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The Earth Observing System Terra Series

These articles focus on the overarching science priorities of the EOS Terra mission
http://terra.nasa.gov

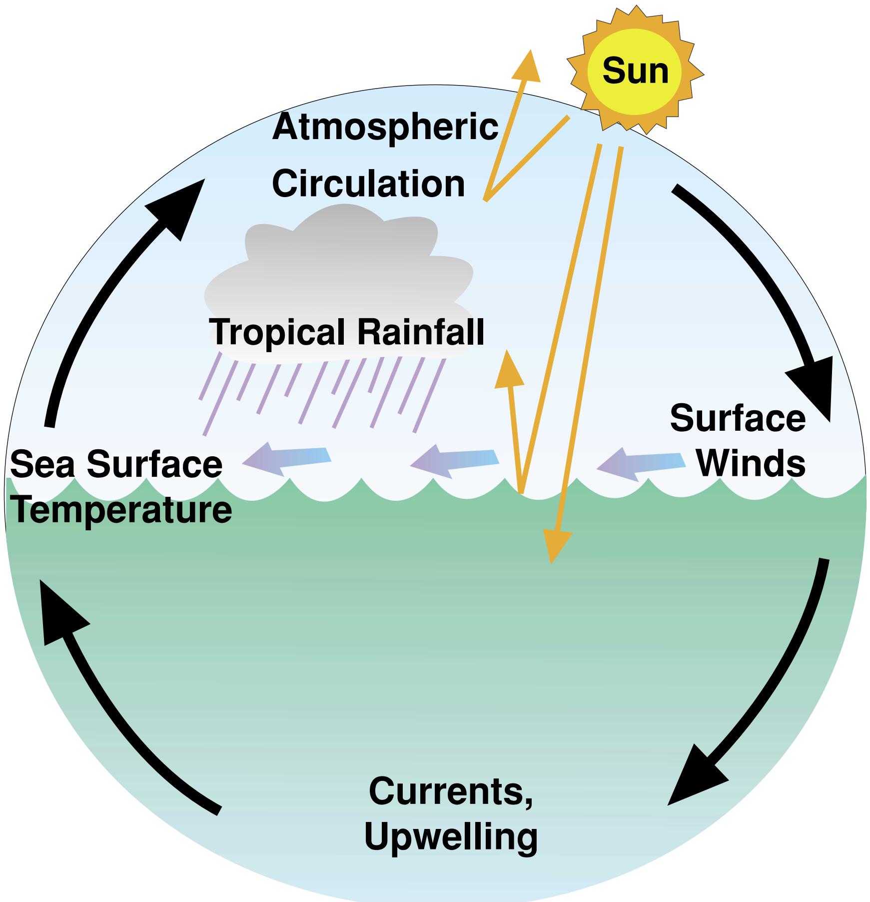
The Roles of the Ocean in Climate Change

Surprisingly, despite a 30 percent increase in carbon dioxide (CO_2) levels, global temperatures haven't risen as much as earlier models predicted. Why? Because greenhouse gases aren't the only influence on temperature—there are many other variables, such as clouds, aerosols, and the ocean. Since the 1960s, scientists have developed sophisticated climate models to help them understand the ocean's role in moderating climate. Yet many questions remain unanswered. Does the ocean help to cool climate and partially offset global warming? Or, over the long run, will the ocean amplify and accelerate the warming trend? How will changes in climate trends and changes in climate variability affect life in the ocean and on land? How will changes in the ocean's chemistry and biology interact with these changes in climate? How are human activities contributing to changes in the marine environment and, in turn, how might these changes affect humans?

Physical Interactions with the Atmosphere

In broad terms, the ocean interacts with the atmosphere in two main ways. The first way is physically, through the exchange of heat, water, and momentum. Covering more than 70 percent of the Earth's surface and containing about 97 percent of its surface water, the ocean stores vast amounts of energy in the form of heat. Moreover, the ocean has a relatively large temperature inertia, or resistance to change.

Previously, scientists perceived the ocean as an unchanging "desert" due to its slow circulation (relative to the circulation of the atmosphere) and its low biological productivity. Yet, today we know the biological and physical functioning of the ocean system can change quickly over both small and large areas (i.e., during an El Niño). Because it often drives the timing and



The ocean has been dubbed the "global heat engine." Energy escapes the ocean in the forms of heat and water vapor. As the atmosphere warms, temperature gradients are created, resulting in surface winds that, in turn, drive ocean currents. These winds and water vapor also dramatically affect meteorological conditions, resulting in the formation of clouds or even rainstorms that are vital for life on land.

patterns of climate change, the ocean was recently labeled by some scientists as the "global heat engine."

As heat rises and eventually escapes the ocean to warm the atmosphere, it creates air temperature gradients and, consequently, winds. In turn, winds push horizontally against the sea surface and drive ocean current patterns. Meanwhile, variations in temperature and salinity (or saltiness) control vertical ocean currents—warmer, fresher waters flow upwards while colder, denser (or saltier) water tends to sink. Over time, a complex circulation pattern is established whereby warm surface waters move poleward where heat escapes more readily to outer space, while cold, deep currents are established in the ocean depths. Through this complex ocean circulatory system, the oceans and atmosphere work together to distribute heat and regulate climate. This circulation transports enormous amounts of heat, resulting in more moderate climates on land areas that are near the ocean. For example, London is warmer in winter than Toronto, even though London is closer to the North Pole.

Global climate modelers recently estimated that over the course of the 20th century, the ocean has reduced by about half the expected surface warming due to rising greenhouse gas levels. Scientists have observed an overall cooling trend in the east despite the strong and frequent El Niño events after 1975. Modelers conclude that as a consequence of the exchanges of heat and momentum (or interaction of air and water currents) between ocean and atmosphere, the mean temperature of the Pacific Ocean increases less than it would if it only exchanged heat. Thus, given its efficiency at redistributing heat poleward, the ocean is effectively delaying and regulating global warming.

But scientists don't know if the ocean's role as "climate moderator" will persist over the long term. There is evidence that large and abrupt changes in the ocean's circulation have had major impacts on global climate in the past. Some scientists question whether the existing ocean circulation pattern is stable enough to withstand the stresses of rising temperatures, heightened greenhouse gases and fresh water runoff due to melting glaciers. As the rate of fresh water runoff increases, it lessens the salinity and density of surface water, thereby raising its freezing point. More surface ice would inhibit the escape of heat and could result in a major reorganization of the ocean's circulation system, which would, in turn, affect the global climate.

Chemical Interactions with the Atmosphere

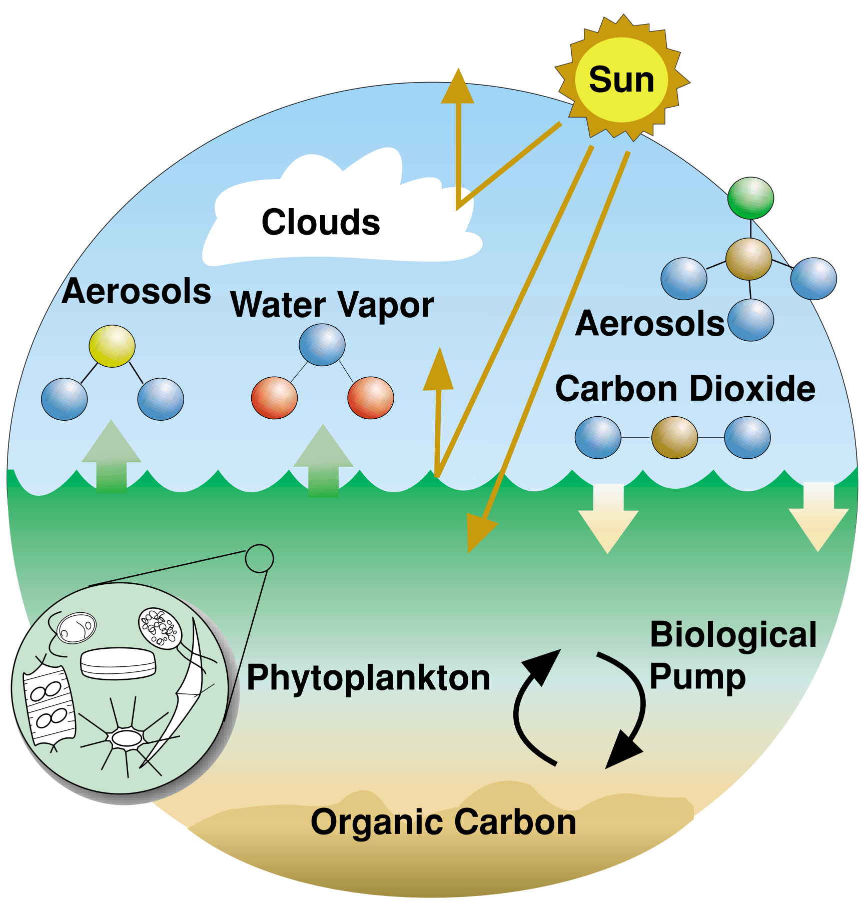
The second way that the ocean and atmosphere couple is chemical, as the ocean is both a source and sink of greenhouse gases. Much of the heat that escapes the ocean is in the form of evaporated water, the most abundant greenhouse gas on Earth. Yet, water vapor also contributes to the formation of clouds, which shade the surface and have a net cooling effect. In the long run, scientists don't know which process (cloud shading or water vapor heat retention) will exert the larger influence on global temperatures.

Of the greenhouse gases, CO_2 is perhaps the most important because of its links with human activities. Most of the world's carbon resides in the ocean, and the processes that result in exchanges between the surface ocean and the atmosphere, and between the upper ocean and the deep ocean, are critical. Carbonate chemistry regulates much of the transfer between these systems, but biological processes, such as photosynthesis which turns CO_2 into organic material, also play an important role. Settling of this organic carbon into the deep ocean is known as the "biological pump." In part, the upper ocean has lower concentrations of total carbon than the deep ocean as a result of the actions of this pump. Some scientists speculate that if the ocean's circulation pattern is disrupted, it could become a source rather than a sink for carbon and atmospheric CO_2 levels could rise much higher than they are now.

One of the key questions in climate change research is how the physical and biological processes of the ocean will respond to chemical and physical changes in the atmospheric. For example, will there be increased storms that increase mixing in the upper ocean? Will phytoplankton become more or less productive in such an environment? Windblown dust from soils and desert sands are rich in iron that, when they settle into the ocean, serve as "fertilizer" for the phytoplankton. Will this dust input increase as a result of climate change? Will this increase the efficiency of the biological pump and thereby increase the removal of CO_2 from the atmosphere by the ocean?

There is some evidence that larger amounts of iron may be deposited in the ocean in the future as global warming causes increases in windblown continental dust. Theoretically, if iron-containing aerosols ("aerosols" are solid or liquid particles suspended in the atmosphere) fall in large regions of the ocean that are rich in other nutrients, then this would act like "fertilizer" to promote burgeoning phytoplankton populations, thus slowing the rate of CO_2 increase in the atmosphere and partially offsetting the anticipated warming.

While we know that short-term events, such as El Niño, dramatically affect phytoplankton concentrations in the eastern Pacific, scientists aren't sure how, over the long-term, changes in ocean circulation and atmospheric forcing will affect the ocean's productivity. During an El Niño event, the whole marine food chain is disrupted. Larger fish and mammals must either starve or move to where phytoplankton are more abundant.



There is ongoing chemical "dialogue" between the ocean and atmosphere that influences regional and global climate in many ways. Sea spray and water vapor form low clouds that ultimately cool temperatures at the surface. Meanwhile, desert dust and carbon dioxide settle into the ocean and act as "fertilizer" to stimulate the growth of phytoplankton, thereby enhancing the ocean's ability to absorb carbon dioxide from the atmosphere—a process known as the "biological pump." Over geological time, more than 90 percent of the world's carbon has settled into the deep ocean.

Linking these intense events with changes in climate variability is one of the most pressing issues in climate research. Yet, long-term trends are difficult to detect when natural variability is so high. A comprehensive program of observations and modeling is necessary to improve our ability to make predictions on the future course of the Earth system.

Space-based Oceanography

Reliable sea surface temperature measurements from space-based sensors have been a goal of oceanographers since the late 1960s. For the first time, Terra will provide oceanographers with the radiometric resolution and precision, the scientific calibration, the spatial coverage, and the ability to remove atmospheric effects (such as clouds and aerosols) that will enable measurements of sea surface temperature accurate to within 0.5°C. These data will enable a better understanding of ocean-atmosphere coupling—particularly during El Niño events.

Terra will make comprehensive measurements of phytoplankton biomass as well as dissolved organic matter in the upper ocean. These measurements of the “standing stock” of the base of the marine food web are critical to understanding the interactions between ocean circulation and productivity. Terra provides for the first time the ability to measure “fluorescence,” or energy emitted by phytoplankton during photosynthesis. Fluorescence measurements will greatly improve the estimates of the rates of marine productivity. The combination of both standing stock (derived from precise measurements of the ocean’s color) and growth rate will significantly improve our understanding of the ocean and climate.

An Earth-orbiting NASA scatterometer (a microwave radar called QuikSCAT) will measure wind velocity (both speed and direction) over the ocean. These data will complement Terra by providing essential information on processes that drive ocean circulation. Winds affect the degree of ocean mixing as well as providing the momentum to drive ocean currents. QuikSCAT will provide high-resolution maps of wind velocity to study specific processes such as coastal upwelling, as well as global-scale maps of winds to examine large-scale processes such as El Niño.

Terra, and QuikSCAT (together with other Earth observing satellites such as SeaWiFS, TRMM, and Landsat 7—all of which are addressed in other NASA Fact Sheets) provide oceanographers with unprecedented data for scientific studies of the air-sea couplings and their effects on the marine biosphere. With these data, scientists can refine their models of the ocean’s physical, biological, and chemical influences on global climatic and environmental change.

The Terra Spacecraft

Terra is the flagship of the Earth Observing System (EOS), a series of spacecraft to observe the Earth from the unique vantage point of space. Focused on key measurements identified by a consensus of U.S. and international scientists, EOS will enable research on the complex interactions of Earth’s land, ocean, air, ice and life systems.

Terra will circle the Earth in an orbit that descends perpendicularly across the equator each day at 10:30 a.m. local time, when cloud cover is at a minimum and the space-based view of the surface is least obstructed. Each individual swath of measurements can be compiled into global images as frequently as every two days. Over a month or more, in combination with measurements from other polar orbiting satellites, Terra measurements will provide accurate monthly-mean climate assessments that can be compared with computer model simulations and predictions.

The Earth Observing System has three major components: the EOS spacecraft, an advanced ground-based computer network for processing, storing, and distributing the resulting data (the EOS Data and Information System); and teams of scientists and applications specialists who will study the data and help users in industry, universities and the public apply it to issues ranging from agriculture to urban planning.

Additional information on NASA’s Terra mission can be found on the World Wide Web at http://terra.nasa.gov.