



What is the Ocean Like off Oregon?

Exploring, Monitoring, and Understanding
the Northern California Current

By John A. Barth, Ph.D. and Robert L. Smith, Ph.D.



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Introduction

The dynamic, ever-changing ocean off Oregon is home to a rich, productive ecosystem, driven by strong seasonal winds forced, in turn, by shifts in atmospheric pressure patterns and storms characteristic of the northern end of the California Current. Oceanography took root at Oregon State College (now University) when Wayne Burt proposed to the administration at Oregon State College that a Department of Oceanography be established and, to the Office of Naval Research, that it be funded. (See the companion article by John Byrne, pages 60-70)¹

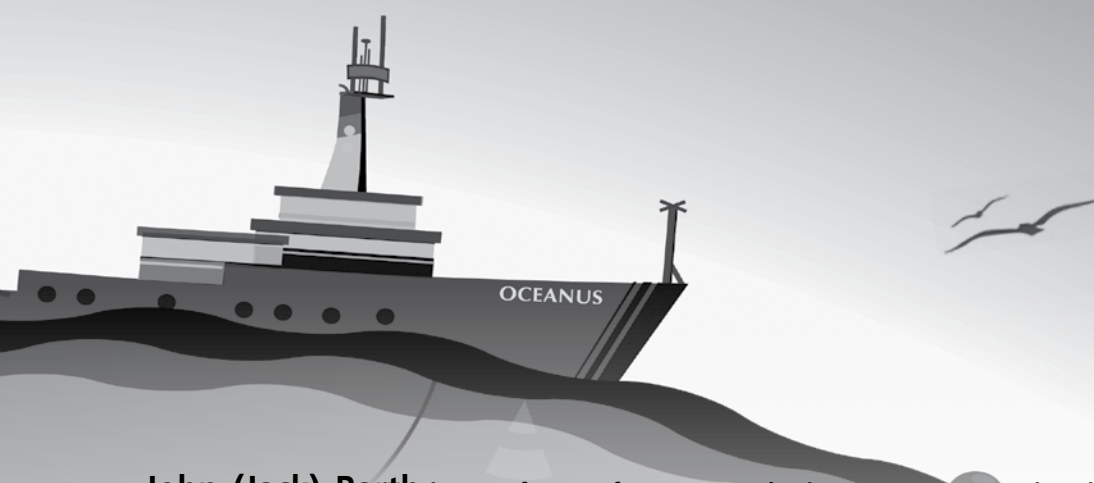
In 1958, Wayne Burt wrote:

In general, coastal oceanography out to the 1000 fathom depth has been neglected. This is particularly true of our west coast ... where the Department of Oceanography at the University of Washington is 360 nautical miles north of the central Oregon coast ... (and) Scripps Institution of Oceanography is almost 1000 nautical miles distant. For these reasons, Oregon State College is in a unique position to carry out a research program of vital importance to the nation.

In the previous article, John Byrne recounts the early history following the establishment of a Department of Oceanography (1959) at Oregon State

College and the generous funding by the Office of Naval Research, which included the construction of the 80-foot RV *Acona* in 1961. Byrne writes: "... much of the pioneering research by Oregon State researchers was descriptive in nature, driven by the question: What is the ocean like off Oregon?"

As in many research institutions, the study of all fields within Oceanography grew in the 1960s and blossomed in the following decades. In this article the contributions of Oregon State University to understanding fundamental ocean processes through long-term oceanographic monitoring are described. Pressured by the need to understand strong variability in coastal ocean ecosystems and aided by technology development, the monitoring evolved into today's ocean observing systems with a permanent presence. Long-term measurements at particular sites or from repeated measurements along sections have been a feature of many oceanographic institutions. In July 2006, a symposium "Time Series of the Northeast Pacific"² explored the scientific value of long oceanographic time series. Among the longest oceanographic time-series along the northeast Pacific coast are the CalCOFI (California Cooperative Oceanic Fisheries Investigations) program from 1949,^{3,4} the Canadian Line P program from 1956,^{5,6} and Oregon State's Newport Hydrographic Line from 1961.⁷



John (Jack) Barth is a Professor of Oceanography in Oregon State University's College of Earth, Ocean, and Atmospheric Sciences (CEOAS). He received a Ph.D. in Oceanography in 1987 from the MIT-Woods Hole Oceanographic Institution Joint Program in Oceanography. Barth has led research, technology development and ocean observing system projects off Oregon and the Pacific Northwest, including serving as Chief Scientist for many months at sea. He presently serves on the Oregon Ocean Policy Advisory Council's Scientific and Technical Advisory Committee and was a member of the NSF's Observatory Steering Committee that launched the Ocean Observatories Initiative. In addition to carrying out an active research program and mentoring graduate students, he serves as the CEOAS Associate Dean for Research.

Robert Smith is a Professor Emeritus at Oregon State University. He came to Oregon State in 1960 to study Oceanography and was the first Ph.D. student of June Pattullo, receiving his degree in 1964 for a study of coastal upwelling. After a post-doctoral fellowship at the National Institute of Oceanography in England and working for the Office of Naval Research, he returned to Oregon State to study eastern boundary currents and coastal upwelling until 2009. For his interdisciplinary work in coastal upwelling studies, he was elected a Fellow of the American Association for the Advancement of Science.

All continue in some form with various interruptions, and all have experienced and evolved with the benefits of modern technology.

The Newport Hydrographic Line

In May 1961, shortly after the launch of RV *Acona*, Professor June Pattullo, the first woman in the United States to receive a Ph.D. in Physical Oceanography, initiated a program of systematic sampling of ocean properties (especially temperature and salinity) along latitudinal sections to 165 nautical miles off the Oregon coast and to a depth of 1000 meters. The sampling grid was reminiscent of the more ambitious CalCOFI survey grid off California, begun in 1950 by Scripps Institution of Oceanography (see fn 3). Wayne Burt and June Pattullo had Ph.D. degrees in Physical Oceanography from Scripps in 1952 and 1957, respectively. Dr. Pattullo's legacy is honored through the naming of the national conference of MPOWIR (Mentoring Physical Oceanography Women to Increase Retention), a community-run mentoring program that provides mentoring to physical oceanographers from late graduate school through their early careers.

The Oregon sampling focused on the Physical Oceanography: funding for the hydrographic sections off Oregon came from the TENOC project of ONR,⁸ while CalCOFI surveys were motivated by the collapse of the California sardine fishery. The principal sampling was initially done with mechanical devices: Nansen bottles with reversing thermometers

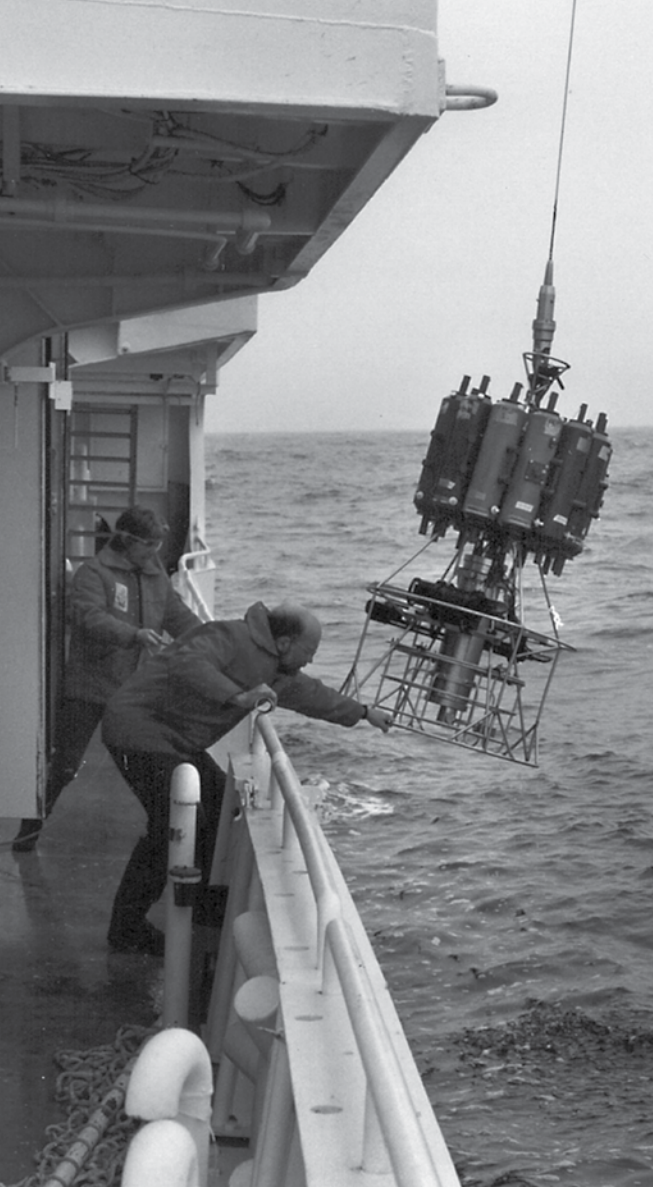
were suspended at specified depths from a wire and "tripped" by a messenger (weight) sliding down the wire. Robert Knox's article (pages 6-17), "Mare Incognitum,"⁹ provides a good description of these basic tools. As Henry Stommel wrote in a 1965 survey of the Somali current during the SW monsoon:

Clearly some important phenomena slip through the observational net, and nothing makes one more convinced of the inadequacy of present day observing techniques than the tedious experience of garnering a slender harvest of thermometer readings and water samples from a rather little ship at sea. A few good and determined engineers could revolutionize this backward field.¹⁰

Those doing hydrographic sections off Oregon during a gale would share the same sentiments.

By 1970, the hydrographic cast no longer used mercury thermometers and chemical titrations of water samples to measure the temperature and salinity measurements. A few good engineers had convinced oceanographers that thermistors and conductivity cells could do the job. A tube full of electronics for measuring conductivity, temperature and depth (CTD) could sample nearly continuously (15 to 20 times a second) as the instrument (CTD) was lowered on conducting cable to a 1000 m, instead of stopping to sample at 15 to 20 "standard" depths.

A "rosette" of water sampling bottles were attached



Bob Smith and Jane Huyer, aboard RV *Wecoma*, catch the CTD with a 'rosette' of sampling bottles being brought up from the deep.

Courtesy of Oregon State University

Right: The Research Vessel *Wecoma* crossing the bar off Yaquina Bay, Oregon, inbound to its home port of Newport.

Courtesy of Demian Bailey, Oregon State University

to the conducting cable and samples collected at depths chosen, while viewing profiles of temperature and salinity data versus depth (pressure). By the 1980s, an oxygen sensor, a transmissometer for light, and a chlorophyll (fluorescence) sensor were often attached to the CTD.

Blanket funding by ONR for the surveys off Oregon ended by 1972, and interest in “monitoring” time-series was eclipsed by process studies. However, the existence of a decade of observations from the Newport Hydrographic Line along latitude 44.6°N, running offshore from the OSU’s vessels home port on Yaquina Bay, encouraged investigators to include observations along this line as part of their process studies. From the mid-1970s, the 185-foot RV *Wecoma* (the “sea” in the Clatsop language of Pacific Northwest Native Americans) has carried many a research team across the bar at the entrance to Yaquina Bay for scientific expeditions in the North Pacific.

Thus a time-series, albeit with gaps, has continued for the Newport Line to present. Regular seasonal sampling resumed from 1997 to 2003, during the GLOBEC (Global Ocean Ecosystem Dynamics) study of inter-decadal fluctuations of salmon populations. The previous physical and chemical techniques used during earlier monitoring periods “had achieved a fair degree of standardization, simplicity, familiarity, and acceptance.”¹⁰ This is especially true for the basic physical oceanography measurements of salinity and temperature, which along with depth, i.e., pressure, determine density and sound velocity. These hydrographic measurement techniques had been internationally standardized early in the twentieth century.¹¹ Thus many earlier measurements remain valid for comparison with modern measurements (see fn 4, 6 and 7).



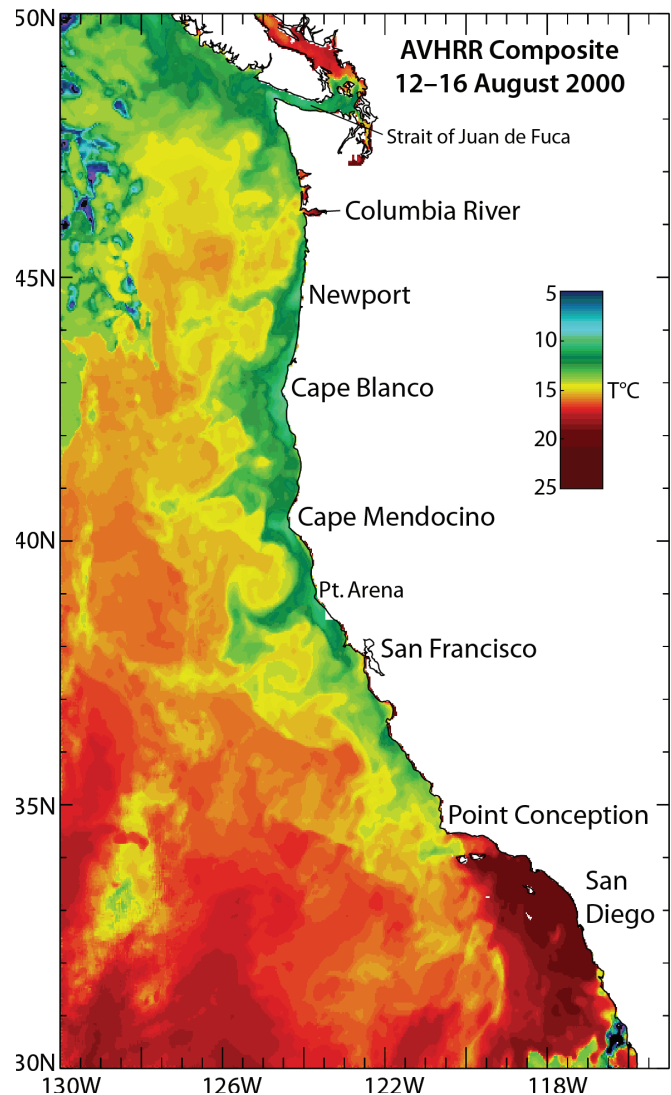
Coastal Upwelling Unveiled

Through ship observations and, spectacularly, from satellite images of sea surface temperature (SST) and ocean color, from which a measure of chlorophyll associated with phytoplankton can be made (that became available in the 1970s), the importance of wind-forced ocean circulation on marine productivity became apparent.

As typical summertime northerly winds blow surface waters to the south off the U.S. West Coast, the Coriolis force acts to spin upper-ocean currents offshore (to the right, facing downwind in the Northern Hemisphere). This water is replaced near the coast by cold, upwelled deep waters, leading to a band of cold water evident in satellite SST images (right). The upwelled waters are also rich in nutrients and when these nutrients reach the near-surface zone lighted by the sun, phytoplankton growth is stimulated. These tiny plants form the base of a productive coastal ocean food chain, as they feed zooplankton that are consumed by fish, then all the way up the food chain to birds, marine mammals and humans.

Oceanographers at Oregon State University, in collaboration with their West- and East Coast colleagues, played key roles in interdisciplinary studies of coastal upwelling ecosystems. The coastal ocean off Oregon is an ideal place to study coastal upwelling because of the clear seasonal signal of increased plankton production near the coast in response to spring and summer “upwelling-favorable” (northerly) winds. The proximity of the coastal upwelling zone to the deep-water port of Newport made logistics simpler and the relatively uniform alongshore seafloor topography north of Newport made for an ideal laboratory. The early sampling along the Newport Hydrographic Line in the 1960s led to the interdisciplinary Coastal Upwelling Experiment (CUE) and Coastal Upwelling Ecosystem Analysis (CUEA) programs of the 1970s.¹² Indeed, results from those experiments form the basis for our textbook understanding of coastal upwelling ecosystems and provided the basis for further investigation of the links between physical forcing and marine fisheries in the California Current, for example the GLOBEC program of the late 1990s and 2000s mentioned above.

The obvious sharp horizontal gradients (“fronts”) and alongshore variations in the SST off the West Coast spawned new Physical Oceanography questions. At the same time, earlier studies had shown the inextricable link between winds, ocean circulation and ecosystem response. It was obvious that new tools were needed to make progress. Early oceanographic measurements were limited in space and time by a number of factors.



Sea surface temperature measured by satellite during 12-16 August 2000. The cold temperatures near the coast north of Point Conception are caused by coastal upwelling, that is, the driving of the ocean surface water offshore by summertime northerly winds, in combination with the Coriolis force which deflects water parcels to the right in the Northern Hemisphere, to be replaced from below by cold, nutrient-rich subsurface waters.

Courtesy of Ted Strub and David Reinert, Oregon State University

Oceanographic research vessels are expensive to operate, can remain on site for only a few weeks to a month and, while underway, are generally slow, cruising at 8-12 knots. As described above, the need to collect water samples for the measurement of salinity also constrained how many stations and depth strata could be sampled. These factors combined to yield data sets on scales of 10-20 m in the vertical and 10-100 km



1. Satellites
2. Radiowave System
3. Argus Imaging System
4. Moored Buoys
5. Hydrophones
6. Water Profiler
7. Acoustics
8. Gliders
9. Seismometers
10. Surface Drifters



Illustrated are a full complement of ocean observing elements deployed across the coastal ocean to study coastal upwelling, marine ecosystems and seafloor motions, and, importantly, to understand the relationships among them.

Courtesy of 208 Design Studio, modified by David Reinert, Oregon State University

horizontally. The advent of satellite images of the sea surface revealed a wealth of variability on scales down to kilometers. Electronic conductivity and chlorophyll fluorescence measurements revealed small-scale layers and patches of physical and biological layers as thin as tens of centimeters in the vertical. Thus the range of scales of interest in oceanography spans nearly nine orders of magnitude, that is, a billion-fold difference between the scales of turbulence and thin layers (centimeters) and global circulation (10,000 kilometers). Recent revelations have shown the importance of the small-scale features profoundly influencing large-scale ecosystems, in the case of biological thin layers, and global circulation and energy transfer, in the case of turbulence. This huge range of scales necessitated the evolution of ocean sensors and platforms from those of the 1960s-1970s, to those of recent times capable of a hundred-fold increase in the spatial and temporal coverage.

Ocean Observing in the New Millennium

A modern ocean observing system employs a mixture of remote sensing techniques (satellite, land-based), moored buoys and seafloor platforms, as well as ships and autonomous underwater vehicles.

Much recent progress has been made on all of these and, collectively, they give us the ability to ask new questions and to build toward better understanding of and predictive capabilities for a range of ocean processes. New ocean observing tools have become reality because of a convergence of many technologies, not necessarily driven by oceanography. As examples, these include the ready availability of powerful Pentium-level computers in small sizes able to be

contained in pressure cases for withstanding high pressures and corrosive seawater, copious electronic storage for data courtesy of flash memory cards from the consumer electronics industry (music, photo and video storage), Global Positioning Systems (GPS) with accuracy unregulated by the military, and reliable global coverage for data communications via satellite cell phones. But, as in any field, challenges remain, especially when designing systems to sample the often unforgiving North Pacific.

Remote sensing of ocean properties has the advantages of obtaining valuable information without having to set sail on bumpy seas and can often be relied upon to provide continuous time and space coverage. Over the past 30 years, oceanographers at OSU have worked to improve the design of oceanographic satellite sensors, providing ever-higher definition of features in the deep and coastal

ocean. To sea surface temperature and ocean color (a proxy for phytoplankton) was added the ability to make global “snapshots” of the winds that drive the ocean, revolutionizing our understanding of air-sea interactions and the ability to provide wind fields to numerical weather and climate models. Other satellites monitor oil spills, map the edges of sea ice, and follow the movement of ice bergs, derelict oil platforms, drifting buoys and floats, and ships. Satellites also pinpoint precise locations via GPS and are used in both emergencies and routine navigation. GPS tags are now used by OSU investigators to map the migrations of marine mammals, birds and sea turtles. Despite their wide-angle vision, however, some satellites cannot see through clouds and none can see beneath the surface layer into the deep ocean due to the basic opaqueness of seawater to electromagnetic signals. This makes it imperative to combine their information with deeper observations obtained from the buoys, autonomous underwater gliders, and acoustic systems described below.

Over the last decade or so, a new technique has emerged for mapping ocean surface currents from

land. Land-based high-frequency (HF) radio waves can detect the speed and direction of ocean currents up to 200 kilometers from shore.¹⁴ Radio waves sent from a land station are scattered from ocean waves by Bragg scattering,¹⁵ and received again on land. The current is determined from the radio-wave Doppler shift induced by the motion of the ocean waves as they are swept along by ocean currents. By measuring the return at different times, multiple measurements may be

obtained along the HF radio beam.

A single HF station gives the velocity of the ocean surface either directly toward or away from the station. By using two stations spaced along the coast, the full vector water velocity, that is, both north-south and east-west components, can be obtained.

Such maps of ocean surface velocity can be obtained hourly with horizontal resolutions of 1-10 km, and are being used to inform shipping, search and rescue, and for potential oil spill trajectories,

not to mention the obvious application for aiding sailors! Another land-based technique based on using off-the-shelf video cameras has provided great insight into nearshore coastal dynamics.¹⁶ From bluff tops and buildings – an ever-increasing number at hotels and state highway departments – the Argus video observation system, founded at Oregon State University, creates time-lapse images of surf and sand movements that help scientists analyze the dynamic processes that build and erode shorelines.

To obtain higher spatial resolution from ship-based measurements, it was recognized early on that stopping the ship frequently to make traditional hydrographic casts (as on page 78) would result in an “aliased” view of ocean properties. That is, the ocean conditions change too fast and would be “smeared out” in a slow, fine-resolution survey. The goal is to sample down into the water column while underway at the oceanographic vessel’s full speed (10-12 knots). For measuring temperature, expendable bathythermographs (XBTs) replaced the tethered bathythermographs and were extensively used starting in the late 1960s. (See fn 9)



Marc Willis, Daryl Swenson and Jack Barth recover a towed, undulating vehicle called SeaSoar, during a typical windy day in the Northern California Current.

Courtesy of Steve Pierce, Oregon State University



However, measuring salinity at depth is more challenging. One method used extensively by Oregon State University oceanographers, during the 1990s and 2000s, was to use a towed underwater vehicle equipped with controllable wing surfaces allowing “flight” from near the sea surface down to depths of 300-400m. The vehicle, one version of which is called SeaSoar, is equipped with a CTD and a wide range of bio-optical sensors for sampling chlorophyll fluorescence (phytoplankton), light transmission (suspended particles), dissolved organic matter (indicator of river input), an zooplankton size distributions. New fast-response temperature and conductivity probes have been mounted on the front of SeaSoar to detect turbulent mixing. By towing the vehicle through the coastal ocean off Oregon, great progress was made by OSU oceanographers in understanding the interactions between strong alongshore currents and coastal capes and submarine banks that lead to much of the horizontal variability evident in satellite SST images (see page 79).

The use of physical and biological instruments on the same platform shed light on the relationships between physical features like upwelling fronts and the aggregations of plankton. Through concurrent net sampling for zooplankton and fish on another research vessel, and observations of marine mammals and birds on the vessel towing SeaSoar, the relationships of the biological communities to the underlying physical oceanography was revealed.^{17, 18}

Because electromagnetic radiation does not propagate in the ocean except over short ranges, modern oceanographers make use of sound (acoustics). Oregon State University researchers use sonar signals to measure the currents from near the surface to substantial depth and to show the ocean ecosystem at work. The frequencies used by oceanographers range from kilohertz for finding the sea bottom, to

tens to several hundred kilohertz for finding fish and zooplankton and measuring ocean currents, to several megahertz for studies of turbulence and currents very near the seafloor. The lower the frequency, the greater the range, and, for reference, the young human ear

can pick up sounds in the 20 hertz to 20 kilohertz range, while dolphins sometimes use sound in the hundred kilohertz band to communicate.

The most common use of acoustics in oceanography today, besides finding the depth of the sea beneath a ship, is in measuring the subsurface currents.

Acoustic Doppler current profilers (ADCPs) are mounted in the hull of almost all research vessels and transmit acoustic energy from a transducer. The sound energy is echoed back by scatterers in the water, typically zooplankton, and when it arrives back at the transducer face, its frequency may be shifted by the velocity of the water relative to the ship (the Doppler effect). As in the case for land-based radio waves described above, listening for the return at different times allows

multiple measurements of velocity along the acoustic beam. By combining multiple acoustic beams, typically 3-4, and using GPS to obtain the ship’s velocity, a profile of “absolute” velocity down through the water column may be determined. ADCPs are also frequently deployed from moored buoys and seafloor platforms.

Using multiple frequencies of acoustic signals can reveal fish and squid feeding, dolphins cooperating,¹⁹ and plankton aggregating. Multibeam sonar emits a fan-shaped beam that can be used to map the seafloor in great detail. When applied in the shallow coastal ocean, especially near the coast, the resulting seafloor maps and even seafloor habitat classification are contributing valuable information to



An acoustic Doppler current profiler, for measuring subsurface currents, goes over the stern as part of an oceanographic mooring. Subsurface floatation is provided by the yellow “hard hats” containing glass balls.

Photo by Jack Barth, Oregon State University

the public dialog and policy decisions regarding multiple uses of the sea (navigation, fishing, energy extraction, marine reserves, etc.). Sound can also be used to monitor underwater volcanic eruptions and earthquakes, to listen for whales, and networks of hydrophones can track animals, both fish and mammals, that have been tagged with acoustic pingers.

In the late 1990s and 2000s, autonomous underwater vehicle gliders capable of extended missions collecting data about the physical, chemical and biological properties of the ocean throughout the water column became commercially available.

These vehicles travel forward not by using a power-hungry propeller, but rather by gliding on wings as the vehicle changes buoyancy relative to the surrounding water by changing its volume. By using buoyancy changes as propulsion, energy costs are low and gliders can operate from several weeks to nearly a year depending on where and how they are operated, and how many sensors they carry. The glider uses a GPS antenna, a compass and a satellite cell phone to navigate and receive commands from, and return data to shore. These gliders and the robotic exploration of the oceans was imagined by Henry Stommel in his science fiction article in 1989²⁰ and, as described above, became possible through a convergence of technologies. The gliders are equipped with a CTD and an echosounder in the nose to detect the seafloor so that the vehicle may gracefully inflect and continue profiling without hitting the seafloor. Additional instruments carried by the gliders include chlorophyll and colored dissolved organic matter fluorometers, dissolved oxygen sensors, a sensor to detect backscattered light from suspended particles, hydrophones, and acoustic Doppler current profilers. The present versions, now in use off Oregon, are about two meters long, can stay at sea for a month, and dive to 200 or 1000 meters depending on the model. Because they are programmed to aim toward a GPS position, researchers can estimate depth-averaged ocean currents by calculating the distance the glider has been swept off course. Gliders can be launched and recovered from just about any vessel, from small inflatables to global-class research vessels.

An autonomous underwater glider is at the surface before diving to measure subsurface ocean properties. The tail fin contains a GPS antenna for location and an Iridium satellite cell phone for sending data to and receiving commands from shore.

*Courtesy of Susan Holmes,
Oregon State University*



Gliders began sampling along the Newport line in spring 2006, continuing the Oregon State University legacy of monitoring this key hydrographic line. To date, gliders off Oregon have traveled in excess of 45,000 km, equivalent to more than once around the globe, and collected some 160,000 vertical profiles of ocean properties. For comparison, the number of ocean profiles off central Oregon residing in the National Oceanographic Data Center for 1950 to 2005 was about four thousand. A recent study of dissolved oxygen concentrations measured off Newport from 1998 to the present (including by glider), compared with those measured in the 1960s shows a noticeable decline in oxygen in subsurface waters upwelled onto the Oregon shelf.²¹ These findings are consistent with other worldwide measurements of declining oxygen concentrations in subsurface waters, likely caused by the warming of the ocean surface layer and changing basin-scale circulation, both resulting from global warming.

The Changing Coastal Ocean

Late in the twentieth century and into the early twenty-first century, fear arose that the oceans are “warming up, turning sour, losing breath” under global change, to use the phrasing of Nicolas Gruber,²² to refer to the possibility of increasing temperature, acidification and decreased oxygen possible in the ocean. The appearance of low-oxygen bottom water off the Oregon coast was mentioned above and its potential impacts on marine ecosystems are of concern.²³ Oregon State University oceanographers have demonstrated the link between drawing recently upwelled, low-pH waters into coastal oyster hatcheries and oyster larval mortality events.²⁴ These societally important changes in the ocean demonstrate the need for sustained time-series of measurements and renewed the interest in “monitoring” the ocean. Fortunately, “good and determined engineers” working with oceanographers have indeed revolutionized the techniques – and observing the ocean on a regular systematic basis is no longer “mindless monitoring” (as it had been referred to by colleagues and program managers focused on process studies). Seasonal ship-borne sampling along a hydrographic section may be largely replaced by a more continuous presence off the coast.

The idea of a “permanent presence” is to extend typical two to five-week campaign-oriented ship surveys to year-round (“24/7/365”) measurements. The goal is to capture episodic events that are key to many oceanographic processes. Examples of these include: high winds and waves from storms and their effect on air-sea transfer of momentum and important gases like CO₂; massive storm-induced river floods, mixing and resuspension events responsible for moving sediment and key chemical elements like iron into, across, and along the coastal ocean; intense phytoplankton blooms that, with increasing frequency, can become harmful algal blooms (HABs); eddies or underwater storms that move material and animals throughout the ocean, and are strong enough to influence man-made structures like oil platforms and drilling rigs; and seafloor volcanic eruptions and injection of nutrients, microbes and gases (e.g., methane) from the seafloor into the water column.

Let us now dive into the twenty-first century: An Ocean Observatories Initiative (OOI, fn. 25) has begun with funding from the National Science Foundation (NSF) in the recognition that long-term high-resolution observations of critical environmental parameters require new technologies. Part of the NSF response is to fund long-term (25-30 years) “laboratories” on the sea bottom, in the water column and at the ocean surface. A schematic of such an array of instrumentation that extends our present version of monitoring the ocean is shown on color pages 72 & 73. Satellite-borne and land-based sensors, sonar, time-lapse video, moored buoys with instruments from bottom to surface of the ocean, and autonomous gliders will provide a more continuous presence to supplement ship-borne sampling. Ships will remain vital to Oceanography. In addition to being used to install and maintain the ocean observing systems, ships will be used for making measurements directly comparable with data from the twentieth century, for deploying instruments not compatible with mooring (e.g., seawater samples, nets), carrying out detailed chemical and biological studies (e.g., investigation of microbial dynamics), conducting purposeful experiments like releasing dye to track flow features, and for exploratory surveys.

In the Pacific Northwest, the OOI will build and maintain the Endurance Array,²⁶ a set of moorings and seafloor laboratories across the continental margin off Newport, Oregon, and another set off Grays Harbor, Washington. Several of the moorings and platforms off Newport will be attached to a seafloor



cable capable of supplying power and internet-quality communications via optical fibers. This will enable interactive use of the OOI instruments, for example changing the sampling frequency, and allow researchers to view data in near real-time. In the spirit of continued innovation, the OOI is taking on new ocean platforms and mooring designs. One such mooring includes a stretchable hose with integrated copper wires and optical fibers for connecting seafloor instruments to a surface buoy, while allowing the mooring line to stretch to nearly twice its length as waves pass by. This mooring is being designed and tested for installation in 25 m of water in the challenging Oregon coastal waters where winter waves often reach 25 feet or more.

An inner-shelf mooring goes over the side off Yaquina Head near Newport, Oregon. The mooring is designed with a stretch hose between the bottom-anchored instrument package and the surface buoy floating astern of the RV *Wecoma*, so that the mooring can stretch and survive the large waves present in 25-m water depths off Oregon in the winter.

*Courtesy of John Lund,
Woods Hole Oceanographic Institution*



In addition to the fixed moorings, a set of autonomous underwater gliders will patrol Pacific Northwest waters, continuously measuring the physical, biological and chemical properties from near the coast to out over 300 km offshore. Importantly, the data from the OOI will be readily and freely available. Oregon State University, along with its partners Woods Hole Oceanographic Institution, University of Washington, Scripps Institution of Oceanography, University of California at San Diego, Rutgers University and the Consortium for Ocean Leadership will operate the Endurance Array for NSF.

Challenges for the Future

While much has been learned about Pacific Northwest waters since the founding of the Department of Oceanography at Oregon State College, and the immediate future looks promising as ocean observatories come on line, there remain substantial challenges and opportunities. Ever more sophisticated, low-energy, robust oceanographic sensors are being developed. Examples include the optical detection of nutrients and the use of a field-effect transistor to measure pH. Advances in microbial and genomic sensors are just now seeing trial in oceanographic settings, holding great promise for identifying the presence of both good and harmful organisms in seawater. We need better ways to combat bio-fouling and there are a number of new high-tech coatings and potential nanotechnology solutions. The robotic exploration of the seas will be aided by better battery power for autonomous underwater vehicles (AUVs) and for moorings and sensors. This will likely result from increased development of battery-powered vehicles on land. There are new ways to locally generate power for AUVs and stand-alone moorings and sensors. These include exploiting the chemical potential difference across the seafloor to generate electricity in a seafloor “battery”²⁷ and the use of moored or bottom-mounted wave energy devices to extract energy from the local wave field.²⁸ The recent successful missions of Liquid Robotics’ Wave Glider²⁹ that propels itself by extracting energy from waves, albeit limited to travel on the sea surface, certainly demonstrate the potential of this innovative platform. As we place more sensors and platforms in the ocean, we’ll need better ways to transmit information to shore. Advances are needed in underwater acoustic networks, in using AUVs and vessels of opportunity (e.g., fishing vessels) as data haulers, and in more robust through-air telecommunication networks.

Reflecting the interconnection of the multiple disciplines that contribute to our understanding of

the ocean and a resurgence in undergraduate student interest in majoring in a field that will help them to understand and guide their future choices as caretakers of our changing planet, Oregon State University’s College of Oceanic and Atmospheric Sciences (COAS), the direct descendent of Wayne Burt’s Department of Oceanography, merged with OSU’s Department of Geosciences in 2011. The new entity, the College of Earth, Ocean, and Atmospheric Sciences (CEOAS) is sailing full-steam ahead with continued interdisciplinary oceanographic research and graduate education, but now with 600-plus students in an undergraduate program with majors in Earth Sciences and Environmental Sciences. Most recently, the venerable RV *Wecoma* was retired in 2012, after thirty-six years of hard work sailing the North Pacific. OSU now operates the RV *Oceanus*, which on 23 March 2012 joined the fleet started by Wayne Burt back in 1961.

Acknowledgements

We thank all our colleagues at Oregon State University and beyond who are actively engaged in developing technologies and applying them to the observation of the seas. A particular thanks to the glider inventors and to our colleagues at the Woods Hole Oceanographic Institution for their innovative mooring designs. We are indebted to the captains, crews and marine technicians onboard the research vessels we’ve used over the years for their skill and dedication in making our work possible. Jane Huyer contributed at every step of the way and helped us assemble the photos used in this article. Thanks also to David Reinert and Ted Strub for their help creating the graphics.

Notes

- 1 John V. Byrne, “Oceanography Pioneers: The Oregon State Story,” *Mains’l Haul*, 48:3&4 (2012), 60-70.
- 2 M. Angela Pena, Steven J. Bograd, “Time Series of the Northeast Pacific,” *Progress in Oceanography*, 75 (2007), 115-119.
- 3 S. J. Bograd, D. A. Checkley Jr., and W. W. Wooster, “CalCOFI: A Half Century of Physical, Chemical, and Biological Research in the California Current System,” *Deep-Sea Research*, Part II, 50 (2003), 2349-235.
- 4 S. J. Bograd and R. J. Lynn, “Long-Term Variability in the Southern California Current System,” *Deep-Sea Research*, Part II, 50 (2003), 2355-2370.
- 5 Howard Freeland, “A Short History of Ocean Station Papa and Line P,” *Progress in Oceanography*, 75 (2007), 120-125.

- 6 F. A. Whitney, H. J. Freeland, M. Robert, "Persistently Declining Oxygen Levels in the Interior Waters of the Eastern Subarctic Pacific," *Progress in Oceanography*, 75 (2007), 179-199.
- 7 Adriana Huyer, P. A. Wheeler, P. T. Strub, R. L. Smith, R. Letelier, P. M. Kosro, "The Newport line off Oregon – Studies in the North East Pacific." *Progress in Oceanography*, II, 75 (2007), 126-160.
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