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Tsunami Balls: A Granular Approach to Tsunami Runup and Inundation

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Abstract. This article develops a new, granular approach to tsunami runup and inundation. The small grains employed here are not fluid, but bits, or balls, of tsunami energy. By careful formulation of the ball accelerations, both wave-like and flood-like behaviors are accommodated so tsunami waves can be run seamlessly from deep water, through wave breaking, to the final surge onto shore and back again. In deep water, tsunami balls track according long wave ray theory. On land, tsunami balls behave like a water landslide. In shallow water, the balls embody both deep water and on land elements. In modeling several 2-D and 3-D cases, we find that wave breaking generally causes relative runup to increase with beach slope and wave period and decrease with input wave amplitude. Because of their highly non-linear nature, runup and inundation are best considered to be random processes rather than deterministic ones. Models and observations hint that for uniform input waves, normalized runup statistics everywhere follow a single skewed distribution with a spread between 1/2 and 2 times its mean.

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Key words: Water wave, tsunami, run up.

1 Introduction

The thorniest issue in tsunami calculation is not deep water propagation, but rather the "first mile" where the waves generate and the "last mile" where the waves run into shallow water and then onto land. Understanding "first mile" events of tsunami birth by landslides, asteroid impacts and earthquakes is critical to fixing the intrinsic level of hazard. Understanding "last mile" events of tsunami runup and inundation is critical to mapping site-specific hazard, to the design of wave resistant structures and to the interpretation of paleotsunami deposits. This article considers those mysterious last mile events–tsunami runup and inundation.

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Modeling of water waves initially incident from deep water through shoaling in shallows, breaking, and finally runup onshore, must confront the changing nature of the tsunami and the movement of material and energy within. In deep water, tsunami motion is oscillatory and wave-like. The net displacement of the water mass is negligible and the velocity of energy transmission far exceeds the velocity of the individual water particles. Wave-like behavior makes for efficient propagation of tsunami over transoceanic distances. As tsunami approach shore, energy concentrates, wave heights increase to breaking, and water surges onshore. In these final flood-like stages, the net displacement of the water mass becomes large and the velocities of energy transmission and particle motion equalizes.

Most existing "last mile" approaches to wave runup and inundation (Synolakis and Bernard, 2006) employ non-linear shallow water equations and impose bore-like solutions to simulate breaking and post-breaking propagation and energy loss (Peregrine, 1966; Hibberd and Peregrine, 1979; Li and Raichlen, 2002). Others employ Boussinesq wave models augmented with extra empirical terms in the equations of motion to attempt to account for turbulent energy losses during breaking (Kennedy et al., 2000; Lynett et al., 2002). Developing numerical fluid dynamic models that span the entire 'last mile' however, has proved problematic. Special difficulties lie in quantifying the physics of turbulence, especially in proximity to the water-substrate and water-atmosphere interfaces. Those computational fluid dynamic models that do attempt to address runup and inundation in realistic three dimensional geometries are demanding computationally and susceptible to numerical instabilities (Herrmann, 2006).

This article develops a new approach to tsunami runup and inundation. The concept springs from recent work by Ward and Day, (2006) who simulated the 1980, Mt. St. Helens Washington landslide. In that simulation, granular debris raced down the mountain and then ran up and deflected from facing slopes much like a bobsled crew vying for a gold metal. The notion occurred to us that, the on-land phases of tsunami runup and inundation with all the vulgarities of deflecting and interacting flows might be modeled as a "water landslide". In debris avalanches, matter and energy do travel at the same velocity, but basal friction eventually slows and deposits solid landslide material. By eliminating basal friction, a water landslide would sooner or later drain back to the sea as does a tsunami. Although water landslides might well-emulate the on-land phase of tsunami inundation, we realized that for the approach to be useful, the deep water and runup tsunami phases have to be addressed too. The challenge posed was, "Can we formulate appropriate accelerations to carry granular water bits or 'tsunami balls' seamlessly from deep water, to breaking, onto land, and back again?"

2 Tsunami balls

We intend to simulate near shore tsunami wave propagation, runup, and inundation by tracking accelerating tsunami balls. Because the physical behavior of water motion takes