REVISION NOTES

In these Revision Notes we explain the changes and corrections we have made to the manuscript according to all reviewers' comments. The document is structured following the sequence: (1) comments from reviewers, (2) authors' response, and (3) authors' changes in manuscript.

At the end of these notes, the revised manuscript showing the new text using highlighting can be found.

REVIEWER #1

This paper describes a method for finding the optimum set of directional sectors for a directional extreme value analysis.

1. ***The goal is interesting and the proposed method seems plausible, but it failed to convince me that the results are optimal. In the example, the sections for analysis are separated from each other. Why are the proposed sectors superior to sectors that match the sections? The sections are far enough separated that independence should not be an issue. The intuitive choice would be to pick sectors centered on the sections and as wide as the data appears to be homogeneous. Why is that not better?***

   The reviewer says he is not convinced that the proposed method is optimal. However, the authors do not pretend to be presenting an "optimal" method, but an objective method of directional classification for directional extreme value analysis. The current state of the art on selection of sectors for directional analysis is subjective. In this work, the objective is to propose an objective method "considering the main sources of uncertainty stemming from sector selection: (1) the validity of the model used to characterize the extreme behavior of the sector samples; (2) the goodness of parameter estimation; (3) the capacity of each model to represent extreme behavior in the total amplitude of the corresponding sector; (4) the validity of the working hypothesis of the independence between extreme values in different sectors" (quoted from first paragraph of section 5).

   Whether or not the sectors division is optimal will depend on its application and on the objective function and the constraints of the optimization. This analysis is out of the scope of this manuscript.

   What the authors do intend is the proposed method to be general and not conditioned by the subsequent use made of the directional sectors, e.g. in the case of the example presented in the manuscript, that the method is not conditioned by the structure that is being designed. In this sense, it is possible that, as the reviewer points out, other specific directional partitioning methodologies can be defined for the analysis of the structure in question, and that these can be considered "optimal" for that particular case. It is important to note that the methodological approach and the tools proposed in this paper would also be useful when objectively determining the sectors if the approach proposed by the reviewer is followed (i.e. conditioned to the structure being designed).

   <u>CHANGES TO THE MANUSCRIPT</u>

   We believe that authors' intention with the proposed method is already present in the manuscript (see, e.g., the fourth and fifth paragraphs of the introduction or the first two paragraphs of the conclusions) and, therefore, we have not added any additional comment in this regard.

2. ***According to Table 2 and Figure 7, all of the extreme value fits are good and do not affect the sector choices. But some of the fits in Figure 6 do not appear to be all that good. (Incidentally, I applaud the selection of Figures that give details of the process). The fit for Sector 1 in C45 is considerably higher than the empirical data. Is that related to why the extreme wind speed for Section 1 and T45 is so high? By comparison with results in Figure 4, 26 m/sec does not seem reasonable.***

   The QQ graph for sector 1 with criterion T45 has values between 14 m/s and approx. 17 m/s. It shows that the model slightly underestimates the observations (in less than 0.5 m/s), as opposed to what was indicated by the reviewer.

   The large values obtained for section 1 in the case of criterion T45 (we assume that the reviewer refers to table 4) are likely to come from sector 2, where the fit of the GPD results in a positive shape parameter (approx. 0.1), unlike all others fits, where the shape parameter is always negative (see table 3). This, if you will, highlights once again the drawbacks of using arbitrary sectors for the analysis of directional extremes.

   <u>CHANGES TO THE MANUSCRIPT</u>

   We have made no changes in relation with this question in the manuscript.

3. ***There are a few places where the text is not clear and I had to read farther on through the examples to understand the process. In heading 3.1, what does "agent" at the site mean?***

   Given that the proposed methodology is applicable not only to wind, but also to other directional climatic agents, such as waves or currents, it was decided to use "agents" instead of "wind" in many paragraphs throughout the text to highlight this generality.

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   In the introduction (line 14, page 2), we have specified some examples of "climatic agents" to set this concept clear from the beginning. We have also changed the heading 3.1 (line 21, page 6) in order to highlight the agent that was analysed in the case study.

4. ***On line 7, page 8, what are "two moments"? Are they six hours apart or do they include the whole storm?***

   The whole storm is included. It refers to the absolute maximum difference of the wind direction that can be found between any two points in time within a given storm, taking into account the direction of rotation (clockwise or counterclockwise).

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   To improve the clarity of the text, we have changed the previous explanation to the one above (lines 6-8, page 8).

5. ***On lines 12-14, page 8, are the peak events just the peak Hs in each storm or the peak Hs in each sector in each storm?***

   For every storm, we obtain the peak of the wind speed for each one of the sectors that the storm passes through.

   <u>CHANGES TO THE MANUSCRIPT</u>

   We have replaced the previous explanation with the one above (lines 13-14, page 8).

6. ***The caption for Table 1 would be much clearer if it read "Directional sectors resulting from applying the different selection criteria."***

   We appreciate the reviewer's suggestion and we will include it in the new version of the manuscript.

   <u>CHANGES TO THE MANUSCRIPT</u>

   We have changed the caption for Table 1 according to the reviewer's suggestion (page 11).

7. ***In equation (8), I don't see where the width of the sector appears.***

   The width of the subsector is considered in the calculation of each Poisson parameter nu_s. This parameter indicates the annual rate of peaks within the subsector, therefore it is influenced by subsector's width.

   <u>CHANGES TO THE MANUSCRIPT</u>

   We have improved the explanation with a specific mention to the sectors' width (lines 4-5, page 17).

<u>REVIEWER #2</u>

The paper presents an original method to be employed for the selection of directional sectors for the analysis of the extreme wind speed in order to develop design of structures exposed to wind action. I found the subject of the manuscript relevant for NHESS and I think that it could be of interest for other scientific and engineering field such as, for example, coastal and offshore engineering. The formulation of the problem, the presentation and the discussion of the results are clear and adequately extended. I have some comment and observation about some aspect of the analysis presented by the authors:

1. ***The authors decided to employ a criterion for the selection of directional sectors based on different statistical requirements and indicators. What could be the difference by the use with some sort of clustering techniques (k-means for example, or similar)? Could the authors comment on this point and eventually add some discussion in the paper***

   Starting from the information of wind direction and speed, a cluster analysis methodology would allow to determine subsets of similar data in terms of some distance measure that could be defined in terms of these two variables. This can be seen as a way to define directional sectors for the extreme analysis. However, cluster analysis does not usually include metrics to ensure that data subsets are homogeneous and independent of each other. In turn, the use of cluster analysis requires defining the clustering methodology, the distance measure between data and the number of clusters.

   It is possible that the methodological approach suggested in this article can be adapted to guide the analyst in the definition of these three points in order to obtain directional groups that meet the requirements imposed for the extremal analysis (i.e. homogeneous and independent sectors such that the variance of estimated extremes is minimized).

   <u>CHANGES TO THE MANUSCRIPT</u>

   A formal discussion on this interesting topic would need some introduction and specific details about clustering techniques, which is, in the authors' opinion, outside the scope of this article. Therefore, we believe that the above considerations fit better in the interactive discussion in NHESSD.

2. ***I would make dimensionless the global indicator: instead of varying between 0 and sqrt(3) I would make it varying between 0 and 1***

We agree with the referee that varying the global indicator between 0 and 1 leads to a more direct understanding of its value and it does not change the method or the results in any way.

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We have changed Equation 5 (page 6) according to the referee's proposal, as well as the explanatory text (lines 8-9, page 6).

3. ***I would add some plot about the minimum data for sectors and subsectors (first paragraph of section 3.4)***

The power curves for the Anderson Darling and Kolmogoroff-Smirnoff tests have been obtained as indicated in Appendix A and have been added to the manuscript (section 3.4), along with a more detailed description of their use in this article.

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Three new plots (Figure 4, page 10) have been added to the manuscript and the first paragraph of section 3.4 (lines 20-29, page 9) has been completely rewritten.

4. ***I would put the x scale of figure 4 for criterion C0 varying from 0 to 360 in order to have a visual comparison with Criterion 45 and 90***

Varying the x scale of C0 from 0 to 360 divides sector S3 into two parts (one on the right and the other on the left of the figure). In our opinion, this makes it more difficult to understand the figure and to place the boxplots in a consistent manner. For this reason, although the referee's proposal has some advantages, we believe it is better to maintain the figure 4 in its current state.

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We have not made any changes related to this question in the manuscript.

5. ***May be I miss something but I do not understand why sigma_s and u are in [m] in table 3***

We appreciate the referee's comment. The units for "sigma_s" and "u" are [m/s].

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We have corrected the units in columns 6 and 7 in Table 3 (page 17).

6. ***I would add bound conditions in table 3 in order to have a clear defined picture of the quantities involved***

We agree with the referee that the inclusion in Table 3 of a column with the upper bound of the wind velocity in each sector helps to illustrate the differences between the extreme-value models for each criterion, as indicated in section 4.1.

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We have included a new column in Table 3 with the upper bound of the wind velocity in each sector (page 17), as well as a reference to the nomenclature (line 8, page 17). We have also corrected an error in the bound value for criterion C0 in the text (lines 9-10, page 17).

7. ***There is any effect on the results on the choice of different inter arrival time (different from 5 days)?***

The inter arrival time between independent storms should have a physical/statistical sense and can be chosen either by rational methods or experience. In any case, performing a sensitivity analysis for testing the impact of this parameter on the results is recommended.

In the case study, an inter arrival time of 5 days between the peaks of consecutive storms has been adopted, which leads to 270 storms. Table 1 shows the results for inter arrival times of 2, 5, 7 and 10 days. In all these cases, the number of directional sectors obtained according to the method is three. First column shows the inter arrival time; second one the number of storms; from third to fifth column, the directional sectors; and from sixth to eighth column, the 100 year return value in each sector.

<table>
<tr><th>Δt</th><th>N_s</th><th>S_1</th><th>S_2</th><th>S_3</th><th>$u_{100,S1}$</th><th>$u_{100,S2}$</th><th>$u_{100,S3}$</th></tr>
<tr><td>[days]</td><td>[-]</td><td>[deg]</td><td>[deg]</td><td>[deg]</td><td>[m/s]</td><td>[m/s]</td><td>[m/s]</td></tr>
<tr><td>1</td><td>294</td><td>140-235</td><td rowspan="5">235-290</td><td>290-140</td><td>21.8</td><td>22.1</td><td>20.4</td></tr>
<tr><td>2</td><td>288</td><td rowspan="4">125-235</td><td rowspan="4">290-125</td><td>21.7</td><td>22.2</td><td>20.4</td></tr>
<tr><td>5</td><td>270</td><td>21.8</td><td>22.1</td><td>20.5</td></tr>
<tr><td>7</td><td>256</td><td>21.6</td><td>21.9</td><td>20.7</td></tr>
<tr><td>10</td><td>238</td><td>21.4</td><td>21.8</td><td>20.3</td></tr>
</table>

TABLE 1

Results show how, in the case study, the method is very little sensitive to changes in the inter arrival time. The directional sectors are the same for the inter arrival times of 2, 5, 7 and 10 days and differ in 15 degrees for the inter arrival time of 1 day. The 100 year return values are also consistent, with variations of less than 2.1% in all sectors.

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Results in the case study are little sensitive to changes in the inter arrival time and therefore, the above discussion has not been included in the manuscript to keep it concise.

8. ***It is not clear to me how the threshold has been chosen (and it would be nice to have indication about CHANGES TO THE results depending on the threshold)***

In this study, the threshold used to define the extreme data was chosen by applying the method in Solari et al. (2017), i.e. the threshold that maximizes the p-value of the Anderson-Darling test, under the assumption that the omnidirectional data come from a Generalized Pareto Distribution.

As shown in Table 2, directional sectors are sensitive to changes in the threshold u (first column), i.e., different definitions of what is an extreme value result in different directional sectors. However, for thresholds above the chosen one, the sectors are quite stable (in particular S2). Therefore, if there is no strong criterion for an a priori selection of the threshold, a sensitivity analysis of the results is recommended. In this situation, p0 (now defined as suggested in (b) in column 9) could serve as an indicator for the final choice of the threshold.

u	N_s	S_1	S_2	S_3	$u_{100,S1}$	$u_{100,S2}$	$u_{100,S3}$	p_0
[m/s]	[-]	[deg]	[deg]	[deg]	[m/s]	[m/s]	[m/s]	[-]
14.0	306	20-140	140-195	195-20	19.9	21.5	23.0	0.9489
14.3	**270**	**125-235**	**235-290**	**290-125**	**21.8**	**22.1**	**20.5**	**0.8822**
14.5	251	145-235	235-285	285-145	22.5	22.0	20.5	0.8799
15.0	203	200-235	235-290	290-200	23.0	20.7	21.5	0.8668

TABLE 2

Solari, S., Egüen, M., Polo, M. J., & Losada, M. A. (2017). Peaks Over Threshold (POT): A methodology for automatic threshold estimation using goodness of fit p-value. Water Resources Research, 53(4), 2833-2849.

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The above considerations have been included in the last paragraph of section 4.2 (lines 3-6, page 19).

9. in last line of page 7 there is a typo "rfrg"

We have corrected this typo.

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The wrong word has been deleted (line 19, page 7).

OTHER CHANGES AND CORRECTIONS

We have corrected the wrong details in the reference Solari et al. 2017 (lines 30-31, page 23):

Solari, S., Egüen, M., Polo, M. J., & Losada, M. A. (2017). Peaks Over Threshold (POT): A methodology for automatic threshold estimation using goodness of fit p-value. Water Resources Research, 53(4), 2833-2849.

The selection of directional sectors for the analysis of extreme wind speed

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Abstract. This paper presents a rational method for the selection of the most suitable directional sectors in the analysis of extreme wind loads on structures. It takes into consideration the main sources of uncertainty stemming from sector selection, and leads to the definition of independent and statistically homogeneous directional sectors.

This method is applied to the selection of directional sectors for the calculation of the design wind speed of a structure located at the mouth of the Río de la Plata. The results in the estimated reliability and costs were compared to those obtained with conventional engineering methods revealing significant differences. It was found that the proposed method is a simple and objective tool for the selection of directional sectors, which comply with the working hypothesis of the directional models and offers better guarantees for dimensioning than the use of more traditional engineering approaches for sectorial division.

1 Introduction

Wind directionality effects have a well recognized impact on the characteristics of the extreme wind loads of structures. The methods for dealing with it usually involves the division of available data into sectors (whose statistical behavior is assumed to be homogeneous) and the evaluation of the extreme behavior of the wind velocity in each of them. The implicit decisions involved in this procedure (and its uncertainty) include: (i) the identification of extreme values; (ii) the selection of the optimal model for data fitting; (iii) the definition of the directional sectors for calculation; and (iv) the characterization of the dependence between directional extremes. From all of them, the selection of the sectors, which is the subject of this article, has received the least attention.

Wind tunnel laboratories and building codes have developed multiple methods in order to consider the influence of directionality on the estimation of extreme wind speeds and wind-induced quantities, such as, the "up-crossing method", the "worst case" method, the "storm passage method", etc. (see, for example., Irwin et al. 2005; Isyumov et al. 2014). Among them, the "sector-by-sector" approaches attempt to produce directional wind speeds, or directional wind-speed multipliers, for a discrete number of defined wind directions. The model of extreme values is fit in each sector separately assuming data allocated in sectors is independent. When the directional wind speeds are combined with the measured structural response coefficients, the largest resulting response from any direction is deemed to be an appropriate design value (Holmes, 2015).

Recently, Zhang and Chen (2015, 2016) propose a methodology to estimate the probability distribution of the load responses of structures under extreme wind conditions, which is an extension of the probabilistic methods of Cook and Mayne (1979, 1980). This method allows the study of both, the directional extreme winds and the directional distribution of the response coefficients, separately. If the directional response coefficients are poorly correlated and if they can be estimated from wind tunnel tests for a particular structure, then the main challenge in applying the method is the calculation of the multivariate distribution of the extreme wind directional velocity.

Using a priori defined divisions to this end results, in general, in correlated directional sectors. This complicates the use of these methods, since the dependence structure between the extreme directional values of wind speeds must be modeled using any of the existing approaches (e.g., Simiu et al. 1985; Coles and Walshaw 1994; Solari and Losada 2016). It also poses other potential issues such as the lack of enough data in some sectors or the existence of non-homogeneous populations, among others. Nevertheless, engineering methods generally opt for the use of simple criteria, mainly based on the definition of sectors of fixed amplitude, oriented according to the cardinal directions (see, e.g.Mayne 1979; Cook 1982, 1983; Cook and Miller 1999, which use $30\deg$ sectors). Also, current regulations and guidelines (API, 2000; DNV, 2010; ISO, 2005) for the design of offshore structures (which consider wind directionality but also other directional climatic agents, such as waves and currents), deal with the division of the compass into sectors. The API Recommendations suggest taking the main direction of the agent as the reference direction whereas the DNV leaves this decision to the engineer. As an alternative to these approaches, ISO (2005) proposes the use of naturally defined sectors based on the directionality inherent in the data measured or obtained in reanalysis. However, this guideline does not provide any specific criteria that can be used to implement this approach.

In this work an alternative methodology that defines the distribution of the extreme wind directional velocity in a non-arbitrary manner is proposed. Both, intrasectorial homogeneity and intersectorial independence conditions are imposed, among others, to obtain the directional sectors. Unlike previous approaches, this methodology results in uncorrelated sectors, so it is not necessary to use dependence models (e. g. copulas) and allows to approximate the multivariate (directional) extreme distribution simply as the product of the marginals. In addition, this method assures directional sectors that contain data in consonance with the working hypotheses of the directional model for the extremes.

This methodology was applied to the study of extreme values of wind speed at the study zone of the mouth of the Río de la Plata, where directional effects are of particular importance. The effect of directional sector selection on the design wind speed of a structure was also estimated. These calculations and their consequences for project design reliability were compared with the results obtained with traditional engineering methods based on the use of divisions with equal size sectors and a northern direction of origin.

The rest of this paper is organized as follows. After defining the research problem, Section 2 delimits the framework and specifies the main sources of uncertainty considered. The methodology for the selection of directional sectors is then explained. The case study in Section 3, describes the wind characteristics in the study zone, followed by the quantification of the impact of sector selection, based on indicators for each source of uncertainty. These results are compared to those obtained with conventional engineering methods. In Section 4, a simple example is used for illustrating the potential consequences of the

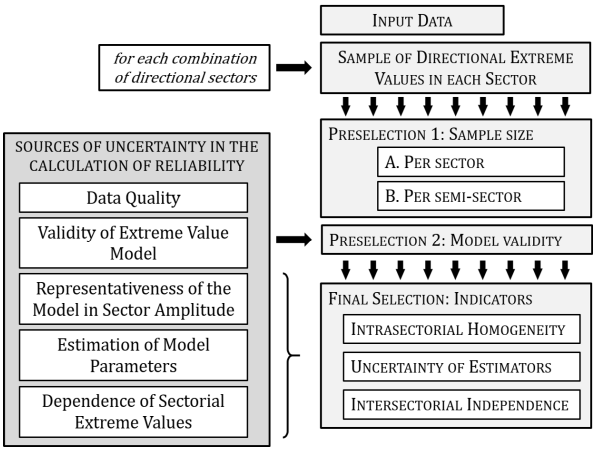

Figure 1. Methodology for sector definition, based on the sources of uncertainty in the calculation of reliability in a system subjected to directional extreme values.

selection of directional sectors for project design reliability. Finally, Section 5 presents the main conclusions that can be derived from this research.

2 Methodology for the specification of directional sectors

2.1 Problem statement

The selection of calculation sectors affects the estimates of directional extreme values, which may impact on the evaluation of project costs and structural reliability. The main factors that influence the result are the following: (1) the procedure followed to identify the extreme events of the sector samples; (2) the validity of the model used to characterize extreme behavior; (3) the goodness of parameter estimation; (4) the capacity of each model to represent extreme behavior in the total amplitude of the corresponding sector; (5) the validity of the dependence model between extreme values in different sectors. All of these factors are in turn conditioned by the quantity of available data and their directional distribution.

For the selection of calculation sectors, this paper describes a procedure that considers the main sources of uncertainty stemming from the choice of sectors. Firstly, the candidate divisions are limited to those whose sectors are compatible with the selected model of extreme values, and which have a given minimum quantity of information. Secondly, the consequences of this selection are evaluated for each division by means of indicators that characterize the intrasectorial homogeneity of the samples, the uncertainty of the estimates of directional extreme values, and their intersectorial independence. Finally, the division with the best overall behavior is selected, based on the set of indicators. This methodology is outlined in the flowchart in Figure 1.

2.1.1 Requirements for the preselection of candidate division

Extreme events are isolated in each sector for different possible angular divisions by means of any appropriate technique, such as peaks over threshold, block maxima (Coles, 2001), weather patterns (Solari and Alonso, 2017), etc. Divisions containing sectors that do not meet the following two requirements are excluded: (1) the division must have the quantity of data minimally necessary to test the validity of the models used for describing the extreme behaviour; (2) the data in each division must also be compatible with these models.

Regarding the first requirement, the minimum acceptable quantity of data in each sector (or semi-sector) should be such that the probability of a Type II error (a false negative finding) in the statistical hypothesis tests that are used in the proposed method is less than a given value β. For this purpose, the power curves of these tests, which relate β to the minimum amount of data, are used. The significance level α and an the effect size of these curves should be defined in consonance to the problem under study. Regarding the second requirement, the extreme events should not be incompatible with the selected model of extreme values. Compliance with this requirement is evaluated by means of bilateral hypothesis testing, e.g., Anderson-Darling (Anderson and Darling, 1952) or Kolmogoroff-Smirnoff (Kolmogoroff, 1941; Smirnoff, 1939), with significance level α.

2.1.2 Selection of the calculation sectors

The next step involves the evaluation of the consequences of sector selection on: (i) the intrasectorial homogeneity of the samples; (ii) the uncertainty of the estimates of directional values; and (iii) their intersectorial independence. To this end, the use of three indicators based on standard statistical analysis and which are measured on a 0-1 scale, is proposed. This approach is also compatible with the use of other indicators specific to the problem under consideration.

The first indicator characterizes the variability of the statistical behavior of extreme events along the arc of each sector. Significant discrepancies between the subsamples of a sector can indicate the presence of different populations, which is incompatible with the hypotheses of the model used. The second indicator reflects the uncertainty of the fit of extreme values by analyzing their asymptotic distribution. Finally, the third indicator evaluates the incompatibility of the sectors with the independence between sectorial extreme values. This independence occurs when each storm event is restricted to one sector and does not move to neighboring ones.

The division selected is the one that shows the best overall performance as reflected in the set of characteristics evaluated by the indicators. This leads to the creation of a new global indicator, which is a function of the other three, and which allows for sorting the candidate divisions according to the selected criterion.

2.2 Specification of indicators

2.2.1 Indicator of intrasectorial homogeneity

In order to compare the statistical homogeneity of extreme values in different regions of the same sector, the sector is divided into two subsectors of equal amplitude (S_1 and S_2). A generalized Kolmogoroff-Smirnoff (Smirnoff, 1939; Kolmogoroff,

1941) test is performed, which evaluates the degree of incompatibility of the two subsamples of POT events in virtue of the null hypothesis that both belong to the same population.

As an indicator of this characteristic in a sector, the p-value of the contrast is used. This indicates the probability, given the null hypothesis H_0 is true, that the KS test statistic, D, has a value that is greater than or equal to that given by the data. The smaller the p-value, the grater the statistical incompatibility of the data with the null hypothesis, if the underlaying assumption used to calculate the p-values holds (Wasserstein and Lazar, 2016). The behavior of the sectors is evaluated by means of the geometric mean given by Eq. 1, where d_m is the test statistic in each sector.

$$\overline{p_1} = \left\{ \prod_{m=1}^{M} Prob\left[D \geq d_m | H_0\right] \right\}^{1/M} \tag{1}$$

2.2.2 Indicator of uncertainty of the estimators

This indicator gives a measure of the uncertainty stemming from the choice of sectors, in the estimations of extreme values. This uncertainty is characterized by analyzing the asymptotic distribution of the extreme values within the context of Delta method hypotheses (e.g. Coles 2001). For this purpose, in each sector, the probability corresponding to the intervals defined by means of the estimated extreme value and a discrepancy $\pm\varepsilon_0$ is evaluated. The performance of the set of sectors is calculated by means of the geometric mean of the results obtained for each one, as shown in Eq. 2.

$$\overline{p_2} = \left\{ \prod_{m=1}^{M} \left[1 - 2\Phi_{0,1}\left(-\frac{\varepsilon_0}{\sigma_{E_m}} \right) \right] \right\}^{1/M} \tag{2}$$

Where $\Phi_{0,1}(\cdot)$ is the value of the standard normal distribution function, σ_E is the standard deviation of the estimator and the discrepancy ε_0 (%) is a parameter that must be previously defined.

2.2.3 Indicator of intersectorial independence

In the case of completely independent sectors, the following relation is verified:

$$Pr\left[Y \leq x\right] = Pr\left[X_1 \leq x\right] \cap Pr\left[X_2 \leq x\right] \cap \dots \cap Pr\left[X_M \leq x\right] = \prod_{m=1}^{M} Pr\left[X_m \leq x\right] \tag{3}$$

where Y is the annual maximum value of omnidirectional variables, and X_m is the annual maximum value of directional variables in sector m.

The *p-value* of the Kolmogoroff-Smirnoff test (Smirnoff, 1939; Kolmogoroff, 1941) is used as an indicator of the incompatibility of the omnidirectional data with a model based on the independence of sectorial extremes corresponding to a given division (Eq. 3). The null hypothesis H_0 is thus assumed, according to which omnidirectional annual maximum values conform to this model. The sample of omnidirectional annual maximums is checked against the distribution obtained by multiplying directional distributions that are fit to the data. The value of the indicator, $\overline{p_3}$, is given by Eq. 4, where d is the test statistic, corresponding to the sample of omnidirectional annual maximums.

$$\overline{p_3} = Prob[D \geq d|H_0] \quad (4)$$

2.2.4 Global indicator

In order to consider the previous indicators as a whole, the expression in Eq. 5 was used,

$$\|\overline{p_i}\| = \sqrt{\left(\overline{p_1}^2 + \overline{p_2}^2 + \overline{p_3}^2\right)/3} \quad (5)$$

where $\overline{p_1}$, $\overline{p_2}$ and $\overline{p_3}$ are the indicators of the intrasectorial maximum homogeneity, minimum uncertainty in estimations, and intersectorial maximum independence, respectively. All the indicators are measured on the same scale 0-1, where 0 represents the worst qualities and 1, the best.

2.3 Outline of the procedure

The procedure involves the following steps:

1. Identification of extreme events per sector
2. Definition of requirements and conditioning factors (section 2.1.1)
   (a) Requirements regarding data quantity
   (b) Requirements for the validity of the models by sectors
3. Preselection of the sets of sectors that meet these requirements
4. Selection of the calculation sectors (section 2.1.2)
   (a) Evaluation of the indicators in each candidate division (section 2.2)
   (b) Selection of the set of sectors with the best overall indicator value

3 Case study

3.1 Description of the wind at the site

The study site is located in front of the mouth of the Río de la Plata [36° S, 55° O] on the east coast of South America between Uruguay and Argentina (Figure 2). The estuary there is one of the largest in the world and is of great interest from both a social

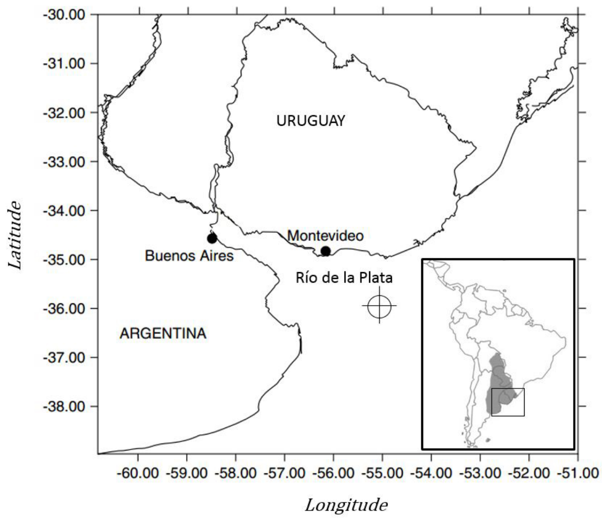

Figure 2. Location of the study site at the mouth of the Río de la Plata

and ecological perspective. Since it is also an extremely active zone of cyclogenesis, it has been the focus of much research (e.g., Framiñan et al. 1999; Guerrero et al. 1997; Solari and Losada 2016).

Atmospheric circulation in the area is controlled by the South Atlantic high-pressure system, which brings hot, humid air to the estuary. In addition, cold-air systems from this anticyclone bring masses of cold air to the zone approximately every four days. This means that wind direction frequently varies since northeasterly winds alternate with southeasterly winds every few days (Simionato et al., 2007).

Furthermore, intense storms, known as "sudestadas" [Southeast blows], often occur during the summer. These events are produced by anticyclonic cells from subtropical latitudes with strong southeasterly winds, loaded with humidity, which bring heavy rain to the estuary. The river's southeast alignment produces rough seas and meteorological tides. During the winter months, masses of cold air from the Antarctic anticyclone ("pamperos") blow from the southeast causing a considerable drop in temperatures.

3.2 Directional variability of extreme events

The research data used in this study come from reanalysis time series of the ERA-Interim program (Dee et al., 2011), belonging to the European Centre for Medium-Range Weather Forecasts (ECMWF). The variables extracted from the database are 10-minute average wind speed components U and V at a height of 10 meters and recorded at a rate of 6 hours. There were 37 years of data available from January 1979 until December 2015. The characteristics of these data (origin, sampling rate, duration and quality of the time series, etc.) add an initial uncertainty that should be considered for the estimation of extreme events. However, in order to focus the discussion on the proposed method, only the sources of uncertainty that arise from the process of directional discretization will be taken into account henceforth.

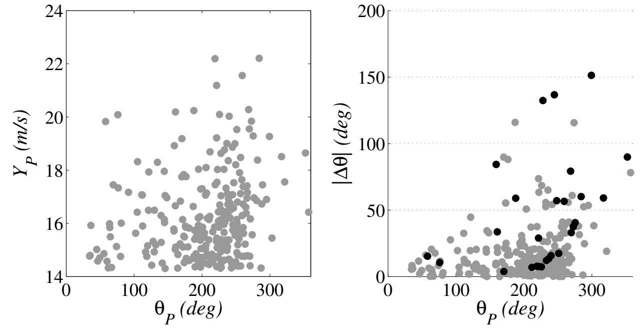

Figure 3. Left panel: Directional variability of the peak velocities of storm events. Right panel: Variability of the angular distance traveled by each storm.

Independent events were identified by applying the Peaks-Over-Threshold (POT) method with a time window of 5 days between storms, to the omnidirectional data. In this way, a total of 270 storms were isolated. Each storm was characterized by its maximum wind speed Y_i^P, the corresponding direction θ_i^P and its angular distance traveled $|\Delta\theta|$. The magnitude and frequency of occurrence of the variable (left panel of Figure 3) suggest that direction is a relevant covariable for the characterization of extreme events. The right panel of Figure 3 shows the maximum angular distance traveled by each storm depending on θ_i^P. For this calculation, the time evolution curve of the direction of each storm event was reconstructed and the absolute maximum difference of the wind direction that can be found between any two points in time within a given storm, taking into account the direction of rotation (clockwise or counterclockwise), was evaluated.

There were significant variations in direction with regard to the values where the peaks occurred. More specifically, there were displacements greater than $45°$ in 12% of the storm events, and one third of them (black dots) have maximum associated wind speeds higher than those in the 90^{th} percentile. This indicated that storm events can extend over more than one directional sector and, therefore, a potential dependence between the extreme values of neighboring sectors.

To take into account this directional dissipation in the extreme value modeling (Jonathan and Ewans, 2007), for every storm, the peak of the wind speed for each one of the sectors that the storm passes through was obtained. The definition of POT events was based on the same threshold obtained from omnidirectional data, which was selected with the method in Solari et al. (2017).

3.3 Analytical framework

The GEV model is often chosen to describe the extremes of natural agents in wind engineering (Brabson and Palutikof, 2000; Gatey and Miller, 2007; Sacré et al., 2007; Torrielli et al., 2013; Valamanesh et al., 2015) and also in several other branches of civil engineering and geosciences. In line with this, a Poisson-Pareto model (Eq. 6) was used to characterize annual maximum values in this work.

$$Pr\left[X_{max} \leq x\right] = exp\left[-\nu\left(1+\xi\frac{x-u}{\tilde{\sigma}}\right)^{-1/\xi}\right], \tag{6}$$

Where ξ, $\tilde{\sigma}$ and u are, respectively, the parameters of form, scale, and location (threshold) of the Generalized Pareto Distribution (GPD), which is fit based on a POT regime (Hosking and Wallis, 1987); and where ν is the Poisson parameter which describes the annual mean rate of occurrence of these events.

To consider the displacement of the storms between sectors, the distribution of the annual maxima in a given sector s, was calculated according to the next steps:

1. Storms were identified as the clusters of sequential values of the omnidirectional wind speed exceeding a given threshold, with a time lag of at least 5 days between their peaks to ensure their independence. In this way, the sequences of wind speeds and directions of the 270 omnidirectional storms were isolated.

2. From the set of 270 storms, the subset of those whose direction belongs at some point to the sector under consideration was selected. The number of these storms was $n_s \leq 270$.

3. For each one of the n_s storms, the maximum wind speed whose direction belongs to the sector s was selected. These set of maximum values was the sample m_s.

4. A GPD with parameters (ξ, $\tilde{\sigma}$, u) was fitted to the sample m_s and the Poisson parameter ν was calculated.

5. The Poisson-Pareto model from Equation 6 was used for describing the distribution of the annual maxima in each sector. From this distribution, any return level can be inferred.

3.4 Values adopted for the definition of requirements and indicators

The power curves of the Anderson-Darling test (Anderson and Darling, 1952) and the KS test (Kolmogoroff, 1941; Smirnoff, 1939) are used to define the minimum number of data in each sector and subsector, respectively. Figure 4 shows these curves, which were obtained for this research by simulation (see the appendix A for more details) for a significance level of $\alpha = 0.05$. The effect size was stated as the absolute displacement between the mean value of the population defining the null hypothesis and the mean value of the population from which the contrasted sample was extracted in each simulation (Kottegoda and Rosso, 2008). Circles, squares and triangles correspond, respectively, to a low (0.25σ), medium (0.50σ) and high (075σ) effect size, where σ is the standard deviation of the reference population for the null hypothesis. As seen in the left panel, for the usual value of $\beta = 0.2$ (probability of false negative) and a medium effect size, the number of data in a sector has to be higher than 30. This value is too low for the KS test between subsamples of a sector to be reliable (upper right panel). According to this, a minimum number of 60 data was chosen for sectors and (see lower right panel for a high effect size) 25 for subsectors.

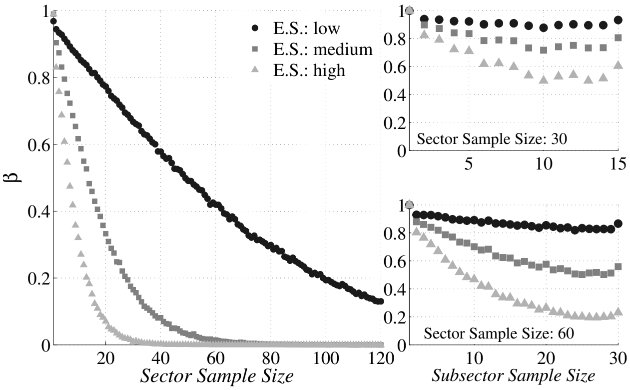

Figure 4. Left panel: Power curves of the AD. test. Upper right panel: Power curves of the KS test for a total sector sample size of 30. Lower right panel: Power curves of the KS test for a total sector sample size of 60.

Furthermore, the study did not consider any division containing sectors that rejected the null hypothesis of the Anderson-Darling test (Anderson and Darling, 1952), with a significance level of $\alpha = 0.05$. To evaluate the $\overline{p_2}$ indicator, a reference return period of $T_r = 100$ years and admissible maximum discrepancy of $\pm\varepsilon_0 = 10\%$ in regard to the estimated value were used.

Finally, some practical limitations to the size of the sectors were considered for this case study in order to reduce the range of divisions considered and to limit computational costs. Specifically, the sector amplitude was restricted to the range from 30° to 300° and only those sectors whose amplitude was a multiple of 5° were considered.

3.5 Effect of the requirements and variation of indicators, depending on directional sectors

The effect of different criteria for sector selection on the extreme value models used to fit the available data was characterized. From now on, the following nomenclature is used to present the results: $C0$ is the criterion proposed in this work (whose definition is summarized in section 2.3) and $T90$ and $T45$ are the comparison criteria, which consist of sectors with a constant width of 90° and 45°, respectively, and a northern direction of origin. Additionally, the definition of criteria $C1$, $C2$ and $C3$ also follows the procedure that is summarized in section 2.3, but at the point 4b of the aforementioned procedure, indicators $\overline{p_1}$, $\overline{p_2}$ and $\overline{p_3}$ are, respectively, used instead of the overall indicator $\|\overline{p_i}\|$.

When applying criteria $C0$, $C1$, $C2$ and $C3$, the selection requirements (section 2.1.1) reduce the number of candidate divisions to 15973. From these divisions, 58.5% correspond to three-sector divisions, 41.4% to four-sector divisions and 0.1% to five-sector divisions. The divisions resulting from each criterion are listed in Table 1. It should be highlighted that only sector S_3 of criterion $T90$ and sectors S_5 and S_6 of criterion $T45$ meet the pre-selection requirements imposed on the other ones ($C0$ to $C3$). This leads to a bias in the guarantees for modeling the directional extreme values given by both sets of criteria and should be kept in mind when judging their results.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Criterion T90	0-90	90-180	180-270	270-360	-	-	-	-
Criterion T45	0-45	45-90	90-135	135-180	180-225	225-270	270-315	315-360
Criterion C0	125-235	235-290	285-125	-	-	-	-	-
Criterion C1	155-235	235-285	285-155	-	-	-	-	-
Criterion C2	170-210	210-265	265-360	-	-	-	-	-
Criterion C3	140-215	215-320	320-140	-	-	-	-	-

Table 1. Directional sectors resulting from applying the different selection criteria

Figures 5 and 6 show the characteristics of the extreme values in each division. Wind direction is represented on the x-axis, where north is zero, and wind magnitude is represented on the y-axis. Each graph presents the sectors that correspond to one of the criteria, as well as the boxplots, which show the median, the upper and lower quartiles, and the variability of the estimated 100 year return values in each sector. The sample of estimations was obtained by means of bootstrapping techniques. For this purpose, the omnidirectional storms were resampled with replacement. The sequence of speeds and directions of each storm remained fixed during each resampling and the size of the resample was always 270 (the original number of storms). Next, the directional 100 year return values from the resample were computed, and this routine was repeated 10000 times to get a precise estimate of the Bootstrap distribution of the statistic.

Also, for each criterion there is a scatter plot showing the data that was used for the fit of the directional extreme values. During any given storm, wind direction may vary in more than one sector and, in these cases, every storm produces more than one extreme value (one for each sector in which it has data). The number of points in each sector is indicated with the letter N. These points are shown in colors blue and red. Blue points are the peak values of the omnidirectional storms. Hence, there are 270 blue points summed over all sectors. The red ones are the maxima in each sector of those storms whose omnidirectional peak occurred in a different sector. These points introduce dependency between the extremes of each sector, and the number of them is indicated with the letter n. Finally, threshold exceedances that do not take part on the fit are depicted in grey.

A comparison of the accuracy of the extreme value models that were used to fit the directional data of each criterion is shown in Figure 7. It depicts the quantile plots for the criteria $T90$ (row 1), $T450$ (rows 2 and 3) and $C0$ (row 4), where the x-axis corresponds to the empirical data and the y-axis to the models.

Figure 8 measures the performance of each solution obtained in regard to indicators $\overline{p_1}$, $\overline{p_2}$ and $\overline{p_3}$. Each indicator is represented along its respective axis, which has its origin in the center. All axes are arranged radially (with equal distances from each other) and all of them have the same scale 0-1. To enhance the understanding of the graphs, the data is connected to form a polygon, and circles of iso-value are also represented. Table 2 shows the values for each indicator for the different criteria.

Criteria $C0$ to $C3$ lead to divisions with three sectors in all cases. A larger one, which roughly covers the W-SE region, and two more in the range where larger and more frequent storms occur. These divisions are consistent with the analysis of

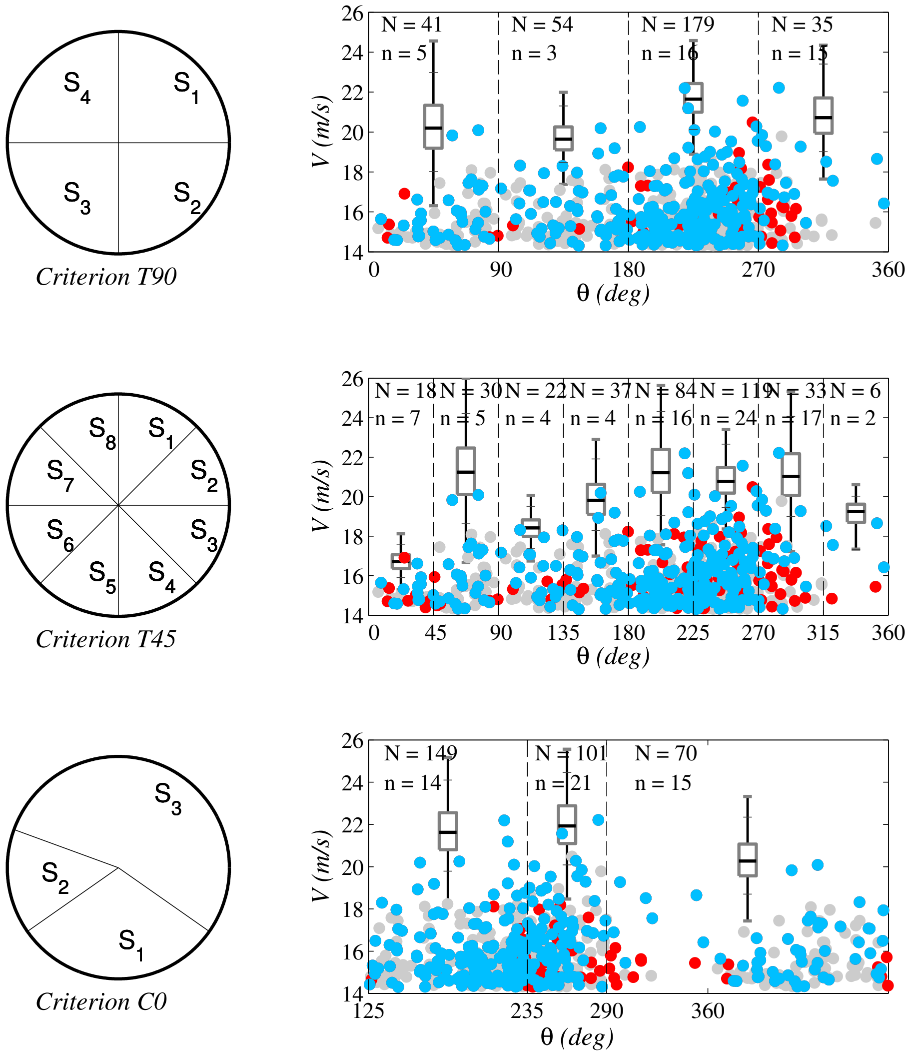

Figure 5. Sectors defined according to criteria T90, T45 and C0

regional wind characteristics. Furthermore, the divisions of criteria $T90$ and $T45$ show worse results in all indicators with striking differences in that of intrasectorial homogeneity and independence of the sectorial extremes.

4 Dependence between sector selection and project design reliability

This section evaluates the effect of directional sector selection on design values and structure reliability. For this purpose, we used the simple example of a structure with three straight sections whose design wind speeds should be adapted to the directional variability of the extreme values of the agent. The normal directions of the sections form angles of $60°$, $180°$, and $300°$ in relation to the north. For ease of exposure, the following working hypotheses are assumed:

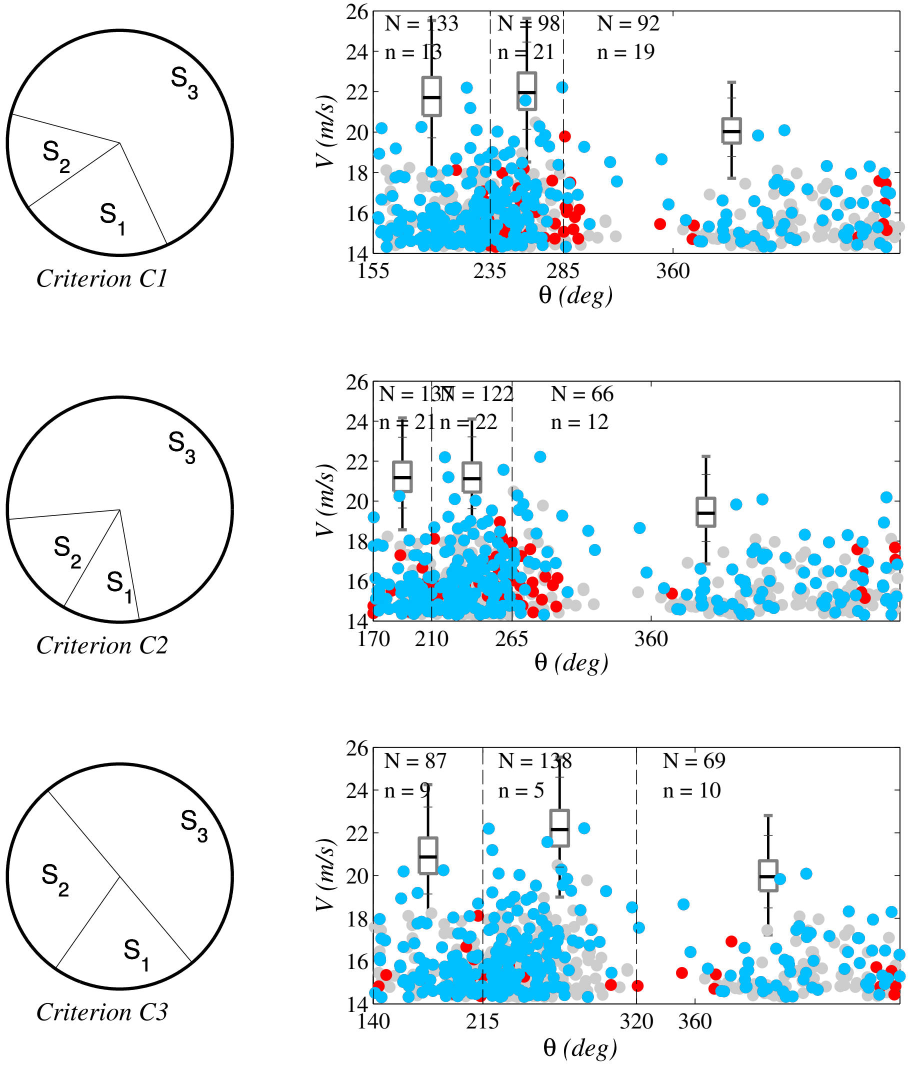

Figure 6. Sectors defined according to criteria $1-3$

1. Failure of the whole structure occurs when at least one of the sections fails.

2. The failure mode does not depend on the direction of the agent's incidence but rather on the section type. In this case, the failure in each section occurs when wind action in the normal direction $\pm 22.5°$ exceeds a given design value and is independent of the failure of the other sections.

3. The response coefficients of the structure are all equal to one.

4. Each directional sector isolates a population of the agent's extreme values with homogeneous characteristics.

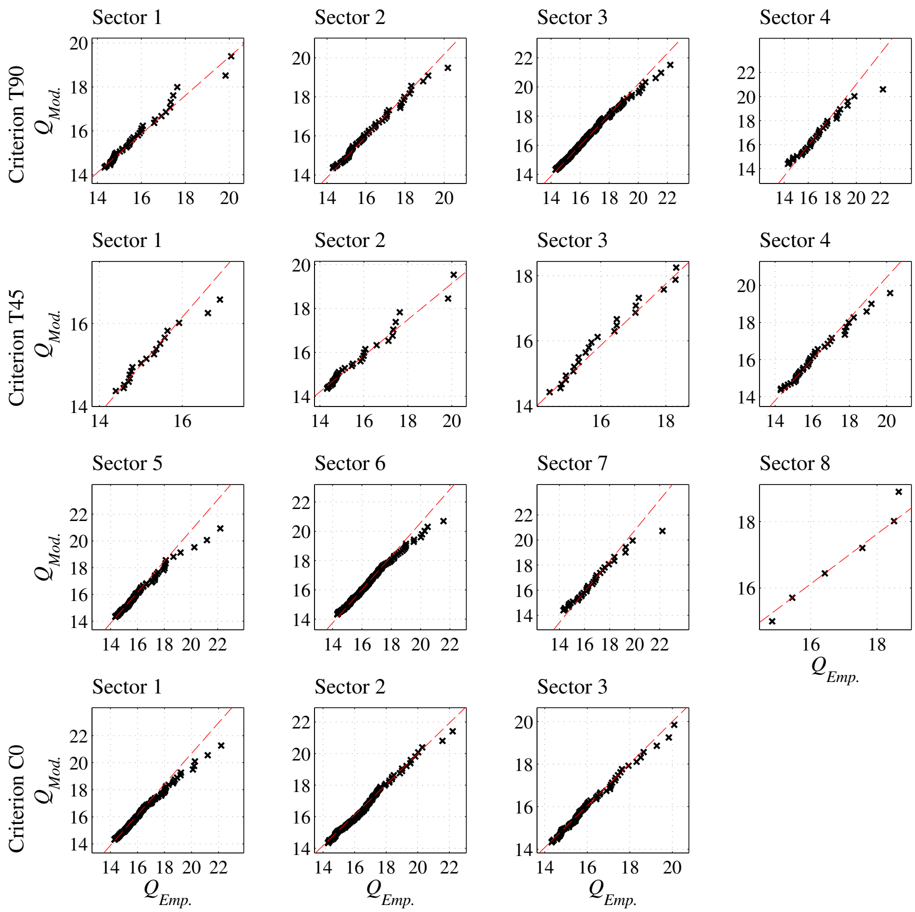

Figure 7. Quantile plots for fitted model in each sector (empirical quantile on the x-axis and model quantile on the y-axis). $T90$: row 1; $T45$: rows 2, 3; $C0$: row 4

	$\overline{p_1}$	$\overline{p_2}$	$\overline{p_3}$
Criterion T90	0.3150	0.9391	0.4571
Criterion T45	0.4031	0.9266	0.2857
Criterion C0	0.8485	0.9421	0.8527
Criterion C1	0.9589	0.9512	0.6543
Criterion C2	0.6111	0.9739	0.4790
Criterion C3	0.4633	0.9440	0.9391

Table 2. Values of indicators for each criterion considered

Given the requirement that the overall failure probability in the useful life of the structure is lower than a given value $P_{f,V}$, there is an infinite number of compatible criteria that can define the failure probability of each section (Forristall, 2005).

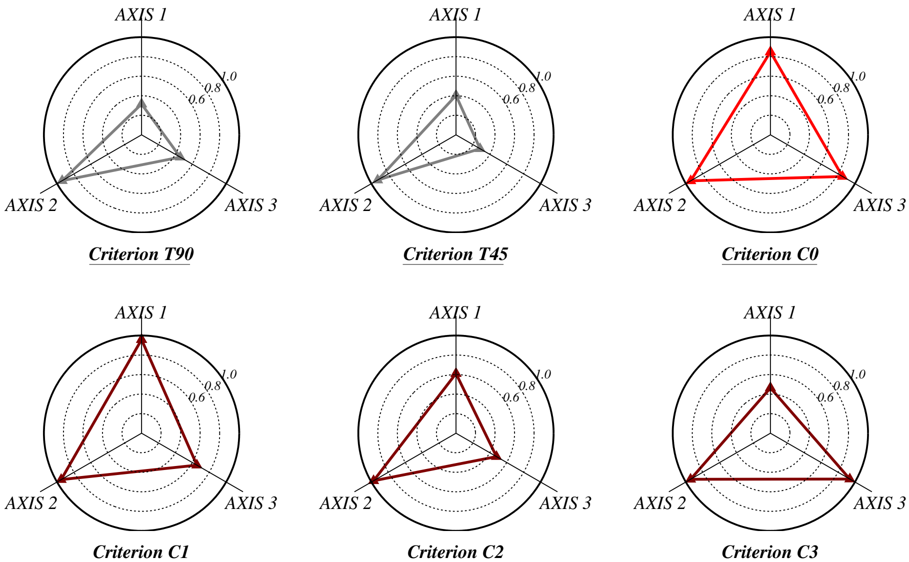

Figure 8. Indicators $\overline{p_1}$ (axis 1), $\overline{p_2}$ (axis 2), and $\overline{p_3}$ (axis 3) for each criterion considered

Jonathan and Ewans (2007) propose fixing these probabilities by minimizing the total cost C of the structure, which they define as an arbitrary function of the value of the design agent expressed as $C = K\sum_{n=1}^{N} x_n^2$, where x_m is the design value in each section and K is a constant. This research proposes an alternative function C that incorporates two summands: (i) the construction cost $C_c(x_n)$, which depends on the value of the design agent; (ii) the risk at each section obtained as the product of its probability of failure $P_{f_n,V}$ and its consequences c_n (Losada, 2010) (Eq. 7).

$$C = \sum_{n=1}^{N} C_c(x_n) + \sum_{n=1}^{N} c_n P_{f_n,V} \tag{7}$$

We compared the design obtained with the sectors defined according to criterion $C0$ with the result of applying (a) the omnidirectional analysis (where the design value of the wind speed is the same for the three sections) and (b) the sectorial divisions obtained from criteria $T90$ and $T45$. For each section and criterion, Figure 9 shows the range of directions that can cause failure (in gray) as well as the directional sectors involved.

Assuming a section n, which is affected by a number S of directional sectors, the probability of an annual failure $P_{f_n,1}$ is obtained with Eq. 8. This equation expresses the complementary value that the annual maximum of the agent not exceed the design value x_n in any of the subsectors s (which are assumed to be independent) and where ν_s, is the Poisson parameter, and ξ_s and $\widetilde{\sigma_s}$ are, respectively, the form and scale parameters of the fitted generalized Pareto distribution in this subsector.

$$P_{f_n,1} = 1 - \prod_{s=1}^{S} Pr\left[\underset{1}{X_{max,s}} \leq x_n\right] = 1 - \prod_{s=1}^{S} exp\left[-\nu_s\left(1+\xi_s\frac{x_n-u}{\widetilde{\sigma_s}}\right)^{-1/\xi_s}\right] \tag{8}$$

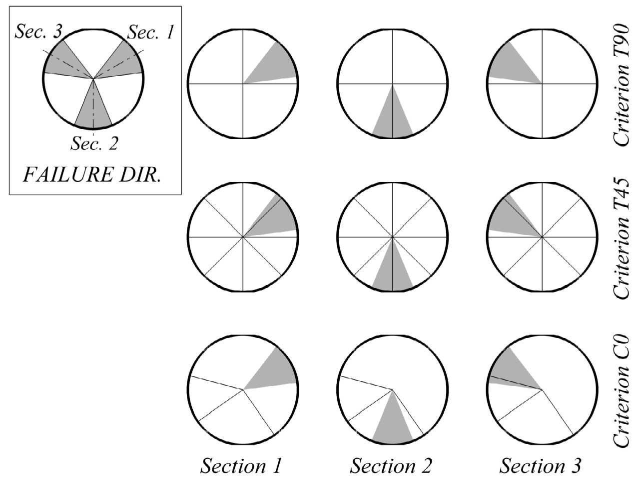

Figure 9. Failure regions in each section and their relation with the sectors of criteria $T90$ (upper row), $T45$ (middle row) and $C0$ (bottom row)

For a maximum admissible failure probability of p_0 and a useful life of V years (Eq. 9), the following optimization problem was formulated:

$$
\begin{aligned}
&\min \quad C = C(x_n, c_n) \quad \forall n \in \mathbb{N}[1,N] \\
&\text{subject to:} \\
&\qquad P_{f_n,1} \leq 1 - (1 - p_0)^{1/V} \\
&\qquad x_n = \underset{n}{max}\{x_s\} \\
&\qquad x_n \in \mathbb{R}^+ \quad \forall n \in \mathbb{N}[1,N]
\end{aligned}
\tag{9}
$$

Where N is the number of sections; $P_{f_n,1}$ is provided by Eq. 8; and x_s is the design value in each of the subsectors that affect the section. For the objective function C, we adopted the expression given by Eq. 10. In this expression, $K = 0.025$ such that the design cost for a wind speed of 20 m/s is 10. The value of the consequences is related to the admissible maximum failure probability in the useful life of the structure (Losada, 2002). Accordingly, $c_n = 50$ was adopted for $p_0 \leq 0.2$ (very low repercussions) and $c_n = 100$ for $p_0 \leq 0.1$ (low repercussions), such the risk is 10 in both cases.

$$
C = \sum_{n=1}^{N} K\, x_n^2 + \sum_{n=1}^{N} c_n\, P_{f_n,V} \tag{10}
$$

Criterion T90	Section	φ_s deg	ν_s [-]	ξ_s [-]	$\widetilde{\sigma_s}$ [m/s]	u [m/s]	u^+ [m/s]	K [-]	CV [-]
Sector 1	1	45	0.554	-0.043	1.482	14.3	48.6	0.0978	0.2076
Sector 2	2	22.5	0.365	-0.441	2.724	14.3	20.5	0.0696	0.1814
Sector 3	2	22.5	1.210	-0.260	2.439	14.3	23.7	0.0339	0.1005
Sector 4	3	45	0.473	-0.504	3.680	14.3	21.6	0.0879	0.2243
Criterion T45	Section	φ_s	ν_s	ξ_s	$\widetilde{\sigma_s}$	u	u^+	K	CV
Sector 1	1	7.5	0.081	-0.466	1.376	14.3	17.1	0.1413	0.3094
Sector 2	1	37.5	0.676	0.110	1.340	14.3	∞	0.0969	0.2417
Sector 4	2	22.5	0.500	-0.353	2.542	14.3	21.5	0.0980	0.2183
Sector 5	2	22.5	1.135	-0.137	1.880	14.3	28.0	0.0622	0.1461
Sector 7	3	37.5	0.743	-0.351	3.109	14.3	23.2	0.0844	0.2308
Sector 8	3	7.5	0.027	-0.750	4.560	14.3	20.3	0.1865	0.5193
Criterion C0	Section	φ_s	ν_s	ξ_s	$\widetilde{\sigma_s}$	u	u^+	K	CV
Sector 1	1	45	0.437	-0.221	1.997	14.3	23.3	0.0599	0.1598
Sector 2	2	45	1.647	-0.157	1.930	14.3	26.6	0.0446	0.1101
Sector 3	3	12.5	0.620	-0.255	2.622	14.3	24.6	0.0474	0.1334
Sector 1	3	32.5	0.315	-0.221	1.997	14.3	23.3	0.0599	0.1598

Table 3. Parameters of the optimization problem for criteria $T90$, $T45$, and $C0$

4.1 Extreme value models

For the omnidirectional analysis we fit a Generalized Pareto Distribution (GPD) to the omnidirectional POT regimen. Next, we used a Poisson-Pareto model to estimate the distribution for the annual maxima in the range of directions that can cause failure of each sector. To take into account the width of the resulting directional ranges, the Poisson parameter was evaluated into them. For the directional results we followed the same scheme but the GPD was fit to the directional POT regimes according to the divisions of each criterion.

Table 3 shows the characteristics of the extreme-value models that intervene in the optimization problem of each criterion. The differences between criteria can be seen, for example, in the upper bound (u^+) for wind speed in each section, which is limited by $u - \widetilde{\sigma_s}/\xi_s$ if $\xi_s \leq 0$. The greater discrepancies can be found in Section 1, where this bound is 48.6 m/s for criterion $T90$, 23.3 m/s for $C0$, and it does not exist for $T45$. For measuring how well the GPD fits the input data, the last two columns show, respectively, the statistic K and the critical value CV of the KS goodness of fit test with a significance level of 0.05. In all cases, the test statistic is less than the critical value.

	Vel. [m/s]	$T90$	$T45$	$C0$	*Omni.*
$p_0 \leq 0.2$	*Section 1*	23.21	26.01	21.79	23.08
	Section 2	22.86	23.61	23.55	23.08
	Section 3	21.59	22.85	23.36	23.08
$p_0 \leq 0.1$	*Section 1*	23.98	27.63	22.06	23.32
	Section 2	23.04	24.06	23.92	23.32
	Section 3	21.60	22.95	23.62	23.32

Table 4. Optimization results for criteria $T90$, $T45$, $C0$ and omnidirectional analysis for $p_0 = 0.2$ (top rows) and $p_0 = 0.1$ (bottom rows)

4.2 Optimization and design wind speeds

The optimization problem was solved with an interior point algorithm (Byrd et al., 2000). Table 4 shows the design wind speeds obtained in each section, depending on the criterion ($C0$, $T90$, $T45$ and omnidirectional). The upper rows of the table show the results for an admissible maximum failure probability in $V = 50$ years of $p_0 \leq 0.2$, whereas the lower rows show the results for $p_0 \leq 0.1$.

All the comparison criteria ($T90$, $T45$ and omnidirectional) show design wind speeds for each section that differ from those of criterion $C0$. Consequently, directional sectors selection can be decisive in the project design if cost is a relevant factor. The greatest discrepancies occurred in section 1. With criterion $T90$, there are variations of 6.54% with $p_0 \leq 0.2$ and of 8.67% with $p_0 \leq 0.1$. With criterion $T45$, there are variations of 19.36% for $p_0 \leq 0.2$ and of 25.24% for $p_0 \leq 0.1$. With the omnidirectional criterion, variations are 5.91% and 5.70%, respectively.

By definition, the design wind speeds corresponding to each criterion fulfill the requirements of the optimization problem, in accordance with their respective probability models. However, only the sectors of criterion C0 have been selected objectively in consonance with the working hypothesis of the directional model for the extremes and, therefore, they offer better guarantees for dimensioning. Thus, in order to compare the impact of ñdesign wind speeds on both, the failure probability during the useful life of the structure and the cost function (Eq. 10), the extreme-values model corresponding to $C0$ was used as a reference.

Table 5 indicates the total failure probability in the useful life of the structure and the result of the cost function. These values were calculated by entering the design wind speeds of each criterion in the directional model obtained from $C0$. The first rows show the results for $p_0 \leq 0.2$, and the last ones show those for $p_0 \leq 0.1$.

Solving the optimization problem for criterion $C0$ led to solutions far from the edge of the validity region. The design wind speeds obtained with the other criteria increase the probability of failure but fulfill the design requirements, with the exception of $T90$ criterion. Particularly noteworthy is the result with $T90$ for $p_0 \leq 0.1$, which almost doubles the maximum acceptable probability of failure during useful life. Regarding the cost function, notable differences can be found, with increases by 26.7%, 12.6% and 3.7% for $T90$, $T45$ and omnidirectional criterion, respectively for $p_0 \leq 0.2$, and 55.8%, 18.9% and 4.6%

		T90	*T45*	*C0*	*Omni.*
$p \leq 0.2$	P_f	0.2584	0.0348	0.0260	0.0445
	C	51.5713	45.8301	40.6956	42.1913
$p \leq 0.1$	P_f	0.2473	0.0265	0.0111	0.0263
	C	64.7100	49.3822	41.5331	43.4366

Table 5. Failure probabilities and cost function (Eq. 10) of $T90$, $T45$, $C0$ and omnidirectional criteria for $p_0 \leq 0.2$ (top row) and $p_0 \leq 0.1$ (bottom row)

for $p_0 \leq 0.1$. These differences show that the selection of directional sectors can have significant implications for the calculation of structure reliability and costs and, thus, should be included as an integral part of project design.

On a final note, the selection of the threshold is an additional source of uncertainty that can affect the results. Different thresholds imply different definitions of what is an extreme value and, hence, result in different directional sectors. If there is no strong criterion for an a priori selection of the threshold, a sensitivity analysis of the results is recommended. In this situation, p_0 could serve as an indicator for the final choice of the threshold. Additionally, preliminary analysis suggest that the calculation of reliability may be also sensitive to the directional variability of the threshold. Nevertheless, a deeper study is still needed to properly incorporate the effect of this variability on the definition of homogeneous and independent sectors and its impact on the uncertainty of the results.

5 Conclusions

This paper has described a procedure for the selection of directional sectors in a non-arbitrary manner, considering the following sources of uncertainty: (1) the validity of the model used to characterize the extreme behavior of the sector samples; (2) the goodness of parameter estimation; (3) the capacity of each model to represent extreme behavior in the total amplitude of the corresponding sector; (4) the validity of the working hypothesis of the independence between extreme values in different sectors.

This research led to the following conclusions. Firstly, the results of modeling the directional extreme behavior of natural agents can be affected by the choice of directional sectors used for calculation. Secondly, the selection of sectors without considering the extreme properties of the data negatively affects the confidence in the estimates on which the project design is based. This makes the use of sectors of equal amplitude not recommended, without sufficient justification. In this sense, the method presented in this research is an objective tool for the selection of directional sectors, which also facilitates the application of standard calculation procedures since it leads to homogeneous and uncorrelated sectors. The results obtained show that it offers better guarantees for dimensioning than the use of more conventional engineering approaches based on divisions arbitrarily chosen, because it reduces the sources of uncertainty in the estimation of design values. Furthermore, this method also assures that sector division by direction is in consonance with the working hypotheses of the directional model. This means that quantification of probabilities is applied within the validity range of this model.

The method was applied to the selection of directional sectors for the calculation of the design wind speed of a structure located at the mouth of the Río de la Plata. The impact that choice of method would have on the failure probability during the useful life of a structure was analyzed, and the results with the proposed method were compared to those based on divisions with equal size sectors and a northern direction of origin. It was found that the procedure followed can have significant repercussions on the cost estimate and reliability, and thus condition the viability of an investment project. Consequently, decisions regarding sector selection should be an integral part of the project design process.

Appendix A

The procedure for obtaining the power curves for the Anderson-Darling test, whose null hypothesis, H_0, is that the sample belongs to a population with a distribution function, $F(x) \sim GPD(\xi, \tilde{\sigma}, u)$ with mean μ and standard deviation σ, was the following:

1. Select the significance level α and effect size c.
2. Define the parameters of a generalized Pareto distribution $G(x) \sim GPD(\xi^*, \tilde{\sigma}^*, u)$ with mean value $\mu^* = \mu + c$ and standard deviation σ.
3. Simulate a number N of random samples with a distribution function $G(x)$ for each sample size of interest.
4. Obtain the result (rejection/non-rejection) of the Anderson-Darling test for each simulated sample.
5. Obtain the value of β for each size as the quotient of the number of positive results and the total number of simulations.

Similarly, the power curves for a Kolmogoroff-Smirnoff test whose null hypothesis, H_0, is that two samples belong the same population, can be obtained as follows:

1. Select the significance level α of the effect size c and of a sample size M.
2. Define the parameters for two generalized Pareto distributions: (i) $F(x) \sim GPD(\xi, \tilde{\sigma}, u)$ with mean μ and standard deviation σ, (ii) $G(x) \sim GPD(\xi^*, \tilde{\sigma}^*, u)$ with mean $\mu^* = \mu + c$ and standard deviation.
3. Simulate a number N of random samples with distribution function $F(x)$ and $G(x)$ for each value of $\tilde{m} = min|m, m'|$ of interest, where m and m' are, respectively, the sample sizes of $F(x)$ and $G(x)$, and $m + m' = M$.
4. Obtain the result (rejection/non-rejection) of the Kolmogoroff-Smirnoff test for each pair of simulated samples.
5. Obtain the value of β for each size $\tilde{m}$ as the quotient of the number of positive results and the total number of simulations.

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