FINAL TECHNICAL REPORT

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Broadband Modeling Local and Regional Seismograms; Southern California

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Investigations

Many earthquakes have occurred in Southern California since the introduction of the TERRAscope array, nearly 400 events with $M_L > 3.5$. These events have produced a huge amount of excellent waveform data with a variety of mechanisms, magnitudes, and depths. This dataset can be used as a test bed in deriving new techniques for extracting source information from regional seismogram for real-time analysis and improving Green's functions (Path Connections).

Our recent modeling attempts indicate that whole seismograms can be used in source estimation by applying a "cut and paste" approach. We start with a set of Green's functions from a standard southern California model. The beginning P-wave portion is removed and aligned to the corresponding observation and similarly for the SV and Rayleigh wave portion. The best fitting source model denoted by strike, rake, dip, and Mo is then obtained by least-squared waveform modeling determined by a direct grid search. The procedure is repeated over a range of depths and the best overall fit determined, see *Zhao and Helmberger (1994).* The above method has been improved by changing the misfit normalization to better utilize absolute amplitude by *Zhu and Helmberger (1996).* The new method has become sufficiently stable to automate and is now servicing the TERRAscope datastream after an event trigger by CUBE. It takes a few minutes to estimate source parameters for an event. In batch mode, it takes a few days to run through the complete TERRAscope data archive and test the influence of a new crustal model on mechanisms, etc. This new tool puts us in a position to use the various "time shifts" between data and synthetics to regionalize and determine the most dependable stations to use for various event geometries and correct stations for path effects, *Jones and Helmberger (1998).*

Another important component of modeling regional recording concerns the response of basins. This can be done effectively by applying 2D finite-difference methods, see *Scrivner and Helmberger (1998)*, or by applying a new method called "Pseudo Green's functions", see *Song and Helmberger (1998)*.

Results

1. Earthquake Source Parameters and Fault Kinematics in the Eastern California Shear Zone

Laura E. Jones and Donald V. Helmberger
(*BSSA*, in press)

Abstract. Based on waveform data from a profile of aftershocks following the north-south trace of the June 28, 1992 Landers rupture across the Mojave desert, we construct a new velocity model for the Mojave region which features a thin, slow crust. Using this model, we obtain source parameters, including depth and duration, for each of the aftershocks in the profile, and in addition, any significant (M>3.7) Joshua Tree--Landers aftershock between April, 1992 and October, 1994 for which coherent TERRAscope data were available. In all, we determine source parameters and stress-drops for 45 significant ($M_w > 4$) earthquakes associated with the Joshua Tree and Landers sequences, using a waveform grid-search algorithm. Stress drops for these earthquakes appear to vary systematically with location, with respect to previous seismic activity, proximity to previous rupture (i.e., with respect to the Landers rupture), and with tectonic province. In general, for areas north of the Pinto Mountain fault, stress-drops of aftershocks located off the faults involved with the Landers rupture are higher than those located on the fault, with the exception of aftershocks on the newly recognized Kickapoo (Landers) fault. Stress drops are moderate south of the Pinto Mountain fault, where there is a history of seismic swarms but no single through-going fault. In contrast to aftershocks in the eastern Transverse ranges, and related to the 1992 Big Bear, California sequence, Landers events show no clear relationship between stress-drop and depth. Instead, higher stress-drop aftershocks appear to correlate with activity on nascent faults, or those which experienced relatively small slip during mainshock rupture.

2. Two-Dimensional Finite Difference Modeling of Two Aftershocks of the 1994 Northridge Earthquake

Craig W. Scrivner and Donald V. Helmberger
(*BSSA*, in press)

Short title: NORTHRIDGE AFTERSHOCK MODELING

Abstract. Two aftershocks of the January 17, 1994 Northridge earthquake are analyzed and modeled with 2D finite difference. The event epicenters both lie at the northwest edge of the San Fernando Basin, but the hypocentral depths differ – one is 4 km deep, the other is 16 km deep. Waveforms were recorded by portable instruments deployed across the basin by a number of institutions following the Northridge mainshock. The waveforms are integrated to displacement and examined in the 0.3 to 4 Hz pass band. For the shallow event, distinctive features in the data are (a) a broad direct S phase at stations in the basin, (b) large amplitude surface waves and extended coda at a cluster of stations 8 km into the basin, and (c) a high-frequency, Hilbert transformed ($\pi/2$ advanced in phase) direct S phase at stations beyond the basin, in the Santa Monica Mountains. The deep event is less strongly affected by the basin. For this event, the direct S phase is broad in the basin. Rather than surface waves at the stations 8 km into the basin, there is a discrete multiple to direct S on the tangential component that can be distinguished from the coda. The stations beyond the basin have higher frequency direct S phases, compared to basin stations, but they are not Hilbert transformed. For both events, the vertical waveforms have low amplitudes at all stations, at least two times smaller than the horizontal components. An array analysis was done with the tangential component records from the cluster of stations 8 km into the basin. This analysis indicates that the surface waves generated by the shallow event and the shear wave multiple generated by the deep event are arriving on-azimuth from the source, and a 2D model can reasonably be applied. These features in the data can be explained by a simple basin model with significant structure below the basin. There is a strong contrast in the basin at about 1 km depth. The lower basin is relatively transparent, but the duration of surface waves generated at the basin edge increases as the source approaches this interface. The Hilbert transformed direct S phases recorded in the Santa Monica Mountains are modeled as a triplication feature. They can be explained by a moderate vertical gradient at 5.5 to 6.5 km depth. These structures below the basin have little effect on propagation from the deep source. The sensitivity of this model is checked by examining the parameter space around it. Variations of 15% in the velocity contrast across the interface in the upper basin degrade the fit of the surface waves with the data. Moving the interface above the shallow source up 1 km also alters the surface waves. This modeling suggests that a strong velocity contrast is needed within the San Fernando Basin to explain 1 Hz waves and that the structure below the basin focuses energy around the basin.

3. Estimates of Regional and Local Strong Motions during the Great 1923 Kanto, Japan Earthquake (*Ms* 8.2). Part 1: Source Estimation of a Calibration Event and Modeling of Wave Propagation Paths

   T. Sato, D. V. Helmberger, P. G. Somerville, R. W. Graves, and C. K. Saikia
   (*BSSA*, V. **88**, No. 1, pp. 183-205, Feb. 1998)

4. Pseudo Green's Functions and Waveform Tomography

   Xi Song and Don V. Helmberger
   (*BSSA*, V. **88**, No. 1, pp. 304-312, Feb. 1998)

5. Variability of Ground Motions in Southern California -- Data from the 1995-1996 Ridgecrest Sequence

   Craig W. Scrivner and Don V. Helmberger
   (*BSSA*, in press)

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