Tracking carbon from the ocean surface into the depths

November 27 2018, by Kim Fulton-Bennett

This NOAA mooring off the coast of Washington carries a variety of carbon-related sensors. Fassbender would like to augment these with a new instrument she and other researchers are developing. Credit: Richard Feely, NOAA PMEL

As disastrous storms, floods, and fires become more common in the US and elsewhere, humans are just beginning to appreciate some of the impacts of global warming. But these impacts would be much worse if the ocean hadn't absorbed roughly 45 percent of the carbon dioxide humans have released since the beginning of the industrial revolution.

Although scientists have long known that the oceans are taking up a lot of carbon dioxide, the details of this process are still fuzzy. MBARI marine chemist Andrea Fassbender is trying to bring this process into focus by studying when, where, and how carbon moves between the atmosphere, upper ocean, and deep sea.

The basics of this carbon-cycling process are relatively well understood. When concentrations of carbon dioxide are higher in the atmosphere than in the surface waters of the ocean, carbon dioxide from the atmosphere will dissolve into the ocean. Some of this carbon dioxide is used by microscopic algae that incorporate carbon into their bodies as they grow and reproduce in the sunlit surface waters.

When the microscopic algae are consumed by animals and microbes, the carbon in their bodies is transferred to these organisms, which carry the carbon within their bodies or release it as waste into the surrounding water. Most of this carbon stays within about 100 meters of the sea surface, where it can easily return to the atmosphere, especially during the winter months, when the ocean waters are more churned up and the concentration of algae is lower.

However, a small but vitally important amount of this carbon sinks to deeper water, hundreds to thousands of meters below the sea surface. Some of this carbon is carried down into the depths in the form of marine snow—tiny flecks of dead algae and animals, waste material, and mucus. The farther down this carbon sinks, the longer it is likely to be stored within the ocean before coming in contact with the atmosphere again.

If the carbon sinks deep enough that it is unlikely to be carried back to the surface by winter mixing, it is considered to have been exported from the surface waters. If the carbon reaches depths at which it is unlikely to be carried back to the surface for hundreds of years or more, it is considered to be sequestered in the deep sea.

Oceanographers call this vertical carbon transport process the biological pump, and it is at the core of much of Fassbender's research. Although the overall concept of the biological pump is relatively simple, the details are extremely complicated and involve many interrelated chemical, biological, and physical processes, which vary from place to place and over time scales ranging from minutes to millennia. The biological pump is also an important component in the computer models that scientists use to predict global warming.

To fully understand the biological pump, oceanographers need to measure carbon in the ocean in all its various forms, including:

- Dissolved inorganic carbon—Carbon in the form of simple molecules dissolved in seawater, including carbon dioxide, carbonic acid, bicarbonate, and carbonate
- Particulate organic carbon—Carbon in the form of particles suspended in seawater that are larger than about one half micron (about one 90th of the diameter of a human hair) across
- Dissolved organic carbon"—Carbon in the form of very tiny particles (less than about one half micron across) and in dissolved organic compounds such as those released during the breakdown of dead animals, algae, and marine snow

Over the past year Fassbender has been actively involved in a number of research projects and publications focusing on carbon cycling in the ocean, with an emphasis on the biological carbon pump and the processes that control how the oceans absorb human-generated carbon. The following text describes some of this groundbreaking work.

The importance of seasons in the sea

In September 2018 Fassbender published a research paper in *Global Biogeochemical Cycles* that highlighted the importance of seasonal changes in carbon dioxide concentrations in different parts of the ocean.

Carbon dioxide gas is more soluble in cold water than warm water. As a result, seasonal warming of surface water during spring and summer increases the partial pressure of carbon dioxide gas in seawater (the partial pressure of a gas is directly related to its concentration). However, microscopic algae grow rapidly during spring and summer, consuming carbon dioxide. In some settings this counteracts the effect of warming waters.

Because carbon dioxide gas is more soluble in cold water, seasonal cooling of the ocean during winter causes the partial pressure of carbon dioxide gas to fall. In addition, turbulence from winter storms brings deep water, rich in carbon dioxide, up toward the surface during the winter, which works to counter the influence of cooler water.

These processes are common to all ocean regions, but their timing and magnitude can differ from place to place, resulting in unique seasonal cycles of carbon dioxide in the surface waters.

As a result of the processes described above, high-latitude ocean areas typically take up carbon dioxide from the atmosphere during the spring and summer months because of biological activity and release carbon dioxide to the atmosphere during the fall and winter as a result of deep mixing.

In low-latitude areas (closer to the equator), seasonal changes in water temperature largely dictate the surface ocean carbon dioxide variations. The result is that these areas tend to have higher partial pressures of carbon dioxide gas during summer and lower values in winter.

Fassbender's recent paper showed that human-generated carbon entering the oceans will alter these seasonal cycles, for example, by amplifying the seasonal extremes in a manner that is asymmetric. For example, some regions may exhibit larger growth in the summer maximum than in the winter minimum carbon dioxide level over time, causing an overall increase in the range of seasonal carbon dioxide variations.

This finding has important implications for how ocean carbon uptake may change in the future. Additionally, it suggests that scientists need to make observations spanning the entire year to accurately estimate long-term trends in surface ocean carbon dioxide gas content, because the trends during winter and summer may not be the same.

Getting field researchers and modelers together

Although scientists definitely need more winter carbon measurements in high-latitude areas of the ocean, there are many other ocean areas where the details of carbon cycling are not well understood. For example, the so-called "western boundary currents," such as the Gulf Stream in the northwestern Atlantic and the Kuroshio Current in the northwestern Pacific, are vitally important in transporting heat and carbon around the world ocean.

In Fall 2017, Fassbender co-organized a workshop at MBARI where field researchers and computer modeling experts could discuss carbon cycling in western boundary currents. The primary goals of the workshop were to get observational scientists and modelers together to compare their findings and to propose methods for filling in the gaps in scientists' understanding of these areas. They were particularly interested in collecting new data that will improve computer models of the ocean carbon cycle.

The workshop was co-sponsored by the US Climate Variability and

Predictability Program (CLIVAR) and the US Ocean Carbon and Biogeochemistry Program. After the workshop Fassbender and colleagues compiled and edited a report that summarizes key questions and recommendations related to carbon cycling in western boundary currents, which was published in August 2018 and presented to the US CLIVAR Inter-Agency Group in October 2018.

Improving satellite-based estimates of ocean carbon update

NASA is taking another approach to the challenge of global, year-round, ocean-carbon monitoring. At the same time as her recent paper came out in Global Biogeochemical Cycles, Fassbender and other MBARI researchers were involved in a large field experiment called Export Processes in the Ocean from Remote Sensing (EXPORTS), which was funded by NASA and the National Science Foundation.

During the summer 2018 EXPORTS research cruise, two large oceanographic research vessels and scientists from over 15 project teams and numerous US research institutions headed out to the North Pacific to collect data on the biological pump, using a wide array of state-of-the art laboratory instruments, autonomous sensors and robots, and satellites.

Satellites provide a long-term, global view of the ocean. However, satellite-based sensors, for the most part, only observe the uppermost layers of the ocean. Thus, a primary goal of the EXPORTS experiment was to tease out the details of the biological pump and their relation to optical properties in the water column (which can be observed by satellites). This meant digging into the physical, chemical, and biological processes involved in the biological pump.

By learning more about the mechanisms involved in the biological pump, the researchers hope to improve satellite-based estimates of how much carbon is exported to the deep sea. By comparing surface and subsurface observations in the North Pacific (as well as in the North Atlantic during a second experiment in 2020), NASA- and NSF-funded researchers will develop better methods for using satellite observations to study the marine carbon cycle.

During the EXPORTS experiment, Fassbender and her colleagues used robots, drifting ocean-chemistry floats, and other automated instruments to measure physical and biological processes in the Northeast Pacific, both at the surface and in the depths. The floats will stay at sea for years at a time, allowing Fassbender and her colleagues to estimate how much carbon is stored at different depths in the ocean and at different times of year. The team is just beginning to analyze the data from these instruments.

Ocean acidification in the Pacific Northwest

All of the projects listed above show the importance of collecting new data that shows how the carbon chemistry in the ocean changes throughout the year. But Fassbender is also interested in historical measurements and long-term trends in carbon chemistry, including the process of ocean acidification.

Ocean acidification occurs when carbon dioxide dissolves in the surface waters of the ocean, decreasing the concentration of carbonate ions, and causing the seawater to become more acidic. In July 2018, Fassbender and her colleagues published a paper in Earth System Science Data that focused on ocean acidification around Washington State—an area where the coastal shellfish industry may already be experiencing the impacts of changing ocean chemistry.

In preparing this paper, Fassbender and her co-authors collated and analyzed virtually all the existing and historical data on carbon chemistry for this region—roughly 100,000 measurements in all. This included historical data from "ocean atlases" as well as data from research ships, monitoring buoys, and field experiments.

This study was unique because it provided modern baseline information about the seasonal variability of numerous data on ocean carbon throughout the region—information that did not exist previously. These carbon data included surface seawater pH (acidity), carbon dioxide, dissolved inorganic carbon, total alkalinity, and the saturation state of aragonite (a mineral that makes up the shells of many marine organisms). The compiled data will serve as a valuable reference that will help scientists detect changes in the seawater chemistry in this region over coming years and decades.

In addition to providing a baseline, or sense of what is presently normal in the ocean waters of Washington State, the research highlighted major differences in carbon chemistry between the semi-enclosed waters of Puget Sound and the open Pacific Ocean. For example, the data showed that the seasonal range in surface seawater acidity within the Hood Canal is about 27 times larger than in the open ocean waters off Washington.

This finding indicates that algae and animals living in the protected waters of the Pacific Northwest are exposed to much larger seasonal changes in acidity (in addition to all other carbonate system variables evaluated) than those living in nearby open ocean waters.

The automated future of ocean-chemistry measurements

These days, Fassbender is continuing her work on carbon cycling on a number of fronts. During 2019, she hopes to develop a new carbon-chemistry instrument for use on ocean buoys and surface robots that can stay at sea for months at a time and traverse large areas of the ocean. Fassbender is working with several engineers at MBARI on this project, as well as researchers at the National Oceanic and Atmospheric Administration (NOAA) and the University of Hawaii.

One of their goals is to install the new instrument on NOAA's climate-monitoring buoys. Existing instruments on these buoys measure carbon dioxide in the atmosphere and in the surface ocean, and some buoys are also outfitted with pH sensors. The new instrument would measure dissolved inorganic carbon in addition to carbon dioxide, providing scientists with new information about ocean carbon uptake and changes in ocean chemistry.

On a global level, Fassbender notes that, over the last 10 years, a concerted effort to expand and compile year-round observations of surface ocean carbon dioxide observations has already given scientists a greater understanding of how much carbon moves between the ocean and the atmosphere each year. She hopes that by developing new instruments and distributing them on platforms around the world, she and her fellow researchers will gain valuable information about the finer details of carbon cycling in remote ocean regions. This in turn, will help improve the critical computer models that scientists use to predict future climate on Earth.

More information: Andrea J. Fassbender et al. Seasonal Asymmetry in the Evolution of Surface Ocean p CO2 and pH Thermodynamic Drivers and the Influence on Sea-Air CO_2 Flux, *Global Biogeochemical Cycles* (2018). DOI: 10.1029/2017GB005855

Provided by Monterey Bay Aquarium Research Institute