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MODELLING WAVE ENERGY IN ARCHIPELAGOS – CASE OF NORTHERN SCOTLAND

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ABSTRACT

Scotland has a complex coastline that includes hundreds of islands and three major archipelagos, Hebrides, Orkneys and Shetlands. In order to predict the wave resources, the spectral wind wave SWAN was designed on an unstructured grid over the Scottish shelf sea. The grid provides a good resolution in nearshore areas and allows long fetched wind waves.

In spite of the domain size, previous simulations suggested that the boundary conditions could have a significant impact on wave predictions. The implementation of boundary conditions derived from 1D spectral data significantly improved the model predictions. A comparison of the wave energy estimated from wave buoy records and model predictions shows only an under-prediction of 3%.

INTRODUCTION

Exposed to high latitude North Atlantic waves and winds, northern Scotland has an important wave energy resource estimated at 45.7 TWh (Marine Energy Group [1]). The evaluation of wave energy is subject to large uncertainties, mainly due to the intermittency and unpredictability of wind waves, but also to their complex pattern in presence of irregular coastlines and bathymetry, or strong currents.

Most of the sites suitable for wave energy extraction or testing around Scotland are located near island chains (Hebrides, Orkneys, Shetlands), where local waves and currents can vary significantly over short distances due to the combination of islands, headlands and channels. Spectral waves modelling around archipelagos is challenging not only because the complex coastline and bathymetry contributes in generating more wave interaction by reflection, shoaling, refraction, diffraction and non-linear triad wave-wave interaction, but also because it questions the pertinence of using regular finite difference mesh grids. Tuomi *et al*. [2] modelled the wave field within a thousand island archipelagos located at the junction of the gulfs of Bosnia and Finland, in the Baltic Sea, using the spectral wave model WAM on regular mesh grids of different resolution (0.1 and 0.5 nautical miles, with or without obstructions). They found a general overestimate of the wave energy propagating inside of the archipelago, compared with actual measurements. Rusu *et al.* [3] conducted similar numerical experiments, configuring the spectral wave model SWAN in the Madeira archipelago. Both models used a selection of regular grids with different resolution. Although the Madeira archipelago consists of lesser islands and is exposed to stronger waves than the Baltic archipelago, both authors found that the prediction results were dependant on the models' resolution, with significant improvement for finer resolution models.

An unstructured mesh grid would therefore provide a good representation of wind waves within archipelagos due to its fine resolution in coastal areas.

METHODOLOGY

In order to provide refined assessments on wave energy in Northern Scottish Seas, the Environmental Research Institute (ERI) implemented the spectral wave domain SWAN on an unstructured grid over a large domain, from 0° to 10°W to 56° to 62°N (Figure 1). This approach allowed for (i) long fetch distances and (ii) a fine resolution near the coast, especially around the Hebrides, Orkneys and Shetland Islands, with a minimum edge of 45 meters.

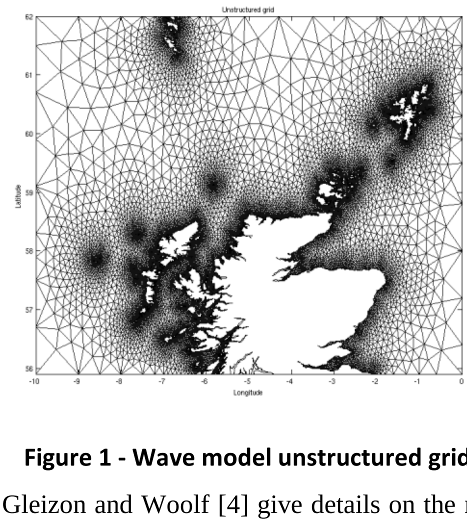

Figure 1 - Wave model unstructured grid

Gleizon and Woolf [4] give details on the model characteristics and setup. In particular the interpolation on the mesh grid of a fine resolution bathymetry data from SeaZone (1 arc sec ~ 30 m) underpins the model's precision in nearshore area. The wind data at 10 m above the mean sea level,

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provided by ECMWF[2], with a resolution of 0.75° and a time interval of 3 hours was interpolated on the model's grid.

Wave data collected within the model domain (Table 1) were used for the calibration and validation. Former predictions of the model replicated well the observed trends of significant wave height and period, but showed a tendency to underestimate the peak values [4]. The results analysis suggested that the domain boundary conditions had a significant influence on the wave predictions, even at distant locations from the boundaries.

Recent work, in collaboration between ERI and Lews Castle College (LCC), has been undertaken to analyse the differences between observations and predictions, and improve the model's simulations. In addition, wave data from buoys deployed by Lews Castle College on the west coast of Lewis has been incorporated into the analysis (Table 1).

Table 1. Wave data

Source	Location	Period	Long.	Lat.
ERI	Brim Ness	02/13-08/13	3.75°W	58.63°N
	Dunnet Bay	12/12-08/13	3.44°W	58.64°N
	Pentland F.	01/12-07/12	3.28°W	58.68°N
	Wick	01/12-07/12	2.79°W	58.46°N
LCC	Bragar	10/11-09/12	6.91°W	58.43°N
	Siadar	10/11-09/12	6.72°W	58.50°N
CeFAS	South Uist	02/09-05/12	7.91°W	57.29°N
	Moray F.	08/08-09/12	3.33°W	57.97°N
	Dounreay	10/97-05/01	3.75°W	58.59°N
Met Off	K7 buoy	04/92-11/01	4.50°W	60.70°N

The significant wave height, mean wave period and direction and wave spreading were derived from ECMWF 1D spectral wave data, and specified at each boundary point. The model was run for 2011 and 2012 with a 3 hour time interval.

OBSERVATIONS

The predicted wave height from January to August 2011 shows a good agreement with wave data at South Uist and in Moray Firth (Figure 2).

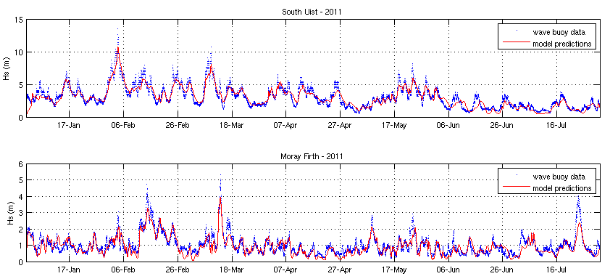

Figure 2 – Model prediction validation. Significant wave height near South Uist (Hebrides) and in Moray Firth

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The performance of the model was measured by a regression analysis between predictions and data during that period. The R^2 values give 0.84 (South Uist) and 0.76 (Moray Firth). This shows a significant improvement from previous simulations where no boundary conditions were applied, for which R^2 were 0.67 and 0.53 respectively. The implication of the difference on wave energy can be calculated from the power matrix of wave energy converters (WEC). Calculating the wave power from the Pelamis power matrix [5], [6], as an example, gives an indication of the wave energy at these locations between January to August 2011. Using this method and as an indication of the model performance, the wave energy was calculated and compared during that period from the wave buoy data and the model predictions, with and without boundary conditions (**Figure 3**).

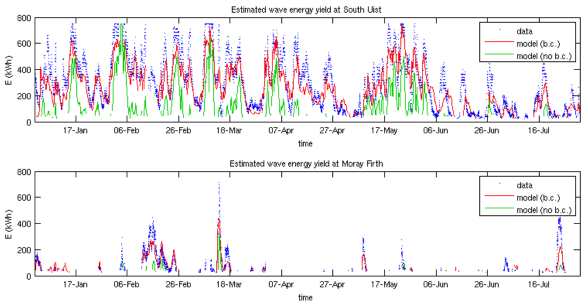

Figure 3. Comparison of wave energy estimates from wave data and model predictions.

The energy yield estimated from the data gives 1,311 MWh at South Uist and 122 MWh at Moray Firth (Table 2). Energy estimates from the model predictions show much closer values with boundary conditions (1,166 MWh at South Uist and 104 MWh at Moray Firth) than with no boundary conditions, showing the importance of the boundaries.

Table 2. Wave energy yield estimate (MWh)

Source	South Uist	Moray Firth
Wave buoy data	1,311	122
Model (b.c.)	1,166	104
Model (no b.c.)	373	17

With boundary conditions, the model is only under-predicting the wave energy by 11% to 15 %. This small difference accounts mainly for the under-estimate of some of the peak values, as shown for instance in the Moray Firth around July 26th (Figure 2). These peak differences could be explained by the response of the wave pattern to rapidly changing wind direction and magnitude.

In order to analyse the validity of this assumption, Figure 4 shows the two-dimensional wave spectra at the same location, indicated by a red dot on the wind maps, on 27th and 28th January 2012 at 12:00 respectively. Although only one day apart, the wind direction has changed from a northern to a southerly direction, rotating anti-clockwise, in the western part of the domain. This change in wind direction induced a split in the wave spectrum from a single peaked (27th January) to a double peaked (28th January) spectrum. The presence of double peaks can influence the wave pattern through non-linear quadruplet wave-wave interaction. Note that in the bottom graph, the highest energy density is observed for southerly wave propagation direction. This is counter-intuitive considering the wind northerly direction at that time and location.

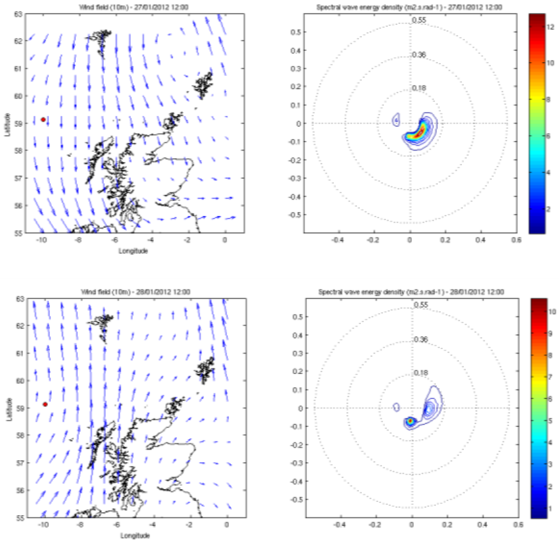

Figure 4. Evolution of wave 2D spectrum in relation to rapid change in wind direction

Refined boundary conditions using two-dimensional wave spectrum are currently being implemented to evaluate the significance of 2D spectra on the model results, in comparison to mean values.

The wave power per metre of wave crest is averaged over the simulation period (January to July 2011) to give the distribution of mean wave power shown in Figure 5. For comparison, it shows similar pattern as given in the Atlas of UK marine renewable energy resources [7], although the order of magnitude appears slightly higher due to the choice of the period of integration, as the wave activity in the first months of 2011 are higher than normal conditions.

Details of the wave power distribution around an archipelago, for instance the Hebrides Islands, shows both the strong gradient of wave power near the shores, and local effects due to the presence of small isolated islands (Figure 6).

CONCLUSIONS

Modelling waves around Scotland is complicated by the convoluted coastlines and the presence of major archipelagos. Applying a spectral model over an unstructured grid provides both a fine resolution near the coast, and the large extent of a shelf scale model. A fine resolution near the shore reveals the influence of islands and headlands on the local distribution of wave power, where a difference up to 10kW/m can be observed between locations distant by only few kilometres.

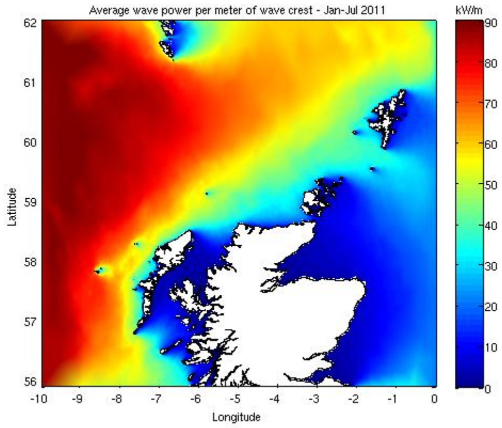

Figure 5. Distribution of wave power over Scottish waters.

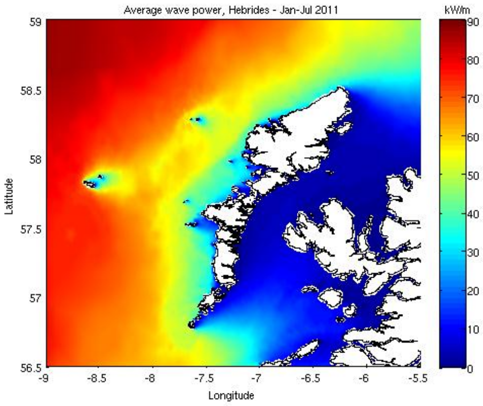

Figure 6. Wave power per metre of wave crest around Hebrides Islands.

Recent work in collaboration between the Environmental Research Institute and Lews Castle College showed the importance of boundary conditions for the model predictions. For instance comparisons of data and model predictions off South Uist island (Hebrides) gave R^2=0.84 for the simulations with boundary conditions, and R^2=0.67 in absence of boundary conditions. In future work, directional spectra may be used to provide better predictions, in particular in presence of rapidly changing wind direction.

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