Hydrophones for Acoustic Exploration of the Extreme Depths of the Ocean

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LONG-TERM GOALS

Characterize the spatial and temporal statistics of the ambient noise field from the sea surface down to the greatest depths in the ocean.

OBJECTIVES

The objective of the deep ambient noise project is to develop and deploy a broadband (0.01 - 40 kHz), multi-sensor system, designated Deep Sound, which is capable of monitoring sound to the deepest depths (11 km) in the ocean. Deep Sound will return depth profiles of the noise spectral level and the vertical and horizontal coherence, along with environmental data and system data.

APPROACH

A Vitrovex glass sphere of approximately 0.5 m internal diameter contains data acquisition and storage electronics along with a control CPU (essentially a stripped down PC). Throughputs connect external hydrophones and CTD sensors to the interior of the sphere. As the system descends into the ocean under the influence of gravity at a terminal speed of about 0.5 m/s, the broadband (0.01 - 60 kHz) ambient noise is detected on a suite of HTI deep-diving hydrophones, with vertical and horizontal separations. At a pre-assigned depth, which may be as deep as 11 km, a drop weight is released via a burn wire, and the system returns to the surface under its own buoyancy. Recovery is achieved with the aid of an Argos antenna, an RF locator beacon and a high-intensity strobe light.

WORK COMPLETED

Two versions of Deep Sound have been designed and built, the Mk. I and Mk. II, the latter having more hydrophones in horizontal as well as vertical configurations and a number of enhanced features which improve performance significantly. The Mk. I version made three descents in the Philippines Sea in May 2009, to depths of 5,200 m, 5,500 m and 6,000 m, and in all three cases was recovered after a six-hour return trip with little difficulty. These deployments returned unique ambient noise data sets, supported by environmental measurements (CTD) and system-monitoring information.
Since the Philippine Sea experiments, new open-pore foam boots have been fitted to the hydrophones to reduce interference from hydrodynamic fluctuations (turbulence), which leads to a dramatic improvement in the acoustic recordings (see Fig. 1). The HTI hydrophones are rated by the

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14. ABSTRACT
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manufacturer to a depth of 7.5 km, but our requirement is more demanding, since we aim to descend to the bottom of the Challenger Deep in the Mariana Trench. Accordingly, we have performed our own static-pressure tests on the hydrophones to 18,000 psi, equivalent to a depth of approximately 12 km, which is deeper than any part of the ocean.

RESULTS

The effect of the new open-pore foam boots on acoustic performance is illustrated in Fig. 1, showing before-and-after noise spectra, taken in the waters off the coast of southern California. The greatly improved quality of the recording from the shielded hydrophone is clearly evident.

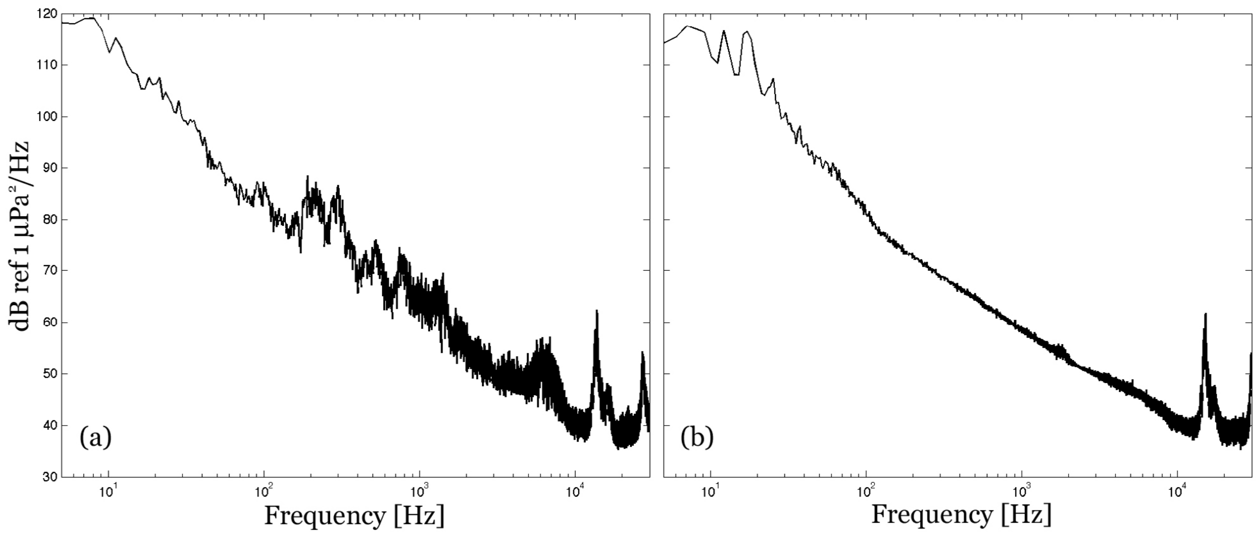

Fig. 1. Ambient noise spectra from HTI hydrophones, taken in the ocean off the coast of southern California. a) Unshielded hydrophone, as used on Deep Sound in the Philippine Sea experiment. b) A similar hydrophone fitted with an open-pore foam boot, which acts as a flow shield, keeping turbulent fluctuations away from the active surface of the sensor.

With regard to our pressure testing of the HTI hydrophones, they came through with flying colors. The acoustic performance of the hydrophones was satisfactory under a static pressure of 18,000 psi (see Fig.2), which represents an equivalent depth of some 12 km. The sensitivity of the hydrophones varied with pressure, but only weakly, and no irreversible damage was inflicted.

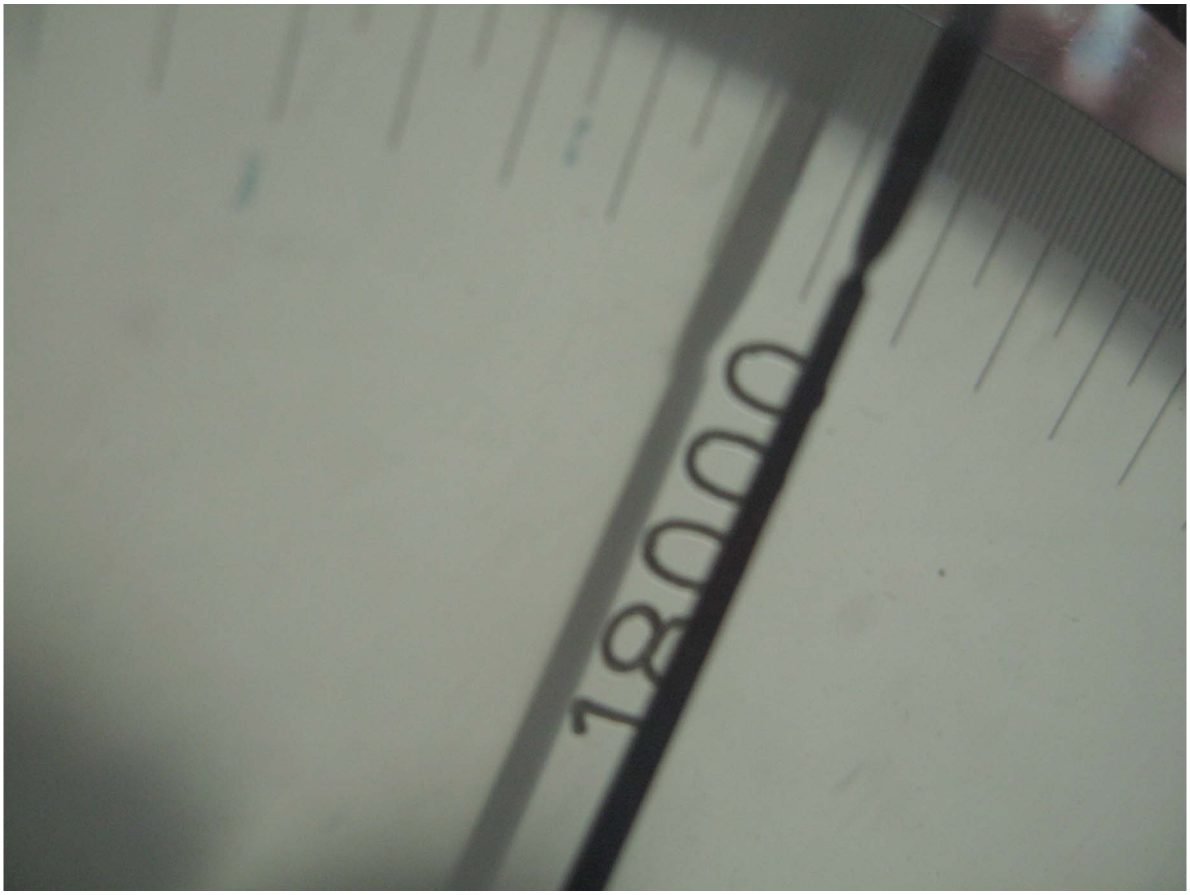

Fig. 2. Pressure gauge indicating maximum static pressure (18,000 psi) to which we subjected the HTI hydrophones.

IMPACT/APPLICATIONS

The extreme depth capability of Deep Sound opens up a number of potential applications, in addition to recording ambient noise. For example, the system could be used to investigate the acoustic properties of hydrothermal vents, which are typically found at depths around 5000 m, well below the performance limit of most hydrophones. Another interesting possibility is the exploitation of the steady descent and ascent rates to provide a synthetic aperture in the vertical. A synthetic vertical aperture of 1 km, say, could yield enhanced signal detection while the system remained entirely covert.

TRANSITIONS

It is too early for a transition, since the deep ambient noise system was only recently conceived and is still under development.

RELATED PROJECTS

None at present.

PUBLICATIONS

Journal Articles & Chapters in Book

1. D. R. Barclay and M. J. Buckingham, “On the shapes of natural sand grains”, *J. Geophys. Res*. **114**, B02209, doi:10, 1-12 (2009) [published, refereed]

2. S. D. Lynch, G. D’Spain and M. J. Buckingham, “Temporal variability of narrow-band tones in a very shallow coastal waveguide”, *J. Acoust. Soc. Am.*, (2008) [submitted, refereed]

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Conferences, Workshops and Seminars

1. M. J. Buckingham, "Sound waves and shear waves in marine sediments", Seminar, Seoul National University, Seoul, Korea, September 2009 [INVITED].

2. M. J. Buckingham, "Geo-acoustic Doppler spectroscopy: a novel technique for surveying the seabed", Shallow Water Acoustics Conference (SWAC-09), Shanghai, China September 2009 [INVITED].

3. M. J. Buckingham, "Geo-acoustic Doppler spectroscopy: a novel technique for surveying the seabed", Joint Assembly of IAMAS, IAPSO and IACS, Montreal, Canada (MOCA-09), July 2009 [INVITED].

4. D. R. Barclay and M. J. Buckingham, "Ambient noise profiling with 'Deep Sound'", ONR-sponsored conference on Underwater Acoustics Measurements: Technologies and Results, June 2009 (David Barclay received an Honorable Mention in the Best student Paper Olympiad) [INVITED].

5. M. J. Buckingham and D. R. Barclay, "Theoretical developments on sound wave and shear wave propagation in marine sediments", ONR-sponsored conference on Underwater Acoustics Measurements: Technologies and Results, June 2009 [INVITED].

6. M. J. Buckingham, "Sound waves and shear waves in marine sediments", Symposium on the Acoustics of Poro-Elastic Materials, Bradford, UK, 17-19 December 2008 [KEYNOTE ADDRESS].

7. M. J. Buckingham, "Sound waves and shear waves in marine sediments", seminar, California Institute of Technology, 30 October 2007 [INVITED].

8. M. J. Buckingham, "Wave propagation in sediments: strain hardening and the G-S dispersion relations", 8th International Conference on Theoretical and Computational Acoustics (ICTCA), FORTH, Heraklion, Crete, 2-5 July 2007.

9. M. J. Buckingham, "Inversions - a radical idea: information from ambient noise", Pacific Rim Underwater Acoustics Conference (PRUAC), Vancouver, Canada, pp. 1-2 [INVITED].

10. M. J. Buckingham, F. Simonet and D. R. Barclay, "Geo-acoustic inversion experiments in shallow water off Kauai using sound from a light aircraft", in *Underwater Acoustic Measurements: Technologies and Results,* edited by J. S. Papadakis and L. Bjørnø (FORTH, Heraklion 2007), pp. 125-131. [published, refereed]

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13. M. B. Porter, B. Abraham, M. Badiey, M. J. Buckingham, T. Folegot, P. Hursky, S. M. Jesus, K. Kim, B. Kraft, V. McDonald, C. de Moustier, J. Preisig, S. Roy, M. Siderius, H. C. Song, and W. Yang, "The Makai experiment: high-frequency acoustics", in the *Proceedings of the 8th European Conference on Underwater Acoustics*, edited by S. M. Jesus and O. C. Rodriguez, (Carvoeiro, Portugal, 12-15 June 2006) pp. 9-18 [PLENARY ADDRESS]. [published, refereed].

14. M. J. Buckingham, "Sediment acoustics measurements using a light aircraft", SA04 Workshop, 22-23 March 2006.

15. M. J. Buckingham, "Inversions for sediment geoacoustic parameters using a high-Doppler airborne sound source", ONR SW Progress Review, MBARI, 14-16 March 2005.

16. M. J. Buckingham, "Inversions for the geoacoustic properties of marine sediments using a high-Doppler, airborne sound source", *Seventh International Conference on Theoretical and Computational Acoustics*, (Hangzhou, Zhejiang, China, 19-23 September 2005). [KEYNOTE ADDRESS]

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19. M. J. Buckingham, "From air to sea to sediment: aircraft sound for ocean-acoustics experiments", Conference Honouring Prof. John Papadakis on the Occasion of His Retirement, Heraklion, Crete, November 2004 [INVITED].

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26. M. J. Buckingham, "Light aircraft, propeller noise and Döppler shifts: tools for estimating the geo-acoustic properties of marine sediments", Seminar, Department of Aerospace and Mechanical Engineering, University of Southern California, October 2003 [INVITED by Prof. H. K. Cheng].

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3. M. J. Buckingham, “Improvements in or relating to sonar systems (HARP), Patent Application No. 8200720, January 1982.
4. M. J. Buckingham, “Acoustic imaging in the ocean using ambient noise”, Patent Application No. 08/012894, Notice of Allowance issued in February 1994.
5. M. J. Buckingham, “Method and apparatus for measuring the speed and attenuation of sound”, 28 November 2003, UCSD Ref. No. SD2004-080-1 [provisional application].

HONORS/AWARDS/PRIZES

1. M. J. Buckingham, Royal Aerospace Establishment, Clerk Maxwell Premium, IERE, U.K., for research on the detection of gravitational radiation (1972).
2. M. J. Buckingham, Royal Aerospace Establishment, A. B. Wood Medal, Institute of Acoustics, U.K. (1982)
3. M. J. Buckingham, Commendation for Distinguished Contributions to Ocean Acoustics at the Naval Research Laboratory, Washington D. C., U.S.A. (1984)
4. M. J. Buckingham, Alan Berman Publication Award from the Naval Research Laboratory, Washington D. C., U.S.A. (1988).
5. M. J. Buckingham, Scripps Institution of Oceanography, Science Writing Award for Professionals in Acoustics from the Acoustical Society of America (December 1997), for the article on “Seeing underwater with background noise”, Scientific American, v. 274 (No. 2), 40-44 (1996).
6. M. J. Buckingham, Scripps Institution of Oceanography, Finalist, Discover Magazine Awards for Technological Innovation, June 1998 (Sight category) for pioneering acoustic daylight imaging.
7. M. J. Buckingham, Scripps Institution of Oceanography, Multiple entries in Marquis Who’s Who and Strathmore’s Who’s Who.
8. M. J. Buckingham,Scripps Institution of Oceanography, Technical Program Chair of the 134th Meeting of the Acoustical Society of America, San Diego, California, 1-5 December 1997.
9. M. J. Buckingham, Scripps Institution of Oceanography, Technical Program Chair of the 148th Meeting of the Acoustical Society of America, San Diego, California, 15-19 November 2004.

My graduate students have been awarded seven “best student paper” prizes for presentations at international acoustics conferences.

1. <u>Thomas Berger</u>, 1st Prize for “Low-frequency acoustic emissions of a plunging water jet. Part 1: experiment”, 136th Meeting of the Acoustical Society of America, 12-16 October 1998.
2. <u>Thomas Hahn</u>, 3rd Prize for “Low-frequency acoustic emissions of a plunging water jet. Part 2: theory”, 136th Meeting of the Acoustical Society of America, 12-16 October 1998.
3. <u>Eric Giddens</u>, 1st Prize for “Sound from a light aircraft for underwater acoustic applications”,144th Meeting of the Acoustical Society of America, Cancun, Mexico, 2-6 December 2002.
4. <u>Eric Giddens</u>, 1st Prize for “Geoacoustic inversions in shallow water using Doppler-shifted modes from a moving source” 148th Meeting of the Acoustical Society of America, San Diego, California, 15-19 November 2004.
5. <u>David Barclay</u>, 1st Prize for “The effect of grain shape on the porosity of marine sediments”, 154th meeting of the Acoustical Society of America, New Orleans, Louisiana, 27 November-1 December 2007.
6. <u>David Barclay</u>, 2nd Prize for “Doppler geo-spectroscopy in the Makai experiment”, 155th meeting of the Acoustical Society of America, Paris, France, 29 June-4 July 2008.
7. <u>David Barclay</u>, Honorable Mention in the Best Student Paper Olympiad for “Ambient noise profiling with ‘Deep Sound’”, Underwater Acoustics Measurements: Technologies and Results, ONR sponsored conference, Nafplion, Greece, June 2009.