Coupled Ocean Acoustics And Physical Oceanography Observations In The South China Sea: The NPS Acoustic Component

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LONG-TERM GOALS

My long-term research objectives are:

1. The characterization of meso to internal-wave-scale oceanographic processes that influence broadband sound transmissions in a coastal environment. Central to the characterization are the formulation of accurate forward relations and the quantification of the sensitivities and variability of the various observable acoustic quantities in relation to environmental differences and changes.
2. The development and improvement of high-resolution tomographic inverse techniques for measuring the dynamics and kinematics of meso and finer-scale sound speed structure and ocean currents in coastal regions.
3. The understanding of three-dimensional sound propagation physics including horizontal refraction and azimuthal coupling and the quantification of the importance of these complex physics in the prediction of sound signals transmitted over highly variable littoral regions.

OBJECTIVES

This effort is part of a large, international program called the Asian Sea International Acoustic Experiment (ASIAEX). In collaboration and coordination with other U.S. and Asia investigators participating in ASIAEX, we are carrying out comprehensive measurements and analysis of the different oceanographic factors affecting low frequency (< 600 Hz) acoustic propagation in a shelfbreak region in the Northeastern South China Sea (SCS). Specifically, the NPS acoustic research objectives are:

1. To understand the physics, variability and predictability of low-frequency sound pulse propagation along and across the NE SCS shelfbreak, including the dependence on frequency, source/receiver depth and path orientation, and the relations to water-column, bathymetric and sub-bottom structures. Acoustic variables to be studied include intensity, travel time and temporal and spatial coherences. Empirical and theoretical relations to the environmental changes are to be derived and compared to investigate predictability and establish statistical variances.
2. To expand the acoustic knowledge acquired from previous shelf-slope experiments including shelfbreak PRIMER and SWARM, with added emphases on the horizontal properties of the sound field. Due to source and receiver limitations, both Shelfbreak PRIMER and SWARM were limited to the study of the vertical properties of sound propagation at two narrow

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frequency bands, 210-235 Hz and 350-450 Hz. The combined ASIAEX assets permit extended investigation into the horizontal properties as well as acoustic transmissions covering the entire low-frequency band from 50 to 600 Hz.

APPROACH

The main experiment was carried out in May of 2001. The approach was to make simultaneous, high-resolution, very high-quality observations of both the acoustic propagation and physical oceanography in the experimental site. Both moored and shipboard oceanographic observations were made, with sufficient spatial and temporal resolution to observe physical phenomena on horizontal scales of a few kilometers and time scales from subtidal to high frequency internal waves (with periods of a few minutes). Simultaneously, acoustic transmissions, aiming at achieving sufficient frequency diversity and spatial coverage, were performed parallel to and across the shelfbreak using both moored and towed sources.

In additional to sampling the oceanographic and acoustic fields in the water column, complimentary measurements of the geoacoustic parameters of the region are also required to allow for a separation of the volume interaction effects from scattering due to bottom inhomogenieties. Critical geoacoustic parameters include bathymetry, sediment density, compressional wave-speed and attenuation coefficient. Echo sounding, coring, high-frequency chirp-sonar and low-frequency towed-source data for mapping these geo-acoustic parameters were also collected during the main experiment.

The measurement and analysis are focusing on the horizontal and vertical properties of the shallow-water sound field, their dependence on source depth and frequency, and their relations to the water-column, bottom and sub-bottom structure. Particularly, the acoustic measurements are to be related to the oceanographic measurements through time-series analyses and coupled-mode modeling studies to gain insights into the detailed physics and variability of the acoustic propagation.

WORK COMPLETED

Work completed in FY03 includes:

1. Studied the impact of a strong ocean current on the signal-processing (pulse-compression) gain, and devised a Doppler-compensation algorithm to minimize the degradation.

2. Completed pulse-compression processing of all phase-modulated acoustic signals transmitted by the moored sources and received by the WHOI/NPS L-shaped hydrophone array for the entire three-week transmission experiment. The L-shaped hydrophone array was moored on the continental shelf that monitored a variety of signals transmitted parallel to and across the shelfbreak by both moored and towed sources.

3. Formulated an *a priori* model for the geoacoustic parameters based on the chirp-sonar images obtained by Shock (2003), and extracted the frequency-modulated (FM) signals transmitted from a towed J15 source on three separate days, May 5, 16 and 17, containing minimal internal wave activities. This work is in preparation for a geoacoustic inversion for the sediment properties. The inferred sediment properties will then be used to investigate the role of the bottom in its contribution to the observed signal intensity fluctuations in FY04.

4. Documented data-analysis and modeling results in manuscripts submitted to the IEEE Journal of Oceanic Engineering. These results are on the space-time structure of the observed sound-speed variability, which was dominated by "transbasin" and local internal tides and by "transbasin" nonlinear internal waves generated remotely in Luzon Strait via shallow ridges-tidal current interactions during spring and neap tides, and on the observed changes in the acoustic signal intensity and coherences due to this volume variability.

RESULTS

The impacts of the observed nonlinear internal waves on various aspects of the acoustic propagation were the focus of several collaborative studies completed in FY03. In collaborations with the Naval Research Laboratory and Woods Hole Oceanographic Institution, we investigated the impact on horizontal coherence and horizontal beamforming performance, and examined the resultant characteristic features in the intensity-fluctuation time series and compared the signal statistics between the along- and cross-shelf paths, respectively. Additionally, a separate study conducted by Chiu *et al.* (2003) explained and contrasted the observed intensity fluctuations of the 400-Hz, cross-shelf transmissions in two separate days having extreme environmental differences: one with the passage of several huge solitons that depressed the shallow isotherms to the sea bottom, and the other with a much less energetic internal wavefield. Specifically, the interpretation of the observed changes in the vertical distribution of sound intensity was aided with coupled-mode propagation modeling facilitated with a space-time continuous, empirical representation of the sound-speed field. Some of the contrasting acoustical results obtained by Chiu *et al.* are described next:

The temporal and spatial structures of the cross-shelf sound-speed field were analyzed from moored temperature data using temporal filtering to first delineate the perturbations in the subtidal, tidal and supertidal bands, followed by principle-component decompositions to capture dominant vertical structures. The results show that the vertical structure in each of the three bands was dominated by two empirical functions through out the entire experiment, and that May 4 and 8 have significantly different environmental conditions, dominated by internal tides and solitons, respectively, leading to significantly different characteristics in the observed sound intensity field. As an illustration, we show in Fig. 1 the variances of the sound intensity levels (SIL) measured over each of the 7.5-min-long transmissions across the VLA on May 4 and 8, respectively. Since these are SIL variances observed over short time intervals, they are associated with internal waves only. With no soliton activity, the variances on May 4 are small as expected. In contract, the variances on May 8 are consistently four times higher than those of May 4, resulting from the passage of the large-amplitude solitons. It is interesting to note that the calm hour (from 07:00 to 08:00) immediately preceding the entrance of the huge soliton on May 8 stands out in the figure as a period of much reduced intensity variances.

As observed on May 8, the sound signal intensity on the shelf generally increased in the upper water-column but decreased in the lower water-column as the internal solitons entered and moved along the acoustic path. This is indicative of a vertical redistribution of the acoustic energy. This apparent diffusion/infusion of sound energy can be explained by coupled-mode physics: The low-mode and high-mode energy are scattered into the intermediate modes that span the entire water-column and attenuate slowly on the shelf. At any given range, our modeling results also show that mode coupling is restricted to the immediate neighbors, resulting in gradual cascades or ascends of modal energy in range. The vertical structure of sound-speed change is responsible for this tight coupling behavior.

The internal tides on May 4 modulated (stretched and compressed) the sound channel, resulting in relatively slow, vertical shifts in the intensity pattern. Unlike the huge internal solitons, the corresponding modeling results show that the internal tides produce little "additional" mode coupling with the depth-integrated energy approximately conserves. To illustrate the dissimilarities, the modeled sound intensity patterns and depth-integrated energies for both May 4 and 8 are displayed in Figs. 2 and 3, respectively.

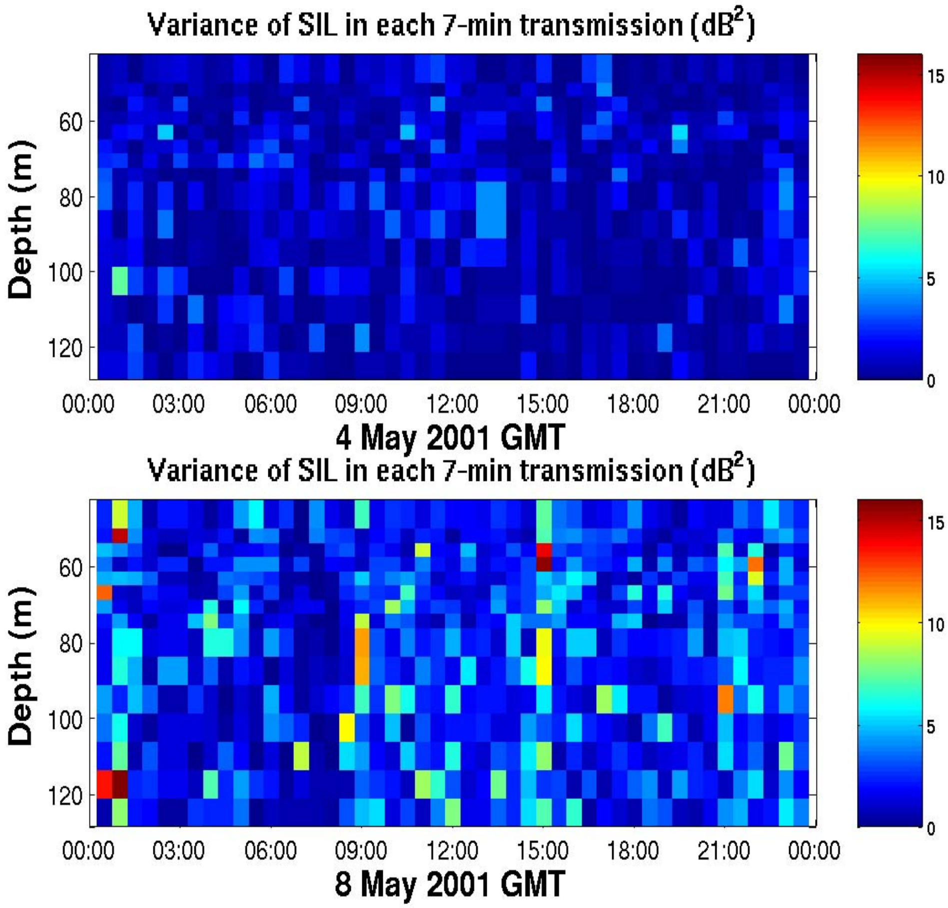

Figure 1. Variances of the sound intensity levels measured over each of the 7.5-min-long transmissions across the VLA on May 4 (top) and 8 (bottom), respectively.

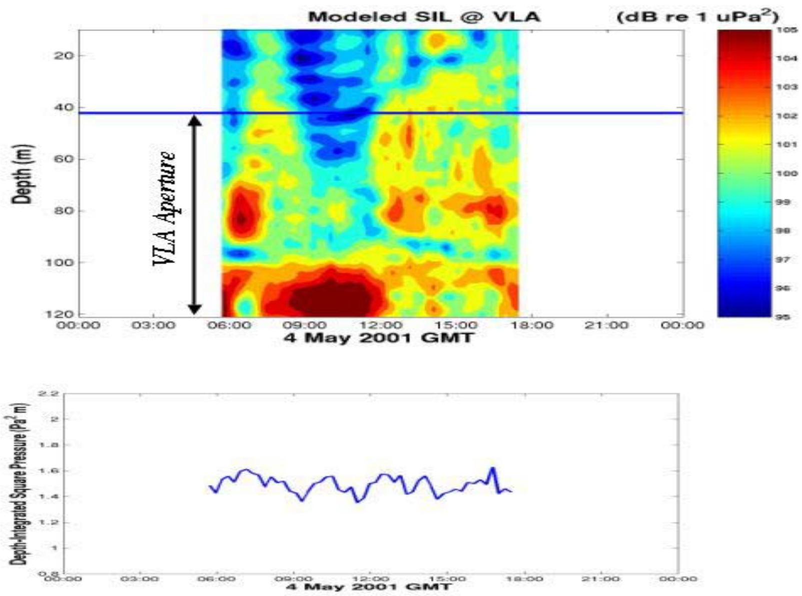

Figure 2. Model sound intensity pattern at the VLA location on May 4 between 06:00 and 17:00.

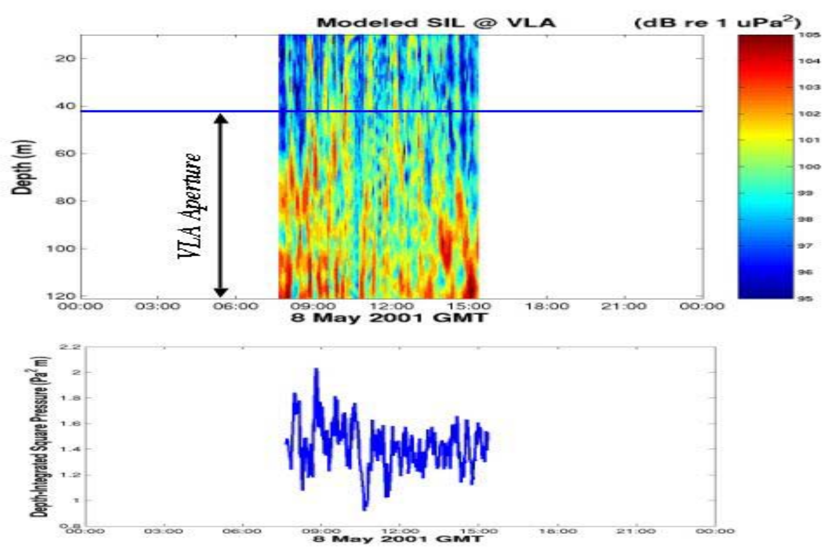

Figure 3. Model sound intensity pattern at the VLA location on May 8 between 07:15 and 15:00. Note that the leading soliton enters the acoustic path at 08:00 and reaches the VLA at 15:00.

IMPACT/APPLICATIONS

The oceanographic and acoustic data gathered in this field study should be valuable in helping to create models of shelfbreak regions suitable for assessing present and future Navy systems, acoustic as well as non-acoustic.

RELATED PROJECTS

This fully integrated acoustics and oceanography experiment should significantly extend the findings and data from SWARM and Shelfbreak PRIMER, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

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