Characterization of the Sea State in the Brazil's Offshore Area

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1. INTRODUTION

Ship's design, like offshore structures, demands information of the real world (Ochi, 1998), specifically information of oceans and seas where they will sail or be installed. This extends to its planning and operability. This information allows that operational, structural and safety requirements are fulfilled and that financial resources are used in an effective manner.

The main parameter used to characterize the sea's state (is the significant wave high (H_s). It expresses the severity of the state of the sea (Guedes Soares e Scotto, 1997). Long term methods to model H_s occurrence, using the total sample with probabilities distribution like Weibull, Normal Log and its variations have been used. The utilization of methods in which the extreme value theory is applied with the annual maximum method to calculate extreme values of H_s has been recommended. To overcome the limitations of this traditional methods (low quality of adjust in the tail region for the first, and short size of the sample for the second), many authors have been developing studies based on the utilizations of the POT (Peak Over Threshold) method. This method is said to be robust to face extrapolation problems.

H_s's association with the wave period cannot be left aside. The floating structures motions' magnitude can achieve critical levels to its integrity, if the wave period is close to the system's natural period (Ochi,2000). This is valid even for structures that have a high value for design wave height.

This work general objective is to determine long term bivariate probabilistic models to the significant wave high and peak period, and to determine unvaried probabilistic models to estimate extreme significant wave high values to be used in offshore platform's design, vessels' design and operation planning in the oil and gas industry. The specifics objectives are to analyze (through algorithms developed in MATLAB®) wave data in five points of the Atlantic Ocean in Brazil's offshore area; and to estimate extreme significant wave high values through three different methods.

2. STATE OF ART

2.1. *Estimated Extreme Valou for H_SEstimativa de Valores Extremos de H_s*

When analyzing the state of the sea, the most relevant characteristic is the significant wave high, because of that many authors have studied it. When it comes to estimating extreme values, one should highlight the work of Guedes Soares and Scotto (2011) that shows a revision of long-term models for wave parameters in many time scales. According to their work, the propositions of distribution that show better adjustments for H_s using all the sample data are: Lognormal distribution, Weibull's distribution, the combination of Lognormal (lower region) and Weibull (upper region) and the generalized Gamma distribution. The authors refer the difficulty of getting a robust answer (even with the help of adjustments test) for the ideal model when the area of interest is in the tail (extreme waves). The authors also attest that when using these models to calculate return values, one needs other grounds besides the adjustments test, since the model may lead to result under or overestimated.

Soares Guedes and Scotto (2011) discuss if (when working with long term models) all data gathered through the years should be used as a homogenic sample or if it should be clustered according to, for example, seasons of the year, with the intend to avoid alterations related to seasonality.

The authors also refer to the application of the distribution of Generalized Extreme Values (GEV) and its application with the Annuals Maximum method, where it is select the higher value for each year and a GEV distribution is adjusted to this set of maximus. The simplicity of using only the set of maximum data is an advantage, but this method will reduce the data available to adjust the parametric distributions.

The POT (Peak Over Threshold) is presented by these authors as an extension of the classic methods. According to them, the POT method adjusts a stochastic model to either the exceedances or the peaks over a threshold. The generalized Pareto distribution is used to the adjustment and, considering a threshold high enough, one can avoid the arbitrary selection of distributions and guarantee the independence of peaks that belongs to different clusters.

Guedes Soares and Ferreira (1998) define cluster as a group of excesses and state that for low threshold the separation of clusters is not well defined, with higher thresholds this lack of definition should disappear.

In the same article, the authors apply the method to calculate extreme waves in the Figueira da Foz region (Portugal). They conclude that the exponential distribution is proper to the region and that the POT enable the use of much more data, compared with the Annual Maximum method.

Caires (2011) presents a study about estimating extreme wave values using two temporal series, one to shallow waters in the North Sea, the other to deep waters in the Pacific Ocean. The author suggests the utilization of POT method combined with the GDP and the AM method with the GEV. She also suggests the utilization of the POT method in the cases where there is scarce data.

Campos and Guedes Soares (2016) extend the application of the POT method to Brazil´s offshore area Campos Basin, using both the data obtained by the spectral wave model WAVEWATCH III (Tolman, 1991), and the obtained by directional buoy. The authors also analyze extreme events with different origins: cyclones and anticyclones.

2.2. *Description of the Sea State Based on Long Term Wave Data*

Guedes Soares and Scotto (2011) refers that to the design and operation of ships, long term H_s distribution alone is not enough. Knowing one of the characteristics periods, the peak period (T_p) or the medium peak (T_m), is needed. They present a revision of works approaching methods to obtain long term bivariate distributions. The first method combines the marginal distribution of H_s and many distributions of wave period. It´s use holds on the premise that H_s is the most important parameter to ocean´s structure´s projects while any of the periods has limited influence. The second method is about the transformation of set data in a Gaussian model using a Box-Cox variant of transformation. The third method involves applying Placket´s bivariate structure to the adjust of H_s and T_p. The last one is a method to the construction of the bivariate distribution H_s x T_m from a non-parametrical model.

Lucas et al (2015) approach three methods of joint distribution to describe the conditions of the sea´s state. In their study the variables used in the joint distributions were: wave significant high and the zero ascendant medium period applied to each component of the two peaks spectrum (meaning swell and wind sea) using 12 years of data from the Australian´s coast. The methods used in the study were: conditional modeling approach (CMA), Plackett´s model, and also the Box-Cox transformation of data, with the objective of making them approximately normals to finally adjust a normal bivariate distribution of the transformed data. The conclusion was that the best result is obtained with the CMA method due to it´s flexibility to include many conditionals distributions.

3. METODOLOGY

Three methods were used to estimate extreme H_s values:

- Total sample/Weibull distribution
- Annual maximum/Gumbel distribution
- POT/GPD

To adjust the H_s and T_p bivariate distribution the CMA method was selected.

Each one of these methods and its applicability in this work, including the identification of estimators is presented next.

3.1. *Extreme value for H_s*

Total Sample with threshold/ Weibull distribution

The total sample method with threshold is based on the classical methods, where one parametric distribution is fitted to total sample.

As the interest in this work is to calculate the extreme value for the H_s, a modification was considered: one threshold is defined by the analyst to eliminate the influence of the realizations below it.

The figure 1 illustrates the fitting obtained using the minimum least squared method and a Weibull probability paper. The threshold is represented by the vertical red line. The model obtained is represented by the inclined red line.

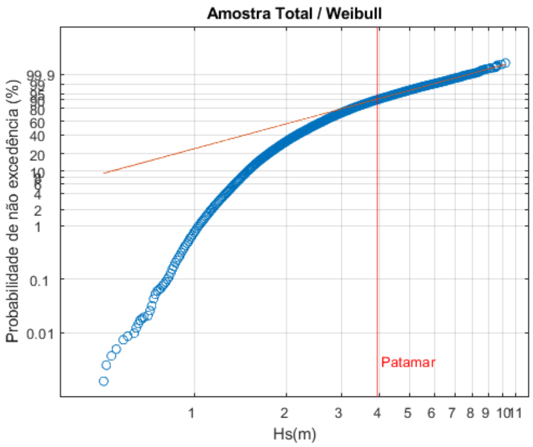

Figure 1 – Weibull probability paper and the model obtained using the sample above the threshold.

It is important to note that, according to this method, one line should be formed by the empirical probability if it could be totally fitted by Weibull distribution.

Once the data form an arc, it is clear that is impossible to obtain a model that can be considered as a good fit. One solution, as cited above, is dived the data, and fit the distribution to the interest region.

In this work, the threshold selection follows the steps below:

a) Sort the sample in ascending order;
b) Select the lowest value of H_s in the 1/10 top group;

The rationale behind it, is to assure that the realizations selected belongs to the tail region and to avoid scarce sample size.

The Weibull method was selected once it has been applied to model the tail region by other authors.

As the distribution parameters were calculated by the minimum least square methods, the Weibull linearization is presented by the expression 3.1.

$$\ln\left[-\ln\left(1-\mathrm{F}(\mathrm{x})\right)\right] = \xi \ln(\mathrm{x}) - \xi \ln(\sigma) \qquad (3.1)$$

where ξ is the shape parameter and σ is the scale parameter.

Once the model parameters are defined, it is possible to calculate the return value.

Os parâmetros para a distribuição de Weibull foram então determinados a partir dos coeficientes obtidos após aplicação dos métodos dos mínimos quadrados

Por fim, os valores extremos foram calculados realizando extrapolação baseada em períodos de retorno entre um e cem anos

Annuals maximum/GUMBEL´s distribution

The maximum annuals method consists of selecting the realization of higher value for each year period. The result is a sample of annual maximum, that in this work will be adjusted to a Gumbel distribution. The Gumbel's CDF expression is show below:

$$F(x) = \exp\left\{-\exp\left[-\frac{(x-\mu)}{\sigma}\right]\right\} \qquad (3.2)$$

Where σ is the scale parameter and μ is the location parameter.

Gumbel is one of the possibilities form of the GEV distribution and its utilization is partially backed up by the Theory of extreme values. Caires (2011) provides more details on that matter.

The application of the method is similar to the one shown in the anterior item. The minimum least squares method was also used as an estimator of Gumbel´s distributions parameters. The Gumbel´s CDF linearized expression is presented below::

$$-\ln[-\ln F(x)] = \frac{x}{\sigma} - \frac{\mu}{\sigma} \qquad (3.4)$$

The method can be summarized as following:

a) Obtain the annual maximum sample from the H_s total sample;
b) Sort the annual maximum sample in ascending order and attributed an index to each realization. In the case of realizations with the same value, the higher index during and after sorting was used;
c) Calculate of the empiric cumulative probability (graphic position) using the expression $\tilde{F}\left(x_{(i)}\right) = \frac{i}{n+1}$, where i is the index and n is the maximum annual sample size;
d) Linearize the empiric cumulative probability $-\ln\left[-\ln\left(\tilde{F}\left(x_{(i)}\right)\right)\right]$;
e) Apply the minimum least square method to estimate the Gumbel's parameters;
f) Calculate the extreme values for H_s, considering extreme periods in the interval between 1 and 100 years.

POT/ GPD

The POT method consists in considering a random sample $x_1, \ldots, x_n$ classified as independent and identically distribuend (iid), select a high threshold u above which the extreme values, or the exceedances $x_i\colon x_i > u$, are situated. Label these exceedances by $x_{(1)}, \ldots, x_{(k)}$, and define threshold excess by $y_j = x_{(j)} - u$, for $j = 1, \ldots, k$. Then it is possible to assume that y_j can be approximeted by a member of generalized Pareto family. The theory that allows this approximation can be found in Coles (2001).

The threshold choice assume an important role for the POT method once the selection of too low threshold is likely to violate the asymptotic basis of the model, leading to bias, while a too high threshold will generate few excess with which the model can be estimated, leading to high variance (Coles, 2001).

In this work, two methods as defined by Coles (2001), are employed to assist the threshold u selection process. The first one is to calculate the mean of the excess for an interval of possible thresholds. As shown by Coles (2001), the mean of excess of the threshold u is a linear function, for which the sample mean of the threshold excess of u provides an empirical estimate. These estimates are expected to change linearly with u, at levels of u for which the generalized Pareto model is appropriate.

The figure below shows an example of the mean of the excesses value variation with u.

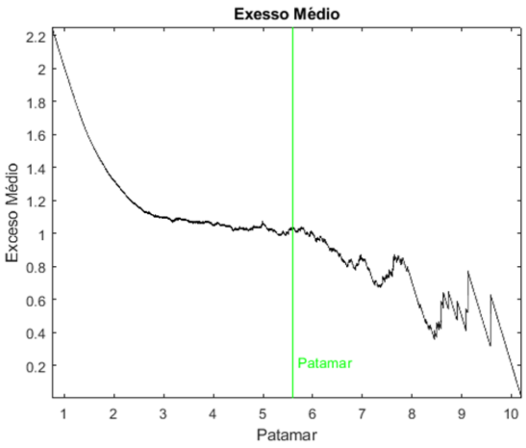

Figure 2 - Example of plot where mean excess varies with threshold.

The second method consist in selecting an interval of possible thresholds and calculate the GPD's scale and shape parameters. As detailed by Coles (2001 if a generalized Pareto distribution is a reasonable model for excesses of a threshold u_0, higher threshold u should also follow the generalized Pareto distribution and the estimates parameters, in this case, must remain near-constant.

To illustrate the process, the following figure shows an example of the scale and shape parameter variation with the threshold.

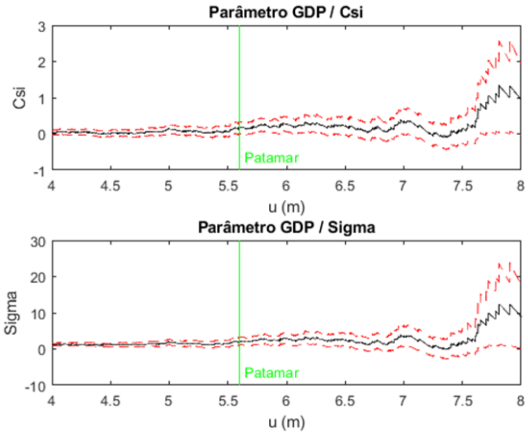

Figure 3 – GPD's scale and shape parameters variation with threshold u.

Once the threshold is selected, the excesses are defined and the GPD distribution can be fitted.

The PWM was selected to estimate the GPD's parameters as recommended by Caires (2011). The calculations were performed using the WAFO's code *fitgenparrange* for MATLAB®.

Eventually, the parameters allow estimation extreme value estimation for H_s.

The POT method applied in this work can be summarized as follows:

a) Prepare the mean of the execess's plot consideringa range of possible thresshold;
b) Prepare the graph showing the scale and shape parameter variation with threshold;
c) Select the threshold based on the linear trend in the mean of excess's plot and in the near constant trend in the parameter's graph;
d) Fit the GPD distribution to the excess sample obtained after the threshold selection;
e) Check the result obtained by QQ Plot, Probability Plot and Cumulative Probability Curve;
f) Calculate the return value for the return period in the interval between 1 and 100 years.

3.2. *Conditional Modelling Approach*

The CMA (Conditional Modelling Approach) model was selected to model a bivariate distribution considering as variables $H_s$and T_p.

Lucas and Guedes Soares (2015) show that the method is based on the total probability theorem, that models a probability density function to H_s and probability density function to T_p conditional to H_s with the objective of estimate the joint probability density function, described in the following expression:

$$f(H_s, T_p) = f(H_s) \times f(T_p | H_s) \qquad (3.5)$$

In wich $f(H_s, T_p)$ is the joint probability density function of H_s e T_p, $f(H_s)$ represents the marginal distribution of H_s and $f(T_p|H_s)$ represents the conditional distribution of T_p. The Lognormal distribution was selected model the marginal distribution and the conditional distributions.

In this work the maximum likelihood method was applied as parameter estimator. The calculations were performed using the WAFO's code *fitlognorm* for MATLAB®.

With the objective of evaluating the quality of the bivariate model´s adjustment to the data, and, based on the work of Lucas and Guedes Soares (2015), the Euclidian distance D^2 between the theorical distribution and empirical of data was used as measurement in the present work. The Euclidian distance measures the distance between the theorical probabilities c_j and the relative frequencies C_j being defined as:

$$D^2 = \sum_{j=1}^{n} \left(c_j - C_j\right)^2 \qquad (3.6)$$

The method is briefly described:

a) Use the Lognormal distribution to fit the H_s sample, modeling the marginal function of probabilistic density of H_s;
b) The initial number of H_s classes is obtained dividing the sample in interval of 0.5 meters;
c) The realizations of H_s are clustered in the classes defined above. The H_s sample indexes are employed to define the T_p sample associated to each class.
d) Evaluate the number of T_p realizations in each class. In the case of scarce sample, the classes must be adjusted, and the process redone until results are adequate;
e) Using the T_p sample obtained to each class, the conditional density functions are obtained fitting the lognormal distribution to theses samples;
f) The distribution of joint probability is finally calculated using the expression 3.5.

4. DATA

When it comes to socio-economic activities in the cost and offshore it is clear that knowing and understanding the marine environment is of huge importance. In Brazil´s case, (9200Km is the cost´s extension, 99 active oil fields and 143 installed platforms) this know is crucial.

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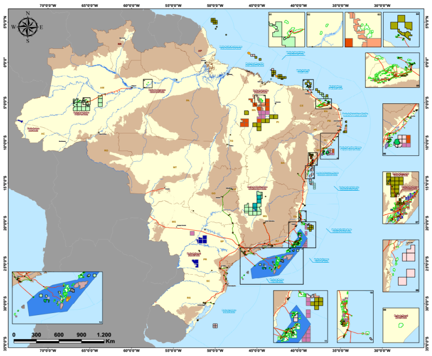

Figure 4 – Brazil' oil fields map - http://rodadas.anp.gov.br/arquivos/mapas/2019/Mapa_Brasil.pdf..

In this work data from reanalysis from five points of Brazil´s cost will be analyzed. This data was produced by the NOAA using a spectral model of waves WAVWWATCH III. These points are in regions of interest for the offshore industry, more precisely they are located in the areas called Campos Basin and Santos Basin.

The record´s frequency is 3h, starting in 1979, ending 2007, resulting 81575 realizations.

Each one of the records shows information of year, month, day, hour, significant high, peak period and main direction.

Figure 5 shows the five points: REG1(22.5S, 39.5W), REG2(22.5S, 45.0W), REG3(29.0S, 48.0W), REG4(27.0S, 41.0W) e REG5(32.0S, 42.0W).

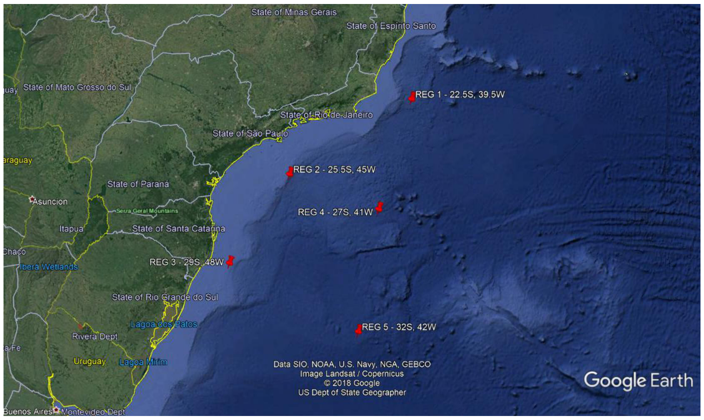

Figure 5 – Geographic location of the 5 points in Brazil´s offshore area (Google Earth adapt).

5. ANALISYS AND RESULTS

5.1. *Total Sample / WEIBULL distribution.*

The Weibull´s distribution fitting was performed considering the realization´s value above the threshold, defined in this study as the inferior limit of the top tenth of the sample.

Table 1 presents the parameters and the return value of significant wave high to return periods equal 10, 50 and 100 years, obtained from the application method.

Table 1 – Size of the sample, threshold´s value, threshold estimated values, and return values for 10, 50 and 100 year for Total Sample Method

Amostra Total com patamar / Weibull							
Caso	Nº Total de Dados	Parâmetros Weibull			Valor de Retorno / H_s [m]		
		u [m]	ξ	σ	10 Anos	50 Anos	100 Anos
REG1	260	2.93	2.00	1.90	2.88	3.76	4.08
REG2	266	2.98	1.99	1.95	2.97	3.88	4.21
REG3	310	3.09	1.78	1.90	3.04	4.09	4.49
REG4	326	3.38	1.77	2.05	3.28	4.43	4.85
RRG 5	433	3.91	1.57	2.26	3.85	5.39	5.99

5.2. Annuals maximum/GUMBEL´s distribution

The results obtained for the annuals maximum method and the estimated parameters to each case analyzed are summarized in table 2.

Table 2 – Sample size, threshold, parameters and returns values for the AM/Gumbel Method

AM / Gumbel						
Caso	Nº Total de Dados	Parâmetros Gumbel		Valor de Retorno [m]		
		μ	σ	10 Anos	50 Anos	100 Anos
REG1	23	4.72	0.43	5.69	6.40	6.70
REG2	27	4.92	0.47	5.99	6.76	7.09
REG3	28	5.42	0.55	6.67	7.58	7.97
REG4	29	5.87	0.65	7.33	8.39	8.85
REG5	27	7.45	0.84	9.34	10.72	11.31

Even though the size of the maximum sample should be ideally equal to the number of years of the original sample, due to the existence of realizations with the same significant wave high, the sample used to the fitting process might be smaller than expected. The total number of data in table 2 shows the final size of the annual maximum sample used for the fitting process.

The coherence of the results is proved as the return values for the return period equal 100 years are superior than the highest realization of H_s of the original sample. Despite of that, the size of the sample used is inferior than the one used in the other two methods, and that may lead to questions about the quality of the distributional models obtained.

5.3. POT / GPD

In the use of POT method, just like in the total sample with threshold method, the choice of the threshold is a choice of the analyst, however there are methods that can be used to help this process.

POT method represents an advance, compared to the annual maximum, when it comes to the size of the sample available (see table 3).

The table 3 shows the sample size, threshold selected, parameters and the return values calculated for 10, 50 and 100 yers.

Table 3 –Result´s summary / POT

POT /GPD							
Caso	Nº Excessos	Parâmetros GPD			Valor de Retorno / H_s [m]		
		u	ξ	σ	10 Anos	50 Anos	100 Anos
REG1	242	3.75	0.20	0.64	4.37	5.09	5.33
REG2	513	3.53	0.20	0.71	4.97	5.56	5.76
REG3	704	3.49	0.10	0.76	5.49	6.31	6.61
REG4	339	4.24	0.13	0.84	5.60	6.56	6.92
REG5	231	5.6	0.19	1.23	6.77	8.18	8.67

In the results, the proximity between the return values for 50 and 100 years draws the attention.

When comparing the maximum H_s of each sample and the H_s estimated value for the return period of 100 years it is possible to notice that in none of the cases the calculated values are superiors. It is also possible to notice that bigger differences were obtained when analyzing the samples REG4 and REG5.

5.4. Joint distribution

The CMA method was applied to each one of the samples in Brazil´s offshore area, the main characteristics are shown in the following table.

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Table 4 - Characteristics Samples H_s e T_p

	REG1		REG2		REG3		REG4		REG5	
Estatística	H_s [m]	T_p [s]	H_s [m]	T_p [s]	H_s [m]	T_p [s]	H_s [m]	T_p [s]	H_s [m]	T_p [s]
Mín.	0.77	3.49	0.16	1.59	0.07	1.77	0.56	3.59	0.51	3.16
Máx.	5.84	23.25	6.31	20.45	7.11	21.58	7.90	21.25	10.21	21.40
Média	2.11	9.66	2.03	9.48	2.11	9.03	2.35	9.57	2.58	9.65
Mediana	2.01	9.51	1.90	9.07	1.97	8.74	2.22	9.27	2.39	9.46
Desv. Padrão	0.62	2.72	0.71	2.35	0.74	2.38	0.79	2.54	1.03	2.43
Assimentria	1.06	0.35	1.06	0.60	1.18	0.44	1.10	0.51	1.34	0.47
Curtose	4.83	2.57	4.54	3.00	5.13	2.94	5.04	2.74	5.87	3.02
Nº Obs.	81575	81575	81575	81575	81575	81575	81575	81575	81575	81575

Table 5 shows the classes considered to model the T_p probability density function conditional to H_s.

Table 5 H_s classes defined to each one of the offshore´s area and size samples

Classe	REG1		REG2		REG3		REG4		REG5	
	Int.[m]	Am.[-]	Int.[m]	Am.[-]	Int. [m]	Am.[-]	Int.[m]	Am.[-]	Int.[m]	Am.[-]
1	[0.50,1.00]	322	[0.00,1.00]	1677	[0.00,1.00]	1392	[0.5,1.00]	351	[0.50,1.00]	612
2	[1.00,1.50]	11829	[1.00,1.50]	17651	[1.00,1.50]	15410	[1.00,1.50]	9186	[1.00,1.50]	7865
3	[1.50,2.00]	28268	[1.50,2.00]	26367	[1.50,2.00]	25726	[1.50,2.00]	21276	[1.50,2.00]	17934
4	[2.00,2.50]	23165	[2.00,2.50]	18241	[2.00,2.50]	19415	[2.00,2.50]	21922	[2.00,2.50]	18478
5	[2.50,3.00]	10915	[2.50,3.00]	9856	[2.50,3.00]	10308	[2.50,3.00]	14498	[2.50,3.00]	14804
6	[3.00,3.50]	4424	[3.00,3.50]	4522	[3.00,3.50]	5102	[3.00,3.50]	7615	[3.00,3.50]	9172
7	[3.50,4.00]	1727	[3.50,4.00]	1928	[3.50,4.00]	2368	[3.50,4.00]	3789	[3.50,4.00]	5342
8	[4.00,4.50]	637	[4.00,4.50]	905	[4.00,4.50]	1103	[4.00,4.50]	1590	[4.00,4.50]	3080
9	[4.50,5.00]	181	[4.50,5.00]	287	[4.50,5.00]	446	[4.50,5.00]	728	[4.50,5.00]	1882
10	[5.00,6.00]	107	[5.00,6.50]	141	[5.00,5.50]	189	[5.00,5.50]	355	[5.00,5.50]	1040
11					[5.50,7.50]	116	[5.50,6.00]	158	[5.50,6.00]	570
12							[6.00,8.00]	107	[6.00,6.50]	340
13									[6.50,7.00]	227
14									[7.00,7.50]	115
15									[7.50,8.00]	50
16									[8.00,10.00]	64

The results were obtained with this method are shown in the following figures:

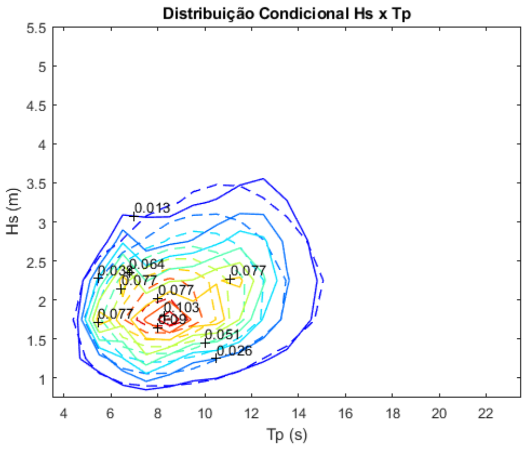

Figure 6 – Results CMA REG 1

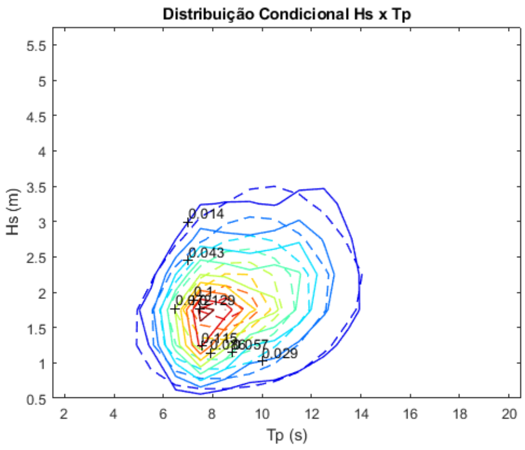

Figure 7– Results CMA REG 2

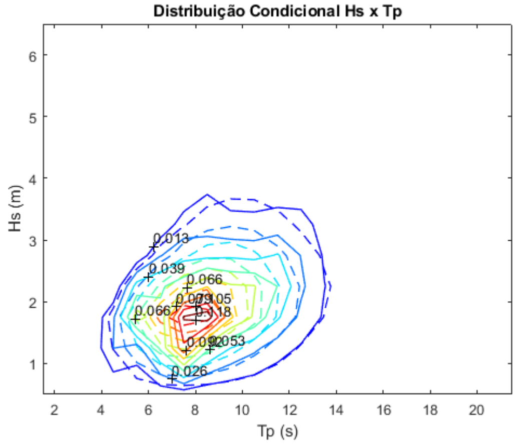

Figure 8– Results CMA REG 3

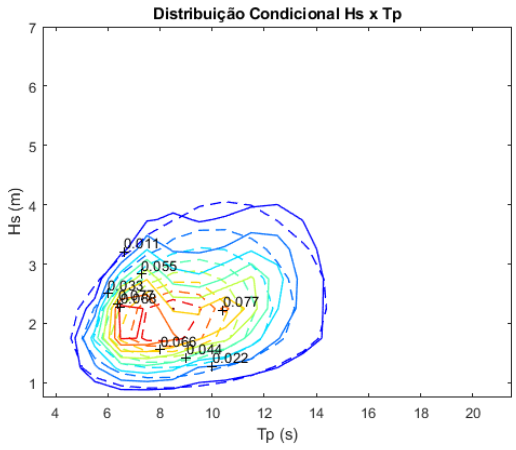

Figure 9– Results CMA REG 4

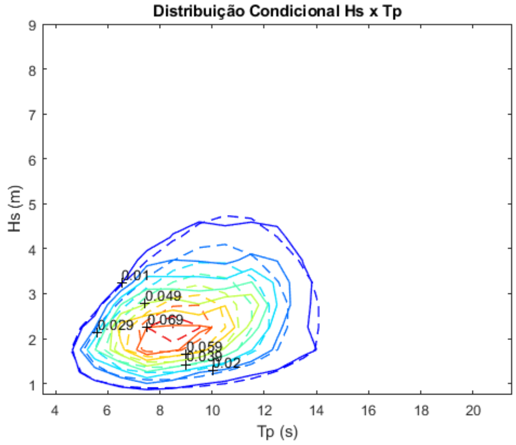

Figure 10– Results CMA REG 5

It is important to highlight that, even though the areas of study are different, the Euclidian distances calculated in this study have the same order of magnitude as the ones calculated using the CMA method by Claudia Lucas and Guedes Soares (2015).

Table 6 – Euclidian distance calculated for each case study

Caso	Distância Euclidiana
REG1	0.10
REG2	0.07
REG3	0.08
REG4	0.09
REG5	0.06

A qualitative study of the graphics in the figure 6 through figure 10 brings to evidence that this method is unable to exactly reproduce the empirical distribution of the probabilities. The origin of that is found in the low quality of the adjustments obtained to the T_p probability distributions conditionate to H_s.

In a general way, one of the divergences listed below, is observed in the cases in which the process does not produce good fit:

a) Empirical distribution doesn´t present peak period interval more frequently
b) Empirical distribution has two peak periods when compared to the intervals that are more frequent.
c) Empirical distribution has an interval of peak period with superior frequency when compared to the frequency of occurrences of the peak periods interval on its side.

6. CONCLUSION

6.1. Extreme values

The methods used in this work allow the estimative of extreme values for H_S considering return periods until 100 years. As it may be noticed on table 7 the methods annual maximum (AM) and POT presents a smaller difference between it´s results than when compared to the Total Sample method with Threshold (AT). The results of both methods are also coherent because they are similar or superior to the realizations that are part of the tail region to each of the samples.

Table 7 – Summary of the return values of significant wave high to return periods of 10, 50 e 100 years

Casos	**Período de Retorno / H_s [m]**								
	10 Anos			**50 Anos**			**100 Anos**		
	AT	***AM***	***POT***	**AT**	***AM***	***POT***	**AT**	***AM***	***POT***
REG1	2.88	5.69	4.37	3.76	6.40	5.08	4.08	6.70	5.33
REG2	2.97	5.99	4.97	3.88	6.76	5.56	4.21	7.09	5.76
REG3	3.04	6.67	5.49	4.09	7.58	6.30	4.49	7.96	6.61
REG4	3.28	7.33	5.59	4.43	8.39	6.56	4.85	8.85	6.92
REG5	3.85	9.34	6.77	5.39	10.72	8.18	5.99	11.31	8.67

Considering the data obtained it is possible to deduce that it is not possible to assume one return value to the entire region in which the five points are located. This conclusion is due to the difference of the extreme values obtained to each of the points where the sample was acquired. Thus, it seems to be more productive to divide Brazil´s offshore area in regions where the climatology has similar behavior and then compared the results obtained for various points in each region.

It is necessary to review the utilization of the total sample method with threshold, or the process to the selection of it´s the threshold, since the values of $H_S$were below than the expected.

The annual maximum method, just like expected, presented coherent estimates, even though its sample was smaller than the ones available to the other methods. Further studies may explore the application of the method dividing the sample according to the seasons of the year and compare the results with the ones obtained in the present work. Other possibility yet to be explored is the substitution of Gumbel´s distribution for the GEV distribution.

The POT method produced coherent results and it shows up as the most indicated to the calculation of extreme values estimative to significant wave high when the sample is limited to few years.

Studies on the dependence of two or more realizations of H_S that belongs to the same storm, are encouraged to this set of data, on the impact on the extreme values results. It is expected a better-quality fit when independent realization, identically distributed, are guaranteed.

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6.2. Bivariate Distribution

The application of the CMA method has led to obtaining the joint probability density distribution to each one of the samples, and has the advantage of being defined by a reduced number of data (parameters of the marginal distribution and the parameters of the conditional distributions) when compared to the use of the realization of two variables.

Despite of these advantages the models obtained are incapable of reproducing exactly the empiric distribution of probabilities. The reason of this limitation seems to be placed mainly on the particularities of each region (that in some classes will tend to bimodal sea), rather than in the kind of parametric distribution chosen to the adjustment of the conditional distributions.

Further studies may benefit from the application of the method to the wind sea and swell components separately.

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