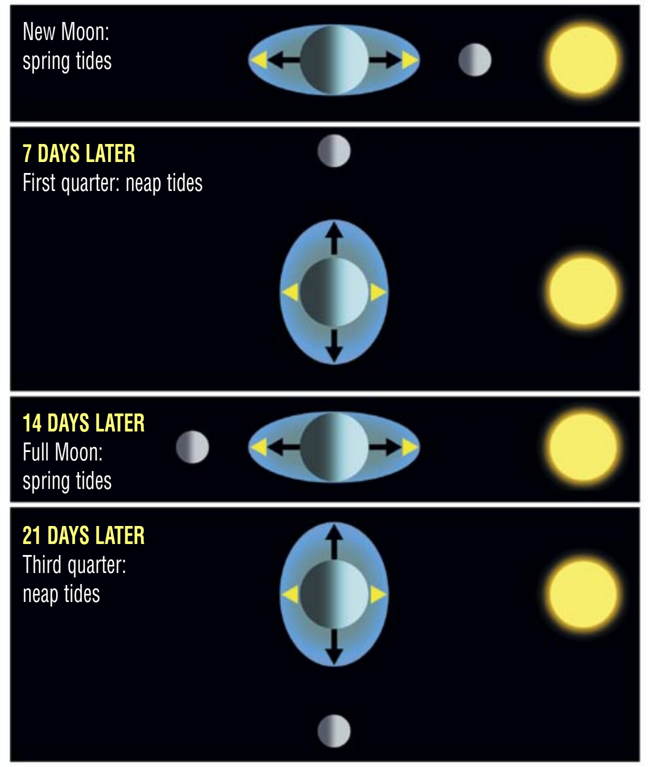
If the celestial body (Moon or Sun) is in the Earth's equatorial plane, then there are two high and two low tides per day.

However the Moon is rarely in the Earth's equatorial plane. The two bulges are along the Earth-Moon or Earth-Sun axis and hence, for a given latitude, the amplitude will not be the same for the two daily tides. Sometimes there is only one tide per day.



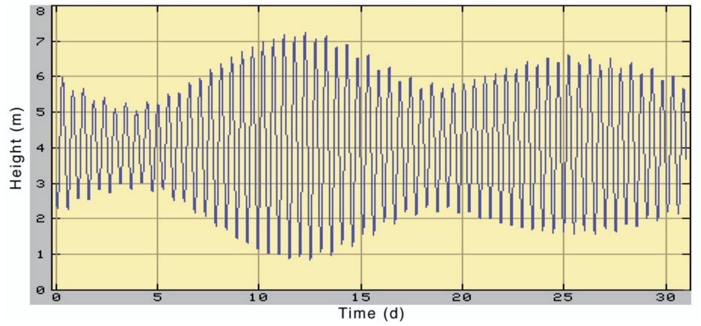
If the celestial body is not in the equatorial plane, then one of the high or the low tides will be greater than the other high or low tide respectively, every day, at middle latitudes.

The respective positions of the Moon and Sun in relation to the Earth cause the cycle of monthly variations. When aligned, their influences are reinforced, when at a right angle, they are reduced, which means that tides are or more less high.



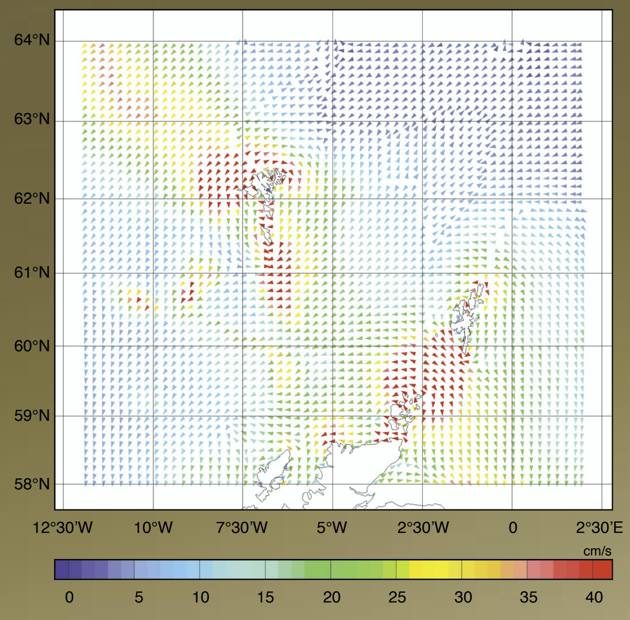
Variations in tides with the lunar cycle

In order to be able to calculate tides, it is thus necessary to know the attractive force of the Moon and Sun and their respective positions. The relief of the bottom of the seas and the shape of the coastline also affect tides and can amplify the phenomenon up to fifteen metres, as is the case for the bays of Mont St Michel (France) or Fundy (Canada).



Tide levels in the port of Brest (France) in December 2000. The illustration shows the alternating high and low tides and, over a month, the variations in amplitude due to the respective positions of the Moon and Sun.

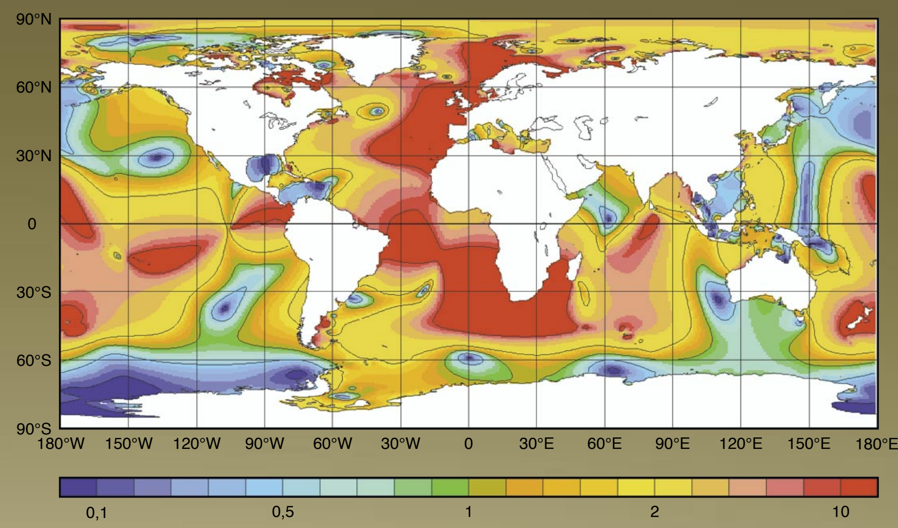
Follow the tides



Speed of currents due to the semi-diurnal, lunar tides close to the Faroes and Shetland islands (North of Scotland).

Changing currents

The tide move water masses, which causes currents. These currents, sometimes violent in straits, are particular in that they change in intensity and direction according to the tides. It is vital for coastal navigation, for preventing pollution and protecting the shoreline, that we understand them and are able to predict them. Project of undersea turbine —like an immersed windmill— to generate electricity from these currents are currently under study.

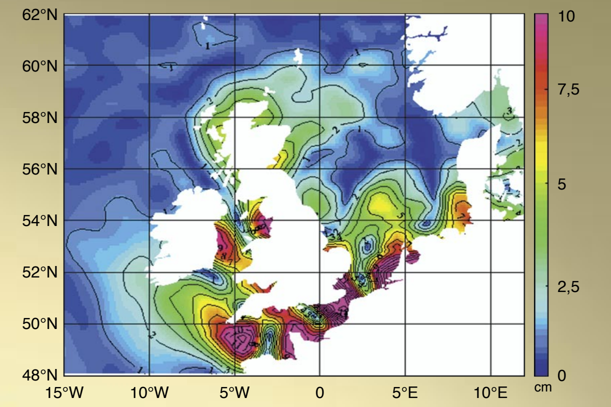


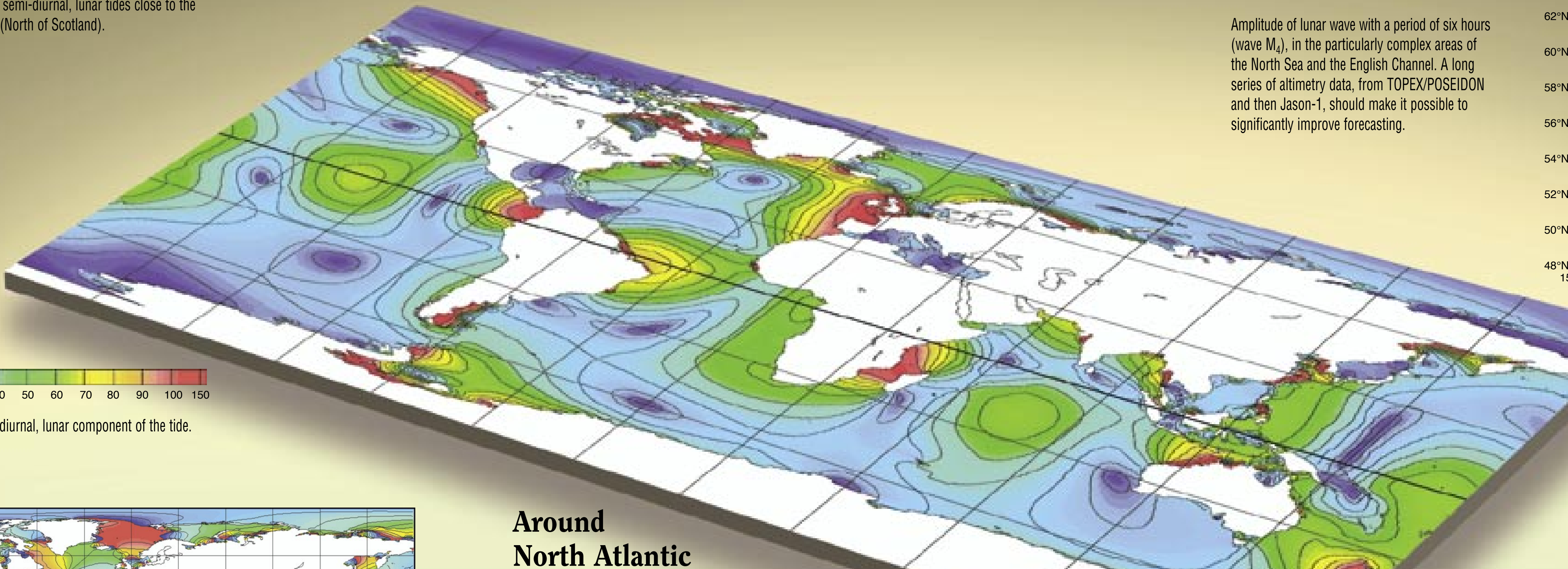
Comparison of semi-diurnal and diurnal tides in the world. The blue/violet areas correspond to dominant, diurnal tides, while the yellow/red areas are semi-diurnal.

Tides are not only semi-diurnal

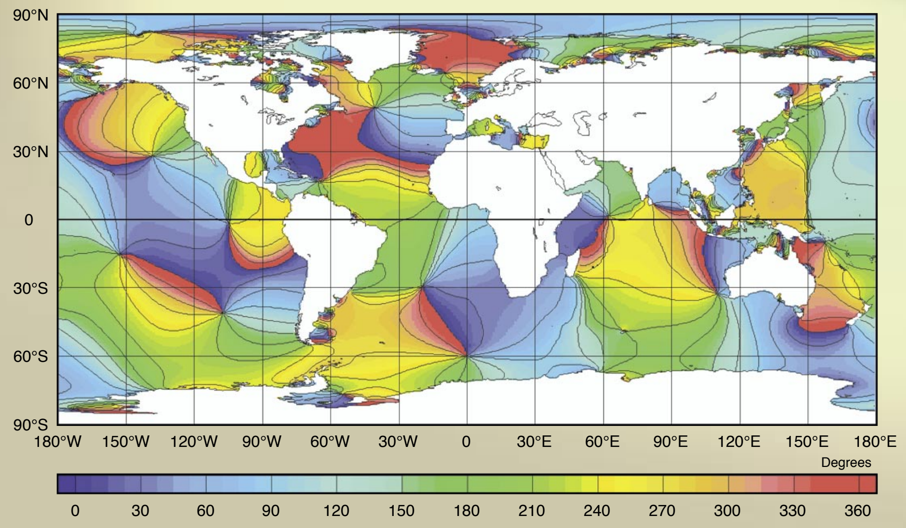
For most people living on the shores of the Atlantic, tides are phenomena which occur twice a day. But some places in the world only have one tide per day (Gulf of Mexico, China Sea, North Pacific, Antarctic Ocean, etc.) Other rarer places sometimes have up to three or four tides in the same day. The breakdown of tides into sinusoidal waves reveals that there are other different periods than the day and half day, for instance 6 hours. (wave M_4). Depending on the areas, some of these waves have to be taken into account.

Amplitude of lunar wave with a period of six hours (wave M_4), in the particularly complex areas of the North Sea and the English Channel. A long series of altimetry data, from TOPEX/POSEIDON and then Jason-1, should make it possible to significantly improve forecasting.





Amplitude of the main semi-diurnal, lunar component of the tide.



Phase of the main, semi-diurnal, lunar component of the tide.

Around North Atlantic in 12h25’

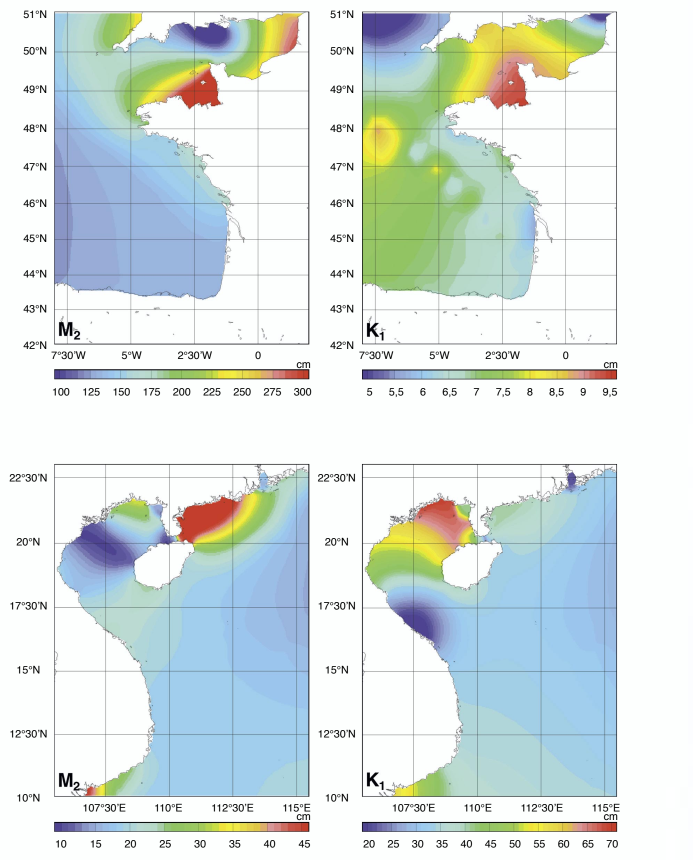
The main semi-diurnal component of the tide (wave M_2), due to the Moon is, in many regions, the dominant component. It may be observed that regions with an increase in tide variations or tidal range (difference in height between successive low and high tides) have significantly high values, in particular near the coasts on the North Atlantic. We can also see regions with very low amplitude, as well as points where the tidal range is nil, around which the tide “turns”. The phase map is used to identify the direction and propagation speed of the wave phase which changes from 0° to 360° during its period (12h25’ in the case of M_2).

Forecasts which are increasingly more reliable

Forecasting of tides requires integrating observations into numerical models for greater precision. Tide gauges and altimetry satellites are both useful and their combination enables tide forecasting to within 2 to 3 centimetres in the middle of the ocean.

Breaking down tides to calculate them better

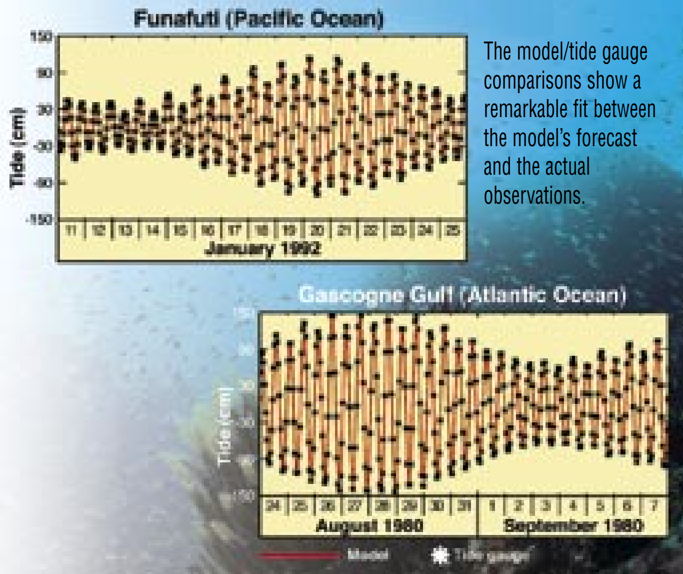
In order to calculate tides, they have to be broken down into sinusoidal waves of given periods, each of which represents one component of the problem. Thus, one of the waves, called M_2, is due to the attraction of an ideal Moon placed on a perfectly circular orbit in the Earth's equatorial plane. It has two high and two low tides per day (semi-diurnal wave). The K_1 wave, with a diurnal period, reflects variations in declination of the Moon and Sun. The amplitude of the tide at a given moment and given place is the sum of all these sinusoidal waves. In certain areas, a hundred of these waves have to be added to obtain a precise forecast.



Amplitude of two main tide components, one semi-diurnal (wave M_2), the other diurnal (wave K_1), in the North Atlantic, near to the French coasts and in the China Sea off the coast of Vietnam (the colour scale is different for each of the figures). While M_2 is clearly dominant on the French coasts (two tides per day) K_1 is dominant in the China Sea where there is only one tide per day.

Models enriched with observations

Tide models are based on physical laws. Their precision can be improved by integrating observation data. Tide gauges installed just off the coast provide precise, local measurements. Altimetry satellites such as TOPEX/POSEIDON, ERS, EnviSat or Jason-1, cover the whole Earth, particularly in the middle of the sea, at regular intervals. Using mathematical procedures, this complementary information can be integrated into tide models. In addition, tides have to be filtered out of altimetry data in order to determine other ocean variations (currents, eddies, seasonal variations, etc.).



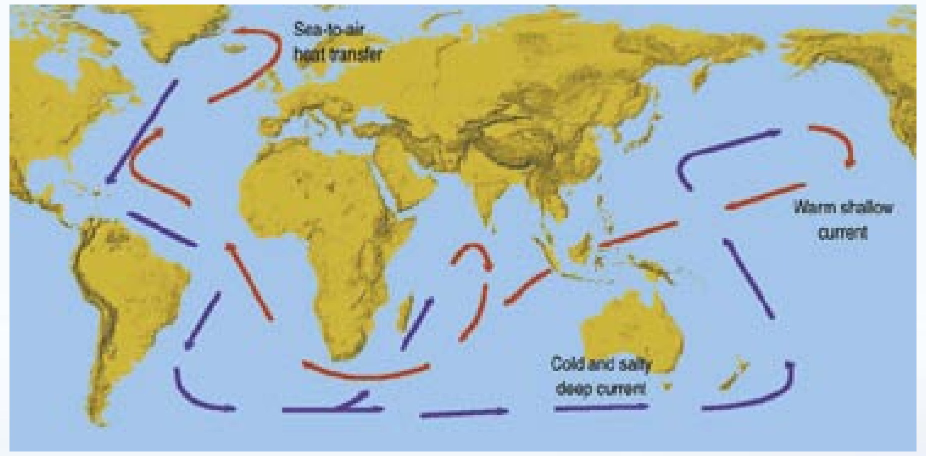
The model/tide gauge comparisons show a remarkable fit between the model's forecast and the actual observations.

Coastal tide gauge

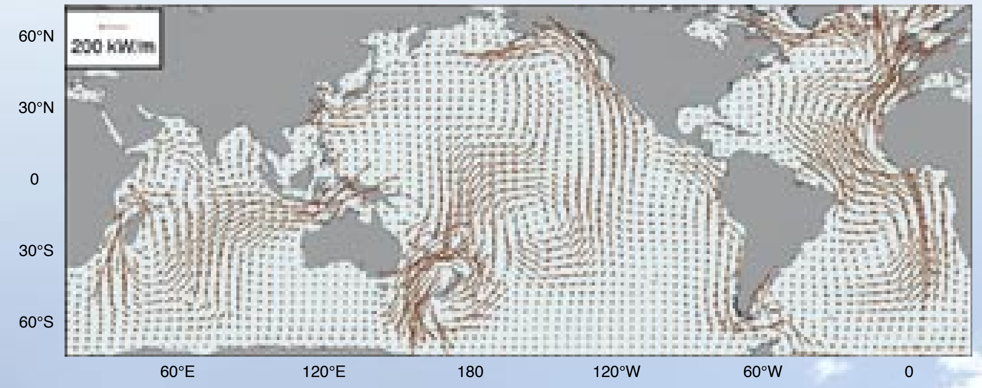
Tides and the climate

In addition to their direct effects on maritime and coastal activities, tides appear to have a less well-known impact on the Earth's climate. This discovery, which was based on almost ten years of highly precise altimetry data, has led to new understanding of the way in which the Moon influences our planet.

Ocean waters are stratified according to their density. The different layers mix with difficulty. However the tidal currents coming into contact with the relief of the ocean bottom (even if this is very deep) creates waves which are propagated at the interface between two layers of different densities. It is currently thought that this mechanism contributes more than half of the vertical mixing of water masses. Now this mixing is fundamental for large-scale ocean circulation (thermohaline circulation) which enables the redistribution of heat from the equator to the poles.



Thermohaline circulation: water from the Tropics cools as it flows into the Norway Sea. It then sinks to the bottom of the ocean where it propels the deep ocean circulation system before eventually welling up and warming again in the Tropics, some 1,000 years later.



Energy flow of the semi-diurnal, lunar tide wave (M_2). The illustration shows the displacement of energy from areas in which it was generated towards dissipation areas. It has been demonstrated, for instance, that the energy dissipated on the Patagonia plateau (to the south-east of America), one of the areas in which tides are the highest, comes from the Pacific and that 40% of the total energy contributed to oceanic tides by the Earth/Moon system, is dissipated in the North Atlantic

Since 1992, TOPEX/POSEIDON has been providing highly precise altimetry measurements which has made it possible to map the energy dissipated by tides. As was previously thought, part of this energy is dissipated in coastal regions through friction with the bottom of the sea, but is has also been observed that a significant part of the energy (one third) is dissipated in the deep ocean. This discovery in turn shed some light on the possible role of tides in thermohaline circulation.

For more information:

AVISO/Altimetry: http://www-aviso.cnes.fr
Tides: http://tidesonline.nos.noaa.gov
http://www.shom.fr

Sources:

CLS, CNES, CNRS/LEGOS, KMS, NASA/GSFC, SHOM

Creation-conception: CLS / Design: Active Design / Publisher: CNES 2001

Observing the oceans from space

Tides, the ocean under influences

High tide, low tide... the rhythm of the tides seems to rock the oceans, reflecting the movements of the Moon and Sun. Precise knowledge of them is vital for many maritime and coastal activities. It is not easy to ignore tides, given that variations in sea level can reach 10 metres in some ports, and that currents change with the ebb and flow. Satellite altimetry now provides regular measurements of sea level in the middle of the ocean, which means that forecasting of tides has been improved. In addition to the publication of tide calendars, we have improved our understanding of the influence of the Moon on the Earth and, somewhat unexpectedly, on its climate.

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