Using geological data to constrain solutions of past earthquakes/tsunamis

B. MacInnes, C. Garrison-Laney

When an earthquake and tsunami occur today, instrumental records can quickly allow us to interpret a wide range of quantitative characteristics of the events, such as earthquake magnitude, rupture location, slip distribution, rupture velocities, etc. and tsunami offshore wave heights, etc. Post-tsunami surveys additionally record inundation, flow depths, runup, etc. However, the same kind of information is not available for pre-instrumental earthquakes and tsunamis, with the exception of eye-witness descriptions from locations with a long written history (like Chile or Japan). Understanding the physics of subduction-zone deformation and accurately assessing the hazards from earthquakes and tsunamis requires earthquake and tsunami histories of considerable detail over multiple earthquake cycles. Imagine the scientific and hazard planning implications of knowing the magnitude of all regional earthquakes for the last few thousand years, or knowing the differences in their slip distributions, or the variations in past tsunamis' over-land flow speeds.

A major goal of our research is to be able to quantify these transient characteristics of known pre-instrumental events by reconstructing parameters of earthquake rupture and tsunami initiation and validating those solutions against geologic field observations. Geologic field studies, especially co-seismic land-level change and tsunami deposit data, are the best resource for validating reconstructions of events that have previously occurred. Advances in land-level change studies are enabling fairly tight constraints on numerical estimates of coastal subsidence or uplift associated with an earthquake, which is tied to the earthquake's source characteristics. Advances in paleotsunami deposits studies are defining proxies for tsunami inundation and sediment transport models of these deposits can calculate flow speeds and flow depths. These kinds of studies are particularly well-advanced in Chile, Japan, and Cascadia, and provide a suite of information to compare to simulations of hypothetical earthquakes. Recently, we have been creating hundreds of randomized slip distributions, forward modeling tsunamis from those earthquakes to sites with geologic data, and performing statistical analyses to determine a range of possible seafloor deformation patterns for known tsunamigenic earthquakes. From the best-fit possible results for specific past events, we can then solve for properties such as earthquake magnitude or slip distribution, and forward model tsunami characteristics to sites with no geologic data.

Successes to date:

1. Isolating locations of high slip (although over low spatial resolution) in past earthquakes by comparing tsunami models to field data and written records: Chile, Aleutians and Kamchatka.
2. Employing randomized slip distributions to create a suite of hypothetical past earthquakes (could be improved).
3. Using AIC statistical methods to differentiate tsunami simulation results to isolate important variables in distinguishing paleo-earthquakes.
4. Converting a geologic/historical observation of a tsunami deposit or land-level change (with all their site-specific variability) into values or value ranges that can be compared to model

results (this is both a success and an ongoing problem)

5. Using geologic data to constrain or ground truth unrealistic earthquake models.
6. Estimating flow depths from sediment deposit grain size and thickness (tsunami sediment modeling such as by R. Weiss, H. Tang, etc).
7. Recreating paleoshorelines for past events to calibrate paleotsunami data (in Kurils and Kamchatka; other researchers have had success in Sendai and Hokkaido), although this is also a problem in that it is not always possible.

Ongoing problems to solve:

1. Quantifying the number of field observations of past tsunamis and land-level change observations necessary to differentiate tsunami models, at what spatial interval, at what accuracy, etc. (i.e. when do you have enough field data and when do you not for statistically significant results?).
2. Finding high-resolution international bathymetry and topography.
3. Reverting bathymetry and topography to its original undeveloped state, if needed.
4. When working with non-subduction zone earthquakes (like in Puget Sound), having confidence of the fault interface parameters.
5. When dealing with older historical records (Japan and Chile), removing the land-level change signal from the tsunami observation of wave heights.
6. Differentiating concentrated high slip in a short but low Mw rupture from more diffused slip in higher Mw ruptures in the local tsunami signal.
7. Distinguishing one large earthquake/tsunami from multiple ones spaced closely in time.
8. Differentiating tsunamis from storms, particularly on shores where a tsunami source does not produce geologically detectable changes in land level.