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► To cite this version:

Maria Kazolea, Paola Bacigaluppi. Introduction to the special issue on numerical methods and applications for waves in coastal environments. Water Waves, 2022. hal-03860569

HAL Id: hal-03860569

<https://inria.hal.science/hal-03860569>

Submitted on 18 Nov 2022

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Introduction to the special issue on numerical methods and applications for waves in coastal environments.

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The goal of this special issue is to provide an overview of recent progress in the area of numerical methods and applications for ocean waves in the coastal environment, to identify current challenges and to present and discuss approaches for performing accurate predictions of nonlinear and dispersive water waves and our ability to understand and predict impacts on coastal structures and urban areas.

Over 1.6 million kilometers of coastlines occur on the earth's surface. These areas are subject to hazards created by a range of natural events, such as earthquakes and hurricanes which are a source for large waves and have a negative economic and social impact on the affected areas. In recent decades, mathematical and numerical modeling of free surface flows in realistic coastal environments has become an active research field and has been developed to the point where it is possible to provide operational information. In many situations, simulations with numerical coastal models represent a necessary complement to laboratory experiments for both site assessment and coastal design. Numerical modeling has also become an essential complement to experimental investigations at small scales, due to the potential of providing a more complete description of the underlying physics.

Significant research efforts have been put into advancing the understanding of important coastal processes such as wave propagation, shoaling, diffraction, refraction, wave breaking and run-up over the shoreline; see for example [1,14] and references therein. These advances improve our ability to understand and predict impacts on coastal structures and urban areas. In this framework, a review of some of the most relevant modeling approaches and numerical discretization techniques can be found in [15].

The collected papers of this issue are directed to discuss modern developments and trends in the accurate numerical modeling of free surface flows. We can divide the contributions into two main categories. The first one involves papers dealing with the discretisation of dispersive equations and the second includes the works on wave breaking. Indeed, in the last decades, asymptotic depth average models like Boussinesq type models that involve dispersive terms, are widely used to simulate the coastal processes. The discretization of these models usually lead to numerical models that are of practical use in design compared to the ones produced by more complicated mathematical models like the Euler equations. A review on the history and all fundamental aspects of the Boussinesq type (BT) models can be found in [3,15]. The works in the first category of this issue aims to answer some open problems concerning the discretisation of this type of models such as the absorbing boundary conditions for the simulation of waves on bounded domains [2], the reduction of the computational cost which arise from the multi-step time

schemes used to discretise the BT models [4] and the efficient discretisation of fully dispersive models with source terms [7].

The second category of this special issue deals with the topic of wave breaking. This is a very wide and active field of research [12]. The contributions in this issue are concerned with wave breaking at the surface of the ocean and not with the breaking of internal waves which is also an important phenomenon and is connected to global ocean circulation [19]. Problems arising from fundamental research and real applications in coastal environments demand accurate descriptions of both breaking inception and the details of the breaking process [1,12-14,16,18]. The directions of research that the works of this issue attempt to contribute are the identification and classification of different type of wave breaking [6], the reduction of the computational cost in the accurate description of wave breaking using non hydrostatic Reynolds Averaged Navier-Stokes equations [10], and the understanding of the wave breaking closures for Boussinesq type models [11].

Contributions in this issue:

In the work entitled *Perfectly matched layers methods for mixed hyperbolic-dispersive equations* [2], the authors deal with absorbing boundary conditions for the simulation of propagation of waves on bounded numerical domains. They study the stability of classical perfectly matched layer (PML) equations for different types of linear dispersive water wave models. They apply the PML strategy to the linearized Korteweg-de Vries equation, and show analytically and numerically that this approach is not always stable. They introduce a hyperbolic system with a source term which formally approximates the Korteweg-de Vries equation and show its ability to mimic most of the classical properties of the Korteweg-de Vries equation. Finally they consider a class of more realistic water wave model, namely mixed BBM-Boussinesq systems that describe the evolution of a shallow layer of inviscid fluid, The authors prove a complete stability for the associated PML equations and illustrate numerically that the PML technique works in this case

The paper of Cauquis, Ricchiuto and Heinrich [3] entitled *Lax-Wendroff schemes with polynomial extrapolation and simplified Lax-Wendroff schemes for dispersive waves: a comparative study* focuses on novel approaches based on the classical Lax-Wendroff strategy to achieve single step high order schemes in time for the Boussinesq and the enchanted Boussinesq equations. To reduce the cost of evaluating the complex correction terms arising in the Lax-Wendroff procedure for Boussinesq equations, the authors propose several simplified strategies which allow to reduce the computational time at fixed accuracy. To evaluate these qualities, they perform a spectral analysis to assess the dispersion and damping error. They then evaluate the schemes on several benchmarks involving dispersive propagation over flat and non-flat bathymetries, and perform numerical grid convergence studies on two of them. Their results show a potential for a CPU reduction between 35% and 40% to obtain accuracy levels comparable to those of the classical RK3 method.

The paper by Desmons and Lubin [6] investigates a new type of breaker, proposed by [20] by detailing several geometric aspects which lead to the unusual size and behavior of some very large plunging jets generated when waves break above some drastic changes of bathymetry. The authors investigate all geometrical aspects of the breaking process, to propose a classification of the breaker types which were

observed in the numerical results. They indicate the influences of the reef parameters (steps heights and lengths) on the subsequent breaking process. They also show that the air entrainment was indeed much larger during the composite breaker occurrence.

In the contribution of Guermond, Kees, Popov, and Tovar [7] a numerical method for approximating the dispersive Serre Green-Naghdi equations with topography using continuous finite elements, is presented. The method is an extension of the hyperbolic relaxation technique introduced in [8]. It is explicit, second-order accurate in space, third-order accurate in time, and is invariant domain preserving. It is also well-balanced and parameter free. Special attention is given to the convex limiting technique when physical source terms are added in the equations. The method is verified with academic benchmarks and validated by comparison with laboratory experimental data.

The contribution by Iravani, Badiel and Brocchini proposes a method to improve the performance of a novel RANS model for breaking water waves. More precisely the method uses a differential grid to reduce the computational cost while maintaining a good accuracy. In this “sub grid” approach [10] the pressure values are computed on a coarse grid while the velocities are solved on a finer grid. The grid resolution is increased near the surface and bottom boundaries. The results show how the computational effort can be reduced up to 70% while providing more than satisfactory results for properties of interest for the coastal engineering practice, like wave height decay and mean water elevation.

In the *Parameter sensitivity for wave breaking closures in Boussinesq-type models* [11], the authors Joshi, Kazolea and Ricchiuto are considering the issue of wave breaking closure for the weakly dispersive fully nonlinear equations of Green-Naghdi. The authors make use of the sensitivity indices computed by means of Analysis of Variance (ANOVA) to provide the sensitivity of wave breaking simulation, using two different wave breaking closures, to the variation of parameters such as the mesh size and the breaking parameters for each breaking model. The first wave breaking closure used is a hybrid method consisting of suppressing the dispersive terms in the breaking region and the second one is an eddy viscosity approach based on the solution of a turbulent kinetic energy model.

In the contribution *Efficient numerical computations of long-wave run-up and their sensitivity to grid nesting* [17], Mihami, Roeber and Morichon present a novel numerical approach to the shallow-water equations based on an explicit second-order finite-volume scheme with a staggered grid. The authors implement their method and demonstrate that the code is well balanced and can handle shock fronts efficiently. Grid nesting is used to improve computational efficiency, and it is shown that accurate predictions of long-wave run-up can be achieved with less computational effort than would be necessary in existing codes.

Acknowledgments

We are grateful to H. Kalisch and M. Groves, the editors-in-chief of this journal for providing a forum for this collection of papers, and we thank the journal staff for providing support throughout the preparation of this Special Issue. Finally, we would like to thank the authors for submitting high-quality contributions, and the reviewers for their valuable service.

References

- [1] Bacigaluppi, P., Ricchiuto, M. and Bonneton, P. Implementation and evaluation of breaking detection criteria for a hybrid boussinesq model. *Water waves* 2, 207-241, 2020.
- [2] Besse, C., Gavriluk, S., Kazakova, M. and Noble, P., 2022. Perfectly Matched Layers Methods for Mixed Hyperbolic–Dispersive Equations. *Water Waves*, pp.1-31.
- [3] Brocchini, M. A reasoned overview on Boussinesq-type models: the interplay between physics, mathematics and numerics, *Proc. R. Soc. A*, 469, 2013.
- [4] Cauquis, A., Ricchiuto, M. and Heinrich, P., 2022. Lax–Wendroff Schemes with Polynomial Extrapolation and Simplified Lax–Wendroff Schemes for Dispersive Waves: A Comparative Study. *Water Waves*, pp.1-33.
- [5] Derakhti, M., Kirby, J.T., Banner, M.L., Grilli, S.T. and Thomson, J., 2020. A unified breaking onset criterion for surface gravity water waves in arbitrary depth. *Journal of Geophysical Research: Oceans*, 125(7), p.e2019JC015886.
- [6] Desmons, F. and Lubin, P., 2022. Numerical Simulations of Waves Breaking over a Rectangular Submerged Reef Consisting of a Double Step: Analogies with massive Natural Wave Breaking over Abrupt Bathymetries. *Water Waves*, pp.1-29.
- [7] Guermond, J.L., Kees, C., Popov, B. and Tovar, E., 2022. Well-Balanced Second-Order Convex Limiting Technique for Solving the Serre–Green–Naghdi Equations. *Water Waves*, pp.1-37.
- [8] Guermond, J.-L. Maier, M., Popov, B. and Tomas, I. Second-order invariant domain preserving approximation of the compressible Navier–Stokes equations. *Computer Methods in Applied Mechanics and Engineering*, 375(1):113608, 2021.
- [9] Hatland, S. and Kalisch, H. Wave breaking in undular bores generated by a moving weir. *Physics of Fluids*, 31, 033601, 2021.
- [10] Iravani, N., Badiei, P., and Brocchini, M. Novel free surface boundary conditions for spilling breaking waves. “Coastal Engineering”, 159, 103717, 2020.
- [11] Joshi, S., Kazolea, M. and Ricchiuto, M., 2022. Parameter sensitivity for wave breaking closures in Boussinesq-type models. *Water Waves*, pp.
- [12] Kalisch, H., Ricchiuto, M., Bonneton, P., Colin, M., and Lubin, P. Introduction to the special issue on breaking waves. *European Journal of Mechanics-B/Fluids*, 73, 1-5, 2019.
- [13] Kazolea, M., Delis, A.I., Synolakis, C.E. Numerical treatment of wave breaking on unstructured Finite Volume approximations for extended Boussinesq-type equations. *J. Comput. Phys.* 271, 281–305, 2014.
- [14] Kazolea, M. and Ricchiuto, M. On wave breaking for Boussinesq-type models, *Ocean Modelling* 123:16-39, 2018.
- [15] Kirby, J.T. Recent advances in nearshore wave, circulation and sediment transport modelling. *Journal of Marine Research* 75 : 263-300, 2017.
- [16] Lubin, P. and Chanson, H. Are breaking waves, bores, surges and jumps the same flow? *Environ. Fluid Mech.* 17, 47–77, 2017.
- [17] Mihami, F.-Z., Roeber, V. and Morichon, D. Efficient numerical computations of long-wave run-up and their sensitivity to grid nesting, *Water Waves*, to appear.
- [18] Robertson, B., Hall, K., Zytner, R., and Nistor, I. Breaking waves: review of characteristic relationships. *Coast. Eng. J.* 55(1), 13500021–135000240, 2013.
- [19] Wunsch, C. and Ferrari, R., Vertical mixing, energy, and the general circulation of the oceans, *Annual Review of Fluid Mechanics* 36, 281–314, 2004.

[20] Yasuda, T., Mutsuda, H., Oya, A., Tada, A., and Fukumoto, T. A new type breaker forming a giant jet and its decaying properties. Proc. 25th International Conferences Coastal Engineering, 300–313, 1996.