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

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LONG-TERM GOAL

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 depth and path orientation, and the relations to water-column, bathymetric and sub-bottom structures. Acoustic variables to be considered include the amplitudes, phases, and arrival times of coupled modes (and rays if the ray picture is applicable). Empirical and theoretical relations to the environmental changes will 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 frequency bands, 210-235 Hz and 350-450 Hz. The combined ASIAEX assets permit extended investigation into the

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14. ABSTRACT
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15. SUBJECT TERMS

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horizontal properties as well as acoustic transmissions covering the entire low-frequency band from 50 to 600 Hz.

3. To investigate the advantages and disadvantages of conducting shallow-water tomography using higher-frequency (> 400 Hz) transmissions. The notion is that a higher-frequency transmitter would excite more modes turning at different depths in the water column. Whether resolution enhancement can be realized or not depends on the stratification (i.e., the sound speed profile) of the experimental region and resolvability of the modes. The latter is limited by the signal-to-noise ratio, processing method and receiver array geometry.
4. To formulate and test a phase or time-based modal tomography inverse method for joint estimations of the water-column and sediment properties. This will be a perturbative scheme relying on the fact that low modes are more sensitive to water column variability, whereas high modes are to sediment parameter uncertainty.

APPROACH

The main experiment was carried out in 2001 and was preceded by a pilot site survey in the prior year. Both cruises were conducted in the Spring and both spanned a period of four weeks. The purpose of the pilot site survey, conducted primarily by our international partners at the National Taiwan University (NTU), was to obtain adequate environmental information to support buoy/mooring engineering and acoustic modeling for optimizing the configuration for the main experiment.

For the 2001 main experiment, 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. 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, their relations to the water-column, bottom and sub-bottom structure, and the feasibility of a joint sediment-water-column inversion using tomographic techniques. Particularly, the acoustic measurements are to be related to the oceanographic measurements through time-series analyses and modeling studies to gain insights into the detailed physics and variability of the acoustic propagation.

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 clear separation of the volume interaction effects from scattering due to bottom inhomogenieties. Critical geoacoustic parameters include bathymetry, sediment density, sediment compressional wave speed and sediment attenuation coefficient. These geoacoustic parameters were measured during the main experiment by the geologists participating in ASIAEX.

WORK COMPLETED

Work completed in FY01 includes:

1. Completed simulation propagation experiments based on the pilot environmental data collected by NTU. The purpose of the modeling was to determine optimum depths and ranges for the placements of the moored sources and receivers.
2. Completed preparation of all NPS acoustic equipment and shipment of the equipment to the staging warehouse at Kaohsiung, Taiwan. The NPS acoustic equipment included moored sound sources and receiver arrays.
3. Jointly carried out the intensive main experiment with the Woods Hole Oceanographic Institution (WHOI), Naval Research Laboratory (NRL), National Taiwan University (NTU) and National University of Singapore (NUS). Specially, the author of this summary was the Lead U.S. PI on the first leg of the research vessel OCEAN RESEARCHER 1, responsible for the deployment of all the environmental moorings. The NPS team also participated in all phases of the field program: preparation, staging, deployment and recovery.
4. Conducted an initial statistical analysis on the moored temperature data to examine the spatial and temporal structures of the across-the-shelfbreak sound-speed perturbation field.

RESULTS

Using the SeaSoar and CTD data collected by NTU during the pilot survey, acoustic model runs were carried out prior to the main experiment to investigate important design questions concerning the placement configuration of the acoustic sensors. Using objective mapping techniques, the NTU data was first analyzed for the sound-speed fields along possible across and along-shelf mooring lines. The analyzed across-shelf sound-speed field for the acoustic propagation simulations is shown in Figure 1. The sediment properties were "conservatively" parameterized by a three-layer bottom model, courtesy of Dr. Chen, NTU, based on historical coring data obtained further offshore. The acoustic wavefields computed along the slope-to-shelf line for various source depths on the slope and various transmission frequencies revealed that (1) the optimum source depth is near the bottom where sound speed reaches its minimum and (2) noise-limited receiver ranges are approximately 45 km, without processing. The latter finding was based on both transmission-loss calculations and an ambient noise time series collected by Dr. Nystuen, Applied Physics Laboratory, University of Washington, in the Spring of 1998 with one of his drifting hydrophone buoys near the ASIAEX site. To give an example of the range estimates, the calculated transmission loss TL curves for various receiver depths at a frequency of 400 Hz are displayed in Figure 2 along with the Figure of Merit (FOM) estimate. The NPS 400-Hz moored sources have a source level SL of 180 dB re 1 μPa and a bandwidth W of 100 Hz, and the ambient noise data gives a noise spectrum level NL of 60 dB re 1 $\mu Pa^2/Hz$ at 400 Hz. The corresponding FOM is therefore SL – NL – 10 log(W) = 100 dB. The signal-to-noise ratio is zero dB when TL = FOM, and this is shown in Figure 2 to occur at a range of about 45 km. Similar findings were obtained along the along-the-shelf line, except for a weaker sound field dependence on source depth.

The main field program was a huge success. It was executed from 25 April to 27 May 2001 by approximately 20 principal investigators from three different countries, U.S., Taiwan and Singapore, using three Taiwanese research vessels FISHERIES RESEARCHER 1 (FR1), OCEAN RESEARCHER 1 (OR1) and OCEAN RESEARER 3 (OR3). The simultaneous, high-resolution observations of the acoustic propagation characteristics and water column properties was accomplished by a combination of moored and shipboard observations. The NPS team was primarily involved in the preparation, design, deployment, and recovery of the moored network. This network consisted of a total of 27 environmental moorings and 6 acoustic moorings stretching the pre-designed across and along-shelf mooring lines. The center piece of this observational network was an L-shaped hydrophone array that was put together by WHOI and NPS. This listening array consisted of 32 hydrophones spanning 472 m along the bottom and 16 hydrophones moored vertically in the water column. These hydrophones sampled at 3.2 kHz continuously for three weeks and collected 600 gigabytes of data. These data are still being quality controlled, backed up and distributed to the participating institutions. A single spectrogram from one of the bottom hydrophones shows how well the array functioned (Figure 3). The arrivals from both along- and across-shelf sources at 225, 300, 400, and 500 Hz are clearly seen as are the arrivals from the towed source aboard the OR3. The processing and analysis of the entire acoustic data set, in conjunction with the oceanographic data, is currently underway with goal to understand the influences of inherent ocean variability on acoustic propagation, coherence and predictability.

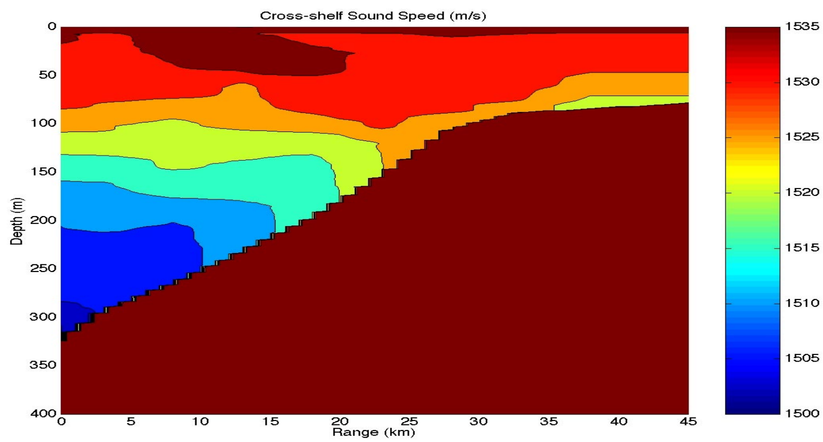

Figure 1. An analyzed sound speed field across the South China Sea shelfbreak. This sound speed field was constructed from the hydrographic data collected by the National Taiwan University (NTU) during the pilot survey in 2000, and was used in a modeling study to design the depths and ranges of the acoustic sensors prior to the main experiment .

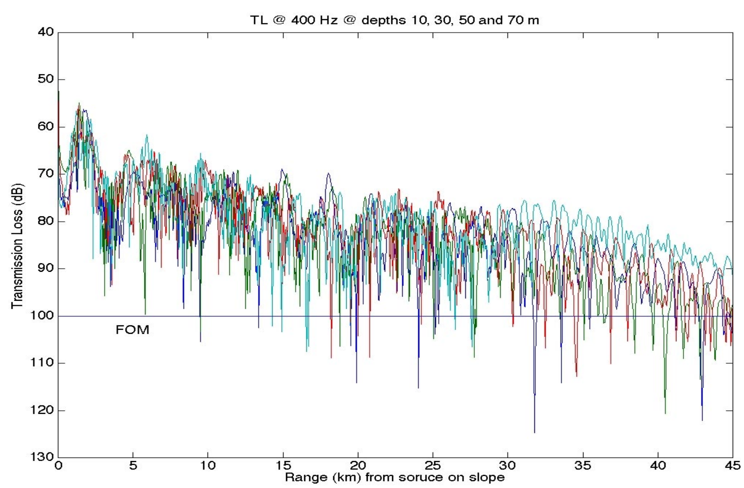

Figure 2. The modeled slope-to-shelf transmission loss (TL) at 400 Hz for various receiver depths and the estimated Figure of Merit (FOM) associated with the 400-Hz NPS sound sources, predicting a noise-limited range of 45 km.

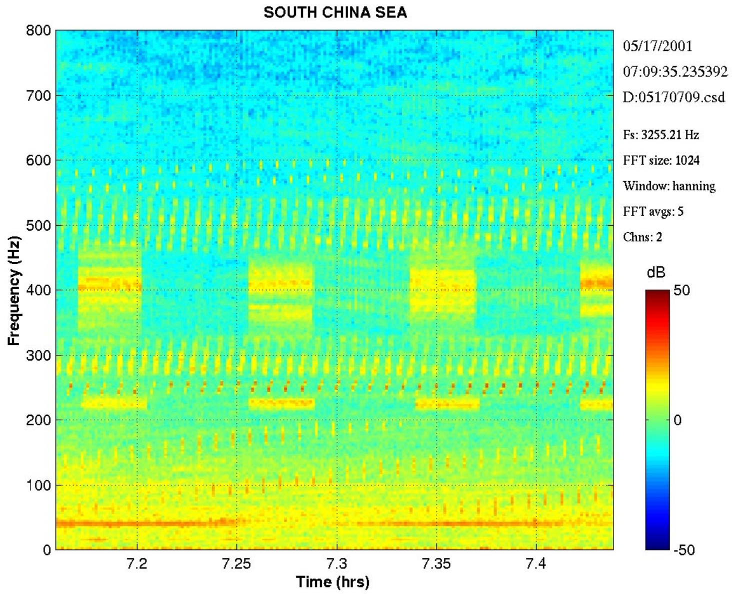

Figure 3. A spectrogram of the acoustic signals received by an element on the horizontal segment of the WHOI/NPS L-array toward the end of the main experiment. The band-passed signals centered at 225, 300, 400 and 500 Hz were either phase or frequency-modulated signals transmitted from a number of fixed sources moored on the shelf and slope. The other signals containing Doppler frequency shifts were transmitted from a towed source. This quick check on the quality of the acoustic data was performed by Arthur Newhall of WHOI.

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.

TRANSITIONS

This basic research project is integrated with NRL's and Harvard University's applied research efforts in ocean data assimilation/nowcasting and acoustic prediction.

RELATED PROJECT

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.

PUBLICATION

Chiu, C.-S., S. R. Ramp and J. F. Lynch, "The ASIAEX 2000 Preliminary Experiment in the East China Sea (ECS)," Proceedings of the 5th International Conference in Theoretical and Computational Acoustics, Beijing, China, 2001, in press.