P1.1 MEASUREMENTS OF BREAKING WAVES USING A UNIQUE FREE-FLOATING SPAR BUOY

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1. INTRODUCTION

The breaking of wind-generated waves plays a significant role in the exchanges of momentum, heat, water vapour, energy and gas between the atmosphere and the ocean. To date, direct measurement of breaking waves in the open ocean has been very limited. To this end an 11 m spar buoy (Figure 1) developed at the National Oceanography Centre, UK (NOC) was recently deployed during two UK-SOLAS funded cruises in the North Atlantic. The aim is to make direct measurements of wave breaking and subsurface bubble cloud populations. Measurements made from instrumentation on the buoy will be used to develop an improved parameterization of wave breaking (building on earlier work by Longuet-Higgins and Smith, 1983) and its contribution to gas exchange. Here we present an initial evaluation of the buoy using data obtained from the first cruise, which took place in November 2006.

2. SCIENTIFIC BACKGROUND

Measuring breaking waves in the open ocean is a challenging problem. In one of the first such measurements, Longuet-Higgins and Smith (1983) used a tethered 5 m spar buoy with a single capacitance wire to investigate the surface elevation and 'jump' associated with a passing breaking wave.

Other studies of breaking waves followed. Some have used waverider buoys (Holthuijsen and Herbers,1986; Banner et al., 2000) to measure the wave field. In both these studies an observer registered the passage of a whitecap over the buoy. Wave measurements were typically made at 4 Hz with record lengths between 34 and 68 minutes. On a smaller scale, Katsaros and Atakurk (1992) used a resistance wave wire gauge located on a tower in lake Washington and identified breaking waves via a video record. A number of plunging, spilling and micro scale breakers were identified. More recently Melville and Matusov (2002) have used video techniques from an aircraft to measure the distribution of whitecapping.

Here the approach originally used by Longuet-Higgins and Smith (1983) is developed further, taking advantage of newer technology. Unlike earlier systems, the NOC buoy has on-board power and data logging which means that the buoy can be free floating rather than tethered to the ship.

Figure 1 The NOC spar buoy deployed in the North Atlantic. The wave wire logging system and cameras were contained in the orange dome. The large hoop next to the dome was used for buoy recovery.

Oceanic bubble populations have been measured in the open ocean previously using both active and passive techniques. Active methods have used both combination frequency (Phelps and Leighton, 1998) and single frequency techniques (Leighton et al., 2004). Many of these experiments have produced good results but have been limited by the number of frequencies that could be used, or by the need to have a cable running from a control base to the equipment sending power and data.

In addition to measuring the properties of bubble clouds, passive acoustic systems have been used to detect breaking waves by the bubble clouds they produce. For example, Ding and Farmer (1994) used a free drifting hydrophone array to track individual breaking events. Recent work by Manasseh *et al.* (2006) used a fixed hydrophone, in conjunction with a capacitance wave wire gauge array and video camera, to detect breaking.

The NOC spar buoy uses both active and passive techniques and can operate over a larger range of frequencies than any other used before, and owing to an on-board computer and sufficient battery power, can run autonomously away from any other control devices.

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3. THE SPAR BUOY

The spar buoy is 11 m in length (Figure 2) and constructed of aluminium to save weight. Three 4 m capacitance wave wires (Figure 2) are arranged orthogonally with a separation distance of 0.1 m. The buoy is designed to float so that the wires are half submerged (Figure 1). The wires provided the information required to calculate the temporal and spatial wave slopes as well as surface elevation. The orange dome (the bottom half is transparent) contained the wave wire electronics and the digital video recorder and a stills camera. In addition, the buoy carried a 3-axis compass, which also outputs pitch and roll, and 3-component accelerometers to measure the motion of the buoy. These were included to determine the possible effects of the long waves on the motion and orientation of the buoy and hence on the wave measurements by the capacitance wires. Ideally the buoy will remain steady in the water, not heaving vertically, and so effectively act as a fixed platform from which the wave elevation can be measured as the waves propagate past it.

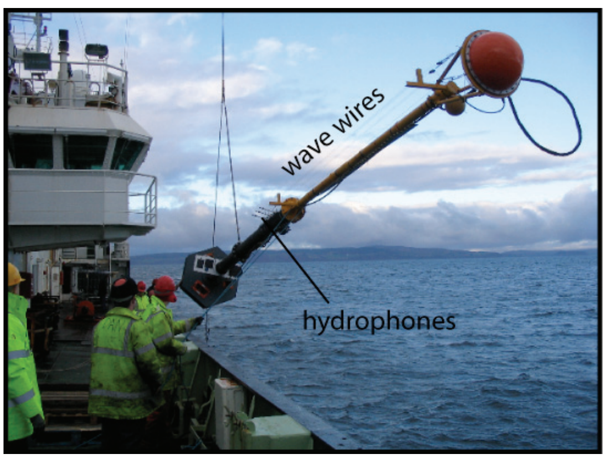

Figure 2 The NOC spar buoy deployed in the shelter of the Western Isles of Scotland, UK. The orange dome contains the wave wire logging system and cameras.

There were also 3 acoustic transducers and 3 hydrophones arranged along the length of the buoy in order to measure accurately the bubble cloud populations produced by the breaking waves (after the manner of Leighton et al. 2004). The transducers for the acoustic system are oriented upwards to face the sea surface and are mounted on the silver aluminium plate above the batteries at the base of the buoy. The array of three hydrophones was used to measure the signals from the transducers and can be seen in the middle of the buoy (Figure 2). The acoustic system electronics were located in a pressure housing directly behind the transducers.

The NOC spar buoy is a unique design. Its systems measure the wave field at a greater resolution than previous studies and was designed to be completely independent of the ship. The battery power available on the buoy allows maximum deployment times of approximately 5 days.

To aid recovery the buoy was located by an Argos positioning system, which was used for radio directional finding and also emails the buoy position every hour.

4. INSTRUMENTATION

4.1 Wave wire system

Wave heights and buoy motion were logged at 40.96 Hz with additional compass data logged at 8 Hz. The wave wires were calibrated pre-cruise and measured the wave elevation with a vertical resolution of 3 mm. The base of the dome was transparent allowing the camera systems to record the waves travelling past the wave wires.

The camera systems were synchronised with the logging time and both the video and stills cameras recorded images at pre-programmed times during daylight hours. Approximately 37 hours of video in Mpeg 2 format can be recorded before the data disk is full. The stills camera recorded 16 images at a resolution of 648x486 pixels over a period of 7 seconds (2.3 images per second) with a 7 second pause in-between each set of 16. The images are arranged in a single image format, composed of a 4x4 matrix (see Figure 4), at 5 Mpixels resolution. The images will fill the 2 Gbyte data card in approximately 17 hours of continuous acquisition.

4.2 Acoustic system

The buoy uses 3 source transducers in order to cover a range of frequencies from 3 to 200 kHz. The transducers are driven by custom designed and built power amplifiers. These amplifiers are designed to run off batteries and output a well-matched, high power source level in the region of 190 decibels.

The signal is measured using hydrophones mounted further up the buoy and digitally recorded using a data acquisition card. The whole process is controlled using a single board computer mounted inside a pressure housing.

The system transmits single-frequency pulses through a cloud of bubbles and measures the attenuation due to the bubbles. The pulses are 1 ms long and are separated by 20 ms.

5. BUOY PERFORMANCE

Five buoy deployments were made during the first *RRS Discovery* cruise, which took place in November 2006. Due to exceptionally bad weather the ship was forced to seek shelter amongst the Western Isles of Scotland, UK. This provided a good testing ground to evaluate the buoy systems before the second cruise, which will take place in June 2007.

The buoy was successfully deployed and recovered from the ship, a non-trivial task for such a large spar. Deployments lasted for periods of up to 3 hours, during which the maximum 10 minute averaged wind speed recorded by the ship's anemometer reached 18 ms^{-1}. The results showed that the buoy experienced vertical displacements of less than 0.01 m for significant wave heights (Hs) of 0.7 m to 1.1 m. The measured Hs from the buoy agreed well with *RRS Discovery's* ship-borne wave recorder. Breaking waves in the wave wire data (e.g. Figure 3) were identified from stills camera images (Figure 4). Further analysis of the wave wire data will develop an automatic thresholding algorithm to identify breaking waves, with the results being validated by the video and stills camera data.

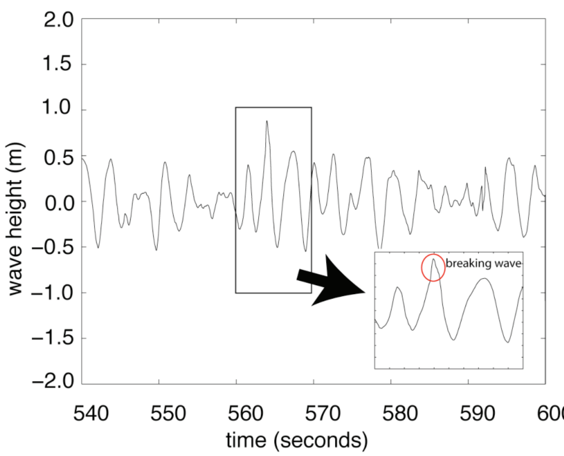

Figure 3 One minute sample of a wave wire trace. The inset panel shows a breaking wave identified from video and stills camera images.

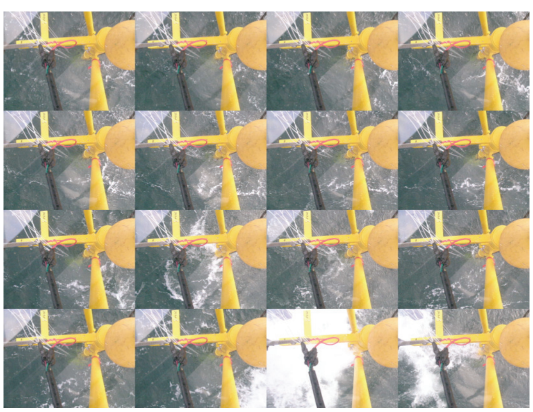

Figure 4 Images from the stills camera showing the breaking wave measured in Figure 3, which can be seen by its white water signature in the bottom row.

During the first cruise the acoustic system proved it can function very well in oceanic waters and transmit, receive and record acoustic pulses over a wide range of frequencies. Unfortunately due to the sheltered conditions in which the buoy was deployed the breaking waves were not large enough to produce bubble clouds that could be detected. It is hoped more acoustic data will be acquired during the second cruise in June 2007.

6. SUMMARY

The NOC spar buoy has been designed to be independent of the ship and measure the wave field at a high vertical and temporal resolution. Significant progress was made from the trial deployments undertaken during the first cruise. These include:

1) successful deployment and recovery from the ship
2) successful trial deployments performed in the seas off the Western Isles of Scotland, UK.
3) waves heights were successfully measured from all three wave wires
4) breaking waves were clearly identified using the camera systems
5) a number of breaking waves have been identified in the wire data and verified from camera images.

***ACKNOWLEDGEMENTS*:** The DOGEE project was funded by the UK Natural Environment Research Council, grant number NE/C001834/1. We would like to thank the Captain and the crew of the *RRS Discovery*.

REFERENCES

Banner, M. L., A. V. Babanin and I. R. Young, 2000: Breaking probability for dominant waves on the sea surface. *J. Phys. Oceanogr.,* **30**, 3145-3160.

Ding, L. and D. M. Farmer, 1994: Observations of breaking surface wave statistics, *J. Phys. Oceanogr.,* **24**, 1368-1387.

Holthuijsen, L. H. and T. H. C. Herbers, 1986: Statistics of breaking waves observed as whitecaps in the open sea, *J. Phys. Oceanogr.,* **16**, 290-297.

Katsaros, K. B. and S. S. Ataktürk, 1992: Dependence of wave breaking statistics on wind stress and wave development, *Breaking Waves*, M. L. Banner and R. H. J. Grimshaw, Eds. Springer, 119-132.

Leighton T. G., S. D Meers, and P. R. White, 2004: Propagation through nonlinear time-dependent bubble clouds and the estimation of bubble populations from measured acoustic characteristics*, Proceedings of the Royal Society of London, Series A (Mathematical, Physical and Engineering Sciences)*, **460**(2049), 2521-2550.

Longuet-Higgins, M. S. and N. D. Smith, 1983: Measurement of breaking waves by a surface jump meter, *J. Geophys. Res.,* **88**, 9823-9831.

Manasseh, R., A. V. Babanin, C. Forbes, K. Rickards, I. Bobevski and A. Ooi, 2006: Passive acoustic determination of wave-breaking events and their severity across the spectrum, *J. Atmos. Oceanic. Technol.,* **23,** 599-618.

Melville W.K. and Matusov P. 2002 Distribution of breaking waves at the ocean surface, *Nature*, **417**, 58-63.

Phelps A. D. and TG Leighton, 1998: Oceanic bubble population measurements using a buoy-deployed combination frequency technique, *IEEE Journal of Oceanic Engineering*, **23**(4), 400-410.