Swimming in the rain

Novel untethered vehicle catches 'marine snow' falling through the sea

Twilight zones, witch hunts, and crossbows usually don't find their way into tales about new oceanographic instruments. This story isn't typical, but it does start in the usual way, with oceanographers striving to coax secrets out of inscrutable oceans.

In this case, scientists were investigating a fundamental but still mysterious process: How do tiny particles—comprised of dead phytoplankton, dead zooplankton, and zooplankton feces—sink from sunlit surface waters where they are produced, through the ocean's "twilight zone" where light penetrates weakly, and into the dark abyss? The rain of this so-called "marine snow" provides the food supply for organisms in the depths. It also has a major impact on Earth's climate by transporting carbon to the deep sea and preventing it from re-entering the atmosphere as a greenhouse gas. (See "A journey to the ocean's twilight zone," page 42.)

To collect the rain of particles, scientists built devices called sediment traps—cones or tubes that hang beneath buoys or float up from seafloor anchors. That, said Ken Buesseler, a biogeochemist at Woods Hole Oceanographic Institution (WHOI), "is like putting out a rain gauge in a hurricane."

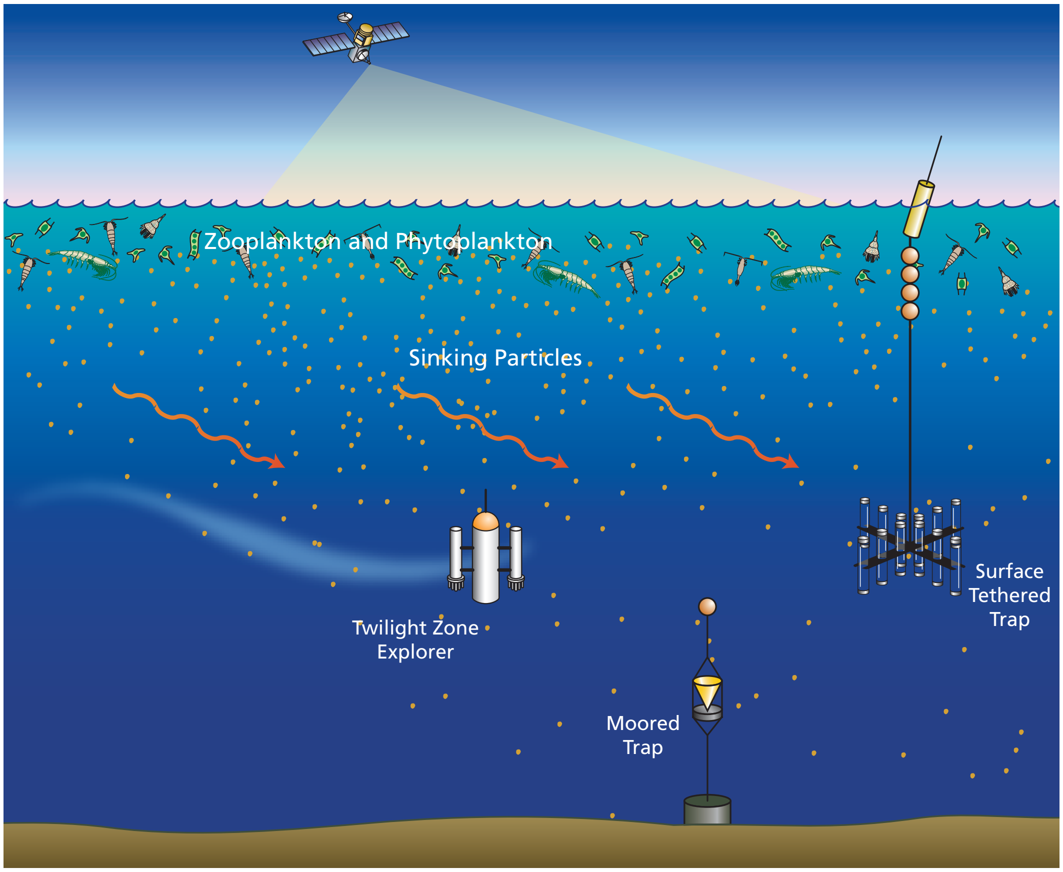
Here's the problem: While particles descend slowly, perhaps 10 to a few hundred meters per day, they are swept sideways by ocean currents traveling at 3 to 27 nautical miles (5 to 50 kilometers) per day. (Imagine a balloon carried away by proportionally high winds from the top of the Empire State Building; it would be in Pennsylvania before it landed on a sidewalk.) "Particles do not fall vertically but 'sink' nearly horizontally, pushed by ocean currents," explained Dave Siegel, an oceanographer at the University of California, Santa Barbara.

In the late 1980s, Buesseler developed a technique to track marine snow by using thorium-234, a naturally occurring radioactive element in seawater that sticks to the particles. In a provocative 1991 paper in *Nature*, he pointed out that his chemical measurements of falling particles did not jibe with those measured by sediment traps.

"That got me into a lot of trouble early in my career," said Buesseler, who is now chair of the Marine Chemistry and Geochemistry Department at WHOI. "I was a junior scientist and was yelled at by some very important scientists for saying that their methods weren't working well. Some said I was off on a witch hunt."

Mark Gall, NIWA

▲ WHOI biogeochemist Ken Buesseler (blue hat) and engineer Jim Valdes (yellow hat) deploy a Neutrally Buoyant Sediment Trap for a three-day mission in the depths of the North Pacific Ocean in 2005. The instrument collects "marine snow," the falling particles of dead phytoplankton and zooplankton feces that sink from sunlit waters into the ocean's "twilight zone."



Jack Cook, WHOI

Particles sinking from sunlit surface waters through the ocean's dimly lit twilight zone are swept sideways by currents. Conventional moored or tethered traps designed to catch the particles are like "rain gauges in hurricanes," said WHOI geochemist Ken Buesseler. He and engineer Jim Valdes are designing a new-generation neutrally buoyant untethered vehicle called the Twilight Zone Explorer, which is swept along with the currents. It surfaces periodically to relay data via satellite.

For several years, Buesseler couldn't get peer-reviewed funding to go beyond the "classic 'put-out-a-coffee-cup-and-see-what-falls-in' sediment trap methods," he said. "It took a little while from putting out the idea to getting some movement."

In 1994, Buesseler, WHOI physical oceanographer Jim Price, and WHOI engineer Jim Valdes received a Cecil H. and Ida M. Green Technology Innovation Award from WHOI, which provided seed money to try a new idea. They wanted to cut the cord and go with the flow—to build a particle collector that would not be attached to a mooring. Instead, it would sink to a programmed depth and remain neutrally buoyant—that is, neither rise nor sink—at a depth between 450 and 1,500 feet (150 to 500 meters) in the twilight zone. It would be swept along with the currents for several days, collecting particles, and then return to the surface.

"Think of a hot air balloon being carried by the wind with a rain gauge attached," Buesseler said.

The team piggybacked on new technology by attaching particle-collecting tubes to floats being developed for physical oceanographers to measure currents, water temperature, and salinity. The floats pump oil into and out of an internal bladder to adjust their volume and regulate their buoyancy.

"The key to the whole endeavor," Valdes said, "is to accurately predict what the instrument will weigh in seawater." Extremely accurately.

"It may sound simple, but it is quite a balancing act to get these Neutrally Buoyant Sediment Traps (or NBSTs) to sink to the exact depth we need," Buesseler said. "If we are off in our weight calculations by the weight of a ¼-inch washer, it can send the instrument down another 100 meters, or more than 300 feet. Imagine if you were swimming and having a few coins in your pocket meant the difference between sinking or swimming."

Over the years, more evidence of the limitations in conventional traps mounted. As Buesseler's most vigorous opponents left the field or died, support for new traps rose. The researchers' work on a prototype NBST earned them a grant from the National Science Foundation.

The team spent more than seven years designing the NBST—testing different instrument configurations in pressurized tanks; precisely estimating how pressure would compress materials in the depths and how this would shift weights; adding or removing items; making tradeoffs; trimming weight by adding small bottles of lead shot; changing glass tubes to aluminum because they were less fragile (though heavier); estimating the density of the water the instrument would travel through; calculating and recalculating the weight of every adjustment.

"It's all in the details," Valdes said. "But when you put an instrument over the side and it's untethered, it has to work the first time, every time, or you'll never get it back."

That's what happened on a 2003 test. The team tracked the loss to a color-coding error in a resistor. "A small error in a 2-cent part resulted in the loss of the instrument," Valdes said.

So with trepidation, Valdes sent seven NBSTs overboard in 2004 in the Pacific Ocean near Hawaii. They sank, gauged and maintained their depths using a microprocessor that measures water temperatures and pressure, collected particles, and then surfaced a few days later and 10 to 20 nautical miles away. Here's where the crossbow comes in. (See article on next page.)

On their first scientific mission, "seven NBSTs went in the water and all seven came back with their precious cargo—a first in ocean sciences history," Buesseler said. A year later, the NBSTs proved their mettle again on another expedition in the northwest Pacific.

Based on their success, the National Science Foundation in July awarded Buesseler and Valdes a $2 million grant to build the next generation, which they call the Twilight Zone Explorer, or TZEX. It would be able to stay out for longer missions—initially for one month—so that scientists can sample particle fluxes over longer time periods without returning to sea.

The researchers are looking at a rotating carousel in TZEX that can open and close and segregate previous samples. They are also contemplating how to keep track of TZEXs that can be swept far and wide the longer they are at sea.

The team also wants to add more sensors to measure chlorophyll and light levels in the oceans, for example. Every addition requires recalculation of the instrument's buoyancy.

Finally, they seek a solution for what Buesseler called "the bane of particle trapping"—zooplankton that swim into sampling tubes in pursuit of food. Scientists call them "swimmers."

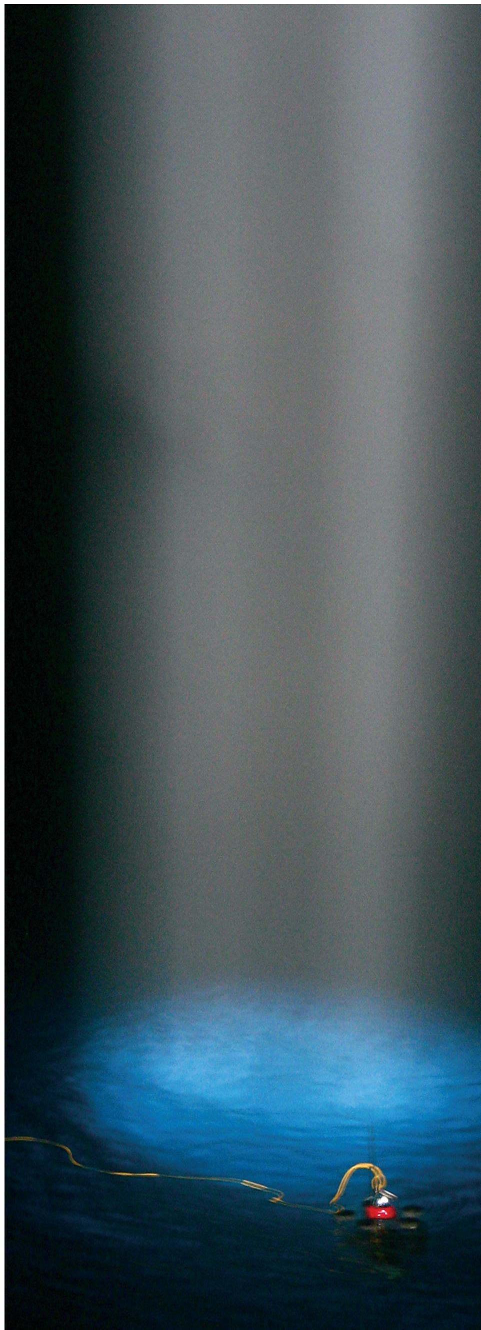
"Collection tubes are like pie plates for all the critters out there that want a free meal," Valdes explained. Swimmers sometimes "eat my data," Buesseler said, and other times mistakenly become data.

"They're carbon, too," Valdes said, and it's difficult to distinguish whether swimmers died and sank, or died after pursuing food into the trap. Researchers spend tedious hours peering through microscopes, picking out swimmers from their samples with tweezers.

"There's a whole art—or Zen—of swimmer picking," Buesseler said, and it creates bias depending on who is doing the picking. Valdes is designing a device with 5-inch rotating dimpled balls that look like golf balls, which shunt smaller particles into bottles while preventing entry by larger swimmers.

"There are going to be challenges," Valdes said, "and it's not clear where it'll take us. We have a lot of concepts that we need to test in the lab and in open water, but we certainly have a destination in mind."

—Lonny Lippsett



R/V Roger Revelle crew

Have crossbow, will travel to track down ocean devices

When a Neutrally Buoyant Sediment Trap surfaces after a three- to five-day particle-collecting mission in the ocean depths, "only its orange cap is visible, about the size of a 2-liter bottle of Coke," said Jim Valdes, an engineer at WHOI, "a proverbial needle in a haystack."

"Couple this with a 6- to 10-foot swell and a wind of 35 or more knots producing whitecaps and blowing water, and you'll have some idea of how daunting a task finding an NBST can be," he said.

"The engineers at Woods Hole, with years of seagoing experience, designed a number of recovery aids into our NBSTs," Valdes said. "They knew that locating an NBST after deployment would not be trivial."

Scientists use an Acoustic Doppler Current Profiler onboard ship to monitor the speed and direction of subsurface currents that have carried the NBST. They estimate where the NBST will surface and steer the ship in that direction.

At the surface, the NBST turns on an internal Global Positioning System receiver and then sends its position to the ship via a series of satellite relays. The NBST also transmits a radio signal that a sophisticated Radio Direction Finding receiver on the ship picks up at a range of 5 to 7 nautical miles (9 to 13 kilometers).

During daylight, it's difficult to see small submerged objects in the water, so recoveries are made at night, when the crew can spot an NBST's flashing light up to 2 nautical miles (3.7 kilometers) away in good conditions. The crew shines a spotlight on it (left) and maneuvers the big research ship within yards of the NBST. The scientists use a crossbow (bottom left) to shoot a line with a grappling hook to reel in the instrument.

"So the crossbow became standard equipment," Valdes said. "But it's not a carry-on item," he said with a smile. "You ship them in advance, so you don't get stopped at Customs."

—Lonny Lippsett

Carolyn Walker, BBSR