Geophysical Research Abstracts
Vol. 13, EGU2011-11924, 2011
EGU General Assembly 2011

Imaging the earthquake rupture from the back projection of body waves

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In the last decades, with the advent of digital seismic networks, instrumental seismology has seen a huge development in the quantity of stations installed worldwide and in the quality of recordings. Today is not uncommon to have continuous, and often real-time, seismic recordings from large number of stations, densely deployed in certain regions of the Earth (e.g. seismic arrays or monitoring networks) or widely distributed around the planet (global networks). This opens up new, exciting perspectives in many research fields, including monitoring and study of the earthquake source processes.

Recently, a new set of techniques has emerged to map seismic sources in time and space: the wave field recorded at a number of stations is projected back to the source region in order to depict the source pattern that generated the recorded signals.
These back projection methods have been successfully employed to detect and characterize coherent source signatures within complex signals, like seismic tremors (e.g. Kao and Shan, 2004), rupture propagation in large earthquakes (e.g. Ishii et al., 2005; Kruger and Ohrnberger, 2005), or secondary events hidden into the recordings of a larger shock (e.g. Allmann and Shearer, 2007).

Following the original approach of Ishii et al. (2005), we developed and implemented a technique for imaging the earthquake rupture, from the back projection of body waves recorded at teleseismic or regional distances.
We model the focal region as a grid where each point can act as an elementary source during the propagation of the rupture. Seismograms are stacked for each potential source to obtain a time evolving image of the rupture. The stacking procedure recovers the energy that is actually radiated from the given point, while limits the contribution of incoherent signals. The squared amplitude of the stacks (which is proportional to the radiated energy) is mapped in space and time, producing an image of the temporal evolution of the rupture. This approach, being a signal-processing technique, does not require any a-priori knowledge or assumption on the source (hypocentral location, origin time, rupture velocity, fault extent and orientation), and is thus able to provide an independent picture of the rupture process, respect to classic inversion schemes.

In this work we describe the methodology, with a particular attention to those aspects that critically control the quality of the result. One is the selection of the optimal frequency band that maximizes the signal coherency across the recording station array. Another is the optimization of the image resolution, improving the array response function through station weighting. Finally, we propose and analyze different stacking strategies, with the aim of improving the image quality, enhancing the contrast between radiating and non-radiating zones and correcting the distortions due to unmodelled travel time residuals.

We present an example application to the 27 February 2010 Mw 8.8 Maule earthquake (Chile), imaged from a global array of worldwide stations and by the USArray.
The resulting images are discussed in light of the slip models obtained from the kinematic inversion of body waves, GPS and satellite radar displacement.