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ARE THERE DIFFERENT KINDS OF ROGUE WAVES?

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ABSTRACT

Inasmuch as there is as yet still no universally accepted definition for rogue waves in the ocean, we think there might just be more than one kind of rogue waves to contend with. While the conventional approach has generally designated waves with Hmax/Hs greater than 2.2 as possible rogue waves, based on Rayleigh distribution considerations, there is conspicuously no provision as to how high the ratio of Hmax/Hs can be. In our analysis of wave measurements made from a gas-drilling platform in South Indian Ocean, offshore from Mossel Bay, South Africa, we found a number of cases that indicated Hmax/Hs could be valued in the range between 4 and 10. If this were to be the case then these records could be considered to be "uncommon" rogue waves, whereas a record of Hmax/Hs in the range between 2 and 4 could be considered to comprise "typical" rogue waves. On the other hand the spikes in the Hmax data could have been caused by equipment malfunction or some other phenomenon. Clearly the question of whether or not there are different kinds of rogue waves can not be readily answered by theoretical considerations alone and there is a crucial need for long-term wave time series measurements for studying rogue waves.

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INTRODUCTION

Prof. Faulkner's "lateral thinking" in the mid 1990's that recognized rogue waves as the likely extraordinary scenario that caused the loss of many large ocean-going ships and vessels over the years, revived the generally overlooked notion of freak waves advanced by Draper (1964) three decades earlier. This thinking led to the implementation of EU MaxWave research program in 2000, and sparked a world wide fascination on rogue waves by oceanic engineers and scientists as well as general publics alike in recent years**.** But the study of rogue waves at the present is only evolving slowly. In presenting part of their MaxWave research results, Bitner-Gregersen and Magnusson (2004) asserted that: **"**Too few data sets including freak events have been recorded making it difficult to develop satisfactory physical and statistical models for prediction of these waves. Further, no consensus has been reached neither about a definition of a freak event nor about the probability of occurrence of freak waves." which clearly suggests that the current state of rogue wave studies is basically tentative and underdeveloped. Indeed as Muller et al. (2005) also pointed out, in their report of a recent workshop on rogue waves, that "Our understanding of rogue waves is greatly hampered by the lack of comprehensive observations in space and time" even though "the evidence for dynamical causes of rogue waves is piling up."

Undoubtedly the key toward fostering further progress in the understanding of rogue waves lies in the crucial need of comprehensive, long-term rogue wave measurements. In this paper we wish to present some results, based on actual measurements, which could either be very large rogue waves, or spikes caused by some other phenomenon. At present actual measurements of rogue waves are still very rare. Beyond the widely acclaimed picture, which was taken by Philippe Lijour and shown in Fig. 1, a 25 m rogue wave, encountered by the oil freighter Esso Languedoc outside the coast of Durban, South Africa in 1980; or the 34 m one observed by Frederick Marggraf onboard USS Ramapo in North Pacific in 1933 which is known to be the highest ever observed; and the universally recognized rogue wave time series of 1995 new years day recorded from the Statoil Draupner platform in the North Sea (Haver, 2004), there are really not many undisputed rogue wave cases available. The crucial need for long-term ocean wave time series measurements for studying rogue waves can not be over emphasized.

Fig. 1. A rogue wave in South Indian Ocean near Durbin.

Fig. 2. A map showing the location of the FA Platform.

Fig. 3. A snapshot of the FA Platform.

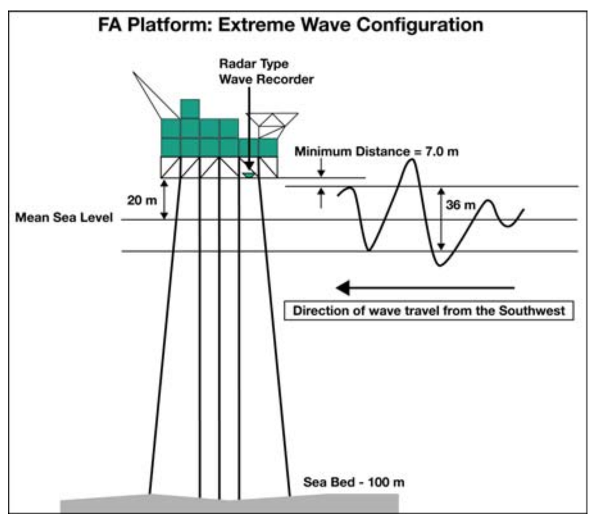

Fig. 4. Schematic illustration of the platform wave measurement.

THE MEASUREMENTS

The measurements used in this study are made from a gas-drilling FA Platform in South Indian Ocean, offshore from Mossel Bay, South Africa, located at 22.10ºE and 34.58ºS, alongside the Agulhas current in 100 m of water depth. (Figs. 2 and 3.) Waves are measured hourly by a Marex Radar Wave Monitor based on 20 minutes of data sampled at a frequency of 2Hz. The wave sensor, as shown in Fig. 4, has a minimum to maximum sensing range of 7 to 50 m respectively, for a possible upper limit for maximum wave height of 43 m. Wave parameters, consisting of significant wave height, maximum wave height, and average zero-crossing wave period, are processed and stored along with meteorological parameters, such as wind speed, wind gust, wind direction, air temperature, and barometric pressure among others. Presently, time series wave data is unfortunately discarded after wave parameters are processed. Nevertheless the availability of maximum wave height jointly with wind speed and wind gust has provided a unique opportunity for us to explore possible rogue waves as well as their potential meteorological connections in this renowned region of colossal waves.

Forristall et al (2004) found on their Wave Crest Sensor Inter-comparison Study (WACSIS) Project that Marex radar wave sensors do record many crests which are significantly higher than those recorded in the same seas by other instruments. They also expressed the opinion that measurements from one instrument cannot conclusively show the presence of a rogue wave. As we are using the data measured by a Marex radar in this paper, we are mindful of the WACSIS results.

DATA AND ANALYSIS

From an examination of the most recent 6 years data that covered the turn of the millennium, 1998 – 2003, we have found some interesting results, which may or may not be immediately intuitive. Based on the customary criterion of defining rogue waves as $H_{max}/H_s > 2$, there are 1563 potential rogue wave cases contained in a total record of 50359 hours over the 6 years. A general occurrence rate of 3.1 percent, which is less than, but reasonably close to, the 3.7 percent Liu and Pinho (2004) found from South Atlantic Ocean. These possible rogue wave cases were examined and generally conformed to the expected configurations as shown in Fig. 5 with H_{max}/H_s lying mostly between 2 and 3. However our primary interest soon became focused a number of isolated cases, which occurred during 1999, 2000, and 2002 where the data appeared to be entirely out of line with the bulk of general conglomeration of the data. These cases include records where H_{max} was hiked up to between 23.2 and 71.4 m with H_{max}/H_s accordingly varying between 4.5 and 21.3, and we were faced with the plight of deciding whether or not they were all just simple outliers?

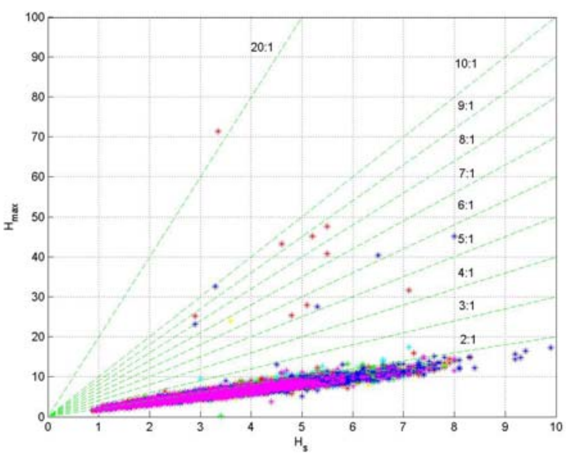

Fig.5. Correlation plot of H_{max} vs., H_s.

Our initial inclination was to respond affirmatively to the above question. It is usually a common practice to conclude that spikes in wave recordings are most probably caused by intermittent equipment malfunctions so that any outliers can be summarily discarded. However, after further deliberation and considering the fact that the wave recorder is positioned 20.0 m above mean sea level with most of the outliers being around the wave height sensing limit of 43.0 m, we concluded that some of the anomalies could very well be real recordings of waves, except the one case which is excessively beyond the sensing range of the instrument: the case of H_{max} = 71.4 m, which is obviously not justifiable and we will eliminate it from general considerations. Without the benefit of time series data, we believed that the aforementioned deduction was not unreasonable, especially given that the recording operated flawlessly both immediately before and after those instances and throughout the years.

A plot of the Percentages of Exceedance of Significant Wave Height (H_s) values for 2000, shown as blue dots, together with their corresponding Maximum Wave Height Values (H_{max}) in black, is given in Fig. 6.

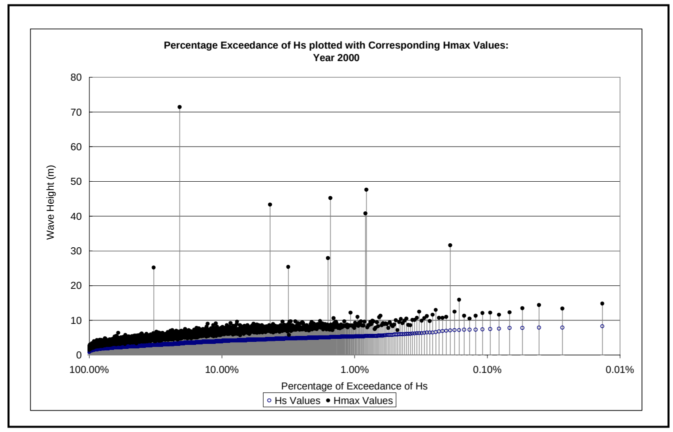

Fig. 6: Percentage of Exceedance of $H_{s,}$ in blue, plotted with corresponding values of H_{max} for the year 2000.

A similar plot of the Percentage of Exceedance for the Maximum Wave Heights for the Year 2000, in black, together with their corresponding Significant Wave Heights, in blue dots, is given in Fig. 7.

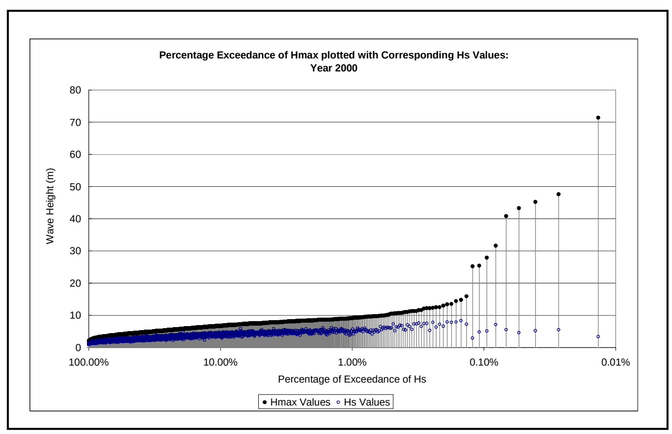

Fig. 7: Percentage of Exceedance of H_{max} plotted with corresponding values of H_s for the year 2000.

These two figures show that while those anomalous H_{max} data may appear to be noncomforming in Fig. 6, the plot of their Percentage of Exceedance in Fig. 7 shows nevertheless they are not necessarily arbitrary, they may be vested in a separate nonlinear framework. Some detailed examinations of the data history surrounding some of these seemingly out of the ordinary H_{max} occurrences are presented in Liu et al. (2004), these occurrences were shown to be in relatively well developed seas, and wind fields were generally quite steady in all cases, with average speeds around 13.5 m/sec. There was nothing extraordinary in the time proximity of the occurrence and there is really no discernable physical reason to expect these anomalous cases to happen as they did. It is certainly conceivable that one could summarily dismiss them as being erroneous for expediency, but this approach would be no different to the ones that denied the existence of freak waves for most of the 20th century and earlier.

We carried on our pursuit over diverse phenomena that could have led to the spikes in the data and momentarily came to the opinion that they could have been caused by actual or "virtual" wave crests that rose to within the minimum range of the wave sensor and caused it to generate false extreme wave height values. Virtual wave crests are caused by bursts of backscatter energy from increased scatterer speeds in whitecaps and breaking waves with or without spume (MacHutchon et al., 2006).

Notwithstanding the varied considerations, we postulate that all the extreme cases could still be indicative of the presence of the real rogue waves this area is famed for. If this is true, we can only be thankful that their occurrences did not cause any disastrous damage. The supertanker *Esso Languedoc* was fortunate to survive the 25 m rogue wave, shown in Fig.1, off Durban, northeast of this area, in 1980 but, regretfully, this was not the case for the passenger liner SS *Waratah* which was totally lost in the area in late July, 1909.

DISCUSSION

One of the consequences of the possible presence of these large rogue waves shown in the previous section is that they could lead to unprecedented large ratios of H_{max}/H_s.

The central concept of the Rayleigh distribution clearly does not overtly preclude large ratios of H_{max}/H_s. One of the well-known equations, which correlates H_{max}/H_s with the number of waves needed for it to occur, is

$$H_{\max} / H_s = \left[\ln(N)/2\right]^{1/2}.$$

So based on the Rayleigh distribution, for ratios of H_{max}/H_s to be equal to 3, 4, 5, and 6, for instance, it simply requires 6.5×10^7, 7.9×10^{13}, 7.9×10^{21}, and 1.9×10^{31} number of waves to occur. These are extremely large numbers, which translate into millions of years for the ratios to occur. This is rather unrealistic as well as impractical. Basically the Rayleigh approach considers large ratio of H_{max}/H_s as extremely rare occurrences.

While there have not been sufficient measurements that can be used to substantiate or refute the Rayleigh distribution implications, the 1995 New Year's Day rogue wave time series (Haver, 2004) with maximum wave height of 26 m and 12 m significant wave height, a H_{max}/H_s value of 2.2 is clearly well within the Rayleigh realm. On the other hand we have the rogue wave shown in Fig.1 where the crest of the monstrous wave is aligned with the top of the short mast on the starboard side which is known to be 25 m above the mean sea level. The photographer estimated that the "mean sea" at the time was 4-9 m, and this value can be taken as an indication of the significant wave height, H_s. In this case the H_{max}/H_s ratio would plausibly to be in the 3 to 6 range. As it was actually observed and attentively estimated, it would be untenable to consider this case an outlier.

Other support for high values of the H_{max}/H_s ratio comes from laboratory experiments such as the one conducted by Wu and Yao (2004). While H_{max}/H_s values were not included in their publication, the ratio of H_{max}/H_s was nevertheless recorded and they varied from 2.947 to 8.731. There were 6 cases of H_{max}/H_s in the 3 to 4 range and 4 cases in the 4 and above range. This is very encouraging. As shown in Liu et al. (2004), the laboratory results are appropriately situated at the extreme boundary of all the cases at the low end of the steepness scale.

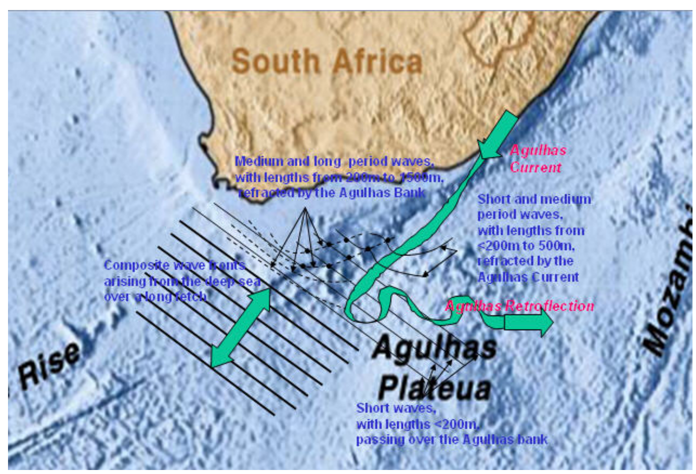

Fig. 8. Physical environment of the area where wave measurements were made.

Furthermore, as can be seen in Fig. 5 most of the occurrences with H_{max}/H_s ratio of 4 or higher took place in moderate sea states with H_s in the 3 – 8 m range, whereas for higher sea states with H_s in the 8 – 10 m range, the ratios of H_{max}/H_s were actually less than 2. Bitner-Gregersen and Hagen (2004) noted the presence of freak waves with higher crest factors C_{max}/H_s in lower and intermediate sea states and this may be analogous to what we found here. Understandably depending upon the applications concerned in general, the waves with higher H_{max}/H_s ratio or C_{max}/H_s crest factor may not always necessarily be considered as dangerous to marine structures.

Other rationalisations of the extreme data may also come from the local complicated and highly dynamic physical environment, which surrounds the area where the data were measured. As shown in Fig. 8 this area is dominated by the Agulhas Current from the northeast and by the composite wave fronts, arising from the deep sea over long fetches, from the southeast. The Agulhas Bank will refract medium and long period waves, with lengths from 200 m to 1500 m, and shorter waves with lengths of 200 m or less will pass over the Agulhas bank to meet the Agulhas retroflection. At the same time the oncoming strong Agulhas current will refract short and medium period waves, with lengths in the range of 200 – 500 m. Surrounded by such a varied assortment of dynamic interactions, it should not be surprising that very large rogue waves could appear from time to time. That's what makes this research exciting and to simply write off the outliers, under these unusual circumstances, would be frivolous.

For additional look at the detail behavior of our data, we noted earlier on the examination the probability of exceedance curves for H_{max} as shown in Figs. 6 and 7. The results are quite intriguing as well as compelling. The significant wave height, represented by the blue dots in Fig. 6, sustained a practically straight line trend on the log-normal scale for all the available data. The recorded maximum wave heights, shown by the black circles in Fig 7, also followed a substantial linear trend up to about H_{max} = 15 m, then it diverts toward a nonlinear, higher order functional relation between H_{max} and the percentages of exceedance, which could be caused by the occurrence of the virtual wave crests referred to previously. As we have alluded to before, the Marex Radar Wave Monitor, which provided the wave data we analysed here, has been known to yield wave crest height data with significantly higher values than other instruments (Forristall, et al., 2004.) Forristall has also suggesteded that "there is clear evidence from measurements in the North Sea that spurious crests due to spray are a problem downwind." This suggests that additional special measures, including the analysis of comparative data and video imagery, would be appropriate when interpreting the Marex data. While it is certainly conceivable that the very large maximum wave heights recorded in the data set could be due to the sensing of virtual crests falling within the minimum range of the recorder, in this case, however, one would have justifiably expecting a more frequent occurrence of the phenomenon, rather than the relatively few scanty occurrences recorded here.

At any rate, we must acknowledge that we are working with limited data from an aging instrument to be adopted for an exploratory research and we just can not over emphasize the crucial need for systematic rogue wave measurements. Until comprehensive and comparable field measurements can be made satisfactorily, we are still very much confined to pondering ceaselessly on what is really happening out there.

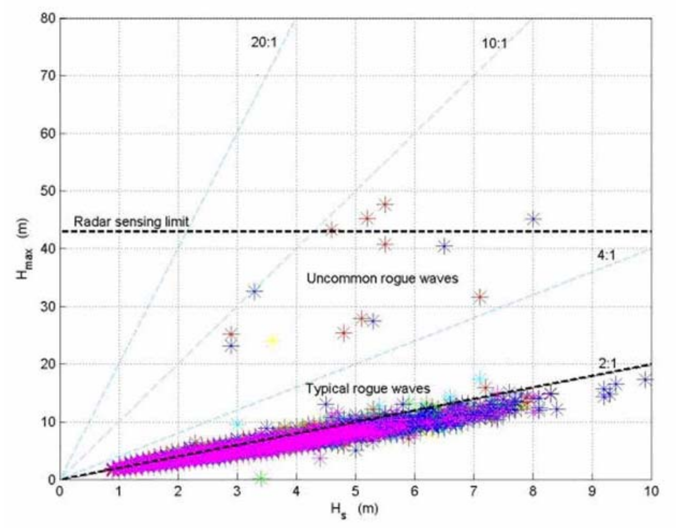

Fig. 9. Proposing a new classification of rogue waves

CONCLUDING REMARKS

While Liu and Pinho (2004) did not consider a 3.7 percent occurrence rate of H_{max}/H_s > 2 cases to be of rare occurrence, the 15 recorded anomalous cases with much higher ratios for H_{max}/H_s, which we discovered from among the 50359 hours of measurements in 6 years, with an occurrence rate of 0.03 percent, would certainly befit the pertinent nature of rareness by which rogue waves have been customarily known. So would it be possible that there can be different kind of rogue waves? Upon deliberation, and in the light of the two clear regimes shown by the curve for the maximum wave heights, we believe that different types of rogue wave do exist, and hereby propose a new classification for them as follows in accordance with the details shown in Fig. 9:

- A description of "*typical* rogue wave" should apply for cases with a ratio in the range of $2 < H_{max}/H_s < 4$
- A description of "*uncommon* rogue waves" should apply for cases with a ratio of H_{max}/H_s of 4 or higher

This proposal will not interfere with the current ongoing rogue wave studies, but it does provide a new category for the past, present and future seemingly outlier cases to reside in. Though these may merely be our speculations, we do feel strongly that the existence of these cases further emphasizes the crucial need for long-term wave time series measurements for studying rogue waves. Without tangible measurements, no amount of theoretical simulations can truly divulge the reality of the phenomenon so long as we still do not have the slightest notion as to whatever is really happening out there.

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