Investigation of Acoustic Wavefield Dynamics
in Quasi-Realistic Ocean Environments

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LONG-TERM GOAL

Our long-term goal is to provide a more complete understanding of the forward propagation of acoustic pulses in range dependent deep ocean environments at multi-megameter range scales.

OBJECTIVES

The objective is to understand the limits of wavefield predictability in ocean environments where refractive scattering is the dominant physical process controlling the dynamics of the wavefield. The canonical scenario is long range acoustic transmissions along the ocean waveguide which has sound speed fluctuations due to oceanic processes characterized by linear Rossby waves and internal waves. The work on this project to date has focused on ocean environments that include the former.

APPROACH

The technical approach involved the development of a three dimensional ocean acoustic ray trace numerical model associated with the solution of the one-way Helmoltz equation. The boundary conditions are specular reflection at the surface, open in the horizontal, and open on the bottom. A Cartesian coordinate system is used, and no account is taken for the sphericity of the Earth. A Hamiltonian prescription is facilitated, and besides the standard ray quantities (i.e. depth, crossrange, vertical momentum, horizontal momentum, and travel time), the model also solves for the elements of the stability matrix M, whose evolution is described by

$$M_{i;j} = K_{i;`} M_{`;j} ; \qquad (1)$$

where the overdot denotes total differentiation with respect to range, and the elements of   depend on the sound speed and its derivatives (up to second order) in crossrange and depth. For sound speed fluctuations due to mesoscale structure, realizations are produced based on first generating a random field of sea surface fluctuations whose two dimensional isotropic spectrum follows what is emperically derived from satellite observations. This field is then 1 weighted in depth with the first baroclynic Rossby mode associated with a deep ocean (5 km) and exponential buoyancy profile. The scale depth and reference buoyancy parameters for the buoyancy profile are taken to be geographically dependent, in accordance to what is reported by Emery et al. [1]. The spectral slope and surface kinetic energy are also geographically dependent [2]. It is in this sense that we denote the ocean structure as quasi-realistic. Of course there are many assumptions and approximations involved in this prescription of mesoscale induced sound speed fluctuations, and in the near future much more realistic mesoscale

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structure will be included by using the temperature salinity and pressure fields taken from high resolution, global ocean circulation numerical models, such as MICOM [3].

WORK COMPLETED

The three dimensional ray model has been completed and simulations have been performed on the Cray T3E supercomputer at the Arctic Region Supercomputing Center at the University of Alaska. The simulations have used parameters for mesoscale structure that are relevant to the eastern North Pacific ocean, where the North Pacific Acoustic Laboratory (NPAL) experiment is being conducted [4].

RESULTS

The primary results are threefold: 1. A late travel time bias and standard deviation in travel time associated with mesoscale structure is very significant. The late time bias is most sensitive to the root-mean-square deviation of sound speed about the depth of the sound channel, and to a lesser extent to the slope of the power spectrum of the mesoscale eddy kinetic energy. 2. At the ranges and scales of the NPAL experiment, no significant dynamic instabilities are expected due to mesoscale structure in the eastern North Pacific. This is in great contrast to the analytical investigations reported by Wolfson and Tappert using a much more idealized horizontal spectrum for describing mososcale structure [6]. 3. We have incorporated an extremely efficient and accurate computational method for handling specular reflections from the ocean surface. For multi-megameter propagation ranges, continuity of the Lagrangian manifold, and piecewise continuity of the time front is lost in environments where a significant portion of acoustic rays multiply interact with the ocean surface, unless great care is taken to accurately obtain the precise range and vertical momentum where a ray trajectory 'hits' the surface. The numerical scheme is very straightforward to implement, and was first introduced by Henon for Poincar'e maps [5]. Some of these results have been presented at the June, 1998 ASA meeting and 4th European Conference on Underwater Acoustics [7]. A manuscript presenting the results regarding the late travel time bias is in preparation. 2

IMPACT/APPLICATION

The three dimensional ray code has been designed to be used as a tool for exploring 'a la brute force numerics' central issues concerning the forward modeling problem in acoustic tomography. The results concerning wavefield predictability have a strong impact on ray-based tomographic methods.
This project addresses issues related to experiments performed by the Acoustic Thermometry of Ocean Climate (ATOC) program and NPAL.

RELATED PROJECTS

We are working on several theoretical albeit more idealized problems with regards to wavefield stability that have not been mentioned in this report. Collaborators include Mike Brown, Fred Tappert, and Steve Tomsovic.

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