Estimation of the offshore wave energy potential of the Mediterranean Sea and propagation toward a nearshore area

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Abstract

In order to assess the feasibility of constructing an energy production plant based on WECs, a proper characterization of the local wave climate as well as the estimation of the available wave energy potentials must be effected. In this work, a set of analyses concerning the wave energy potential of the Mediterranean Sea has been carried out to obtain distribution maps in the Mediterranean Sea and the power matrixes of selected sites. The analysis is based on wave data arising from numerical models for wave generation coupled with atmospheric models. This numerical model wave data have been obtained by IFREMER that has developed a pre-operational system, called PREVIMER. Although the offshore wave energy potential is known from the previous analysis, the processes affecting waves as they propagate towards the nearshore can modify the wave energy potential, leading to reductions or, sometime, local enhancements due to focusing mechanisms. To quantify these processes, and thus select the most energetic locations, a numerical simulation was used to propagate the power matrixes from deepwater into the nearshore area of the selected test sites. The numerical simulations were carried out by the MIKE21-Spectral Wave.

Keywords: Mediterranean Sea, Mike21 - Spectral Wave, Previmer, wave energy.

1. Introduction

Currently in the energy sector there is an increasing interest in renewable energy sources and, within this context, the possibilities of producing energy from the waves in the sea is also emerging. The quantification of the availability of such an energy form is the first step to take and constitutes a fundamental element at the base of studies into the practicalities inherent in its conversion to usable forms through the Wave Energy Converter (WEC) technologies [1-2].

On a European level, important contributions have been supplied in this sector such as [3], [4], but the Mediterranean has still only received little attention [5-6]. This study adds to the knowledge of the availability of energy from the Mediterranean Sea. In addition to the analyses concerning the availability of energy from the wave motion offshore in the whole of the Mediterranean Sea, a procedure has been developed based on a numerical simulation for the detailed analysis of coastal areas with a serviceable depth of less than 100m which can be useful in the identification of eventual focus zones.

2. Methodology

The analyses of this paper are based on wave data arising from numerical simulation models for wave generation coupled with atmospheric models. The data was provided by IFREMER that has developed a pre-operational system, called PREVIMER, aiming to provide short-term forecasts concerning the coastal environment along the French coastlines bordering the English Channel, the Atlantic Ocean and the Mediterranean Sea.

The data used in the present study arise from the numerical simulation model called MED 6MIN, a WaveWatch III model, with a third-order accuracy propagation scheme in space and time. The weather forecast conditions were provided by Météo-France and covered the twelve hours duration and the following six days. The results are provided in the NetCDF format at

3 hour intervals and the variables are, for example, wave height, period, direction.

The data set analysed covers the whole of the Mediterranean Sea with a resolution of 0.1° in latitude and longitude for a period of 2 years and 9 months, from July 2009 to March 2012. The formula used to compute the monthly and yearly mean wave power, in the case of irregular waves propagating in deep waters, is reported in eq. (1)

$$P = \frac{1}{64}\frac{g^2}{\pi}\rho H_{mo}^2 T_{m-1,0} \qquad (1)$$

with ρ water density and providing that $H_{m0}=4m_0^{1/2}$ is the significant wave height and $T_{m-1,0}=m_{-1}/m_0$ is the mean spectral wave period.

3. Wave energy characterization

The spatial distribution of the monthly mean power has been computed and reported in the form of contour maps for each month of a given year (not shown in this paper for brevity). The maximum values of the monthly mean power that resulted in the studied spatial domain have been highlighted in Fig.1. Moreover, the spatial distribution of the mean power for the years 2010 (Fig.2) and 2011 (Fig.3) has been computed as the mean of the monthly mean powers.

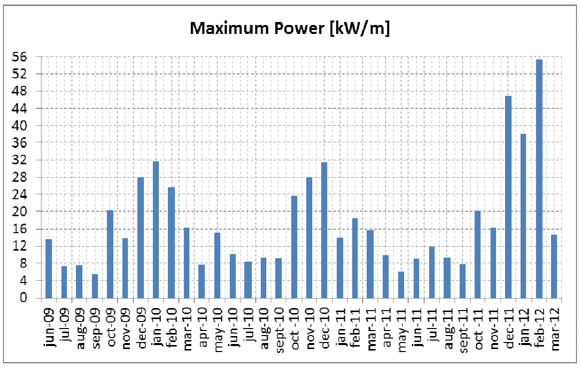

Figure 1: Maximum values of the monthly mean power.

It is worth noting that during the autumn and winter months and therefore in October, November, December, January and February, the maximum monthly mean power in the studied domain is always greater than 20 kW/m (except Nov 09, Jan11 and Feb11).

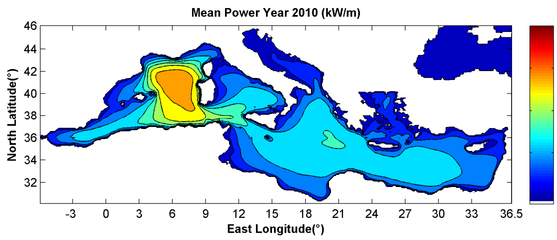

Figure 2: Spatial distribution of the Yearly Mean Power computed by using the data for the Year 2010 [kW/m].

It is also evident that the most energetic parts of the northern Mediterranean are those on the Western coasts of the islands of Corsica and Sardinia. In this area the maximum annual average power reaches values equal to 15.8 kW/m for 2010 and 12.8 kW/m for 2011.

For the exploitation of wave energy, supporting infrastructures are necessary (for examples harbours) and so, to limit the cabling costs, the distance from the coast should be around 5-10km [7]. This topic is of particular interest when studying this resource in coastal waters.

Moreover, the offshore wave energy potential can easily be obtained by means of the analysis of deep water wave data, but the processes affecting waves as they propagate towards the nearshore can modify the wave energy potential, leading to reductions or, sometimes, local enhancements due to focusing mechanisms. Furthermore, due to such mechanisms, the spatial variability of wave energy potential can be remarkable, thus suggesting the need for accurate knowledge for the placing of a pilot plant in order to maximize the harvesting of wave energy.

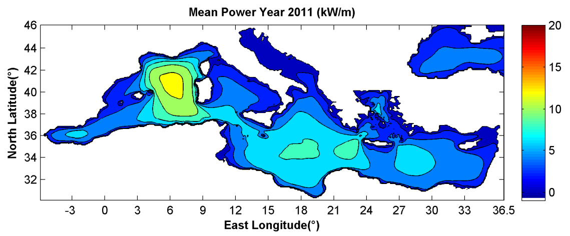

Figure 3: Spatial distribution of the Yearly Mean Power computed by using the data for the Year 2011 [kW/m].

4. Propagation model

For the numerical simulation of wave propagation, from offshore sites toward coastal sites characterized by water depths less than 100m, the Spectral Wave module of the MIKE21 software was used. The MIKE21-SW is a spectral wind-wave model based on unstructured mesh that allows the simulation of the following physical phenomena: non-linear wave-wave interaction, dissipation due to white-capping, dissipation due to bottom friction, dissipation due to depth-induced wave breaking, refraction and shoaling due to depth variations.

The model is used with the fully spectral formulation, based on the wave action conservation equation, where the directional-frequency wave action spectrum is the dependent variable and with the quasi-stationary mode, where the time is removed as an independent variable and a steady state solution is calculated at each time step.

As offshore boundary conditions the values of wave height, peak period, the average direction and spreading factor, of the six points extracted by the PREVIMER model on a depth of 100m, were used. The model mesh is flexible with a triangular side of 2000m in water depths of 100m to 50m, a side of 1000m in water depths of 50 to 30m, a side of 500m until the water depth of 20m and then a triangular side of 300m, see Fig.4.

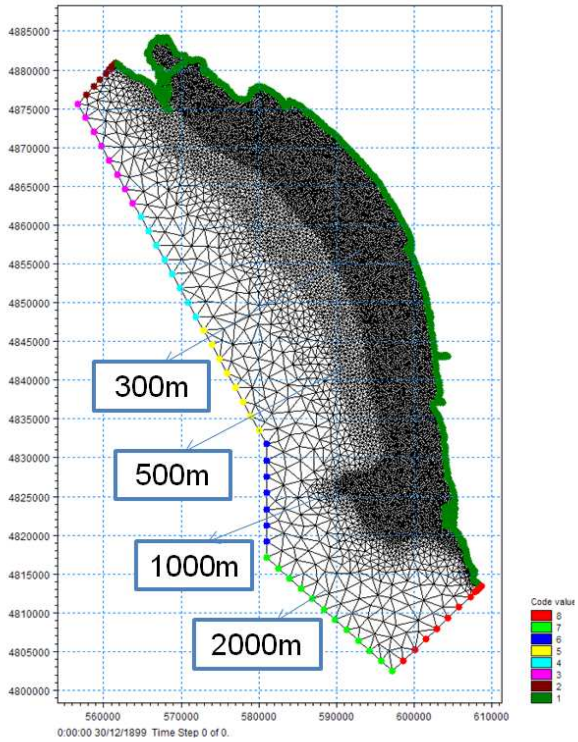

Figure 4: Boundary conditions and resolution mesh.

The model domain is about 60 km x 85 km with a maximum water depth of approximately 100 m (see Fig.5).

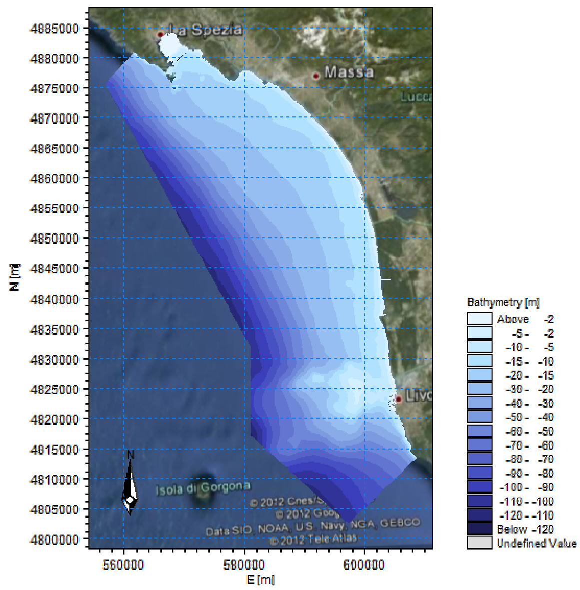

Figure 5: Propagation area bathymetry.

All the time series of the PREVIMER data set (from July 2009 to March 2012) was propagated and a constant value was assumed for the bottom friction equal to 4cm (Nikuradse formulation) as well as a constant value representing the white capping dissipation source function, equal to 4.5. In output maps were obtained of the variation of the wave height, mean direction and wave power. In fact the MIKE21-SW allows the wave power to be obtained directly as in eq. (8)

$$P_{energy} = \rho g \int_0^{2\pi} \int_0^{\infty} c_g(f,\theta) \cdot E(f,\theta)\, df d\theta \qquad (8)$$

where E is the energy density, c_g is the celerity group, ρ is the density of water, g is the acceleration of gravity, f is the wave frequency and θ is the wave direction.

4.1 Results

The maps of wave power were computed for each time step and Fig.6 illustrates an example for one of the most energetic sea states (H_{m0} = 4.2m, Tm = 7.3s, Dir = 240°N) on the 5th of January 2010, hour 18.00.

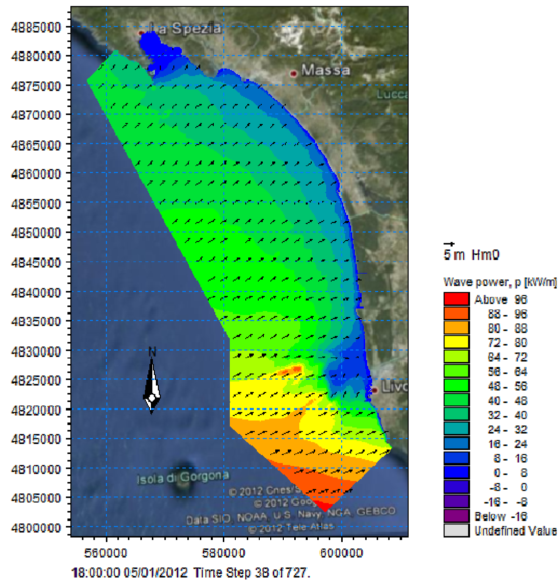

Figure 6: Spatial distribution of the wave power for the 5th of January 2010, hour 18.00 [kW/m] and wave height values (arrows).

Then the monthly mean power for each month was computed from July 2009 to March 2012, and only for the years 2010 (Fig.7) and 2011 (Fig.8), the yearly mean power.

In addition to the above analysis, it was also considered important to analyse the monthly and yearly mean power in 20 different points (see Table 1), 10 located in the water depths of 15m (from 1 to 10) and another 10 in water depths of 50m (from 11 to 20). At each point the wave roses are also computed (Fig. 9).

It is evident that the most energetic points are the 9 in the water depths of 15m and the 19 in the water depths of 50m, and these points are located on the Meloria shoals (Secche della Meloria) where a focusing mechanism is effective.

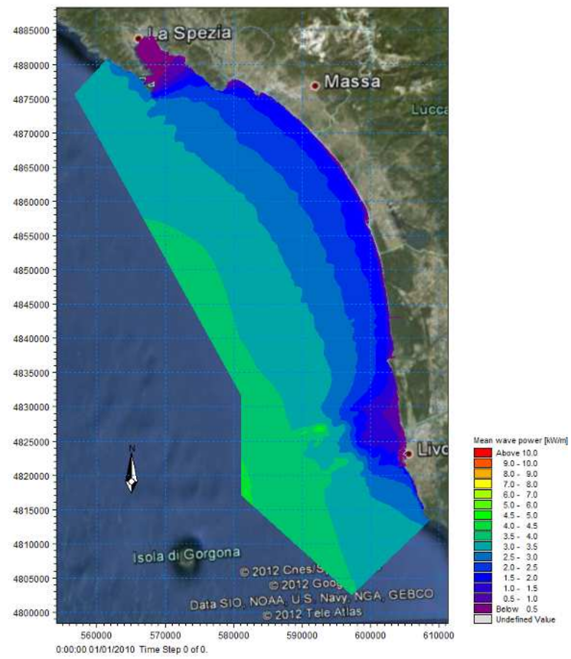

Figure 7: Spatial distribution of the Yearly Mean Power computed by using the data for the Year 2010 [kW/m].

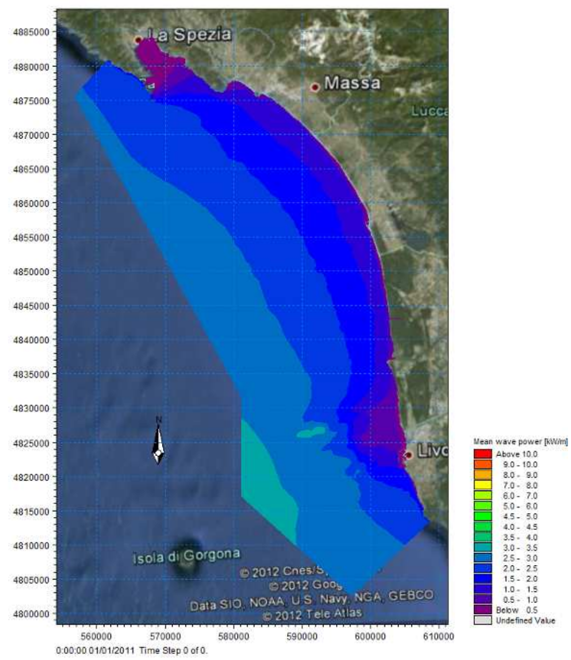

Figure 8: Spatial distribution of the Yearly Mean Power computed by using the data for the Year 2011 [kW/m].

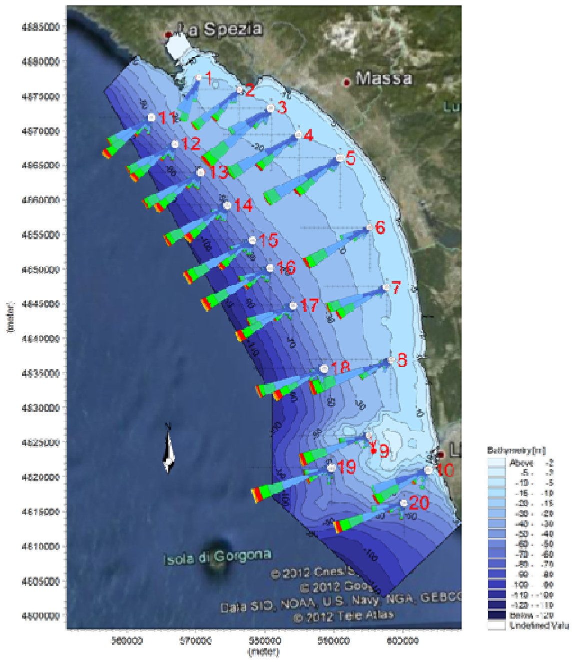

Figure 9: Location and wave rose of the points extracted.

Point	Mean Power 2010 [kW/m]	Mean Power 2011 [kW/m]
1	0.97	0.72
2	2.23	1.55
3	2.23	1.61
4	2.21	1.61
5	2.06	1.48
6	2.16	1.6
7	2.28	1.71
8	2.44	1.86
9	*2.89*	*2.23*
10	2.1	1.6
11	3.16	2.51
12	3.16	2.5
13	3.23	2.54
14	3.33	2.61
15	3.4	2.66
16	3.38	2.65
17	3.31	2.6
18	3.36	2.65
19	*3.63*	*2.93*
20	3.07	2.43

Table 1: Yearly mean values of the wave power in the extracted points.

5. Conclusions

This study presents a brief contribution to the knowledge of the availability of wave motion energy in the whole of the Mediterranean sea. The results constitute both an up-date of previous, older studies [3] and a deeper knowledge, in terms of spatial resolution, of wave energy potentials also in respect of more recent studies [5-6]. With reference to [3] it can be confirmed that the area with the most availability of average annual power is that to the West of the islands of Corsica and Sardinia. However, the maximum values supplied in [3] for the area of Alghero (5 kWm^{-1} average annual), are much lower than those obtained from the more recent studies by [5] and [6] in the same area (9.5 kWm^{-1} average annual). These studies are based on data registered punctually from a few wavemeter buoys whereas the present study is based on data coming from numerical simulations (MED 6MIN-IFREMEER), something which has permitted a higher spatial resolution knowledge and so the highlighting of maximum values of up to approximately 15.5 kWm^{-1} located in other points offshore of the same area.

The analyses are limited to the aspect of the quantitative definition of the energy availability without examining the sustainability of the use of WEC technologies. Nevertheless, given that evident technical-economical limitations suggest that the potentially exploitable areas for supplying energy to inland zones must be located, amongst other things, between 5-10 km from the coastline, a procedure has been developed based on a second numerical model (MIKE21-SW). This takes as off-shore boundary conditions the output of the MED 6MIN model, permitting the reconstruction, with very precise location definition, of the energy availability of areas close to the coastline with sea-bed depths of less than 100m. As a first area for testing the procedure a stretch of coastline was chosen between Leghorn and the Gulf of La Spezia. The simulations have highlighted the high spatial variability of the wave energy resource and the formation of hot-spots due to phenomena of focusing in correspondence with areas on the Secche della Meloria (the Meloria shallows). At present, other coastal areas are under examination and the results will be presented in subsequent papers.

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