should involve representatives from industry, such as hydrocarbon exploration companies and offshore geotechnical survey companies that have accumulated a large volume of data useful to seabed gas studies and are familiar with the challenges posed by gassy sediments.

Acknowledgments

Financial support is gratefully acknowledged from the U.K. Natural Environment Research Council, the U.S. Naval Research Laboratory, and the U.S. Office of Naval Research (Contracts N00014-05-1-0175 and N00014-03-1-142).

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An Acoustically Linked Moored-Buoy Ocean Observatory

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A team from Woods Hole Oceanographic Institution (WHOI; Woods Hole, Mass.) recently developed and successfully deployed a buoy-based ocean observatory that uses acoustic communication to retrieve data from sensors in the water column and on the seafloor out to ranges of about three kilometers from the buoy (Figure 1).

Each buoy is equipped with an Iridium satellite link that can transmit more than one megabyte of data per day to shore. The near-real-time data provided by this system, and two-way communication that enables control of sensors from shore, affords new opportunities for observing episodic events—such as earthquakes, volcanic eruptions, and phytoplankton blooms—and changing ocean conditions over seasons and years, or during times of the year when measurements from shipboard platforms are simply not possible.

A key feature of this system is the ability to add or remove sensors from the observatory at any time without recovery of the buoy and mooring, providing considerable flexibility in the operation and maintenance of the sensor network. In collaboration with investigators from the University of Washington and Scripps Institution of Oceanography, the observatory was deployed in May 2004 for 13 months off Vancouver Island in the northeastern Pacific to study the correlation of seismicity and fluid flow in a seep area along the Nootka fault.

As our understanding of the oceans has advanced, it has become increasingly apparent that many critical processes occur at time and space scales that cannot be effectively sampled or studied with traditional ship-based approaches. Sustained observations at ocean observatories, such as those envisioned by the proposed U.S. National Science Foundation's (NSF) Ocean Observatory Initiative [*ORION Steering Committee*, 2005], will enable ocean scientists to investigate episodic events and study dynamic systems that change over time periods longer than a few months. Regional cabled observatories, such as the proposed NEPTUNE observatory [*Barnes et al.,* 2004], could provide unprecedented levels of power and bandwidth to networks of sensors in the water column, and on or below the seafloor. However, most cabled observatory networks will be located within a few hundred kilometers of shore because of the high cost of installing cable. In contrast, moored buoys can be located almost anywhere in the world's oceans.

Moored-buoy systems using acoustic communication to wirelessly link sensors to a surface buoy, such as NOAA's New Millennium Observatory [*NOAA Vents Program,* 2005], have demonstrated the feasibility of yearlong deep-water deployments, but with relatively low acoustic data rates (~600 bits per second). The acoustically linked observatory described here is a significant improvement on previous designs and takes advantage of custom-built acoustic modems with higher data rates (~5400 bits per second) and the availability of a low-power, Linux-based control system for remote configuration and operation.

Description of the Nootka Moored-Buoy System

The surface mooring is an inverse catenary design with a scope of 1.08 to minimize the diameter of the buoy's watch circle and keep it within acoustic range of the instruments on the seafloor (Figure 1). The surface buoy consists of a 2.7-meter-diameter Surlyn float with 6800 kilograms of net buoyancy. The aluminum structure mounted atop the float includes a tower for mounting instruments and antennas as well as four 150-watt solar panels (Figure 2). The float includes a large, removable instrument well for the system control electronics and batteries. The buoy's average six-watt power consumption is provided by a rechargeable bank of lead acid cells augmented by a backup battery that can provide power for up to three months.

The system uses high-data-rate, power-efficient (of the order of 1000 bits per joule) acoustic modems developed at WHOI [*Freitag et al.,* 2000]. Two transducers are suspended just below the surface buoy to poll and receive data from each of the sensors. Each sensor package is also equipped with an acoustic modem to receive commands from the surface and to transmit data. The modems all use directional transducers with 60° beams. Two-way communication to shore is accomplished using two Iridium 9505 satellite modems.

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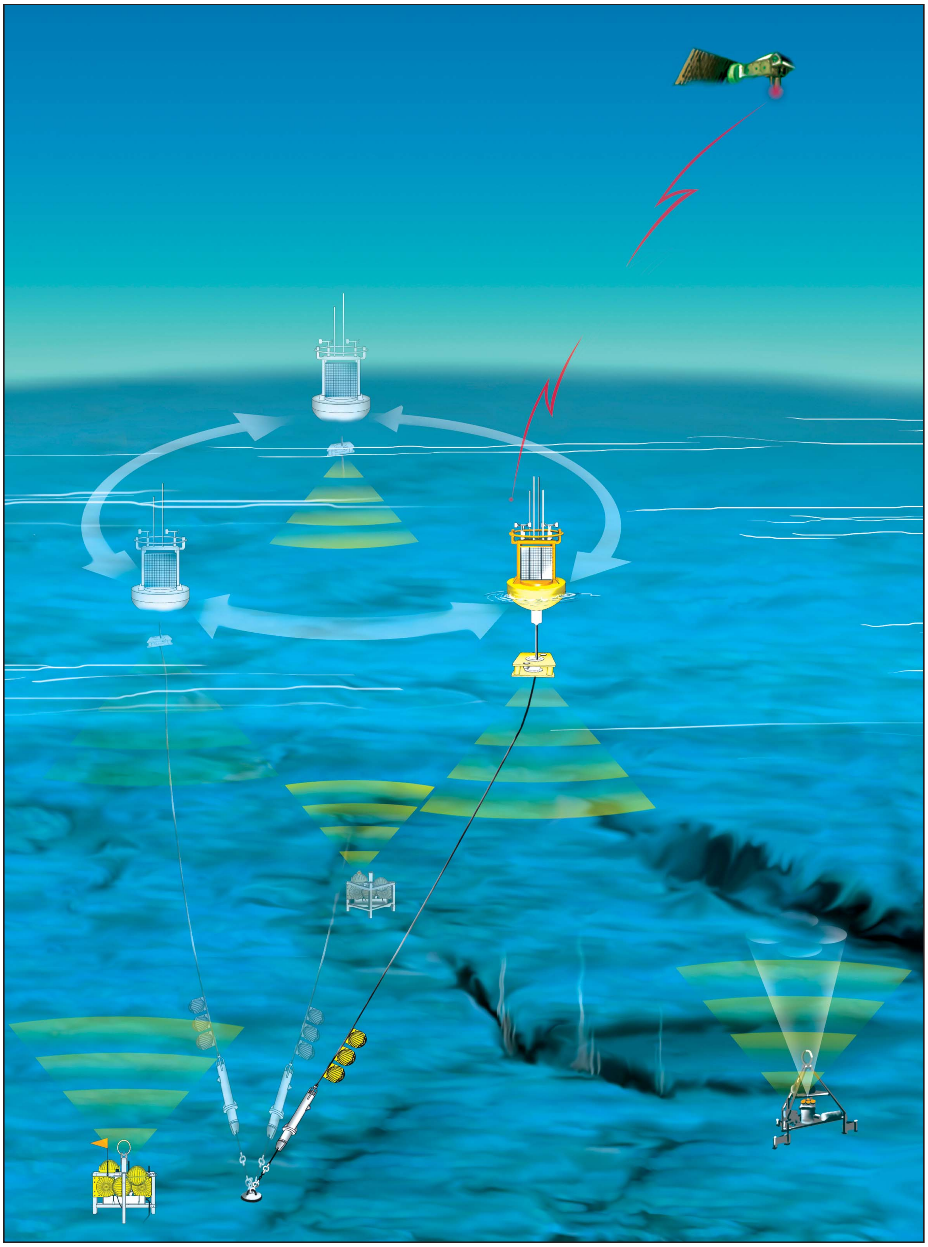

Fig. 1. Cartoon showing the acoustically linked moored-buoy observatory that was deployed at the Nootka fault for 13 months in 2004–2005, recording data from an ocean bottom seismometer (lower left) and a suite of hydrothermal sensors (lower right). This system uses acoustic modems to telemeter data from multiple instruments on the seafloor to a surface buoy, and from the buoy to shore via an Iridium satellite link.

The buoy controller is a low-power Linux-based system with a remote login capability that allows the acoustic communication schedule to be modified when instruments are added or removed from the network or system software needs to be updated. For this deployment in the northeastern Pacific, the buoy initiated a connection and transferred all files every six hours. The data were automatically posted to a Web site where they could be accessed by investigators.

System Performance

The system described above was deployed in May 2004 about 80 kilometers off the coast of Vancouver Island along the Nootka fault (Figure 3a). The Nootka fault is characterized by an about 50-kilometer-wide band of intense earthquake activity that extends along the fault from offshore Vancouver Island to the Juan de Fuca–Pacific plate boundary [*Hyndman et al.*, 1979]. A number of cold seep sites have been found along the fault, and the Nootka observatory was located near one of these seeps in order to measure fluid expulsion along the fault and to examine the links between seismic deformation and episodic fluid flow.

A WHOI ocean bottom seismometer (OBS) equipped with a three-component, one-hertz seismometer and a long-period differential pressure gauge was deployed near the fault. The OBS recorded two data streams sampled at one and 40 hertz on four channels (three seismometer and one long-period pressure). The compressed data were stored locally on disk, and all of the data were retrieved when the seismograph was recovered at the end of the experiment. All of the one-hertz data were also transmitted to shore daily and used, along with shore-based seismic data, to identify events of interest. Selected portions of the 40-hertz data stream were retrieved by sending a command from shore to the instrument.

The University of Washington/Scripps (UW/SIO) sensor package was deployed on the fault 3580 meters from the surface mooring anchor to monitor fluid flow along the fault. Sensors included a fluid resistivity

Fig.2. A 2.7-meter-diameter surface buoy deployed at the Nootka observatory with solar panels, meteorological sensors, and antennas mounted on an aluminum frame atop the float. A universal joint between the buoy and the mooring provides for up to 60° of motion in two planes, protecting the conductors from bending strain produced by the motion of the buoy in severe sea states.

probe, a heat flow probe with four thermistors, and an electronic flowmeter designed for high-resolution measurements in flow rate regimes between 0.1 and 1000 meters per year. In addition to these seafloor sensors, the meteorological conditions (wind speed, barometric pressure, and relative humidity) at the buoy were measured every 10 minutes.

During the 13-month deployment, 151 megabytes of data were transferred to shore. Average data throughput of the Iridium link ranged between 220 and 240 bytes per second depending on file length. Typically about 544 kilobytes of data were transmitted to shore each day. Maximum data throughput of more than 1.6 megabytes per day was achieved during the deployment, and up to four megabytes per day were transferred during system testing.

On 28 February 2005, a cluster of small (M_w4.8–5.0) earthquakes occurred near the intersection of the Nootka fault and the Sovanco fracture zone 173–222 kilometers south-southwest of the Nootka observatory (Figure 3a). Ocean bottom seismic and fluid flow data for this period were retrieved within hours of the event. Vertical-component, ground-motion data (Figure 3b) show arrivals from three moderate-sized, strike-slip earthquakes and from other smaller events. Any fluid flow fluctuations related to this swarm were undetectable (Figure 3c), possibly because the plumbing system of the flowmeter had become saturated with the tracer dye used to determine variations in flow rate due to the low flow rates at this site. However, prior to the 2 November 2004 Explorer plate earthquake, spikes in transmittance indicate the occurrence of flow events (Figure 3c inset).

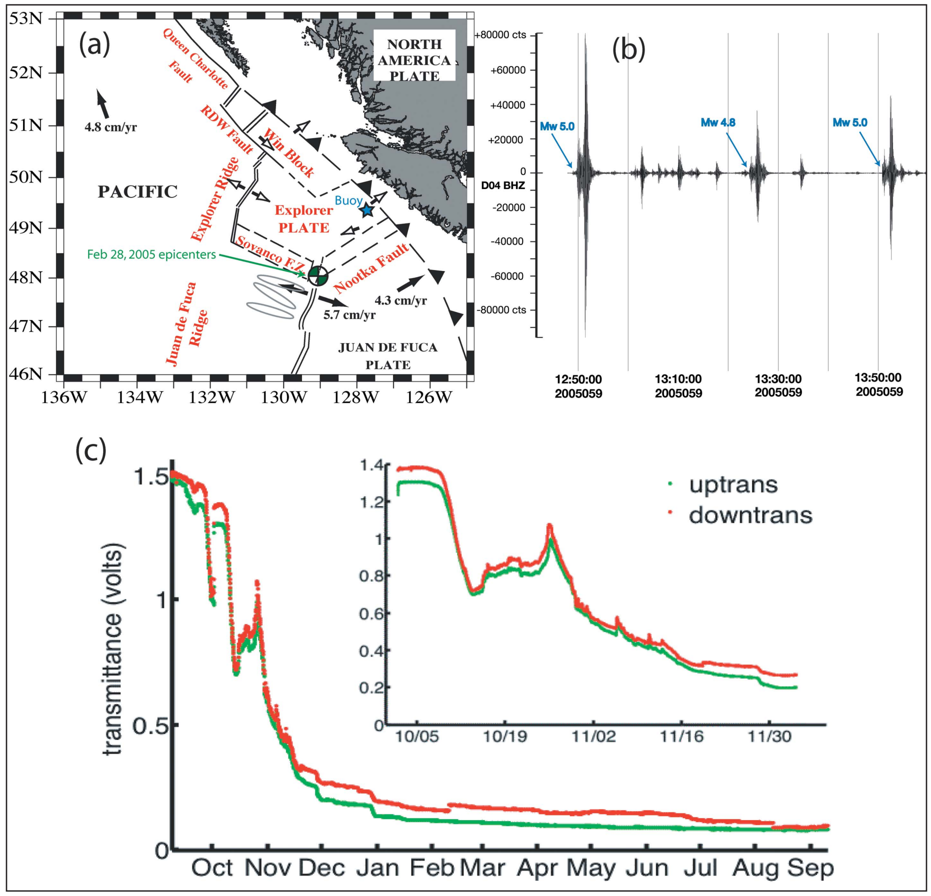

Fig.3. (a) Tectonic framework of the northeastern Pacific showing locations of the buoy and Nootka fault and the epicentral locations of a cluster of small (M_w 4.8–5.0) earthquakes that occurred near the intersection of the Nootka fault and the Sovanco fracture zone 173–222 kilometers south-southwest of the Nootka observatory on 28 February 2005 (based on a figure provided by R. Dziak). (b) Seismograms from the 28 February 2005 events recorded by an ocean bottom seismometer deployed at the Nootka observatory. These vertical-component, ground-motion data show arrivals from three moderate-sized, strike-slip earthquakes and from other smaller events. The source-receiver distances for the events labeled with moment magnitude (M_w) values are, in time progressive order, 179, 222, and 173 kilometers. The 20-hertz data are band-pass filtered five to nine hertz. (c) SIO optical aqueous transport flowmeter recorded transmittance voltages, a proxy for flow rate, at photodiode detection stations on upflow and downflow side of tracer injection for entire deployment year, and one-month period around 2 November 2004 (inset).

Future Capabilities

Acoustically linked moored-buoy observatories can play a significant role in future ocean observatory systems. As presently configured, the system can request data from up to 16 separate seafloor or water column instrument packages out to ranges of about three kilometers from the buoy. However, by using horizontally directional transducers on the sensors and transmitting data to a relay transducer in the water column, this range might be extended up to about 10 kilometers, expanding the instrumented area for a single mooring to over 300 square kilometers.

The mechanical design of the Nootka mooring proved to be very robust, and it survived several periods of extreme weather and sea conditions during its test deployment. With some modifications, this design would be suitable for extended deployments in the Southern Ocean. These modifications include (1) more buoyancy in the surface buoy; (2) strengthened mooring components and hardware; (3) a 10-meter-high meteorological tower to raise the sensors out of the wave shadows most of the time; (4) provision for heating sensors exposed to the weather; and (5) a wind-driven power generator to supplement the solar panels.

Acknowledgments

Jonathon Ware (WHOI), Matt Grund (WHOI), Marv Lilley (UW), and William Wilcock (UW) contributed significantly to the success of the project described in this article. The work described here was funded by the NSF Division of Ocean Sciences, with additional support from the W. M. Keck Foundation and WHOI. Satellite telemetry services were provided by the Ocean.US Iridium project.

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SECTION NEWS

OCEAN SCIENCES

Research Vessels: Underutilized Assets for Climate Observations

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Sustained, global observations of the ocean and atmosphere, which are coordinated by the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS), include various international and national mooring networks, Argo floats, surface drifters, and measurements from satellites, volunteer observing ships (VOSs), and research vessels (R/Vs). These sustained measurements have to some extent drawn attention away from the role of R/Vs in collecting global observations, yet R/Vs' global coverage and onboard technical support make them uniquely valuable to climate observing no matter what the primary scientific discipline is for any particular cruise.

Remarkably, there is no systematic compilation of global R/V tracks. This article presents documentation of R/V coverage for 1997 using the positions of about 80,000 individual meteorological reports (Figure 1) from 154 oceangoing R/Vs. If 1997 is typical, then each year R/Vs cover almost the entire globe and thus have great value since their missions often take them far from commercial shipping routes. A University of Delaware database (http://www.researchvessels.org/) shows 60 R/Vs capable of working across entire ocean basins (≥50-meter length and 30-day endurance).

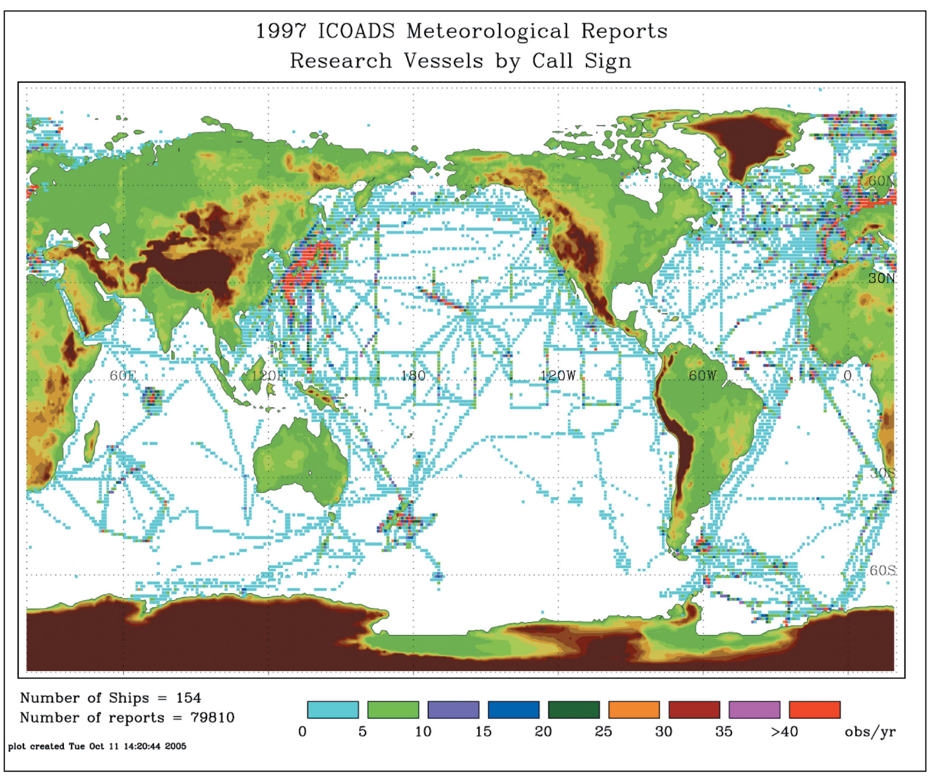

Fig. 1. Number of marine reports from 154 research vessels in the International Comprehensive Ocean-Atmosphere Data Set (Release 2.1) in 1° bins during 1997.

Since R/Vs carry a high level of technical and computer/communications support, they have the potential to collect valuable ocean observations during their typical 270 days at sea each year.

R/V Observational Capabilities

Typical sensors employed on R/Vs while on passage include meteorological packages, acoustic Doppler current profilers, and thermosalinographs. Many R/Vs collect conductivity-temperature-depth (CTD) profile data and deploy floats, drifters, and moorings. Ship-based observations in GOOS and GCOS are coordinated through dedicated programs (Table 1); however, none of these programs has yet achieved its target level of data collection from R/Vs. This article indicates how R/V observations can complement and enhance a variety of GOOS and GCOS elements.

For example, data on sea surface salinity is extremely valuable for monitoring and modeling the ocean. The Ocean Observations Panel for Climate, sponsored by GOOS and GCOS, has defined the strategy for making sustained global ocean observations for climate studies; for surface salinity, this calls for one sample per 200-kilometer square every 10 days and with an accuracy of 0.1 practical salinity units (psu).

To meet these goals, the mission of the International Oceanographic Commission's Global Ocean Surface Underway Data pilot project (GOSUD) is collecting, processing, archiving, and disseminating sea surface salinity (SSS) and other underway variables from R/Vs and VOSs (Figure 2). Although almost all research vessels have a thermosalinograph installed, comparison of Figures 1 and 2 highlights how few R/Vs provide SSS observations. Improving this situation would require personnel to run the thermosalinograph, the collection of calibration water samples, and their analysis at the end of the cruise. The calibrated data would need to be transmitted to the relevant data center.