Robotic floats provide new look at ocean health and global carbon cycle

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MBARI researchers demonstrated that a fleet of robotic floats could provide important insight into ocean primary productivity on a global scale. Data from these floats can be used to improve computer modeling of Earth's carbon cycle, climate change predictions, and ocean health. Credit: Natalie Freeman © 2019 SOCCOM

Microscopic marine life plays a fundamental role in the health of the ocean and, ultimately, the planet. Just like plants on land, tiny phytoplankton use photosynthesis to consume carbon dioxide and convert it into organic matter and oxygen. This biological transformation is known as marine primary productivity.

In a new study in *Nature Geoscience* today, MBARI Senior Scientist Ken Johnson and former MBARI postdoctoral fellow Mariana Bif demonstrated how a fleet of robotic floats could revolutionize our understanding of primary productivity in the ocean on a global scale.

Data collected by these floats will allow scientists to more accurately estimate how carbon flows from the atmosphere to the ocean and shed new light on the global carbon cycle. Changes in phytoplankton productivity can have profound consequences, like affecting the ocean's ability to store carbon and altering ocean food webs. In the face of a changing climate, understanding the ocean's role in taking carbon out of the atmosphere and storing it for long periods of time is imperative.

"Based on imperfect computer models, we've predicted primary production by marine phytoplankton will decrease in a warmer ocean, but we didn't have a way to make global-scale measurements to verify models. Now we do," said MBARI Senior Scientist Ken Johnson.

By converting carbon dioxide into organic matter, phytoplankton not only support oceanic food webs, they are the first step in the ocean's biological carbon pump.

Phytoplankton consume carbon dioxide from the atmosphere and use it to build their bodies. Marine organisms eat those phytoplankton, die, and then sink to the deep seafloor. This organic carbon is gradually respired by bacteria into carbon dioxide. Since a lot of this happens at great depths, carbon is kept away from the atmosphere for long periods of time. This process sequesters carbon in deep-sea water masses and sediments and is a crucial component in modeling Earth's climate now and in the future.

Marine primary productivity ebbs and flows in response to changes in our climate system. "We might expect global primary productivity to change with a warming climate," explained Johnson. "It might go up in some places, down in others, but we don't have a good grip on how those will balance." Monitoring primary productivity is crucial to understanding our changing climate, but observing the response on a global scale has been a significant problem.

Directly measuring productivity in the ocean requires collecting and analyzing samples. Limitations in resources and human effort make direct observations at a global scale with seasonal to annual resolution challenging and cost prohibitive. Instead, remote sensing by satellites or computer-generated circulation models offer the spatial and temporal resolution required. "Satellites can be used to make global maps of primary productivity, but the values are based on models and aren't direct measurements," cautioned Johnson.

"Scientists estimate about half of Earth's primary productivity happens in the ocean, but the sparsity of measurements couldn't give us a reliable global estimate for the ocean yet," added Mariana Bif, a biogeochemical oceanographer and a former postdoctoral fellow at MBARI. Now, scientists have a new alternative for studying ocean productivity—thousands of autonomous robots drifting throughout the ocean.

These robots are giving scientists a glimpse at marine primary productivity across area, depth, and time. They are dramatically transforming our ability to estimate how much carbon the global ocean accumulates each year. For example, the Indian Ocean and the middle of the South Pacific Ocean are regions where scientists have very little information about primary productivity. But this changed with the deployment of Biogeochemical-Argo (BGC-Argo) floats across the globe.

"This work represents a significant milestone in ocean data acquisition," emphasized Bif. "It demonstrates how much data we can collect from the ocean without actually going there."

The BGC-Argo profiling floats measure temperature, salinity, oxygen, pH, chlorophyll, and nutrients. When scientists first deploy a BGC-Argo float, it sinks to 1,000 meters (3,300 feet) deep and drifts at this depth. Then, its autonomous programming gets to work profiling the water column. The float descends to 2,000 meters (6,600 feet), then ascends to the surface. Once at the surface, the float communicates with a satellite to send its data to scientists on shore. This cycle is then repeated every 10 days.

For the past decade, an increasing fleet of BGC-Argo floats has been taking measurements across the global ocean. The floats capture thousands of profiles every year. This trove of data provided Johnson and Bif with scattered measurements of oxygen over time.

Knowing the pattern of oxygen production allowed Johnson and Bif to compute net primary productivity at the global scale.

During photosynthesis, phytoplankton consume carbon dioxide and release oxygen at a certain ratio. By measuring how much oxygen phytoplankton release over time, researchers can estimate how much carbon phytoplankton produce and how much carbon dioxide they consume. "Oxygen goes up in the day due to photosynthesis, down at night due to respiration—if you can get the daily cycle of oxygen, you have a measurement of primary productivity," explained Johnson.

Although this is a well-known pattern, this work represents the first time that it has been quantitatively measured by instruments at the global scale rather than estimated through modeling and other tools.

But profiling floats only sample once every 10 days, and Johnson and Bif needed multiple measurements in one day to get a daily cycle. A novel approach to analyzing the float data allowed Johnson and Bif to calculate ocean primary productivity. With each profiling float coming up at a different time of day, combining data from 300 floats and samples from various times of day allowed Johnson and Bif to recreate the daily cycle of oxygen going up and down and then calculate primary productivity.

To confirm the accuracy of the primary productivity estimates computed from the BGC-Argo floats, Johnson and Bif compared their float data to ship-based sampling data in two regions—the Hawaii Ocean Time-series (HOT) Station and the Bermuda Atlantic Time-series Station (BATS). The data acquired from the profiling floats near those regions gave similar results as monthly sampling from ships at these two sites over many years.

Johnson and Bif found that phytoplankton produced about 53 petagrams of carbon per year. This measurement was close to the 52 petagrams of carbon per year estimated by the most recent computer models. (One petagram is 1,000,000,000,000 kilograms, or one gigaton, and roughly the equivalent of the weight of 200 million elephants.) This study validated recent biogeochemical models and highlighted how robust these models have become.

High-resolution data from the BGC-Argo floats can help scientists better calibrate computer models to simulate productivity and ensure they represent real-world ocean conditions. These new data will allow scientists to better predict how marine primary productivity will respond to changes in the ocean by simulating different scenarios such as warming temperatures, shifts in phytoplankton growth, ocean acidification, and changes in nutrients. As more floats are deployed, Johnson and Bif expect the results of their study can be updated, decreasing uncertainties.

"We can't yet say if there is change in ocean primary productivity because our time series is too short," cautioned Bif. "But it establishes a current baseline from which we might detect future change. We hope that our estimates will be incorporated into models, including those used for satellites, to improve their performance."

But already, the wealth of data from these floats has proved invaluable in bettering our understanding of marine primary productivity and how Earth's climate is linked to the ocean.

The BGC-Argo floats have been instrumental to the Southern Ocean Carbon and Climate Observations and Modeling project (SOCCOM), an NSF-sponsored program focused on unlocking the mysteries of the Southern Ocean and determining its influence on climate. And last year marked the debut of the Global Ocean Biogeochemistry Array (GO-BGC Array) project, which will allow scientists to pursue fundamental questions about ocean ecosystems, observe ecosystem health and productivity, and monitor the elemental cycles of carbon, oxygen, and nitrogen in the ocean through all seasons of the year.

The information gathered by these collaborative global initiatives provides data essential to improving computer models of ocean fisheries and climate and monitoring and forecasting the effects of ocean warming and ocean acidification on marine life.

More information: Constraint on net primary productivity of the global ocean by Argo oxygen measurements, *Nature Geoscience* (2021). DOI: 10.1038/s41561-021-00807-z ,

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