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An investigation of the impacts of climate change on wave energy generation: The Wave Hub, Cornwall, UK

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A B S T R A C T

In this paper a generic methodology is presented that allows the impacts of climate change on wave energy generation from a wave energy converter (WEC) to be quantified. The methodology is illustrated by application to the Wave Hub site off the coast of Cornwall, UK. Control and future wave climates were derived using wind fields output from a set of climate change experiments. Control wave conditions were generated from wind data between 1961 and 2000. Future wave conditions were generated using two IPCC wind scenarios from 2061 to 2100, corresponding to intermediate and low greenhouse gas emissions (IPCC scenarios A1B and B1 respectively). The quantitative comparison between future scenarios and the control condition shows that the available wave power will increase by 2–3% in the A1B scenario. In contrast, the available wave power in the B1 scenario will decrease by 1–3%, suggesting, somewhat paradoxically, that efforts to reduce greenhouse gas emissions may reduce the wave energy resource. Meanwhile, the WEC energy will yield decrease by 2–3% in both A1B and B1 scenarios, which is mainly due to the relatively low efficiency of energy extraction from steeper waves by the specific WEC considered. Although those changes are relatively small compared to the natural variability, they may have significance when considered over the lifetime of a wave energy farm. Analysis of downtime under low and high thresholds suggests that the distribution of wave heights at the Wave Hub will have a wider spread due to the impacts of climate change, resulting in longer periods of generation loss. Conversely, the estimation of future changes in joint wave height-period distribution provides indications on how the response and power matrices of WECs could be modified in order to maintain or improve energy extraction in the future.

1. Introduction

The Wave Hub project is a wave energy research project for testing arrays of wave energy converter devices being developed at a location 10 miles offshore from the north coast of Cornwall, in the south west of the UK, at about 50m water depth, see Fig. 1. The project is designed to accommodate up to four different wave energy converter (WEC) technologies to generate wave power, which will be connected to the national grid to supply electricity for thousands of homes (www.wavehub.co.uk). The Wave Hub is being constructed as part of the broader effort to develop renewable energy technology with the intention that CO_2 and other greenhouse gas emissions will be reduced, thereby mitigating the climate change associated with burning fossil fuels. However, as wave energy is generated by surface wind forcing, which will change in response to alterations in the atmospheric climate, wave energy generation at the Wave Hub may in turn be affected by climate change.

In order to accurately predict the long-term energy yield for a wave farm, it is essential to take natural variability and climate change into account. Reliable long-term predictions of the Earth's atmospheric evolution over the period of many years are not available. For this study we have used climate simulations based on specific scenarios defined by the IPCC (Intergovernmental Panel on Climate Change). The aim of this study is to quantify the relative changes in wave energy power and WEC energy yield corresponding to the different future climate scenarios, as well as to evaluate the statistical significance of those changes. This knowledge will give a better understanding of the possible changes in wave energy generation at the Wave Hub due to climate changes, while the methodology can be extended to other sites and WEC devices.

The current knowledge of how to assess the impacts of climate change on wave energy resource is rather limited. An early study of

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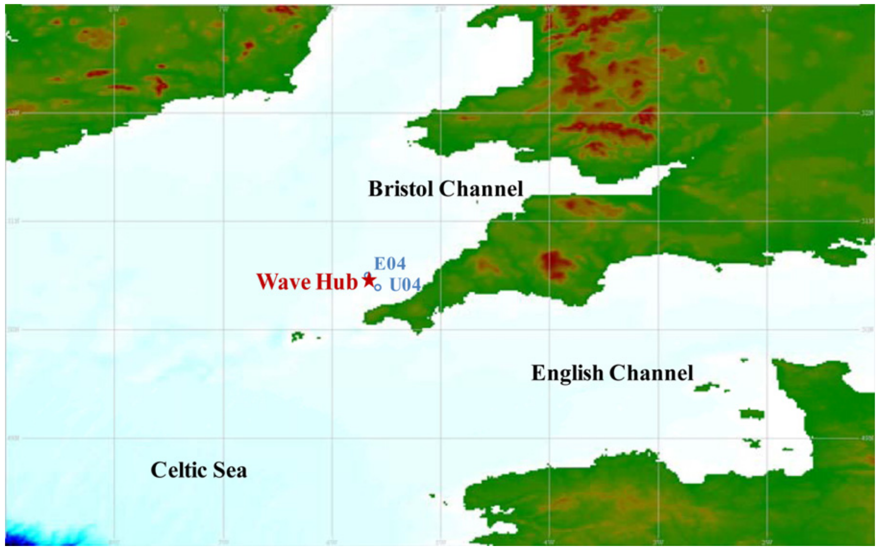

Fig. 1. Location of the Wave Hub site.

the sensitivity of wave energy yield to climate change [1],, suggested that the wave energy resource could be quite vulnerable to wind forcing changes. A simple relationship between wind speed and the Pierson-Moskowitz wave spectrum was used to investigate how changes in wind speed may affect available wave power and expected energy yield from a Pelamis WEC. A parametric model for wind speed was used to generate the joint distribution of wave height and period at the study site so that the energy yield could be calculated according to the given Pelamis power matrix. The results from sensitivity tests illustrated that a 10% increase in wind speed may result in a 60% increase in available wave power and a 20% increase in expected energy yield. However, this method did not take into account the presence of swell waves.

Recently, a more sophisticated analysis of the sensitivity of WEC yield to climate change was presented by [2,3] through a correlative link with the North Atlantic Oscillation (NAO) index. With assumptions of a linear relationship between the WEC yield and the NAO index and positive correlation between the NAO index and changes in the level of CO_2 emissions, the variance of WEC yield was linked to possible changes in CO_2 emissions. Their analysis was specific to a site to the north of Scotland. Their sensitivity tests suggest that changes in annual energy yield arising from anthropogenic climate change may not be detectable amongst the natural variability. As there is a low correlation between available wave power and the NAO index at the Wave Hub site [4],, this method is not directly applicable in this case.

In the present study, we propose a more generic method that is based on numerical wave modelling driven by past/present wind field and future wind scenarios associated with different levels of greenhouse gas emissions. A comparative assessment between a ‘control’ climate and different climate scenarios has been widely used as a method for assessing the impacts of different emission scenarios for the future [5–8]. Here, we use the time histories of surface winds generated under present-day conditions and in different climate change scenarios to drive numerical wave models and thence to evaluate the relative changes in power generation for a specific wave device with a prior known power matrix. Furthermore, dynamical wave modelling generates time histories of wave conditions which can be used to perform statistical analyses of WEC parameters such as idle time, downtime and maintenance windows.

Here, we have built on the results of [9] which employed a third generation wave model, WAVEWATCH III (WW3), to carry out the control and future scenario wave climate simulations at the Wave Hub site. This paper is organised as follows: Section 2 introduces the methodology and details of the data; Section 3 presents the results of available energy resource, WEC energy yield and downtime for the control case; Section 4 presents the impacts of future change in those parameters by comparison of future scenarios to present/control condition, followed by conclusions and discussions in Section 5.

2. Methodology

2.1. Climate model

This study uses the Global Climate Model (GCM) and Regional Climate Model (RCM) wind output provided by the Max Planck Institute for Meteorology at resolutions of 1.875° × 1.875°and

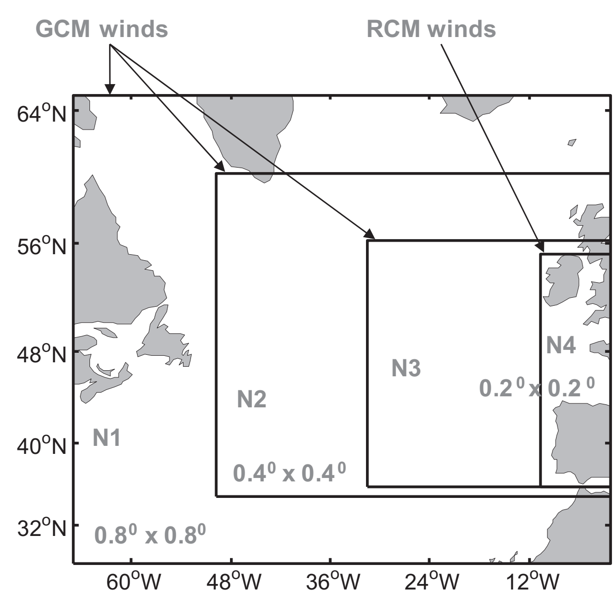

Fig. 2. Framework of four nested domains (N1-N4). Wave simulations on N1, N2 and N3 domain are forced with GCM wind forcing while the N4 domain is driven with RCM wind forcing (adapted from [9]).