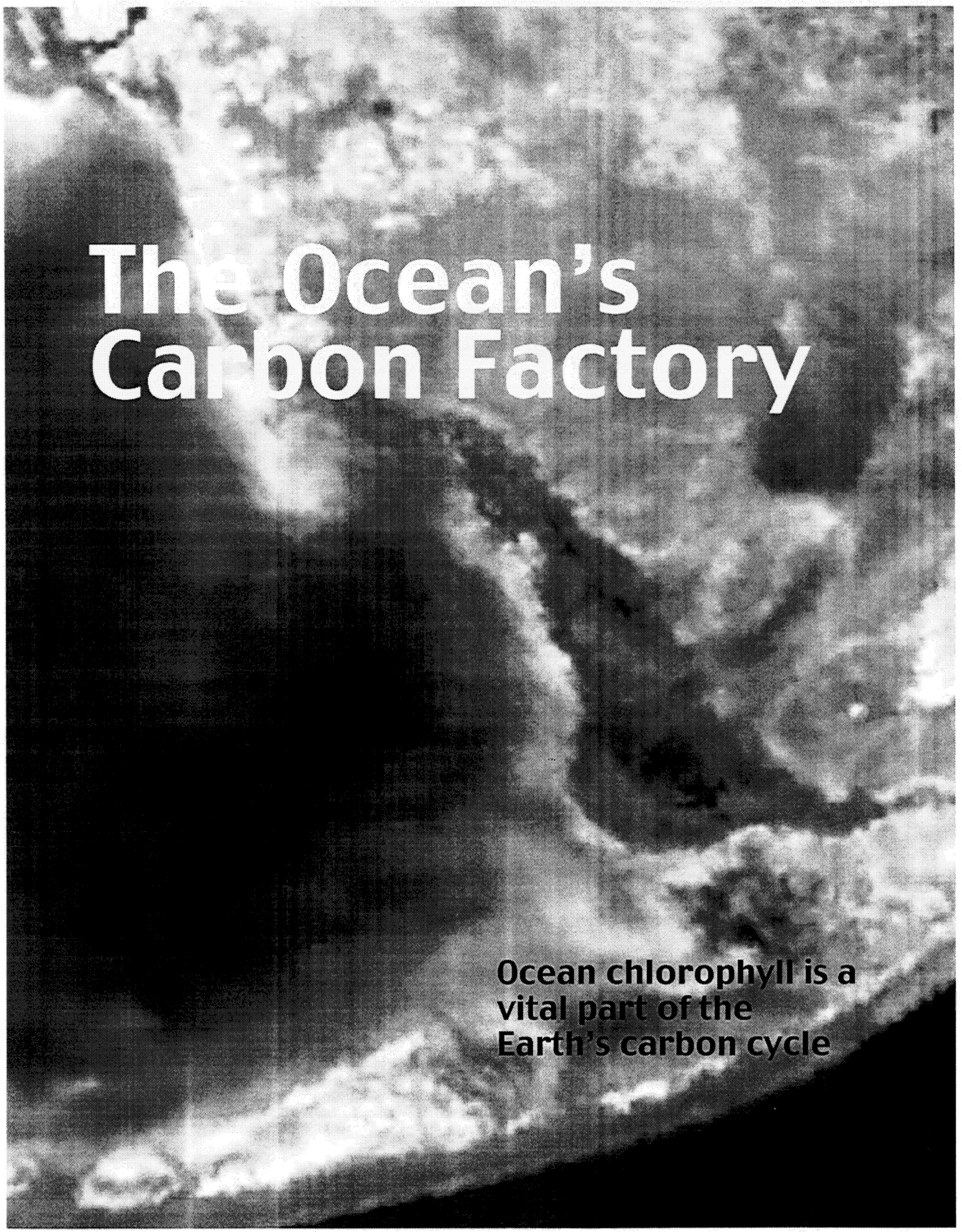
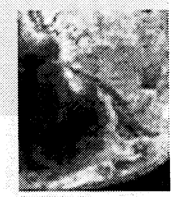
The Ocean's Carbon Factory



Ocean chlorophyll is a vital part of the Earth's carbon cycle



According to biological data recorded by the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) satellite, the ocean contains nearly half of all the Earth's photosynthesis activity. Through photosynthesis, plant life forms use carbon from the atmosphere, and in return, plants produce the oxygen that life requires. In effect, ocean chlorophyll works like a factory, taking carbon and "manufacturing" the air we breathe.

Most ocean-bound photosynthesis is performed by single-celled plants called *phytoplankton*. "These things are so small," according to Michael Behrenfeld, a researcher at NASA Goddard Space Flight Center, "that if you take hundreds of them and stack them end-to-end, the length of that stack is only the thickness of a penny."

The humble phytoplankton species plays a vital role in balancing the amounts of oxygen and carbon dioxide in the atmosphere. Therefore, understanding exactly how phytoplankton growth works is important.

Major types of phytoplankton

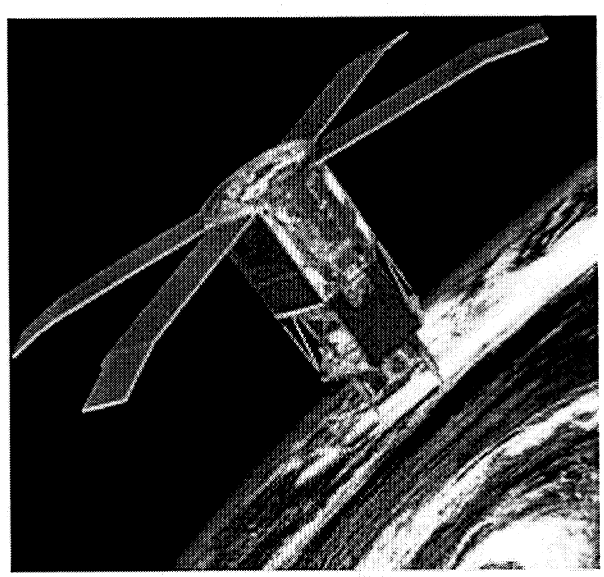
Thousands of phytoplankton breeds exist. They differ in several ways:

- Color
- Rate of growth
- What they feed on
- The portion of the light spectrum that they absorb most readily
- How quickly they sink after dying

Scientists use observations of these characteristics to distinguish phytoplankton in satellite recordings.

Common phytoplankton species include diatoms, picoplankton, and chlorophytes.

Diatoms grow quickly and, therefore, tend to dominate other phytoplankton species in areas with plentiful nutrients. On the other hand, they sink relatively quickly, so diatoms may link up in chains to slow their rate of descent. Diatoms require silica as well as nitrogen nutrients, and



The SeaWiFS satellite tracks the rate of photosynthesis across both land and ocean by measuring the color of light reflected off the Earth's surface. *Image Credit: SeaWiFS Project, NASA Goddard Space Flight Center, and ORBIMAGE*

the amount of iron in the ocean may also limit their growth.

Picoplankton are small, even compared to other phytoplankton. Because of their small size, they are nearly buoyant. Although they grow slowly, they recycle nutrients efficiently. Therefore, they tend to grow mostly in still waters that do not contain enough nutrients for other species to flourish.

Chlorophytes are the happy medium between diatoms and picoplankton, in terms of growth rate and nutrient requirements. The many distinct species of chlorophytes are commonly known as *green algae.*

Measuring the seasonal cycle

Scientists can determine the amount of phytoplankton in a particular area by measuring the chlorophyll that the phytoplankton produce. However, this amount changes according to the seasons and the differing levels of sunlight exposure.

At first, ocean chlorophyll was determined by in situ (at-the-site) observations. People onboard ships would draw water from different locations, and scientists would measure the chlorophyll in these samples. However, gathering samples from all over the ocean at any particular time was logistically too difficult.

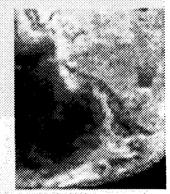
Remote observation from satellites provides a much more feasible method for measuring the global coverage of ocean chlorophyll. Using instruments to quantify the color of the waters, scientists can determine the concentration of plant pigments near the ocean surface. Although this method is an improvement over the older method of collecting data, it has its own challenges. For example, cloud cover blocks a satellite's view and obscures data readings.

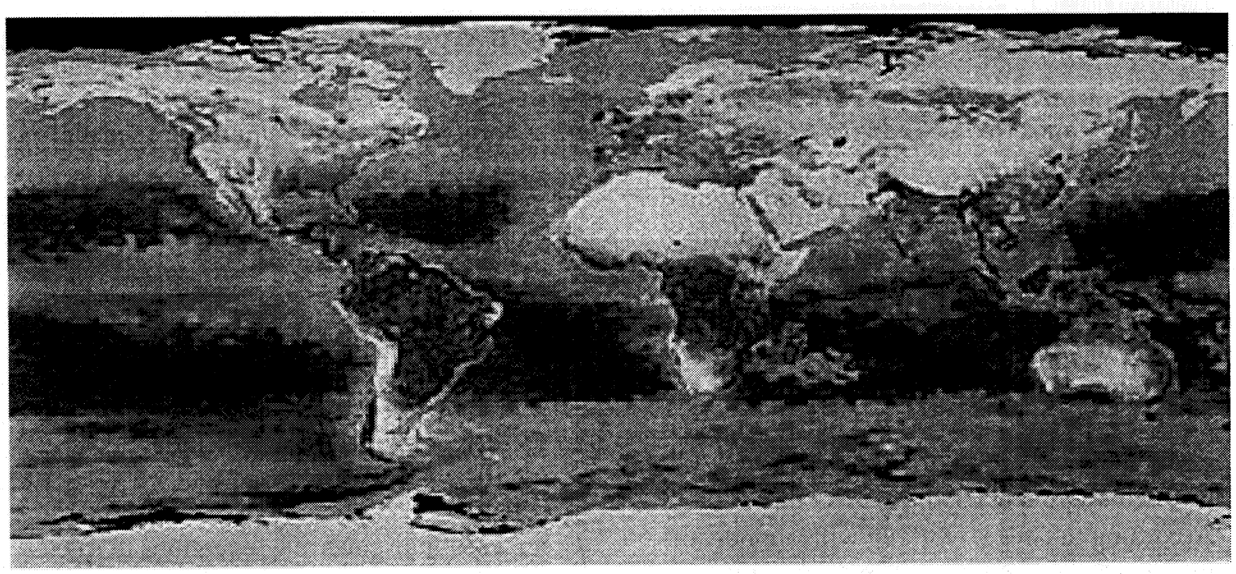
After readings are taken over a number of years, seasonal patterns emerge. For example, at different times, phytoplankton grow rapidly in different areas. These occasions of rapid plant growth are called *blooms*. Scientists now search for broader patterns in the manifestation of phytoplankton blooms across the years.

The following are some of the environmental factors that influence the growth of phytoplankton:

- Sunlight exposure—Phytoplankton reside near the ocean surface, where they are exposed to sunlight. This region is known as the *euphotic zone,* defined as the depth at which only 1 percent of the surface light survives. Although all phytoplankton require solar radiation, different species derive energy from different portions of the light spectrum.

- Nutrients—Besides sunlight, all phytoplankton require nitrogen, in the form of nitrate or ammonium. Some





The SeaWiFS instrument provides the first full record of photosynthetic productivity in the oceans. The color coding of this SeaWiFS data map is based on the rainbow spectrum: red and orange represent a high level of photosynthesis; green and yellow indicate a moderate amount of photosynthetic activity; and blue and purple show low levels of photosynthesis. *Image credit: SeaWiFS Project, NASA Goddard Space Flight Center, and ORBIMAGE*

species also need other types of nutrients, for example, the mineral iron. Most of the iron found in the oceans comes from soil dust blown into the waters by wind currents. Scientists hypothesize that some phytoplankton species require small amounts of iron to aid in photosynthesis. Even if an area of the ocean is rich in other nutrients, some phytoplankton may not survive without enough iron.

- Ocean currents—The movement of the ocean waters determines the distribution of phytoplankton and how close to the surface they can reside. Currents from the depths can bring rich nutrients up to the surface, where phytoplankton can feed on them and grow.

References

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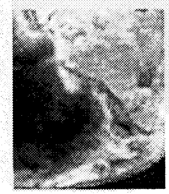


Research Profile: The Growth Patterns of Phytoplankton Species

Investigator:
Watson Gregg, NASA Goddard Space Flight Center, Laboratory for Hydrospheric Processes

Watson Gregg developed a computerized model to simulate the growth of ocean chlorophyll throughout the seasons. He intended to compare the model results with real-world observations to see if the rules under which ocean chlorophyll are presumed to work are accurate.

A standard global run of this simulation works through approximately 4.25 GB of data. According to Gregg, working with a model of this size "just couldn't be done without the NCCS" because the model requires such intense computing.

In fact, Gregg estimates that the recent upgrades at the NCCS to the Cray SV1 processors cut his computation time by a factor of about 2.5. The time required to process a year of phytoplankton growth dropped from 4 days to less than a day and a half. "Considering we need about 20 years to spin up to steady state," Gregg says, "this makes a huge difference." (See the NASA Center for Computational Sciences section for more information on this upgrade.)

Unlike previous models of chlorophyll distribution, Gregg's model did not develop separate systems for different regions. To fully understand the growth of phytoplankton, Gregg devised a single three-dimensional system to cover the entire globe. The system boosted the level of detail by calculating for three types of phytoplankton separately:

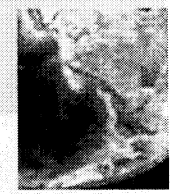
- Diatoms
- Picoplankton, which include cyanobacteria and prochlorophytes
- Chlorophytes, which include flagellates

Gregg used four governing equations to calculate the abundance of the following:

- Chlorophyll carried by diatoms, chlorophytes, and picoplankton
- Nutrients in the ocean (nitrate, ammonium, and silicate)
- Sea creatures that feed on phytoplankton
- Detritus left behind by dead phytoplankton

The numerical data plugged into these governing equations was generated by three distinct models: the Poseidon ocean general circulation model (OGCM), the biogeochemical model, and the general radiative transfer model. These coupled models ensured that the single system of governing equations remained accurate throughout the entire global region.

Ocean Composition



The Poseidon OGCM determines the horizontal and vertical currents that carry and move organisms and nutrients. The grid of this reduced-gravity model is nearly global in scale and has a resolution of approximately 0.8 degrees. The OCGM requires monthly averages of observed wind currents, changes in air temperature, and sea surface temperatures. Poseidon was developed by Paul Schopf at the George Mason University Center for Ocean-Land-Atmospheres.

The biogeochemical model uses Poseidon ocean current results to predict the amount of phytoplankton, herbivores, and detritus throughout the ocean. The biogeochemical model bases the growth of phytoplankton on temperature as well as the availability of sunlight and nutrients.

Phytoplankton consume nutrients, only to be consumed in turn by herbivores. The herbivores produce ammonium in the process of excretion. Phytoplankton that die naturally and rot also produce ammonium. All this ammonium feeds the remaining phytoplankton, and so the cycle continues.

The biogeochemical model also calculates the rate at which phytoplankton sink. This information is important because the faster phytoplankton sink, the less light they get to fuel photosynthesis. The speed at which plant life moves down the ocean depths is governed by plant size and Stokes' Law, which determines the drag on a spherical body in motion.

A general radiative transfer model calculates the amount of sunlight available for absorption by phytoplankton at any given time. The model uses observation data for the presence and thickness of clouds to determine how much sunlight reaches the oceans. This model also uses precipitation records to account for the ability of airborne moisture to block solar energy from the ocean surface. Other required observation data include surface pressure, wind speeds, and relative humidity.

To start the simulation, Gregg used annual climatology data from the National Oceanographic Data Center archives to set the initial values for the nutrients nitrate and silicate. The values for the phytoplankton groups were set at an equal, arbitrary amount. Once the model began calculating throughout time, phytoplankton distributions changed according to the model's rules.

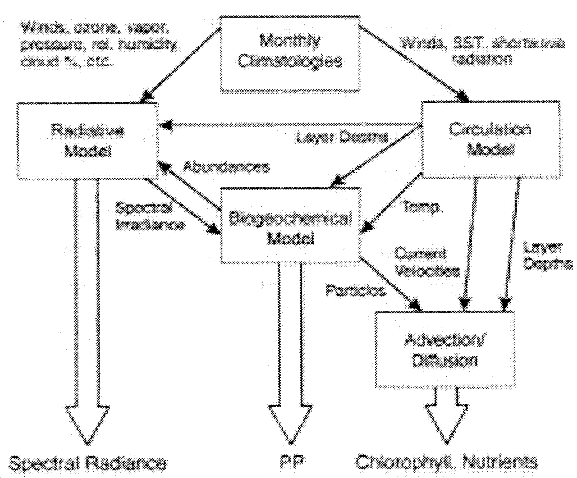
As the model calculations progressed, the phytoplankton distributions grew more stable, changing less and less between time steps. In the 20th year of simulation time, the biogeochemical constituents (phytoplankton groups and nutrients) reached a steady state. In other words, the distributions in the 20th year were nearly identical to those of the 19th year.

At this point, Gregg was able to compare the results to existing observation data. The seasonal distribution of the three phytoplankton groups in the simulation mostly matched real-world distributions.

For further verification, Gregg checked the total ocean surface chlorophyll amounts against remote measurements from the satellites Coastal Zone Color Scanner (CZCS) and SeaWiFS. For this test, the ocean was divided into 12 basin regions for comparison. The simulation achieved a 95-percent confidence match with SeaWiFS for all 12 basins and with CZCS for 9 of the 12 basins.

Although the results were encouraging, such disagreements between the simulation and observation data might indicate the need for improvement in the simulation.

One notable improvement could be the inclusion of iron as a variable in the coupled model. That factor might explain why the simulation rated high diatom growth in areas that are observed to be dominated by other forms of phytoplankton.



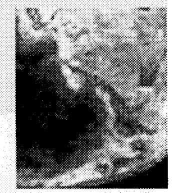
Numerous data fields feed the coupled ocean general circulation, biogeochemical, and radiative models that calculate phytoplankton distributions.

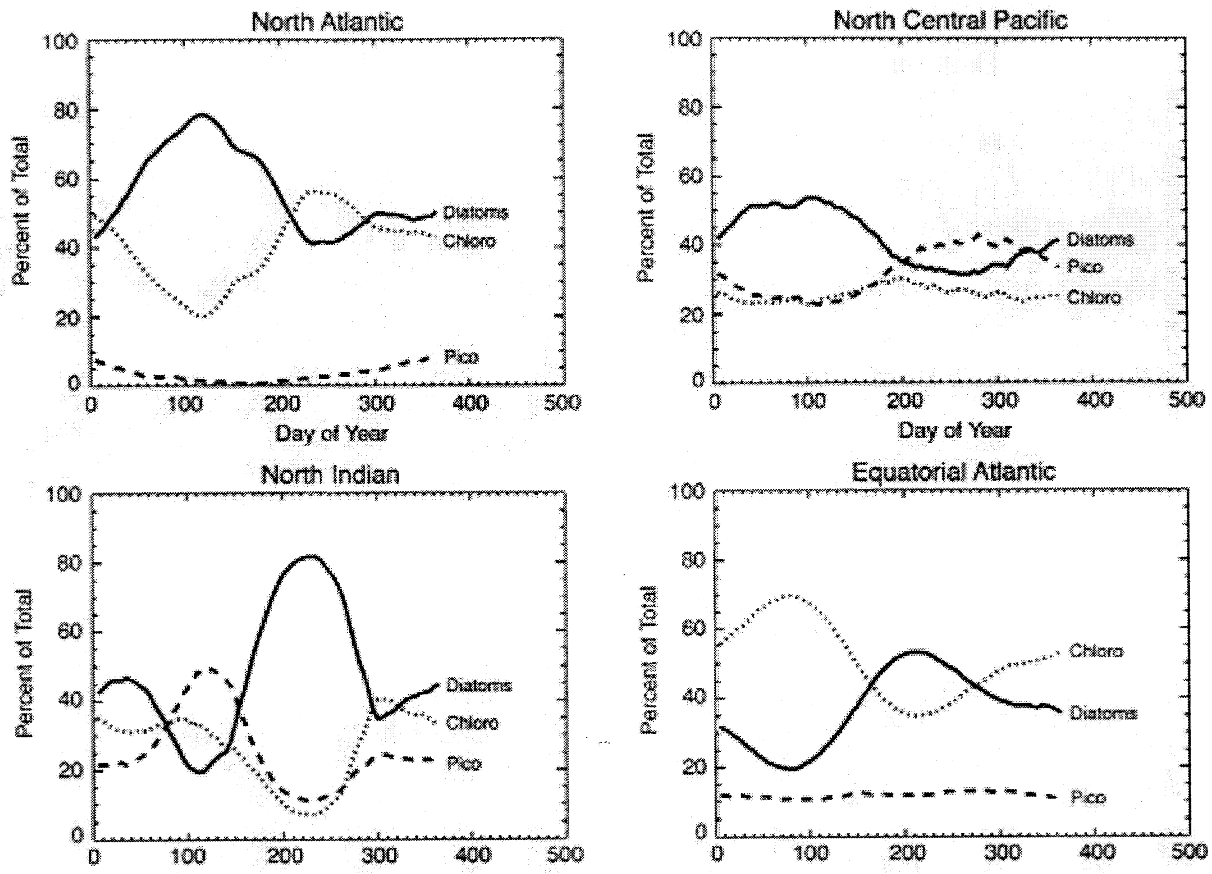
These ocean areas are high in nutrients and normally would be conducive to diatom growth; however, they are also known to have low amounts of iron. According to the iron limitation theory, a low amount of iron in the oceans prevents some types of phytoplankton, such as diatoms, from flourishing.

Gregg plans to explore the iron limitation theory in a research proposal with Paul Ginoux, a scientist from the Atmospheric Chemistry Dynamics Branch at NASA Goddard. They would modify the ocean chlorophyll modeling system to account for the effect of iron content on phytoplankton growth.

Several other factors might have contributed to inaccuracies in the simulation:

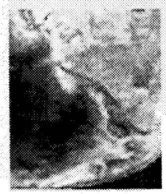
- Poor sampling in CZCS data, which does not show seasonal variability
- Inaccurate representation of vertical movement in ocean currents because of the reduced-gravity nature of the OGCM
- No simulation of the ability of ocean ice to cool water and limit phytoplankton growth
- No accounting for the effect of the ocean floor and coasts on circulation

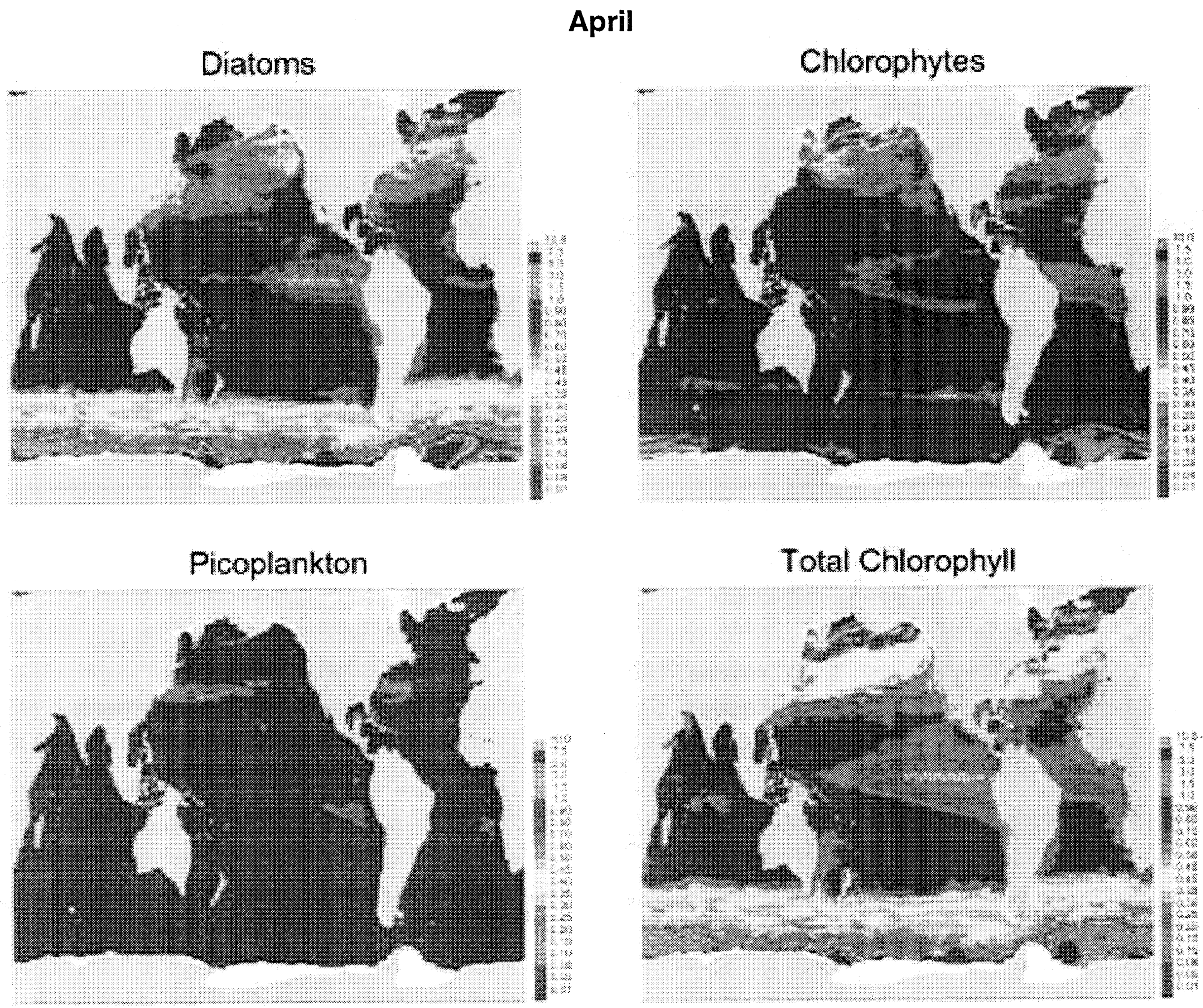




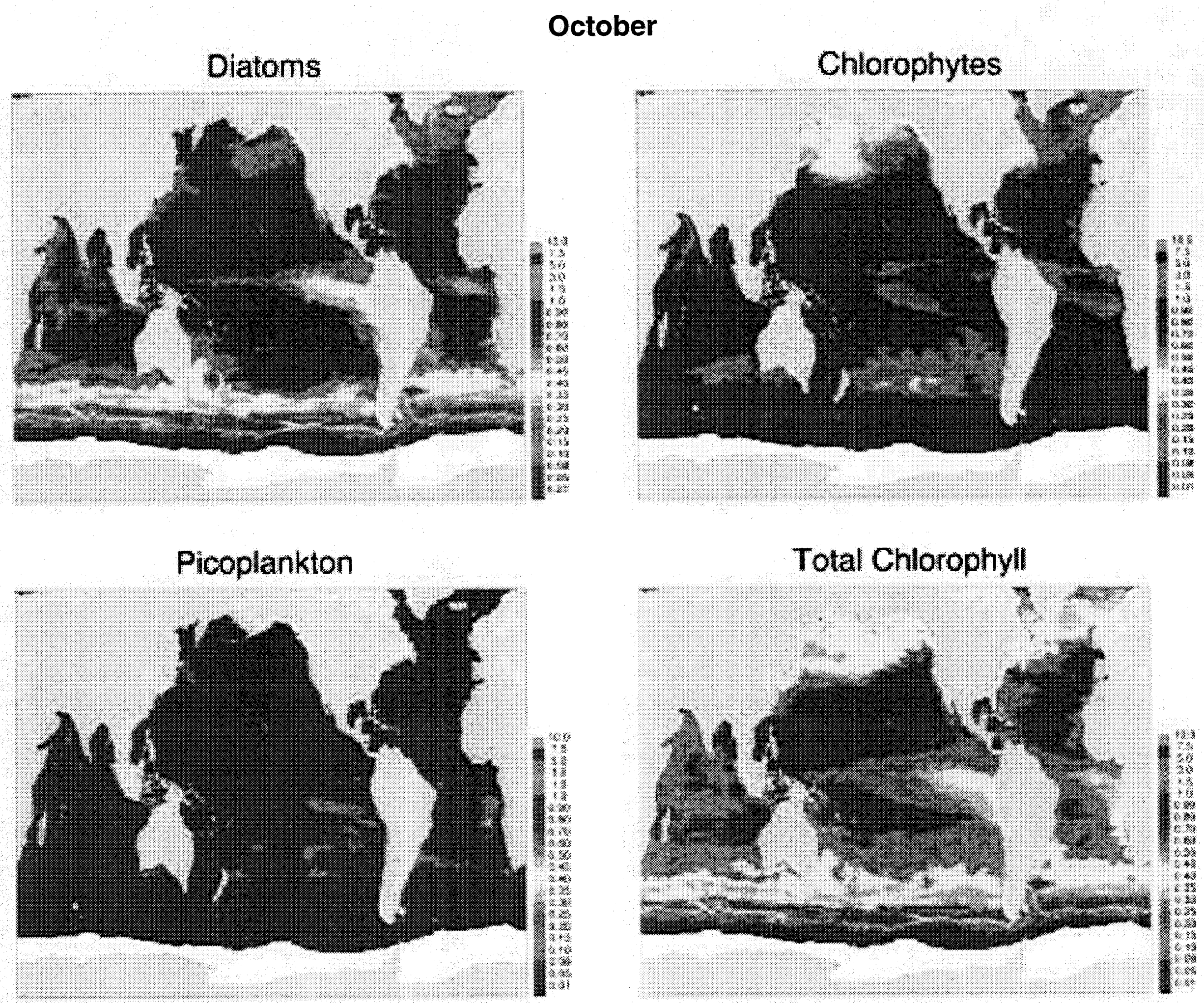
This study charted the seasonal variability of diatoms, chlorophytes, and picoplankton in four ocean regions. These areas represent the range of most ocean conditions.

Despite these disparities, the accuracy of the model results indicate that current knowledge of phytoplankton, on which the model equations were based, is largely accurate.





The phytoplankton growth model generated these distribution charts for the month of April after 4 years of simulation. The results generally conformed to expectations.



Group distributions of phytoplankton were computed for the month of October after 4 years of simulation. These maps represent totals for a single day near the beginning of the month, rather than monthly averages. The remnants of a monsoon in the Arabian Sea are visible, with a dominance of diatoms in the area. Diatoms also thrive in the southern oceans.