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# Long-term wind climate in a large oceanic island harbour

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## Abstract

Knowledge of wind climate is of great importance for the adequate design and construction of harbours and for operational considerations. Statistical properties of wind climate at Las Palmas Port, a large harbour located in an small oceanic island, are studied by using an incomplete data set of maximum daily wind speed covering a period of 10 years. Annual and seasonal variabilities, as well as probability of extreme values occurrence are examined. Additionally, a time-frequency representation of this nonstationary time series is developed.

## 1 Introduction

Wind climate is an essencial input for many engineering practices related to ports and marinas design and functioning. Harbour facilities should be designed to sustain extreme wind forcing during their lifetime. Furthermore, while in general the wind loads on ships constitute a relatively small part of the total environmental load, the accurate knowledge of the magnitude and character of the wind loads plays an important role in connection with harbour and near harbour operations, such as manoeuvring, mooring, stability, and dynamic positioning, among others. The problem of wind loads on berthing structures is more complex because of loads can be exerted directly on the structure and indirectly through the forces on moored ships, which are transmited to the structure along the mooring lines. A detailed description of wind effects on structures can be found in [1], while mathematical models to estimate the wind forces and moments on a vessel have been described in [2].

It is well known that wind is a phenomenon of random nature. Furthermore, wind characteristics in coastal zones are the result of interacting meteorological, oceanographic and topographic factors. Consequently, meteorological flows in coastal zones display a very complex stochastic behaviour and their practical study must rely on probabilistic methodologies. Additionally, it is also well known that, in general, wind

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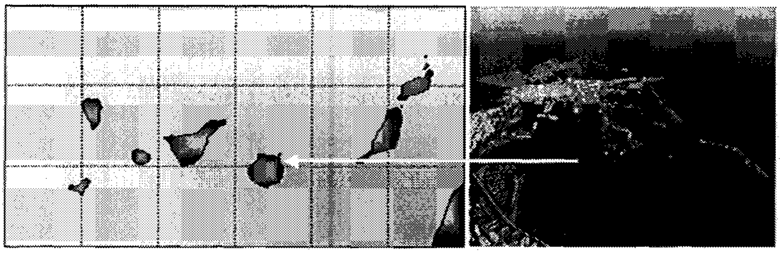

Figure 1: Geographical location of Canary Islands and aerial view of Las Palmas Port

speed is larger at offshore than at onshore areas, and small oceanic islands may be considered as locations offshore the main continental lands. Then, knowledge of wind climate at a large port located in an small oceanic island, such as the Port of Las Palmas, results of great practical interest.

This study deals primarily with long-term wind characteristics based on daily maximum wind speed observations recorded at Las Palmas Port. The rest of the paper first gives a brief description of the study area and the characteristics of the analysed data set in section 2. Directional and non-directional long-term statistical properties of wind velocity, as well as seasonal variabilities, are examined in section 3. Section 4 presents the probability of occurrence of extreme wind speeds. The time-frequency description of wind speed time series using continuous wavelet transform is presented in section 5. Section 6 presents the discussion of results and conclusions.

## 2 Study area and data

Prevailing winds of the Atlantic subtropical oceans are the Trade Winds, which blow steadily westward and slightly toward the equator at average speeds of around 18 to 21 kilometers per hour. These are found at around 30 degrees north and 30 degrees south latitude, sandwiched between a band of low pressure near the equator and high pressure belts in the middle latitudes.

The Canary Archipelago is located on the Northwest African continental shelf, in the Eastern Central Atlantic off the Saharan coast, and consists of seven major islands and several islets. These islands extend about 450 km from East to West and are placed between $27^o$ and $30^o$ of North latitude, see Fig. 1. Due to its geographical location, in the Southern edge of Azores High, Canaries are within the fairly regular Trade Winds belt.

Las Palmas port is located at Gran Canaria island, which is over 2000 m high. The presence of this high island produces important disruption in the wind flow. However, the port is situated north of the island, under the direct influence of the Trade Winds, just partially sheltered by an small islet, as shown in the right side of Figure 1.

Data used for the analysis of wind climate were collected at the harbour by means of an anemometer placed at the 10 meters above mean sea level standard height and spanned the period from January 1984 to March 1994. Data set contains maximum daily wind speed and the corresponding direction. The time series presents several gaps and missed data represent 13.5% of the total expected data, approximately. Due

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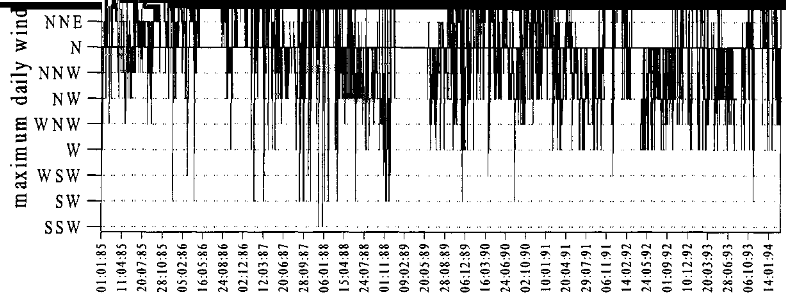

Figure 2: Temporal variability of maximum daily wind speed direction.

to the existence of gaps as large as one month no procedures to fill gaps were applied. Fortunately, data gaps are not grouped in the same month or season but are irregularly distributed in time.

## 3 Long term statistical analysis

Annual and seasonal behaviour of winds in a harbour location are of great importance for construction and operational considerations. Naturally, due to the vectorial character of wind velocity, directional information results of great interest. Figure 2 shows the maximum daily wind speed direction in Las Palmas harbour for the whole period of observation. It can be readily observed the predominance of winds from NNW, N, NNE and NE directions, mainly during summers. This is due to the intensification of the Azores High and the associated enhancement of the trade winds during that period. Winds from this sector remain the most frequent, representing more than the 70% of the total time, but the approaching of low pressure systems to the islands, specially from the NW during winter, and ocassionally from West or Southeast, gives rise to a considerable variability.

Furthermore, it can be observed in the frequency distribution of maximum daily wind speed direction, Figure 3, that there is a relatively important fraction of wind events from the E-SE sector. This situation usually occurs during periods of wind trades weakening and give rise to warm winds blowing from the Saharan desert, which some times carries along a large concentration of suspended dust. This phenomenon, locally named "calima", takes place once or twice per year, aproximately. Nevertheless, Figure 3 displays the clear predominance of winds blowing from the NW-NE quadrant in the study area.

Then, as expected, the wind direction distribution at Las Palmas Port reflects general atmospheric circulation, mainly during summer. Synoptic disturbances are the major determining process when synoptic circulation, i.e. Trade Winds, intensity weakens.

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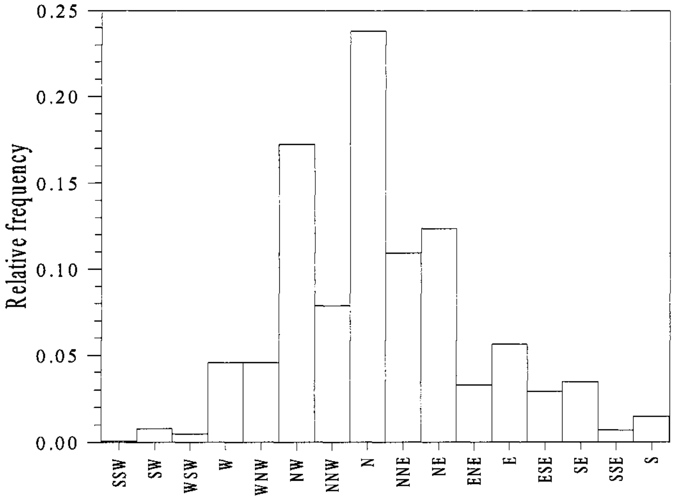

Figure 3: Relative frequency of maximum daily wind speed direction.

The mean values and its standard deviations for the maximum daily wind speeds in 1984-1995 are represented, in form of daily averages, in Figure 4. The results indicate the existence of an apparent annual course, the latter summer and the early autumn being the calmest periods and the winter the windiest season. The spring is a transitional time which varies from year to year.

Empirical probability of exceedance distributions of maximum daily wind speeds for the whole data set and for the mean year are presented in Figures 5a and 5b, respectively. It is observed, Fig. 5a, that maximum wind speeds during the observation period is about $26m/s$, with a probability lower than $0.1\%$ of been exceeded, i.e.. The modal value of maximum daily wind speed is about $7m/s$. In average, the maximum wind speed is $13m/s$, with an exceedance probability close to $1\%$, that is 3.65 days by year.

### 3.1 Seasonal variability

The seasonal pattern commented in relation to Figure 4 is easiest visualised in Figure 6, which shows the monthly averages for the whole observational period. The monthly mean values of wind speeds are represented together with their standard deviations. It is possible to observe quantitative diferences between the variability of monthly average values during the latter spring, summer, and the early autumn period and the rest of the year. The largest inter-annual variability corresponds to the period from the late autumn to the early spring. As expected, the lowest speeds appear during the summer season, when the prevailing Trade Winds are enhanced, weaking progressively from autumn to winter and reinforcing from the spring to summer. The variability observed during the period extending from late autumn to the early spring is due to the intermittent intrusion of cyclonic systems, particularly from the Northwest Atlantic.

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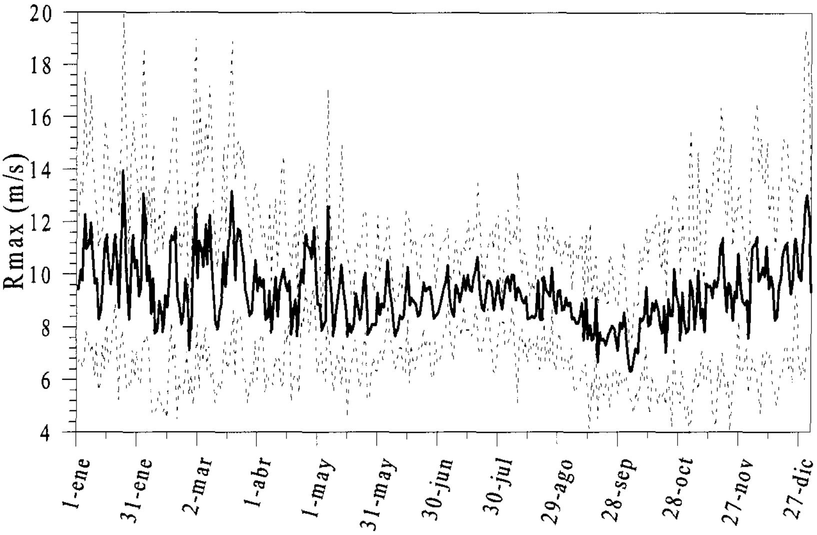

Figure 4: Mean year as daily averaged and standard deviation of maximum daily wind speeds.

Figure 7 shows the probability distribution of exceedance estimated from observation for each season. Observation of these figures clearly reflects the seasonal beaviour of wind speeds. It is observed that larger speeds are observed during winter, Fig. 7d, with maximum speed values over $25m/s$ and probabilities of exceedance for $20m/s$ about 2%. Note that the maximum wind speed occuring during spring, Figure 7a, and summer, Fig. 7b, is below this value, which is also reached during autumn but with a significantly lower probability. A simple observation of the falling slope for wind speeds larger than the modal value for each season reveals a decrease of wind speed from winter to summer, with similar intermediate values during spring and autumn.

## 4 Extreme value analysis

A traditional extreme value model used in wind speed studies is the Gumbel, or Ficher-Tippett I, distribution. It can be shown that this distribution is a special case of the generalised extreme value and the generalised Pareto distributions, which have been extensively applied during recent years in extreme value statistics. However, most researchers have used the Gumbel distribution for modelling extreme wind speeds, mainly for temperate latitudes [5]. The daily maximum wind speed data set observed at Las Palmas Port has been fitted to various extreme value distributions commonly used in practice. The best results have been obtained for the Gumbel distribution.

The two parameters Gumbel probability density function is given by

$$p(x) = \frac{1}{b} \exp\left(-\frac{x-a}{b}\right) \exp\left[-\exp\left(-\frac{x-a}{b}\right)\right] \qquad (1)$$

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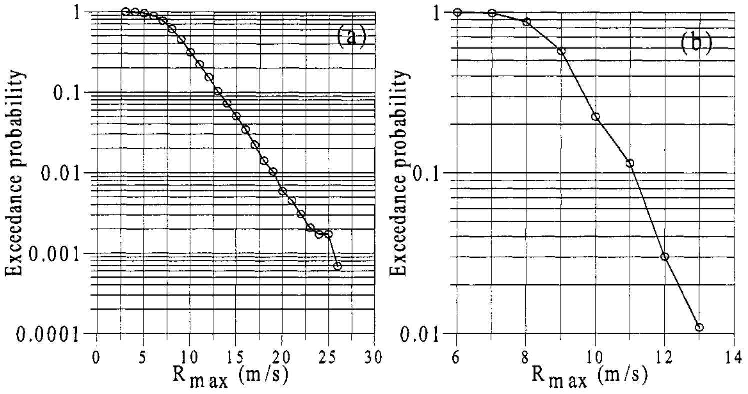

Figure 5: Probability of exceedance for the whole data set (a) and the mean year (b).

where $a$ and $b$ are the location and scale parameters, respectively. The corresponding distribution function takes the following expression

$$P(x) = \exp\left[-\exp\left(-\frac{x-a}{b}\right)\right] \tag{2}$$

Taking natural logarithms twice and after some algebraic manipulations, the Gumbel distribution adopts the form of an straight line,

$$y = \ln\left(-\ln\left(P(x)\right)\right) = -\frac{1}{b}x + \frac{a}{b} = \hat{b}x + \hat{a} \tag{3}$$

Gumbel [3] sugessted a simple and robust procedure for extreme value analysis that can be summarised as follows [4]. Given a set of $N$ data values which represent, (say the annual largest values of the hourly mean wind speed at a particular site, the values are ranked in ascending order of size, i.e. the smallets is accorded rank $m = 1$, and the largest rank $m = N$. Each of the wind speed values is plotted versus the variable $y$ derived from its rank

$$y = \ln\left(-\ln\left(P(x)\right)\right) = \ln\left(-\ln\left(\frac{m}{N+1}\right)\right) \tag{4}$$

Then, a straight line is fitted to the plot, from which the slope and the intercept on the windspeed axis are obtained. Note that the values of $m/(N+1)$ are identified with the probability of the corresponding wind speed not being exceeded in one year.

Figure 8 shows the probability distributions of daily maximum wind speeds for the whole data set (a) the mean year (b) and the seasons, spring (c), summer (d), autumn (e) and winter (f), fitted to the Gumbel distribution by means of the above procedure. The parameters model have estimated by the least squares method and are shown in the right lower side of each picture jointly with the correlation coefficient between the observations and the model. It can be observed that, in general, the Gumbel distribution produces an adequate fit to empirical observations. Both, the whole data set and the mean year values, as well as each of the seasons reveals a good agreement with the Gumbel distribution.

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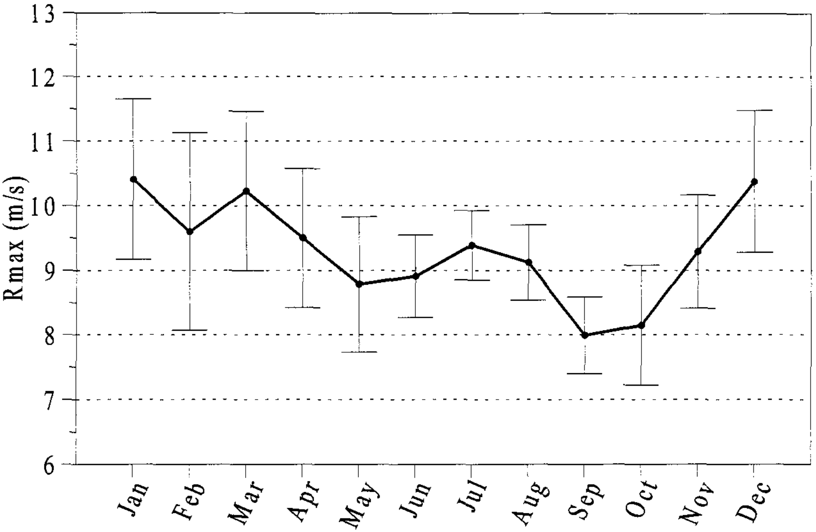

Figure 6: Monthly average of wind speed and standard deviation.

It is interesting to note that most important deviations are observed during summer and winter. In the latter case, notable deviations are observed for high wind speeds, probably due to storm invasions from the Northwest North Atlantic. This deviations are clearly reflected in the statistical behaviour of the whole data set.

## 5 Time-frequency analysis

Classical spectral analysis can not be applied for the analysis of time series spanning over very large periods because of the basic hypothesis of stationarity is not fulfilled. However, time-frequency methods of signal analysis make possible the description of a nonstationary signal in terms of its frequency composition as a function of time. One of the most commonly used time-frequency methods in time series analysis during the last decade is the Wavelet Transform (WT) analysis.

The WT can be considered as the correlation between the analysed time series, $x(t)$, and a set of functions called wavelets. Each wavelet, also called daughter wavelet, is generated by scaling and translating one initial wavelet, called mother wavelet, $\psi$. Scaling implies a dilation or compression of the mother wavelet and translation implies its shifting in the time domain. The Continuous Wavelet Transform for a real signal is given by

$$W_{a,b} = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} x(t)\psi^* \left(\frac{t-b}{a}\right) dt \tag{5}$$

where $\psi^*(t)$ denotes the complex conjugate of the mother wavelet and $a$ and $b$ are the dilation and translation parameters, respectively. The scale parameter is proportional

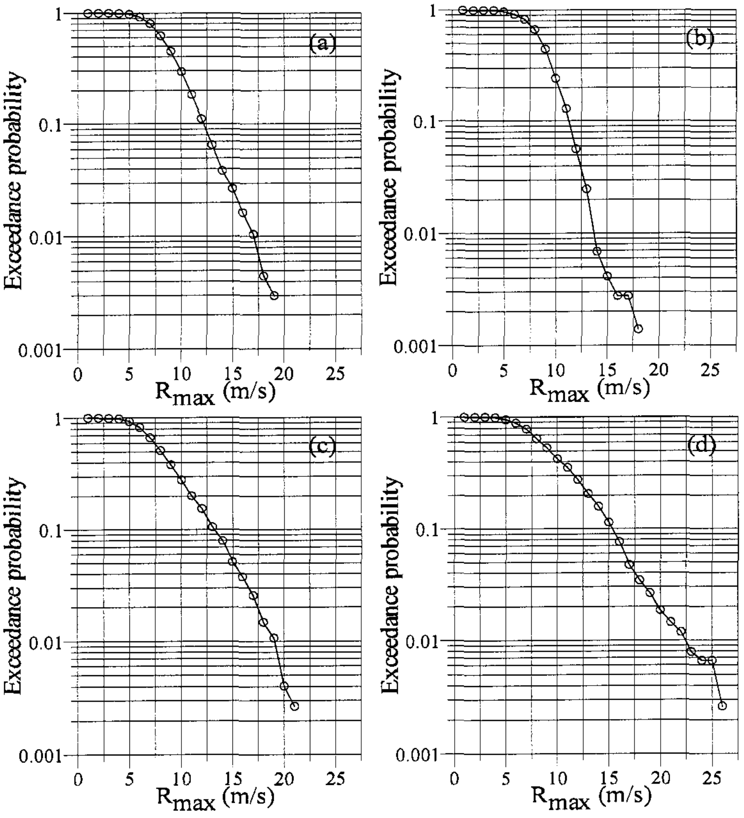

Figure 7: Distribution of exceedance of maximum daily wind speeds for seasons, (a) Spring, (b) Summer, (c) Autumn, (d) Winter.

to the reciprocal of frequency and the translation parameter stands for time. A detailed description of wavelet transform analysis can be found in a large number of review papers and books, e.g. [6] [7].

The wavelet spectrum for a segment of the maximum daily wind speed time series is presented in Figure 9. The continuous wavelet transform has been evaluated by using the well-known morlet wavelet. Visual inspection of the wavelet spectrum reveals the nonstationary character of the process, with its frequency composition varying with time. It can be observed the persistence of the semi-annual and seasonal periods, while bi-monthly, monthly, bi-weekly and weekly periodicities present a large intermittency which increases with the frequency.

## 6 Discussion and conclusion

The knowledge of wind climate, including mean windspeeds and directions throughout the year, seasonal variations, and extreme winds that may occur at the structure site, results vital for the adequate design and for the operational purposes in harbours.

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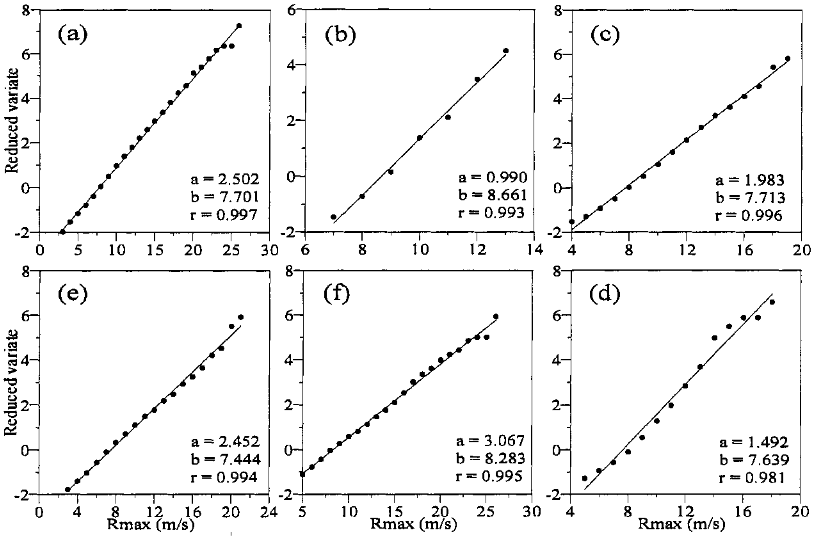

Figure 8: Fit to Gumbel probability distribution of maximum daily wind speed for the whole period (1984-1994), annual average and seasons.

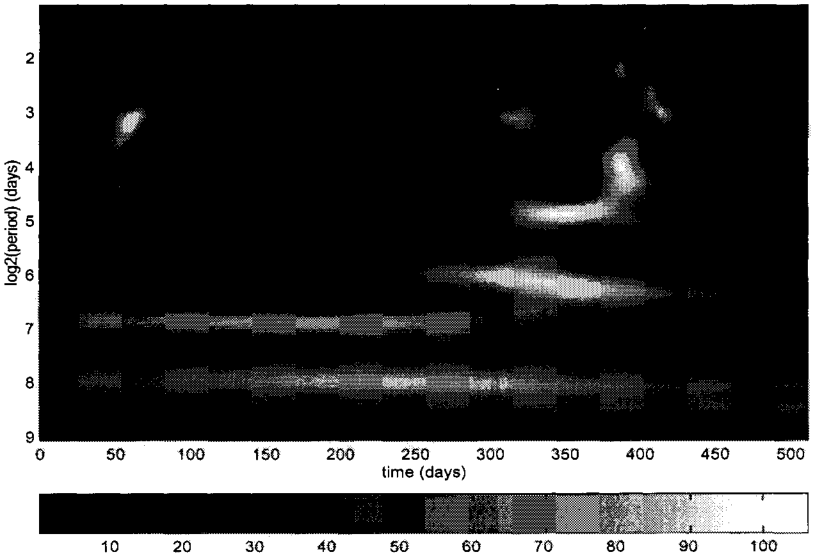

Figure 9: Wavelet spectrum of maximum daily wind speeds.

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Long-term statistical characteristics of daily maximum wind speed observations recorded at Las Palmas Port, Canary islands, during a period of 10 years have been examined. Due to their geographical location the Canary archipelago is under the direct influence of the prevailing trade winds during the main part of the year. It has been observed that the predominant direction of winds reaching the port is the sector NW-NE, accounting for more than the 70% of the observations, reflecting the prevailing character of the trade winds, particularly during summer. In relation to wind speeds, it has been recealed the existence of an apparent annual periodicity with the calmest period spanning from the latter summer to the early autumn, while the windiest season is the winter. In average, maximum daily wind speed is about $13m/s$ with a probability of being exceeded close to 1%.

Maximum daily wind speed long-term statistical behaviour, as well as annual average and seasonal values, are adequately characterised by means of the two-parameter Gumbel distribution. Furthermore, time-frequency analysis of the maximum daily wind speeds at Las Palmas Port, by using the continuous wavelet transform reveals the nonstationary character of this physical process, and the significant persistence of semi-annual and seasonal variabilities, while smaller periodicities present a substantially intermittent character.

While interesting results on the long-term climate at Las Palmas Port have been obtained, it should be desireable the use of larger time series and with smaller sampling period, hourly or less, to reduce the uncertainty on the probability of occurrence of extreme events, as well as small time scale effects.

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