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Wave Induced Bubble Clouds and their Effect on Radiance in the Upper Ocean

David M. Farmer
Graduate School of Oceanography (educational)
University of Rhode Island
Narragansett, RI 02882
phone: (401) 874-6222 fax (401) 874-6889 email: dfarmer@gso.uri.edu

Svein Vagle
Institute of Ocean Sciences
9860 West Saanich Road
P.O. Box 6000
Sidney, BC, V8L 4B2
Canada
phone: (250) 363-6339 fax: (250) 363-6798 email: Svein.Vagle@dfo-mpo.gc.ca

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LONG-TERM GOALS

The goal of this project is to measure wave induced bubble clouds and their effect on radiance in the upper ocean. Our aim is to address the 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). We want to investigate the role of upper ocean bubbles in these processes.

OBJECTIVES

During this project, which is a component of the much larger RaDyO project, we are addressing the following scientific questions:

- How does radiant light fluctuate beneath a sea in which waves are breaking?
- Can this variability be explained in terms of measured bubble populations with wave scattering models using Mei theory as a kernel for light-bubble interactions?
- Can a predictive model be developed for radiant light that includes wave conditions and predicted subsurface bubble injections?

The presence of surfactants on the surface of the bubbles decreases their buoyancy and therefore their rise speed. The presence of compounds on the bubbles will also modify their dissolution rate and will therefore change the dynamics of the temporal and spatial evolution of bubble clouds and their size

distributions. Bubbles are effective at scattering light; thus a proper understanding of the role of surfactants on the bubble field is important to understanding observed radiance modulations.

With our collaborators at IOS and the larger RaDyO group of investigators, we will measure and model bubble injection and radiance fluctuations in the upper ocean during wave-breaking conditions. The critical measurements of bubble size distributions, and the way in which they evolve with time after wave breaking, will be carried out using an array of acoustical resonators and dense bubble clouds will be monitored with conductivity cells. The surface wave field will be measured with an array of Doppler sonars. The radiance distribution will be measured on meter length scales in the top 10 m of the ocean by other RaDyO participants. The bubble clouds will be further characterized with optical systems and sonars.

To improve our understanding of the role of the microlayer and the microlayer surfactants the IOS team is gathering surfactant data. We plan to incorporate this information in models of bubble rise and dissolution rate, so that we can better estimate bubble populations, and hence their contribution to optical scattering.

APPROACH

The instruments and technology for carrying out this work have been developed collaboratively by the PI and his collaborator Svein Vagle (IOS) and as part of a program to study the role of the microlayer in air-sea gas exchange processes. The instrumentation required to detect tiny bubbles (radius < 10 μm) is presently being developed as part of a separate, but obviously connected, project (N000140610379). Post-doctoral fellow Helen Czerski has played a major role in all aspects of the project.

The core of the work this year consisted of participating in the field campaign off Hawaii from R/P FLIP and R/V Kilo Moana in September 2009 and also developing improved methods to analyse the data from this deployment. During this field campaign, we carried out monitoring of sub-surface bubble populations for several hours each day from R/V FLIP. During the deep water FLIP based measurements, the following measurements were made:

- The size distribution of bubbles were measured continuously at approximately 1 meter depth with a set of acoustical resonators operating over the frequency range 20 kHz to 1 MHz.
- Dense bubble plumes were characterized at a few points in depth using air fraction sensors detecting electrical conductivity.
- The broader distribution of the bubble cloud were measured with a sonar mounted on a surface following frame supporting the other sensors.
- Data for calculating gas dissolution, which shapes the bubble size distribution, were acquired with a gas tension device and a dissolved oxygen sensor so as to get both dissolved oxygen and nitrogen, which is required for accurate bubble dissolution calculations.
- Data for calculating the sound speed profile and vertical temperature field were acquired with an array of thermistors.

In addition, a resonator was deployed daily from the R/V Kilo Moana on the Wet Labs MASCOT package. This provided data for comparisons between our acoustical bubble measurements and independent optical scattering measurements made by the MASCOT device.

WORK COMPLETED

The acoustical resonator developed by Svein Vagle and the IOS team for broadband measurements, was successfully tested in the Scripps Pier experiment in 2008. Analysis of the data from the Santa Barbara experiment has guided the manufacture of several newer instruments and has provided the basis for considerable improvements to the experimental protocols. In order to interpret the resonant peaks at higher frequencies (where peak quality is generally lower), a more accurate theoretical model of resonator performance has been built. The result of these efforts is that our instrumentation can now measure acoustical attenuation very accurately at a rate of 1 Hz and meaningful results can be acquired over a acoustical frequency range from 20-700 kHz. In addition, a new method for inverting the measured attenuation to infer the bubble population present has been developed and tested. This method is considerably more efficient than the methods used previously, while also being more accurate. The overall consequence is that resonator data now be inverted accurately very quickly after an individual experiment, so that deployments can potentially be modified while at sea in response to the bubble populations measured.

The acoustically-measured bubble populations are currently being compared with the optical scattering measured simultaneously by the WetLabs MASCOT instrument. Analysis is ongoing, but the preliminary results show good agreement between the measured bubble populations and the optical scattering data. The low levels of particulates in the water off Hawaii make this comparision relatively straightforward, since bubble effects are expected to dominate the optical scattering.

RESULTS

Typical bubble populations measured during the Hawaii experiment are shown in figure 1. These are unsmoothed data, and show that the bubble plumes at the resonator are changing on timescales of seconds. The data shown in figure 1 was collected while the resonator was 1 meter below the surface.

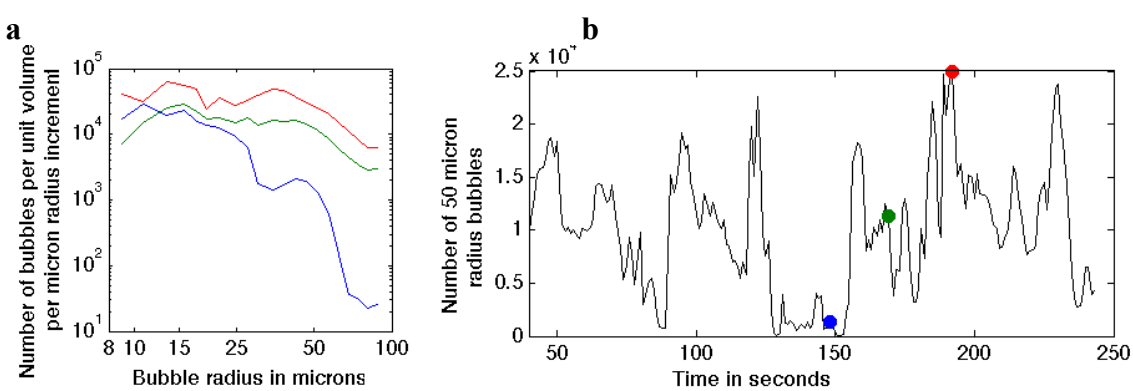

Figure 1. Typical bubble populations measured during the Hawaii experiment. Each line in plot 1(a) represents a single measurement of the bubble size distribution (spectra were recorded every second). Plot 1(b) shows a timeseries of the numbers of bubbles with a radius of 50 microns. The colored dots correspond in time to the colored lines in the plot on the left.

These measured bubble populations can be used to calculate the expected optical scattering, using Mie theory for coated bubbles. We do not expect to predict all the optical scattering because the acoustical bubble measurements only include bubbles from 8 to 100 microns in radius, and bubbles smaller than 8 μm radius will contribute significantly to the optical scattering. The temporal variability of the acoustical and optical results is very similar, as shown in figure 2. Analysis of both optical and acoustical results together is ongoing, in order to investigate the presence of bubbles with radii less than 20 microns and to combine the strengths of both techniques to provide more in-depth information about the bubble size distribution in this challenging region.

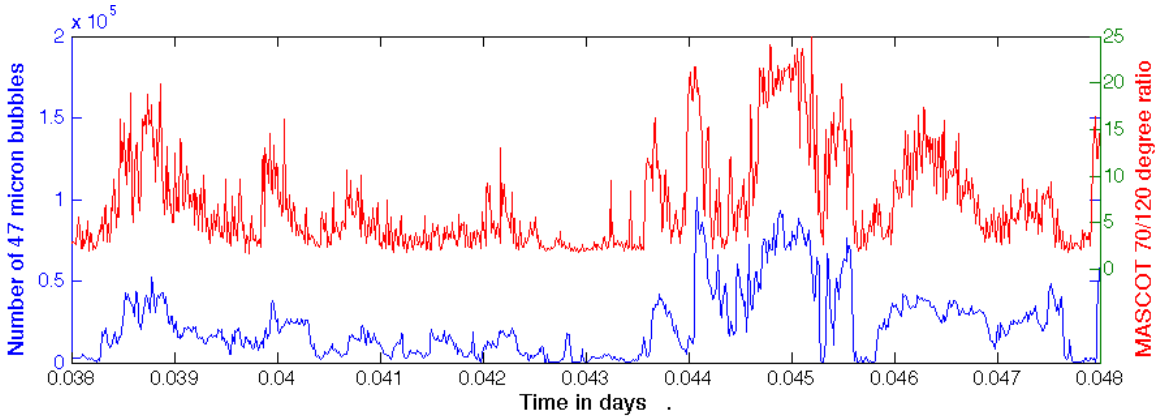

Figure 2. Timeline of bubble effects from the Hawaii experiment. The blue line shows the number of bubbles with a radius of 47 μm and the red line shows a simultaneous optical measure of bubble presence. This measure is the ratio of scattered light at 70 degrees and 120 degrees, which is a sensitive indicator of bubble presence. The total time range shown is approximately 14 minutes.

RELATED PROJECTS

The bubble sensing technology being explored in this project is directly relevant to work being carried out in an acoustic communications project N000140210682 and associated MURI project.

PUBLICATIONS

"The inversion of acoustical attenuation measurements to deduce bubble populations". H. Czerski. [submitted to the Journal of the Acoustical Society of America]

"Improvements to the methods used to measure bubble attenuation using an underwater acoustical resonator", H. Czerski, S. Vagle, D.M. Farmer, N. Hall-Patch. [submitted to the Journal of the Acoustical Society of America.]