Numerical Modeling Efforts in Support of 3-D Environmental Variability and Acoustic Vector Field Studies

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LONG-TERM GOALS

The goals of this research included the study of the effects of three-dimensional (3-D) environmental variability on the flow of energy in the complex intensity field, and two-dimensional (2-D) scattering from evolving rough surfaces. In the former case, the fully 3-D forward problem was modeled in order to gain a deeper understanding of the impact of shallow water features, such as solitons, on the propagation of acoustic energy. In the latter, broadband rough surface scattering was computed by incorporating sophisticated models of an evolving one-dimensional (1-D) rough surface into the propagation model. In addition to characterizing the statistics of the scattered field, the evolving surface will allow direct analysis of the associated Doppler from rough surface scattering.

OBJECTIVES

The overall objective of this work was to study the three-dimensional response of the acoustic vector field in the presence of environmental variability, and the two-dimensional scattering response of the acoustic field due to an evolving rough surface.

APPROACH

For the 3-D propagation portion of this work, a previously developed technique for computing the acoustic vector field from a PE model,[1,2,3,5,6] was expanded to generate solutions in 3-D environments using a Cartesian coordinate system. The model was then employed at the Univ of Rhode Island to produce vector field data in a 3-D shallow water environment which incorporated perturbations due to shallow water non-linear internal wave structures.[7]

For the 2-D scattering portion of this work, an exact rough surface scattering treatment was implemented in the PE model,[4] and interfaced with an evolving rough surface model developed at UDel. This will be used to compute the time-evolving acoustic field as the rough surface evolves, which will allow direct calculations of acoustic scattering and associated Doppler.

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WORK COMPLETED

The Monterey-Miami PE (MMPE) model, which was updated in FY09 to compute the full 3-D propagation in Cartesian coordinates, was employed by Georges Dossot at the University of Rhode Island to compute the effects of a train of non-linear internal waves (NLIW) propagating on a continental shelf. The structure of this synthetic data was then compared with experimental data collected during the Shallow Water 2006 (SW06) experiment off the coast of New Jersey.

The model was run for varying NLIW positions propagating across the source-receiver path. The goal was to show the effects of 3-D refraction, focusing (ducting), and defocusing (anti-ducting) as the NLIW train passes by the primary propagation path.

The rough surface scattering work was performed by Joseph Senne at the University of Delaware. He was also able to interface an evolving rough surface dynamical model with the 2-D MMPE model. The goal of his work is to utilize the model to examine the statistics of the scattered field as well as the predicted Doppler response from the dynamically evolving surface.

RESULTS

3-D Propagation Studies:
For propagation in the presence of a train of NLIWs, Georges Dossot took measured 2-D environmental data and expanded it to create a 3-D environmental sound speed field. The expanded sound speed field assumed each NLIW front was parallel to the others, and straight in the cross-range direction. This sound speed field was then evolved by moving it across the central propagation axis of the calculation, thereby simulating the passing NLIW train between the source and receiver.

Figure 1 shows the depth integrated intensity of the acoustic field at various positions of the NLIW train. In the upper left panel, the position of the NLIWs is about 0.5km from the central propagation axis (cross-range of 0km) of the calculation. The field exhibits strong horizontal refraction effects, observed by the interference pattern. In the upper right panel, the first NLIW front is directly aligned with the source along the central propagation axis, thereby creating a strong defocusing region (anti-duct). The bottom panel then displays the effect created when two NLIW fronts exist on either side of the source, bounding the central propagation axis. In this case, strong focusing (ducting) occurs, and a high-intensity region is observed to propagate between the NLIW fronts for long ranges.

Figure 2 displays the acoustic intensity at the receiver range. In these panels, both intensity point observations and the depth structure of the intensity are displayed. The panels on the left display the results when the receiver is assumed to reside directly along the central propagation axis. In this case, there are some fluctuations leading up to the passage of the NLIW train, but the most significant effects are observed when ducting occurs and high focus regions create large intensity fluctuations. The panels on the right display the results when the receiver is assumed to be slightly off the central propagation axis (as was more consistent with some SW06 data sets). In this case, there is no source-receiver path directly between two NLIW fronts, and no direct ducting occurs. However, there is still a noticeable ramping up of the signal level prior to the arrival of the first NLIW front, due to strong horizontal refraction.

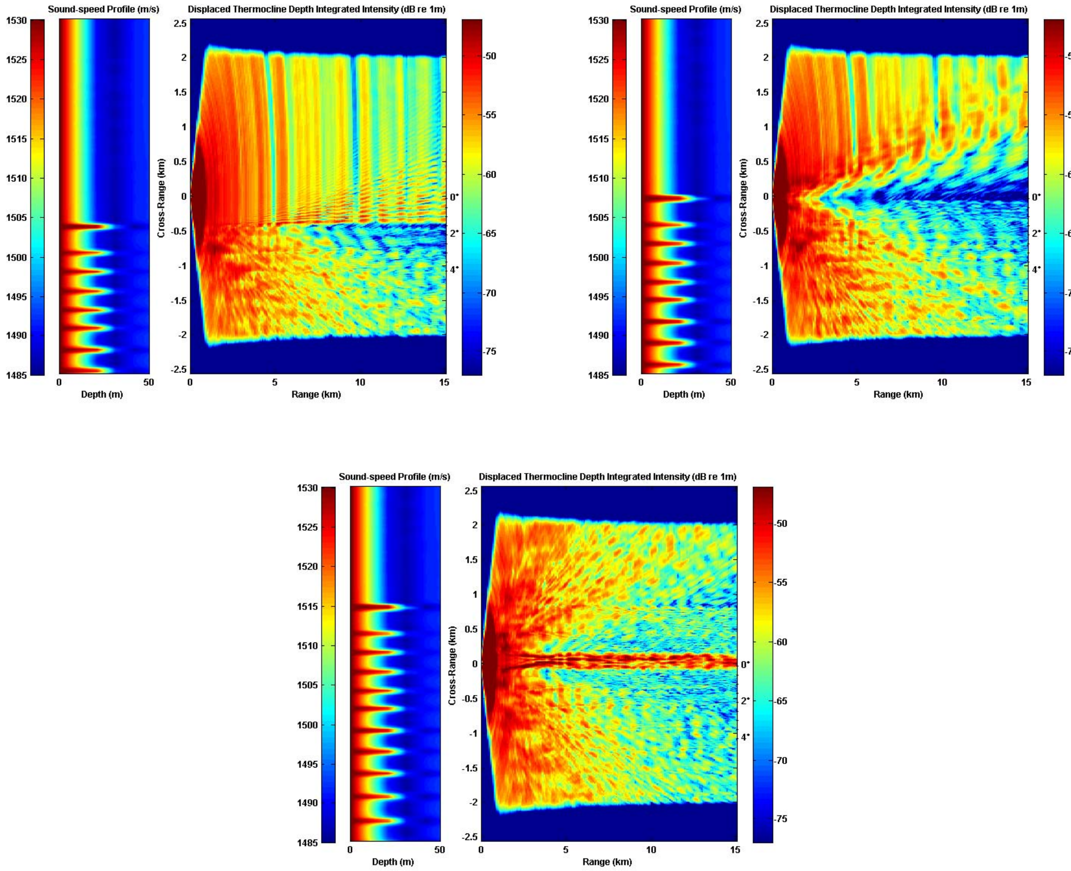

Figure 1: Depth integrated intensity as NLIW packet passes by source position.

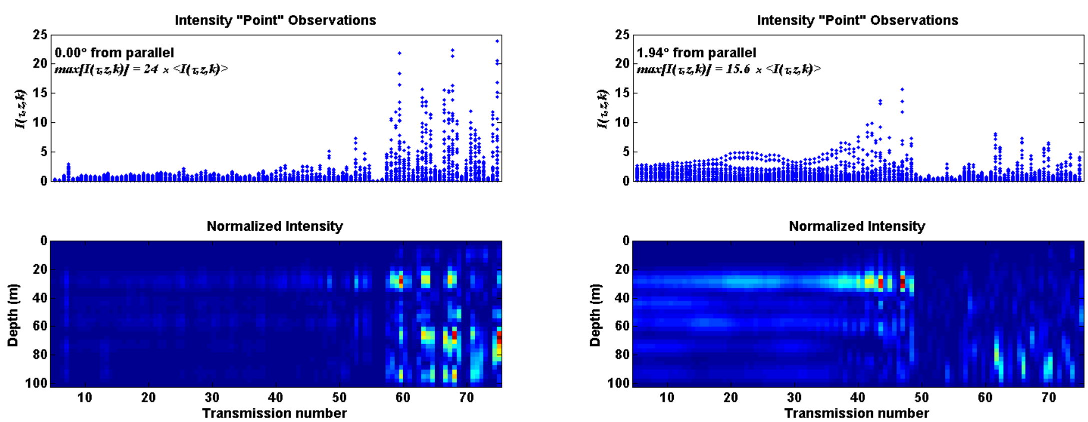

Figure 2: Intensity fluctuations at receiver range when observed directly parallel to NLIW front (left) and at approximately 2 deg off parallel (right).

Rough Surface Scatter Studies:
For the rough surface scatter studies, the PE model was updated to incorporate an exact surface scatter technique. A measured spectrum of a rough surface was then incorporated into this model by Joseph Senne, who began computing broadband scattering statistics of the 2-D field. Most recently, he has begun computing multiple realizations based on a dynamically evolving rough-surface model, which will allow direct computation of the time-evolving acoustic arrival time structure. This data will allow direct analysis of scattering statistics and Doppler spread.

Figure 3 displays the 2-D scattered acoustic arrival time structure from one realization of the rough surface. Figure 4 shows how the rough surface dynamically evolves at discrete time intervals (left panel, evolution from blue to red), and how the acoustic arrival structure at a single depth (70m) evolves. Note that the first two arrivals are due to the direct path and bottom reflected path, and so do not change. Subsequent arrivals include rough surface scattering, and so change as the surface evolves.

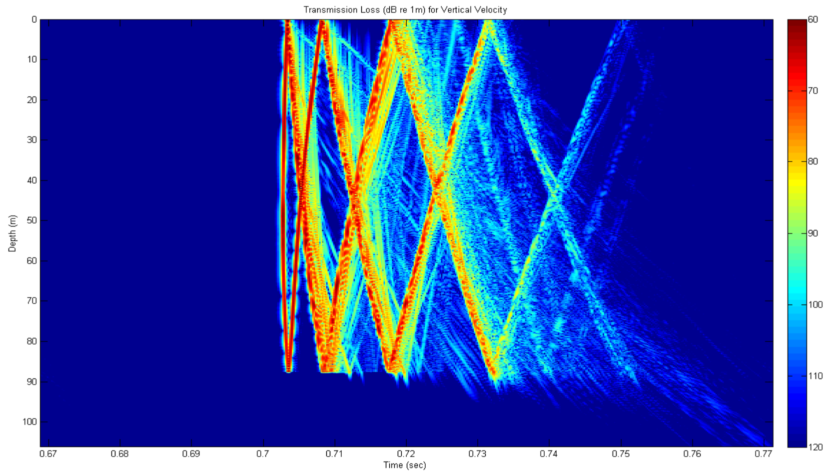

Figure 3: MMPE arrival time structure for single rough surface realization.

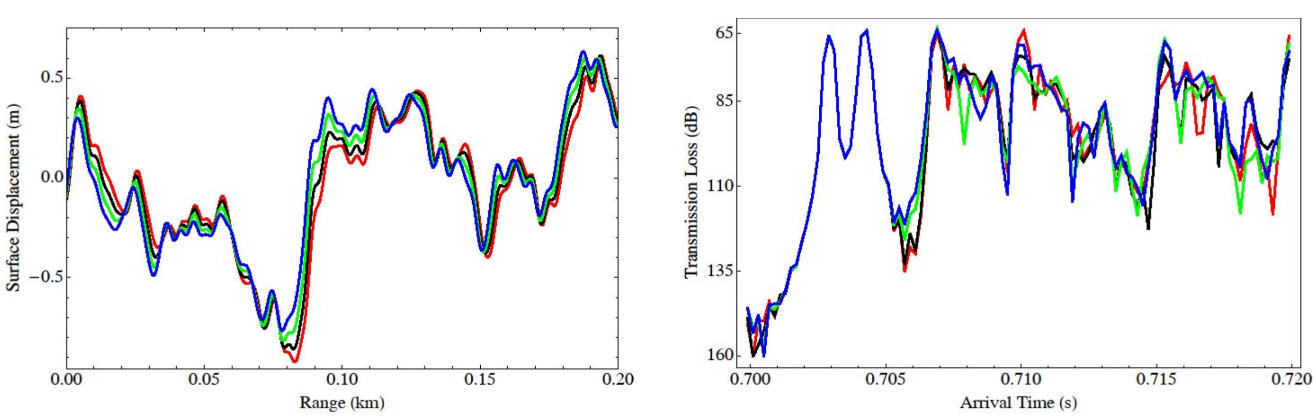

Figure 4: Snapshot expanded views of evolving rough surface (left), and corresponding snapshots of acoustic arrival structure (right), showing variations in signals scattered from rough surface.

IMPACT/APPLICATIONS

The shallow-water environment poses many obstacles to submerged and surface operations. Not the least of them are the obstacles posed to acoustic detection of quiet contacts. The presence of Non-Linear Internal Waves (NLIWs) within this environment induce acoustic variability and phase fluctuations which limit signal processing capability and further complicate operations in this environment. However, a better understanding of how NLIWs affect sound propagation may lead us to take advantage of some of these effects, such as how NLIWs focus acoustic energy into certain modes allowing detection of quiet sources above background noise. An understanding of the phase fluctuation may also lead to better processing algorithms.

At higher frequencies, the impact of rough surface scattering becomes significant. With the introduction of the dynamically evolving rough surface into the propagation model, a better understanding of the time-evolving statistics and Doppler spread of acoustic signals may assist in the design of future systems or deployments. This may be particularly relevant for mine-hunting sonar or underwater acoustic comms.

RELATED PROJECTS

On-going work studying the 3-D effects of NLIWs is being conducted by Prof Jim Miller and his students (Univ of Rhode Island), as well as Prof Mohsen Badiey and his students (Univ of Delaware). The evolving rough surface model was developed at the Univ of Delaware

REFERENCES

1. Smith, K.B., D'Spain, G.D., and Hodgkiss, W.S., "Modeling acoustic particle velocity in range dependent environments with a parabolic equation code," J. Acoust. Soc. Am., Vol. 94, pp. 1885, 1993.
2. Smith, K.B., "Convergence, stability, and variability of shallow water acoustic predictions using a split-step Fourier parabolic equation model," J. Comp. Acoust., Vol. 9, pp. 243-285, 2001.
3. Smith, K.B., "Validating range-dependent, full-field models of the acoustic vector field in shallow water environments," J. Comp. Acoust., Vol. 16, pp. 471-486, 2008.
4. Ead, R., Smith, K.B. and Badiey, M., "Numerical investigation of rough surface scattering in a fetch-limited environment using a parabolic equation model," J. Acoust. Soc. Am 115, pp. 2551, 2004.

PUBLICATIONS

5. Smith, K.B., "Theory and Phenomenology of the Acoustic Vector Field," Proceedings of 20th International Congress on Acoustics, Sydney, Australia, 23-27 August, pp. 276-283, 2010. (Invited paper, published.)

6. Smith, K.B., "Modeling the Acoustic Vector Field Using Parabolic Equation and Normal Mode Models," J. Acoust. Soc. Am. 127, pp 1819, 2010. (Invited presentation, abstract only.)

7. Dossot, G., Miller, J.H., and Smith, K.B., “Comparison of modeled and measured intensity fluctuations due to a strong nonlinear internal wave event,” Proceedings of 10th European Conference on Underwater Acoustics, Istanbul, Turkey, 5-9 July, pp. 141, 2010. (Published, abstract only.)