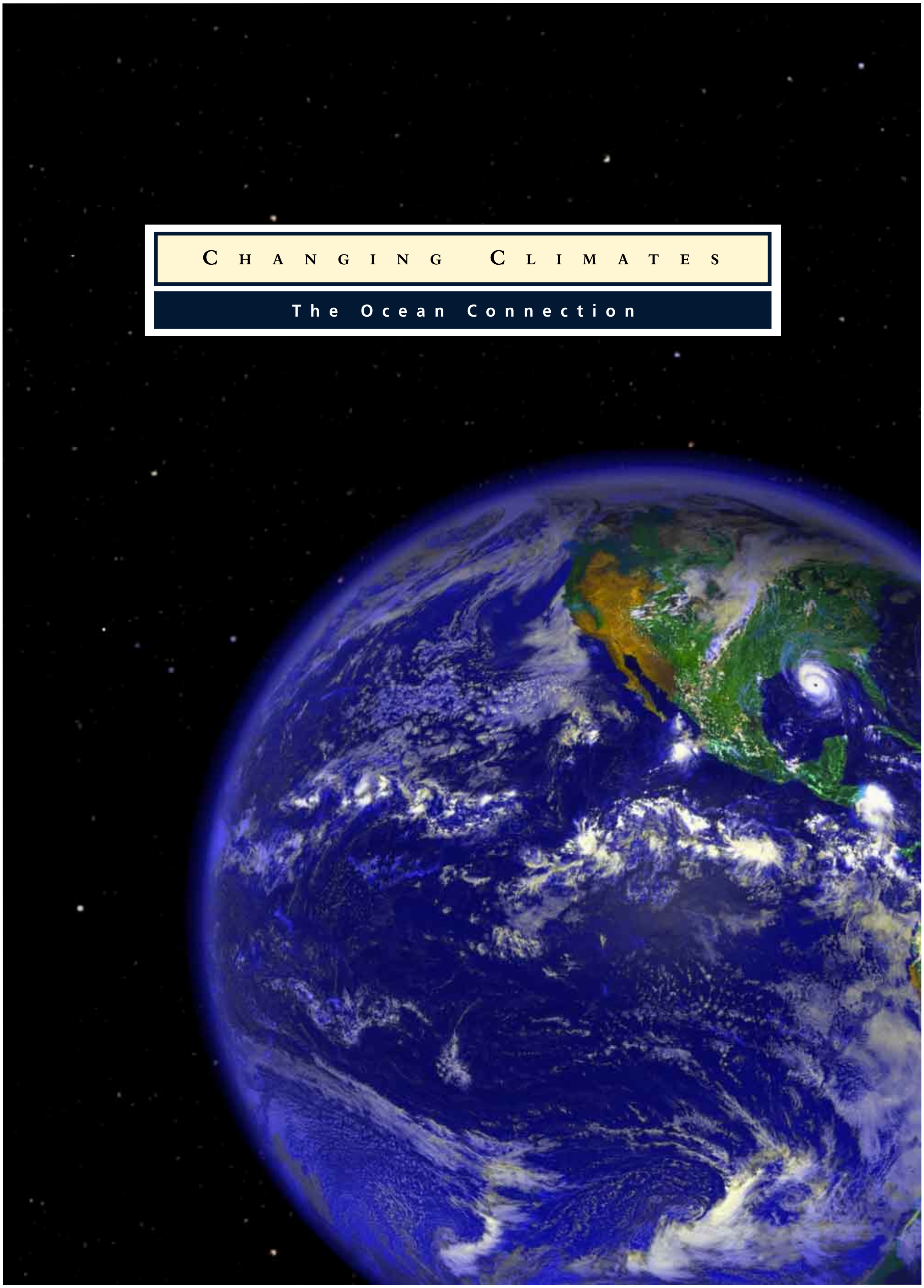
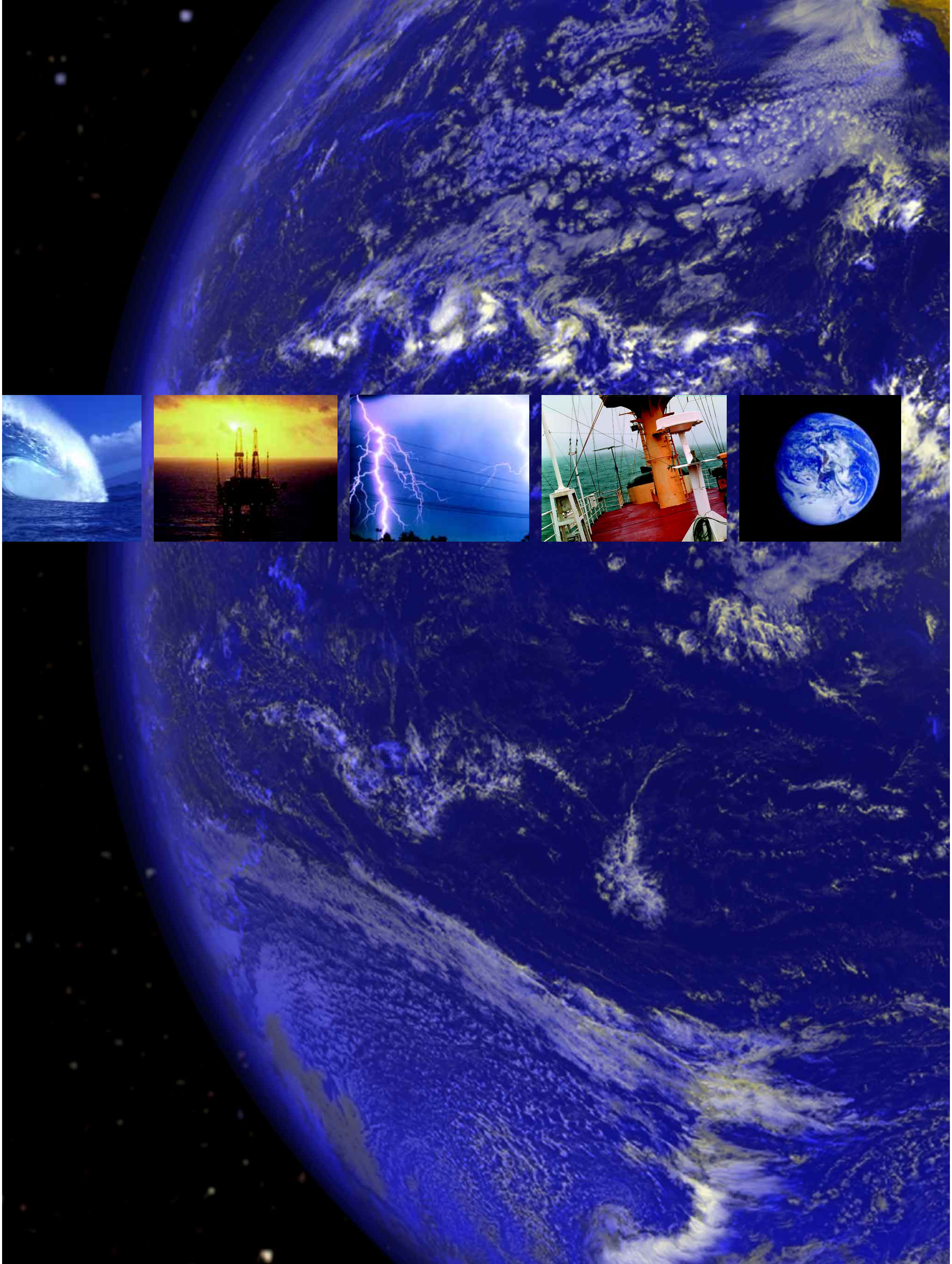
Changing Climates

The Ocean Connection



The Ocean Connection

Why does NASA study oceans? The oceans are the single most significant influence on Earth's weather and climate. This should not surprise us; viewed from space, our beautiful blue marble stands in stark contrast to its planetary neighbors, informing all would-be visitors that ours is an ocean planet. Seventy percent of the global surface is covered by water. This great reservoir continuously exchanges heat, moisture, and carbon with the atmosphere, driving our weather patterns and controlling the slow, subtle changes in our future climate. Changes in the atmosphere are driven by heat transfer, and heat transfer is governed by the storage capacity of the heat source. Since the oceans store more heat in their uppermost 3 meters (10 feet) than the entire atmosphere, the key to understanding global climate change is inextricably linked to the oceans.



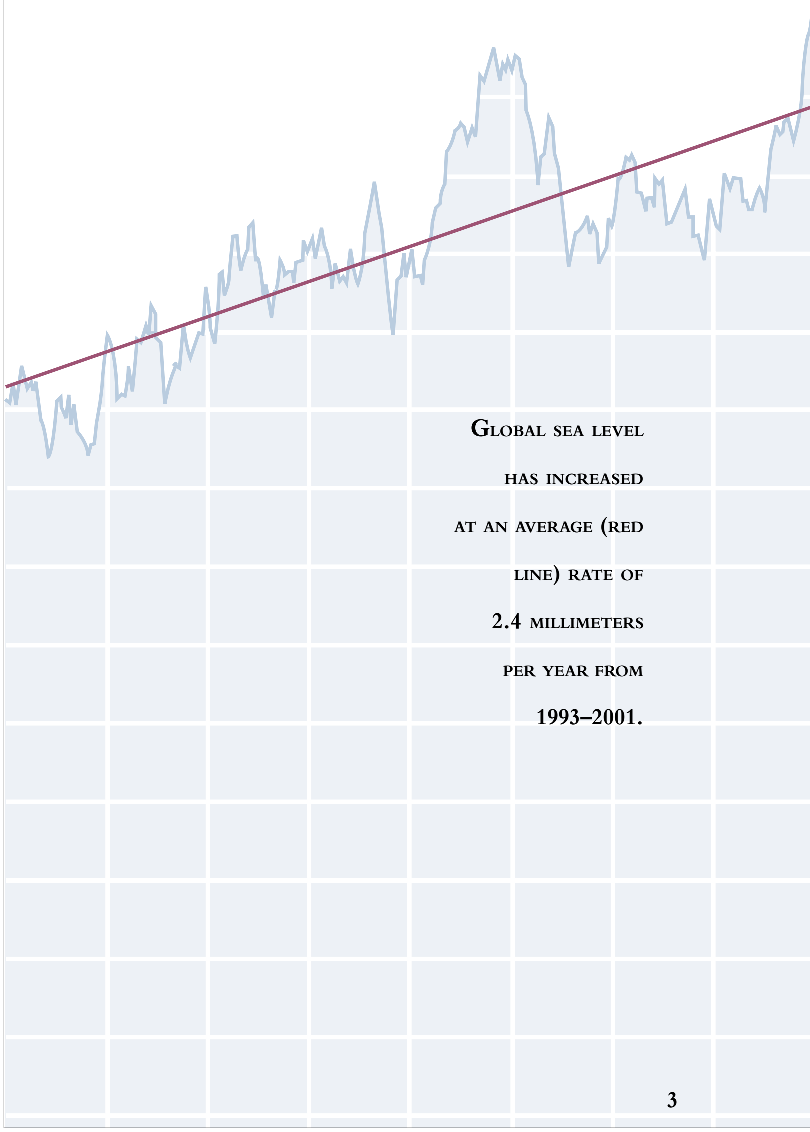
At the end of the last ice age, about 12,000 years ago, glaciers covered much of Europe and North America. Fed by evaporation of ocean waters, the polar ice caps thickened and expanded, causing the global sea level to drop far below its current level. Earth is about 5 degrees Celsius (9 degrees Fahrenheit) warmer today than it was then.

Global Warming or Global Climate Change?

Still recovering from the ice age, global sea level continues to rise. The past century alone has seen global temperature increase by 0.6 degree Celsius (1 degree Fahrenheit), and the average global sea level over the past decade has risen steadily. Is this just part of a natural cycle? How much of this warming is due to the burning of fossil fuels? Is human nature affecting Mother Nature? What should we do? Our response to the challenge of global warming begins by formulating the right set of questions.

The first step in addressing the issue of global warming is to recognize that the warming pattern, if it continues, will probably not be uniform. The term “global warming” only tells part of the story; our attention should be focused on “global climate change.” The real threat may not be the gradual rise in global temperature and sea level, but the redistribution of heat over Earth’s surface. Some spots will warm, while others will cool; these changes, and the accompanying shifts in rainfall patterns, could relocate agricultural regions across the planet.

Fortunately, the oceans provide abundant clues to help analyze the world’s changing climate. Since water expands and contracts with temperature changes, the height of the sea at any point on its surface tells us how much heat is contained in the water column below that point. With the aid of remote-sensing satellites, sea-surface height and other ocean attributes can be monitored continuously and globally, providing powerful information for studying climate change and predicting its effect on agriculture and the environment. As our ability to collect and interpret data improves, our political leaders will look to the ocean for the answers needed to plot the course of society to the next century and beyond.



Global sea level has increased at an average (red line) rate of 2.4 millimeters per year from 1993–2001.

Sea-level data: Steven Nerem, CCAR, U. Colorado.

NASA's Jet Propulsion Laboratory (JPL) is at the forefront of oceanographic research. Our missions are studying the oceans from space, unlocking their vast store of information about our changing environment. The NASA Physical Oceanography Program is aimed at answering the key questions:

- How are global climate changes driven by ocean circulation?
- Will climate variations induce major changes in the deep ocean that could affect us in the future?
- How are shifts in local weather, precipitation, and water resources related to global climate change?
- How will climate change and rising sea level impact coastal regions?
- Can we better understand and predict transient climate variations?

Winds and Currents: Balancing the Ocean Planet's Climate

Like a massive flywheel that regulates the speed of an engine, the vast amount of heat in the oceans regulates the temperature of Earth. Both the oceans and the atmosphere transport roughly equal amounts of heat from Earth's equatorial regions — which are intensely heated by the Sun — toward the icy poles, which receive relatively little solar radiation. The atmosphere transports heat through a complex, worldwide pattern of winds; blowing across the sea surface, these winds drive corresponding patterns of ocean currents.

But the ocean currents move more slowly than the winds, and have a much higher heat storage capacity. These currents form an oceanic "conveyor belt," transporting warm water to the poles along the sea surface, releasing their heat to the atmosphere, then sinking to the ocean floor and returning toward the equator, where they upwell to the surface 1,000 years later and repeat the cycle. Changes in the

THE OCEANIC "CONVEYOR BELT" CARRIES UPPER-OCEAN CURRENTS OF WARM WATER (SOLID LINES) TOWARD THE POLES. THE WATER BECOMES COLDER AND HEAVIER, SINKS TO THE DEEP OCEAN (DOTTED LINES), AND TRANSFERS HEAT TO THE ATMOSPHERE. THE DEEP COLD WATER EVENTUALLY UPWELLS TO THE SURFACE AND REPEATS THE CYCLE.

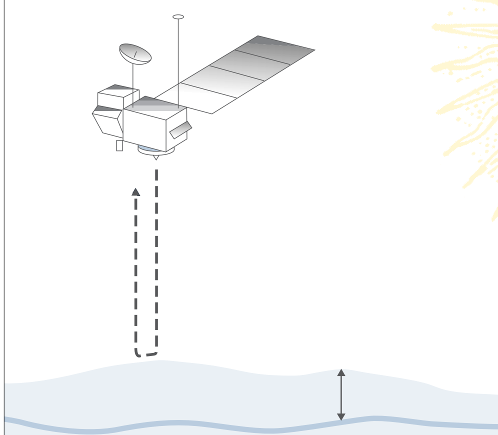
distribution of heat within the conveyor belt are measured on time scales from tens to hundreds of years. While variations close to the ocean surface may induce relatively short-term climate changes, the heat that drives these changes may not be seen in the deep ocean for many generations. The ocean is the thermal memory of the climate system.

What Can We Measure?

Ocean-surface topography, vector winds (both wind speed and direction), sea-surface temperature, and salinity are the critical factors in understanding the ocean–climate connection. Of these, only surface temperature and wind speed have been routinely observed from operational satellites. In collaboration with international partners, NASA and JPL have made revolutionary strides in observing ocean-surface topography and vector winds. And ideas are now being considered for measuring ocean salinity from space, with which tomorrow's oceanographers may improve our understanding of global climate change.

Mapping the Ocean Surface: Radar Altimeters

The key to measuring ocean currents from space is ocean-surface topography — mapping the height of the sea surface at all points on the globe. Just as wind blows around

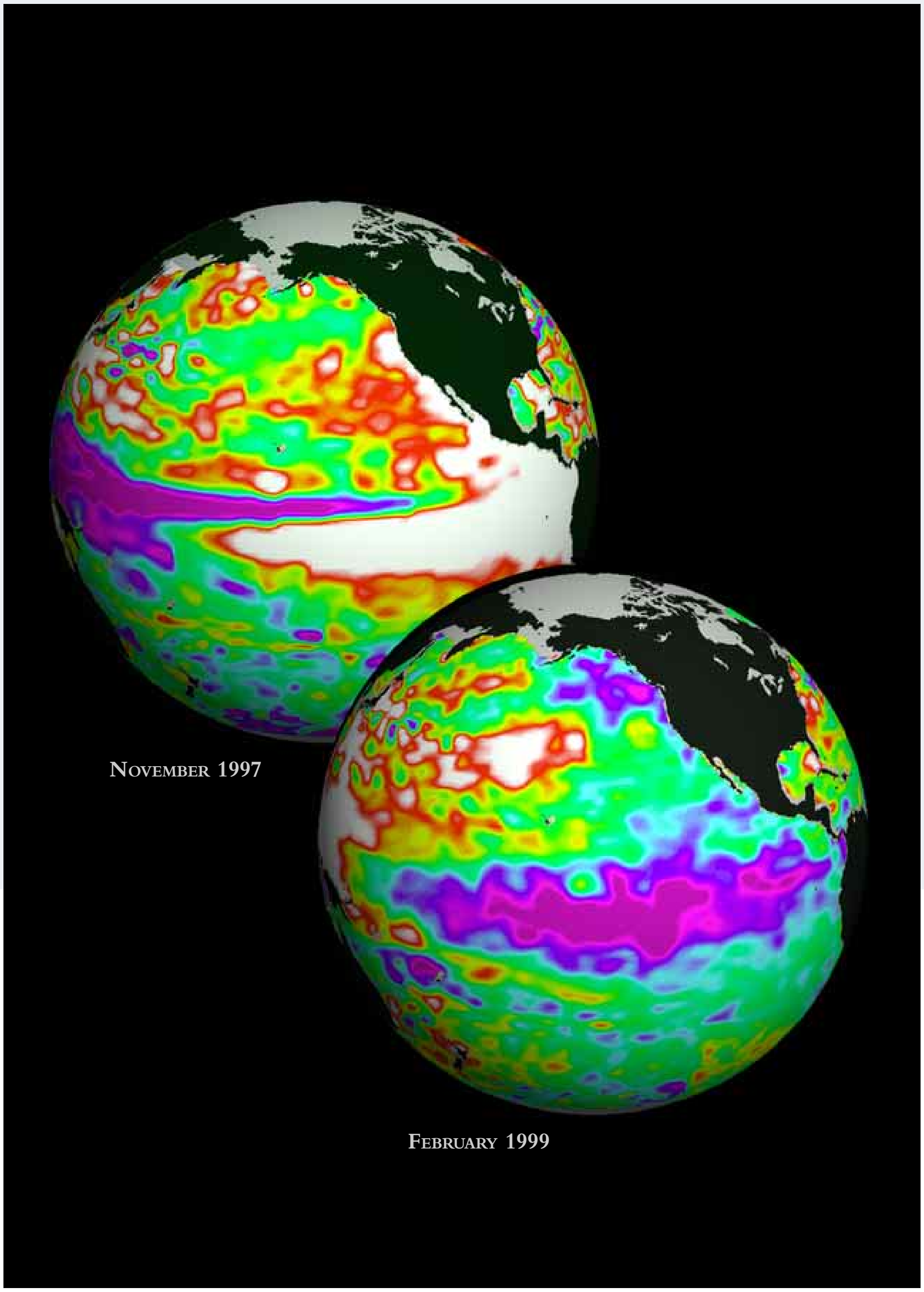


high- and low-pressure centers in the atmosphere, water flows around the highs and lows of the ocean surface, allowing us to determine the speed and direction of surface currents from topographic maps. Sea-surface height also reveals the heat storage of a water column, due to the expansion and contraction of water volume with changes in temperature. The combination of these techniques provides a powerful tool for modeling both surface currents and currents at depth.

The development of radar altimeters has given us the ultimate tool for measuring ocean-surface topography. Bouncing radio waves off the ocean and timing their return with incredible accuracy, these instruments tell us the distance from the satellite to the sea surface within a few centimeters (about 1 inch) — the equivalent of sensing the thickness of a dime from a jet flying at 35,000 feet.

The satellite's altimeter bounces radar signals off the ocean surface to measure distance to the water. Gravity's influence (solid blue line) is subtracted from the data to obtain ocean-surface topography.

TOPEX/Poseidon, a joint U.S.–France mission launched in 1992, has used radar altimeters to generate a complete topographic map of the world's ice-free waters every 10 days for nearly a decade, giving us the most detailed and longest continuous picture of the oceans' changes ever collected. A second joint U.S.–France altimetry mission, named Jason-1, is now preparing to continue the legacy of TOPEX/Poseidon. Jason-1 and its successors will enable critical topographic measurements to extend without interruption over the long time scales needed to observe changing global weather patterns. This continuity is critical to successfully analyzing the intricate links between human influences, such as the burning of fossil fuels, and changes in the global environment.



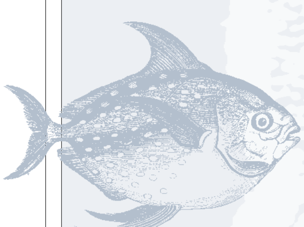
MAPS OF SEA-SURFACE HEIGHT FROM TOPEX/POSEIDON PROVIDED EARLY WARNING OF THE 1997–1998 EL NIÑO, SAVING LIVES AND PROPERTY. EL NIÑO'S WARM WATER RAISED SEA-SURFACE HEIGHTS IN THE EASTERN PACIFIC, SHOWN IN WHITE (ABOVE). LA NIÑA THEN BROUGHT COOL WATER TO THIS REGION, CAUSING SEA-SURFACE HEIGHTS TO DROP, SHOWN IN PURPLE (BELOW).

Mapping Gravity with GRACE

Earth is not a perfect sphere; it bulges at the equator and flattens at the poles. Similarly, even if the ocean were perfectly still, its surface would have hills and valleys due to variations in the pull of gravity. Because matter is distributed unevenly within Earth's crust — densely packed within mountain ranges, thinned by valleys — Earth's gravity field varies substantially over both the continents and the seas.

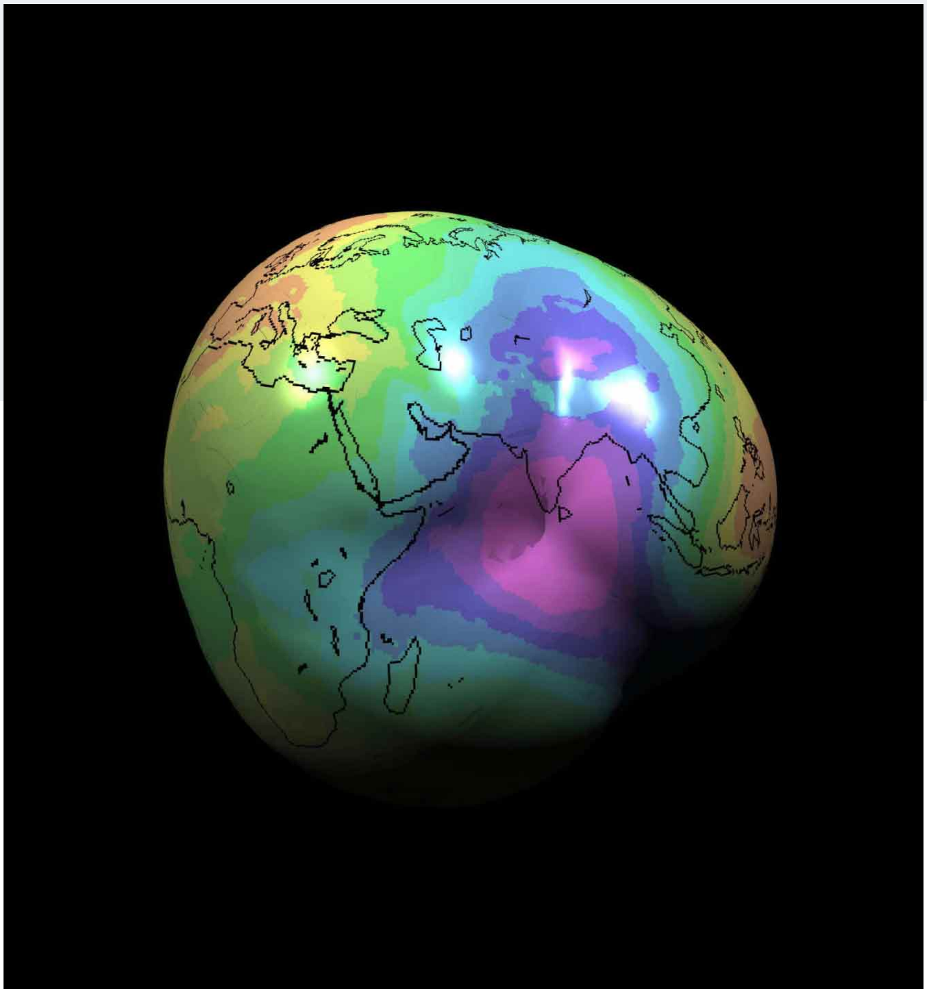
Radar altimeters can tell us the changing height across an ocean current, but not the total amount of water flow. For this, we must compare the sea-surface height with a gravitational reference surface that models the hills and valleys of a motionless ocean. Currently, gravity measurements are not as accurate as those of altimeters, so our ability to measure total current flow is limited. If our knowledge of ocean circulation is to improve, we must have better gravity maps. This is the mission of GRACE, the Gravity Recovery And Climate Experiment.

GRACE is expected to provide gravity measurements that are up to 100 times more accurate than our present values. The improved accuracy will lead the way to breakthroughs in our understanding of ocean circulation and heat transport, and changes in these processes



over time. GRACE, and the gravity missions that build on it, will measure changes in ocean-bottom currents by measuring ocean-bottom pressure, providing new insights on the global movements of the oceans' deep waters.

THE UNEVEN EARTH



THIS EXAGGERATED VIEW DEPICTS THE UNEVEN DISTRIBUTION OF EARTH'S GRAVITY FIELD. ACCURATE KNOWLEDGE OF EARTH'S GRAVITY FIELD IS ESSENTIAL TO COMPUTING OCEAN-SURFACE TOPOGRAPHY.

Measurement of Vector Winds: Scatterometry

Launched in 1999 on the QuikSCAT satellite, the SeaWinds scatterometer has provided scientists with the longest continuous, global view of ocean-surface winds to date, including the detailed structure of hurricanes, wind-driven circulation, and changes in the polar sea-ice masses. Scatterometers can penetrate through clouds and haze to measure conditions at the ocean surface, making them the only proven satellite instrument capable of measuring vector winds at sea level day and night, in nearly all weather conditions.

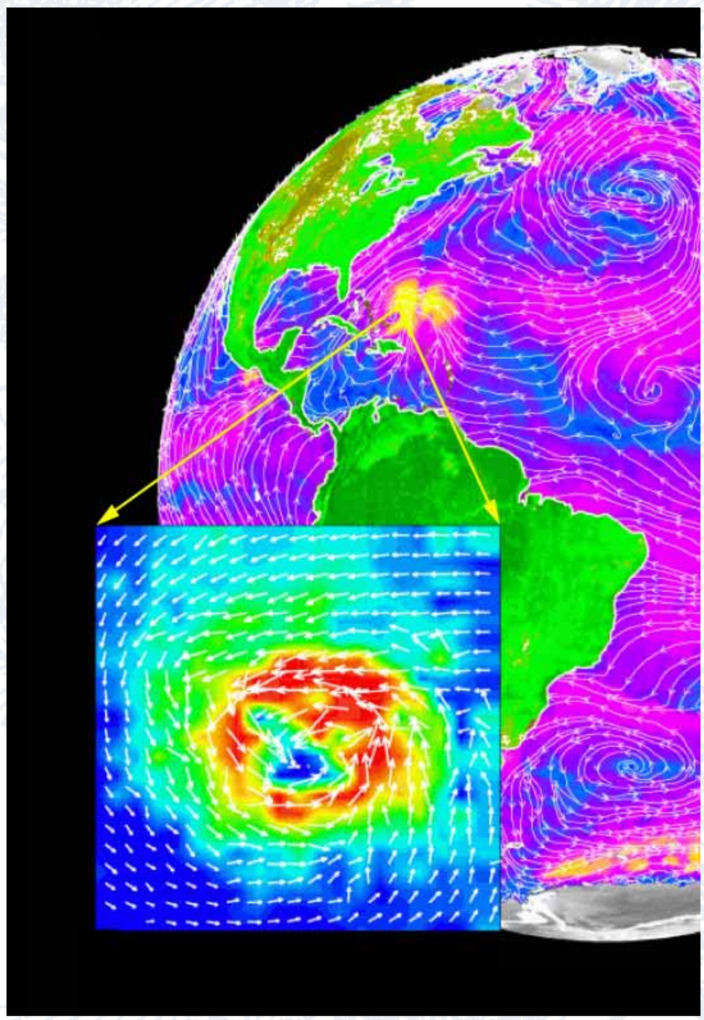
Combined with data from TOPEX/Poseidon, Jason, and weather satellites, data from SeaWinds and its follow-on missions will be used to study long-term phenomena — such as global climate change, El Niño, and the effects of deforestation on our rain forests — that affect the hydrologic and biogeochemical balance of the ocean–atmosphere system.

Measuring Surface Salinity from Space

Salinity can be as important as temperature in determining the changing currents of the seas. It often controls the sinking of surface water to the deep ocean, which affects long-term climate change. Such sinking is also the principal mechanism by which the oceans store heat and carbon dioxide. Ocean salinity measurements have been few and infrequent, and in many places salinity has remained unmeasured. Remotely sensed salinity measurements hold the promise of greatly improving our ocean models. Preliminary tests of airborne methods for salinity measurement have shown promising results, and may lead the way to the next generation of satellite instruments for refining our understanding of the ocean–climate connection.

Hurricane Floyd

Satellite measurements from the SeaWinds scatterometer reveal the speed and direction of ocean-surface winds. Slower wind speeds (blue and purple) are contrasted with the high-speed winds (yellow and red) of Hurricane Floyd.



Why does NASA study oceans? By now, the answer should be clear. Satellite observations of the oceans over the past three decades have revolutionized our understanding of global climate change through global measurements and modeling of the ocean–atmosphere climate system. Global data sets available on time scales of days to years (and, looking ahead, to decades) have been and will be a vital resource for scientists and policy makers in fields from ocean commerce to disaster mitigation. The social and economic benefits of JPL's satellite ocean data include:

Climate Research: Scientists can study the evolution of weather patterns by modeling changes in the distribution of the oceans' heat.

Hurricane Forecasting: Altimeter and scatterometer data are incorporated into atmospheric models for hurricane season forecasting and individual storm severity.

El Niño and La Niña Prediction: Understanding the pattern and effects of climate cycles such as El Niño helps us to predict and mitigate the disastrous effects of floods and drought.

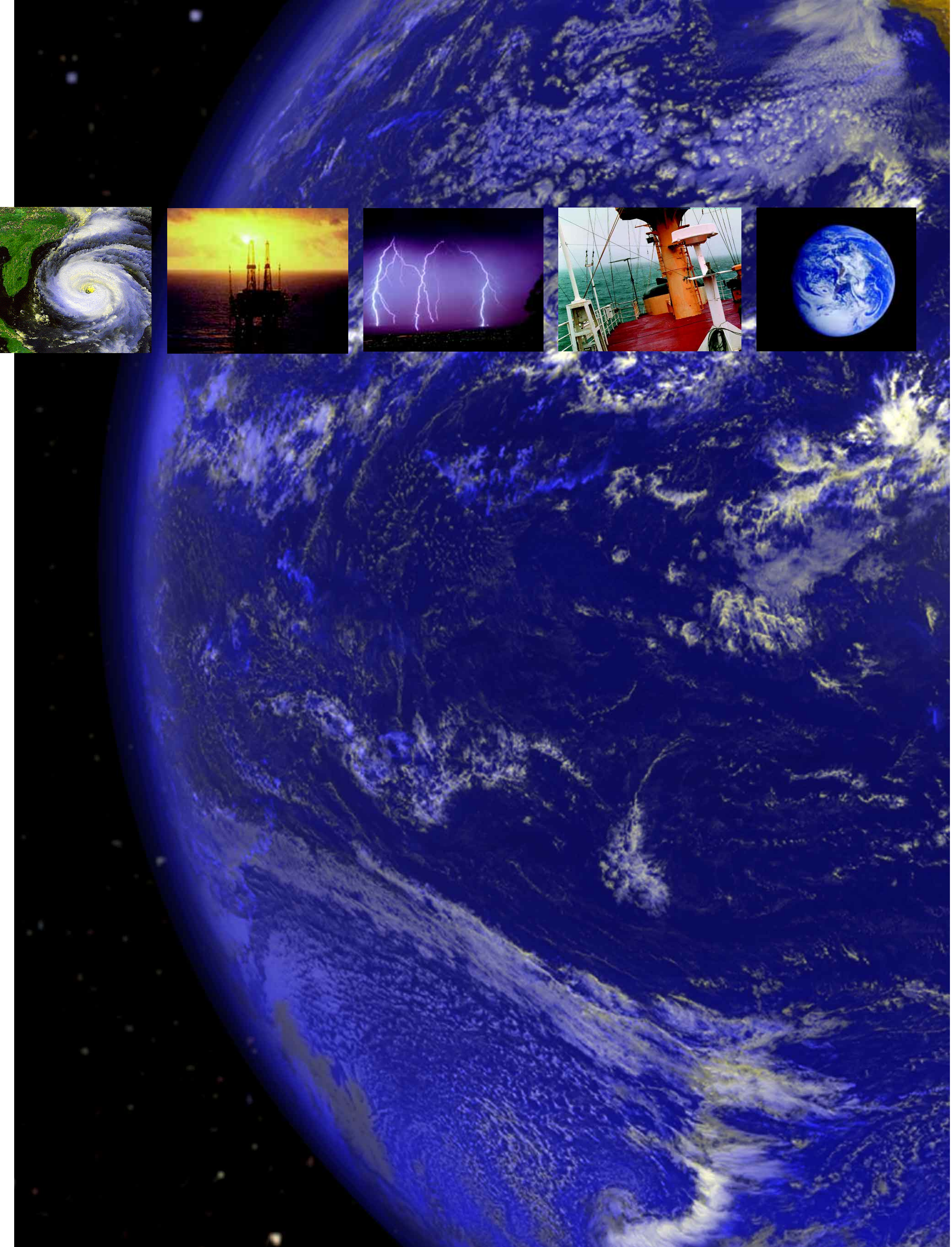
Ship Routing: Maps of currents, eddies, and vector winds are used in commercial shipping and recreational yachting to optimize routes.

Offshore Industries: Cable-laying vessels and offshore oil operations require accurate knowledge of ocean circulation patterns to minimize impacts from strong currents.

Fisheries Management: Satellite data are used to identify ocean eddies, which bring an increase in organisms that comprise the marine food web and attract fish and fishermen.

Marine Mammal Research: Sperm whales, fur seals, and other marine mammals can be tracked and studied around ocean eddies, where nutrients and plankton are abundant.

Coral Reef Research: Remotely sensed data are used to monitor and assess coral reef ecosystems, which are sensitive to changes in ocean temperature.



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For additional information on JPL's Ocean Science, visit the Earth/Ocean Motion section of our website at — **http://www.jpl.nasa.gov/earth**