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Sea state description of Asabo offshore in Nigeria

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Abstract. A study of the wave conditions for the Asabo offshore location at the Qua Iboe oil field in Eastern Nigeria has been carried out. Statistical analysis was applied to three (3) years of data comprising spectral periods, Tp and significant wave heights, H_s. The data was divided into two (2); data from October to April represents one set of data and data from May to September represents another set of data. The results were compared with similar studies at other locations offshore of West Africa. It was found that there is an absence of direct swellwaves from the Southern Ocean reaching the location under study (the Asabo site). This work suggests that the wave system is largely emanating from the North Atlantic storms. The presence of numerous islands near the Asabo location shields the site from effects of storms from south west and therefore swells from the Southern Ocean. It is noted that the local wind has little or no contribution. An H_s maximum of 2 m is noted at the Asabo offshore location. It is found that the Weibull distribution best describes the wave distribution at Asabo. Thus, the Weibull distribution is suggested to be adequate for long term prediction of extreme waves needed for offshore design and operations at this location.

Keywords: sea state; significant wave height; spectral density; time history; returns period; offshore Nigeria

1. Introduction

It is a general knowledge that the spectra for West African Offshore locations due to swells are at least two-peaked. This has been widely discussed by Ewans *et al.* (2004),Olagnon *et al.* (2013), Prevosto *et al*. (2013), Akinsanya *et al.* (2017), Agbakwuru and Akaawase (2018), etc.These studies were carried out using both in-situ measurements and hindcast wave modeling to describe and analyze the swells offshore West Africa at several locations, such as Bonga in Nigeria, Kudu in Namibia, Ekoundou in Cameroun, etc.

Olagnon *et al*. (2013) showed some typical examples of swell systems that are possible in West African waters using data from a location near Offshore Angola. The South-South-West swell is not generated by the biggest storms of the South Atlantic, but by "moderate" storms (H_s~8m) closer to the West Coast of Africa. Dominating is a multiple wave system comprising a sea-state of very long waves (T_p=22s, the waves of the South Pacific storms), a second swell system (T_p=15s), and a third

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wave system (T_p=6s) which seems to be a wind sea. A North-West swell exists during winter as some North Atlantic storms generate swell sufficiently powerful to travel long distances reaching the West African Coast. These swells are, however, much less severe than the south swell (with H_s of 0.3 m typical) according to Olagnon *et al.* (2013) and Akinsanya *et al.* (2017). They argued that the occurrence of South-South-West swells as described above is not common due to rare storms in West African Offshore. It is noted by the work of Olagnon *et al*. (2013) that the diversity of the situations shows the difficulty of a fine statistical description of the swell climatology in West Africa.

In this work, Asabo Offshore with several islands around the oilfield is studied to verify compliance with general knowledge of the West African Offshore wave conditions. The work aroused from low wind speed values obtained at Asabo in a wind potential analysis carried out by Agbakwuru and Akaawase (2018). Asabo offshore is a shallow water location; 47 meters depth. It is suggested by the authors that the presence of islands may result to swell shield and reflections.

2. Asabo data

From 1981 through 1983, a Baylor Wavestaff was used to collect wave data at the Nigeria Asabo platform site. Time series of wave elevations were recorded as well as the spectra period. The Asabo platform is located at the Qua Iboe Oil field in Gulf of Guinea, Nigeria. The Asabo field is developed by a floating unit with 464 persons accommodation capacity connected to a fixed platform through a heave compensated telescopic gangway. The data provided for this study contains the significant wave heights (H_s), wave directions and peak periods (T_p) corresponding to these H_s and the measured directional data.

3. Methodology

The WAVESTAFF measured data for Asabo contains the significant wave heights, H_s, the maximum wave height H and the spectral peak period, T_p. Relevant to this study are the significant wave heights and peak period. About three years of data is provided for this work.

These measurements were taken every 60minutes during the period of data collection (1981 to 1983) with the number of samples found to be 5097 implemented in a MATLAB format. It is noted from the data provided that during some months, measurements were not available.

Statistical approach is used in this work. This is largely due to stochastic nature of ocean sea state. The check ratio will be performed on the data to verify the quality of data obtained at Asabo platform. Thereafter, the data are tested on two common wave statistical distributions, namely the Weibull and Log-normal distributions. The best fitted model is used to compute for short and extreme wave heights. The wave distribution at Asabo will also be compared with other locations in Nigerian Offshore.

3.1 The check ratio

The check ratio k(f)is defined as follows

$$k(f)= ((Var(elev))*(pi^2)*.fp)$$

Where;

elev = measured wave height

fp = frequencies computed from zero crossing periods.

Tp=1.3*Tz; fp=1/Tp;

The slight deviation from unity indicates the shallow-water effects around this offshore location.

3.2 The approach

The values of the measured significant wave heights, H_s are arranged in an increasing order $\{H_{s1} < H_{s2} < H_{s3} < \ldots\ldots\ldots\ldots < H_{sk}\}$, where k is the total number of H_s samples in the measurements. Thereafter, the distribution functions are linearized as shown below.

The average significant wave height, m_{Hs}, the sample variance, $s_{Hs}{}^2$ and the coefficients of skewness, g_1 are determined as explained by Akinsanya *et al.* (2017)

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

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

$$g_1 = \frac{\frac{1}{k}\sum_{k=1}^{k}(h_{sk} - m_{H_S})^3}{[s_{Hs}^2]^{3/2}} \quad (3)$$

Weibull distribution;

The expression for the distribution of the 3-parameter Weibull distribution is given as

$$F_{wH_s}(h) = 1 - exp\{-(\frac{h-\lambda}{\alpha})^{\beta}\} \quad (4)$$

Where

α = scale parameter

β = shape parameter

h = wave height

λ = location parameter

These parameters of the Weibull distribution are determined using the method of moments. For equations adopted for estimating these parameters, see Sabique *et al.* (2012)

a) *Shape parameter, β;*

The shape parameter, β, can be estimated by a simple iteration process, as explained by Akinsanya *et al.* (2017).

b) *Scale Parameter, α;*

Introducing this estimate for β into Eq. (6) below, and requiring ${\sigma_{Hs}}^2 = {s_{Hs}}^2$, the scale parameter, α, is estimated from Ardhuin e*t al.* (2009)

$$\sigma_{\mathrm{Hs}}^2 = \alpha^2[\gamma\left(1+\frac{2}{\beta}\right) - \gamma^2(1+\frac{1}{\beta})] \tag{5}$$

Where;

$$\gamma = 0.1783\ exp(1.352 + 0.2225\frac{T_p}{\sqrt{H_s}}) \text{ valid for } \frac{T_p}{\sqrt{H_s}} > 4.2 \tag{6}$$

σ_{Hs}^2 is the sample variance as described in Eq. (2). Details on the computation of the other parameters are shown in the APPENDIX.

c) *Location Parameter, λ;*

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

$$\mu_{Hs} = \lambda + \alpha\gamma(1+\frac{1}{\beta}) \tag{7}$$

where

m_{Hs}= the averaged significant wave height as shown in Eq. (1).

These parameters are found by solving the above equations using MATLAB, as explained vividly by Akinsanya *et al*. (2017).

Log-Normal;

The expression for the Log-normal Distribution is given as

$$\mathrm{F_{LNHs}(h)} = \frac{1}{2}\mathrm{erfc}\left(\frac{\mathrm{lnHs}-\mu}{\sigma\sqrt{2}}\right) = \phi\left(\frac{\mathrm{lnHs}-\mu}{\sigma}\right) \tag{8}$$

Where the erfc isthe complementary error function, and Φ is the cumulative distribution function of the standard normal distribution, H_s is the significant wave height, μ is lognormalscale parameter and σ is the lognormal location parameter.These two lognormal parameters are estimated using the method of moments as presented in Eqs. (9) and (9*) any other details can be found in the APPENDIX.

c) *Scale Parameter,* μ;

The scale parameter is estimated using Eq. (9) as discussed by Ginos (2009)

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

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

The location parameter is estimated using Eq. (9*), Ginos (2009).

$$\sigma^2 = \ln\left(\sum_{i=1}^{k} Hs_i^2\right) - 2\ln\left(\sum_{i=1}^{k} Hs_i\right) + \ln(k) \tag{9*}$$

Selection of model;

One way to get an early indication of whether or not the probability model can reasonably predict the variable (wave Hs) is to plot the data 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 (Haver 2013). Hence the data are plotted in section 4.4.1 on separate probability papers assuming two probability models, followed by a comparison with an empirical distribution. Any other details are featured in the APPENDIX.

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

$$\ln\left(-\,ln\left(1 - F_{wHs}(h)\right)\right) = \beta\ln(h-\lambda) - \beta ln\alpha$$

Hence, for the empirical distribution we will consider a plot of; refer to 4.4.1 for results.

$$\beta\ln(h-\lambda) - \beta ln\alpha \quad versus\ \ \ln(h-\lambda)$$

And for the fitted distribution a plot of

$$\ln\left(-\,ln\left(1 - F_{wHs}(h_k)\right)\right) versus \ln(h-\lambda)$$

From Eq. (8) above, the Log-normal distribution function is linearized as

$$-erfc^{-1}[2F_{LNHs}(h)] = \frac{lnh}{\sigma\sqrt{2}} - \frac{\mu}{\sigma\sqrt{2}}$$

Hence, the plot to be considered for the empirical distribution is give as

$$\frac{lnh}{\sigma\sqrt{2}} - \frac{\mu}{\sigma\sqrt{2}} against \quad \ln(h_k)$$

Where;

$h_k$is the sample wave height for k = 1,2,3,4,……………………,n
While for the fitted distribution, the plot to be considered is given as

$$-erfc^{-1}[2F_{LNHs}(h)] against\ \ \ln(h_k)$$

$F_{Hs}(h_k)$ is as given in Eq. (10)

$$F_{Hs}(h_k) = \frac{k}{n+1}; k = 1,2,3,\dots,n \tag{10}$$

Hence we will consider plots of Log-normal and Weibull distributions as suggested by Akinsanya *et al.* (2017).

Log-normal;

From Eq. (8) above, the Log-normal distribution function has been linearized as

$$-erfc^{-1}[2F_{LNHs}(h)] = \frac{lnh}{\sigma\sqrt{2}} - \frac{\mu}{\sigma\sqrt{2}} \tag{11}$$

Hence, the plot to be considered for the empirical distribution is give as

$$\left[\frac{\ln h}{\sigma\sqrt{2}} - \frac{\mu}{\sigma\sqrt{2}}\right] \text{versus } \ln(h_k)$$

For k = 1,2,3,4,……………………,n

While for the fitted distribution, the plot to be considered is given as; (see Hanson and Phillips 2001)

$$-erfc^{-1}[2F_{LNHs}(h_k) vs\ \ln(h_k)]$$

Where $F_{HS}(h_k)$ is as given in Eq. (10).

$$F_{LNHs}(h_y > h) = 1 - \frac{1}{2} erfc\left(-\frac{lnh - \mu}{\sigma\sqrt{2}}\right) = \frac{1}{n_{3h}}$$

and

$$exp\left\{-\sigma\sqrt{2}\left(erfc^{-1}\ \left(2(1 - F_{LNH_s}(h)\right)\right) + \mu\right\} = h$$

3. parameter Weibull

If h_y is the single largest wave height while n_{3h} is the total number of samples in the period considered, Akinsanya *et al.* (2017) puts Eq. (4) as

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

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

$$\frac{1}{\beta}\ln(-\ln(F_{wHs}(h))) + ln\alpha = \ln(h-\lambda)$$

$$\exp\{\tfrac{1}{\beta}\ln(-\ln(F_{wHs}(h))) + ln\alpha = \ln(h-\lambda)\} \tag{12}$$

In both cases of the probability model, the annual exceedence probability F_{Hs} is given

$$F_{Hs}(h) = \frac{1}{n_{3h}} \tag{13}$$

4. Results and discussions

4.1 Data presentation.

The data were provided by Shell. Details on the interpretation and application of the data have been considered in the APPENDIX.

4.2 Data quality check

As discussed in Section 3.1, a quality control (QC) check was carried out on the data (Asabo). It is noted that the check ratio spectra, $k(f)$ (Fig. 1) indicates that most spectral estimates are associated with values of $k(f) = 1$. There are no spectra with spurious low frequency peaks (Fig. 5). The values of k (f)>1.0 occurred for low frequency estimates, i.e., below the spectral peak frequency which is from f = 0.12 Hz through 0.17 Hz. Accordingly, one can conclude that the Asabo data is of good quality as the deviation from unity indicates shallow-water effects (47 m).

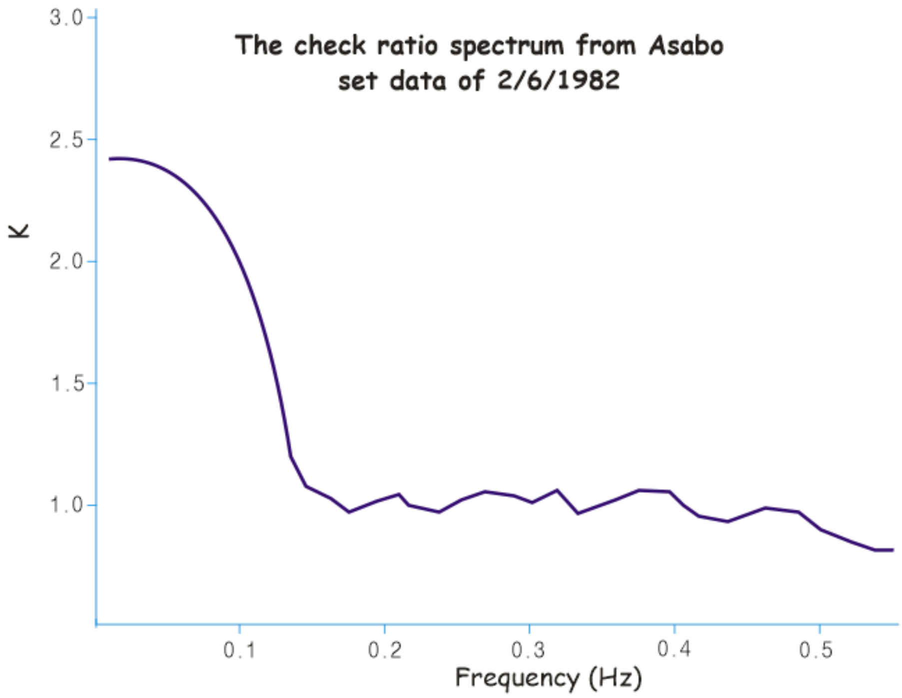

Fig. 1 The check ratio wave spectrum at Asabo

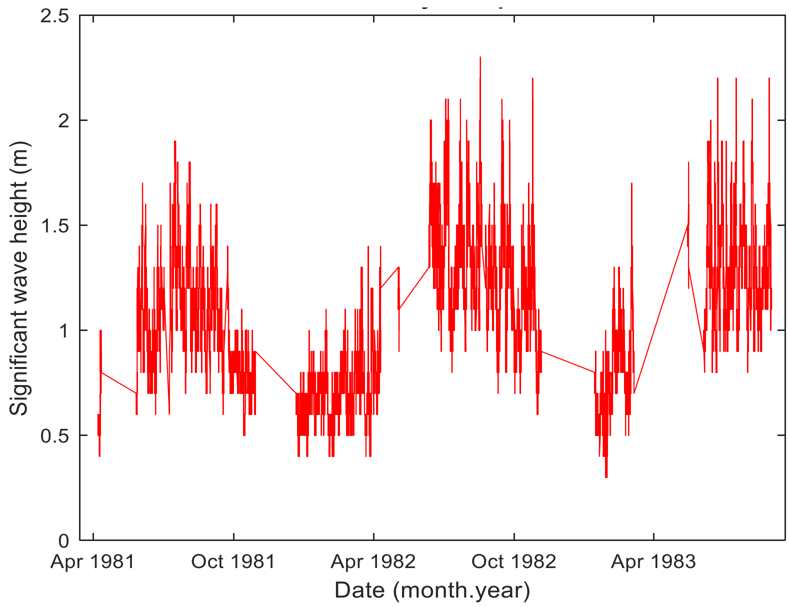

Fig. 2 Hs Time History for Asabo, April 1981 to 1983

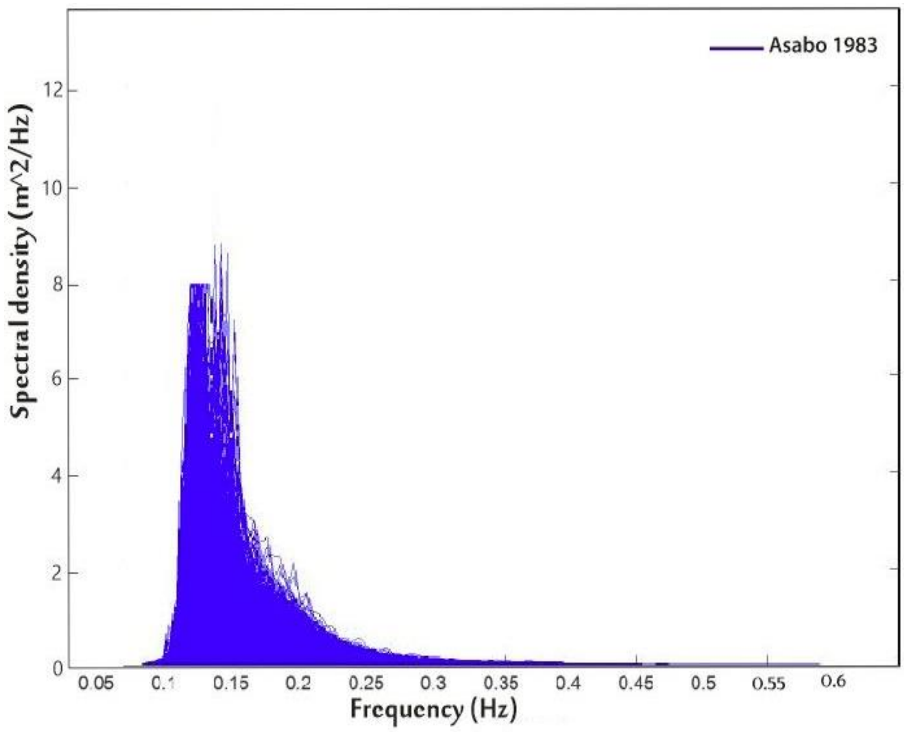

Fig. 3 Asabo wave data variance density frequency spectra

4.3 Asabo data partitioning

Fig. 2 displays some discontinuity of the measurements made. As there was no measured data within the discontinuities, this formed the basis to partition the available data in order to obtain the most appropriate description of the sea-states. Which involved running of 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 useful data point obtained is 5,097.

4.4 Spectral and scatter plots

Fig. 3 represents the entire data set, comprising both the rainy and dry season's data. Fig. 4 is an extract from Olagnon *et al.* (2004). Comparing the two Figures, the number of peaks and the relationship between spectral densities and frequencies for the different locations are observed. Asabo sea state has one peak, the Bonga spectrum has two peaks.

Fig. 5 shows a seasonal scatter plot of the Asabo data. It is noted from Fig. 5, that the values of Hs are generally low during the dry season (November to March) and are relatively high during the raining season (April to October).

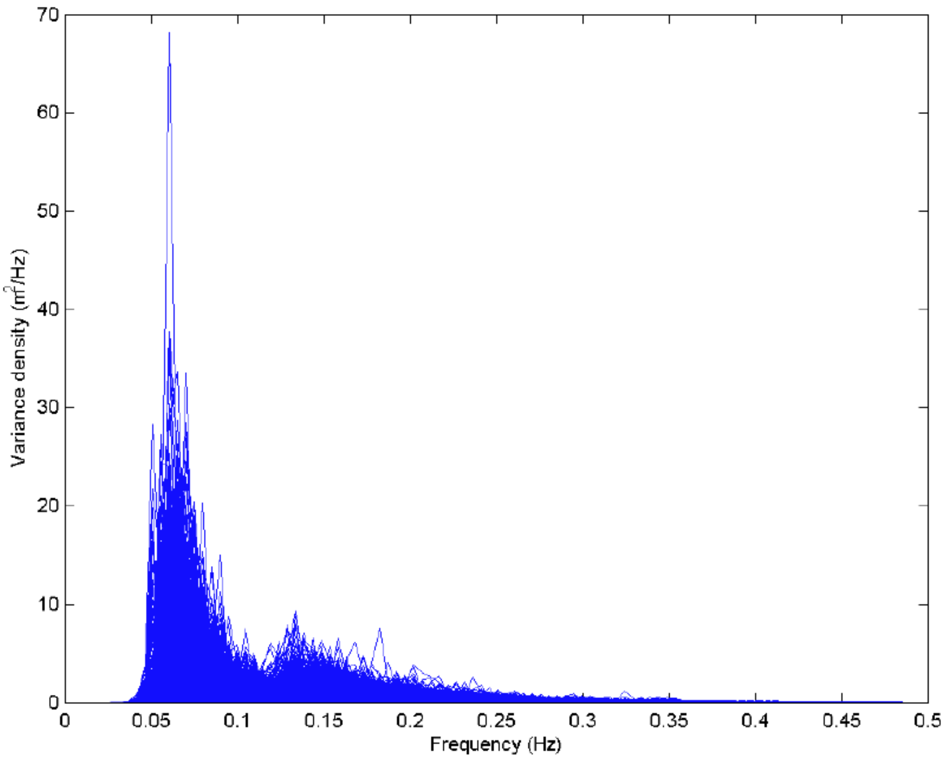

Fig. 4 Bonga wave variance density frequency spectra (Source: Olagnon *et al.* 2004)

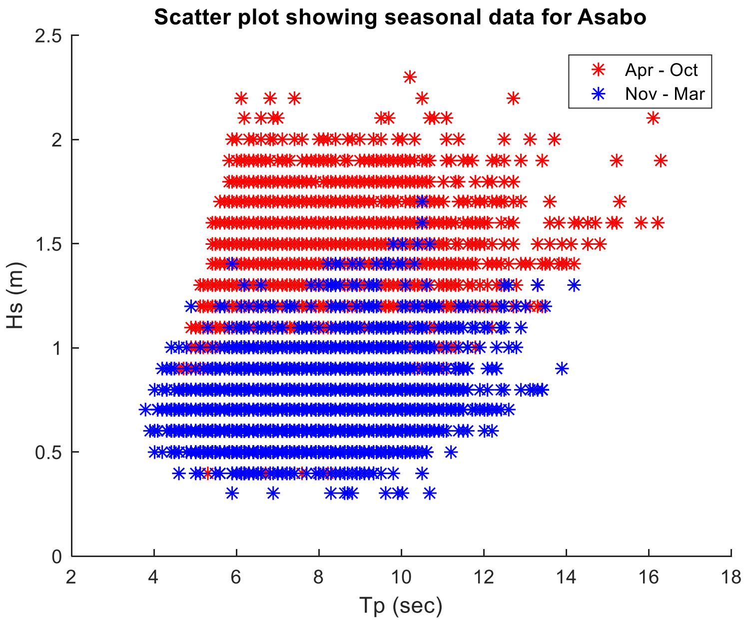

Fig. 5 Asabo Hs and Tp scatter. Plot including all data available

4.5 Fitting distributions to data

The measured data were fitted to two different probability models as mentioned previously. The results of the plots are presented on probability paper in this section in order to identify the most suitable model.

4.5.1 Weibull and Log-normal models

Fig. 6 below shows a comparison of the 3-parameter Weibull distribution with the empirical distribution for the wave received at Asabo location. The procedure for computing the empirical and fitted distribution is described in section 3.0 from Eq. (9*) through 10. The Log-normal distribution plot is shown in Fig. 7. The MATLAB analysis containing other details is presented in the APPENDIX.

The emperical distribution given in Fig. 7 shows that the log-normal model under-predicts the significant wave height at high values of Hs. This is not adequate because extreme wave heights computation is required for design purposes. Comparing Fig. 7 with the 3-parameter Weibull plot of Fig. 6, (Weibull) presents a better prediction than the Log-normal. Hence, the 3-parameter Weibull is recommended for prediction of the wave extreme Hs at the Asabo site.

4.6 Probability weibull model parameter estimations

The parameters of the selected probability model (Weibull) for the wave components are calculated. Details on computing each of these parameters have been presented in section 3. Details of the estimation are; m_{Hs}=0.7562, s_{Hs}^2 =0.0959, g_1=0.9404, β = 1.6212, α= 0.5949, λ = 0.5090 and k= 5,097. See also Table 1 for resulting values.

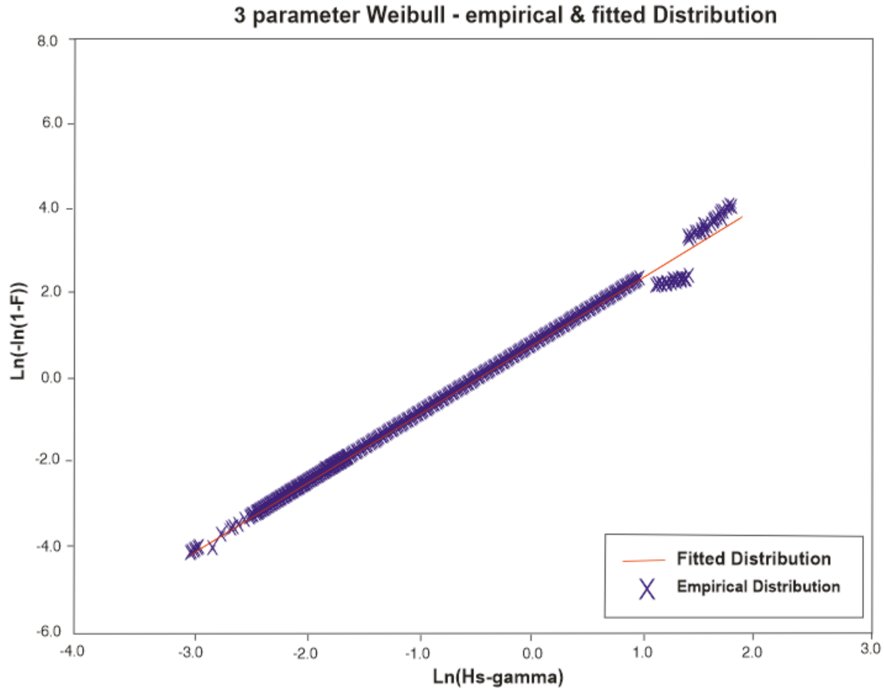

Fig. 6 3-Parameter Weibull-empirical fitted distribution for Asabo wave system

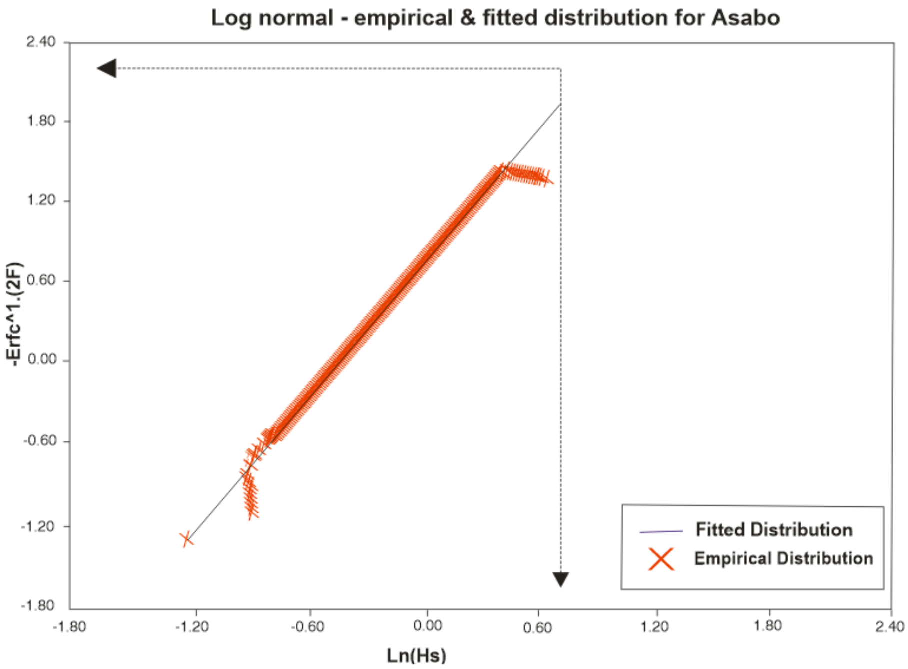

Fig. 7 Log normal – empirical and fitted distribution for Asabo

Table 1 Values of 3-parameter Weibull Distribution of Hs for Different Return Periods.

Return Period (years)	$\mathbf{n_{3h}}$	**ln(-ln(1-F)**
1	8,760	1.03
10	87,600	1.562
100	876,000	3.187

The results of the calculations for different return periods are given in Tables 2 and 3.

1-year significant wave height prediction

In a short-term prediction, a 1-year return period, the number of samples $n_{3h,}$ is estimated as;

n_{3h} = (24/1)x365 = 8,760

thus, from equation (15), the probability of exceedance is estimated as;

$F_{Hs}(h) = 1.142\times10^{-4}$

Hence, from Table 2, the parameters are given as

Note that there is a disparity of 1.2m between the maximum measured Hs of the averaged samples recorded by the WAVESTAFF at the Asabo site during 1981 and 1983 and the 1-year estimated Hs so the 1-year estimate is not considered to be well predicted by the data.

Table 2 Maximum Hs of the Average Samples & Estimated Hs for 1-year return period

Probability Model	**Weibull**
n_{3h}	8,760
$F_{Hs}(h)$	$1.142\text{x}10^{-4}$
Max. Hs from the Averaged Samples	2.3
Estimated Hs, Return Period 1 year	1.13

Table 3 Max. H_s of the average samples and estimated Hs for 100-years return period

Probability Model	**Weibull**
n_{3h}	876,000
$F_{Hs}(h)$	$1.142\text{x}10^{-6}$
Max. $H_s$from the Averaged Samples	2.3
Estimated Hs, Return Period 100years	3.197

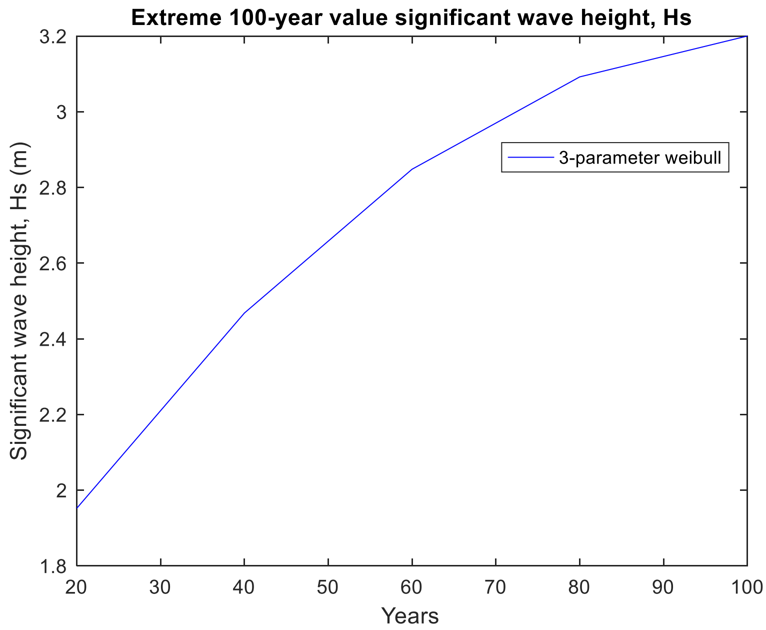

Fig. 8 Distribution of Significant Wave Height as a function of return period (Years)

Extreme 100-year significant wave height

For the extreme value prediction, a 100-year return period will be considered in this case. For a 100-year return period, the number of samples are:

n_{3h} = (24/1)x365x100 = 876,000.

Thus, the probability of exceedance is estimated as;

$F_{Hs}(h) = 1.142*10^{-6}$

Results are given in Table 3.

Distribution of H_s with return period

Figure 8 shows the distribution of the significant wave height with return period for the wave conditions. It shows how the Weibull distribution predicts the return period. It is noted that that the prediction is reasonable from 20-years return period.

4.7 Summary of discussions

In summarizing the results of this work, a typical offshore location in Nigeria, Bonga was used as a reference. It is very notable that comparing Figs. 3 and 4 (the wave spectral density of Bonga and Asabo), there is a clear indication that the wave characteristics are different. An important observation is that the single-peaked spectrum of Asabo (0.12 Hz -0.15 Hz or 8 sec - 6 sec) with highest spectral density value of 8 m^2/Hz seems approximately the same as the one of the two-peaked Bonga's spectra peaks (0.14 Hz or 7 sec) with nearly similar highest spectral density value of 8 m^2/Hz. T_p is an important parameter for marine designs and operations. For instance, for marine operations and for the responses of floating construction vessels, close attention should be paid to resonance with the vessel's Eigen-periods because of the presence of swell waves with periods within period range of 6 sec -8 sec.

From the results and presentations in Figs. 3 and 4, it can be deduced that swell from the Southern Ocean is not present at Asabo platform. The implication of this deduction is that Asabo wave system is emanating from storms within the Atlantic Ocean and that effect of southern storms (i.e., swell from the Southern Ocean) is shielded by numerous islands near Asabo offshore. This is evidenced in Fig. 9.

To confirm an absence of local wind wave effect, an attempt is made to perform a regression analysis to verify the dependence of the wave system on the local wind speed. Shell Nigeria provided recorded wind speed corresponding to significant wave heights Hs. Note that a statistical technique is used here to find the relationships between the two aforementioned variables. In this case, regression analysis helps us to know whether the wave characteristics are influenced by the local wind or not. The tendency of getting a unity value for R-Square in Table 5 indicates the action of the local wind on the Hs values (dependent variable). A simple regression plot (straight line graph) was made in the form;

$$Y = mX + C$$

m is the slope of the graph, C is the intercept, Y and X are the averaged corresponding daily significant wave heights and wind speed respectively. Determination of regression coefficient, R^2 is a measure of fit as described in Ododo *et al.* (1996). The results are tabulated in Table 4.

Table 4 Regression analysis for local wind speed versus Significant Wave Height

Months	**1981**	**1982**	**1983**
	R. Square	R Square	R Square
January	-	0.005627	-
February	-	0.004726	0.202743
March	-	0.117707	0.295285
April	0.669927	0.351531	-
May	0.585243	-	-
June	0.501459	-	0.705219
July	0.555097	0.27467	0.488835
August	0.359481	0.408863	0.159022
September	-	0.065258	-
October	-	0.001097	-
November	-	-	-
December	0.207454	-	-

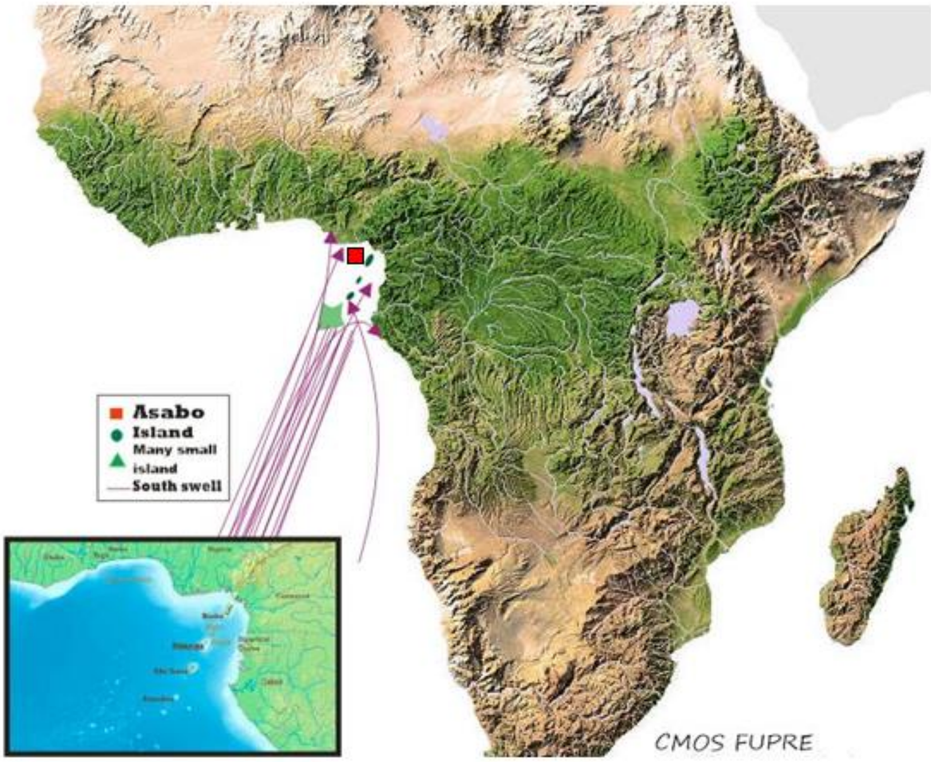

Fig. 9 Wave tracks for Asabo

As evident in the results presented, the absences of values like 0.9 to 1.0 tells that the waves with such heights were not generated by the effect of local wind.
In general, the study of wave system at Asabo offshore showed some common features. It is found that the Weibull distributions can be used to predict the Asabo wave system and the extreme wave conditions. It is important to note that only 3 years of data was used for the 100-year significant wave height estimation. This is useful as there is scarcely long year data series available for use in this region. The obtained extreme value appears reasonable for design purposes. More data, however, may improve the result and reduce uncertainties in the estimates.

Geographically, these islands can be described as follows;

Bioko Island:
Coordinates: $3^0$30'N, $8^0$42'E, twelve (12) kilometers away from Asabo. 70 km in length, 32 km width, covering a total area of 2017 km^2 with over 360,000 people living on the island.

Sao Tomé and Principe:
It is a country with a population of 250,000, 1001 km^2 land area and just 165 km away from Asabo.

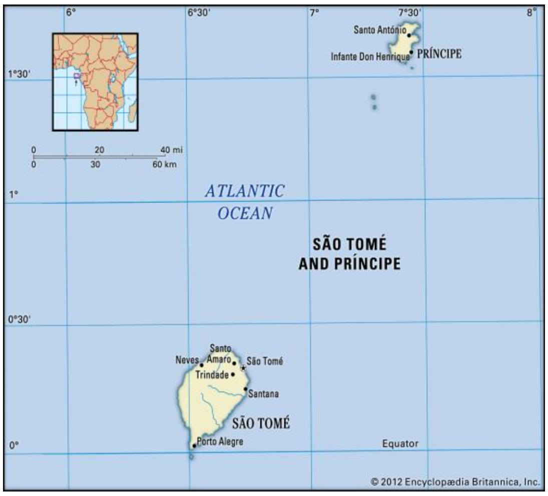

Fig. 10 Satellite picture of the major island (Bioko) and map of Sao Toméand Principe in South West direction of Asabo

Annobon:
This Island (situated to the south west of Sao Tomé) has a total area of 17 km^2, it has a population of 6,000 and located about 180 km from Asabo in the south west direction.

These three islands coupled with the variation in depth around the Asabo field is believed to shieldthe Southern Atlantic waves from reaching Asabo directly. Satellite image/mapof these islands are presented in Fig. 10.

5. Conclusions

The investigation of the Asabo wave system has shown the specific characteristic at the site compared to the general understanding of waves Offshore of West Africa. This study points to the importance of particular studies for locations on which marine activities are planned. This paper concludes that Asabo Offshore wave system is largely emanating from the North Atlantic storms. The presence of numerous islands near the Asabo location shields the site from effects of storm in the Southern Ocean. It is noted that the local wind has little or no contribution. The shallowness of the Asabo has also minimal contribution. The study has raised the importance of the effect of islands and near land on the wave conditions at sites for marine operations and offshore designs considerations.

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QM

Appendix

MATLAB FILE; ASABO WAVES STATISTICAL ESTIMATIONS AND PLOTS

```
Closeall
Clearall
clc
% the data sample was average at 1hour
%READING THE DATA
DATA2=xlsread('average_data3.xlsx');
elev=(DATA2(:,1));
elev2=(DATA2(:,2));
n=5097; % Total number of samples for the 1hr average

%Asabo wave analysis
%reading the periods
Tp=1.3*Tz; %conversions
fp=1./Tp;

% parameter of Lognormal Model; based on method of moments
Hs1=sum(elev);
Hs0=sumsqr(elev);
u=-log(Hs0)/2 + 2*log(Hs1)-(3/2)*log(n)
p=sqrt(log(Hs0)-2*log(Hs1)+log(n))
y=log(elev); % natural log of wave Hs
F=(y/(p*sqrt(2)) - u/(p*sqrt(2)));

%%Empirical Distribution
e=(elev2/(n + 1));
L=-(erfcinv(2*e));

% Fitting of LOGNORMAL Model
plot(y,F);
```

```
title('log-normal probability paper - empirical and fitted distribution')
xlabel('ln(Hs)');
ylabel('-(erfc^-1.(2F)');
holdon
scatter(y,L,'+','r'); % plot of emperical distribution
legend('Fitted Distr', 'Empirical Distr', 'Location','southeast');
t=(y*(2+1/p-u/p));
s=-2*log(e*p*sqrt(2*pi));
%plot(y,t);
%hold
%scatter(y,s);
lognfit(elev)
h=(erfc(-(y-u))/(p.^2 * sqrt(2)))/2;

%    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

syms A;
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,'+','r');
legend('Fitted Distr', 'Empirical Distr','Location','southeast')

% Probability density function
yy=lognpdf(elev,u,p);
plot(elev,yy);
title('log-normal & 3 parameter Weibull density function of Hs')
xlabel('Hs (m)')
ylabel('Probability density function')
holdon
Y=(B/A)*(elev/A-Ga/A).^(B-1).* (exp(-(elev/A-Ga/A).^B));
plot(elev,Y,'r');
legend('log-normal CDF', '3 parameter Weibull','Location','northeast')


%                   1-year Hs calculation - 3-parameter Weibull
n1=1;
N = 24/1 * 365 * n1;
Fhs = 1/N
hw = exp(1/B*(log(-log(Fhs)))+ log(A)) + Ga

%     1-year Hs calculation - Log-normal
```

```
hl=exp(-p*sqrt(2)*(erfcinv(2*(1-Fhs))) + u)


%       100-year Hs calculation - 3-parameter Weibull
n2= 100;
Fhs2 = (24/1 * 365 * 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 = (24/1 * 365 * n3).^(-1)
%Fhs2 = 1/N2
hwd = (exp(1/B*(log(-log(Fhs3)))+ log(A)) + Ga);

plot(n3,hwd);
title('Extreme 100-year Value Significant Wave Height,Hs');
xlabel('years');
ylabel('Significant Wave Heights,Hs (m)');
holdon
plot(n3,hld, 'r');
legend('3-parameter Weibull','Location','southeast');
end;
```

Alphabetic symbols

erfc	Cumulative Error Function
F_{Hs}	Cumulative Probability
$F_{Hs}(h_k)$	Fitted distribution
g1	Sample Coefficient of Skewness
h	Wave Height
h_K	Sample wave height
h_{sK}	Sample significant wave height
$H_s = h_s$	Significant Wave Height
k	Sample number
k(f)	Check ratio
n_{3h}	Number of 3-hour sample
$s_{Hs}{}^2$	Sample Variance
T_p	Peak wave period
y_1	Probability Model Coefficient of Skewness

Greek symbols

λ	3-parameter Weibull Location Parameter
$\boldsymbol{\sigma}$	Log-normal Location Parameter
$\sigma_{Hs}{}^2$	Probability Model Variance
Φ	Cumulative Standard Normal Distribution