Applications of Quantum Chaos Concepts to Long Range Ocean Acoustics

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LONG-TERM GOALS

The long-term goals are: 1) to take advantage of the ever-changing ocean environment's effects in order to provide a more complete understanding of long-range acoustic pulse propagation, 2) to understand the extent of fundamental limitations on ray-based acoustic tomography of particular interest is the breakdown range of semiclassical methods, 3) to develop the theory of the statistical fluctuations of the wavefield, and 4) to address important basic physics issues that arise in the ocean problem, but within a more general wave propagation in random media context.

OBJECTIVES

There are three primary scientific objectives of this work: 1) to begin developing a geometric acoustics theory that addresses parametrically varying ocean environments in the presence of raychaos, determines what information survives under such conditions, and determines how to extract it, 2) to develop the geometric acoustics theory of wavefield fluctuations, and 3) to determine the sensitivity of acoustic wave#elds to relevantoceanenvironment parameters thereby connecting the scale of changes in the ocean to range scales of wave#eld correlation decay.

APPROACH

We consider acoustic propagation problems that allow for parabolic equation description. Advantage is taken of new semiclassical approaches to approximate time-evolving wavefields in systems possessing classically chaotic analogs. The methods rely on wavepackets, hetero-clinic orbit summations, and have been shown to be remarkably accurate in spite of relying on highly unstable chaotic trajectories. The approach is similar in spirit to the van Vleck approximate propagator, and the Gutzwiller trace formula. From this starting point, we consider systems whose governing equations can be expressed as varying with respect to a parameter; this can model, for example, a time-changing internal wave configuration. To study response and sensitivity, it is fruitful to apply perturbation theory to describe the changes arising in ensembles of classical trajectories underlying the wavefields. We compare semiclassical predictions with 'exact' numerical wavefield calculations.

Report Documentation Page

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WORK COMPLETED

The work completed this year falls into two projects, one in collaboration with M. Wolfson, and the other with a WSU Ph. D. graduate student, Nicholas Cerruti. Dr. Wolfson and I submitted a paper to Journal of the Acoustical Society of America on the stability of rays propagating through mesoscale structure in the ocean. The model is simplified, possessing a single scale of weak random structure, involves only the horizontal plane, and is isotropic. Nevertheless, it has some key features of rays propagating in random media similar to ocean acoustic rays. There is now evidence that the same probability densities show up in models incorporating a background sound speed profile and internal waves. It has the advantage that Wolfson and Tappert have worked out some previous analytic results helpful for our current study. The second project was an investigation of the stability of chaotic wave systems with respect to changing a parameter in their governing equations. We have begun with abstract maps as dynamical models, but also have developed a more general theoretical approach that will eventually be valid for making connections to changing mesoscale and internal wave field fluctuations.

RESULTS

Dr. Wolfson and I have found that the stability of rays discussed above fluctuate as lognormal random variables. Our results also predict the scaling of the width of the distribution, how it collapses in the in#nite range limit, and gives us a prediction for the number of remaining nearly stable or intermittent rays as a function of the range. The same stability measures appear in ray theories for the amplitudes of various contributions to the wave fields. The remaining stable rays may be important for helping tomographic techniques where mostly chaotic rays exist, and the lognormal distribution may have ramifications for the wavefield statistics at finite range. In the second project, we have found that a semiclassical theory based on first order classical perturbation theory describes well the stability and response of a wave field in a chaotic system undergoing parametric variation.

IMPACT/APPLICATION

The work is aimed at understanding the predictability and/or other limitations of ray methods in the presence of unstable dynamics. In addition, parametric variation, once understood, is often found to be one of the only successful ways of deducing otherwise difficult-to-ascertain information about complex systems such as the ocean environment. It may lead to new ocean acoustic tomography techniques.

TRANSITIONS

It is too early to discuss how these results will eventually be used by others.

RELATED PROJECTS

Additional work currently underway, but not described in this report, involves collaborations with the following individuals: M. Wolfson (WSU), J. Colosi (WHOI), and M. Brown (RSMAS-AMP).

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