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Numerical investigation of freak waves

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Paper describes the results of more than 4,000 long-term (up to thousands of peak-wave periods) numerical simulations of nonlinear gravity surface waves performed for investigation of properties and estimation of statistics of extreme ('freak') waves. The method of solution of 2-D potential wave's equations based on conformal mapping is applied to the simulation of wave behavior assigned by different initial conditions, defined by JONSWAP and Pierson-Moskowitz spectra. It is shown that nonlinear wave evolution sometimes results in appearance of very big waves. The shape of freak waves varies within a wide range: some of them are sharp-crested, others are asymmetric, with a strong forward inclination. Some of them can be very big, but not steep enough to create dangerous conditions for vessels (but not for fixed objects). Initial generation of extreme waves can occur merely as a result of group effects, but in some cases the largest wave suddenly starts to grow. The growth is followed sometimes by strong concentration of wave energy around a peak vertical. It is taking place in the course of a few peak wave periods. The process starts with an individual wave in a physical space without significant exchange of energy with surrounding waves. Sometimes, a crest-to-trough wave height can be as large as nearly three significant wave heights. On the average, only one third of all freak waves come to breaking, creating extreme conditions, however, if a wave height approaches the value of three significant wave heights, all of the freak waves break. The most surprising result was discovery that probability of non-dimensional freak waves (normalized by significant wave height) is actually independent of density of wave energy. It does not mean that statistics of extreme waves does not depend on wave energy. It just proves that normalization of wave heights by significant wave height is so effective, that statistics of non-dimensional extreme waves tends to be independent of wave energy. It is naive to expect that high order moments such as skewness and kurtosis can serve as predictors or even indicators of freak waves. Firstly, the above characteristics cannot be calculated with the use of spectrum usually determined with low accuracy. Such calculations are definitely unstable to a slight perturbation of spectrum. Secondly, even if spectrum is determined with high accuracy (for example calculated with the use of exact model), the high order moments cannot serve as the predictors, since they change synchronically with variations of extreme wave heights. Appearance of freak waves occurs simultaneously with increase of the local kurtosis, hence, kurtosis is simply a passive indicator of the same local geometrical properties of a wave field. This effect disappears completely, if spectrum is calculated over a very wide ensemble of waves. In this case existence of a freak wave is just disguised by other, non freak waves. Thirdly, all high order moments are dependant of spectral presentation – they increase with increasing of spectral resolution and cut-frequency.

Statistics of non-dimensional waves as well as emergence of extreme waves is the innate property of a nonlinear wave field.

Probability function for steep waves has been constructed. Such type function can be used for development of operational forecast of freak waves based on a standard forecast provided by the 3-d generation wave prediction model (WAVEWATCH or WAM).