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Wave energy potential assessment in the Caribbean Low Level Jet using wave hindcast information

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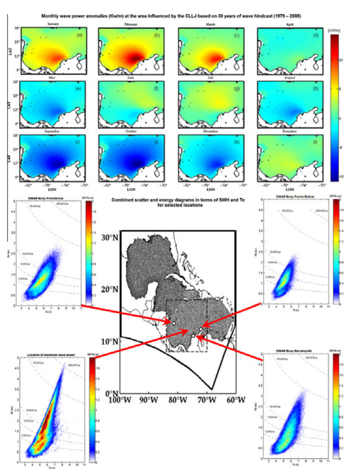
HIGHLIGHTS

- A wave energy assessment for the Caribbean was performed based on hindcast data.
- The Caribbean Low Level Jet modulates the wave climate in the central Caribbean Sea.
- Wave energy potential shows a bimodal peak with highs in February (higher) and July.
- Results suggest that only the area of the CLLJ is suitable for wave energy extraction.
- Nearshore wave energy devices may be suitable during winter at small communities.

GRAPHICAL ABSTRACT



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ABSTRACT

We investigate the wave energy potential in the Caribbean Sea using a 30-year wave hindcast. Wave energy in enclosed sea basins, such as the Gulf of Mexico and the Caribbean Sea, is commonly associated with lower energy production rates. However, an easterly zonal wind reaching 13 m/s, known as the Caribbean Low-Level Jet (CCLJ), is shown to control the wave climatology in the Caribbean Sea. The wave hindcast information is validated with altimetry (Globwave) and buoy (DIMAR) data from the Colombian Caribbean Sea. The wave hindcast performance is very satisfactory at two buoy locations (Barranquilla and Providencia) and with respect to altimetry information, but presents an underprediction of extreme events at Puerto Bolivar. Therefore, an assessment of wave energy in the study area, based on wave hindcast information, is conducted to investigate the wave energy potential in such enclosed area. Numerical results suggest that the CLLJ region is suitable for wave energy extraction (8–14 kW/m) and presents important spatial gradients that need to be considered for the installation of wave energy devices. Furthermore, it is found that locally generated (sea) wave energy can be suitable for energy production and hence future technology development should be devoted to its harvesting.

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1. Introduction

Ocean energy is considered one of the main renewable energy resources, as a substitute of fossil-fuels-derived energy, from which ocean waves are one of the most evident forms of such energy. Therefore, a wide variety of devices for wave energy extraction have been developed in the past decades (see Falcão [1] and McCormick [2] for a thorough review). Nevertheless, an essential step towards the use of wave energy is the resource characterization. The latter consists in the determination of the wave climate in terms of wave power, instead of the standard wave characterization (i.e., mean and extreme wave climate) commonly employed in ocean/coastal engineering applications (e.g., offshore and coastal structures, navigation, nourishment projects, etc.).

The assessments of the ocean wave energy resource has been done more recently at global scale, e.g. [3–5], as well as regional and local scales for selected sites [6–20]. However, most studies have been performed in areas subject to highly energetic wave conditions, whereas less effort have been devoted to areas subject to milder wave conditions [7,15,18,21–26]. The latter areas present practical advantages for implementation, operation, and maintenance of wave energy devices, allowing feasibility for energy production [22], with the downside of obtaining lower energy production rates. This is usually the case of enclosed sea basins such as the Caribbean Sea (CS), where few wave energy studies have been conducted [16,27]. Despite the perception that the CS may not provide enough wave energy potential, there is an area where a maximum of easterly trade winds has been observed to produce sustained wind speeds larger than 10 m/s at 925 hPa (two peaks per year during July and February) with a 16% of annual exceedance. This wind is correlated with the Caribbean Low Level Jet (CLLJ) which has been described by Amador [28], and later by Wang [29], who studied the CLLJ characteristics and its (diurnal and seasonal) variability to establish relationships between both the CLLJ and the North Atlantic Subtropical High (NASH) and between the sea level pressure and the sea surface temperature anomalies. Cook and Vizy [30] studied the horizontal momentum balances in the CLLJ in order to understand the relationship between diurnal and seasonal time scales associated with this phenomenon and its role towards precipitation in the CS and other regions. The CLLJ was confirmed to represent a salient feature in terms of wind speed and humidity (and energy) transport to North and Central America, having the potential to dominate the regional wave climate. However, the role of the CLLJ on wave energy potential has not been investigated before. Therefore, we employ a 30 years of a the North American Regional Reanalysis (NARR) [31] and the corresponding wave hindcast [32] information for the assessment of the wave energy potential in the area influenced by the CLLJ. This paper is organized as follows: Section 2 provides information on the wind data and climate as obtained from 30 years of reanalysis, as well as a brief description of the wave hindcast and its validation based on buoys and satellite data. The description of the wave climate in the region of the CLLJ is presented in Section 3, whereas Section 4 is devoted to an assessment of the wave power climate. Finally, Section 5 presents the conclusions of this study.

2. Materials and methods

2.1. Area of study and data description

This study employs the wave hindcast information presented by Appendini et al. [32] covering the area of the Gulf of Mexico (GOM) and the CS (Fig. 1). More specifically, we focused in the area under the influence (8°N–18°N and 84°W–70°W) of the CLLJ (Fig. 1b). A brief description of the NARR wind data used to force the wave model, as well as the wave model validation in the study area are presented in this section.

2.2. Wind data

The wind data corresponds to the NARR from The National Center for Environmental Prediction (NCEP). The reanalysis domain covers North America including the GOM, the CS, and partially the Northeastern Pacific (Fig. 1a). A detailed description of the NARR can be found in Mesinger et al. [31]. For the modeling forcing, the 10 m zonal and meridional wind components were employed with a three hour time step (0, 3, 6, 9, 12, 15, 18, 21 UTC), and a horizontal grid spacing of 32 km, including the area under influence of the CLLJ depicted in Fig. 1b.

The monthly mean wind speed and the monthly wind speed anomalies in the study area are shown in Figs. 2 and 3 respectively. The CLLJ is directed toward the west following the trade winds with a jet with an axis lying between 15°N and 14°N, spanning

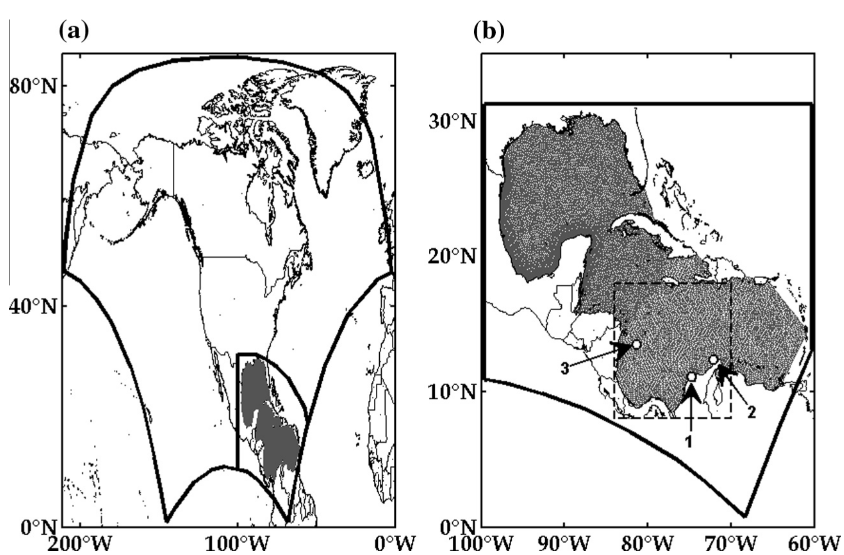

Fig. 1. (a) NARR coverage and cover area used as forcing for the wave model (adapted from Mesinger et al. [31]) and (b) wave model computational domain showing the NARR coverage used in the model, area of the CLLJ analyzed in this study and location of DIMAR buoys (1 Barranquilla, 2 Puerto Bolivar, 3 Providencia).