

# **Uncertainties and Interdisciplinary Transfers Through the End-to-End System (UNITES): Oceanographic Contributions to the Quantification of Uncertainty in Sonar Performance**

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## **LONG TERM GOALS**

UNITES is a unique, interdisciplinary team with expertise spanning the environment (physical oceanography, bottom geology), ocean acoustics (propagation, ambient noise, reverberation and signal processing), and tactical sonar systems. The overall goals of the research are to enhance our understanding of the uncertainty in the ocean environment (including the sea bottom), characterize its impact on sonar system performance, and provide the Navy with guidance for understanding sonar system performance in littoral areas.

## **OBJECTIVES**

Specific objectives of the UNITES team are: 1) Develop generic methods for simply and efficiently characterizing, parameterizing, and prioritizing sonar system variabilities and uncertainties arising from regional scales and processes, 2) Construct, calibrate, and evaluate uncertainty and variability models for sonar systems and their components, thus addressing the forward and backward transfer of uncertainty, and 3) transfer uncertainty from the acoustic environment to the sonar and its signal processing, in order to effectively characterize and understand sonar performance and predictions.

## **APPROACH**

The WHOI component of the UNITES team is focused on physical oceanography and acoustics issues in the end-to-end system, specifically mesoscale oceanography, finescale oceanography, and the acoustic fluctuations due to mesoscale and finescale oceanography.

In the mesoscale oceanography portion of this work, we are initially pursuing the following specific tasks: 1) quantifying the amplitude and spatial structure of the variance of the soundspeed field using both PRIMER experiment data as well as existing historical data and 2) relating simple frontal

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| 14. ABSTRACT<br><b>UNITES is a unique, interdisciplinary team with expertise spanning the environment (physical oceanography, bottom geology), ocean acoustics (propagation, ambient noise, reverberation and signal processing), and tactical sonar systems. The overall goals of the research are to enhance our understanding of the uncertainty in the ocean environment (including the sea bottom), characterize its impact on sonar system performance, and provide the Navy with guidance for understanding sonar system performance in littoral areas.</b>                                                                                                                                                                                                                                                                                     |                                    |                                     |                                                           |                                                     |                                 |
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parameters such as cross-frontal temperature difference and the baroclinic Rossby radius to the spatial structure of the variance of the soundspeed.

In the finescale oceanography portion of our work, we are initially concentrating on the effects of nonlinear internal waves on the coastal acoustic field. To represent the internal wave field, we have developed an  $n \times 2D$  numerical model based on the range-dependent Korteweg-deVries (KdV) equation, which also inputs PRIMER data from SAR imagery and moored temperature sensors to constrain the calculations.

In the third component of our study, acoustics, we are concentrating on three topics, 1) so called “rules of thumb” for acoustic variability, 2) the ground truth quantification of acoustic uncertainty from high resolution field experiments such as PRIMER and ASIAEX and 3) the uses of Kravtsov’s predictability theory to determine acoustic uncertainty given measurement error in key environmental variables.

All of the WHOI PI’s are also actively engaged in working with other members of the UNITES team on the “en-to-end” problems that were originally formulated, and have since been refined.

## **WORK COMPLETED / RESULTS**

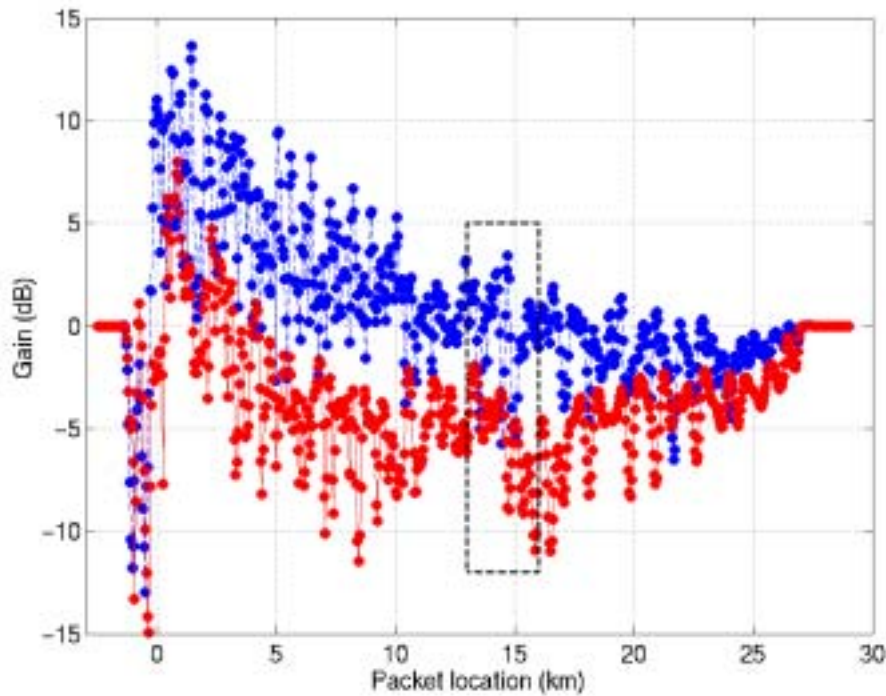
In terms of the mesoscale oceanography environmental data analysis, a number of manuscripts appeared in the past year dealing with the Shelfbreak PRIMER data set. Gawarkiewicz et al. (2001) analyzed data from the spring and found significant interactions between a slope eddy adjacent to the shelfbreak front and the frontal thermohaline and velocity fields. The net effect was to steepen the front and intensify the alongshelf jet to the northwest of the anti-cyclonic eddy, and flatten the front and weaken the jet to the northeast of the eddy. This lead to significant alongfront acceleration. Lynch et al. (2002) examined this data in terms of acoustic propagation and found a significant "shadow zone" beneath the front which was not well ensonified, due to the upwards refraction of sound near the bottom. In addition, Lozier and Gawarkiewicz (2001) examined Lagrangian trajectories of drifters within the shelfbreak front and found an offshore bias in the loss of drifters from the frontal jet. Lozier, Reed, and Gawarkiewicz (2001) examined the linear stability of an idealized shelfbreak front and found growth rates of one day or less, consistent with previous observations. Gawarkiewicz et al. (2002) used the summer PRIMER data to examine the characteristics of a frontal meander. They found that there were significant effects of curvature of the frontal jet, with ageostrophic velocities approaching 30 cm/s in spots. They also calculated cross-shelf heat and salt fluxes, and found an onshore salt flux which was roughly three times as large as climatological estimates of salt fluxes obtained from oxygen isotope budgets.

Additional work during the past year included analysis of the EOF modes of the summer front. The first mode structure was a pycnocline-trapped mode which is consistent with previous linear stability calculations. However, the second and third modes involved a vertical heaving of the seasonal pycnocline and an onshore motion of the foot of the front, neither of which is similar to the linear modes. This analysis is continuing at the present time. The effect of strong wind forcing on the front, using data collected during the winter PRIMER experiment, was presented at the Ocean Sciences meeting (Bahr et al., 2002). During upwelling favorable winds, cold shelf water was carried up to 30 km offshore within a day, resulting in the rapid formation of surface acoustic ducts. In addition, a previous climatology of the front has been re-computed using improved methodology. This new climatology has been used by other UNITES team members in their analysis of the uncertainty of

acoustic propagation across the front. Also, the seasonal variations in the characteristics of the detached bottom boundary layer within the shelfbreak front has been examined using data from the three Shelfbreak PRIMER cruises as well as additional high-resolution transects from the ONR Coastal Mixing and Optics experiment, as well as other sections from historical archives. This work has been presented at a workshop.

Turning to the finescale oceanography, the KdV computer codes to generate the nonlinear internal waves have been finalized and tested, and are now being routinely employed. The PRIMER satellite SAR images and moored data constrain the computer simulation fields generated.

Regarding the acoustics efforts, we have also made progress in several areas. The nonlinear internal wave code outputs have been input to acoustic parabolic equation codes to generate acoustic field fluctuation versus range estimates. These estimates agree well with PRIMER field data (which could be only be taken at a very limited number of range points – thus the recourse to numerics to extend the results.) We have also continued our work on quantifying the acoustic time series fluctuations seen in the summer PRIMER data. By breaking the data into oceanographic bands (high frequency, tidal, and sub-tidal) we clearly see how the oceanographic forcing affects the acoustics, and also how these acoustic scattering effects can add in a very interesting, non-linear fashion (Lynch et al, 2002).



**Figure 1. Vertically integrated 400 Hz acoustic field strength measured at a vertical array receiver as a soliton packet transits from just before the acoustic source (located at 0 range) to just past the receiver (located at 27 km). The blue points show the result of placing the source in a high sound-speed near surface layer. In this case, quasi-random mode coupling from the higher modes originally excited to the lower modes typically results in a net gain of energy when the solitons are near the source. When they are further away, the coupling is from the surviving low modes to high modes, giving loss. The red points show the similar but not identical results when one change is made; the addition of the shelf-break front (essentially horizontal) which creates a midwater duct. The low modes dominate the signal nearer the source, so the gain/loss transition is at 3 km from the source rather than at 11 km and higher losses are seen.**

Finally, Duda has extended his simulation work on the acoustic effects of solitons, both for a generic (widely applicable) three-layer coastal ocean and for the PRIMER region, showing how the very large biases in propagation loss observed depend in a rather regular and predictable way on source position relative to the vertical sound speed profile, and the presence of the shelf-break front. Frequencies from 50 to 1200 Hz were examined. An example of this is shown in Figure 1.

## **IMPACT/IMPLICATIONS**

The primary application of our work is to assist the sonar prediction community by quantifying what the expected environmental variability will be in various coastal environments. By using our highest quality basic research measurements of ocean variability, we can thus use a detailed understanding of the environmental processes affecting uncertainty to contribute to the transfer of uncertainty from the environment to systems performance.

## **TRANSITIONS**

We see our work being transitioned to the Navy community by two principal means. First, there are the “rules-of-thumb” that are being developed, that should be easily presented to the operational Navy via briefs and, eventually, via Tactical Memos. Second, there are the research results on coastal phenomena that will be included into probabilistic models of sonar performance, such as the one being developed under this DRI by Phil Abbot and Ira Dyer of the UNITES team.

## **RELATED PROJECTS**

The work being done under the auspices of the Uncertainty DRI relates closely to our work in three other ONR projects, specifically: 1) the shelfbreak PRIMER experiments, 2) the ASIAEX experiments, and 3) the ESME initiative.

## **PUBLICATIONS**

J. Lynch, A. Newhall, B. Sperry, G. Gawarkiewicz, P. Tyack, and C.S. Chiu, “Spatial and Temporal Variations in Acoustic Propagation Characteristics at the New England Shelfbreak Front.” Submitted to IEEE. *J. Oceanic Eng’g.*

Bahr, F., G. Gawarkiewicz, K. Brink, R. Beardsley, M. Caruso, Response of the shelfbreak front to strong wind forcing. Abstract, AGU Ocean Sciences Meeting.

Gawarkiewicz, G., F. Bahr, R. Beardsley, and K. Brink, Interaction of a slope eddy with the shelfbreak front in the Middle Atlantic Bight, *J. Phys. Oceanogr.*, *31*, 2783-2796, 2001.

Gawarkiewicz, G., F. Bahr, K. Brink, R. Beardsley, M. Caruso, J. Lynch, and C. Chiu, A large amplitude meander of the shelfbreak front south of New England: Observations from the Shelfbreak PRIMER Experiment. *JGR-Oceans*, accepted.

Lozier, M. S., and G. Gawarkiewicz, Cross-frontal exchange in the Middle Atlantic Bight as evidenced by surface drifters, *J. Phys. Oceanogr.*, *31*, 2498-2510, 2001.

Lozier, M. S., M. S. C. Reed, and G. G. Gawarkiewicz, Instability of a shelfbreak front, *J. Phys. Oceanogr.*, 32, 924-944, 2002.

B. Sperry, J. Lynch, G. Gawarkiewicz, C. Chiu, and A. Newhall, Characteristics of acoustic propagation to the eastern vertical line receiver during the summer 1996 New England shelfbreak PRIMER experiment, submitted to *IEEE J. Oceanic Eng'g*.