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Feasibility of Real-Time Broadband Waveform Inversion for Simultaneous Moment Tensor and Centroid Location Determination

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Abstract We present a feasibility study for an automated system to simultaneously determine centroid source location and seismic moment tensor (MT) for regional earthquakes. This system uses continuous real-time waveforms in a time window that is continuously shifted forward with a short time interval (~20 sec) from a sparse network of broadband seismic instruments, and unlike the current standard method, it performs inversion without prior knowledge of the location and origin time information. We tested 68 earthquakes with $M_L \geq 4.2$ that occurred in northern and central California between 1993 and 1999 and that have well-calibrated solutions obtained by an established procedure of MT determination. The solutions determined by the new system are compared with the well-calibrated solutions for performance appraisal. Results show that onshore earthquakes with $M_w \geq 4.5$ can be detected and adequately characterized in terms of MT and approximate centroid location. The threshold value of variance reduction to detect an event is about 70%. In contrast, events that occurred off the Mendocino coast are not as reliably constrained, reflecting the unmodeled complexity of the transitional structure from ocean to the continent using the current 1D model as well as the gap in azimuthal coverage. Significant improvement of the computational efficiency is expected if the system is fully configured on a powerful PC with multiple CPUs of approximately 1 Gbyte memory and the monitoring of event location and MT determination over the grid can be updated within the time frame of shifting the time window (~20 sec).

Introduction

The Berkeley Seismological Laboratory (BSL) operates a regional network (Berkeley Digital Seismic Network [BDSN]) of 25 very broadband stations to monitor regional seismic activity in northern and central California (Romanowicz *et al.,* 1992, 1994). The real-time waveform data are continuously telemetered to BSL using frame relay. The broad frequency band and high dynamic range of this network is particularly suitable for detailed characterization of earthquakes (centroid location, moment-tensor [MT], and source characteristics). The current system of automated MT determination at BSL has been developed as part of the BSL/U.S. Geological Survey (USGS) joint notification system, namely, the Rapid Earthquake Data Integration (REDI) (Gee *et al.,* 1996; Pasyanos *et al.,* 1996). It relies on the availability of earthquake onset times and locations provided to BSL by the USGS at Menlo Park, where they are determined in real-time from the dense array comprised primarily of short-period (~1 sec) vertical-component sensors (Northern California Seismic Network [NCSN]) (Oppenheimer *et al.,* 1992).

Efforts aimed at developing a stand-alone system have recently been implemented at BSL with an introduction of azimuth and *P*- and *S*-arrival-time information into the earthquake location determinations and the development of an adaptative grid search method for event location (Dreger *et al.,* 1998; Uhrhammer *et al.,* 2001). This method is based on the arrival time (i.e., high frequency) information of *P* and *S* waves and therefore does not take full advantage of the bandwidth of broadband waveform data. In addition, the automatic *S*-phase arrival pick and azimuth determination are not sufficiently reliable to provide an accurate source location using the sparse BDSN network data alone.

With the present quality of broadband seismic data, it is possible to determine source location and MT of significant events independently of the short-period data. Kawakatsu (1998) presented the basic concept for a fully automated system that continuously monitors the background seismic wavefield and determines MT solutions for virtual point sources distributed on a grid in the region of interest. Variance reductions (VRs) calculated on the grid are evaluated at each point in space and time so as to identify a point of maximum VR that may exceed a threshold value corresponding to a real earthquake. Such an approach will be particularly relevant in areas of occurrence of less frequent