AUXILIARY MATERIALS

Teleseismic inversion for rupture process of the 27 February 2010 Chile (M\textsubscript{w} 8.8) earthquake

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Figure S1. (top) P waves used in the back-projection, aligned and normalized with a multi-channel cross-correlation algorithm (VanDecar and Crosson, 1990). The corresponding station locations are indicated on the map by white dots, while the inset shows the array response function (in decibels) for a frequency of 0.5 Hz. Ideally, this would be a delta function. Further details of the back-projection method and application to other data sets for this event can be found at: http://www.eas.slu.edu/People/KKoper/BP/Chile/index.html.
Figure S2. Time integrated beam power from the back-projection of North American observations. Aftershocks ($m_b \geq 5.0$) occurring within the first three weeks are show with circles and the mainshock epicenter is represented by the star. The lack of beam power in the southern aftershock zone may be due to variable high frequency radiation or an artifact resulting from insensitivity to southward rupture propagation away from the network.
Figure S3. Rayleigh wave short-arc (R1) source time functions (STFs) obtained by deconvolving point-source synthetics computed using the GCMT solution and PREM with corrections for aspherical phase velocity heterogeneity. The STFs are sorted with respect to azimuth from the source, and a Gaussian filter with averaging weight of 0.1 has been applied. The STFs show narrow pulses toward the NW and N, and broader pulses to the south, suggesting asymmetry in the slip distribution relative to the epicenter.
Figure S4. Directivity analysis of the total duration of the R1 STFs (from onset to end), with measurements for the signals in Figure S3 shown as a function of directivity parameter, Gamma = \( \cos(\phi_{sta} - \phi_{rup})/c \), where \( \phi_{sta} \) is the station azimuth, \( \phi_{rup} \) is an assumed unilateral rupture azimuth, and \( c \) is a reference phase velocity (\( c \) is chosen as 4.0 km/s, the phase velocity for 80 s period Rayleigh waves for model PREM). The optimal rupture azimuth is found to be 355°. The total duration estimate must be corrected for a Gaussian filter applied in the deconvolutions, which reduces the estimate by ~60 s. Assuming a 10% rise time for the particle dislocation, a lower bound on the rupture velocity of ~1.7 km/s is found, if the rupture is assumed to be unilateral. Tighter constraints on the rupture velocity are provided by inverting the STF shapes as shown below.
Figure S5. Comparison of observed (black curves) and predicted (red curves) for the finite-fault inversion with rupture velocity $V_r = 2.5 \text{ km/s}$ using teleseismic P and SH observations. The amplitudes are plotted with true relative amplitudes except that the SH amplitudes are reduced by a factor of 5 relative to P wave amplitudes. Each station is identified and the corresponding azimuth from the source is shown.
Figure S6. Comparison of R1 STF observations (gray) and predictions (orange) for the fault model obtained from inversion of P and SH signals. Intra-rupture dispersion is ignored. The STFs are plotted as a function of azimuth from the source. The predictions account for gross aspects of the observations, with narrowing of pulses to the north (including a factor of 2.5 increase in peak amplitude not apparent in the amplitude normalized traces) and long-duration STFs to the south.
**Figure S7.** The waveform fits from the joint inversion of P, SH and R1 STF signals. Data are black lines, synthetics are red lines. The fault model is shown in Figure 3b. A rupture velocity of 2.25 km/s was found to optimize the fit to the R1 STFs. Minor degradation in the fit is found when using a rupture velocity of 2.5 km/s, as indicated by the short-period back-projections. Overall, the first-order features in all the data are captured. Fitting small details in the body waves requires a more flexible model that includes variable time functions, rake, and/or rupture front expansion.
Figure S8. Slip models from the joint inversion of P, SH and R1 STF signals for the data set shown in Figure S7, for varying assumed rupture velocity. The geometry of the faulting is the same in all cases and is indicated by the focal mechanism at the lower right. The assumed rupture velocity, maximum slip estimate and residual waveform power are indicated for models with rupture velocities of (a) 1.75 km/s, (b) 2.0 km/s, (c) 2.25 km/s, (d) 2.5 km/s and (e) 2.75 km/s. The slip distributions stretch in length proportional to the rupture velocity. The contours indicate slip strength relative to the maximum with darker regions having larger slip. The preferred model is for \( V_r = 2.25 \) km/s.
Figure S9. Plot of the percent of the signal power fit by inversions of P+SH+R1 STFs in Figure S8 for a range of rupture velocities. The best formal fit occurs for a rupture velocity of 2.25 km/s, but that is marginally better than for 2.0 km/s. Careful study of the misfit at CASY and SNZO R1 STFs, which show strong directivity effects, indicates that rupture speeds of 2.00 or 2.25 km/s fit those signals observably better. Considering the uncertainty in the data, the Green's functions, and the model parameterization leads us to favor a rupture velocity in the range of 2.00 to 2.5 km/s.
Figure S10. Finite-fault slip patterns from inversions of P and SH data for various inversion constraints and parameters. All inversions except for (e) use the P and SH data set shown in Figure S5. (a) The preferred solution with \( V_r = 2.5 \text{ km/s}, \) fault dip = 18°, centroid depth \( H = 35 \text{ km}. \) The source time function centroid, \( t_c = 66 \text{ s}, \) and the residual waveform variance (var.) is 0.115. The waveform fits for this case are shown in Figure S5. Waveform fits for the other solutions here with comparable value of var. are not dramatically different, so are not shown. (b) Solution with variable fault dip from 10.5° at the shallowest row to 22.5° at the deepest row. (c) Solution with dip = 12°. The waveform fit is significantly degraded (var. = 0.159). (d) Solution with all parameters the same as in (a), except a centroid depth of 30 km. (e) Solution for a P wave data set of 55 stations using the same parameters as (a). The value of var. is reduced relative to (a) because the P waveforms are better fit in general than the SH waveforms. (f) Solution for the same parameters as in (a), except \( V_r = 2.0 \text{ km/s} \) and the grid is re-scaled proportionately.
Figure S11. Finite-fault slip patterns from inversions of P and SH data for various subfault source time function parameters. All inversions use the P and SH data set shown in Figure S5. 

(a) The preferred solution with $V_r = 2.5$ km/s, with subfault source functions comprised of $N = 5$ triangles with rise times, $T_1 = 2.5$ s and shifts of $dT = 2.5$s. The source time function centroid, $t_c = 66$ s. The waveform fits for this case are shown in Figure S5. All solutions fit the data about the same visually, so the waveform fits are only shown for this case. 

(b) Solution with $T_1 = 3$ s, $dT = 3$ s. 

(c) Solution with $T_1 = 3.5$ s, $dT = 3.5$ s. 

(d) Solution with $T_1 = 4.0$ s, $dT = 4.0$ s. 

(e) Solution with $T_1 = 4.5$ s, $dT = 4.5$ s. 

(f) Solution with $T_1 = 5.0$ s, $dT = 5.0$ s. 

Note the stability of the slip distributions even for doubling of the subfault rupture durations. Shorter subfault rupture durations are preferred because they agree better with the observed centroid time (61.4 s) and give comparable fits with fewer degrees of freedom.
**Movie S1.** Animation of the aftershock sequence from February 27 to March 28, 2010. The red dots indicate epicenters from the US Geological Survey, scaled proportional to seismic magnitude. The animation allows event locations to fade out after 48 hours so that the time evolution of the sequence is clear.

http://es.ucsc.edu/~thorne/GRL_CHILE_LAKKSH/LAKKSH_Movie.S1.mov

[H.264 Encoded QuickTime Movie; ~4.5 MB].
**Movie S2.** Animation of the time sequence of back-projections of P-waves from 49 North American stations to a grid around the Chile source region. The left panel shows results for actual data, the right panel shows results for synthetics at the same stations predicted for the preferred finite fault model obtained from inversion of data at all azimuths. The waveforms are shifted to each grid position with lags appropriate for their propagation distances, and the 4th root stack of the 0.2-2.0 Hz bandpass signals is computed. The peak value of the stack at each time instance is shown at the top, with a marker indicating the time step for which the map plots the relative beam power over the grid.

http://es.ucsc.edu/~thorne/GRL_CHILE_LAKKSH/LAKKSH_Movie.S2.mpg

[H.264 Encoded QuickTime mpg; ~2.2 MB].
**Movie S3.** Animation of the cumulative slip on the source model grid for the $V_r=2.5$ km/s rupture inversion of teleseismic P and SH waves. Darker amplitudes represent larger cumulative slip. The expanding circles indicate the kinematically activated portion of the rupture bounded by the outer circle with 2.5 km/s rupture and a 15 s later circle defined by the 15 s subfault total rupture duration.


[H.264 Encoded QuickTime Movie; ~1.4 MB].
**Movie S4.** Animation of the moment-rate history on the source model grid for the $V_r=2.5$ km/s rupture inversion of teleseismic P and SH waves. Darker amplitudes represent larger cumulative slip. The expanding circles indicate the kinematically activated portion of the rupture bounded by the outer circle with 2.5 km/s rupture and a 15 s later circle defined by the 15 s subfault total rupture duration.


[H.264 Encoded QuickTime Movie; ~1.3 MB].
Auxiliary References