2020
review + outlook

Applied Physics Laboratory
UNIVERSITY OF WASHINGTON

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 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.

Scientific discoveries

Engineering innovations

Solutions for regional, national, and worldwide problems

contents

2020
a year like no other

COMET NEOWISE PHOTOGRAPHED BY
APL-UW PRINCIPAL ELECTRICAL ENGINEER
JAMES TILLEY ON 11 JULY 2020

*Welcome to the inaugural **Annual Review + Outlook** from the Applied Physics Laboratory of the University of Washington. Since 1993 we have shared highlights of scientific discoveries, engineering innovations, and educational achievements every other year with colleagues and friends. Early in 2020 we decided to increase the frequency of our reports, and because this year has turned out to be like no other, there is more urgency to communicate with the entire APL-UW community.*

resilience + accomplishments

Our individual and collective responses to the COVID-19 pandemic have been at the forefront of how we have lived our lives and pursued our work during 2020. Witnessing the disparate effects of the pandemic and the shocking events that spurred protests against racial injustice this year has required that we re-examine our understanding of biases implicit in our actions and the institutions in which we work.

We have spent much of the year focused on the health and safety of our APL-UW community and working to mitigate the impacts of COVID-19 so that we could best continue our mission of scientific research, technology development, and advanced education. We have also sought to fulfill our civic and humanitarian responsibilities by initiating efforts to advance diversity and inclusivity in what we do within our community, how we seek new members to join us, and what we do to advance these issues in our professions. With the help of many individuals and groups at APL-UW we are working to expand mentoring, develop internships, and re-examine our past recruiting efforts. Enhancing the professional environment for our staff and combating systemic bias are metrics for success that we see as essential to fulfilling our purpose.

The UW was one of the first major research universities to devise a response to the pandemic. Together, APL-UW researchers and administrators worked with our University partners, as well as local, state, and federal agencies, to chart a path through the unprecedented disruption caused by COVID-19. We implemented strict guidelines for social distancing, frequent decontamination of work spaces and instruments, and correct use of personal protective equipment. We trained our staff and developed an online log of daily location and contact tracing to mitigate the risk of the virus moving into our workspaces as we resumed critical operations. I am proud of the resilience I have seen demonstrated repeatedly by the APL-UW community this past year in the face of these public health and societal challenges.

"I believe that current times have demonstrated yet again that the core asset of any institution is its people. I find myself continually amazed by the commitment of APL-UW staff to rise to the occasion. What shows up in these pages, in part, documents that commitment."

– Kevin Williams
APL-UW Executive Director

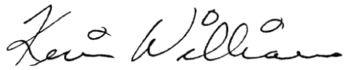
Throughout this year research and engineering teams made advances in all of the Laboratory's areas of expertise. In these pages acousticians report successful experiments to understand the environmental effects on sound propagation through the ocean as well as new ultrasonic technologies and methods to destroy tumors in the human body. Oceanographers are testing theory and deploying innovative sensors and research platforms to probe the physical and biological systems of marine environments around the world. Ocean engineers are applying expertise gained designing the Ocean Observatories Initiative Regional Cabled Array to the global problem of detecting violations of the nuclear test ban. Physicists are crafting models of nonlinear acoustic propagation to guide medical device development and collaborating on an X-ray instrument that is now on a journey to Mars.

We report with pride that seven graduate students advised by APL-UW scientists completed degrees in 2020. The Laboratory has a reputation of attracting top-flight postdoctoral scholars to pursue their last years of formal training with APL-UW mentors before embarking on careers as independent scientists and engineers. In 2020 we have a record number of postdocs in our ranks. I am happy to report examples of their accomplishments and those from APL-UW's cohort of early career principal investigators—our future leaders.

Our investigators continue to pursue with success research funding despite the unprecedented challenges faced by APL-UW and many of our program sponsors. We won 262 awards in fiscal year 2020, for new and continuing projects, resulting in a record $77.7M in research funding. The discretionary funds generated from these awards are being used in new ways to further the Laboratory's human capital. We have established a Technical Staff Development Program, ensuring continued learning and skill development, and an Interdepartmental Independent Research and Development Program, encouraging cross-departmental collaborations to seed new funding opportunities and scientific discoveries. Earnings from the APL-UW endowment remain strong, allowing us to fund every year a postdoctoral scholar for a two-year appointment.

The core of our identity as a University Affiliated Research Center sponsored by the U.S. Navy is our Naval Sea Systems Command contract. This year we celebrate the successful renegotiation of our 10-year contract with NAVSEA. To meet the challenge posed by the increasingly complex technology and compliance requirements of our Navy and other Department of Defense sponsors, we have completed a comprehensive review of our information technology resources and identified how they can better support our entire research portfolio—from basic research grants requiring open access to results, to classified contracts requiring strict control procedures, or something in between. We have established a cohesive IT vision, and created a roadmap that guides APL-UW through the many new information controls being incorporated into funding documents, and ensures our researchers have the technology support they need.

APL-UW continues to move forward to fulfill our purpose of scientific discovery and engineering innovation for the good of our region, nation, and world. This year has proven yet again that our people are our core asset in fulfilling this purpose. This ***Annual Review + Outlook*** highlights some of our many accomplishments during 2020 made possible by the Laboratory's dedication to our mission and values, as well as the spirit with which we approach the work ahead. We must thoughtfully and deliberately incorporate the momentum of the present into resilient and equitable systems of the future.



This year we lost ***Thomas B. Sanford****, a great scientist, colleague, mentor, and friend. He pioneered a theory of how ocean currents interact with the Earth's magnetic field and developed instruments to measure the rich variability of the real ocean.*

Tom was the founding editor of the Journal of Atmospheric and Oceanic Technology*, and a fellow of both the American Geophysical Union and American Meteorological Society. He received the AMS Henry Stommel Research Medal and IEEE/OES Distinguished Technical Achievement Award, and acted as Secretary of the Navy/Chief of Naval Operations Chair of Oceanographic Sciences.*

His exceptionally distinguished career in Navy-relevant research and contributions to the global ocean sciences community gave luster to the Laboratory's reputation for over four decades.

clearing seafloor hazards from coastal areas

This year the Multi-Sensor Towbody (MuST) flew survey patterns in both Lake Washington and Sequim Bay to test hardware and software and quantify capabilities. Improving the accuracy and speed with which it detects, classifies, and geolocates targets on the bottom or buried in the sediment has remained the central goal. MuST sonar data that stream across its communications/tow cable to computer acquisition systems on board the vessel can now be processed in real time. This has required that the MuST science and engineering team optimize both the operational procedures and the image processing algorithms. The team's continued success has been acknowledged by the Environmental Security Technology Certification Program, which awarded MuST their 2020 Project of the Year.

harvesting power from the sea

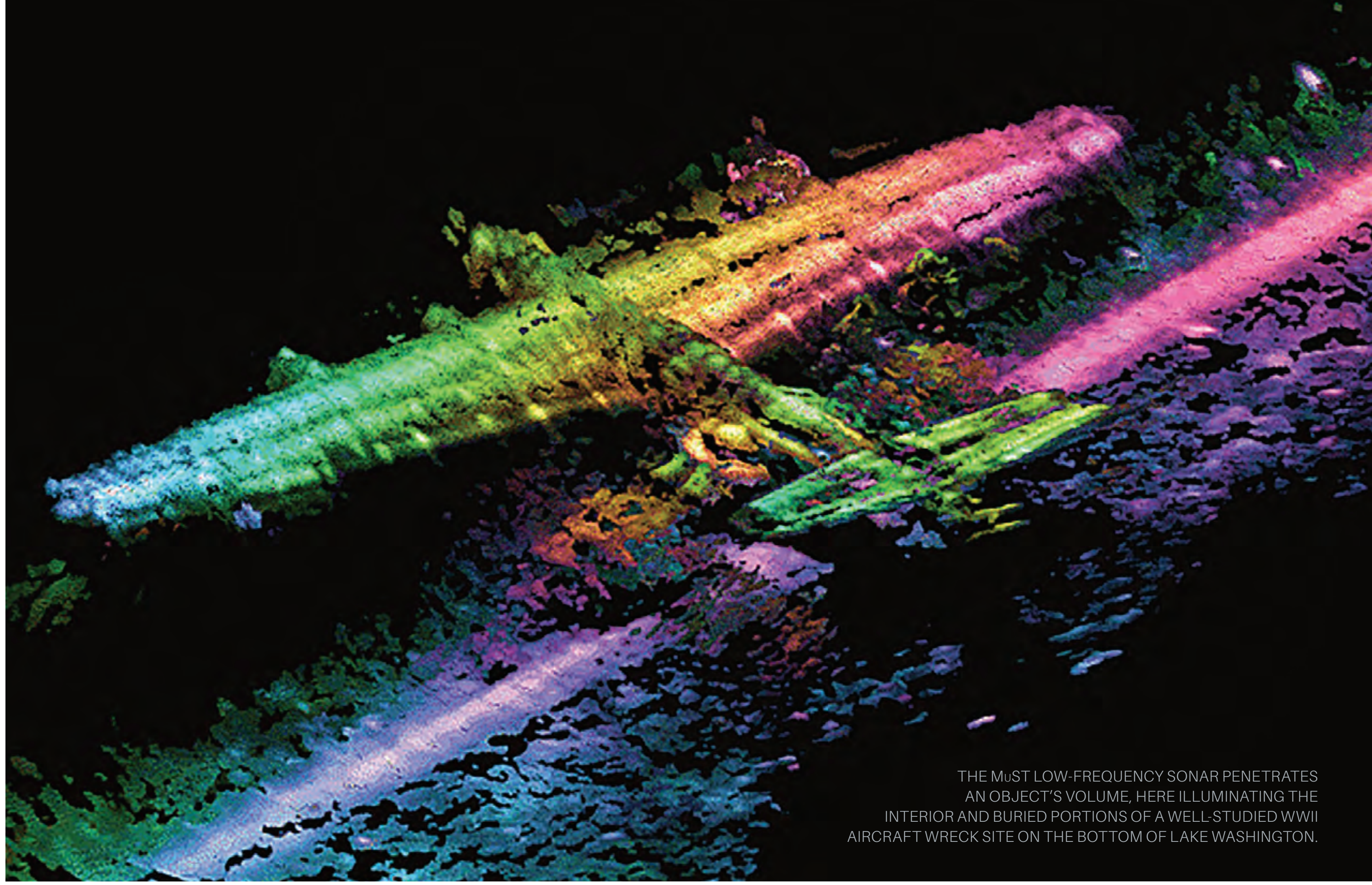
Tests on board APL-UW's R/V *Russell Davis Light* continue to establish the reliability and performance—mechanical, electrical, and control stability—of tidal and river current turbines. Funding is now secured to integrate a cross-flow turbine with a four-legged seafloor lander that will also host control electronics and an Adaptable Monitoring Package (AMP). The marine energy engineering team is developing the system to be deployed from a small vessel and harness tidal energy at a scale appropriate for distributed networks to power offshore sensors or recharge autonomous underwater vehicles. The AMP's persistent eyes and ears will be trained on and powered by the turbine to detect, track, and classify any interactions with marine life.

ultrasonic treatment of kidney stones

For 25 years an APL-UW team has been part of a multi-institutional consortium of researchers funded by the National Institutes of Health to attack kidney stone disease with ultrasound. Previously, we've shared how the team perfected devices and methods to push stones out of the kidney with the acoustic radiative force and how to crumble stones with bursts of acoustic energy instead of breaking them with high-intensity shock waves, lessening the potential for kidney tissue damage during treatment. In early 2020 the team began a human clinical trial with their all-in-one treatment system to break and move stones and stone fragments from

progress reports

Many of the research initiatives shared in our most recent reports continue in 2020. Here, we share important findings and advances made this year.



THE MuST LOW-FREQUENCY SONAR PENETRATES AN OBJECT'S VOLUME, HERE ILLUMINATING THE INTERIOR AND BURIED PORTIONS OF A WELL-STUDIED WWII AIRCRAFT WRECK SITE ON THE BOTTOM OF LAKE WASHINGTON.

LONG SPIDER LEGS CUSHION THE HPIES FREE-FALL LANDING ON THE BOTTOM.

AFTER SAFE LANDING, A ROV DIVES TO ITS LOCATION AND PLUGS HPIES INTO THE CABLED ARRAY NETWORK.

photo: Mitchell J. Elend | UW

the kidney. This is a significant advance toward the treatment goal: urologists, holding an ultrasound probe against the patient's skin, can image, break, and push stones to facilitate their natural clearance, all while the patient is awake and feeling no discomfort.

maintaining the world's largest ocean observatory

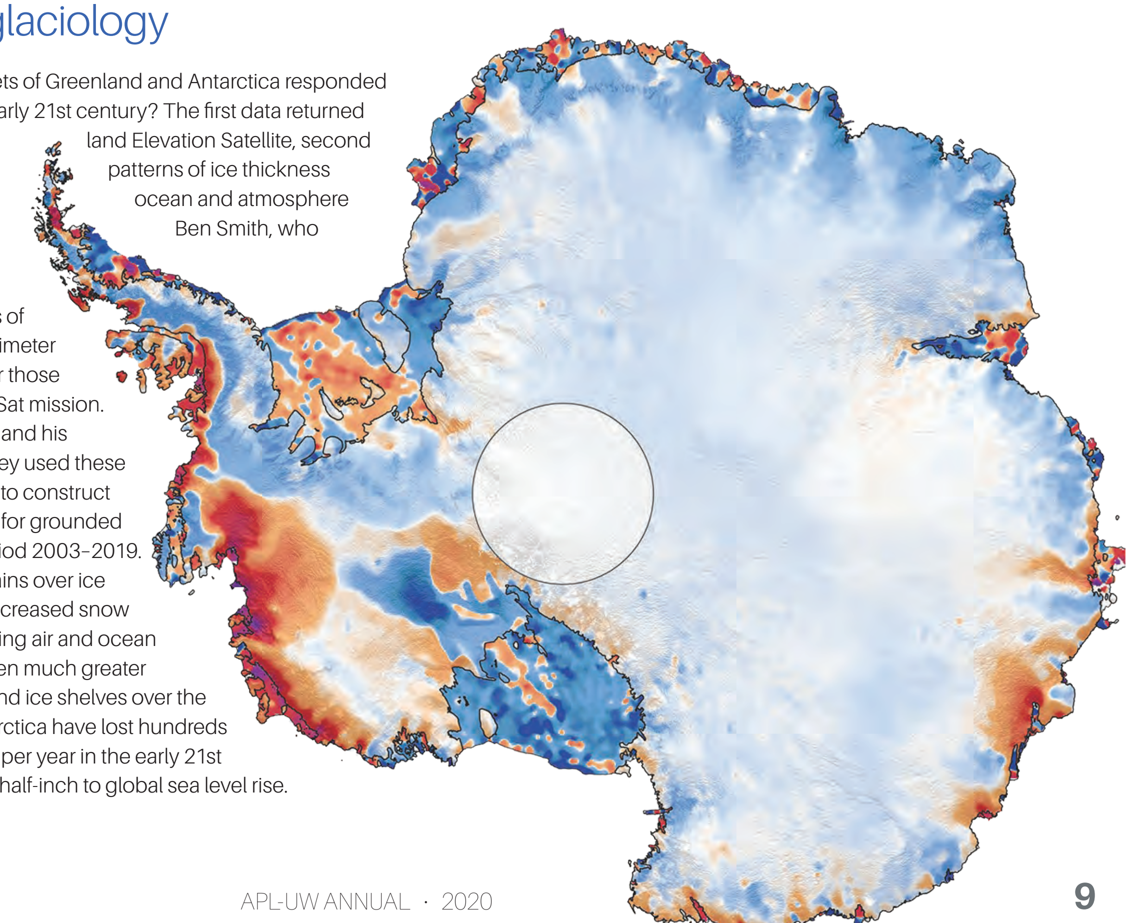
Every summer, 2020 no exception, an APL-UW engineering team embarks on a VISIONS cruise to maintain and enhance the Ocean Observatories Initiative Regional Cabled Array. Engineering team members went into a strict quarantine for 14 days and had two COVID tests to ensure the health and safety of all on the 30-day expedition aboard the R/V *Thomas G. Thompson*. Over 40 tons of Cabled Array infrastructure and equipment were shipped from Seattle to Newport, OR, in seven semi-trailer trucks and then mobilized on the *Thompson*. With support from the remotely operated vehicle *Jason*, the team recovered over 100 instruments from the network and replaced or reinstalled them on the array so that the valuable time series of scientific data continues flowing to users 24/7/365.

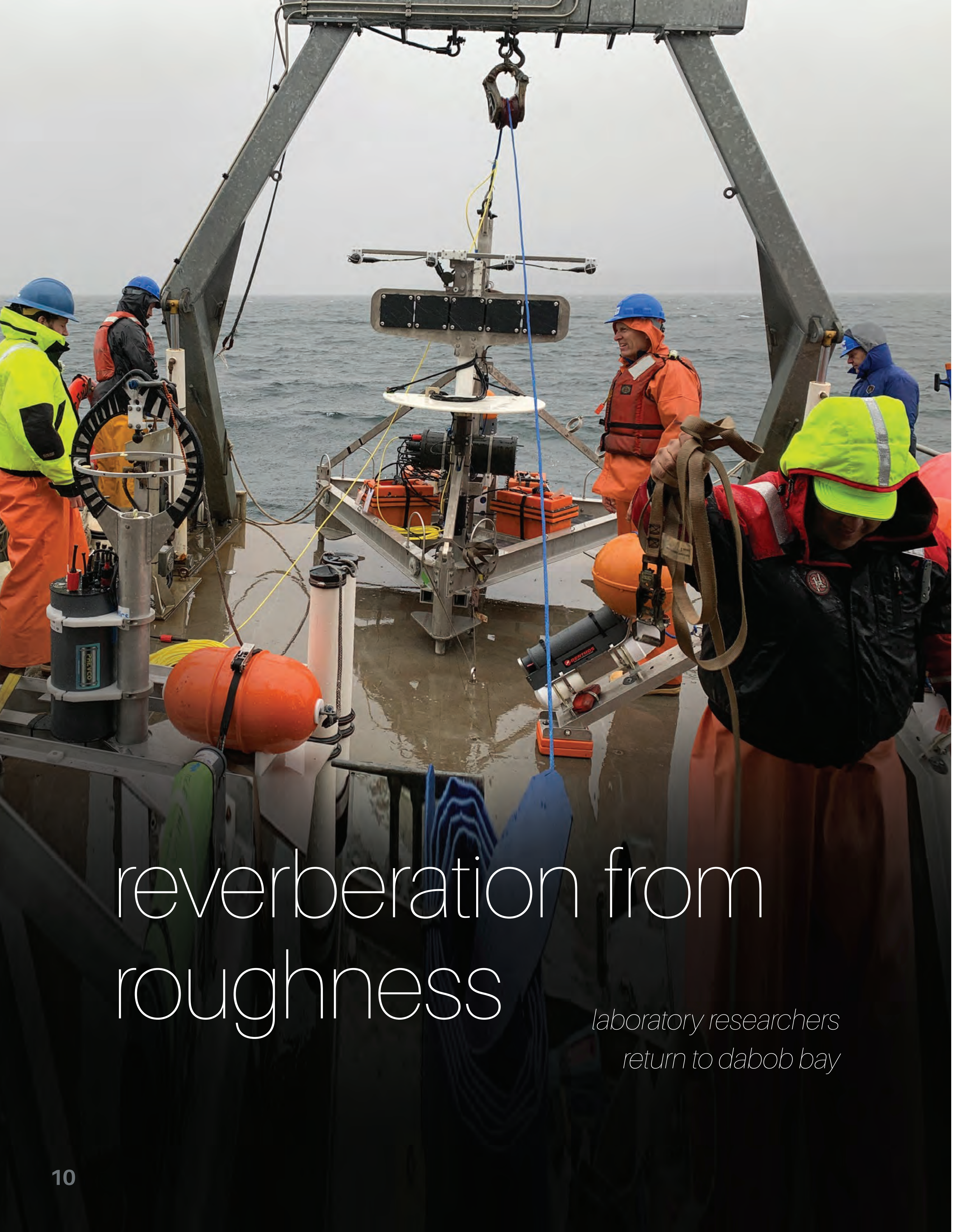
pixelated ultrasound speeds disease research

PIXUL, the multi-sample sonicator developed collaboratively between the Laboratory's Center for Industrial and Medical Ultrasound and UW Medicine, is now being offered for sale to labs around the world. PIXUL—fast, easy to use, and consistent—shears genetic material into precise fragment sizes for next-generation sequencing applications. The APL-UW start-up Matchstick Technologies commercialized PIXUL with funding from the NIH and their corporate partner, Active Motif. Matchstick recently received additional NIH funding to develop PIXUL to process formalin-fixed paraffin-embedded specimens. All clinical laboratories in the U.S. are required to retain diagnostic tissue blocks for several years, and there are millions of these FFPE samples stored in biobanks around the world. Researchers plan to use PIXUL's high-throughput processing of these preserved tissues to greatly improve utilization of these samples for epigenetic and genomic studies in research and clinical practice, such as cancer and Alzheimer's.

a new era for glaciology

How have the great ice sheets of Greenland and Antarctica responded to climate pressures in the early 21st century? The first data returned from the Ice, Cloud, and land Elevation Satellite, second generation (ICESat-2), show patterns of ice thickness change from competing ocean and atmosphere processes. Glaciologist Ben Smith, who was on the NASA satellite's science definition team, led an effort to chart the millions of locations where ICESat-2 altimeter measurements crossed over those from the decade-earlier ICESat mission. Published in *Science*, Smith and his colleagues describe how they used these comparable measurements to construct maps of the rates of change for grounded and floating ice over the period 2003–2019. There have been modest gains over ice sheet interiors because of increased snow accumulation. But due to rising air and ocean temperatures there have been much greater losses from outlet glaciers and ice shelves over the period. Greenland and Antarctica have lost hundreds of gigatons of grounded ice per year in the early 21st century, contributing over a half-inch to global sea level rise.





reverberation from roughness

laboratory researchers return to dabob bay

Sonar detection and identification of targets in shallow, nearshore ocean environments is complicated by the seafloor and sea surface boundaries. Reverberation caused by bathymetric features, surface waves, and dynamic oceanographic properties injects greater uncertainty for mid-frequency (1–10 kHz) than low-frequency sonar operations. Senior Principal Physicist Todd Hefner explains, "A long-term goal of APL-UW acoustics researchers is to develop a fundamental physical understanding of mid-frequency propagation and reverberation through carefully controlled field experiments and theoretical modeling."

Since recent experiments conducted in the Gulf of Mexico off Panama City, Florida, the team had been searching for an experiment site where the effect of a rough sea surface on mid-frequency propagation and reverberation could be isolated. Ideally, they needed to deploy equipment for an extended duration and orient it such that acoustic propagation aligned with the direction of the prevailing wind and waves. And placing the equipment on the seafloor, as opposed to towing it from a vessel, eliminates measurement uncertainties introduced by motion and changing distances between acoustic sources and receivers.

Dabob Bay, part of a long, narrow series of fjords in the Puget Sound basin, is home to the three-dimensional acoustic test range maintained by the Naval Undersea Warfare Center, Division Keyport. It was APL-UW's collaboration with NUWC Keyport that developed the range beginning in the 1950s. Since then, the range has been in continuous operation to improve naval undersea systems and to understand how variable ocean environments affect their performance. With decades of study, this environment is well characterized, replete with enabling infrastructure, and near APL-UW.

The planned experiments required a consistent wave field. And though Dabob Bay is fetch-limited, there are periods during winter when storms blow from the south–southwest, setting up the lengths of Hood Canal and the bay to generate waves. "We scheduled our experiment during what we hoped would be a stormy period and planned to deploy our equipment along the length of the bay to align with the waves," recalls Hefner.

In late January the team set down to the seafloor from the R/V *Jack Robertson* two acoustic research instruments developed at APL-UW. ARMS, the Autonomous Reverberation Measurement System, uses a small, horizontal receive array mounted near and above a directional transducer to record reverberation. It can be programmed to rotate horizontally, hence taking reverberation data as a function of local wind and surface wave direction. The Intensity Vector Autonomous Recorder, IVAR, hosts a vector acoustic sensor that hears sound differently than a conventional hydrophone. It records sound pressure and particle velocity at a single point above the seabed, sensing the direction of the sound. Both are self-contained and battery-powered, able to operate untethered for many days.

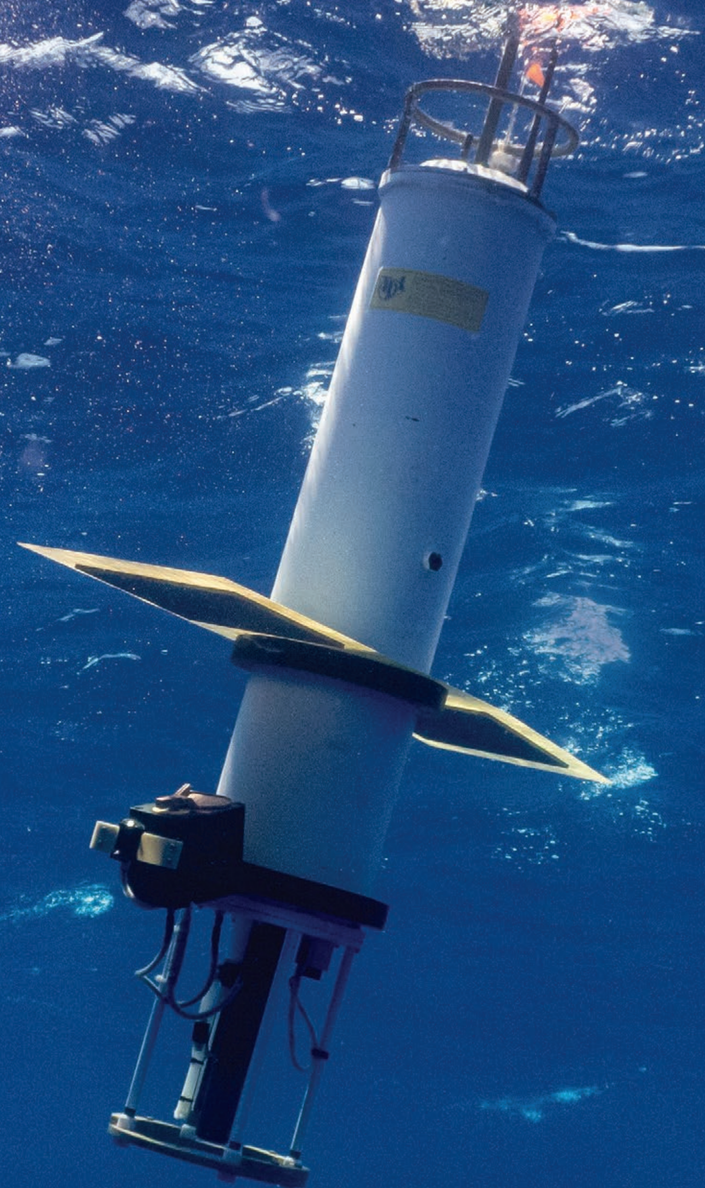
NUWC scientists also recorded ARMS transmissions on a vertical line array deployed several kilometers away. A bottom-mounted, upward-looking acoustic Doppler current profiler, a Waverider buoy deployed on the surface, and intensive surveys by the R/V *Robertson* measured currents, waves, and oceanographic properties simultaneously and co-located with the acoustic experiments.

The field experiment hit the weather bullseye. Hefner notes, "We had a few periods of calm, where the sky was clear and the bay glassy, but mostly the weather was terrible—rain, and the wind aligned with the canal and bay to create maximum waves." The team collected about 100 hours of data, with transmissions every 15 seconds. Transmission sequences covered rough and calm conditions, providing data that can be used in ongoing studies to test the sensitivity of propagation and reverberation to sea surface roughness.

apl-uw team members: PAUL AGUILAR, ERIC BOGET, BEN BRAND, PETER DAHL, DAVID DALL'OSTO, TODD HEFNER, KEITH MAGNESS, ANDREW REAY-ELLERS, DJ TANG

sponsor: OFFICE OF NAVAL RESEARCH

photo: Ocean Voyages Institute



A Mixed-layer Lagrangian Float was dropped into the Great Pacific Garbage Patch for a two-month mission last summer.

The float hitched a ride from Hawaii to the GPGP aboard S/V *Kwai*—a sailing cargo ship that picked 170 tons of plastic out of the ocean on two reconnaissance cruises arranged by the Ocean Voyages Institute.

Millions of tons of plastic litter the world's oceans. Over time large pieces degrade to tiny fragments. These microplastics have buoyancy near that of seawater, becoming suspended in the upper ocean. Debris can also serve as a vector for coastal species to invade the open ocean.

In the GPGP the MLF's accurate and highly adaptable buoyancy control was used to observe how different layers of the upper ocean move, and how these movements affect the drift of debris with various buoyancies. And for the first time, the float was outfitted with a camera system to observe biological colonization in real time.

Piloted every day through a satellite communications link to Seattle, APL-UW oceanographers directed their float to profile, settle at various depths, or follow water parcels on a neutrally buoyant drift to mimic the drifting behavior of microplastics, and microbial plants and animals.

This NASA Interdisciplinary Sciences effort brought together non-profit groups, sailors, and oceanographers from several institutions to better understand the accumulation of plastic in the North Pacific Subtropical Gyre. MLF data allow researchers to connect observations of surface currents and convergences with vertical mixing to the ocean interior.

apl-uw team members: ERIC D'ASARO, MIKE KENNEY, NICK MICHEL-HART, MIKE OHMART, ANDREY SHCHERBINA

oceanography, biology, conservation

Fisheries scientists and oceanographers are teaming with expert anglers and Wildlife Computers—manufacturer of satellite-linked fish tags—to gain new insights to broadbill swordfish behavior and their deep-ocean ecosystem.

The mesopelagic or 'twilight' zone hundreds of meters below the surface is home to the largest fish biomass on Earth. This ecosystem is not well studied, and growing interest to harvest mesopelagic stocks makes research more urgent. At night mesopelagic fish rise to the ocean surface to feed and at sunrise they migrate back to deeper water. Swordfish follow this vertical migration every day to pursue prey, making them ideal platforms to study this habitat.

Chartering sport fishing boats and partnering with swordfish experts, the team has now fished in the Atlantic and Pacific oceans and the Red Sea. They have affixed customized, satellite-linked tags that transmit position each time the fish breaks the ocean surface, and others that archive temperature and depth measurements, popping off to the surface at the programmed end of mission to send data. In development is a bio-logging tag package that includes high-precision accelerometers to detect head movements and tail beats, signaling feeding behavior, and a camera to record what the fish are eating.

The team is in early days of collecting swordfish position and dive data to understand the distribution of their food. Combined with other remote sensing and in situ observations, their long-term goal is to build a forecasting model of swordfish movement behavior—an important tool to manage the greater mesopelagic ecosystem.

team members: MARTIN AROSTEGUI, PETER GAUBE (APL-UW); CAMRIN BRAUN (UW Aquatic and Fishery Sciences)

photo: Steve Dougherty Photography

Arctic coastlines are eroding at rates of meters per year. With increasing frequency and severity, storm surge flooding inundates northern Alaska coastal communities on the Beaufort and Chukchi seas.

APL-UW researchers and their collaborators from the UW Department of Civil and Environmental Engineering think that coastal processes are changing in response to increased wave energy.

coastal ocean dynamics in the arctic

wind, waves, and the increasing vulnerability of northern alaska coastlines

"Two things we're observing in the Arctic are well documented — the water is getting warmer and the waves are getting bigger."

– Jim Thomson

photo: John Guillote | Onpoint Outreach LLC

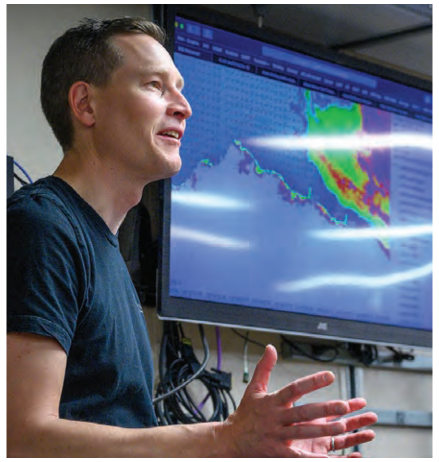


photo: John Guillote | Onpoint Outreach LLC

sharing science

In Nome, Alaska, before embarking on the November 2019 cruise, CODA researchers met with members of the community who are leading edge observers of climate change. Residents shared their experiences and knowledge as Jim Thomson talked about the team's motivation to study unusual ice conditions, storms, waves, and severe flooding events.

CODA outreach efforts had tremendous support from John and Becca Guillote, freelance public educators specializing in arctic science. Aboard R/V Sikuliaq, *they coordinated the broadcast of three live stream programs via satellite during the 21-day cruise in 2019. Geared toward STEM students in grades 4–9, those joining the stream asked questions and heard answers live on screen from scientists. And when R/V* Sikuliaq *made a January 2020 port stop at the University of Washington in Seattle, the Guillotes collaborated with Thomson to stage a public open house to share what had been accomplished and learned so far during the CODA initiative.*

A chronicle of John and Becca's experiences on the cruise, social media outreach, and recordings of the live streams are shared at **iceinmotion.com**.

In recent decades the dramatic summertime retreat of sea ice in the Arctic leaves great expanses of open water where waves can form and grow. Now, with a long season of open water in the deep basins and an early breakup and late freeze-up of shore-fast ice, there is less wave energy dampening or protection on the coast. Senior Principal Oceanographer Jim Thomson's research team is executing a multi-year study at three sites off the northern coast of Alaska to observe offshore wave conditions and shoreward wave transformations in a variety of sea ice conditions.

The research team set out from Nome on the R/V *Sikuliaq* in early November 2019, cruising north through Bering Strait to study sites in the Chukchi and Beaufort seas. "This is the first time a U.S. ship has been conducting science experiments so late in the year," notes Thomson. The observed shift of autumn freeze-up occurring one or two days later per year means that the ice advance is now a full month later than it was a few decades ago. Thomson continues, "If we had planned this project 10 years ago we would have done this research expedition in September. So the shift has been dramatic." These ice trends correlate directly with surface wave trends. Studies show that over the past 25 years wave heights and periods are growing, even though wind speeds have remained the same.

The three coastal sites targeted—from Icy Cape on the Chukchi coast in the west to Jones and Flaxman islands on an eastward trajectory along the Beaufort coast—are all sand barrier systems, presumed to be the most exposed to wave events. Because sea ice advances from the north and east in autumn, the three CODA sites represent a range of seasonal coastal sea ice duration.

At each site moorings were deployed on a line of increasing depth at 3, 6, 9, and 12 km from shore. Outfitted with sensors studded along the upward rising cable, the moorings were left by the team to record seasonal nearshore temperature, wave heights, currents, and turbulence until retrieved in September 2020. Over that period they observed shore-fast ice formation in autumn, ice drift in winter, ice breakout in spring, and open water in summer. Thomson notes, "This spectacular data set shows the importance of shore-fast ice in early summer. It remains locked along the coast for several weeks, or even months, longer than the rest of the ice offshore, protecting the coast from wave inundation."

Retrieving the moorings and their trove of data this past September capped successful CODA field seasons. Back in November 2019 the goal was to work along the evolving ice edge of the autumn freeze-up and to observe wind–wave–ice–ocean dynamics under a variety of conditions. Surveys at study sites were made with ship-based underway ADCP, CTD profiling, and a stereo video imaging system. The team also tossed up to 10 Surface Wave Instrument Float with Tracking (SWIFT) buoys into the ocean in conditions ranging from open water to heavy ice cover. These free-drifting floats, developed at APL-UW, observe wind, waves, temperature, and turbulence near the ocean surface, as well as the optical field surrounding their position—all in a wave-following reference frame. From all these platforms, the team hopes to resolve wave energy, wave energy fluxes, wave directions, sea surface temperatures, ice coverage and thickness, and coastal currents. About the SWIFTs, Thomson adds, "We let them go, and their camera images of the ice conditions around the buoy are really valuable pieces of data adding to the wave observations."

The first station at Icy Cape (the most westward) was conducted in open water and moderate sea state. Several days later at Jones Island (to the east) the research team endured freezing spray conditions on deck and observed only a small fetch of open water remaining between the shore-fast ice and the pack ice to the north. And at Flaxman Island (the most eastward) the *Sikuliaq*'s progress was slowed and operations were conducted in complete ice cover.

As operations moved back west to Icy Cape the weather worsened. The team worked on deck in air temperatures well below freezing and winds blowing 30–50 mph. Waves were building, reaching 3 m on the first day and then settling to sustained 2-m height for the next couple days. Thomson recalls, "It was big storm that came through, generating big waves. There was a lot of sea ice around that had just formed, but when the waves began rolling through, it broke up, and then disappeared completely." The intense sampling during this 3-day event provides a snapshot of wave attenuation by sea ice, decreasing the waves' height and energy, followed by sea ice melt from residual ocean heat. Warmer offshore water, as measured by SWIFTs and underway CTD profiles, may have been transported and mixed into the nearshore environment by wind and waves, or the sea ice may have been advected offshore by currents to melt when it encountered warmer offshore water. The drifting reference frame of the SWIFT buoys is invaluable to understanding the mechanisms at play during this event.

Thomson's recent experience in the cold, dark arctic autumn aboard R/V *Sikuliaq* was as chief scientist for the ONR-funded Sea State Departmental Research Initiative. "We've done a lot of work in the deeper waters of the western Arctic looking at how waves and ice interact, especially during the ice advance in the autumn," notes Thomson. These deep-water observations and modeling studies reveal a clear trend of increasing surface wave activity and a delicate balance among ice, waves, and wind during freeze-up in the Arctic Ocean. Thomson explains, "CODA takes that signal of increasing waves into the coastal zone, where there are immediate impacts for people and their community infrastructure."

photo: John Guillote | Onpoint Outreach LLC

In summer 2019 Thomson led a small team, working out of Prudhoe Bay, Alaska, in a moderately sized vessel, to deploy the most shoreward of the CODA moorings. When visited by the R/V Sikuliaq *months later, they were retrieved and replaced.*

Mooring data reveal an October marked by wave activity and one spectacular event when waves nearly 4 m high roared through the nearshore environment. This record is a strong contrast to known climatology. This time of year, the region is expected to be quiescent, where little fetch remains between the ice edge advancing from the north and shore-fast ice.

Leading the CODA modeling efforts is UW Assistant Professor Nirnimesh Kumar, who is taking the recent understanding of wave-ice interactions in the deep basin and porting them to coastal models. The challenges are many—nearshore wave and circulation models have neither basic wave propagation dynamics nor accurate simulations of wave-ice interactions in coastal waters. And how do these processes differ in spring, when shore-fast ice is breaking out, from autumn, when new ice is forming as grease and pancake ice? Modeling must achieve a level of sophistication to distinguish between seasonal ice types and properties.

Being a member of the science team aboard R/V *Sikuliaq* is important to Kumar. His work needs data—wave forcing, sea ice observations, nearshore circulation, and sediment transport—from the intense process studies and the seasonal records retrieved from the moorings. The quantification of shore-fast ice persistence in spring and summer is especially helpful to ongoing refinements of forecast models and climate scenarios. He explains, "Going into the field is a big part of trying to build the hypothesis of how the system worked and what's possibly going to happen in the future. Understanding the physics, we can build better models and make better forecasts, both short- and long-term." The ultimate goal: to develop and couple models of nearshore processes to provide hindcast climatology and forecast capability for coastal wave conditions, circulation, and water temperature.

CODA team members: ALEX DE KLERK, LUCIA HOSEKOVA, JIM THOMSON (APL-UW); LETTIE ROACH (UW Atmospheric Sciences); NIRNIMESH KUMAR, MIKA MALILA (UW Civil and Environmental Engineering); EMILY EIDAM (University of North Carolina); ERICK ROGERS (U.S. Naval Research Laboratory)

sponsors: NATIONAL SCIENCE FOUNDATION, OFFICE OF NAVAL RESEARCH

With sadness we note the passing of our friend and colleague, Nirni Kumar. We will miss his presence and contributions to the CODA project, the Environmental Fluid Mechanics Group and UW College of Engineering, and the wider ocean modeling community.

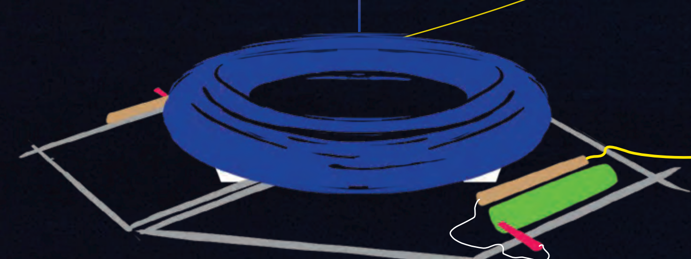
photo: John Guillote | Onpoint Outreach LLC

Ocean engineers at APL-UW are conducting design studies that could improve the sustainability of the undersea hydroacoustic component of the International Monitoring System — a global alarm system to enforce the Comprehensive Nuclear-Test-Ban Treaty. The IMS network of hydroacoustic, seismic, infrasound, and radionuclide stations can locate a nuclear detonation anywhere in or on the Earth's surface, atmosphere, or oceans.

Lead engineer Geoff Cram notes, "We now have over a decade of experience designing, installing, and maintaining a modular ocean observatory, and some lessons could be brought to bear on the problem." The team has applied their expertise to propose modular design options for the IMS hydrophone stations with the goal of facilitating the repair or replacement of underwater components without compromising the station's design lifetime and proven deployment approach.

modular design studies

for IMS hydroacoustic stations



listening always and everywhere

The six undersea hydroacoustic stations in the IMS are distributed among the Atlantic, Pacific, and Indian oceans. Because sound propagates great distances underwater, the six hydrophone stations provide global coverage. Data from the IMS stations are telemetered continuously to the International Data Centre in Vienna, where analysts from the CTBT Organization review and archive events detected on the network.

Sustaining the undersea listening stations — mainly based on remote islands in some of the harshest environments on Earth — is an ongoing challenge. Five of the six stations are comprised of two sets of three hydrophones (a triplet) deployed on opposite sides of an island with each set cabled to a shore station that houses computer processing and satellite communications equipment.

Installation of each triplet is a complex ocean engineering operation that usually requires a global class cable laying ship. The three hydrophone nodes are cabled in line and staged on deck. The operation of setting the nodes down one-by-one to the seafloor in a continuous string that is connected to the trunk cable must be completed without interruption. This triplet design is efficient to deploy and has achieved reliable data coverage.

maximizing sustainability

The APL-UW team envisions a triplet design upgrade that incorporates technologies and at-sea operations that have been proven efficient and reliable on the Ocean Observatories Initiative Regional Cabled Array in the Northeast Pacific. There, power and communications junction boxes, many kilometers of secondary cables, and about 150 scientific instruments are strung together with wet-mate connections. All the modular components in the network can be coupled and decoupled by a remotely operated vehicle tethered to a ship.

How would these technologies benefit the IMS hydroacoustic stations? In their current configuration, damage or failure anywhere along the triplet string — at the hydrophone riser assemblies or inter-node cables — would require complete triplet recovery to the deck for replacement and redeployment. Making the triplet modular with the strategic placement of wet-mate connectors would ease and speed service missions. "In many scenarios we have worked through, a ROV would perform the repair on the seafloor," notes Cram. The additional challenge is to make the modular connections robust enough to sustain the proven sequential deployment of the system and minimize installation time.

Any maritime operation can be limited by adverse weather. The most recently installed IMS hydroacoustic station at Crozet Islands has the harshest conditions. There, in the 'roaring 40s' of the South Indian Ocean, winds exceed 100 km/hr 100 days/year, on average, and significant wave height is rarely less than 2.5 m, even during the best conditions of austral summer. Would triplet servicing operations by a tethered ROV be possible here?

To best predict the engineering and operational benefits and risks of modular design options, the APL-UW team devised an ad hoc Monte Carlo simulation driven by surface wave height and wind speed data from NOAA's worldwide network of buoys. The resulting hindcasts of environmental conditions are combined with operation thresholds for vessels and ROVs to generate duration curves of elapsed time to complete a given deployment or service scenario at a specific site and time of year. "This aided our downselection of options for the triplet design study, and we arrived at a proposal that works for all hydroacoustic station sites, even Crozet with the most challenging conditions," says Cram. "We are confident our proposed design maximizes reliability, minimizes deployment and servicing durations, and best maintains data availability from the stations."

apl-uw team members: GEOFF CRAM, SUZANNE DICKINSON, MIKE HARRINGTON, KEVIN WILLIAMS

sponsor: THE PREPARATORY COMMISSION FOR THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION

theoretical + applied science from station data

On 15 November 2017, two IMS hydrophone stations detected at distances of 6000 km and 8000 km an acoustic anomaly originating in the vicinity of the last reported location of the missing Argentine navy submarine ARA San Juan. This IMS recording was critical evidence leading to its discovery one year later. To reduce the localization area, CTBTO scientists incorporated in their analysis an additional recording from a land-based seismic sensor. It was shown that this combination of data from different sensors improved the localization of the acoustic anomaly.

Senior Acoustician David Dall'Osto devised an alternative approach based exclusively on the two hydrophone stations. Dall'Osto employed a 3-D acoustic propagation model to reconstruct another acoustic arrival path to the hydroacoustic station in the mid-Atlantic Ocean. This acoustic path had been refracted by the continental slope off Argentina. He chose to model an arrival at 10 Hz because of its distinct arrival time and because the frequency is low enough to propagate great distances without significant perturbations from horizontal temperature gradients in the ocean. This 3-D acoustic arrival from the source serves as a virtual third hydroacoustic station, giving Dall'Osto the ability to decouple location and time, thereby triangulating the event source location. His analysis agrees well with CTBTO results computed with hydroacoustic and seismic data.

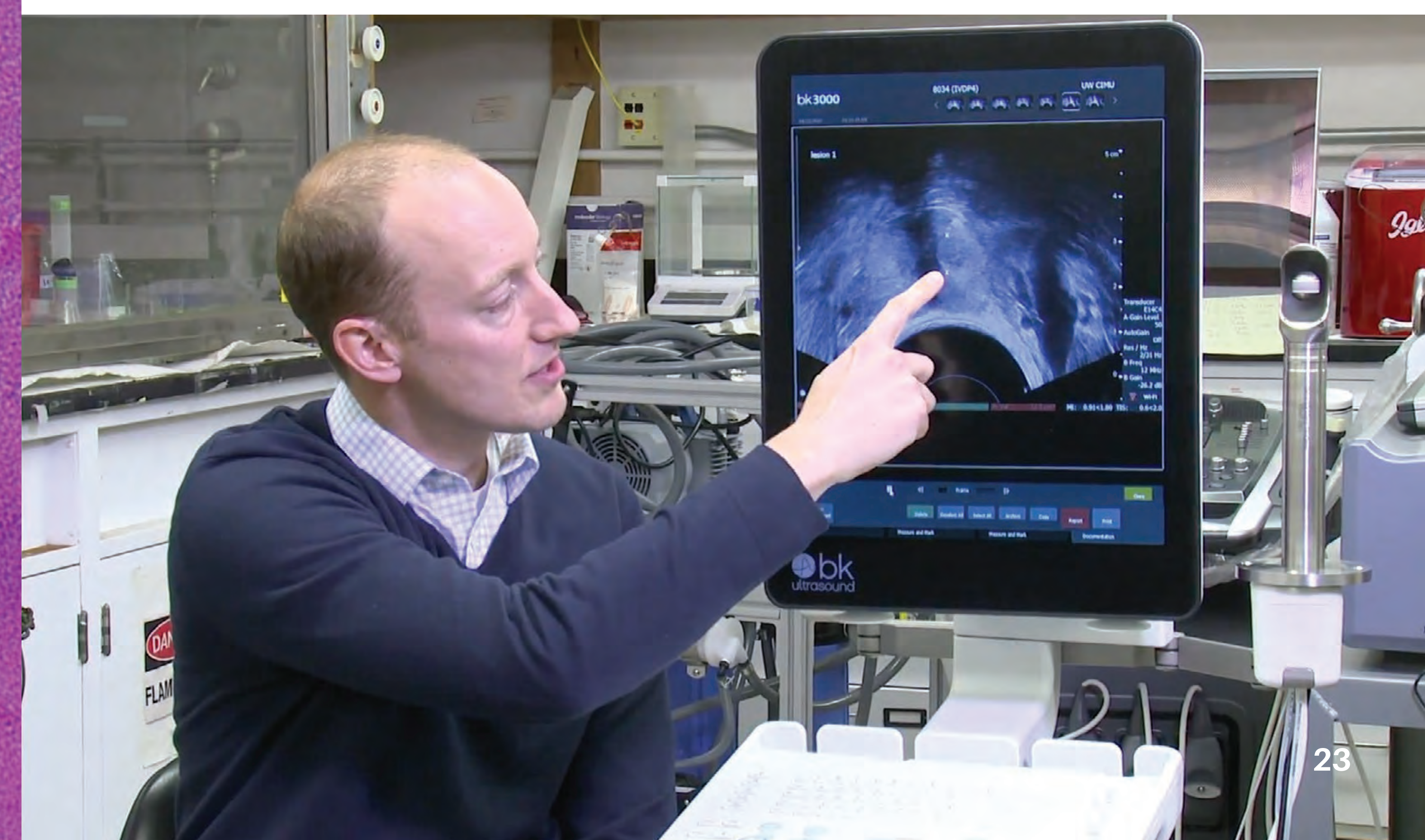
destroying prostate tumors

with ultrasound

An international team of engineers and scientists has built a preclinical device for prostate tumor tissue ablation and performed successful feasibility studies.

Their work builds on the approved use of high-intensity focused ultrasound (HIFU) to treat benign and malignant prostate tumors. HIFU energy delivered from a probe is targeted precisely to a small focal region within the body, where it can destroy tumors with no damage to intervening tissues.

Dr. George Schade, Assistant Professor in the UW Department of Urology, has been working with a team at APL-UW's Center for Industrial and Medical Ultrasound to develop new technologies for focal therapy of prostate cancer. "After the FDA approved thermal HIFU, there was a dramatic uptake in using the technology to treat patients, with the goal of minimizing side effects in prostate cancer treatments while delivering the same benefits as more traditional surgical approaches," notes Schade. But the approved devices have some limitations. It is difficult to monitor treatment in real time and their mechanism of action relies on HIFU's ability to generate intense heat at the focus — imagine a magnifying glass focusing the sun's energy to burn a spot. Dr. Schade explains that with a treatment that destroys tissue by cooking it, there is a potential for thermal diffusion from the focal region, which increases the risk of side effects.



mechanical vs. thermal

CIMU researchers and their international collaborators have developed an alternative technique to deliver ultrasound energy for focal therapy of prostate cancer. With it, tissue is liquefied mechanically at the focus rather than ablated thermally. "Our team has developed a technology we call boiling histotripsy," explains Senior Principal Engineer Vera Khokhlova. "It generates precisely controlled lesions with sharp margins, there are no heat-sinking effects, and we can monitor and control treatment progress in real time with plain ultrasound imaging."

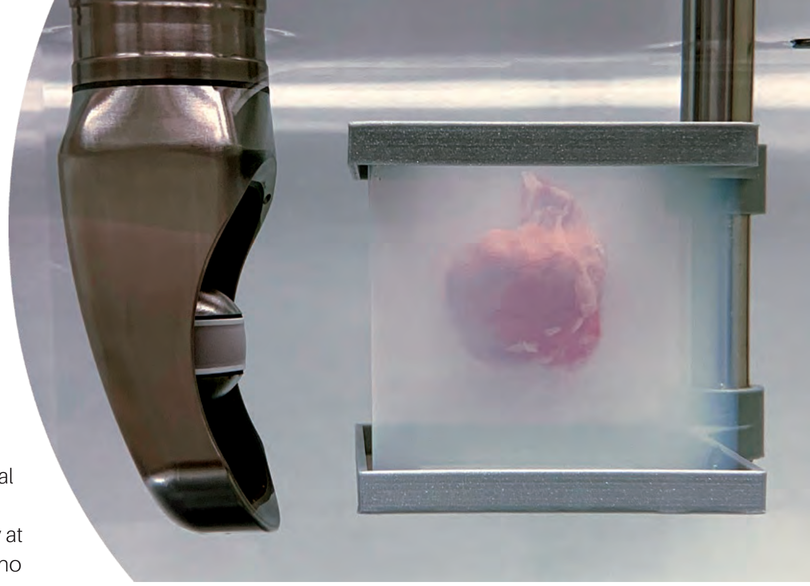
Boiling histotripsy relies on two nonlinear wave phenomena. HIFU is delivered as sequences of millisecond-long pulses. As the sound waves propagate from the transducer to the focus, the initially harmonic waves become nonlinear, transforming to shock waves, like the steepening and breaking of ocean waves when they reach the coast. These shock waves heat the focal tissue to very high temperatures within each pulse, forming tiny vapor bubbles. Subsequent incoming shock waves interact with the vapor bubbles, creating mechanical cavitation at the vapor–tissue interface, finally resulting in tissue liquefaction.

"The ultimate goal is performing first-in-human trials with this improved technology for the focal treatment of prostate in the next few years."

– George Schade

prototype design

One of the greatest challenges of the project is to build the treatment probe itself. It must house both the therapeutic and imaging ultrasound transducers, be small enough to account for patient anatomy, and powerful enough to create the nonlinear pulses that result in tissue disintegration through boiling histotripsy. Senior Principal Engineer Oleg Sapozhnikov details how the design was a multi-parameter optimization problem involving transducer dimensions, focal distance, frequency, power, and several other factors. Once a prototype was built, "We needed to characterize it," continues Sapozhnikov. "We did this using acoustic holography." Similar to the creation of three-dimensional optical holograms, CIMU researchers measure the two-dimensional pressure distribution in an ultrasound beam emanating from the transducer and then reconstruct mathematically the exact field on the surface of the transducer and in the entire 3-D space to create the acoustic hologram. Reconstructing the behavior of the transducer and knowing the acoustic properties of the human body assures that boiling histotripsy conditions are achieved at the focus of the treatment probe.



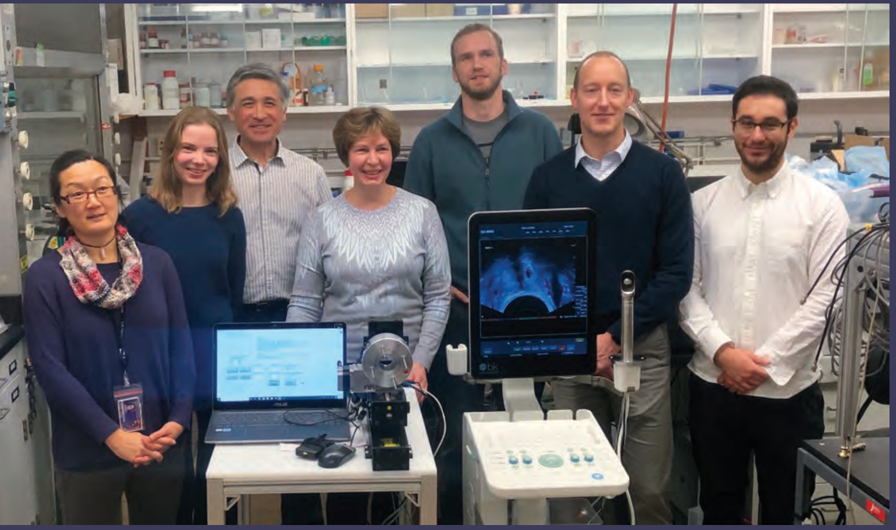
bioeffects

With the prototype system, the team has performed several pre-clinical ex vivo studies using prostate tissue, excised and embedded in gel and placed either in a water tank or coupled directly to the treatment probe. During experimental treatments, lesion formation within the tissue is clearly visible as hyperechoic regions in real-time ultrasound imaging. Senior Engineer Yak-Nam Wang processed the treated tissues for histological and ultrastructual evaluation. "We found that the lesion contained homogenized material lacking cellular structure and a clear margin is evident between the lesion and normal, untreated tissue," says Wang. "And looking closely at the lesion contents, we see a complete loss of cellular structure, with no organelles present."

treatment efficacy

The team's treatment system positions and moves the ultrasound focus with sub-millimeter precision, liquefying clinically significant volumes of prostate tumor tissue. Perhaps the greatest advantage of histotripsy vs. a thermal ablation technique is the integration of B-mode ultrasound to target and give real-time feedback of treatment efficacy. Shade explains, "As the treatment evolves, we monitor the resulting hyperechoic bubbles at the focus. And as these are replaced by a dark, hypoechoic cavity, we know we've achieved treatment success." Khokhlova adds, "Boiling histotripsy is being evaluated for several clinical indications, but focal therapy for prostate cancer is perhaps closest to clinical implementation."

team members: CHRISTOPHER HUNTER, VERA KHOKHLOVA, WAYNE KREIDER, ALEX PEEK, OLEG SAPOZHNIKOV, STEPHANIE TOTTEN, YAK-NAM WANG (APL-UW); TATIANA KHOKHLOVA (UW Medicine); GEORGE SCHADE (UW Urology), SERGEY BURAVKOV, MARIYA KARZOVA, EKATERINA PONOMARCHUK, PAVEL ROSNITSKIY, SERGEY TSYSAR (Moscow State University)



seattle-moscow connection

*The successful development of focal therapy for prostate tumors based on noninvasive, ultrasound-guided, mechanical disintegration of tissue has grown from the close collaboration among researchers at the **University of Washington** and **Moscow State University**.*

The groups have complementary strengths. Moscow State physicists are renowned for their expertise in non-linear wave phenomena and designing therapeutic high-intensity focused ultrasound transducers. The UW team has proven ability to design therapeutic HIFU devices, evaluate the bioeffects induced by HIFU, and conduct translational 'bench-to-bedside' experiments.

*This collaboration has been made possible by a first-ever joint sponsorship between the **U.S. National Institutes of Health** and the **Russian Foundation for Basic Research**.*

> ***"I've been dreaming about it ... watching data from Mars stream back to Earth."***
>
> — Tim Elam

PIXL heads to Mars

The morning blastoff on 30 July marked the culmination of many years of exacting work for all involved with the Mars 2020 mission. *Perseverance*, a car-size rover, is now on its 300-million-mile journey to Mars, scheduled to touch down in February 2021. Aboard *Perseverance* is the Planetary Instrument for X-ray Lithochemistry—PIXL. Deployed on the rover's robotic arm, PIXL will be up front in the search for fossilized signs of Martian life preserved from billions of years ago.

Senior Principal Physicist Tim Elam got involved with the NASA team to develop PIXL nearly eight years ago. As the team's 'chief spectroscopist' Elam collaborated with engineers, geoscientists, and astrobiologists to design PIXL and integrate it with the rover's many science instruments. PIXL uses a powerful X-ray beam to scan a postage-stamp-sized area of rocks, zooming in to single grains of sand—about 100 microns. Analysis of the emission spectrum excited by the X-ray beam reveals the sample's chemical composition. "The thing that makes PIXL such a cool instrument is that it tells us both the composition and structure of materials—what elements are in different places," explains Elam. "These maps of the spectral distribution of elements are critical to detect biosignatures."

If there were microbes on Mars billions of years ago when rocks were being formed, PIXL will detect the chemical fingerprints left behind. To maximize chances of finding evidence of fossilized microbes, *Perseverance* will touch down in Jezero crater, which once held a lake and has well-preserved delta deposits left behind by outflowing water. When the rover begins exploration of the crater, PIXL will send data back to Elam and the team on Earth every Martian day. "I've been dreaming about it… watching data come down," says Elam. And each day, based on their analysis, the team will send a new set of commands that *Perseverance* will execute autonomously for the next daily cycle.

Elam had looked forward for many years to gathering with other members of the Mars 2020 mission team at Cape Canaveral for the launch. But because of the pandemic, he watched with his family at home. Still, the launch was a spectacular moment. Elam remembers exclaiming, "Wow! This thing is really going to Mars." He adds, "This is my first space mission. It's just as complicated, challenging, and exciting as I had imagined."

image: NASA/JPL-Caltech

The Applied Physics Laboratory advances the education mission of the University of Washington. Our scientists teach in academic departments, advise student thesis and dissertation projects, and mentor aspiring independent investigators focused on careers in research.

About 40 APL-UW scientists hold faculty appointments in University of Washington academic departments, principally in the College of Engineering and College of the Environment, and ranging across disciplines including oceanography and fishery sciences, electrical and mechanical engineering, earth and space sciences, and statistics.

Every year APL-UW scientists and engineers teach, advise, and mentor scores of students across the academic spectrum of our world-class research university—undergraduate physics majors, those pursuing graduate degrees in over a dozen disciplines, and postdoctoral scholars whose career interests align with the Laboratory's areas of expertise. Students pursuing University of Washington degrees are integrated directly into their advisors' sponsored research projects, where they gain specialized training, experience, and broad professional support.

generations next + now

graduate students, postdoctoral scholars, early career investigators

students, their graduate degrees earned, thesis titles, and APL-UW advisors

Ryan Elliott, Electrical and Computer Engineering, Ph.D., 2020
Trajectory Tracking Wide-Area Control for Power Systems
Daniel S. Kirschen (ECE) and Payman Arabshahi

Megan Erickson, Political Science, M.A., 2020
Blood Avocados: Trade Liberalization and Cartel-Related Violence in Mexico
Michael Gabbay

Ryan Hammond, Bioengineering, M.S., 2020
Reduction of Off-Axis Clutter in Plane-Wave Ultrasound Imaging
Matthew Bruce

Alex Huth, Earth and Space Sciences, Ph.D., 2020
A Generalized Interpolation Material Point Method and Anisotropic Creep Damage Model for Shallow Ice Shelves
Benjamin Smith

Sam Kastner, Civil and Environmental Engineering, Ph.D., 2020
The Fate and Dynamics of a River Plume in the Surf Zone
Jim Thomson and Alex Horner-Devine (CEE)

Gordon Maxwell Showalter, Oceanography, Ph.D., 2020
Acquisition, Degradation, and Cycling of Organic Matter Within Sea Ice Brines by Bacteria and Their Viruses
Jody Deming (Oceanography) and Rebecca Woodgate

Zhihua Zheng, Oceanography, M.S., 2020
Evaluation of Monin–Obukhov Similarity Theory in Unstable Oceanic Surface Layers
Ramsey Harcourt and Eric D'Asaro


Sam

Martin

Ali

photo: Francoise Morison | URI

postdoctoral scholars, their disciplines, and APL-UW mentors

Martin Arostegui, Aquatic and Fishery Sciences, University of Washington
Peter Gaube

Bàrbara Barceló-Llull, Oceanography, Universidad de Las Palmas de Gran Canaria
Kyla Drushka and Peter Gaube

Ali Chase, Oceanography, University of Maine
Kyla Drushka

Dipanjan Chaudhuri, Climate Science, Indian Institute of Science
Eric D'Asaro

Nan-Hsun Chi, Oceanography, University of Washington
Andrey Shcherbina

Alice Della Penna, Quantitative Marine Science, University of Tasmania
Peter Gaube

Alex Fisher, Marine, Estuarine, and Environmental Science, University of Maryland
Jim Thomson

Mohamed Ghanem, Aerospace and Aeronautical Engineering, University of Washington
Mike Bailey

John Guthrie, Physical Oceanography, University of Washington
Jamie Morison

Alexis Kaminski, Applied Mathematics and Theoretical Physics, Churchill College, University of Cambridge
Eric D'Asaro

Sina Khani, Applied Mathematics, University of Waterloo
James Girton

Michalea King, Earth Science, Ohio State University
Ian Joughin

Aurelie Moulin, Oceanography, Oregon State University
James Girton

Daniel Shapero, Applied Mathematics, University of Washington
Anthony Arendt

Madison Smith, Civil and Environmental Engineering, University of Washington
Bonnie Light

Tyler Sutterley, Earth System Science, University of California, Irvine
Benjamin Smith

Anne Takahashi, Earth and Planetary Physics, University of Tokyo
Ren-Chieh Lien

Gilles Thomas, Biomedical Engineering, University of Lyon
Vera Khokhlova

Anda Vladoiu, Physical Oceanography, Sorbonne University
Ren-Chieh Lien

Guangyu Xu, Marine Sciences, Rutgers University
Todd Hefner

science + engineering
enrichment + development program

Scholars showing outstanding potential to establish independent research careers have been supported by the APL-UW SEED postdoctoral fellowship program since 2014. Two highly competitive fellowships per year provide two years of support. SEED fellows have research goals aligned with APL-UW areas of expertise and define their research program in conjunction with an APL-UW principal investigator.

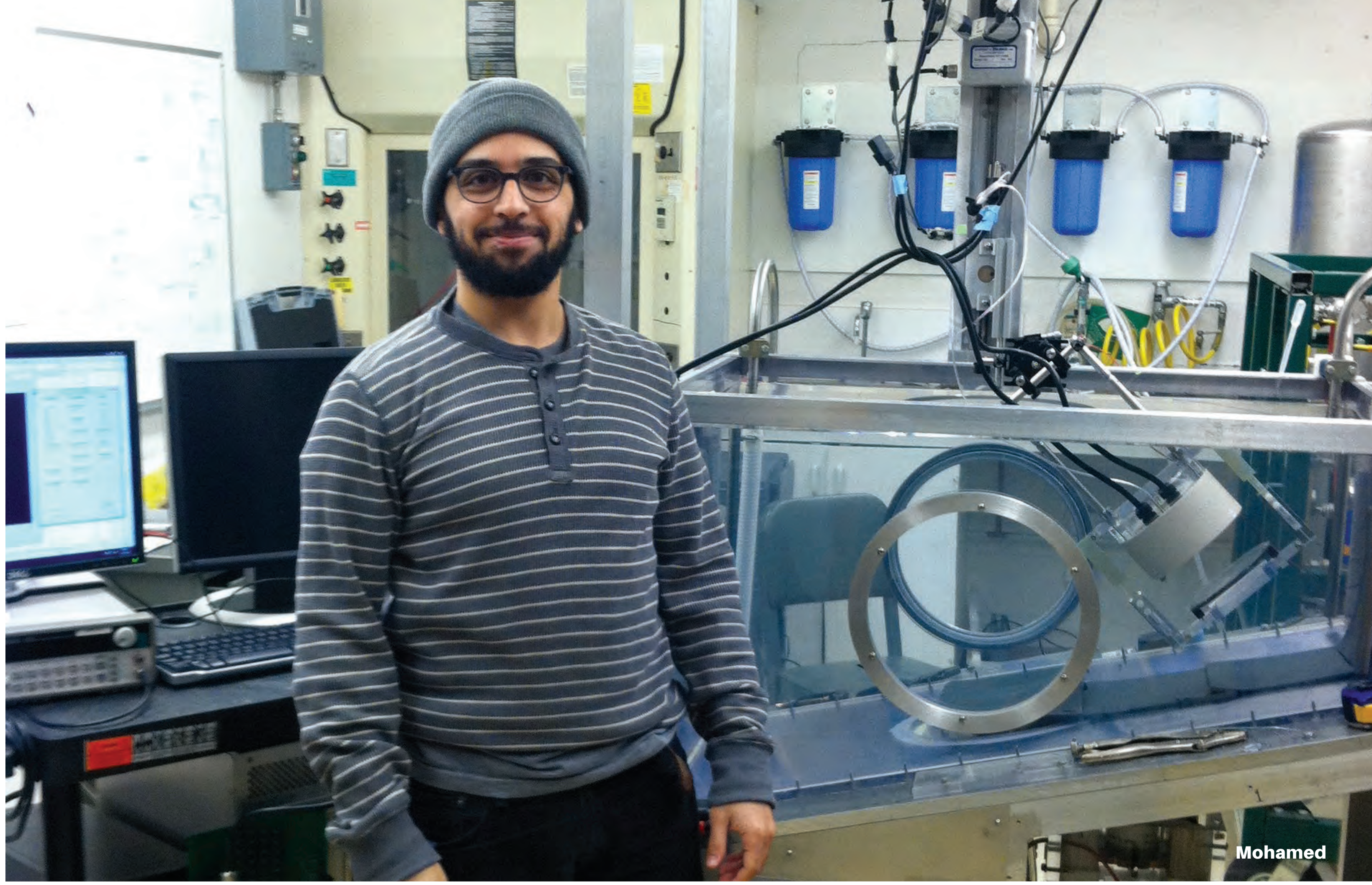
2020 SEED fellows are **Mohamed Ghanem**, working with Mike Bailey at the Center for Industrial and Medical Ultrasound, and **Michalea King**, working with Ian Joughin at the Polar Science Center.

Levitating, holding, and moving objects with 'tractor beams' may sound like science fiction, but **Mohamed Ghanem** has demonstrated this as science fact. In a paper published this year, Ghanem describes a 256-element ultrasound transducer used to create vortex-shaped beams that trap and move millimeter-scale objects in three dimensions inside a living body.

These pioneering efforts to create acoustic tweezers have opened new areas of inquiry for Ghanem. During the fellowship he plans to continue research into complex acoustic beam shaping and work to perfect the transducer by integrating ultrasound imaging and applying acoustic field correction techniques that account for variable propagation media. A goal is to add acoustic manipulation technology to an ultrasonic therapy system that non-invasively breaks and moves stones out of the kidney. Mentor Mike Bailey says, "I believe this is very high-level science… and it adds luster to the Laboratory's reputation. I am very optimistic that this work will change how kidney stones are managed."

Melting of the Greenland Ice Sheet is the greatest single contributor to rising sea levels. Glaciologist **Michalea King** reports in a paper published this year that the rate of ice loss accelerated abruptly in the early 21st century and has been sustained since. Leading an international team that analyzed over 30 years of remote sensing observations, King and her collaborators point to the retreat of Greenland's outlet glaciers — conveyor belts draining the ice sheet interior to the sea — as the driver of this new dynamic state. "Michalea's work thus far demonstrates a strong capacity for independent research and an ability to collaborate, which will be important for pursuing a research career," notes mentor Ian Joughin.

Every summer, meltwater forms on the ice sheet surface and can drain through deep crevasses to the glacier bed. King plans to use her fellowship to understand how this injection of meltwater can separate the ice from the underlying bedrock and sediments, and cause a temporary acceleration of the glacier's flow. High-resolution, multi-decadal data sets of glacier flow speeds will be used to pinpoint glaciers sensitive to destabilization by meltwater, and altimetry from NASA's ICESat-2 will be used to detect surface bulging and depression events that signal meltwater injection to and transport from the glacier bed.



Mohamed

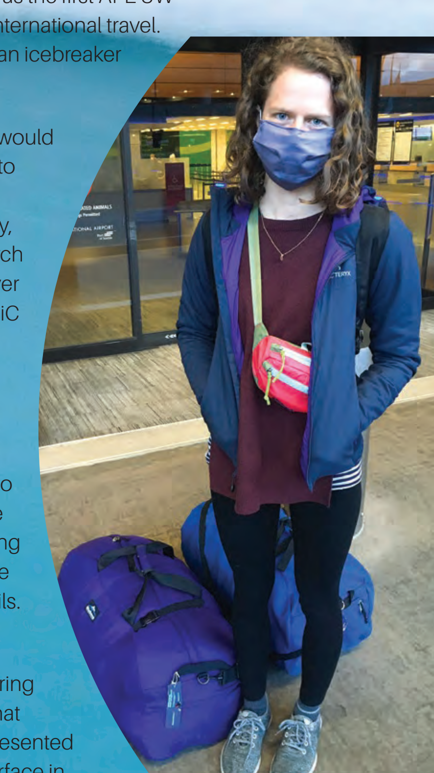
Michalea

> ***"Working alongside biologists, chemists, and atmospheric scientists was a great opportunity, and it benefits our science, too, making it easier to discover linkages among our research areas."***
>
> – Maddie Smith

Postdoctoral scholar **Madison Smith** spent two months last summer on a sea ice floe in the Arctic. With the German icebreaker *Polarstern* as home base, Smith ventured out on the ice every day to measure how the sun's energy is reflected by, transmitted through, and absorbed by the ice and the underlying ocean during the melt season. Smith teamed with scientists from 20 countries on the Multidisciplinary drifting Observatory for the Study of Arctic Climate—MOSAiC—expedition. The *Polarstern* and the ice floe it was frozen into in October 2019 was the expedition's central drifting observatory until August 2020.

"When I arrived, the floe was still covered in snow, but it melted away completely. Melt ponds formed on most of the floe, then deepened, and eventually melted through to the ocean below," Smith recounts. Her colleague and mentor, Principal Physicist Bonnie Light, spent a similar summer melt season on the sea ice during SHEBA (Surface Heat Budget of the Arctic Ocean) just over 20 years ago. That was the last time a science team froze an icebreaker into the ice to collect a spatially representative and temporally resolved sea ice albedo history over an entire annual cycle. Those observations were made in the Beaufort Sea, while the MOSAiC drift was across the eastern Arctic, and since then, sea ice has become much thinner and younger across the Arctic Ocean.

The COVID-19 pandemic put Smith's participation in jeopardy. The logistics—moving 600 scientists and staff on and off the *Polarstern* in six legs over the course of an entire year—were challenging, even before COVID-19. Smith was the first APL-UW researcher to secure a waiver to the University's restriction on international travel. But because Norway had closed its borders, the plan to board an icebreaker in Svalbard for the trip to the MOSAiC floe was cancelled.



A nearly unthinkable contingency plan was crafted: *Polarstern* would leave the central observatory and transit to a Spitzbergen fjord to rotate crew and supplies, then return to the floe to salvage the mission. After a two-week quarantine in Bremerhaven, Germany, Smith and her leg-four colleagues boarded two German research vessels to head north and rendezvous with *Polarstern*. "After over six weeks since I had left Seattle, we finally arrived at the MOSAiC observatory," said Smith.

Some instruments that had been deployed above, in, and under the ice at the MOSAiC observatory continued data collection autonomously during *Polarstern*'s absence. Most measurements, however, required Smith and the sea ice team to descend the gangway to the floe to conduct daily surveys. "We measured albedo on the floe, took measurements in the evolving leads that opened all around us, and monitored stakes in the ice that helped quantify melt from the top and bottom," Smith details.

MOSAiC field measurements will ultimately enhance the representation of the sea ice cover in climate models, empowering scientists to more reliably predict its future state. Smith hopes that observations targeting processes that are least realistically represented in current models, for example, how the sun-warmed ocean surface in leads melts floes from their edges, will be particularly beneficial.

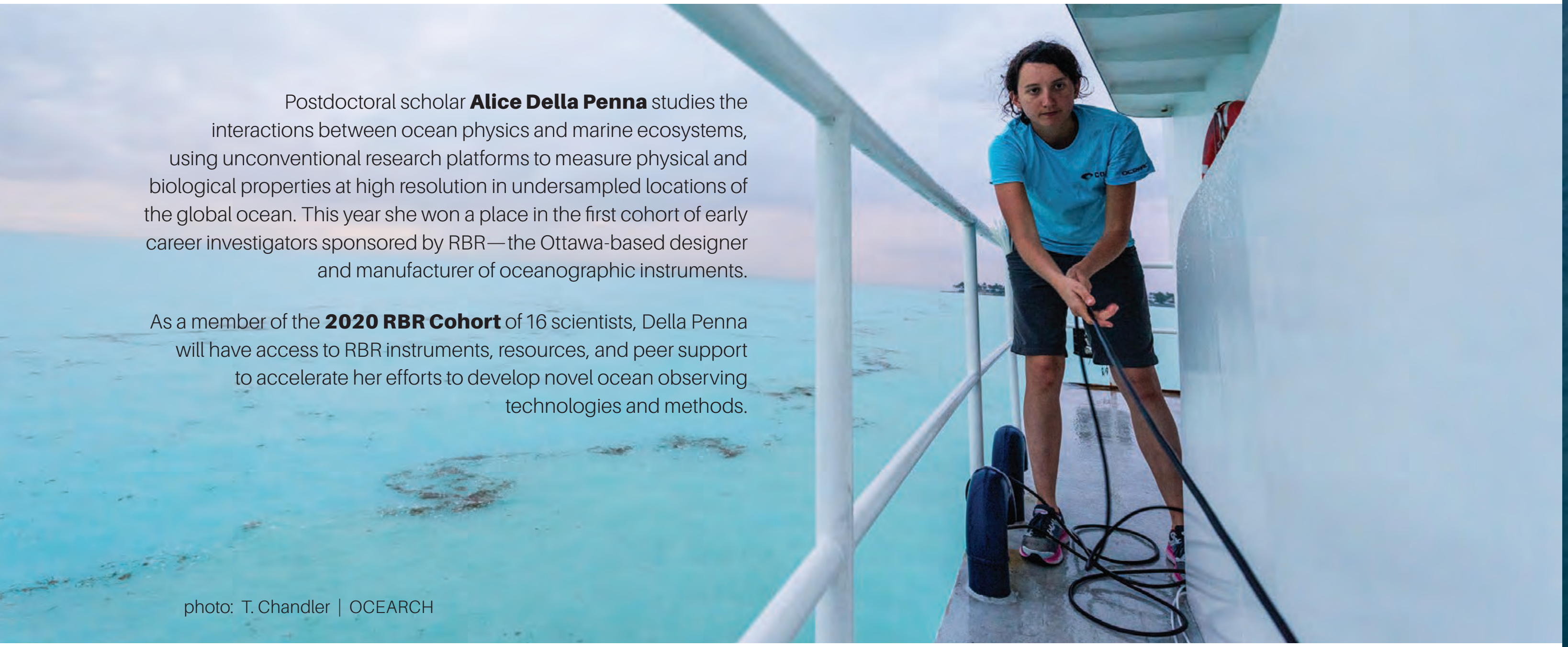
photo: Amy Macfarlane

APL-UW is a premier 'launching pad' for independent researchers. In 2020 the Laboratory's ranks include over 20 postdoctoral scholars—a record number—pursuing programs across the Laboratory's areas of expertise: ocean acoustics, physical and biological oceanography, polar science, and ultrasound physics.

With the guidance of their APL-UW mentors, postdocs hone their academic talents and expand expertise through multidisciplinary collaborations, they gain professional experience, build a support and resource network, and develop the soft skills of grant writing and field experiment planning. All are necessary to launch robust independent research careers. Postdocs make significant contributions to the Laboratory, often becoming long-term additions to the science and engineering staff.

Beyond postdoctoral training, APL-UW leadership is making strategic investments in our newest generation of scientists and engineers. The Early Career Principal Investigators Group at APL-UW is comprised of over 40 self-identifying researchers. The group meets regularly to tackle the most pressing issues facing early career PIs: career development and building relationships with UW research collaborators. The Laboratory provides travel funds for these PIs to strengthen relationships with research sponsors, the broader science and engineering community, and industry partners.

Optical oceanographer **Ali Chase** received a prestigious **Washington Research Foundation Postdoctoral Fellowship** in 2020 to support her studies of microscopic life in the ocean. Single-celled phytoplankton come in many sizes, shapes, colors, and, most importantly, have differing functions in the ecosystem. From the vantage of orbiting satellites, phytoplankton blooms color the ocean surface. At sea Chase has collected data with automated microscopy to determine distributions of different phytoplankton groups in surface waters across entire ocean basins. Now she is developing algorithms to link these data to the 'fingerprints' revealed by hyperspectral analysis of these groups. The goal is to use upcoming NASA satellite hyperspectral measurements to determine global phytoplankton community composition from space.



Postdoctoral scholar **Alice Della Penna** studies the interactions between ocean physics and marine ecosystems, using unconventional research platforms to measure physical and biological properties at high resolution in undersampled locations of the global ocean. This year she won a place in the first cohort of early career investigators sponsored by RBR—the Ottawa-based designer and manufacturer of oceanographic instruments.

As a member of the **2020 RBR Cohort** of 16 scientists, Della Penna will have access to RBR instruments, resources, and peer support to accelerate her efforts to develop novel ocean observing technologies and methods.

photo: T. Chandler | OCEARCH

Melissa Moulton and 25 other early career scientists from 19 institutions are the recipients of 2020 **Office of Naval Research Young Investigator Program** awards. Over the three-year award period, Moulton will pursue naval-relevant research to forecast coastal exchange processes from remote sensing observations. "It's critical that we attract the best and brightest scientists and engineers from across academia to address naval warfighting challenges," said Rear Admiral David Hahn during the announcement.

ONR has funded multi-investigator initiatives to improve understanding of the complex nearshore environment to achieve battlespace awareness and forecasting capabilities that extend from the deep ocean to the shoreline. During the Inner Shelf Dynamics experiments near Point Sal, California, Moulton executed a plan of airborne observations and small vessel transects. With award funding, these data will be used to drive numerical simulation experiments to investigate the episodic ejections offshore of objects and sediments from the surf zone. Moulton will also broaden the limits of remote sensing platforms—autonomous aerial systems and satellites—to observe and forecast these processes. Accurate forecasts of rip currents and turbidity across the inner shelf region will benefit Navy amphibious operations, shallow water acoustics, and optical sensing.

FOAM, SEDIMENT, AND ALGAE MOVING BETWEEN BEACH AND SHELF BY RIP CURRENTS, INTERNAL WAVES, AND FRONTS ON A ROCKY COASTLINE OBSERVED FROM THE COMPACT AIRBORNE SYSTEM FOR IMAGING THE ENVIRONMENT.

During fiscal year 2020 the Applied Physics Laboratory received $77.7M in contract and grant awards, a 23% increase from 2019. This is the greatest annual total award amount for APL-UW and represents a near-record 262 distinct awards.

Early in 2020 Laboratory leadership changed our financial reporting period to align with that of the University of Washington, shifting the fiscal year period from 1 October–30 September to 1 July–30 June.

The U.S. Navy remains the largest sponsor of Laboratory research and development, representing 52% of all awards received in FY2020. This year funding from the Office of Naval Research and the Naval Sea Systems Command (NAVSEA) was twice that received during FY2019. Support from non-Navy federal sponsors remains strong, with significant increases in funding from NASA, NOAA, and NIH.

In October 2020 the Laboratory received its fully executed NAVSEA contract, continuing the valued partnership between APL-UW and NAVSEA that has spanned over 75 years. The contract is a cost-plus-fixed-fee, indefinite-delivery/indefinite-quantity (IDIQ) contract with two 5-year options, and supports research and development programs within the Laboratory's approved core competency areas. The continuing contracted relationship positions the Laboratory to respond quickly to U.S. Navy and Department of Defense needs and priorities.

A valuable dividend of increased awards is the corresponding growth in funds to make strategic investments in APL-UW staff and facilities. Prorated Direct Cost revenues support research administration and facilities, while discretionary revenues are invested in people and infrastructure, ensuring APL-UW will continue to lead in scientific discovery and technology innovation.

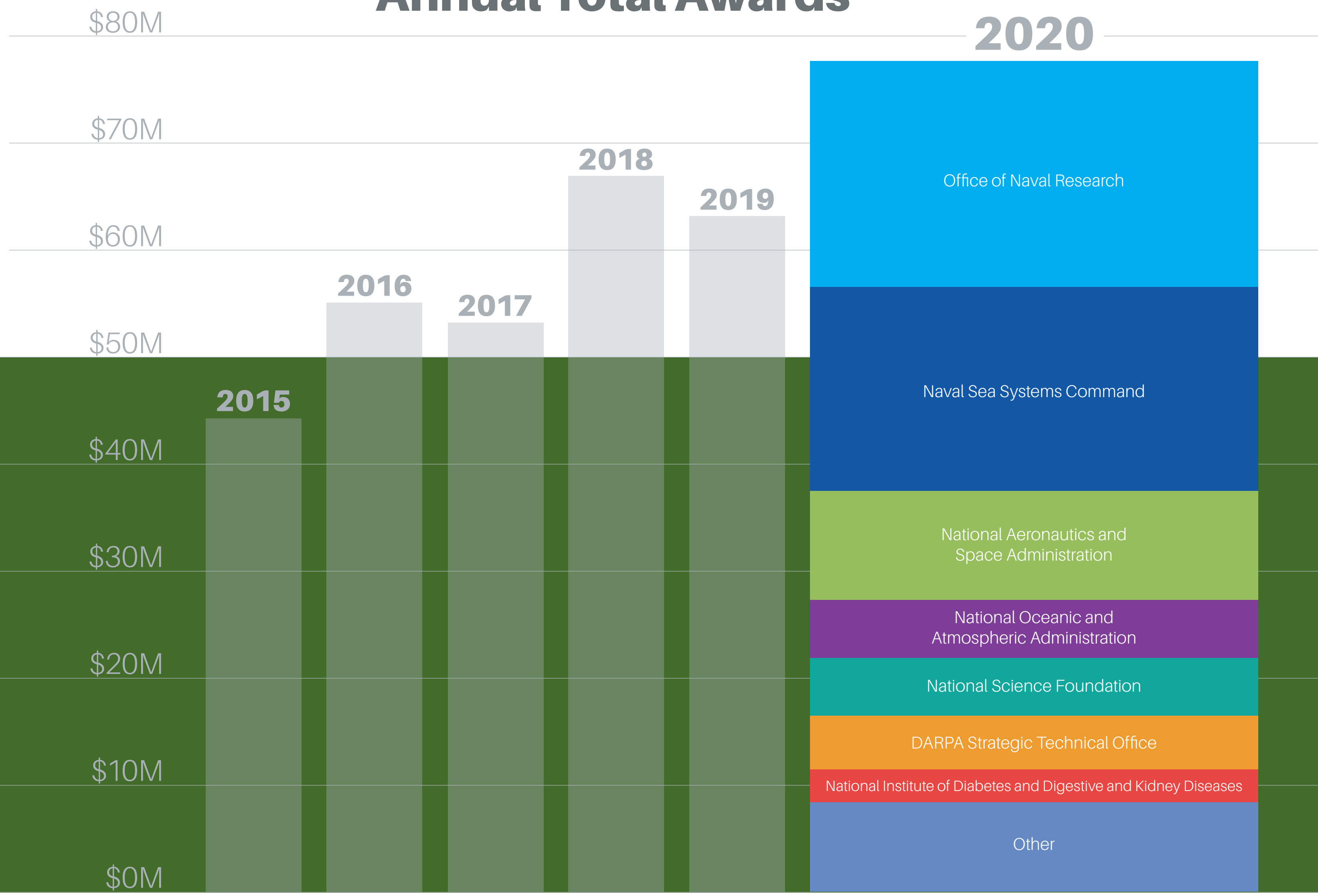
The Interdepartmental Independent Research and Development Program, launched in early 2020, fosters multidisciplinary efforts across APL-UW's eight research and technical departments. Encouraging the diversity of thought across APL-UW, these collaborations will result in innovative, high-quality proposals to sponsoring agencies. The Technical Staff Development Program was started just over one year ago to broaden and refresh engineering and information technology skills across the Laboratory.

Central to APL-UW's field research and seagoing capabilities is our vessel fleet and floating pier. To ensure these resources are available to our researchers and collaborators far into the future, we have begun work to replace the 50-year-old floating pier with a modern facility by early 2022.

The Laboratory's financial outlook is robust. Investigators continue to win competitive awards at historically high levels. Endowment earnings are allocated to support more postdoctoral scholars and discretionary funds are advancing diversity, equity, and inclusion efforts. The impacts and duration of the COVID-19 pandemic are yet unknown. During 2020 the Laboratory worked with partners at the University, state and federal government, and sponsoring agencies to weather unprecedented challenges. Our response and strategic investments in the safety of our staff and resilience of our research programs will benefit the Laboratory for years to come.

financial health

Annual Total Awards



SEATTLE NIGHT SKYLINE PHOTOGRAPHED BY APL-UW ENGINEER BEN BRAND FROM THE STERN OF R/V *ROBERTSON* RETURNING TO THE LABORATORY AFTER A DAY OF ACOUSTICS EXPERIMENTS ON DABOB BAY

leadership

laboratory

KEVIN WILLIAMS	Executive Director
WARREN FOX	Deputy Executive Director Director, Environmental and Information Systems
RAMSEY HARCOURT	Chair, Ocean Physics
MIKE HARRINGTON	Director, Electronic and Photonic Systems
TODD HEFNER	Chair, Acoustics
ANDREW JESSUP	Chair, Air–Sea Interaction and Remote Sensing
THOMAS MATULA	Director, Industrial and Medical Ultrasound
NICK MICHEL-HART	Head, Ocean Engineering
AXEL SCHWEIGER	Chair, Polar Science
BEN ADAMS	Facility Security Officer
KATIE AVRIL	Director, Information Technology
MARIA CARD	Director, Human Resources
DIAN GAY	Director, Resources and Facilities
AUTUMN SALAZAR	Director, Business and Finance

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