ON THE MODELLING OF TSUNAMI GENERATION AND TSUNAMI INUNDATION

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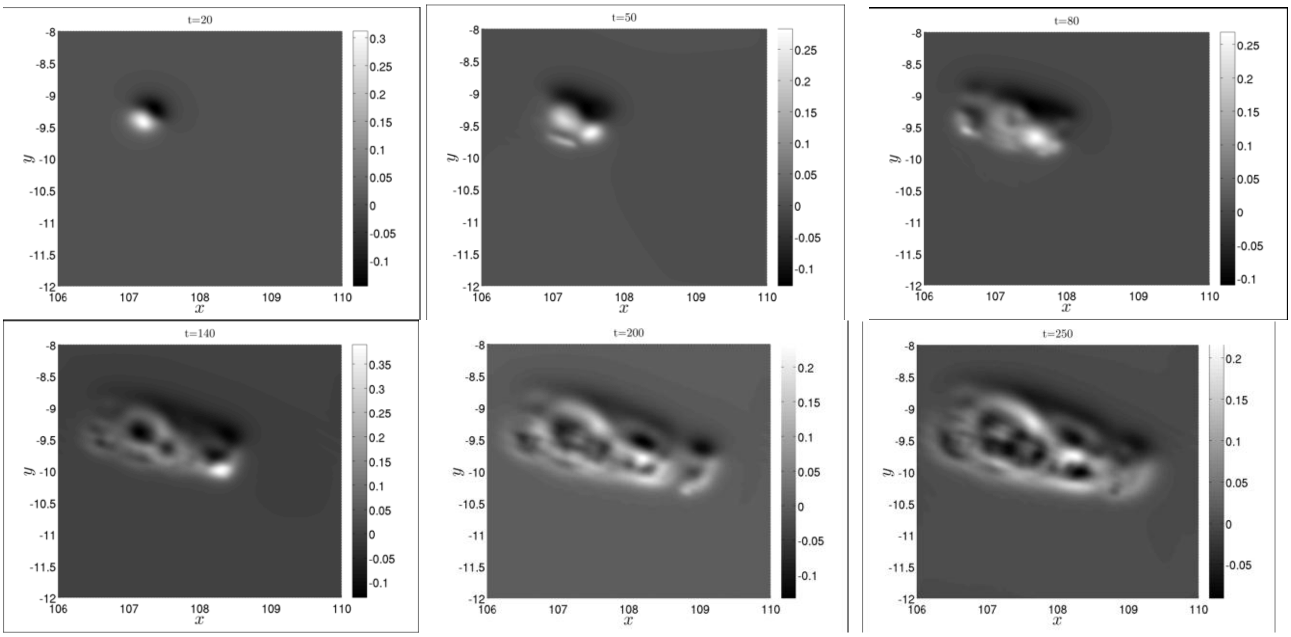
Summary While the propagation of tsunamis is well understood and well simulated by numerical models, the generation of tsunamis and the subsequent inundation still are active areas of research. We review the basic generation mechanisms as well as their simulation. In particular, we present a simple and computationally inexpensive model that describes the seabed displacement during an underwater earthquake. This model is based on the finite fault solution for the slip distribution under some assumptions on the dynamics of the rupturing process. We also review the theories for tsunami runup. In particular, we explain why the first wave of a tsunami is sometimes less devastating than the subsequent waves. A resonance effect can boost the waves that come later. This is joint work with Dr. Denys Dutykh and M. Themistoklis Stefanakis.

TSUNAMI GENERATION

The way that tsunami waves develop and also impact on beaches depends greatly on how the water surface is perturbed. There are three main types of disturbances: underwater earthquakes concentrated in zones where there is slipping or subduction of tectonic plates, submarine landslides which are often but not always triggered by earthquakes, and sudden earth surface movements adjacent to the ocean (volcanoes, rock falls, sub-aerial landslides). The generation of tsunamis by earthquakes is a challenging problem. The key point is to predict the displacement of the sea bottom, and then to understand the energy transfer to the water column. Computations of the deformation of the tectonic plates are essential in order to provide predictions. It is now possible to infer from the seismic wave behaviour what kind of generation event might have occurred.

The modelling of tsunami generation was initiated in the early 1960's by the prominent work of Kajiura [1], who proposed the translation of the static sea bed displacement towards the free surface as an initial condition. Classically, the celebrated Okada solution [2] is used to compute the co-seismic sea bed displacements. This approach is still widely used by the tsunami wave modelling community. Here we review some recent advances in seismology and show how to reconstruct better co-seismic displacements of a tsunamigenic earthquake. More precisely, we use the so-called finite fault solution developed by Ji and his collaborators [3], based on static and seismic data inversion. This solution provides multiple fault segments of variable local slip, rake angle and several other parameters. By applying Okada's solution to each subfault, the sea bed displacement is reconstructed with higher resolution. Since Okada's solution consists of relatively simple closed-form analytical expressions, all computations can be done efficiently enough so that they can be used in a real-time Tsunami Warning System. Seabed displacements are then coupled with a water wave model. Further details can be found in [4]. The figure below shows snapshots of the free surface elevation for the July 17, 2006 tsunami generation. The *x*-axis is the longitude while the *y*-axis is the latitude. The times are in seconds. The water elevation is in meters.



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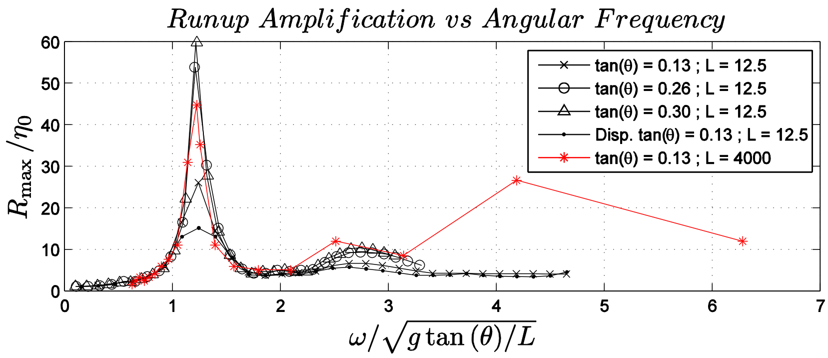
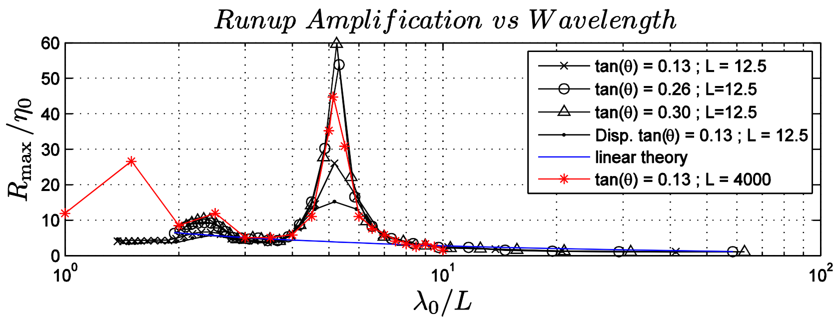
TSUNAMI INUNDATION

Wave runup (maximum vertical extent of wave uprush on a beach above still water level) and wave inundation (maximum horizontal extent) have been extensively studied during the last fifty years. Progress was first made to the one-dimensional long wave problem. From the 1950's until 1990 several major contributions were made to the initial value problem (IVP) of long wave runup, mainly through the use of the Carrier and Greenspan (CG) transformation [5], that allows the reduction of the two Nonlinear Shallow Water Equations (NSWE) used in water wave theory into a single linear equation. After the two 1992 tsunamis (Nicaragua and Flores Island), measurements suggested that the shoreline receded before inundation took place, an observation that lead Tadepalli and Synolakis [6] to propose a new N-shaped wave profile as a leading wave model.

But until now the analysis of long wave runup on a plane beach has been focused on finding its maximum value, failing to capture the existence of resonant regimes. One-dimensional numerical simulations in the framework of the NSWE are used to investigate the Boundary Value Problem (BVP) for plane and non-trivial beaches. Monochromatic waves, as well as virtual wave-gage recordings from real tsunami simulations, are used as forcing conditions to the BVP. Resonant phenomena between the incident wavelength and the beach slope are found to occur, which result in enhanced runup of non-leading waves. Runup amplification occurs for both leading elevation and depression waves. Further details can be found in [7]. The figure below shows the maximum runup amplification ratio (R_{max}/η_0) as function of non-dimensional frequency and non-dimensional wavelength for two beach lengths, namely L = 12.5 m and 4000 m. Here η_0 is the incoming wave amplitude, ω the frequency, g the acceleration due to gravity, θ the beach slope, λ_0 the incoming wavelength. These results are in an ideal setting (plane beach, incoming sinusoidal wave) but have been shown to persist in more realistic situations (arbitrary bathymetry, complex wave signal).





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