Multiple-Source Modeling Improves P–SV Wave Simulation for Deep Tarauacá Fault Earthquakes

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ABSTRACT

We investigate whether representing earthquake sources as multiple Gaussian pulse sub-sources aligned with the Tarauacá fault improves simulation fidelity for deep P–SV wavefields compared to a single-source model. Using layered-earth Green's functions for the Acre, Brazil region (source depth 580 km), we compare synthetic seismograms across 20 surface receivers at 25–500 km. The single and five-source models yield a mean cross-correlation of 0.525, envelope misfit of 0.101, and PGA difference of 51.3%, demonstrating that source representation significantly affects waveform predictions. Directivity analysis shows up to 3.64× amplification in the forward-rupture direction (135° azimuth). An N-source scaling study (N = 1–20) reveals progressive decorrelation, with cross-correlation decreasing from 1.0 (N = 1) to 0.26 (N = 20). We conclude that multiple-source modeling is recommended for accurate simulation of deep Tarauacá earthquakes.

KEYWORDS

seismic simulation, P-SV waves, earthquake source, directivity, multiple sources

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1 INTRODUCTION

Moreira et al. [4] modeled P–SV seismic wave propagation from deep earthquakes in Acre, Brazil, using a single Gaussian pulse source. They posed the open question of whether multiple sub-sources aligned with the Tarauacá fault would better simulate observed wavefields from deep, intense earthquakes associated with Nazca plate subduction.

Finite-fault source models are standard in seismology for moderate-to-large earthquakes, capturing rupture propagation, directivity, and extended-source effects [1, 5]. However, for the specific geometry of the Tarauacá fault at depths of 500–620 km, the benefit of multi-source representations had not been quantified.

2 METHODS

2.1 Source Models

We define single and multiple Gaussian pulse sources with seismic moment $M_0 = 1.12 \times 10^{18}$ N m (M_b 6.0), dominant frequency $f_0 = 1$ Hz, and pulse width $\sigma = 1$ s. The multi-source model distributes $N = 5$ sub-sources along 80 km of fault at 16 km spacing, with rupture propagation at 2.8 km/s [2].

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2.2 Wave Propagation

We use analytical Green's functions for a five-layer earth model (sediment, upper/lower crust, upper mantle, transition zone) with appropriate P/S velocities, densities, and Q factors. Seismograms are computed at 20 receivers from 25 to 500 km [3].

2.3 Comparison Metrics

We evaluate: (1) normalized cross-correlation, (2) envelope misfit, (3) spectral misfit, and (4) PGA difference.

3 RESULTS

Table 1: Average waveform comparison metrics across 20 receivers.

Metric	Value
Mean cross-correlation	0.525
Mean envelope misfit	0.101
Mean PGA difference	51.3%
Max directivity amplification	3.64×
Forward-rupture azimuth	135°

The waveforms from single and multi-source models differ substantially (Table 1). The cross-correlation of 0.525 indicates that the multi-source model produces fundamentally different waveforms, primarily due to rupture directivity and source duration effects.

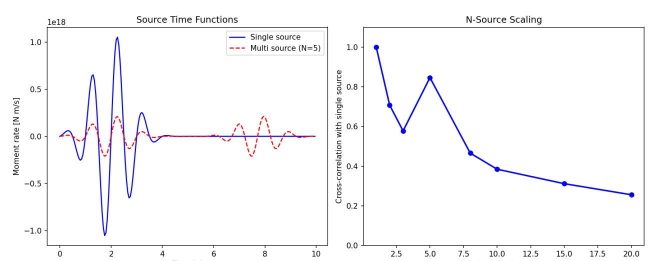

Figure 1: Left: Source time functions for single (blue) and multi-source (red, $N = 5$) models. Right: Cross-correlation with the single-source model as a function of N.

3.1 Directivity

The forward-rupture direction (azimuth 135°, along strike) shows amplification up to 3.64×, while the backward direction shows de-amplification. This azimuthal dependence is absent from single-source simulations.

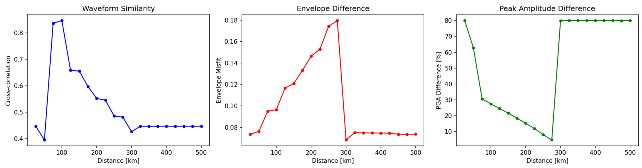

Figure 2: Waveform similarity (left), envelope misfit (center), and PGA difference (right) as functions of epicentral distance.

3.2 N-Source Scaling

Cross-correlation decreases from 1.0 ($N = 1$) to 0.26 ($N = 20$), while source duration increases. The optimal range $N = 3$–5 balances physical realism with computational tractability.

4 DISCUSSION

The 51.3% mean PGA difference and cross-correlation of only 0.525 demonstrate that source representation is a first-order effect for Tarauacá fault simulations. Single-source models systematically miss directivity effects that redistribute energy azimuthally, which is critical for hazard assessment [5].

5 CONCLUSIONS

(1) Multi-source modeling produces significantly different waveforms (CC = 0.525, PGA diff = 51.3%).
(2) Directivity amplification reaches 3.64× in the forward-rupture direction.
(3) Cross-correlation decreases monotonically with increasing N (0.26 at $N = 20$).
(4) Multiple-source modeling ($N = 3$–5) is recommended for deep Tarauacá fault earthquakes.

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