Uncertainties and Interdisciplinary Transfers Through the End-To-End System (UNITES)

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LONG-TERM GOAL

The overall goals of this research are:

1. To define and characterize the variabilities and uncertainties in the components and linkages of the general physical-geo-acoustical system relevant to the support of naval operations.

2. To transfer quantitatively the spatial-temporal environmental variabilities and uncertainties through the interdisciplinary system, including coupled interactions, in order to determine uncertainty measures, sensitivities and feedback needed to improve operational predictions and parameters.

OBJECTIVES

This effort is part of a multi-institutional team effort to capture uncertainty in the common tactical picture. The team's name is UNITES, which stands for UNcertainties and Interdisciplinary Transfers through the End-to-End System. Led by Abbot, OASIS, Inc., and Robinson, Harvard University (HU), the UNITES team, with expertise spanning the ocean environment, underwater acoustics and tactical sonar systems, consists of a total of twelve principal investigators from nine different organizations including the Naval Postgraduate School (NPS), Woods Hole Oceanographic Institution (WHOI) and University of North Carolina (UNC).

The NPS component in the UNITES team's paradigm to solve the interdisciplinary, end-to-end problem has two objectives:

1. To characterize acoustic prediction uncertainties, including their connections to the uncertainties in the ocean and geo-acoustic parameter estimates.

2. To forecast and improve acoustic baselines and their uncertainties in a data-assimilation framework involving coupled ocean and acoustic state variables.

APPROACH

The research focuses on a shelfbreak environment, encompassing the outer continental shelf and the continental slope, where the physical oceanography, specifically the shelfbreak front, internal tides and internal solitary waves, play a significant role in introducing acoustic prediction uncertainty at multiple time and space scales. The acoustic prediction uncertainty is further complicated by the variable

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14. ABSTRACT
The overall goals of this research are 1. To define and characterize the variabilities and uncertainties in the components and linkages of the general physical-geo-acoustical system relevant to the support of naval operations. 2. To transfer quantitatively the spatial-temporal environmental variabilities and uncertainties through the interdisciplinary system, including coupled interactions, in order to determine uncertainty measures, sensitivities and feedback needed to improve operational predictions and parameters.

15. SUBJECT TERMS

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bathymetry and inhomogeneous sediment properties as the water-column variability shifts the insonified bottom locations from time to time.

The approach entails both data analysis and modeling utilizing the coupled environmental and acoustic data sets from both Shelfbreak PRIMER and the Asian Sea International Acoustics Experiment (ASIAEX). The Shelfbreak PRIMER data set, obtained in the Middle Atlantic Bight (MAB) shelfbreak region during the summer of 1996, is utilized in the first two years of this research, 2001 and 2002, to gain fundamental insights into uncertainty transfer and characteristics, and to test and refine methodologies and the associated computer codes for linking and integrating ocean, acoustic and sonar models and data. The ASIAEX data was collected in May of 2001 in the South China Seas (SCS) with enhanced resolution in the environmental (both ocean and geo) parameters as well as the acoustic wavefields. The ASIAEX acoustic measurements have much improved coverage in frequency, source depth and range, propagation path orientation, and the spatial properties of the sound field. The processed data will become available in 2003. In the final two years of this effort the techniques developed in the previous years will be applied to the ASIAEX data to capture and characterize acoustic prediction uncertainty in the SCS shelfbreak region that are geographically and dynamically different from the Shelfbreak PRIMER site. Comparison between the acoustic prediction uncertainty characteristics for the MAB and SCS shelfbreaks will be conducted to resolve differences, similarities and dependency. This understanding is crucial to the design of sonar tactics such as optimum selection and placement of sonar systems for different types of shelfbreak regimes.

In acoustic prediction uncertainty characterization and linkage, the NPS work is closely tied to that of OASIS, UNC, WHOI and HU. Depending on the space and time scales, probability density functions (PDF's) of uncertainties in the acoustic variables, TL, amplitude, phase, time, etc., will be either estimated from observed environmental and acoustic data or based on Monte Carlo simulation using the Harvard Ocean Prediction System (HOPS) ocean realizations and UNC's geo-acoustical parameter realizations. Climatological data and first-order bottom models are used to define the acoustic baselines from which uncertainties are realized. The broadband, coupled normal-mode model of Chiu et al. (1996) is used to perform all sound propagation calculations. The estimated uncertainty statistics will be provided to OASIS, who will transfer the acoustic uncertainties to sonar performance uncertainties for several selected systems. Additionally, these sophisticated data products and model calculations will be used to crosscheck the first-order, but more physically insightful, analytical models, to be developed by WHOI, for acoustic uncertainty statistics and predictability. These simplified moment solutions by WHOI, in turn, will be used to facilitate the development of simple, robust rules-of-thumb.

For acoustic baseline and uncertainty forecast, a coupled ocean and acoustic methodology to assimilate oceanographic and acoustic data into HOPS is to be developed. The basic approach is that of error subspace data assimilation of Lermusiaux and Robinson (1999). The novelty here is that the acoustic variables are treated as additional state variables in the ocean forecast model that is tightly coupled to the acoustic propagation model. The algorithm, therefore, simultaneously tracks, i.e., forecasts, the dominant error/uncertainty structures in both the ocean and acoustic variables, in addition to improving the baselines.

WORK COMPLETED

In acoustic field uncertainty characterization, the focus of the NPS FY02 work was on the tidal and shorter-scale uncertainties. Using Shelfbreak PRIMER acoustic and oceanographic data, the acoustic uncertainty statistics and their linkages to oceanographic variability in a slope-to-shelf transmission were investigated. In particular, NPS constructed the daily probability density functions of both the transmission loss of a pulse signal (350-450 Hz) in an energy estimate and the in-band noise level to allow for a quantification of the homogeneity of the inter-daily fluctuations as well as the nonstationarity of the intra-daily statistics. Also in collaboration with OASIS, the statistics of the peaks of the corresponding matched-filtered signals were developed and analyzed.

In acoustic field uncertainty reduction and forecast, the focus of the NPS FY02 work was on the small mesoscale and longer-scale uncertainties. In collaboration with WHOI and employing the SeaSoar CTD survey and acoustic transmission data from Shelfbreak PRIMER, we empirically demonstrated that daily (mean) transmission loss predictions could be upgraded from climatology with updated ocean field estimates with small mesoscale resolution. Additionally, in collaboration with HU, the coupled ocean and acoustic prediction model developed in the previous year for the Shelfbreak PRIMER region was upgraded to include a data-assimilation module. We tested the improved model with simulated data. Joining both acoustic and ocean variables in the state vector, the simulation experiment showed that the data-assimilative model can produce simultaneous ocean and acoustic field predictions with reduced small mesoscale errors.

RESULTS

Using the acoustic data measured by the western vertical line array (VLA) in Shelfbreak PRIMER and based on energy ratio and an observed multipath spread of 1 s, the transmission losses (TL) of a 42-km slope-to-shelf propagation were estimated to within a precision of 0.3 dB. These high-quality TL data are shown in Fig. 1 as green dots, revealing the multi-scale nature of the acoustic variability typical for a shelfbreak environment. Note that the VLA was moored on the shelf in 80 m of water and the source was moored 40 km away on the slope at the 300-m isobath. The source transmitted band pass (350-450 Hz) signals repeatedly over a period of 10 days. The moored oceanographic data collected along the transmission path during the same time period attest that the observed multi-scale TL fluctuations were induced by a combination of internal tides and solitary waves on the shelf, internal tides at the shelfbreak, and synoptic-scale ocean processes consisting of a cold front propagating seaward from the shelf and a warm filament intruding shoreward from the slope.

Using seasonal climatology for the Shelfbreak PRIMER region, a TL for the same path was calculated to represent a zeroth-order prediction (shown as a dotted blue line near the bottom in Fig. 1). As is seen with the actual TL, the errors in the predicted TL can be conceptualized as consisting of both long-scale (e.g., daily) biases and short-scale (e.g., inter-daily) randomness. While the latter uncertainties demanded statistical characterizations, the former uncertainties were shown to be reducible with improved small-mesoscale-resolving ocean estimates derived from ocean data or a combination of data and model. To demonstrate this finding, upgraded daily TL based on daily sound speed fields mapped by the SeaSoar CTD are shown as a blue staircase curve in Fig. 1, showing obvious improvements from the climatology-based prediction.

The statistical characterizations of the TL and in-band NL fluctuations in Shelfbreak PRIMER were accomplished by constructing normalized daily histograms using the data. Figure 2 shows some of the daily histograms of the TL deviations (from the time-varying daily mean) as a function of day (in the rows) and depth (in the columns). Based on the shapes and moments of these histograms, an important finding is that while the statistics of the TL deviations varied from day to day (i.e., nonstationary), they were rather homogeneous in depth. Similar conclusions can also be drawn on the noise field, although the daily noise-level histograms are not shown here.

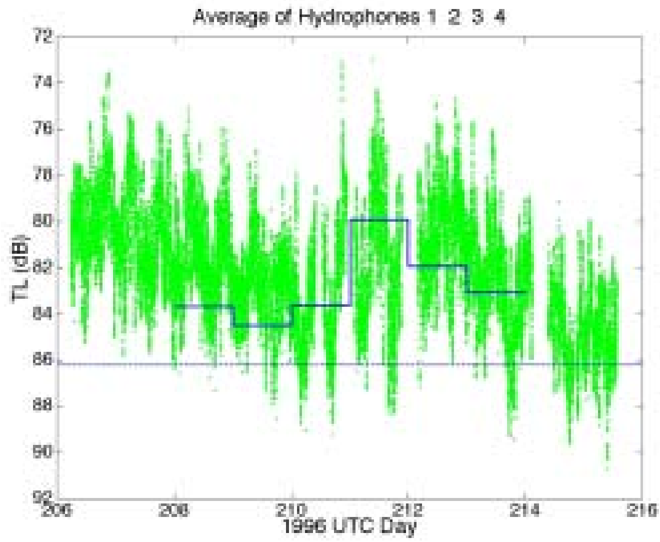

Figure 1. TL predicted using seasonal climatology (blue dashdots), updated using daily SeaSoar maps (blue solid line), and measured by the top quarter of the western VLA (green dots).

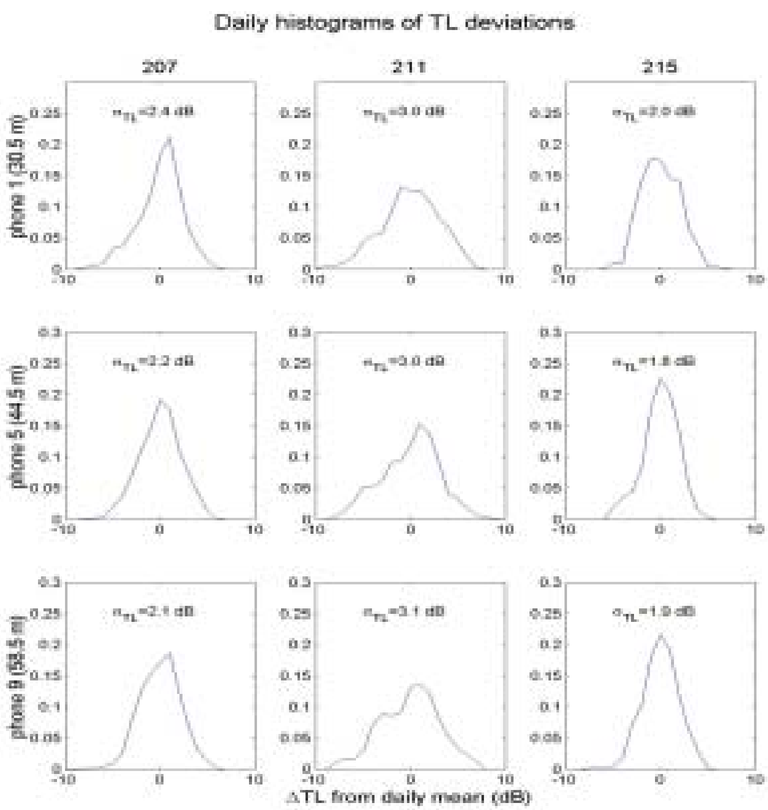

Figure 2. Histograms of the intra-daily TL fluctuations versus time (day) and depth (hydrophone #). The histograms shown were normalized to have unit area to represent PDF estimates.

IMPACT/APPLICATIONS

The characterization of the uncertainties in the ocean and acoustic estimates and the understanding of the linkage of these uncertainties are crucial to the design of sonar tactics such as optimum selection and placement of sonar systems in different environmental regimes.

TRANSITIONS

This work will estimate the acoustic wavefield uncertainty statistics. These statistics will be provided to OASIS, Inc., another member of the UNITES team, to evaluate the performance of three fleet sonar systems in a probabilistic framework.

RELATED PROJECT

This project utilizes the experimental data sets obtained in Shelfbreak PRIMER and ASIAEX.

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