A new high resolution wave modeling system for renewable energy applications in California and the Mediterranean Sea

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Introduction

The use of integrated high accuracy wave systems is of critical importance today for applications on renewable energy assessment and monitoring, especially over offshore areas where the availability of credible, quality controlled corresponding observations is limited.

In this work a new wave modeling system developed by the Hellenic Naval Academy and the University of Athens, Greece the Center of Excellence in Earth Systems Modeling & Observations of Schmid College of Science in Chapman University, USA and the Naval Ocean and Analysis Laboratory of the US-Naval Postgraduate School, is presented. The new wave system has been based on WAM (ECMWF parallel version) model and focuses on parameters that directly or not affect the estimation of wave power potential in offshore and near shore areas.

The results obtained are utilized for monitoring the wave energy potential over the California and Eastern Mediterranean coastline. A detailed statistical analysis based on classical and non-conventional measures provides a solid framework for the quantification of the results. Extreme value-cases forming a potential threat for renewable energy parks and platforms, are particularly analyzed.

Wave Energy – A new challenge

The use of renewable resources for energy production is receiving increased attention the last few years as a result of the adaptation of novel policies in the energy market and the new framework posed by the global economic crisis and the security problems concerning the nuclear energy.

State authorities and private sector consider ways of exploiting new forms of energy trying to:

- Decrease the dependence on the conventional energy activities
- Address directions/restrictions posed by organizations and governments in connection with global warming and climate change effects
- Explore new investment chances

Ocean waves is one of the most stable sources of renewable energy,.

New technologies allow the exploitation of the energy from waves, currents and sea surface winds

Oscillating water column devices

Point absorbers

Wave Energy – Benefits

- It 's easier adopted to the general grid due to its continuous behavior.
- Wave power may be produced even in the absence of local winds by exploiting the swell component of the waves.
- It may contribute in reducing greenhouse emissions
- Ecological damages or consequences appear negligible
- Wave energy has the potential to meet a significant proportion of Mediterranean Sea and California's energy demands:
  - ✓ The International Energy Agency states that ocean energy has a potential to reach 3.6 GW of installed capacity by 2020 and close to 188 GW by 2050 (Brito-Melo and Huckerby, 2010)
  - ✓ The global wave power resource has been estimated as around 2.1 TW (Gunn and Stock-Williams C, 2012).

Wave Energy Monitoring

The available wave power potential is estimated based either on the full 2-dimensional wave spectrum E(f,θ) over frequencies and directions or utilizing statistical characteristics of the wave field:

$$P_w = \rho g \int_0^{2\pi}\int_0^{\infty} f^{-1}E(f,\theta)df d\theta = \frac{\rho g^2}{64\pi}H_s^2 T_e \quad [W/m]$$

where $H_s = 4\sqrt{m_0}$ is the significant wave height and $T_e = \frac{m_{-1}}{m_0}$ the mean energy wave period estimated by the mooments of the wave spectrum $m_n = \int_0^{2\pi}\int_0^{\infty} f^n E(f,\theta)df d\theta$

Since dense and accurate, quality controlled data over sea areas are not as easy to utilized as in the case of land areas, the employment of numerical wave simulation models provide an excellent alternative.

For the present study the wave model WAM (Komen et al., 1994, Bidlot J. et al., 2007) has been employed:

- It is a third generation wave model, which computes the spectra of random short-crested wind-generated waves without any preasumptions on the wave spectrum
- It solves the complete action density equation, including non-linear wave-wave interactions
- WAM is able to cover offshore deep and near-shore shallow water simulations taking advantage of the new advection scheme and features adopted (Bidlot et al., 2007)

Wave modeling Systems for the Mediterranean Sea and the California coastline

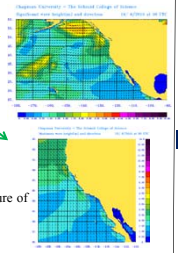
High resolution wave modeling systems based on the WAM model have been adopted for both areas of interest:

Mediterranean Sea

- Area Covered: 30N – 47N, 6E – 42E)
- Horizontal Resolution: 0.05x0.05 degrees
- Spectrum discretization 25 frequencies x 24 directions

Pacific Ocean

- Coarse Domain: North Pacific, ensuring the capture of all swell information
- Nested area: West US coastline
- Horizontal Resolution: 0.1 x 0.1 degrees



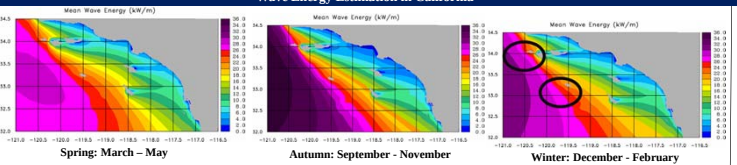
Statistical Analysis

The first four moments of the statistical analysis of the modeled data have been employed in order to determine not only the mean and deviation values of the sample but also the asymmetry and the kurtosis measures revealing the extend of impact of non-frequent incidents:

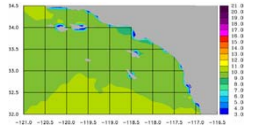
mean value: $\mu = \frac{1}{N}\sum_{i=1}^{N} x(i)$ *st. deviation:* $\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x(i)-\mu)^2}$ *skewness:* $g_1 = \frac{\frac{1}{N}\sum_{i=1}^{N}(x(i)-\mu)^3}{\sigma^3}$ *kurtosis:* $g_2 = \frac{\frac{1}{N}\sum_{i=1}^{N}(x(i)-\mu)^4}{\sigma^4} - 3$

On the other hand, the Probability Density Function that optimally fits the data under study is estimated through statistical fitting tests in order to reveal the full package of information of the samples.

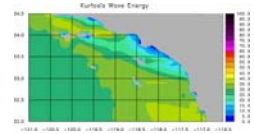
Wave Energy Estimation in California



Spring: March – May | **Autumn: September - November** | **Winter: December - February**



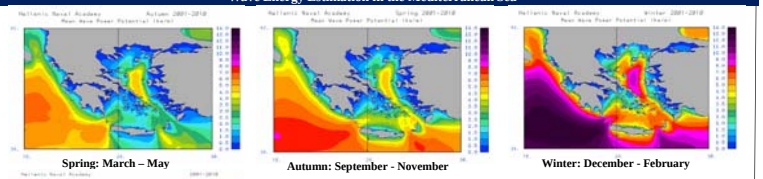
Mean Wave Period



Kurtosis of Wave Energy

- The wave energy potential over the California coast line is significant especially during Autumn-Winter period with values exceeding 30 KW/m locally
- Taking in to account the estimated uncertainty one could expect energy potential in the range of 10 – 40 Kw/m
- The prevailing swell waves ensure the availability of significant wave energy amounts through the whole year, even in periods with low local winds and favor the development of joint wind-wave energy exploitation structures
- The energy estimated data have low kurtosis values a fact ensuring independence of possible extreme events.

Wave Energy Estimation in the Mediterranean Sea



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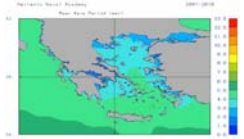
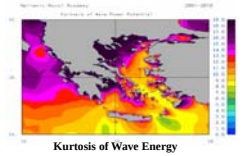


Mean Wave Period



Kurtosis of Wave Energy

- In the area around Greece, the wave energy potential is giving promising values mainly during Winter period with values exceeding 14 KW/m locally
- The areas with elevated power potential are associated with local wave climatology in which swell waves dominate
- The prevailing swell waves in the south and western parts ensure the availability of considerable wave energy amounts, even in periods with low local winds and favor the development of joint wind-wave energy exploitation structures
- The energy estimated data appear high kurtosis values indicating the increased impact of non-frequent/extreme events.

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