Oregon Tsunami Sources

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Like most US coasts, the main threat to life safety of Oregonians from tsunamis is from those generated immediately offshore. These waves arrive in minutes and reach elevations much higher than any conceivable distant-sourced tsunami. The closest distant tsunami source is the Gulf of Alaska, and tsunamis from there take at least 4 hours to reach Oregon shores, allowing ample time for evacuation. Oregon has already experienced a near maximum event from Alaska, the M_w 9.2 1964 Prince William Sound Earthquake. That event produced tsunamis mostly a few meters high, locally reaching ~5-6 m at the open coast. Damage was modest and loss of life in Oregon was from one family camped on the beach. On the other hand, the paleoseismic record clearly demonstrates that great Cascadia earthquakes and tsunamis have struck the Oregon coast at least 19 times over the last 10,000 years with substantial evidence for more frequent albeit smaller events on the southern Oregon Coast (e.g., Goldfinger et al., 2012). For this reason, the Oregon Department of Geology and Mineral Industries and Oregon Emergency Management emphasize assessment of the local tsunami hazard. The distant tsunami hazard is treated as an extreme value analysis, tsunami inundation mapped only for the largest historical event (1964, SLIDE 2) and a maximum-considered hypothetical event in the Gulf of Alaska (SLIDE 3). The hypothetical subduction zone fault source is a M_w 9.2 earthquake with maximum directivity to the Oregon coast (SLIDE 4) and up to 30 m slip focused near the deep sea trench (Source 3 Tsunami Pilot Study Working Group (2006); SLIDE 3). While this amount of slip is not as large as the ~40 m peak slip for the maximum-considered Cascadia event, it exceeds the 20-22 m peak slip estimated by Johnson et al. (1996) for the Mw 9.2 Prince William Sound Earthquake (SLIDE 5). Note that peak uplift and peak slip, the main determinants of tsunami size, vary greatly among these three maximum events (SLIDE 5) even though all are ~M_w 9.2 events. This fact demonstrates the fallacy of using only moment magnitude to estimate tsunami threat. Inundation and runup have a near perfect positive linear correlation to peak slip (Priest et al., 2009). While peak slip is the most important determinant of tsunami size, location of the peak slip is also important. For local subduction zone earthquakes, peak slip located further offshore generally causes bigger tsunamis than peak slip near shore owing to seafloor movement in deeper water and the possibility of creating a leading depression wave. Likewise, splay faults amplify uplift and tsunamis.

In Oregon, local Cascadia tsunami hazard assessments are not treated as an extreme value analysis. Instead, a wide but scientifically defensible range of hazard is mapped in order to serve a variety of users, including emergency managers, design professionals, and land use planners. Unique in the US, Oregon limits construction of new critical, essential, and hazardous facilities in a mapped tsunami inundation zone that is part of the Oregon Building Code. This zone is based on a "most likely" Cascadia event similar to the best documented event in 1700. To satisfy this broad constituency, Oregon inundation maps depict five "T-shirt" size Cascadia events (S, M, L, XL, XXL; M_w = 8.7-9.2) and the two extreme distant tsunami events. The Cascadia scenarios are the result of two pilot studies, one on the northern Oregon coast and one on the southern Oregon Coast (Priest et al., 2009; Witter et al., 2011) that examined hundreds of simulations of tsunami inundation for a wide variety of hypothetical Cascadia earthquake sources. The final sources chosen were constrained by paleoseismic observations, observations of global analogues, and fault dislocation theory. While these sources are not probabilistic in the strict sense, weights on the five basal branches of the logic tree are derived from an interpretation of the number of the 19 full-margin Cascadia fault ruptures that fall into the five "T-shirt" sizes over the last 10,000 years, as follows: S = 5, M = 10, L = 3, XL and XXL = two possibilities for 1 outsized event (SLIDES 6-9). Peak slip, the most critical determinant of tsunami size, is estimated from the observation that there is a fair correlation between turbidite thickness/mass and the interseismic (inter-turbidite) interval after each full-margin turbidite (SLIDE 9). The final peak slip values are also adjusted so that total slip over the last 10,000 years for these 19 events approximately matches total plate convergence. We assume a coupling ratio of 1.0 when calculating peak slip from each modeled interseismic time interval but also assume that coseismic slip decreases to zero up and down dip on the subduction zone; the result is a roughly Gaussian slip distribution with peak centered approximately on the continental shelf-slope break. The full logic tree uses three slip distributions for each of these five peak slips, resulting in 15 Cascadia sources for a full hazard assessment. In practice, the only distribution used for published inundation maps is the source incorporating a splay fault, since that source produces the largest tsunamis. Peak slip for the S or "small" event also approximates the minimum needed to produce the 13 Cascadia tsunamis that deposited sand in Bradley Lake (southern Oregon coast) over the last 7,300 years, many of which must be from southern margin segment ruptures demanded by observations of turbidite data (Witter et al., 2011; submitted) (SLIDE 6). The M or "medium" event approximates the minimum peak slip needed to inundate past tsunami sand deposited by the AD 1700 tsunami in Bradley Lake (Witter et al., submitted) and in the Ecola Creek wetland on the northern Oregon coast (Priest et al., 2009) (SLIDE 6). The AD 1700 turbidite deposit is considered of average thickness compared to the other 19 margin-wide turbidites deposited over the last 10,000 years (Goldfinger et al., 2012; Priest et al., 2009; Witter et al., 2011)(SLIDE 6).

The importance of these ground truth checks of models to paleotsunami deposits cannot be over emphasized. While one might disagree with the choices for the slip distributions (Gaussian shape, peak slip at the slope break, coupling ratio of 1.0 at the peak slip locality, slip with or without a splay) the sensitivity tests at Bradley Lake and Ecola Creek require certain minimum peak slips in order to make tsunamis big enough to account for the deposits: ~14-15 m at Ecola Creek to cover the last 3 Cascadia deposits (contemporaneous with "M"-size turbidites) (Priest et al., 2009) and ~14-16 m for the "M"-size AD 1700 tsunami to reach Bradley Lake (Witter et al., 2011; submitted). Minimum peak slip to get tsunamis to Bradley Lake using the easternmost eroded shoreline was the approximate "S"- model value of 8-9 m (Witter et al., submitted). The 1-m range in each minimum peak slip estimate is the effect of having slip with or without a splay fault. Tests of tidal effects had little effect on the Bradley Lake estimates (Witter et al., submitted). The paleotsunami constraint thus independently tests input parameters and, despite any errors in the underlying fault model, verifies that models produce minimum inundation. This observation does not, of course, mean that other models could not pass the test, but they should pass the test and be at least as geologically reasonable as the Oregon models.

Since most published inundation maps for Oregon illustrate inundation from just the splay fault sources, it is important to understand how much this amplifies the tsunami relative to "megathrust-only" sources. Inundation is generally amplified by 6-20% and wave elevation at the open coast is amplified by 27-31% (Priest et al., 2009) (SLIDE 10). Vertical deformations and location of the seismic slip for the three sources are illustrated on SLIDE 12 using the “M” slip assumption.

Cascadia tsunami sources for Oregon do not incorporate along-strike asperities, because lack of uplift along strike (between asperities) produces a negligible tsunami at the adjacent shore, effectively testing a “no tsunami” scenario -- a waste of computational time. SLIDE 11 illustrates the rapid fall off of tsunami elevation (at the 50 m isobath) north of southern Cascadia segment ruptures for Segments C and D illustrated in SLIDE 7 (unpublished simulations by Joseph Zhang). The fall off is quite rapid in spite of bathymetry which amplifies the tsunami on the northern coast (see wave elevation for the full Cascadia rupture from splay fault source XXL on SLIDE 11). A similar experiment for the northern coast pilot study looking at the effect of asperities with concentrated slip separated by zones of negligible slip also found little tsunami inundation north or south of an asperity (Priest et al., 2009). Asperities tested on the northern coast approximated the size of submarine basins and banks, the hypothesized location of subduction zone asperities in global analogues (Priest et al., 2009).

In light of substantial data from the 2011 Tohoku earthquake supporting “slip to the trench,” lack of an extreme seaward-skewed slip distribution in Oregon Cascadia sources may be problematic for southern Cascadia (SLIDE 10). The steep continental slope and near lack of a Pleistocene accretionary wedge in southern Cascadia are analogous to Tohoku, so a “slip-to-the-trench” event may be possible there. The wide Pleistocene accretionary wedge on most of the northern Cascadia margin probably produces velocity strengthening behavior in coseismic ruptures, making slip to the trench unlikely. In any case, a slip-to-the-trench scenario would not receive a great deal of weight in a logic tree, since the Japanese geologic and historic record is consistent with these events being infrequent relative to slip concentrated in a more landward position, similar to the Oregon models. Seismic surveys of the Cascadia trench sediments looking for disturbances analogous to those observed in the Tohoku event should resolve whether slip to the trench has actually occurred.

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