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Recent climate model predictions indicate that rising levels of atmospheric carbon dioxide may trigger a dramatic shift in phytoplankton communities in the Southern Ocean, according to Kevin Arrigo, Assistant Professor of Geophysics at Stanford University.

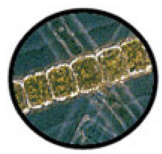
Phytoplankton, plantlike organisms consisting mostly of algae and bacteria, are the foundation of the marine food chain. Drifting in a nearly invisible mass within the top surface layer of the ocean, they are thought to produce at least 40 percent of the food (i.e., organic carbon) made by photosynthesis on Earth each year. The presence and success of phytoplankton determine the biological characteristics of any ocean region.

Phytoplankton play a significant role in global climate. Since they use carbon dioxide for photosynthesis, they help keep atmospheric levels of the greenhouse gas in check. The larger the world's phytoplankton population, the more carbon dioxide gets pulled from the atmosphere, and the lower the average temperatures on Earth.

But not all phytoplankton are created equal. Arrigo found that some types of phytoplankton dominate waters that are shallow and highly stratified, while others prefer more deeply mixed waters. According to Arrigo, *Phaeocystis antarctica (P. antarctica)* and diatoms are the principal phytoplankton assemblages throughout Antarctic and Arctic waters. Diatoms, the dominant photosynthetic organisms in the world ocean, abound where freshwater from melting sea ice results in mixed layers that are more shallow and strongly stratified. *P. antarctica,* single-celled algae that can grow in lower light conditions, tend to populate more deeply mixed waters.

P. antarctica and diatoms differ geochemically, too, in that diatoms don't take up carbon dioxide as efficiently as *P. antarctica*. In fact, the ratio of carbon uptake to phosphorus uptake for *P. antarctica* is nearly twice as high as that for diatoms. "Should the phytoplankton community shift from *P. antarctica* to diatom dominance in response to enhanced upper ocean stratification, the capacity of the biological community to draw down atmospheric carbon dioxide could diminish dramatically," Arrigo said in a recent article in the journal *Science*.

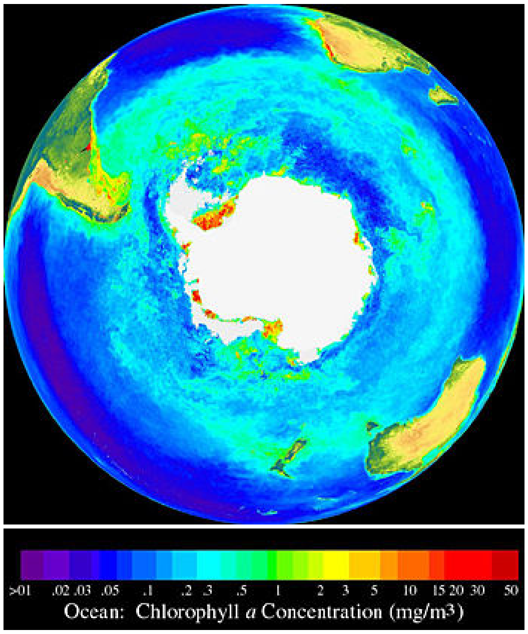
Arrigo's study in the Southern Ocean is unique in that it combines modeling, field work, and the use of satellite data. "The same researcher who is doing the modeling is also out collecting field data," said Arrigo. "Your perspective changes when you go to the Antarctic and actually see the system you're modeling."



Phytoplankton are the basis of the marine food chain and a significant factor in global climate. See What are Phytoplankton? for more information.

Diatoms are phytoplankton that produce a glass (silicate) covering. These diatoms, from the San Francisco Bay area, are chain-forming. (Image courtesy of the USGS.)

The Ross Sea is one of the most productive regions of the Southern Ocean, partly owing to the large and persistent polynyas that form there. Kevin Arrigo, Assistant Professor of Geophysics at Stanford University, and colleagues examined the relationship between polynya formation and phytoplankton



SeaWiFS image of the Southern Hemisphere, September 1997 to August 1998. Red and yellow pixels show where there are high concentrations of phytoplankton, while dark blues and purple show very low concentrations of the microscopic plants. (Image courtesy of the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. A new browser window will open.)

Phytoplankton typically thrive at or near the sea surface where sunlight is most abundant. But since they can't swim, they are extremely sensitive to ocean dynamics. "Phytoplankton are at the mercy of the currents, so ocean physics determine how fast they will grow," Arrigo said.

Climate models indicate that over the next half century, increased precipitation in the Southern Ocean could have a significant effect on ocean dynamics, particularly ocean surface stratification. Ocean water typically consists of layers that differ in density, temperature, and salinity. The surface layer stratifies, or divides into layers, in response to atmospheric conditions. Stratification increases when surface waters warm, or when precipitation adds freshwater to the surface layer. "Increased stratification in the Southern Ocean is going to favor the diatoms, because they prefer to live in water that is not mixed very well," Arrigo said.

Focusing on the Ross Sea, a small region in the Southern Ocean, Arrigo and colleagues developed a model to examine the relationship between ocean physics and phytoplankton. "Historically, the Ross Sea has been considered one of the most productive regions of the Southern Ocean," he said. "It contains the largest and most persistent concentration of polynyas."

Polynyas, areas of open water surrounded by ice, form in areas where the wind blows the ice away or where warm water moves up from lower depths and melts the ice cover. "It's really difficult to get the models to form polynyas in the right locations, and the biology is very dependent on that," said Arrigo. When sea water freezes, it discharges salt into the ocean. Therefore, Arrigo's ocean circulation model uses sea ice concentration data to calculate salt and heat balances in the ocean, measurements that are essential to simulating water movement.

A long time-series of sea ice concentration data from microwave sensors, available from the National Snow and Ice Data Center DAAC, enabled Arrigo to examine how variations in sea ice cover affect biology. "We used the microwave data to help explain patterns we see in blooms in the southwestern Ross Sea.

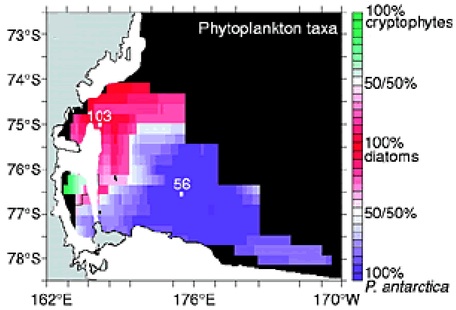
Comparing ocean pigments from Coastal Zone Color Scanner (CZCS) data with passive microwave sea ice data, Arrigo found an association between the timing of polynya formation and the timing of declines in phytoplankton blooms in the Ross Ice Shelf. According to Arrigo, the interaction between seasonal changes in winds and yearly differences in the timing of polynya formation control the start of phytoplankton blooms in the Ross Sea. "When the Ross Sea polynya forms early, stronger and more frequent winds result in phytoplankton losses in surface waters and a delay in the phytoplankton bloom," Arrigo reported in the *Journal of Geophysical Research*. "If polynya formation is delayed until after the winds diminish, the phytoplankton bloom will develop earlier."

According to Arrigo, understanding the dynamics of phytoplankton growth is crucial to defining the role of the Southern Ocean in the global carbon cycle. "Phytoplankton play a major role in the carbon cycle, but we know little of their seasonal and spatial distributions in the Southern Hemisphere," he said.

For more information, visit the SeaWiFS Project and the Coastal Zone Color Scanner from the Goddard Space Flight Center DAAC (now named the GSFC Earth Sciences DAAC). (A new browser window will open.)

Diatom image in title graphic courtesy of USGS.

biology," said Arrigo. "Surprisingly, much of the productivity in the Southern Ocean is going on in the ice, not in the water."



Phytoplankton taxa in the Ross Sea (Image courtesy of Arrigo et al.: Phytoplankton Community Structure and the Drawdown of Nutrients and CO2 in the Southern Ocean, 1999)

Satellite data are an essential ingredient in Arrigo's primary production models, which use light, nutrients, and phytoplankton chlorophyll to estimate biological productivity. To determine phytoplankton concentrations, the research team analyzed ocean color data obtained from the Goddard Space Flight Center DAAC. Ocean color data are collected by satellite sensors that can distinguish variations in ocean color caused by chlorophyll and other plant pigments undetectable by the human eye.

Arrigo was intrigued to find that productivity in the Southern Ocean is higher than originally believed. "It's always been a paradox, because prior estimates of annual primary production in the Southern Ocean were insufficient to support the existing Antarctic food web," he said. The team's large-scale model projected productivity in the Southern Ocean to be four to five times higher than previous estimates made using *in situ* data.

According to Arrigo, biological responses to predicted changes in ocean dynamics have been poorly understood, but understanding the relationship between phytoplankton community structure and ocean dynamics is an essential part of modeling climate change. "For the first time, we can include the effect of this shift in phytoplankton species dominance in our large-scale models," said Arrigo.

Arrigo sees the Southern Ocean ecosystem as a biological hotbed that, due to its remote location, has been under studied by the research community. "In terms of global biology and chemistry, the Southern Ocean ecosystem is one of the richest regions in the world," said Arrigo. "Lots of people are studying the Pacific or the Indian Ocean, but not many people are studying the Southern Ocean and the Antarctic region, so there are opportunities to make significant impacts quickly," he said.

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