

Acoustic Tomography with Navy Sonars

John Spiesberger
Scientific Innovations, Inc.
6 Derring Dale Rd., Radnor, PA 19087
phone: 610 293 0834 fax: 610 293 0834 email: johnsr@sas.upenn.edu

Contract Number: N00014-00-C-0317

LONG-TERM GOALS

The long-term goals of this research are to determine the reliability of predicted sounds over long distances in the ocean and to use sounds to understand some physical changes by means of acoustical tomography. SOund SURveillance Systems (SOSUS) have traditionally been used to obtain data for acoustical tomography. The Navy has many more sonars than these, and their use should significantly enhance the kinds of acoustical investigations available for study and provide more tomographic paths than possible with SOSUS.

OBJECTIVES

We want to show that many types of active and passive sonars in the Navy can be used to collect high quality signals from sources at long distances. We will utilize data from towed arrays that could provide a synthetic aperture for increasing the resolution and accuracy of tomographic maps (Spiesberger *et al.*, 1997). We want to determine if acoustic and oceanographic models can predict the acoustic signals, and if not, determine what is needed to make better predictions. We want to compare the quality of the data and models with traditional studies conducted with sounds from scientifically deployed sources that were received on SOSUS stations (Spiesberger and Metzger, 1992, Norris *et al.*, 1998).

APPROACH

Data will be collected from a variety of Navy sonars. Traditional means to process the signals will be done including beamforming, coherent averaging (when dealing with periodic signals), correcting for Doppler shifts (when dealing with mobile sonars), and matched filtering (when a replica with the emitted waveform is available). The data will be interpreted using rays and the sound speed insensitive parabolic approximation (Tappert *et al.* 1995) in collaboration with Frederick Tappert and Andrew Jacobson. The acoustic models will be used in conjunction with oceanographic models that contain the best available digital data sets for bathymetry, sound speed fields that vary with range and depth, and internal waves.

WORK COMPLETED

Data have been collected and processed from a wide variety of sonars over basin-scales in the Pacific Ocean. Acoustic models have been developed that incorporate realistic bathymetry, sound speed fields that change with geographic location, and time dependent fluctuations of internal waves obeying a linear dispersion relation. Comparison between models and data have been made to see what features

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 2002		2. REPORT TYPE		3. DATES COVERED 00-00-2002 to 00-00-2002	
4. TITLE AND SUBTITLE Acoustic Tomography with Navy Sonars				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) Scientific Innovations, Inc.,6 Derring Dale Rd.,Radnor,,PA,19087				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 The long-term goals of this research are to determine the reliability of predicted sounds over long distances in the ocean and to use sounds to understand some physical changes by means of acoustical tomography. SOund SURveillance Systems (SOSUS) have traditionally been used to obtain data for acoustical tomography. The Navy has many more sonars than these, and their use should significantly enhance the kinds of acoustical investigations available for study and provide more tomographic paths than possible with SOSUS.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

can be predicted and what features will require improvements in either the models or model inputs to yield reliable predictions for future work.

RESULTS

We found it possible to predict the coherence time of sound over basin-scales between the Kaneohe source (133 Hz, 16 Hz bandwidth) at Oahu and a SOSUS station at 3709 km near the coast of northern California (Fig. 1 and Spiesberger *et al.*, 2002). The predictions for coherence time were based on the time evolution of a linear internal wave field whose spectrum is given by Garrett and Munk (1972), a realistic bottom, our best guess of the geoacoustic properties of the sub-bottom, a range-dependent background of sound speed derived from Levitus' data base (1982), and the sound speed insensitive parabolic approximation (Tappert *et al.* 1995).

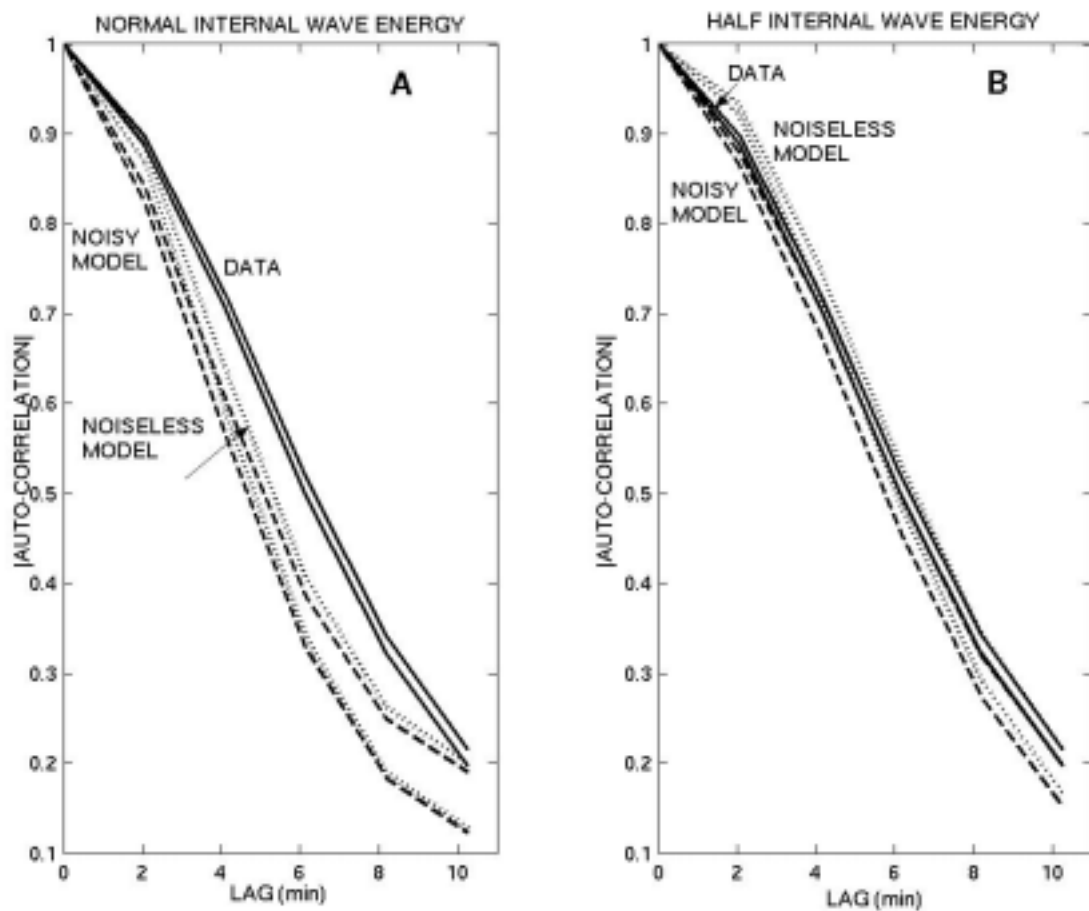


Figure 1. Correlation time of sound from data and models with 95% confidence limits. The data come from a 3709 km section between Oahu and California in 1983 when the Kaneohe source broadcast continual transmissions for days at 133 Hz and a bandwidth of 16 Hz. The peak signal-to-noise ratio in each data record at 2-min intervals is used to set the same in each model record to produce the “noisy model” results. A) Uses 100 data and model records at 2-min intervals. The model uses the normal Garrett-Munk (1972) energy for internal waves. B) Uses 59 data and model records at 2-min intervals. The model uses one-half the normal Garrett-Munk energy. The upper 95% limit for the noisy model is just below the lower 95% limit for the data.

Neither the one-half or normal energy level of the Garrett-Munk spectrum fits all the data. The predicted coherence time is not sensitive to the chosen level.

It is possible to obtain high quality data from an array towed by a U.S. research vessel at 3100 km from a coherent source at Kauai (75 Hz, 30 ms resolution). Most of the acoustic paths are predicted from both ray and parabolic equation models (Spiesberger, 2002). The parabolic equation model that propagates sound through a field of internal waves provides the best match with the data. Amplitudes from the parabolic model are more realistic than those from rays.

We found it possible to utilize signals from explosive sources to study acoustic propagation between 1000 and 3000 km in the Pacific. Models for the propagation predict most of the features in the data.

It is significant that oceanographic and acoustic models predict the coherence time of broadband signals over basin-scales in the single experiment checked so far. Predictions need to be made with other data sets. In any case, it may be possible to predict the coherence time of sound, which may be of considerable interest for theoretical studies and surveillance.

Results show that existing sonars can be used to collect high quality signals over long distances. Models can be used to predict many but not all of the acoustic arrivals. Although models can be used to predict many features in the data, the modeling process itself does not appear to be easily automated at this time. There are discrepancies between the models and data, and the modeling process itself takes considerable thought and computational time.

A new mechanism was discovered for transmitting sound from either shallow to deep or deep to shallow water via a so-called acoustic "mud-slide" effect (Tappert *et al.*, 2002). This mechanism may be useful for explaining signals of the T-phase associated with seismic events. The acoustic mudslide appears to provide a mechanism for transmitting sound into the deep ocean from shallow water without having to place a source in deep water.

IMPACT/APPLICATIONS

Reliable models for the propagation of sound are useful for designing and operating sonar and surveillance systems. Many Navy sonars provide an inexpensive and reliable means for collecting data over long distances. These data will accelerate the understanding of how sound propagates, and will offer a practical means for imaging the sound speed and temperature fields using acoustical tomography.

TRANSITIONS

The results of this research are not yet utilized by the operational Navy.

RELATED PROJECTS

REFERENCES

Levitus, S., Climatological atlas of the world ocean, in NOAA Prof. Pap. 13. U.S. Government Printing Office, Washington, DC, (1982).

Norris, D. E., Spiesberger, J.L., and Merdes, D. W., Comparison of basin-scale acoustic transmissions with rays and further evidence for a structured thermal field in the northeast Pacific, *J. Acoust. Soc. Am.*, 103(1), 182-194 (1998).

Spiesberger, J.L., Fabrikant, A., Silivra A., and Hurlburt, H. E., Estimating climatic temperature change in the ocean with acoustic tomography: Navigational requirements, *I.E.E.E. J. Ocean. Eng.*, 22(1), 128-142 (1997).

Spiesberger, J.L., Hurlburt, H.E., Johnson, M., Keller, M., Meyers, S., and O'Brien, J.J., Acoustic thermometry data compared with two ocean models: The importance of Rossby waves and ENSO in modifying the ocean interior, *Dyn. Atm. and Oceans*, 26(4), 209-240 (1998).

Spiesberger, J.L., and Metzger, K., Basin-scale ocean monitoring with acoustic thermometers, *Oceanography*, 5, 92-98 (1992).

Tappert, F. D., Spiesberger, J., and Boden, L., New full-wave approximation for ocean acoustic travel time predictions, *J. Acoust. Soc. Am.*, 97, 2771-2782 (1995).

PUBLICATIONS

Spiesberger, J. L., An updated perspective on basin-scale tomography, *J. Acoust. Soc. Am.* 109, 1740-1742 (2001).

Spiesberger, J. L., Tappert, F. D., and Jacobson, A. R., Predicting coherence time of broadband sound at basin-scales, submitted to *J. Acoust. Soc. Am.* (2002).

Spiesberger, J. L., Synthetic aperture for estimating acoustic and thermal climatic fluctuations in the ocean, submitted to *J. Acoust. Soc. Am.* (2002).

Tappert, F. D., Spiesberger, J. L., and Wolfson, M. A., Study of a novel range-dependent propagation effect with application to the axial injection of signal from the Kaneohe source, *J. Acoust. Soc. Am.*, 111, 757-762 (2002).