National Aeronautics and Space Administration

UNDERSTANDING EARTH

Our Ocean

Coral reefs surround Babeldaob, Palau—the second largest island in the Micronesia region of Oceania. The turquoise areas are covered with approximately one meter (3 feet) of water. Sometimes called the "rainforests of the sea," coral reefs are one of the most prized ecosystems in the ocean. They are home to about a quarter of all ocean fish species, making them hot spots of biodiversity.

Image credits: NASA (this page); Anita Ritenour, Morguefile.com (cover)

UNDERSTANDING EARTH:

Our Ocean

Image credit: luisrock62, Morguefile.com

Image credit: NASA

[Above] *Water in the ocean is continuously replenished by precipitation, ice melt, and runoff from major lakes, watersheds, and waterways. Mostly covered by ocean water, Earth has been described as a blue marble when seen from space.*

Earth's Ocean

Viewed from space, Earth appears as a blue marble, as approximately 70% of Earth's surface is covered by ocean water. The vast ocean holds roughly 97% of the planet's water and represents 99% of the living space on Earth. Below the surface, the ocean is teeming with life; in fact, most of our planet's lifeforms live in the ocean, from tiny microscopic organisms to the enormous blue whale—the largest known animal on Earth.

Image credit: NASA

[Above] ***What color is the ocean?*** *The color of an object is actually the color of the light scattered while all other colors are absorbed. In clear water, absorption is weak in the blue, with the red, orange, yellow, and green wavelengths of light preferentially absorbed. Therefore, what we see are the blue and violet wavelengths* [top right in the above image]. *The depth of the ocean, and the presence of dissolved and particulate material, can change the apparent color of the water; near the Bahama Islands, where the water is shallow, sunlight is reflected off white sand and coral reefs, making the water appear turquoise* [middle].

OCEAN FACT: Scientists know more about the surface of Mars than they do about the landscape at the bottom of Earth's ocean.

In addition to its diverse spectrum of life, the ocean is well known for its salty seas. Processes that took place throughout Earth's history, such as the weathering of rocks, evaporation of ocean water, and the formation of sea ice, have altered the ocean's chemical properties, making it salty. At the surface, ocean water contains about 3.5% salt.

The ocean also holds a tremendous amount of heat. The main source of heat is energy from the sun. The tropics receive more energy from the sun than the polar regions; in addition, the presence of ice in the polar regions reflects a large amount of incoming solar radiation. As a result, water near the equator is much warmer than ocean water near the poles. This equator-to-pole solar heating imbalance is the primary mechanism that drives atmospheric and oceanic circulation. In the upper ocean, surface winds drive currents. Below the surface, global density gradients caused by differences in temperature (thermo) and salinity (haline) drive the ocean's thermohaline circulation. Currents, waves, and tides help transport water, heat, and nutrients throughout the seven ocean basins—the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian, Southern, and Arctic.

Image credit (left to right): NASA; photo © Miriam Godfrey, Woods Hole Oceanographic Institute; NASA

[Above] *River runoff and phytoplankton—microscopic marine plants—scatter and absorb certain wavelengths of light, which can change the color of the water. Phytoplankton use chlorophyll (a green pigment that reflects green light) and other light-harvesting pigments to carry out photosynthesis; ocean water with high concentrations of phytoplankton can appear as various shades of green* [left]*, depending upon the type and density of the phytoplankton population. Other types of algae can make water appear reddish* [middle] *or deep yellow. Closer to the coast, the presence of dissolved organic matter, for example from decaying land plants, can induce a yellow or brown color. Suspended sediment from river runoff or resuspension can increase the scattering of light and also change the color of the near-shore waters* [right].

OCEAN FACT: Coral reefs cover about 1⁄50 of the ocean floor, and house about ¼ of all marine species.

The ocean's physical (e.g., temperature), chemical (e.g., nutrients, salinity), and biological (e.g., living organisms) components are in a constant state of flux and interact with one another in different ways. Such interactions structure marine ecosystems and influence Earth's weather and climate; they also have an impact on the global carbon cycle. Without Earth's ocean, our planet would be uninhabitable.

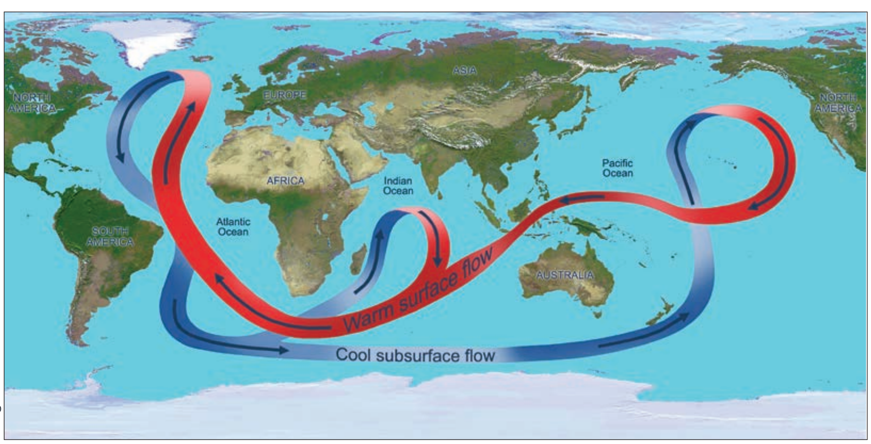


Image credit: NASA

[Above] *In certain areas near the polar ocean, cooler surface water becomes saltier due to evaporation or sea ice formation and becomes dense enough to sink to the ocean depths. This sinking motion forces water near the ocean floor to move horizontally, or circulate. The ocean's thermohaline circulation is driven by global density gradients such as these. The image above illustrates the general themohaline circulation, sometimes referred to as the "global conveyor belt." Other forces, such as wind, tides, and Earth's rotation also influence ocean circulation, while the shape of the seafloor and adjacent landmasses influence the path of circulation.*

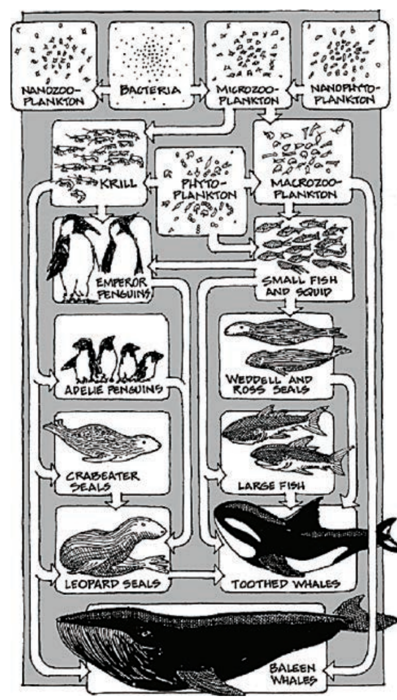


Image credit: ©2010 Gulf of Maine Research Institute

[Above] *Phytoplankton are the foundation of the aquatic food web (called primary producers), feeding everything from minuscule, animal-like zooplankton to multi-ton whales. Small fish and invertebrates also graze on the plant-like organisms, which are eaten by larger marine animals, and so on. Like land plants, phytoplankton consume carbon dioxide and produce oxygen during photosynthesis. In fact, phytoplankton created about half the oxygen we breathe today.*

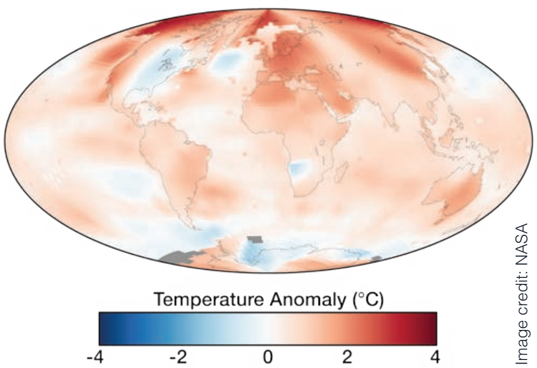


Image credit: NASA

[Above] *This map shows global, annual temperature anomalies from 1880 to 2014 based on analysis conducted by NASA's Goddard Institute for Space Studies (GISS). Red and blue shades show how much warmer or cooler a given area was compared to an averaged base period from 1951 to 1980. Generally, warming is greater over land than over the ocean, because water is slower to absorb and release heat.*

Ocean Changes

The world is getting warmer. Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years. The ocean has absorbed much of this increased heat, with the top 700 meters (about 2,300 feet) of ocean showing a warming of 0.302 degrees Fahrenheit since 1969. With global average sea surface temperatures on the rise, scientists have also noticed a decline in phytoplankton in many ocean regions.

At Earth's poles, both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades, and the Greenland and Antarctic ice sheets have decreased in mass. Global sea level rose about 17 centimeters (6.7 inches) in the last century.

Since the beginning of the Industrial Revolution, the global surface ocean has experienced a 30 percent increase in acidity. This increase is the result of the ocean absorbing atmospheric carbon dioxide (CO_2). On average, about 4 kilograms (~9 pounds) per day per person of human-generated, or *anthropogenic*, CO_2 is being added to the ocean. As atmospheric CO_2 continues to increase, more CO_2 enters the ocean, which reduces pH (and increases acidity) in a process referred to as *ocean acidification*. It is estimated that the annual global ocean uptake of CO_2 is ~1.4 to 2.5 billion tons per year.

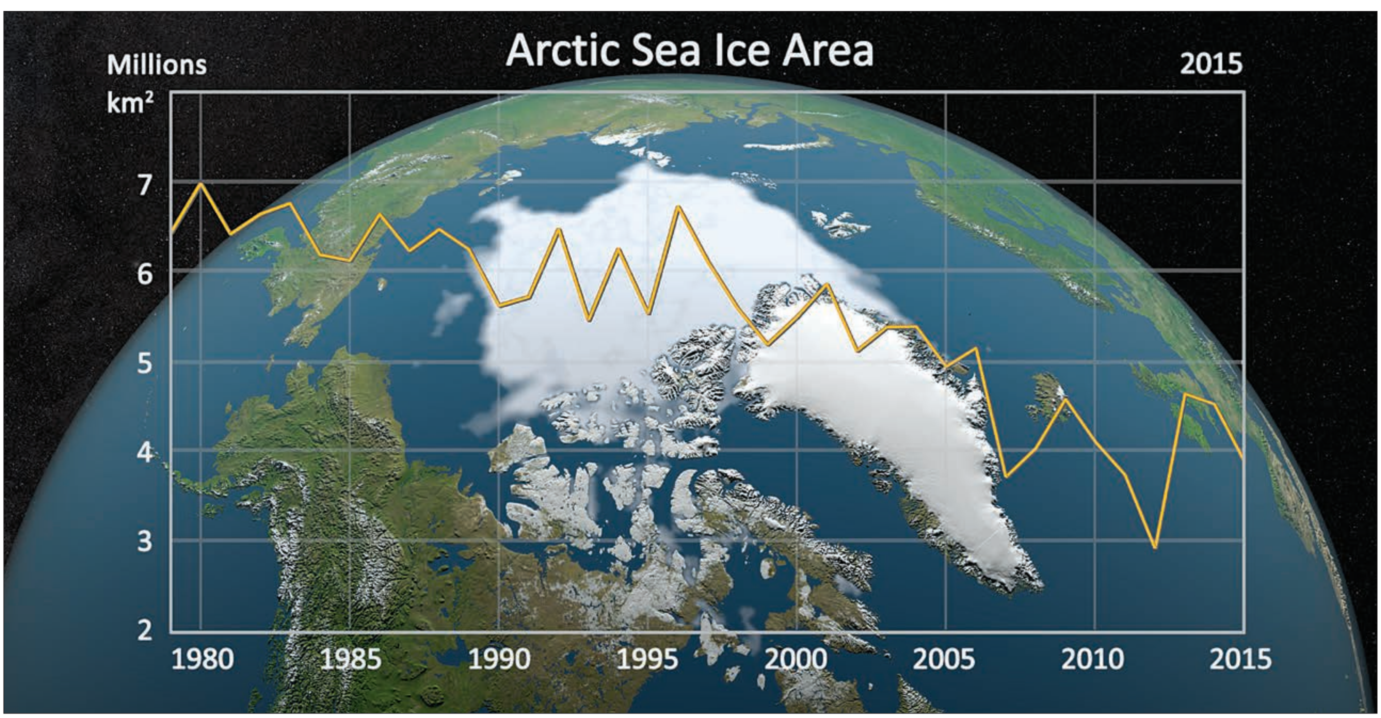


Image credit: NASA

[Above] *As temperatures rise in the Arctic, the extent of sea ice (i.e., frozen ocean water) declines. Every summer, the Arctic ice cap melts down to what scientists call its "minimum" before colder weather begins to cause ice cover to increase. This graph displays the area of the minimum sea ice coverage, derived from satellite observations, each year from 1979 through 2015.*

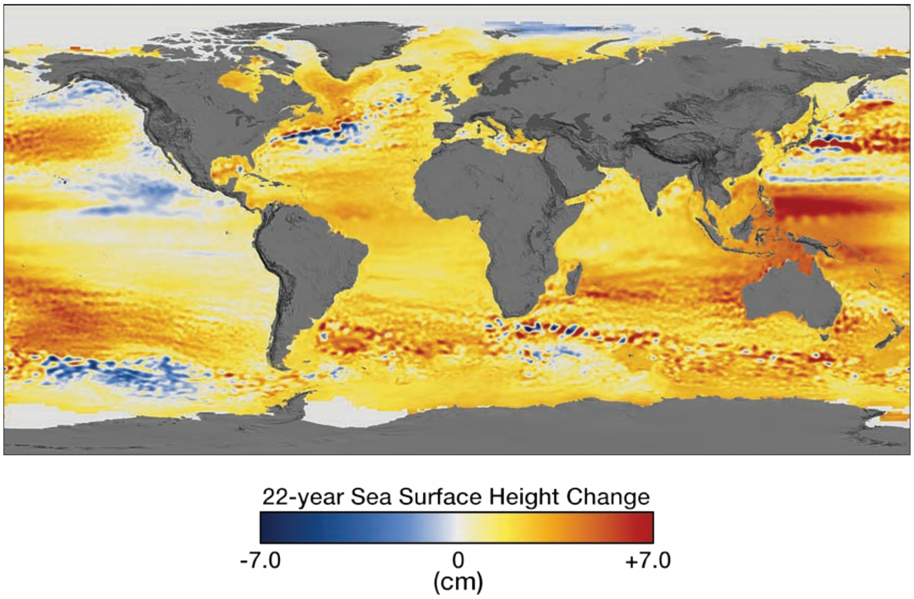


Image credit: NASA

[Left] *Earth's rising seas are some of the most visible signs of our warming planet. Over the last 23 years, NASA satellite missions have observed a steady rise in global sea levels as the ocean warms and polar ice sheets melt. As Earth continues to warm, new research suggests sea levels could rise by as much as 3 feet (~1 meter) in the next 100 years. This image shows total sea level change between 1992 and 2014, based on data collected from the TOPEX/Poseidon, Jason-1, and Jason-2 satellites. Blue regions are where sea level has gone down, and orange/red regions are where sea level has gone up. Since 1992, seas around the world have risen an average of nearly 3 inches (~8 centimeters).*

In addition to higher amounts of CO_2 being absorbed by the upper ocean, historical data show that North Atlantic sub-tropical surface waters have become saltier in the last 40 years, while sub-polar North Atlantic deeper waters have become less salty. Such changes in salinity appear to be related to changes in evaporation, precipitation, and ocean circulation. Melting of polar ice caps and glaciers also impacts salinity at high latitudes. Changes in salinity patterns can have adverse effects on global circulation and on the ability of the ocean to absorb CO_2.

Remotely sensed satellite and airborne (i.e., airplane) data, combined with high-quality ship-based measurements and computer modeling techniques, enable scientists to study ocean characteristics and patterns at regional and global scales, as well as over time. Scientists use this information to understand how the ocean is changing, the drivers of the changes, and to predict the impact environmental changes will have on Earth's ocean in the future.

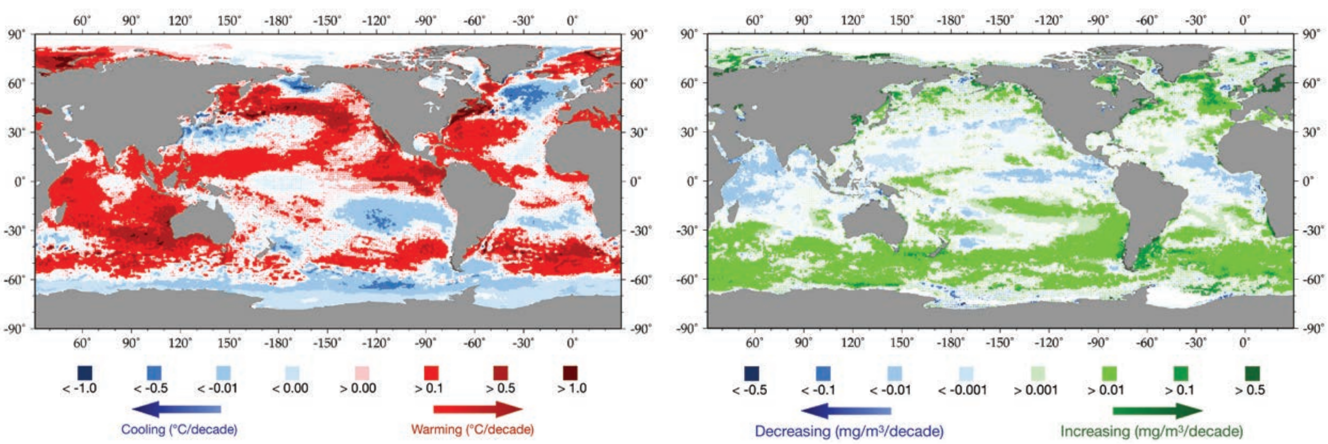


Image credit:s .IOC/UNESCO

[Above] *Trend maps help scientists identify regions that experience significant changes over different time scales and can also provide information on the rates of change. These maps compare surface chlorophyll* [right] *and sea surface temperature* [left] *trends over a 15-year time window (2001-2015), based on satellite observations. In general, changes in chlorophyll are inversely related to sea surface temperature. However, chlorophyll-increasing areas do not always correspond with temperature-decreasing areas. This means that other factors besides warming (for example changes in winds, currents, and nutrients) also impact chlorophyll concentrations.*

Image credit: NASA

[Above] *Artist's concept showing Seasat in Earth orbit.*

Observing the Ocean

Scientists can measure ocean properties *directly*, through *in situ* sensors and by taking water samples, or *indirectly*, using remote sensing techniques (e.g., from Earth-observing satellites). Remote sensing techniques measure the characteristics of light, or radiance, coming from the Earth's surface. Unlike ship-based measurements, which can only sample small portions of the ocean at a time, Earth-observing satellites can provide continuous, global coverage over long timescales. Even so, ship-based sampling remains critical for validating remotely sensed measurements.

NASA has been observing Earth's ocean from space for more than 38 years, beginning with the launch of the first civilian oceanographic satellite, *Seasat*, on January 28, 1978. The mission was designed to demonstrate the possibility of global satellite monitoring of oceanographic phenomena and to help determine the requirements for an operational ocean remote sensing satellite system. Seasat operated in Earth orbit for 105 days, measuring sea surface winds and temperatures, wave heights, atmospheric liquid water content, sea ice features, and ocean topography. October of that same year saw the launch of the first ocean color mission, the Coastal Zone Color Scanner Experiment (CZCS), which lasted until December 1986. The CZCS was designed as a proof-of-concept to determine if satellite remote sensing of color could be used to identify and quantify material suspended or dissolved in ocean waters. These satellite missions laid the groundwork for future ocean missions.

Today, there are several ocean-observing satellite and airborne missions that measure a variety of parameters including ocean surface topography, currents, waves, winds, phytoplankton content, dissolved and suspended organic matter, sea-ice extent, rainfall, sunlight reaching the sea, and sea surface temperature and salinity. NASA works with its domestic and international partners to support several of these missions, and plans to extend existing as well as new measurements into the future.

DID YOU KNOW?

Researchers used marine gravity models derived from satellite altimetry to map the entire seafloor. Prior to such satellite measurements, only ~10 percent of the seafloor had been mapped at high resolution using ships. These newer high-resolution seafloor maps will provide a better understanding of Earth's geology; aid in navigation; and be of use to the oil, gas, and mineral industry—among other uses.

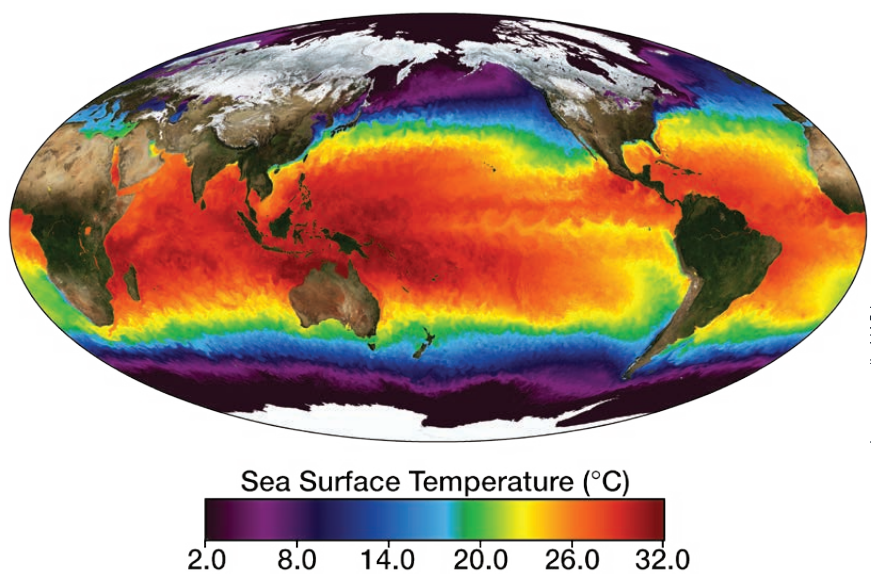


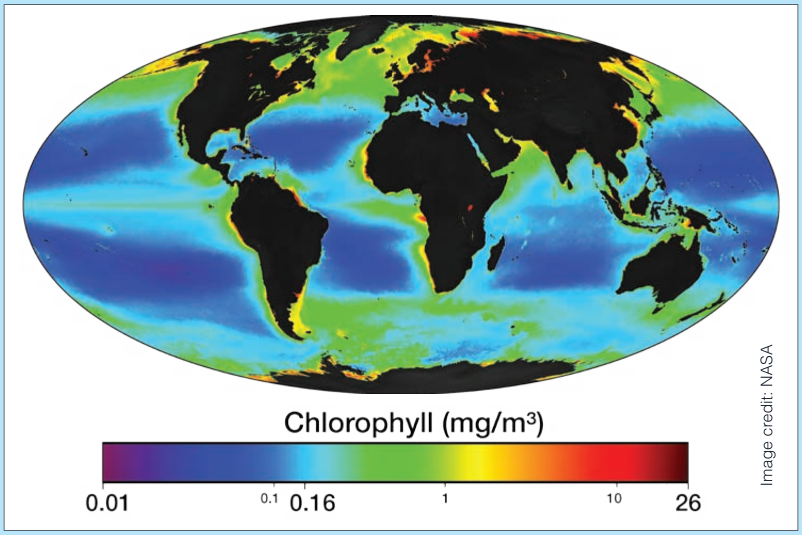
Image credit: NASA

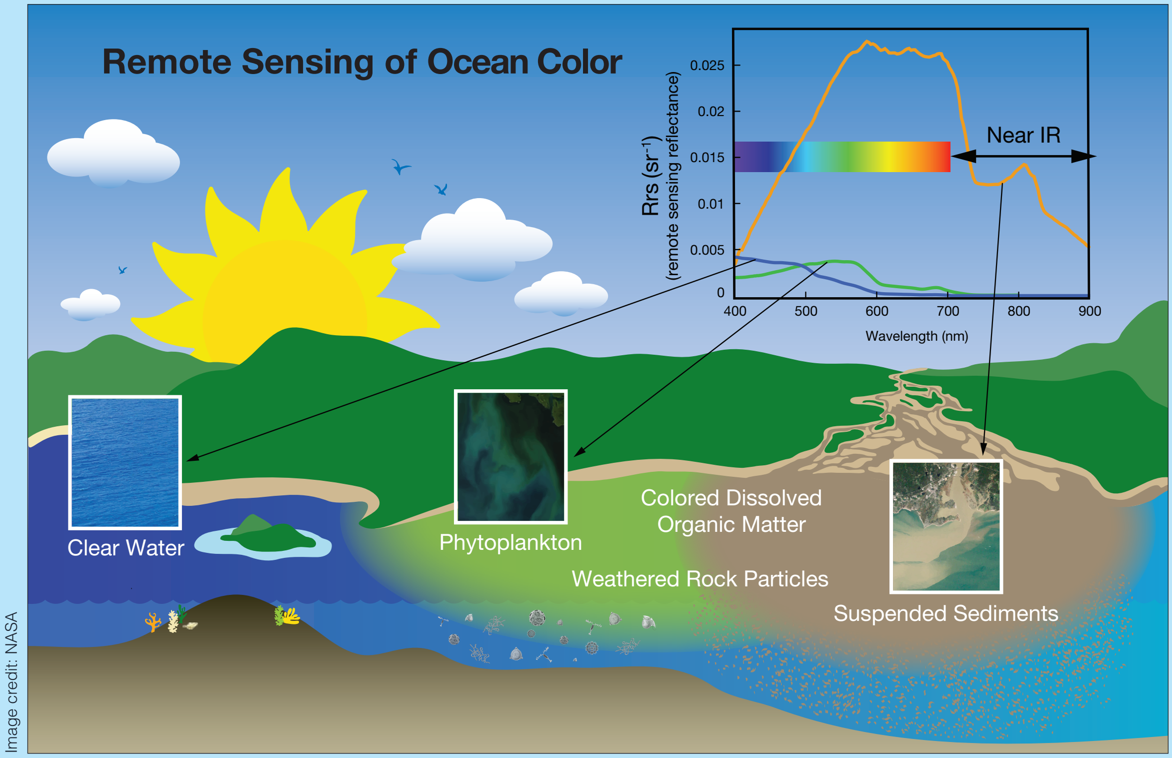
[Right] *This map was created using measurements from the Multi-scale Ultra-high Resolution (MUR) sea surface temperature dataset, which combines data from several satellite instruments.*

DID YOU KNOW?

Scientists use ocean color data to study fundamental questions about phytoplankton, the aquatic food web, and fisheries; the storage of carbon in the ocean and the role of the ocean in Earth's climate; and ocean health and water quality to assist resource managers.

[Right] *The first dedicated global ocean color sensor, Sea-viewing Wide Field-of-view Sensor (SeaWiFS), operated from September 1997 until December 2010. More than a decade of observations from the SeaWiFS satellite are represented in this image, which shows average chlorophyll concentrations in Earth's ocean from September 4, 1997 through November 30, 2010. Areas with high chlorophyll concentrations appear red, orange, yellow, and green.*





[Above] *Ocean color instruments measure light coming back to the satellite from Earth's surface at different wavelengths. Differences in the shape of the spectra* [inset, top right] *can be used to determine the type of suspended and dissolved material in the water, such as sediments (orange line) or chlorophyll (green line). Brighter objects (e.g., sediments) scatter more light in all wavelengths.*

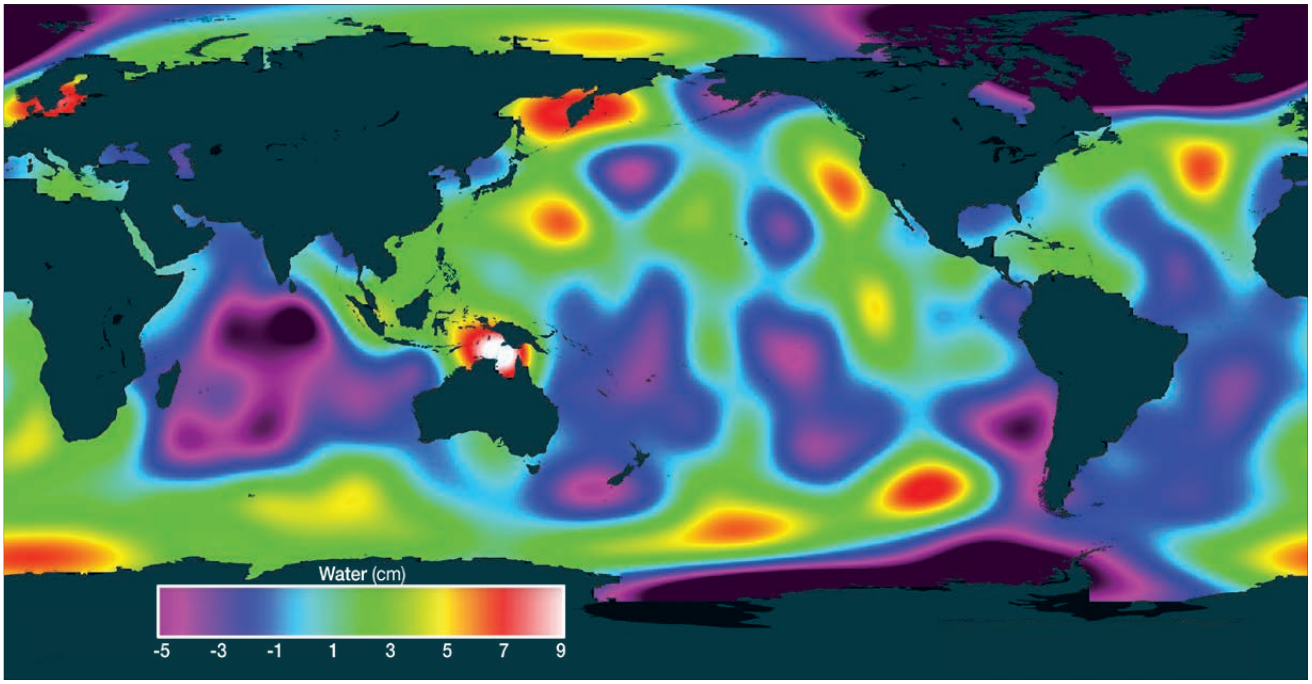


Image credit: NASA

[Above] *The twin Gravity Recovery and Climate Experiment (GRACE) satellites, launched on March 17, 2002, have been making detailed measurements of Earth's gravity field from space and revolutionizing investigations about Earth's ocean, water reservoirs, large-scale solid Earth changes, and ice cover. This image shows ocean bottom pressure data obtained by the GRACE satellites in January 2012. Ocean bottom pressure is the sum of the mass of the atmosphere and ocean in a "cylinder" above the seafloor. Scientists use these data to observe and monitor changes in deep ocean currents.*

DID YOU KNOW?

Ocean surface topography is the height of the ocean surface relative to Earth's *geoid*—the shape that the surface of the ocean would take under the influence of Earth's gravitation and rotation alone. Ocean surface topography is measured from space using a *satellite altimeter*, which measures the time it takes for microwave pulses to travel from the spacecraft to the ocean's surface and back to determine the height of the ocean surface at a given location. These measurements allow scientists to monitor the variations in global mean sea level, map changes in general ocean circulation patterns, and improve our understanding of tides.

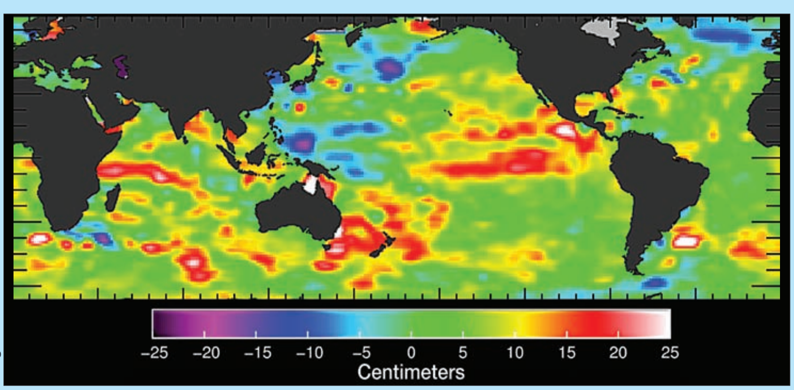


Image credit: NASA

[Left] *This map shows global sea surface height measurements from February 12-20, 2016, collected by the Jason-3 satellite. Higher-than-normal sea levels are red; lower-than-normal sea levels are blue. Launched on January 17, 2016, Jason-3 is the fourth mission in the U.S.-European series of satellite missions that measure the height of the ocean surface.*

DID YOU KNOW?

The Aquarius/Satélite de Aplicaciones Científicas (SAC)-D mission (June 10, 2011–June 8, 2015), an international collaboration between NASA and Argentina's space agency, made NASA's first space-based measurements of *salinity*—the concentration of dissolved salt—at the ocean surface. Its instruments measured changes in sea surface salinity equivalent to about a pinch (i.e., ⅛ of a teaspoon) of salt in 1 gallon of water.

[Right] *The ocean's salinity is key to studying the water cycle and ocean circulation, both of which are important to Earth's climate. This map, created using data from NASA's Aquarius mission, shows global sea surface salinity measurements. Several well-known ocean salinity features, such as higher salinity in the subtropics, higher average salinity in the Atlantic Ocean compared to the Pacific and Indian ocean basins, and lower salinity in rainy belts near the equator and in the northernmost Pacific Ocean, are visible. These features are related to large-scale patterns of rainfall and evaporation over the ocean, river outflow, and ocean circulation.*

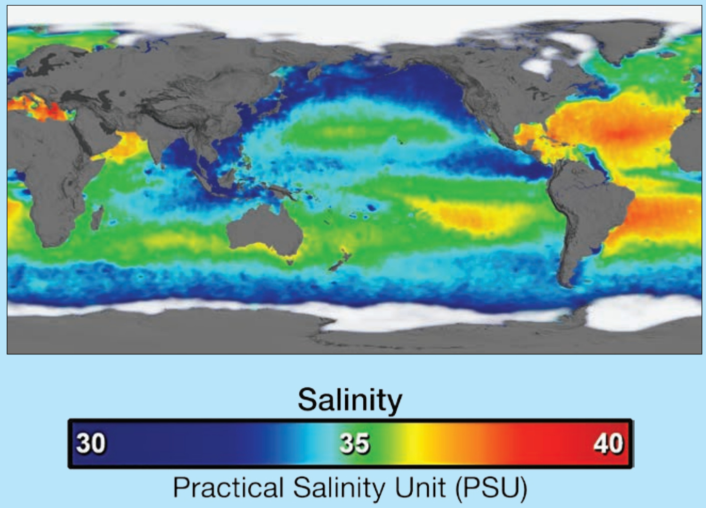


Image credit: NASA

DID YOU KNOW?

Radar scatterometers are the only remote-sensing instruments that can provide accurate, frequent, high-resolution measurements of ocean-surface wind speed and direction in most weather and cloud conditions.

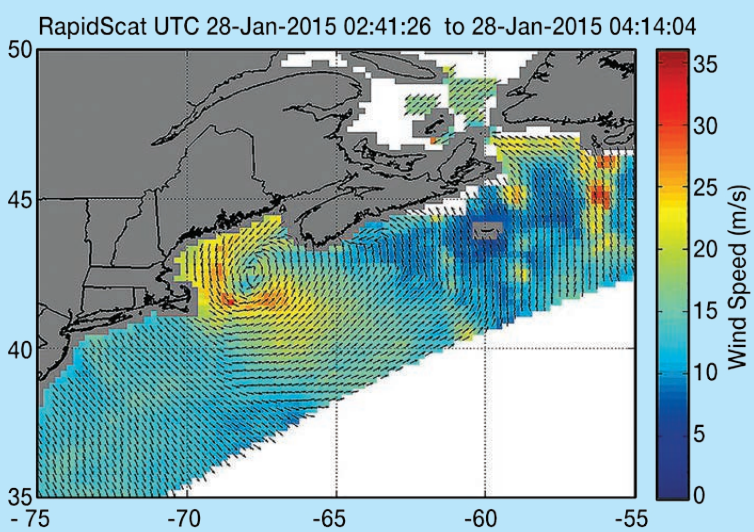


Image credit: NASA

[Left] *On January 28, 2015, the International Space Station Rapid Scatterometer (ISS-RapidScat) observed a Nor'easter weather system offshore from eastern Cape Cod, Massachusetts with sustained winds between 25 to 30 miles per second (56 and 67 miles per hour/90 to 108 kilometers per hour). The ISS-RapidScat is a radar scatterometer designed to sense near-surface winds over the ocean.*

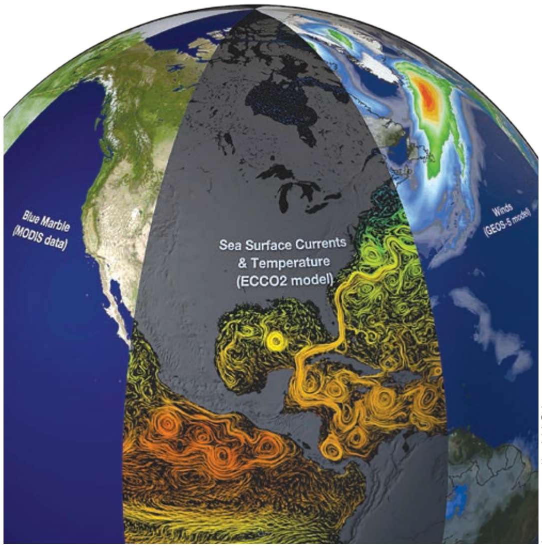


Image credit: NASA

[Above] *While scientists learn a great deal from studying individual Earth components, improved observational and computational capabilities increasingly allow them to study the interactions between these interrelated environmental parameters, leading to unprecedented insight into how the Earth system works—and how it might change in the future.*

Combining Ocean Measurements to Observe Interactions

Like the human body, Earth's systems interact with one another in complex ways. For example, the naturally occurring El Niño and La Niña phenomenon showcases an intricate relationship between the atmosphere and ocean in the equatorial Pacific, with impacts at a global level. Sea surface temperature is a critical variable, connecting the atmosphere and the ocean; scientists study changes in global sea surface temperature patterns to understand, and predict, future ocean conditions. Since sea surface height measurements yield critical information about the depth of the subsurface temperatures (in general, warm water expands and cold water contracts), they too provide key information about the ocean, such as the onset, maintenance, and dissipation of El Niño and La Niña.

Physical changes often drive biological changes in the ocean. For example, during El Niño the easterly trade winds weaken, allowing warmer water from the western Pacific to surge eastward towards South America. This leads to the sinking of the*rmocline*—the transition layer between warmer surface water and cooler, nutrient rich deep water—in the eastern Pacific. The deeper thermocline curtails the usually vigorous upwelling of deep-ocean nutrients to the surface, causing declining phytoplankton concentrations. The opposite phase, La Niña, is characterized by strong trade winds that cause upwelling to intensify in the eastern Pacific. More intense upwelling generally coincides with higher phytoplankton concentrations.

OCEAN FACT: Physical changes in the ocean often drive biological changes.

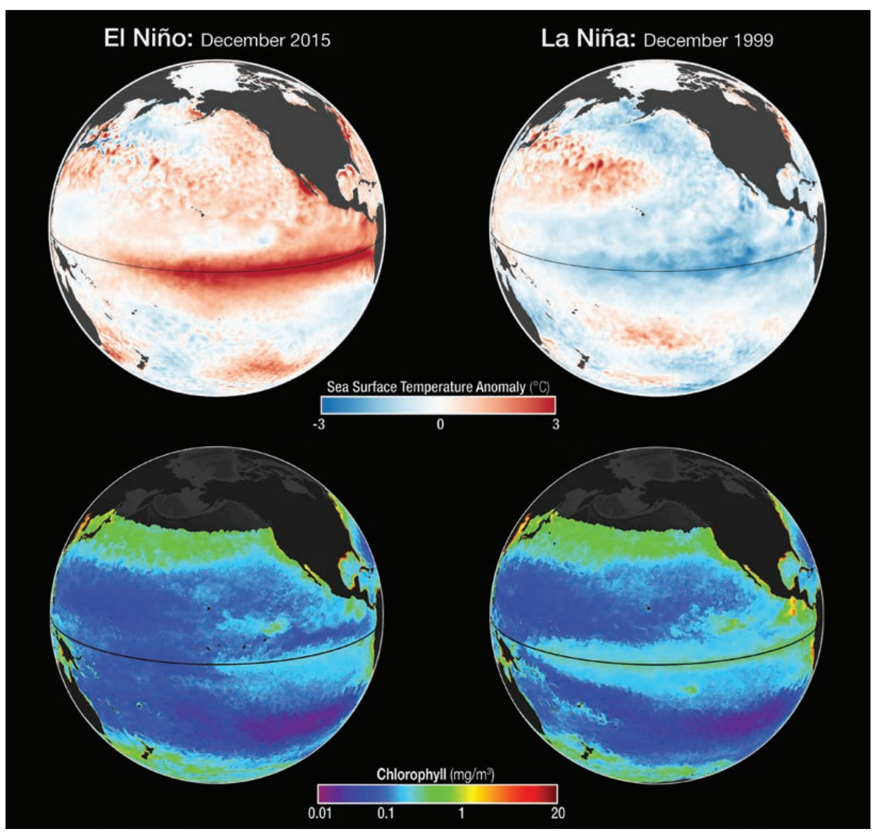


Image credit: NASA

[Right] *Monthly sea surface temperature anomalies* [top] *and surface chlorophyll concentrations* [bottom] *during El Niño in December 2015* [left side] *and La Niña in December 1999* [right side]. *Note how El Niño conditions coincide with relatively low chlorophyll concentrations, and La Niña conditions coincide with relatively high chlorophyll concentrations.*

El Niño-induced decreases in phytoplankton biomass, which is the base of the food web, have severe impacts further up the food chain. Major fishery collapses have occurred during El Niño years, and this has implications for larger marine animals that depend on this food supply. In fact, during the 1997-98 El Niño, severe declines in fish, marine mammals, and seabird populations within the eastern Pacific marine food web were reported. However, the La Niña events that often follow have the opposite effect: stronger east-to-west trade winds increase nutrient upwelling which fertilize surface waters, leading to large phytoplankton blooms. These blooms are accompanied by increases in fish populations.

Combining physical and biological observational capabilities enables scientists to achieve a better understanding of the ocean. Such observations, coupled with numerical computer models, increasingly allow us to better comprehend interactions between components, and more accurately forecast future scenarios in light of the changing climate, providing unprecedented insight into how Earth's air, land, and water components function as one integrated *system of systems*.

DID YOU KNOW?

Images generated by ocean-observing satellite missions tell us volumes about Earth's most fundamental climate changes. During the last decade, forecasting models have benefited from satellite data as they have improved the ability to predict events such as El Niño and other global and regional climate cycles. These models will become more sophisticated as scientists and forecasters further develop the ability to simulate certain ocean phenomena and thus better predict when they will occur.

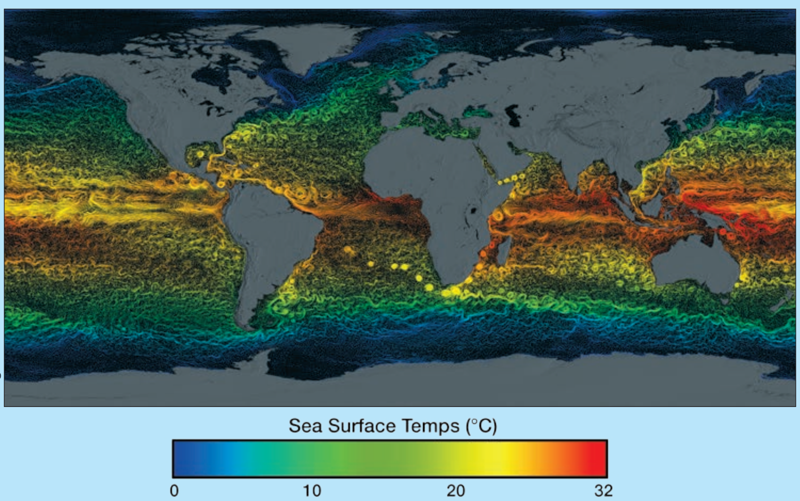


Image credit: NASA

[Left] *In this image, colors represent sea surface temperatures while the flow lines represent sea surface currents, mainly driven by prevailing winds. Scientists use model simulations like this one—produced by the Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2)—to help resolve ocean eddies and other narrow-current systems that transport heat and carbon in Earth's ocean.*

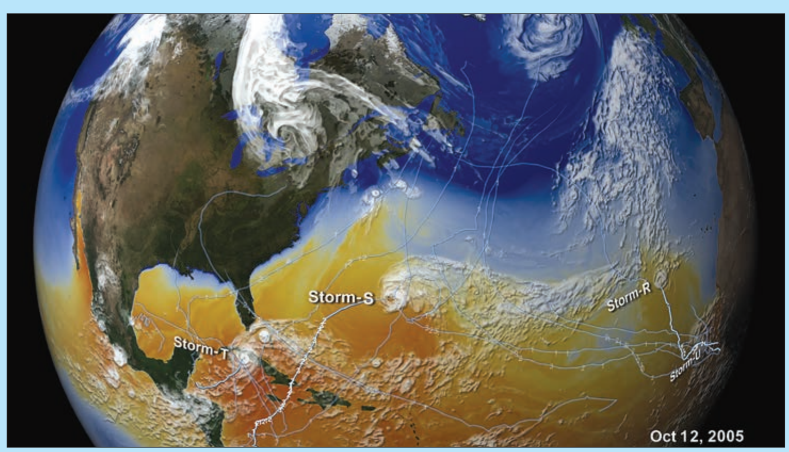


Image credit: NASA

[Right] *This image shows results from the Goddard Earth Observing System Model, Version 5 (GEOS-5). The model was used to simulate the 2005 hurricane season driven by sea surface temperature. What's interesting is that even though the model did not perfectly duplicate all 27 storms from that very active 2005 hurricane season, it did show 23 storms during that same period. Considering this was an anomalous year, the model did a good job of simulating the large number of storms for that season.*






Image credits top of the page (left to right): sante1, Morguefile.com; DodgertonSkillause, Morguefile.com; RoganJosh, Morguefile.com; NASA; Woods Hole Oceanographic Institute; David Young

Image credit: Kai Schumann, NOAA

[Above] *Certain species of phytoplankton produce powerful toxins, making them responsible for harmful algal blooms, sometimes called red tides. Toxic blooms can kill marine life and pose a health risk to those exposed to such blooms.*

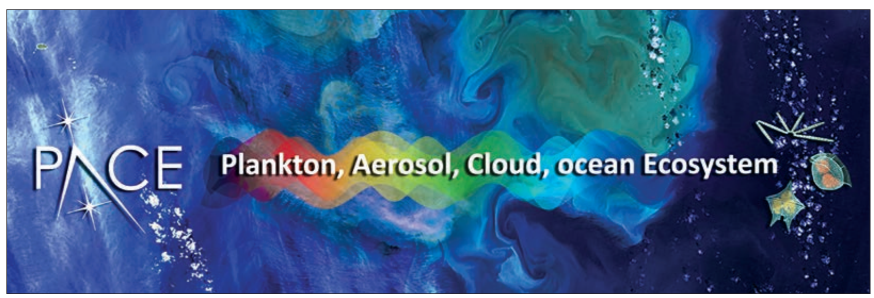
The Ocean, You, and NASA

Earth's ocean provides essential goods and services to humankind, called *ecosystem services*. These services include seafood, medicine, energy sources (from oil and gas, wind, and waves), storm protection (by way of coastal barriers such as mangroves, marshes, and coral reefs), detoxification (by trapping sediment and nutrients in estuaries), marine transportation and trade, recreational and educational resources, among many others.

Humans are directly impacted by changes in ecosystem services on a range of scales. For example, large-scale changes in Earth's climate can increase storm frequency or drought at a given location. A rise in sea level can increase the flood potential for entire countries, states, cities, and even individual homes. Declines in ocean productivity can have global and regional impacts on food supply. Beach closures and fish kills that result from polluted waters or harmful algal blooms negatively impact the regional economy and recreation potential.

NASA has the ability to observe and detect changes in the ocean (and on Earth as a whole) on a variety of spatial and temporal scales. This allows scientists to conduct research on the causes and consequences of those changes, which uniquely positions the Agency to improve life on our planet.

[Above] *The SWOT mission is being jointly developed by NASA and the Centre National d'Etudes Spatiales (the French space agency), with contributions from the Canadian Space Agency and the United Kingdom Space Agency.*



[Above] *NASA's PACE mission is scheduled to launch in 2022. The high spectral resolution of PACE will enable scientists to distinguish phytoplankton types, which will help, among other things, to identify harmful algal blooms from space.*

Future Earth-observing satellite missions, such as the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) and Surface Water and Ocean Topography (SWOT) missions, are scheduled to launch in the 2020–22 timeframe. The PACE mission will deliver the most comprehensive global combined ocean-atmosphere measurements in NASA's history. Not only will PACE monitor the health of our ocean and its living marine resources, it will provide extensive measurements of aerosols (tiny airborne particles) and clouds. The SWOT mission brings together international communities whose focus is to better understand Earth's ocean and terrestrial surface waters, and the interplay between them. These and other missions will ultimately unveil a variety of new products to aid our understanding of the atmosphere, land, and ocean and their roles in Earth's changing climate for many years to come.

FIELD CAMPAIGNS

Field campaigns are observational studies planned for specific locations over a defined time period, during which measurements are conducted from a variety of platforms. The following field campaigns will provide data to benefit either the PACE or SWOT missions.

North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)

NAAMES is a five-year (2015-2019) investigation to resolve key processes controlling ocean system function, their influences on atmospheric aerosols and clouds and their implications for climate. Observations obtained during four targeted ship and aircraft measurement campaigns, combined with the continuous satellite and *in situ* ocean sensor records, will enable improved predictive capabilities of Earth system processes and will inform ocean management and assessment of ecosystem change.

COral Reef Airborne Laboratory (CORAL)

The three-year (2016-2018) CORAL mission will survey a portion of the world's coral reefs to assess the condition of these threatened ecosystems and understand their relation to the environment, including physical, chemical, and human factors. CORAL will use advanced airborne instruments, including the Portable Remote Imaging Spectrometer (PRISM), and in-water measurements. The investigation will assess the reefs of Palau, the Mariana Islands, portions of Australia's Great Barrier Reef, and Hawaii. With new understanding of reef condition, the future of this global ecosystem can be predicted.

AirSWOT

As the name implies, AirSWOT is an airborne instrument suite that flies onboard a King Air B200. The instrument provides the calibration/validation and science support for the SWOT mission.

The core of AirSWOT is a multi-purpose Ka-band radar, called KaSPAR. The instrument collects two swaths of data that are used to obtain centimeter-level topographic maps of water surfaces and flood plains. AirSWOT is currently performing engineering test and measurement validation flights.

Image credit: NASA

[Above] *NASA's C-130H Hercules airborne laboratory began research flights for NAAMES over the North Atlantic in November 2015, from St. John's, Newfoundland, Canada.*

OCEAN FACT: Fish account for 16% of world animal protein consumption.

OCEAN FACT: Around 90% of all trade between countries is carried by ships.

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

www.nasa.gov

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