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# The role of tides in shelf-scale simulations of the wave energy resource

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ABSTRACT

Many regions throughout the world that are suitable for exploitation of the wave energy resource also experience large tidal ranges and associated strong tidal flows. However, tidal effects are not included in the majority of modelling studies which quantify the wave energy resource. This research attempts to quantify the impact of tides on the wave energy resource of the northwest European shelf seas, a region with a significant wave energy resource, and where many wave energy projects are under development. Results of analysis based on linear wave theory, and the application of a non-linear coupled wave-tide model (SWAN–ROMS), suggest that the impact of tides is significant, and can exceed 10% in some regions of strong tidal currents (e.g. headlands). Results also show that the effect of tidal currents on the wave resource is much greater than the contribution of variations in tidal water depth, and that regions which experience lower wave energy (and hence shorter wave periods) are more affected by tides than high wave energy regions. While this research provides general guidelines on the scale of the impact in regions of strong tidal flow, high resolution site-specific coupled wave-tide models are necessary for more detailed analysis.

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## 1. Introduction

To aid sustainable development, it is essential that we deliver a secure source of energy services, with minimal environmental impact [1]. To address this, many countries are investing in renewable energy technologies, including bioenergy, solar, geothermal, hydropower, wind, and ocean energy. In relation to the latter, the ocean is a vast and largely untapped energy resource which has the potential to provide all of our electricity demand [2]. The global wave power resource has been estimated as around 2.1 TW [3], and tidal as around 2.5 TW [4]. Although tidal range power stations like La Rance have been operating since the 1960s, and other large schemes have been built or are under construction in South Korea, there are concerns about the environmental impacts of exploiting tidal range [5,6]. Therefore, recent government investment, and so most research and development, has tended to focus on tidal stream (tidal energy convertor, TEC) and wave (wave energy convertor, WEC) devices and arrays [7].

There are many regions throughout the world which concurrently experience a high wave and a high tidal energy resource. These regions include the northwest European shelf seas, the Gulf of Alaska, New Zealand, northwest Australia, and the Atlantic seaboard of Argentina. Due to wave-tidal interactions, special consideration needs to be given to energy schemes developed in such regions. In particular, resource assessments of such regions should account for the way that one marine resource (e.g. waves) modulates other marine resources (e.g. tides) at a variety of timescales from semi-diurnal, spring-neap, to seasonal.

The northwest European shelf seas are one of the most attractive regions in the world for the development of wave energy projects. The climate (and hence wind) of the northwest European shelf is dominated by the atmospheric polar front. The instability of this front causes depressions to form, tracking across the north Atlantic and following a preferred route which passes between Iceland and Scotland [8]. Additionally, the strengths of tidal currents as well as tidal range are very high in many regions of the northwest European shelf seas, particularly around the UK and in the English Channel. For instance, with a mean spring tidal range of 12.2 m, and a mean neap range of 6.0 m at Avonmouth, the Bristol Channel has one of the highest tidal ranges in the world [9]. Consequently, many tidal projects are under development in parallel with wave energy projects across the northwest European shelf seas (Fig. 1).

Although the tide can significantly alter wave properties through various wave-current interaction mechanisms [10–13],

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such interactions are not routinely considered in the majority of wave energy resource assessments that are based on numerical modelling [14,15]. It has been demonstrated that neglecting tidal effects could lead to significant errors in regions which experience low wave energy [16] or high wave energy [17,18].

By virtue of recent advances in marine hydrodynamic modelling and high performance computing, it is now becoming increasingly feasible to develop coupled wave-current models of a region to examine wave-tide interactions (e.g. Refs. [19,17]).

In the present study, the impact of the tide on the wave energy resource of the northwest European shelf seas is investigated using a coupled SWAN–ROMS wave-tidal model. Further, a simplified analysis based on linear wave theory is presented, which can be used to give a rapid estimate of the impact at a region, based on basic wave and tidal information.

## 2. Methods

A simple analysis of the effect of the tide on wave power is presented first. The details of the coupled wave-tide model will be presented consequently.

### 2.1. *Effect of tide on wave energy; idealised cases*

Quantifying how the tide affects the wave power resource for simple idealised domains helps us understand these inter-related processes, and enables us to estimate the order of magnitude of the associated error. Such an idealised study also provides us with an idea about which regimes will be most affected by wave/tide interaction, in terms of water depth, tidal regime, and wave exposure.

Many wave models are based on the assumptions of linear wave theory. Therefore, a simple case with an analytical solution based on linear wave theory is a good starting place. We assume that a regular wave with a wave period $T$ and wave height $H$ is propagating in constant water depth $h$. Based on the Airy wave theory, the average energy flux per unit width over a wave period is given by

$$P=\int_{0}^{T}\int_{-h}^{\eta}p_D u\mathrm{d}z\mathrm{d}t=\frac{1}{8}\rho gH^2C\left\{\frac{1}{2}\left(1+\frac{2kh}{\sinh 2\,kh}\right)\right\}=EC_g, \qquad (1)$$

$$C_g=C\left\{\frac{1}{2}\left(1+\frac{2kh}{\sinh 2\,kh}\right)\right\}$$

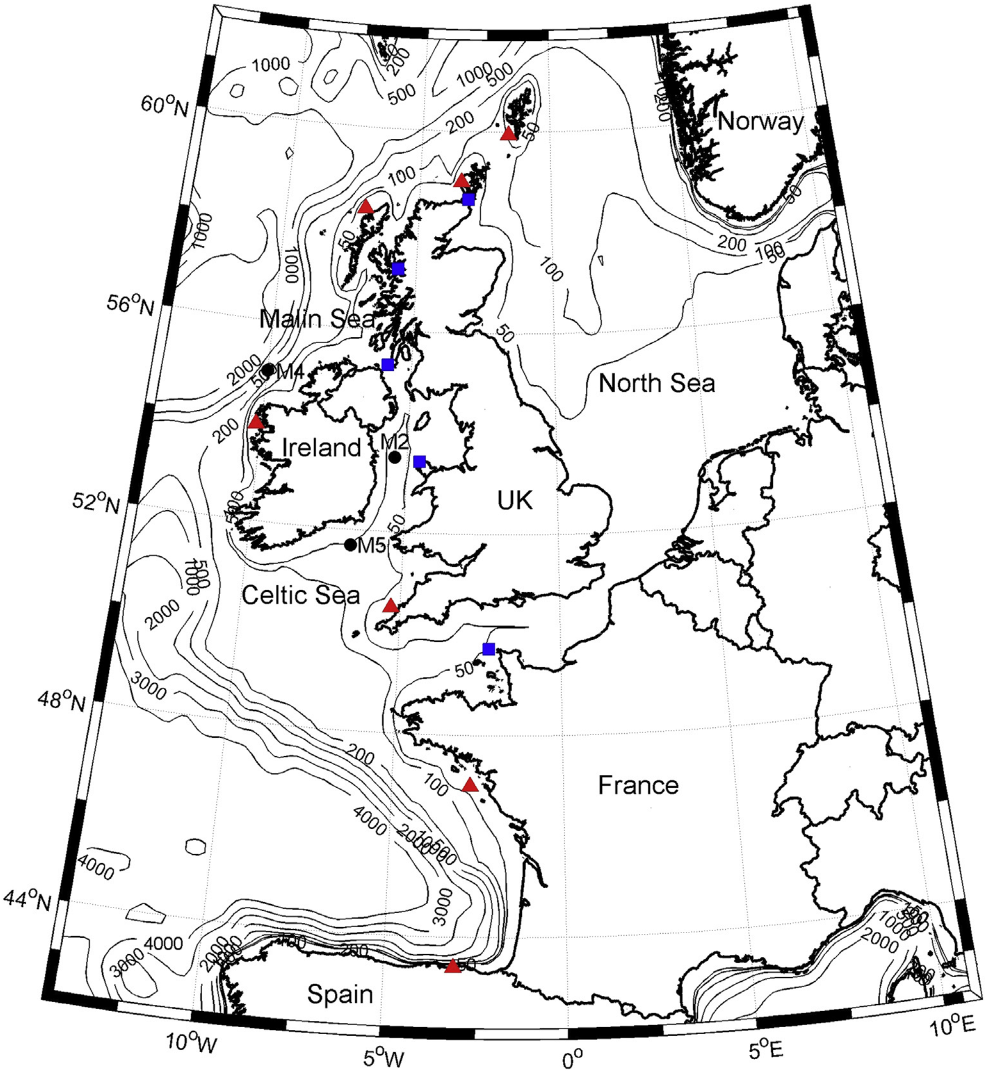

**Fig. 1.** Overview of the study region, including examples of wave and tidal energy projects (blue squares = tidal sites, red triangles = wave sites). Further details of these sites are provided in Table 1. Also shown are bathymetry contours (in metres relative to mean sea level), and the three wave buoys (M2, M4, M5) used for model validation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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