A Special Production

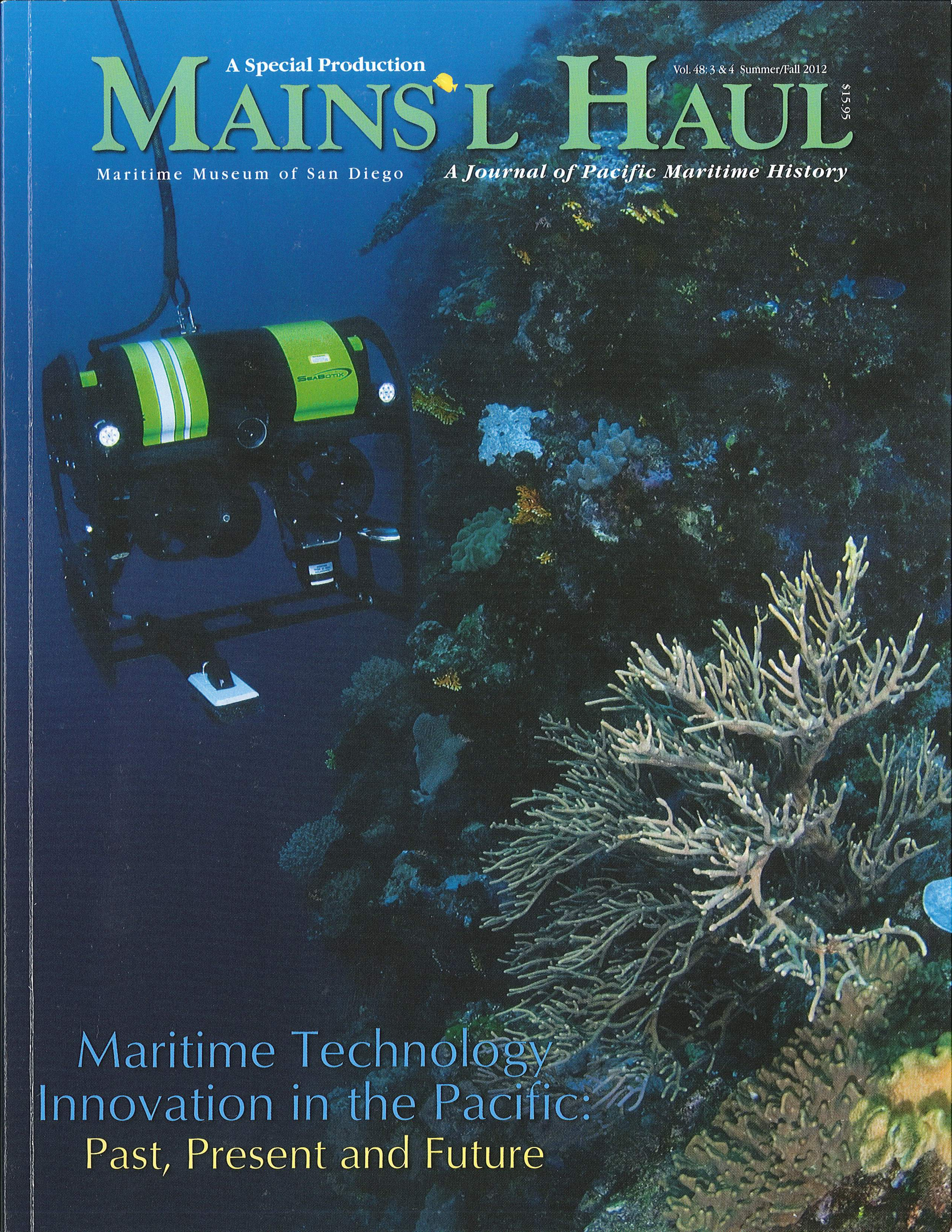
MAINS'L HAUL

Vol. 48: 3 & 4 Summer/Fall 2012

$15.95

Maritime Museum of San Diego

A Journal of Pacific Maritime History



Maritime Technology Innovation in the Pacific: Past, Present and Future

MAINS'L HAUL is published by the Maritime Museum of San Diego, wind and weather permitting, aboard the ferryboat *Berkeley*.

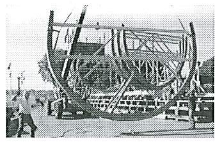
MAINSAIL HAUL-An order in tacking ship bidding, "Swing the main yards."

Maritime Museum of San Diego Vol. 48: 3 & 4 Summer/Fall 2012

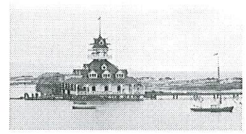
MAINS'L HAUL

A Journal of Pacific Maritime History

Maritime Technology Innovation in the Pacific: Past, Present and Future

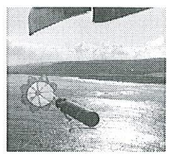


4 **Ray Ashley, Ph.D.**
From the Helm

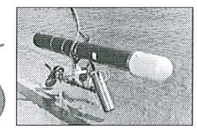


6 **Robert A. Knox, Ph.D.**
Mare Incognitum: How Scripps Institution of Oceanography took root on the Pacific Shore and some of the Maritime Technological efforts that resulted.

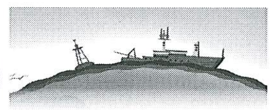
18 **Russ E. Davis, Ph.D.**
It Takes a Network to Build an Ocean Observing System



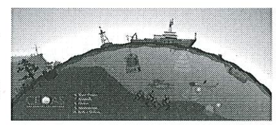
32 **Tom LaPuzza**
Information Dominance: How the Navy's first (and second and third) laboratory on the Pacific provided information resources to the Nation's warfighters to dominate in battle and deter in peace.



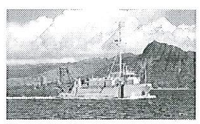
46 **Tom LaPuzza**
SSC Pacific: Underwater Vehicle Development



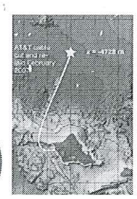
60 **John V. Byrne, Ph.D.**
Oceanography Pioneers: The Oregon State Story



76 **John A. Barth, Ph.D. and Robert L. Smith, Ph.D.**
What is the Ocean Like off Oregon? Exploring, Monitoring, and Understanding the Northern California Current



88 **David M. Karl, Ph.D.**
Mid-Pacific Oceanography: University of Hawaii and the Sea



100 **Bruce M. Howe, Ph.D.**
Frederick K. Duennebier, Ph.D.
Rhett Butler, Ph.D.
Roger B. Lukas, Ph.D.
Scientific uses of Submarine Cables: Evolutionary Development leading to the ALOHA Cabled Observatory

120 **Brock J. Rosenthal**
San Diego's Marine Technology Industry

138 **Michael B. Jones**
Promoting the Blue Economy: The Role of Maritime Technology Clusters

Financial support for this publication is provided by the City of San Diego Commission for Arts and Culture.

vibrant culture vibrant city
Commission for Arts and Culture
City of San Diego

Unified Port of San Diego

Subscribe to *Mains'l Haul* by joining the Maritime Museum of San Diego.

Members also receive an online and printed newsletter and many other benefits.
To subscribe or comment, visit the *Mains'l Haul* pages at **www.sdmaritime.org**

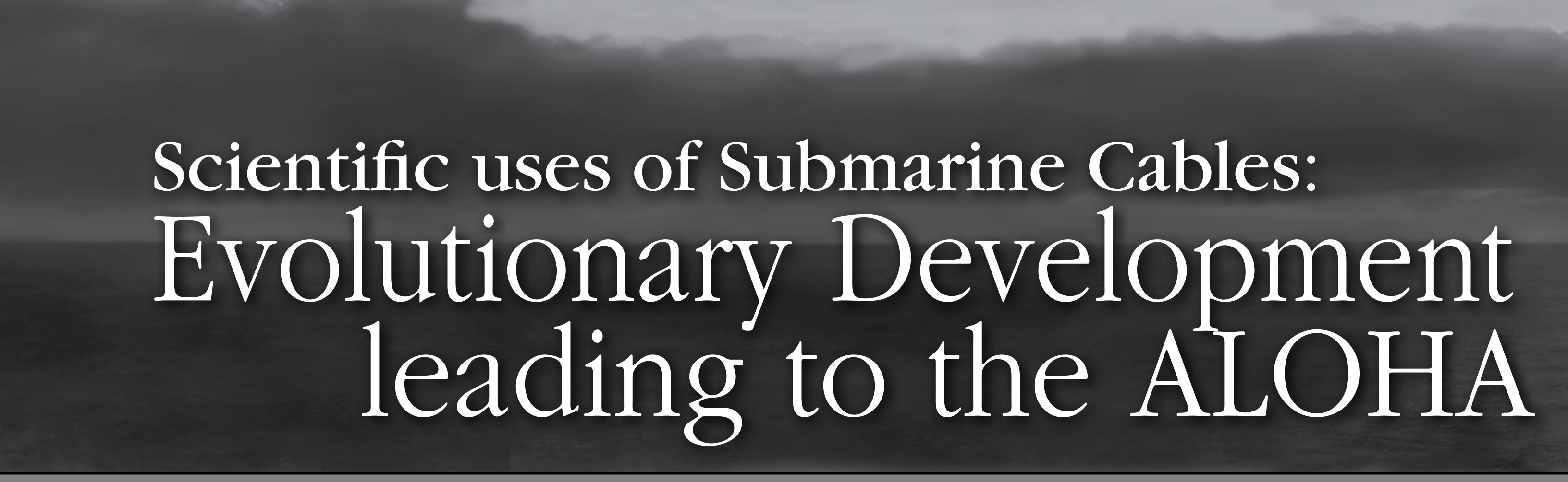
email: editor@sdmaritime.org, or write to *Mains'l Haul*, Maritime Museum of San Diego, 1492 N. Harbor Dr., San Diego, CA 92101
Phone: 619-234-9153

Our mission is to engage members and the public in the study of maritime history, while promoting scholarly research.

Articles are indexed for researchers worldwide at **www.sdmaritime.org** - *Mains'l Haul*, and in *America: History & Life and Historical Abstracts.* ISSN# 1540-3386.

Editor/Neva Sullaway
Art Director/Tony Enyedy **Printer**/Crest Offset Printing Company

ISBN 0-944580-32-7



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

Bruce M. Howe, Ph.D.
Frederick K. Duennebier, Ph.D.
Rhett Butler, Ph.D.
Roger B. Lukas, Ph.D.

School of Ocean and Earth Science and Technology
University of Hawaii at Manoa

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.

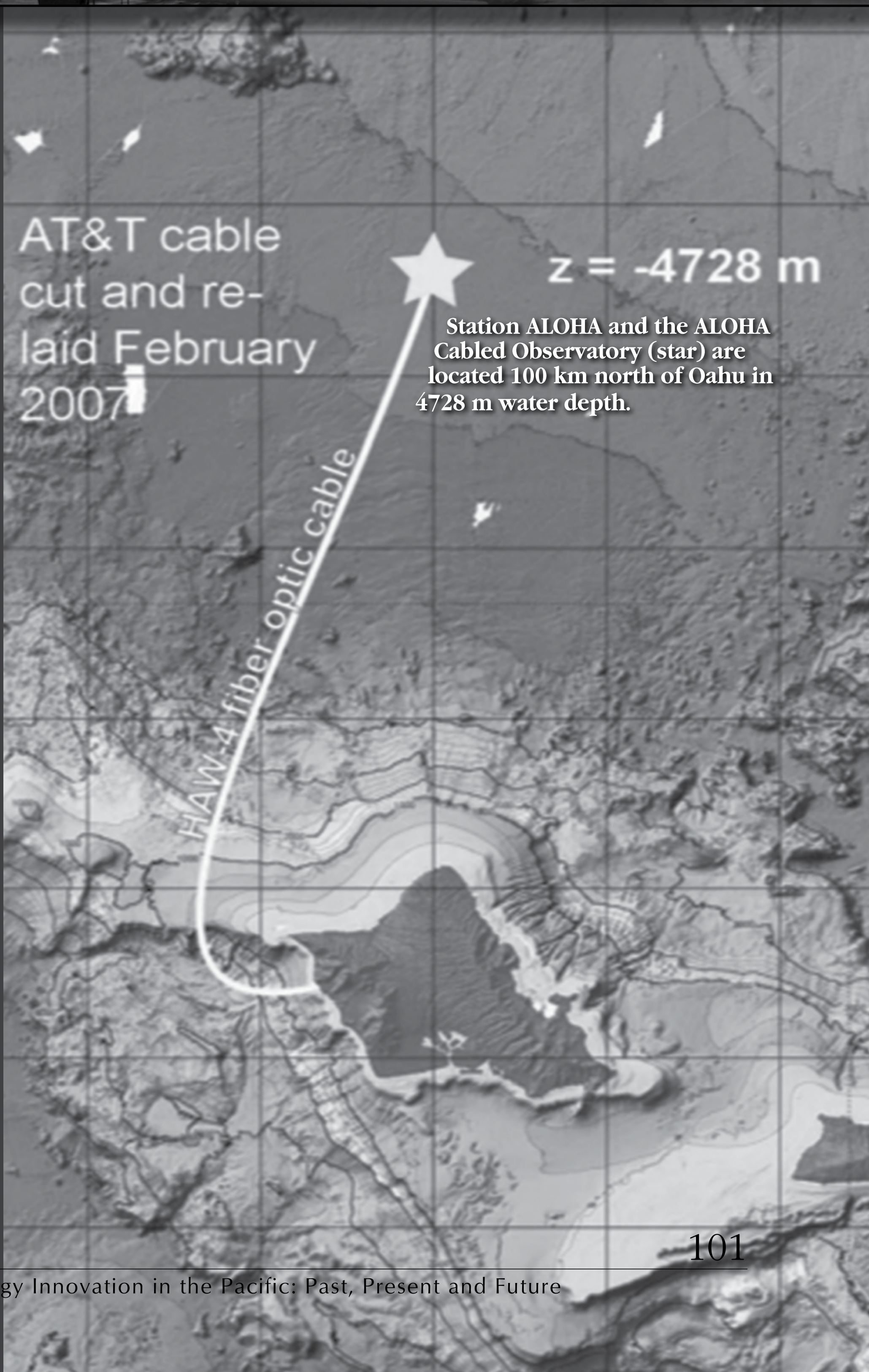
Roger Lukas is a professor of Oceanography in the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa. He received his Ph.D. in Oceanography in 1981 from the University of Hawaii, following a Master's degree in Oceanography from UH in 1977. He received his B.A. in Mathematics 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.

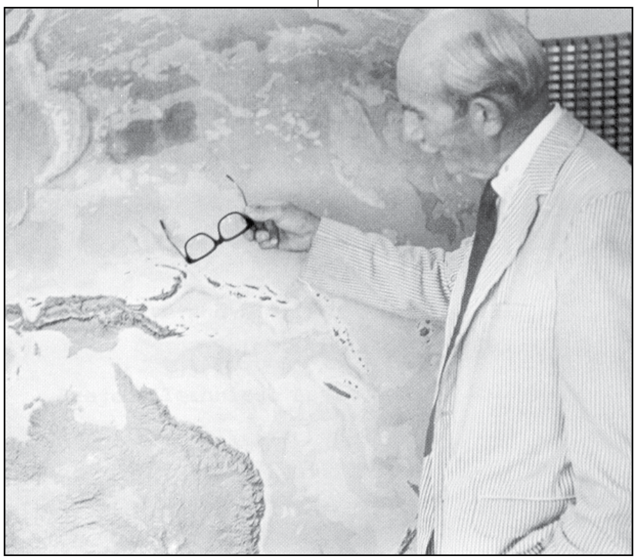
Thus, sustained observations of the ocean are difficult. Ocean science requires improved ways to observe the ocean in order to advance our understanding and lay the foundations for predictive models and their applications. Recent technological advancements, such as mobile platforms (floats, gliders and 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.

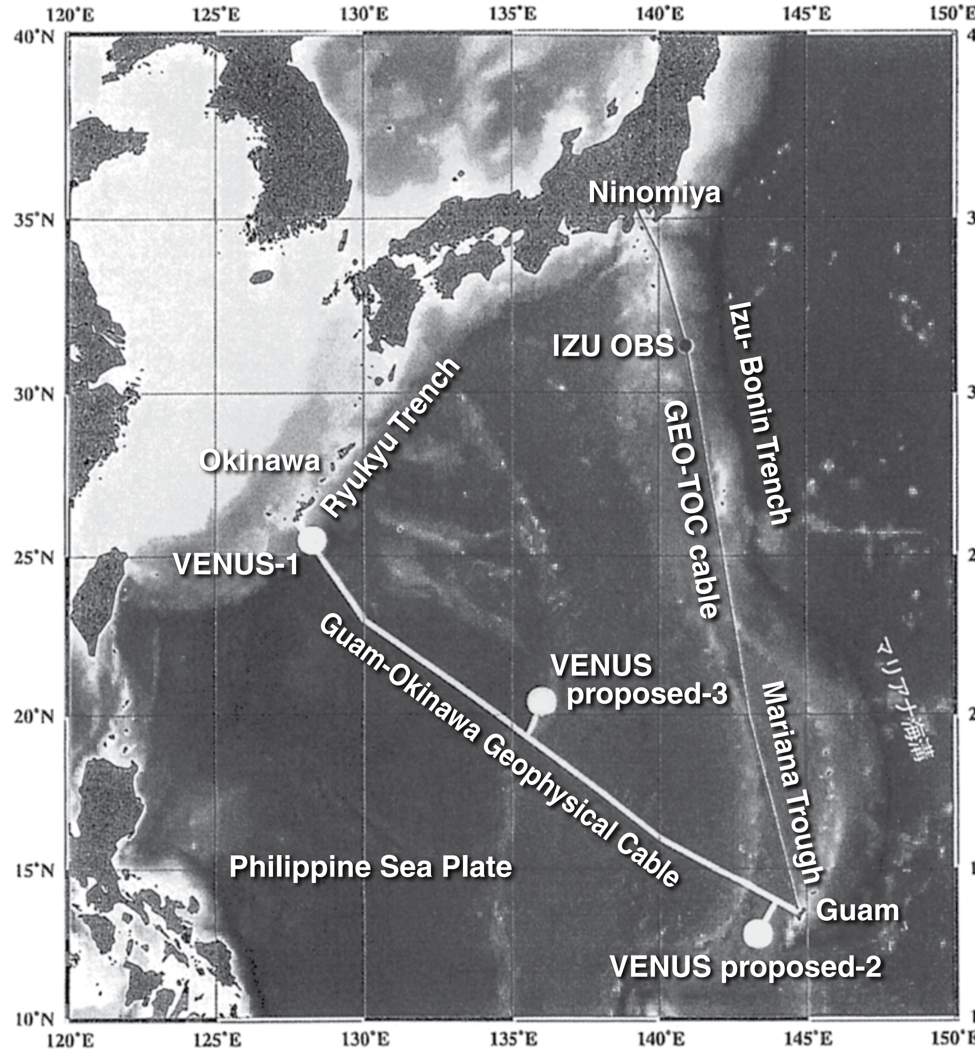
During the summer of 1989, IRIS and JOI (Tom Pyle) wrote a proposal to NSF, U.S. Geological Survey, ONR, and NOAA to support a scientific workshop on re-use of undersea cables. This workshop was held in Honolulu at the end of January 1990.[6] Managers and engineers from AT&T and KDD outlined the engineering 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.

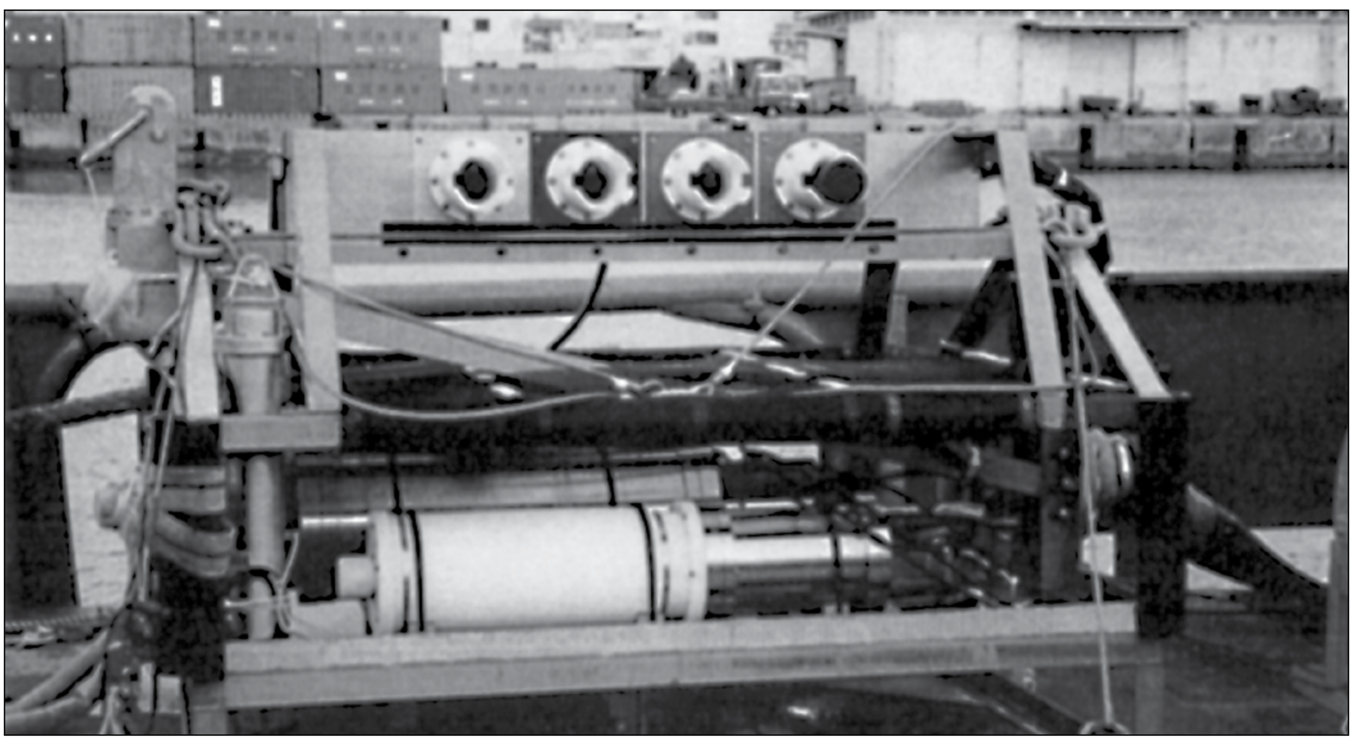
This effort included the Japan Marine Science and Technology Center (JAMSTEC), the Hydrographic Department of the Maritime Safety Agency, the Meteorological Institute of the Japan Meteorological Agency (JMA), ERI, the Geological Survey of Japan, the Communications Research Laboratory, the Electro-technical 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).*



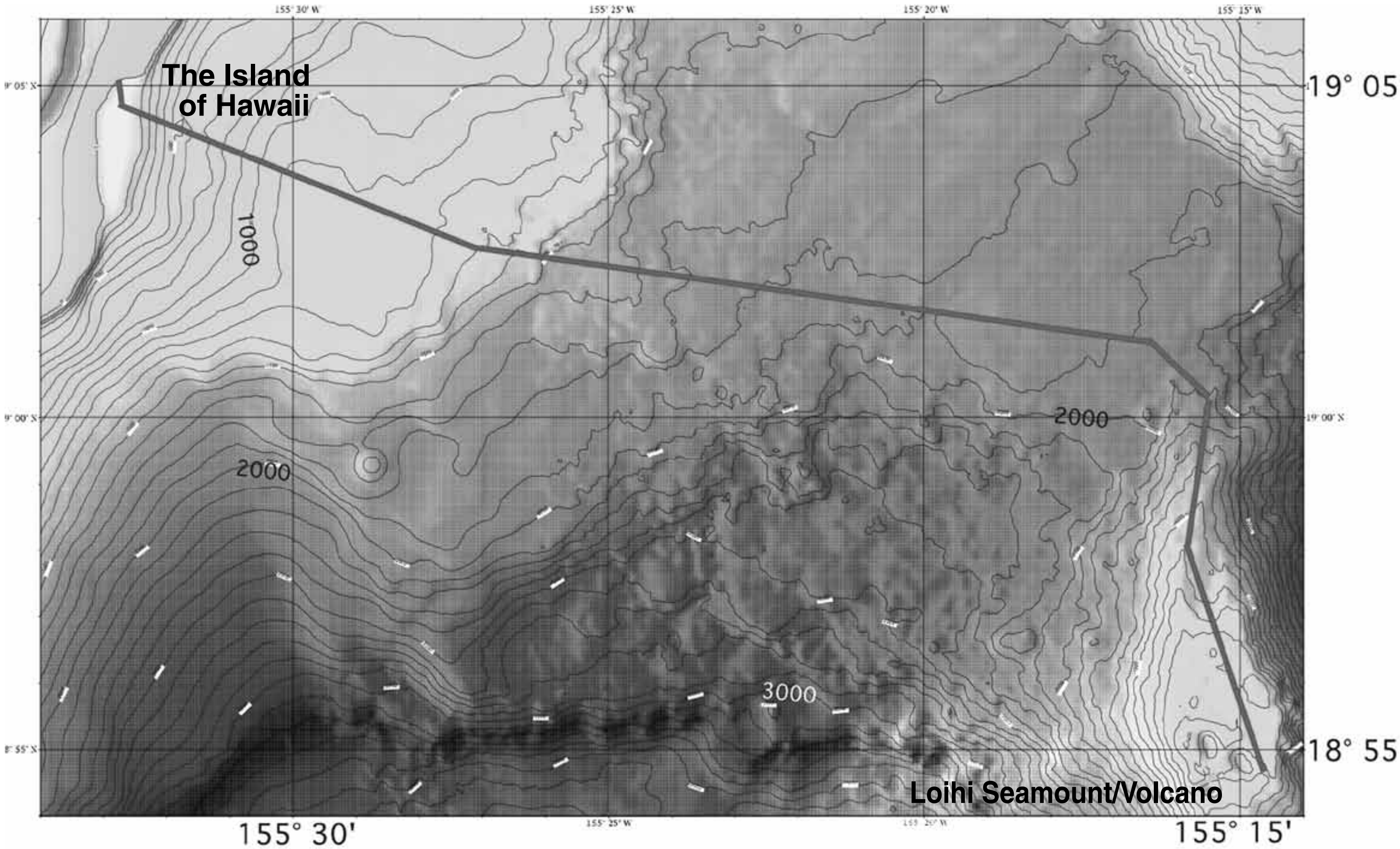
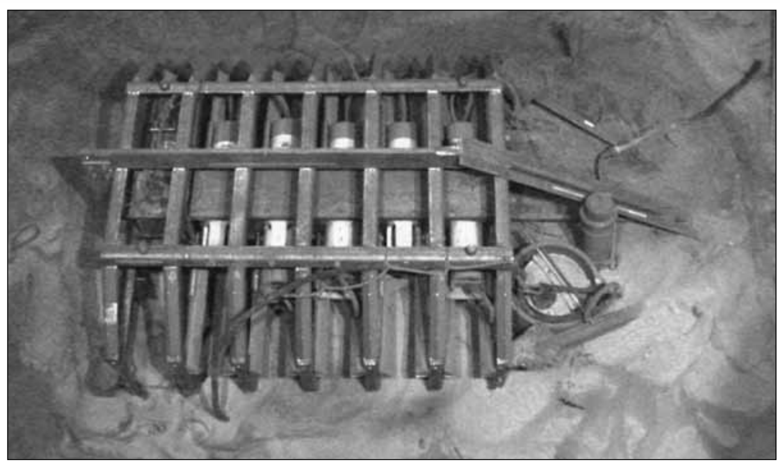


Illustration Courtesy University of Hawaii at Manoa

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.

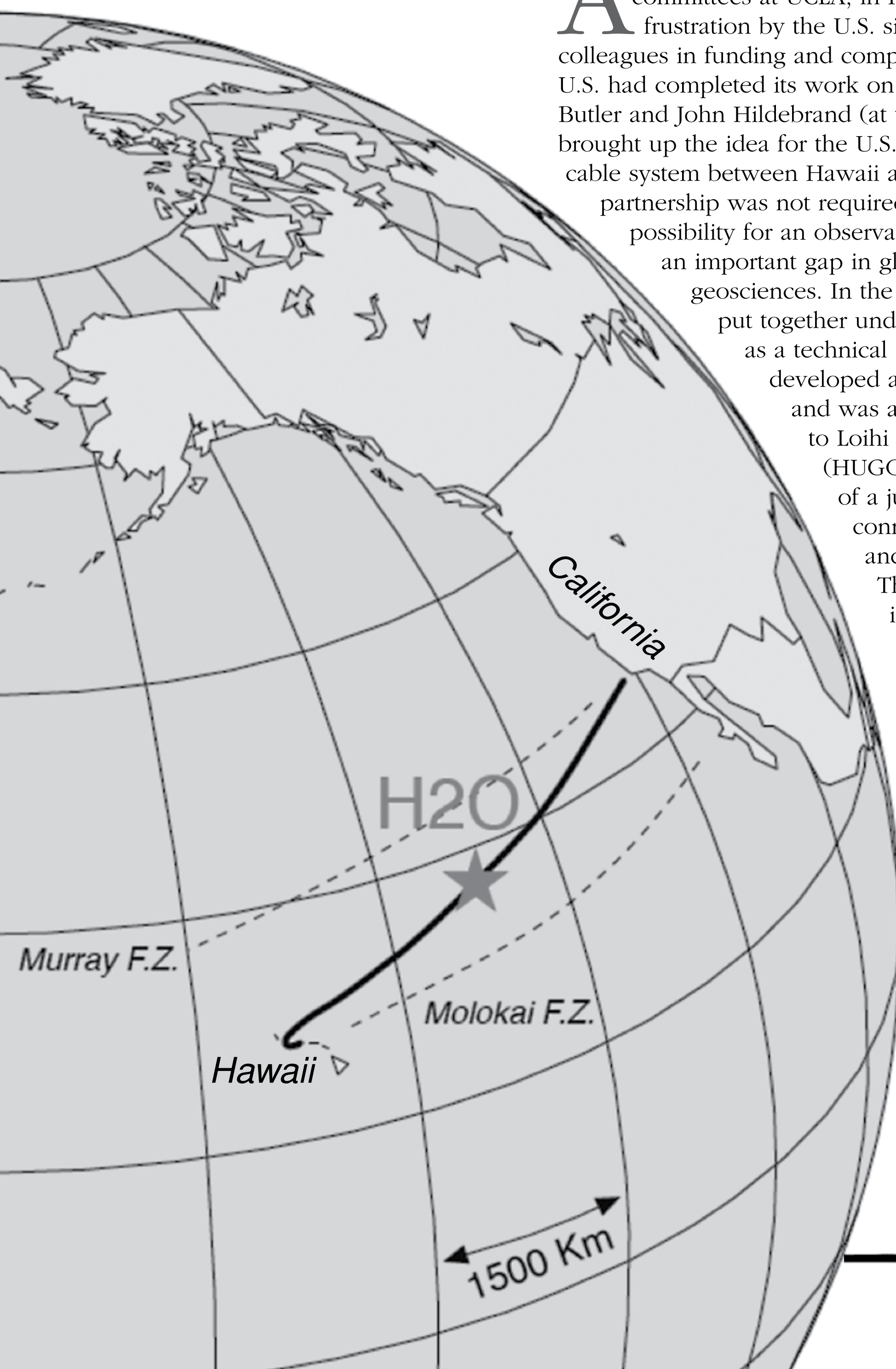
Despite the cable failure, all the essential elements of purpose-built cabled ocean observatories were demonstrated, including the successful small-ship lay of the 47-km electro-optical cable from the Island of Hawaii to the summit of Loihi submarine volcano; the



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).*

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".

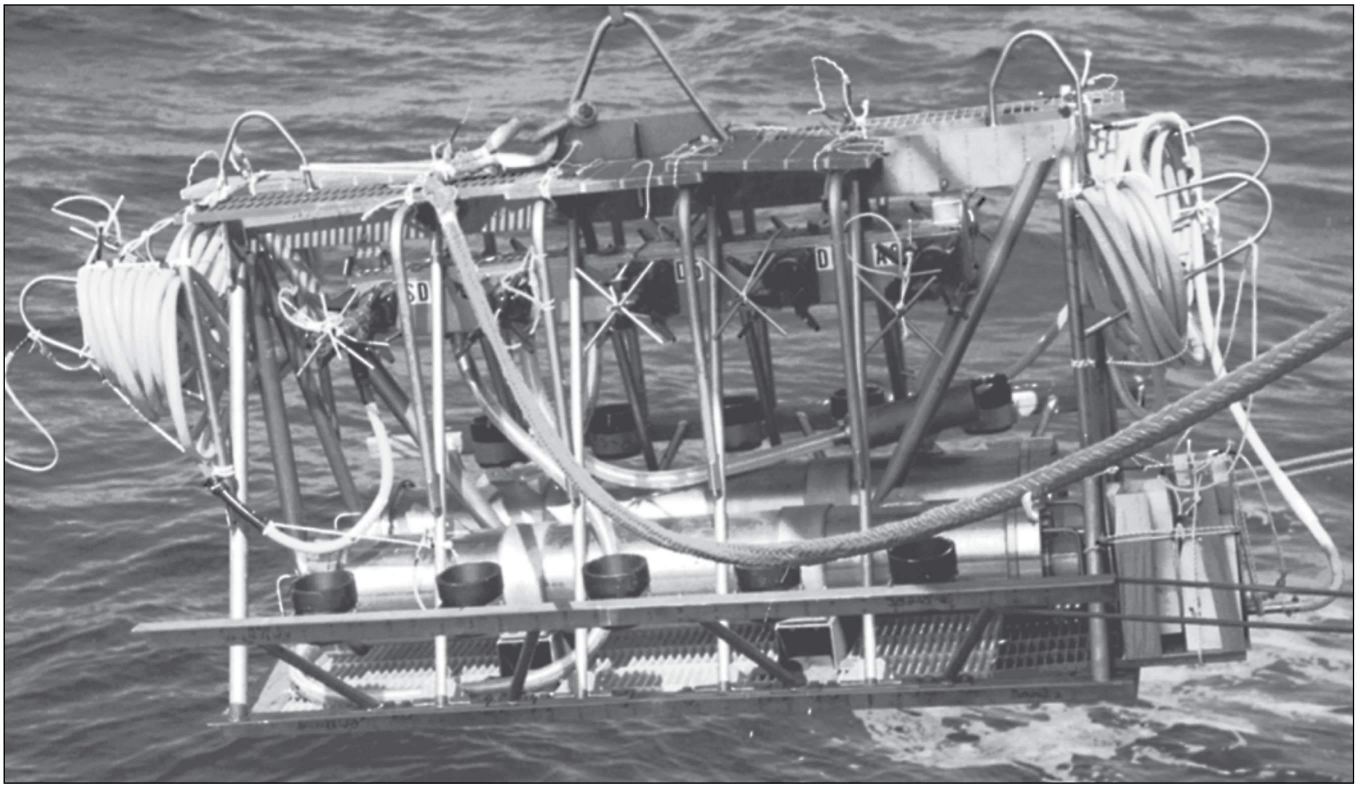


Hawaii-2 Observatory (H2O) map. *From* EOS Trans. AGU, *"Hawaii-2 Observatory Pioneers Opportunities for Remote Instrumentation in Ocean Studies" (2000), by R. Butler, A. D. Chave, F. K. Duennebier, D. R. Yoerger, R. Petitt, D. Harris, F. B. Wooding, A. D. Bowen, J. Bailey, J. Jolly, E. Hobart, J. A.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

The 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



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.

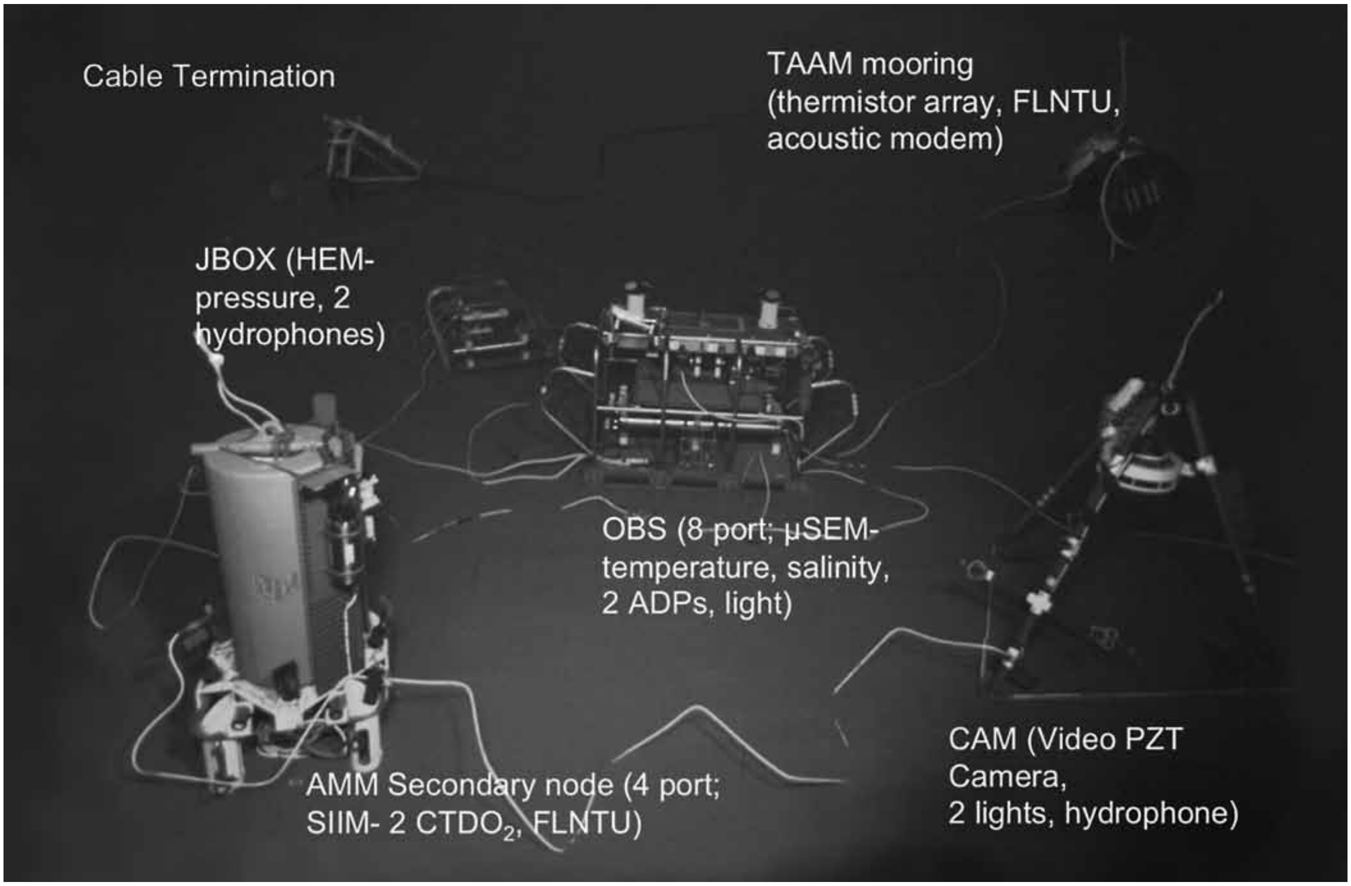
In October 2003, with the Cabled Regional Observatory Workshop,[13] the National Science Foundation decided to focus on transformative technologies involving laying new cables for its planned Ocean Observatories Initiative (OOI, at the time called ORION), rather than the evolutionary re-use of retired 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.

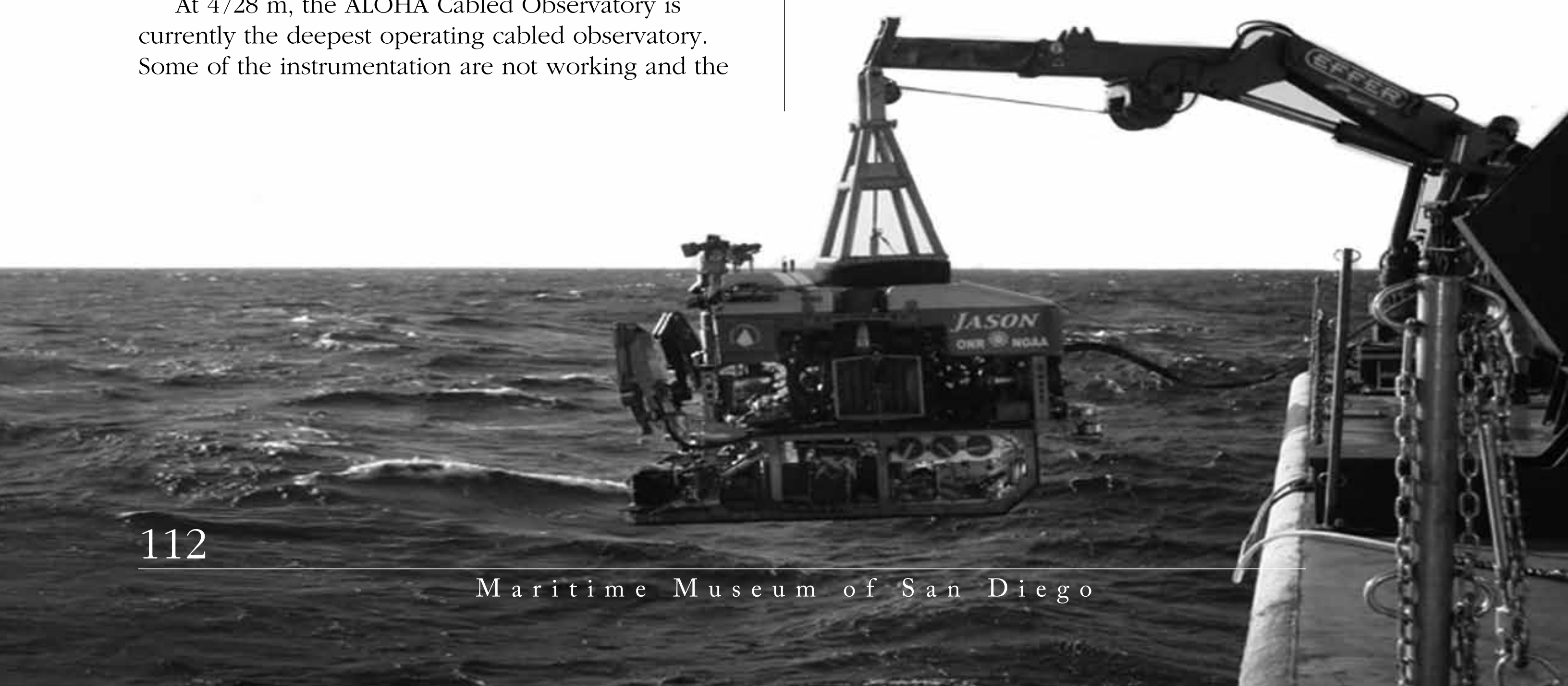


This photograph (taken by ROV Jason) is true to scale, except the cable termination and the TAAM mooring, in the background, have been pasted in.

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.



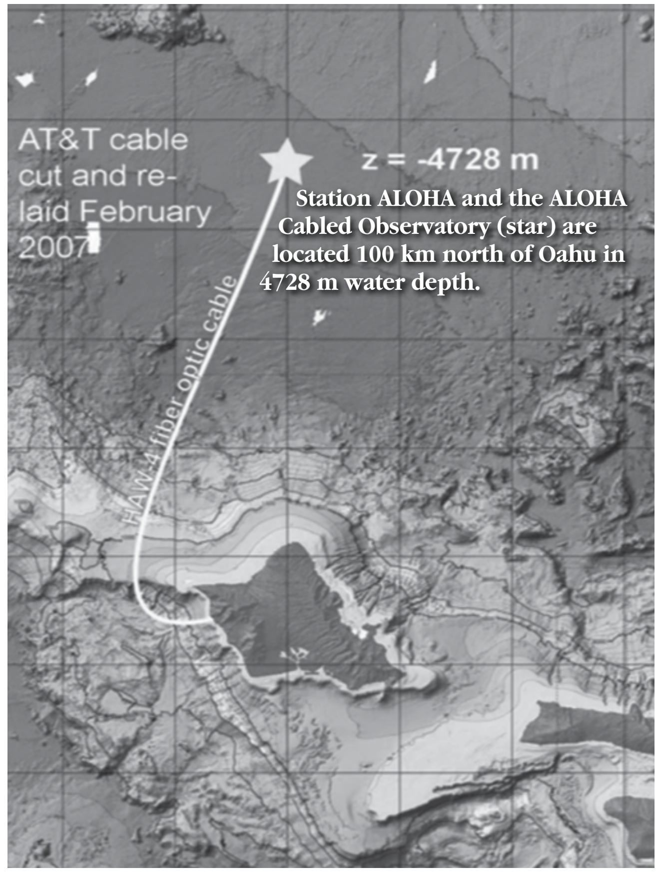
Concluding Remarks

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

1 http://calcofi.org/

2 Baker, 1981 Baker, D. J., "Ocean Instruments and Experimental Design," in *Evolution of Physical Oceanography*. Eds B. Warren and C. Wunsch, (MIT Press: Cambridge, MA., 1981), 396–433.

3 Sutton et al., 1965, Sutton and Barstow, 1990 Sutton, G.H. W. G. McDonald, D. D. Prentiss, and S. N. Thanos, "Ocean-bottom Seismic Observatories," *Proceedings of the IEEE*, 53,12, 1909-1921, DOI: 10.1109/PROC.1965.4468, December 1965. Sutton, G. H., and N. Barstow, "Ocean-bottom Ultralow-frequency (ULF) Seismo-acoustic Ambient Noise: 0.002 to 0.4 Hz," *J. Acoust. Soc. Am.,* 87, 2005-2012, 1990.

4 Delaney, J. R., F. N. Spiess, S. C. Solomon, R. Hessler, J. L. Karsten, J. A. Baross, R. T. Holcomb, D. Norton, R. E. McDuff, F. L. Sayles, J. Whitehead, D. Abbott and L. Olson, "Scientific Rationale for Establishing Long-term Ocean Bottom Observatory/Laboratory Systems," *in Marine Minerals Resource Assessment Strategies,* eds. P.G. Teleki, M.R. Dobson, J.R. Moor and U. von Stackelberg, 389-411, 1987.

5 Chave et al., 1990 Chave, A., R. Butler, and T. Pyle, Eds., Workshop on Scientific Uses of Undersea Cable, Joint Oceanographic Inst., Washington, D.C., 1990.

6 Ibid.

7 Kasahara, J., T. Sato, H. Momma, and Y. Shirasaki, "A New Approach to Geophysical Real-time Measurements on a Deep-sea Floor using Decommissioned Submarine Cables," *Earth Planets Space*, 50, 913–925, 1998.

8 Duennebier, F. K., D. W. Harris, J. Jolly, J. Babinek, D. Copson, and K. Stiffel, "The Hawaii-2 Observatory Seismic System," *IEEE J. Oceanic Engineering*, 27, 2, 212-217, 2002.

9 Petitt, R., D. Harris, B. Wooding, J. Bailey, J. Jolly, E. Hobart, A. Chave, F. Duennebier, R. Butler, A.D. Bowen, and D.R. Yoerger, "The Hawaii-2 Observatory," *IEEE J. Ocean Engineering*, V 27, 2, 245-253, April 2002.

10 Harris, David H, and Fred K. Duennebier, "Powering Cabled Ocean Bottom Observatories," *IEEE J. Oceanic Engineering*, 27, 2, 202-211, 2002.

11 Farrell, W. E., and W. Munk, "Booms and Busts in the Deep," *J. Phys. Oceanogr.*, 40, 2159-2169, DOI: 10.1175/2010JPO4440.1, 2010.

12 National Research Council, *Illuminating the Hidden Planet: The Future of Seafloor Observatory Science,* (Washington, D.C.: National Academy Press, 2000).

13 Purdy, M., and D. Karl, RECONN, Regional Cabled Observatory Network (of Networks), "Report of the Cabled Regional Observatory Workshop," October 7-10, 2003, San Francisco, CA, http://geo-prose.com/pdfs/reconn_rpt.pdf, 2003.

14 Tremblay, M. D., and F. K. Duennebier, "Format and Bit Rate Independent Communications over Regenerated Undersea Fiber Optic Cable Systems," *Proceedings of the Scientific Submarine Cable 2006 Conference*, 182–185, Marine Institute, Dublin Castle, Dublin, Ireland, 7-10 February 2006.

15 Duennebier, F. K., R. Lukas, E.-M. Nosal, J. Aucan, and R. A. Weller (2012), "Wind, Waves, and Acoustic Background Levels at Station ALOHA," *J. Geophys. Res.*, DOI:10.1029/2011JC007267, in press, 3 January 2012.

16 Howe, B. M., R. Lukas, F. Duennebier, and D. Karl, "ALOHA Cabled Observatory Installation," *MTS-IEEE Conference Proceedings*, Kona, Hawaii, 2011. Howe, B. M., F. K. Duennebier, R. Lukas, "The ALOHA Cabled Observatory," in *Seafloor Observatories: A new vision of the Earth from the Abyss*, Eds. P. Favali, L. Beranzoli and A. De Santis, Springer/Praxis Publishing, in press, 2012.

17 Peterson, V.Z., "Ocean Technology Employed by the Dumand Project," *OCEANS '91 Proceedings,* 1, 525-529, 1-3 Oct 1991, DOI: 10.1109/OCEANS.1991.614013, 1991.

18 Dushaw, B. D., P. F. Worcester, W. H. Munk, R. C. Spindel, J. A. Mercer, B. M. Howe, K. Metzger, Jr., T. G. Birdsall, R. K. Andrew, M. A. Dzieciuch, B. D. Cornuelle, and D. Menemenlis, "A Decade of Acoustic Thermometry in the North Pacific Ocean," *J. Geophys. Res*., 114, C07021, DOI:10.1029/2008JC005124, 2009.

19 NEPTUNE Phase 1 Partners (University of Washington, Woods Hole Oceanographic Institution, Jet Propulsion Laboratory, Pacific Marine Environmental Laboratory), "Real-time, Long-term Ocean and Earth Studies at the Scale of a Tectonic Plate: NEPTUNE feasibility study" (prepared for the National Ocean Partnership Program), University of Washington, Seattle, 2000.

20 Dewey, R., A. Round, P. Macoun, J. Vervynck, and V. Tunnicliffe, "The VENUS Cabled Observatory: Engineering meets Science on the Seafloor," *OCEANS 2007*, pp.7. DOI:10.1109/OCEANS.2007.4449171, 2007.

21 Barnes, C. R., M. Best, L. Pautet and B. Pirenne, "Understanding Earth-ocean Processes using Real-time Data from NEPTUNE," "Canada's widely Distributed Sensor Networks, Northeast Pacific," *Geosciences Canada*, 38, 21-30, 2011.

22 Matsumoto, H., H. Mikada, T. Watanabe, K. Kawaguchi, K. Mitsuzawa, K. Asakawa, T. Goto, T. Kasaya, R. Otsuka, S. Morita, "Seismological Findings Using Real-Time Cabled Observatories," *Proceedings of the Scientific Submarine Cable 2006 Conference*, 182–185, Marine Institute, Dublin Castle, Dublin, Ireland, 7-10 February 2006.

23 Kawaguchi, K., S. Kaneko, T. Nishida, T. Nishida, and T. Komine, "Construction of Real-time Seafloor Observatory for Earthquakes and Tsunami Monitoring," in *Seafloor Observatories: A New Vision of the Earth from the Abyss*, Eds. P. Favali, L. Beranzoli and A. De Santis, Springer/Praxis Publishing, in press, 2012.

24 You, Y., "Harnessing Telecoms Cables for Science," *Nature*, 466, 690-691, 2010.

Hawaii Ocean Time-series (HOT)

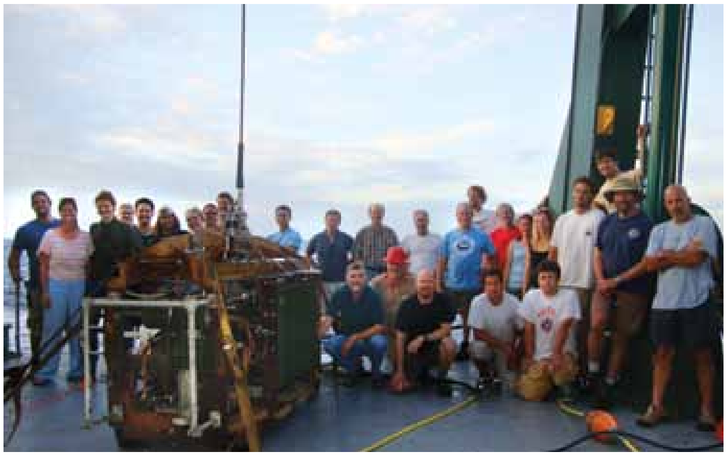
The Hawaii Ocean Time-series (HOT) aims to document, describe, and understand the physics and biogeochemistry of the ocean at Station ALOHA. Through research on monthly HOT cruises and analyses on land and sea, these objectives have been pursued for 23 years. Of particular importance is the documentation 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.

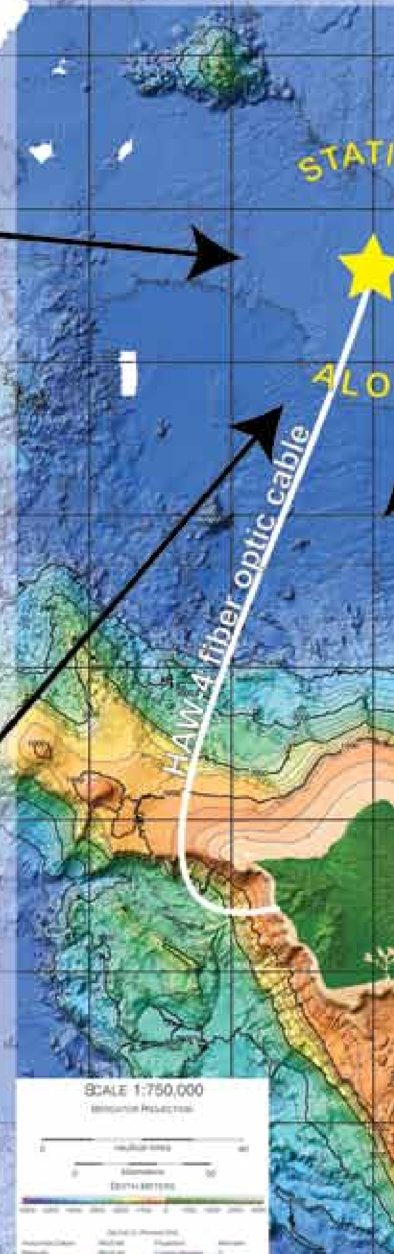
Image taken from the ACO Camera: First Light.
(ROV Jason to the left.)

University of Hawaii Ocea

http://aloha.

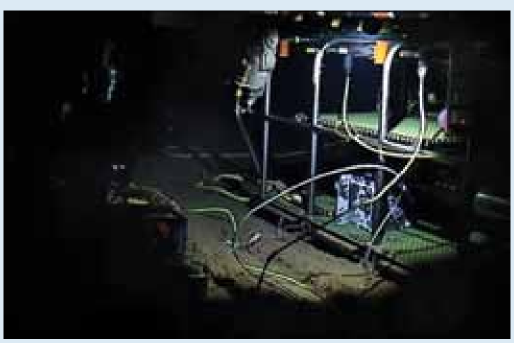
Woods Hole Oceanographic Institution Hawaii Ocean Time-series (WHOTS)

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.