Coherence of Sound Using Navy Sonars

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LONG-TERM GOALS

The long-term goal of this research is to understand and predict the temporal and spatial coherence of broadband sound in the ocean at low frequencies.

OBJECTIVES

We will compare broadband acoustic signals at basin-scales with predictions for spatial coherence. Degradation of coherence will be modeled using spectra of internal waves in the ocean.

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) . 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. Spatial coherence will be modeled using the sound speed insensitive parabolic approximation and spectra of internal waves.

A secondary goal of this contract is to theoretically quantify which regions in the ocean significantly affect temporal and spatial coherence. Theories of diffraction are used and developed for this purpose as well as to understand how to predict the scattering of waves in general.

WORK COMPLETED

Data have been collected and processed from several types of sonars at 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. Comparisons with some data sets have been completed.

We developed a theory to understand the regions of a medium that significantly affect coherence of any transient wave-like signal. Numerical evaluation of the theory has been applied to the ocean.

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RESULTS

A 3115 km section in the Pacific was studied using sounds from a bottom-mounted source at Kauai (75 Hz, 0.03 s resolution) and a towed array in the Gulf of Alaska (Fig. 1). The transmitted signal consisted of 44 consecutive 27.28 s periods of a M-sequence lasting 20 min. Data from the receiver were beamformed and Doppler corrected to yield the largest signal-to-noise ratio. This processed signal yielded many acoustic arrivals over a 7-s duration. This 7-s was subdivided into 250 windows of 0.03 s each. Starting from the first of 44 periods, the signal-to-noise ratio was computed for each window as a function of the number of windows coherently averaged with the first. Coherence time, T, for each window was calculated using T=N*27.28 s where N is the window yielding the largest signal-to-noise ratio (N=1,2,3,...,44). Fig. 2 (top) shows the histogram of coherence time from these data.

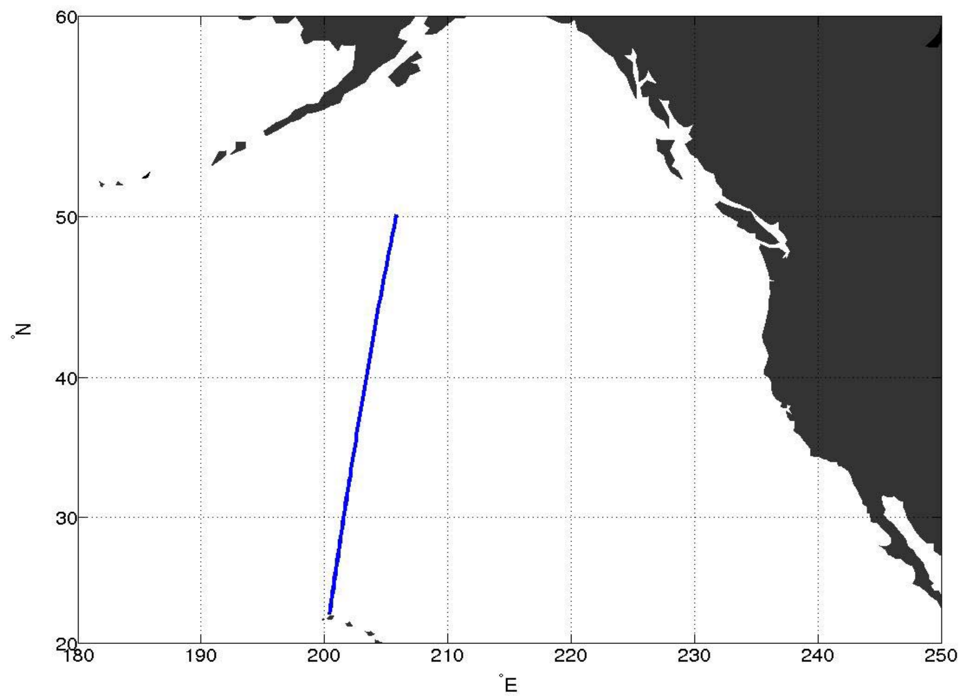

Fig. 1. 3115 km section between acoustic source at Kauai and towed array.

A model is used to predict, without any tuning to data, the histogram of coherence time from the data. The model uses digital data bases for bathymetry and the climatological background of temperature, salinity, and depth along the section. Values of temperature and salinity are converted to sound speed with an algorithm. To this, we add temporal fluctuations due to internal waves at 4-min intervals using the linear dispersion relation obeying a standard spectrum. An approximate solution for the acoustic impulse response is computed using the sound-speed insensitive parabolic equation. The histogram of modeled coherence time look very much like the data (Fig. 2, bottom). Details of this comparison are found elsewhere (Spiesberger and Green, 2006).

We developed a theory to quantify regions of any media that significantly affect any specified window of signal arrival time (Spiesberger, 2006a). The method is somewhat analogous to Fresnel zones for single frequency signals, except our method provides a high-resolution image for transient signals. We applied the theory to the acoustic waveguide in the ocean at low frequencies.

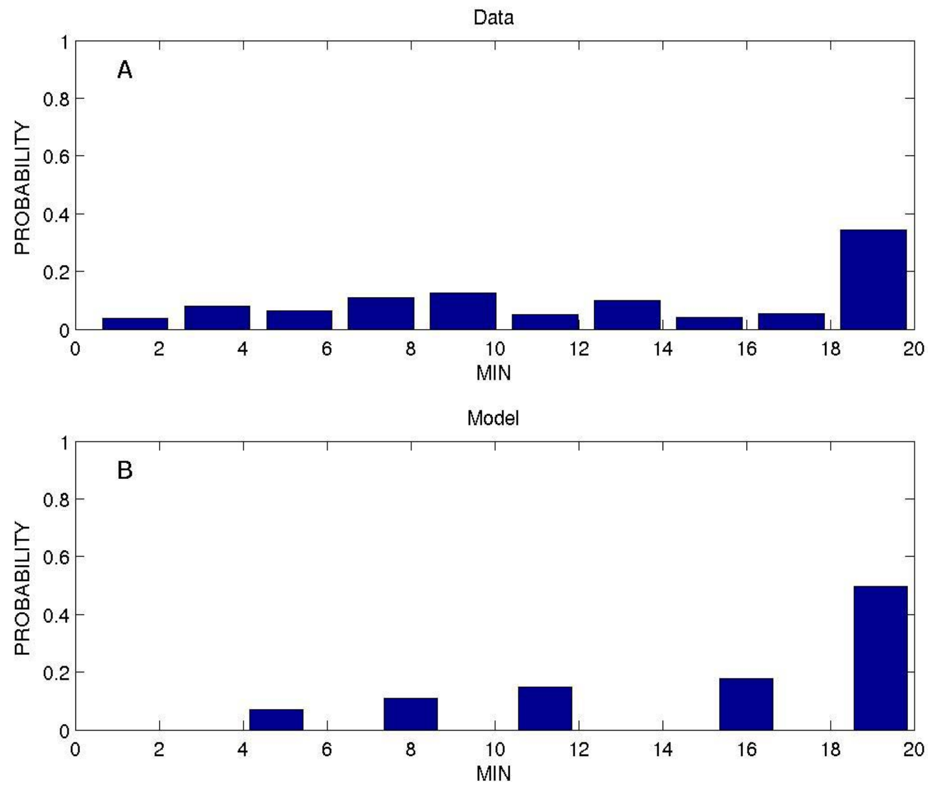

Fig. 2. Histograms of measured and modeled coherence time for section in Fig. 1.

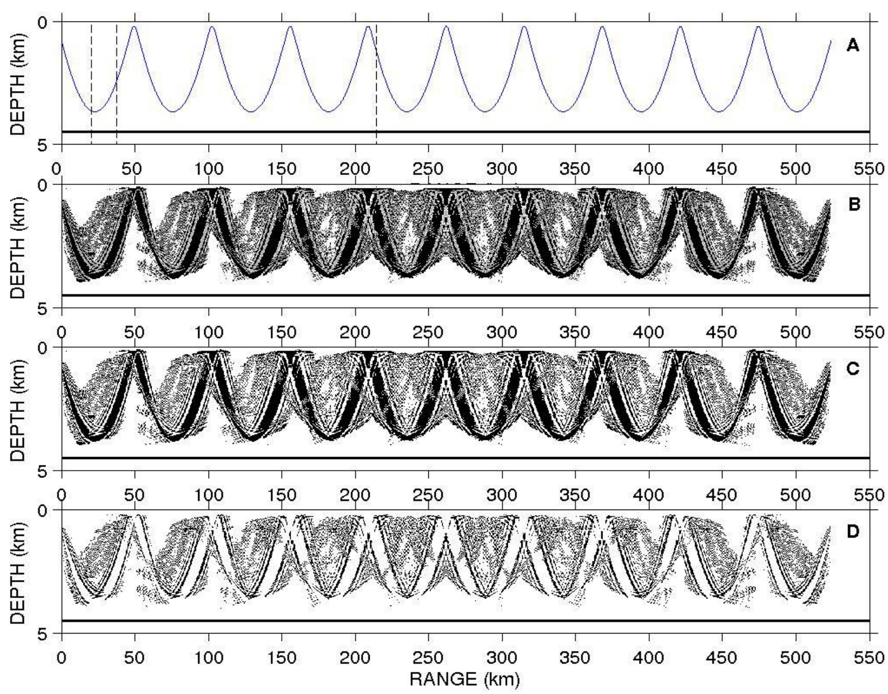

Fig. 3. Ray path (A) compared with regions that significantly affect the signal from this path at 100 Hz and 0.05 s resolution (B). Regions of constructive and destructive influence are given in panels C and D respectively.

At 100 Hz and 0.05 s resolution, the regions that significantly affect the signal are different than that approximated with a ray (Fig. 3B). For simple situations, we have investigated **how high the center frequency need be so that the regions of influence look like a ray (Spiesberger, 2006b).**

IMPACT/APPLICATIONS

Reliable models for the coherence of broadband sound are useful for designing and operating acoustic surveillance and communication systems. Developing theories for understanding the scattering of sound is potentially useful for other waves such as electromagnetic, water, and cosmic gravity waves.

RELATED PROJECTS

Dr. Brown and colleagues at the U. of Miami are developing complementary theories for understanding the diffraction and scattering of sound in the sea. Drs. Voronovitch, Ostashev, and Godin at NOAA in Boulder, CO., are developing theories for the three-dimensional scattering of sound in the sea.

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