An Analysis of Long-Range Acoustic Propagation Fluctuations and Upper Ocean Sound Speed Variability

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LONG-TERM GOALS

The long-term goal of this research is to use observations to study the nature of acoustic variability for long range propagation in the deep ocean, and to place these observations into a theoretical framework in which the predictability of acoustic fields can be evaluated for different regions of the world oceans.

OBJECTIVES

The scientific objectives of this work are threefold. The first objective is to use data from basin-scale acoustic transmissions in the eastern North Pacific Ocean to estimate acoustical coherence, and signal phase and intensity variability. The second objective is to use observations of upper ocean sound speed variability to go beyond the simple Garrett-Munk characterization of the internal wave induced sound speed variability. Finally, the third objective is to use the notions of ray chaos and/or broadband scattering to interpret long-range acoustic field variability.

APPROACH

Our approach is to utilize acoustic and oceanographic observations to quantify variability, and to explore, through both simple and complex models (analytic and numerical), the underlying physics of statistical acoustic wave propagation.

WORK COMPLETED

This year we were able to complete a thorough analysis for intensity fluctuations for a 75 Hz, broadband, 3250-km acoustic transmission experiment in the Pacific [1], and we began work on comparisons of observed and computed 2-D coherence as a function of time and depth lag [2]. Numerical simulations of ray propagation through realistic ocean internal wave and mesoscale sound speed fields were carried out to examine the connections between observations presented in [1] and ray chaos theory [3,4].

RESULTS

This year, analysis of observations [1] has deepened the notion that our present theories of wave propagation are sorely inadequate to describe acoustic variability for ranges at and in excess of 1000km. Predictions of wave propagation regime based on $\Lambda\Phi$ theory clearly place the propagation in the fully saturated regime, where as the observations show a dual regime in which early arriving

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14. ABSTRACT
The long-term goal of this research is to use observations to study the nature of acoustic variability for long range propagation in the deep ocean, and to place these observations into a theoretical framework in which the predictability of acoustic fields can be evaluated for different regions of the world oceans.

15. SUBJECT TERMS

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energy behaves as if it were near the border of unsaturated/partially saturated regimes and late arriving energy behaves as if it were in the saturated regime. The correct prediction of regime for the late arriving energy is fortuitous, as the assumptions of the theory are grossly violated. The nature of the early arriving energy is quite interesting. Firstly, the travel time wander of the early pulses is much greater than the pulse time spread. Second, the ensemble average pulse is very narrow near the peaks, but strongly and symmetrically broadened several inverse bandwidths away. Third, intensity variances are 2-3 times larger than the limit of weak fluctuation theory, and intensity variance is a strong function of delay time from the peak of the pulse (smaller variances are observed at the peaks, and values increase with increasing time delay from the peak). Fourth, the PDF of peak and time delayed intensity is log-normal, a property of weak fluctuations. Finally, there is significant fracturing or multipathing on the wavefront and on average there are 2 closely spaced wavefront segments; multipathing is not a property of weak fluctuations. Collectively all of these properties do not fit into a standard category of unsaturated, partially saturated and fully saturated propagation.
With regard to the late arriving energy our analysis has shown that this energy behaves much like Gaussian random noise (fully saturated) with a 40% modulation of the mean intensity [1].

With regard to coherence, Matt Dzieciuch and I find temporal and vertical coherences to be significant out to maximum observable lags of 16 minutes and 700m. We find that both phase and amplitude correlation are important in the analysis of coherence. Utilizing a ray based theory and the GM internal wave spectrum, we have compared the observed and predicted phase structure functions with the result that temporal variability is predicted within about a factor of 2, but depth behavior is off by about a factor of 6 [2]. This result is obtained after correcting for the observed phase variance, therefore the GM energy level cannot be used to reconcile the differences; other GM or internal wave parameters are important! Utilizing a simple mesoscale model based on 3 years of TOPEX/POISEIDON data we find that mesoscale and internal wave contributions to horizontal coherence are comparable [2].

Finally extensive numerical simulations have been done to study the ray nature of long-range propagation through internal waves. Working with Mike Brown, Fred Tappert, Frank Henyey, and Mike Wolfson, I have been able to show that the PDF of Lyapunov exponent is very closely normal and that the variance scales like 1/R (in agreement with Wolfson and Tomsovic's theory which utilizes a simple single scale random medium model). Further I have been able to show the dependence of numerically computed Lyapunov exponent on the modal and spectral content of the internal wave model. It is found that steep rays are relatively insensitive to increases in the vertical modal content of the internal wave field, but these rays are sensitive to the high horizontal wavenumber cutoff. Small angle rays have the opposite behavior, and a small band of intermediate rays show little sensitivity to either variation. Interestingly these intermediate rays have the smallest Lyapunov exponent and they delineate the transition region between the aforementioned dual propagation regimes.

IMPACT/APPLICATIONS

The results of this study will have direct impact on naval acoustical remote sensing in the deep ocean.

TRANSITIONS

None envisioned at this time.

RELATED PROJECTS

This work is related to the Effects of Sound on the Marine Environment (ESME) program, since both projects are concerned with acoustic and oceanographic variability. This project is closely related to the North Pacific Acoustic Laboratory (Worcester and Spindel), and semiclassical approximations and predictability in ocean acoustics (Brown).

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