Cascadia tsunami sources: Sensitivity analysis of inundation at Cannon Beach

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Abstract

Field observations (e.g. Plafker, 1972) and the elastic fault dislocation model of Okada (1985) support the common occurrence of an "S" shaped coseismic deformation at subduction zones with uplift over the up-dip tip of the megathrust and subsidence over the down-dip portion of the rupture, both increasing with increasing slip. Numerical simulations of Cascadia tsunami inundation at Cannon Beach, Oregon utilizing 22 source scenarios reveal sensitivity of inundation to coseismic uplift and subsidence. Twelve of the scenarios are from Geist (2005), 9 are from Priest and others (1997), and one is from SEATOS (Discovery Channel tsunami). Inundation and run-up rise as coseismic water deformation (both subsidence and uplift) rises, particularly when deep water is displaced. Run-up and inundation are highly sensitive to location of coseismic subsidence. If coseismic subsidence is substantially offshore (narrow ruptures), then the initial tsunami arrival is a leading depression wave (water withdrawal). The combination of a leading depression wave followed by the main elevation wave produces a large amplitude tsunami with high run-up (Tadepalli and Synolakis, 1994). If coseismic subsidence is mostly onshore (wide rupture), then only a leading elevation wave strikes shore and run-up is lower for the same amount of slip on the subduction zone. Uplift at two scenario asperities (6-m high Gaussian mounds) in a typical shelf gravity low at Cannon Beach does not increase inundation or run-up owing to the small volume of water uplifted in the shallow water and interference from reflected and refracted waves. Gravity lows in the epicentral region for the 1960 Chilean earthquake also appear to be on the continental shelf and therefore in relatively shallow water (e.g. Wells and others, 2003). This may be why tsunami run-up for the 1960 Chile tsunami was only ~10-15 m (NOAA database), even next to asperities of Barrientos and Ward (1960) with up to 30 m of slip.

Modern and paleoseismic data on coseismic deformation and tsunami inundation offer significant constraints to the source problem. For example, paleoseismic data for Cascadia earthquakes at the Columbia River are consistent with a maximum of ~2.3 ± 0.65 m of subsidence mostly onshore (Leonard and others, 2004). About the same maximum subsidence has been measured in the field for the magnitude 9+ subduction zone events like the 1964 Prince William Sound earthquake and the 1960 Chile earthquake (Plafker, 1972). Some stochastic sources developed by Geist (2005) and the deterministic model of SEATOS have coseismic subsidence of 3-4 m. These sources produce up to 30 m run-up in some parts of the Cascadia coast and ~18 m run-up at Cannon Beach, nearly twice as high as simulations of sources with a maximum of ~2 m of subsidence. If ~2 m is indeed the maximum coseismic subsidence for magnitude ~9 events, is this a verification of the transition zone model of Hyndman and Wang (1995)? For example, eliminating the transition zone in elastic fault dislocation models of Cascadia nearly doubles the coseismic subsidence for a given total slip. Can paleo-water depth and inundation estimates from tsunami deposits place constraints on the offshore deformation (where there is no paleoseismic record)? Clearly, a holistic approach to tsunami source specification is needed that can produce a suite of source models that are geologically and geophysically reasonable but that also produce coseismic deformation, tsunami inundation, water depth, and velocity that match historic or and prehistoric estimates. Producing a suite of such sources for Cascadia should be a top priority for the NOAA National Tsunami Hazard Mitigation Program and USGS. Producing the tools to create these sources should be a top priority for National Science Foundation.