Ocean Surface Topography: Past, Present, and Future

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TOPEX/Poseidon was the first major oceanographic research vessel to sail into space instead of out to sea. The satellite was a joint effort between NASA and the French Space Agency, Centre National d'Etudes Spatiales (CNES). In 1979, NASA was developing the Ocean Topography Experiment (TOPEX) mission, while CNES was planning a similar mission called Poseidon. In 1983, the two agencies decided to pool their resources into a single mission: hence the name TOPEX/Poseidon. On August 10, 1992, the satellite launched aboard an *Ariane II* rocket from the European Space Agency's launch facility in French Guiana. The California Institute of Technology's Jet Propulsion Laboratory (JPL) managed the U.S. portion of the mission for NASA.

TOPEX/Poseidon vastly exceeded its objectives and transformed our understanding of ocean currents and their roles in global climate change. The satellite's radar altimeter measured global ocean surface topography while its Global Positioning System (GPS) receiver and additional instruments determined precision orbit. With these instruments, the satellite achieved an unprecedented accuracy—better than 5 cm in ocean surface topography, or sea-surface height. Planned as a five-year mission, TOPEX/Poseidon operated successfully for more than 13 years. It provided over 98% of the scientific data it was designed to collect for an international team of more than 600 scientists representing 54 countries.

With TOPEX/Poseidon's considerable success, NASA and CNES agreed to extend the time series and update the instrumentation, so Jason-1 was launched on December 7, 2001, and Jason-2 and Jason-3 are currently in development. TOPEX/Poseidon and Jason-1 data revolutionized the way we study the global ocean. During a period when the two satellites operated in a tandem mission mode, they were able to collect twice the amount of data, revealing details of smaller-scale ocean phenomena such as coastal tides, ocean eddies, and ocean currents.

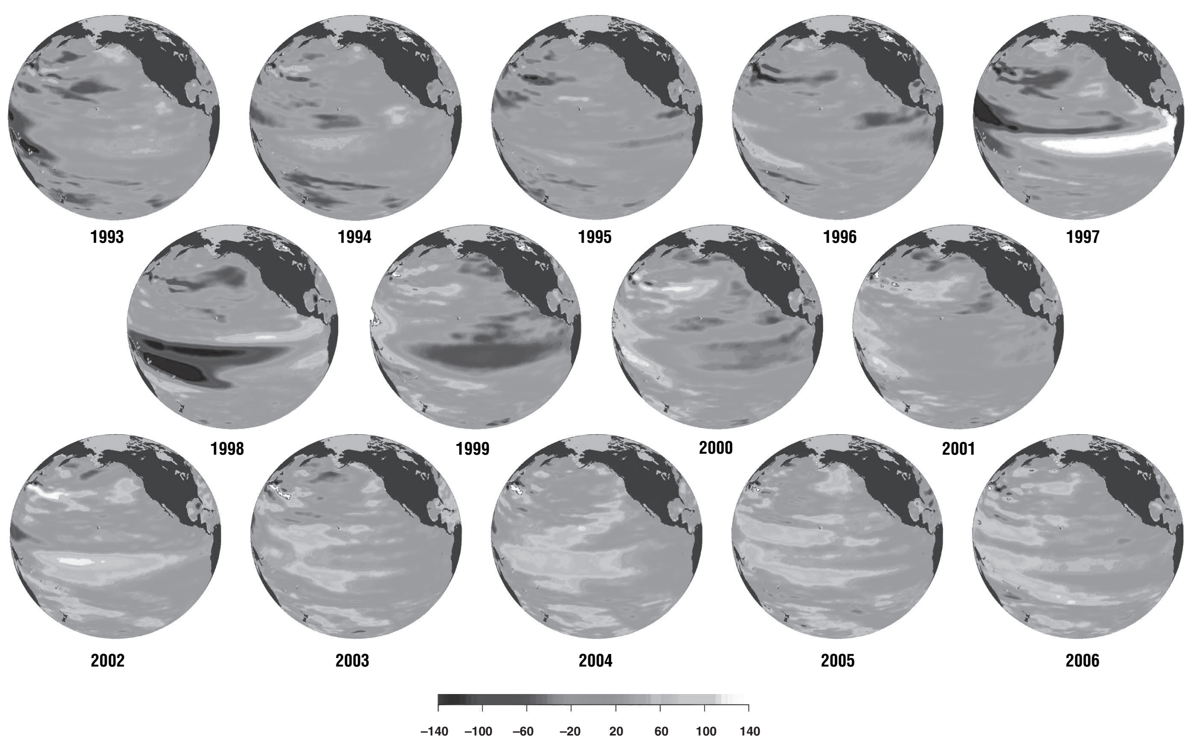

Figure 1. Faces of a Changing Ocean. These data globes show the annual average sea-surface height anomalies for the period from 1993 to 2006. An *anomaly* refers to the difference between the height of the sea surface measured by the satellites and the scientifically accepted normal sea-surface height. In these images, the white areas represent sea surface heights between 8 and 24 centimeters above normal, indicating warmer expanded water. Dark areas represent sea surface heights between 8 and 24 centimeters below normal, indicating cooler contracted water. Sea-surface heights move up and down in a regular yearly pattern as the Sun warms the water of the upper ocean in accordance with the seasons. The seasonal signal was removed from these maps to highlight year-to-year variations. For a color version go to: *sealevel.jpl.nasa.gov/gallery/posters/gifs/14-globe_Litho.pdf*.

One of the most important achievements of TOPEX/Poseidon and Jason-1 has been the highly accurate determination of global patterns of ocean circulation and heat transport in the ocean—see **Figure 1**. "The oceans are Earth's heat capacitors, absorbing over 80% of global warming heat," states oceanographer **Josh Willis** [NASA/JPL]. Thermal expansion is one of the causes of elevated sea-surface height, and therefore signifies the amount of heat stored in the upper ocean. Ocean altimeters measure changes in sea-surface height, and consequently heat storage can be inferred based on these measurements. **The top three meters of the ocean can store as much heat as the entire atmosphere**, and for that reason, oceanographers maintain that ocean circulation is the most important driving force in climate regulation.

TOPEX/Poseidon and Jason-1 have provided the most complete, long-term, global record of sea-level changes, ocean circulation, and basin-wide current variations ever collected. With this invaluable data, scientists can compare computer models of ocean circulation with actual global observations and use this information to better understand changes in sea-level as well as the effects of currents on global climate, and to make improvements in climate predicting ability.

TOPEX/Poseidon also gave us the first global perspective on El Niño and La Niña, part of a cycle that repeats every 3–7 years in the Pacific Ocean and has profound effects on world climate. This global view presented ocean and climate scientists with the opportunity to observe the development of these events and to follow their evolution. For example, observations from TOPEX/Poseidon—e.g., **Figure 2**—enabled scientists to forecast some of the impacts of the 1997-1998 El Niño. Additionally, the data record from TOPEX/Poseidon and Jason-1 supplied unprecedented views of ocean variability on decadal scales, revealing large-scale patterns of ocean circulation and air-sea interactions in the global oceans. These data provide evidence of longer-lasting phenomena, such as the Pacific Decadal Oscillation, a fluctuation in the Pacific Ocean that waxes and wanes over a 20–30 year period.

Additionally, the data from TOPEX/Poseidon and Jason-1 benefit society in several respects including operational applications, such as hurricane prediction, navigation, marine mammal research, offshore operations, fisheries, mapping global tides, and other scientific research in physical oceanography.

In October 2005, TOPEX/Poseidon's *pitch reaction wheel*, which helps keep the spacecraft in its proper orbital orientation, stopped working which prevented further science operations. Ground controllers transmitted the final command terminating the historic mission in January 2006. Today, the satellite remains safely in orbit 1,336 kilometers above Earth. Jason-1 flew in a tandem mission with TOPEX/Poseidon for nearly three years before the older spacecraft ceased operations. Now flying solo, Jason-1 will continue to collect valuable data on ocean circulation and ocean topography for researchers and operational users worldwide. The expectation is that Jason-1 continues to function well and will be able to fly in tandem with Jason-2 for a time after it launches.

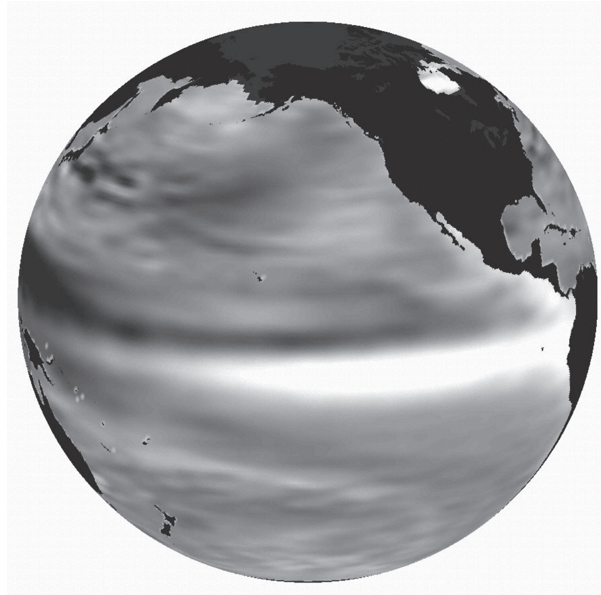

Figure 2. The TOPEX/Poseidon satellite produced this image of the Pacific Ocean in the winter of 1997 during a strong El Niño. The large bright white band that stretches from the eastern Pacific across the center of the ocean represents an immense area of unusually warm water.

Ongoing science investigations for Jason-1 include studying ocean variability on decadal scales in relationship to climate; understanding how changes in the ocean's heat content and mass affect global sea-level; producing better tide models for the coastal oceans where the scales of tides are too small to be resolved by a single altimeter; and studying ocean eddies and their effects on large-scale ocean circulation and heat transport. Another objective of the Jason-1 satellite is to determine the characteristics of deep-water tides. Tides are the most visible change in the ocean on a daily basis and play a significant role in navigation; they are the main source of mixing in the ocean, and influence biological activity. Jason-1 has demonstrated that high accuracy radar altimetry is no longer experimental; the data are fundamental to NOAA and many other operational entities.

The successes of the TOPEX/Poseidon and Jason-1 satellites continue to motivate further investigation. A comprehensive view of the world ocean is the only way to measure global climate change and other large-scale changes in ocean conditions. Changes in sea-level are the primary indicators of global warming, yet according to Willis; "Sea-level rise is the most highly visible and poorly predicted impact of global warming." We need to find out how global sea-level is affected by natural variability as well as by human influence.

Changes in oceanic thermohaline circulation are another aspect of climate change that requires further study. In order to understand the relationship between climate change and change in global ocean circulation, we first need to understand how global ocean circulation varies on interannual, decadal, and longer time scales. Our ability to improve climate forecasting depends on the extent of the data collection time series; therefore, as we lengthen the time series we improve our ability to anticipate future conditions. Furthermore, as the climate continues to change, the data that form the basis of our present predictions may no longer be relevant, so our methods of forecasting must adapt to the most recent observations.

The best way to obtain these vital global-scale observations is from satellite altimetry. The next NASA ocean altimetry mission slated to expand the efforts of TOPEX/Poseidon and Jason-1 is the Ocean Surface Topography Mission (OSTM) on Jason-2—see **Figure 3**. OSTM/Jason-2 is scheduled for launch in June 2008 from Vandenberg Air Force Base. This new mission, also a collaborative effort between NASA and CNES, includes two new partners: the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and the National Oceanic and Atmospheric Administration (NOAA). With new partners, and improved instrumentation and satellite tracking, OSTM/Jason-2 will extend the ocean-surface topography time series even further to accomplish two decades of observations, and move closer to the goal of establishing operational as opposed to experimental satellite radar altimetry for oceanographic applications. The OSTM/Jason-2 satellite will carry the next generation instruments including CNES's Poseidon-3 dual-frequency radar altimeter to measure sea-surface height, NASA/JPL's Advanced Microwave Radiometer (AMR) to measure total water vapor along the altimeter path to correct for pulse delay, and NASA/JPL's Global Positioning System Payload (GPSP) receiver, which provides precise orbit ephemeris data. These instruments will have lower noise and be programmed with algorithms that enable better tracking over land and ice. NOAA will provide management of flight operations during the routine operational phase, archival and distribution services for the OSTM/Jason-2 raw mission data, near-real-time operational products, and will acquire, produce, and distribute geophysical data to all interested users.

The benefits of OSTM/Jason-2 are many, ranging from high-resolution, small-scale views of eddies and coastal conditions, to the largest global-scale measurements of sea-level rise, changes in ocean circulation, and open-ocean tides. It will help us improve our understanding of El Niño, La Niña, droughts, and floods. OSTM/Jason-2 will also extend the length of the record of sea- surface height, improving our understanding of long timescale climate events such as the Pacific Decadal Oscillation (PDO) and our ability to predict and understand long-term changes to Earth's climate.

Because long-term, time-series climate data are of such vital importance, scientists are already preparing for the follow-on to Jason-2, even before Jason-2 is launched next year. Jason-3, also proposed as a joint CNES, EUMETSAT, and NOAA mission, will launch in 2012 and should overlap in tandem with Jason-2, thus ensuring continuity. As climate conditions become ever more pertinent in this changing world, the next two ocean-surface topography missions will extend this invaluable data into the coming decades, improve our understanding of the ocean's role in climate, and provide for continued operational successes.

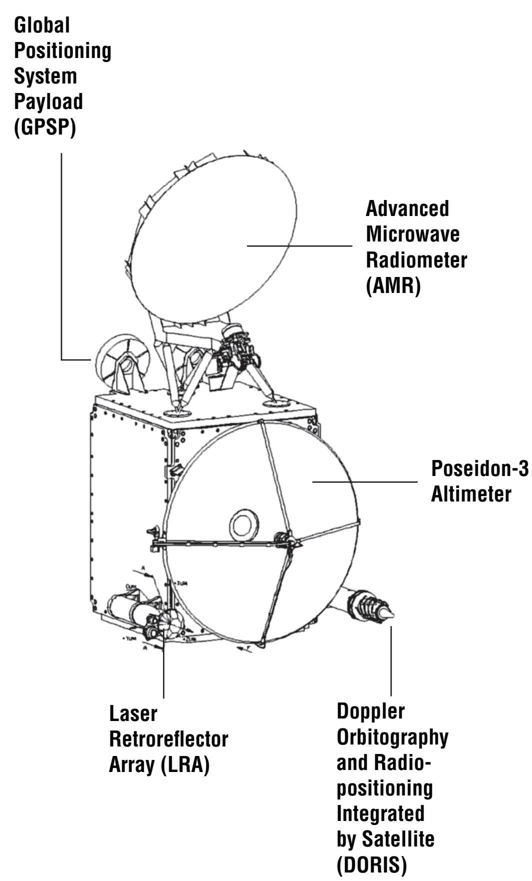

Figure 3. OSTM/Jason-2 is currently undergoing extensive testing in preparation for a June 2008 launch. It will be a follow-on to the two previous ocean topography missions that will extend our understanding of long-term oceanographic conditions.