DETERMINING CURRENTS FROM MARINE RADAR DATA IN AN EXTREME CURRENT ENVIRONMENT AT A TIDAL ENERGY TEST SITE

Paul S. Bell[1], *John Lawrence*[2] & *Jennifer V. Norris*[2]

[1]National Oceanography Centre, Joseph Proudman Building, 6 Brownlow Street, Liverpool, L3 5DA, UK
[2]The European Marine Energy Centre (EMEC) Ltd., Old Academy, Stromness, Orkney, KW16 3AW, UK

ABSTRACT

A marine X-band radar has been deployed at a coastal location overlooking a region of extreme tidal currents used for the testing of tidal stream energy turbines. Near-surface tidal currents are known to reach 3.8m/s in water depths of the order of 50m.
Preliminary results from the analysis of radar data collected at this site will be presented with particular reference to the currents determined using an inversion of the wave spectrum. Comparisons will be made with current profile data collected using an Acoustic Doppler Current Profiler (ADCP) deployed within the field of view of the radar.

Index Terms— Marine Radar, Wave Inversions, Remote Current Mapping, Tidal Energy, Current Measurements

1. INTRODUCTION

The development of wave and tidal energy extraction devices has progressed significantly in recent years as the engineering challenges associated with the sustained operation of such devices in extreme environments are addressed. The Fall of Warness tidal energy test site (see Figure 1) is located off the south west corner of the island of Eday one of the north isles of Orkney, off the north east tip of Scotland.

This general region has one of the largest potentials for the commercial development of marine renewable energy extraction in the world, with both extreme tide and wave resources being concentrated in a relatively small geographic area. The test site itself is characterised by semidiurnal tides running north-west to south-east on the flood and vice versa on the ebb through a narrow channel between the island of Eday and the small island of Muckle Green Holm. Spring tidal currents are quoted as reaching speeds of 3.5 m/s (~7 knots), while neap currents are of the order of 1.4 m/s (~2.5 knots) [1]. Waves, including long period swell, are able to propagate into the site from the north-west and south east only. Water depths in the areas used for testing tidal energy devices are typically of the order of 30-50m and the sea bed is rock substrate.

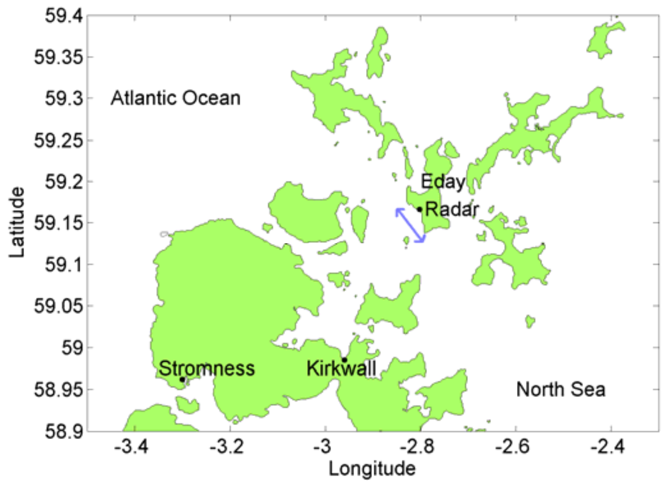

Figure 1. Location of the Radar on the island of Eday in the northern isles of Orkney. The EMEC Fall of Warness tidal energy test site is represented by the blue marker. Coastline data obtained from the NOAA GSHHS Shoreline Database.

Designated test areas for tidal devices are linked to a shore based substation by individual armoured underwater cables.

2. MARINE RADAR DATA

A shore based 10kW Kelvin Hughes marine X-band radar with a 2.4m high speed rotating antenna and operating on short (50ns) pulse setting was deployed approximately 10m above sea level at the EMEC electricity substation during 2011 as part of the UK NERC & DEFRA funded FLOWBEC project (Figure 2). The low height of the antenna relative to sea level is not ideal for this type of work and may compromise the quality of the data, particularly at the longer ranges, but due to planning constraints a more elevated location was not possible.

The antenna completes a 360 degree sweep of the area in approximately 1.3 seconds and sequences of 256 images were recorded every 15 minutes using a Wamos radar recorder digitising at 32MHz, giving a radial sample interval of 5m. The antenna has a horizontal beam width of approximately 0.8m, giving a tangential sample size of the order of 30m at a range of 2km.

Figure 2. The X-band radar deployed at the EMEC substation on the island of Eday, Orkney.

Data were routinely recorded to a range of 4.8km, a range chosen to include the small island of Muckle Green Holm to the south west that bounds the western side of the main tidal flow at the Fall of Warness.

The images produced by marine radars detect not only hard targets such as ships and coastlines, but also reflections from the sea surface – known as sea clutter. This sea clutter is a product primarily of Bragg scattering from small centimeter-scale capillary ripples on the sea surface, the visualisation of which are in turn modulated by ocean waves. As a rule of thumb, sea clutter can generally not be seen if there is insufficient wind (< 3m/s) to roughen the sea surface, and/or the significant waveheight is much below 1m. Rainfall is also visible on radar imagery and this radar frequency is used by weather radars to monitor rainfall. The backscatter caused by heavy rainfall can be sufficient to completely obscure sea clutter.

3. ADCP DATA

A 600kHz RDI Workhorse Acoustic Doppler Current Profiler (ADCP) was deployed by the EMEC team on a bottom mounted frame, collecting data from the 4/11/2011 - 27/11/2011 at 59° 08.815'N 002° 48.986'W. This location is in approximately 40m of water on the eastern edge of the main region of flow and a distance of just over 2km from the radar. For the purposes of this initial comparison the data have been depth averaged to a current value every minute for simplicity.

4. RADAR DATA ANALYSIS

Waves are directly influenced by the depth and current of the water in which they propagate. In waters of depth less than half the wavelength of the waves, wavelength and speed (celerity) of the waves decreases with decreasing depth in a predictable manner. In the presence of a current, the waves also experience a Doppler shift, further altering the wave propagation characteristics. If the wave length and speed at a range of wave periods can be measured, it is therefore possible to fit the equations governing wave behaviour to determine the most likely water depth and current that caused the observed wave behaviour. This technique has a long though little known history and was used as long ago as the 1940s to remotely map beaches for amphibious landings using carefully timed aerial photographs.

The ability of the radar to produce image sequences of waves allows the required parameters to be measured using spectral (Fourier) analysis of areas representing a few hundred metres square [2][3]. The analysis 'window' is translated across an area allowing maps of depth and current to be built up.

The spectral analysis makes the assumption that the wave behaviour is homogeneous within the analysis window and for the duration of each image sequence. This assumption is adequate in most circumstances, but may introduce problems in areas of high horizontal current sheer or strongly varying bathymetry. Such highly varying conditions within a single analysis window may introduce more than one possible solution for the water depth and current in that window, which may result in increased noise in results at those locations.

The current determined by this method can be thought of as the current that the waves are 'feeling'. Although not a true 'surface current', this wave derived current should theoretically be biased to the upper part of the water column as it is based on the layer of water in which the waves are propagating. Since waves penetrate to greater depths for longer wavelengths, the definition of this layer varies as it will depend on the wave spectrum present at that time. A practical rule of thumb is that variations in wave behaviour due to water depth variations are significant enough to be measured when the depth is less than a quarter of the wavelength of the ambient waves. By analogy the same should be true for the depth of the currents being detected by this method.

In the present study an in-house wave inversion analysis has been used for the radar data processing. The water depths at the study site have been well mapped using conventional survey techniques and as the sea bed is rock in the majority of the area, is unlikely to change. As a result and to simplify the analysis, the depth has been clamped to that of the survey plus mean water level, leaving the current as the only free variable. The tide height variation has been neglected as it is relatively small in relation to the depth at this site (of the order of +/- 1m). The analysis window used to generate these results was 640m square and was translated across the study area at 160m intervals – a size chosen both to minimise noise in the results and also for ease of presentation. Considerably finer analysis windows are possible with high quality data [4][5], but can lead to increased noise with low quality data (poor visibility of waves on the radar imagery) such as can be found in parts of the present study area at the longer ranges and more sheltered areas.

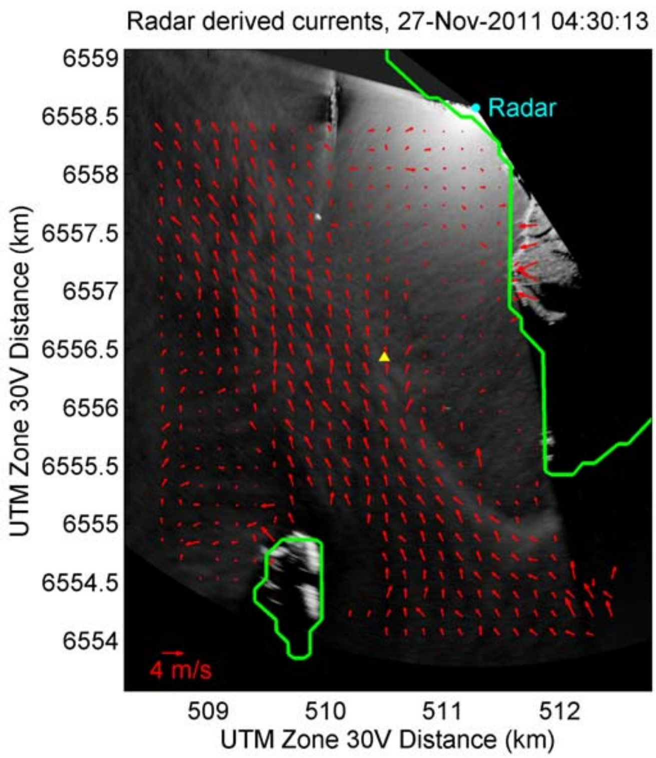

Figure 3. A mean (timelapse) radar image overlaid with radar derived current vectors during the ebb tide. Approximate coastlines are marked in green, and the ADCP deployment location in yellow.

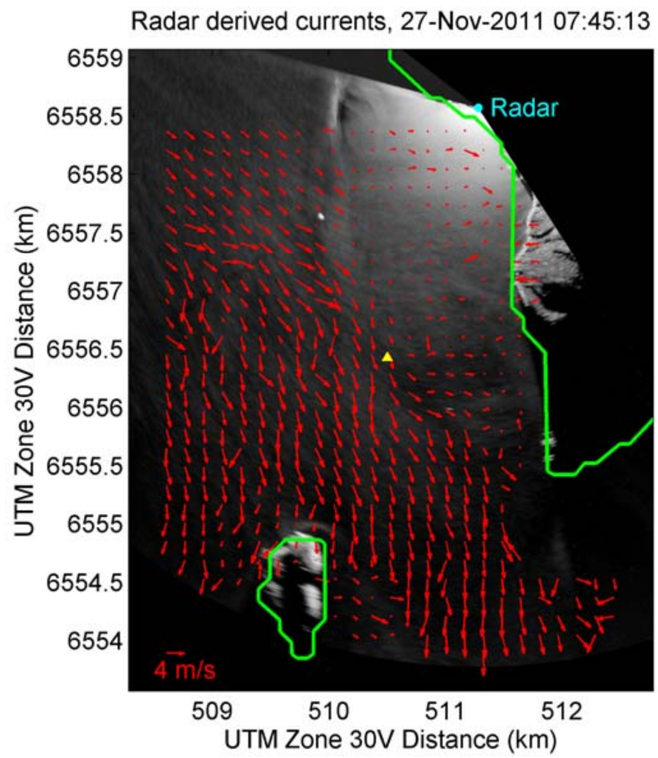

Figure 4. A mean (timelapse) radar image overlaid with radar derived current vectors during the flood tide. Approximate coastlines are marked in green, and the ADCP deployment location in yellow.

5. PRELIMINARY RESULTS

During the period in which the ADCP was deployed, there were noticeable waves on the radar data from around 23rd November 2011 to 27th November 2011. During this time, the wave height and hence the wave signal on the radar imagery fluctuated but generally remained at a level sufficient for the wave inversion analysis to function over most of the study area.

Two examples of current vector maps are shown from the 27th November 2011. They are overlaid on the averaged radar backscatter image for that 5-minute record, in which brighter shades indicate stronger backscatter, e.g. from land.

The flow patterns shown in Figures 3 and 4, derived from the wave inversion of radar data, are consistent with known behaviour at the site. The main region of strongest flow is funnelled past the small island of Muckle Green Holm, visible at the bottom left of Figures 3 and 4 and the southern tip of Eday on the right. Radar derived currents easily reach 4 m/s and approach 5 m/s in places. On either side of the main flow the current speed falls off rapidly over a relatively short horizontal distance – representing a region of high horizontal sheer and turbulent waters that often shows up as higher mean radar backscatter due to the increased surface roughness.

Large kilometer-scale eddies form in the bay to the north east of the main flow and are evident in the current vectors. These features were also observed in the MIKE21 modelling study of the area [7]. On the ebb, the obstruction of Muckle Green Holm creates a more sheltered region to the north in which large eddies also appear to form, while on the flood, the flow sweeps through this area and to the west of the island.

Radar derived currents have been selected from an analysis window slightly to the west of the ADCP position but with the ADCP on its eastern edge to avoid the sheer zone. The purpose of avoiding the sheer zone at this stage is simply to investigate whether the radar analysis is reproducing realistic currents in a region of the study area with relatively stable, if extremely strong currents. Some additional spatial averaging has also been employed, averaging a square of 5 x 5 radar current measurements (two measurements either side of the chosen location near the ADCP) to further reduce noise for the plot in Figure 5.

Figure 5 illustrates a single 24 hour period of radar derived current speeds from the main flow region close to the ADCP (plotted in black). It is plotted together with a depth-mean current speed from the ADCP, plotted in blue.

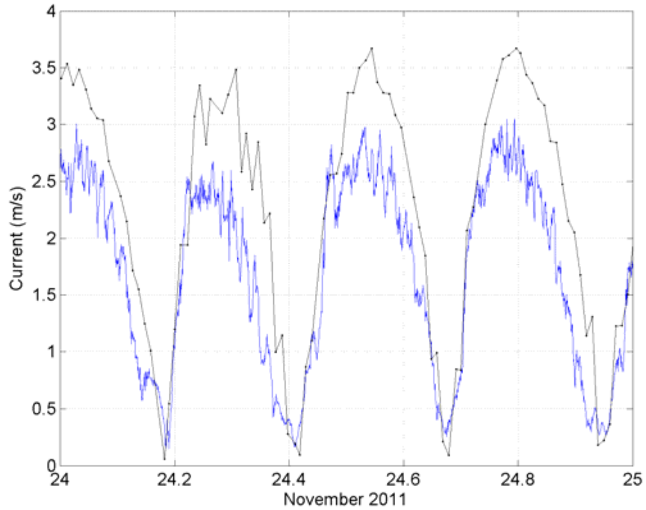

Figure 5. A plot of 24 hours of current speeds from the 24th November, derived using a wave inversion of radar data (black line) compared with one minute averages of the ADCP depth mean current data (blue line).

The radar derived currents can be seen to consistently exceed the depth-mean ADCP current. Some deviations between the ADCP and the radar derived currents should be expected as the ADCP is effectively a point measurement, while the radar provides an area average. The ADCP location can be seen in Figure 6 to be centred on the boundary between two current regimes – slightly out of the main region of current flow to the west, and towards the calmer bay area to the east. The radar is only able to determine the best fit to the observed waves over the whole analysis window of 640m square, and tends to reproduce either the strong main channel flow *or* the weaker currents of the bay area as the analysis window is translated from one side of the sheer zone to the other. Interestingly, the radar current measurements in Figure 5 are consistent with those of an earlier ADCP deployment [7] (FOW-8) located on the edge of the main flow region that showed peak current speeds of 3.5m/s.

The intention is to make comparisons with other ADCP records in the area as the research progresses in order to provide a number of validation locations for the radar derived currents, and also test the commercial Wamos bathymetry and current mapping software module.

7. ACKNOWLEDGEMENTS

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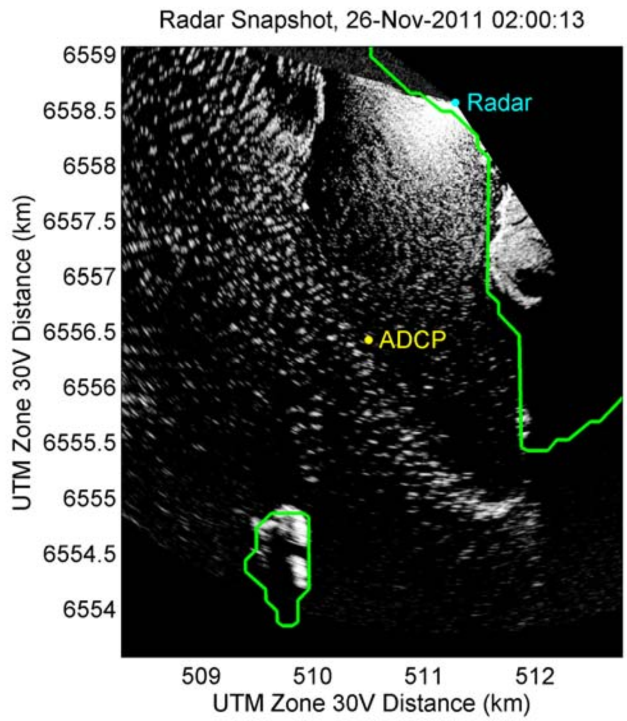

Figure 6. A radar image of the sea surface backscatter, showing the ADCP to be slightly to the east of the main flow region that exhibits the stronger wave patterns. The ADCP is marked in yellow.

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