University of Washington

Applied Physics Laboratory 2024

ANNUAL REPORT

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APL-UW

The Applied Physics Laboratory is a research unit of the University of Washington. We serve as a trusted research and development agent by anticipating broad scientific and engineering challenges and responding quickly to rising national research priorities. Core expertise is in ocean physics and engineering, ocean and medical acoustics, polar science, environmental remote sensing, and signal processing.

Designation by the U.S. Navy as a University Affiliated Research Center – UARC – requires that APL-UW operate in the public interest. From our integral position within the University of Washington scholarship, research, and innovation enterprise, we apply rigorous scientific inquiry and engineering excellence in pursuit of solutions for the good of our region, nation, and world.

SCHOLARSHIP DISCOVERY INNOVATION APPLICATION

UARC

APL-UW has a formal, strategic relationship with the Department of Defense, offering a unique arrangement of basic and applied research within one organization, and ensuring that essential engineering and technology capabilities are maintained.

welcome

FROM EXECUTIVE DIRECTOR WARREN L. J. FOX

Hello! I am new this year to the role of Executive Director at the Applied Physics Laboratory, University of Washington, but I am not new to the organization. I am a prime example of how the Laboratory benefits from and contributes to the University's education mission. I started at APL-UW as an undergraduate intern. With some math, science, and computer skills, I soon contributed to project work, while also learning an enormous amount about real world science and engineering disciplines. I acquired a lot of experience at APL-UW, and have also worked in industry, government, and international organizations. Working other places has given me experiences that I would never give up, but has taught me something very important — APL-UW is an exceptional and special organization, and I would not want to be working anywhere else at this point of my career.

Part of what makes APL-UW special is its balanced breadth of research at all levels, from answering fundamental physics-based questions up through satisfying Department of Defense requirements in applied programs. This balance, fairly unique in the UARC community, can be challenging, but by being able to conduct these varied activities within one organization and leveraging the overall knowledge base of APL-UW staff and colleagues across the University, the benefits to our sponsors and society-at-large make addressing the challenges a worthy endeavor. Our people are the primary drivers of APL-UW success, and the partnership between research and administration in addressing our challenges is key to making the overall organization exceptional.

As I took on the role of Executive Director, APL-UW was in a very good place. Incoming grant and contract funding levels have been increasing in recent years, enabling increases in staffing levels for research and administration, as well as investments in infrastructure to enhance our efficiency and agility. What I have attempted to do so far is keep us flying straight and level, and continue the record of achievement we have become accustomed to. At the same time, it is important to avoid stagnation by continuing to innovate, making sponsoring agencies aware of what we can do for them, and remaining aware of sponsor requirements and responding in kind. I am excited to see what APL-UW can do on these fronts in the coming years, and will find ways to support and extend the significant capabilities of our excellent people.

This report highlights exciting research conducted at APL-UW over the last year. The stories cover a wide swath of the Laboratory's areas of expertise, and over half the stories center on work done by early career principal investigators. Supporting and mentoring the next generation of staff is an important mission for APL-UW, in keeping with our status as a UARC and maintaining our core competencies. I hope you enjoy the individual stories presented in this **Annual Report**, and take away a big picture understanding of our organization's overall story.

"What makes APL-UW special is its balanced breadth of research at all levels, from answering fundamental physics-based questions up through satisfying Department of Defense requirements in applied programs."

highlights

BASIC RESEARCH & APPLIED SCIENCE

San Nguyen

global reach and influence

APL-UW research teams make important contributions to Departmental Research Initiatives — the ambitious programs focused on themes and topics selected by the Office of Naval Research. They are conducted in regions throughout the world's oceans where the target processes will dominate the physics. ONR DRIs have been the drivers of scientific progress in areas including internal wave dynamics, ocean mixing, submesoscale processes, monsoon prediction, and atmosphere–sea ice–ocean interactions in the Arctic.

To assemble the expertise needed to address the scope of a topic or theme, initiatives are comprised of many projects led by individual principal investigators. Coordination and integration among the multi-institutional, and often international, investigative teams is key to initiative success. Together, they realize far more capability than multiple investigations conducted in parallel.

Two examples follow of APL-UW investigators integrating the science goals of their projects into the coordinated, international efforts of ONR DRIs.

"DRIs have produced some of the most rewarding experiences of my career. They've been a chance to work in talented and collegial teams with the resources to tackle big problems and try new approaches."

— Craig Lee, Senior Principal Oceanographer and Assistant Director for Research

GREEN ISLAND: KUROSHIO CURRENT

Over a two-week period, an APL-UW team aboard a chartered fishing vessel launched clusters of profiling oceanographic floats into the ocean north of Green Island, a small, volcanic island east of Taiwan. The EM-APEX floats were carried by the fast-flowing Kuroshio western boundary current that sweeps along the coast of Taiwan, around Green Island, and onward into the North Pacific. In a drifting mode, the floats rode the current, profiling continuously from the surface to about 300 m. The next day the team set out again with the local fishermen to recover the floats about 30 km downstream.

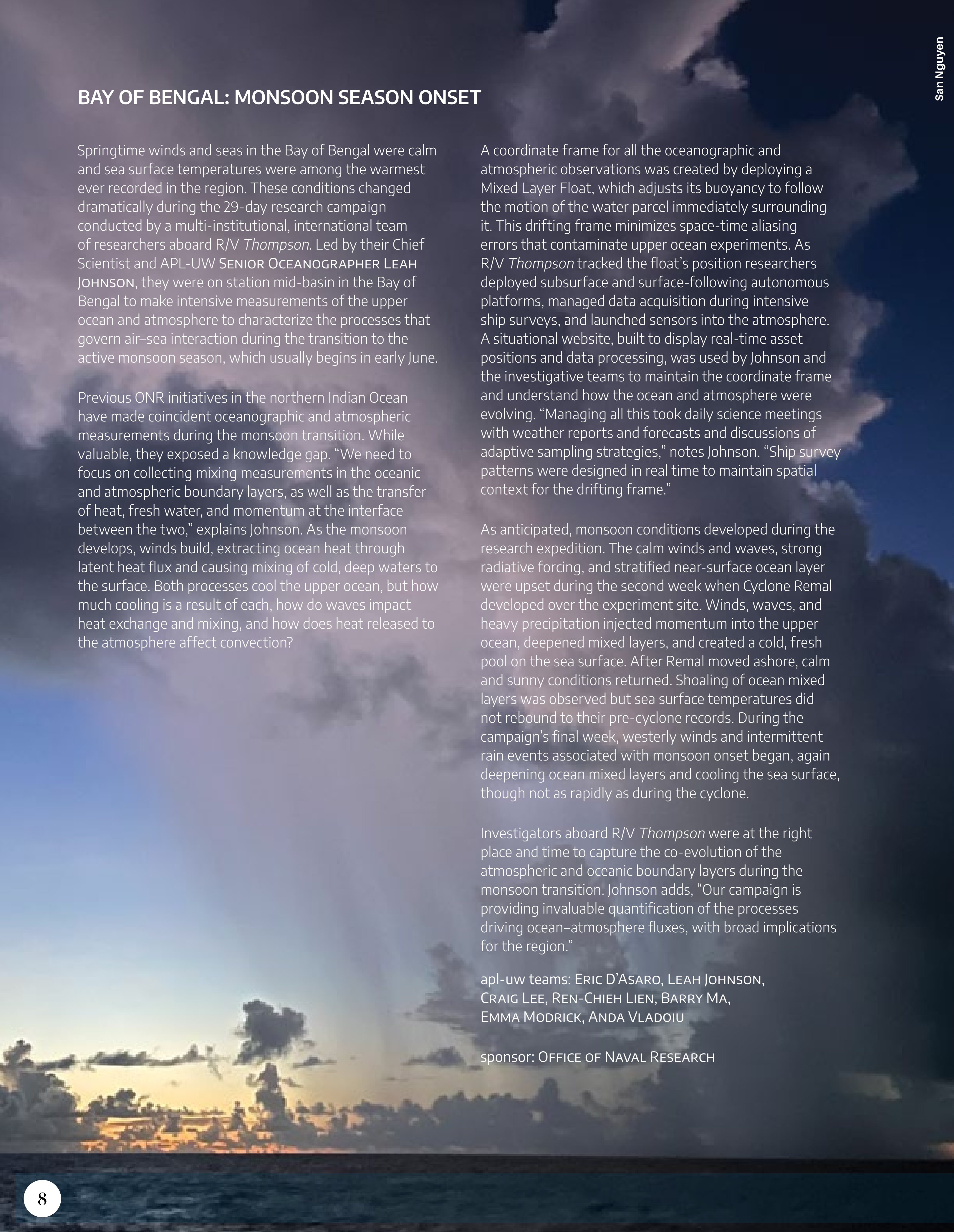
"The objective of our project is to observe the evolution of the wake generated by the fast-moving Kuroshio as it flows around Green Island," explains Senior Oceanographer Anda Vladoiu. As the Kuroshio flow is interrupted by the island, vorticity is generated by frictional torques and pressure drag at the bottom boundary. The wake structure evolves: downstream the flow becomes unstable and generates mixing that entrains surrounding water masses. "We know these turbulent exchanges can enhance biological productivity," says Vladoiu, "... and our local guides were a big help directing our surveys to the best fishing and turbulence hot spots."

The APL-UW team's experiments are part of the **Island Arc Turbulent Eddy Regional Exchange** initiative. In the eastern Pacific, between Luzon and the Mariana Islands arc, several strong currents interact with the myriad of islands and dramatic seafloor topography, generating turbulent eddy exchanges throughout the region. International teams deployed across the region are targeting observations on relatively small fronts and eddies — with lateral scales of 100 m to 10 km. These 'submesoscale' circulation features are ubiquitous throughout the world's oceans. Oceanographers understand that they are important in the cascading transfer of energy from major currents to local turbulence and dissipation. Unlike large-scale currents, however, features on these scales are inherently chaotic and evolve quickly, limiting their predictability.

The floats were deployed, recovered, and re-deployed eight times during the experiment. Entrained in the billowing structures and advected northward, the floats gathered multiple time series realizations of wake properties. Even though the deployment location was the same each day, release into the Kuroshio was at different tidal phases, which explains the variability among deployments in each cluster's dispersion.

"We observed clear, robust signals of turbulent dissipation that decayed northward," says Vladoiu. The team is now preparing papers to report an enhanced turbulent kinetic energy rate created by vertical and horizontal instabilities in the wake that decreases with distance downstream of Green Island. Taiwanese collaborators are similarly preparing reports on tidal modulation of wake properties.

Senior Principal Oceanographer Ren-Chieh Lien explains how these experiments fit in a larger question for physical oceanographers. "Ultimately the scientific goal is to know how energy cascades from the boundary current — here, the Kuroshio — to wakes, vortices and internal waves, down to microstructure turbulence, which is a scale difference of 10^7."



San Nguyen

BAY OF BENGAL: MONSOON SEASON ONSET

Springtime winds and seas in the Bay of Bengal were calm and sea surface temperatures were among the warmest ever recorded in the region. These conditions changed dramatically during the 29-day research campaign conducted by a multi-institutional, international team of researchers aboard R/V *Thompson*. Led by their Chief Scientist and APL-UW Senior Oceanographer Leah Johnson, they were on station mid-basin in the Bay of Bengal to make intensive measurements of the upper ocean and atmosphere to characterize the processes that govern air–sea interaction during the transition to the active monsoon season, which usually begins in early June.

Previous ONR initiatives in the northern Indian Ocean have made coincident oceanographic and atmospheric measurements during the monsoon transition. While valuable, they exposed a knowledge gap. “We need to focus on collecting mixing measurements in the oceanic and atmospheric boundary layers, as well as the transfer of heat, fresh water, and momentum at the interface between the two,” explains Johnson. As the monsoon develops, winds build, extracting ocean heat through latent heat flux and causing mixing of cold, deep waters to the surface. Both processes cool the upper ocean, but how much cooling is a result of each, how do waves impact heat exchange and mixing, and how does heat released to the atmosphere affect convection?

A coordinate frame for all the oceanographic and atmospheric observations was created by deploying a Mixed Layer Float, which adjusts its buoyancy to follow the motion of the water parcel immediately surrounding it. This drifting frame minimizes space-time aliasing errors that contaminate upper ocean experiments. As R/V *Thompson* tracked the float’s position researchers deployed subsurface and surface-following autonomous platforms, managed data acquisition during intensive ship surveys, and launched sensors into the atmosphere. A situational website, built to display real-time asset positions and data processing, was used by Johnson and the investigative teams to maintain the coordinate frame and understand how the ocean and atmosphere were evolving. “Managing all this took daily science meetings with weather reports and forecasts and discussions of adaptive sampling strategies,” notes Johnson. “Ship survey patterns were designed in real time to maintain spatial context for the drifting frame.”

As anticipated, monsoon conditions developed during the research expedition. The calm winds and waves, strong radiative forcing, and stratified near-surface ocean layer were upset during the second week when Cyclone Remal developed over the experiment site. Winds, waves, and heavy precipitation injected momentum into the upper ocean, deepened mixed layers, and created a cold, fresh pool on the sea surface. After Remal moved ashore, calm and sunny conditions returned. Shoaling of ocean mixed layers was observed but sea surface temperatures did not rebound to their pre-cyclone records. During the campaign’s final week, westerly winds and intermittent rain events associated with monsoon onset began, again deepening ocean mixed layers and cooling the sea surface, though not as rapidly as during the cyclone.

Investigators aboard R/V *Thompson* were at the right place and time to capture the co-evolution of the atmospheric and oceanic boundary layers during the monsoon transition. Johnson adds, “Our campaign is providing invaluable quantification of the processes driving ocean–atmosphere fluxes, with broad implications for the region.”

apl-uw teams: Eric D’Asaro, Leah Johnson, Craig Lee, Ren-Chieh Lien, Barry Ma, Emma Modrick, Anda Vladoiu

sponsor: Office of Naval Research

San Nguyen

San Nguyen

INTERNATIONAL PARTNERSHIPS

Since 2014 ONR has funded a series of initiatives centered in the Indian Ocean to bring together scientists and oceanographic research infrastructure from Indian, Sri Lankan, and U.S. institutions to understand more fully the ocean’s role in monsoon onset and variability through observational and modeling process studies. APL-UW investigators have contributed continuously to all. The initiatives have produced an important body of scientific literature and trained scores of early career scientists and engineers in the latest oceanographic technology, data analysis, and modeling.

Taiwanese collaborators on the Green Island experiment, Professors Je-Yuan Hsu and Ming-Huei Chang of National Taiwan University, have long-term connections to the Laboratory. Hsu was an oceanography graduate student at the UW from 2011 to 2017 and Chang visited APL-UW as a graduate student in 2005, then returned as a postdoctoral researcher in 2008. Both were advised by Senior Principal Oceanographer Ren-Chieh Lien.

EARLY CAREER INVESTIGATORS TAKE THE LEAD

Anda Vladoiu joined the Laboratory as a postdoctoral scholar advised by Ren-Chieh Lien in early 2019 after earning her Ph.D. from the Sorbonne University in Paris. With research support from ONR and the National Science Foundation, she became a member of the permanent research staff in January 2024. Leah Johnson’s first association with APL-UW was as a UW graduate student pursuing a Ph.D. in oceanography (2018) advised by Senior Principal Oceanographer Craig Lee. After a postdoctoral fellowship at Brown University, she returned to the Laboratory’s permanent staff in 2021. Johnson is the recipient of the 2024 American Geophysical Union Ocean Sciences Early Career Award.

An affinity group of early career principal investigators, self-organized at APL-UW and with funding support from the Executive Director, is dedicated to the particular challenges of beginning an independent research career. The group develops guidance materials in consultation with more senior researchers and administrative experts, distributes professional development grants, and coordinates regular peer-mentoring and networking opportunities.

PACE:
extend and enhance global ocean observations

NASA's latest satellite mission to study Earth's oceans and atmosphere blasted off in early February 2024. In the viewing gallery and listening to the final countdown to launch at the Kennedy Space Center was SENIOR OCEANOGRAPHER ALI CHASE, who uses optics and remote sensing technologies to study phytoplankton dynamics on regional-to-global scales. In orbit hundreds of miles above Earth, the **Plankton Aerosol Cloud and ocean Ecosystem** (PACE) satellite is providing new views of phytoplankton — the microscopic photosynthetic organisms that inhabit the sunlit waters, are the first level of the marine food web, and are responsible for approximately half of global primary production.

Since the late 1970s, NASA has flown satellite missions to detect multispectral ocean color, in turn used to estimate chlorophyll *a*, phytoplankton's primary photosynthetic pigment, in the near-surface ocean. This measurement — the 'greenness' of the water — acts as a proxy for phytoplankton biomass. Now, aboard PACE, the Ocean Color Instrument (OCI) measures the ocean across a spectrum of ultraviolet, visible, and near-infrared light. These hyperspectral sensing capabilities enable scientists to track the distribution of phytoplankton and, for the first time from space, identity which types of these organisms are present on daily, global scales.

"The OCI is extremely exciting for science because it measures every few nanometers throughout the visible light spectrum," explains Chase. "We'll be able to parse out subtle differences in the hues of the ocean that we haven't been able to in the past." In addition to chlorophyll *a*, different phytoplankton have evolved accessory pigments to harvest as much light as possible from their watery habitat. The OCI senses the pigments' various light absorbing and scattering properties and scientists can use these 'spectral fingerprints' to identify phytoplankton community composition.

The advances made possible by the global remote sensing capabilities of PACE depend on past and ongoing in situ data collection. As a graduate student, Chase received a NASA fellowship to conduct research on ships, making optical observations of light absorption and reflectance and measuring phytoplankton communities in water samples. "By linking the two, we've developed algorithms for the PACE mission to predict what is in the water based on the optical sensing," says Chase. As a postdoctoral researcher at APL-UW, Chase participated in the PACE Science and Applications team — a diverse group of investigators that brainstorm and help carry out the breadth of basic and applied research opportunities using PACE data.

Now and for the next three years, Chase is leading a team of researchers who are sailing on ships of opportunity instrumented with radiometers and underway flow-through optical systems. Their measurements of radiances, optical absorption and backscatter, and phytoplankton communities at the time and location of PACE overpass are providing direct comparisons for the satellite retrieval products. "Going full circle, what we are measuring in the ocean is being used to evaluate and validate the PACE products we developed on the Science and Applications team," adds Chase.

NASA

"We'll be able to parse out subtle differences in the hues of the ocean that we haven't been able to in the past."

Vittorio Brando

Collaborating with researchers from the UW School of Oceanography and University of Maine, Chase conducted a successful, two-week research cruise during the summer of 2024 in the Mediterranean Sea. The team acquired 10 clear-sky overpass matchups between ship-based measurements and the PACE satellite. Evaluation–validation cruises in the Pacific Ocean during October through December 2024 span a range of oceanic environments. For all in situ data collected, the team prioritizes efficient processing for timely data delivery to NASA for their validation efforts.

Soon after launch the remote sensing reflectance data from the OCI were being used to assess phytoplankton taxonomic classes in the ocean and pigment concentrations. Chase adds that the hyperspectral information collected by the OCI on PACE has never been seen before, so work is ongoing to understand the spectral features present in the data. The PACE mission team at NASA is working to adapt their atmospheric correction algorithms, which are necessary to remove the influence of the atmosphere on the spectral reflectance reaching the satellite, so that the water-leaving reflectance signal can be isolated and subsequently used to assess ocean optical properties and phytoplankton communities.

Numerous research teams from around the country are collecting field data for science product validation, as well as for ongoing algorithm development. Acquiring more data from varied ocean ecosystems helps to constrain uncertainties in algorithms that have been developed with limited datasets, and increases the applicability of satellite-based science products to use with a broader set of science questions. Importantly, this work relies on efficient data processing pipelines to mitigate the bottleneck that can occur when 'big data' are involved. To this end, Chase's group at APL-UW is also focused on developing efficient and robust tools for processing phytoplankton community composition data collected in situ.

> *"PACE allows us to learn things about the ocean that we just don't know yet, steering our research in new directions."* – Ali Chase

MENTOR: COLLABORATOR

Postdoctoral scholar Hannah Joy-Warren's current research relies on PACE observations. She joined Ali Chase's lab in 2024 and is particularly interested in efforts to help develop algorithms to estimate phytoplankton community composition in the Southern Ocean. Her research focuses on the relationship between phytoplankton community composition and the air–sea flux of CO_2 in the Southern Ocean.

The Southern Ocean is vast, remote, and harsh, and therefore ship surveys of the region that include phytoplankton sampling are much less common than in the rest of the world's oceans. The number of in situ observations has grown recently with the adoption of autonomous platforms including biochemical-sensing floats, surface vehicles, and gliders; however, these only measure chlorophyll *a* (just as satellites have prior to PACE) and not phytoplankton community composition. Satellite ocean color measurements remain the only tool available to observe Southern Ocean total phytoplankton biomass (estimated from chlorophyll *a*) at high temporal and spatial resolution, even if only at the surface layer and when sunlight reaches the region. PACE, however, is set to change this by enabling estimates of phytoplankton community composition. Hannah's work contributes a database of in situ phytoplankton observations that will help develop remote sensing algorithms to estimate phytoplankton community composition, specifically for the Southern Ocean.

Gert van Dijken

Gert van Dijken

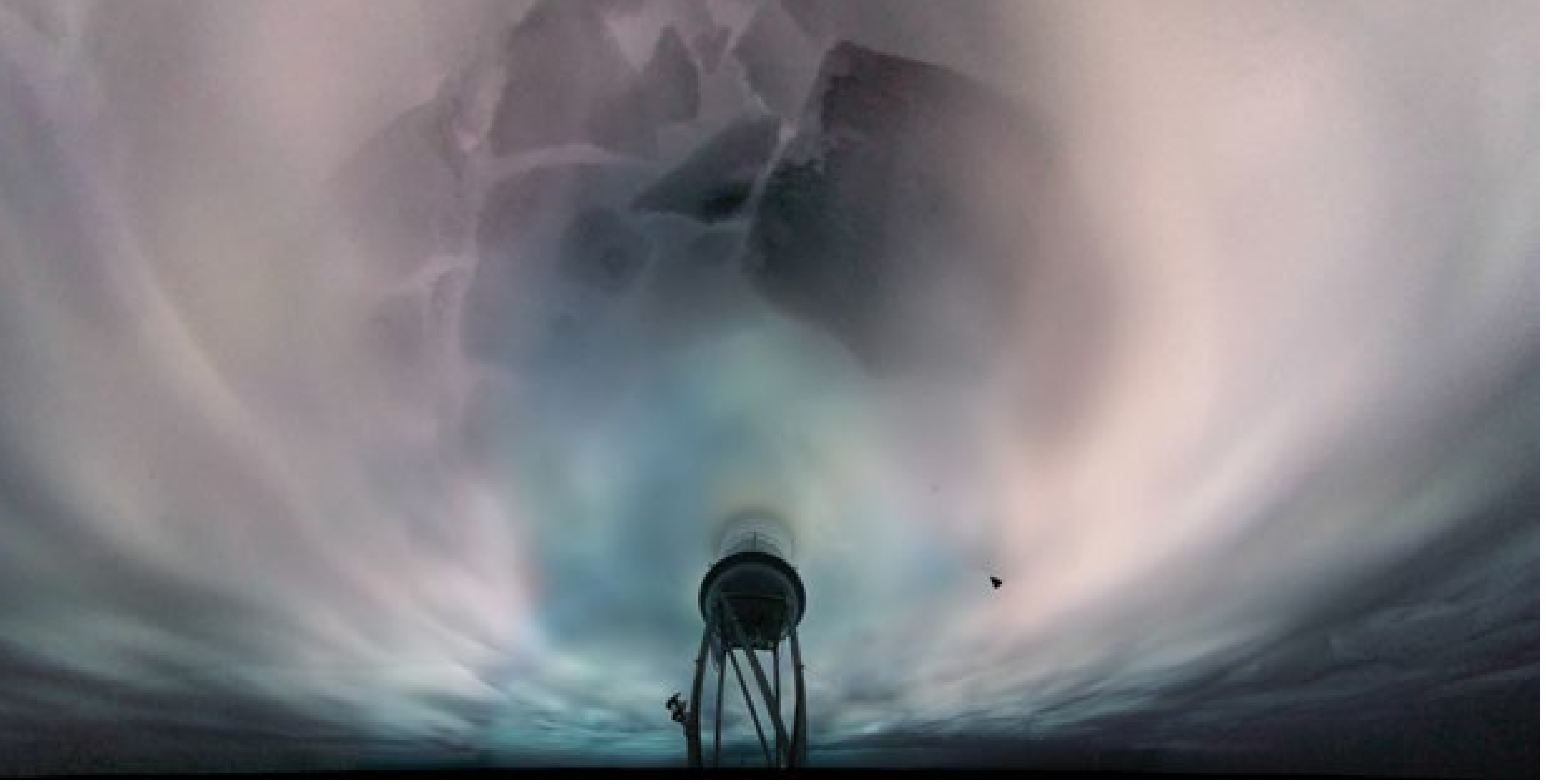
During Ph.D. studies at Stanford University, Hannah pursued research on how phytoplankton use light and their interactions with the availability of limiting nutrients in polar regions. This required ship-based experiments, as well as pigment and image analyses of phytoplankton on research cruises to determine which organisms were present where and when. Her work is driven by trying to understand if the various types of phytoplankton impact carbon cycling differently because different types use different amounts of carbon dioxide.

There are few opportunities for in situ measurements coincident with PACE overpasses of the Southern Ocean, so Hannah and Ali are using the in situ database to map a PACE observation to a data point that matches closely the location and time of year. Mapping as many representative matches as possible, their goal is to tune the satellite's algorithm to return robust phytoplankton community composition products for the region. The database is built to allow easy addition of new observations collected since PACE's launch to enable regional algorithm development.

Hannah has used these in situ observations to model the likelihood of presence of different phytoplankton taxa across the Southern Ocean. She is eager to compare modeled phytoplankton distributions to estimates from PACE, with the hopes of improving the models.

apl-uw team: Claire Berschauer, Ali Chase, Peter Gaube, Hannah Joy-Warren

sponsor: National Aeronautics and Space Administration



a gateway to persistent arctic ocean observations

A large, ice-hardened buoy designed and fabricated by APL-UW engineers is key to extended duration, autonomous scientific observations in the Arctic. It has now been deployed successfully during several field seasons, most recently last July, in the Beaufort Gyre. Riding this dominant current in the western Arctic, the buoy could theoretically circulate indefinitely.

The challenges of high-quality scientific observations in the Arctic are to collect data above and below the ice simultaneously and to remain operable in all sea ice regimes. The **Heavyweight Ice Gateway Buoy** is designed to float on the open ocean at the height of summer, be locked in the pack ice during winter, and withstand the changing stresses of the melt and freeze-up seasons.

The buoy serves as the central scientific, communication, and data exfiltration node in the Office of Naval Research's **Arctic Mobile Observing System** (AMOS). APL-UW engineers began their design with a nearly 5-m-long cylindrical steel, spar-like buoy reinforced by circular I-beams to prevent the hull from crushing in the ice. Inside, batteries chosen for their cold temperature capability power electrical and communication systems, and science instrument payloads.

Above- and below-ice observations include meteorology, surface temperature and albedo, ice and snow thickness, and, with instruments below the hull, mixed-layer ocean temperature, salinity, and currents down to 80 m. Augmenting these measurements are two networked cameras, one mounted on the buoy superstructure in a heated dome, and the other subsurface and facing upward. Their images add situational awareness for contemporaneous science observations and provide a visual reference of buoy health. The buoy's two satellite communication systems offload the large data sets and high-resolution images.

Powerful as a science platform on its own, the buoy's great contribution to AMOS is as a central communication and navigation hub for a cloud of subsea ocean robots. Networked with long-endurance gliders and floats, it serves as a bridge across the ice–ocean interface, enabling controlled, coordinated, and cooperative sampling and data relay.

apl-uw team: Jacob Anderson, Eleanor Brosius, Benjamin Cunningham, Anthony Falcone, Aaron Jost, Philip LaMothe, Craig Lee, Rowan Sharman, Kira Smith, Sarah Webster

sponsor: Office of Naval Research

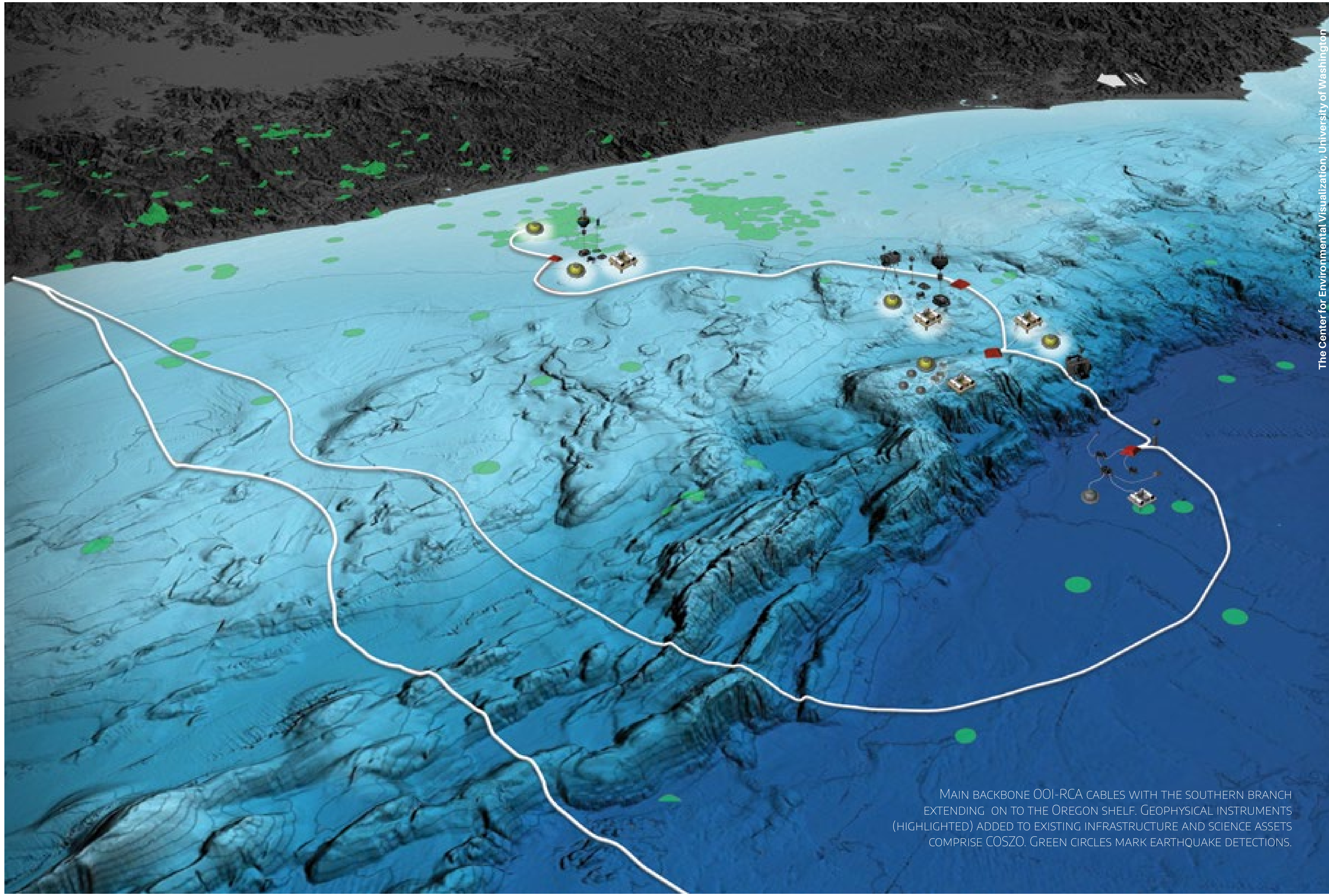
engineering a seafloor subduction zone observatory

Subduction zones are the source of the most powerful earthquakes and can trigger devastating tsunamis. The Cascadia subduction zone extending from California to Vancouver Island has been the site of magnitude ~9 earthquakes, rupturing its length about every 500 years. Nobody knows when, but a major earthquake will happen again.

The APL-UW engineers who designed, installed, and now maintain the **Ocean Observatories Initiative Regional Cabled Array** (OOI-RCA) are tackling a significant expansion of what is already the world's largest cabled undersea observatory. With research infrastructure funding of over $10M from the National Science Foundation, they are creating the **Cascadia Offshore Subduction Zone Observatory** (COSZO) by adding new seafloor junction boxes and a suite of geophysical instruments to three of the array's primary nodes off the Oregon coast in 2026.

From the outset, the OOI-RCA network stretching hundreds of miles off the Pacific Northwest coast was designed for future expansion with extra power, bandwidth, and plug-in ports to accommodate additional science instruments. "The COSZO expansion takes advantage of this aspect of the cabled array more than any other project so far," says Senior Principal Engineer Mike Harrington, who leads the engineering team on the project. "It will also significantly expand the footprint of geophysical instrumentation in this critical seafloor environment." Now and over the next two years of the design, fabrication, and installation phase, University of Washington Professor of Oceanography William Wilcock, a marine geophysicist and lead Principal Investigator for COSZO, is working closely with Harrington and the team on the optimal configuration of new instrumentation to achieve scientific goals.

Wilcock notes that the National Science Foundation has invested in worldwide studies of subduction zones because they all behave differently and pose grave risks and hazards. Seismically, the Cascadia subduction zone is very quiet, with almost no small earthquakes detected at the megathrust — the boundary where the Juan de Fuca plate is dipping under the North American plate. This could be because the plates are completely locked, or creeping or slipping slowly, producing tremors that are too small or too infrequent to be detected from shore.



Main backbone OOI-RCA cables with the southern branch extending on to the Oregon shelf. Geophysical instruments (highlighted) added to existing infrastructure and science assets comprise COSZO. Green circles mark earthquake detections.

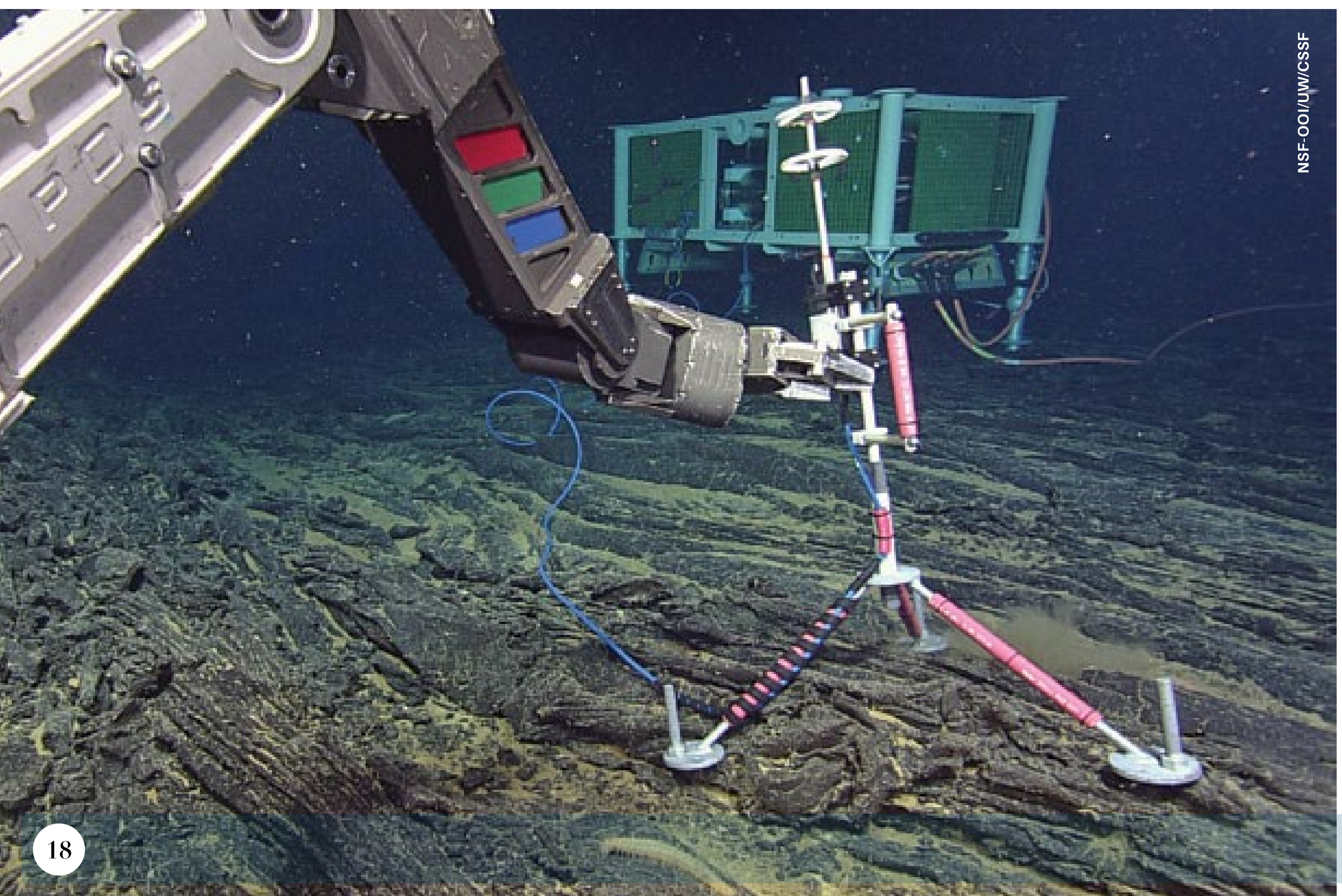
The OOI-RCA is situated perfectly for geophysical studies of the subduction zone, because the primary cables cross it. To the north and south of the OOI-RCA network, terrestrial data suggest that the subduction zone is mostly locked. Off central Oregon, however, two shallow clusters of earthquakes have been observed, and one is almost directly beneath an OOI-RCA shallow node on the shelf. Leveraging existing infrastructure, the team is adding geophysical observations where none had been made before and where the most offshore earthquakes have been detected.

REFURBISHING THE FIRST UNDERSEA CABLED OBSERVATORY

APL-UW ocean engineers are turning attention back to the **Monterey Accelerated Research System** (MARS), the first demonstration of a cabled undersea observatory with plug-in ports for science instruments, commissioned in 2008. Designed and fabricated in collaboration with the Jet Propulsion Laboratory, Woods Hole Oceanographic Institution, and the Monterey Bay Aquarium and Research Institute, the single science node of MARS has now logged over 15 years of reliable service. Last fall the electronics package from the science node was recovered from the seafloor of Monterey Bay.

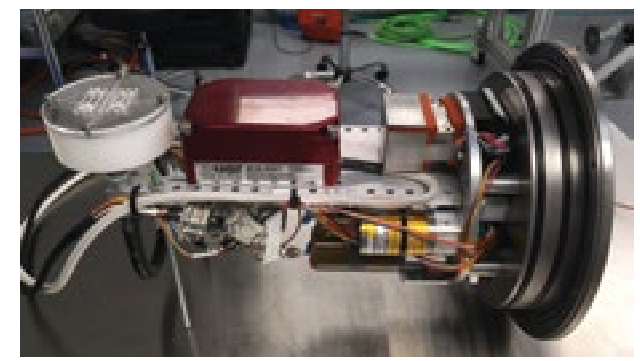
APL-UW engineers are designing an updated low-voltage power system that distributes, controls, and monitors the power to the node electronic components and eight external science ports, and upgrading the data connectivity to 1 Gb Ethernet. The system's mechanical components are being refurbished to prepare for the new APL-UW power electronics and MBARI networking equipment.

When the electronics package was pulled up from the seafloor, a mini-node was installed to maintain the continuous time series from the science instruments streaming to MBARI. Engineers will deliver the power system by the end of 2024 and MARS node components will be integrated, tested, and installed in early 2025.



NSF-OOI/UW/CSSF

When operational, COSZO will provide 24/7/365 measurements to address several urgent questions. Are the Juan de Fuca and North American tectonic plates slipping past each other slowly, producing very low-frequency earthquakes? If so, are these miniquakes



redistributing stress on the megathrust? How are the clusters of shallow earthquakes offshore linked to the megathrust, and at what rate is the seafloor deforming? Because OOI-RCA data stream to shore at the speed of light, an operational COSZO will provide input to real time earthquake detection and warning systems.

COSZO expansion of the OOI-RCA network begins by adding a secondary node, or science junction box, to extend off each of three primary nodes distributed on the continental shelf and slope. Controlled by custom APL-UW electronics, these secondary nodes are the critical interface between the cable infrastructure and the science instruments. Plugged into the new junction boxes are buried broadband seismometers, low-frequency hydrophones, strong motion accelerometers, high-resolution pressure gauges, and current meters. Each employ wet-mate connectors so that an entire junction box does not have to be recovered in the event of a single instrument failure.

High-quality broadband seismic, strong motion acceleration, and seafloor pressure observations at multiple locations enable scientists to detect and localize shallow tremor signals and very low-frequency earthquakes accurately, and to measure temporal changes in the velocity structure of the seafloor. By measuring ocean currents, scientists can remove the influence of oceanographic pressure gradients that introduce false readings on seafloor pressure sensors, giving confidence that detected signals are true tremor events.

Harrington adds that the team has learned many lessons over the past decade of OOI-RCA operations and maintenance. Instruments must be designed with materials, control systems, and networking interfaces that will perform on the seafloor without interruption for many years. The team will put all the COSZO components through several rounds of integration testing — in saltwater tanks, under high pressure to simulate seafloor deployment, and networked into lab-based, OOI-RCA specification power and communications systems — to assure proper and robust behavior when plugged into the array.

apl-uw team: Keith Blood, Geoff Cram, Grant Dunn, Mike Harrington, Dana Manalang, Chuck McGuire, Kira Smith, James Tilley

sponsor: National Science Foundation

naval oceanography and acoustics experiments

OFF THE WASHINGTON COAST

Washington coastal waters are rich with complex temperature and salinity variations that create surface and subsurface acoustic ducts, affecting passive and active sonar operations, especially in the mid-frequency range. Acoustic ducts, or layers of sound speed minima that can extend tens of meters in the vertical and tens of kilometers in the horizontal on the Washington shelf, can trap and focus sound energy, often channeling this sound over long distances, thus affecting naval undersea communications and sensing operations.

An interdisciplinary and complementary team of acousticians, physical oceanographers, experimentalists, and modelers conducted a joint oceanographic–acoustics field campaign in the summer of 2022. Using historical observational data and global operational ocean models, they selected an experimental site likely to be a region of pervasive, seasonal subsurface ducts, roughly 40 km west of Westport, Washington on the outer continental shelf.

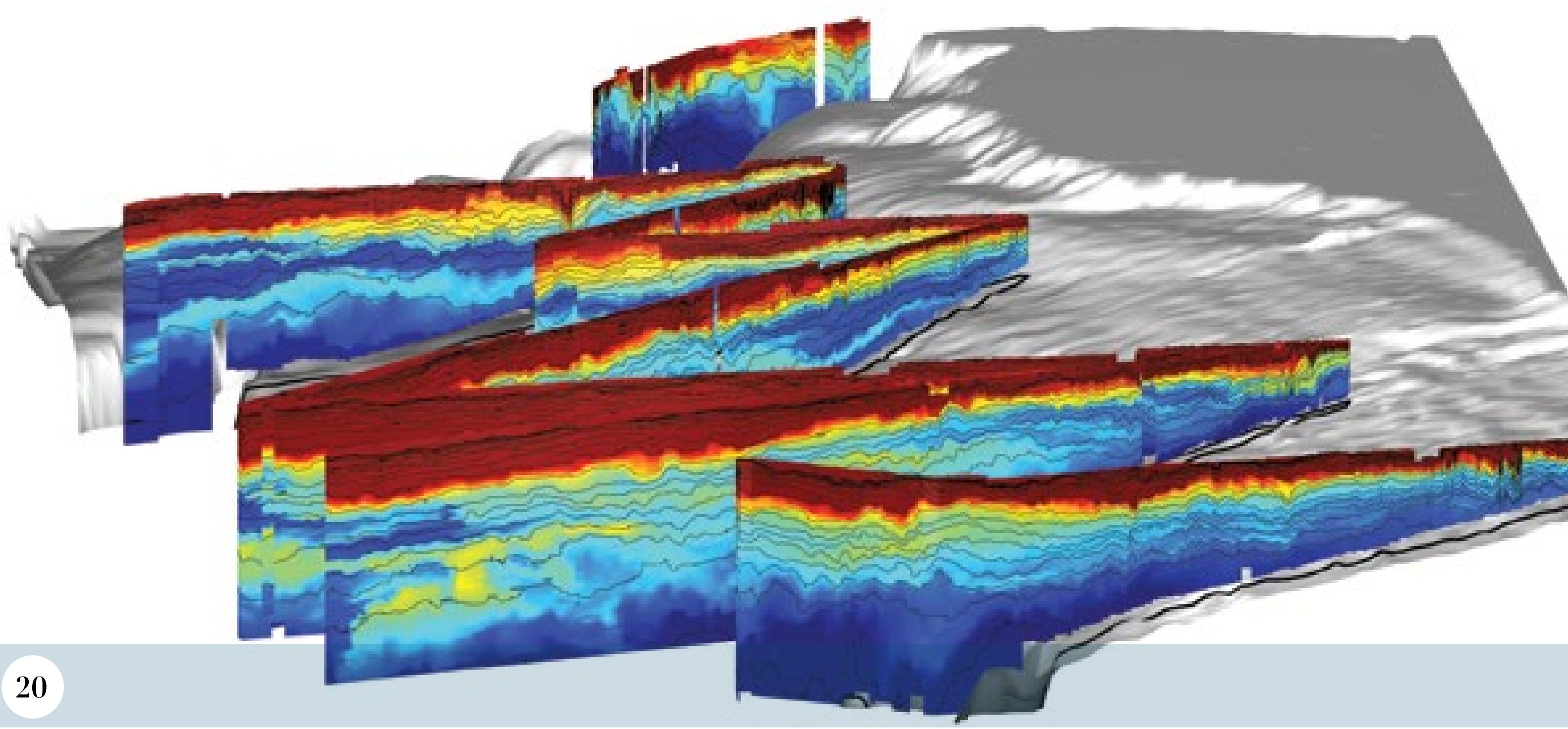
High-resolution towed-body measurements mapped sound speed and other water properties in three dimensions over 1200 km in total over 13 days. Concurrent acoustics experiments were conducted with sources and receiver arrays distributed along a 20-km-long cross-shelf transmission path.

Subsurface ducts were sampled extensively, spanning depths of 50 to 90 m and extending from mid-shelf offshore over the continental slope. These observations have been used to improve model predictions of subsurface ducts and their mid-frequency acoustic trapping on the Washington coast and are being used as the ocean state for ongoing oceanographic and acoustic modeling studies. With data assimilation, Navy models have been improved to predict duct presence near the time and location of the observations.

The team returns in summer 2025 to the same coastal region because they can reliably anticipate the presence and dominant acoustic characteristics of subsurface ducts at this time of year. Expanding the scope of acoustic and oceanographic measurements, the towed body and oceanographic moorings will be equipped with more sensors to better resolve the vertical and horizontal structure of the sound speed environment. Acoustics experiments will use towed and moored sources transmitting at various depths, frequencies, and ranges to moored and mobile receiving arrays. Adding these refined observations, the team can increase the capacity of coupled ocean and acoustic models to predict transmission loss in this coastal environment.

apl-uw team: Ramsey Harcourt, Todd Hefner, John Mickett, Kumar Ravi Prakash, Dajun Tang, Eric Thorsos, Guangyu Xu

sponsor: Office of Naval Research, Task Force Ocean



ON THE SE ALASKA COAST

A team of APL-UW scientists was invited in early summer 2024 to contribute their expertise to a collaborative oceanographic experiment in support of the U.S. Navy. Their task: to better understand ocean conditions at the air–sea interface by measuring near-surface temperature, salinity, turbulent mixing, solar heating, currents, and waves. The goal: to improve the predictive capabilities of how the surface ocean evolves in time and space in response to various forcings.

"The forecast models of the surface ocean that we have now perform best in the open ocean and on timescales of a day or more, and over spatial scales greater than 1 km," explains Senior Oceanographer Kristin Zeiden "We know there is a lot of variability in upper ocean characteristics and surface forcing on much finer scales that are beyond current modeling capabilities." The experiments last June were the first in a series of planned experiments with other partners in coastal waters sheltered from the influence of the open ocean.

The key contribution of the APL-UW team was to deploy custom instrumentation and platforms in the air and on the ocean. Visible light and infrared cameras were mounted on a fixed-wing aircraft and flown above the experiment site to observe features on the two-dimensional surface that often have strong temperature signals, such as fronts and internal waves. Observations made by surface wave following buoys and from the University of Washington's R/V *Rachel Carson* were used to measure the vertical structure of the upper ocean, particularly stratification and turbulence, and the dynamics at the atmosphere–ocean interface. "Stitching these observations together by measuring the same variables, say sea surface waves and currents, with both types of platforms gives us new insights to how strong vertical variability relates to horizontal variability and vice versa," adds Zeiden.

apl-uw team: Chris Chickadel, Alex de Klerk, Michael James, Jim Thomson, Kristin Zeiden

sponsors: Office of Naval Research and Naval Sea Systems Command

STEM EDUCATION IN THE FIELD

Joining the field experiments in June was Michael James, a doctoral student and technician at the Naval Surface Warfare Center Carderock. With several years of experience performing field engineering and oceanographic observations analysis at NSWCCD, Michael took responsibility for several observing systems and their data streams aboard R/V *Carson*, then created pipelines for data parsing and structuring.

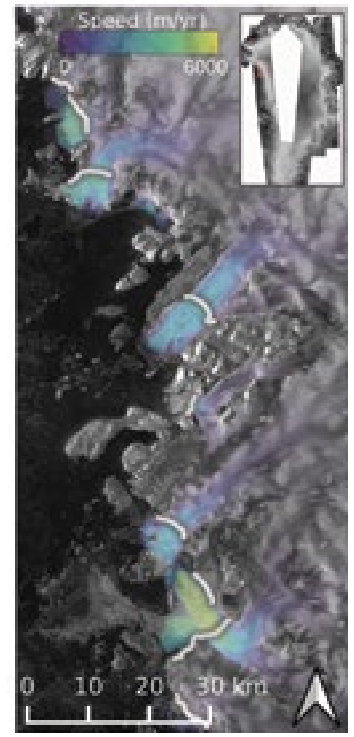
Michael is pursuing a Ph.D. in the UW Department of Civil and Environmental Engineering, co-advised by Senior Oceanographer Kristin Zeiden and Senior Principal Oceanographer Jim Thomson who hold faculty appointments in the department. His studies are supported by the Department of Defense SMART scholarship program (Science, MAthematics, and Research for Transformation). The June field experiments in coastal Alaska are likely the first of many where James will gain hands-on research experience with co-advisors Zeiden and Thomson. "This opportunity allows me to learn in a diverse, collaborative, and cross-disciplinary environment," says James. "It's exciting to work on a project where all parties form a cohesive effort that benefits the scientific community and the Navy."

mélange in motion

More than 200 large outlet glaciers drain ice from the Greenland Ice Sheet into the surrounding ocean. Since the late 1990s, the satellite record has shown that one-third to one-half of the ice lost from Greenland has been due to the acceleration of ice discharge from the marine-terminating glaciers, with implications for global sea level rise.

A steady supply of icebergs calved from outlet glaciers combine with seasonal sea ice to form an aggregate mixture — mélange — in Greenland's fjords. "Glaciologists hypothesize that glacier-fed fjords choked with rigid mélange can crowd the glacier front and temporarily inhibit calving, allowing glaciers to advance down fjord," says Senior Research Scientist Michalea King, "… and we often observe glacier front calving and retreat occurring after the mélange flushes out." Mélange can vary in thickness and strength, and calving behavior is thought to be most sensitive to mélange when bergs and ice together form a rigid aggregate, rather than a weakly connected mixture with freely flowing elements moving within the fjord.

King designed a study to assess proglacial mélange variability and its role in retreat of Greenland's large outlet glaciers. Glacier behavior is highly heterogeneous, even for neighboring glaciers, with varying timing and patterns of seasonal calving front advance and retreat. Therefore, each glacier could respond differently to mélange based on its unique characteristics. King's first task of the project, which began in spring 2024, is to map the extent and distribution of rigid mélange surrounding the entire Greenland Ice Sheet. She is using synthetic aperture radar imagery from the European Space Agency's Sentinel-1 satellites, which provide coverage of most areas of the Greenland coastline every 6 to 12 days since 2015.



Working with project co-investigator Senior Principal Engineer Ian Joughin, King is adapting methods Joughin developed for the Greenland Ice Sheet Mapping Project. The project's workflow estimates velocity of grounded glacial ice by comparing pairs of satellite images and measuring the relative change in position of trackable features. "The method can be applied to identify and mask areas of rigid mélange in motion. In rigid mélange, the pattern and arrangement of icebergs and sea ice can be correlated from one image to the next due to the mélange flowing altogether in a uniform speed and direction through the fjord," explains King. "When mélange is not rigid, individual features move randomly relative to each other resulting in decorrelation between images, so velocity cannot be derived." These data and methods are enabling large-scale mapping and analysis of rigid mélange evolution and interactions with calving events across the entire ice sheet.

Early results demonstrate that mélange coverage varies greatly from one year to the next and the duration of rigid mélange coverage typically decreases with distance from the calving front. Mentoring DINO SIP (p. 34) intern Mikayla Morris, King designed a study to apply the methods to a multi-glacier system in western Greenland. Results from the summer project show the importance of determining mélange rigidity, because glaciers were more likely to calve and retreat when non-rigid mélange was present near the glacier front. These results agree with ongoing analyses at several other glaciers around Greenland with seasonally varying calving fronts: extensive rigid mélange coincides with advance, while retreat occurs during periods with little to no rigid mélange. Velocity mapping has also been instrumental to document the evolution of mélange formation and breakup. King and Joughin observed instances of increased flow speeds near the outermost extent of rigid mélange, followed by incremental mélange breakup progressing from the outermost extents inward, and culminating in large calving events once the mélange was completely flushed away from the glacier front.

The discoveries of mélange evolution and glacier calving behavior are now being aggregated over the entire ice sheet to identify regional patterns of change. King is also drawing on other satellite data sources, such as ice freeboard heights from NASA's ICESat-2 altimeter and digital elevation models from ArcticDEM, to estimate temporal changes in mélange thickness and volume. Together, King aims to use these observations to better understand the physical characteristics, such as fjord ice volume, residency time, and iceberg size and distribution, most important to mélange seasonal variability, its interactions with glacier calving, and potentially how mélange coverage and rigidity will evolve in the future.

apl-uw team: Ian Joughin, Michalea King, Ben Smith

sponsors: National Science Foundation Office of Polar Programs and National Aeronautics and Space Administration

ICE SHEET MASS BALANCE INTERCOMPARISON EXERCISE

Glaciologists use several methods based on satellite remote sensing observations to measure mass changes in the great ice sheets of Greenland and Antarctica. Three main methods are: altimetry (surface elevation change, volume), gravimetry (relating Earth's gravity field to mass), and input-output (snowfall accumulation minus glacier outflow velocity). Since 2011, an international community of cryosphere scientists funded by the European Space Agency and NASA has collaborated to reconcile these methods to improve estimates of ice sheet mass balance and contributions to sea level rise.

APL-UW Senior Research Scientist Tyler Sutterley is the current U.S. lead for the program and Michalea King leads the input-output working group. For the latest IMBIE assessment in 2023, the team combined and compared 50 independent estimates and report that the polar ice sheets have together lost ice every year since the early 1990s and the rate of loss has more than tripled over the 1992–2020 study period. Current ice loss from the ice sheets now accounts for more than 25% of global sea level rise.

Prior to being tasked with IMBIE leadership, Sutterley contributed to IMBIE assessments in both the gravimetry and altimetry sections. Gravimetry, or the use of temporal fluctuations in the Earth's gravitational field to determine mass change, is a relatively modern technique for monitoring ice sheet mass balance. By tracking month-by-month changes in gravity, Sutterley has amassed records of ice sheet and sea level change going back to 2002 with the launch of the original Gravity Recovery and Climate Experiment (GRACE) mission. These results have shown long-term mass loss at both poles and large climatic events, such as dramatic melt in the Greenland interior and massive snowfall events in East Antarctica.

King is a newer member of the IMBIE. Of the three main working groups, input-output-based IMBIE submissions are fewest in number (one for Antarctica and three for Greenland). King developed a new extended mass change record for Greenland, and her dataset will be incorporated in the upcoming IMBIE assessment, which is nearing completion. In addition to Sutterley and King, Senior Principal Physicist Ben Smith leads the altimetry working group, and Ian Joughin has served on the IMBIE executive committee.

coast, camera, action!

The community of North Cove, Washington, on the north shore of Willapa Bay, had the fastest eroding beaches on the U.S. West Coast until a state agency and community activists joined forces.

Since 1997, the Washington State Department of Ecology (Ecology) has conducted seasonal shoreline transect surveys that show how the erosion and accretion cycle has been out of balance for decades. In 2016, Ecology partnered with a local community activist group — Wash Away No More — to install dynamic revetments along North Cove's beaches. This strategy mimics other natural Pacific Northwest beaches by adding rocky cobbles and driftwood of various sizes to the back beach, which can absorb wave energy and limit beach erosion during winter storms and improve sand retention during the summer accretion season. Revetment material, however, requires continuous monitoring, care, and feeding.

To keep an eye on these dynamic revetments, Wash Away No More erected metal sculptures in the likenesses of local photographers at two popular beach access points and encouraged visitors to take photos of the beach and upload them to an online image repository. When viewed in succession, these images (over 500 per site) produce time-lapse videos of beach change over days, weeks, months, and years.

Senior Oceanographer Roxanne Carini, whose research uses remote sensing measurements to study coastal hydrodynamics and hazards, and nearshore wave physics, leads a research project that builds on this community and agency work. One component of the project is designed to extract quantitative information from the beachcombers' smartphone photos.

Carini, Allen, and Kolenski

CoastSnap, a method developed by environmental engineers in Australia, is being applied by Carini on North Cove beaches. It relies on a steel smartphone cradle installed some height above a beach to orient all photos from the same position and in an alongshore aspect. Then, by mapping ground control points such as stable structures and landmarks within the field of view, photogrammetry techniques are used to map the coastline position in each photo.

Now, the sculptures above the North Cove beaches have been modified by a local artist, Earl Davis of the Shoalwater Bay Tribe, to include the CoastSnap photo cradle and an informational display on how to take and upload photos for the research project. As partners on the project, Ecology conducted a GPS survey to measure the ground control points, and Carini has rectified hundreds of photos, all submitted by community members since a May 2024 'relaunch' event for the photo stations.

While beach width measurements derived from smartphone photos are less accurate than Ecology's GPS beach mapping, the high frequency of photo submissions from the community can fill in the gaps between seasonal surveys. Combined with concurrent environmental observations, Carini and her research partners seek a better understanding of how, when, and why dynamic revetment efforts are working or failing.

Carini thrives in this type of research environment. "Working closely with folks living in North Cove keeps me accountable and adaptable. Our conversations often challenge me to think creatively about research paths that advance our scientific understanding and answer questions of interest to the community. If they don't see themselves in this work, they won't submit photos, and if they don't submit photos, I have no data to work with." When asked if it would be easier to do this analysis from a camera installed on a telephone pole overlooking the beach, Carini laughs. "Sure, but it wouldn't be as much fun, nor would it contribute to lasting community engagement, education, and buy-in."

This past summer, Carini and a DINO SIP (p. 34) intern, Megan Kolenski, extracted beach width metrics from the crowd-sourced photos, and preliminary analysis shows good agreement with the Ecology surveys. Outreach to the community over social media resulted in an increase in photo submissions before and after a summer storm, providing an opportunity to analyze beach response to the event.

Carini and the project team met with several engaged community members, including Wash Away No More founder Connie Allen, to co-design a suite of data products — beach trend plots and before and after beach comparisons to visualize storm impacts — that can be updated as new imagery becomes available. In early 2025, the team will host an event in North Cove to share results, celebrate successes, and plan future work with the community.

sponsors: Washington Sea Grant and UW EarthLab

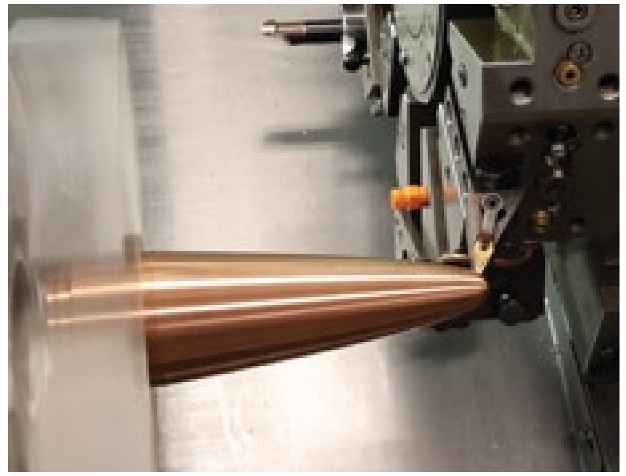
Van Adam Davis

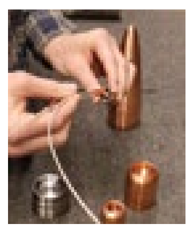
specialized facilities support research enterprise

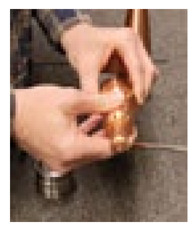
MACHINE SHOP: DIVING DEEP INTO THE GREENLAND ICE SHEET

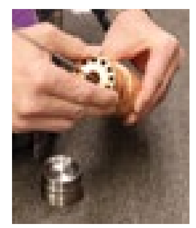
The Ice Diver team of scientists and engineers has a successful record of developing and deploying melt probes that descend through glacial ice using modest amounts of electrical power. The instrument maintains connection to the surface and its electrical heating supply through wires spooled inside the probe body that unwind during descent. Melt probes are exciting for deep polar ice exploration because they can potentially place more instruments than conventional ice drilling, thanks to their much lower operational costs.

The 11-foot-long spear-shaped Ice Diver is a unique and almost entirely custom instrument that began as a scientific goal to sample the oldest ice on Earth and some conceptual drawings presented to the Laboratory's Machine Shop fabrication engineers. The tapered nose is a copper shell that houses several assembly components to accommodate two dozen tiny heater cartridges and their wiring. Team engineers approached Machine Shop Manager Pete Frane with a wishful design for the part. "I thought I was asking for a custom part that would be impossible to manufacture," says Mechanical Engineer Justin Burnett. "But Pete and the shop proposed a solution quickly and we were able to move forward with a detailed design." CAD drawings were transformed by milling machine software to craft the many nose cone components from blanks of heat-conductive copper.









At Summit Station on the Greenland Ice Sheet in June 2024, Ice Diver achieved a depth of 350 m. All systems performed as engineered and instrument payloads returned valuable scientific data. A laser scanner logged dust particles trapped in the layers of ice, which are used by scientists to infer ice age because the atmosphere was dustier in past, colder epochs, and an optical fiber unspooled from the probe body during descent returned temperature profiles even when the filament was frozen in the ice above Ice Diver.

The mission was limited by off-the-shelf heating cartridges. Engineers are redesigning the heating supply to provide better electrical isolation and redundancy, and are now collaborating with the Machine Shop to revise the nose cone assembly components to meet the new specifications. In this way, the unique combination of people, institutional knowledge, facilities, and can-do spirit will enable future Ice Diver science missions.

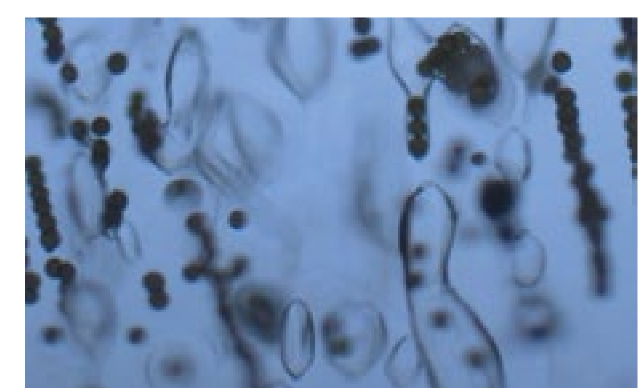
CRYOLAB: MICROPLASTIC POLLUTION IN THE ARCTIC

In its climate controlled rooms that can be maintained at temperatures as low as –30°C, Senior Principal Physicist Bonnie Light is growing sea ice littered with extremely small polyethylene beads.

Microplastics are a massive pollution problem in the world's oceans. Even in the far north, microplastics are found everywhere in the Arctic ecosystem. For a project funded by the National Science Foundation, Light and colleagues are using the APL-UW Laboratory for Environmental Cryosphere Science (ALECS) to understand one component of microplastic circulation through the sea ice–ocean system.

In experiments designed to simulate how microplastics may be entrained into and released from seasonally growing and melting sea ice, plastic particles engineered to remain suspended in the water column are observed as the 'liquid ocean' becomes 'sea ice'. "Our hypothesis is that they would be entrained in the small, numerous inclusions of liquid seawater that form naturally as the ice freezes," explains Light. "But we found microplastics in the ice matrix itself. Some are associated with the brine inclusions, but most are not." The particles frozen into the ice matrix are also arranged in linear strings, which is consistent with entrainment at the ice–ocean growth interface.

To simulate the release of microplastics from melting sea ice, Light and Principal Biological Oceanographer Monica Orellana will add some biology to the Cryolab's 'ocean' and 'sea ice' physical system. Marine polymer gels are dissolved organic matter produced by ice algae and phytoplankton in the Arctic. They are very sticky. When added, will the gels entrap particles, inhibiting their release? In experiments replicating the slow, partial melt of the pack ice during summer in the Arctic, they will test the mechanisms by which gels may collect and concentrate microplastics in the ecosystem.



nontraditional collaborations spark innovation

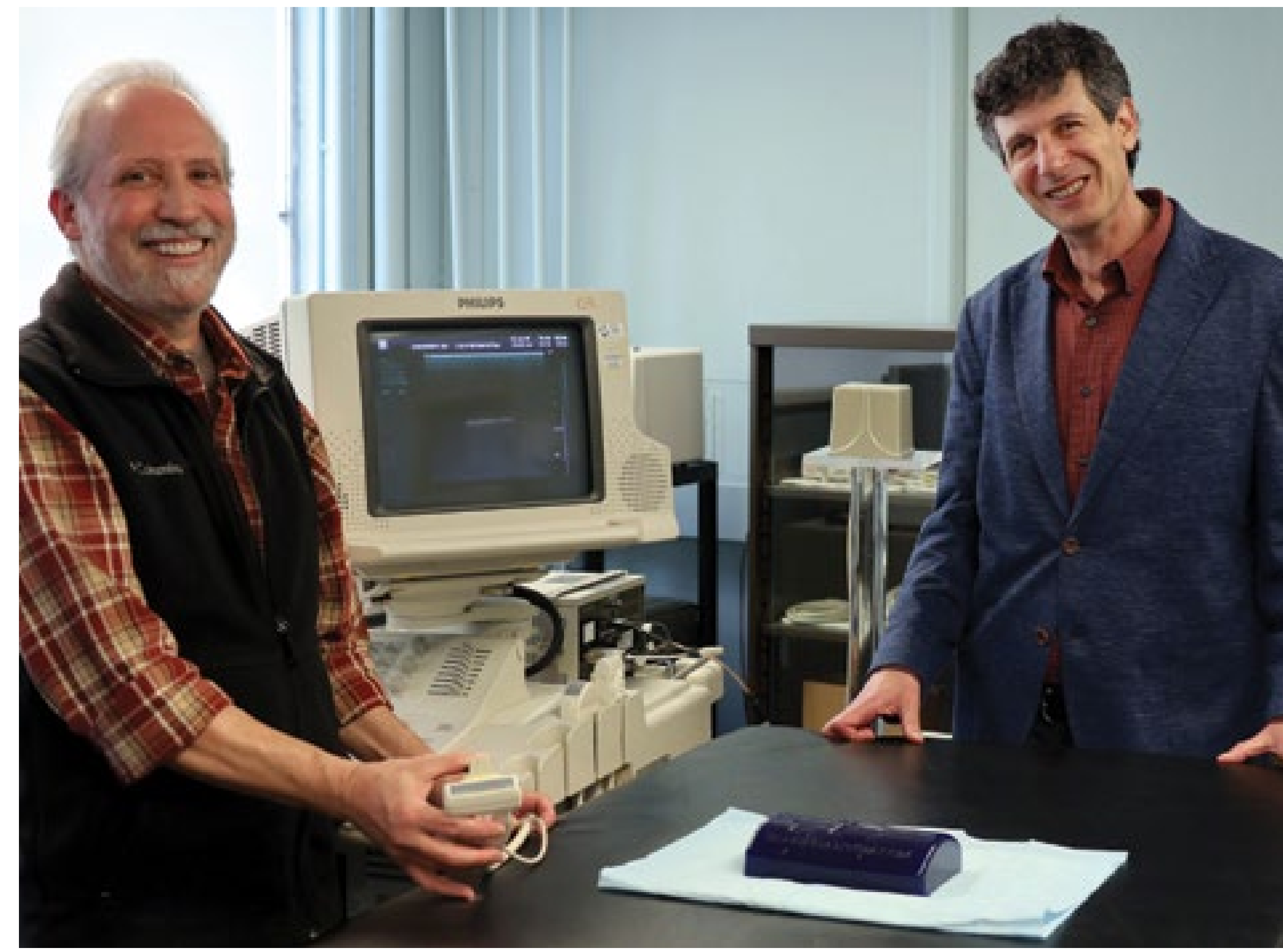
Since 2000, the Laboratory's Executive Director has funded an internal, competitive program to seek and support new ideas proposed by multidisciplinary workgroups. The criteria: teams must be comprised of nontraditional collaborators and the proposed effort must lead to innovations that can win funding from government research sponsors and/or will advance capabilities that enable future Laboratory research and development programs.

MACHINE LEARNING FOR FREEHAND THREE-DIMENSIONAL ULTRASOUND IMAGING

Principal Research Scientist Vitaly Ablavsky and Senior Engineer Dan Leotta first met virtually in 2020 during the pandemic, when nearly all APL-UW staff were working remotely or in isolation. Leotta recalls that he and colleagues at the Laboratory's Center for Industrial and Medical Ultrasound were working on three-dimensional ultrasound imaging technologies and had identified the potential of machine learning methods. Ablavsky's expertise in computer vision and machine learning, and his desire to work on a problem related to human health, presented a real opportunity to collaborate on 3D ultrasound imaging, with the goal of expanding its availability.

Current state-of-the-art, clinical 3D ultrasound imaging relies on expensive hardware systems to run 2D matrix probes that can image a volume of interest in real time. "At CIMU we have attacked the problem by adding a spatial tracking device to a standard ultrasound probe so that 2D images are registered in 3D space, allowing for 3D reconstructions," explains Leotta. The goal of the collaboration is to develop a software solution based in machine learning that converts a standard 2D ultrasound system into a 3D imaging system, removing the cost and complexity of additional hardware.

"One fundamental challenge is that ultrasound data are very different from videos we collect with our smartphones, so off-the-shelf computer vision and AI methods don't apply," says Ablavsky. The problem is inherently that of estimating a hidden (latent) state, that is, the 3D trajectory of the ultrasound probe and the 3D volume of the tissue, given the 2D temporally adjacent ultrasound image 'slices'. "We are taking a two-stage approach. First, we're estimating the 3D trajectory of the ultrasound probe, then, conditioned on that trajectory, reconstructing the 3D volume by analytical computations."



The team quickly discovered the real-world limitations of prior published 3D ultrasound imaging methods. With the help of student researchers Soofiyan Atar and Griffin Golias the team has made progress by tackling the many technical details one by one. Breakthroughs have been made by partitioning the computational problems. "We are finishing up the first automatic computational pipeline that goes from 2D data captured on an ultrasound system all the way to a 3D volume," says Ablavsky. The collaboration will continue after the internal R&D funding period. Given the progress made, Leotta and Ablavsky are confident in securing future research support and bringing the technology to clinical field testing in low-resource healthcare settings such as community or rural health clinics.

of scientists & engineers NEXT GENERATION

APL-UW scientists teach, advise, and mentor scores of students across the academic spectrum of our world-class research university every year. They range from undergraduate and graduate students pursuing degrees (p. 31) in over a dozen disciplines to postdoctoral scholars (p. 38) whose career interests align with the Laboratory's areas of expertise.

Over 40 Laboratory scientists hold faculty appointments in UW academic departments, principally in the College of Engineering and College of the Environment. Students pursuing UW degrees are entrained into their advisors' sponsored research projects, where they gain research experiences beyond the classroom and build professional support networks. Graduate engineering students in John Mower's lab, for example, are working on low-frequency acoustic communication problems sponsored by the Office of Naval Research by applying signal processing methods learned while preparing the winning entry in a professional society technical competition (p. 37).

Senior Scientist Morteza Derakhti, who is also an Assistant Professor of Civil and Environmental Engineering, is involving doctoral students in projects sponsored by the U.S. Coastal Research Program and NAVFAC, where they are applying high-resolution meshless computational fluid dynamics modeling to coastal hydrodynamics and fluid–structure interaction problems. Meshless methods offer improved robustness and accuracy in simulations involving complex, rapidly changing interfacial flows, outperforming traditional mesh-based approaches. Additionally, these methods are well-suited for execution on GPUs, which significantly enhance computational scalability and efficiency compared to CPU-based models.

Alireza Zarei is studying turbulence and sediment suspension and transport beneath breaking waves using high-resolution computational fluid dynamics modeling and laboratory experiments. Ethan Evans is applying the smoothed particle hydrodynamics modeling technique to explore the dynamics and power generation potential of submerged wave energy converters at varying depths, which offer advantages including greater durability compared to those riding surface waves. "Advising graduate students fosters fresh ideas and new perspectives," says Derakhti. "It also expands my network of collaborators, allowing us to address larger and more complex challenges together."

Beyond UW academic programs, Laboratory staff inspire and train students and educators at every level. Polar scientists Harry Stern and Ignatius Rigor, respectively, coordinate a weekend of hands-on activities for early learners at Washington State's largest science museum and an interactive experience for educators and students across the U.S. and around the world that immerses them in long-term observations of Arctic Ocean circulation (p. 32).

Ongoing internship programs organized by APL-UW scientists and administrators open STEM research opportunities for Navy ROTC students and seniors graduating from an HBCU. Now in its second year, the Diverse and Inclusive Naval Oceanographic Summer Internship Program (p. 34) invites to APL-UW a growing number of undergraduates from historically underrepresented groups in STEM for an eight-week immersive research experience.

We recognize with pride every year the graduate students who earned degrees in UW departments and the APL-UW scientists who served as their research and thesis advisors.

Tongxin Cai • Oceanography, M.S., 2024
Internal Tide Variability off Central California: Multiple Sources, Seasonality, and Eddying Background
Zhongxiang Zhao and Eric D'Asaro

Ian Good • Mechanical Engineering, Ph.D., 2024
Torque Responsive Metamaterials for Efficient Energy, Inertia, and Force Transduction
Aniruddh Vashisth (UW ME) and Aaron Marburg

Lily Nguyen
Civil and Environmental Engineering, M.S., 2024
Laboratory Observations of Foam Generation from Field-Scale Breaking Waves
Chris Chickadel and Chris Bassett

Nicole Pham
Electrical and Computer Engineering, M.S., 2024
Radar Remote Sensing Research and Applications
John Mower and Matt Reynolds (UW ECE)

Megan Toomey
Electrical and Computer Engineering, M.S., 2024
Using an Off-The-Shelf Rigid Gripper to Grasp Objects of Different Strengths and Compliances
Aaron Marburg and Howard Chizeck

Marie Zahn • Aquatic and Fishery Sciences, Ph.D., 2023
Quantifying Features of Arctic Odontocete Echolocation and Marine Habitat Variation in West Greenland
Kristin Laidre

sharing cool science

The opportunity for thousands to explore cool science returned to the Pacific Science Center in Seattle last March after a hiatus caused by the COVID-19 pandemic. Organized by Principal Mathematician Harry Stern, the 2024 **Polar Science Weekend** reinstated the Laboratory's tradition of engaging the public, and especially curious, young learners, with interesting research conducted in the Earth's polar regions.

Hands-on activities included the ever-popular salinity taste test, a real ice core from Greenland, and a listening station where visitors eavesdrop on the underwater sounds of whales and seals in the Arctic Ocean. At screenings of the IMAX movie ***The Arctic: Our Frozen Planet***, Principal Quantitative Ecologist Eric Regehr described his work studying the polar bear population on Wrangel Island and Senior Principal Engineer Ian Joughin shared the many methods scientists use to measure changes on the great ice sheets of Greenland and Antarctica as the Earth's climate warms.

Since the first **Polar Science Weekend** in 2006, the partnership between Pacific Science Center and APL-UW, with the financial support of NASA and NSF, has created outreach activities where polar scientists communicate directly with tens of thousands. Stern stresses that the event's success depends on scores of volunteers — APL-UW researchers, University scientists and students, and many others from the community.

launching curiosity about the arctic

One of the activity tables at **Polar Science Weekend**, piled with small wooden boats and colorful paints and markers, drew crowds. Participants learned about Arctic Ocean circulation, sea ice, and how they are changing while they decorated 8-inch-long wooden boats.

Organized by the International Arctic Buoy Programme (IABP), **Float Your Boat** began in 2015. In that inaugural year, 1400 boats were decorated by Pacific Science Center visitors as well as school children and community groups across the U.S., then deployed in a flotilla on the Arctic Ocean from the USCGC *Healy*.

Over the past two years, **Float Your Boat** has increased its reach and impact 10-fold, now engaging students and educators from across the U.S. and internationally. Participants from over 40 institutions decorated 2230 boats last year. They were launched during research expeditions to the North Pole, the Eurasian Arctic, and the Beaufort Sea. Senior Principal Scientist Ignatius Rigor, Coordinator of the IABP, is an enthusiastic leader of the program. "We are out on the sea ice conducting research and deploying buoys many times during the year. Adding the wooden boats to our deployment plans is one of the most creative parts of our work."

research experiences for summer interns

This past summer the second cohort of students accepted to the **Diverse and Inclusive Naval Oceanographic Summer Internship Program** — DINO SIP — were hosted at APL-UW. The program is directed by STEM Development Program Coordinator Amanda Labrado. With lessons learned from the inaugural DINO SIP experience, she reports increased capacity and several program enhancements in 2024.

The program's purpose is to provide undergraduate students the opportunity to experience and conduct project-based research, participate in professional development, build community with young scientists, and learn how to navigate pathways to a career in maritime and oceanographic science, technology, engineering, or mathematics (STEM). Members of historically underrepresented groups, including African-, Hispanic-, and Native-Americans, Pacific Islanders, first generation and LGBTQ+ college students, military veterans and families, and disabled persons are encouraged to apply. From over 150 applicants — a 400% increase over 2023 — 16 students were invited to participate.

At the heart of each intern's experience is an independent research project under the guidance of an APL-UW research staff member. Projects are designed to have some built-in challenges for the students to face after developing skills and confidence, and to generate data to analyze and present in public science poster fairs. For 2024, mentors enhanced their independent projects by ensuring they could accommodate any intern's beginning skill level and learning speed.

Labrado, responding to prior interns' feedback, also designed a professional development curriculum for 2024 tailored to the DINO SIP experience and APL-UW research culture, instead of having interns enroll in a University course covering undergraduate research skills broadly. In a series of seminars, interns learned about APL-UW and similar research institutions, explored ocean sciences and maritime industry career pathways, practiced scientific writing and poster presentation skills, and discussed the professional literature on the meaning of diversity, equity, and inclusion in STEM fields.

Key to the program's success are the peer-to-peer mentoring and community building activities. Some are designed into the cohort's program, but most are self-organized. Labrado adds, "Many students from underrepresented minority groups lack a sense of belonging in STEM fields, which diminishes attainment, achievement, and retention. DINO SIP puts students on a firm footing and the friendships formed will be a source of support for years after the internship."

We find that specifying diverse and inclusive in the program's name has made a difference by attracting students who are seeking a welcoming and supportive environment for a STEM research experience.

— Amanda Labrado, STEM Development Program Coordinator

a showcase for undergraduate research

For undergraduate research experiences to be successful, mentors must design projects that are reasonable in scope and feasible, allowing students opportunities to generate data, perform analyses, and present results. Senior Research Scientist Mohamed Ghanem had these criteria in mind when pitching a project to colleagues in the UW Department of Bioengineering who organize the department's capstone program.

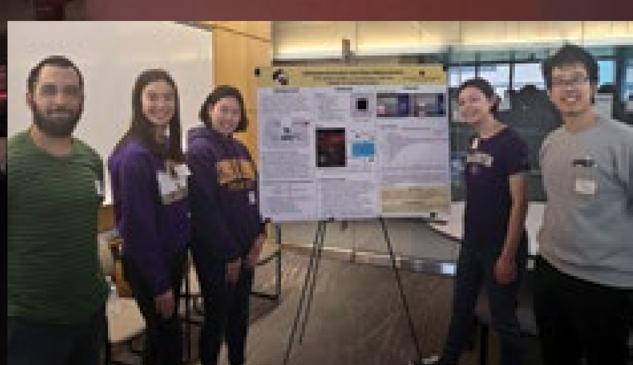
Amy Holden, Sophia Lu, Kai Schroeder, and Leqi Zhao, all senior bioengineering students, created a team to pursue the project, "Ultrasound Contact-less Mass Measurement," for their spring quarter capstone research experience. Working in Center for Industrial and Medical Ultrasound labs under Ghanem's mentorship, they ran novel experiments with a 256-element transducer to trap particles and measure their mass using focused ultrasound.

The transducer array, developed in CIMU labs, has been used to demonstrate noninvasive acoustic manipulation of objects in a living body, with applications to kidney stone treatment in humans. "By synchronizing the acoustic energy firing from the transducer surface, we create three-dimensional fields of high and low pressure," explains Ghanem. "Effectively 'acoustic tweezers', we can use the ultrasound beam to grip, lift, and move small objects in the body."

Student experiments used small glass spheres in a water-filled acoustic test tank with the transducer mounted below. Powering up the ultrasound created a pressure field around the bead resting on the bottom, trapping and lifting it. After an initial bounce from the radiation force, the bead oscillated vertically and then reached an equilibrium height above the bottom. By measuring the bead's position, velocity, and acceleration during the oscillatory pattern, and knowing the acoustic force, students used a mass-spring model to calculate the bead's mass. They presented their results at a showcase event with over 70 other seniors last May.

"I had the idea, but we never used this experimental transducer to measure the mass of small objects. This was novel research."

— Mohamed Ghanem, Senior Research Scientist



Mentoring undergraduate students with limited research experience was a test of Ghanem's teaching and communication skills. "Important to the success of the capstone project was to reassure students that adopting a research mindset means that most of the time you don't know the answer."

student engineering excellence

Graduate students mentored by Senior Engineer John Mower pursued a complex project encompassing component and systems engineering, signal processing, and data collection in the field, for which they received professional society accolades. Now they are applying the skills learned to sponsored research in Mower's lab.

Electrical and computer engineering Ph.D. student Nicole Pham and mechanical engineering M.S. student Dylan Wesen were encouraged by Mower to team up and enter a competition conducted by the IEEE Aerospace and Electronic Systems Society Radar Conference. Each team was provided an X-band phased array beam forming receiver kit from Analog Devices and then challenged to determine how to apply the hardware to a research problem. Nicole and Dylan created a land-based device to image passing vessel traffic with inverse synthetic aperture radar (ISAR) techniques. Their goal: a low-cost system to monitor and perhaps classify vessel traffic, even in poor visibility conditions such as heavy fog or darkness that inhibit optical systems.

"We weren't just entering for fun. We wanted to be seriously competitive," says Nicole. "We wanted to make use of the full capabilities of the radar kit, while also considering the skillset we wanted to develop." Though their experience with ISAR techniques and data collection in the field varied they set to work experimenting with transmit frequencies, writing data acquisition software, and creating data pipelines to capture images at rates that would follow accurately the vessel motions they expected in the field. "Then we moved to field experiments pretty quickly," explains Dylan, "... because it's hard to collect moving target data in the lab."

The team's presentation in the challenge was awarded first prize at the conference. "We successfully used the low-cost, provided radar system to create ISAR images of vessels undergoing different types of motion, and developed a range-Doppler imaging algorithm with motion compensation," states Dylan.

As they pursue their academic studies, they are continuing work in Mower's lab, now on low-frequency acoustic communications research sponsored by the Office of Naval Research. His mentoring goal is to show how the signal processing skills learned in the radar challenge are transferable to active research questions.

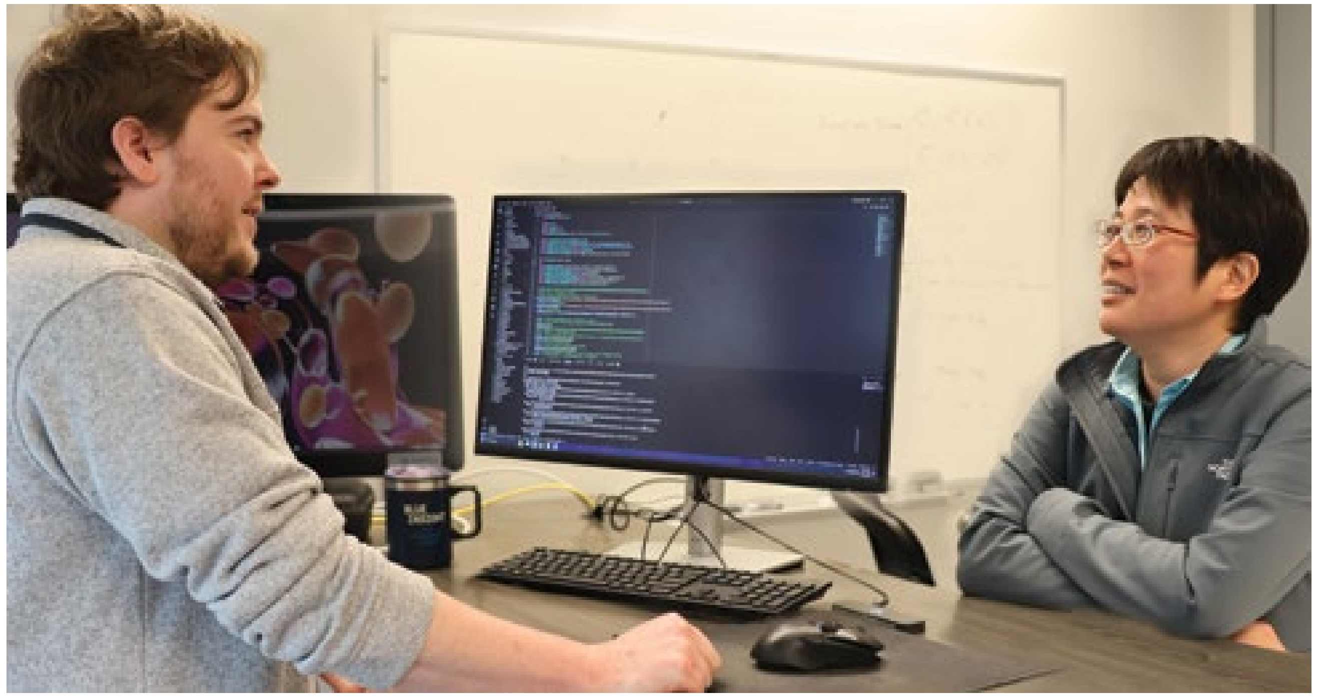
"It's exciting to say that I was able to do experiments in the field, taking a project from start to finish in my first year of graduate school."

— Nicole Pham

support for aspiring investigators

The Laboratory supports postdoctoral scholars showing outstanding potential to establish independent research careers with two-year fellowships. Science and Engineering Enrichment and Development scholars have research goals aligned with Laboratory areas of expertise and receive mentoring from APL-UW principal investigators. SEED fellows make significant contributions to the Laboratory's success and often become long-term additions to our science and engineering staff.

ACTIVE ACOUSTICS AND THE BIOLOGICAL OCEANOGRAPHER



Biological oceanographer Brandyn Lucca embraced active acoustics during his Ph.D. studies. With extensive experience at sea gathering ground truth data, he developed methods to process scientific echosounder data — the echoes scattered by marine organisms from sound energy transmitted into the water column — to detect and classify different types of animals, track their movements, and infer abundance.

With the mentorship of Principal Oceanographer Wu-Jung Lee, Lucca has begun his SEED fellowship research extracting knowledge from an enormous volume of acoustic survey data. "I'm developing open-source software to generate population estimates of Pacific hake," explains Lucca. Biennially since the late 1990s, joint U.S.–Canada hake acoustic trawl surveys that stretch from the California to British Columbia coasts have collected biological backscatter and biometrics data. Hake, a valuable commercial fishery, are a swim bladder fish. These air-filled chambers return strong echoes because of the density difference between air and the surrounding seawater. Hence, Lucca calls his software EchoPOP.

Lucca is analyzing past survey data, but the greatest and most rewarding effort of the fellowship so far has been to develop a live data processing pipeline so that population estimates are returned while the survey is being conducted at sea. "We got the at-sea EchoPOP pipeline up and running, which provided visualizations on a regularly updating server for folks to access both by sea and land," explains Lucca.

Next, he proposes to study echosounder data collected from two platforms off the Oregon coast that are plugged into the OOI Regional Cabled Array. He seeks to infer general community composition at these highly productive and biologically diverse sites, and to assess how oceanographic, atmospheric, hydrographic, and biological variables that are measured on co-located cabled array platforms influence the spatiotemporal distribution of different classes of marine organisms. He adds, "… skills I have been developing with Wu-Jung's mentorship to process huge amounts of ocean acoustic data will be particularly valuable when I begin to address research questions with the massive time series of the OOI Regional Cabled Array."

SOFT, ADAPTABLE ROBOTS MODELED ON OCTOPUS BIOLOGY

Lacking a skeleton and capable of seemingly infinite degrees of freedom, the octopus's arms are used for locomotion, foraging, exploration, and manipulation. Amazingly, most of the octopus's neurons are in its arms, not its brain.

As a graduate student, Dominic Sivitilli investigated octopus arm search patterns over simple and complex surfaces to determine their underlying mechanisms. He discovered that the suckers' interaction with the environment has a major role in how the arms are configured during a behavior. When a sucker encounters a relevant stimulus, it signals to neighbors; they orient toward the stimulus and then signal to their neighbors in turn, propagating as a wave down the arm.

"Sucker recruitment allows the octopus to delegate the decision of arm shape to the arms themselves," explains Sivitilli, "… alleviating the need for the brain to determine how to configure arms with seemingly infinite possible configurations." He adds that this model of recruitment and delegation is computationally simple when applied to robotic engineering. "Repeating a single optimized unit into a functional limb could lead to control algorithms that produce fault tolerant, complex motion in soft robots."

As a SEED fellow, Sivitilli's goal is to develop soft robotic ocean explorers that can manipulate and register the shape of geometrically irregular objects, even without visual feedback. Admitting that his experience with robotics is limited, he sought the mentorship of

Principal Electrical and Computer Engineer Aaron Marburg, whose expertise is in mechatronic ocean systems and software design for robotic perception and control. With his guidance, Sivitilli plans to conduct more complex experiments focused on sucker recruitment as a key mechanism of octopus arm control, establish a mathematical framework representing sucker control using a quasi-continuum dynamic model, and collaborate with UW Aeronautics and Astronautics researchers to translate the octopus's morphological characteristics into soft robotic components. Together, they hope to achieve rapid fabrication and testing of bio-inspired robotics.

"The goal of the SEED fellowship is to bring in people pursuing novel areas of research," says Marburg. "I was a SEED fellow myself, and I see my role now as a supporter of Dominic's research in all aspects, opening opportunities for collaboration and ensuring successful navigation of APL-UW culture and the Department of Defense research ecosystem."

Postdoc mentoring is a chance for me to engage with new research questions that stretch the bounds of my own expertise.

— Aaron Marburg, SEED Mentor

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