



INDIVIDUAL FELLOWSHIPS



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Project Acronym: DeRogue Waves

Project Full Name: Deterministic Forecasting of Rogue Waves in the Ocean

Marie Curie Actions IEF-IOF-IIF- IIFR -Final Report

FINAL PUBLISHABLE SUMMARY REPORT

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The project creates the scientific basis for new methodologies for deterministic rogue wave forecasting (when it is possible) and for improvement of probabilistic forecasting. Its aims can be subdivided into two general tasks: **i)** scientific background for deterministic rogue wave forecasting and **ii)** deterministic forecasting for rogue waves on currents.

The generality and limitations of approximate weakly nonlinear models in describing steep waves are examined by means of weakly, strongly and fully nonlinear simulations of the Euler equations. The results of simulations are compared with predictions of weakly nonlinear analytic models and with available data of laboratory measurements. Simulations of irregular intense waves are performed within the framework of a variety of different models, and also compared with laboratory data. The essentially non-stationary evolution of the stochastic wave system is studied in detail. Precursors of emergence of coherent nonlinear wave groups have been identified.

The general problem of the ‘most extreme wave’ is addressed. Occurrence of very high waves from initially almost uniform wave trains is considered by means of both a weakly nonlinear analytic approach and numerical simulations of strongly nonlinear and fully nonlinear models. The initial conditions were chosen to correspond to single ‘unstable modes’ of the modulational instability (Kuznetsov-Ma-Peregrine-Akhmediev solitons or breathers), and hence the results provide the key element for *deterministic rogue wave forecasting* with one-to-one mapping of the weakly nonlinear solutions into the strongly nonlinear ones. That is, when the wave propagation is strictly one-dimensional the way to predict the outcome of arbitrary localized initial conditions within the limitations of integrable weakly nonlinear models has been known for a long time. The new findings enable us to make two important steps: **(i)** to identify the wave groups which might evolve into potentially anomalously high waves (rogue wave events) at the stage when the field is still weakly nonlinear, **(ii)** to translate the known weakly nonlinear predictions into quantitative predictions of strongly nonlinear events using the constructed one-to-one mapping.

The evolution pattern of the highest wave in a group is obtained in numerical simulations and with the help of appropriate laboratory experiments. Modulated periodic wave trains and solitary wave groups are considered. The highest wave crest in a modulated group is found to be close to the Stokes wave shape, its amplitude is limited by the crest breaking; hence the local wave steepness is a good indicator of closeness to the onset of breaking. The most amplified non-breaking wave group is short and consists of just a few individual waves. Very steep and short structurally stable nonlinear wave groups have been thoroughly investigated. It was shown that waves inside the groups exhibit asymmetry similar to that of Stokes waves, but the groups propagate noticeably faster than Stokes waves. These simulations demonstrate the existence of solitary-like envelope patterns in realistic conditions in the strongly nonlinear regime, their robustness with respect to weak perturbations, interactions with other waves and unstable modes. The conclusions provide strong support of the principle possibility of short-term *deterministic forecasting* of rogue wave events.

Waves propagating on jet currents can be trapped by the current, then the dynamics of such waves becomes in certain sense one-dimensional. Thus, this is the first practically important example for which a *deterministic approach to rogue wave forecasting* can be developed. A

closed novel theory for description of weakly-nonlinear wave dynamics on jet currents with negligibly weak vertical shear is developed employing the modal representation of waves. The theory can be applied to both trapped and passing-through modes. Crucially, it reduces the physically 3D problem to 1D evolution equations, even if the angular distribution of wave field is broad and even if the waves are short-crested. The approach introduces the concept of a trapped mode as the fundamental element of interaction instead of a wave; the vertical and transverse dependences of the wave solution are determined by the modal structure. The interactions between the modes are shown to be qualitatively different from those between the waves the modes are made of. In particular, three-wave interactions become always allowed. Three-wave and four-wave interactions between trapped modes have been examined. The dispersion relations, mode structures, interaction coefficients due to the hydrodynamic resonances and inter-mode interaction were derived and analyzed. A variety of different novel linear and nonlinear mechanisms of intensifications of waves on currents has been found. Most of the results are obtained assuming the current to be slowly inhomogeneous in the transverse direction; some of the results are obtained under the additional assumption that the current is weak compared to the wave velocity.

Natural oceanic conditions are discussed through the prism of the trapped mode approach. The theory is applied to the case of the notorious Agulhas current off the South-East coast of Africa, where navigation is known to be dangerous. The modes trapped by the Agulhas current were specifically examined, the number of trapped modes is found to be about a few hundreds depending on the wave conditions. It was found that the Agulhas current provides favourable conditions for trapped modes to exhibit essentially nonlinear dynamics.

The project results improve competitiveness of the European research concerned with rogue waves in several different ways. In particular, the developed methodology has no analogues in the world, it will be an important element in establishing European leadership in dangerous sea wave forecasting and preventing fatalities and serious ship incidents in sea. The results are also applicable to many other physical contexts, where the underlying mathematics is the same or quite similar. The impact of the project should become apparent in many different ways: through contribution to development of the marine industry making seafaring safer, by establishing scientific links between European and Russian scientific institutions. The results will be also used in educational purposes, which might attract gifted students to science and engineering.