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Impact of climate change on wave energy resource: The case of Menorca (Spain)

J.P. Sierra [a, b, *], M. Casas-Prat [a, b, 1], E. Campins [a, b]

[a] Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya, Jordi Girona 1-3, Mòdul D1, Campus Nord, 08034 Barcelona, Spain
[b] Centre Internacional d'Investigació dels Recursos Costaners, Jordi Girona 1-3, Mòdul D1, Campus Nord, 08034 Barcelona, Spain

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ABSTRACT

The aim of this paper was to analyse how changes in wave patterns, due to the effect of climate change, can affect wave energy power and yield around Menorca (NW Mediterranean Sea). The present and future wave energy conditions were derived from recently developed high-resolution wave projections in the NW Mediterranean. These wave projections were forced by surface wind fields obtained, respectively, by 5 different combinations of global and regional circulation models (GCMs and RCMs) for the A1B scenario. The results showed that the projected future spatial and directional distributions of wave energy are very similar to those of the present conditions. The multi-model ensemble average illustrated a slight general decrease in the annual and seasonal wave power (except for summer). However, the inter-model variability is large since two models showed opposite trends to the other 3 in most cases. Such inter-model variability is lower(higher) for winter(autumn). Another result is the reduction of the temporal variability in the future, considering both the multi-model mean and each single model projection. Such a decrease is consistent with the future seasonal redistribution of energy throughout the year. This would entail an increase in the efficiency of wave energy converters deployed in this area due to the more regular temporal distribution of the energy.

1. Introduction

Wave energy appears to be one of the most promising alternatives to fossil fuels and one of the most environmentally friendly since it could contribute to reduce greenhouse gas emissions. It is expected that over the next decades wave energy conversion will undergo significant advances in research, design and testing [1] due to the rising demand of renewables in energy supply [2].

In general, research on wave energy production focuses on locations that have high energy potential. In addition, wave energy is particularly appropriate for many islands because they receive a large amount of this resource and are usually highly dependent on external energy sources. For this reason, wave energy potential has been assessed on various islands in the Atlantic Ocean, including the Canary Islands [3–6], Madeira [7] and the Azores [8]; in the Pacific Ocean, on islands such as Hawaii [9,10] and Taiwan [11]; in the Caribbean Sea [12]; and even in the Mediterranean Sea [13,14]. In the Mediterranean area, although the wave energy potential is modest, wave energy production could still be economically viable [15] and many technical issues related to extreme sea climate probably could be solved more easily [14,15].

In order to accurately predict the long-term energy resource and yield for a wave farm, it is essential to take natural variability and climate change into account [16]. However, few studies have addressed the impacts of climate change on wave energy resource. Some examples are [17–19], in which the uncertainty in predicted energy yield resulting from uncertainty in future wave conditions has been estimated. More recently, the impact of climate change on wave energy generation has been investigated based on numerical wave modelling driven by past/present wind fields and future wind scenarios associated with different levels of greenhouse gas emissions [16].

This paper focuses on the assessment of wave power potential and wave energy yield around Menorca, an island in the Spanish Mediterranean Sea. This assessment is carried out based on the present and future wave projections developed by Ref. [20], following an approach similar to that used in Ref. [16].

* Corresponding author. Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya, Jordi Girona 1-3, Mòdul D1, Campus Nord, 08034 Barcelona, Spain.
E-mail address: joan.pau.sierra@upc.edu (J.P. Sierra).
[1] Now at: Environment and Climate Change Canada, Toronto, Canada.

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Nevertheless, in Ref. [16] only one combination of Global Circulation Models (GCMs) and Regional Circulation Models (RCMs) was used for two scenarios (A1B and B1), while in this study five combinations of GCMs and RCMs are used for the A1B scenario. The use of several models allows to assess the inter-model variability, one of the largest factors of uncertainty in climate change projections.

The remainder of the manuscript is structured as follows. Section 2 briefly describes the study area. Section 3 presents the available data and the methodology used. The wave power resource and wave energy yield for present conditions in the study area, including their spatial distribution and seasonal variations, are assessed in Section 4. Section 5 focuses on the climate change signals. Finally, the conclusions of the paper are presented in Section 6.

2. Study area

The study area, Menorca, is located in the northwestern Mediterranean Sea (39.81–40.09°N, 3.79–4.32°E) and forms part of the Balearic Islands (see Fig. 1). It has a surface area of 701.8 km^2 and a population of about 100,000 inhabitants, mainly concentrated along the coast. The island was declared a Biosphere Reserve in 1993.

The study area has been selected based on: (i) the availability of data, (ii) the high wave energy potential in the area located between the Balearic Islands and western coast of Sardinia in comparison with the rest of the Mediterranean Sea [14,15] and (iii) the low (2%) current percentage of electric energy extracted from renewable sources in the island (two solar facilities and one wind farm) [14].

The present climate in the Mediterranean basin is dominated by extra-tropical cyclones [21] formed via baroclinic instability, which is higher during the winter season [22]. In this season, one of the most active areas of cyclogenesis is the Gulf of Genoa, generating some local features like the *Tramontana* and *Mistral* winds (intense and persistent N and NW winds), which are channeled and intensified through the valleys between mountain ranges existing on the NW Mediterranean. Moreover, the climate is affected by moving depressions generated either in the Atlantic Ocean or in northwestern Europe [23]. Additionally, many subregional and mesoscale effects take place in this area producing large spatial and seasonal variability [24]. The reduced scale of the basin, along with its peculiar features (complex orography and the moisture of a relatively large mass of water) makes the Mediterranean climate more difficult to predict than climates in other places [21].

In summer seasons, thermal and orographic effects, like the temperature contrasts between land and sea, play a greater role in the genesis and maintenance of cyclones which are mainly located in the Gulf of Genoa and over the Iberian Peninsula [24]. During summer seasons, the Mediterranean is also exposed to tropical systems [25] as a result of its location in a transitional zone between humid mountains in the north and arid regions in the south. From a climatic point of view, spring and autumn are transitional periods between winter and summer [25].

Concerning the future climate, it is very difficult to know exactly how the aforementioned atmospheric patterns will react to climate change due to the many competing processes that interact [20]. Many studies have found a consistent poleward shift of the location of extratropical cyclones [21] which, at the European scale, would be translated into enhanced wind speeds over northern Europe, and a decrease in southern Europe [26,27] where the study area is located. As a result of this and other factors like sea surface temperature (SST) gradients and concentration of water vapor in the atmosphere most studies concur that there will be a decrease in the number of Mediterranean cyclones [20]; however, there is a lack of consensus on whether the number of intense cyclones will increase or decrease [25,28].

Regarding the variation in wind direction, the analysis of the results of model simulations suggest that the predominant westerly flow over Europe will be significantly enhanced, whereas the cyclonic weather type (large cyclone located over central Europe associated with above-average wind speed over the Mediterranean Sea) is expected to decrease [29]. Nevertheless, it is relevant to point out that there is a large uncertainty, even larger than for the wind speed, since some models exhibit contrasting patterns (i.e. enhance of easterly flow instead).

The aforementioned generally expected weakening of storms in the future Mediterranean climate will in turn entail a major reduction of the significant wave height (Hs), especially during

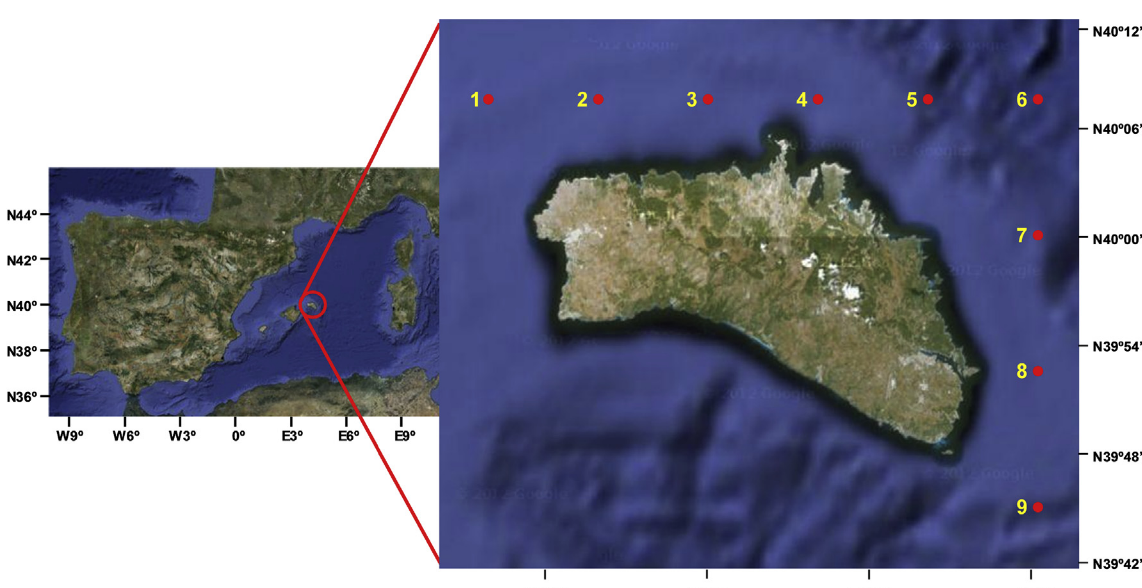

Fig. 1. Location of the study area (left panel) and the analyzed points (right panel).