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Modelling changes to physical environmental impacts due to wave energy array layouts

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ABSTRACT

This paper describes the first stage of an approach developed through the NERC/Defra EBAO (Optimising Array Form for Energy Extraction and Environmental Benefit) project to model the potential environmental impacts of a range of wave farm designs. The eventual aim of the methodology is to inform array design in order to minimise negative environmental impacts or even produce benefits. The modelling study considers differing array sizes and layouts, allowing issues such as the most appropriate device spacing, or the need for a 'corridor' between clusters of devices, to be assessed from an environmental perspective. The results presented in this paper focus on the physical wave climate, using the EMEC test site as a case study. The modelling uses the SWAN spectral wave model to assess the potential far-field change in the wave climate due to different array layouts and spacing. Preliminary results indicate that although designing arrays as sub-array clusters with corridors between them will have a notable effect on the wave climate impact in the immediate wake of the array, at far-field distances (>5km), differences in the impacts when compared with regularly-spaced arrays are negligible. These results are discussed in the context of other physical impacts including acoustic noise, and conclusions drawn regarding the overall impact of array design on the marine environment.

INTRODUCTION

With a number of wave energy devices having undergone successful full-scale sea trials, developers are increasingly looking to take the next steps towards commercialisation through the deployment of initially small-scale, and eventually large-scale, arrays of devices. Inevitably, these early arrays will be designed to maximise power generation and thus profitability. However, this need not occur at the expense of environmental factors. It has already been proposed that large-scale wave farms may benefit the marine environment by providing protected areas for marine fauna [1], but these benefits are usually offset by potential negative impacts such as increased underwater noise and electromagnetic radiation affecting subsea habitats, and physical changes to the environment in the wake of the array [2].

The following sections describe a methodology for assessing the impacts of different wave farm array layouts and the application of this to the test site at EMEC in Orkney, Scotland.

METHODOLOGY

Three potential wave farm scenarios were assessed in this study. The basic array configuration, defined as scenario A (Figure 1), comprises ten 1MW devices, representative of point absorbers or attenuators. These are laid out in a cluster of three rows with 600m spacing between each row, and individual device spacing of 400m. The rows are perpendicular to the mean wave direction, and the middle row is offset from the first and third by 200m so that devices in the second and third rows do not lie directly in the wake of devices in the previous row. This size of array is designed to be typical of the early stage commercial deployments expected to be seen in the next five years.

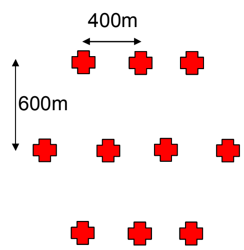

Figure 1 Wave farm scenario A: 10 x 1MW point absorber/attenuator devices

Scenarios B and C (Figures 2 and 3) scale up to the size of the potential large-scale arrays that will be seen in the future when smaller arrays have been proven commercially. It is at this type of scale that environmental impacts are likely to become more significant. Both comprise 50 of the same 1MW devices used in scenario A, with identical individual and row spacings. However, while scenario B (Figure 2) is a single block of five rows of 10 devices, scenario C (Figure 3) breaks the array down into five clusters, each laid out as the array in scenario A. The spacings between the clusters are designed to allow impacts to be reduced across the full array, and provide corridors for vessels and marine mammal migration.

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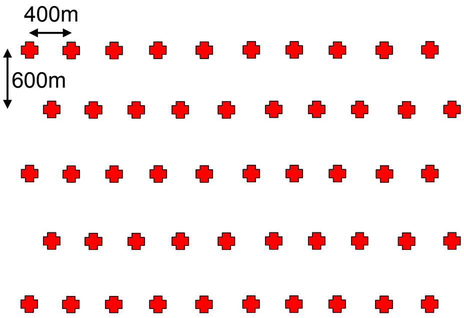

Figure 2: Wave farm scenario B: 50 x 1MW point absorber/attenuator devices in a single array.

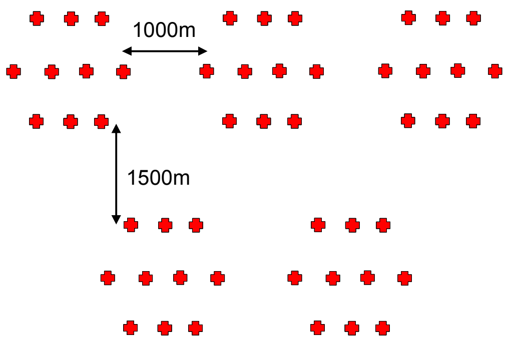

Figure 3: Wave farm scenario C: 50 x 1MW point absorber/attenuator devices in five clusters of ten devices. Intra-cluster spacing is as for scenario A.

The methodology for this study uses the SWAN (Simulating WAves Nearshore) spectral wave model [3], a phase-averaged model that propagates spectral wave states across a grid, accounting for depth-limited interactions such as bottom friction, depth-induced breaking and triad wave-wave interactions. The aim is to use the model to predict potential changes to the wave climate in the lee of the array. These changes are primarily due to the conversion of the energy transported by the waves into electrical energy. As wave energy is proportional to the square of the significant wave height of the sea state, it would be expected that a reduction in the energy in the sea state would be seen as a reduction in wave height. Devices are represented as barriers in the model which permit a defined percentage of the incident energy to be transmitted, described in more detail by Millar *et al*. [4].

Initially, a theoretical study was performed, using a 50m resolution bathymetry grid measuring 27500 x 16000m with parallel depth contours to represent a simple seabed. Depths ranged from 100m at the western boundary, to 0m in the east. Over most of the grid, a consistent 1:500 seabed slope, representative of a typical wave farm site such as Wave Hub in the southwest UK [5] was applied. The steepness increased in the nearshore region to represent a realistic shoreline. The wave farm arrays were located between 50 and 60m depth.

The model was run for two sea states input along the northern, western and southern model boundaries to avoid energy loss from the grid. The sea states were intended to be representative of 'normal' conditions and 'large' conditions without being extreme. They were taken from a significant wave height (H_{m0}) – energy period (T_{mm10}) scatter plot of results for a 22-year model hindcast for the Wave Hub site in Southwest England [6]. Clusters of four bins were identified in order to identify the sea states to be used as follows (see Figure 4):

1. *'Normal' sea state*: The mean H_{m0} and T_{mm10} values from the cluster of four neighbouring bins with the total highest percentage occurrence.
2. *'Large' sea state*: The mean H_{m0} and T_{mm10} values from the cluster of four neighbouring bins with the largest values of H_{m0} where each bin of the cluster had a percentage occurrence greater than 0.2%.

The values of T_{mm10} were converted to mean period (T_{m01}) to comply with SWAN input requirements using a relationship between T_{mm10} and T_{m01} defined from measurements at the site [7] as:

$$T_{m01} = \frac{T_{mm10} - 0.26}{1.15} \qquad (1)$$

Results were output along vertical grid transects at 200m, 1000m, 5000m and 10000m distance from the arrays, with the percentage change in significant wave height (compared with a baseline case with no devices present) calculated at each grid point along the transect.

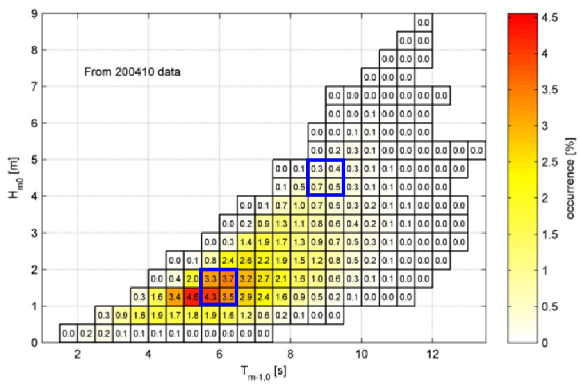

Figure 4: Scatter plot from 22-year hindcast for the Wave Hub site, with blue boxes indicating the groups of sea states used to identify 'normal' and 'large' seas.

A similar methodology was then applied to the EMEC site in northern Scotland. A SWAN model was set up using 1/600° resolution bathymetry, and output from one year of regional model data as input boundary conditions. The same three array scenarios, deployed at 50-60m depth, were incorporated into the model.

RESULTS

Results for the theoretical study were output along vertical grid transects at 200m, 1000m, 5000m and 10000m distance from the arrays, with the percentage change in significant wave height (compared with a baseline case with no devices present) calculated at each grid point along the transect. An example of the results for each array scenario for 'normal' sea states is shown in Figure 5. It illustrates that although notable differences in impact between the three arrays are seen in the immediate vicinity of the device, by 5000m the differences between impacts due to the two large arrays is negligible.

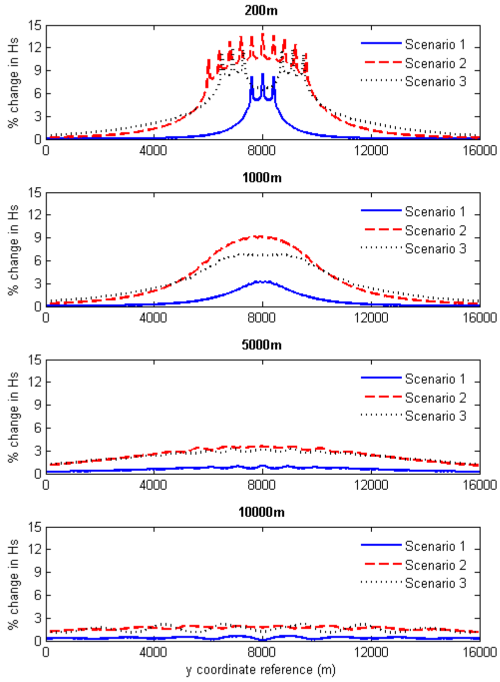

Figure 5: Percentage change in significant wave height along transects across the grid at a range of distance from the array.

Results from the EMEC case study showed similar patterns, e.g. Figure 6. However, it should be noted that the seabed at EMEC is steeper than that used in the theoretical study, and the shoreline impacts are therefore magnified.

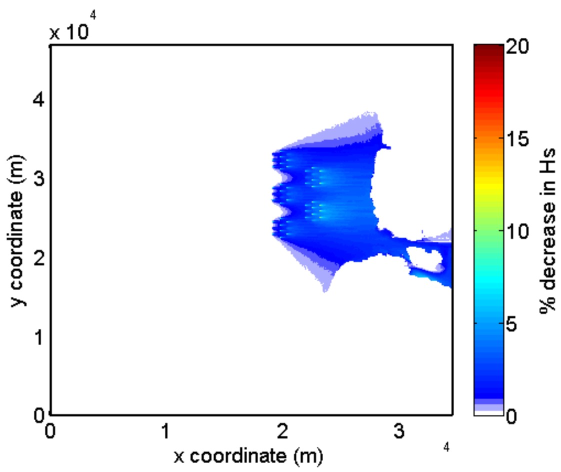

Figure 6: Example change in wave height at the EMEC case study site for scenario 3.

CONCLUSIONS

Modelling results have illustrated that array layouts may have significant implications for the impact on wave heights in their immediate wake; however, differences due to layout are negligible in the far-field. The issue of array layout must therefore be considered in the context of wider concerns, such as device noise and impacts on marine mammals. Further research is ongoing to investigate the transmission of acoustic signals for the array layouts investigated in this study, and the potential implications for marine mammal behaviour in the vicinity of the arrays.

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