Geophys. J. Int. (2008) **174,** 585–592 doi: 10.1111/j.1365-246X.2008.03797.x

Stable inversions for complete moment tensors

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Accepted 2008 March 16. Received 2008 March 16; in original form 2008 January 12

SUMMARY

The seismic moment tensors for certain types of sources, such as volcanic earthquakes and nuclear explosions are expected to contain an isotropic component. Some earlier efforts to calculate the isotropic component of these sources are flawed due to an error in the method of Jost & Herrmann. We corrected the method after Herrmann & Hutchensen and found great improvement in the recovery of non-double-couple moment tensors that include an isotropic component. Tests with synthetic data demonstrate the stability of the corrected linear inversion method, and we recalculate the moment tensor solutions reported in Dreger *et al.* for Long Valley caldera events and Dreger & Woods for Nevada Test Site nuclear explosions. We confirm the findings of Dreger *et al.* that the Long Valley volcanic sources contain large statistically significant isotropic components. The nuclear explosions have strikingly anomalous source mechanisms, which contain very large isotropic components, making it evident that these events are not tectonic in origin. This indicates that moment tensor inversions could be an important tool for nuclear monitoring.

Keywords: Inverse theory; Earthquake source observations; Seismic monitoring and test-ban treaty verification; Volcano seismology; Computational seismology; Theoretical seismology.

1 INTRODUCTION

Earthquake source mechanisms are routinely determined through moment tensor inversions. This process requires that synthetic seismograms be represented as the linear combination of fundamental Green's functions, where the weights on these Green's functions are the individual moment tensor elements. An analytical representation of this system for a general moment tensor was derived in Jost & Herrmann (1989) (appendix A), based on the work of Langston (1981) for a deviatoric (zero trace) moment tensor (Method 1). However, an error in the Jost & Herrmann (1989) derivation precludes their moment tensor inversion scheme from correctly recovering source mechanisms which include isotropic components, although it is accurate for analysing deviatoric sources. In this paper, we present a correction to their inversion scheme after Herrmann & Hutchensen (1993) (Method 2). Method 2 can accurately recover moment tensors for both deviatoric and non-deviatoric sources. Tests of this method using synthetic data show that it works well, and we have used the new inversion scheme to determine moment tensors for several real volcanic and nuclear explosion sources.

2 METHODOLOGY

Analytical solutions for surface displacement have been derived for a double-couple source (Helmberger 1983), a deviatoric source (Langston 1981) and for a general moment tensor (Jost & Herrmann 1989). A deviatoric point source can be represented by using Green's functions for three fundamental faults: a vertical strike-slip fault; a vertical dip-slip fault and a dip-slip fault with a dip of 45° (Langston 1981). However, for a complete moment tensor, $\boldsymbol{M}$, we must also include the explosion Green's functions, so that

$$\begin{aligned} u_Z &= A_1 \cdot ZSS + A_2 \cdot ZDS + A_3 \cdot ZDD + M_{\text{iso}} \cdot ZEP, \\ u_R &= A_1 \cdot RSS + A_2 \cdot RDS + A_3 \cdot RDD + M_{\text{iso}} \cdot REP, \\ u_T &= A_4 \cdot TSS + A_5 \cdot TDS, \end{aligned} \tag{1}$$

where u is the surface displacement, SS is the vertical strike-slip Green's function, DS is the vertical dip-slip Green's function, DD is the 45° dip-slip Green's function and EP is the explosion Green's function. Z, R and T refer to the vertical, radial and tangential components, respectively, and

$$M_{\text{iso}} = \frac{\text{tr}(\mathbf{M})}{3}. \tag{2}$$

It is in the calculation of the A_i coefficients that the two methods diverge.

2.1 Method 1 (Jost & Herrmann 1989)

Method 1 wrongly uses the A_i coefficients for a deviatoric source,

$$\begin{aligned} A_1 &= \frac{1}{2}(M_{xx} - M_{yy})\cos(2az) + M_{xy}\sin(2az), \\ A_2 &= M_{xz}\cos(az) + M_{yz}\sin(az), \\ A_3 &= -\frac{1}{2}(M_{xx} + M_{yy}), \end{aligned}$$