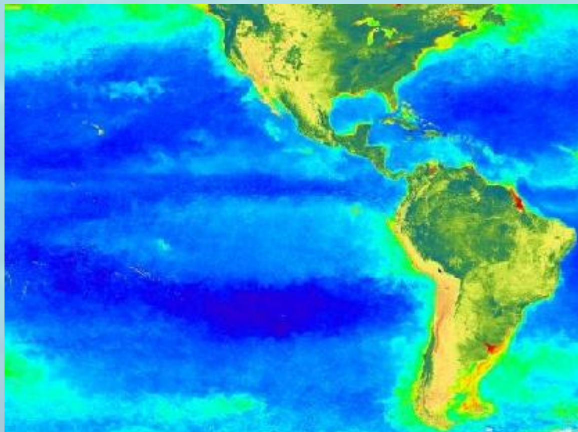
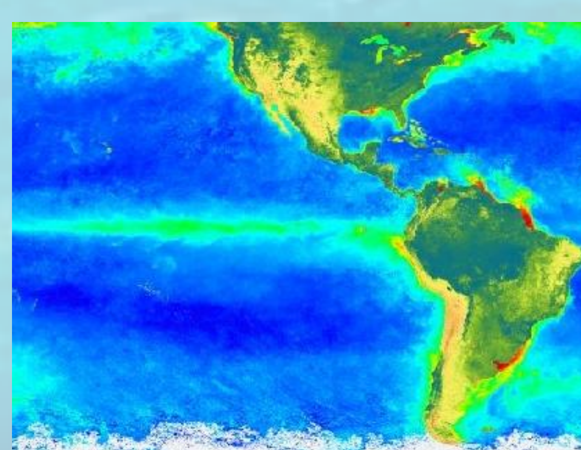
SCIENCE FOCUS: The Carbon Cycle

SeaWiFS and Global Warming*





Take a look at the two SeaWiFS images shown above. Do you see a difference?

These special Level 3 composite images show the Pacific Ocean and the continents of North and South America for two periods of time: September to November 1997 (on the left), and June to August 1998 (on the right). The images are "special" for two reasons. One, they show both the chlorophyll concentration in the oceans and the vegetation cover on land. (The vegetation cover is expressed by a quantity called the Normalized Difference Vegetation Index (NDVI). It basically measures the amount of "greenness" on the surface. Thus, both deserts, mountains, and ice-covered areas are brown, while savannas and forests will be increasingly green.) Two, the images combine data over three-month periods. The standard products from the SeaWiFS Project that are available to scientists combine data for extended periods of eight days, a month, and a year.

Hopefully, the major difference between these two images is fairly obvious. In the image on the right, there is a large area of elevated chlorophyll concentration in the Pacific Ocean that is nearly absent in the image on the left. This is an area called the *Pacific Equatorial Upwelling*.

*** This article was written in the year 2000. Some of the time-dependent information in it is therefore outdated.**

When the Pacific Ocean is in what oceanographers consider a "normal" state, wind/water interactions along the Equator result in the world's largest upwelling zone, which brings nutrient-rich subsurface waters to the surface. These nutrients sustain the growth of phytoplankton. However, when the Pacific Ocean is experiencing the phenomenon called El Niño, warmer water at the surface of the ocean suppresses upwelling, and phytoplankton growth is severely diminished.

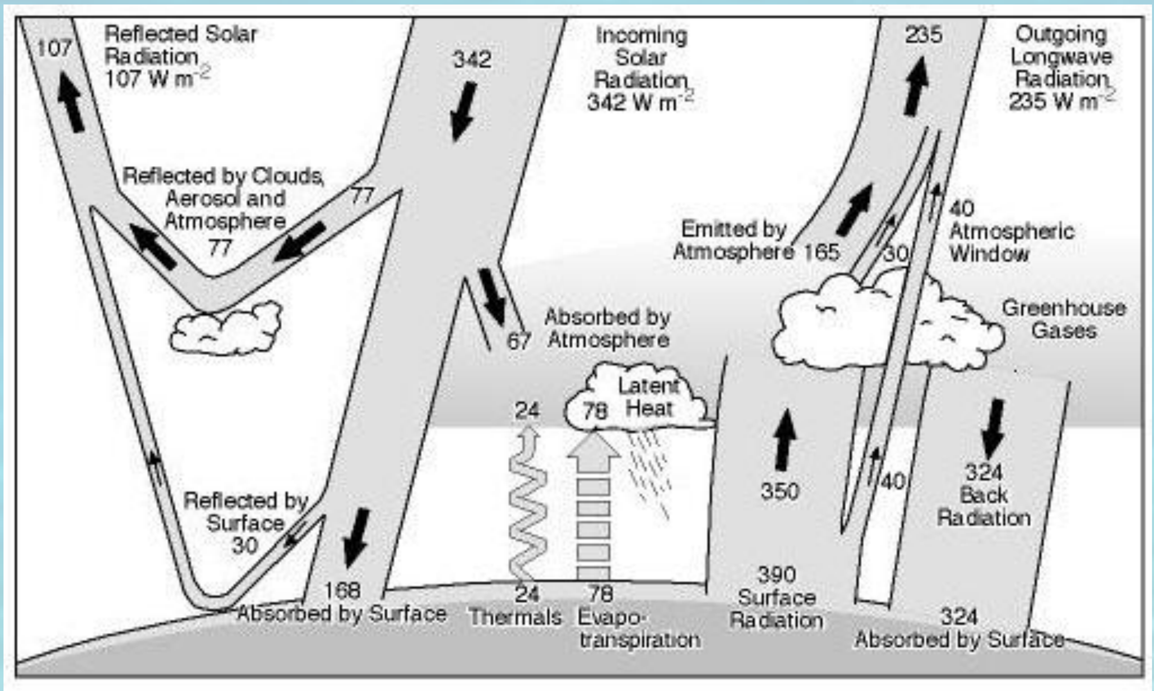
In the autumn of 1997, the Pacific Ocean was in the grip of a strong El Niño event, one of the strongest ever observed. The El Niño state persisted into the early summer of 1998. Then, and remarkably fast, oceanic conditions converted to La Niña (which means, generally speaking, that the conditions are reversed compared to El Niño) and the Pacific Equatorial Upwelling reappeared. Just as El Niño conditions suppress upwelling along the Equator in the Pacific, La Niña conditions actually enhance upwelling, which helps explain the rapid reappearance of the Pacific Equatorial Upwelling zone.

There are numerous World Wide Web links that describe El Niño in detail. The purpose of this *Science Focus!* feature is not to describe El Niño; actually, as the title indicates, it will examine how SeaWiFS data (and ocean color data in general) is related to the important issue called "global warming".

A quick summary of global warming basics

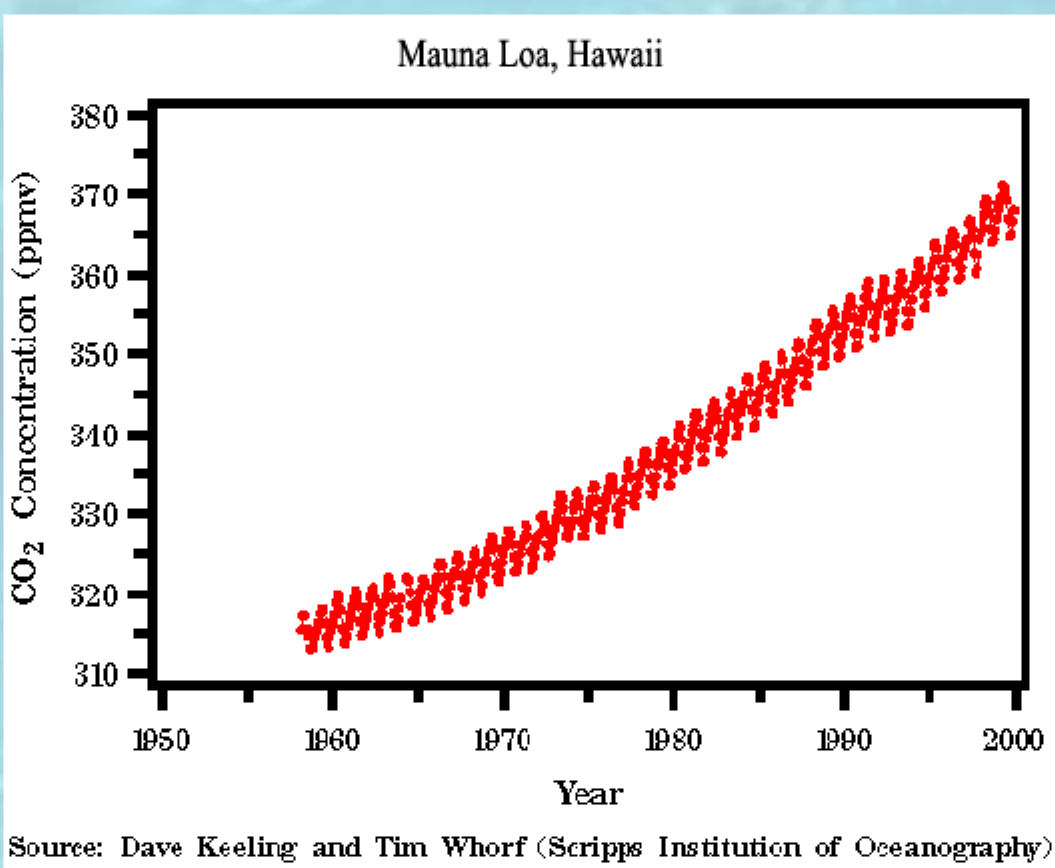
I. The Earth receives energy from the Sun (shortwave radiation), and this energy is absorbed by the ground surface, ocean, and atmosphere. The absorbed energy is re-radiated as long-wave radiation. Some of the re-radiated energy returns to space, and some is trapped by "greenhouse gases", the most important of which is water vapor. Carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFCs) are also greenhouse gases. Aerosols, both natural and man-made, may also affect energy absorption, and they can also reflect some incoming solar radiation.

If it were possible to examine a theoretical state of affairs in which nothing involved in Earth's climate system changed, the Earth would eventually achieve radiative energy balance, which means that the incoming energy would be exactly balanced by the outgoing energy. If, however, either the incoming or outgoing energy changes by some amount (which is what is always happening) then the system has to compensate. For example, when the Earth receives less solar energy due to changes in its orbit or rotational axis, the mean temperature of the Earth decreases, which can lead to Ice Ages if the temperature decreases enough. (The time periods for changes in the orbit and rotational axis are well-known, and their effects have a cyclic effect on Earth's climate. These cycles are called "Milankovitch cycles" after the scientist who first described them.)



In the schematic diagram above, **W m^{-2}** stands for "watts per square meter", the amount of energy received or released by the various components of the climate system. All of the numbers are in these units.

II. The activities of mankind have apparently contributed to increasing amounts of CO_2, CH_4, and CFCs in the atmosphere. The most notable increase has been in the concentration of CO_2, as demonstrated by measurements taken at the Mauna Loa volcano in Hawaii since 1950. Other records, such as ice cores obtained from Greenland and Antarctica, indicate that CO_2 has been steadily increasing since about 1850.



The Keeling CO_2 curve, measured at Mauna Loa volcano, as of the year 2000.

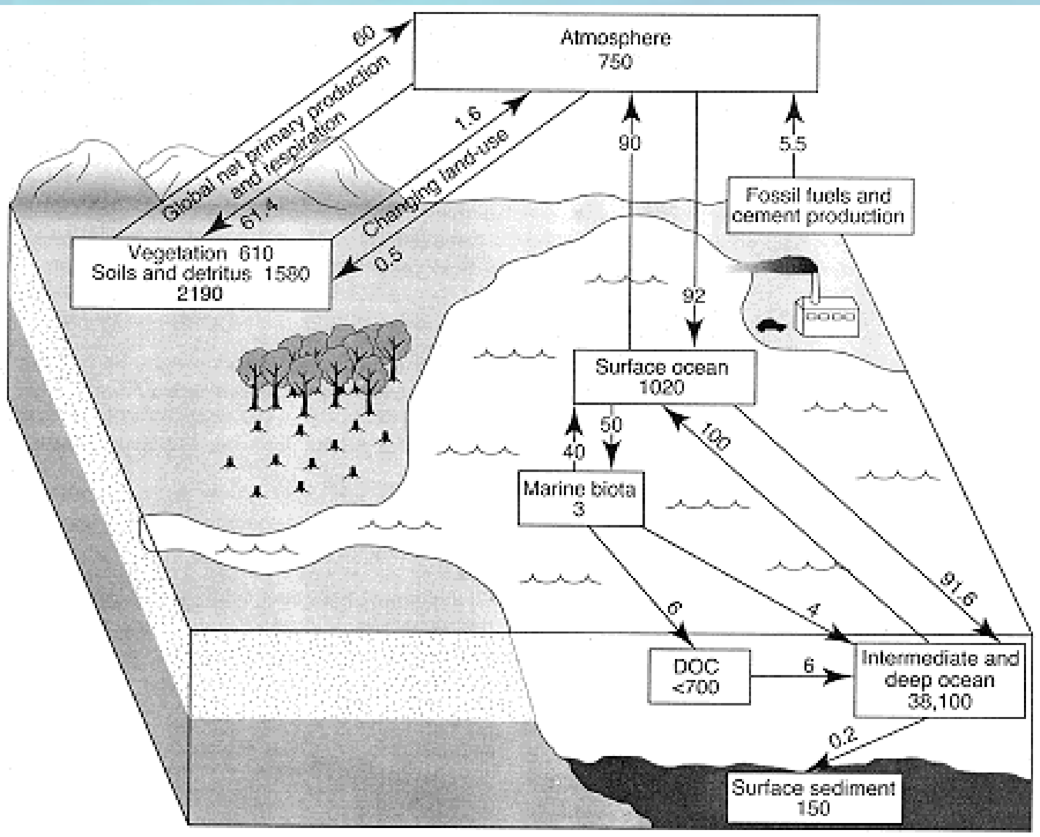
III. The increasing concentrations of greenhouse gases will affect the radiative balance of the Earth by trapping more longwave radiation, and this process should cause the mean temperature of the Earth to increase.

Point III is where the global warming issue gets complicated, because Earth's climate system is very complex.

Take another look at the Mauna Loa CO_2 curve above. Obviously, it isn't a smooth curve. Although the concentration of CO_2 is clearly increasing, every year the concentration increases and decreases. That seasonal cycle is due, primarily, to the growing season in the Northern Hemisphere. As deciduous trees spread their leaves (and also as the North Atlantic blooms) in the spring, a large amount of CO_2 is removed from the atmosphere. During the Northern Hemisphere winter, the concentration of CO_2 rises again.

Now look closely at the Mauna Loa curve about 1991. A slight "flattening" of the curve should be evident. That flattening may be due to the massive eruption of Mount Pinatubo in the Philippines. The eruption injected a large amount of sulfur dioxide (SO_2) aerosols into the stratosphere. This cloud ofSO_2 reflected incoming solar radiation, which actually reduced the Earth's temperature (temporarily) by about 1 degree Centigrade. The lower temperature appears to have caused sea surface temperatures in the Northern Hemisphere to be slightly lower than normal, which caused the absorption of more CO_2 from the atmosphere. In general, where ocean waters are cold and windy, CO_2 will be absorbed, and where ocean waters are warm and calm, CO_2 will be released. Overall, the oceans absorb CO_2 from the atmosphere.

The above discussion leads us to the Earth's carbon cycle, which is where SeaWiFS data is particularly valuable.



The diagram above provides a particularly good perspective of all the processes that affect the cycling of carbon in the Earth's biosphere. (The diagram is from Schimel, D.S., I. Enting, M. Heimann, T.M. Wigley, D. Raynaud, D. Alves, and U. Siegenthaler, "CO_2 and the carbon cycle", in the book *Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios*, published by Cambridge University Press.) In the diagram, carbon **reservoirs** (where carbon is stored) are represented by boxes, and those units are the gigatons of carbon contained in each reservoir. Carbon **fluxes** (transfers of carbon between reservoirs) are represented by arrows, and their units are gigatons of carbon per year. A gigaton is the same quantity as a petagram, which is 10^{15} grams.

The main sector of the carbon cycle where SeaWiFS data lends insight is in the reservoir called "marine biota". One of the remarkable things about the marine biota reservoir is that the size of the reservoir is much smaller than the fluxes in and out the reservoir. Everywhere else in the carbon cycle, the reservoirs are much larger than the fluxes. What this means is that the marine biota reservoir is very dynamic, and any changes in the activity of this reservoir can mean substantial changes in the fluxes to related reservoirs, i.e., in the ocean and also in the atmosphere.

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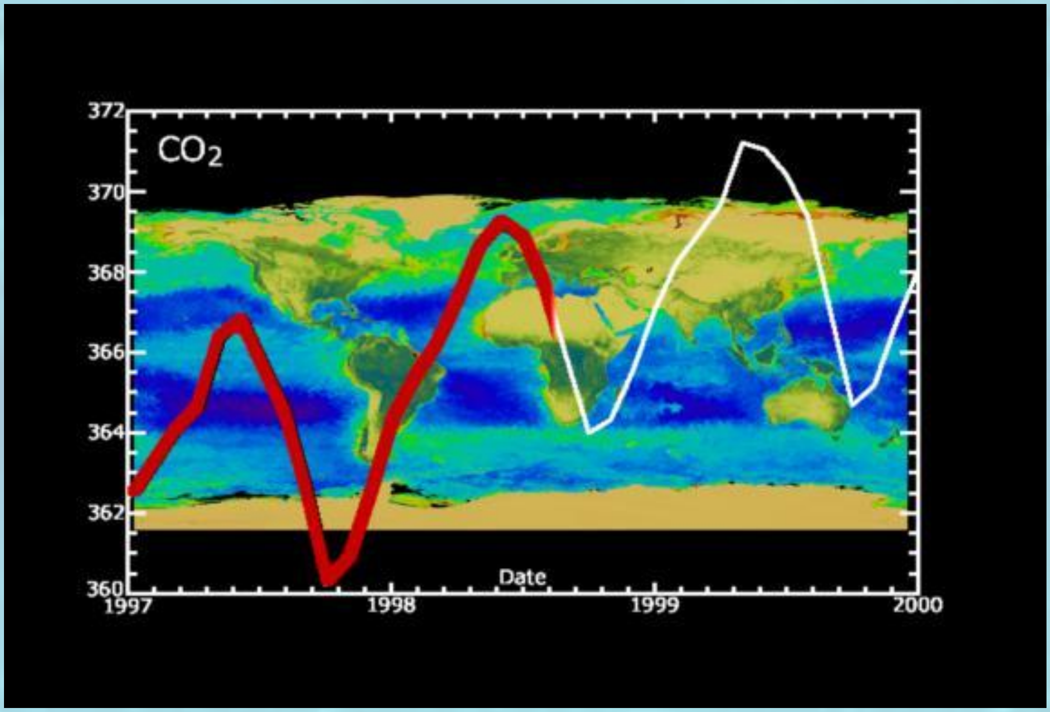
The 1997-1998 El Niño caused a significant change in the activity of the marine biota, as shown by the two images that began this feature. In fact, a recent article in the journal Science quantified the difference in *net global primary productivity* between the El Niño year and the following year, when the Pacific Ocean switched to the La Niña state. *Primary productivity* simply means the production of organic carbon by the process of photosynthesis, either by plants on land or in the ocean (the latter called phytoplankton). In the article, Biospheric Primary Production During an ENSO Transition, the authors determined that net primary productivity increased by 6 petagrams (a petagram is 1 billion metric tonnes) in the year following the 1997-1998 El Niño. Although most of the change occurred in the oceans, the authors also used SeaWiFS data to estimate primary productivity on land using the NDVI data.

[Note: NDVI was originally calculated from data acquired by an instrument that orbits on National Oceanic and Atmospheric Administration (NOAA) satellites. This instrument, the Advanced Very High Resolution Radiometer or AVHRR, has been observing the Earth for almost 20 years. SeaWiFS data can also be used to calculate NDVI, and thus SeaWiFS is the first instrument whose data can be used to estimate primary productivity both on land and in the oceans, an estimate of global primary productivity.]

So SeaWiFS data provides a very good way of estimating how much carbon is being cycled through the oceans and the plants living on land. How does that help us understand global warming?

The data allow scientists to distinguish between natural fluctuations in the carbon cycle and man-made fluctuations in the carbon cycle. Despite the changes in global primary productivity that occurred over the 1997-1999 period, the CO_2 concentration in the atmosphere continued to increase, as shown in this close-up view of the Mauna Loa CO_2 data over that period of time:



This image is one frame from an older version of an animated view of the data that can be seen here: [Colors of Life: The Carbon Cycle](). The image shows that despite the increase in global primary productivity that occurred at the end of the El Niño event, which resulted in the removal of more CO_2 from the atmosphere (and the minimum CO_2 concentration that occurred near the end of 1998), the atmospheric concentration of CO_2 continued to increase.

And there's a good reason for that. In the diagram on page 6, there's a small building with a smokestack. That building, and the automobile parked next to it, represents the addition of CO_2 to the atmosphere by the burning of fossil fuels (oil, coal, and natural gas) to produce energy. This *anthropogenic* (human-related) process is the main change to the Earth's carbon cycle that has occurred in the last 200 years. Additional CO_2, and also methane, may be added to the atmosphere due to changes in the way land is used, such as the conversion of forests to agricultural areas.

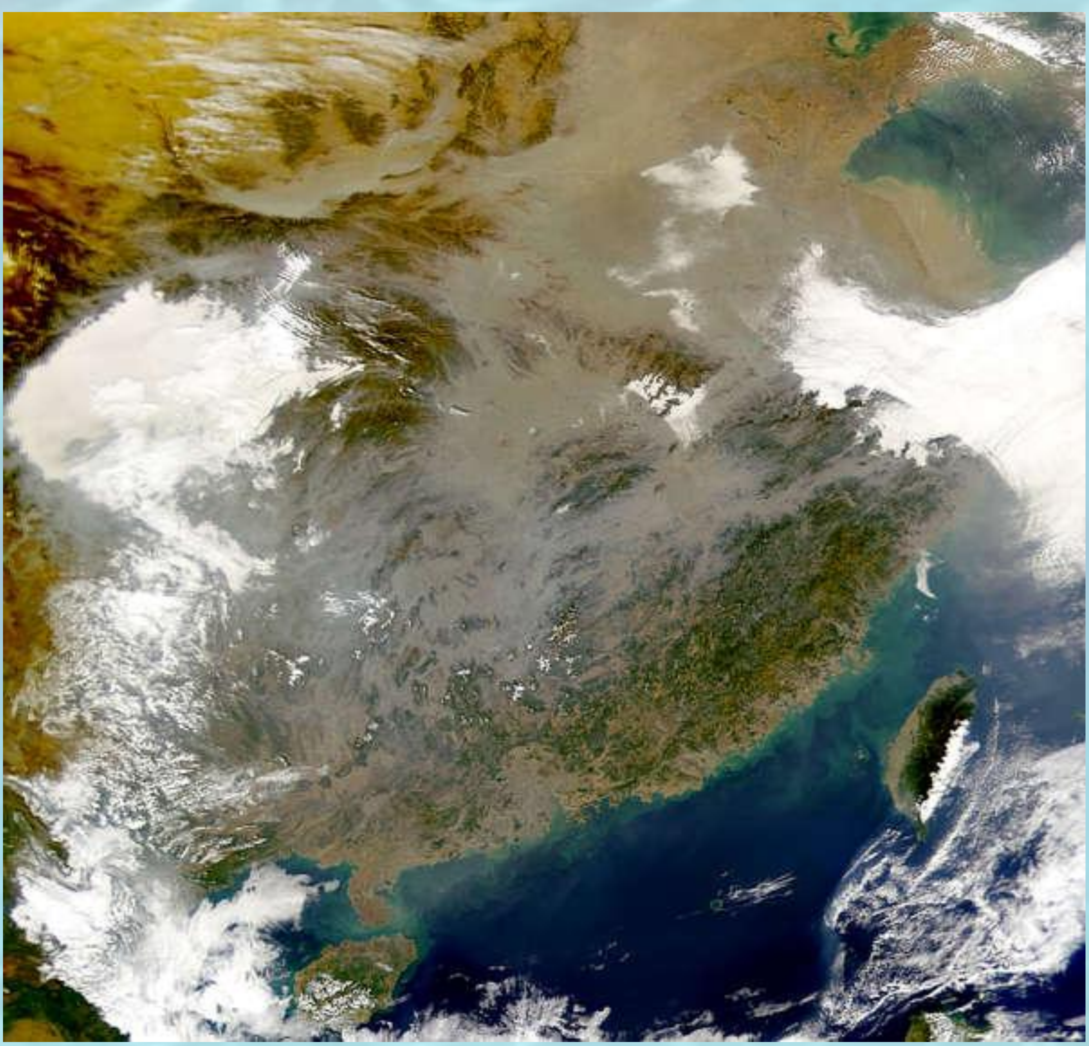
The main question facing scientists who study Earth's climate is how the increasing amount of CO_2 in the atmosphere will ultimately affect the average temperature of the Earth. While almost all scientists expect the temperature of the Earth to increase, predicting the exact amount of temperature increase is very difficult. The Intergovernmental Panel on Climate Change recently predicted on the basis of climate modeling that the temperature of the Earth could increase by as little as 1.5 degrees Centigrade to as much as 5.8 degrees Centigrade by the end of this century. The majority of the models indicated a 2-3 degree Centigrade increase in global temperature.

There are still a lot of uncertainties, and those uncertainties make decisions on what can be done about global warming difficult indeed. SeaWiFS has actually provided several views of processes that can affect global warming. One process is the burning of forests. Near the end of the 1997-1998 El Niño, SeaWiFS captured this view of smoke from burning rain forests in the Yucatan Peninsula:

Subsequently, lack of rain in Florida led to several large fires. In an image obtained on May 18, 2000, two such fires can be seen burning southwest of Lake Okeechobee, in the Big Cypress National Preserve:

Fires such as these in the Big Cypress Swamp affect wetlands, where methane is produced due to the decay of organic matter by *anaerobic* microbes (bacteria that function without oxygen). The rate of increase of methane concentration in the atmosphere has slowed recently, and this may be due to a loss of wetland area. Global warming might increase precipitation in some areas, leading to more wetlands, but it can also decrease precipitation in other areas, so the net effect is not known.

In early January 2000, SeaWiFS viewed China when a dense haze, from both coal-burning power plants and industrial emissions, covered much of the country.



Smoke and soot may be important to global warming, and it may be more feasible to control smoke and soot than to control emissions of CO_2, which has been the main goal of international political agreements on global warming. In fact, the head of the Goddard Institute of Space Studies (GISS), Dr. James Hansen, proposed an alternative scenario that he and his co-authors believe would be more effective in mitigating global warming than the current international treaties.

The primary points of the alternative scenario were: reduction in "black carbon" aerosols that are released by coal and wood burning (which may also provide a health benefit for respiratory disease); reduction in methane emissions, primarily via changes in agricultural practices (which may also produce a health benefit for infectious disease transmission); and reductions in CFC production and tropospheric ozone. Reduction of tropospheric ozone also provides benefits to health and agriculture. The alternative scenario expects that reductions in CO_2 emissions can be best achieved by increasing use of renewable energy sources, more use of natural gas as opposed to coal and oil for energy production, and improvements in energy efficiency, such as more efficient "hybrid" automobile engines.

So, while SeaWiFS provides a much better quantification of one part of the global carbon cycle, this improved insight doesn't answer the critical question of global warming: how much will the average global temperature increase in the next century? However, the answer to this question depends on improved climate models, and SeaWiFS data aids the improvement of our understanding of the global carbon cycle, which is a critical element in these models.

Acknowledgment
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