Orkney wave environment : Predicted changes to 2100

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Introduction

The effects of climate change on future ocean wave conditions have been investigated for various regions of the globe. To the authors' knowledge such studies have yet to be conducted for Orkney waters, yet with 600MW of wave power capacity proposed in the area (based on the Crown Estate Round 1 development sites, shown in Fig. 1) it is important to understand how the available resource will change.

For this work two periods are considered: a "present day" scenario using a model based on 2010 wind speeds (described below), and a "future" scenario for 2100, assuming the RCP8.5 profile for future emissions, described to the right. In this work we explain how the future scenario was created, and compare the predictions of the two.

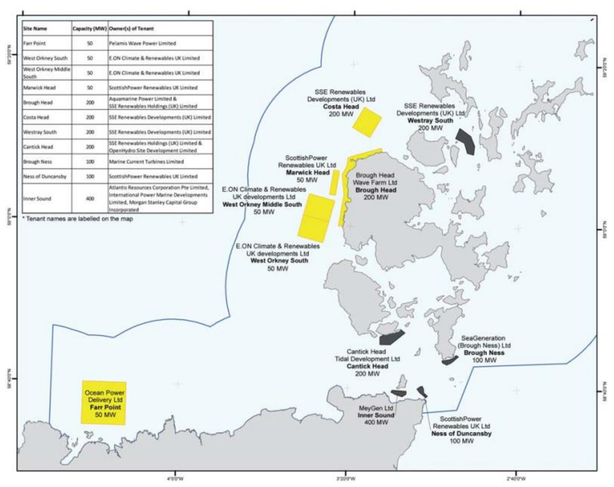

Figure 1: The Crown Estate Round 1 development sites. Although now outdated, this map gives a perspective of the scale of development envisaged for the west of Orkney. Sites shaded in yellow are for wave energy.

Existing model & 2010 scenario

An existing, validated, spectral wave model of the north Atlantic, built using the MIKE 21 code, was adopted for this work. For details of the model and its validation, see [1].

The model simulates the growth, decay and transformation of wind-generated seas and swells using a directional, fully spectral formulation with 24 frequency bins. It includes wind-induced wave growth, wave-wave interaction, white-capping, bottom friction and wave breaking, refraction and shoaling.

An unstructured triangular computational mesh was built with a typical resolution of 70-100 km in mid-ocean and 0.5-2 km close to the Scottish coast. The domain and mesh may be seen in Figure 2.

For 'present-day' simulations, which use the year 2010, the model was forced by near-surface wind velocities sourced from the European Centre for Medium Range Weather Forecasts (ECMWF), which were supplied on a 1/8° grid at six-hour intervals. Interpolation from this grid to the model mesh is handled automatically by the MIKE software.

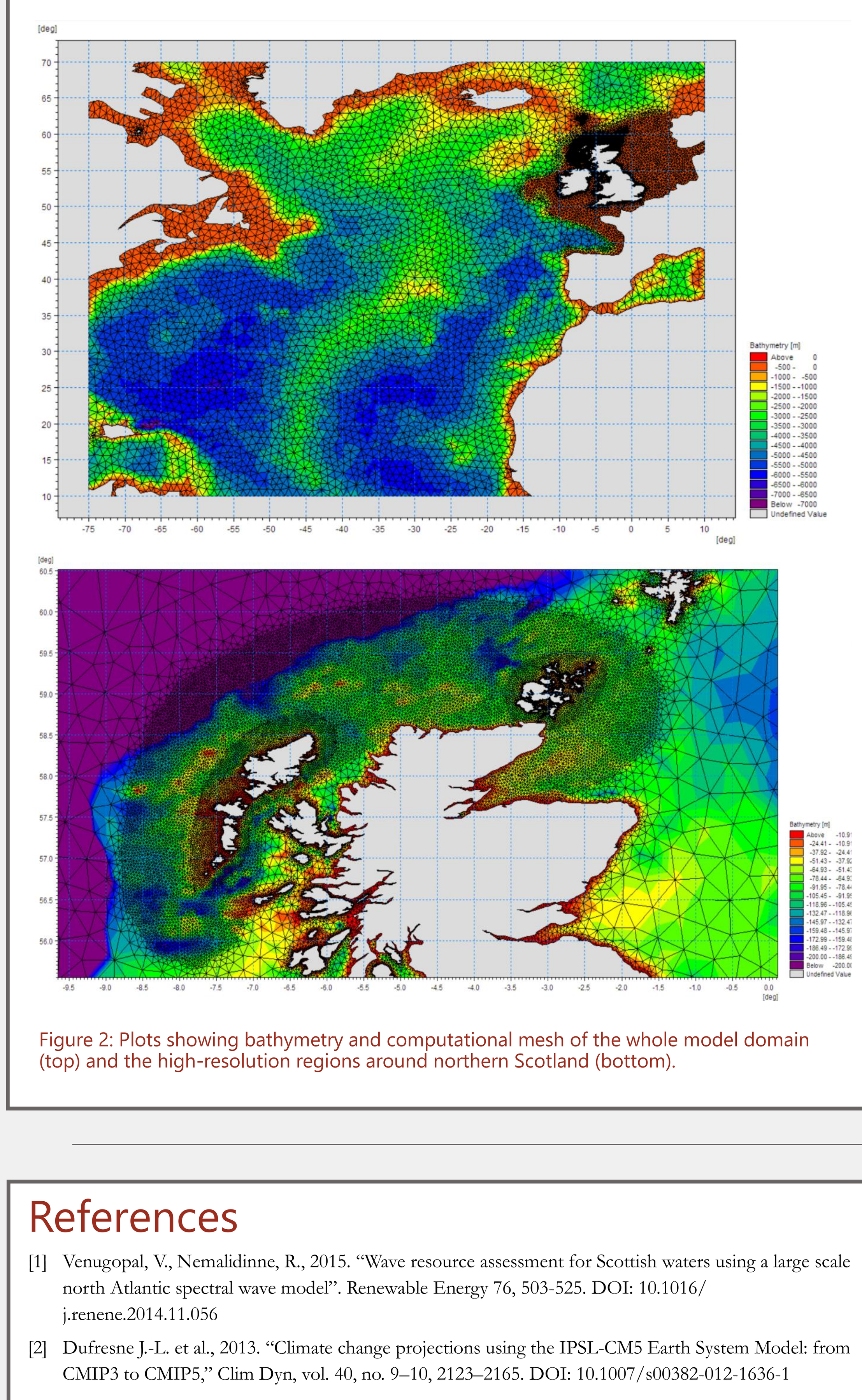

Figure 2: Plots showing bathymetry and computational mesh of the whole model domain (top) and the high-resolution regions around northern Scotland (bottom).

Adjusting for future climate

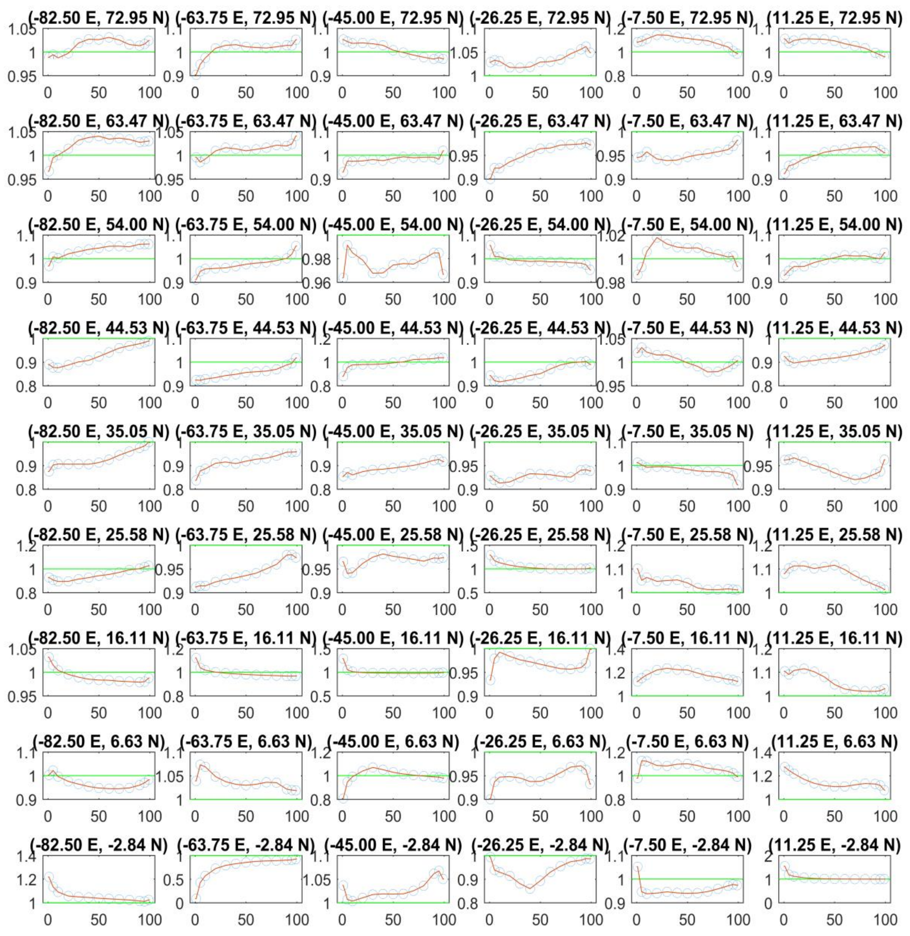

Figure 3: Adjustment curves, shown on a spatial grid covering the area of the north Atlantic. For space reasons, only every tenth location on each axis is shown here; the actual number of curves used was 100x greater.
For each curve, the x-axis shows the percentile and the y-axis shows a scaling factor by which a present wind speed should be multiplied to estimate its future equivalent The red lines show the adjustment curves, and the green lines are fixed at values of 1.0 (*i.e.* no adjustment).

Due to limitations of computing power it was only practical to simulate one year of waves for each scenario (present & future). A naïve approach would be to use a year of wind predictions from 2100 to force the future scenario. However, because wave energy is stochastic, there would be no way to know whether differences were due to climate change or to random variation between the two years in question. Instead, the method adopted was to take the 2010 wind data — thus retaining the same storms and other events as 2010 — and scale them in line with expected changes to 2100.

Two time series of near-surface wind speeds, using the RCP8.5 profile for future emissions, were obtained from the CMIP5 project: a 30-year period centred on 2010, and a 30-year period centred on 2100. In each period and at each relevant location on the grid, all timesteps were ranked by the magnitude of the wind speed and percentile values were recorded. Adjustment curves were then calculated for each location to convert, for example, a 65th-percentile 2010 wind speed to a 65th-percentile 2100 wind speed. Examples of these curves can be seen in Figure 3. These curves were then used to adjust each timestep and each grid point in the model's wind forcing file.

The data selected were from the IPSL-CM5A-LR global model [2], ensemble r1i1p1. The reason for this choice was that it was the only model in the CMIP5 project that offered 10 m wind speeds with the range of dates required. The use of only a single ensemble member, rather than an ensemble average, is for the same reason, and is identified as a weakness in this study.

A further limitation is intrinsic to this method: that only changes in predicted wind speeds, and not their directions, are applied. However, visual inspection of wind roses from the past and future 30-year periods (Figure 4) suggests that changes in wind direction are small.

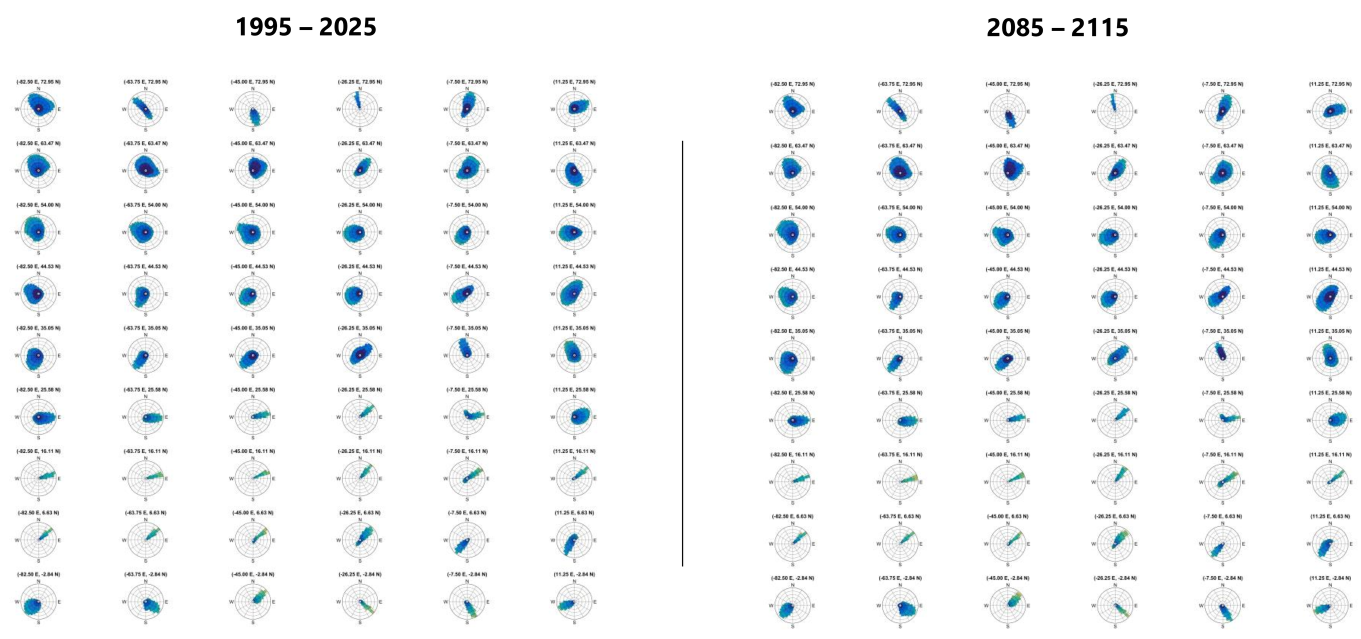

Figure 4: Wind roses computed from 30-year periods of IPSL-CM5A-LR output, shown on a spatial grid covering the north Atlantic.

Results & Discussion

From 2010 to 2100, a small reduction (2-3%) in the mean significant wave height (H_s) is predicted to the west of Scotland (Figure 5) along with a very small (~1%) increase in mean wave period (not shown). This results in a modest reduction in the wave power reaching the coast (Figure 6).

Figure 5 shows a very small *increase* in mean H_s in parts of the model that are sheltered from westerly winds. Speculating somewhat, this may be due to an increase in the strength of northerly winds in the global model, but this is not of importance to renewable energy generation and has not been investigated further.

Figure 7 shows the frequency distribution of 6-hourly wave power predictions at a location approximately 5km off the west coast of mainland Orkney (*i.e.* amid the areas of planned wave energy development). Evaluating the total wave energy passing this point over the year shows a reduction of 7%, from 193 GWh in 2010 to 180 GWh in 2100. This does not necessarily represent a 7% loss in electrical output, because the proportion of the incoming power transformed by wave energy convertors varies with the sea state, but it does indicate that a small decrease is likely.

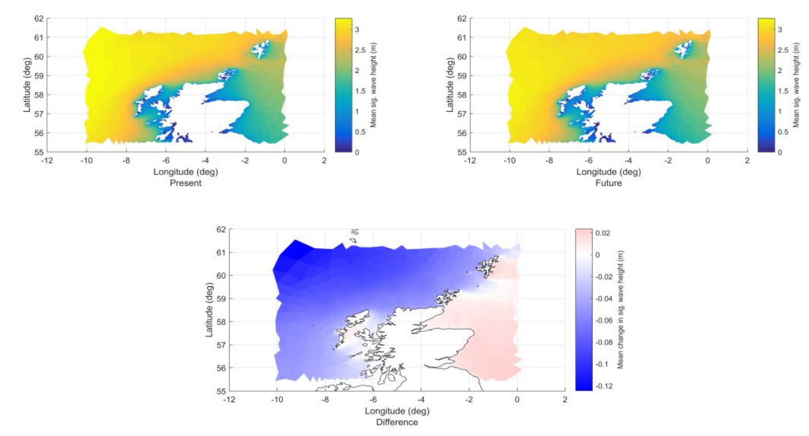

Figure 5: Plots showing present and future annual mean values for H_s, as well as the mean difference between present and future, around the north of Scotland.

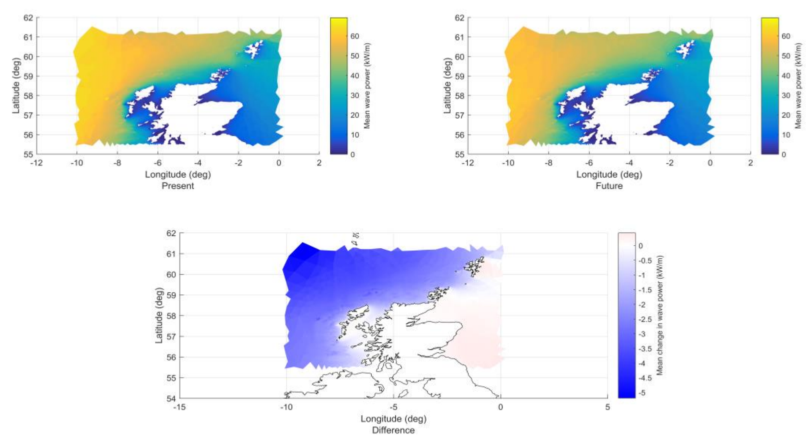

Figure 6: Plots showing present and future annual mean values for wave power per metre of wavefront, as well as the mean difference between present and future, around the north of Scotland.

Concluding remarks

If a 7% reduction in wave power is to occur during this century, this will be of importance to site developers for their financial planning. However, the use of only a single CMIP ensemble member lends some uncertainty to this figure, and further work to reduce this would be advisable.

A useful further step would be to use the outputs of this north Atlantic model to drive a more detailed smaller-scale model with realistic wave energy convertor performance, so as to ascertain the likely change in output of a given machine or array of machines.

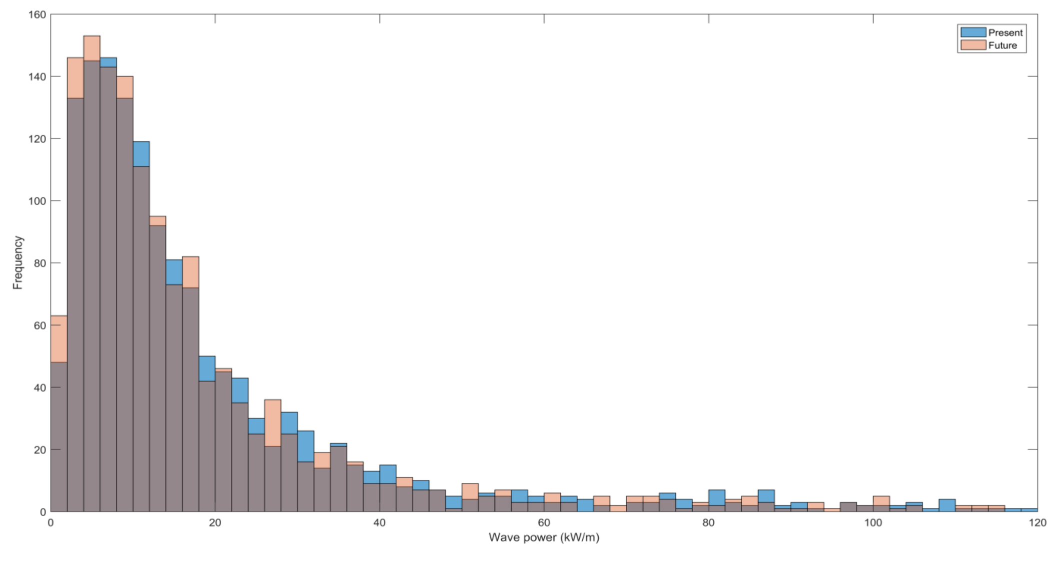

Figure 7: Frequency distribution of wave power per metre of wavefront over one year divided into six-hour periods, for present and future, at a location 5 km west of Orkney.

References

[1] Venugopal, V., Nemalidinne, R., 2015. "Wave resource assessment for Scottish waters using a large scale north Atlantic spectral wave model". Renewable Energy 76, 503-525. DOI: 10.1016/j.renene.2014.11.056

[2] Dufresne J.-L. et al., 2013. "Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5," Clim Dyn, vol. 40, no. 9–10, 2123–2165. DOI: 10.1007/s00382-012-1636-1

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