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# Three-dimensional freak waves and higher-order wave-wave resonances

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Quite often the freak wave phenomenon is associated with the mechanism of modulational (Benjamin-Feir) instability resulted from resonances of four waves with close directions and scales. This weakly nonlinear model reflects some important features of the phenomenon and is discussing in a great number of studies as initial stage of evolution of essentially nonlinear water waves. Higher-order wave-wave resonances attract incomparably less attention. More complicated mathematics and physics explain this disregard partially only. The true reason is a lack of adequate experimental background for the study of essentially three-dimensional water wave dynamics.

We start our study with the classic example of New Year Wave. Two extreme events: the famous wave $26.5$ meters and one of smaller $18.5$ meters height (formally, not freak) of the same record, are shown to have pronounced features of essentially three-dimensional five-wave resonant interactions. The quasi-spectra approach is used for the data analysis in order to resolve adequately frequencies near the spectral peak $f_p \approx 0.057$Hz and, thus, to analyze possible modulations of the dominant wave component. In terms of the quasi-spectra the above two anomalous waves show co-existence of the peak harmonic and one at frequency $f_{5w} = 3/2 f_p$ that corresponds to maximum of five-wave instability of weakly nonlinear waves. No pronounced marks of usually discussed Benjamin-Feir instability are found in the record that is easy to explain: the spectral peak frequency $f_p$ corresponds to the non-dimensional depth parameter $kD \approx 0.92$ ($k$ – wavenumber, $D \approx 70$ meters – depth at the Statoil platform Draupner site) that is well below the shallow water limit of the instability $kD = 1.36$.

A unique data collection of wave records of the Marine Hydrophysical Institute in the Katsiveli platform (Black Sea) has been analyzed in view of the above findings of possible impact of the five-wave instability on freak wave occurrence. The data cover period October 14 – November 6, 2009 almost continuously. Antenna of 6 resistance wave gauges (a pentagon with one center gauge) is used to gain information on wave directions. Wave conditions vary from perfect still to storms with significant wave heights up to $H_s = 1.7$ meters and wind speeds $15$m/s. Measurements with frequency $10$Hz for dominant frequencies $0.1 - 0.2$Hz fixed $40$ freak wave events (criterium $H/H_s > 2$) and showed no dependence on $H_s$ definitely. Data processing within frequency quasi-spectra approach and directional spectra reconstructions found pronounced features of essentially three-dimensional anomalous waves. All the events are associated with dramatic widening of instant frequency spectra in the range $f_p - f_{5w}$ and stronger directional spreading. On the contrary, the classic Benjamin-Feir modulations show no definite links with the events and can be likely treated as dynamically neutral part of wave field. The apparent contradiction with the recent study (Saprykina, Dulov, Kuznetsov, Smolov, 2010) based on the same data collection can be explained partially by features of data processing. Physical roots of the inconsistency should be detailed in further studies.

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