

# REPORT DOCUMENTATION PAGE

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## **Final Report**

### **Directional Properties of surface waves observed with HF radar**

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#### **ABSTRACT**

The goal of the work at Sheffield is to demonstrate that wave measurements obtained using HF radars are of sufficient accuracy and availability for them to contribute to the investigation of changes to the directional spectrum of waves subject to meteorological, bathymetric and current variability in coastal environments for both scientific and operational applications. This report summarises the measurements made with the OSCAR HF radar, in collaboration with the University of Miami, during the SHOWEX experiment in fall 1999 using inversion algorithms developed at the University of Sheffield. The data set obtained contains interesting examples of shoaling waves and fetch limited wave development but the amount of data obtained was limited by the hardware constraints of the OSCAR system. Comparisons with directional wavebuoys confirmed the results of earlier work that signal-to-noise and antenna sidelobes are the main sources of error in the radar wave measurements.

#### **OBJECTIVES**

My objectives for this program of research were:

- a) to measure the directional properties of surface waves in the coastal ocean using the University of Miami OSCAR HF radar;
- b) to validate the measurements using other available data sources;
- c) to measure the evolution of the directional spectrum as the waves shoal;
- d) to determine the response of the directional spectrum to surface current shears and variable bottom bathymetry.

These were to be achieved through collaboration with the University of Miami during the Shoaling Waves Experiment (SHOWEX) which took place in the coastal waters of Duck, NC, USA in the fall of 1999.

#### **ACHIEVEMENTS AGAINST OBJECTIVES**

- a) The University of Miami group deployed their OSCAR HF radar at the FRF site, Duck, and at Corolla to provide measurements of the directional wave spectrum, surface currents and wind direction. The directional spectrum and wind direction

measurements have been made using a method developed at Sheffield over the last few years. All of the radar-derived spectral and wind data have been provided to the University of Miami on a set of 9 CDs. Copies can be provided on request and this information is included on our Showex website:

<http://www.shef.ac.uk/~sceos/environmental/showex/showex.html>

- b) Detailed intercomparisons with in-situ instruments have been made. We have completed intercomparisons with the directional waveriders (X1-X3). Comparisons with the ASIS buoys (Bravo and Yankee) were not possible during the period of the grant due to problems with their analysis that are being addressed at Miami. X1 was located at the edge of the radar coverage area where the signal-to-noise levels for the Corolla (northern) radar are at the limits for wave measurement. In fact we have reduced our usual signal to noise requirement in order to obtain more than a handful of measurements at this location. In previous work we have carried out detailed intercomparisons with wave buoys that have been located in the position that is optimum for signal-to-noise from both radars (e.g. Wyatt et al, 1999, 2003a) and have demonstrated good agreement. The SHOWEX experiment has provided us with an opportunity to look at deterioration in accuracy as we move away from optimum conditions. The results appear to be consistent with comparisons we have carried out in a similar situation in Spain using the WERA HF radar and between UK OSCR wave measurements and a wave model (Caires, 2000).

Our quality control procedures identify certain problems, including signal-to-noise levels, before further processing. Limited signal to noise levels are the main reason for, at most, 80% data return for this experiment.

Previous work has suggested that, at the edges of the region, antenna sidelobe influences are likely to be seen in the form of spurious contributions to the directional spectra and hence noise in derived parameters. On one occasion (2<sup>nd</sup> Dec 1999) the radar measurements are very different from the buoy measurements in both wave parameters and in the shape of the directional spectrum. This large difference is untypical. We have established that these differences are most likely to be due to antenna sidelobe effects which are a particular problem when there is a strong current as seems to have been the case on this day. A rough estimate of the antenna pattern has been obtained by examining the variation in amplitude of particular peaks in the Doppler spectrum and suggests that sidelobe levels are much higher than would be expected. This shows the importance of careful measurements of and, if needed, improvements to antenna patterns before any period of measurement. A paper on this work has been submitted for publication (Wyatt et al, 2003b).

Apart from the signal-to-noise limitation and the impact of antenna sidelobes, a number of other problems, both problems specific to this deployment and also limitations that are already under investigation from European HF radar deployments have been identified. Some attention has been focussed on radar signal processing developments with a view to understanding and alleviating some of these problems. In particular, we began an investigation into the use of the Continuous Complex Gabor Wavelet Transform using the WaveLab802 package (written by a team from Stanford University) of MatLab routines with a few

modifications to suit our needs. Preliminary results show some interesting variations in the amplitude of the first order Bragg peaks, however, it is not yet absolutely clear, whether they correspond to real dynamics or are just a result of statistical variability.

- c) Figure 1 shows an example of the sort of data we have obtained to demonstrate the measurement of the directional spectrum evolution as long waves shoal. The map shows significant waveheight and mean direction at each location where measurement was possible at this time. Full directional spectra at three locations showing changes across the region are also plotted in the figure. The spectra are clearly bi-modal. Close to the coast mean direction is mostly dominated by the swell from the south-east which turns more shore normal as it approaches the coast (lower spectrum). Further offshore the fetched-limited wind waves propagating towards the north-east are more dominant.
- d) There was not sufficient time to make any progress with this during the period of the grant. It was the subject of a new proposal but this has not yet been funded.

### **Collaboration arrangements**

The HF radar wave inversion and other processing software used during this project remain the property of the University of Sheffield. The work involved collaboration with Hans Graber at the University of Miami formalised with a Memorandum of Agreement which set out the individual roles and areas of collaboration. A licensing agreement (still under discussion) would enable Graber to use the University of Sheffield inversion software package.

### **References.**

- Caires S., 2000. *Comparative study of HF radar measurements and wave model hindcasts in shallow waters*. PhD thesis, University of Sheffield.
- Wyatt L.R., S.P. Thompson & R.R. Burton, 1999. *Evaluation of HF radar wave measurement*. Coastal Engineering, 37, 259-282.
- Wyatt L R , J J Green, K-W Gurgel , J C Nieto Borge , K Reichert , K Hessner, H Günther, W Rosenthal , O Saetra and M Reistad, 2003a. *Validation and intercomparisons of wave measurements and models during the EuroROSE experiments*. Coastal Engineering, 48, 1-28.
- Wyatt L R , G. Liakhovetski, H C Graber and B K Haus, 2003b, *Factors affecting the accuracy of Showex HF radar wave measurements*. Submitted to Journal of Atmospheric and Oceanic Engineering.

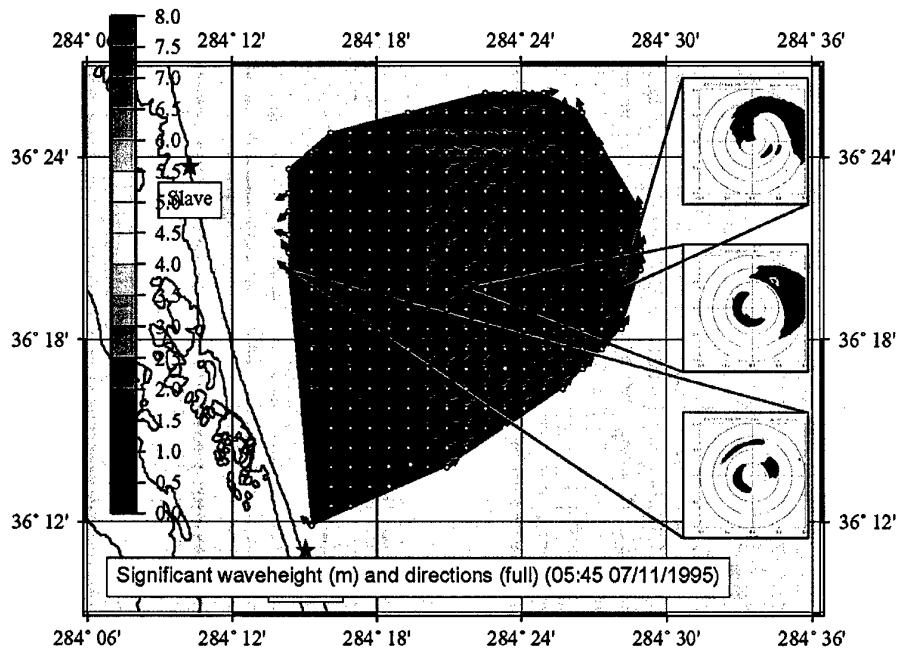


Figure 1. Significant waveheight (colour-coded) and mean direction (arrows) measured by OSCAR during SHOWEX. Directional spectra are plotted at three locations showing swell towards the north west and fetch limited wind sea towards the north east,. The transition from onshore to offshore mean directions is consistent with the directional spectra.

## APPENDIX

### Finance summary compared to budget.

|               | Budget \$      | Cost \$           | Budget £          | Cost £            |
|---------------|----------------|-------------------|-------------------|-------------------|
| Staff         | 99,200         | 96,860.54         | 60,132.15         | 58,714.03         |
| Travel        | 16,000         | 15,852.54         | 9,698.73          | 9,609.35          |
| Publication   | 1,600          | 1,066.45          | 969.87            | 646.45            |
| Miscellaneous | 9,600          | 10,798.49         | 5,819.24          | 6,545.73          |
| Overheads     | 49,600         | 49,599.86         | 30,066.07         | 30,065.99         |
| Equipment     | 0              | 2,114.03          | 0                 | 1,281.46          |
| <b>TOTAL</b>  | <b>176,000</b> | <b>176,291.91</b> | <b>106,686.06</b> | <b>106,863.01</b> |

### Equipment purchased

Sun Ultra 5 Model 36 workstation. Agreed with Tom Kinder, ONR, 18/4/2000.