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Engineering attributes of ground motions from the August 2026

San José del Palmar, Colombia, earthquake

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Abstract

The 10 August 2026 M_w 7.4 San José del Palmar earthquake provides an unusually dense strong-motion dataset for a large intraslab earthquake in Colombia, where previous $M_w \geq 7$ events are represented by only a few recordings. We compile and quality-control recordings from the Colombian Geological Survey and local networks and characterize peak ground acceleration (PGA), spectral acceleration, peak ground velocity (PGV), Arias intensity (AI), cumulative absolute velocity (CAV), and significant duration. The observations are compared with global and regional subduction ground-motion models (GMMs), including a northern South America model. The regional model more closely reproduces the first-order attenuation of the spectral intensity measures, while conditional models for PGV, AI, and CAV provide consistent descriptions of the corresponding non-spectral measures. Significant durations are systematically longer than model predictions and than comparable Japanese intraslab recordings. The motions also exhibit azimuthal directionality: amplitudes are generally larger toward the southwest, whereas durations are shorter in the same sector. The preferred direction for $S_a(1.0\text{ s})$ is stable across alternative residual formulations and aligned with the independently inferred southwestward finite-fault rupture direction, supporting a source-directivity contribution, while shorter-period motions appear to reflect a combination of source and regional propagation effects. Finally, distance- and direction-detrended residuals are spatially interpolated to develop event-specific ground-motion fields for engineering and post-earthquake applications.

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1 Introduction

The 10 August 2026 M_w 7.4 San José del Palmar earthquake occurred at intermediate depth beneath western Colombia. The Colombian Geological Survey (Servicio Geológico Colombiano, SGC) reports a hypocentral depth of 103 km (Servicio Geológico Colombiano (SGC), 2026), consistent with independent global solutions of approximately 103–108 km. The event is consistent with intraslab seismicity associated with subduction beneath the northern Andes. Figure 1 shows the earthquake location and a cross section of the subducting slab based on the Slab2 model of Hayes et al. (2018). The closest large historical intraslab event to the 2026 earthquake was the 1975 M_w 7.2 earthquake, whose epicenter was also located in western Colombia near the recent event and at a similar depth, although no strong-motion time histories are known to be available. According to SGC reports, the 1975 earthquake caused damage in several Colombian cities, but the documentation is limited. The 2026 earthquake likewise produced damaging shaking in major urban areas, including Cali, Pereira, and Manizales. The 2026 event was recorded by the SGC strong-motion network and by local instrumentation in Cali (CAL), Manizales (MAN), Pereira (PER), and Bogotá (BOG).

A reviewed finite-fault inversion by the U.S. Geological Survey (USGS) National Earthquake Information Center (NEIC) (U.S. Geological Survey, National Earthquake Information Center, 2026) indicates rupture on a single, steeply dipping oblique-slip plane with strike 225.6° , dip 71.8° , and rake 33.2° (Figure 2a). Rupture nucleated near the northeastern, downdip portion of the modeled fault and propagated predominantly southwestward and updip. Maximum slip was approximately 4.0 m and occurred at a depth of about 96.5 km, substantially shallower and southwest of the finite-fault hypocenter. The inversion therefore indicates a strongly asymmetric rupture geometry.

The finite-fault geometry is also important for defining source-to-site distance measures used in ground-motion models (GMMs). Approximating rupture distance solely from hypocentral distance, as is sometimes done in engineering applications when finite-fault information is unavailable, would be particularly misleading for stations southwest of the hypocenter. We therefore used the finite-fault model to evaluate rupture, hypocentral, and epicentral distances (Figure 2b–d). The differences among these metrics are substantial at several locations. For example, Cali lies at a hypocentral or epicentral distance of approximately 175–220 km, whereas its rupture distance is only about 120–130 km. Ground motions were recorded at rupture distances of approximately 100–

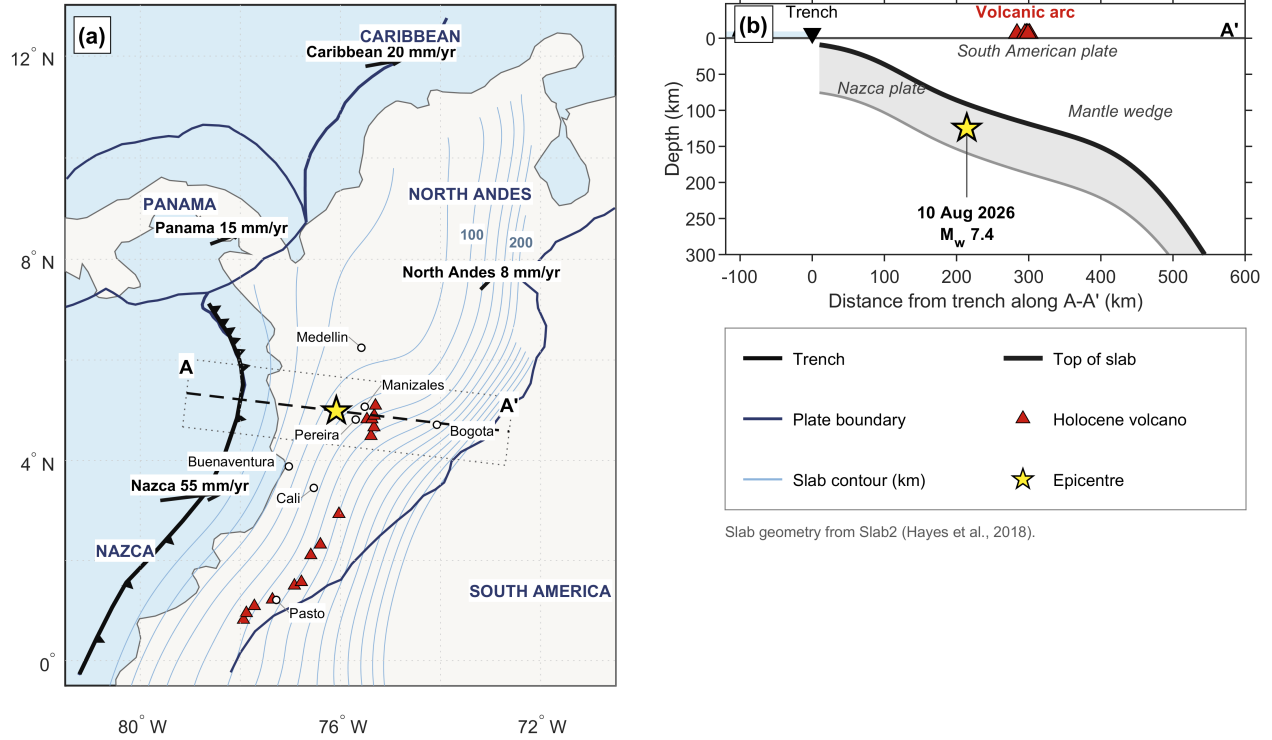


Figure 1: Tectonic setting of the 10 August 2026 M_w 7.4 San José del Palmar intraslab earthquake, northwestern Colombia. (a) Regional plan view, (b) Cross section along A–A'. The heavy black line is the top of the slab and the grey line is its base, both from Slab2, with the slab shaded.

110 km in Manizales, Pereira, and Armenia; about 95 km in parts of Valle del Cauca; 120–130 km in Cali; approximately 225–235 km in Bogotá; approximately 110 km in the Buenaventura area toward the Pacific coast; and approximately 300 km in the Pasto area south of the source. The recordings therefore provide broad spatial coverage of the shaking generated by this intermediate-depth intraslab earthquake.

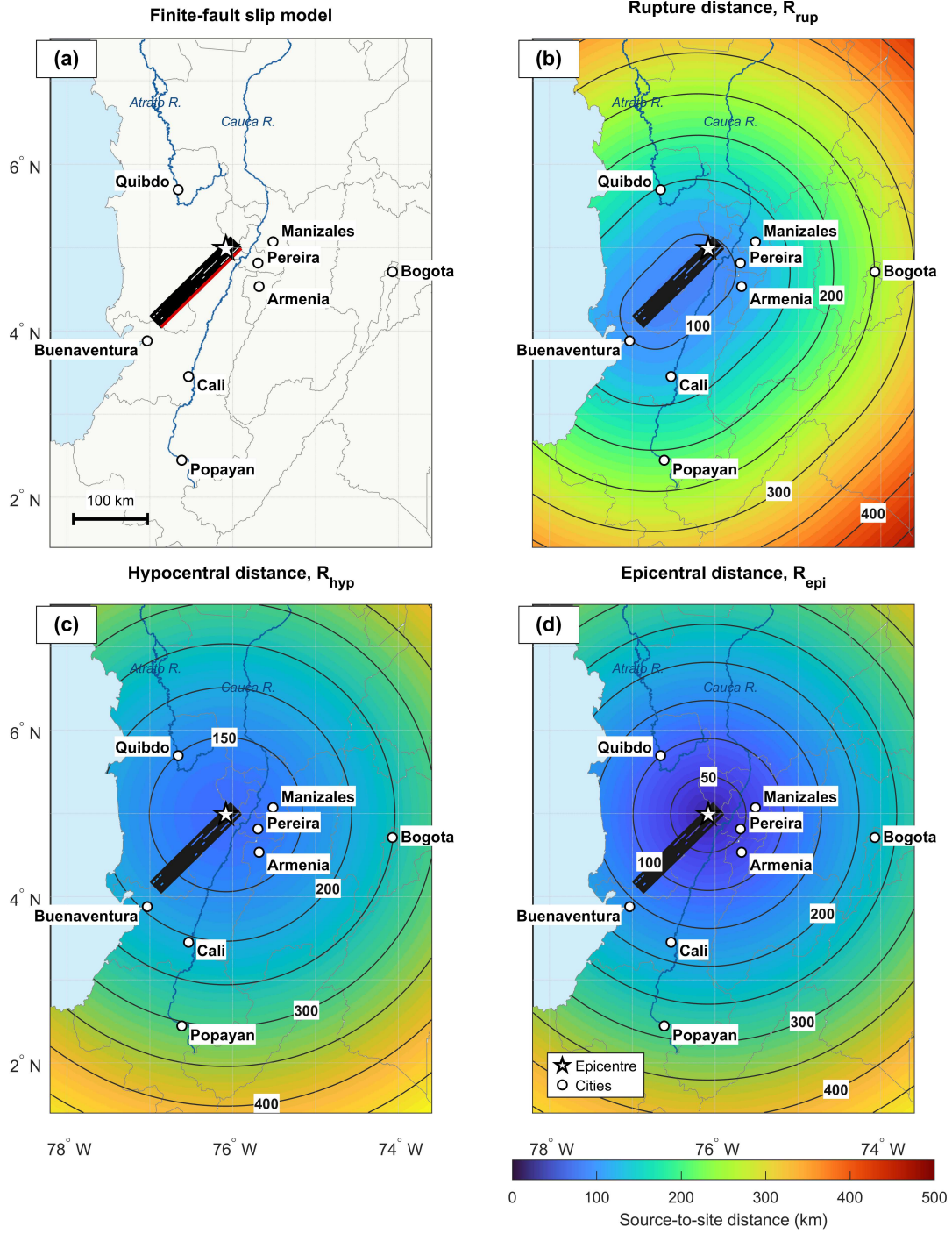


Figure 2: Finite-fault geometry and source-to-site distance measures for the 10 August 2026 M_w 7.4 San José del Palmar intraslab earthquake. (a) Surface projection of the USGS finite-fault solution, including the finite-fault hypocenter and maximum-slip location. (b) Rupture distance, R_{rup} . (c) Hypocentral distance, R_{hyp} . (d) Epicentral distance, R_{epi} . Department boundaries, major rivers, and selected cities are shown for geographic reference.

bian intraslab earthquakes was assembled by SGC and [Arteta et al. \(2022\)](#). That database contains only a limited number of recordings from large intraslab events, including two recordings from M_w 7.0 events and two from M_w 7.2 events. The 2026 M_w 7.4 San José del Palmar earthquake therefore provides an unusually large set of instrumental observations from a major Colombian intraslab event and offers an important opportunity to improve the characterization of intraslab ground motions in the region.

In this study, we examine the engineering characteristics of ground motions recorded during the M_w 7.4 San José del Palmar earthquake, with emphasis on intensity measures (IMs) relevant to ongoing post-earthquake reconnaissance and seismic-hazard applications. We first describe the available recordings and the processing procedures used to obtain a quality-controlled waveform dataset. We then evaluate the observed attenuation of peak ground acceleration (PGA), spectral acceleration at 0.2 and 1.0 s [$S_a(0.2\text{ s})$ and $S_a(1.0\text{ s})$], peak ground velocity (PGV), Arias intensity (AI), and cumulative absolute velocity (CAV), and compare the observations with GMMs applicable to subduction intraslab earthquakes. Given the unprecedented number of recordings and spatial coverage of the 2026 dataset for Northern South America, these comparisons provide insights on the performance of existing subduction intraslab GMMs. We further investigate azimuthal directionality and possible rupture-directivity effects associated with the finite-fault geometry. Finally, spatially continuous estimates of selected IMs are developed using kriging to support post-earthquake assessments at locations without recordings. A flatfile containing the ground-motion parameters is made available, together with raster files for estimating the intensity measures discussed in this study from the 2026 M_w 7.4 San José del Palmar earthquake.

2 Analysis of ground motion data

2.1 Ground-motion recordings and processing

Figure 3 shows the seismic stations considered in this study, grouped around the principal urban areas of interest, including Cali, Manizales, Pereira, Armenia, and Bogotá. Only one recording is available in Buenaventura and only few recordings north from Quibdó.

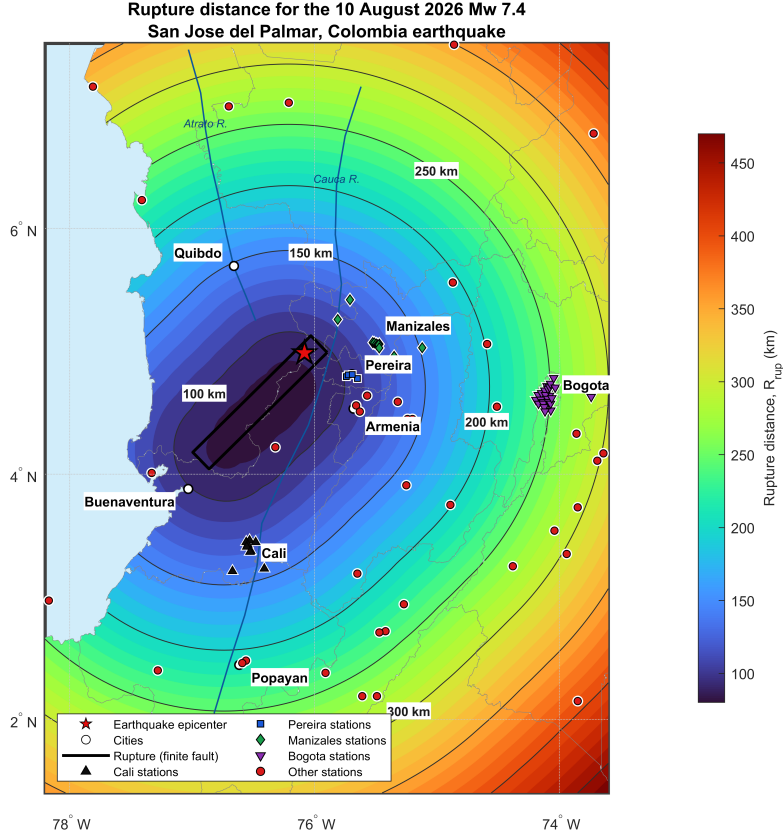


Figure 3: Strong-motion stations that recorded the 2026 San José del Palmar earthquake.

Each three-component record was processed individually following procedures consistent with the Next Generation Attenuation for Subduction Regions (NGA-Sub) project (Bozorgnia et al., 2022). Processing included baseline correction and high- and low-pass Butterworth filtering, with corner frequencies selected from signal-to-noise-ratio (SNR) evaluations relative to a pre-event noise window. The electronic supplement presents the processing results for all stations. For the SGC stations, noise characteristics were evaluated directly from the MiniSEED waveforms using portions of the records outside the principal strong-motion interval. Of the 88 SGC records, RAC2C was discarded because the acceleration time history was truncated, whereas CLBC was excluded because an adequate SNR could not be obtained (Figure 4). Three additional stations, RAC03, JAMC, MAN1C required station-specific processing because of identifiable waveform anomalies, Figure 5, illustrates the issues in RAC03 and JAMC. At RAC03, all three components exhibit a simultaneous, same-sign low-frequency excursion between approximately 65 and 87 s that produces nonphysical velocity and displacement upon integration. The common behavior of the three orthogonal com-

ponents suggest an instrumental or electronic transient. The anomalous low-frequency component was isolated within a 60–90 s window using a rank-1 decomposition of the three-component motion and only this common-mode contribution was removed, with smooth blending at the limits of the correction window. The final record was then processed using a 0.30–25 Hz fourth-order zero-phase Butterworth band-pass filter. Sensitivity analyses indicate that PGA and spectral ordinates through approximately 1.5 s are comparatively insensitive to reasonable variations in the high-pass corner, whereas results beyond approximately 2 s are increasingly processing dependent. Additional details are provided in the electronic supplement.

At JAMC, frequency-band analysis revealed an abrupt increase in cross-component correlation above approximately 15 Hz during strong shaking. In particular, the nominally orthogonal components approach near-copy or mirror behavior in the 20–25 Hz band. Because the available metadata do not identify a unique instrumental mechanism, the affected high-frequency content was treated as non-robust rather than explicitly corrected. JAMC was retained as conditionally usable after applying a 0.20–15 Hz fourth-order zero-phase Butterworth band-pass filter. The choice of the 15-Hz low-pass corner substantially reduces the anomalous very-short-period content while leaving response spectral ordinates essentially unchanged for periods greater than approximately 0.15 s. Further processing diagnostics and sensitivity analyses are presented in the electronic supplement.

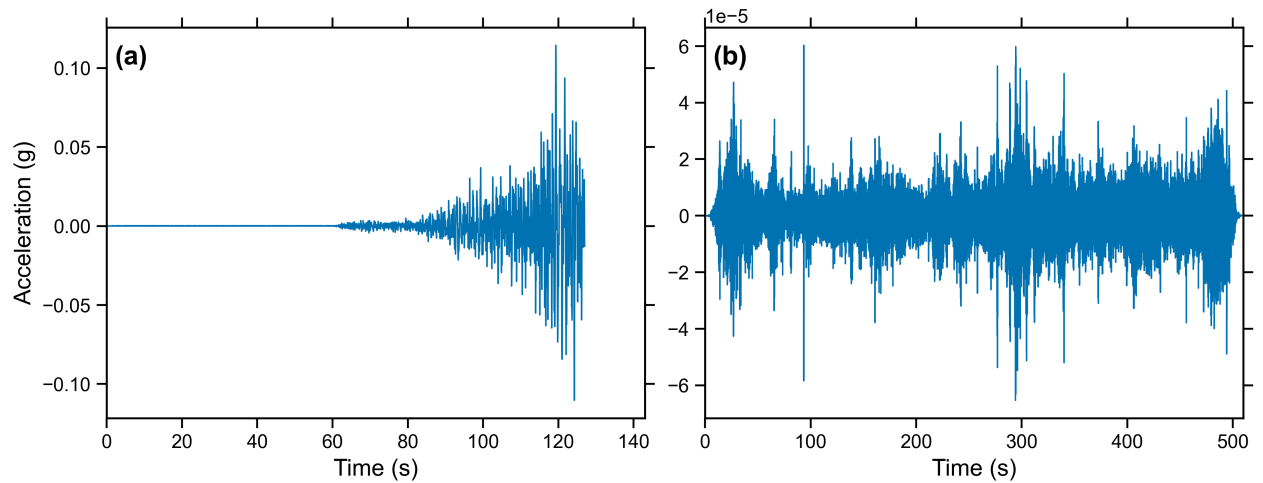


Figure 4: Horizontal (H1) acceleration time histories for (a) RAC2C and (b) CLBC stations.

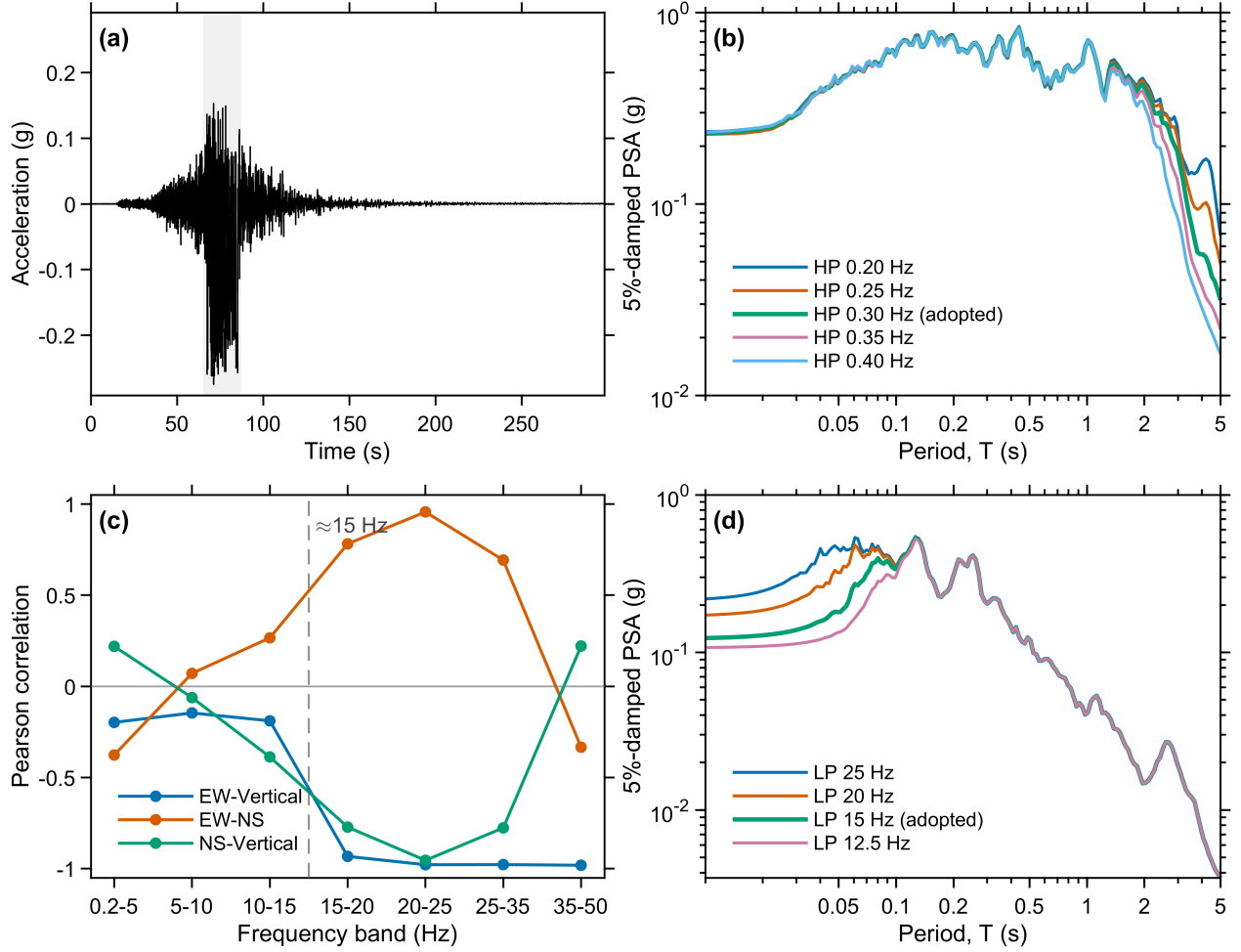


Figure 5: Processing diagnostics for stations requiring additional quality-control evaluation. (a) Representative raw RAC03 acceleration time history, showing the nonphysical low-frequency excursion between approximately 65 and 87 s. (b) Sensitivity of the RAC03 corrected motion to the selected high-pass corner, illustrating increased uncertainty at longer periods. (c) Frequency-band cross-component correlations for JAMC, showing an abrupt increase in coherence above approximately 15 Hz during strong shaking. (d) Sensitivity of the JAMC response spectra to the adopted low-pass corner; differences are concentrated at very short periods, whereas the spectra are comparatively stable for periods greater than approximately 0.15 s. Additional processing details are provided in the electronic supplement.

114 Additional recordings were obtained from local strong-motion networks in several Colombian
 115 cities. For these records, MiniSEED files were unavailable; consequently, noise-window selection was
 116 based on the available waveform duration and the earthquake origin time as the common temporal
 117 reference. Four additional recordings are available in Pereira and 15 in Manizales. At stations
 118 MUCC and CPALE in Manizales, only one horizontal component and the vertical component were
 119 recorded.

In Cali, the local network provides two additional free-field recordings, RAC03 and COALA, and one recording at JARC, located beneath a building without a basement. Four additional building recordings were digitized from [Salazar et al. \(2026\)](#). Because the original digital waveforms were not available, the digitized time histories were checked against the response spectra reported by [Salazar et al. \(2026\)](#); agreement was considered adequate for their inclusion. In Bogotá, 23 records were processed. These motions generally exhibit low amplitudes ($\text{PGA} < 0.02g$), consistent with the larger source-to-site distances.

Site conditions were characterized using the time-averaged shear-wave velocity in the upper 30 m, V_{S30} , together with the fundamental period, T_n , and peak amplitude, P^* , of the horizontal-to-vertical spectral ratio (HVSr), following the site-classification framework adopted for Colombia by [Mercado et al. \(2024\)](#) and [Mercado et al. \(2023\)](#). Where direct V_{S30} measurements or station-specific microtremor measurements were available, those values were used. Measured V_{S30} values were provided by SGC, and [Mercado et al. \(2024\)](#) report measured values of T_n and P^* for a subset of stations.

Where measured V_{S30} values were unavailable, they were estimated from the Colombia-wide V_{S30} model developed by SGC ([Eraso and Montejo, 2019](#)). Where direct measurements of T_n and P^* were unavailable, values inferred from low-intensity ground motions following [Mercado et al. \(2024\)](#) and [Arteta et al. \(2021\)](#) were adopted. The resulting T_n and P^* values were used to assign the corresponding site category ($s1$ – $s5$) following the classification of [Arteta et al. \(2021\)](#). Figure 6 shows the distributions and ranges of the recorded PGA, $S_a(0.2\text{ s})$, $S_a(1.0\text{ s})$, PGV, AI, and CAV.

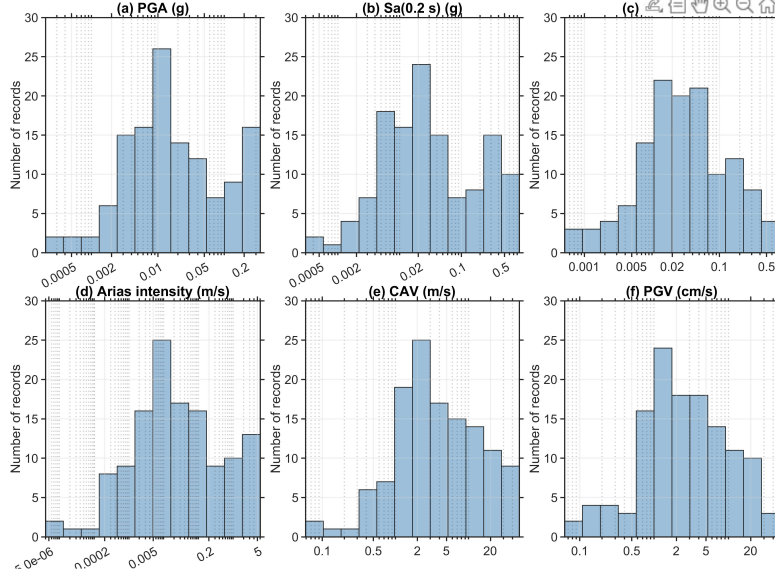


Figure 6: Distributions of selected ground-motion intensity measures recorded during the 10 August 2026 M_w 7.4 San José del Palmar earthquake: (a) PGA, (b) $S_a(0.2\text{ s})$, (c) $S_a(1.0\text{ s})$, (d) AI, (e) CAV, and (f) PGV.

2.2 Comparison with ground-motion models

The recorded IMs are compared with predictions from recently developed GMMs for subduction intraslab earthquakes. Spectral IMs are evaluated using three NGA-Sub models: Abrahamson and Gülerce (AG2020; [Abrahamson and Gülerce, 2022](#)), Parker et al. (PSBAH20; [Parker et al., 2022](#)), and Kuehn–Bozorgnia–Campbell–Gregor (KBCG20; [Kuehn et al., 2023](#)). Two regional models are also considered: the Chilean model of [Macedo et al. \(2026\)](#) (MLA2026), representative of southern South America, and the northern South America model of [Arteta et al. \(2021\)](#) (AEA2021), developed using recordings from Colombia and Ecuador.

For non-spectral IMs, Arias intensity and CAV are evaluated using the conditional models of [Macedo et al. \(2019\)](#) (MAB2019) and [Liu and Macedo \(2022a\)](#), respectively. Both condition their median predictions on PGA and $S_a(1.0\text{ s})$, in addition to magnitude and site parameters; therefore, the corresponding AEA2021 predictions are used as conditioning IMs. PGV is evaluated using the conditional model of [Liu and Macedo \(2022b\)](#), conditioned on $S_a(T_{\text{PGV}})$, where T_{PGV} is magnitude dependent, with the corresponding spectral ordinate obtained from AEA2021. This formulation allows the regional spectral scaling represented by AEA2021 to propagate into the conditional predictions of AI, CAV, and PGV. The non-conditional PGV model of [Liu and Macedo \(2022b\)](#) is

also considered for comparison. Finally, significant duration, D_{5-95} , is evaluated using the GMM of Pinilla-Ramos and Abrahamson (2024) (PA2024). Figures 7(a) and 7(b) compare the observed PGA distance scaling with predictions from the global and South America regionalized versions of the NGA-Sub models and from MLA2026. The NGA-Sub models were developed with comparatively limited data from northern South America, particularly for large-magnitude intraslab earthquakes. This limitation is especially relevant for Colombia, where previous $M_w > 7$ intraslab events are sparsely represented in the strong-motion database. For example, the 2012 $M_w 7.2$ La Vega, Cauca, earthquake, the largest Colombian intraslab event included in the AEA2021 database, is represented by only four recordings (Arteta et al., 2021); the 2013 $M_w 7.0$ Guaitarilla earthquake is similarly represented by four recordings. The $M_w 7.4$ San José del Palmar earthquake is therefore, to our knowledge, the first densely recorded $M_w > 7$ intraslab earthquake in Colombia, providing a unique regional dataset for evaluating the magnitude and distance scaling of GMMs in a range that was poorly constrained by previous Colombian observations.

To facilitate comparison of median distance scaling, the NGA-Sub and MLA2026 models in Figures 7(a) and 7(b) are evaluated for a common $V_{S30} = 450$ m/s. The global NGA-Sub models and the globally constrained MLA2026 branch generally predict higher PGA than observed over much of the distance range [Figure 7(a)]. Differences among the regionalized models are more evident in Figure 7(b). The South America versions of AG2020 and KBCG20 remain comparatively high, whereas the South America version of PSBAH20 predicts lower median PGA, although generally near the upper range of the observations.

Figures 7(c)–7(f) compare the observations with AEA2021 predictions for PGA, $S_a(0.2\text{ s})$, $S_a(0.4\text{ s})$, and $S_a(1.0\text{ s})$, respectively. A representative $s4$ site is considered, with $T_n = 0.6$ s and $P^* = 4.24$, consistent with the period-based site characterization adopted for northern South America. AEA2021 more closely follows the observed PGA distance scaling [Figure 7(c)]. Similar first-order agreement is observed for the spectral ordinates, although greater record-to-record scatter is evident at the longer periods [Figures 7(d)–7(f)].

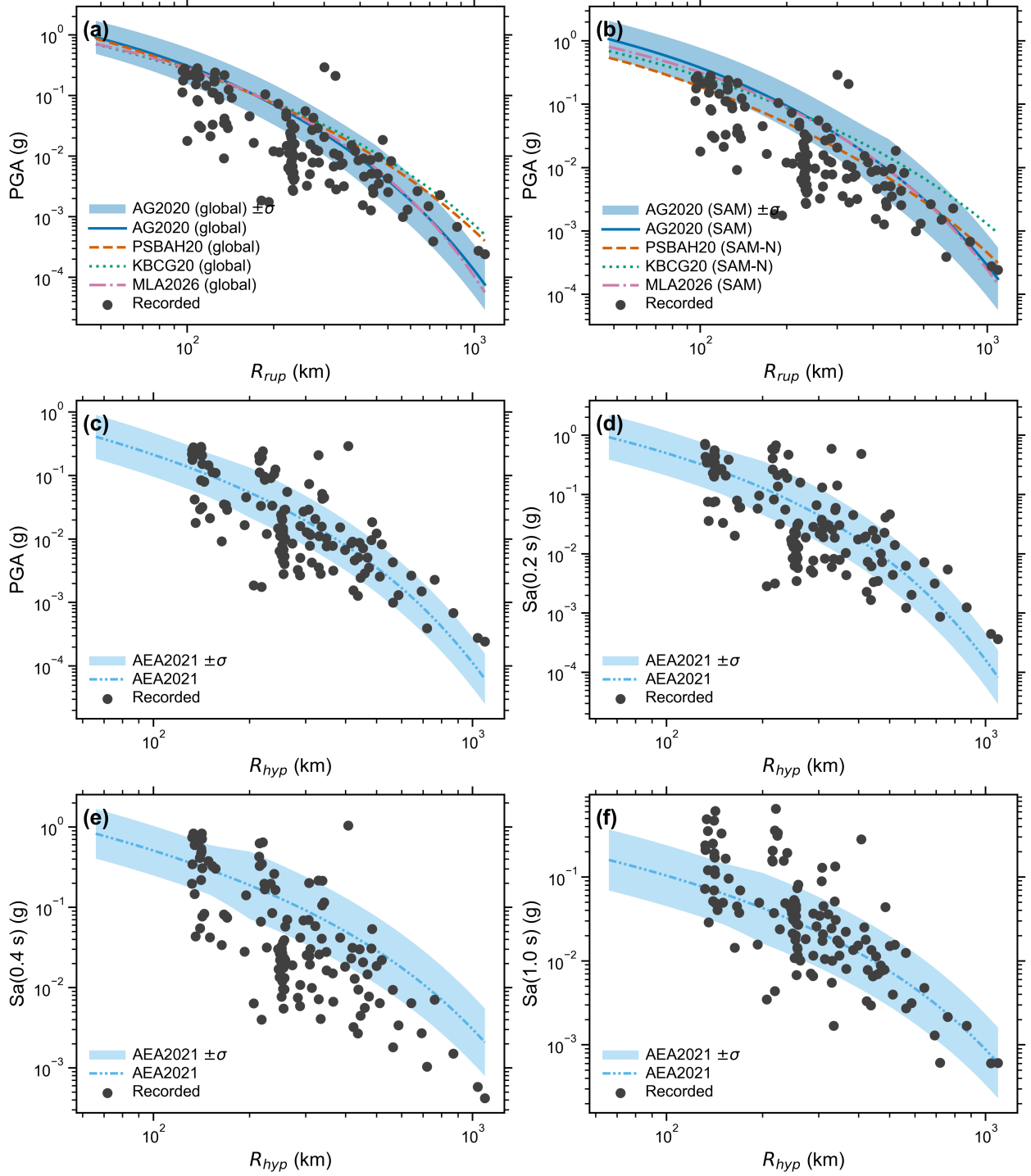


Figure 7: Distance scaling of recorded PGA and spectral acceleration for the earthquake. (a) PGA versus R_{rup} compared with the global AG2020, PSBAH20, KBCG20, and MLA2026 models, evaluated at $V_{S30} = 450$ m/s. (b) Same as (a), using the corresponding South America regionalizations. (c-f) PGA, $S_a(0.2 \text{ s})$, $S_a(0.4 \text{ s})$, and $S_a(1.0 \text{ s})$ versus R_{hyp} , respectively, compared with AEA2021 for a representative $s4$ site ($T_n = 0.6$ s, $P^* = 4.24$).

182 The influence of site conditions is examined more explicitly in Figures 8 and 9. Figure 8 com-
 183 pares PGA observations with AG2020 after grouping the records by V_{S30} , whereas Figure 9 groups
 184 the observations according to the five AEA2021 site categories. Accounting for site conditions ex-
 185 plains part of the dispersion; however, the AG2020 median remains systematically higher than the
 186 observations, producing an event term of approximately -1.22. In comparison, the event term ob-
 187 tained using AEA2021 is 0.32, indicating substantially smaller event-specific bias. AEA2021 also
 188 includes an explicit forearc-backarc adjustment for intraslab earthquakes. Application of this term
 189 improves consistency with the observations at the Bogotá stations located in the backarc region.
 190 No corresponding backarc adjustment is available in the AG2020.

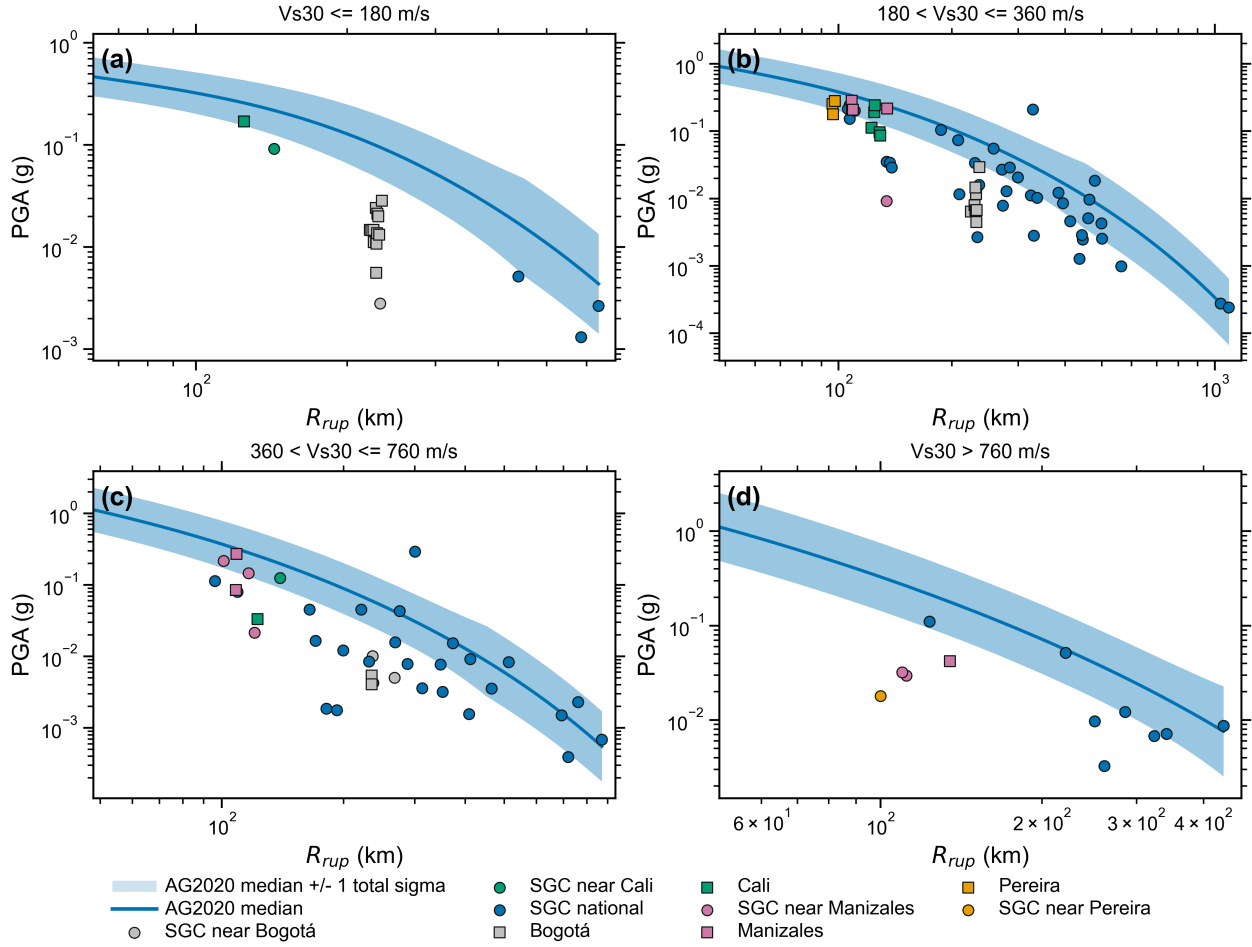


Figure 8: Distance scaling of recorded PGA versus R_{rup} , grouped by V_{S30} . The AG2020 median and $\pm 1\sigma$ curves in each panel are evaluated at the mean V_{S30} of the corresponding class.

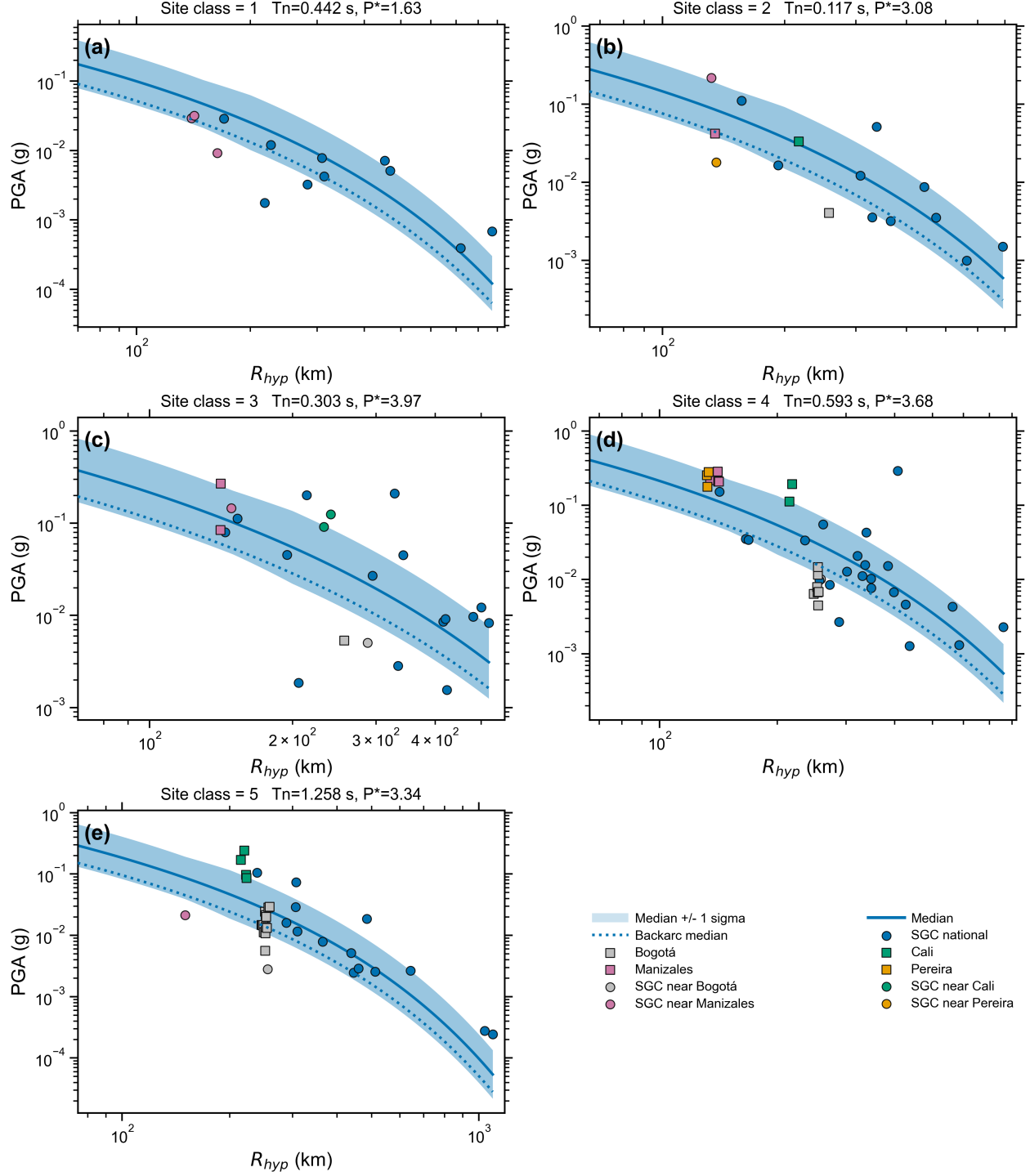


Figure 9: Distance scaling of recorded PGA versus R_{hyp} , grouped by AEA2021 HVSR-based site class. Each panel lists the representative predominant period T_n and HVSR amplification P^* .

191 Figure 10 compares the site-class-binned AI observations with the MAB2019 conditional model,
 192 using AEA2021 predictions of PGA and $S_a(1.0\text{s})$ as conditioning IMs. For each site class, the

193 attenuation curves are evaluated using representative class-average site parameters. The conditional
 194 model captures the first-order distance decay of AI across the five site classes, although within-class
 195 scatter and some residuals exceeding two standard deviations remain.

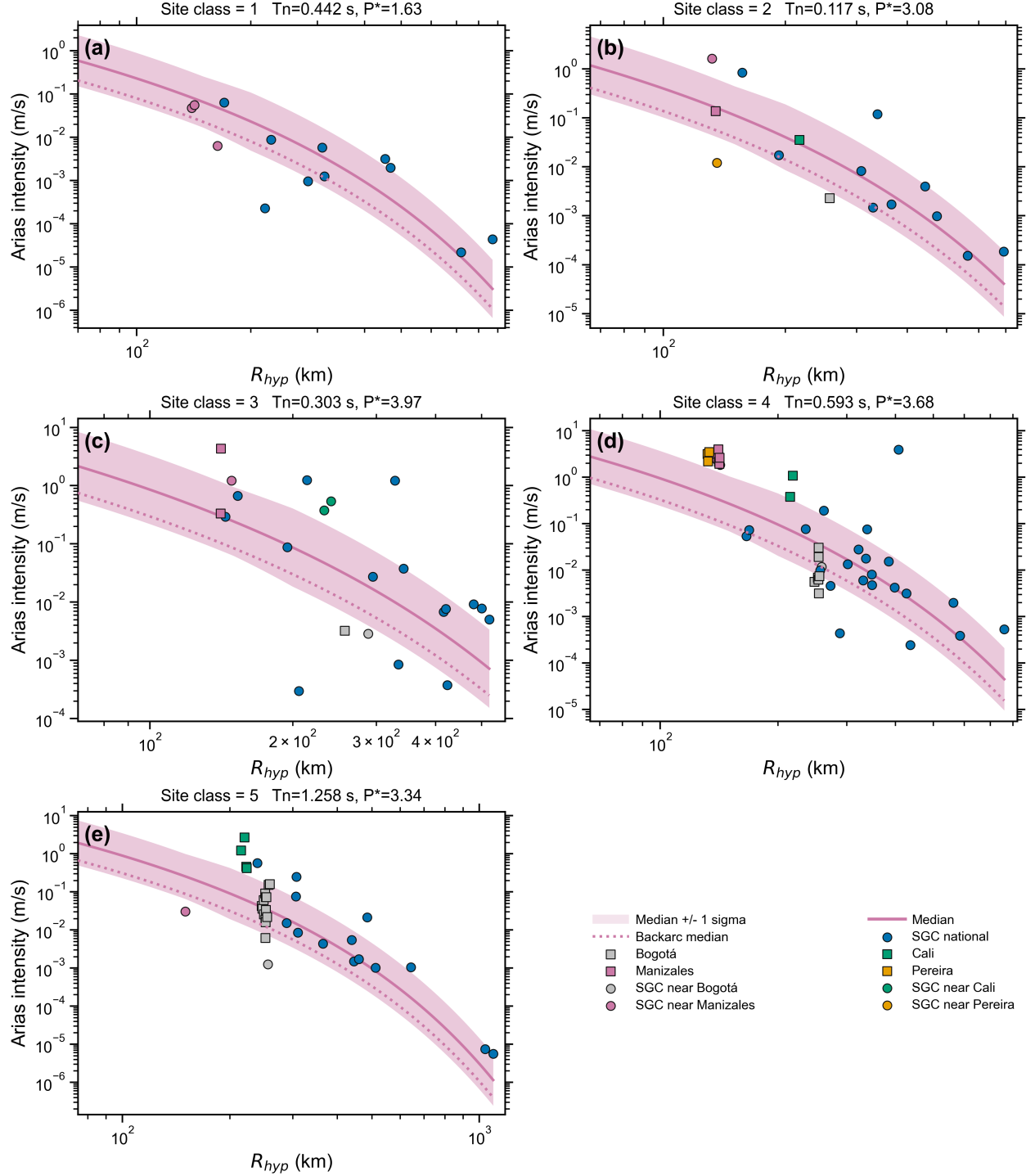


Figure 10: Distance scaling of recorded AI versus R_{hyp} , grouped by AEA2021 site class, compared with the MAB2019 conditional model and AEA2021 GMM.

196 A similar comparison is presented for CAV using the conditional model of [Liu and Macedo](#)
197 [\(2022a\)](#) [Figure 11]. The conditional CAV predictions broadly reproduce the observed attenuation
198 trends across the site classes, while retaining record-to-record variability and some large residuals.
199 For PGV, Figure 12 compares the observations with the conditional model of [Liu and Macedo](#)
200 [\(2022b\)](#). The conditional PGV model similarly captures the first-order distance scaling and site-
201 class dependence of the observations, although departures from the median remain for some stations.

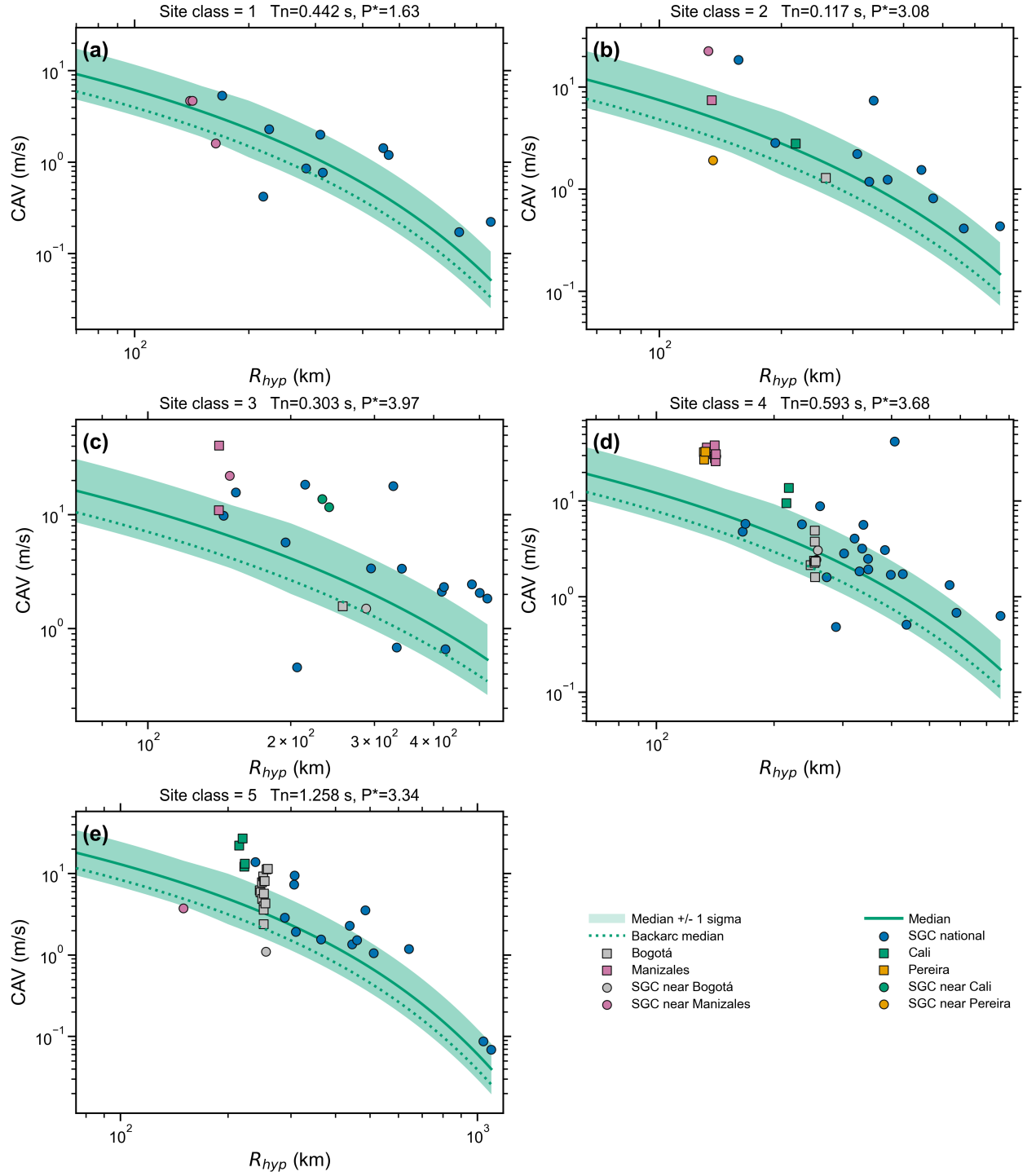


Figure 11: Distance scaling of recorded CAV versus R_{hyp} , grouped by AEA2021 site class, compared with the conditional CAV model of [Liu and Macedo \(2022a\)](#), and AEA2021 GMM.

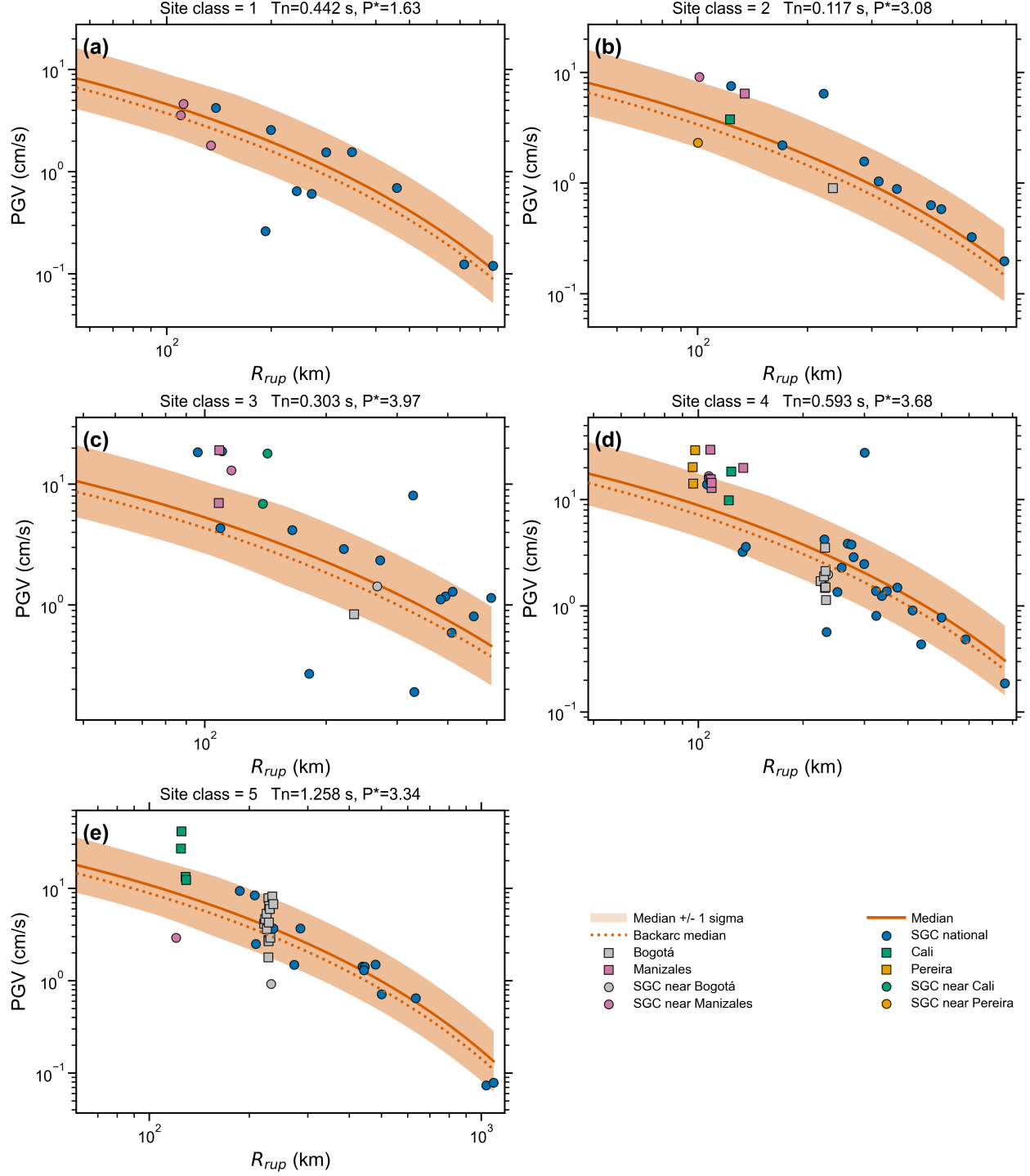


Figure 12: Distance scaling of recorded PGV versus R_{rup} , grouped by AEA2021 site class, compared with the conditional PGV model of [Liu and Macedo \(2022b\)](#), and AEA2021 GMM.

For comparison, Figure 13 evaluates the non-conditional PGV model of [Liu and Macedo \(2022b\)](#) using its V_{S30} -based site formulation. The model reproduces the overall decrease of PGV with

distance across the four V_{S30} classes and does not exhibit an obvious systematic bias for either the softest or stiffest sites. Several residuals exceeding two standard deviations are nevertheless observed, particularly for the $180 < V_{S30} \leq 360$ m/s and $360 < V_{S30} \leq 760$ m/s classes. The comparisons with the conditional and non-conditional formulations should not be interpreted as a formal ranking because the models use different site descriptors and conditioning frameworks. Rather, they show that both formulations capture the first-order PGV attenuation for this event, while the conditional formulation additionally allows the regional source, path, and site scaling represented by AEA2021 to influence the PGV predictions.

Collectively, these comparisons illustrate an important characteristic of conditional GMMs: features represented in the spectral GMM used to provide the conditioning IMs can propagate into predictions of non-spectral IMs. In the present application, combining the conditional AI, CAV, and PGV models with the regionalized AEA2021 spectral GMM provides first-order consistency with the observed attenuation in Colombia, despite the conditional non-spectral models having been developed primarily from the global NGA-Sub database. This behavior is consistent with the scenario-based formulations of [Liu and Macedo \(2022a\)](#) and [Liu and Macedo \(2022b\)](#), in which regionalization and other ground-motion effects represented by the conditioning spectral GMM can be inherited by the resulting non-spectral IM predictions.

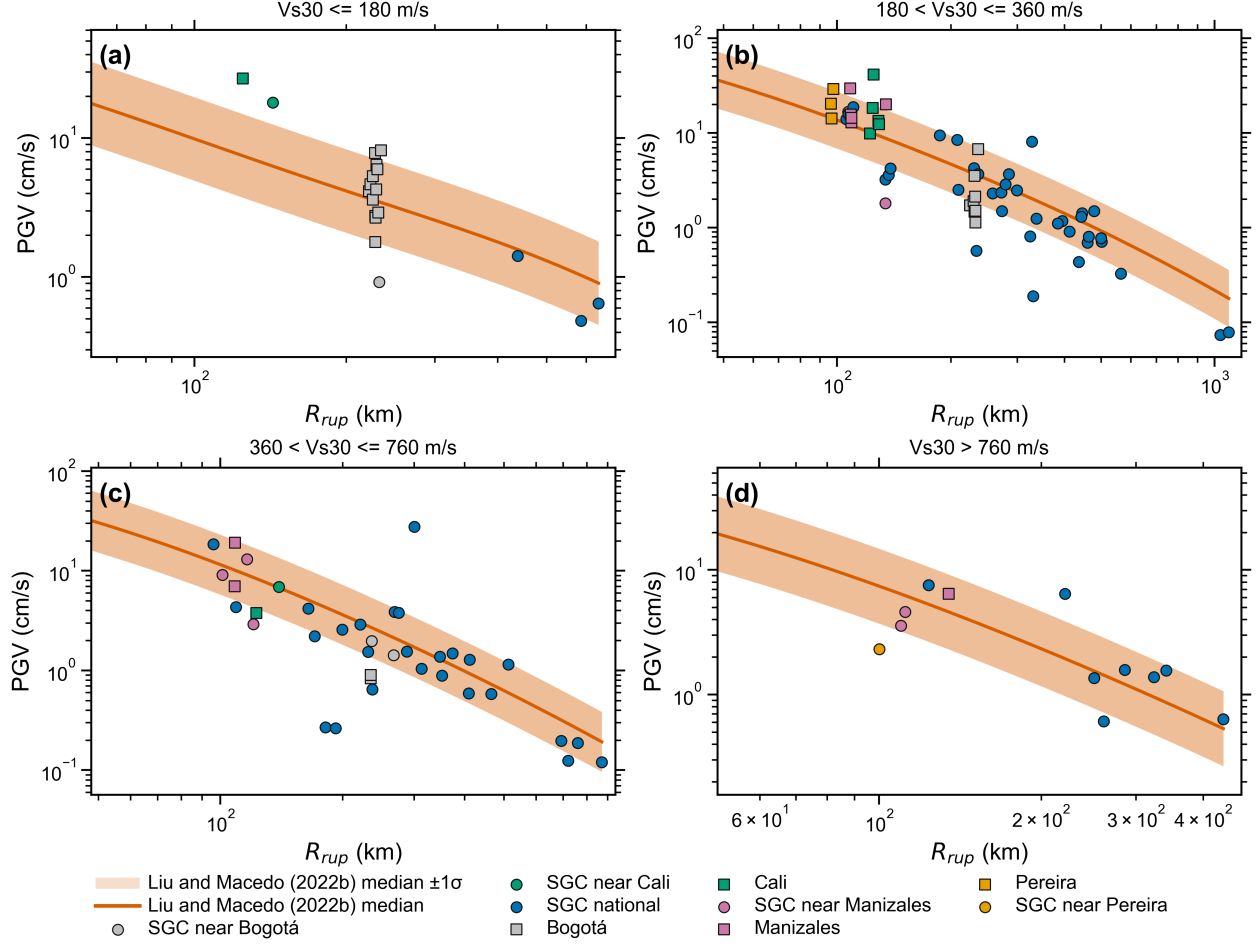


Figure 13: Distance scaling of recorded PGV versus R_{rup} , grouped by V_{s30} . The non-conditional PGV model of Liu and Macedo (2022b) is shown as the median and $\pm 1\sigma$ curves evaluated at the mean V_{s30} of each class.

Figure 14 compares the observed significant durations, D_{5-95} , with predictions from the PA2024 GMM for different site classes. The model systematically underpredicts the observed D_{5-95} values, indicating that the 2026 $M_w 7.4$ Colombia earthquake produced unusually long-duration ground motions relative to the model expectations. For context, Figure 14 also includes NGA-Sub recordings from Japanese intraslab earthquakes with magnitudes between $M_w 7.2$ and 7.6. These recordings are generally more consistent with the PA2024 predictions, highlighting the comparatively long durations observed during the Colombia event. This behavior represents a distinctive feature of the earthquake, particularly for recordings located in the direction opposite to rupture propagation, as discussed in more detail later.

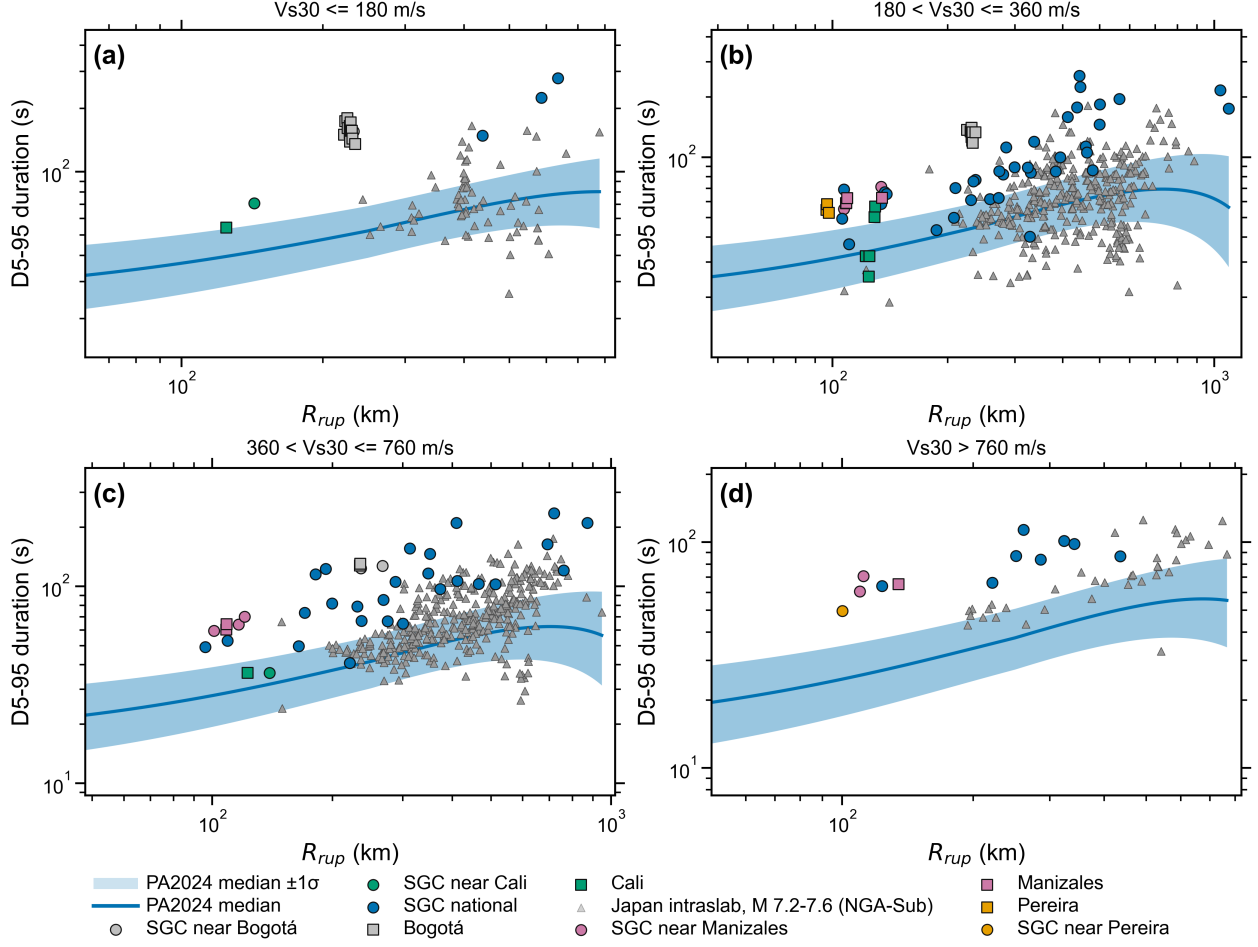


Figure 14: Distance scaling of recorded D_{5-95} versus R_{rup} , grouped by V_{S30} . The PA2024 (Pinilla-Ramos and Abrahamson, 2024) median and $\pm 1\sigma$ curves in each panel are evaluated at the mean V_{S30} of the corresponding class.

2.3 Site response

The ground-motion dataset also permits comparisons among recordings obtained at representative rock and soil sites in several of the principal affected cities. These comparisons illustrate the potential influence of local site effects, although they should not be interpreted as direct empirical amplification functions because the stations differ in source-to-site distance and propagation path, and may also be affected differently by source effects.

Figure 15(a) illustrates the contrast in the Cali region. RAC03 is located near the boundary between microzone 3, characterized by piedmont deposits along the western margin of the Cali basin, and the Cañavalejo deposits, whereas COALA is located in microzone 6 on the Cauca

River alluvial plain. Microzone 6 is characterized by overconsolidated silty clay overlying loose-to-medium sands. CTRUJ, located on rock in the Cauca Valley, is used as a regional reference station. Although the rupture distances differ ($R_{\text{rup}} \approx 96$ km for CTRUJ compared with approximately 125 km for RAC03 and COALA), the spectral amplitudes and shapes differ substantially, suggesting an important contribution from local site response.

A similar comparison for Pereira is shown in Figure 15(b). CBOCA provides the reference bedrock recording, whereas CPER4, CPER5, and CPER6 are soil stations. CPER4 and CPER5 are located in seismic Zone 4, associated with relatively soft volcanic-origin soil profiles, whereas CPER6 is located in Zone 5, associated with soil profiles containing anthropogenic fills over volcanic deposits (Díaz et al., 2021). The soil stations exhibit different spectral characteristics and amplification relative to the rock station. CPER5 shows a pronounced short-period response, consistent with a relatively shallow stiff-soil-over-bedrock profile, whereas CPER4 exhibits stronger long-period amplification, consistent with a deeper sedimentary profile. CPER6 shows a broader response over intermediate periods. These contrasts are consistent with the strong spatial variability in seismic site response documented for Pereira.

Figure 15(c) presents an analogous comparison for Manizales. The MINFD–MINFS downhole array is located at a fill site in Zone B, NIZA represents rock conditions in Zone C, and MUCP is located on volcanic-ash soils in Zone A. The recordings again show marked differences in spectral shape and amplitude between rock and soil sites. Finally, Figure 15(d) presents a corresponding comparison for Bogotá using the CGRAL–CGRAL11 downhole array. The surface and downhole recordings provide a more direct indication of the modification of the incoming motion through the local soil column.

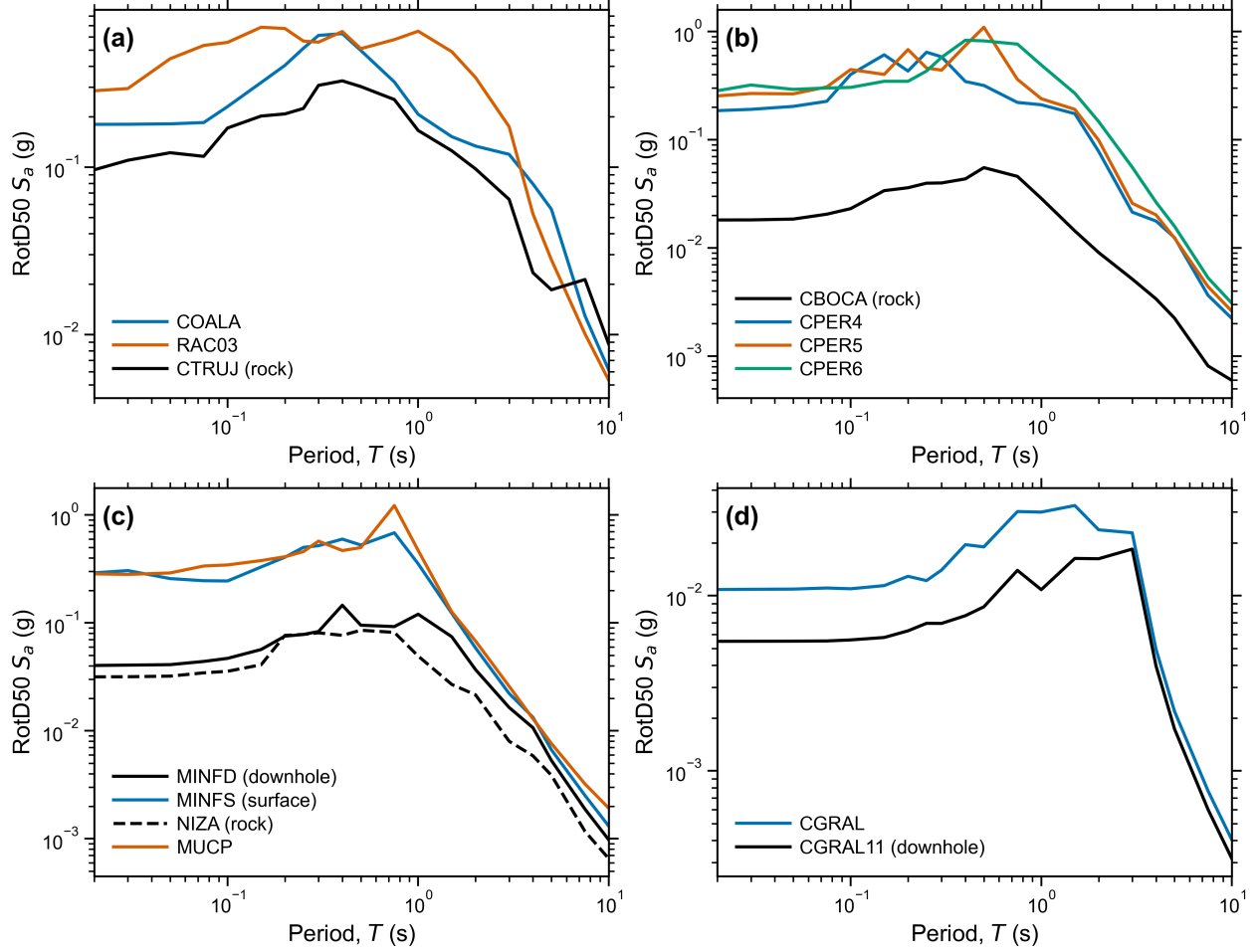


Figure 15: RotD50 (Boore, 2010) acceleration response spectra illustrating representative site-response contrasts in (a) Cali: COALA and RAC03 versus rock station CTRUJ; (b) Pereira: CPER4–CPER6 versus rock station CBOCA; (c) Manizales: MINFS and MUCP versus downhole station MINFD and rock station NIZA; and (d) Bogota: surface station CGRAL versus downhole station CGRAL11. Rock and downhole reference motions are shown in black.

Collectively, the comparisons in Figure 15 indicate substantial modification of the recorded motions by local site conditions in several of the principal affected cities. These differences should not, however, be attributed exclusively to site response, because the stations also differ in source-to-site distance and propagation path and may be affected by direction-dependent source effects. In particular, the systematic southwest–northeast differences in ground-motion amplitude and duration discussed later suggest that source directivity may contribute to part of the observed interstation variability. The comparisons are therefore interpreted as evidence of site-response effects superimposed on source and path variability, rather than as isolated measurements of site amplification.

3 Azimuthal directionality effects

We evaluated whether the recorded ground motions exhibit a systematic azimuthal dependence and whether that dependence is consistent with the finite-fault rupture geometry. The primary analysis used the 87 stations with $R_{\text{rup}} \leq 300$ km. The finite-fault model defines an independent southwestward forward direction of 225.6° ; the hypocenter-to-maximum-slip bearing is 218.2° (Figure 2).

Three amplitude residual formulations were considered: (1) a simple regression that removes first-order R_{rup} and V_{S30} scaling; (2) residuals relative to the AG2020 intraslab model; and (3) residuals relative to the AEA2021 model, using the station-specific forearc/backarc classification. For the GMM-based analyses, a potential linear trend between total residual and $\ln(R_{\text{rup}}/100)$ was removed before testing for azimuthal effects, resulting in the residuals r_i . Directionality was evaluated first along the independently specified finite-fault axis,

$$r_i = \alpha + \beta_F \cos(\theta_i - \theta_F) + \epsilon_i, \quad (1)$$

where $\theta_F = 225.6^\circ$. Because the cosine takes values of $+1$ and -1 in the forward and backward directions, respectively, the fitted forward/backward difference ratio is $\exp(2\beta_F)$. A free first-harmonic model was also fit,

$$r_i = \alpha + \beta_c \cos \theta_i + \beta_s \sin \theta_i + \epsilon_i, \quad (2)$$

allowing the preferred azimuth to be estimated directly from the data. These regressions are used as diagnostics of systematic azimuthal components in the residuals and are repeated for each considered GMM.

Figure 16 shows systematic azimuthal trends whose preferred directions vary with spectral period and residual formulation. For PGA and $S_a(0.2\text{ s})$, the simple regression and global AG2020 residuals place the free-harmonic maxima near $273\text{--}275^\circ$, whereas the AEA2021 residuals place them near $236\text{--}238^\circ$. The sensitivity of the short-period preferred direction to the adopted GMM suggests that regional propagation effects contribute to the observed azimuthal pattern. In particular, inclusion of the station-specific forearc/backarc classification in AEA2021 shifts the inferred maxima substantially closer to the finite-fault forward direction.

In contrast, the preferred $S_a(1\text{ s})$ direction is considerably more stable across the three residual

formulations. The free-harmonic maxima are approximately 217.4° for the simple regression, 227.7° for AG2020, and 219.5° for AEA2021, corresponding to angular differences of approximately 8.2° , 2.2° , and 6.1° from the independently inferred finite-fault direction. We therefore give the $S_a(1\text{ s})$ result greater interpretive weight primarily because the preferred direction is insensitive to the adopted residual model and consistently agrees with the finite-fault rupture direction. Short-period motions are also generally more sensitive to frequency-dependent attenuation, scattering, and small-scale source/path heterogeneity, providing a plausible explanation for the greater model dependence observed for PGA and $S_a(0.2\text{ s})$.

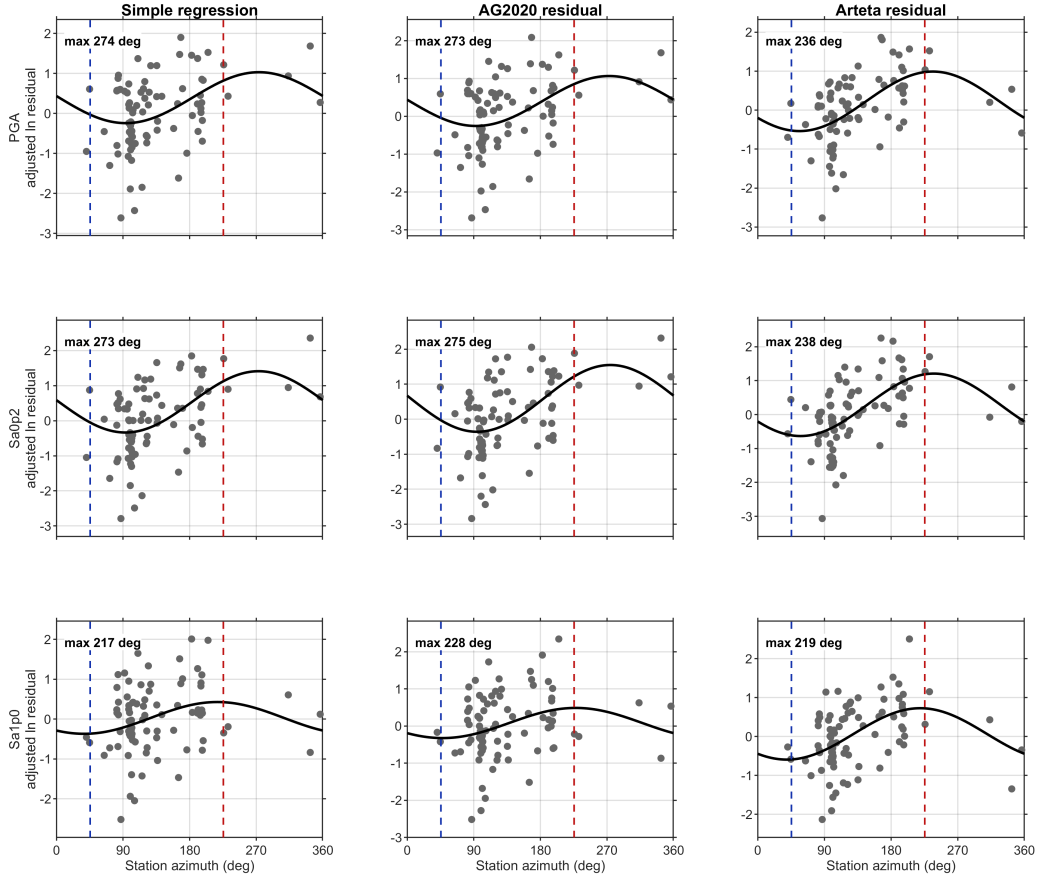


Figure 16: Adjusted residuals as a function of station azimuth for PGA, $S_a(0.2\text{ s})$, and $S_a(1.0\text{ s})$. Columns correspond to the simple regression, global AG2020, and AEA2021 residual formulations. Black curves are the fitted free first-harmonic model of Equation (2); the red dashed line denotes the independently inferred finite-fault forward direction (225.6°), and the blue dashed line its opposite direction.

As an additional check, Figure 17 compares only stations within $\pm 45^\circ$ of the forward and backward directions using the fixed-direction regression of Equation (1) to estimate forward/backward factors. The resulting discrete-sector factors are 1.91, 1.95, and 3.16 for PGA; 2.63, 2.56, and 4.15 for $S_a(0.2\text{ s})$; and 2.04, 1.88, and 2.98 for $S_a(1\text{ s})$, for the simple, AG2020, and AEA2021, respectively. The sector comparisons provide an independent check that adjusted amplitudes are generally larger in the forward than in the backward sector.

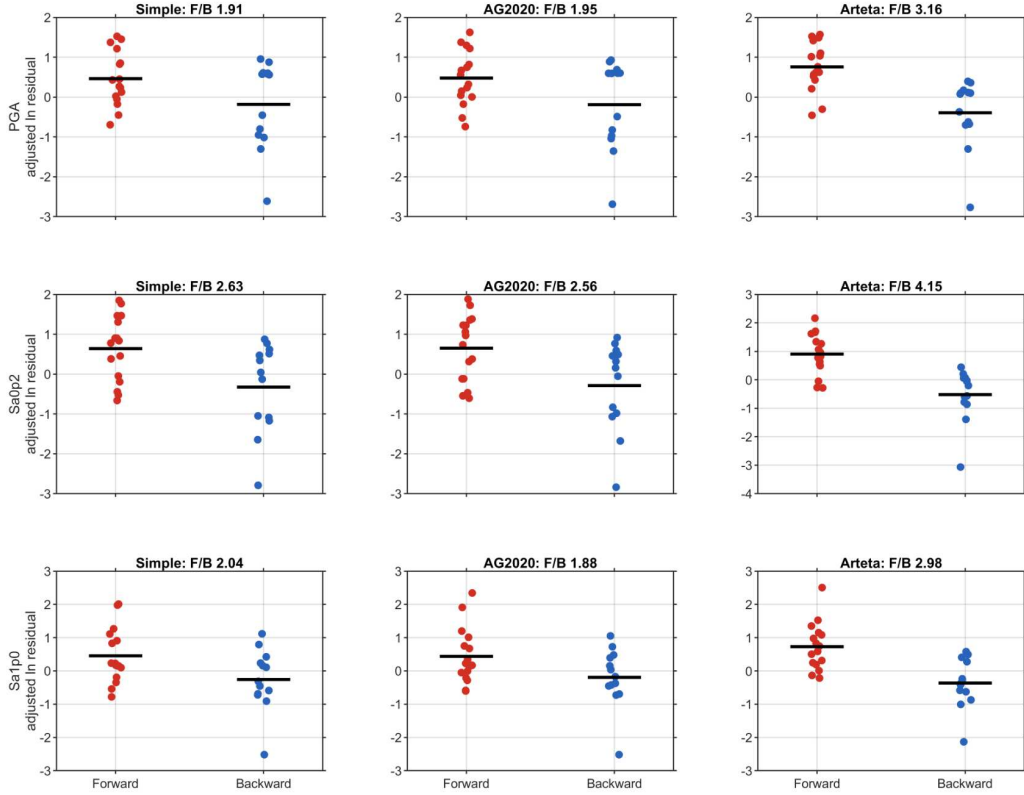


Figure 17: Adjusted residuals for stations within the $\pm 45^\circ$ forward and backward sectors. Rows correspond to PGA, $S_a(0.2\text{ s})$, and $S_a(1.0\text{ s})$, and columns to the simple regression, global AG2020, and AEA2021 residual formulations. Horizontal black lines show the mean residual within each sector. Reported F/B values are $\exp(\bar{r}_F - \bar{r}_B)$, where $\bar{r}_F$ and $\bar{r}_B$ are the mean adjusted logarithmic residuals for stations within the forward and backward sectors, respectively.

Significant duration provides an independent and complementary diagnostic. A regression using residuals from the PA2024 South America intraslab duration GMM results in a D_{5-95} forward/backward sector factor of approximately 0.53, indicating shorter motions in the forward sec-

311 tor. The free-harmonic minima occurs near 247–248°, close to the finite-fault forward direction
 312 (Figure 18). The duration analyses identify shortening toward the general southwestward sector.

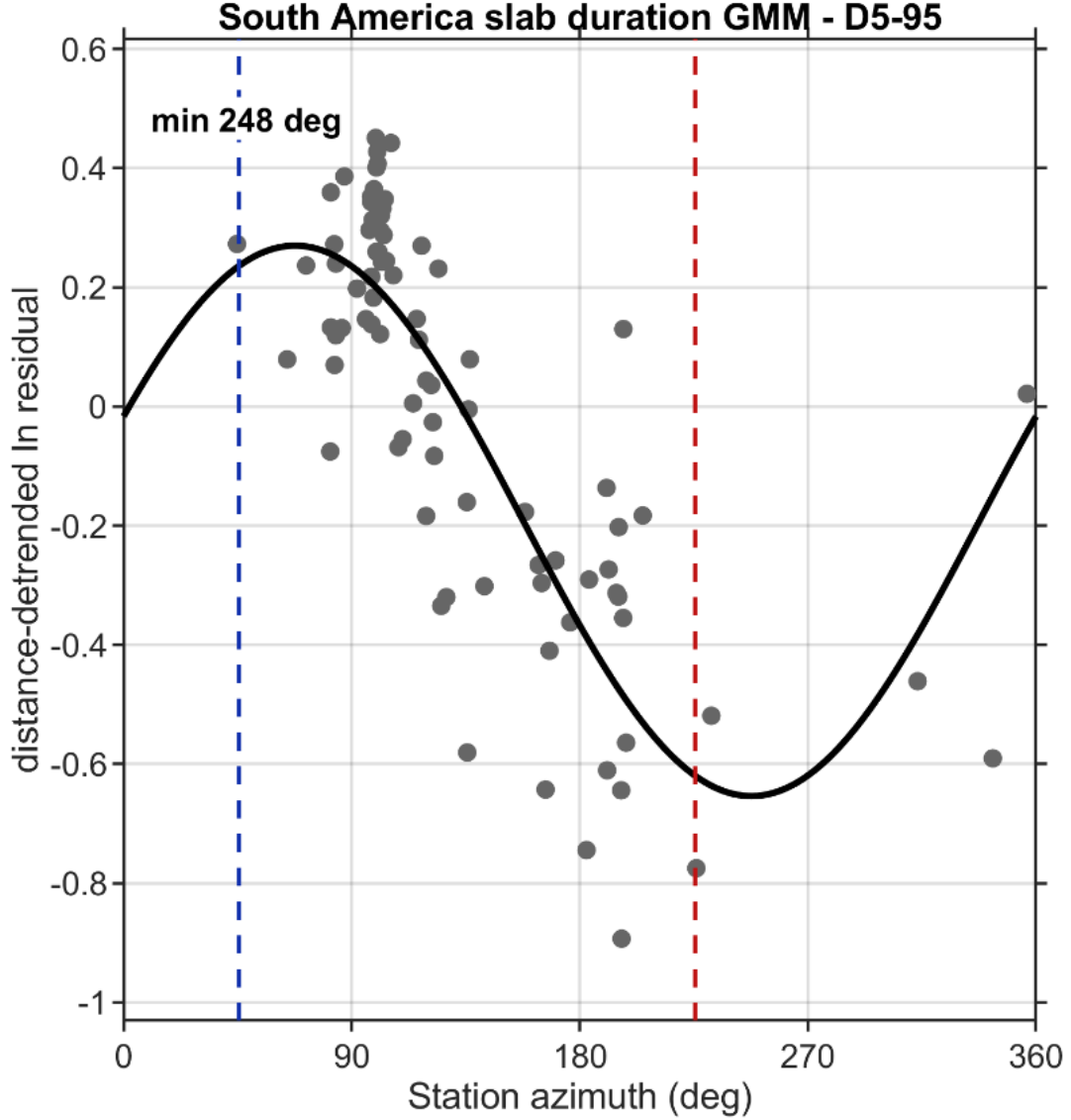


Figure 18: D_{5-95} residuals versus station azimuth for the simple duration regression. The black curves correspond to free first-harmonic fits. For duration, the directivity-consistent extremum is the minimum, which is identified toward the southwestward sector.

313 Taken together, the recordings suggest systematic azimuthal directionality. The combination
 314 of (i) a model-stable $S_a(1s)$ preferred direction closely aligned with the independently inferred
 315 southwestward rupture propagation and (ii) substantially shorter D_{5-95} toward the same general

sector is consistent with a source-directivity contribution. PGA and $S_a(0.2\text{ s})$ also exhibit substantial directional differences, but their preferred directions are more sensitive to the adopted GMM and are therefore interpreted as reflecting a combination of source and regional propagation effects.

4 Spatial analysis

In this section, estimations of the spatial variations of the IMs discussed in this study are conducted. The ground-motion residuals exhibit spatially coherent structure that cannot be represented solely by the event-average model bias. To characterize this structure, the residual for station i is first defined as

$$r_i = \ln Y_i - \ln \mu_i, \quad (3)$$

where Y_i is the observed IM and μ_i is the corresponding median prediction from the baseline model. A single event term is estimated as the mean total residual,

$$\delta B = \bar{r}, \quad (4)$$

and the within-event residual is subsequently defined as $\delta W_i = r_i - \delta B$. Separating δB before the spatial analysis prevents the subsequent spatial terms from absorbing the event-wide bias.

Based on the discussions in the previous section, the spatially varying mean of δW is represented using distance and azimuthal terms. The deterministic component adopted for the reconstructed fields is

$$m_i = \beta_R \ln \left(\frac{R_i}{R_g} \right) + \beta_F \left[\cos(\theta_i - \theta_F) - \overline{\cos(\theta - \theta_F)} \right], \quad (5)$$

where R_i is source-to-site distance, R_g is the geometric-mean distance of the recording stations, θ_i is the source-to-site azimuth, and $\theta_F = 225.6^\circ$ is the forward rupture direction inferred independently from the finite-fault model. Both predictors are centered over the recording stations. Hypocentral distance is used for the AEA2021-based spectral IMs and for the conditional AI and CAV analyses; rupture distance is used for PGV because R_{rup} is included in its conditional model. After removal of the deterministic trend, the remaining stochastic residual is

$$\eta_i = \delta W_i - m_i. \quad (6)$$

337 Spatial dependence in η is characterized using the Matheron empirical semivariogram. An expo-
 338 nential model is adopted for the spatial interpolation,

$$\gamma(h) = c_0 + c_1 \left[1 - \exp \left(-\frac{3h}{a} \right) \right], \quad (7)$$

339 where h is the interstation separation, c_0 is the nugget, c_1 is the partial sill, and a is the approx-
 340 imate 95%-sill practical range. The resulting semivariograms and fitted parameters for each IM
 341 are provided in the electronic supplement. Ordinary kriging is then applied to η using an isotropic
 342 covariance model.

343 The reconstructed IM at a grid location $\mathbf{x}$ is therefore

$$\ln \hat{Y}(\mathbf{x}) = \ln \mu(\mathbf{x}) + \delta B + m(\mathbf{x}) + \tilde{\eta}(\mathbf{x}), \quad (8)$$

344 where $\tilde{\eta}(\mathbf{x})$ is the ordinary-kriging estimate of the stochastic residual. Thus, the reconstructed fields
 345 preserve the baseline ground-motion model while incorporating the event-specific bias, the observed
 346 distance and directional dependence, and the remaining locally correlated residual structure.

347 For PGA and spectral acceleration, $\mu(\mathbf{x})$ is evaluated using the AEA2021 GMM. Station residuals
 348 use the station-specific (T_n, P^*) parameters described previously, whereas grid-node (T_n, P^*) values
 349 are assigned from the available V_{S30} raster. The same procedure is applied to PGA, $S_a(0.2\text{ s})$, and
 350 $S_a(1.0\text{ s})$. An additional $S_a(0.78\text{ s})$ field is reconstructed for use as the conditioning IM in the PGV
 351 model.

352 For the non-spectral IMs, the spatial analysis is performed on residuals from the corresponding
 353 conditional models. At recording stations, Arias intensity and CAV are conditioned on the observed
 354 PGA and $S_a(1.0\text{ s})$. At grid nodes, their conditional medians are evaluated using the event-specific
 355 reconstructed PGA and $S_a(1.0\text{ s})$ fields. PGV is similarly conditioned on $S_a(T_{\text{PGV}})$, together with
 356 R_{rup} and V_{S30} ; for the $M_w 7.4$ event considered here, $T_{\text{PGV}} = 0.78\text{ s}$.

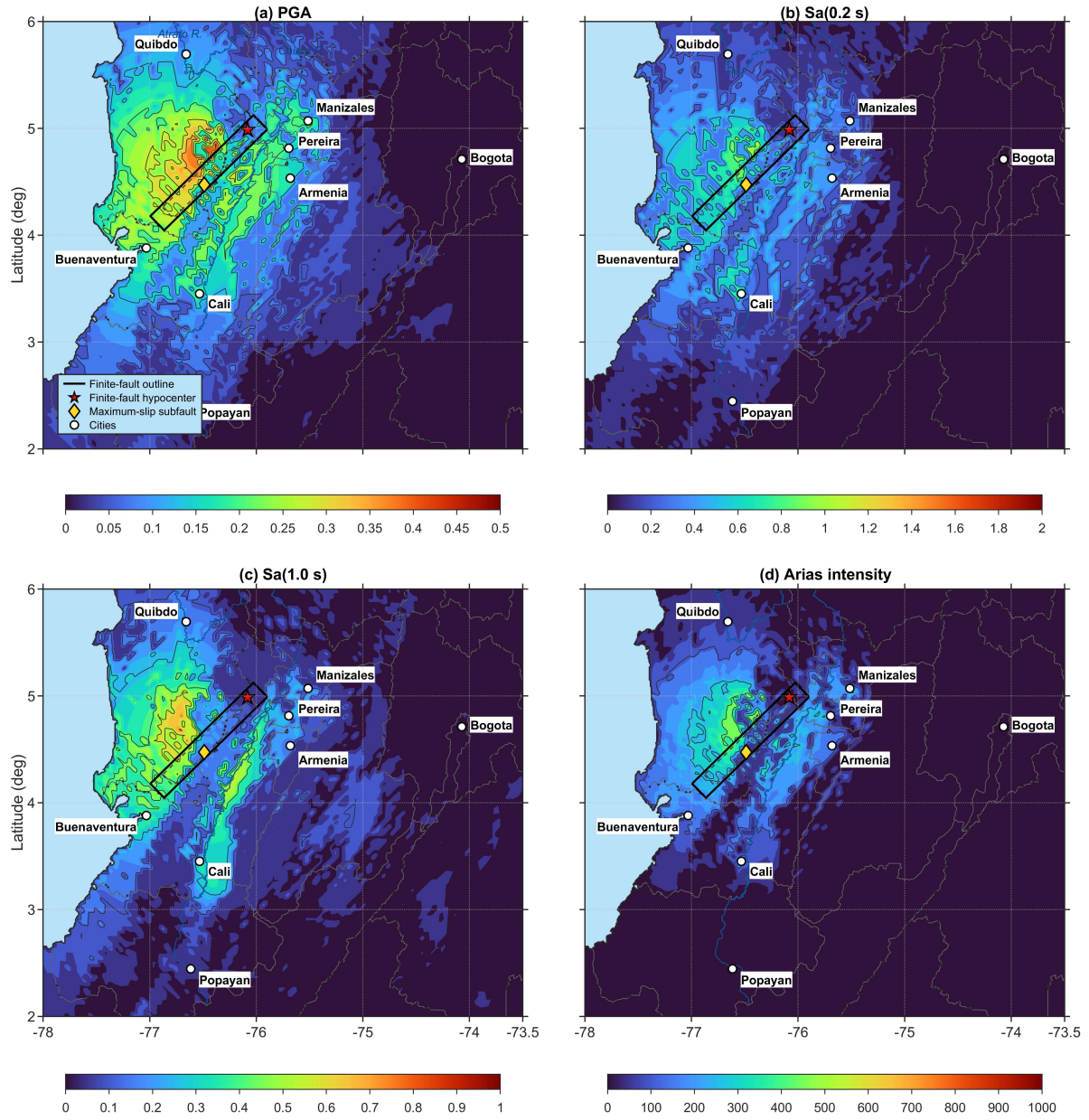


Figure 19: Event-specific reconstructed ground-motion fields for the 10 August 2026 M_w 7.4 San José del Palmar earthquake: (a) PGA, (b) $S_a(0.2\text{ s})$, (c) $S_a(1.0\text{ s})$, and (d) Arias intensity.

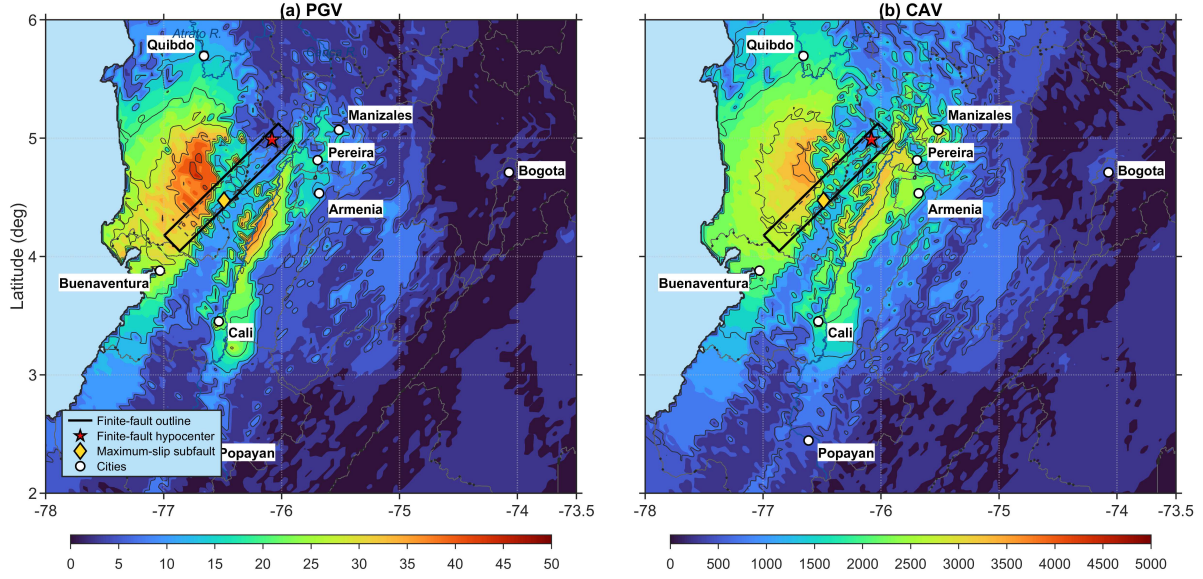


Figure 20: Event-specific reconstructed ground-motion fields for the 10 August 2026 M_w 7.4 San José del Palmar earthquake: (a) PGV, (b) CAV

Figures 19 and 20 present the resulting reconstructed fields for PGA, $S_a(0.2\text{ s})$, $S_a(1.0\text{ s})$, Arias intensity, CAV, and PGV. These maps are interpreted as event-specific reconstructions supported by the available station network rather than as regional ground-motion models.

Rasters for these IMs are provided in the electronic supplement for use in ongoing post-earthquake engineering assessments.

5 Summary and conclusions

This study characterizes the engineering attributes of ground motions recorded during the 10 August 2026 M_w 7.4 San José del Palmar, Colombia, intraslab earthquake. The event provides an unusually dense strong-motion dataset for a large Colombian intraslab earthquake and therefore offers an opportunity to evaluate ground-motion characteristics in a magnitude and regional setting that are sparsely represented in existing databases. Recordings from the Colombian Geological Survey and local strong-motion networks were compiled, quality controlled, and processed to obtain PGA, spectral acceleration, PGV, AI, CAV, and significant duration. The observations were compared with global and regional subduction GMMs, including models developed specifically for northern

South America. Finite-fault information was incorporated to characterize source-to-site distances and rupture geometry, and the dataset was further used to investigate local site-response contrasts, azimuthal directionality, and the spatial distribution of ground-motion intensity measures. Event-specific ground-motion fields were subsequently reconstructed by combining the selected GMMs with distance- and direction-detrended spatial residuals.

Several findings emerge from the analyses. First, the observations demonstrate the importance of regional ground-motion characterization for northern South America. The global NGA-Sub models generally predict higher PGA than observed over much of the distance range, whereas the northern South America model AEA2021 more closely reproduces the first-order attenuation of the recorded spectral intensity measures. Conditional models for AI, CAV, and PGV, when combined with the regional spectral model used to provide their conditioning intensity measures, also provide a generally consistent description of the observed attenuation. This result illustrates the potential of conditional formulations to transfer regional source, path, and site characteristics represented by a spectral GMM into predictions of non-spectral engineering intensity measures.

Second, significant durations for the Colombia event are systematically longer than the adopted duration-model predictions and are also generally longer than recordings from Japanese intraslab earthquakes of comparable magnitude. The duration characteristics therefore represent a distinctive feature of this event and complement the information provided by conventional amplitude-based intensity measures.

Third, the recordings exhibit azimuthal directionality. Ground-motion amplitudes at spectral periods are generally larger toward the southwest, while significant durations are shorter toward the same sector. The preferred direction obtained for $S_a(1.0\text{ s})$ in particular aligns with the independently inferred southwestward finite-fault rupture direction. The combined amplitude and duration observations therefore suggest a source-directivity contribution. In contrast, the preferred directions obtained from PGA and $S_a(0.2\text{ s})$ are more dependent on the adopted GMM, suggesting that short-period motions reflect a combination of source directivity and regional propagation effects rather than source effects alone.

The recordings also demonstrate substantial local variability among stations within the principal affected urban areas. Comparisons among rock, soil, surface, and downhole recordings in Cali, Pereira, Manizales, and Bogotá indicate important modifications of spectral shape and amplitude

associated with local site conditions. These observations emphasize that regional source and path effects alone are insufficient to characterize urban shaking and that local site-response information remains important when translating regional ground-motion estimates into engineering demand.

Finally, the spatial analysis provides event-specific continuous estimates of PGA, spectral acceleration, PGV, AI, and CAV at locations without recordings. The reconstruction separates the event-wide bias and deterministic distance and directional trends before kriging the remaining spatially correlated residuals. The resulting fields should be interpreted as event-specific reconstructions constrained by the available recording network rather than as regional ground-motion models. Nevertheless, they provide a useful framework for supporting reconnaissance, comparison with observed engineering performance, and assessment of locations where instrumental recordings were unavailable.

More broadly, the San José del Palmar dataset provides new constraints on the characteristics of large intraslab ground motions in northern South America. The observed combination of regional attenuation behavior, long significant durations, direction-dependent amplitudes, and strong local site variability is directly relevant to earthquake-engineering applications because these characteristics influence structural demand, slope and dam response, liquefaction potential, and other cumulative or deformation-related effects that cannot be represented adequately by PGA alone. The results also illustrate the value of considering amplitude, duration, spectral shape, and spatial variability jointly when evaluating the engineering significance of large intraslab earthquakes.

Future work should extend the analysis to additional intraslab events to separate repeatable regional effects from event-specific source behavior and to evaluate whether the directional patterns identified here can be incorporated into regional or nonergodic ground-motion models.

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