Energy from seas and oceans

Marine energy can represent an important source of renewable energy in the near future. In Italy, activities performed in this sector are growing rapidly both in terms of assessment of the resource and of development of new devices

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The growing interest in the Blue Energy sector represents an opportunity for sustainable growth of maritime economies, sustainable development of marine areas, and sustainable use of marine resources. The EU's Renewable energy directive has established a target of 20% of energy production from renewable energy by 2020. Seas and oceans have the potential to become an important source of clean and renewable energy contributing to reach such a target, the contribution of ocean energy to the EU power demand has been estimated to be around 10% by 2050. Five different marine resources have been identified as liable for ocean energy exploitation:

- **tidal current** extracts kinetic energy from tidal flow;
- **tidal range** captures the potential energy created by the difference in sea level between high and low tides;
- **wave** converts kinetic energy transmitted by the wind to the upper surface of the ocean;
- **ocean Thermal Energy Conversion** exploits the temperature difference between deep and surface ocean layers;
- **salinity gradients** exploits the chemical potential due to salinity gradients in water bodies.

These resources are not uniformly distributed on the globe; moreover the degree of maturity of the technology necessary to their exploitation is different. In the Mediterranean Sea, the two most interesting ocean sources are represented by tidal currents confined in the Strait of Gibraltar and Messina and by waves. Concerning the exploitation of tidal energy, devices based on tidal range technology have been operating since 1960s. Devices are based on barrages that harvest energy from the height difference between high and low tide, converting potential energy into electricity. A tidal power plant with maximum capacity of 240 MW has been operating since 1966 at the Rance River estuary in France. In the tidal currents technologies, instead, energy is derived by water currents and is exploited by means of horizontal or vertical axis turbines. Tidal current converters have not yet reached the same level of maturity as tidal barrages, however an intense research activity is actually carried out. Many large industrial companies are deploying pre-commercial arrays and new technical solutions are under study.
Research in the wave energy sector started in the 1970s, and was initially devoted to the design of large-scale devices to be installed in regions characterized by the largest amount of energy. Due to costs and problems related to the survivability of the devices to the most intense wave extremes, in the last few years research moved on small-scale devices and to exploitation of lower energy sites. These smaller devices present some operational advantages such as lower costs of installation and maintenance; moreover they are generally designed to operate in farms, ensuring energy production also during maintenance activities.
Actually, there is a variety of devices based on different technologies but none of them has taken a leading role. Many different methods have been used to classify wave energy converters. Based on their operating system, the following main classes can be considered:

- oscillating Water Columns (OWC) are located on the shoreline or near shore and are constituted by a submerged structure that contains a chamber with air that is alternatively compressed and uncompressed following the entering waves. The pressure of the air is then converted into energy by a turbine. Some floating devices have been developed on the same principle;
- oscillating body systems are offshore devices constituted by oscillating bodies, either floating or submerged. To induce an oscillatory motion between two bodies they use the incident wave mo-

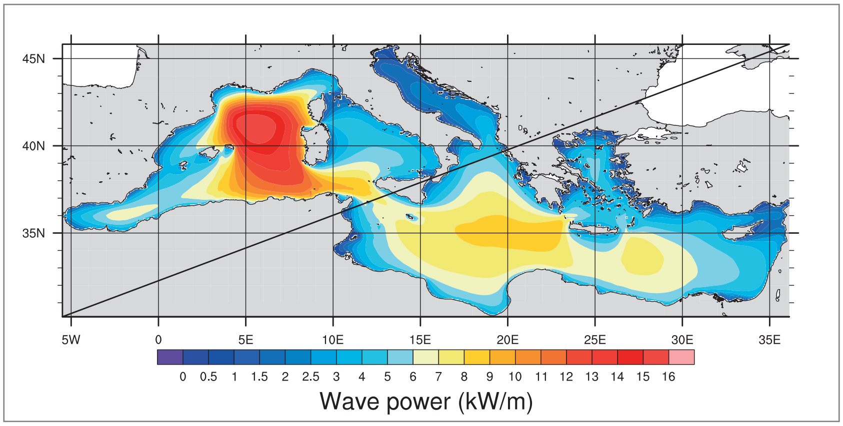

Fig. 1 Distribution of wave power for unit crest, averaged over the period 2001-2010

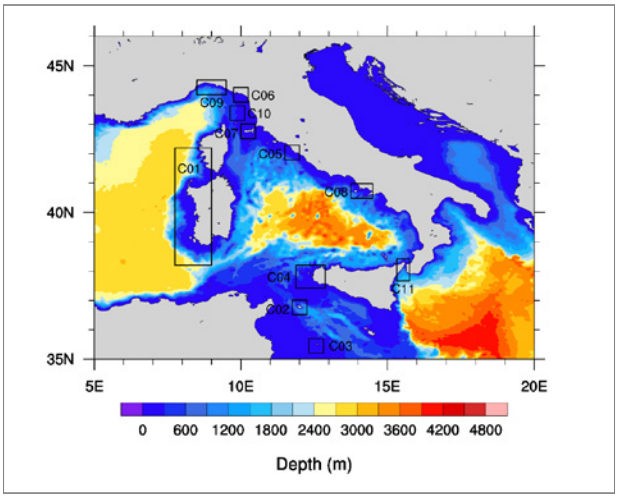

Fig. 2 Bathymetry of the Mediterranean model in the area around Italy with indicated the areas of the highest resolution models

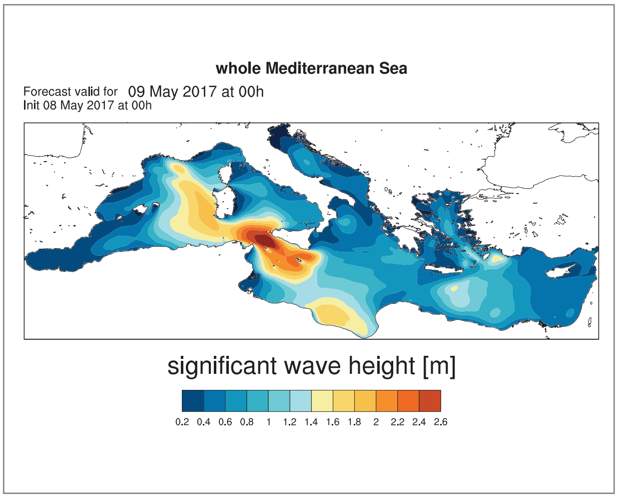

Fig. 3 Example of significant wave height forecast for the Mediterranean basin

tion, that drives the power take-off system. Their main disadvantage is the distance from the coast that requires solving mooring problems and needs long underwater electrical cables;

- overtopping converters are based on the use of a reservoir of water at a level higher than the free surface of the sea; the potential energy of the water is converted into energy through low-head hydraulic turbines. Overtopping converters can be floating structures or incorporated into breakwaters.

Resource assessment

Feasibility studies of wave energy plants require a detailed knowledge of the available energy and of its distribution among different sea states. Wave energy atlases are based on wave measurements obtained from buoys, satellite data and output from model simulations. Wave buoys are the most accurate and reliable data, however time series from wave buoys describe wave climate only locally and often present large data gaps, caused by temporary failure or by routine maintenance operations. In enclosed seas like the Mediterranean, where wave generation and propagation shows a high spatial variability due to the surrounding lands topography, wave models represent the most important tool to assess wave energy distribution.

At ENEA the available wave energy climatology, for the entire Mediterranean Sea, covering the period 2001-2010 has been performed using a state-of-art wave model (WAM) at the horizontal resolution of 1/16° [1]. The model has been forced with six-hourly wind fields obtained from ECMWF operational analysis. An accurate validation of the wave parameters obtained from the model simulation has been performed against available buoys data, collected by the Italian Data Buoy Network (RON), managed by ISPRA; wave heights have also been compared against satellite radar altimeters data. Both comparisons have shown very good statistical agreement. A map of the available wave power flux per unit crest averaged over the entire 10 years of the Mediterranean simulation is shown in Figure 1. The most productive area is located in the western Mediterranean, between the Balearic Islands and the western coast of Sardinia; as for the Italian coasts, other areas characterized by high levels of wave energy are the north-western and southern coasts of Sicily.

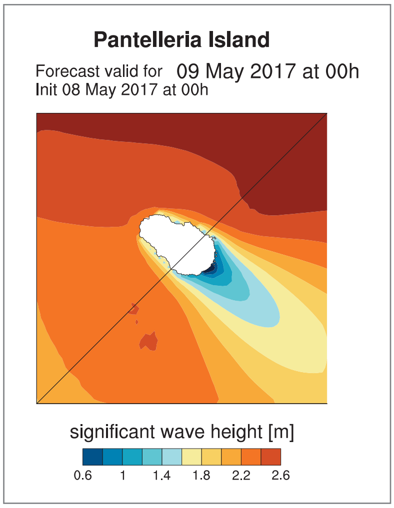

Fig. 4 Example of significant wave height forecast for the area of the island of Pantelleria

While the wave assessment is crucial to design the devices and define the place where to install wave converters, the operational phase can be supported by forecast of wave conditions. The performances of some devices can be optimized by calibrating some parameters to meet the characteristics of the incoming waves. Moreover, high-resolution forecasts are necessary in the operational stage for the management of the energy network in which the wave energy will be inserted and in the planning of maintenance operation on the device.

A high-resolution wave forecast system for the entire Mediterranean Sea has been developed at ENEA, at the spatial resolution of 1/32° using WAM model. The surface forcing is represented by winds from the meteorological operational system SKIRON, developed by the Atmospheric Modelling and Weather Forecasting Group of the University of Athens [2]. Higher resolution models have been developed in eleven areas around the Italian coasts, particularly interesting for the installation of wave converters.

In Figure 2, the domains of the highest resolution models are shown with the bathymetry of the Mediterranean model. The largest area includes the western coast of Sardinia, identified in the wave energy climatology as the most interesting area in the Mediterranean Sea. Other high-resolution models are centred on some minor Italian islands, where wave energy can represent a significant contribution to the energy independence. These simulations are performed with the SWAN (Simulating Wave Nearshore) model [3], that was specifically designed to be used in shallow water, at the resolution of 1/124°. In order to take into account waves propagating from outside the domain, boundary conditions provided by the Mediterranean model are used to force laterally these models. The forecasts cover a period of five days. All the principal wave parameters are saved hourly.

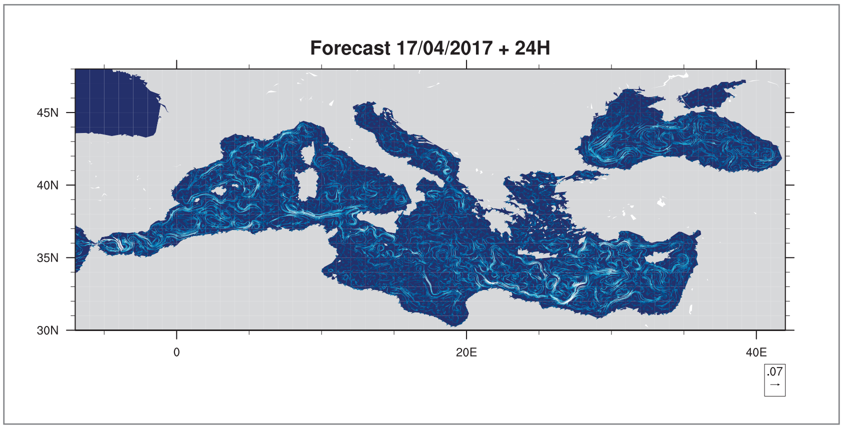

Fig. 5 Example of circulation forecast

The forecast system has been running since summer 2013 and a validation against data derived from satellite measurements has been performed [4]. In Figures 3 and 4 examples of forecasts of the significant wave height for the Mediterranean Sea and for the island of Pantelleria are shown.

As already said, tidal currents represent the other source of ocean energy that can be exploited in the Mediterranean Sea. An accurate knowledge of the hydrological conditions in the basin is mandatory for the development of this resource. Therefore a new circulation model covering the Mediterranean and the Black Sea has been developed based on MITgcm [5]. The model presents a series of peculiarities with respect to the existing models developed for the area. The complex bathymetry of the Strait of Gibraltar at west and that of the Turkish Strait System at east control the exchanges of water of the Mediterranean Sea with the Atlantic Sea and Black Sea, respectively. Moreover the two-way exchange with the neighbouring seas is highly variable due to the intense influence of tides. Both these elements have been considered in the construction of the new model, that includes directly the effect of tides and is based on a numerical grid characterized by a horizontal regular resolution of 1/48° in the central part of the domain, increasing both in the Strait of Gibraltar and in the eastern straits, where it reaches a resolution of the order of hundreds of meters.

The model, after a testing phase, is running in operational mode providing forecasts for the next 4.5 days. The surface forcing data are derived

Fig. 6 PEWEC 1:12 prototype during test operations in the towing tank in Rome

from the same SKIRON atmospheric simulation used to force the wave forecast system. Moreover data from a coarser Mediterranean forecast system (MFS) are used to initialize the model and to obtain lateral boundary conditions in the Atlantic and in the Black seas.
Hydrological fields are produced hourly over the entire grid of the model; in Figure 5 an example of the water circulation forecast obtained over the entire model domain is shown.
Waves in the Mediterranean Sea can represent a profitable resource if energy converters are designed specifically to face its characteristics. In the last years, ENEA has contributed to the wave energy development in Italy collaborating with different Italian Universities both in the development of new devices and in the support to field activities.
Among the different prototypes actually under development or in the prototype phase in Italy, ENEA has developed a prototype designed for coasts characterized by waves of low height and low frequency. The study was performed in collaboration with Politecnico di Torino in the framework of the Programme Agreement between the Italian Ministry of Economic Development and ENEA on the Electric System Research. The PEWEC (Pendulum Wave Energy Converter) is a floating system similar to a raft to place offshore, that can produce electric energy from the oscillation of the hull due to the incoming waves.
A 1:12 scaled, prototype with weight of 3 tons, and dimensions of 3m x 2m x 2m (see Figure 6) has been realized and tested in the INSEAN's towing tank in Rome [6]. ENEA and Politecnico di Torino are working on the project of a device with a nominal power of 400 kW.

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