Numerical wave modeling and wave energy estimation

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Abstract In a rapidly evolving operational and research framework concerning the global energy resources, new frontiers have been set for the scientific community working on environmental and renewable energy issues. In particular, new numerical techniques supporting the accurate estimation of renewable energy sources are highly emphasized. In this framework, wave energy - the energy that can be captured from sea waves - provides an alternative option with critical advantages. In the present paper, recent advances and some preliminary results obtained in two European projects will be discussed: Marina platform and E-wave projects are focusing on the estimation of the wave energy potential in North Atlantic coastline of Europe and in Eastern Mediterranean Sea, respectively. Special emphasis is given to the utilization of numerical atmospheric and wave modeling systems able to accurately monitor the atmospheric and sea conditions in the area of interest. On the other hand, advanced statistical techniques are utilized for the local adaptation of the results and the estimation of the spatial and temporal distribution of the wave energy potential.

1 Introduction

During the last decade most of the developed European and American countries have set as a primary target the adaptation of novel policies and methodologies that will lead to a substantial increase of the use of renewable resources for energy production. The recent global economic crisis further strengthened this political decision leading to a reduced dependence of oil products. Within this framework, the exploitation of wave energy potential, that is the energy produced by the sea waves, seems to be one of the most promising solutions especially for countries with extended coastline like Greece and Cyprus.

Wave energy has some critical advantages compared to other renewable sources: it is far more stable than wind power and, therefore, it is easier to be merged into the general grid. Moreover, wave power can be produced even in the absence of local winds by exploiting the swell component of the waves while ecological damages or consequences appear negligible. Still, there are issues that should be taken into consideration in order to ensure the successful exploitation of this type of “clean” energy: The wave energy potential in the area of interest should be monitored in a credible way and local activities that could be affected (fisheries, touristic companies, marine structures, wildlife, hazards to navigation) must be taken into account.

In the present work, the main activities and results of two European projects dealing with wave energy potential estimation are presented. The E-wave project, coordinating by the Oceanography Centre at the University of Cyprus and the MARINA project, in which the Atmospheric Modeling and Weather Foreacting Group of the University of Athens is participating, focusing on the development and application of novel methodologies for the accurate estimation of the wave energy potential in the Mediterranean and the North Atlantic coastline of Europe. Towards this target, state of the art numerical atmospheric and wave simulation systems are utilized while novel statistical approaches are developed and exploited in order to support the credible monitoring of the wave energy potential in the areas of interest.

The present work is organized as follows: In Section 2 the main directions and components of the above mentioned projects are presented. The models and the techniques employed are discussed in Section 3, while some first results that have been reached are outlined in Section 4.

2 The projects

The primary objectives and methodologies of the Marina and E-wave projects are outlined in this section. Special emphasis is given on the components relevant to the wave power estimation.

2.1 The E-wave project

In January 2011, a research project started in Cyprus focusing on the opportunities for exploitation of wave energy in the Eastern Mediterranean Sea with special emphasis to the Exclusive Economical Zone (EEZ) of Cyprus. The E-wave project is co-funded by the Republic of Cyprus and the European Regional Development Fund of the EU through the National Framework Programme for Research and Technological Development & Innovation 2009-2010 by the Research Promotion Foundation of Cyprus. It is coordinated by the Oceanographic Centre (University of Cyprus) while a number of research and operational groups participate: the Atmospheric Modeling and Weather Forecasting Group of the University of Athens, Greece (http://www.mg.uoa.gr), the Ocean Analysis Lab - USA Naval Postgraduate School (http://www.oc.nps.edu/~chu/noap.html), the Cyprus Energy Agency (http://www.cea.org.cy/), and the Meteorological Service of Cyprus (http://www.ms.moa.gov.cy). The duration of the project is 24 months.

The main aim of E-wave is the development of an integrated, fully operational high resolution system for monitoring the energy potential from sea waves at the EEZ of Cyprus and the wider eastern Levantine basin, coupled with the well-established Cyprus Coastal Ocean Forecasting System (CYCOFOS). The new system will include:

- A complete, high resolution digital atlas consisting of detailed maps for the coastal and offshore areas of the EEZ of Cyprus, in which sea wave and wind climatological characteristics as well as the distribution of the wave energy potential will be monitored.
- Novel models for the prediction and quantification of wave energy in short and long forecasts, a tool of significant value for grid designers and regulators.

More details for the E-wave can be found in the project's web page: http://www.oceanography.ucy.ac.cy/ewave/.

2.2 The MARINA project

The Atmospheric Modeling and Weather Forecasting Group of the University of Athens participates in the Marine Renewable Integrated Application Platform (MARINA) project, with sixteen other research groups and companies from twelve European countries. MARINA project is funded within the 7th Framework Program for R&D of the European Union.

The main objective is to support the development of offshore deepwater structures in the Mediterranean and the North Atlantic coastline of Europe that can exploit the energy from wind, wave, tidal and ocean current energy. In particular, research criteria will be defined ensuring the successful integration and develop innovative and viable new concepts. In this context a set of solutions are being investigated for: working principle, design, manufacturing, installation (including mooring and grid connection), operation and maintenance, and decommissioning.

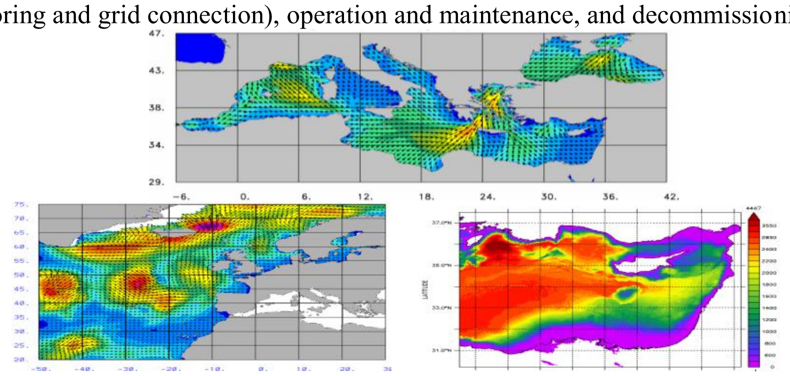

Fig. 1. The study area of the Ewave and the Marina project.

One of the most important effects to be accounted for is the coupling between wind- and wave-induced motions. Non-linear platform mechanics and hydrodynamic effects need to be modeled at different levels of approximation according to the physics of the problem and the accuracy required. MARINA project will contribute in assessing the adequate level of approximation for such applications and will conduct risk assessments like concerning safety, environment and survivability. Further details for the MARINA project can be found in the project's web site: http://www.marina-platform.info/.

3 Models and Methodologies

The objectives of both projects, described in the previous section, are essentially based on the accurate knowledge of the local wind and wave climate over the area of interest. The main tools that the research community utilizes today to obtain such information are based on physical and statistical numerical models that simulate the wind/wave evolution.

Within the framework of the E-wave and the MARINA projects, the atmospheric parameters required for the wind power estimation (e.g., wind speed, turbulence, atmospheric pressure) are provided by the regional atmospheric modeling system SKIRON (Kallos 1997). The high horizontal grid of the model configuration (5km x 5km) allows the detailed description of the atmospheric fields and the provision of highly resolved atmospheric data.

Concerning the sea wave simulation, the latest version of the wave model WAM (WAMDIG 1988; Bidlot et al. 2007; Janssen 2000) is utilized at the same resolution. The model provides a number of integrated wave parameters (e.g. the significant wave height, mean and peak wave period, wind driven and swell components of the waves) that are crucial for the wave power estimation. Moreover, the full wave spectrum at specific preselected locations is also available.

The results of the above numerical models are compiled by a combination of statistical procedures - Kolmogorov-Zurbenko (KZ) and Kalman filters (Eskridge et al. 1997; Rao et al. 1997) - to remove possible biases and provide accurate wind and wave information and resource mapping. The Kalman filter, in particular, recursively combines observations and model simulations based on least square methods. The main advantage is the easy adaptation to new conditions and the limited background information needed. KZ filters, on the other hand, support the homogenization of the time series used and the removal of high frequencies and noisy intervals.

4 Results and Conclusions

Some preliminary results obtained within the framework of the MARINA and E-wave projects are presented here focusing on the wave characteristics over the areas under study and the corresponding distribution of the wave energy potential.

A first point that is worth noticing is the high accuracy of the wave simulations. A characteristic evaluation is presented in Fig. 2. It concerns the area of Hadera port in Israel where, despite the fact that the observational platform was located very close to the coastline – a fact that theoretically poses extra difficulties to an offshore system - the simulated and observed time series are almost identical.

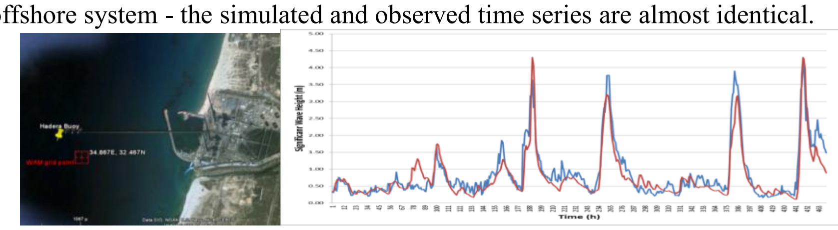

Fig. 2. Evaluation of the SWH in the framework of the E-wave project. The blue line corresponds to in-situ observation wave data and the red to the models corresponding outputs

Some characteristic results for the main wave parameters that affect the wave power estimation, i.e. the significant wave height and the mean wave period in the NE Levantine area for a period of three months are presented in Fig. 3.

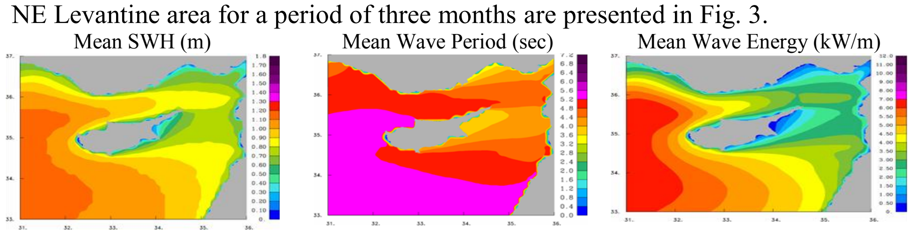

Fig. 3. Mean values of Significant Wave Height, Wave Period and Wave Energy

Increased values of wave energy at the west coastline of Cyprus can be attributed to the prevailing swell waves in the area and the elevated values of Significant Wave Height (SWH). SWH values are well fitted by the Weibull distribution. However, the corresponding shape and scale parameters emerge a non-trivial spatial variation (Figure 4).

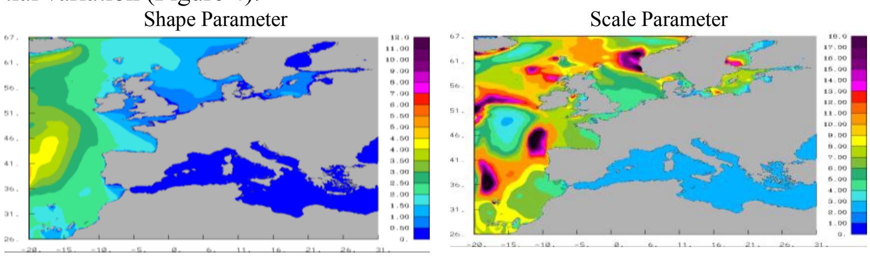

Fig. 4. The shape and scale parameter values of the Weibull distribution

The distribution of SWH is close to the usually adopted Rayleigh probability density function (shape parameter 2) near shores. However, it deviates offshore. On the other hand, increased scale parameter values are revealed near Spain and Norway. This spatial distribution is information of potential value for grid designers and researches working on wave energy issues.

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