Station ALOHA Stands Sentinel

CHRISTOPHER PALA

Samples collected near this remote buoy provide an exquisitely detailed record of the ocean’s changing condition during the past 21 years.

With one hand on the wheel and the other on the throttle, Second Mate Kim Krueger, her long blond hair tied into a ponytail, slows the Kilo Moana to a crawl. A screen shows the boat inching toward the holy grail of ocean acidification, Station ALOHA, which stands for “a long-term oligotrophic habitat assessment”.

But there is no there, there: it’s simply a point in the open ocean at the center of a circle, six nautical miles across, where scientists have been measuring 40 core parameters for two decades. A buoy floating at the eastern limit of the circle is the only marker for the station. The ship glides to the center of the circle, or 22° 45’ north and 158° west, which is 115 kilometers (km) north of the Hawaiian island of Oahu. Krueger stops the electric motors and switches on the Kongsberg of the circle, or 22° 45’ west, which is 115 kilometers (km) north of the Hawaiian island of Oahu. Krueger stops the electric motors and switches on the Kongsberg dynamic positioning computer that will keep the ship within half a meter (m) of its position over the ocean bottom 4740 m below. On the afterdeck, Vic Polidoro—a tall, lanky marine technician with wraparound dark glasses, a red life jacket, and a white hard hat—holds a rope stabilizing the yellow tubing frame called a rosette. It carries 24 three-foot-long gray bottles that are open on both ends. Working seamlessly with the crane operator, he eases the package into the ocean at the end of a cable that contains a wire connected to a half-dozen sensors. After the splash, the package is lowered at a speed of 60 meters per minute to a point just above the ocean floor.

In a cubicle a few yards away, Fernando Santiago-Mandujano, a University of Hawaii (UH) physical oceanographer, peers at a computer screen as the rosette descends, noting the densities of the different layers of water it traverses. An hour and 20 minutes later, the rosette reaches the bottom, and the first bottle is closed, locking in water that last saw the surface 1000 years ago. As the rosette is slowly winched up, Santiago-Mandujano closes the other 23 bottles at different depths. The operation will be performed 20 times on this four-day cruise, though most of the time the rosette only goes down about 1000 m.

Once the bottles have been lifted out of the sea and onto Kilo Moana’s spacious afterdeck, Dan Sadler, a UH research associate, takes out less than a liter of water and measures its pH, dissolved inorganic carbon, and alkalinity.

More than one dozen ships have taken turns coming to this spot every month, measuring the different characteristics of the ocean at various depths, since the research vessel Moana Wave took the first samples in October 1988. Station ALOHA was chosen because it sits near the center of the world’s biggest and most stable body of water and is just a day’s sail from Honolulu. A sister site, where temperature and salinity data also have been collected since 1988 under the same program, is 86 km south of Bermuda.

Since the first cruise, the program has “just gotten bigger and bigger,” recalls Jef Snyder, a burly UH electronics technician who was on that maiden voyage. So big, in fact, that last year Kilo Moana served as the platform for the first attempt to use a wave pump to remove CO2 from the atmosphere and sequester it on the seafloor.

“When the program was founded, there was no clear understanding of just how much of the CO2 emitted into the atmosphere had been absorbed by the ocean,” Sadler says. “The atmospheric record could only account for about half of it, and that led us to look more closely at the uptake by the ocean. The idea was to investigate the process by starting a detailed time series that would complement the data from the transects that were being made by oceanographic vessels.” This would allow detailed examination of physical and biogeochemical processes that underlie how the ocean absorbs—or emits—CO2.

As the speed and extent of the ocean’s acidification became apparent, Station ALOHA’s proximity to the Mauna Loa Observatory has increased its value, says David M. Karl, a UH professor of oceanography. (Karl participated in the founding of Station ALOHA and is a cofounder of the Hawaii Ocean Time-series project.) Mauna Loa, located a mere 400 km away on Hawaii’s Big Island, is home to the so-called Keeling Curve, the world’s longest time series of CO2 in the atmosphere; the Keeling Curve was started in 1958.

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A dangerous trajectory

The ALOHA time series was started none too soon, according to Ken Caldeira of the Carnegie Institution’s Department of Global Ecology, located at Stanford University. Although volcanoes naturally emit about half a billion tons of CO2 per year—most of it naturally absorbed by the shells of marine organisms via the reaction with basalt—the small, isolated Hawaiian biota are at increasing risk. As the atmosphere becomes more acidic, the shells of corals and fish could become more easily dissolved.

“With the change in ocean chemistry that we have observed in the past 21 years, the extent to which such a change might affect the Hawaiian and global biota is now clear,” says Caldeira. This, he believes, will be a useful warning for researchers in the future.

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organisms—humans are now releasing 30 billion tons from burning oil and coal, and another 7 million tons from deforestation, he says. One-third of the total CO₂ produced since the start of the Industrial Revolution (circa 1800) has now been absorbed into the sea, Christopher L. Sabine and others concluded in a 2004 study (Science, DOI 10.1126/science.1097403). As a result, the oceans’ average pH (it varies depending on depth and location) has fallen from 8.2 to 8.08, which, because it’s a logarithmic scale, is a 30% decrease. And about one-fifth of that reduction happened in the 20 years since the ALOHA measurements began.

The effects are already being felt. “The problem began when we reached 320 ppm [parts per million] in the early 1980s,” says Ove Hoegh-Guldberg, a coral biologist at the University of Queensland (Australia). “In the Great Barrier Reef, the calcification rate has slowed 15% since 1990.” Because cold waters absorb more atmospheric CO₂ than warm ones, the sharpest drop in pH has been in the polar oceans. “The amount of krill in the Southern Ocean is 10% today what it was 30 years ago,” he adds, though acidification is only one of several possible culprits.

Many researchers believe that by mid-century, atmospheric CO₂, which is now at 386 ppm, will reach 560 ppm—double what it was in 1800. At that point, the thinking goes, the shells of marine organisms will start dissolving in some parts of the ocean. A March 2009 paper (Geophys. Res. Lett. DOI 10.1029/2008GL036282) asserts that this will happen just about everywhere by 2050 if the effects of global warming are added to the equation. For instance, even short periods of exceptionally warm water—which have become increasingly frequent—cause corals to reject the algae with which they live symbiotically; as a result, the corals turn white and often die, a phenomenon called coral bleaching. “[By] the time atmospheric partial pressure of CO₂ will reach 560 ppm, all coral reefs will cease to grow and start to dissolve,” the authors assert in the paper’s abstract.

In a December 2007 paper (Science, DOI 10.1126/science.1152509), lead author Hoegh-Guldberg accounts for more factors, such as bleaching and competition, and concludes that the decline will start even earlier, in about 25 years. That’s when he predicts the CO₂ in the atmosphere will reach 450 ppm.

“Very few corals will survive this century, and they will be in very bad shape,” predicts Caldeira. “Acidification’s effect on corals is easy to predict because they’re the architecture of the ecosystem,” he adds. “We also know that acidification makes it harder for shellfish to reproduce and contributes to asphyxiation of fish and squid, but it’s much harder to predict what effect that will have on the whole marine ecosystem.”

That’s because the past, it turns out, provides few insights into the future: tomorrow’s ocean will be “aqua incognita”.

Gregory Ravizza, a geologist at UH, says that 55 million years ago, the atmosphere took in 2000 billion tons of CO₂ over 10,000 years, warming the planet by 5 °C. This period is being intensely studied because it brought a rate of global warming similar to the present one.

The good news, he says, is that this ancient warming period brought no major mass extinction like the one that knocked out the dinosaurs 65 million years ago. The bad news: “The world then was a much warmer place and had been for a long time,” he says. “The huge ice sheets that dominate the poles were absent, and earth’s biosphere was radically different. The coral reef ecosystems we know did not begin to develop until after 34 million years ago, when a major ice sheet grew on Antarctica.”

For the past 700,000 years at least, we’ve had a glaciation about every 100,000 years, with ice sheets covering the temperate zones for thousands of years and then melting back to preindustrial conditions. “Industrialization happened at the hottest point of the cycle, which means that life on earth today is much less prepared for more heat than it was 55 million years ago,” Ravizza says.

The problem isn’t the atmospheric CO₂ alone: until the appearance of the Antarctic ice, CO₂ levels in the air may have reached 2000 ppm, yet the ocean at that time appears to have been rich in fauna and flora, albeit quite different from today’s. “The climate had been quite stable for tens of millions of years, so life had ample time to adapt,” says Ravizza.

The big difference now is that we’re emitting more CO₂ than ever before and at a much faster rate, scientists agree. “We have about 5000 billion tons of fossil fuels that we could burn in the next few centuries, and if we do, we’ll add more CO₂ to the atmosphere than was released in more than 5000 million years ago,” says Richard Zeebe, a UH oceanographer. “The ocean and the sediments are the main buffers, and their ability to absorb CO₂ is very slow.” In other words, we are emitting CO₂ 10,000 times faster than the planet can absorb it.

Hoegh-Guldberg isn’t optimistic. “The rate of change now is 1000 times faster than in all of the ice ages that we’ve had in the past million years,” he says. The geological record shows oscillations from 280 ppm down to 200 ppm in each 10,000-year cycle. “Sure, today we have mussels and oysters that live in much more acidic water in lakes, but they’ve had millions of years to adapt.”

Can anything be done?

Karl, who directs the Center for Microbial Oceanography: Research and Education, participated in the first paper to scrutinize two decades of acidification data from top to bottom at Station ALOHA. The paper published in Proceedings of the National Academy of Sciences on July 28 (DOI 10.1073/pnas.09044106), describes evidence that the likelihood of our huge oceans may be their smallest denizens.

“Looking at the pH in 17 different layers of water, we found that at certain depths, the rate of acidification was elevated: at 250 m, for instance, the rate was about double what it was at the surface,” lead author John Dore of Montana State University Bozeman says. “We know the water in that layer originated at the surface about 1300 km northwest of ALOHA and that it takes about five years to get to us, but we’re not sure why it’s been getting acidic so much faster.”

Dore thinks that the growth of microscopic algae in the region has increased in the past decade. As the algae die, their carbon-rich corpses sink to the bottom; along the way, most are eaten by bacteria that exhale CO₂ back into the water, increasing its acidity. If the algae sink fast enough, that CO₂ ends up far below the surface. This is a form of carbon sequestration, because that water may not return to
the surface—where it will send the CO₂ back into the atmosphere—for 1000 years.

"Alternatively, this could be a purely physical phenomenon," Dore says. "Acidification may be more rapid up north where this water leaves the surface, and ocean circulation transports that signal to our station at depth."

Another surprise, he adds, was that for the years 1999-2003, the surface ocean at Station ALOHA actually saw its pH rise instead of drop. Here too, Dore suspects that biology was involved. Blue-green microscopic algae that are able to fix nitrogen may have bloomed because phosphate increased in the water.

A two-year period of unusual mixing immediately preceding the pH rise may have brought this phosphate from deep water to the surface, enhancing the removal of CO₂ by the algae through photosynthesis and causing the pH anomaly. "We may be seeing a natural version of ocean fertilization in action," says Dore. "It raises the possibility that we might be able to slow ocean acidification, at least in some places—but we need to understand the process a lot better than we do."

A take-home lesson of the 20-year study is that the acidification process is not just a matter of chemistry. "It looks like biology and ocean circulation are going to play bigger roles in the acidification process than we thought," he says.

Karl sees two ways in which we could harness the power of algae and bacteria to send carbon to the sea bottom and slow the acidification of the surface waters.

"If we can speed up the system by a factor of three, then we can send 20 billion tons of CO₂ to the bottom instead of the six that goes down naturally," he says. "That’s nearly half the 37 billion tons we’re producing."

"One way to do it is to fertilize the ocean, for instance with iron, to cause an algal bloom," he explains. But the repercussions of that step are unknown, and it’s forbidden by the 1972 London Convention on marine dumping. "The other way is to pump up three times as much deep water, [which is] rich in phosphate and nitrogen, as nature does," he says. As these nutrients reach the surface, algae will bloom, die, and sink to the bottom.

Last year, just such an apparatus was tested on Kilo Moana. A 300-m-long plastic tube was connected to a buoy that had a wave-activated valve at the bottom; this setup was designed to pump water to the surface and create a bloom. Three prototypes were tested, but the plastic tube shredded, so the experiment failed to generate a measurable biological response. The attempt was filmed by the Discovery Channel for its Hungry Ocean series.

"Now, we’re looking for funding to test a gasoline-powered pump on a stronger 300-m tube," Karl says. "It should bring up much more water than the other system."

He adds, "The clock is ticking, and it’s unacceptable to sit idle because the stakes are very high. We need to use our knowledge of microbial processes in the oceans to offer potential solutions."