

THE IMPLICATIONS OF WAVE-TIDE INTERACTIONS IN MARINE RENEWABLES WITHIN THE UK SHELF SEAS

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ABSTRACT

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.

In the present research, a coupled wave-tide model of the NW European shelf seas has been developed using SWAN-ROMS. After model validation at a number of tidal gauges and wave buoys the effect of tides on the wave resource assessment is presented. Results of analysis based on linear wave theory, and the application of a non-linear coupled wave-tide model, suggest that the impact of tides on waves can be significant in site assessment, and can exceed 10% in some regions. We also conclude that it is the tidal currents, rather than tidal depth variations, that are the main factor at this scale. While a coupled model can theoretically implement many wave-tide interaction processes, the application of the model at shelf scale is highly constrained by computational cost, model resolution and data availability.

INTRODUCTION

The NW European shelf seas, and in particular the UK shelf seas, dissipate around 10% of global tidal energy (i.e. 0.25TW), and are also considered to be amongst the most energetic of wave climates, due to their exposure to the North Atlantic. Therefore, understanding the interaction of tides and waves is essential in many studies of this region, including studies of the marine renewable energy resource, and their impacts [1].

By employing recent advances in marine hydrodynamic modelling and high performance computing, it is now more feasible to develop coupled wave-current models of a region. Due to

the attractive features of COAWST (Coupled-Ocean-Atmosphere-Wave-Sediment Transport Modeling System) [2] compared with other models, we here developed a COAWST model of the NW European shelf seas. Then, the effect of tides on quantifying the wave energy resource has been studied using this 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.

METHODOLOGY

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 point for understanding wave/tide interactions. Assuming that a regular wave with a wave period T and wave height H is propagating in constant water depth h , the average energy flux per unit width over a wave period is given by,

$$P = \int_0^T \int_{-h}^{\eta} P_D u dz dt = \frac{1}{8} \rho g H^2 C_g(k, h, C)$$

where P_D is the dynamic pressure and u is the horizontal wave induced velocity. The group velocity C_g is dependent on the wave celerity C , wave number k , and water depth; all of which are related to tidal elevation particularly in shallower waters. Further, the wave period and consequently the wave celerity are affected by tidal currents. To estimate the effect of tide on estimates of the wave power resource, these variables were modified according to the typical tidal conditions of the region. The significance of including tidal effects was quantified by comparing the wave power affected by the tide and the wave power estimated in the absence of tides. Referring to Fig. 1, the contour lines represent the absolute relative difference of the wave power in the presence and absence of tide over a wave period. The horizontal and vertical axes represent the dimensionless water depth and tidal amplitude respectively. As this figure shows, the effect exceeds 10% for shallower waters.

For a more accurate analysis, the COAWST model of the region which comprises the ROMS ocean model, and SWAN wave model was developed [2].

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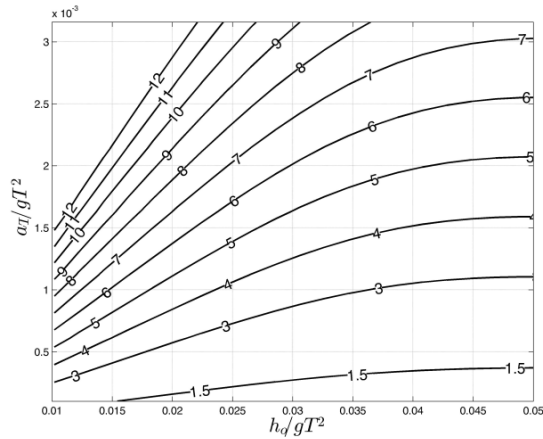


Figure 1 Percentage effect of tides on wave power estimate for a tidal current with 1.5m/s amplitude using linear wave theory

The ROMS model domain was discretised with a horizontal curvilinear grid, with a longitudinal resolution of $1/24^\circ$ and variable latitudinal mesh. The model bathymetry was based on ETOPO - a global bathymetric dataset, which is available at a resolution of 1 arc-minute. The vertical grid consisted of 11 layers distributed according to the ROMS topographic-following coordinate system. The open boundaries of the tidal model were forced by elevation (Chapman boundary condition) and tidal velocities (Flather boundary condition), generated using 10 tidal constituents.

SWAN was applied to the same curvilinear grid and bathymetry as the ROMS model. However, the open boundaries for the wave model may need further treatment. In SWAN, it is possible to run a larger scale outer model first, and provide the boundary information for the nested model. Wind forcing was provided by European Centre for Medium-Range Weather Forecasts (ECMWF; www.ecmwf.int). ERA (Interim reanalysis) full resolution data was used, which is available 3-hourly at a spatial resolution of 0.75° . January of 2005, as a typical month with relatively high wave energy, was selected as the modelling period.

RESULTS

Fig. 2 shows the results of the average impact of tides on the wave power estimation during January 2005. The contour lines denote the mean wave power in this figure. The mean wave power over the entire model domain during January 2005 is 74kW/m . Consequently, the impact is as high as 10% in regions of high tidal flow. The order of magnitude of this impact is consistent with the simplified method.

CONCLUSIONS

In terms of model coupling, while the COAWST model can theoretically implement many wave-tide interaction processes, the application of the model for shelf scale simulations is highly constrained by computational costs (about 5 times the cost of decoupled simulations), and model resolution.

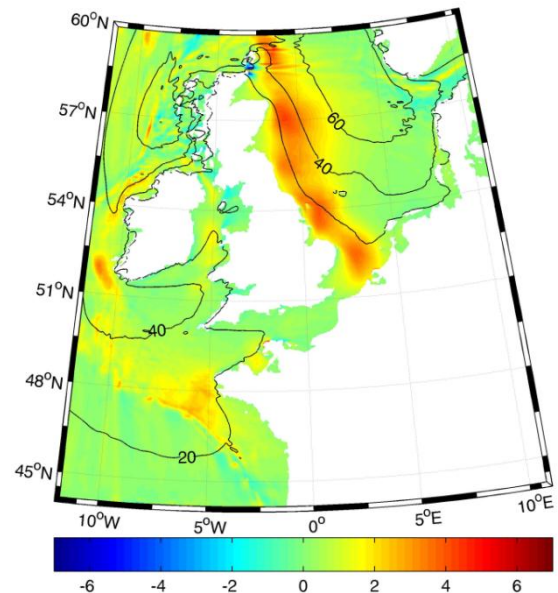


Figure 2 Effect of wave-tide interaction on the wave energy assessment for Jan-2005. The colour scale represents the effect of tide on the wave power estimation (kW/m)

The results of the simple approach, as well as the rigorous numerical study, demonstrate that tides have a significant impact on the simulated wave energy resource. The magnitude of the impact exceeds 10% of the resource (around 8kW/m at some locations such as Orkney (Scotland) and west coasts of Ireland over the northwest European shelf seas) in high tidal current regions. Results showed that the effect of tidal currents on wave power is much greater than the effect of tidal elevations at the scale of this study.

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