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MAINSAIL HAUL–An order in tacking ship bidding, "Swing the main yards."

Maritime Museum of San Diego

MAINS'L HAUL

Vol. 48: 3 & 4 Summer/Fall 2012

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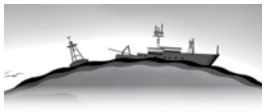
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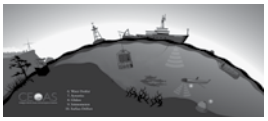
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Dear Friends:

I am pleased to join the Maritime Museum of San Diego, The Maritime Alliance, and the contributors to this Journal in bringing attention to the importance of the maritime industry.

Representing California's 53rd Congressional District, my district includes major naval installations, world class research institutions, and scores of private businesses in the maritime sector. With such a deep maritime presence, tradition, and commitment to innovation, San Diego is at the center of the global debate about how to best promote and expand the maritime industry.

If the United States is to continue to innovate in this field, we must invest in maritime infrastructure, support centers of research and development, and provide incentives for marine-based industries to grow. We must also educate the next generation of maritime innovators in order to compete in the global economy and provide solutions to some of the world's most challenging problems.

This edition of *Mains'l Haul* will review many of these issues and provide policy makers, researchers, and industry leaders with a greater understanding of where the industry is today and how we can best move it forward in the future.

With warmest regards,

Susan A. Davis

SUSAN A. DAVIS
Member of Congress

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National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
Office of National Marine Sanctuaries
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Silver Spring, Maryland 20910

Dear Readers:

Congratulations to the Maritime Museum of San Diego, the Maritime Alliance and the contributors to this special issue of *Mains'l Haul*. There are many important messages you will find in the pages that follow. They focus on the importance of ongoing exploration of the sea, and the role of science, engineering and technology in the quest to continue to better understand the oceanic world. The saga of exploration of the Pacific in particular has been a part of our history for thousands of years, as early navigators followed a raw coastline emerging from the last great ice age, to the endeavors of European explorers who charted, studied marine flora and fauna, and visited and interacted with the first nations of the coast and islands over the past five centuries.

Exploration, as you will also read, is not just about the past. Innovative and ever-evolving technology, and institutions and organizations such as those represented in these pages provide the means for the exploration of Earth's final frontier, the oceans. After a century of oceanographic research, 95% of the ocean remains unknown. With 72% of the planet covered by water, not only is the territory left to explore vast, but it is also ripe with promise for us to boldly go. This and future generations have the ability to be explorers who seek out new life, evidence of past civilizations, and lost ships.

The age of exploration is just beginning. As American innovators and entrepreneurs, as the insatiably curious and the "can do" people that we are, we can and will plot a future that reconnects us with the ocean that has dominated our planet for billions of years, from which all life sprang, and which remains the most important habitat on the Earth.

Sincerely,

James P. Delgado, PhD
Director, Maritime Heritage Program

FROM THE HELM

by Ray Ashley, Ph.D.

President and CEO,
Maritime Museum of San Diego

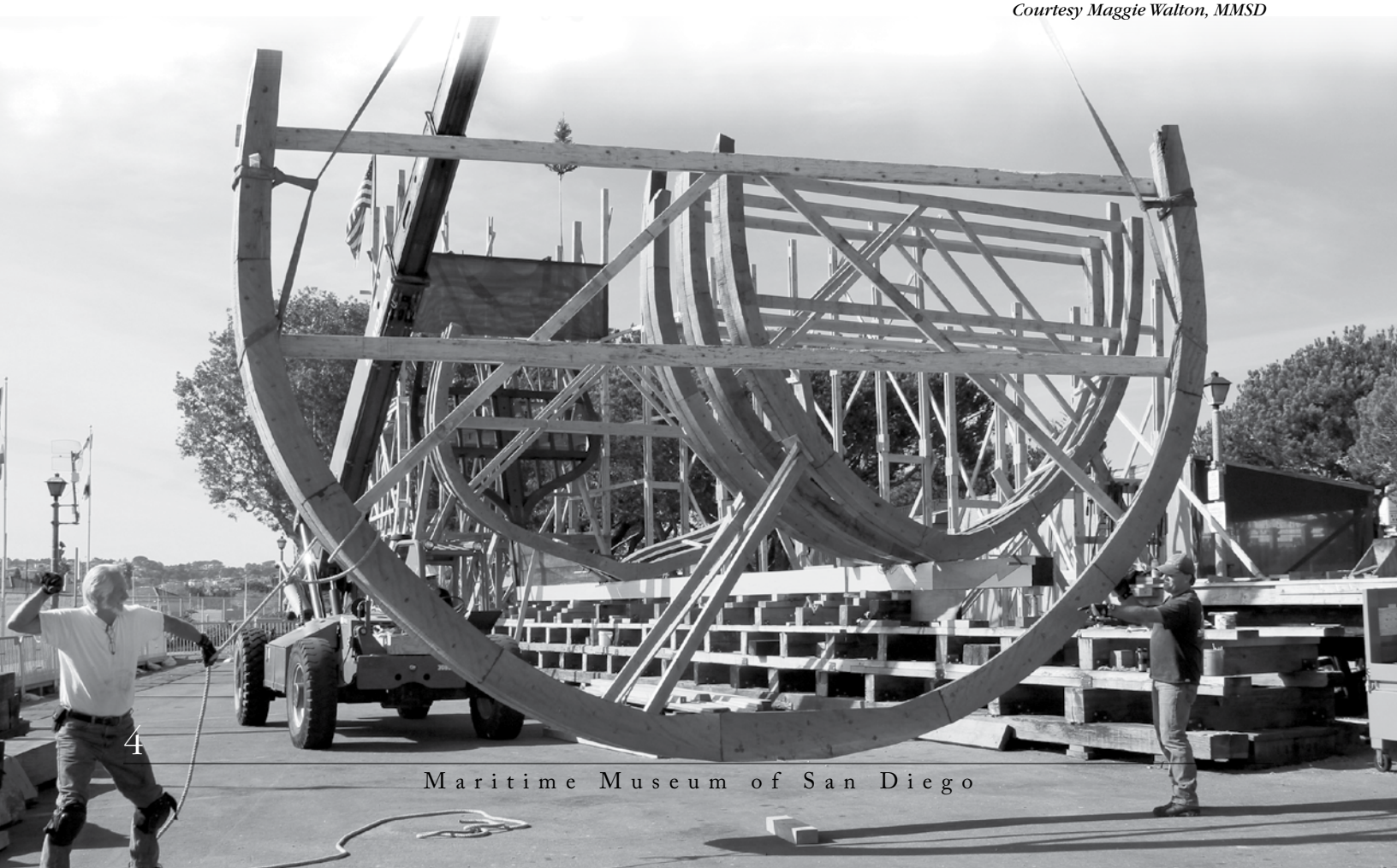
As with most creative enterprises, ocean science and the technology it generates tend to coalesce as a regional specialty. In the articles that follow, the presence of the ocean, a major port, nearby research universities, a concentration of naval power, an entrepreneurial culture, access to capital, and an investment climate, all render San Diego, and other places along the West Coast and greater Pacific with like attributes, ideal "hot spots" for the genesis of maritime science and technology. When speaking of the Pacific seaboard, we are regionally bereft in only one category – close access to the center of political power – Washington D.C. However, the rising economic and political clout of California, the global shift of power from the Atlantic to the Pacific, and the tendency of communication technology to negate some limitations of distance have overcome that one geographical disadvantage, with the result that San Diego, in particular, now possesses one of the greatest concentrations of enterprise devoted to maritime science and technology in the world.

So, the conclusion naturally follows that maritime science and technology are a major (perhaps *the* major) growing and *inevitable* product of our region, to a degree that suggests taking them for granted. After all, the momentum of creation is a central theme of this issue.

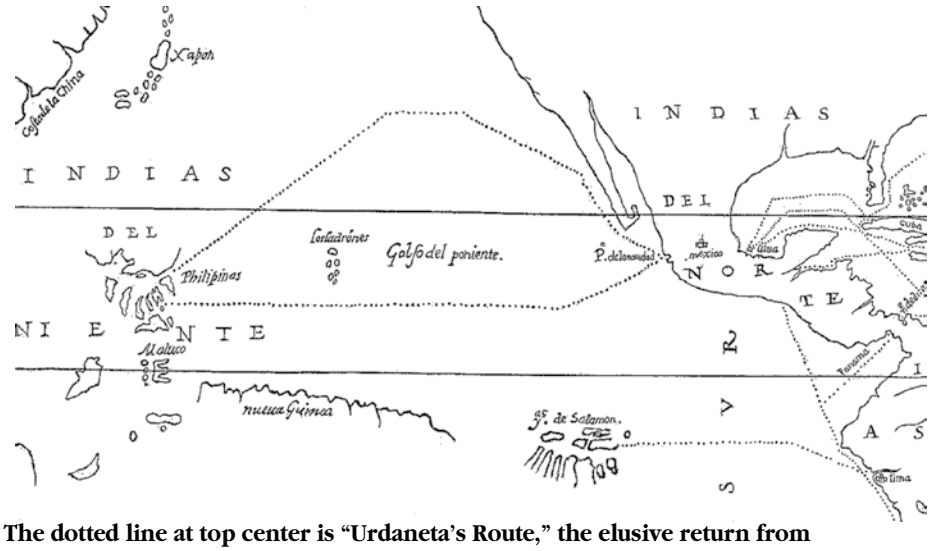
But there is perhaps another dimension to at least consider. The oldest "origin" date cited within any of the papers in this issue is 1903 – within an historical timeline that is literally yesterday. In addition, the enormous spectrum of enterprise depicted in this issue is quite fragmented, with major segments within the maritime science-technology enterprise mutually unaware of each other, of the scope of the entire phenomenon, of the political and economic potential for growth, and of the mutual support that such awareness brings. Without that awareness, and with so short a history, despite the advantages enumerated previously, it is also clear that the enterprise is yet ephemeral, something indicated in the narratives of maritime-specific companies and research programs relocated elsewhere, or those that have withered away. The point is that maritime science and technology are perhaps our region's most important intellectual and industrial specialty, but we would be more likely to sustain it if, as a community, we at least knew how transcendent it really is. That is the corollary theme of this issue and indeed, part of its purpose.

The building of the 16th-century galleon of discovery, *San Salvador*, is well underway at Spanish Landing. Among her attributes, she represents the science and technology of another era, now brought forward in time. *San Salvador* reminds us that if not for the sailing ship, the Pacific (and all the oceans of the world) would have indeed remained dark, vast and unknowable – "Mare Incognitum."

Courtesy Maggie Walton, MMSD



As President of the Maritime Museum of San Diego, with a *primary mission to serve as the community memory of our seafaring experience by collecting, preserving and presenting our rich maritime heritage and connections with the Pacific world…* I'd like to proffer another "origin" date – 1542. In that year a small group of European ships sailed on the first oceanographic research expedition into the vast and unknown Pacific. With our customary land-bound and presentist bias we tend to think of this as a voyage to discover new lands, but the Spanish were not primarily interested in new lands, they were desperate to crack the code of the winds of the Pacific in order to establish a trade route to China, the very thing Columbus attempted, until the Americas turned out to be such a massive and inconvenient barrier. By 1542, four successive Spanish expeditions sailing west into the Pacific either came to ruin, or were forced to sail around the world without intending to, because they could not figure out a way to get back across the Pacific by an eastward route. Finding such a route was Cabrillo's primary mission, and though he failed to find it, he inadvertently discovered what would be the west coast of the United States.



The dotted line at top center is "Urdaneta's Route," the elusive return from the Philippines to Mexico. Once it was discovered, Spaniards followed roughly the same loop for over 250 years.
Detail from ca. 1565-70 map by Juan López de Velasco, John Carter Brown Library, Providence, Rhode Island.

In 1565, an Augustinian monk and sometime sea captain and navigator, Andrés de Urdaneta, finally did crack the code of the winds and discovered a route, difficult and dangerous though it was, eastward across the Pacific. From that discovery ensued the fabled Manila galleons and the first emergence of a truly global trading network. Urdaneta could be considered the first and most successful of Pacific oceanographers, and the crude (ca. 1565-1570) map presented here is the oldest known chart depicting that route, and by inference it could also be considered a founding document of Pacific oceanography.

Compelling concepts sometime take form in conspicuous symbols. Moving forward in time, USS *Dolphin* AGSS 555, the Navy's deepest diving submarine, and one of the storied research ships mentioned herein, today sits placidly at her mooring at the Maritime Museum preserved for history. In a few months, she will be joined by her figurative ancestor in the history of oceanography, the *San Salvador* of 1542, which will be moored less than 100 feet away. In keeping, we might consider that in some respects, just as San Diego's origin was derived from the maritime science and technology of 1542, we continue to build upon that legacy, co-joining our history, ocean science and maritime technology, while persevering as " ingenious adopters, adapters, improvers and appliers of…existing technologies drawn from numerous sources." (see Dr. Robert Knox, "Mare Incognitum," p. 6)



USS *Dolphin* (AGSS-555)
Official U.S. Navy Photo

Mare Incognitum

How Scripps Institution of Oceanography took root on the Pacific Shore and some of the Maritime Technological efforts that resulted.

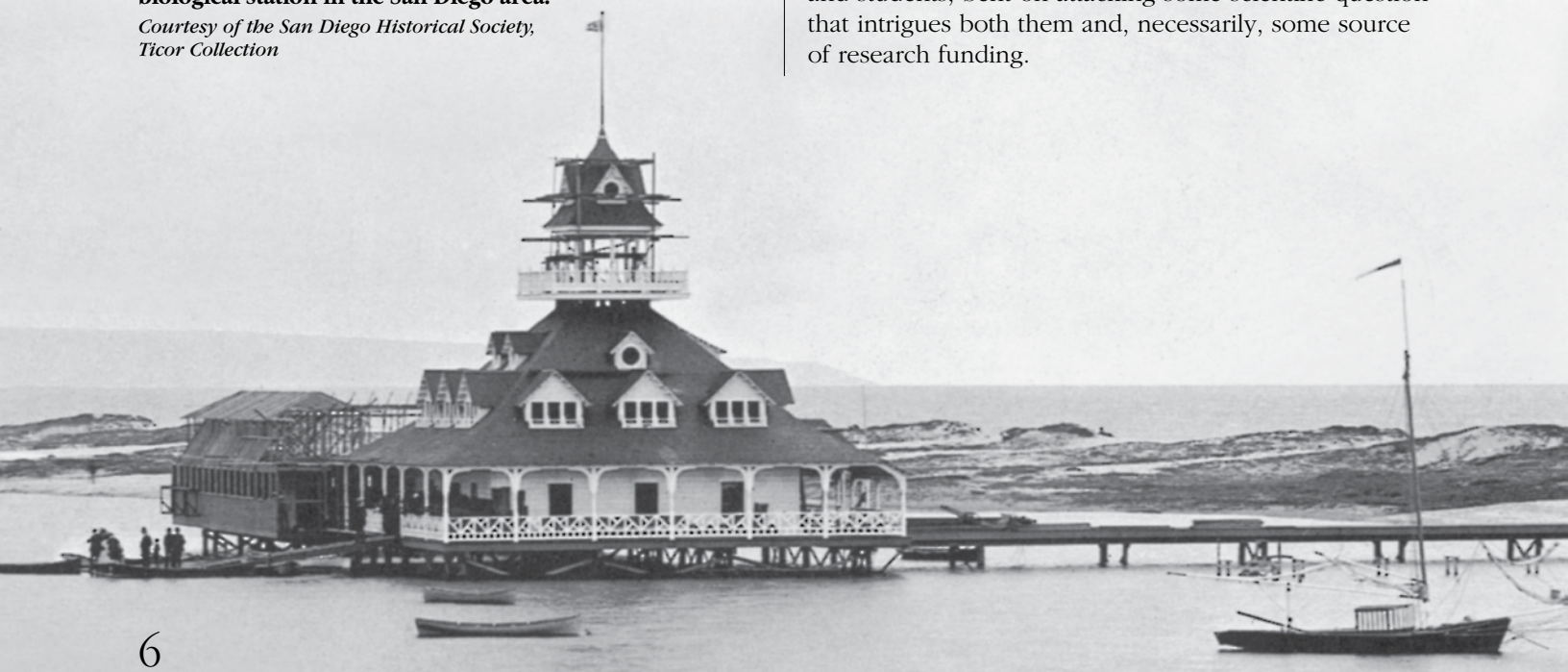
By Robert A. Knox, Ph.D.

Introduction

One purpose of this issue of *Mains'l Haul* is to outline the stories of the major ocean research institutions of the Pacific and their adoption of, involvements in, and sometimes leadership of advances in "maritime technology," broadly construed. In a few of these instances of technological involvement the results have had impacts beyond the research communities themselves, and into areas of commercial development or military significance. This issue seeks to highlight such cases of broader impact. But it must be noted that for the most part the ocean research community, including Scripps Institution of Oceanography, has been less an originator of radically new technology with widespread application, as in the manner of inventing the transistor, laser, GPS or the cell phone, and more an ingenious adopter, adapter, improver and applier of more or less existing technologies drawn from numerous sources. Scripps' contribution has been to incorporate them cleverly into instruments and systems that answer the needs of the research agendas that form the *raison d'être* of Scripps and sister institutions. In turn, those agendas, since the earliest days, have been heavily influenced by the enormous lack of pertinent observations and measurements of marine phenomena – a huge lack by comparison to the observational base on land or in the atmosphere – and by the resulting scientific imperative to improve that observational portfolio so as to build up clearer understanding and prediction of the phenomena. In all of this it must be borne in mind that Scripps *per se* has not and does not accomplish much as a well-organized entity in the manner of, say, an army division. Rather, the advances stem from the efforts of individual scientists or like-minded groups of scientists, and their staffs and students, bent on attacking some scientific question that intrigues both them and, necessarily, some source of research funding.

The Coronado Boathouse, pictured in 1887, provided the earliest platform from which to study the marine environment. It was from this boathouse that Dr. Fred Baker and William Ritter began to gather information from local waters with the hope of some day having a marine biological station in the San Diego area.

Courtesy of the San Diego Historical Society, Ticor Collection





Robert A. Knox is a Research Oceanographer and Associate Director (Emeritus) at the Scripps Institution of Oceanography, UCSD, in San Diego. His research has focused on the dynamics of the equatorial currents of the oceans, taking him to sea on chartered yachts in the Seychelles, a Royal Air Force launch in the Maldives, and on the USS *Midway*, in addition to various research vessels. As Associate Director, Dr. Knox was responsible for the fleet of Scripps research vessels (right) and their technical support groups. His Ph.D. is from the MIT-Woods Hole Oceanographic Institution Joint Program in Oceanography.



The staff of the Marine Biological Association of San Diego in June 1904, at the boathouse of the Hotel del Coronado, where Ritter's work was based before the acquisition of the La Jolla site. Front row, left to right: J.F. Bovard, Effie Rigden (Mrs. Michener), Alice Robertson, Calvin O. Esterly. Back row, left to right: Robert Day Williams, B.D. Billinghurst, William E. Ritter, Loye Holmes Miller, Charles A. Kofoid, Harry B. Torrey.

Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

Nearshore Beginnings

Scripps Institution of Oceanography is now (in 2012) 109 years old and as its website[1] notes: it is "one of the oldest, largest, and most important centers for ocean and earth science research, education, and public service in the world. Research at Scripps Institution of Oceanography encompasses physical, chemical, biological, geological, and geophysical studies of the oceans and earth." The beginnings were much more modest and delicate. Save for some remarkable coincidences of geography and a handful of individuals, Scripps Institution might never have existed, or might have been established elsewhere.

The story of the early years is ably told in the Scripps history[2] on which much of this section is based. William E. Ritter came to California in 1885, spending one year teaching at Fresno before entering the University of California, Berkeley, graduating in 1888. He spent a further year at Berkeley, then two years at Harvard, obtaining a Ph.D. in Zoology for a thesis on the eyes of the Blind Goby, a rare species to be found along the Point Loma shore. He returned to Berkeley in 1891 to chair the new Zoology department and to marry Mary Bennett, whom he had met during his Fresno teaching year. They honeymooned in San Diego, where he could collect more marine specimens. More importantly, he met medical Drs. Fred and Charlotte Baker. Fred was active in many civic circles and was an enthusiastic amateur marine naturalist, in addition to his professional medical work. He became a primary and persistent proponent of San Diego as the best location to fit Ritter's ongoing search for a permanent location for his summertime, and later full-time, marine biological investigations.



The Scripps Institution ca. 1909 on its present site, looking south toward La Jolla Shores and Point La Jolla. The building is the George H. Scripps Memorial Building ("Old Scripps"). It and the land were provided by Ellen B. Scripps as discussed in the text. The building was designed by noted architect Irving Gill. In the late 1970s, the building was slated for demolition for reasons of age and presumed seismic hazard. A campaign to save the building was led by a few members of the Scripps community, and upon investigation the building proved less vulnerable to seismic hazard than presumed. Funding from several sources, including important private donations, enabled the necessary renovations. The building was designated a National Historic Landmark in 1982. It remains in use for offices and a small meeting room.

Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

Ritter spent several subsequent summers assessing the pros and cons of various coastal locations, notably San Pedro, for his field programs. His fundamental perspective was of the untapped promise of the Pacific Coast for basic marine biological surveys – understanding what organisms lived where and how. As he wrote later: "Imperfectly as had any of the fields of Zoology in Western America been cultivated, the least studied of all had been the teeming life of the great ocean on whose margin the University is located."[3] His scientific target was to reveal the biogeography of a nearly unknown marine realm, one ripe for investigation. Other marine biological stations already existed elsewhere, for example the Marine Biological Laboratory in Woods Hole (1888), and the Stazione Zoologica in Naples (1872). The California coast was to be Ritter's province.

Pros and cons of the sites were many. San Francisco Bay was, of course, handy to the University, but was nearly landlocked and under the influence of rivers. Pacific Grove already had the Hopkins Laboratory of Stanford University, a much more substantial effort than the fledgling University of California program under Ritter's direction. In San Pedro, harbor improvements and dredging would demolish some of the best collecting grounds. Baker kept up his advocacy. The San Diego region had much to offer – rich diversity of nearshore marine forms, accessible and deep water nearby, and benign weather enabling boat work in most months of the year. And there was serious effort by Baker and others to obtain the funds needed to underwrite Ritter's work, something at which the Los Angeles/San Pedro interests had fallen short of for the summer of 1902. The San Diego Chamber of Commerce, goaded by Baker, established a Marine Laboratory Committee to seek private funds. They met with good success, including a promise of $500 from a "wealthy rancher," who hoped that Ritter could meet him when he next came to San Diego. That "rancher" was newspaper magnate E. W. Scripps, whose support (and that of his half-sister Ellen B. Scripps) would prove absolutely crucial to the establishment, survival and growth of the institution.[4] The Ritter-Scripps meeting took place in the summer of 1903, following which Ritter reported to the Chamber of Commerce Committee: "I am not going to report now that San Diego is unquestionably the best place on earth for such an institution. I am simply going to say that it is undoubtedly an excellent place from several points of view – one of the best." Further, "There can be no doubt that a laboratory capable of great things for biological science might be built in San Diego."[5]

Thus, in September 1903, the San Diego Marine Biological Association was formed, in the words of its



This 1939 photo places Roger Revelle (second from left) on the deck of the *E.W. Scripps*. Purchased in 1937, the ship made the first of the Institution's long research voyages. Of the sixty years of Revelle's involvement with Scripps, he was part of deep-sea explorations for nearly three decades.

Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

by-laws: "to carry on a biological and hydrographic survey of the waters of the Pacific Ocean adjacent to the coast of Southern California; and to prosecute such other kindred undertakings as the Board of Trustees may from time to time deem it wise to enter upon."[6] Initially an independent association, it was contemplated *ab initio* that in due course, "the founding of the institution having been perfected and its endowment secured, the whole or such part thereof as may in the judgment of the Trustees seem best, shall, under such conditions as the Trustees may impose, be transferred to the Regents of the University of California to become a department of the University co-ordinate with its already existing departments." That joining with the University took place in 1912, though another forty-eight years would pass before a complete university campus (UCSD) was initiated in La Jolla through the remarkable leadership and insight of Scripps director Roger Revelle. UCSD took good advantage of the by-then considerable intellectual luster and physical resources of Scripps as a kernel from which to grow, thereby enjoying a running start into the major leagues of U.S. research universities such as very few latter-day startups have enjoyed.

Prewar Years

Scripps began small and stayed that way for some time. The 1918 roster lists just twelve "officers," including both scientists and such functions as librarian and business agent,[7] sometimes combined in one person. Even by 1934 this roster had grown only to twenty-six. In these prewar years the emphasis continued to be heavily along the marine biological lines begun by Ritter. In terms of maritime technology, these efforts did not demand much nor did they give rise to novel developments. In the main the work was the classical laboratory-based study of collected specimens, needing microscopes, sample jars, chemicals and dissecting apparatus, none of which was peculiarly marine or novel. One niche in which there was a small technological flowering at Scripps and elsewhere, albeit one that had little impact beyond the research community, was in the design of different sampling bottles, primarily for biological specimens. As Peter J.S. Franks noted in "A Century of Phytoplankton Research at Scripps,"[8] "Lest I give the impression that Scripps was a hotbed of sample-bottle development, it seems that between the late 1800s

and mid-1900s any oceanographer worth his salt had developed a bottle bearing his name. In a haphazard search of the National Oceanic and Atmospheric Administration image archives, I came across more than 100 bottles developed during this time, mainly in Europe and Scandinavia."

To Ritter's credit he also recognized the need to understand the physical and chemical surroundings (the ocean) in which the organisms of study lived. But even these physical and chemical studies mainly used tools that had already been developed elsewhere and had achieved a fair degree of standardization, simplicity, familiarity and acceptance.

In the realm of physical oceanography, as one example, the Norwegian polar explorer Fridtjof Nansen had designed the eponymous sampling bottle in 1910. Fastened to a wire lowered over the side of the ship by a winch, the bottle was "tripped" (upended) by a small weight ("messenger") sliding down the wire from above. Tripping served to close the bottle valves and capture a seawater sample for later laboratory analysis of its salinity and other properties, and also to release another messenger to fall farther down the wire to trip the next bottle, and so on through a series of bottles placed at desired intervals along the wire. Attached to the upending bottle would be one or more "reversing" mercury thermometers, a clever design due to Negritti and Zambra in 1874. The upending breaks off a column of mercury in the thermometer, preserving a record of how long the column was (*i.e.,* of the in-situ ocean temperature) at the time of reversing. A second kind of reversing thermometer, with its mercury column exposed to ocean pressure, captured an indication of the depth of the instrument at reversal.

Such mechanical and a handful of electro-mechanical devices were the norm during this period. A good overview from the perspective of the early 1940s is given in Chapter X of the famous 1942 text/encyclopedia of oceanography, *The Oceans,*[9, 10] by a trio of Scripps authors. Modern readers will be struck by the absence of electronics, let alone anything in the way of digital circuitry, from these devices. With the exception of some early underwater sound sources, used for sonic depth measurements and also for target (submarine) detection, none of these devices had appreciable impact beyond research uses, nor did any survive the postwar electronics/computer revolutions.

Waves and The War

World War II, of course, overturned the plans of nearly everyone, and Scripps scientists were no exception. For the Western Allies the war had enormous maritime components – the Battle of the Atlantic that came perilously close to choking off the life of Britain, and the rolling up of the Japanese forces in the Pacific, one island landing and one naval operation at a time. Objects of inquiry suddenly shifted from U.S. coastal marine biology à la Ritter, to matters of underwater sound and target detection, conditions on beaches for amphibious operations, and more. These kinds of questions demanded rapid answers involving the state of the ocean and its variability in real time, or even into the near future (forecasts); retrospective reference to climatic atlases, seasonal averages or museum specimens were not enough.

The problem of trying to create useful forecasts of waves on landing beaches fell on the desk of young Austrian-born Ph.D. student Walter Munk, who had left his Scripps studies for Army duty and was assigned as Assistant Oceanographer in the Army Air Force Directorate of Weather in July 1942. There he was apprised of some of the plans for the North Africa landings later that fall, and learned that waves on that coast

commonly exceeded what the landing craft could bear. The urgent problem then was to try to predict, shortly ahead of time, a day on which the surf would be acceptably small.

There clearly was no time to invent or deploy any new technology or hardware for the purpose. Everything had to be based on whatever already existed in the way of instruments, data sources and physical understanding of waves – an extreme case of the "ingenious adaptation and application" noted in the Introduction, and one with lives on the line. Munk quickly decided to involve his famous mentor in the effort, the Norwegian-born[13] Director of Scripps Harald Sverdrup, and the two of them produced wave forecast schemes based on available weather maps and their indications of storms, on empirical rules for the strength of waves that propagate away from storms ("swell") and for waves generated by weather closer at hand ("sea"), plus a few elementary dynamical principles of wave propagation. By today's standards these empirical formulae are very crude. But they were taught at Scripps to some two hundred military officers for later use in making wave predictions for various landings, including those at Iwo Jima, Okinawa, the Philippines, Sicily and Normandy, and thus made their way into the war effort with notable success. For Normandy, a combined US-UK team gave Eisenhower the fateful advice that waves for June 5 would be too great, while those on June 6 would be difficult but manageable, so June 6 became D-Day. (Parallel UK work on wave forecasting is recounted in Chapter Four of *Of Seas and Ships and Scientists: The Remarkable Story of the UK's National Institute of Oceanography*.[14]) This forecast was primarily for sea and surf, and based on nearby weather, since the Cherbourg peninsula shields the Normandy beaches from all but very large swells coming in from the open Atlantic.



Walter Munk (l) and Harald Sverdrup at Scripps, 1940

Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

In the years since the war, this audacious undertaking – to cobble together existing information and understanding of wave dynamics and thereby to fashion a useful forecast – has burgeoned into sophisticated computer models of the wave spectrum and wave generation process, global observations of winds and wave heights inferred by satellite instruments, regular global wave predictions by civil and military weather services, commercial services to advise ships about optimal routes to skirt storms and high seas, and any number of regular wave forecast products tailored to local areas and used by surfers and beachgoers. But the lineage – the realization that it is actually possible to use science to do more than guess about future wave conditions – traces to Sverdrup and Munk.[15, 16] And the broader impact of their first step was fundamental. Taking into account all the wartime operations that made use of wave forecasting, a modern text on waves writes, in a pedagogical tone to its student readers: "If you will admit the obligation of the scientist to the society that makes his science possible, then you will from time to time find yourself in a position similar to that of Sverdrup and Munk. I am sure that they were aware of the inadequacies of what they did and that if they had known at the time how to remedy them they would have. The point is that in meeting a practical situation you need not be – in fact you should not be – apologetic about making assumptions that are doubtful and working on an inadequate data base. If you can produce anything helpful, that is your justification. The danger lies in becoming enamored with what you have done and mistaking palliatives for insight. Sverdrup and Munk never made this mistake, and as evidence of the discharge of their moral obligation there are some thousands of World War II veterans alive today who would have been dead in the surf had Sverdrup and Munk not done their best with what they had."[19]



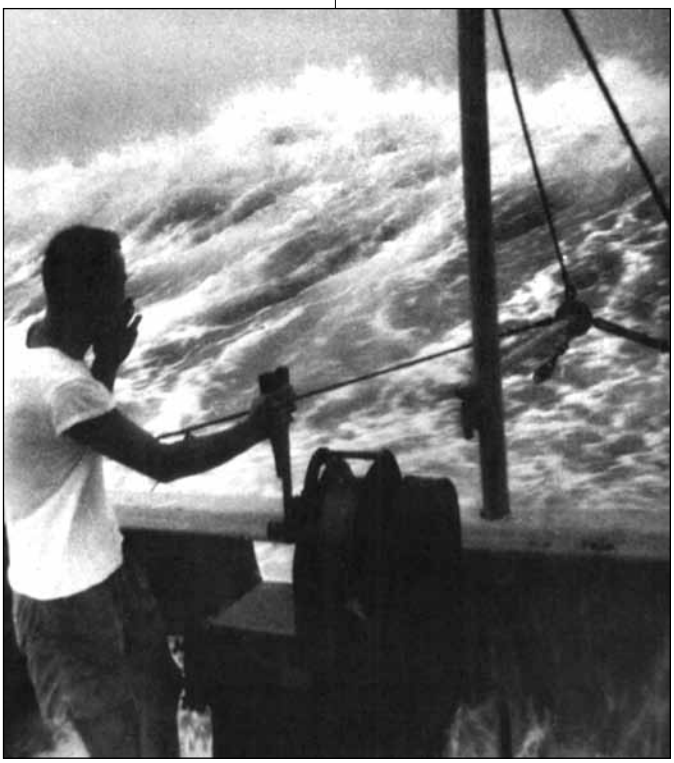
Ed Barr and the MBT on deck in benign conditions aboard RV *Horizon*, 1952. The towing cable is attached near the nose of the device. Pressure and temperature sensors are exposed to the sea via the perforations nested within the tailfins.

Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

Mechanical Bathythermographs (MBTs) and Expendable Bathythermographs (XBTs)

By the late 1930s it had become apparent to many oceanographers, particularly those involved in ocean acoustics of naval relevance, that the variability of conditions in the upper ocean (the top few hundred feet, where submarines of the time operated), particularly of temperature, gave rise to variability of the speed of sound in the ocean and hence to variable refraction or bending of sound rays in that region. Thus the ability to measure and understand the acoustic ramifications of this upper ocean variability in terms of target detection for destroyers, or destroyer avoidance for submarines, loomed large as an unmet need in the run-up to the war. Atlases and compilations of average conditions were insufficient; current observations of actual variable conditions were needed. The tedious business of stopping a ship to lower a Nansen bottle was altogether too time consuming and sparse a sampling method; something to be done rapidly and repeatedly from a ship underway was required.

The first step in this direction was the creation of the purely mechanical bathythermograph or BT (sometimes later called MBT for Mechanical BT, to differentiate it from its electronic successor the expendable bathythermograph or XBT). Rossby and Spilhaus built the first BT in 1937 at the Woods Hole Oceanographic Institution (WHOI). Vine and Ewing added important improvements of functionality and durability in 1940. The WHOI director Columbus Iselin, who was convinced, correctly, of the importance of rapid underway upper-ocean temperature measurement, to underpin advancements in the understanding of underwater sound and its tactical application to submarine warfare problems, supported the BT development and urged its use by the Navy. Getting the operational Navy to subscribe to this view proved harder than actually building the BT.[20]



Louis Garrison manning the BT winch in distinctly non-benign conditions, aboard RV *Horizon*, 1950.
Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

The BT had its innings in the war and, subsequently, as a naval device and as a research instrument for upper ocean studies. It was purely mechanical. A small smoked glass slide, about the size of a microscope slide, was pushed in one direction by pressure as the BT descended, while a stylus was driven at right angles by the ocean temperature acting on a thermostat-like coiled metal tube, thus scratching a graph of temperature versus depth on the smoked glass. But it was a bother to keep calibrated, a nuisance to retrieve the data from a bit of smoked glass, and a terror to operate at sea. The device consisted of a heavy brass rocket-shaped body that was dropped over the side of the moving vessel, rapidly spooling out wire from a small freewheeling winch. Inside the brass body, but in contact with the water, lay the temperature and pressure sensitive components and the glass slide. The operator was a sitting duck:

"In any kind of rough weather this BT position was frequently subject to waves making a clean sweep of the deck. In spite of breaking waves over the side the operator had to hold his station, because the equipment (the BT) was already over the side. One couldn't run for shelter as the brake and hoisting power were combined in a single hand lever. To let go of this lever would cause all the wire on the winch to unwind, sending the recording device and all its cable to the ocean bottom forever. It was not at all uncommon, from the protective position of the laboratory door, to look back and see your watchmate at the BT winch completely disappear from sight as a wave would come crashing over the side."[21]

When the end of the wire was reached (and at even moderate ship speeds this was at disappointingly small BT depths, constrained by the amount of wire on the winch and how effectively the BT could pull it off the winch in order to sink), the BT was winched back aboard, frequently breaking the surface, skipping on a wave crest, and hurtling aboard to endanger people on deck. "Probably the greatest hazard was a swinging BT after it had left the water. A familiar saying was: 'sight, surface, oh son of a gun,' or words to that effect, as the instrument swung in circles around the boom."[22]

In the postwar era engineer James Snodgrass of Scripps felt that the time had come to step away from purely mechanical devices and embrace the new possibilities of electronics. Snodgrass conceded the prior track records of the two approaches: "When I first came to Scripps Institution of Oceanography in 1948 it was quite evident that the word "electronics" was in many ways what might be considered a dirty word and, more often than not, preceded by an uncomplimentary adjective. Mechanical instruments had been used in oceanography literally for decades and were performing creditably. Since mechanical instruments



A modern XBT probe is launched nose-down and outboard of the hand-held launcher. The operator can be much more shielded from the weather. The wire connecting the probe and launcher is too fine to be visible in this photo.
NOAA Teacher at Sea, Catherine Prenot Fox onboard NOAA ship, Oscar Dyson
July 24 - August 14, 2011

had achieved relatively high reliability there was little or no inclination to turn to electronic instruments, which, aside from being relatively fragile, was [*sic*] at the time quite temperamental and admittedly unreliable."[23] This view echoes the edgy remark of Roger Revelle to the effect that "the best oceanographic instruments should contain less than one vacuum tube per unit."[24] Revelle, of course, would be open to new techniques of demonstrable capability, but at that time the key factor "demonstrable" was lacking.

For Snodgrass, however, the times were changing, and the MBT was an instrument in urgent need of change for the reasons noted. With the new possibility of an inexpensive electronic temperature sensor (thermistor) and electronic means of recording its output, there arose the key possibility of breaking the system into two parts – an expendable probe with its thermistor dropped into the water from the ship underway, and a permanent recording system inside the shipboard laboratory. A thin insulated wire connection from probe to ship, but one with its insulation free of pinhole leaks was needed; this proved feasible. Snodgrass urged this expendable approach to the Navy and to interested commercial firms. The primary result was the XBT, as built by Sippican Corp. (now Lockheed Martin Sippican).[25]

The fine insulated wire is wound on two spools, like fishing reels. One spool in the probe unwinds as the probe sinks. The other in the shipboard launcher unwinds as the ship continues to steam away from the point of launch. The part of the wire that enters the ocean at the launch point thus stays more or less still as the two unwinding spools move away from it. There is no pressure sensor. Depth is determined by the time the probe first contacts seawater and the known fall rate of the probe. The thin electrical wire is expendable and no longer a limiting factor, in contrast to the MBT where the mechanical wire must have the strength to recover the probe, so the XBT can routinely achieve much greater depths than the MBT, and at greater ship speeds. The overall survey economics, when both ship time costs and expendable probe costs are factored in, decidedly favor the XBT. Sippican has produced over 5 million XBT probes for research

and military use since the 1960s. There are related expendable instruments for sensing ocean conductivity and temperature jointly (and thus computing salinity) and for sound velocity. Air-deployable versions with a radio link to the aircraft also exist (at greater unit cost) enabling even more rapid surveys if required. MBTs now reside only in museums. Both research uses: rapid reconnaissance of upper ocean variability to study its fundamental properties and dynamics and military ones, rapid reconnaissance of such variability and its acoustic consequences as an aid in submarine and anti-submarine warfare tactics, have been the clear beneficiaries of this early incorporation of electronic techniques in the arsenal of oceanographic instrumentation to observe ocean variability.

Concluding remarks

Space has not allowed this paper to give either a full history of Scripps Institution of Oceanography, or a complete survey of those occasions on which Scripps-related technological efforts have propagated into broader commercial or military impacts, let alone the more numerous occasions on which such efforts have fed back into crucial advancements in ocean research and observing capability. The companion paper by Dr. Russ Davis (see pages 18-31) discusses some of these other occasions, particularly ones enabled by the fundamental revolutions in electronics and digital systems of the last few decades. Here we have simply noted two somewhat eclectically chosen and historically earlier examples – wartime wave forecasting, and the application of early postwar electronics to shift from the MBT to the XBT – as illustrative of the ingenuity that Scripps people have brought to the task of understanding the ocean and revealing its behavior through any and all technologies that could be brought to bear. In these two cases the uses of the technological developments have spread well beyond research purposes alone. As the second century of Scripps unfolds this kind of seizing upon technological possibilities continues. The core incentive remains to create new instruments and measurement systems that will help peel back the darkest layers of the unknown sea for the scientists who seek to understand it – to render the *mare* less *incognitum*. Both the enhanced understanding and some of the new devices doubtless will continue to open up new advantages and new economic possibilities to sectors of society well beyond the confines of Scripps Institution and the ocean research community.

The aerial view of Scripps about one century later than on page 8. The original "Old Scripps" building is the building south of the pier at the cliff's edge, partly obscured by a group of trees, and bounded on its north, west and south sides by more recent buildings.

Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library



Notes

1 http://sio.ucsd.edu/ (accessed Oct. 24, 2011).

2 Helen Raitt and Beatrice Moulton, *Scripps Institution of Oceanography – First Fifty Years,* The Ward Ritchie Press, 1967.

3 Ibid., 5.

4 Ibid., 17. The initial input of funds from E. W. Scripps was only the first of several crucial contributions from him and other members of the Scripps family. Ellen B. Scripps, relying on her half-brother's financial advice, underwrote the purchase of the 170 acres on which the Institution is now located and the construction of the first building, shown on page 12, both for under $20,000. When the solitary research vessel *Scripps* was lost in an explosion in 1936, Robert P. Scripps purchased the yacht *Serena*, had it refitted and modified, and donated it to the Institution as the *E.W.Scripps*. In this century the new Robert Paine Scripps Forum, with major Scripps family donations, has become a conference and meeting focal point, and an architectural landmark along the La Jolla coast. More complete mention of the Scripps family generosity and impacts in the early decades can be found throughout *Scripps Institution of Oceanography – First Fifty Years* [fn. 2].

5 Ibid., 16.

6 Ibid., appendix B.

7 Ibid., 184.

8 Peter J.S. Franks, "A Century of Phytoplankton Research at Scripps," *Oceanography,* 16(3)(2003), 60-66.

9 H. U. Sverdrup, Martin W. Johnson and Richard H. Fleming, *The Oceans – Their Physics, Chemistry and General Biology,* (Englewood Cliffs: N.J., Prentice-Hall, Inc., 1942, 13th printing 1964).

10 The importance of this book in its time can scarcely be overstated. It was as comprehensive as the authors could manage, although some reviews felt it left out some significant aspects of the subject. It influenced a generation of Scripps students and, through them, the establishment of oceanographic departments and curricula at new institutions that they went on to found. It had enough potential military use to be restricted to U.S. and Canadian circulation during its first years of publication. Good histories of the book and its impacts are referenced in fn. 11 and fn. 12 (below).

11 Deborah Day, "Scripps Before World War II: The Men, the Science and the Instruments," *Oceanography,* 16(3)(2003), 15-28.

12 John A. Knauss, "The Oceans as Educational Philosophy," *Oceanography,* 16(3)(2003), 29-31.

13 Sverdrup's Norwegian origins, and Munk's Austrian ones, cooked in the unholy cauldron of wartime fear and suspicion of foreigners, became ingredients for initiating loyalty investigations of both men and for retraction of their security clearances. Munk's clearance was later restored and he went on to an ongoing role as a key adviser to the Navy on all manner of highly classified topics and to the honor of a Secretary of the Navy Chair in Oceanography. Sverdrup's work on the wave problem

was not tripped up by his lack of clearance, but he was barred from some other work of possible military usefulness where he might have contributed much to the war effort. For a man who had lost a brother to the Nazis and who had had two sisters jailed by them, the wound must have been deep. After the war he returned to Norway and died there in 1957, never having learned the full story of the unfounded suspicions that had given rise to his clearance problems. Munk [fn. 17} recounts this sad history in short form. Day and Munk [fn. 18] give a much more complete account, including many details unearthed from FBI and military intelligence agency files via a Freedom of Information Act request in 1993. Tragically, some of the initial inputs of mere suspicion that triggered the investigations are traceable to Scripps colleagues of Sverdrup and Munk. As Munk and Day [fn. 18] have observed, "Wars, and the present included, awaken paranoid instincts." The Sverdrup clearance revocation stemmed not from malevolence on the part of the Scripps colleagues involved, but from the inherently risk-averse structure of the clearance machinery and its officials, with large incentives not to let any possibly-disloyal person through the filter. A consequence, as in the Sverdrup case, is that "in balance the true security of the country may well end up on the losing side."

14 Michael Longuet-Higgins (compiler), "Group W at the Admiralty Research Laboratory – Personal Reminiscences by Some of Its Members," in Anthony Laughton, John Gould, "Tom" Tucker and Howard Roe, *Of Seas and Ships and Scientists: The Remarkable Story of the UK's National Institute of Oceanography,* (Cambridge, The Lutterworth Press, 2010), 41-66.

15 H. U. Sverdrup and W. H. Munk, "Theoretical and Empirical Relations Between Wind, Sea and Swell," *Transactions of the American Geophysical Union,* 27(6), (1946), 823-827.

16 H. U. Sverdrup and W. H. Munk, "Empirical and Theoretical Relations In Forecasting Breakers and Surf," *Transactions of the American Geophysical Union,* 27(6), (1946), 828-836.

17 Hans von Storch and Klaus Hasselmann, *Seventy Years of Exploration in Oceanography: A Prolonged Weekend Discussion with Walter Munk,* (Heidelberg, Dordrecht, London, New York, Springer, 2010), 21-23. Hasselmann, a longtime colleague of Munk, is a key figure in the postwar science of ocean wave physics and dynamics that underpins postwar advances in wave forecasting.

18 Walter Munk and Deborah Day, "Harald U. Sverdrup and the War Years," *Oceanography,* 15(4)(2002), 7-29.

19 Blair Kinsman, *Ocean Waves,* (Englewood Cliffs: N.J., Prentice-Hall, Inc., 1965), 321.

20 Gary E. Weir, "Fashioning Naval Oceanography: Columbus O'Donnell Iselin and American Preparation for War, 1940-1941," in *The Machine in Neptune's Garden,* Helen M. Rozwadowski and David K. Van Keuren (eds.), (Sagamore Beach: MA, Watson Publishing, 2004), 65-91.

21 Elizabeth Noble Shor, *Scripps Institution of Oceanography: Probing the Oceans 1936 to 1976,* (San Diego, Tofua Press, 1978), 246. This book is the fundamental general history of Scripps for the period following that referenced in fn. 2, with some overlap.

22 Ibid., 247.

23 James M. Snodgrass, "Instrumentation and Communications," in John F. Brahtz (ed.), *Ocean Engineering: Goals, Environment, Technology,* (New York, London, Sydney, John Wiley & Sons, Inc., 1968), 397.

24 E. N. Shor, *op. cit.,* 89.

25 http://www.sippican.com/contentmgr/showdetails.php/id/312 (accessed Oct. 24, 2011).

It Takes a Network to Build an Ocean Observing System

By Russ E. Davis, Ph.D.

In the last twenty years oceanographers have put in place large observing systems to keep tabs on how the ocean works and how it is changing. Today, NOAA maintains the TAO array along the Pacific's equator to observe and predict the evolution of El Niños and La Niñas. A global array of instruments includes autonomous floats that bob up and down to a mile depth, expendable probes dropped from commercial vessels, and drifters that measure surface currents and observe changes in the ocean over seasons to decades. The technology to observe broad expanses of the ocean is the product of a remarkable period of progress born of the realization during World War II that knowledge of the ocean had value, and it was enabled by the technological explosion during the Cold War and Sputnik era. It is, most of all, the product of a network of scientists and engineers enticed by the opportunity to do and learn new things in the ocean. Scripps Institution of Oceanography (SIO) is a leader in that global network because, as this article tries to tell, Scripps is itself a network of people and ideas.

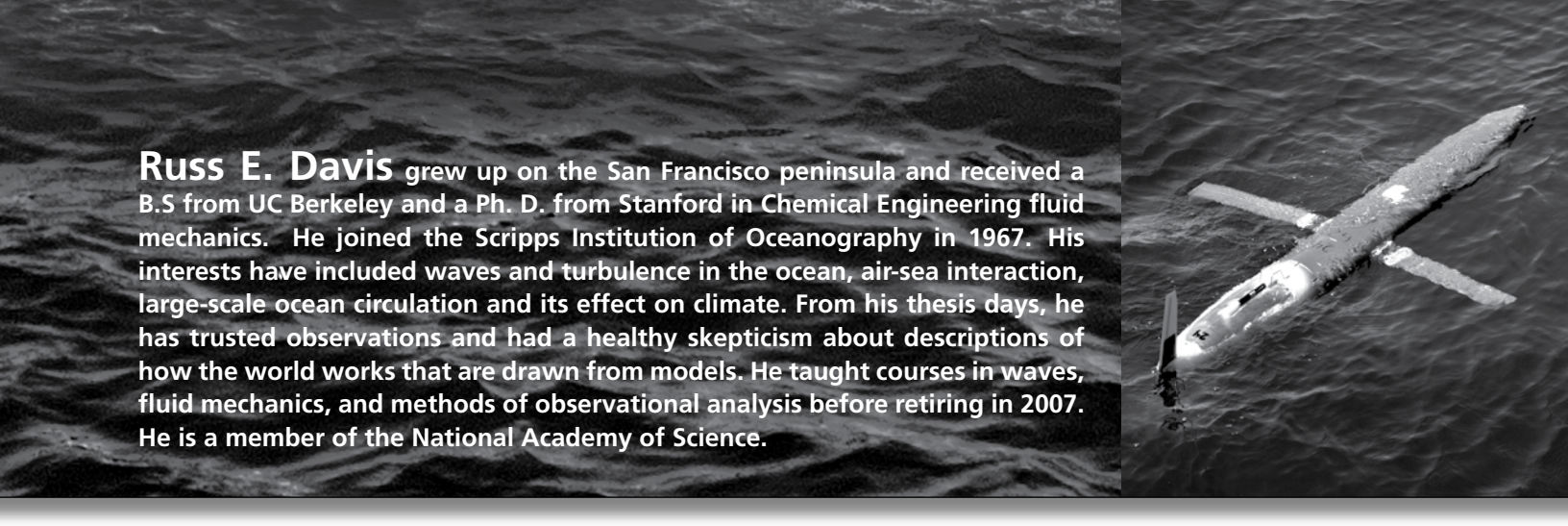
WWII began a remarkable change in how the ocean was studied. Historically, oceanographers had observed the subsurface ocean using water-sampling devices lowered from isolated seagoing research vessels, inferred currents from water properties using the same pressure-velocity relation employed by meteorologists to infer winds from pressure measurements, and measured surface temperature with samples lifted aboard in buckets. Perhaps, because repeated measurements were rare, the ocean circulation was thought of as basically steady, perturbed by small-scale phenomena and capped by a thin near-surface layer that responded to the wind. El Niño was known along the west coast of South America, but its global extent and relation to global climate were unknown.

As Dr. Knox's companion article explains,[1] the realities of acoustic propagation made the variations of the ocean in time and space important and resulted in MBTs and XBTs (mechanical and expendable bathythermographs) that enabled any boat or ship to measure temperature several hundred feet below the surface. This was the first serious effort to proliferate ocean measurements. Scientifically, it was important in enabling repeated and far-flung measurements. This was the first step toward today's global observing system that observes marine weather, tracks the El Niño and La Niña cycles, observes the changing temperature of the ocean that contributes to sea-level rise, and monitors the rate at which the ocean's circulation transports heat from the tropics to the poles. This article describes the network of pioneers who made it possible to maintain large-scale ocean observing systems.

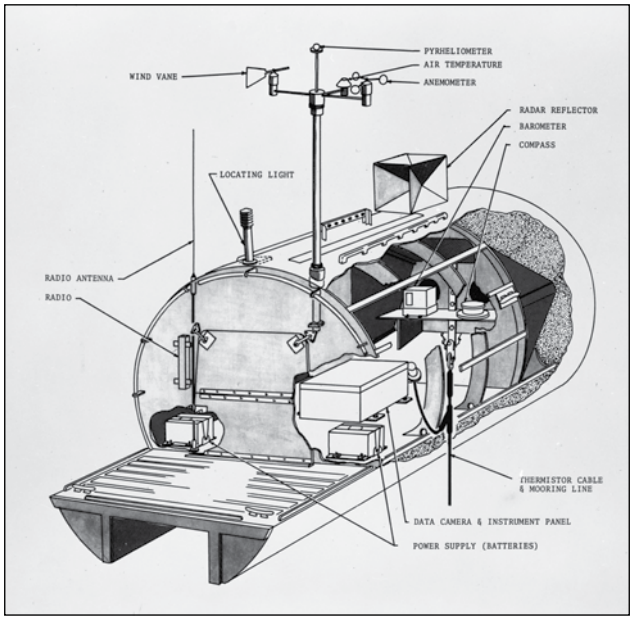
Early Moorings

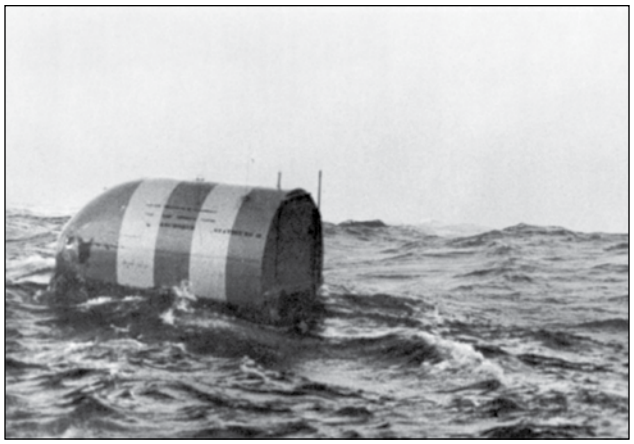
Ships traveling at speeds fast compared with ocean currents give a picture of the ocean's spatial structure, but not how it changes in time. To do that, measurements must be sustained at one place. From the late 1950s through the 1970s two groups, more or less simultaneously, began to develop "moorings" (instrument systems that were temporarily anchored to the bottom and then returned to the surface for recovery) in order to gather the needed "time series". One group was led by Bill Richardson, at Woods Hole Oceanographic Institution (WHOI), and another by John Isaacs, at SIO.

John Isaacs, an inventive professor at Scripps, who knew how to leave an impression on all he met, was one of the first to see how the observational reach of ships could be extended using "free vehicles". These relatively small packages[2] were dropped from a ship, reached the bottom where they might stay for hours, and then returned to the surface to be located by radar and recovered. Free vehicles collected multiple samples in the water column, or on the bottom, from a ship that was otherwise engaged. The potential to measure near bottom currents this way fostered an effort at Scripps to develop a current meter for light-weight moorings. The resulting current meter[3] used



Russ E. Davis grew up on the San Francisco peninsula and received a B.S from UC Berkeley and a Ph. D. from Stanford in Chemical Engineering fluid mechanics. He joined the Scripps Institution of Oceanography in 1967. His interests have included waves and turbulence in the ocean, air-sea interaction, large-scale ocean circulation and its effect on climate. From his thesis days, he has trusted observations and had a healthy skepticism about descriptions of how the world works that are drawn from models. He taught courses in waves, fluid mechanics, and methods of observational analysis before retiring in 2007. He is a member of the National Academy of Science.





Bumble Bee buoys, whose shape and yellow and red stripes gave the impression of a giant floating bee, were stationed in the central North Pacific to discover the dynamics of long-lasting sea-surface temperature anomalies associated with climate patterns over the U.S.
Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

a vane to orient into the current and a Savonius rotor to measure current speed. Rotor speed, sensed optically, and current direction from a compass-driven low-torque potentiometer, were recorded on a Rustrack chart recorder.[4] Bottom currents in the deep ocean being very weak, the rotor was made to respond to very slow flow (less than 1 cm/s). This capability and a compact configuration made the Isaacs meter useful into the 1990s.

At the same time, SIO and WHOI were both developing tall moorings to carry multiple instruments and span full ocean depths for months or years. These huge structures of wire and/or rope were supported by flotation at the surface (surface moorings), or below the surface (subsurface moorings) and were held in place until recovery by anchors frequently weighing over a thousand pounds. The lengthy development of these complex moorings has been called "an experimental war against Murphy's Law," because the unanticipated problems were myriad. Moorings were lost to strong currents that broke them, to shark bites that severed the mooring lines, and hardware that lost its strength with time in service. These challenges were overcome by large teams of dedicated, ingenious and, above all, patient scientists and engineers.

At Scripps, interest focused on air-sea interaction. In the 1960s, Isaacs and others noticed that persistent sea-surface temperature patterns in the North Pacific were correlated with seasonal and annual weather patterns over the Pacific and North America and this relation became a focus of Scripps research for decades. Isaacs' goal was to use surface moorings to see what was happening in the North Pacific to link air and sea. His group explored various mooring configurations, including the first taut-nylon mooring lines and catamaran surface buoys, with the aim of making long-term surface weather observations and measuring upper ocean temperature profiles.

This eventually led to the "Bumble Bee buoy,"[5] whose surface appearance was that of a yellow and red striped bee floating on the ocean. Thermistors placed in the mooring line, or a single thermometer raised and lowered by a winch measured temperature at depth, while air temperature, barometric pressure and wind speed were measured on the buoy. The signature feature of the buoys was a recording system based on a movie camera photographing a panel of electrical gauges indicating voltages from the various sensors.

The pinnacle of Bumble Bee technology came during the North Pacific Experiment (NORPAX) that studied large-scale air-sea interaction and climate variability. Multiple widely spaced Bumble Bee moorings were maintained in the central North Pacific from 1968 to 1972. It was planned to replace them with commercially developed Monster Buoys[6] that were 12-meter discus buoys weighing 50 tons. The capital and maintenance costs of these buoys were, however, so high that ONR and NSF reorganized NORPAX to be led by Charles Cox, a renowned Scripps oceanographer known best for his pioneering studies of microstructure (the tiniest scales of velocity and temperature variability in the ocean). Remarkably, Cox had no trouble moving from these tiny signals to the size of ocean basins and the observing system he organized is discussed below.



John Swallow prepares an early Swallow Float for deployment, while the ships' cat looks on curiously.

Courtesy of John Swallow

Compared with SIO, Richardson's group emphasized currents and the ocean well below the surface layer. As was learned later, the ocean is stirred by "mesoscale eddies", the oceanic analogues of the atmosphere's weather systems that are strongest on the western side of each ocean. This was a big challenge to Richardson's efforts to get moorings to survive in the western North Atlantic, adding to the sharks that attacked mooring lines deeper in the Atlantic, and the way the polypropylene, first used as mooring line, was structurally inferior to the nylon adopted later. At first the ocean won and, in 1967, all of a seven-mooring array vanished before recovery. But the WHOI Buoy Group was determined, well-funded and took a methodical approach to perfecting both surface and subsurface moorings. By the mid-1970s their moorings were reliable for many months, much had been learned about currents in the western North Atlantic from them, and the technology was developed into the basic form that was used for years. The story of this heroic battle is succinctly summarized in "Building Them Tough, Bringing them Back."[7]

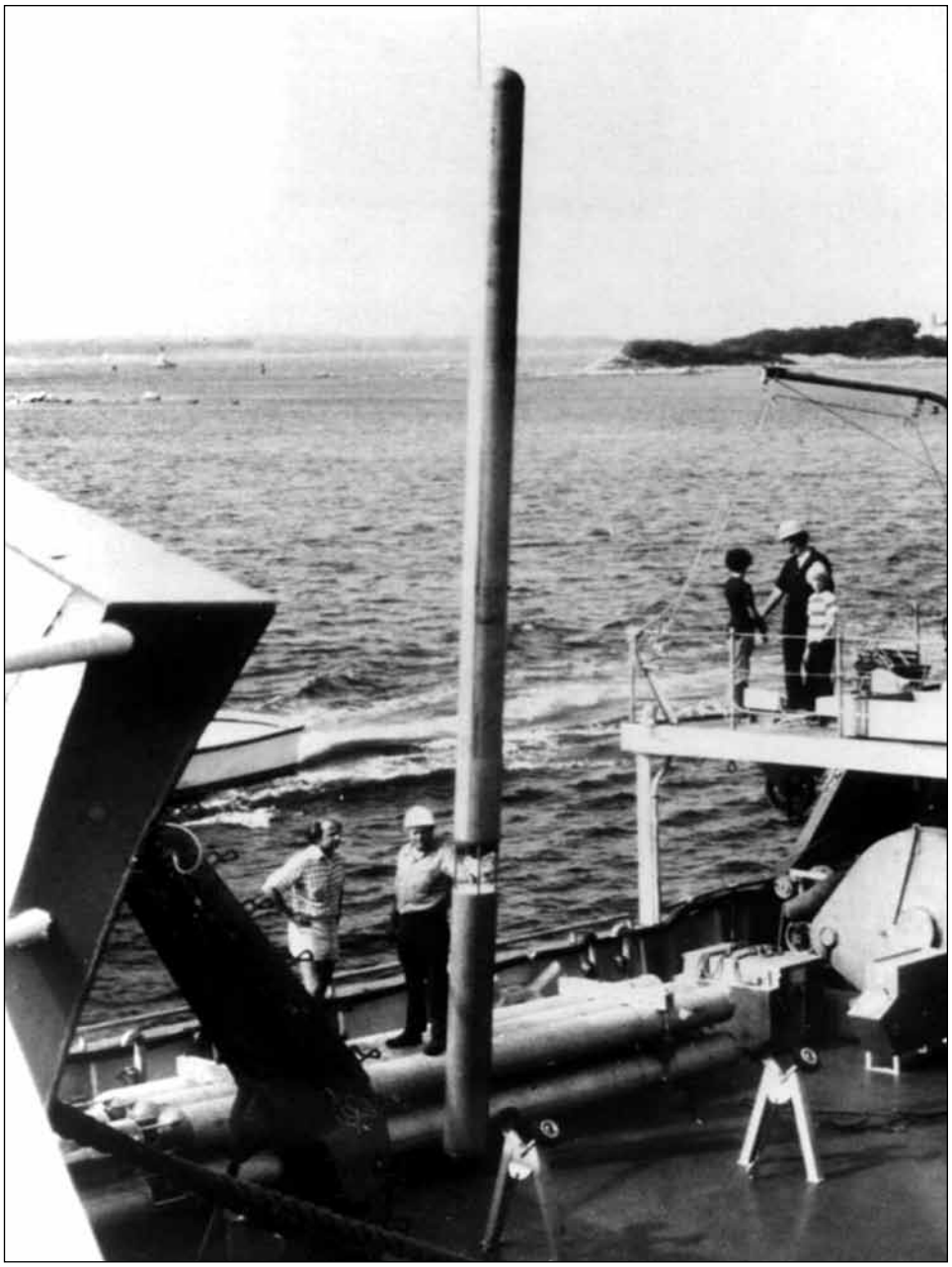
The Swallow Float Revolution

While this pioneering mooring work was going on at SIO and WHOI, the British oceanographer John C. Swallow began measuring deep subsurface currents by following acoustically tracked "floats" as they drifted at depth, carried by the currents. His floats were made of aluminum tubing that was strong enough to resist the pressure of the mid-depth ocean and light enough to be neutrally buoyant (with the same overall density as seawater). Swallow discovered that such a float would be less compressible than seawater, so if it was a little negatively buoyant at the surface it would sink until its density matched the water density, at which point it would float on the ocean's density gradient while being carried along by currents.

In post-war England materials suitable for floats were scarce, so Swallow used aluminum scaffold tubing subjected to caustic baths to adjust its wall thickness. These "Swallow floats"[8] were fitted with acoustic pingers that could be tracked from a ship if it stayed within a few miles range. These simple devices became a prime example of Scripps Professor Walter Munk's insightful saying: *Every time we look at the ocean with a new instrument we learn something*. Based on infrequent low-resolution historical ship surveys in the 1960s, currents were believed to be weak (a few millimeters per second) and to vary little over months and hundreds of kilometers. When Swallow and WHOI oceanographer Henry Stommel set out to measure deep ocean currents, their Swallow floats immediately belied

conventional wisdom: the floats moved fast and changed direction in 50 km.

Swallow's discovery was revolutionary. Stommel, Alan Robinson, of Harvard, and Carl Wunsch, of MIT, were energized to discover the structure and dynamics of whatever Swallow had observed. Under NSF funding, they assembled the first large-scale collaborative ocean study, the Mid-Ocean Dynamics Experiment (MODE) that involved U.S. and Soviet Union observers and modelers. Their goal was to develop the analog of weather maps for an ocean region and to use these to learn the phenomenon's dynamics using the day's best numerical models. Using a remarkably objective and cooperative procedure, the MODE team designed a regional array matched to their scientific question, setting a high bar for designing future observing arrays. MODE stretched over the first half of the 1970s and provided a high quality description and dynamical diagnosis of what are now called "mesoscale eddies" (that had made WHOI's mooring work so difficult).



The huge SOFAR float looms over its inventors Tom Rossby and Doug Webb.
Courtesy of Doug Webb

In addition to hydrographic sampling from ships and WHOI moorings, MODE designers had a much improved current-following float to work with. The original Swallow float demanded nearly constant tending by an expensive ship. Tom Rossby, of the University of Rhode Island, and Doug Webb (WHOI) used low-frequency acoustic tracking in the SOFAR channel (the acoustic waveguide that traps sound transmission well below the surface in the MODE region). This extended tracking range well beyond 1000 km. These "SOFAR Floats"[9] were huge (600 pounds) projectors that efficiently transmitted sound to distant moored or bottom mounted listening stations that located them. Freed from ships, SOFAR floats made practical long-duration measurements of currents around the world. Later, Rossby[10] improved on the SOFAR float by reversing the roles of large sound sources and listening stations. In this RAFOS (SOFAR reversed) system, a few large sound sources are moored and many small listening stations are carried by floats that tracked themselves from received signals. This greatly increased the feasibility of deploying large arrays of current-following floats.

Regional and Global Observing Systems

The expensive NORPAX plans for Monster Buoys made Cox realize that moorings were impractical for covering ocean basins. He directed attention toward developing a mix of more sustainable observing tools that could observe air-sea interaction over large areas. These tools included XBTs dropped from commercial vessels and aircraft, satellite measurements of surface temperature, satellite-tracked surface drifting buoys, and Acoustic Doppler Current Profilers (ADCPs) measuring upper-ocean currents from research vessels. XBTs were already widely used, but their accuracy was uncertain and Meredith Sessions and Tim Barnett, of Scripps, made advances understanding and correcting for the errors.[11] Satellite sea-surface temperature (SST) observations disclosed complex patterns associated with major currents and nearly ubiquitous mesoscale eddies, but their SST accuracy was low because the intervening atmosphere affected satellite calibration. Drifting surface buoys were used to reference the satellite measurements.

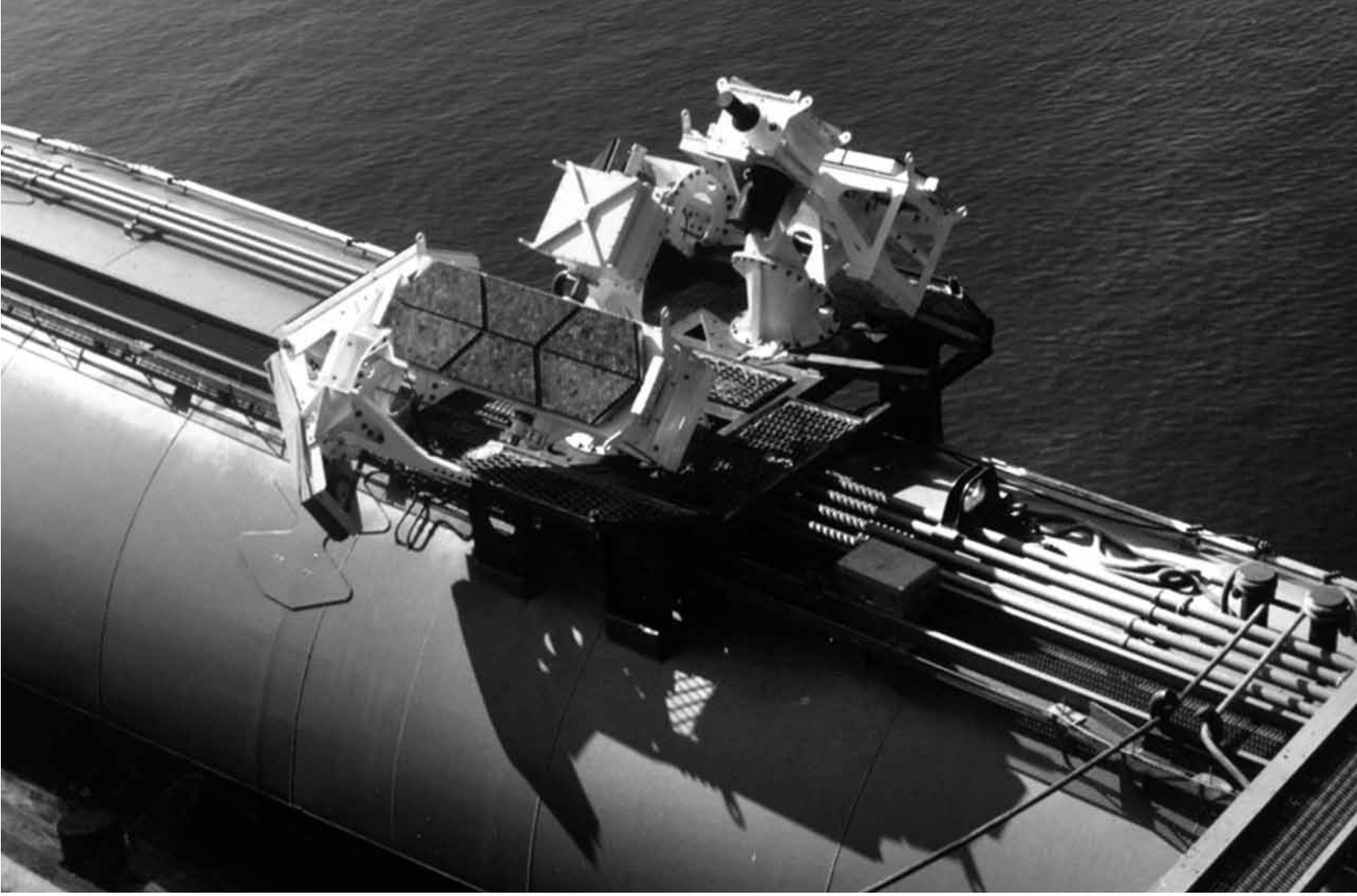
Surface currents have been measured by tracking something drifting on the surface since pre-history. Until the advent of satellite tracking, the surface drifter and observer had to be reasonably close for visual or radar contact. Satellites provided tracking, so the challenge became making the drifter follow upper-ocean currents rather than being blown by the wind. This was done by attaching "drogues" (parachutes or other pliant structures that were hard to drag through the water) to the drifters. The challenge was to make the whole thing hang together for months while following currents. NORPAX testing of heavy weather buoy performance brought tragedy. The same Bill Richardson who began the WHOI Buoy Project and Wayne Hill of SIO were using the RV *Gulf Stream* to test the survivability of NORPAX designs off Maine, in January 1975. For reasons never fully understood, the ship and all hands were lost at sea during what were typically unpleasant but not extreme conditions. Gerald McNally continued the NORPAX drifter program and gathered results that showed dramatic year-to-year changes in the surface circulation of the North Pacific.[12]

A detour in time is required to explain Cox's proposal to develop ADCPs so that ships could measure upper ocean currents in NORPAX. Fred N. Spiess, a veteran of 13 WWII submarine patrols and recipient of Bronze and Silver Stars, brought to Scripps an imagination that made things happen. As head of the Marine Physical Laboratory, he led the development of the Floating Instrument Platform (FLIP) as a platform for acoustics research and Deep Tow, one of the first remotely operated vehicles to survey the ocean bottom at great depth. FLIP is a unique vehicle/platform that has the bow of a ship and the after-body of a submarine.[13] This structure allows the stern to be flooded until the hull is vertical, leaving FLIP's bow sticking above the surface. In this vertical configuration, FLIP is a very stable platform that responds little to the sea or swell. It was first used for research related to military needs, particularly acoustics, but over time civilian research uses emerged.

Spiess and graduate student Rob Pinkel saw that FLIP could hold steady very large acoustic transducers to form narrow sound beams. When the sound from these



Floating Instrument Platform FLIP becoming vertical.
Courtesy Scripps Institution of Oceanography Archives, UC San Diego Library

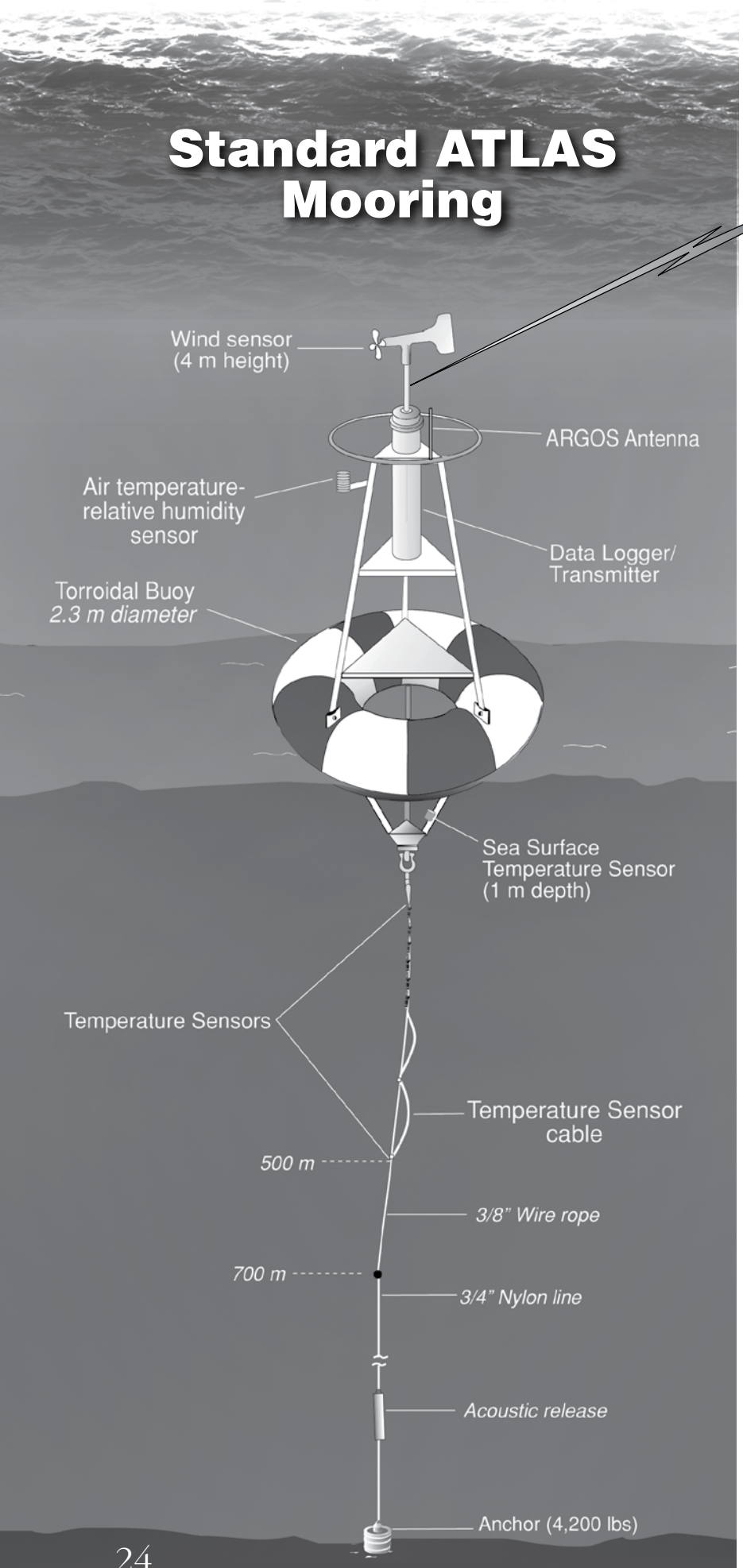


Pinkel's Doppler profilers mounted on the submersible part of FLIP.
Courtesy of Rob Pinkel

beams scattered off small particles, typically zooplankton, it would return with a frequency that was Doppler shifted by the scatterer motion, which is essentially the water's motion. With multiple beams and appropriate processing, ocean velocity could be profiled. Pinkel developed large acoustic transducers mounted to FLIP and a Doppler processing system that was efficient at measuring velocity. He used this pioneering system to probe ocean currents, internal waves, zooplankton migration and stirring in the ocean's upper kilometer.[14]

When Cox saw Ametek-Straza's ship's log, which measured ship motion over the bottom using a Doppler shift principal, he suggested adapting it to profile currents in the way Pinkel did. Lloyd Regier, Scripps' Shipboard Computer Group and I collaborated with Fran Rowe and Kent Deines, of Ametek, to add equipment to the ship's log on RV *Thomas Washington* to extract the Doppler signal. Myriad problems, including ship noise, bubbles that scattered the acoustic beams, and errors in ship compasses and navigation, had to be solved, but by 1978 the ADCP system worked reliably down to about 100 meters.[15] When WHOI put our plans to work on one of their ships, Ametek saw a commercial opportunity and developed a shipboard Doppler unit with improved performance. At the same time, Rowe and Deines left Ametek to start RD Instrument (RDI) and developed their own shipboard ADCP. Today, most research vessels carry an ADCP.

With the success of the shipboard unit, we contracted with RDI to build a self-contained ADCP for moorings. This required miniaturizing everything, adjusting the side-lobes of the acoustic beams to avoid sound reflections off the mooring line, finding a low-power onboard processor



and recorder for the data, and adjusting the Doppler processing scheme. RDI solved these problems, but our testing was delayed because they kindly delivered our prototypes to another new customer. Eventually, we deployed five ADCPs on surface moorings in the Gulf of Alaska to study oceanic response to winter storms.[16] Over nine months encompassing the winter of 1987, the ADCPs worked well except that the tape recorders in units looking down from surface buoys stopped when the first large storms arrived to shake their mechanical tape-transport systems. Today, ADCPs are the standard for current measurements from moorings.

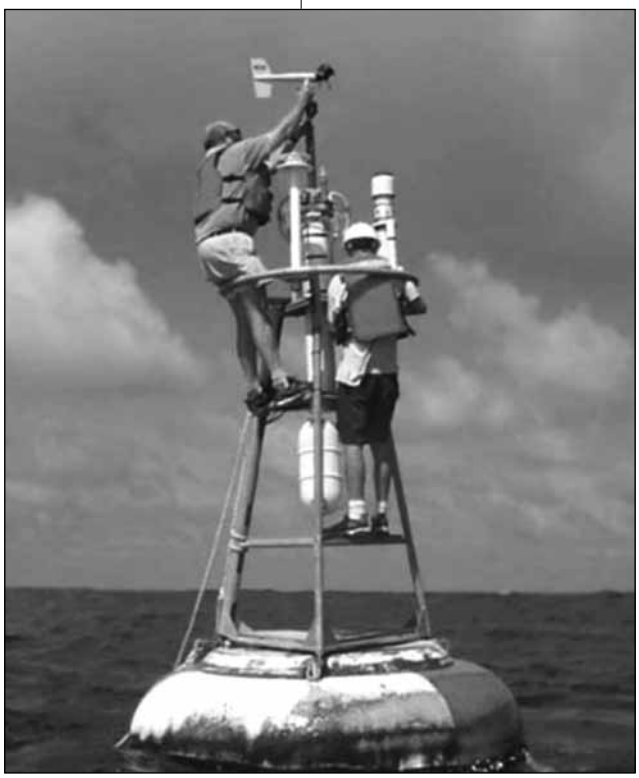
TOGA/TAO

As NORPAX was putting new elements of today's ocean observing systems into the North Pacific to study persistent sea-surface temperature anomalies, scientific interest in climate variability shifted to the equatorial zone in the Pacific. The reasons for this shift were: modeling and theoretical studies indicated that the ocean's influence on the atmosphere was greatest at the equator; time series analyses suggested a connection between the ocean phenomenon El Niño and atmospheric anomalies; and the feasibility of sustained measurements in the equatorial zone had been demonstrated. When David Halpern moved from WHOI to NOAA's Pacific Marine Environmental Lab (PMEL), he used his understanding of WHOI mooring technology to establish successful moorings near the equator. Stan Hayes accelerated this effort by developing a new class of mooring buoys with real time data transmission and greater reliability; he established a small equatorial array in 1984.

Diagram of an ATLAS mooring in the Tropical Ocean Atmosphere (TAO) array.

A productive collaboration of NOAA and university scientists initiated the Tropical Ocean Global Atmosphere (TOGA) experiment, which extended from 1985 through 1994.

As the name indicates, TOGA studied how changes in and over the tropical ocean impacted global climate on seasonal and interannual time scales. Much of TOGA was concerned with new and promising models and one TOGA modeler argued that only one mooring was needed to verify them. Nevertheless, the heart of TOGA was: the Tropical Ocean Atmosphere (TAO) array of equatorial moorings; a ship to service the TAO moorings that also carried out surveys using hydrographic and ADCP sampling; and an extensive array of surface drifters to observe currents. Today, TOGA is credited with establishing the ability to forecast seasonal climate variability, particularly over the Americas, more than six months in advance.[17]



Two PMEL technicians service a TAO-array buoy.
Courtesy PMEL, the Seattle NOAA Lab

The TAO array was a technical triumph that remains part of today's global ocean observing system. Scientific leaders of the effort were Stan Hayes and Mike McPhaden, but the backbone was Hugh Milburn, who made improving the TAO moorings a well-organized engineering project. A big problem was the high cost of servicing the array. This made extending the servicing interval and streamlining sensor servicing essential to minimize ship time. Milburn's team studied failures and inspections and learned; new materials and methods were introduced and procedures improved. By 1994 performance was good, except where vandalism was endemic. The full TAO array included 70 moorings that measured wind, air temperature and humidity, as well as ocean temperature at 10 depths down to 500 m. The utility of TAO data to long-range weather forecasting led NOAA to continue the array after TOGA. Technical improvement continued and the western end of the array was replaced by the allied Japanese TRITON moorings in 1998. TAO remains a mainstay of today's global ocean observations.

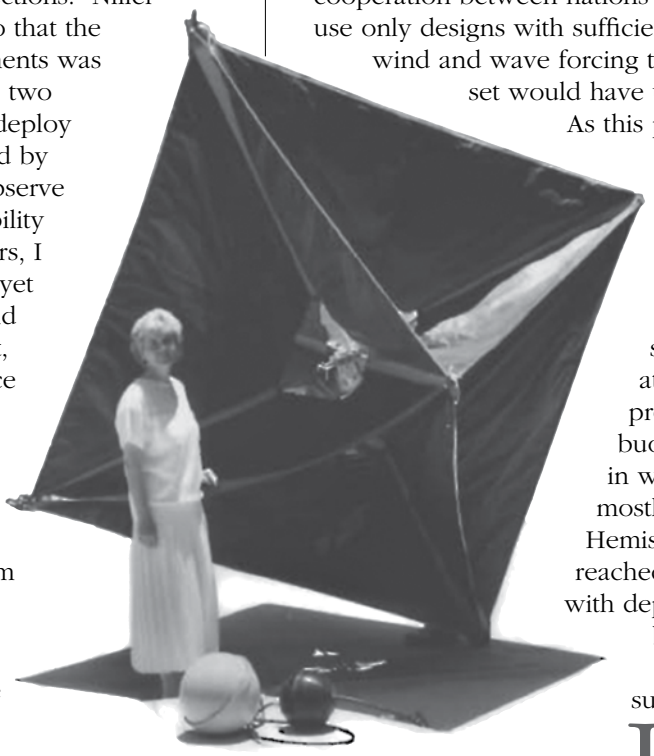
Professor Pearn (Peter) Niiler, who joined Scripps in 1982, was best known for his theoretical skills, but his long interest in tropical dynamics taught him that the ocean was more complex than the TOGA models suggested. Niiler argued successfully to add surface current observations well outside the narrow equatorial zone covered by TAO. Niiler helped organize and implement the TOGA surface drifter program that described tropical surface circulation and measured surface temperatures to reference NOAA satellite measurements, which by themselves had unacceptable errors. The utility of this drifter program led to its continuation after TOGA. Niiler had the dream to map the circulation of the world's oceans. He was irrepressibly creative in art, science and life, so after TOGA he continued to improve satellite-tracked surface drifters, analyze drifter data, and seek funds for a global drifter program.

World Ocean Circulation Experiment

As TOGA was gathering data, another international group was planning the World Ocean Circulation Experiment (WOCE) with the intent of understanding how the ocean transports heat from the tropics to the poles (where it radiates back to space) and what might cause the climate to change over decades to centuries. WOCE was led by Carl Wunsch (MODE) and Worth Nowlin from Texas A&M. The plan was to measure transports through various top-to-bottom sections crossing all the world oceans from shore to shore. Ships would measure density and a large number of ocean tracers across these sections and use density to infer velocity. Contrasts with old data would describe climate change over decades and tracers with built in clocks (like the decay of unstable isotopes) provided measures of the age (usually since touching the atmosphere) of the sampled waters.

Niiler and I argued for broad-scale direct measurements of velocity to supplement the inferences made from the ship sections. Niiler had improved surface drifters[18] so that the effect of wind on their measurements was small and they survived for up to two years. He encouraged WOCE to deploy these devices globally. Impressed by the ability of Swallow floats to observe subsurface currents and of the ability of satellites to track surface drifters, I proposed global deployment of (yet to-be-developed) floats that would drift at depth like a Swallow float, but occasionally rise to the surface to be located.

The World Climate Research Program was convinced that a global array of accurate surface drifters was central to the global ocean observing system that would support both WOCE and tropical climate research. Niiler organized the international Global Drifter Program (GDP), achieving cooperation between nations and an agreement to use only designs with sufficiently low errors from wind and wave forcing that the resulting data set would have uniformly high quality. As this program was put in place, Niiler continued improving drifters to measure surface winds and, amazingly, considering these buoys were frequently submerged by waves, atmospheric sea level pressure. The pressure buoys were of particular use in weather prediction in the mostly water-covered Southern Hemisphere. The GDP array reached its target size of 2005 with deployment of the 1250th buoy and continues today with an expanding suite of sensors.



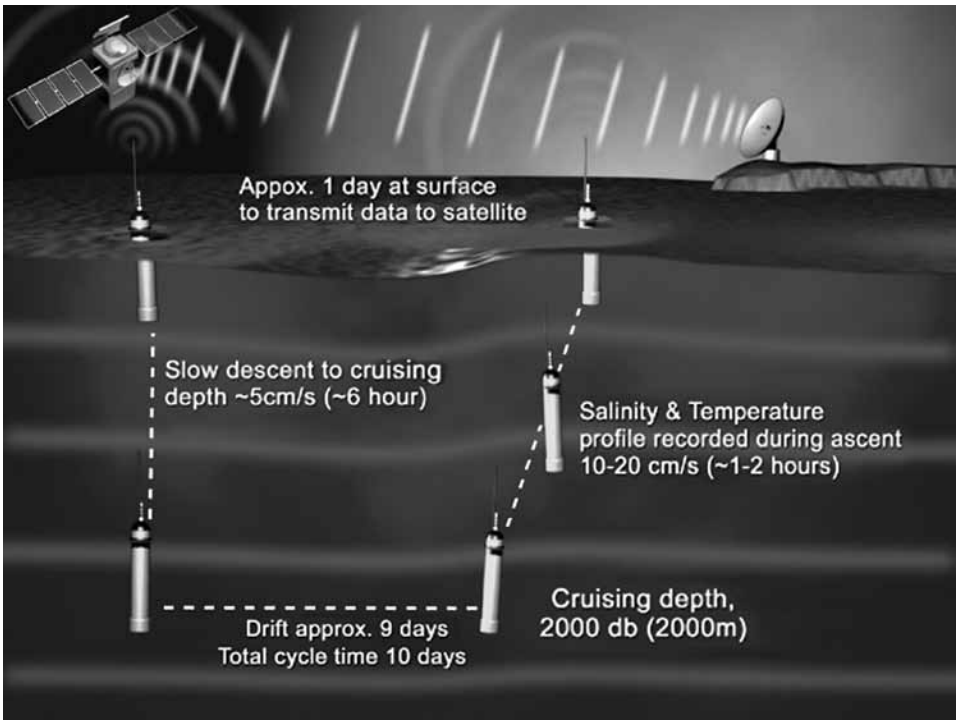
Pictured is the Tristar surface drifter, which consists of a tent-like drogue and two spherical balls.
Courtesy the Author

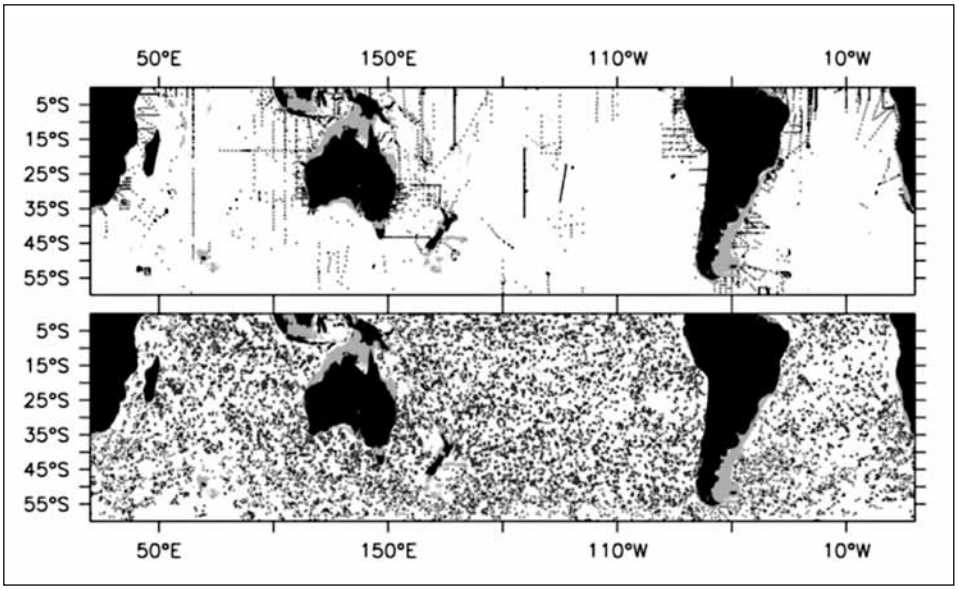
I contracted with Doug Webb (of the SOFAR float) to develop the new surface-tracked subsurface float. He engaged in a several-year search for ingenious ways to make floats change their buoyancy to change depth. I was aware of the Cartesian Diver[19] that Charles Cox (the NORPAX leader) had built to profile up and down while measuring turbulence, and when the time for testing before WOCE became short, I insisted that we abandon exotic buoyancy devices and use batteries and an electric motor to power the volume changes of our profiling float, as Cox had. By 1986, we were



Labrador Sea deployment of profiling float with vanes that measured vertical currents.
Courtesy of George Tupper

testing the prototype of what became the Autonomous Lagrangian Circulation Explorer (ALACE). ALACEs[20] descended to 1000 m depth, drifted for about a month, rose to the surface for locating, and then dove again. Typical lifetimes were 60 dive-cycles over five years. The first deployments in the Southern Ocean were exciting as our prototypes travelled two-thirds of the way around the world in the Circumpolar Current. During the 1990s, Scripps deployed 534 ALACE floats in the South Pacific, Indian Ocean and Southern Ocean. SIO developed an improved "SOLO" float that reported profiles. Some SOLOS, augmented with circumferential propeller blades to measure the vertical component of ocean motion in wintertime deep convection, were deployed in the Labrador Sea. After years of data were gathered, it was possible to produce the first maps of broad-scale currents based on direct measurements.[21, 22]





Argo and Underwater Gliders

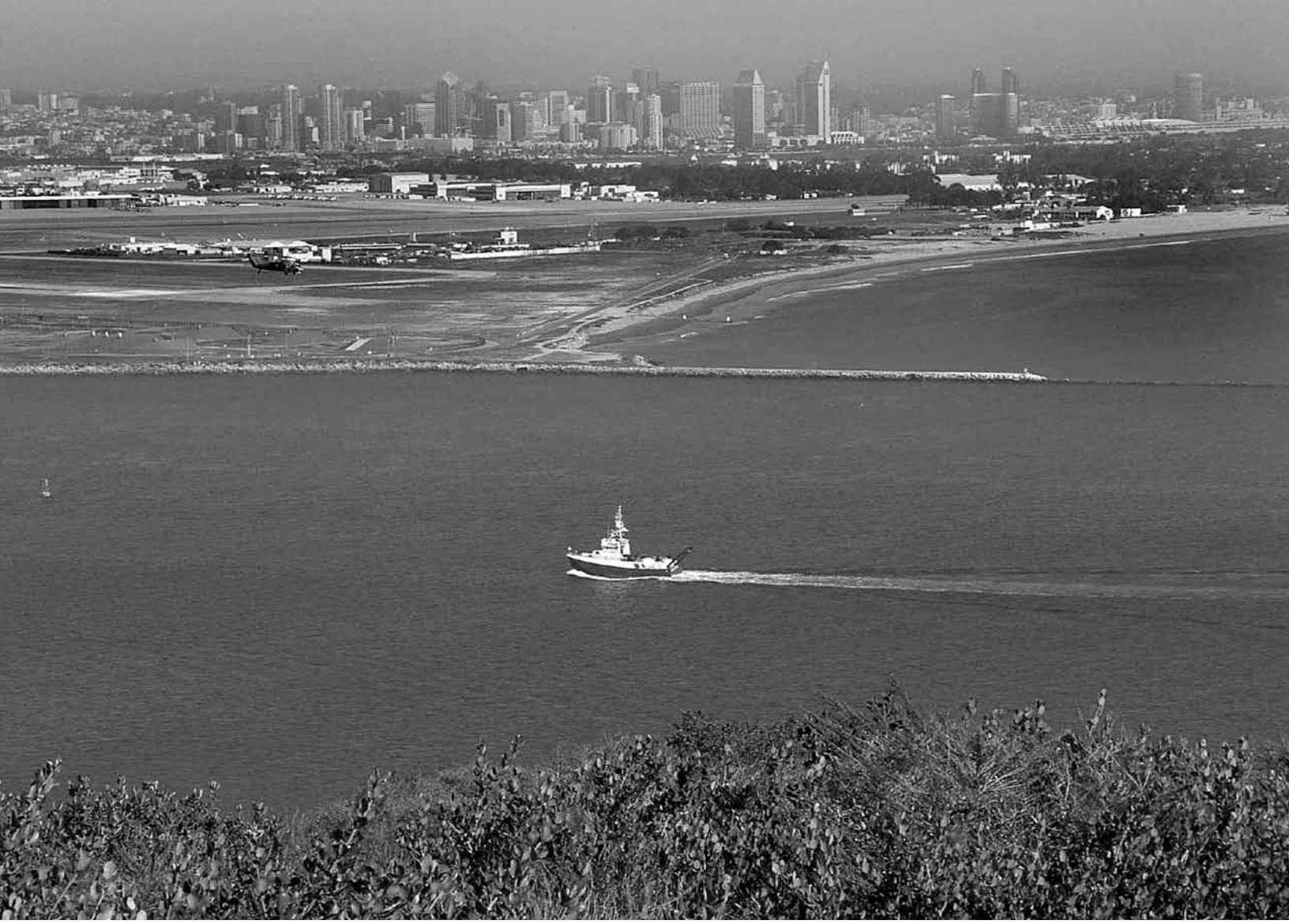
A group led by Dean Roemmich (SIO) was quick to realize that a global array of profiling floats equipped with accurate salinity, temperature and pressure sensors was feasible and could continuously observe geostrophic currents and the transport and storage of heat and freshwater that define the ocean's role in climate. Roemmich's group convinced the NOAA Administrator James Baker that the float array, he called Argo, would fulfill part of NOAA's ocean mission. The group also lobbied U.S. scientists, leadership of the World Climate Research Program, and international scientific groups that the idea was feasible and worthwhile. Baker committed the U.S. to pay for half the array and, with his assistant Stan Wilson, convinced the governments of thirty nations to support the other half. Extensive international planning led to an agreement that produced a global, uniformly distributed array of over 3000 floats profiling to 2000 m depth every ten days.

The upper drawing shows the dive cycle of an Argo float.

The lower pair of charts show how Argo increases measurement density. Top chart shows all measurements from 1950 to 2001 that reach 1000 m depth.

The lower chart shows the location of all 2000-m Argo profiles from 2007 through 2011.

Courtesy the Argo Program



Argo's "little ship that could" RV *Kaharoa* entering San Diego Bay.
Courtesy the Author

The technical key to Argo was an accurate Salinity-Temperature-Depth instrument that ran on low enough power that floats could achieve 100 or more profiles. Sea Bird Electronics developed the needed instrument by modifying their well respected units used on moorings. Scripps and Webb Research Corporation, the latter supported by Steve Riser of the University of Washington, developed floats to use this instrument; manufacturers in other nations followed suit. Argo deployments began in 1998 and the array reached its target size of 3300 floats in 2007. A sophisticated data quality control was put in place and the quality of the resultant profiles was found comparable to shipboard measurements. While the average total cost of a profile in the WOCE global survey was over $10,000, the analogous cost of an Argo profile was less than $250 because ship use was dramatically reduced. This economy permitted Argo to truly revolutionize temperature and salinity measurements by providing sampling where it had been unavailable, particularly below 1000 m depth and at high latitudes through all seasons. This data has become the basis for the operational ocean analyses of thirty national forecast centers and has led to 960-plus scientific publications.

Although Argo floats are autonomous, they need to be deployed everywhere in the world's oceans. Even as design improvements extended float life to four years (150 cycles to 2000 m depth), one quarter of the array must be replaced each year. While the Northern Hemisphere was well covered by transiting research vessels and commercial shipping, the two thirds of the ocean in the Southern Hemisphere was not. Argo devised some

unique and cost-effective solutions. A small (28 m length overall, crew of 6) New Zealand research vessel, RV *Kaharoa*, deployed nearly 1000 Argo floats in the South Pacific and South Indian Oceans. Without that ship, Argo would not be a global array. The multi-national structure of Argo allowed discovery of some even smaller Argo deployment vessels including the 20 m staysail schooner *Lady Amber* that launched 20 floats between Cape Town and Fremantle, and SRV *Discovery* (18 m motor/sailing catamaran) that deployed 15 floats along the Pacific equator.

While ALACE was being developed, Henry Stommel (see Swallow float and MODE) published a bit of science fiction predicting a global array of small unmanned submarines that moved very slowly by gliding, as they cycled up and down in the manner of profiling floats. As SIO struggled to make ALACE reliable, Doug Webb turned to developing such a vehicle, soon called an underwater glider. Anxious to accelerate slow progress, the Office of Naval Research funded glider developments at Webb Research, University of Washington and Scripps. This effort led to three different glider designs,[23] each with somewhat different strengths.

With the ability to fly 1000-4000 km, autonomous gliders are not ready for the global coverage Stommel imagined, but they have proven particularly attractive when launched by a small boat. They are being used in regional observations around the world, including the Arctic. For example, gliders off the coast of Central and Southern California are continuously monitoring alongshore flow, eddies, upwelling, and planktonic response to seasonal and climate variability. They have documented the northward flowing undercurrent and Davidson flow, as well as phytoplankton and zooplankton clustering around oceanic fronts. As interest in the coastal ocean grows, a fleet of gliders may well come to supplement Argo sampling around the ocean's perimeter where Argo sampling density is inadequate and gliders are efficient.



An autonomous underwater glider carrying a salinity-temperature-depth sensor, Acoustic Doppler Profiler that measures shear and acoustic backscatter from zooplankton, and a chlorophyll fluorometer to observe phytoplankton.
Courtesy Robert Todd

Conclusions

Between WWII and the present, oceanography has matured from a specialty of a few physicists and geographers working with occasional ship-based profiles of the ocean. Today's science is based on dynamical principles and a rapidly growing base of global ocean observations. The questions being addressed have gone from "where does the water go," to the fundamentals of how energy from the wind and solar insolation cascade from scales of thousands of kilometers to millimeters and how this process distributes heat and the nutrients that support marine life. Forecast agencies in many nations receive data daily from all over the globe and use it to predict everything from where an oil spill might go, to whether next winter will be cold or warm, dry or wet, in locations around the world.

This progress depended on developments and teams that were led by energetic and innovative people who were, frankly, having a ball inventing new things and using them to discover how the ocean works. As is true of most history, oceanographers tend to think of the major steps along this road as being carried out by a few now-famous individuals like John Swallow, Bill Richardson, Charles Cox, Doug Webb, Peter Niiler and Dean Roemmich. This is correct, but as I hope this article shows, the truth is that the effort was much more distributed. Much depended on the Cold War and space race that brought new technologies, like satellites and micro-electronics, that we could borrow. Beyond that, there was a network of ideas shared by a network of people around the world. There was little money to be made in this effort, but the rewards of intellectual stimulation and satisfaction when things worked were much more effective motivation. Scripps Institution of Oceanography played an important role in this progress, and it remains today a place where ideas can be implemented and proven out.

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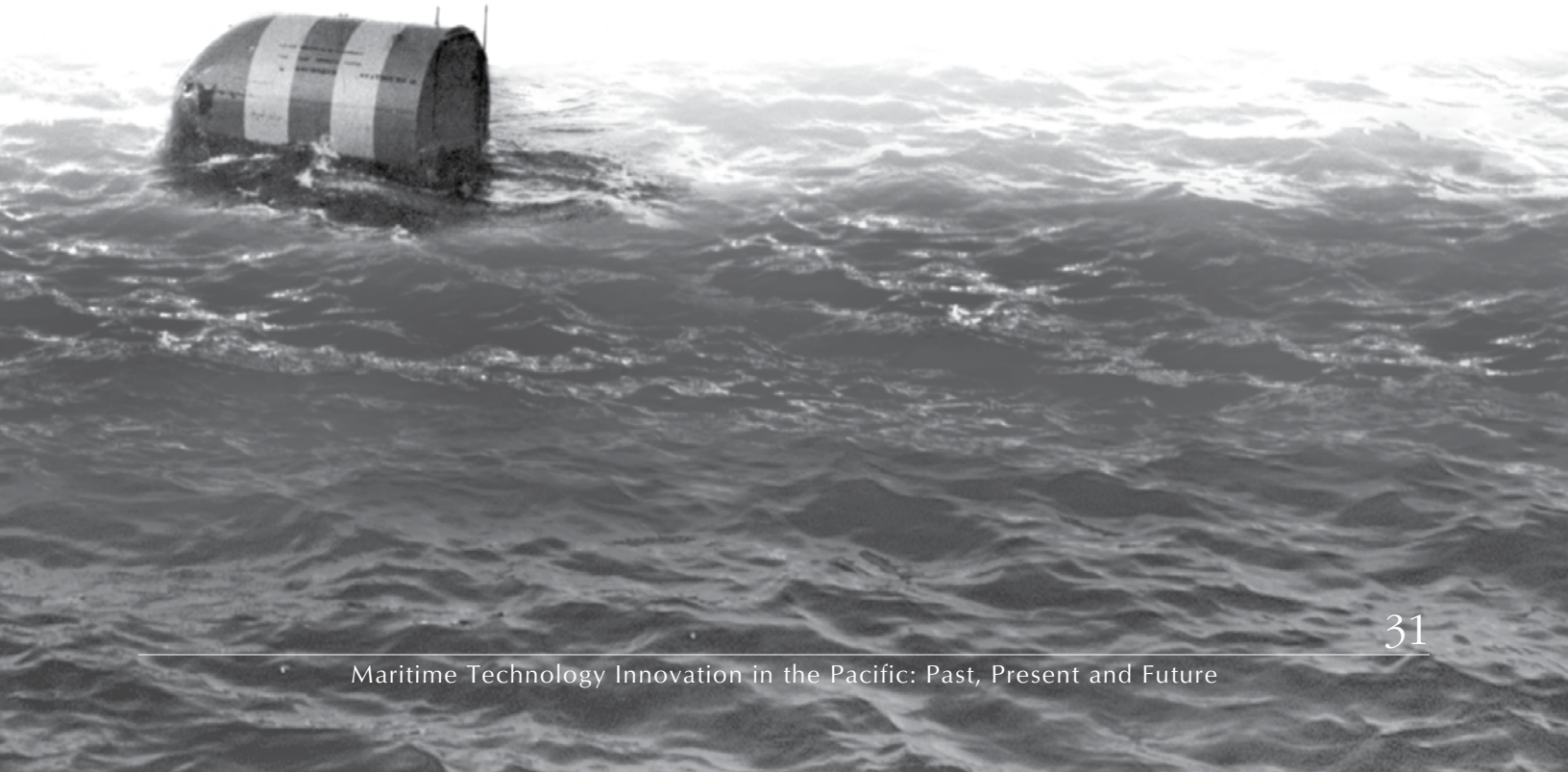
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Information Dominance

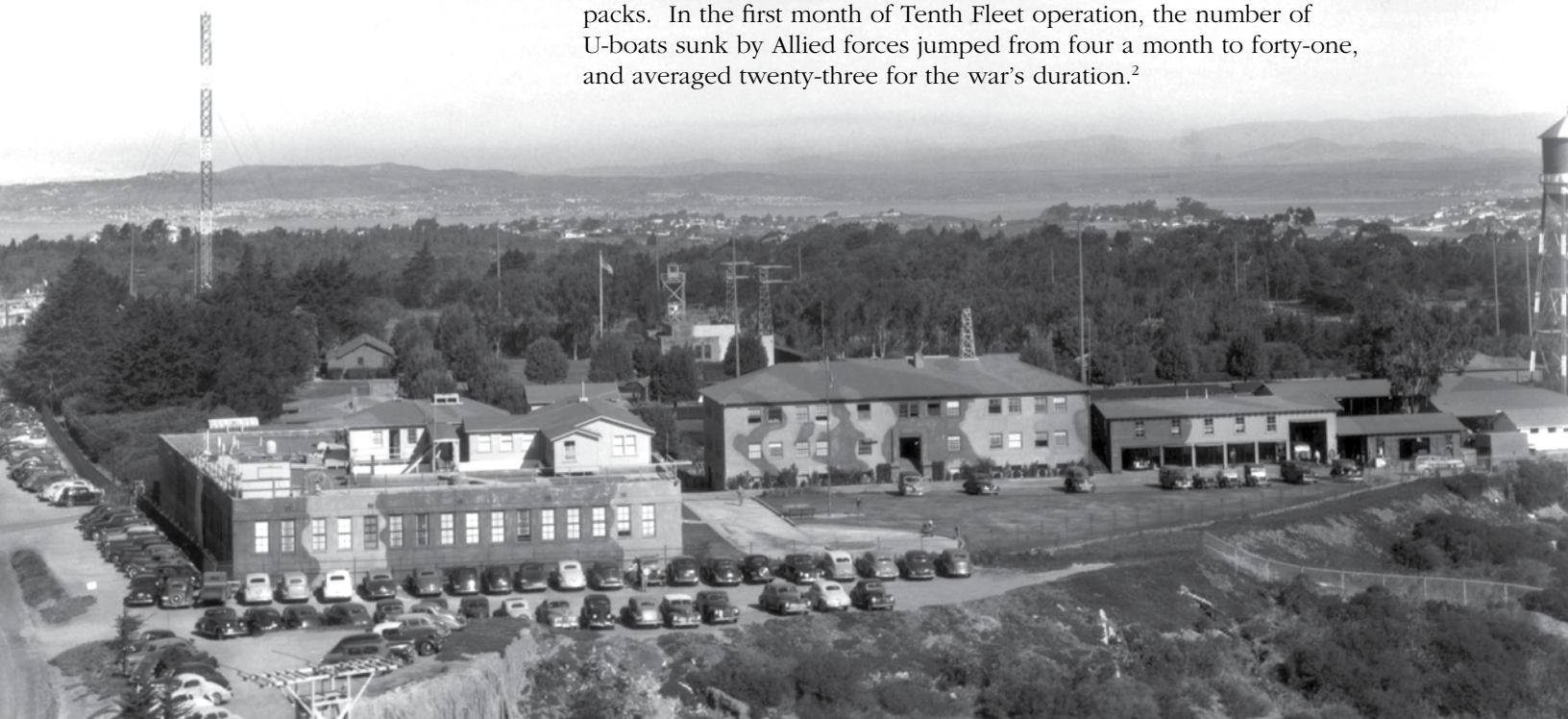
How the Navy's first (and second and third) laboratory on the Pacific provided information resources to the Nation's warfighters to dominate in battle and deter in peace.

By Tom LaPuzza

Conceived in War

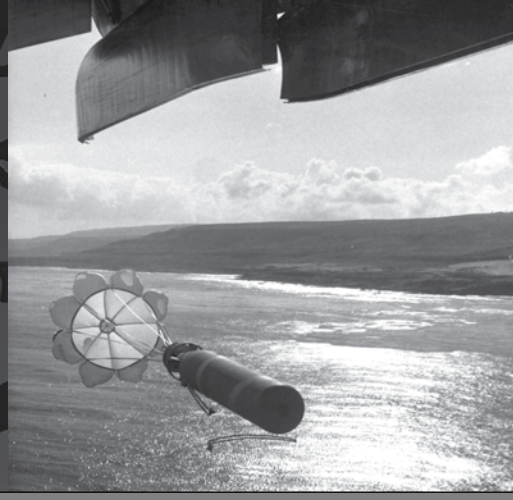
The "war to end all wars" was followed, a mere generation later, by a much more devastating conflict, due in large part to technology. Newly developed weapons: rockets, submarines, heavily armored tanks, aircraft carriers with their deadly contingents of modern warplanes and state-of-the-art ordnance, and two atomic bombs, contributed substantially to the deaths of an estimated sixty million people, a large percentage of them non-combatants, during World War II. While later actions proved the more horrific to civilians caught in the middle, the months before the general conflict were notable for the rendering of a theoretically neutral ocean dangerous, if not deadly, by the presence of large numbers of one of those new weapons. German submarines (*unterseeboot*) operating in the Atlantic, first singly and then in "wolf packs," took an unprecedented toll of merchant ships, with little capability on the part of their escorts to respond.[1]

To counter what it perceived as its most significant threat in the Atlantic at the war's outset, the U.S. Navy began coordinated action against the U-boats in February 1942, culminating in activation for the first time of its Tenth Fleet, an anti-submarine intelligence command, in mid-1943. Located in Washington, D.C., the command gathered and collated information on U-boat locations and operations. Intelligence thus collected led to more effective convoy defense against the wolf packs. In the first month of Tenth Fleet operation, the number of U-boats sunk by Allied forces jumped from four a month to forty-one, and averaged twenty-three for the war's duration.[2]



War-time dictated camouflage for the buildings of the new U.S. Navy Radio and Sound Laboratory on Pt. Loma shown in this 1943 photo. The building on the left, Building 4, was the first headquarters. Building 2, in the middle, was one of the research lab buildings. Both are still in use.

Tom LaPuzza a 1968 graduate of the University of San Diego worked in the Public Affairs Office of what is today the Space and Naval Warfare Systems Center, (SSC) Pacific, from 1969 until 2010. During 18 years of that time, he was Public Affairs Officer for SSC and its predecessor organizations, also serving as the principal spokesman for the Navy Marine Mammal Program. After his retirement in 2006, he continued to work at the Center. LaPuzza is an SSC emeritus. His current project is supporting development of a comprehensive SSC Pacific history for its 75th Anniversary in 2015.



Tenth Fleet was de-activated after the war, slumbering in the naval archives, until a threat considered as difficult to detect and deadly as wolf pack submarines surfaced in recent years. On January 29, 2010, the Chief of Naval Operations (CNO) re-commissioned Tenth Fleet in Maryland, to oversee the Navy's computer networks, information operations and cyber warfare, and to protect that most valuable of commodities and most lethal of weapons – information. The CNO noted that the fleet, like its first instantiation, would depend "less on manned and massed fire power than on intelligence and information." [3]

The two Tenth Fleet commissioning ceremonies on the East Coast, sixty-seven years apart, essentially book-end the existence of a West Coast Navy laboratory whose primary functions have substantially supported the missions assigned to that fleet.

Space and Naval Warfare Systems Center Pacific (SSC Pacific), headquartered in San Diego, traces its direct-line heritage to the Navy's first two technology laboratories on the West Coast, the U.S. Navy Radio and Sound Laboratory (NRSL) and the Naval Ordnance Test Station. NRSL was established June 1, 1940, on San Diego's Point Loma, its 400-foot-high isolation on the peninsula provided an ideal venue for its primary function – improving Navy shipboard communications. Within months of its establishment, however, NRSL was given high-priority tasking to study underwater acoustics, specifically in support of anti-submarine warfare (ASW) efforts to counter the alarming depredations of the wolf packs. NRSL turned to the Hollywood film industry for help, the only source of expertise at the time in electrical recording and sound projection.[4] Thus began pioneering efforts in a multi-faceted study over many decades to understand and utilize underwater acoustics for Navy requirements. That research had significant impact on the lab's programs over those decades for ASW torpedoes, undersea surveillance, navigation, marine mammals, submarine communications, Arctic submarine warfare, and ocean engineering.

The Navy's second West Coast lab, the Naval Ordnance Test Station (NOTS), was established November 8, 1943, in the Mojave Desert at China Lake. Although some favored what the name implied, a war-time facility to test weapons, others hoped for a more permanent base with greater responsibilities. The latter won out, as evidenced by the Secretary of the Navy's letter establishing NOTS, and they immediately launched themselves into the business of designing and developing weapons, as well as testing them.[5] The mission of some of the key early NOTS weapons was anti-submarine warfare. As the laboratory in San Diego was administered by the University of California, the lab in the desert was the outgrowth and, in fact, the direct development of the war-related program at California Institute of Technology (Caltech) in Pasadena. Caltech's World War II projects included an ASW rocket and its attendant Mousetrap launcher; its small size allowing weapon launch from an array of small ships the Navy included in its ASW fleet during the war.

Through a complex history of re-organizations and mergers (see page 43), a partial successor of the NOTS organization merged with the organization that succeeded NRSL to form the Naval Ocean Systems Center in 1977. Following additional mergers and re-organizations, coupled with actions of the Defense Department's Base Closure and Realignment Commission, the organization is today's SSC Pacific.

It is an organization with a lengthy list of assigned technology development areas, all contributing to and summarized in the underlying theme implied for many years and specifically stated in recent ones – information dominance, that is, ensuring U.S. and allied warfighters have the information and information tools needed to execute their missions successfully and return home safely, while denying those resources to the enemy. It is a mission substantially in support, once again, of the recent re-instantiation of Tenth Fleet.

The seven-decade history of SSC Pacific began with a focus on two technology program areas of critical importance to the Navy – electronics and weapons.

Electronics Lab

NRSL, as noted above, was commissioned in mid-1940 to conduct research to improve radio transmission and reception, radar and sonar. Based on a National Academy of Sciences recommendation for fundamental research on underwater acoustics, the University of California established its Division of War Research in the spring of 1941 to administer NRSL. The joint organization, formally titled UCDWR at the U.S. Navy Radio and Sound Laboratory, was sited on Point Loma for isolation for communications research, but also for proximity of deep water, a nearby Navy sonar school, and available real estate – most of Point Loma was already owned by the federal government.

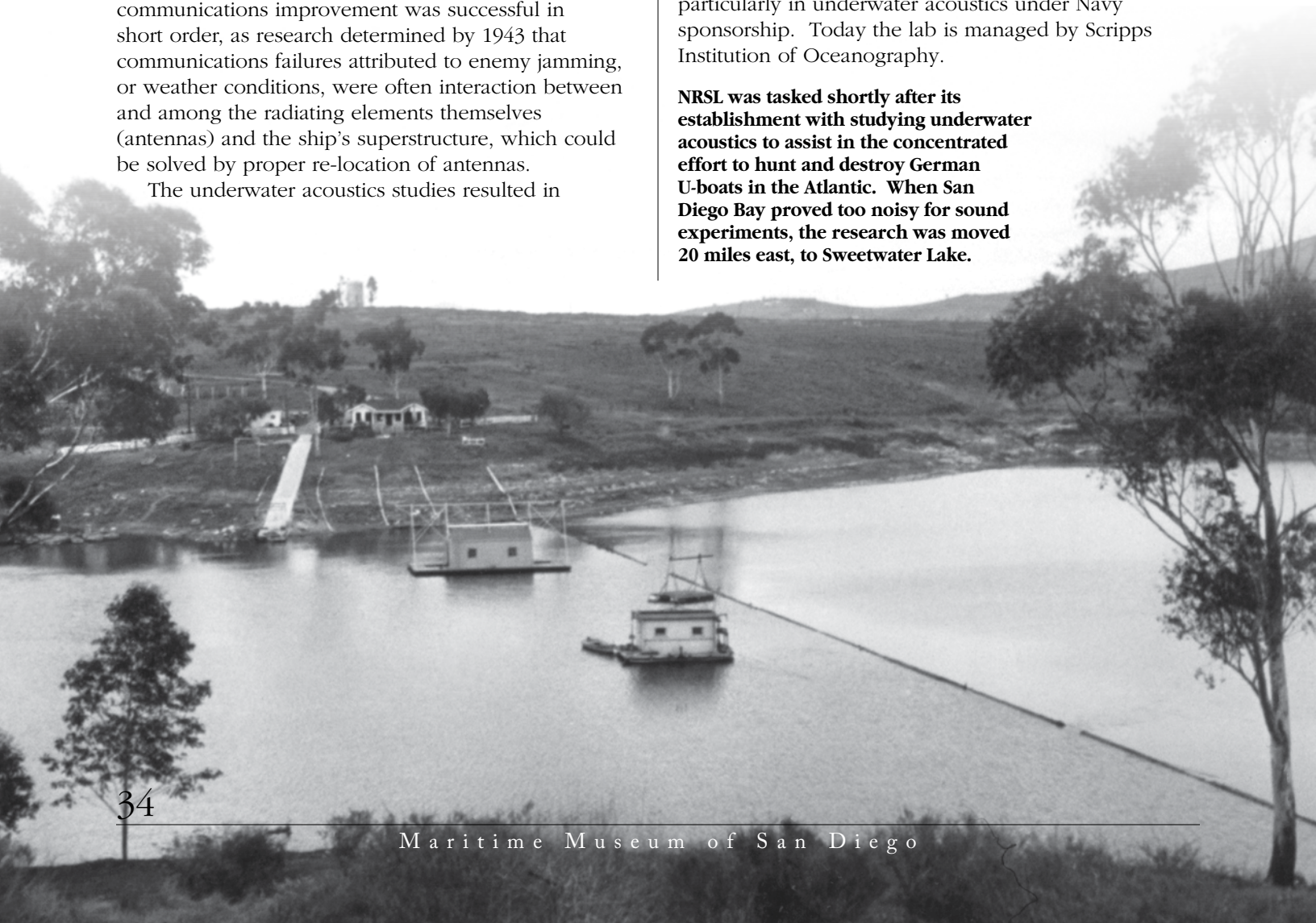
NRSL had required little real estate at its establishment, since its total complement was one officer, nine enlisted personnel and three civilian scientists. However, the numbers increased dramatically during the war – NRSL grew to 150 personnel, UCDWR to 575. The lab's mission of communications improvement was successful in short order, as research determined by 1943 that communications failures attributed to enemy jamming, or weather conditions, were often interaction between and among the radiating elements themselves (antennas) and the ship's superstructure, which could be solved by proper re-location of antennas.

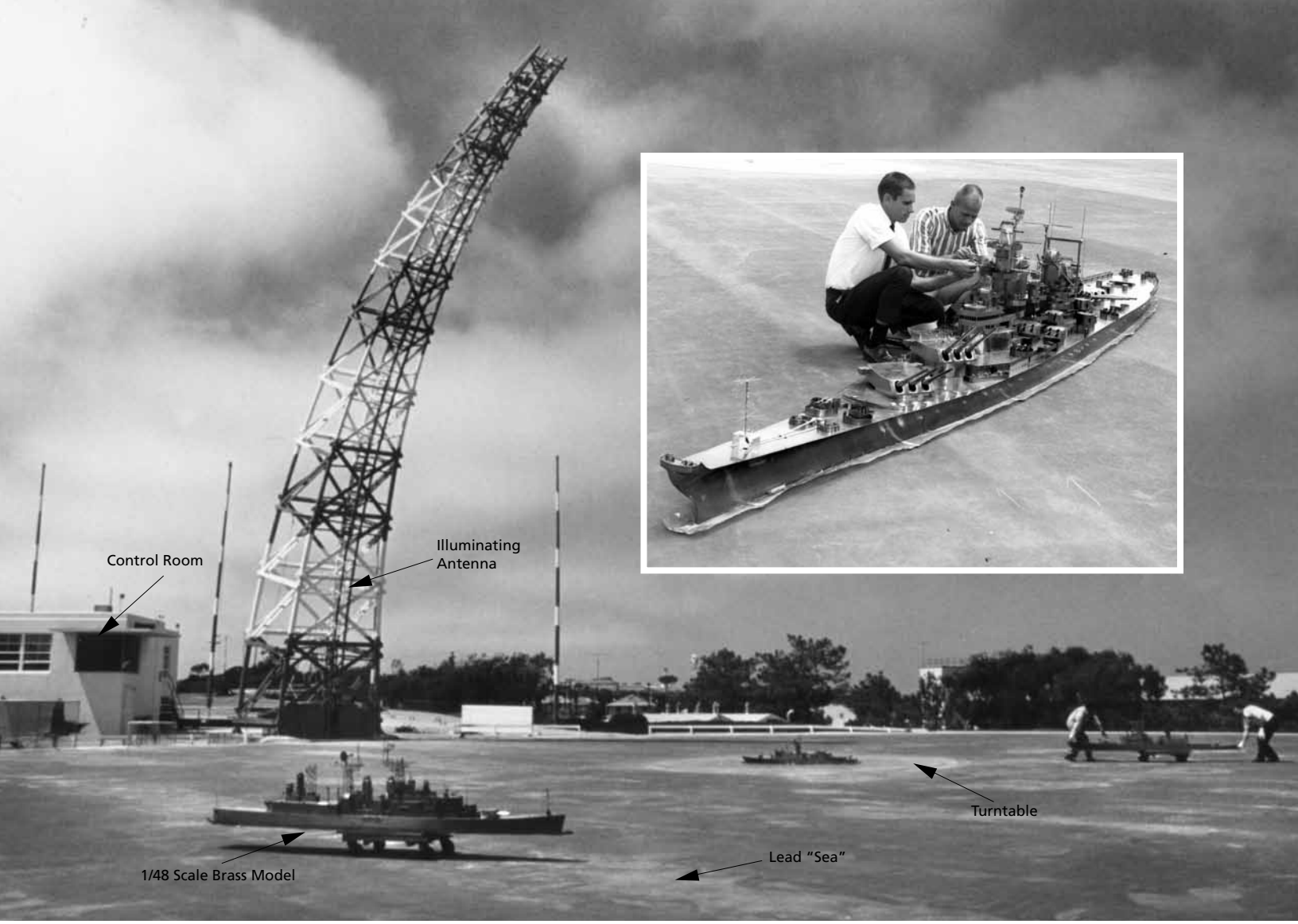
The underwater acoustics studies resulted in capabilities both for ASW and for evasion of enemy sonar. In addition, the lab tested the Navy's first operational radar set, then trained pilots and radar operators in its use. Sound decoy devices to simulate submarines and navigation devices were among war-focused efforts of the lab.

The post-war stand-down was typical with troops discharged, ships mothballed, units decommissioned, with one notable exception, the Navy laboratories. They had made significant contributions to the victory, and were not only maintained, but they were expanded. The UC/NRSL lab in San Diego became the U.S. Navy Electronics Laboratory (NEL), with a wide range of responsibilities in employing electronic technology to meet Navy requirements. The principal focus was basic research into acoustic propagation in the atmosphere and underwater, improvement of electronic systems on ships, and the development of more effective radios, radars and sonars, including operator training.

A number of the UC/NRSL scientists maintained their University affiliation after the war. In 1946, the Marine Physical Laboratory was established at NEL to continue basic scientific research, particularly in underwater acoustics under Navy sponsorship. Today the lab is managed by Scripps Institution of Oceanography.

NRSL was tasked shortly after its establishment with studying underwater acoustics to assist in the concentrated effort to hunt and destroy German U-boats in the Atlantic. When San Diego Bay proved too noisy for sound experiments, the research was moved 20 miles east, to Sweetwater Lake.





A zenith arch provided lab engineers a means of determining the source of, and correcting, interference to shipboard communications, exchanging signals with 1/48th scale brass model ships.

Beginning in 1947, construction of a model range allowed more formal studies of shipboard antennas. Model range engineers used scaled-down model ships (the standard is 1/48) and proportionally scaled-up radio frequencies to perform precise measurements that not only reduced communication interference, but allowed substantial reduction in the numbers of required antennas. After re-engineering by NEL, the amphibious force command ship USS *Mount McKinley* was re-commissioned, its communications requirements fully met with only one-third the antennas previously carried.

The lab's post-war technology development included precision navigation systems, identification friend or foe technology, oceanographic research, and electronic warfare simulators. The underwater acoustics research supported studies in mine warfare, submarine navigation and physical oceanography. Emergence of computer technology prompted development of computer systems and programming languages, particularly valuable for shipboard information and command and control systems.

As the lab approached the end of its second decade, its numerous programs and projects resulted in several remarkable achievements prompting national and world headlines:

August 3, 1958: The Navy's first nuclear-powered submarine, USS *Nautilus*, reached 90° North and passed under the North Pole submerged under the polar ice cap, piloted between shallow sea beds and jagged ice keels by NEL's Dr. Waldo Lyon.[6] One of the first Point Loma employees, his keen interest in the Arctic resulted in the lab's leadership in establishing the Navy's capability to operate nuclear submarines in the ice fields. The following March he was ice pilot and science adviser aboard USS *Skate* as it surfaced through the ice at the North Pole. President Kennedy's personal presentation of the Distinguished Federal Civilian Service Award for the Arctic efforts had an alternate recipient, as Dr. Lyon, submerged in his work, sent his wife to accept.



The USS *Skate* surfaced at the North Pole in 1959

The historic three-submarine rendezvous at the North Pole in 1986. The officer in charge of the operation, Captain Merrill Dorman, USN, was the Director of the Center's Arctic Submarine Laboratory.

January 23, 1960: Two years later, thousands of miles southwest, and miles deeper, the bathyscaph *Trieste*, operated by the lab, descended into the abyssal depths of the Challenger Deep of the Mariana Trench near Guam, touching absolute ocean bottom at 35,800 feet.[7]

August 26, 1960: The Navy Department announced the world's first all-digital system, the Navy Tactical Data System (NTDS), developed by three contractors whose products NEL coordinated, completed and fielded. NTDS automated shipboard processing of sensor information that provided senior officers the means of analyzing the environment around them for threats. It was the beginning of the lab's leadership, usually as system engineer, integrator and installer, of the Navy's principal surface ship command and control systems.

1961: NEL completed construction of a 60-foot-diameter, solid parabolic antenna reflector to support basic research in radio physics, and to advance future communications employing satellites.

With what it learned from that research, NEL installed the first shipboard satellite antenna seven years later, aboard the guided-missile cruiser USS *Providence*. After initial demonstrations that the lab's low-cost equipment met service requirements, six Atlantic Fleet ships equipped with the antennas participated in the Navy's first large-scale test of satellite communications. During the exercise, engineers on Point Loma demonstrated long-distance relay of tactical data to the aircraft carrier USS *Independence* in Norfolk, Va. Efforts proceeded to establish a Navy-wide satellite communications capability, with the San Diego laboratory leading the program.

In addition to land, sea surface and space communications, the lab also provided effective means of communicating with operational submarines, including deeply submerged ballistic missile boats, using low-frequency/very low-frequency technology, as well as satellite systems.

Many technology developments over the next several decades were possible based on unique facilities, such as the Transducer Evaluation Center, which provided a precisely controllable environment for continued underwater acoustics studies, and the Integrated Circuits Fabrication Facility, whose ultra-clean environment allowed major advances in integrated circuit technology. The lab eventually became the DoD production facility for non-commercial chips. To further testing of new information display and processing technology in the emerging computer age, a facility was built in the lab's headquarters building to replicate a shipboard combat information center.

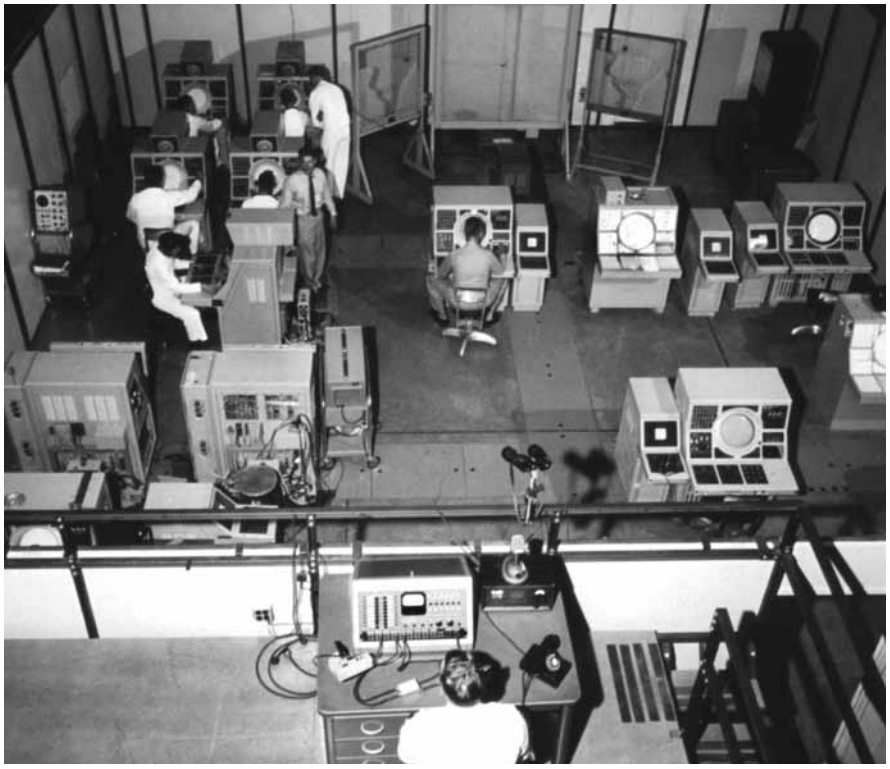
Lasers, increasingly sophisticated radars, automated shipboard and submarine communication systems, and a system for thermal mapping of the oceans were products of the lab during this period.

Weapons Lab

While the San Diego lab was supporting Navy electronic requirements, the lab to the north was demonstrating similar capabilities in weapon development. Principal contributions of NOTS to the war effort were ASW torpedoes, radio proximity fuzes and rockets. Prior to establishment of the station, Caltech engineers had transformed the Mark 13 air-dropped anti-ship torpedo from the dangerous dud of the Battle of Midway to the weapon of choice for the Battle of Leyte Gulf.[8] NOTS continued pursuit of ASW torpedoes, as well as "throw-ahead" rockets fired from small launchers.

The NOTS post-war experience was similar to that of the San Diego lab – rather than the reductions facing troops, platforms and bases, the station surged in personnel, funding and construction. In the desert, a large pilot plant had been constructed just before war's end to extrude rocket propellant. Office space, housing and recreation facilities contributed to a desert building boom.

In Pasadena, the rocket production work was contracted out to General Tire and Rubber Company, whose large facility (a handful of miles from Caltech) would eventually become Navy property and whose employees, shortly, would become Navy civilian personnel. NOTS Pasadena continued the Caltech torpedo program with development of an acoustic homing torpedo; the first lightweight ASW torpedo designed for launch by helicopters, fixed-wing aircraft and surface ships; and an electrically powered, acoustic homing torpedo, the Mark 44, with a unique new feature, an active sonar. At Fleet introduction in 1958, the weapon's launch platforms were aircraft and surface ships. Within months, lab engineers would modify it for helicopter launch and see it as a payload on another Center development, the Anti-Submarine Rocket (ASROC). Although the Navy sponsor requested a nuclear depth charge as ASROC's payload, NOTS, less taken with the inflexibility of a nuclear weapon, suggested the Mark 44 torpedo as an alternative. The sponsor agreed, and station engineers completed the design for dual payloads. When, decades later, the Navy transitioned its new-construction surface ships (USS *Spruance* class destroyers, USS *Arleigh Burke* guided missile destroyers, USS *Ticonderoga* guided



The Navy Tactical Data System was the world's first all-digital system. Mocked-up in the lab's headquarters building, it provided engineers a means of testing before installing the system on Navy ships, and as a venue for training users.

missile cruisers) to vertical launch systems for their weapons, the lab re-designed ASROC for vertical launch. It served as the principal surface ship ASW weapon.

One of the station's most significant developments was the Mark 46 torpedo (see opposite page), an active/passive acoustic homing weapon designed to counter increasingly faster and larger, and more lethal, Soviet submarines. Its seeker head could home in on the target's radiated noise or, lacking that, switch to active sonar. Additionally, the torpedo featured the most revolutionary guidance system since World War II. Perhaps of most significance was the fact the Navy lab supervised the entire process of torpedo research and development, testing, production, assistance with Fleet introduction, and continued maintenance and in-service engineering. The Mark 46 was carried by ships of more than a score of allied navies for decades.

Like any new technology, and conceivably more so, a weapon must be extensively tested before it is put in the hands of users, and weapons testing can be expensive. Shortly after World War II, NOTS devised two major improvements in testing capabilities. One, a 300-foot-long torpedo tube mounted in what looked like a railroad bridge at the Morris Dam test facility, allowed testing of torpedo water-entry in a manner replicating launch from aircraft. Of more significance in supporting development, while reducing costs, was a hydrodynamic simulator. The simulator increased markedly in complexity, sophistication, and thus in value over the decades, allowing designers to simulate hydrodynamic conditions, acoustic and pressure parameters, and target characteristics. The ability to put an actual torpedo guidance and control system in the simulation loop enhanced its value.

While simulation allowed multiple tests at substantial cost savings, eventually the weapon required testing at sea. The station's ranges near Long Beach and around San Clemente Island were the usual test sites. Since much of the critical test data was recorded on the torpedo itself, recovery following the test was essential to allow analysis. The Cable-controlled Underwater Recovery Vehicle (CURV I), one of the world's first remotely operated vehicles, provided a safe, reliable means of recovering torpedoes and other objects from the seafloor, including hardware at depths inaccessible to divers.

The Navy's most lethal weapons are its submarine-launched ballistic missiles, the Navy's component of the Nation's strategic weapon triad. The weapons lab played the key role in developing the "pop-up" capability to get the first of those missiles, Polaris, away from the sub and high enough above the water for the flight motor to activate and boost the missile to the target. (The electronics lab in San Diego, meanwhile, solved a significant problem in inertial navigation for Polaris.) The weapons lab performed substantial testing on all three of the Navy's ballistic missiles, and on succeeding ones, Poseidon and Trident, solved critical navigation and launch problems. On April 14, 1960, NOTS engineers demonstrated the first Polaris underwater launch culminating in powered flight, a few months before the missile was installed in the launch tubes of the Navy's first ballistic missile submarine, USS *George Washington*.[9]

While NOTS engineers in Pasadena were developing torpedoes and launching missiles, the stuff of legends was occurring out in the desert, in the person of a young man who had spent the last eight years studying a few miles from the Pasadena facility. Dr. William B. McLean, a physicist with three degrees from Caltech, arrived at NOTS in 1945, after brief but important assignments at the University of Iowa and the National Bureau of Standards. The latter assignment, working on radio proximity fuzes and rocket and missile development, led him to China Lake. Within months of his arrival, he conceived the idea for an anti-aircraft weapon that would revolutionize air warfare.

Nearly as important as the weapon would be his exceptional approach to its development. His unorthodox methodology was: *if a part of your engineering process is not working, don't try to solve it, eliminate it.* In the case of the Sidewinder air-to-air missile, he suggested eliminating dependence on guidance control from the launching aircraft, designing the weapon with the control unit inside and taking advantage of an integral aspect of the target to guide the weapon. Within a decade President Eisenhower would personally present him a special gold medal, one of the first, for his development of the heat-seeking Sidewinder.

During several years of recognition (LIFE magazine called him "the Navy's top handyman"), the "legendary" part of the story was McLean invented Sidewinder in his garage. While numerous ingenious devices emerged from that venue, the fairly simple concept of a weapon that tracked the heat radiating from its target required a substantial investment in time, money and brainpower to turn it into a reality. McLean employed a dozen engineering teams on various aspects of the weapon, including five design teams working on the most critical component, the heat-seeking head. Throughout his career, while thinking far into the future, imagining possibilities, he never forgot the old inspiration/perspiration percentages, and committed not only himself but significant numbers of others to engineer an idea to a successful conclusion.

While he continued hands-on participation in projects, McLean's efforts had vaulted him to the top







civilian position of NOTS Technical Director less than a decade after his arrival. Surrounded by the success of Sidewinder, significant advances in ASW torpedoes and ballistic missile testing, Dr. McLean switched gears, or rather the focus of his interests. His attention now on manned submersibles and marine mammals, he sent trusted associates to Hawaii to scout locations for a lab to address those new interests.

Then an interesting, perhaps coincidental, event occurred. In 1967, the Navy announced major re-organization of its laboratory community, as the service sought to establish "core laboratories," centers of excellence, in critical fields. The weapons laboratory (NOTS) was re-designated the Naval Weapons Center, and continued its efforts on surface- and air-launched weapons in the desert. Its Pasadena Annex, specializing in underwater weapons, joined with the Undersea

The weapons laboratory played a major role in the development of all three of the Navy's submarine-launched fleet ballistic missiles, including the first live launch of Polaris (above), the Mark 46 anti-submarine warfare (ASW) torpedo (top right) carried by the U.S. Navy and a score of its allies, and the Vertical Launch Anti-Submarine Rocket (right) – the surface Navy's ASW stand-off weapon.

Technology Department of the electronics lab in San Diego to form the new Naval Undersea Warfare Center (NUWC), the prototype for the new core laboratory. NUWC's headquarters was established initially in Pasadena but moved a year later to San Diego, which provided closer water access and room for the expansion necessitated by increased tasking. (After another year, the name changed to Naval Undersea Research and Development Center, finally shortened in 1972 to Naval Undersea Center, NUC.)

The electronics lab, minus the underwater acoustics and Arctic research work, which also transferred to the undersea warfare laboratory, continued making major improvements in communications and information-processing technology. Given a new name that was so unpopular it lasted only a few months, it reverted to a slightly altered Naval Electronics Laboratory Center (NELC) in 1968.

At the outset of these changes, Dr. McLean, who had spent more than two decades at China Lake, accepted appointment as Technical Director of the new NUWC, the Navy's third laboratory on the West Coast. He retained his office at China Lake initially as re-organization and lab establishment details were addressed.

Even before he left China Lake, he dispatched personnel to Hawaii to begin facility set-up there. By the summer of 1968, the lab was up and running, with bottlenose dolphins training for operational Navy tasking, and a prototype manned submersible on open-house display, signaling initiation of major underwater observation and work system development at the Hawaii Lab.

Technology Development Continues

Organizationally, NEL/NELC and NUWC/NUC continued to pursue separate technologies for the next decade, while located within physical sight of one another on the heights and on the waterfront of the Point Loma peninsula.

Significant electronic lab programs included a major effort at automating submarine communications and development of a synthetic aperture radar. Ground-breaking atmospheric propagation studies supported communications improvement programs. That research resulted in a prediction system enabling operational commanders to assess the effect of refractivity in the atmosphere on their sensors and weapons, a capability since deployed on all the Navy's aircraft carriers.

The undersea warfare laboratory addressed a wide variety of technology challenges, including:

- Substantial improvement of the Mark 46 torpedo. With realization of Soviet submarine advances, the Center was named lead laboratory for a leap-ahead Advanced Light-Weight Torpedo, which ultimately became the Mark 50. Torpedo development, testing and simulation continued in Pasadena until 1974, when the laboratory's employees and projects moved to San Diego.
- The lab assumed responsibility for the new field of undersea surveillance, essentially the long-range detection and monitoring of submarines. Improvements were made, including addition of digital signal processing, to the bottom arrays of the Sound Surveillance System (SOSUS), a stationary and dedicated resource to track the burgeoning Soviet submarine force. Augmenting those permanent capabilities were SOSUS-like towed arrays, ship-mounted systems that provided mobile platforms for similar purposes that could be deployed anywhere a ship could steam.
- Important but smaller programs included environmental research programs in San Diego and Hawaii, the latter of which was cited with the first Secretary of the Navy environmental improvement award.
- In 1966, CURV I garnered world headlines when it recovered a hydrogen bomb from the floor of the Mediterranean Sea. Seven years later, an improved model, CURV III, made its own headlines for its role in the rescue of two submariners stranded 1,475 feet underwater in the North Atlantic. (See related article on undersea vehicles, pages 46-59.)
- In addition to development of small, shallow-water submersibles and deep-ocean work systems, the lab provided major support to the Navy's Man-in-the-Sea Program, and several lab personnel, and a dolphin, participated in the Sea Lab experiments.

Consolidation

In 1977, after years of close physical proximity but little organizational interaction, the Navy consolidated NELC and NUC, as a cost-saving strategy. More importantly, the new organization, Naval Ocean Systems Center (NOSC), demonstrated the synergy of pursuing sensing (ocean surveillance), combined with information processing (command and control) and information sharing (communications) components, and the reactive element (weapons). Also, at the first level of importance in its tasking was the capability to pursue the target of choice into its most hostile and inaccessible environment – Arctic submarine warfare.

The consolidation furthered the Navy's quest to gain information dominance, ensuring own-force access to



The warfighter at sea is particularly in need of information to determine appropriate action. In the early 1980s, the Center designed and installed a dedicated space on all the Navy's aircraft carriers for the senior officer of the carrier battle group, so he could effectively fight the 8-10 ships, one or two subs, and 80-90 aircraft at his command.

information and information technology, denying those resources to the enemy. The NOSC-developed surveillance systems – undersea, surface and space-based – collected information on the huge ocean environment surrounding Navy ships and submarines, as did the research associated with Arctic submarine warfare; command and control systems furnished the processing power to analyze that vast amount of data and render it into a form meaningful to and supportive of the warfighter; communications technology allowed increasingly rapid means of moving that information to those who needed it; undersea weapons provided an effective means of dealing with that part of the environment that was hostile and threatening.

Command and control technology that had originated with the groundbreaking NTDS evolved and gained complexity, providing increasing utility to personnel at every level, from the individual sailor at his or her station, to the ship's captain, to the carrier battle group commander, to the fleet commander-in-chief. When DoD directed the services to discontinue development of service-specific (termed "stovepipe") systems and seek joint capabilities, NOSC played a key role in fielding joint command and control system hardware and software serving every level of command. In addition to information-processing systems, it has been the premier developer of command centers, including the first dedicated shipboard space for the embarked battle group commander, constructed on all Navy aircraft carriers in the 1980s. That effort was followed up recently with in-depth study of and design work on the command centers for the Navy's 21st Century carriers.

Basic research in radio waveforms and integrated circuit technology has been transitioned into new capabilities for satellite communications. With its expertise in this area, the Air Force selected NOSC as the lead lab for developing the technology to manage the assets of the joint service Military

Strategic and Tactical Relay (MILSTAR) satellite communications constellation. Throughout most of the 1980s, the center led the effort to upgrade submarine communications resources.

In the weapons area, the Mark 50 ASW torpedo was nearing completion and poised for fleet introduction at the end of the 1980s. A sophisticated new ASW Control System developed by the center provided the capability to employ automated sensor data to detect, localize, classify, track and prosecute underwater targets in much greater numbers at much greater ranges.

Navy Re-organization Base Closure

NOSC proceeded with its increasingly complementary electronic and weapons development for a decade and a half, until the Navy directed major re-organization of its seven R&D laboratories and 29 engineering centers in the early 1990s. Based on timing, the Navy folded that into the Department of Defense (DoD) Base Closure and Realignment Commission (BRAC) process, which provided a non-political means of shuttering unneeded bases. In the BRAC '91 process, the electronic and undersea weapon center's simple and descriptive title (Naval Ocean Systems Center) was transformed into the challenging Naval Command, Control and Ocean Surveillance Center (NCCOSC) Research, Development, Test and Evaluation Division (abbreviated as NRaD). There were both negative and positive aspects to the realignment process: the undersea weapons work and Arctic submarine research and operational support were transferred to other labs. At the same time, two Navy commands and a significant portion of a third were merged into NRaD, which assimilated expertise in software development for major command and control systems, integration of Navy payloads on DoD launch vehicles and the Space Shuttles, and navigation capabilities for fleet ballistic missile submarines and the Global Positioning System.

A subsequent BRAC closed the Hawaii Laboratory, transferring its marine mammal and undersea vehicle programs to San Diego.

The re-organization that created the NCCOSC RDT&E Division also created two In-Service Engineering Divisions (NISE West in San Diego and NISE East in Charleston, S.C.) In 1996, the West Coast Division was merged into NRaD. The major significance was the organization was now full-spectrum: Not only did it research, design and develop new information technology for Navy shore stations and surface, undersea and air platforms, it also installed, maintained and repaired them. The merger added installation and maintenance facilities in Hawaii, Guam and Japan to the command.

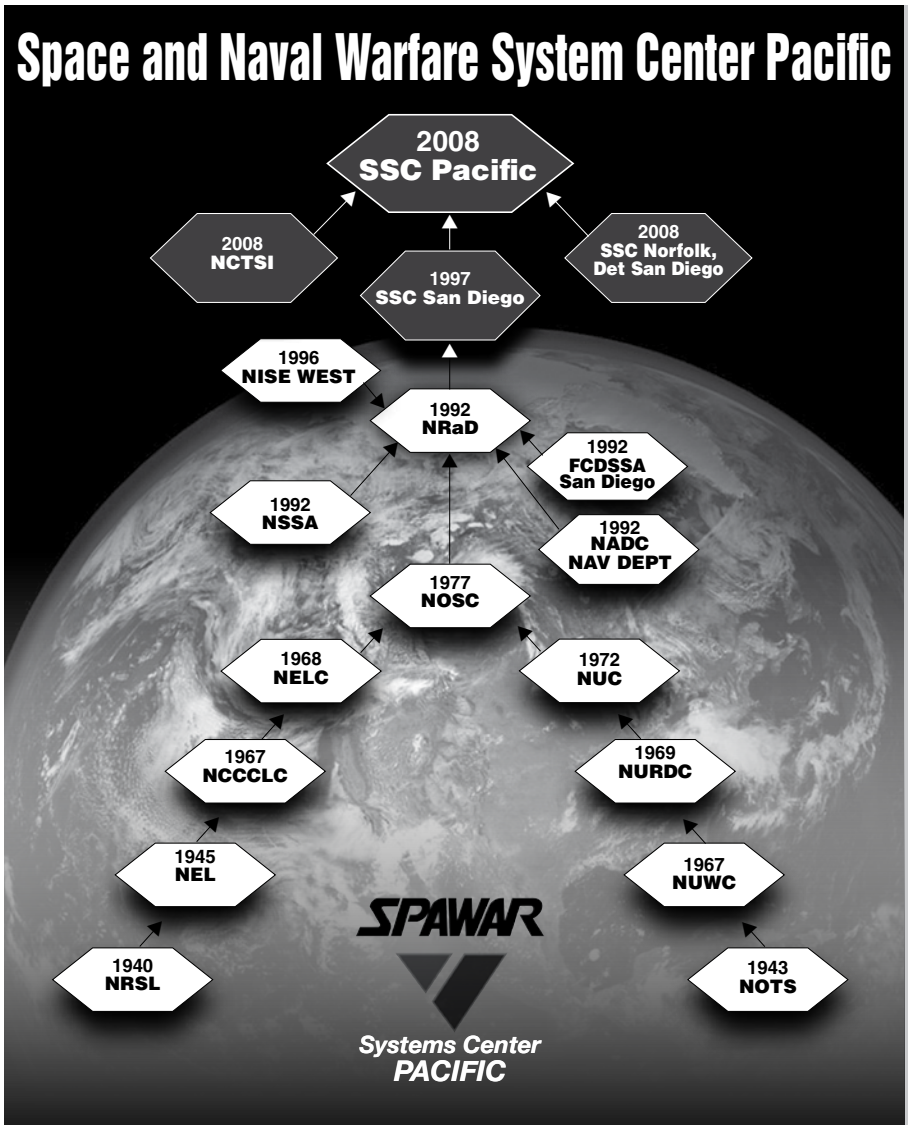
As part of the BRAC 1995 process, Space and Naval Warfare Systems Command (SPAWAR), NRaD's senior command, was transferred to San Diego. The transfer more closely aligned sponsor funding and direction with the RDT&E process exemplified by the laboratory on Point Loma and with the actual end users – the fleet, specifically in this case the U.S. Third Fleet, homeported in San Diego. With this transfer and closer alignment, NRaD's name changed yet again, to Space and Naval Warfare Systems Center (SSC) San Diego in 1997, and, with subsequent minor re-organization, to the current SSC Pacific in 2008.

Despite the major name changes and minor modifications in tasking, the center's assigned mission remained essentially the same, expressed in a major warfare area titled "C4ISR," the expansion of which is: Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance. Detailed explanation would take many pages; however, in reasonable terms, the purpose of C4ISR can be viewed as answering seven questions of life-and-death importance to the captain of a ship or submarine, the commander of an aircraft, or the individual warfighter. They involve the basic information required to complete the mission successfully and return home safely: detection (What platforms are out there, near our position?); localization (Where are they?); characterization (What are they doing?); classification (Are they friendly, unfriendly or neutral?); threat assessment (Are the unfriendly ones likely to take hostile action?); analysis (If so, what should I do about it?) Added to those is a final critical question: *Where am I?*

Complexity notwithstanding, a warfighter with that information readily available is in a reasonable position to execute the assigned mission. C4ISR, the conglomerate of complex technologies pursued in hundreds of SSC Pacific projects, provides that information.

War on Terror

As we initiated this study of the Navy laboratory on Point Loma with establishment just prior to and in the middle of a war, so we close in a similar vein, discussing subsequent conflicts. The Cold War, with massive spending on the technology of conflict, ended without a major battle or a peace treaty; it concluded more with a throwing in of the towel. NOSC/NRaD/SSC felt justified pride that its innovation, brainpower and hard work in developing critical technologies had been a solid factor in the quiet demise of the superpower adversary.



SSC Pacific Organizational History

SSC Pacific	Space and Naval Warfare System Center Pacific
NCTSI	Navy Center for Tactical Systems Interoperability
SSC Norfolk, Det. San Diego	Space and Naval Warfare Systems Center Norfolk Detachment San Diego
SSC San Diego	Space and Naval Warfare Systems Center San Diego
NRaD	Naval Command, Control and Ocean Surveillance Center RDT&E Division
NISE West	Naval Command, Control and Ocean Surveillance Center In-Service Engineering West Coast Division
NSSA	Navy Space Systems Activity
FCDSSA	Fleet Combat Direction Systems Support Activity
NADC	Naval Air Development Center
NOSC	Naval Ocean Systems Center
NUC	Naval Undersea Center
NURDC	Naval Undersea Reseach and Development Center
NUWC	Naval Undersea Warfare Center
NOTS	Naval Ordnance Test Station
NELC	Naval Electronics Laboratory Center
NCCCLC	Naval Command Control and Communications Laboratory Center
NEL	U.S. Navy Electronics Laboratory
NRSL	U.S. Navy Radio and Sound Laboratory

Lurking in the shadowy background, however, were the next critical conflicts. Americans woke on September 11, 2001, to discover to their horror something that had not occurred in more than two centuries – the enemy had come ashore on the continent and killed thousands of Americans going peacefully about their daily business. A number of the perpetrators had died with them, leaving the masterminds in remote hidden locations. Military leaders called for a war, not on a superpower or a dictator backed by troops and weapons but on an anonymous thing called "terror."

The Point Loma laboratory responded with a series of initiatives that put civilians into the war as they had never been before, even in World War II. Their technology to support the Global War On Terror was a weather forecasting system, dolphins and sea lions, an air traffic control system, a portable command center and robots. Even their weapons testing, done many years earlier on surface ship- and submarine-launched Tomahawk cruise missiles, contributed to the "shock and awe" of the U.S. response to 9/11.

Space and Naval Warfare Systems Center Pacific's technologies in the fight:

Meteorology and Oceanography (METOC) integrated data from environmental satellites, shore facilities and on-site sensors with weapon system data and other intelligence to provide an accurate assessment of environmental conditions potentially affecting the mission. In late 2001, a METOC system was scheduled for installation on the nuclear aircraft carrier USS *John C. Stennis* in thirty months. The day after 9/11, the Navy ordered installation in thirty days to meet the ship's upcoming deployment schedule. The Center teamed with its sponsor and senior command SPAWAR, and a number of contractor organizations, and met the deadline. The carrier sailed on schedule, with the updated weather system contributing substantially to the embarked air wings' capability to hit critical targets in Afghanistan.



The Center's contributions to Operation Iraqi Freedom included swimmer defense dolphins and sea lions protecting coalition ships in Bahrain, and dolphins supporting the force of coalition divers clearing mines in the Iraqi harbor of Umm Qasr. The device on the dolphin's pectoral fin is a transmitter to assist in re-uniting animal and trainer separated in the fog of war.

Knowledge Wall The SSC-developed large-screen SmartBoards and web-based enabling technologies that allowed warfighters to "capture" knowledge generated during operations and distribute it in real time to improve the speed of command. One was installed for evaluation aboard the nuclear aircraft carrier USS *Carl Vinson*, deployed to the Fifth Fleet operating area. The battle group commander abandoned "testing" and employed the capability as his primary planning tool for taking the fight to the enemy within days of 9/11.

Marine mammals The Center's swimmer defense dolphins had been deployed to Vietnam in 1970, to protect an ammunition pier. In early 2003, a planned upgrade employing California sea lions was deployed to Bahrain to provide security for coalition ships tied up at the pier. In the spring, the operational swimmer defense dolphins replaced the sea lions, remaining for a record-breaking two-and-a-half year deployment. SSC Pacific civilian personnel were assigned to the combat area throughout the period to provide health care and training. Dolphin mine-hunting systems, never before deployed in combat, were flown to Iraq at the start of Operation Iraqi Freedom, and played a key role in clearing mines from the harbor of Umm Qasr.

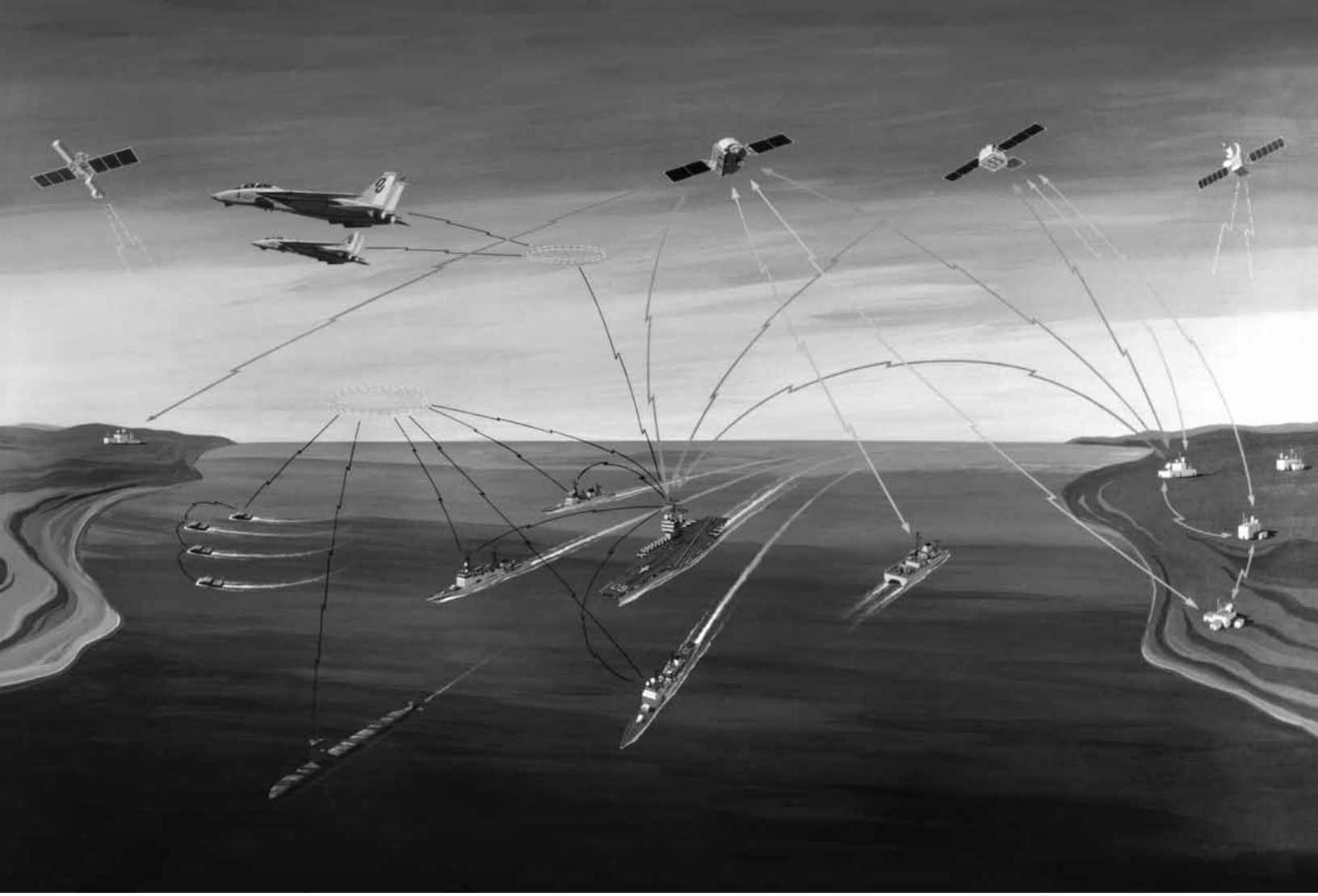
Robots Days after 9/11, on September 15, several of the center's robots, with a small number of center civilians, were flown to Ground Zero to aid in rescue operations. They deployed immediately from there to Afghanistan, to assist in tunnel clearance and prosecution of Improvised Explosive Devices.

The **Marine Air-Traffic Control And Landing System** is a self-sufficient, self-contained, easily transportable system maintained by SSC to support all-weather air operations. One system was moved into Iraq at the outset of Operation Iraqi Freedom and has been there ever since, supporting more than 200,000 aviation operations annually, including medical evacuations, combat sorties, and cargo flights. It allows Marines to launch and recover helicopters, fighter planes and unmanned aerial vehicles safely, sometimes using local roads as the "landing strips." Despite aging equipment and the harsh environment, SSC has kept the system operating for eight years, day and night, in clear weather and blinding sand storms.

The U.S. Central Command, headquartered in Florida, was tasked with leading Operation Iraqi Freedom. Faced with the need for a command structure in theater, CENTCOM turned to SSC Pacific, which in short order constructed and fielded the Command Deployable Headquarters, from which the command fought the war. As noted above, the Center has been involved heavily in development of command centers, which now include Headquarters 21, the Nimitz-MacArthur headquarters for the U.S. Pacific Command in Hawaii. In addition, it made substantial contributions to a major upgrade of the White House Situation Room.

Concluding Remarks

As stated earlier, the conclusion of worldwide conflict in 1945 that signaled the discharge of personnel and decommissioning of ships contrarily led to expansion of the Navy's laboratories. The San Diego-based laboratory grew from its original ten military and three civilian scientists to today's 2,200 scientists and engineers, 250 military and 2,000 additional staff. Highly educated and motivated, they continue seven decades later to serve the Navy and the Nation with innovative products designed to support the warfighter. That means providing the most necessary and essential product – information – at the precise time and in the exact place the warfighter needs it to complete his mission. Today's most pressing challenge is exemplified by the recent re-commissioning of Tenth Fleet, ensuring that the information gathered at such great investment of time and money is protected not only from unauthorized eyes and the enemy, but from cyber terrorists.



SSC Pacific supports the Navy and the Department of Defense in establishing viable means of communication and data exchange between and among platforms on the ground, on and under the sea, in the air and in space, providing U.S. warfighters information dominance.

All Images Official U.S. Navy Photos

Notes

1 One of the most notable of these attacks, which often continued over several nights, occurred October 16-19, 1940, when a mass of U-boats attacked two convoys, SC7 and HX79, sinking 34 ships in three days. The actions came to be known as "The Night of the Long Knives." (See www.uboataces.com/tactics-wolfpack.shtml, accessed November 4, 2011)

2 www.public.navy.mil/fcc-c10f/Pages/history2.aspx, accessed January 20, 2012

3 www.navy.mil/search/display.asp?story_id=50954, accessed January 12, 2012

4 NOSC TD 1940, *Fifty Years of Research and Development on Point Loma, 1940-1990*, (San Diego: Naval Ocean Systems Center, September 1990), 8.

5 Albert B. Christman, *History of the Naval Weapons Center, China Lake, California, Volume 1. Sailors, Scientists and Rockets: Origins of the Navy Rocket Program and of The Naval Ordnance Test Station, Inyokern* (Washington, D.C.: Naval History Division, 1971), 179-181, 194.

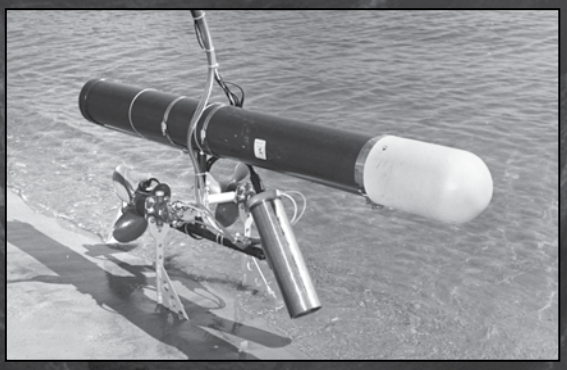
6 William M. Leary, *Under Ice* (College Station, Texas: Texas A&M University Press, 1999), 130.

7 George W. Martin, Lt., U.S. Navy. "Trieste–The First Ten Years," *U.S. Naval Institute Proceedings*, 90 (8)(1964), 56. The author preemptively responds to potential claims the depth was not the "actual deepest spot," estimating it to be within "a thousand feet" and suggesting inaccuracies in measuring instruments might preclude ever knowing the precise depth. The more important point was not "holding the world's mythical record," but recognizing and exploiting the potential opportunities afforded by deep submergence programs.

8 NOSC TD 1940, *Fifty Years of Research and Development on Point Loma, 1940-1990,* (San Diego: Naval Ocean Systems Center, September 1990), 15-16.

9 Cliff Lawson. *History of the Naval Weapons Center, China Lake, California, Volume 4.*, Chapter 3. In press.

SSC Pacific: Underwater Vehicle Development



By Tom LaPuzza

It all started with a test torpedo that sank. A torpedo is expected to sink, of course, because its strategy is to explode underwater, producing a large hole in a ship's hull and thereby upsetting the carefully planned balance of displacement air that allows the heavy mass of metal to float in the first place. Test torpedoes, on the other hand, do not explode, but run their course and then, with their fuel expended, they float to the surface. This optimizes their recovery, a significant benefit because test torpedoes are expensive and re-usable, and, most importantly, much of the data to be analyzed is recorded by and on the torpedo itself.

Space and Naval Warfare Systems Center Pacific (SSC Pacific), the Navy's first (and part of the second) laboratory on the West Coast, provides the technology that allows Navy, Marine and other U.S. warfighters to collect, process, analyze, understand, and utilize information to their advantage, and to the detriment of opposing forces. In language important to its sponsors: SSC Pacific supports U.S. military information dominance.

As detailed in the previous article, however, the two 1940s laboratories that eventually merged to form SSC Pacific (one dedicated to electronics, the other to weapons) initially pursued efforts in underwater acoustics and weapons development to counter the World War II German U-boat threat in the Atlantic. The acoustics research led to sonar development; the principal weapons were anti-submarine warfare (ASW) torpedoes.

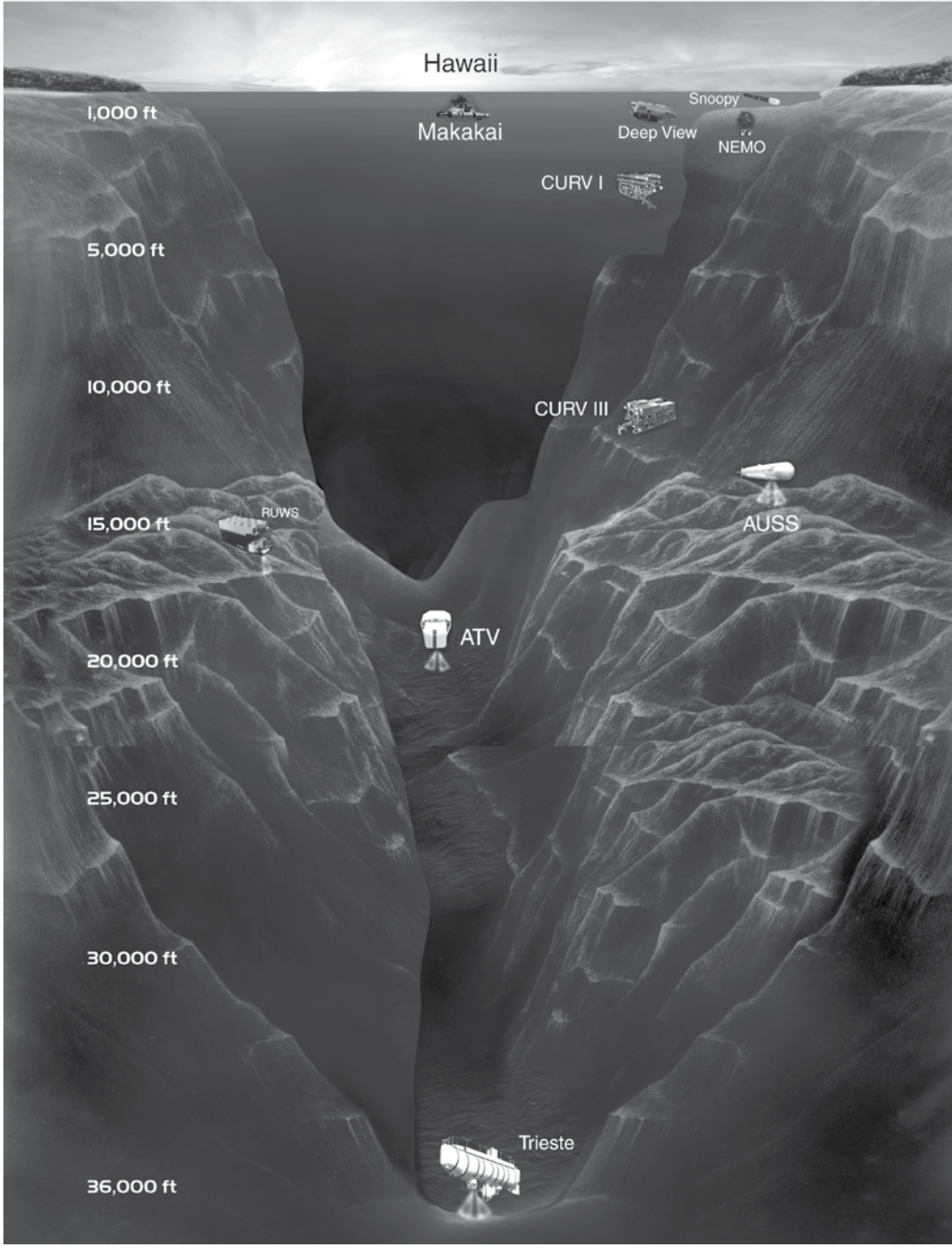
Anti-submarine warfare development continued after the war. At-sea torpedo testing, critical to the development and evaluation process, required a means of recovery for analysis of data gathered by the weapon during its run. In the late 1950s, the technology available for the task was a barge with a center well, through which a rectangular frame was lowered on wires to retrieve the torpedo from the bottom, which at the weapons laboratory's Long Beach sea range was about 2,000 feet down. The recovery process was "antiquated, very time-consuming, very expensive…. Sometimes they took as long as four days to recover a unit," according to Larry Brady.[1] A contractor on another project at the time, Brady became the operator of the technology that replaced the rectangular frame.

The weapon developers' dream, he said, was "a robot they could drive right up" to recover the torpedo. A commercial vehicle designed to support an underwater cable operation was purchased and stripped of its poorly functioning equipment, essentially down to its frame and buoyancy tanks. Lab personnel rebuilt it with new thrusters, sonar, TV cameras, lights, and a grabber claw, and christened it the Cable-controlled Underwater Recovery Vehicle (CURV). On the test range, CURV and its crew were able to recover a torpedo in a matter of hours, and early on recovered four torpedoes in a single day.

Thus began the many-decades history of underwater vehicle development and involvement at what is today SSC Pacific. That history comprises ten manned vehicles including a bathyscaph and a Navy submarine, nearly two dozen unmanned vehicles, and ancillary craft, platforms and structures, all directed toward two important missions: to provide the Navy underwater work capabilities, from shallow water down to extreme ocean depths, and to allow humans the opportunity to view the underwater environment in an "up-close-and-personal" manner.

Manned Vehicles

The underwater vehicle involvement actually started before CURV, with a request from the Office of Naval Research (ONR) that the electronics lab evaluate potential use by the U.S. Navy of the bathyscaph *Trieste*, purchased by ONR from Swiss designer Auguste Piccard. Lab personnel began diving *Trieste* off Point Loma just before Christmas in 1958. In all, nearly 80 dives were made to study geology, marine biology and characteristics of the water column, with a special series called Project Nekton to test the vehicle's depth capability. The most critical single dive was made January 23, 1960,

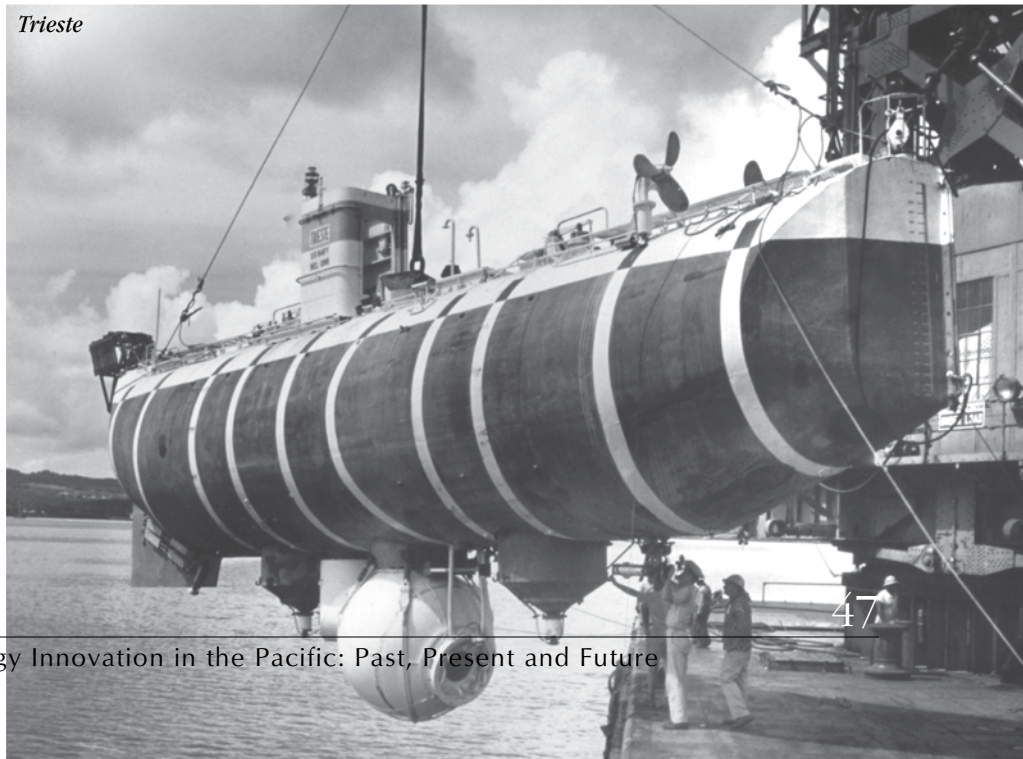


Right: Depth chart illustrating depth capabilities of various Center underwater vehicles, from the 100 feet of Snoopy to the 35,800 feet of *Trieste*.

The bathyscaph *Trieste* (below), operated by the Navy lab on Pt. Loma, descended 35,800 feet in 1960 to demonstrate U.S. Navy access to any ocean depth. The cylinders fore and aft of the pressure sphere carried ballast pellets that were jettisoned to bring the craft back to the surface.

when the San Diego team located the ultimate ocean depth in the Challenger Deep of the Mariana Trench, 200 miles southwest of Guam. With Piccard's son and a U.S. Navy lieutenant aboard, the vehicle descended to a depth of 35,800 feet in a nine-hour dive.[2] The feat has never been matched, until 2012 (see page 129).

Several years later, *Trieste* resumed its headline-making career with a grim task – locating and positively identifying the wreckage of USS *Thresher*, a Navy nuclear submarine that sank with all hands in April 1963. Less than a week after the sinking, the bathyscaph was shipped to the East Coast, where in several series of dives over the next sixteen months crewmembers of *Trieste* (and a refurbished version titled *Trieste* 2) located,


Trieste

photographed and recovered some of the wreckage at a depth of 8,400 feet.

With the loss five years later of USS *Scorpion*, *Trieste* was again tasked with verifying and photographing the sub's final resting place, at a depth beyond 10,000 feet.

Aside from the human tragedy, the loss of *Thresher* focused attention on the antiquated technology available to rescue crews of submarines disabled on the bottom. Although *Thresher* sank substantially beyond crush depth, the Navy was ill-equipped to launch a rescue operation even in a few hundred feet of water. The McCann Rescue Chamber, which had been used in a successful submarine rescue, was developed in 1930. In succeeding years, no improvements had been made.

Shortly after the *Thresher* loss, the Navy Department established the Deep Submergence Systems Review Group to evaluate the department's plans for locating, identifying, and recovering objects from the deep ocean and rescuing personnel from disabled undersea craft, and to recommend immediate and long-term improvements in those plans. On May 26, 1966, the Deep Submergence Systems Project (DSSP) was chartered to develop capabilities in four areas, including submarine crew rescue and large object salvage. The following month, the Director of Navy Laboratories appointed several committees to review the Navy's research and development programs for pertinence to the DSSP effort, with an engineer from the electronics lab and another from the weapons lab chairing two of the committees. Subsequently, a trio of Navy personnel (two from the weapons lab) formulated and published the "Technical Development Plan of the Deep Ocean Technology [DOT] Project." Its primary thrust was the Large Object Salvage System.



A commissioned Navy submarine, USS *Dolphin* (AGSS-555) was constructed as a research sub, with substantial stimulus for its design and construction coming from an SSC Pacific predecessor lab. Assigned to a Navy fleet unit, *Dolphin's* schedule was directed by the Point Loma laboratory to test new sonars and deep-ocean technology. (USS *Dolphin* is currently on display at the Maritime Museum of San Diego.)

Norm Estabrook, who spent his career at SSC developing underwater technology, explained: "The Technology Development Plan established what were termed 'demonstration projects,' high-minded engineering goals whose importance was more in the outgrowths, the technologies developed to attain the goal, than the goals themselves. One of those goals was deep salvage, down to 850 feet, which defined the continental shelves. The philosophy behind that was: If *Thresher* had bottomed out at 800 feet, the hull would not have crushed, but the crew would have died because there was nothing in the inventory to rescue them. Work began on the Large Object Salvage System, with a number of individual projects aimed at achieving that goal."[3]

Significant DOT funding was directed to the weapons lab. Resulting projects are discussed below.

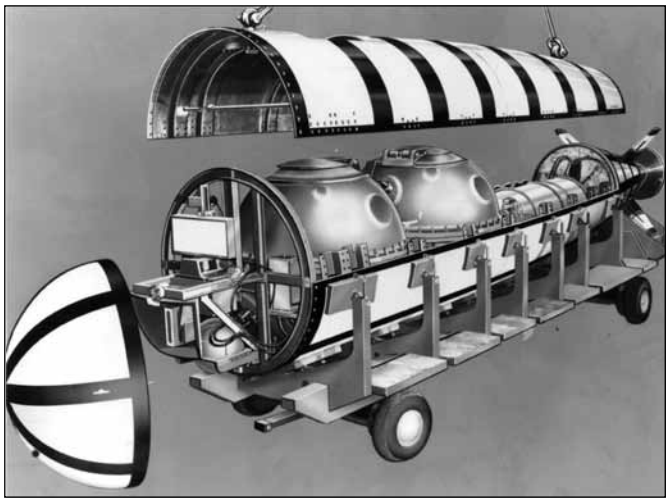
One of the first products of DSSP was the Deep Submergence Rescue Vehicle (DSRV), the McCann Chamber replacement. Designed to dive to a stranded sub, DSRV could rescue twenty-four crewmen at a time. The weapons laboratory assisted in development of the optics suite and fabricated the Vehicle Handling System for land transport. Most importantly, the lab fabricated the Simulated Distressed Submarine, a 60'x35'x30' steel structure with a simulated submarine escape hatch positioned on the seafloor at the San Clemente Island range. The hatch, mounted on a drum, could be rotated to simulate a sub on the bottom in a variety of orientations, providing DSRV operators realistic training in rescue procedures.

Undersea platform involvement included the Navy's deepest diving submarine, USS *Dolphin*. With substantial stimulus from the weapons lab, the Navy built *Dolphin* as a platform to test sonars, exploit deep-diving submarine technology, perform acoustic and oceanographic research at great depths, and test ASW weapons. A commissioned U.S. Navy submarine, *Dolphin* was assigned to an operational unit at the submarine base in San Diego, with its project scheduling managed by the SSC Pacific predecessor lab at the sub base front gate. After three decades supporting a variety of programs, including testing satellite-submarine communication, *Dolphin* was decommissioned in 2007 and is now part of the Maritime Museum of San Diego.

Dr. William McLean, Weapons Laboratory Director from the mid-1950s to the mid-1970s, was personally cited by President Eisenhower for his role in development of the Sidewinder missile. During an era when America was turning its interest and scientific sights toward space, he had a different take: "There are many jobs to be done in the ocean. The oceanographic program, like the space one, is experimental, but it will have more payoff and won't be nearly so costly." [4] McLean was particularly enthused about one project that combined his weapons and ocean-related interests.

"Next to the Sidewinder missile, *Moray* was probably the single NOTS development program closest to Dr. McLean's heart…*Moray,* at least in its initial proposal stage in 1959, was an undersea weapon, a two-man, high-speed submersible vehicle that would carry underwater rockets with shaped-charge warheads. Launched from a ship or a submarine, *Moray* would seek out and destroy enemy submarines." [5]

Moray was conceived by the West Coast ASW Laboratories, a confederation of organizations comprising both the Navy labs that eventually formed SSC Pacific, Scripps Institution of Oceanography, and the University of Washington. The weapons lab at China Lake designed and fabricated *Moray* as a weapons platform, later expanding its missions to include research. After initial test dives, the vehicle was publicly announced at a Pasadena news conference and in the station newspaper in November 1965.[6] By that time, Navy officials had determined developing a squadron of "underwater fighter planes", as they were sometimes advertised, would necessitate unacceptable investment in training, schools, and so on. Thus, the public notice characterized the vehicle as an "undersea laboratory device," without mention of the weapon application. After test dives to about 250 feet to prove the concept, the program was discontinued due to lack of funding.



Illustrated is the interior view of the Navy's *Moray* deep-diving vehicle, showing two pressure-resistant aluminum spheres. The upper half of the craft was designed to be removed to increase its utility as a piece of laboratory equipment.



***Deep Jeep*, built by the weapons laboratory, was designed with propellers that could be tilted to various angles and varied in speed, to allow it to "fly" through the water.**

Sharing billing at the news conference was another manned vehicle called *Deep Jeep*. Conceived and built by World War II naval aviator turned ocean engineer Will Forman, the vehicle was launched January 21, 1964. At that time, "it was the first American-made deep submersible."[7]

Forman's interest was stimulated in 1960 by Bill McLean's belief that a manned system could perform undersea tasking better than the recently purchased commercial vehicle that became CURV. Over the next several years, Forman designed and built a vehicle with a five-foot-diameter spherical pressure hull in which two operators rode in a semi-reclining position. Each had a separate optical system for viewing the undersea environment through a small common acrylic window. Electric motors powered propellers that could be adjusted in speed and angle to allow "flying" the vehicle underwater like a helicopter. Even before the news conference, the decision had been made to provide *Deep Jeep* to Scripps as an indefinite loan. [8] As the crew prepared it for transfer, however, *Deep Jeep* was among Navy resources ordered to the Mediterranean

to participate in the search for a lost H-bomb. Vehicle and crew arrived in late January 1966, assigned to search shallow-water areas. On his own, Forman dove to a deep-water location and found potential evidence of the bomb. With the arrival of other undersea vehicles including CURV, and maintenance issues on their own craft, the team went home, and *Deep Jeep* went to Scripps.

Meanwhile, Bill McLean began, in a sense, bringing his recreational activities to work. An extreme water sports enthusiast, he was interested in surfing, boating, canoeing, water skiing and SCUBA diving.[9] In addition to his interest in furthering Navy capabilities to explore and work underwater, he saw a substantial commercial opportunity for low-cost undersea vehicles with panoramic viewing capabilities. He wanted to combine both attributes: a scientist/engineer seeking knowledge, and a recreationist seeking fun. Thus, while he was directing his engineers to develop Navy undersea technology, he was investing his $10,000 Rockefeller Public Service Award in a similar vehicle he envisioned as a pleasure craft.



***Hikino's* major material, glass, allowed panoramic visibility, enjoyed by NBC national newscaster Frank McGee, during a dive at the Center's Hawaii Lab in 1968.**

He expressed his thinking in a 1969 magazine article: "The number of people who would submit to a dark, minimum-volume can is considerably smaller than the number of people who would like to dive enclosed in a transparent hull, and therefore the market for a transparent vehicle will be much greater than for a non-transparent one with windows."[10]

McLean directed Navy development of a submersible consisting primarily of glass, called *Hikino* (Hawaiian for "Can do"). It was constructed of two 56-inch-diameter glass hemispheres that opened like a clam shell, resting on the fiberglass pontoons of a catamaran. Exterior control mechanisms were operated by light beams projected through the glass. The vehicle's four-bladed cycloidal thrusters for propulsion and control provided better maneuverability than submersibles with vertical and horizontal thrusters.

In 1967, the Navy substantially reorganized its laboratories. A third West Coast lab, formed from the Pasadena component of the weapons lab and the undersea technology portions of the electronics lab in San Diego, was established, with McLean as its technical director and with facilities in Pasadena, San Diego, and Hawaii. Even before the re-organization, McLean had sent advisers to Hawaii to locate real estate for a facility to pursue underwater vehicle technology. *Hikino* was shipped to Oahu; its pioneering concepts formed the basis of a new vehicle.

Makakai (Hawaiian for "Eye in the Sea") was a refined version of *Hikino*, launched April 14, 1972. The primary difference was a pressure hull formed from 12 pentagon-shaped spherical segments of acrylic plastic glued together. The original such hull had been fabricated by Dr. Jerry Stachiw, a materials engineer at the Naval Civil Engineering Laboratory (NCEL), who had conducted substantial research in underwater use of transparent materials.[11] One fruit of that research was an underwater inspection vehicle called NEMO (Naval Experimental Manned Observatory). After fabricating and testing the prototype in 1967, Stachiw had contracted for additional 66-inch-diameter hulls, one of which was installed on NEMO. Hawaii engineers purchased another one for *Makakai*.

The 19-foot-long *Makakai*, with cycloidal thrusters positioned behind and over the operators' heads, looked remarkably like a helicopter with rotor blades miniaturized and positioned behind the cabin. Like *Hikino*, it employed light signals passing through the transparent hull to activate exterior-mounted control mechanisms. *Makakai* made about 50 dives in Hawaii, achieving certification for 600-foot operation. Following appearance at the lab's ocean engineering exhibition at San Clemente Island, the vehicle went on display, first at Sea World in San Diego, then at the Naval Undersea Museum in Keyport, Washington.

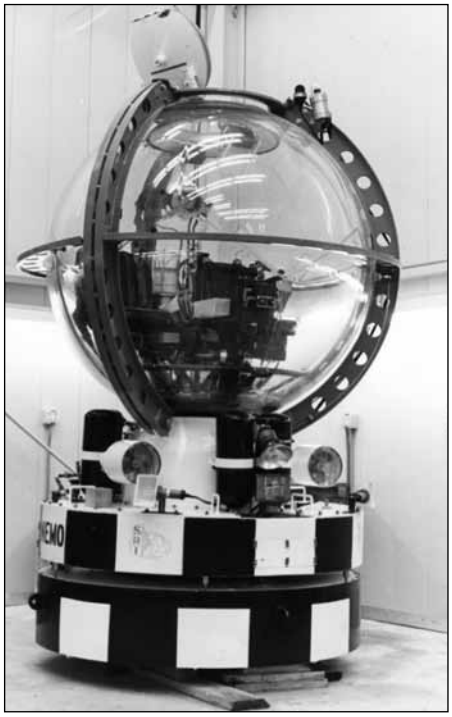
As *Makakai* was under development in Hawaii, NEMO and its designer were transferred from NCEL to the undersea weapon-technology lab in San Diego. Stachiw expanded his research, developing through private-industry contracts, the capability for massive 5,000-pound acrylic plastic castings to eliminate NEMO's glued joints, and for studying alumina ceramic and other materials for underwater pressure hulls. Simultaneously, the vehicle was pressed into service for scientific research.

NEMO's operation was atypical of manned vehicles, in that its movement was vertical: an anchor was dropped at the scene of interest, and the vehicle was winched down to it. Designed with a circular metal base painted in large black and white squares, mounted by the spherical acrylic pressure hull, one wag described it as "a gigantic gumball machine." The vehicle had been certified for operation to 600 feet, during ninety test dives in the Bahamas. Upon its transfer to San Diego, it was used as an underwater observatory for shark research. Its last dive was in October 1973, after which it also went on display, serving as a focal point for the submarine ride at Disneyland in Anaheim.

Will Forman re-emerged in December 1972 with his latest invention, *Deep View*, after a six-year development effort. Counter to the *Hikino/Makakai* switch from glass to acrylic plastic pressure hull, Forman exchanged the small acrylic viewport of *Deep Jeep* for a massive glass bow on the mostly steel-pressure hull of *Deep View*. Research had demonstrated the strength of glass under the compressive forces of the deep ocean, but Forman believed availability of appropriately sized glass hemispheres was several years away. He proposed instead use of excess 44-inch hemispheres fabricated for a transatlantic cable crossing. McLean authorized him to proceed at once. The resulting 17-foot-long vehicle had a ring-stiffened steel cylinder pressure hull, six feet long by four feet in diameter. The challenge was developing the process for joining the glass to the steel. Initial testing with ten-inch glass hemispheres set in steel rings indicated an optimistic potential for operation at depths of several miles. However, an early test with a 44-inch model resulted in an explosion Forman characterized as "equivalent to about three sticks of dynamite" and the disintegration of the hemisphere.[12]

Two years of experimentation were required before proper configuration of glass and steel at the interface was determined. With that completed, Forman began initial test dives off the lab's piers on Point Loma. *Deep View* completed a lengthy series of tests at Santa Catalina Island and at the Center's Hawaii Laboratory. As with all Navy lab projects, *Deep View* required a funding sponsor to continue development, but none surfaced. The vehicle went the way of its peers, displayed at the Stennis Space Center in Mississippi.





The lab experimented with panoramic visibility vehicles in the 1970s, employing acrylic plastic pressure hulls for *Makakai* (above) and NEMO **(left), and a large glass hemisphere for the bow of *Deep View* (below). All three were operational to 600 feet, and carried two pilots/observers.**



The McLean interest in large pieces of transparent materials for unobstructed observation led to several platforms for that purpose, including a *Hikino*-like double-hemisphere glass "observation elevator" at the Center's Oceanographic Research Tower situated a mile offshore Mission Beach in San Diego; a catamaran named *Sea See* which featured an observation chamber that extended ten feet under the vehicle deck for viewing sea life; and an innovative 190-ton surface-effects craft called the Stable Semi-submerged Platform, with an acrylic plastic observation chamber fronting one of its underwater hulls (see pages 58 & 59).

Unmanned Vehicles

While Bill McLean visualized a bright future for manned submersibles for military, commercial and recreational purposes, one of his top ocean engineers had a divergent opinion. Howard R. Talkington held increasingly responsible positions in the Center's management hierarchy, ultimately becoming McLean's deputy. In a 1973 paper only circulated internally, he asked the question, "Why Man?" He posited the value of human presence underwater did not justify the potential danger to that human and the resultant cost of manned submersibles, costs which he discussed in detail in one of his several books.[13] Talkington believed the majority of undersea tasks could be accomplished more safely, efficiently and economically with unmanned systems. His belief was based on personal experience.

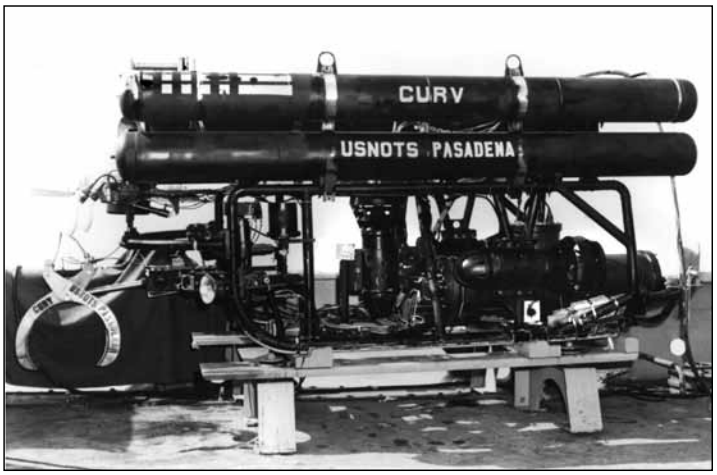
Talkington was on scene in the Mediterranean near Palomares, Spain, in 1966, during the months-long hunt for a hydrogen bomb that parachuted into the sea when a U.S. Air Force B-52 bomber collided with its re-fueling plane. The lost H-bomb prompted a massive search by a Navy task force of ships and various underwater vehicles and equipment. After several failures at recovery, the CURV crew was called to support the operation. Arriving on-scene, the crew was told the bomb was on the bottom at 2,850 feet. Larry Brady and another team member quickly spliced the 55 conductors of the cable that controlled CURV to add another 1,000 feet to the standard 2,000-foot cable, thus providing the length required to reach the bomb. On three dives, Brady attached three recovery lines. When the vehicle became entangled in the various lines and the parachute, the entire conglomerate was winched safely to the surface.



Over the next decade and a half, six more models of CURV were developed, with increasing depth capability and some limited new technology. While many of the Navy lab's manned vehicles were for technology demonstration and scientific observation, the unmanned models were work vehicles. The intent behind purchase and re-design of the first CURV, and building of the later CURV models, was to work daily on the Long Beach and San Clemente Island test ranges, recovering torpedoes and other test ordnance.

On rare occasions, an incident similar to the H-bomb occurred, and it was then the technology





Newspapers in Spain were filled with coverage of the recovery of a hydrogen bomb lost in the Mediterranean Sea, following the collision of two U.S. Air Force planes in 1966. The weapons lab's CURV ROV played a critical role in the recovery.

evolving during day-to-day operation proved invaluable. One of those occurred in August-September 1973, when a Canadian manned submersible called *Pisces* III sank in the North Atlantic off Cork, Ireland. The two pilots were stranded at a depth of 1,475 feet, with about three days of air and few rescue resources available. With a few hours' notice to gather equipment and people and get a lift from two U.S. Air Force cargo planes, the CURV III team flew to the scene. Operating from a somewhat unsuitable ship of opportunity, the vehicle was launched in Sea State 6, with Larry Brady at the controls, and attached a recovery line that allowed rescue of the men with a small amount of oxygen left.

In describing vehicle development, Bob Watts, program manager for the last decade-plus of CURV III operation, including the *Pisces* event, said, "We were trying to make a system that could go to 7,000 feet and survive and have something left over to do some useful work. The task was more integration of commercially available systems than technology development."[14]

Brady echoed that thought: "We're like the farmer who's out there tinkering with his tractor and his combine and making it a little better. It's not rocket science; it just isn't." The "tinkering" was borne out by on-scene jury-rigging during the *Pisces* rescue, including taping a diver's compass in front of the vehicle's TV camera for navigation when CURV's onboard compass failed, and using a "toggle bolt" fashioned from a crescent wrench, two pieces of steel and bungee cords as the rescue attachment device.

The most significant development in the evolution from CURV I/II/IIIA to CURV IIIB and C was replacement of metal buoyancy tanks with blocks of syntactic foam, a technology newly available at the time to increase buoyancy while reducing weight. Although the vehicle's work site was



Sea State 6 conditions did not prevent the launch of the lab's CURV III ROV in a dramatic rescue operation. Despite the conditions, the vehicle thrust a jury-rigged "toggle bolt attachment device" into the flooded machinery compartment, enabling the rescue of the two men inside *Pisces* III, resting on the bottom in 1,475 feet of water.



the seafloor, a critical mission consideration was getting the vehicle back.

"The cardinal rule with unmanned vehicles is always go down positively buoyant," Watts said. "Use your power and thrust to get down. If you have a failure, chances are good the vehicle will float back to the surface and you can recover it, which we did several times."

As commercial vehicles became available in the early 1980s, CURV III's value diminished, and the vehicle was transferred to the Navy's Supervisor of Diving and Salvage.

The San Diego Navy lab developed a substantial number of unmanned vehicles over several decades, including:

- A hydraulic vehicle named Snoopy, little more than an underwater camera mounted on a depth-regulating cylinder with a propeller, followed up with a larger vehicle with a grabber, an electric one for 1,500-foot depths, and a model for optical survey of underwater construction sites
- Two models of the Submersible Cable-Actuated Teleoperator to demonstrate and evaluate advanced teleoperation concepts, including head-coupled TV
- An ROV to locate, classify and neutralize mines; another to recover Space Shuttle booster rockets for re-use;[15] another to replace side-scan sonars with a "flying-spot scanning sensor system designed to provide an optical map of the ocean floor" [16]
- A torpedo-tube-launched, self-propelled decoy developed to enhance the security of the Navy's fleet ballistic missile submarines.

Deep-ocean Work Systems

Two of the CURV III models were capable of working at 7,000-foot depths, with one modified to operate at 10,000 feet on special tasking. Much of the Pacific Ocean, particularly around the Hawaiian Islands, is substantially deeper,[17] and Navy operational requirements dictated remote work capability to those depths. One of the major vehicle developments under DOT was the Remote Unmanned Work System (RUWS), envisioned as a 20,000-foot vehicle to demonstrate new technologies for deep-ocean work systems, including recovery, repair, instrument implant, survey, documentation and oceanographic data gathering.

Dan Hightower was one of the first Center employees to arrive at the new Hawaii Lab on the Marine Corps Air Station at Kaneohe Bay. Selected as the RUWS program manager, he recalled several conversations with Bill McLean, who encouraged the development team to seek alternatives to traditional vehicle design.

"He wanted us to develop new control/display technology so the operator would believe he was literally there on the bottom," Hightower said. "That's when we started using terms like 'remote presence,' 'telepresence' and 'teleoperation'." [18]

RUWS had a primary operator to maneuver and control the vehicle while a second person seated next to him controlled the TV cameras and the manipulator to perform the required work task. Teleoperation allowed that individual to slip his hand into a controller and operate the vehicle's manipulator with normal hand and arm movements.

"Even though we weren't able to implement the head-mounted display system we developed, the integrated displays and vehicle control and the natural ease of using the manipulator did push people to start thinking along the lines of McLean's concept of remote presence, putting the operator 'virtually' on the sea floor."

Other RUWS innovations included the first use of Kevlar for the control cable's strength member. Weight and flexibility issues precluded the use of traditional steel strength members, so Kevlar-epoxy strength members were contra-helically wrapped around a coaxial cable on which power, television signals and controls were multiplexed. The result was a cable with substantially reduced diameter and weight.

In operation, the control cable dropped relatively vertically to the depth of choice, where it was attached to a device called the Primary Cable Termination (PCT). The PCT provided a stabilizing weight to aid in station-keeping and limit dynamic forces on the vehicle. The vehicle itself "rode" down to the work site on the PCT, then swam away to perform work functions, required only to pull a short control cable. If the vehicle reached the end of its tether, the self-propelled PCT could be re-positioned. The vehicle cable, fabricated of a new type of buoyant rubber, required no floats that might influence vehicle movement.

Buoyancy of the vehicle itself was a major challenge at the 10,000-pounds-per-square-inch pressure of 20,000-foot depths.

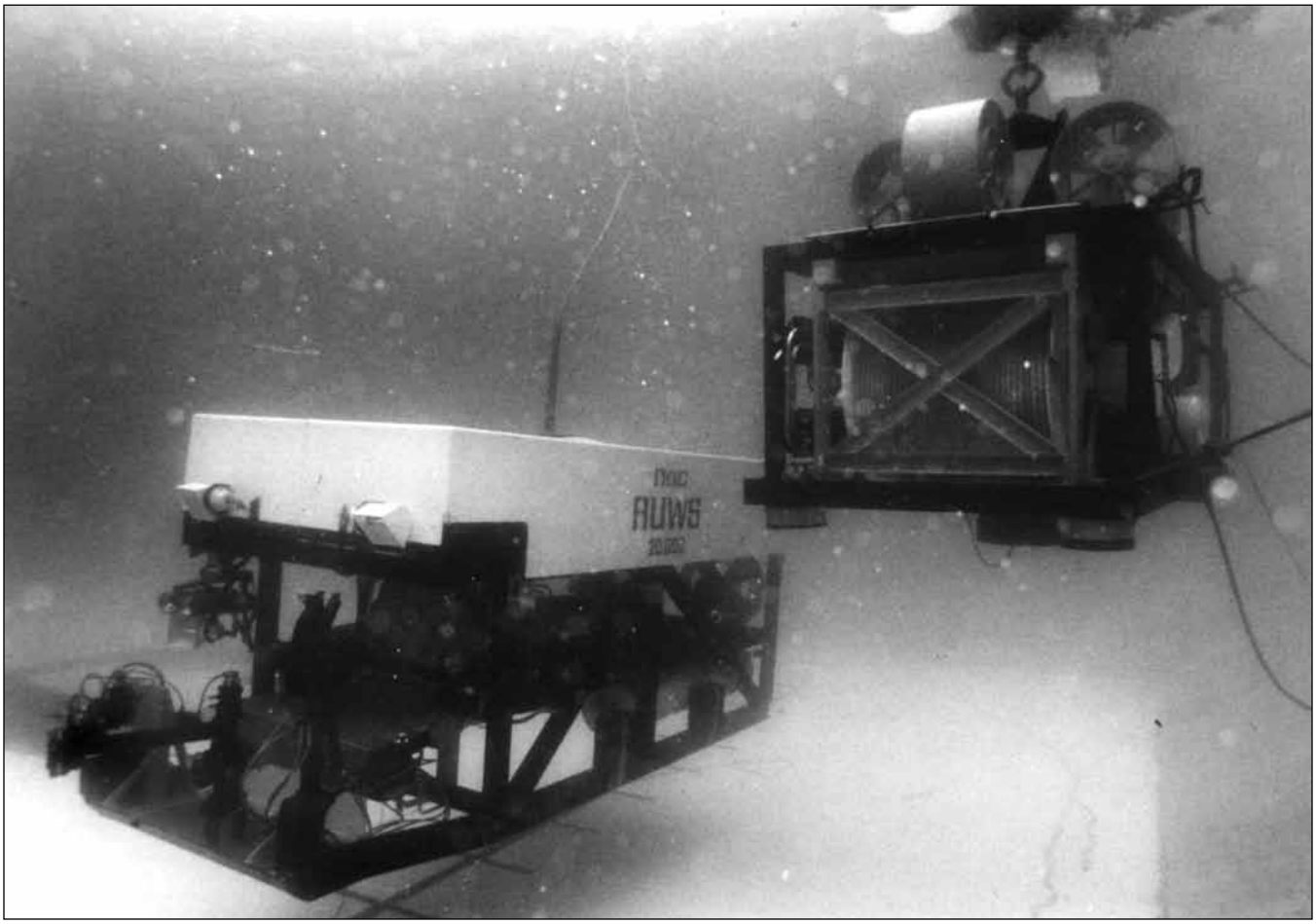
"That's when McLean, always looking for technology advances, suggested we use syntactic foam, tiny microspheres of glass embedded in epoxy, providing substantial buoyancy but adding little weight," Hightower said.

Before the system's first deep-water test, it was used in shallow water to locate and attach a recovery line to an anchor and 1,080 feet of anchor chain lost from one of the Navy's fleet oilers, which was out of commission until the anchor was recovered.

During a developmental dive to 15,500 feet in January 1980, the shock absorber at the end of the primary cable failed. The PCT and the work vehicle were lost, but the cable was recovered intact, and served as the initial control cable for the next Hawaii Lab deep-ocean vehicle, ATV.

The Advanced Tethered Vehicle was in several respects the culmination of the Center's underwater vehicle efforts. Consisting of a deep-ocean vehicle with five thrusters and required control devices, a work package, and a TV viewing system, ATV development also included surface systems for tether handling, launch and retrieval. The 23,000-foot cable was jacketed and used four layers of Kevlar for the strength member, resulting in a break strength and safety factor substantially greater than steel would have provided.[19] ATV engineers took advantage of the emerging availability of fiber optics for underwater applications, employing a single fiber for all bi-directional signal transmission. Video with 23 Mhz bandwidth was transmitted over a single fiber. The communications function could be switched between three available fibers in case of fiber or bottle failure. The work system was an integrated suite of tools, visual subsystems, and three manipulators – one for gripping the target work piece, the other two seven-degree-of-freedom units to perform complex work tasks, directly or with tools. Tools could be interchanged without moving the vehicle. The vehicle, positively buoyant for recovery in case of emergency, was driven to depth and navigated to the work site utilizing a long-baseline acoustic

The Remote Unmanned Work System featured a work vehicle and a vehicle-like device called a Primary Cable Termination. The work vehicle "rode" down to the work depth on the PCT, swam off, and performed its operations at the end of a short cable, thereby precluding the necessity of dragging the 20,000 feet of primary cable behind it.



transponder field deployed before ATV was put in the water. While RUWS was a developmental vehicle for technology demonstration, ATV was designed as an operational vehicle for the fleet.

"Design of the deliverable began in 1985," said Terry Hoffman, the ATV project manager. "It took three years to design and build most of the system and begin wet testing, then another two years to finish up details and test it against the master development plan."

The vehicle successfully dove to 20,600 feet in June 1990, after which it was transferred to Norm Estabrook's division in San Diego for joint operations with Submarine Development Group One, located about a mile south of the Navy lab on Point Loma. The sometimes difficult transition from laboratory to fleet unit was eased considerably by the three full-time years and seven part-time ones Estabrook had served as the ocean engineering advisor to the development group. Laboratory personnel trained sailors to operate the vehicle, which was transferred to the fleet unit in 1992, and operated there for more than ten years.

Autonomous Vehicles

In the mid-1970s, the San Diego lab began development of several small autonomous vehicles, nicknamed "Free Swimmer". The first was a test-bed submersible funded by the U.S. Geological Survey to overcome basic barriers to a truly autonomous platform for search, location, inspection and monitoring of underwater cables, pipelines and structures. The nine-foot-long vehicle was propelled by electric motors, designed to follow pre-determined tracks after specific mission programming. Initial depth capability was 2,000 feet.

Free Swimmer II had a two-computer, supervisory-controlled architecture. Real-time joystick control was added for direct operator intervention. A fiber-optic communication link, automatic homing and retrieval mechanism, magnetic sensor for following pipes and analog color graphics display for fast operator interaction were demonstrated.

The two vehicles provided test beds for design and fabrication of a free-swimming mine neutralization vehicle, and for a deep-ocean search system to rival, or rather complement ATV.

The original Navy plan following the loss of *Thresher* included four major development areas, one of which was deep-ocean search.

"That was a manned search vehicle, which showed our ignorance at the time because that's a stupid idea, to use a manned submersible to do search," commented Norm Estabrook. "You can't stay down long enough and you can't cover enough area; it just doesn't make sense."

The Navy's technology for deep search at the time was surface-towed instrument sleds. The San Diego Navy lab was tasked under DOT to develop an underwater vehicle to replace and enhance that technology. Their response was the Advanced Unmanned Search System (AUSS), a semi-autonomous torpedo-shaped vehicle 17 feet long and 30 inches in diameter. The pressure hull was fabricated of graphite-fiber-reinforced plastic, developed as one of Jerry Stachiw's research projects. Capped fore and aft with titanium hemispherical end closures, the vehicle had sufficient net buoyancy to preclude the need for syntactic foam. AUSS was designed to operate to depths of 20,000 feet, maintaining a speed of six knots for ten hours while autonomously following a pre-planned search pattern, breaking off that search to examine an object of interest. Both the navigation commands from the surface to the vehicle and image transmission from the vehicle to the surface employed a near-vertical acoustic communication link. Using that link, the vehicle could transmit fairly high-resolution optical images every 20 seconds. With no heavy cable to tow, the operator on the surface could command the vehicle to change direction immediately, hover over an object of interest, and send up a stream of images for evaluation.

Like ATV, AUSS was developed as a fleet system. It was envisioned AUSS would quickly search a large area for an object of interest and provide images to ensure it had been located, after which ATV would be launched to perform appropriate work on, or recover it. The AUSS development team conducted 45 dives to depths ranging from 2,500 to 12,000 feet, generally achieving all program goals. The program was cancelled by the Navy in 1991 in favor of pursuing other objectives.

"I have to say of all the experiences that I've had, AUSS was probably the crown jewel of what we did at the lab," said Norm Estabrook. "It was a marvelous development, and to this day no one has ever developed anything like it, not in the commercial world, not in government circles."

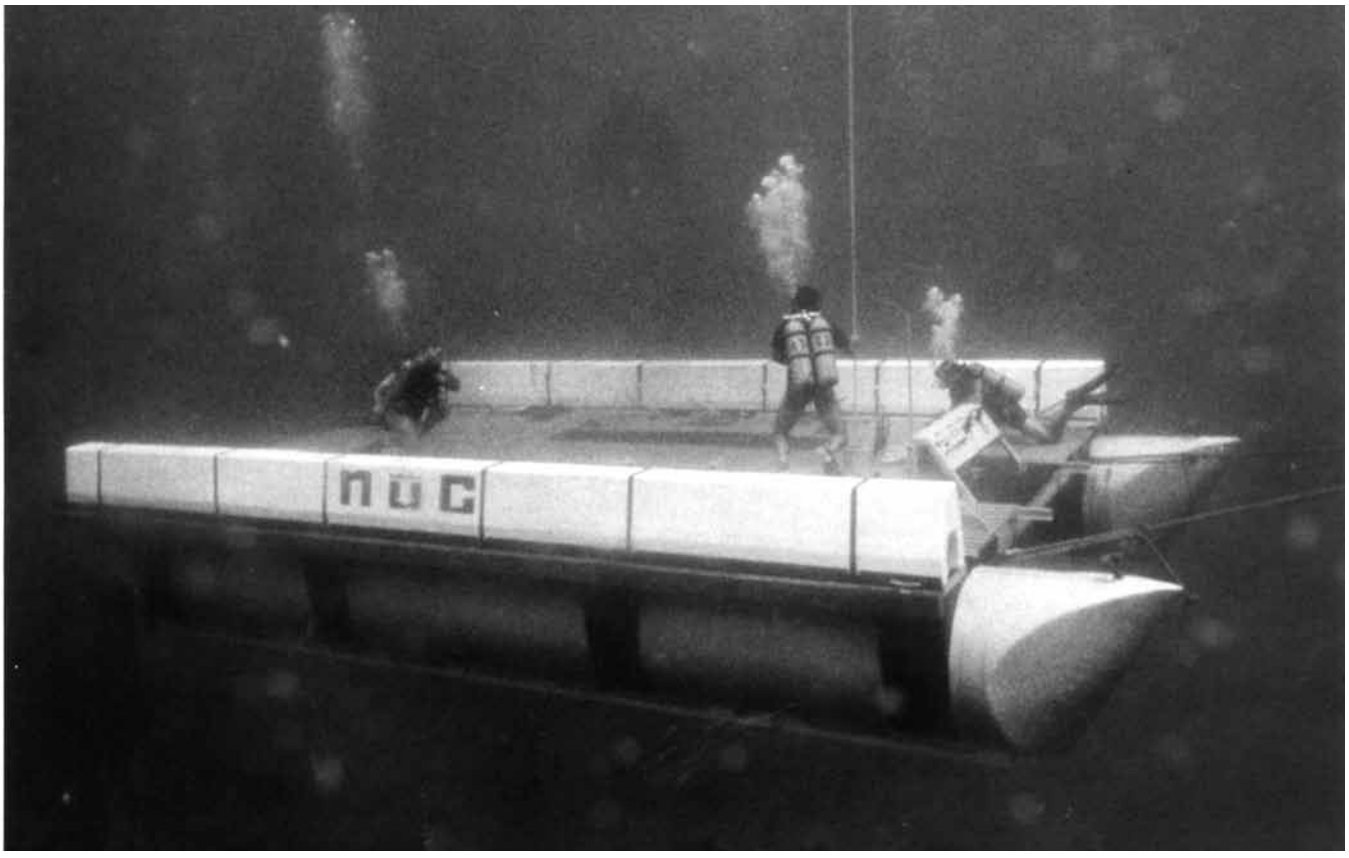
Other Technologies

SSC Pacific has spent the last half-century developing underwater vehicles. Also developed were several diver-operated technologies, including the Launch and Recovery Platform, of which Estabrook was project engineer. It provided a safer and more effective means of launching and recovering manned and unmanned submersibles. A Center engineer, who had worked with Navy SEALs,

suggested a LARP-like platform to allow special forces personnel to practice launching and recovering their swimmer delivery vehicles underwater. Two Submarine Training Platforms were fabricated and delivered to the SEALs at Coronado across the bay from SSC Pacific, and to Little Creek, Virginia. The Buoyancy Transport Vehicle, another Estabrook project for which he received a patent, was a diver-operated "fork lift" that carried heavy loads underwater from one work location to another, or aided in object recovery from diver-accessible depths. It could transport loads up to 1,000 pounds at depths to 850 feet.

The Work Systems Package (WSP) was a tubular framework with two work-site "grabbers" and a dexterous seven-function manipulator to perform work in the deep ocean. The work manipulator had a "jaw" designed to grasp, operate and quickly replace on-scene hydraulic tools that included drill and grinding motors, synthetic line cutting knife, impact wrench, winch, jack, spreader and cable cutter. WSP was designed for attachment to a variety of manned and unmanned submersibles.

Bob Wernli was project engineer for WSP early in his career with the SSC Pacific. More important than his engineering work, however, was his participation in ocean engineering societies. The engineers featured in this article, and scores of others on their teams, write and present numerous papers for peer-reviewed journals and symposia sponsored by ocean-related organizations such as the Marine Technology Society (MTS). Wernli joined MTS for professional development, shortly becoming an officer and later chairman of the local section, then moving ahead to become a founding member and first chairman of the MTS Remotely Operated Vehicle (ROV) Committee. He suggested MTS host an ROV conference, which he



Launch and Recovery Platform



Bill McLean (left) in the acrylic plastic "elevator" at the Oceanographic Research Tower, off Mission Beach, San Diego, in 1972: *…believed, and argued persuasively that the future of the Navy lay not on top of the ocean but under it.…*

organized and chaired in San Diego in 1983, with the theme "a technology whose time has come." The conference grew substantially during the ten years it was staged in San Diego, forcefully demonstrating the region's leadership in ocean engineering. Wernli expanded the effort, organizing the first MTS/Institute of Electrical and Electronics Engineers Oceans conference. After many years of conferences around the world, Oceans returns to San Diego in 2013, and Wernli is still involved.

With substantial mission changes for Navy R&D laboratories, SSC Pacific is no longer responsible for underwater vehicle development. Still, there are on-going projects to support the labs assigned that responsibility. One is the Large Unmanned Undersea Vehicle, an autonomous mini-sub designed to carry mission packages (ASW, mine warfare, intelligence) thousands of miles underwater, over periods up to two months. SSC Pacific personnel are developing fuel cell technology for long-term power, onboard sensors, and collision avoidance technologies, plus off-board tools for precise navigation.

In addition to undersea vehicle technology, the Point Loma lab was named the Center of Excellence for Small Robots by the Defense Department's Joint Ground Robotics Program. A major exercise at the lab in 2006 involved a series of "collaborative behavior demonstrations" of autonomous systems in a force-protection scenario, with centrally controlled unmanned sea-surface, ground, air and underwater vehicles working together to detect, track and capture "armed intruders," all without human intervention.[20]

Bill McLean moved from China Lake, where he developed air-to-air weapons, to San Diego, with emphasis on ocean-related technologies, because he "…believed, and argued persuasively, that the future of the Navy lay not on top of the ocean but under it… He was convinced that the world's ocean depths offered endless possibilities for the Navy as well as for civilian habitation, recreation, and commerce." [21]

SSC Pacific continues to employ its expertise supporting undersea technology development, which the Navy sees as critical to achieving information dominance.

Notes

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3 Norm Estabrook, Head, NOSC/NRaD Ocean Engineering Division, interview, 5 January, 2012.
4 "The Navy's Top Handyman," LIFE magazine, January 6, 1967, 31.
5 Cliff Lawson, *History of the Navy at China Lake, California, Volume 4, The Station Comes of Age: Expansion, Innovation, and Leadership in the Final Years of the Naval Ordnance Test Station, 1959-1967.* (In press)
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8 Will Forman, *The History of American Deep Submersible Operations, 1775-1995,* (Flagstaff, Arizona: Best Publishing Co.,1999), 45.
9 W.H. Pickering. "William B. McLean – A Biographical Memoir." National Academy of Sciences, 1985. Reproduced in *The China Lake,* Vol. 13, No. 3, Summer 2010, 400-402.
10 *Astronautics and Aeronautics*, April 1969, 33.
11 J.D. Stachiw. "Transparent Structural Materials for Underwater Research and Exploration." *Industries Atomiques & Spatiales* 3, 1974.
12 Forman, op. cit., 253.
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14 Bob Watts, CURV III program manager, interview, 20 December 2011.
15 A.J. Schlosser, "Solid Rocket Booster Dewatering System," Naval Undersea Center Technical Publication 514, June 1976, 5.
16 Paul J. Heckman, Jr. and Peter D. McCardell. "A Real-Time Optical Mapping System." Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 160, Ocean Optics V, Aug. 30-31, 1978, San Diego, 189.
17 Mean sea depth is 12,447 feet. See: Martin, op. cit., 57.
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19 Terry Hoffman, private communication, January 28, 2012.
20 SSC San Diego Outlook, March 24, 2006, 1.
21 Lawson, op. cit.



Pictured is the NOSC Oceanographic Tower (with viewing elevator) that lay off Mission Beach, San Diego, where acoustic experiments took place, until the Tower was destroyed by a storm in 1988.

All Images Official U.S. Navy Photos



Oceanography Pioneers: The Oregon State Story

By John V. Byrne, Ph.D.

In late 2011, Oregon State University created a new academic and research college, the College of Earth, Ocean, and Atmospheric Sciences (CEOAS), focusing on the Earth as an integrated system. CEOAS was formed by transferring the Department of Geosciences from the College of Science to the College of Oceanic and Atmospheric Sciences. The newly formed college was the latest step in the evolution of the oceanography program that started in 1954 when Wayne V. Burt returned home to Oregon. Burt, who grew up in Oregon, came back with the vision of starting an oceanography program in his home state. Before his return to Oregon there were few marine scientists in Oregon and very little was known about the waters off the Oregon coast. Now, in 2012, the new CEOAS has almost 300 oceanographic personnel (75 teaching and research faculty, 100 research associates and post docs, 105 graduate students) and brings in about $32,000,000 in grant and contract funds annually, just in the ocean sciences. In addition to its own oceanography efforts, the college has spawned strong programs in the marine biological sciences and in ocean engineering elsewhere within Oregon State University. It all started with the vision and persistence of one man at the right time.

There is a tide in the affairs of men,
Which taken at the flood, leads on to fortune;
Omitted, all the voyage of their life
Is bound in the shallows and in miseries.
On such a full sea are we now afloat;
And we must take the current when it serves,
Or lose our ventures.

Brutus to Cassius, Act IV, Scene 3, of Shakespeare's *Julius Caesar*

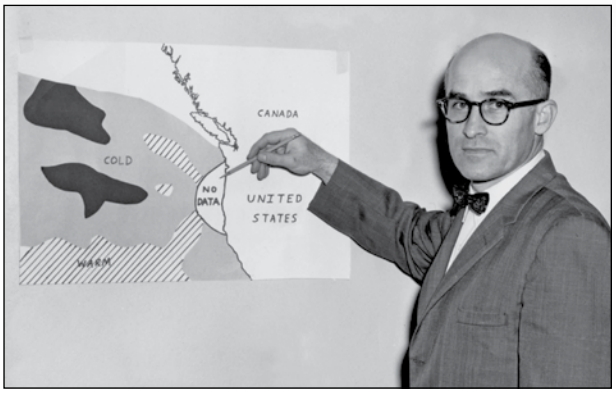
THE BEGINNING

The awakening of scientific ocean research in the United States following World War II started with the establishment of the Office of Naval Research (ONR) in 1946, followed by the creation of the National Science Foundation (NSF) in 1950. ONR took the lead in emphasizing the need for ocean research during the 1950s and began funding oceanographers at existing laboratories at the Woods Hole Oceanographic Institution, the Scripps Institution of Oceanography and the University of Washington.

Wayne Burt came to Oregon State College (OSC) in 1954. After receiving his doctorate from the Scripps Institution of Oceanography, he served as the Associate Director of the Chesapeake Bay Institute in Maryland, and then spent a year in the oceanography program at the University of Washington. But for Wayne, Oregon was home and it was in Oregon that he wished to establish an oceanography program. While at the University of Washington he contacted Francois A. Gilfillin, Dean of the School of Science at Oregon State, with a proposal: if he could get funding from ONR to support his salary at OSC, would Oregon State create a position for him? In a letter to Burt, Gilfillin responded, "If the grant is allowed, we will request the State Board of Higher Education have you appointed with the proper professorial title so you may appear on the college staff roster. This would be on an annual basis until such time as our instruction and research programs on state funds might warrant a permanent appointment." Gilfillin and Oregon State College (converted to Oregon State University in 1961) had nothing

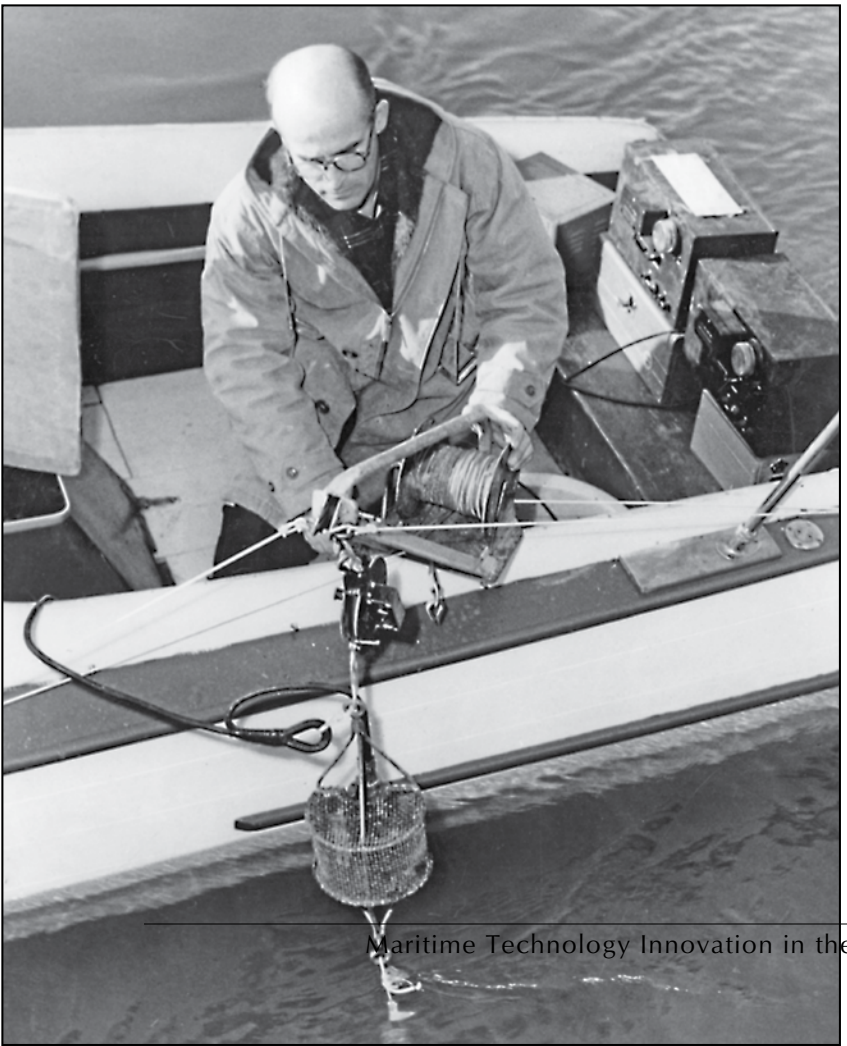
John Byrne is President Emeritus of Oregon State University. After spending three years in the petroleum industry, Byrne joined the new department of Oceanography at Oregon State University where he served as a faculty member, department Chairman and Dean of the School of Oceanography. He then moved into administration as the University's Dean of Research and subsequently as Dean of the Graduate School and Vice President for Research and Graduate Studies. During his tenure at Oregon State, he took leave twice for positions in the federal government, first as a Program Manager for Oceanography at the National Science Foundation and, later, as the Administrator of the National Oceanic and Atmospheric Administration, and United States Commissioner to the International Whaling Commission. He then served as the President of Oregon State University for eleven years. During his retirement he has been the Executive Director of the twenty-five member Kellogg Commission on the Future of State and Land-grant Universities. His academic degrees are all in geology; his Ph.D. was from the University of Southern California.

to lose and, as it turned out, everything to gain. The proposal was approved, ONR provided the grant money and, in September 1954, Wayne Burt started a project on the coastal oceanography of Oregon waters. He had an appointment in the Department of General Science in the School of Science at OSC and was paid $7,000 for twelve months employment.



Above: Wayne Burt, in 1958, with a chart of the Northeast Pacific Ocean, pointing out the absence of data off the Oregon coast.
Courtesy of OSU Archives

During the fall of 1958, the geophysics branch of the Office of Naval Research proposed a ten-year program for an expansion of Navy-sponsored oceanographic research. It was called "Project TENOC: A Ten-Year Plan for Oceanography." The plan called for Navy support of at least ten institutions of oceanography throughout the United States over a ten-year period. The primary objective would be to create knowledge relevant to naval operations through basic research. Wayne Burt, who had come to Oregon State College four years earlier, learned of the TENOC program and was excited by it. Wayne's wife, Louise Burt, in her history of the first two decades of the School of



Wayne Burt, in 1957, measuring currents in Yaquina Bay from a small motorboat.
Courtesy of OSU Archives

Oceanography, recalls: *On the evening after learning of the TENOC proposal, Wayne came home and told me about its possibilities. Perhaps even Oregon State would be one of the institutions selected. He had a restless night and the next morning at breakfast he asked me to look up the quote from Shakespeare's* Julius Caesar: 'There is a tide in the affairs of men, which taken at the flood, leads on to fortune. Omitted, all the voyage of their life is bound in the shallows and in miseries. On such a full sea are we now afloat and we must take the current when it serves or lose the venture.' *Wayne was bold enough to 'take the tide at the flood.' And it was the right thing to do at the right moment. What an appropriate quote for a physical oceanographer!* (It was indeed the right thing to do at the right time, and before the century was over it would result in OSU Oceanography becoming one of the top five or six Oceanography programs in the United States.)



RV *Acona* **at sea off Oregon, 1962.**
Courtesy OSU Ship Operations

By September 1958, Burt had been at OSC four years, teaching courses in Oceanography and carrying on ONR-funded research along the Oregon coast and in its estuaries. The total Oceanography budget for 1958 was approximately $25,000, most of it coming from the Office of Naval Research. Burt had been in frequent contact with Gordon Lill and Art Maxwell at ONR. He had convinced them that, with ONR support, an Oceanography program at Oregon State College was feasible and, with the announcement of the TENOC program, he was ready to move forward. He submitted a detailed proposal for TENOC support and at the same time indicated to the OSC administration he was confident the Navy would support a "Department of Oceanography at a significantly higher level." He had an oral agreement with Lill and Maxwell at ONR that with approval of the creation of an Oceanography Department at OSC, ONR would provide both operating funds and funds for capital improvement: $250,000 in fiscal 1960 for a research vessel, and $200,000 for the construction of an Oceanography laboratory. Wayne convinced the administration at OSC to create an academic Department of Oceanography, the administration convinced the State Board of Higher Education, and a Department of Oceanography at Oregon State College came into existence July 1, 1959.

Early Pioneers

Burt wasted no time in assembling a department faculty; programs of instruction and research were initiated and students attracted. With little to offer but opportunity and potential growth, Burt persuaded a group of scientists to join him as faculty of the new department. The department was organized according to traditional disciplines of Oceanography: Physical, Chemical, Biological and Geological/Geophysical. In 1959, Herb Frolander (Biological) and Bruce McAllister (Physical) joined Wayne Burt as faculty. McAllister was an instructor and at the same time was working on his Ph.D. June Pattullo (Physical), John Byrne (Geological) and Bill Pearcy (Biological) arrived in 1960. Graduate students, in addition to Bruce McAllister, included Bob Smith (Physical), who came from the University of Oregon, and Vern Kulm, already a geology graduate student at Oregon State, who transferred to the Oceanography Department. In 1961, Andrew Carey, Herb Curl, Jim McCauley, Larry Small (all in Biological Oceanography), Kilho Park (Chemical) and Joe Berg (Geophysical) joined the group. At the end of ten years, in 1968, there were thirty-one faculty members and a total staff of 122. From that early group, the pioneers who stayed with the Oceanography program until their respective retirements include: Frolander, Byrne, Pearcy, Carey and Small. June Pattullo, an early pioneer, died while still a faculty member. Smith and Kulm received their doctorates and then signed on to the faculty for the remainder of their careers. These individuals served as the core faculty as the department grew into a School of Oceanography in 1972, later to become the College of Oceanography in 1983, and then in 1993, after acquiring the Atmospheric Science Department from the College of Science, became the College of Oceanic and Atmospheric Sciences (COAS).

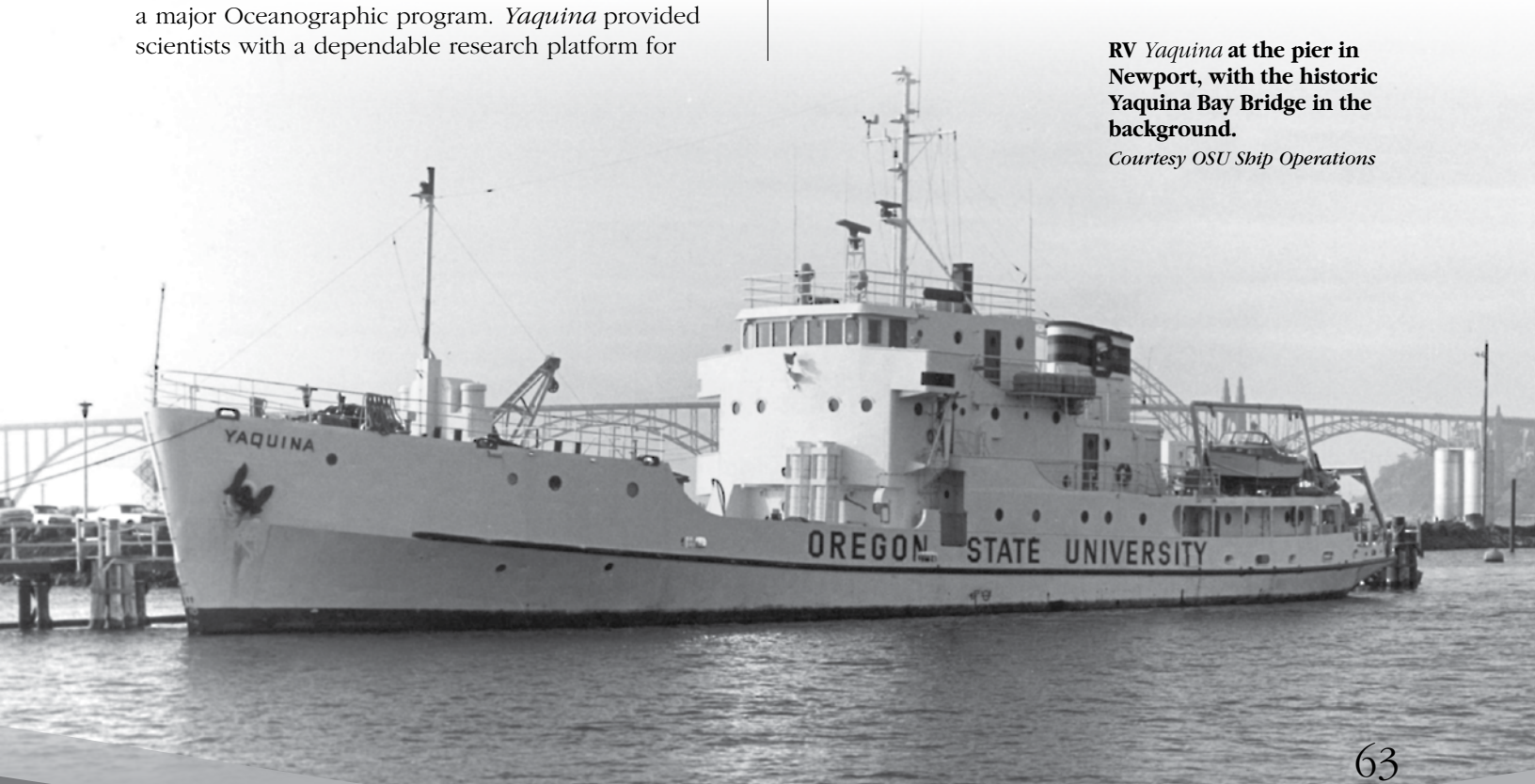
Additional faculty came and some left for a variety of reasons, often to grasp other opportunities. They all left on good terms and would spread the word of the rapidly developing, high-quality Oceanography program at Oregon State. Those early faculty members who stayed at Oregon State had the qualities of successful pioneers: vision, motivation and the courage to take risks in order to achieve their vision.

Facilities

To have a viable Oceanography program it is necessary to have ships and buildings; ships are critical. The folks at ONR made good on their promise to provide funds for a ship, a 65-footer. They didn't anticipate that Wayne Burt would manage to stretch the 65-footer into the 80 foot, 154-ton *Acona*. Launched in 1961, the *Acona* was a rough-riding research vessel that could accommodate fifteen scientists and crew. It operated off Oregon to a distance of 165 miles. The waters off Oregon served as the research ocean for all of the Oregon State scientists. Conducting ocean research in the same area helped to create a collaborative interdisciplinary approach to the oceanography efforts by Oregon State researchers. In 1964, *Acona* was replaced with the 180-foot, 800-ton *Yaquina*, a converted World War II FS with accommodations for forty scientists and crew. The *Yaquina* was capable of operating in all but the most severe ocean areas of the world and gave Oregon State a blue-ocean capability, a capability critical to being a major Oceanographic program. *Yaquina* provided scientists with a dependable research platform for twelve years before being replaced with the newly constructed 177-foot *Wecoma*. In 1968, the *Cayuse*, another new 80-foot research vessel, was added to the OSU oceanographic fleet for coastal studies. It was later transferred to the Moss Landing Research Laboratories of California State University.

In the early 1960s, with a new ship and an expanding staff, the need for land facilities was obvious. Ever in the market for new funds, Wayne approached the National Science Foundation for facilities money for an oceanography building on campus and a ship support facility at the coast. Because OSU did not have its own dock, the *Acona* was berthed in the municipal dock in Newport, for which docking fees were constantly required. Proposals were submitted, site visits organized and NSF came through with funds, but only for the building on campus, now referred to as Burt Hall #1.

A ship support facility in Newport was still badly needed. Occasionally good things happen to those who are prepared and in this case funds were provided from a surprising source. The short-lived federal Area Redevelopment Administration (ARA) recognized that Lincoln County, in which our home port, Newport, is located, was a depressed area and therefore eligible for funds to stimulate the local economy. Wayne Burt and other leaders at OSU recognized the opportunity, submitted a proposal to ARA, and obtained funds to build a coastal laboratory, complete with a public wing to attract tourists, and a



RV *Yaquina* at the pier in Newport, with the historic Yaquina Bay Bridge in the background.
Courtesy OSU Ship Operations



Aerial view of *Yaquina* and her pier in Newport, with the OSU Hatfield Marine Science Center in the background.
Courtesy OSU Ship Operations

ship support building and dock. The Marine Science Center (later named in honor of Senator Mark Hatfield) and a new dock were ready to receive and welcome the *Yaquina* when she arrived in Newport as a replacement for *Acona* in 1964.

Pioneering Research

The lack of data and knowledge of the ocean off the Oregon coast was used as a strong argument by Wayne Burt for establishing an Oceanography program at Oregon State. He felt that coastal oceanography out to a depth of 1000 fathoms had been neglected, particularly off the west coast of the United States and notably off Oregon. Consequently, much of the pioneering research by Oregon State researchers was descriptive in nature, driven by the question, "What is the ocean like off Oregon?" This question provided motivation for much of the early ocean research, be it physical, biological, or geological.



June Pattullo in her office, welcoming students and faculty alike.
Courtesy of OSU Archives

In 1961, with the newly commissioned RV *Acona*, Professor Pattullo initiated a program of systematic sampling and measurement of ocean properties regionally and with depth off Oregon. Seasonal sampling and measurement of temperature, salinity, oxygen and nutrients, begun in 1961 and continued until 1971, provided a valuable basis for future studies, including climate change related to ocean conditions. Based on the initial data, Bob Smith completed his Ph.D. dissertation in 1964 on upwelling along the Oregon coast, with June Pattullo as his major professor. In 1965, Pattullo, with graduate students Curt Collins and Chris Mooers, made the first direct measurements of currents over the continental shelf using moored current meters. Bob Smith and Dale Pillsbury continued to develop the current measurement program, which later became a major component of several international

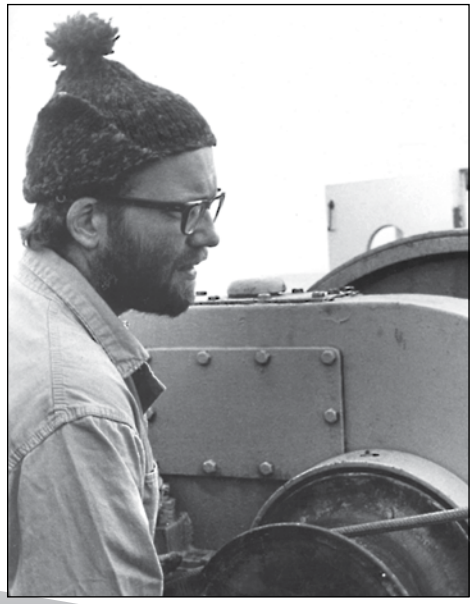
Oceanographic programs, notably the Coastal Upwelling Ecosystem Analysis studies off Oregon, Northwest Africa, Peru, and the International Southern Ocean Studies off Antarctica.

The results of the study of the physical and chemical nature of the ocean off Oregon, started by Pattullo, were of considerable benefit to the early biological studies by Professors Small, Frolander, Pearcy and Carey. The team of biologists addressed research questions of the trophic levels of the food web. Professor Small studied the phytoplankton; Frolander, the zooplankton; Pearcy, the nekton, notably fish, squid and shrimp; and Carey studied the benthic animals.

Immediately after arriving at Oregon State, Dr. Small began to implement a Phytoplankton Ecology Program that involved course development, research and library acquisitions. He and his graduate students began the first programmatic studies of primary production off Oregon. Small's group noted the two major features of the area that affected primary production: summer upwelling and the Columbia River plume. They were the first to document in detail primary production responses to the onset and the cessation of coastal upwelling. The Columbia River Plume delivered into the ocean low-level radionuclides discharged into the Columbia River at Hanford. Small's team, together with the radiochemistry group within the department, recognized that these radionuclides would serve as acceptable tracers of biological trophic level patterns that could be tracked in space and time. This led to an investigation of biological transfer of phyto-carbon into zooplankton grazers in upwelling and non-upwelling regions.



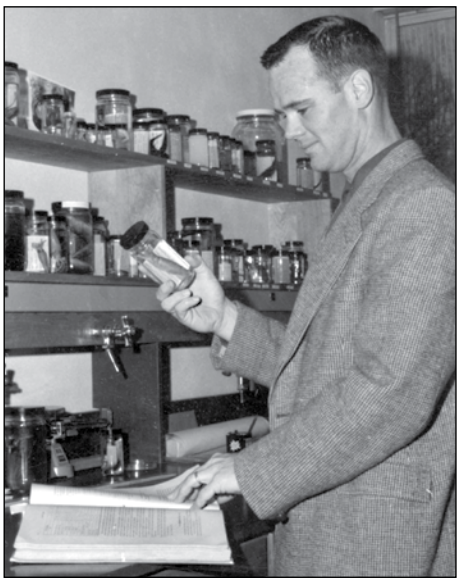
Above: Herb Frolander points out details of octopus anatomy to Portland Rose Festival princesses.
Courtesy of OSU Archives



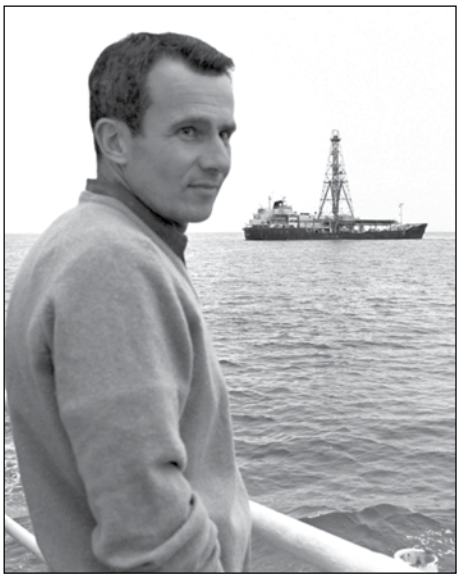
Professor Frolander initiated studies of the identification and distribution of zooplankton species in near-shore waters and their relationship to the zooplankton of Yaquina Bay. Regularly scheduled sampling trips served not only to identify daily, seasonal and long term patterns of zooplankton distribution, but they were also significant as training exercises for graduate students. The archived zooplankton samples were of value in later decisions involving location of water

Left: Bob Smith guides a mooring line during deployment of a current meter mooring from RV *Yaquina*, summer 1973.
Courtesy of Jane Huyer

intakes for the aquaria at the OSU Hatfield Marine Science Center and in research involving the landward intrusion of upwelled water. Also, much credit is due Dr. Frolander for developing the beginning Oceanography course, which brought attention to Oceanography at the undergraduate level throughout Oregon State College/University. Dr. Frolander was frequently called on by Dr. Burt to spread the word about the growing Oceanography department throughout Oregon, by means of public presentations to service clubs and other organizations.



Bill Pearcy sorts preserved fish samples, early 1960s.
Courtesy of the OSU College of Earth, Ocean and Atmospheric Sciences



John Byrne aboard RV *Yaquina* with Glomar Challenger in the background, 1971.
Copyright Gwil Evans

Bill Pearcy came to Oregon State directly after receiving his Ph.D. from Yale and immediately started a program that would continue throughout his career as an OSU Oceanographer. Little was known about the nekton off Oregon, other than the knowledge possessed by commercial fishermen. Pearcy changed that. He and his students conducted the first in-depth study of the distribution of small nekton off Oregon to 200 miles offshore and to a depth of 1000 meters. Together with Drew Carey, he researched the relationship of benthic nekton to depth and bottom sediment and rock types. Other research addressed the relationship of mesopelagic animals and sound scattering layers. He related catch rates of albacore to remotely sensed surface temperature, studied the radioecology of marine organisms, initiated submersible observation of offshore banks and pioneered research on the ocean ecology of juvenile salmonids off the west coast, demonstrating the critical importance of ocean conditions to their survival and distribution during their first year in the ocean.

When John Byrne arrived at Oregon State he set out to do two things: describe the geology of the area off Oregon and develop a curriculum of Marine Geology courses that would serve graduate students in both Geology and Oceanography. Little was known of the detailed bathymetry of the continental margin, the distribution and sources of continental shelf sediments, the subsurface geologic structure of the shelf and slope, the nature of the abyssal area beyond the continental slope, or the relationship of continental shelf geology to that of the Oregon landmass. With the help of two Geology graduate students, Vern Kulm and Neil Maloney, who had already been attracted to the Oceanography program, the Marine Geology program began to address these questions. As additional graduate students were added, attention was directed to the geology of Astoria submarine canyons and the Cascadia abyssal plain beyond the canyon. When Vern Kulm became a faculty member in 1964, he conducted the first comprehensive sedimentation investigations of a modern submarine fan and abyssal deep-sea channel off Oregon. Detailed study of these deep ocean deposits continues today. These studies have added significantly to the earthquake history of this region during the past 10,000 years. Subsequently, Kulm went on to serve as co-chief scientist of the Deep Sea Drilling leg off Oregon and later to be co-Director of the joint OSU-University of Hawaii IDOE-sponsored study of the entire lithospheric plate off Ecuador, Peru and Chile – the Nazca Plate.

The early Physical, Chemical, Biological and Geological studies off Oregon, although limited by the capabilities and the range of the *Acona*, served to establish a cooperative attitude among the scientists, leading to multi- and interdisciplinary results that otherwise would not have been possible. The sense of collaboration among OSU scientists generated in those early days continues today; cooperation is still a hallmark of Oregon State Oceanography.

A National Change of Sea State

The decade of the 1960s in the United States was marked by unprecedented attention to the sea. In 1966, the National Sea Grant College Act was passed. The United Nations convened the U.N. Law of the Sea Convention that would continue for years. Passage of the Marine Resources and Engineering Development Act created the National Council on Marine Resources and Engineering Development, with Vice President Hubert H. Humphrey as its chair. That same act called for a fifteen-member Advisory Commission on Marine Science, Engineering and Resources, chaired by Julius Stratton that henceforth was known as the Stratton Commission. Oceanography would be shaped by the Stratton Commission report, "Our Nation and the Sea," released in 1969. In March 1968, President Lyndon Johnson endorsed an "International Decade of Ocean Exploration (IDOE)" for the 1970s and, in December 1968, the United Nations General Assembly formally welcomed the proposed Decade. The national posture regarding the oceans was changing rapidly.



Vern Kulm emerges from the submersible after diving off the Oregon coast, September 1988.
Courtesy of David L. Stein

Changes were also taking place at Oregon State University. In 1967, Wayne Burt resigned as Chairman of the Oceanography Department and assumed the role of OSU's Associate Dean of Research for Oceanographic Programs; he continued as Principal Investigator of the ONR contract. Herb Frolander filled in as interim department chairman, until John Byrne was appointed Chairman of the Oceanography Department in 1968. During that same year, OSU received one of the first Sea Grant College awards and Professor Frolander was appointed coordinator of the Sea Grant program. In 1971, OSU was officially named one of the nation's first Sea Grant Colleges.

Expansion of the OSU Oceanography Department continued. In 1968, eight new faculty members were added; in 1969, five more; and in 1970 another five. Many of these faculty members were transferring from other established Oceanography programs. In 1970, there were 150 faculty and staff and over 100 graduate students. OSU's Oceanography program was growing and so was its reputation.

In the early 1970s, two major changes at a national level would affect the manner in which ocean research was conducted: United States funding for the IDOE (International Decade of Oceanographic Exploration) and UNOLS (University National Oceanography Laboratory Systems). OSU oceanographers were not exempt from the impact of those changes.

IDOE was assigned to the National Science Foundation and would support major multi-disciplinary, multi-institutional programs, with OSU oceanographers participating and providing leadership for a number of the programs. The IDOE Coastal Upwelling Experiment (CUE) conducted off the Oregon coast addressed the physical aspects of coastal upwelling. Led by Bob Smith and James O'Brien of Florida State University, it included researchers from Florida State, Woods Hole, the University of Washington, Pennsylvania State University and the University of Chicago, as well as OSU. It was the precursor to the Coastal Upwelling Ecosystem Analysis (CUEA) studies off Oregon, Northwest Africa and Peru, which included investigators from ten U.S. institutions, including Oregon State, and institutions in twelve other countries. The IDOE Seabed Assessment Program included the Nazca Plate project off South America led by Vern Kulm, and the Galapagos Rift study during which deep-sea hot vents and their unique faunal communities were first discovered by OSU scientists. The decision to participate in the Seabed Assessment Program was not taken lightly, for it would mean the *Yaquina* would be away for months at a time, precluding its use at home. Other IDOE projects that Oregon State researchers participated in included the Geochemical Ocean Sections (GEOSECS) program and the Climate Long-Range Investigations Mapping and Prediction (CLIMAP) program. Big science

had arrived at Oregon State. Participation in IDOE was significant in elevating OSU's Oceanography program to a national level.

The second major change in the way oceanographic research was conducted resulted from the adoption of the University National Oceanography Laboratory System (UNOLS) in 1972. Prior to UNOLS, ships were operated by each oceanographic institution for its own scientists. After the adoption of UNOLS, all ships operated by universities were scheduled jointly in a collaborative manner. The system made efficient use of vessels, standardized basic equipment and created uniform safety requirements and resulted in the cooperative use of the nation's entire oceanographic fleet operated by academic institutions. It meant that OSU's vessels would sometimes operate without an OSU researcher aboard, and that OSU oceanographers would sometimes conduct their research from another institution's ship. The UNOLS concept was adopted following almost two years of vigorous debate between the laboratory directors and leadership at NSF; it has operated successfully since 1972. John Byrne was one of the five laboratory directors who drafted the original proposal; he served as the first chair of the UNOLS council, which monitored the program. Both IDOE and UNOLS fostered a cooperative approach to the conduct of ocean research to the benefit of all United States oceanographers.



Coffee break during the meeting of the international Scientific Committee on Oceanic Research (SCOR) Working Group on Coastal Upwelling Processes in Corvallis, March 1973. OSU's Larry Small (left) and John Byrne (2nd from right) are shown with Konstantin Federov from the USSR and James O'Brien of Florida State University.

Leadership at OSU

Strong leadership at Oregon State was a hallmark of the Oceanography program from its beginning. Each department chair and dean moved the program forward in terms of personnel and budget, and each added innovative programs and approaches to the challenges and opportunities presented. The oceanography presence at Oregon State also had a profound effect on other programs at the University, increasing the scope of the Fisheries and Zoology programs and creating new dimensions for Engineering programs. Without a strong oceanography presence at OSU, it is doubtful that the Oregon State University Hatfield Marine Science Center would have become a major multi-agency facility in Newport, Oregon. The O. H. Hinsdale Wave Research Laboratory might not exist, nor would the first supercomputer in the state of Oregon (located in the Oceanography Complex on campus). The International Oceanography Educational Program and the Marine Resource Management Program are further testimony to oceanography leadership.

The story of Oceanography at Oregon State is a story of vision, persistence, dedication and cooperation by intelligent people who have common goals. It is a story of the scientists who came to Corvallis, saw the opportunity to create a program, were persistent in pursuing that opportunity and left a history of what is possible. It is a story of pioneers who sought new knowledge, succeeded and dedicated their careers to leaving things better than they found them.

OREGON STATE UNIVERSITY	Oceanography Leaders
Department Chairs and Deans	
Wayne V. Burt	Chairman (1959-1967)
Herbert Frolander	Interim Chair (1967)
John V. Byrne	Chairman (1968-1972), Dean (1972-1976)
George Keller	Interim Dean (1976-1978)
G. Ross Heath	Dean (1978-1984)
Douglas Caldwell	Dean (1984-1993)
Lawrence F. Small	Interim Dean (1993-1994)
G. Brent Dalrymple	Dean (1994-2001)
Mark Abbott	Dean (2001-present)

Epilogue

W. BURT - Wayne Burt, who had initiated the Oceanography program, stepped down as department head in 1967, and continued to provide leadership as the University's Associate Dean/Vice President for Oceanic Research. In 1991, he died of a heart attack while fishing off Newport, Oregon.

J. BYRNE – John Byrne left the Oceanography program in 1976 to become the University's Vice President for Research. In 1981, he left the University to become Administrator of the National Oceanic and Atmospheric Administration, returning to OSU in late 1984 to serve as University President for eleven years, before retiring from Oregon State at the end of 1995.

A. CAREY - Andrew "Drew" Carey, a scientist dedicated to advancing the knowledge of benthic communities in the Pacific and Arctic Oceans, continued his research on the ecology of benthic faunal communities throughout his career and beyond his retirement from Oregon State in 1987. After retiring, he donated extensive collections of invertebrate specimens from the deep sea and the Arctic to major West Coast museums.

H. FROLANDER - Herb Frolander, a teacher both on a research vessel and in the classroom, initiated a number of the early courses in Oceanography, received awards for his teaching excellence and on his retirement created the Frolander Graduate Teaching Assistant Award, given annually for excellence in teaching by graduate student teaching assistants. During his career as an oceanographer, he became the first Director of the Oregon Sea Grant Program. An avid gardener, Dr. Frolander says he has "enjoyed retirement on 'our farm' since 1986."

V. KULM - LaVerne "Vern" Kulm was the first graduate student of John Byrne. He dedicated his oceanographic career to Oregon State University, serving as co-director of the IDOE Nazca Plate Project, co-chief scientist on the Glomar Challenger deep sea drilling leg off Oregon and Alaska in 1971, and leading the research effort on fluid expulsion zones and active faults on the Oregon-Washington continental margin. He retired in 1997 and continues to serve as a lecturer to school groups, senior citizen groups and civic organizations, to which he provides expert advice on marine geological problems.

J. PATTULLO – June Pattullo, one of the first woman oceanographers, received her Ph.D. from Scripps Institution of Oceanography on studies of global sea level under Professor Walter Munk. She earned a reputation as a world authority on sea levels and their dependence on heating and cooling of the world ocean. Professor Pattullo was a dedicated teacher and researcher, until her career was cut short by death early in 1972.

B. PEARCY – Bill Pearcy continued to teach and do research on the nekton of the Pacific Ocean past his retirement from Oregon State in 1990. He is best known for his contributions to the understanding of aspects of northeast Pacific salmon during their marine phase. In 2003, the North Pacific Marine Science Organization (PICES) presented him with the Warren Wooster Award for his studies of the fish and squid of the North Pacific. He presently serves as a consultant to fisheries groups and operates a small farm in western Oregon.

L. SMALL – Larry Small and his group were involved in a number of major multi-institutional projects designed to understand the relationships between phytoplankton and zooplankton. One example is the CABS (California Basin Studies) DOE-sponsored multi-institutional program established to understand the flux of energy-related materials into the coastal environment with unique bathymetry. He served as the editor of the final volume of research papers that summarized the results of the research. Small served as Associate Dean of the College of Oceanography (1984-1992), and subsequently as Acting Dean of the College of Oceanic and Atmospheric Sciences (1993-1994). He retired from OSU early in 1995.

R. SMITH – Bob Smith was the first Ph.D. student of June Pattullo (1964). He left OSU in 1965 for a post-doctoral fellowship in England, and then worked as a science officer of the Office of Naval Research (1969-1971) before returning to Oregon State, where he studied coastal upwelling and eastern boundary currents. He was co-editor of the international journal *Progress in Oceanography* from 1985 until 2003. He retired from teaching in 1997, but continued research as an emeritus professor until 2009.

Acknowledgements

Oceanography in the twenty-first century is a cooperative venture. Researchers and their technical assistants from different agencies and universities often work together on multidisciplinary research projects. So too, is the preparation of a paper such as this one a cooperative venture. A number of scientists provided information included herein. For this and much more, special thanks are extended to Bob Smith, one of the oceanography pioneers, who edited the manuscript, provided information on himself and on June Pattullo, and served as the principal contact for Oregon State University with the Maritime Museum of San Diego editor.

The pioneers provided information on their research and activities after retirement. In addition to Bob Smith, they are Drew Carey, Herb Frolander, Vern Kulm, Bill Pearcy and Larry Small. Jane Huyer helped with the selection of photos and Gwil Evans provided the photo of the author from his personal files. Of particular value was the history of the early days of the Oceanography program prepared by Louise Burt, Wayne's wife, and Miriam Ludwig, 1998, *Oceanography at Oregon State University: the First Two Decades, 1954-1975.*

Carol Mason, the only non-scientist on this project, made this paper eminently more readable through her keen editorial eye and non-scientist questions.

Thank you all.





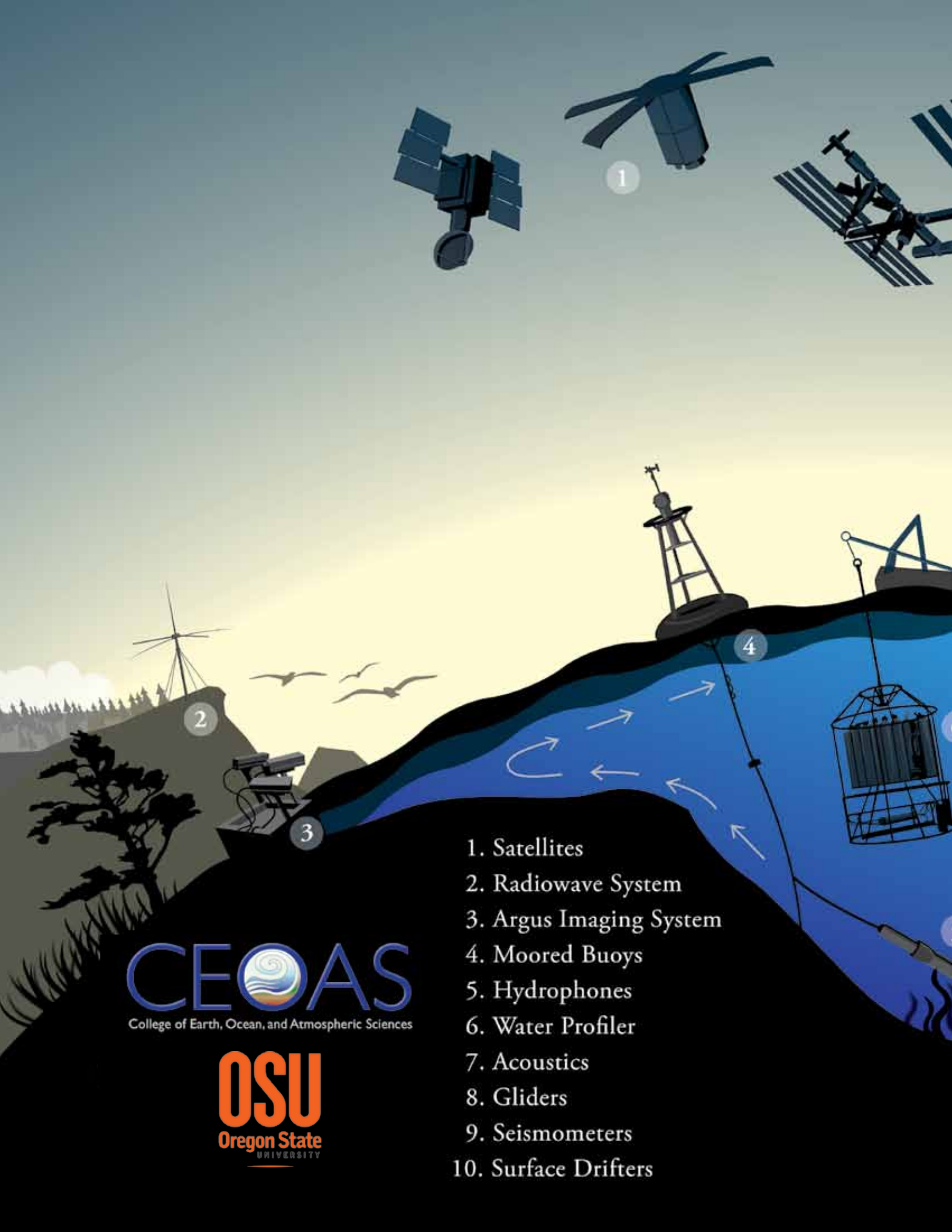


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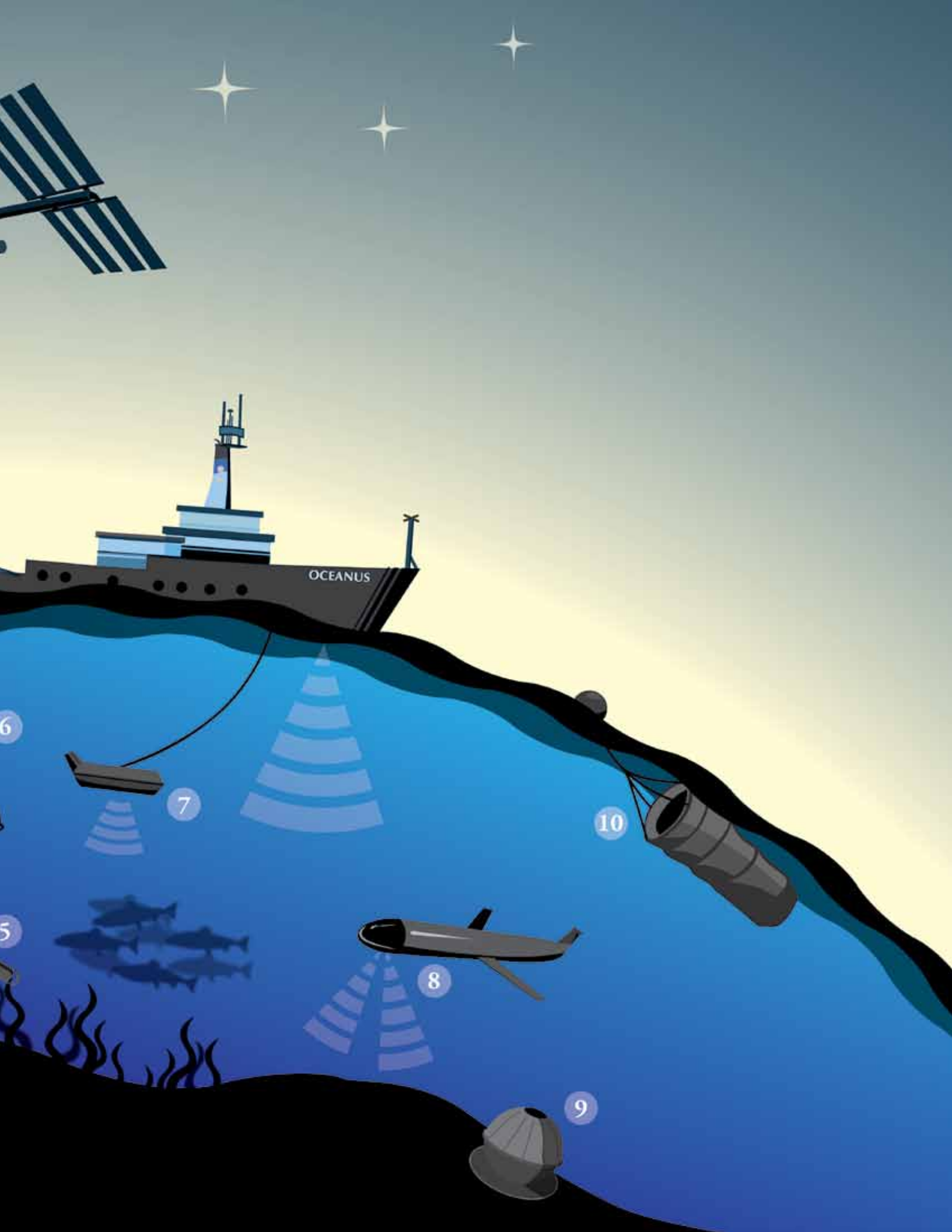




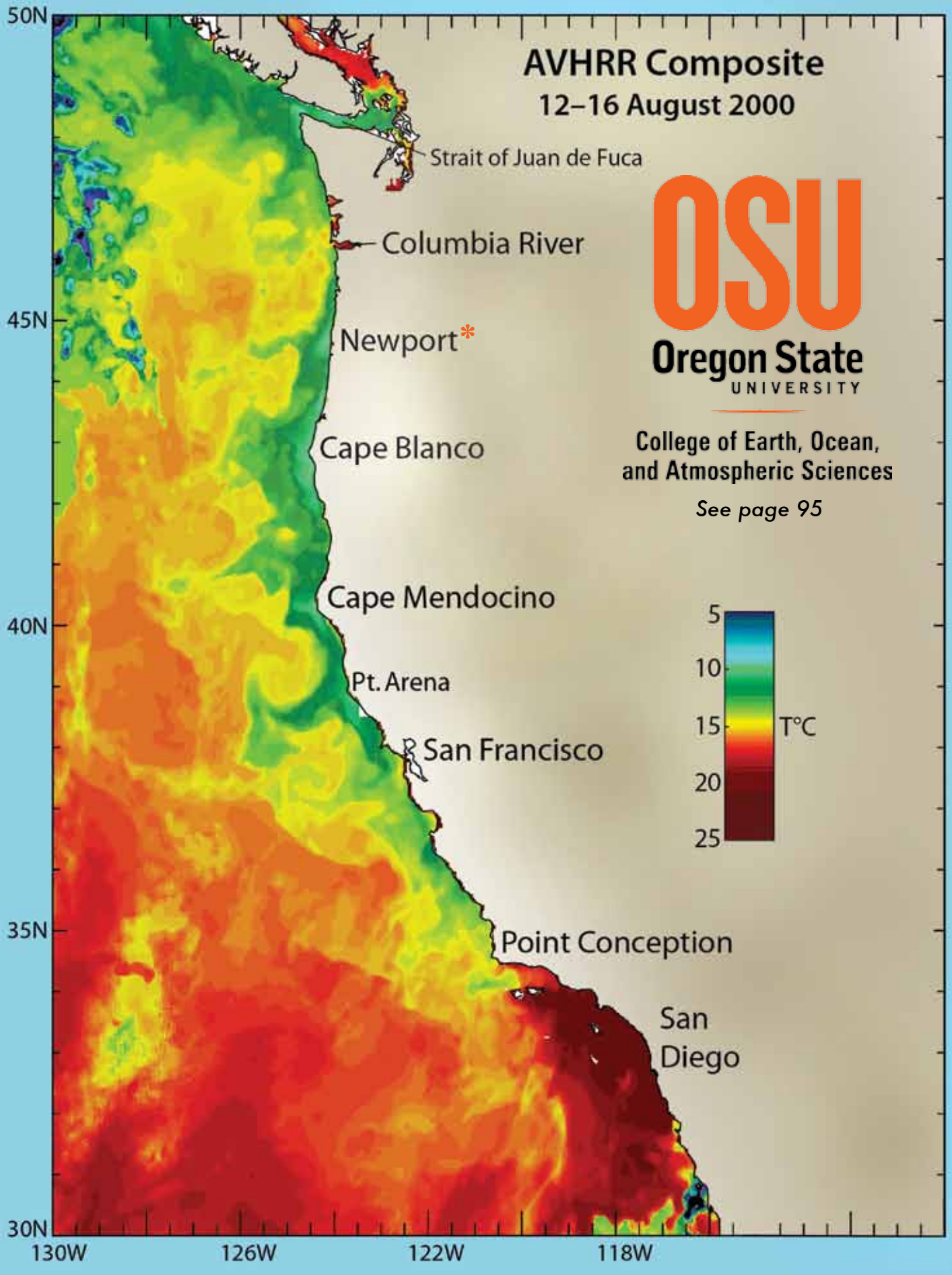
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OSU
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1. Satellites
2. Radiowave System
3. Argus Imaging System
4. Moored Buoys
5. Hydrophones
6. Water Profiler
7. Acoustics
8. Gliders
9. Seismometers
10. Surface Drifters


OCEANUS
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Sea surface temperature measured by satellite during 12-16 August 2000



See page 95

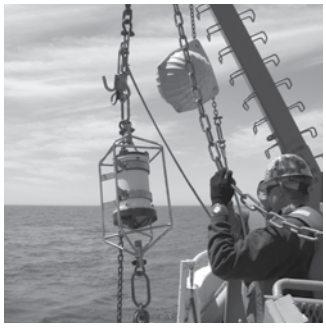
Color Pages Reference Guide



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



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



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



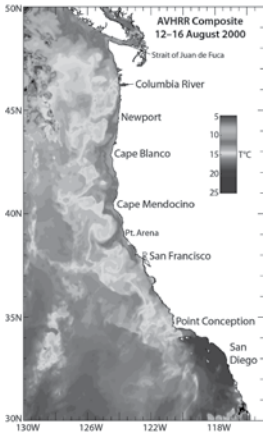
***Wecoma* crossing the Yaquina Bay bar. This was its final inbound trip across the bar (30 November 2011), before being "replaced" by *Oceanus*, its older sister on 23 March 2012.**
Courtesy of Demian Bailey, Oregon State University



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



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



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

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.

Introduction

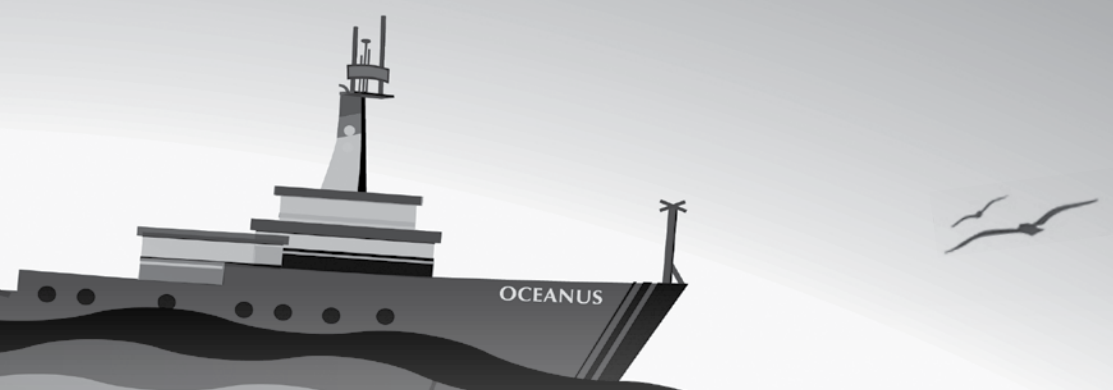
The dynamic, ever-changing ocean off Oregon is home to a rich, productive ecosystem, driven by strong seasonal winds forced, in turn, by shifts in atmospheric pressure patterns and storms characteristic of the northern end of the California Current. Oceanography took root at Oregon State College (now 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 in1964 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.

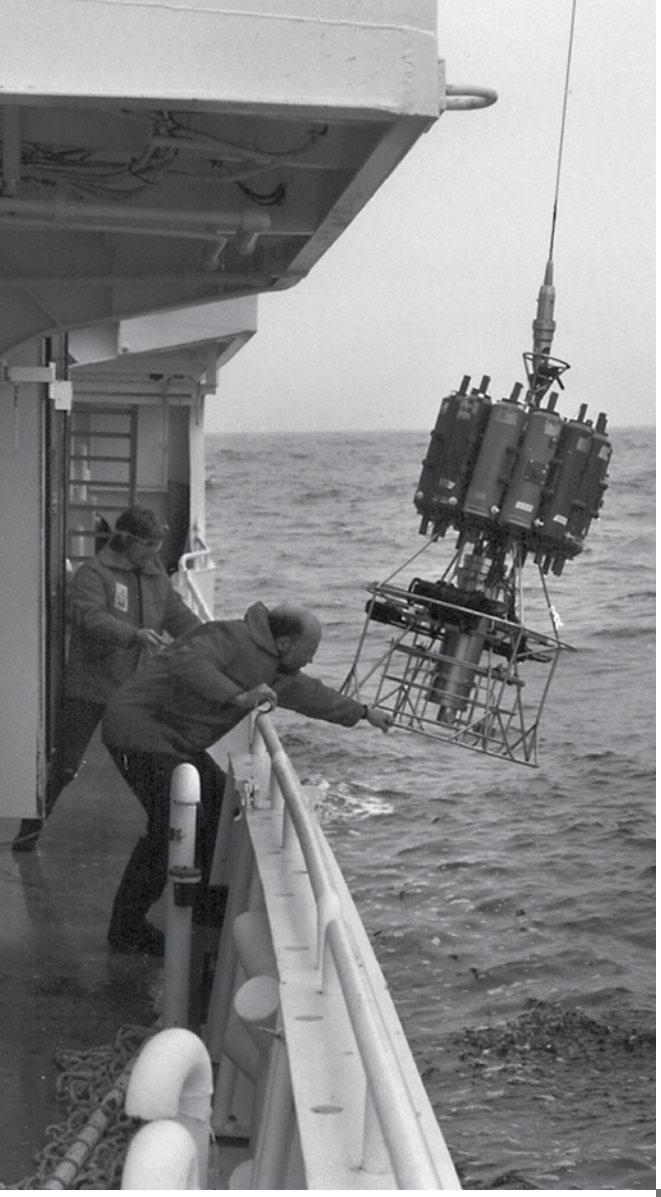
The Oregon sampling focused on the Physical Oceanography: funding for the hydrographic sections off Oregon came from the TENOC project of ONR,[8] while CalCOFI surveys were motivated by the collapse of the California sardine fishery. The principal sampling was initially done with mechanical devices: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

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).



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

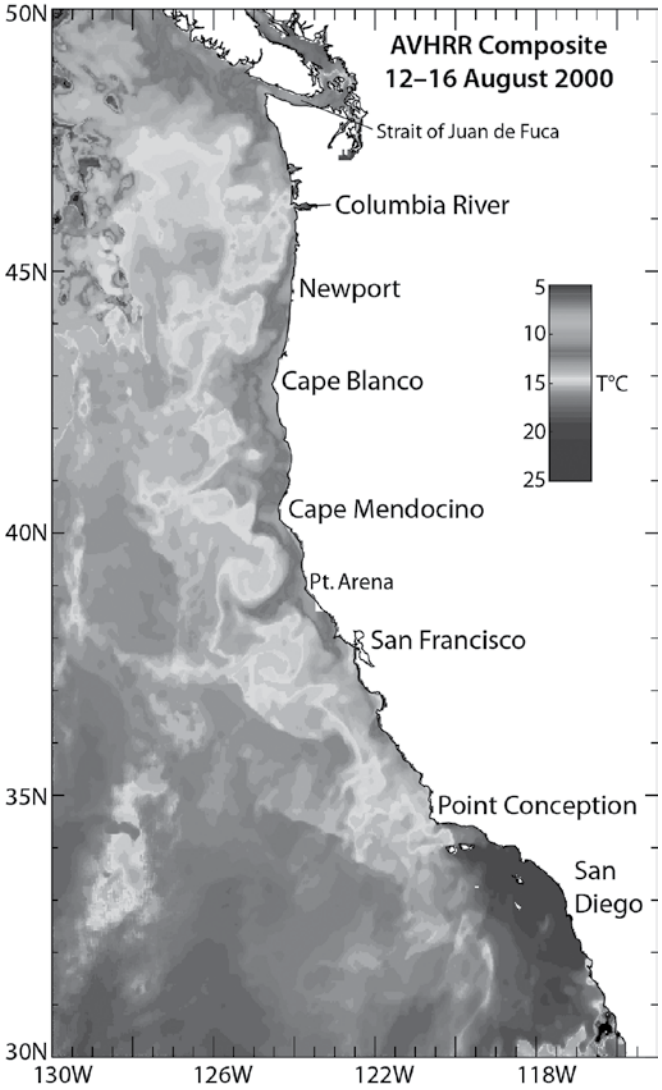
Coastal Upwelling Unveiled

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.

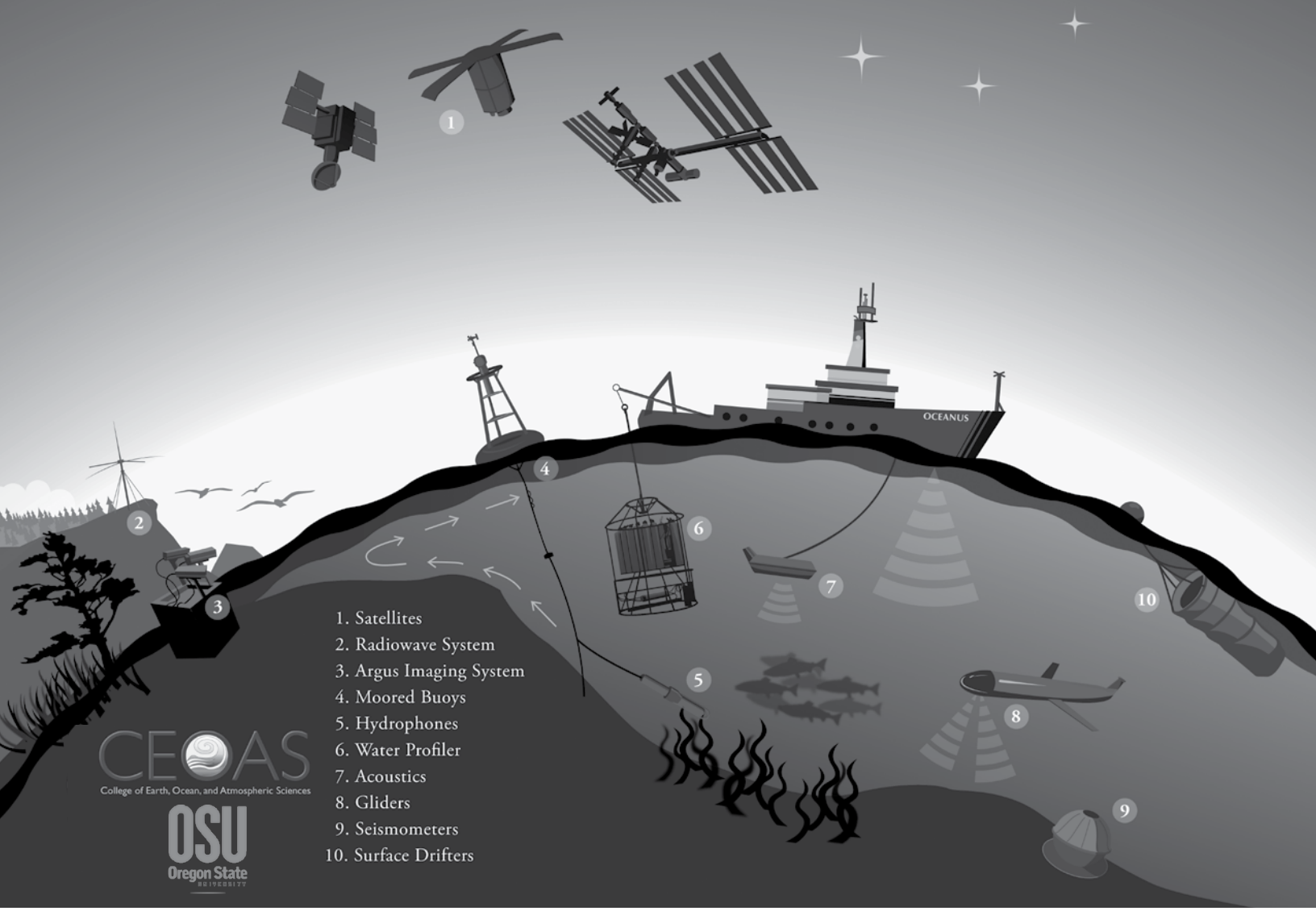
Oceanographers at Oregon State University, in collaboration with their West- and East Coast colleagues, played key roles in interdisciplinary studies of coastal upwelling ecosystems. The coastal ocean off Oregon is an ideal place to study coastal upwelling because of the clear seasonal signal of increased 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



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

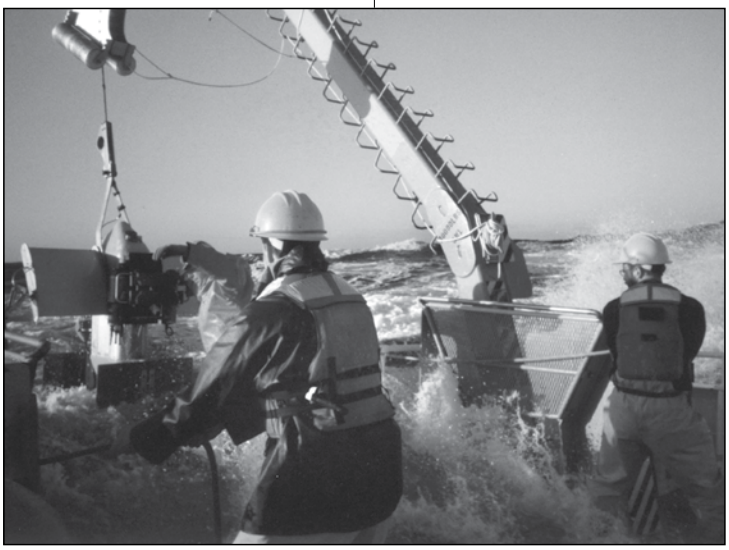
A modern ocean observing system employs a mixture of remote sensing techniques (satellite, land-based), moored buoys and seafloor platforms, as well as ships and autonomous underwater vehicles.

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.

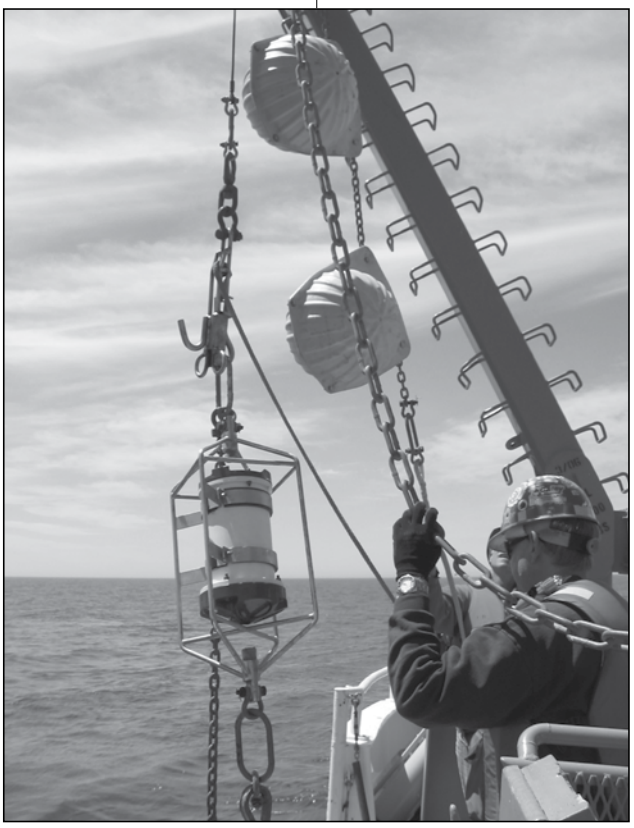


Marc Willis, Daryl Swenson and Jack Barth recover a towed, undulating vehicle called SeaSoar, during a typical windy day in the Northern California Current.

Courtesy of Steve Pierce, Oregon State University

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)

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]



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

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

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 1989[20] 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 Glider[29] 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

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13 This figure was created by an undergraduate graphic design group "208 Design Studio" at Oregon State University, when challenged to show an ocean observing system spanning the coastal ocean.

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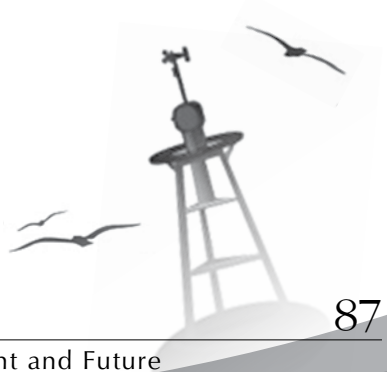
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Mid-Pacific Oceanography: University of Hawaii and the Sea

By David M. Karl, Ph.D.

Introduction

The people of Hawaii have a long and enduring heritage with the sea. For this reason, academic interest in maritime studies in Hawaii, and especially expeditionary and field research, pre-date the founding of the College of Agriculture and Mechanical Arts in 1907. However, a comprehensive academic program for graduate research and training in Oceanography emerged at the University of Hawaii (UH) just fifty years ago. The Oceanography program had two distinct roots: one in Geological and Physical Sciences, and the other in Marine Biology and Fisheries. Prior to 1962, Marine Science training was spread over a number of isolated, and sometimes competing, academic units without centralized management, common mission, or effective leadership. The integration of these separate units would take decades to achieve despite strong administrative support. This year marks the 50th anniversary of the formation of Oceanography as a graduate field of study (1962-2012), which, since its founding in 1988, has been a focal discipline in the School of Ocean and Earth Science and Technology (SOEST) at UH.

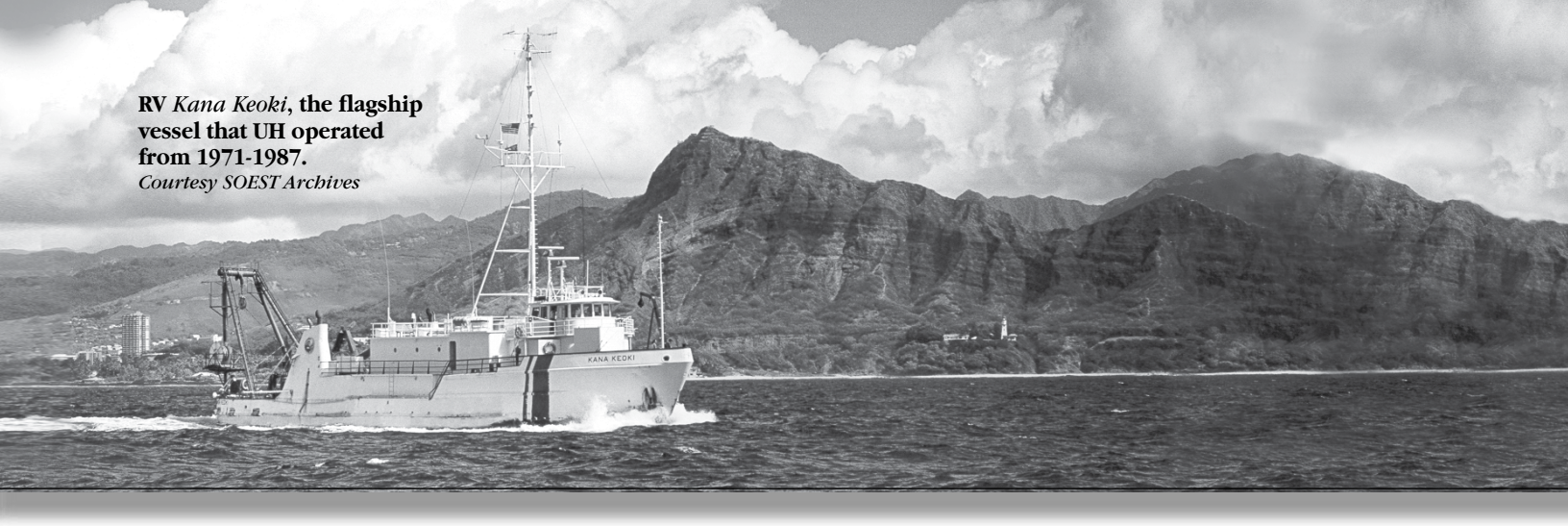
The Founding of the University of Hawaii

The Morrill Land Grant Act, signed into law by U.S. President Abraham Lincoln in 1862, permitted states to apply for federal land grants, the proceeds of which could be used to support post-secondary education. The act to create the College of Agriculture and Mechanical Arts in Hawaii was unanimously passed by the legislature and signed into law on 27 March 1907, by Territorial Governor George Carter. Classes commenced on 14 September 1908. In 1911, the name changed to the College of Hawaii (C of H), and in 1912 the College moved to its present location in Manoa Valley. In 1919, the territorial legislature passed a second act that transformed the C of H into the University of Hawaii (UH) with the addition of the College of Arts and Sciences, and on 30 April 1919, Territorial Governor C. J. McCarthy added his approval to this change in status and stature, to take effect 1 July 1920. Long after statehood in 1959, the campus took its present name, University of Hawaii at Manoa (UHM), in 1972, to distinguish it from other units in the growing state-wide university system. An excellent historical account of the first thirty years of UH (1907-1937), written by William George, is available at UHM's Hamilton Library (*The University of Hawaii: A Short History*, 1938).

From its beginning, UH has always had an academic interest in the sea. The origins of Oceanography can be traced back to the establishment and expansion of several coastal marine laboratories. According to a historical account by Leslie Matsuura in *Building a Rainbow*, the original Honolulu Aquarium (HA) opened to the public on 19 March 1904 as a private project under James B. Castle, Charles M. Cooke, and Lorrin A. Thurston, then directors of the Honolulu Rapid Transit Authority. The main purpose of the HA was to attract the public to Kapiolani Park – the end of the transit line. Frederick Potter, a clerk for the Honolulu Rapid Transit Authority, served as the Aquarium's first director. At the time of its creation, the HA had no basic research or education mission.

Right: This is a view of the College of Hawaii's Manoa campus in 1920 looking north. Hawaii Hall, the first structure on the Manoa campus, is in the center. To the lower right is the first of what would become several buildings that comprised the Young Engineering complex (this building was just demolished last year to make way for a new Campus Center), and the L-shaped building is the chemistry lab that was moved there from another location on Oahu, and, of course, the football field!

Courtesy University of Hawaii at Manoa Library Archives

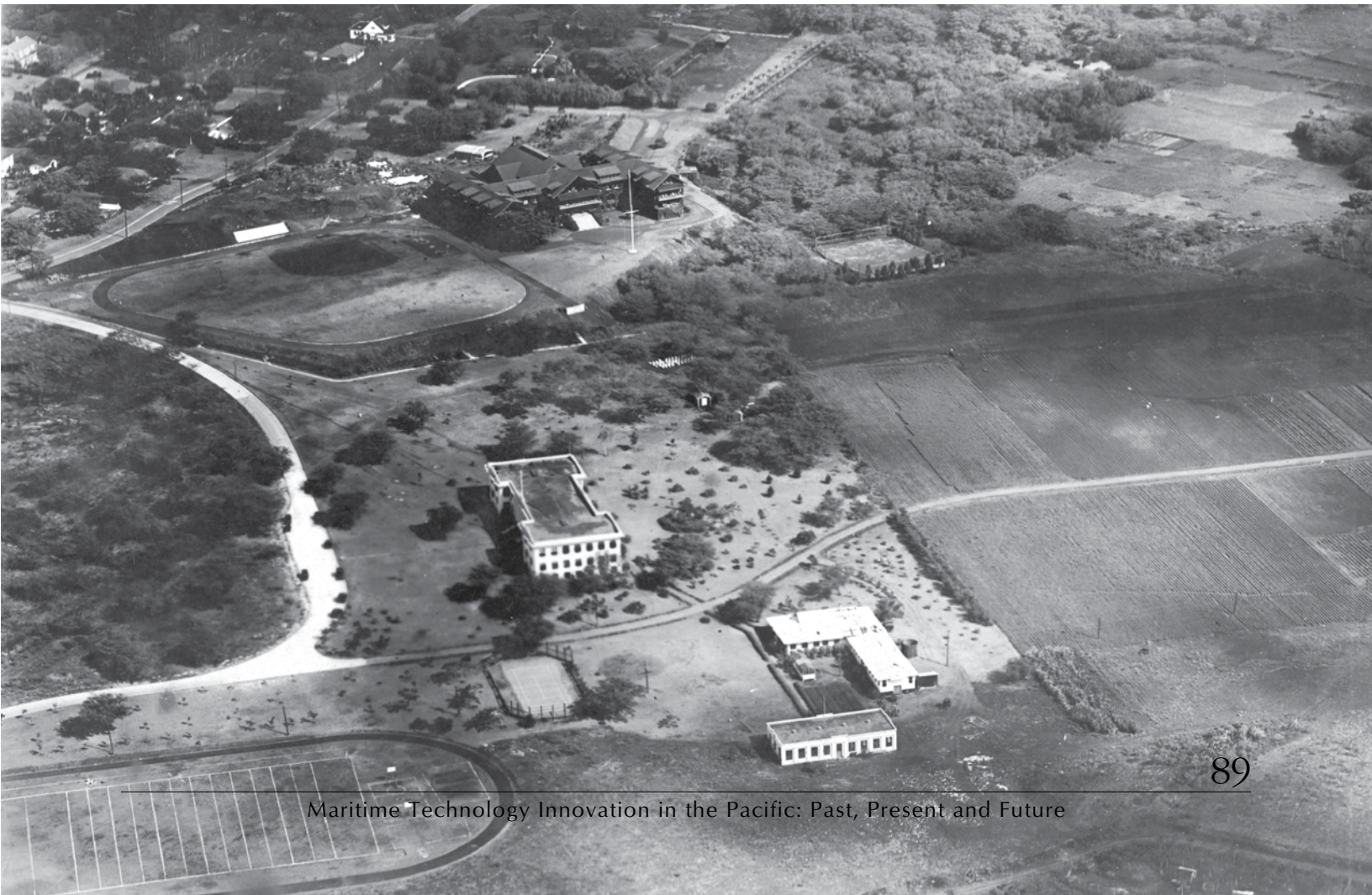


RV *Kana Keoki*, the flagship vessel that UH operated from 1971-1987.
Courtesy SOEST Archives

David M. Karl

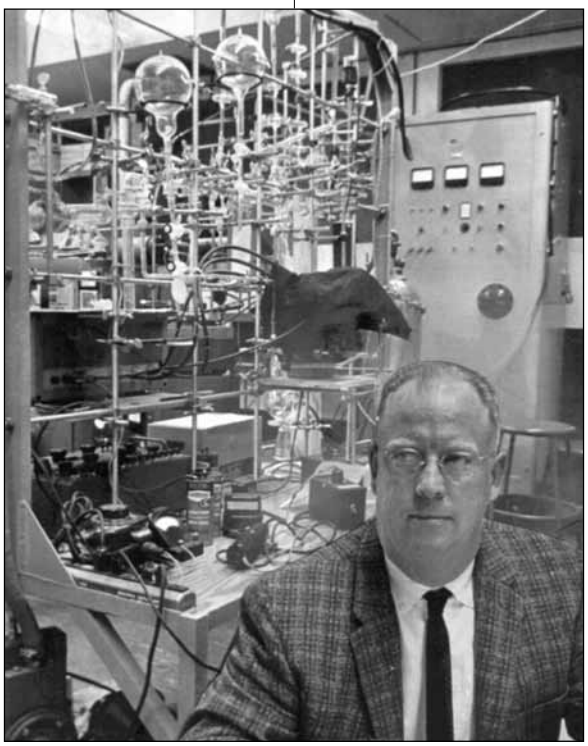
A microbial biologist and oceanographer in the School of Ocean and Earth Science and Technology, David Karl has focused his research on the ecological role of microorganisms in the sea and has enjoyed many groundbreaking research discoveries along the way. He is Director of the University's Center for Microbial Oceanography: Research and Education, and has received numerous national and international honors and awards throughout his thirty-four years at UH Manoa. In the course of his career, Karl has spent more than three full years at sea, including twenty-three expeditions to Antarctica.

In August 1908, John Washington Gilmore was appointed the inaugural president of the C of H. "Our teaching should be in accordance with our environment," said Gilmore, "there should be a logical focus on agriculture and marine sciences." Each year, the Board of Regents filed one or more reports with the Legislature on matters related to the academic affairs of the College. These reports were known as the *College Records* beginning with No. 1 in 1908, and ending with No. 20 in 1920, when the C of H became the UH. After that time, these same materials were contained in the *University Records* series and eventually in the annual *University Catalog,* which is still published today. According to the *College Records,* 1911, there was a formal proposal by Gilmore to establish a Marine Biological Laboratory as a branch of the Department of



Zoology as early as 1910. It was stated that, "It is quite probable that if the college could make a beginning in this work, aid might be secured from the U.S. Fish Commission." (NOTE: The U.S. Commission of Fish and Fisheries was created by Congress in 1871. Since 1903, the Commission has been within the Department of Commerce. In 1949 a Honolulu Branch, the U.S. Pacific Ocean Fisheries Investigation (POFI), was established. POFI was the predecessor of the Fish and Wildlife Services Bureau of Commercial Fisheries which, after the National Oceanic and Atmospheric Administration (NOAA) was created in 1970, became the National Marine Fisheries Service.)

By 1911, there already was a formal 3-credit course in Oceanography taught by Professor William Alanson Bryan (*College Records*, 1911-1912). In *College Records,* 1915, a textbook – Murray and Hjort's *The Depths of the Ocean* – was added as required reading for this course.



Robert Hiatt, "the Father of UH Oceanography," in his lab ca 1963.
Reproduced with permission from the Honolulu Advertiser

According to *College Records,* 1913, there was a well articulated need for "A Marine Biological Laboratory for Hawaii" based on a paper by Department of Zoology Professor Allan Herbert. The plan called for a seashore laboratory at Waikiki, in the park adjacent to the Honolulu Aquarium. A seaside lab, when available, the report stated, "would give the College access to the fascinating world that lies hidden in the ocean." The second C of H president, Arthur Dean, served from 1914-1927 and continued Gilmore's vision of Hawaii's potential as an out-of-doors natural laboratory with a focus on marine sciences, especially Marine Zoology. Hawaii's strategic mid-Pacific location with easy access to the deep sea provided many unique educational and research opportunities. In *College Records,* 1917, it was reported that "The most noteworthy advance made during the past two years in the development of the Department of Zoology has been the securing of temporary quarters on pier 6 for the equipment of a small marine laboratory on Honolulu harbor."

In 1919 (*College Records*), more permanent marine research facilities began to materialize. It was announced that "the HA stands on government land the lease of which will expire on 3 June 1919. The land will then pass into the Waikiki park system. The Aquarium, however, has possibilities far beyond its use as a show place, excellent as that is. As a beginning for a marine biological station it opens up the opportunity of carrying on scientific investigations and instruction of the very highest value." This report, submitted by President Dean further stated that by change in existing laws it would be possible to turn over the two existing lots at Waikiki, where the Aquarium stood, to the Board of Regents to establish a marine research laboratory in connection with the Aquarium. The plan would also "put at least two men at work on investigations: one a trained biologist, the other a man with experience in fish hatchery work." The Territorial Legislature of 1919 placed the HA under the care of the College of Hawaii. The Charles M. Cooke Estate generously provided $10,000 for the construction of a laboratory for Marine Zoology in conjunction with the Aquarium. This facility, the Charles M. Cooke Memorial Marine Laboratory (CMML), was ready for use in summer 1920.

Professor Bryan, who had handled work in Marine Zoology and had worked tirelessly to establish new programs in Marine Biology, left in the summer of 1919. With the transformation from C of H to UH in 1920, the faculty was expanded to include Charles H. Edmondson, Ph.D., University of Iowa, 1906, as Professor of Zoology (*College Records,* No. 20, 1920-1921). An arrangement was entered into with the Bishop Museum whereby Edmondson would be on the staff of the Museum as well as the UH. Edmondson became the founding director of the newly acquired CMML, which was administratively separate from the Aquarium. According to a biography of Edmondson written by Hank Banner, the "Beach Lab," as it was called in those days, was to become an active center for diverse marine research activities over the next few decades. Edmondson served as director until 1943, when he retired from UH.

A New Emphasis on Marine Education Programs

The Master of Science (M.S.) degree was created at the C of H in 1914, and by the end of 1933, one hundred twenty-two M.S. degrees had been granted. Most of these were in the fields of Entomology and Agriculture, reflecting the original land grant focus of the curriculum. Post-World War II growth included several new academic programs and significant capital improvement projects for basic research. President Gregg Sinclair presided over this unprecedented growth in the capacity for science and technology. According to newspaper reports, Sinclair wanted UH to be "not a big University, but a significant one."

In 1947, as part of the 40th anniversary of the founding of UH – the Hawaii chapter of Sigma Xi – the national honorary scientific society, was founded. This marked the beginning of an increased awareness of, and emphasis on, the study of natural sciences. In 1948, the Graduate Division was created to promote and facilitate the expanding graduate programs, including marine sciences. By this time, Robert Hiatt had already begun to provide the much needed leadership in his capacity as "senior" Professor of Marine Zoology.

As emphasized in the inaugural Graduate Division catalog, "The location of the islands offers students of Marine Biology a natural laboratory for the study of marine life in the tropics."

In his "end of the year" report for 1950, UH President Gregg M. Sinclair reviewed progress on two significant marine related projects. He stated that the University now holds a lease to part of Coconut Island, where a laboratory has been established and a research vessel *Salpa* (I) collects marine samples and data. Second, the U.S. Fish and Wildlife Service (FWS)

Robert W. Hiatt:
The Father of UH Oceanography



Robert and Mrs. Hiatt at his UH retirement luncheon in April, 1969.
From UH at Manoa Masao Miyamoto collection: negative C69-00055

Robert W. Hiatt was born on 23 December 1913 in San Jose, CA, one of 7 children. According to information contained in a University of Alaska press release following his death in 1997, Robert was the only one of his siblings to attend college. He went on to receive a Ph.D. in Marine Zoology, in 1941, from the University of California, Berkeley. He joined UH in 1943 and served for twenty-six years in various capacities, ranging from Professor to acting President.

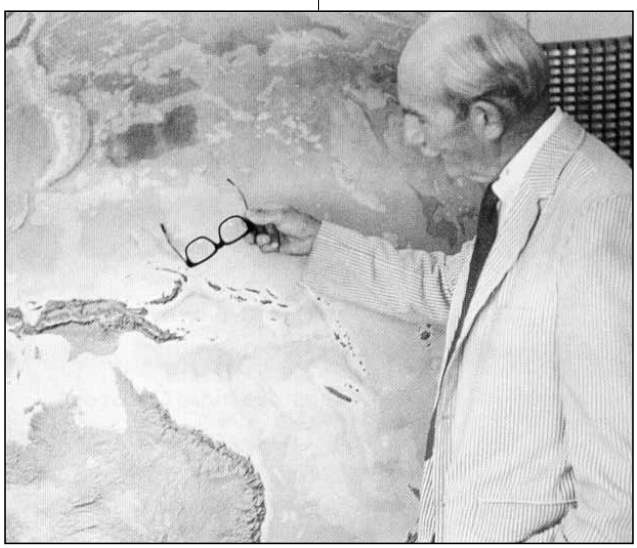
In his dual capacity as Dean of the Graduate School and Director of Research (1955-1963), and later Vice President for Academic Affairs (1963-1968), Hiatt was deliberate and articulate in his support of Oceanography as a new and important field of study. Hiatt was also a strong advocate for basic research: he argued forcibly that while it was expensive, it would eventually pay its own way. Research, he argued, was the basic foundation on which great universities are built.

His efforts led to the creation of Oceanography as a graduate field of study in 1962, and eventually to the Department of Oceanography two years later. He also founded and directed the Hawaii Marine Laboratory (HML, later renamed Hawaii Institute of Marine Biology – HIMB) and the Enewetak Marine Biological Laboratory (EMBL), created the Hawaii Institute of Geophysics (HIG) and the Pacific Biomedical Research Center (PBRC), and served as the inaugural Executive Director of the Research Corporation of the University of Hawaii (RCUH), a non-profit organization that he created during his term as vice president and, later, acting president. The aggregate impact of these marine education and research units is unprecedented in the one-hundred year history of UH.

After leaving Hawaii, Hiatt served as consular officer and secretary at the U.S. Embassy in Tokyo (1970-1973), and in 1973 he became the fifth President of the University of Alaska, a post he held until 1977. Robert Hiatt died on 6 September 1997, at the age of 83. On 9 February 1998, a memorial service was held at Kaneohe Yacht Club and later his ashes were scattered in the waters near HIMB, one of the many marine academic and research centers that he had established during his tenure at UH.

recently completed a building on 2.8 acres of land made available from UH to the federal government. At that time the FWS scientists were already operating three oceangoing vessels to gather data and it was expected that a new graduate training program aimed at common interests would soon be created at UH.

By 1951, Hiatt had become chairman of the Department of Zoology, and in that capacity he promoted the development of an expanded curriculum in Biological Oceanography. Hiatt taught the Marine Ecology class; Albert Tester and Vernon Brock taught the Fisheries Biology courses, and Albert H. ("Hank") Banner taught Oceanography. Albert Tester, a fisheries biologist with world-class expertise in the study of tunas and sharks, joined the UH Department of Zoology in 1948. Tester would later serve as Director of POFI; Banner would serve as Director of the Hawaii Marine Laboratory (HML), and Brock would serve as the inaugural chair of the Department of Oceanography when it was established in 1964.



Inaugural HIG director George Woollard expounds on the "famous" globe. In April 1964, this was the only globe to show both physical relief on the continents and ocean depth contours. It was built by Rand McNally and Company for UH, at a cost of $13,000 dollars.
Courtesy SOEST Archives

Hawaii Institute of Geophysics

A New Research Organization with an Emphasis in Oceanography

As mentioned previously, the Department of Oceanography had distinct roots in both the biological and physical sciences. The Department of Zoology and the CMML-HML comprised the former, and the Hawaii Institute of Geophysics (HIG) comprised the latter. According to an informative *Honolulu Star-Bulletin* account, the origin of HIG can be traced back to a gathering of scientists in 1953, Robert Hiatt among them. At that time Hiatt was chairman of the Department of Zoology and director of the HML, so it can be reasonably stated that Hiatt was the interdisciplinary bridge. Under his leadership, a proposal was submitted to the Rockefeller Foundation requesting a $50,000 grant to establish a laboratory for geophysical research. The proposal was declined. The next step would be an attempt to establish a federally-sponsored geophysical laboratory that would be patterned after the Alaska Geophysical Institute established by the U.S. Congress in the late 1940s. According to newspaper reports at that time, the Institute would include "oceanography, meteorology, cloud physics, and allied subjects."

In 1955, Hans Pettersson, past President of the United Nations Joint Commission on Oceanography and Marine Biology and Professor of Oceanography at the University of Göteborg in Sweden, was appointed to the UH faculty for a 6-month term as Professor of Geophysics. UH President Paul S. Bachman told the Board of Regents that Pettersson would be instrumental in the effort to gain U.S. congressional approval of a new Geophysics institute in the territory of Hawaii. In 1955, behind the leadership of John A. Burns, then a delegate for the Territory of Hawaii, Congress passed a joint resolution charging the National Science Foundation (NSF) with conducting an evaluation of the need and the feasibility of such an institute and directed them to report back to Congress with their recommendation. The "blue-ribbon" panel selected to evaluate Hawaii as a site for conducting research in Earth and Ocean Sciences included: William Benson, Phil Abelson, Cecil Green, King Hubbert, William Rubey, and A. E. Eckhardt. NSF director Alan Waterman took a positive recommendation to the National Science Board, and bills were introduced in Congress in 1956 and 1957 by the Territory of Hawaii. The Geophysics Institute, as an integral part of the research mission of UH, was recommended in a NSF report that was ordered by the U.S. Congress in 1956, under public law 909. On 30 December 1958, it was formally announced that NSF intended to fund the construction of the Geophysics Institute building. This preceded Hawaii becoming the 50th State of the U.S.A. in 1959.

The Fiscal Year 1962 budget request for the HIG building was presented to the National Science Board, the governing body of the NSF, on 31 August 1961, in Honolulu, during the Pacific Science Congress; this was the Board's first meeting outside of Washington, D.C. By this time, however, it was only a matter of protocol



RV *Kana Keoki* (Hawaiian for "St. George") with George Woollard inside of ring buoy and UH President, Harlan Cleveland, on left.
Photo by Albert Yamauchi, March 1971. Reproduced with permission from the Honolulu Advertiser

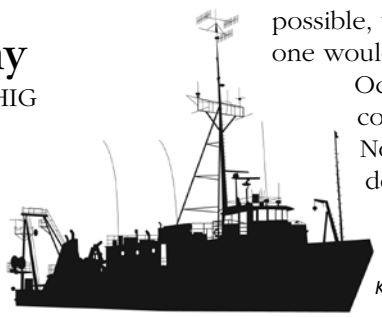
– the funding was certain. The members of the Board, including Chairman Detlev W. Bronk, were present the next day, 1 September 1961, to participate in the HIG ground-breaking ceremonies.

With the new HIG building fully funded and under construction, it was time to recruit a permanent director for the Institute. The administration was seeking an outstanding scientist, someone with a grand vision for the future and excellent leadership skills. In 1963, George Prior Woollard was appointed inaugural Director of HIG. When Woollard joined UH, he was one of the leading geoscientists in the world, with expertise in the area of gravity and magnetics, and was President of the American Geophysical Union (AGU).

Crossing a Turbulent Sea Toward Departmental Status for Oceanography

On 1 August 1956, two years before HIG was established, Robert Hiatt, then UH Dean of the Graduate School and Director of Research, convened an *ad hoc* committee to establish Oceanography as a graduate field of study for the M.S. degree at UH. The committee was chaired by Agatin Abbott, chairman of the Department of Geology and Geophysics, and included the following members: T. Austin (POFI), H. Banner (Zoology), M. Doty (Botany), I. Miyake (Physics), A. Tester (Zoology), and H. Zeitlin (Chemistry). In his final charge, Dean Hiatt asked the committee to "move rapidly in order to take advantage of the interest, which will be developed during the period in residence at the university of Hans Pettersson and Norris Rakestraw," two world-class marine scientists. Rakestraw was on leave from Scripps Institution of Oceanography, where he was the first Graduate Dean of Students. A positive recommendation from this "blue ribbon" committee on Oceanography would be carried forward by Hiatt, and others, with great vigor and momentum.

A meeting on 22 August 1956, asked the members to submit to Chairman Abbott, as soon as possible, the suggested undergraduate preparation one would deem necessary for a prospective Oceanography M.S. degree candidate. The committee did not meet again until 13 November, when the following verbatim decisions and recommendations were made: (1) that plans for a M.S. degree


Kana Keoki

in Oceanography be shelved, for reasons of lack of proper and sufficient course offerings and lack of teaching personnel, (2) that a M.S. degree be given in Marine Biology, (3) that UH consider an undergraduate program in Oceanography for future years, and (4) that present course offerings in Oceanography and closely related subjects be coordinated in content to avoid overlap of material and in time of offering to avoid crowding in one semester. Dean Hiatt, the lead supporter of the "Oceanography movement," was disappointed, but agreed to hold this project in abeyance until further developments occurred.

UH Department of Oceanography

A Second Attempt

In spring 1960, the UH Board of Regents approved a split of the Department of Geology and Geophysics into the Department of Geology and the Department of Meteorology and Oceanography, effective 1 July 1960. On 3 April 1962, Mariano A. Estoque, the Chairperson of the Department of Meteorology and Oceanography with research interests in numerical analysis and prediction, and atmospheric boundary layer phenomena, submitted a formal proposal to Graduate Dean Hiatt for the establishment of a M.S. degree program in the field of Oceanography. The faculty listed in the 1962 proposal as "principally involved" in the new M.S. degree program in Oceanography were: Carl Adams, an Assistant Professor since 1960, and an expert in Tropical Meteorology; Tairo Laevastu, an Associate Professor since 1962, and an expert in fisheries; Richard Barkley, Chief of the Oceanography Investigation Unit of the U.S. Bureau of Commercial Fisheries, Honolulu Biological Laboratory since 1960, and Gunter Seckel, an oceanographer with the same unit since 1953.

According to the proposal, the initial focus of this new program would be on sea-air interactions and oceanographic forecasting – a very modest beginning. In fact, biological sciences, namely Fisheries, Invertebrate and Vertebrate Physiology, and Marine Ecology, were integral to the new academic program; three of the four founding Oceanography faculty were fisheries oceanographers. With time, and with the anticipated expansion of graduate faculty, other specializations became possible. Besides formal courses and laboratory studies, sea practice on research ships would be required. On 1 June 1962, in a memorandum to UH President Laurence H. Snyder, Bruce E. White, then Vice President and Dean of Faculties wrote: "The Administrative Council voted approval of the proposed program leading to the Master of Science degree in Oceanography." A few weeks later, on 14 June 1962, the UH Board of Regents added their final approval to the new program, effective 1 September 1962. A formal graduate degree-granting academic program in Oceanography was finally launched in the State of Hawaii. Once the field of study was established, formal departmental status quickly followed about two years later.

During a visit to UH in August 1964, H. Burr Steinbach (described in newspaper reports as "the top biological statesman in the U.S." and a leading marine scientist, educator, and administrator who would go on to assume the position as founding Dean of the WHOI-MIT joint Ph.D. program in 1968), praised UH President Tom Hamilton, Vice President for Administration Richard Takasaki, and then Vice President for Academic Affairs Robert Hiatt for their collective "ability, dreams and brains to pull it off." The "it" he was referring to was the creation of a comprehensive, interdisciplinary, and world-class program in marine sciences, including the newly established graduate degree program in Oceanography. UH was finally on the map!

Mariano Estoque was the acting chairperson of the graduate field of Oceanography for the first two years. When the Department of Oceanography was created prior to the start of the Fall 1964 semester, Vernon Brock, a Fisheries Biologist, was selected as the inaugural chairperson to lead this new department. Since 1964, the Department of Oceanography and the Oceanography graduate field of study have been led by the same chairperson.

The Department of Oceanography was initially staffed by faculty who were reassigned from HIG and the Departments of Geoscience and Zoology and, later, by new hires. From the beginning, faculty in Oceanography combined graduate education and research to provide young apprentice-level scientists with a broad interdisciplinary exposure to contemporary concepts. Many, but not all, of the Oceanography faculty had split appointments with HIG, or Hawaii Institute of Marine Biology (HIMB), two marine-oriented organized research units at UH. In 1964, when the Department of Oceanography was established, Zoology 201–Science of the Sea, became Ocean 201–Science of the Sea. Robert Hiatt's course would eventually become one of the most popular survey courses at the University.

Initially, the Department of Oceanography offered only a M.S. degree, while the Ph.D. degree was restricted to the Department of Geosciences (the predecessor of the current Department of Geology and Geophysics). The addition of the Ph.D. degree was a key benchmark in the academic maturation of the Department of Oceanography. According to a letter

UH Research Vessels 1962-2012





RV *Salpa* at Hawaii Marine Lab, 1959.
From UH at Manoa Masao Miyamoto collection: negative B59-00004



RV *Neptune*, ca. 1963
Courtesy SOEST Archives

from Oceanography Professor Klaus Wyrtki, dated 18 January 1965, to prospective graduate student William Patzert: "…I can inform you that the Department of Geosciences of this University has at present a Ph.D. program and that the Department of Oceanography will probably offer such a program within one year. In both Departments you can study Oceanography." Wyrtki's timetable turned out to be a bit optimistic, but the eventual outcome was exactly as he had predicted. On 28 August 1967, the faculty Senate Executive Committee recommended the establishment of the program leading to the Ph.D. degree in Oceanography, and two days later it was approved by the Council of Deans. The new degree program took effect in Fall 1967, and the first Ph.D. degree in Oceanography was awarded in spring 1970.

Our Nation and the Sea: The Origins of SOEST

The emergence of marine science programs in Hawaii has always been closely tied to key initiatives at the federal level. On 10 November 1957, the U.S. National Academy of Sciences (NAS) established a Committee on Oceanography (NASCO) to study the needs and opportunities in the field of Oceanography; this was the second NAS committee to evaluate this discipline, the first was convened three decades earlier. The NASCO included Harrison Brown (Chair), Maurice Ewing, Columbus Iselin, Fritz Koczy, Sumner Pike, Roger Revelle, Gordon Riley, Milner Shaefer, and Athelstan Spilhaus. In February 1959, NASCO released a 12-volume report, *Oceanography*

Now is the time we must propose to our own nation, and the other Pacific nations, that Hawaii is the logical – indeed the ideal – place for oceanographic headquartering for major ocean research projects and for gatherings fostering international cooperation in marine affairs.

–Governor John A. Burns

1960-1970, describing the status of marine science with numerous recommendations for possible implementation over the next decade.

Immediately after the report was published, U.S. Senator Warren Magnuson, of Washington State, introduced Senate Resolution #136 to establish a special subcommittee on Oceanography in the House Merchant Marine and Fisheries committee to hold hearings on the NASCO findings and recommendations. In 1966, the U.S. Congress passed the Marine Resources and Engineering Development Act authorizing a Commission on Marine Science, Engineering and Resources. Julius Stratton, Chairman of the Board of Ford Foundation and former President of Massachusetts Institute of Technology, was selected chair of the commission. This group soon became known as the "Stratton Commission" and their report, *Our Nation and the Sea*, was known as the Stratton Report.



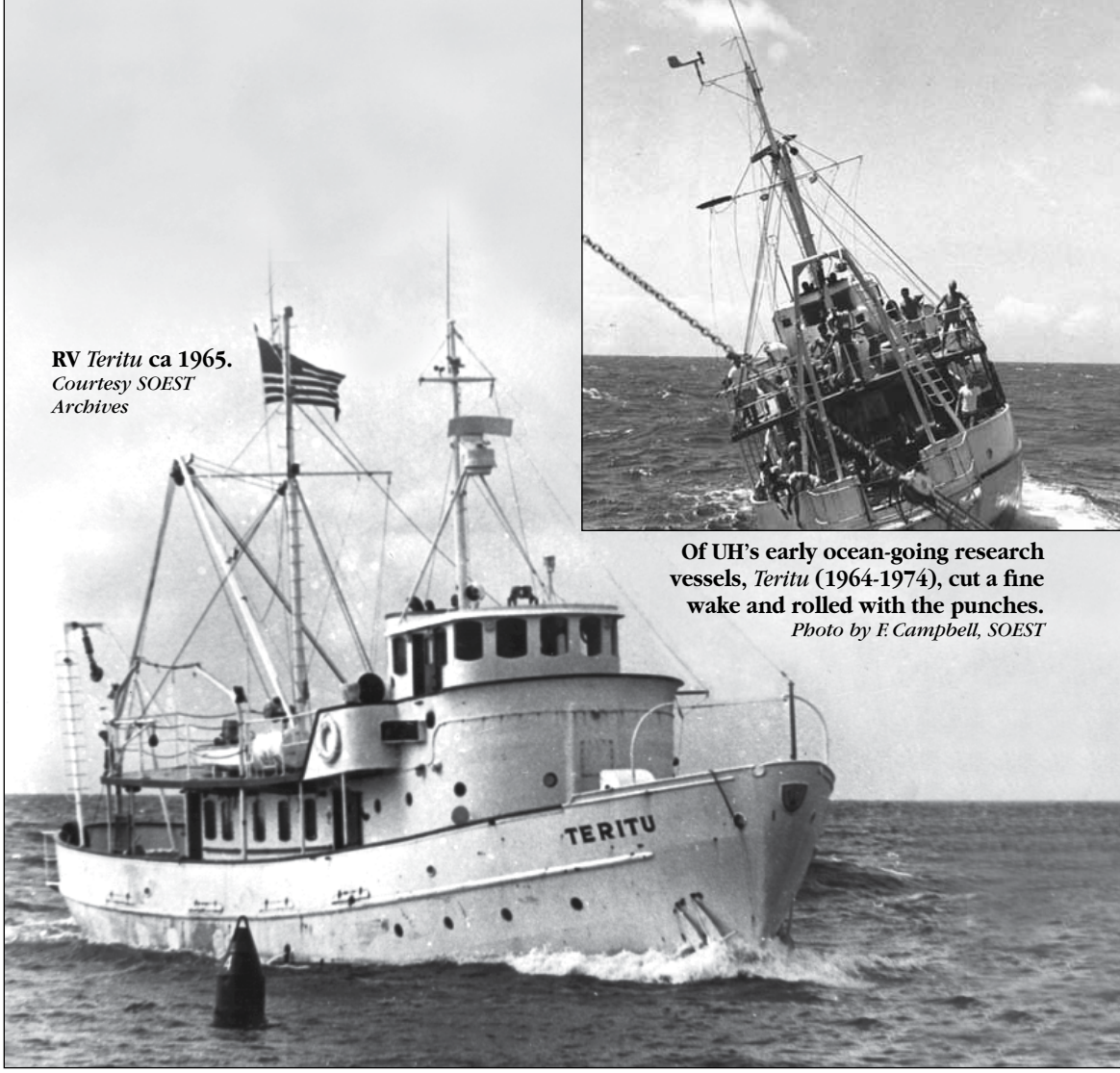
Hawaii's governor John Burns (left) greets William Beller and his wife at a reception following the release of the 300-page report, ***Hawaii and the Sea*****.**
Reproduced with permission from the Honolulu Advertiser, 12 September 1969.

Before the print ink was dry on the Stratton Report, opportunities for the State of Hawaii were being hailed by Taylor A. ("Tap") Pryor, President of Oceanic Foundation, in Honolulu, and a member of the Stratton Commission. He organized interested parties to determine how Hawaii could best respond to the Stratton Commission recommendations. In January 1969, Hawaii's Governor John Burns appointed a state task force on Oceanography to "promote and coordinate state and private sector ocean science development in the islands." The eight-person commission included Adrian Perry (Chair), Vice Admiral Harold G. Bowen, Jr. (U.S. Navy), Captain (retired) Jesse B. Burks (Burks was also a graduate of UH having received one of the first M.S. degrees in Oceanography in Fall 1967), George Hansen, Robert Hiatt (then acting UH president), Major General Edmond H. Leavey (U.S. Army, retired), Shelley M. Mark, Tap Pryor (president of Oceanic Foundation), and George P. Woollard (UH-HIG director). The task force was assisted in their work by William S. Beller, who was on loan from the U.S. Department of Interior. Beller had been a staff support person to the Stratton Commission, and had written portions of the final Report.

On 11 September 1969, the task force submitted their report, *Hawaii and the Sea,* to Governor Burns. In an article published in the *Honolulu Advertiser,* the day following the release of *Hawaii and the Sea*, Burns said: "The sea is one of the most dramatic, important things we have… it can put Hawaii in the forefront of the whole world in endeavors like these – which are so important to the human race." On 26 January 1970, Governor Burns gave the Hawaii State Legislature a package of "bold" ocean-related initiatives. In the governor's words:

Now is the time we must propose to our own nation, and the other Pacific nations, that Hawaii is the logical – indeed the ideal – place for oceanographic headquartering for major ocean research projects and for gatherings fostering international cooperation in marine affairs.

Included among his proposals was a new position in the governor's office – the Marine Affairs Coordinator (MAC). In September 1970, John Piña Craven was appointed the inaugural state of Hawaii Marine Affairs Coordinator. Craven was also given the new title, UH Dean of Marine Programs, and, in that capacity, had the responsibility to consolidate and integrate various marine programs at the University and across the state. A major problem, however, was that Craven had no line authority over any significant academic unit at UH, each of which already had a Dean or Director. According to information in the *UH catalog*, the administrative structure of the office



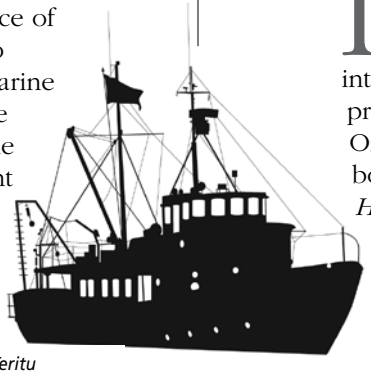
RV *Teritu* ca 1965.
Courtesy SOEST Archives

Of UH's early ocean-going research vessels, *Teritu* (1964-1974), cut a fine wake and rolled with the punches.
Photo by F. Campbell, SOEST

of the Dean of Marine Programs included the newly founded Sea Grant College Program and the Marine Options Program (MOP). Neither of these was directly responsible for graduate education in marine sciences or for research. Craven was effectively a Dean without a faculty. This parallel organizational structure precluded any serious reorganization or consolidation of the diverse marine-related interests.

In 1977, UHM Chancellor Douglas Yamamura established a blue ribbon panel of marine experts from the U.S. mainland and invited them to Hawaii to review the University's marine programs and to make recommendations to the UH administration on quality and organizational structure. The site team: John V. Byrne (chair), John Costlow, Phillip Eisenberg, Ned Ostenso, and Roberg A. Ragotzkie, visited UHM from 29 August to 2 September, and met with representatives of the various programs. On 21 November 1977, Chairman Byrne transmitted the committee's findings along with a set of recommendations; this became known as the "Byrne Report on UHM Marine Programs." (Note: John Byrne had a distinguished career as a Professor of Oceanography, Dean of the School of Oceanography and President of Oregon State University and, for the period 1981-1984, he was the administrator of NOAA. (See John Byrne's article this issue, pages 60-70)

The Byrne Report identified several problems. For example, the establishment of the office of Dean of Marine Programs was intended to provide leadership and coordination of marine programs, but it carried no comprehensive plan or financial resource base. The Byrne Report also concluded that the Department of Oceanography, an academic and research unit at the core of marine programs, "suffers from low morale due to a lack of coordination with HIG." The Byrne report ended with a section entitled, "Options for Revitalization," and a final set of recommendations. Two key recommendations were: (1) a new graduate School of Marine Studies should be established and a Dean should be appointed as the leader of the School, and (2) HIG and HIMB should be abolished. In his cover letter to Chancellor Yamamura, Byrne commented: "Not everyone at the University of Hawaii will be pleased by our observations or by our recommendations…however, we hope that the report will be of value in helping to bring the University of Hawaii closer to its potential for excellence in the area of marine studies."



Teritu

During the summer of 1980, recently appointed UHM Chancellor Durward Long announced his intentions to reorganize several academic programs, including marine sciences. On 7 December 1980, it was reported in both *The Honolulu Advertiser* and the *Honolulu Star-Bulletin* that Craven would be terminated as Dean of Marine Programs, effective 30 June 1981, but he would remain at UHM.



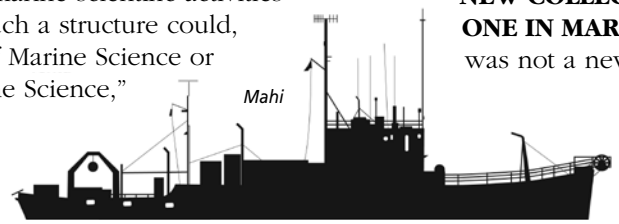
UH Marine Center at holiday stand-down, pier 45, mid-1980s. *Courtesy SOEST Archives*

Long added that the excellent marine science programs have suffered for lack of an overall plan and that this would now become a high priority for the Manoa campus. He cited the recently completed Byrne Report, and was apparently committed to their major recommendation for meaningful and comprehensive reorganization of UH marine programs, one that would consolidate all efforts into a single college. On 25 September 1981, Long was fired as Manoa chancellor. The official reason given was incompatibility of style, rather than lack of substance. According to a *Honolulu Star-Bulletin* article, published on 26 September 1981, Long described himself as "an independent, aggressive administrator who had to battle constantly with vengeful deans and faculty members below him as well as suspicious and hostile UH system officials above him." He went on to say that he will leave the job just as he entered it – "fired with enthusiasm!"

On 22 March 1985, acting UHM Chancellor Richard H. Kosaki enlisted a group of distinguished marine scientists to advise him on relevant matters. In his invitation letter to the prospective members Kosaki wrote, "I would appreciate your considering yourselves the new Marine Council, under the leadership of Chairman Lorenz Magaard. I encourage you to set your own agendas and initiate activities as you think proper, as well as to respond to requests from this office."

In April 1985, Magaard took the initiative to prepare a draft mission statement. Two noteworthy objectives that he listed were "to develop plans for an adequate organizational structure of marine scientific activities within the UHM system. Such a structure could, for example, be a School of Marine Science or a School of Earth and Marine Science," and "to be a focus for UHM marine scientific activities before a new organizational structure for such activities is established." It was also decided that the Marine Council would meet monthly.

On 9 August 1985, the Board of Regents unanimously approved the appointment of Albert Simone as the tenth president of the UH system. It did not take Simone very long to get down to the difficult task of university reorganization including marine sciences. In December 1985, President Simone responded favorably to the Marine Council's suggestion to organize a new School of Marine Sciences and invited the Council to come forward with a proposal. Seventy-five minutes into the eigth meeting of the Marine Council, on 23 April 1986, President Simone entered the meeting room without any advanced notice. Simone addressed the Council and requested that they come up with a new organizational structure for marine programs, one that would create a separate College of Marine Science, much in line with the 1977 recommendations of the Byrne Report. He assured the Council that he was very serious about all this and that he would promote the establishment of the new college in the next biennium budget and would make a sales pitch of the strategic plan to the State Legislature. He answered a few questions, then departed as quickly as he had appeared. The shocked Marine Council decided that, given the magnitude and significance of the President's charge, they would meet weekly until the prospectus for a new college was completed. The agenda for the next Marine Council meeting, 30 April 1986, had only one bold-face item: "**PLANNING A NEW COLLEGE AND MAKING UH NUMBER ONE IN MARINE SCIENCE**." This goal was not a new one and many UH marine scientists remained skeptical that anything – much less a major reorganization – would ever



occur. But the Marine Council members who were present at the historic 23 April 1986 meeting, including the author, sensed that this time, under this leadership, something good may really happen.

The next few Marine Council meetings were filled with excitement and grand visions of the future. Subcommittees were formed to deal with the substance and structure of the new college, and recruitment of the new Dean. Comments and opinions were invited from across the campus. The Council prepared several draft organizational charts and also debated the name. At the eleventh meeting of the Marine Council, 14 May 1986, the Council approved an initial "working title" – College of Marine and Earth Science. However, Simone demanded that "technology" appear in the title. The working name soon became College of Ocean and Earth Science and Technology. As David Yount discussed in his book, *Who Runs the University?* it was awkward to have "and" appear twice, and he too was inclined to drop the words "and technology" at the end. When questioned on this point, according to Yount's written account of these events, Simone quipped, "our job was not to write poetry but to acquire and transfer knowledge." A few months later, President Simone decided that the new academic unit should be a "school" not a "college", so it immediately became the **School of Ocean and Earth Science and Technology (SOEST)**.

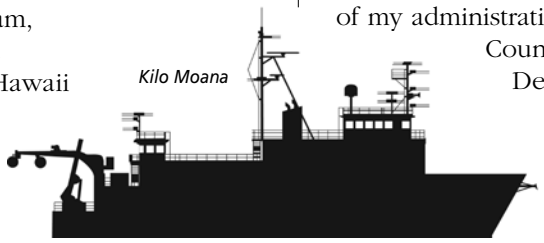


RV *Kilo Moana*, SOEST's current flagship vessel.
Courtesy SOEST Archives

As originally constituted, the School consisted of four academic departments (Oceanography, Meteorology, Geology and Geophysics, and Ocean Engineering), three organized research units (Hawaii Institute of Geophysics, Hawaii Institute of Marine Biology, Hawaii Natural Energy Institute), the UH Sea Grant College Program, the Joint Institute for Marine and Atmospheric Research, and the Hawaii Undersea Research Lab.

On 9 December 1987, the UH Faculty Senate approved the plan to establish SOEST after an hour-long debate. Two days later, Simone sent his SOEST prospectus to Board of Regents Chair Gladys Brandt to begin the formal process of creating the School. He also thanked the Marine Council members and, especially chair Magaard, for their "excellent work." As Simone so aptly stated, "It appears that, now, the future is ours." The decades-long burden of "great potential" for excellence in marine science at UH was finally lifted.

On 22 July 1988, SOEST was approved by the UH Board of Regents, just three years after President Albert Simone had presented his grand vision to the Marine Council. In a 13 August 1988 *Honolulu Star-Bulletin* article, by Helen Altonn, titled: "Ocean-Earth Science School Called Triumph," Marine Council Chair Magaard is quoted as saying, "Hawaii is finally getting its act together, finally capitalizing on its geographical and environmental advantages…." Altonn had also interviewed President Simone who said "while the various units were ironing out their differences, he was selling the concept to the governor (John Waihee) and state legislators." The Marine Council continued to serve in an advisory capacity to the President, until inaugural SOEST Dean Barry Raleigh (previously Director of Lamont-Doherty Geological Observatory of Columbia University) joined the University on 1 October 1989. In a memo to the Council members dated 21 September 1989, President Simone expressed his gratitude for distinguished service, perseverance, and professionalism. He also stated, "I consider Dr. Raleigh's recruitment and the creation of SOEST among the significant achievements of my administration." He then retired the Marine Council in order to give the new Dean a free hand in establishing whatever internal administration he thought best.



Scientific uses of Submarine Cables: Evolutionary Development leading to the ALOHA

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Bruce Howe received the B.S. in Mechanical Engineering and M.S. in Engineering Science in 1978 from Stanford University, and the Ph.D. in Oceanography from UCSD, in 1986. From 1986 to 2008 he worked at the Applied Physics Laboratory, University of Washington. He is presently Professor and Chair of the Department of Ocean and Resources Engineering at the University of Hawaii at Manoa. Howe has worked on many ocean acoustic tomography projects, including Acoustic Thermometry of Ocean Climate. He helped establish on-going Ocean Observatories efforts, working on fixed infrastructure (cable systems and moorings), mobile platforms (gliders) and hybrids (moored vertical profilers). Most recently, he lead the installation of the ALOHA Cabled Observatory seafloor node, described in this paper. A long-term goal is to integrate acoustics systems in ocean observing for navigation, communications, timing, and science applications.

Fred Duennebier is an Emeritus Professor of Geology and Geophysics at the University of Hawaii. He received a B.S. in Physics from Trinity College, and M.S. and Ph.D. in Geology and Geophysics at the University of Hawaii. His early seismic research included work in Apollo lunar seismology and the earthquake T-phase. He has worked on the development of ocean bottom seismometers and was a principal investigator on numerous ocean bottom observatory projects, including the HUGO, H2O, and ACO observatories.

Rhett Butler (B.S. MIT 1974, Ph.D. Caltech 1979) served as the Program Manager for the Global Seismographic Network (GSN) from its inception in 1986 through 2010 at the Incorporated Research Institutions for Seismology (IRIS). With 154 broadband seismic stations globally distributed with free and open, real-time data access, the GSN is a primary data source for Earth research and education, earthquake monitoring and tsunami warning, and nuclear treaty monitoring. Butler initiated and fostered re-using submarine telecommunication cables (negotiating donation from AT&T) for undersea observatories, and led the Hawaii-2 Observatory (H2O). He also established advanced seismic capabilities in polar environments both at the South Pole and with the Greenland Ice Sheet Monitoring Network. He has authored or co-authored 51 refereed scientific publications, and over 100 other scientific abstracts and reports. Currently an adjunct Geophysicist at the University of Hawaii at Manoa, he serves as a consultant for the United Nations International Telecommunication Union on using submarine telecommunication cables for science, and for NASA on a Mars Discovery mission.

Roger Lukas is a professor of Oceanography in the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa. He received his Ph.D. in Oceanography in 1981 from the University of Hawaii, following a Master's degree in Oceanography from UH in 1977. He received his B.A. in Mathematics from the University of Southern California in 1973. Lukas teaches graduate courses in Physical Oceanography and air-sea interaction. He conducts ocean and climate research on topics including ocean currents, temperature and salinity distributions, sea level, air-sea interaction, El Niño, and decadal climate variability. He is the co-author of the book, *The Near-Surface Layer of the Ocean*. Lukas and colleagues have conducted the Hawaii Ocean Time-series observational program at Station ALOHA, north of Oahu, documenting changes of ocean physics, chemistry and biology since 1988.

Illustration Courtesy University of Hawaii at Manoa

Cabled Observatory

Photo by R. David Beales, UH

The current era of submarine cabled ocean observatories began in the early 1980s in the seismological community led by the Hawaii Institute of Geophysics (HIG) at the University of Hawaii, the Earthquake Research Institute at the University of Tokyo, and the Incorporated Research Institutions for Seismology (IRIS). The primary motivation for this work was seismological studies. By 1990 efforts were well underway to use the retired telecommunications TPC-1 cable. This culminated in the Japanese GEO-TOC and VENUS observatories. In parallel, the Hawaii Undersea Geo-Observatory (HUGO) was built and installed in 1997 on Loihi Seamount, an active volcano just south of the island of Hawaii. With its own cable, it was the first to depend on submersibles or remotely operated vehicles to connect the sensors on the seafloor, and to provide general purpose user ports delivering high power and bandwidth using fiber optics. These efforts lead to the Hawaii-2 Observatory (H2O) halfway between Hawaii and California that was installed in 2001 and operated for 4 years. Installation of the ALOHA Cabled Observatory (ACO), just north of Oahu, was begun in 2007, and was recently completed in 2011; it is the deepest operating cabled ocean observatory. The successes of the ACO and other on going cabled observatories around the world are built on the earlier efforts – successes and failures – described here.



Station ALOHA and the ALOHA Cabled Observatory (star) are located 100 km north of Oahu in 4728 m water depth.

Introduction

In addition to far-reaching shipboard spatial surveys and maps of marine characteristics conducted by early oceanographers that revealed many secrets of the world oceans, time series measurements were required to explore the variations of the ocean at a single location. Repeated shipboard observations at particular sites provide access to such variations;[1] but the temporal sampling is limited by the duration capabilities of the ship and crew. And, the ocean changes between lowerings of instruments because the ocean contains large amounts of energy at high frequencies, and such measurements were easily aliased. To cope with the sampling requirements, engineers packaged sensors (e.g., temperature, pressure, acoustic, seismic) into pressure-resistant cases along with batteries and tape recorders. While these provided great insights, the records were always limited by either battery capacity or data storage.[2] Understanding dynamical processes requires long-time series to quantify underlying statistics.

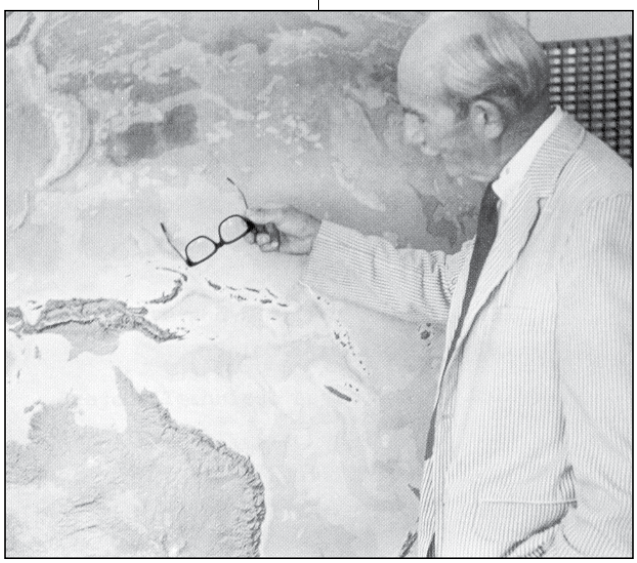
Thus, sustained observations of the ocean are difficult. Ocean science requires improved ways to observe the ocean in order to advance our understanding and lay the foundations for predictive models and their applications. Recent technological advancements, such as mobile platforms (floats, gliders and powered autonomous undersea vehicles, AUVs), satellite communications and acoustic data links are providing new data acquisition and platform control methods. However sensors, instruments and platforms requiring high power, high data rates or continuous access to the water column and seafloor are as yet out of reach of these technologies. Cabled observatories – such as the ALOHA Cabled Observatory – provide remote interactive instrument control, continuous real-time data streams and large amounts of electric power. Cabled and autonomous technologies are complementary in that the cable systems can provide the power and communications interface to subsurface autonomous fixed and mobile platforms using docking stations and acoustic communications, without the routine use of ships, thus significantly increasing the spatial footprint and the overall observing system efficiency

Between this exciting new vision of Oceanography and the age of exploratory surveys is a rich history of ocean observing. We cannot review all of it here, but we can focus on the development of the concept of ocean instrumentation attached to an observatory on the seafloor that provides continuous power and communications via cable to researchers ashore.

The obsolescence and retirement of the first-generation fiber-optic telecommunication cables, installed in the 1980s and 1990s, provided a valuable resource for ocean science. The relatively large amount of power and data transmission bandwidth that they provided made it possible to continuously power instruments and obtain real-time high rate geophysical data from distant ocean observatories using cable infrastructure that still had decades of useful life. This resource takes advantage of instrumentation and technology developed by the telecommunications, cable, connector, and ROV (remotely operated vehicle) industries to evolve from existing stand-alone instrument systems into permanent observatories for relatively low cost. Testing using the existing cables prior to the installation of the observatory demonstrated that the communications system could operate error-free over ocean basin distances.

The military had been using cabled hydrophone and long sonar range systems since the 1950s (e.g., Project Caesar, aka Sound Surveillance System or SOSUS, and Project Artemis). However, the seismological community, recognizing the essential need for ocean seismic stations for good global coverage of Earth, initiated the use of submarine cables for science in deep water and ideally far from land. George Sutton, at the University of Hawaii, and colleagues deployed a cabled ocean-bottom seismic station off Point Arena, California, at a water depth of 3903 m that worked from 1965-1972.[3] In 1987, John Delaney and the University of Washington and colleagues proposed establishing long-term ocean bottom observatory/laboratory systems based on cables.[4] In the 1980s, many in Japan and the United States began to seriously consider cabled systems for ocean use.

This article begins by reviewing the early history in using retired telecommunications cables for scientific use. A major early milestone in this was the Conference on the Scientific Uses of Submarine Cables, in Honolulu, in 1990.[5] During the 1990s and early 2000s, several cables were re-used by Japanese and U.S. scientists, some with "hard-wired" sensors and some with general purpose "nodes" to support arbitrary sensors (e.g., GEO-TOC,VENUS, and H2O). The Hawaii Undersea Geo-Observatory (HUGO) on Loihi submarine volcano included a general-purpose node attached to a cable laid to the island of Hawaii; this was the first prototype of what we now consider to be a "cabled ocean observatory." Upon this experience base the ALOHA Cabled Observatory (ACO) was built. The core theme throughout this paper is the human effort to organize and execute these endeavors.



In 1963, George Prior Woollard was appointed inaugural Director of the Hawaii Institute of Geophysics. When Woollard joined UH, he was one of the leading geoscientists in the world, with expertise in the area of gravity and magnetics, and was President of the American Geophysical Union (AGU).

First Steps

The Hawaii Institute of Geophysics (HIG) was founded under the leadership of George Woollard at the University of Hawaii at Manoa (UH) in 1966, motivated by the need in Hawaii for understanding of volcanoes and earthquakes. By the time that Charles (Chuck) Helsley was appointed as HIG Director in 1977, a very active ocean seismology observational program was already underway, including Fred Duennebier who had started at HIG as a graduate student. Duennebier continued on, developing and deploying self-contained ocean bottom seismometers that were free-falled to the seafloor and recovered after some interval. Helsley and Rhett Butler (also at HIG) were interested in focusing the direction of a new initiative being started by the Incorporated Research Institutions for Seismology (IRIS) toward the oceans. HIG named Butler to the IRIS Board in 1984, where he raised ocean seismology as a direction for the Global Seismic Network (GSN) at the first Board meeting. IRIS asked Butler to serve as liaison, and to review and coordinate with the Ocean Bottom Seismometry (OBS) community on possibilities. In 1984, Butler wrote to Dr. Shozaburo Nagumo at the Earthquake Research Institute (ERI), of University of Tokyo, about Japanese efforts. A number of letters were exchanged leading to a fruitful and friendly relationship. In 1986, Butler took a leave of absence from HIG to become GSN Program Manager at IRIS, while still continuing efforts to develop an ocean-based seismic observing effort.

Initial work with the TransPacific Cable-1 (TPC-1)

In 1987, Dr. Nagumo wrote to Rhett Butler about the idea for a "telluscope" looking into the earth based upon an earlier article, "Telluscope Plan – A Submarine Cable System for Observing the Earth's Interior," by Nagumo, Tabata, and Suzuki, presented at the 1981 Pacific Telecommunications Conference. The idea was to re-use submarine telecommunications cables to link to seafloor seismic stations. Dr. Nagumo noted that the TransPacific Cable-1 (TPC-1) installed in 1964 was soon to be retired from telephone service. This SD-analog coaxial cable ran from Japan to Guam, and then Midway and Hawaii (this SD cable carried 128 telephone calls, each in a 3 kHz band).

At the 1987 International Union of Geodesy and Geophysics meeting in Vancouver, Dr. Nagumo approached the President of IRIS, Stewart Smith, to request help in re-using TPC-1. The Japanese scientific community had been encouraged by the Japanese international telephone company, Kokusai Denshin Denwa Co. (KDD), to pursue scientific re-use of the cable. However, as KDD, AT&T and Hawaiian Telephone jointly owned the cable, a U.S. partner was necessary for liaison efforts with the U.S. companies. IRIS undertook this opportunity, having substantial interest in the possibility for using retired cables for real-time oceanic global seismographic network stations, and assigned the task to Butler as the GSN Program Manager. Thereafter, nearly all actions on behalf of IRIS in the area of submarine cables were initiated and led by Butler. In late 1987, Dr. Nagumo and George Sutton of the U.S. wrote to AT&T and KDD formally introducing the interest of the scientific community in the scientific re-use of TPC-1.

In 1988 and 1989, Butler attended a series of meetings and visits at AT&T headquarters for cable operations in Morristown, NJ; the Honolulu Office; the Makaha Cable Landing Station on Oahu; and on the Cable ship *Charles L. Brown*. In each of these meetings and visits, the engineers and managers at AT&T were very supportive of the idea for re-use of the retired systems. The company was very proud of its engineering design, and was receptive to giving the cable to the scientific community after retirement from service.

Through Chuck Helsley, the University of Hawaii and HIG expressed interest and support of the ideas for cable re-use, and offered to assist in the Pacific activities from its Hawaii vantage. HIG offered to serve as U.S. counterpart for the Japanese effort, but it was recognized that IRIS or JOI (Joint Oceanographic Institutions) as scientific consortia offered the basis for a broader, community-wide undertaking.

In early May 1989, the University of Tokyo, JOI, the National Science Foundation (NSF), the Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA), held a meeting at IRIS to discuss ownership models for the cable transfer. It was the consensus of the group that IRIS would accept ownership of the AT&T share of the cable on behalf of the U.S. scientific community. In late May, the President of IRIS and the Director of the Earthquake Research Institute of the University of Tokyo wrote to AT&T and KDD requesting the transfer of ownership of TPC-1 to the American and Japanese scientific communities.

During the summer of 1989, IRIS and JOI (Tom Pyle) wrote a proposal to NSF, U.S. Geological Survey, ONR, and NOAA to support a scientific workshop on re-use of undersea cables. This workshop was held in Honolulu at the end of January 1990.[6] Managers and engineers from AT&T and KDD outlined the engineering of cable systems, costs, and maintenance issues. A tour of the Makaha Cable station provided by AT&T gave immediacy and reality to the scientific discussions at the workshop. The head of the Cable Maintenance division of AT&T gave a very important talk on areas that AT&T could help with in the transfer; these included donation of cable and associated spare cable and repeaters, nominal technical advisory support, benefit of disposal costs (charges only for incremental costs over retirement costs), an invitation to join the International Cable Protection Committee, and temporary housing of spare stock after retirement.

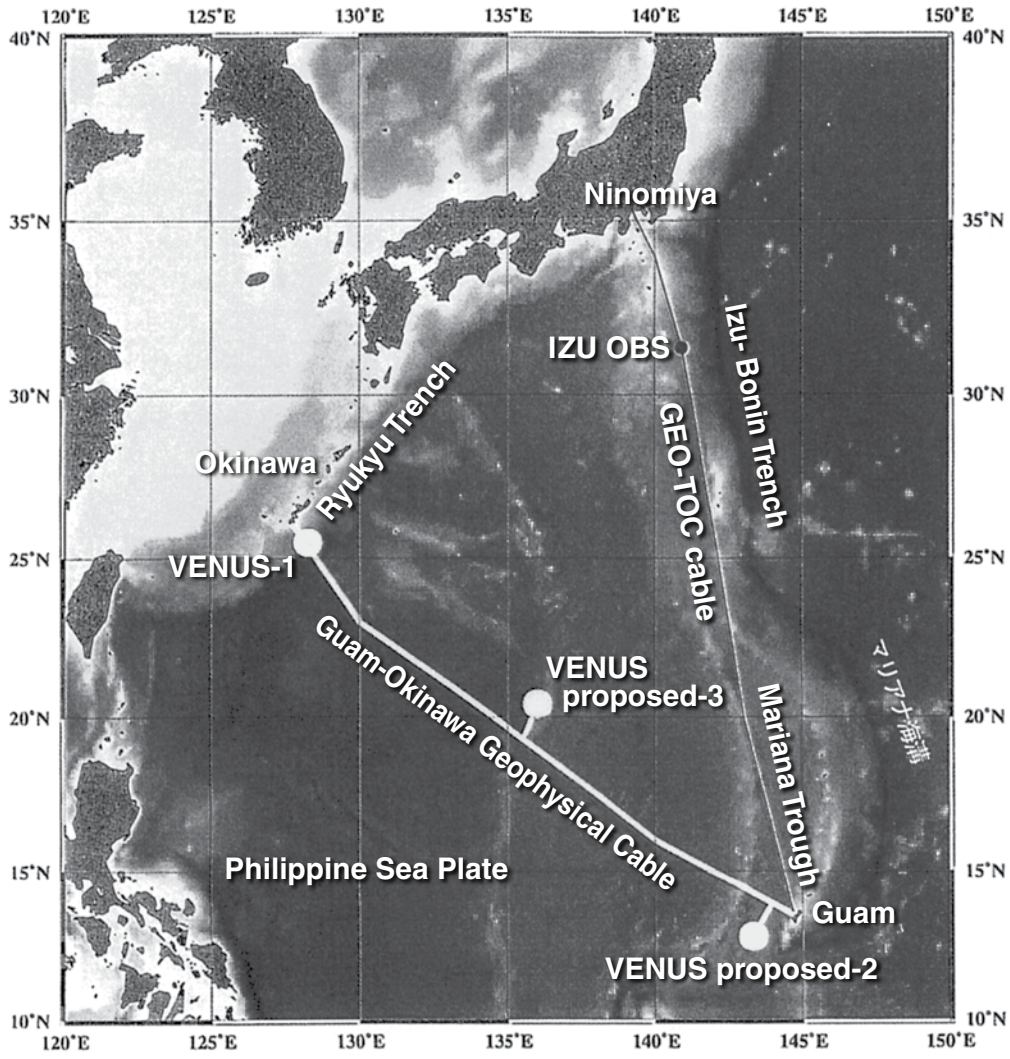
A steering committee was formed at the meeting to carry out the recommendations of the workshop. The primary recommendation was to work with the Japanese toward transferring the ownership of the Guam–Japan segment of TPC-1 to the scientific community. Although there was strong interest in the Guam–Hawaii segment of TPC-1, neither the Japanese nor the American communities felt that sufficient funding could be raised for all of TPC-1 at one time, and they chose to focus on the Guam–Japan segment. Action by interested scientists (Lou Lanzerotti and Les Medford) within AT&T's Bell Labs retained the Guam–Hawaii TPC-1 segment (and subsequently the retired Hawaii-2 cable) for scientific electromagnetic potential measurements. This latter action with Hawaii-2 enabled its later use for the Hawaii-2 Observatory project (H2O).

The U.S. scientific steering committee, working in concert with its Japanese counterpart, wrote a proposal to NSF to re-engineer the Guam–Japan segment of TPC-1. The timing of the ownership transfer was crucial. AT&T was to retire the cable in September of 1990, but it was clear that funding for the re-engineering effort could not be obtained in this time frame. Working with scientists from Bell Labs, IRIS wrote to AT&T requesting that the cable continue to be powered after its retirement from service. A one-year extension was made.

The American scientific community was successful in funding the Guam portion of TPC-1 in a NSF grant to IRIS (1991-1995). For the engineering work the services of Margus Company – a group of former AT&T engineers who had originally designed, installed, and maintained the AT&T cables – were contracted. IRIS formed a non-profit corporation, IRIS Ocean Cable,

Inc., to accept the AT&T and Hawaiian Telephone shares of the cable. The KDD share went to ERI. The transfer officially took place on 1 November 1990. The transfer was a gift to the scientific community with no tax advantage to AT&T, as the equipment had been amortized over its useful lifetime for telephone service.

The re-engineering work originally called for building a structure next to the Guam cable station to house the transferred cable terminus equipment. AT&T offered a better arrangement, to lease space within the cable station to IRIS Ocean Cable, and a license agreement was negotiated. Re-engineering work in Guam was carefully coordinated among IRIS, ERI, AT&T, KDD, and Margus. The work was completed in December of 1991. The quadruply redundant power system and high-frequency line equipment were reduced to simply redundant, and the additional SD terminal transmission equipment was shipped to HIG storage on Oahu and saved as spares. System tests of the new facility indicated essentially no aging in the cable system since its original installation in 1964 (according to the U.S. Cable Steering Committee, 1992).



Map showing the GEO-TOC cable and instrument location (Izu OBS). The VENUS system was installed at the VENUS-1 location.

From Earth Planets Space, *"A New Approach to Geophysical Real-time Measurements on a Deep-sea Floor using Decommissioned Submarine Cables," by J. Kasahara, T. Sato, H. Momma, and Y. Shirasaki (see fn. 7).*

GEO-TOC

During the time frame of the U.S. effort in Guam, the Japanese scientific community received substantial assistance from KDD in re-engineering their end of TPC-1, and also leased space within the Ninomiya cable station in Japan. The Japanese Ministry of Education eventually provided the funding for instrumenting and deploying the GEO-TOC (Geophysical and Oceanographical Trans Ocean Cable) system in 1997, at a site 300 km south of Tokyo. The GEO-TOC sensors included: three-axis accelerometers, hydrophone, quartz thermometer for external temperature, thermometers for internal temperature, and quartz pressure sensor for external pressure. The sensors were installed within a cable repeater, which was spliced inline into the TPC-1 cable using a cable ship. The GEO-TOC system operated until October 2002, when a cable fault occurred near Ninomiya due to fishing activity. Although attempts were made to resurrect the system, repairs were impossible to accomplish due to proximity of newer fiber-optic cables laid over the 1960s vintage TPC-1 cable. Passive cable voltage measurements are still continued by ERI from Guam.

VENUS

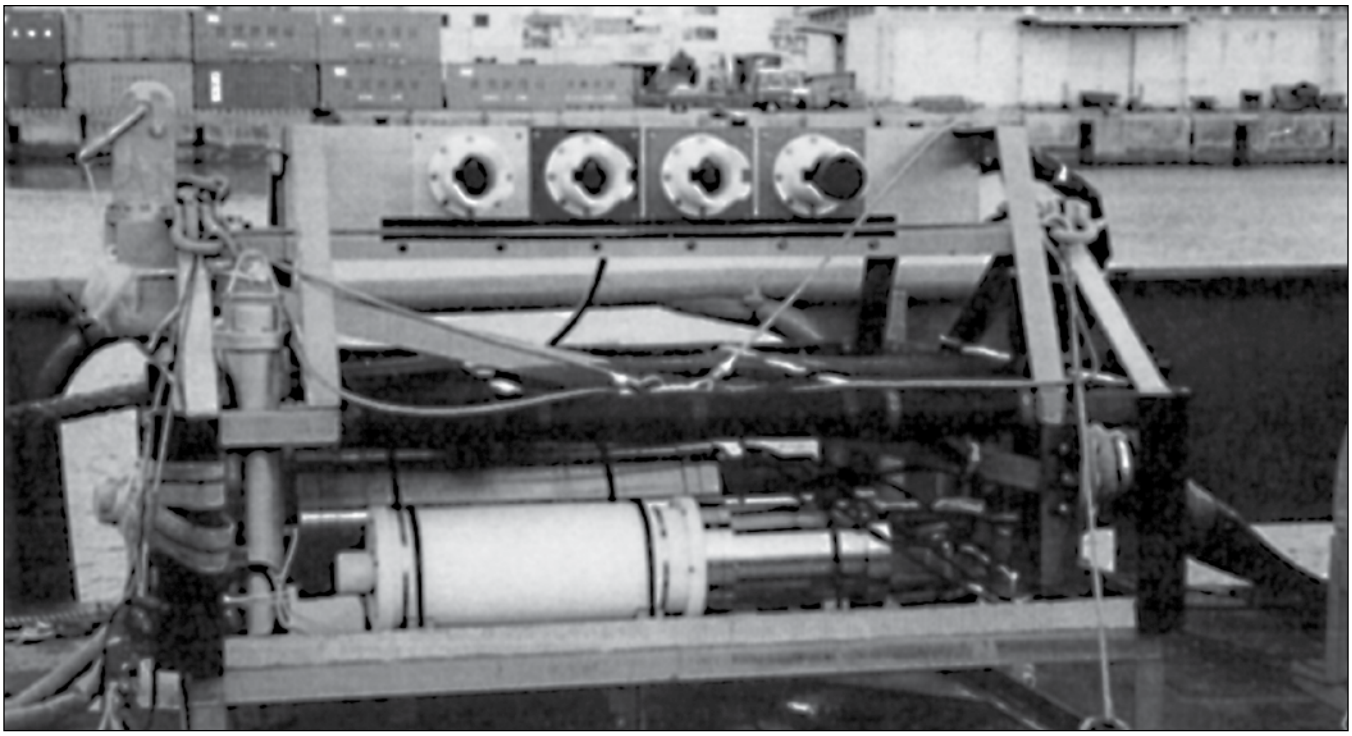
In the mid-1990s, the TPC-2 cable installed in 1976 came up for retirement. This SF system paralleled TPC-1 from Hawaii to Guam, and then ran to Okinawa (SF systems could carry 845 telephone calls). The Japanese team, now led by Dr. Junzo Kasahara, approached the U.S. again for collaboration. The U.S. Cable Steering Committee decided to aid our Japanese colleagues, but not to actively participate, as the work in TPC-1 had not yet been completed by Japan. On behalf of IRIS and the U.S. scientific community, Rhett Butler wrote to AT&T to encourage them to transfer (with KDD) ownership of TPC-2 to the Japanese scientific community. This was accomplished, and the TPC-2 was retired in 1996. The system was removed from Guam, and a new sea ground was established in the Mariana trough west of Guam. All system power was provided from the Japanese cable station in Okinawa. The multi-disciplinary VENUS (Versatile Eco-monitoring Network by Undersea-cable System) observatory on TPC-2 was installed between 1999-2001, on the slope of the Ryukyu Trench near Okinawa.

This effort included the Japan Marine Science and Technology Center (JAMSTEC), the Hydrographic Department of the Maritime Safety Agency, the Meteorological Institute of the Japan Meteorological Agency (JMA), ERI, the Geological Survey of Japan, the Communications Research Laboratory, the Electro-technical Laboratory, and the KDD Research Laboratory. VENUS incorporated a junction box with underwater-mateable connectors. A wide array of instrumentation included broadband seismic, magnetic, oceanographic, and geodetic sensors.[7] The VENUS system collected about one and half month's of useful data before failing due to a connector fault.

HUGO

At UH, related work proceeded in parallel with the above mentioned cable re-use efforts. After working with ocean bottom seismometers dropped to the ocean floor from ships and recovered either months later, or not at all, with low up-front costs but considerable ship time and luck required, the University of Hawaii (Fred Duennebier, Alex Malahoff and others) decided to move toward cabled observatories that could be potentially installed for years without required maintenance. Just after the Conference, a proposal was submitted to NSF for the development and installation of HUGO and it was funded in August 1990. The intent was to lay a cable to the Loihi submarine volcano/ seamount and establish a power and communications node to support the scientific investigation of the active undersea volcano.

VENUS-1 junction box showing wet-mate connector ports (above) and electronic pressure cases (below).
From Earth Planets Space, *"A New Approach to Geophysical Real-time Measurements on a Deep-sea Floor using Decommissioned Submarine Cables," by J. Kasahara, T. Sato, H. Momma, and Y. Shirasaki (see fn. 7).*



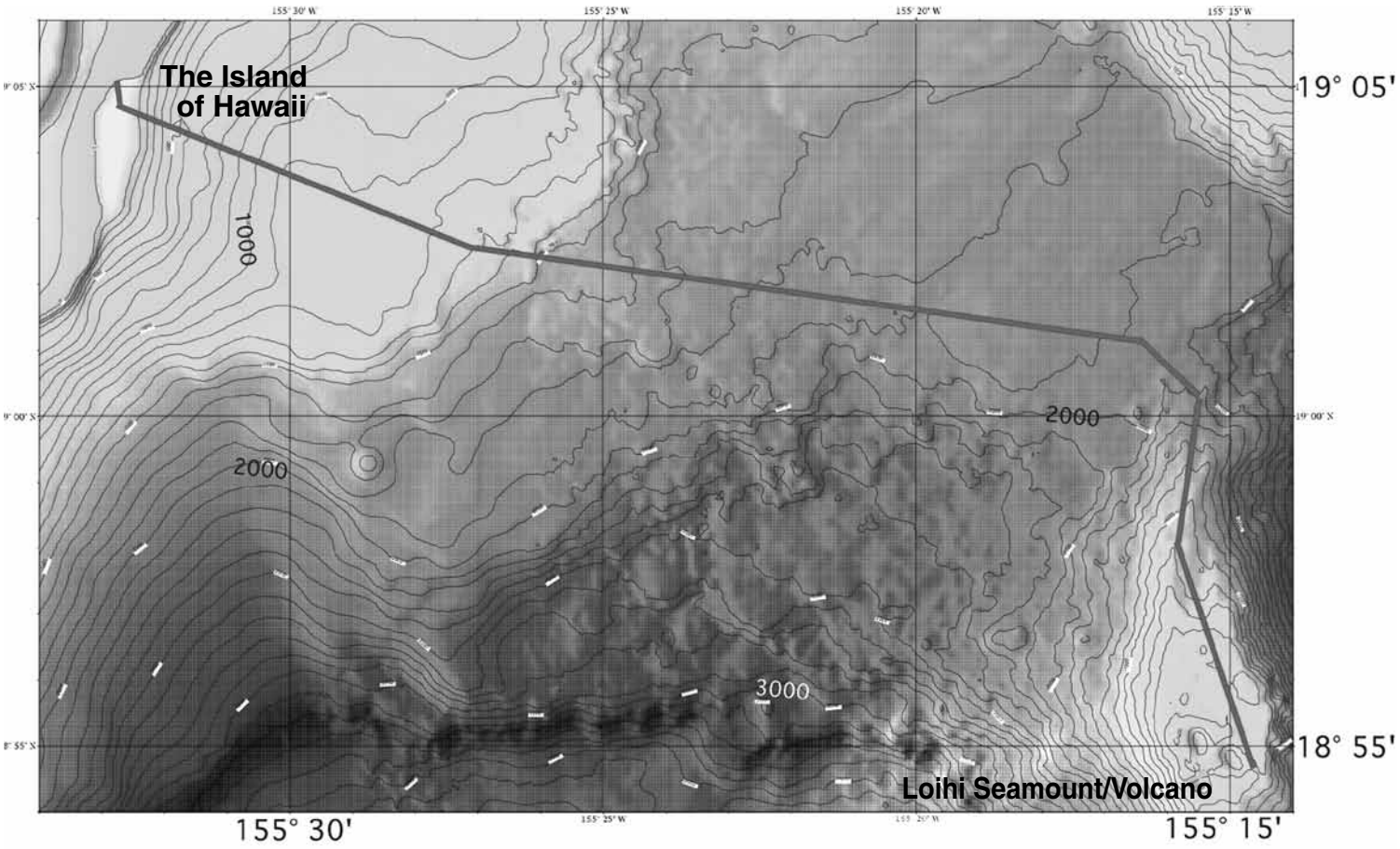
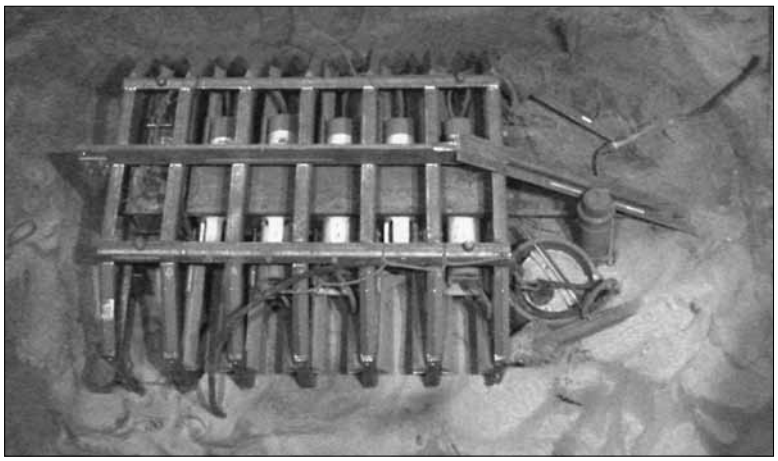


Illustration Courtesy University of Hawaii at Manoa



The picture shows the HUGO junction box buried about 30 cm in the mud, on the Loihi Seamount/Volcano. The larger cylinder on the right is the shunt regulator for dissipating power supply heat. The smaller cylinder is a transponder/pinger that was programmed from shore.

From IEEE J. Oceanic Engineering, *"HUGO: The Hawaii Undersea Geo-Observatory," by F. K. Duennebier, D. W. Harris, J. Jolly, J. Caplan-Auerbach, R. Jordan, D. Copson, K. Stiffel, J. Babinec, and J. Bosel (see fn. 8).*

HUGO was the first observatory connected to land utilizing electro-optical telecommunications cable. It was installed in October 1997, from the Island of Hawaii to Loihi volcano, 30 km SE of Hawaii, at 1000 m depth. The observatory utilized a 47-km section of spare "submarine lightwave" SL cable donated by AT&T and laid by a small oceanographic vessel. While optical fibers in principle can support very high data rates, the particular realization here was 40 Mbit/s governed by electronics. Instruments were attached to the observatory at the ocean floor using the PISCES V submersible with a hybrid electro-optical connector designed at the University of Hawaii. It gave scientists real-time acoustic signals from ships, marine mammals, earthquakes, Kilauea volcano lava flows, and information about the state of Loihi, which had by then become an international laboratory for the study of undersea volcanism. Real-time digital recording terminated when the cable to shore developed an electrical short to seawater in the rough volcanic terrain after six months of operation. ROV Jason recovered the HUGO package in 2004, and parts were used for construction of the ACO cable termination.

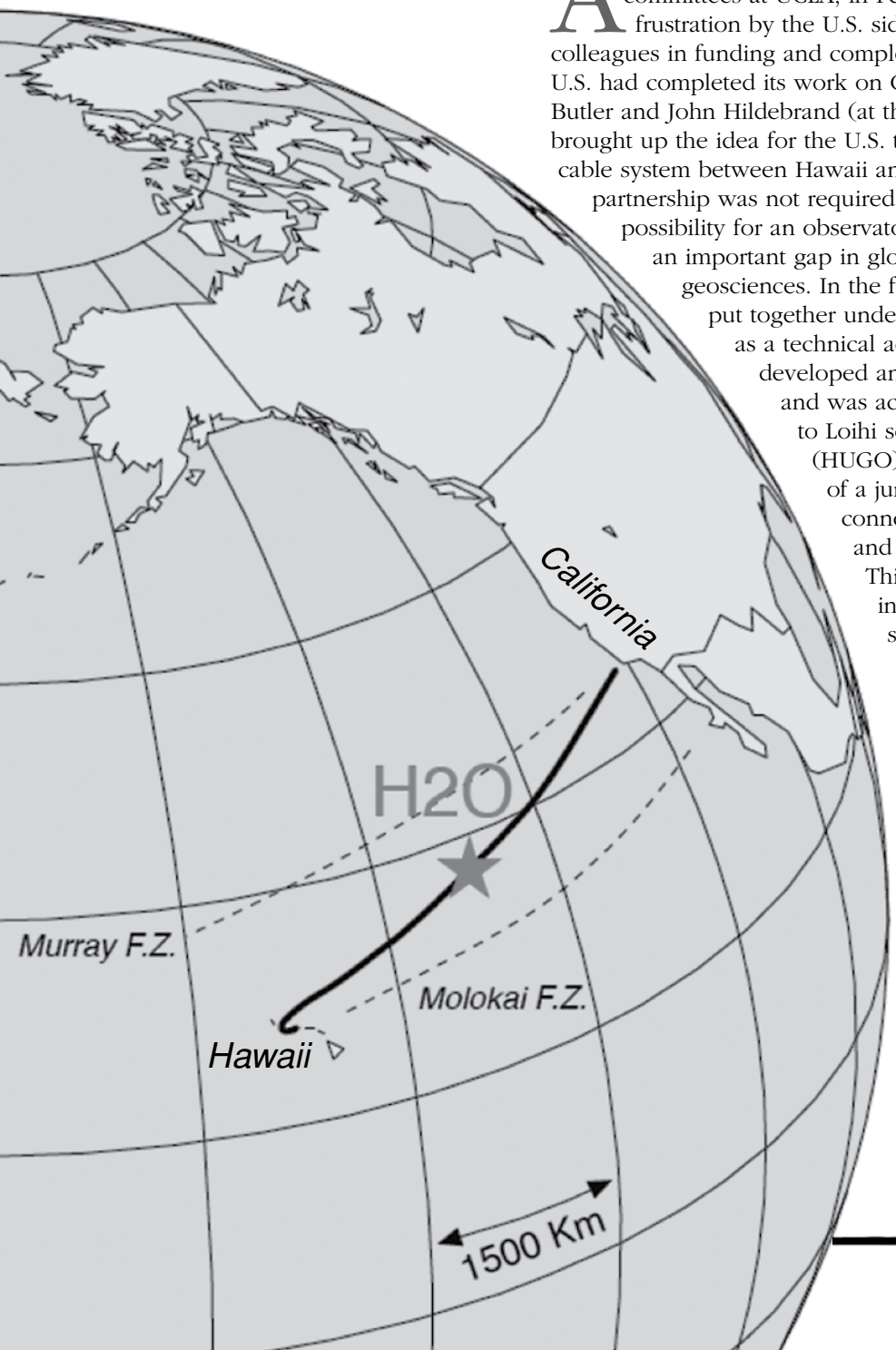
Despite the cable failure, all the essential elements of purpose-built cabled ocean observatories were demonstrated, including the successful small-ship lay of the 47-km electro-optical cable from the Island of Hawaii to the summit of Loihi submarine volcano; the

installation and servicing of the Junction Box; the successful operation of electro-optical connectors on the ocean floor by submersible; the installation and removal of experiments on the ocean floor; provision of substantial power based on a constant current/shunt regulator design; transmission of commands from shore to experiments installed at HUGO; the transmission of high-rate, high-fidelity data from the summit of Loihi to shore in real time; and the recording of volcanic, earthquake, biological, ocean wave, and ship noises for a period of six months. Thus, HUGO provided the proof-of-concept for all the essential elements of what we now think of as a "cabled ocean observatory".

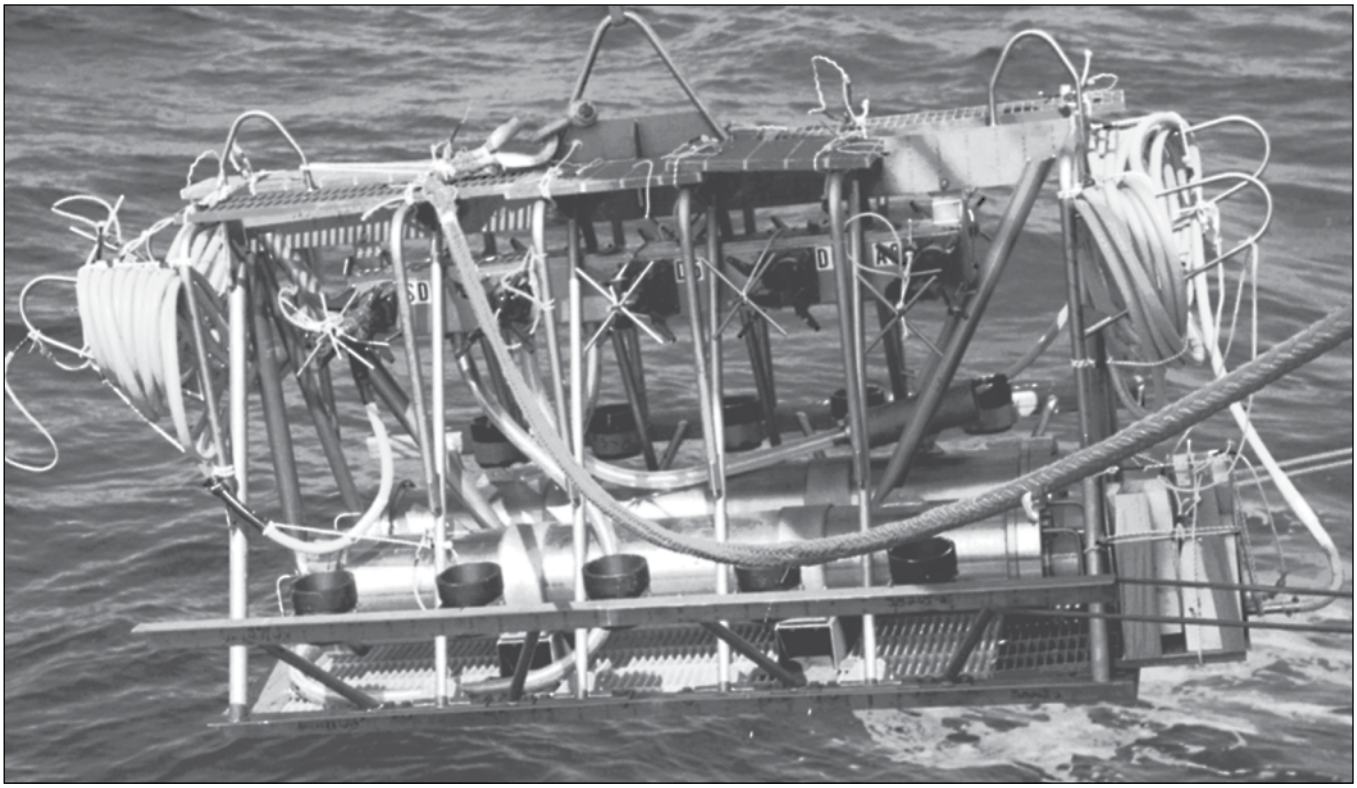
The Hawaii-2 Observatory (H2O)

At a joint meeting between the U.S. and Japan cable steering committees at UCLA, in February 1993, there was some quiet frustration by the U.S. side in the slow progress of our Japanese colleagues in funding and completing the TPC-1 project, in as much as the U.S. had completed its work on Guam in 1991. Following the meeting Rhett Butler and John Hildebrand (at the Scripps Institution of Oceanography) brought up the idea for the U.S. to take the lead in re-using the Hawaii-2 cable system between Hawaii and California, where an international partnership was not required. The Hawaii-2 cable presented the possibility for an observatory between Hawaii and California, filling an important gap in global coverage for seismology and other geosciences. In the following months a proposal team was put together under Butler's leadership, with Hildebrand as a technical advisor. Fred Duennebier, at UH, had developed an available broadband seismometer system, and was actively pursuing a cabled observatory to Loihi seamount from the island of Hawaii (HUGO). Following the HUGO lead, the concept of a junction box with underwater-mateable connectors was adopted to provide for flexibility and diversity in potential instrumentation. This latter feature also overcame limitations in the GEO-TOC design, wherein all of the sensors were incorporated in-line with a cable repeater housing, and could not be repaired, changed, or updated. Bell Labs (Lanzerotti and Medford) had been passively monitoring cable voltage on Hawaii-2 since its retirement, and were approached to make the cable available for actively powered observatory use. This was agreed to, as they were also monitoring the older Hawaii-1 cable parallel to Hawaii-2.

The initial H2O proposal was written during the summer of 1993, with Butler at IRIS as principal investigator, and Alan Chave, at WHOI, and Fred Duennebier, at UH, as co-investigators. The H2O project was eventually funded in two stages in 1996



Hawaii-2 Observatory (H2O) map. *From* EOS Trans. AGU, *"Hawaii-2 Observatory Pioneers Opportunities for Remote Instrumentation in Ocean Studies" (2000), by R. Butler, A. D. Chave, F. K. Duennebier, D. R. Yoerger, R. Petitt, D. Harris, F. B. Wooding, A. D. Bowen, J. Bailey, J. Jolly, E. Hobart, J. A. Hildebrand, A. H. Dodeman (pp. 81, 157, 162–163).*



The junction box during deployment.

From EOS Trans. AGU, *"Hawaii-2 Observatory Pioneers Opportunities for Remote Instrumentation in Ocean Studies" (2000), by R. Butler, A. D. Chave, F. K. Duennebier, D. R. Yoerger, R. Petitt, D. Harris, F. B. Wooding, A. D. Bowen, J. Bailey, J. Jolly, E. Hobart, J. A. Hildebrand, A. H. Dodeman (pp. 81, 157, 162–163).*

(for land work) and 1998 (ocean installation). Several challenges presented themselves. When Hawaii-2 was retired several years earlier with TPC-1, none of the equipment in the cable station had been preserved. With good foresight, the redundant TPC-1 SD equipment from Guam had been preserved and stored on Oahu, and was available for re-using the Hawaii-2 system. To accomplish this, the Margus team, who had worked for the U.S. on TPC-1, was again enlisted. Transfer of cable ownership of Hawaii-2 to IRIS Ocean Cable, Inc. was successfully requested in 1995, with the transfer occurring after the proposal was funded in 1996. Space for the equipment in the Makaha Cable Station on Oahu was also favorably negotiated from AT&T in a license agreement with reasonable terms for ten years. Funding from the proposal was being sought from the NSF Major Research Instrumentation program, which required cost sharing. For this the Hawaii-2 cable system itself was creatively used as the cost-sharing component, by obtaining an independent appraisal of its value by the cable industry.

The H2O system was installed in September of 1998, and immediately become a source of real-time data from the seafloor. The system included eight ports for experiment installation on the ocean floor using Ocean Design Inc. wet-mate connectors. The initial complement of sensors included a broadband Guralp seismometer (CMG-3ESP, buried in the seafloor), geophones, a hydrophone, Cox-Webb differential pressure gauge, a quartz pressure gauge, a thermal sensor, and 2-component current meter. Technical details can be found in Duennebier et al. (2002),[8] Pettit et al. (2002),[9] and Harris and Duennebier (2002).[10] The system operated for two months when a failure of a sensor subsystem limited data to pressure for tsunami research. The system was repaired and reinstalled in October 1999, and operated through May 2003. The H2O system ultimately provided more than 267 GBytes of real-time data (available from IRIS) with 92% data recovery during its operation. The data are still actively being analyzed, e.g., for surface ultragravity waves.[11]

In May 2003, the junction box was recovered for telemetry and power system upgrades. However, during the re-installation in October 2003, the failure of a key underwater-mateable connector ended the observatory. Although efforts were made to revive the system, funding was not obtained, due in part to the perception that these retired analog SD cables were obsolete technology at a time when fiber-optic submarine cable systems were beginning to be retired by the telecommunication industry. The H2O equipment was removed from the Makaha Cable Station, making way for the ALOHA Cabled Observatory system.

ANZCAN (Australia-New-Zealand-Canada) Coaxial Cabled Observatory

With the experience of HUGO and H2O, and following the participation of Roger Lukas in writing the NRC report on seafloor observatories,[12] the University of Hawaii approached Teleglobe regarding scientific re-use of the analog ANZCAN (Australia-New-Zealand-Canada) coaxial cable, which was retired in sections between 1999 and 2002. The concept was to move and re-use the section from Oahu to Canada for the Hawaii Ocean Time Series (HOT) site Station ALOHA located north of Oahu.

This would require cutting the cable and relaying the portion connected to Oahu. The concept of picking up and relaying cable had been studied during the 1990s and utilized by the telecommunications industry for cable repair. The ACO project was proposed to NSF and first funded in October 2002, with principal investigator Fred Duennebier and co-principal investigators Roger Lukas and David Karl.

Earlier in the early 1980s, Lukas recalls being asked by Helsley and Duennebier whether physical oceanographers were interested in measurements at the seafloor from re-used cables. His response at the time was that the signals were small, and that the ability of the sensors was not up to the task of producing "climate quality" data. This was true of temperature and pressure sensors at the time, but this situation improved sufficiently over roughly the next twenty years so that the potential for Physical Oceanography became clearer, leading to Lukas' participation.

However, developments in the cable industry changed the direction of this project. This was not just an era of replacement of cables with better technology. It was also an era of severe overbuilding of oceanic telecommunications cable networks in anticipation of Internet expansion. The dot.com bust in March 2000 put a large number of cable companies into financial distress, with many going out of business. This is an important perspective, especially as it tangibly impacted the ACO project.

In July 2002, AT&T approached IRIS with the news that the first generation of fiber-optic cables were to be retired starting in late 2002. These first systems had data rates of 280 Mbit/s in a single fiber pair (roughly equivalent to 4,375 voice channels). These systems had replaced the prior analog systems, but were now themselves obsolete after only ten years service of their twenty-five-year lifetime. The first-generation of fiber optic submarine cables began a revolution in telecommunications. The bandwidth available in these systems truly created the information superhighway across the oceans, between North America, Europe, Japan, and other centers of digital culture that we now so depend on. The development and installation cost of these systems exceeded USD two billion. These electro-optical systems, though state-of-the-art in their time, had now been surpassed by purely optical systems with vastly greater capabilities. Because the second-generation systems are purely optical, using in-line lasers to amplify the signals rather than electro-optical regenerators, they could be upgraded "in place" – by changing only the terminal equipment, the bandwidth may be increased by 1-2 orders of magnitude. In the Pacific, the opportunity for scientific re-use became available for HAW-4 and -5 (Hawaii-California), TPC-3 (Hawaii-Guam-Japan), GPT (Guam-Philippine-Taiwan), PacRimEast (Hawaii-New Zealand), and PacRimWest (Australia-Guam), and these cables are ideal for scientific purposes in that they provide more power as well as communications to seafloor instruments.

IRIS served as an intermediary with AT&T and its telecommunications partners in bringing the scientific opportunity to the scientific communities in the U.S., Japan, and Europe (for Atlantic cables), and raised funding from NSF to retain options for using these cables for science in the future as the scientific community and NSF developed consensus regarding the opportunity, and established a framework for the basic infrastructure and management necessary toward acquiring these systems for scientific use. Ideas were also put forward for re-laying sections of cables (TPC-3, HAW-5, PacRimEast, GPT, respectively) for new coverage of remote areas of the South and Central Pacific, and into the Tonga-Kermadec and Mariana subduction zones.

There were several specific events that impacted the ANZCAN project. One was the transition of Teleglobe into receivership just weeks before the cable was to be transferred to UH. Another was identification of an AT&T engineer, Mark Tremblay, who thought he could solve the problem of translating AT&T fiber optic transmission coding into something that ACO

could use. It was going to cost extra money, and it wasn't certain how long it would take and if it would be successful. Sandy Shor, the NSF program manager at the time, contacted Roger Lukas at one point to say that the project should consider using the balance of the funding to purchase instrumentation and to plan for autonomous deployments on the seafloor at Station ALOHA.

Fortunately for all concerned, Tremblay was retained for guidance. His expertise and goodwill with the telecommunication companies was invaluable not only to IRIS, but also for the University of Hawaii effort. With the imminent retirement of GPT and the loss of key equipment, IRIS Ocean Cable, Inc. received the donation of over 200 km of GPT spare fiber cable and several repeaters, with the consent and encouragement of the NSF in June 2003. Electro-optical repeaters located in East Coast cable depots were saved and stored by IRIS to provide key components and spares for HAW-4 and other prospective systems. Just as important, Tremblay solved the crucial technical problem of interfacing to the fiber-optic system. This state of affairs was sufficient to persuade NSF to continue the project.

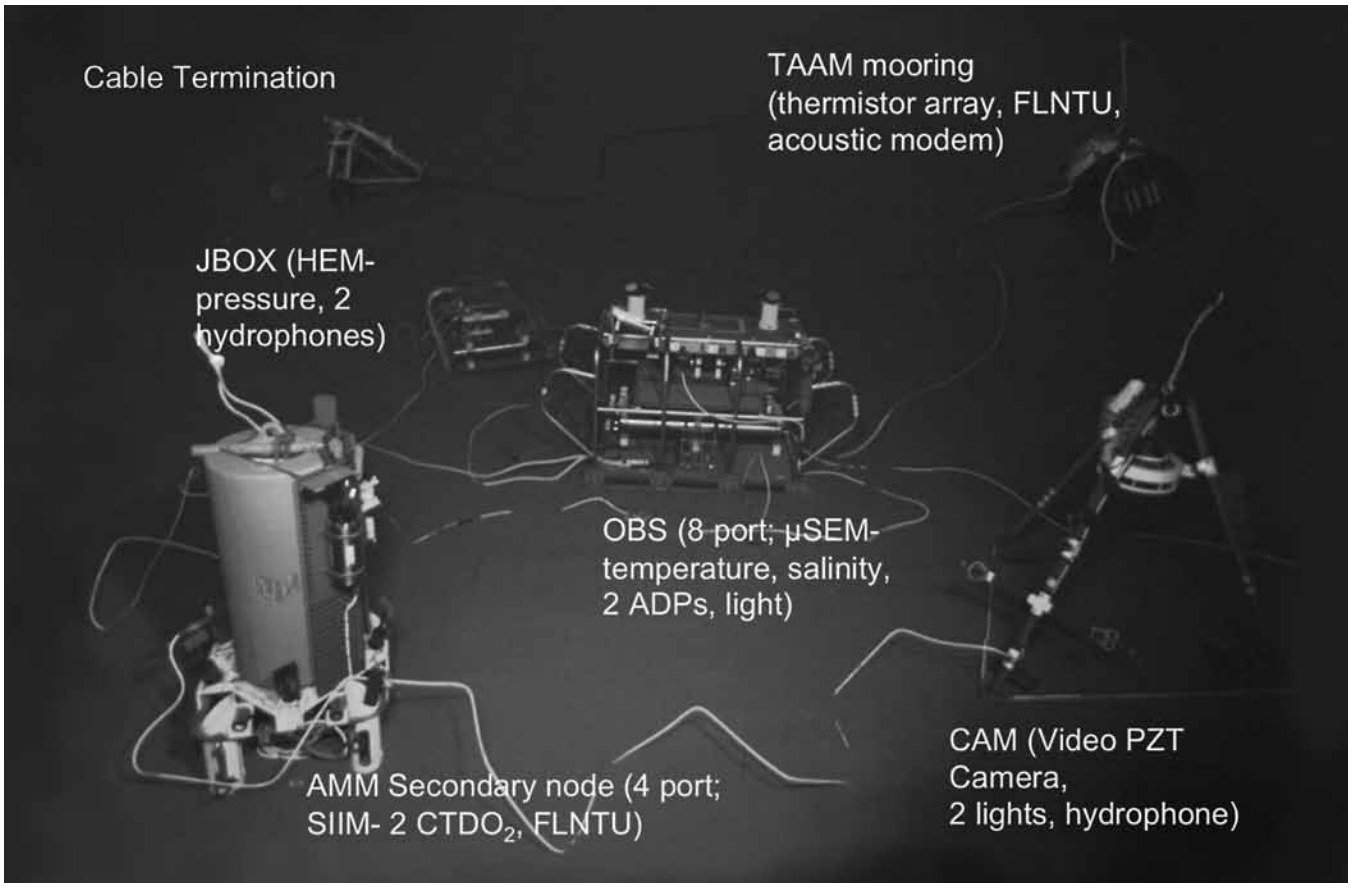
In October 2003, with the Cabled Regional Observatory Workshop,[13] the National Science Foundation decided to focus on transformative technologies involving laying new cables for its planned Ocean Observatories Initiative (OOI, at the time called ORION), rather than the evolutionary re-use of retired telecommunication systems. Other than the funded effort for HAW-4, led by the University of Hawaii, support for cable re-use effectively ended in the U.S. With the end of prospective new funding, the saved equipment was dispersed to minimize long-term storage costs. University of Hawaii shipped key spares for HAW-4 to Oahu. A large earthquake in Taiwan, in December 2003, broke most telecommunication cables near the Taiwan coast except for GPT. This event motivated return of GPT spares to AT&T from IRIS Ocean Cable. After concluding the dispersal of spare equipment, IRIS Ocean Cable Inc. ceded its share of ownership of TPC-1 to ERI. IRIS then dissolved IRIS Ocean Cable Inc. in 2007, relinquishing to the University of Hawaii the leadership for submarine cable re-use.

ALOHA Cabled Observatory (ACO)

After it was decided to use the HAW-4 cable, it was necessary to learn how to best interface with the AT&T optical communications protocol. A protocol developed by Tremblay provided an elegant solution to this problem that utilized hardware available for repeaters and cable station hardware, but was independent of the protocols used in the industry.[14] This protocol made the use of the first generation electro-optical cables for observatory use possible.

Another challenge was bureaucratic. As the time to go to sea approached, the UH Risk Management Office was reluctant to approve the transfer of ownership from AT&T to the University because of the legal responsibilities and liabilities that are associated with cable ownership, and for which AT&T required indemnification. It was only through the persistent lobbying of Brian Taylor (then SOEST Associate Dean of Research) and acceptance of Michael Hamnett, Executive Director of the Research Corporation of the University of Hawaii (RCUH a separate entity from the University) and his staff, that the necessary actions were taken to take advantage of the generosity of AT&T. Ownership was transferred just days before sailing. AT&T has been very accommodating throughout the project, including the provision of space at the Makaha cable station.

The next step was to cut and move the cable to the desired location at Station ALOHA, 100 km north of Oahu, the site of the unique Hawaii Ocean Time-series site (see http://aloha.manoa.hawaii.edu). This was accomplished in February 2007, using the U.S. Navy cable ship *Zeus*. A "proof module" with a hydrophone and pressure sensor was deployed and provided twenty months of excellent, nearly continuous data.[15] In September of that year, a pressure case for the general-purpose node was delivered with cracks, resulting in the cancellation of the October 2007 planned deployment cruise. A rescheduled deployment cruise took place in October 2008, but multiple connector failures prevented a successful deployment. And, bad weather prevented the re-deployment of the proof module. Finally, during eighteen days in May-June 2011, the observatory node was deployed from the RV *Kilo Moana* using the ROV Jason, and connected successfully to the cable termination.

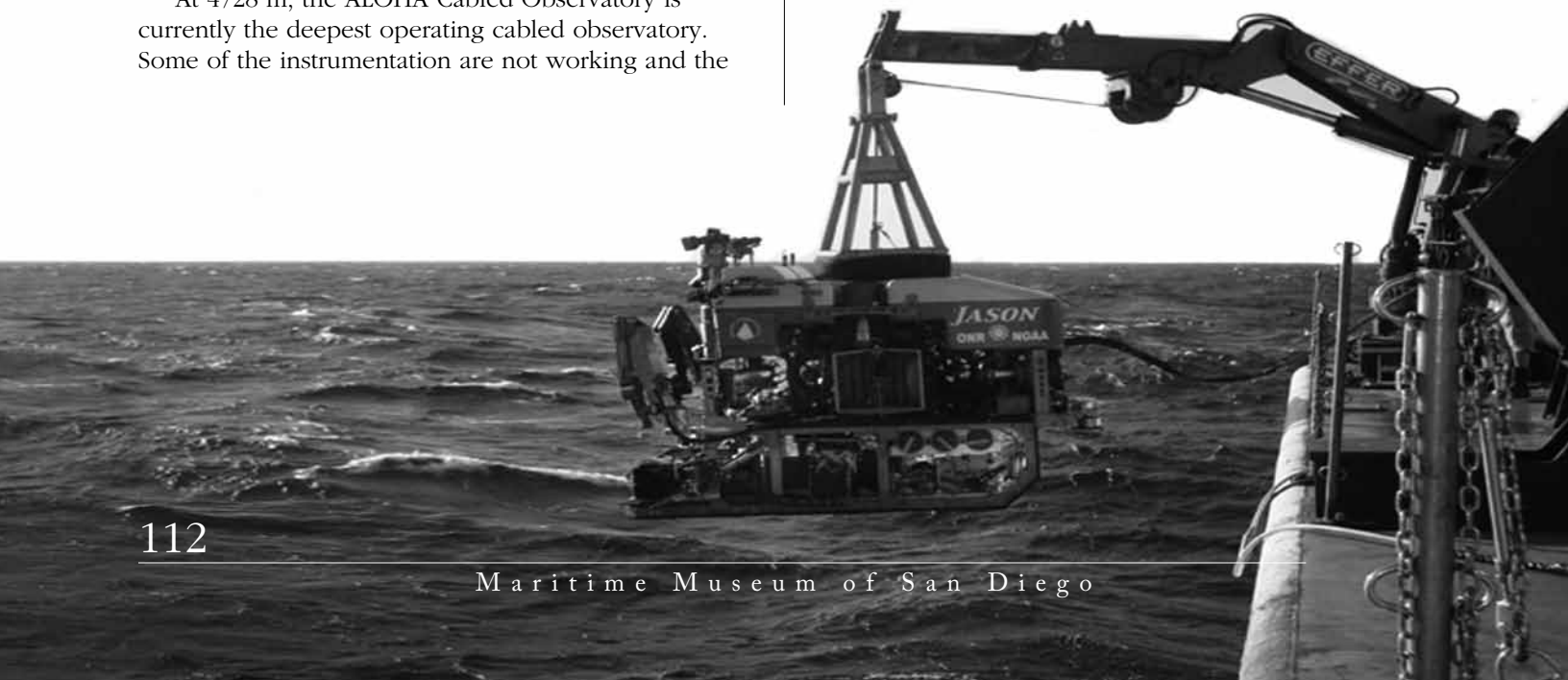


This photograph (taken by ROV Jason) is true to scale, except the cable termination and the TAAM mooring, in the background, have been pasted in.

Illustration Courtesy University of Hawaii at Manoa

Instruments/sensors include temperature, conductivity, pressure, hydrophones, camera and lights, a 200 m thermistor mooring, and an acoustic modem. A more detailed description and current status of the system can be found in Howe et al. (2011 and 2012)[16] and the project website: http://aco-ssds.soest.hawaii.edu.

At 4728 m, the ALOHA Cabled Observatory is currently the deepest operating cabled observatory. Some of the instrumentation are not working and the high pressure and near-freezing temperature, coupled with the still-all-too-common cable and connector problems are likely factors in these failures. The community is fortunate to have this facility to improve and perfect the engineering, and to begin sampling the abyssal and overlying ocean at this location.



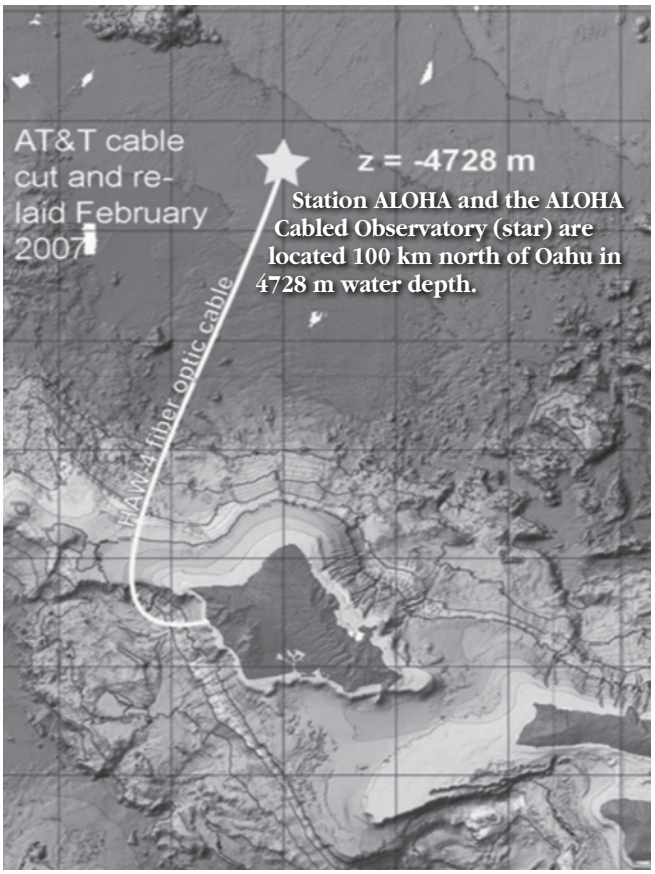
Concluding Remarks

Much of the emphasis here has been on the effort to re-use cables in the deep open ocean. It is clear that a large amount of effort was and is needed to plan and coordinate these types of activities, interfacing science, industry, and sponsors. Typically, five to ten years are needed from initial planning to fruition; this takes dedication and a degree of stubbornness to persevere through all the obstacles and challenges, many of which are non-technical. Further, a long-term plan is necessary for the operations and maintenance of an observatory. At the UH, a 6000-m capable ROV is being acquired from DOER Marine to support the ACO and other future observatories in the Pacific.

It should be understood that this history is by no means all-inclusive, and is somewhat Hawaii-centric. Other related work was going on in parallel. Based on planning from the 1970s, the DUMAND (Deep Underwater Muon And Neutrino Detector) project attempted to install a cabled neutrino detector on the seafloor off Hawaii in the early 1990s.[17] The Acoustic Thermometry of Ocean Climate (ATOC) project installed two cabled acoustic sources, one off Kauai and one on Pioneer Seamount off California. By measuring travel times between these sources, and a combination of vertical line array receivers and SOSUS receivers, path estimates of basin scale ocean heat content were determined.[18]

In 1990s, the DEOS Committee worked toward developing systems for open ocean seismic networks. Over time this committee broadened its outlook as reflected by its name changing from Deep Earth Observatories on the Seafloor, to Dynamics of Earth and Ocean Systems. This effort evolved into what is now the NSF Ocean Observatories Initiative (OOI). In this process, in 1997, planning began for a major cable system in the northeast Pacific, NEPTUNE.[19] Canadian colleagues led in 2006 with the installation of VENUS system in the inland seas between Vancouver and Victoria.[20] They were able to obtain significant funding in 2003 for the offshore NEPTUNE Canada system that was installed and commissioned in 2009. This is the first truly regional ocean cabled observatory.[21] The U.S. portion became part of the planned OOI; it should be installed in the next two years (see www.oceanobservatories.org). MARS, a 900-m deep system in Monterey Bay was installed in late 2008, primarily as an instrumentation test bed for OOI and other programs (see www.mbari.org/mars).

In Europe, the physics community installed several cabled systems that are incrementally working toward the capability to support a deep ocean neutrino observatory (ANTARES, NEMO, NESTOR). Cable systems, supporting ocean and seismic observing, are being installed off Norway and in the Marmura Sea.



At 4728 m, the ALOHA Cabled Observatory is currently the deepest operating cabled observatory.
Illustration Courtesy University of Hawaii at Manoa

In Japan, there were seven operating coastal-cabled observatories.[22] These efforts led to the installation of the DONET system adjacent to the Nankai Trough, starting in 2010. Its primary purpose is to provide early seismic and tsunami warning for offshore earthquakes, as well as improved scientific understanding.[23] The system will be incrementally expanded over time to cover a significant geographical extent.

While we started with the concept of re-using retired telecommunications cables, then more recently purpose-built systems, it may be that we will return to telecommunications cables. Or rather, submarine cable manufacturers may adapt their systems, specifically the repeaters, every 50 km or so along the cable, to accommodate scientific instrumentation.[24] As new cables continue to be laid between continents, providing the fabric of interconnectivity required by our rapidly evolving technical society, an entirely new paradigm of ocean and geophysical measurements may be enabled.



Notes

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Hawaii Ocean Time-series (HOT)

The Hawaii Ocean Time-series (HOT) aims to document, describe, and understand the physics and biogeochemistry of the ocean at Station ALOHA. Through research on monthly HOT cruises and analyses on land and sea, these objectives have been pursued for 23 years. Of particular importance is the documentation of variation over time in both physical and biogeochemical characteristics of the ocean - such as temperature and primary production - and its role in the earth's climate. Consistent and long-term data are crucial in finding and understanding any trends or abnormal events.

Right: HOT Cruise 200, 2008.



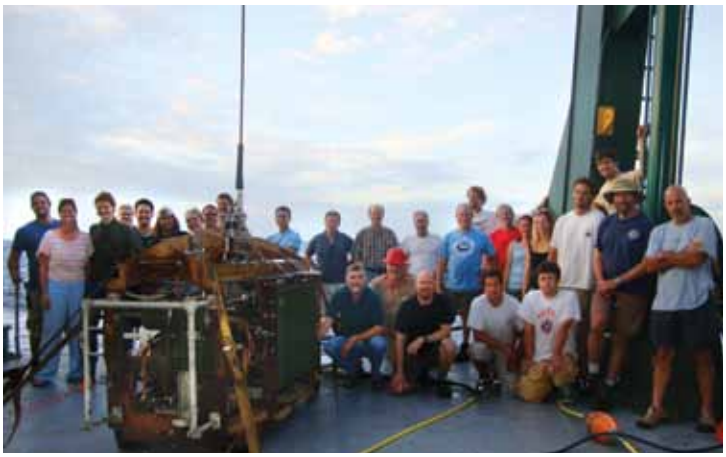




Above Left: The University of Hawaii research vessel, R/V *Kilo Moana*. Above Right: Crew deploying the 24 12L-bottle rosette and CTD package during the HOT 202 cruise on board the R/V *Kilo Moana.*

ALOHA Cabled Observatory (ACO)

Five kms (3 miles) beneath the surface of the ocean at Station ALOHA, the ALOHA Cabled Observatory brings an infrequently observed and little understood habitat into light. It provides real-time ocean observations via a submarine fiber optic cable that comes ashore at Makaha on Oahu. In addition to ocean sounds, continuous observations of temperature, salinity, and ocean currents are obtained and shared with the oceanographic community and the general public. See the ACO website, http://aco-ssds.soest.hawaii.edu, for real-time and recorded data.



Crew after successfully deploying the ALOHA Cabled Observatory.



Image taken from the ACO Camera: First Light.
(ROV Jason to the left.)

SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY

University of Hawaii Ocean

http://aloha.

Woods Hole Oceanographic Institution Hawaii Ocean Time-series (WHOTS)

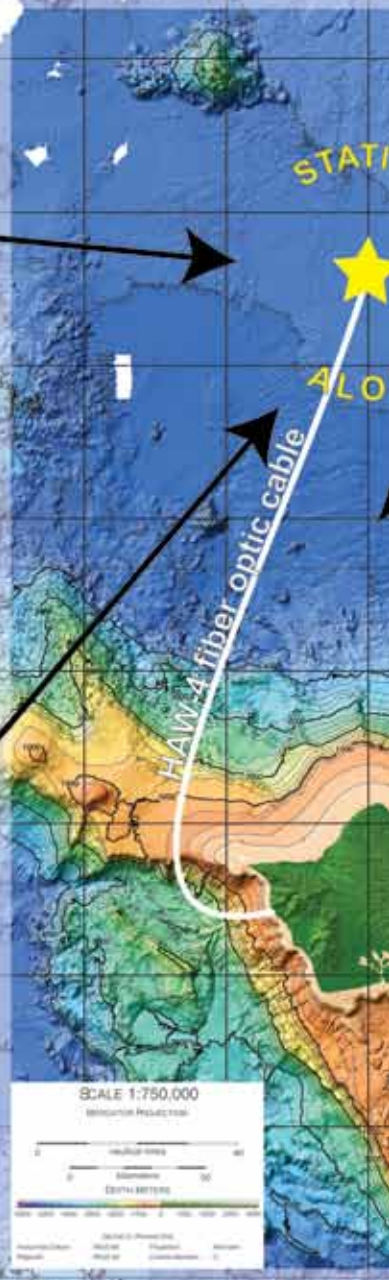


In 2004, the WHOI Hawaii Ocean Time-series Site (WHOTS), began deploying a mooring yearly to observe upper ocean-atmosphere interaction.

ALOHA Cabled Observatory (ACO)

The ALOHA Cabled Observatory (ACO) was installed on June 2011. With ACO, researchers now have the ability to extract data from and send commands to instruments on the seafloor at Station ALOHA instantly, and observe the little-seen habitat for years to come.





Hawaii Ocean Time-s (HOT)

Scientists from the University of Hawaii (UH) conduct almost monthly, 4-day research cruises to Station ALOHA to study physical and biogeochemical properties for the Hawaii Ocean Time-series (HOT) project.

N STUDIES AT STATION ALOHA

MANOA.HAWAII.EDU

Station ALOHA is a 6 mile radius circle in the Pacific Ocean, north of Hawaii, where varied oceanographic research projects converge to produce a remarkable collection of observations about our dynamic oceans and atmosphere.

Station ALOHA is the focal point of a range of oceanographic studies conducted over great temporal scale that intend to understand and explain the trends of the greater North Pacific Ocean. Station ALOHA was established in 1988, at the start of A Long-term Oligotrophic Habitat Assessment (ALOHA), and this assessment continues today in many forms.

SOEST Ocean Gliders (SOG)

SOEST Ocean Gliders (SOG) are mobile platforms "flying" through the water making measurements over months around Station ALOHA.



SERIES



BATHYMETRY MAP FROM HAWAII MAPPING RESEARCH GROUP
HTTP://WWW.SOEST.HAWAII.EDU/HMRG/

SOEST Ocean Gliders (SOG)

A seaglider is an efficient tool for ocean observations capable of recording data while diving and traveling hundreds to thousands of kilometers at ~0.5 knots as commanded by shore-based pilots. Starting in 2008, gliders deployed by the UH School of Ocean and Earth Science and Technology (SOEST) Ocean Glider facility (SOG) began visiting Station ALOHA. One to three gliders typically measure temperature, salinity, optical, and other data to 1000 m, as does the HOT cruises, but the gliders remain for 3 months rather than 3 days. Unfortunately, they cannot collect water samples needed for sensor calibration and for many other biogeochemical variables.

More recently, the wave glider is being used as an autonomous surface vehicle (ASV). It converts wave energy directly to forward thrust to achieve speeds of 1.5 knots, again under the control of a shore-based pilot. NOAA scientists have used this for pCO2 measurements at ALOHA, and UH scientists and engineers are integrating acoustics for marine mammal and other work.



Left: Crew prior to deploying the seaglider and wave glider.

Right: Seaglider deployment.

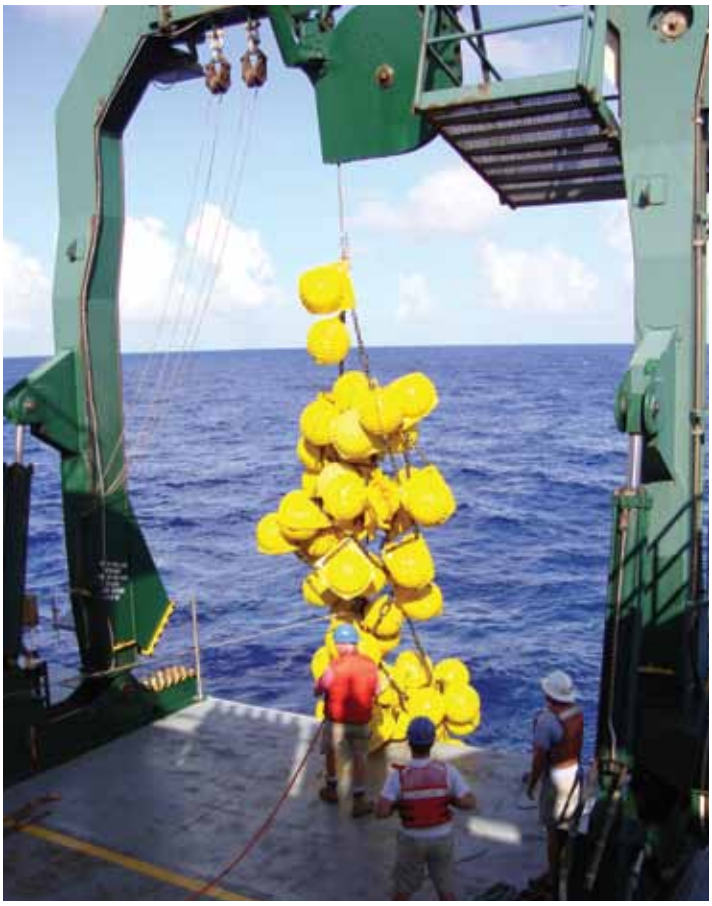


Woods Hole Oceanographic Institution Hawaii Ocean Time-series (WHOTS)

WHOTS is a coordinated part of HOT, funded by NOAA and NSF, and consists of a full ocean depth mooring with surface buoy at Station ALOHA that has been providing state-of-the-art measurements of meteorology, along with the associated upper ocean response, since August 2004. The objective of this project is to provide long-term data on fluxes between the air and sea including heat, fresh water, momentum, and chemical fluxes at a representative location in the North Pacific Subtropical Gyre.

Right: Crew watching WHOTS buoy after deployment.
Below: Deploying glass floats for the WHOTS mooring.







MARITIME RISING
PORT OF SAN DIEGO

San Diego's maritime industry is a diverse economic engine that creates jobs and plays a critical role in national defense. In 2011 maritime revenues reached $35.1 million and the Port of San Diego is one of only 17 "strategic ports" in the U.S.

Onward and upward, the future of maritime includes:

- **Business from new and emerging markets, including China, India, Latin America**
- **Export opportunities with local manufacturers**
- **Growth in green energy sector**

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* Port of San Diego SAP System

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San Diego's Technology

By Brock J. Rosenthal

Introduction

In the early days of oceanography scientists largely made their own equipment. While this tradition continues today, along the way specialized manufacturing companies sprang up to fill this niche. Many of these companies were started by scientists or engineers who had left ocean research labs. Over time new markets for these products were developed for offshore oil and gas, defense, environmental monitoring, hydrographic surveying and other applications. Today, there is a thriving worldwide trade for underwater products in what is often called the marine technology industry.

San Diego is one of the leading, if not the leading center of marine technology. It can trace its roots to Scripps Institution of Oceanography, dating back to 1903. Scripps has influenced local industry in many ways: from transferring technology, supplying people knowledgeable in ocean engineering and instrumentation, to purchasing products and services. Another large factor in the San Diego marine technology scene is the presence of several Navy facilities, especially the research lab in Pt Loma (see pages 32-59, this issue).

Many key marine technologies have been invented, developed, and/or evolved in San Diego. This article will highlight the role industry has had in this process.

Sampling Devices

The study of the oceans started as a descriptive science describing and cataloging biological and geological specimens. Many clever mechanical collecting devices were devised to remotely retrieve samples. Initially, by necessity, all were built by the scientists who used them.

One of the earliest companies in the U.S. to make sampling equipment for marine scientists was Kahl Scientific Company, sometimes known as Kahlsico. Started in New York City, by Joseph Kahl in 1935, Kahl Scientific began making metrological equipment; they soon catered to requests from customers for field equipment such as water and seafloor samplers.

In the aftermath of World War II, Kahl participated in Operation Paperclip – an Office of Strategic Services (OSS) program that recruited scientists from Nazi Germany. Kahl took on several experts in scientific glassblowing, who knew how to make reversing thermometers that, at the time, no one in the U.S. could make. These instruments locked in a temperature reading when flipped upside down and were used by oceanographers to record temperatures at various depths.

The Kahl family moved to El Cajon, in San Diego County, in 1948. Their product line of instruments steadily grew in number year by year, until eventually they had over 1500 devices. Most of their instruments were mechanical and many were designed in collaboration with scientists at various institutions, including Scripps. Their massive catalog was a testament to man's ingenuity. Joseph's son, Gerald Kahl, took over the reins in the late 1980s from Joseph, who passed away in 2003. Gerald semi-retired a few years ago and closed up the office, but kept some items available via the company's website. In 2011, Gerald died and Kahl Scientific came to a close.

Another early entry in the local scene was Ocean Instruments, started by "Moon" Hedricks in 1947 as a welding shop. Moon was a mechanic at Scripps and built gadgets for scientists there. Eventually he built up a line of marine biological and geological sampling equipment such as plankton nets and box corers.

Marine Industry



Brock Rosenthal is President of Ocean Innovations, a supplier of oceanographic instruments and underwater equipment. He has worked in the maritime technology field for nearly thirty years. Rosenthal has twice served as chairman of the San Diego section of the Marine Technology Society and as a vice president of its national board. For the past twelve years, he has been editor of the Southern California Marine Technology eNews.

His son John (aka "Half Moon") took over in 1977 and ran the company, until he retired a few years ago and sold the business to his chief machinist, Tim Marrs, who continues to operate the company today out of the original Quonset hut building. Ocean Instruments also makes a fish egg sampler under license from Scripps, which is used to study the distribution of fish eggs from a moving ship.

Sediment coring is important for bringing geological samples of the seafloor back to the lab for analysis. Vibracoring is a method for obtaining long, well-preserved cores in water-saturated sediments from wetlands, harbors and lakes, to the deep ocean. Equipment for vibrocoring was pioneered by André Rossfelder, an Algerian émigré who came to Scripps to study underwater geology. In the mid-1960s, he started his own company, Rossfelder Corporation. In addition to selling equipment, his company provided vibracoring services all over the world. Although Rossfelder passed away in 2011, his San Diego-based company is carrying on.

Underwater Acoustics

During World War II, the anti-submarine warfare program to counter German subs necessitated the rapid development of underwater acoustic research. A focal point for this was the University of California's Division of War Research, which had its headquarters next to the Navy Lab in Pt Loma. During the course of the war, UCDWR employed up to 575 people. When UCDWR closed after the war, Navy contracts for research in basic science were transferred to the newly formed Marine Physical Laboratory (MPL), which became part of Scripps Institution in 1948. One of the key researchers at MPL was Dr. Victor Anderson. Some of the pioneering developments he worked on included multi-element hydrophone arrays, multi-beam sonars, beam steering, and multiplexing power and data signals onto a single coax conductor.

In 1946, Anderson and two colleagues formed a company called InterOcean Systems, to work on Navy contracts for acoustic arrays. Other products that followed were devices that when commanded they could release anchors from the seafloor, a remotely operated subsea crawling vehicle, and a music analyzer! Later, InterOcean developed integrated monitoring systems for the nascent offshore petroleum industry that used some of the first acoustic and radio telemetry. In 1969, Mike Pearlman was hired as the business manager; he eventually bought the company. Today, InterOcean has a diverse product line of current meters, tide gauges, acoustic releases, winches, instrumented moored buoys, and oil spill detection systems.

Buoy Technology

Scripps has long been an innovator in buoy technologies (see "It Takes a Network to Build an Ocean Observing System," pages 18-31, this issue) from deep ocean moored buoys to ones that drift lockstep with near surface currents.

Drifting buoys are useful for studying ocean circulation as well as the dispersion of surface particles such as fish larvae and other plankton, and buoyant pollutants such as oil.

One popular design was developed by the late Peter Niiler, of Scripps, and subsequently licensed to one of his engineers, Andy Sybrandy, who founded the company Pacific Gyre in 1999 to build them on a commercial basis.

Another group at Scripps developed buoys (known as floats) that map subsurface currents by drifting at a specific depth and occasionally rising to the surface to report their position via satellite. Sensors have been added to some to measure other parameters such as salinity and temperature. An international program called Argos maintains a constellation of over 3000 floats across the world's oceans. Scripps has licensed the design of their Argo floats to several manufacturers, including MRV Systems in San Diego. MRV is headed by Jim Dufour, who recently left Scripps after a long career as an engineer working on the development of Argo floats, underwater gliders, and related systems.

Licensing of buoy designs has also come to San Diego from other directions. In 2005, a unit of SAIC in San Diego, licensed the design of the tsunami warning buoys developed by NOAA's PMEL lab in Seattle. SAIC commercialized the design and markets them to foreign countries. Data from one of the SAIC buoys was used to forecast the inundation of the March 11, 2011, Japan tsunami.

As an alternative to sending ships out to sea to collect data, moored buoys have long been used by Scripps as data collection platforms. The Navy also uses buoys to collect environmental data and to relay underwater acoustic communications up to satellites where they can be beamed anywhere. An expert in the field was Henri Berteaux, who literally wrote the book on the subject. After a long career at WHOI, Berteaux moved his consulting company to San Diego, which he operated until his death in 2007.

Connectors and Cable

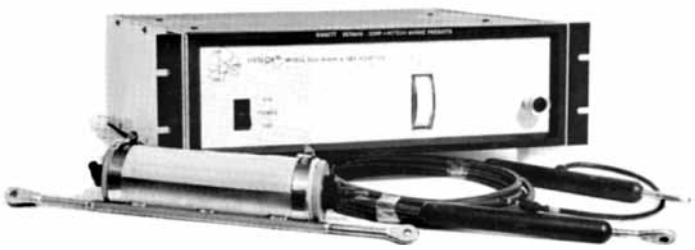
The link from underwater electronics to the surface, or to each other, is underwater cable and connectors. Underwater connectors are ubiquitous in marine technology and are another area that San Diego has long been a leader.

In 1963, Art Nelson started a company in Encinitas called Electro-Oceanic that made underwater connectors. Its product was the first wet-mateable connector based on interference fit, rubber-molded parts that is now a common design. E-O was the first of many underwater connector companies in the San Diego region and it was the second underwater connector company in the U.S. After just a few years in San Diego County, E-O moved to Los Angeles and was sold to Crouse Hinds, who in turn was subsequently acquired by Cooper Industries. Along the way at least two other underwater connector companies were started by people who had left Electro-Oceanic.

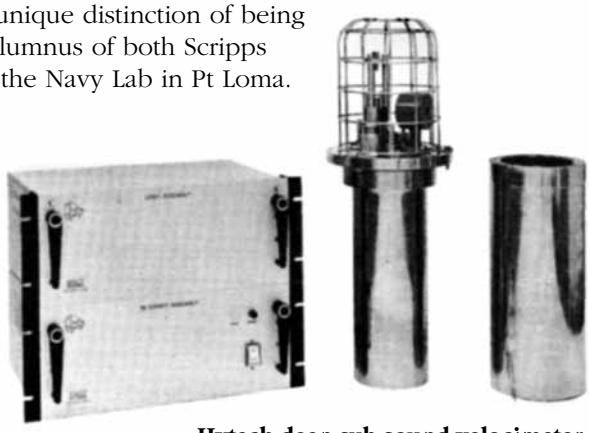
In 1964, Willard Brantner founded Brantner & Associates in El Cajon as a marketing representative for Texas-based Marsh & Marine, the only other underwater connector manufacturers in existence at the time. A few years later he started molding his own underwater connectors for the Navy. He later expanded his customer base to research institutions, including Scripps, and the offshore oil industry. Today, Brantner is one of the largest manufacturers of underwater connectors in the world and has production facilities in California, Texas, Mexico, and the UK.

San Diego is also home to Impulse Enterprises, which got its start in 1978 as a machine shop. A few years later, Impulse started making underwater connectors as well as distributing some made by another manufacturer. Over the years they expanded these initial product lines into several other types of underwater connectors. At the end of 2006, Teledyne Technologies acquired the company and renamed it Teledyne Impulse.

Another connector company with ties to San Diego was Challenger Marine. The company was started in Florida in the early 1980s by Dr. Jim Cairns, who has the unique distinction of being an alumnus of both Scripps and the Navy Lab in Pt Loma.



Hytech wave tide monitor



Hytech deep sub sound velocimeter

Challenger made some of the first connectors that could be mated by an ROV. The basic design consisted of a fluid-filled pressure-compensated chamber, which housed receptacle sockets. Male contacts penetrated the chamber through sealed openings; connections were made within the dielectric fluid, and removed from the hostile outside environment. The advantages of such connectors are that they may be mated and unmated repeatedly underwater, at any pressure.

In 1985, the company was sold to a division of Lockheed Martin in San Diego, which continued the development of the product line and expanded it to include fiber optic connectors. In 1997, Lockheed entered into a licensing agreement with Brantner & Associates to manufacture and market the connectors with technical support from Lockheed Martin. Cairns went on to found another connector company in Florida, Ocean Design Inc. (ODI), which ultimately was sold to Teledyne.

Connectors can't be used without cables, and specially designed cables are required for use in the harsh underwater environment. In 1973, ITT's Cable-Hydrospace Division built a massive manufacturing plant, totaling 317,000 square feet, in south San Diego. The plant specialized in building submarine telephone cables that were often hundreds of miles long. Cable-laying ships could dock right at the factory and be loaded from an overhead conveyor direct from the production facilities. After years of operation, ITT shuttered the plant when the telecom industry collapsed. The unique 4-story, 1,100-foot long building was demolished in 1997.

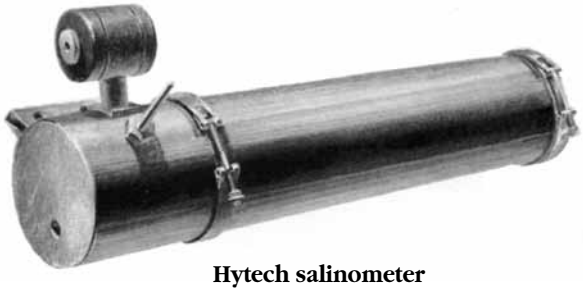
North San Diego County became home to another underwater cable manufacturer when Lewis "Pinky" Falk moved his company, Falmat, to San Marcos in 1988. The company started in Los Angles as a wire and cable distributor in the mid-1960s. Upon relocating to San Diego, Falmat discovered that local marine technology companies were in need of specialized cables and it began making some simple designs. Today, the company is run by the next generation of Falks and has expanded into three buildings. Its capabilities extend the entire spectrum of cable types used above and below the water.

CTDs (Conductivity/Temperature/Depth)

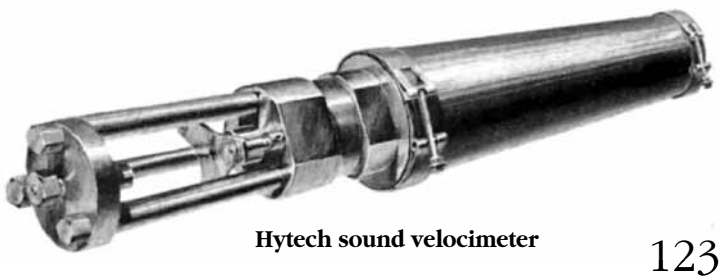
CTDs measure how the electrical conductivity and temperature of the water column changes relative to depth. Conductivity and temperature information is valuable because the speed of sound in seawater can be derived from these variables. This is used to correct devices that use sound underwater. CTD data can also be used to calculate water density. Oceanographers use CTDs to study the physical properties of water, which can help them understand currents, mixing, biological processes and other phenomena. For this reason, they are one of the most common instruments used by marine scientists

The first commercially made CTDs can be traced back to a company called Hytech, which was formed in San Diego (ca. 1960) by Don Cretzler. Initially, it made a bathythermographs, current meters, and a wave and tide monitor. These were amongst the first electronic ocean instruments. In 1962, an engineer named Neil Brown joined the company to develop a laboratory instrument to measure salinity. Soon after, he designed the electronic components that were the key to making in-situ computations of salinity enabling the first CTD to be built. The following year the Navy contracted with Hytech and Santa Monica based Bissett-Berman, who was one of the few companies at the time with computer technology. Together they made the first automated ocean data collection system that was used to collect large volumes of data to evaluate the underwater acoustic environment. As a result of this collaboration, Bissett-Berman acquired Hytech. In 1964, the Navy awarded them a contract to develop the first oceanographic sensors capable of continuous operation for up to one year in-situ. This was followed by other Navy contracts for specialized sensor systems. In 1969, the San Diego division moved into a 33,000 square foot purpose-built building in Kearny Mesa. In 1970, Bissett-Berman was purchased by the British company Plessey Ltd. and the San Diego Division was renamed Plessey Environmental Systems. Ten years later, Grundy bought the parent company of Plessey Environmental and a short time later phased out the oceanographic equipment.

Photos Courtesy of Hytech/Bissett-Berman



Hytech salinometer



Hytech sound velocimeter



Ocean Sensors' APV (Autonomous Profiling Vehicle) off the coast of Cuba, 1992.
Courtesy Kim McCoy

Neil Brown left Hytech in 1969 and moved to the East Coast where he eventually started his own company making CTDs. Neil Brown Instruments was later acquired by EG&G. He continued to develop improved CTDs for a company called Falmouth Scientific. In 2009, this product line was acquired by Teledyne RDI – Neil Brown's CTDs had come full circle and returned home to San Diego.

Not to be outdone, RDI's cross town rival, Sontek, came up with their own CTD, the CastAway, an innovative handheld deployable instrument with integrated GPS and LCD display.

Ocean Sensors, Inc. (OSI), formed by Kim McCoy and Scripps' graduate Michael Head, grew out of the pioneering efforts to create a lightweight internally recording conductivity-temperature-depth (CTD) instrument. The advent of the low power microprocessor and digital memory storage in the early 1980s enabled OSI to commercialize one of the first autonomous solid-state data loggers in the world.

In 1993, OSI integrated Global Positioning System (GPS) into its products. In the same year, OSI commercially introduced the Autonomous Profiling Vehicle (APV), which repeatedly profiled to 1000 meters depth. The APV transmitted to land via satellite radio and, when submerged, it used acoustic communications to other subsurface platforms.

Head left OSI in 1990 and started his own company, Precision Measurement Engineering. PME's initial product was a CTD designed to make very fine-scale measurements of ocean and lake waters. They have since added other sensors and systems for water quality monitoring.

A novel method for deploying CTDs from a moving ship was developed by Scripps and licensed to the Oceanscience Group – a company started in 1988 by SIO graduate Ron George. Oceanscience also makes surface buoy mounts, seafloor frames, and remotely-controlled boats, all for acoustic Doppler current profilers (ADCPs).

Current Meters

San Diego has also been a leader in developing instruments to measure the speed and direction of water currents.

In 1966, Plessey Environmental Systems introduced an electromagnetic current meter that recorded data on magnetic tape. After twelve years, production was taken over by Grundy Inc., also of San Diego.

InterOcean Systems introduced its S4 current meter, which senses current using two pairs of titanium electrodes mounted on a 10" diameter sphere that houses electronics and batteries. One of the key InterOcean engineers who worked on the development of the S4 was Ken Lawson; he left to start his own business, Sea-Bird, which was devoted to the development of CTD products.

Another approach to determining flow rates is to transmit an acoustic pulse in the water and measure the signal that is reflected back from particles in the water. The Doppler frequency shift can be used to compute the velocity of the particles and thus the water in which they are suspended. San Diego based Ametek Straza used Doppler techniques to measure ships' speed. Two engineers from Ametek, Fran Rowe and Kent Deines, collaborated with Russ Davis and others at Scripps, to develop a sonar that could obtain vertical profiles of water currents. Ametek was not interested in pursuing this, so Rowe and Deines left and started their own company, RDI, to commercialize Acoustic Doppler Current Profilers (ADCPs). They were very successful and ADCP's are now a standard oceanographic tool (see Russ Davis' article, pages 18-31, this issue).

Several former RDI employees formed companies using Doppler technology, including San Diego-based Sontek and LinkQuest. Sontek was formed by Ramon Cabrera and Atle Lohrmann in 1992. Their first product was the Acoustic Doppler Velocimeter (ADV) for making high precision single point measurements in laboratories. The product line has since grown into a diverse mix of instruments for all types of environments. In 1996, Lohrmann went back to his home country of Norway and started Nortek. In 2001, Cabrera sold the company to YSI, a large manufacturer of environmental monitoring equipment. The company remains in San Diego and after a sabbatical of several years, Cabrera returned to head up Sontek's new product development efforts.

LinkQuest was founded by former RDI engineer Dr. Xiolong Yu and Ning Xiao in 1998. In addition to ADCPs, LinkQuest has become a leading manufacturer of acoustic modems, which are used to transmit data wirelessly through the water. LinkQuest also makes acoustic tracking and positioning systems based on their broadband spread spectrum technology.

In 2005, RDI was acquired by Teledyne where it has continued to grow by acquisition and product development. Founders Rowe and Deine left subsequently, with each starting new endeavors. Deines developed products for the medical industry using laser Doppler technology. Rowe joined his sons in 2009, at Rowe Technologies, to develop new underwater Doppler sonar products.



Saturation Systems' Helinaut gas reclaim diving helmet.
Photo by the Author



Saturation Systems' deck recompression chamber.
Courtesy Don Rodocker

Diving Technology

San Diego was home to the first free diving club, the Bottom Scratchers, which started in 1933 and whose members invented much of the equipment they used. In 1949, when SCUBA diving gear first became available in the U.S., some of the first sets made their way into the hands of Scripps scientists. They developed the first non-military training program in the nation which served as a model for training agencies that came along later. Some of Scripps diving scientists started a consulting company with their diving colleagues at the Navy Electronics Lab called Geological Diving Consultants. Another group of divers at Scripps formed Scientific Diving Consultants, Inc. These prototypical companies developed equipment and techniques that would later be copied and commercialized.

One problem faced by divers was how to stay warm. Hugh Bradner, a physcist at UC Berkeley (and subsequently Scripps) was asked to think about this by some Navy divers.

Bradner came up with the idea that suits do not need to be watertight if thermal insulation is obtained by air entrapped in the material of the suit. His insight deemed that the diver does not have to be dry to stay warm. After trying several materials, Willard Bascom, an engineer at Scripps, suggested Bradner use a new material called neoprene and hence was borne the wetsuit.

Bradner set up two companies with others to make and market wetsuits to Navy divers: Engineering Development Company (EDCO) in Berkeley, and Beaver International of La Jolla. However, the Navy did not adopt their wetsuits out of concerns that the gas bubbles in the neoprene would make it easier for divers to be detected by sonar. Another disappointment was the U.S. Patent Office's rejection of their application because the design was viewed as too similar to a flight suit. Bradner decided to leave commercialization of the wetsuit to others and pursue his academic interests.

Drysuits are diving thermal protection designed to prevent water from entering the suit, as opposed to wetsuits that allow a thin layer of water in. One of the early manufacturers of drysuits was started in San Diego, in 1963, by Dick Long. His Diving Unlimited International has become a world leader in drysuits. Long also perfected the hot water suit in the early 1970s, which was used by commercial oil field divers who would sometimes make saturation dives for weeks at a time. Today, Long pursues his passion for converting retired ships into reefs and has turned the reins of DUI over to his daughter, Susan.

Jeremiah Sullivan is another local innovator in diving technology. His company, Neptunic, developed a flexible suit of armor for divers to wear while working around sharks.



Drew Michel (with controller), of Taylor Diving, accepts three Hydro Products RCV 225 from Chuck Strickland. These were some of the first ROVs used in the Gulf of Mexico (ca. 1976).

Courtesy Drew Michel

Saturation diving is a technique that allows divers to work at great depth for long periods of time without suffering from the bends. The U.S. Navy pioneered this technology. Their manned SeaLab underwater saturation habitat was operated for forty-five days without problems, northwest of the SIO Pier on a ledge in Scripps Canyon, at a depth of 205 feet in 1965.

In the early 1970s, former U.S. Navy saturation divers Don Rodocker and Chris DeLucchi started a company in San Diego to make saturation diving systems for the offshore oil industry. Appropriately called Saturation Systems, Inc., the company's founders proved their technology by making the first saturation dives on the fabled wreck of the *Andrea Doria*, a luxurious Italian ocean liner that sank off New England in 1956. The company's systems included a portable, submersible recompression chamber and a control van, as well as specialized diving helmets known as Sat Hats.

Rodocker was also the creator of the "Gas Mizer" deep diving gas reclaim system. This is a helium-oxygen diver gas recovery system that takes expired gas from the diver's helmet and passes it back up a return line, ganged to the diver's umbilical. The gas is then cleansed of its carbon dioxide, small particulates and excess moisture. Oxygen is then added and the gas is pumped back down to the diver. With this equipment expensive helium gas is conserved.

Divers working in saturation can have problems communicating with personnel on the surface due to the affect of helium on the human voice – the affect makes them sound like they are imitating Donald Duck. A local company, Helle Engineering, solved this by supplying electronic devices known as helium unscramblers. The company was started by Jim Helle, a former engineer at Scripps. Helle was Scripps' liaison with Jacques Cousteau's team when the famous French diver brought his diving saucer to SIO for a series of local dives in late 1964/ early 1965. For this effort, Helle developed underwater navigation equipment using acoustic pingers. Soon, others were asking him to build the equipment. Helle toyed with the idea of starting a company to sell them and consulted with the director of Scripps. He was cautioned that no one who had left Scripps had ever successfully started a company. Helle ignored the advice and followed his instincts. His pingers became a big success in the new industry of offshore oil and gas. Helle pioneered the development of other underwater electronic devices for communication and relocation. Helle eventually relocated to Scotland and the company was acquired by Nautronix in 1995.

Another local company making helium unscramblers and diver communication devices is Amron International, which was started by Norma Ockwig, a former employee of Saturation Systems. Amron started in 1978, operating out of Norma's home selling commercial diving equipment. Today, it is a full-line distributor and manufacturer of commercial diving, tactical, and hyperbaric equipment run by Norma's daughter out of a 40,000 sq ft building.

The tradition of diver communication device development in San Diego is being carried on today by Hydrolinx, which was formed in 2011 by former Amron engineer Todd Sadik, who saw a need for improved technology. By using digital signal processing, Hydrolinx reduces background and inhalation noise thereby making diver's speech clearer.

Underwater Cameras

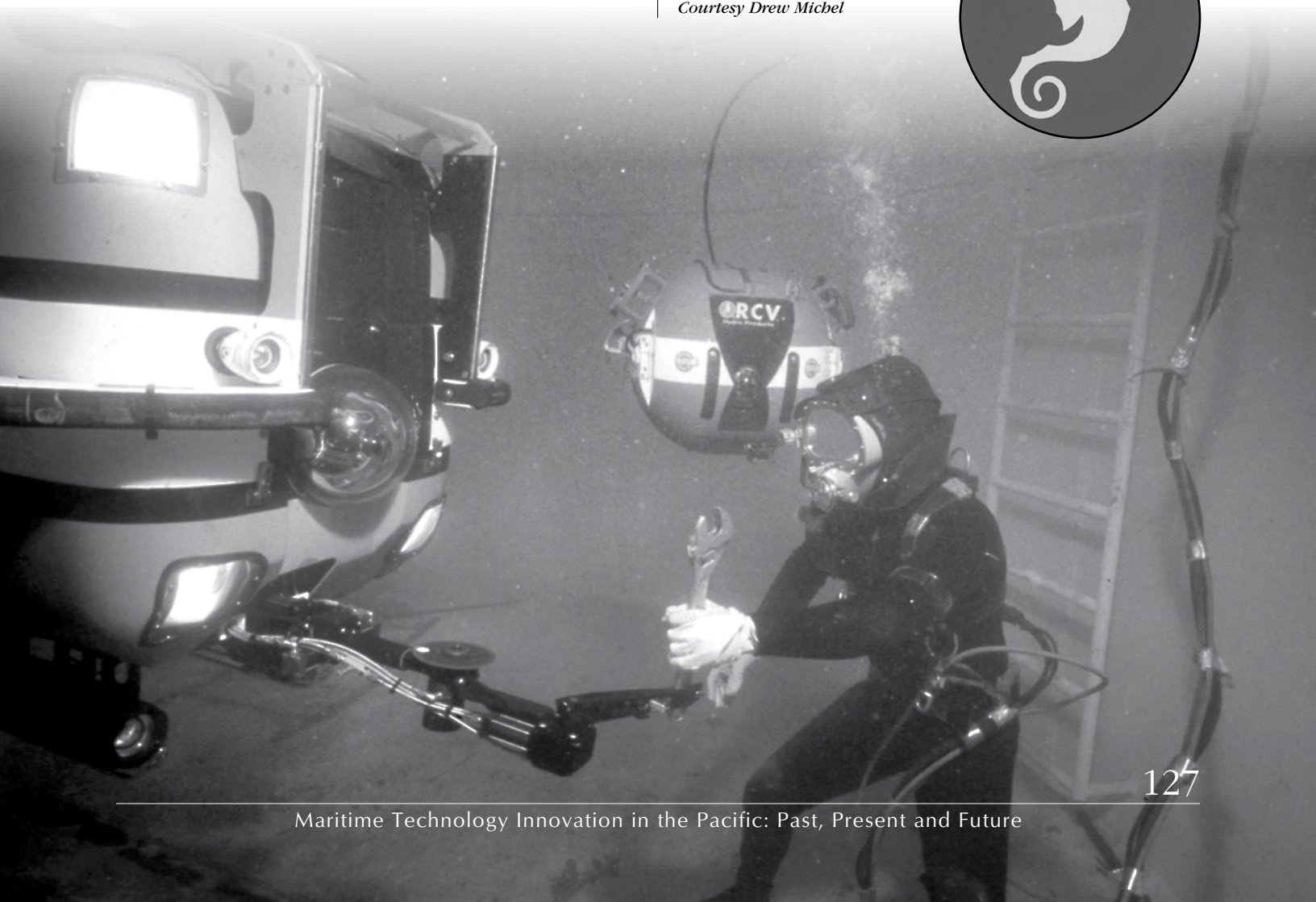
San Diego has been home to several of the world's foremost underwater photographers starting with Ron Church in the 1960's, to Chuck Nicklin who was an underwater cameraman on several Hollywood pictures including "The Deep," "The Abyss," and several James Bond movies; his son Flip Nicklin, a National Geographic photographer; Marty Snyderman and the current top cinemagraphic duo of Howard and Michelle Hall.

San Diego is also where underwater video cameras were first developed as a commercial product. The distinction for doing this goes to Oceanographic Engineering Corporation in 1959. After initially making pressure housings for Scripps scientists, OEC started making underwater television cameras. After some tumultuous early years, OEC expanded its product range to have a broader base of revenue. It introduced a wide variety of new products such as photographic cameras, current meters, wave recorders, wave samplers, sediment samplers, and devices to measure light transmission underwater. In recognition of having underwater instrumentation for almost all applications the company was renamed Hydro Products. Eventually Hydro Products grew into one of the largest marine tech companies the industry has ever seen.

One of the managers of Hydro Products, Joe Granville, became unhappy with how things were going and left in 1963 to start Sub Sea Systems in Escondido. Sub Sea found a new market for underwater TV cameras in the nascent offshore oil industry, as at that time Hydro Products was focused on the scientific and military markets.

Hydro Products went on to develop a great number of underwater products including a 35mm film camera. When Chuck Strickland, the engineering manager who became president of Hydro Products, decided to leave and form his own company, he was given the rights to their 35mm film camera. This was PhotoSea's first product, which was followed by a 70mm camera, stereo cameras, various lights and eventually video cameras. PhotoSea rose to become an industry leader. In 1991, Strickland decided to retire and sold PhotoSea to a Texas company called Hydro Vision International, who had also bought the Hydro Products camera line in 1984.

Hydro Products RCV 225 ROVs assist a diver.
Courtesy Drew Michel



In the 1980s, one of the biggest competitors for the American underwater camera manufacturers was a British company called Osprey. It had a large market in its backyard – the offshore oil contractors working in the North Sea. In 1984, Osprey opened a small office in Houston, Texas, to service some of the same customers. In the late 1980s, a dizzying binge of acquisitions occurred. Osprey purchased Sub Sea Systems of Escondido and moved the operation to San Marcos, at the same time closing their Houston facility. Osprey Ltd and its U.S. subsidiary was then purchased by the Norwegian company Simrad in 1993. What had then become Simrad Osprey acquired Hydro Vision, who had previously purchased PhotoSea and the Hydro Products camera lines, and integrated those operations into the San Marcos facility. Shortly thereafter Norwegian government majority-owned Kongsberg purchased all the Simrad operations and then, in 2001, closed down the San Marcos operation, laying off all but a couple of employees. This was the end of the line for some of the pioneering San Diego companies.



Brock Rosenthal holds a Hydro Products TC-125 camera and a DSPL Nano SeaCam.
Photo by Jake Rosenthal

Remote Ocean Systems, or ROS, was started by former Navy Lab engineers Bob Acks and Bruce Fugitt in 1978, with the intent of developing and manufacturing ROVs. Their first product, Telesub, was a 2000 ft. rated vehicle that had evolved from the ROVs designed by the entrepreneurial engineers when they were employed by the Navy. When sales for the vehicle were not forthcoming, they leased it for underwater surveys and inspections. ROS also did product development for SubSea Systems, who for a time owned a part interest in ROS. Eventually, they started offering the cameras, lights and pan & tilts they developed for Telesub to other ROV manufacturers. This developed into their main business and Telesub was sold off. ROS later branched out into sales of underwater inspection systems to nuclear power plants with significant sales in nuclear fuel pool lighting. In 1992, Fugitt left ROS to start his own company in Colorado. ROS has continued on with their product line of underwater video cameras, underwater lights, rugged pan and tilt units, and video inspection systems; manufactured primarily for the oceanographic, nuclear and defense industries.

DeepSea Power & Light (DSPL) was founded in 1983 by Scripps graduate student Mark Olsson, with Brock Rosenthal, Bill Hagey, and Ray Merewether. Their first product was a lead-acid battery that could be used at any depth. It was a commercialized version of a battery Olsson used for his deep ocean photography research at SIO. This was followed by small underwater lights that could go to great depths. The first use of their SeaLite was on Jason Junior, the small ROV Bob Ballard used to explore the *Titanic* in 1986. This was followed by making underwater versions of large studio-type lights called HMIs that were used to light up the famous wreck for nearly every film that followed its discovery.

Eventually DSPL got into the video camera business, making the first commercially available underwater cameras that used solid state imaging chips. Prior to this cameras used video tubes that were larger and more fragile. In the mid-1990s, DSPL diversified by making video cameras designed for inspecting inside sewer pipes. This business was eventually spun out to a separate company called SeekTech, which has now grown to be several times larger then DSPL. Another diversification for DSPL was to develop a line of lighting and cameras that are installed on the hulls of recreational boats. DSPL is managed by John Chew, whose pedigree harks back to PhotoSea and Hydro Products.

Hagey went on to found Pisces Design, in 1987, initially making devices to encode data on video. Today, Pisces makes animal-borne video cameras that are also data recorders. By correlating video images with sensor data, scientists use them to study the physiology and behavior of large marine animals, including seals, turtles, sharks and whales.

Insite Pacific was started by Tom Olkowski in 1994, to produce high-end underwater video cameras. Olkowski is an alumnus of Hydro Products, Sub Sea Systems, Photosea, and ROS. Insite's initial product was a low light camera that was the first to use software to control the settings. It has since gone on to make digital stills cameras and high definition video cameras.

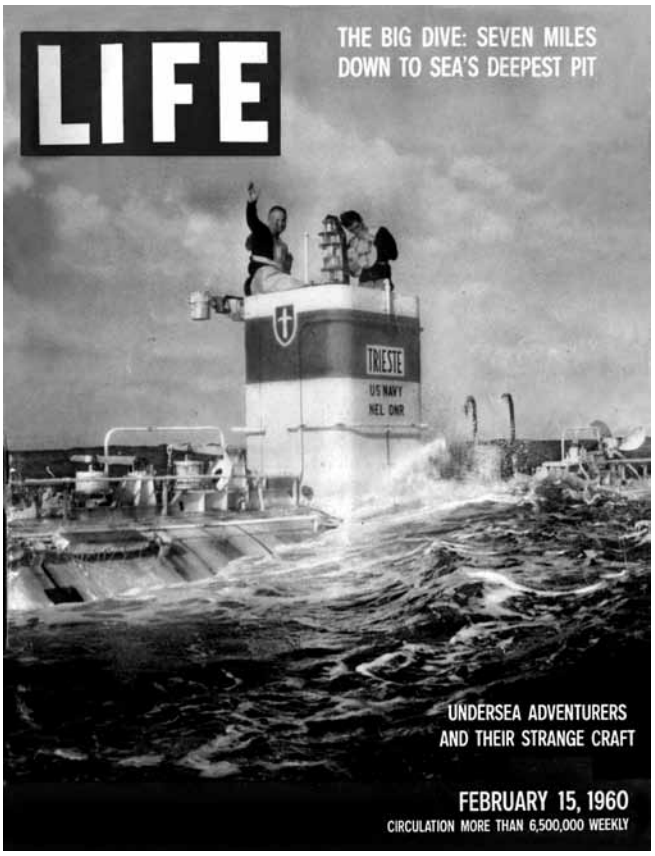
Sidus Solutions is another local San Diego underwater video camera manufacturer. It was started by Leonard Pool in 2000. His previous experience included stints at ROS and Nautronix, as well as owning a marine electronics store. In addition to cameras and lighting, Sidus also makes underwater positioning equipment and integrated systems that

combine all of their capabilities. In 2010, Sidus merged with Topside Offshore Technology, a Dutch company that makes crane load indicator systems, weighing systems, CCTV and control systems for on- and offshore applications.

Today, carrying on the tradition of underwater camera innovations in San Diego, is a company called Bellamare, started by Charles Cousin in 2006. In conjunction with the University of Miami, Bellamare has designed a plankton imaging system that is operated from a towed vehicle. Using this system scientists can study geo-referenced images of plankton in their natural environment, as opposed to looking at ones compressed into the end of a net that were captured while the net was being towed.

Manned Submersibles

In 1958, the Navy bought a deep diving machine called a bathyscaphe from its Swiss inventor August Piccard, and brought it to San Diego. Scripps graduate, Andreas Rechnitzer, was hired to be the program manager for a series of deep research dives that would culminate in a visit to the deepest spot in the world – the Mariana Trench. The exact location of the deepest dive was determined with the help of SIO oceanographers. On January 23, 1960, Jacques Piccard, son of the inventor, and Navy Lt. Don Walsh made a dive to the record depth of 35,800 feet. No one had attempted a return in fifty-two years, until filmmaker James Cameron ("Titanic", "Avatar," "The Abyss") recorded the deepest solo dive in *DeepSea Challenger*, on March 26, 2012.



(Above) Don Walsh and Jacques Piccard emerge from the bathyscaphe *Trieste*, after their record-setting dive in 1960.
Courtesy the Author's collection/LIFE Magazine

Other deep diving subs kept in San Diego by the Navy's Deep Submergence unit were the *Sea Cliff* and *Turtle*. The same group also operated the *Mystic* and *Avalon,* which were designed to rescue the crew of a stricken submarine if ever needed. Technical support for these specialized vessels was provided by a division of Lockheed based in San Diego.

In an interesting mix of academia, navy and commercialism, a group of Scripps trained geologists (H. W. Menard, Robert Dill, Dave Moore, Bob Dietz and Ed Hamilton), some of whom worked for the Navy Electronics Lab, formed a company in 1953 called Geological Diving Consultants, later called General Oceanographics, and then Nekton, Inc. This group mapped much of the geology to 150 feet off California, from the Mexican border to Oregon, and in several other parts of the world, by scuba diving. Later, under the Nekton banner, they built submersibles that they sold and also used for their consulting work.

NATIONAL GEOGRAPHIC Daily News

James Cameron Completes Record-Breaking Mariana Trench Dive

Solo sub dive is deepest ever.



The explorer-filmmaker emerges from his sub after returning from Challenger Deep.
Photograph by Mark Thiessen, National Geographic

See http://news.nationalgeographic.com

Dynamic Positioning

Dynamic Positioning, or DP, is a method used to maintain a ship in a fixed position relative to the seafloor. It was invented by one-time Scripps engineer, Willard Bascom, for a project (Project Mohole) conceived by Scripps scientists to drill a hole through the earth's crust to the mantle. It was determined the crust is much thinner in the oceans, so drilling methods had to be invented that could be done from a ship. Foremost among these methods was how to keep the ship parked directly above the hole it was drilling without drifting off too far. Bascom came up with the idea of putting a large outboard motor on each of the four corners of the drilling barge that could be manually controlled by a central joystick. Over the years, this has evolved to a GPS-guided, computer-controlled system that maintains a vessel's position using its own propellers and thrusters installed in the bow. Today's multi-billion dollar offshore oil & gas industry would not be possible without dynamic positioning.



Deploying a taut-line buoy for Project Mohole.
Courtesy National Academy of Science

At the forefront of making DP systems has been Nautronix, a company that was co-founded by Randy Jones, a former sales manager at Hydro Products, who bought some of the ship-keeping systems from Hydro Products' parent company, Honeywell Marine Systems. In 1993, the defense conglomerate L-3 acquired Nautronix. Today, the former manager of the Simrad Osprey office, Tony Gardiner, runs this business now known as L-3 Dynamic Positioning & Control Systems.

ROVs

ROVs are underwater robotic vehicles that are controlled from the surface via a cable. While the very first ROV was not built in San Diego, nearly all the ones that followed in the early years had ties to the area, starting with a series of vehicles the Navy built in the early 1960's (see "SSC Pacific," pages 46-59, this issue). Scripps also got in the act with its Remote Underwater Manipulator (RUM), which essentially was an underwater tractor with a large mechanical arm. San Diego is considered the birthplace of the ROV industry, as it was here that they were first commercialized. For a time San Diego was the hub of the ROV industry with two major manufacturers, numerous component and accessory suppliers in the area, an annual conference dedicated to the new technology and home base for a magazine devoted to the subject.

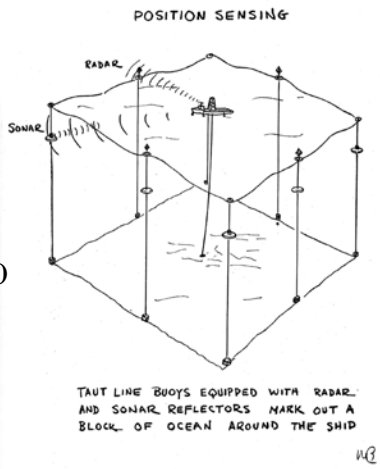
Hydro Products produced the first commercial ROVs. They were contracted by the Navy to build the ANTHRO (Anthropomorphic) ROV that was a test bed for many new concepts such as a head-coupled display to control the vehicle and using hydrophones to provide acoustic feedback for the operator (see pg 120). In the midst of this program an emergency requirement arose. The Navy was sending the manned sub *Trieste* II to examine the wreckage of the submarine *Scorpion* that had mysteriously sunk. They did not want the sub to become entangled in the wreckage so they tasked Hydro Products with developing a new ROV called El Tortuga. The crash program was only seventy-one days from start to delivery. By necessity the vehicle was simple and consisted of a video camera and lights encased in a barrel-shaped block of foam. For propulsion, El Tortuga used bird bath pumps rather then propellers. The vehicle flew out of a cage mounted to the *Trieste* and was connected by a cable covered in small blocks of foam to make it neutrally buoyant.

The Navy then funded Hydro to develop the Advanced Maneuverable Undersea Vehicle System. AMUVS, as it was called, was more advanced then its

predecessors. Commercial versions were sold under the name RCV-125 for Remote Controlled Vehicle. The first one was delivered to a Norwegian contractor to the offshore industry in 1975. With the benefit of operational experience, a series of improvements were made and a new model was released called the RCV-225. Hundreds of 225's were sold worldwide and a new industry was born. Hydro Products flourished and, by 1981, had grown to 550 employees.

Hydro Products went through a series of owners. First was the Hawaiian maritime construction firm, Dillingham. Then, in 1974, Tetra Tech bought Hydro Products from Dillingham. In 1982, Hydro Products' partner in the Navy's Mine Neutralization System (MNS) program, Honeywell, bought the company from Tetra Tech. Its interest was in military systems and soon after it divested all the commercial products. Production on the MNS vehicle continued on for over twenty-five years from the first contract in 1978.





Willard Bascom (upper right) leans against a motor from his Dynamic Positioning System.

(Right) Diagram by Bascom of his positioning system for Project Mohole.
Courtesy of the National Academy of Sciences

Hydro Products was an innovator and driving force in many underwater products. It pioneered markets for these products in the offshore oil & gas industry, the nuclear power industry, science, and defense. Former employees of Hydro Products went on to start and lead other companies. The impact of Hydro Products on the marine technology industry was significant.

In the 1970s, the Ametek division of Straza, in El Cajon, started manufacturing large, work-class ROVs. Their first vehicle, called Deep Drone, was delivered to the U.S. Navy in 1975, to support deep ocean salvage projects. This was followed by SCARAB, which stood for "submersible craft assisting recovery and burial". It was built for AT&T and was the first ROV built for underwater cable burial and repair. Next was the very successful line of vehicles called Scorpios. They were used in the offshore oil & gas market as well as by the military for rescue and salvage operations. The division was spun off in 1988 to become a publicly traded company, Ketema Inc., in an effort to distance itself from charges of price fixing in government contracts. Ketema later divested itself of it marine tech business. In 1990, Ametek pled guilty to charges of defense contracting fraud in connection with the 1986 bids for sonar systems used on two classes of Navy nuclear submarines.

After the demise of Hydro Products and Ametek, San Diego had no commercial ROVs being built in the area. In the early 1980s, a young and enterprising engineer named Andrew Bazley started a company called Hydroscan to make ROV manipulators that used seawater as a hydraulic fluid. The product was not a big success, but his assistant, Tyler Schilling, went on to start a company in Northern California that has become one of the largest ROV manufacturers. In Bazley's next venture, Bentex, he designed the highly successful Sprint ROV that was manufactured in Norway by Bennex. He applied what he had learned from this effort and started a company, in 1985, specializing in the manufacture of ROV thrusters. Tecnadyne has since branched out into producing other ROV components such as hydraulic valve packs, pressure compensators, actuators, pan & tilts, and controllers.



Commercial ROV manufacturing returned to San Diego in 2000, when Don Rodocker, and son Jesse, founded SeaBotix. The company builds mini ROV systems. These small, highly portable vehicles have made ROV technology accessible to a new group of users due to their low cost and ease of operation. SeaBotix has developed several unique ROVs including one that is intended to rescue people in the water and another for hull inspection that has wheels and a low pressure generator enabling it to stick to the hull as it crawls along it. In 2011, the company was sold to Bolt Technologies, which has kept the company in San Diego, operating as an independent business unit.

AUVs

Autonomous Underwater Vehicles, or AUVs, are robotic submarines that are not cabled to the surface. They rely on pre-programmed routes, onboard navigation systems, and logic circuits to react to information detected by its sensors. In the last few years, AUVs have come into their own and have become popular for military, hydrographic, and scientific missions.

The first company to commercially manufacture AUVs was Advanced Remote Technologies. ART was formed in 1984, in San Diego, by Ron Walrod, the former ROV engineering manager at Hydro Products. Initially the company worked on subsystems and

SeaBotix's highly capable vLBV300 MiniROV.
Courtesy SeaBotix

work packages for ROVs. In 1986, ART was awarded a contract from Martin Marietta to design and build an AUV called MUST on a one year fixed price contract. To mitigate risk they built an in-house test vehicle called the XP-21. MUST was delivered on time and within budget, and ART was able to use the XP-21 for years to develop new payload packages. An important offshoot of the MUST project was the development of an acoustic data link in a joint project with the Navy Lab on Pt Loma, which had its own AUV program. These were the first commercially available acoustic modems and they were integrated into several other AUVs.

ART also developed an underwater laser line scan imaging system that was capable of making long range images underwater. A competing laser line scan system was built in San Diego by Westinghouse Underwater Laser Systems. Both worked by sweeping a narrow beam of laser light onto the seafloor and assembling the reflected light line-by-line to create an image. This technique eliminated the glare from back-scattered light, allowing views of up to ten times farther underwater then with conventional cameras.

In 1989, ART was sold to General Dynamics, which in turn sold it to Raytheon in 1993. In 1995, after sales contracts did not materialize, Raytheon shut down the company and transferred its laser imaging technology to a division on the East Coast, where it is still considered to be state of the art for long range undersea imaging.

Sonars

In addition to building ROVs, Ametek Straza built a sophisticated type of sonar using continuous transmission frequency-modulated (CTFM) technology. Unlike typical sonars that send out a ping and listen for its reflected return signal, CTFM sonars sweep through a band of frequencies, and thereby providing better range and resolution.

SunWest Technologies was founded in 1990 by former Ametek engineer, Jim Christensen, to continue the manufacture of CTFM sonars after Ametek's demise. He was subsequently joined by another ex-Ameteker, Richard Hess, who is now president of SunWest.

Remote Sensing

Remote sensing is the acquisition of information about an object or phenomenon, without making physical contact with the object. In the marine context, the term generally refers to the use of aerial sensor technologies used to measure properties of water at, or near, the surface of the ocean. Two San Diego companies have been pioneers in this arena.

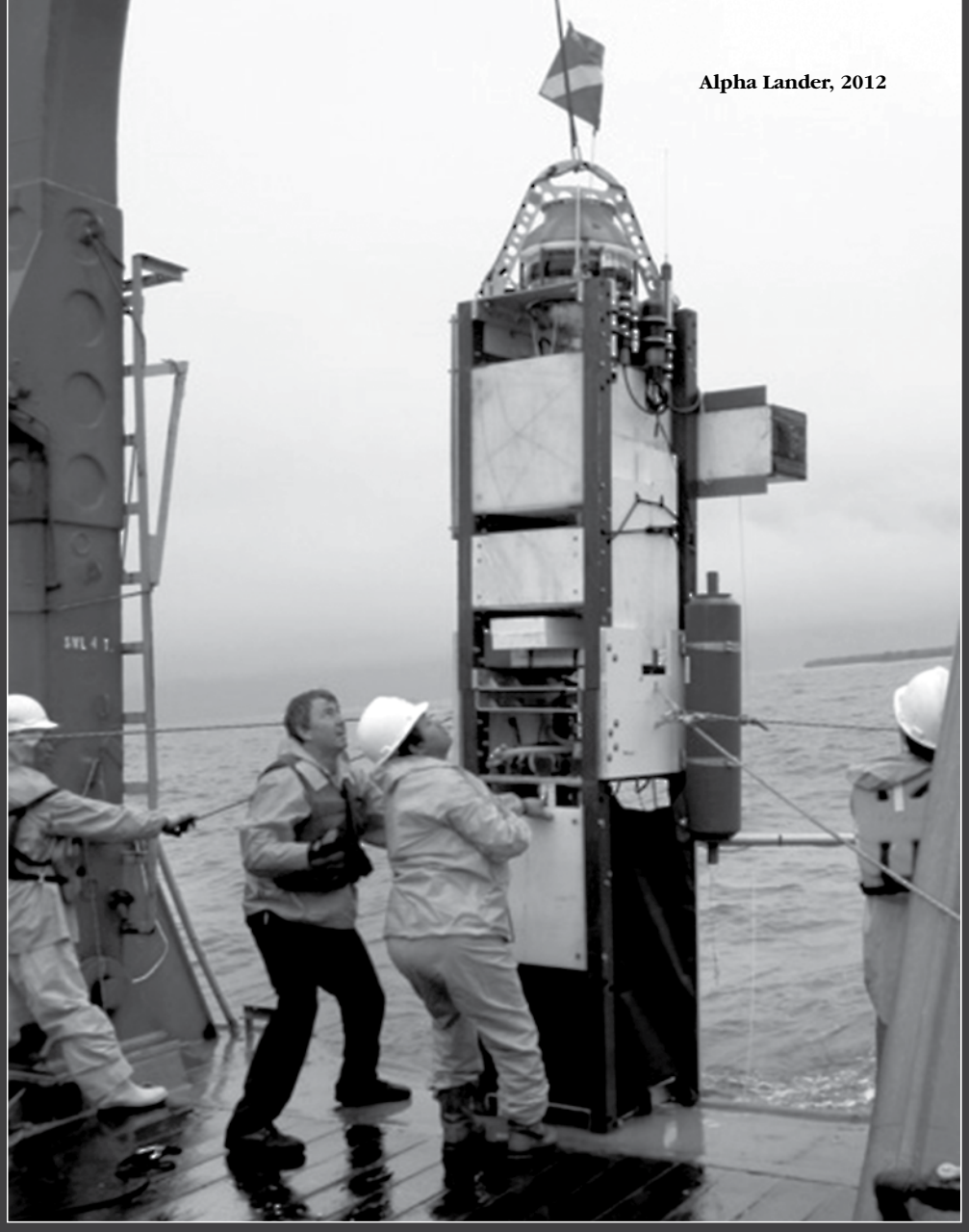
Ocean Imaging, started by Scripps graduate Jan Svejkovsky in 1984, specializes in satellite-derived ocean temperature analyses for fishing fleets and the derivation of ocean current and ice drift trajectories for the offshore oil industry. Its remote aerial imaging technology is also used for oceanic and coastal environmental studies. Most recently, it provided daily aerial oil thickness distribution and trajectory mapping for the entire Deepwater Horizon oil spill response community, during summer 2010.

Poway-based SeaSpace Corporation was founded by Scripps Institution of Oceanography scientist Robert Bernstein, who wanted to research changing water temperatures, but found that getting access to information collected by satellites was too expensive. He started SeaSpace to take information collected by government satellites and make it more readily available to users. Eventually, the internet made it far easier and cheaper to access satellite information, so the company shifted its business to the design and manufacture of satellite ground stations and processing software for remote sensing applications. In 2007, the company was acquired by Hyong Ossi, who previously was a sales rep for SeaSpace.

Optical Oceanography

Optical oceanography is the sub-discipline of oceanography concerned with the propagation and interaction of optical radiation. Ocean optic instruments are principally used to study photosynthesis and to calibrate remote sensing data.

One of the first companies to offer commercial products in this area is San Diego's Biospherical Instruments. Started by Charles ("Rocky") Booth in 1977, after he worked at Scripps, Biospherical makes a wide variety of ultra violet, visible, and IR region radiometers (single and multiple wavelength, and spectrographic) for use in oceanographic and atmospheric research. Its products are used for terrestrial and oceanographic global change studies, water quality assessment systems for municipal reservoirs, and other types of environmental monitoring.



Alpha Lander, 2012

For James Cameron's Deep Challenge Project, Scripps development engineer, Kevin Hardy, drew on decades of experience with free vehicles and seafloor landers, plus an extensive network of local and international contacts, to create the towering, multipurpose "Alpha Landers." The Alpha Landers function as both HD stereo video and still camera platform and ultimate remote science station. Scripps scientists and their academic colleagues will also obtain seawater, sediment cores and deep-sea animals to enable the detailed study of life forms adapted to the radically different environment of the deep sea. Similar research programs have discovered and isolated sources of novel natural products with important biomedical value.

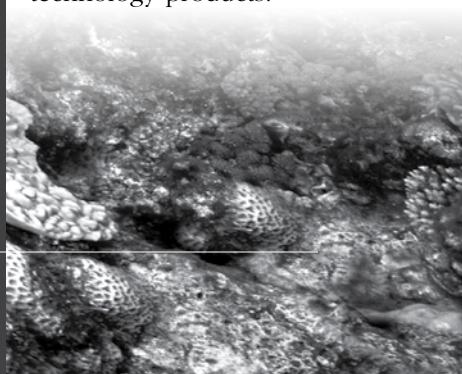
James Cameron's Alpha Landers are classified as "free vehicles," meaning they operate independent of surface support ships. They are known as "landers" because they descend from the sea surface to land upright on the seafloor at the bottom of the ocean trench. The surface ship then moves off, and, after the lander touches down, Cameron, inside his *Deepsea Challenger* submarine, is launched from the mother ship, the *Mermaid Sapphire*. Later, after Cameron's submarine is recovered, the Alpha Lander is recalled to the surface using a coded acoustic signal from the lander support ship.

San Diego companies that provided equipment on board Cameron's Alpha Landers include: **Ocean Innovations, Teledyne Impulse, Brantner SeaCon, Built Machine, Harrington Plastics, REI, Marshalls Industrial, and Southern California Plating.** Significant fabrication was done by the experienced crew of the Scripps machine shop.

Courtesy Kevin Hardy, Development Engineer, Scripps Institution of Oceanography

Conclusion

San Diego has a rich history in the field of maritime technology. Many key underwater technologies and devices have been invented or developed in San Diego, perhaps more than in any other region of the world. The genesis of these accomplishments can be traced to the influence that Scripps Institution of Oceanography and the Navy have had on the area. Scripps has developed many tools for their scientists to make new measurements. Along the way many of their staff have seeded local marine technology companies. The Navy Lab on Pt Loma has undertaken many technology development programs that ultimately led to commercial products and it has been a key customer to many of the region's maritime technology companies. Some of the pioneering marine technology companies in San Diego are gone, but many of those involved have moved on to other companies throughout the industry. Their legacy is the large number of companies in the San Diego region today making marine technology products.



Acknowledgements

The author wishes to thank the many people who shared their recollections with him including: Bob Acks, Jim Allen, Andrew Bazley, John Chew, Brian Falk, Bruce Fugit, Tony Gardiner, Michael Head, John Hedrick, Jim Helle, Joe Hughes, Jack Jaeger, Gerald Kahl, Dick Long, Bruce Marshall, Hayden Moore, Chuck Nicklin, Tom Olkowski, Steve Pearlman, Glenn Pollock, Leonard Pool, Don Rodocker, Sheldon Rubin, Ron Walrod, and Bob Wernli.

Thanks also to Peter Brueggeman, Archivist/Librarian, Scripps Institution of Oceanography Archives, UC San Diego Library: **http://libraries.ucsd.edu/locations/sio/scripps-archives/index.html**

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SAN DIEGO MARITIME TECHNOLOGY

equipment
feeding & servicing
harvesting
monitoring
processing
site development

building & repair
design & prototyping
outfitting

command & control
environmental
logistics & efficiency
mapping, tracking & visualization
maritime domain awareness
safety & security

diving equipment
electronics & navigation
marinas
safety & security

cameras & housings
coastal zone management
data fusion
education & research
engineering & technology
ocean modeling & forecasting
oceanography & marine science

AUV
ROV
USV
peripherals
software
submarines

commercial port expansion
floating infrastructure
offshore energy
seasteading

THE MARITIME ALLIANCE

"Promoting Blue Tech & Blue Jobs"

CLUSTER

1 AQUACULTURE & FISHING

2 BIOMEDICINE

3 BOAT & SHIPBUILDING

4 CABLES & CONNECTORS

5 DEFENSE & SECURITY

6 DESALINATION & WATER TREATMENT

7 MARINE RECREATION

8 OCEAN ENERGY & MINERALS

9 OCEAN OBSERVATION & SCIENCE

10 PORTS & MARINE TRANSPORTATION

11 ROBOTICS & SUBMARINES

12 TELECOMMUNICATIONS

13 VERY LARGE FLOATING PLATFORMS

14 WEATHER & CLIMATE SCIENCE

development
exploration
production

cables & umbilicals
connectors
parts & supplies

ballast water treatment
chemicals
land-based treatment plants
membrane-based deionization
ship and offshore
platform-based

exploration
minerals extraction
oil & gas extraction
production & processing
renewables
surveying
transportation
underwater intervention

cargo control & security
environmental
logistics & efficiency
naval architecture
navigation
performance enhancement
& evaluation
safety & security
vessel monitoring

in-ship
underwater
wireless & satellite

coastal zone management
disaster preparation & mitigation
environmental monitoring
forecasting & monitoring
infrastructure adaptation & risk management
oceanic & atmospheric research

Promoting the Blue Economy: The Role of Maritime Technology Clusters

By Michael B. Jones

The Maritime Alliance is pleased to have collaborated with the Maritime Museum of San Diego – one of the foremost maritime museums in the world – in developing an unprecedented maritime technology publication. This seminal issue of *Mains'l Haul* on, *Maritime Technology Innovation in the Pacific: Past, Present & Future*, is designed to put forth the case for the importance of maritime technology development for the U.S. and for mankind.

The Pacific is by far the largest of the oceans;[1] it represents 30.5% of the earth's total surface area, which is more than twice the size of the Atlantic – the second largest ocean at 15.1% – and, as a result, has provided more challenges and opportunities to mankind throughout history. Its vastness, depth, and number of islands have stimulated technological development to facilitate exploration, and four of the five top-ranked U.S. institutions for oceanographic research, between 2005 and 2009, are located on the Pacific.[2]

We are honored to be in the company of representatives of some of the leading ocean science and research institutions in the world, pioneers in the field, developing innovative technologies and techniques. In the first article in this issue (see pages 6 - 17) Dr. Robert Knox, of Scripps Institution of Oceanography, notes: "…for the most part the ocean research community…has been less an originator of radically new technology with widespread application…and more an ingenious adopter, adapter, improver and applier of more or less existing technologies drawn from numerous sources." Nonetheless, "demand creates supply" and the scientific community's demand for technology, whether developed internally or resourced from another institution, or the government, or the private sector, has led directly and indirectly to significant maritime technology development. As a corollary, the availability of government and military research funding is important to ensure future maritime research and technology development.

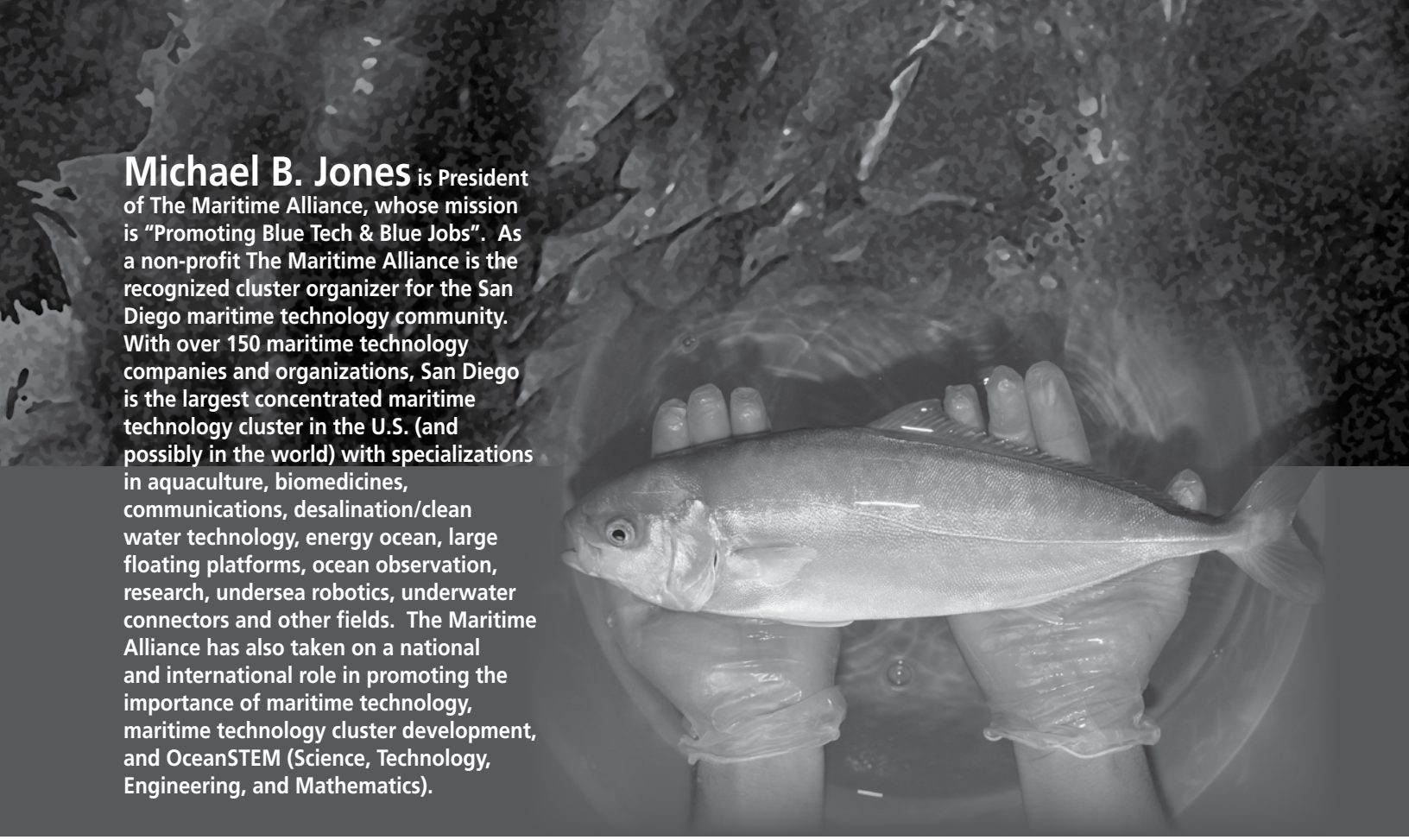
Introduction

Water covers 72% of the earth's surface (oceans occupy 65.7%),[3] so in reality we live on "Planet Ocean". With the combination of burgeoning world population, a growing middle class around the world, as much as 80% of the world population living near the coast,[4] and rising ocean levels;[5] arguably, the only way to provide enough food, water and "coastal" real estate (and some would add medicines and renewable power) is to develop sustainable usage of the oceans. It is an essential part of our Past, critically important (if not yet widely recognized) in the Present, and both a frontier and economic and social imperative for the Future.

On June 9, 2009, the U.S. Senate Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard held a one day hearing called: "The Blue Economy: The Role of the Oceans in our Nation's Economic Future."[6] The Opening Statement from the Honorable Maria Cantwell, U.S. Senator, from the State of Washington, set the stage:

> "Today, we are trying to shine a spotlight on the Blue Economy…The Blue Economy, the jobs and economic opportunities that emerge from our oceans, Great Lakes, and coastal resources, is one of the main tools to rebuilding the U.S. economy. We also rely on our oceans for trade in goods vital to our economy…. There is great untapped wealth in our oceans, and that will lead to new jobs and new business opportunities…Our Blue Economy has been the foundation of our economy for centuries in the past, and it holds tremendous potential to growing economic opportunities for future generations."
>
> —The Honorable Maria Cantwell

The Mission of The Maritime Alliance is: "Promoting Blue Tech & Blue Jobs". The intent of this article is to put forth the case for the importance of maritime technology development and to argue that the Blue Economy and Blue Jobs are critical for the future of the U.S. and for society as a whole.



Michael B. Jones is President of The Maritime Alliance, whose mission is "Promoting Blue Tech & Blue Jobs". As a non-profit The Maritime Alliance is the recognized cluster organizer for the San Diego maritime technology community. With over 150 maritime technology companies and organizations, San Diego is the largest concentrated maritime technology cluster in the U.S. (and possibly in the world) with specializations in aquaculture, biomedicines, communications, desalination/clean water technology, energy ocean, large floating platforms, ocean observation, research, undersea robotics, underwater connectors and other fields. The Maritime Alliance has also taken on a national and international role in promoting the importance of maritime technology, maritime technology cluster development, and OceanSTEM (Science, Technology, Engineering, and Mathematics).

Courtesy Hubbs-SeaWorld Research Institute

What is Maritime Technology?

Inside the "Blue Economy" label, it is hard to draw a "bright line" between "the maritime industry" and "the maritime technology industry" (also referred to as "the marine technology" or "ocean technology" industry). Depending on the industry segment being analyzed, it often falls into the proverbial "I'll know it when I see it" category. However, it is important to try to provide delineation, even if it is unlikely to be completely satisfactory. For The Maritime Alliance, the maritime technology industry is that portion of the larger maritime industry that is expanding maritime technology and knowledge boundaries and that the "casual" observer would likely think is technology oriented. Examples are: desalination & clean water technologies (the sector has existed for decades, but constant innovation is steadily increasing efficiency), ocean observation (the domain of scientists and many innovative companies), and maritime robotics (an enormously important developing field with many government, military, and private sector applications and implications). Other industry sectors are mixed between the traditional and the developing: fishing and aquaculture are one such combination, new techniques and technologies in the large, traditional boat and shipbuilding industries are another. Some industry segments are "future music" but seem inevitable, for example, biomedicines from the oceans, and large floating platforms (i.e. floating infrastructure) are two of those.

How Big is the Maritime Technology Industry and How Fast is it Growing?

Other than to say they are enormous and growing, no one knows how big the U.S. maritime industry and maritime technology markets are today (unfortunately, North American Industrial Classification System [NAICS] codes do not fully identify ocean-related activities), but each of the 14 sectors that The Maritime Alliance has identified in the San Diego Maritime Technology cluster already represent large worldwide markets, or are expected to be such in the future (see the cluster chart on pages 136-137).

A number of other countries have recognized the opportunity in maritime technology and are analyzing and promoting it at a national level. To illustrate the growth opportunity, reports from Canada and the UK describe strong growth in their respective maritime technology industries: 18% per annum between 2004-2009 for the well-organized maritime technology cluster in St. John's, Newfoundland, and 12-month revenue growth of 76% for the UK Marine Science and Technology (MST) industry, based on an April 2011 survey.[7]



The first graphic representation that man was developing a maritime technology appears in tomb paintings in ancient Egypt, dating from 1800 B.C. The bas-relief carvings of Deir al-Bahri were ordered by Queen Hatshepsut to commemorate a voyage to the land of Punt in approximately 1500 B.C. One of these carvings shows a man using a long slender pole as a sounding pole (for measuring depth), from the bow of a vessel under oar and sail.
From Captain Albert E. Theberge, NOAA Corps (Ret.), "Sounding Pole to Sea Beam," Technical Papers 1989, ASPRS/ACSM Annual Convention, Surveying and Cartography Volume 5, 1989, 334-346.

Maritime Technology Development: Past, Present & Future

The Past

The Historical Context of Maritime Technology Development

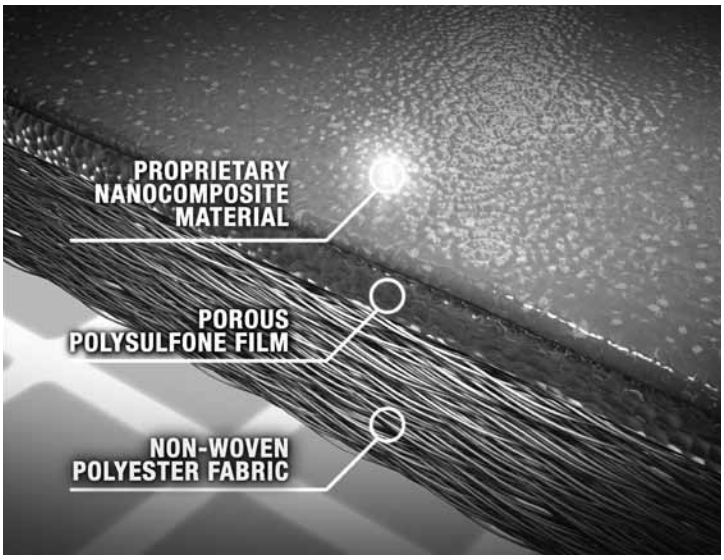
The ocean has provided critical resources and has been a principal method of transportation for all recorded history. An uncountable number of technologies have been developed to permit safe usage of the ocean, or to create an advantage for one navy over another. A national focus on the ocean and a maritime technological "lead" over other countries, including specific, significant maritime technological advances like the development of detailed charts & maps,[8] mass production techniques in Venice,[9] the creation of the first marine timekeeper (essential for navigation),[10] and creation of sonar by the British (and allies) in the early twentieth century, have provided advantages to one nation or empire over another since the days of the Phoenicians. Some technologies were likely created for non-maritime purposes, but became indispensible in the maritime domain, for example, the magnetic compass[11] and the radio. Mastery of state-of-the-art technology led to mastery of the seas and, in the case of Athens, arguably, to the creation of history's first great democracy for 158 years, from 480 to 322 BC.[12]

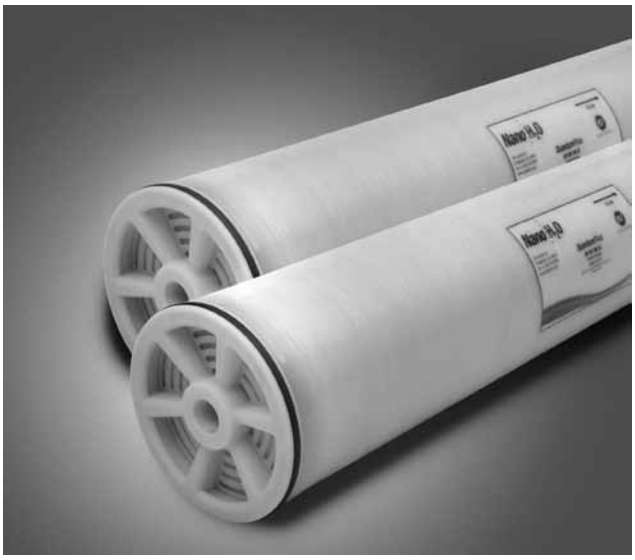
The Present

As indicated earlier, as much as 80% of the global population is estimated to live close to the coast, which means that most current and future infrastructure and economic activity is concentrated there as well. June 2009 testimony by Dr. Judy Kildow emphasizes this is as true for the U.S. as it is for other countries: "The ocean and coastal and ocean economies…really are the U.S. economy."[13]

An understanding of the importance of the **Blue Economy** and the potential for **Blue Tech** and **Blue Jobs** for the U.S. economy is vital. Unfortunately, as stated previously, there is no complete economic baseline information nor has there ever been a national census of maritime technology companies. The Maritime Alliance estimates that there are over 4,000 maritime technology companies nationwide.[14] While most of those are located on or near the East, West, Gulf, and Great Lakes coasts, some are located well inland. Where information has been captured and analyzed, recent historical Blue Job growth appears to be very significant.[15]

Anecdotal discussion and research by The Maritime Alliance and local organizations confirm this in the San Diego region. A first study, "the Maritime Economic Impact & Cluster Analysis,"[16] published in early 2009, reported that the maritime industry in San Diego county had 28,000 employees (excluding military and other government employees) and revenue exceeding seven billion. Of that, "High Technology" had 6,000 jobs, and in excess of two billion in revenues was called a "fast-growing sector with…the greatest opportunities for sustainable growth in employment and economic impact."





Above: Nanocomposite chemistry increases membrane permeability and salt rejection, an important advance in Desal. Above Right: Industry-standard 8-inch elements for easy retrofits. *Courtesy* Nano H_2O

Based on the experience of The Maritime Alliance, some general observations on the U.S. maritime technology community can be drawn:

- The industry is made up primarily of small to medium sized, independent companies.
- There are many industry segments.
- Maritime technology represents the "ultimate export industry". There are potential customers and markets in every country with coast and bodies of water.
- Depending on the market segment and company, export sales may vary from 30-95% of total sales.
- Virtually every company needs local partners worldwide to sell, install, and service.
- Most companies create multi-use, specialized technologies that allow them to compete internationally.
- With clients worldwide, local maritime technology companies are largely invisible around the world because they typically don't belong to local business associations.
- There are few elected supporters at the local and state level, because the industry is both invisible ("out of sight, out of mind"), and there are few relevant issues to stimulate contributions and political engagement.
- To date, technology sub-sectors have shown little self-identification with the Blue Economy and the broader Maritime Technology community nor do they understand the value in doing so, which is likely to continue until the maritime technology industry matures, formal clusters develop, and there is national recognition of the importance of Blue Tech and Blue Jobs.

The Future

This section will focus on five areas critical for the future of society: **Water, Food, Coastal Real Estate, Medicine,** and **Energy**. Although it is impossible to quantify "how big is very big", all of them represent enormous Blue Tech/Blue Jobs opportunities. These are addressed by five of the sectors in the San Diego maritime cluster (San Diego and California detail is used to the extent it is available to provide context):

Water

Desalination & Clean Water Technology[17]

> *If we could ever competitively, at a cheap rate, get freshwater from saltwater, that would be in the long-range interest of humanity [and] would dwarf any other scientific accomplishments.*
>
> —President John F. Kennedy, April 12, 1961

Premise: Desalination represents an important, drought-proof supply of clean, potable water.

- 96.5% of the world's water is in the oceans, 1% is saline ground & lake water, and 2.5% is freshwater, of which 68.6% is in glaciers & ice caps leaving only 0.75% as ground, surface and other freshwater sources.[18]
- It is believed that one sixth of the world's population does not have access to clean drinking water.
- San Diego imports 90% of its water from Northern California and the Colorado River via aqueducts. The water sources are subject to changing environmental regulations, drought, international treaties, ownership disputes, and use conflicts and combined with population growth, increasing water shortages are expected.
- Water conservation efforts are important and being implemented, but enhanced supply is crucial.



Pictured are cultured California yellowtail which are important to the sushi market and are sold as Hamachi. Within the next 20 years, the growing world population is expected to require an additional 60 million metric tons of seafood, which can only be provided by aquaculture.
Courtesy Hubbs-SeaWorld Research Institute

- Ten seawater desalination projects are proposed in the State of California through 2025, at a total investment of approximately $4 billion to provide 256.5 million gallons per day (at an average assumed consumption of 150 gallons daily per person, that would supply 1.7 million people, or 4.6% of the state's population).
- The cost of desalination has been reduced by over 45% in the past decade. Public/Private partnerships have performed full-sized demonstrations and confirmed the cost/performance of desalination technology.
- Over 14,000 desal plants exist around the world, as communities such as Perth, Singapore, Tianjin, Trinidad, and other cities, large and small, supplement dwindling water supplies with reliable, cost effective desalination.

Opportunity:

- San Diego is the world leader in desalination technology. The reverse osmosis spiral module was patented in San Diego in 1964, by General Atomics. An estimated 3,000 professionals and workers are employed by companies in the region, which includes two of the three world market share leaders in membrane supply.
- Desalination technology is a growth industry with high export percentage. The industry was estimated to be $10 to $12.5 billion revenue in 2010 and projected to expand to $30 billion by 2016 and $52.4 billion by 2020.[19]
- California has a long coastline that offers many suitable locations for desalination.
- Modern plants are constructed in low profile buildings, with intake and outfall structures designed to minimize environmental impact. Plants can also be built on ships and platforms offshore.
- Desalination in Southern California could help reduce strain on the aqueduct system allowing populations inland, and in Arizona, Nevada, and Mexico, to utilize more Colorado River water. Inland and neighboring state utilities could help pay for such plants in a "Win-Win" cost and water sharing scenario.

Food

Aquaculture & Fishing[20]

Premise: Aquaculture is important to feed the growing world population and growing middle class.[21]

- Currently, half of the world's seafood comes from fisheries (60 million metric tons) and half from aquaculture (60 million metric tons).
- 70% of the aquaculture seafood comes from Asia using methods that may not meet U.S. standards.
- U.S. is the world's third largest consumer of seafood, but imports more than 80% of its supply.
- U.S. imported $14.6 billion of fish & shellfish in 2010 (up $1.6 billion from 2009. The first nine months of 2011 were up $1.6 billion from the first nine months of 2010). Exports in 2010 were $4.6 billion (up $486 million from 2009).[22]
- Within the next 20 years, the growing world population is expected to require an additional 60 million metric tons, which can only be provided by aquaculture.

- Within 25 years, the U.S. is expected to need 1.5 million more metric tons of seafood annually to meet demand. (Will developing countries export when they need protein for their own growing middle classes?)
- Southern California (Pt. Conception to Mexico) has over 250 miles of coastline (excluding bays and islands), and over 19,000 square miles of open-ocean water; commercial fisherpersons in 2010 landed over 150,000 metric tons of all marine species (finfish, shellfish, squid, etc.) with an ex-vessel value of $97 million.
- Current aquaculture revenue in California (trout, abalone, sturgeon, etc.) is approximately $100 million annually.

Opportunity:

- Ideal fish species for California include California Halibut, Striped Bass, White Seabass, and California Yellowtail.
- Using currently available open-ocean cage technology, San Diego could farm 150,000 metric tons using less than one square mile of surface area.
- The ex-vessel value of White Seabass from that one sq. mile alone (at $6 per kilo) would be $900 million annually (worth $3.6 billion on the table) and would support 6,000 California seafood industry jobs (rule-of-thumb: 40 upstream/downstream jobs per 1,000 metric tons of annual fish production).
- Multiple additional opportunities: As an example, the U.S. imports 50,000 metric tons of yellowtail for hamachi (sushi) annually (primarily from Australia and Japan). At $12 per kilo, this equals $600 million annually.





Above: The availability of wild-caught fish, like the white seabass on deck, depend on seasonal abundance, management restrictions and day-to-day market constraints.

Left: An experimental white seabass pen system off Catalina Island, CA.

Bottom: Large cages located in the open ocean can produce thousands of tons of seafood making it available as the market demands without measurable impacts.

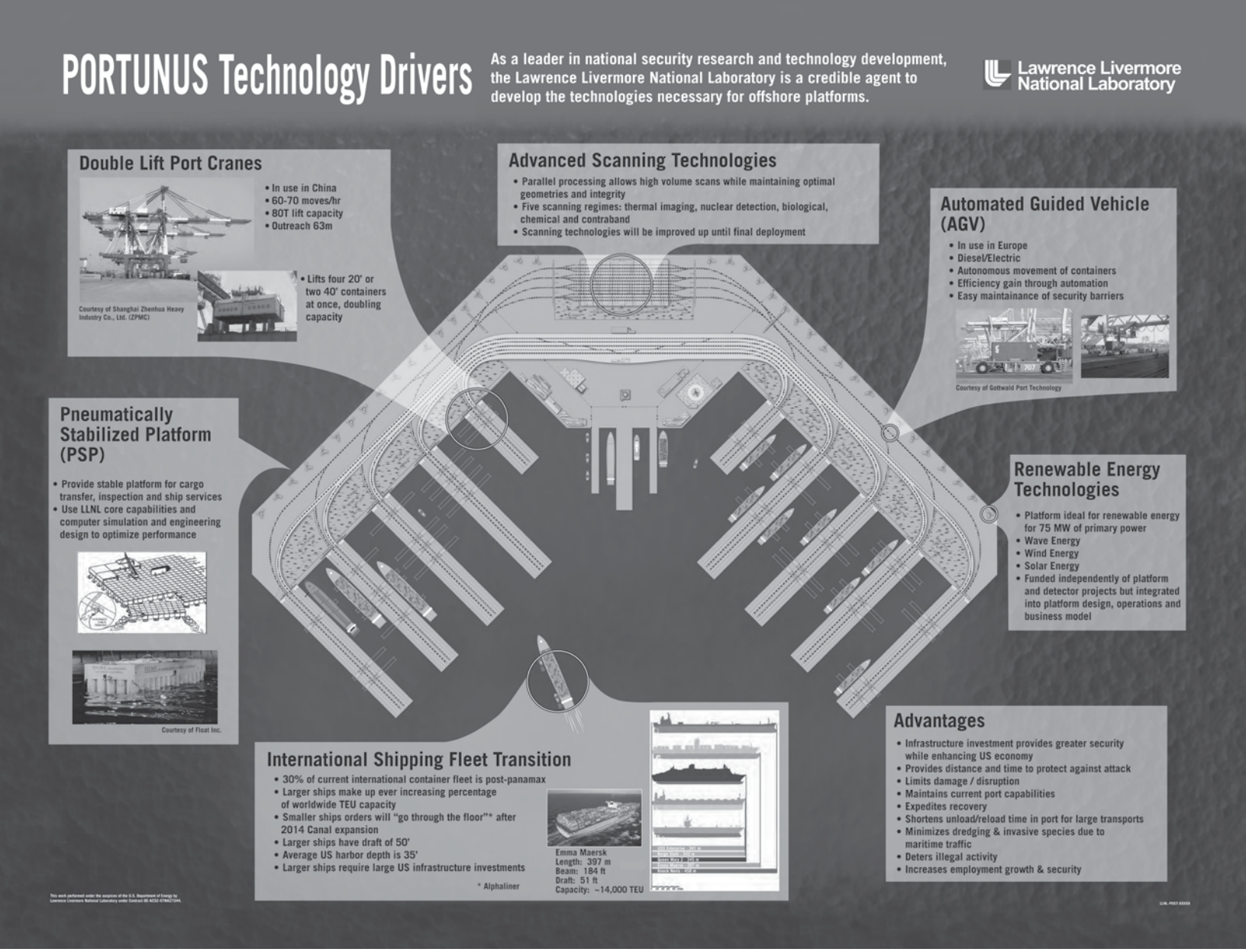
Courtesy Hubbs-SeaWorld Research Institute

Sustainable Aquaculture Requires a Juvenile Supply of Fish:

- Traditional practice was to capture juveniles and feed them in captivity (not sustainable or expandable).
- A 20 million annual fish hatchery costs $10 to $15 million and, depending on species, pays for itself in one to two years.
- San Diego has a White Seabass hatchery that can be expanded, as needed.

The U.S. is a leader in the technology development, but not in the implementation. It is an expensive and time consuming local, state, and federal approval process that can take years.





Pioneering design work is being done on floating harbors off the U.S. coast.

Courtesy Lawrence Livermore National Laboratory

Coastal Real Estate

Floating Infrastructure

Premise: Floating infrastructure can help address future coastal and ocean infrastructure needs.

The idea of floating infrastructure is not new.[23] Successful implementation goes back hundreds of years, but has become more common in the twentieth century, particularly for oil rigs. The reason they will become vital going forward is that it will be increasingly difficult to find suitable locations on the coast, in increasingly dense population centers, to build infrastructure. "Developable real estate" will be necessary for government facilities such as airports and ports, and to accommodate commercial industries such as aquaculture and food processing, boat and shipbuilding, desalination and energy plants, hospitality, and tourism. Added to that is the uncertainty of knowing how much oceans will rise and when. Investing billions of dollars in land-based infrastructure along the coast will seem increasingly risky. And an important, impossible-to-answer question will be "how far inland" to move existing facilities, assuming the money and desire exist to do so.

Lawrence Livermore National Laboratory has done pioneering work related to floating harbors. An article on its Portunus Project[24] study indicated: "In another decade or two, ports in the U.S. may never be the same…tomorrow's ports may be strategically sited in a new location – in the ocean 20 to 40 miles away from the shore." Floating harbors could be large, perhaps 400 acres in size, and built with reinforced, pre-stressed concrete with a density less than water. Such ports could cost $8 to $10 billion and have multiple advantages, including port and homeland security-related (terrorists attacks via containers and/or ships would be contained offshore), provide flexible and composable real estate (something typically in short supply along coasts and in land-based ports), provide multi-use functionality (e.g. airport, desalination, functional port and wave-action related energy creation plants together), avoid future vulnerability of ocean rise, and could likely be funded by the private sector. Offshore ports potentially link the most efficient way to move goods internationally (ultra large container ships) with the most efficient way to move goods domestically (short sea shipping).

Medicine

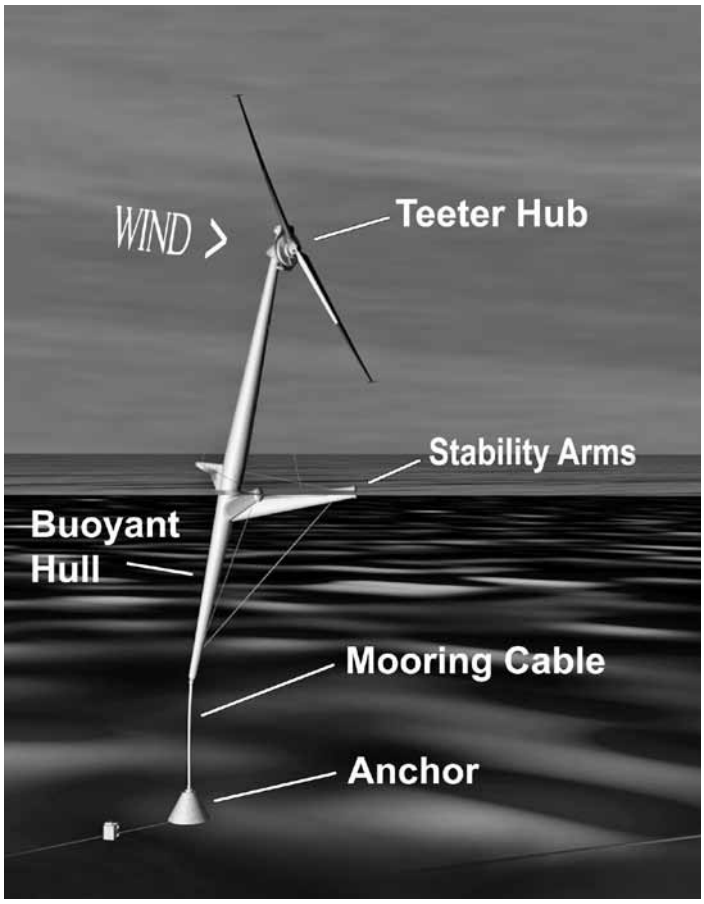
Biomedicines from the Sea

Premise: Ocean organisms represent the next great source for medicine.

The medical community is in an "arms race" against infections, with new strains of bacterial infection appearing annually, many increasingly resistant to antibiotics. This puts an enormous financial strain on the country, starting with government reimbursement programs, hospitals and the insurance industry, in addition to the emotional and financial strain and trauma for patients.

A great opportunity exists to develop medicines from the seas. The 2009 testimony of Dr. William Fenical, of Scripps Institution of Oceanography, highlighted the opportunity:

> *As we enter the decades to come, it is crucial that the U.S. lead in marine biological research providing for the creation of new industries based upon discoveries made from the ocean…. While this is the largest ecosystem of planet Earth, we have only now realized that it is the most important of our biological resources…it is easily predicted that the oceans are our most prolific source for new chemical compounds…. But why has it taken so long to accept this reality? As terrestrial beings, humans have classically been unable to comprehend the scope of marine environments…. Despite the enormous benefits, the U.S. pharmaceutical industry has been slow to embrace marine drug discovery…. This is an amazingly unique community that is distinct from its terrestrial counterparts….When one considers the medical emergency we face with drug-resistant infectious diseases, and the fact that microorganisms are the best source of antibiotics, it is clear that marine bacteria and fungi represent the next great source for the discovery of new antibiotics to control human infectious diseases.*[25]
>
> —Dr. William Fenical, SIO



These illustrations show a radical new deep water, wind-energy design that could reduce operating costs dramatically.
Courtesy Nautica Windpower

Energy

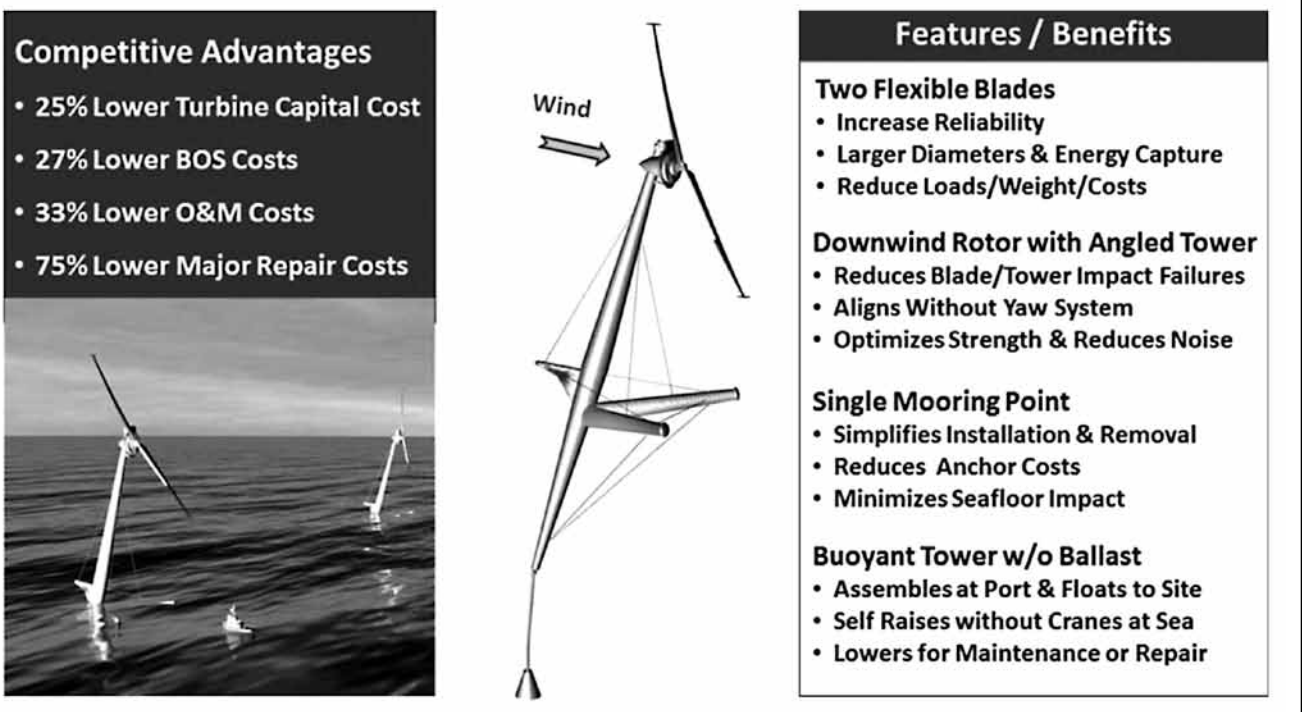
Ocean Energy & Minerals

Premise: There is enormous energy (and mineral) potential in the ocean that can be developed.

There is no way to know how much renewable energy can be developed working with the ocean, but it is clearly enormous, with a low to negligible carbon footprint. A number of countries are experimenting with energy ocean renewable projects related to current, tidal, and wave power. "Pressure retarded osmosis" (PRO), also called forward osmosis, is a new concept in renewable power generation.

Offshore wind energy is easy to understand. It is considered the most abundant renewable source, the most commercially ready, close at hand, and the area that has been studied the most. The 2009 comments of Dr. Willett Kempton, Associate Professor of University of Delaware, highlight the potential in wind energy:

Unfortunately, careful resource assessments have not been done for any ocean energy sources other than oil & gas…let us compare the U.S. energy use and electricity, 419 gigawatts.… The offshore wind resource…is 450 gigawatts. That is, it is greater than the entire electric use of the country. That is by a DOE estimate, which, I believe, is low.[26]



What is the role of Maritime Technology Clusters?

The U.S. Small Business Administration has defined a cluster as "Geographic concentrations of interconnected firms and supporting organizations that draw productive advantage from mutual proximity and connection." Around the U.S. and around the world, there are maritime technology communities that are, or could become, "formal" organized clusters focusing on one or more of the maritime technology sectors that have developed in their respective regions.

The Maritime Alliance is the recognized maritime technology cluster organizer for the San Diego region, which includes individuals and entities representing government, military, non-profits, private sector, public-private partnerships, research organizations, universities, and other interested parties. Its tag-line and mission is **"Promoting Blue Tech & Blue Jobs"**. The Maritime Alliance is promoting the Blue Tech cluster identity across all sectors active in the greater San Diego region, which it sees as including partner organizations in nearby Ensenada, Baja California, a leading maritime technology center in Mexico. In addition to working with multiple local partner organizations to strengthen the business eco-system in the region, it actively promotes relationships with organizations around the U.S. and abroad, including Australia, Canada, Finland, France, Mexico, New Zealand, and the UK. The Maritime Alliance has taken on a national role in helping promote the importance of maritime technology, maritime technology cluster development, and OceanSTEM (Science, Technology, Engineering, and Mathematics). It has worked with a growing number of Federal organizations, including Ex-Im Bank, NOAA, the U.S. Commercial Service (part of the U.S. Department of Commerce), the U.S. Trade and Development Agency, and the U.S. Navy.

The ocean does not end at the territorial waters, or the 200 mile Exclusive Economic Zone (EEZ)[27] of a country. It continues around the world touching 151 countries, over three quarters of the countries in the world. Sustainable development of the oceans is a common responsibility and will require enlightened leadership and international collaboration. Collaboration among Maritime Technology Clusters around the U.S. and the world is an essential step in achieving such sustainable development.

THE MARITIME ALLIANCE

"Promoting Blue Tech & Blue Jobs"

Concluding Remarks

This article contends that understanding and promoting the Blue Economy is critical for the future of the U.S. and the world. Researchers and scientists at universities and research institutes around the U.S. and the world are on the leading edge by helping create Blue Tech. And Blue Tech created in both public and private sectors is essential for the creation of high-paying, environmentally and economically sustainable Blue Jobs to meet the needs of a growing global population. Recognition and financial support to strengthen existing maritime technology clusters, and to create new ones where appropriate communities exist, will be important for the maritime technology industry to develop its full potential.



Notes

1 Michael Pidwirny (Lead Author); J. Emmett Duffy (Topic Editor) "Ocean," in *Encyclopedia of Earth*. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the *Encyclopedia of Earth,* April 7, 2010; Last revised date, December 20, 2010; Retrieved March 3, 2012, http://www.eoearth.org/article/Ocean. "The Pacific Ocean is the largest ocean region covering about 30.5% of the Earth's surface area (about 15 times the size of the United States). The ocean floor of the Pacific is quite uniform in depth having an average elevation of 4,300 meters (14,100 feet) below sea level. This fact makes it the deepest ocean on average. The Pacific Ocean is also home to the lowest elevation on our planet…About 25,000 islands can be found in the Pacific Ocean region. This is more than the number for the other four ocean regions combined. Many of these islands are actually the tops of volcanic mountains created by the release of molten rock from beneath the ocean floor….the surface area of the Pacific is about 1,000% greater than the land area that drains into it."

2 U.S. Institutions: Most Prolific in Oceanography, 2005-09, Thomson Reuters release reported in "Science Watch," Nov. 13, 2011. http://www.sciencewatch.com/dr/sci/11/nov13-11_1/. The top five U.S. institutions on the list of the most prolific institutions in oceanographic research between 2005 and 2009 (in alpha order) are Oregon State, Scripps Institution of Oceanography (UCSD), University of Hawaii, University of Washington and Woods Hole Oceanographic Institution.

3 Op. cit. "Ocean," 3 March 2012.

4 Accurate information is not available. Estimates vary from 39% within 100 km of the coast in 1995, to those that contend that by 2010 eighty percent of people were expected to live within sixty miles of the coast. A U.S. Navy poster states: "80% of people live near water." http://www.cnrc.navy.mil/Graphic-Elements/public-affairs/Navy%20Message.jpg. This trend to concentrate on the coasts is expected to continue. Wikipedia defines a "Megacity" as being a metropolitan area with a total population in excess of ten million people and thirteen of the world's top fifteen current Megacities are located directly on the ocean or – in the case of two of them – have a neighboring port city. It states: "If the trend continues, the world's urban population will double every thirty-eight years. The UN forecasts that today's urban population of 3.2 billion will rise to nearly 5 billion by 2030, when three out of five people will live in cities."

5 It is not relevant for this article to discuss how or why ocean levels are rising – scientific and historical evidence points to that fact. David Abulafia, *The Great Sea: A Human History of the Mediterranean*, (Oxford University Press, 2011). "In remote geological time it [the Mediterranean] was entirely closed, and between about 12 and 5 million years ago evaporation reach the point where the Mediterranean basis became a deep and empty desert; once breached by the Atlantic, it is thought to have been flooded with water in a couple of years."

p. xxvii. "Around 8,000 BC there was a very gradual warming….The sea gradually rose, by as much as 120 metres, as the ice caps melted." p. 6. Also, "Current Sea Level Rise", Wikipedia, 3 March 2012: "Sea level rise is expected to continue for centuries. In 2007, the Intergovernmental Panel on Climate Change (IPCC) projected that during the 21st century, sea level will rise another 18 to 59 cm (7.1 to 23 in)… Although IPCC explicitly refrained from projecting an upper limit of total sea level rise in the 21st century, one meter of sea level rise is well within the range of more recent projections." One of the biggest problems is weather aberrations, with the rising seas, what was a "once in a 100 year" flood or tide, could become a once every 30 years, or once every 10-year event with even modest sea-level increases.

6 "The Blue Economy: the Role of the Oceans in our Nation's Economic Future," hearing before the Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard of the Committee on Commerce, Science, and Transportation, United States Senate, One Hundred Eleventh Congress, first session, June 9, 2009, Volume 4.

7 St. John's, Newfoundland and Labrador – Ocean Technology Cluster, National Research Council Canada, Feb. 4, 2011: "Ocean technology in St. John's is an industry-led, highly profitable enterprise that accounts for $500 million in annual economic activity in Newfoundland. A vibrant and highly innovative cluster, the St. John's community comprises more than 50 of the province's many ocean technology companies and has grown by 18 percent every year since 2004." Also, the UK Society of Maritime Industries conducted a third survey focused on UK companies operating primarily in Marine Science and Technology (MST) activities at a trade show in April 2011: "The estimated market size for the UK-based MST business sector is over £1.1 billion, a marked increase on previous years, pointing toward a positive outlook for the future of the MST sector….companies reported a substantial increase in employment with an overall increase of 63%, which is reflected in the turnover increase of 76% in the past 12 months….The MST sector is set for considerable growth with over 90% of the companies surveyed predicting an increase in the market for their products and services over the next 12 months." Source: Ocean News & Technology, http://www.ocean-news.com/news-archives/ocean-science/1288-third-business-survey-of-uk-marine-scientific-industries-highlights-strong-growth-

8 Nigel Cliff, *Holy War*: *How Vasco da Gama's Epic Voyages Turned the Tide in a Centuries-Old Clash of Civilizations*, (HarperCollins Publishers, 2011). "It was next to impossible to obtain a map of the Portuguese voyages…'for the king has decreed the death penalty for anyone who sends it out of the country'." p. 280.

9 Wikipedia: "The Venetian Arsenal (Arsenale di Venezia) was a complex of state-owned shipyards and armories clustered together in Venice in northern Italy. It was responsible for the bulk of Venice's naval power during the middle part of the second millennium AD. It was also arguably the first recognized mass production complex using standardized and interchangeable parts."

10 Dava Sobel and William J. H. Andrews, *The Illustrated Longitude: The True Story of a Lone Genius who Solved the Greatest Scientific Problem of his Time*, (Walker & Company, 1998). "…the greatest scientific problem of the 18th and three prior centuries: determining how a captain could pinpoint his ship's location at sea…. Thousands of lives and the fortunes of nations hung on a resolution to a longitude problem."

11 Amir D. Aczel, *The Riddle of the Compass*, (Harcourt, Inc., 2001).

12 Garry Strauss, *The Battle of Salamis: The Naval Encounter that Saved Greece – and Western Civilization*, (Simon & Schuster Paperbacks, New York, 2004). "In 480 B.C. the trireme embodied state-of-the-art naval technology in the Mediterranean. For two centuries, the trireme would reign as the queen of the seas; Salamis was its greatest battle." p. xvii. "The world had never seen a battle like it…. Salamis represented a huge demographic fact. More than 200,000 men fought in the battle…In today's statistical terms, it is equivalent to about 20 million people." p. 4. "…a revolution had turned Athens into one of history's first democracies. Only a democracy could have put together the manpower to staff two hundred triremes – forty thousand men – and the willpower to use them well." p. 13. Also, John R. Hale, *Lords of the Sea: The Epic Story of the Athenian Navy and the Birth of Democracy*, (Penguin Books, 2009). "Athenians were a people wedded to the sea…. The City staked its fortunes on a continuing quest for sea rule…. A naval tradition that depended on the muscles and sweat of the masses led inevitably to democracy: from sea power to democratic power." pp. xxiv and xxvii.

13 Op. Cit., The Blue Economy. Statement of Judith T. Kildow, Ph.D., Director, National Ocean Economics Program: **"The ocean and coastal economies are no longer a subset of the U.S. economy. They really are the U.S. economy…four out of five people who live in this country live along our coasts and generate more than 80% of the U.S. economy…. The landscape along the coast will definitely shift and change due to inundation and sea level rise. And shoreline communities that host these industries that are the foundation of the U.S. economy are going to have huge challenges in how to sustain their economies…. In 1983, the U.S. acquired an exclusive economic zone offshore of more than 4 million square miles that more than doubled U.S. territory; yet its value has barely been estimated until now, and its management is currently under intense discussions…. The coastal economy alone – that is the counties that border the oceans, Gulf of Mexico, and the Great Lakes – totaled $5.7 trillion in 2007, despite**

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comprising only 18% of U.S. land area, and more than 108 million people reside and hold more than 48 million jobs. More than three-quarters of the growth of the entire U.S. economy has taken place in coastal states. Parenthetically, 83% of the U.S. GDP is in those coastal states…. My report comes with a caveat: it under reports the true size and impact of the coastal and ocean economies. This is because throughout the 10 years, we have not been able to fully utilize the data that are gathered by the Federal Government's North American Industrial Classification System, which is our primary source of information for market sectors. The NAICS accounts as established do not fully identify ocean-related activities…. Our research team projects that over the next 30 years the Nation will see the most significant changes in the ocean and coastal economies since the arrival of industrialization and urbanization. Shoreline communities…will have to adapt to an increasingly hostile environment."

14 This estimate would seem reasonable based on an extrapolation using data from the well-developed Canadian Ocean Technology Sector, an interactive online map, which shows 547 participants nationwide (427 "Private Sector Developers, Manufacturers & Suppliers" with the balance in Education & Training, NGOs, and Public R&D organizations & facilities). http://ocean.cinmaps.ca/asset_map, March 6, 2012. Using a simple 10:1 ratio of U.S. to Canada (roughly equivalent to the ratio of population and number of businesses in the respective countries), the U.S. would have over 4,200 Private Sector "Developers, Manufacturers & Suppliers" plus 1,200 other maritime technology related organizations.

15 Op. cit. (Note 6). In the UK Society of Maritime Industries survey, Marine Science & Technology companies reported a 63% employment growth in 12 months. Also, in St. John's, Newfoundland, in a population of just under 197,000 in 2011, OceansAdvance in its Outward Bound 2015 Strategic Agenda, 2009, p. 1, reported that in 2006 "…the ocean technology industry in the province comprised 52 companies with annual revenues of more than $225 million and annual growth of 15 percent. At the time the industry employed 1,430 people, including 11 public institutions, the total value of private and public sector activities was just over $260 million." In an article, "Five Minutes with the Honorable Shawn Skinner, Minister, Responsible for Rural Secretariat, Newfoundland & Labrador," in *Marine Technology Reporter*, October 2009, Minister Skinner answered: "We have recently announced a $28 million ocean strategy investment, an investment designed to help the industry grow from a $300 million to a $1 billion industry by 2015. We want employment to rise in this sector, and are targeting 6,000 new jobs (from this investment and subsequent industry growth)."

16 Maritime Economic Impact & Cluster Analysis, www.sandiegobusiness.org/media/docs/021010_maritime_report.pdf

17 Unless otherwise footnoted, information in this section was provided primarily by Randy Truby, former CEO of Toray Membrane USA, past President of the International Desalination Association (IDA), and Chair of The Maritime Alliance Desalination / Water Technology Sector Working Group.

18 U.S. Geological Survey, "Where is the Earth's water located?" http://ga.water.usgs.gov/edu/earthwherewater.html.

19 Global Water Intelligence, "Desalination Markets 2010: Global forecast and analysis, "This means the desalination market will nearly triple in value over the next six years, reaching $30 billion a year in 2016." And SBI Energy August 23, 2011 press release, "Depleting water supplies, coupled with increasing water demand, are driving the global market for desalination technology, which is expected to reach $52.4 billion by 2020, up 320.3% from $12.5 billion in 2010."

20 Unless otherwise footnoted, information in this section was provided primarily by Hubbs-SeaWorld Research Institute: www.hswri.org.

21 Various Authors (four cited below): "Growth Ahead for Global Agriculture," SAISPHERE 2011-2012, published by The Paul H. Nitze School of Advanced International Studies of the Johns Hopkins University. Available on-line: http://media.sais-jhu.edu/saisphere/articles/Features. Robert L. Thompson, "Gaining Ground?" "There are only two ways to expand agricultural production: Increase the area planted…or increase the production per unit of land…however, there is only about 10 percent more potentially arable land that is not forested, highly erodible or subject to desertification…. Most of the potentially arable land is inferior to that already in production and is located in remote areas…Availability of freshwater for agriculture may become an even larger constraint…. Farmers

account for about 70% of the freshwater used in the world…by 2050, the world's farmers will no longer have access to 70% of the freshwater. Cities will outbid farmers for available water." Tabitha Grace Mallory, "The Sea's Harvest: China and Global Fisheries." "Approximately 2.6 billion people depend on the ocean for their primary source of protein. Yet these resources are just as finite as those on land…the UN Food and Agriculture Organization stated that, as of 2008, an unprecedented 85% of marine fish stocks were fully exploited, over-exploited or depleted…. China's own waters are already virtually empty…. China has invested in distant-water fishing and aquaculture to relieve some of the pressure…. Because of constraints on wild-catch fisheries, China has expanded its aquaculture sector and is currently the world's largest producer. Between 1990 and 2000, employment in Chinese aquaculture grew by 189%." Charles Pearson, "Global Warming, Agriculture and Biofuels: A Combustible Mix." "World food demand is expected to double by mid-century. Global warming is a fact, and even with a serious world climate policy, which is not yet in sight, food supplies will be under pressure. Putting expanding biofuel mandates into this mix is risky. Widespread conversion of land to biofuels, as is happening now, can increase near-term carbon emissions and can seriously disrupt world food markets, with the heaviest costs borne by the poor." Mariano Turzi, "Soil-The New Oil?" **"In the coming years, access to edible commodities will become a key strategic source of power, bringing back to the forefront an old fault line in international relations: food geopolitics… If energy scarcity can disrupt the normal functioning of a society, the absence of food and water can cause its sudden breakdown…. The global population, which grows by around 80 million people per year, was expected to surpass the 7 billion mark by late 2011 and to reach 9 billion by the end of the century. Renowned agronomist Normal Borlaug estimated in 2009 that over the next 50 years, the world will have to produce more food than it has in the past 10,000 years. This mean a structural upward shift in food demand…. On the supply side, climate change is generating increased temperature volatility and alteration of precipitation patterns. In 2010, for example a drought and heat wave decimated the Russian wheat harvest, leading to a rise in the price of flour and bread worldwide."**

22 U.S. Bureau of Economic Analysis, June 9, 2011.

23 Details from various Wikipedia articles: Floating docks have been used for centuries with perhaps the best known being the "floating harbour" of Bristol, England, which was opened on 1 May 1809. In 1927, a Canadian-born engineer and inventor, named Edward Robert Armstrong, proposed a series of "seadrome" floating airport platforms for airplanes to fly from the East Coast of North America to Europe. Although the original concept was made obsolete by long-range aircraft, the idea was re-purposed into floating oil rigs. A "Mulberry" harbor was a British-built temporary harbor developed in WWII to support the landing at Normandy. Two prefabricated military harbors were taken across the English Channel in sections and assembled. One was used for 8 months after the invasion. The "Thames Sea Forts" in WWII were a series of small fortified towers placed on the shallow bottom of the Thames to protect Britain and are considered forerunners of modern offshore platforms. In 1967, billionaire shipping magnate Daniel Ludwig purchased 4 million acres near the mouth of the Amazon River for his agricultural Jari project and had two large ship-shaped platforms built in Japan and floated to the site – one contained a pulp mill and the other power module.

24 LLNL Lab Newsline, Plan floated to ship cargo inspection offshore, Vol. 3, No. 26, July 2010. https://newsline.llnl.gov/_rev02/articles/2010/jul/07.02.10-ports.php

25 Op. cit., The Blue Economy. Statement of William Fenical, Ph.D., Distinguished Professor of Oceanography and Pharmaceutical Science, Scripps Institution of Oceanography (SIO), University of California San Diego. Dr. Fenical is one of the founders of the marine natural products field and is currently the Director of the Center for Marine Biotechnology and Biomedicine (CMBB) based at SIO.

26 Op. cit., The Blue Economy. Statement of Willett Kempton, Ph.D., Associate Professor, College of Earth, Ocean and Environment, and Director, Center for Carbon-Free Power Integration, University of Delaware; Chair, R&D Subcommittee, Offshore Wind Working Group, American Wind Energy Association.

27 "Exclusive Economic Zone", Wikipedia, 4 March 2012: The U.S. EEZ is the largest in the world covering 11,351,000 km² followed closely by France with 11,035,000 km² and then dropping significantly with (in order of size): Australia, Russia, UK, New Zealand, Indonesia, Canada, Japan, and Chile rounding out the top ten.

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