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

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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. In this project we are working closely with Svein Vagle (IOS).

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 Mie 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?

In addition, we will investigate the effects of natural surfactants on bubble plumes. The presence of surfactants on the surface of the bubbles decreases the bubble rise speed and modifies its dissolution rate. These compounds will therefore change the temporal and spatial evolution of bubble clouds and affect the bubble size distributions. Bubbles are effective at scattering light; thus a proper

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understanding of the role of surfactants on the bubble field is important for understanding observed radiance modulations.

With our collaborators at IOS and the larger RaDyO group of investigators, we planned to 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, was carried out using an array of acoustical resonators and dense bubble clouds were monitored with conductivity cells. The surface wave field was measured with an array of Doppler sonars. The radiance distribution was measured on meter length scales in the top 10 m of the ocean by other RaDyO participants. The bubble clouds were also characterized with optical systems and sonars.

To improve our understanding of the role of the microlayer and the microlayer surfactants the IOS team has gathered surfactant data. We have incorporated this information in models of bubble rise and dissolution rate, in order to understand their effect on 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) as part of a program to study the role of the microlayer in air-sea gas exchange processes. For the final two years of the project, a postdoc (Helen Czerski) worked on improving the theoretical framework for interpreting resonator data and she also collected and analysed the data using these new methods. The instrumentation required to detect tiny bubbles (radius < 10 μm) is presently being developed as part of a separate, but obviously connected, project (N000140610379).

The core of the work this year consisted of analysing the bubble data from the field campaign off Hawaii from R/P FLIP and R/V Kilo Moana in September 2009. The project funding only covered two months of this year, and this time was used in writing up the project results. Additionally, we took advantage of the opportunity to use the instruments during two externally-funded deployments, which provided valuable data complementary to the RaDyO project. These were a short cruise in the East Sound in Washington State and a beach deployment at Duck in North Carolina. During these field campaigns, we carried out monitoring of sub-surface bubble populations for several hours each day, and compared our data with simultaneous optical and holographic measurements made by other groups.

The most useful data analysed this year came from the deployment of a resonator on the Wet Labs MASCOT package. The data produced could be used to compare our acoustical bubble measurements with independent optical scattering measurements made by the MASCOT device. This resulted in the development of a novel technique for measuring bubble coatings in situ, since coatings affect both the optical and acoustical properties of bubbles.

WORK COMPLETED

The two papers written this year have focussed on inferring natural bubble coatings by making simultaneous optical and acoustical measurements, and by monitoring the evolution of the bubble plume with time. Helen Czerski has developed the first methods which use comparative bubble measurements from independent techniques *in situ* in the ocean to deduce information about natural bubble coatings. This paper was recently accepted for publication in JGR. This is the first publication to consider the effects of bubble coatings on the acoustical properties of ocean bubbles, and we found that comparing simultanous optical and acoustical data allowed us to constrain the bubble coating properties. In particular, the match between the two sets of measurements was significantly improved if a bubble coating thickness of 10 nm was assumed, which agrees with previous laboratory estimates. Figure 1 is from that paper, showing how accounting properly for the optical and acoustical effects of bubble coatings improves the match between optical and acoustical measurements.

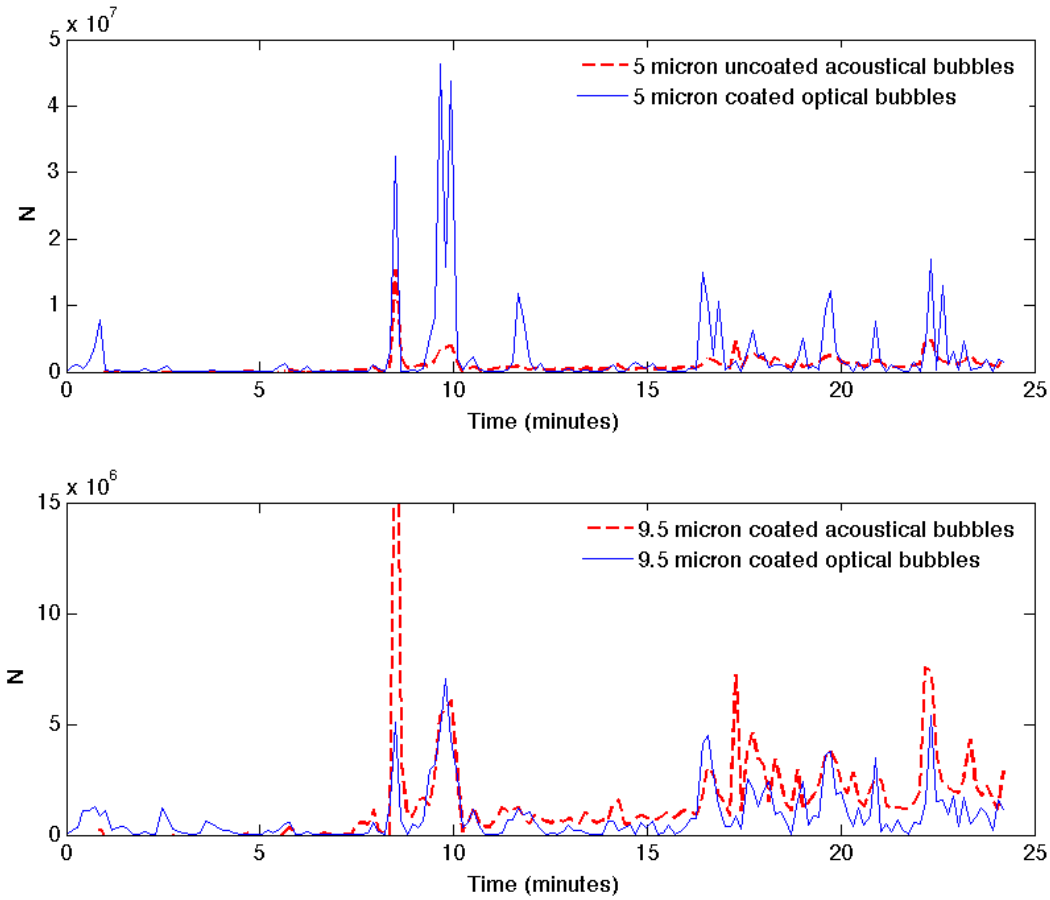

Figure 1. Example time series comparison of optical and acoustic measurements showing effect of correction for bubble coating in bubble density estimates, shown in a time series. An uncoated bubble with a radius of 5 µm resonates acoustically at the same frequency as a coated bubble with a radius of 9.5 µm, so the dotted red line represents the same data in both plots. N is the bubble number per unit volume per µm radius increment. (a) shows the comparison between optical and acoustical results if the acoustical bubbles are assumed not to be coated. (b) shows the equivalent plot with the correction. The agreement in (b) is significantly improved.

In addition, we collected another data set using a resonator attached to the MASCOT package in East Sound. On a flat calm day, the instrument package was towed through cross-sections of a ship wake as it dissipated (one wake took over an hour to disappear). This provided a very detailed record of the evolution of the bubble plume with time, and the behaviour of these bubbles provided enough information to constrain the bubble coatings which must have been present. The final stages of this work are ongoing, and the manuscript is in preparation.

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

H. Czerski, S. Vagle, D.M. Farmer, N. Hall-Patch, Improvements to the methods used to measure bubble attenuation using an underwater acoustical resonator, 2011, Journal of the Acoustical Society of America, *in press.*

H. Czerski, M. Twardowski, X. Zhang, S. Vagle, Resolving size distributions of bubbles with radii less than 30 microns with optical and acoustical methods, 2011, Journal of Geophysical Research – Oceans, *in press.*

H. Czerski, The inversion of acoustical attenuation measurements to deduce bubble populations, Journal of Atmospheric and Oceanic Technology, *In Review*.