Proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering
OMAE2013
June 9-14, 2013, Nantes, France

OMAE2013-10183

DRAFT: WAVE ENERGY ESTIMATION IN FOUR ITALIAN NEARSHORE AREAS

Valentina Vannucchi
DICEA, University of Florence
Florence, Italy

Lorenzo Cappietti
DICEA, University of Florence
Florence, Italy

ABSTRACT

In this work, a set of analyses concerning the deep water wave power of the whole Mediterranean Sea has been carried out. These analyses cover the period from July 2009 to March 2012. Processes affecting waves as they propagate towards the coasts can modify the wave power, leading to reductions or, sometime, local enhancements due to focusing mechanisms. To quantify these processes, and thus to select the most energetic locations, numerical simulations were used to propagate the offshore time series into four selected near-shore areas. Monthly and yearly mean wave power maps are presented. Moreover some hot-spots, located at water depths in the range of 50 m to 15 m, are highlighted.

INTRODUCTION

Currently in the energy sector there is an increasing interest in renewable energy sources and, within this context, the possibilities of producing electrical energy from wind waves is rising. A proper characterization of the local wave climate is the first steps needed to assess the feasibility of constructing a power plant based on Wave Energy Converter (WEC) technologies (Falnes, 2007 and Falcão, 2010). Concerning European seas, important contributions have been supplied (e.g. Pontes et al. 1996), but the Mediterranean Sea received less attention. Recently this attention increases, Cavalieri, (2005), Martinelli, (2011), Vicinanza et al., (2011), Vicinanza et al., (2013), Liberti et al., (2013). The present study gives an additional contribution on the basis of a new data set focused on the last three years. In addition, a procedure has been developed, based on numerical simulations, to conduct a detailed analysis of coastal areas with a serviceable depth of less than 100 m which can be useful in the identification of hot-spots.

METHODOLOGY

The analyses are based on wave data arising from the model called MED-6MIN, a WaveWatch III model, with a third-order accuracy propagation scheme in space and time. The data-set was obtained by the pre-operational system called Prévimer and was provided by IFREMER (French Research Institute for Exploitation of the Sea). The validation of the model was done using large-scale measurements of surface buoys and satellites (see Previmer Website and Lecornu & De Roeck, 2009). For the present analysis the wave data were compared with values measured by wave buoys, when available, and the correlation coefficient concerning measured and computed significant wave heights equaled 0.9 (Vannucchi, 2012).

The data are provided at 3 hour intervals in terms of the significant wave height, H_{m0}, the energetic period, $T_{m-1,0}$, and the mean wave direction. The analyzed spatial domain covers the Mediterranean Sea from 6° W to 36.5° E of longitude and from 30° N to 46° N of latitude, with a resolution of 0.1°. The analyzed period covers 2 years and 9 months, i.e. from July 2009 to March 2012. Monthly and yearly mean wave power, for random waves propagating in deep waters, was computed according to eq. (1)

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

ρ is the seawater density (1025 kg/m^3),

ANALYSIS OF DEEP WATER DATA

Once the spatial distribution of the monthly mean power was computed (Vannucchi, 2012), the maximum values inside the studied spatial domain was extracted (Fig. 1). Moreover, the spatial distribution of the yearly mean power of the years 2010 (Fig. 2) and 2011 (Fig. 3) were computed as the mean of the monthly mean powers.

It is worth noting that during the autumn and winter months the maximum monthly mean wave power at points of the studied domain is almost greater than 20 kW/m (exceptions are Nov09, Jan11 and Feb11). Such points are located in the most energetic area of the Mediterranean Sea that is the West of Corsica and Sardinia Islands.

In this area the maximum annual average power reaches 15.8 kW/m for the 2010 and 12.8 kW/m for the 2011.

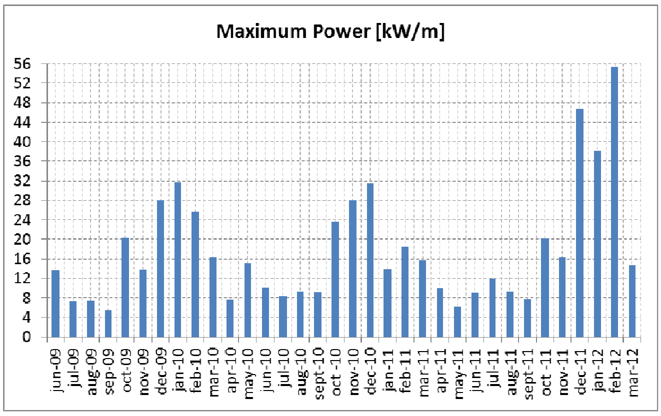

Figure 1. Maximum values of the monthly mean power reached at points of the studied spatial domain.

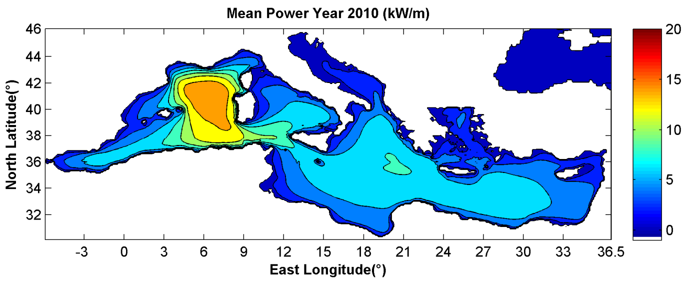

Figure 2. Spatial distribution of the Yearly Mean Power computed by using the data of the Year 2010 [kW/m]

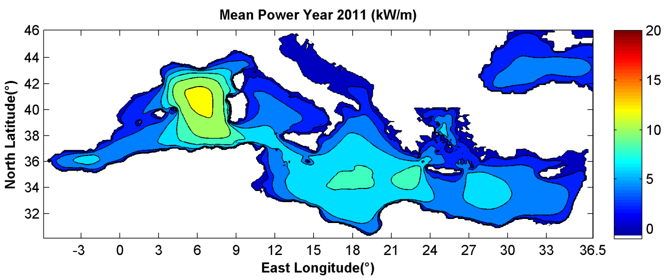

Figure 3. Spatial distribution of the Yearly Mean Power computed by using the data of the Year 2011 [kW/m]

NEARSHORE CHARACTERIZATION

The numerical simulations were carried out by using the Spectral Wave (SW) module of the MIKE21 package (DHI Website). The SW is a third generation 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 (DHI, 2010).

The values of significant wave height, energetic period, mean wave direction and spreading factor extracted from the MED-6MIN Prévimer model on a depth of 100 m, were used as offshore boundary conditions for the SW model.

This methodology was applied to four selected areas: the North side of the Tuscany Region (La Spezia – Livorno), the Central part of the Tuscany Region (Livorno – Piombino), the West side of Liguria Region (Ventimiglia – Imperia), the North-West side of Sardinia Region (Stintino – Alghero), see Fig. 4.

Figure 4. Site selected locations

The model domain sizes were about 30 km x 85 km for the North Tuscany area, 25 km x 80 km for the central Tuscany, 7 km x 75 km for the West Liguria, 30 km x 70 km for the North-West Sardinia.

The model meshes in the Tuscany areas were characterized by a triangular side of about 2000 m in water depths over 50 m, 1000 m in water depths between 50 m and 30 m, 500 m in water depths between 20 m and 30 m and of about 300 m from water depth of 30m until the coast (Fig. 5).

The model meshes in Liguria and Sardinia areas were characterized by a higher resolution to properly represent the continental platforms characterized by higher slopes and so to properly simulate the phenomena of wave transformation toward the nearshore area. The total number of computational nodes was equal to 13188 for the North Tuscany, 8246 for the central Tuscany, 4521 for the Liguria and 5461 for the Sardinia.

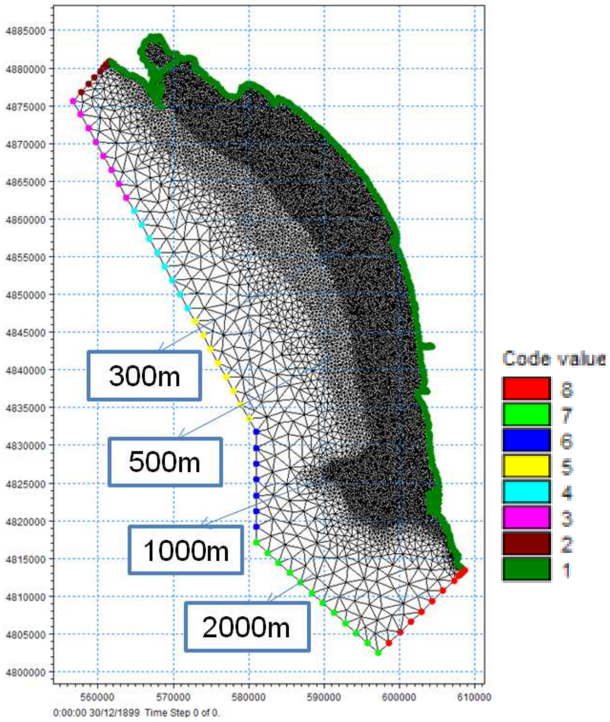

Figure 5. Boundary conditions and resolution mesh

All the 8028 events of the Prévimer data-set (from July 2009 to March 2012) were propagated with the fully spectral and quasi-stationary formulation. The spectral discretization was performed on frequency and direction. The frequency discretization was of logarithmic type with a number of frequencies equal to 25, a minimum frequency value equal to 0.04 and a frequency factor equal to 1.12. The discretization along the direction was performed on a 360 degree rose and the number of directions was chosen equal to 16. In the wave breaking model the gamma value was chosen constant and equal to 0.8, while the alpha value was 1. A constant value was assumed for the bottom friction equal to 4 cm (Nikuradse formulation) as well as a constant values for the two dissipation coefficients, Cdis, equal to 4.5, that is a proportional factor on the white capping dissipation source function and thus control the overall dissipation rate, and DELTAdis, equal to 0.5, that is controlling the weight of dissipation in the energy/action spectrum. The JONSWAP fetch growth expression with the classical parameters (σ_a=0.07, σ_b=0.09, γ=3.3) was used as initial condition.

Output maps concerning the spatial distribution of nearshore wave power were computed as in eq. (8)

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

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

RESULTS

The yearly mean power was computed and reported as contour maps in Figs. 6-9.

In the North Tuscany area (Fig. 6) the decay of the wave power toward the coast is almost uniform, except on the Meloria shoals, located in front of Livorno. In this area there is evidence of a hot-spot, on a water depth of about 13 m with the highest yearly mean values, equal to 4.78 kW/m for 2010 and to 3.55 kW/m for 2011.

In the Central Tuscany (Fig. 7) the decay of wave power toward the coast is particularly evident on the area south of Rosignano, due to the sheltering effect leads by the Corsica Island.

In case of the Liguria area (Fig. 8), the wave power decrement toward the coast is uniform from offshore to coastline. The focusing mechanisms are less emphasized with respect to the Meloria shoals area (Tuscany), but anyway they generate, near some headlands and submerged cusp (on about 30 m water depth between Sanremo and Imperia), local maximum values of 1.84 kW/m for the 2010 and to 1.59 kW/m for the 2011.

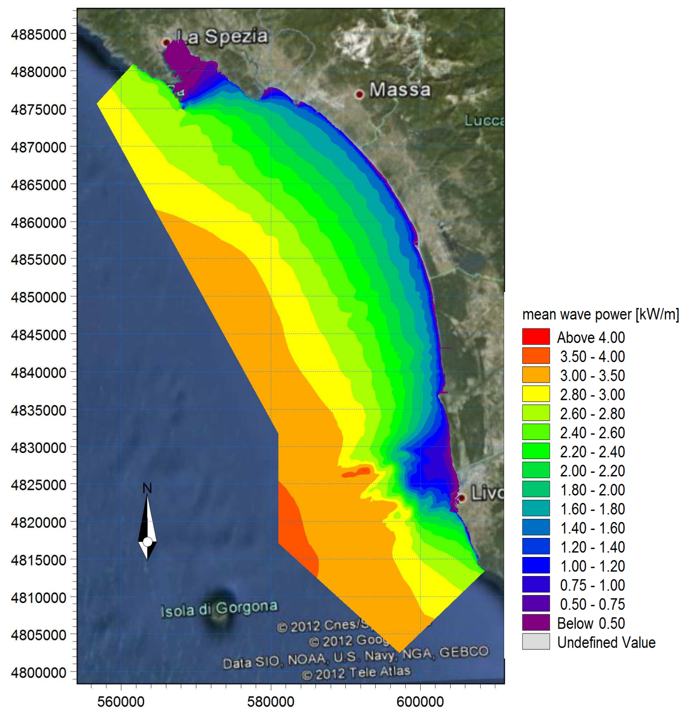

Figure 6. North Tuscany: yearly mean power [kW/m]

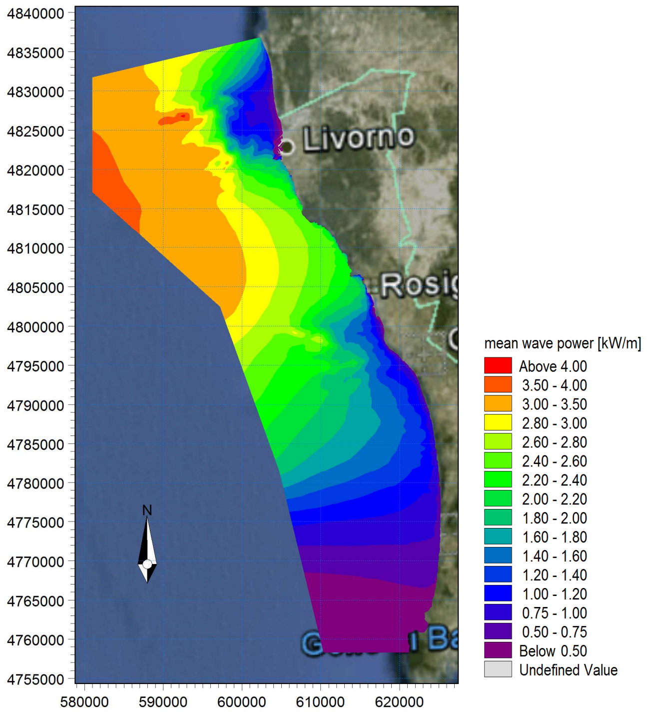

Figure 7. Central Tuscany: yearly mean power [kW/m]

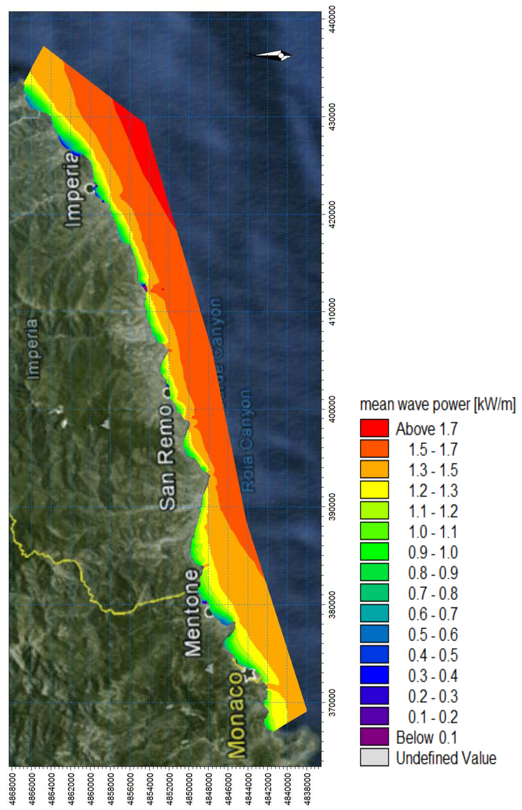

Figure 8. Liguria: yearly mean power [kW/m]

In the case of Sardinia nearshore area (Fig. 9), accordingly to the results related to deep water data, the wave power values are much higher than in the other studied sites. It is particularly evident on the northern part of the studied Sardinia nearshore, where the continental platform is characterized by higher slopes. The maximum values are equal to 12.16 kW/m for the 2010 and to 8.45 kW/m for the 2011 on a water depth of about 20 m.

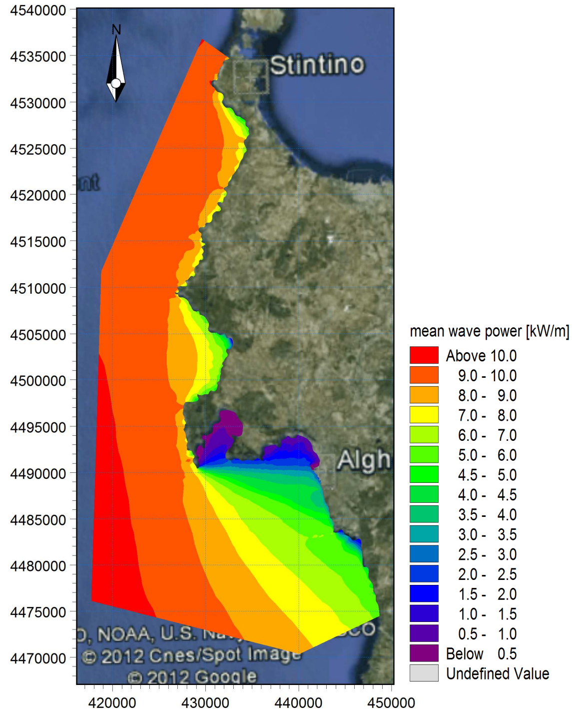

Figure 9. Sardinia: yearly mean power [kW/m]

In addition to the above analysis, it was also considered important to analyse the monthly and yearly mean power in different points located at points on of 15 m and of 50 m .

In case of the North Tuscany nearshore, the most energetic points (see figure 10) are the point 9, in the water depth of 15 m, and the 19, in the water depth of 50 m. Still these points are located on the Meloria shoals where a focusing mechanism is effective (see Tab. 1 and figure 10).

In the Central Tuscany nearshore (Fig. 11), the highest values of wave power are located at the point 2 (15m of water depth) with a yearly value of 2.4 kW/m, at the point 10 (50m of water depth) on the north of Meloria shoals, with a yearly mean value of 3.3 kW/m (Tab 2).

Table 1. Northern Tuscany: yearly mean wave power values of the extracted points

	Yearly Mean Power (kW/m)	*Water depth (m)*
1	0.85	-15
2	1.89	-15
3	1.92	-15
4	1.91	-15
5	1.77	-15
6	1.88	-15
7	2.00	-15
8	2.15	-15
9	2.61	-15
10	1.85	-15
11	2.84	-50
12	2.83	-50
13	2.89	-50
14	2.97	-50
15	3.03	-50
16	3.02	-50
17	2.96	-50
18	3.01	-50
19	3.28	-50
20	2.75	-50

Table 2. Central Tuscany: yearly mean wave power values of the extracted points

	Yearly Mean Power (kW/m)	*Water depth (m)*
1	1.38	-15
2	2.61	-15
3	*2.43*	*-15*
4	1.99	-15
5	2.37	-15
6	1.29	-15
7	0.84	-15
8	0.29	-15
9	*2.99*	*-50*
10	3.28	-50
11	2.65	-50
12	2.43	-50
13	2.43	-50
14	1.80	-50
15	0.95	-50
16	0.32	-50

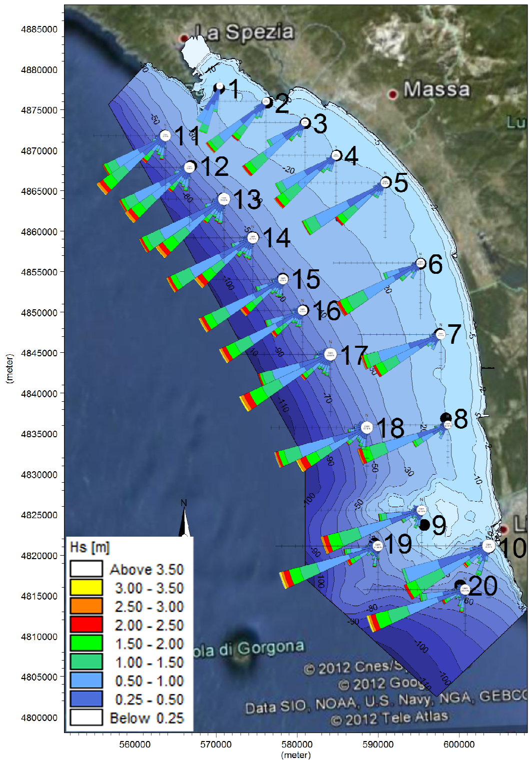

Figure 10. North Tuscany: location and wave roses of the extracted points

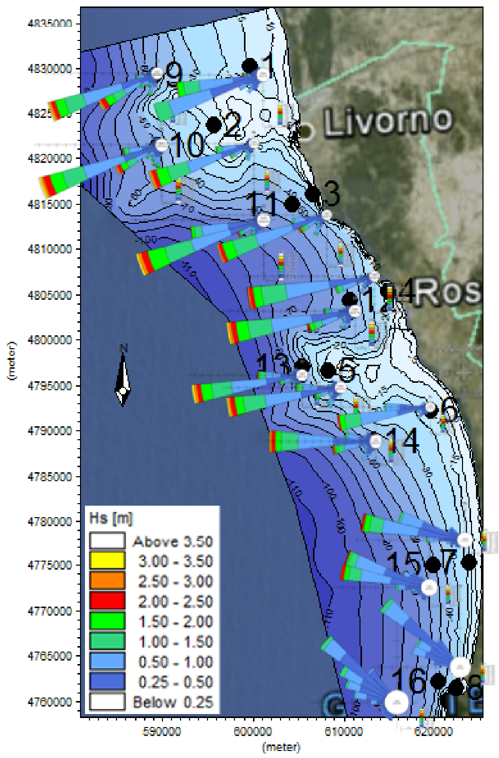

Figure 11. Central Tuscany: location and wave roses of the extracted points

Figure 12. Liguria: location and wave roses of the extracted points

Table 3. Liguria: yearly mean wave power values of the extracted points

	Yearly Mean Power (kW/m)	*Water depth (m)*
1	1.00	-15
2	1.26	-15
3	1.32	-15
4	1.48	-15
5	1.28	-15
6	1.11	-15
7	1.58	-15
8	1.29	-15
9	1.18	-15
10	1.07	-15
11	1.15	-50
12	1.30	-50
13	1.34	-50
14	1.55	-50
15	1.49	-50
16	1.52	-50
17	1.65	-50
18	1.53	-50
19	1.65	-50
20	1.41	-50

Table 4. Sardinia: yearly mean wave power values of the extracted points

	Yearly Mean Power (kW/m)	*Water depth (m)*
1	10.18	-15
2	8.16	-15
3	9.13	-15
4	9.46	-15
5	8.52	-15
6	6.17	-15
7	3.09	-15
8	5.39	-15
9	9.74	-50
10	9.11	-50
11	9.44	-50
12	9.52	-50
13	9.26	-50
14	7.99	-50
15	6.11	-50
16	6.34	-50

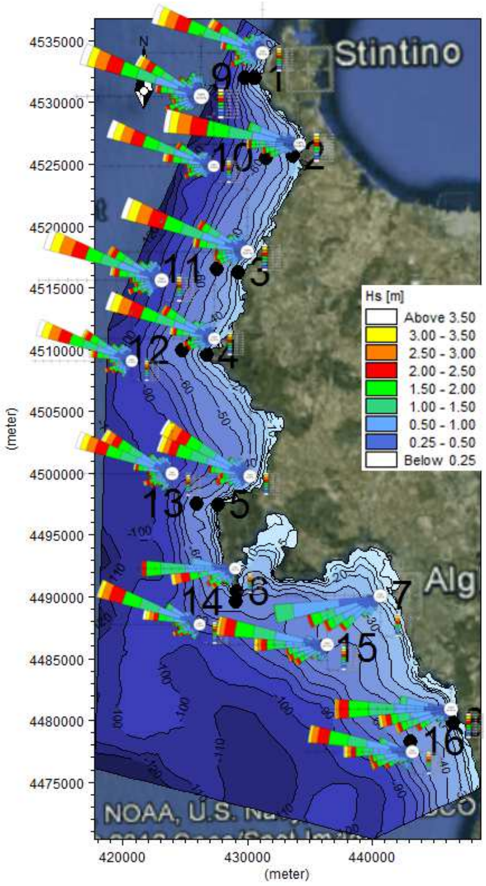

Figure 13. Sardinia: location and wave roses of the extracted points

In case of Liguria nearshore, the highest wave power values are at the point 7 (among all the point located on 15 m of water depth) and at the points 17 and 19, for the 50 m water depth points. The yearly mean wave power values are around 1.60 kW/m for all of these (Tab. 3). The points 7 and 17 are located in front of an headland among Sanremo and Imperia, and the point 19 in front of Imperia (Fig. 12). Their wave roses show that the main wave direction is S-SW.

In case of Sardinia nearshore, the points with the highest values of wave power are the point 1 and 9. The point 1 is on 15 m water depth and reaches a value of 10.2 kW/m. The point 9 is on 50 m water depth and reaches a value of 9.8 kW/m (Tab. 4). It is worth to note that the wave power value at the point 1 is higher than the value at the point 9 due to focusing mechanism that occurs in front of the headland in the northern part of the domain (Fig. 13).

CONCLUDING REMARKS

This study presents a brief contribution to the knowledge of wave power of the whole Mediterranean Sea.

The results constitute both an up-date and a deeper knowledge, in terms of spatial resolution, of wave power potentials of previous studies (Pontes et al., 1996, Cavalieri, 2005, Martinelli, 2011, Vicinanza et al., 2011, Vicinanza et al., 2013, Liberti et al., 2013). With reference to Pontes et al. (1996) 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 Pontes et al. (1996) for the area of Alghero (5 kW/m average annual), are much lower than those obtained from the more recent studies in the same area by Vicinanza et al., 2011 (9.05 kW/m yearly mean wave power value at the Alghero Buoy) and Vicinanza et al., 2013 (10.9 kW/m yearly mean wave power value on the south of Alghero in front of Porto Alabe).

The results of Vicinanza et al. (2011) are based on data registered punctually from 15 wave-measuring buoys around Italy whereas the present study is based on data coming from numerical simulations (MED-6MIN Prévimer model). This has permitted a higher spatial resolution knowledge and so the highlighting of maximum values of up to approximately 15.5 kW/m located in other points of the same area. The present 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 and non-technical 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 (Dalton et al., 2009), a procedure has been developed based on a second numerical model (SW-MIKE21).

This takes as offshore boundary conditions the output of the MED-6MIN model, permitting the reconstruction of the energy availability of areas close to the coastline with seabed depths of less than 100 m. The simulations have highlighted a considerable spatial variability of the wave energy resource on the selected nearshore and the formation of hot-spots due to focusing mechanisms on the Meloria shallows (Tuscany), on headlands among Sanremo and Imperia (Liguria) and headland on the northern part of the studied Sardinia nearshore.

ACKNOWLEDGMENTS

The authors wish to thank: i) IFREMER for the used data and in particular Dr Fabrice Lecornu; ii) DHI- Italia for having supplied the software MIKE21, and in particular Engineer Andrea Pedroncini. This study has been conducted in the framework of MARINET Project EU-FP7, www.fp7-marinet.eu, UNIFI-CRIACIV Research Unit.

REFERENCES

Falnes J., 2007. Review - A review of wave-energy extraction. Marine Structures Vol.20, pp 185-201.

Falcão A., 2010. Wave energy utilization: a review of the technologies. Pp 899-918. Renewable and Sustainable Energy Reviews Vol.14.

Pontes M.T., Athanassoulis G.A., Barstow S., Cavaleri L., Holmes B., Mollison D. and Oliveira Pires H., 1996. WERATLAS - Atlas of Wave Energy Resource in Europe, Technical Report, DGXII Contract No. JOU2-CT93-0390, INETI, Lisbon.

Cavaleri, L., 2005. The wind and wave atlas of the Mediterranean Sea – the calibration phase. Advances in Geosciences, 2, pp. 255–257.

Martinelli L., 2011. Wave Energy Converters Under Mild Wave Climates. Proceedings of the OCEANS 11 IEEE Santander Conference.

Vicinanza D., Cappietti L., Ferrante V., Contestabile P., 2011. Estimation of the wave energy in the Italian offshore. Journal of Coastal Research Vol.64, pp 506-521.

Vicinanza D., Contestabile P., Ferrante V., 2013. Wave energy potential in the north-west of Sardinia (Italy). Renewable Energy Vol. 50, pp. 613-617.

Liberti L., Carillo A., Sannino G., 2013. Wave energy resource assessment in the Mediterranean, the Italian perspective. Renewable Energy 50, pp. 938-949.

Previmer WebSite, http://www.previmer.org

Lecornu, F., & De Roeck, Y. H., 2009. PREVIMER-Coastal observations and forecasts. Houille Blanche, Vol.1, pp. 60-63.

Vannucchi V., 2012. “Wave energy harvesting in the Mediterranean Sea”. PhD Thesis, Doctorate course on "Civil and Environmental Engineering", Department of Civil and Environmental Engineering, University of Florence .

DHI Website, http://mikebydhi.com

DHI, 2010. Nearshore Spectral Wind-Wave Module Scientific Documentation. Denmark.

Dalton G., Rousseau N., Neumann F. and Holmes B., 2009. Non-technical barriers to wave energy development, comparing progress in Ireland and Europe. In Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden.

