Coastal Bubble Sensors and Deployment Methods

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Abstract

Microbubbles generated by wave breaking in coastal areas have significant effects on underwater acoustic and optical propagation and contribute to marine aerosol production. So far, only very limited field measurements of these bubbles have been made, mainly due to the the difficulty involved in designing suitable bubble sensors and deployment techniques in these highly dynamical situations.

In this paper, we shall first review the state of the art of bubble sensors, which are based on optical, acoustical and electrical characteristics of bubbles. Next, we examine various techniques for deploying these sensors in the littoral zone, in order to measure both spatial and temporal variations of bubble fields.

Finally, we shall describe our (NRL) efforts, in the last several years (1997-1999) in developing new bubble sensors, deployment techniques, and their usage in three large-scale field experiments at the US east coast. Examples of bubble size density and distributions obtained from these experiments shall be presented also.

1 Introduction

Breaking waves play a very important role in nearshore dynamics. Their principal effects are loss of energy/momentum to cause rip currents, longshore currents, and sediment transport. Another important effect of breaking waves is air entrainment into the water in the form of bubbles ranging in radius from about 10 microns to several centimeters. These bubbles affect the heat and mass transfer across the sea surface, and further cause strong effects on underwater acoustics and optical scattering and propagation. As bubbles escape from the surface and burst into smaller droplets into the air above, salt particles are formed. These particles are the main components of near surface aerosols that absorb strongly in the infrared light spectrum.

This paper is divided into three parts. The first part reviews the bubble sensors; their different purposes and operating principles. The second reviews the deployment techniques for installing the bubble sensors into the coastal waters. The third part describes our (NRL) efforts in the last several years in participation in field experiments using newly developed sensors and deployment techniques, with several typical examples of bubble data and their characteristics from these field experiments. Useful references are: Thorpe (1982) and Leighton (1994).

2 Bubble Sensors

There are three major classes of sensors for measuring oceanic bubbles generated by wave breaking - either swell-type or wind generated waves. The first class measures the total amount of air entrainment (regardless of the size of bubbles) at a particular point in space, expressed as the percentage of air within a unit volume of seawater. This physical quantity is normally called void fraction. The second class of sensors measures the distribution of various sizes of bubbles and their respective numbers within a unit volume of seawater. This physical quantity is usually called the bubble size distribution (or density). Clearly, the second class of bubble sensors provide more information about bubbles generated than the first class of bubble sensors - since the bubble size distribution can be integrated to determine void fraction. In general, the second class of sensor are more sophisticated, and harder to design, construct, and calibrate. The third class of sensor measures the position and movement of various sizes of bubbles using consecutive exposures of bubble images.

Another way to classify bubble sensors is by the physical principles on which the sensors are based. Since oceanic bubbles cause various optical, acoustical and electromagnetic effects, we can make use of one of those effects as a means to measure the bubble quantity. Therefore, there are are various optical sensors, acoustic sensors and electromagnetic sensors for bubble measurement.

Obviously, the above different types of sensors have differing accuracy, noise-to-signal problems, relative ease in data processing, statistical errors, and relevant sampling volumes. Some sensors are more suitable for use in the laboratory for more accurate and controlled experiments, while others are more suitable for employing in the ocean, where the problems caused by wave action and bio-fouling are most prominent, so that robust sensors are more appropriate.

In this paper we shall discuss briefly the relative advantages of and limitations of the these classes of sensors, and their underlying design principles. Some pertinent references in this regard are: Johnson and Cooke (1979), Su et al., (1988, 1994), Breitz and Medwin (1989), Lamarre (1993), Farmer et al. (1998), Vagle and Farmer (1998), Phleps and Leighton (1998), Bowyer (1999) and Su, Wesson and Burge (1999).

3 Deployment Techniques for Coastal Bubble Measurement

Once we have some kinds of bubble sensors in hand (either off the shelf or custom made), the next problem we face is how to deploy them in the coastal water with mean water depth (D) less than 20 m. Since the the tidal variation of up to 1.5 m and significant wave heights of up to 2 m are fairly common in Atlantic and Pacific coasts, we may further divide the coastal zone into two regions with a mean water depth of 5 m as a dividing line.

Furthermore, since the bubble density and/or void fraction, generated by surface wave breaking, has the highest value near the surface and lower values for deeper water, we would obtain the maximum information about the bubble characteristics by deploying bubble sensors near the surface with additional sensors, if available, located further below in order to obtain a depth profile of the bubble characteristics.

For the coastal region ($20\,\mathrm{m} > D > 5\,\mathrm{m}$), the conventional surface following buoy with attached cables anchoring it to the sea bottom is the best technique for deploying a vertical array of bubble sensors. For the region ($D < 5\,\mathrm{m}$), which includes the surf zone, where most consistent wave breaking occurs, the surface following buoy is not suitable due to the large and rapid surface variation as well as slower tidal depth variation. In the past, almost all the sensor deployments, whether for current, wave height, sediment or other purpose, have used botttom fixed structures to mount sensors. However, due to the special characteristics of bubbles, with their highest values near the surface, these conventional bottom-fixed techniques are not ideal. To improve this situation, we have developed a new deployment method for the surf zone, called the swing-bar technique. This technique uses a neutrally buoyant rigid bar with length about 1.5 times the mean water depth. Its bottom end is hinged and anchored to the sea bottom, and its upper end has a float attached to maintain it at the moving sea surface. The bubble sensors and an inclinometer are attached along the bar. With this deployment, the maximum information on bubble characteristics over the local depth may be obtained. The swing bar system is shown in Figure 1. Void fraction sensors along the staff sample different depths, and when the staff is nearly horizontal, the seaward sensors detect void fraction plumes before the shoreward sensors. References for more information on the deployment techniques are: Su, Burge, Wesson and Teague (1998), and Su, Wesson, Burge and Teague (1999a)

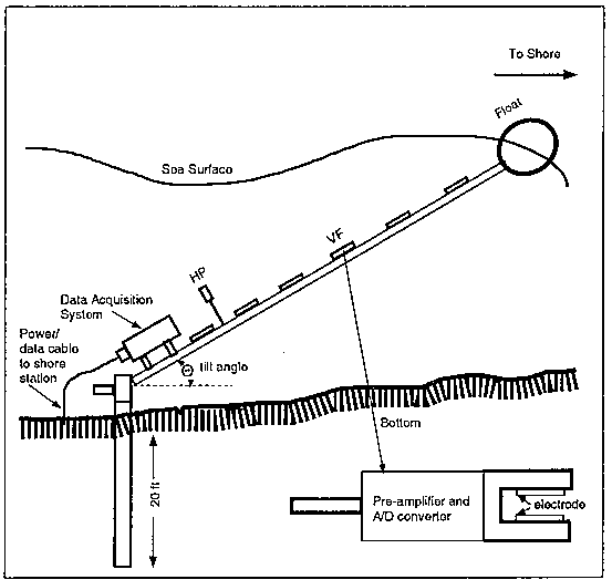

Figure 1: A schematic of the swing-bar void fraction sensor deployment system. The void fraction sensors on the staff use an electromagnetic technique to detect air fraction in the water.

4 NRL Field Experiments

During the last three years (1997, 1998 and 1999), NRL has participated in three large-scale joint coastal field

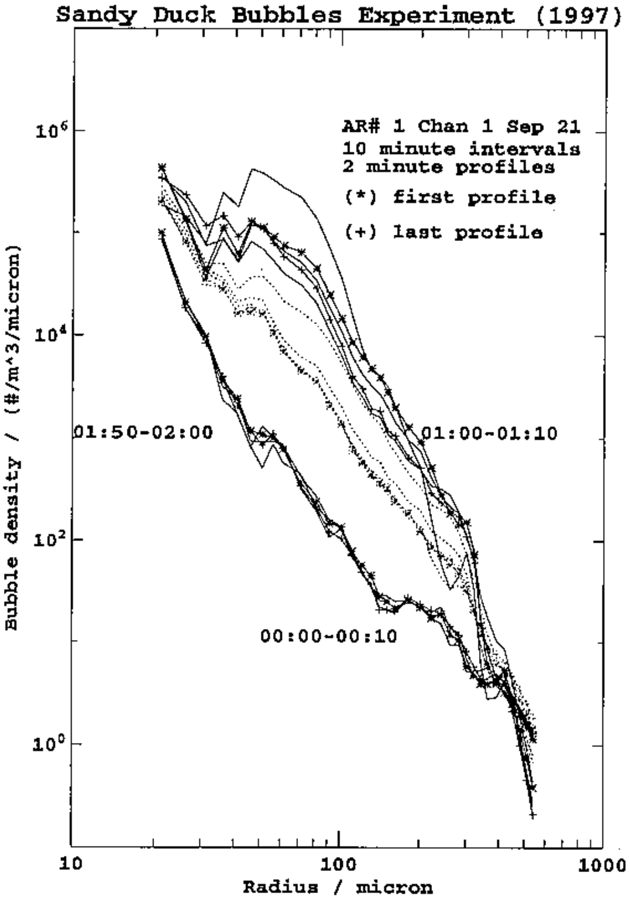

Figure 2: Bubble distribution variation shown as ten minute sections of data, showing the variation of bubble density with time. These data were from a floating array 2.3 km offshore in 14 m depth water. The dashed curves correspond to 01:50-02:00.

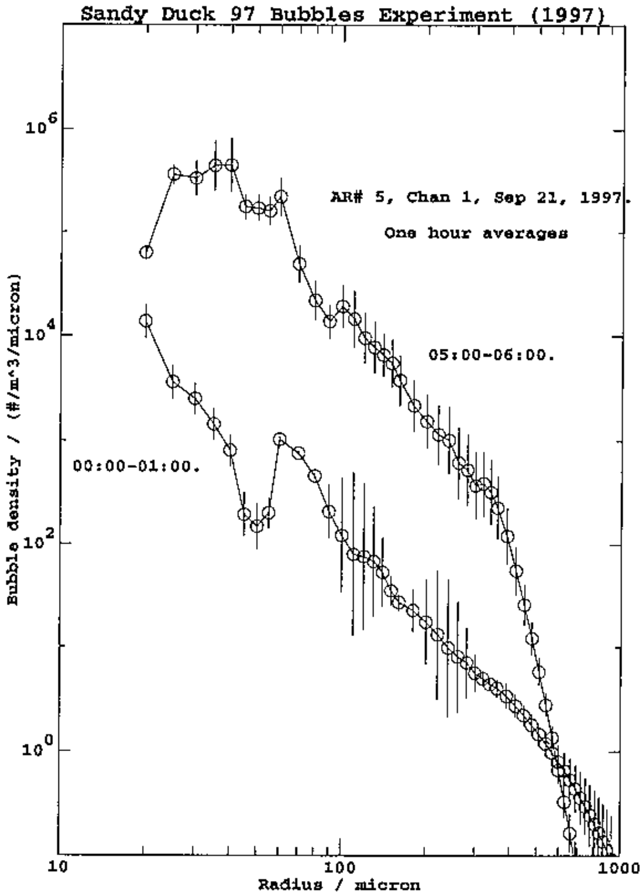

Figure 3: Bubble distribution for before and after the arrival of the storm in the inshore acoustic resonator system.

experiments with many other research groups at the Field Research Facility of the US Army Corps of Engineers at Duck, NC. The NRL-SSC team's main interest in these experiments has been to obtain the bubble characteristics in the coastal zone with ($D < 15\,\mathrm{m}$) and within about 2 km offshore. For the 1997 and 1999 experiments we deployed two kinds of of bubble sensors, one for void fraction measurement using the electromagnetic principle, and one for bubble size distribution using the acoustic princicple. We used both sensor types on conventional surface following buoys and deployed void fraction sensors using the new swing-bar technique. For the 1998 experiment, the bubble sensors were mounted on the FRF Sensor Insertion System (SIS), which is a movable platform traveling on the 600 m pier at the Duck facility. The SIS has a long ($> 20\,\mathrm{m}$) crane for inserting instruments into the water alongside the pier.

We shall present briefly in this paper several major finding from these three bubble experiments about the temporal and spatial variation from offshore toward the surf zone, and under various weather conditions. More detailed descriptions can be found in the following papers by NRL and other researchers Birkemeier (1997a,b), Su, Burge, Wesson and Teague (1998), and Su, Wesson, Burge and Teague (1999a,b).

The following figures present data taken during the Sandy Duck 97 field experiment. This was a very large cooperative experiment conducted from August-November, 1997 at the Duck Field Research Facility on the North Carolina (US) coast. We deployed four floating vertical arrays with acoustic resonators from 0.9 to 2.3 km offshore, in water depths of 8 to 14 m. We also deployed one bottom anchored acoustic resonator array in the surf zone, at a water depth of 4 m, and three void fraction swing-bar staffs in the surf zone from 4 m depth to 1.6 m depth.

Floating array data is shown in shown in Figure 2. These data were obtained at 2.3 km offshore by a floating array of acoustic resonators, just before and after the arrival of a storm. At the start of storm there were high winds which caused breaking of short waves. Although significant wave heights continued to increase, wave steepness was highest at the beginning of the storm. This figure also shows that the predominant growth in the bubble density is for the radius range from 30 to 300 microns for the initial strong wind forcing.

In the same storm, the response of acoustic resonators on a bottom anchored frame in the surf zone are quite different than the offshore resonators. This is demonstrated by the acoustic resonator bubble densities shown in Figure 3. At this location the peak bubble density occurs only after significant wave heights have reached their maximum. For the period from 00:00-01:00 there is essentially no effect of the storm on bubble densities. The peak bubble density occurs at 05:00-06:00, five hours after the storm front arrived. The differing responses of the bubble density to the wave conditions at the offshore and surf zone locations is shown in Figure 4. The upper panels show the variation of wind speed, wave height, and wave slope as the storm arrives at approximately 00:40 in the morning of September 21, 1997. Wind speed and wave slope both increase rapidly near their peak values, but significant wave height grows much more gradually. In the lower panel, the average void fraction (obtained by integrating the bubble density distributions) and associated sound speed due to bubbles, as measured by the acoustic resonators outside the surf zone, are generated rapidly due to the higher wave slope and wave breaking. Inside the surf zone the void fraction grows more slowly, following the growth of wave height.

A brief example of data from the void fraction staffs mounted in the surf zone is shown in Figure 5. This data was obtained during a storm later in the Sandy Duck 97 experiment. The features demonstrated by this figure are (1)the peak void fraction is measured by sensor VF1, which is nearest the surface and (2)the void fraction signal is detected first in sensor VF6, which is furthest offshore, even though this is the deepest sensor. The data from the void fraction staffs has been further analyzed to characterize the temporal and spatial characteristics of the many void fraction plumes sampled during the experiment.

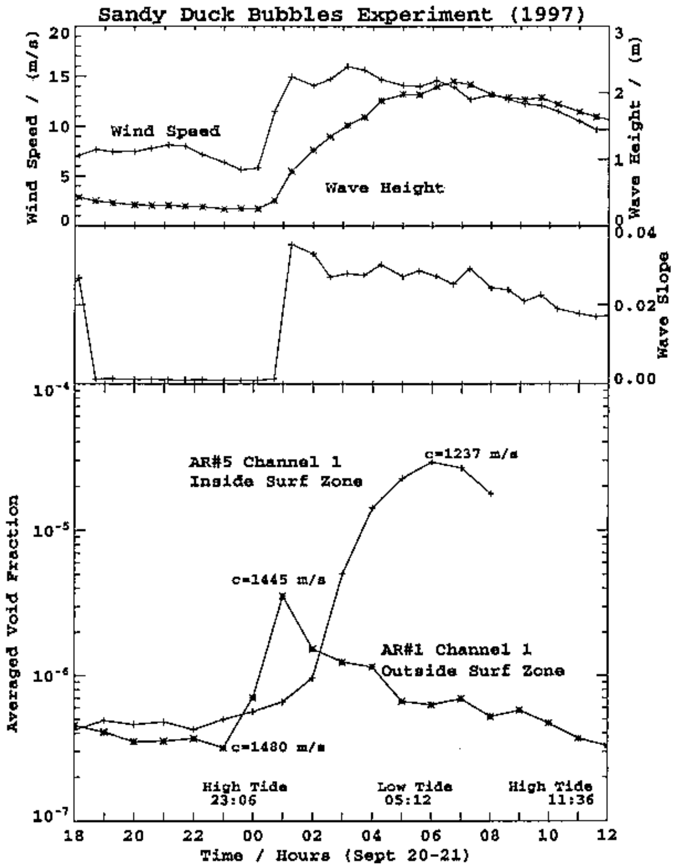

Figure 4: Environmental forcing - wind speed, wave height, and wave slope in the upper panels, and bubble void fraction and sound speed in the lower panel. The bubble density outside the surf zone responds directly to wind speed and wave slope, while the bubble density inside the surf zone follows the wave height.

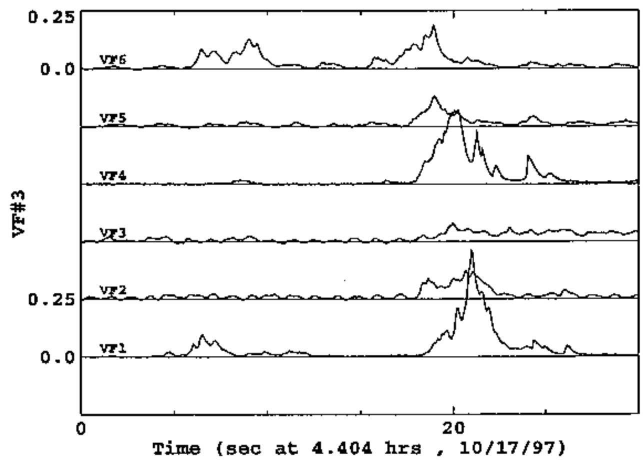

Figure 5: Void fraction staff measurements of a bubble plume advected shoreward. The deepest sensor (VF6) detects the wave first, while the largest value of void fraction is in the shallowest sensor (VF1).

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