

## Bottom Interaction in Ocean Acoustic Propagation

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### LONG-TERM GOALS

The long term objective is to understand the dominant physical mechanisms responsible for propagation and scattering over distances from tens to thousands of kilometers in the deep ocean where the sound channel is not bottom limited. The specific goal is to study the role of bottom interaction and bathymetry on the stability, statistics, spatial distribution and predictability of broadband acoustic signals observed just above and on the deep seafloor (greater than the critical depth). What is the relationship between the seismic (ground motion) noise on the seafloor and the acoustic noise in the water column? What governs the trade-offs in contributions from local and distant storms and in contributions from local and distant shipping? How effective is seafloor bathymetry at stripping distant shipping noise from the ambient noise field?

This project addresses "the effects of environmental variability induced by ocean internal waves, internal tides and mesoscale processes, and by bathymetric features including seamounts and ridges, on the stability, statistics, spatial distribution and predictability of broadband acoustic signals..." (quote from the Ocean Acoustics web page). Understanding long range acoustic propagation in the ocean is essential for a broad range of Navy applications such as the acoustic detection of ships and submarines at long ranges, avoiding detection of ships and submarines, long range command and communications to submerged assets, and improving understanding of the environment through which the Navy operates.

### OBJECTIVES

During the 2004 Long-range Ocean Acoustic Propagation Experiment (LOAPEX) (Mercer *et al.*, 2009) a new class of acoustic arrivals was observed on ocean bottom seismometers (OBSs) for ranges from 500 to 3200km (Stephen *et al.*, 2009). The arrivals were called Deep Seafloor Arrivals (DSFAs), because they were the dominant arrivals on the ocean bottom seismometers (OBSs), but were very weak on the deep vertical line array (Deep VLA), located above 750 m from the seafloor. Stephen *et al.* (2013) attributed some of these arrivals to bottom-diffracted, surface-reflected (BDSR) energy that scattered from a seamount near the Deep VLA and subsequently reflected from the sea surface before arriving at the OBSs. BDSR arrivals are a palimpsest in the propagated ocean acoustic field. They are barely observable when the ambient noise and PE predicted arrivals are loud (such as in the sound

channel), but become the dominant arrivals when the ambient noise and PE predicted arrivals are quiet (such as on the deep seafloor).

Since NPAL04 we have carried out two experiments specifically aimed at studying DSFAs and BDSRs. The first experiment (OBSAPS - Ocean Bottom Seismometer Augmentation in the Philippine Sea) was carried out in April-May 2011 near the location of the PhilSea10 Distributed Vertical Line Array (DVLA) (Stephen *et al.*, 2011). The second experiment (OBSANP - Ocean Bottom Seismometer Augmentation in the North Pacific) was carried out in June-July 2013 near the location of the NPAL04 Deep Vertical Line Array (Stephen *et al.*, 2014). Both experiments quantitatively compared the signal and noise levels in the 50-400Hz band on the hydrophones and geophones at the seafloor to the hydrophones suspended up to 1 kilometer above the seafloor, for ranges from near zero to 250km. We also acquired seafloor ambient noise at the sites in the band from 0.03 - 80Hz that can be compared to other deep-water sites in the Pacific Ocean.

The objective of these grants is to analyze the data from the two experiments and to disseminate the results. Specific questions to be addressed include: i) Is there evidence for Deep Seafloor Arrivals on OBSAPS and OBSANP that are similar to the ones observed on NPAL04? ii) What is the frequency dependence of the deep arrival structure from 50 - 400Hz? iii) What is the range dependence of the deep arrival structure out to 250km? iv) What is the azimuth dependence of the deep arrival structure? v) What are the relative SNRs of arrivals on vertical and horizontal geophones, co-located seafloor hydrophones and moored hydrophones (from 20m to 1000m off the bottom)? vi) What are the phase relationships between pressure and vertical and horizontal particle motion for deep seafloor arrivals and ambient noise? vii) What is the relationship between the observed deep arrival structure and the PE predicted arrival structure?

## APPROACH

Three types of figures form the basis for the data reduction and analysis:

- 1) Time series of the time compressed traces as a function of range (for the 50km radials and the one 250km long line), as a function of azimuth (for the Star of David pattern) and as a function of time (for the station stops). For the 50km radials and Star of David we transmitted M-sequences at 77.5, 155 and 310Hz; for the 250km long-range tow we transmitted one M-sequence at 77.5Hz; and for the station stops we transmitted M-sequences at 77.5, 102.3, 155, 204.6 and 310Hz.
- 2) SNR summaries, similar to Figure 26 of the OBSAPS cruise report (Stephen *et al.*, 2011), are an excellent way to reduce intensive data sets (we transmitted for 11.5 days and 15 days on OBSAPS and OSNANP, respectively) into a few meaningful parameters.
- 3) Spectrograms for all receivers for the whole recording period show the variability with time and frequency of the ambient noise field. On OBSAPS we recorded during the typhoon on JD130/2011 and on OBSANP we recorded during an extremely quiet period on JD171-172/2013 so we have samples of calm and rough conditions.

After the data reduction the first step is to identify as many instances of DSFAs on the 77.5Hz transmissions as possible and to describe their characteristics. How do they appear across the various receivers (DVLA and OBSs)? How do they appear on the various sensors on the same OBS (vertical

geophone, horizontal geophones, hydrophones)? How is their appearance affected by background noise levels? Where are the diffraction points located and do they correspond to particular seafloor features? Is the occurrence of DSFAs the same at all of the transmitted frequencies (77.5, 155, 310Hz)?

## **WORK COMPLETED**

We have identified four seafloor diffractors in the OBSAPS experiment (Figure 1) based on their time delay and move-out with range. Three of these (A-C) correspond to small seamounts on the seafloor. Diffractor D however does not correspond to any obvious seafloor feature. Figures 2 to 5 show maps of the transmission locations that excite BDSRs. Essentially no BDSR arrivals are observed on the DVLA. There seems to be something special about the vertical component seismometer channels that makes them sensitive to BDSR arrivals. Strangely even though the OBSs are relatively close to the seafloor diffractors, it is rare for the same transmission to excite a BDSR from the same diffractor that is observed on all three OBSs. Furthermore BDSR arrivals from Diffractor D seem to be significantly excited by transmissions only on the Southwest radial.

## **RESULTS**

Although there are circumstances where bottom-diffracted surface-reflected arrivals are robust and relatively loud their range and azimuth dependence, both source to diffractor and diffractor to receiver, can be highly variable. Also although they are commonly associated with small seamounts they can occur where there is no obvious seafloor relief. The specific characteristics of the seafloor that excite BDSR arrivals are still unknown. Preliminary results from the OBSAPS experiment were presented at the PhilSea Data Analysis Workshop in October 2014 and the 2015 Spring ASA in Pittsburgh. A cruise report for the OBSANP experiment was published (Stephen *et al.*, 2014).

## **IMPACT/APPLICATIONS**

Leakage of energy into BDSRs will have at least three consequences. First, if energy leaks out of the waveguide in a systematic fashion, it will increase transmission loss for known modes in the waveguide. These will be scattering losses as opposed to intrinsic attenuation. If the leaked energy re-emerges down range (as BDSR multipath arrivals), perhaps only to near-seafloor receivers, there will be less overall transmission loss (more signal). In this case interpretations may require new types of modes. Second, leakage into BDSRs will result in long-range detections and observations on non-traditional sensors such as deep boreholes in the seafloor in water depths well-below the critical depth (Araki *et al.*, 2004). Third, the physics of short and long-range sound propagation that we are observing in the controlled-source transmissions also applies to local and distant shipping noise. For example, the BDSRs observed on NPAL04 provided a mechanism for taking long-range energy from 4250m depth into the deep shadow zone at 5000m depth. So the presence of BDSRs on various sensors requires a re-evaluation of the signal and noise energy budgets.

## **TRANSITIONS**

Transitions to 32ASW project "Behavior of very low frequency near bottom ambient noise in deep water".

## RELATED PROJECTS

LOAPEX - ONR Award Number N00014-1403-1-0181

SPICEX - ONR Award Number N00014-03-1-0182

PhilSea09 and PhilSea10 - ONR Award Number N00014-08-1-0840

OBSAPS - ONR Award Number N00014-10-10994 and N00014-10-1-0990.

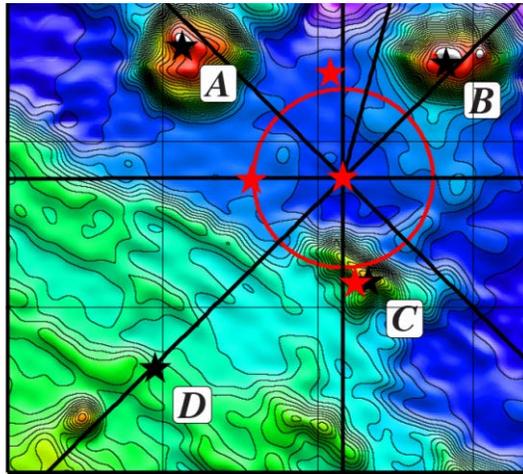
OBSANP - ONR Award Number N00014-10-10987 and N00014-12-M-0394

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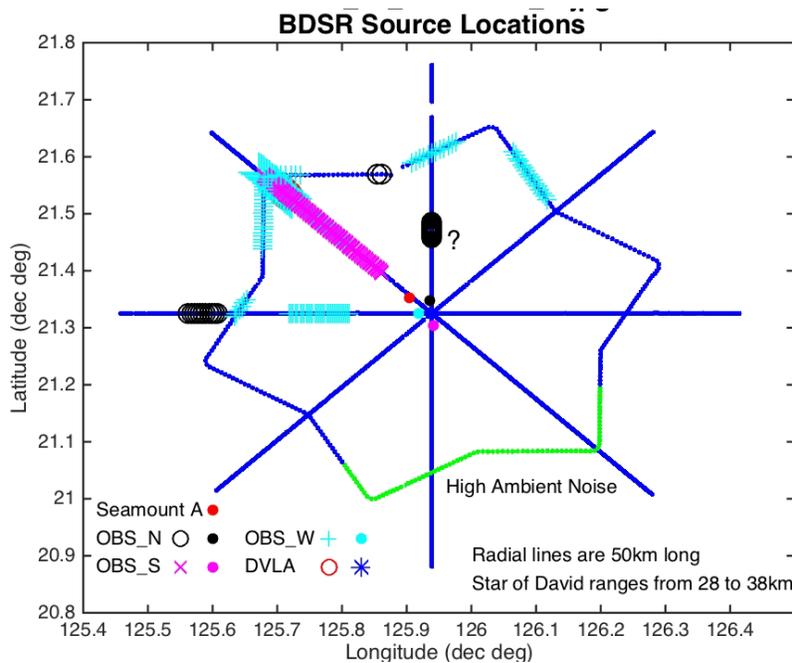
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## PUBLICATIONS

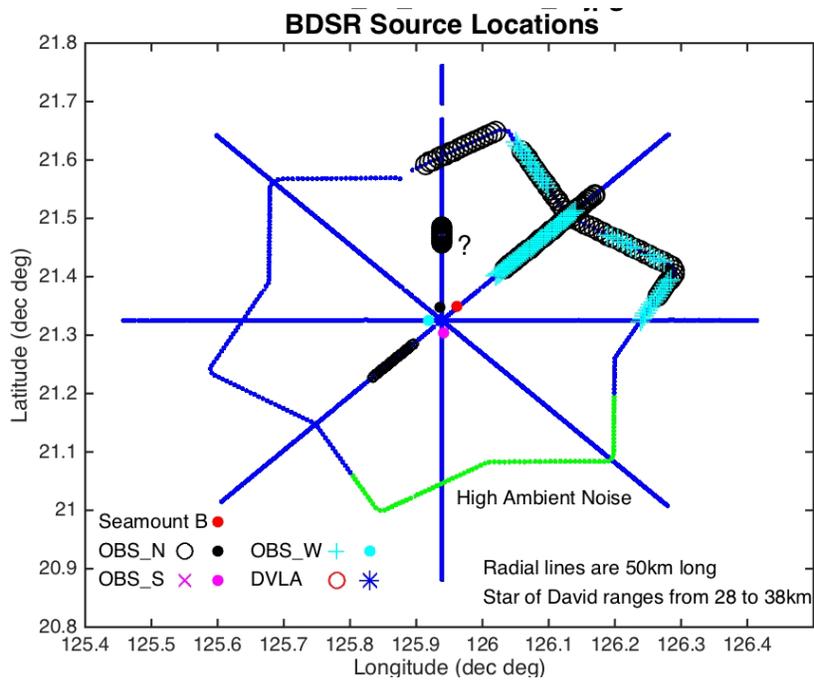
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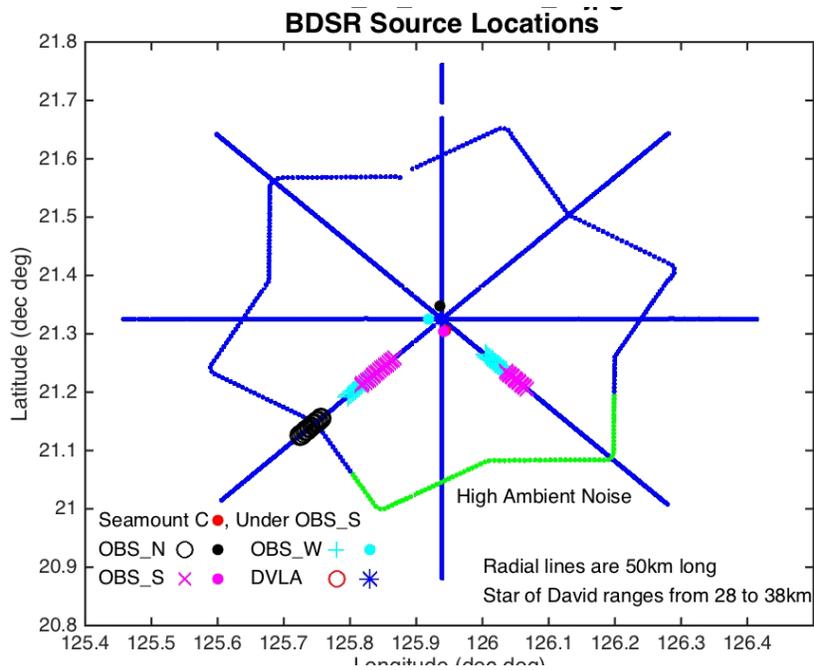
**Figure 1:** Receivers (red stars) and potential seafloor diffractors (black stars, labelled A-D) are overlain on the bathymetry for the OBSAPS experiment in the Philippine Sea. The red circle is 2km from the O-DVLA (middle red star). The red stars North, West and South of the O-DVLA are OBSs. Diffractors A, B, and C are on small seamounts. Diffractor D does not correspond to any obvious seafloor relief. The acoustic source was towed along the black lines at ranges out to 50km. The O-DVLA is in 5433m water depth and the tops of Seamounts A and B are at ~4900m. [Ralph\_Box.jpg]



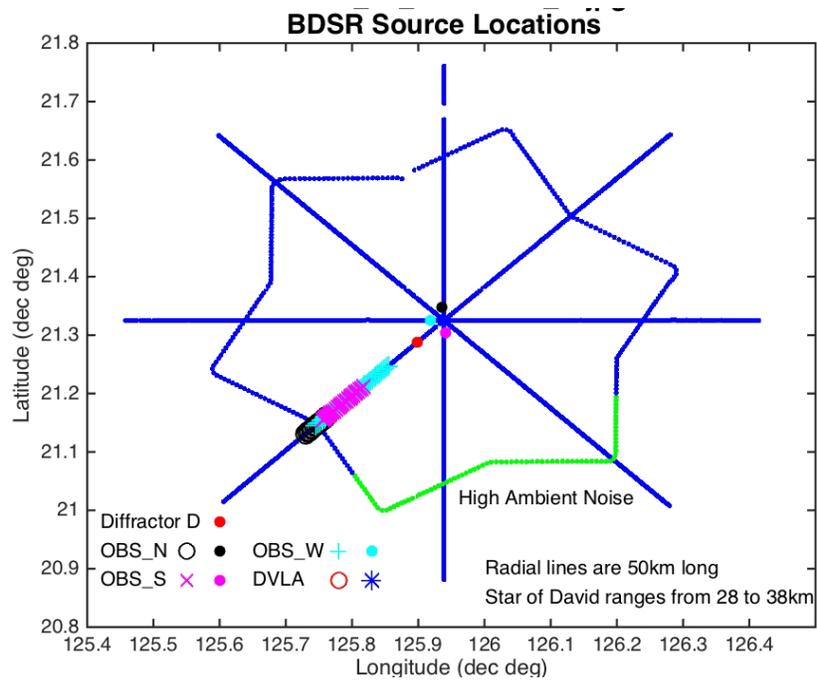
**Figure 2:** The source locations for which BDSR arrivals were identified as scattered from Seamount A (Figure 1) are overlain on the radial line and Star of Data cruise tracks (blue and green lines). Because of high winds and sea state signal-to-noise ratio was poor along the green track. The locations of Seamount A and the three OBSs are given as dots (see legend). The DVLA was located at the center of the pattern. No BDSR arrivals were observed on the DVLA. BDSR arrivals from Seamount A were observed on the South OBS only for transmissions on the Northwest radial line. BDSR arrivals from Seamount A were observed on the West OBS from a range of azimuths to the North. [BDSR\_Locations\_A.jpg]



**Figure 3:** As Figure 2 for BDSR arrivals that were identified as scattered from Seamount B (Figure 1). BDSR arrivals from Seamount B were observed on the North and West OBSs from a range of azimuths. The North OBS even observed back-scattered BDSRs from Seamount B (on the Southwest radial). [BDSR\_Locations\_B.jpg]



**Figure 4:** As Figure 2 for BDSR arrivals that were identified as scattered from Seamount C (Figure 1, under the South OBS). BDSR arrivals from Seamount C were observed on all three OBSs but only for transmissions on the Southwest and Southeast radials. [BDSR\_Locations\_C.jpg]



**Figure 5:** As Figure 2 for BDSR arrivals that were identified as scattered from seafloor diffractor D (Figure 1, under the Southwest radial). BDSR arrivals from this diffractor were observed on all three OBSs but only for transmissions on the Southwest radial. [BDSR\_Locations\_D.jpg]