Earthquake Source Modeling using Time-Reversal or Adjoint Methods

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In recent years there have been great advances in earthquake source modeling. Despite the effort, many questions about earthquake source physics remain unanswered. In order to address some of these questions, it is useful to reconstruct what happens on the fault during an event. In this study we focus on determining the slip distribution on a fault plane, or a moment-rate density, as a function of time and space. This is a difficult process involving many trade offs between model parameters. The difficulty lies in the fact that earthquakes are not a controlled experiment, we don’t know when and where they will occur, and therefore we have only limited control over what data will be acquired for each event. As a result, much of the advance that can be made, is by extracting more information out of the data that is routinely collected.

Here we use a technique that uses 3D waveforms to invert for the slip on a fault plane during rupture. By including 3D wave-forms we can use parts of the wave-forms that are often discarded, as they are altered by structural effects in ways that cannot be accurately predicted using 1D Earth models. However, generating 3D synthetic is computationally expensive. Therefore we turn to an ‘adjoint’ method (Tarantola Geoph. 1984, Tromp et al. GJI 2005), that reduces the computational cost relative to methods that use Green’s function libraries. In it’s simplest form an adjoint method for inverting for source parameters can be viewed as a time-reversal experiment performed with a wave-propagation code (McMechan GJRA 1982). The recorded seismograms are inserted as simultaneous sources at the location of the receiver and the computed wave field (which we call the adjoint wavefield) is recorded on an array around the earthquake location.

We show that for source inversions for a moment tensor (distributed) source, the time integral of the adjoint strain is the quantity to monitor. We present time-reversal experiments using synthetic seismograms computed for point sources and finite sources, building intuition for what to expect, and show an example for a real event.