Modelling storms and extreme events impacting sand beaches in Taiwan

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Since a decade, by a fortunate reconciliation of physical oceanography and coastal engineering, sandy littoral dynamics forced by fair weather or storm conditions have been extensively studied. The same is applicable to the generation and the propagation of typhoons, and to their consequences in terms of continental rain falls and oceanic storm surges. But in contrast, it exists a very little number of studies discussing the combination of both topics that is the **peculiar nature** of the impact of typhoons – or extreme storms – on a sandy littoral system. Nevertheless, fundamental questions arise: "*are typhoons so strong that their littoral hydro-morphodynamics differs totally from that of classical storms? Do the impact of extreme storms to the shore is controled by thresholds in meteo-marine forcings or in nearshore hydro-morphodynamics?*". In particular, we identify striking open questionings: 1) what is the instantaneous water level at the shoreline during typhoons?, 2) how extreme waves attenuate towards the beach during typhoons?, 3) what are the peculiar beach morphologic changes during typhoons?, 4) What is the upgrowth of the liquefaction in the sand beach during typhoons and what are the features of water table dynamics?

The objective of this presentation is to provide an overview of what is actually possible to tackle these questionings with numerical modelling. Obviously, simulations must be performed together with and compared to in-situ field measurements and flume/basin experimentations. Here, we definitely focus on simulations, simply suggesting experimental/ in-situ results from the on-going project KUNSHEN, a Taiwan/ France collaborative funded program focussing on littoral dynamics and extreme coastal events in Taiwan. Indeed, in the Pacific Ocean, typhoons and extreme storms strike Taiwan from late April to late November, July–September being an apex. There are 3–4 typhoons crossing Taiwan each year, and more than ten class +IV storms evolve off the numerous taiwanese sandy beaches, either within the Taiwan Strait or along the eastern coast. The occurrence of typhoons usually combines strong winds, torrential rains and huge waves which always evoke terrible disasters to people. To the coast, typhoons have major consequences such as destructions of the sand barrier by total over-washing or massive sand/ boulder transports in the nearshore and onto the beach. Taiwan is thus a very good place to analyze the specific impact of extreme storms onto littoral systems.

The strategy to simulate extreme hydro-morphodynamics is to develop a full numerical workflow with a systematic downscaling from the region (westernmost central Pacific), through the coastal domain (a 10–50 km wide domain in less than 100 m of water depth) to the nearshore (a km wide domain in less than 10 m of water depth). At the regional and coastal scales, simulations necessarily rely on models such as Wave Watch III and Symphonie. WW3 creates and transform full wave spectra forced by academic of realistic winds. Symphonie solves primitive equations, forced by rivers, tides, air/sea fluxes, global ocean circulation at the boundaries, and provides with 3D currents and temperature/salinity gradients. Besides, the forcing of currents by waves has been implemented in Symphonie (Michaud et al., 2012) following the glm2z RANS formalism of Ardhuin et al. (2008), so that wave-induced pressure gradient, vortex force and other air/wind/wave interactions are taken into account in the computation of 3D currents. This is particularly pivotal as typhoon-driven waves (e.g H_s up to 10 m in less than 20 m of water depth, or up to 3.2 m in 4.5 m of water depth) result in huge radiation stresses which dominate the other forcings by far. At the regional and coastal scales, realistic simulations can be performed using global forcings such as ECMWF (meteo-marines) and MERCATOR (hydrodynamics) worldwide data sets, leading to the most accurate simulation of hydro-morphodynamics possible at now.

Things are somewhat much more complicated at the nearshore scale. A first strategy is to extend the wave/ circulation coupling to the surf zone with the introduction of non-adiabatic terms dedicated to nearshore such as the effect of roller and others, but keeping the same numerical models. It was done recently for a realistic case in France in the Gulf of Lion (Michaud et al., 2012; Chailan et al., 2012) and will be performed in the framework of KUNSHEN in Taiwan. However, a strong bias arises when models are used in the vicinity of the shoreline. There, the seabottom vertical changes in the nearshore (especially the sand bars) are so strong that their effect on waves and circulation is preeminent. As a consequence, the use of classical 3D hydrodynamic coupled models may be irrelevant under some conditions, especially when seabottom change quickly. Another strategy is to couple the simulation of nearshore hydrodynamics with that of the particle transport, thanks to well established transport laws. With a simple flux balance, the seabottom elevation can be recomputed at each point of the simulation grid so that morphologic changes drive hydrodynamics at each time step. This approach could be planed along Taiwan beaches in a near future.

At the same time, we prone two innovative approaches. The first one aims at modelling nearshore hydro-morphodynamics thanks to the optimization theory (Bouharguane et al, 2010; Bouharguane and Mohammadi, 2012). Basically, minimization principles are used in fluid-structure coupling to model sandy seabottom evolutions. The sandy bed is seen as a structure with low stiffness. The water motion in shallow domains is described by the Saint Venant equations. This coupling is based on the assumption that the bed adapts to the flow in order to minimize some energy quantity together with minimal sand transport. The approach is equivalent to the use of an Exner equation for the bed with a nonlocal flux expression. It offers really interesting perspective in the modelling of hydro-morphodynamics under extreme conditions.

The second approach is based on SPH (Smooth Particle Hydrodynamics). It aims at modelling both water and sediment by a single formalism based on the idea that all materials can be considered to be particles submitted to extreme forcing (Oudart et al., 2013). In Taiwan, SPH models are deployed to model the ultimate propagation of waves and extreme waves on the beach and beyond.

During the presentation, we illustrate the various on-going simulations of extreme storms in Taiwan with the strategies mentioned above. We mention some striking results and on-going discussions.

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