Bottom Interacting Acoustics in the North Pacific (NPAL13)

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LONG-TERM GOALS

To avoid confusion with other projects we are using a new acronym for this work - OBSANP (Ocean Bottom Seismometer Augmentation in the North Pacific).

This project, OBSANP, addresses the coherence and depth dependence of deep-water ambient noise and signals. Seafloor signals are studied in the band from 50-400Hz and seafloor ambient noise is studied in the band from 0.03 - 80Hz. On NPAL04 we observed a new class of arrivals in long-range ocean acoustic propagation that we call Deep Seafloor Arrivals (DSFAs) because they are the dominant arrivals on ocean bottom seismometers (Mercer *et al.*, 2009; Stephen *et al.*, 2009; Stephen *et al.*, 2008). We recently resolved that many of the DSFAs observed on NPAL04 are diffracted energy from a near-by seamount that is reflected from the sea surface (bottom-diffracted surface-reflected - BDSR - paths). This diffracted energy is a relatively weak signal on hydrophones on the DVLA, more than 750m above the seafloor, but it is by far the strongest signal on vertical geophones on the seafloor for signals out to 3200km range. One goal of OBSANP is to study these BDSR paths at shorter ranges and at more azimuths than were available from the 2004 experiment. This work is relevant to the Navy because it seeks to quantify and understand the signal propagation and noise floors that are necessary to evaluate and exploit seismo-acoustics for operational ASW systems.

OBJECTIVES

The objective here is to understand the relationship between seafloor pressure and seafloor particle motion for both ambient noise and short- and long-range signals. 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? By returning to the NPAL04 site with more OBSs, a deep DVLA extending from the seafloor to 1000m above the seafloor, and a towable, controlled source (J15-3) we aim to further define the characteristics of DSFAs, to understand the conditions under which they are excited and to understand their propagation to the seafloor.

In addition to studying DSFAs we will be acquiring ambient noise data over a 21 day period. Although it has been recognized for a long time that acoustic noise in the 0.1 to 30Hz band is a function of surface gravity wave conditions (McCreery *et al.*, 1993; Webb and Cox, 1986), recent studies indicate that seafloor ambient noise in deep water (~5,000m) in the 1-30Hz band carries significant information about even very short ocean surface waves (wavelengths from 6m to a centimeter) (Duennebier *et al.*, 2012; Farrell and Munk, 2008; 2010). Since our ship will be in the vicinity of the seafloor sensors during the whole recording period we will have direct observations of sea surface conditions to compare with the seafloor ambient noise data.

APPROACH

To date the only definitive observation of DSFAs has been at the NPAL04 site. During the LOAPEX/NPAL04 experiment sources, centered near 68 and 75Hz, were deployed at three depths, 350m, 500m and 800m, and at seven ranges, 50km, 250km, 500km, 1000km, 1600km, 2300km and 3200km. All of the source stations were intentionally located along the same geodesic, that is at the same azimuth to the receivers. Oddly DSFAs were only observed at 500km range and greater. We will return to the site to fill-in these gaps: a) extend the frequency range to cover M-sequences from 77.5 to 310Hz, b) include hydrophones and three component geophones on the seafloor and a DVLA extending from the seafloor to 1000m above the seafloor, c) have continuous tows and station stops for a controlled source in the upper 100m, d) source tows would include radial lines at a variety of azimuths as well as arcs and circles around the receivers and around Seamount B.

We are planning a 30 day cruise in the Spring of 2013 to deploy twelve OBSs and a near-seafloor DVLA in the vicinity of the NPAL04 site. We will carry out a two week transmission program using J15-3s (similar to the OBSAPS transmission program (Stephen *et al.*, 2011)). Each OBS will have a three-component seismometer and hydrophone or differential pressure gauge. Eight OBSs will have short period sensors sampling at 1000sps suitable for the frequency band from 1-400Hz, and four OBSs will be long period instruments sampling at 200sps and suitable for the frequency band from 0.03 to 80Hz. These are essentially the same units that we had on OBSAPS. Autonomously recording SIO hydrophone modules, identical to the units on the DVLA, will be attached to each of the short period OBSs; these sample at 1953.125sps and are suitable for the band 4Hz to 780Hz. The long period OBSs will provide seafloor ambient noise data for comparison with other deep-water, broadband data sets in the Pacific such as H2O (Duennebier *et al.*, 2002; Stephen *et al.*, 2006) and the OSNPE (Stephen *et al.*, 2003).

The near-seafloor DVLA will be deployed at the location of the Deep VLA during NPAL04: Lat: 33° 25.135'N, Lon: 137° 40.948'W, Depth (multi-beam): 5045 m. The DVLA will consist of one 1000-m DVLA section, with a D-STAR at the top. The DVLA will have 30 Hydrophone Modules, extending from the seafloor to above the surface conjugate depth. The deepest hydrophone will be located 12 m above the seafloor, as during the OBSAPS experiment in the Philippine Sea. A current meter will be located at the bottom of the DVLA. Four acoustic transponders will be deployed around the near-seafloor DVLA to measure the motion of the mooring.

WORK COMPLETED

This project had a start date of March 1, 2012 and our work is just beginning. The 30 day cruise will be carried out in the Spring or Summer of 2013. In preparation for the cruise we continued the analysis of the NPAL04 DSFAs, we are preparing a paper for the Deep Water Ocean Acoustics Special Issue of JASA (Stephen *et al.*, in prep-b), and we are preparing a technical report with the details of the analysis (Stephen *et al.*, in prep-a).

RESULTS

In the past year we resolved the physical mechanism for the DSFAs observed on NPAL04. These are bottom-diffracted surface-reflected arrivals. One key development was the observation of DSFA arrivals on the DVLA (Figure 1). Although much weaker compared to PE predicted arrivals than the DSFAs on the OBSs, the DSFAs on the DVLA and OBSs are kinematically equivalent (Figure 2). Triangulation of the arrival times at the DVLA and three OBSs indicates that the conversion point from PE predicted to DSFA/BDSR is at Seamount B, which is offset by 2 to 4km from the source-receiver geodesics (Figure 3). The arrival times can be predicted well by a ray tracing model for surface-reflected paths from the seamount to the receivers. In addition to the depth constraint (between 4200 and 4300m) there are three error surfaces: least-square-error of linear fit, travel-time offset and phase speed (inverse slope of travel-time curve). The minima of all three error surfaces pass over Seamount B (Figure 4). The locations of the two test points, whose travel-time curves are shown in Figure 2, are shown in Figure 4.

IMPACT/APPLICATIONS

Clearly the ability of Navy systems to detect and identify ships and submarines by acoustic techniques will depend on at least the following factors: i) the system noise of sensors used to detect the acoustic field, ii) the true field noise for a given sensor type and location, and iii) accurate knowledge of how sound travels in the ocean including bottom interaction if necessary. The observation of deep seafloor arrivals on NPAL04 showed that there is a significant path for coherent sound propagation to the deep seafloor that was previously unrecognized and is still poorly understood. If this path is as ubiquitous as we expect it will have significant consequences for the performance of any ASW system that uses seafloor receivers in deep water, for predictions of long- and short-range propagation to seafloor receivers, and for models of near seafloor ambient noise in the deep ocean.

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 Numbers N00014-10-10994 and N00014-10-1-0990,

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HONORS/AWARDS/PRIZES

Ralph Stephen, WHOI, Edward W. and Betty J. Scripps Chair for Excellence in Oceanography, WHOI.

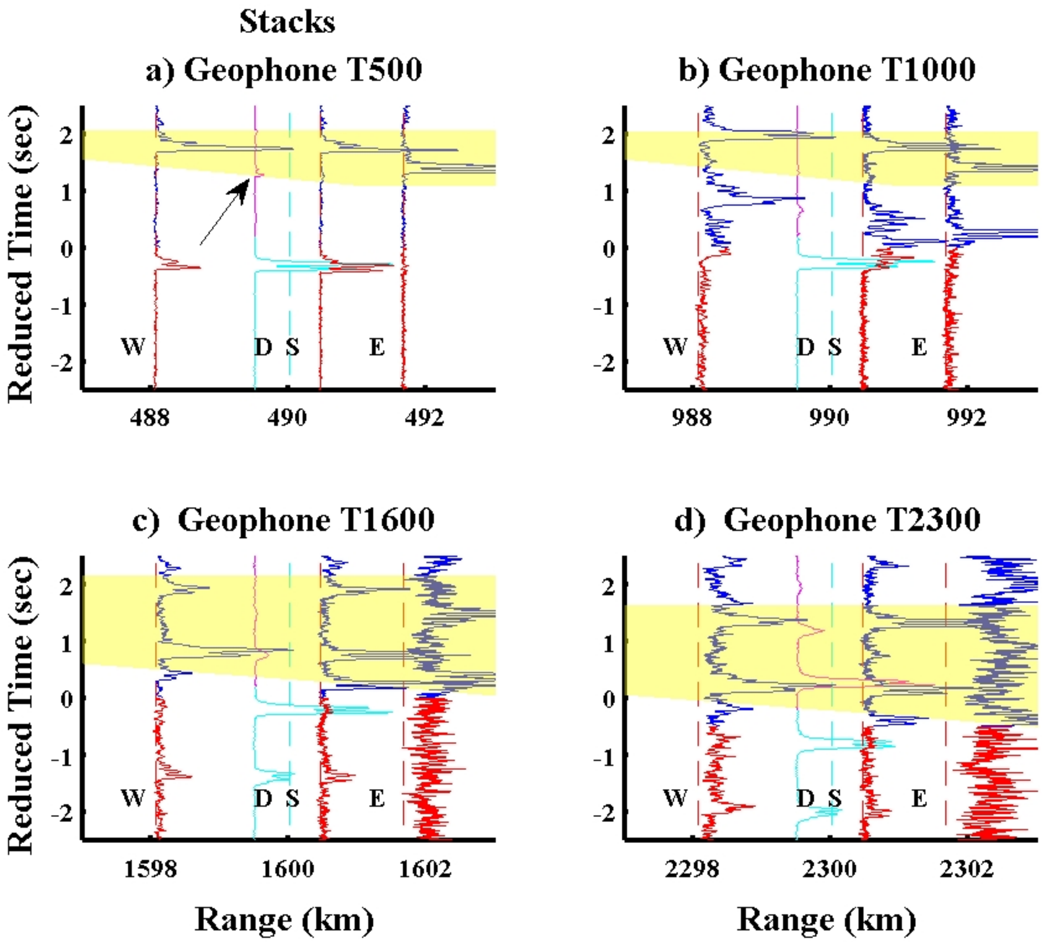
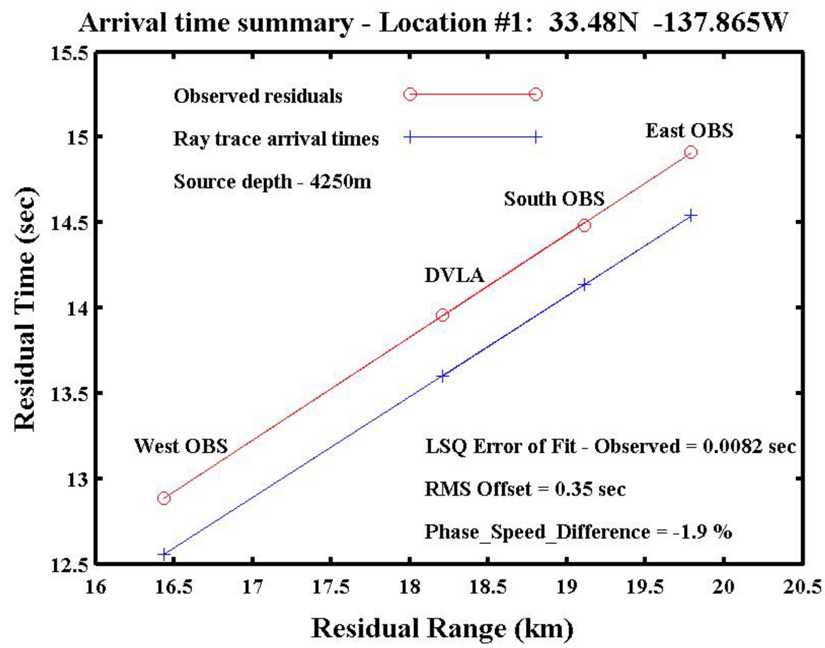
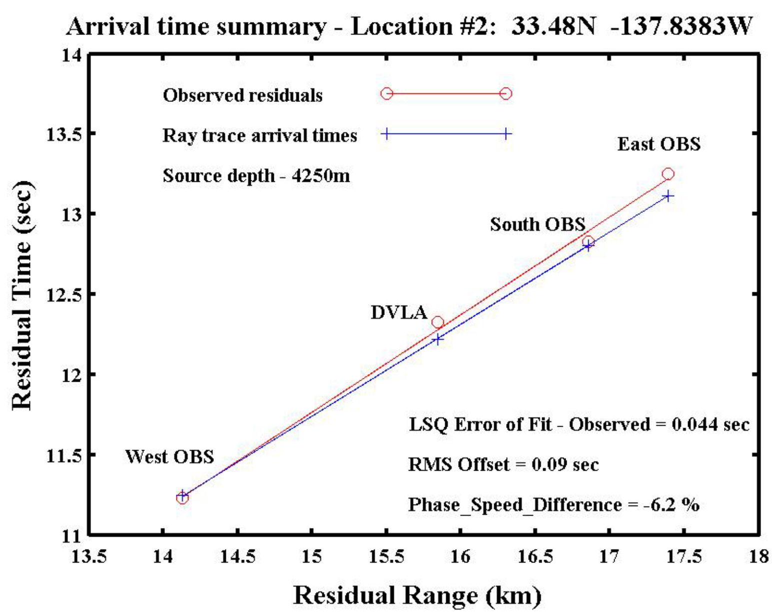


Figure 1: Detailed summary of the NPAL04 arrival structure for ranges from T500 to T2300. The cyan/magenta line is the DVLA hydrophone trace (D) and the red/blue lines are the OBS traces (West-W, South-S, and East-E). Red and cyan portions correspond to PE predicted arrival times. Blue and magenta portions correspond to later arriving energy that is not predicted by the PE solution. The yellow shading highlights the late arrivals that form a robust and distnctive pattern on the three OBSs. The small amplitude arrival, in magenta, at about 1.2sec reduced time on the DVLA trace at T500 (arrow) has recently been shown to be a BDSR arrival, the same physical event as the DSFAs on the blue traces highlighted in yellow. This arrival does not appear at the further ranges. The late arrivals on the DVLA traces (magenta) at the other ranges are deep shadow zone arrivals (DSZA). Figure from Stephen et al (in prep-b). [Geo_Stacks_Fig_1_new_arrow.jpg]



a) [new_BDSR_Arrival_Time_2_1.jpg]



b) [new_BDSR_Arrival_Time_2_2.jpg]

Figure 2: Examples of residual arrival time data for two test points on Seamount B (Figure 4). Red points are observed data; blue points are ray traced predictions for surface reflected paths. All times have been adjusted to correspond to a common receiver depth at 4997m (the depth of the West OBS). The PE-predicted to DSFA conversion point is assumed to be at 4250m. Moving this depth from 4200 to 4450m changes the ray traced arrival times by less than 0.1sec.

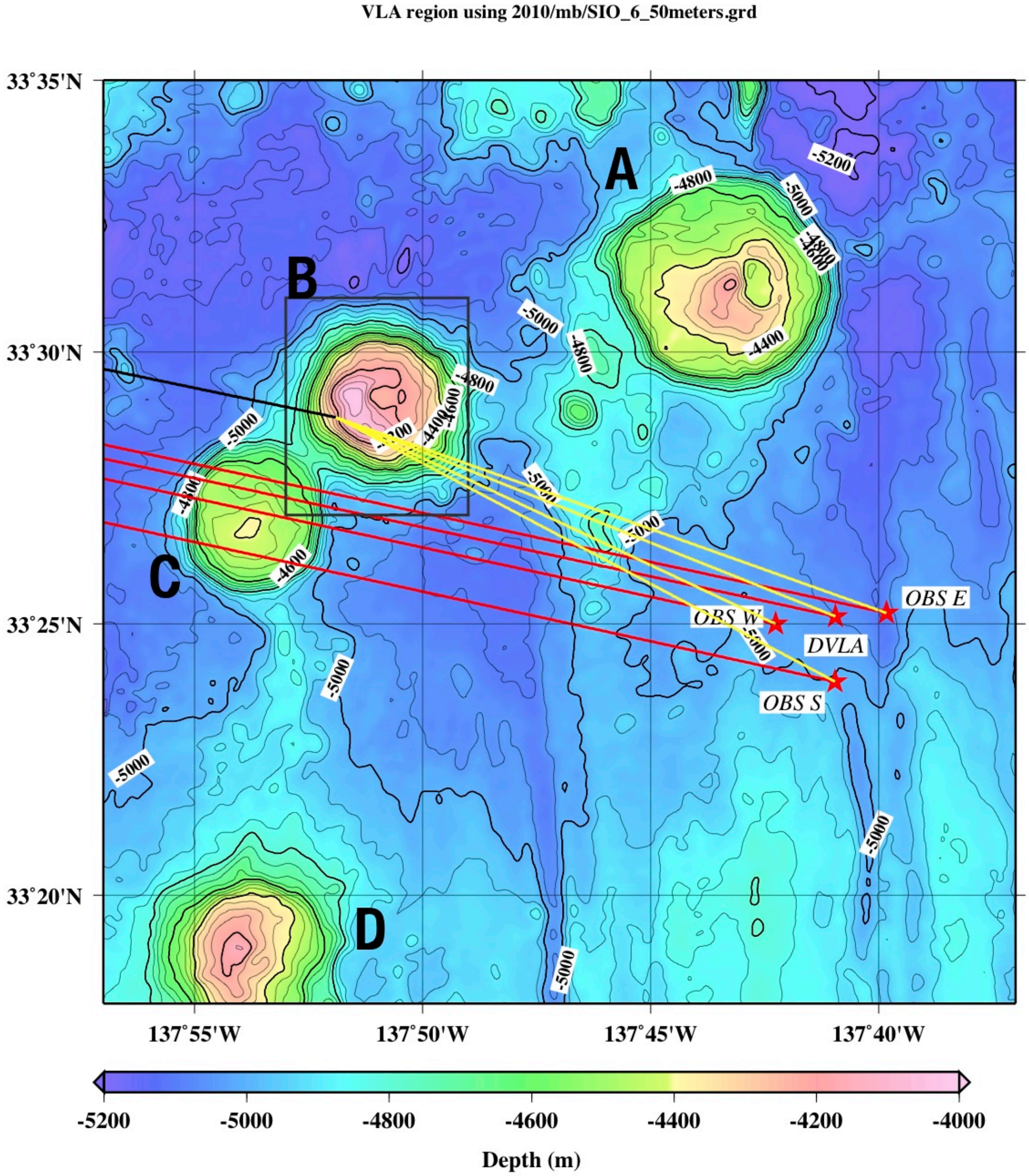


Figure 3: The locations of the three OBSs and the DVLA with their geodetic paths (red lines) to the source locations are overlain on swath map bathymetry (Worcester, 2005). The DSFA pattern on the OBSs (Figure 1) and the BDSR arrival on the DVLA (Figure 2) are consistent with conversion from a PE-predicted source-to-receiver path (black line) to a DSFA/BDSR seamount-to-receiver path (yellow lines). Seamount B gave the best agreement between observed and predicted arrival times (Figures 2 and 4). Error surfaces within the box at Seamount B are shown in Figure 4. [VLA_region_6.jpg]

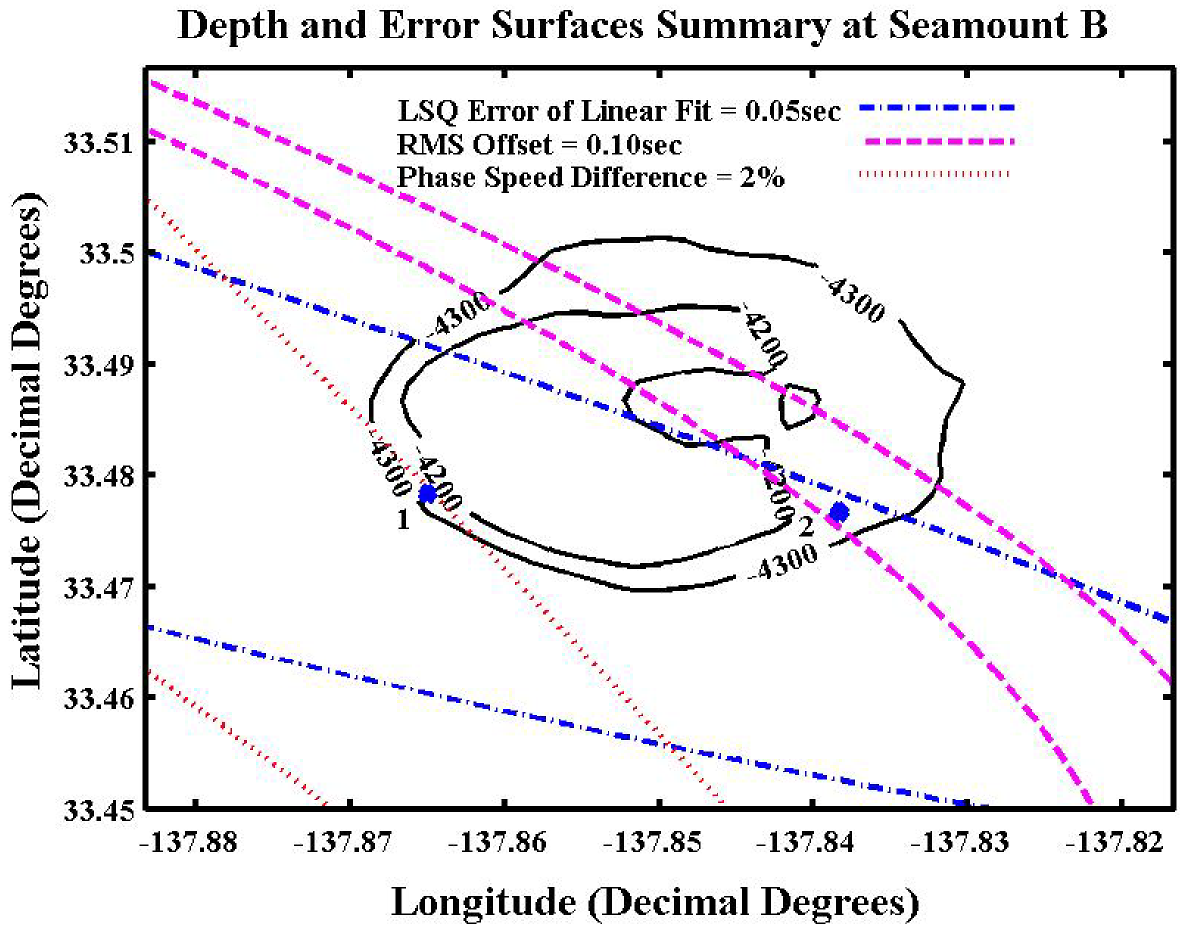


Figure 4: Error contours are overlain on the 4200 and 4300m isobaths at Seamount B. Three error contours are shown: a) least-square fit of the linear regression to the observed residual arrival times, b) the RMS offset between the observed and ray traced arrival times at the four ranges, and c) the difference in the phase speed (inverse slope of the linear fits) for the observed and ray traced arrivals. In each case the minima fall between the lines. The residual travel-times for test points #1 and #2 are given in Figure 2. [new_BDSR_Arrival_Summary_2_1a.jpg]