REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
19-11-2009	Final Technical Report	14-05-2007 to 30-09-2008

4. TITLE AND SUBTITLE
Final Technical Report: Bubble Clustering in the Ocean and Acoustic Implications

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-07-1-0983

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Weber, Thomas C.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of New Hampshire
24 Colovos Road
Durham, NH 03824

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR 321

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution is Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
It has previously been shown [Weber, T.C. et al. (2007). "Acoustic propagation through clustered bubble clouds," IEEE J. Ocean Eng. 32, 513-523] that clustering in clouds of bubbles can play an important role in determining acoustic field characteristics. However, measurements of clustered bubble clouds in a manner that allows the clustering to be incorporated into acoustic field theory have not previously been made. This report describes observations of bubble clustering made under oceanic breaking waves during a storm (14.6 m/s wind speed) in the Gulf of Maine using a multibeam sonar. The observed clustering is parameterized using correlation functions, and incorporated into acoustic field predictions of short-range attenuation at frequencies between 10-350 kHz. Results show that the observed clustering can cause the attenuation to change by 20%-80% from that which would be observed in the same bubble cloud but with no clustering present.

15. SUBJECT TERMS
acoustics, bubbles, clustering

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	6	Tom Weber
					19b. TELEPHONE NUMBER *(Include area code)* (603)862-1659

Reset

Final Technical Report: Bubble Clustering in the Ocean and Acoustic Implications

Tom Weber
Center for Coastal and Ocean Mapping, 24 Colovos Road
University of New Hampshire, Durham, NH 03284
phone: (603) 862-1659 fax: (603) 862-0839 email: weber@ccom.unh.edu

Award Number: N00014-07-1-0983
http://marine.unh.edu/people/faculty/weber-tom.html

LONG-TERM GOALS

This research is intended to further the understanding of how high-frequency acoustic fields interact with bubble clouds in highly dynamic environments (e.g., in ship wakes or near the ocean surface). The results of this type of research can be used to help refine high frequency sonar performance models, to select optimal sonar frequencies, and to refine detection and classification routines. The results of this research can also be used to refine acoustic inversion techniques for estimating parameters related to bubble clouds in the ocean (e.g., void fraction, bubble size distribution).

OBJECTIVES

The objectives of this work were to exploit a measurement of opportunity to quantify bubble clustering under breaking oceanic wind waves, and to predict the impact of the observed clustering on acoustic field characteristics (e.g., attenuation, sound speed dispersion).

APPROACH

The approach used in this work consisted of two tasks: a bubble clustering analysis and subsequent acoustic field predictions.

Bubble clustering analysis. A Reson SeaBat 7125 (400 kHz) multibeam sonar was used in October 2006 (prior to this work) to collect high spatial and temporal resolution backscatter for breaking wave bubble plumes in the Gulf of Maine. This data was analyzed in order to quantify the degree of of bubble clustering present. In particular, the pair correlation function was inferred directly from the multibeam data.

Acoustic field predictions. Acoustic field predictions (frequency dependent attenuation) that incorporated the observed bubble-bubble correlation functions were made. This was done using modifications to the multiple scattering theory first described b y Foldy [1945], and modified to incorporate clustering as part of this work. Predictions of attenuation were made for frequencies ranging from 10-350 khz.

WORK COMPLETED

Both tasks described above were completed. A complete description of this work, including the methodology for 1) extracting the pair correlation function from the multibeam data; and 2) incorporating the pair correlation function into an effective medium model is given in the principal publication resulting from this effort [Weber, 2008].

RESULTS

As reported in Weber [2008], this work represents the first quantified measurements of clustering in bubble clouds found under open ocean breaking wind-waves. A single ping from the multibeam, which was mounted at a depth of 4 m on the R/V Hugh Sharp, is shown in Figure 1. This type of data was analyzed to estimate a pair correlation function (computed across many realizatons of the bubble cloud) describing the relationship between the joint and marginal probability density functions (pdf) describing the simultaneous locations of two bubbles. The pair correlation function corresponding to a depth of 6 m is shown in Figure 2. When the pair correlation function is equal to unity, the joint pdf is equal to the marginal pdf and clustering is not present. When the pair correlation function is greater than one, clustering is present. Figure 2 shows that clustering was present at ranges of up to ~1.5 m (that is, given the location of a bubble, it is more likely to find another bubble at ranges less than 1.5 m than it is to find one farther away).

The pair correlation estimate shown in Figure 2 was then used to predict the attenuation of the coherent acoustic field over a range of frequencies (10-350 kHz) as it propagated through the clustered bubble cloud. To do this, the bubble size distribution for a β-plume at a wind speed of 14.6 m/s and a depth of 6 m was used, following the parameterization given by Novarini et al (1998). Given this bubble size distribution, the effect of clustering can be examined by comparing the attenuation through a bubble cloud with and without clustering. This results in the frequency dependent attenuation curves shown in Figure 3, which describes a difference in attenuation between the clustered and nonclustered bubble clouds that varies between 20% and 80% over a frequency range between 10 and 350 kHz. The attenuation is lower than that predicted for the nonclustered bubble cloud at frequencies between 10 and 230 kHz, and higher at frequencies between 2530 and 350 kHz, even though the number and sizes of the bubbles are equivalent in both cases.

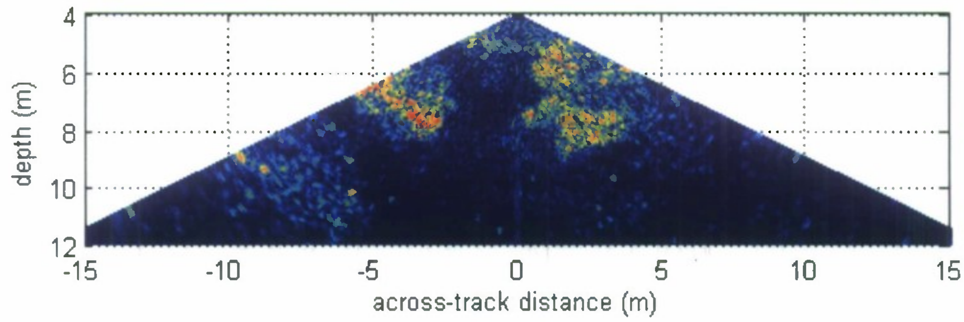

Figure 1. A single ping from the Reson 7125 multibeam sonar. Backscatter from bubbles is shown as yellow and red.

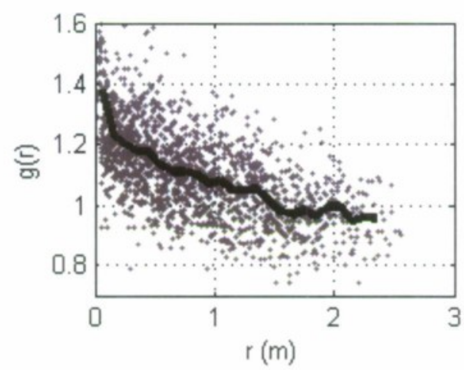

Figure 2. The pair correlation function g(r) estimated from the multibeam data at a depth of 6 m.

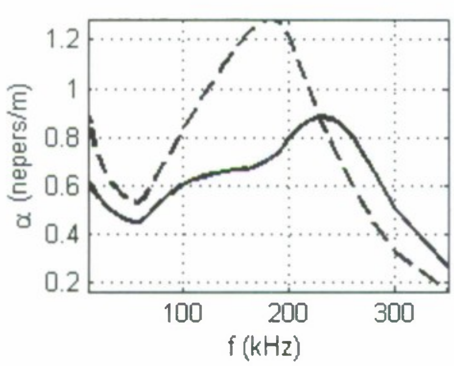

Figure 3. The predicted attenuation for nonclustered (dashed line) and clustered bubble clouds (solid line).

IMPACT/APPLICATIONS

This work demonstrates that accurate predictions of attenuation (and sound speed, which is coupled to attenuation through the dispersion relations) must incorporate clustering when it is present. This will impact those wishing to acoustically estimate bubble distributions at sea and in laboratory environments, and also those wishing to predict the effects of bubbles on high frequency sonar (under breaking waves, in ship wakes, etc.).

RELATED PROJECTS

This work is related to on-going research (ONR grant N000140910575: The effect of clustered scatterers on volume reverberation). In the on-going research, the presence of clustering in fish aggregations is being examined, and the effects of clustering are being extended to lower frequencies and shallow water (i.e., propagation distances that are several water depths).

REFERENCES

Foldy, L., The multiple scattering of waves, *Phys. Rev.* 67, 107-119, 1945.

Weber, T., A. Lyons, D. Bradley, Acoustic propagation through bubble clouds exhibiting spatial structure in the fluctuating number density, *IEEE J. Oceanic Eng.* **32**(2), 513-523, 2007.

Weber, T., Observations of clustering in oceanic bubble plumes and acoustic implications, *J. Acoust. Soc. Am.*, 124, 2783-2792, 2008.

PUBLICATIONS

Weber, T., Observations of clustering in oceanic bubble plumes and acoustic implications, *J. Acoust. Soc. Am.*, 124, 2783-2792, 2008. [published, refereed]