

Bottom Interacting Acoustics in the North Pacific (NPAL13)

Ralph A. Stephen
Woods Hole Oceanographic Institution
360 Woods Hole Road (MS#24)
Woods Hole, MA 02543
phone: (508) 289-2583 fax: (508) 457-2150 email: rstephen@whoi.edu

Peter F. Worcester
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California 92093-0225
Telephone: (858) 534-4688, Fax: (858) 534-6354, E-mail: pworchester@ucsd.edu

Award Numbers (WHOI): N00014-10-1-0987 and N00014-12-M-0394
Award Number (SIO): N00014-10-1-0990
<http://msg.whoi.edu/msg.html>

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). The OBSANP cruise to the NPAL04 site was carried out on R/V Melville, San Diego to Seattle, June 12 –July 11, 2013.

This project, OBSANP, addresses the coherence and depth dependence of deep-water ambient noise and signals. Seafloor signals are studied in the band from 15 - 400Hz and seafloor ambient noise is studied in the band from 0.03 - 400Hz. 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) (Stephen *et al.*, 2013). 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

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2013		2. REPORT TYPE		3. DATES COVERED 00-00-2013 to 00-00-2013	
4. TITLE AND SUBTITLE Bottom Interacting Acoustics in the North Pacific (NPAL13)				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) Woods Hole Oceanographic Institution, 360 Woods Hole Road (MS#24), Woods Hole, MA, 02543				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					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 12	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

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 acquired ambient noise data over a 15day 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) (Duennebie *et al.*, 2012; Farrell and Munk, 2008; 2010). Since our ship was in the vicinity of the seafloor sensors during the whole recording period we 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 returned 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.

WORK COMPLETED

On the OBSANP cruise (R/V Melville, San Diego to Seattle, June 12 –July 11, 2013) we deployed twelve OBSs and a near-seafloor DVLA in the vicinity of the NPAL04 site (Figure 1) and we carried out a two week transmission program using J15-3s (Worcester and Stephen, 2013). The near-seafloor DVLA, which had 32 Hydrophone Modules distributed along one 1000-m DVLA section (Figure 2), was deployed at the location of the Deep VLA during NPAL04.

The four short period (SP1 to SP4) and four long period OBSs (LPA to LPD) in the immediate vicinity of the ODVLA were aligned with respect to the LOAPEX (NPAL04) source geodesic. Each of the four short-period OBSs, at 2km range from the ODVLA, had a hydrophone module attached. Two short period OBSs also with hydrophone modules attached (SP7 and SP8) were located as near as possible to the tops of Seamounts B and C respectively to measure directly the incident field at these features. Two short period OBSs without hydrophone modules (SP5 and SP6) fall on a line between Seamount B and the ODVLA. The four long period OBSs (LPA to LPD) were distributed about the ODVLA at 4km range. Two of these, LPA and LPC, acquired data from SAIC low-noise hydrophones in addition to the three inertial channels on the Trillium seismometers and the differential pressure gauge.

J15-3 operations on OBSANP were quite successful with no down-time due to equipment failure and essentially two weeks of scheduled transmissions. We transmitted primarily m-sequences at various frequencies spanning 20 to 310Hz with the source at depths from 60m to 100m. The m-sequences fall into four categories: 1) multi-frequency, short range ($<1/2CZ$) tows at 77.5, 155 and 310Hz; 2) single frequency, long range (up to 250km, $\sim 3-1/2CZ$) tows at 77.5Hz, 3) multi frequency station stops at $1/2$, $1-1/2$, $2-1/2$ and $3-1/2CZ$ at 77.5, 102.3, 155, 204.6, and 310Hz) and 4) low frequency transmissions (19.375, 25.575, 38.75 and 51.15Hz) at short ranges ($< 1/2CZ$) that would provide field data for modeling with SPECFEM3D. We also tested Minimum Shift Keying (MSK) format m-sequences, which are an alternative to our usual phase shift keying (PSK) format and could potentially have improved properties for some applications.

In the first phase of the transmission program we carried out a “pin cushion” pattern of station stops spanning $1/2CZ$ ranges to the ODVLA and Seamount B (Figure 3). This pattern was designed to insonify Seamount B at a variety of sagittal and azimuthal angles and to distinguish bottom-diffracted from bottom-reflected energy.

We attempted to replicate the LOAPEX results as closely as possible by carrying out a series of long- and short-range tows and station stops along the LOAPEX geodesic out to 250km range (Figure 4). On LOAPEX DSFAs were observed using the ATOC source at ranges of 500km and greater, so we could not duplicate the 2004 results directly. These transmissions will, however, fill-in the long-range propagation story for short ranges along the same path.

In order to obtain a comprehensive view of propagation and scattering within $1/2CZ$ to receivers on and near the seafloor we carried out a series of radial line tows out to 50km range at eight azimuths and half of a “Star of David” pattern over the seamounts across $1/2CZ$ ranges (Figure 5.) This pattern is very similar to the OBSAPS experiment in the Philippine Sea in 2011, so propagation and scattering characteristics at the two sites can be compared.

In the fourth phase we occupied two station stops within $1/2CZ$ of both the ODVLA and Seamounts B and C in order to carry out source tests that will be useful in subsequent experiments (Figure 6). We transmitted identical m-sequences in both MSK and PSK formats. We had not done MSK format transmissions in the past but they have smoother phase than the PSK format and this could be an advantage for some types of sources. Also, although the J15-3 is not recommended for use below 100Hz, we tested the source with CW and m-sequence transmissions down to 20Hz. Source levels are quite low at these frequencies but we are at very short ranges from the receivers and we are optimistic that we will see useful returns. Full three-dimensional bottom-interaction problems with shear, that can be studied using codes like SPECFEM3D, are more tractable at these low frequencies.

RESULTS

We are in the initial stages of data reduction, analysis and interpretation of the two weeks of data on 83 channels. The signal-to-noise of the 77.5Hz time compressions is good out to at least 50km (Figure 7).

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". On the OBSANP cruise we acquired data to support projects of Bill Farrell, Walter Munk and Jon Berger.

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,

Bottom Interaction in Ocean Acoustic Propagation - ONR Award Number: N00014-10-1-0510

REFERENCES

- Duennebie, F. K., Lukas, R., Nosal, E.-N., Aucan, J., and Weller, R. A. (2012). "Wind, waves, and acoustic background levels at Station ALOHA," *J. Geophys. Res.* **117**, doi:10.1029/2011JC007267.
- Farrell, W. E., and Munk, W. (2008). "What do deep sea pressure fluctuations tell about short surface waves?," *Geophys. Res. Lett.* **35**, doi:10.1029/2008GL035008.
- Farrell, W. E., and Munk, W. (2010). "Booms and busts in the deep," *Journal of Physical Oceanography* **40**, 2159-2169.
- McCreery, C. S., Duennebie, F. K., and Sutton, G. H. (1993). "Correlation of deep ocean noise (0.4 to 30 Hz) with wind, and the Holu Spectrum - A worldwide constant," *J. Acoust. Soc. Am.* **93**, 2639-2648.
- Mercer, J. A., Colosi, J. A., Howe, B. M., Dzieciuch, M. A., Stephen, R., and Worcester, P. F. (2009). "LOAPEX: The long-range ocean acoustic propagation experiment," *IEEE J. Ocean. Eng.* **34**, 1-11.
- Stephen, R. A., Bolmer, S. T., Dzieciuch, M. A., Worcester, P. F., Andrew, R. K., Buck, L. J., Mercer, J. A., Colosi, J. A., and Howe, B. M. (2009). "Deep seafloor arrivals: An unexplained set of arrivals in long-range ocean acoustic propagation," *J. Acoust. Soc. Am.* **126**, 599-606.
- Stephen, R. A., Bolmer, S. T., Udovychenkov, I. A., Worcester, P. F., Dzieciuch, M. A., Andrew, R. K., Mercer, J. A., Colosi, J. A., and Howe, B. M. (2013). "Deep seafloor arrivals in long range ocean acoustic propagation," *J. Acoust. Soc. Am.* **134**, 3307-3317.

Stephen, R. A., Bolmer, S. T., Udovydchenkov, I., Worcester, P. F., Dzieciuch, M. A., Van Uffelen, L., Mercer, J. A., Andrew, R. K., Buck, L. J., Colosi, J. A., and Howe, B. M. (2008), NPAL04 OBS data analysis part 1: Kinematics of deep seafloor arrivals, WHOI Technical Report 2008-03, (Woods Hole Oceanographic Institution, Woods Hole, MA).

Webb, S. C., and Cox, C. S. (1986). "Observations and modeling of seafloor microseisms," J. Geophys. Res. **91**, 7343-7358.

Worcester, P. F., and Stephen, R. A. (2013), Ocean bottom seismometer augmentation in the North Pacific (OBSANP): Cruise Quick-look Report, edited, p. 7, Scripps Institution of Oceanography, La Jolla, CA.

PUBLICATIONS

None

HONORS/AWARDS/PRIZES

None

OBSANP Instrument Locations

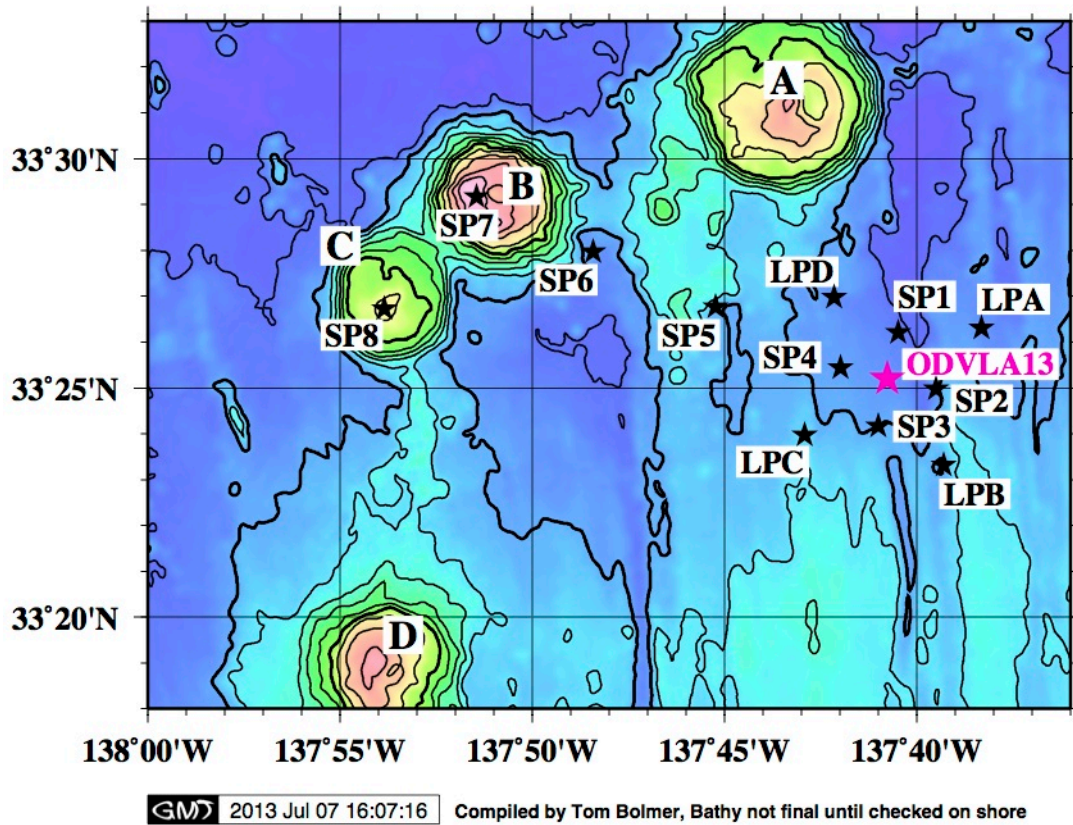


Figure 1: Locations of the eight short period OBSs (SP), the four long period OBSs (LP*), and the ODVLA13 with respect to the bathymetric relief. [OBSANP_Ralph_Instruments.jpg]*

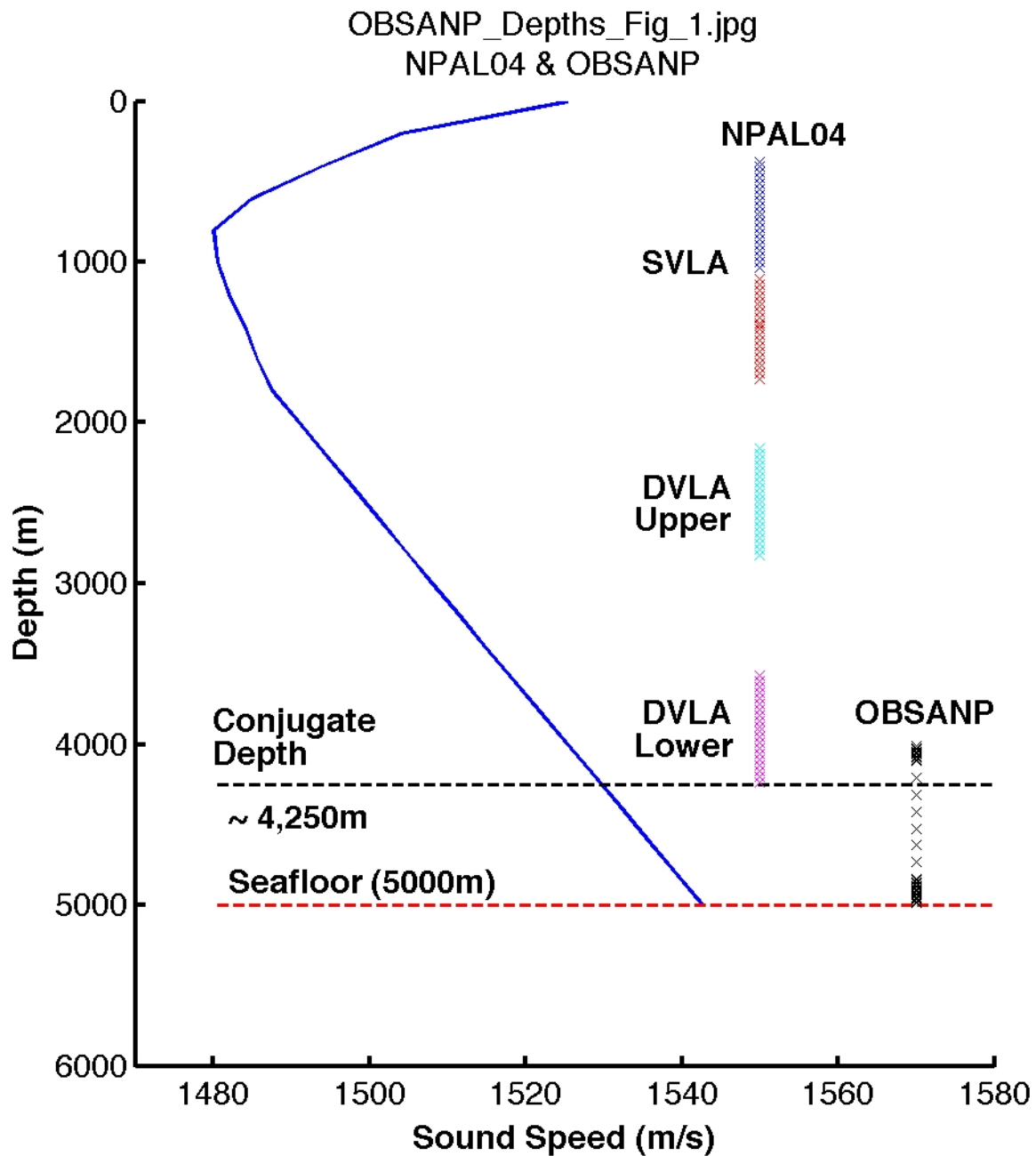


Figure 2: The OBSANP DVLA (black x's) is designed to span from the seafloor to the conjugate depth. There are 16 elements at 10m spacing (half wavelength at 75Hz) at the bottom and ten elements at 10m spacing at the top. The two mini-arrays are separated by 6 elements at 105m spacing. The shallow and deep VLA's deployed on NPAL04 are shown for comparison. A nominal sound speed profile from NPAL04 is shown.

OBSANP Events 1 to 4 Summary

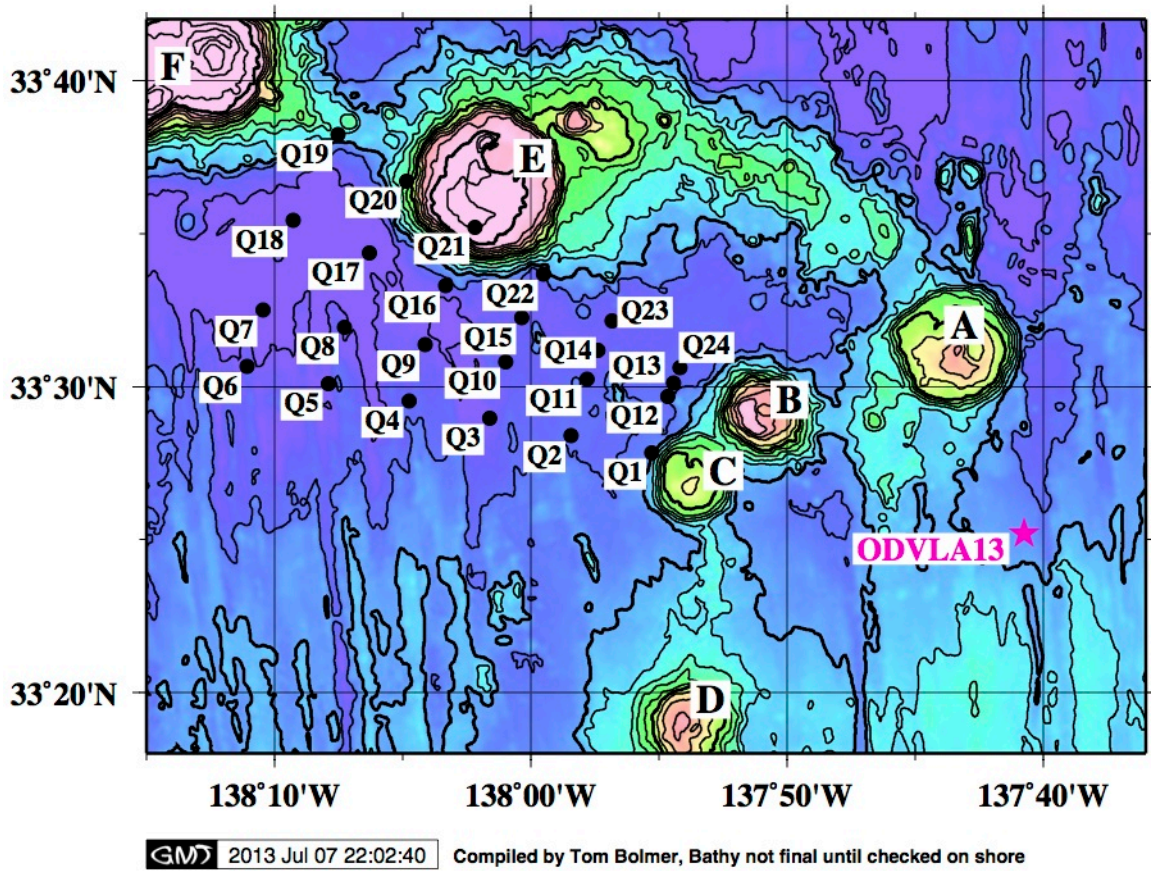
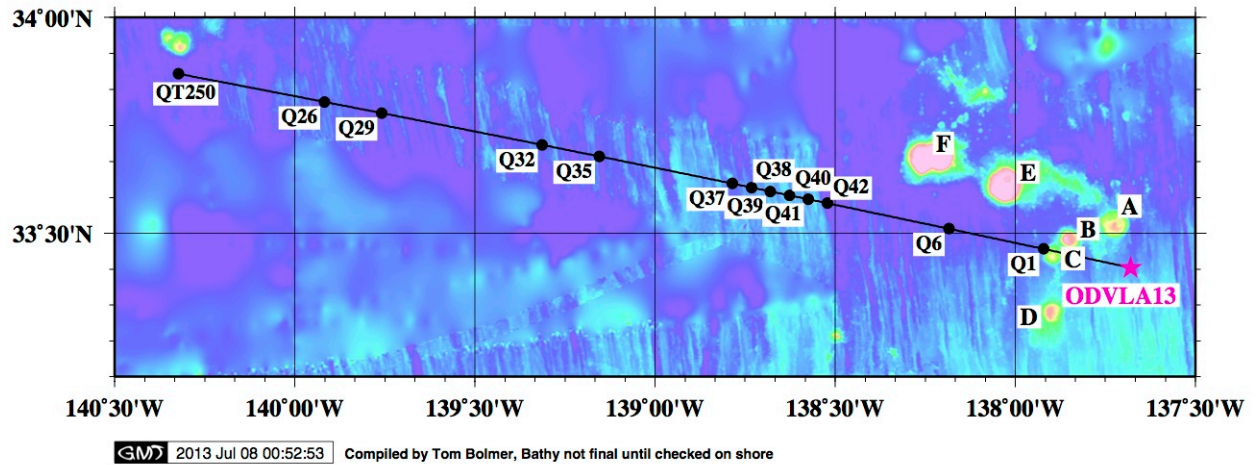


Figure 3: A “pin cushion” of station stops was designed to insonify Seamounts B and C at a variety of sagittal and azimuthal angles. The stations span 1/2CZ from the DVLA and the seamounts. Q1 to Q6 are on the LOAPEX geodesic. Q13 to Q18 are collinear with Seamount B and the DVLA. [OBSANP_Ralph_Event_1_4_Summary.jpg]

OBSANP Events 1 to 4 Summary



*Figure 4: In an attempt to replicate the 2004 LOAPEX results we transmitted continuously out to 250km range on the LOAPEX geodesic and then occupied station stops at ½, 1-1/2, 2-1/2 and 3-1/2 CZ's from the DVLA. Stations between Q1 and Q6 are shown in Figure 3.
[OBSANP_Ralph_Event_1_4_Summary.jpg]*

OBSANP Radial Line and Star Summary

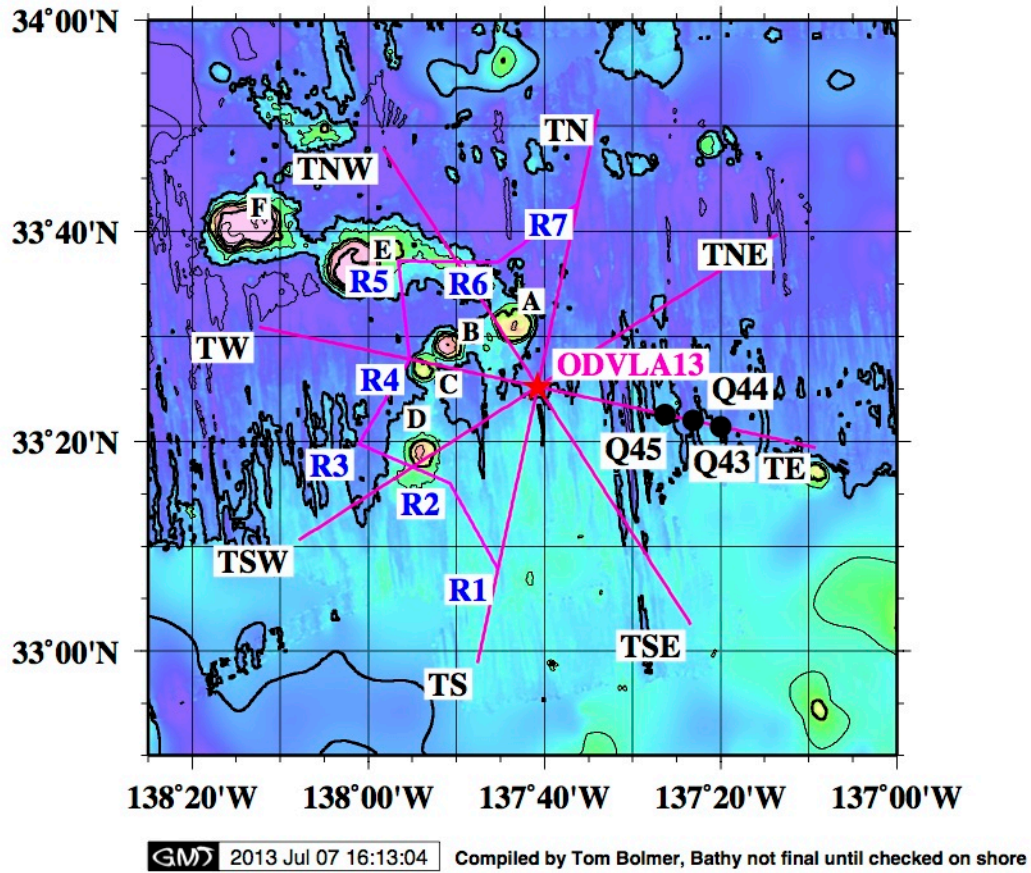


Figure 5: Phase 3 of the transmission program carried out a comprehensive survey (out to 50km) around the DVLA. [OBSANP_Ralph_Spokes_Star.jpg]

OBSANP Low Frequency Station Stops

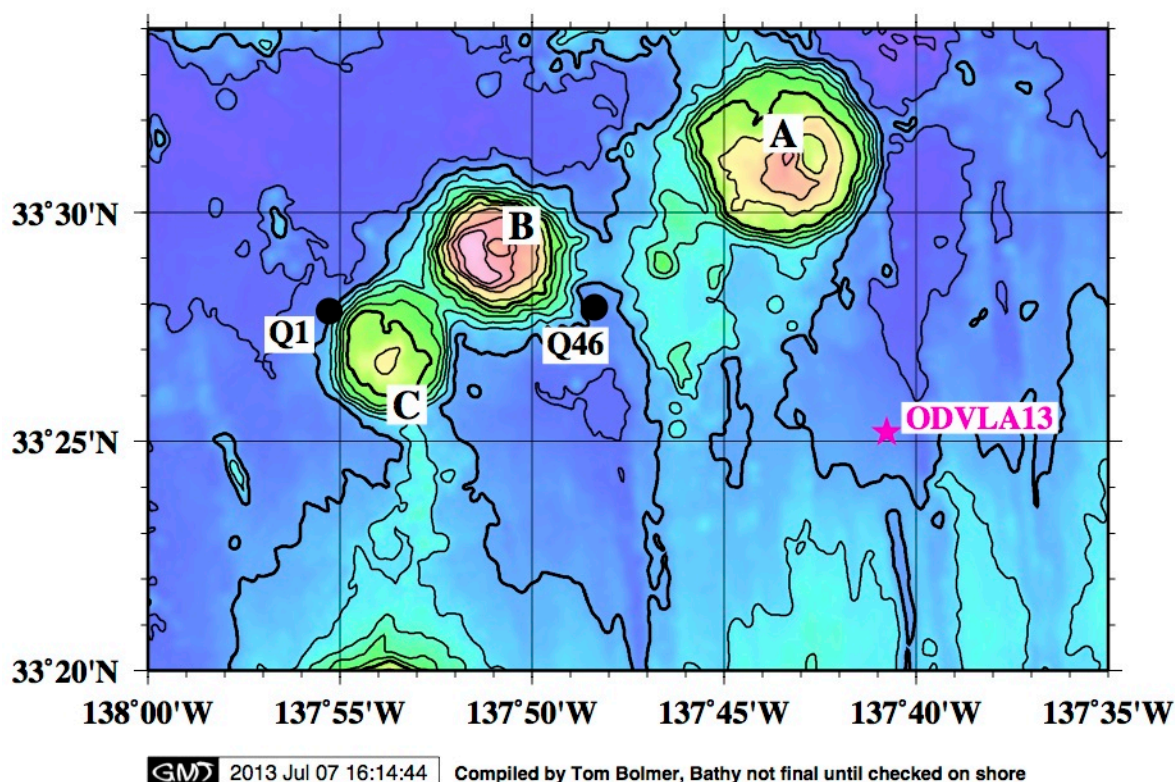


Figure 6: Q1 and Q46 were the locations of the MSK and low frequency tests. It is conceivable that 20Hz scattering from Seamounts B and C could be modeled using a fully elastic, three-dimensional propagation code such as SPECFEM3D. [OBSANP_Ralph_Q1_Q46.jpg]

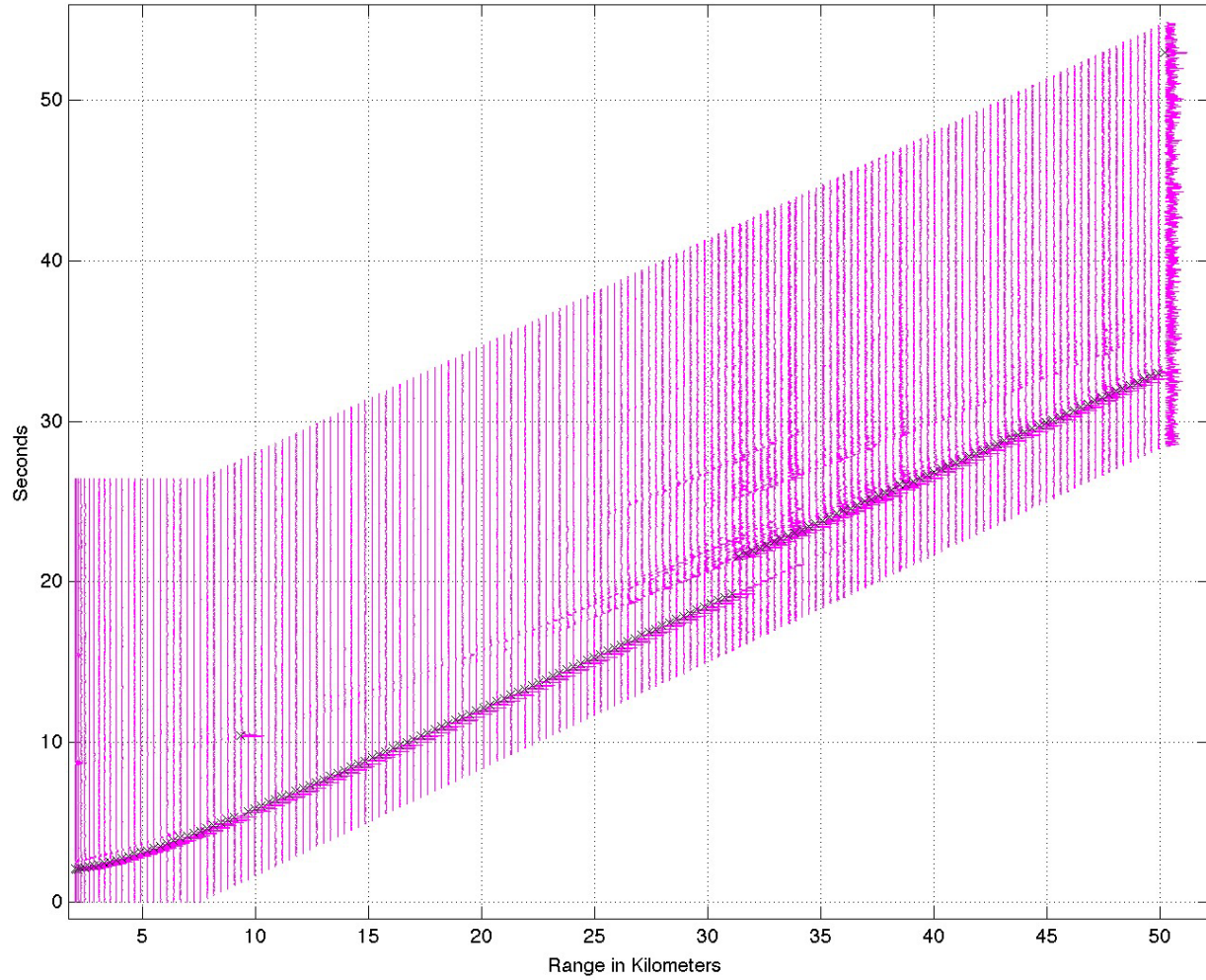


Figure 7: Example of 77.5Hz time compressions for transmissions on the North radial line to the hydrophone module on SP2. Good signal-to-noise is obtained for transmissions out to 50km range. [N_HM_OBS_SP2_775.jpg]