

# North Pacific Acoustic Laboratory

A Collaborative Project Conducted by

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## LONG-TERM GOAL

The ultimate limits of long-range sonar are imposed by ocean variability and the ambient sound field. Scattering from internal waves limits the temporal and spatial coherence of the received signal. Low frequency noise is dominated by shipping and ultimately, by wave-breaking processes. The resulting “granularity” of the noise field can be exploited for detection and localization purposes. Our ultimate objective is to understand the fundamental limits to signal processing imposed by these ocean processes, to enable advanced signal processing techniques, including matched field processing and other adaptive array processing methods, to capitalize on the three-dimensional character of the sound and noise fields.

## OBJECTIVES

The objective of this research is to understand the basic physics of low frequency, broadband propagation and the effects of environmental variability on signal stability and coherence. In particular, it focuses on 3-D wave front coherence (horizontal, vertical, and temporal), on the details of signal energy redistribution through mode scattering, on signal and noise variability on ocean-basin scales, and on environmental processes such as internal waves that most affect long-range coherence.

## APPROACH

The North Pacific Acoustic Laboratory (NPAL) program takes advantage of the acoustic network installed by the Acoustic Thermometry of Ocean Climate (ATOC) program, as well as instrumentation developed for that network and data previously obtained using it. Existing network components include two low frequency (75 Hz), broadband acoustic sources installed on Pioneer Seamount off central California and north of Kauai, 14 U. S. Navy SOSUS arrays instrumented to receive the source transmissions, and two autonomous vertical line arrays installed near Hawaii and Kiritimati Island from November-December 1995 to August-September 1996. NPAL will augment the existing network with a sparse billboard array at Sur Ridge off Point Sur, California, to receive the 3900-km-range transmissions from the Kauai source. The billboard array will be fabricated by reconfiguring largely existing VLA components developed for ATOC into five 700-m-long, 20-element vertical

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arrays, to allow measurement of the full 3-D signal wave front. The data previously collected by ATOC will be combined with data to be collected using the billboard array and the U. S. Navy SOSUS receivers:

- To study the temporal, vertical, and horizontal coherence of long-range, low frequency resolved rays and modes and to compare the measurements to predictions.
- To study scattering/diffusion effects (mode scattering, steep ray scattering),
- To study horizontal multipathing,
- To study the effects of bottom interaction at the source,
- To measure directional ambient sound spectra and noise granularity,
- To improve basin-scale ocean nowcasts via assimilation of average temperature derived from acoustic travel-time data and of other data types into models, and
- To determine environmental limitations on signal processing.

A CTD/XBT section and two moorings are planned between the Kauai source and the billboard array to provide direct measurement of the sound speed field on the acoustic path.

This research is a joint effort involving B. Cornuelle, M. Dzieciuch, W. Munk, and P. Worcester at the Scripps Institution of Oceanography (SIO) and B. Dushaw, B. Howe, J. Mercer, and R. Spindel at the Applied Physics Laboratory (APL) of the University of Washington. We expect to collaborate in the analyses with A. Baggeroer (MIT), J. Colosi (WHOI), and S. Flatté (UCSC).

## **WORK COMPLETED**

Operation and maintenance of the Pioneer Seamount and Kauai acoustic sources, as well as the SOSUS receivers continued during FY98. The Pioneer Seamount undersea cable was repaired (joint SERDP/DARPA, DOE/ONR, and ONR funding) at the beginning of FY98 and has remained operational since that time. Unfortunately, due to limited observations by the Marine Mammal Research Program, there have been relatively few transmissions from Pioneer Seamount this year. For example, there was only one day of transmissions between 1 November and 4 May, and only eight days of transmissions between 21 May and 17 August. The number of days did increase during the latter part of the year with the deployment of acoustic monitoring pop-up buoys. Transmissions from the Kauai source have been very consistent, although a cable break did cause an outage from 26 December to 20 January. The successful repair was partially supported with additional funding from ONR.

Discussions have been initiated with regulatory agencies regarding the disposition of the acoustic sources and their undersea cables following the period of permitted operations. The Pioneer Seamount source is scheduled to end transmissions on 31 December 1998 and the Kauai source is scheduled to continue until approximately October 1999. Unless some relief is obtained from the regulatory agencies, the underwater hardware will be removed at the end of these permit periods.

A major program milestone was completed this July with the successful installation of the NPAL billboard receiving array (BRA). During the installation cruise five autonomous vertical line array (AVLA) acoustic receivers were successfully deployed in water about 1800 m deep west of Sur Ridge off central California. The five AVLA's were deployed approximately in a line transverse to the acoustic path from the 75-Hz source installed north of Kauai, as planned, with a total length of about 3600 m. Eight acoustic transponders were also installed and their locations were surveyed. The transponders will allow precise position tracking of the arrays during their year-long deployment.

Following the installation of the NPAL array, an environmental data cruise (IW98) was conducted in August along the path from the Kauai source to the NPAL BRA. During the cruise

conductivity/temperature/depth (CTD, 30 casts) and expendable bathythermograph (XBT, 300 460-m T6 probes and 110 760-m T-7 probes) sections along with shipboard ADCP measurements were made to observe the horizontal structure of the temperature and velocity fields at varying resolutions. Two moorings each with upward-looking ADCPs, 6 temperature/conductivity/depth sensors, and 20 temperature sensors in the upper part of the water column were deployed to measure the vertical and temporal structure. The moorings will be recovered in June 1999. The observations will be used to test theories that predict acoustic fluctuations (as measured on the BRA) from the internal wave sound speed (temperature) fluctuations. In addition during the cruise, 5 pop-up data capsules from each of the 5 vertical line arrays of the BRA were recovered for timely system performance evaluation and data analysis. Also, two Cornell University acoustic data recorders were deployed on Pioneer Seamount so as to satisfy permit-monitoring requirements for continued operation of the ATOC source there.

A new method of obtaining reciprocal transmissions/receptions was implemented this year. In effect, the Pioneer Seamount and Kauai sources were transformed into hydrophones. Modifications to the shore-based electronics and relay system for the Kauai and Pioneer Seamount sources were made this past summer and the two transducers are providing an interesting data set. The reciprocal path data sets are only possible on those days when the schedules for both sources happen to coincide. On some of these opportunities we have adjusted the transmit times from the Pioneer Seamount source to occur simultaneously with the Kauai source.

Maintenance of the SOSUS receivers has continued. There have been no significant long-term outages, but the undersea cables for the Pt. Sur, Coos Head, and Pacific Beach arrays continue to deteriorate. The cable attached to the Barber's Point array crosses a portion of the Naval Air Station that is scheduled to be returned to local governments. With the help of ONR, an easement for continued use of this cable was obtained.

## **RESULTS**

A preliminary analysis of transmissions from the Pioneer Seamount source to the SOSUS arrays has been completed (Dushaw, et al., 1998). At 5-Mm range, travel time variations at tidal frequencies (about 50 ms peak-to-peak) agree well with predicted values, providing verification of the acoustic measurements as well as the tidal model. Ray-like receptions at our deepest receiver arrays, however, are still not explained by present ocean models and propagation theories. On the longest and northernmost acoustic paths, the time series of resolved ray travel times show an annual cycle peak-to-peak variation of about 1 s and other fluctuations caused by natural oceanic variability. An annual cycle is not evident in travel times from shorter acoustic paths in the eastern Pacific, though only one realization of the annual cycle has been analyzed so far. The low-pass-filtered travel times are estimated to an accuracy of about 10 ms. In order to linearize the subsequent inversions (Dushaw, 1998), the dominant annual cycle was removed by referencing the measured travel times to the Levitus monthly ocean atlas. This linearization results in a more accurate time series of range- and depth-averaged temperatures. Standard error bars for the 0 to 1000 m depth average are typically +/- 0.012°C, while annual peak-to-peak temperature variation is about 0.4°C for this range- and depth-average temperature. The analysis of the VLA data received off Hawaii indicates significant subsurface salinity compensated temperature changes. A comparison of heat content estimates inferred by the TOPEX/POSEIDON altimeter and those from our acoustic data revealed that as much as one half of the altimeter variability may be due to processes other than heat content change, e.g., advection and barotropic mass redistribution (The ATOC Consortium, 1998).

Ambient sound measurements have been made using single SOSUS hydrophones for the last several years (Curtis et al., 1998). The most distinctive feature in many of the long-term spectrograms is a blue/fin whale signature at 17-22 Hz with an annual cycle 10 dB peak-to-peak. Noise in the 200-400-Hz band is found to be highly correlated with wind (not unexpected), and also, in some cases, with the noise in the 10-15-Hz band. An explanation for the latter observation is being sought.

## **IMPACT/APPLICATIONS**

This research has the potential to affect the design of long-range acoustic systems, whether for acoustic remote sensing of the ocean interior or for other applications. The data from ATOC indicate that existing systems do not begin to exploit the ultimate limits to acoustic coherence at long range in the ocean.

Estimates of basin-wide sound speed (temperature) fields obtained by the combination of acoustic, altimetric, and other data types with ocean general circulation models have the potential both to improve our understanding of gyre-scale ocean variability on seasonal and longer time scales and to improve our ability to make the acoustic predictions needed for matched field and other sophisticated signal processing techniques.

## **TRANSITIONS**

None.

## **RELATED PROJECTS**

(i) NPAL exploits the acoustic network, instrumentation, and data of the Acoustic Thermometry of Ocean Climate (ATOC) program (PI's: P. Worcester and R. Spindel, SERDP/DARPA).

(ii) NPAL will also exploit data obtained as part of the dual-frequency Alternate Source Test performed for the "Ocean Acoustic Observatories" program to improve our understanding of the frequency dependence of horizontal and vertical coherence (PI's: Worcester, Mercer, and Spindel, ONR).

(iii) Supplemental NPAL funding was provided by DARPA to enhance our research on the limits of exploiting coherent acoustic processing methods in the ocean, using data already collected by the ATOC program and data to be collected by the NPAL billboard array, as well as to help support our participation in the ad hoc Synergy Working Group meetings to explore possible collaboration between the NPAL program, the DARPA and ONR supported Full Field Program (FFP), and other related programs.

(iv) A consortium led by R. Spindel was funded by the National Ocean Partnership Program (through ONR) to conduct research closely related to NPAL in response to a proposal entitled "Monitoring the North Pacific for Improved Ocean, Weather, and Climate Forecasts." Among other tasks, this program has deployed an acoustic receiver coupled to a nearby surface mooring via an acoustic modem in the central North Pacific to record transmissions from the Pioneer Seamount and Kauai sources. A simple acoustic receiver is being designed to permit a broader application of acoustic tomographic methods by the oceanographic community.

(v) A consortium led by J. Orcutt was funded by the National Ocean Partnership Program (through ONR) to conduct research partially in support of NPAL objectives. The proposal is entitled "Ocean

Acoustic Observatory Federation.” This effort will provide limited maintenance and improvements to the San Nicholas Island and Barber's Point SOSUS receivers.

(vi) An integral part of NPAL involves studying the possible effects of low-frequency sound on marine mammals, for which support has been provided to C. Clark and W. Munk in response to a proposal entitled “Potential Effects of Low Frequency Sound on Distribution and Behavior of Marine Mammals” (SERDP/ONR). The Pioneer Seamount and Kauai sources are only permitted to transmit in conjunction with marine mammal research.

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