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THE HEBRIDEAN WAVE MODEL

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ABSTRACT

Any investigation of the interaction between marine renewables and their physical environment requires detailed information about the baseline wave resource. Hebridean Marine Energy Futures (HebMarine) have been conducting a high resolution spectral wave model of the Outer Hebrides of Scotland, site of several planned wave energy deployments. The simulation, performed using DHI Mike 21 spectral wave software, was fully calibrated and validated with data from three wavebuoys and two acoustic devices. Estimating energy loss due to bottom friction, wavebreaking and whitecapping involves optimisation over a four dimensional space of calibration parameters, to ensure the model reproduces measured behaviour over a suitably representative time period. We believe that the temporal and spatial variation of wave height, period and power will be of local interest to stakeholders while the methodology and software tools will be of interest to the wider wave resource modelling community.

INTRODUCTION

Due to a highly energetic wave climate, the Outer Hebrides of Scotland are of significant strategic importance to the wave power industry, which is currently gearing up for the first phase of commercial array deployments. These will include a 10MW array of Pelamis devices 10km off Bernera[1], and a 40MW nearshore array of Aquamarine Oyster devices off Siadar, currently the world's largest fully consented wave energy development[2]. With the increased interest in the area, a wealth of data has become available in recent years. These datasets include wave measurements for extended deployment periods (>12 months consecutively) from multiple sensors deployed by the Hebridean Marine Energy Futures project at intermediate and shallow water depths [3, 4], (see Figure 1), Marine Scotland bathymetry surveys, and baseline biotope mapping in the intertidal and shallow water zone. This data has been used to produce the first publicly available high resolution wave spectral model covering the Western Isles of Scotland. This will provide detailed baseline wave data for any investigation of the interaction between marine renewables and their physical environment, and can also be used to drive sediment transport and biodiversity models.

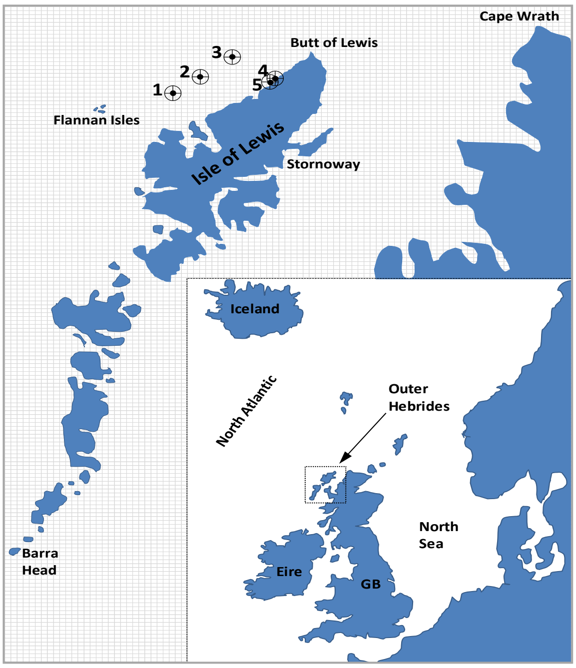

Figure 1 Sensor Locations. 1,2 and 3 are the Waverider buoys, 4 and 5 are Nortek AWACs [4]

THE MODEL

The model covers the western seaboard of the Outer Hebrides island chain from the Butt of Lewis to Barra, although it is designed to maximise its accuracy at the north-west coast of Lewis, which is the area of most interest to the wave power industry, and with the greatest quantity of sensor and bathymetry data. It covers 250km in the long-shore direction, and extends 75km out to sea. The mesh, shown in Figure 2, starts at 5km resolution. In the northern part, the resolution becomes 1km, 500m, and finally 250m around the coast. In the southern region, it becomes 2km and then 1km by the coast. The model boundaries are driven by results from a larger WAVEWATCH III simulation. The resolution of this larger simulation enabled the seaward boundary to be divided into fifteen sections: nine for the western boundary, two each for northern and southern and two for the non-land parts of the eastern boundary. Wind input for 10m above sea-level was obtained from ECMWF at 0.75° resolution.

The simulation was performed using the Spectral Wave module of the DHI Mike 21 software suite [5], which uses the Wave Action Conservation Equation to track the evolution of the wave spectrum in space and time [6]. Physical processes such as

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wind forcing, white capping, seabed frictional interaction and wave breaking are described by semi-empirical source terms. These incorporate four free parameters (two for whitecapping, and one each for wavebreaking and bottom friction), which are chosen by the user to achieve the closest possible match between modelled and measured results. There is considerable leeway available in the choice of these quantities, and accurate modelling depends on the availability of high-quality survey data to drive this calibration process. It was decided to use the northernmost wave buoys and one ADCP (Sensors 2, 3 and 4 in Figure 1) for calibration, and the remaining buoy and second acoustic sensor (Sensors 1 and 5 in Figure 1) for model validation.

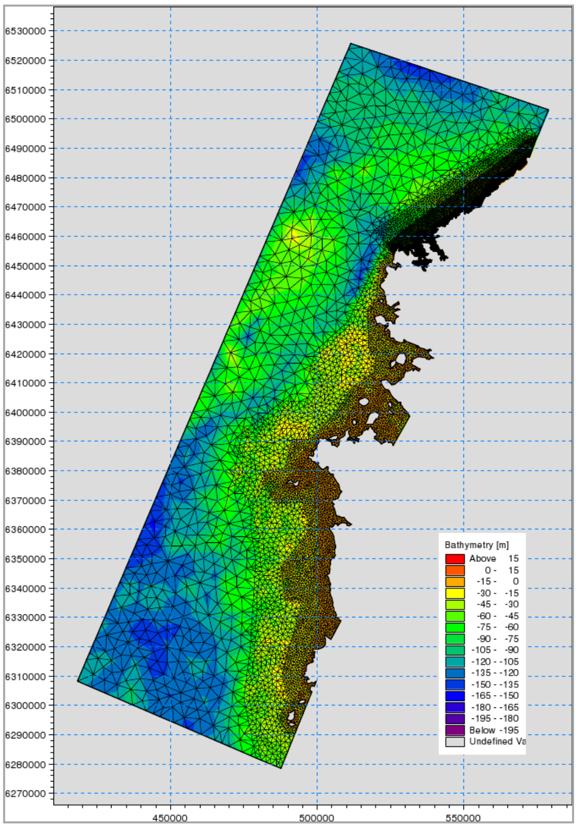

Figure 2 The Model Domain

The simulation was carried out for one year, with an hourly timestep.

CALIBRATION

For a modelled quantity x_j^{model} and observed quantity $x_j^{measured}$, we define the scatter index as $S = \frac{RMS\ error}{\bar{x}}$ where $\bar{x}$ is the mean of the quantity (measured or modelled) and the RMS error is defined by $RMS = \sqrt{\frac{1}{N}}(x_j^{model} - x_j^{measured})^2$. We seek to minimise the scatter indices of the significant wave height and mean wave period at the various sensor locations. We also require that the bias (the difference between the means of measured and modelled quantities) is not too large. There are four model parameters which the user can vary: whitecapping C_{dis} and $Delta_{dis}$ (representing the total degree of whitecapping, and the part of the spectrum most affected), Nikuradse bottom roughness and wavebreaking γ. In principle, this would involve seeking global optima in a four-dimensional parameter space. However, sensitivity analysis confirms that the wavebreaking and bottom friction have a negligible effect on the outputs at the wavebuoy locations. It was therefore decided to fix the two whitecapping parameters by calibrating against the buoy locational data, then set the remaining parameters using the AWAC data.

It was found that the two whitecapping parameters could not be treated independently: the optimal value of C_{dis} depends on the choice of $Delta_{dis}$ and vice versa. One approach would be to iterate towards the optimal values by alternately working with each parameter. However, it was ultimately decided to form a two dimensional grid of values and find a “surface” of scatter indices and biases. This enabled confirmation that the optima were indeed global. It also enabled judgements to be made about how to balance the optimisation of wave height and wave period estimates. A coarse grid covering the whole range of possible C_{dis} and $Delta_{dis}$ values was first generated, to find the approximate location of the optima. This was then narrowed down using a second set of simulations at finer resolution in parameter space. An example of the results from the coarser grid covering the full parameter space is shown in Figures 3 and 4.

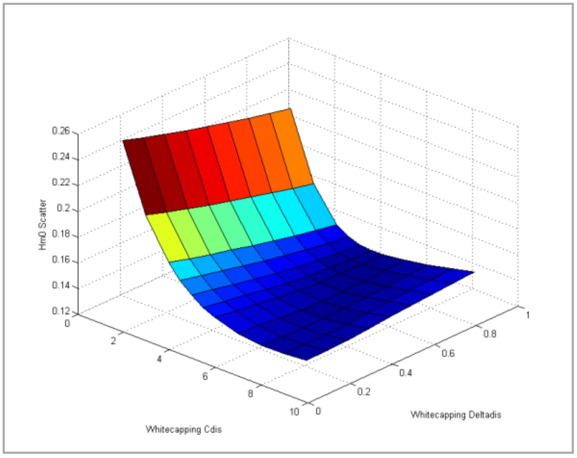

Figure 3 Waveheight scatter index varying with the two whitecapping parameters

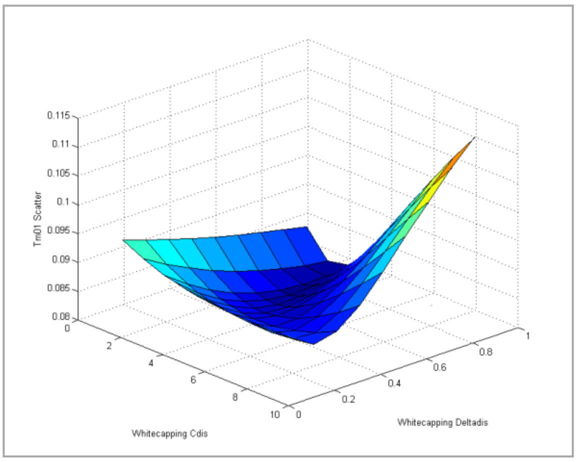

Figure 4 Mean period scatter index varying with the two whitecapping parameters

Having fixed the whitecapping parameters at the buoys, the bottom friction and wavebreaking could be set using AWAC data. As the wavebreaking parameter had a significantly smaller effect than the bottom friction, these could be treated independently: bottom friction fixed first, and finally wavebreaking chosen.

A year's worth of sensor data was available at each of the calibration points. Running the model for a year would be too computationally intensive, so a suitable subset was sought. To ensure that the time period represented the wave conditions over the course of the year, it was decided to take an ensemble of short (24 hour) periods, of sufficient quantity to provide a suitable statistical sample of all conditions. Several timesteps were added at the beginning of each simulation to ensure the boundary conditions could propagate across the domain. This ensemble approach is thought to make the best use of available data, and also enables additional validation to take place using the same buoy locations but at different times.

The chosen calibration process, particularly the ensemble of short simulations, involves setting up, running, and postprocessing a significant number of Mike models. Software was created to automate this process and will be made available to interested parties in the near future. From a given set of parameters and dates, this code generates a series of Mike files, a Windows batch file to run the simulations, and some additional index files. Once the models are run, a second piece of software collates all the simulation outputs, reads the sensor data and generates two dimensional surfaces or one dimensional plots of overall scatter indices or biases for the combined time period.

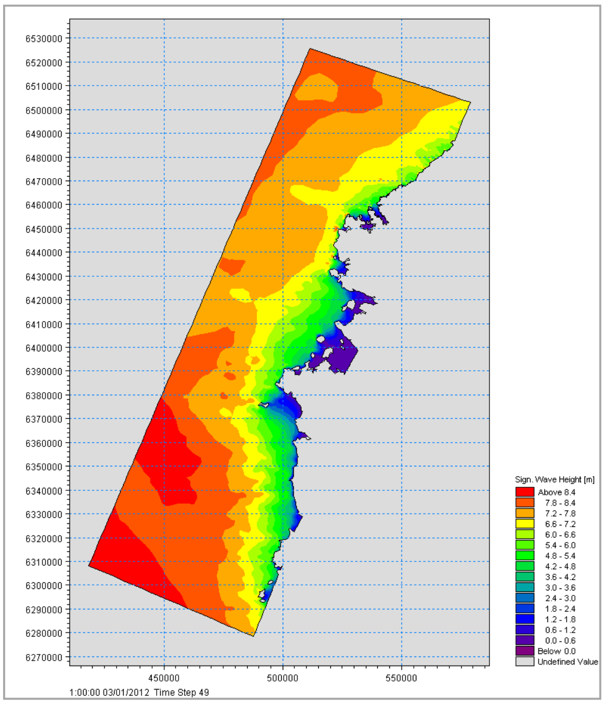

Figure 5 Significant wave height, single timestep

RESULTS

The model yields area maps of wave parameters, including significant wave height, directional peaks, means and spreads, mean wave period, and power flux. An example area plot of significant wave height for a single timestep is shown in Figure 5. Time varying directional spectra were also generated for all the sensor locations.

CONCLUSION

The model will produce area maps of various wave parameters, and directional spectra at the locations of the wave sensors. Validation data and error estimations will be available following the end of the model run. Software tools for generating and postprocessing simulations for multiple parameters and times have also been produced.

ACKNOWLEDGEMENTS

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Further acknowledgement is made to Open Ocean [7] for providing model boundary data to this project free of charge.

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