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Wave power in the Mediterranean Sea

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Abstract. In this work, the analysis of the wave energy flux and the identification of potential sites for future development of wave energy converters in the Mediterranean Sea, is presented. The most recent reanalysis wave dataset (MEDSEA_MULTIYEAR_WAV_006_012), from the platform of Copernicus Marine Service was used, featuring high spatial and temporal resolution (~3.5 km and 1 h, respectively). The study considered a time series of wave spectral parameters (significant wave height and mean energy period) of 27 – years (1993 – 2020) length, in order to estimate the trends and the variability of the wave energy flux in the Mediterranean basin. The highest values of wave energy flux encountered in the area extending between the Gulf of Lyon and southwest Sardinia Isl. through the Balearic Sea, south to the areas near the Algerian coasts. A significant increasing trend was observed for the extreme values of wave energy flux, i.e., the 95th and the 99th percentiles. The results from the wave energy analysis combined with the corresponded relative water depths, revealed 3 areas with great wave potential for a potential future development of wave energy converters: the offshore areas near the coasts of Menorca Isl., Alghero and Annaba, respectively. Winter was the most energetic season for all areas, while Alghero was the area with the highest mean annual values of wave energy flux.

Key words. Significant wave height, mean energy period, wave energy, Mediterranean Sea, long – term trend.

1. Introduction

Today, a significant part of energy production, still relies on fossil fuels. Global warming, as well as the extinction of the available fossil fuels and the increased energy needs, indicated the immediate need for alternative and renewable energy sources. Although offshore wind energy is more mature and advanced in terms of technological development, wave energy converters (WEC), are promising technologies, while sea waves represent a significant and inexhaustible energy source in the global ocean. Wave energy represents the offshore hydrokinetic energy, derived from the propagation of the ocean surface waves, which are generated by interactions between the wind and the sea surface. Compared to offshore wind energy, wave energy offers higher power density, providing greater power availability per unit volume. Moreover, the correlation between the demanded energy and the seasonal variability of wave resources is high, since higher energy demand in winter is combined with the highest wave power that is also encountered during the same season. Nevertheless, the temporal variability of wave energy, is intricately linked to wind variability, introducing important uncertainties in estimations and wave forecasts. Complex hydrodynamic phenomena (refraction, diffraction, reflection), complicate the harnessing of the available wave energy and its conversion into electricity. Moreover, the identification of potential sites for wave energy exploitation is a complex and multifaceted procedure. Based on the experience from offshore wind farms, this procedure comprises environmental, technological, and socio-economic considerations. The environmental impact assessment addresses *inter-alia* the mitigation of negative and the enhancement of positive effects that a wave farm may have on the surrounding biotic and abiotic environment of the area. The technological considerations define and characterize wave farm developments as regards energy efficiency, distance from shore, bottom suitability, coastal infrastructures, shore-based stations and underwater connecting grids, etc. Finally, socio-economic analysis aims to identify the potential positive and negative effects that a wave farm may have on the social and economic status of the relevant coastal communities, [1].

The idea of converting wave energy into electricity emerged in the early 19th century, although research and development of technologies capable of harnessing wave energy did not occur until the early 1970s. Research to assess the potential wave energy began in the late 20th century. In 1973, Isaacs and Seymour [2], estimated that the global wave power resources were in the range between 1 and 10 TW. In recent years, the numerical wave models of high spatiotemporal resolution, combined with satellite data, allowed more reliable estimates of wave power density, presented in a series of related works.

Despite that the Mediterranean Sea is not considered as a hot-spot for wave energy applications, however, several works focus on this research subject. Most of these works are based on numerical hindcast/reanalysis wave data obtained from Wavewatch III, WAM and SWAN wave models.

Specifically, Besio et al. [3], using the wave model Wavewatch III for a period of 35 years (1979 – 2013), estimated the global wave power to 2 TW, while they suggested the following favorable areas for potential WEC development in the Mediterranean basin: Alghero, Annaba, Benghazi, and Manzana del Vallo, with the highest values corresponding to Alghero (9.49 kW/m). Liberti et al. [4], using the WAM wave model, have also evaluated the mean wave power density for selected sites of the Mediterranean basin, including Alghero, Menorca Isl., Ras Angela, Ajaccio, Ras Al Hilal, Hyères, and Manzara del Vallo. The highest wave power has been identified for Alghero (12 kW/m) and Menorca Isl. (10.90 kW/m). Using the numerical model SWAN, Archambeau et al. [5], analyzed wave power density on the annual and seasonal scale. According to their results, the most favorable areas for wave energy development in the Mediterranean are Greece (1.71–5.28 kW/m), Italy (1.02–8.03 kW/m), Spain (0.93–7.13 kW/m), France (1.16–2.43 kW/m), Tunisia (1.69–6.16 kW/m), and Libya (3.24–6.16 kW/m). Lavidas et al. [6], using *in-situ* wave measurements from oceanographic buoys, evaluated a 35-year hindcast wave dataset (1980-2014) obtained from the numerical models WAM3 and WAM4 for the Aegean Sea. Their analysis showed that the highest wave energetic areas of the Aegean Sea are located on the E and W coasts of Crete and some specific areas of the Cyclades complex. They then focused on three specific locations (East Crete, Kythnos and Paros), where they estimated the maximum annual energy production from three different types of WECs. Guillou & Chapalain [7], assessed the wave energy flux in south Brittany and France, as well as the annual energy production of three WECs, i.e., Pelamis, Wave Dragon and AquaBuoy. The analysis of the complementarity between wave and offshore wind energy in the Greek Seas, using the ERA5 database over a 20 – year timeseries, was conducted by Kardakaris et al. [8], while Soukissian and Karathanasi [9], presented the joint evaluation of wave power density and sea state direction, using *in-situ* wave measurements and reanalysis data, for several sites in the Mediterranean basin, including Mykonos Isl., Santorini Isl., Zakynthos Isl., and Gulf of Lyon; see also [10].

The detailed description and modeling of the wave climate is important to identify optimal locations for WEC development. In this paper, a detailed wave energy potential analysis is performed taking into account the monthly and annual variability, combined with a preliminary analysis of the 95th and 99th percentiles of wave power on the monthly and annual time scales, in order to identify the linear trends at these scales.

2. Theoretical background

A. *Wave power*

Wave power (or wave energy flux) is usually described as the energy transmitted per wave length, in a plane of width B, perpendicular to the direction of the wave propagation, is given as:

$$P = \frac{1}{8} c_g \rho g H^2 B, \tag{1}$$

where c_g is the group velocity, ρ is the water density, g is the acceleration of gravity, and H is the wave height. For waters of arbitrary depth, the group velocity is provided as follows:

$$c_g = \frac{1}{2}\left[1 + \frac{2kd}{sinh\,(2kd)}\right]\sqrt{\frac{g}{k}\tanh(kd)}, \tag{2}$$

where $k = \frac{2\pi}{\lambda}$ is the wave number, λ is the wave length, and d is the water depth. For deep ($d \rightarrow \infty$) and shallow waters, the above equation simplifies as follows:

$$c_{g,D} = \frac{gT}{4\pi}, \quad \text{and} \quad c_{g,S} = \sqrt{gd}, \tag{3}$$

respectively. Therefore, the wave power per unit crest width for deep and shallow waters is provided through the following relations:

$$P_D = \frac{1}{32}\rho g^2 H^2 T, \text{ and } P_S = \frac{1}{8}\rho g H^2 \sqrt{gd}, \tag{4}$$

respectively, where T is the wave period.
Real sea states, however, are not composed of deterministic simple harmonic waves and stochasticity should be also included. In this respect, the Pierson and Longuet-Higgins model is the basis on which the stochastic modeling of sea waves has been developed, [11], [12]. According to this model, the sea surface elevation is described as a stationary, ergodic and Gaussian stochastic process of the following form:

$$\eta(t;\beta) = \sum_{i=1}^{N} A_i \, cos(\,\omega_i t + \phi_i(\beta)), \tag{5}$$

where $\eta(t;\beta)$ denotes the sea surface elevation, A_i, ω_i, and ϕ_i are the amplitude, frequency and phase of component i, respectively. ϕ is a random variable uniformly distributed in $[0,2\pi]$. For a stationary, ergodic and Gaussian sea state, its description is made through the wave power spectral density function $S(f)$, where f is the frequency. In practice, only some few spectral parameters are used, as e.g., the significant wave height H_S, the mean energy period T_e, the spectral peak wave period T_P, etc. The wave power per unit wave-crest length for a real sea state is estimated as follows:

$$P = \frac{\rho g^2}{64\pi} H_S^2 T_e, \tag{6}$$

where ρ is the sea water density (1025 kg/m^3). The significant wave height and the energy period are defined through the zeroth and negative first – order spectral moments, i.e.:

$$H_S = 4\sqrt{m_0}, \; T_e = \frac{m_0}{m_{-1}}, \tag{7}$$

where,

$$m_n = \int_0^{2\pi}\int_0^{\infty} f^n S(f,\theta) df d\theta \, , \; n = \cdots, -1,0,1,2 \ldots \tag{8}$$

B. *Statistical analysis*

The variability of the wave energy flux at different times scales is described by the following measures:

i) the mean annual variability (denoted as MAV), i.e., the variability within a year, defined as the mean annual coefficient of variation;
ii) the inter-annual variability IAV, i.e., the year-to-year variability, defined as the ratio of the standard deviation of the annual mean wave energy flux to the overall mean wave energy flux.

The linear trend of the wave energy flux at the annual and monthly scales, was identified through the Theil-Sen estimator [13], [14]. This estimator was selected due to its resistance to outliers and its robustness.

3. Evaluation of the reanalysis wave data

In this section, the wave reanalysis dataset used in this work and the *in-situ* wave data obtained from 8 oceanographic buoys in the Greek and Spanish seas, were compared in order to assess the reliability of the first.

A. Wave reanalysis data

The spectral wave parameters (significant wave height and wave energy period) that have been used in this work, are available from the Copernicus Marine Service platform (https://data.marine.copernicus.eu/product/MEDSEA_MULTIYEAR_WAV_006_012/services). The reanalysis wave data set is a multi – year (1993 to 2020) product, based on the WAM 4.6.2. wave model, which is fed with daily mean currents from Med- Physics with a 1 h time step and wind fields at 10 m above sea level from ERA5, with 0.25° horizontal resolution. The wave model domain covers the area 18.125° W, to 36.2917° E and 30.1875° N to 45.9792° N, with a temporal resolution of 1- h and a spatial resolution of 1/24° x 1/24° (approximately 3.65 km), [15], [16].

B. In-situ wave measurements

The *in-situ* measurements of the wave spectral parameters are provided by the POSEIDON marine monitoring network, for the buoys in the Greek seas [17], and the Spanish Operational System of Monitoring and Forecasting of the Sea Climate – Spanish Port Authority (Puertos del Estado), for the buoys in the Spanish seas. Wave measurements were taken at hourly intervals for the Spanish buoys, while POSEIDON buoys provided data every 3 hours. The locations and the recording period of the wave parameters are provided in Table 1.

Table 1. Locations and duration of the wave measurements in the Mediterranean Sea

Location	Duration
Athos [39.96° B, 24.72° A]	5/2000- 7/2015
Mykonos [37.51° B, 25.46° A]	5/1999-7/2012
Pylos [36.83° B, 21.62° A]	11/2007-7/2015
Santorini [36.26°B, 25.50° A]	5/1999-7/2012
Begur [41.90° N, 3.66° E]	3/2001 - 3/2011
Cabo de Gata [36.57° B, 2.34° Δ]	3/1998 - 5/2011
Mahon [39.71° N, 4.42° E]	4/1993 - 5/2011
Palos [37.65° B, 0.31° A]	7/2006 - 3/2011

In order to compare the reanalysis data with the *in-situ* measurements, the model data should be collocated with the buoy data in space and time; this procedure is based on the four nearest grid points using a simple inverse distance weighting interpolation function, defined as follows:

$$Hs_R = \frac{\sum_{i=1}^{4}\frac{Hs_{Ri}}{d_i^2}}{\sum_{i=1}^{4}\frac{1}{d_i^2}}, i = 1,2,3,4, \qquad (9)$$

where, $Hs_{Ri}, i = 1,2,3,4$ is the significant wave height in the 4 nearest (to the buoy location) grid points and $d_i, i =$ 1,2,3,4, are the corresponding distances from the buoy location.

C. Evaluation of reanalysis data

In order to compare and evaluate the significant wave height H_S provided by the reanalysis data set, the following parameters were used: the mean relative absolute error ($MRAE$), the mean absolute error (MAE), the bias, the root mean square error ($RMSE$), and the Pearson correlation coefficient (ρ). The definitions of these metrics are provided below:

$$MRAE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Hs_{Bi}-Hs_{Ri}}{Hs_{Bi}}\right|, \qquad (10)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Hs_{Bi} - Hs_{Ri}|, \qquad (11)$$

$$bias = \frac{1}{n}\sum_{i=1}^{n}(Hs_{Bi} - Hs_{Ri}), \qquad (12)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Hs_{Bi} - Hs_{Ri})^2}, \qquad (13)$$

$$\rho = \frac{\sum_{i=1}^{n}\left(Hs_{Bi}-m_{Hs_B}\right)\left(Hs_{Ri}-m_{Hs_R}\right)}{\sqrt{\sum_{i=1}^{n}\left(Hs_{Bi}-m_{Hs_B}\right)^2}\sqrt{\sum_{i=1}^{n}\left(Hs_{Ri}-m_{Hs_R}\right)^2}}. \qquad (14)$$

In the above equations, H_{s_B} and m_{Hs_B} represent the significant wave height and the mean value provided by the buoy, and Hs_R and m_{Hs_R} denote the significant wave height and the corresponding mean value provided by the reanalysis dataset, respectively.

Regarding the Greek Seas, the best performance of the model, has been observed in Pylos with the minimum values of $MRAE$ (0.180), MAE(0.168), $bias$ (0.080 m) and $RMSE$ (0.237 m). The highest value of the correlation coefficient (0.959) has been also encountered in Pylos. The performance of the model was also very good in Athos, with small values for $MRAE$ (0.290), MAE (0.170), $bias$ (0.064 m), $RMSE$ (0.239 m) and a high value for ρ (0.953). In Santorini, lower performance of the model has been observed: $MRAE$ (0.290), MAE (0.231), $bias$ (0.161 m) and $RMSE$ (0.319 m) and a smaller correlation coefficient (0.913). In the Spanish seas the model was effective at the different locations examined, with the corresponding values of $MRAE$ being around 0.18, MAE around 0.18m $bias$ ranging between -0.064 m and 0.049 m, and $RMSE$ between 0.226 m and 0.289 m. In general, for all the examined buoys, $MRAE$ was fluctuating between 0.167 and 0.291. MAE between 0.157 m and 0.231 m, while $bias$ took both positive and negative values, approximately centered around 0 (ranging between -0.161 m and 0.080 m). $RMSE$ values were rather low ranging from 0.226 m and 0.319 m (in Santorini). As for the correlation coefficient ρ, it takes high values (greater than 0.9), for all examined locations. Consequently, Hs_R (from reanalysis data) is in very good agreement with H_{s_B} (from buoy measurements) in the Greek and Spanish Seas.

3. Numerical results

A. Wave energy flux

The spatial distribution of the mean annual wave energy flux in the Mediterranean Sea, for the period 1993 - 2020, is presented in Fig.1. The highest (by far) values have been observed offshore the Gulf of Lyon up to the coasts of Algeria. In addition, the southern offshore areas parts of the central Mediterranean, the central Aegean Sea, the straits between Crete Isl. and Peloponnesus, Crete Isl. and Karpathos Isl. and between Sicily Isl. and Africa, exhibit also increased values as regards the mean annual wave energy flux (ranging from 6 to 10 kW/m), while the entire Adriatic Sea is characterized by poor wave potential.

The spatial behavior of MAV and IAV of wave energy flux is presented in Fig. 2. MAV takes relatively higher values close to the coasts, and especially in the coasts of Thrace in Greece, where it reaches values up to 500%. In most of the Mediterranean coasts, MAV takes values around 250-350%. Almost the same behavior is observed for the IAV that takes values up to 40% in the coasts of Thrace in Greece.

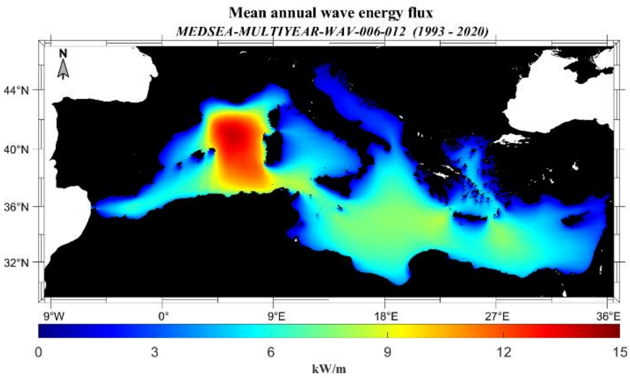

Fig.1. Mean annual wave energy flux in the Mediterranean Sea

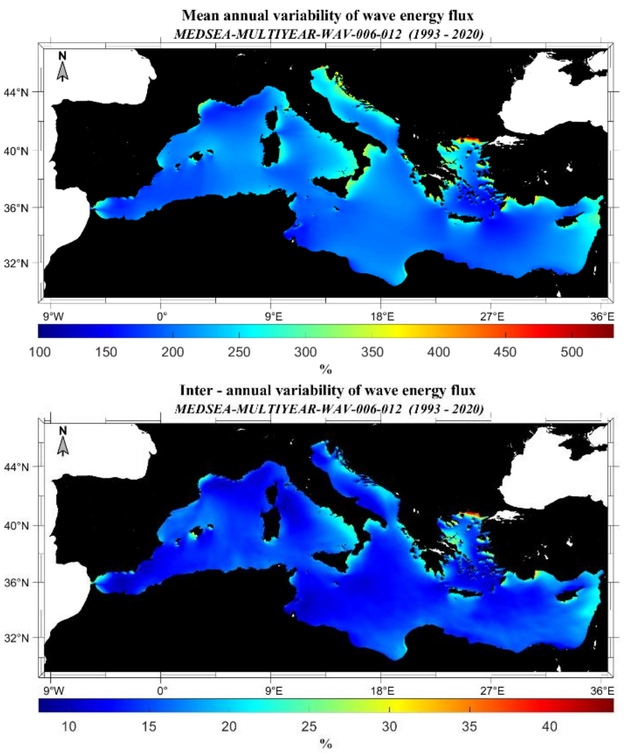

Fig. 2. Mean annual variability (upper panel) and inter – annual variability (lower panel) in the Mediterranean Sea

In Fig.3. the mean monthly wave energy flux is depicted for three representative months of the year, i.e., December, April, and June. The color scale in Figure 2 has been kept the same in order to clearly reveal the differences. The highest available wave power was observed during winter (December, January, February), reaching values close to 22 kW/m in the extended offshore area between the Gulf of Lyon and the coasts of Africa. June is a month characterized by very low values of wave power (reaching values close to 17 kW/m only in the above-mentioned area and in the strait between Crete Isl. and Karpathos Isl. in the Aegean Sea). September is a transitional month since the available wave power starts to increase after the summer season (June, July and August).

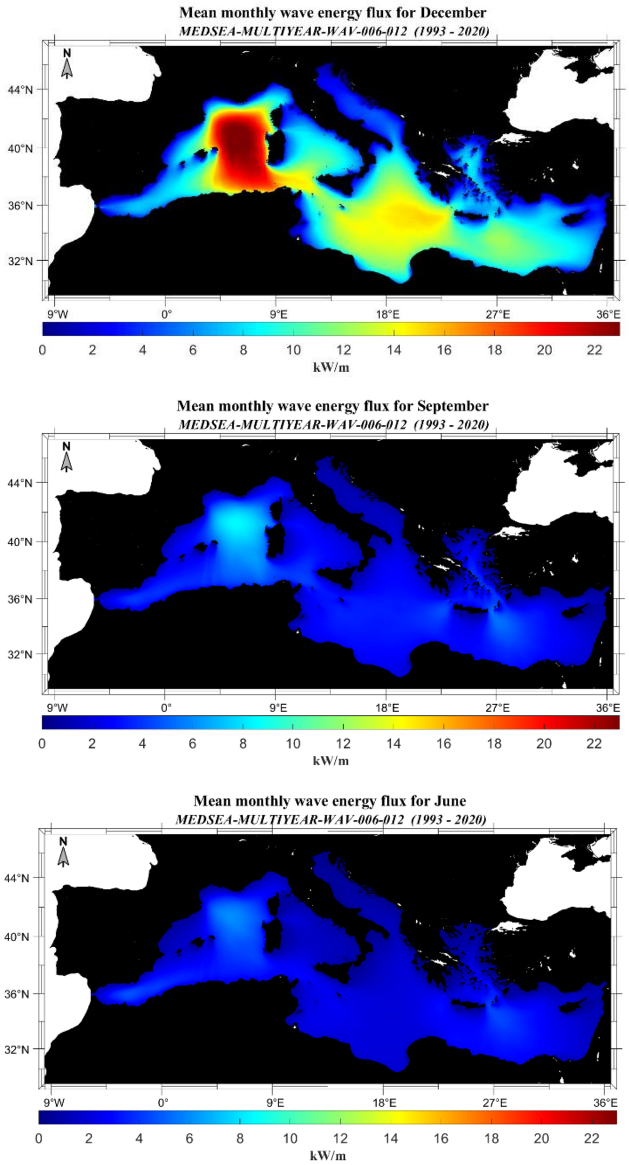

Fig.3. Mean monthly wave energy flux in the Mediterranean Sea for December (first row), June (second row), and September (third row).

B. *Slopes of the wave energy flux*

In Fig.4 and Fig.5, the spatial distribution of the linear slopes of the mean annual wave power, as well as, of the annual 95^{th} and 99^{th} percentiles are presented. The mean annual values of wave power exhibit an increasing trend (of the order of 0.07 kW/m/year) only in the area between the Gulf of Lyon, Sardinia Isl. and the coasts of Algeria.

On the other hand, the 99th percentile values exhibit an important increasing trend for several areas of the Mediterranean Sea, and especially at the south eastern part of the basin, reaching values of the order of 0.2 kW/m/year. For June, the trend is either slightly increasing (~0.05 kW/m/year for the central Mediterranean Sea) or decreasing (for the western and south eastern Mediterranean Sea). For September, there is an increasing trend in the Aegean Sea (~0.07 kW/m/year) and a decreasing trend in western Mediterranean Sea.

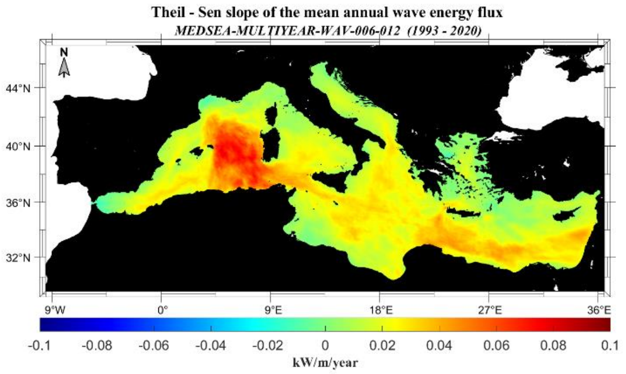

Fig.4. Slope of the mean annual wave energy flux.

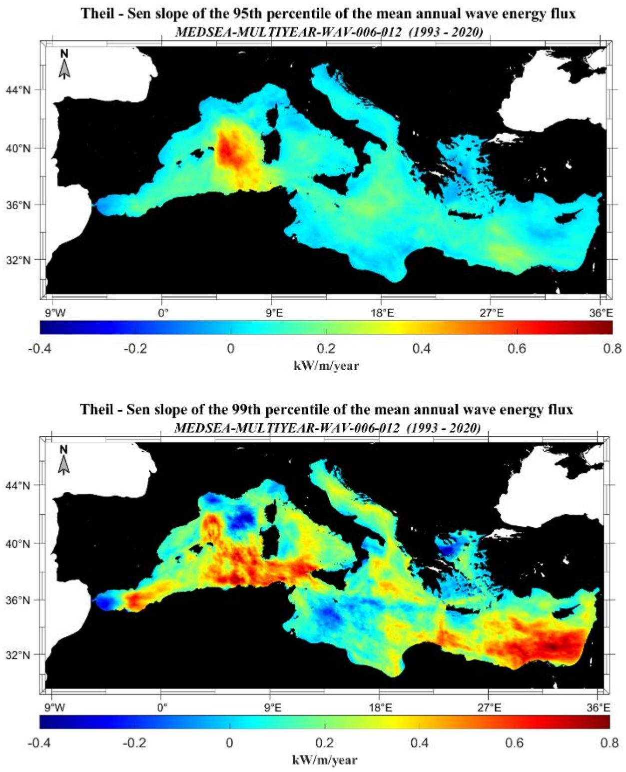

Fig.5. Slope of the 95 and the 99 percentiles of the annual wave energy flux.

In Fig.6, the Theil-Sen linear monthly slopes are presented for December, April and June. As is seen from this figure, during December there is an important increasing trend reaching values close to 0.25 kW/m/year at the western coasts of Sardinia Isl. and the offshore area between Crete Isl. and the coasts of Egypt.

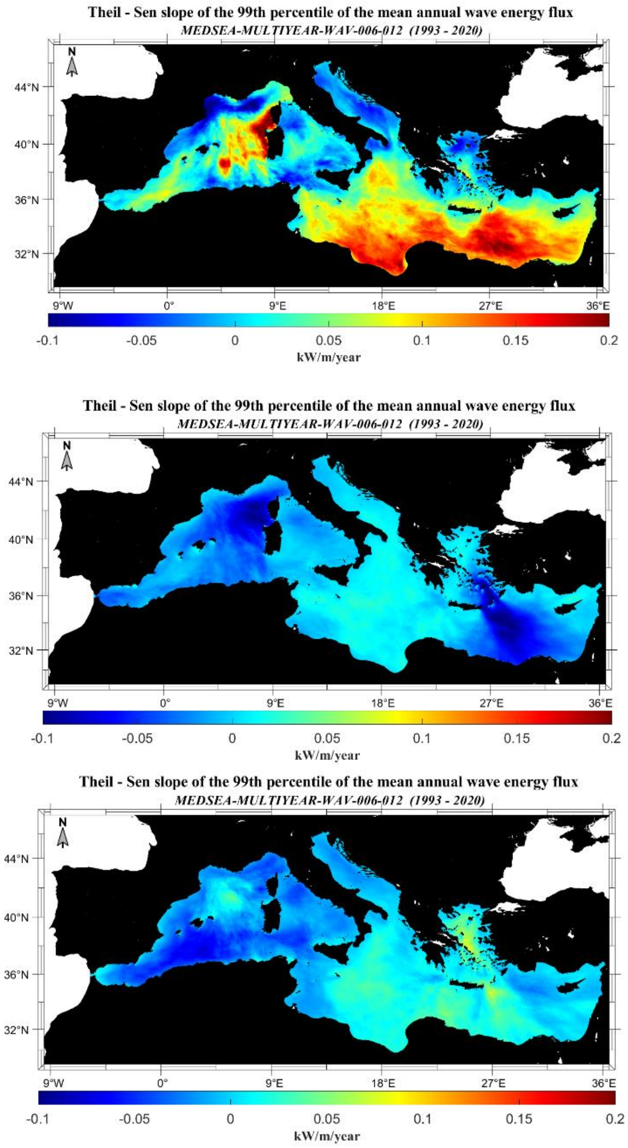

Fig.6. Slope of the mean monthly wave energy flux for December (first row), June (second row), and September (third row).

C. Locations with high wave power

The areas with the highest values of wave power, i.e., the most favorable areas for potential WEC development, should combine high values of mean annual wave power density, with low seasonal variability. Furthermore, a relative shallow water depth is essential for the development of WECs, ensuring the proper anchoring, combined with a short distance from coasts for economic reasons. As the distance from the shore increases, the cost of energy transportation also rises. In this study, a maximum depth of 100 meters was considered. In respect of the above, three areas emerged from the analysis:

- The NE areas near coast of Menorca Isl. in the Balearic Islands.
- The offshore areas near the coasts of Alghero in

Sardinia Isl.
- The offshore areas near the coasts of Annaba in Algeria.

In Menorca Isl. (40.06°N – 4.29°E), the mean wave power is close to 9.3 kW/m, while during winter it reaches values close to 15 kW/m, in spring 8 kW/m, in summer 5 kW/m and in autumn 10 kW/m. The prevailing direction of the sea state in this area was between 0° and 15°. The seasonal variations were generally more pronounced during the winter and autumn periods. In Alghero (40.73°N – 8.04° E), the mean annual wave power was estimated at 11.03 kW/m; during winter ~ 18 kW/m, in spring ~10 kW/m, in autumn 11 kW/m and in summer 5 kW/m. In Annaba (37.06°N – 7.83° E), the corresponding estimates are 7.75 kW/m, 14 kW/m, 6 kW/m, 8 kW/m and 3 kW/m. The seasonal variability patterns observed in Annaba, were similar with those in Menorca and Alghero. The main characteristics of each site are presented in Table 2.

Table 2. Information about the potential locations of WEC development

		Mean values of wave power(kW/m)					
Location	Depth	AN	W	SP	SU	A	Prevailing direction
Menorca	100 m	9.31	15	8	5	10	0°-15°
Alghero		11.03	18	10	5	11	295°-315°
Annaba		7.75	14	6	3	8	300°-345°

4. Conclusions

The spatiotemporal distribution of the wave energy resources in the Mediterranean basin was evaluated, using the database from the Copernicus Marine Service platform, with 1 h temporal and 1/24° spatial resolution. To ensure the accuracy of the used data, a comparative study of the significant wave height from the reanalysis dataset and the significant wave height measured from buoys in the Greek and Spanish Seas has been performed. The study included an extensive assessment of the wave energy flux in the Mediterranean Sea. Local winds significantly affect the wave energy flux in certain areas such as the Gulf of Lyon and the Aegean Sea. The highest wave power values have been observed in the area extending from the Gulf of Lyon to SW Sardinia Isl. through the Balearic Sea up to the coasts of Algeria. In general, the main contribution to the annual mean wave energy flux occurred during winter, reaching values up to 22 kW/m, due to the existence of stronger winds in this season. In spring and autumn, lower values have been observed but still suitable for the potential development of WEC, while in summer, the available resources were significantly lower.

Three specific areas have been identified for the potential development of WECs, due to their favorable conditions; Menorca Isl., Alghero and Annaba. Among these areas, Alghero is characterized by the highest wave resource, while the same seasonal patterns characterize all three areas. The variability was generally more pronounced during winter and autumn.

Currently, with the available technologies, the Mediterranean Sea does not seem very suitable for the development of WECs. However, in the future, with new and scaled devices, it may be possible to harness wave energy and the three examined areas, could potentially be suitable areas for the installation of WECs.

5. References

1. Boero, F., et al., *CoCoNet: Towards coast to coast networks of Marine Protected Areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential* Scires-It-Scientific Research and Information Technology, 2016. **6**: p. 1-95.
2. Isaac, J.D. and R.J. Seymour, *The Ocean as a Power Resource.* International Journal of Environmental Studies, 1973. **4**(3): p. 201 - 205.
3. Besio, G., L. Mentaschi, and A. Mazzino, *Wave energy resource assessment in the Mediterranean Sea on the basis of a 35-year hindcast.* Energy, 2016. **94**: p. 50-63.
4. Liberti, L., A. Carillo, and G. Sannino, *Wave energy resource assessment in the Mediterranean, the Italian perspective.* Renewable Energy, 2013. **50**: p. 938-949.
5. Archambeau, P., et al., *Sustainable Hydraulics in the Era of Global Change: Proceedings of the 4th IAHR Europe Congress (Liege, Belgium, 27-29 July 2016).* 2016.
6. Lavidas, G. and V. Venugopal, *A 35 year high-resolution wave atlas for nearshore energy production and economics at the Aegean Sea.* Renewable Energy, 2017. **103**: p. 401-417.
7. Guillou, N. and G. Chapalain, *Annual and seasonal variabilities in the performances of wave energy converters.* Energy, 2018. **165**: p. 812-823.
8. Kardakaris, K., I. Boufidi, and T. Soukissian, *Offshore Wind and Wave Energy Complementarity in the Greek Seas Based on ERA5 Data.* Atmosphere, 2021. **12**(10).
9. Soukissian, T.H. and F.E. Karathanasi, *Joint Modelling of Wave Energy Flux and Wave Direction.* Processes, 2021. **9**(3): p. 460.
10. Soukissian, T.H., *Probabilistic modeling of directional and linear characteristics of wind and sea states.* Ocean Engineering, 2014. **91**: p. 91-110.
11. Longuet-Higgins, M., *On the statistical distribution of the heights of sea waves.* Journal of Marine Research, 1952. **11**(3): p. 245–266.
12. Pierson, W.J., *A unified mathematical theory for the analysis, propagation, and refraction of storm generated ocean surface waves.* New York University, College of Engineering, Dept. of Meteorology, 1952.
13. Theil, H., *A Rank-Invariant Method of Linear and Polynomial Regression Analysis*, in *Henri Theil's Contributions to Economics and Econometrics: Econometric Theory and Methodology*, B. Raj and J. Koerts, Editors. 1992, Springer Netherlands: Dordrecht. p. 345-381.
14. Sen, P.K., *Estimates of the Regression Coefficient Based on Kendall's Tau.* Journal of the American Statistical Association, 1968. **63**(324): p. 1379-1389.

15. Korres, G., Oikonomou, C., Denaxa, D., & Sotiropoulou, M., *Mediterranean Sea Waves Monthly Climatology (CMS Med-Waves, MedWAM3 system) (Version 1), Copernicus Marine Service (CMS),* *https://doi.org/10.25423/CMCC/MEDSEA_MULTIYEAR_WAV_006_012_CLIM*. 2023.
16. Zacharioudaki, A., et al., *Mediterranean Production Centre MEDSEA_MULTIYEAR_WAV_006_012, Issue: 2.3, Approval date by the CMEMS product quality coordination team: 22/11/2023*. 2023.
17. Soukissian, T.H., et al., *Advancement of Operational Oceanography in Greece: The Case of the Poseidon System.* Journal of Atmospheric & Ocean Science, 2002. **8**(2-3): p. 93-107.