Comparison of the Characteristics of Abnormal Waves on the North Sea and Gulf of Mexico

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Abstract

Abnormal waves that have occurred in various storms in more than one location in the North Sea and during a hurricane in the Gulf of Mexico, are considered here. This work compares the parameters that describe the characteristics of these abnormal waves and the sea states in which they occurred.
It was found that in general there were not major differences between the characteristics of the abnormal waves but some sea states that occurred during the hurricane Camille seem to show a higher degree of non-linearity than the ones in the North Sea.

1. Introduction

There has been much interest during last decade about abnormal or freak waves and various possible mechanisms for their generation have been identified, as reviewed by Kharif, and Pelinovsky (2003) and Guedes Soares et. al. (2004a), for example. However, the nature of abnormal or freak waves is not known yet, the wave generation mechanisms are not fully understood, and there is no generalized agreement about the criteria to classify one extreme wave as an abnormal one.

Dean (1990) has considered that freak waves are those that occur within a sequence of waves that have been identified as being higher than can be expected from the Rayleigh distribution of wave heights. He noted that the most probable maximum wave in a record of about 2000 waves is about 2 times the significant wave height according to the Rayleigh distribution. Thus a freak wave in such a long record would need to have a height larger than that limit. Other definitions are based on the ratio between the crest of the maximum wave and significant wave, and different authors have chosen different level of this ratio (see e.g. Guedes Soares et al 2004a). Tomita and Kawamura (2000) have chosen a combination of the two ratios.

For this study the abnormal waves were selected according to definition given by Dean (1990) that is: the abnormality index ($AI = H_{max}/H_s$) was higher than 2. As it is possible to calculate the abnormality index defining the wave heights from down-crossings and up-crossings of the mean sea surface, two possible definitions for AI were used. If any of the two possible abnormality indexes indicated a presence of a freak wave, the time series was included in this investigation.

This study builds upon results presented by Guedes Soares et al (2003) for North Sea waves and Guedes Soares et al (2004a) for waves that occurred during the Camille hurricane in the Gulf of Mexico. It considers the main properties identified in those abnormal waves and in the sea states in which they occurred, in order to determine if any significant differences exist in any of the parameters describing those data sets.

2. Description of the data

The raw data used in this study were collected at three different locations. One data set was recorded in Gulf of Mexico during hurricane Camille on 17th of August 1969. There are 6 time series chosen from all the data for further analysis. These contain records of freak waves satisfying condition: $AI_D>2$ or $AI_U>2$, where AI_D is the down crossing abnormality index calculated as $AI_D = Hmax_D / Hs$ and AI_U is the corresponding parameter for waves defined with zero up-crossings. As this is wave-by-wave analysis the Hs was calculated as the average height of the highest third of the waves. One of the 6 identified waves satisfies the Tomita and Kawamura condition for a freak wave.

Another time series considered in this study contains the well-known “New Year Wave” and was collected on Central North Sea on Draupner platform on 1st of January 1995 at 15:20 PM. The “New Year Wave” is a freak wave according to definition of Tomita and Kawamura.

Finally use is made of northern North Sea data recorded in the North Alwyn platform during the storm from 16 to 22 of November 1997. Among these data 25 time series were identified as having abnormal waves defined as in case of hurricane Camille.

Between these 25 waves 20 of them satisfy the Tomita and Kawamura condition. From the three data sets all together 32 records will be the basis for further analysis.

3. Results and discussion

To relate the occurrence of the abnormal waves with the stage of development of a storm the evolution of the significant wave height was plotted together with the occurrence of the abnormal waves. Figure 1 shows that the record of the hurricane Camille corresponds to a developing storm with very rapidly increasing Hs, until the recording equipment failed. During this period 6 abnormal waves were identified.

The record with the New Year Wave which was included in this investigation comes from a period in which there is a stable value of H_S, which might have coincided with the peak of the storm see (figure 2). In the case of North Alwyn (figure 3), abnormal waves have occurred both in the phase or storm development and of storm decay, although the majority of freak waves were registered after the storm peak.

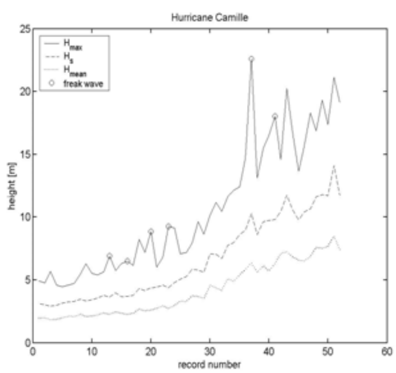


Figure 1. Time development of wave height characteristics during Hurricane Camille.

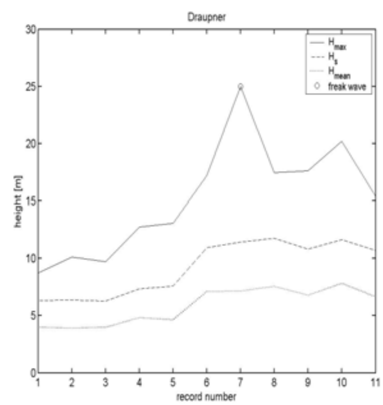


Figure 2. Storm recorded at the Draupner platform.

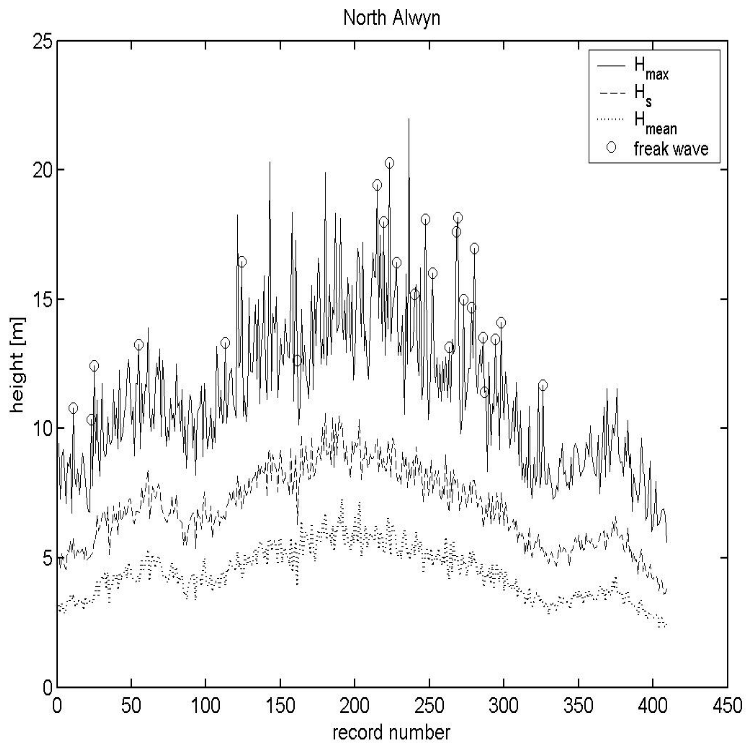
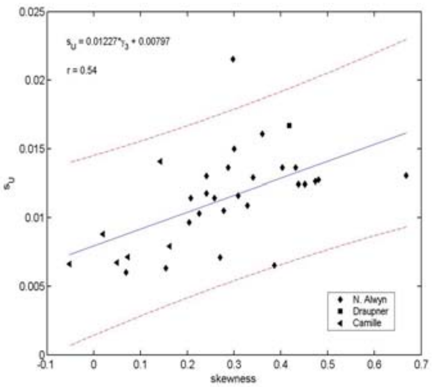


Figure 3. Time development of wave height characteristics during storm on North Alwyn.

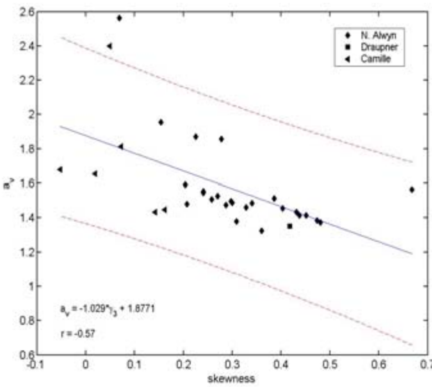
Properties of the individual abnormal waves were studied and the correlation between various parameters has been analysed. Scatter plots of magnitudes which have shown the highest correlations are plotted in figures 4 a-d, which shown the individual wave steepness coefficient s_U, vertical asymmetry a_v, and maximum crest height as a function of the skewness of the sea state, as well as the relation between the vertical and horizontal asymmetry a_h. The definitions of different singular wave characteristics can be found in Guedes Soares at al. (2004b).

The differences between characteristics of the individual freak waves are not apparent and even hurricane Camille waves seem to follow behaviour of the rest of the North Sea freak waves.

a)



b)



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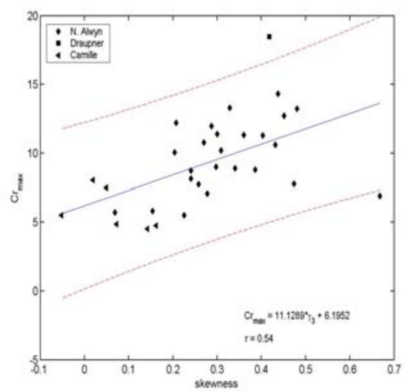

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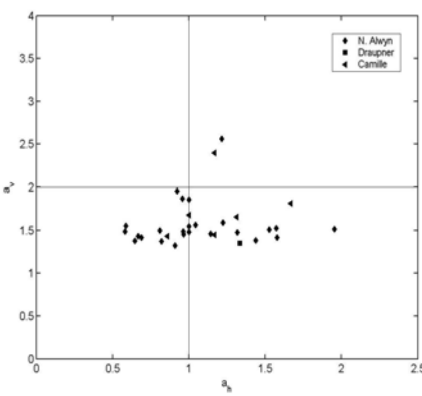

Figure 4. Characteristics of individual freak waves correlation between: a) down-crossing steepness and skewness of the sea state, b) vertical asymmetry and skewness, c) crest of the wave and skewness, d) vertical asymmetry plotted against horizontal one.

Since these large waves tend to occur in non-linear sea states, the degree of non-linearity was also studied. The non-Gaussian behaviour of wave record is reflected through its statistical moment-based parameters: skewness and kurtosis. In this study the excess kurtosis is used - that is sample kurtosis minus 3 – and from now on excess kurtosis will be called simply kurtosis. Table 1 shows mean values of different sea state parameters.

Skewness values indicate some differences between North Alwyn and hurricane Camille sea states: mean values differ significantly, being close to zero for Camille and clearly positive for the North Sea data. The Camille data also tends to have a lower value of the ratio of maximum crest height to H_s. The rest of characteristics shown in the table do not reveal major differences between the different locations.

	γ_3	γ_4	AI_{up}	AI_{down}	Cr_{maxD} / Hs_D	H_{maxD}	Cr_{maxD} / H_{maxD}	H_{sD}/L_p
North Alwyn								
mean (N=25)	0,32	0,73	2,03	2,06	1,34	14,83	0,65	0,0356
standard deviation	0,13	0,45	0,18	0,15	0,20	2,83	0,08	0,0032
Draupner								
(N=1)	0.42	1.07	2.23	2.19	1.62	25.01	0.74	0.0379
Camille								
mean (N=6)	0,07	0,50	1,95	1,97	1,08	10,47	0,59	0,0257
standard deviation	0,08	0,31	0,21	0,17	0,24	4,42	0,10	0,0091
Total (N=32)								
mean	0,28	0,70	2,02	2,05	1,30	14,33	0,64	0,0338
standard deviation	0,16	0,43	0,19	0,15	0,24	4,01	0,09	0,0061

Table 1. Mean values and standard deviations for magnitudes calculated from time series with freak waves.

Figure 5 shows the scatter plot of kurtosis against skewness of all investigated time series. There are 3 time series recorded in hurricane Camille which do not follow the regression curve derived by Guedes Soares at al. (2003). Their skewness is close to zero and their kurtosis is high. There are also time series from hurricane Camille that have the same properties as time series from North Alwyn and Draupner.

It is reasonable to group the sea states in two sets: sea states with high kurtosis and skewness close to zero and these with existing correlation between kurtosis and skewness. The sea states with high kurtosis and very small skewness cannot be described by a second order theory but could eventually fit a third order theory. On the other hand the rest of the sea states, which show both skewness and kurtosis different from zero exhibit the presence both of second order and third order interactions in the wave field as identified in Guedes Soares et al (2003).

Stansberg (1998) presented results from comparison of numerically simulated second-order waves with theory. Figures 7 and 8 show his results together with the sea data considered here. Only sea states with low values of kurtosis and middle values of skewness seem to obey the theory (see figure 8). Records with high kurtosis and almost zero skewness do not follow theoretical line for second order nonlinearities, what was to expect, and the sea state steepness is not in the region of highest values. Figure 7 shows comparison of vertical asymmetry and steepness of maximum waves and higher asymmetry of sea waves is visible very well.

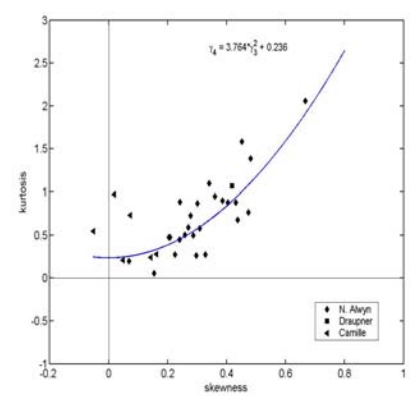

Figure 5. Relation between skewness and kurtosis for sea states with freak waves.

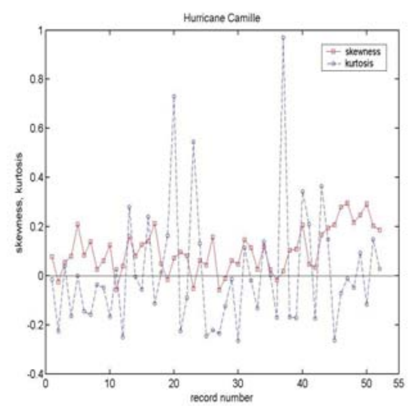

Figure 6. Time development of the coefficients of skewness and kurtosis, showing individual estimates and moving average trend – hurricane Camille.

The value of skewness shows increasing trend in case of all storms before the peak of the storm. However in the case of Camille the skewness very often drops below zero, what is not typical for the other storms. Hurricane Camille data was recorded before peak of the storm with quite a big distance from the storm (23 km) and as skewness is proportional to the wave steepness (Huang and Long, 1980) one would expect rather slow growth of the skewness value as it is in case of Draupner and North Alwyn wave records.

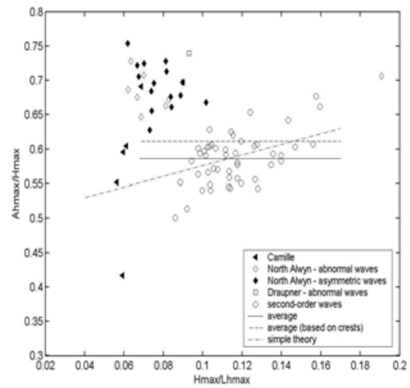

Figure 7. Comparison between vertical asymmetry of in-situ data and second-order theory and simulations.

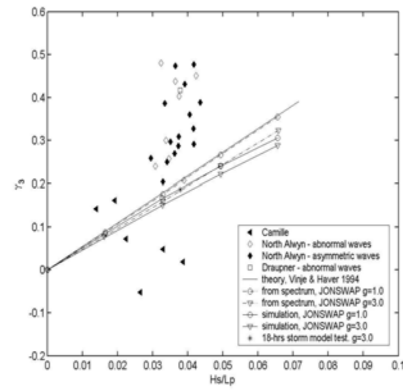

Figure 8. Skewness from second order simulations of sea states, theory and measurements in the North Sea.

Mori and Yasuda (2002) showed that the value of kurtosis is directly proportional to the probability of the occurrence of large waves in a wave record. Storm waves have high steepness and the majority of the water elevation records analysed have high kurtosis, as is visible in figure 5 and table 1. Surprisingly, the correlation coefficient of kurtosis with wave height (maximum, mean, or significant - calculated for up- and down-crossing waves) is very low. Nevertheless storm waves are higher than calm water waves and kurtosis higher than zero can be an indicator of that.

Conclusions

The analysis of data from the North Sea and Gulf of Mexico indicates that the difference between the characteristics of the individual freak waves do not seem to be significant, although the Camille waves tend to have a lower ratio of maximum crest to significant wave height. However these conclusions must be considered with care as the length of records and the number of abnormal waves considered is not very large.

There appears to exist a clear difference between the characteristics of the sea states in which freak waves occur in North Sea storms and in the Gulf of Mexico hurricane, namely in North Sea records did not appear clear cases of clean third order nonlinearity, while they appeared in records from Camille. This may be associated with the nature of hurricanes that induce a very high transfer of energy locally and this may lead to a higher degree of non-linearity of the generated sea states.

Analysis and comparison of storm waves with second order simulations and theory indicates discrepancies that could be associated with the presence of third order nonlinearities, especially visible in case of hurricane Camille sea states with skewness close to zero.

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