Acoustic Measurements of Tiny Optically Active Bubbles in the Upper Ocean

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LONG-TERM GOALS

In this project, which is closely linked to a separate project where the goal is to measure wave induced bubble clouds and their effect on radiance in the upper ocean (N000140710754), we intend to address the disturbing fact that despite the fundamental importance of optical backscatter in the ocean it is still not possible to explain more than 5 to 10 percent of the particulate backscattering in the ocean based on known constituents even during periods with no active wave breaking (Terrill & Lewis, 2004). One hypothesis is that very small bubbles that have been stabilized by surfactants may be responsible for part of the “missing” backscatter. The long-term goal of this project is to detect these small bubbles using acoustical techniques, investigate possible surfactants and their role in bubble dynamics, and determine the role of these bubbles on upper ocean radiance.

OBJECTIVES

The main objective is to improve on an existing instrument design to allow for *in situ* measurements of bubbles over a wide range of bubble radii from approximately 500 micrometer at the upper end and down to less than 3 micrometer. We are pushing the technology to its limit with a goal of reaching bubble radii as small as 1 micrometer. We now have three systems where we obtain data at frequencies as high as 1MHz, corresponding to a smaller bubble radius limit of 3 micrometer. These systems were incorporated into the RadyO Scripps Pier experiment in January 2008 and the experiment conducted in Santa Barbara channel during September 2008. After extensive modifications and improvements to the systems during the winter, spring and summer of 2008-2009 the systems were again successfully deployed from R/P FLIP and R/V Kilo Moana off Hawaii during September 2009.

One interesting aspect of these particular measurements will be to investigate how these tiny bubbles, if they exist, develop from the breaking wave bubble size distributions and how the distribution and number density of these bubbles evolve following storms and periods with and without wind and wave breaking. Data are now available from the Santa Barbara channel and Hawaii studies to investigate these issues.

A major component of this year’s work has been the development of suitable inversion routines to infer bubble size distributions from the acoustical resonator data. This work has primarily been undertaken by Helen Czerski at University of Rhode Island under a grant to David Farmer at URI.

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APPROACH

Different acoustical techniques utilizing the resonant behaviour of small bubbles have for some time been used to obtain bubble size distributions in the ocean (e.g., Vagle and Farmer, 1998). These approaches make use of the fact that bubbles will resonate at a frequency proportional to their size and that the resulting scattering cross section of these bubbles is orders of magnitude higher than the corresponding geometrical scattering cross section from a particle of the same size, i.e. the bubbles have minimal damping of the incoming acoustical waves and therefore have high Q factors. (This fact also makes acoustical techniques less prone to effects from other particles in the sampling volume, a problem that often becomes critical in optical bubble sizing techniques).

The freely flooding acoustical resonator, pioneered by H. Medwin allows bubble size measurements through inversion of the bulk acoustic properties of the fluid (Farmer, Vagle & Booth, 1998; 2005). A reverberant cavity between two parallel plates is ensonified with broadband noise producing multiple resonant modes that are detected with a hydrophone. Excitation of the bubbles modifies the bulk complex sound speed of the fluid leading to attenuation and frequency changes of the resonator response. By utilizing the broadband sensitivity of the resonator both resonant and off-resonant contributions to acoustic properties over a wide frequency range provide data that are inverted to recover the distribution of bubbles of different sizes within the cavity. The instrument operates at low signal intensity, justifying application of linear acoustical theory to the inversion. Near-continuous transmission of sound into the cavity avoids uncertainties in the time dependent acoustic response of bubbles to short pulses and multiple reflections of the reverberant signal increase the effective signal-to-noise of the device.

We are building on acoustical resonator technology developed over a number of years with support from ONR to measure open ocean bubbles with radii between 15 and 500 micrometer using acoustical frequencies between 4 kHz and 200 kHz (Farmer, Vagle & Booth, 1998; Vagle & Farmer, 1998; Farmer, Vagle & Booth, 2005). The frequency spacing of the resonant peaks in the resonator depends on the size of the resonant cavity and is approximately 6 kHz in the current design. A numerical model of the operation of these devices combined with laboratory experiments show that the characteristics of their operation depend on the size of the cavity, the thickness and density of the reflecting plates, the piezoelectric film used to generate and receive the acoustical signals and the input electrical signals.

WORK COMPLETED

Our present version of the resonator is now capable of routinely operating at acoustical frequencies up to 1MHz, corresponding to a lower bubble radius of approximately 3.2 μm. However, some data were recently collected at frequencies as high as 2MHz, corresponding to bubble radii as small as 1.6 μm. These data will be investigated in the coming months.

Based on experiences from the Santa Barbara channel experiment, a number of unexpected scientific issues had to be dealt with before the recent Hawaii experiment, including:

-Modifications to the USB interface electronics now allow for reliable measurements of the bubble size distributions at a rate of 1Hz.

-Other modifications to the electronics lead to reduced electrical noise and therefore to improved acoustical spectra and subsequently improved bubble size distribution estimates.

-The use of MHz electrical signals driving the acoustical transducers lead to transducer failures due to connector failures inside the transducers. This was an issue never before experienced while using these transducers. This issue was dealt with using different connector techniques.

-A second issue only discovered when trying to increase the frequency response of these systems was attenuation and absorption of the sound waves in the potting compound used to water proof the transducers. This issue has so far only been partly solved and the search for suitable compounds continues.

- Experimenting with different sized transducers to improve their high-frequency response. Our testing has found that smaller (7 1/2" diameter) transducers indeed have better high frequency signal levels than the 10 ½ " diameter transducers used in the past . However, these results show that resonant peaks are small at frequencies above 1.5MHz and that lower frequency peaks are attenuated at higher clock frequencies. During the Hawaii experiment the surface following float was equipped with two resonators of different sizes. The plan is to combine the two data sets to cover a wider range of bubble sizes.

One of the major scientific challenges has been to develop inversion routines where the non-resonant contribution from larger bubbles can be removed from the higher-frequency attenuation measurements to obtain estimates of small bubble radii densities in observed bubble plumes. Helen Czerski at University of Rhode Island has been working on this over the last number of months and has recently made significant progress on this problem using an iterative approach. In the figure below, one of the first bubble size distributions obtained this way (blue line), at a depth of 0.5m behind the R/V Kilo Moana is compared to a low-bubble period (red line) from the previous day. The red line indicates the lower threshold, or noise floor, of bubbles densities being detectable with this particular sensor.

During the coming months the significant data sets from both the Hawaii and Santa Barbara Channel experiments will be analysed according to the objectives outlined above.

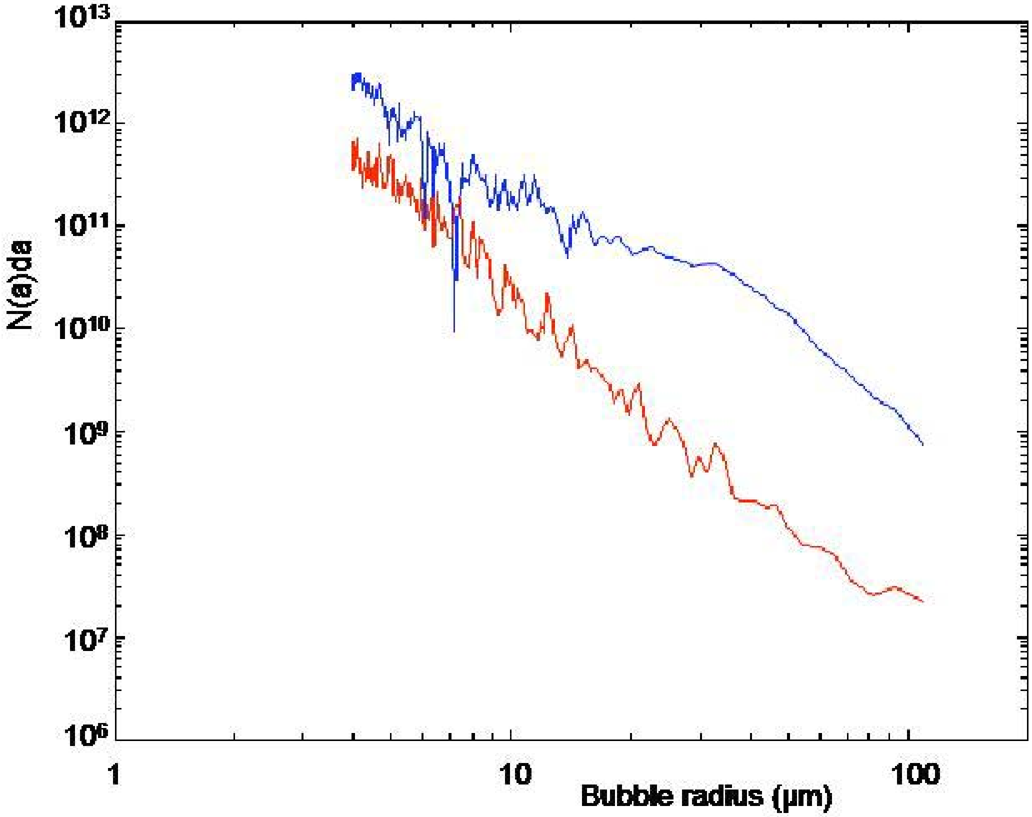

Figure 1. Bubble size distribution obtained from R/V Kilo Moana 30 August 2009 (blue line) and noise threshold (red line) of high-frequency acoustical resonator system deployed from the ship during the Hawaii RadyO experiment.

IMPACT/APPLICATIONS

This effort will provide more detailed information about the presence and number of smaller bubbles in the upper ocean and their potential role in optical scatter.

RELATED PROJECTS

The development of a high-frequency, tiny bubble detection device is being utilized in the closely associated RadyO project N000140710754. In this project the goal is to measure and model bubble injection and radiance fluctuations in the upper ocean during wave-breaking conditions. However, the instrumentation developed here will also support the interpretation of most of the other RadyO projects when bubbles are present.

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