PROJECT SUMMARY

We propose to design, construct and emplace infrastructure for a cabled ocean bottom observatory at Station ALOHA, a major oceanographic research site 100 km north of Oahu. The observatory will provide power and communications capability necessary for real-time continuous monitoring of the ocean environment for at least a decade. We will retrieve part of the retired ANZCAN telecommunications cable from the ocean floor, and terminate it with an electrical connection, allowing attachment of a broad range of sensors to measure under-explored variability of the ocean climate and deep-ocean phenomena. The major tasks to be funded by this proposal are the design, construction and emplacement of the observatory infrastructure. Additional infrastructure and individual instruments will be proposed separately by investigators from institutions around the world.

Observatory investigators will be able to monitor their experiments and modify them remotely as conditions warrant via Internet connection. Web access will allow grade school and college students to observe the data and draw their own conclusions concerning implications about important topics such as global warming and the state-of-health of the oceans.

Station ALOHA has been the site of monthly monitoring for more than 13 years under the H.O.T. (Hawaii Ocean Time-series) Program, with nearly monthly cruises sailing to the site to take samples and to monitor ocean parameters. While the data from these cruises have resulted in publication of well over 100 scientific papers, the inadequate sampling technologies have resulted in under-sampling of rapid fluctuations and the likelihood of aliasing. With the installation of the AAO, periodic cruises will still be required to obtain physical samples, provide broad spatial coverage, and to install new systems at the observatory, but the capabilities of the observatory will greatly improve the value of these data by eliminating aliasing, providing power and control for experiments, and providing expanded opportunities for research.

We are fortunate that Station ALOHA lies within 26 km of the ANZCAN coaxial marine telecommunications cable, installed in 1983 and retired from service in 1997. The University of Hawaii is currently negotiating with Teleglobe, Inc. to obtain ownership of the cable for observatory use, and indications are that this transfer of ownership will be approved. This cable can provide about one kilowatt of power to the observatory and transmit data at rates of more than 2 mBaud. As the cable has been retired, it will no longer be protected under the auspices of the International Cable Protection Committee, and it could be removed from the cable station and rendered unusable unless ownership is transferred to a group which will use the cable for scientific purposes.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

	Section	**Total No. of Pages in Section**	**Page No.* (Optional)***
	Cover Sheet (NSF Form 1207) (Submit Page 2 with original proposal only)		
A	Project Summary (not to exceed 1 page)	1	
B	Table of Contents (NSF Form 1359)	1	
C	Project Description (plus Results from Prior NSF Support) (not to exceed 15 pages) **(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**	15	
D	References Cited	2	
E	Biographical Sketches (Not to exceed 2 pages each)	8	
F	Budget (NSF Form 1030, plus up to 3 pages of budget justification)	10	
G	Current and Pending Support (NSF Form 1239)	4	
H	Facilities, Equipment and Other Resources (NSF Form 1363)	0	
I	Special Information/Supplementary Documentation	15	
J	Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

3.a. Results from PREVIOUS NSF SUPPORT

HUGO: The Hawaii Undersea Geo-Observatory

Fred K. Duennebier, Alexander Malahoff
OCE 95-28856, OCE98-18793
HUGO - The Hawaii Undersea Geo-Observatory
Award Period: 5/1/96-4/1/2001
Award Amount: $972,514; $207,314

HUGO, the Hawaii Undersea Geo-Observatory, was installed at Loihi volcano in October, 1997 and operated for 6 months. Several important tasks were accomplished, including: 1) the successful lay of the 47-km electro-optical cable from the shore of the Island of Hawaii to the summit of Loihi submarine volcano; 2) installation and servicing of a "Junction Box" on Loihi submarine volcano; 3) operation of electro-optical connectors on the ocean floor by submersible; 4) installation and removal of experiments on the ocean floor by submersible; 5) transmission of power and commands from shore to experiments installed at HUGO; 6) transmission of high-rate, high-fidelity data from the summit of Loihi to shore in real time; and 7) recording of volcanic, earthquake, biological, ocean wave, and ship noises for a period of three months. A recent test shows that the optical fibers are still intact from the shore station to the junction box. The project will continue with the recovery of the Junction Box in late 2002.

Publications from this grant:

Duennebier, F. K., D. Harris, J. Jolly, J. Caplan-Auerbach, J. Babinec, R. Jordan, D. Copson, J. Bosel, **HUGO: The Hawaii Undersea Geo-Observatory**, *IEEE Jnl of Oce. Eng.*, in press, 2002.

Caplan-Auerbach, J. and F. Duennebier, **Seismic and acoustic signals detected at Loihi seamount by the Hawaii Undersea Geo-Observatory**, *Geochem. Geophys. Geosyst, v.2,#2000GC000113, May 25*, 2001.

Caplan-Auerbach, J., C. G. Fox and F. K. Duennebier, **Hydroacoustic detection of submarine landslides on Kilauea volcano**, *Geophys. Res. Lett.*, 28, (9), 1811-1813, 2001.

Caplan-Auerbach, J. and F. Duennebier, **Seismicity and velocity structure of Loihi seamount from the 1996 earthquake swarm**, *Bull. Seis. Soc. Am.*, 91(2), 178-190, 2001.

Human resources: This grant has provided sea-going experience and primary data for the dissertation research of Jackie Caplan-Auerbach.

HUGO web site: http://www.soest.hawaii.edu/HUGO/hugo.html

H2O: The Hawaii –2 Observatory

Rhett Butler (I.R.I.S.), Alan Chave (W.H.O.I.) Fred K. Duennebier,
The Hawaii-2 Observatory
Grant #: EAR –0004370, Sub-grants through Incorporated Research Institutes for Seismology (IRIS)
Award Period: 1996-2003

The Hawaii-2 Observatory is a joint project between IRIS, Woods Hole Oceanographic Institution, and the University of Hawaii to install an ocean bottom observatory about half way between Oahu, Hawaii and California utilizing a decommissioned telephone cable donated by AT&T. The observatory, installed in 1998, is at a depth of about 5,000 meters, has been sending high-quality seismic data to the shore station on Oahu. Hawaii for more than two years. The University of Hawaii engineers who will design and build ANZCAN-ALOHA also designed and built the H2O power supply and the H2O seismic system. Reviewers are directed to the publications and web pages for more detail.

Publications resulting from this project:

Butler, R. , Chave, A. D. , Duennebier, F. K. , Yoerger, D. R. , Petitt, R. , Harris, D. , Wood - **Hawaii-2 Observatory pioneers opportunities for remote instrumentation in ocean studies**, *Eos, Transactions, American Geophysical Union* (April 11, 2000)

Duennebier, F.K., D. W. Harris, J. Jolly, J. Babinec, D. Copson, Kurt Stiffel, **The Hawaii-2 Observatory Seismic System,** IEEE Jnl. Oce. Eng., in press, 2002

David Harris, F. Duennebier, **Powering Cabled Ocean Bottom Observatories**, *I. E. E. E.*, Jnl. Oce. Eng. in press, 2002.

R. Petitt, D. Harris, B. Wooding, J. Bailey, J. Jolly, E. Hobart, A. Chave, F Duennebier, R. Butler, A. Bowen, D. Yoerger, **The Hawaii-2 Observatory**, *I. E. E. E.*, Jnl. Oce. Eng. in press, 2002.

H2O web pages: http://www.whoi.edu/science/GG/DSO/H2O/index.html
http://www.soest.hawaii.edu/h2o/

Acquisition of a Deep-Ocean Instrumented Mooring Facility at the University of Hawaii
(D. Karl, P.I., P. J. Flament and R. Lukas, co-P.I.s) OCE96-01850; 10/96-9/99; $309,500

In January 1997, with financial support from NSF (Academic Research Infrastructure [ARI] Program) and the State of Hawaii, a group of scientists from the University of Hawaii (D. Karl, P.I.; P. Flament and R. Lukas, co-PIs), Oregon State University (R. Letelier and M. Abbott), University of Washington (S. Emerson) and the Monterey Bay Aquarium Research Institute (H. Jannasch) successfully constructed and deployed a full ocean depth mooring near the HOT program Sta. ALOHA. The experiment, dubbed HALE (Hawaii Air-sea Listening Experiment; Hale is also a Hawaiian word translated “at the house of”) ALOHA. HALE ALOHA - I was configured as a semi-taut mooring consisting of a 3-m diameter Guardian style buoy with running lights, radar reflector, solar panel and Argos satellite position-only transmitter (and scientific instrumentation detailed below), 3/8" plastic jacketed torque balanced, wire rope and 3/4" chain (0-125 m), 5/16" plastic jacketed torque balanced wire rope (125-2000 m), 3/4" nylon line (2000-3500 m) -- short spliced to 3/4" polypropylene line (3500 - 5000 m), 36 - 17" glass floatation spheres on 34 m 3/8" chain (5000-5034 m), dual Benthos model 865A deep-sea acoustic releases on a stainless steel mount (5034-5035 m), 5 m of 1/2" chain (5035-5040 m), 10 m of 1" nylon line (5040-5050 m), 5 m of 1/2" chain (5050- 5055 m), 3600# (wet weight) anchor; total water depth (4830 m). Scientific instrumentation included: 2 marine anemometers, 2 meteorological probes w/multi-plate radiation shield, 1 rain gauge, 1 Precision Spectral Pyranometer w/aluminum base, 1 air/water temp difference thermocouple (experimental), 1 data logger, 1 4-channel relay driver, 1 card storage module (w/2Mb memory card), ocean temperature data loggers deployed at depths of 2 m (2 instruments attached to the subsurface portion of the buoy) and at 40, 50, 60, 80, 90, 100, 110, 120 130 and 150 m (1 instrument per depth), and a Downwelling Irradiance sensor (OCI-200, Satlantics Inc., Canada) deployed at 25 m. Seven discrete channels with 10 nm bandwidth centered at 412, 443, 490, 510, 555, 670 and 680 nm measured the downwelling irradiance which is recorded every 20 min in the data logger. Initially, the data collected were used to estimate the temporal variability of dissolved organic matter, chlorophyll and chlorophyll natural fluorescence in the upper layer of the euphotic zone at Station ALOHA (22°45'N, 158°W). The mooring was successfully recovered in May 1996, and reset at the same location. Additional instrumentation, including two water samplers (Ed Boyle, MIT; MITESS: designed for trace metal and nutrient analyses), current meters, Seacats and a cellular phone for daily data transmission and instrument interrogation, was added during the HALE ALOHA-II experiment. Since that time, the mooring was recovered and redeployed a total of five more times; the mooring configuration has remained more or less the same before the experiment was terminated in October, 2000, when the mooring was recovered for the last time. The data collected by this deep-sea mooring facility are critical for the detection and understanding of the mesoscale processes that we hypothesize are dominant causes of biogeochemical variability in this subtropical gyre habitat.

Publications resulting from this grant:

Letelier, R. M., D. M. Karl, M. R. Abbott, P. Flament, M. Freilich, R. Lukas and T. Strub, **Role of late winter mesoscale events in the biogeochemical variability of the upper water column of the North Pacific Subtropical Gyre**, *J. Geophys. Res.*, 105, 28,723-28,739.

Emerson, S., C. Stump, B. Johnson and D. M. Karl, **In situ determination of oxygen and nitrogen concentrations in the upper ocean**, *Deep-Sea Res. I,* in press, 2002.

3.b. Research Activities

3.b.1. Project Goals

The goal of the ANZCAN-ALOHA Observatory project (AAO) is to establish observatory infrastructure at Station ALOHA for the next generation of the Hawaii Ocean Time-series and other observation systems. AAO will provide power to scientific equipment and real-time two-way communication between experiments and scientists for at least the next ten years. The resulting continuous monitoring will enable scientists and students to detect trends in variations in this important environment that are not well observed by standard ship-based observations. AAO will be designed for maximum flexibility, with the ability to support a wide range of experiments, from simple listening devices to vertical arrays with ports for removable sensor systems. Observing systems from the deep ocean floor to the ocean surface can benefit from AAO.

We will retrieve part of the retired ANZCAN telecommunications cable, and terminate it with a deep-sea junction box, providing attachments for a variety of sensors to measure under-explored variability. Moving the cable to Station ALOHA, and termination of the cable to prepare for the AAO represents almost 75% of the cost of this proposal. The remainder will fund the design and construction of the cable termination, junction box, shore station electronics, and control station. We plan to install a "mini" junction box at AAO during installation cruise that will immediately support two-way acoustic data transfer with instrument systems. Installation of a junction box that will allow hard-wire connections to AAO will need to wait for a later cruise with an ROV and additional funding. Note that, with the exception of the cable and termination, the system will be completely replaceable if new technologies present better ways of delivering power and data to and from the AAO.

Reviewers and agencies should be aware that this model of a cabled observatory requires the use of remote operating vehicles (ROV) or submersibles capable of working at depths of 5 km to install and service instrument systems and infrastructure. Since there are very few vehicles that can reach the deep ocean floor, and those are heavily scheduled, the lack of support assets in the community could seriously limit the cost effectiveness of this type of observatory. Serious funding of deep ocean observatories will require substantial parallel support of additional submersible assets and sensor system technologies (National Research Council, 2000).

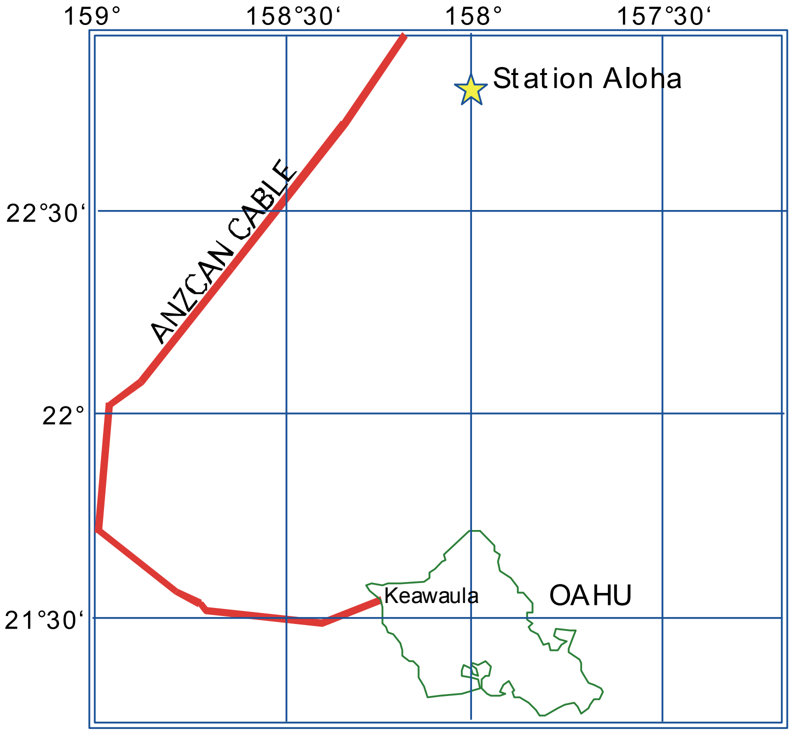


FIGURE 1. ANZCAN-D cable segment. The cable comes ashore at the Keawaula Cable Station on Oahu and passes within 26 km of Station ALOHA, the proposed location of the ANZCAN-ALOHA Observatory.

3.b.2. SCIENCE:

3.b.2.a: The HOT Program

Long time-series measurements of ocean variables in the deep ocean are still very rare, even though any understanding of the variable ocean and its ecosystems demands such information. The HOT program was initiated by UH professors David Karl and Roger Lukas in late 1988 with support from the National Science Foundation and the State of Hawaii (Karl and Lukas, 1996). The driving rationale behind the HOT program is to sample the North Pacific Subropical Gyre, one of the largest circulation patterns on the earth, and establish base line data for its characteristics and variations. Since 1988, approximately 10 research cruises (4-5 days duration) per year have been conducted to the HOT deep ocean Station ALOHA (22°4'5N, 158°W, FIGURE 1) to measure biogeochemical and physical properties of the water column from the surface to the sea floor at a depth of 5000 m. Dozens of research projects have been conducted by scientists from all over the world at this site, leveraging the infrastructure that has been provided by the two core projects initially funded under the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS) auspices. Many papers have been published in prestigious scientific journals (http://hahana.soest.hawaii.edu/hot/hotpub.html), documenting many new and unexpected discoveries. One of these is the discovery that the ecological balance of the central North Pacific subtropical gyre is strongly affected by the climatic variations on inter-annual through decadal time scales (Karl et al., 2001).

The effort and cost of going to sea nearly every month are considerable, yet even these intensive, but short cruises are not sufficient to observe all the important variations that occur. Rapid changes and high frequency variations, if not measured, confound our ability to understand the dynamics that are responsible for variations that occur over years. Data taken during these cruises often show considerable variation that cannot be explained by instrumental noise or errors, implying that variations with periods shorter than about two months are aliased into the data. Aliasing causes variations generated by phenomena such as tides, storms, internal waves, mesoscale eddies, and dust deposition events to contribute to energy observed at periods longer than twice the sample period (about two months). Since aperiodic events with time scales of weeks to months appear to dominate the dynamic height signal to such an extent that there is no clear annual cycle, the need for continuous high sample rates is very clear. "Burst sampling" (Karl and Winn, 1991, Chiswell, 1994) during HOT cruises helps to define the energy at tidal and diurnal periods, but a sampling gap at periods shorter than two months and longer than two days is still present. Contributions by stochastic transient events are certainly missed, although their effects are likely to contribute to transfer of nutrients and energy to the euphotic zone. From 1997 through 2000, a mooring was maintained not far from Station ALOHA to capture these variations, but continuing this mooring required additional funding that has not been obtained. If AAO becomes a reality, HOT research will be strongly augmented by experiments and monitoring in real-time at high rates with reduced need for routine servicing.

After 13 years of operation in the very successful, but challenging mode of monthly cruises, we propose to develop the infrastructure to enable transition to a new mode of continuing this important interdisciplinary research program. This new mode will involve a considerable reliance on remotely operated technology, increasing over time, with less frequent, longer research cruises to conduct innovative new in situ process studies within the framework of the HOT deep ocean laboratory and AAO. In addition to maintaining the observatory measurement systems, these cruises will also include testing of new technology to enhance the capability and scope of autonomous measurements. New variables will be observed through this technology development, and more of the measurements will be reported to shore in real-time.

The National Academy of Sciences Ocean Studies Board report (NRC, 2000), “Illuminating the Hidden Planet: The Future of Seafloor Observatory Science”, addresses this new paradigm for ocean research. The report describes scientific challenges that can only be met with new time-series information, and articulates the requirements for a network of cabled and autonomous seafloor observatories that include the use of moored sensors and remotely-controlled autonomous vehicles. In addition to enhancing the ability of the marine science community to study and understand variations of interdependent marine systems, this report envisions the acquisition and distribution of real-time data such that information about the evolving state of the ocean can be made widely available. Bringing the ocean into schools and homes around the world will capture the fascination of young children and the voting public, including senior citizens. It will also provide an opportunity for science and mathematics education, a major objective set out for the NSF by its governing body, the National Science Board.

A number of prototypical seafloor observatories are in operation, including LEO-15 offshore of New Jersey (Traykovski, et al, 1999) and the Hawaii-2 Observatory, half way between Hawaii and California (Petitt, et al, in press). Such pioneering activities are crucial for identifying the many challenges and their solutions for implementing the vision of the NAS report. These issues include sensor design, standards, and governance.

Development of new optical, chemical, and biological sensors affords new opportunities for experimentation in the deep ocean that can capitalize on the capabilities of a cabled observatory (Dickey et al., 1997; Chavez el al., 1999; Johnson et al., 2000). To support experiments and monitoring with such sensors, a McLane Moored Profiler (MMP) (Morrison, et al., 1999) can be deployed and coupled acoustically to the AAO junction box. The concept of acoustic links has been used with mixed success by several groups, and is currently in testing by the MMP group (John Toole, personal communication). The MMP is deployed on a taught-wire mooring, climbing up and down the wire under program control measuring pressure, temperature, conductivity, and velocity. Other sensors can be integrated, dissolved oxygen and fluorescence, for example. Because the MMP mooring will not be physically attached to the seafloor junction box, recovery and redeployment can be done without a remotely operated vehicle. While the MMP is self-powered, observations will be available in real-time, allowing anyone to access the latest profiles. We plan to have two-way communications with the MMP, allowing us to change the profiling program when unexpected events require closer inspection. This ability to adapt sampling based on the latest information is a critical aspect of shipboard work that is only made possible by the real-time observatory. Meteorology and surface optics, ocean physics, biogeochemistry, and bio-optics are all fields that can benefit from AAO. A solar-powered AUV that will soon be tested for use at Station Aloha could communicate with the AAO to dump data and receive instructions.

With this system in place, we should be able to observe cold bottom water overflow events from the neighboring Maui Deep (Lukas et al., 2001), for example, and then make more frequent profiles near the bottom in order to observe the recovery of the thermal structure by turbulent diffusion over the following months. It would even be possible to make measurements frequently enough that we could begin to understand why levels of turbulence appear to be so high after such overflow events. The high-salinity intrusions that episodically appear at depths from 500 m to 1200 m (Kennan and Lukas, 1996) are another example where conditional sampling would allow us to better understand water mass variability.

The study of turbulence in the ocean is frustrated by technical issues (some of which have been overcome recently) and by sampling issues. Turbulence is very important for mixing of heat, salt, nutrients and other biochemical compounds, but while its effects are long lasting, the turbulent motions are intermittent. Parameterizing the effects of these small-scale motions requires an understanding of the processes that modulate turbulent kinetic energy and the pathways by which this energy is created. This requires long, simultaneous measurement of macro-scale motions and stratification, collocated with turbulence measurements (National Research Council, 2000). We would strive to incorporate a high-frequency acoustic Doppler current profiler (ADCP) into the AAO to accomplish this for the cold overflow events. Here, the ability to power the ADCP would be a major factor in its longevity, and would greatly reduce required maintenance. In turbulence measurement mode, such an instrument requires many Mb/day of data to be stored, and it is not feasible to make long deployments with an internally-recording system. Bringing the data back to shore via cable is critical to the feasibility of such an experiment.

Eulerian vs. Lagrangian:
Much of the ocean observing strategy is presently focused on Lagrangian systems, such as surface drifters and profiling ARGO floats (http://www.argo.ucsd.edu/ : US CLIVAR SSG).. Data from drifters and from satellite observations are limited to near-surface measurements, while temperature and salinity profiles from Argo floats will be sparse and only reach to 2000 m. While these measurements are extremely valuable, they require assimilation into state-of-the-art ocean general circulation models in order to describe climate signals such as the decadal variations of salinity in the thermocline near Hawaii associated with slow changes in rainfall over the North Pacific (Lukas, 2001). Such observational-analysis systems require verification by comparison with high quality Eulerian (fixed) time series. In addition, the strong variations of the slow circulation and episodic mixing events of the deeper ocean must be measured to complete the picture. Towards this end, Eulerian systems, such as AAO must be included in the observing strategy to effectively verify and improve models of deep-ocean variability.

3.b.2.b : Ocean bottom Ecology: Variations in the deep ocean floor ecology and biosystems are almost completely unknown. AAO will provide a base for study of such variations to be studied by Ken Smith and others using an autonomous bottom crawler and camera system with docking capability to the AAO. (see attached letter).

3.b.2.c: Earthquakes and tsunami:
Oceanographic measurements are the prime motivation for establishing an observatory at Station ALOHA, but the site is also an excellent location for observation of earthquakes and tsunami. A seismic system(Similar to that used in the Hawaii-2 Observatory, (Duennebier, et al, in press), including seismometers, acoustic monitoring sensors, and a pressure sensor for measurement of tsunami as they approach the Hawaiian Islands, will be an important

instrument for future emplacement at AAO. Recent studies (Bromirski, et al, 1999) imply that seismic noise levels can be used as a proxy for the ocean wave spectrum and wind speed, observing sea conditions without a surface buoy.

3.b.2.d: Acoustic Thermometry:
Station Aloha can provide a listening post for acoustic thermometry, (Worchester,1999) measuring average temperature variation across large sections of the ocean from changes in acoustic travel times. Although the data are relatively high-rate, they are intermittent, and can be stored in the sensor package for transmission to shore in the available bandwidth.

3.b.2.e: High-energy physics:
Physicists have been attempting to observe high-energy neutrinos by observation of light emissions in the deep ocean. One such system has recently been installed in the Mediterranean Sea (http://www.nestor.org.gr/). AAO could provide the infrastructure for testing prototype sensors and arrays.

3.b.3: Options other than AAO for use of the cable:
There are other options for use of the ANZCAN cable for scientific use, including using it for a Juan de Fuca observatory, or similarly to the Hawaii-2 Observatory. While the cable crosses the Juan de Fuca spreading center, it is too far from Hawaii to be able to provide significant power to an observatory there. Use for another observatory in the middle of the eastern Pacific, much like a second H2O, appears to lack science support.

There is some question as to whether it would be reasonable to install the proposed AAO at the current location of the cable, rather than moving it 26 km to Station ALOHA at considerable expense. After much thought, we propose to move the cable. Otherwise, the climatology that has been built up over 13 years will be much less useful for some purposes, not all of which can be known at this point. In addition, we would lose all possibility of observing the abyssal cold overflow events in real-time and in detail, making the AAO less interesting for the study of deep-sea physics. That is because of the present location of ALOHA relative to the sill between the Maui Deep and the Kauai Deep. We have observed temporal variations in near-bottom vertical eddy diffusivity that range nearly two orders of magnitude. We need to understand the physics of this if we are ever to develop a parameterization of vertical mixing near the seafloor that includes such potentially important temporal variations.

3.c. Instrumentation and Needs

3.c.1 PHYSICAL DESCRIPTION:

3.c.1.a. ANZCAN cable:

We are fortunate that Station ALOHA lies within 26 km of the ANZCAN coaxial marine telecommunications cable, installed in 1983 and retired from service in 1997. The last section of the ANZCAN was recently shut down, and the more than 50 associated electronic racks are currently being removed from the Keawaula Cable Station on Oahu. The University of Hawaii is negotiating with Teleglobe, Inc. to obtain ownership of the cable and its spares for observatory use, and indications are that this transfer of ownership will be approved. Without the protection provided by active use, the cable could be removed from the cable station and shore conduits, rendering it useless. The projected lifetime of the cable is at least thirty more years, as the system has shown no degradation since shortly after its installation. It was retired because newer electro-optical cables have orders of magnitude more capacity at about the same operating cost. This cable can provide more than a kilowatt of power to the observatory and transmit data at rates of more than 2 mBaud. The available bandwidth of the ANZCAN cable is about 14 times that of the Hawaii-2 cable used for the Hawaii-2 Observatory (Petitt et al, in press). The cable has been removed from the continental shelf off the coast of Canada to prevent liability from fishing.

3.c.1.b: System description:

The ANZCAN-ALOHA Observatory will consist of several sub-systems:1) the command center, 2) shore station, 3) main cable, 4) cable termination, 5) junction box, 6) experiment nodes, and 7) instruments. Much of the system is patterned after the Hawaii-2 Observatory (Petitt et al, in press), which operates on a similar, but older, coaxial cable. Instruments will be connected to the junction box or experiment nodes that will condition power for distribution to the instruments and format and multiplex data for transmission to the junction box. Autonomous (self-powered) instruments will be able to communicate with the observatory by low-power two-way acoustic telemetry, while high data rate and high power instruments will be connected by wire to the observatory. We expect to deploy a programmable acoustic beacon/transponder in the water column to link the AAO with autonomous instruments. While this technology is still in testing and optimal data rates and granges are still to be determined, AAO should be well suited to acoustic communication.

The junction box provides the central hub for power distribution and data transmission. It is connected to the main cable termination by an underwater mateable connector to allow recovery without lifting the cable back to the surface. In this way the capabilities of the system to deliver power and data can be expanded as demand grows and as technology improves. While the power system for AAO will be nearly identical to that used for H2O (Petitt et al, in press), the data telemetry system will be very different, since the capacity of ANZCAN is about 14 times that of Hawaii-2. If a similar data scheme were used, we would need to house more than 200 modems in AAO compared to 20 in the H2O junction box. Initially, we plan to install a relatively simple junction box that will have very high reliability at the expense of relatively low data rates (about 2 MBaud). Note that this rate is still far higher than is economical using satellite telemetry from a buoy. The large available bandwidth allows us to use broad-band modems that are far less efficient in bandwidth than modern telephone system modems but far less demanding in signal-to-noise specifications, resulting in higher reliability of the data link.

The junction box will be similar to that built by Woods Hole Oceanographic Institution and the University of Hawaii for the Hawaii-2 Observatory. (FIGURE 2) It will contain submersible-mateable connectors for installation of instrument systems that will each provide data and command channels and protected electrical power for experiment systems. We will transmit data to shore in real-time serial format rather than in Internet protocol, making it unnecessary to label data packets with their transmission time, or to store data on the ocean floor. The junction box will be replaceable, allowing upgrades for all observatory components (except the cable itself) as new technology becomes available. The limiting technology will likely be the constant-current cable power system, which cannot be replaced since it is necessary to operate the repeaters. Power to the AAO can be increased by increasing the voltage on the cable, but higher voltage has the price of higher risk of failure, particularly at connectors.

The cable termination is a passive frame and underwater mateable connector that the junction box plugs into. This high-reliability device cannot be easily replaced, and thus contains no electronics or failure-prone systems. It will be installed (with a mini-junction box during the installation cruise. The other end of the ANZCAN cable is terminated on Oahu at the AT&T Keawaula Cable Station on the Makaha coast. We have been assured that space can be made available at the cable station for the AAO systems, including power supply, telemetry systems, data formatting computer, and system monitor. Data will be transmitted via frame relay link using Internet protocol over land telephone lines from the cable station to the command center at the University of Hawaii. Data will be stored at the cable station in a ring buffer in case the link between the cable station and the University is lost. Power and commands to experiments will be controlled at the command center at the University, and data will be archived and immediately passed to the scientists via the Internet.

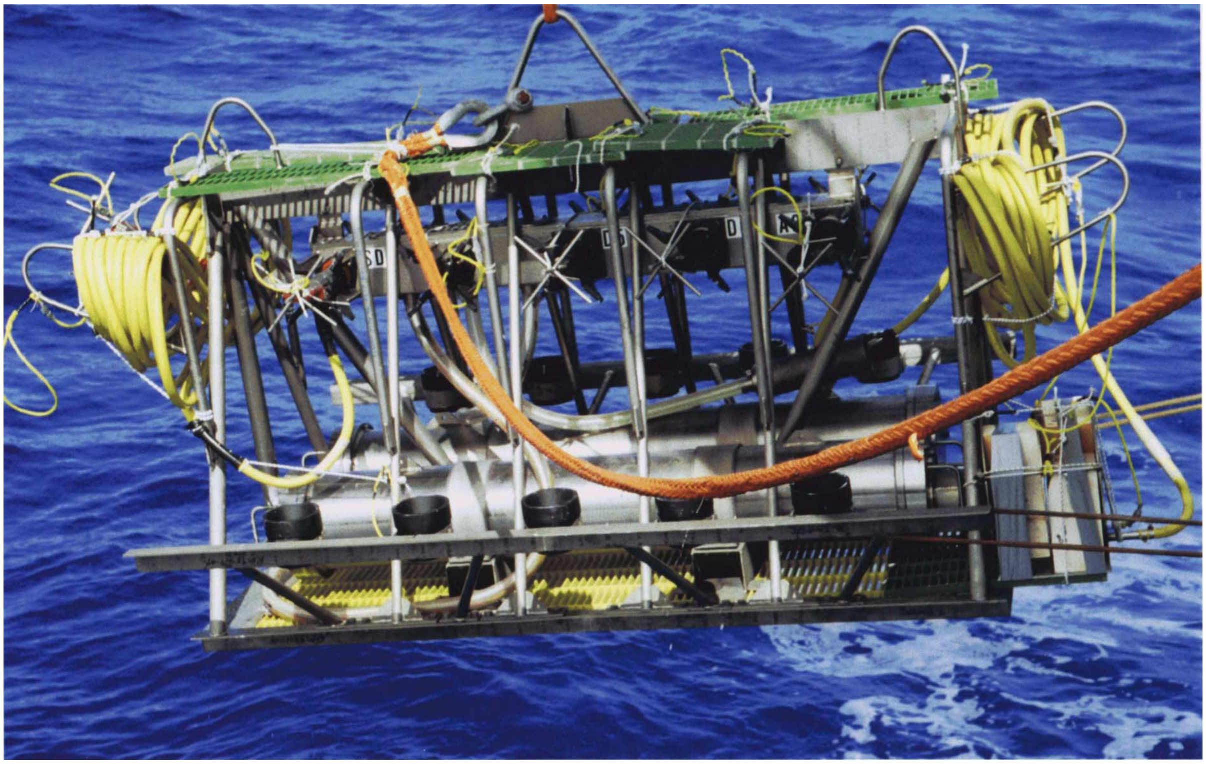


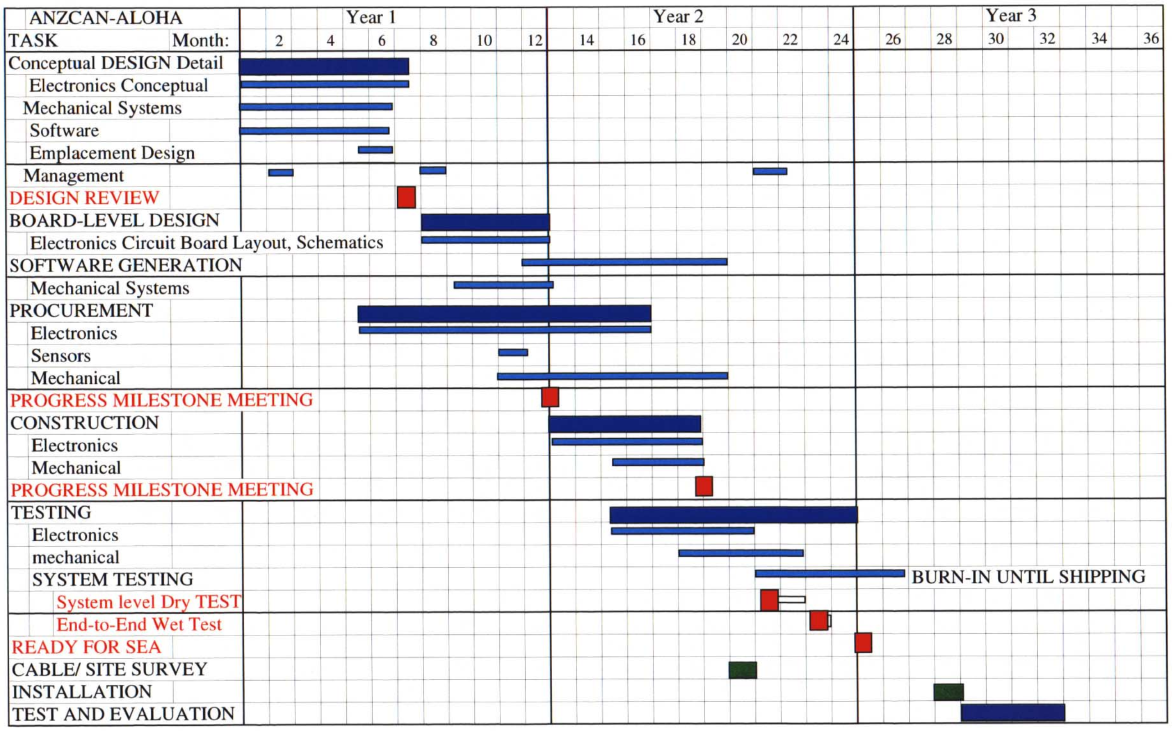
Figure 2. The ANZCAN-ALOHA Observatory junction box will be similar to the junction box above, built by Woods Hole Oceanographic Institution and the University of Hawaii for the Hawaii-2 Observatory.

3.c.1.c: Schedule:

The table below shows our intended development schedule for the AAO system. Procurement of some electronics components is begun before completion of circuit board design so that the form factors of available components can be used in board design. Funding for the site survey cruise will be requested separately.

3.c.1.d: Installation:

Partnering:
Installation of the observatory infrastructure will be a sizeable cost of this project, requiring close coordination between the University of Hawaii system developers and the group providing installation services. For this reason, we have chosen to enter into a partnership with MariPro, Inc. for this project to insure close communications between these two important tasks. MariPro personnel and equipment were used to install the HUGO system (Duennebier et al, in press), with excellent results. Cable laying precision was so good that only about 100 m of extra cable was left at the tie point after deploying 47 km of cable. MariPro is used extensively for cable laying by the US Navy and by other academic groups (see additional materials).



ANZCAN-ALOHA Observatory development schedule.

Installation scenario:
The following scenario is driven by two facts: 1) the cable just north of the point where it will be moved rests on relatively fresh Hawaiian arch lava flows (FIGURE 3) (Clague et al, 1990). It would be extremely risky to cut the cable and lift it to the surface within these flows. 2) Extra cable lying on the ocean floor is available to the east of the site, where it can be relatively easily recovered, cut, and used for the red section in Figure 3.

Prior to the installation cruise, all shore station hardware will be installed in the AT&T Keawaula Cable Station on the west side of Oahu, where the end of the cable is currently available. While space in the station is at a premium, we have been assured that limited space can be found for our hardware.

Abbreviated installation procedure:

1. Mobilization:
    a. UNOLS vessel arrives at Port Hueneme, CA
    b. Cable handling equipment (linear engine, chute, gantry, cable pan, splicing gear) loaded, secured, and tested
    c. Cable termination, mini-junction box, test systems loaded on vessel.
2. Cable recovery:
    a. Vessel transits to cable recovery location
    b. Cable is cut (see "survey" below) and Hawaii-end recovered
    c. Cable is tested from Hawaii to insure operation of all repeaters
    d. 30 km of cable, including 2 repeaters are recovered
3. Cable cut:
    a. Vessel transits to closest-approach to Station ALOHA
    b. During transit, the AAO cable termination is spliced to 30 km section on board
    c. Ship cuts and recovers Hawaii-end of cable (Figure 3).
    d. Cable is spliced to the 30 km section on-board.

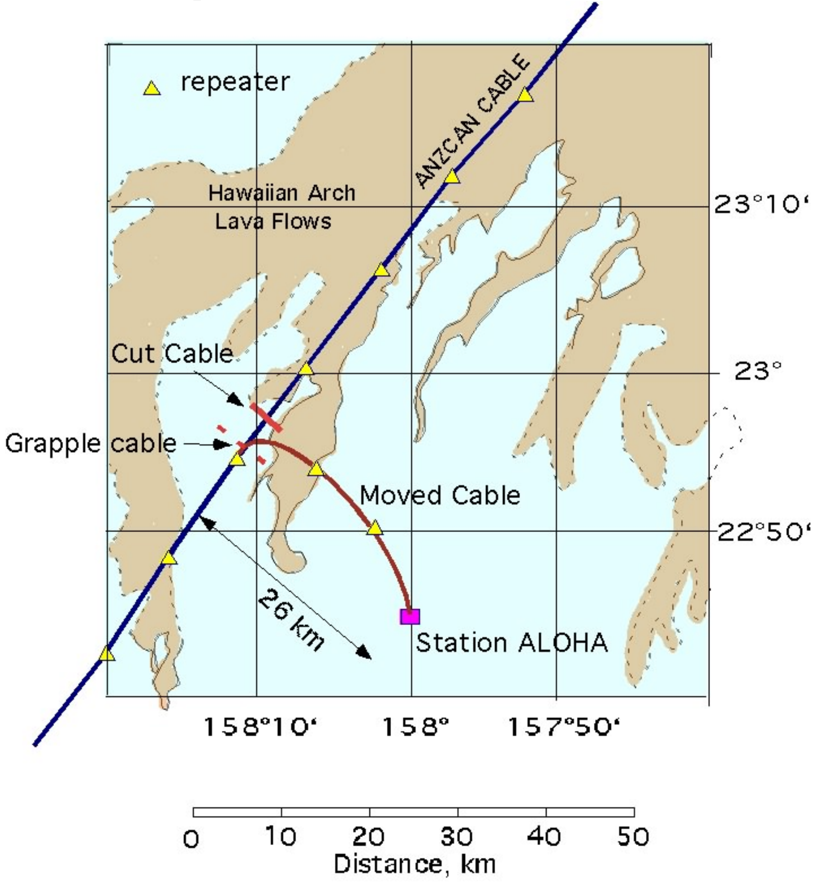


Figure 3. Map of the Station ALOHA area. The cable shown in red is moved from an area (off the map) to the north east where the cable can be recovered from sediment-covered ocean floor, rather than lava covered ocean floor.

4. Deploy:
   a. Ship moves to Station ALOHA, deploying cable.
   b. Cable and observatory systems are tested during transit.
   c. Termination and junction box are lowered to sea floor at Station ALOHA.
5. Demobilization:
   a. Vessel transits to Honolulu for debarkation of science and installation personnel, and possible further cable work
   b. Ship transits to Port Hueneme for demobilization.

After this step, the observatory will contain a hydrophone and acoustic transponder that will transmit data from any acoustically coupled systems at the observatory. Thus, even without a visit from an ROV, the observatory can begin functioning.

3.c.1.d: Cable survey:

MariPro, Inc. has suggested that it would significantly increase odds of success if the cable were located and surveyed in the areas where it will be cut and moved prior to the installation cruise. Towards this end, we will propose a survey cruise under separate funding. During that cruise, using an ROV to survey the cable on the bottom, we could make the initial cut of the cable (step 2.b. above) to save time during the installation cruise.

3.d. Broader Impact

The ANZCAN-ALOHA Observatory will likely become an international hub of oceanographic observatory activity (Figure 4). Improved understanding of climate variations appears to be critical as we observe rapid changes in ice thickness and glacier retreat on land. Similar long-term changes modulated by other phenomena are likely to be observed in the ocean also, but, without continuous long-term records of these variations, we have little on which to base predictions of the future. Measurements at sites such as Station ALOHA, augmented by the proposed permanent observatory facility, are one step in this process of accessing global changes in the climate.

3.d.1: OUTREACH**:**

In addition to enhancing the ability of the marine science community to study and understand variations of interdependent marine systems, we envision an outreach program such that information about the evolving state of the ocean can be made widely available and easily understood by the general public. Bringing the ocean into schools and homes around the world will capture the fascination of both young children and senior citizens. It will also provide an exciting opportunity for science and mathematics education, a major objective set out for the NSF by its governing body, the National Science Board. While some parameters require years of data recovery before trends can be established, the observatory will also make available earthquake and tsunami recordings, and even the songs of whales as they approach the Hawaiian Islands for their winter stay. We envision the AAO data as available to the public through a central facility, such as UCAR, that would compile and filter oceanographic and environmental data from many sources for distribution. A concerted effort by educational specialists at such a facility will result in far more useful and easily available products than could be supplied by individual groups. We will strongly support such efforts, and look forward to providing data and information from AAO.

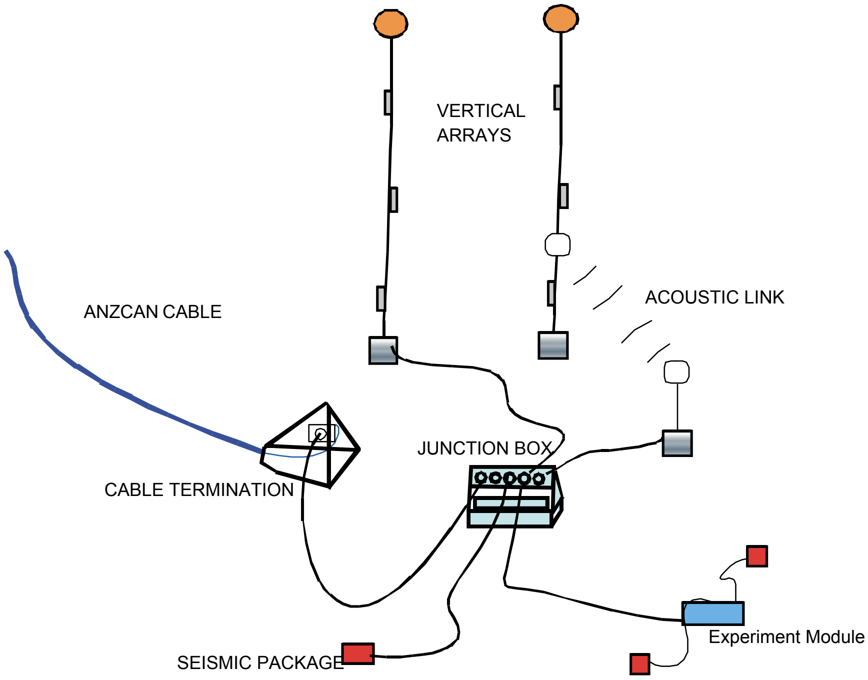


Figure 4. ANZCAN-ALOHA Observatory as it might appear in 2007.

3.e. MANAGEMENT:

During the design and development stage of AAO, decisions will be made by the P.I. and the SOEST engineering team with advice from the MariPro group and from a design review to be scheduled approximately 6 months after funding start. We will invite experts in cable power systems, data transmission, and marine instrumentation to attend this review, as well as potential users. For logistical reasons, the Command Center will be located at SOEST, and a system test bed where experiments are tested and approved for inclusion in the system would also be located at SOEST. To insure proper documentation of the observatory systems, we will hire a student in technical writing to aid us in producing useful and readable manuals and reports

We envision this observatory as a "national facility" available to any funded project that has sensor systems that conform to the requirements of the observatory for power and data protocols, regardless of institutional affiliation. Publicity on the availability of this resource in the form of a web site and mailing lists will begin as soon as funding is assured. As candidate experiment systems are completed, they will be tested prior to emplacement to insure nominal operation and system safety at the system test bed. Observatory data will be made public immediately or as quickly as practical.

When the AAO is well established, but before resources begin to reach saturation, we expect that an advisory group made up principally of users will direct policy and make decisions on how resources (power, bandwidth, ship time, etc.) would be allocated. As a heavily involved and conflicted player, SOEST should not be directly involved in determination of the selection of this group, or its purview. We will request the support of the NSF to attack this issue at the appropriate time.

Proposer Qualifications:

Duennebier and Harris have considerable experience in the design, installation and operation of cabled observatories on the ocean floor beginning in 1981 with a deep-ocean borehole seismometer (Byrne et al., 1987), an ocean floor fiber-optic seismic system for the Navy in 1991 (Duennebier et al., 1991), and the HUGO system in 1997 (Duennebier, et al. A, in press). They currently have operating responsibility for the Hawaii-2 Observatory (H2O), connected to the retired Haw-2 coaxial cable. The observatory is located about half way between Hawaii and California in 5 km of water. The SOEST engineering group designed and constructed the seismic system and power supply for the observatory junction box. The observatory has been transmitting data to Hawaii continuously for more than two years (Petitt, Duennebier et al, in press).

Lukas and Karl have been instrumental in the success of the HOT program, and have been the principal investigators and authors of numerous scientific papers related to data obtained at Station ALOHA.

Bromirski, Peter D., Flick, Reinhard E., Graham, Nicholas, **Ocean wave height determined from inland seismometer data; implications for investigating wave climate changes in the NE Pacific,** Journal of Geophysical Research, C, Oceans, 104 (9), p. 20,753-20,766, 1999.

Byrne, D.A., D. Harris, F.K. Duennebier, and R. Cessaro**, 6. The Ocean sub-bottom sesimometer system installed in DSDP hole 581C, Leg 88: a technical review,** *Init. Repts. DSDP, 88*, Washington (U.S. Govt. Printing Office), 65-88, 1987.

Chavez, F.P.,P.G.Strutton, G.E. Friederich, R.A. Feely, G.C. Feldman. D.G. Foley, and M.J. McPhaden, **Biological and chemical response of the equatorial Pacific to the 1997-1998 El Nino**, Science, 286, 2126-2131, 1999.

Chiswell, S.M.: Vertical structure of baroclinic tides in the central North Pacific subtropical gyre. J. Phys. Oceanogr., 24, 2032-2039, 1994.

Clague, David A., Holcomb, Robin T., Sinton, John M., Detrick, Robert S., Torresan, Michael E, **Pliocene and Pleistocene alkalic flood basalts on the seafloor north of the Hawaiian Island***s*, Earth and Planetary Science Letters, 98 (2), p. 175-191 .,1990.

Dickey, T.D., D. Frye, H. Jannasch, E. Boyle, and A.H. Knap**, Bermuda sensor system test bed**, Sea Tech., 38(4), 81-86, 1997.

Duennebier, F.K., D. W. Harris, J. Jolly, J. Babinec, D. Copson, K. Stiffel, **The Hawaii-2 Observatory Seismic System**, IEEE Jnl. Oce. Eng., Spec. Issue, in press.

Duennebier, F.K., D. Harris, J. Jolly, J. Caplan-Auerbach, J. Babinec, R. Jordan, D. Copson, J. Bosel, **HUGO, The Hawaii Undersea Geo-Observatory**, IEEE Jnl. Oce. Eng., Spec. Issue, in press.

Duennebier, F.K., D. Harris, S. Poulos, B. Hahn, J. Babinec, J. Bosel, J. Dafoe, P. Lyle, W. Lyle, C. Ison, P. Mahosky, J. Glynn, W. McBride, and T. Payne, **Geoacoustic Noise from 0.1 to 100 Hz Recorded Off Oregon: The ULF/VLF Experiment**, in *Oceans '91 Proceedings* V 1, Honolulu, IEEE, 107-110, 1991.

Johnson, K.S., V.A. Elrod, J.L.Nowicki, K.H. Coale, and H. Zamzow, **Continuous flow techniques for on-site and in situ measurements of metals and nutrients in sea water**, in : In situ Monitoring of Aquatic Systems: Chemical Analysis and Speciation, J. Buffle and G. Horvai, eds. John Wiley, 2000.

Karl, D.M. and R. Lukas: **The Hawaii Ocean Time-series (HOT) Program: Background, rationale and field implementation**, Deep-Sea Res. II, 43, 129-156, 1996.

Karl, D.M. and R. Lukas: **The Hawaii Ocean Time-series (HOT) Program: Background, rationale and field implementation**, Deep-Sea Res. II, 43, 129-156, 1996.

Karl, D.M., and C.D. Winn, **A sea of change: Monitoring the oceans' carbon cycle**, Environ. Sci. Tech., 25, 1976-1981, 1991.

Kennan, S.C. and R. Lukas: **Saline intrusions in the intermediate waters north of Oahu, Hawaii**. Deep-Sea Res. II, 43, 215-241, 1996.

Lukas, R.: **Freshening of the Upper Thermocline in the North Pacific Subtropical Gyre Associated With Decadal Changes of Rainfall**. Geophys. Res.Lett., 28, 3485-3488, 2001.

Lukas, R., F. Santiago-Mandujano, F. Bingham and A. Mantyla: **Cold bottom water events observed in the Hawaii Ocean time-series: Implications for vertical mixing**. Deep-Sea Res. I, 48 (4), 995-1021, 2001.

Lukas, R.,et al: **Cold bottom water events observed in the Hawaii Ocean time-series: Implications for vertical mixing**. Deep-Sea Res. I, 48 (4), 995-1021, 2001.

Morrison, A.T., J.M. Toole, R. Lukas, S.E. Worrilow, and K. W. Doherty, **Results from the first successful deployment of the McLane Moored Profiler**, Proc. IEEE 6th Working Conference on Current Measurements, p 144-149, 1999.

National Research Council: **Illuminating the Hidden Planet: The Future of Seafloor Observatory Science**. National Academy Press, Washington, D.C., 135 pp, 2000.

R. Petitt, D. Harris, B. Wooding, J. Bailey, J. Jolly, E. Hobart, A. Chave, F Duennebier, R. Butler, A. Bowen, D. Yoerger, **The Hawaii-2 Observatory**, *I. E. E. E.*, Jnl. Oce. Eng. in press, 2002.

Traykovski, P., Hay, Alex E., Irish, James D., Lynch, James F., **Geometry, migration, and evolution of wave orbital ripples at LEO-1**5, Journal of Geophysical Research, C, Oceans, 104 (1), p. 1505-1524, 1999.

U.S. CLIVAR Scientific Steering Committee, 2000: **Implementing US CLIVAR 2001-2015**. U.S. CLIVAR Office, Washington DC. (Available at http://www.usclivar.org/USCLIVAR_V1/IMPL_PLANS/US_CLIVAR_IP.HTM)

Worcester, P. F., B. D. Cornuelle, M. A. Dzieciuch, W. H. Munk, B. M. Howe, J. A. Mercer, R. C. Spindel, J. A. Colosi, K. Metzger, T. G. Birdsall, and A. B. Baggeroer, "**A test of basin-scale acoustic thermometry using a large-aperture vertical array at 3250-km range in the eastern North Pacific Ocean,**" *J. Acoust. Soc. Am.*, **105**,(6), (1999)