AUTONOMOUS SPAR-BUOY MEASUREMENTS OF BUBBLE POPULATIONS UNDER BREAKING WAVES IN THE SEA OF THE HEBRIDES

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Abstract: *An understanding of the evolution of bubble clouds under breaking waves in rough at-sea conditions is important for assessing the role of such wave-generated activity on climatologically important processes. These processes include the fluxes between atmosphere and ocean of mass, heat and momentum. This paper describes the development and testing of sensors for an experiment which forms the first stage in a project to combine at-sea measurements and modelling to elucidate bubble cloud evolution and its role in the above fluxes. It was undertaken as a component of DOGEE (Deep Ocean Gas Exchange Experiment), which in turn is part of UK SOLAS (Surface-Ocean / Lower-Atmosphere Study) funded by the UK Natural Environment Research Council. Sensors are mounted along the length of an 11 m autonomous spar buoy, which was deployed off RRS Discovery. The upper part of the buoy, which protruded above the ocean surface, and was equipped with downward-looking video which monitored wave activity, a feature also monitored using capacitive wave wires. Below the surface, bubble populations and size distributions were measured using acoustic sensors. The data are to be compared with a model for the evolution of wave-generated bubble clouds to estimate gas transport and flux.*

Keywords: *Bubbles, atmosphere/ocean gas flux, underwater acoustics, ocean waves*

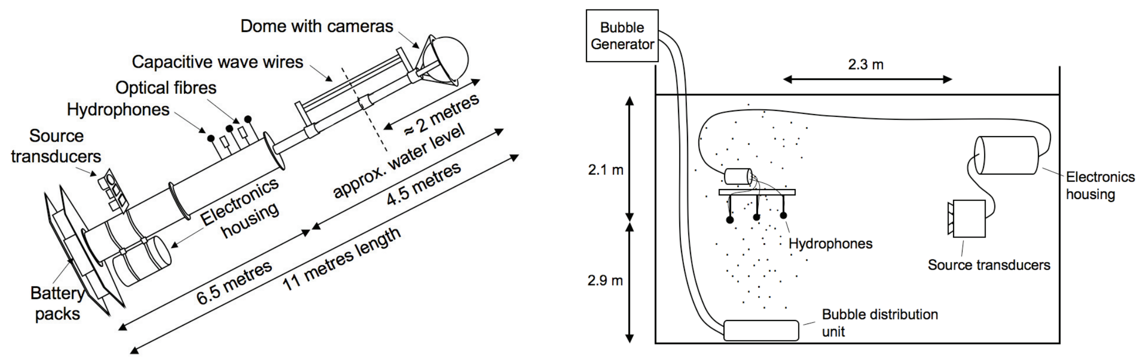
1. INTRODUCTION

The measurement of bubbles at sea is important for increasing the current uncertainty in our knowledge of how trace gases are exchanged between the air and the sea [1]. Bubbles provide a significant contribution to the transfer of gases between the sea surface and the atmosphere, and parameterisation of these bubble populations would increase the accuracy of climate change models [2]. A range of techniques is available [3], including combination frequency methods [4] and techniques based on narrowband pulses [5]. If such measurements are to be exploited effectively, then it is important to include with these measurements ancillary environmental data (air and sea temperatures, wind speeds, etc.) and to incorporate the investigation into a wider study which involves air-sea flux measurements, tracer patch measurements, etc.

This paper describes the development of a spar buoy for use in such a study. Tanks tests and a preliminary test deployment from *RRS Discovery* in the Sea of the Hebrides are reported here. This investigation formed part of the DOGEE (Deep Ocean Gas Exchange Experiment) SOLAS (Surface-Ocean Lower-Atmosphere Study) initiative.

2. APPARATUS

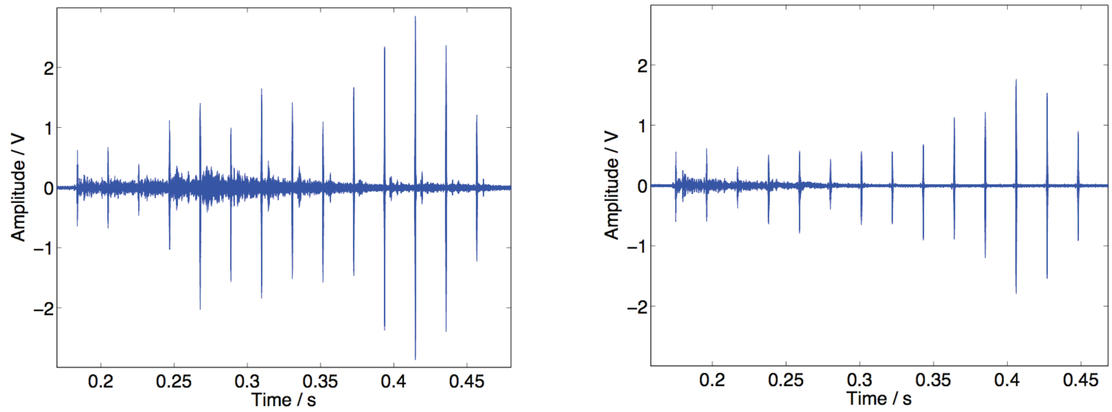
Fig. 1(a) shows the buoy. The mid-section contains acoustic sensors and optical fibres for bubble detection. The base of the buoy contains battery packs, acoustic sources and electronics housings. The top section (which works independently of the mid-section) contains capacitive wave wires to monitor wave height and, above water, a dome containing downward-looking cameras. The electronics housing for the acoustic system contained a MagnumX 1000 computer, which controlled the equipment as well as generating the output waveforms. Data acquisition was accomplished using a National Instruments PCI-6110 multifunction DAQ card. Power distribution (Vicor DC-DC converters) was also handled inside the housing, as were the power amplifiers which were custom designed and built by Paul Doust of Blacknor Technology. The hydrophones used were D/140 broadband hydrophones. Optical fibres provide an independent measure of void fraction. They were not used on the first sea trial.



(a) *(b)*

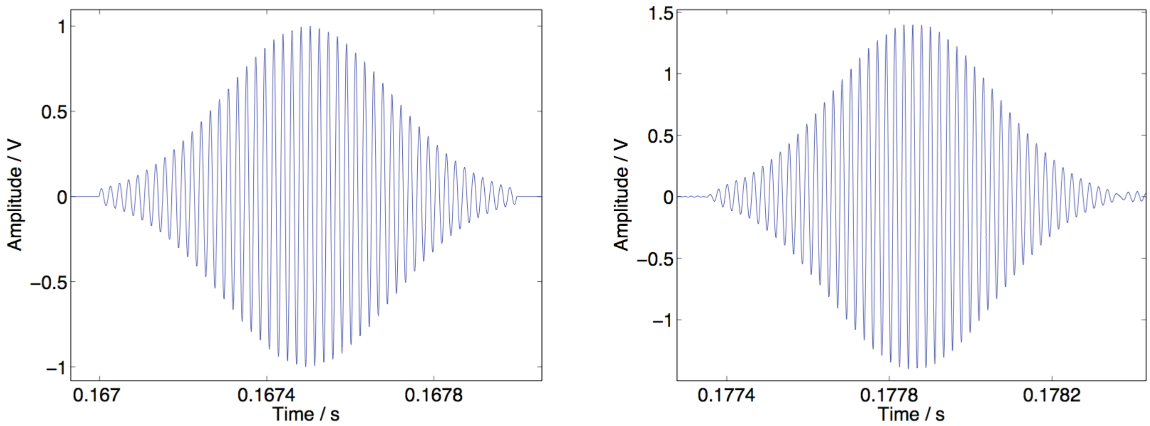
Fig. 1: (a) *Schematic (not to scale) of the buoy which, at sea, is vertical with the dome at the top. (b) Tests in the 8×8×5 m^3 AB Wood tank (Hydrophone spacing: 0.31 m).*

The buoy was designed such that the side containing the hydrophones and wave wires was presented first to the approaching breaking waves in order that there be no interference on the measurements from the hull of the buoy. Hydrodynamic tests were carried out in waters next to the National Oceanography Centre Southampton in order to ensure correct angular rotation of the buoy. Ancillary data taken on the first *RRS Discovery* cruise are listed in reference [6].



(a) *(b)*

Fig. 2: (a) The pulse train measured at the second hydrophone with no bubbles present. (b) The increased attenuation at the same hydrophone when there are bubbles present.

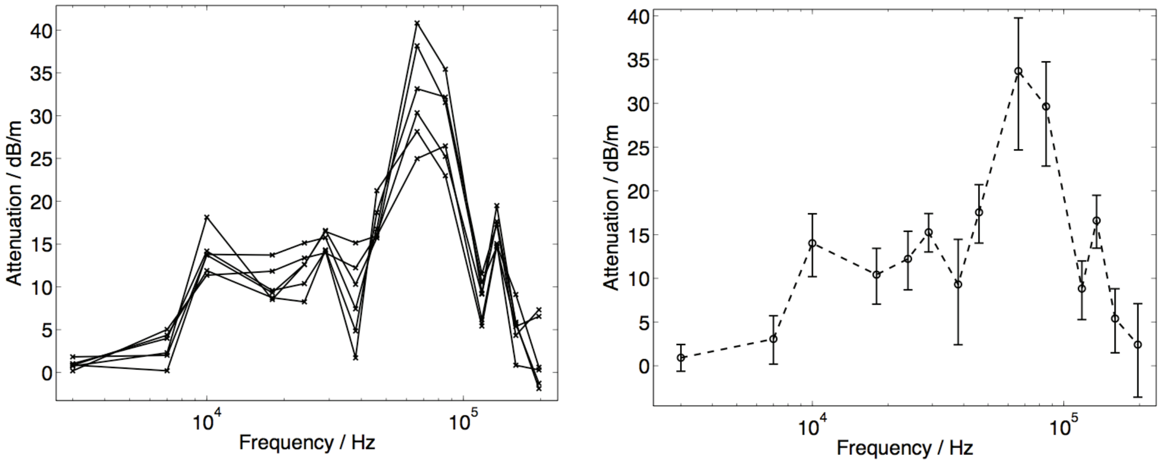


(a) *(b)*

Fig. 3: (a) The outgoing 46 kHz pulse signal that was transmitted to the power amplifiers prior to output into the water. (b) The same pulse as measured by the hydrophones in bubble-free conditions.

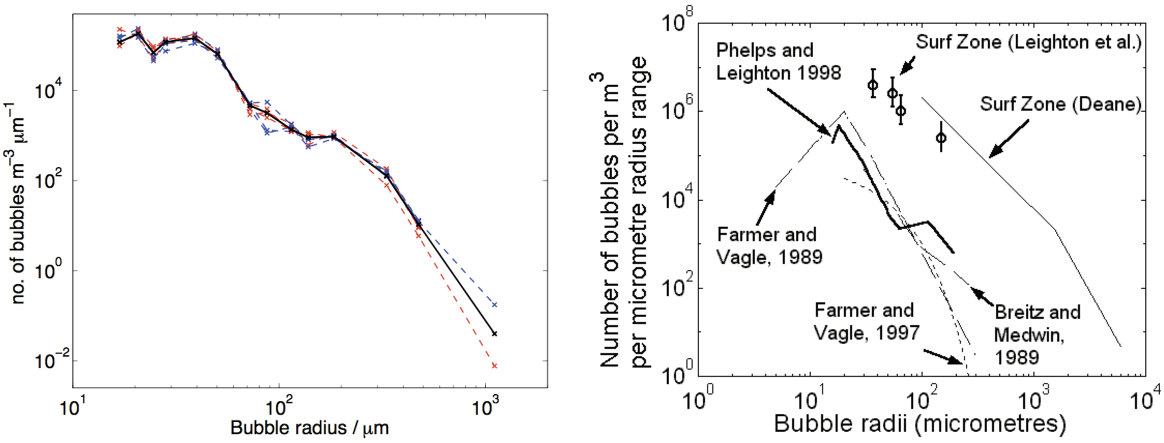
3. TANK TESTS: METHOD

Fig. 1(b) shows the test setup in the tank. The outgoing signal was a train of 14 pulses, varying in frequency from 3 to 197 kHz (Fig. 2). This enabled measurements for bubble sizes ranging from 17 – 1107 μm in radius to be carried out. Each pulse was 1 ms long, short enough so the received signal was not to be affected by any multi-path reflections. There was a 20 ms off-time between pulses to allow for bubble ring-down. The time between pulse trains was approximately 1 second, dictated by the speed at which the computer could save the data files. The attenuation between the hydrophones at each frequency was measured. To generate bubbles, a Venturi system designed to produce a population similar to that which will be encountered at sea was used [7] (Fig. 1(b)). The pulses in the water were specifically designed to follow with high fidelity the waveforms supplied by the data acquisition card (Fig. 3). This was achieved largely owing to the technical input from Paul Doust.



(a) *(b)*

Fig. 4: (a) The additional attenuation due to bubbles between the 1st and 3rd hydrophones, which were at a distance of 0.62 metres apart. The figure shows 6 separate readings, spaced approximately 1 second apart. (b) The mean of the 6 values shown in (a) (calculated from linear pressure data, not dBs). The error bars represent 1 standard deviation from the mean of the 6 values and also take into account the uncertainty of the hydrophone calibrations.



(a) *(b)*

Fig. 5: (a) Bubble size distributions as calculated from measured attenuations. The bold black line shows the 6 second average population, the dashed lines show the six individual populations which make up the average. (b) Previously measured oceanic bubble populations (taken from [8], where the sources are listed in full).

4. TANK TESTS: RESULTS

An example of the measured attenuation due to bubbles is shown in Fig. 4(a) & (b). The error bars in Fig. 4(b) are at times large because of the fluctuating nature of the bubble cloud as it rises through the tank. The mean attenuation data from 6 readings were inverted following the method of reference [9] to obtain bubble size distributions (Fig. 5(a)). As would be expected from Fig. 4, very few bubbles were found at the largest bubble radius (1107 μm). The distribution measured in the tank (Fig. 5(a)) is very similar in gradient and magnitude to historical measurements (Fig. 5(b)). The bubble populations shown in Fig. 5(a) were those exploited in references [10,11].

5. AT SEA PROOF-OF-CONCEPT

On 29th November 2006 the buoy was deployed in the Sea of the Hebrides (56°49.73017' N 006°00.12459' W) (Fig. 6). Data was recorded for 2 hours before the buoy had to be recovered owing to deteriorating weather conditions (Fig. 7).

(a) *(b)*

Fig. 6: (a) The 11 metre spar buoy being deployed off RRS Discovery. (b) The spar buoy as it sits in the sea.

Both the acoustic and the camera systems worked well at sea. However, since the physical handling of the buoy was challenging, and the weather very rough (at times reaching storm force 11, Fig. 7), the ship was taken to relatively sheltered waters for this test deployment, where the bubbles did not penetrate in sufficient numbers to the depths of the hydrophones (3 metres) to give a statistically meaningful measurement.

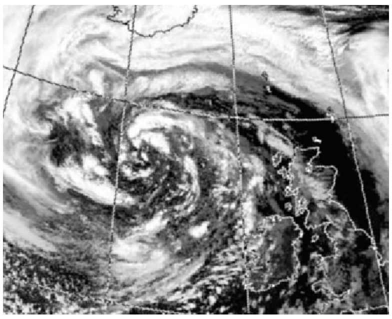


Fig. 7: Thermal infra-red image showing the low pressure systems in the area of operation (north-west of Scotland) during the cruise (picture used courtesy of NERC Satellite Receiving Station, Dundee University, Scotland, http://sat.dundee.ac.uk).

6. CONCLUSIONS

Bubble population information is vital in increasing the accuracy of the air/sea transfer components of ocean-based climate change models. This paper reports successful trials of a system designed to measure autonomously bubble populations in deep ocean. The second cruise is scheduled for 16th June to 18th July 2007 on the *RRS Discovery*. The aim is to measure bubble population data from a range of sea states.

7. ACKNOWLEDGEMENTS

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