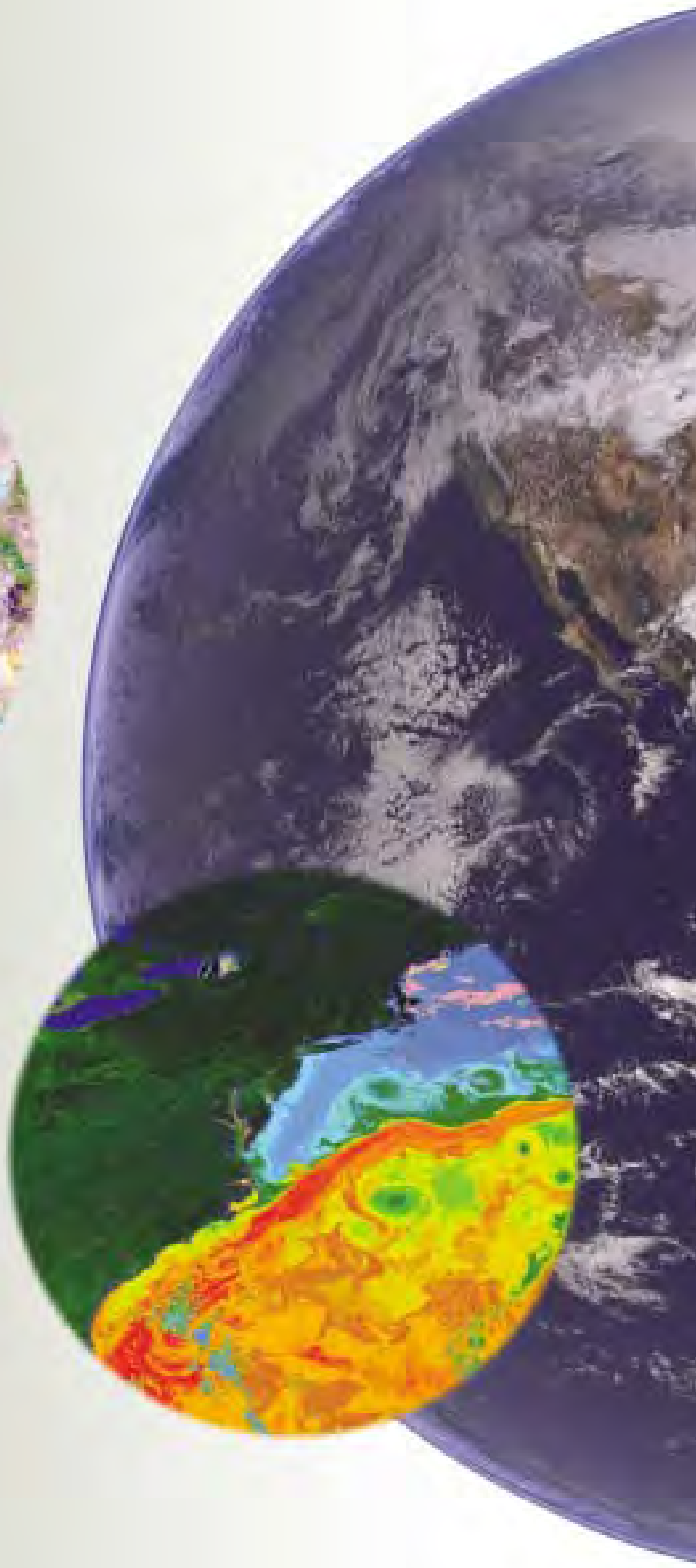

Goddard Space Flight Center
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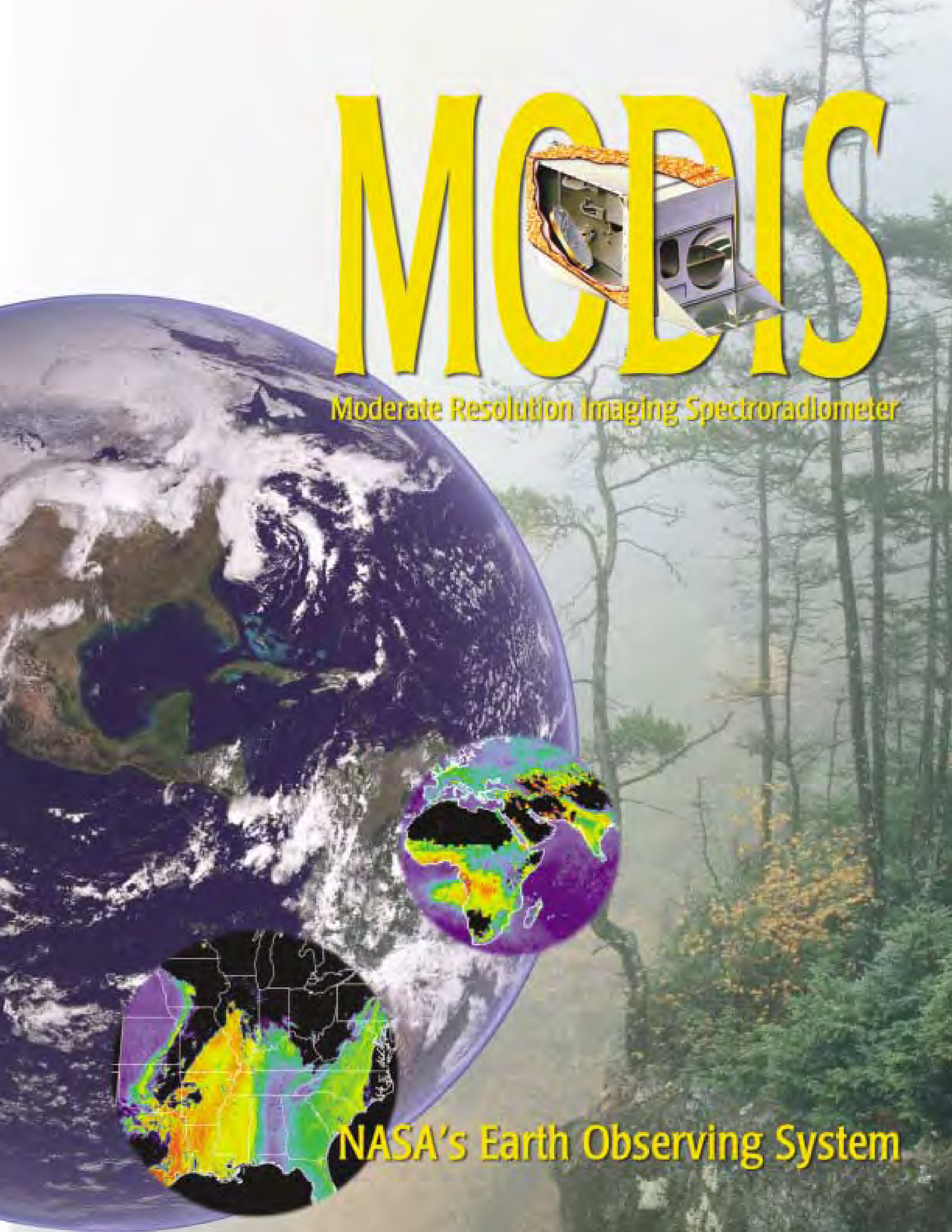
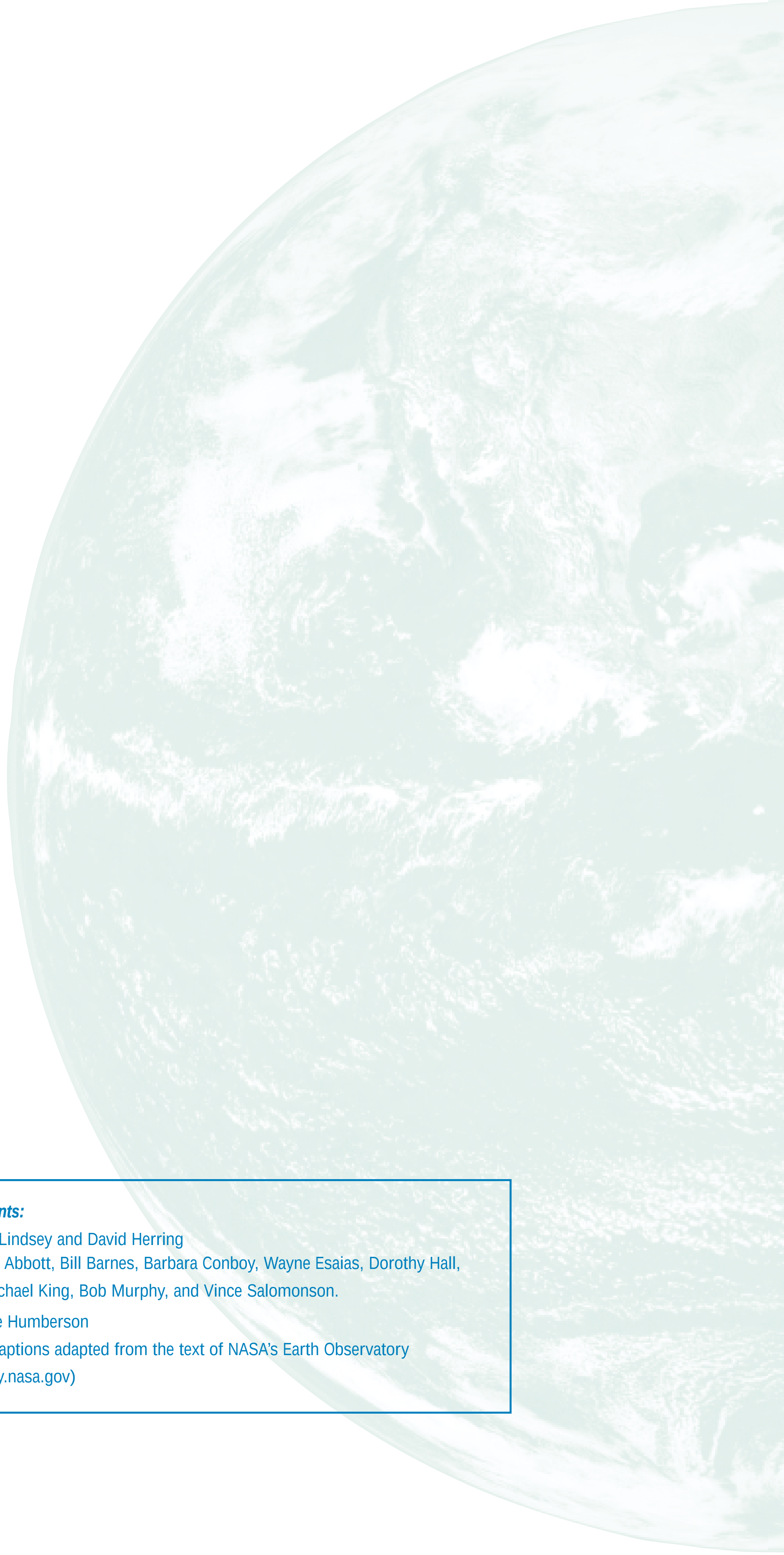

MODIS
Moderate Resolution Imaging Spectroradiometer
NASA's Earth Observing System



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Text by Rebecca Lindsey and David Herring

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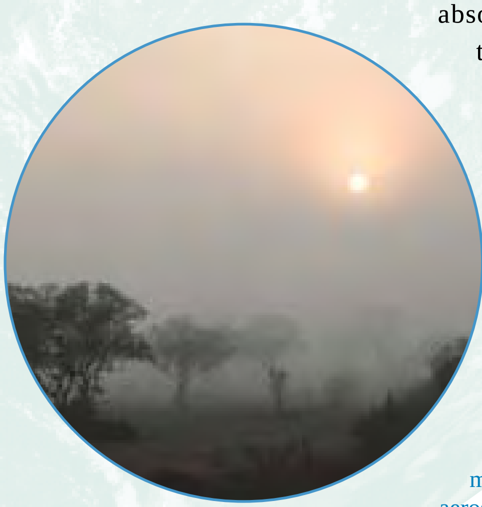
Design by Winnie Humberson

Selected image captions adapted from the text of NASA's Earth Observatory (earthobservatory.nasa.gov)

Global Change and Life on Earth

Jacques Descloitres

Philippine Institute of Volcanology & Seismology, 1991



NASA

For decades scientists have been piecing together clues about Earth's climate from ancient rocks, ice cores, patterns in the growth rings of trees, historical weather records, and satellite data. They know that Earth's climate has changed many times throughout its history. Changes in the tilt of the Earth's rotation on its axis, ocean currents, and volcanic eruptions have all impacted Earth's climate and life. Now scientists are accumulating evidence that human industrial and agricultural activities are accelerating naturally occurring changes in our climate, and that we are contributing to such hazards as desert expansion, rising sea level, ozone depletion, acid rain, and loss of biodiversity. People all over the world—not just scientists, but also farmers, fishermen, and policymakers—are asking questions about global change and the consequences for life on Earth.

To answer those questions, scientists must study the Earth as an interacting system because the relationships among life, land, oceans, and atmosphere are tightly interwoven. Clouds, gases, and aerosol particles in the atmosphere affect both land and oceans. For example, air pollution can reduce crop yields. Marine plant life depends on iron-rich dust that winds pick up over arid regions and deposit into the oceans. Changes occurring on the land can affect the atmosphere as well. Studies from around the world have shown that the asphalt and concrete of urban development can absorb and re-radiate enough heat energy back into the atmosphere to trigger thunderstorms. And because trees and other vegetation participate in the rainfall cycle by releasing water vapor into the atmosphere, scientists predict that massive tropical deforestation could result in significant decreases in tropical rainfall.

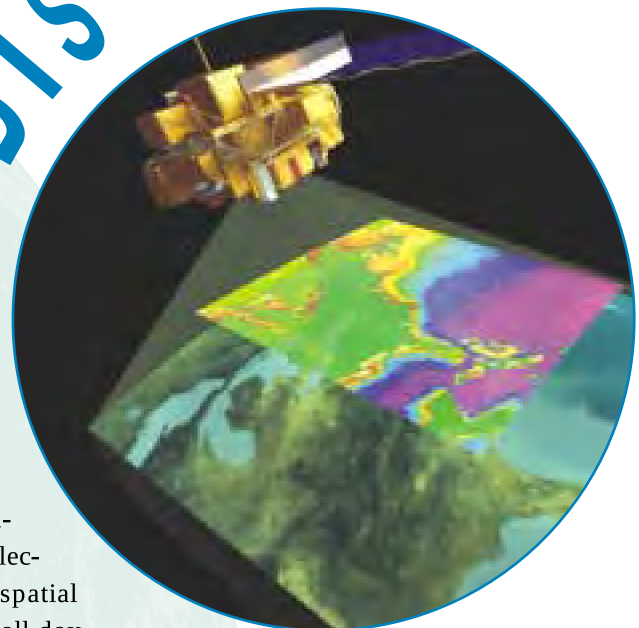
Earth's land, oceans, and atmosphere interact and undergo constant change. (Top) A natural fertilizer, dust from arid regions is rich in iron on which marine ecosystems depend. (Middle) Volcanic eruptions inject sulfur gases high into the atmosphere. (Bottom) Land use patterns in Southern Africa include massive prescribed burns that transform ecosystem vegetation and release soot and aerosols into the atmosphere.

Clearly, the Earth is a complex, changing system. The cycles of change in Earth's atmospheric, oceanic, and terrestrial processes are called global dynamics. Scientists are modeling global dynamics to better understand natural climate changes and human impact on those changes. To improve global models, scientists need information, or data, for every region of the Earth every day for many years. A powerful way to collect such comprehensive data is through the use of satellite sensors that measure different types of energy coming from the Earth. The way the Earth reflects or emits electromagnetic energy into space gives scientists valuable information about its ecological, hydrological, and meteorological conditions.

Understanding the importance of studying global dynamics, the United States Congress instituted the U.S. Global Change Research Program in 1990. NASA's Earth Science Enterprise is making substantial contributions to the program through its Earth Observing System (EOS). Through EOS, NASA is working with the national and international scientific community to design, develop, and launch advanced satellite sensors that collect data across a wide spectrum of energy—ultraviolet, visible, infrared, and microwave. With these sensors, NASA will collect multi-year data sets that will help to answer questions about global change.

The eastern United States seen by MODIS on March 6, 2000. MODIS captured the green sweep of spring vegetation creeping northward, as well as geologic features such as the Appalachian Mountains, seen prominently in Pennsylvania as alternating dark and light bands. Image credit: MODIS Land Team/Jacques Descloitres, SSAI.

MODIS



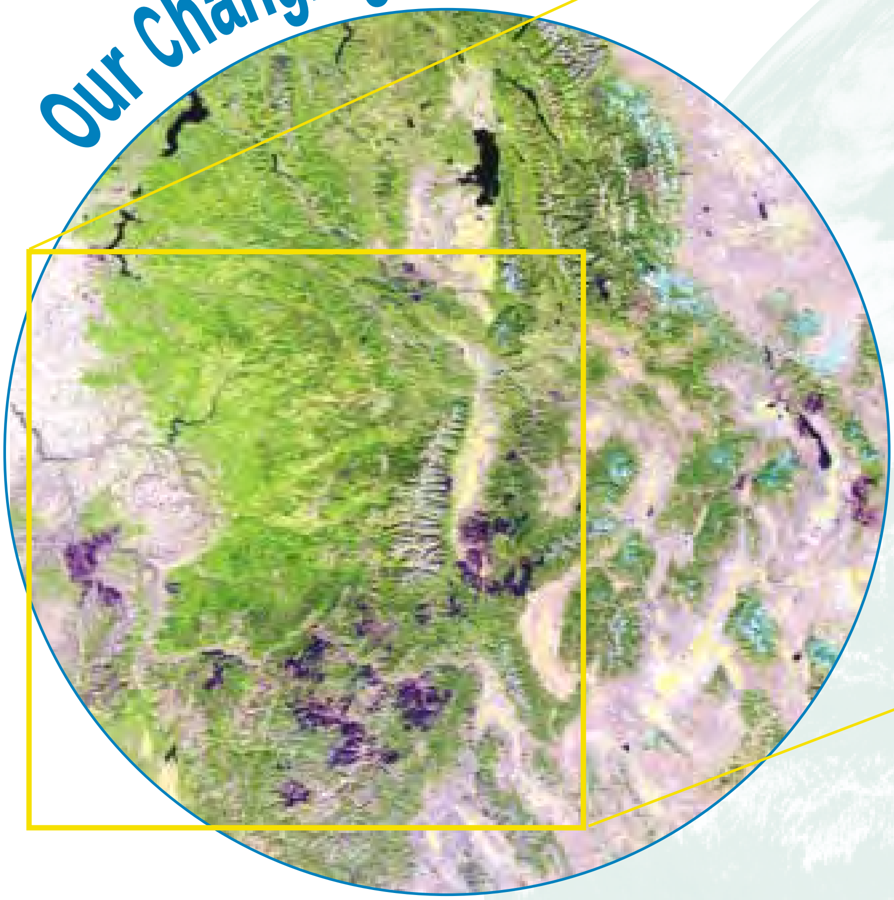
MODIS' continuously rotating scan mirror can make an image of nearly half the continental United States in a single orbital pass. Image credit: NASA-GSFC TV/Susan Byrne, HTSI.

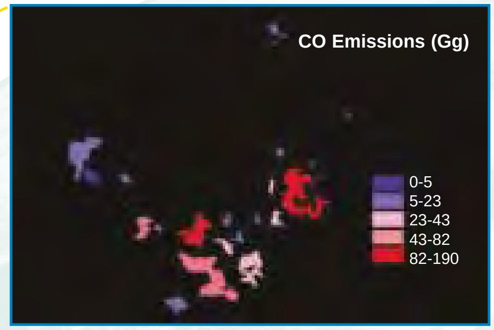
The first EOS satellite, called Terra, was launched on December 18, 1999, carrying five remote sensors. The most comprehensive EOS sensor is MODIS, the Moderate Resolution Imaging Spectroradiometer. MODIS offers a unique combination of features: it detects a wide spectral range of electromagnetic energy; it takes measurements at three spatial resolutions (levels of detail); it takes measurements all day, every day; and it has a wide field of view. This continual, comprehensive coverage allows MODIS to complete an electromagnetic picture of the globe every two days. MODIS' frequent coverage complements other imaging systems such as Landsat's Enhanced Thematic Mapper Plus, which reveals the Earth in finer spatial detail, but can only image a given area once every 16 days—too infrequently to capture many of the more rapid biological and meteorological changes that MODIS observes.

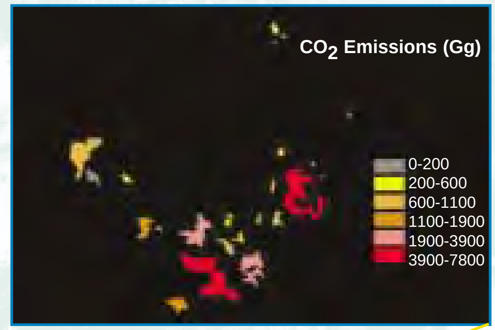
Terra is the first large, multi-instrument EOS satellite, and its orbit around the Earth is timed so that it passes from north to south across the equator in the morning. A second EOS satellite, Aqua, will also carry a MODIS instrument. Aqua will pass south to north over the equator in the afternoon. Working in tandem to see the same area of the Earth in the morning and the afternoon, the two satellites will help scientists ensure MODIS' and other instruments' measurement accuracy by optimizing cloud-free remote sensing of the surface and minimizing any optical effects—like shadows or glare—that are unique to morning or afternoon sunlight. Having morning and afternoon sensors also permits investigation of changes that occur over the course of the day, such as the build-up or dissipation of clouds and changes in sea or land surface temperature.

These MODIS instruments are designed to take measurements in spectral regions that have been used in previous satellite sensors. MODIS is adding to existing knowledge by extending data sets collected by heritage sensors such as the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR), used for meteorology and monitoring sea surface temperature, sea ice, and vegetation; the Coastal Zone Color Scanner (CZCS) and the Sea-viewing Wide Field of View Sensor (SeaWiFS), used to monitor ocean biological activity; Landsat, used to monitor terrestrial conditions; and NOAA's High Resolution Infrared Radiation Sounder (HIRS), used to observe atmospheric conditions. By extending these data sets, MODIS promotes the continuity of data collection essential for understanding both long- and short-term change in the global environment.

Our Changing Land







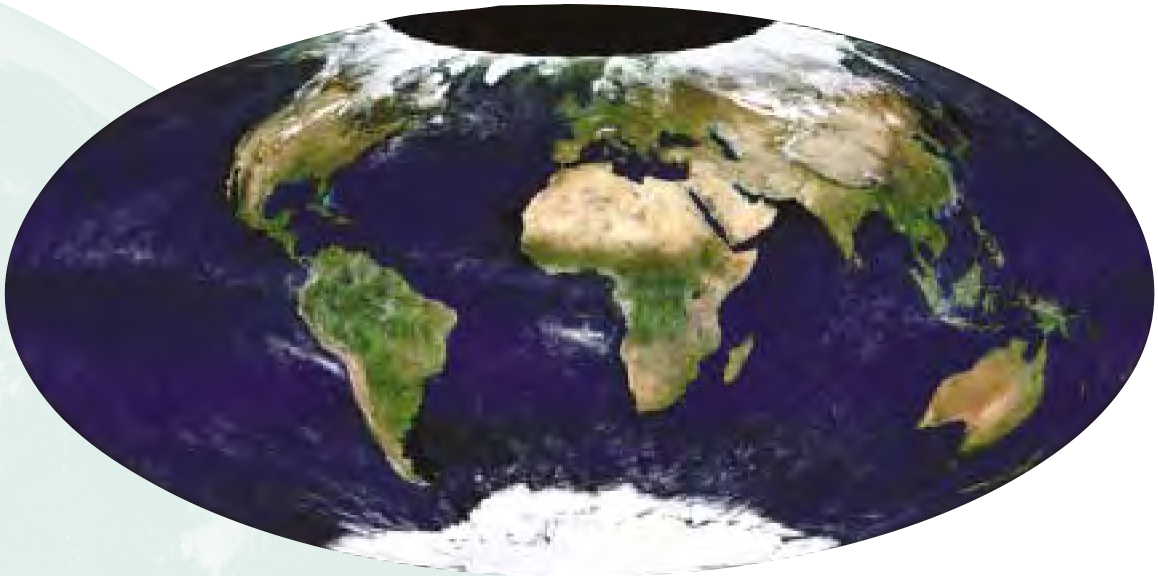
Severe forest fires scorched Montana and Idaho in August 2000. This false-color, 250-m resolution MODIS image from September 26, 2000, shows the scars (dark purple) left by the Wilderness Complex, Valley Complex, and various smaller wildfires along the Idaho/Montana border. The burned areas in this image totaled about 1,250,595 acres, accounting for about 14% of all burned area in the United States in 2000. The pictographs at right correspond to the burn scars, and are color-coded to show different amounts of gases released by individual fires. These fires released about 31,026 gigagrams of carbon dioxide and 760 gigagrams of carbon monoxide.

With its 2,330-km viewing swath width, MODIS can monitor far more land surface than can be covered by ground crews or airplanes, and it can detect thermal energy from fires even through a thick cloud of smoke. MODIS imagery is being used for rapid response by the US Forest Service to plan burned area rehabilitation and watershed protection efforts. Image credits: False-color composite, MODIS Land Team/Mark Carroll, University of Maryland, College Park. Pictographs, MODIS Land Team/Chris Justice, Principal Investigator, and Stefania Korontzi, University of Maryland, College Park.

Some of the most easily recognizable changes are occurring on land. Human-induced changes such as deforestation, urbanization, and hydroelectric and irrigation projects combine with the Earth's existing cycles of fire, erosion, and floods to change our landscape. While we can often see these changes happening on a local scale, it is impossible to assess global effects through fieldwork alone. With its near-daily coverage of the Earth's surface, MODIS provides comprehensive measurements that scientists and land managers need to make informed decisions about managing Earth's natural resources from season to season, year to year, and decade to decade.

Monitoring and assessing conditions on the Earth's surface is critical to understanding the impacts of weather and climate change and human activities. MODIS provides global maps of several land surface characteristics, including surface reflectance, albedo (the percent of total solar energy that is reflected back from the surface), land surface temperature, and vegetation indices. Vegetation indices tell scientists how densely or sparsely vegetated a region is and help them to determine how much of the sunlight that could be

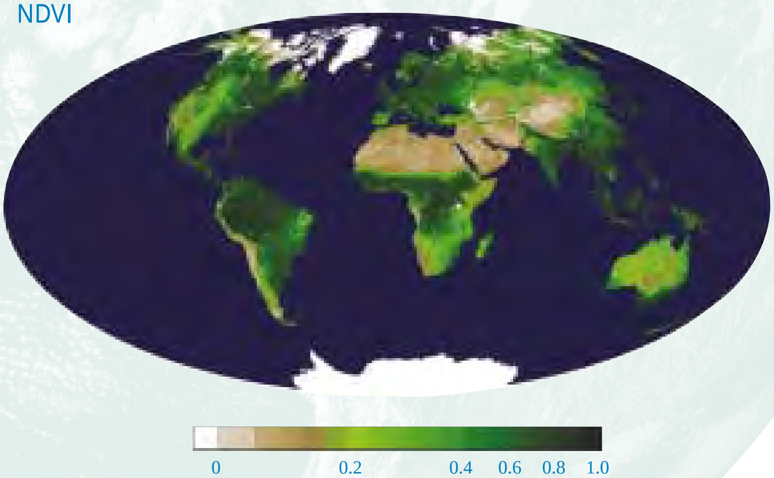
Surface reflectance is an estimate of the reflectance at specific wavelengths as it would have been measured at the Earth's surface if the atmosphere did not scatter or absorb radiation. To produce such images, scientists must take into consideration the effects of gases, aerosols, and thin cirrus clouds. This image was made from data collected by MODIS during November of 2000, during polar night in the Northern Hemisphere. The surface reflectance product is the foundation of most land products, including vegetation indices. Image credit: MODIS Land Team/Surface Reflectance Product, Eric Vermote, Principal Investigator, University of Maryland, College Park, and Nazmi El Saleous, Raytheon, ITSS.



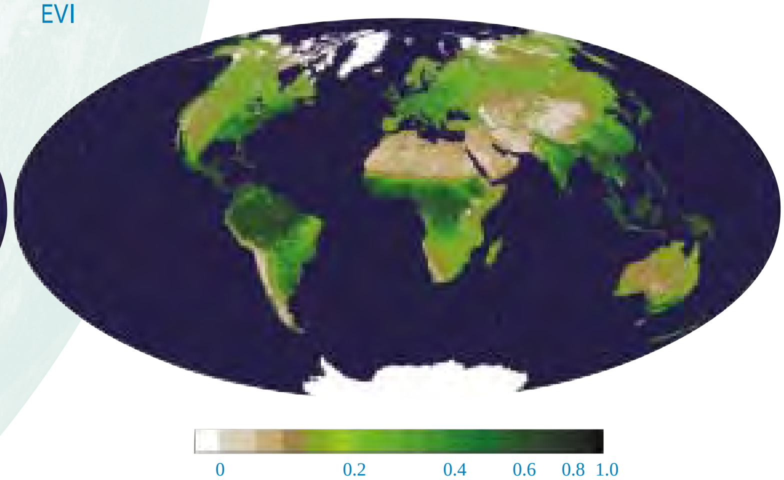
used for photosynthesis is being absorbed by the vegetation. The maps will provide the basis for MODIS' real-time global monitoring of subtle changes in vegetation that may signal biospheric stress, such as pollution, drought, or temperature extremes, which in turn could be used to predict and prevent wildfire danger or crop failure.

MODIS provides data for land cover maps that tell scientists not only whether an area is vegetated, but also what kind of vegetation is growing there, separating coniferous forests from deciduous forests, or cropland from grassland. In addition to 11 categories of vegetation, the maps recognize various non-vegetated surfaces, including bare soil, water, and urban areas—17 land cover types in all. MODIS' high-quality, daily measurements allow scientists to track changes in land cover types and land use, to determine where forested land is becoming deforested, where grassland is becoming cropland, or where burned land is returning to natural vegetation.

NDVI



EVI

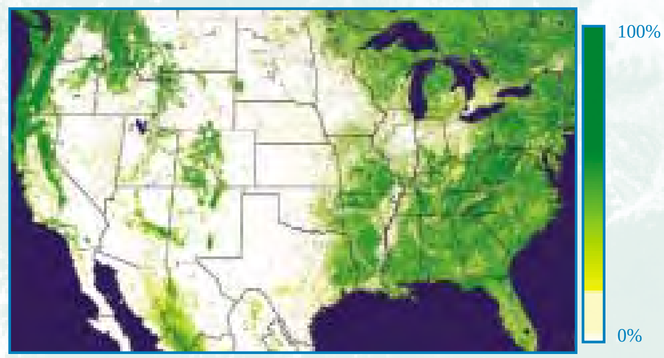


This pair of Vegetation Indices highlights some of the refinements of the MODIS Enhanced Vegetation Index (EVI, right) over the traditional Normalized Difference Vegetation Index (NDVI, left) that has been used with previous satellite instruments. NDVI tends to "saturate" over dense vegetation such as the rainforests of South America, failing to distinguish variability. The MODIS EVI provides a more detailed look at variability within such highly vegetated regions. Production of MODIS NDVI provides continuity with data sets from heritage instruments, while EVI provides added detail about global vegetation variability. Data for the images were collected between September 30 and October 15, 2000. Values range from 0, indicating no vegetation, to nearly 1, indicating the densest vegetation. Image credit: MODIS Land Team/Vegetation Indices, Alfredo Huete, Principal Investigator, and Kamel Didan, University of Arizona.

MODIS collects data on land surface characteristics that are crucial for modeling the Earth's carbon cycle, or the exchange of carbon between the Earth's life, land, oceans, and atmosphere. Modeling the carbon cycle is especially important given that increases in atmospheric carbon dioxide, a known greenhouse gas, are occurring. Land surface variables such as amount and type of vegetation, soil composition, and temperature play a significant role in calculating mass and energy exchange between the Earth's surface and the atmosphere.

Since plants remove carbon dioxide from the atmosphere as they grow, scientists call them a carbon sink; when vegetation is burned, it becomes a carbon source. Estimates of carbon storage in plants vary widely, but MODIS data will help reduce that uncertainty by allowing scientists to make more accurate estimates of global photosynthesis and productivity. However, other questions remain. Will plants increase their uptake of carbon dioxide in response to atmospheric

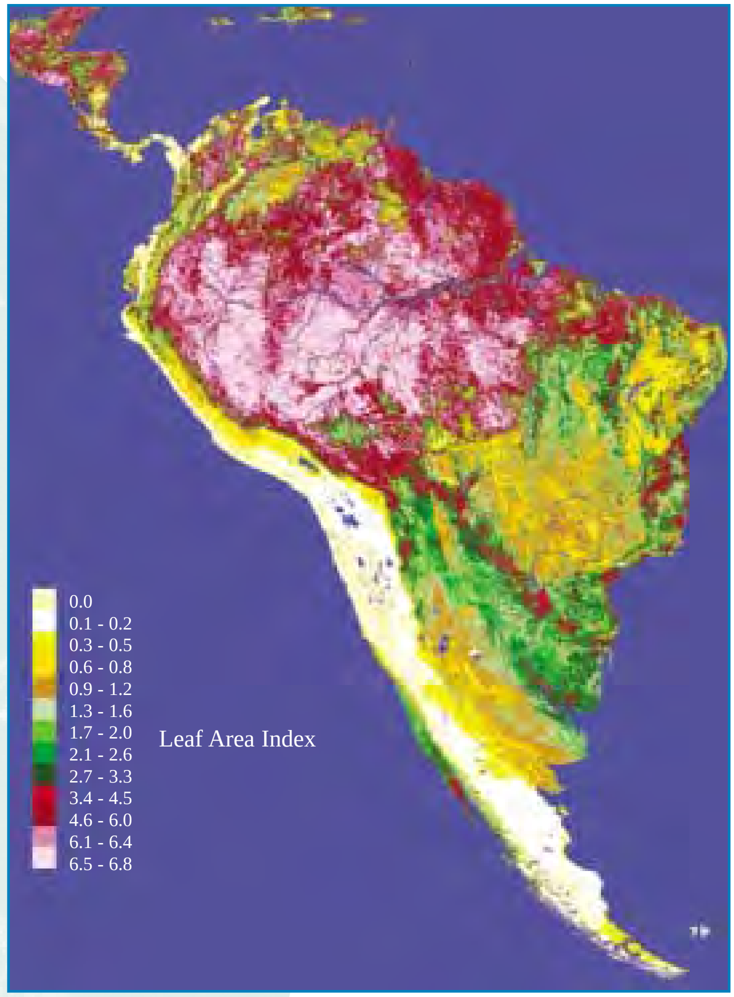
North American Land Cover Classification map using MODIS data collected from July 2000 through January 2001. Image credit: MODIS Land Team/Land Cover Classification Product, Alan Strahler, Principal Investigator, and John Hodges, Boston University.



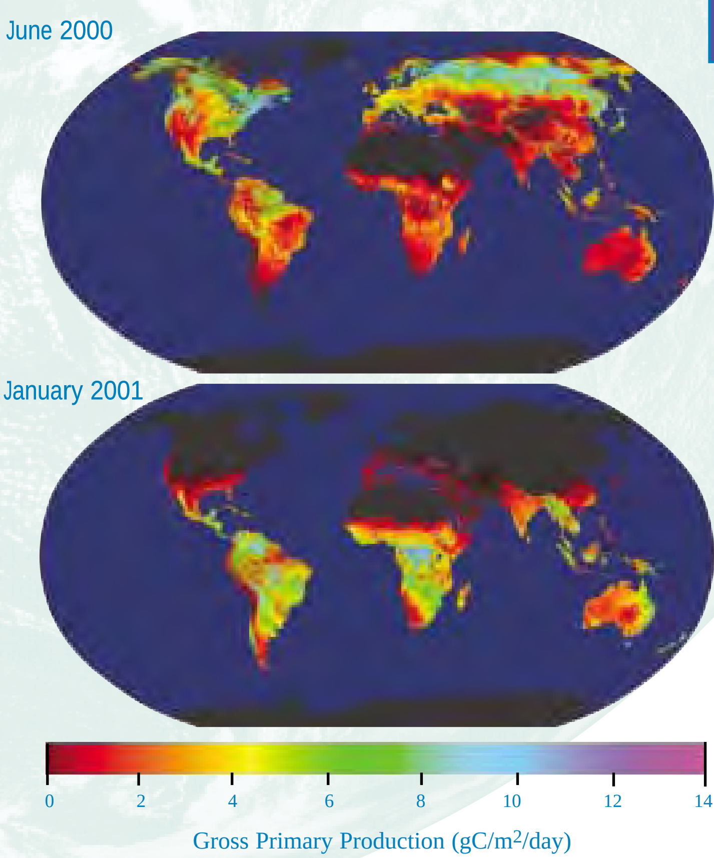
Percent tree cover map of the United States using MODIS data from the summer and fall of 2000. The color bar represents 0% tree cover (white) to 100% cover (dark green). Image credit: MODIS Land Team/Vegetation Continuous Fields Product, Ruth DeFries, Associate Team Member, and Matt Hansen, University of Maryland, College Park.

0 Water
1 Evergreen Needleleaf Forest
2 Evergreen Broadleaf Forest
3 Deciduous Needleleaf Forest
4 Deciduous Broadleaf Forest
5 Mixed Forests
6 Closed Shrublands
7 Open Shrublands
8 Woody Savannas
9 Savannas
10 Grasslands
11 Permanent Wetlands
12 Croplands
13 Urban and Built-up
14 Cropland/Natural Vegetation Mosaic
15 Snow and Ice
16 Barren or Sparsely Vegetated

increases? What are the effects of diminishing carbon sinks through land use changes such as deforestation and urbanization? Will increasing land surface temperatures melt frozen arctic soils, transforming them into a carbon source rather than a sink? MODIS land data will help scientists to model these biogeochemical processes and find answers to these increasingly more urgent questions.



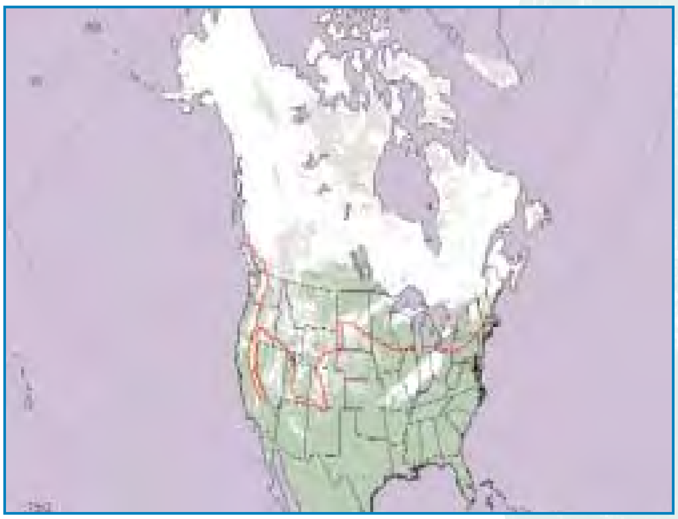
This South American Leaf Area Index (LAI) map provides an estimate of one-sided green leaf area per unit land area (m^2/m^2). Before MODIS, LAI was produced by individual researchers for selected regions, using different unvalidated techniques. The MODIS LAI is the first global-scale operational production of this important vegetation parameter, which is used as an input to large-scale climate and carbon models. Image credit: MODIS Land Team/Leaf Area Index, Ranga Myneni, Principal Investigator, and Seth Hoffman, Boston University.



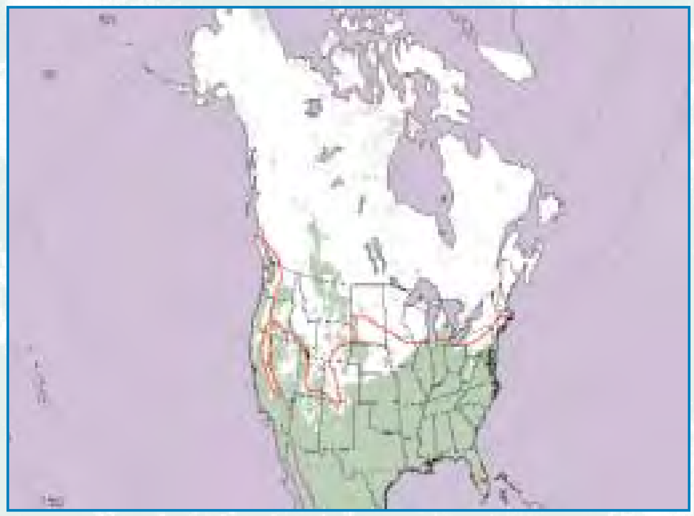
This pair of images shows MODIS measurements of gross primary production (GPP) in Northern Hemisphere summer (top) and winter (bottom). Measured in grams of carbon taken up by vegetation per square meter each day, GPP shows how actively the Earth's vegetation was photosynthesizing during a week in June 2000 and January 2001. Black areas are regions where vegetation activity is virtually nonexistent, such as Africa's Sahara Desert and polar regions. These images generally represent the maximum and minimum annual photosynthetic activity of vegetation, and illustrate the ranges of variability found at different latitudes. Image credit: MODIS Land Team/Gross Primary Production, Steve Running, Principal Investigator, and Petr Votava, University of Montana; Rob Simmon, SSAI.

In their development of global dynamical models, scientists are confronted with another uncertainty: the role of snow cover and sea ice in climate change. Snow cover greatly influences the Earth's albedo, which is the percent of total solar energy that is reflected back from the surface. Snow and ice cool the Earth's surface by reflecting radiation from the Sun away from the Earth. In the short term, many scientists suspect that climate warming will mean more evaporation from the oceans and thus more moisture in the air. Increases in moisture and subsequent increases in precipitation could actually increase snow cover for a time, as temperatures in arctic regions increase, but remain below freezing. MODIS will help scientists to analyze the effects of global temperature increases on Earth's snow and sea ice extent—key elements of the planet's energy balance.

March 5-12, 2000



March 6-13, 2001



Winter snow cover and the resulting spring thaw play an important role in recharging underground aquifers and refilling lakes that supply plants, humans and other animals with water. Changes in extent and duration of regional snow packs are associated with both short- and long-term climate change. For these reasons, monitoring snow cover is an important part of understanding hydrological, ecological, and climatological cycles.

These two MODIS snow maps of North America show the maximum extent of snow cover from March 5-12, 2000 (left), and March 6-13, 2001 (right). In March of 2000, snow cover during this eight-day period was well below the average for that time of year (red line), and this "snow drought" contributed to a devastating summer fire season in the American West. In March of 2001, the snow cover was considerably closer to average conditions. In both images, light gray areas indicate persistent cloud cover. Image Credit: MODIS Land Team/Snow Cover, Dorothy Hall, Associate Team Member, NASA-GSFC; Janet Chien, SAIC/GSC; Nick DiGirolamo, SSAI; James Foster, NASA-GSFC; and George Riggs, SSAI.

Our Changing Ocean

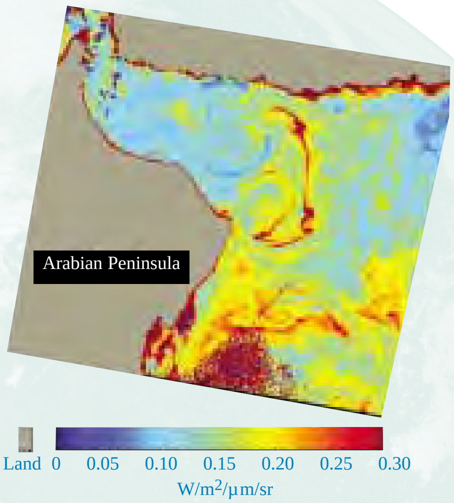
Given the enormous expanse of Earth's oceans, their crucial role in climate change is not surprising. Oceans absorb solar radiation and modulate the Earth's temperature, they exchange gases with the atmosphere, and they harbor an astounding diversity of plants and animals, many of which human cultures all over the world depend on for food. The oceans act as the "memory" of the Earth system. They store enormous amounts of carbon and heat, reflecting the integrated result of many centuries of climatic variation. In general, the upper layers of the ocean reflect recent weather and short-term climate change, and deeper layers reflect progressively older climatic records. Because oceans are slower to change than the atmosphere, long-term data collection is especially important. Scientists are using MODIS data to understand the complexities of how oceans both react to and bring about global change.

One way MODIS helps scientists studying oceans is through collection of data that they can use to make global maps of *ocean color*. Variations in ocean color are related to the concentration of organisms in the surface waters of the world's oceans. Sunlight strikes the ocean and is reflected by these organisms. Among the most abundant organisms are microscopic marine plants called phytoplankton. Like other plants, phytoplankton use chlorophyll pigments to capture energy for photosynthesis. The pigment-containing organisms make the detectable color patterns across the ocean surface.

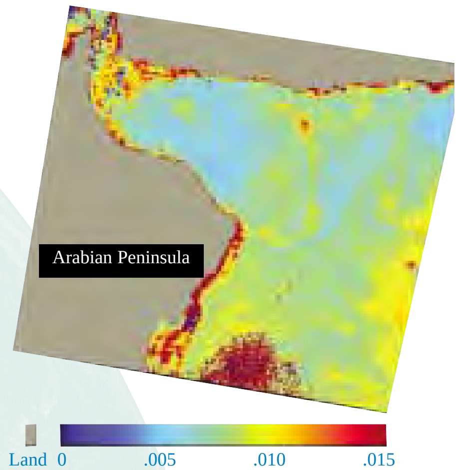
Despite their microscopic size, phytoplankton have a great impact on global change. Like other plants, phytoplankton transform carbon dioxide into organic molecules during photosynthesis; they do so at about the same rate as land plants. This process is called carbon fixation, and it's the beginning of a biological pump that draws carbon from the atmosphere and stores it in the ocean, Earth's largest carbon sink. Some of the carbon that is taken up by phytoplankton sinks to the ocean floor, where it can remain for millions of years. Indeed, 99.5% of all carbon on Earth is found within sediments of marine origin.

Phytoplankton bloom in the Black Sea in June 2000. Brown sediment discharge from the Danube delta is hugging the western coast, and the phytoplankton bloom is evident by the green and blue colors in the central and eastern side of the image. Image credit: MODIS Land Team/Jacques Descloitres; MODIS Ocean Team/Ron Vogel, SAIC/GSC.

Fluorescence Line Height



Chlorophyll Fluorescence Efficiency

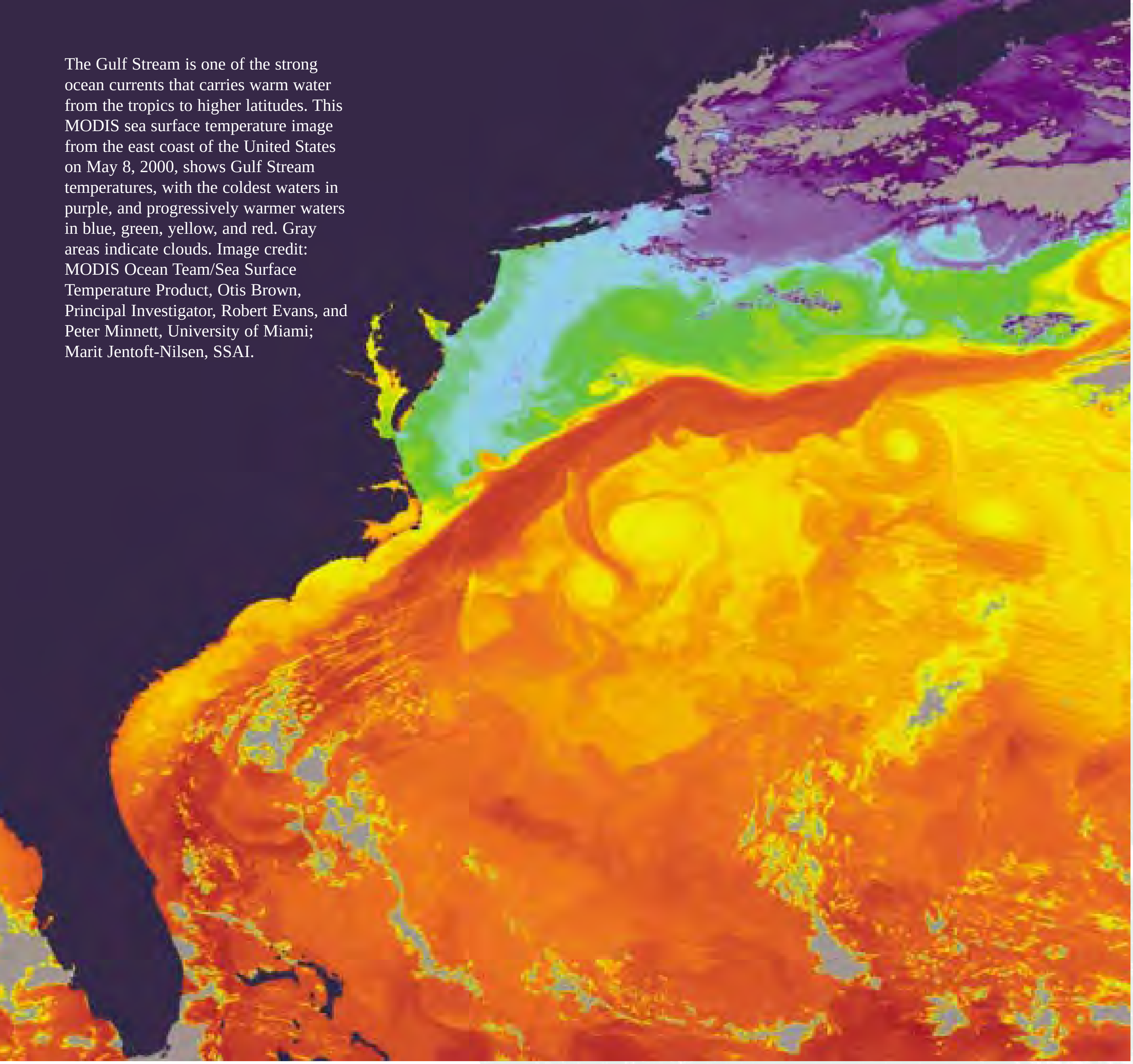


Fluorescence Line Height (FLH, left) and Chlorophyll Fluorescence Efficiency (CFE, right) from the northwestern portion of the Arabian Sea, collected by MODIS on December 2, 2000. Higher values of FLH generally correspond to higher chlorophyll values, indicating phytoplankton. Note the paired vortices (the "hammerhead" feature) off the tip of the Arabian Peninsula, near the center of the image.

CFE is a measure of how much light is captured by phytoplankton and then re-emitted as fluorescence, with high values being a sign that light is not being used for photosynthesis. In the CFE image above, the bottom vortex shows higher CFE values than the top, suggesting less photosynthesis is occurring. This is consistent with predicted levels of nutrient availability, as the top vortex is spinning counterclockwise, a rotation that draws up nutrient-rich water from deeper ocean layers, while the bottom vortex is spinning clockwise, forcing water downward. Fewer nutrients in the bottom vortex means less photosynthesis and higher values of CFE. Image credit: MODIS Ocean Team/Ocean Fluorescence Product, Mark Abbott, Principal Investigator, Oregon State University.

Because of phytoplankton's role in the oceanic carbon cycle, scientists are very interested in how much phytoplankton the oceans contain, called biomass, and how photosynthetically productive they are. MODIS' measurements of chlorophyll and other pigments allow scientists to estimate phytoplankton biomass, since the amount of chlorophyll detected is related to the amount of phytoplankton. MODIS can also tell scientists about phytoplankton productivity because it measures not only visible light reflected from the chlorophyll and other pigments, but also chlorophyll fluorescence.

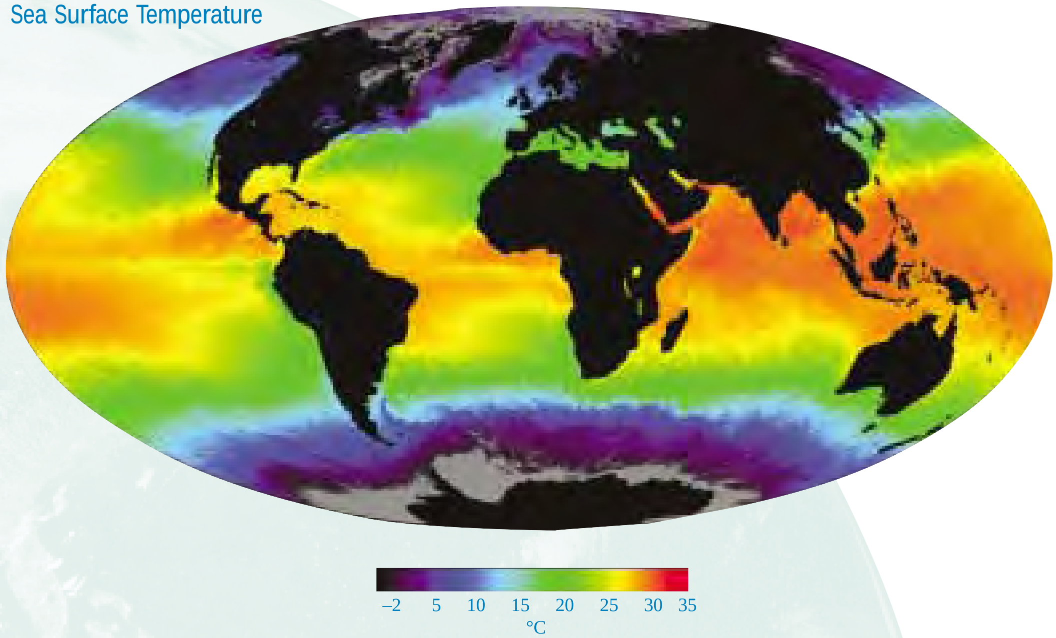
Normally, sunlight falling onto a plant is harvested by chlorophyll to be used for photosynthesis. But when phytoplankton don't have the nutrients they need to make food, they use less sunlight for photosynthesis, and re-radiate more sunlight as fluorescence. High proportions of fluorescence to chlorophyll mean less photosynthesis and less carbon fixation. By combining fluorescence measurements with ocean color measurements, scientists hope to better understand the impact of phytoplankton physiology in oceanic carbon cycling.



The Gulf Stream is one of the strong ocean currents that carries warm water from the tropics to higher latitudes. This MODIS sea surface temperature image from the east coast of the United States on May 8, 2000, shows Gulf Stream temperatures, with the coldest waters in purple, and progressively warmer waters in blue, green, yellow, and red. Gray areas indicate clouds. Image credit: MODIS Ocean Team/Sea Surface Temperature Product, Otis Brown, Principal Investigator, Robert Evans, and Peter Minnett, University of Miami; Marit Jentoft-Nilsen, SSAI.

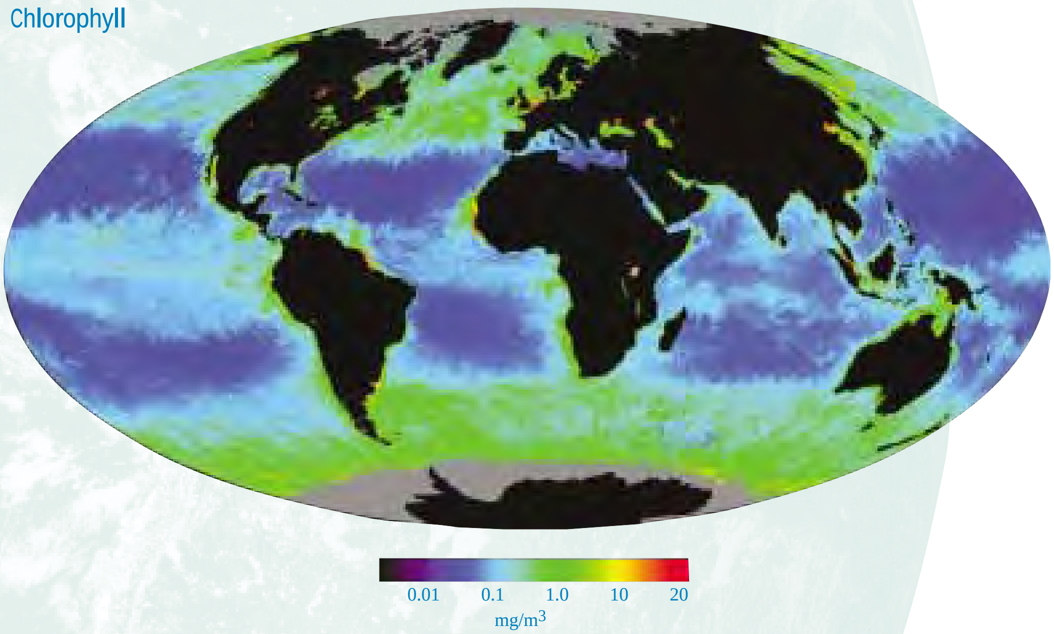
In addition to ocean color measurements that tell scientists about ocean productivity and carbon movement, MODIS is taking daily global measurements of sea surface temperature (SST). SST is important to the study of global change for many reasons. The exchange of heat, moisture, and gases between the ocean and the atmosphere determines Earth's habitability, and SST largely determines the rate of exchange. The rate at which carbon dioxide dissolves in water is temperature dependent, as is the rate of water evaporation. Since water vapor is a potent greenhouse gas, the rate of evaporation is an important factor in climate change. SST also factors into cloud formation, including thunderstorms and hurricanes.

Sea Surface Temperature



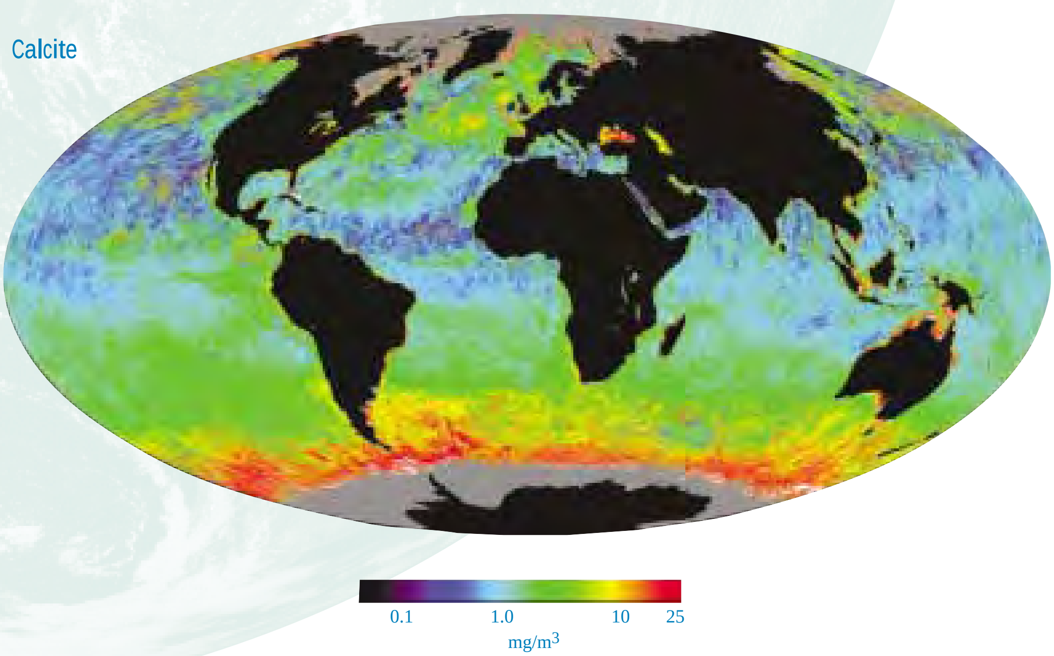
Nighttime sea surface temperature (SST) for May 2001. Temperatures were collected using MODIS’ 4-µm channel, a design innovation that improves retrievals in moist areas, such as the tropics, where accurate SST measurements are often hindered by water vapor in the atmosphere. Large-scale temperature patterns are apparent, such as the Gulf Stream off the east coast of the United States and the Kuroshio Circulation southeast of Japan. Image credit: MODIS Ocean Team/SST, Otis Brown, Principal Investigator; Kevin Turpie, SAIC/GSC.

Chlorophyll

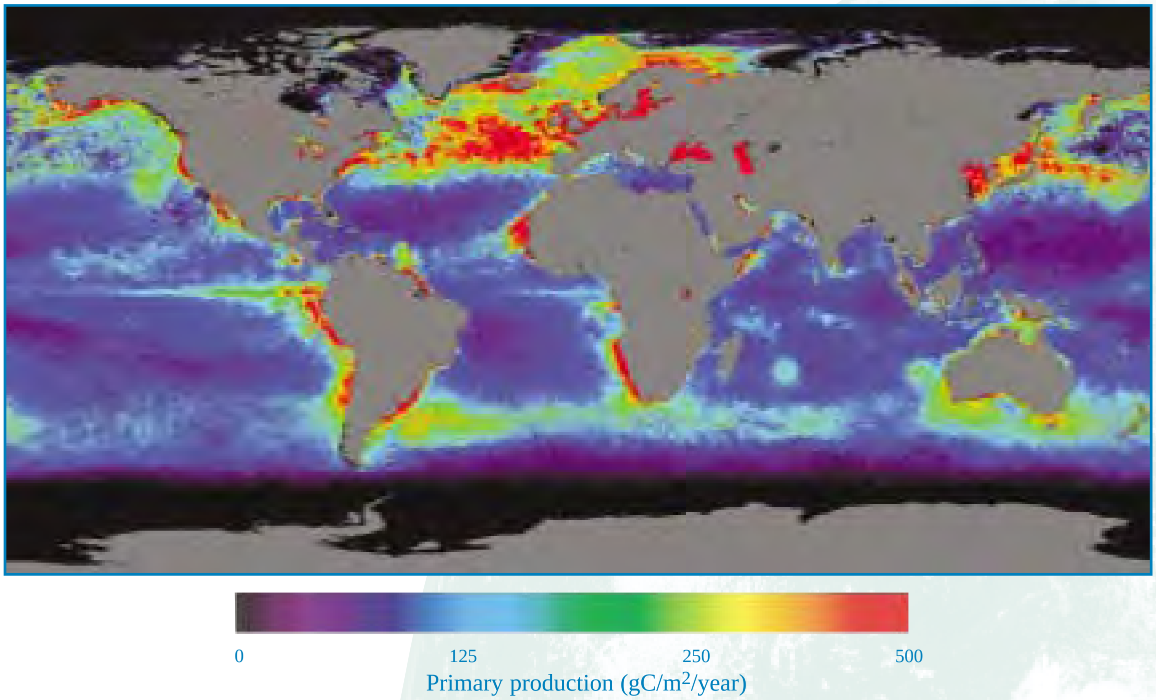


Ocean chlorophyll-*a* concentration for May 2001. As an indicator of phytoplankton, chlorophyll concentration is typically low in the central basins of the large oceans, but higher in polar regions, equatorial regions, and along coasts, where water circulation brings up cold, high-nutrient waters to support the phytoplankton. Image credit: MODIS Ocean Team/Chlorophyll Product, Kendall Carder, Principal Investigator; Kevin Turpie.

Calcite



Calcite concentration for May 2001. Phytoplankton such as coccolithophores produce calcite skeletons using carbon dioxide dissolved in the ocean water. MODIS offers the first satellite estimates of global calcite concentration—contributing to scientists’ understanding of the role ocean biology plays in the carbon cycle. Like chlorophyll, calcite concentrations are high in polar and coastal regions. Image credit: MODIS Ocean Team/Calcite Product, Howard Gordon, Principal Investigator; Kevin Turpie.



The global carbon cycle is greatly influenced by ocean primary productivity, the rate of carbon dioxide uptake via marine plant photosynthesis minus the rate that carbon dioxide is put back into the ocean's carbon reservoir through respiration. This MODIS composite from May 9 to June 9, 2001, shows how variable the rates of carbon exchange are across the Earth's oceans. Productivity tends to be high at northern and southern latitudes, where mixing from deep ocean waters brings up nutrients, and at the margins of continents, where currents draw up nutrients in the shallower waters of the continental shelves. Black areas indicate regions where productivity could not be calculated, typically because of clouds or sea ice. Image credit: MODIS Ocean Team/Ocean Primary Productivity, Wayne Esaias, Principal Investigator, NASA-GSFC; Kevin Turpie.

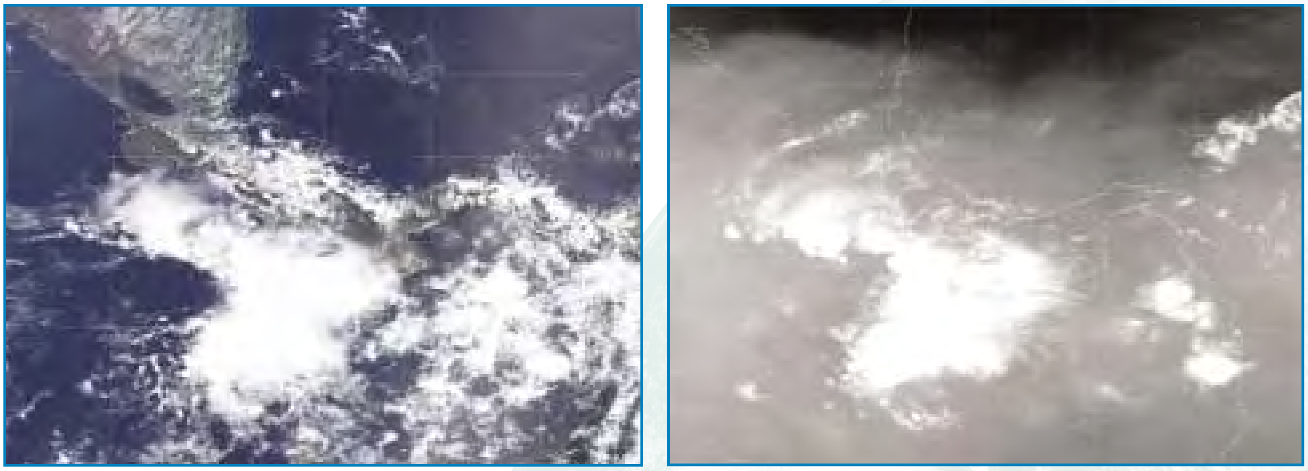
SST also influences ocean productivity. Every three to five years Pacific coast fishermen experience a significantly smaller than average catch around December and January; they named the phenomenon El Niño. Scientists determined that the small catch was related to fluctuations in SST and wind patterns. Normally, winds push the warmer waters of the equatorial Pacific westward, allowing colder, nutrient-rich water from deeper layers of the ocean to well up to the surface. The influx of nutrients supports a lush phytoplankton population, which in turn supports the fish. During an El Niño event, the easterly winds die off, and warm water replaces the cold, nutrient-rich water, causing populations to decline. El Niño events also radically alter rainfall and drought patterns in North America, Africa, South America, Australia, India, and Indonesia. Accurate global measurements of SST will help scientists understand and predict short-term climate events like El Niño as well as long-term climate change.

Our Changing Atmosphere

Earth's climate is significantly moderated by the atmosphere's interaction with incoming and outgoing radiation. The atmosphere scatters and absorbs radiation coming from the sun, influencing how much energy reaches the surface. Of the radiation that reaches the surface, some is reflected, some is absorbed, and some is re-radiated as heat. The atmosphere can absorb and scatter this outgoing radiation as well, creating a balance between incoming and outgoing energy. Changes in the balance are called radiative forcing, and many atmospheric characteristics contribute to this forcing, including clouds, water vapor and aerosols.

Clouds and water vapor play a changing role in radiative forcing, alternatively warming and cooling the Earth. Heavy cloud cover during the day shields the surface from incoming solar energy, cooling the Earth. At night, clouds trap outgoing radiation, warming the Earth. Will increasing global temperatures result in increased evaporation and cloudiness, ultimately cooling the Earth by reflecting solar energy? Or will water vapor's heat-trapping effect outweigh the cooling? Unraveling such complex cause-and-effect relationships, called feedback loops, requires precise measurements of cloud properties: area of coverage, droplet size, cloud-top altitude and temperature, and liquid water content. MODIS' near-daily global coverage combined with its high spatial resolution and carefully selected spectral bands will significantly improve scientists' understanding of clouds.

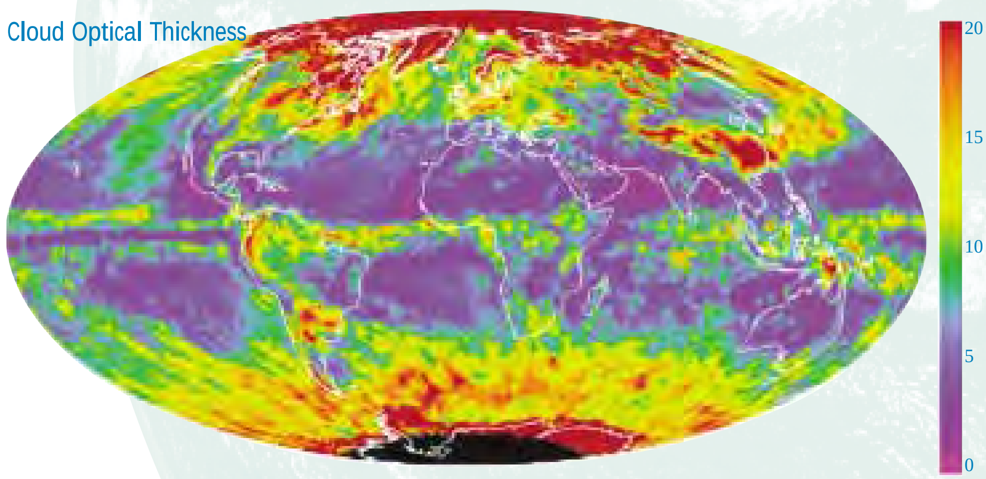
Cloud measurements are also important because clouds often obscure the Earth's surface, complicating observations of land surface conditions such as vegetative cover or sea surface temperature. At the time of any individual satellite overpass, the Earth scene below MODIS may be covered with clouds. However, the exact same areas aren't likely to be cloudy every day, and scientists can combine, or composite, data over many days to produce weekly and monthly cloud-cleared products that can be used as input to global change models. MODIS' cloud-detection capability is so sensitive that it can even detect clouds that are indistinguishable to the human eye.

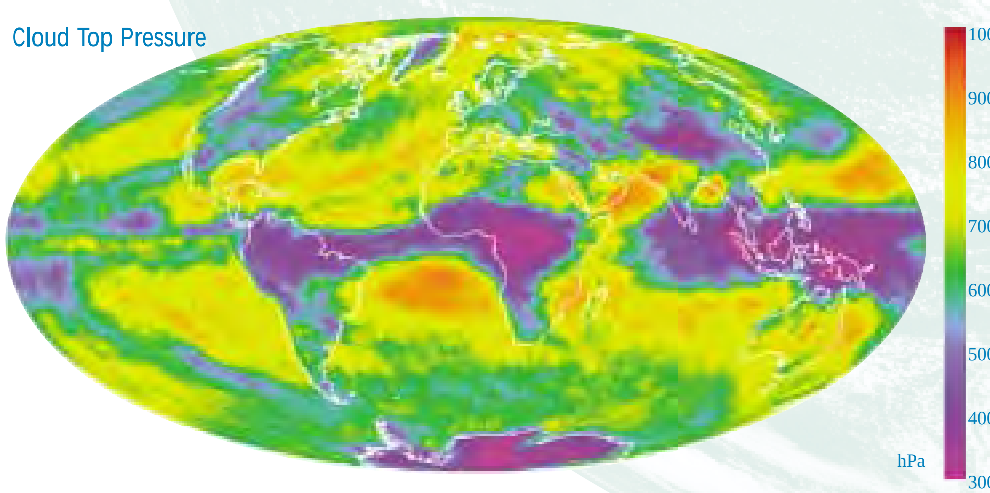


This pair of images over Central America highlights MODIS' ability to detect what scientists refer to as "sub-visible" cirrus clouds. The image on the left shows the scene using data collected by MODIS in the visible part of the electromagnetic spectrum. Cloud cover is apparent in the center and lower right of the image, while the rest of the image appears to be relatively clear. However, data collected at 1.38 µm shows that a thick layer of previously undetected cirrus clouds obscures the entire scene (right). MODIS' cloud detection using the 1.38 µm channel is a new remote sensing capability. Image credit: MODIS Atmosphere Team/Mark Gray, EITI, and Bill Ridgway, SSAI.

(Top) Cloud optical thickness for April 2001. Cloud optical thickness is a measure of how much light is able to pass through a cloud and is based on characteristics such as the size of the particles, cloud phase (ice, water, or mixed), particle concentration, and height from top to bottom. Notice the persistent cloud cover in the "roaring forties," between 40° and 50° South latitude, where strong westerly winds, unhindered by large land masses, blow steadily.

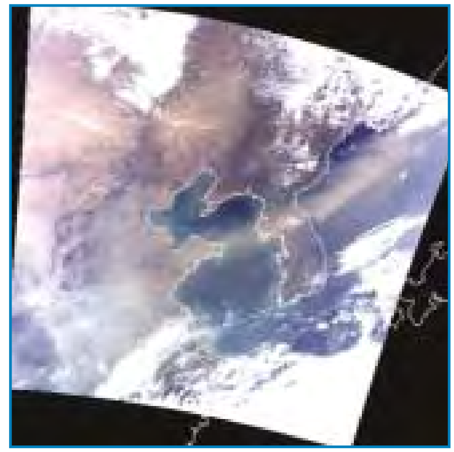
(Bottom) Cloud top pressure for April 2001. This cloud top pressure image shows typical atmospheric circulation patters, such as the low pressure systems in the tropics associated with the Walker circulation, part of the weather "engine" that moves heat and moisture from the tropics to higher latitudes. Image credits: MODIS Atmosphere Team/Cloud Optical Properties, Michael King, Principal Investigator, NASA-GSFC; Cloud Top Properties, Paul Menzel, Principal Investigator, NOAA-NESDIS, University of Wisconsin-Madison; Paul Hubanks, SSAI.

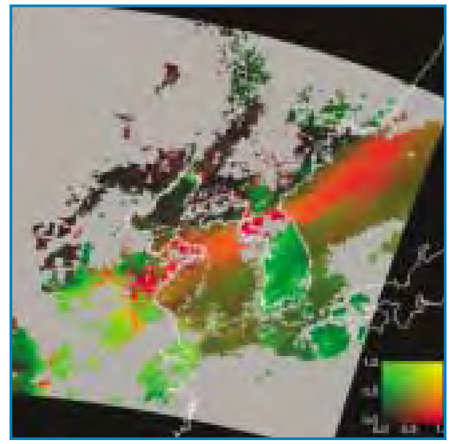




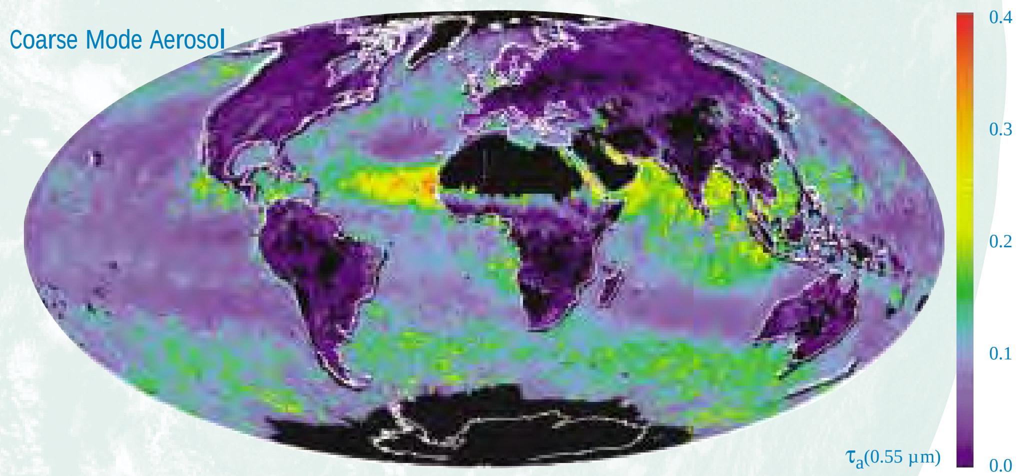
In addition to its observations of clouds, MODIS also measures aerosols, which influence climate both directly and indirectly. Aerosols, which include dust, sea salt, volcanic emissions, smoke from forest fires, and some kinds of pollution, directly affect how much sunlight reaches the Earth by scattering and absorbing incoming radiation. Scattering of radiation by light-colored particles tends to cool the Earth's surface, and absorption by dark-colored particles tends to warm the atmosphere. Aerosols can simultaneously cool the surface, but warm the atmosphere.

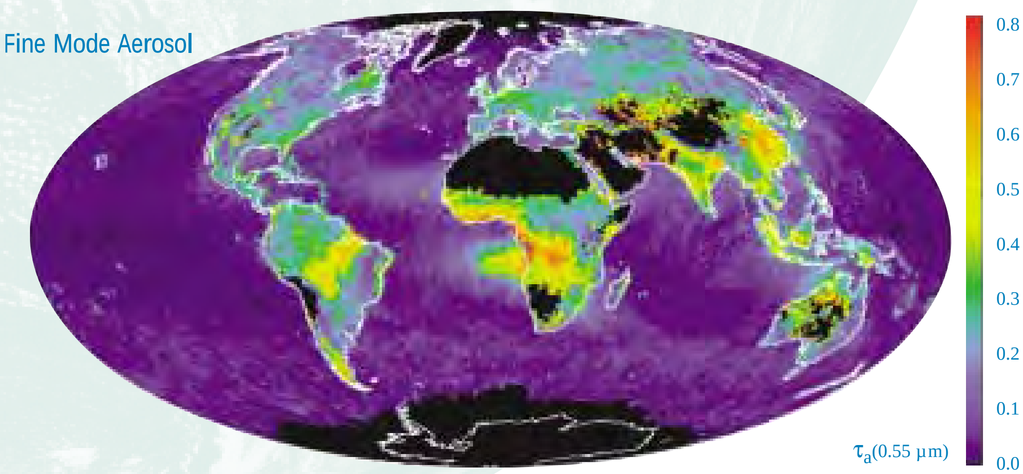
Climatologists have long thought that aerosols' cooling effects outweigh their warming effects. They know, for example, that a volcanic eruption can spew dust, ash, and sulfur dioxide into the upper atmosphere (the stratosphere). The light-colored sulfuric acid particles that form in the stratosphere as a result of the eruption can produce a cooling effect at the surface that can last for years. However, recent studies suggest that soot from fossil fuel and biomass burning may contaminate more aerosols than scientists previously thought and that the warming of the atmosphere by these black-carbon aerosols might exceed the cooling effect at the Earth's surface. The resulting atmospheric heating could alter global air circulation and rainfall patterns across the world.





▲ In March 2001, a sand storm swept across the Taklimakan and Gobi Deserts in western China and Mongolia, moving a dust cloud out over eastern China, where it mixed with industrial pollution from southeast Asia. The true-color image (top) shows the brownish-yellow haze caused by the combination of aerosols. The bottom image represents the combination of small aerosols, shown in green, to large aerosols, shown in red. Small particles are characteristic of pollution, while the large particles are characteristic of dust. Image credit: MODIS Atmosphere Team/Aerosol Product, Yoram Kaufman, NASA-GSFC, and Didier Tanré, Laboratorie d'Optique Atmospherique, Principal Investigators; Rong-Rong Li, SSAI.



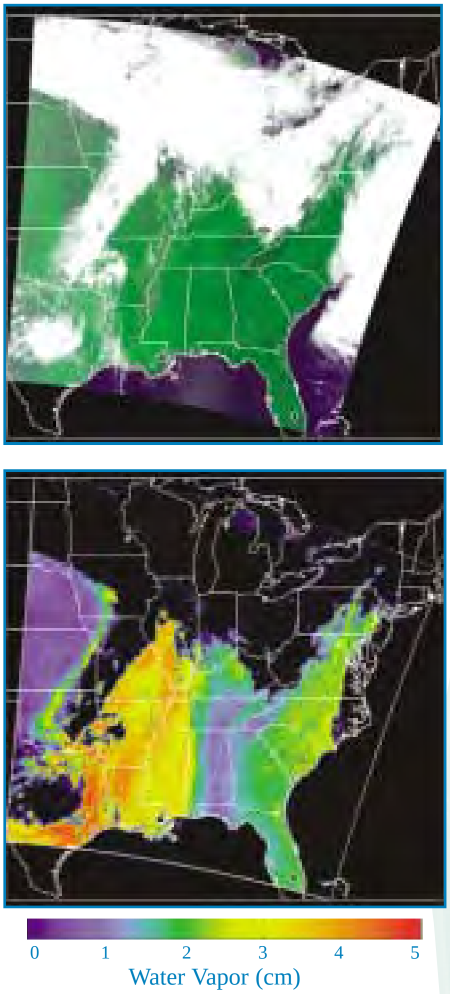


◀ Coarse mode aerosol (top) and fine mode (bottom) from September 2000. MODIS' coarse mode aerosol product detects naturally occurring aerosol, such as the dust that spreads out over the Atlantic Ocean from Africa's Sahara Desert. Human-produced emissions are smaller and finer, for example, biomass burning in southern Africa and South America and industrial pollution on nearly every continent. Image credit: MODIS Atmosphere Team/Aerosol Product, Yoram Kaufman and Didier Tanré, Principal Investigators; Allen Chu, SSAI.

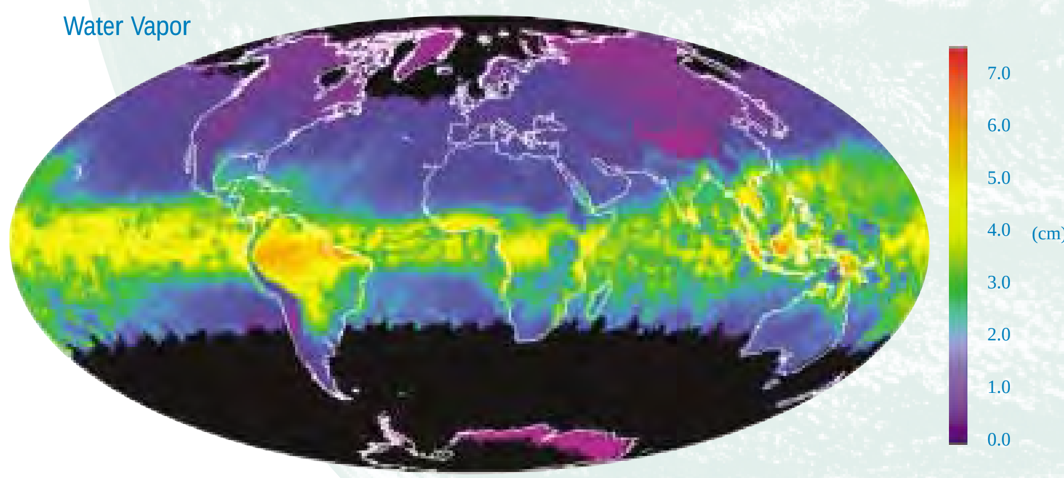
In addition to their direct interaction with sunlight, aerosols also influence climate indirectly, by interacting with clouds. When water evaporates from the Earth's surface, it disperses throughout the atmosphere. Without aerosols, water vapor would continue to disperse until it was distributed evenly throughout the atmosphere, but there would be no clouds and no rain. This is because water vapor needs a surface on which to condense, or form liquid droplets. Aerosols provide this surface, serving as a "seed" for attracting condensation.

Increasing concentrations of aerosols may increase condensation by providing more surfaces on which raindrops can form, but clouds formed from manmade aerosols are different from clouds formed from natural ones. Because manmade aerosols are typically smaller and more numerous than natural ones, clouds containing lots of manmade aerosols contain larger numbers of smaller liquid water drops. Clouds with many small drops are brighter than those with larger drops, meaning that they reflect more solar radiation back into space. This increased brightness has a cooling effect, which might be expected to counteract a carbon dioxide-induced warming trend. However, small drops often evaporate before they can fall from the sky as rain. One possible outcome of increasing aerosol pollution could be more clouds, but less rain.

MODIS multi-spectral data on aerosols and cloud properties will be combined with data from other sensors on the Aqua spacecraft to give scientists a better understanding of the relationships between clouds, precipitation, and aerosols. MODIS will also improve their understanding of the effects of these atmospheric characteristics on regional and global radiative forcing—an understanding that is essential for modeling and predicting the consequences of global change.

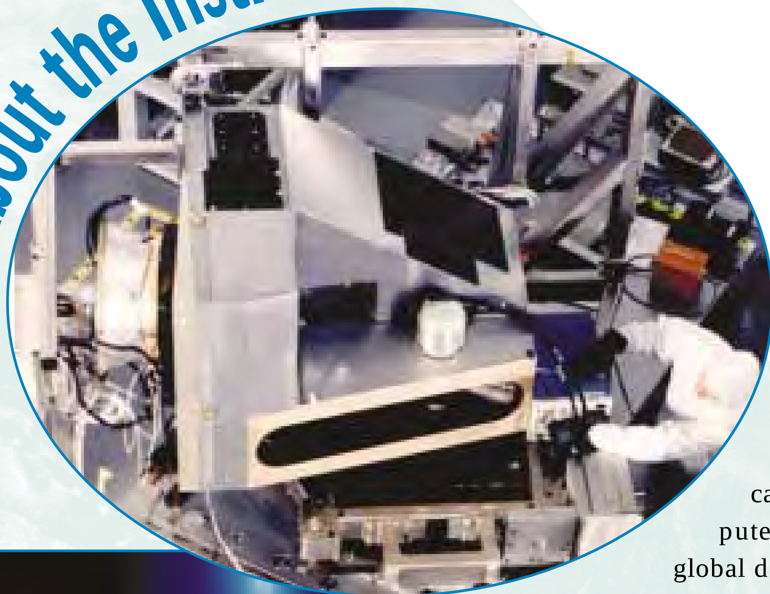


▲ Water vapor over the Eastern United States on April 19, 2000. The top image in this pair is the true-color scene, showing cloud cover over the northern Mid-West and Mid-Atlantic states. The bottom image shows total column water vapor in centimeters, which is a measure of the height of the water vapor (if it were compressed) in a given column of atmosphere. Image credit: MODIS Atmosphere Team/Total Precipitable Water Product, Bo-Cai Gao, Principal Investigator, Naval Research Laboratory; Rong-Rong Li.



▲ Water vapor, or total precipitable water, from April 2001. Water vapor is the most potent greenhouse gas, capable of trapping outgoing radiation at a rate many times that of other gases, such as carbon dioxide or methane. Water vapor is most prevalent in the tropics and decreases toward the poles. Water vapor can only be detected over land surfaces or where there is sun glint, or glare, over the ocean. During the month of April, the angle of the sun is such that there is no glint in the far southern hemisphere at the time of the MODIS overpass. Image credit: MODIS Atmosphere Team/Total Precipitable Water Product, Bo-Cai Gao, Principal Investigator, Naval Research Laboratory; Paul Hubanks.

About the Instrument



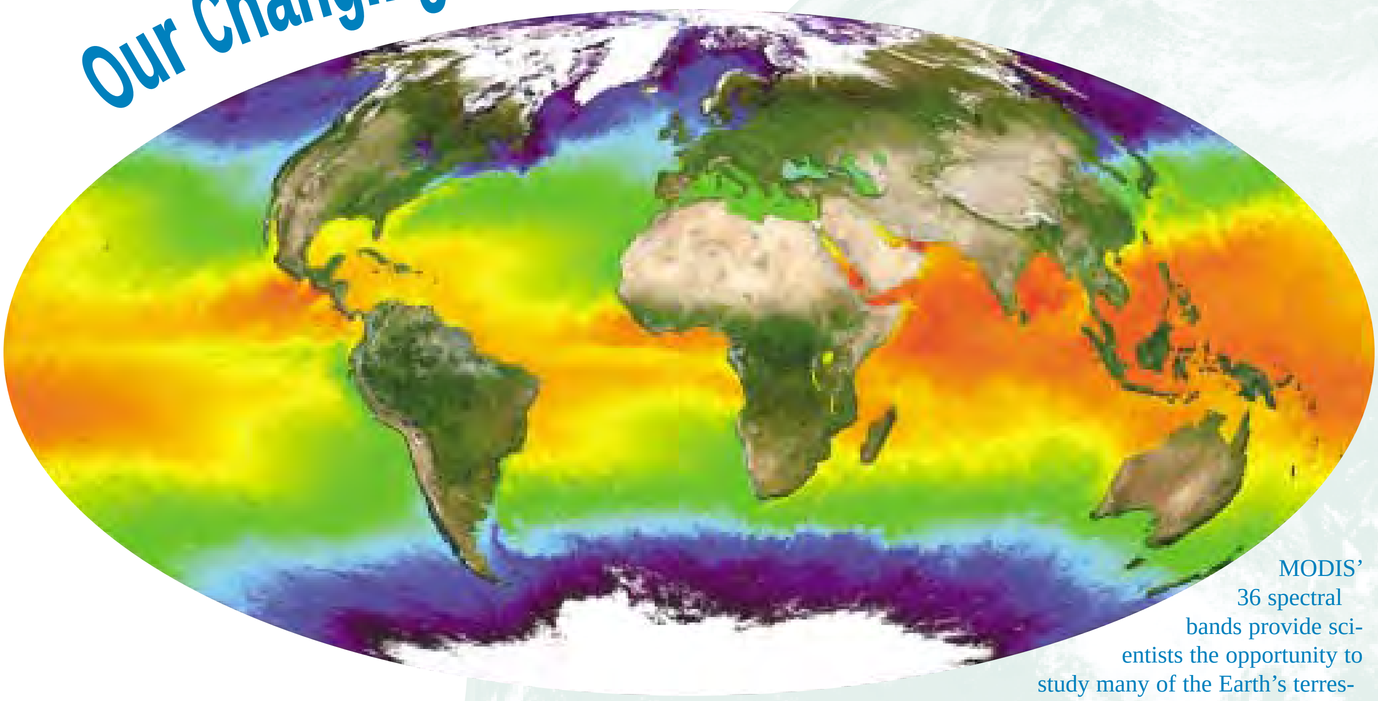
Within its 1.6 m^3 frame (top right), MODIS houses a continuously rotating scan mirror weighing over 9 pounds (above). The mirror deflects visible and infrared energy coming from the Earth onto MODIS' photon detectors. Image credit: Santa Barbara Remote Sensing, CA.

MODIS has a viewing swath width of 2,330 km, and it images the Earth in 36 spectral bands, or groups of wavelengths, ranging from 0.405 to 14.385 µm. It collects data at three spatial resolutions: 250, 500, and 1,000 meters. The average rate of data collection is 6.1 megabits each second. Using physically and empirically based algorithms, high-speed computers process MODIS data to yield 44 global data products describing many of Earth's vital signs, from ocean and land surface temperatures to the physical properties of clouds. Each MODIS instrument has a design life of five years. When combined with similar instruments that will follow them, the MODIS instruments will provide a decadal-scale data set for comprehensive global change research.

Science Team

MODIS' comprehensiveness provides a unique opportunity for scientists from diverse fields to work together to understand global dynamics. The MODIS Science Team employs 28 science team members and 21 validation scientists from the United States, Australia, Canada, France, Nigeria, Saudi Arabia, South Africa, and the United Kingdom. The scientists specialize in one of four disciplines: Atmosphere, Land, Oceans, or Calibration. The Calibration Group does the meticulous work of characterizing and monitoring each MODIS' performance to ensure its accuracy and reliability over time. Their activities provide the foundation for the Atmosphere, Land, and Ocean group studies described throughout this brochure.

Our Changing Earth



MODIS' 36 spectral bands provide scientists the opportunity to study many of the Earth's terrestrial and oceanic characteristics with a single instrument. The land portion of this image is made from the reflectance at three wavelengths: 645 nm (red), 555 nm (green), 469 nm (blue). This combination of bands is similar to what our eyes would see. Combined with the land surface reflectance are MODIS' measurements of sea surface temperature (SST) using detectors that capture thermal radiation at 3.9 and 4.0 μm. Waters near the poles are cooler (shown in purple), and get steadily warmer toward the equator (green to yellow to red). All data were collected during May 2001. MODIS' multi-spectral capabilities make it uniquely equipped for interdisciplinary studies of the Earth. Image credit: MODIS Land Team/Surface Reflectance, Eric Vermote, Principal Investigator; MODIS Ocean Team/Sea Surface Temperature, Otis Brown, Principal Investigator, Nazmi El Saleous and Kevin Turpie.

NASA's EOS program will encourage and facilitate wide use of MODIS data to promote Earth science and interdisciplinary interaction. To make sound decisions about protecting and managing Earth's biological and physical resources, policymakers worldwide need information about how the atmosphere, oceans, and land surfaces interact with one another in Earth's natural cycles of change. Some of those changes happen quickly and are immediately recognizable, but many processes that shape the Earth and its climate happen slowly, imperceptibly, and may not be revealed in a human lifetime. The MODIS instruments on board Terra and Aqua will significantly augment the kind of long-term data collection needed to monitor and understand our changing Earth.

The MODIS instrument is managed by NASA / Goddard Space Flight Center, Greenbelt, Maryland, and was built by Raytheon / Santa Barbara Remote Sensing, Goleta, California. For further information, access the MODIS Homepage at modis.gsfc.nasa.gov, or contact the MODIS Science Team Leader, Dr. Vince Salomonson, NASA Goddard Space Flight, Code 900, Greenbelt, Maryland, 20771.

MODIS STANDARD DATA PRODUCTS

These are the principal MODIS data products. Other products will also be developed and made available.

- ❑ **Radiances** at 250 m, 500 m, and 1000 m resolution.
- ❑ **Cloud mask** at 250 m and 1000 m resolution during the day and 1000 m resolution at night.
- ❑ **Aerosol concentration and optical properties** at 10 km resolution during the day.
- ❑ **Cloud properties** (optical thickness, effective particle radius, thermodynamic phase, cloud top altitude, cloud top temperature, cirrus reflectance) at 1-5 km resolution during the day and 5 km resolution at night.
- ❑ **Total precipitable water** at 1-5 km resolution during the day and 5 km resolution at night.
- ❑ **Atmospheric profiles** (temperature and water vapor) and total ozone content at 5 km resolution.
- ❑ **Gridded atmosphere products** at 1° latitude/longitude resolution globally for daily, eight-day, and monthly periods.
- ❑ **Vegetation and land-surface cover, conditions, and productivity,** defined as
  - ❖ Surface reflectance at 250 m, 500 m, and 1 km resolution, and albedo at 1 km.
  - ❖ Vegetation indices corrected for atmospheric effects, soil, and directional effects at 250 m and 500 m resolution.
  - ❖ Land cover
    - Global, 1-km IGBP Land Cover Classification.
    - Vegetation continuous fields, sub-pixel land cover components.
    - Vegetative cover conversion, global land cover change alarm at 250 m resolution.
  - ❖ Net primary productivity, leaf area index, and intercepted photosynthetically active radiation at 1-km resolution
- ❑ **Fire and thermal anomalies** at 1 km resolution.
- ❑ **Snow and sea-ice cover and snow albedo** at 500 m (snow cover), 1 km (sea ice cover and albedo), and 5 km resolution Climate Modeling Grid (snow cover and sea ice).
- ❑ **Surface temperature**
  - ❖ Land surface temperature and emissivity at daily 1 km resolution, with absolute accuracy goals of 1°C.
  - ❖ Sea surface temperature (skin) daily at 1 km, and global daily, weekly, and monthly at 4.6 km, 36 km, and 1° latitude/longitude resolution.
- ❑ **Ocean bio-optical properties**, including water-leaving radiances at daily 1-km resolution, and productivity at weekly 4.6 km, 36 km and 1° latitude/longitude resolution.
  - ❖ Water-leaving radiance corrected for atmospheric, polarization, and directional effects.
  - ❖ Chlorophyll-*a* concentration from 0.01 to 50 mg/m^3.
  - ❖ Chlorophyll-*a* fluorescence and fluorescence efficiency.
  - ❖ Coccolithophore pigment concentration and calcite concentration.
  - ❖ Suspended sediment concentration.
  - ❖ Phytoplankton spectral absorption.
  - ❖ Dissolved organic matter absorption.
  - ❖ Primary productivity weekly indices.

For more information:

- ◆ MODIS atmosphere or oceans products, visit the GSFC Earth Sciences Distributed Active Archive Center (DAAC) web site, daac.gsfc.nasa.gov.
- ◆ MODIS land products, visit the EDC DAAC web site, edcdaac.usgs.gov.
- ◆ MODIS snow and ice products, visit the NSIDC DAAC web site, nsidc.org.

MODIS TECHNICAL SPECIFICATIONS

Orbit:	705 km, 10:30 a.m. descending node or 1:30 p.m. ascending node, sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (across track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	250 kg
Power:	225 W (orbital average)
Data Rate:	11 Mbps (peak daytime)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2)
(at nadir):	500 m (bands 3-7), 1000 m (bands 8-36)
Design Life:	5 years

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud	1	620-670	21.8	128
Boundaries	2	841-876	24.7	201
Land/Cloud	3	459-479	35.3	243
Properties	4	545-565	29.0	228
	5	1230-1250	5.4	74
	6	1628-1652	7.3	275
	7	2105-2155	1.0	110
Ocean color/	8	405-420	44.9	880
Phytoplankton/	9	438-448	41.9	838
Biogeochemistry	10	483-493	32.1	802
	11	526-536	27.9	754
	12	546-556	21.0	750
	13	662-672	9.5	910
	14	673-683	8.7	1087
	15	743-753	10.2	586
	16	862-877	6.2	516
Atmospheric	17	890-920	10.0	167
Water Vapor	18	931-941	3.6	57
	19	915-965	15.0	250

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NEΔT(K)[4]
Surface/Cloud	20	3.660-3.840	0.45	0.05
Temperature	21	3.929-3.989	2.38	2.00
	22	3.929-3.989	0.67	0.07
	23	4.020-4.080	0.79	0.07
Atmospheric	24	4.433-4.498	0.17	0.25
Temperature	25	4.482-4.549	0.59	0.25
Cirrus Clouds	26	1.360-1.390	6.00	150[3]
Water Vapor	27	6.535-6.895	1.16	0.25
	28	7.175-7.475	2.18	0.25
	29	8.400-8.700	9.58	0.05
Ozone	30	9.580-9.880	3.69	0.25
Surface/Cloud	31	10.780-11.280	9.55	0.05
Temperature	32	11.770-12.270	8.94	0.05
Cloud Top	33	13.185-13.485	4.52	0.25
Altitude	34	13.485-13.785	3.76	0.25
	35	13.785-14.085	3.11	0.25
	36	14.085-14.385	2.08	0.35

[1]Bands 1 to 19, nm; Bands 20-36, µm

[2](W/m^2-µm-sr)

[3]SNR=Signal-to-noise ratio
[4]NEΔT=Noise-equivalent temperature difference } Performance goal is 30%-40% better than required

"Talk of mysteries! Think of our life in nature—daily to be shown matter, to come in contact with it—rocks, trees, wind. . .! The Solid Earth! The actual World!"

— *Henry David Thoreau*, 1848

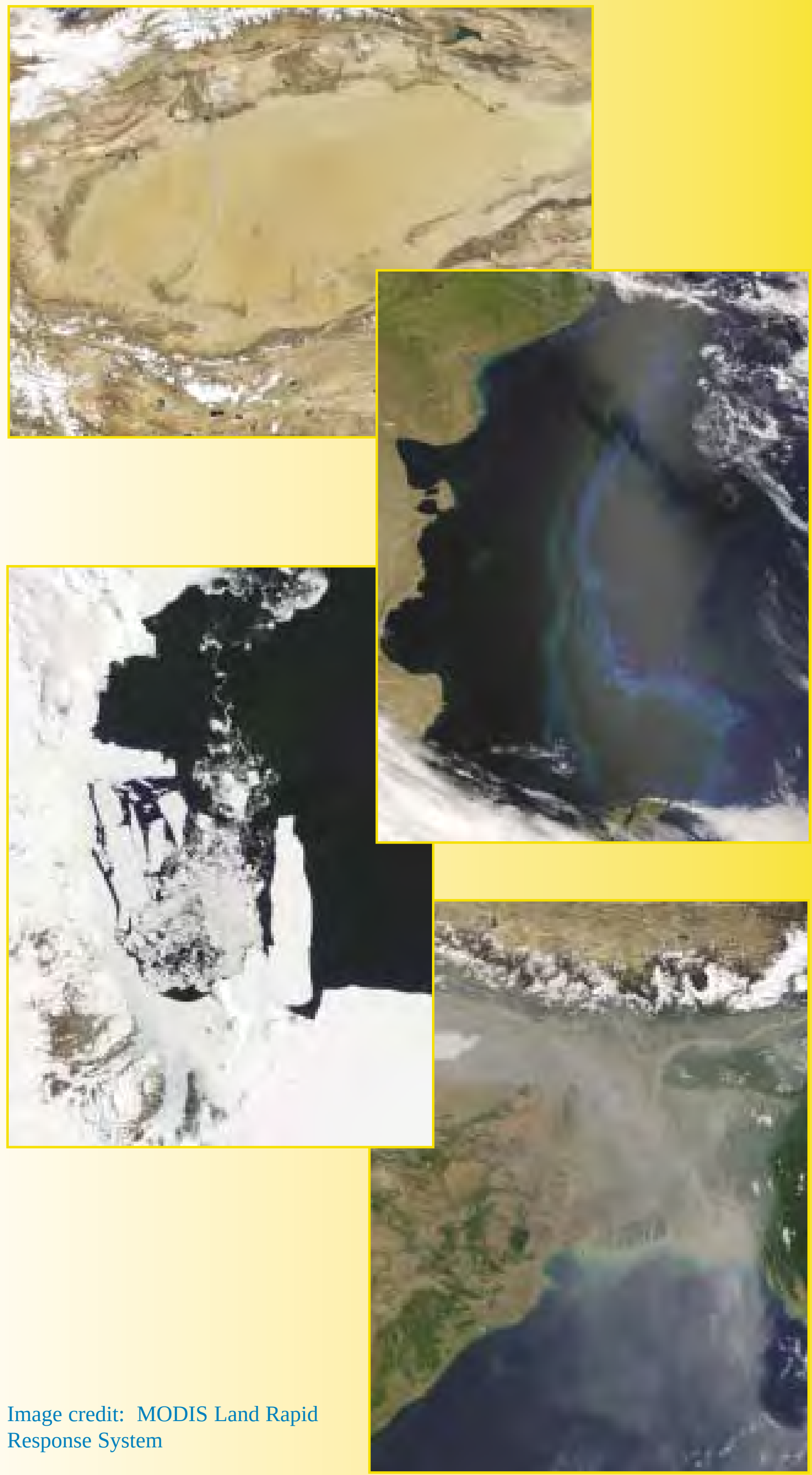


Image credit: MODIS Land Rapid Response System