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Statistical Wave Description of Forcados Offshore in Nigeria

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Abstract
Wave description in Forcados offshore in Southern Nigeria is presented. Wave data obtained between 1980 and 1982 are partitioned and fitted using some suitable statistical models to enable short and long term predictions of extreme significant wave heights in this location. The Weibull model used in the work is found suitable for such predictions. The general description based on the available data indicated occasional swell component and a dominant wave component that can be regarded as resulting interactions from the shallow depths and landmass on oncoming waves to the location. A value 3.02 meter is estimated from the data as the 100 year return period significant wave height. The mean period is about 7 seconds.

Keywords: Prediction models, sea state, wave height, peak frequency, Forcados offshore,

1 Introduction

Forcados Offshore is a shallow offshore location in Burutu Local Governmnet Area of Delta State in Southern Nigeria. The metaocean data in this paper was made at Forcados Offshore Platform located at latitude 5.1722 and longitude 5.1791, (see Figure 1 below). The water depth is approximately 22m. In line with discussions of Akinsanya et al. (2017) and Agbakwuru and Idubor (2019), the study of Forcados Offshore is vital for a successful marine operation in the location.

Figure 1: Map showing Forcados

Moreso, the growing increase in activities of drilling and use of floating vessels and the renewed efforts by the Atlantic States to invest into offshore fish production off the coast of West Africa makes the descriptive understanding of the of sea states in a given location an utmost necessity . The study intends to further provide a distinctive description of the sea states for the location aforementioned, with short and long term prediction of wave heights using some suitable mathematical model that fits the data. In-situ wave data/measurements were collected by a directional wave-rider positioned at the Forcados location at an interval of 30 minutes and averaged every 3 hours.

Although extensive studies have been performed using both In-situ measurements and hind cast, to describe and analyze the swells offshore West Africa by several studies and researches such as the West Africa Swell Project of 2004 *(Ewans et al., 2004*) and Olagnon et al. (2013) This present paper intends to add value to the work of Ewans et al. (2004) in the area of development of model prediction tool using available data on Forcados location specifically.

2. Theoretical Background of the Study

2.1 Data Acquisition

The data provided for this study contains only the significant wave heights (Hs) and zero-up crossing periods (Tz) corresponding to these Hs values. No information was given about the corresponding peak periods (Tp). However, for this study the Tp was determined by conservatively multiplying the Tz by a factor of 1.3 as recommended by *Akinsanya et al., (2017).*

A wave system is a random system since it involves a high level of randomness, thus its state cannot be easily predicted nor described deterministically, hence, its future conditions can only be indicated in terms of probabilities for their various possible outcomes, that is; we can only indicate their outcomes by associating probabilities to the various possible outcomes. The accuracy of the prediction depends on the amount of historic data as studied by Akinsanya et al., (2017)

2.2 Partitioning of Forcados Data

Some days and months between 1980 and 1982 have no data. This formed the basis to partition the available data in order to obtain the most appropriate description of the sea-states. This involves running checks for possible groupings and then fitting each individual wave partition with the frequency spectrum shapes. The partitioning was done as recommended by Olagnon et al. (2013) for measured data where the distribution is expanded as Fourier series. Thus, the number of data point k is obtained as 2321.

2.3 Data Analysis

The models considered for this study are 3-parameter Weibull and the Log normal; the reason being that these models have proven to be the best models for various other locations in the Atlantic of West Africa (see Ewans et al., 2004 and Agbakwuru and Idubor, 2019). These probability models are considered adequate to predict the wave Hs with a reasonable level of accuracy.

2.4 The Approach

First, the values of Hs were arranged in an increasing order {Hs_1 < Hs_2 < Hs_3 <…………..<Hs_k}, where k is the total number of Hs samples in the measurements. Then the average significant wave height, m_{Hs}, the sample variance,$_{Hs}{}^2$and the coefficient of skewness, $g1$ are determined using equations 1 to 3 respectively; (Akinsanya et al., 2017)

$$m_{Hs} = \frac{1}{k}\sum_{i=1}^{k} Hs_i \qquad (1)$$

$$S_{Hs}^2 = \frac{1}{k-1}\sum_{i=1}^{k}(Hs_i - m_{Hs})^2 \qquad (2)$$

$$g_1 = \frac{\frac{1}{k}\sum_{k=1}^{k}(h_{sk}-m_{Hs})^3}{[S_{Hs}^2]^{3}/_2} \qquad (3)$$

2.4.1 3-parameter Weibull

The method of moment is considered adequate in this study; this is because it gives more weight to the tail and is easy to implement (*Akinsanya et al., 2017).* This method is adopted for calculating the parameters of the Weibull distribution functions as shown below. It is easy to estimate the parameters of the 3-parameter Weibull distribution and moreso, if one is not too concerned regarding non-exceeding parameters for significant wave close to the 3rd parameter (location parameter, λ), a 3-parameter Weibull is recommended by Haver (2013).Adopting the Akinsanya et al. (2017)

$$F_{Hs}(h) = 1 - \exp\left\{\left(\frac{h-\lambda}{\alpha}\right)^{\beta}\right\} \qquad (4)$$

Where: $\alpha = scale\ parameter\ r, \beta = shape\ parameter,$
$\lambda = location\ parameter$

a) *Shape Parameter, $\boldsymbol{\beta}$;*

$$\boldsymbol{\gamma_1} = \frac{\boldsymbol{\Gamma}(\mathbf{1}+\frac{3}{\beta}) - \mathbf{3}\boldsymbol{\Gamma}\left(\mathbf{1}+\frac{1}{\beta}\right)\left(\mathbf{1}+\frac{2}{\beta}\right) + \mathbf{2}\boldsymbol{\Gamma}^{\mathbf{3}}(\mathbf{1}+\frac{1}{\beta})}{[\left(\mathbf{1}+\frac{2}{\beta}\right) - \boldsymbol{\Gamma}^{\mathbf{2}}(\mathbf{1}+\frac{1}{\beta})]^{3}/_2} \qquad (\mathbf{5})$$

The shape parameter, β, can be estimated by a simple iteration process. In this study, the equation is solved with MATLAB software.

b) *Scale Parameter, **α**;*

The scale parameter, is estimated base on the condition in equation 4. Thus;

$$\sigma_{Hs}{}^2 = s_{Hs}{}^2 \qquad (6)$$

c) *Location Parameter, $\boldsymbol{\lambda}$;*

Finally, the location parameter, λ, is estimated from Eq. (7) by requiring μ_{Hs} = m_{Hs}

$$\mu_{Hs} = \lambda + \alpha\Gamma\left(1 + \frac{1}{\beta}\right) \qquad (7)$$

These parameters are found by solving the above equations using MATLAB and the results are presented in Table 1.

2.4.2 Log-normal

One could also obtain a fit using a hybrid model such as Log-normal distribution for $hs \leq \eta$ and a 2-parameter Weibull distribution for $hs>\eta$ (Haver, 2013).
The expression for the Log-normal Distribution is given as;

$$F_{Hs} = \frac{1}{2} erfc\left(-\frac{lnh-\mu}{\sigma\sqrt{2}}\right) = \phi\left(\frac{lnh-\mu}{\sigma}\right) \qquad (8)$$

Where the **erfc** is a complementary error function, and **Φ** is the cumulative distribution function of the standard normal distribution.

The two parameters are estimated using the method of moments

a) *Scale Parameter,* **μ**;

The scale parameter is estimated using equation (9), *Ginos (2009)*

$$\mu = -\frac{ln\left(\sum_{i=1}^{k} Hs_i^2\right)}{2} + 2ln\left(\sum_{i=1}^{k} Hs_i\right) - \frac{3}{2} ln(k) \qquad (9)$$

b) *Location Parameter,* $\boldsymbol{\sigma^2}$;

The location parameter is estimated using Equation (10) *Ginos, (2009).*

$$\boldsymbol{\sigma^2 = ln\left(\sum_{i=1}^{k} Hs_i^2\right) - 2ln\left(\sum_{i=1}^{k} Hs_i\right) + ln(k)} \qquad (10)$$

These parameters are found by solving the above equations using MATLAB and the MATLAB results are presented in Table 2 and 3.

2.5 Plotting in Probability Paper

One way to get an early indication of whether or not the probability models can reasonably predict the variable, in this case the wave Hs, is to plot thedata assuming an empirical distribution function in a probability paper. If the plot looks like it could be a straight line, the model assumption is to a certain extent supported *(Akinsanya et al., 2017).* Hence the data are plotted on probability paper assuming a probability model, followed by a comparison with an empirical distribution.

<u>*3-parameter Weibull;*</u>

From equation (4) above, the Weibull distribution function is linearized as

$$\ln\left(-\ln\left(1 - FH_s(h)\right)\right) = \beta\ln(h-\lambda) - \beta ln\alpha \qquad (11)$$

Hence, for the empirical distribution we will consider a plot of;

$$\beta\ln(h-\lambda) - \beta ln\alpha \ vs \ \ln(h-\lambda)$$

And for the fitted distribution a plot of;

$$\ln\left(-ln\left(1 - F_{Hs}(h_k)\right)\right) vs \ \ln(h-\lambda)$$

2.6 Significant Wave Height Prediction

The expression for short and long term prediction of the significant wave height of the waves for the weibull probability model as derived below.

From equation 4,

$$F_{Hs}(h_y > h) = \exp\left\{-\left(\frac{h-\lambda}{\alpha}\right)^{\beta}\right\} = \frac{1}{n3h}$$

$$\ln(-\ln(F_{Hs}))) = \beta\ln(h-\lambda) - \beta ln\alpha$$

$$\frac{1}{\beta}\ln\left(-\ln\left(FH_s(h)\right)\right) + ln\alpha = \ln(h-\lambda)$$

$$exp\left\{\frac{1}{\beta}\ln\left(-\ln\left(FH_s(h)\right)\right) + ln\alpha\right\} + \lambda = h \qquad (12)$$

The probability model for the annual exceedence probability F_{Hs} is given as;

$$FH_s(h) = \frac{1}{n_{3h}} \qquad (13)$$

3. Results and Discussions

The Weibull and Log-normal parameters are presented in the Table 1 and 2.

Table 1: Values of the 3-Parameters of the Weibull Model

m_{Hs}	s_{Hs}^2	g_1	β	α	λ	k
0.2231	0.0017	0.3232	1.5433	0.3764	0.1321	2321

Table 1: Values of the 2-Parameters of the Log-normal Model

M	σ	k
-0.4132	0.2311	2321

Figure 2 shows the plot of significant wave heights and peak periods for the Forcados for the entire data set.

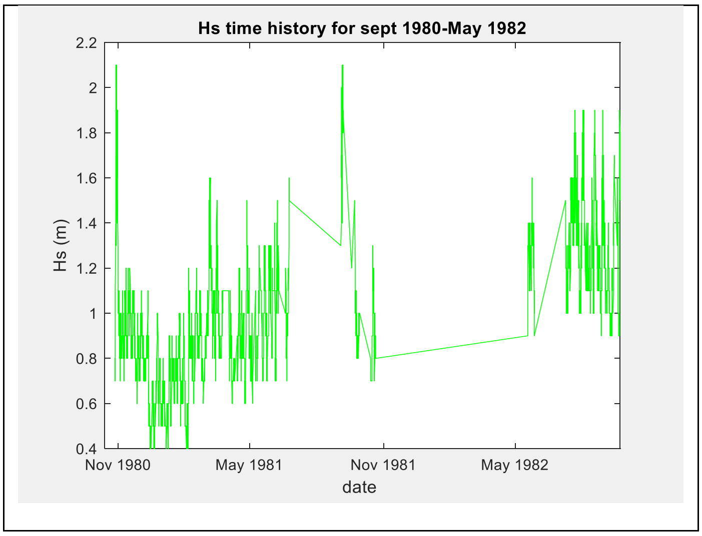

Figure 2: Forcados Hs Time History for Jan 1980 to 1982

It also follows that from the Hs and Tp scatter in Figures 3, the wave's Hs values falls within a certain range. The red plots in Figure 3 are indication relatively long periodic wave. This indicates that here is no instrument error, showing the instrument ability to record but short and long periodic waves.

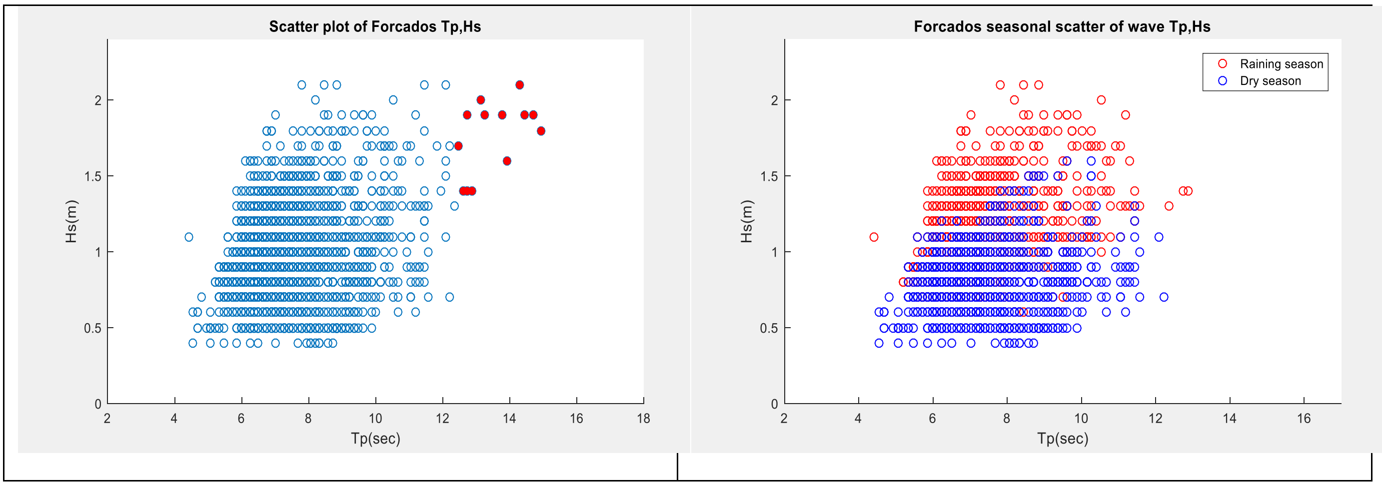

Figure 3: Hs and Tp Scatter Plot for seasonal and entire data

The significant wave heights Hs and peak periods Tp have been scattered above. A maximum value of 2.1m was measured for the three years duration. Although the duration of the available in-situ measurements might seem insufficient to make long term predictions, a lower and upper bound of the wave Hs can be established.

The measured data are fitted to two different probability models as mentioned earlier. The purpose is to identify the most suitable model applicable to the Forcados location. See Figures 4 and 5.

A comparison of the 3-parameter Weibull and Log-normal distribution with their empirical distributions shows that Weibull model has a good fit correlation between the empirical distributions and the model distribution. The 3-parameter Weibull distribution can be a useful prediction tool for this location.

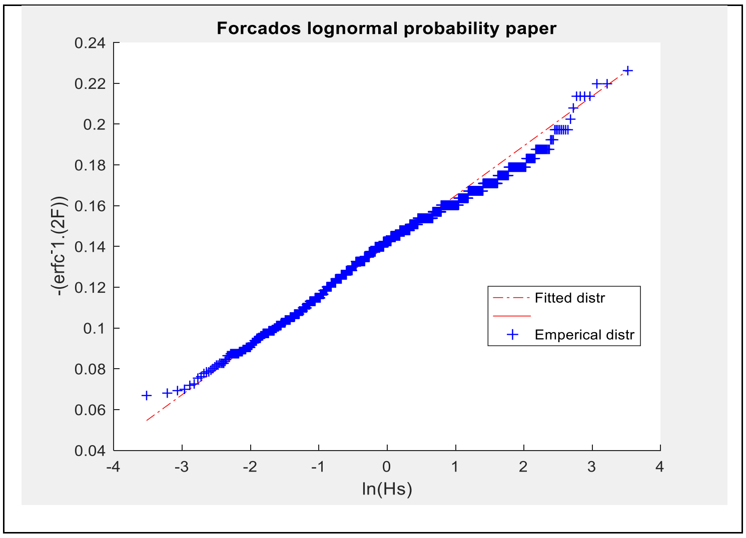

Figure 4: Empirical and fitted for lognormal Distr.

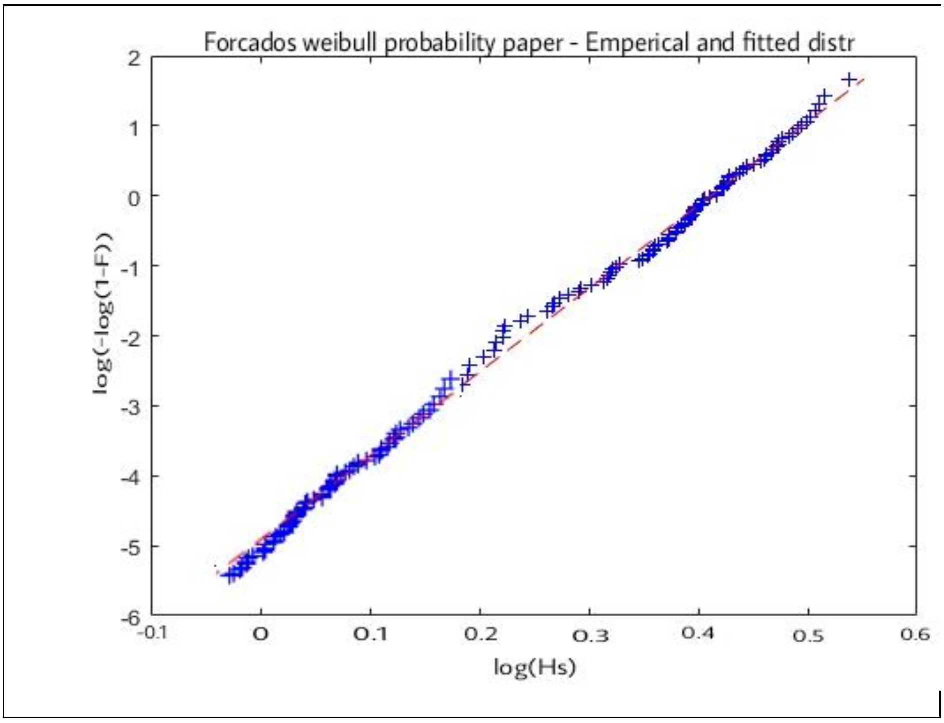

Fig5.ForcadosWeibull probability paper comparing fitted and empirical

The entire set of wave variance density spectra and the kernel density estimator derived from the Forcados Directional Wave-rider buoy is plotted in Figures6 and 7 to demonstrate conformance and relevance of the used Forcados data.

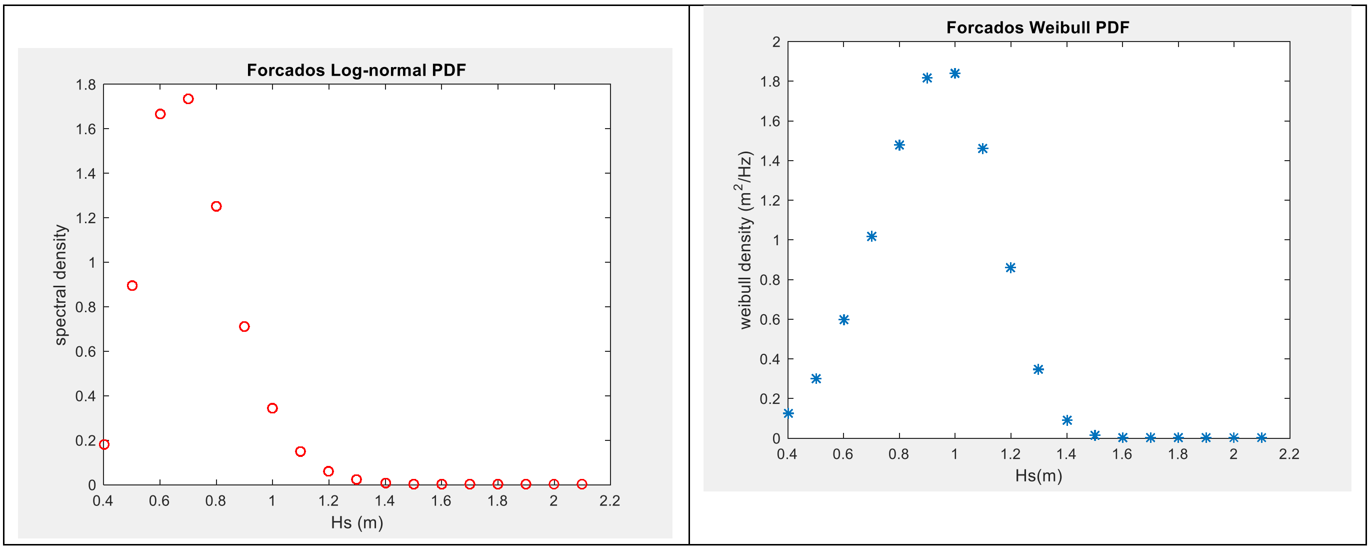

Figure 6: Log-normal and Weibull probability density function of Forcados

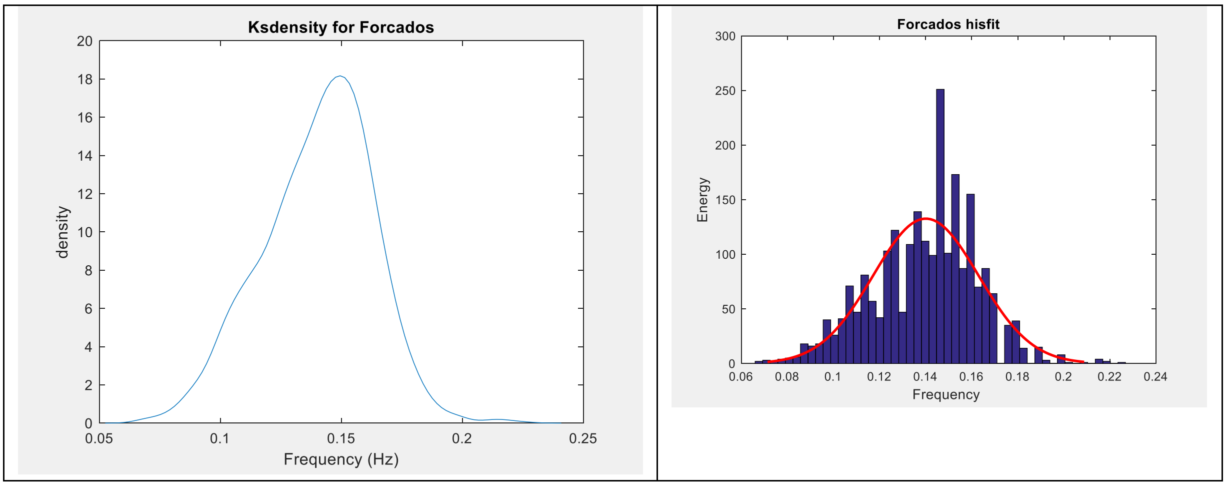

Figure 7: ks density and histogram with normal fit for Forcados peak periods

3.1 One Year Significant Wave Height Prediction

The expression for predicting the significant wave height is derived above in equation 12. For a 1-year return period, the number of samples $n_{3h,}$ is estimated to be 2321.

Hence, from equation (13), the probability of exceedance is estimated as; $F_{Hs}(h) = 4.31*10^{-4}$

3.2 Extreme 100 years significant wave height.

For the extreme value prediction, only the 100-year return period will be considered in this case. The 100-year return period for the number of samples are: n_{3h} = 2321x100 = 232100.

Thus from equation (13, the probability of exceedance is estimated as; $F_{Hs}(h) = 4.31*10^{-6}$

Table 3: Plot Function Values of 3-parameter Weibull Distribution for Different Return Periods

Return Period (years)	n_{3h}	ln(-ln(1-F)	ln(Hs)	Exact value (m)
1	2321	1.82	0.58	1.78
10	23210	2.01	0.80	2.23
100	232100	2.35	1.11	3.02

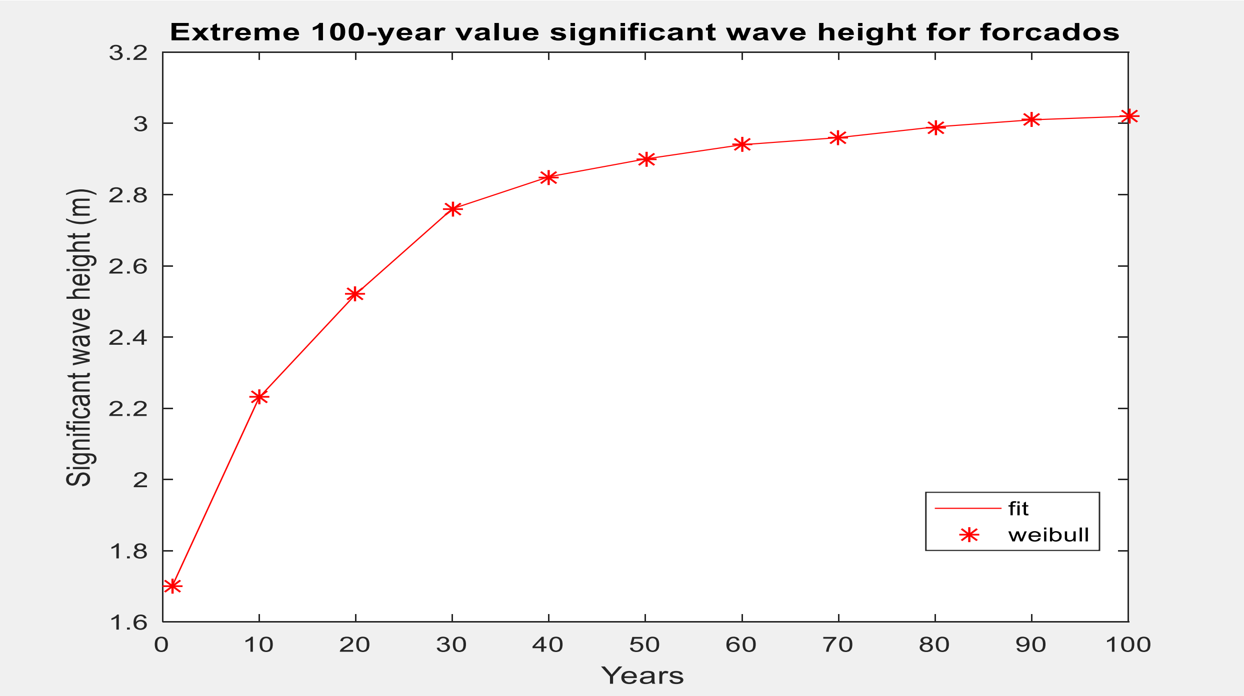

Figure 11: Disribution of significant wave height in years

Conclusion

The data collected at the Forcados shallow location have been properly analysed. The general description of the wave is not dominated by swell as widely described in many academic literatures. The methodology has enabled calculation of extreme significant wave that is largely relevant to design of structures marine/offshore structures. It is noted that the data is limited. Increased data could be used to further improve the description as has been presented in this work.

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Appendix

Alphabetic Symbols

Hs	Significant Wave Height
Tp	Peak wave period
Tz	Zero up-crossing wave period
F_{HS}	Cumulative Probability
H_s	Significant Wave Height
h_K	Sample significant wave height
Ks	Kernel Spectra
n_{3h}	Number of 3-hour sample
Erfc	Cumulative error Function
g1	Sample Coefficient of Skewness
y1	Probability Model Coefficient of Skewness
$\sigma_{Hs}{}^2$	Probability Model Variance
$s_{Hs}{}^2$	Sample Variance

Greek Symbols

σ	Log-normal Location Parameter
μ	Log normal scale parameter
B	3-parameter Weibull Shape Parameter
ɲ	3-parameter Weibull Scale Parameter
Λ	3-parameter Weibull Location Parameter
K	Sample number
Φ	Cumulative Standard Normal Distribution