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Data review and the development of realistic tidal and wave energy scenarios for numerical modelling of Orkney Islands waters, Scotland

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ABSTRACT

The Orkney Islands and surrounding waters (known as the Pentland Firth and Orkney Waters Strategic Area, PFOW) contain a significant portion of Scotland's tidal and wave energy resource. This paper forms part of a wider study modelling tidal and wave processes, and planned renewable energy extraction, in PFOW using 3D hydrodynamic and spectral wave numerical models. Such hydrodynamic models require a number of spatial data, i.e. high resolution bathymetry, model boundary conditions and measurements for model validation, which are hard to obtain in extreme environments such as PFOW. This paper examines the characteristics and selection criteria of the data used for the development of the models. Most of these data are freely available, and could form part of an open source marine renewable energy hydrodynamic modelling toolbox.

In order to include the planned tidal and wave energy developments in the hydrodynamic models of the wider study, realistic tidal and wave device array scenarios are required. However, there is still considerable uncertainty regarding the type of devices that will be deployed and device array layouts. Here, we describe the process undertaken, in consultation with industry, to develop a small number of generic device types and array scenarios for the PFOW, based on insight provided by documentation submitted by developers as part of the Scottish marine licensing process. For tidal developments, an algorithm was developed to determine the site specific array configuration, taking into account the number of turbines, water depth, tidal current direction and the spatial distribution of mean kinetic energy. The wave development sites did not require such detailed site specific placement of devices, and the generic layouts could simply be constructed in most cases without the need for detailed site specific resource characterisation.

It is anticipated that the renewable energy industry will be able to adopt our data selection criteria to ensure models developed for environmental impact assessments satisfy the quality requirements of the regulator. Similarly, the methodologies developed for characterising generic device types and array layouts will be useful to academia and government researchers, who do not necessarily have access to detailed device and site specific information.

1. Introduction

It is estimated that Scotland's marine area contains 25% of Europe's tidal resource, and 10% of Europe's wave resource (The Scottish Government, 2015). One area of particular interest is the Orkney Islands and surrounding waters, which contain a significant portion of Scotland's tidal and wave energy resource (Black and Veatch, 2005; Carbon Trust, 2011). For this reason, a number of sites have been granted agreement for lease by The Crown Estate (TCE) (the semi-independent, incorporated public body which manages the UK's seabed from mean low water to the 12-nautical-mile limit) as areas for commercial renewable energy development within the region known as the Pentland Firth and Orkney Waters Strategic Area (PFOW) (The Crown Estate, 2013). In 2010 TCE granted lease agreements to five tidal and six wave development sites, forming the *PFOW Round One Development Sites* (Fig. 1). Each designated site had a nominal maximum power rating (or energy generating capacity) assigned to it, with a total of 1 and 0.6 GW for the tidal and wave sites, respectively.

The Scottish Government is committed to the sustainable development of the tidal and wave energy sector, as incorporated in

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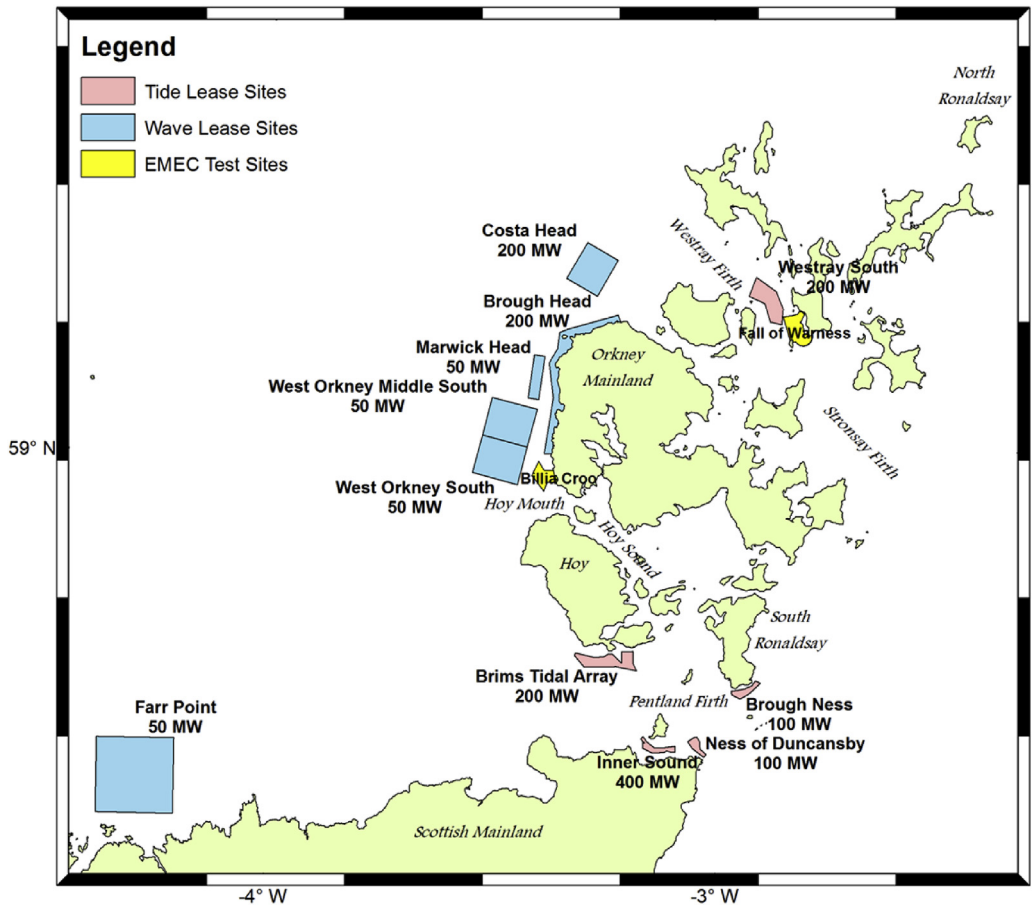

Fig. 1. Map showing the Pentland Firth and Orkney Waters Round One Development Sites, their nominal capacity, and the European Marine Energy Centre (EMEC) test sites. Modified from The Crown Estate (2013).

the National Marine Plan (The Scottish Government, 2015). There is, however, some degree of uncertainty regarding the potential physical and ecological environmental impact of large scale developments. One approach to understand the potential impact on the physical environment is hydrodynamic modelling of both the baseline, or undisturbed, state and a state which includes marine renewable energy (MRE) extraction. This is an emerging field and a number of methods for representing tidal and wave energy extraction in hydrodynamic models are being developed. For example Rennau et al. (2012) introduced an additional friction sink term in the momentum equations of the 3D hydrodynamic General Estuarine Transport Model (GETM) to represent tidal turbines at a sub-grid scale. van der Molen et al. (2016) have since modelled tidal energy extraction the Pentland Firth to explore the impact on both the physical and biological environments using GETM coupled with the European Regional Seas Ecosystem Model-Biogeochemical Flux Model (ERSEM-BFM).

The work we present here forms part of a wider project (the *TeraWatt* project, Side et al., 2016). The primary aims of the wider study were to model the tidal flow and wave fields in the PFOW, to include wave and tidal energy extraction in the models, and to assess the impact of wave and tidal energy extraction on the physical and biological environment. In this paper, we describe the PFOW region, including details of recent tidal and wave energy resource assessments (Section 2). In order to develop three dimensional hydrodynamic and spectral wave models of this complex region, a number of datasets are required. Section 3 describes the data used in the wider modelling study and examines the characteristics, and selection criteria, of the data used for the development of the models, such as their spatial resolution and the types of forcing data used. The wider study used two main hydrodynamic and spectral wave modelling packages, (1) MIKE by DHI, including MIKE 3 Flexible Mesh Hydrodynamic module (MIKE 3 FM HD, hereafter referred to as MIKE 3) and MIKE 21 Flexible Mesh Spectral Wave module (MIKE 21 FM SW) (https://www.mikepoweredbydhi.com/download/product-documentation) to model currents and waves, respectively, and (2) DELFT 3D (Deltares, 2014) and SWAN to model currents and waves, respectively. Based on the outputs of those models, realistic tidal stream (Section 4) and wave (Section 5) array scenarios for the PFOW Round One Development Sites have been developed. Such scenarios were used by the wider project to investigate how large scale tidal and wave energy development in the PFOW may change the physical and ecological processes in the region. It is anticipated that the renewable energy industry will be able use the principles explored in this paper to ensure models developed for environmental impact assessments are likely to satisfy the quality requirements of the regulator. Similarly, the applicability of the generic device types and layouts to future model development by academia and government, who do not necessarily have access to detailed device and site specific information, is discussed.

2. The Pentland Firth and Orkney Waters

The Orkney Islands lie off the north coast of the Scottish mainland, and are separated from the mainland by a narrow channel, the

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