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

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LONG-TERM GOALS

A goal of this project is to measure wave induced bubble clouds and their effect on radiance in the upper ocean and 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 (Terrill & Lewis, 2004). We want to investigate the role of upper ocean bubbles in these processes. In this work we are working closely with 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 is to improve on 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

With our collaborators at URI and the larger RadyO group of investigators, we are measuring 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, have been carried out using three acoustical resonators and an array of three, 2 MHz coherent Doppler sonars.

The instruments and technology for carrying out the ‘bubble’ work have been developed collaboratively by the PI and his collaborator David Farmer and the role of microlayer surfactants as part of a program in collaboration with Dr. Oliver Wurl to study the role of the surface microlayer (SML) in air-sea gas exchange processes. The instrumentation required to detect bubbles as small as 3.2 μm has been developed as part of a separate, but obviously connected, project (N000140610379).

The core of the work this year consisted of two field campaigns, one at Scripps Pier in January 2008 and one in Santa Barbara Channel in September 2008 onboard R/P FLIP and R/V Kilo Moana. During the Scripps Pier experiment bubble size distribution measurements were made in the surf zone along the pier to compare our acoustical approach with independent optical measurements using the WET Labs MASCOT and the Satlantic Inc. IOP profilers. These types of collocated measurements continued onboard the Kilo Moana during the September field campaign.

In addition to the Kilo Moana measurements the following measurements were made from R/P FLIP:

- Bubble size distributions were measured continuously for up to 10 hours a day between September 9 and September 21 from a small wave following float deployed between the center and starboard booms on FLIP (Figure 1).

- Dense bubble plumes were detected from the same float using an air fraction sensor detecting electrical conductivity.

- The broader distribution of the bubble field was measured with a 200 kHz backscatter transducer deployed 5 m below the surface from the surface following float (Figure 1) and an array of four 100 kHz sidescan transducers mounted at a depth of 30 m on FLIP’s hull.

- Gas dissolution which shapes the bubble size distribution was measured with a gas tension device and a dissolved oxygen sensor attached to a Seabird SBE 19 plus mounted on FLIP's hull at a depth of 30 m.

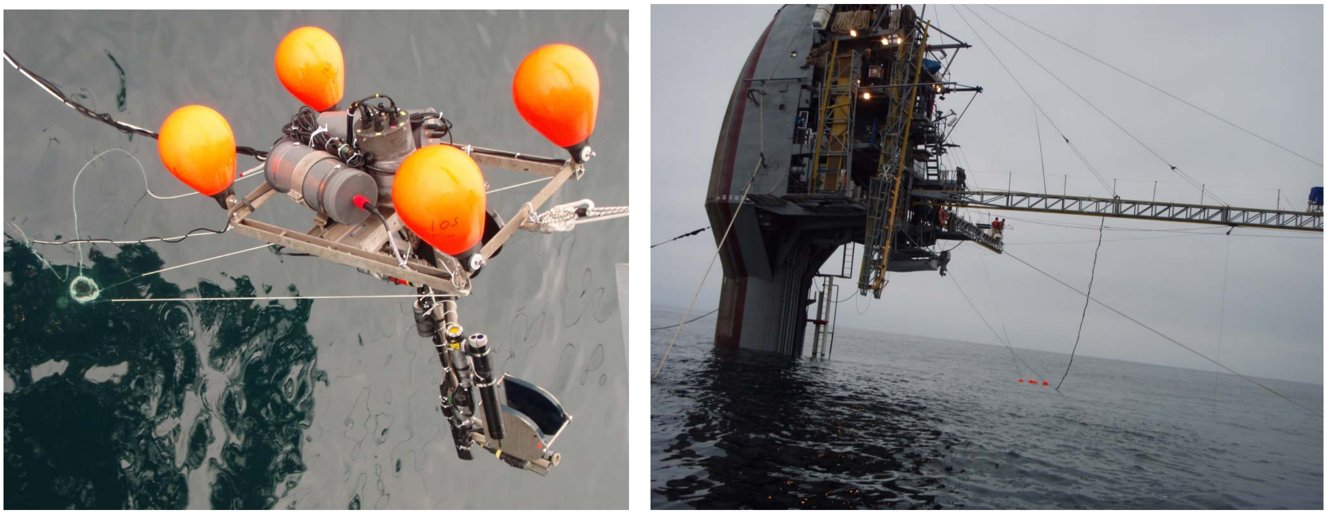

Figure 1: Wave following float deployed from the starboard and center booms on FLIP. Left photo shows the float being lowered into the water. The lower acoustical resonator is easily seen in the photo. The float was also equipped with 3 2 MHz Coherent Doppler sonars, Conductivity and Temperature sensors and a motion sensor package. Also seen, hanging in strings, is the 200 kHz vertical transducer deployed 5m below the surface. The right photo shows the float in place between the booms during a very calm morning.

During the Santa Barbara Channel experiment in September 2008 we experienced a wide range of wind and wave conditions from flat calm up to wind speeds approaching 15 m/s. An example of the acoustical backscatter cross section at 200 kHz from a depth of 5 m beneath the surface following float has been plotted for a 30 minute period in Figure 2 (upper panel). During this time the wind speed was approximately 10 m/s. The high backscatter, or red in the figure, around 5 m comes from the ocean surface and with bands of higher backscatter (yellow and red) in the range from 5 m to 3.4 m being due to sensors and mounting gear on the surface following float. The high backscatter in the range from about 0.7 m and up to 3.2 m from the transducer is due to bubble plumes associated with coherent Langmuir cell flow. This was confirmed by visual observations from above where long streaks of foam and debris, trapped in the downwelling regions of the Langmuir cells were detected passing the surface following float whenever a strong backscatter signal was detected (Figure 2 (lower panel)). It is interesting to find a fine structure within the Langmuir cell bubble field with high backscatter followed by a region with significantly less backscatter, followed by a second region with increased backscatter again; this time the highest backscatter being closer to the transducer.

One interesting scientific issue will be to determine whether we can detect differences in the bubble size distributions detected by the acoustical resonators between the bubble-field in Langmuir cells as compared to the bubble-field associated with breaking waves. It is hypothesized that a breaking wave bubble field will have a higher number of larger bubbles and that the velocity field associated with Langmuir cells will sort the bubbles in some fashion.

The 100 kHz Doppler sonars on FLIP’s hull clearly detected the bands of Langmuir cells out to a range of 250 m from FLIP, giving us information about the coherent bubble field around FLIP.

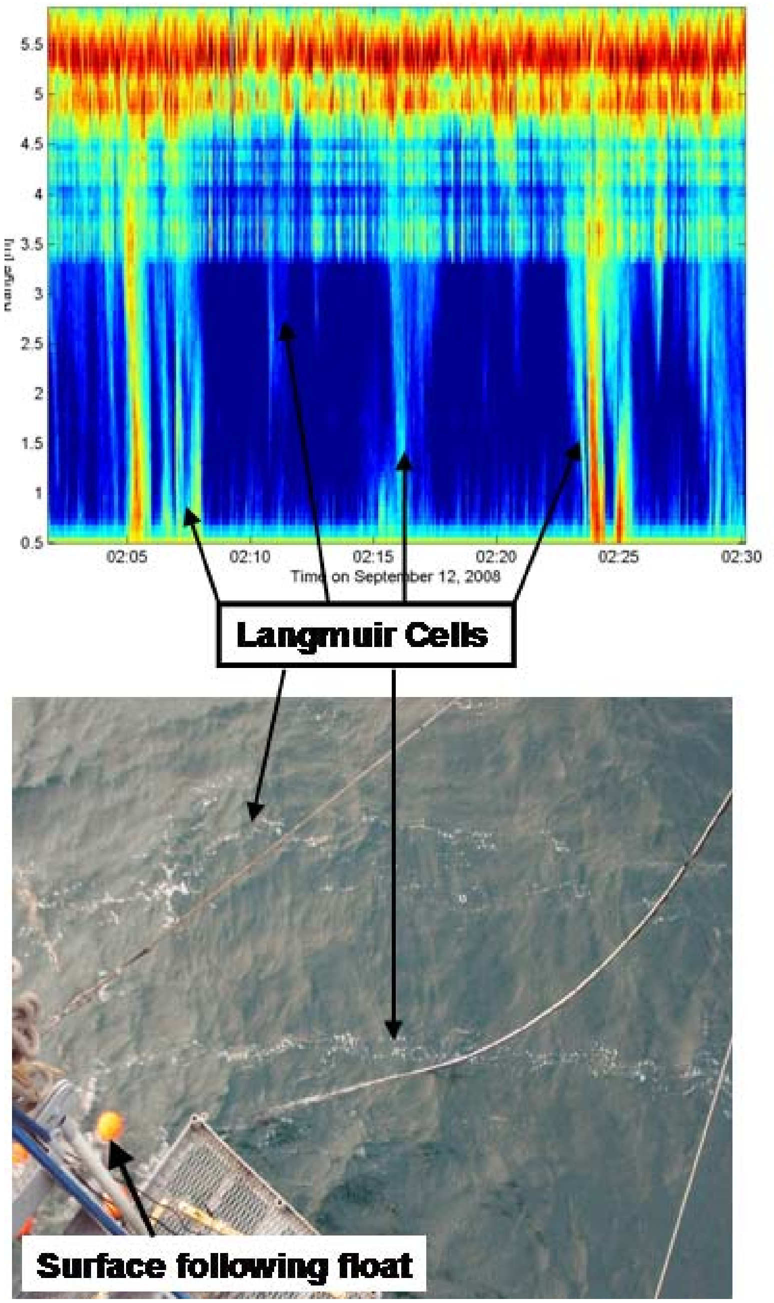

Figure 2: Foam and debris field associated with the downwelling regions of Langmuir cells drifting by the surface following float and FLIP during the evening of September 12th, 2008. The drift speed was monitored with sidescan sonars mounted at a depth of 30 m on FLIP’s hull.

Surfactants Fields during the Santa Barbara Channel RaDyO experiment

The Surface MicroLayer (SML) was collected from a radio-controlled microlayer sampler (Figure 3) and by using a glass plate lowered vertically into the water from a small boat.

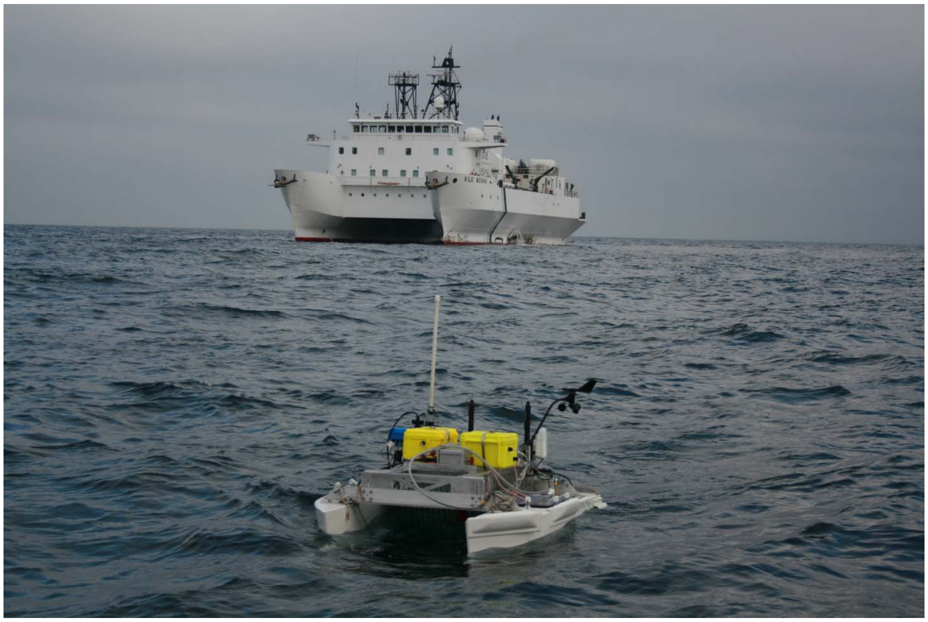

Figure 3: Surface MicroLayer (SML) sampler running transects ahead of R/V Kilo Moana in Santa Barbara Channel, September 2008. The sampler can collect up to 8 sets of SML and bulk-water samples during each mission. The sampler was also equipped with a 1.7 m mast with WET Labs ECO backscatter sensors, an optode dissolved oxygen sensor and an array of up to 5 fast response thermistors. The sampler was deployed from the back of Kilo Moana for 1.5-2 hour deployments.

During the first days of the RaDyO experiments, small and large slicks were observed in the study area. Sea-surface microlayer samples have been skimmed within such areas as well from non-slick areas and different particle concentrations were observed between the Surface MicroLayer (SML) and bulkwater collected at a depth of 1 m. In addition, water from the CTD was collected several times for analysis of surfactant contents. Figure 4 shows an example of surfactant content obtained from these data.

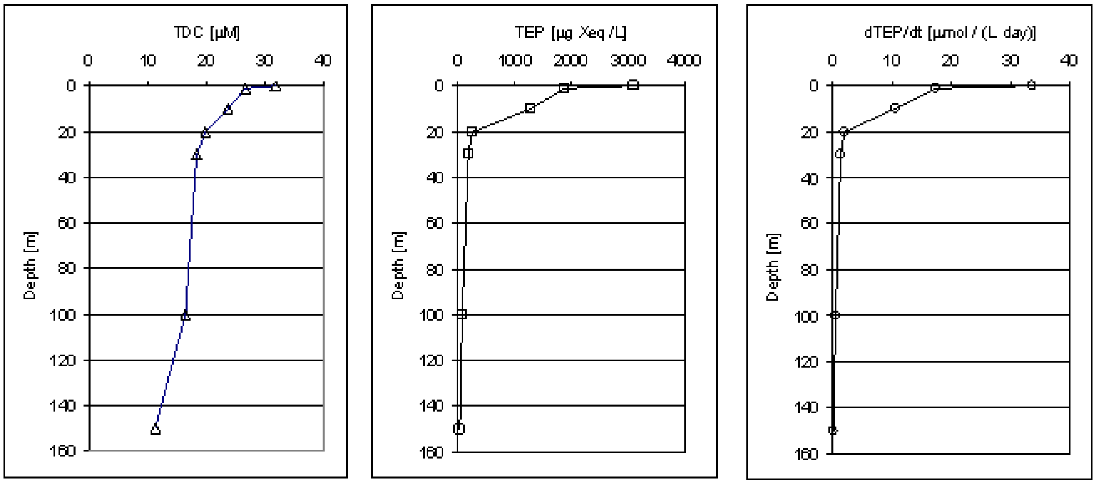

Figure 4: Deep profiles showing accumulation of surface-active substances in surface waters. a) of total dissolved carbohydrates (TDC), b) transparent exopolymer particles (TEP) and c) production rate of TEP from the aggregation of carbohydrates calculated according to Engel et al. (Engel et al. 2004, Nature 428, 929).

Analysis on chromophoric dissolved organic matter (CDOM), conducted by Dariuz Stramski’s group onboard the Kilo Moana through absorption analysis, indicated that CDOM in the SML (non-slick) is typically 10 to 50% higher compared to bulkwater concentrations. CDOM absorption in SML samples collected from slicks is higher by > 100%. It was rather surprising to find higher CDOM absorption in SML samples (50% higher) during higher sea states, with wind speeds of up to 8 m/s. Selected samples have been measured on particle absorption and very distinctive absorption spectra have been found in the SML compared to bulk water samples. Soot particles, deposited from the atmosphere and floating in the SML, may be the source of the differences in the absorption spectra.

Further onboard analysis on forward/backward scattering and particle size distribution conducted by Darius Stramski, has shown other new features of the SML with high scattering and unique particle size distributions, which may lead to new insights in the light absorption through the ocean surface.

RELATED PROJECTS

The development of a high-frequency, tiny bubble detection device is progressing under a separate RadyO project (N000140610379). This project is also highly integrated into several of the other RadyO projects.

REFERENCES

Terrill, E. & M. Lewis, 2004, Tiny bubbles: and overlooked optical constituent. Oceanography, 11, 11.