First controlled experiments on ocean acidification in the deep sea

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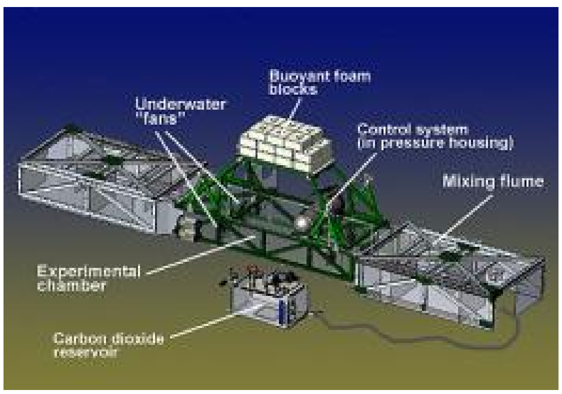
This photo shows the 10-meter-long FOCE system on the seafloor in Monterey Bay. In the center of the image, you can see the clear plastic cover for the chamber where deep-sea animals are exposed to acidified seawater. Credit: © 2011 MBARI

(PhysOrg.com) -- After six years of design and testing, MBARI scientists have a sophisticated new tool for studying the effects of ocean acidification on deep-sea animals. This complex system, the Free-Ocean Carbon Enrichment (FOCE) experiment, is the only experiment in the world that allows researchers to study ocean-acidification impacts on deep-sea animals in their native habitat, using free-flowing seawater.

The idea behind FOCE is relatively simple—to create a semi-enclosed test area on the seafloor where the seawater's pH (an indicator of acidity) can be precisely controlled for weeks or months at a time. Small seafloor animals are placed in the test chamber, where their behavior and physiological responses can be monitored. The idea is to observe the behavior of seafloor animals without subjecting them to the stresses of being removed from the deep sea and living in a laboratory on shore.

MBARI marine chemist Peter Brewer came up with the idea for FOCE in about 2003. Brewer had read about experiments on land, in which terrestrial plants were exposed to elevated levels of carbon dioxide for long periods of time. Such Free-Air Carbon dioxide Enrichment (FACE) experiments use a series of carbon-dioxide emitters arranged in a large ring, up to 30 meters (100 feet) across. Carbon dioxide is released from emitters from the windward side of the ring. The result is that plants within the ring are exposed to consistently elevated concentrations of carbon dioxide, regardless of the wind speed or direction.



This diagram shows some of the main components of the deep-water FOCE system. The foam blocks are in different places on the current version of the experiment. Credit: © 2011 MBARI

Brewer decided to try similar experiments underwater. His initial design looked a bird cage, with pipes emitting acidified seawater from the up-current side of the cage. However, after a few tank and ocean tests, Brewer's team discovered that it took several minutes for the acidified seawater to come to chemical equilibrium with the surrounding seawater. By this time, the acidified seawater had been carried hundreds of meters down-current of the cage.

Faced with this challenge, the researchers went back to the drawing board and developed an entirely new system—a 10-meter-long, rectangular flume made out of clear plastic. Seawater mixed with carbon dioxide is released at one end of the flume and is pulled through the flume by small impellers. Seawater can be introduced from either end of the flume, depending on the direction of the prevailing currents. The acidified seawater flows slowly through a series of baffles, allowing it to completely mix with the surrounding seawater before it enters a central experimental chamber in the center of the flume.

Within the experimental chamber, researchers can place the seafloor animals whose response to ocean acidification is to be tested. Around the edges of the pen are sensors to measure pH, water temperature, salinity, and currents, as well as cameras to record the activity of animals within the chamber.

For the past three years, a team of engineers and scientists led by William Kirkwood have been testing and refining the deep-sea FOCE system. Along the way they had to solve a number of technical challenges. For example, none of the commercial pH sensors they tried would give reliable data when deployed on FOCE in the deep sea for months at a time. So the MBARI engineers had to redesign and replace the electronics within the pH sensor. They also had to develop a computer-controlled system that would mix liquid carbon dioxide with seawater and feed carefully controlled amounts into either end of the flume. By summer 2011, they had gotten the system to the point where they could keep the pH inside the chamber relatively constant (to within 0.1 pH unit).

The FOCE experiment is currently hooked up to the MARS cabled observatory, about 25 kilometers west-northwest of Monterey and 900 meters below the ocean surface. The observatory supplies power to the experiment's motors, lights, cameras, and sensors. The observatory's fiber-optic data link to MBARI allows researchers to monitor the instruments and video cameras and to control the FOCE experiment in real time from their offices on shore.

In September and October 2011, MBARI marine biologist Jim Barry conducted the first biology experiments using the FOCE flume. To test the effects of acidification on a type of common deep-sea urchin, Strongylocentrotus fragilis, Barry devised an ingenious system for documenting changes in the urchin's behavior.

Barry's team prepared for the experiment by using MBARI's remotely operated vehicles (ROVs) to gather about 60 urchins from an area near the MARS observatory. About 30 of these urchins were placed in a mesh bag in the experimental chamber of the FOCE flume. Another 30 urchins were placed in a bag in a similar chamber nearby, which was exposed to normal seawater. Being held in mesh bags did not bother the urchins because they often gather in dense aggregations on the seafloor.

Within each experimental chamber, the ROV placed a plastic box containing five urchin "raceways" (see photo). Every week or so, Barry's team used an ROV to remove five urchins from the bag in each chamber. They then placed one urchin at the end of each of the five raceways. At the other end of the raceways, the researchers placed the urchins' favorite food—a mass of decomposing kelp.

After placing the urchins in the raceways, both in the FOCE experimental chamber and in the chamber containing normal seawater, the researchers used video cameras to observe how rapidly each urchin moved toward its food. After each week-long "race," the urchins were removed from the raceways and taken to the laboratory, where the researchers looked for physiological effects on the animals. After the urchins were removed, a new group of urchins was placed in the raceways, and the experiment was repeated.

Seawater in the deep waters of Monterey Bay is often slightly basic, with a pH of about 7.6 (neutral freshwater has a pH of 7.0). Brewer and other researchers have estimated that by the year 2100, the average pH of surface waters across the world ocean could drop by as much as 0.4 pH units. Eventually, that pH reduction will work its way down into the deep sea. During the recent experiments, Barry's team tested their urchins in seawater that had a pH as low as 7.1.

The initial results were surprising. Barry said, "Based on previous laboratory experiments, I expected the urchins to just shut down. But even after three weeks in the chamber, they were running back and forth in the raceways like little ping-pong balls."

Over the next few months, Barry's team will analyze videos of urchins in both acidified and normal seawater and apply statistics to look for differences in their activity levels—how fast and how far they moved. Barry suspects that this particular species of urchin is relatively tolerant to somewhat acidic conditions, but will likely show somewhat less activity in acidified seawater than in normal seawater.

Having gotten the deep-sea FOCE experiment up and running, MBARI engineers have now turned their attention to several similar projects to measure the effects of ocean acidification in shallow water. One such system is already in operation at Heron Island in Australia. Closer to home, the team is designing a system to be placed just outside the kelp beds in at Hopkins Marine Station in Pacific Grove. They are also working with researchers planning similar experiments on the east coast of the United States, in France, England, and China, and even under the Antarctic ice.

With the completion of initial deep-water experiments in Monterey Bay, and the development of several shallow-water systems, FOCE has become a yet another example of a long-term MBARI engineering effort that is benefiting ocean researchers around the world.

Provided by Monterey Bay Aquarium Institute