Wave and Tidal Power measurement using HF radar

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Abstract

HF radar measurements are presented focussing in particular on the estimation of both wave and tidal power to demonstrate that HF radar has a role to play in both measuring the resource and providing monitoring data during power extraction, device installation, testing and operations..

Keywords: HF radar, wave power, tidal power, buoy.

1 Introduction

HF radar systems located on the coast measure surface currents and the ocean wave directional spectrum simultaneously from close to the coast to more than 100km offshore. A minimum of two radar sites is required to resolve the direction and amplitude ambiguities found for single radar measurements [1]. Measurements can be made from every 10 minutes to every hour and with spatial resolutions of 300m to 15km as needed. HF radar current measurement is now a well accepted technology and there are many systems of different types in operation around the world. The wave and current measurements, using methods originally developed at the University of Sheffield, have been validated in numerous short and long-term deployments at many different locations (e.g. UK [2,3,4,5,6], Norway [7], Spain [7], USA [8]) with several different radar systems: OSCR [4,5,8], WERA [8,9] and Pisces [6]. See www.seaviewsensing.com and follow ocean data links for more information and access to data from some of these deployments.

In this paper I present some HF radar measurements focussing in particular on the estimation of both wave and tidal power. There is a lot of interest in the UK and elsewhere in the exploitation of marine renewables and with this paper I hope to demonstrate that HF radar has a role to play in both measuring the resource and providing monitoring data during power extraction, device installation, testing and operations. One big advantage of HF radar is its siting on land so if there are any problems with the system these can be dealt with without any need to wait for weather windows, shiptime etc as would be required for offshore measurement systems. Furthermore all the data, both current and wave directional spectrum, can be delivered in near real time (within ten minutes of the radar data collection) over broadband links.

The measurements presented here were obtained during a trial of the Pisces HF radar system in the Celtic Sea which was completed in June 2005 [6]. A directional waverider was deployed about 60km away from both radar stations. Pisces can operate at a range of different radio frequencies in order to minimise the impact of interference and propagation conditions on metocean measurements. The accuracy of the measurements are also affected by waveheight with a low waveheight limit at low radio frequencies and a high limit at high frequencies. The Pisces trial was primarily at lower radio frequencies, 7-10MHZ, and provided the information needed to quantify the lower limit which affects primarily the spectral characteristics and not the waveheight. The lower limit is given by a low value for the product of the radio wavenumber and waveheight [10,11]. This criteria has been used to filter the wave spectral data presented here and thus there are some gaps in the radar coverage. For future operations this number should be used to automatically control the radio frequency to keep it above the limit.

2 Wave power measurement

The directional spectrum is measured by the radar up to a maximum frequency which depends on radar operating frequency being about 0.2Hz at the lower end of the HF radar band and 0.35Hz at the upper [12]. Below this upper limit the full directional wavenumber spectrum is the primary product from which wave parameters are calculated using standard techniques. Note that buoys do not measure the full directional spectrum. They provide a limited number of Fourier coefficients from which the directional spectrum can be estimated using statistical methods (e.g. [13, 14]). Using the spectrum we can calculate basic wave parameters such as significant waveheight (Hs), mean and peak period and direction, and also wave power and energy period (TE).

In this paper we derive power directly from the 2D spectrum. Power is sometimes estimated from period and waveheight parameters if these are all that is available. The period one should use for this is the energy period [15] but sometimes only the zero-crossing period is available. As can be seen in Fig. 1,

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although these are correlated, they are not the same. Fig. 1 also demonstrates that the relation between the two is measured similarly by the radar and buoy.

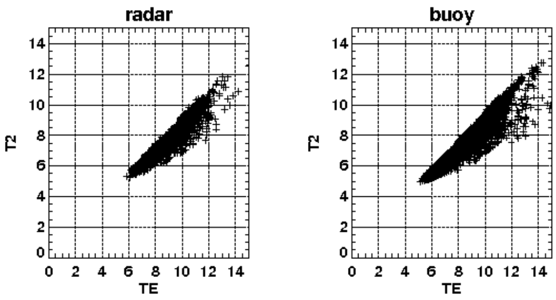

Figure 1. Comparison of energy and mean periods, radar on left, buoy on right.

Comparisons of some of the derived parameters with buoy measurements for a four month period in 2005 are presented in Fig. 2 to demonstrate the accuracy of the measurements. Some statistics for these comparisons are given in Table 1.

The reduction in spectral data after imposing the low waveheight limit is clearly seen in the reduction in the number of cases. Some of the differences in energy period can be accounted for by the variable upper wave frequency in the radar measurements referred to above. Some of the differences in peak period and direction can be attributed to small differences in the relative magnitude of swell and wind-sea in bi- (or multi-) modal seas.

Note the period at the beginning of January when unfortunately there were no buoy measurements due to a fault that had occurred in December which had to wait for calmer weather for repairs to be carried out. The radar significant waveheight measurements agreed well with those of the Met Office wave model during this stormy period.

Parameter	Correlation coefficient	Mean difference	rms	Number of cases
Power [kW/m]	0.92	4.25	10.56	1338
Signficant waveheight [m]	0.92	0.17	0.44	1338
Energy period [s]	0.75	0.66	1.39	1338
Peak Period [s]	0.61	0.3	2.69	636
Peak Direction [°]	0.55	-6.7	38.49	636

Table 1. Statistics of radar/buoy comparison.

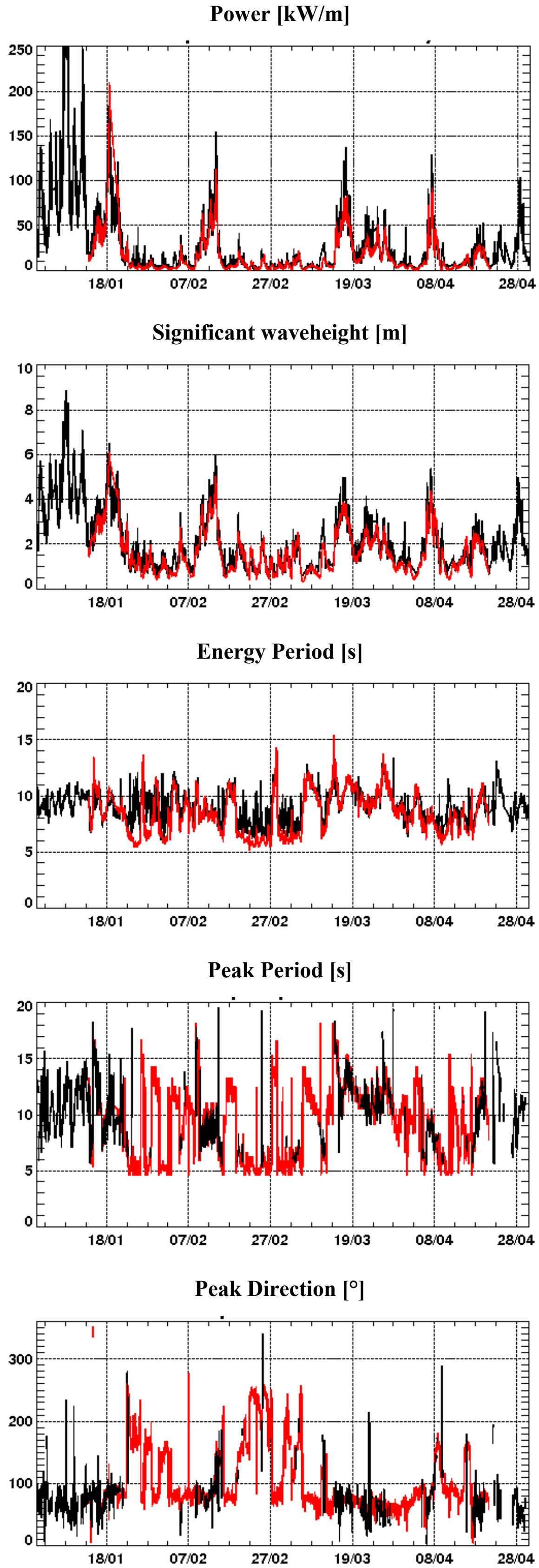

Figure 2. Time series of wave parameter comparisons radar in black, buoy in red.

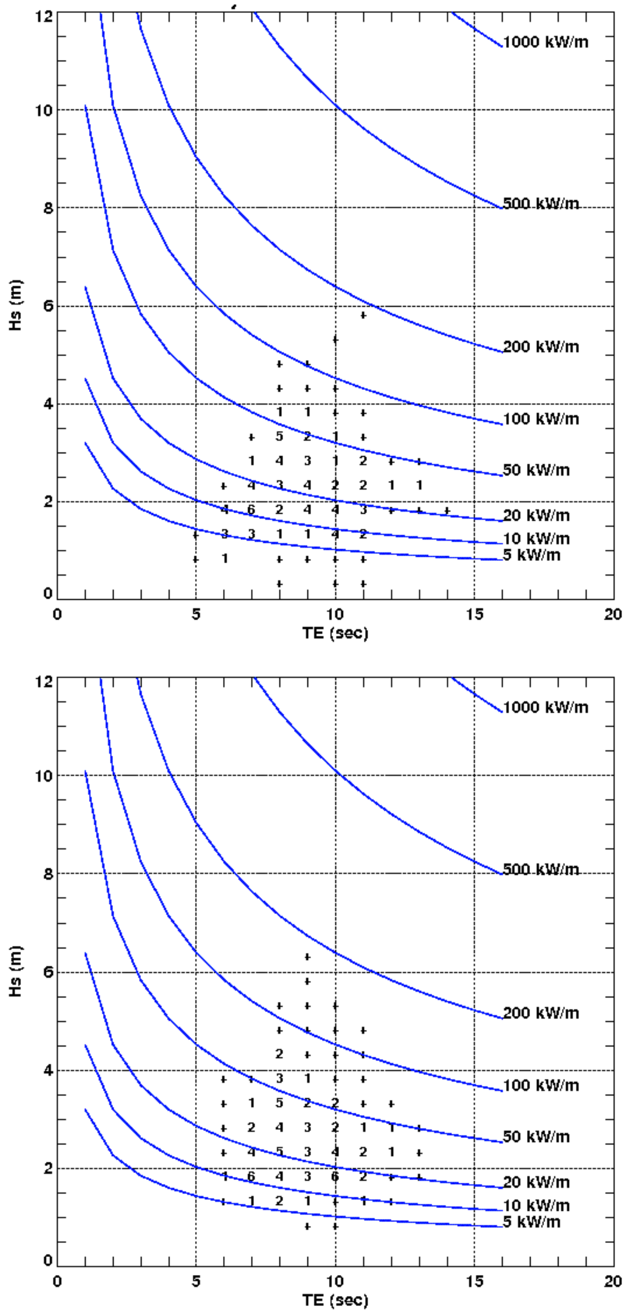

Figure 3. Percentage of data in significant waveheight-energy period bins. buoy above, radar below.

In the UK, guidance documents are being prepared through BSI for wave resource and wave device performance assessment [16]. The wave measurement requirements are similar in both cases. The documents discuss the use for energy matrices to summarise the wave climate at a site in terms of the parameters which affect the performance of wave energy conversion systems. The recommendation is that these be presented with bin sizes of 0.5m for Hs and 1.0s for TE. Comparisons of such matrices for the radar and buoy are shown in Fig. 3. The distributions are very similar again giving confidence in the radar measurements.

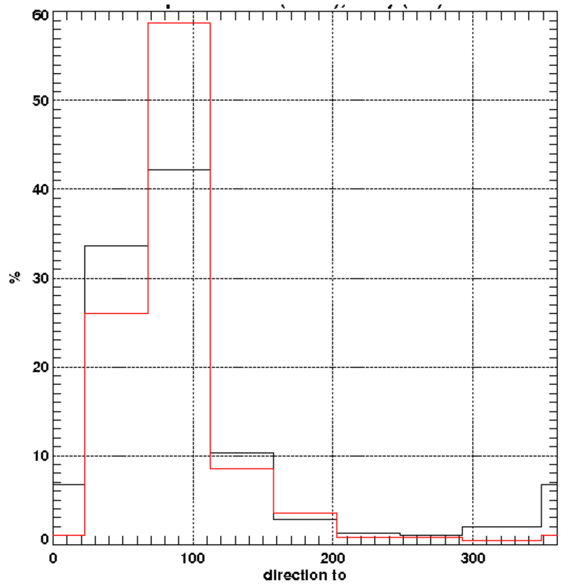

Figure 4. Directional distribution of mean power. Radar black, buoy red.

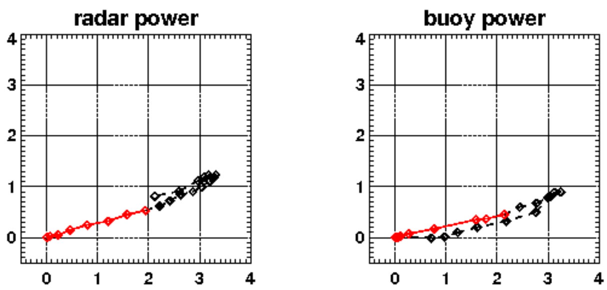

Figure 5. Mean power [kW/m] directional variation with frequency. Frequencies below 0.1Hz are shown in red.

The directional distribution of power is also important for many proposed wave energy conversion devices. This could be provided in the form of energy matrices in 8 direction bins. Fig. 4 shows a comparison of radar and buoy histograms of wave power in these direction bins for this data set. In Fig. 5 the directional characteristics as a function of wave frequency are shown. This is a polar plot with only the top right quadrant displayed since this is where the average power is located. The distance from the origin at each point is the mean power and the angle from the y-axis is the direction measured from North. The frequencies are joined up with dashed lines in order, with the lower frequencies (<0.1Hz) being shown in red. Small differences can be seen between radar and buoy at frequencies beyond the peak.

3 Current power measurement

The radar is measuring surface current and not the current profile with depth. However in the strongly tidal regimes where tidal power is likely to be exploitable this is not a major limitation – many tidal constituents have been successfully extracted from such data and compare well with current profiler data [17].

For this data set we do not have current profile measurements within the dual radar coverage. We do have some data from an Anderaa current meter at 2m depth on a Seawatch buoy located in a region where one of the radars provided current components along the radar look direction (usually called the radial current in the radar community). This was 150km from the radar site and we also had Met Office 2D current model data for this location. The comparisons are shown in Fig. 6 and confirm that useful current measurements can be made with such radar systems. The statistics for this comparison are given in Table 2.

Seawatch		Model
0.99	Correlation coefficient	0.93
1.5	Mean difference [cm/s]	5.4
8	rms [cm/s]	13.5

Table 2. Statistics of radial current comparison.

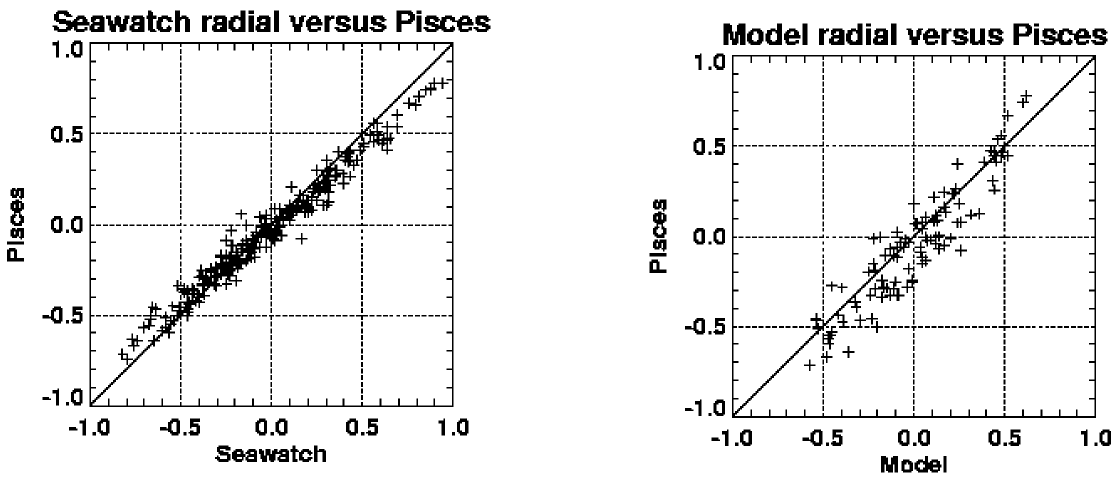

Figure 6 Radar radial current [m/s] comparisons with left current meter at 2m and right 2D model.

The radar is providing maps of surface current or current power, not just a single point measurement, thus potentially contributing to the fine detail of siting decisions for current profiling and for tidal stream power systems. Fig. 7 shows some current power and direction maps at around the time of a peak spring tide to show the variability in the power over this region and thus the need for this spatial overview. The need for this is referred to in the draft document on Tidal Performance Assessment [16]: "*It may be helpful to obtain measurements showing the spatial variability of the currents in order to ascertain an appropriate measure of closeness, for example with an array of in-situ sensors or using a remote sensing technology.*" Closeness here refers to the region around the proposed siting of a device where measurements are needed in order to explore any bathymetric, wave-current interaction or seasonal effects associated with current migration. Note that the spatial density of current (and also wave) measurements was low for this trial compared to many other HF radar operational systems to limit costs.

4 Concluding remarks

Other measurement systems exist that will provide wave and current measurements but many 10s to 100s of such instruments would be needed to provide the same spatial picture available from an HF radar system. HF radar measurements have demonstrated that wave and current fields, in coastal waters where power capture systems will be deployed, vary over spatial and temporal scales that would be difficult to identify in any other way. There are several stages in a wave or current power project where HF radar can make a useful contribution. Assessing resource, environmental impact assessment, monitoring during installation and operation of the power extraction device, estimating the efficiency of the device all need the sort of data that HF radar can provide. The accuracy of the wave measurements is not yet as good as that obtainable with a buoy but improvements are under development in robust quality control parameters, in inversion procedures and in suppression of non-ocean signals (e.g. ships, wind turbines, interference) in the radar data all of which will contribute to improvements in performance in the near future. Measuring surface current is a more direct process and is at least as reliable as a current measurement with an acoustic Doppler profiler although without the profiling capability.

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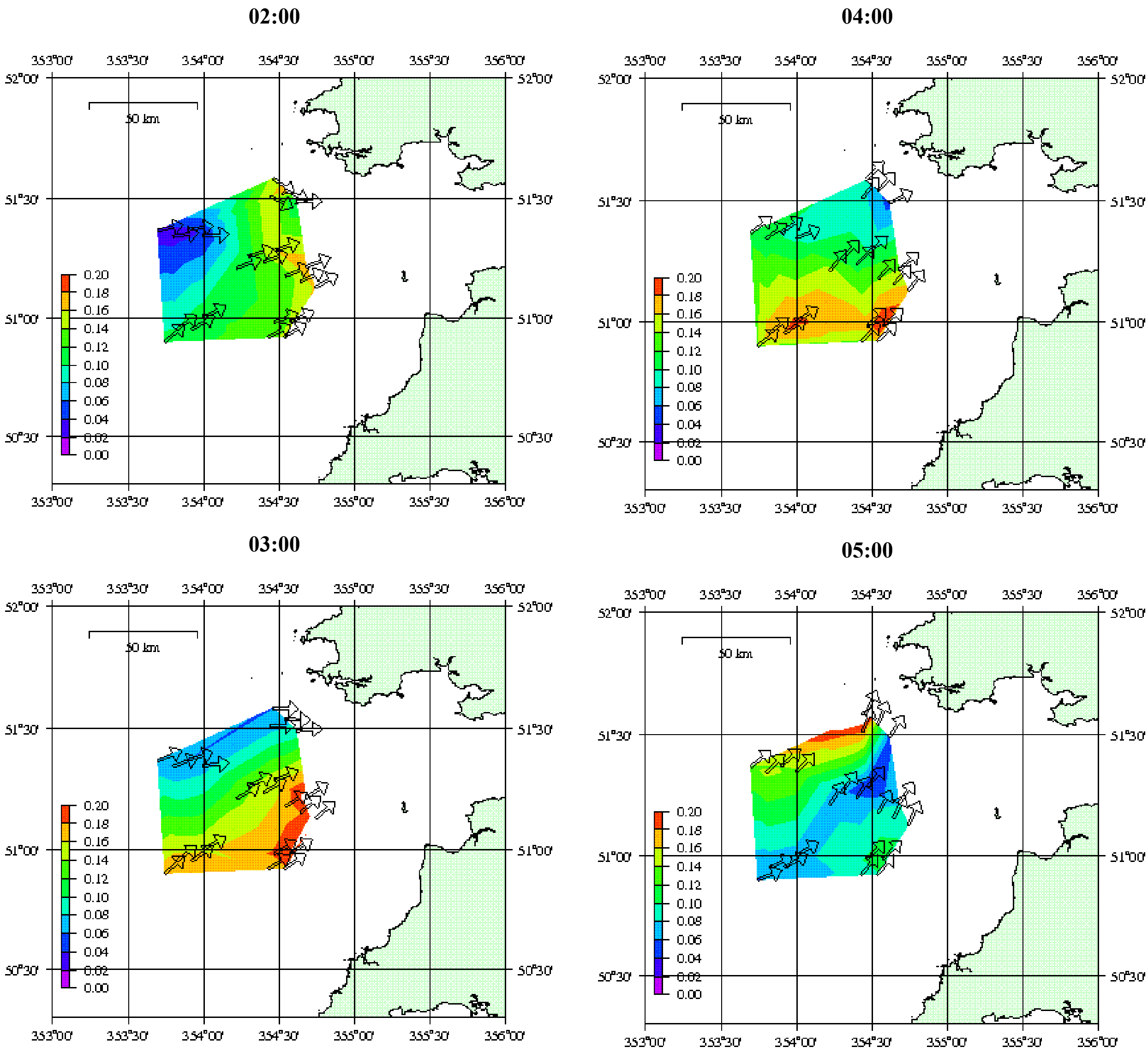

Figure 7 Maps showing radar measured current power [kW/m^2] and direction over a four hour period during a high spring tide on 6/4/2005.

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