

Ocean Acoustic Observatories: Data Analysis and Interpretation

Peter F. Worcester

Scripps Institution of Oceanography, University of California at San Diego
La Jolla, CA 92093-0225

phone: (858) 534-4688 fax: (858) 534-6251 email: pworcester@ucsd.edu
Award: N00014-95-1-0589

James A. Mercer and Robert C. Spindel

Applied Physics Laboratory, College of Ocean and Fishery Sciences

University of Washington

Seattle, WA 98105-6698

phone: (206) 543-1361 fax: (206) 543-678 email: mercera@apl.washington.edu
phone: (206) 543-1310 fax: (206) 543-3521 email: spindel@apl.washington.edu
Award: N00014-95-1-0800

LONG-TERM GOALS

The ultimate limits to the coherence of long-range acoustic transmissions are imposed by ocean processes, including internal waves, mesoscale variability, interior ocean boundaries (fronts), and bathymetric scattering. An understanding of the effects of these processes on acoustic signals is crucial to the use of acoustic remote sensing methods for a broad range of purposes, including undersea surveillance, ocean acoustic tomography, and large-scale acoustic thermometry. The long-term goals of this research are to enhance our understanding of the ocean processes that ultimately determine the limits of useful long-range acoustic transmissions and to improve our capability to both generate and detect very long-range transmissions.

OBJECTIVES

Theoretical considerations suggest that acoustic scattering due to internal-wave-induced sound-speed perturbations will be small at very-low frequencies, i.e., below about 30 Hz, even at multi-megameter ranges. The objective of this research is to understand the frequency dependence of scattering from internal waves and other oceanographic features at multi-megameter ranges.

APPROACH

A short term transmission test, the Alternate Source Test (AST), was conducted during June-July 1996 to compare broadband transmissions at 28 Hz and 84 Hz (phase-locked coherent signals, each with a 10-Hz bandwidth). An HLF-6A acoustic source suspended from shipboard near Pioneer Seamount off central California transmitted to two autonomous vertical line array (AVLA) receivers and to ten horizontal line array (HLA) receivers, at ranges from 150 km to about 5 Mm. The combination of temporal and spatial resolution makes it possible to isolate individual rays and, at the AVLA receivers, low order modes, in order to elucidate the basic scattering physics. The data collected on the AVLA and HLA receivers are being used to compare a variety of measures of the scattering at the two

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 30 SEP 1999		2. REPORT TYPE		3. DATES COVERED 00-00-1999 to 00-00-1999	
4. TITLE AND SUBTITLE Ocean Acoustic Observatories: Data Analysis and Interpretation				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of California, San Diego, Scripps Institute of Oceanography, 9500 Gilman Drive, La Jolla, CA, 92093				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			

frequencies, including travel time variance and spread, scintillation index, and coherence in time, frequency, and space. The AVLAs provide information on vertical coherence and modal structure, and the HLAs provide information on the horizontal coherence and spatial variability of the scattering. The computed statistics will be compared with theoretical predictions. SIO investigators are playing the leading role in analyzing the data from the AVLA receivers, while APL/UW investigators are taking the lead in analyzing the data from the HLA receivers.

WORK COMPLETED

Signal processing of the dual-frequency receptions has been completed and routine clock and mooring motion corrections have been applied to the AVLA data (receivers at ranges of approximately 3500 km and 5100 km). Data from the AVLAs and two of the HLAs (at approximately 150 and 700 km) have been analyzed.

The dual-frequency AVLA data have also been used to test a modified vertical beamformer that explicitly takes account of the depth dependence of the sound-speed profile, using a local WKBJ approximation. The modified beamformer, called a turning-point filter, permits a uniform treatment of the arrival pattern, from the early ray-like arrivals to the late mode-like arrivals. A manuscript on this work is nearly ready for submission.

RESULTS

Internal-Wave-Induced Scattering. Both the vertical and horizontal line array data clearly show that the 28-Hz receptions have a more stable arrival pattern than the 84-Hz receptions, as expected (Worcester, 1999). The VLA data show that this difference holds for both the early ray-like arrivals and for late mode-like arrivals. The horizontal line array data obtained on a receiver located below the sound-channel axis approximately 700 km west of the source give rms travel-time fluctuations for one resolved “ray-like” arrival of 7.8 ms at 28 Hz and 10.2 ms at 84 Hz, in the range of expected values. The predicted ray arrivals turn above the receiver, however, and so the propagation is not fully understood. The scintillation index is approximately 0.11 at 28 Hz and 0.65 at 84 Hz, again indicating much more stable amplitudes at the lower frequency. Travel-time spread is near zero for both frequencies. For the 150-km receiver there were no single resolved ray arrivals; the arrival peak analyzed had two predicted ray arrivals separated by 15 ms. In this case the rms travel time fluctuations were much larger than one would expect for a single ray at this range because of interference effects (order 14 ms for both frequencies compared to a few milliseconds expected for a single ray). The scintillation index was 0.26 at 28 Hz and 0.64 at 84 Hz. Although these scintillation estimates are also contaminated by ray interference, they nonetheless show less fluctuation at lower frequency, as expected.

Bias and Coherence. The quality of ocean acoustic travel-time measurements depends on the coherence as well as the bandwidth of the signal. If the coherence bandwidth is less than the signal bandwidth, it is possible to consider subbands of the signal as separate measurements (Dzieciuch *et al.*, 1999). The separate measurements can then be combined incoherently to improve the quality of the travel-time measurement. Theoretical work and computer simulations predict that the travel-time of acoustic signals is biased by the ocean internal wave field (Colosi *et al.*, 1999). The path-integral theory for scattering predicts that the size of the travel-time bias depends on the logarithm of the center

frequency of the acoustic signal, thus separate subbands would have different travel-times and incoherent recombination would not be an optimal procedure. Data from the dual-frequency transmissions make it possible to measure the bias experimentally and to determine the efficiency of subband averaging. Data from the Hawaii AVLA suggest that the bias is about 50 ms at 3500 km range, which is roughly as large as expected (Dzieciuch *et al.*, 1999). For the HLAs, the difference in travel time between the two frequencies is 18 ms at 150 km and 31 ms at 700 km, with the 28 Hz signal arriving later than the 84 Hz signal, again roughly in agreement with predictions.

Turning Point Filter. The 28-Hz receptions on the Hawaii AVLA have been interpreted using a technique that we call a “turning point filter.” The method can be viewed either as an improvement to linear beamforming, by accounting for ray curvature, or as modal horizontal wavenumber filtering with a vertical array. It allows a uniform treatment of the arrival pattern, from the early ray-like arrivals to the late mode-like arrivals, providing robust observables as peaks in travel-time, vertical-arrival-angle space identified with particular rays or modes, as well as peaks that cannot be identified as either rays or modes. The turning point filter implicitly includes modal dispersion and unambiguously provides an observable for broadband modal arrivals. There is no need to separate modes because those with the same turning-point slowness carry the same information about the ocean, and an inverse solution would recombine them anyway. The turning-point filter reduces to a linear beamformer when the wave front curvature is small. It includes single-frequency mode experiments as a special case.

IMPACT/APPLICATIONS

Existing systems, whether active or passive, are not anywhere near the limits of what can be done in underwater acoustics. A full understanding of the ultimate limits to acoustic coherence at long range in the ocean is essential to the design of any acoustic system for remote sensing of the ocean interior, whether it be for measurement of ocean temperatures, tracking of whales, detection of submarines, or the study of volcanic processes at mid-ocean ridges. At the conclusion of our analyses we expect to have a much fuller understanding of the frequency dependence of acoustic scattering from ocean features at multi-megameter ranges, and of the potential for exploiting the anticipated reduction in scattering, and corresponding increase in coherence, at very low frequencies.

TRANSITIONS

None.

RELATED PROJECTS

This work has been closely coordinated with, and partly supported by, the Acoustic Thermometry of Ocean Climate (ATOC) project and the North Pacific Acoustic Laboratory (NPAL) project.

PUBLICATIONS

Colosi, J. A., and the ATOC Group (A. B. Baggeroer, T. G. Birdsall, C. Clark, J. A. Colosi, B. D. Cornuelle, D. Costa, B. D. Dushaw, M. A. Dzieciuch, A. M. G. Forbes, B. M. Howe, D. Menemenlis, J. A. Mercer, K. Metzger, W. H. Munk, R. C. Spindel, P. F. Worcester, and C. Wunsch), “A review of

recent results on ocean acoustic wave propagation in random media: Basin scales,” *I.E.E.E. J. Oceanic Eng.*, **24**, 138–155 (1999).

Dzieciuch, M. A., P. F. Worcester, T. Birdsall, K. Metzger, B. Howe, J. Mercer, and R. Spindel, “Measurements of multi-megameter travel-time bias and coherence,” *J. Acoust. Soc. Am.*, **105**, Pt. 2, 137th Meeting of the Acoustical Society of America and the 2nd Convention of the European Acoustics Association, Berlin, Germany, March 15–19, 1999, 1116 (1999).

Worcester, P. F., “A comparison of long-range acoustic propagation at ultra-low (28 Hz) and very-low (84 Hz) frequencies,” Proc. International Symposium on Acoustic Tomography and Acoustic Thermometry, Tokyo, Japan, 8–9 February 1999, 98 (1999).