Tsunami Modeling of Complex Fault Sources

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Complexity associated with megathrust earthquakes can have a significant effect on tsunami generation. Three types of complexity endemic to subduction zones are examined with respect to tsunami generation: (1) structural and material heterogeneity, (2) splay faulting, and (3) heterogeneous slip distribution. Particular attention is paid to recent developments in earthquake physics to determine whether proposed mechanisms of anomalous tsunami generation are consistent with theories of dynamic earthquake rupture. The objective of this overview is to highlight areas of research in earthquake physics that can substantially contribute to our understanding of tsunami generation.

Subduction zones exhibit both large-scale heterogeneity in rock types and depth-dependent variations in fault zone properties. Large-scale heterogeneity, most often characterized in coseismic deformation models by variations in elastic moduli, has been shown to have a significant effect on seafloor displacements. In particular, deformation of material with a lower shear modulus relative to a homogeneous or reference model (e.g., PREM) results in higher seafloor displacements. In addition, depth-dependent variations in shear modulus, which may be over an order of magnitude for seismogenic depths, has a marked effect when converting seismic moment to fault slip—the controlling parameter for tsunami generation. It should also be noted that there is a fundamental ambiguity of defining moment density on a bimaterial surface (e.g., fault separating oceanic crust from accretionary wedge material), suggesting that slip-based, rather than moment-based, source models be employed where possible.

There has been substantial progress in recent years towards understanding off-fault selectivity of dynamic rupture that can be applied to splay faulting in subduction zones. Whether or not rupture from a primary fault continues on to a branching secondary fault depends on a number of factors, including branch angle, rupture velocity, and pre-stress conditions. Simultaneous rupture on both primary and secondary faults requires either a large branch angle or rupture velocities near Rayleigh wave speeds. When secondary splay rupture does occur, a short-wavelength, high amplitude component is added to the initial tsunami wavefield from the megathrust.

Dynamic rupture models can also be examined more generally to understand the origin of static slip distributions obtained from seismic/geodetic inversions that in turn are used in models of tsunami generation. A surprisingly rich array of rupture behaviors have been obtained from dynamic models, most using rate and state-dependent friction laws. In particular, rupture studies of the onshore 1999 Chi-Chi thrust earthquake where surface deformation has been directly measured provide an important analog for offshore subduction zone earthquakes. One hypothesis to explain anomalously large localized slip (and associated surface displacement) relative to the magnitude of this earthquake and "asperities" in general is thermal pressurization of pore fluid.

Regional and far-field tsunami forecast models based on a coarse discretization of coseismic slip perform well primarily because slip is constrained by real-time tsunami observations. Thus, uniform slip on coarse sub-faults serves as a proxy for more complicated rupture behavior. Rupture complexity is responsible, however, for a great deal of uncertainty in predicting *local* tsunami amplitudes for an earthquake of a given magnitude. Future advances in understanding the physics of megathrust earthquakes coupled with tsunami generation models will likely reduce this uncertainty.