Wave height and power trends in Mexican Seas

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Keywords—**Long-term trends, Mexican Seas, Wave height trends, Wave power trends.**

I. INTRODUCTION

The present study aims to investigate the long-term variability and trends of wave climate in Mexican seas using a 43-year wave hindcast over a period from 1980 to 2022. The dataset corresponds to numerical results from a simulation using the third-generation spectral wave model WaveWatch III.

Wind-waves are a widely available energy resource with great potential. Some of its advantages is that waves travel naturally from generation zones to the coasts with practically no energy loss, the highest percentage of the world population is near coasts, wave energy is also within reach of remote communities in islands or archipelagos, and implementing technology for its use has a minimal environmental impact. However, there are certain challenges with opportunities for further studies, such as the fact that wave energy converter devices (WECs) may interfere with navigation, the need to study more about the impact on marine fauna, and the design and construction of efficient and adequate WECs to harvest the resource with different characteristics, and above all, as more technology is developed, to lower costs, which has been the main reason why this type of marine energy source has not yet been so widely distributed [1].

Studies for wave trends commonly have used the significant wave height H_s. This parameter contains valuable information for studying future scenarios such as flooding due to sea level rise, coastal erosion, the design of coastal protection and climate change [2]. Yet, as we look for alternative sustainable energy sources, it is important to have accurate resource assessments. In that matter, characterization of wave energy is vital. The main parameter to this purpose is the omni-directional wave power P_w.

As surface gravity waves are generated solely by wind, they are particularly affected by atmospheric fluctuations. Climate periodic patterns like El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) have bimodal variations that have a direct effect on the wind patterns, which might have effect on the wave climate and power.

Typically to conduct a wave energy assessment in a site it has been suggested to be performed for period of at least 10 years, nevertheless to study the long-term variability of waves it is recommended to have more than 3 decades of data to reduce uncertainties [3].

It is important not only to have a reliable resource assessment but also study the changes on the long-term, and the physical mechanisms that occur.

II. METHODS

The dataset used correspond to numerical results from the latest version (v6.07) of the third-generation spectral wave model WaveWatch III [4]. The dataset consists of hourly wave parameters, on regular nested grids with spatial resolution of 8 km, covering the Mexican Pacific, the Gulf of Mexico and the Caribbean. The model was forced with ERA-5 wind reanalysis data from the European Centre for Medium-Range Weather Forecast (ECMWF), and the bathymetry is from the GEBCO 2022 dataset.

In order to study the long-term variability, it is necessary to eliminate seasonal and short-term variability, we applied a running mean method within a 5-year window [5]. Then to calculate the significant wave and power trends we used the combined Mann-Kendall (MK) test and the Theil-Senn (TS) slope method. The MK test assesses the significance of the trends with several levels of confidence. For our study the level of confidence was 95%.

The TS slope is a robust method suitable for the analysis of wave climate, and is insensitive to outliers. In accordance with [6] this method determinates the slope a_{ij} in a set of values distributed in time, by considering all possible pairs, then is determined as the median value of a_{ij}

$$a_{ij} = \frac{(\Upsilon_i - \Upsilon_j)}{(t_i - t_j)} \quad \text{with} \quad 1 < i < j < n \qquad (1)$$

where i and j are the indexes that point out the position of all pair used for the slope estimation, Υ is the monthly averaged data, t is the year and n is the total observations.

III. RESULTS AND DISCUSSIONS

The numerical results on wave climate for MS present an important spatial and temporal variability. In Fig. 1, mean maximum values of Hs (>1.7 m.) were found in the northern coasts of the Pacific, in the Baja California Peninsula (BCP). The BCP western coast presents an important seasonal variability with maximum values of H_s specially during winter season. Numerical results of wave power, P_w, present a similar geographic distribution as expected, due to the direct relation between the wave height and the energy flux. The maximum mean values range from 20 to 25 kW/m in the northwest pacific coast of Mexico. The long-term variability in the BCP is affected by the duration and intensity changes in storms in the Pacific [7]. Other considerable high to moderate energetic zones were found in the Isthmus of Tehuantepec region where intense local wind events occur.

When it comes to the GM and Caribbean we found in general a less energetic region principal due the fact that it is enclosed sea basin, so in general is protected from energetic remote waves or swell, yet in the Caribbean, the Caribbean Low-Level Jet (CLLJ) act as the principal local mechanism that affects the wave climate in this region. The CLLJ has his maximum values of easterly zonal wind speed during summer and winter [8].

The long-term trends in wave climate are presented in Fig. 2. In the top panel the long-term trend is shown in color blue, the black lines are the monthly mean time series of H_s. However, we noticed an increasing trend on the first section of our complete time series, following by a decrease. This pattern can be seen in the bottom panel of Fig. 2. This positive trend, followed by a negative trend, is clear when the analysis of two periods of time, from 1980 to 2001 and from 2001 to 2022, is carried out. The H_s trend corresponding to the first period was of 0.63 cm/year, whereas the following period is of -0.47 cm/year. The trend of H_s for the 43-year wave hindcast analisys was about 0.27 cm/ year.

Trends in H_s and P_w were calculated in 8 points or stations within MS, 4 in the Pacific coast, and four more on the GM and the Caribbean. Table I. shows the following results for this analysis.

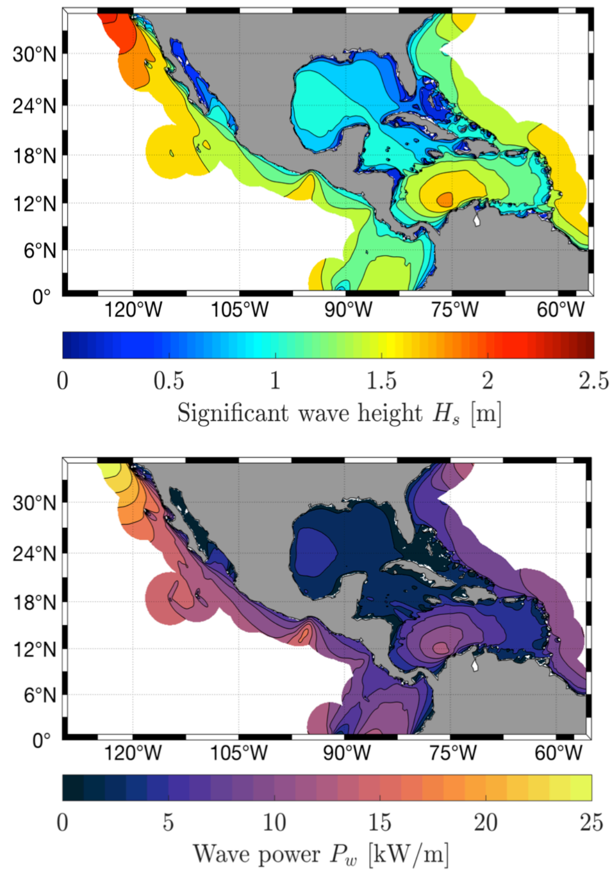

Fig. 1.- Significant Wave Height (top panel) and Wave Power (bottom panel) climate on Mexican territorial waters obtained from a 43-year hindcast.

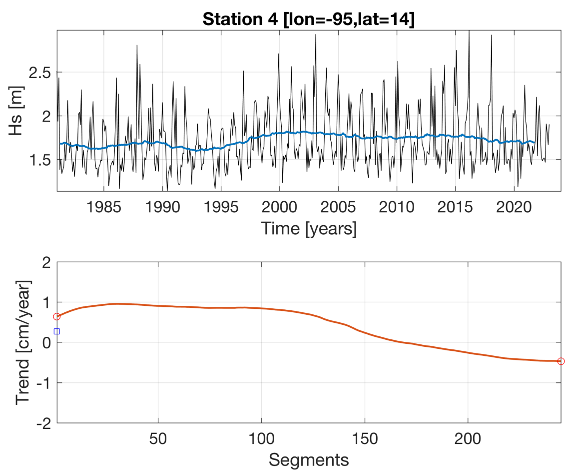

Fig. 2. Significant wave height (Hs) time series for a site in the Mexican Pacific. Top figure in black are the monthly mean (Hs) time series, in blue the long-term variability. Bottom figure shows the trend in cm/year on a moving window of half of the complete period (~ 21 years)

TABLE I.
HS TRENDS IN MEXICAN SEAS

Station	Trend Hs (1980-2001)	Trend Hs (2001-2022)	Trend Hs (1980-2022)
Pacific			
S1 32.0°N,120.0°W	0.22 cm/year	-0.01 cm/year	-0.01 cm/year
S2 27.0°N,116.3°W	0.45 cm/year	-0.16 cm/year	0.01 cm/year
S3 18.0°N,106.0°W	0.51 cm/year	-0.15 cm/year	0.12 cm/year
S4 14.0°N,95.0°W	0.63 cm/year	-0.47 cm/year	0.27 cm/year
GM and Caribbean			
S5 25.0°N,96.0°W	0.33 cm/year	0.05 cm/year	0.08 cm/year
S6 20.0°N,94.0°W	0.32 cm/year	0.05 cm/year	0.14 cm/year
S7 22.3°N,88.3°W	0.28 cm/year	-0.29 cm/year	0.02 cm/year
S8 20.0°N,85.0°W	0.26 cm/year	-0.28 cm/year	0.09 cm/year

IV. CONCLUSIONS

A wave hindcast of 43 years were used to calculate the trend and long-term variability of wave parameters in Mexican Seas. The results on H_s have shown a positive trend in center and south Mexican Pacific, the most significant trend in the Pacific for the whole analysed period is about 0.27 cm/year. Also, a negative trend of -0.01 cm/year was found in the north of BCP. During the same period, in the GM region the most significant trend was about 0.14 cm/year. Nevertheless, the most significant positive wave trends were during the period from 1980 to 2001, with the highest value of 0.63 cm/year, in the Mexican Pacific.

To further expand this work, we aim to investigate the correlation between the long-term variability of wave parameters and climate oscillations.

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