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

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LONG-TERM GOALS

The main goal of this project was to be able to characterize the upper ocean bubble field in terms of both bubble size distributions and overall bubble concentrations both in space and time. With this information available we are now able to assess the role of the bubbles on the upper ocean radiance field. In this work we are working closely with Helen Czerski and David Farmer at GSO/URI.

The role of manmade and natural surfactants in upper ocean processes is presently poorly understood. Therefore, a second goal of this project was to improve our understanding of how these surfactants modify the bubble field, the surface wave field and ultimately the upper ocean radiance.

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. To improve on our understanding of the role of the microlayer and the microlayer surfactants we are addressing the following scientific questions:

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- What is the spatial and temporal variability of the air-sea interface microlayer and how does the surfactant concentration and composition vary throughout the onset and decay of wind events?
- How does this variability relate to observed variability in the horizontal and vertical bubble size distribution?
- What are the effects of these surfactants on the scattering properties of bubbles?
- What are the effects of microlayer surfactants on radiance fluctuations in the upper ocean?

APPROACH

The data sets used in the present analysis were collected during the different field campaigns within the RadyO Departmental Research Initiative (DRI). The critical measurements of bubble size distributions and turbulence and the way in which they evolve with time after wave breaking, have been carried out using three acoustical resonators, side-looking and upward looking 100 and 200 kHz backscatter sonars and an array of three, 2 MHz coherent Doppler sonars. The role of microlayer surfactants is investigated jointly with Dr. Oliver Wurl.

RESULTS

Bubbles and turbulence

Using the high-frequency acoustical resonators constructed as part of this DRI and based on the instrumentation developed by Farmer, Vagle and Booth (1998, 2005) bubble size distributions were obtained from broad-band attenuation measurements estimated using the eigenvalue technique developed by Czerski et al. (2010). Figure 1 shows a 30 minute period from September 3, 2009 when significant wave breaking was taking place with wind speeds exceeding 8 ms^{-1}.

The lower panel shows $\log_{10}$ of the number of bubbles per m^3 within a 1 μm radius increment as measured with a resonator mounted on a surface following float approximately 1.5 m below the instantaneous ocean surface. The upper panel shows the overall air-fraction as calculated from these bubble size distributions. It is apparent from these data that at this depth and at these wind speeds the bubble size distribution is dominated by bubbles with radii between 25 and 100 μm. Only occasionally, when a wave breaks over or near the instrument do we see signs of larger and smaller bubbles in this field. We are presently working through all our data to characterize the bubble field in more detail.

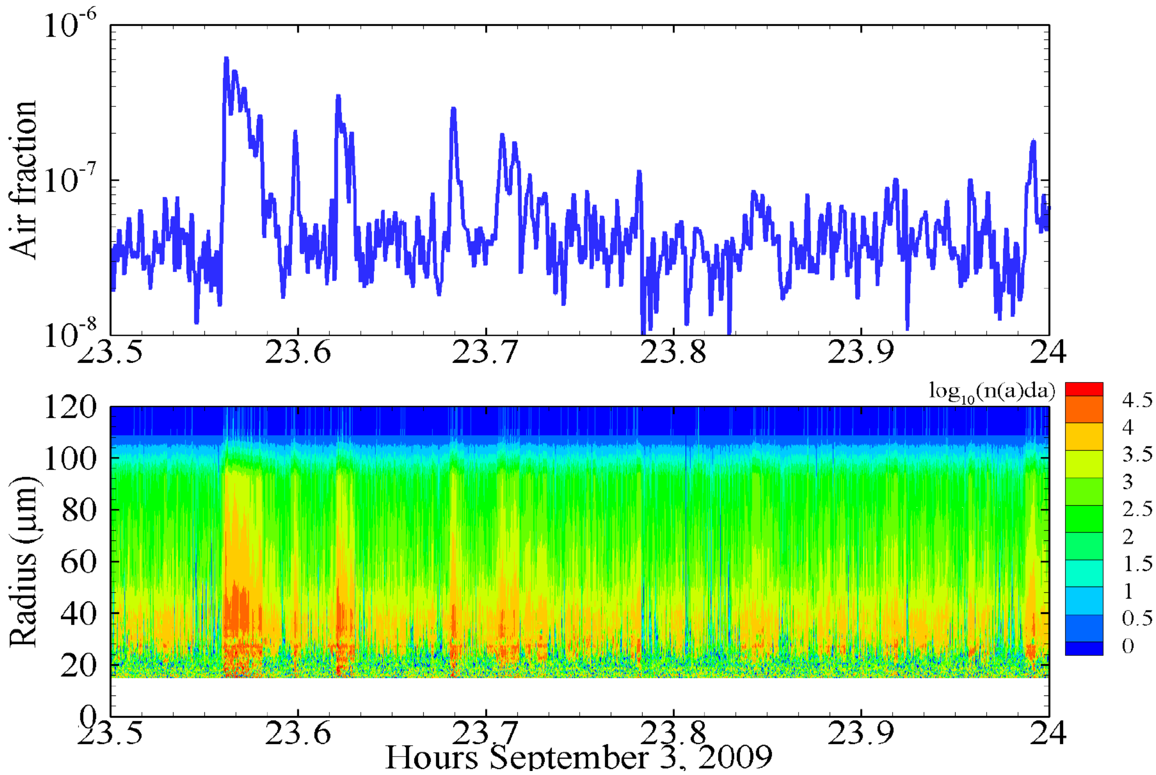

Figure 1: (Upper panel) Total air-fraction as a function of time calculated from the bubble size distributions shown in the lower panel. It can be seen that the dominant bubble radii are between 25-30 µm and 100 µm. Only during breaking events with increased air-fractions (e.g., hour 23.57) are significant number of bubbles smaller than 20 µm observed.

The turbulence dissipation rates ε were calculated for different depths from three 2 MHz coherent dopbeam sonars also deployed on the surface following float during the RadyO experiments. Figure 2 summarizes these results and shows a very interesting correlation between near surface temperature stratification and reduced near-surface turbulence. Here we use the temperature difference between a temperature logger mounted at a depth of 3 m on the hull of R/P FLIP and loggers mounted at depths of 7, 15, and 31 m. These results are presently being investigated further in terms of their role in modulating the upper ocean bubble field.

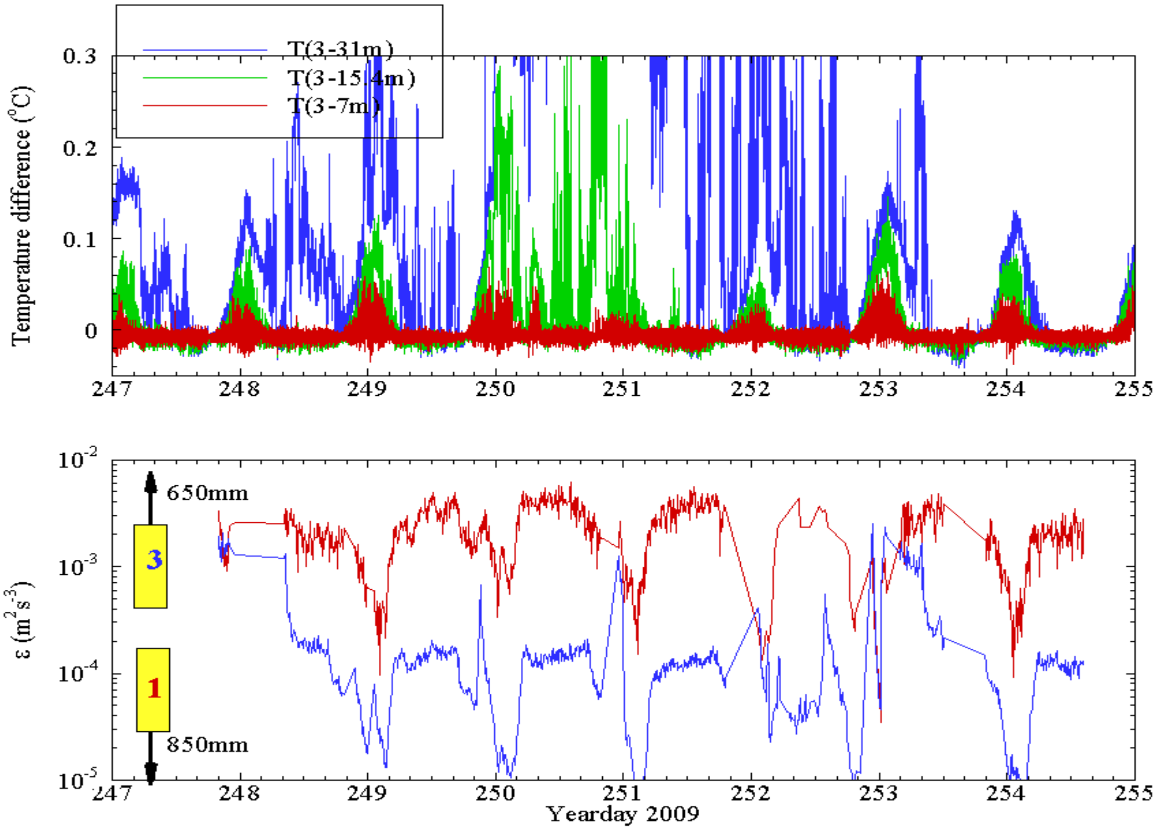

Figure 2: (Upper panel) Temperature differences between temperature loggers mounted on R/P FLIP's hull at depths of 3, 7, 15, and 31m show significant diurnal stratification and mixing periods during the Hawaii experiment. During the afternoon (midnight UTC) the solar heating results in stratification (increased temperature differences) that breaks down during nighttime. Correspondingly the turbulent dissipation rate ε (lower panel) shows significantly reduced turbulence during periods with increased near surface stratification.

Surfactants Fields during the Santa Barbara Channel and Hawaii RaDyO experiments

During the two RadyO ocean experiments twenty one microlayer surfactant stations were occupied and sampled. At these stations both the microlayer and water at a reference depth of 1 m were sampled for subsequent analysis back in the laboratory. The primary analysis was conducted by phase-sensitive alternating current voltammetry with a hanging mercury drop electrode in unfiltered samples (Wurl et al., 2009) resulting in concentrations of surfactants equivalent to concentrations of Triton X, which is a well know surfactant. Figure 3 summarizes the results of these measurements for the two RadyO experimental sites.

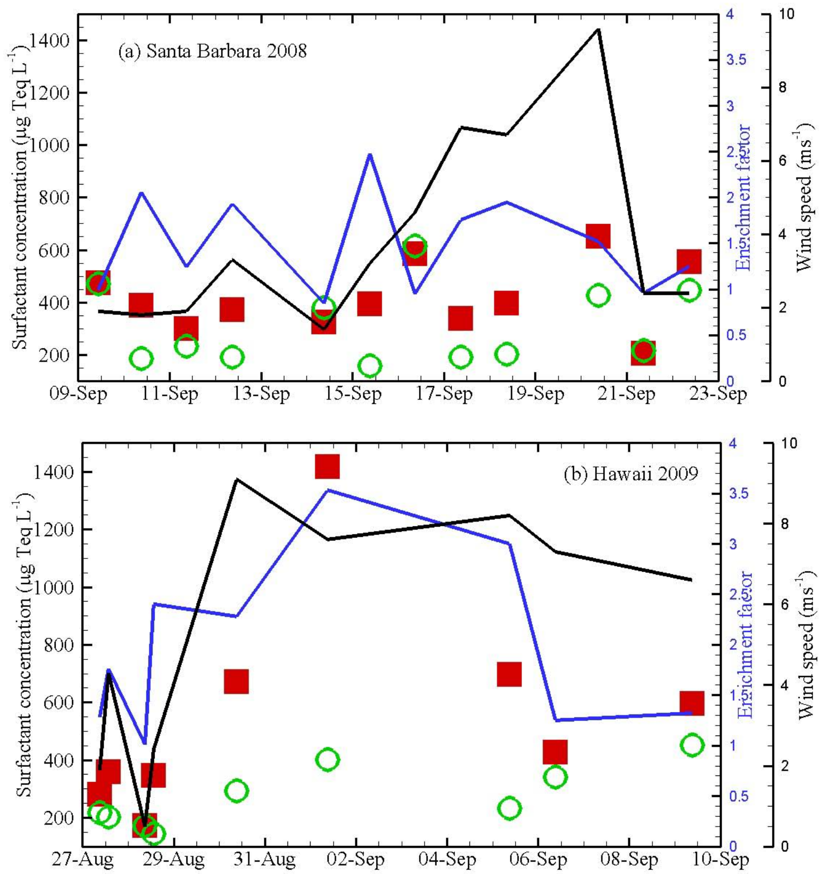

Figure 3: Surfactant concentrations equivalent to Triton X as observed at sampling stations near Kilo Moana in Santa Barbara (a) and off Hawaii (b). Red squares are the observed surface microlayer concentrations while the open green circles are the corresponding concentrations in the bulk water at a depth of 1 m. The enrichment factor, defined as the ratio of surface microlayer concentrations to bulk water concentrations, are shown as the blue curve. As a reference the measured wind speeds at the location of the sampling have been included in black. Most of the sampling was done between 9 and 10AM local time.

During the Santa Barbara channel sampling a number of slicks were observed in the area, but none of the samples collected in these slicks are included in the data presented in Fig. 3. No identifiable slicks were observed off Hawaii. No obvious correlation between wind speed and surfactant concentrations was observed in Santa Barbara, while in Hawaii the surface layer concentration and consequently the enrichment factor increased dramatically during the increasing winds during the initial period of the experiment. The maximum surface microlayer surfactant concentrations off Hawaii reached level nearly three times the observed concentrations in Santa Barbara channel. Also, the enrichment factor was higher off Hawaii during a significant portion of the experiment. These data and results are presently being investigated further to determine the implications on the bubble and turbulence fields and ultimately on the optical properties of the upper ocean.

IMPACT/APPLICATIONS

This effort will provide more detailed information about the bubble size distributions, turbulence and surfactants in the upper ocean at a range of environmental conditions.

RELATED PROJECTS

The development of a high-frequency, small bubble resonator was done under a separate RadyO project (N000140610379).

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