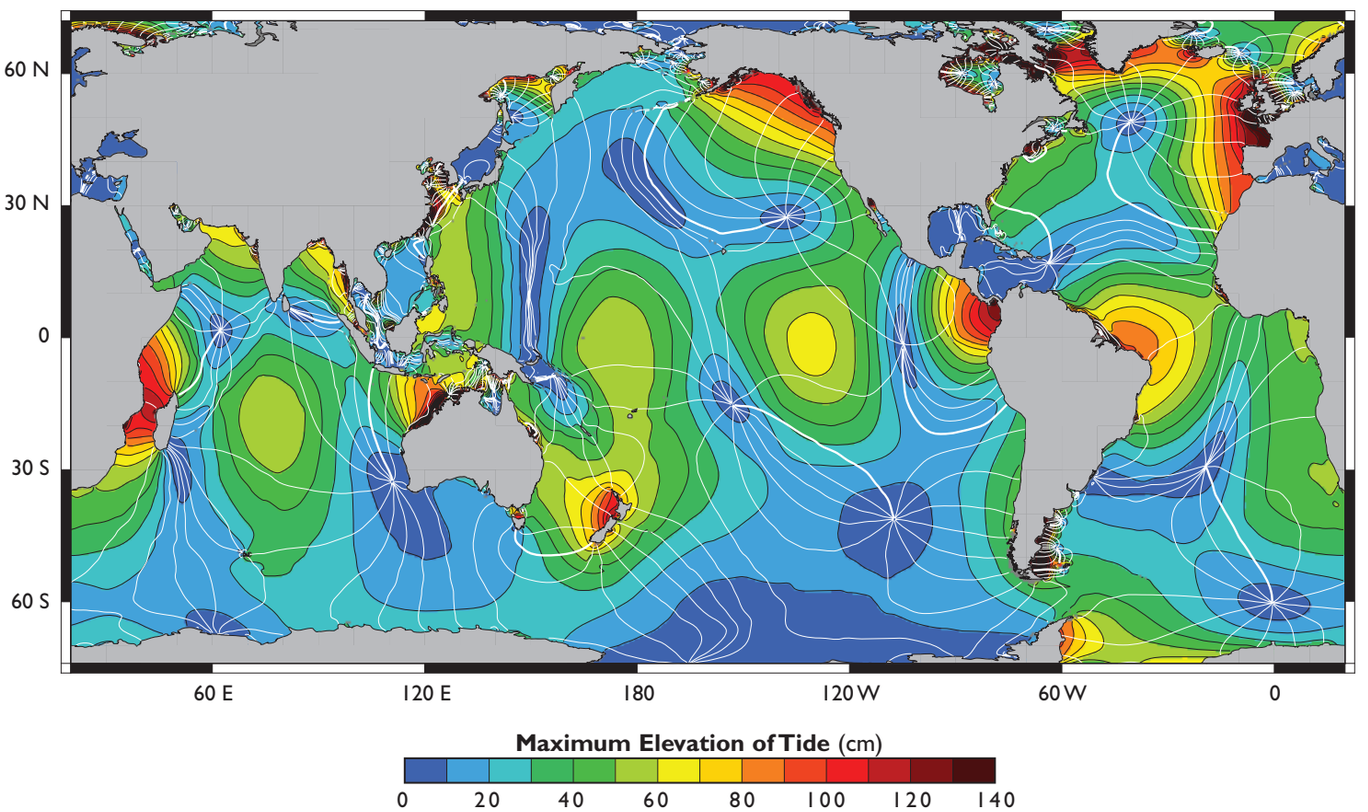
Tides

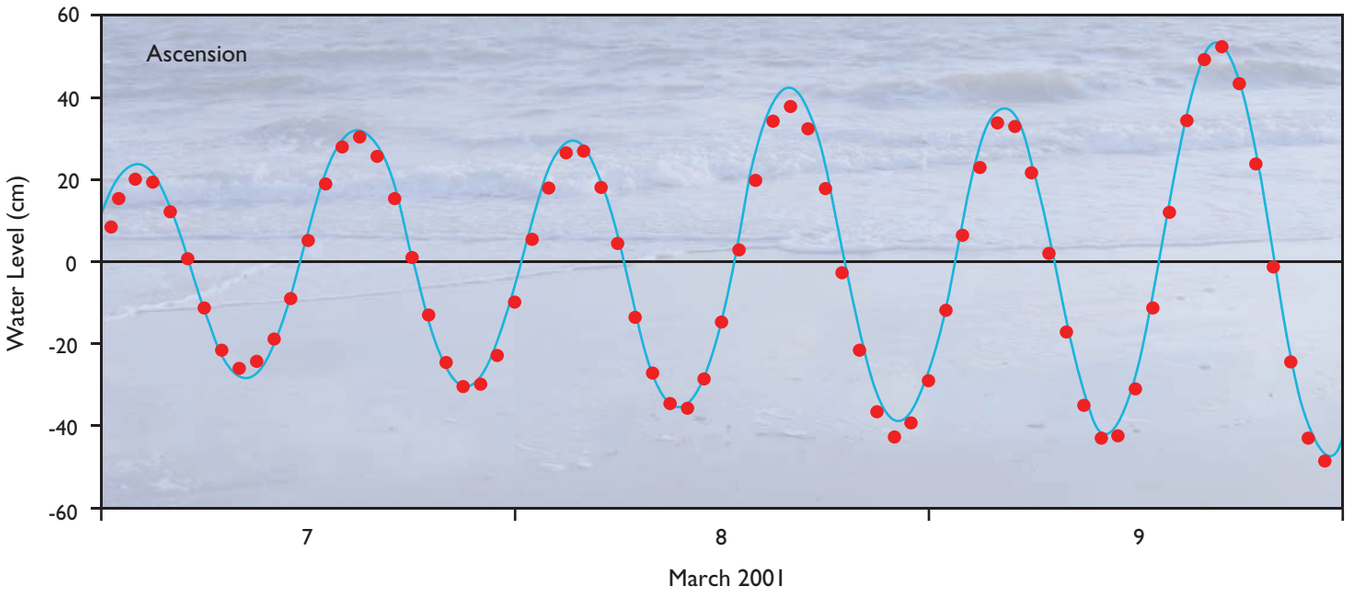
Richard D. Ray



The tide is composed of multiple waves, the largest of which is denoted M2, shown here as determined by TOPEX/Poseidon measurements. This M2 wave cycles once in half a lunar day, or about every 12.4 hours. Colors show maximum elevation at M2 high tide, in centimeters. White lines connect places that experience high tide simultaneously. To predict the full tide at any place, a dozen or more such waves must be added together.

Pick up a newspaper in almost any coastal city and you find predictions for the day's tides. It seems as easy as clockwork. What is not evident, however, is that these tidal predictions are always based on long series of hourly sea level measurements, taken in close proximity to the city, and usually over many years. These data must then be analyzed by methods at least as sophisticated as the motions of the sun and moon, and remember that Sir Isaac Newton claimed that determining the moon's motion precisely was the one problem that made his head ache. The theory of the moon's motion and tides is now understood, but accurate tidal predictions still require building upon historical observations.

What if one is living on a small isolated island with no historical tide-gauge data available? Or, what if one needs to know the tide in the middle of the ocean? Scientists have successfully addressed this problem by using altimeter measurements collected by TOPEX/Poseidon, a satellite launched in 1992 by the United States and France. The satellite altimeter acts as a flying tide gauge, repeatedly measuring sea level over the global ocean, and these data have subsequently been analyzed to allow tide predictions in the open sea and, somewhat less accurately, in coastal waters. The predictions are based on adding together many waves, or constituents,each of which is described by a 'cotidal chart', such as



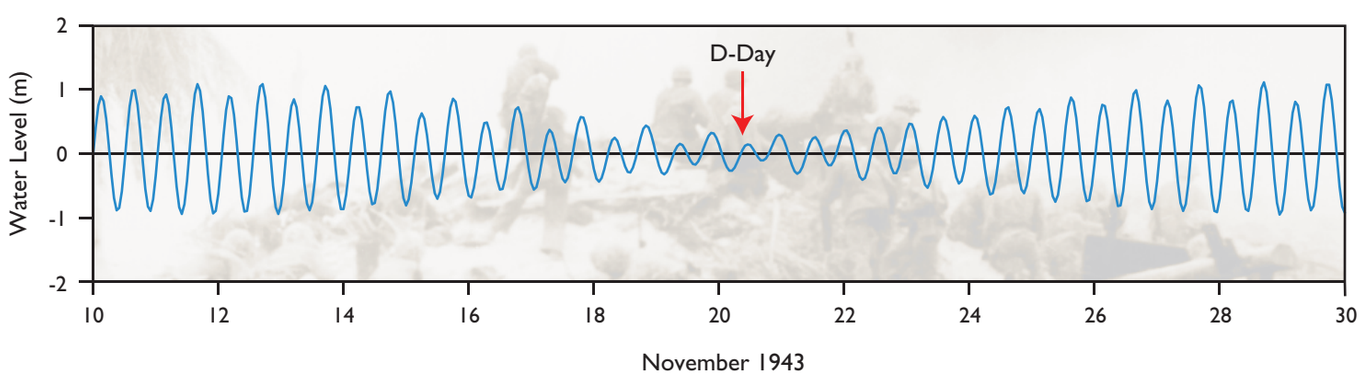
Ground-truth validation of satellite-based tide predictions. A tidal prediction (blue curve), based on analysis of TOPEX/Poseidon satellite altimeter data collected in the vicinity of Ascension Island, in the middle Atlantic Ocean, is found to compare well with actual hourly water level measurements made at the island (red circles.) (Hourly data courtesy of Proudman Oceanographic Laboratory, U.K.)

the one shown here for the moon's principal half-daily tidal wave. At many locations the gravitational tide can now be predicted with an accuracy of a few centimeters or better (although weather effects like storm surges can sometimes spoil the prediction of sea level).

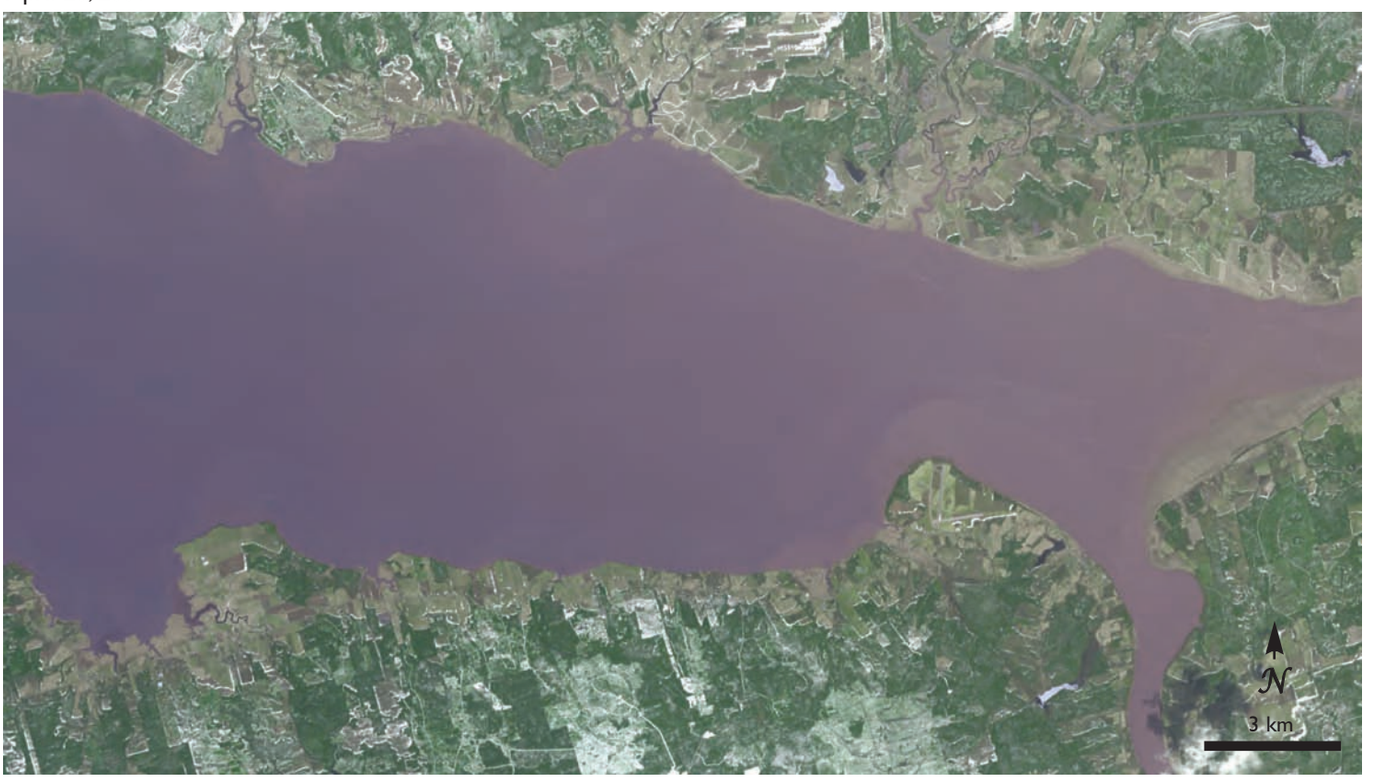
Accurate knowledge of tides is required in countless applications, both military and civilian, coastal and pelagic. Oceanographers are especially keen to predict open-ocean tides with very high accuracies, because the tide can often mask the ocean's smaller, and far more subtle, climate signals. In fact, to use satellite altimetry for any non-tidal science requires first removing the ocean's dominating tide signals from the data.

Organizations like NASA have a special interest in tides, because accurate tidal predictions are critical to all facets of modern space geodesy. Geodesy determines positions, such as a person's position on the Earth's surface or a satellite's position above the surface, and these kinds of measurements, if sufficiently precise, are always affected by tides. For example, a satellite's orbit is perturbed by the gravitational attraction of the ocean's tidal masses; special geodetic satellites like GRACE and LAGEOS are extremely sensitive to such perturbations.

World War II Tide Disaster. "The tide that failed" during the U.S. Marine amphibious landing at Tarawa, November 20, 1943. Unexpectedly low water stranded United States landing craft on coral reefs more than 500 meters from shore, leaving Marines to wade in against withering Japanese defensive fire. The blue curve is a hindcast based on modern tidal measurements, unavailable to military planners during the war.



April 20, 2001



September 30, 2002

High and low tides on the Bay of Fundy, on April 20, 2001 and September 30, 2002, respectively. Situated between the Canadian provinces of New Brunswick and Nova Scotia, the Bay of Fundy is famous for having dramatic differences between its high and low tides. Under typical conditions, high tide at the head (the most inland part) of the Bay of Fundy is as much as 17 meters (about 56 feet) higher than low tide. (Data from the ASTER instrument on the Terra satellite.)