Modelling Wave Energy in Archipelagos
Case of Northern Scotland

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Introduction

Scotland had one the most abundant wave energy resources in Europe, estimated at 45.7 TWh [1]. However the evaluation of the wave energy is subject to large uncertainties due to the inherent intermittency and the unpredictability of wind waves. Mathematical models are a useful resort for assessing wave energy but the complexity of the Scottish coastline introduces an additional challenge. Tuomi et al. [2] and Rusu et al. [3] showed that regular grid models can introduce an overestimate of the wave energy in archipelagos by misrepresenting the wave dissipation induced by a cluster of islands. The SWAN model was implemented on an unstructured grid over a large domain, both providing a high resolution in nearshore areas and allowing for long fetched wind waves and swells.

Model

Grid characteristics

- Vertices: 48144
- Elements: 85547
- Min edge: 45 m
- Max edge: 80 km

Bathymetry

Seazone, 1arc sec
Shetlands,
Orkneys,
North Scotland
Outer Hebrides

Seazone, 30 arc sec
Continental shelf

Gebco, 1 arc min
Offshore areas

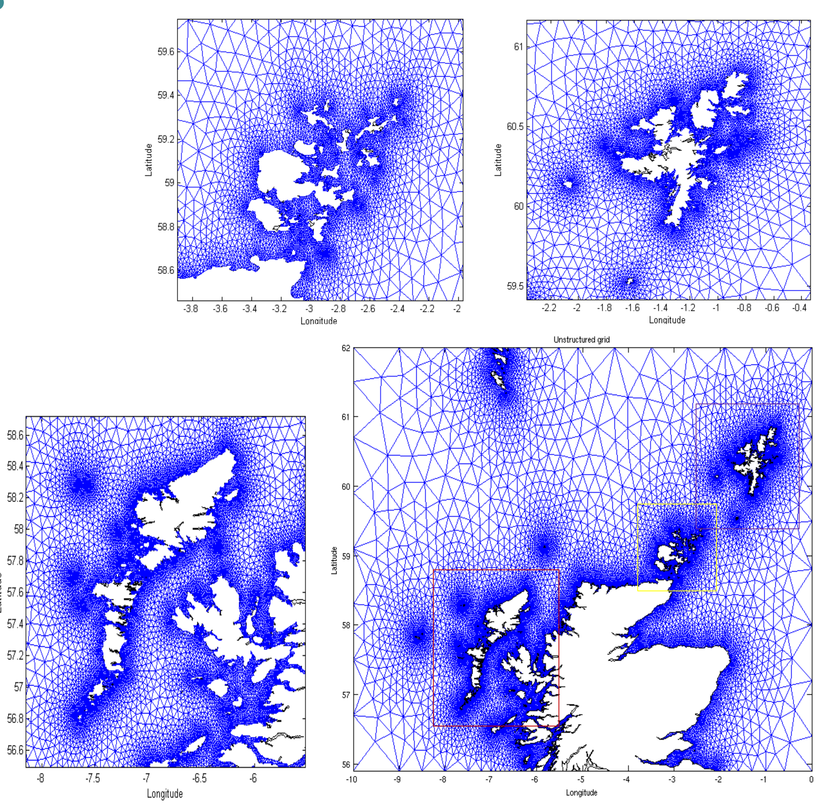

Figure 1. Model unstructured grid

Wind input

The wind data was obtained from the European Centre for Medium-range Weather Forecast (ECMWF) at 10 m above sea level on a 0.75° resolution and 3 hour time interval.

Boundary conditions

Previous studies [4] showed that swells and waves propagating from outside the modelling domain influence the wave characteristics, even far from the boundaries. Boundary conditions are specified at each time by the significant wave height, mean wave period and direction, derived from ECMWF one-dimensional spectral wave data.

Validation

The model replicates well the observations, as shown by the comparison of significant wave heights against data recorded at South Uist and Moray Firth in 2011 (Figure 3). A linear regression analysis applied to the entire year give R^2=0.84 at South Uist and R^2=0.72 at Moray Firth. This shows a significant improvement from previous simulations where no boundary conditions were applied and for which R^2 were 0.67 and 0.53 respectively [4]. It also indicates, through a series of tests, that boundary conditions are one of the most critical input parameters in spectral wave models.

As shown in Figure 3, some peak values are still under-predicted, which could be explained by the response of the wave pattern to rapidly changing wind direction and magnitude. Figure 4 illustrates the impact of rapid meteorological change on the directional wave spectrum. Within a day, the wind in the western part of the domain turned from a southerly to a northerly direction, inducing a double peak pattern of the wave directional spectrum at a location near the western boundary (red dot). Boundary conditions using two-dimensional wave spectrum are currently being implemented to study the impact of complex wave spectra on predictions.

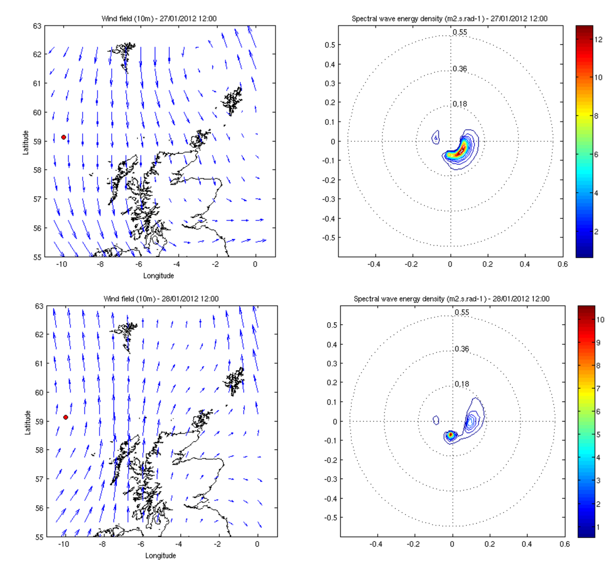

Figure 4. Evolution of wave 2D spectrum in relation to rapid change of wind direction

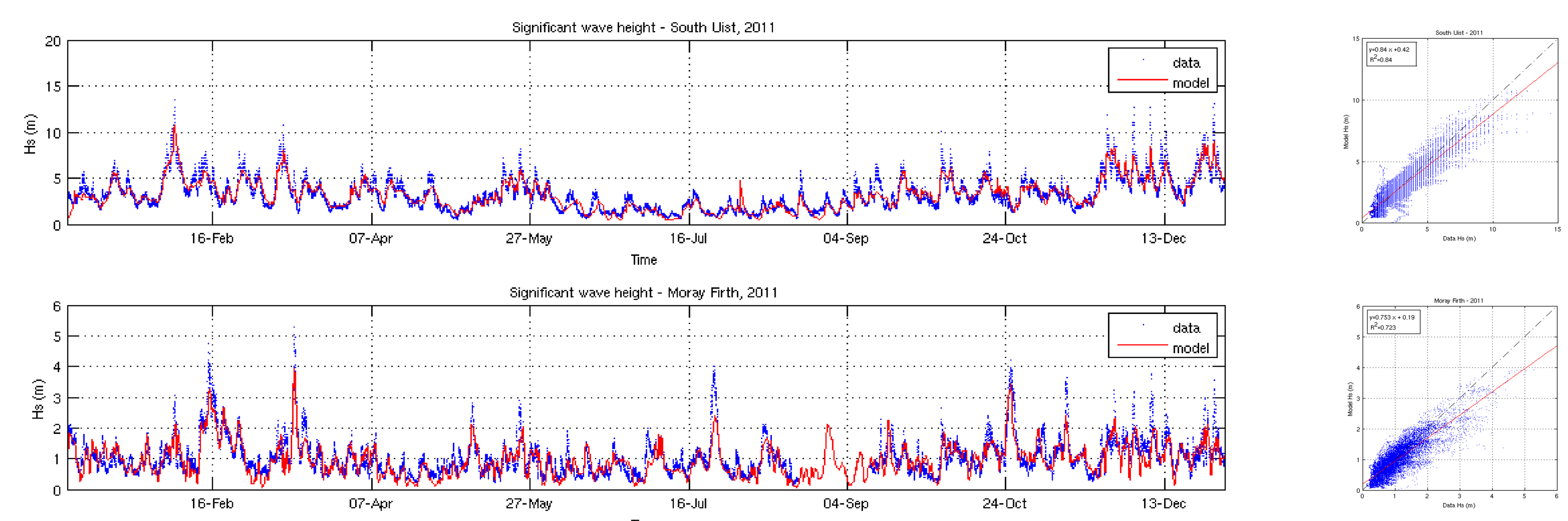

Figure 3. Significant wave height validation at South Uist (top graphs) and Moray Firth (bottom graphs)

Monitoring data

Wave data were collected by directional wave buoys along the Northern Coast of Scotland (Figure 2), from 2008 to 2013. Wave records from earlier K7 buoy and CeFAS' WaveNet buoys at Dounreay, Moray Firth and off South Uist Island were complemented by Lews Castle College (LCC) wave monitoring northwest of Lewis Island from October 2011 to September 2012, and by the Environmental Research Institute (ERI) series of wave monitoring near the Pentland Firth in the first halves of 2012 and 2013 (Table 1). Monitoring data are used for the model validation and for characterising the wave directional spectra at locations of interest.

Table 1. Wave buoys monitoring

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

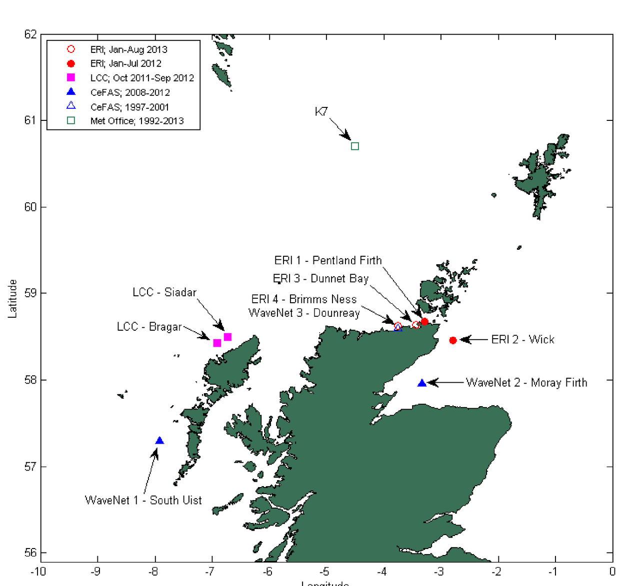

Figure 2. Wave buoys location map

Wave energy estimate

The performance of the model can also be evaluated from the wave energy comparison. As an example, the energy yield was calculated at South Uist and Moray Firth applying the Pelamis power matrix given by [5] and [6] to the data and model predictions with and without boundary conditions. The calculated wave power time series show a closer agreement between model predictions and data when boundary conditions are implemented (Figure 5). This is further highlighted by the total wave energy yield estimated for 2011 (Table 2). The energy yield calculated from the data gives 2,520 MWh at South Uist and 201 MWh at Moray Firth. The same estimates from the model predictions show closer values with boundary conditions (2,327 MWh and 162 MWh) than with no boundary conditions (957 MWh and 40 MWh).

Table 2. Estimated wave energy yield (MWh) in 2011

Source	South Uist	Moray Firth
Wave buoy data	2,520	201
Model (b.c.)	2,327	162
Model (no b.c.)	957	40

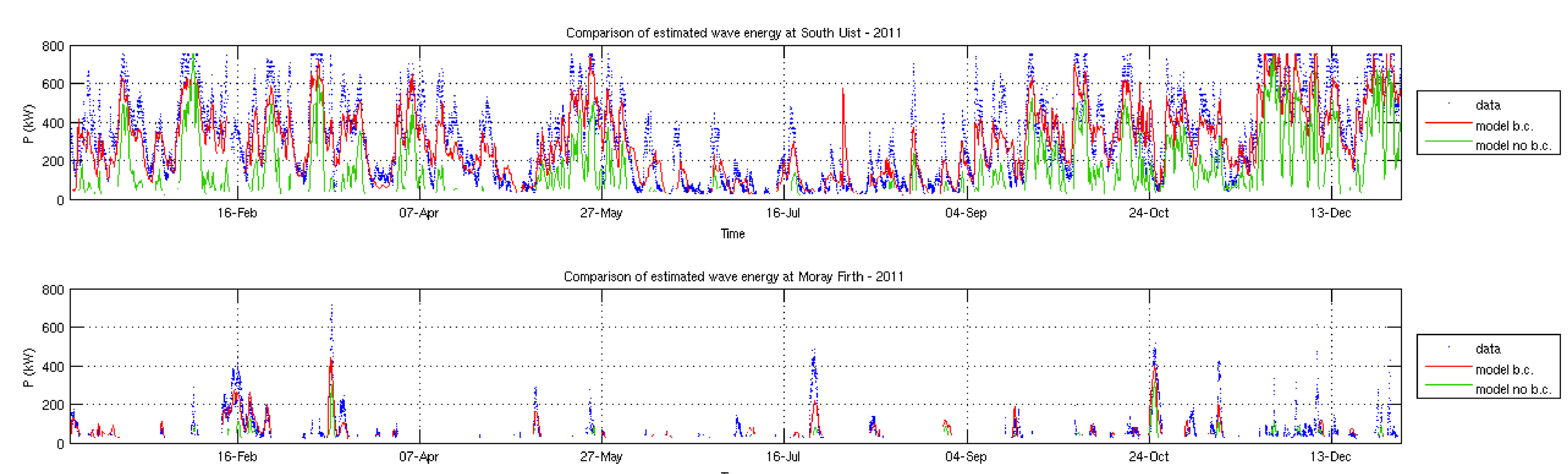

Figure 5. Comparison of wave energy estimates from wave data and model predictions

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Acknowledgments

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