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Automated rapid finite fault inversion for megathrust earthquakes: Application to the Maule (2010), Iquique (2014) and Illapel (2015) great earthquakes

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Rapid estimation of the spatial and temporal rupture characteristics of large megathrust earthquakes by finite fault inversion is important for disaster mitigation. For example, estimates of the spatio-temporal evolution of rupture can be used to evaluate population exposure to tsunami waves and ground shaking soon after the event by providing more accurate predictions than possible with point source approximations. In addition, rapid inversion results can reveal seismic source complexity to guide additional, more detailed subsequent studies.

This work develops a method to rapidly estimate the slip distribution of megathrust events while reducing subjective parameter choices by automation. The method is simple yet robust and we show that it provides excellent preliminary rupture models as soon as 30 minutes for three great earthquakes in the South-American subduction zone. This may slightly change for other regions depending on seismic station coverage but method can be applied to any subduction region. The inversion is based on W-phase data since it is rapidly and widely available and of low amplitude which avoids clipping at close stations for large events. In addition, prior knowledge of the slab geometry (e.g. SLAB 1.0) is applied and rapid W-phase point source information (time delay and centroid location) is used to constrain the fault geometry and extent. Since the linearization by multiple time window (MTW) parametrization requires regularization, objective smoothing is achieved by the discrepancy principle in two fully automated steps. First, the residuals are estimated assuming unknown noise levels, and second, seeking a subsequent solution which fits the data to noise level. The MTW scheme is applied with positivity constraints and a solution is obtained by an efficient non-negative least squares solver. Systematic application of the algorithm to the Maule (2010), Iquique (2014) and Illapel (2015) events illustrates that rapid finite fault inversion with teleseismic data is feasible and provides meaningful results. The results for the three events show excellent data fits and are consistent with other solutions showing most of the slip occurring close to the trench for the Maule an Illapel events and some deeper slip for the Iquique event. Importantly, the Illapel source model predicts tsunami waveforms of close agreement with observed waveforms. Finally, we develop a new Bayesian approach to approximate uncertainties as part of the rapid inversion scheme with positivity constraints. Uncertainties are estimated by approximating the posterior distribution as a multivariate log-normal distribution. While solving for the posterior adds some additional computational cost, we illustrate that uncertainty estimation is important for meaningful interpretation of finite fault models.