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HEBRIDEAN WAVE DATA

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ABSTRACT

The Hebridean Marine Energy Futures (HebMEF) project's overarching aim is to accelerate the commercialisation of wave energy converter (WEC) projects. To support the investment case a reliable yield forecast of planned developments is essential. High resolution spectral wave models are an important part in energy forecasting, either by providing direct information on the wave resource at a given site, or by providing detailed boundary data for small scale nested simulations using Boussinesq or CFD applications.

During the setup, and also to prove the accuracy, of numerical wave resource models, measured wave data is used for calibration and validation. Good practice requires the use of different measured data sets from varying geographical locations for validation, than what was used for calibration of the models.

This paper gives an overview of the wave data acquisition activities undertaken under the HebMEF programme between 2011 and 2014 at the north-west coast of the Isle of Lewis of the Outer Hebrides of Scotland. A data acquisition array of three floating wave measurement buoys and two submerged acoustic sensors was commissioned in intermediate and shallow water depths to successfully obtain time series displacement data together with fully directionally resolved spectral information for deployment periods of more than 12 consecutive months at a coastline with one of the most energetic wave power resources globally.

INTRODUCTION

The wave energy resource of the north-westerly coastline of the Isle of Lewis, Outer Hebrides of Scotland, has been identified as one of the highest in Europe, or even globally, and is home to the world's largest fully consented wave energy conversion (WEC) project (40MW) by Aquamarine Power Ltd [1]. The area is also targeted for WEC projects by Pelamis Wave Power (10MW) [2], and, until the strategic repositioning of their parent company Voith Hydro in 2012, was also developed for a 30MW energy breakwater project by Wavegen [3].

With an open exposure to North Atlantic swell waves, the nearest landmasses across the ocean are Iceland, some 800km to the north-west, Greenland, approximately 2,000km to the west, and Newfoundland and Labrador at a distance of 3,100km to the west-south-west of the islands. With such an exposed coast line and generally situated in the jet stream that conveys low pressure weather systems across the North Atlantic from the Great Lakes of Canada, the Outer Hebrides feature a combination of strong winds and long period swells from a predominant westerly direction.

Due to the combination of often severe weather and sea conditions in the area and a limited port infrastructure, information on both the physical and biological environment in the shallow water zone around the north-west of the isle of Lewis is sparse. Past and present uses of and activities in the areas currently targeted for wave energy developments are limited to fishing, primarily with static gear (creels), and surfing. Other activities such as aquaculture developments or yachting play a growing role, but are mainly limited to transient traffic in the target area. The sparse availability of measured wave data has been described previously by the author and no or only limited historic wave observations appear to be available for the areas in the Outer Hebrides currently targeted for WEC developments [4].

The importance of using high quality measured wave data for calibration and validation of wave resource models has been widely accepted by the scientific community, and this is reflected by the current standardisation of incorporating measured data into numerical models by the International Electrotechnical Commission (IEC) in TC114, which prescribes that: "*all numerical modelling shall be validated using measured wave data…from one or more locations close to where wave energy converters might realistically be deployed….* W*here measured wave data is available for validation, this data may also be used to calibrate the numerical model to improve the accuracy of the model's predictions.*" [5, page 14-15]. TC114 furthermore prescribes that the use of measured datasets must represent a minimum of 97% of occurring sea states at a development site to support resource assessments during detailed design studies of WEC developments.

Driven by the shortage of relevant wave data and aimed to enhance the detailed understanding of the wave resource to the north-west of the Isle of Lewis the HebMEF project has successfully deployed and operated a wave sensor network consisting of three floating measurement buoys and two subsea sensors in varying configurations over the period 2011-2014. Sensors were deployed in intermediate and shallow water depths of 60m and 12m respectively and the

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returned data has been used widely by the project to support numerical modelling studies. Geographical sensor locations and individual deployment periods are shown in table 1 and figure 1 below. The data acquisition network was supplemented with wind data from a shore based weather station during the deployment periods of the wave buoys and more detailed descriptions of the system configuration and initial data returns are given in [4] and [6].

Table 1. Sensor deployment periods

	2011				2012												2013											2014			
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Buoy 1	½	■	■	■	■	■	■	■	■	■	■	■	½																		
Buoy 2		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
Buoy 3		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
ADCP 1													½	■	■	■	■	■	■	■	■	■	■	■	■	½					
ADCP 2					½	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	½

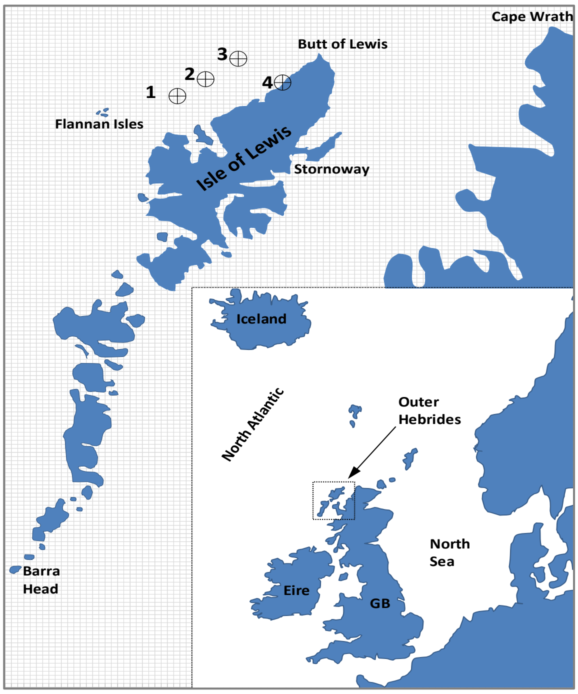

Figure 1. Sensor deployment locations to the west of the Isle of Lewis. Wave buoy locations: No 1, 2, 3; ADCP locations: No 4 (adapted from [4])

SENSORS AND DEPLOYMENT

An initial stage during the design phase of the wave measurement array was the desk based assessment of maximum wave heights, velocities and resulting forces to ensure survivability of the sensor configurations. The Health and Safety Executive have published a 50 year design wave height of $H_s(50) \approx 17$m for the shelf area west of the Outer Hebrides [7] and this suggests maximum wave heights of >30m may be possible under extreme conditions in intermediate to deep water in the target area. Forces and theoretically maximum wave heights in the shallow water near shore zone were estimated by following Holthuijsen's guidance [8] which concluded in theoretically maximum values for the significant wave height of around 10m in 14m water depth and horizontal surge velocities of 12.8ms^{-1} at the seabed and throughout the shallow water column.

Following an assessment of factors such as technical requirements, environmental conditions, deployment feasibility, availability of equipment and procurement costs, the decision was made to deploy three Datawell Directional Wavereider buoys and two Nortek 1MHz wave enabled AWAC ADCPs. The wave buoys were deployed some15km offshore at a depth of 60m with approximately 11km spacing between buoys, and the ADCPs in shallow water of 14m with a distance of 500m between sensors. The sensors were located so that the likely prevailing peak wave direction was following a line from the buoys to the nearshore sensors to obtain maximum information on the shoaling process. Furthermore the locations were chosen to provide data useable to support the site development of the three main wave energy developers targeting the area, i.e. Aquamarine Power, Pelamis Wave Power, and at the time Voith Hydro Wavegen. Availability of an additional sensor at locations between buoys and ADCPs, to provide interim information on wave shoaling transformation was desired, but due to budget constraints this was not possible.

To maximise the likelihood of securing good data returns and minimising the risk of losing equipment, the buoy mooring configuration was slightly amended from manufacturer's recommendations, and a bespoke subsea sensor frame and installation strategy was developed for the seabed mounted ADCPs. Maximum acting forces on the sensor frame from the wave induced mass transport of water at ground level were calculated as 38.4kN, and based on a design safety factor of 3 it was decided to secure the frames with three M24 rock bolts fixed into core-drilled holes in the bedrock with injectable mortar. Figures 2 and 3 show the general assembly workshop drawing of the final frame combination and the fully configured and deployed unit in situ off the Isle of Lewis.

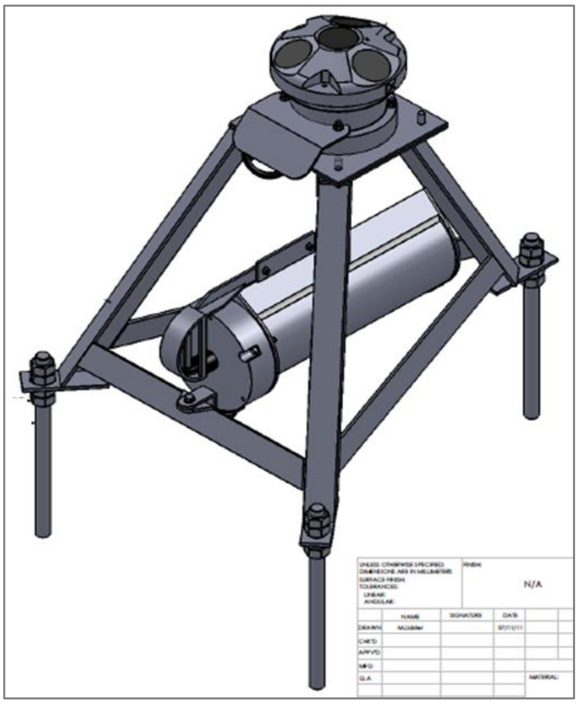

Figure 2. GA drawing of bespoke sensor frame unit

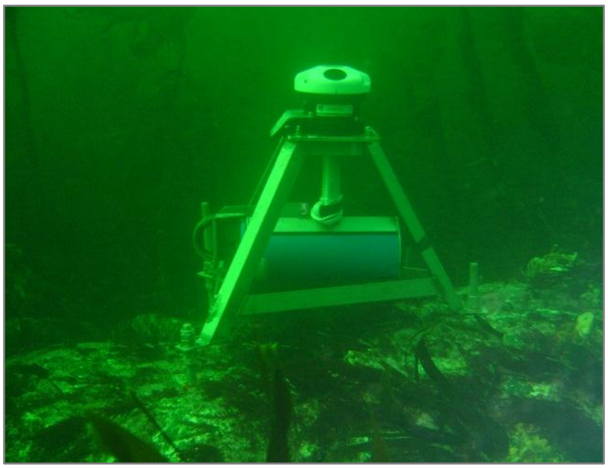

Figure 3. ADCP successfully deployed on seabed

OBSERVATIONS

Data returns have been very successful throughout the deployment periods with nearshore consecutive wave datasets of one and two years obtained by ADCP 1 and 2 respectively (return rate close to 100%) and >12 consecutive month datasets for three wave buoy locations. Analysis of these rich datasets is still ongoing, but first investigations clearly show the effect of bottom induced refraction resulting in energy dissipation through loss of wave height closer nearshore, and also towards the north-east of the study area as shown in the wave roses in figure 4 for a full year. Figure 5 compares the wave power at the sensor locations for two buoys and both ADCPs for autumn 2012, calculated using linear wave theory. Of great interest here is the difference in direction, wave height and power between the ADCP locations, which are in close proximity to each other, as this reinforces the significance of identifying energy hotspots on a small scale to achieve a maximisation of energy yield at WEC development sites.

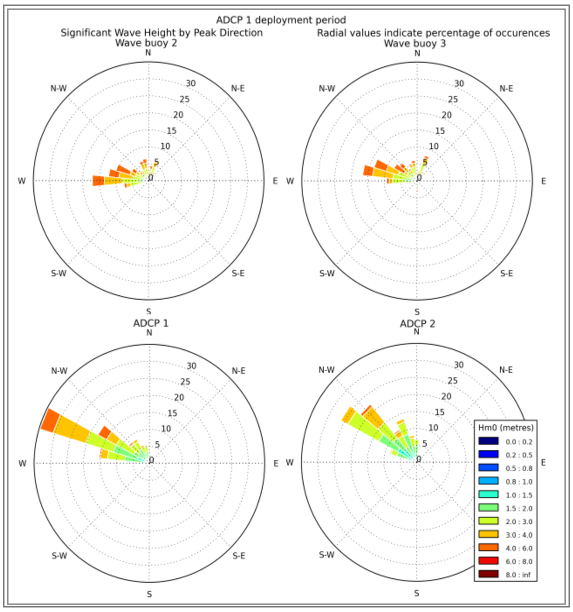

Fig. 4 Wave roses for buoys 1 and 2, and both, ADCPs; Sept - Dec 2012 (Hm0), adapted from [6]

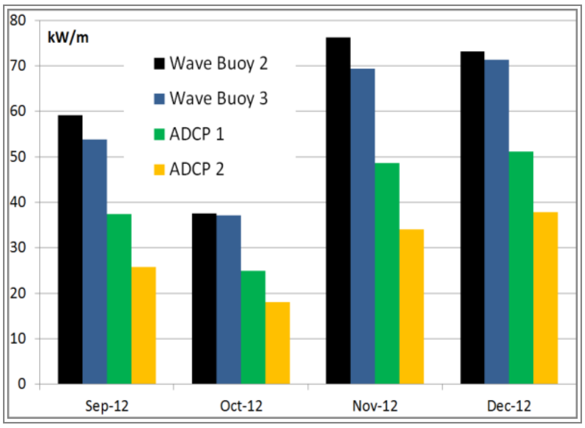

Fig. 5 Wave power distribution across the sensor network, adapted from [6]

CONCLUSIONS

The data acquisition activities undertaken in work package 2 of the Hebridean Marine Energy Futures project have returned wave datasets in displacement time series format, and also fully spectrally resolved, of durations and wave situations sufficient to support detailed and credible numerical wave resource modelling studies. The wave buoy data has already been used as boundary condition in DHI Mike21 SW models, with model calibration carried out against the nearshore ADCPs and results have been published by Greenwood et al [9], [10].

The wave buoy data has also been used by Open Ocean to calibrate an Outer Hebrides boundary model, with model outputs driving another DHI Mike21 SW model under the HebMEF work package 1. This latter model covers the entire west coast of the Outer Hebrides island chain and has been calibrated and validated against both buoy and ADCP data for whitecapping at the buoy locations and additional calibration parameters such as bottom friction and wave breaking applied against the nearshore measured data with results showing high similarity [11].

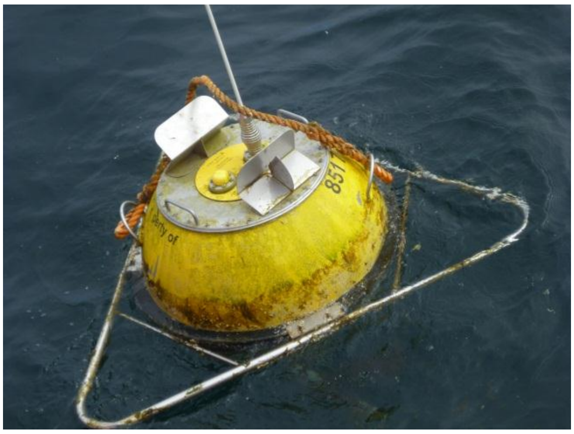

Fig. 6 Datawell Waverider buoy off Isle of Lewis

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