

Coherence of Sound using Navy Sonars: Deep Water Acoustics

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LONG-TERM GOALS

The long term goals are 1) to determine when methods can be used to reliably and accurately predict the temporal and spatial coherence of sound at low frequencies in the sea, 2) to develop reliable and accurate methods to make such predictions and, 3) to determine the physical mechanisms affecting coherence. The first two goals are to be achieved without tuning with data in any way whatsoever.

OBJECTIVES

The primary objective is to determine when the temporal and spatial scales of temporal and spatial coherence are accurately predicted by solving an approximation of the acoustic wave equation for climatological conditions in the ocean perturbed by a time-evolving field of internal gravity waves following a standard spectrum. These waves have long been thought responsible for coherence in the deep ocean at low frequencies. However despite decades of theoretical work to predict coherence, theoretical models to date are highly unreliable, often been inaccurate by several orders of magnitude. We are comparing numerical predictions for coherence with data collected with Navy sonars.

APPROACH

To pin down whether the problems for predicting coherence were due to the theories or the ascribed physical mechanism of internal waves, we began seven years ago a numerical set of computations of the acoustic field with standard models at time intervals matching measurements (Spiesberger et al, 2003). These computations have the advantage of not using any theoretical support from scattering theories. This allows a strong test for the hypothesis that internal gravity waves determine coherence at low frequencies in the sea. The sound speed field for the numerical model is synthesized by adding sound speed perturbations due to internal waves to a climatological background of speed. The linear dispersion relation is used to temporally evolve a standard spectrum of internal waves. For each snapshot of sound speed along a section, the split-step sound-speed insensitive parabolic approximation (Tappert et al, 1995) is solved on a computer for the frequencies used for each acoustic transmission. The temporal response is computed using the inverse Fourier transform. The predicted acoustic field at the receiver is saved. This collection is analyzed in exactly the same manner as the data, including setting the signal-to-noise ratio from the model to be the same as for each measured acoustic reception.

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WORK COMPLETED

Work for this contract began four months ago, so results are just starting to be produced. We finished analysis of a 3709 km transmission in the Pacific from our global acoustic warning experiment that began in 1983 (Oreskes, 2004). The 1983 component of these data are particularly useful measurements because they consist of continuous transmissions at two-minute intervals lasting five days. Both the source and receiver are mounted on the seafloor with time bases controlled by atomic clocks. The ocean is only thing that affects the acoustic measurements, as there are no aberrations from instrument motion.

RESULTS

Section C in Figure 1 shows the 3709 km section from the 1983 transmission centered at 133 Hz and a temporal resolution of 0.06 s. It is one of five experiments analyzed to date where temporal measurements of coherence have been compared with numerical computations without tuning with data. Three of the other sections yielded studies where comparison between measurements and models yielded very good results. In one section (D), the comparison yielded no conclusion because the data were not analyzed correctly for this application (Spiesberger, 2006).

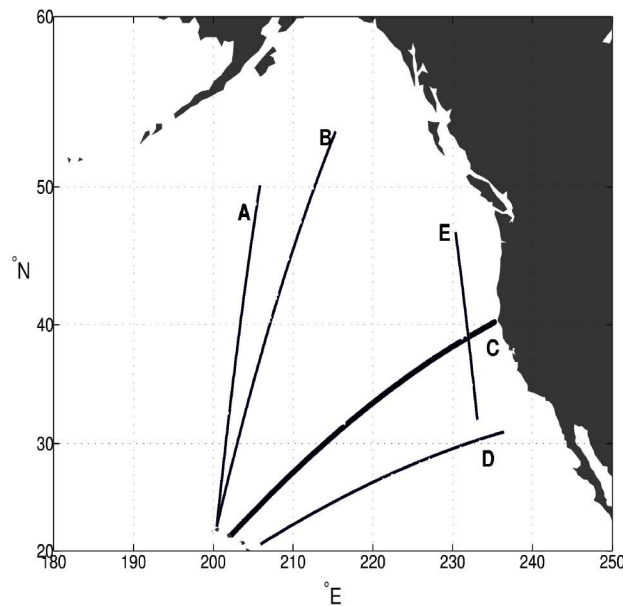


Figure 1. Five sections where the temporal coherence of sound has been compared with models without tuning with data.

The current comparison with data computed the probability distribution of coherence time. Coherence time is defined to be the duration of a coherently integrated acoustic signal yielding maximum signal-to-noise ratio at the receiver.

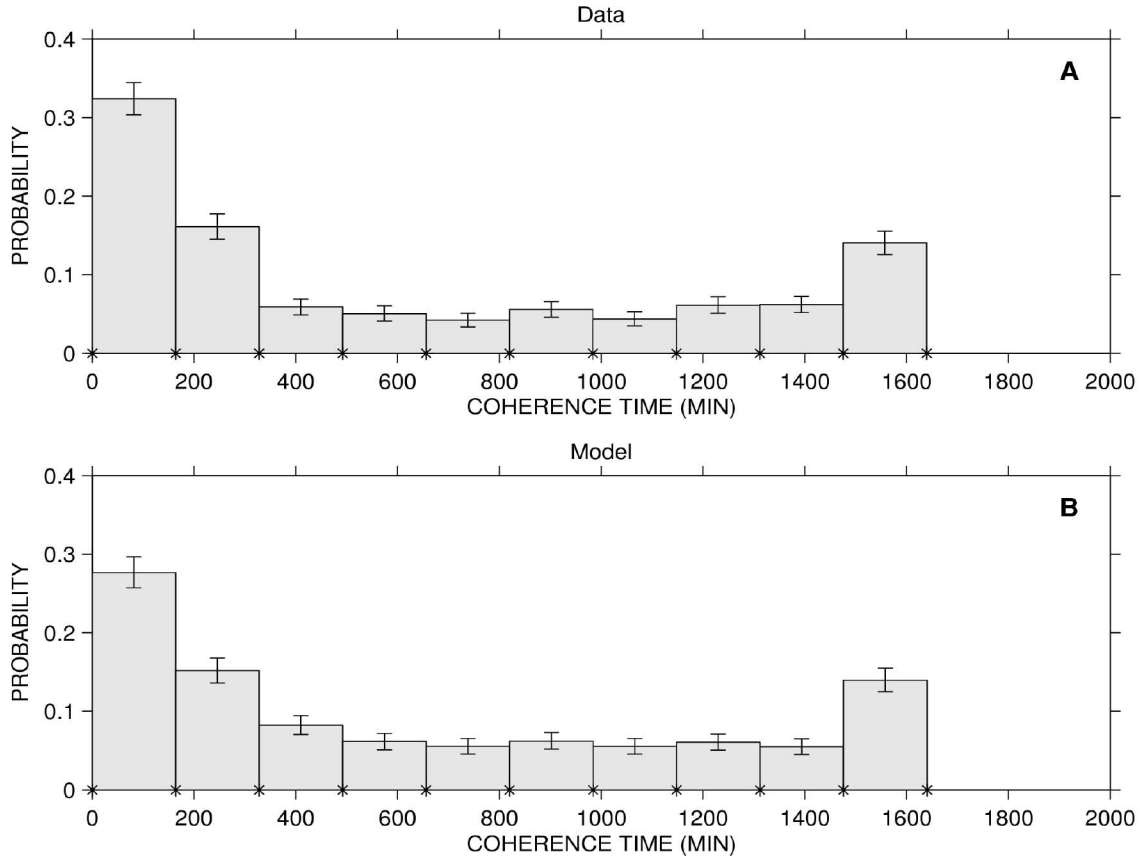


Figure 2. Comparison between data and model of the probability distributions of coherence time for section C in Figure 1. Sound is centered at 133 Hz along a 3709 km section between the Kaneohe source and a receiver near N. California. The model is not tuned with data.

Figure 2 gives the comparison between measured and modeled probability distribution functions. The sum of the probabilities is one. The distributions look nearly identical, with 95% confidence limits indicated. The probability bin on the right includes coherence times of about 1470 min or *longer*. If we had many years of continuous transmissions, the tall bin on the right would be spread out into bins to the right with lesser probability. We cannot explore longer coherence times such as this with a five-day experiment. The most likely coherence time is between 0 and 180 min but there is significant probability that the signal-to-noise ratio can reach a maximum value at times of 1500 to 1600 min, which is a day.

The most important result is that the model yields a very accurate prediction for coherence time without turning with data. The comparison indicates that it is unnecessary to invoke physical mechanisms beyond internal waves to explain temporal coherence in this experiment.

IMPACT/APPLICATIONS

Accurate computations and predictions for temporal coherence have applicability to surveillance, theoretical work in scattering theory, design of acoustic experiments, and underwater acoustic communication systems. Understanding and reliably predicting temporal coherence of sound has been one of the most important issues of concern since WWII.

RELATED PROJECTS

Because of the importance of acoustical coherence both theoretically and practically, many scientists study the coherence of sound. These include Drs. Buckingham, Worcester, Vera, Godin, Voronovich, Colosi, Morozov, Orr, Rouseff, Kuperman, and Duda. Many others not listed here have or are making important contributions.

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PUBLICATIONS

Spiesberger, J., Comparison of two and three spatial dimensional solutions of a parabolic approximation of the wave equation at ocean-basin scales in the presence of internal waves: 100-150 Hz, *J. Computational Acoustics*, 18, No. 2, 117-129, 2010.