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Sea State Characteristics of Bonny Offshore in Nigeria

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Abstract

The sea state characteristics of the wave system in Bonny location in offshore Nigeria is studied. The wave data used in this study covers a duration of 1979 to 1982 and the data was analysed by means of statistical measures mainly focusing on the probability distributions, number of peaks and return cycle for extreme wave condition. Though the data for the study is not sufficiently large, the result of the work identified the Weibull distribution as reasonably appropriate for short term and long term prediction of the extreme wave heights which is relevant to most offshore designs and marine operations. Moreso, there was lack of evidence of low frequency Swell components in this location. Instead, a high frequency wave system with period not exceeding about 10 seconds is noted.

Keywords: ***Sea state, zero crossing period, peak frequency, Bonny offshore, Weibull model.***

1. Introduction

It is important to test the presence of sea swell which most literatures on the subject claims dominate the offshore West Africa, including Nigeria (Ewans et al., 2004). The full understanding of the sea state in busy locations such as Bonny offshore becomes more considerable for the planning of successful marine operations which include the newly designed ocean underwater current power turbine as presented by Agbakwuru et al. (2019). This generator according to Agbakwuru et al. (2019) is deployable in the Nigerian Offshore. The offshore is characterized with reduced current velocity of about 0.3 m/s. Furthermore, due to the growing increase in maritime and offshore activities off the coast of the country, this knowledge becomes relevant to specifying the sea states not only for delicate offshore operations (such as drilling) but also for the safe operations of weather sensitive floating vessels in the ocean in this region. It is worthy to note that this knowledge is not limited to marine operations; it is also very well applicable for adequate design of offshore facilities specific to this region.

The general knowledge of the West African mildness and dominancy in swell said to have been generated by high wind energies, far away from offshore West Africa, in the South Atlantic and North Atlantic during the austral winter and austral summer, respectively is well agreed in many literatures (*Prevosto et al., 2013, Olagnon et al., 2013 etc)*. In this work, a test for such swell dominancy is studied and could be generalized for, most especially for the shallow water regions of the Nigerian offshore. There is a great demand for research in this area due to the need to be equipped with good knowledge of sea state in Nigerian Offshore.

Bonny is located in the East of the River Niger, at a shallow depth of about 19.0m off the coast of the Atlantic Ocean. It is one of the busiest offshore locations in Nigeria due to the oil and gas exploration, existence of local ports and Islands and availability of Nigeria Liquefied Natural Gas Company (LNG) in the zone. Bonny location in West Africa and Nigeria is shown in Figure 1.

Figure 1: Maps Showing Bonny Offshore

It is noted that 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 researchers such as the West Africa Swell Project of 2004 *(Ewans et al., 2004*) and the Bonga swell description (*Akinsanya et al., 2017*). This work intends to add value to these projects in the area of development of model prediction tool using available data.

A distinctive description of the sea states for the location aforementioned, with short time prediction of the wave heights for marine operations will be presented. The Nigeria - Bonny In-situ wave measurements collected by SHELL Nigeria from a directional wave-rider launched at the bonny site will be used in this analysis.

1.1 Data Acquisition

The data provided by SHELL Nigeria contains zero crossing periods (Tz). As recommended in work of *Akinsanya et al. (2017*), a constant of 1.3 was used to get the corresponding Tp values. The measured data also contains the following information; the characteristic wave height, Hs, maximum wave heights, H and directions. Relevant to these study are Hs and Tp values. SHELL Nigeria collected wave measurements from 1979 through 1983 at the Bonny field (see Figure 1). These measurements were taken every 30 minutes and averaged every 3 hours, with a total number of 5024 samples.

Unlike the deterministic system whose future state can easily and accurately be determined, wave system is a random system, thus its future state cannot be easily predicted nor described even when its present condition is well known. 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 (Alves, 2006). The accuracy of the prediction depends on the amount of historic data. It relevant to note that since wave loads and the responses of floating structures depend largely on this random wave system, they are therefore random in nature as well. Thus, because of this random nature of ocean waves, a statistical approach is adopted in order to predict, with a reasonable level of accuracy, the future nature of the ocean waves.

2. Theoretical Background

First, the values of Hs were arranged in an increasing order {$Hs_1 < Hs_2 < Hs_3 < \ldots\ldots\ldots\ldots < Hs_k$}, 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, g_1 are determined using equations 1 to 3 respectively in line with the work of *Akinsanya et al.,(2017*).

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

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

$$g_1 = \frac{\frac{1}{k}\sum_{i=1}^{k}(Hs_i - m_{Hs})^3}{(S_{Hs}^2)^{3/2}} \qquad (3)$$

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. This method is adopted for calculating the parameters of the Weibull distribution functions as shown below.

2.1: 3-parameter Weibull

Since it is easier to estimate the parameters of the 3-parameter Weibull distribution and 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 Akinsanya et al.(2017*).

$$f(t) = \frac{\beta}{\alpha}\left(\frac{t-\lambda}{\alpha}\right)^{\beta-1} e^{-\left(\frac{t-\lambda}{\alpha}\right)^{\beta}} \quad (4)$$

Where:

$f(t) \geq 0$; $t \geq \gamma$ and $-\infty < \lambda < +\infty$.

Shape Parameter, β;

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

The shape parameter, β, can be estimated by a simple iteration process, but in the case of this study, the equation is solved by MATLAB.

Kernel density, $\oint$;

Thisis estimated by;

$$\oint(\mathrm{x}) = \frac{1}{n_h}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right) \quad (6)$$

a) *Location Parameter, λ;*
Finally, the location parameter, λ, is estimated from Eq. (7) by requiring $\mu_{Hs} = m_{Hs}$

$$\boldsymbol{\mu_{Hs}} = \lambda + \propto \Gamma\left(1 + \frac{1}{\beta}\right) \quad (7)$$

These parameters are found by solving the above equations using MATLAB and the results are presented in Table 1. It is noted that only 1981 data is fairly continuous with 1980 samples. The computations of the Weibull paramenters were done using the 1980 samples. The MATLAB formulation is shown in Appendix 1.

2.2 Plotting in Probability Paper

Plotting the data and assuming an empirical distribution function in a probability paper is one way of getting to know whether or not the probability model can reasonably predict the variable. If the plot looks like it could be a straight line, the model assumption is to a certain extent supported (*Akinsanya et al., 2017*).

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

$$\ln\left(-\ln\left(1 - FH_s(h)\right)\right) = \beta \ln(h - \lambda) - \beta ln\alpha \quad (8)$$

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;

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

2.3 Significant Wave Height Prediction

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

From equation 4,

$$F_{Hs}(h_y > h) = exp\left\{-\left(\frac{h-\lambda}{\alpha}\right)^{\beta}\right\} = \frac{1}{n_{3h}}$$

$$exp\left\{\frac{1}{\beta}\ln\left(-\ln\left(FH_s(h)\right)\right) + ln\alpha\right\} + \lambda = h \quad (9)$$

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

$$FH_s(h) = \frac{1}{n_{3h}} \quad (10)$$

2.4 Partitioning and Parameterization of Bonny Spectra

The reason for parameterizing this work is to obtain the most appropriate spectral 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 for measured data where the distribution is expanded as Fourier series.

3. Results and Discussion

3.1 Results Presentation

3.1.1. 3-Parameter Weibull results

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

m_{Hs}	s_{Hs}^2	g_1	β	α	λ	k
0.6351	0.0872	0.8123	1.6325	0.4324	0.1121	1980

Figures 3 shows the plot of the significant wave heights for the Bonny data for years; 1979 through 1981, for the waves arriving at the location, it is observed that there is a consistent increase in wave height for mid years and a relative strong difference between the measurements of Hs recorded in November of the three years. The reason for this behavior can be well understood by a close study of the ocean environment at the source location.

3.1.2 Significant Wave Height Result

The Figure 2 shows the time history of the wave Hs for both dry and raining seasons. Although the duration seems insufficient to make long term predictions, it should be noted that, this location receives waves that are of lower heights during the dry season when compared with the raining season. As shown in the plots of Figures: 5 and 6.

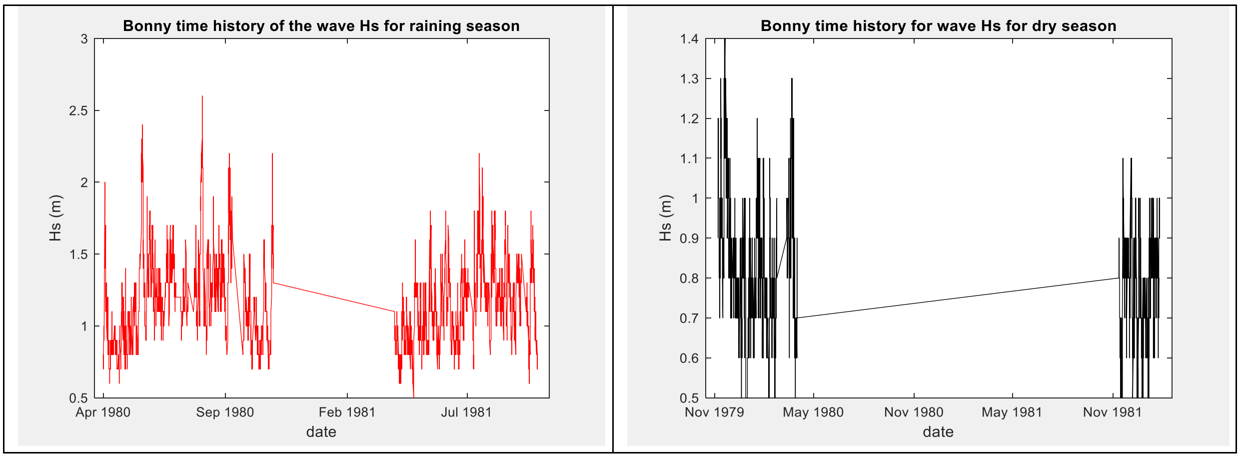

Figure 2: Hs Time History for dry season

The normal plots matches the quantiles of the measured data to the quantiles of a normal distribution. The data is sorted and plotted on the x-axis from the data size (N). The y-axis represents the quantiles of the normal distribution valued at mid-point between evaluation points of the empirical cumulative function of the data which is later converted into probability values as shown in Figures 7 and 8.

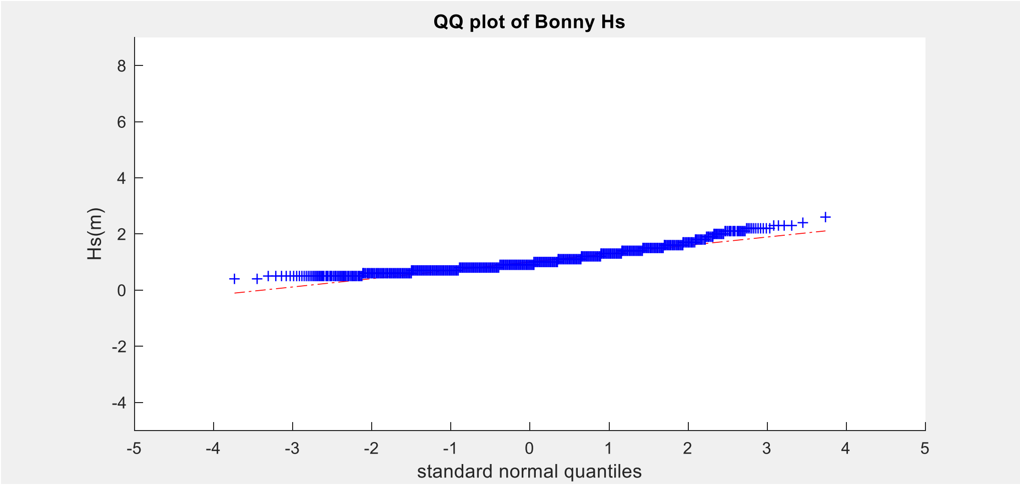

Figure 3: Hsquantiles-quantiles plot for the entire data

3.1.3. Peak Period

As earlier stated, the peak period (Tp) values were computed from mean zero-up crossing periods (Tz) for both years. The Figures 4, 5 and 6 present the entire and monthly variation in the Bonny wave Tp.It is obvious to see that the waves are mostly 6 to 8 seconds. A pure indication that the components of swell described in the WASP project are not present in this location. WASP is West African Swell Project carried by Shell Nigeria. However one is also convinced that it is not an instrument error, as it recorded values up to 14 and 16 seconds in some instances.

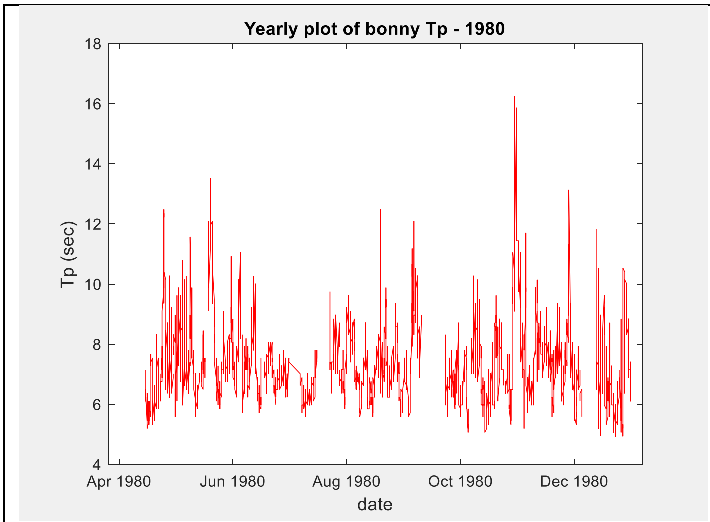

Figure 4: Tp time history for 1980

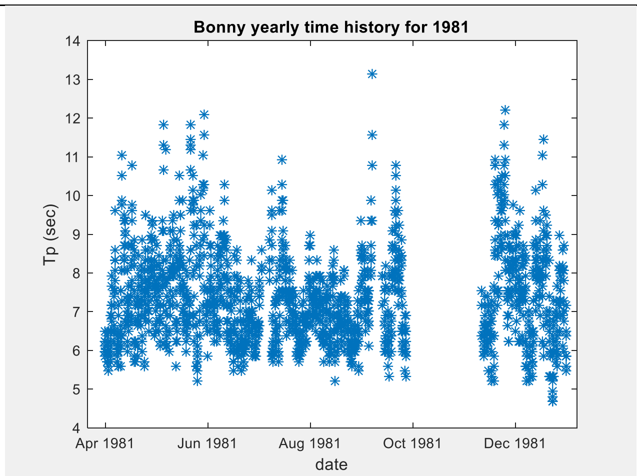

Figure 5: Tp time history for 1981

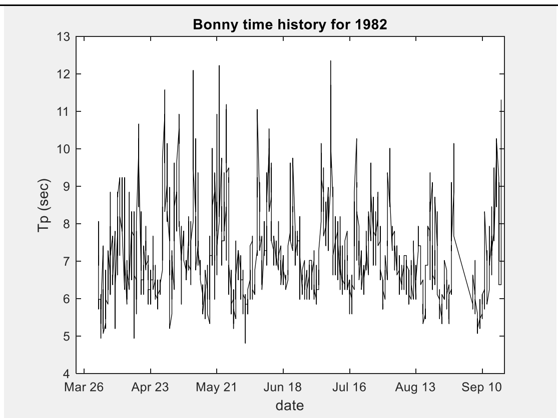

Figure 6: Bonny Tp time history for 1982

The Hs and Tp scatter plots are presented in Figures 7 and 8. The red points of Figure 7 indicate the Tp range of 4 to 10 seconds. It is interesting to see in Figure 8 that in the raining season, the Hs increased. It can therefore be noted that the range of Hs differs depending on the month of the year. Hence it can be suggested that sea states predictions for a particular month or season can be made using a monthly or seasonal range.

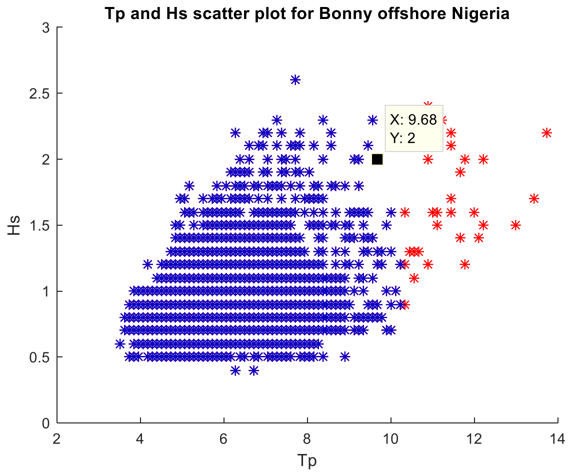

Figure 7: Hs and Tp Scatter Plot for 1979 and 1983

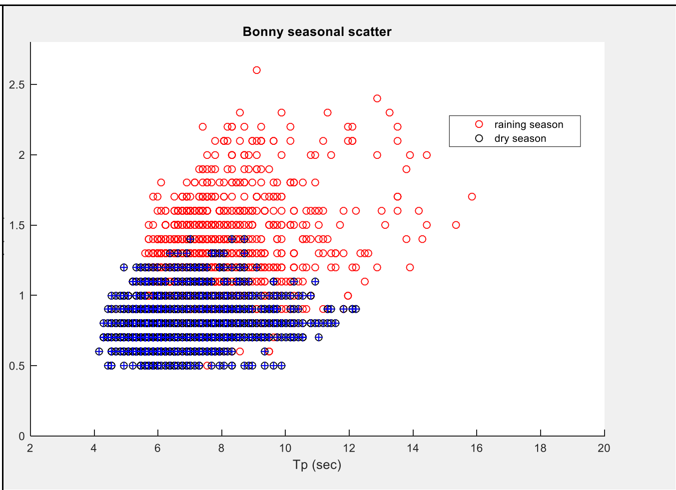

Figure 8: Hs and Tp seasonal Scatter Plot for the entire data

3.2 Data Analysis and Predictions

In Figure 9, the measured data are fitted in the Weibull probability model as mentioned previously. The result obtained for the model is presented. Attempt to repeat the process for Log Normal distribution as suggested in other literatures for most sea state locations indicated that the Log Normal distribution is inadequate (see Figure 9). The 3-parameter Weibull is used as a suitable model for Bonny Offshore and the rest of the computations in this work will refer to the 3-parameter Weibull distribution.

A comparison of the 3-parameter Weibull fitted distribution with the empirical distribution for the wave analysis is shown in Figure 10. It is observed that there is good fit correlation between the empirical distribution and the model distribution; this reveals the adequacy of the 3-parameter Weibull distribution. It is noted that from the tail of the fitted distributions, there is an indication of over prediction of the significant wave height Hs. On the other hand at the extreme end of the fit, there seem to be under prediction of the extreme Hs. In general however, it is considered adequate. This observation simply means that more measured data for a reasonable number of years may be required to conclude the performance of the 3-parameter Weibull model.

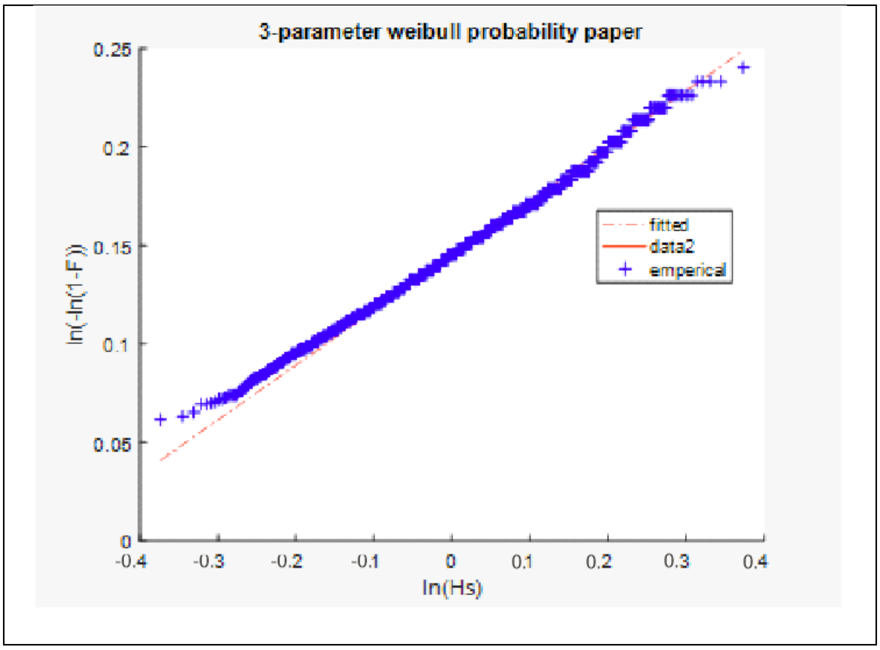

Figure 9: Empirical and fitted for Hs

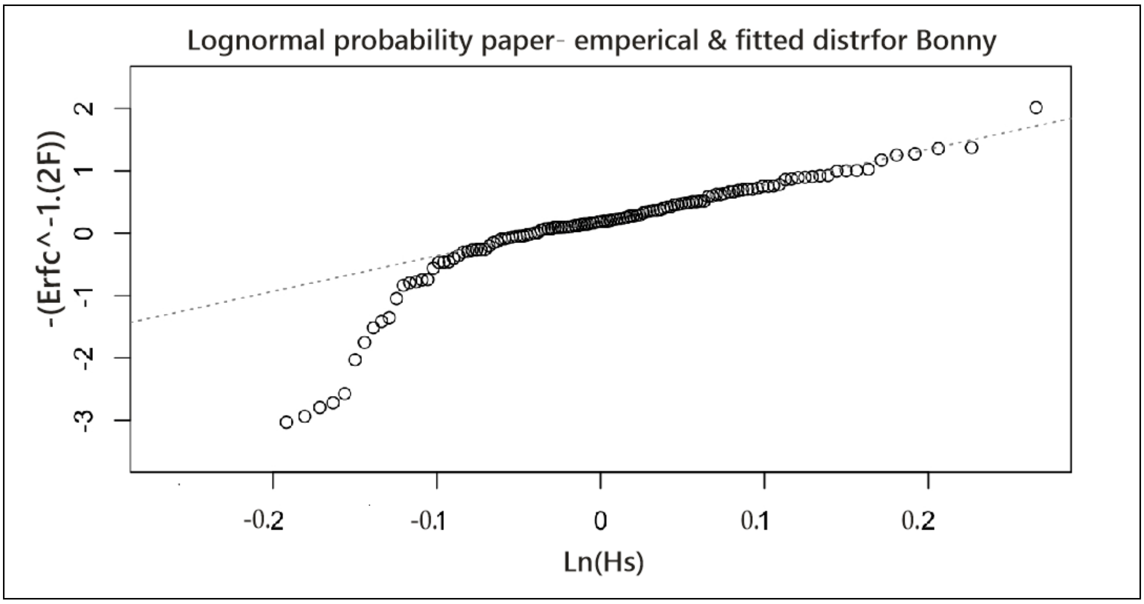

Figure10: Lognormal probability paper-Empirical and fitted for Hs

One year significant wave height prediction

The expression for predicting the significant wave height is derived above in Equation 9. For a 1-year return period, the number of samples $n_{3h,}$ is estimated to be 1980.
Hence, from Equation (10), the probability of exceedance is estimated as;

$F_{Hs}(h) = 5.05*10^{-4}$

Extreme 100-year 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:

$$n_{3h} = 1980x100 = 198000.$$

Thus from equation (14), the probability of exceedance is estimated as;

$F_{Hs}(h) = 5.05*10^{-6}$

Table 2 refers to the values of different return periods estimated from the 3-paramter Weibull distribution.

Table 2: Plot Function Values of 3-parameter Weibull for Different Return Periods

Return Period (years)	n_{3h}	ln(-ln(1-F)	ln(hs)	Exact values (m)
1	1980	0.249	0.39	1.47
10	19800	0.321	0.58	1.78
100	198000	1.384	0.89	2.45

Distribution of significant wave height with return period

Figure 11 shows the distribution curves of the significant wave height with return period for the wave condition. Hence it can be deduced that the over-prediction of Hs occurs from return periods of 1 year and above. This validates the fact that more measured significant wave height samples may be required to establish best the behavior of the empirical distribution. Figure 12 shows the cumulative density function (CFD) plot.

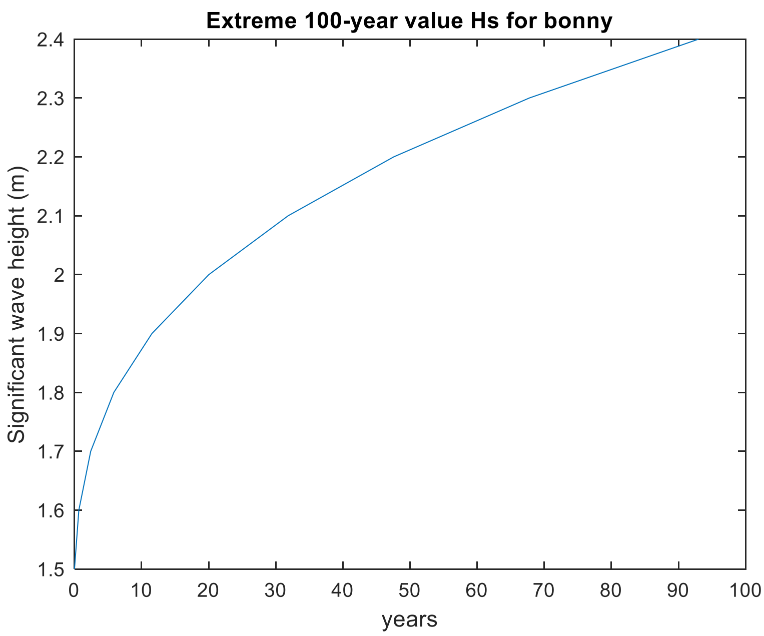

Figure 11: 100 years extreme value for bonny.

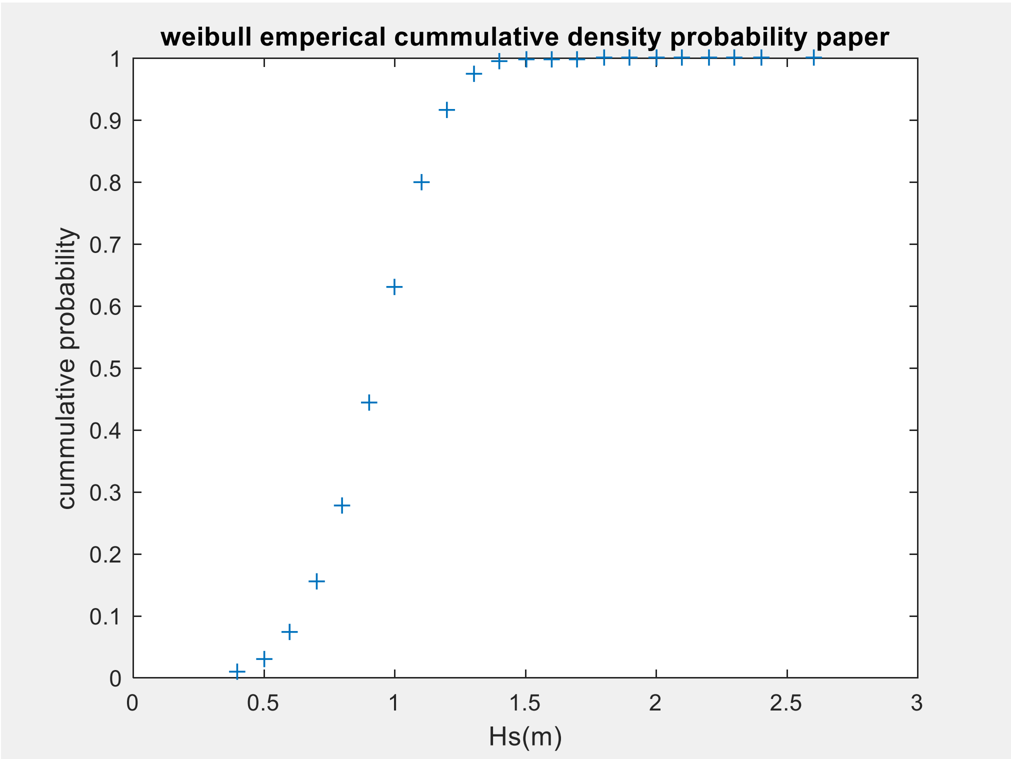

Figure 12: Weibull CDF for wave Hs

Bonny directional wave-rider buoy

The entire set of wave variance density spectra derived from the Bonny Directional Waverider buoy is plotted in Figure 13. The kernel density estimator is a very important technique thus, it was employed in this analysis. As the estimate is formed by replacing each sample data point with a probability density function and then summing over all the resulting distributions in one dimension.

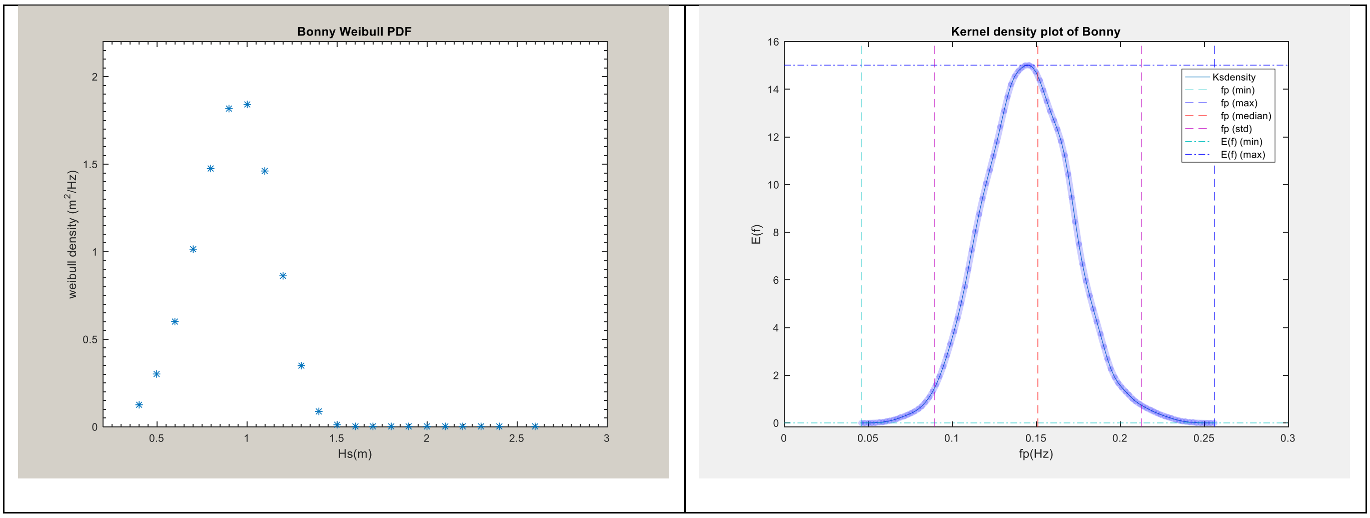

Figure 13: Weibull and ks density spectral of Bonny

Following the plots (Figures 10 to 13), it becomes reasonable to adopt the 3-parameter Weibullfor the prediction as recommended by *Akinsanya et al.,(2017*).

Conclusions

The data collected at the Bonny location has been analysed with the aim of producing an improved description of the sea stateat this location. The region being part of the West African waters, one will naturally expect two peak wave system.The analysis has demonstrated a single peak with low period range not exceeding about 10 seconds. The authors are convinced that the Bonny island at the Bonny locationhas a shielding effect; shielding the Bonny location from the Swell components that predominates the West African wave conditions. One sees this effect as producing a tertiary form of reflected, constructive and destructive wave pattern characterised high wave frequencies. It is also suggested that the shallowness of the location is a contributing factor. Of course, the high frequency description is likely to be more important than the low frequency description for the response of floating systems.

The model considered in this study is the 3-parameter Weibull which has proven to be the best model for this location. This probability modelis considered adequate to predict the wave Hs with a reasonable level of accuracy as earlier tested for the Asabo location by Agbakwuru et al., 2017. It is however noted that future work will be to have increased data to verify the performance at tail and extreme of the Weibull distribution fit.

Acknowledgement

The authors are grateful to SHELL Nigeria for providing the in-situ measurements used for this study.

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Appendix 1

```
closeall
clearall
clc
% the data was collected at an interval of 3hours by shell Nigeria
%READING THE DATA
DATA2=xlsread('bonny_offshore_data.xlsx');
elev=(DATA2(:,3));
elev2=(DATA2(:,2));
n=1980; % Total number of samples for the 3hr interval

%  parameter of 3_Parameter Weibull Model; based on method of moments
avHs=mean(elev)
varHs=var(elev)
g1=(1/n * sum((elev-avHs).^3))/((varHs).^(3/2))

symsB;
beta=solve((gamma(1+3/B)-
3*gamma(1+1/B)*gamma(1+2/B)+2*(gamma(1+1/B))^3)/((gamma(1+2/B)-
(gamma(1+1/B))^2)^1.5)==g1);
B= beta

symsA;
alpha=solve(A^2 *(gamma(1+2/B)- (gamma(1+1/B))^2)==varHs);
A = abs(alpha(1,:))

symsC;
gam=solve( C + A*gamma(1+1/B)==avHs);
Ga = gam

% Fitting 3-Parameter Weibull Model
F=B*(log(elev-Ga) - log(A));
%M=B*(F)-B*log(A);
d=log(-log(1-e));
q=log(elev-Ga);
plot(q,F);
title('3-parameter Weibull probability paper - empirical and fitted distribution')
xlabel('ln(Hs-gamma)')
ylabel('ln(-ln(1-F)')
holdon
scatter(q,d,'*','b');
legend('Fitted Distr', 'Empirical Distr')

%  Probability density function
Y=(B/A)*(elev/A-Ga/A).^(B-1).* (exp(-(elev/A-Ga/A).^B));
plot(elev,Y,'k');
title('3 parameter Weibull density function of Hs')
xlabel('Hs (m)')
ylabel('Probability density function')

%   Cumulative distribution function
```

```
xx=logncdf(elev,u,p);
plot(elev,xx);
title('3 parameter Weibull CDF of Hs');
xlabel('Hs (m)');
ylabel('Cummulative Probability');
holdon
kk=1 - (exp(-(elev/A-Ga/A).^B));
plot(elev,kk, 'b');
legend('3-parameter Weibull');

%  1-year Hs calculation - 3-parameter Weibull
n1=1
N = 1980 * n1
Fhs = 1/N
hw = exp(1/B*(log(-log(Fhs)))+ log(A)) + Ga

%  100-year Hs calculation - 3-parameter Weibull
n2= 100;
Fhs2 = (1980 * n2).^(-1);
%Fhs2 = 1/N2
hw100 = (exp(1/B*(log(-log(Fhs2)))+ log(A)) + Ga)

%   100-year Hs calculation - 3-parameter Weibull
n3= 1:5:101;
Fhs3 = (1980 * n3).^(-1);
% Fhs2 = 1/N2
hwd = (exp(1/B*(log(-log(Fhs3)))+ log(A)) + Ga);

plot(n3,hwd,'b');
title('Extreme 100-year Value Significant Wave Height');
xlabel('years');
ylabel('Significant Wave Heights,(m)');
legend('3-parameter Weibull');
```

Appendix 2

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
n_{3h}	Number of 3-hour sample
H	Width of density
Erfc	Cumulative error Function
g_1	Sample Coefficient of Skewness
y_1	Probability Model Coefficient of Skewness
X	Kernel density function
$\sigma_{Hs}{}^2$	Probability Model Variance

${s_{Hs}}^2$	Sample Variance

Greek Symbols

Β	3-parameter Weibull Shape Parameter
Α	3-parameter Weibull Scale Parameter
Λ	3-parameter Weibull Location Parameter
Κ	Sample number
Φ	Cumulative Standard Normal Distribution
∳	Kernel density