EARTH SCIENCE

'Real-Time' Oceanography Adapts to Sea Changes

For a month last summer, a flotilla of robotic submersibles, sensors, acoustic transmitters and receivers, and other instruments probed the Haro Strait, a narrow, freighter-clogged channel between Vancouver Island and Washington state. The immediate goal of this experiment was to trace a so-called tidal front in the strait—an invisible barrier separating fresh water discharged by rivers from the open ocean's salt water—and to learn how the two water masses mix across the front. But the Haro Strait experiment was also a test of an approach that some researchers call a new paradigm for working in the ocean.

Oceanographic experiments have traditionally been like space probes: vast data-collecting expeditions with limited flexibility. Ship schedules are usually too rigid and data analysis too slow for oceanographers to modify their plans partway through an experiment to follow a lead suggested by new data. "Normally, we take our measurements and are long gone by the time we're able to analyze the data," explains Henrik Schmidt, an ocean engineer at the Massachusetts Institute of Technology (MIT). The Haro Strait project was one of the first large-scale scientific studies to employ "adaptive sampling," or "real-time oceanography." This approach allows oceanographers to change their plans in midstream—or, in this case, midocean.

The key was a feedback loop between the instruments positioned in the strait and a data-analysis effort onshore. A computer simulation of the tidal front, developed by Allan Robinson and his Harvard University colleagues, crunched through each day's results and made forecasts about where the front, and hence the "action," would be found in the strait the next day. And two robots called autonomous underwater vehicles, or AUVs (see sidebar), provided a rapid-response capability: They could be reprogrammed each evening to explore new parts of the strait. "As the AUVs started turning in data, we could send them to places where the most noteworthy things were happening," says Schmidt,

Robotic Subs for Rapid-Response Science

The Haro Strait experiment tested a new method of doing oceanography in "real time" (see main story)—and a versatile new tool for collecting the data. Along with an array of buoys and a ship, the experiment relied on two robotic submersibles known as autonomous underwater vehicles (AUVs).

MIT/SEA GRANT AUV LABORATORY

AUVing a look. As conditions in the ocean change, scientists can reprogram autonomous underwater vehicles to explore new regions.

No more than a few meters long, capable of probing deep-ocean waters while laden with acoustic, chemical, and thermal sensing equipment, AUVs have already made forays into the Arctic Ocean, the seas off Antarctica, and waters over the Juan de Fuca Ridge near Washington state. Most recently, AUVs searched for the elusive giant squid in an undersea canyon off New Zealand.

The Haro Strait experiment established several milestones. It was the first to use AUVs in a so-called "adaptive sampling" mode, which involved reprogramming the vehicles based on computer analysis of each day's data. It also marked the first time that two AUVs had worked together side by side on a scientific mission.

As such, the experiment was a step toward ocean engineers' audacious vision for these craft: releasing fleets of them to explore remote parts of the sea. Explains James Bellingham, who runs the Massachusetts Institute of Technology's (MIT's) Sea Grant AUV Laboratory (a leader in AUV development), "It's a big ocean, and ships don't sample it that well." Large oceanographic vessels can cost $10,000 or more per day to operate and often must be booked years in advance. In contrast, "if we hear about an undersea volcanic eruption, or some other rarely seen event, we can take our AUVs out right away on a small fishing boat," says Bellingham.

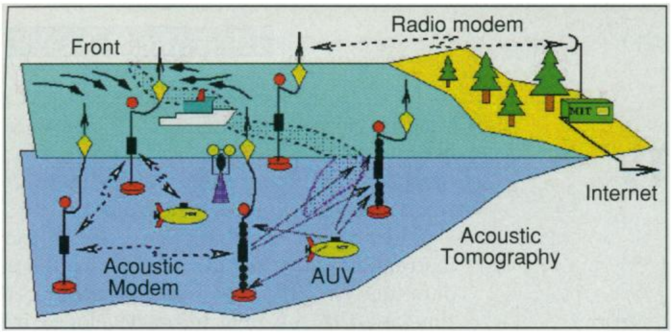
AUVs can also be dispatched to risky environments—beneath the polar ice sheets or inside murky, underwater caves. "At $16,000 per vehicle, we can afford to lose a couple, and even plan on it, for a good cause," Bellingham notes.

Bellingham and his colleagues still need to develop an effective method of "docking" the AUVs: programming them to park themselves at an unattended mooring, where they can recharge their batteries, dump some data, and upload new commands. "Docking is like landing an airplane," says Bellingham. "If you can't land it, it's not much good." For now, AUVs must surface and wait to be retrieved by boats.

In spring 1996 tests in the shallow, calm waters of Buzzards Bay, Massachusetts, AUVs successfully followed acoustic homing signals to a docking site. But Bellingham is eager to try this technology in the open ocean. That test should come in January or February 1998, in an experiment in the Labrador Sea that will combine remote operation, docking and undocking, direct acoustic communications with the vehicles, and real-time adaptive programming. Three AUVs and two propellerless "glider" vehicles that ride the sea currents will independently explore a region where salty surface waters lose so much heat that they become dense enough to sink into the abyss, generating much of the cold, salty water that blankets the ocean floor.

"The Labrador Sea is one of the few regions in the ocean where water plummets to great depths," explains MIT oceanographer John Marshall. "We're trying to understand exactly how the water sinks and the implications this process holds for the oceans, atmosphere, and climate in general." Bellingham adds that "this whole complicated experiment will be done completely with robots. We'll leave the vehicles there, and by the time the real action is occurring, we'll be back here in Cambridge looking at the data sent via satellite."

Even if the Labrador Sea experiment succeeds, it won't spell the end for ships, submersibles with human crews, and other research vehicles, says Bellingham: "Rather than trying to eliminate such vessels, we're trying to make them more productive." Dan Fornari, who oversees submarine and remotely operated vehicle (ROV) programs at the Woods Hole Oceanographic Institution, agrees. "People have suggested that ROVs will replace submersibles, and that AUVs will replace ROVs, but that's not likely to happen," he says. "It's the synergy of these systems working together that will revolutionize the way deep-ocean science is conducted in the next century." –S.N.



SOURCE: AUV LABORATORY

Flexible flotilla. Moorings, a buoy, robotic submersibles, and a surface ship relay data on the front between fresh and salt water to shore.

who was one of the lead investigators.

Although final results aren't in, the researchers say this strategy has yielded the most refined view yet of how water masses interact in the Haro Strait front. "It was [also] a demonstration that feedback can work," says Robinson, and a prelude to more ambitious applications of the strategy. Adaptive sampling, says James Miller, an ocean engineer at the University of Rhode Island, has shown that it "[can be] a really effective observational technique, especially for studying complicated coastal environments."

The strategy is not entirely new. Robinson and his Harvard colleagues began running small-scale experiments guided by real-time forecasts as early as the 1980s, and since then his team has used the technique in a dozen or so spots around the world—from Bermuda to Iceland and California to Sicily. But these earlier experiments were done with ships, which have response times on the order of days rather than the minutes to hours of AUVs. And few tests have taken place in environments as dynamic and fast-changing as Haro Strait.

The details of how incoming seawater collides with outgoing fresh water at a tidal front have never been pinned down, but they are crucial to understanding the biological richness of tidal regions, as well as fighting pollution there. David Farmer, an oceanographer at the Institute of Ocean Sciences in Sidney, British Columbia, who coordinated the Canadian side of the research effort, explains, "The mixing process determines the salinity and density differences of the resultant water layers, which, in turn, influence circulation in the vicinity of the strait." The circulation stirs nutrient-rich waters toward the surface, where they nourish plankton—and it can also spread spilled oil and other pollutants.

To explore these circulation patterns, the team unleashed a network of navigational beacons and current meters, the pair of AUVs, a drifting buoy, and four moorings equipped for acoustic communication with the AUVs. The AUVs, moorings, and drifter all carried sonar devices that could trace changes in water characteristics across the front by passing sound waves through it along many different paths. This technique, called acoustic tomography, is analogous to computerized tomography scans in the world of medicine.

The AUVs also carried temperature and salinity sensors, as well as a Doppler imaging system that measured current velocities. "By using various technologies, some new and some not so new, we acquired pictures of this environment that would be impossible to get by any single means," Farmer says.

Feedback to the Harvard model helped sharpen these pictures. Based on each day's findings, the model predicted where the front would be in the morning. The oceanographers used that prediction to send their vehicles off to find the front and collect new data, which were then fed back into the model. "Sometimes, the front wasn't exactly where it was predicted to be," notes James Bellingham, who runs the Sea Grant AUV Laboratory at MIT. "By putting new information into the model, with the latest corrections, we were able to get a steadily improving model."

The technology did fall short in some ways, however. Underwater noise from the heavy boat and tanker traffic through the strait interfered with acoustic communications between the AUVs and the moorings. As a result, says Bellingham, the experimenters couldn't revise their sampling efforts minute by minute—"talking to the vehicle while it's out there, getting a picture every minute, and at the same time sending commands telling it where to go."

Once those kinds of hitches are overcome, says Schmidt, adaptive sampling with AUVs will be a powerful tool for specific kinds of ocean tasks—among them monitoring oil spills, tracking pollution plumes, or searching for objects on the sea floor. Large-scale measurements of the ocean, he adds, will still require ships, which can move faster and have a much bigger range than AUVs. "A decade ago, this technique was virtually nonexistent," says Robinson. "Today, it's a workable technique, and a decade from now it should be commonplace."

–Steve Nadis

Steve Nadis is a writer in Cambridge, Massachusetts.

BIOPHYSICS

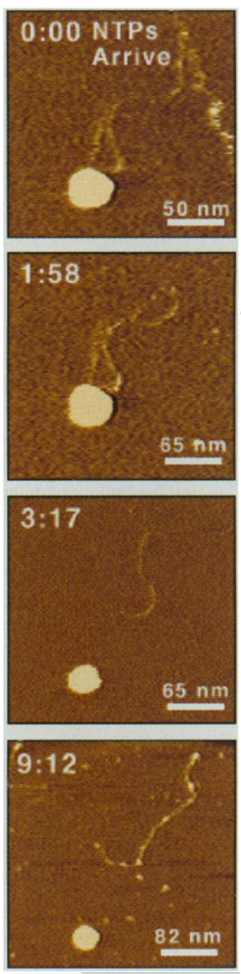
DNA on the big screen. It wasn't up for an Oscar, but a video of a performer new to the silver screen is winning rave reviews. This 8-second clip, aired in Kansas City, Missouri, last week at a meeting of the American Physical Society, shows the first sequential images of an enzyme sliding down a strand of DNA. The film is a tantalizing first glimpse of how researchers might someday study enzymes in action.

While electron microscopes can make high-resolution images of DNA and RNA, the samples must be stained and motionless. Such images are "like snapshots of a ballerina," says Paul Hansma, a physicist at the University of California, Santa Barbara. "They won't tell you about the ballet."

Hansma and colleagues at Santa Barbara and the University of Oregon were intent on watching the ballet itself, so they borrowed an instrument from physics: the atomic force microscope. An AFM doesn't require a fixed, stained specimen; instead, it creates an image by tapping an ultrafine probe across the sample, with a touch gentle enough not to disturb a busy molecule. With it, Hansma's group took pictures of RNA polymerase (blob in images at right) at work on a DNA molecule (faint strand). RNA polymerase ratchets down the DNA strand, linking nucleotide bases to create an RNA copy that in turn serves as a template for a protein.

To see this process, Hansma and his colleagues faced the challenge of anchoring the molecules so that they would stay put for inspection without hampering their activity. After several attempts, the team found that zinc ions added to the water would loosely attach the molecules to the sample dish. The DNA strand could still wiggle, but not so much as to blur the image. The team also had to slow down the enzyme to keep it from outdistancing the AFM. By putting fewer nucleotide bases into solution, the researchers reduced the polymerase's transcribing speed from about 45 bases per second to 1 base per second.

Experts are impressed with the video. At a preview in Texas last year, biologists in the audience "were all on the edges of their seats," says Mike MacLeod, a molecular biologist at the M. D. Anderson Cancer Center in Houston. Hansma himself envisions a gripping sequel: An AFM movie might reveal subtle changes in the shape of RNA polymerase as it passes over different letters of the genetic code on its way down a DNA strand. And that, he says, "could revolutionize the sequencing of DNA." **–Erik Stokstad**



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