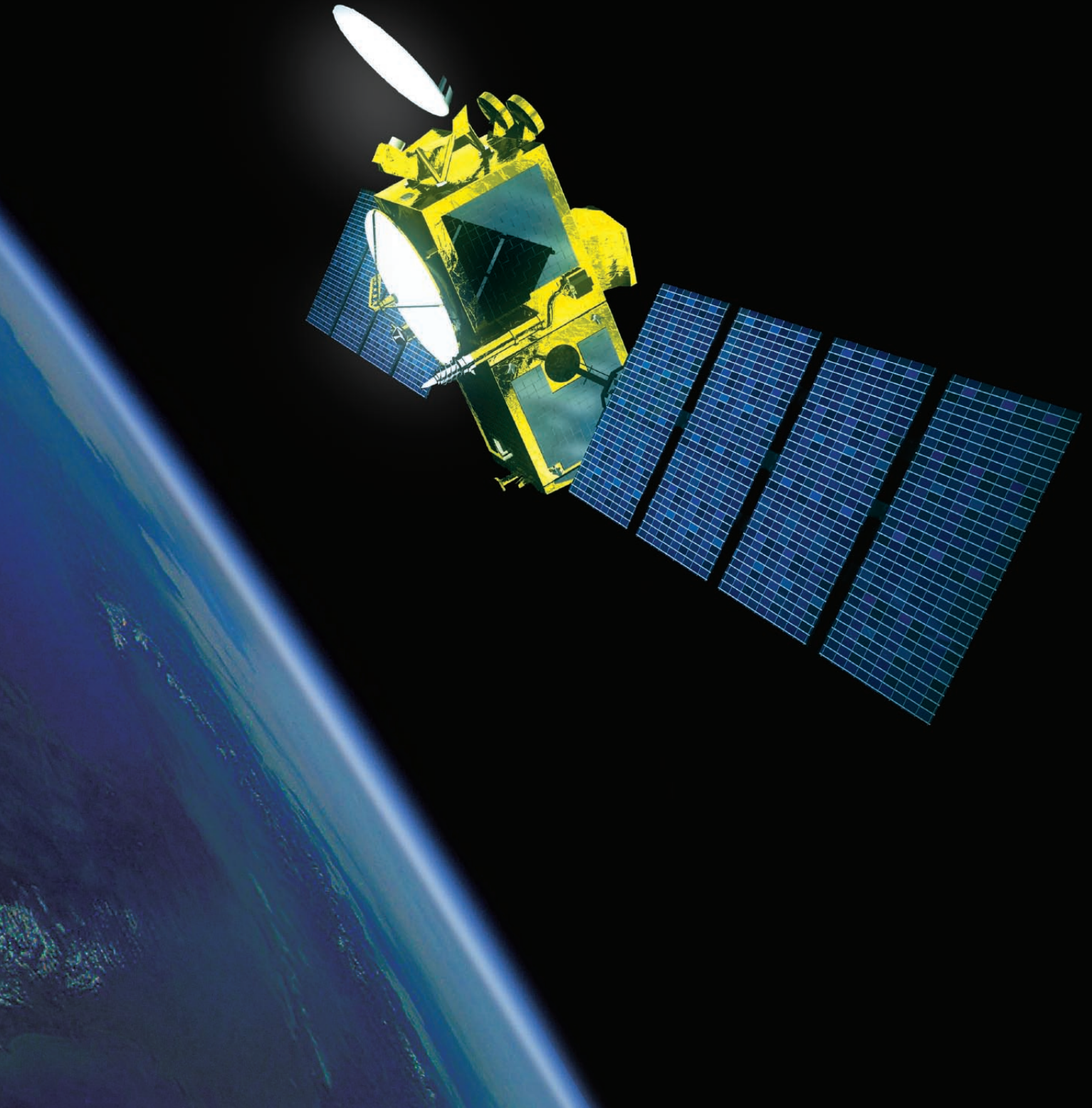


National Aeronautics and Space Administration



Ocean Surface Topography Mission/Jason-2

Watching Over Our Ocean



Acknowledgments

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CNES Web site
<http://www.aviso.oceanobs.com/en/missions/future-missions/jason-2/index.html>

EUMETSAT Web site
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Cover image: NASA, CNES

A satellite altimetry satellite is shown in orbit above the ocean. The satellite is gold-colored with a large white parabolic antenna and solar panels. The background shows the Earth's surface with blue oceans and white clouds, and a bright sun in the sky.

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The Ocean in a Changing Climate



Image credit: WH Films

We see it on the evening news; we witness it in our own backyards—our climate is changing. From heat waves to more devastating floods and hurricanes to melting glaciers and sea level rise, the effects of climate change are all around us. The vitality of crops, our drinking water supply, animal populations, the spread of diseases, and, ultimately, the rise and fall of civilizations are all influenced by climate. Scientists know that natural variability in Earth's climate affects weather patterns, but it's also increasingly clear that the burning of fossil fuels by humans is a major contributor to the changes we are experiencing.

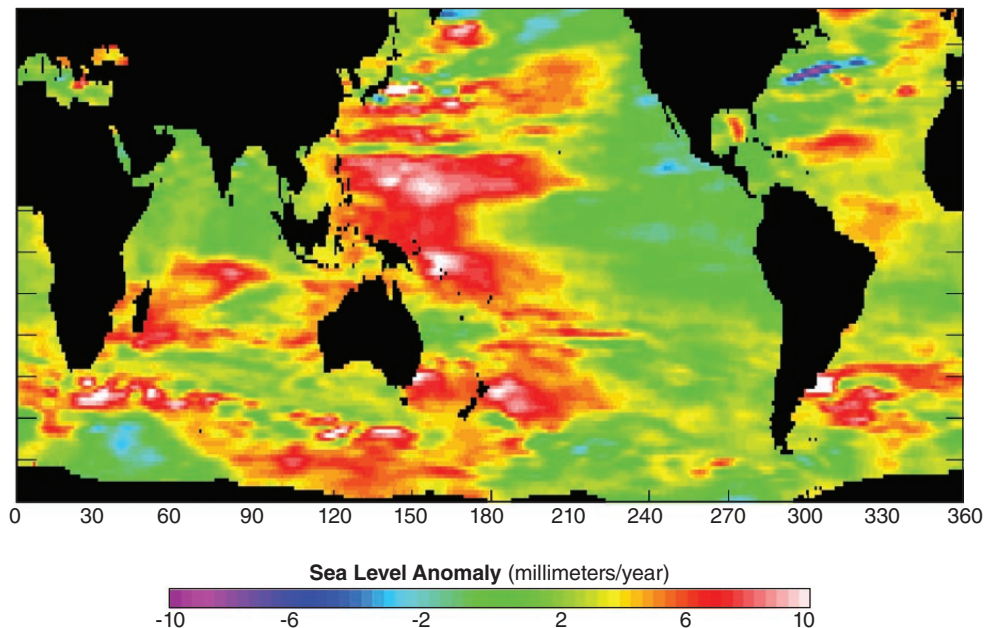
During the last century, carbon dioxide emissions caused by human activities have been the main contributor to the 0.6°C (1°F) increase in Earth's average global air temperature—a seemingly small amount, but enough to cause global environmental impacts. It is unclear, though, how much warming will occur in the future and how widespread it will be. To predict how Earth's climate will

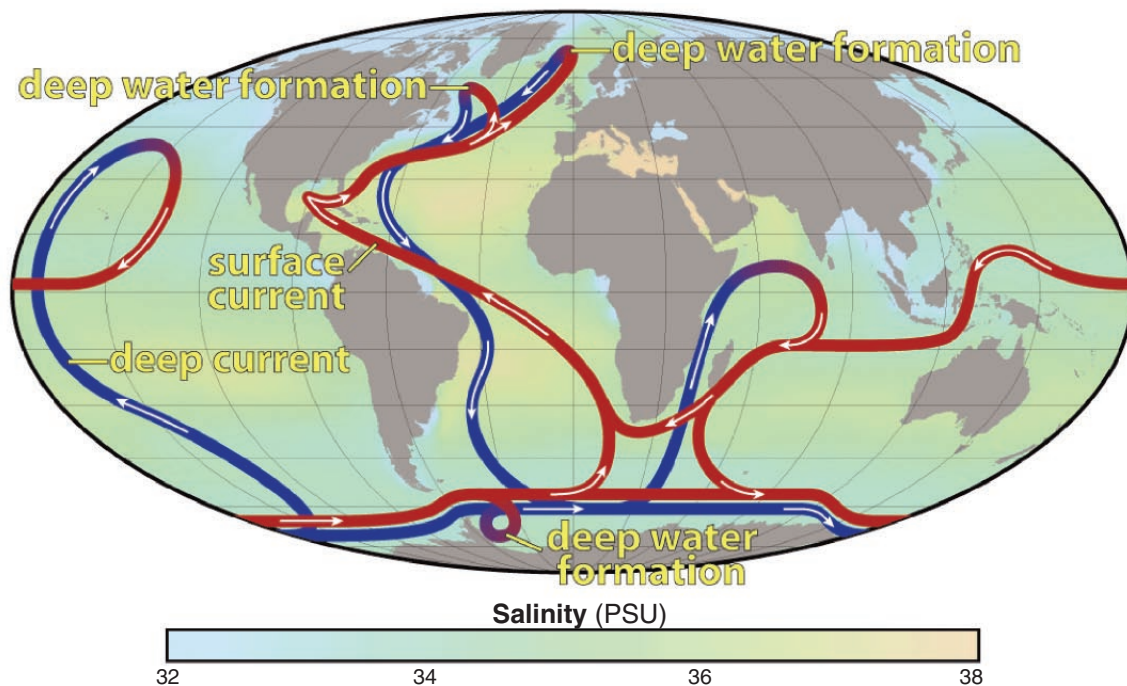
continue to change, it is first necessary to understand what drives it.

The Ocean's Role in Climate

The ocean is one of the biggest “drivers” of Earth's climate system. Global climate is the result of a complex interplay between the atmosphere and ocean. The world ocean stores immense amounts of heat—much more than the atmosphere—and recirculates this energy around the planet in a process called the *oceanic heat conveyor belt*. The ocean covers more than 70 percent of Earth's surface and absorbs a large amount of the energy our planet receives from the Sun. Solar energy is not distributed evenly over the surface, though. Equatorial regions receive more solar radiation than they emit back to space, while polar regions emit more radiation than they receive from the Sun. The ocean, along with the atmosphere, helps to move heat between the equator and the poles.

The image at right shows the dominant patterns for the change of sea level of the global ocean from 1992 to 2008. The yellow and red regions illustrate that over most of the ocean, the sea level is rising at rates from 1-10 millimeters per year. The patterns of sea level rise are not uniform and are determined by the ocean circulation and the processes through which heat is absorbed and transported by the ocean. Credit: L. Fu, NASA JPL





Atmospheric winds blow across the ocean surface to create currents that swirl in *gyres* around areas of high and low sea level. These currents release heat as they travel from the equator to the poles, and some of this heat is transferred to the atmosphere through evaporation over tropical and subtropical waters. As the currents lose heat, they begin to cool and become more dense, slowly sinking and spreading throughout the deep parts of the ocean. Eventually, they will reach the surface once again and perpetuate the cycle in this oceanic heat conveyor belt. In this way, the ocean regulates the temperature on our planet much like the thermostat in your home acts to warm or cool your surroundings.

The Ocean and Rising Temperatures

As global temperature rises, the excess heat is absorbed and stored in the upper layers of the ocean—a process that slows atmospheric warming. More than 80 percent of the heat from global warming over the past 50 years has been absorbed by the ocean. This heat, however, is not stored without consequence. Increased sea surface temperatures cause evaporation to intensify, introducing more

water vapor—the most abundant greenhouse gas and one that’s 50 times as powerful as carbon dioxide—into the atmosphere. At the same time, warmer ocean temperatures cause the ocean’s volume to increase in a process called *thermal expansion*. The result is higher sea levels that threaten coastal communities and habitats. While we don’t know exactly how much more heat the ocean can absorb from global warming, it is already clear that significant changes in Earth’s hydrologic cycle and climate result from any excess storage of heat.

With the evaporation rate higher, scientists have found that the salinity of the ocean is changing. Water in the polar regions is becoming fresher, while tropical waters are getting saltier. Changes in the salinity of the ocean can disrupt its circulation patterns, stalling the movement of heat and leading to global or regional cooling within several decades. Earth has experienced these abrupt climate changes throughout its history, with the most recent one—known as the *Little Ice Age*—triggered about 700 years ago. Charting the behavior of the ocean over time allows us to better foresee changes in Earth’s climate.

The oceanic heat conveyor belt is also known as the *Thermohaline Circulation*. Thermohaline because these surface and deep currents are driven both by heat (“thermo”) and salinity (“haline”). It is estimated that the round trip journey of a single section of this conveyor belt can take from 1,000 to 2,000 years. Image credit: NASA, adapted from the IPCC 2001 and Rahmstorf 2002.

Note: PSU stands for *Practical Salinity Unit*. One PSU is approximately equivalent to 1 gram of sea salt per kilogram of seawater.

Mapping the Ocean

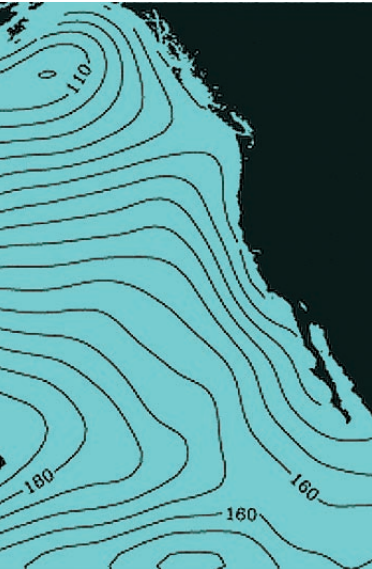


Image credit: Bo Qiu

Ocean Surface Topography

The ocean surface has highs and lows, just like the hills and valleys of Earth's land depicted on a topographic map. The variations in height, called *ocean surface topography*, can be as much as 2 meters (6.5 feet) from place to place.

Earth's gravity field imposes a greater influence on sea surface height. By causing the sea surface to assume an irregular shape called the *geoid*, gravity is responsible for height differences of up to 200 meters (656 feet).

Ocean surface topography is determined by removing the effect of Earth's gravity from the total sea surface height to reveal the 2-meter variations caused by ocean circulation, temperature, and salt content. It is a valuable indicator of the ocean's role in our climate, telling us where the ocean stores and transports heat and how it interacts with the atmosphere.

Accurate maps of ocean surface topography are crucial to understanding the ocean's influence on our weather patterns and long-term climate. The dramatic impact that rising sea levels have on coastal regions is just one of many examples of how changes in the ocean greatly affect our society.

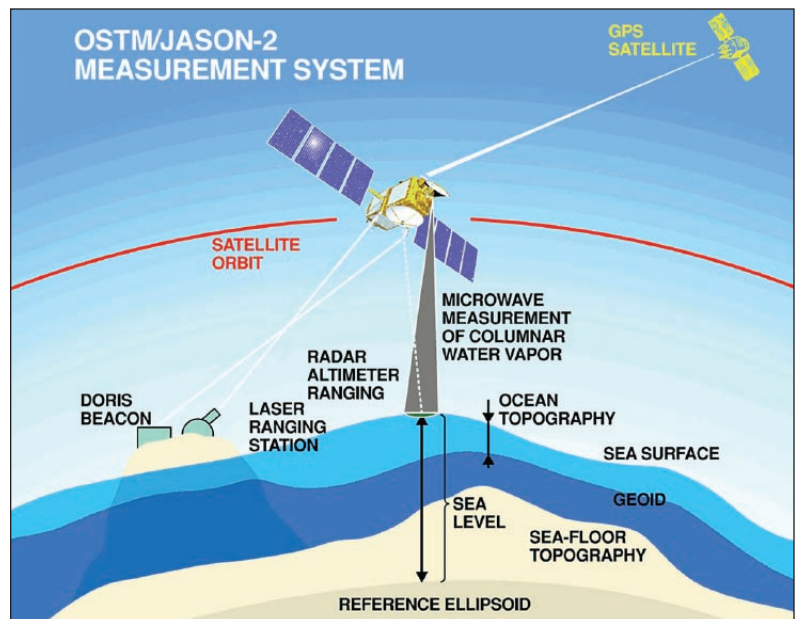
Satellite radar altimeter measurements of ocean surface topography are greatly improved by instruments that provide precision orbit determination. The Poseidon-3 altimeter on OSTM/Jason-2 is complemented by three such instruments: the GPSP, LRA, and DORIS. (See *The Instruments* section on page 14.) Image credit: NASA JPL

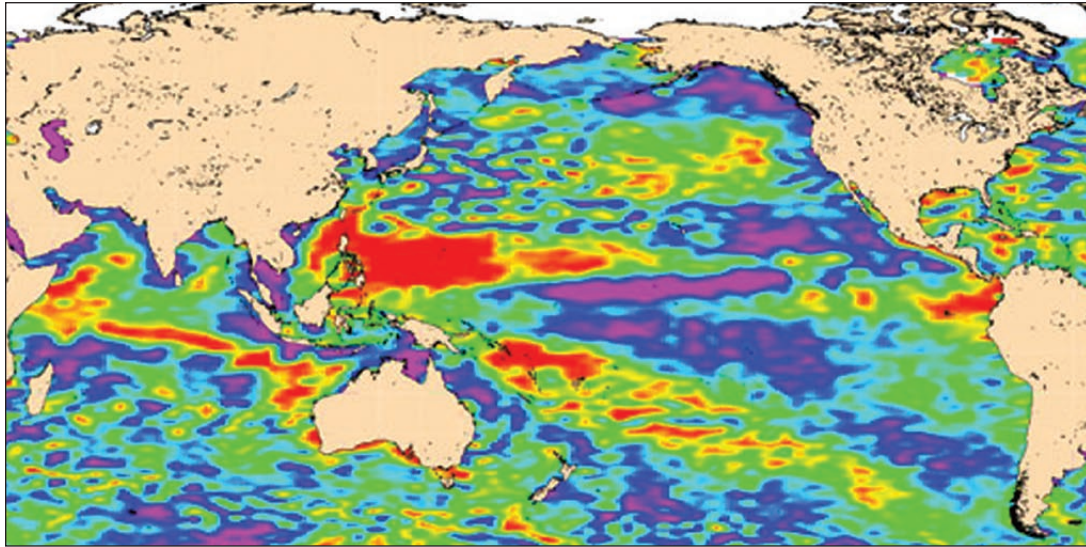
Altimetry

The height of the sea surface is measured with *satellite altimetry*. Radar altimeters measure the distance between the satellite and the sea surface by calculating the time it takes for a microwave pulse to reach the sea surface and travel back to the satellite.

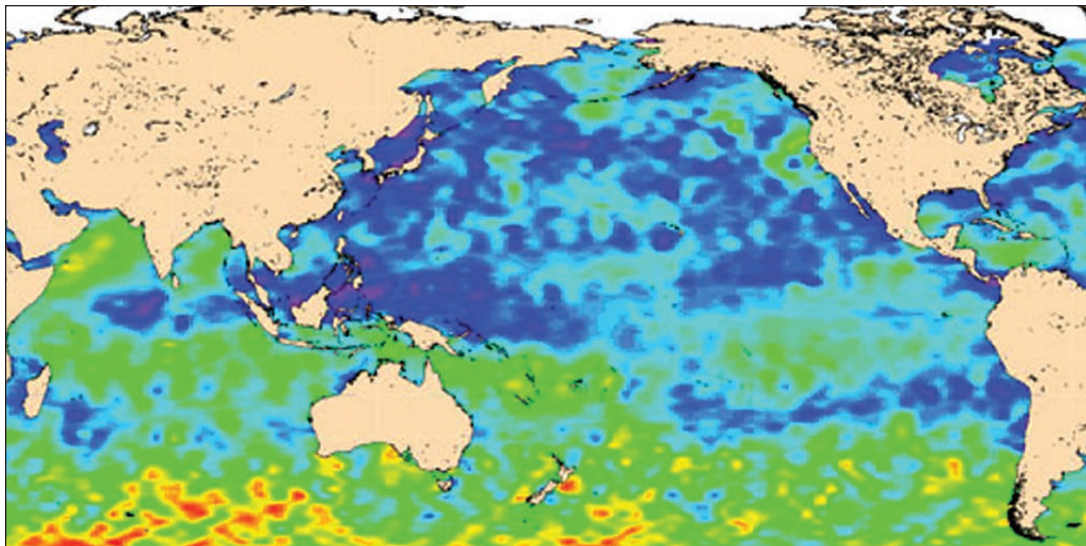
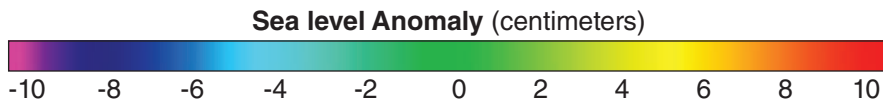
The measurements are corrected to account for anything that may delay the microwave pulses, such as water vapor in the lower atmosphere, free electrons in the upper atmosphere (ionosphere), and the dry air mass of the atmosphere. The result is remarkably precise sea surface levels—to within a few centimeters (about one inch) height.

Measurements of wave height, ocean current velocity and direction, and wind speed can also be obtained using satellite altimetry.

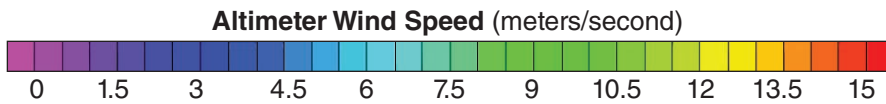




OSTM/Jason-2 map of sea level anomalies from July 4 to July 14, 2008. Image credit: CNES



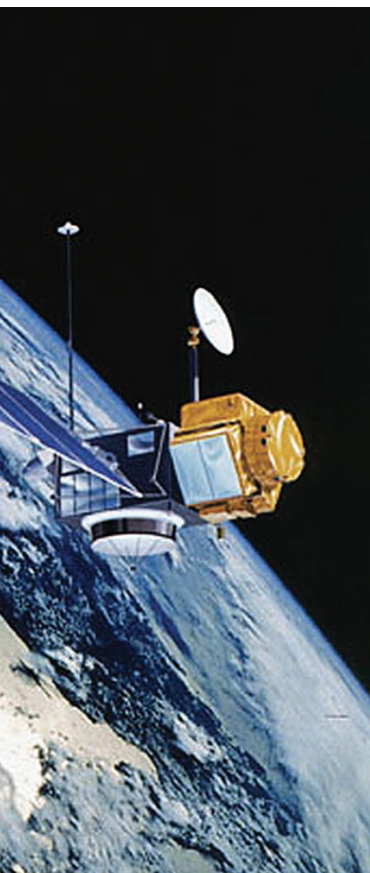
OSTM/Jason-2 map of wind speeds from July 4 to July 14, 2008. Image credit: CNES



A Satellite Altimetry Family Tree

Launched in 1978, Seasat (right) collected more data in 100 days than ships did in the previous 100 years. Image credit: NASA

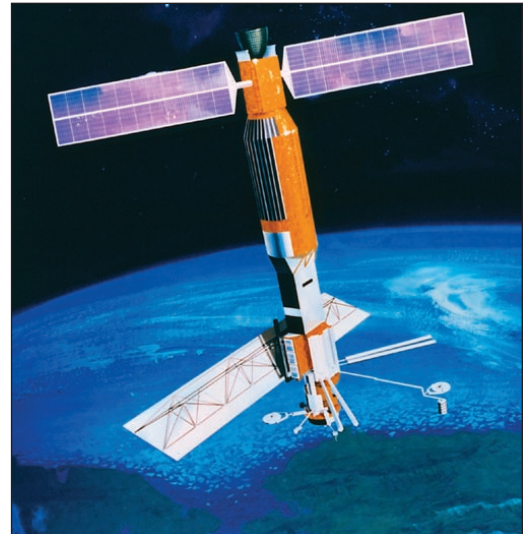
Launched in 1992, TOPEX/Poseidon (below) began an international effort to characterize the global ocean. Image credit: CNES



The use of satellite altimetry to map the ocean surface began in 1973 with the launch of NASA's Skylab, a space science and engineering laboratory sent into Earth orbit. Following Skylab, the GEOS-3 satellite carried the first spaceborne altimeter and was used to delineate the major trenches of the ocean. Subsequent satellites continued to explore the use of ocean altimetry and, in 1978, NASA's Seasat provided never-before-seen data on Earth's ocean. With Seasat, the resolution of ocean surface topography measurements increased dramatically. The mission provided a tantalizing glimpse into the many applications possible by monitoring the ocean from space.

Ushering in a new era marked by the long-term collection of ocean surface data, NASA and the French space agency, the Centre Nationale d'Etudes Spatiales (CNES), teamed up to launch the Ocean Topography Experiment (TOPEX)/Poseidon mission in 1992. TOPEX/Poseidon began an international effort to characterize the world's ocean and exceeded expectations with its extended lifespan. Measuring sea surface height over 95 percent of Earth's ice-free ocean once every 10 days, TOPEX/Poseidon gathered oceanographic data with unprecedented accuracy (to within 4 centimeters—less than 2 inches) for more than a decade.

With the success of TOPEX/Poseidon, scientists recognized the importance of extending the time-series of ocean observation data for use in science and other ongoing applications as well as improvements in our ability to make long-term climate projections. Launched in 2001, Jason-1 joined with TOPEX/Poseidon to obtain double global coverage until the earlier mission's hardware failure in 2005. Jason-1, also a joint project between NASA and CNES, measures ocean surface topog-



raphy to 3.3 centimeters (1.3 inches). Data from Jason-1 are available four days after being recorded and are used by weather and climate agencies for improved forecasting.

To further extend the record of Earth's oceanographic data and enable greater data usage by the forecasting community, four organizations collaborated to launch the Ocean Surface Topography Mission on the Jason-2 satellite (OSTM/Jason-2) in 2008. NASA, the National Oceanic and Atmospheric Administration (NOAA), CNES, and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) worked together to develop and launch OSTM/Jason-2. The altimeter aboard the OSTM/Jason-2 satellite follows Jason-1 in its quest to continue mapping the ocean surface. With NOAA and EUMETSAT as newcomers to the ocean surface topography missions, both organizations will gain experience in the field by managing OSTM/Jason-2's operation and data processing. NASA and CNES will maintain OSTM/Jason-2's instruments.

OSTM/Jason-2 was launched on June 20, 2008, from Vandenberg Air Force Base in California atop a United Launch Alliance Delta II rocket. At an operational orbit of 1,336 kilometers (830 miles), the spacecraft repeats its ground track every 10 days to cover 95 percent of the world's ice-free ocean. During the first six to nine months of its mission, OSTM/Jason-2 flies in line with Jason-1 (approximately 55 seconds or 300 miles behind) while scientists compare the operation and accuracy of both satellites' instruments and data products. Once the cross-calibration and validation are complete, Jason-1 is moved to a position parallel to OSTM/Jason-2, facilitating double global coverage of the world's ocean.

Since Earth's geoid influences ocean surface topography measurements, it's important to have a clear picture of our planet's shape. A "close relative" on the Altimetry Family Tree is the Gravity Recovery and Climate Experiment (GRACE). GRACE, launched in 2002, maps monthly variations in Earth's gravity field and provides a closer approximation of the geoid or true physical figure of Earth. Gravity field variations reflect changes in ice mass in Greenland and Antarctica, ocean mass changes, water content

in river basins on land, or changes caused by large earthquakes. Data from GRACE are critically important when it comes to obtaining an accurate measurement of ocean surface topography.

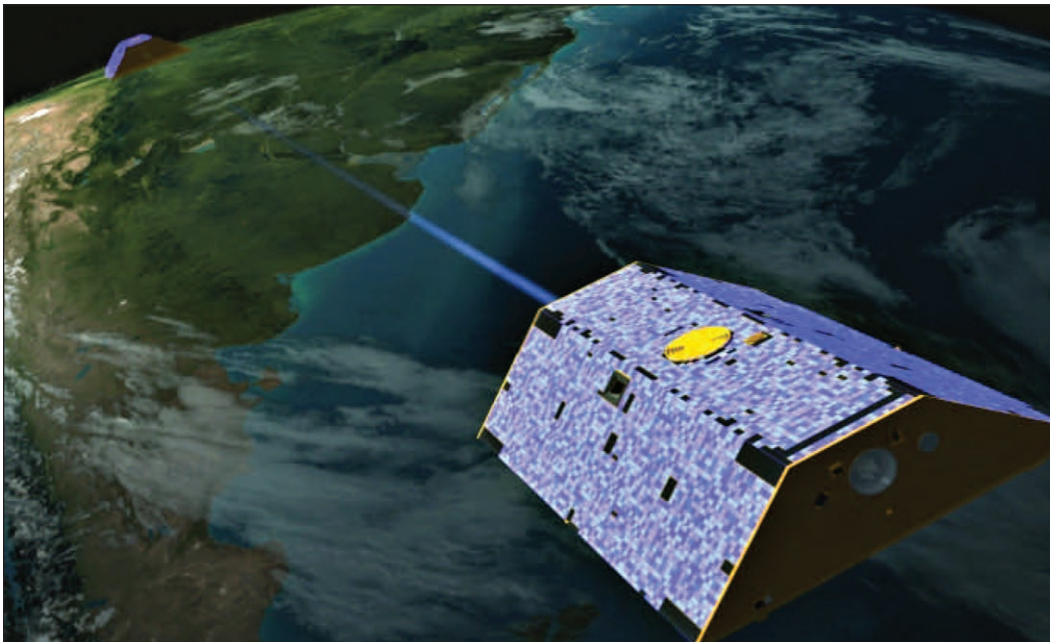
Satellite Altimetry Applications

The interdisciplinary study of Earth's ocean is achieved through global partnerships of agencies such as NASA, NOAA, CNES, and EUMETSAT. By combining their expertise and experience, these agencies facilitate the vast study of ocean surface topography. As a result, satellite altimetry has contributed a wealth of information to the fields of oceanography, climatology, and meteorology.

The time series of sea surface height measurements, approaching sixteen years, has provided oceanographers and marine operators with an exceptional opportunity for new discoveries in both scientific research and operational applications. In combination with other data streams such as ocean color, winds, gravity, and ocean profiling floats, scientific researchers are discovering new ways to view ocean processes and are increasingly able to discern more intermediate-scale ocean structures and phenomena.



The 12:46 a.m. launch of OSTM/Jason-2 from Vandenberg Air Force Base on June 20, 2008, enabled it to go into orbit directly behind Jason-1. Image credit: ULA



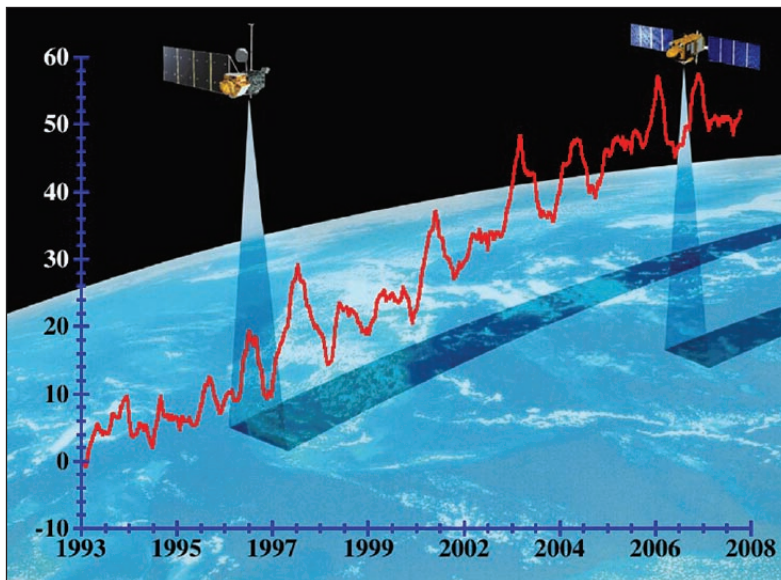
GRACE's precise gravity measurements improve the accuracy of ocean altimetry data. Image credit: GFZ

Global sea level has risen about 3 millimeters (0.1 inch) per year since TOPEX/Poseidon (on the left) began its precise measurement of sea surface height in 1993 and was followed by Jason-1 in 2001. In this graph, the vertical scale represents globally averaged sea level in millimeters. Seasonal variations in sea level have been removed to show the underlying trend. Credit: University of Colorado

Results from satellite altimetry missions have led to significant improvements in forecast accuracy. NOAA scientists routinely use satellite altimetry data to anticipate the weather-related effects of El Niño and La Niña events and the climatic effects of the Pacific Decadal Oscillation—a 20- to 30-year-long ocean temperature shift

between a “warm phase” and a “cool phase”. Data on the amount and distribution of heat in the ocean are used to predict hurricane frequency and intensity. This forecasting ability becomes increasingly important as we may see heightened hurricane activity with warming of the globe.

By having access to data every several days, offshore industries can be prepared for rough weather that may interfere with operations or threaten safety. Information on *ocean eddies*—currents that bring up nutrients from deeper waters—and ocean temperature is used to follow animal migration patterns and evaluate coral reef health. The data can be used to map



ocean currents and eddies, which have a major impact on coastal fisheries, offshore oil facilities, ocean shipping, and marine ecosystems. Private companies use and distribute altimetry data tailored specially for commercial and operational applications.

With the addition of OSTM/Jason-2, the methodologies of ocean altimetry measurements will transition from basic research and technology verification to these operational uses. The focus will move from research objectives to data applications that benefit society. Operation of the OSTM/Jason-2 satellite will be turned over to the operational weather and climate agencies—NOAA in the United States and EUMETSAT, the European meteorological satellite agency. NASA and CNES will continue to support instrument and spacecraft operations and will archive select data from the mission. They will also continue to support an international science team that uses the data to conduct important ocean science studies. Again, many of the study objectives include benefits to society.

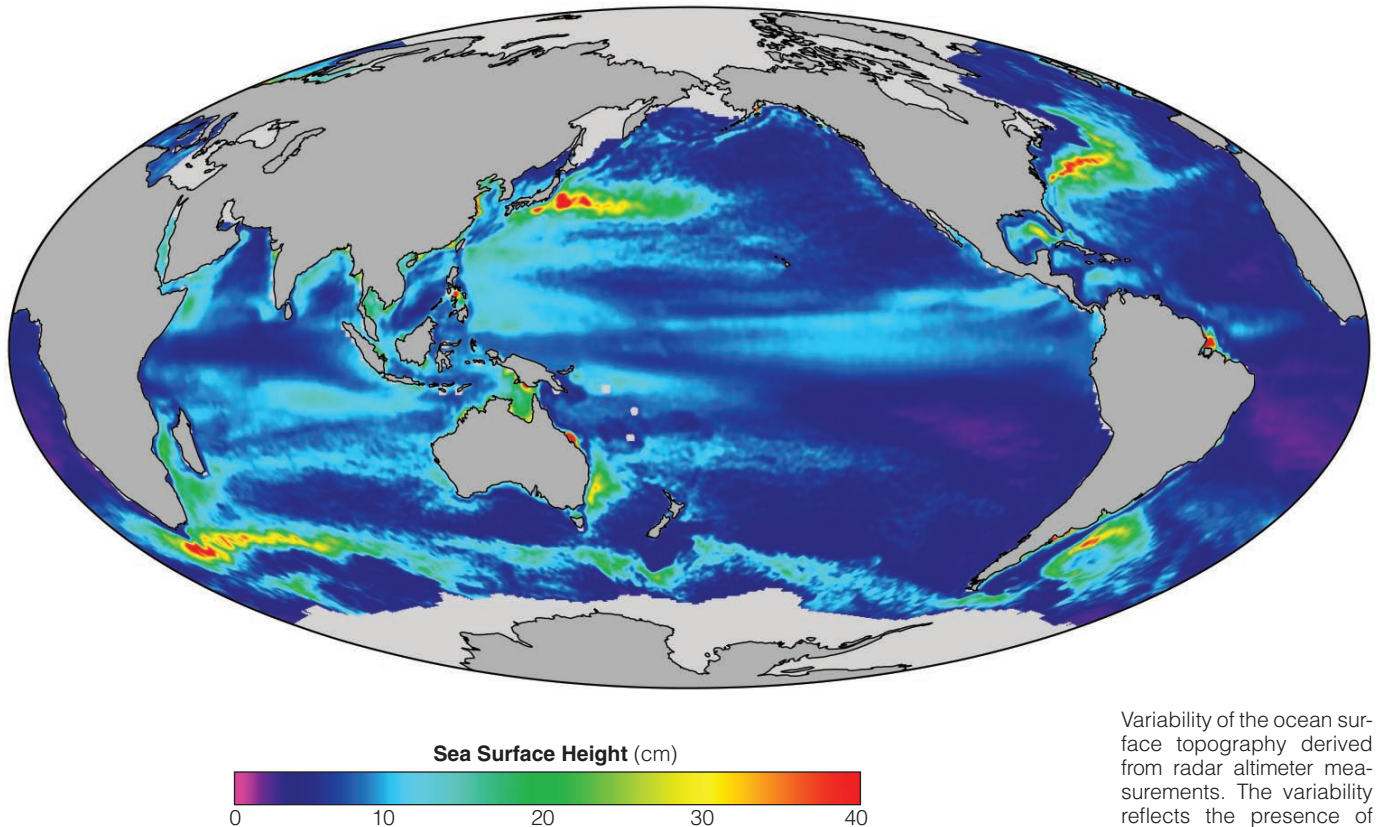
The applications of ocean surface topography are numerous and continue to grow as instrument sophistication and data processing capabilities are enhanced.



Seaturtle.org uses satellite altimetry data to study migratory routes of hawksbill turtles in relation to surface eddy fields in their ocean habitats. Image credit: E. van Wier

TOPEX/Poseidon and Jason-1

Lessons Learned



Variability of the ocean surface topography derived from radar altimeter measurements. The variability reflects the presence of ocean eddies. Data from TOPEX/Poseidon and European Remote Sensing (ERS) satellites; image processing by L. Fu, NASA JPL

While altimeters on early missions demonstrated that ocean surface topography could be measured from space, it wasn't until TOPEX/Poseidon and Jason-1 that the importance of ocean monitoring became widely known. Perhaps most striking about what we've learned from TOPEX/Poseidon and Jason-1 is that our ocean is constantly changing.

From these missions, we've achieved our first glimpse of the global ocean—its seasonal current changes and large-scale oscillations—and have been able to chart its changes over

time. We can finally begin to understand how ocean circulation works and can use satellite data to test the accuracy of our computer models. We now know that the ocean has changed since the launch of TOPEX/Poseidon in 1992—it's now warmer, sea level has risen, and ocean gyres have sped up and slowed down over a time span of 15 years. Without TOPEX/Poseidon and Jason-1, we'd still be very much in the dark about the ocean and limited in our ability to determine how its changes will impact our climate and society.

OSTM/Jason-2

Continuing the Altimetry Legacy

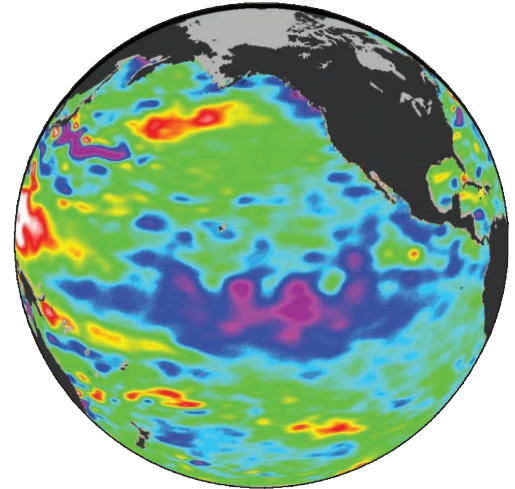


Argo profiling floats measure temperature, salinity, pressure, and current velocity of the ocean. When combined with sea surface height data from satellites, a complete description of the upper ocean is achieved. Image credit: Japan Coast Guard

The globe image at right shows Jason-1 data indicating February 2008 La Niña conditions. Image credit: NASA

Many oceanic phenomena take place over long time periods and require many years of continuous observations to study them. OSTM/Jason-2 will extend the important data time-series of ocean observations into a third decade and will provide scientists with the information they need to answer increasingly complex questions about how our ocean functions. The observations from OSTM/Jason-2 open up new possible applications for satellite altimetry data while also improving upon the accuracy of existing applications.

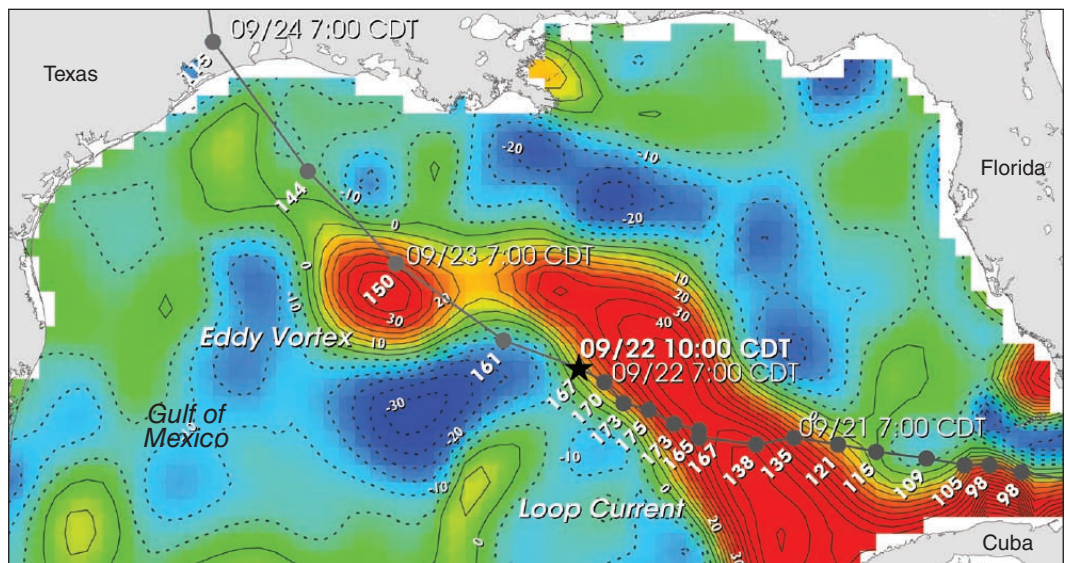
With this new information, operational users, such as private companies and ocean/weather forecasting agencies, will be more confident of conditions predicted by their models. The accuracy of hurricane predictions will also increase, saving lives and property while assisting in disaster relief planning. Continuing to collect data on river and lake levels will help us to improve management of our water resources. Finally, offshore industries and the military rely on the latest marine data for their



efficient operations and safe navigation and will benefit from OSTM's observations.

The data from OSTM/Jason-2 will be used in conjunction with data sets from GRACE and Argo (a global array of 3,000 ocean-profiling floats) for comprehensive coverage of ocean salinity, temperature, velocity, and surface topography.

Hurricane Rita rapidly intensified to Category 5 status as it passed over the warm waters of the Loop Current in the Gulf of Mexico in September 2005. The storm diminished to Category 3 by the time it traveled over cooler waters. Data source: merged TOPEX/Poseidon, Jason-1, Geosat Follow-On (GFO), and Envisat altimeter data processed by the University of Colorado's CCAR group. Image credit: University of Colorado



How It All Works

The “Nuts and Bolts” of OSTM/Jason-2



has also been used for several other satellites, including the NASA/CNES Cloud-Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO) mission. The OSTM/Jason-2 platform has service and payload modules designed and adapted specifically for the mission.

The OSTM payload (left) is shown here fully integrated onto the PROTEUS spacecraft bus. Image credit: NASA

Weighing approximately 510 kilograms (1,124 pounds), OSTM/Jason-2 runs on 500 watts of energy—enough to power about eight household light bulbs. The spacecraft collects its energy via eight solar panels, four on each solar wing array. OSTM/Jason-2 has a primary mission of three years, with a planned extended mission of two years.

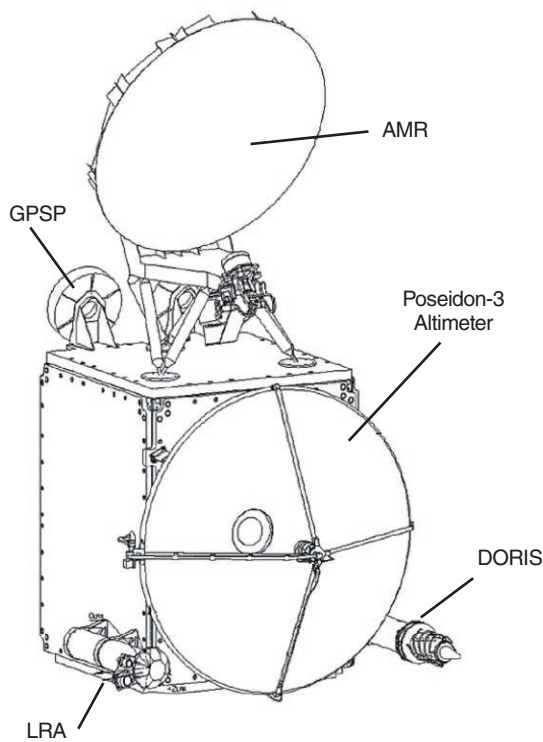
The payload of OSTM/Jason-2 is made up of five primary science instruments, supplied by NASA and CNES, and three “passenger” instruments, supplied by CNES and Japan.

The OSTM/Jason-2 mission is based on the Jason-1 and TOPEX/Poseidon missions. The spacecraft design began with the selection of a spacecraft *bus*—the platform onto which the payload instruments are attached. OSTM/Jason-2’s bus is based on Thales’ PROTEUS low-Earth-orbit platform. PROTEUS is a French acronym that translates to “reconfigurable platform for observing, telecommunications, and scientific uses”. First used for Jason-1, this bus



A technician oversees the attaching of the OSTM/Jason-2 spacecraft to a tilt dolly inside the Astrotech processing facility at Vandenberg Air Force Base. Image credit: NASA

The Instruments



The Poseidon-3 altimeter is OSTM/Jason-2's main instrument. The AMR, DORIS, LRA, and GPSP provide data to improve the altimeter measurement. Image credit: NASA

The Primary Instruments

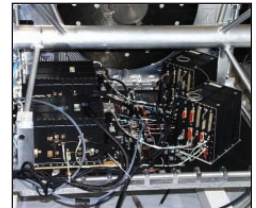
Poseidon-3 is OSTM/Jason-2's altimeter and main instrument. It is an advanced version of the Poseidon-2 altimeter on Jason-1. Emitting pulses at two frequencies, Poseidon-3 measures ocean surface topography by calculating the distance between the satellite and



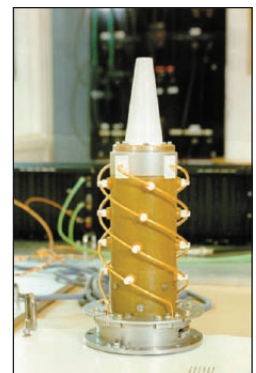
AMR

the sea surface. The **Advanced Microwave Radiometer (AMR)** improves the accuracy of Poseidon-3's ocean surface topography measurements by correcting for water vapor in the atmosphere. To keep track of its velocity and place in orbit, OSTM/Jason-2 employs the **Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS)** instrument.

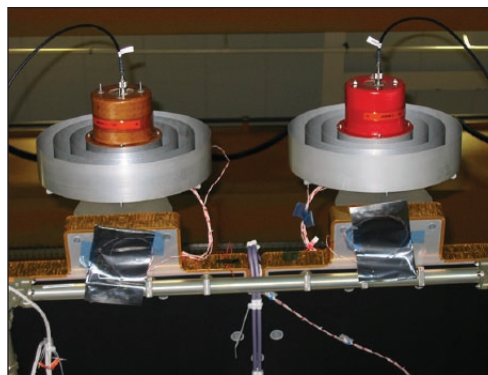
Poseidon-3 uses DORIS to help improve measurements over coastal zones, inland areas, and ice. Much like a Global Positioning System (GPS) unit helps you find your destination, the **Global Positioning System Payload (GPSP)** on OSTM/Jason-2 triangulates



Poseidon-3 electronics

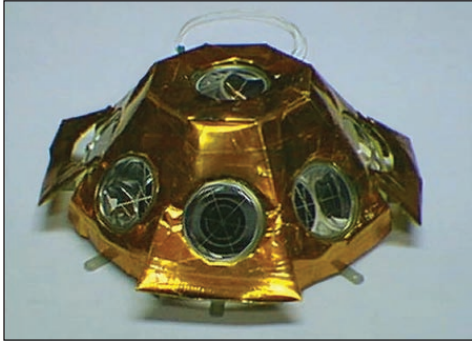


DORIS



GPSP

lates the spacecraft's position at any given time with up to 12 GPS satellites. The **Laser Retroreflector Array (LRA)** is a mirror array that is used with ground-based laser ranging stations to track the



LRA

satellite. Several of OSTM/Jason-2's primary instruments are complementary, performing similar functions to ensure that the satellite's position is monitored precisely.

The Passenger Instruments

The passenger instruments on OSTM/Jason-2 will be used to study additional topics of interest. The Environment Characterization and Modelisation-2 (Carmen-2) instrument and Light Particle Telescope (LPT) will examine how radiation influences the satellite's components. With the Time Transfer by Laser Link (T2L2) instrument, scientists can compare and synchronize ground clocks with high accuracy.

Data Products

NOAA, CNES, and EUMETSAT will process the raw data from OSTM/Jason-2 into data products and distribute them to users. Data will be grouped into three products: the Operational Geophysical Data Record (OGDR), the Interim Geophysical Data Record (IGDR), and the Geophysical Data Record (GDR). The OGDR consists of near real-time data, delivered to the user in less than three hours. Unique to OSTM/Jason-2, the OGDR is specially suited for near real-time forecasting. Meteorological agencies will be able to use surface wind speed, sea surface height, and wave data for atmospheric and oceanic predictions. Both the IGDR and GDR are "offline", made up of data collected a few days or weeks prior to distribution. With data produced within one to one-and-a-half days of being recorded, the IGDR is used in seasonal forecasting and to predict ocean weather five to seven days in advance. The GDR will be used in climate modeling and provides sea surface data within 60 days of being recorded.



T2L2 is an optical time transfer experiment on Jason-2. Using pulses of light, it allows synchronization of remote clocks on Earth and high-accuracy monitoring of the satellite's clock. Image credit: G. Benjamin, CNES

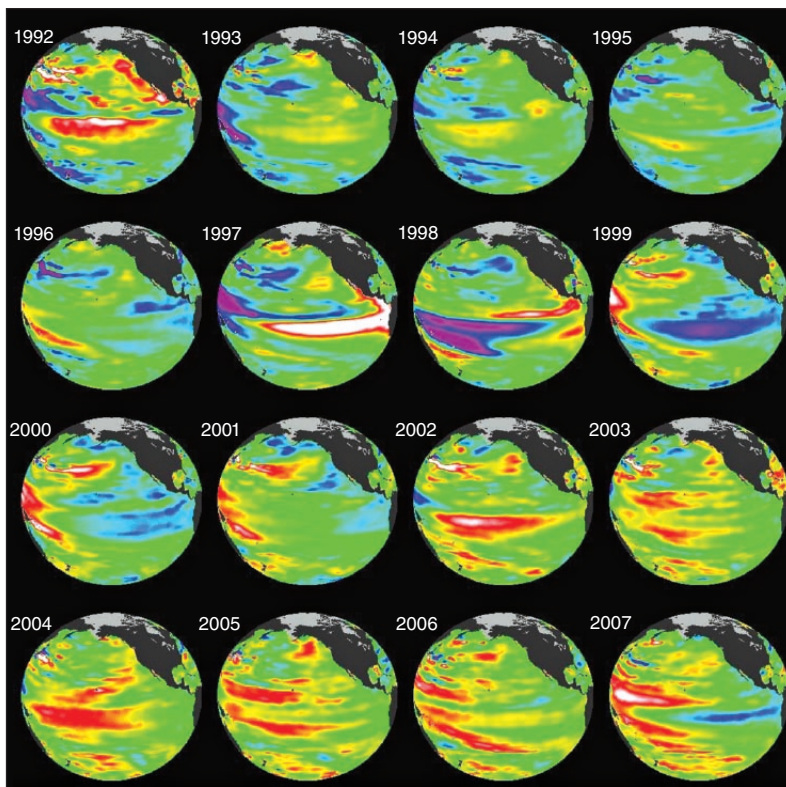
OSTM/Jason-2

How Is It Different?

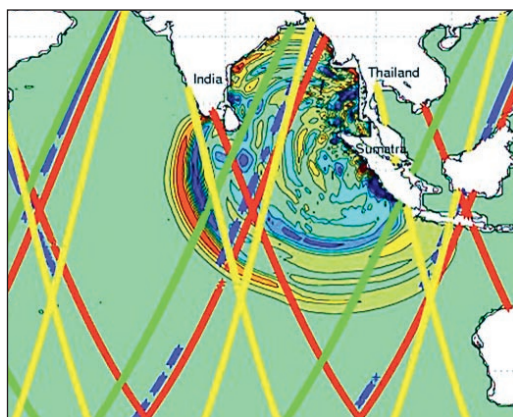
These data globes, created with radar altimeter measurements from TOPEX/Poseidon and Jason-1, represent 16 years of average annual sea-surface height anomalies for the period from 1992 to 2007. Image credit: NASA JPL

OSTM/Jason-2 continues the important time-series of ocean observations, adding to the 16 years of data collected by TOPEX/Poseidon and Jason-1. Operational weather forecasters will observe changes in ocean conditions more quickly than ever before and will be able to make more accurate predictions of short-term weather events.

Scientists will have the long-term data that they need to predict large-scale events like El Niño and La Niña, and to understand how ocean circulation is affected by climate change. Advancements made to instruments on OSTM/Jason-2 will allow observations to be made



On December 26, 2004 a Magnitude 9 earthquake struck off the coast of Indonesia and triggered a devastating tsunami. Four altimetry satellites—Jason-1, Topex/Poseidon, Envisat and GFO—passed over the Indian Ocean between two and six hours after this event and collected an abundance of data that has been used to help refine tsunami wave propagation and dissipation models and improve tsunami warning systems. Image credit: NASA JPL



almost 50 percent closer to coastal regions—where the majority of Earth’s population lives. This increased accuracy will provide data on the ever-changing coastal currents and sea level variation that impact population, trade and commerce, and tourism.

The international partnerships fostered by the development of OSTM/Jason-2 will bring Europe’s and America’s investments in satellite altimetry research toward fully functioning operations. Cooperation between countries and agencies is necessary for future Earth missions—without international cooperation, it will be difficult to collect the global data we need to understand climate change.

The Future

Jason-3 and Beyond...

Targeted for launch in 2013, Jason-3 will follow OSTM/Jason-2's legacy of ocean monitoring from space. NOAA and EUMETSAT will use their experience with OSTM/Jason-2 to design and implement Jason-3. The operation of Jason-3 will prevent any gap in ocean surface topography data and supply weather forecasters with the information they need. Jason-3 will also ensure that accurate predictions of sea level change and the accompanying impact to coastal populations can be made.

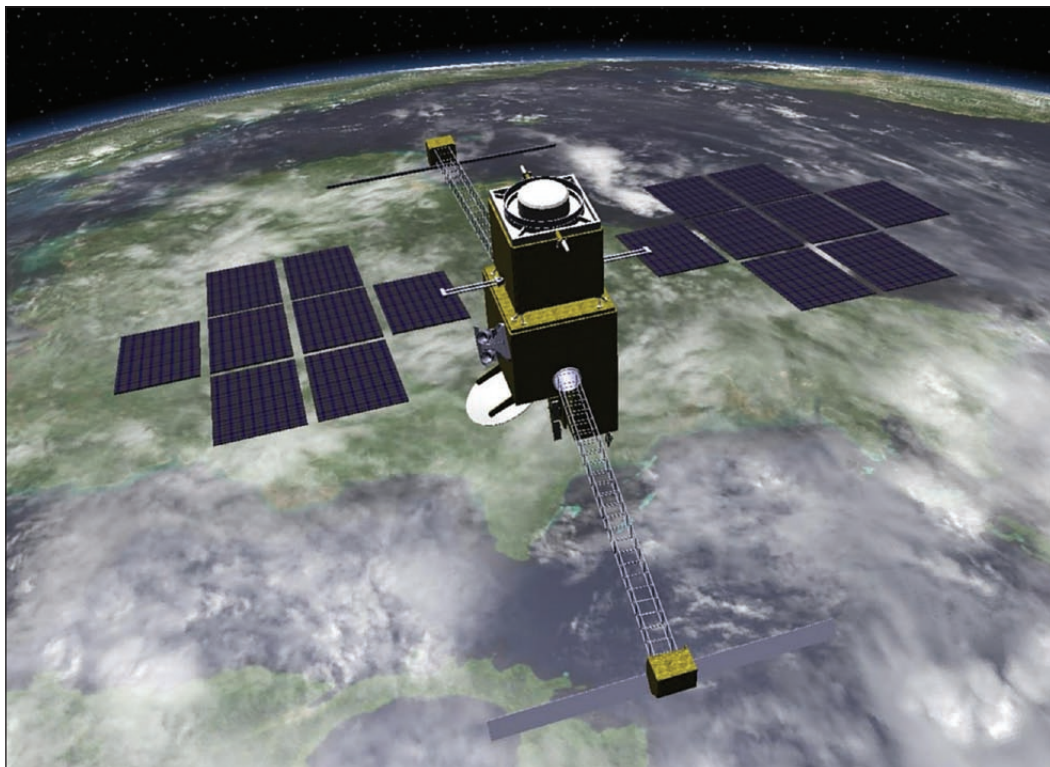
Next-generation satellites will seek to answer questions about the relationship between ocean and terrestrial waters (rivers, lakes, and wetlands) in the hydrologic cycle, as well as the small-scale ocean processes

affecting climate change. One of the satellites planned to do this, the Surface Water Ocean Topography Mission (SWOT), will help us to manage our water resources in the face of climate change.

Satellite altimetry missions have already radically changed our understanding of the ocean and its role in Earth's climate. From the weather forecast on your vacation to the beach to the predicted ferocity of the next hurricane, ocean surface topography measurements are ingredients essential to planning our lives. With data from OSTM/Jason-2 and missions that follow, we will be even better equipped to assess future climate change and how we will safely respond to it.



The Columbia River-Pacific Ocean boundary. Note the color contrast where river water and ocean water meet. Image credit: NOAA



The SWOT spacecraft, shown here in an artist's conception, will make accurate measurements of mesoscale ocean features and surface water parameters. Image credit: NASA JPL

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