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10-year high resolution study of wind, sea waves and wave energy assessment in the Greek offshore areas

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ABSTRACT

Nowadays, renewable energy resources are one of the top priority issues for the environmental and political community. In particular, wind and wave energy are two of the most promising solutions, with great potential from research and technological point of view. In this work, an integrated high resolution platform, consisting of state-of-the-art wind-wave numerical models, has been utilized and produced a 10-year database containing all the relevant environmental parameters for a detailed resource assessment over the Greek seas. The results of the atmospheric and sea wave numerical models concerning the environmental parameters that directly affect the wave energy potential were evaluated. High resolution maps for the coastal and offshore areas of Greece present sea wave and wind climatological characteristics, as well as the relevant distribution of the wave energy potential. A number of statistical indices have been employed for analyzing the output of the models, including the potential impact of extreme values and the corresponding distribution of the above parameters, which optimally describe the spatial and temporal analysis of the wave power potential over the area of interest. It is shown that the regions with increased wave energy potential are mainly the western and southern seas of Greece, which are usually exposed to swell from central and south Mediterranean Sea.

1. Introduction

A very important issue concerning the scientific and the political community is global warming. A major factor that contributed to these problems is the use of oil-dependent energy resources, which are not environmental friendly. On the other hand, the danger from the nuclear power infrastructures due to natural disasters (earthquakes, extreme weather events) is increased. Both these issues make the necessity of exploring new energy resources more important than ever.

Solar and wind energy are the first of this kind of solution, mostly used until today. Taking into account that 2/3 of the earth is covered by water, sea surfaces may be also used towards this scope. The last years, wave energy combined with wind is investigated by European countries and the US. The energy produced by sea waves has some specific advantages; the most crucial one is the low variability in time compared to the one of wind energy. On the other hand, the technology for exploiting this kind of energy is not at a satisfactory level of progress.

The sea waves energy has been a subject of discussion raised even from the 19th century, as referred to [35]. However, the systematic research in this domain has begun the last twenty years, when the cost of other sources of energy has been raised up and the consequences of the maximization of gas emissions contributed to the global warming effect. Then, several projects involving green energy sources have been supported globally and especially by the European Commission. These projects have been focused in different regions, with different models and statistical tools. Reikard et al. [49] used the ECMWF wave model and some time series methods for forecasting Ocean Wave Energy. Denfe et al. [13] tried to focus their study in the southeast Atlantic coast of the United States based on the measurements of buoy stations. Pontes [45];

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presented a European Wave Energy Atlas based on annual and seasonal wave statistics derived from a coarse grid wave modeling simulations and Iglesias et al. [21–23] used hindcast simulated data and buoy measurements for studying the wave energy distribution over different areas of Spain (Death Coast, Galicia and Bares). The area of Azores is discussed in Ref. [50]; when the Black Sea was studied over a 13-year period in Ref. [2] and a 15-year study in Ref. [10]. In the Mediterranean Sea, [54]; studied the area of Sardinia, Italy, based on the Italian buoy network and corresponding hindcast data by ECMWF. More relevant work for the European Atlantic coast has been done by Joana et al. [30] and Gonçalves et al. [19]. Stopa et al. [51] performed a hindcast analysis along the Hawaiian coastline. Chiu et al. [11] focused on wave energy resources in Taiwan and Hughes and Heap [20] presented a study for Australia's shelf waters based on numerical models Finally, Mazarakis et al. [39] focused on validation of WAM (WAve Model) over Ionian and Aegean Seas with buoy and altimeter Jason-2 data, while Ayat [5] studied Mediterranean and Aegean Seas wave power by using MIKE 21 SW and validated the model with 3 buoy stations. Further hindcast studies can be also found in Refs. [42,48].

In this paper, the main meteorological parameters affecting the sea waves' energy potential are studied in detail for the major Greek area, including Aegean and Ionian Seas, for a time period of ten years (2001–2010). A high resolution atmospheric and wave modeling system has been employed in order to simulate wind speed and direction, significant wave height and energy wave period. With these tools, we studied the way that the previous parameters affect the wave energy potential distribution. This system has been operated in a hindcast mode, exploiting the advantages of data assimilation procedure, using the available observations-measurements in this area (satellite records, meteorological observations, buoys). By this way, an optimum representation of the environmental parameters and a detailed wave climatology map of the area have been produced.

The results from these simulations have been elaborated through a detailed statistical analysis, for the meteorological, the sea and the wave energy potential parameters. The statistics refer not only to the usual indices (mean values, standard deviation), but also to asymmetry measures of the results and the impact of possible extreme values. This information could be useful for the site assessment of wave energy devices. On the other hand, probability distribution functions are examined for better description of the main parameters affecting the wave energy potential.

The paper has been organized as follows: In Section 2, the numerical wind and wave models, as well as the way of estimating the wave power potential are presented. In Section 3, the statistical measures used for analyzing the model results and the wave energy related parameters are described. Section 4 contains the discussion of the results, while the conclusions are summarized in Section 5.

2. Models

In this study, the ocean wave model WAM [7,34,53] was used for the simulation of sea wave conditions of the Greek seas for a period of ten years (2001–2010). WAM is a third generation wave model, where the wave transport equation is solved explicitly without any presumptions on the shape of the spectrum. In particular, the ECMWF (European Centre for Medium Range Weather Forecasting) version CY33R1 [6,28] has been employed. A number of improvements have been implemented, like the extension of the advection scheme in the wave energy balance equation for the corner points, using the Corner Transport Upstream scheme, which provides uniform propagation in all directions. Moreover, a new parameterization of shallow water effect, affecting the time evolution of the wave spectrum and the determination of the kurtosis of the wave field [29] has been used. In addition, two extreme wave parameters have been introduced: the average maximum wave height and the corresponding wave energy period [41].

The wave model is calculating the 2-d wave spectrum $F(f, \vartheta, \varphi, \lambda)$, where f stands for frequencies, ϑ for directions, overall latitudes and longitudes (φ, λ) of the domain used. The necessary parameters for this study are obtained as integrated byproducts, based on the moments of the spectrum:

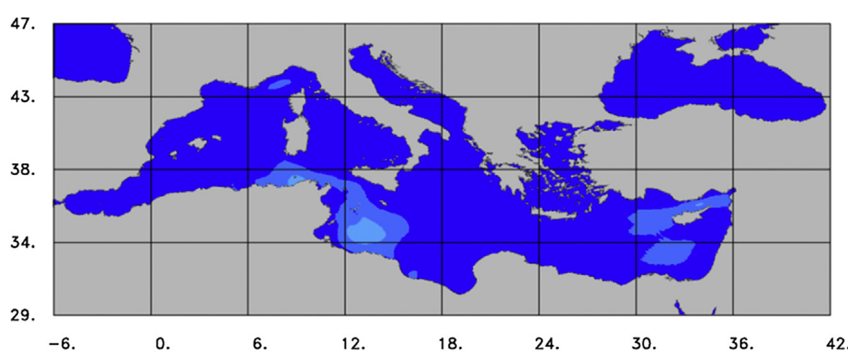

Fig. 1. The simulation area.

Table 1
Summary of the wave model characteristics.

Wave model	WAM, ECMWF version CY33R1
Area covered	29N–47N, 6W–42E
Horizontal resolution	0.05 × 0.05°
Frequencies	25 (range 0.0417–0.54764 Hz logarithmically spaced)
Directions	24 (equally spaced)
Time step	45 s
Wind forcing	SKIRON atmospheric model
Wind forcing time step	3 h