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Performance of artificial neural networks in nearshore wave power prediction

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ABSTRACT

In this paper the assessment of the wave energy potential in nearshore coastal areas is investigated by means of artificial neural networks (ANNs). The performance of the ANNs is compared with *in situ* measurements and spectral numerical modelling (the conventional tool for wave energy assessment). For this purpose, 13 years of records of two buoys, one offshore and one inshore, with an hourly frequency are used to develop an ANN model for predicting the nearshore wave power. The best suited architecture was selected after assessing the performance of 480 ANN models involving twelve different architectures. The results predicted by the ANN model were compared with the measured data and those obtained by means of the SWAN (Simulating Waves Nearshore) spectral model. The quality in the predictions of the ANN model shows that this type of artificial intelligence models constitutes a powerful tool to forecast the wave energy potential at particular coastal site with great accuracy, and one that overcomes some of the disadvantages of the conventional tools for nearshore wave power prediction.

1. Introduction

Fossil fuels, energy dense and relatively inexpensive, supply nowadays the majority of the global energy consumption. Nevertheless, it is clear that, in the short to medium term, they should be replaced to a great extent by carbon-free renewable sources [1]. While wind and solar energy exploitation have matured over the last decades and are increasingly being installed today, ocean wave energy exploitation is still unproven at a commercial scale. However, its enormous potential explains the intensive research currently dedicated to the development of wave energy conversion systems [2–8] and to the assessment of the wave resource in various regions [9–11].

In spite of their importance, the technological considerations are not the only factor to be considered in bringing wave energy to a commercial stage. Another crucial aspect is the spatial and temporal variability of the resource, which is particularly significant in the nearshore – the area with the greatest practical interest; thus, the first step to exploiting wave energy is understanding the resource and being able to perform a thorough and accurate assessment of the energy available at a site of interest [12].

There exist different methodologies and data sources to carry out a wave resource assessment which have been implemented in different coastal regions. Wave buoy data are indeed very useful, but the wave buoys may be too expensive to maintain for the periods of time needed for long-term wave climate assessment. The back-scattered signal from satellite altimeters can provide relatively cheaply [13] enormous amounts of wave data with nearly the same accuracy as a wave buoy if correctly interpreted [14]. These data, together with data obtained from global wind-wave models, are an effective approximation to the wave power in deepwater. However, they provide a poor estimate of the wave power at nearshore locations, where the complex bathymetry and coastline gives rise to shoaling, refraction and diffraction and thus to significant variations in the distribution of wave energy over small areas.

Currently, spectral numerical models are the most popular tool to investigate these wave transformations and thus the available wave energy resource in the nearshore. These models compute accurately the propagation of swell in nearshore areas [15–17] without the need of an important investment of resources as it is the case of *in situ* measurements. However, they have some critical disadvantages, they are very time consuming, need of care and

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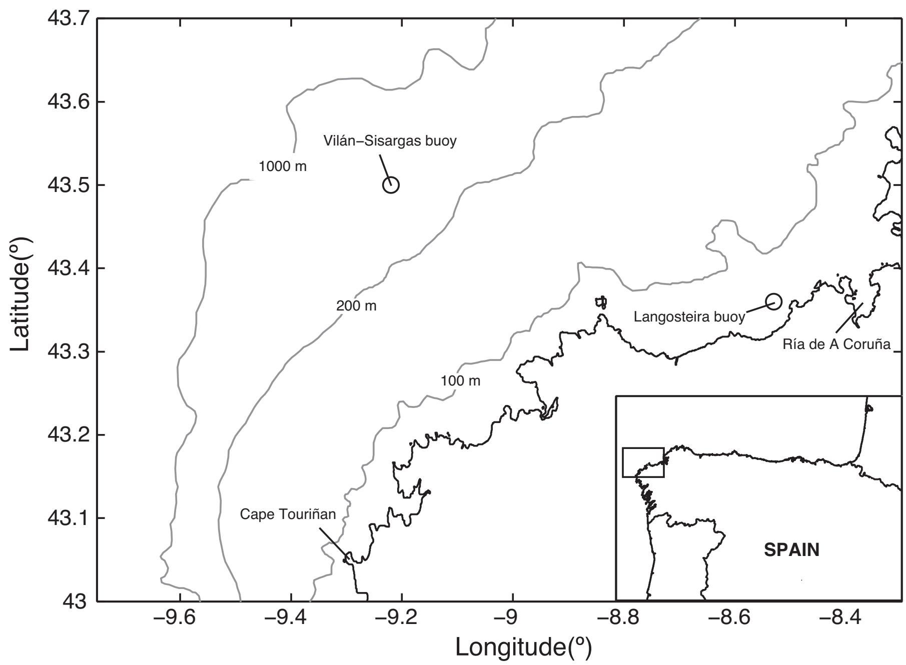

Fig. 1. Map of the study area with the location of offshore buoy (Vilán-Sisargas) and the inshore buoy (Langosteira).

expertise when implementing the model, and are very sensitive to different parameters (as it may be the bathymetric data). For these reasons, in the last years, different attempts have been made to supplement or replace numerical results with other techniques [13,18,19].

In this paper, a new approach to characterising the wave energy resource at a particular coastal point based on Artificial intelligence (AI) is presented. In particular, the AI tool developed is an Artificial neural network (hereafter ANN) model, which is capable of predicting wave power at a nearshore location. Artificial neural networks have proven to be a very powerful technique capable of resolving complex physical problems [20–23]. Indeed, they have already been applied to other Coastal engineering problems with excellent results, such as the forecasting of wind and wave climate time series [13,24], wave reflection at submerged breakwaters [25], floating boom performance [26], headland-bay beach planforms [27–29] or rubble-mound breakwater stability [30]. These works have shown that ANN modelling presents key advantages such as computational efficiency or potentially predictive power, but without the need of testing numerous physical and numerical parameters or to obtain detailed geographic information [31].

The final aim of this work is to assess the performance of the ANN model and its suitability for nearshore wave power prediction. For this purpose the model results are compared with those obtained from *in situ* measurements and from a state-of-art spectral numerical model.

2. Wave data and wave energy characterisation

The data used in this work were obtained from two types of buoys operated by Spain's State Ports: one offshore (Vilán-Sisargas) and one nearshore (Langosteira) (Fig. 1), covering nearly 13 years (from 13/5/1998 to 8/4/2011) with an hourly frequency. The offshore and nearshore buoys are located at water depths of 386 m and 40 m, respectively.

The data records from the buoys present gaps of different nature. First, there exist an important number of small gaps of a few hours which are presumably due to errors in the transmission of the data, maintenance issues or specific device failures. Another more important type of gaps are those spanning longer periods of time, from days to, in some cases, months. These gaps occur predominantly during winter months, when high energetic sea states prevail, leading to permanent failures and unfavourable climatic conditions for repair operations. Owing to this fact and the need for simultaneous data records from both buoys – a key point towards the validation of the ANN and spectral wave models – a previous step towards the development of the ANN model was to apply a filter to the original wave records of each buoy with the objective of identifying the gaps and selecting only the time periods in which both buoys were operating simultaneously. As a result of this process a total number of 72,747 valid datapoints were finally selected.

The fundamental parameters for wave energy characterisation which can be obtained from buoy records were the significant wave height (H_{m0}) and the energy period (T_e) at both the offshore and nearshore buoys and the mean wave direction (θ_m) at the offshore buoy. The nearshore wave power at the Langosteira buoy corresponding to each sea state is determined according to:

$$J_{Buoy} = \frac{\rho g}{16} H_{m0}^2 c_g = \frac{\rho g}{16} H_{m0}^2 cn \quad (1)$$

where ρ is the seawater density, g is the gravitational acceleration, c_g is the group velocity, c is the phase velocity and n is the ratio c/c_g. Both c and n are calculated following linear wave theory as,

$$c = \frac{L}{T} = \frac{gT}{2\pi} \tanh(kh) \quad (2)$$

$$n = \frac{1}{2}\left(1 + \frac{2kh}{\sinh(2kh)}\right) \quad (3)$$

where L is the wave length, $k = 2\pi/L$ is the wave number and h the local water depth.

The above equations were solved for each sea state recorded by the nearshore buoy.