Estimation of the wave energy potential of the northern Mediterranean Sea

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Abstract

This paper presents some preliminary analyses of a wave data set arising from a numerical simulation model carried out to obtain distribution maps of the wave energy potential in the northern Mediterranean sea. The most energetic areas are highlighted, as well as the values of the monthly mean power in front of several existing harbours in the studied domain with the aim of providing supporting evidence for further studies on the localization and assessment of wave energy pilot plant.

1 Introduction

At present, the energy sector is obliged to use a renovating process directed towards environment friendly renewable energy. This process has seen the emergence of the use of wave energy. The EU Commission publications "WERATLAS—Atlas of Wave Energy Resource in Europe" by Pontes et al. (1996) and "Ocean Energy Conversion in Europe, Recent Advancements and Prospects, (2006), OEC2006 indicate a basis of the potential for extracting energy from sea waves (see also Nielsen, 2005), however, the idea of converting the energy of ocean surface waves into useful energy forms is not new (Salter 1974). There are techniques that were first patented as early as 1799 (Girard & Son, France). Indeed, the amount of research and development work on Wave Energy Converters (WEC) is quite large and extensive reviews have been provided, among others Salter (1989), Thorpe (1992), Thorpe (1999), Ross 1995, Petroncini (2000), Clément et al. (2002), Falnes 2007 and Falcao, 2010.

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 perspective, the Mediterranean sea has received less attention since it is much less energetic than the oceans. However, the utilization of the wave energy available in the Mediterranean sea could be of some interest, for example, in a circumstance such as WECs embodied into harbour breakwaters. In this case, the harbour breakwater becomes a multifunctional structure where the cost of the infrastructures required by both functionalities are shared (harbour tranquillity and energy production) thus enhancing the value of the use of the WECs.

In this work, a preliminary set of analyses concerning the wave energy potential of the Northern Mediterranean Sea has been carried out.

2 Used wave data set

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.

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The numerical simulation model used is the WaveWatch III, with a third-order accuracy propagation scheme in space and time (the model used in the present paper is Menor4000M). 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 available, at the time of this writing, covers a period of 1 year and 10 months, from July 2009 to April 2011, so the only complete year, up to now, is 2010.

3 Methodology

It is well known that in case of regular waves the specific wave power is equal to eq. (1)

$$P = \frac{1}{8}\gamma H^2 C_g \tag{1}$$

with γ specific weight [N/m^3]

H wave height [m]

C_g group celerity [m/s]

Irregular waves can be considered a superposition of an infinity number of regular components and the total power is calculated as the sum of the power associated to any component, according the eq. (2).

$$P = \sum_{i=1}^{\infty} \frac{1}{8}\gamma H^2(f_i) C_g(f_i) \tag{2}$$

In terms of frequency spectrum, $S(f_i)$, the wave height squared is expressed as in eq. (3)

$$H^2(f_i) = 8 \cdot S(f_i)\Delta f \tag{3}$$

In case of deep water the group celerity is computed as in eq. (4)

$$C_g(f_i) = \frac{1}{4}\frac{g}{\pi}\frac{1}{f_i} \tag{4}$$

with g acceleration of gravity [m/s^2]

π Pi constant [-]

f frequency [1/s]

Substituting eq. (3) and eq. (4) into eq. (2), the eq. (5) is obtained:

$$P = \frac{g\gamma}{4\pi} m_{-1} \cdot \frac{m_0}{m_0} \tag{5}$$

where

$$m_k = \sum_{i=1}^{\infty} S(f_i) f_i^k \,\Delta f \tag{6}$$

Finally, in case of irregular waves, wave power per unit length of wave front is calculated as in eq. (7)

$$P = \frac{1}{64}\frac{g^2}{\pi}\rho H_{mo}^2 T_{m-1,0} \tag{7}$$

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

4 Results

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 figure 1 and the localization of the related points is depicted in figure 2. Moreover, the spatial distribution of the mean power for the year 2010 has been computed as the mean of the monthly mean powers, see figure 3.

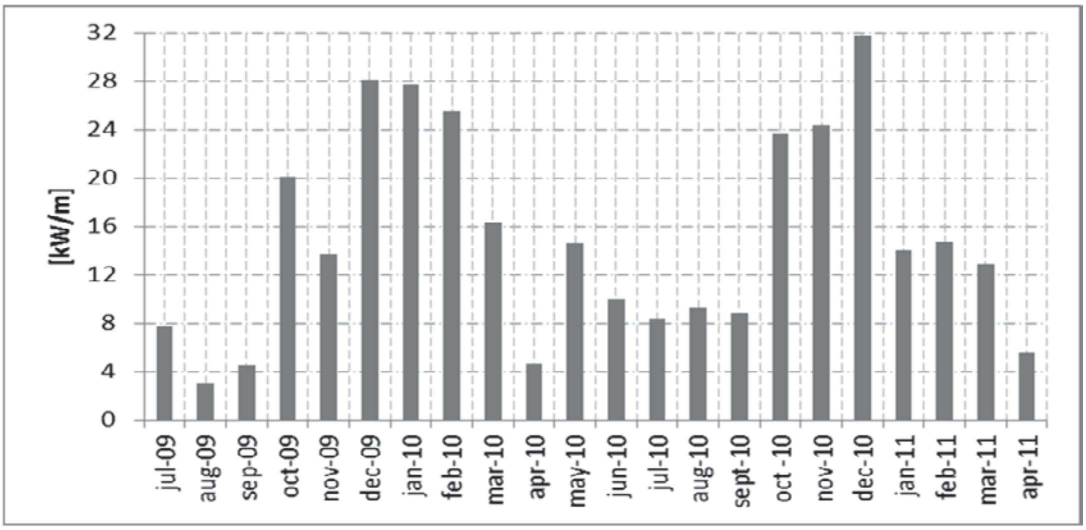

Figure 1: Maximum values of the monthly mean power and its spatial localization as reported in figure 2.

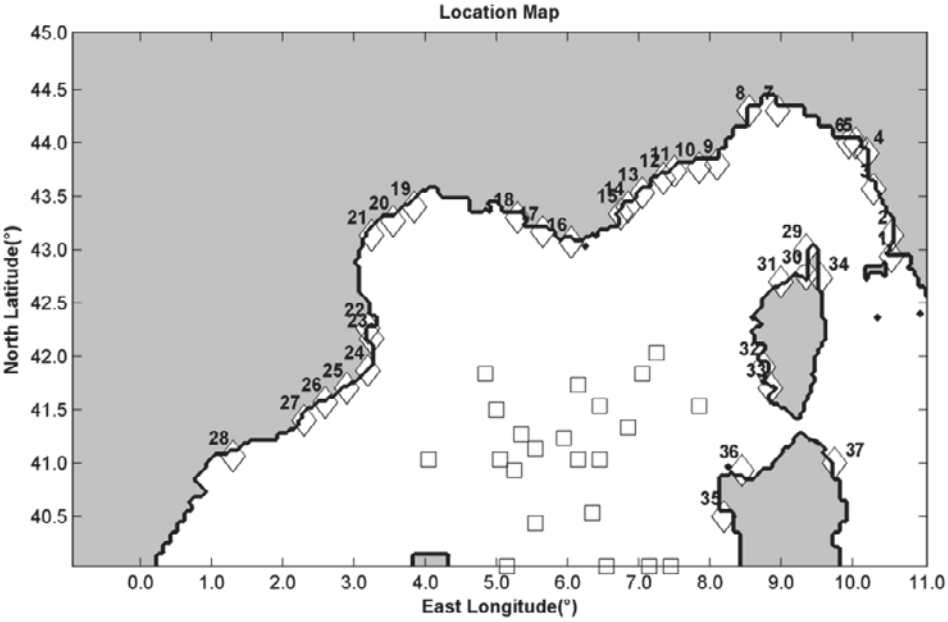

Figure 2: Location map of sea sites characterized by the maximum monthly mean power (□) and of harbours in front of which the values of monthly mean power were extracted, see figure 4, 5 and 6 (◊ and the corresponding number).

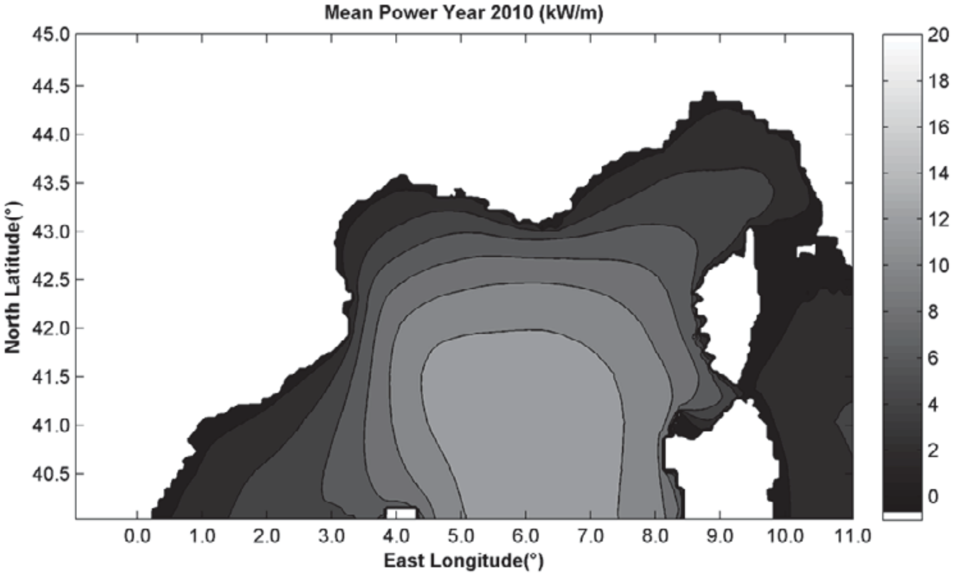

Figure 3: Spatial distribution of the Yearly Mean Power computed by using the data for the Year 2010 [kW/m]

In addition to the above analysis, it was also considered important to analyse the monthly mean power in 37 different points located in front of the main harbours present in the Northern Mediterranean, see figure 2. In fact we extracted the values computed at the points of the numerical domain that are close to the harbours locations. These values are reported in the following figures: i) figure 4 for the Italian harbours, ii) figure 5 for the French harbours; iii) figure 6 for the Spanish harbours.

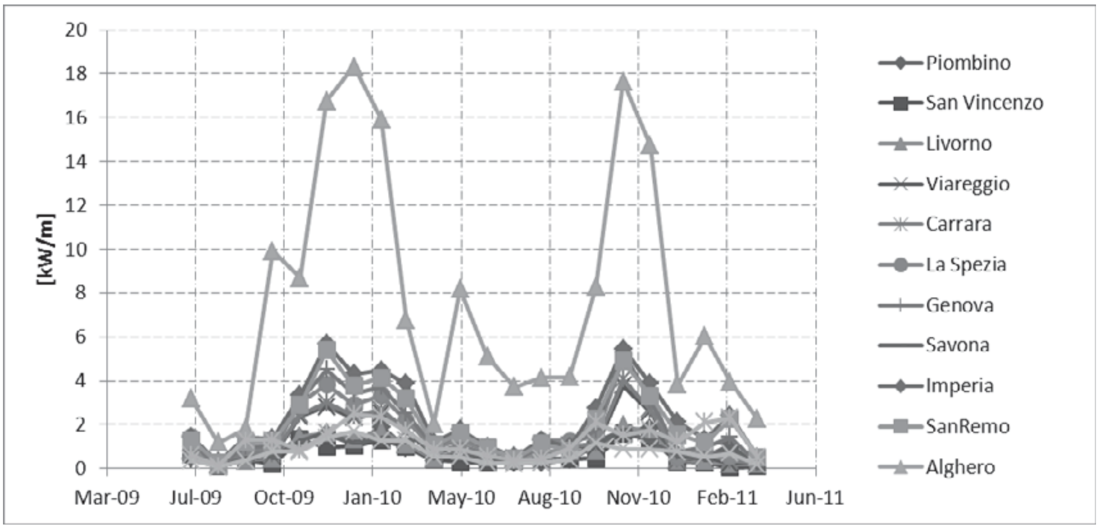

Figure 4: Mean Power Italian Harbours [kW/m]

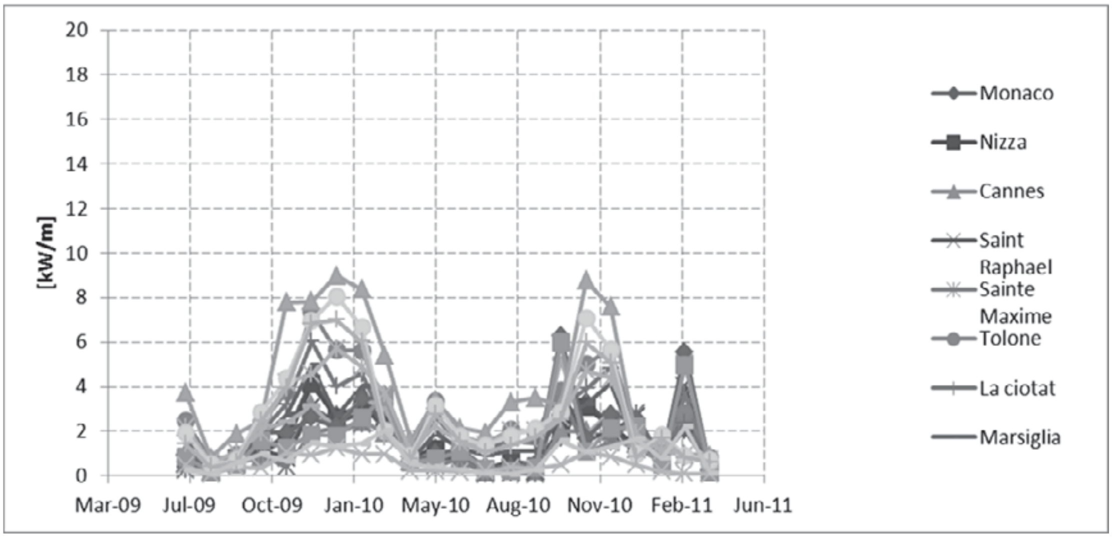

Figure 5: Mean Power French Harbours [kW/m]

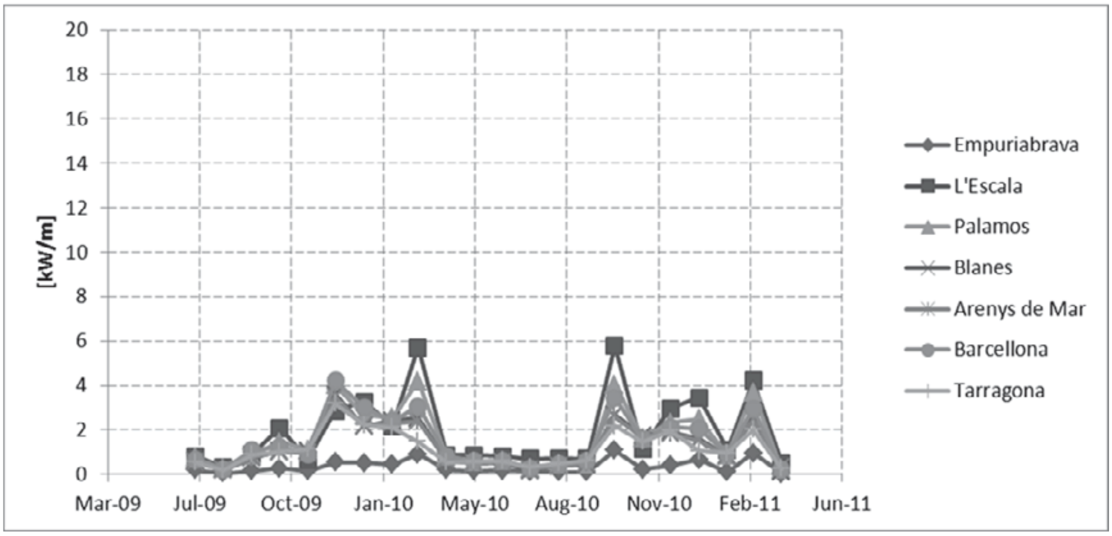

Figure 6: Mean Power Spanish Harbours [kW/m]

Table 1: Yearly mean power computed by using the wave data for the Year 2010 [kW/m] at the 37 harbours analyzed, see figure 2.

			Mean Power Year 2010 [kW/m]				**Mean Power Year 2010 [kW/m]**
1	**Italy**	**Piombino**	0.90	**20**	**France**	**Port Cap d'Adge**	2.00
2		**San Vincenzo**	0.74	**21**		**Gruissan**	1.71
3		**Livorno**	1.01	**22**	**Spain**	**Empuriabrava**	*0.36*
4		**Viareggio**	1.56	**23**		**L'Escala**	2.13
5		**Carrara**	1.63	**24**		**Palamos**	1.71
6		**La Spezia**	2.02	**25**		**Blanes**	1.34
7		**Genoa**	2.15	**26**		**Arenys de Mar**	1.31
8		**Savona**	0.86	**27**		**Barcellona**	1.58
9		**Imperia**	2.63	**28**		**Tarragona**	1.21
10		**SanRemo**	2.30	**29**	**France (Corsica)**	**Port de Cent.**	4.84
11	**France**	**Monaco**	1.63	**30**		**San Fiorenzo**	0.59
12		**Nice**	1.63	**31**		**Isola Rossa**	3.01
13		**Cannes**	1.24	**32**		**Ajaccio**	3.61
14		**Saint Raphael**	1.62	**33**		**Propriano**	3.12
15		**Sainte Maxime**	1.39	**34**		**Bastia**	0.87
16		**Toulon**	3.37	**35**	**Italy (Sardinia)**	**Alghero**	*9.08*
17		**La ciotat**	2.66	**36**		**Porto Torres**	0.78
18		**Marseille**	2.14	**37**		**Golfo Aranci**	1.33
19		**Sete**	1.88				

5 Discussions

It is evident that the most energetic parts of the northern Mediterranean are those on the Western coasts of the islands of Corsica and Sardinia, see figure 3. It is worth noting that during the months of October, November and December, the maximum monthly mean power in the studied domain is always greater than 20 kW/m (except Nov 09). It is interesting to notice that the monthly mean power values in front of all harbours analysed: i) do not exceed the value of 8 kW/m during the autumn-winter months (except Alghero that reaches the considerable value of 18 kW/m) and ii) do not exceed the value of 4 kW/m, during the spring-summer months. Between the Italian (figure 4), French (figure 5) and Spanish (figure 6) harbours it seems that those located on the French cost are characterized by slightly higher values of monthly mean power in their waterfronts, at least considering the studied spatial domain, see also Table 1.

Previous analysis carried out by Vicinanza et al. 2011, using wave buoys located at Alghero (Sardinia) and La Spezia have indicated a yearly mean power equal to 9.05 kW/m and 3.46 kW/m. Their results, that are based on wave time series of about 18 years in length, are quite close to the values presented here (see table 1).

6 Concluding remarks

The yearly mean wave power, calculated by using the wave data registered in the year 2010, in the different points located in front of the main harbours present in the Northern Mediterranean, are usually below 3.0 kW/m, and the only values close or over 5 kW/m are in front of the harbours at Alghero (9.08 kW/m,) and Port de Centauri (4.84 kW/m). These values are considerably lower than the potential energy in the oceans (approximately 20-80 kW/m), and it would seem that the construction of power plants based on WECs, in the studied area, would not be a viable option if merely for economic reasons. The Northern Mediterranean, however, may be of some interest for the testing of scale models in order to assess their effectiveness and to achieve an optimization before the installation of the final prototype. Moreover, the sustainability of the construction of multifunctional structures devoted to harbours/shore defence and energy production could be studied considering the added value which would arise from the sharing of construction costs.

7 Acknowledgements

This work has been conducted as partial fulfilment of the PhD student-program of the author V. Vannucchi, PhD course on Civil and Environmental Engineering, DICeA, University of Florence.

The authors wish to thank the IFREMER centre for data delivery and Doct. Fabrice Lecornu for his help regarding the understanding of data structure.

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