

## **Modeling of Acoustic Field Statistics for Deep and Shallow Water Environments**

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### **LONG-TERM GOALS**

The long-term goals of this research are to understand the statistics of acoustic fields in both deep and shallow water ocean environments.

### **OBJECTIVES**

The primary objective of this work is the development of accurate, and computationally efficient, reduced-physics acoustic propagation models for the prediction of the statistics of ocean acoustic signals in both shallow and deep-water environments. Examples of acoustic field statistics of interest are mean intensity, coherence, and intensity variance. The focus here is primarily on the Philippine Sea, and the SW06 site off the New Jersey coast, since these are the most recent and complete data sets. Reduced physics models are important not only because they are computationally efficient but also because they elucidate the relevant space-time scales of ocean variability affecting acoustical fields. This knowledge allows for more focused study on those oceanographic processes that will have large acoustical influences. Therefore centrally related to the primary objective of this research is an effort to characterize ocean sound-speed variability, and develop ocean models that can be easily assimilated into acoustic fluctuation calculations. In the Philippine Sea, models of eddies, internal tides, internal waves, and fine structure (spice) are needed, while in the shallow water case a models of the random linear internal waves and spice are lacking.

### **APPROACH**

The approach to this research is to rigorously test acoustic fluctuation models using Monte Carlo numerical simulation thereby isolating the important acoustical physics when the environment is perfectly known. Once the models have passed the Monte Carlo test, they can be subsequently used for the interpretation of observations where the environment has considerably more uncertainty. Experimental analysis involves the study of both acoustical and oceanographic observations.

### **WORK COMPLETED**

Work completed in the previous year has focused on adapting transport theory for use in shallow water to predict mean transmission loss, transmission loss errorbar, and various coherences. The theory has also been adapted to include both internal wave and surface wave stochastic fields. This work has

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culminated in a JASA publication, and one that is in review. In addition, Peter Worcester and I obtained a contract with Cambridge University Press to publish a book entitled ``Ocean sound propagation through the stochastic internal wave field''. Over this year we have written the book and we are now working on the illustrations and distributing chapters to colleagues for critique.

## RESULTS

### A. Transport Theory: Shallow water

Work on shallow water transport theory for mean intensity and intensity variance (e.g. mean TL and errorbar) has focused on extending the theory to handle kilohertz frequencies and to simultaneously account for random internal waves and random sea surface roughness. Working with my postdoc Dr. Kaus Raghukumar we have developed a hybrid transport theory that is accurate and can handle the large number of modes needed at high frequency. In the hybrid approach we solve for second and fourth order mode amplitude correlation matrices by assuming that cross mode correlations are dominated by adiabatic phase effects. Mode energy redistribution from coupling is handled by replacing the initial mode amplitude terms in the adiabatic expressions with range evolving ones based on Creamer's approximation. The method works exceptionally well for mean intensity and scintillation index at kilohertz frequencies for the SW06 environment with random sound speed perturbations from internal waves. Over the year we have discovered that the hybrid theory does not work well for surface gravity waves and so a full transport theory treatment is required. Our work on internal waves alone was published in JASA and our work with both surface and internal waves is under JASA review.

### B. Monograph: ``Ocean Sound Propagation Through the Stochastic Internal Wave Field''

Since March of 2013 Peter Worcester and I have been working on a monograph that will be the sequel to the 1979 classic ``Sound Transmission through a Fluctuating Ocean'', By Flatte, Munk, Dashen, Zachariasen, and Watson. We submitted a book proposal to Cambridge University Press (CUP), which was accepted by the editorial board in September, 2013. Seven of the eight chapters are now written and we expect to complete the book for publication by summer 2015.

### C. Resurrection of the $\Lambda$ - $\Phi$ Diagram

New work on weak fluctuation theory over the year has yielded useful new insights and adjustments to  $\Lambda$ - $\Phi$  theory and the estimation of wave propagation regimes denoted by unsaturated, partially saturated and fully saturated. Figure 1 below shows the new boundaries of the diagram along with contours of log-intensity variance computed from weak fluctuation theory. The placement of several experiments on the diagram reasonably represents the observed propagation regimes.

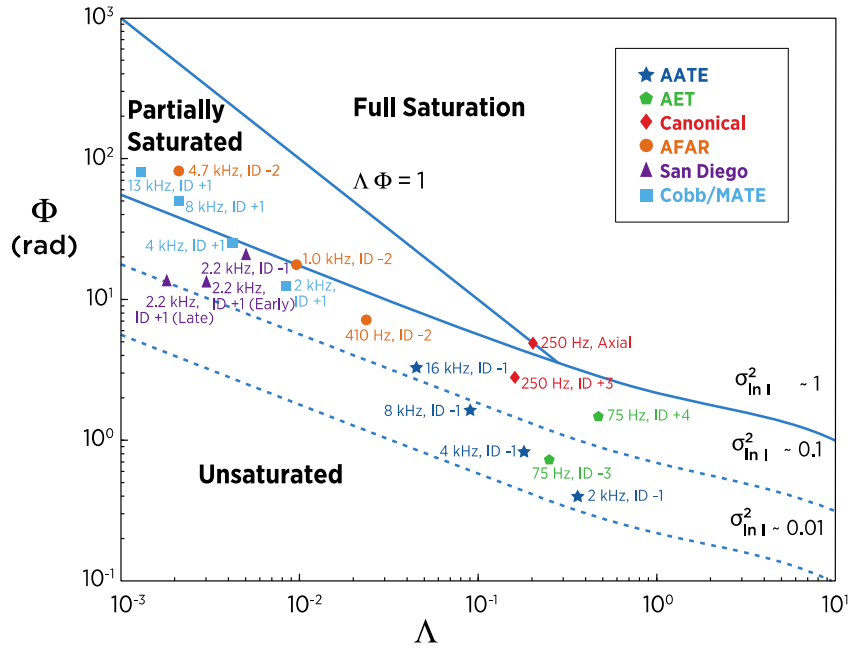


Figure 1:  $\Lambda$ - $\Phi$  diagram with several short range experiments marked.

## IMPACT/APPLICATIONS

There are several implications of this work to the understanding of acoustic predictability. A short list of the major issues/impacts are given below.

1. Many observations and numerical studies have shown that internal wave induced sound speed perturbations have a large effect on mean intensity (transmission loss) in both shallow and deep water environments. The coupled mode/ transport theory developed by our group could conceivably be used as a Navy model for predicting low and high frequency mean TL, errobar, and coherence. Work is underway to develop computationally tractable codes that also handle random sea surface effects.
2. The writing of a monograph covering the development of the subject of sound transmission through the stochastic internal wave field will establish where we have gone in this important area over the last 30 years and it will point to new directions in which the field can go in the future. The authors hope this book will be an indispensable part of students, researchers, and academics libraries on underwater acoustics.
3. Development of a means to predict acoustic propagation regimes is extremely valuable for the planning of ocean acoustic activities associated with remote sensing, communications, or navigation.

## TRANSITIONS

None

## RELATED PROJECTS

1. MURI – Integrated Ocean Dynamics and Acoustics (Tim Duda, WHOI MURI Leader)
2. THAAW – Thin ice Arctic Acoustic Window (Peter Worcester, SIO Leader)

## REFERENCES/ RECENT PUBLICATIONS

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12. Jones, B.A., J.A. Colosi, T.K. Stanton, R. C. Gauss, J.M. Fialkowski, and J. Michael Jech ``Classification and statistics of long range mid-frequency sonar measurements of aggregations of fish'', J. Acoust. Soc. Am., submitted, 2014.
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14. Raghukumar, K. and J.A. Colosi, ``High frequency normal mode statistics in a shallow water waveguide: I. The combined effect of random linear surface and internal waves'', J. Acoust. Soc. Am., under review, 2014.

## **PATENTS**

None

## **HONORS/AWARDS/PRIZES**

1. Cecil H. and Ida M. Green Scholar, Scripps Institution of Oceanography, 2000,2014
2. Fellow, Acoustical Society of America, 2013
3. Medwin Prize in Acoustical Oceanography, 2012, for furthering the understanding of ocean sound-speed structure and its effects on acoustic propagation in both deep and shallow water. Acoustical Society of America.
4. A. B. Wood Medal, 2001, for "significant contributions to the understanding of acoustic scattering by internal waves in long-range propagation". Institute of Acoustics and Acoustical Society of America.
5. ONR Young Investigator Award, 1997.