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MARINE RADAR DERIVED CURRENT VECTOR MAPPING AT A PLANNED COMMERCIAL TIDAL STREAM TURBINE ARRAY IN THE PENTLAND FIRTH

Paul S Bell[1] **&**
David L. McCann
National Oceanography Centre
Joseph Proudman Building
6 Brownlow Street
Liverpool, L3 5DA

Sarah Crammond
MeyGen Ltd
King's Scholars House
230 Vauxhall Bridge Road
London, SW1V 1AU

Jason McIlvenny &
Juvenal Dufaur
Environmental
Research Institute
Castle Street, Thurso
Caithness, KW14 7JD

Philip Archer
Atlantis Resources Ltd
King's Scholars House
230 Vauxhall Bridge
Road
London, SW1V 1AU

ABSTRACT

A marine radar was deployed on a remote clifftop overlooking a 4.8km radius area of the Inner Sound of Stroma in the Pentland Firth for 3 months during spring 2013. The area viewed by the radar includes the Crown Estate lease areas for MeyGen Ltd (Inner Sound of Stroma) and Scottish Power Renewables (Ness of Duncansby), although the data analysis has focussed solely on the MeyGen area. Data were post processed to extract current vector maps based on determining the Doppler shift of sea surface waves by the tidal current. Comparisons between current time series from the ADCP and the radar derived data are presented and show excellent correlation. The quality of the data has enabled tidal analyses to be performed and spatial variations in tidal current constituents to be mapped.

INTRODUCTION

At present, measurements of tidal currents involve high cost in-situ deployments of current meters, usually at a low number of specific locations, which involve a significant risk of equipment loss or damage in such high energy environments. Alternatively, ADCP surveys may be performed from a small vessel over a moderate area and the results used in conjunction with model predictions to produce a number of snapshots of the current vector patterns [1]. Such data can then be used to calibrate numerical models from which a more detailed understanding of the spatial variability may be derived to aid decision making on turbine positions and facilitate predictions of energy yield. The ability to collect time series of current vector maps using a shore based system will add value to in-situ measurements by enabling validation of model outputs at a large number of points across a site of interest and placing the in-situ measurements into a broader context, reducing risk and increasing confidence in resource assessments and turbine placement decisions.

METHODOLOGY

The radar installation consisted of a Kelvin Hughes Nucleus 3000 X-band unit coupled to a 2.4m, horizontally-polarised antenna mounted on a scaffold approximately 12m above mean sea level. The raw radar video signal was intercepted by a WaMoS II radar computer through a WiBA interface (supplied by OceanWaveS GmbH) and converted into time-stamped, digitised images of radar backscatter intensity, an example of which can be seen in Figure 1. The installation was in constant operation between 5th March and 11th June 2013 and was set to record for intervals of 128 images every 20 minutes. Due to the rotation speed of the antenna this produced 5.5 minutes of continuous measurements every 20 minutes.

Due to the requirements of the project and the need for analytical expediency, the analysis area was restricted to cover the MeyGen lease site (white and red lines respectively, Figure 1).

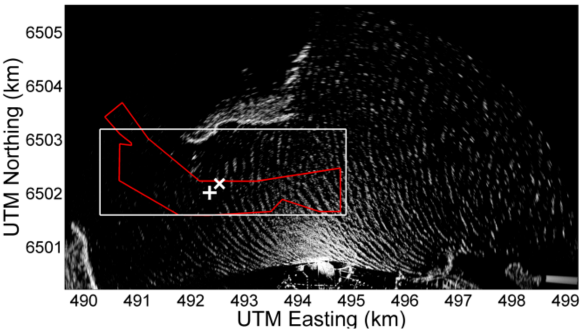

Figure 1. Example of a single radar image, showing the signals from large, Easterly waves (sea-clutter).

The NOC current analysis method involves the extraction of spectral wave parameters from time-indexed radar images of waves on the sea surface – visible due to the phenomenon of Bragg resonant scattering of incident microwaves (wave patterns on Figure 1). The wave parameters are then used to resolve the effect of an unknown depth and mean current on the Doppler shift of the wave dispersion relation – a process known as inversion. Further information on the wave inversion method can be found in [2], [3], [4] and [5]. The calculation of wave parameters requires the analysis of a finite area of sea surface carrying the assumption that the wavenumber and frequency spectra across the discrete analysis area are homogenous. The analysis

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[1] Corresponding author: psb@noc.ac.uk

algorithm therefore works on areas of sea surface typically 500-800m across and transposes this area step-wise at one quarter of the analysis box size in order to produce a map of calculated velocity component magnitudes. In this case, the marginal quality of the data in some of the most sheltered areas necessitated the larger analysis area of 800m, translated at 200m intervals to build up the current and depth maps. Intensive quality control (QC) techniques developed at the NOC are employed on the calculated currents to minimise the secondary effect of poorly resolved current vectors on subsequent analyses. This is vitally important as poor wave data (a product of low wind / waves) and meteorological effects can have a significant impact on the quality of calculated currents.

Calculated mean flow speeds were validated against two in-situ 600kHz 4-beam ADCP deployments that overlapped portions of the radar survey period. The Environmental Research Institute (ERI) survey was located at the cross symbol on Figure 1 and covered 14 days of the data set. The Meygen (MG) survey was located at the plus symbol on Figure 1 and covered 24 days of the data set.

There is yet an undetermined relationship between the current derived from X-band radar and the current the waves actually ‘feel’. However the results at this site in water depths of around 30m indicate a good correlation between the radar derived current and the depth-mean flow speed from the ADCP records.

Tidal harmonic analysis was performed on the radar derived u and v current vectors, employing the open-source tidal analysis and prediction toolbox ‘UTide’ [6] which was chosen due to its ability to handle non-continuous data series. UTide attempts to fit up to 40+ tidal constituents to a tidal current record, discarding fits that show a poor signal to noise ratio. Harmonic analysis is very sensitive to the quality and record length of input data – both of which must be taken into consideration when interpreting the results.

OBSERVATIONS

Figure 2 shows an example snapshot of tidal flow vectors derived from the NOC current analysis during an Ebb tide over the MeyGen lease area. Over 7,500 of such records were analysed to

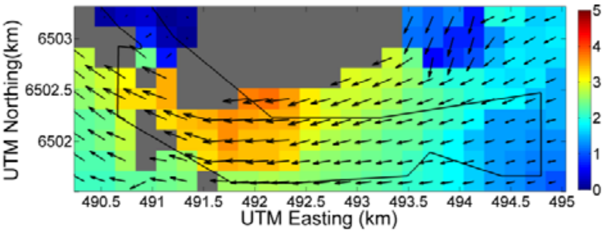

Figure 2. Representative snapshot of radar-derived tidal current vectors (ms^{-1}) from the NOC current analysis. Grey areas denote QC blanking.

Figure 3 shows the results of the ADCP validation for both the ERI and MG datasets. The *u* component of the radar-derived currents is shown to have an excellent correlation with the depth-averaged ADCP *u*-component velocity with R^2 values of 0.98 for both the ERI and Meygen datasets. The *v* component velocities are shown to have a very poor correlation – this is due to the comparison between point (ADCP) and area (radar) measurements. In the location of the ADCP surveys there are extensive sub-grid-scale flow features and strong residual circulations originating from the inertial flow around the Isle of Stroma which may not be accounted for in the radar analysis due to its assumption of homogeneity across a grid cell (800m). Additionally, the *u* component velocities show a much better fit due to the prevailing axial offset between wave and tidal current directions. Waves are most affected by currents travelling against or along with the direction of wave propagation, increasing the signal to noise ratio of the radar analysis. It is expected that a comparison with an in-situ survey in a much more rectilinear tidal environment (e.g. towards the East of the MeyGen lease, out of the influence of Stroma and the Inner Sound) would provide a much better validation for the *v* velocity component.

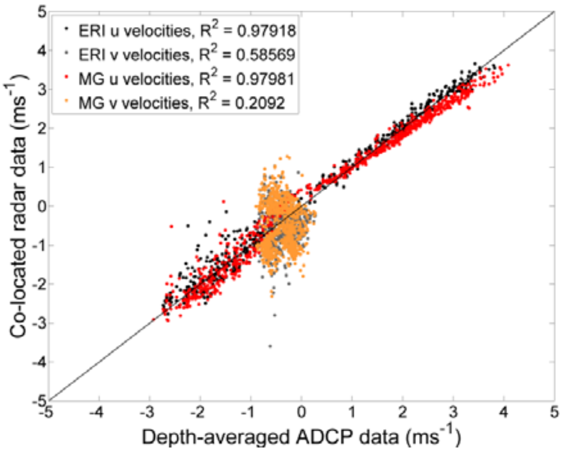

Figure 3 Comparison plot between the ADCP and radar-derived current data.

Harmonic analysis was applied to each grid point in the NOC dataset where sufficient data was available. Over 40 tidal harmonic constituents were fitted to the data set but the dominant harmonics were found to be restricted to the lunar and solar diurnal and semidiurnal with the majority of the spectral energy found in the principal lunar semidiurnal M_2.

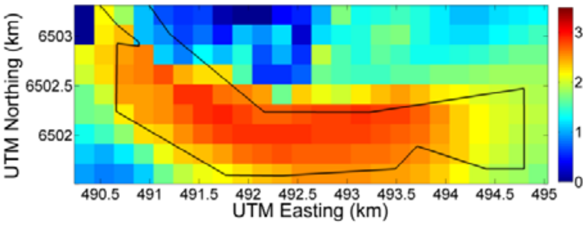

Figure 4. Absolute magnitude (ms^{-1}) of the M_2 tidal constituent from harmonic analysis of radar derived currents

Figure 4 shows the absolute magnitudes of the amplitudes of the M_2 tidal current constituent and Figure 5 its phase relative to Greenwich. The sensitivity of the analysis to poor data is visible in the noisy areas towards the north of the analysis area where wave shadowing and the prevalence of sub-grid-scale flow features hinder the accurate resolution of flow vectors.

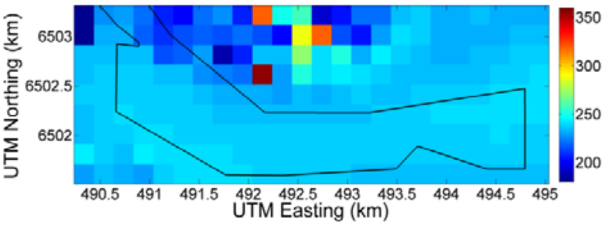

Figure 5. Phase (degrees from Greenwich) of the M_2 tidal constituent from harmonic analysis of radar derived currents

CONCLUSIONS

The application of X-band radar to an area as dynamic as the Inner Sound of Stroma was challenging both operationally and scientifically. However the resulting data set, although (at present) only covering the MeyGen lease area, has proven to be an extensive and useful addition to the knowledge of the hydrodynamics of the Inner Sound of Stroma.

Calculating the speed of tidal flow from a remote position on land using microwave images of the sea surface is a non-trivial exercise. With careful consideration of the limits of X-band radar images and the analytical methods applied to them, the resulting tidal current dataset is excellent, attested by the quality of the ADCP validation. It is therefore concluded that the radar-derived tidal current dataset from the NOC research-grade analysis, once the recommended QC has been applied and limitations are taken into account, can be used for further model validation/ comparison and to form the basis of resource estimation and future locations of in-situ surveys.

The production of spatial maps of tidal harmonic constituents, although technically possible, is not feasible using in-situ surveys due to the long record length required. The harmonic analysis of long time series of radar-derived current maps can provide a significant amount of information on the spatial variability of tidal harmonic current amplitudes which, in turn, could be used to form the basis of resource estimation for the marine renewable energy sector. The importance of effective QC of the radar-derived current vector maps on the reliability of such harmonic predictions must be stressed however, as the effect of record length and 'gappy' data on the fitting of harmonic constituents can be significant.

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