Modeling, experiments and case studies of long wave processes in coastal areas

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Shallow water non-linear waves propagating in the coastal seas include swells, infragravity waves generated by breaking of high frequency waves, tsunamis … Even though the first description of these wave motions goes back to the nonlinear shallow water equations or Barré de Saint Venant equations derived in the 19th century, there are still serious mathematical, numerical and experimental challenges in this field.

1. Derivation of long wave equation models

We will review a general method for the derivation of asymptotic nonlinear models in shallow water in various regimes (e.g. weakly, or strongly nonlinear); this method starts from the Hamiltonian formulation of the water wave equations with the surface elevation and the velocity potential at the free surface as main unknowns. It relies on a simple asymptotic analysis in terms of the shallowness parameter (depth over wavelength) and/or amplitude parameter (amplitude over depth). We will show how models such as the Serre/Green-Naghdi equations can be derived with this method and discuss the relevance of various variants of these models in several contexts: modeling of strongly dispersive effects, numerical implementation, etc… Several extensions of this method will also be addressed, such as deep water modeling and the influence of the presence of a non zero three-dimensional vorticity field.

2. Experimental modeling

This part of the short course will focus on how nonlinear shallow water models perform in various experimental and natural situations. These different situations will all be relevant to near-shore hydrodynamics. More specifically we will show how wave breaking can be taken into account in order to describe wave transformation on beaches. These models capable of propagating waves from intermediate water depth to the inner surf zone are used to simulate wave breaking driven currents and infra-gravity wave generation, and compare well to recent experimental results. We will also give some indications on how the nonlinear wave theories provide useful solutions to experimentally generate nearly exact nonlinear waves. We will show how these nonlinear waves experimentally reflect on submerged steps, beaches, and diffract around surface piercing obstacles.

3. Long wave models for tsunami simulations and their application to recent case studies

We will present and detail the main features and physics of recent classes of dispersive long wave equations (Boussinesq type) and non-hydrostatic models used for modeling tsunami generation due to various geophysical processes, such as subaerial and submarine landslides and earthquakes, and their propagation and coastal impact (runup, inundation). A series of recent modeling case studies will then be discussed (e.g., PNG 1998; Indian Ocean 2004, Tohoku 2011; hypothetical Cumbre Vieja Collapse) that illustrate both the practical application of these equations and the salient physical processes they express. Both the importance and effects of dispersion and nonlinearity will be illustrated for the various types of simulated tsunamis produced in these case studies, as well as coastal bathymetry (e.g., short or wide shelf, bottom slope). Recent modeling issues and topics will finally be presented, such as the proper representation of breaking dissipation in complex tsunami wave trains, including both long and short wave (e.g., undular bores) components, and their effect on the corresponding coastal tsunami hazard.