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

1. REPORT DATE *(DD-MM-YYYY)*: 10-20-05

2. REPORT TYPE: Progress Report

3. DATES COVERED *(From - To)*: 06/15/04-06/14/05

4. TITLE AND SUBTITLE
Acoustic Focusing in Shallow Water and Bubble Radiation Effects

5a. CONTRACT NUMBER

5b. GRANT NUMBER: N00014-04-1-0728

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Deane, Grant

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Marine Physical Laboratory
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive La Jolla, CA 92093-0701

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Ballston Centre Tower One
800 N. Quincy Street
Arlington, VA 22217
Dr. Bob Headrick Code 321

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

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

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report describes the research performed on behalf of the Office of Naval Research (grant # N00014-04-1-0728). The goal of the Acoustic Focusing in Shallow Water and Bubble Radiation Effects project is to 1) understand the role of wave-induced bubbles in the upper ocean boundary layer on the performance of underwater communications systems and ambient noise generation, 2) study the implications of focusing by surface gravity waves on Doppler sonar and acoustic communications systems in shallow and very shallow water, and 3) study the performance of acoustic vector sensors in very shallow water.

15. SUBJECT TERMS
Ambient Noise, Bubble Radiation, wave-induced bubble noise, underwater communications systems, acoustic vector sensors, shallow water

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
unclassified	unclassified	unclassified	None	7	Erika Wilson
					19b. TELEPHONE NUMBER *(Include area code)* 858-534-1802

Marine Physical Laboratory of the Scripps Institution of Oceanography University of California, San Diego

For Office Use Only

Acoustic Focusing in Shallow Water and Bubble Radiation Effects

Grant B. Deane

Marine Physical Laboratory
Scripps Institution of Oceanography
8820 Shellback Way
La Jolla, CA 92037

October 20, 2005

Technical Report

Contract N00014-04-1-0728
MPL TM-488

For the Period
15 Jun 2004 – 14 June 2005

Acoustic Focusing in Shallow Water and Bubble Radiation Effects

Grant B. Deane
Marine Physical Laboratory,
Scripps Institution of Oceanography
UCSD, La Jolla, CA 92093-0238
Phone: (858) 534-0536 fax: (858) 534-7641 email: gdeane@ucsd.edu

Grant Number: N00014-04-1-0728

LONG-TERM GOALS

The long term goals are to (1) understand the role of wave-induced bubbles in the upper ocean boundary layer on the performance of underwater communications systems and ambient noise generation, (2) study the implications of focusing by surface gravity waves on Doppler sonar and acoustic communications systems in shallow and very shallow water, and (3) study the performance of acoustic vector sensors in very shallow water.

OBJECTIVES

The goals of the research are to: (1) measure the radiation strength of isolated bubbles fragmenting in turbulent flow as a function of bubble size, (2) measure and model the three dimensional effects of surface gravity wave focusing in the littoral zone, and (3) plan and execute experiments to measure the performance of vector sensor arrays in the shallow water north of. These goals are developed more fully below.

Goal 1: Measure the radiation strength of fragmenting bubbles as a function of bubble size. The motivation for this research is the importance of ambient noise in the ocean for the operation of acoustic systems in general and, in particular, the importance of upper ocean boundary layer bubbles on the performance of underwater acoustic systems. The connection between the noise radiated by whitecaps and wind speed is well known. However, the connection between bubble creation mechanics within white caps and noise level is not well understood. Recent advances in our understanding of the scale dependence of bubble creation mechanisms in breaking waves has raised the possibility of creating a quantitative link between ambient noise level and bubble production rates by ocean waves. This would both advance our understanding of oceanic ambient noise and allow the use of noise to predict acoustical conditions at the ocean surface.

Goal 2. Measure and model the three dimensional effects of sound focusing by shoaling surf. Recent studies have demonstrated that shoaling surf acts like a time-evolving, moving mirror to sound reflected from the ocean surface. Wave crests focus surface reflections into high intensity regions that propagate through the water column at a depth and velocity that depends on the properties of the wave crest and the geometry of the crest relative to the source. These high intensity regions have been shown to have a first-order impact on the performance of underwater communications systems in the surf zone. The two specific questions addressed by this research are: (1) what are the three dimensional effects (both across-shore and along-shore) dominating surface scattering by shoaling surf, and (2) at what transmission ranges and for what surface wave spectra do deterministic focusing effects become best described by a statistical model?

Goal 3. There are three principal scientific objectives to the vector sensor component of the research. These are to: (a) determine how closely the performance of an array of vector sensors deployed and operated in a real ocean environment approaches theoretical predictions, (b) compare the performance of an array of vector sensors and an equivalent array of pressure sensors, and (c) determine if any differences in performance can be related to the relevant physical properties of the water column, such as internal wave activity.

APPROACH

The three components of the research (surface wave focusing, fragmenting bubbles, and vector arrays) are approached with a combination of field experiments, data analysis, and interpretation within a theoretical context. Both the surface gravity wave focusing and vector sensor array studies involve deployments in the very shallow waters (5 m to 10 m) of La Jolla Shores beach. The SIO pier and a submerged data and power node (recently deployed with NSF funding) provides a convenient platform for supporting these studies. The field deployments typically involve propagation paths 50 m to 100 m long with arrays of receivers and directional or spherical sources operating in the frequency range of 8 kHz – 25 kHz. The key to understanding the acoustic measurements is obtaining adequate environmental characterizations, and this is done with arrays of pressure and temperature sensors, conductivity measurements and acoustic wave gauges.

In the case of surface gravity wave focusing, the properties of the surface-scattered sound field to be studied are those relevant to modem performance, such as the time-varying structure of wave-induced Doppler shifts and the statistics of sound intensifications. The theoretical interpretation of the data has thus centered on understanding the micro-path structure of surface reflections and how these can be exploited to improve the performance of modem front-end equalizers.

The vector array studies are still in the planning stages. Three deployments in the shallow waters to the northwest of the SIO pier are proposed. The first, during February of 2006, will consist of a 4-week trial deployment of one or two pressure and vector sensors, along with a CTD logger. This initial deployment will test the deployment methodology and provide an initial data set of ambient noise and selected acoustic transmissions. Two additional, more comprehensive, deployments will occur in the winter of 2006 and summer of 2007. These experiments will be undertaken with fully populated pressure and vector arrays and additional environmental sensors, including three vertical thermistor chains and a bottom-mounted acoustic wave gauge. Seasonal deployments will provide a full range of environmental conditions which could impact array performance. An 8 element vector sensor array spaced for 1 kHz using Wilcoxon elements with orientation sensors and a 16 elements hydrophone array have been proposed. A bottom-mounted acquisition system will sit between the NSF-funded SIO pier node and the arrays. It is anticipated that a through environmental characterization will be important when interpreting the array beam forming response. In particular, the level of internal wave energy present in the water column is expected to impact the spatial coherence of acoustic signals, which may shift the relative performance of pressure versus vector sensor arrays.

The fragmenting bubble studies require a somewhat different approach. As the fundamental mechanisms controlling the acoustic emissions of bubbles fragmenting in turbulence are not well understood, the initial studies have had a strong emphasis on the development of data collection equipment. Ideally, the fragmenting bubbles would be studied within naturally occurring or laboratory breaking waves, but the complexity of the flow within the waves and the superposition of the sound from many fragmenting bubbles requires the bubbles to be studied in isolation. The equipment developed to do this is described in the next section.

WORK COMPLETED

1. Surface Gravity Wave Focusing. The main accomplishment here is the successful completion of a experiment to measure the effects of surface gravity wave focusing in the littoral zone, north of the SIO pier (Wavefronts 5). This experiment was conducted in collaboration with Dr. James Preisig at WHOI, who provided the hydrophone arrays and acoustic recording systems, and participated in the design and execution of all aspects of the experiment. Figure 1 shows the experiment layout. Three propagation paths were established in the along-shore, across-shore and angled to shore directions. The along-shore path was populated with a mid-path cross array and a vertical array of hydrophones (see the legend on the left hand side of Fig. 1). Arrays of pressure sensors were deployed along each propagation path to measure surface gravity wave activity, and a 3D acoustic wave gauge was deployed at the source location to measure the surface gravity directional spectrum and along-shore and off-shore currents.

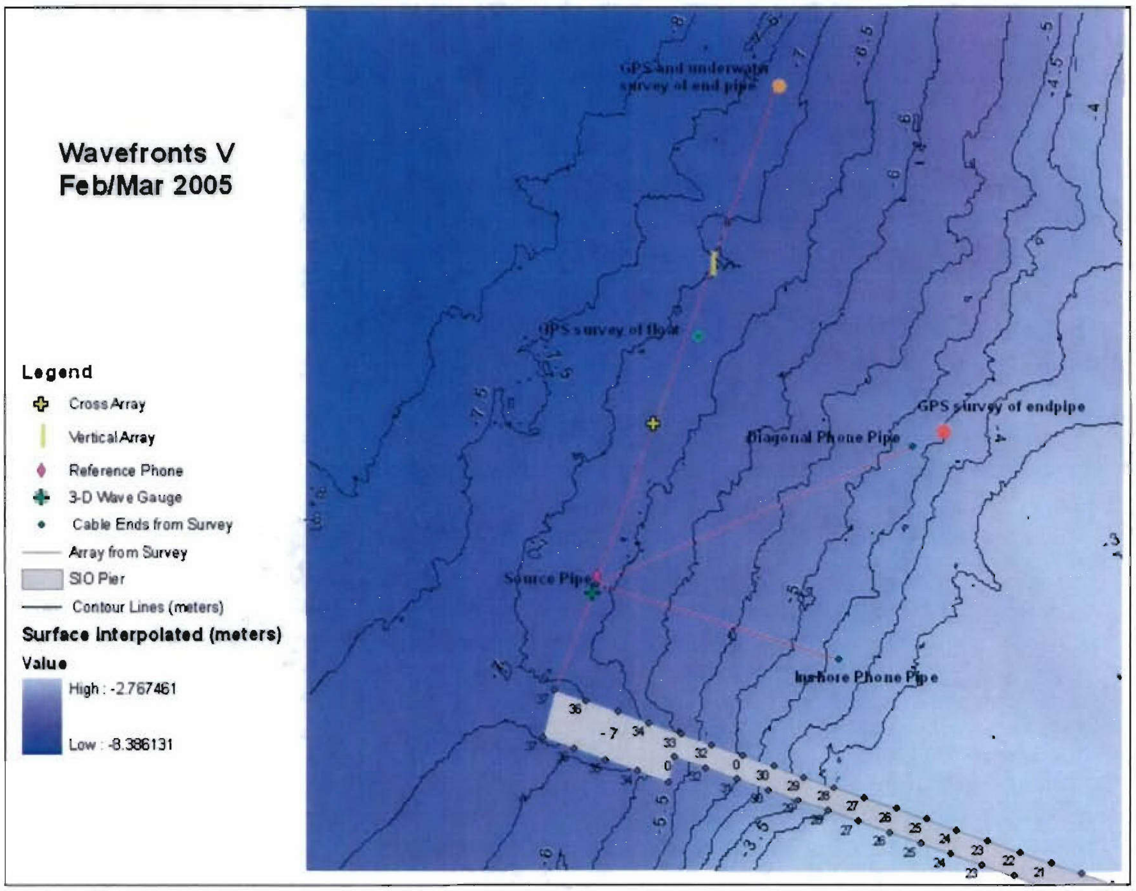

Figure 1. A contour map of the near-shore bathymetry and surveyed positions of sensors for the Wavefronts V experiment conducted in the shallow waters north of the SIO pier to study surface gravity wave focusing.

2. Vector Sensor Array Studies. This research is still in the planning stages. A white paper and experiment plan has been presented at an ONR planning meeting on September 22nd, and a DURIP proposal requesting funding to build an array of vector sensors has been submitted.

3. Fragmenting Bubbles in Turbulence. A system to inject individual bubbles beneath two colliding fluid jets has been designed and tested, and has yielded a preliminary dataset of bubble fragmentation noise. The bubbles fragment in the region of high shear stress created by the jets where they are imaged by a high speed camera. The camera images provide bubble fragmentation metrics such as bubble elongation before rupture and instantaneous fluid shear estimated from the velocities of the fragmentation products. The sound of the bubble fragmentation is monitored with a hydrophone mounted near the bubble-jet interaction region. An initial series of experiments using this equipment to observe fragmenting bubbles in fresh water have been conducted in a large test pool at SIO. The results from these experiments are described in the next section.

RESULTS

Results for the surface scattering study have come from the Wavefronts I through IV experiments, which have focused on transmission in the in-shore direction over ranges of 40 m to 100 m and frequencies of 18 kHz up to 25 kHz. The most significant results include a better understanding of the statistics of acoustic intensifications from shoaling waves, and the impact of Doppler shifts in surface reflection micro-paths on underwater acoustic communications systems. The Wavefronts V experiment was designed to study the differences between in-shore and along-shore propagation focusing effects, and the bulk of the data collected in this experiment is not yet analyzed. A preliminary analysis of the data has shown that intensifications do occur in along-shore propagation, and they can impact underwater communications algorithms.

There are two significant results determined from the bubble fragmentation experiments so far, both of which are summarized in Figure 2. Figure 2 shows the acoustic emission intensity of bubble fragmentation products as a function of radiation frequency on a log-log scale. The vertical axis is in arbitrary units, but is proportional to sound intensity. The data was obtained by recording the noise of bubble fragmentation events and processing the recordings into spectrograms. Analysis of the spectrograms enabled us to estimate the amplitude and frequency of the acoustic emissions from the bubble products. The first point to note from Figure 2 is the broad range of frequencies present in the acoustic emissions. Since there is an inverse relationship between emission frequency and bubble size, the high frequencies present imply the presence of small (< 1/10 of the Hinze scale) bubbles. It was initially thought that binary fragmentation events, with a single bubble splitting into two smaller bubbles, dominated the fragmentation process. In addition, it was thought that the fragmentation products were of comparable size. In fact, a broad range of bubble fragmentation sizes have been observed, which could go some way towards explaining the large numbers of bubbles observed smaller than the Hinze scale, which is the scale at which bubbles are stabilized against the fragmentation by the action of surface tension.

The second point of interest is the roll-off in intensity with bubble size. The roll-off follows a $f^{-5/3}$ power law scaling. The physics controlling this power law scaling have not been identified, but it is likely the same mechanism controlling the similar spectral roll-off observed in the spectrum of white-cap noise in the open ocean.

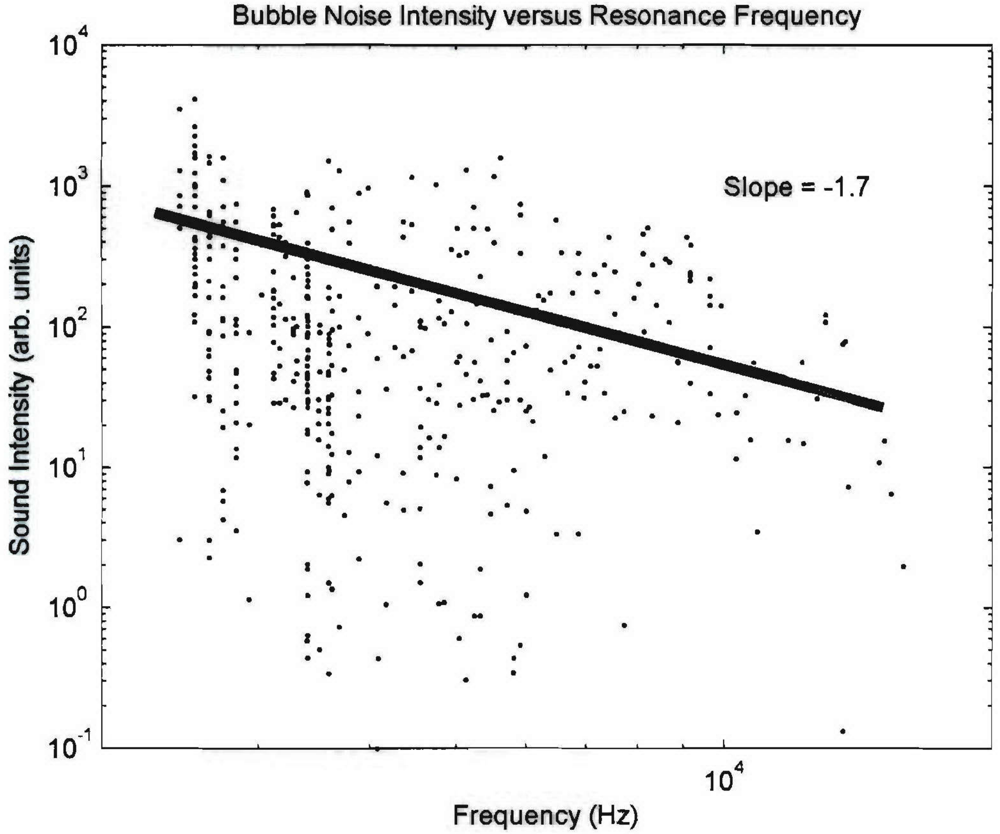

Figure 2. The observed sound intensity of fragmenting bubbles plotted as a function of radiation resonance frequency on a log-log scale. The sound intensity decreases with increasing frequency, and follows a general $f^{5/3}$ power law scaling.

IMPACT/APPLICATIONS

The potential future impact of the surface scattering studies on systems applications is an improved ability to predict the performance of acoustic communications systems in shallow and very shallow water, and improve processing codes based on the physical properties of the transmission channel. The surface gravity wave focusing work has proven particularly productive in terms of understanding environmental factors that limit the performance of acoustic systems in the littoral zone, and providing a physical motivation for the development of improved signal processing algorithms.

The bubble fragmentation work has the potential to provide a quantative estimate of bubble emission spectra within whitecaps, which would provide a fundamental advance in out ability to understand and interpret wave-induced noise in the open ocean. Combined with other recent work on bubble creation mechanisms within whitecaps, it could also form the basis of a remote monitoring tool for air-sea gas exchange and improve our understanding of the oceanic properties of bubbles within the upper ocean boundary layer.

PUBLICATIONS

Preisig, J.C. and G.B. Deane. "Surface wave focussing and acoustic communications in the surf zone" J. Acoust. Soc. Am. **116** (4) p.2067-2080, 2004 [refereed].

Deane, G.B. and M.D. Stokes. "A quantitative model for flow-induced bioluminescence in dinoflagellates." J. Theoretical Bio. **237** p. 147-169, 2005 [refereed].

Tindle, C.T. and G.B. Deane, “Shallow water sound propagation with surface waves”, J. Acoust. Soc. Am. **117** (5) p.2783-2794, 2005 [refereed].

DISTRIBUTION OF TECHNICAL REPORTS AND FINAL REPORTS

N00014-04-1-0728

(1) Program Officer
Dr. Bob Headrick
Office of Naval Research
Code 321
800 N. Quincy Street
Arlington, VA 22217

(1) Administrative Contracting Officer
Mr. Lee Washington
ONR, San Diego Regional Office
4520 Executive Drive, Suite 300
San Diego, California 92121-3019

(1) Director, Naval Research Laboratory
ATTN: Code 5227
Washington, D. C. 20375

(1) Defense Technical Information Center
8725 John J. Kingman Road
STE 0944
Ft. Belvoir, VA 22060-6218