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# Marine Physical Laboratory

## Acoustic Properties of Bubble Plumes

**W. Kendall Melville**

Supported by the  
Chief of Naval Research  
Grant N00014-93-1-0061

Final Report

September 2000

**20040809 068**

University of California , San Diego  
Scripps Institution of Oceanography

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# REPORT DOCUMENTATION PAGE

*Form Approved*  
*OMB No. 0704-0188*

Public reporting burden for this 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, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

<b>1. Agency Use Only (Leave Blank).</b>		<b>2. Report Date.</b> September 2000	<b>3. Report Type and Dates Covered.</b> Final Report	
<b>4. Title and Subtitle.</b> <b>Acoustic Properties of Bubble Plumes</b>			<b>5. Funding Numbers.</b> N00014-93-1-0061	
<b>6. Author(s).</b> W. Kendall Melville			Project No. Task No.	
<b>7. Performing Monitoring Agency Name(s) and Address(es).</b> University of California, San Diego Marine Physical Laboratory Scripps Institution of Oceanography San Diego, California 92152			<b>8. Performing Organization Report Number.</b>	
<b>9. Sponsoring/Monitoring Agency Name(s) and Address(es).</b> Office of Naval Research Ballston Centre Tower One 800 North Quincy Street Arlington, VA 22217-5660 Jeffrey Simmen, Code 3210A			<b>10. Sponsoring/Monitoring Agency Report Number.</b>	
<b>11. Supplementary Notes.</b>				
<b>12a. Distribution/Availability Statement.</b>  Approved for public release; distribution is unlimited.			<b>12b. Distribution Code.</b>	
<b>13. Abstract (Maximum 200 words).</b>  The scientific goal of this work was to better understand the process of air entrainment by breaking waves and its influence on the sound speed field in the surface layers of the ocean. The program had two principal components:  (a) The development and deployment of an autonomous sound speed profiling buoy, its deployment, and the analysis of the collected data.  (b) The development of models for the evolution of the bubble size distribution.  The initial development of the program focussed on participation in the Acoustic Surface Reverberation Experiment (ASREX) in the N. Atlantic in the winter of 1993-94. Other components of the program included the analysis of ambient sound and environmental data collected during SWADE and NOBS, and the completion of doctoral thesis research and publications at MIT.				
<b>14. Subject Terms.</b> sound speed profiling, ambient sound, air entrainment			<b>15. Number of Pages.</b> 5	
			<b>16. Price Code.</b>	
<b>17. Security Classification of Report.</b> Unclassified	<b>18. Security Classification of This Page.</b> Unclassified	<b>19. Security Classification of Abstract.</b> Unclassified	<b>20. Limitation of Abstract.</b> None	

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Grant N00014-93-1-0061  
for the Period 10/1/92 - 12/31/98

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## *Introduction*

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The scientific goal of this work was to better understand the process of air entrainment by breaking waves and its influence on the sound speed field in the surface layers of the ocean. The program had two principal components:

- (a) The development and deployment of an autonomous sound speed profiling buoy, its deployment, and the analysis of the collected data.
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### *Scientific Accomplishments*

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The relationship between low frequency sound speed and void fraction provided the basis for a narrow band sound velocimeter initially developed at MIT by Lamarre (1993) for use in a tethered configuration. It was extensively refined by Terrill & Melville (1997) for direct autonomous measurements of the low frequency sound speed fluctuations resulting from the bubbles injected by breaking surface waves during the Acoustic Surface Reverberation Experiment (ASREX). Here, low-frequency refers to frequencies below the resonant frequencies of the majority of the bubbles. For most oceanic bubble populations, this low frequency limit can be considered to be frequencies less than 5kHz because very few bubbles with resonant radii of 650  $\mu\text{m}$  persist in the water column.

For the ASREX experiment, direct sound speed measurements at 3.3kHz, 5kHz, and 10kHz were performed over 1m horizontal path lengths at seven different depths ranging from 0.7m - 7m from a surface following buoy. The buoy was deployed in the North Atlantic over a winter season and exposed to a number of severe winter storms (typical storms had 7 m significant wave heights and average winds of 18 m/s). The 2Hz ping rate provided by the travel time technique allowed the direct observation of the sound speed fluctuations with sufficient temporal resolution to resolve individual bubble injection events.

Sound speed fluctuations due to the entrained air near the surface were typically several hundred meters per second; an order of magnitude greater than had been measured using remote backscatter techniques. Due to the wide range of oceanographic conditions that were sampled, we were able to not only characterize the average and rms sound speed fluctuations with the typical parameters characterizing the sea state (ie. wind speed and wave height), but also the coupling between the entrained air and the steepness of the overlying surface wave field and dissipation of energy from the wave field was clearly shown .

Other significant results from our efforts in the ASREX experiment (summarized in Terrill & Melville (1997) and Terrill (1998)) were an accurate description of the depth dependence of the bubble field; the correlation of the bubble injection events with the group structure of the surface wave field; the characterization of the probability distribution of the sound speed fluctuations as a lognormal process, and an indication that dispersion may occur at the shallowest measurement depths at frequencies as low as 5kHz.

Related work by Felizardo (1993) showed that the traditional correlation of ambient noise in the ocean with the wind speed was equaled by correlations with certain parameters describing the wave field especially the wave slope and energy dissipation.

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*Publications Resulting from this Grant*

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**Theses**

Felizardo, F.C. 1993. Ambient Noise and Surface Wave Dissipation in the Ocean. Ph. D. Thesis, MIT/WHOI Joint Program, Cambridge/Woods Hole MA , 219pp.

Lamarre E. 1993. An experimental study of air entrainment by breaking waves. Ph. D. Thesis. MIT/WHOI Joint Program, Cambridge/Woods Hole MA. 327pp.

Terrill, E.J. 1998 Acoustic Measurements of Air Entrainment by Breaking Waves. Ph.D. Thesis. Scripps Institution of Oceanography. 244 pp.

**Journal Articles**

Lamarre, E. & Melville W. K. 1994. Void-fraction measurements and sound speed fields in bubble plumes generated by breaking waves. J. Acous. Soc. Am., 95:1317-1328.

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Melville, W.K., Terrill, E.J., & Veron, F. 1997 Bubbles and turbulence beneath breaking waves. Natural Physical Processes Associated With Sea Surface Sound. Proceedings of Sea Surface Sound 1997. Southampton, England. Ed. T.G. Leighton. pp 135-145.

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**Publications Resulting from this Grant**

Terrill, E., Melville, W.K. 1999 Field measurements of bubble size distributions in the upper mixed layer'. In 'The Wind-Driven Air-Sea Interface: Electromagnetic and Acoustic Sensing, Wave Dynamics and Turbulent Fluxes. Proc. Symp on the Wind-Driven Air-Sea Interface, Sydney Australia. (M.L. Banner, Ed), ADFA, pp. 247-255.

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