Analysis of South China Sea Shelf and Basin Acoustic Transmission Data

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LONG-TERM GOALS

My long-term research goals are: (1) The characterization, understanding, and prediction of the statistics (mean, variance and coherence) of low-frequency acoustic signals and ambient noise in the littoral zone. The signal statistics are primarily influenced by the ocean variability and bottom properties. The noise statistics are influenced by atmospheric forcing and shipping in addition to the ocean and bottom variability. (2) The development and improvement of 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 is a multiyear project to analysis the shelf and basin acoustic data collected from the Northeastern South China Sea (NE SCS) during the Windy Island Soliton Experiment (WISE). These data were collected between April 2005 and October 2006. The objective of the shelf transmission is to study the physics of sound propagation through nonlinear, internal tides, elevation waves and depression waves in shallow water, and to compare the associated fluctuations in the sound intensity. The objectives of the basin study were twofold: The first is to study and characterize the supertidal-to-seasonal-scale impacts of the transbasin, nonlinear internal waves on the long-range transmission loss. The second is to study the characteristics and variability of ambient noise in the NE SCS basin, and in particular, to elucidate the statistical relations of shipping density, wind speed, precipitation, and nonlinear internal wave (NIW) activities to the observed noise levels. Completing the modeling analysis of the shelf transmission data, and modeling the statistics of the shipping noise and identifying other dominant noise sources in the SCS basin constituted the two primary focuses of this research project in FY11.

APPROACH

Shelf Transmission The shelf transmission in WISE was conducted from 13 to 15 of April 2005 near the shelf-break. A 400-Hz sound source that has a bandwidth of 100 Hz and an 8-element receiving

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vertical line array (VLA), separated by ~ 17 km, were deployed on the 110-m and 90-m isobaths, respectively. The sound source transmitted 30 5.11-s phase encoded signals every five minutes from a depth of 100-m during the three-day experiment. Additionally, five environmental moorings consisting of temperature sensors spaced every 10-m vertically were deployed along the transmission path to sample the water-column variability that was dominated by the evolution of nonlinear internal tides and high-frequency nonlinear internal waves. The analysis entails first the development of a space-time continuous sound speed model capturing the water-column variability along the transmission path using the environmental data. A coupled-mode sound propagation model is then employed to examine the propagation physics and variability by linking the observed sound-speed structure to the observed features and statistical properties of the intensity fluctuations.

Basin Ambient Noise A hydrophone was moored at mid depth in the NE SCS basin from November 2005 to October 2006. In addition to monitoring a 400-Hz signal, the hydrophone provided a yearlong time series of the ambient noise. Operated with a 1-min-on and 14-min-off duty cycle and sampled at 1.6 kHz, the measured time series captures the spectral characteristics and variability of the ambient noise in the 0-to-800 Hz band over an annual cycle. The relations between the observed noise levels and the relevant environmental variables are then examined using spectral estimation methods, scattered diagrams, and computer simulations.

WORK COMPLETED

Shelf Transmission

Applying time-series filtering, principal component analysis and a feature tracking technique to the oceanographic data, a continuous space-time empirical model for the sound-speed field was developed. Using a coupled-mode sound propagation model, interfacing with the sound-speed model, the temporal variations of the vertical distribution of signal intensity at the hydrophone array were computed. Analyzing the model results and comparing them to the measured signal intensities have allowed for quantification and comparison of the effects of the nonlinear internal tides, depression waves, and elevation waves on the sound transmission.

Basin Ambient Noise in the 0-300 Hz Band

The hydrophone was located in a region of important shipping traffic. Because of the close proximity of the receiver to heavily-used ship routes, omni-directional ambient noise levels at frequencies below 300 Hz varied widely over a few hours time due to transiting commercial traffic. To simulate this variability, noise estimations were calculated using a ship motion simulator that characterized the distribution of discrete nearby ships as a function of time as well as applying statistical spatial distributions for more distant shipping.

The Navy's Historical Temporal Shipping database (HITS) was used for the basis of both the distant shipping distribution and the time-varying discrete locations of nearby ships. HITS describes the spatial worldwide distribution of commercial shipping based on 3-years of Lloyd's Ship Movement data. The database classifies ships into four ship types (supertanker, large tanker, merchant and tanker) that transit along more than 500 defined ship routes. HITS also uses statistics from the UN Food and Agriculture Organization to characterize the seasonal presence of commercial fishing vessels operating in various regions of the world.

The HITS Vessel Motion Simulator (HVMS) applies information from HITS about the number of ships of each type that can be found on a given route. A random seed generator is used to initiate the discrete ship distribution in the vicinity of the receiver and repopulate the ship routes throughout the simulation period in accordance with HITS statistics. Ships transit the region within the defined boundaries of the ship routes at speeds based on ship type. In the simulation applied to the hydrophone location, ships within 300 km of the receiver were treated as discrete ships with time-varying positions. Noise contributed by distant shipping (>300 km from the hydrophone) was calculated using static shipping densities.

In the simulation, estimates of noise and its variability were based on contributions from shipping and wind-generated sources only. In the region near the hydrophone, shipping noise dominates the wind contribution at frequencies under 300 Hz. The Navy Standard Parabolic Equation (NSPE) model, a variant of RAM, was used for acoustic propagation modeling of the noise. The input to the acoustic model included climatological ocean profiles and winds. The bathymetry was derived from the unclassified Navy digital bathymetry database. The geoacoustic model was based on previous research conducted in this region (Marburger, 2004, and Bernotavicius et al., 2010). The noise was then calculated as the sum of the distributed contributors (shipping and winds) out to 1000 km.

RESULTS

Shelf Transmission

Key findings from the modeled sound-speed and sound-intensity fields and their comparisons to the measured data are:

- Sound speed variability on the NE SCS shelf is dominated by the propagation of nonlinear internal tides, and the propagation and transformation of the high-frequency (HF) NIWs.
- The observed (long-scale) modulation in the sound intensity level (SIL), shown in Fig. 1 together with the modeling result that accurately captures the observed modulation, is induced by the interplay between the internal tides (IT) and the bottom: lower intensity during depressing IT (increasing bottom interaction), and higher intensity during lifting IT (reducing bottom interaction).
- Elevation NIWs tend to cause stronger scattering of acoustic energy into the higher low modes, and working opposite to the co-existing depressing IT, they reduce the average loss to the bottom (Fig. 2).
- Depression NIWs tend to cause weaker mode coupling, and working opposite to the co-existing lifting IT, they enhance the average loss to the bottom loss (Fig.2).
- Sound intensity level statistics is bandwidth (number of arrivals) dependent. A simple extension of Dyer’s theory (1970) appears to bound the observed windowed variances well, with the observed converging to the theoretical prediction as the estimation window increases.

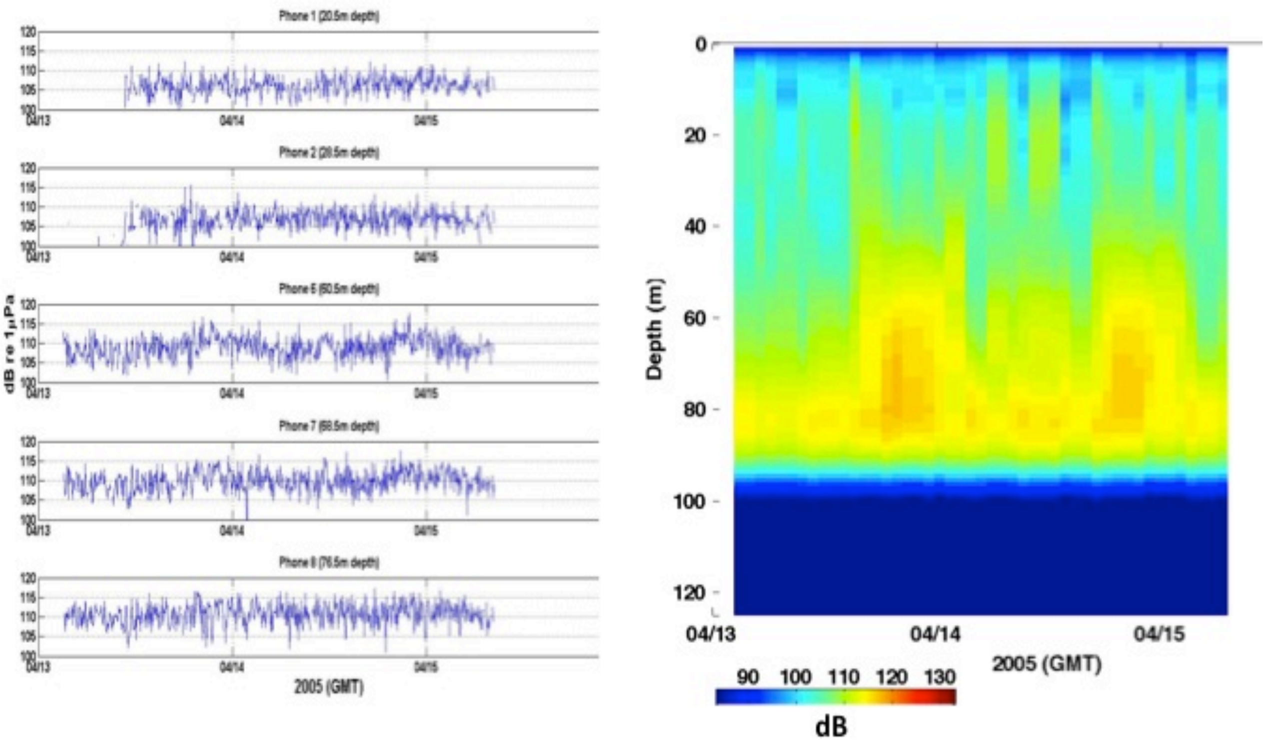

Figure 1. Measured intensity fluctuations as a function of depth and time (left), and the modeled intensity fluctuations with internal tide-induced sound speed change only (right). Not shown here are the modeled rapid intensity fluctuations induced by a combination of the internal tides and high-frequency depression and elevation internal waves.

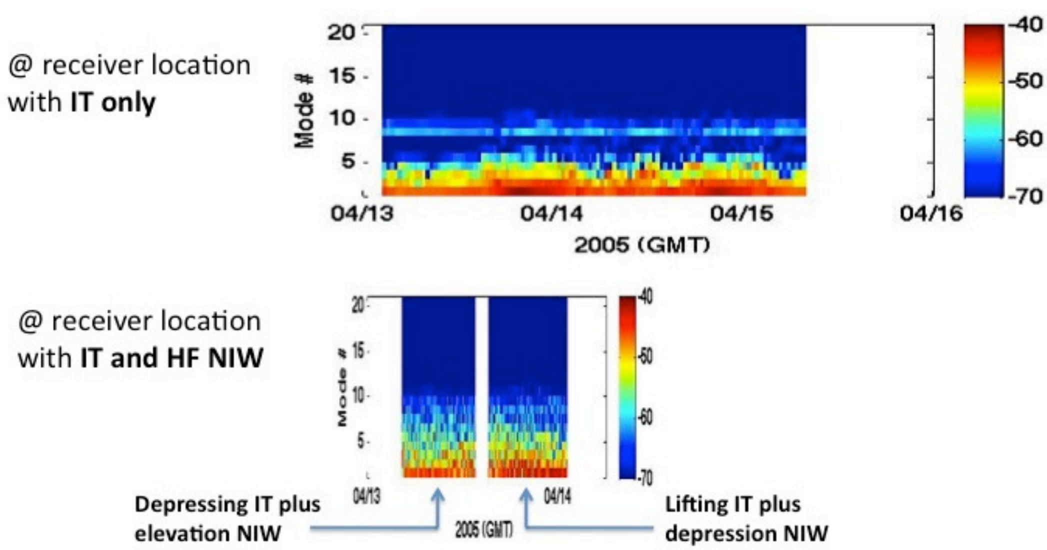

Figure 2. Modeled relative modal magnitude (dB) with internal tides only (upper) and with both internal tides and HF nonlinear internal waves (lower), showing that the HF elevation and depression internal waves tend to work against the co-existing internal tides to reduce and enhance the average loss to the bottom, respectively.

Basin Ambient Noise in the 0-300 Hz Band

Several 72-hour simulations were run with ship positions recalculated every 6 minutes of simulation time. A snapshot of the distribution of discrete ships during the simulation is shown in Fig. 3. The results of the time-varying noise estimates at four frequencies (25, 50, 100 and 200 Hz) are shown in Fig. 4. Histograms of the simulated and measured noise levels are shown in Fig. 5 for comparison. Average noise from the simulation underestimates the measured noise at 50, 100 and 200 Hz. The measured histograms are both broader and have extended right-hand "tails" in their distributions. The moderately higher mean and variance as well as the extended tails of the data histograms are indicative of other significant noise contributors that the simulation does not account for. Four of these significant noise sources, other than shipping, are clearly identifiable in the data set (Fig. 6). Further work is needed to do a budget on these other significant noise sources. The simulation accuracy of noise may also suffer from lack of precise knowledge of the environment and pattern of shipping with respect to the hydrophone. Ship source levels and the number of ships are other potential sources of error and warrants further investigation.

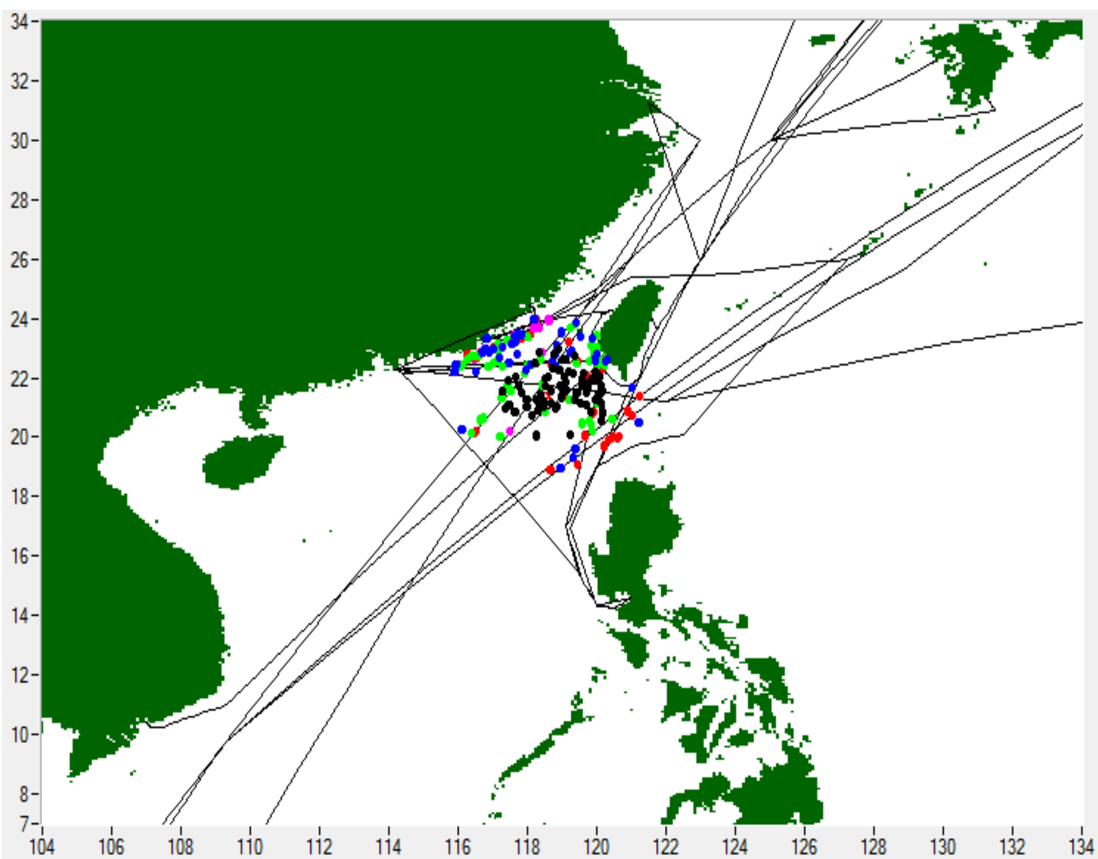

Figure 3. Snapshot of Vessel Movement Simulation within 300 km of the hydrophone. Color dots denote supertankers (magenta), large tankers (red), merchants (green), tanker (blue), and fishing vessels (black).

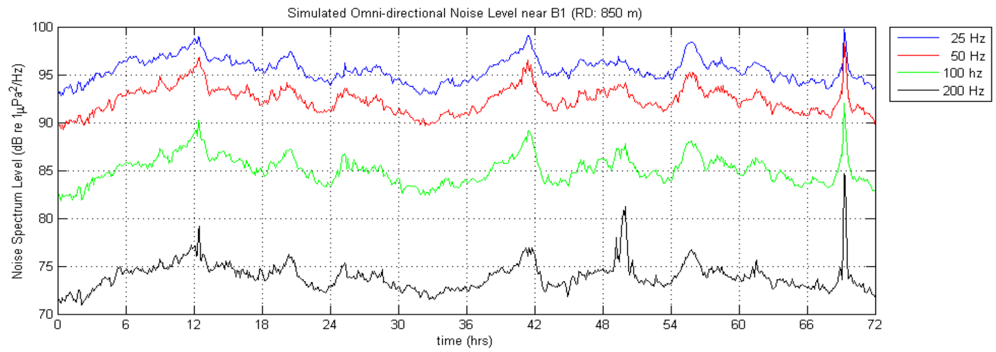

Figure 4. Simulated shipping noise level variability over a 72-hour window.

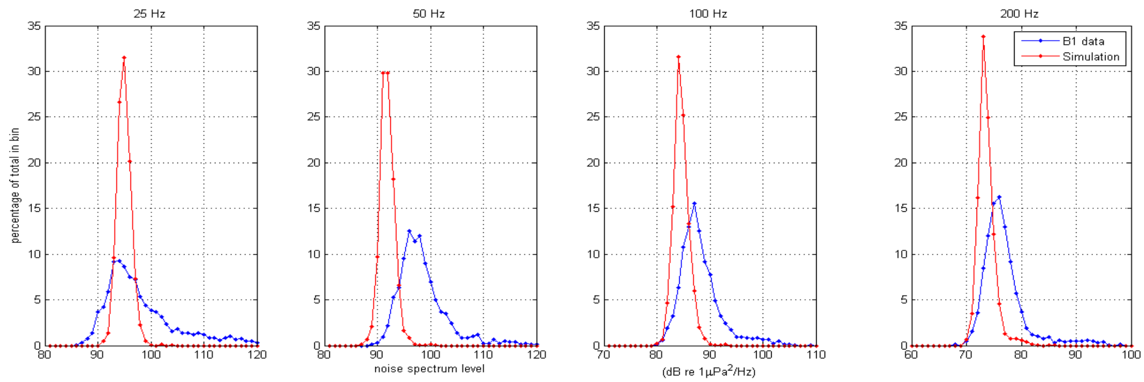

Figure 5. Simulated (red) and measured (blue) histograms of noise level distribution at 4 frequencies based on six 72-hr time series realizations.

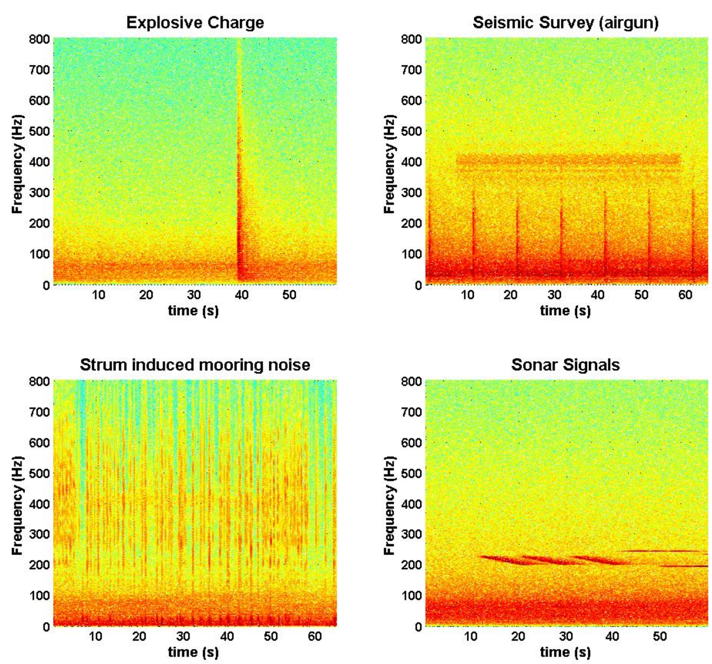

Figure 6. Other significant (frequent-enough) noise sources identified in the data that can contribute to the mean and variance of the low-frequency ambient noise.

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 PROJECT

This fully integrated acoustics and oceanography experiment should extend the findings and data from SWARM, Shelfbreak PRIMER, ASIAEX and SW06, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

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