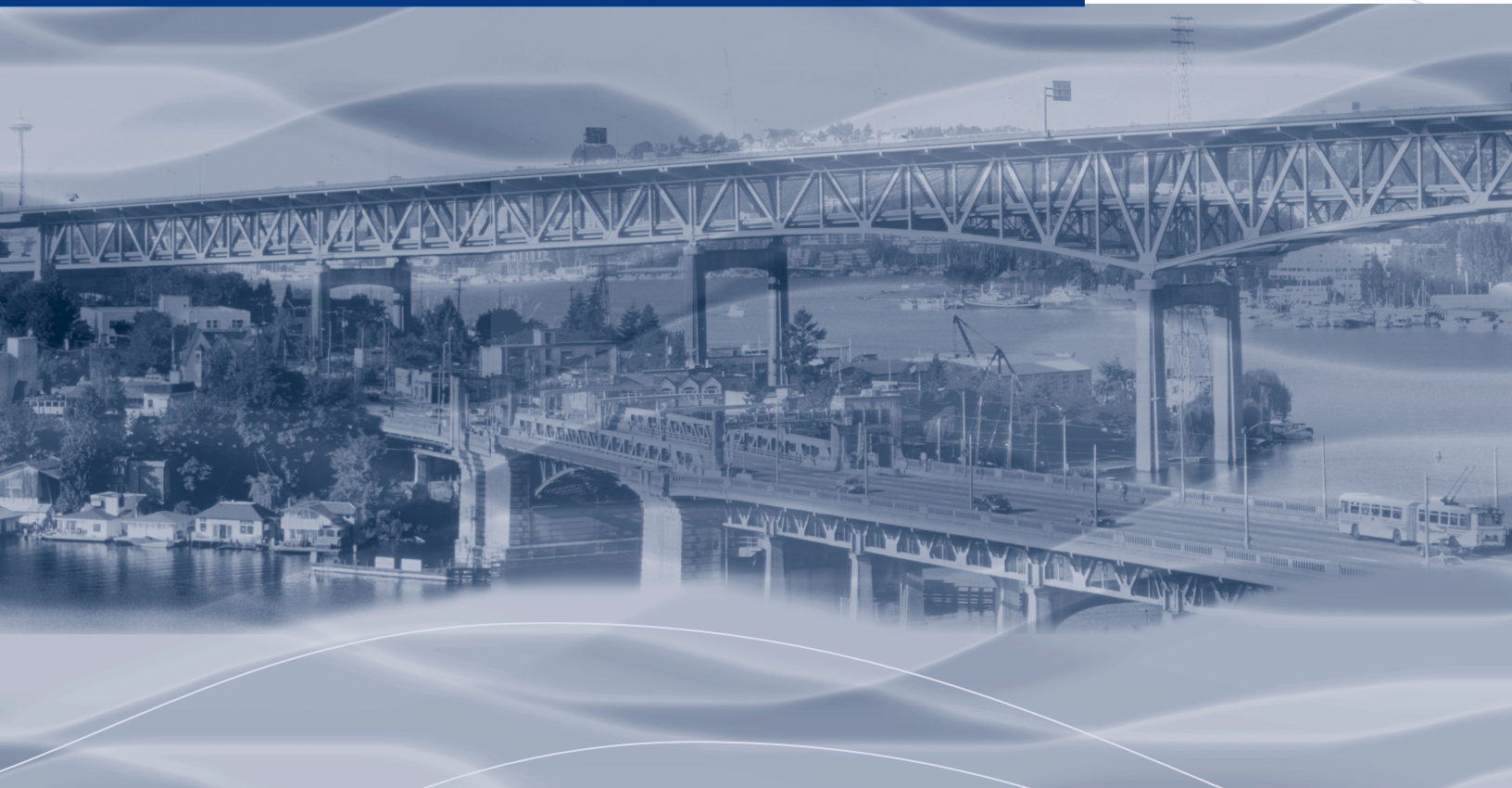


2001 BIENNIAL REPORT



Applied Physics Laboratory

College of Ocean and Fishery Sciences
University of Washington



The Applied Physics Laboratory's mission is to conduct a university-based program of fundamental and applied research, development, engineering, and education for science, industry, and national defense.



The Applied Physics Laboratory building, Henderson Hall, at the University of Washington west campus. Flags at half-staff mourn the thousands of lives lost in New York, Pennsylvania, and Virginia on September 11, 2001.

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Research Highlights

Gliding Through the Sea at 1/3 Knot
The unmanned underwater vehicle called Seaglider has completed extensive design and field tests. Seaglider is prepared for a range of applications and is now on a 4-year deployment to study the processes governing the physical and biological variability in the Alaska Coastal Current.

Reading the Earth's Climate Compass at the North Pole
The Arctic may be a sensitive indicator of global environmental change. To understand the recently observed changes in the atmosphere, ocean, and ice, Polar Science Center researchers have established a year-round observatory in the central basin of the Arctic Ocean that is staffed for a short period each year.

Flipped Out for 32 Days at Sea
Organized by members of the newly formed AIRS Department, the FAIRS experiment aboard the R/P *FLIP* investigated the effects of ocean surface waves on remote sensing techniques and air-sea fluxes of momentum, heat, and gas.

Improving Naval Weather Forecasting
Recognizing that a Navy meteorologist must gather, process, and analyze information from a variety of sources to make real-time forecasts, APL-UW has applied its expertise to constructing new technologies and procedures that improve the accuracy and reduce the time of naval weather forecasting.

Sound in the Seafloor
High-frequency sonar is used to detect objects in the water column or resting on the seafloor. In shallow water just off the Florida Panhandle, APL-UW scientists worked to quantify acoustic backscattering from the seafloor sediment, acoustic penetration into the sediment, and acoustic propagation within the sediment.

Controlling Sonars in Shallow Water
The EIS Department is developing technologies to enable automated, environmentally-adaptive active sonars, which are especially critical to a Navy commander operating in shallow water. Employing a trained artificial neural network to compute acoustic models, the sonar controller produces real-time pictures of the underwater environment.

Saving Lives with Sound
The Center for Industrial and Medical Ultrasound leads a pioneering program to study the use of ultrasound to image internal bleeding that results from trauma and to stop the bleeding—to arrest hemorrhage with sound.

Ocean Mixing at the Hawaiian Ridge
Interaction of the astronomical tide with the remarkable topography of the Hawaiian Ridge produces local mixing and generates internal waves that radiate away from the ridge and into the deep ocean. Recent and future HOME research efforts will yield an understanding of how topographic mixing contributes to global ocean stratification.

Director's Message



Kim Reading

Director Robert C. Spindel

The two years since our last Biennial Report have been exciting, eventful and very good ones for APL. Sixteen new principal scientists and engineers joined the staff. Darrell Jackson was awarded the Acoustical Society of America's Pioneers Medal in Underwater Acoustics, and Larry Crum was awarded its Helmholtz-Rayleigh Silver Medal in Physical Acoustics. Grant and contract awards rose during both years, and so did the total population of the Laboratory. We created three new departments to reflect new directions and strengths—Ocean Acoustics, Air-Sea Interaction and Remote Sensing, and the Center for Industrial and Medical Ultrasound.

We completed major renovations in Henderson Hall and we expanded into offices and laboratories in the old Fisheries Research Center building about one-half mile away. We also conducted an intense, Laboratory-wide strategic planning activity to assess APL's role in the face of a much changed national security environment, a university more focused than ever on undergraduate education, and rapid growth in basic research grants versus applied development contracts. The bottom line was a clear affirmation of two guiding principles: our long-standing commitment to excellence in research and development for national defense, especially with our long-term and loyal partner, the U.S. Navy, and our strong focus on the fundamental physics required to understand and solve pressing societal problems such as global warming. Although the world today is very different from 1943 when APL was founded as a WWII defense laboratory, or during the Cold War when APL focused on torpedo technologies for submarine warfare, it is no surprise that our vision and commitment remain unchanged—national defense and national welfare. The problems are different, but solutions are still needed.

Today's Navy, faced with overcoming new threats and executing new missions, emphasizes warfare in littoral regions, land attack, power projection, information superiority, maneuver from the sea, and joint and coalition operations. Network-centric warfare, knowledge-based operations, common tactical picture, asymmetric warfare, cooperative engagement, and anti-terrorist operations are new concepts, and new ways of doing business, requiring new science and innovative technology. Naval operations in coastal, shallow waters differ from the deep, blue water scenario of the Cold War. They demand an understanding of small-

scale oceanography and perhaps even new physics. We have an important role to play in developing the new technology our Navy must have to continue to be the best in the world.

On the civilian side, environmental issues have leaped to the fore. The fact of global warming is no longer debated. What to do about it is. We now know that understanding the detailed modes of regional climate variability such as the Pacific Decadal Oscillation or the Arctic Oscillation are essential to understanding global climate change, whether natural or anthropogenic. Powerful computer simulations attempt to predict the effect of increasing or decreasing greenhouse gases, but fall short because they lack details of essential physics, such as the mechanisms for heat and gas exchange at the air-sea interface, the true role of the ocean in the global carbon cycle, or the fundamental mixing processes governing heat transport into, through, and out of the ocean.

These important issues, military and civilian, form the core of APL's programs. On the defense side, we are developing techniques to automate sonar operations, to improve submarine towed arrays, and to enhance mine countermeasures. We provide the submarine force with systems to help ensure optimum performance of on-board sonars. On the non-defense side we are leaders in deciphering the role of the Arctic in climate change and global warming, in developing and deploying instruments to study energy balances in the ocean, and in using remote sensing methods to study the exchange of heat and gases at the air-sea boundary, all of which feed the development of accurate weather and climate models. The last few years have witnessed major growth in our medical acoustics programs, which are focused on both military casualty and civilian care. These include ultrasonically enhanced delivery of therapeutic agents, high-intensity focused ultrasound for non-invasive surgery and tumor treatment, and acoustic hemostasis for battlefield casualty care.

This report highlights selected current projects on these subjects. For example, sonars operating in near-shore waters are faced with rapid shifts in operating conditions—abrupt changes in temperature and salinity resulting from fresh water outlets and uneven surface heating, changes in bottom composition and roughness, and varying depth. If the effects of these changes are not compensated by adjusting numerous sonar settings, performance can be seriously compromised. The article on sonar control in shallow water describes how compensation will be accomplished automatically, using a combination of continuous *in situ* database updates, through-the-sensor measurements, and nonlinear optimization. Not only does this ensure that settings are always optimized, but it also reduces personnel requirements, a critical step in developing the Navy's 21st century Fleet with its greatly reduced manning goals.

David Jones's article on human-computer studies in naval meteorology and oceanography is another example of research aimed at coping with changes in the environment that affect naval operations. It describes how we seek to present warfighters with information and knowledge, rather than data, to facilitate swift and accurate decision making. In a different vein, but still focused on naval concerns, is the article on SAX99, the Office of Naval Research's 1999 Sediment Acoustics Experiment. The goal of the program is to understand conditions that allow penetration of acoustic energy into the seabed, thus enabling sonars to detect and identify buried mines, a particularly nasty shallow water problem. Eric Thorsos is ONR's Chief Scientist for the entire five-year program which runs through 2002, and Kevin Williams led APL's participation in the experiment itself.

The Hawaii Ocean Mixing Experiment and the North Pole Environmental Observatory are examples of programs focused on global climate change. The

The Laboratory's two guiding principles are our long-standing commitment to excellence in research and development for national defense, and our strong focus on the fundamental physics required to understand and solve pressing societal problems.

The Laboratory's graduate students bring a measure of vitality and new discovery that is unique to young people, and essential to the health of a first-rate research institution.

former seeks to understand the role of mid-ocean ridges and large bathymetric features in generating ocean internal waves, which are believed to be one of the important energy sources for driving oceanic mixing, thus affecting global heat circulation and carbon cycling. The latter places recording instruments directly at the Pole to obtain data for initiating and proofing climate models. These models predict that the earliest and most severe effects of global warming will be observed at the North Pole. Drew Rothrock's recent pioneering research using Navy submarine sonar data collected under the ice has begun to unravel the relationship between ice thickness, temperature, and wind circulation patterns.

Under Larry Crum's dynamic leadership, medical ultrasound research at APL is growing by leaps and bounds. Last year, APL's new department, the Center for Industrial and Medical Ultrasound (CIMU), was formally and officially recognized by the university as a disciplinary center, and its rapid growth has forced us to expand into another building not far from Henderson Hall. An illustration of the exciting research in CIMU is provided by the article on acoustic hemostasis, a method that uses high-intensity focused ultrasound to stop internal bleeding.

Education in many forms, from high school through post-doctoral, also plays a major role in the life of the Laboratory. The approximately 55 graduate students doing their thesis research at APL under the supervision of an APL staff member bring a measure of vitality and new discovery that is unique to young people, and essential to the health of a first-rate research institution. And because they are matriculated in a dozen or so university departments ranging from Electrical, Mechanical and Bioengineering to Oceanography, Fisheries, Geophysics and Atmospheric Sciences, they help create the kind of interdisciplinary atmosphere required to tackle successfully today's complex scientific and technical challenges. We have an undergraduate program as well, where students have an opportunity to work side-by-side with APL staff gaining unique insight into the exciting world of research, and we frequently host high school groups hoping to spark their interest in science and engineering careers.

As a final note, this is an opportunity for me personally, and also as Director on behalf of the entire Laboratory, to thank all of you who champion and support APL—a superb staff of creative scientists, talented engineers, accomplished technicians and skilled administrators, a wise Advisory Board, friends, colleagues, loyal sponsors, and especially our long-term partner, the United States Navy. We are grateful for your faith in us as an institution, and your confidence in our ability to contribute to our nation's well-being and security.



Kim Reading

Director Bob Spindel and Administrator Dian Gay attend to business.

Formed in 1943 in response to a Navy request for assistance in developing a reliable torpedo influence exploder, the Applied Physics Laboratory of the University of Washington has evolved into a well-known and respected source of research and development in marine-related science and engineering. The partnership with the Navy that began over 50 years ago continues today with a program based in fundamental research and grounded by expertise developed over years of working on Navy problems. Basic research includes ocean physics, polar oceanography, remote sensing, and ocean and physical acoustics, all of which draw upon the Laboratory's demonstrated expertise in designing and deploying specialized instrumentation. This fundamental research underpins and facilitates applications to real-world problems, which range from medical imaging to ice-sheet behavior to measuring rainfall at sea. The articles selected for inclu-


The Applied Physics Laboratory



sion in this report provide a sampling of a program that, at any time, may comprise hundreds of individual projects.

A research unit of the College of Ocean and Fishery Sciences, the Laboratory is located in Henderson Hall on the University of Washington campus. The full-time staff of approximately 200 includes 130 scientists and engineers. APL staff collaborate closely with University faculty, and 38 currently hold faculty appointments. Most supervise graduate students.

The Laboratory is equipped with a machine shop, a library, and publication facilities. Computing needs are addressed by a combination of special purpose machines, central facilities, and networked personal computers and workstations. Special laboratories are available for microwave remote sensing, image processing, transducer development and testing, electronic system development, and physical acoustics. The Laboratory's two research vessels, including a self-propelled acoustic test facility, operate from a marine facility on nearby Lake Union. Access to Puget Sound and deep water is available through a nearby system of locks.

The Applied Physics Laboratory is funded entirely by grants and contracts and receives over two-thirds of its support from Navy sponsors. Other major sources of funding include the National Science Foundation, the National Aeronautics and Space Administration, and the Defense Advanced Research Projects Agency. 

Ocean Physics

The Ocean Physics Department (OPD) focuses on research in small-scale to medium-scale physical oceanography and ocean acoustics. Programs of instrument development, ocean measurement, data analysis, theory, and numerical modeling are applied to understanding heat fluxes, ocean currents, waves, turbulence, mixing, and acoustic propagation and scattering. The relationship between ocean acoustics and physical oceanography is central to the acoustics studies.



OPD researchers aboard the R/V Wecoma.

OPD researchers have international reputations in their fields. Eight hold joint appointments in University of Washington academic departments, teach and train graduate students, and serve as Principal Investigators on research projects, funded mostly by the Office of Naval Research (ONR) and the National Science Foundation (NSF). OPD scientists and engineers design and build prototype instrumentation to collect data along the coastlines, in estuaries and straits, and in the deep oceans of the world.

During 1998–2000, as part of an APL strategic planning effort, OPD recruited several young scientists to the department to complement the

"graying" scientific staff. The outcome is a dynamic department, where new research thrusts augment the old. One new thrust is the development of a prototype refractometer, which will provide a measurement of turbulent density/salinity in the ocean. Such data will allow a more complete scientific understanding of global ocean circulation. In initial lab tests, the refractometer is proving to be many times more sensitive than previous ocean-going instruments of its type. In 2001, it was mounted on the unique Modular Microstructure

Profiler (MMP), previously developed in OPD, and tested in Puget Sound, with the ultimate goal of ocean deployment.

A new effort is under way to use theory and numerical models to study the electrodynamic processes of the ocean. As the ocean flows through the Earth's magnetic field, secondary electric and magnetic fields are generated. Various instruments have been developed at APL that obtain estimates of the flow by measuring these electric fields. In most cases the electric field can be related to the flow using simple theory, but some are more complex and require a better understanding of these electrodynamic processes. OPD

scientists use theory and numerical models to study these complex cases. Other studies of ocean electrodynamic processes are under way to understand the impact of environmental electromagnetic fields on undersea navigation and communication. This includes the study of the oceans' electromagnetic fields produced by oceanic, atmospheric, ionospheric, magnetospheric, and artificial sources.

The Lagrangian float, which tracks the three-dimensional movement of water parcels, was originally developed and built at APL for use in the deep ocean, but in 1998 it was modified for deployment in two new environments—in hurricanes and on the continental shelf. Three Lagrangian floats were dropped from an airplane ahead of Hurricane Dennis off the Florida coast, and the resulting data showed that the hurricane had cooled the upper ocean dramatically. More drops are planned for future hurricane seasons. Recently, several Lagrangian floats were deployed on the Oregon continental shelf, the results showing that the large-scale motion of the floats conformed to existing ideas about the upwelling circulation. Float modifications for the future include adding components to measure ambient noise, vertical shear, and vector acceleration and orientation.

OPD researchers are at the forefront of understanding the effects of internal waves on the propagation of sound through the ocean, through the coupling of their expertise in internal wave oceanography and acoustic propagation through random fluctuations in the ocean. The fundamental knowledge gained from the ongoing synthetic aperture sonar primer research can be applied to the Navy's development of SAS systems for use at ranges to a target on the order of one to a few kilometers.

Theoretical and numerical modeling studies are directly linked to observation programs or to issues related to the interpretation of data

obtained using new instrumentation or measurement techniques. Recent studies have focused on internal wave energy transfers, turbulent exchange flows in straits and estuaries, and interpretation of data obtained along near-Lagrangian trajectories. These studies also encompass both forward and inverse problems in ocean acoustics, i.e., how oceanic variability caused by internal waves and turbulence affects the propagation of sound in the ocean, and how measurements of acoustic signals in the ocean can be used to infer the ambient environmental conditions.

OPD scientists also participate in interdisciplinary studies investigating the links between physical, biological, and bio-optical variability. A recently completed ONR-sponsored field program examined the physical and bio-optical response of the subpolar front in the Japan/East Sea to strong wintertime atmospheric forcing. Synoptic, three-dimensional surveys executed with a towed profiling vehicle revealed evidence of convective overturning and subduction at the front, and will facilitate detailed investigations of processes that communicate atmospheric forcing to the ocean interior. As part of the Northeast Pacific GLOBEC (Global Ocean Ecosystem Dynamics) program, OPD investigators will employ Seagliders to measure physical and biological variability of the Alaska Coastal Current at timescales ranging from weeks to years (see "Gliding through the sea at 1/3 knot," on page 14). Upcoming research includes use of a new towed, undulating vehicle to study the dynamics and bio-optics of the Po River plume and of mid-basin fronts in the Adriatic Sea.

Polar Science Center

Scientists in the Polar Science Center (PSC) focus on observing and modeling the physical processes that control the nature and distribu-

tion of sea ice and polar ice sheets, the structure and movement of high-latitude oceans, and the interactions between air, sea, and ice. PSC was formed in 1978 at the conclusion of the Arctic Ice Dynamics Joint Experiment by a group of scientists committed to pursuing basic research in the polar regions. Major sponsorship for PSC research comes from the National Science Foundation, the Office of Naval Research, and the National Aeronautics and Space Administration. Research, analysis, and modeling studies conducted at PSC contribute to a growing understanding that the arctic system has undergone major changes during the past two decades. As more and more evidence points to the Arctic's major influence on global climate conditions, there is increased urgency for a more complete understanding of these complex processes.

PSC scientists are currently serving in major roles in international research programs involving process studies and large-scale observations and hold leadership positions in the International Arctic Buoy Program, the World Climate Research Program, and the Scientific Ice Expeditions (SCICEX) program in which U.S. nuclear submarines operating beneath the polar pack ice have collected data of scientific interest. PSC has a lead role in the Community Climate System Model effort at the National Center for Atmospheric Research, and overall management of the Surface Heat Budget of the Arctic

Ocean (SHEBA) project. A PSC principal oceanographer has taken the lead in defining a major new research program, Study of Environmental Arctic Change (SEARCH), which enjoys broad support among arctic scientists.

In April 2000, PSC scientists established a research camp at the North Pole, laying the groundwork for a five-year project to take the pulse of the Arctic Ocean and learn how the world's northernmost sea helps regulate global climate (see "Reading the Earth's climate compass at the North Pole," on page 18). In 2001 the team returned to the Pole and deployed a system of floating buoys, and anchored to the ocean floor 2.5 miles of cable outfitted with over a dozen instruments to monitor the condition of the upper 1,330 feet of ocean.

To support our research, the Center has developed a variety of instruments and platforms for measuring aspects of the ocean, ice, and atmosphere in polar regions. The Polar Ocean Profile



Research equipment and supplies at the North Pole Environmental Observatory.

Jim Johnson

buoy automatically measures ocean temperature and salinity, air temperature, and barometric pressure and transmits the data through a satellite link. A bottom-moored upward-looking sonar measures the draft of the ice above it. Several of these

sonars are monitoring ice thickness in various regions of the Arctic, providing statistics on the mass of ice in the Arctic Basin. A new autonomous microconductivity/temperature vehicle was successfully used during SHEBA to study spatial variability of the ocean heat flux under leads and various types of ice.

Satellite remote sensing of the earth system is especially important in the polar regions, where *in situ* observations may be too difficult or too expensive. PSC scientists play a leading role in the development and application of remote sensing techniques for solving polar geophysical problems. They use synthetic aperture radar for automatic sea ice feature identification and motion tracking, estimate sea ice thickness and temperature from visible and infrared imagery, measure surface and atmospheric heat budgets from satellite multiband radiance data, and estimate surface temperature and accumulation rate fields over polar ice sheets from microwave emission observations. PSC played a leading role in the planning and implementation of Polar Exchange at the Sea Surface, a major interdisciplinary investigation supported by the NASA Earth Observing System program.

In addition to field research, PSC plays a leading role in the development and application of physical-mathematical models of the ocean, ice, and atmosphere. Included are studies of ocean circulation, sea-ice kinematics, dynamics and thermodynamics, boundary-layer processes in the atmosphere and ocean, atmospheric radiation, ocean convection, and time evolution of the coupled air-sea-ice-climate system. The development, testing, and application of predictive models is closely tied to observations of the system—data are used for the initialization, forcing, and evaluation of the models. These studies contribute to a better understanding of how the polar regions function within the

global climate system, and to greater confidence in climate simulations, predictions, and assessments.

Air-Sea Interaction and Remote Sensing

Research in the AIRS department covers a wide range of atmospheric and oceanographic topics, all involving the use of remote sensing measurements. Research techniques comprise field experiments, aircraft overflights, laboratory studies, numerical modeling, instrument development, and sophisticated data analyses. AIRS members collaborate with researchers in the School of Oceanography, the Atmospheric Sciences Department, and both Electrical and Civil Engineering. Several AIRS scientists have joint appointments in these areas. Sponsors for AIRS research include the Office of Naval Research (ONR), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF).

Several AIRS groups are active in NASA's Ocean Vector Wind Science Team (OVWST), which provides advice to NASA on the measurements and applications of satellite-based active microwave instruments—scatterometers. One group compares aircraft and laboratory data, and studies theoretical factors that affect radar backscatter, seeking to improve the model functions that relate the backscatter to estimates of wind speed and direction. These studies should improve measurements of winds in both the high and low ranges.

Another group studies the structure of the atmospheric marine boundary layer using scatterometer measurements. This study aims to improve the assimilation of scatterometer winds into weather forecast models and to improve the simulation of rapidly developing orographically influenced storms. A third group is examining the use of scatterometer wind measurements to estimate air-sea fluxes. In the

tropics, relatively large differences in flux estimates arise because the scatterometer (correctly) measures the motion of the atmosphere relative to the moving ocean. Comparisons with the anemometers on the Tropical Atmosphere Ocean (TAO) array has demonstrated that ocean currents make a large contribution to momentum fluxes in the tropics. The goal of these analyses is to improve ocean circulation modeling.

In addition to the OVWST, several AIRS groups are active in other NASA-sponsored science teams, including the Tropical Rainfall Measuring Mission (TRMM), and Moderate Resolution Imaging Spectroradiometer (MODIS). Another group is working with the ONR-sponsored WindSat science team, providing advice to ONR on the development of a passive microwave instrument for measuring vector winds.

Participation in field experiments to study air-sea interaction is another major thrust of the department. The ONR-sponsored Fluxes, Air-sea Interaction and Remote Sensing (FAIRS) experiment was designed by AIRS members to make measurements of foam, wave breaking, and gas transfer rates (see “Flipped out for 32 days at sea,” on page 20). AIRS researchers also are active in the Coupled-Boundary Layer, Air-Sea Transfer (CBLAST) program, also sponsored by ONR. The goal of the AIRS CBLAST study is to understand variations in ocean surface temperature measured by infrared under low wind conditions.

A new enterprise within AIRS is the development of non-contact methods of measuring river discharge from bridges, riverbanks, and helicopters to allow operation during flood conditions. One system is being tested in a cooperative project with Taiwan and another system is being operated in western Washington State in conjunction with the USGS. The measurements allow the mapping of surface

currents with a goal of obtaining flow volume estimates.

Velocity inferred from the radar altimeter TOPEX/Poseidon is being used to diagnose the upper ocean heat budget in both the western North Atlantic and the western North Pacific oceans. The most difficult term to quantify in these budgets is temperature advection, owing to the difficulty of making synoptic velocity measurements over a large region of the ocean. This research has demonstrated that energetic western boundary currents, which transport large amounts of heat poleward, make an important contribution to heat content and likely contribute to atmosphere-ocean coupling on interannual to decadal time scales. The goal of these analyses is to improve predictability of climate variations such as the Pacific Decadal Oscillation.

AIRS research also encompasses acoustical remote sensing of the ocean. The ambient sound field contains information about ocean surface processes; by “listening” to the ocean environment, it is possible to detect and measure rain, drizzle, wind speed, and ambient bubbles. These processes are crucial components of air-sea fluxes of mass, heat, momentum, and gas.

Other research projects in AIRS include the development of a new stochastic, multiscale model of microwave backscatter from the ocean to understand the processes that generate and maintain ocean surface waves; analyses of scatterometer surface wind data and synthetic aperture radar (SAR) imagery of the ocean surface to understand the air-sea momentum transfer and to extract surface buoyancy fluxes from SAR images; development of a policy/

operation program to predict the cycling and fate of volatile organic compounds in lakes and reservoirs; and evaluation of cool-skin and warm-layer effects in radiative models.

Center for Industrial and Medical Ultrasound

The Center for Industrial and Medical Ultrasound (CIMU) became a new department at APL in November 2000 and received sanction as an official university center in January 2001. These appointments speak to CIMU’s emerging role as a world-class leader in ultrasound research and development, and to CIMU’s participation in the tremendous expansion of the medical ultrasound industry. The Center is committed to bringing together the foremost government, industry, and research organizations to explore and

3) to form partnerships with industry that enable this technology to be transferred to the commercial sector; and

4) to educate and train students and technical professionals working in the fields of industrial and medical ultrasound.

Key sponsors include the Defense Advanced Research Projects Agency, the Office of Naval Research, the National Science Foundation, and the National Institutes of Health. Sponsorship has also been received from Dual Use Science & Technology (DUST) programs, which require significant industrial cost-sharing from inter-university consortia, and from grants and contracts with private industry.

CIMU research efforts fall into three focus areas: diagnostic and therapeutic ultrasound, extracorporeal

shock wave lithotripsy (ESWL), and sonophysics and sonochemistry. A major project in the area of diagnostic and therapeutic ultrasound is the investigation into the use of high-intensity focused ultrasound (HIFU) to stop bleeding (see “Saving lives with sound,” on page 28). The vision is that HIFU therapy will be used by surgeons in the operating room and to treat patients through the skin (transcutaneously) without surgery. Accurate detection and targeting are essential to the success of HIFU

treatment, so the Center is investigating not only the therapeutic mechanisms and means, but also developing novel imaging techniques, such as harmonic vector Doppler, pulsatility and integrated real-time ultrasound scanning. Other diagnostic and therapeutic applications include ultrasound-assisted drug delivery and gene therapy, and tumor treatment.



CIMU colleagues in the ultrasound lab. (Clockwise from left: Dahlia Sokolov, Franco Curra, Larry Crum, Tom Matula, Pierre Mourad, Lisa Couret, and Marilee Andrew.)

develop new uses for ultrasonics through its four-fold mission:

- 1) to foster research collaboration between UW faculty and their industrial partners on industrial and medical ultrasound projects;
- 2) to develop industrial and medical ultrasound technology, including instruments, techniques, ideas, and products that have value to our society;

CIMU participates in an inter-university collaboration to better understand the role of cavitation in extracorporeal shock-wave lithotripsy (ESWL), a technique employed to destroy kidney stones and gallstones. By improving the control of cavitation during lithotripsy treatment, effectiveness can be increased while reducing the likelihood of collateral damage to the kidney.

The Center has played a vital role in understanding sonoluminescence, a phenomenon that may involve temperatures of millions of degrees. Other studies in the areas of sonophysics and sonochemistry include using high-intensity ultrasound to influence chemical reactions, improving industrial ultrasonic cleaning technology, and understanding the physics of ultrasound contrast agents—microbubbles of various compositions that when injected into patients enhance the clarity of ultrasound images.

CIMU depends upon a talented, multi-disciplinary staff of physicists, engineers, technicians, and undergraduate and graduate students. The research program is strengthened by collaborations with other UW researchers and medical professionals in the departments of Bioengineering, Electrical Engineering, Chemistry, Anesthesiology, Surgery, and Radiology. The Center's interest in developing paths to commercialization has also led to strong collaborative ties with industry, from small start-up companies in the Puget Sound region to major ultrasound manufacturers.

Electronic Systems

From the time a submarine gets underway until it returns to port, its sensors are tuned into the environment. A staggering amount of data is collected, and more often than not it is recorded on systems designed, developed, tested, and produced by the Electronic Systems Department of

the Applied Physics Laboratory. This association between APL-UW and the U.S. submarine force is now in its 32nd year. Over this time, recording technology has made breathtaking advances. Where once reel-to-reel recorders were used, current data recording systems incorporate commercial, off-the-shelf (COTS) systems, including ever improving VCR technology.

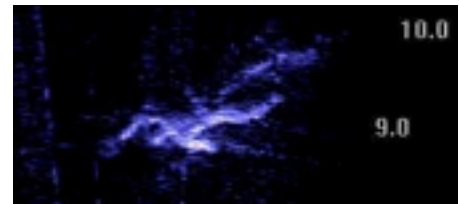
In addition to submarine data collection systems, the Department develops sophisticated shore-side processing hardware and software for use by the Navy for acoustic analysis. These systems also integrate the latest commercial processing, display, and fiber-optic network technology with custom hardware to interface between special-purpose Navy systems and commercial computing and display hardware.

Another key area of research that is being adapted to an ever-increasing number of applications involves the use of high-definition sonars, formerly referred to as acoustic lenses. The ES Department is developing a class of high-definition sonars that can be used for inspection and identification of objects in turbid water where optical systems fail.

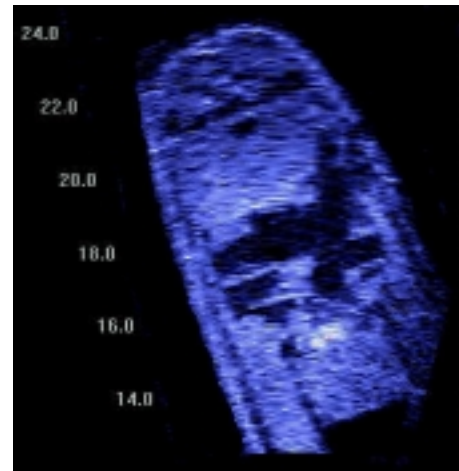
The Department is working towards the goal of providing the Navy with systems that will allow identification of mines in turbid water and retire the dangerous job of tactile examination. Two diver-held sonars, the Lens Underwater Imaging System (LUIS) and Limpet Mine Imaging Sonar (LIMIS), have been developed and tested. They were designed to identify and recover bottom mines and limpet mines on the hulls of ships. Two LIMIS systems were sent recently to Bahrain and deployed in field exercises.

This same technology is used in a project sponsored by the Space and Naval Warfare Systems Center; the Dual-frequency IDentification SONar

(DIDSON) is a very high resolution imaging sonar that gives near video quality images for inspection and identification of underwater objects. It operates at two frequencies that allow sharp images from 1 m to over 30 m in range. The sonar is finding an interesting application in fisheries science. For example, the Battelle Memorial Institute built deflectors on dams to keep fish out of the turbine intakes, but the turbid water prevented optical monitoring of fish behavior,



A swimmer from 9 m imaged by DIDSON.



DIDSON image of a shipwreck resting in 28 m of water. This image was taken in the low-frequency mode (1 MHz). Low frequency is routinely used for ranges that exceed 15 m.

which if known, could lead to improved deflector design. A DIDSON will be mounted by Battelle on at least one dam to monitor fish behavior around a deflector and intake.

The Laboratory's strength in developing new technologies for scientific and commercial applications, as well as its long-term and productive relationship with the Navy continue in the Electronic Systems Department.

Environmental and Information Systems

The Environmental and Information Systems (EIS) Department develops technologies and conducts analyses that improve the use of information. We analyze problems and then apply intelligent processing of information, integrating data acquisition, data storage, adaptive signal processing, and the use of intelligent software agents for data distribution and workflow planning. Members of the department form a multidisciplinary group of physicists, earth scientists, computer scientists, signal processors, and interface designers who team with scientists at university and Navy laboratories to create new systems and system components that use knowledge of the environment for improved performance and decision making.

Expertise in data acquisition and signal processing is focused on the use of wideband acoustic detection, classification, and modeling for use by antisubmarine warfare sensors and torpedo and mine countermeasure systems. Experimental arrays and data acquisition systems have been built to acquire target, propagation, reverberation, and clutter data. New signal processing techniques such as spatial correlation, wavelets, and morphological processing are used to reduce interference, improve target echoes, and enhance classification using knowledge of the environment.

Acoustics, physics, applied mathematics, and computer science are combined in projects such as the Environmentally Adaptive Sonar Controller, which teams EIS members with experts in fuzzy logic, neural nets, and evolutionary computation (see "Controlling sonars in shallow water," on page 26).

A critical component of the controller is the Sonar Environmental Parameters Estimation System (SEPES). SEPES provides the feedback

loop for the controller through *in situ* evaluation of the acoustic environment. This system allows a user to display sonar reverberation data and to choose a segment of the time series. Bottom or surface backscatter and reflection loss information are extracted from the data as a function of grazing angle or bottom properties. Within this system is a nonlinear optimizer that efficiently minimizes the difference between the data and an acoustic model by taking into account the sensitivity of the acoustic model with respect to acoustic model parameters. SEPES is also being used to evaluate sensor requirements for a new environmental sonobuoy.

The Department's efforts in adaptive signal processing have expanded to include underwater and electromagnetic communications, optimal time-frequency algorithms used for signal recognition, and auditory processing used for broadband impulsive active signal returns. This expertise is being expanded in tasks for the Army and the Air Force. We have recently teamed with Lockheed-Martin and others in a Defense Advanced Research Projects Agency (DARPA) project on robust passive sonar that will explore new techniques to improve the U.S. Navy's passive sonar capabilities in a dynamic littoral environment.

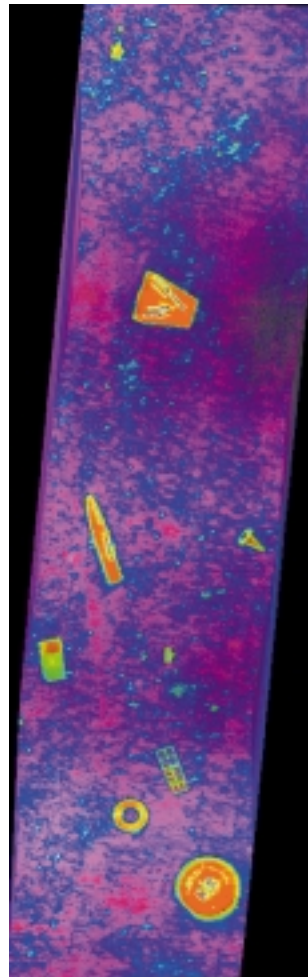
The Department's acoustic modeling

efforts have provided the Oceanographer of the Navy the Generalized Acoustic Bottom Interaction Model (GABIM) that incorporates a physics-based acoustic backscatter model for active acoustic systems from 100 Hz to 10 kHz. GABIM provides a consistent physics approach to the current Navy bottom reflection loss models and databases and is consistent with the high-frequency bottom backscatter and reflection models already approved by the Navy. In another significant milestone, APL-UW's Sonar Simulation Toolset, which produces synthetic digital time series for passive and

active sonar, has been extended to incorporate broad frequency bands in range-dependent environments. This capability now enables us to examine complex, broadband signal and information processing algorithms in a variety of environments.

Our first implementation of software capable of intelligent information processing automates a workflow for naval meteorologists that more efficiently gathers, processes, and displays data from which dangerous ocean wave conditions are determined. The High Seas Warning system is currently in use by the U. S. Navy at the Naval Pacific Meteorology and Oceanography Center in San Diego.

A key new area of research is the characterization and utilization of uncer-



Andy Gause

The EIS Department is conducting research on automatic mine identification in support of ONR's electro-optic mine countermeasures program. The techniques and algorithms developed are applied to complex imagery obtained from a variety of electro-optic sensors.

tainty in the environment. In response to the Department of Defense's Multi-disciplinary Research Initiative, we have begun work with the university's departments of Atmospheric Sciences, Psychology, and Statistics to determine improved methods of characterizing uncertainty in mesoscale atmospheric modeling. New methods of visualizing uncertainty will be developed that improve a person's use of uncertainty in weather forecasting to support air strike missions (see "Improving naval weather forecasting," on page 22).

A complementary project examines the characterization and tactical utilization of uncertainty in the ocean environment to support undersea warfare as a part of the Office of Naval Research's Departmental Research Initiative. Department scientists are developing an environmental picture of the battlespace.

The EIS Department's Multimedia Development Team has completed a computer-based training program for a system that uses and maintains specialized, acoustic data-collection hardware aboard submarines. A new project for the Office of Naval Research is developing innovative 3-D visualization techniques to improve the use of laser imaging systems on helicopters that locate and identify mines on the bottom of the ocean.

Ocean Acoustics

The Ocean Acoustics (OA) Department focuses on the propagation and scattering of sound in the ocean using theory and numerical modeling backed by ocean experiments. A major goal of the OA Department is to transition basic research discoveries into practical solutions to applied problems. We study the effects of variability in the ocean environment on sound—the "forward" ocean acoustics problem—and we exploit our understanding to solve the "inverse" acoustic oceanography problem—where sound is used as a probe to study the ocean environment itself. Research spans the

frequency range from a few Hz to hundreds of kHz. The department works in close collaboration with the Ocean Engineering, Ocean Physics, and Environmental and Information Systems departments.

At the lowest frequencies (a few Hz) we use a coupled mode theory to examine acoustic/elastic wave propagation within the ocean and seabed to understand how seismic wave energy originating in the seabed is converted to acoustic energy that then propagates in the ocean. These low-frequency water-borne sound waves, which travel thousands of kilometers, are useful in many ways. By monitoring them, we can remotely detect volcanism on the seabed or monitor the world's oceans for violations of the nuclear weapons test ban.

As low-frequency sound travels through the ocean it is altered by changes in ocean temperature, currents, and bottom and surface characteristics. Understanding these effects is part of North Pacific Acoustic Laboratory (NPAL) activities being conducted in collaboration with several other laboratories and institutions. NPAL focuses on three-dimensional wavefront coherence, the details of signal energy redistribution through mode scattering, signal and noise variability on ocean-basin scales, and the effect of environmental processes such as internal waves. This understanding is key to the operation of long-range Navy surveillance systems as well as to Acoustic Thermometry of Ocean Climate (ATOC), where sound transmissions are used in the "inverse" to monitor global warming by measuring trends in ocean temperature on basin scales. The information provided by NPAL will improve the capability already demonstrated by the ATOC project.

At higher frequencies of hundreds of Hz to several kHz, enhancing Navy mid-frequency sonar operation in shallow water is of particular interest. We are involved in theoretical and experimental efforts to better understand and model the physics of propagation and scattering at these frequencies. Modeling is aimed at producing better research models that include the rough ocean surface and seafloor, and then using these new



Ocean Acoustics scientists during SAX99 field research.

Eric Thorsos

research models to improve Navy standard models that must balance fidelity against computational speed. Experimentally, the focus is on obtaining high quality measurements of mid-frequency acoustic reverberation from the sea floor and sea surface, along with environmental measurements to interpret these results. The experiments are being carried out as part of the Asian Seas International Acoustics Experiment (ASIAEX) in the South China and East China seas. OA scientists led the mid-frequency effort in the East China Sea experiment.

At still higher frequencies (tens to hundreds of kHz) we are involved in a variety of projects including acoustic communications, detection of buried mines at shallow angles, monitoring biological processes near the top of the seabed, and quantifying deep ocean hydrothermal flow.

OA scientists are exploring the limits of a new technique for underwater communication—passive phase

conjugation—through theory and experiment. Applying the principles of time-reversal processing, they have shown that passive phase conjugation can compensate for multipath propagation and scattering, thus enabling reliable, high-data-rate communication in difficult underwater acoustic channels.

Predicting the capability of sonar to detect buried mines at shallow grazing angles (long ranges) requires an understanding of the mechanisms of scattering from the seabed, penetration into the seabed, and propagation within the seabed. As part of the recent Office of Naval Research Sediment Acoustics Experiment 1999 (SAX99), OA scientists designed and executed experiments in a sand sediment to examine all three phenomena. They have shown that diffraction due to sand ripples is the main mechanism of penetration at shallow grazing angles. Furthermore, they have demonstrated that accounting for the porous nature of the sediment leads to a better quantitative understanding of the propagation within the sediment and scattering from the sediment. SAX99 (and ASIAEX) included detailed, concurrent environmental measurements sufficient to allow quantitative model vs. data testing (see “Sound in the seafloor,” on page 24).


OA researchers are using high-frequency sound to examine benthic biological processes at temporal and spatial scales not available with other sampling methods. Recently OA scientists used a multibeam sonar to image and quantify hydrothermal flow on the Juan de Fuca Ridge. The long-term goal of this research is to use acoustic inversion methods to better understand the mechanisms and fluxes of heat and chemical emissions from mid-ocean spreading ridges, how water is entrained in the earth’s crust, and how newly discovered, unique biological systems operate in these regions.

Ocean Engineering

Hands-on experience at sea is a hallmark of the Laboratory, and the Ocean Engineering (OE) Department, where much of this expertise resides, is a resource both to other APL departments and to the Navy.

OE Department engineers have extensive experience in the design, fabrication, and deployment of complex systems in the deep ocean and in coastal waters. APL pioneered the development of unmanned underwater vehicles for making scientific measurements at sea and continues to use such systems to gather data in various environments, including under the polar ice pack, in Puget Sound, and in Monterey Bay. APL has used its engineering expertise and fabrication skills to develop the Seaglider, a unique, reusable, profiling glider. Conceived in the UW School of Oceanography, the Seaglider is an unmanned underwater vehicle containing sensors that measure and record a continuous profile of conductivity and temperature as the instrument glides between the surface and depths up to one kilometer. Oxygen and optical sensors have been incorporated into several Seagliders to complement the existing CTD. An onboard Global Positioning System (GPS) receiver determines the Seaglider’s position at the end of each profile, and a satellite data telemetry system provides communications for uploading data and downloading new instructions. The use of satellite communications allows for near real-time data distribution and analysis from any location on the Earth. Oceanographers are now able to have new data on an hourly basis and can command the Seaglider to change its operation as new phenomena unfold. Seagliders have been successfully deployed for durations of over one month in Puget Sound making a total of over 500 profiling dive cycles (see “Gliding through the sea at 1/3 knot,” on page 14).

In an ongoing project the department has worked with Laboratory scientists to develop and deploy the CIRIMS (Calibrated Infrared Radiometer *In Situ* Measurement System), a low cost, autonomous system to measure calibrated, reflection-corrected radiometric sea surface temperature. Simple system set-up and installation allows the CIRIMS to be deployed on ships of opportunity. The primary objective is to meet the need for an inexpensive and robust system to make autonomous infrared measurements. A secondary objective is to support MODIS satellite validation. Department engineers have also developed and deployed the IMP system (*In Situ* Measurement of Porosity), a unique instrument deployed on the ocean bottom that probes the sediment in 1-cm increments using 16 conductivity probes that can traverse over a distance of 1 meter. The instrument has been deployed from ships and adjusted and activated by divers in water depths of 60 feet and in water depths of 300 feet without diver intervention.

Corrosion prevention and failure analysis of components on Navy submarine, surface-ship, and bottom-mounted sonar systems is another department program. Team members inspect cables, connectors, and transducers, autopsy in-service components, test and autopsy newly designed components, identify failure modes and mechanisms, and recommend solutions. Electro-optical cables and all-optical short time (< 2 years) and long time cables used in various seawater bottom environments have been the core of recent design reviews, testing, and development tasks in this program. Video documentation provides an instantaneous, permanent record that elucidates cause, effect, and corrective action for program managers, field service personnel, and fleet operators. 

Research Highlights

Gliding Through the Sea at 1/3 Knot

Agnes Sieger and Russ Light

Until now, oceanographers have been forced to choose between technologies optimized to sample either long time series or extended spatial regions. Seaglider provides both.

– Craig Lee

Principal Engineer Russ Light, program manager for the APL-UW unmanned underwater vehicle (UUV) called Seaglider, has a good reason for smiling. If the large, multi-institutional MOOS Upper-Water-Column Science Experiment (MUSE) in August 2000 in Monterey Bay were an Olympic event, Seaglider would have won a gold medal. At one time three vehicles, one of which was assembled on the spot, were in the water simultaneously—and they all worked flawlessly.

The MUSE triumph follows a month-long deployment in June 2000 in Possession Sound, which Russ characterizes as, “... truly the first deployment where the glider operated successfully both from an engineering and a scientific instrumentation perspective.”

What is Seaglider?

The result of a collaborative effort begun between Jim Osse of APL-UW and Charlie Eriksen of the UW School of Oceanography, Seaglider is a small, free-swimming UUV that can gather conductivity-temperature-depth (CTD) and other data from the ocean for months at a time and transmit it back “home” in near-real time.



Seaglider components. (From top to bottom: external hull, internal pressure case, internal electronics and mechanics, and antenna.)

Kim Reading

Seaglider does not depend on an external propulsor to travel. Instead, it uses changes in buoyancy for thrust and a stable hydrodynamic shape to achieve flight in the water. A low drag shape, horizontal wings, and a fixed rudder create the ability to fly up or down through the water column.

The changes in buoyancy are effected by changing the vehicle's volume. The glider is designed to be nominally neutrally buoyant. To get it to rise, Seaglider activates a pump that moves about 200 cc's of oil (oil pumps better than water) from a reservoir



Seaglider antenna breaking the surface of Elliot Bay within view of Seattle's Space Needle.

inside the hull into a bladder just outside in the free-flooded tail. This makes it just a little less dense than the surrounding seawater resulting in an ascent through the water column. Similarly, oil is drained from the external bladder to the internal reservoir to descend through the water column.

A mass shifter inside the pressure hull is controlled by the glider's computer to set the flight attitude. The mass shifter is a mechanical system that can move the glider's battery pack fore and aft to set the glider's pitch angle. Depending upon the amount of movement, Seaglider can be made to travel at a steep angle and, hence, only move small distances during a profile. This type of flight would be useful for studying a section of water for long periods of time—similar to a standard oceanographic mooring. A shallow glide angle could be used to transverse large distances to study large-scale oceanographic processes. In either case the movement is slow (its top speed is about 0.3 knot), but the power required is almost nil, enabling it to stay out for periods as long as 6 months.

The mass can also be rotated to produce a turn while in any of the pitch positions. This allows the glider to steer a heading while profiling the ocean in both a climb and dive. During profiling the glider uses dead-reckoning techniques with the help of an electronic compass to steer to a commanded GPS coordinate.

Because Seaglider is designed to operate to depths up to 1000 meters, a unique hull was designed to maintain steady flight and conserve energy. Due to the enormous pressure at these depths, seawater compresses and increases in density. As Seaglider moves from lower to higher density water the glider will become lighter. To maintain the same rate of descent and flight characteristics the glider would need to bleed off some oil in the external bladder to match the new density. This oil would in turn need to be pumped back into the reservoir at the bottom of the dive using energy from the battery pack. But the Seaglider hull is designed to compress as it sinks, matching the compressibility of seawater. This isopycnal hull maintains its buoyancy no matter what its depth at a cost of zero energy from the battery pack.

One of the great advantages of Seaglider is its ability to transmit back data in near-real time and to change position at any time in response to changing circumstances or new priorities. Trailing behind the vehicle is a 5-foot-long antenna for satellite data telemetry and GPS. Each time it surfaces after a dive, Seaglider dips its nose down to the maximum angle of about 45°, raising about three feet of the antenna out of the water and into the air. First, the vehicle determines its position via the GPS; then it calls "home" via low earth orbit data telemetry satellites (Globalstar and Iridium), uploads its GPS position, the oceanographic data it just collected, and status information, and then downloads a command file that tells it what to do next.

Why It's Important

Until recently, oceanographers have had to rely on taking measurements along a transect or at set stations from an oceanographic research vessel or using those vessels to deploy strings of moored sensors. Both methods are expensive (a research cruise costs about \$20,000/day) and yield only point data. In addition, the data from moored sensors are unavailable until the sensors are retrieved, months afterward. The push is on for ways to



Seaglider team in Puget Sound. (From left to right: Andrew Chiodi, School of Oceanography graduate student; Pete Sabin; Charlie Eriksen; Tom Lehman; Jim Osse; and Tim Wen.)

monitor parts of the ocean continuously for long periods of time in order to gain a better understanding of dynamic processes. "We're on the brink now of ushering in a new age of oceanography using robotic, autonomous systems such as the Seaglider," says Light.

From Monterey Bay to the Gulf of Alaska

During the two-week MUSE experiment, the three Seagliders deployed made over 1000 profiles combined. Theirs was a unique contribution to the multi-institution effort to track the evolution of biological communities across the nutrient-rich upwelling fronts of Monterey Bay. There, as in other coastal marine environments, wind-driven upwelling supplies the upper ocean with nutrients. This supply, combined with light and oxygen, produces phytoplankton blooms that support, in turn, entire ecosystems.

All three Seagliders were outfitted with the standard scientific payload, a CTD instrument. One of the gliders incorporated the latest dissolved oxygen sensor for measuring the amount of oxygen in the seawater and a new optical instrument designed specifically for Seaglider. This optical instrument combines both an optical backscatter and fluorometer sensor into a package about the size of two hockey pucks. The optical backscatter device uses light to "see" singled-celled

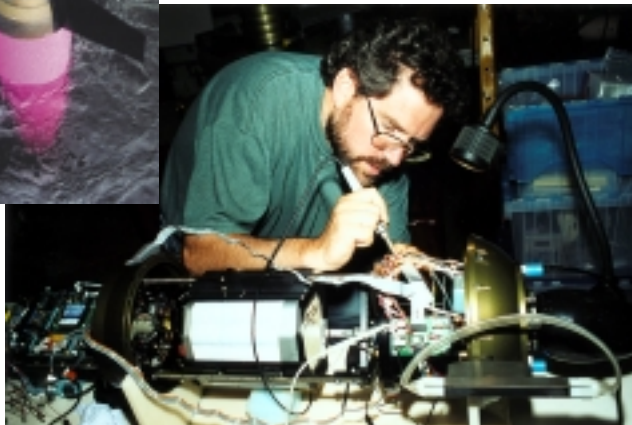
phytoplankton and zooplankton, measuring their concentrations. The fluorometer measures how much algae is in the water by measuring chlorophyll content.

Just off the coast of Seward, Alaska, APL-UW Senior Oceanographer Craig Lee and Professor of Oceanography Charlie Ericksen are beginning a study of the Alaska Coastal Current (ACC). Here, in spite of the down-welling winds and large volume of nutrient-poor freshwater runoff, the broad, deep shelf is a productive ecosystem, serving as a nursery for several commercially important fish species including salmon. Their effort contributes to a larger research program, the Global Ocean Ecosystems Dynamics (GLOBEC) Gulf of Alaska Monitoring Program, including scientists from fisheries science



Charlie Ericksen

(Above) Tom Lehman recovering a glider in Monterey Bay.
(Right) Russ Light performs internal surgery on Seaglider.



Charlie Ericksen

The capability of Seaglider extends beyond the range of oceanographic applications. Proposals are submitted to the Navy to apply Seaglider to problems in maritime reconnaissance, undersea acoustic networks, and undersea navigation.

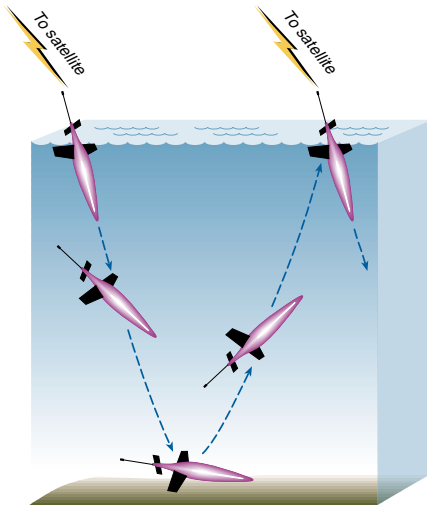
—Russ Light

to ocean physics. Seagliders will run profiles of the ACC in Blying Sound one after another for nearly 4 years. As at Monterey, this research will address questions of the region's physical environment—an important component of the ecosystem's dynamics.

The ACC is a fresh, fast-moving stream of water that typically remains within 30 km of the coast, flowing westward past Prince William Sound and eventually exiting to the Bering Sea. In winter, frequent storms produce strong, cyclonic winds and precipitation. Coastal mountains constrain winds and hold precipitation as snow, releasing it from May through October. The down-welling winter winds trap the freshwater plume near the coast, maintaining a pressure gradient. Tom Weingartner of the Marine Science Institute at the University of Alaska, Fairbanks, has hypothesized that in summer, onshore transport of slope water occurs along the bottom boundary, as the foot of

the ACC front shifts inshore in response to the relaxation of along-shore winds. The nutrients carried onto the shelf in this dense, saline intrusion remain isolated near the bottom boundary until the following winter, when vertical mixing entrains them into the surface layer. Thus, nutrients are finally consumed in the spring phytoplankton bloom a year after their initial onshore movement.

Because they will be deployed year-round, Seagliders will be able to



measure the seasonal and interannual variability of freshwater content and transport in the ACC, map the evolution of the springtime mixed layer, and with the fluorometer and optical backscatter sensors on board, track the development and migration of the spring phytoplankton bloom. The ACC's importance is not limited to its regulation of nutrient flux; because juvenile salmon cannot outswim the current, the path of the ACC exerts a strong influence on where the fish spend the early phases of their lives. It is thought that young fish survival is enhanced if they remain close to the coastal areas and are not dispersed to the open ocean.

The GLOBEC research effort will include ship-based measurements in the ACC, but Seaglider's contributions will be unique because the vehicle combines large spatial scales with high

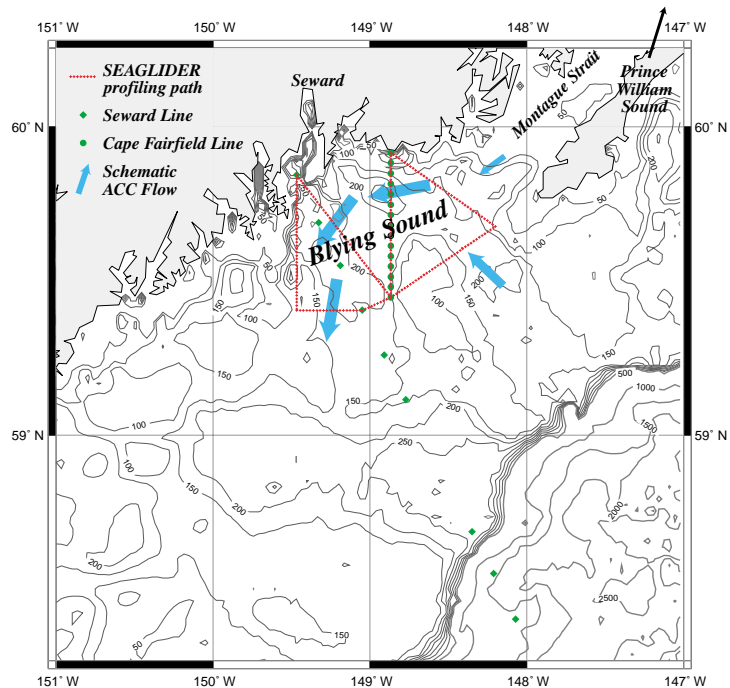
resolution. Ship-based measurements typically achieve 10- to 20-km resolution, but Seaglider will work its sawtooth pattern through the water column and surface nearly every kilometer—a resolution that should be able to quantify biological phenomena, which are spotty and greatly variable over small time scales. A Seaglider will traverse a survey pattern designed to make five sections across the ACC, extending from the coast to 55 km over the shelf and requiring about 3 weeks to complete. During each unit's mission, the pattern will be repeated several times, and then it will be commanded to swim to protected waters, recovered, and replaced with another Seaglider instructed to continue the profiling surveys. Moreover, they will not be hindered by winter storms, thus filling a large gap in data sampling for the region. Over the course of the program, Seagliders will make about 450 cross-current sections.

At two months for each mission, these deployments will be the longest and, because of the harsh environment and distance from a support crew, the riskiest in Seaglider's history. In spite of this, Lee notes that, "Four years of continuous Seaglider sections will provide a unique opportunity to explore the ACC's response to seasonal and interannual variability in atmospheric forcing and freshwater discharge." Until now, oceanographers have been forced to choose between technologies optimized to sample either long time series or extended spatial regions. Seaglider provides both.

Sponsors include ONR for Seaglider development and vehicle fabrication, and for Monterey Bay science; NSF and NOAA for GLOBEC Gulf of Alaska operations and science.

APL-UW team members for Seaglider: Mike Kenney, Craig Lee, Russ Light, Vern Miller, Pete Sabin, Dan Stearns, Mike Welch, Tim Wen.

School of Oceanography-UW team members for Seaglider: Neil Bogue, Charlie Eriksen, Tom Lehman.



Proposed profiling track of Seaglider across the Alaska coastal current. Portions of the track correspond with established moorings.

Reading the Earth's Climate Compass at the North Pole

Scientists have speculated that the recently observed decreased ice thickness, and reduced ice extent of the Arctic Ocean are symptoms of global climate change. The Arctic Ocean is vast and remote, which has made access difficult for past and present-day researchers. There is remarkably little known about historic changes in the Arctic circulation, and there are very few measurements that extend over a time scale long enough to address the processes driving recent phenomena.

Led by Principal Oceanographer James Morison of the Polar Science Center, establishing the North Pole Environmental Observatory is a large step in creating a data collection network that can address the Arctic Ocean's response and contributions to changes in the Earth's climate. "The North Pole region is an important place to study this because great changes have been observed there," notes Morison. During the first season of the North Pole station in April 2000, a suite of drifting buoys was deployed. APL-UW researchers returned in April 2001 to deploy more of these buoys and to place under the ice a set of oceanographic instruments tethered to a fixed mooring extending from the sea floor to just below the ice. These experiments are the first phases of a five-year project to which the National Science Foundation has committed \$3.9 million so that we may better understand how the world's northernmost ocean factors in global climate.

Getting scientists, their supplies, and equipment to the North Pole is a complex logistical challenge, and once there, of course, the team must do their experiments in the extreme conditions of the polar environment. Principal Engineer Andy Heiberg was master-mind of the logistics. The flight from Alert on Ellesmere Island (the northernmost point of year-round

habitation and therefore a valuable staging post) to the North Pole is 3.5 hours by twin-engine planes outfitted with skis for snow and ice landings. In 2001 the first plane carried the three-person camp setup team who were left on the ice to establish camp while the plane returned to Alert. In three hours the team erected a tent, installed the oil-fired heater, and did an initial survey of the site. Subsequent flights brought more personnel, scientific instruments, support equipment, and also shuttled scientists to other locations on the frozen ocean to measure ice and water properties. Although there is continuous sun at the pole after the spring equinox, temperatures were near -40°F during much of the time at the temporary station, and radio communications with Alert were often blocked entirely by intense solar storms.

The buoys deployed during the occupation of the North Pole station gather atmospheric data (pressure, air and water temperatures, wind, and solar radiation).

These data are transmitted back to Seattle via satellite and appear on the Polar Science Center's Website, some variables being updated hourly. Over the course of the year the buoys drift with the ice toward Fram Strait. The buoys deployed at the North Pole will play a significant role to fill gaps in the data collected from the International Arctic Buoy Programme, which has more deployments near the ocean's margins.

Conductivity-temperature-depth (CTD) measurements were also taken

on sections between the North Pole and the Canadian coast. This meant landing the plane, drilling a hole through the ice, and lowering the CTD instrument down to 1000 meters. The CTD package was outfitted with a small water sample bottle as part of the hydrographic survey planned by Senior Oceanographer Mike Steele (APL-UW) and Kelly Falkner of Oregon State University. The chemical analysis of the water will help them understand the changes in properties and circulation in the upper layers of the water column.

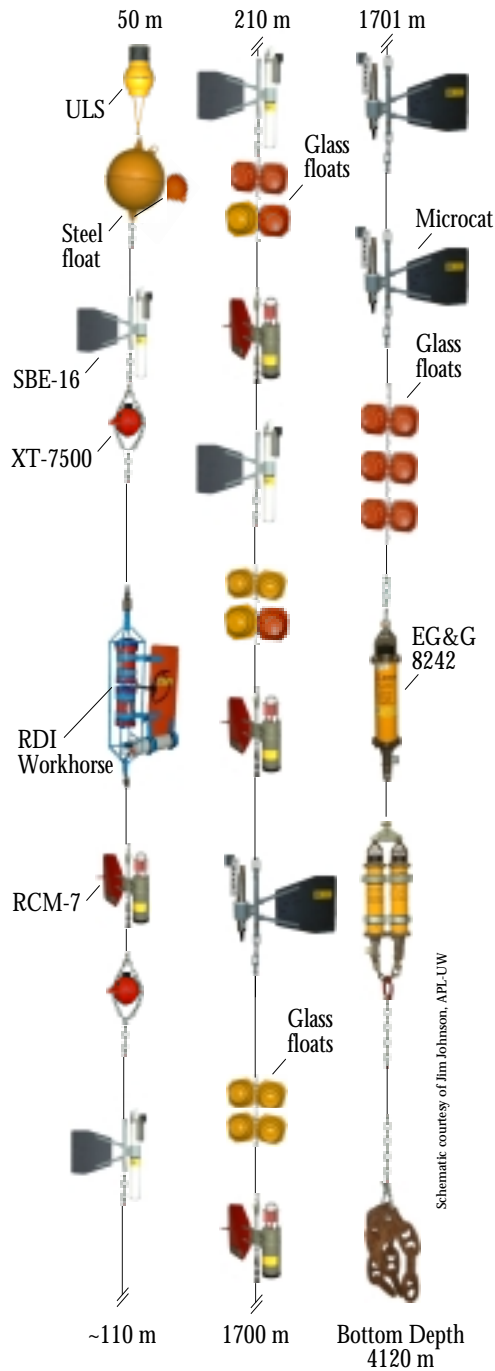
In order to monitor the subsurface Arctic Ocean, a team led by Principal



Jamie Morison takes a CTD measurement. A makeshift tent is erected outside the airplane's door to provide some shelter.

Kelly Falkner

Oceanographer Knut Aagaard anchored a highly-instrumented mooring within 30 miles of the North Pole. After careful soundings to determine the depth of the ocean underneath the ice camp, the team lowered a 1400-lb. anchor 4293 meters to the seafloor, fastening instruments, floatation devices, and acoustic beacons at predetermined places on the line. Despite the mooring being almost as long as Mt. Rainier is tall, the top of the mooring was only 2 meters off the design depth. Rebecca Woodgate



Schematic of mooring array. This set of 13 separate instruments will measure hourly for 1 year in depths between 50 and 2500 meters. In three consecutive year-long deployments, these time series will provide valuable information on both seasonal and interannual changes in the water column at the North Pole, information that will be used to tie together the once-yearly CTD measurements and help make a continuous picture of the changes in the Arctic.

reported from Alert, "After two days of assembly and preparation, deployment took about 15 hours, finishing at about 5 in the morning. It was a long day, but we had a great day; -30° , calm, and sunny."

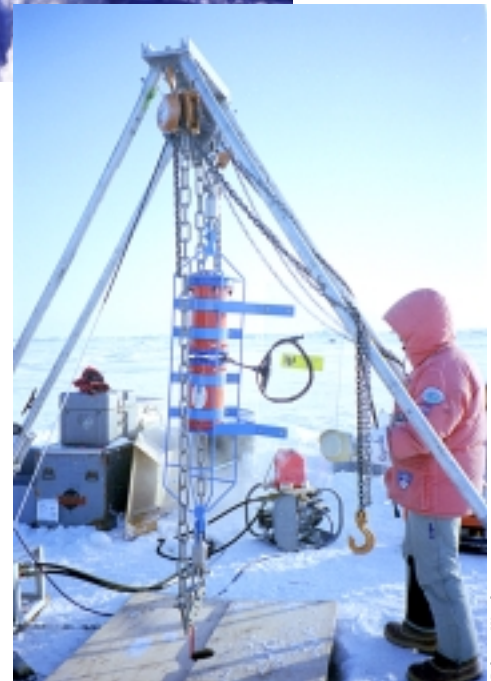
Because data signals cannot be sent to satellites from under the ice, the mooring will be recovered and replaced next year from a similar ice camp. A team from APL-UW will release the mooring from its anchor by sending a coded acoustic signal. The instruments and cable will float up under the ice, be located by its acoustic beacons, and be recovered through a hole with the help, if necessary, of divers.

These seasons of observations on and under the ice may help unravel the complexities of the Arctic Ocean's role in global climate, and the importance of recent arctic change; the multiyear observations are certainly a large step to deciphering the Arctic we see today.

Team members: Knut Aagaard, Andy Heiberg, Jim Johnson, Jamie Morison, Dean Stewart, Rebecca Woodgate.



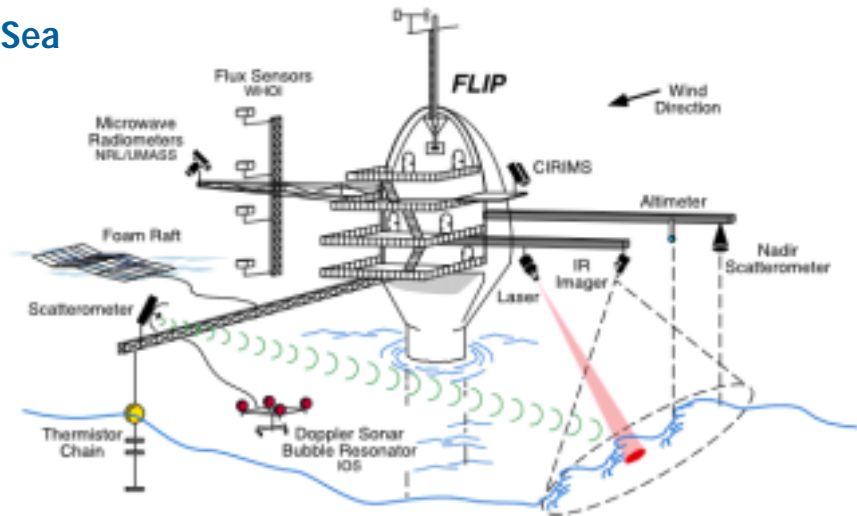
(Above) After removing the ice core the mooring array was deployed. (Right) Deploying the RDI Workhorse on the upper portion of the array.



Flipped Out for 32 Days at Sea

To the casual observer, the most obvious phenomena at the air-sea interface are ocean surface waves, especially large-scale breaking waves, or whitecaps. Less obvious is the phenomena of microscale wave breaking, or microbreaking, which occurs when small, wind-generated waves about 10 cm to 1 m long gently break. Because they do not generate visible bubbles when they break, microbreakers cannot be detected by the naked eye. However, remote sensing instruments using infrared and microwave technology can be used to detect and quantify the effect of these small but ubiquitous generators of turbulent mixing and surface roughness.

These short waves, driven by winds, increase to a height of a few centimeters until they become too steep to support themselves and consequently “break” in the sense that they overturn



Instrument positioning aboard R/PFLIP. The FAIRS experiment was designed to investigate the effect of ocean surface waves on remote sensing techniques and air-sea fluxes. (All instrumentation deployed by APL-UW, unless otherwise indicated.)

the newly formed AIRS Department has revealed that microbreaking waves contribute significantly to air-sea fluxes.

Can these fluxes—the transfer of momentum, heat, and gas across the air-sea boundary—be characterized and quantified by measuring their underlying physical mechanisms using remote sensing instruments? Principal Oceanographer Andy Jessup and Senior Oceanographer Bill Asher organized a recent field experiment to examine this and other current topics emphasizing the use of remote sensing to study air-sea interaction. The Fluxes, Air-sea Interaction, and Remote Sensing (FAIRS) experiment was a 32-day excursion aboard the research platform *FLIP* off the coast of Monterey, CA. *FLIP* is a unique 360-foot vessel that is towed to sea and is literally flipped up on end so that only the top 60 feet are above the water surface. The result is a stable platform for housing scientists and their instruments that is ideal for making remote sensing measurements at sea.



Ruth Fogelberg

“The FAIRS experiment was designed to see if our laboratory results apply in the field. In wavetanks, we have shown that the mixing generated by microbreaking waves is much stronger than background mixing. Since microbreaking is always present in nature, we believe that it plays a vital role in the flux of heat and gas across the air-sea interface.”

— Andy Jessup

FAIRS was jointly funded by three ONR programs—Remote Sensing, Marine Meteorology, and Physical Oceanography. The exercise included the participation of scientists from the Institute of Ocean Sciences at Sydney, B.C., the Naval Research Laboratory, Washington, D.C., the University of Massachusetts, and Woods Hole Oceanographic Institution.

The remote sensing instruments mounted on the decks and booms of *FLIP* included an infrared imager, microwave radiometers, microwave radars, and video cameras. Jessup and Asher

the water right at the surface. This process transfers momentum into the upper ocean as turbulence and mixing that enhances the transfer of heat and gas between the ocean and atmosphere. Recent work by members of

used two infrared techniques to measure the turbulence generated by both whitecaps and microbreaking waves. A passive technique used the infrared imager to take a picture of the ocean’s surface temperature, concentrating on the small but measurable temperature variations that occur when a breaking wave causes water from below to be mixed to the surface. An active technique used a CO₂ laser to heat a patch of water. This heated patch was then monitored by the

imager to time its decay. During rough seas when the surface was broken frequently and repeatedly by microbreaking, the heated patch cooled down in less than a second. During very calm conditions, the patch remained visible in the infrared image for several seconds. This length of time for the heated patch to revert to the surrounding surface temperature can be used to quantify the flux of heat at the surface as well as the amount of turbulent mixing.

One characteristic of a microbreaking wave is that small capillary waves of a few centimeters or less in length are generated on its forward face and travel along



Andy Jessup

(Above) R/P FLIP was towed from its home base in San Diego, "flipped" to a vertical position, and then allowed to drift freely with the currents so that the hull rotated to remain in the same orientation to the prevailing wind.

(Right) The raft was deployed periodically in low to moderate wind speed to simulate the effect that foam generated by breaking waves has on passive microwave measurements.



Andy Jessup


emissivity of foam generated by large-scale breaking waves becomes significant. While it has been known for some time that foam can affect microwave radiometer measurements, the emissivity of foam on the ocean surface has never been characterized in the open ocean.

To characterize the effect of foam on radiometer measurements, a 3 x 7 meter raft made of gas permeable tubing was designed and deployed by Asher. The raft generated a uniform area of sea foam that filled the footprint of the microwave radiometer. This way, the researchers did not have to wait for the chance of a large breaking wave to pass and generate foam within the area of the radiometer's view. By measuring the microwave signal from the sea surface with and without foam, Asher and others can determine the foam's emissivity.

with the wave as it breaks. Principal Research Scientist Bill Plant is studying how these "parasitic" capillary waves on the leading edge of a microbreaker have an important effect on microwave radar measurements. These capillary waves ride along on the steep front face of microbreakers, thus they appear tilted with respect to the look angle of the radar. Because the amount of energy reflected back to the radar increases with the tilt of the surface, this tilting effect may explain why more reflected energy is observed than is predicted by current models. By combining infrared and microwave techniques, Plant and Jessup believe they can better answer questions about the role of microbreaking in surface fluxes and radar backscatter than if they applied their respective techniques alone.

Microwave radiometers are currently used to measure wind speed from satellites by exploiting the dependence of ocean surface emissivity on surface roughness. Researchers are now working on a technique to extract wind direction using microwave radiometry. Because the wind direction signal is so small, the

The FAIRS experiment was the first time that this combination of infrared and microwave sensors has been deployed with an extensive suite of above- and below-surface measurements. The results demonstrate the value of comprehensive, multi-institutional collaborations in air-sea interaction and remote sensing.

Team members: Bill Asher, Ruth Fogelberg, Ken Hayes, Andy Jessup, Bill Keller, Trina Litchendorf, Bill Plant, Chris Siani. 

Improving Naval Weather Forecasting

David Jones

As anyone who has planned an important event outside knows, bad weather can ruin your whole day. Now imagine yourself on a ship, 200 miles off a remote coastline and responsible for planning numerous difficult and dangerous events spread over a wide geographic area. This is the daily life of a Navy battle group commander.



David Jones (left) and colleagues from the Naval Research Lab.

Because weather can adversely affect many of the battle group's operations, the commander looks to the Navy's meteorology and oceanography (METOC) organization for help. Yet, as most people know, accurate weather forecasting is not a simple matter. Difficulty is compounded for the Navy because ships and aircraft operate in areas not covered by the expansive weather observing systems common in the United States. Sea-based forecasters must deal with a variety of information systems that display everything from raw numerical model data to complex satellite visualizations. A further complication is that every time a forecaster's ship steams off to a new geographic location, the forecaster needs to rapidly assimilate the environmental characteristics of the new area and then revise his forecasting "rules-of-thumb."

Principal Physicist Bob Miyamoto, head of the Environmental and Information Systems Department, has developed several research initiatives that address some of the Navy's METOC challenges. These projects have a common theme—a focus on the forecaster as a decision maker. In particular, APL-UW has been investigating the forecaster's workflow.

METOC workflow consists of the steps through which meteorological information is gathered, processed, analyzed, and converted into useable knowledge. An understanding of the workflow can be used to construct new technologies and procedures that help improve the accuracy

and reduce the time of weather forecasting.

Using the application of workflow analysis, the Laboratory has been involved in a research project called METOC Human Systems Interaction Improvement, which is sponsored by the Office of Naval Research. The project's main focus is to improve the Navy's ability to forecast weather for naval air strikes.

Members of the EIS Department, along with scientists from the Naval Research Lab, the Naval Undersea Warfare Center, and San Diego State University have participated in several experiments designed to collect data from weather forecasters as they prepare air strike

forecasts. The team has used video cameras, laptop data recorders, an eye tracking system, and expert note takers to make detailed observations of the forecasters' workflow.

The first experiment was conducted in July 1999 at the Naval Pacific Meteorology and Oceanography Center (NPMOC) in San Diego, California. A room was divided with one side simulating the shore METOC center, and the other simulating an at-sea aircraft carrier weather office. The only means of communication between the two groups was via computer network. Some of the key concerns in this experiment were to test whether land-based forecasters could assist at-sea forecasters by means of on-line discussions via Internet Relay Chat, and to test whether the use of the Navy's distributed mesoscale weather prediction technology, installed at NPMOC in 1999, would improve the timeliness and quality of the carrier-based forecast.

The success of this first experiment led to a second experiment with the METOC center and an aircraft carrier in port. Following the second experiment, the next step was to collect human system data during high-tempo flight operations on a carrier at sea. Senior Oceanographer David Jones,



USS Carl Vinson in San Diego.



David Jones



David Jones

The author and other members of the research team returned to land in the C2 COD "catapulted" from the Vinson flight deck.

along with three scientists from NRL, embarked on the USS *Carl Vinson* (CVN-70) during her pre-deployment exercise in the waters off southern California. During the 5 days underway, the team collected over 40 hours worth of video tape, observed the forecasters *in situ*, and held numerous interviews with pilots and tactical decision makers. This data, in addition to the data from the previous experiments, is being used to develop a better understanding of the cognitive task associated with naval weather forecasting.

The Laboratory's involvement in METOC research has also included software development. With sponsorship from DARPA, through a CEROS grant, and SPAWAR PMW-155, an APL-UW team has developed an operational workflow tool called the High Seas Warning (HSW) system. HSW was designed for a specific problem identified by NPMOC. Too many hours were being spent collecting, error-checking, and analyzing the wave height information needed to develop a warning sent to ships at sea. A development team led by Senior Computer Engineer Keith Kerr carefully studied the workflow required for this task, then developed a system that uses a state-of-the-art inference engine and intelligent agent software. The development team also worked closely with the personnel who performed the high seas warning task and from their inputs, the system was refined to meet their needs. HSW became operational in the fall of 2000 and now saves the center nearly two hours of work per watch section.

METOC research continues to grow. In 2001, the Laboratory participated in two successful proposals: a Multidisciplinary University Research Initiative on uncertainty in mesoscale forecasting, and a Future Naval Capability project in environmental visualization. The knowledge gained in these projects will broaden our understanding of how humans deal with diverse and uncertain information and point to ways to improve their decision-making processes.

Team members: Greg Anderson, David Jones, Keith Kerr, Bill Kooiman, Mark Kruger, Bob Miyamoto, Nathan Ratliff, and Patrick Tewson.



A focus on the weather forecaster as decision maker is central to the Laboratory's research devoted to Naval METOC challenges.



David Jones

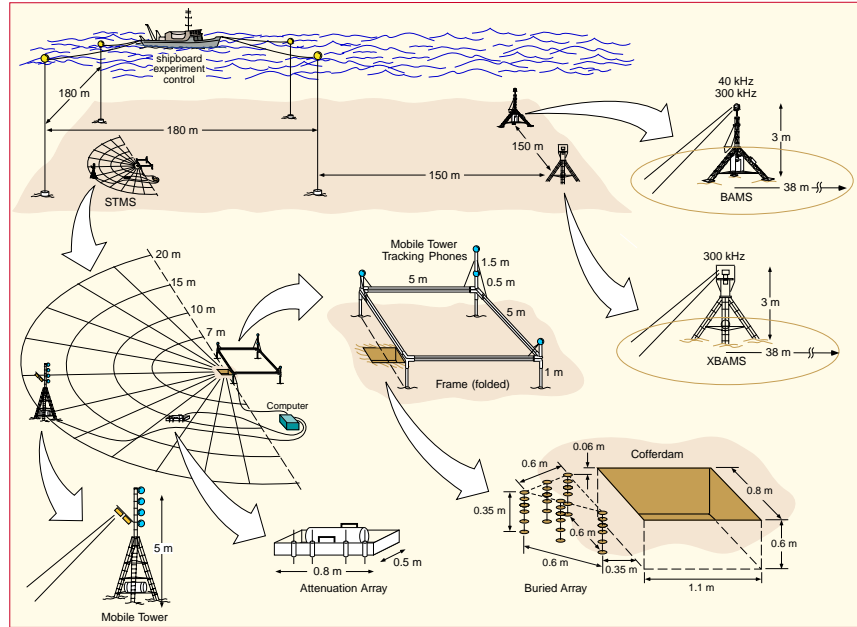
Assistant Forecast Duty Officer prepares a weather brief.

Sound in the Seafloor

Eric Thorsos

High-frequency sonar is used to “see” objects in the water column or even on the seafloor, such as ship wrecks and airplane crash debris. Of particular interest to the Navy, anti-ship mines in shallow water can often be located using sonar. In some cases mines may become partially or totally buried in the seafloor—they are still hazardous and more difficult to detect. There has been increasing interest in whether sound can be used to find and identify buried mines, or, for example, locate buried pipelines or archaeological sites underwater.

It is not a straightforward task to detect objects buried in sediments using sonar. Because the sound speed in sediments is usually higher than in the water column, sound refracts to a direction closer to horizontal when it propagates from water into sediment. Below a certain grazing angle for the sound approaching the seafloor (called the critical angle), the sound totally reflects from the interface. Above the critical angle some sound energy propagates into the seafloor. For sandy sediments the critical angle can exceed 30°. For buried object detection



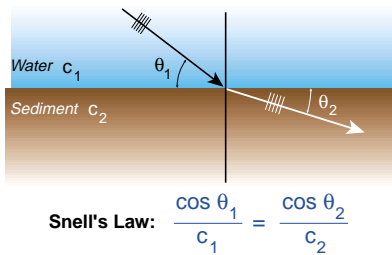
Schematic of APL equipment used during SAX99. The mobile tower was used as the source for acoustic penetration measurements, and divers moved the tower to different positions on a radial grid. A 30-element buried array, located near the center of the grid, was used to measure the sound penetrating into the sediment.

by sonar to be considered practical, the method must work from at least a moderate distance away, meaning that the sound would approach a sandy seafloor at a shallow grazing angle that is below the critical angle.

Recently, evidence has begun to accumulate that buried objects are indeed sometimes detected with sonar

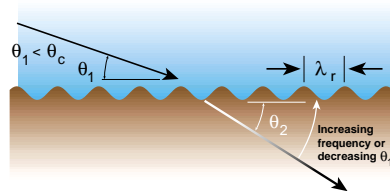
at angles below the critical angle, and hypotheses have been put forward to explain these observations. An ONR-sponsored Departmental Research Initiative was established to better understand how high-frequency sound penetrates into sandy sediments, how it propagates within the sediment, and how it backscatters from it. Principal Physicist Eric Thorsos (Chief Scientist), Kevin Williams, Darrell Jackson, and DJ Tang, in collaboration with scientists from many other institutions, took part in a major sediment acoustics experiment, SAX99, in the fall of 1999 at a site close to shore along the Florida Panhandle.

APL-UW deployed three towers for acoustic measurements during SAX99, and all three were used for studies of acoustic backscattering from the seafloor. One was also the source tower for acoustic penetration measurements and could be moved by divers to change grazing and azimuthal angles of the acoustic field incident on the seafloor in the region just above a buried array.



Snell's Law: $\frac{\cos \theta_1}{c_1} = \frac{\cos \theta_2}{c_2}$

In the simplest picture of sound penetrating into the seafloor, the sediment surface is considered flat, and the sound speed in the sediment (c_2) is greater than in the water (c_1). Then a sound wave with grazing angle θ_1 refracts to angle θ_2 given by Snell's law. The value of θ_c that gives $\theta_2 = 0^\circ$ from Snell's law is called the critical angle (θ_c). For a typical sand sediment, $c_2/c_1 = 1.15$, and $\theta_c = 30^\circ$. For $\theta_1 < \theta_c$ there is no propagating wave in the sediment (only an exponentially decaying “evanescent” wave), and the incident wave totally reflects from the seafloor.



Lowest-order diffraction scattering:
 $\cos \theta_2 = \frac{c_2}{c_1} \left(\cos \theta_1 - \frac{\lambda_1}{\lambda_r} \right)$

When the sediment surface is rough, sound will scatter and will penetrate into the sediment even when $\theta_1 < \theta_c$. If the ripple on the seafloor is idealized as a sinusoidal ripple of wavelength λ_r , lowest-order diffraction scattering would scatter sound to a direction represented by angle θ_2 (diagram on right). In the equation for θ_2 , the acoustic wavelength in the water is denoted by λ_1 . This simple model predicts that, for a given ripple wavelength, there will be a cut-off frequency, above which lowest-order scattering will not occur.



Tom Lehman

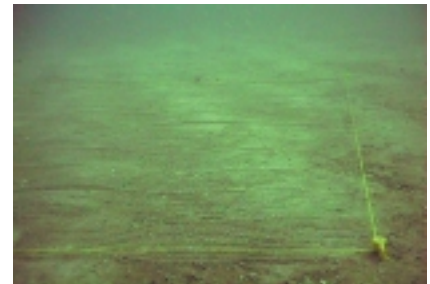
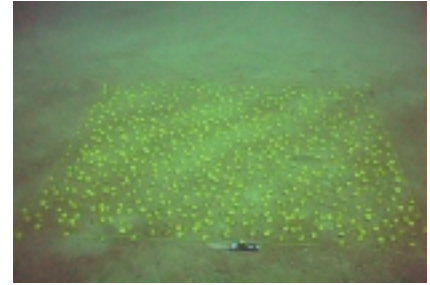
To avoid disturbing the sediment surface, the hydrophones in the buried array were inserted horizontally into position by APL-UW divers from a nearby cofferdam.

Analysis of the penetration measurements made with the buried array clearly showed that sound penetrated into the sediment even when it was incident at grazing angles below the critical angle. Comparison of measurements with numerical simulations of the penetrating fields showed conclusively that scattering from the nearly periodic sand ripple was responsible for the acoustic penetration at angles below the critical angle. The amount of sound energy that penetrates into the sediment from ripple scatter appears sufficient to be used for detecting buried objects. While further work is needed to fully understand the buried target detections, it appears that scattering from seafloor ripple could play an important role in a method to detect buried objects with sonar at low grazing angles.

While understanding acoustic penetration into sandy sediments at low grazing angles was a key element of SAX99, many other issues were also addressed. Measurements were made of propagation within the sediment and backscattering from the sediment, combined with comprehensive environmental characterization. Through this work we are investigating how the seafloor sediment should be described when modeling sediment acoustics. We are finding that the common approach of treating the sediment as a single heavy fluid can be improved upon by treating the

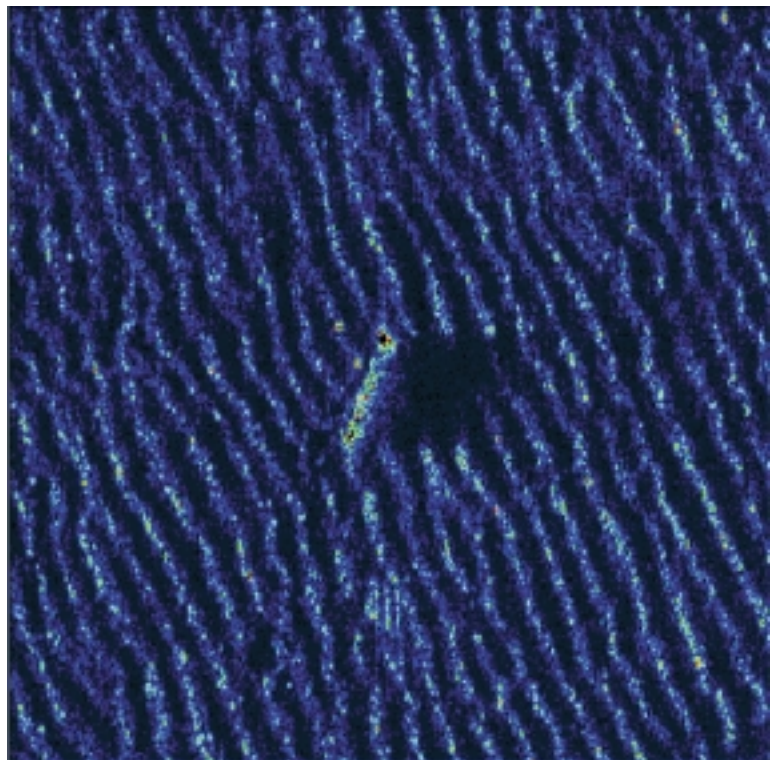
sediment as a two-component medium. One component is a framework of sand grains, and the other component is simply sea water that moves relative to the grains when sound waves propagate through the sediment. (This “poroelastic” model is referred to as a “Biot model” in honor of its pioneer, M.A. Biot.) In addition, certain sites on the seafloor were modified from the natural state, either by adding extra scatterers such as shells or marbles, or by using divers to increase or decrease the roughness. The study of scattering from these “treatment sites” will help advance our fundamental understanding of acoustic scattering from the seafloor.

Team members: Paul Aguilar, Kate Bader, Eric Boget, John Elliot, Darrell Jackson, Mike Kenney, Skip Kolve, Tom Lehman, Russ Light, Vern Miller, Le Olson, Mike Ohmart, DJ Tang, Eric Thorsos, Mike Welch, and Kevin Williams.



Ricky Ray, NRL-SSC

Examples of SAX99 2 x 2 m treatment sites for backscatter measurements. The site in the upper panel has 750 large “cat’s-eye” marbles. A small scale ripple with a wavelength of about 2 cm was raked (lower panel) onto the seafloor perpendicular to the acoustic path to increase backscatter at 40 kHz.



Synthetic aperture sonar image made at 180 kHz by scientists from the Coastal Systems Station in Panama City, Florida, shows sand ripples at the SAX99 site. The image area is 9 x 9 m and the ripple wavelength is about 0.5 m. The feature near the center is a 1.5-m long cylinder on the seafloor. The cylinder’s acoustic shadow is evident.

Controlling Sonars in Shallow Water

Janet Olsonbaker and Warren Fox

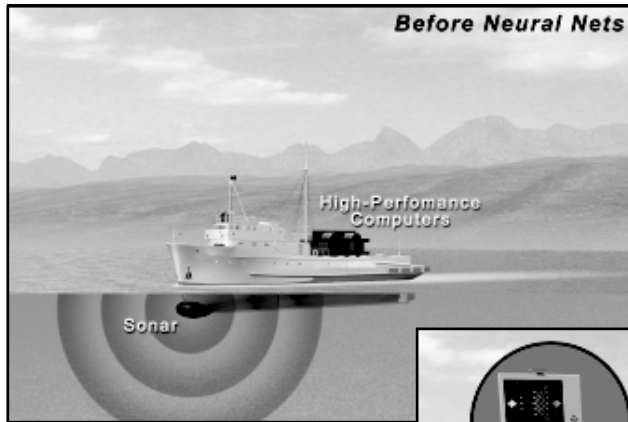
The U.S. Navy of the future requires new, portable, and scaleable sonar control systems to improve performance in shallow water. Whereas the role of the acoustic environment on sensor performance in the deep-water engagements of the past was reasonably well understood, littoral environments present a more complex challenge. Sound speed profiles—the speed of sound as a function of depth—play a major role in determining how sound propagates through the ocean. Sonar systems designed for deep water could count on sound speed profiles to be stable in relation to time and space. In shallow, coastal areas, the properties of the water column can be very dynamic, both temporally and spatially. Sound propagating through a shallow water environment is also more likely to interact with the sea bottom and sea surface, creating even greater complexity in the acoustic propagation.

Controlling the sonar refers to choosing, for example, the type of waveform transmitted, the vertical steering angle for a hull-mounted sonar, or the transmitter and receiver depth of a variable-depth sonar. Shallow water variability makes it difficult for sonar operators, who may or may not understand the physics of sound propagation, to adjust the sonar for each task's optimum performance. For instance, the operator, upon detection of a target in a wide-area

search, may need to re-set the sonar in order to focus the sonar's acoustic energy on that specific contact for classification purposes. This requires a high-fidelity predictive capability, incorporating knowledge of both the sonar system's attributes and the acoustic propagation conditions in the ocean. The result of the complicated physics and sonar control require-

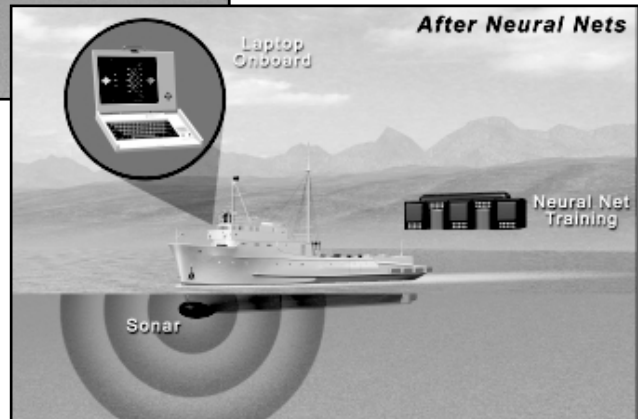
the computer power available on the ship to run the acoustic models might solve the problem, the increases in cost, space, and power requirements aboard ship are too great.

The Environmental and Information Systems Department is developing technologies to enable automated, environmentally-adaptive active sonars. Along with the Computational Intelligence Applications Laboratory in the Department of Electrical Engineering at the University of Washington, the EIS Department is applying computationally intelligent control methods using artificial neural networks—mathematical



Troy Tanner

With neural net technology, the necessary performance predictions can be achieved with modest computing resources. Neural net training takes place on shore, where supercomputer-type resources and, most importantly, time are available. The resulting neural net subroutines are all that is necessary to go to sea; they can run acoustic model performance predictions in a fraction of the time.



Troy Tanner

ments can mean missed target detection opportunities.

Acoustic models can aid the sonar operator's task. These physics-based computer programs take descriptions of the ocean and the sonar system, and predict how the sonar will perform in that environment. Acoustic models simulate the way sound behaves in the ocean, but accurate models are usually computationally intensive, and the long run times associated with the models can slow performance prediction to a standstill. While increases in

constructs that mimic biological interneural connections. In this case, neural nets are being trained to emulate acoustic models. Properly trained neural networks can produce sonar performance predictions in a fraction of the time it takes the original acoustic model.

One way an automated sonar controller might function is to create a list of all the possible modes in which a sonar might function. The controller then makes performance predictions for all these possible configurations in

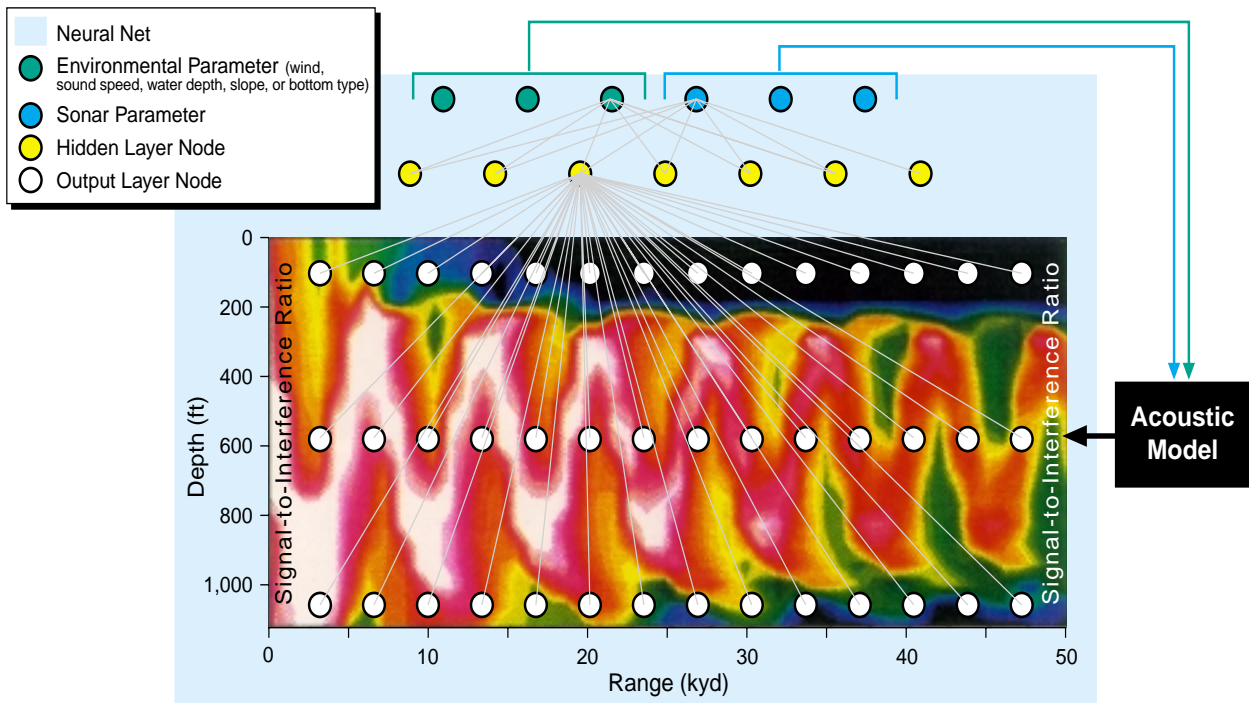
the current environment, and decides which one is best for the particular task at hand. Especially for modern sonars, with a plethora of possible configurations, this list of possible modes can be long. The speed enhancement that the neural network technology brings to the controller is crucial for allowing the sonar to adapt to the rapidly changing environment in tactically useful timeframes.

Ultimately, this controller and the neural net will be used for performance prediction, not just locally, but globally. As the controller learns the local environment, this knowledge can be used to tell the ship captain or the fleet commander how to proceed within the entire area of operation. For example, the commander may want to transit through an area along a path that gives the longest possible detection range. Given the pictorial representation of the battlespace provided by the controller, an optimal path can be chosen. Neural nets are fast enough to allow the production of “pictures” of the battlespace in real

An environmentally-adaptive active sonar controller, using neural net emulation of acoustic models, is fast enough to produce real-time visualizations of performance predictions— invaluable information for a ship captain or Fleet commander.

time rather than merely diagnostic maps. APL-UW is working collaboratively with the Naval Research Laboratory at Stennis Space Center in Mississippi on candidate methods to present the environmental preparation of the battlespace and the common undersea picture. The presentation is in the form of maps that assess the area and show how the sonar will perform throughout the battlespace. This is a global estimate of performance that is informed by measured local conditions. The estimate shows how all oceanographic features interact with sensors and planned maneuvers, allowing commanders to see these elements functioning in the global picture.

Team members: Greg Anderson, Chris Eggen, Warren Fox, Ed Gough, Megan Hazen, Bob Miyamoto. 

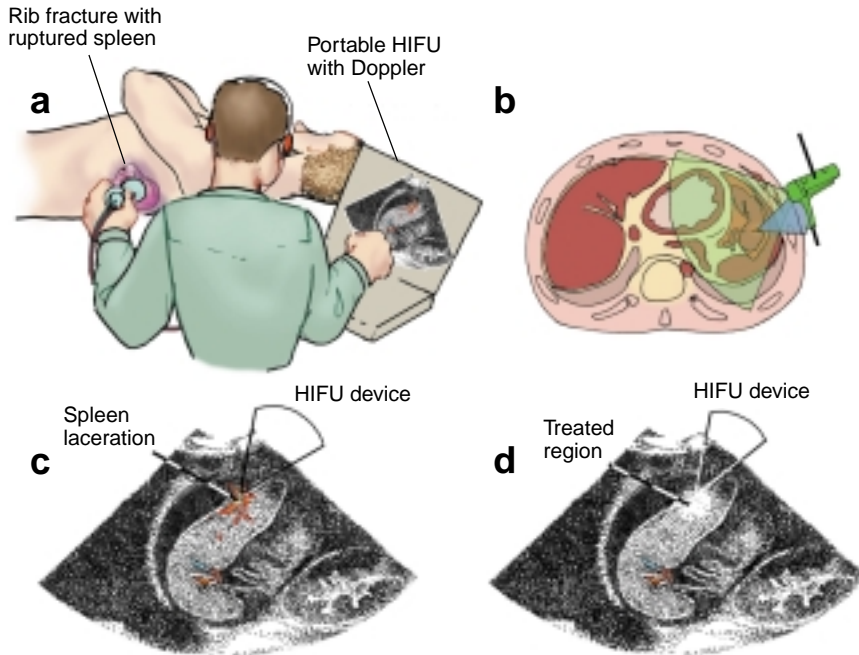


Both environmental parameters and sonar parameters are fed into the neural net and into the acoustic model. The neural net is trained to achieve an emulation of the acoustic model. The connection from the hidden layer to the output layer is represented here for only one node of the hidden layer.

Saving Lives with Sound

Marilee Andrew

In spite of nearly 150 years of medical and technological advancement since the Crimean War, casualty rates have not been reduced for soldiers who cannot be stabilized prior to evacuation from the battlefield. Part of the challenge lies in treating the seriously wounded within what physicians call the “golden hour,” or the critical period during which medical treatment can often save the lives of the severely injured. If medics could quickly locate and stop bleeding, which causes 40% of combat mortality, many wounded would be saved.



How image-guided ultrasound could treat a casualty with an injured spleen. (a) The injured patient is scanned using ultrasound imaging. (b) The anatomical cross-section of the injured spleen. The ultrasound-imaging probe (green) and HIFU device (blue) are coupled together to guide the focal point of the acoustic energy during treatment. (c) An ultrasound image of the spleen before treatment shows lacerations and bleeding. (d) After treatment the bleeding has stopped. The bright region on the diagnostic ultrasound image of the spleen indicates the treated region.

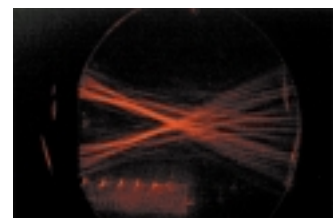
Scientists at the Center for Industrial and Medical Ultrasound hope to develop a tool to make such rapid treatment possible. Over the past several years the Center’s research initiative, “An Acoustic Hemostasis Device for Advanced Trauma Care,” has been funded by the Defense Advanced Research Projects Agency (DARPA), via the Office of Naval Research (ONR) Multidisciplinary Research Initiative (MURI). This program involves researchers at APL-UW, in collaboration with the UW Departments of Surgery, Anesthesiology, Radiology, and Bioengineering, and subcontracts to FOCUS Surgery, Inc., Sonic Concepts, and Boston University. The program is a pioneering study on the use of ultrasound to image internal bleeding that results from trauma and to stop that bleeding—to arrest hemorrhage with sound.

Such lifesaving technology would be just as powerful in the ambulance, emergency room, and operating theater; thus, our research offers significant promise in improving civilian medical care. In fact, one of the most exciting applications of this technology lies in cancer treatment, because the same therapeutic mechanisms that stop bleeding can destroy tumors.

How Ultrasound Therapy Works

Most people are familiar with the ultrasound imaging machines used to visualize the fetus in the womb. These instruments deliver a low-intensity dose of ultrasound into the body and, by processing the backscattered echo, reconstruct an ultrasound “image” of the tissue being scanned. In ultrasound therapy, however, acoustic energy is delivered at high intensities and focused upon a small area within the tissue. This high-intensity focused ultrasound (HIFU) can deliver treatment deep into the body with minimal damage to the surrounding tissue; indeed, CIMU researchers have shown that HIFU can be delivered transcutaneously (through the skin), which would enable doctors to treat traumatic injuries and other medical conditions *without* surgery.

HIFU’s therapeutic action results from two principal mechanisms. First it generates high heat, a thermal effect, at the focal point in the tissue. Second, HIFU can induce mechanical effects such as cavitation, streaming, and radiation pressure. The cessation of



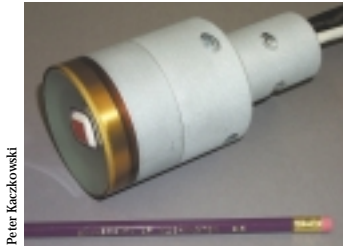
Bryan Cumitz

HIFU in action. (Above) Schlieren optical image of the acoustic field shows how the ultrasound energy is focused into a narrow region. (Below) Formation of a HIFU lesion (area of necrotic tissue) within a bovine lens. The treated area is the size of a rice grain.



Cyril Lafon

blood flow that results from these combined actions is called *acoustic hemostasis*.



Peter Kaczkowski



Peter Kaczkowski



Roy Martin

CIMU researchers have developed several types of HIFU applicators. A multi-element phase-adjustable array optimized

for 2.2 MHz with variable focal depth of 50-80 mm (top). Curved, single-element transducers (that can be coupled to water-filled cones) and a single-element transducer coupled with a solid aluminum cone (center and bottom). These units have fixed frequencies from 1-10 MHz and fixed focal depths from 35-55 mm.

Treatment Demonstrations

A variety of *in vitro* and *in vivo* tests have been conducted to characterize and improve therapy applicator performance, better understand the physical and biological mechanisms of acoustic hemostasis, and assess the efficacy of HIFU treatment. A key finding is that image-guided acoustic therapy can dramatically reduce the time required to arrest hemorrhage. Extensive *in vivo* studies have demonstrated that HIFU can stop bleeding in traumatic injuries such as punctured arteries, severed capillary beds, and fractured organs. Additional funding from NIH and the U.S. Army has extended this work to include long-term survival studies to evaluate the safety and efficacy of HIFU treatment to stop bleeding in the liver, spleen, and femoral artery. Preliminary results are encouraging and will be used to prepare for clinical testing of CIMU's technology.

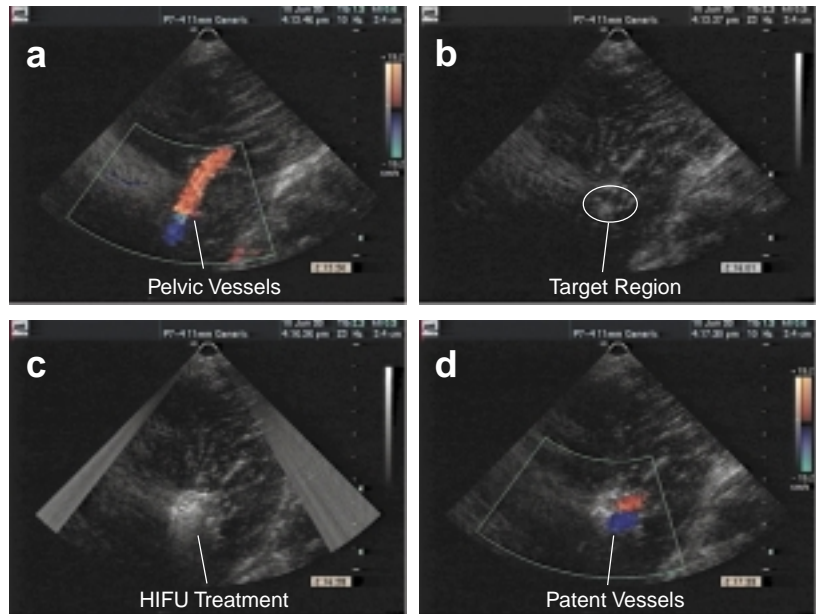
The Role of Simulation

CIMU has developed a comprehensive theoretical model under this program that couples the fully nonlinear acoustic wave and bioheat equations in order to simulate acoustic pressure and intensity as well as temperature distributions in tissue. Simpler, faster models are also being developed that can be tailored to specific tasks such as improving transducer performance, helping plan *in vitro* and *in vivo* studies, or determining optimal treatment design for specific applications. Ultimately, CIMU scientists hope to integrate simulation with the therapy system to provide a fully-interactive treatment planning and monitoring capability.

Team members: Marilee Andrew, Kirk Beach (Department of Surgery), Andy Brayman, Stephen Carter (Department of Radiology), Larry Crum, Bryan Cunitz, Franco Curra, Peter Kaczkowski, Steve Kargl, Roy Martin, Pierre Mourad, Misty Noble, Sandy Poliachik, Tyrone Porter, Andrew Proctor, Shahram Vaezy.

The Importance of Treatment Visualization

Visualization of the treatment site is key to the success of HIFU therapy because it enables precise targeting of the dose and monitoring during treatment to assess dosage effectiveness. Magnetic resonance imaging and various ultrasound imaging techniques have been under investigation by researchers around the globe. As part of our initiative, we have designed and built sophisticated technology to integrate real-time B-mode ultrasound imaging with the therapy system, making CIMU a leader in the development of image-guided acoustic therapy.



Targeting a bleeding pelvic vessel using an integrated imaging/therapy system. (a) The vessels were identified using color Doppler. The vessels were severed using a scalpel, and (b) gray-mode was activated. (c) HIFU treatment using ultrasound image-guidance was applied. (d) Color Doppler assessment after successful treatment and hemostasis showed patent vessels. The bleeding was arrested completely within 70 seconds.

Ocean Mixing at the Hawaiian Ridge

For four weeks in October 2000, two teams from the Ocean Physics Department observed strong mixing and large internal tides over and around the Hawaiian Ridge. And while there were days of strong, sustained winds that added some anxiety and drama to the operations, Tom Sanford's group deployed the Absolute Velocity Profiler (AVP) and other instruments on a nearly round-the-clock schedule from the R/V *Wecoma*. Working aboard the R/V *Revelle*, Mike Gregg's group used Deep Advanced Microstructure Profilers (DAMPs) and Modular Microstructure Profilers (MMPs) to observe turbulent overturns and dissipation. The *Revelle* was equipped with a powerful low-frequency Acoustic Doppler Current Profiler (ADCP), developed by Rob Pinkel of the Scripps Institution of Oceanography, that provided continuous shear profiles to 700 meters to understand the mixing observed with the DAMPs.

During recent years oceanographers have discovered that tidal currents often mix intensely over rough topography, but mixing in the deep ocean far from land seems to be too weak to drive the large-scale thermohaline circulation around the globe. Numerical models show that tidal interactions are much stronger where tides flow across topography than where they flow along it, which is the situation along the margins of ocean basins. The remarkable topography of the Hawaiian Ridge—a 2500-km-long chain of islands, shoals, seamounts, deep and shallow channels—is an especially attractive location to test model calculations because the tide travels from the northeast almost perpendicularly to the ridge. If tidal interactions with topography create internal waves that propagate to the deep ocean, this is one place where they are to be found.

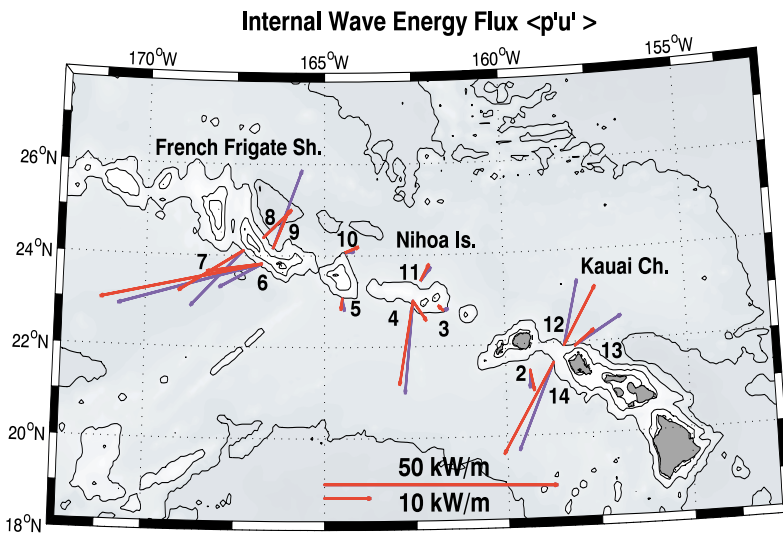
Twenty APL-UW staff members are part of the National Science Foundation-sponsored Hawaii Ocean Mixing Experiment (HOME) organized by Rob Pinkel of Scripps. HOME is divided into five programs including historical analysis, modeling, survey, nearfield, and farfield studies; the three-week cruise aboard the R/V *Wecoma* and the four-week cruise on the R/V *Revelle* were part of the survey program.



Jonathan Nash

The AVP is a great piece of equipment to measure the flux of internal waves, delivering exactly the data needed for the survey experiment. "If it hadn't already existed, it would have been invented for the job."

—Tom Sanford



Internal wave energy flux from four transect stations from AVP. Downward (blue) and upward (red) profiles are shown.

Both teams steamed out to the French Frigate Shoals from Honolulu and then worked their way back sampling over different types of topography and at distances up to 100 km from the ridge axis. AVP deployments were concentrated near the 3000-m isobath along the ridge and were taken on both sides of the ridge axis to confirm that internal wave fluxes were coming from the ridge rather than passing through it. The AVP takes about 2 hours to go from the surface to 3000 meters and back up again. At this rate, 5 drops could be completed within the 12.4-hour tidal cycle. DAMP drops were taken at

stations for 25 hours, two tidal cycles, and sampled the upper 1000 meters unless the bottom was shallower. In those cases, the drops were taken repeatedly along a track to observe how tidal flows, displacements, and mixing evolved from flood to ebb. The deepest stations yielded about a dozen drops per tidal cycle, and many more were obtained at the shallowest stations. Survey lines were also run in Mamala Bay, off Oahu's south shore, to examine mixing produced by the huge internal tides discovered earlier during a pollution study and which provided part of the impetus for HOME.

The groups found strong mixing over and close to the ridge and energetic internal waves radiating outward from several regions. Mixing rates over the ridges were 1000 times more intense than typically found away from topography and gradually decayed to 10 times more intense 100 km off the ridge axis. The most dramatic action was over the Kaena Point ridge, which extends into the Kauai Channel from the northwest tip of Oahu. There the mixing appeared



Wet to the skin: Craig Lee, Eric Kunze, Jonathan Nash, and Alana Althaus after a day of ocean data collection despite inclement weather.

to be generated where the tidal flow encountered an internal hydraulic control over the ridge crest. Gregg found that the patterns were similar to ones he and colleagues found earlier in beams of the internal tide generated off Monterey Bay, California. French Frigate Shoals, Kauai Channel, and a site near Nihoa Island produced the largest internal wave fluxes coming from the ridge. Sites near deep channels did not produce large energy fluxes, presumably because the tide flows through without impediment.

Long before the teams went to sea, considerable effort had been spent on the HOME numerical modeling studies. Consequently, the original survey plan was altered to test the calculations. A one-to-one correspondence of areas that did and did not generate internal wave fluxes was found between the modeling results and field experiments. Sanford admits that, "This is the first time that I, as an old-style observational oceanographer, would change my plans based on numerical models."

Instruments are already in the water for HOME's farfield program. Moorings supporting an ocean acoustic tomography package were deployed at depths of 4500–5500 m about 500 km north of the ridge; they will record measurements for about six months then be picked up and reset on the south side. Farfield measurements will map tidal currents and show how much energy is radiated from the ridge by low-mode internal waves to estimate the total amount of tidal energy lost from the surface tide at the ridge.

During the upcoming nearfield program, Gregg's and Sanford's teams will return to the sites identified during the survey to study the physical processes producing the mixing and generating the internal wave fluxes. They hope to construct a budget of where the energy lost from the surface tide goes: how much is dissipated locally in mixing and how much is radiated away as internal waves. Together with studies from other locations, HOME results should improve the understanding of mixing processes applicable to the global ocean.



A DAMP recovery. The thin blue line is a loose tether that transmits data and allows the profiler to be cycled continuously behind the ship.

Mike Gregg

Team members: Paul Aguilar, Matthew Alford, Alana Althaus, Art Bartlett, Steve Bayer, Eric Boget, Glenn Carter, Bob Drever, Brian Dushaw, Mike Gregg, Bruce Howe, Earl Krause, Eric Kunze, Craig Lee, John Mickett, Jack Miller, Jonathan Nash, Tom Sanford, Dean Stewart, and Dave Winkel. 

Education



Kim Reading

Associate Director, Education Programs,
Robert I. Odom

Since the last Biennial Report our role in the educational mission of the university has continued to expand. There are currently 57 graduate students working with 42 APL faculty representing 12 departments. APL faculty members offer a diverse selection of graduate research opportunities that reflect the exciting work carried out at the Laboratory. Gretchen Novak, working with Senior Engineer and Research Professor of Fisheries Gordon Swartzman, studied the migratory patterns and feeding habits of radio-tagged cutthroat trout in Lake Washington. Melanie Plett, with her committee chair Kirk Beach and Senior Mathematician Don Percival, used ultrasound to investigate vibration associated with interior arterial bleeding. George Kapodistrias and Principal Engineer Peter Dahl studied acoustic multiple scattering from closely spaced bubbles.

These are just three of the exciting projects carried out by graduate researchers and their APL advisors. The diligent work of the APL graduate students has resulted in the conferral of 19 advanced degrees in the last two years. APL faculty members serve on the graduate committees of over 70 students either as chair or in a supporting advisory role. Although research is the primary focus of the APL faculty, we also taught 15 university courses ranging from Principal Engineer Colin Sandwith's popular "Corrosion and Surface Treatment of Materials" in Mechanical Engineering to Principal Oceanographer Tom Sanford's "Methods and Measurements in Oceanography."

The activities of APL graduate students extended beyond the walls of Henderson Hall. Fellowships from the Christine Mirzayan Internship Program of the prestigious National Academies were awarded to CIMU members John Kucewicz and Dahlia Sokolov, both bioengineering students. They moved to Washington, D.C. for 10 weeks where John helped prepare a policy report on emerging technologies for breast cancer screening and diagnosis, and Dahlia worked with the Committee for Science Education. The internship program is designed to familiarize students with the interaction of science, technology, and government, and impart experiences different from those acquired through graduate study, thus aiding the transition from student to professional life.

In addition to our talented contingent of graduate students, APL continues to offer unique opportunities for undergraduate research; 31 students participated

during 1999–2000. Working with CIMU Engineer Mike Bailey, Stephanie Chung studied the localized heating of blood cells by high-intensity focused ultrasound, bringing the goal of truly bloodless surgery a step closer. Chris Siani and Jason Shirley, both electrical engineering students, have been constructing and installing radar equipment with Principal Research Scientist Bill Plant. These radars are used to make measurements from aircraft of directional ocean surface wave spectra, as well as wind speed and direction over the ocean.

APL has also funded the Hardisty Undergraduate Scholarship to confirm and support outstanding students who have selected a major in science or engineering. The two most recent Hardisty scholars are physics major Paige Randall, working with Principal Oceanographer Kathryn Kelly, and




Graduate student Ruth Fogelberg aboard R/PFLIP as it is towed.

Andy Jessup

bioengineering student Adam Oliver who is working with Mathematician Ignatius Rigor. Adam first came to APL as an ALVA (Alliance for Learning and Vision for Underrepresented Americans) student. The program promotes industry-college-community partnerships to improve minority participation in science and engineering. During the 10-week summer program, students are enrolled in an intensive mathematics course but spend three-quarters of their time each week with their faculty mentor. Joanna Valencia, working with AIRS Oceanographer Ellen Lettvin, was another ALVA student at the Laboratory during the past biennium.

APL has also become an annual destination of choice for a number of K-12 school groups from around the Northwest, some groups traveling from as far as Idaho and Montana. The students are treated to tours of individual laboratories where they may see a lithotripter in action, graphic demonstrations of wave motion by oceanography graduate student Alana Althaus, a “guided tour” from Earth to Jupiter’s moon Europa by Engineer Andy Ganse, or hear the fascinating story of Engineer Megan Hazen’s journey from the artistic world of dance to the esoteric heights of neural nets and software development.

We continue our regular participation in Math Day, an annual event sponsored by the university’s Mathematics Department. Demonstrations of infrared sensing by Ellen Lettvin, and salt finger formation by Ocean Physics Senior Oceanographer Steve Reynolds were presented to several hundred 7th to 9th graders who are participants in the GEAR-UP Project aimed at increasing college participation of students from low-income areas in Washington State.

Although the students often come to us, we just as often go to the students, or sometimes we go to the teachers. At the invitation of the American Geophysical Union, Principal Oceanographer Mike Steele and Principal Physicist Bob Odom gave presentations on arctic research and waves to the Washington Science Teachers Association. 

Student Profiles

Alana Althaus and Principal Oceanographer Eric Kunze met at an ocean sciences meeting in early 1998. Because he had already read the application she had submitted to the University of Washington Department of Oceanography, he took the opportunity to recruit her into one of his research projects. Upon enrollment in the fall, Alana began work on tide-generated internal wave energetics near Mendocino Escarpment.

For her M.S. degree, she analyzed full-depth profiles of velocity, temperature, and salinity collected across the escarpment—a deep step in the ocean floor extending west off the coast of northern California. Alana notes that here, “The surface tide interacts with rough topography on the ocean floor to generate internal waves at the tidal frequency. This may be an important source of energy for mixing in the deep ocean, as well as a mechanism for

dissipation of surface tidal energy.” It was found that internal tides flux energy away from the escarpment and that the peak value was observed about 20 to 60 km from the step. The energy flux calculated from the *in situ* data was approximately 10 times that inferred from satellite altimetry.

Because of her expertise gained from the Mendocino data, Alana was a great asset to the OPD team on the HOME cruise in September 2000.

During the Mendocino data analysis, she found that 5 AVP profiles were necessary for good resolution of the internal tidal signal. Furthermore, because the internal tide energy flux signal was generally weak within about 10 km of the ridge crest, the sampling for HOME was focused on the 3000-m isobath where it was shallow enough to complete 5 AVP drops within a tidal period, but far enough from the ridge crest to capture the peak internal tidal fluxes.

Alana completed her M.S. degree in Oceanography in January 2001 and will pursue a Ph.D. in math and science education at Oregon State



Alana Althaus gives her children an early lesson in physical oceanography.

University. No doubt she will be an outstanding science teacher for her own children, but Alana wishes to work for change in the K-12 educa-

tional system to improve math and science literacy in the general student population.

Before moving on though, Alana continues to perform further analysis on the Mendocino data (sorting out the difficulties with the spectral analysis of the AVP data) and hopes this will be valuable for interpretation of HOME data. Kunze notes, "What impresses me most about Alana is the care and skepticism she brings to her work, never taking a result at face value, but checking and double checking it until she understands it fully."

Wen-Shiang Chen is on the leading edge of research in the nascent medical discipline of therapeutic ultrasound. His work focuses on the physical characteristics of ultrasound contrast agents (UCAs), and the mechanisms governing their therapeutic application. Wen received an M.D. from the Department of Medicine, National Taiwan University, Taipei, in 1991 and continued resident training at the University Hospital's Department of Physical Medicine and Rehabilitation, where he first encountered therapeutic ultrasound. When the hospital asked for doctors to do

more research in the area, Wen knew that he would have to study abroad to develop the expertise needed.

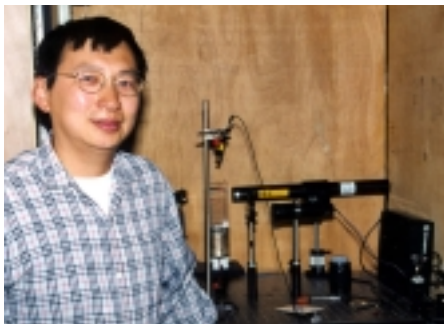
Wen came to the university's Department of Bioengineering in 1997, but after attending a lecture given by APL's Senior Mathematician Pierre Mourad, who then introduced him to Lawrence Crum, Wen joined Dr. Crum's laboratory. Crum notes that, "Wen is of great value to the department and brings a rare perspective to his work because of his clinical experience."

UCAs are bubbles engineered to a size of about 5 microns. Because of their small size they can inhabit any tissue in the body, including brain capillaries, and they have no deleterious effects. Wen has demonstrated that by gradually increasing the acoustic pressure level on contrast bubbles they lose their acoustic scattering effect—this fragmentation threshold describes the bubbles' shattering and loss of effectiveness as an imaging agent. The first trace of inertial cavitation (IC) activity—the growth and violent collapse of bubbles in

response to an applied sound field—was found near this acoustic pressure level. Upon follow-up experiments he was surprised to find that further increases in acoustic pressure did not induce scattering until another threshold, the sustained IC threshold, was realized. The sustained IC threshold likely describes the self-replenishing ability of cavitation nuclei to form microbubbles anew. These thresholds depend on frequency, pulse length, and pulse repetition.

These UCA properties have important clinical applications, especially for stroke and myocardial infarction patients. Coupled with tiny transducers affixed to the tips of catheters, UCAs can be activated at the treatment site with ultrasound and speed thrombolysis, perhaps by the oscillation of the bubbles at their sustained cavitation threshold.

At the conclusion of his Ph.D. studies, Wen hopes to have a one-year post-doctoral appointment in a research institute before he and his family return to Taiwan. He has never lost sight of his ultimate goal—to coax maximum therapeutic effect from accepted and emerging technologies.



Kim Reading

Wen-Chiang Chen uses a standing wave to levitate a few bubbles at a time and then subjects them to controlled ultrasound waves. Laser scattering detects minute changes in contrast bubbles so he is able to quantify precisely their physical dynamics, which are dependent on properties of the outer shields and internal gases.

Robb Contreras completed an M.S. in atmospheric sciences in the summer of 2001. He came to the University of Washington and APL from the Scripps Institution of Oceanography where he worked as a computer programmer. After being accepted to the university, he drew from his experiences with scientists at Scripps when it came time to choose an advisor and research topics. He knew that it was paramount to have interest in and respect for his mentor's work, but also to be able to establish an easy working rapport. Robb found all of these in APL-UW Principal Research Scientist William Plant of the AIRS Department. Robb recognized that Plant's work in scatterometry was fundamental to how scientists in the discipline of remote sensing interpret the data collected from the instruments, and he knew he had found his academic mission.

One project Robb has pursued entailed obtaining a climatology of tropical instability waves (TIWs) from ERS 1 and 2 scatterometer data together with current meter and ADCP measurements from the TAO buoy array, and sea surface temperature data. These data consist of multiple



Robb Contreras amid remote sensing laboratory equipment.

year observations of the waves and have illuminated the annual and interannual behavior of TIWs.

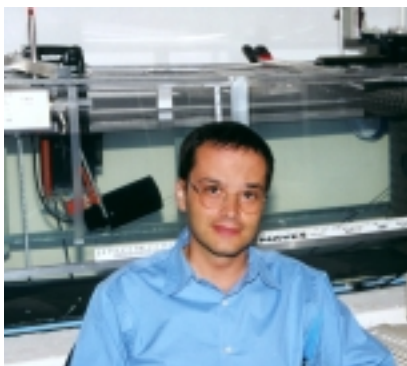
Scatterometers operate by transmitting microwave pulses to the sea surface and "reading" the returned "backscattered" radar pulses. They sense the surface wave field, from which surface wind speed and direction can be calculated. TIWs are shear-created instabilities in the ocean currents that propagate westward at speeds from 0 to 0.7 m s^{-1} . They are visible in the sea surface temperature (SST) due to the advection of the equatorial SST front by these waves. The SST signature of TIWs serves to couple the atmosphere to the ocean and as a result, space-borne scatterometers are useful in observing

TIWs and analyzing the phenomenon of their coupling.

For his thesis research, Robb analyzed the radar data taken on the R/V *Ron Brown* during the 1999 TRMM Kwajalein Experiment to determine the effect of rainfall on backscatter from the ocean surface. A number of physical assumptions are made to convert satellite radar backscatter measurements to wind speed and direction. When it is raining, these assumptions are further complicated. "He is getting good results and this topic is of great interest to those wanting surface wind fields from satellite scatterometry," notes Plant. His analysis of data from low incidence angles has implications for altimeter and precipitation radars that are commonly used in observing the local weather, while analysis of data taken at large incidence angles has application for space-based scatterometers and their ability to infer surface winds over the ocean.

Robb is now enrolled in a Ph.D. program in atmospheric sciences and wishes to extend his work to obtain a more comprehensive picture of the effects of rain on backscatter from the ocean surface.

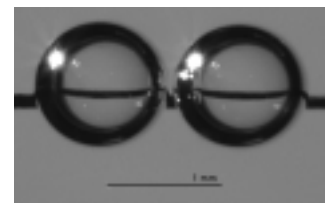
George Kapodistrias defended his dissertation for a Ph.D. in mechanical engineering at the end



George Kapodistrias in front of a plexiglass laboratory water tank designed for small-scale underwater acoustic experiments.

of 2000. First trained in aerospace engineering, his interest in acoustics brought him to APL where he began work on acoustic scattering from assemblages of bubbles under Principal Engineer/Research Associate Professor Peter Dahl's direction. Bubbles, introduced to the sea surface by breaking waves or precipitation, can have dramatic effects on the behavior of underwater sound.

George is described by his mentor and other Lab personnel as a real "lab rat." He was instrumental in helping Dahl set up the Underwater Ultrasonics Laboratory. Here, he devised a method to hold bubbles less than 1 mm in diameter in water on a



Tiny bubbles held on $150 \mu\text{m}$ -thick nylon thread.

$150\text{-}\mu\text{m}$ thick waxed nylon thread. The technique allowed for controlled studies of multiple scattering problems of bubbles in water and verification of theoretical models. Experiments included the scattering response of two identical bubbles as a function of their proximity to each other and their relative position in the sound field,

and the response of a single bubble close to an air-water interface. "This was the first experimental verification of a seminal result by Victor Twersky on interaction between two monopole scatters," notes Dahl. This knowledge is fundamental to understanding how acoustic signals scatter from oceanic bubble clouds, schools of fish, plankton, ultrasound contrast agents, and blood.

George has not moved too far from the Laboratory since completing his degree. He is now a senior engineer at ATL Ultrasound-Philips Medical Systems in Bothell, Washington, working on new high-tech ultrasonic scanheads. Here he brings his experience in acoustics, signal processing, data analysis, and modeling to bear on his work in medical ultrasound. He continues to collaborate with Dahl and

makes it in to the UUL from time to time. In a recently published paper, they present detailed modeling and experimental analysis of acoustic scattering from a bubble close to the water's surface. "These models can be easily modified to determine the scattering of more complex objects close to the surface of the water, or incorporate roughened surfaces," adds George.

Ignatius Rigor was hired by APL as a 16-year-old college freshman in 1981 through the Laboratory's Student Assistant Program. His first job included running back and forth between the Laboratory and the campus mainframe computing center, delivering computer punch cards and picking up output. By the end of his undergraduate program he was providing scientific and technical assistance in the objective analysis of data and the study of arctic climate. After completing a B.S. in cell and molecular biology in 1986, he was hired as a mathematician/data analyst in the Polar Science Center. His responsibilities and contributions to projects, including the Arctic Nuclear Waste Assessment Program, SHEBA, and the International Arctic Buoy Programme (IABP), continued to grow over the years. By 1995 he had assumed responsibility for the IABP. He was also elected by the members of the IABP to be the Programme's Coordinator—a post he continues to fill.

In 1998 Ignatius realized that returning to school and pursuing a Ph.D. would broaden his scientific knowledge so that he could pursue




Ignatius Rigor

Kim Reading

new investigations. He was awarded an APL graduate fellowship and received his M.S. in atmospheric sciences in summer 2001; he is on track to complete the Ph.D. in 2002.

Guided by John Wallace, Professor of Atmospheric Sciences, and his research on the Arctic Oscillation (AO) phenomenon—a decades long cycle of atmospheric circulation variability in the Northern Hemisphere, where a high index translates to stronger westerlies at subpolar latitudes and lower sea level pressure over the Arctic—Ignatius has used data

gathered from the IABP to study the role of sea ice in a changing arctic climate. Did changes in surface air temperature drive the thinning and reduction in area of arctic sea ice, or did the thinning sea ice and increased area covered by leads allow more heat to flux from the ocean to warm the surface air? "Ignatius has brought fresh insights to the problem of interpreting recent changes in the thickness and extent of arctic sea ice. He's presented observational evidence that changes in wintertime wind patterns over the Arctic are responsible for much of the thinning and summer melting that have been attributed to global warming," notes Wallace.

Twenty years ago the goal of the APL Student Assistant Program was to help confirm women and minority students in their choice of an engineering or scientific career. Ignatius's successes, from student helper to scientist to graduate student, exemplify the value of the Laboratory's support. It is uplifting to note that during summer 2001, Ignatius mentored two young students, perhaps helping to launch their scientific careers. 

Alana Althaus	Internal wave energies	Kunze
Carlos Alvarez-Flores	Fisheries management	Swartzman
Ajay Anand	Ultrasound tissue characterization	Kaczkowski
Oleg Babko	Thickness distribution of sea ice	Rothrock
George Barrett	Harmonic vector Doppler velocimetry	Beach
Glenn Carter	Mixing around the Hawaiian Ridge	Gregg
Arthur Chan	HIFU treatment of uterine fibroids	Vaezy
Wen-Shiang Chen	Acoustic imaging	Crum
Lorenzo Ciannelli	Modeling fish growth	Swartzman
Robert Contreras	Rain effects on short surface waves on the ocean	Plant
Cynthia Cooper	Fish-plankton acoustics	Swartzman
Peter Craigmile	Wavelet-based statistical analysis	Percival
Francesco Curra	Acoustic hemostasis	Crum
Patricia Dell Arciprete	Pollock spatial distribution	Swartzman
Shenfu Dong	Ocean circulation with satellite data	Kelly
Eric Ellsworth	Evolution of internal solibores in Knight Inlet	D'Asaro/ Heney
Billy Ernst	Crustacean migration	Swartzman

Graduate Students, Their Research Topics and Faculty Advisors

John Flynn	Underwater acoustic communications	Fox
Ruth Fogelberg	Wave effects on infrared radiometry	Jessup
Cliffton Frensley	Sonochemistry	Matula
David Groves	Freshwater balance in the Arctic Ocean	Rothrock
Jingfeng Guan	Sonoluminescence	Matula
Tim Hammond	Fish school classification	Swartzman
Adam Haulter	Bottom interacting shallow water acoustics	Odom
Dan Hayes	Horizontal variability in the upper Arctic Ocean	Morison
Lingyun Huang	Ultrasonic characterization of vascular and cystic walls	Beach
Joo Ha Hwang	Endoscopic high-intensity ultrasound treatment of gastrointestinal bleeding	Vaezy
George Kapodistrias	Multiple scattering from closely spaced bubbles	Dahl
John Kucewicz	Ultrasound tissue pulsatility measurement	Beach
Jennifer MacKinnon	Mixing in coastal regions	Gregg
Arni Magnusson	Salmon survival	Swartzman
Denise McKelvey	Fisheries species discrimination with acoustic backscatter	Swartzman
John Mickett	Mixing levels and mechanisms in Puget Sound	Gregg
Gretchen Novak	Lake Washington cutthroat trout migration prediction	Swartzman
Melanie Plett	Medical sonar	Percival
Sandra Poliachik	Acoustic hemostasis	Crum
Tyrone Porter	Acoustic hemostasis	Crum
Adrian Prokop	Polymers for acoustic coupling	Vaezy
Christine Richardson	Infrared measurements of waves	Jessup
Ignatius Rigor	Response of sea ice to the Arctic Oscillation	Rothrock
Aaron Rivers	Modeling arctic ice clouds in a single column model	Moritz
Alex Robinson	Sonochemistry	Matula
Nicoles Segabarth	Sonochemistry	Matula
Xuegon Shi	High-intensity focused ultrasound	Crum
Dahlia Sokolov	Lithotripsy	Crum
Darin Soukup	Low-frequency sound propagation in range-dependent shallow water	Odom
Suzann Speckman	Fisheries acoustics	Swartzman
Elizabeth Steffen	Mixed-layer dynamics	D'Asaro
Jay Stokes	Communication theory	Percival
Brian Strully	Acoustic remote sensing of bubbles in the surf zone	Dahl
Jack Turnock	Animal abundance; fisheries data display; spatial analysis	Swartzman
Andreas Winter	Bering Sea fisheries	Swartzman
Mike Yargus	Acoustics of porous media	Jackson
Jonathan Yuen	Acoustic hemostasis	Vaezy
Jong Tae Yuk	Hemorrhage and aortic aneurysm detection using 3D ultrasonic imaging	Beach
Christopher Zappa	Gas transfer using infrared imagery	Jessup
Vesna Zderic	Ultrasound-enhanced drug delivery to the eye	Vaezy

Oleg Babko	Atmospheric Sciences, M.S., 2000	Rothrock
Peter Craigmile	Statistics, Ph.D., 2000	Percival
Shen Dong	Oceanography, M.S., 1999	Kelly
Ruth Fogelberg	Physics, M.S., 1999	Jessup
Ibrahim Hallaj	Electrical Engineering, Ph.D., 1999	Crum
Tim Hammond	Fisheries, Ph.D., 2000	Swartzman
Daniel Hayes	Oceanography, M.S., 1999	Morison
Christopher Jones	Electrical Engineering, Ph.D., 1999	Jackson
George Kapodistrias	Mechanical Engineering, Ph.D., 2000	Dahl
Jennifer MacKinnon	Oceanography, M.S. 1999	Gregg
Denise McKelvey	Fisheries, M.S., 2000	Swartzman
Garfield Mellema	Electrical Engineering, Ph.D.	Ewart
Gretchen Novak	Fisheries, M.S., 2000	Swartzman
Melanie Plett	Electrical Engineering, Ph.D., 2000	Beach
Christine Richardson	Civil Engineering, M.S., 2000	Jessup
Elizabeth Steffen	Oceanography, M.S., 2000	D'Asaro
Brian Strully	Mechanical Engineering, M.S., 2000	Dahl
Chris Walter	Geophysics, Ph.D., 1999	Mercer
Christopher Zappa	Civil Engineering, Ph.D., 1999	Jessup

Advanced Degrees Awarded to APL Students and Staff

Undergraduate Students, Their Research Topics and Faculty Advisors

Vassilios Bezzerides	Single-bubble sonoluminescence in microgravity	Matula
Justus Brevik	Cavitation field imaging	Matula
Dorothy Caplow	Analysis of microgravity experiments	Wettlaufer
Stephanie Chung	Localized heating of blood cells by HIFU	Bailey
Andrew Cook	Software for acoustic data analysis	G. Anderson
Lisa Couret	Single-bubble sonoluminescence in microgravity	Matula
Peter Derrick	Ultrasonic measurement of organ displacement in microgravity	Bailey
Maile Hadley	Drug-sound synergy	Mourad
Dave Halaas	Transducer housing design and construction	Matula
Kurt Heinze	Processing and analysis of Bosphorus Strait data	Gregg
Paul Hilmo	Sonoluminescence in microgravity	Matula
Justin Huff	Software development for continuous wave pulsed radar	Plant/Hayes
Michael Jacobs	Develop computer-based training programs and 3D visualizations	Olsonbaker
Nick Kohler	Journey to the North Pole (SHEBA)	Moritz
Bryan Kovacs	Software development for continuous wave pulsed radar	Plant/Hayes
Mark Kruger	Meteorological and oceanographic data display	Kerr
Eric Macdonald	Analysis of Bosphorus Strait data	Gregg
Nathan Miller	Cavitation detection in lithotripsy and imaging of HIFU	Bailey
Adam Oliver	Build and install research equipment	Rigor
Ryan Ollos	Ultrasonic measurement of organ displacement in microgravity	Bailey
Trevor Olson	Single-bubble sonoluminescence in microgravity	Matula
Mark Peebles	MAP Program (ATOC/NPAL)	Mercer
Faina Pulvermahker	Medical applications of lithotripter	Bailey
Justin Reed	Sonochemistry and nanoparticle formation	Matula
Chris Siani	Build and install research equipment	Plant
Bernard Silvan	Hardware development for CORAR pulsed radar system	Plant/Keller
Patrick Tewson	Meteorological and oceanographic data display	Kerr
Laurence Tomsic	Medical applications of HIFU	Kaczkowski
Lorne Walker	Ultrasonic treatment of peripheral nerve injury	Mourad
Nicole White	Ultrasonic measurement of organ displacement in microgravity	Bailey
Andrew Ziegwied	Data analysis and processing for oceanographic cruises	Gregg

Visiting Scientists

Many of APL's research programs include collaborations with scientists outside the Laboratory, frequently in other departments of the University of Washington but also from other national and international institutions. Visitors, their affiliation and APL collaborator, included the following:

1999

Robert Arthern—UW Dept. of Electrical Engineering—*Dale Winebrenner*
 Anatoliy Ivakin—N.N. Andreev Acoustic Institute, Russia—*Darrell Jackson*
 Vera Khokhlova—Moscow State University, Russia—*Lawrence Crum*
 Mark Lowen—Toronto University, Canada—*Andrew Jessup*
 Emin Öszoy—Institute of Marine Sciences, Middle Eastern Technical Institute, Turkey—*Michael Gregg*
 Oleg Sapozhnikov—Moscow State University, Russia—*Lawrence Crum*
 Gail ter Haar—Royal Marsden Hospital, England—*Lawrence Crum*
 Barry Uscinsk—Assistant Director of Research, Dept. of Applied Mathematics and Theoretical Physics, Cambridge University, England—*Terry Ewart*

2000

Cecilia Bitz—University Corporation for Atmospheric Research—*Richard Moritz*
 Muhammed Ilyas—Baruna Jaya Technical Services, Indonesia—*Michael Gregg*
 Anatoliy Ivakin—N.N. Andreev Acoustics Institute, Russia—*Darrell Jackson*
 Rolf Käse—Institut für Meereskunde, Germany—*Thomas Sanford*
 Vera Khokhlova—Moscow State University, Russia—*Lawrence Crum*
 Cyril LaFon—INSERM, France—*Lawrence Crum*
 Oleg Sapozhnikov—Moscow State University, Russia—*Lawrence Crum*
 A. Sulaiman—Baruna Jaya Technical Services, Indonesia—*Michael Gregg*
 Gail ter Haar—Royal Marsden Hospital, England—*Lawrence Crum*
 Frédéric Vivier—U. Pierre et Marie Curie, France—*Kathryn Kelly*
 Grae Worster—University of Cambridge, England—*John Wettlaufer* 

Honors, Visitors and Events

1999

Director Bob Spindel was appointed to the Naval Research Advisory Committee.

Principal Engineer Ed Gough was presented the Navy Superior Public Service Medal.

Principal Physicist Eric Thorsos was awarded a bronze medal from the National Defense Industrial Association.

Principal Engineer Le Olson was presented the UW Distinguished Staff Award and the College of Ocean & Fishery Sciences Research Award.

Professor Emeritus Terry Ewart was named Chair of the UW Faculty Council on Research.

Senior Oceanographer Brian Dushaw was appointed Affiliate Assistant Professor of Oceanography; Principal Oceanographer Eric Kunze, Associate Professor of Oceanography; Senior Oceanographer Jeff Nystuen, Affiliate Assistant Professor of Oceanography; and Senior Physicist John Wettlaufer, Affiliate Associate Professor of Physics.

Principal Physicists Frank Henyey and Kevin Williams were named Fellows of the Acoustical Society of America.

Senior Mathematician Pierre Mourad was presented the Editors' Citation for

Excellence in Refereeing, by the *Journal of Geophysical Research-Oceans*.

Mechanical Engineering student Brian Strully was awarded a graduate fellowship from the National Defense Industrial Association.

Physics major Paige Randall was the recipient of the 1999 APL Hardisty Scholarship, an annual undergraduate assistantship named to honor Patricia M. Hardisty, late APL scientist.

Senior Computer Specialist Neil Bogue, Library Specialist Supervisor Jane Doggett, and Library Specialist Priscilla Schneider received the APL Director's Award.




Eric Thorsos



Le Olson retired in 2000 after 40 years of service.

Eric Thorsos

Innovative Technology Awards were presented to Vassilios Bezzerides, Lawrence Crum, Peter Kaczkowski, Thomas Matula, Pierre Mourad, Fran Olson, Sandra Poliachik, Tyrone Porter, Colin Sandwith, and Dahlia Sokolov.

Administrator Dian Gay, Principal Engineer Andreas Heiberg, and Senior Oceanographer Richard Moritz received Arctic Service Awards from the National Science Foundation. 



Dorothy Lowell

On October 15, 1999 the Hon. Jerry MacArthur Hultin, Undersecretary of the Navy, visited the Applied Physics Lab. (From left to right: Bob Spindel, the Undersecretary, Ed Gough, and Bob Miyamoto.)

2000

Principal Oceanographer Knut Aagaard was named Fellow of the American Geophysical Union and bestowed an honorary membership in the American Polar Society.



Rebecca Woodgate

Knut Aagaard at Alert, ready for the North Pole

Associate Director Lawrence Crum was presented the Helmholtz-Rayleigh Interdisciplinary Silver Medal in Physical Acoustics by the Acoustical Society of America.

Principal Physicist Frank Henyey was given the Editor's Award by the *Journal of Physical Oceanography*, and Senior Research Scientist Dale Winebrenner was recognized as an exceptional reviewer by the *Journal of Glaciology*.

Visiting Scientist Cyril Lafon was recognized as an outstanding young researcher in the life sciences by the city of Lyon, France.

Principal Oceanographers Kathryn Kelly and Eric Kunze were appointed Affiliate Professor and Professor, respectively, School of Oceanography.

Maintenance Custodian Jojo Austria and Oceanographer Mark Ortmeier were recognized with the APL Director's Award.

Bioengineering student Adam Oliver was presented the 2000 Hardisty Scholarship.



Kim Reading

Adam Oliver

Suzan Huney served a one-year term as Chair of the university's Professional Staff Organization.


Peggy Hartman, Assistant to the Assistant Director of Management and Finance, was appointed to the President's Staff Forum of the University of Washington.



Kim Reading

Bob Bratager

Robert Bratager, Manager of Human Resources, was recognized by the University of Washington with the Combined Fund Drive Leadership Award.

Innovative Technology Awards went to Lawrence Crum and Jeff Nystuen. 



Kim Reading

Peggy Hartman

Location	Program	Activity	Leader	Date
Lake Superior	NSF, Lake Superior's Keweenaw Current	Deploy and recover moorings to monitor the impact of the Keweenaw Current on the cross-margin transport in Lake Superior	Johnson/Aagaard	May '99/May '00
Faroe Banks, NSF	Faroe Bank Overflow Study	Study flow and mixing using EM-POGO and XCP	Sanford	Jul '99
Florida Straits	NSF, Towed Transport Meter	Evaluate the TTM3 instrument by measuring three components of the 'electric field'	Sanford	Jul '99
Bering Strait	NOAA/ONR, Time Series	Measurements in Bering Strait, deploy and recover moorings	Roach/Johnson/Woodgate	Jul '99/Sep '99/ Aug-Sep '00
Washington Coast	NSF, Hydrothermal Flow Imaging	Image hydrothermal plumes on the Juan de Fuca Ridge	Jackson/Jones	Jul-Aug '00

Field Operations

Japan Sea	ONR, East Japan Sea	Study physical and bio-optical variability process in the upper ocean using SeaSoar	Lee	Jul-Sep '99/ Dec-Mar '00
Puget Sound/ Port Susan	AOSN Seaglider	Test and evaluate systems	Osse	Sept '99
Beaufort Sea	MMS/UAF, Circulation	Measure thermohaline structure, and cross-shelf transport in the Alaskan Beaufort Sea, recover moorings	Andersen/ Johnson	Sep-Oct '99/ Sep-Oct '00
Florida Coast, Gulf of Mexico	ONR, Sediment Acoustics Experiment (SAX99)	Characterize seafloor environment to permit accurate modeling of acoustic measurements	Thorsos	Sep-Nov '99
Banda Sea, NSP	ONR, Arlindo	Study mixing in the Indonesian Throughflow	Gregg/Miller	Oct-Nov '99
Western Washington Rivers	River Flow Measurements	Measure river velocities with CORAR and USGS ground penetrating radar	Plant	Oct '99-Feb '00
North Carolina Coast	ONR, Shoaling Waves Experiment (SHOWEX)	Study bottom and wind influence on wave development across the continental shelf	Plant	Nov '99
Oregon to Hawaii Transit, Pacific Ocean	NSP and ONR, Lagrangian Floats	Construct and deploy Lagrangian floats to study the dynamics of the wind-forced upper ocean boundary layer	D'Asaro	Dec '99/Jul '00/ Sep '00
North Pole	NSF, North Pole Environmental Observatory	Deploy drifting buoy station and perform airborne hydrographic survey	Morison	Apr '00
Puget Sound	ONR, Passive Phase Conjugation for Underwater Acoustic Communications	Investigate methods for underwater acoustic communication	Rouseff/Jackson/ Fox/Jones	May '00
Spanish Coast, Mediterranean	ONR, Environmental Effects on Sonar Signal Processing	Observed Navy sonar operation	Fox	June '00
Puget Sound/ Possession Sound	NOPP Seaglider	Environmental study	Light	Jun-Jul '00
USS <i>Carl Vinson</i> (CNV-70) Bremerton, Washington	Navy METOC	Refine weather forecasting methodologies used during high-tempo aircraft carrier exercises	Miyamoto	Jul '00
Monterey Bay, California	AOSN/MUSE Seaglider	Profile nutrient rich upwelling fronts	Light	Aug '00
Hawaiian Ridge, Pacific Ocean	NSF, Hawaii Ocean Mixing Experiment	Survey, identify "hot spots" of mixing activity with AVP and MMP2	Gregg/Miller	Sep '00
California Coast	ONR, Fluxes, Air-Sea Interaction and Remote Sensing (FAIRS)	Aboard R/V <i>FLIP</i> , investigate the effect of ocean surface wave processes on remote-sensing techniques and air-sea fluxes	Jessup/Asher	Sep-Oct '00
Washington Coast	NSF, Thermal Grid	Measure vertical heat flux at the ocean floor	Jones	Oct-Nov '00

The Applied Physics Laboratory began the new millennium in sound financial condition. Grant and contract awards totalled \$30.9M in Federal Fiscal Year (FFY) 1999 and \$31.6M in FFY 2000. Research project work for the United States Navy accounted for about 67% of the total.

world-renowned scientists and engineers. Basic research conducted at the Laboratory represented about 64% of APL's funding in FFY 2000 and remains a strength.

APL's discretionary resources, derived almost entirely from contract fees are approximately 2.6% of total

Finances



Kim Reading

Assistant Director, Management and Finance, William T. Bakamis

The Navy's research and development budget was constrained in FFY 1999 and FFY 2000 and the Laboratory expects this trend to continue in future fiscal years. Despite this funding uncertainty, APL is optimistic that it will continue to receive significant research and development grants and contracts, since it has a very strong, diversified R&D base and numerous

income and are used to support a variety of business expenses and strategic initiatives not covered by grants and contracts. The largest portion of these funds is used to support internal APL Independent Research and Development efforts, which are currently focused on building additional Navy-related expertise. Other Laboratory fee expenditures include graduate student support, staff fellowships, building and vessel improvements, and general-use equipment.

APL remains committed to ensuring that the Navy's considerable investment in the Laboratory continues to be applied to national technical needs, and to preserving its ability to respond effectively and efficiently to present and future Navy needs. We expect the Navy to remain our principal sponsor. In addition, the Laboratory will continue to pursue opportunities with other government agencies and industry.

APL's grant and contract funding from the Department of Defense exceeds that of all other units at the University of Washington combined. The Laboratory's overall research and development budget remains among the largest on the University of Washington campus.

Sponsor	FFY 1999	FFY2000
Office of Naval Research	14,012,000	11,784,000
Naval Surface Warfare Center	3,341,000	3,008,000
Office of Naval Intelligence	2,055,000	1,552,000
Naval Sea Systems Command	788,000	853,000
Naval Air Systems Command	645,000	720,000
Space and Naval Warfare Systems Command	443,000	1,016,000
Naval Undersea Warfare Center	352,000	427,000
Other Navy	443,000	249,000
National Science Foundation	4,587,000	6,401,000
National Aeronautics and Space Administration	1,388,000	1,594,000
Army		1,723,000
National Institute of Health	679,000	690,000
National Oceanic Atmospheric Administration	346,000	280,000
Jet Propulsion Laboratory	235,000	140,000
Guidenet		255,000
Lockheed Martin		212,000
Woods Hole Oceanographic Institution	315,000	
University of Alaska-Fairbanks	248,000	
Advanced Research Projects Agency	177,000	
Washington Technology Center	148,000	
Other	713,000	670,000
TOTAL FUNDING	30,915,000	31,574,000

Personnel

DIRECTORATE

Robert C. Spindel - Director; Prof., Electrical Engineering;
Adj. Prof., Oceanography
William T. Bakamis - Asst. Director, Management and Finance
Robert T. Miyamoto - Assoc. Director, Applied Research &
Technology
Robert I. Odom, Jr. - Assoc. Director for Education Programs;
Principal Physicist; Res. Assoc. Prof., Geophysics

Staff

Dian L. Gay - Administrator
Jeannette Marr - Office Asst.

Ocean Physics Department

Craig M. Lee - Chair, Scientific Committee; Senior Oceanographer;
Affil. Asst. Prof., Oceanography
Matthew H. Alford - Oceanographer; Affil. Asst. Prof., Oceanography
Arthur C. Bartlett - Senior Field Engineer
Stephen J. Bayer - Senior Engineer
Glenn S. Carter - Res. Asst.
Eric A. D'Asaro - Principal Oceanographer; Prof., Oceanography
John H. Dunlap - Senior Engineer
Terry E. Ewart - Prof. Emeritus
Zachary C. Frazier - Student Helper
James B. Girton - Res. Asst.
Michael C. Gregg - Prof., Oceanography
Kurt R. Heinze - Student Helper
Frank S. Henyey - Principal Physicist; Affil. Prof., Physics
Michael F. Kenney - Oceanographer
Jody M. Klymak - Predoctoral Res. Assoc.
Earl J. Krause - Oceanographer
Eric L. Kunze - Principal Oceanographer; Prof., Oceanography
Ren-Chieh Lien - Senior Oceanographer
Jennifer A. MacKinnon - Predoctoral Res. Assoc.
John B. Mickett - Res. Asst.
Jack B. Miller - Principal Engineer
Jonathan D. Nash - Res. Assoc.
Eileen S. Peery - Student Helper

Stephen A. Reynolds - Senior Oceanographer
Thomas B. Sanford - Principal Oceanographer; Prof., Oceanography
Elizabeth Steffen - Predoctoral Res. Assoc.
Zolton B. Szuts - Helper
Robert H. Tyler - Oceanographer; Affil. Asst. Prof., Geophysics
David P. Winkel - Oceanographer
Kraig B. Winters - Senior Mathematician; Affil. Asst. Prof., Applied Math.

Staff

Phyllis P. Adams - Secretary Senior
Sheila S. Ocoma - Fiscal Specialist
Nancy J. Sherman - Administrator

Polar Science Center

Richard Moritz - Chair, Principal Investigator Council; Senior
Oceanographer
Knut Aagaard - Principal Oceanographer; Prof., Oceanography
Roger H. Andersen -
Mathematician
Oleg Babko - Predoctoral
Res. Assoc.
Wendy S. Ermold - Physicist
Daniel R. Hayes - Predoctoral
Res. Assoc.
Andreas Heiberg - Principal
Engineer
James M. Johnson - Senior
Field Engineer
Jee Sook Kutz - Student Helper
Ronald W. Lindsay - Senior
Physicist
James H. Morison - Principal
Oceanographer; Affil. Prof.,
Oceanography
Adam W. Oliver - Student
Helper
Mark L. Ortmeier - Oceanog-
rapher
Alan W. Rempel - Postdoctoral
Scientist



Rebecca Woodgate

Ignatius G. Rigor - Mathematician, Graduate Fellow
 D. Andrew Rothrock - Principal Res. Scientist; Assoc. Prof.,
 Oceanography; Adj. Assoc. Prof., Atmospheric Sciences
 Kay A. Runciman - Mathematician
 Axel J. Schweiger - Oceanographer
 Michael Steele - Senior Oceanographer
 Harry L. Stern - Mathematician
 Dean J. Stewart - Field Engineer
 Vadim L. Tsemekhman - Postdoctoral
 Scientist
 Mark R. Wensnahan - Physicist
 John S. Wettlaufer - Senior Physicist;
 Affil. Assoc. Prof., Physics
 Dale P. Winebrenner - Senior Res.
 Scientist; Res. Assoc. Prof., Electrical
 Engineering; Adjunct Res. Assoc.
 Prof., Geophysics
 Rebecca A. Woodgate - Res. Asst. Prof.,
 Oceanography
 Yanling Yu - Oceanographer
 Jinlun Zhang - Oceanographer

Staff

Suzan V. Huney - Administrator
 Beverly A. Pelto - Manager
 Susan J. Wiley - Program Coordinator



Kate Bader maneuvering equipment during field research.

Eric Thorso

Bradley M. Bell - Principal Mathematician
 Tushar Bhargale - Predoctoral Res. Assoc.
 Andrew A. Brayman - Senior Physicist
 Wen-Shiang Chen - Predoctoral Res. Assoc.
 Bryan W. Cunitz - Engineer
 Francesco Curra - Predoctoral Res. Assoc.

Donald L. Davis - Project Assignment
 Barbrina Dunmire - Engineer
 Sewan Fan - Postdoctoral Scientist
 Jingfeng Guan - Predoctoral
 Res. Assoc.
 David J. Halaas - Student Helper
 Paul R. Hilmo - Physicist
 James M. Hosack - Engineer
 Peter J. Kaczowski - Senior Engineer
 Steven G. Kargl - Physicist
 John C. Kucewicz - Predoctoral
 Res. Assoc.
 Cyril Lafon - Visiting Scientist
 Janelle B. Lee - Student Helper
 Roy W. Martin - Principal Engineer;
 Res. Prof., Anesthesiology
 Thomas J. Matula - Senior Physicist;
 Affil. Asst. Prof., Electrical
 Engineering
 Nathan A. Miller - Student Helper
 Pierre D. Mourad - Senior Mathematician

**APPLIED RESEARCH &
 TECHNOLOGY GROUP**

Air-Sea Interaction and Remote Sensing Department

Kathryn A. Kelly - Chair; Principal Oceanographer;
 Affil. Prof., Oceanography
 William E. Asher - Senior Oceanographer
 Robert F. Contreras - Res. Asst.
 Suzanne Dickinson - Oceanographer
 Shenfu Dong - Predoctoral Res. Assoc.
 Ruth A. Fogelberg - Predoctoral Res. Assoc.
 Ralph C. Foster - Physicist
 Kenneth O. Hayes - Engineer
 Andrew T. Jessup - Principal Oceanographer; Affil. Assoc. Prof.,
 Civil Engineering
 William C. Keller - Senior Physicist
 Christopher Lamb - Student Helper
 Ellen E. Lettvin - Oceanographer
 Jonathan M. Lilly - Helper
 Trina Litchendorf - Laboratory Technician
 Jeffrey A. Nystuen - Senior Oceanographer; Affil. Assoc. Prof.,
 Oceanography
 William J. Plant - Principal Res. Scientist; Affil. Prof.,
 Atmospheric Science
 Christopher Siani - Student Helper
 Frédéric Vivier - Res. Assoc.

Center for Industrial and Medical Ultrasound

Lawrence A. Crum - Assoc. Director; Res. Prof., Electrical
 Engineering Center for Bioengineering
 Ajay Anand - Res. Asst.
 Marilee A. Andrew - Engineer
 Michael R. Bailey - Engineer
 George A. Barrett - Predoctoral Res. Assoc.

Terrence W. Myntti - Electronics Technician
 Misty L. Noble - Res. Technologist
 Ryan Ollos - Student Helper
 Gerald A. Pagel - Res. Asst.
 Marla Paun - Engineer
 Sandra L. Poliachik - Predoctoral Res. Assoc.
 Andrew H. Proctor - Senior Field Engineer
 Andrian F. Prokop - Predoctoral Res. Assoc.
 Justin A. Reed - Student Helper
 Laurence C. Tomsic - Student Helper
 Shahram Vaezy - Senior Engineer; Res. Asst. Prof., Bioengineering
 Jonathan C. Yuen - Predoctoral Res. Assoc.

Electronic Systems Department

Gary L. Harkins - Department Head
 Edward O. Belcher - Principal Engineer; Affil. Asst. Prof.,
 Electrical Engineering
 A. John Black - Software Engineer
 John A. Blattenbauer - Engineer
 Clark A. Bodyfelt - Engineer
 Matthew R. Carpenter - Engineer
 William H. Hanot - Senior Engineer
 Benjamin M. Henwood - Senior Engineer
 Brian J. Hopkins - Engineer
 Robert E. Johnson - Principal Engineer
 William A. Jump - Senior Engineer
 Carl J. Larson, Jr. - Field Engineer
 James C. Luby - Principal Engineer; Affil. Asst. Prof.,
 Electrical Engineering
 Larry D. Nielson - Field Engineer
 J. Aaron Nix-Gomez - Engineer
 T. Martin Siderius - Engineer
 Marcelino Soriano - Manager
 Eric W. Streng - Field Engineer

Marvin L. Strenge - Principal Engineer
Robert E. Van Note - Senior Field Engineer



APL's Financial Management Group. (Clockwise from left: Hien Tran, Tony Nice, Tina Stremick, Kannie Cheung, Becky Harrison, and Cheuk Chhann.)

Environmental and Information Systems Department

Robert T. Miyamoto - Department Head
Gregory M. Anderson - Senior Engineer
Catherine M. Bader - Mathematician
Michael L. Boyd - Senior Physicist
Peter M. Brodsky - Engineer
Andrew K. Cook - Student Helper
Christian J. Eggen - Principal Physicist
William J. Felton - Senior Field Engineer
Leah D. Foechterle - Engineer
Warren J. L. Fox - Engineer; Affil. Asst. Prof., Electrical Engineering
Andrew A. Ganse - Engineer
Robert P. Goddard - Senior Physicist
Edward C. Gough, Jr. - Principal Engineer
Megan U. Hazen - Engineer
David W. Jones - Senior Oceanographer
R. Keith Kerr - Senior Engineer
William C. Kooiman - Engineer
Mark Kruger - Physicist
Charlotte Leigh - Senior Physicist
Michael C. Macaulay - Senior Oceanographer
Christopher W. May - Environmental Engineer
Kou-Ying Moravan - Senior Physicist
Donald B. Percival - Senior Mathematician; Affil. Assoc. Prof., Statistics
James W. Pitton - Senior Engineer; Affil. Asst. Prof., Electrical Engineering
Nathan D. Ratliff - Student Helper
Marc S. Stewart - Senior Physicist
Gordon L. Swartzman - Senior Engineer; Res. Prof., Fisheries
Troy T. Tanner - Multimedia Specialist
Patrick G. Tewson - Student Helper
Joseph S. Wigton - Engineer
Andreas G. Winter - Predoctoral Res. Assoc.

Ocean Acoustics Department

Kevin L. Williams - Department Chair; Principal Physicist; Assoc. Prof., Oceanography
Rex K. Andrew - Engineer
Linda J. Buck - Helper
Peter H. Dahl - Principal Engineer; Res. Assoc. Prof., Mechanical Engineering
Brian D. Dushaw - Senior Oceanographer; Affil. Asst. Prof., Oceanography
John Flynn - Predoctoral Res. Assoc.
Eric C. Higgins - Student Helper
Bruce M. Howe - Principal Oceanographer; Res. Assoc. Prof., Oceanography
Christopher Jones - Engineer
James A. Mercer - Principal Physicist; Res. Assoc. Prof., Geophysics
Robert I. Odom - Principal Physicist; Res. Assoc. Prof., Geophysics
Mark E. Peebles - Student Helper
Daniel Rouseff - Senior Engineer
Darin Soukup - Predoctoral Res. Assoc.
Dajun Tang - Senior Oceanographer
Eric I. Thorsos - Principal Physicist; Res. Assoc. Prof., Electrical Engineering
Michael A. Wolfson - Mathematician
Michael W. Yargus - Predoctoral Res. Assoc.
Ernest T. Young - Principal Engineer

Ocean Engineering Department

Russell D. Light - Department Head; Principal Engineer
Paul A. Aguilar - Field Engineer
Joe A. Burch - Engineer
John B. Elliott - Engineer
Lyle F. Gullings - Senior Field Engineer
Frederick W. Karig - Principal Engineer
Michael F. Kenney - Oceanographer
Harold A. Kolve - Principal Engineer
Victor C. Lo - Principal Engineer
Timothy M. McGinnis - Senior Engineer
Vernon W. Miller - Senior Engineer
Michael A. Ohmart - Field Engineer
Francis G. Olson - Senior Field Engineer
T. James Osse - Senior Engineer
Peter L. Sabin - Senior Field Engineer
Colin J. Sandwith - Principal Engineer; Res. Assoc. Prof., Mechanical Engineering
Daniel A. Stearns - Field Engineer
Michael L. Welch - Senior Engineer
Timothy Wen - Senior Engineer

AR&T Group Support

Caitlain K. Anderson - Student Helper (AR&T)
Robert M. Bolstad - Res. Manager (OA/CIMU)
Lori J. Ferro - Administrative Specialist (CIMU)
April J. Greenwell - Fiscal Specialist (OA/CIMU/OE)



Vern Miller soaks up some deckside sun during field operations.

Eric Thorsos

Dorothy F. Lowell - Administrative Specialist (CIMU)
Janet I. Olsonbaker - Coordinator-Res. (EIS)
Colin H. Saari - Coordinator-Res. (OE)
Carole R. Underhill - Program Coordinator (ES)
Angela Van Valkenburg - Administrative Specialist (EIS)
Keith A. Walls - Coordinator-Res. (OA/AIRS)
William D. Woodman - Engineer (ES)
Lan Yu - Office Asst. (EIS)

ADMINISTRATIVE & TECHNICAL SERVICES

Resource Department

Gordon K. Glass - General Manager, Physical, Technical & Central Support Resources

Building Services

Jim Fahey - Manager
Ponciano Austria - Maintenance Custodian
O. Ray Hartman - Maintenance Mechanic
Keith E. Magness - Student Helper
Stuart R. Woolfield - Maintenance Mechanic

Distributed Computing Services

David D. Fetrow - Senior Computer Specialist
Derek A. Eve - Student Helper
Adam L. Morehead - Computer Support Analyst
David Sudarmaji - Student Helper
Nicolas P. Turchin - Student Helper



Jane Doggett and Leslie Harding

Library

Jane M. Doggett - Library Specialist Supervisor
Leslie Harding - Library Specialist
Naeem S. Nulwala - Student Helper

Machine Shop

Robert L. Prong - Manager
John P. Gutensohn - Instrument Maker
Timothy W. Jansen - Instrument Maker
Douglas S. Jordan - Instrument Maker
Milford T. Knutson - Instrument Maker
Patrick T. McCrory - Instrument Maker
Leo P. McGinnis - Instrument Maker Lead
Richard W. Syverson - Maintenance Mechanic

Marine Department

Eric S. Boget - Marine Supervisor;
Field Engineer

Publications

Brian S. Rasmussen - Manager
Ronald L. Carnell - Office Asst.
Kim E. Reading - Graphic Illustrator/
Designer Lead

Purchasing & Property Control

Peggy K. Buschmann - Manager
John J. Albin - Fiscal Technician
Samantha Auflick - Fiscal Technician
Thomas F. Guthrie, Jr. - Truck Driver
Thomas A. Kerrigan - Fiscal Specialist
Johnny W. Siu - Student Helper
Angela K. Ward - Fiscal Technician
Susan L. Womack - Fiscal Specialist

Security, Safety & Central Services

Kelley P. Knickerbocker - Manager
Charlotte A. Boynton - Program Coordinator
Chris L. Craig - Maintenance Mechanic
Mariann DomBek - Office Asst.

Shipping & Receiving

Michael G. Miller - Program Support Supervisor
Loren Alexander - Warehouse Worker

Business and Administration

William T. Bakamis - Asst. Director, Management and Finance Administration
Peggy L. Hartman - Asst. to the Asst. Director

Financial Information Systems

Larry C. West - Senior Computer Specialist

Financial Management

Anthony J. Nice - Manager
Kannie Cheung - Fiscal Technician
Cheuk Chhann - Program Asst.
Anne L. Clark - Administrator
Becky E. Harrison - Fiscal Specialist
Tina M. Stremick - Office Asst.
Hien D. Tran - Accountant

Grant and Contract Administration

Moira G. McCrory - Administrator

Human Resources/Personnel

Robert M. Bratager - Manager
Linda M. Marsh - Coordinator, Program Operations

Assigned to Washington D.C.

Kenneth W. Lackie - Manager
Ronald P. Radlinski - Principal Physicist
Lilia L. Ramirez - Manager



Rich Syverson ready for his commute.

PERSONNEL

—personnel as of June 2001

Publications and Presentations

Technical Reports and Memoranda, issued in 1999

- Jones, C.D., "High-Frequency Acoustic Volume Scattering from Biologically Active Marine Sediments," APL-UW TR 9903, October 1999 (Ph.D. thesis).
- Lee, C.M., C.E. Dorman, R.W. Gould, and B.H. Jones, "Preliminary Cruise Report: Hahnaro 5 Dynamics, Biology, Optics and Meteorology of the Subpolar Front in the Japan/East Sea," APL-UW TM 3-99, July 1999.
- Luby, J., and M.L. Boyd, "Final Report on Spatial Correlation Processing (U)," APL-UW TM 2-99, July 1999 (Confidential).
- Rigor, I., and M. Ortmeyer, "International Arctic Buoy Programme 1997 Data Report," APL-UW TM 5-99, November 1999.
- Zappa, C.J., "Microscale Wave Breaking and Its Effect on Air-Water Gas Transfer Using Infrared Imagery," APL-UW TR 9904, December 1999 (Ph.D. thesis).

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- Dahl, P.H., H.J. Geiger, D. Hart, J.J. Dawson, S.V. Johnston, and D.J. Degan, "The Environmental Acoustics of Two Alaskan Rivers and Its Relation to Salmon Counting Sonars," APL-UW TR 2001, August 2000.
- Goddard, R.P., "SST Bistatic Reverberation Modeling: North Sea Experiment, April–May 1998," APL-UW TM 5-00, May 2000.
- Jackson, D.R., "High-Frequency Bistatic Scattering Models for Elastic Seafloors," APL-UW TM 2-00, February 2000.
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- Rigor, I., and M. Ortmeyer, "International Arctic Buoy Programme Data Report 1 January 1999–31 December 1999," APL-UW TM 6-00, June 2000.
- Sanford, T.B., M.D. Allison, and J.H. Dunlap, "R/V *Seward Johnson* Cruise 9908: Cruise Report and Preliminary Results," APL-UW TM 7-00, August 2000.
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- Aagaard, K., D. Darby, K. Falkner, G. Flato, J. Grebmeier, C. Measures, and J. Walsh, *Marine Science in the Arctic: A Strategy* (Arctic Research Consortium of the United States–ARCUS, Fairbanks, AK, 1999).
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