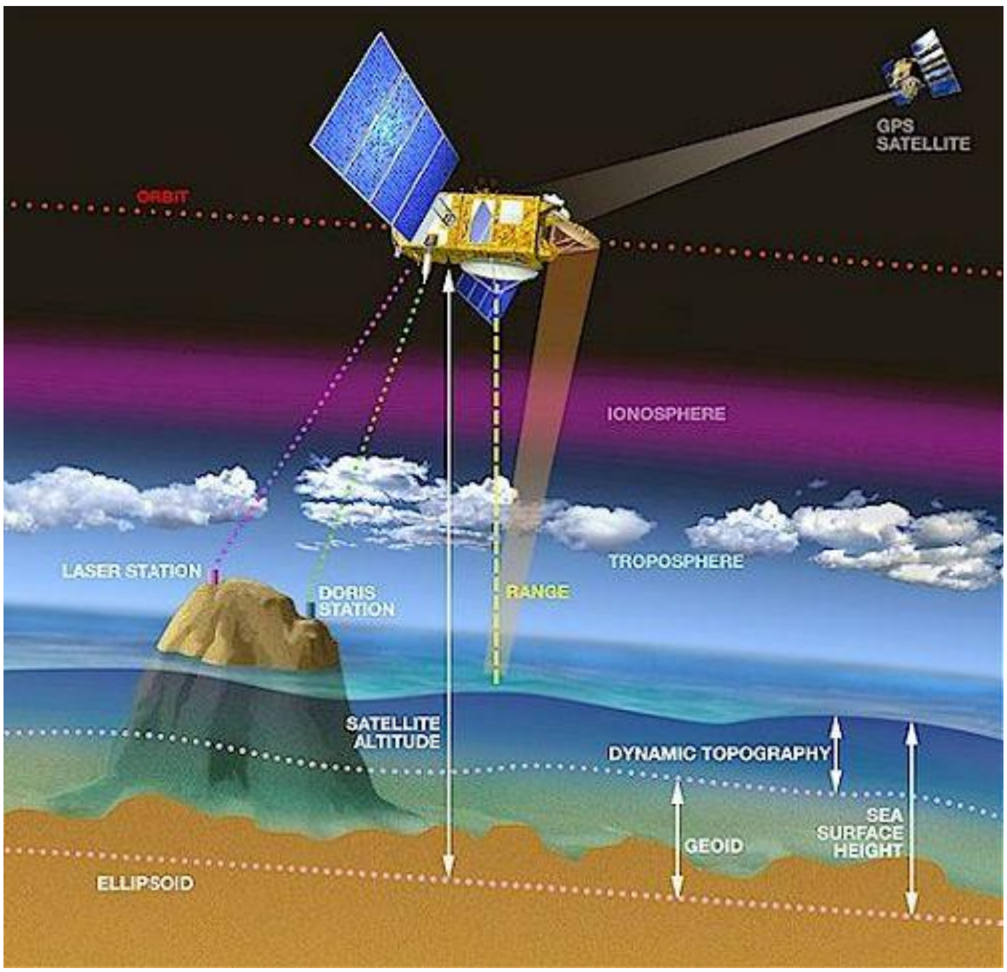
Introduction to Sea Level Anomaly (SLA) data

Adapted from: http://www.aviso.oceanobs.com/html/alti/welcome_uk.html

Altimetry is a technique for measuring height. Satellite altimetry measures the time taken by a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver. Combined with precise satellite location data, altimetry measurements yield sea-surface heights.

How altimetry works



1.1 From radar altimeter to altimeter range (satellite-to-ocean range R)

Radar altimeters on board the satellite permanently transmit signals at high frequency (over 1700 pulses per second) to Earth, and receive the echo from the sea surface. This is analyzed to derive a precise measurement of the round-trip time between the satellite and the sea surface. The time measurement, scaled by the speed of light (at which electromagnetic waves travel), yields a range measurement. By averaging the estimates over a second, this produces a very accurate measurement of the satellite-to-ocean range.
However, as electromagnetic waves travel through the atmosphere, they can be decelerated by water vapor or by ionization. Once these phenomena are corrected for, the final range R is estimated within 2 cm.
The ultimate aim is to measure sea level relative to a terrestrial reference frame. This requires independent measurements of the satellite orbital trajectory, i.e. exact latitude, longitude and altitude coordinates.

1.2 Satellite orbit and tracking (S)

The critical orbital parameters for satellite altimeter missions are altitude, inclination and period. Take the Topex/Poseidon satellite. It flies at an altitude of 1330 km, on an orbit inclined at 66° to Earth's polar axis; this is why it can "see" only up to 66° North and South. The satellite on its so-called "repeat orbit" passes over the same ground position every ten days, uniformly sampling the Earth's surface.
The satellite can be accurately tracked in a number of ways. The Doris system on board Topex/Poseidon uses a network of 50 ground beacons, worldwide, transmitting to the satellite. It was developed by Cnes. Doris uses the Doppler shift on the beacon signals to accurately determine the velocity of the satellite on its orbit, and dynamic orbitography models to deduce the satellite trajectory relative to Earth.

1.3 Reference ellipsoid

This position is determined relative to an arbitrary reference surface, an ellipsoid. This reference ellipsoid is a raw approximation of Earth's surface, a sphere flattened at the poles. The satellite altitude above the reference ellipsoid, distance S, is available to within 3 cm.

1.4 Sea surface HEIGHT (SSH)

The sea surface HEIGHT (SSH), is the range at a given instant from the sea surface to a reference ellipsoid. Since the sea depth is not known accurately everywhere, this reference provides accurate, homogeneous measurements. The sea level is simply the difference between the satellite HEIGHT and the altimetric range:

SSH= S - R.

The SSH value takes account of such effects as:

The sea surface HEIGHT which would exist without any disturbances (wind, currents, tides, etc.). This surface, called the **geoid**, is due to gravity variations around the world, which are in turn due to major mass and density differences on the seafloor. For example, a denser rock zone on the seafloor would deform sea level by tens of metres, and be visible as a hill on the geoid.

The ocean circulation or **dynamic topography**. The ocean circulation, which comprises a permanent stationary component (permanent circulation linked to Earth's rotation, permanent winds, etc.) and a highly variable component (due to wind, seasonal variations, etc.). The mean effect is on the order of one metre.

To derive the dynamic topography, D, the easiest way would be to subtract the geoid HEIGHT, G, from SSH. In practice, the geoid is not yet known accurately enough, and mean sea level is subtracted instead. This yields the variable part of the ocean signal.

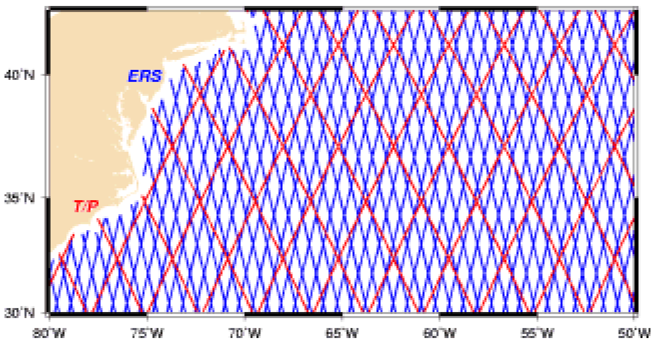
1.5 The advent of satellite altimetry

In the 1970s, satellites began regularly transmitting data on the physics, chemistry and dynamics of the land, ocean, atmosphere and biosphere. This era also saw the first altimetry measurements to map the topography of the ocean surface. The first country to fly a satellite-borne altimeter was the United States, with the Skylab and Geos3 missions, Seasat in 1978 and Geosat in 1985.

More missions were launched in the 1990s: ERS-1 (1991-1996), Topex/Poseidon (since 1992) and ERS-2 (since 1995). These missions are part of international oceanographic and meteorological programmes, such as Woce (World Ocean Circulation Experiment) and Toga (Tropical Ocean and Global Atmosphere), both linked to the World Climate Research Programme, WCRP.

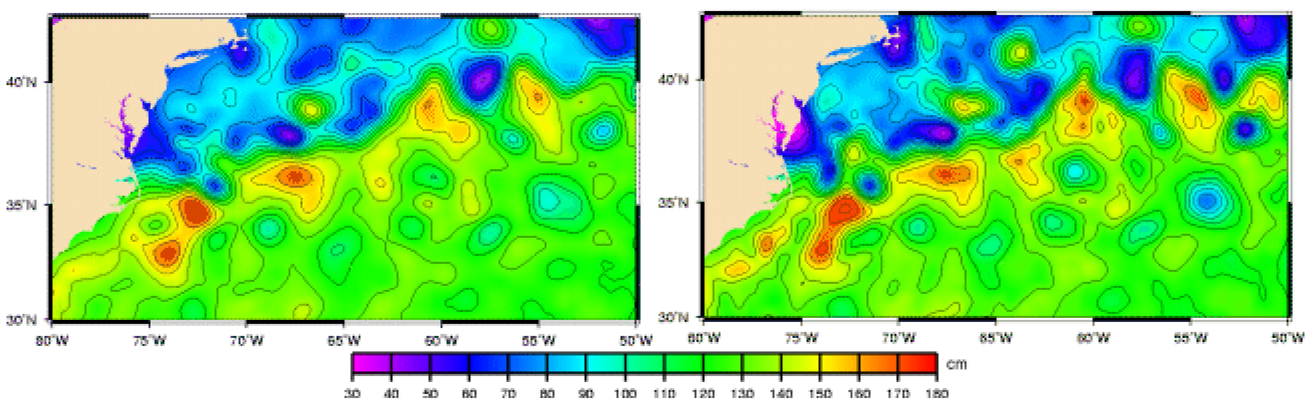
2 High-precision altimetry with satellites working together

In many ways, the orbit of an altimetry satellite is a compromise. But one point that deserves special attention is getting the right balance between spatial and temporal resolution: a satellite that revisits the same spot frequently covers fewer points than a satellite with a longer orbital cycle. One solution is to operate several satellites together.



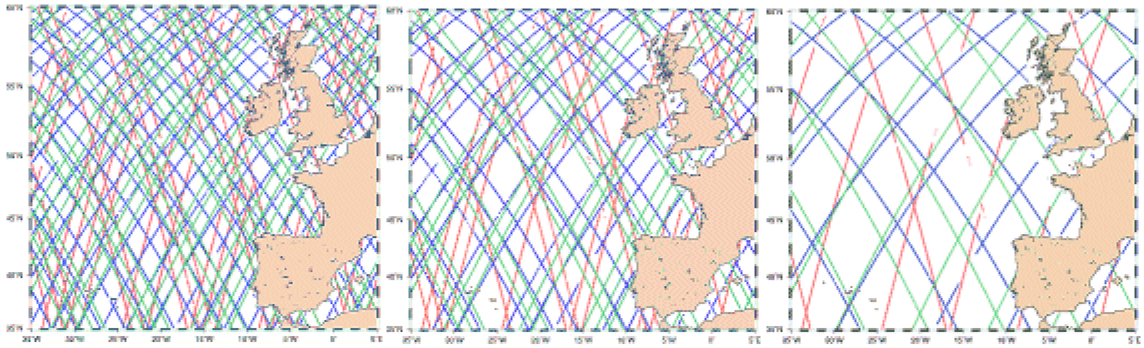
ERS-T/P superimposed ground tracks

Topex/Poseidon-ERS and Jason-Envisat are fine examples of how altimetry satellites can operate together. Topex/Poseidon and Jason-1 follow a repeat cycle of ten days designed to monitor ocean variations, so they pass over the same points fairly frequently but their ground tracks are some 315 kilometers apart at the equator-more than the average span of an ocean eddy. On the other hand, ERS-2 and Envisat only revisit the same point on the globe every 35 days but the maximum distance between two tracks at the equator is just 80 kilometers.



Dynamic topography in the Gulf Stream, December 5, 1999. Left: T/P data only. Right: T/P + ERS data. The resolution of the numerous eddies in this ocean current is clearly better.

Other combinations are possible, but at least two altimetry satellites are required to map the ocean and monitor its movements precisely, particularly at scales of 100 to 300 kilometers (mesoscale). Combining GFO data with Topex/Poseidon and ERS-2 data significantly improves the description of ocean mesoscale variability and reduces mapping errors by up to 30 per cent.



Grid of sea surface height measurements by T/P, ERS-2 and GFO in the Northeast Atlantic over 10 days (a), 7 days (b) and 3 days (c). There are gaps in coverage of 200 km and more over three days. Combining data from all three missions increases coverage.

2.1 Why do we need higher resolution?

High-resolution sampling is needed for many applications:

Higher spatial resolution makes it possible to resolve mesoscale processes at high latitudes.
These mesoscale processes can only be resolved using data from a constellation of optimally deployed satellites.
To measure isotropic slopes (i.e., geostrophic velocities) in both directions. This can be done by flying satellites with a ground track separation of less than 70 km (in near-polar orbit, like all altimetry satellites) to calculate cross-track slopes. Alternatively, wide-swath altimetry measurements would also make it possible to measure slope gradients of the dynamic topography.
To better describe the dynamic topography near the shoreline: a denser constellation will increase spatial and/or temporal resolution. Further, future altimeters should have smaller footprints and onboard tracking algorithms will be better adapted to sharp terrain variations. These enhancements will in turn allow us to gain a clearer understanding of tidal variations: today, tides are poorly modeled in coastal zones and over the continental slope, which are highly dissipative and non-linear.
High temporal resolution-obtained by revisiting the same point several times daily-will make it possible to describe the variability of high-frequency barotropic signals, forced by wind and atmospheric pressure fields, as well as transient phenomena at large spatial scales, such as internal waves.
The study of sea ice and continental ice.
The study of sea state.
The combined study of vegetation.

