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Wave energy resource in the Estaca de Bares area (Spain)

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ABSTRACT

The area around Cape Estaca de Bares (the northernmost point of Iberia) presents a great potential for wave energy exploitation owing to its prominent position, with average deepwater wave power values exceeding 40 kW/m. The newly available SIMAR-44 dataset, composed of hindcast data spanning 44 years (1958–2001), is used alongside wave buoy data and numerical modelling to assess this substantial energy resource in detail. Most of the energy is provided by waves from the IV quadrant, generated by the prevailing westerlies blowing over the long Atlantic fetch. Combined scatter and energy diagrams are used to characterise the wave energy available in an average year in terms of the sea states involved. The lion's share is shown to correspond to significant wave heights between 2 and 5 m and energy periods between 11 and 14 s. The nearshore energy patterns are then examined using a coastal wave model (SWAN) with reference to four situations: average wave energy, growing wave energy (at the approach of a storm), extreme wave energy (at the peak of the storm) and decaying wave energy (as the storm recedes). The irregular bathymetry is found to produce local concentrations of wave energy in the nearshore between Cape Prior and Cape Ortegal and in front of Cape Estaca de Bares, with similar patterns (but varying wave power) in the four cases. These nearshore areas of enhanced wave energy are of the highest interest as prospective sites for a wave energy operation. The largest of them is directly in the lee of a large underwater mount west of Cape Ortegal. In sum, the Estaca de Bares area emerges as one of the most promising for wave energy exploitation in Europe.

1. Introduction

The Western European coastlines facing the Atlantic present a large wave energy potential owing to the wind regime (prevailing westerlies) and the long oceanic fetch [1,2]. Galicia, the region at the NW corner of Iberia, is no exception, with annual energy values in deepwater exceeding 200 MWhm^{-1} along most of its coastline [3]. In this energetic context two areas stand out: the Cape San Adrián – Cape Finisterre coastline and the area around Cape Estaca de Bares (Fig. 1). At a latitude of 43° 47′ 25′ N, Cape Estaca de Bares is the northernmost point of the Iberian Peninsula; owing to this salient location, the area is exposed to waves from a variety of directions from the I and, most notably, the IV quadrant, generated by winds blowing over the Bay of Biscay and the Atlantic Ocean, respectively.

As with other renewable energy sources, a thorough resource assessment is a prerequisite for the successful exploitation of wave energy. In addition to the well-known wave atlases (e.g. [4–6]), a number of studies dealing with specific areas have been published recently [7–13]. The object of this work is to assess the wave energy resource in the Estaca de Bares area both in deepwater and in the nearshore, as most Wave Energy Converters are intended for deployment in water depths lower than 100 m [14–16]. The wave climate is investigated in detail, characterising the sea states that provide the resource in terms of their wave heights, periods and directions. Newly available hindcast data spanning a 44-year period are used alongside wave buoy data. As regards the nearshore distribution of wave energy, it is important to bear in mind that wind waves, in their propagation from deepwater into the nearshore, experience significant modifications due to refraction, shoaling, diffraction (in some cases) and other phenomena [17,18,19]. To take these effects into account, the nearshore wave energy patterns are investigated with the SWAN coastal wave model [20], which has been successfully applied in previous wave energy studies [21]. Four study cases are selected, corresponding to as many wave conditions of interest. It is found that the irregular bathymetry of the Estaca de Bares region leads to the concentration of wave energy in certain nearshore areas, while others are left with a relatively low resource. The knowledge of these nearshore energy patterns is most important for selecting the optimum site for a wave energy operation.

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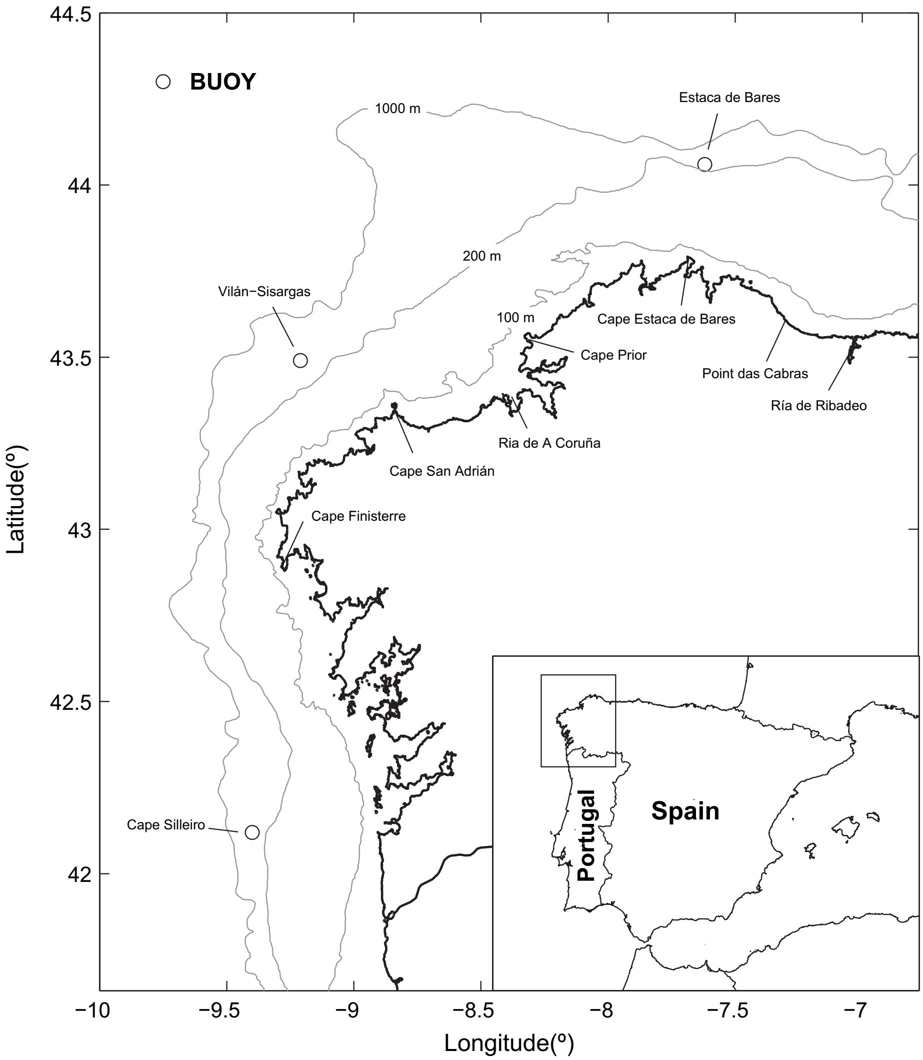

Fig. 1. Map of Galicia (NW Spain) showing the location of the deepwater wave buoys. Cape Estaca de Bares is the northernmost point.

2. Wave data

Two sources of wave data were used: wave buoy records and hindcast data. Three deepwater wave buoys (Fig. 1) have been in operation in the region since 1998, as part of the oceanographic data system of Puertos del Estado (Spain's State Ports), recording data with an hourly frequency. Table 1 shows their coordinates and water depths, alongside the main wave climate statistics from the standpoint of wave energy: maximum significant wave height and its standard deviation, average and maximum wave power and annual wave energy per unit length of wave crest. The first buoy in Table 1 (Cape Silleiro) is located near the SW end of the Galician coastline, close to the Spanish–Portuguese border; the second (Vilán-Sisargas), to the north-west of Cape San Adrián; and the third (Estaca de Bares), off the eponymous Cape (Fig. 1). The largest values of significant wave height, mean and maximum wave power, and annual wave energy correspond to the Estaca de Bares buoy—an indication of the particularly large wave energy resource of the area.

For a detailed assessment of this resource, the wave buoy data were complemented with SIMAR-44 data [21,22]. The SIMAR-44 dataset is composed of hindcast wind, sea level and wave data covering the period 1958–2001 (more precisely, from 1.I.1958 to 31.XII.2001) with a three-hourly frequency. Based on the global atmospheric reanalysis carried out by the U.S. National Center for Environmental Prediction (NCEP) using instrumental and satellite data, the wind data for the period were obtained by Puertos del Estado using the regional atmospheric model REMO, in the

Table 1
Deepwater wave buoys in Galicia (NW Spain). [$(H_s)_{mean} \pm$ std. dev., mean significant wave height and standard deviation; $(H_s)_{max}$, maximum significant wave height; J_{mean}, mean wave power; J_{max}, maximum wave power; $(E)_{annual}$, total annual wave energy in the average year].

Name	Location	Depth (m)	$(H_s)_{mean} \pm$ std. dev. (m)	$(H_s)_{max}$ (m)	J_{mean} (kW/m)	J_{max} (kW/m)	$(E)_{annual}$ (MWh/m)
Cape Silleiro	42.12°N, −9.40°W	323	2.26 ± 1.23	11.1	34.80	987.28	304.87
Vilán-Sisargas	43.49°N, −9.21°W	386	2.34 ± 1.21	12.7	37.25	1296.1	326.29
Estaca de Bares	44.06°N, −7.62°W	382	2.40 ± 1.28	12.8	41.30	1329.3	361.75