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RESEARCH ARTICLE

A Methodology for Statistical Mean Wave Climate Regime Characterisation in Oceanic Islands: The Case of the Southern Coast of Tenerife

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Abstract

Oceanic islands of volcanic origin tend to have peculiar characteristics, such as: exposure to many wave directions; grouping in archipelagos; steep coastal slopes; and small coastal shelves. All these features require certain considerations in wave climate studies. These types of studies, when wave spectra are not available and have to be performed with parametric data, can be unreliable without an adequate systematic treatment. In this work we propose a methodology consisting of pre-classification according to the peak period and subsequent separation into different sectors according to the geographical fetch. The island of Tenerife is the case study, and in particular the waves reaching its southern coast. Data from the existing deep-water buoy have been used in this work. A range of fetch lengths between the few miles of distance to the neighbouring islands, and more than 5500 nautical miles that separate it from the Antarctic region have been considered. The dominant type of waves and the direction of provenance in each season of the year have been characterised. The proposed methodology has been designed to be applied to any oceanic archipelago with similar characteristics to those mentioned above.

Keywords: Fetch, Oceanic archipelago, Peak period, Statistical wave description

1. Introduction

A large number of volcanic islands are scattered in the oceans as the result of hot spot activity and are usually grouped in archipelagos. Many of these volcanic edifices are imposing structures, several thousand meters high. Examples of these formations are the Galapagos or Hawaiian archipelagos in the Pacific Ocean, and the Canary or Tristan da Cunha archipelagos in the Atlantic Ocean.

Hot spots are produced by the upwelling of plumes of hotter and lighter material from the mantle. It is estimated that there are between 45 and 70 hot spots around the world, a large part of them in the oceanic lithosphere [1]. The term hot spot was already introduced by Morgan in the early 1970s [2,3].

Compared to continental shorelines, volcanic islands have a narrow coastal shelf, which in many cases have steep slopes [4]. On the other hand, due to their shape and location, the range of wave directions to which these geological formations are exposed is very wide. On many stretches of their coasts they may be sheltered by other islands of the archipelago they belong to [5], and on other stretches they may be totally exposed to fetches of several thousand miles, which separate them from remote continental coasts.

Taking these considerations into account, the type of waves to which they may be exposed is often very varied, and therefore, the state of the sea at any

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given moment will be the sum of innumerable families of waves, very diverse in characteristics and origin.

Although the sea state can be defined as surface gravity waves with periods shorter than 5 min [6], for this work the definition will be more restrictive, and will be limited to ordinary gravity waves, with periods between 1 and 30 s, following the oceanic waves classification proposed by Munk decades ago [7].

In this wave class, a distinction is usually made between two types, with an infinite number of intermediate states in the middle: Sea and Swell [8]. While the Sea waves are irregular and chaotic, with high wave steepness, Swell waves are much more orderly and with smaller wave steepness.

This distinction has been made since the early days of maritime engineering. In the First Conference on Coastal Engineering, venue in Long Beach, California, in 1950, the term Sea was being defined as waves under the direct influence of generating winds, while the term Swell referred to waves which have left the generating area and subject to decay [9]. Similar definitions can be found in the Shore Protection Manual, a reference work for many generations of coastal engineers [10].

Although this distinction between these two types of waves is real, useful, and commonly used, the fact that there are many intermediate cases, coupled with the common use of spectral models to describe the sea state, greatly complicates this classification.

Irregular and multidirectional waves in an area are most common [11]. Over the years, different algorithms have been developed to classify waves from time series of directional spectra [12], but when only lists of wave height, period and direction are available, which are widely used by practitioners in the industry, this separation is not so clear-cut. Without the use of wave spectra, there is a risk of oversimplification.

All these characteristics of the waves, together with the specific features of the volcanic islands, need to be taken into account in wave climate studies, which are necessary for coastal and port management as well as for the design of new infrastructures.

The aim of this paper is to describe a systematic statistical method taking into account these particularities. For this purpose, the method is applied to the southern waters of the island of Tenerife, in the Canary Islands, where a deep-water ocean buoy has been in operation for several years. The study is focused on the mean wave climate regime.

Although this article refers mainly to intraplate oceanic volcanic archipelagos, originated by a hot spot, the method can be extrapolated to any island whose characteristics coincide with those described above.

2. The coast of tenerife island

The island of Tenerife is part of the Canary Archipelago, whose origins, after years of scientific controversy, are recognised as being associated with the activity of a hot spot [13,14].

The island rests on the crust, at a depth of 4000 m, and is crowned by the stratovolcano Pico Teide, which is more than 3700 m above sea level. As in all the western islands of the Archipelago, the coastal shelf is narrow and steep, for this reason, incident waves usually undergo less transformation and energy loss than in continental shorelines, in addition, the coastal infrastructures constructed on this scarce coastal shelf are exposed to the most adverse circumstances in marine storms, the situation of breaking waves [4].

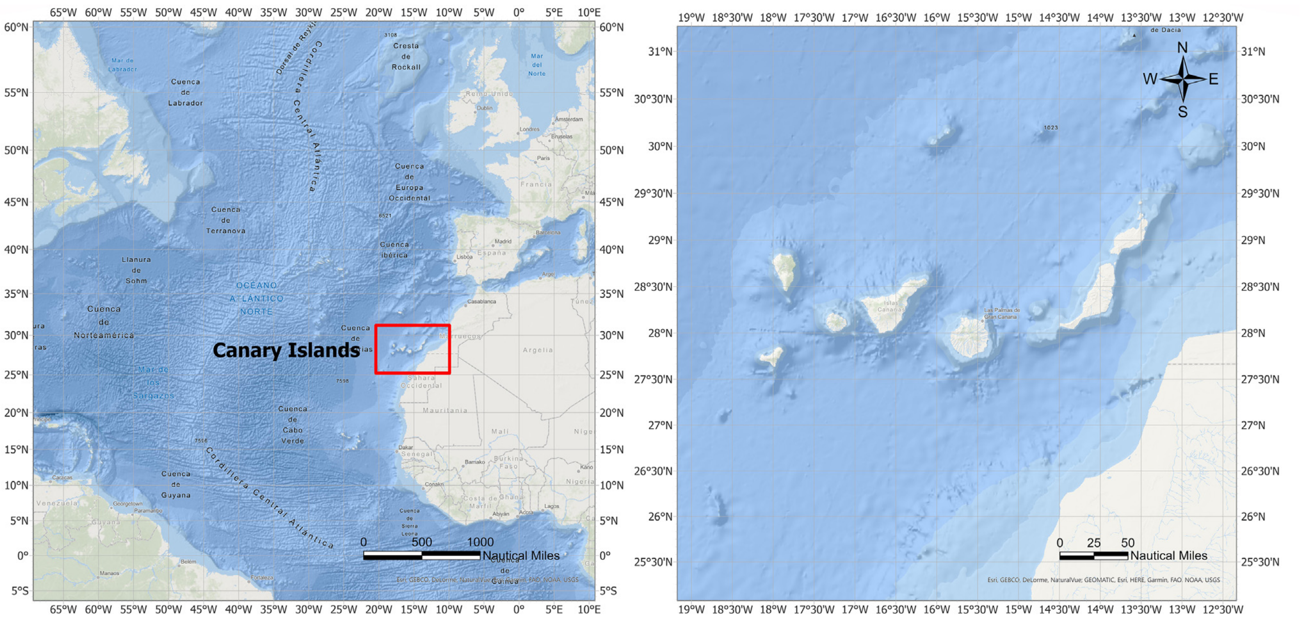
The Canary Islands are located on the African plate, between 27 and 29° North latitude and 13 and 18° West longitude. Situated off the coast of Africa and South of Madeira (Fig. 1a and b). Unlike other volcanic archipelagos such as Hawaii, the phenomenon of subsidence is very limited in the Canary Islands, due to the great thickness and rigidity of the crust on which they are based [15].

Several studies have been dedicated to the wave climate of the Canary Islands [16–18]. It should be added that perhaps the climatic factors that most influence this wave climate are the North Atlantic Oscillation (NAO), and the North-easterly Trade Winds with cycles of increased intensity and calm periods [19].

With regard to studies of the southern part of the coast of Tenerife, there are some important works more focused on the extreme wave climate and its effects [20,21]. The present work aims to focus on the study of the average climate.

3. Material and methods

The data used are those collected by the deep-water buoy that the Spanish State Institution Puertos del Estado has moored in the south of Tenerife, known as Tenerife Sur Buoy. These data can be requested in the web application of Puertos del Estado (https://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx). This buoy has been in service since 1998. Initially, it only recorded wave scalar data, but since 2003 the buoy can collect directional data. It is part of the REDEXT deep-water buoy network [22]; its main characteristics are listed in Table 1.



(a) (b)

Fig. 1. Geographical location of the Canary Islands. (a): Geographical location in the Atlantic basin; (b): Canary Islands off the coast of Africa.

Fig. 2 shows the position of the buoy, and the proposed sectorisation to divide the wave directions to which it is exposed depending on the distance to the shore. Section 4.3 describes the different sectors in detail. The full range of directions to which the buoy is exposed is limited by the two headlands near the buoy shown in the enlarged image.

The most important Swell that reaches the Canary Islands comes from the fourth quadrant [16]. The Tenerife Sur buoy is protected from this direction thanks to its location. In this case it is a great advantage, as it means having a natural filter, allowing us to study the rest of the waves more easily; without this protection observation would be more difficult. The observed sheltering effect, particularly for the Swells originating from the Northwest, is a prevalent and notable characteristic in oceanic archipelagos. Should the study location be situated on the northern coast of these islands, the Swells with the maximal fetch (those originating from the Southern Hemisphere) would be absent.

Table 1. Technical features Tenerife Sur Buoy.

Features	Values
Longitude	16.61° W
Latitude	28.00° N
Data Sampling	60 min
Code	2446
Mooring depth	710 m
Type of sensor	Directional Oce-Met
Model	SeaWatch
Data set	REDEXT

Every hour, the buoy measures a series of instantaneous elevations of the sea surface around the mean sea level during a period of approximately 30 min. This sample is considered as representative of hourly wave data. Standard zero-crossing and spectral analyses are then applied to this time series of elevations to obtain the most representative wave parameters, which Puertos del Estado make available, after the corresponding quality control, on their web site [22,23]. Similarly, the buoy measures wind speed and direction, in this case, the measurement period is 10 min every hour.

Wave data parameters taken were the spectral significant height (*Hm0*, hereinafter significant height *Hs*), the peak period (*Tp*), and the mean wave direction at spectral peak (*Dmd_P*). In addition,

Fig. 2. Tenerife Sur Buoy location and sectors proposed for the wave climate study (Authors).

mean wind velocity ($Vv\text{-}md$) and mean wind direction ($Dv\text{-}md$) were used. Data from 12 years (2009–2020) was considered. Wave records are available for 97% of this time span.

Regarding the method proposed for this study, each of the steps are shown in Fig. 3 and can be summarised in the following stages:

- On the one hand, once the values of Hs, Tp and directions have been obtained, a screening process is carried out in which all the records with directions of origin that do not affect the point of study are eliminated.
- The histogram of Tp is prepared from this data, and from this the thresholds that will divide the set of records into two (Sea and Swell) or three groups (Sea, Young Swell and Old Swell) are selected.
- On the other hand, the possible directions of provenance are separated according to the geographical fetch. This will be done taking into account the main geographical features that determine important changes. As a final result, the range of directions will be divided into different sectors.
- Once the data has been classified by wave type according to the peak period, and the range of directions of provenance according to the values of the geographical fetch, the statistical work is carried out on the values of the significant heights. The results obtained can be analysed together with the wind and fetch values.

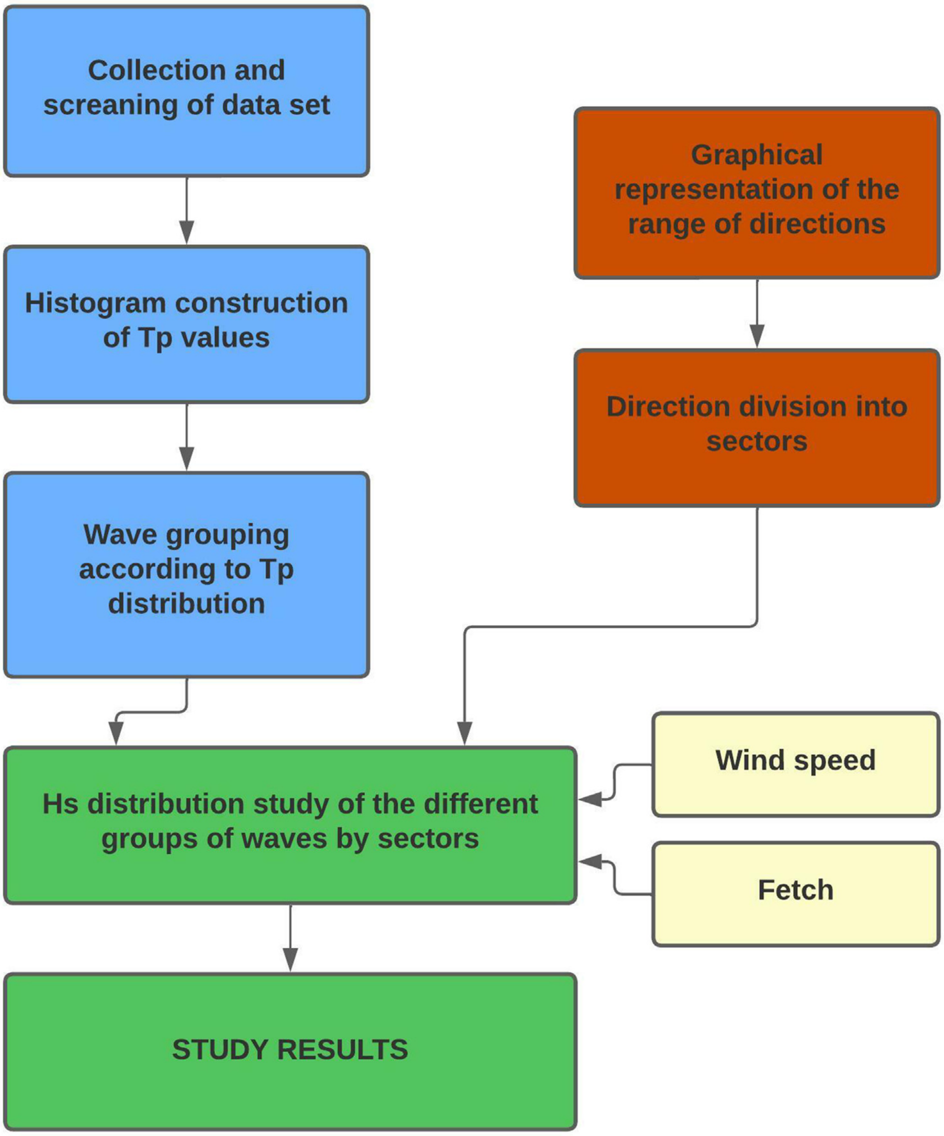


Fig. 3. Statistical methodology scheme. Blue: Wave classification by peak period; Brown: Definition of sectors under study; Yellow: Other factors in study.

The proposed methodology of wave grouping according to the *Tp* value, is a simplified and intuitive method without great mathematical apparatus, which, without having the rigour of other much more advanced studies carried out for medium or extreme regimes to separate Sea and Swells [24−27], serve as a tool for engineers and managers of the so called blue economy as a first approach to the environment in which their work is carried out. The data used are numerical tables of wave height, direction and period. This type of data is usually available in different institutions dedicated to research and management of the marine environment. These data also have the great advantage of being user-friendly and more understandable for the final users, who are usually far removed from the methods and concepts more closely related to scientific research.

Non-linear higher-order interactions between different wave trains, which could be of great importance [28], have not been taken into account separately as they are outside the scope of this work.

4. Results

4.1. Wind description

With regard to wind intensity, there is a clear seasonality marked by the trade winds, which are the main protagonists. Fig. 9 shows the evolution of the mean velocity over the year (blue line), the highest average monthly wind speed values occur during the summer months, and the lowest in spring and autumn. Regarding the direction of origin, during all months of the year, the most important direction is from the first quadrant, with just over 70% of the records for the period under study coming from this quadrant. The Northeast and East-Northeast directions are the most frequent. Table 2 shows the quadrant distribution of the buoy records.

It is important to note that the orography of the islands greatly influences the winds, acting as a natural barrier and canalising them.

4.2. Wave classification by peak period

The histograms of the total *Tp* recordings were made. Values were grouped into two different class intervals: 0.5 s and 0.1 s (Fig. 4). It is very interesting to see how the perception of the histogram changes depending on the magnitude of the intervals of the data grouping.

Table 2. Distribution of the directions of provenance and mean velocity of the winds recorded by the Tenerife Sur Buoy (2009−2020 period).

Quadrant	Direction limits (°)	% Records	Mean wind velocity (m/s)
First	[0−90)	70	6.5
Second	[90−180)	10	3.1
Third	[180−270)	10	4.1
Fourth	[270−360)	10	3.5

Based on the first histogram (Fig. 4a), it can be clearly seen how the distribution of values is concentrated around various peaks, the highest values of which are approximately 6 and 14 s.

Bimodal distributions sometimes appear when Sea and Swell coexist [29]. The proposed division between Sea and Swell would be a value between these two clearly differentiated curves, where the number of records is minimal (around $Tp = 10$ s), this value coincides with the "crude separation value" of *Tp* mentioned by other authors [30].

However, if attention is paid to the histograms with the *Tp* values grouped in 0.1 s (Fig. 4b), a second division could be seen for the larger values of *Tp*, and taking into account the great diversity of fetch values observable in the Canary Islands, it may

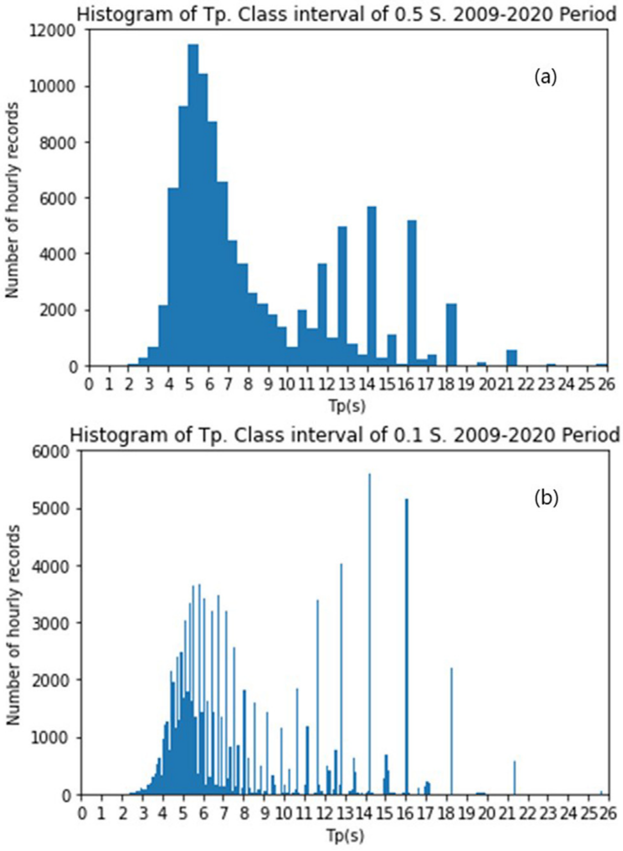


Fig. 4. Tp histograms grouped into different class intervals: (a): 0.5 s; (b): 0.1 s.

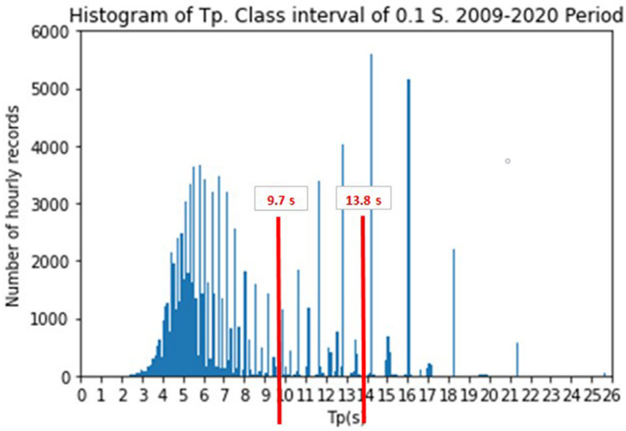


Fig. 5. Tp threshold values proposed (Class interval of 0.1 s).

be interesting to group the values not only between Sea and Swell, but in three groups of waves, by separating the Swells into Young and Old Swells according to *Tp*. The aim is to independently study the locally produced waves, as well as the already well-developed Swell that has been produced outside the area under study, and finally the very mature Swell that reach the Canary Islands after travelling long distances (several thousand nautical miles).

The classification of the waves into more than 2 groups has already been done. For instance, Thompson et al. categorised waves into Sea, Young Swells, Mature Swells and Old Swells according to their steepness [31]. More recently, Semedo also discriminated between Wind Sea, Young and Old Swells when commenting on the different ages and origins of the waves in the Canary Islands area [18].

The threshold values shall be chosen from the histogram, at the values of *Tp* with a null number of records, which serve as the boundary between the three sets of records (Fig. 5).

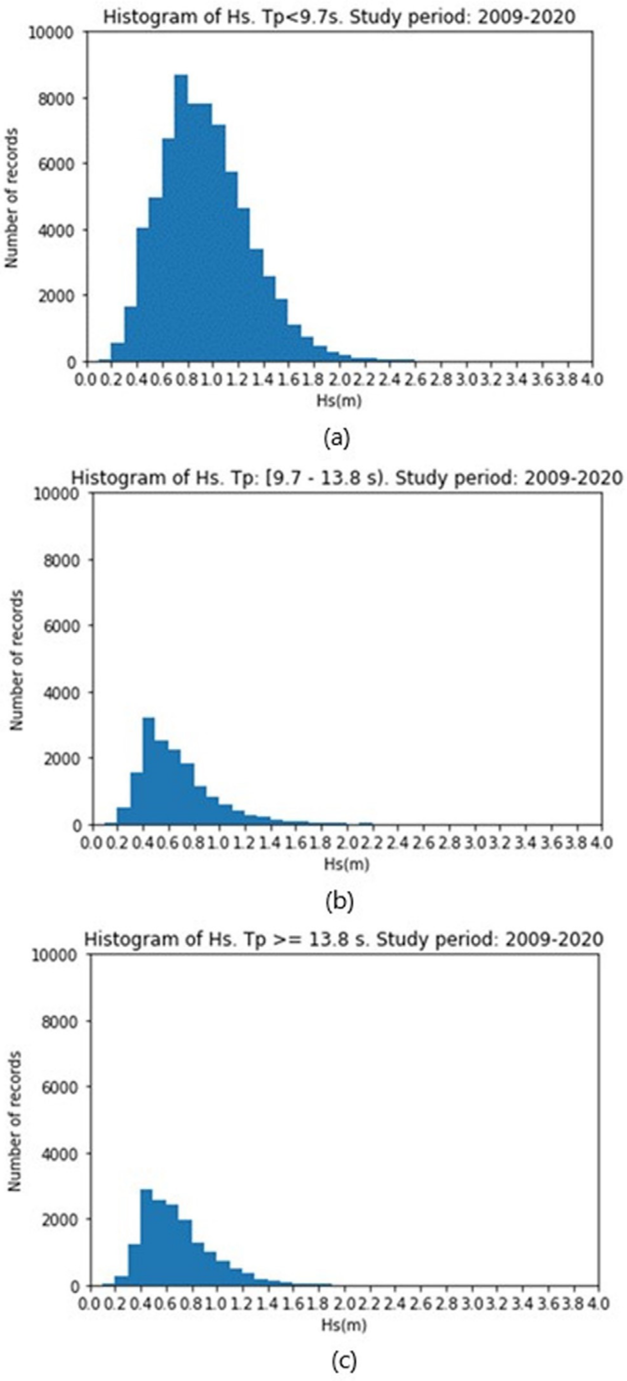
Therefore, the different wave classes proposed, according to their *Tp*, are shown in Table 3. The proportion of time that each group has been the main incident wave is also indicated.

The histograms of the resulting *Hs* for each group are shown in Fig. 6. It can be seen that the distribution of wind-sea waves is quite centred with only a slight skewness, whereas the other two have a marked right-skewness distribution.

Table 3. Wave classes.

Wave class	*Tp* limits (s)	% records
Sea	<9.7	70
Young-Swell	[9.7, 13.8)	15
Old-Swell	≥13.8	15

Once the three groups have been defined, a statistical descriptive study can be carried out. In Figs. 7 and 8 it can be seen how the Sea is the great protagonist of the study area. Only in spring and autumn, when the Sea decreases, the Swell takes on a certain significance. The relationship between the wind speed value and the monthly mean significant height is also clear (Fig. 9).



(a)

(b)

(c)

Fig. 6. Hs histogram of: (a): Sea; (b): Young Swell waves; (c): Old Swell waves.

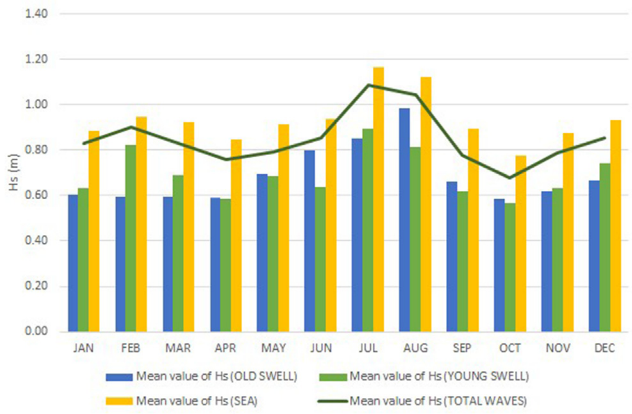


Fig. 7. Hs values per month. Period 2009–2020.

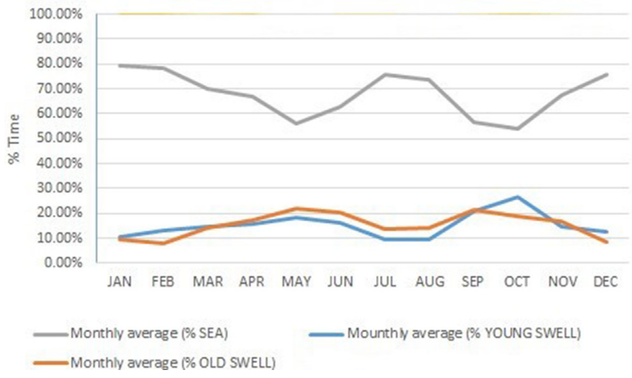


Fig. 8. Predominant waves per month. Period 2009–2020.

4.3. Definition of sectors under study

For the case under study, it can be seen that the distance between the buoy and the shore varies radically depending on the direction in which it is measured, so the nature of the different types of waves that can reach it from each direction will vary enormously. Sectorisation of the directions is necessary in order to be able to carry out an independent study of each of them.

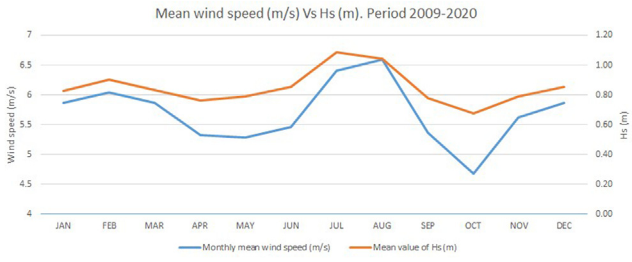


Fig. 9. Mean wind speed vs Hs. Period 2009–2020.

Fig. 2 has already shown the proposed division in seven sectors, a description of each of them is given in Table 4.

The distances separating the buoy from the coast vary from less than 100 nautical miles for sectors 2 and 6 (a distance unlikely to produce fully developed Swells), to more than 5500 nautical miles from the Antarctic Circle in the case of sector 4. This great distance allows the arrival of trans-hemispheric Swells, events that have been studied previously [19,32,33].

About 2 percent of the records come from directions outside these sectors, namely from the coast of Tenerife (268°–64°). These waves, which are outside the scope of this study, have a varied range of *Tp* (with values from a few seconds to records of more than 20 s). Its origin can be very diverse, ranging from locally produced Sea, to reflected Swells, which deserves a separate future research.

4.4. Statistical study of every sector

Once the three wave groups (Sea, Young Swells and Old Swells) and the seven sectors have been defined, the descriptive statistical study is carried out.

First, by way of introduction, Fig. 10 shows two wave rose diagrams, which describe in general terms the annual mean *Hs* and the percentage of predominance of the waves coming from each sector, throughout the range of directions studied (65°–267°, both inclusive).

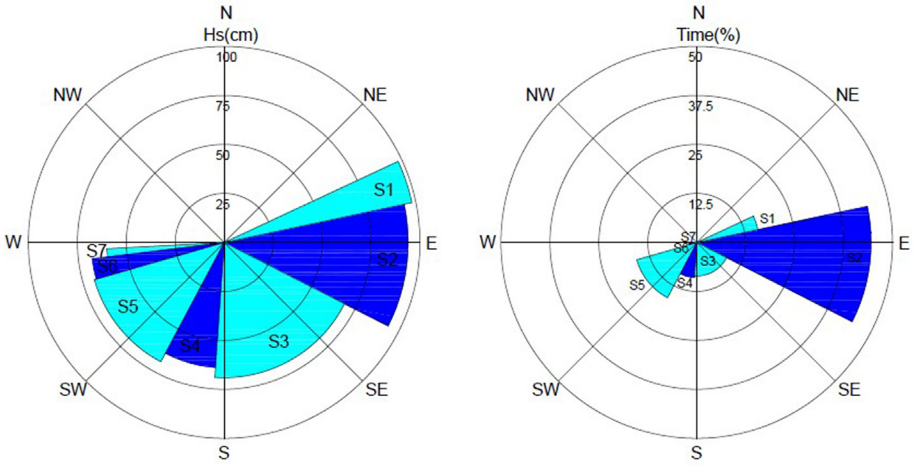
Subsequently, Fig. 11 shows the monthly mean *Hs* for each sector, treated in general and according to wave typology. Fig. 12 shows the evolution of the proportion of predominant waves coming from each sector throughout the year. In the same way, the data have been treated as a whole and separated by wave type. In both cases, the mean monthly wind speed is also shown.

Finally, Fig. 13 shows for each sector, relative frequency curves of *Hs* for the three wave types.

For every type of wave and sector, distribution function fitting has been made for Weibull and Log-

Table 4. Sectors proposed.

Sector	Limits (∘)	Coastline in front
S1	65–78	Lanzarote and Fuerteventura
S2	79–107	Gran Canaria
S3	108–184	Western Sahara
S4	185–208	Antarctic region
S5	209–254	South-America
S6	255–263	El Hierro
S7	264–267	Lesser Antilles



(a) (b)

Fig. 10. Wave rose of the directions under study. (a): Hs (annual means); (b): Annual % of time of predominant sector.

normal functions. Results are attached in the Supplementary Material.

5. Discussion and conclusions

5.1. Study of the results obtained

After studying the results obtained, the following comments are made:

Considering the proportion of time in which each direction is predominant (Fig. 10b), it is clear that sector 2 is the most important. In terms of average annual *Hs* values, sector 2 is only outweighed by sector 1 (Fig. 10a).

With respect to the trend in *Hs* over the course of the year (Fig. 11), it can be seen how the total waves graph indicates the concordance in the evolution of the wind speed with the waves of sectors 1 and 2. The same is true for the Sea curves, with peak values in summer and winter. This is logically explained by the fact that these are the two sectors best aligned with the trade wind directions. In addition, the channel effect produced for winds, currents and waves by the proximity of the island of Gran Canaria to Tenerife must also be taken into account. On the other hand, it is very remarkable how the maximum winter values for the Sea are given for sector 5. They could be originated from winter low pressure storms in the West of the Archipelago.

Regarding the Young Swells, the maximum mean *Hs* occurs for sector 7 during the month of March, reducing in height until disappearing in this sector during the summer. Its origin can also be explained by these squalls that appear West of the Canary Islands and Madeira in winter.

With regard to the Old Swells, the increase in the mean *Hs* in summer is generalised in all sectors; the most logical explanation would be that as the intensity of the trade winds increases, and the Sea grow, the rest of the waves, in order not to be masked, must have a sufficient height.

With respect to the proportion of time in which each sector and type of wave is the predominant one (Fig. 12), it can be clearly seen that for total waves, sector 2 is the predominant one, far above the rest (agreeing with what has already been commented for Fig. 10). In terms of Sea, this trend is repeated, followed by sector 1. In the summer months, when the trade winds are at their most important, this type of wave disappears for the rest of the sectors.

In the case of Young and Old Swells, the predominant sectors are 4 and 5, with a very different trend to that of the monthly mean wind speed. They peak in spring and autumn. It is logical to think that when the intensity of the wind, and therefore of the Sea waves, is lower, the Swell type waves will be less masked. It should be noted that due to the long fetches in these two sectors, the Swell may be very modified, with small wave heights but long periods.

Finally, regarding the relative frequency of the *Hs* (Fig. 13), in general, the Swell curves tend to have a higher degree of kurtosis than the Sea curves, except for sectors 6 and 7, where all the wave types have a very similar distribution. A positive skewness appears in all cases. In curves of sectors 1 and 2, it can be seen that the wind-sea distributions are shifted more to the right, indicating higher values of *Hs*.

The most important conclusions, both of the wave climate of the area under study and of the proposed

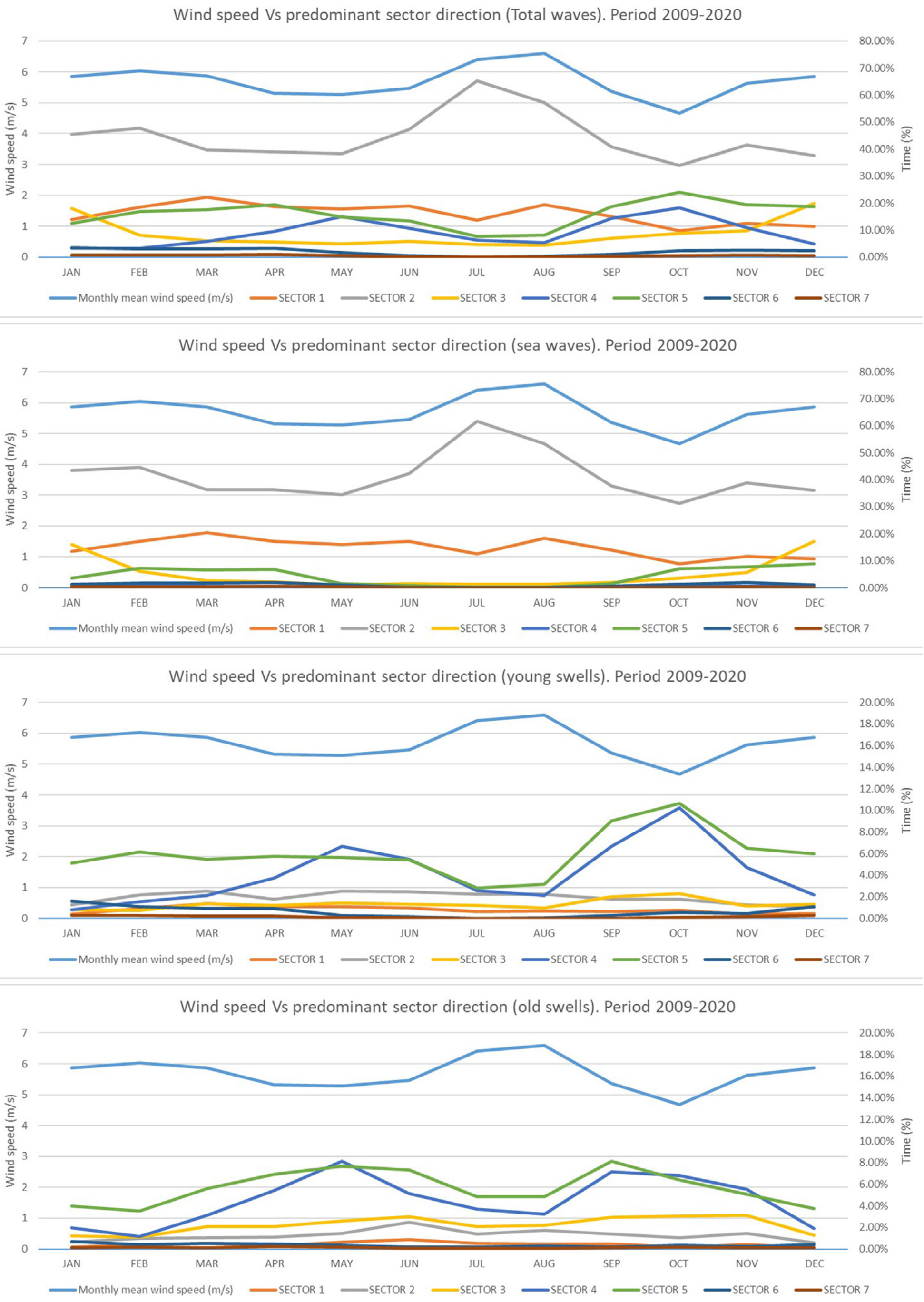
Fig. 11. Hs (monthly means) for every sector and set of waves (Sea, Young Swell and Old Swell).

methodology, point by point will be presented below.

5.2. Wave climate

With regard to the wave climate studied, the main conclusions that can be drawn are as follows:

- It has been confirmed that the trade winds, coming from the North-east, are one of the main factors in the maritime climate of the study area, hence the great importance of the Sea type waves compared to the Swell type.
- The predominant sectors are sectors 1 and 2, where Sea are most important.


Wind speed Vs predominant sector direction (Total waves). Period 2009-2020

Wind speed Vs predominant sector direction (sea waves). Period 2009-2020

Wind speed Vs predominant sector direction (young swells). Period 2009-2020

Wind speed Vs predominant sector direction (old swells). Period 2009-2020

Fig. 12. Monthly % of time of predominant sector direction.

- It is very remarkable how sector 2, with the shortest fetch of all the sectors, and only 14% of the arc of directions, accumulates 45% of the total records as the predominant direction.
- At the other extreme, sectors 4 and 5 are where Old Swells are more important. These sectors have the longest geographic fetches. Another sector of long fetch is sector 7, but the small range of directions, limited by the islands of La Gomera and El Hierro, make it unrepresentative.
- It is very remarkable how Old Swells in sector 4, with the longest fetch of all the sectors, accumulate more than 4% of time as the predominant direction, with only 11% of the arc of directions. Swells from the South Atlantic Ocean may arrive from those directions.

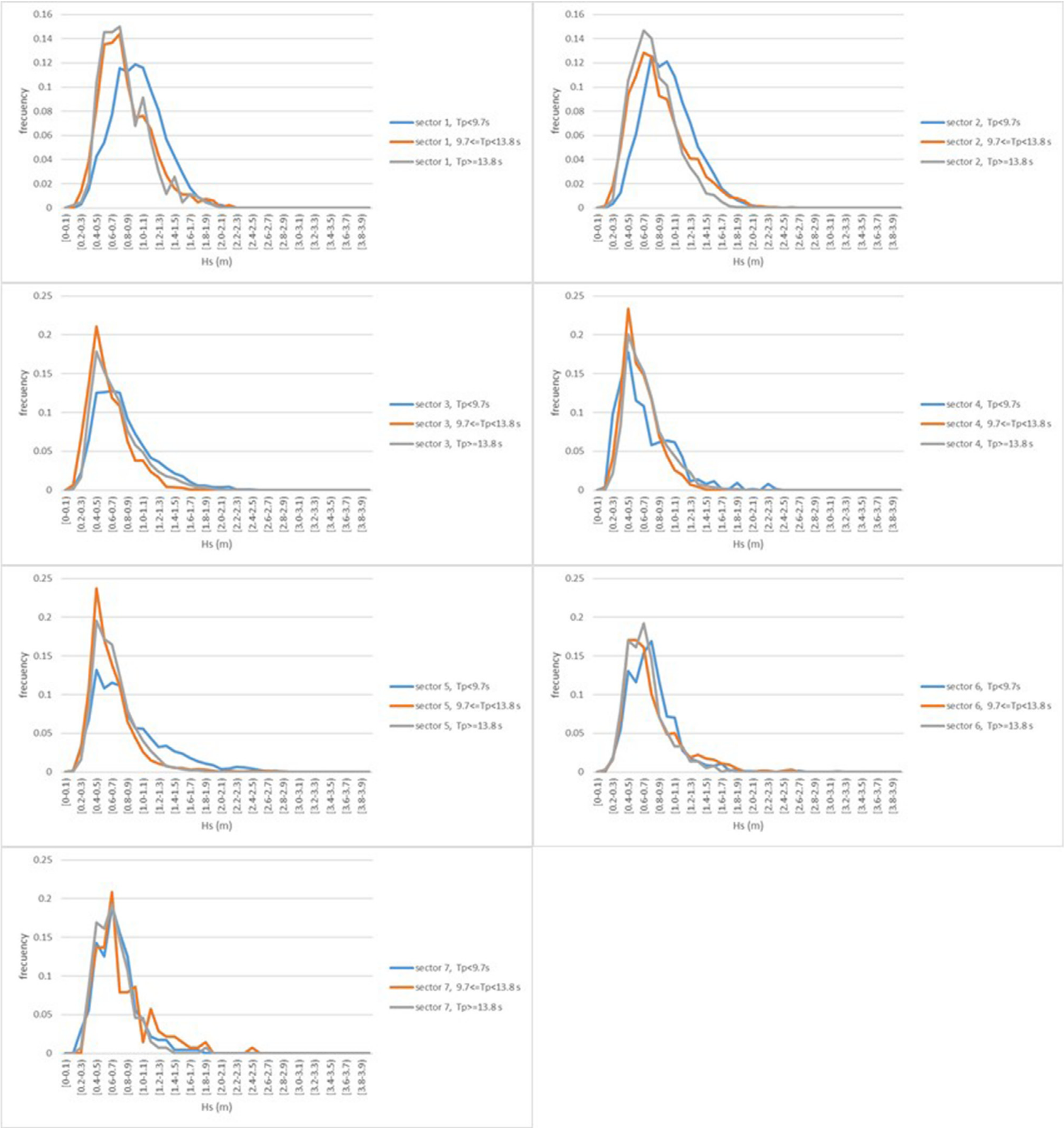


Fig. 13. Relative frequency curves of Hs for every sector.

5.3. Methodology

With regard to the methodology exposed, the main conclusions that can be reached are as follows:

- Over the years, many methods and criteria have been used to separate the Sea and Swell from the spectrum, either by using 1D or 2D spectra [34]. In this case, a simplified method is proposed, where the wave climate of a specific area can be characterised using tables of records, with the usual wave parameters (*Hs*, *Tp* and wave direction).
- In this search for agility and simplicity of the proposed method, any form of frequency discrimination by the use of complicated mathematical apparatus proposed by other authors [35,36], have been avoided.

- This method could be used with both buoy and synthetic data, as long as the number of records is sufficiently representative.
- As mentioned in the introduction to this article, the method proposed here is designed for oceanic volcanic archipelagos, but it can be used in any place where similar characteristics are present. More precisely, the three special conditions considered are: The existence of different wave systems coming from different directions; the wide range of existing fetches due to the great distance from the continents and at the same time the sheltering of other neighbouring islands; and finally, the small size of the coastal shelf, which means that the parameters under study (*Hs*, *Tp* and wave direction) remain unchanged until very close to the coast. This latter condition will also allow the deep-water buoys used to be closer to the shore, compared to those anchored on continental coastlines.
- From the authors' point of view, the great advantage of this method is that it is intuitive and easy to apply, without the need to analyse wave spectra. In addition, *Tp* pre-classification prevents low *Hs* waves with high period values from being masked by higher waves, despite their importance on this type of shoreline where the coastal shelf is usually narrow and steep [37].
- Although this pre-classification of *Tp* could be done in two groups (Sea and Swell), in complex seas with many different wave systems, such as the case under study, it is advisable to group the Swell waves into at least 2 groups (Young and Old Swells) to avoid that the most transformed, with long *Tp*, but with very low *Hs*, are masked by the rest of the waves.
- Its major disadvantage is that each record is classified into only one type of wave (Sea, Young Swell or Old Swell), whereas a spectral record may contain information from more than one wave system, something much closer to the real sea state (Fig. 14). This may result in gross mistakes and loss of valuable information. As part of this screening process, some sort of discrimination between narrow band or broad band spectrum is also carried out. There are hourly data sets, which unlike the one used in this case study, show the parameters of more than one family of waves at the same time. In that case, the study will be much more complete and closer to reality.
- Although only the mean regime has been worked on, it seems possible to use it for the characterisation of the extreme wave climate.

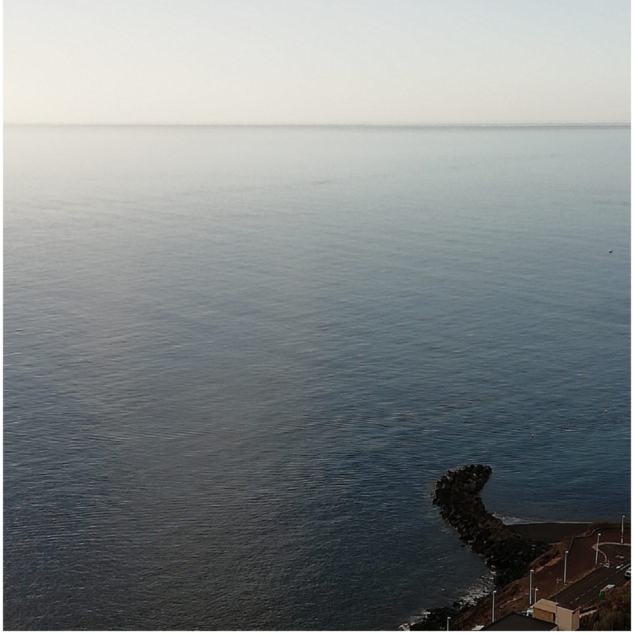


Fig. 14. Photograph taken on the East coast of Tenerife in February 2022 (Punta Callao), where two families of waves (cross swell) can be appreciated. Author: Emilio Megías.

- Despite the limitations mentioned here, this methodology can be useful for a variety of situations, such as initial wave climate characterisations for the design and management of infrastructures. With the method presented, applying basic statistical concepts, and with the help of a spreadsheet, it is possible to obtain data on *Hs*, *Tp* and wave direction in deep waters of the different families of the most characteristic waves of a particular area.

6. Recommendations

As in any study of this kind, the final quality of the result will depend on the reliability of the baseline data. Therefore, it is essential that adequate quality data are available for an area close to the study site, whether they are of instrumental (measurements) or synthetic (reanalysis) in origin.

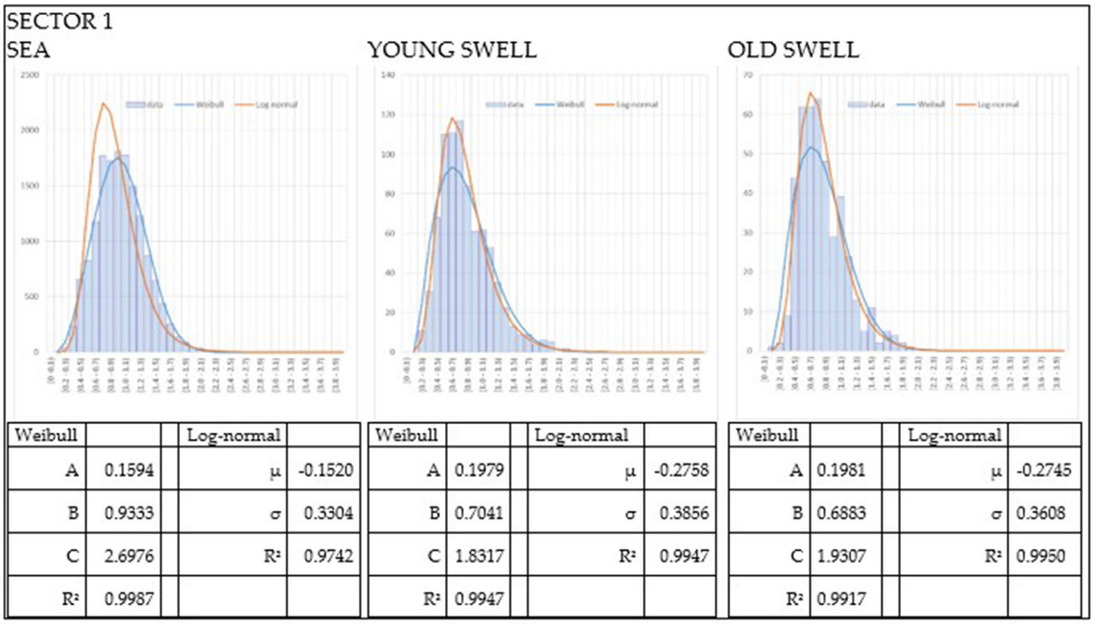
The Spanish State Institution Puertos del Estado has two deep-water buoys in service in the Canary Islands [38]. The one used in this work is moored to the South of Tenerife, and the second one anchored to the Northwest of Gran Canaria. A third deep-water buoy to complement the two existing buoys has been sorely lacking in the approach of this research. This buoy, if located to the West of the island of La Palma, would be outside the shadow produced by the islands for the directions with the highest fetch, those coming from the third and fourth quadrants. It is striking how neither of the two existing buoys can measure the most important waves arriving in the Canary Islands from the northwest, due to the shelter produced by the island of Tenerife.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Appendix A. Supplementary Material: Distribution function fitting for Sea, Young and Old Swells

The parameters defining the Weibull ($F(x) = 1 - e^{-\left(\frac{x-A}{B}\right)^{C}}$) and Log-Normal ($F(x) = \varnothing\left(\frac{\ln x-\mu}{\sigma}\right)$) probability distribution functions for each wave type and sector are shown below (Figs. A1 to A7).



SECTOR 1

SEA

Weibull		Log-normal	
A	0.1594	μ	-0.1520
B	0.9333	σ	0.3304
C	2.6976	R²	0.9742
R²	0.9987		

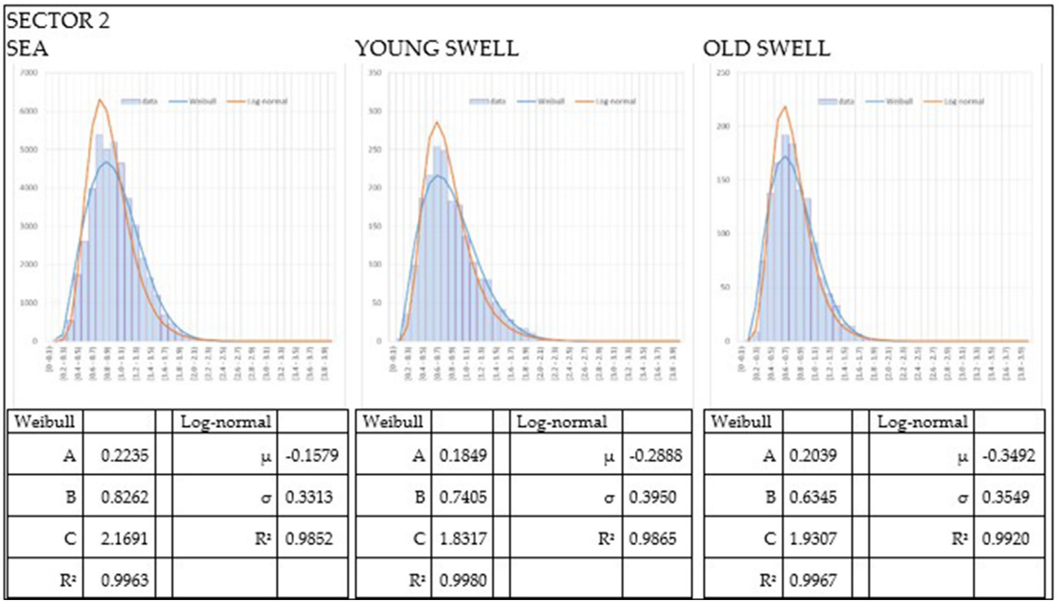
YOUNG SWELL

Weibull		Log-normal	
A	0.1979	μ	-0.2758
B	0.7041	σ	0.3856
C	1.8317	R²	0.9947
R²	0.9947		

OLD SWELL

Weibull		Log-normal	
A	0.1981	μ	-0.2745
B	0.6883	σ	0.3608
C	1.9307	R²	0.9950
R²	0.9917		

Fig. A1. Weibull and Log-Normal distributions (sector 1).



SECTOR 2

SEA

Weibull		Log-normal	
A	0.2235	μ	-0.1579
B	0.8262	σ	0.3313
C	2.1691	R²	0.9852
R²	0.9963		

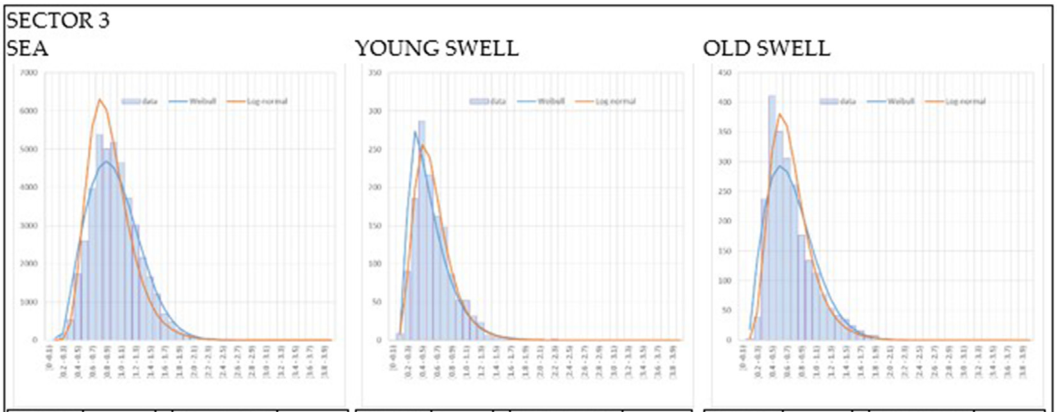
YOUNG SWELL

Weibull		Log-normal	
A	0.1849	μ	-0.2888
B	0.7405	σ	0.3950
C	1.8317	R²	0.9865
R²	0.9980		

OLD SWELL

Weibull		Log-normal	
A	0.2039	μ	-0.3492
B	0.6345	σ	0.3549
C	1.9307	R²	0.9920
R²	0.9967		

Fig. A2. Weibull and Log-Normal distributions (sector 2).

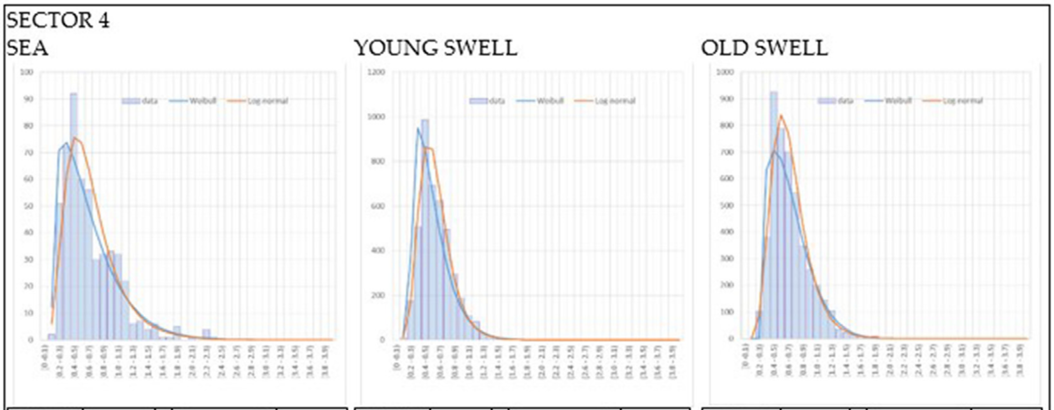


Weibull			Log-normal	
A	0.2235		μ	-0.1579
B	0.8262		σ	0.3313
C	2.1691		R^2	0.9852
R^2	0.9963			

Weibull		Log-normal	
A	0.2273	μ	-0.5903
B	0.3634	σ	0.4103
C	1.2392	R^2	0.9968
R^2	0.9834		

Weibull			Log-normal	
A	0.1572		μ	-0.4167
B	0.6308		σ	0.3890
C	1.8078		R^2	0.9900
R^2	0.9927			

Fig. A3. Weibull and Log-Normal distributions (sector 3).

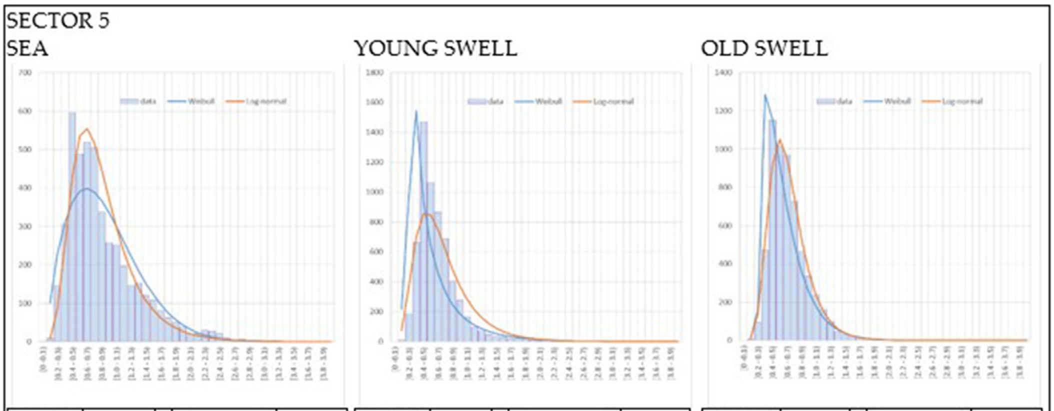


Weibull			Log-normal	
A	0.1754		μ	-0.4885
B	0.5156		σ	0.4947
C	1.2278		R^2	0.9879
R^2	0.9846			

Weibull		Log-normal	
A	0.2497	μ	-0.5841
B	0.3225	σ	0.3549
C	1.2848	R^2	0.9878
R^2	0.9519		

Weibull			Log-normal	
A	0.2087		μ	-0.4533
B	0.4877		σ	0.3643
C	1.5464		R^2	0.9982
R^2	0.9943			

Fig. A4. Weibull and Log-Normal distributions (sector 4).

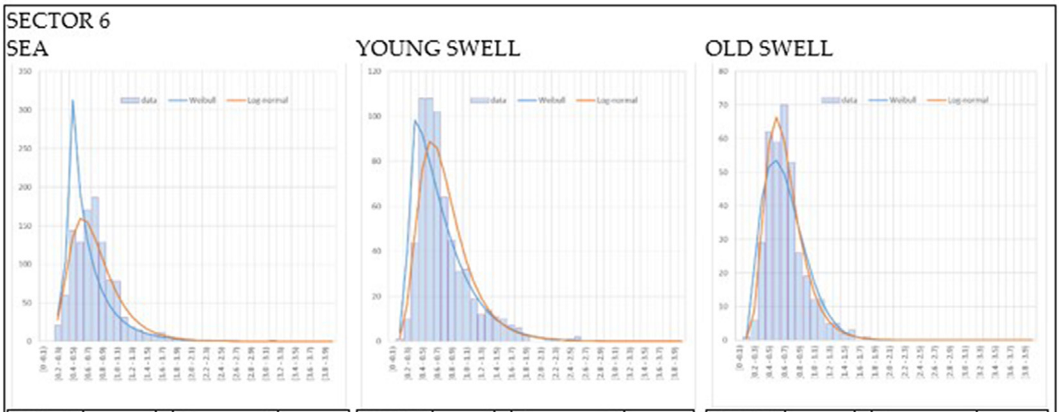


Weibull			Log-normal	
A	0.1017		μ	-0.2579
B	0.8868		σ	0.4630
C	1.7218		R²	0.9807
R²	0.9877			

Weibull			Log-normal	
A	0.2600		μ	-0.4568
B	0.2755		σ	0.5101
C	0.8014		R²	0.9688
R²	0.9880			

Weibull			Log-normal	
A	0.2835		μ	-0.4620
B	0.3413		σ	0.3769
C	1.1711		R²	0.9969
R²	0.9833			

Fig. A5. Weibull and Log-Normal distributions (sector 5).

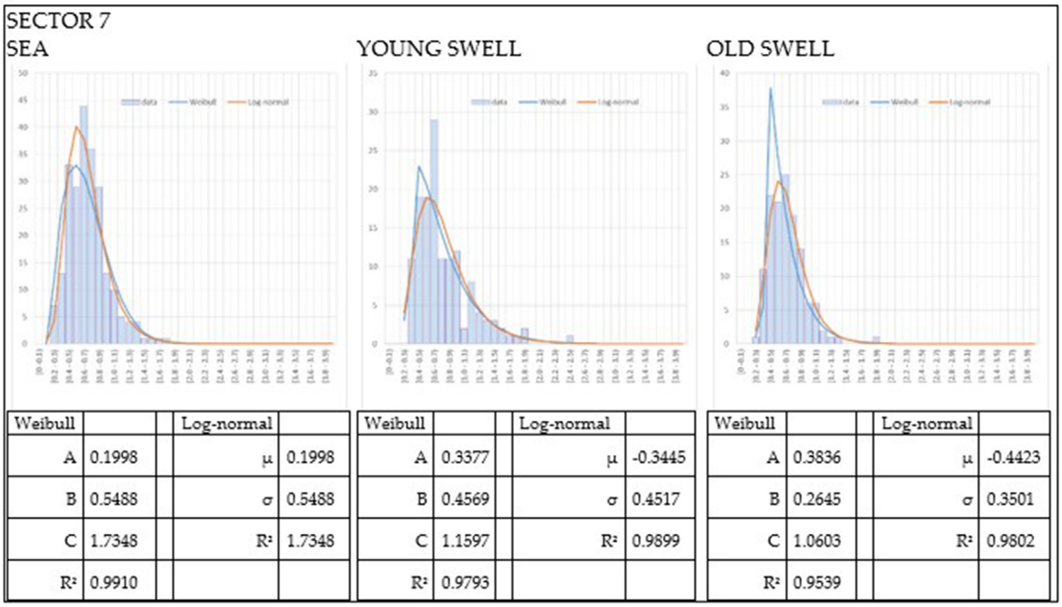


Weibull			Log-normal	
A	0.3737		μ	-0.3639
B	0.2651		σ	0.4313
C	0.8753		R²	0.9873
R²	0.9767			

Weibull			Log-normal	
A	0.2487		μ	-0.3591
B	0.4838		σ	0.4429
C	1.1800		R²	0.9937
R²	0.9885			

Weibull			Log-normal	
A	0.1861		μ	-0.4726
B	0.5395		σ	0.3732
C	1.7715		R²	0.9953
R²	0.9925			

Fig. A6. Weibull and Log-Normal distributions (sector 6).



Weibull			Log-normal	
A	0.1998		μ	0.1998
B	0.5488		σ	0.5488
C	1.7348		R²	1.7348
R²	0.9910			

Weibull			Log-normal	
A	0.3377		μ	-0.3445
B	0.4569		σ	0.4517
C	1.1597		R²	0.9899
R²	0.9793			

Weibull			Log-normal	
A	0.3836		μ	-0.4423
B	0.2645		σ	0.3501
C	1.0603		R²	0.9802
R²	0.9539			

Fig. A7. Weibull and Log-Normal distributions (sector 7).

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