Coupled Ocean Acoustics and Physical Oceanography Observations in ASIAEX: 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 close collaboration and coordination with other US and Asia investigators participating in ASIAEX, we will carry out comprehensive measurements and analysis of the different oceanographic factors affecting low frequency (< I kHz) acoustic propagation in a shelfbreak region in the Northeastern South China Sea (SCS) or East China Sea (ECS). The exact site location depends on research vessel clearances. Specifically, the NPS acoustic research objectives are:

1. To understand the physics, variability and predictability of low-frequency (< I kHz) sound pulse propagation along and across the NE SCS shelf-slope (or the ECS Kuroshio) front, including the dependence on frequency, source depth and path orientation, and the relations to water-column, bottom 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.

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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 and the propagation physics, variability and coherence of higher-frequency (600- 1 000 Hz) transmissions. Due to source and receiver limitations, both Shelfbreak PRIMER and SWARM were limited to the study of the vertical properties of sound propagation at frequencies below 500 Hz. The combined ASIAEX assets will permit extended investigation into the horizontal properties as well as higher frequency transmissions.

3. To investigate the advantages and disadvantages of conducting shallow-water tomography using higher-frequency and larger-bandwidth (600- 1 000 Hz) transmissions. The notion is that a higher-frequency and larger-bandwidth 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 will be carried out in 2001 and will be preceded by a pilot site survey in the prior year. Both cruises will be conducted in the Spring and both will span a period of four weeks. The purpose of the pilot site survey is to obtain adequate environmental information to support buoy/mooring engineering as well as acoustic modeling for optimizing the configuration for the main experiment. The collection of three types of data is planned for the pilot survey. These include moored ocean current time series, geophysical measurements of the required geoacoustic parameters, and hydrographic sound-speed (i.e., temperature and salinity) measurements.

NPS will rely on the ASIAEX geologists to obtain adequate, complimentary measurements of the geoacoustic parameters of the region 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 parameters shall be sampled along anticipated cross-shelf and along-shelf acoustic tracks at adequate resolutions during the pilot survey. The required vertical resolution and depth extent are approximately I and IO wavelengths, respectively. These will allow for an accurate calculation of the wavenumbers and shapes of the low-angle modes. For the horizontal resolution, a fraction (- 1/10) of the smaller of the modal interference distance and horizontal de-correlation length of the bottom properties should be sufficient, as mode coupling is sensitive to environmental changes that have spatial scales comparable to the modal interference distance and the modal phase structure depends strongly on the horizontal de-coffelation lengths of the environmental variability. Together with representative sound-speed profiles from a CTD section, these pilot environmental information will be used to facilitate experimental design through acoustic modeling.

For the 2001 main experiment, the approach is 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 observations will be 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, low frequency (<1,000 Hz) sound transmissions will be performed along and across the shelf using both moored and towed sources. TheNPSandWHOltransmittersincludingtheJ-15-3towedsource(to be rented by WHOI) are limited to transmission frequencies of 600-Hz and below. However, it is anticipated that this US frequency range will be extended by higher-frequency (600-1,000 Hz) transmitters provided by the Asian participants. The higher-frequency source(s) will be moored on the shelf next to one of our sources to provide frequency diversity along the same path for studying the frequency-dependent propagation physics and to explore the advantage of higher-frequency tomography inversion. The measurement and analysis will focus 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 will 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.

WORK COMPLETED

Work completed in FY00 includes:

1. Participated in the 2000 pilot survey with three current meters and a floatation sphere. The current meters and floatation sphere were successfully deployed and collected important pilot oceanographic data to support acoustic modeling studies.

2. Finalized the mechanical and electronic design of the NPS L-shape hydrophone array and prepared the NPS 400-Hz sound sources. These sonar equipment will be deployed during the 2001 main experiment to collect both cross-shelf and along-shelf acoustic transmission data in the vicinity of the shelfbreak.

3. Conducted simulation propagation experiments based on data from the 2000 pilot survey. The purpose of the modeling was to generate some preliminary understanding of the controlling propagation physics and ocean factors. This helps to design optimized (i.e., fine tune) experimental configuration.

RESULTS

Using the pilot survey data obtained in the East China Sea (ECS), acoustic model runs to investigate important design questions concerning the bottom and volume acoustic interaction experiments of 2001 were carried out. The specific questions which were addressed include:

1. Is the water-column variability in northwest quadrant of the ECS survey site robust enough to pen-nit unambiguous observations of the acoustic effects caused by the ocean bottom, if the bottom interaction experiment is to take place there?

2. What is the optimum source depth, receiver range, and frequency in a slope-to-shelf transmission, in the event that the volume interaction experiment is to take place in the vicinity of the shelfbreak inside the ECS survey site?

To explore the answer to the first question, the yo-yo CTD time-series collected on 9 April 2000 was used to estimate the temporal variability of the transmission loss along the water-sediment interface inside the northwest quadrant. Being far away from the Kuroshio Current and with a minimal stratification in Spring, the measured time-series show a very small sound speed variation as anticipated, only 3 m/s over a 4-hour span and was mostly confined in the top layer. However, to a small surprise, the calculated transmission loss show moderate temporal fluctuations of ±4 to 5 dB along the interface. These calculations were performed for a frequency of I kHz and a nominal source depth of 20 in. The transmission loss fluctuations are reducible by local spatial averaging, i.e., trading resolution for a reduced uncertainty. However, depending on the accuracy and resolution requirements for studying bottom parameters and their acoustic effects, the modeling results indicate that adequate water-column monitoring can be important for a clear separation of bottom and volume effects in the bottom interaction experiment.

The second question was examined using the two cross-front CTD sections, obtained on 18 and 24 April 200, respectively (Figure 1). The acoustic wavefields simulated in a slope-to-shelf geometry for a sound source located at the 300-m isobath reveal that (i) the optimum source depth is near the bottom where sound speed reaches its minimum (Figure 2), (ii) the optimum frequency band is broad, up to at least I kHz, and it peaks at about 200 Hz, and (iii) receiver ranges with adequate signal-to-noise ratio well exceeds 70 km. Furthermore, based on the transmission loss calculations using the two CTD sections obtained on the different days, appreciable changes of ± 15 dB due to frontal variability were found.

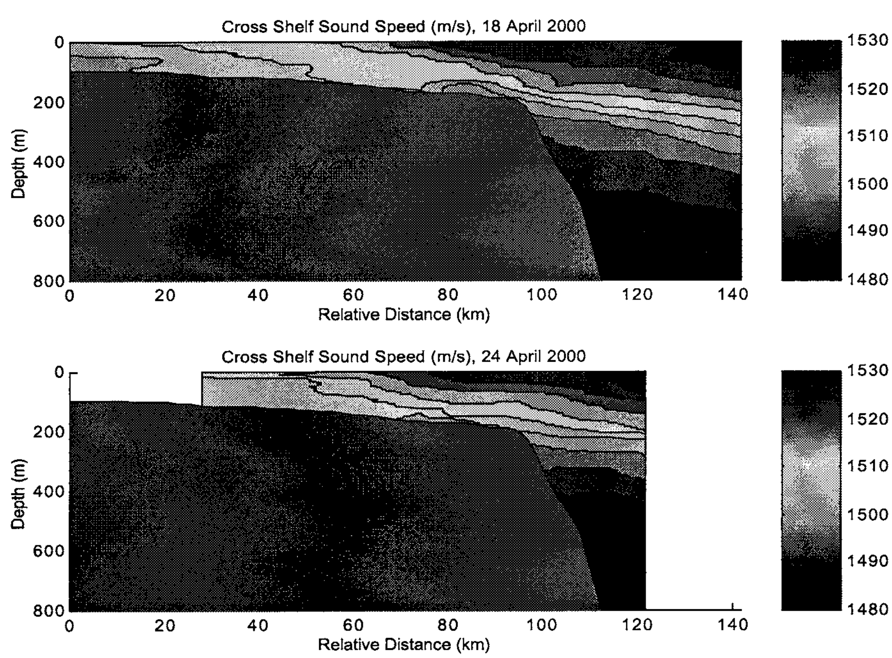

Figure 1. Measured sound speed across the Kuroshio Front. The two sections were measured on different days, 18 April (top) and 24 April (bottom), along the same path during the pilot survey.

IMPACT/APPLICATIONS

The oceanographic data gathered in this field study should be valuable in helping to create a general environmental model of shelfbreak regions suitable for assessing present and future Navy systems, acoustic as well as non-acoustic. In conjunction with the oceanographic data, the acoustic data will allow for an in-depth understanding of the coherence of the sound field in a shelf-slope environment, as well as for validating tomography as a useful tool for coastal monitoring.

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.

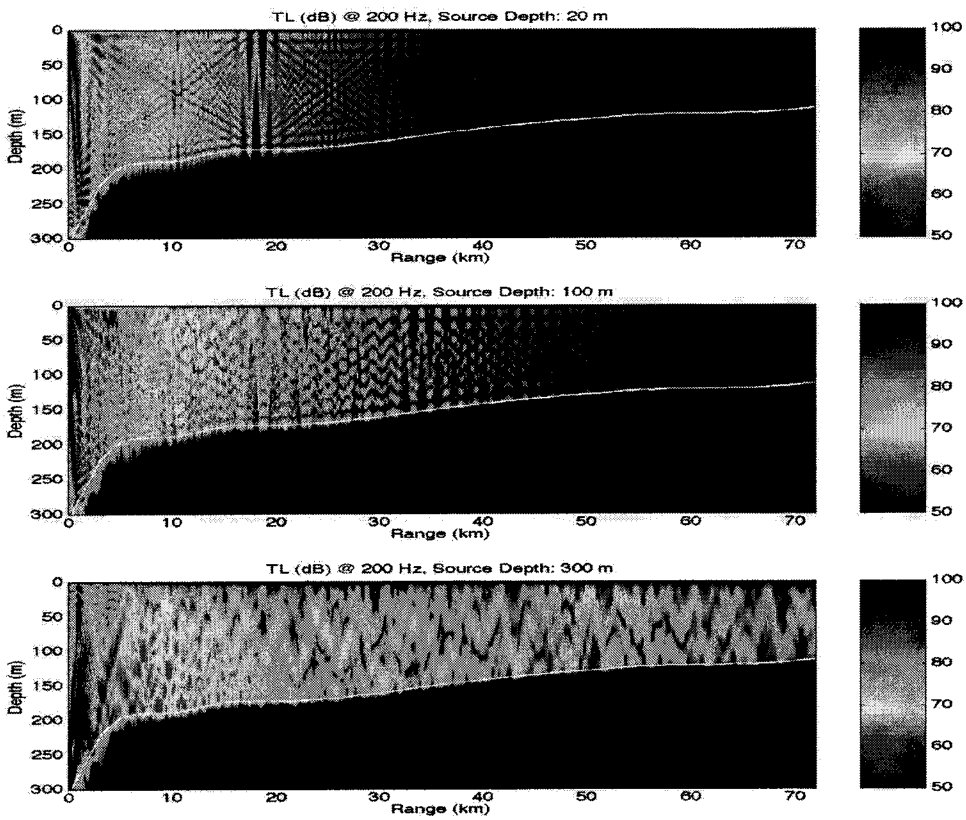

Figure 2. Slope-to-shelf transmission loss at 200 Hz for three different source depths, 20 m (top panel),100 m (middle panel) and 300 m(bottom panel). Calculated based on a CTD section obtained in the ECS pilot survey, they show a general increase in the distance of sound energy penetration onto the shelf as the depth of the source increases. This dependence on source depth is common to most downward refracting sound channels.

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

Denner, W. W., C.-S. Chiu, and S. R. Ramp, "Report on the Office of Naval Research Phase III International Workshop on Shallow-Water Acoustics, Alyeska Resort, Girdwood, Alaska, July 12 - *15,* 1999," NPS Technical Report NPS-OC-OO-OOIPR, 40pp., 2000.