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High resolution earthquake source mechanisms in a subduction zone: 3-D waveform simulations of aftershocks from the 2010 Mw 8.8 Chile rupture

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The earthquake rupture process is extremely heterogeneous. For subduction zone earthquakes in particular, it is vital to understand how structural variations in the overriding plate and downgoing slab may control slip style. The large-scale 3-D geometry of subduction plate boundaries is rapidly becoming well understood (e.g. Hayes et al., 2012); however, the nature of slip style along any finer-scale structures remains elusive. Regional earthquake moment tensor (RMT) inversion can shed light on faulting mechanisms. However, many traditional regional moment tensor inversions use simplified (1-D) Earth models (e.g. Agurto et al., 2012; Hayes et al., 2013) that only use the lowest frequency parts of the waveform, which may mask source complexity. As a result, we may have to take care when making small-scale interpretations about the causative fault and its slip style. This situation is compounded further by strong lateral variations in subsurface geology, as well as poor station coverage for recording offshore subduction earthquakes. A formal assessment of the resolving capability of RMT inversions in subduction zones is challenging and the application of 3-D waveform simulation techniques in highly heterogeneous media is needed.

We generate 3-D waveform simulations of aftershocks from a large earthquake that struck Chile in 2010. The Mw 8.8 Maule earthquake is the sixth largest earthquake ever recorded. Following the earthquake, there was an international deployment of seismic stations in the rupture area, making this one of the best observed aftershock sequences to date. We therefore have a unique opportunity to compare recorded waveforms with simulated waveforms for many earthquakes, shedding light on the effect of 3-D heterogeneity on source imaging.

We perform forward simulations using the spectral element wave propagation code, SPEFEM3D (e.g. Komatitsch et al., 2010) for a set of moderate-sized aftershocks (Mw 4.0-5.5). A detailed knowledge of velocity structure for the region as well as robust earthquake locations (Hicks et al., 2014) ensure that our 3-D simulations are robust. We perform regional moment tensor inversion using the ISOLA software package (Sokos & Zahradnik, 2008), incorporating 3-D Green's functions from the forward simulations. With this approach, we are able to test the resolving capability of traditional 1-D strategies.

We find that focal mechanism dip and source depth are the parameters that are most biased parameters in 1-D RMT inversions, particularly for events that are located far offshore. We also describe and interpret observations of normal faulting earthquakes along the plate interface. This finding may have important implications for post-seismic fluid release.