COLLEGE OF EARTH, OCEAN, AND ATMOSPHERIC SCIENCES | 2019

ELEMENTS

THE INSTRUMENTS ISSUE:

THE WORLD-CLASS TOOLS BEHIND OUR DISCOVERIES

Oregon State University

ON THE COVER:

The in situ ichthyoplankton imaging system (ISIIS) awaits deployment at sea. ISIIS is used by CEOAS researcher Bob Cowen and his colleagues to collect images of zooplankton as it is towed through the ocean. For more, see pp. 14-15.
Photo by Mark Farley.

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About Elements
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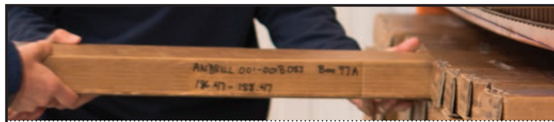
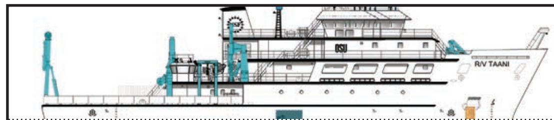
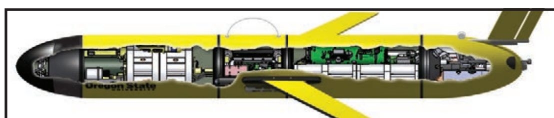






Instruments

Understanding the unreachable

For millennia, humans have imagined new ways to extend our senses and abilities, to see and explore the unreachable, to make the unknown known. The use of tools is part of what makes us human. With instruments and technologies, we have been able to observe and measure myriad phenomena – the movement of the Earth's magnetic field, tiny photosynthesizing marine organisms, the existence of planets and galaxies and tremors beneath our feet, all of which inform our understanding and stewardship of the world.

At the College of Earth, Ocean, and Atmospheric Sciences, we have a strong tradition of intrepid experimentation and observation, of imagining and then building new instruments to make novel measurements or gain critical insights. Whether the tools are simple and timeless – the geologist's hammer or the plankton net – or at the leading edge – underwater robots and mass spectrometers – CEOAS has strived to be at the forefront of developing or obtaining the research infrastructure needed to understand the Earth.

In the early days of CEOAS, mechanical devices such as reversing thermometers, rain gauges and sediment traps gave us basic but crucial information about our coastal ocean, atmosphere and landscape. We experimented with ocean telemetry that would deliver data from sea to shore as early as the late 60s. In the 90s, we launched an oceanographic "undulating vehicle" called the SEASOAR, acquired an advanced plasma spectrometer to perform geochemical analysis and pioneered the use of in situ chemical sensors.

What have we learned because of these instruments? Our scientists have uncovered our vulnerability to Cascadia Subduction Zone earthquakes. They developed the first paleomagnetic reversal timescale that helped verify sea floor spreading and deployed the first successful year-long, sub-surface mooring to measure how currents influence global weather patterns.

Today, our pioneering spirit continues. We are overseeing the construction of a new class of research vessels that will share a multitude of environmental data with researchers and educators in real-time. Our new OSU Marine and Geology Repository will enhance the discoverability of samples and data that hold clues to ancient Earth. State-of-the-art mass spectrometers allow geologists and paleoclimatologists to analyze environmental samples with increased precision and speed, providing new information about the evolution of volcanoes and shrinking ice sheets. Behind it all, our CEOAS Machine and Technical Development Facility continues to design, prototype and then realize the imagined instruments of our creative scientists.

In this issue, we celebrate the instruments and analytical facilities behind our decades of success. Throughout, readers will learn about our dedication to understanding the unreachable, to making the unknowable knowable, to delivering sound science for the benefit of the planet and people. Enjoy.

Roberta Marinelli, Dean

Science goes low-tech

Some research requires state-of-the-art underwater robots, finely tuned mass spectrometers or uber-powerful computer systems. Some requires zip ties and duct tape. Scientists are known for turning household items into essential tools of their trade. Here are some CEOAS examples.

Truck jack

Rob Wheatcroft and his students are always ready to replace a truck tire ... or extract sediment cores from the mud. They use a heavy-duty truck jack to retrieve the cores, necessary in the viscous, stubbornly sticky mud they sample in salt marshes. A sledgehammer and an orchard ladder are also in their field kit.

Oranges

Rob Holman measures currents and other physical phenomena in the surf zone. One quick and dirty (juicy?) way to measure alongshore currents when setting up an experiment is to toss an orange into the ocean and time its drift along the beach. Plus, a bonus snack is always in the field gear!

Electric skillet

Brady Fry, a technician for Adam Schultz, often needs to solder prototype printed circuit boards for instrumentation in the lab. This process usually uses a reflow oven, a machine with careful temperature controls that helps set the solder. But why spend hundreds of dollars when you can spend $30 on an electric skillet? Fry finds the skillet to be a perfectly acceptable replacement.

For some hilarious reviews by scientists of decidedly non-scientific items for sale on Amazon, check out #reviewforscience on Twitter!

A new home for the expanded OSU Marine and Geology Repository

At the Oregon State University Marine and Geology Repository (OSU-MGR), rows of orange metal racks run the length of a cavernous room, easily the size of an airplane hangar. The geometry is dizzying. Shelves climb almost 20 feet high, each one holding a honeycomb pattern of white tubes.

Inside those white tubes is mud. Not just any mud – marine sediments from the bottom of the ocean, carefully obtained by plunging giant pipes, or pistons, into the sediment. For almost 60 years, CEOAS scientists have been collecting ocean mud and archiving it. With almost $9 million in funds, the OSU-MGR recently expanded into a 33,000 sq.-ft facility, while doubling its collection by adding samples from the Southern Ocean and Antarctica, previously stored by Florida State University.

Tens of thousands of cores, dredged rocks and other marine geologic samples live here, a veritable library of the world's oceans. Together these samples chronicle a deep and unfamiliar history. Some date back tens of millions of years, when the Himalayas or the Cascades were just forming, when kelp first appeared in the Miocene seas and became one of the most productive ecosystems. Major events in Earth's history – from earthquakes to shifts in the magnetic field – are recorded in those samples, hidden in chemical and physical clues that help us understand our past and forecast our future. The new facility and its cutting-edge curation and analytical services are vital for ensuring these samples remain discoverable for scientists across the globe. For in the rock and mud may be the next clue to further unlocking Earth's storied past.

Two-cent building, billion-dollar collection

Before there was a repository, there was a Chinese restaurant called the Toa Yuen. In the 1960s, the restaurant's cooler stored the first cores, keeping them at the right temperature for preservation. In 1971, two CEOAS scientists drummed up enough support to establish the Core Lab, an early iteration of the OSU-MGR. Funds from the

Center image:
A core collected from the Oregon Margin in 2017. The CT scan on the right highlights density changes in the core (light = higher density; dark = lower density). The layering reflects deposits of sediment laid down during mega-floods of the last Ice Age.

National Science Foundation enabled them to relocate to a building with 4,800 cubic feet of refrigerated space a few years later.

Bobbi Conard, long-time assistant curator for the lab, kept paper records of each core. The archiving was perhaps the most critical part of her job, because it meant a core could pay scientific dividends down the road.

"A core becomes instantly more valuable once you know something about it. It's tremendously expensive to go to sea and return samples. If someone comes up with a new theory, they can come back and sample the same core," she says.

Joe Stoner, the co-director of the facility in charge of sediment core curation, estimates the OSU collection is worth almost a billion dollars, if you add up the ship time to re-acquire all the samples. He marvels that the original, no-frills facility has been able to sustain such a valuable and well-managed collection.

"We're a small state, we don't have deep pockets, and yet we compete with the big players in the world. And because of that, we've made our old repository work exceedingly well. We've been in a two-cent building with a billion-dollar collection," he says.

Digital-born data

After roughly four decades of operation in the same facility, the OSU-MGR was running out of room. Growing pressure to make records as accessible as a Google search has left many repositories scrambling to digitize their collections and program sophisticated databases.

The OSU-MGR needed to modernize and get its digital house in order, says co-director Anthony Koppers, who is in charge of rock curation and data management.

"It's very useful to come here and physically see the materials. But we are living in a digital age, so if you can take images, or CT scans, or collect some other data and broadcast that through a database online, people are way more informed," he says.

Curators Maziet Cheseby and Val Stanley are overseeing the Herculean effort of bringing the OSU and Florida collections under one roof and ensuring a standard data preservation method. They are helping to create an ecosystem of digital-born data – where information is digital from the get-go and never transcribed, thus reducing error and time. Samples at the new facility all have QR code labels that when scanned bring up key information and their location within the facility, much like the metadata assigned to a library book.

"If you really want to preserve the value of the material, you need that metadata. It makes it easier to find, easier to use and easier to curate," Stanley says. "Otherwise, it's just a rock. It's just a chunk of mud."

Miles of mud

Today, the new Marine and Geology Repository is a marvel. It contains the largest collection of geologic samples from the Southern Ocean. Roughly 20 miles of mud and more than 10,000 rocks provide a breadth of potential scientific inquiry. The mud is kept in refrigerators at a constant 4 degrees C. Freezers at -25 degrees C can accommodate sediment or rocks that are in a frozen state. Labs and collaborative work spaces bring the whole cycle of marine geology research into one facility – a far cry from the days of storing cores in a Chinese restaurant.

"We designed and built the OSU-MGR facility to capture the scientific needs in our fields for decades to come," Koppers says.

Joe Stoner agrees. "It's going to be the nicest core repository in the country. We built it, now the cores have to come."

Info: osu-mgr.org

The RCRV project

Developing the next generation of ships for science

One of the most important pieces of oceanography equipment is the research vessel, a ship that serves as a floating lab, sampling platform and field camp for marine scientists. While satellites orbiting the Earth and buoys affixed to the sea bottom can collect continuous data about our oceans, scientists still need access to the sea.

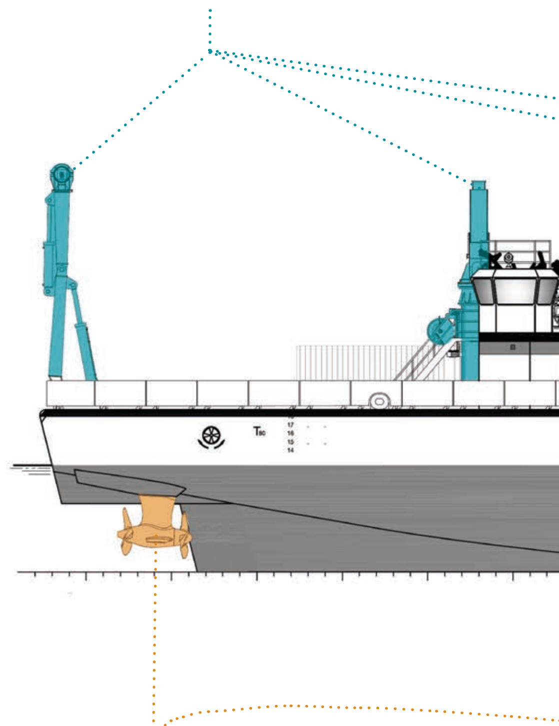
Research vessels range from tiny Zodiacs that hold only a few people to massive polar ice breakers nearly 400 feet long. Somewhere in the middle is the regional class research vessel (RCRV). This category, designated by the University-National Oceanographic Laboratory System (UNOLS), contains ships that will operate in the coastal ocean ranging from nearshore environments to the outer continental rise.

With a $121 million grant from the National Science Foundation, the largest grant ever awarded to Oregon State University, CEOAS began construction of three new vessels, the newest generation of RCRVs for the nation. The first of the three 199-foot vessels will be operated by Oregon State, with the others to be operated by institutions on the East and Gulf Coasts. Oregon State's vessel will be named *Taani*, a word used by the Siletz people meaning "offshore." Construction of *Taani* is just getting underway at a shipyard in Houma, Louisiana. John Byrne, former OSU president and NOAA Administrator, and his wife, Shirley, have agreed to be the ship's ceremonial sponsors and will inscribe their initials into the ship's keel, assuring it is "truly and fairly" constructed. They will preside over the christening of *Taani* when it is launched. The ship will be launched some time in 2020 and delivered to OSU for science trials in 2021.

The new RCRVs will be the most efficient, capable and green in the U.S. research fleet. Here are some of the features that will make *Taani* and her sister ships so special.

Gear deployment/recovery equipment

Research vessels need to be able to deploy and retrieve various types and sizes of equipment safely and accurately. Off the stern, *Taani* will be equipped with a flexible, multi-jointed A-frame for deployment of nets, buoys and other sampling equipment. Amidships on the starboard side, the ship will have an advanced robotic "arm" that, with a push of a button, will be able to deploy oceanographers' principal sampling and measurement tool, the conductivity, temperature and depth sensor (CTD), without the need for extra safety lines for control. The arm can also be reconfigured to safely launch and recover underwater robots.



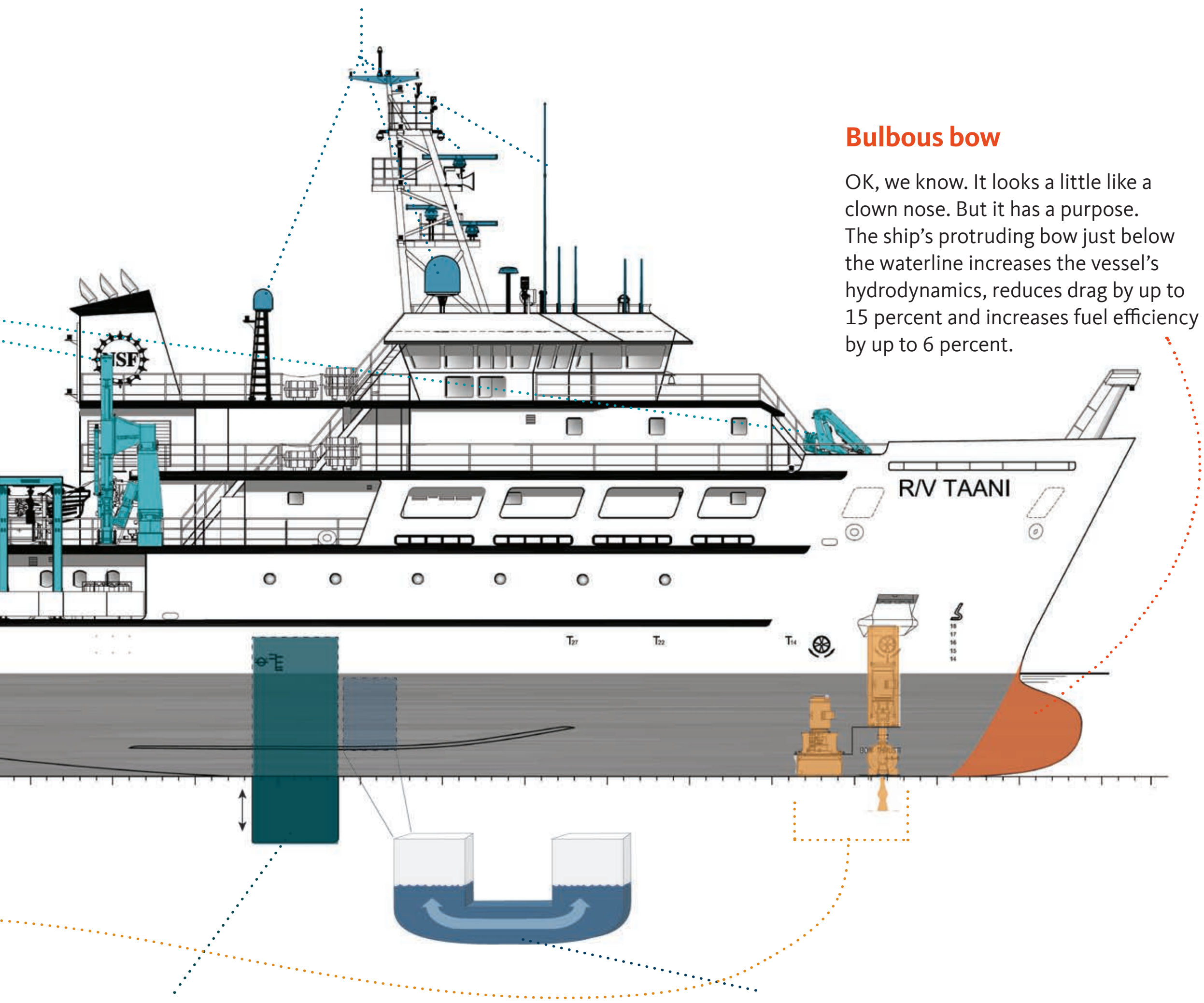
Dynamic positioning

This just in: the ocean moves. Many oceanographic operations require the ship to remain stationary or follow a survey line very precisely as data is collected. The RCRVs will include a state-of-the-art dynamic positioning system to "hold station" and increase maneuverability. This system will include two sets of twin thrusters in a push-pull configuration – one in the stern and another in the bow. The computer-designed propellers on these thrusters will behave more like wings than the traditional screw-type propeller and operate very efficiently.

Datapresence

The new RCRVs will be equipped with advanced "datapresence" technologies that will enable remote transmission of data from ship to shore, including constant real-time measurements of temperature, salinity, light transmission, dissolved oxygen and other critical parameters. Scientists on shore will be able to participate in research projects remotely, and teachers will be able to display real-time ocean data in their classrooms or have direct interactions with scientists working at sea.

RCRV does *not* stand for really cool research vessel, but it could.



Bulbous bow

OK, we know. It looks a little like a clown nose. But it has a purpose. The ship's protruding bow just below the waterline increases the vessel's hydrodynamics, reduces drag by up to 15 percent and increases fuel efficiency by up to 6 percent.

Centerboard

This retractable centerboard will provide a versatile platform on which a wide variety of acoustical sensors, called transducers, can easily be installed and switched out based on specific mission requirements. These could include instruments to identify schools of fish and other organisms, measure currents, capture images of the bottom of the ocean, or even talk to swarms of autonomous underwater vehicles.

U-tube anti-roll tank

The lateral rolling motion of a ship can cause even the most stouthearted scientists to toss their cookies (that's a technical term). Rolling can also make deployment and retrieval of instruments difficult and even dangerous. To minimize rolling, a large, U-shaped tank within the hull will use gravity to slosh water from side to side, counter to the ship's natural roll frequency. The shifting water weight dampens the ship's roll, making operations safer and more comfortable.

Science behind the scenes

Decades-old facility builds instruments that set the stage for Earth science research

Behind a chain-link fence, in a cluster of corrugated metal buildings, sits the CEOAS Machine and Technical Development Facility (CMTDF). Constructed by faculty in the late 60s, the facility still bears the hallmarks of its rustic beginnings: A faded tan façade, a crosshatch of pipes, slapdash walls. Rusted buoys are scattered around the building like beached whales alongside a row of shipping containers. And yet, it's here that arguably the most innovative work occurs in support of the Earth sciences at Oregon State.

Pull back the curtain, and the CMTDF shines. Facility employees serve as science stage-hands, rigging and devising near-magic systems in service of a dazzling show. They imagine scientific instruments that operate at the top of a mountain or bottom of the ocean. They dream up levers, pullies and other mechanical marvels to transport and affix instruments to a ship, then to drop and retrieve them at just the right moment.

If you ask Ben Russell, manager of the CMTDF, what his facility does, you'll get a tidy answer: "We provide prototype development and support for scientific equipment and device deployment."

Russell's colleague, Jay Simpkins, who ran the shop before Russell and has been with CEOAS since 1977, offers a grittier depiction.

"Our specialty really is, a PI (principal investigator) can come in with something scribbled on the back of a Beanery napkin, and we can turn it into a reality," he says.

However you describe it, the work is a little of everything, an alloy of art, engineering and material science, carried out by a team of MacGyvers. Russell, Simpkins and the shop's newest recruit, Tige Kurth, make a stunning array of creations — pressure cases, heat flow probes, custom tripods, whale tag components, lab fixtures, coring equipment and carrying cases that fit together like a jigsaw puzzle and keep instruments protected during transport. Projects range from larger-than-life buoys packed with instruments, to tiny sensor caps with intricate threading.

This variety means never-ending challenges: How do you plant an instrument in the energetic surf zone? How do you secure an ocean profiler on a ship and make sure it doesn't roll off (until you want it to)? How do you anticipate pressure, wear, corrosion, ice and the hundred other variables that could interfere with measuring and understanding the environment?

Fortunately, Russell has some clever tools to help him anticipate points of failure. His team uses the software SolidWorks to model a design in 3D, allowing them to discover what Jay Simpkins calls "gotchas," or flaws that could spell disaster.

Once an instrument is ready for prototyping, employees take great care to select the right material. Some plastics, for example, are surprisingly durable and inherently corrosion proof. But plastics have limited impact resistance and strength, making them unsuitable for pressure cases at full ocean depth. Exotic metals like titanium and stainless steel are strong, durable and resistant to corrosion but are expensive and difficult to machine. Aluminum is lightweight and relatively cheap but subject to corrosion under some circumstances. Even stainless steel can succumb to crevice corrosion in low-oxygen conditions.

The range of projects brought to the shop's gurus is incredible. In one project, the CMTDF worked with nearshore ocean scientist Greg Wilson to build a robust housing for a multi-frequency Doppler profiler, or MFDop for short. Similar to how a Doppler radar uses radio energy to record the scattering off rain drops and measure precipitation in the atmosphere, the MFDop uses sound waves to measure ocean sediment particles.

"You could almost look at the MFDop as a turbulence microscope. We're looking at little areas of the ocean that are literally the size of a milk cap. What this instrument allows us to do is see how many particles are being stirred up in the water," Wilson says.

Observing that fine-scale movement will give Wilson an understanding of how entire shorelines are created and maintained.

Wilson says that there are only a few such instruments in the world. "I was basically able to come to Ben with a 'kid sketch' of my concept, and he came back to me with something they can build efficiently," he says.

Russell holding a thermistor tube end plug that he machined.

Faculty Research Assistant June Marion approached the CMTDF to devise a cooling system for her autonomous kayak used to measure glacier melt. Because it is dangerous to get close to calving glaciers to study them, the remote-controlled kayak enables her and lead scientist Jonathan Nash to observe how local tide water dynamics affect glacial melt rates and stability, which could contribute to sea-level rise or impact local marine life. When the kayak engine was overheating, Russell developed a snorkel exhaust system to keep the engine cool.

Russell has future plans to enhance the CMTDF to include a full-service electronics shop and expanded machining, fabrication and testing capabilities. "I want to make a world-class research support facility, right here. And so far, I think we've come a long way toward accomplishing that," he says.

Until then, CMTDF creations continue to go out into the world and observe our planet, serving as sentinels for science.

When the data come back, scientists scurry to publish scholarly papers. Careers are made. Promotions are granted. Awards and accolades pour in. And throughout it all, this top-notch support facility carries on backstage.

The CMTDF facility may not get the standing ovation, but the show could not go on without it.

The SuperSucker

Machined by Jay Simpkins for chemical oceanographer Burke Hales, the SuperSucker may be the only CEOAS instrument with a moniker inspired by a cowpunk rock band. "When I was playing their music in the shared lab in the ship, it really struck a chord, or three chords, really," Hales says. The name is also fitting because the towed instrument sucks seawater up to a shipboard lab, where Hales can measure ocean chemistry in near real-time. In particular, he measures CO_2 cycling and its effect on ocean acidification.

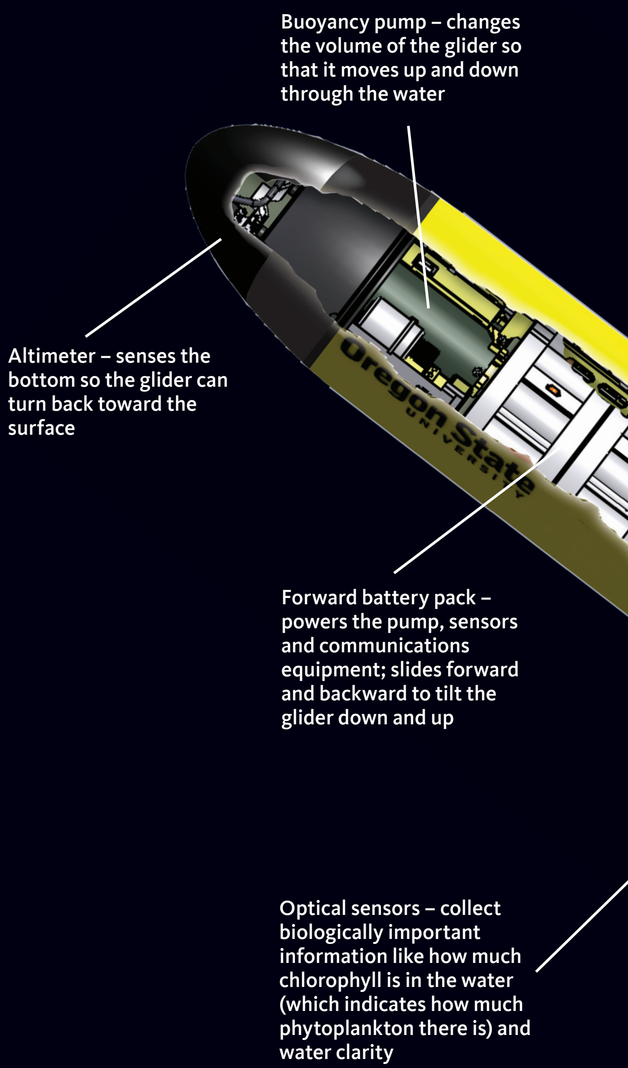
Anatomy of a glider

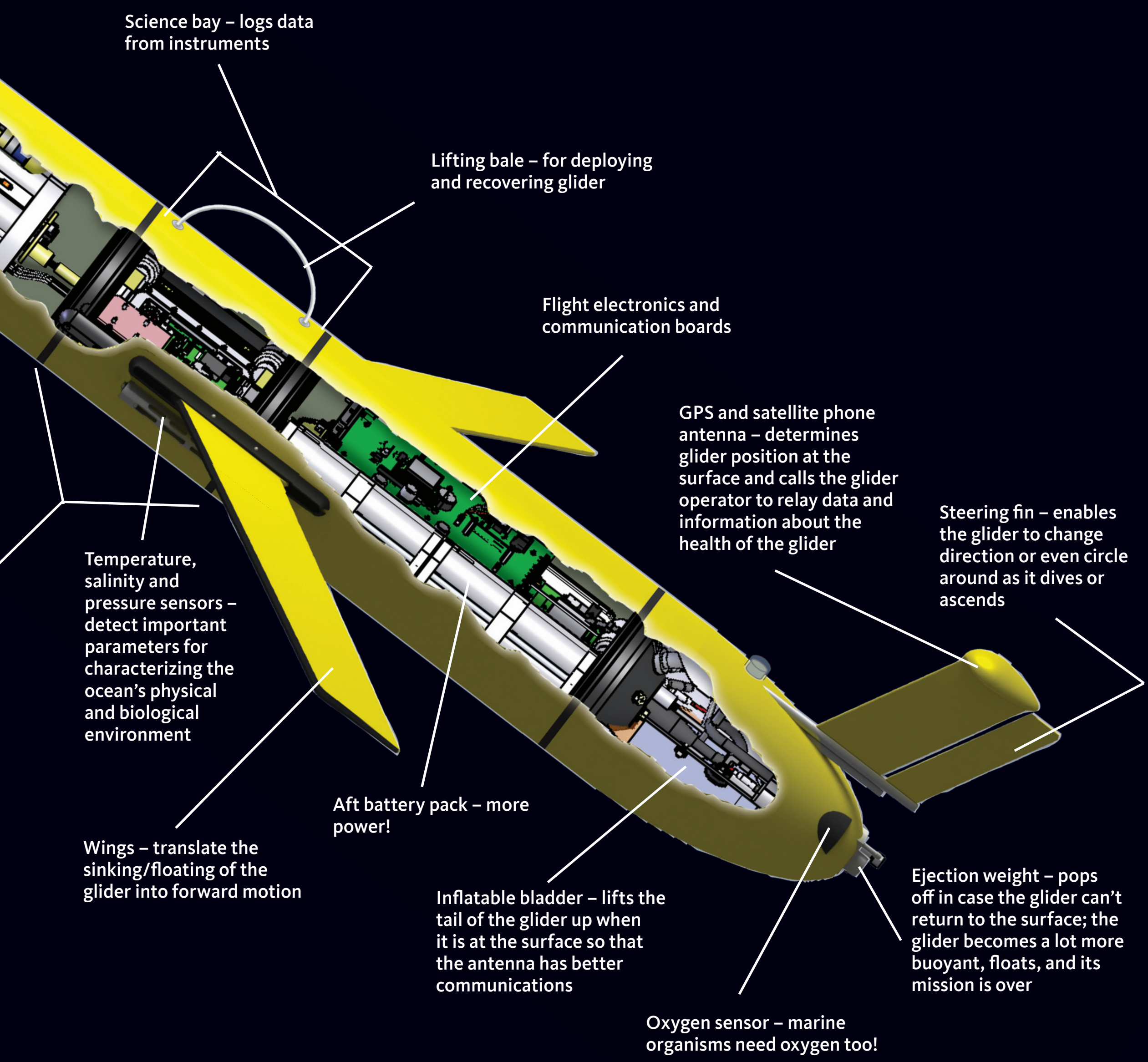
As you read this, multiple sunny yellow airplane-shaped robots are criss-crossing Oregon's coastal ocean on preprogrammed undulating paths, collecting vast amounts of data as they go. These autonomous underwater vehicles take the pulse of our coastal oceans, 24/7, 365, collecting data about currents, temperature, salinity, oxygen and other parameters. Motorless, the gliders move by changing their buoyancy, rendering them silent as they carry out their missions.

Gliders are often used for individual research projects, but the regular tracks they follow in Oregon's coastal ocean are part of one of the most comprehensive ocean monitoring programs in history: the NSF-funded Ocean Observatories Initiative (OOI). OOI is a networked system of instruments to measure physical, chemical, geological and biological properties in the ocean, the atmosphere and on the seafloor. In the northeast Pacific, the OOI Endurance Array, operated and maintained by Oregon State University, is a transformational set of technologies that includes buoys, gliders and cabled monitoring equipment providing near-real time information to ocean scientists, researchers, policymakers and the public.

The gliders are deployed for up to three months at a time, surfacing every six hours or so to transmit data and get their bearings by checking in with satellites. Each time they surface, they ping out a "here I am and here's how I'm doing" signal so scientists can monitor their status and check the latest data. When they reach the end of their battery life, scientists retrieve them, download all the data, replace their batteries and send them on their way again.

Here's what they look like and how they work.




Science bay – logs data from instruments
Lifting bale – for deploying and recovering glider
Flight electronics and communication boards
GPS and satellite phone antenna – determines glider position at the surface and calls the glider operator to relay data and information about the health of the glider
Steering fin – enables the glider to change direction or even circle around as it dives or ascends
Temperature, salinity and pressure sensors – detect important parameters for characterizing the ocean's physical and biological environment
Aft battery pack – more power!
Wings – translate the sinking/floating of the glider into forward motion
Inflatable bladder – lifts the tail of the glider up when it is at the surface so that the antenna has better communications
Ejection weight – pops off in case the glider can't return to the surface; the glider becomes a lot more buoyant, floats, and its mission is over
Oxygen sensor – marine organisms need oxygen too!

Dismantling matter

To answer critical questions, mass spectrometry smashes molecules into bits

Sometimes science requires taking something apart to find out what makes it tick. Need to dissect an animal specimen? Use a scalpel. If you want to smash apart a molecule, as many scientists do, you usually use a mass spectrometer. This high-tech sledgehammer-cum-detector allows researchers to examine the molecular and atomic makeup of many kinds of samples. With this information, they can examine past ocean temperatures, learn how volcanoes evolve, or determine concentrations of toxic chemicals in the environment. CEOAS is the proud owner of multiple mass spectrometers, sometimes called "mass specs," including one new cutting-edge instrument designed to measure isotope ratios. Two more mass specs are coming soon, thanks to a generous grant by the M.J. Murdock Charitable Trust.

Mass spectrometers identify molecules and atoms by determining their mass, or more accurately, their mass-to-charge ratio. To do so, they smash apart a sample — ionize it — and then separate the resulting fragments by weight using electric or magnetic fields. A detector then records the amount of particle in each size range contained in the sample. While there are varying methods for carrying out each of these steps, CEOAS' Keck Collaboratory, an analytical facility specializing in mass spectrometry, houses multiple instruments that use a plasma, a high temperature ionized gas, to break up molecular samples into their constituent parts.

The Keck Lab's most recent mass spec arrived in fall 2017: a $750,000 instrument called a Nu Plasma 3D MC-ICP-MS, the very first one of this model shipped out from the factory. This instrument has multiple sensors for detecting different ions simultaneously, allowing it to precisely measure isotope ratios of elements across the periodic table (that's the MC — multi-collector — bit). It uses inductively coupled plasma (ICP) to ionize samples, and it is made by Nu Instruments.

Assistant Professor Alyssa Shiel, one of the investigators who led the initiative to bring the new instrument to the college, explains that CEOAS had to submit an internal proposal to the Oregon State Office for Research Development before even being allowed to submit the successful proposal to the National Science Foundation. Universities such as OSU are only allowed to submit three such proposals each year. "We applied to be able to apply," she says. NSF funds underwrote most of the purchase, with significant matching funds from Oregon State.

The Nu instrument arrived from the UK in multiple large wooden crates, two of which could only come into the lab through a removed second-story window. Shiel and her colleagues held their collective breath as the massive crates were lifted up by a forklift and then maneuvered through the hole in the building.

The instrument joins four other mass specs in the lab, all specialized to answer particular kinds of questions. The new machine leaps ahead of the others with respect to accuracy and precision, and allows analysis of much smaller samples and detection of tinier concentrations of elements. It is also used specifically to measure isotope ratios, which can indicate the source or age of a molecule and answer other questions about the Earth and its history.

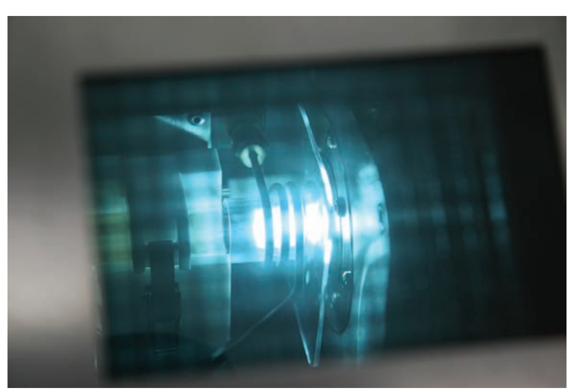
"Several researchers in the college have had samples we've wanted to run for a while, and we haven't been able to because concentrations of what we're trying to detect are so low. We've been waiting for this instrument to make those measurements," Shiel explains.

Shiel and her students will use the Nu Plasma 3D to measure traces of heavy metals in soil and vegetation samples collected near a zinc mine in northwest Alaska. Ore from the Red Dog mine, one of the world's largest zinc and lead mines, is transported via a road through a National Monument in open trucks. Shiel's lab is examining how ore dust is deposited, transformed and transported in the environment along the road.

CEOAS geologist Adam Kent and students are planning to use the instrument to measure the ratio of lead isotopes in crystals and melt inclusions from the Taupo volcanic zone, New Zealand. Melt inclusions are small bubbles of magma trapped inside crystals as they grow. They act as magmatic "fossils," preserving the composition of earlier magmas that may be obscured by subsequent processes. In combination with laser ablation — where a laser is used to sample very small areas within an individual crystal — the high sensitivity of the Nu Plasma 3D makes this project feasible. "Ultimately, we hope to learn about the way that volcanic systems evolve in the lead-up to large volcanic eruptions," Kent says.

In addition to the Keck Lab, CEOAS houses the Stable-Isotope Mass Spectrometry Center, a facility boasting five mass specs that are tuned to analyze natural abundances of carbon, nitrogen, oxygen and hydrogen isotopes in a variety of environmental, geological and biological sample types. The lab will house the two instruments funded by the Murdock Charitable Trust; one will be tuned specifically to measure trace gases in ice samples, and the other will be capable of measuring miniscule carbon dioxide concentrations, on the order of what might be found in the shell of an individual single-celled organism. Both data types have vast implications for the paleoclimatology research carried out by CEOAS faculty, including Ed Brook, who researches ancient climates by examining air bubbles trapped in ice cores, and Jennifer Fehrenbacher, who uses the chemicals in the shells of single-celled organisms (called forams) as proxies for past climates. The two new instruments will arrive some time in early 2019.

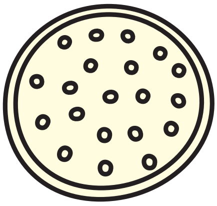
While the Stable Isotope Lab focuses on the "light" stable isotopes of C, N, O and H, the Keck Lab focuses on so-called "heavy" stable isotopes from across the periodic table. The combination of these capabilities will significantly expand the range of questions researchers can pursue. "For the college, having both sets of equipment opens up the entire periodic table," Alyssa Shiel observes.



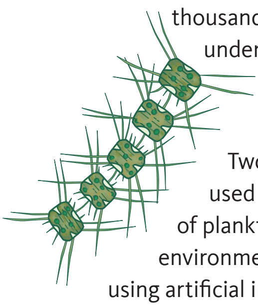
Mobile microscopes

Technologies to help identify plankton in the field

The ocean teems with microscopic plants and animals — phyto- and zooplankton — in a mind-boggling array of forms. These organisms form the basis of complex food webs, fueling fisheries and impacting ecosystems in countless ways. For these reasons, scientists often want to find, identify and count them.



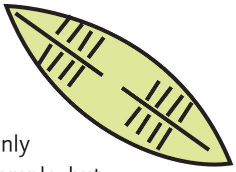
But determining which plankton species are where and for how long is labor intensive. It used to be that the only way to examine plankton communities was to take water samples in the field, preserve them and bring them back to the lab. Thousands of scientists have spent tens of thousands of hours examining such samples under microscopes all over the world.



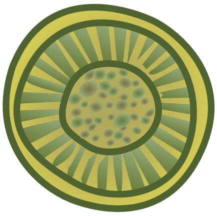
Now, new technologies are making studies of plankton much easier. Two amazing instruments are being used by CEOAS scientists to take pictures of plankton species in situ (in the natural environment), and even identify them to species using artificial intelligence and machine learning.

Photogenic phytoplankton

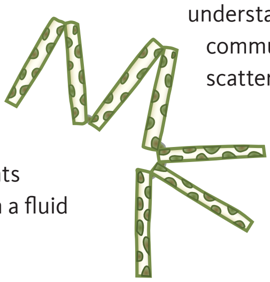
Flow cytometers, now standard equipment in biomedical labs, are instruments that count and photograph individual cells in a fluid flowing past a camera. They have been used for decades to look for cancer cells, examine immune deficiencies and determine cell function. Scientists at Woods Hole Oceanographic Institution had the brilliant idea to adapt this instrument for monitoring phytoplankton in the field, adding image recognition to the device's repertoire so it can record not only how many phytoplankton cells are in a sample, but also the species present.



A cross-university team of researchers led by Angel White and Ricardo Letelier of CEOAS and Kim Halsey of the Department of Microbiology purchased one of these imaging flow cytobots (IFCBs) for use in multiple research projects. Now led by Maria Kavanaugh (CEOAS), the team has been working with the IFCB for about a year, teaching it to identify local species and learning the capabilities of this incredible instrument.



"It's so beautiful," Kavanaugh says of the IFCB's capabilities. "Before, we were relegated to understanding phytoplankton community structure through parameters like light scattering properties. Now we can get counts, size structure of the population, *actual* species abundances … it's a great tool."



The IFCB can either be deployed directly in the water, sampling for multiple months, or it can sit safely on a benchtop inside a laboratory. In either case, the meter-long device sips a small sample of water which is entrained into a tube containing a "sheath fluid," a tunnel of water with similar optical properties as the sampled water. The sample flows through the tunnel of sheath fluid in a stream so narrow that only one cell at a time passes in front of a laser. The laser then triggers a camera to take an image of the single cell. The IFCB files the photo away, and goes on to the next cell in the stream. In one ten-minute sampling period, the IFCB can collect and categorize about 5,000 images. The old-school way of examining that one same sample under a microscope would have taken six to eight neck-stiffening hours.

Machine learning plays an important role here. The IFCB crops the image, then a series of algorithms identify the plankton species based on measurement of more than 250 attributes of each cell. The images are compared to a "field guide" prepared and fed to the algorithm by scientists. The scientists check the machine's work and correct it, and over time, the classifications get more and more accurate.

CEOAS scientists will be using the IFCB for a range of projects. Kavanaugh used it as a teaching tool last summer with a field biological oceanography class. It is being used to examine the phytoplankton community in the waters of Netarts Bay, by sampling the water intake at the Whiskey Creek Shellfish Hatchery. And in the fall Kavanaugh and others began using it to characterize the plankton communities over Oregon's continental shelf.

Regional phytoplankton better get ready for their close-up.

Fantastic beasts and how to find them

In addition to microscopic plants, the ocean is home to spectacularly diverse wee beasties, otherwise known as zooplankton, including the larval stages of fish and crustaceans. CEOAS oceanographer Bob Cowen has been studying larval fish ecology for decades. Cowen and his team have dragged lots of nets through the water, filtering out larval fish and examining them under a microscope to identify them.

For the past decade, though, he's been using a more high-tech approach to examine larval fish (called ichthyoplankton) and other zooplankton in situ. Along with colleagues at the University of Miami and elsewhere, he developed the in situ ichthyoplankton imaging system (ISIIS), a camera system towed by a research vessel that takes pictures of the critters on the fly.

While in situ imaging systems existed pre-ISIIS, they had significant shortcomings when it came to finding larval fish. "Existing systems could only image very small volumes of water," explains Christian Briseño-Avena, a post-doc in Cowen's lab. "There was no way to capture the least abundant zooplankton groups like fish larvae."

ISIIS solves the problem by using a line scan camera, which emits a sheet of light a few microns thick. The sheet is projected from one port through the water to another port, and the instrument is towed through the water perpendicular to the sheet of light. Because the organisms in the frame are backlit, the camera is capturing the shadows of whatever comes through that plane. "It scans the water line by line, stacking the lines to make a picture," Briseño-Avena says. "If we tow it for a kilometer, it's creating a kilometer-long picture."

The catamaran-shaped instrument, a bit larger than a mini-fridge (see its picture on our cover), can be towed at a specific depth (up to about 200 m), or towed in an undulating pattern, taking images from several liters of water at a time. Environmental data are collected simultaneously, so that plankton data can be compared to critical variables like temperature and salinity.

All of the critters in the ISIIS portraits need to be identified, and just like with the IFCB, Cowen's research group and others are working with an image-recognition system to automate that process. "We create learning libraries for ISIIS by identifying the species we know," Briseño-Avena explains.

ISIIS data have been used to examine larval distribution and transport in the Florida Keys, to determine the distribution of larvae in areas of the Gulf of Mexico affected by the Deepwater Horizon oil spill, and to look at food web dynamics in the Mississippi River plume. Currently the lab is engaged in a four-cruise study comparing larval dynamics in two regions of the California Current system, in Oregon and California.

There is no end to the questions that the lab can answer using ISIIS. "We keep pushing the boundaries of the instrument all the time," Briseño-Avena says.

Diatoms courtesy of: Tracey Saxby, Integration and Application Network, University of Maryland Center for Environmental Sciences. ian.umces.edu

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