Exploring Rogue Waves from Observations in South Indian Ocean

Paul C. Liu[1], **Keith R. MacHuchon**[2] , **and Chin H. Wu**[3]

[1] NOAA Great Lakes Environmental Research Laboratory
Ann Arbor, Michigan 48105, U.S.A.
(email: paul.c.liu@noaa.gov)

[2] Liebenberg & Stander International (Pty) Ltd
Cape Town, 8000 South Africa
(email: lsi@liebstan.co.za)

[3] University of Wisconsin-Masison,
Madison, Wisconsin 53706, U.S.A.
(email: chinwu@engr.wisc.edu)

Abstract. Amidst all the enticing advancements on rogue waves in recent years, the conspicuous scarcity of actual, in situ, rogue wave measurements still represents an inevitable hindrance shadowing over the horizon of rogue wave studies. In this paper we wish to present an exploratory observational study of rogue waves based on wave measurement made in South Indian Ocean. As there have been significant theoretical advancements in numerical simulation of rogue waves, the need for actual field observations of rogue waves should certainly be commensurably supplemented. We hope our efforts in this study can be ventured toward further understanding of rogue waves in reality.

1 Introduction

Amidst all the enticing advancements on rogue waves in recent years, the conspicuous scarcity of actual, in situ, rogue wave measurements still represents an inevitable hindrance shadowing over the horizon of rogue wave studies. From the meager observational rogue wave studies based on available wave measurements, on the other hand, the results usually provide objective outcomes that tend to refute rather than confirm some of the familiar conceptualizations of rogue waves. For instance, rogue waves have always been considered to be rare occurrences, but a radar satellite study (e.g. http://195.173.17.24/news/pr2003/2.php) carried out by the German Aerospace Centre recently found 10 monster waves around the world, ranging from 26 m to 30 m in height. They concluded that "it looks as if freak waves occur in the deep ocean far more frequently than the traditional linear model would predict." Another recent study by Liu and Pinho (2004) based on wave measurements made from Campos

Basin outside Brazil coast in South Atlantic Ocean also concluded that freak waves are more frequent than rare.

In this paper we wish to present an exploratory observational study of rogue waves based on wave measurement made in South Indian Ocean. As there have been significant theoretical advancements in numerical simulation of rogue waves, the need for actual field observations of rogue waves should certainly be commensurably supplemented. We hope our efforts in this study can be ventured toward further understanding of rogue waves in reality.

2 The Measurement

The measurement used in this study is made from a gas-drilling FA Platform in South Indian Ocean, offshore from Mossel Bay, South Africa, located at 22.17ºE and 37.97ºS, alongside the Agulhas current in 100 m of water depth. (Figs. 1 and 2.) Waves are measured hourly from a Marex Radar Wave Monitor based on 20 minutes data sampled at 2 Hz frequencies. The wave sensor, as shown in Fig. 3., has a 7 to 50 m of minimum to maximum sensing range, 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, were 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 rogue waves as well as their potential meteorological connections in this renowned region of colossal waves.

Fig. 1. A map showing the location of the FA Platform in the red spot.

Fig. 2. A snapshot of the FA Platform.

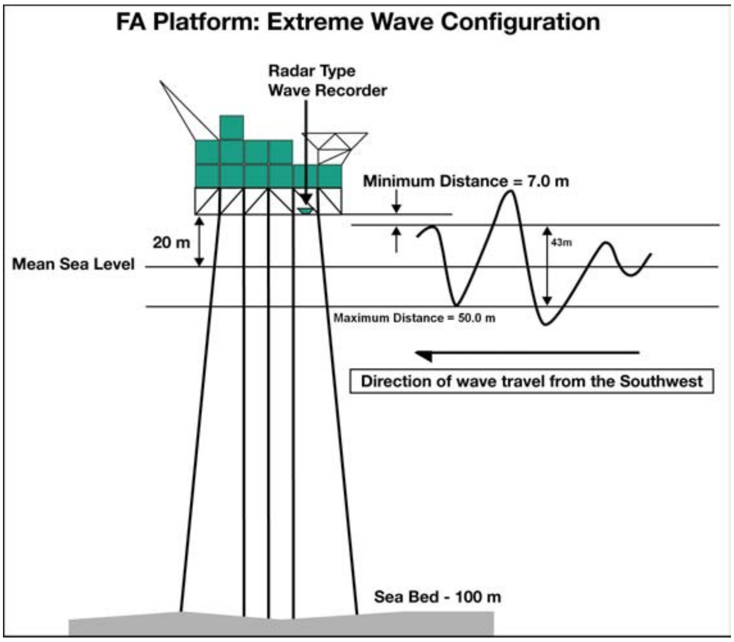

Fig. 3. Schematic illustration of the platform wave measurement.

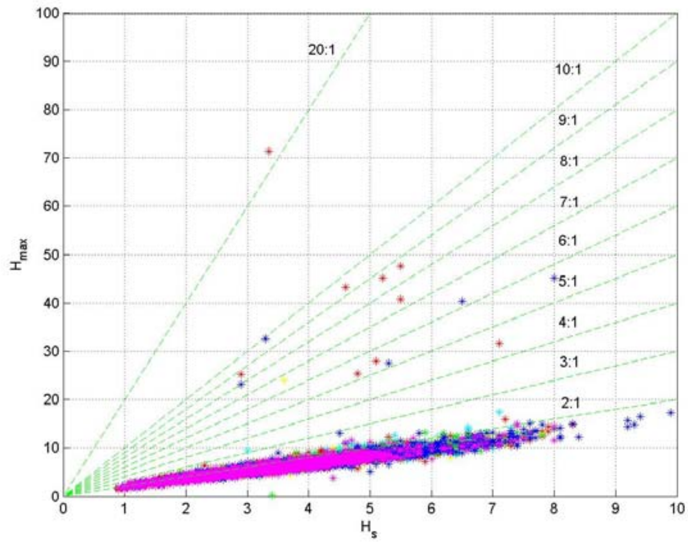

Fig. 4. Correlation plot of H_{max} vs, H_s.

3 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 $H_{max}/H_{sig} > 2$, 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 presumably rogue wave cases we examined generally conform to the expectable configurations as shown in Fig. 4 with H_{max}/H_{sig} lying mostly between 2 and 3. However our primary interest have unwittingly engrossed by a number of isolated cases 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 show that H_{max} hiked up to between 23.2 and 71.4 m and with H_{max}/H_{sig} accordingly varying between 4.5 and 21.3. Are they just simple outliers?

Our initial inclination tends to respond affirmatively to the above question. It is usually non-disputive to implicate that the recording can somehow be temporarily in malfunction, so the 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 and most of the outliers are around the wave height sensing limit, we now believe that some of the anomalies may very well be real recordings of waves, including taking tides and surface spray into account. In these cases the maximum wave heights could reasonably be expected to be within the sensing range of 43.0 m or more and thus it generally accounts for all the very high H_{max} cases shown in Fig. 4 except the one case with H_{max} = 71.4 m which is obviously not justifiable. Since we kept an open mind on outliers, we included all the data in for now. Without the benefit of time series data the aforementioned inference is certainly not unreasonable, especially given that the recording operated flawlessly both immediately before and after those instances and throughout the years.

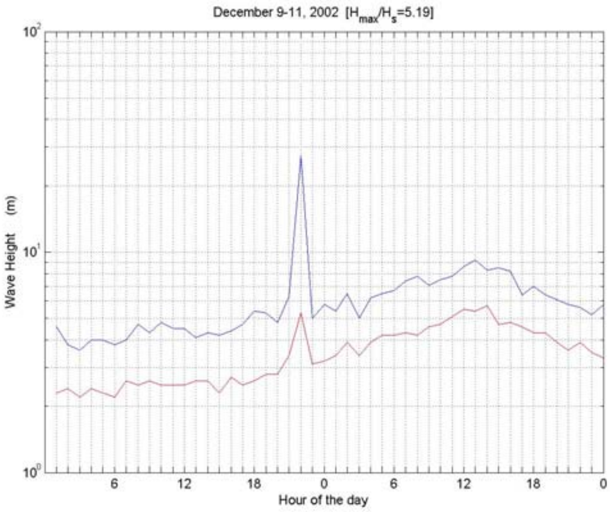

Fig. 5. Hourly data plot of maximum wave heights shown as the upper blue curve and significant wave heights as the lower red curve for the Dec. 9-11, 2002 case.

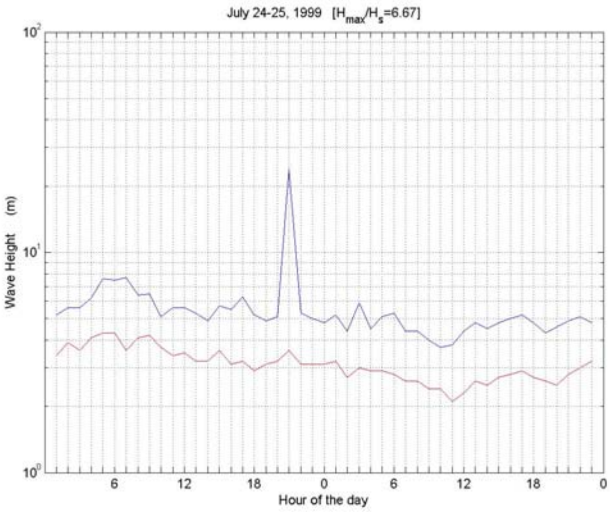

Fig. 6. Same as **Fig. 5** for July 24-25, 1999 case.

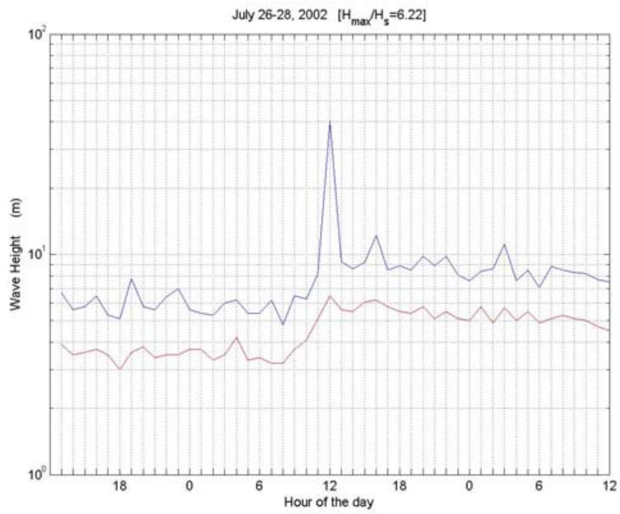

Fig. 7. Same as **Fig. 5** for July 26-28, 2002 case.

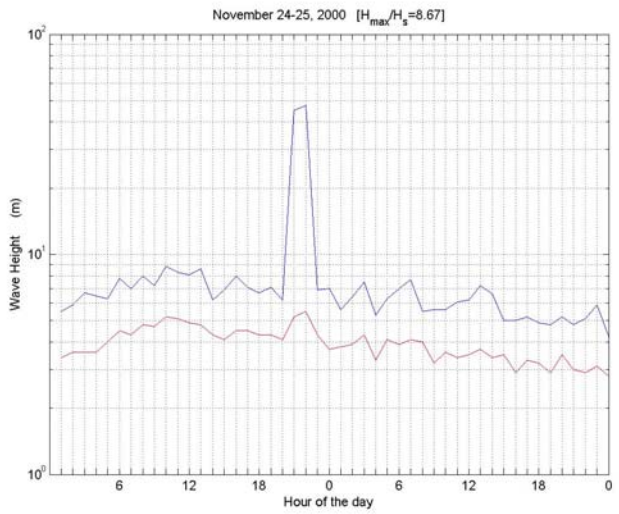

Fig. 8. Same as **Fig. 5** for Nov. 24-25, 2000 case.

As shown in the plots of sample cases presented in Figs. 5 – 8, these cases were in relatively fully-developed seas, and wind fields were generally quite steady in all cases, there is really no discernable physical reason for these anomalies. One plausible reason for these exceptionally high maximum wave height records could be that the wave monitor was momentarily under water during the over passing of these waves and we are not certain if the wave monitor can still accurately sense the water surface under these circumstances. In any event, the actual wave amplitudes would certainly have been far beyond 20 m. In the end we are inclined to postulate that these cases are actually 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. [Recall the lost of passenger liner SS *Waratah* in this area in late July, 1909. See, e.g., http://www.numa.co.za/sswaratah.htm .]

4 Discussion

One of the consequences of the presence of these large rogue waves shown in the previous section is that they led to unprecedented large ratios of H_{max}/H_s. What do these large ratios signify? Are they for real or are they outliers?

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 correlates H_{max}/H_s with the number of waves needs for it to occur as

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

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

Conceivably plausible indications can also come from laboratory experiments such as the one conducted by Wu and Yao (2004). While H_{max}/H_s was not included in the publication, the ratio of H_{max}/H_s was nevertheless available. They varied from 2.947 to 8.731 along with 6 cases of H_{max}/H_s in the 3 to 4 range and 4 cases in the 4 to over 5 range. This is very encouraging. In order for us to be able to directly compare the field data with laboratory data. We have to first normalize the available data with the length parameter gT^2, where T is the corresponding mean wave period for each available data set. This is effectively converted the process of correlation of H_{max} versus H_s to the correlation of corresponding wave steepnesses between the average conditions versus the extreme cases. Of course the field data do not have the wave period when the extreme cases occurred. The results are shown in Fig. 9 that presents a rather more coherent appearance than the H_{max} versus H_s results. The laboratory results appropriately situated at the extreme boundary of all the data cases at the low end of the steepness scale. But it is also clearly corresponds to the lower boundary of large wave cases, that provides some indication that the large wave cases may not be simply outliers.

Further rationales may also come from the local complicated and perplexing physical environment surroundings where the data were measured. As shown in Fig. 10 this area is dynamically dominated by the Agulhas current from the northeast and from the

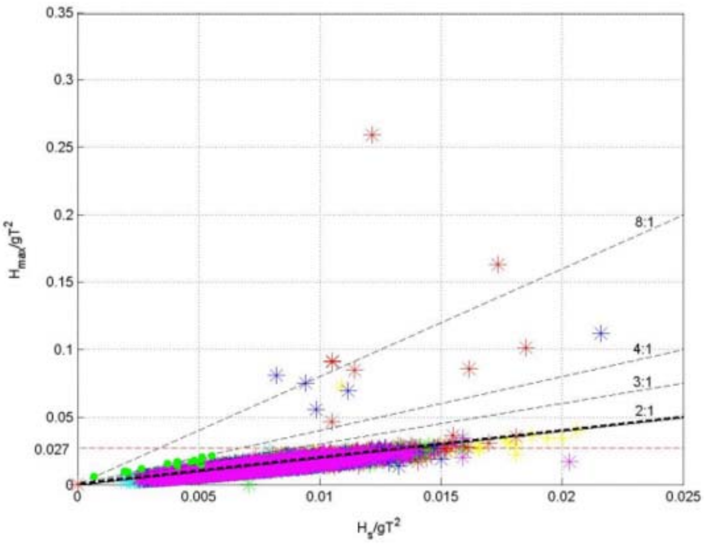

Fig. 9. Comparing wave measurement from FA platform in stars with laboratory measurements in closed green circles.

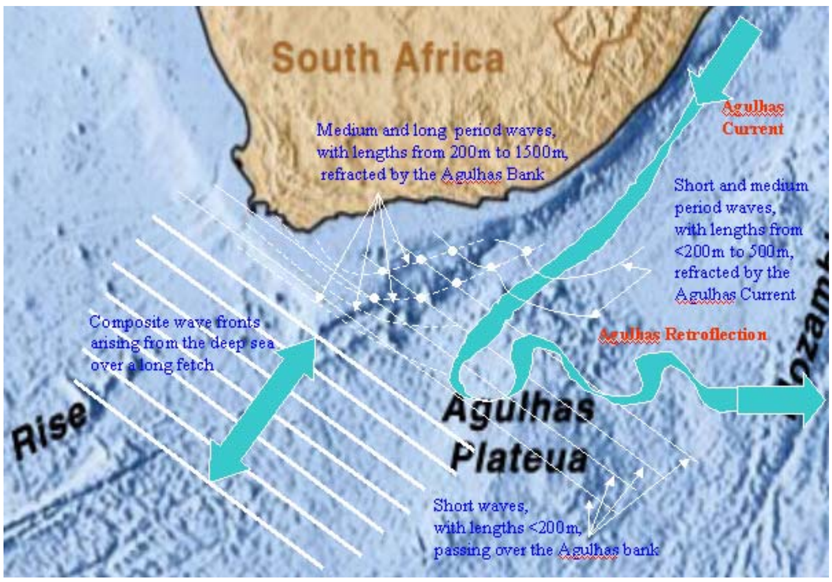

Fig. 10. Physical environment of South Indian Ocean area where the wave measurements were made.

southeast there are composite wavefronts arising from the the deep sea over long fetches. As medium and long period waves with lengths from 200 m to 1500 m refracted by the Agulhas plateau, short waves with wave length of 200 m or less passing across the Agulhas bank and meeting the Agulhas retroflection. At the same time short and medium period waves with length in the range of 200 – 500 m further refracted by the oncoming strong Agulhas current. Surrounded by such an varied assortment of dynamical interactions, it should not be surprised that very large rogue waves can appear from time to time. That's what makes the exploration invigorating and an envision of these unusual cases as simply outliers would be frivolous.

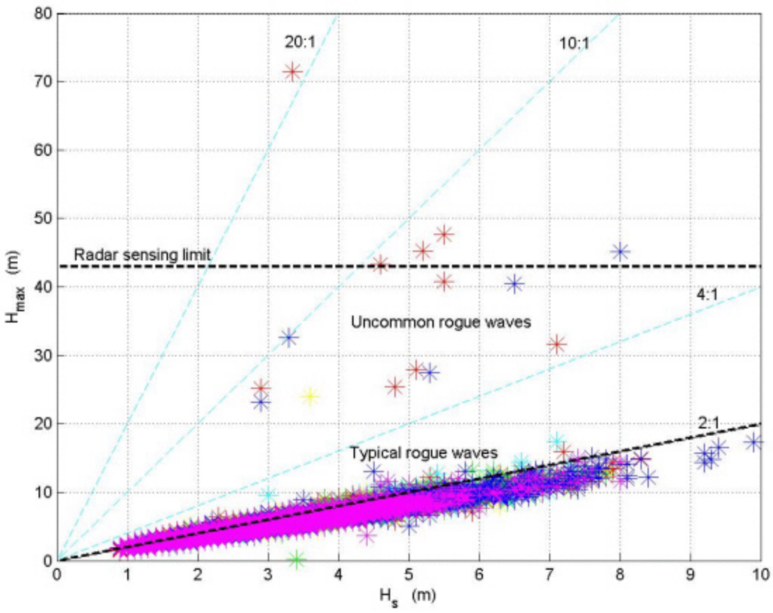

Fig. 11. Proposing a new classification of rogue waves

5 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, we are hereby to propose that may be a new classification for rogue waves can be considered. As shown in Fig. 11, for the cases of ratio range of $2 < H_{max}/H_s < 4$, which embodies most of currently known and available data and analysis, we call them the "*typical* rogue waves." For the cases of H_{max}/H_s ratios of 4 or higher, we propose to call them the "*uncommon* rogue waves." This action will not interfere with the current ongoing rogue wave studies. But this does provide a new realm for the past, present and future seemingly outlier cases to reside. 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.

Acknowledgements

The authors gratefully acknowledge Petro SA, the owners of the Platform, and the CSIR of South Africa, who generously made the information used in this paper available to us.

References

1. Liu and Pinho, 2004, Freak waves - more frequent than rare! *Annales Geophysicae*, Vol. 22, 1839-1842.

2. Wu, C.H. and Yao, A., 2004 Laboratory measurements of limiting freak waves on currents, *J. Geophysical Research-Oceans*, 109, C12, C12002, 1-18.