## The Big Picture

As we learn more about our home planet, new questions arise, drawing us deeper into the complexities of Earth's climate system. We don't know the answers to many important questions, like: Is the current global warming trend temporary, or is it the beginning of an accelerating increase in global temperatures? As temperatures rise, how will this affect weather patterns, food production systems, and sea level? Are the number and size of clouds increasing and, if so, how will this affect the amount of incoming and reflected sunlight, as well as the heat emitted from Earth's surface? What are the causes and affects of ozone fluctuations? How will climate change affect human health, natural resources, and human economies in the future? NASA's Earth Observing System and Terra will help scientists answer these questions, as well as some we don't even know to ask yet.

## Learn more about the Earth

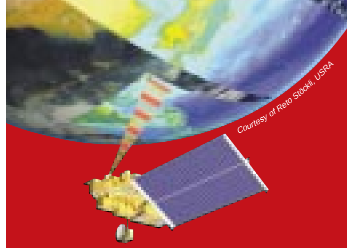
While the major goal of NASA's Earth Observing System is to increase understanding of our changing planet, information from Terra is not limited to serving the needs of just the scientific community. Rather, the ultimate product of this mission is education in its broadest forms. There are many information resources and educational materials available from NASA to inform the general public on the goals, objectives, and results of its missions. For more information on these resources, visit NASA's Earth Science Enterprise web site at http://earth.nasa.gov; the EOS Project Science Office web site at http://eos.nasa.gov; or the Terra home page at http://terra.nasa.gov.

## Conclusion

In scope and complexity, Terra is truly a milestone mission. If you compared the Earth to a middle-aged person who has never had a physical health check-up, then by comparison Terra will provide scientists with the best scientific tool for conducting the first thorough global examination of our planet. It will take at least one year after launch to complete the first round of tests and to make an initial assessment of the state of the planet. It will take two or three years after launch to complete the in-depth statistical analyses needed to understand whether our planet is in good health, or whether there are specific symptoms that must be addressed.

The information that Terra gathers will be shared freely with scientists, resource managers, and commercial enterprises around the world. Findings from this research will benefit us all, no matter where we are, no matter what our occupation. Eventually, the data will come to us via the internet, broadcast and print media, new text books, interactive communication technologies, and more. In the future, our local meteorologist, farmer, fisherman, forest rangers, water treatment managers, medical care givers, insurance agents, and industrial companies may routinely consult Terra data to enhance their products and services.

Courtesy of Reto Stöckli, USRA



Courtesy of Reto Stöckli, USRA

"...the astonishing thing about the Earth...is that it is alive. It has the organized, self-contained look of a live creature, full of information..."

Lewis Thomas

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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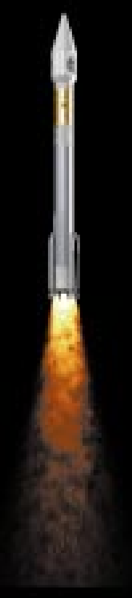

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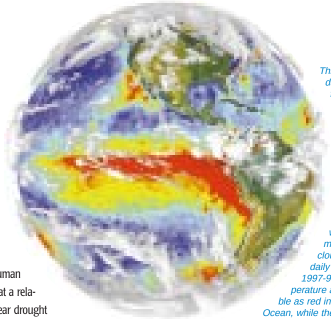
## Introduction



*This globe shows data collected from multiple sensors and integrated into one image. Notice the three-dimensional cloud measurements; these will be collected by ASTER and MISR, while MODIS measures total cloud cover on a daily basis. The 1997-98 El Niño temperature anomaly is visible as red in the Pacific Ocean, while the red dots on land show the locations of forest fires. The ASTER, MISR, MODIS, and MOPITT instruments are all uniquely designed to observe fires and help us measure the smoke and gases they release. Together with CERES, these instruments will help us understand the Earth as a whole, integrated system. (Image by R.B. Husar, Washington U.; the land layer from the SeaWiFS Project; fire maps from ESA; the sea surface temperature from the Naval Oceanographic Office's Visualization Laboratory; and the cloud layer from SSEC, U. of Wisconsin)*

Earth's 4.5-billion-year history is a study in change. Natural physical forces have been rearranging the surface features and climatic conditions of our planet since its beginning. There is scientific evidence that some of these natural changes have not only led to mass extinctions of species like the dinosaurs, but have also severely impacted human civilizations. For instance, there is evidence that a relatively sudden climate change caused a 300-year drought that contributed to the downfall of Akkadia, one of the most powerful empires in the Middle-East region around 2200 BC. More recently, the "little ice age" from 1200-1400 AD forced the Vikings to abandon Greenland when average temperatures there dropped by about 1.5°C, making it too difficult to grow enough crops to sustain the population. Today, there is compelling scientific evidence that human activity is impacting global climate conditions. Carbon dioxide levels in the atmosphere have risen 25 percent since the industrial revolution, and about 40 percent of the world's land surface has been transformed by human activity (see Figure 1).

Scientists have been monitoring individual climate phenomena using information from Earth-viewing satellites for several years, but don't yet comprehensively understand the cause-and-effect relationships among land, ocean, and atmospheric conditions. Consistent measurements are needed globally over several years in order to understand the interactions among the Earth's ecosystems, and to accurately predict climate change and its impact on our daily lives.

NASA's Earth Observing System (EOS) has begun a long-term, comprehensive study of the Earth that is comprised of a series of satellites specially designed to study the complexities of global change, an advanced computer network for distributing scientific data, and international teams of scientists who will study the data. In 1999, NASA launches the EOS satellite Terra to collect a new 15-year global data record on which to base future scientific investigations about our complex planet.

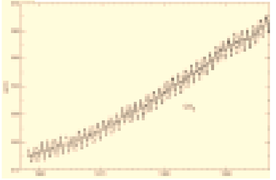
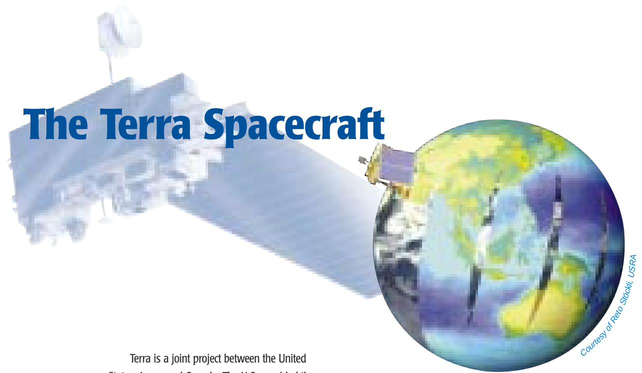


*Figure 1. Atmospheric carbon dioxide monthly mean mixing ratios as observed by Tans and Keeling at Mauna Loa, Hawaii.*

# The Terra Spacecraft



Courtesy of Reto Stöckli, USRA

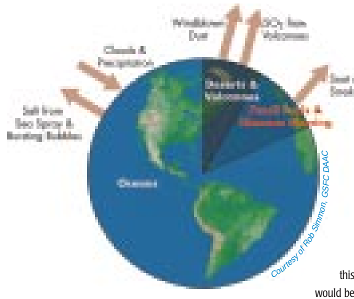
Figure 2. As the Earth rotates below the orbiting Terra spacecraft, adjacent orbits are offset somewhat at the equator and there is a small gap between Terra's viewing swaths. It will take a little more than one day for these gaps to be filled on subsequent overpasses, so that Terra will provide us snapshots of the entire surface of the Earth every two days.

Terra is a joint project between the United States, Japan and Canada. The U.S. provided the spacecraft and three instruments—the Clouds and the Earth's Radiant Energy System (CERES) the Multi-Angle Imaging Spectroradiometer (MISR) and the Moderate-resolution Imaging Spectroradiometer (MODIS). The Japanese Ministry of International Trade and Industry provided the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The Canadian Space Agency/University of Toronto provided an instrument called Measurements Of Pollution In The Troposphere (MOPITT).

Physically, the Terra spacecraft is roughly the size of a small school bus. It carries a payload of five state-of-the-art sensors that will simultaneously collect information about the Earth's atmosphere, lands, oceans, and solar energy balance. Each sensor has unique characteristics that will enable EOS scientists to meet a wide range of science objectives.

Orbiting the Earth very nearly from pole to pole at an altitude of 705 km, Terra descends across the equator at the same local time in the morning when cloud cover over land is minimal and its view of the surface is least obstructed (see figure 2). Terra's orbit will be roughly perpendicular to the direction of the Earth's spin, so that the viewing swaths from each overpass can be "stitched together" into whole global images. Over time, these global images will enable scientists to more clearly understand the causes and effects of global climate change. Their goal is to understand how Earth's climate and environment function as an integrated system.

The life expectancy of the Terra mission is 6 years. Several other satellites will also be launched over the following years to complement the information collected by Terra, and take advantage of new developments in remote sensing technologies. These increasingly advanced satellites will both extend and build upon NASA's study of our planet in the new millennium.



Courtesy of Rob Simmon, GSFC DAAC

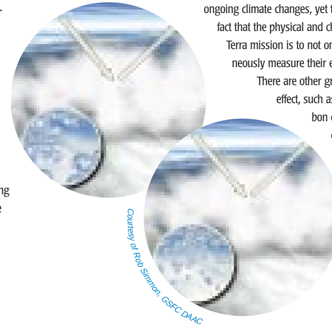
Figure 3. Aerosol particles larger than about one micrometer in size are produced by windblown dust and sea salt from sea spray and bursting bubbles. Aerosols smaller than one micrometer are mostly formed by condensation processes such as conversion of sulfur dioxide ($SO_2$) gas (released from volcanic eruptions) to sulfate particles and by formation of soot and smoke during burning processes. After formation, the aerosols are mixed and transported by atmospheric motions and are primarily removed by cloud and precipitation processes.

## The Atmosphere

If you shrank Earth down to the size of a basketball, by comparison its atmosphere would have roughly the thickness of a sheet of plastic wrap. All that is essential to life on Earth is contained in this relatively thin sheet. Without its "wrapper," our world would be as cold and barren as the moon. With it, the Earth is blanketed in all the essential ingredients—air, water, nutrients, and heat—needed to sustain the vast web of life. Over billions of years, the atmosphere has evolved into a complex system in which life and climate are intricately interwoven. The atmosphere shields the harsh rays of the sun, helps contain heat in the biosphere, and nourishes life on Earth. When we measure the amount of incoming sunlight at the top of Earth's atmosphere, and compare it with the amount of sunlight received at the surface, we find that roughly 8 percent of the sun's energy is lost before it reaches the surface. The amount of energy lost varies depending on the amount and characteristics of clouds and the land surface below them. Because of the complexity and ever-changing conditions in the atmosphere, scientists aren't sure of the impact that clouds and other aerosols (solid and liquid molecules suspended in the atmosphere) have on reducing the sun's energy at the surface (see Figure 3). Terra will enable scientists to accurately measure the effects of the atmosphere on sunlight and, subsequently, greatly improve our understanding of long-term climate change.

Scientists have observed that clouds polluted with aerosols generally appear whiter and brighter than those unpolluted (see Figure 4). We know that due to their interactions with Earth's radiant energy, clouds and aerosols play important roles in ongoing climate changes, yet the extent of their contributions is not fully understood. The mystery lies partly in the fact that the physical and chemical make-up of the atmosphere changes rapidly. One of the major challenges of the Terra mission is to not only observe how and why clouds, aerosols and other gases change, but to also simultaneously measure their effects on the Earth's total radiant energy.

There are other greenhouse gases in Earth's atmosphere that trap heat and contribute to its greenhouse effect, such as methane. While there is far less methane in our atmosphere than water vapor or carbon dioxide, on a per-molecule basis methane is much more efficient than water vapor or carbon dioxide at trapping heat. Moreover, of Earth's greenhouse gases, methane levels are rising the fastest—increasing at an average rate of 1 percent per year. The reason for the rising methane levels is currently unknown; but an instrument on Terra will measure levels of the gas in the lower atmosphere and help us track down and quantify its sources.



Courtesy of Rob Simmon, GSFC DAAC

Figure 4. (top): Clouds with low aerosol concentration and a few large droplets do not scatter light well, and allow much of the Sun's light to pass through and reach the surface. (bottom): Clouds with high aerosol concentrations provide the nucleation points necessary for the formation of many small liquid water droplets. Up to 90% of visible radiation (light) is reflected back to space by such clouds without reaching Earth's surface.

## The Land

Millions of plant species thrive on land with a delicate balance of heat, light, nutrients, and water. These plants in turn feed and shelter hundreds of thousands of animal species, including humans. Not only do plants form the foundations of our ecosystems, they also interact dynamically with the atmosphere to moderate climate through the exchanges of moisture, heat, and greenhouse gases. One of plants' most significant influences on climate is their regulation of the global carbon cycle. Via photosynthesis, plants take in carbon dioxide from the atmosphere and then use sunlight as energy to "fuse" carbon dioxide and water into complex molecules called carbohydrates. The basic raw materials that feed Earth's biosphere, plants use carbohydrates as food and to make plant structures. Then, animals and humans consume plants to get these same carbohydrates that also serve as building blocks in our bodies. Both plants and animals breathe (or "respire"), thereby "burning" carbohydrates as fuel for metabolism and converting them back into separate water and carbon dioxide molecules that are eventually released back into the atmosphere. Hence, through biological respiration and decomposition of dead tissue, carbon is returned back to the atmosphere and the carbon cycle is complete (see Figure 5).

Scientists have observed that the amount of carbon dioxide in the atmosphere has risen by 25 percent over the last 100 years, contributing to a 0.5°C increase in average global temperatures. We have recently discovered that these two trends have prolonged the growing season in the Northern Hemisphere over the last 20 years, resulting in more annual plant productivity. Some scientists theorize that increasing plant productivity will effectively act as a "storehouse" for the excess carbon dioxide in the atmosphere, and that the two trends will balance each other. However, new scientific data suggest that as the rate of increase in carbon dioxide accelerates, and temperatures rise, land plants could begin regulating their evapotranspiration (water loss due to evaporation) rates in order to conserve water. If this plant response occurs on a large scale, scientists predict that greenhouse warming will be amplified over tropical land areas by as much as 50 percent above the current greenhouse warming trend.

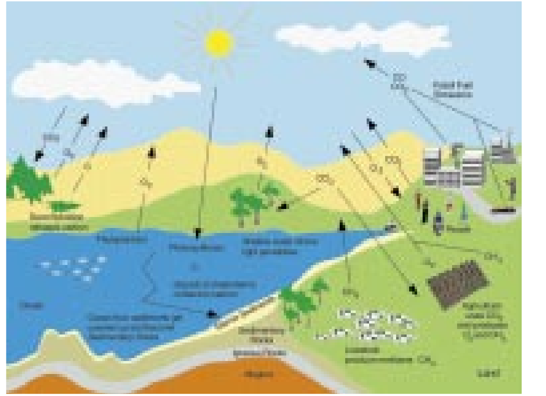


Figure 5. The carbon cycle is a complex web of processes that help maintain Earth's surface environment in a condition suitable for life. Large quantities of carbon (C) exist in all four of Earth's spheres: the atmosphere, the hydrosphere, the biosphere, and the solid Earth. Global sinks of carbon include land vegetation, soil, and the oceans. Sources of carbon dioxide ($CO_2$) in the Earth's atmosphere include decomposition of organic matter (such as trees), the carbon dioxide that animals and people exhale, volcanic activity, and human activities such as the burning of fossil fuels and wood (Courtesy of the SeaWiFS Project).

The Terra spacecraft will enable scientists to compare plant productivity with carbon dioxide and other important greenhouse gases, as well as global temperature trends. This information will better enable scientists to predict how changes in the climate will impact Earth's ecosystems. The new data will also allow us to measure how certain human activities, such as biomass burning and deforestation, may be contributing to climate change.

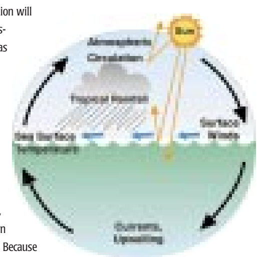
## The Oceans

The ocean also harbors abundant plant life, including microscopic plants called phytoplankton, which serve as the foundation for the marine food chain. Like their land-based relatives, phytoplankton use the sun's energy and photosynthesis to produce carbohydrates. Small fish and whales eat the phytoplankton, bigger fish eat the smaller fish, and humans eat many of the bigger fish.

Periodic regional ocean temperature shifts, such as occur during an El Niño event, can have dramatic effects on the health and distribution of phytoplankton, which in turn can have adverse effects on the animals that depend upon phytoplankton for nutrition. Because phytoplankton selectively absorb red and blue light, and reflect green light, satellites can precisely measure the abundance of microscopic marine life in the ocean based on its color. Scientists can also measure the difference between incoming sunlight and that which is reflected back up into the atmosphere (see Figure 6). This difference in sunlight represents the amount being used for photosynthesis, from which the abundance of phytoplankton is derived.

Covering more than 70 percent of the Earth's surface and containing 97 percent of its surface water, the ocean has been labeled "the heat engine of global climate" due to its influence on the timing and patterns of climate change. The ocean possesses a vast capacity to absorb and store sunlight as heat. This heat is transported by currents and eventually released into the atmosphere where it directly influences temperature and precipitation patterns, and indirectly influences land vegetation through precipitation or drought events. These ocean temperature trends also affect the marine life in the ocean. When the sea surface is cold, deeper waters flow to the surface, bringing critical life-sustaining nutrients with them. Yet when sea surface temperatures increase during an El Niño event, there is less vertical circulation of water, which means nutrients at the surface become more scarce and phytoplankton productivity drops. Larger fish and mammals that require phytoplankton to survive migrate to where the food source is more abundant. South American fishermen who fish the Pacific know well that El Niño is a time when their livelihood is interrupted.

How will the frequency and severity of El Niño affect ocean productivity? How will concentrations of phytoplankton shift in response to changes in ocean circulation? How do changes in ocean productivity affect ocean transparency, and therefore impact the exchange of heat between the ocean and atmosphere? The Terra satellite will measure these parameters with unprecedented accuracy to help scientists answer these questions.



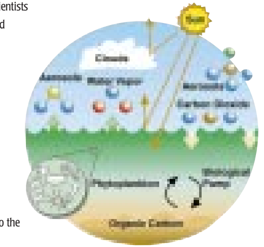


Figure 6. (top) The ocean has been dubbed the "global heat engine." Energy escapes the ocean in the form of heat and water vapor. As the atmosphere warms, temperature gradients are created, resulting in surface winds that, in turn, drive ocean currents. These winds and water vapor also dramatically affect meteorological conditions, resulting in the formation of clouds or even rainstorms that are vital for life on land. (bottom) 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 geologic time, more than 90 percent of the world's carbon has settled into the deep ocean (Courtesy of David Herring, SSAI).