Modeling tsunami observations to evaluate a proposed late tsunami earthquake stage for the 16 September 2015 Illapel, Chile, $M_W$ 8.3 earthquake

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Introduction

Supporting information includes 12 figures and 2 animations.
**Figure S1.** The main stage source model for the 16 September 2015 $M_W$ 8.3 Illapel, Chile, earthquake from inversion of P and SH waves. The fault model has a strike, $\phi = 5^\circ$, dip $\delta = 15^\circ$ and average rake $\lambda = 95.8^\circ$. (a) The moment rate function for the finite fault slip distribution, with seismic moment $M_0$, $M_W$, centroid time $T_c$, and total duration $T_d$ being shown. Each subfault is parameterized with 7 3.0 s rise-time triangles shifted by 3.0 s, with rake allowed to vary for each triangle. (b) Far-field source spectrum for the event, with the spectrum of the moment rate function in (a) used for frequencies less than 0.05 Hz, and logarithmically averaged P-wave displacement spectra corrected for radiation pattern, geometric spreading, and attenuation used for frequencies from 0.05 to 2.0 Hz. A reference $\omega^2$-squared spectrum with the same moment and a stress parameter of 3 MPa is shown by the dashed line. The broadband radiated energy $E_r$ and moment-scaled radiated energy $E_r/M_0$ are shown. (c) Finite-fault slip distribution with the slip color-coded and indicated by the vectors in each subfault, along with the subfault source time functions. (d) P and SH radiation patterns and lower hemisphere data sampling for waveforms used in the inversion for the average focal mechanism. Corresponding waveform matches are shown in Figure S2.
Figure S2. Comparison of observed (black lines) and computed (red lines) P-wave and SH-wave broadband ground displacement waveforms for the finite-fault model in Figure S1 for the main stage rupture process of the 2015 Illapel earthquake. The azimuth and distance of each station is shown below the station name. The blue numbers indicate the peak-to-peak amplitude of the observed signals in microns.
Figure S3. Similar to Figure 1, showing bilateral models and corresponding seafloor uplift for (a) Case III, with uniform slip of 5.43 m over a 30 km (2-row) width, (b) Case IV, with uniform slip of 3.62 m over a 45 km (3-row) width, and (c) Case V, with a two-asperity slip distribution with slip of 8.69 m in the asperities and 2.17 m elsewhere.
Figure S4. Comparison of observations (black lines) with computed tsunami waveforms (red lines) from the main stage (Figure 1a) plus Case III bilateral tsunami earthquake model (Figure S3a) at water-level stations. (a) Regional DART stations. (b) Local tide gauges. Good agreement of both amplitude and phase at the DART stations could be achieved by a number of model grids, but only models with slip constrained to be north of the hypocenter match the first arrivals at the tide gauges. Horizontal arrowheads indicate amplitude mismatches and vertical arrowheads indicate timing mismatches.
Figure S5. Comparison of observations (black lines) with computed tsunami waveforms (red lines) from the main stage (Figure 1a) plus Case IV bilateral tsunami earthquake model (Figure S3b) at water-level stations. (a) Regional DART stations. (b) Local tide gauges. Good agreement of both amplitude and phase at the DART stations could be achieved by a number of model grids, but only models with slip constrained to be north of the hypocenter match the first arrivals at the tide gauges. Horizontal arrowheads indicate amplitude mismatches and vertical arrowheads indicate timing mismatches.
Figure S6. Comparison of observations (black lines) with computed tsunami waveforms (red lines) from the main stage (Figure 1a) plus Case V bilateral tsunami earthquake model (Figure S3c) at water-level stations. (a) Regional DART stations. (b) Local tide gauges. Good agreement of both amplitude and phase at the DART stations could be achieved by a number of model grids, but only models with slip constrained to be north of the hypocenter match the first arrivals at the tide gauges. Horizontal arrowheads indicate amplitude mismatches and vertical arrowheads indicate timing mismatches.
Figure S7. Similar to Figure 1, showing unilateral northward models and corresponding seafloor uplift for (a) Case VI, with uniform slip of 9.5 m over a 30 km (2-row) width, (b) Case VII, with uniform slip of 6.34 m over a 45 km (3-row) width, and (c) Case VIII, with a single-asperity slip distribution with slip of 15.2 m in the asperities and 3.8 m elsewhere.
Figure S8. Comparison of observations (black lines) with computed tsunami waveforms (red lines) from the main stage (Figure 1a) plus Case VI bilateral tsunami earthquake model (Figure S7a) at water-level stations. (a) Regional DART stations. (b) Local tide gauges. Good agreement of both amplitude and phase at the DART stations could be achieved by a number of model grids, but only models with slip constrained to be north of the hypocenter match the first arrivals at the tide gauges. Horizontal arrowheads indicate amplitude mismatches and vertical arrowheads indicate timing mismatches.
Figure S9. Comparison of observations (black lines) with computed tsunami waveforms (red lines) from the main stage (Figure 1a) plus Case VII bilateral tsunami earthquake model (Figure S7b) at water-level stations. (a) Regional DART stations. (b) Local tide gauges. Good agreement of both amplitude and phase at the DART stations could be achieved by a number of model grids, but only models with slip constrained to be north of the hypocenter match the first arrivals at the tide gauges. Horizontal arrowheads indicate amplitude mismatches and vertical arrowheads indicate timing mismatches.
Figure S10. Comparison of observations (black lines) with computed tsunami waveforms (red lines) from the main stage (Figure 1a) plus Case VIII bilateral tsunami earthquake model (Figure S7c) at water-level stations. (a) Regional DART stations. (b) Local tide gauges. Good agreement of both amplitude and phase at the DART stations could be achieved by a number of model grids, but only models with slip constrained to be north of the hypocenter match the first arrivals at the tide gauges. Horizontal arrowheads indicate amplitude mismatches and vertical arrowheads indicate timing mismatches.
Figure S11. A source model for the 16 September 2015 $M_W$ 8.3 Illapel, Chile, earthquake from inversion of only P waves with signal durations of 200 s at distances greater than 65° to avoid PP entering the data window. The fault model has a strike, $\phi = 5^\circ$, dip $\delta = 15^\circ$ and average rake $\lambda = 95.8^\circ$. (a) The moment rate function for the finite fault slip distribution, with seismic moment $M_0$, $M_W$, centroid time $T_c$, and total duration $T_d$ being shown. Each subfault is parameterized with 7 3.0 s rise-time triangles shifted by 3.0 s, with rake allowed to vary for each triangle. (b) Far-field source spectrum for the event, with the spectrum of the moment rate function in (a) used for frequencies less than 0.05 Hz, and logarithmically averaged P-wave displacement spectra corrected for radiation pattern, geometric spreading, and attenuation used for frequencies from 0.05 to 2.0 Hz. A reference $\omega$-squared spectrum with the same moment and a stress parameter of 3 MPa is shown by the dashed line. The broadband radiated energy $E_r$ and moment-scaled radiated energy $E_r/M_0$ are shown. (c) Finite-fault slip distribution with the slip color-coded and indicated by the vectors in each subfault, along with the subfault source time functions. (d) P and SH radiation patterns and lower hemisphere data sampling for waveforms used in the inversion for the average focal mechanism. Corresponding waveform matches are shown in Figure S12.
Figure S12. Comparison of observed (black lines) and computed (red lines) P-wave broadband ground displacement waveforms for the finite-fault model in Figure S11 for the main stage rupture process up to 95 s of the 2015 Illapel earthquake inverted from only P waves at distances greater than 65°. The azimuth and distance of each station is shown below the station name. The blue numbers indicate the peak-to-peak amplitude of the observed signals in microns. Note that the reverberations from 100-200 s, which Lee et al.
attribute to the late stage tsunami earthquake are largely accounted for by water reverberations generated by the main state rupture, even using 1D Green's functions.

Animations

**M1** – QuickTime .mov animation with H.264 compression showing the sea-surface amplitude from the tsunami wave generated by (left) main stage rupture, (middle) bilateral tsunami earthquake model Case I, and (right) combined tsunami computed for both models together.

**M2** – QuickTime .mov animation with H.264 compression showing the sea-surface amplitude from the tsunami wave generated by (left) main stage rupture, (middle) unilateral tsunami earthquake model Case II, and (right) combined tsunami computed for both models together.