

## Coherence of Sound and Understanding Where it is Influenced in the Ocean

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### LONG-TERM GOALS

The goal is to understand and reliably predict the temporal and spatial coherence of sound in the ocean due to influences from the sub-bottom, bottom, surface, and the sound speed and current fields in the fluid.

### OBJECTIVES

The objective of this research is to develop software that accurately quantifies the spatial regions that influence the propagation of sound between a source and receiver in the ocean. Recent studies indicate that in some circumstances accurate predictions of temporal coherence can be made without knowing where the sound is being influenced (Spiesberger, 2011a,b). The present study will develop software to map where the sound is being influenced. Understanding where the sound is influenced will make it easier for scientists to develop theories to predict coherence. At very high acoustic frequencies, the regions that influence sound are shown by rays. Our research will develop software that shows the analogy of the ray path at all finite frequencies. Even moderately high frequencies are influenced by regions that are quite different than ray paths (Spiesberger, 2006b).

### APPROACH

The maps where sounds are influenced between a source and receiver can be constructed by starting with the theory by Kirchoff and Raleigh from the 19th century (Born and Wolf, 1999). The approach uses openings in opaque screens to compute the received signal when the screen is placed anywhere between the source and receiver. Bowlin (1991) used this idea and showed that the regions of the ocean that influence sound for broadband signals are not given by the first Fresnel zone as some theories had assumed (Flatte *et al*, 1979). Spiesberger (2005,2006a) discussed subsequent problems associated with Flatte *et al*'s theory to predict temporal coherence and developed an exact method for computing the regions of influence. In order to implement the approach, an approximate solution of the wave equation must be utilized that obeys reciprocity (Born and Wolf, 1999). Godin (1999) invented a parabolic approximation called OWWE that obeys reciprocity for media whose sound speed field varies in two spatial dimensions, normally with range and depth. Mikhin (2001) produced a numerical scheme to implement OWWE. In this contract, the regions of influence will be constructed through a

collaboration between Dr. Mikhin at Acacia Research and Dr. Spiesberger at Scientific Innovations, Inc.

## **WORK COMPLETED**

Software was written to compute the acoustic field for broad-band sources using the OWWE approximation. Its outputs were compared with the Collins' (1994) RAM parabolic approximation and Tappert's (1995) sound-speed insensitive approximation. The latter two approximations do not obey reciprocity when the speed of sound varies with range and depth.

## **RESULTS**

We demonstrated that Dr. Mikhin's numerical implementation of OWWE for broadband signals yields a reciprocal solution over ocean-basin scales, even with significant variations in the depth of the ocean and the sound speed field. Reciprocity is obeyed with a very high level of accuracy.

## **IMPACT/APPLICATIONS**

Ray theory has wide applications. The current approach for computing the regions that influence sound are exact at all finite frequencies. Although the current approach is much more computationally demanding than tracing rays, computers get faster and we believe that the exact approach will someday be widely used for the same reasons that ray theory is widely used.

## **RELATED PROJECTS**

There is another approach for mapping where a medium affects the propagation of sound between a source and receiver. The method was invented by Marquering et al. (1999) who applied it to seismic problems. Sarsoulis and Cornuelle (2004) used Marquering's approach for application to underwater acoustics. If one wishes to map the regions in space that affect sound, the method we are using is valid at all orders, and Marquering's approach is valid to first order in the perturbations with respect to the reference state. The approaches are not identical in other respects and both offer valuable insights into where sound is influenced.

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