# Distribution of extreme surface gravity waves from large scale simulations.

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In recent years an abundance of papers on "freak" or "rogue" waves have been published. The occurrences of dangerous wave conditions in coastal waters are well known and may be explained by focussing (or caustics) due to refraction by bottom topography or current gradients, and even reflection from land. Well documented are the giant waves sometimes found in the Aguhlas current on the eastern coast of South Africa (Lavrenov (1998)).

On the open deep ocean there does not seem to be any special geophysical causes for extreme waves other than the wind. Even here, however, there are indications (Sand et.al. (1990), Skourup et.al.(1996)) of extreme events that may not be plausibly explained by the current state of the art wave statistics (see Haver & Andersen 2000). [1] Skourup et.al.(1996) analyzed 12 years of wave records from the the Gorm field in the central north sea. They found a few events where the crest height, $a_c$, exceeds $2H_s$ (here $H_s$ is the significant waveheight). That is a crest height larger than 8 standard deviations of the sea surface! The probabilities by Gaussian (linear) theory $\sim 10^{-14}$, and by second order theory $\sim 10^{-11}$ are clearly too small for a few such events to have been recorded within a timespan of 12 years.

The much referred to "Draupner wave" that was recorded in January 1995 (with $a_c = 18.5$ m!) had a ratio $a_c/H_s$ between 1.5 and 1.6 corresponding a crest height of a little more than 6 standard deviations. The probabilities by Gaussian and by second order theory are $\sim 10^{-8}$ and $\sim 10^{-6}$ respectively. The wave conditions lasted for approximately 6 hours so that roughly 2000 waves passed. Thus the a priori chances (by second order statistics) for the event to happen in that storm would be roughly 1 in 500 (or 1 in 100 if the highest estimate of $H_s$ is chosen).

To get some insight into the occurrence of extreme waves during a severe sea state we have performed simulations with a fairly narrow band numerical gravity wave model (higher order NLS type) with a rather large "numerical ocean" containing approximately $10^4$ waves at any time. The simulations are started with $\sim 6 \cdot 10^4$ Fourier modes of random phases chosen from a truncated JONSWAP spectrum with an angular distribution (long crested or short crested). A development of the spectrum on the so-called Benjamin-Feir timescale is seen, rather like the one that was reported by Dysthe et.al. (2003).

The probability distributions of surface elevation and crest height are investigated. We find that the simulated data fit theoretical second order distributions

[1] In fact these authors suggest as a definition of a freak wave event, that it is not plausibly explained by socalled second order models.

found by Tayfun (1978) very well, for surface elevations up to four standard deviations.

The influence of the spectral evolution seems insignificant on this part of the distribution. For the wings of the distributions a significant influence can be seen for very long crested waves only. For this case we find that the density of large waves increase during spectral change in agreement with a recent experiment by Onorato et.al. (2004).

For short crested waves we investigate the extreme distribution. It is found that the simulated data fits the theoretical extreme distribution (based on the Tayfun distribution) very well at least up to 5 standard deviations, which is as far as we have checked it till now.

Whether "freak" waves are rare occurrences from the above mentioned distribution, or need some special physical explanation, is briefly considered.

# References

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