# FINAL TECHNICAL REPORT
## Award Number G09AP00082

# "MODELING BROADBAND SEISMOGRAMS"

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## Abstract

It appears that the greatest barrier to modeling the P-wave onset at short-periods (< 2s) or wavelengths less than 10 km is simply the complications introduced by the surface geology. This is no surprise to those researchers working with down-hole arrays, but it is surprising how simple path-specify calibration works to correct for these effects (.5 to 8 Hz) at most stations, *Tan and Helmberger* (2007). One advantage of working at these frequencies is that the details of the rupture process become visible with rupture velocity and fault dimension determined independently. We find that aftershocks outside weak fault-zones display slow rupture velocities, higher stress-drops, and weaker coda than those inside, at least for the Big Bear sequence.

We plan to further document these features for the Landers and Hector Mine sequences and expand our efforts into the greater Los Angeles region. In particular, we plan to calibrate both the broadband TriNet and the short-period SCSN by working jointly with Egill Hauksson who has the latter data on a Raid System. The major products will be well-determined source mechanisms of events with magnitude down to 2 and rupture directivities of intermediate magnitude events, M>3.5. Our main contribution to the NEHRP program will be to provide a better understanding of earthquake sources, fault zones beneath important locations (LA) which could help emergency planners prepare for the future earthquakes.

## Results

### 1. Earthquake Centroid Locations Using Calibration from Ambient Seismic Noise

**Zhongwen Zhan, Shengji Wei, Sidao Ni, and Don Helmberger**

**(*BSSA*, in review)**

**Abstract.**

Earthquakes occur in complex geology and prove difficult to locate because of uncertainties in the seismic models. Essentially, solving for both source location and 3D structure simultaneously depends on the starting model and source distribution of past events. Regional earthquakes, $M_W$>3.5, at ranges from 100 km to 300 km normally produce stable surface waves

at period 10-100s. If the travel times or lags of the phases due to path effects are known relative to a reference model, we can locate events without knowledge of past events. Here, we use ambient seismic noise for such a calibration. We cross-correlate the seismic stations near the earthquake with stations 100-300 km away to obtain the 10-100s surface wave Green's functions. Then the travel times of these surface waves are measured relative to the reference model. The new method is tested in southern California to locate the 2008 Chino Hills earthquake and seismic stations not used in the calibration. A distribution of 5-10 stations with azimuthal gaps less than 120 degrees is sufficient to locate events within a few kilometers.

## 2. Source Mechanism and Rupture Directivity of the $M_W$ 4.6 May 18, 2009 Inglewood, California Earthquake

**Yan Luo, Ying Tan, Shengji Wei, Don Helmberger, Zhongwen Zhan, Sidao Ni, Egill Hauksson, and Yong Chen**

**(*BSSA*, in press)**

**Abstract**

On May 18, 2009, a $M_W$ 4.6 earthquake occurred beneath Inglewood, California and was widely felt. Though source mechanism and its location suggest that the Newport-Inglewood Fault (NIF) may be involved in generating the earthquake, rupture directivity has to be modeled to establish the connection between the fault and the earthquake. We first invert for the event's source mechanism and depth with the Cut And Paste (CAP) method in the long period band (>5s). Because of the shallow sediments in the Los Angeles (LA) basin, we use two velocity models in the inversion for stations inside LA basin and those outside. However, little difference is observed in the resolved source mechanism (Mw4.6, strike 246°/145°, dip 50°/77°, rake 17°/138°) and depth (7~9 km), compared to an inversion using the standard SC model. With the resolved source parameters, we calibrate the amplitude anomaly of the short period (SP) (0.5-2Hz) P-waves with Amplitude Amplification Factors (AAF). These AAFs are used as corrections when retrieving source mechanisms of the smaller aftershocks using SP P-waves alone. Most of the aftershocks show similar source mechanisms as that of the mainshock, providing ideal empirical Green's functions (EGF) for studying its rupture process. We use a forward modeling approach to retrieve rupture directivity of the mainshock, consistent with movement on the NIF with rupture towards the southeast. Although we focus on P-waves for analyzing rupture directivity, the resolved unilateral pattern is also confirmed with the azimuthal variation of the duration of SH waves observed in the basin. The high rupture velocity near the shear velocity and relatively low stress drop is consistent with the hypothesis of rupture on a mature fault.

## 3. Rupture Directivity Characteristics of the 2003 Big Bear Sequence

**Ying Tan and Don V. Helmberger**

**(Published: *Bulletin of the Seismological Society of America*, 100, No. 3, 1089-1106, doi.10.1785/0120090074)**

**Abstract.**

We have developed a forward modeling technique to retrieve rupture characteristics of small earthquakes (3<M<5), including rupture propagation direction, fault dimension, and rupture speed. The technique is based on an empirical Green's function (EGF) approach, where we use data from co-located smaller events as Green's functions to study the bigger events. We tend to chose smaller events with similar focal mechanisms for EGFs; however, we show that the events with different focal mechanisms can work equally well when corrected for radiation pattern effect. Compared to deconvolution, this forward modeling approach allows full use of both the shape and amplitude information produced by rupture propagation. Assuming a simple 1D source model, we parameterize the source time function of a target event as the convolution of two boxcars, featuring the rise time $\tau_r$ and the rupture time $\tau_c$; we solve for $\tau_r$ and $\tau_c$ in a grid search manner by minimizing the waveform misfit between the three-component data and the synthetics constructed from the EGFs. The rupture propagation direction, fault length, and rupture speed can then be estimated by fitting the observed azimuthal pattern of $\tau_c$ from P and S-waves. We apply the approach to the 12 largest events $\left(M_w \geq 3.3\right)$ of the 2003 Big Bear sequence (excluding the mainshock) in southern California. Among them, seven events are found to exhibit robust rupture directivity. The fact that the ruptures of these events propagate in all directions reveals complicated fault geometry at depth. We compute the stress drop $\Delta\sigma \sim \frac{2}{\pi}\frac{M_0}{L^3}$ for each event using the resolved fault length. The results show large variations ranging from ~1 to 90 Mpa, with no dependence on moment. However, $\Delta\sigma$ appears inversely correlated with rupture speed $V_r$; in particular, events with larger $\Delta\sigma$ tend to propagate at smaller $V_r$, whereas events with smaller $\Delta\sigma$ propagate faster.

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