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Empirical Green's function analysis: Taking the next step

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Abstract. An extension of the empirical Green's function (EGF) method is presented that involves determination of source parameters using standard EGF deconvolution, followed by inversion for a common attenuation parameter for a set of colocated events. Recordings of three or more colocated events can thus be used to constrain a single path attenuation estimate. I apply this method to recordings from the 1995-1996 Ridgecrest, California, earthquake sequence; I analyze four clusters consisting of 13 total events with magnitudes between 2.6 and 4.9. I first obtain corner frequencies, which are used to infer Brune stress drop estimates. I obtain stress drop values of 0.3-53 MPa (with all but one between 0.3 and 11 MPa), with no resolved increase of stress drop with moment. With the corner frequencies constrained, the inferred attenuation parameters are very consistent; they imply an average shear wave quality factor of approximately 20-25 for alluvial sediments within the Indian Wells Valley. Although the resultant spectral fitting (using corner frequency and κ) is good, the residuals are consistent among the clusters analyzed. Their spectral shape is similar to the the theoretical one-dimensional response of a layered low-velocity structure in the valley (an absolute site response cannot be determined by this method, because of an ambiguity between absolute response and source spectral amplitudes). I show that even this subtle site response can significantly bias estimates of corner frequency and κ, if it is ignored in an inversion for only source and path effects. The multiple-EGF method presented in this paper is analogous to a joint inversion for source, path, and site effects; the use of colocated sets of earthquakes appears to offer significant advantages in improving resolution of all three estimates, especially if data are from a single site or sites with similar site response.

1. Introduction

Independent resolution of source, path, and site effects from waveform recordings of small-to-moderate events has proven to be an elusive goal. While several early studies relied on subjective determination of corner frequencies [e.g *Bakun et al.*, 1980; *Archuleta et al.*, 1982], many of these studies were shown to be flawed because of an incomplete accounting of the attenuation; in particular, near-surface attenuation [*Anderson*, 1986; *Hough et al.*, 1989]. Recent studies have achieved more reliable independent resolution of source and attenuation characteristics by using an empirical Green's function (EGF) method, in which attenuation effects are deconvolved from an earthquake recording by using a nearby smaller event [e.g. *Mueller*, 1985; *Frankel et al.*, 1986]; however, resolution of corner frequency can still be limited, especially for smaller events [*Hough*, 1996]. The method also requires a specialized data set: nearly colocated events with similar waveforms.

Alternatively, several studies have presented joint simultaneous inversions for source, path, and site terms [*Boatwright and Fletcher*, 1991; *Humphrey and Anderson*, 1995].This approach is attractive because data are not limited to earthquakes for which a suitable EGF recording is available.

In spite of advances in methodology, fundamental questions remain unanswered, including the scaling relationship between stress drop and seismic moment. Because this issue is critical to various aspects of earthquake source mechanics and seismic hazard, it is important to extract as much information as possible from small-to-moderate earthquake recordings.

The scaling of stress drop with seismic moment has been debated at some length in previous studies. Because a wide range of moments is required to determine the scaling, resolution of this issue necessarily involves the determination of stress drop for small events. Most studies have focused on Brune stress drop σ_b determined from the inferred corner frequency or pulse width, assuming it to be representative of static stress drop. As discussed by *Boatwright* [1984], absolute static stress drop σ_s will depend on both the initial and final stress state of the fault, which may be impossible to

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