

June 9, 2014  
Peter Worcester

**Final Technical Report**  
**“North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the  
Philippine Sea”**

**ONR Grant N00014-08-1-0840**

01 April 2008 – 31 December 2013

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**1. Publications (Refereed)**

Thirty-three (33) refereed publications were fully or partially supported by ONR Grant N00014-08-1-0840, “North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea.”

Fourteen (14) of these publications appeared in the “Special Issue on Deep-water Ocean Acoustics” in the *Journal of the Acoustical Society of America* (Vol. 134, No. 4, Pt. 2 of 2, October 2013).

Chandrayadula, T. K., Colosi, J. A., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., and Howe, B. M. (2013). “Observations and transport theory analysis of low frequency, acoustic mode propagation in the Eastern North Pacific Ocean,” *J. Acoust. Soc. Am.* **134**, 3144–3160.

Chandrayadula, T. K., Wage, K. E., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., and Howe, B. M. (2013). “Reduced rank models for travel time estimation of low order mode pulses,” *J. Acoust. Soc. Am.* **134**, 3332–3346.

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June 9, 2014

Dr. Robert H. Headrick  
Office of Naval Research, Code 322 OA  
875 North Randolph Street, Suite 1425  
Arlington, VA 22203-1995

Dear Bob:

Attached is the Final Technical Report for ONR Grant N00014-08-1-0840, "North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea," listing both the refereed and unrefereed publications supported in full or in part by this grant. This grant overlapped with the preceding ONR Grant N00014-03-1-0182, "North Pacific Acoustic Laboratory," and with the following ONR Grant N00014-12-1-0226, "North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea." The publications listed in the attached Final Report in some cases were also partially funded by one of these other grants.

Please contact me should you need any additional information or desire reprints of any of these publications.

Sincerely yours,

A handwritten signature in black ink, appearing to read "Peter Worcester".

Peter Worcester, Ph.D.  
Research Oceanographer

- Colosi, J. A., Van Uffelen, L. J., Cornuelle, B. D., Dzieciuch, M. A., Worcester, P. F., Dushaw, B. D., and Ramp, S. R. (2013). "Observations of sound-speed fluctuations in the western Philippine Sea in the spring of 2009," *J. Acoust. Soc. Am.* **134**, 3185–3200.
- Colosi, J. A., and Worcester, P. F. (2013). "Introduction to special issue on deep water ocean acoustics," *J. Acoust. Soc. Am.* **134**, 3115.
- Dzieciuch, M. A., Cornuelle, B. D., and Skarsoulis, E. K. (2013). "Structure and stability of wave-theoretic kernels in the ocean," *J. Acoust. Soc. Am.* **134**, 3318–3331.
- Farrell, W. E., and Munk, W. (2013). "Surface gravity waves and their acoustic signatures, 1–30 Hz, on the mid-Pacific sea floor," *J. Acoust. Soc. Am.* **134**, 3134–3143.
- Freeman, S. E., D'Spain, G. L., Lynch, S. D., Stephen, R. A., Heaney, K. D., Murray, J. J., Baggeroer, A. B., Worcester, P. F., Dzieciuch, M. A., and Mercer, J. A. (2013). "Estimating the horizontal and vertical direction-of-arrival of water-borne seismic signals in the northern Philippine Sea," *J. Acoust. Soc. Am.* **134**, 3282–3298.
- Powell, B. S., Kerry, C. G., and Cornuelle, B. D. (2013). "Using a numerical model to understand the connection between the ocean and acoustic travel-time measurements," *J. Acoust. Soc. Am.* **134**, 3211–3222.
- Skarsoulis, E. K., Cornuelle, B. D., and Dzieciuch, M. A. (2013). "Long-range asymptotic behavior of vertical travel-time sensitivity kernels," *J. Acoust. Soc. Am.* **134**, 3201–3210.
- Stephen, R. A., Bolmer, S. T., Udovydchenkov, 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.
- Udovydchenkov, I. A., Brown, M. G., Duda, T. F., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., Howe, B. M., and Colosi, J. A. (2013). "Weakly dispersive modal pulse propagation in the North Pacific Ocean," *J. Acoust. Soc. Am.* **134**, 3386–3394.
- Van Uffelen, L. J., Nosal, E.-M., Howe, B. M., Carter, G. S., Worcester, P. F., Dzieciuch, M. A., Heaney, K. D., Campbell, R. L., and Cross, P. S. (2013). "Estimating uncertainty in subsurface glider position using transmissions from fixed acoustic tomography sources," *J. Acoust. Soc. Am.* **134**, 3260–3271.

White, A. W., Andrew, R. K., Mercer, J. A., Worcester, P. F., Dzieciuch, M. A., and Colosi, J. A. (2013). "Wavefront intensity statistics for 284-Hz broadband transmissions to 107-km range in the Philippine Sea: Observations and modeling," *J. Acoust. Soc. Am.* **134**, 3347–3358.

Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., Dushaw, B. D., Baggeroer, A. B., Heaney, K. D., D'Spain, G. L., Colosi, J. A., Stephen, R. A., Kemp, J. N., Howe, B. M., Van Uffelen, L. J., and Wage, K. E. (2013). "The North Pacific Acoustic Laboratory deep-water acoustic propagation experiments in the Philippine Sea," *J. Acoust. Soc. Am.* **134**, 3359–3375.

The remaining 19 refereed papers that were also fully or partially supported by ONR Grant N00014-08-1-0840 are (in chronological order):

## 2008

Farrell, W. E., and Munk, W. (2008). "What do deep sea pressure fluctuations tell about short surface waves?," *Geophys. Res. Lett.* **35**, L19605.

Raghukumar, K., Cornuelle, B. D., Hodgkiss, W. S., and Kuperman, W. A. (2008). "Pressure sensitivity kernels applied to time-reversal acoustics," *J. Acoust. Soc. Am.* **124**, 98–112.

Roux, P., Cornuelle, B. D., Kuperman, W. A., and Hodgkiss, W. S. (2008). "The structure of raylike arrivals in a shallow-water waveguide," *J. Acoust. Soc. Am.* **124**, 3430–3439.

## 2009

Colosi, J. A., Xu, J., Worcester, P. F., Dzieciuch, M. A., Howe, B. M., and Mercer, J. A. (2009). "Temporal and vertical scales of acoustic fluctuations for 75-Hz, broadband transmissions to 87-km range in the eastern North Pacific Ocean," *J. Acoust. Soc. Am.* **126**, 1069–1083.

Dushaw, B. D., Worcester, P. F., Munk, W. H., Spindel, R. C., Mercer, J. A., Howe, B. M., Metzger, K., Jr., Birdsall, T. G., Andrew, R. K., Dzieciuch, M. A., Cornuelle, B. D., and Menemenlis, D. (2009). "A decade of acoustic thermometry in the North Pacific Ocean," *J. Geophys. Res.* **114**, C07021.

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.

Munk, W. H. (2009). "An inconvenient sea-truth: Spread, steepness and skewness of surface slopes," *Annual Review of Marine Science* **1**, 377–415.

Skarsoulis, E. K., Cornuelle, B. D., and Dzieciuch, M. A. (2009). "Travel-time sensitivity kernels in long-range propagation," *J. Acoust. Soc. Am.* **126**, 2223–2233.

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.

Song, H.-C., and Dzieciuch, M. A. (2009). "Feasibility of global-scale synthetic aperture communications," *J. Acoust. Soc. Am.* **125**, 8–10.

Van Uffelen, L. J., Worcester, P. F., Dzieciuch, M. A., and Rudnick, D. L. (2009). "The vertical structure of shadow-zone arrivals at long range in the ocean," *J. Acoust. Soc. Am.* **125**, 3569–3588.

## 2010

Dushaw, B. D., Au, W. W. L., Beszczynska-Möller, A., Brainard, R. E., Cornuelle, B. D., Duda, T. F., Dzieciuch, M. A., Forbes, A. M. G., Freitag, L., Gascard, J.-C., Gavrilov, A. N., Gould, J., Howe, B. M., Jayne, S. R., Johannessen, O. M., Lynch, J. F., Martin, D., Menemenlis, D., Mikhalevsky, P. N., Miller, J. H., Moore, S. E., Munk, W. H., Nystuen, J., Odom, R. I., Orcutt, J. A., Rossby, T., Sagen, H., Sandven, S., Simmen, J., Skarsoulis, E., Southall, B., Stafford, K. M., Stephen, R., Vigness-Raposa, K. J., Vinogradov, S., Wong, K. B., Worcester, P. F., and Wunsch, C. (2010). "A global ocean acoustic observing network," in *Proc. OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2)*, edited by J. Hall, D. E. Harrison, and D. Stammer (Venice, Italy), ESA Publication WPP-306.

Farrell, W. E., and Munk, W. H. (2010). "Booms and busts in the deep," *J. Phys. Oceanogr.* **40**, 2159–2169.

Van Uffelen, L. J., Worcester, P. F., Dzieciuch, M. A., Rudnick, D. L., and Colosi, J. A. (2010). "Effects of upper ocean sound-speed structure on deep acoustic shadow-zone arrivals at 500- and 1000-km range," *J. Acoust. Soc. Am.* **127**, 2169–2181.

## 2011

Dushaw, B. D., Worcester, P. F., and Dzieciuch, M. A. (2011). "On the predictability of mode-1 internal tides," *Deep Sea Research Part I: Oceanographic Research Papers* **58**, 677–698.

Skarsoulis, E. K., Cornuelle, B. D., and Dzieciuch, M. A. (2011). "Second-order sensitivity of acoustic travel times to sound speed perturbations," *Acta Acust. Acust.* **97**, 533–543.



## 2012

Udovydchenkov, I. A., Brown, M. G., Duda, T. F., Mercer, J. A., Andrew, R. K., Worcester, P. F., Dzieciuch, M. A., Howe, B. M., and Colosi, J. A. (2012). “Modal analysis of the range evolution of broadband wavefields in the North Pacific Ocean: Low mode numbers,” *J. Acoust. Soc. Am.* **131**, 4409–4427.

Udovydchenkov, I. A., Stephen, R. A., Duda, T. F., Bolmer, S. T., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., and Howe, B. M. (2012). “Bottom interacting sound at 50 km range in a deep ocean environment,” *J. Acoust. Soc. Am.* **132**, 2224–2231.

## 2013

Dushaw, B. D., Worcester, P. F., Dzieciuch, M. A., and Menemenlis, D. (2013). “On the time-mean state of ocean models and the properties of long range acoustic propagation,” *J. Geophys. Res. Oceans* **118**, 4346–4362.

## 2. Publications (Unrefereed)

The following unrefereed publications, including conference papers and reports, were fully or partially supported by ONR Grant N00014-08-1-0840 (in chronological order):

### 2008

Stephen, R. A., Bolmer, S. T., Udovydchenkov, I., Worcester, P. F., Dzieciuch, M. A., Van Uffelen, L. J., 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,” (Woods Hole Oceanographic Institution Technical Report WHOI-2008-03), 94 pp.

### 2009

Heaney, K. D., Baggeroer, A. B., D'Spain, G. L., Becker, K. M., Murray, J. J., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., and Andrew, R. K. (2009). “Towed array signal and noise measurements in the Philippine Sea,” in *Proc. 3rd International Conference on Underwater Acoustic Measurements: Technologies and Results*, edited by J. S. Papadakis, and L. Bjørnø (Foundation for Research and Technology Hellas (FORTH), Heraklion, Greece), pp. 121–126.

Worcester, P. F., Carey, S., Dzieciuch, M. A., Green, L. L., Horwitt, D., Lemire, J. C., and Norenberg, M. (2009). “Distributed Vertical Line Array (DVLA) acoustic receiver,” in *Proc. 3rd International Conference on Underwater Acoustic Measurements: Technologies and Results*, edited by J. S. Papadakis, and L. Bjørnø (Foundation for Research and Technology Hellas (FORTH), Heraklion, Greece), pp. 113–118.

Worcester, P. F., and Munk, W. H. (2009). "The role of acoustics in ocean observing systems," in *Oceanography in 2025*, edited by D. Glickson (The National Academies Press, Washington, D.C.), pp. 58–62.

## 2010

Headrick, R., Hodgkiss, W., Kuperman, W., Song, H.-C., and Worcester, P. F. (2010). "Long-range, deep-water, coherent acoustic communications (U)," in *Submarine Technology Symposium 2010* (Laurel, Maryland).

Worcester, P. F., and Dushaw, B. D. (2010). "A decade of acoustic thermometry in the North Pacific," in *Proc. OceanObs'09: Sustained Ocean Observations and Information for Society (Annex)*, edited by J. Hall, D. E. Harrison, and D. Stammer (Venice, Italy), ESA Publication WPP-306.

## 2011

Stephen, R. A., Kemp, J. N., McPeak, S., Bolmer, S. T., Carey, S. D., Aaron, E., Campbell, R. C., Moskovitz, B., Calderwood, J., Cohen, B., Worcester, P. F., and Dzieciuch, M. A. (2011). "Ocean Bottom Seismometer Augmentation of the Philippine Sea Experiment (OBSAPS) Cruise Report," *WHOI Technical Report WHOI-2011-04* (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts), 183 pp.

## 2012

Southall, B., Dushaw, B. D., Moore, S. E., Howe, B. M., Clark, C., Gedamke, J., and Worcester, P. F. (2012). "Ocean acoustic monitoring in IOOS: Tools for measuring natural systems and human impacts," Community White Paper, *IOOS (Integrated Ocean Observing System) Summit 2012* (Herndon, Virginia).

Stephen, R. A., Bolmer, S. T., Udovydchenkov, I. A., Dzieciuch, M. A., Worcester, P. F., Andrew, R. K., Mercer, J. A., Colosi, J. A., and Howe, B. M. (2012). "Analysis of Deep Seafloor Arrivals Observed on NPAL04," *WHOI Technical Report WHOI-2012-09* (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts), 88 pp.

Wage, K. E., Buck, J. R., Dzieciuch, M. A., and Worcester, P. F. (2012). "Experimental validation of a random matrix theory model for dominant mode rejection beamformer notch depth," in *IEEE Statistical Signal Processing Workshop (SSP) 2012* (IEEE, Ann Arbor, Michigan), pp. 816–819.

2013

McPeak, S. P., D'Spain, G. L., Stephen, R. A., von der Heydt, K., and Worcester, P. F. (2013). "OBSANP Data Acquisition System: Operator's Manual and System Overview," *WHOI Technical Report WHOI-2013-06* (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts), 54 pp.

Van Uffelen, L. J., Howe, B. M., Nosal, E.-M., Carter, G. S., Worcester, P. F., and Dzieciuch, M. A. (2013). "Long-range glider localization using broadband acoustic signals and a linearized model of glider motion," in *Oceans 2013* (IEEE, San Diego, California).



**REPORT DOCUMENTATION PAGE**

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