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Coastal defence using wave farms: The role of farm-to-coast distance

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ABSTRACT

The location of a wave farm and, in particular, its distance to the coast is one of the key aspects in a wave energy project. The effects of the farm on the coast, which can be instrumental in mitigating storm-induced erosion and thus contribute to coastal defence, are sometimes disregarded in selecting its location, possibly due to the inexistence of an *ad hoc* methodology. In this context, the objective of this work is to examine the influence of the farm-to-coast distance through a sensitivity analysis in a case study: Perranporth (UK). The impacts of a wave farm on the beach morphology are examined in four scenarios with different farm-to-coast distances using a high-resolution suite of numerical models. The results show that a wave farm closest to the beach offers the highest degree of coastal protection (up to 20% of beach erosion reduction). The downside of this enhanced coastal protection is that the wave resource available at this location would be slightly smaller (approx. 10%) than in the case of the wave farms further from the coast. More generally, we find that the farm-to-coast distance is a critical variable in determining the effectiveness of a wave farm for coastal defence.

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1. Introduction

The importance of wave energy is reflected in the number of very active research lines: the resource characterisation [1–17], the technology development [18–29] or the environmental impacts [30–43]. Conventionally, the main criterion to establish the optimum location for wave farms was the maximisation of wave power [44,45], and other important aspects were often disregarded, such as the effects on the nearshore wave conditions [46,47] and, in particular, the eventual contribution to coastal protection provided by a wave farm. Abanades et al. [48,49], proved that a nearshore wave farm reduced the erosion at the beach face by as much as 35% after storm events due to the extraction of wave energy by Wave Energy Converters (WECs). On this basis, the objective of this work is to establish the dependence of the degree of coastal protection offered by the farm on its distance from the coastline by means of a sensitivity analysis.

To accomplish this objective, four scenarios are compared, corresponding to three locations of the wave farm at different distances from the coast, plus the baseline (no farm) scenario, under different wave conditions. First, the impacts of the wave farm on the wave conditions are examined using a nearshore wave model, SWAN, Simulating Waves Nearshore [50]. This is a phase-averaged spectral model that computes the effects of the wave farm using an energy transmission coefficient, whose values are obtained from the laboratory tests carried out by Fernandez et al. [27]. The wave farm is implemented on a high-resolution grid at different distances from a reference (10 m water depth) contour: (i) 2 km, (ii) 4 km; and (iii) 6 km. Second, based on the results of the aforementioned scenarios a coastal processes model, XBeach [51], is used to compare the effects of the wave farm at the different locations with the baseline scenario. A set of impact indicators is developed, specifically, to quantify these effects and establish the role played by the farm-to-coast distance.

This methodology is applied to a case study at Perranporth Beach (Fig. 1), Cornwall (UK). A 3.5 km long sandy beach facing directly toward the North Atlantic Ocean, Perranporth is in an area with a great potential for marine renewable energy [52] – as corroborated by the Wave Hub pilot test site. The extremely energetic storms of February 2014 proved that Perranporth is subject to increased erosion risks from rising sea level and storminess [53]. In view of these risks, and given that a wave farm consisting of floating WECs adapts naturally to any sea level changes [54], Perranporth constitutes a prime area for using such wave farms for coastal protection.

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Nomenclature

N	wave action density
c_x and c_y	velocity propagation in the x- and y-space, respectively
c_θ and c_σ	velocity propagation in the direction and σ the relative frequency space, respectively
S	source term
ρ	water density
g	gravity acceleration
h	water depth
H_s	significant wave height
T_p	wave peak period
θ	wave direction
K_t	wave transmission coefficient
t	time
RSH	reduction in the significant wave height
D	distance between the twin bows of a WEC
$H_{s,b}$	significant wave height in the baseline scenario
$H_{s,fi}$	significant wave height in the i-th wave farm scenario
J	wave power
$E(\sigma,\theta)$	directional spectral density
H_{rms}	root mean square wave height
T_{m01}	mean absolute wave period
θ_m	mean wave direction
s	directional spreading coefficient
C	wave group varying depth averaged
D_h	sediment diffusion coefficient
u^E and v^E	depth-averaged velocities
C_{eq}	equilibrium concentration
MSR	mean spring tide range
LCD	local chart datum
BLI	bed level impact in the i-th wave farm scenario
FEA_b	beach face eroded area in the baseline scenario
FEA_i	beach face eroded area in the i-th wave farm scenario
NER_i	non-dimensional erosion reduction in the i-th wave farm scenario
CEA_b	mean cumulative eroded area in the baseline scenario
CEA_i	mean cumulative eroded area in the i-th wave farm scenario
ζ	seabed level

2. Materials and methods

2.1. Wave model

The wave propagation was computed using SWAN v40.41, a third-generation spectral wave model based on the action balance equation that can be solved in spherical or geographical co-ordinates [55]:

$$\frac{\partial N}{\partial t}+\frac{\partial (c_x N)}{\partial x}+\frac{\partial (c_y N)}{\partial y}+\frac{\partial (c_\theta N)}{\partial \theta}+\frac{\partial (c_\sigma N)}{\partial \sigma}=\frac{S}{\sigma} \tag{1}$$

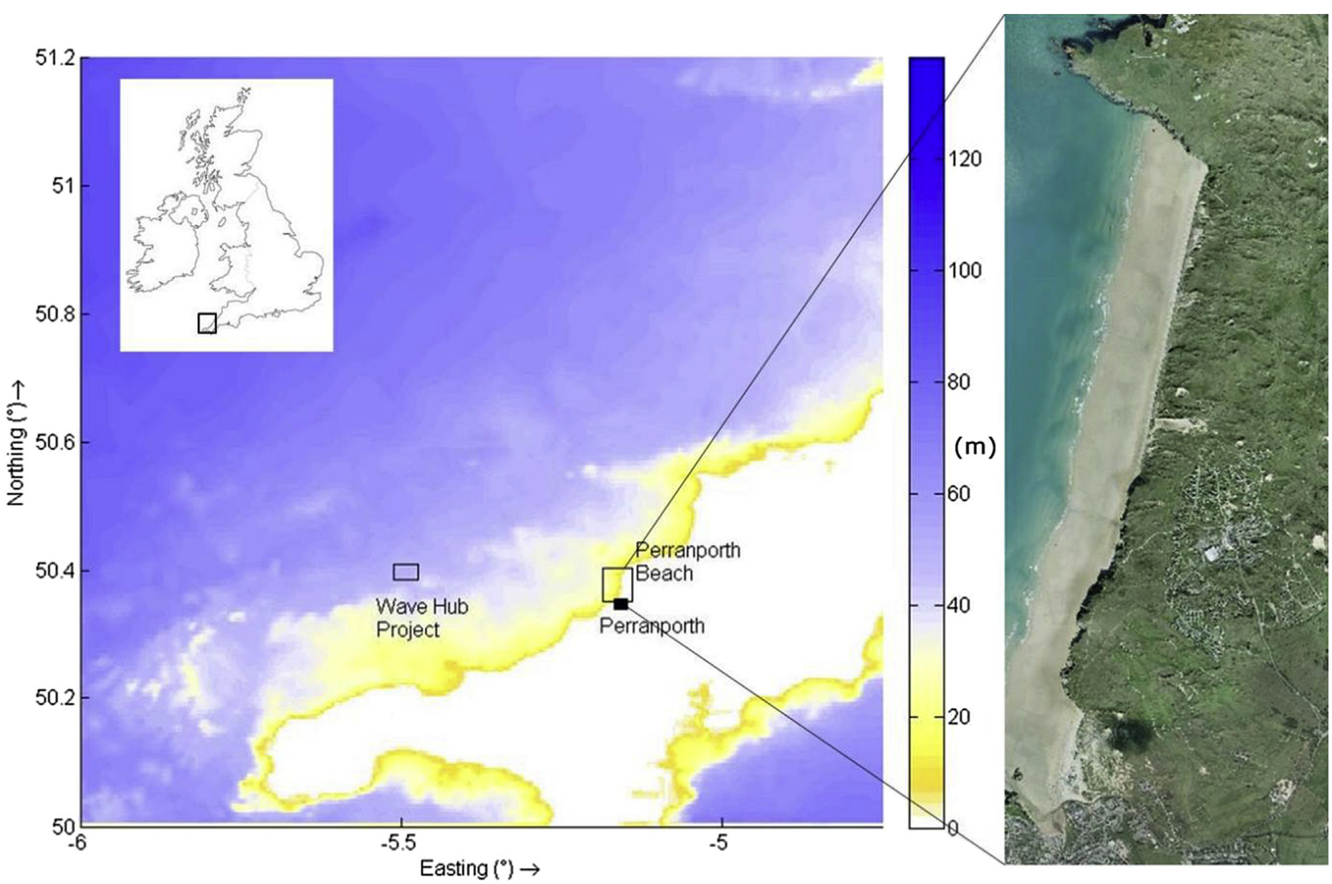

Fig. 1. Bathymetry of SW England [water depths in m] including the location of Perranporth Beach, Wave Hub Project and an aerial photo of Perranporth Beach [source: Coastal Channel Observatory].

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