Modeling of Acoustic Field Statistics for Deep and Shallow Water Environments and 2015 CANAPE Pilot Study Moored Oceanographic Observations

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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 culminated in two JASA publications.

This year work has also been completed on the prediction of wave propagation regimes, termed unsaturated, partially saturated, and fully saturated, using the $\Lambda\Phi$ diagram. Important corrections were made in the treatment of diffraction, in the internal wave spectral cut off, and in the estimation of the boundary between unsaturated and stronger scattering. This work was published in JASA.

Lastly, I have finished my book entitled ``Sound Propagation through the Stochastic Ocean''. The book will be published by Cambridge University Press, sometime in 2016.

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 hydrid 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. The hybrid theory does not work well for surface gravity waves and so a full transport theory treatment is required. Two papers have been published in JASA on this research.

B. Monograph: ``Sound Propagation through the Stochastic Ocean''

Since March of 2013 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. The new book, entitled ``Sound Propagation through the Stochastic Ocean'', is now complete and will be handed off to the publisher, Cambridge University Press, this month. The book is expected to be available in 6-12 months time.

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

New work on weak fluctuation theory over the year has yielded useful new insights and adjustments to Λ–Φ 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.

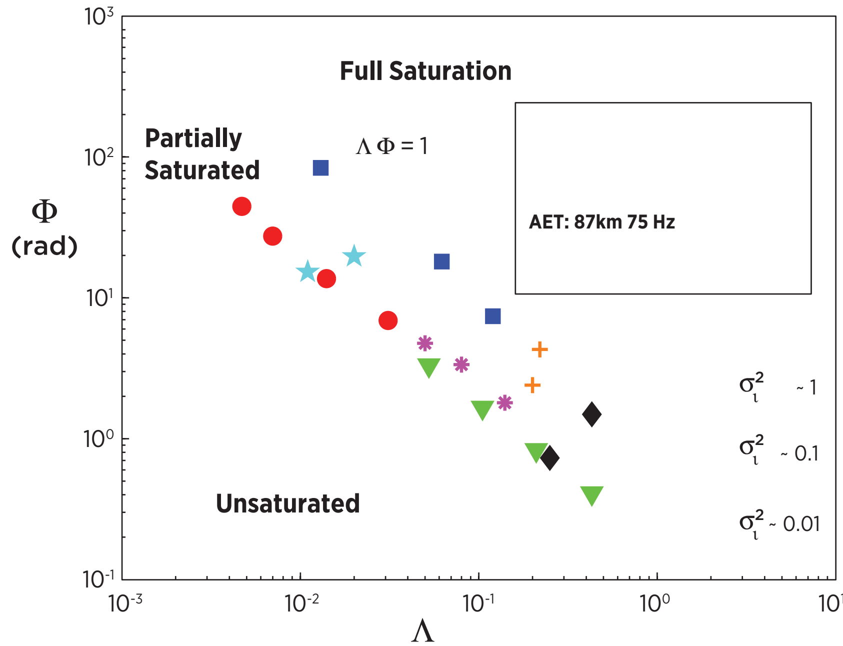

Figure 1: $\Lambda-\Phi$ diagram with several short-range experiments marked.

In this work important corrections have been made in 1) the computation of the Fresnel zone, which quantifies diffraction, 2) the estimation of the spectral cut off in the Garrett-Munk internal wave spectrum, and 3) the estimation of the boundary between unsaturated propagation and stronger scattering regimes. This work was published in JASA.

D. Oceanographic Observations for the CANAPE Pilot Study

Peter Worcester's group and my group successfully deployed and recovered 24 microcats and 2 ADCPs as part of the CANAPE 2015 pilot study. The equipment performed well with both ADCPs and 22/24 microcats providing quality data.

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.
4. Oceanographic observations in the Arctic will help provide new insight into the changing acoustical environment, and they will help guide the design of the CANAPE main experiment to go in the water summer of 2016.

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

1. Lynch, J.F., T.F. Duda, and J.A. Colosi, ``Acoustical horizontal array coherence lengths and the ``Carey Number'' '', Acoustics Today, 10, pp10-19, 2014.
2. Jones, B.A., J.A. Colosi, and T.K. Stanton, ``Echo statistics of individual and aggregations of scatterers in the water column of a random oceanic waveguide'', J. Acoust. Soc. Am., 136, pp90-108, 2014.
3. 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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6. Colosi, J. A., ``A re-formulation of the $\Lambda\Phi$ diagram for the prediction of ocean acoustic fluctuation regimes'', J. Acoust. Soc. Am., 137(5) , pp2485-2493, 2015.
7. Morozov, A.K., and J.A. Colosi, ``Entropy rate defined by internal wave scattering in long range propagation'', J. Acous. Soc. Am., 138, 1353-1364, 2015.
8. Andrew, R. A. White, J. Mercer, P. Worceter, M. Dzieciuch, and J.A. Colosi, ``A test of deep water Rytov theory at 284 Hz and 107 km in the Philippine Sea'', J. Acous. Soc. Am., accepted, 2015.
9. Radko, T. J. Ball, J.A. Colosi, J. Flanagan, ``Double-diffusive convection in a stochastic shear'', J. Phys. Oc., in revision, 2015.
10. Ramp, S.R., J.A. Colosi, P.F. Worcester, F.L., Bahr, K. Heaney, J.A. Mercer, and L.J. Van Uffelen, 2015. ``Direct observations of the mesoscale variability in the Western Philippine Sea'', J. Phys. Oceanogr.

11. Colosi, J.A. *Sound Propagation through the Stochastic Ocean*, Cambridge University Press, in press.

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.