Nat Hazards (2016) 84:S431–S436
DOI 10.1007/s11069-016-2633-1

EDITORIAL

Advances in nonlinear wave research for hazard warning and mitigation

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Published online: 24 October 2016

Many natural disasters can be related to wave processes, either due to the destructive wave impact, as in the case of tsunamis, storm waves and surges, and oceanic rogue waves, or due to indirect effects, such as wave sediment transport, landslides induced by earthquakes, etc. These phenomena affect millions of people annually and may result in billions of dollars losses.

From the scientific point of view, catastrophic wave phenomena are often related to *essentially nonlinear dynamics* and *nontrivial nonlinear effects*. Thus, vital practical needs lead to challenges in nonlinear physics and mathematics. The consequent fundamental theoretical problems are important in their own right, and the dynamical understanding develops and may even change in the course of obtaining solutions. The application stage is when the developed theoretical approaches are directed back to the geophysical issue with success in improved understanding, or the contrary, with insufficient effectiveness which motivates further fundamental research.

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The aim of the Special Issue is to highlight a selection of important actual problems in the investigation of nonlinear wave phenomena directed to natural hazard warning and mitigation: physical and mathematical models for geophysical problems, advances in related academic researches, theoretical and experimental modelling and *in situ* experiments and observations. The scope of the Special Issue covers various wave processes in the open and coastal ocean. The construction and application of simplified theoretical models which capture the essential physics, advanced numerical codes, and incisive measurements, are together approaches which lead to the comprehension and efficient description of natural phenomena. The Issue consists of three groups of research papers, relating to tsunami waves, abnormally high sea waves (so-called rogue waves) and wave dynamics in the coastal zone.

Tsunami waves are mainly produced by earthquakes but can also be caused by submarine landslides, volcanic eruptions, and very infrequently by asteroid impacts. A further category of tsunamis is the so-called meteotsunamis that are generated by special atmospheric perturbations. Tsunamis can be very devastating, and recent catastrophes in the Indian Ocean (26 December 2004) and in Japan (11 March 2011) have pointed out the need for establishing and improving early warning systems, and for carrying out systematic studies of hazard and risk assessments at national and local levels. The paper by *Choi et al.* outlines recent efforts on tsunami emergency planning and hazard mapping in Korea and stresses that advances of national tsunami mitigation strategies can only be achieved through multidisciplinary approaches involving studies on tsunami sources and impact, and numerical modelling of tsunami waves. It describes an emergency action plan (EAP), including evacuation of the inundation areas, which has been devised for the Imwon Port of Gangwon-do Province that was seriously damaged by the 1983 tsunami in the Japan Sea due to an earthquake close to the Japanese island of Okushiri. An example of a hazard map for the same area is also shown, which is at the same time a basic part for the local EAP and a tool for urban and industrial developing planning of the local community.

Submarine and coastal landslides can produce tsunamis that are locally more intense than those typically produced by earthquakes. Okal and Synolakis (2003) pointed out how landslide-induced tsunamis are generally more localized than the ones produced by earthquakes and showed that the run-up distribution on the nearest coast can be used to discriminate between landslide- and tectonic-generated tsunamis. The paper by *Zaniboni et al.* treats the case of a landslide-induced tsunami that was one of the most lethal in the entire tsunami history of Italy. It occurred in 1783 when part of a coastal mount collapsed into the sea as the result of prolonged earthquake shaking due to a disastrous seismic crisis that affected Calabria, South Italy. The waves killed more than 1500 people that had gathered on a beach in the town of Scilla to escape the effect of the earthquakes. Simulation of a historical landslide-induced tsunami involves a number of steps: reconstruction of the landslide body from geomorphological niche and run-out data, simulation of the solid landslide motion and of the tsunami that can be made through separate models, or through a single multiphase model (see Løvholt et al. 2015 for a review). The process of tsunami generation is rather complex and, especially when the landslide is subaerial, is strongly nonlinear. The 1783 Scilla tsunami event is very interesting because there exist very detailed observations of the effects of the tsunami, including several run-up height values, which is surprising for that epoch. Using a Lagrangian model for the landslide and a shallow water nonlinear model for the tsunami, the paper is able to reproduce the documented inundation depth and run-up observations in Scilla.

Meteotsunamis are generated by atmospheric perturbations, such as travelling squalls associated with meteorological fronts, and can be enhanced by Proudman resonance

(Monserrat et al. 2006) causing severe damage at the coast. Observations of meteotsunamis offshore are quite rare. The paper by *Sheremet et al.* analyses a unique data set where for the first time a meteotsunami has been recorded by a high-resolution large array of oceanographic instruments deployed off Louisiana, USA. The meteotsunami appeared persistently in many stations over an alongshore distance of about 150 km as a lone soliton followed some minutes later by an undular bore. Meteotsunami is often described by the Korteweg–de Vries (KdV) equation or by the variable-coefficient KdV equation (vKdV), first introduced by Johnson (1973a, b) and Ostrovsky and Pelinovsky (1975) to study the transformation of nonlinear waves in the beach zone. The crucial point is that theory can explain how a long wave meteotsunami can evolve into an undular bore while travelling toward the coast or into a solitary wave (soliton), but it cannot easily explain a transformation into both types of waves at the same time. The solution, combining theory with high-resolution observations, was that the analysed meteodata show that two distinct meteotsunamis were generated in different areas off Louisiana coasts almost simultaneously, and vKdV modelling demonstrated that one produced the observed lone soliton and the other the following undular bore.

KdV theory is also used by *Grimshaw & Yuan* to study the transformation of tsunami waves on the continental slope. The interest is on the amplification of the wave in case of a leading depression or a leading elevation, which is a topic which has been addressed by a number of authors. The novelty here is that the analysis shows that the amplitude of a wave with a leading elevation results to be proportional to the offshore wave amplitude and inversely proportional to the ocean depth, while the amplitude of a wave with a leading depression is proportional to the square root of the displaced depression mass and to the inverse of the fourth root of the ocean depth. This makes a big difference for long waves with small offshore amplitude like tsunamis and predicts that tsunamis with a leading depression can amplify much more than tsunamis with a leading elevation on the same ocean bathymetry.

Tsunami propagation offshore is usually modelled by shallow water equations. The effects of multiscale sea floor irregularities on the tsunami waves have attracted the attention of several authors. The paper by *Mei & Li* is on this topic and derives equations of Kadomtsev–Petviashvili (KP) type adequate to compute tsunami propagation from a slender fault. Random bottom perturbation (or sea floor roughness) is imposed in the direction normal to the fault, which is the preferential direction of tsunami propagation and also in both directions, normal and parallel, and the corresponding KP equations with variable coefficients are derived and discussed.

So-called rogue waves are another natural disaster. They are anomalously high wind waves which occur occasionally on the sea surface. The discovery and scientific recognition of the fact that these sea waves may be much more dangerous than previously thought have produced a huge stream of academic and applied research. A series of new improved hydrodynamic models capable of the efficient description of nonlinear wave effects has emerged as a part of this rogue wave boom. The paper by *Dyachenko et al.* is an authoritative derivation of a new applicable wave model from the basic hydrodynamic equations. The new model is based on fundamental physical principles of the Hamiltonian approach and exploits delicate truncation and modification of physically insignificant terms in the kernel of the model. As a result, much simpler versions of the Zakharov equations are obtained compared to the classic equation, which may be used for the solution of the initial-value or boundary-value problems.

The crucial issue of the relation between wave statistics and wave spectrum is addressed in the paper by *Onorato & Suret*. As soon as the importance of the phase coherence in situations of extreme waves is accepted, the assumptions of the conventional kinetic theories fail. On the other hand, current forecast systems deal with measurements and predictions of the linear wave spectra associated with solutions of the kinetic equations. In *Onorato & Suret*, simple exact relations between the key statistical moments and the spectrum bandwidth are suggested within the frameworks of model nonlinear equations for deep and shallow water. The approaches by *Dyachenko et al.* and *Onorato & Suret* may be applied to a broader class of physical problems. Extensive computer simulations of the hydrodynamic equations are now possible and are employed to solve the problem of probabilistic description of extreme waves by means of direct stochastic modelling. This approach requires efficient codes, but may be applied to the solution of primitive Euler equations for water waves as done by *Slunyaev et al*. These simulations look very realistic and may provide much statistically homogeneous data, which is practically unavailable in situ. In simulations by *Slunyaev et al.*, an asymmetry of rogue waves with respect to the vertical line is observed in severe sea states in deep and intermediate waters, which presently is unexplained.

Adverse currents are a recognized source of occurrence of extreme waves. In favourable situations, the energy of the current may be transferred to the waves, or the waves may be refracted by the uneven current, what leads to focusing. These processes become more complicated when the nonlinearity is taken into account. In the study by *Duan et al.*, the effects of the following and opposing currents at the shallow water condition are considered alone and in the presence of a submerged bar. Simplified models are validated by means of comparison with experimental data and results obtained in the framework of Boussinesq equations. The study of the famous dispersive wave focusing mechanism in the condition when the horizontal current varies with depth is described in the work by *Touboul & Kharif*. The vertical gradient of the current yields nonzero vorticity. The effect of vorticity on the dispersive focusing may be described in the leading order by a linear kinematic model; this approximation is compared to direct numerical simulations of primitive hydrodynamic equations. The process of large wave generation is found to be significantly affected by the vorticity due to the current and by the wave nonlinearity.

People are naturally near the sea in coastal regions, and hence, a proper understanding of wave dynamics near shore and onshore is crucial for human safety at the coast, and for the adequate planning, design and use of coastal infrastructure. Waves in shallow waters and especially in the coastal zone are strongly influenced by bathymetric changes, which may lead to wave refraction, diffraction and focusing, possibly forming some kind of "coastal rogue waves". One such example which favours long wave focusing and extreme wave amplification is a bay of parabolic cross section. In this Special Issue, *Pedersen* derives the fully nonlinear Boussinesq equations for such bays. Results from this model are in rather good agreement with the analytic shallow water solutions until the latter breaks. *Pedersen* demonstrates that the dispersion reduces the run-up heights only slightly, while its major effect is a shift of the breaking limit to higher amplitudes.

Soldini et al. focus on the evolution of trains of shock waves on a planar beach. They validate a quasi-analytical solution for a train of shock waves forced by a constant Riemann invariant, which was obtained by them before, and clarify its validity and value for benchmarking nonlinear shallow water equation solvers. A good match of the long-time evolution suggests that the quasi-analytical solution can serve as a test for those solvers that aim at a correct description of the wet or dry interface evolution. The violent impact of extreme waves caused by waves when interact with structures is still not very much investigated. *Akrish et al.* in their study of the impact of extreme waves on a vertical wall consider typical patterns of nonlinear extreme waves over shallow and deep waters within realistic framework of potential Euler equations. Multiple maximum force values have been detected for the highest run-up peaks.

It is our great pleasure to celebrate with this Special Issue the *70-year anniversary* of *Professor Efim Pelinovsky*. Efim Pelinovsky is a well-recognized scientist in geophysics and natural hazard-related research, an author of more than 500 publications, including 10 books. The content of the Special Issue reflects a significant part of the scientific interests of Efim Pelinovsky; the authors of the papers are his friends and colleagues.

Efim Pelinovsky has been working on tsunamis since 1976. During this 40-year period, he covered a wide range of topics, from physical effects such as nonlinearity, dispersion and dissipation, which influence tsunami generation and propagation to tsunami field surveys and case studies and tsunami hazard and risk assessment (Pelinovsky 1982, 1996). He paid special attention to nonseismic tsunami sources, i.e. landslides, volcanos, asteroid impacts, and worked on their generation mechanisms.

The first review on the topic of rogue waves by Kharif and Pelinovsky (2003) is very well known in this community, as well as the first monograph dedicated to rogue waves (Kharif et al. 2009). A noticeable contribution to the interdisciplinary approach to the rogue wave problem was due to the dedicated paper collections (Pelinovsky and Kharif 2008, 2016) and journal special issues (European Physical Journal) edited by E. Pelinovsky.

For 10 years starting from 2000, Efim Pelinovsky was organizing special sessions on tsunamis and nonlinear waves in the sea at General Assemblies of the European Geosciences Union (EGU), former the European Geophysical Society (EGS), which also resulted in a series of journal special issues published in Natural Hazards and Earth System Sciences, Nonlinear Processes in Geophysics, European Journal of Mechanics—B/Fluids and Marine Geology. For his contribution in the field of tsunami, Efim Pelinovsky was awarded the Nekashizuka Award (the International Tsunami Society 1991), W. Adams Award (the International Natural Hazards Society, 1993) and the International Tsunami Society Award (2012). In 2006 in recognition of his world leadership in predicting the consequences of tsunamis and rogue waves, and in the avoidance and mitigation of these severe natural hazards he was awarded Sergey Soloviev Medal by European Geosciences Union.

For 20 years from 1995 till 2015, Efim Pelinovsky was a member of editorial board of Natural Hazards. Therefore, it is symbolic to congratulate him with a Special Issue of Natural Hazards.

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