Measurements and analysis of phenomenology and statistics of sound propagation over sand dunes on upper slope of the Northeastern South China Sea

Ching-Sang Chiu
Department of Oceanography
Naval Postgraduate School
Monterey, CA 93943-5001
Phone: (831) 656-3239 Fax: (831) 656-7970 E-mail: chiu@nps.edu

Award #: N0001412WX20501

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

The objectives of this three-year (FY12-14) research project are threefold:

1. In collaboration with Taiwan scientists, Drs. T.-Y. Tang and C.-F. Chen of the National Taiwan University (NTU), Drs. L. Chiu and R .Wei of the National Sun Yat-Sen University (NSYSU), Dr. Y.-J. Yang of the Taiwan Naval Academy (TNA), and Dr. M.-H. Chang of the National Taiwan Ocean University (NTOU), to jointly plan and execute a pilot field study consisting of systematic, concurrent acoustic propagation, bottom/sub-bottom profiling, and oceanographic measurements to study the effects of the large sand dunes, and the combined effects of the sand dunes and nonlinear internal waves, on sound transmissions over the upper slope of the NE SCS. Specifically, the join field study has the following scientific objectives:

   - To characterize the time and space scales and the distribution of sand dunes on the upper slope southeast of the WISE shelf transmission location.
   - To study the associated sediment resuspension process as the transbasin NIWs propagate upslope producing large negative pressures sucking up the sands, which are then advected by the current and redistribute.
   - To study the impact of the sand dunes, and the combined impact of sand dunes and nonlinear internal waves, on sound propagation, in terms of phenomenology including anisotropic

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Measurements and analysis of phenomenology and statistics of sound propagation over sand dunes on upper slope of the Northeastern South China Sea**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Oceanography Naval Postgraduate School Monterey, CA 93943-5001**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

propagation characteristics, and two-dimensional (2D) and three-dimensional (3D) focusing/defocusing scattering phenomena.

- To study the associated statistics (mean, variance and coherence) of sound signal propagating over the sand dunes on the upper slope and their dependence on range, frequency and orientation.

2. To continue and complete the synthesize of the acoustic signal propagation results from three transmission experiments, ASIAEX, WISE and NLIWI, all carried out in the vicinity of the northeastern South China Sea (NE SCS) shelfbreak, to form a knowledge base on the dependence of the signal fluctuations on the locale, orientation, range and type and strength of nonlinear internal waves.

3. To quantify the annual ambient noise budget in the South China Sea basin using data collected from November 2005 to October 2006.

APPROACH

Field study: All fieldworks for this project are to be carried out in collaboration and coordination with our long-time Taiwan colleagues from NTU, NSYSU, NTOU and TNA, and will utilize their Research Vessels (RVs), Ocean Research 2 (OR 2), Ocean Research 3 (OR 3) and their newest vessel Ocean Research 5 (OR 5). Pilot cruises are to be carried out in the first two years of this project with OR 2 that is instrumented with a multibeam system to survey the spatial distribution and scales of the sand dunes over a 60 km by 60 km area spanning the upper slope, shelfbreak and outer shelf. This survey data are then used to design the main acoustic propagation experiment for 2014, including choosing the mooring locations and source-receiver geometries.

The main acoustic propagation experiment will be performed in Spring 2014. We envision a two-week cruise with three vessels, OR 1, 2 and 5, operating together. One of the two weeks will span a spring cycle of the tides and the other an adjacent neap cycle, during which the internal waves will have maximum and minimum amplitudes, respectively. During the two weeks, OR 2 will be dedicated to perform multibeam survey, while OR 3 and 5 will be used to deploy receiver arrays, oceanographic moorings, lowered sources and a towed source. These will allow us to capture the changes in spatial scales and distribution of the sand dunes between the two cycles, and examine and contrast the associated impacts on the sound fields. It is our hypothesis that, the sound field and its statistics are primary controlled by the spatial scale and distribution of the sand dunes during the neap cycle, whereas during the spring cycle, they are controlled by a combination of the sand dunes and internal waves. One of the moorings, instrumented by our Taiwan colleagues, will have high-resolution pressure, current and turbidity sensors to characterize the sediment resuspension process and capture the associated intra-cycle time and space scales that are expected to be short, on the order of 30 mins and a few hundred meters.

The acoustic receivers to be fielded during the small propagation experiment would include three vertical line arrays (VLAs). A limitation of these VLAs is their short apertures relative to the full water depth of the upper slope (100 m versus 400 m). Therefore, we plan to moor them at different depths such that the combined aperture will span most of the water column. The VLAs will be moored on a single mooring, or on separate moorings that are close together, to allow for measurement and quantification of the resultant scattering of sound in the vertical direction.

Two newly acquired sound sources from the DURIP program, transmitting 500-1,200-Hz frequency modulation signals, will be lowered from OR 5 at pre-assigned stations spanning a straight-line path down slope and cross slope from the VLAs. Each station will be occupied with enough time to repeat a signal to allow for proper measurement of the received signal statistics. A towed source transmitting at the 3.5-5 kHz band, provided by Taiwan, will be used to investigate anisotropy and 3D phenomena.

The analysis of the acoustic data would begin in summer of FY14 after the main experiment. It would entail time series analysis and modeling to characterize and elucidate the anticipated nonstationary statistics as well as anisotropic, 2D and 3D focusing/defocusing phenomena in the measured sound field. The focus of the analysis would be to relate the observed statistics and phenomena to the scales and distribution of the sand dunes, with and without the coexistence of the nonlinear internal waves.

Synthesis of ASIAEX, WISE and NLIWI results: The approach entails surveying the existing relevant literature and gathering new or updated findings from investigators who are presently working on data from and/or models for those sites. Both experimental and modeling results are to be synthesized in two broad categories, phenomenology and statistics. This synthesis work is in collaboration of Dr. J. Lynch of the Woods Hole Oceanographic Institution (WHOI).

Noise budget: The approach entails a reanalysis of a one-year long ambient-noise dataset collected in the South China Sea basin. This reanalysis involves carefully combing through the entire data set to identify intermittent noise sources and then constructing the noise budget. The data review is laborious and is accomplished with a combination of visual review of spectra and spectrograms of data records and listening to the corresponding audio files.

WORK COMPLETED

The preparation and planning for the FY14 main experiment to study sound propagation over the large sand dunes in the upper slope of the northeastern South China Sea has commenced in earnest in FY12. The joint work completed includes:

- In spring of 2012, a one-week pilot multibeam survey was successfully carried out.
- In August 2012, a workshop was carried out to review the multibeam data collected, and based on this data, an experimental plan for another pilot cruise for FY13 was formulated. Additionally, the preliminary experimental configuration for the FY14 main experiment was reviewed and agreed upon by all participants, and complementary modeling efforts outlined and assigned.
- Some, not all, of the long lead-time mooring hardware and equipment were procured.
- In collaboration with Dr. Y.-T. Lin of WHOI, the development of a fast 3D raytrace, eigenray search and arrival structure synthesis MATLAB model was in progress. This new 3D ray theory-based model replaces the obsolete Hamiltonian Raytracing Program for the Ocean code that only runs in slow, legacy workstations. This new, fast and machine independent 3D ray model will complement the 3D PE model used by other PIs of this project to provide additional physical insights into the phenomena of sound propagation over sand dunes.

For the synthesis of results from previous shallow-water experiments in the northeast South China Sea, the gathering of the available historical datasets and literatures for those experiments was in progress. In collaboration with Dr. J. Lynch, we continued to work on the outline of a review article on shallow-water internal waves and their acoustic effects. We plan to invite additional coauthors to work on this review article.

On the noise budget, the reanalysis of the South China Sea ambient noise time series was carried out. This time, we carefully comb through the entire data set to identify intermittent noise sources and quantify the noise budget.

RESULTS

Field Study: A pilot high-resolution multibeam survey was carried out on Taiwan RV OR2 in April, with Dr. Reeder of NPS participating in that cruise. A screen capture of the multibeam data are shown in Figure 1. Our Taiwan geologist participant processed the data. We have a workshop in August in Taiwan to examine the analyzed results to get a good first understanding of the spatial scales and distribution of the dunes, and using it to formulate acoustic modeling and experimental plans for a second pilot cruise in FY13 and the main experiment in FY14. One of the important results from the FY12 pilot multibeam survey is the affirmation of the single-beam, single-transact finding by Reeder et al., 2010 that the largest sand dunes are consistently located between the 300 m and 400 m isobaths. With this consistency check on the sand dunes locations, the preliminary experimental configuration for the main propagation experiment, shown in Figure 2, was reexamined, discussed and agreed upon by all investigators.

Our Taiwan collaborators have secured a total of 20 days of ship time on RVs OR2, OR3 and OR5 for April 2013. The jointly formulated FY13 pilot survey plan calls for going back to occupy the same area with another high-resolution multibeam survey. This will allow us to examine changes and thus obtain an appreciation on the temporal scales. In the FY13 pilot cruise, we will also collect some ambient noise data with single receivers, some initial transmission data with the Taiwanese towed source, and test some new mooring design and equipment in situ to make sure that they won't be severely affected and buried by the re-suspending sands.

Noise budget analysis: A sound record measured by a moored hydrophone in the South China Sea basin was reanalyzed. Sampled at a rate of 1.6 kHz and with a duty cycle of 40-s-on and 14-min-and 20-s-off, the measured time series captures the spectral characteristics and variability of the ambient noise in the less-than-800-Hz band over an annual cycle. In the reanalysis, we used a combination of automated and manual screening methods to identify the dominant intermittent noises. The major categories of intermittent noises identified include discrete ships (producing pronounced line spectra or bathtub spectral patterns), seismic air-gun surveys, shots (such as explosives and earthquakes), sonar signals (transmitted by electronically controlled transducers), and squeaks (intermittent self noise "squeaking sounds" that prevailed at times during the passage of the very large-amplitude internal waves. Figure 3 shows the scatter diagram of the 20-220 Hz band level versus the 500-700 Hz band level associated with each of the 40-s records. Each data point in the scatter diagram is color-coded or marker-symbol coded to depict the intermittent noise that dominates. Blue dots denote all data points. If a blue dot is not plotted over by a different color dot or marker, then the corresponding data point does not contain discernable intermittent noises.

The temporal distributions of the identified intermittent noises are revealed in Figure 4 with the same color codes. The measured band levels are shown as blue and green dots, denoting the 20-220 Hz band and the 500-700 Hz band, respectively. A summary of the noise budget is given in Table 1. Note that noise spectrum level is 23 dB lower than the band level of noise in a 200-Hz band discussed here.

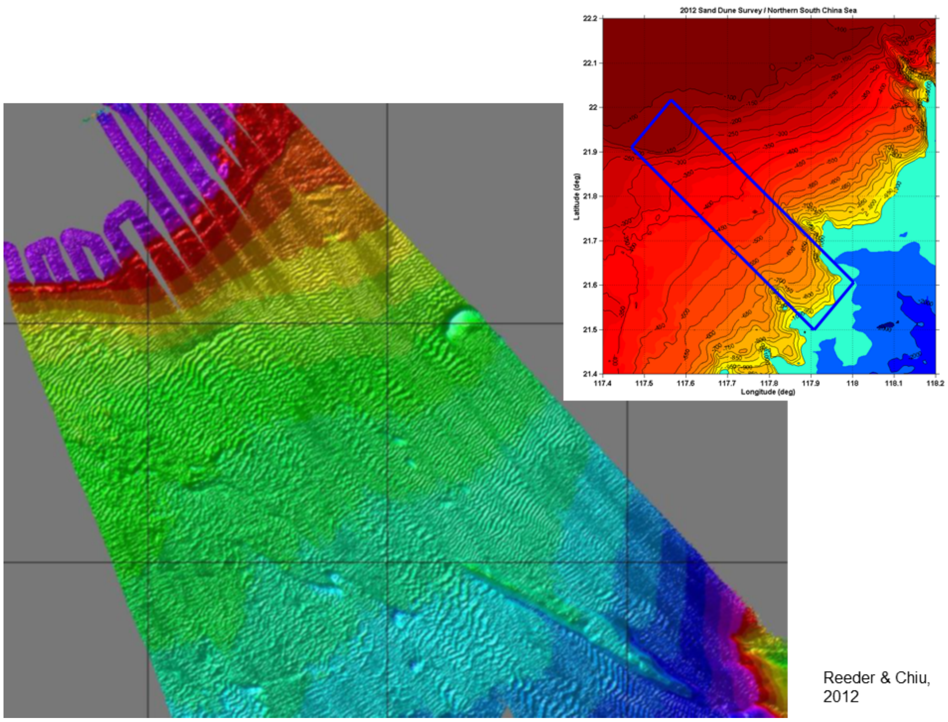

Figure 1. Screen capture of part of the multibeam data from the pilot survey in April/May 2012.

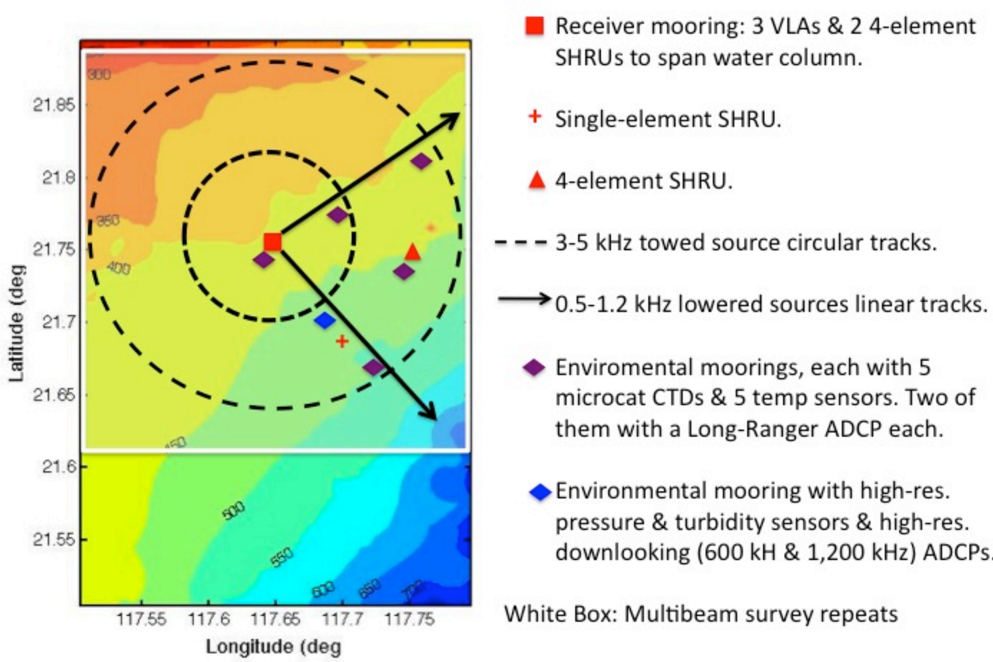

Figure 2. Planned configuration for the main experiment in 2014.

Withholding the identified intermittent noises allowed for an improved correlation analysis on the degree of dependence of the measured noise levels on wind speed and precipitation. The results are depicted in Figure 5 where the 20-220 Hz and 500-700 Hz band level data are plotted against wind speed and precipitation. The wind speed and precipitation data were obtained from the US Naval Operational Global Atmospheric Prediction System (NOGAPS). The results, shown in the top two panels of the figure, clearly demonstrate a lack of dependence of the 20-220 Hz noise to both wind speed and precipitation. This is expected, since shipping is the dominant noise sources at these low frequencies. In contrast, as displayed in the two bottom panels of Figure 5, the 500-700 Hz noise band levels show a clear dependence on both wind speed and precipitation. The Wenz curve for wind noise predicts the 500-700 Hz levels very well, particularly for wind speed larger than 5 m/s, with the observed data standard deviation decreases as wind speed increases. A linear regression of the 500-700 band level data versus the 12-hr precipitation accumulation shows a noise level increase of about 0.45 dB per 1-mm increase in the12-hr precipitation accumulation.

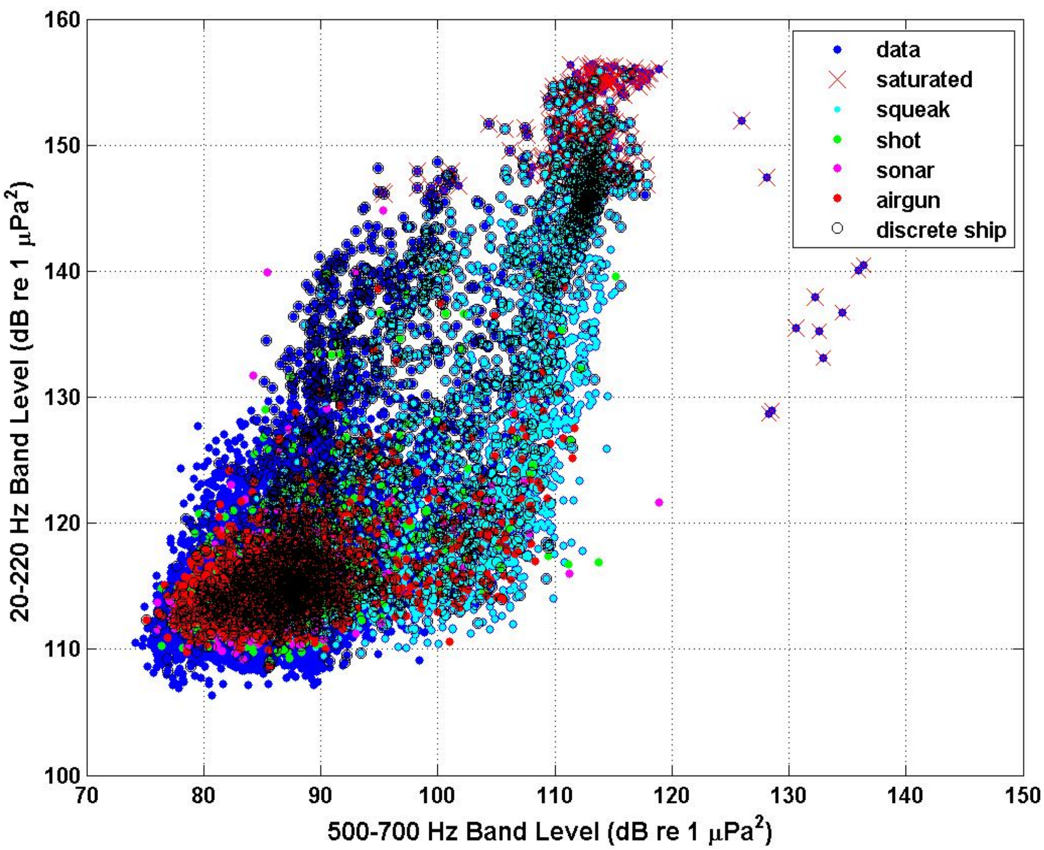

Figure 3. Scatter diagram of the 20-220 Hz versus 500-700 Hz band level data. Each data point in the scatter diagram is color-coded or marker-symbol coded to denote the type of intermittent noise that dominates. Blue dots denote data points containing no identifiable intermittent noise.

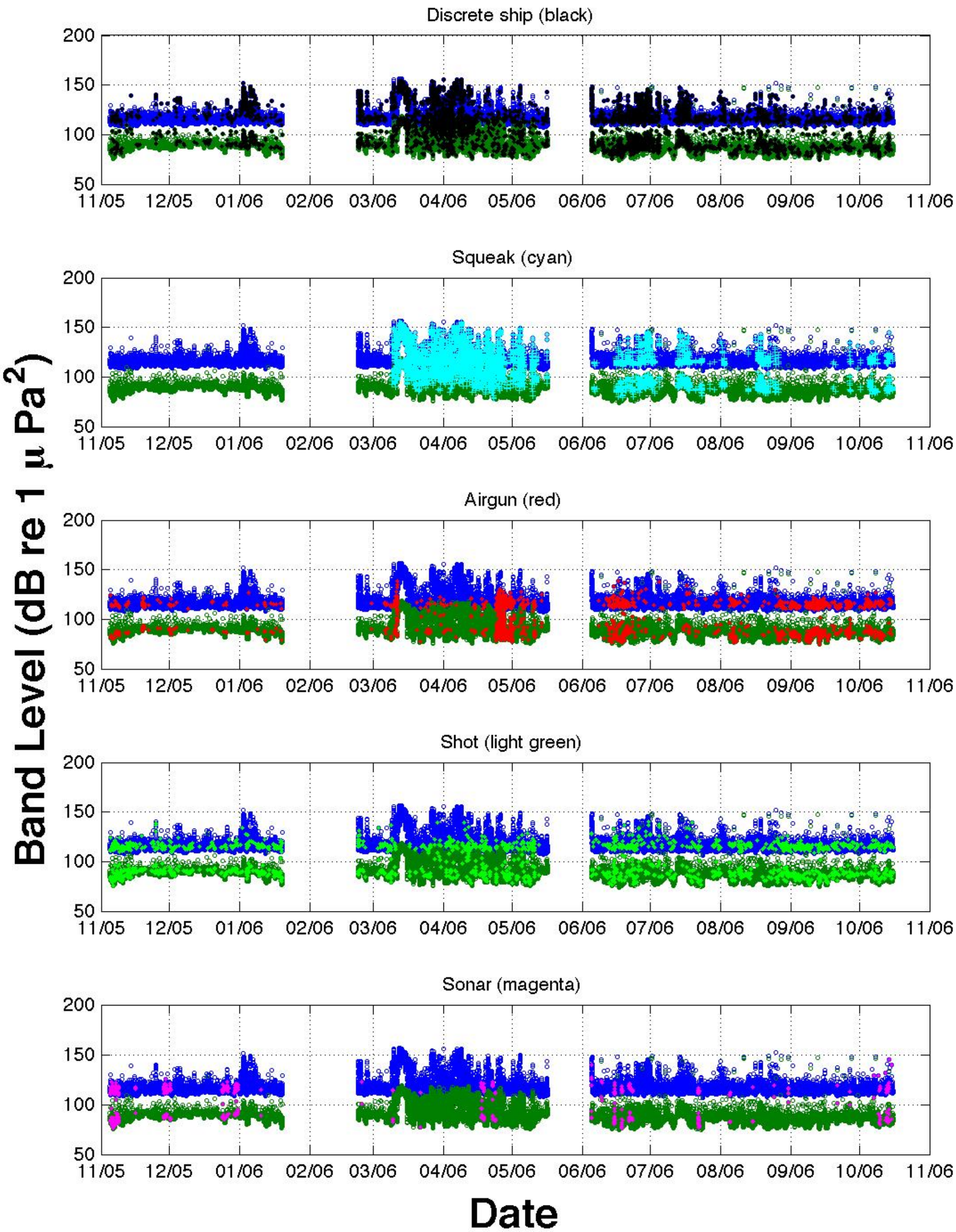

Figure 4. Times of occurrence of the identified intermittent noises. Blue denotes 20-220 Hz band level and dark green 500-700 Hz band level. Dots with other colors, each associated with the time of occurrence of an identified intermittent noise, are superimposed on the blue and dark green dots.

Table 1. Summary of noise budget. Note that the band levels were calculated using a 40-s averaging time. Therefore, the difference of a fraction of a dB from the baseline is significant particularly for pulsed intermittent noises.

Identifiable Intermittent Noises	% of Time	20-220 Hz Band Level Mean (dB)	20-220 Hz Band Level Standard Deviation (dB)
Airgun Surveys	4.5	115.7	3.6
Single Shots	3.0	116.5	4.6
Sonar Signals	1.2	115.7	4.3
Discrete Ships	11.5	126.1	12.1
*Baseline		115.0	3.1

* With all identified intermittent noises removed

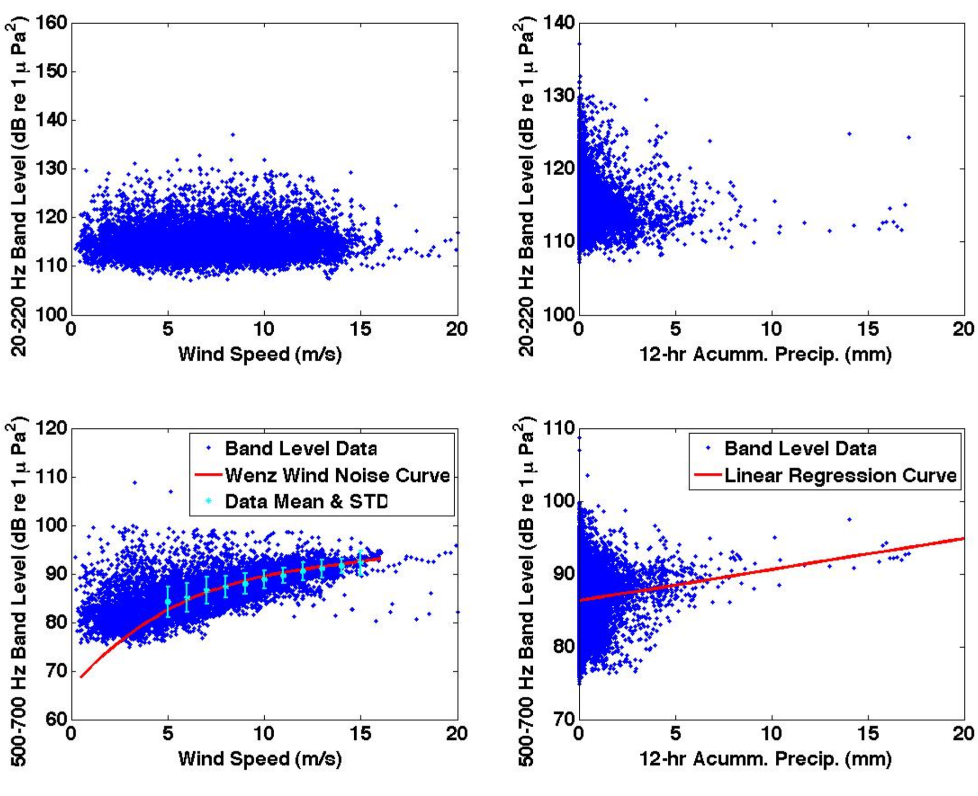

Figure 5. Measured 20-220 Hz (top) and 500-700 Hz (bottom) noise band levels versus wind speed (left) and precipitation (right). Additionally, the Wenz curve for wind noise is shown in the bottom left panel together with the respective data mean and standard deviation; the linear regression curve for the 500-700 Hz band level data versus precipitation is shown in the bottom right panel.

IMPACT/APPLICATIONS

The oceanographic, bottom and acoustic data gathered in this field study will 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 integrated acoustics, oceanography and geology experiment should extend the findings and data from SWARM, Shelfbreak PRIMER, ASIAEX, SW06 and NLIWI, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

REFERENCES

Reeder, D.B., Ma, B.B., and Yang, Y.-J., "Very large subaqueous sand dunes on the upper continental slope in the South China Sea generated by episodic, shoaling deep-water internal solitary waves," Mar. Geol., 2010.

PUBLICATIONS

Chiu, L., Chen, Y.-Y., Chen, C.-F., Reeder, D.B., Chiu, C.-S., Lin, Y.-T. and Lynch, J.F., "Enhanced nonlinear acoustic mode coupling resulting from an internal solitary wave approaching a shelf break," *J. Acoust. Soc. Am.* [submitted].