H2O: The Hawaii-2 Observatory

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A permanent deep ocean scientific research facility—the Hawaii-2 Observatory or H2O—was installed on the retired HAW-2 commercial submarine telephone cable in mid-1998. H2O consists of a seafloor submarine cable termination and junction box in 5000 m of water located halfway between Hawaii and California. The H2O infrastructure was installed from a large research vessel using the Jason ROV and standard over-the-side gear. The junction box provides two-way digital communication at variable data rates of up to 115 kbit/s using the RS-422 protocol and a total of 400 watts of power for both junction box systems and user equipment. Instruments may be connected by an ROV to the junction box at 8 wet-mateable connectors. The H2O junction box is a “smart” design which incorporates redundancy to protect against failure and with full control of instrument functionality from shore. Initial instrumentation at the H2O site includes broad-band seismometer and hydrophone packages.

1. INTRODUCTION

The Hawaii-2 (HAW-2) submarine telephone cable was laid in 1964 between San Luis Obispo, California, and Makaha, Oahu, Hawaii. It is a second generation vacuum tube repeater (AT&T SD series) analog system [1] which continued in service until 1989, when a cable break off California led to its retirement from commercial service. In 1996, the entire HAW-2 wet plant was acquired by the Incorporated Research Institutions for Seismology (IRIS) from AT&T on behalf of the US scientific community.

H2O was installed close to the midpoint between two repeaters (which are spaced 20 nm apart) near 28°N, 142°W at about 5000 m water depth (Figure 1). The lithosphere west of 140°W in this area was formed between the Pacific and Farallon plates under normal spreading conditions, but at a fast half rate of 7 cm/y [2,3]. The crustal age based on magnetic lineations is about 45 Ma (isochron 20) or mid-Eocene. The regional physiography is one of abyssal hills with a nominal but variable 50-100 m cover of terrigeneous clay sediment. The local relief around the H2O junction box is quite subdued; a deep-towed survey for 1 km around that point reveals no rock outcrops and very gentle relief of a few tens of meters on a smoothly sedimented bottom.

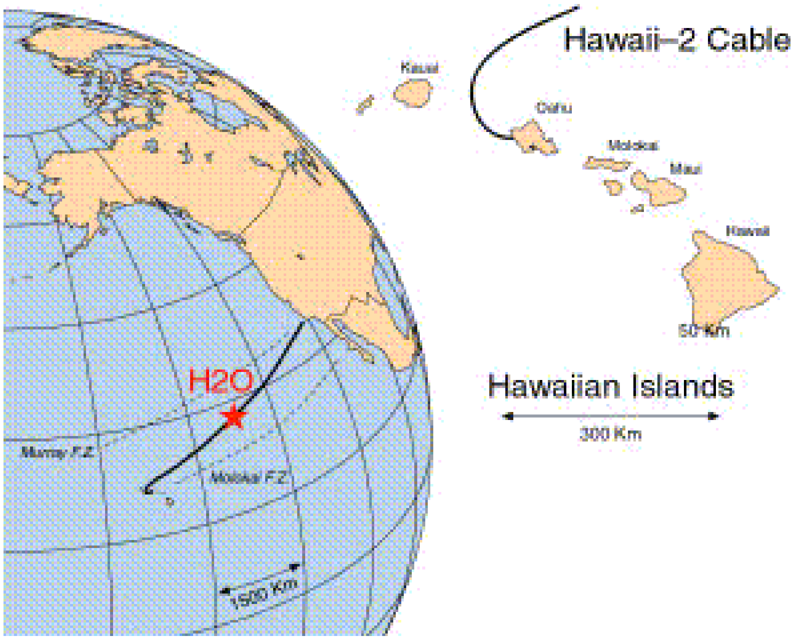

Figure 1. The Hawaii-2 Observatory is sited 1750 km east-northeast of Honolulu. The path of the Hawaii-2 cable runs between Oahu and Kauai, then heads northeast toward California

The science drivers behind the installation of H2O are primarily in global geophysics, especially seismology. The H2O site is located at a point on Earth's surface where there is no land for about 2000 km in any direction. For this reason, it is a high priority site for the Ocean Seismic Network (OSN) component of the Global Seismic Network (GSN) [4], and serves as the first operational OSN station. While the present H2O seismometer utilizes a buried broadband sensor, the Ocean Drilling Program (ODP) is scheduled to drill a re-entry borehole close to the H2O site at the end of 2001 for subsequent installation of a downhole seismometer. The H2O site is also one of eight seafloor locations identified by the geomagnetic community where permanent observatories are required [5]. Finally, H2O is located at a logistically-convenient place for testing permanent seafloor instrumentation and observatory concepts in the deep ocean.

2. SHORE INSTALLATION

Originally, HAW-2 was powered both from the California and Hawaii ends of the system using opposite polarity power supplies and a telecommunications-standard seawater return. In 1992, the California end of HAW-2 from the shore station out to deep water was removed by AT&T, and hence H2O was designed to be a single-end system powered from Hawaii with a local sea ground. Because the shore plant had been removed from the Makaha cable station, this also required the re-installation of high voltage power supply and high (radio) frequency line equipment.

In the original HAW-2 installation, Makaha was a B terminal with a negative power supply operating at a nominal 5000 V and low band (150-550 kHz) receive/high band (650-1050 kHz) transmit, yielding 138 3 kHz analog frequency domain multiplexed telephone channels. The original performance characteristics of the system were maintained at re-installation by using actual SD shore equipment previously salvaged from a commercial installation on Guam. The power supply was reduced from quad to dual redundancy and the high frequency line was modernized by replacing vacuum tubes with solid state devices, but all passive components remain the same, and hence the equalization properties of the system have not been altered. In fact, system tests after shore plant re-installation showed that repeater performance was not substantially different from the initial values measured in 1964.

In addition to the analog high frequency line, it was necessary to install modulation/demodulation equipment and associated computing hardware at Makaha to provide a mirror image of the H2O junction box electronics, as described in the next section. This provides a series of digital data streams which are transmitted over a frame relay from Makaha to the University of Hawaii, and then onto the Internet. One of the design goals of H2O was minimization of the need for local data archiving and instrument control by utilizing the Internet. In effect, instrument owners can control their bottom packages from anywhere on Earth.

3. THE H2O JUNCTION BOX

From the outset, it was deemed necessary to design a seafloor installation that minimizes the cost of instrument connection and which provides a simple mechanical and electronic interface for scientific users. The former precludes the connection of dedicated in-line instruments using standard industry cable handling practices, both because of the high initial expense and because future instrument failures or upgrades require a second costly recovery and re-installation. In addition, this approach deters future usage of the cable by the broad community due to the necessity for sophisticated and expensive installation tools. Instead, an approach was used which focuses the electronic complexity in a seafloor junction box into which scientific users can simply plug their instruments using standard deep submergence assets, and which provides a comparatively simple digital communications interface as well as DC power. Finally, it was also required that the junction box be installed using a conventional, large oceanographic ship assisted by a remotely operated vehichle (ROV) rather than a specialized cable ship.

The H2O junction box was designed with a number of goals intended to maximize reliability and flexibility. The mechanical aspects include 1) minimizing corrosion concerns, 2) maintaining compatibility with a generic ROV so that a specialized vehicle will not be necessary in future instrument installations, 3) simplifying the deployment, and 4) ensuring *in situ* stability. Figure 2 shows a cartoon of the mechanical layout of a seafloor installation that satisfies these criteria. The first condition is met by constructing the junction box of titanium alloys and plastic, thus avoiding the usual corrosion problems encountered with aluminum. The SD cable is terminated at a gimbal recovered from an SD repeater and attached to a titanium frame containing a wet-mateable underwater connector. Use of this termination frame allowed the SD cable to be lowered to the seafloor during installation without the complications which entail from attachment to the main H2O junction box, which is deployed separately. It also allows the junction box to be easily retrieved and serviced either for upgrades or in the event of a failure. The SD cable is connected to the main junction box by a short (~30 m) oil-filled underwater-mateable umbilical. The power conditioning pressure case on the junction box contains a shunt regulator to extract power from the constant current

SD system, and is terminated by a sea ground which is deployed far enough from the junction box to eliminate corrosion concerns. The junction box electronics pressure case contains all of the systems necessary to control the power to and communicate digitally with instruments, multiplex the digital data they produce, and transmit it to Makaha on the submarine cable. It also contains the control systems necessary to adjust the communications systems and control power to individual instruments. The electronics pressure case is connected to an oil-filled connector manifold which provides eight ROV-compatible, wet-mateable 8 pin connectors, with four connectors on either side of the manifold. These provide an RS-422 communications interface with external instruments as well as 48 volt power. The connector manifold also houses two additional, 4 pin connectors to which the termination frame and sea ground are attached. The connector manifold is designed to provide space for ROV access, and the connectors are specifically intended to be compatible with a standard ROV manipulator, being based on the Ocean Design Nautilus family. The entire junction box sits on a broad weighted base and frame that protects vulnerable pressure cases and associated connectors, yet places the connector manifold well clear of the seafloor.

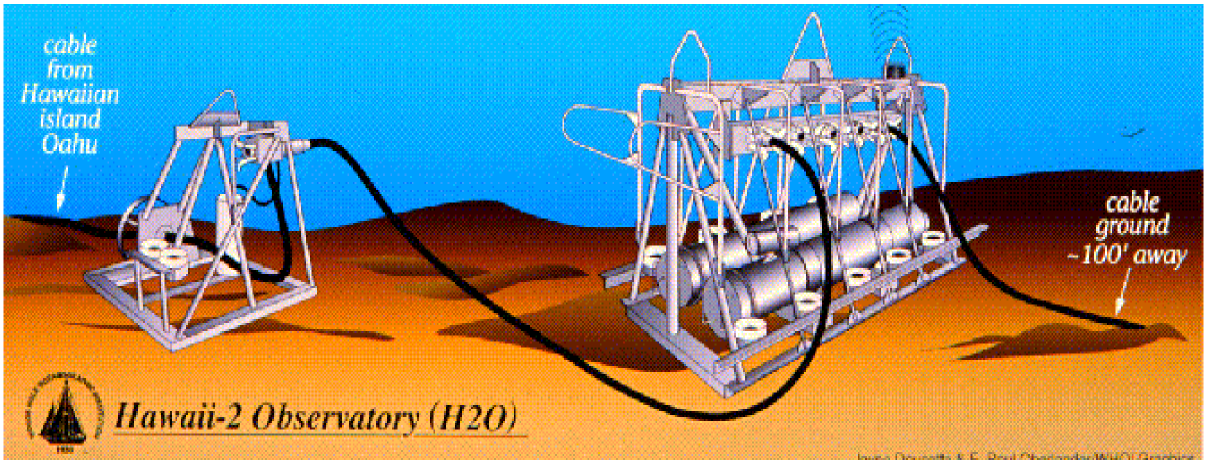

Figure 2. Cartoon showing the H2O site. The termination frame is shown at the left, while the junction box is on the right. The sea ground is off to the right of the picture.

The electronic systems for the H2O junction box were also designed to meet a set of criteria, including 1) making use of the available bandwidth on HAW-2 in an efficient manner, 2) accommodating both low and high data rate users, 3) making the main interface between plug-in instruments and the junction box digital to simplify future design work and minimize noise, 4) protecting the cable system from interference or damage by users, 5) providing a down-link capability to control junction box and user instrument functions, 6) making use of commercial hardware whenever possible to minimize engineering costs, and 7) using high reliability design principles with fail-safes and fallbacks in case of partial failures. The first two criteria preclude simply maintaining the existing frequency division multiplex (FDM) SD architecture and assigning channel space directly to individual instruments, as this makes inefficient use of the available bandwidth for low data rate instruments and may be inadequate for higher rate ones.

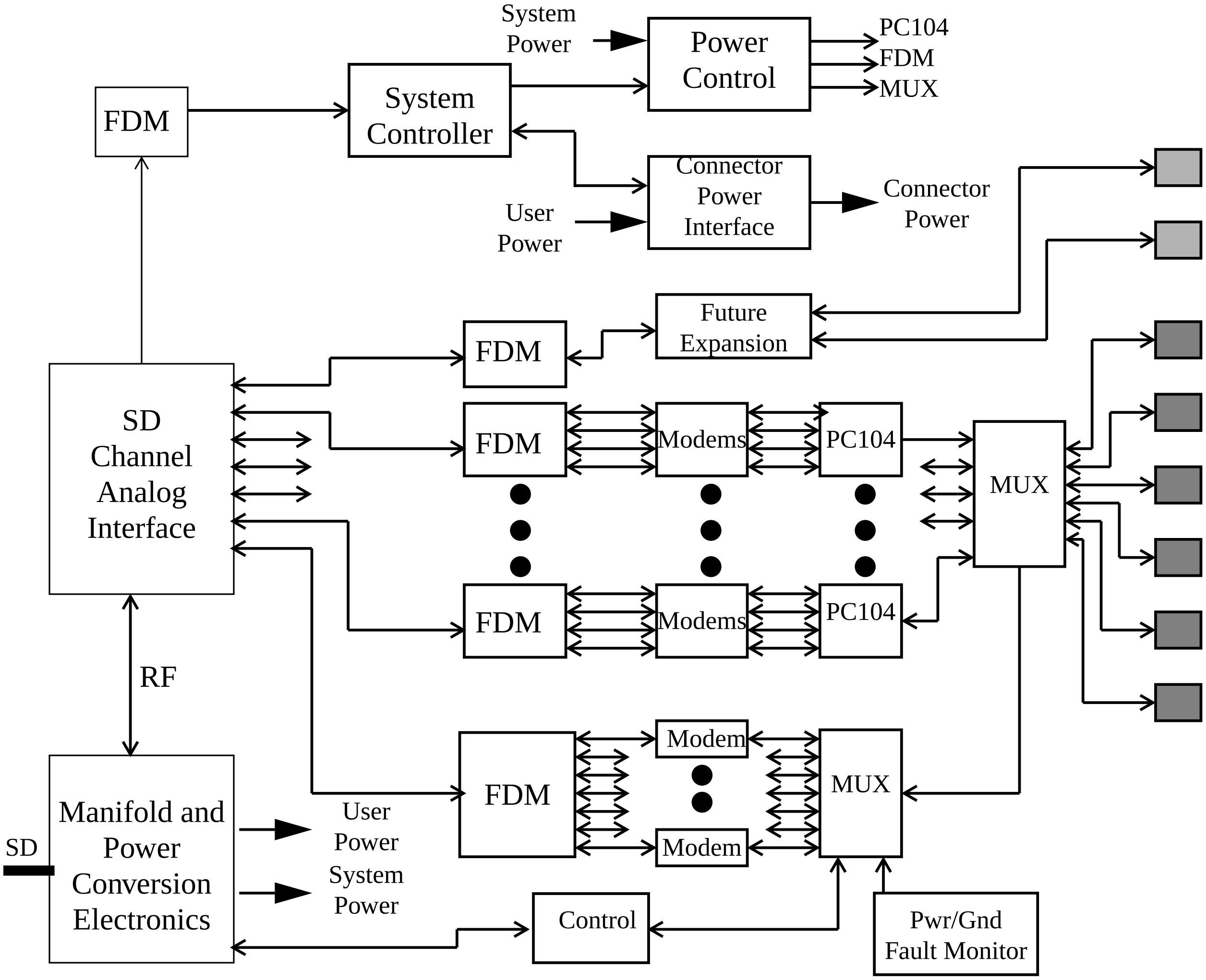

Figure 3. Block diagram of the H2O junction box electronics. See text for details.

The DC and RF components arriving from Hawaii on the SD cable are separated at a power separation filter (PSF) located in the oil-filled manifold. The DC component is sent to the power supply pressure case. Because the SD system operates in a constant current mode at 370 mA, it is necessary to produce a voltage drop across a stack of shunt regulators to extract power from the system. The shunt regulators must extract a fixed amount of power from the cable, dissipating that which is not used by the junction box or instruments as heat. There are eight shunt regulators in series, each providing a nominal 50 watts so that about 400 watts is available to power both the junction box electronics and user instruments. When the cable is powered on, two stacks come up automatically to support the system bus, and additional stacks can be brought on line as needed to power the user bus. Both the system and user bus power are generated by DC-DC converters to give electrical isolation of the cable and junction box systems. Standard levels of 48 volts are sent to the main electronic pressure case. The power conversion electronics can be monitored and adjusted using a control computer which is completely independent of the remainder of the junction box, providing a degree of failsafe operation.

The RF component is sent to the main electronic pressure case, where it is fed into the SD channel analog interface (Figure 3). The main electronic pressure case contains the remainder of the junction box systems for communications and control. The SD channel analog interface is a passive filter and summing network which separates the uplink (to H2O) highband and downlink (from H2O) lowband signals, and further combines or splits the FDM spectrum in each band while matching to the impedance of the SD cable. Control of most junction box functions is provided through a system controller, which is a dual tone multiple frequency (DTMF) interface to the junction box and user power systems, and to the more fundamental electronic functions of the junction box. The system controller provides the ability to turn junction box subsystems on and off, select backup systems in the event of failure, halt and reboot junction box computer systems individually or collectively, and control power distribution to users. A separate system telemeters junction box electronic parameters like system and user bus voltages and currents or subsystem status information back to shore on a dedicated channel. It also provides a ground fault detection capability to protect connectors and pressure cases from damage in the event that a component failure allows electric current to pass through the pressure case wall. Overcurrent at each user connector is protected through a foldback current limiter, preventing a single user from drawing more than about 50 watts.

The heart of the junction box is a communications block consisting of an FDM interface, a set of five V.34 protocol modems, and a PC104 computer. Each of the five blocks provides bidirectional communications at up to 80 kbps using the standard RS-422 protocol. In addition to the five blocks, there are seven individual modem channels for low data rate users. A multiplexer or crosspoint switch allows a given block or modem to be connected to any of the six connectors under command of the system controller. The PC104 is a compact implementation of the PC bus which satisfies reduced space requirements and power constraints for embedded control applications. These computers serve to packetize and time stamp the data arriving from instruments and distribute the packets among four modems. Precise (about 1 ms) timing is provided by an IRIG board in each stack. The reverse function is performed for data arriving from shore. Each modem occupies a 10 kHz dual sideband channel which is frequency domain multiplexed onto a section of the downlink low or uplink high band. Each communications block occupies about 40 kHz of spectrum including guard bands, so the five blocks plus seven modem channels require about 270 of the available 400 kHz. The remaining approximately 130 kHz of bandwidth is held in reserve to accommodate future expansion.

A mirror image of the junction box set of communications blocks and modems is connected to the high frequency line at Makaha. A computer system at Makaha provides full remote control of all multiplexing, monitoring, and stack control functions through a graphical user interface. It also separates the control and user data streams to enhance security.

4. Installation

The H2O junction box was installed in September 1998 using a large US oceanographic research vessel (*R/V Thomas G. Thompson*) and the Woods Hole Oceanographic Institution *Jason* ROV. The installation site was selected based on prior site survey data to be approximately halfway between the lay positions of repeaters to minimize the possibility of damage while handling the SD cable. The cable was first located visually using the ROV and found to be about 3/4 nm south of the nominal lay position (which is based on 1964 navigation capability). The ROV then transited along the cable for 5 km (1 water depth) toward California. The cable was cut at this point using a hydraulic cable cutter on the vehicle.

The Hawaii end of the cut cable was recovered using a flatfish grapnel attached to the oceanographic 9/16” trawl wire on *Thompson*. The recovery point was 5 km toward Hawaii from the cut point, so that an equal amount of cable would hang from either side of the grapnel to avoid slippage and cable loss during retrieval. The cable recovery took about 24 hours with trawl wire tension that was continuously near the operating limit of 24,000 lb. The vessel was maneuvered using its dynamic positioning system to minimize cable tension and maintain a nearly vertical cable throughout the operation. The cable was recovered to the fantail of the research vessel through a stern chute and secured to bitts on deck. It was then cut at the lift point so that the Hawaii end could be identified. The remaining 5 km cable stub was discarded.

The cable termination depicted in Figure 2, which had an SD pigtail already attached to its gimbal, was then spliced into the main cable using standard industry methods. The junction box next underwent a thorough alignment and final checkout on deck after the cable was re-powered from the Makaha end. This required about 4 days of closely coordinated effort between shipboard and Makaha engineers during which the cable was hung from the *Thompson's* stern A-frame and the ship maintained station using dynamic positioning.

Once testing was complete, the junction box was unplugged from the cable termination and the latter was maneuvered over the stern to be lowered to the seafloor on the end of the trawl wire through a set of acoustic releases. During this operation, the 1/2" chain holding the load on the acoustic releases failed, sending the cable and termination plunging to the seafloor. The resulting pile of cable was surveyed using a towed camera system and the termination frame was found to be intact, upright, on top of the cable pile, and within 2 m of open seafloor. The system was tested by installing a shorting plug on the termination frame with *Jason* and powering it up. Functionality was found to be normal, although the final location of the termination frame was about 2 km west of the intended installation site.

The junction box was lowered to the open seafloor north of the termination frame on an acoustically-navigated trawl wire through acoustic releases. *Jason* proceeded to hook up the umbilical cables linking the junction box to the termination frame and the sea ground, respectively. The system was tested and found to function correctly, but a total failure occurred about 12 hours later which necessitated recovery of the junction box. This was done by hooking a lift line dropped from the ROV depressor weight to the top of the junction box with *Jason* and recovering all 3 components (depressor, junction box, and ROV). The problem was quickly traced to contaminated oil in the manifold and repaired. The junction box was then re-installed.

The primary sensor which was deployed at the H2O site is a ULF seismic system consisting of two packages. The main acoustic sensor package (ASP) houses most of the electronics along with both absolute and differential pressure sensors, a hydrophone, a temperature sensor, and a two component current meter. This package is connected to the H2O junction box with a short tether to provide communications and power. The ground motion sensor package (GMSP) is pulled away from the ASP by *Jason* and lowered into a caisson that the ROV had previously buried in the sediments using a hydraulic pump. The GMSP sensors include a Guralp CMG-3 broadband triaxial seismometer along with tiltmeters, a temperature sensor, and a leveling system. The sensor stage also contains a mechanical shaker consisting of an offset cam on a motor that can be used to vibrate the package at frequencies from 5-60 Hz for calibration and coupling tests. Further calibration can be performed on command by sending specified inputs to the Guralp feedback coils. The Guralp sensor is digitized over both high and low gain ranges, effectively yielding 24 bit resolution, as is standard Global Seismic Network practice. Figure 4 shows a sample seismogram from the broadband sensor package.

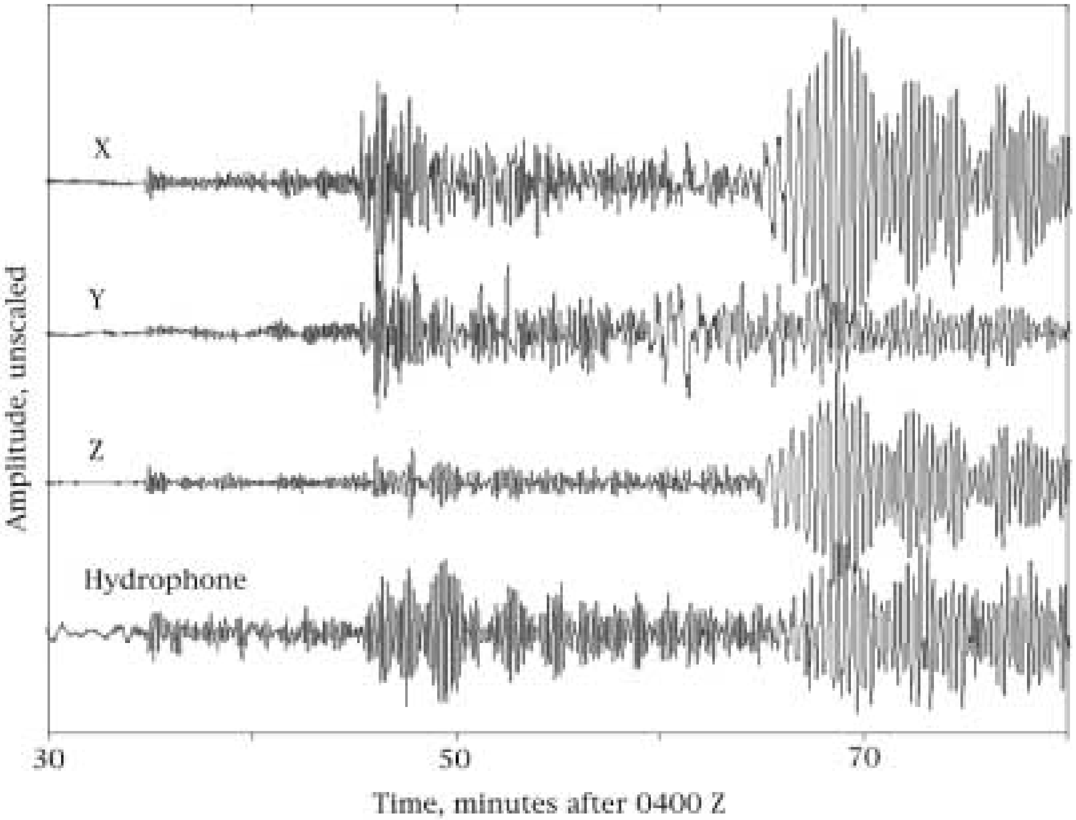

Figure 4. Earthquake recorded at the H2O seismic system on May 4, 2000. This magnitude 7.3 quake occurred at 04:21:33 Z at 1.41˚S, 123.6E, at a distance of 90˚ from the H2O Observatory. The X and Y traces show movement in the horizontal direction, while the Z trace shows movement in the vertical direction. The hydrophone shows changes in pressure. The data have been filtered to display signals at frequencies below 0.12 Hz.

About 2 months after installation in 1998, the seismic package failed due to catastrophic flooding of the current meter. In September 1999, the H2O site was visited to repair this package and install some upgrades to the junction box to improve performance. A separate high frequency hydrophone was also added to the instrument suite. The entire system has performed well since this time. Seismic data from H2O is archived at the IRIS Data Management Center in Seattle, from which it is freely available to scientists around the world.

Further plans for instrument installations at H2O include a benthic biology experiment and a seafloor geomagnetic observatory. A borehole seismometer will be installed in 2002. It is anticipated that H2O will serve the scientific community for many years.

REFERENCES

1. Ehrbar, R.D., et. al., The SD submarine cable system, *Bell Syst. Tech. J., 43*, 1155-1184, 1964.
2. Atwater, T., Plate tectonic history of the northeast Pacific and western North America, in E.L. Winterer, D.M. Hussong, and R.W. Decker (eds.), *The Eastern Pacific Ocean and Hawaii*, Boulder: Geol. Soc. Am., pp. 21-72, 1989.
3. Cande, S.C., and D.V. Kent, A new geomagnetic polarity time scale for the late Cretaceous and Cenozoic, *J. Geophys. Res., 97*, 13917-13951, 1992.
4. Purdy, G.M., and J.A. Orcutt (eds.), *Broadband Seismology in the Oceans*, Washington D.C.: Joint Oceanographic Inst., 106 pp., 1995.
5. Heirtzler, J.R., et al.., *An Enhanced Geomagnetic Observatory Network*, Report to the US Geodynamics Committee, National Research Council, 62 pp., 1994.