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Wave energy resource assessment in the Mediterranean Sea on the basis of a 35-year hindcast

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ABSTRACT

A state-of-the-art, in terms of spatio-temporal resolution (about 10 km and on a hourly basis) and temporal span (35 years), wave hindcast is exploited to update existing assessments of wave energy potential in the Mediterranean Sea. The hindcast, covering the period 1979–2013, has been obtained using WavewatchIII with calibrated source-term parameters recently proposed by L. Mentaschi et al. (2015) [1]. The main advantage of such a calibration is that it takes into account the peculiarity of the Mediterranean basin with respect to other calibrations carried out in the oceans. The high resolution allowed to perform a detailed analysis of wave energy potential characteristics providing information on seasonal and longer term variability necessary for reliable and optimal design of wave energy conversion devices. As a result, the identification of areas where the mean wave power reaches values of the order of 10 kW/m clearly emerge. However, these regions are not necessarily optimal in relation to the efficiency of energy extraction, due to possible relevant time variation of the energy availability. The high temporal resolution allows to address issues related to the time variability of the available resource and thus to provide a complete set of statistical information to carry out optimal design of WEC (wave energy converter).

1. Introduction

In the last decades the exploitation of renewable natural resources, such as wind, solar and geothermal, has significantly increased for the sake of energy production. Major attention has been payed to the ocean resources, focusing on the energy harvesting from tidal currents and ocean surface waves.

The conversion of wave energy to common grid has been analyzed in the scientific community following two basic approaches. The first one is dedicated to the development, design and experimentation of devices capable of converting wave energy into electrical power [e.g. [2]]. The second line of research is focused on wave energy assessment along the coast of the different continents, in order to provide detailed figures of the available energy potential and its characteristics to the developers of WEC devices for an optimal design.

Even if the idea of energy conversion from wind waves arises at the beginning of the nineteenth century, a boosting of the research and technology development started in the early seventies due to a dramatic increase of the price of oil products [2]. Wave energy potential has hence been assessed both from field measurement through buoy stations [3] and from numerical model.

A first attempt to assess the wave energy potential along European coasts has been carried out by Ref. [4] on the basis of coarse numerical simulations employed to compile an European Wave Energy Atlas. Hence the employment of wave hindcast has been widely used to assess oceans wave energy potential on global scales [i.e [5–8]].

The availability of extended wave data obtained through numerical simulations opened the possibility to develop a detailed wave energy assessment giving an insight about waver power availability on regional and local scales in order to provide refined and accurate estimates of wave energy flux characteristics for WECs (wave energy converter) design. Different authors developed analysis on the European Atlantic coasts, for example for France [9,10] or over different regions of continental Spain and its islands [11–16], and for Portuguese coasts and islands [17,18]. Assessments

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have been developed for the Northern Atlantic Sea, where even some full scale devices have been tested [19–22]. The analysis has been performed also in different worldwide spread locations [3,23–31].

Generally a major attention has always been payed to higher energy areas such as Pacific, Atlantic and Indian oceans. Despite this tendency, different authors in the last years begun to perform wave energy assessment in less energetic basins which nevertheless could provide interesting information for the harvesting of wave energy. In particular, only recently [32–34], carried out evaluations of Black Sea wave energy potential on the basis of different wave hindcast while [35] gave some insights about wave energy distribution in the Baltic Sea.

The Mediterranean Sea represents, in terms of wave energy power availability, an intermediate level between the open oceans and the enclosed small-fetch basins such as the Black Sea or the Baltic Sea. Hence, wave energy exploitation seems to be promising even if the net quantities are not as significant as in the open ocean. Different authors performed wave potential evaluations on the basis of medium-short term wave datasets obtained through numerical simulations or field observations for restricted areas [36–40] and for the whole basin [41].

The present study follows the line opened by Ref. [41] concerning the use of hindcast for the assessment of wave power distribution in the Mediterranean Sea and it is an extension in greater detail of the previous work. Indeed resolution of the atmospheric forcing has been increased from 1/4° used by Ref. [41] to 1/10° in the present work. Furthermore the range of the numerical simulation has been extended from 10 to 35 years (from 01/01/1979 to 31/12/2013) and the time step for the recording of wave characteristics is equal to 1 h instead of three. Spatial resolution of the wave model is the same of the atmospheric model and is about 10 *km* in both longitude and latitude. The spatial resolution is important in order to resolve and properly describe the wave characteristics on a local scale, but it is not the most important aspect for an assessment on the basin scale, on the contrary a high temporal resolution is strictly necessary to provide detailed information on the variability of the wave energy resource in different parts of the Mediterranean basin. The feasibility of wave energy harvesting projects resides in the correct design of the devices which should be planned to work at the maximum efficiency tuned on the local wave climate. This condition is reached if the temporal variability of the available wave energy potential and its distribution over wave height, peak period and mean direction is known: the optimum design should indeed take into account variations of the resources and not be based on the sole mean value. Variability of the energy resource is indeed expected to be significant thus appreciably reducing the efficiency of a device designed to work under average conditions [22,42–44].

The present manuscript is organized as follows: in section 2 the basic methods of wave energy resource assessment are presented together with the description of the numerical models employed for the wave hindcast. Section 3 presents the results on both the basin scale and on some locations which are promising for energy harvesting projects. Finally, some remarks and conclusions are drawn in section 4.

2. Methods

The assessment of wave energy potential in the Mediterranean basin has been carried out on the basis of a hindcast of sea wave conditions for 35 years, from 01/01/1979 till 31/12/2013. The analysis thus presents a long temporal span, giving insights on long trend variations and reliable seasonal behavior.

2.1. Atmospheric model

The wave model is forced by the 10-m wind fields obtained from the non-hydrostatic model WRF-ARW (weather research and forecasting – advanced research WRF) version 3.3.1 [45]. In the present study a Lambert conformal grid covering the whole Mediterranean Sea with a resolution of about 10 *km* has been used (Fig. 1).

Topography, land use and land-water mask dataset have been interpolated from the 2′-resolution USGS (U.S. geological survey) data sets. Initial and boundary conditions for atmospheric simulations were provided from the CFSR (climate forecast system reanalysis) database [46]. Use of CFSR reanalysis data for wave modeling provides reliable results, even if sometimes the simulation of extreme wave conditions is not properly performed [47–51]. For the whole extent of the hindcast, series of 24-hr-long simulations were performed. The analysis (i.e. atmospheric initial conditions) have been updated every 24 h, while conditions on the boundaries of the computational grid were imposed every 3 h. Even if the imposition of boundary and initial conditions can lead to some discontinuities in the numerical simulations, these unbalances are however absorbed quite quickly (because they affect the sole small scales) with characteristic times of the order of the smallest resolved time-scale which is of the order of few time-steps (few minutes). For further details of the set-up and validation of the meteorological model readers can refer to [52].

2.2. Wave model

The generation and propagation of sea waves have been modeled using the wave model WavewatchIII®, version 3.14 [53]. A 336 × 180 regular grid (finite differences) covers the whole Mediterranean Sea with a resolution of 0.1273 × 0.09 degrees, corresponding to about 10 *km* at the latitude of $45^\circ N$ (cfr. Fig. 2).

Source terms of growth-dissipation introduced by Ref. [54] have been expoited. These source term are based on [55] for the growth part, and improve the representation of wave dissipation merging the results of recent studies [e.g. [56, 57]] and introducing a new term for the dissipation of long swell, deduced on the basis of the observations of satellite altimeters [58]. During the elaboration of the hindcast the reference parameterization was calibrated in order to reduce a slight tendency to overestimation of moderate seas [1]. Spectral resolution is characterized by 24 bins in direction and 25 frequencies ranging from 0.06 to 0.7 *Hz* with a step factor of 1.1. Wave model has been forced with the wind fields provided by the atmospheric model described in section 2.1 with an hourly time step. The time step chosen for spatial propagation in the wave model is of 100*s* for the fastest spectral component, which guarantees a Courant number close to zero for spatial propagation. The spectral propagation time step was chosen in 900*s*, which is satisfactory for simulations where slopes are averaged over 10 *km* wide cells. The main time step, i.e. the time step relative to the application of the source terms, has been set to half an hour, which is in the order of magnitude of the crossing time of the cell by the fastest spectral components. This is a satisfactory time step, considering that the wind data have a time step of 1 h, and that WWIII has a limiter which automatically reduces the main time step for strong variations. The output has been recorded hourly in all points of the computation grid for integrated quantities (i.e. significant wave height H_s, mean period T_m and mean direction θ_m). The validation of the 35-years wave hindcast has been carried out through extensive comparison of simulated quantities and wave buoy data [cfr. [1,59]].