

Next-Generation Ground-Motion Models for Georgia and the Surrounding Caucasus Region

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Abstract

The manuscript presents updated ground-motion models (GMMs) for peak ground acceleration (PGA) and 5% damped spectral acceleration (SA) for shallow crustal earthquakes in Georgia and the surrounding area. These models are developed exclusively from the strong-motion network of Georgia and its neighboring countries. The final dataset consists of 2262 high-quality three-component accelerograms with magnitudes ranging from 3.5 to 7.0 and hypocentral distances of up to 300 km. The developed GMMs incorporate moment magnitude, hypocentral distance, faulting mechanism, and site conditions represented by Vs30. Such a selection of the data reduces the heterogeneity associated with converting broadband velocity records into acceleration records. It also avoids mixing them with direct acceleration records, as in previous hybrid models. Regression analysis combined with a magnitude-based weighting scheme was used to improve the representation of moderate-to-large earthquakes in the dataset. Model performance was evaluated using residual analysis and goodness-of-fit statistics. The resulting models predict slightly lower PGA and short-period SA amplitudes than the previously published hybrid models, particularly for periods shorter than 0.3 s, and exhibit stronger attenuation at intermediate and large distances. Site conditions and faulting mechanism remain important controls on ground-motion amplitudes, with thrust-fault earthquakes and soft-soil sites producing the highest motions. The updated models show reduced inter-event variability, with inter-event standard deviations approximately 15-20% lower than those of the previous hybrid models, indicating more stable and reliable predictions. These results suggest that GMMs derived exclusively from strong-motion data provide a more robust basis for seismic hazard assessment and engineering applications in the Caucasus region.

Keywords: Strong-motion network; Ground motion models; Peak ground acceleration; Spectral acceleration; Shallow crustal earthquakes

1. Introduction

Precise prediction of ground motions caused by earthquakes is fundamental for sophisticated seismic hazard assessment. In earthquake-prone regions such as Georgia and the Caucasus, which lie at a key segment of the Alpine-Himalayan collision belt, moderate to strong earthquakes occur frequently, thereby increasing the seismic risk in urban areas and critical infrastructure. Because regional tectonic settings are highly complex, generating

thrust, strike-slips, and normal fault systems, it is necessary to refine and improve ground-motion models that reflect local source, path, and site characteristics.

Ground motion models (GMMs) provide quantitative relationships between earthquake source characteristics, propagation effects, and site conditions, and the resulting amplitudes of ground shaking, such as peak ground acceleration and response spectra. These relationships constitute a key component of probabilistic seismic hazard analysis, in which regional source, path, and site effects must be represented in a statistically consistent manner. A variety of global models exist; some were developed within the NGA-West2 and various European projects. However, they cannot fully capture the seismotectonic and site-specific variability of the Caucasus region due to its different geological conditions. Therefore, deriving local GMMs for Georgia remains a critical task.

The first ground-motion prediction models for the Caucasus region were based on a limited number of strong-motion datasets. Smit et al. (2000) developed attenuation relationships for the Caucasus region using recordings from the Georgian strong-motion network. Then, to extend the usable magnitude-distance range, Jorjiashvili et al. (2022) introduced hybrid models that combined broadband and accelerometric recordings. Although this strategy increased the dataset size, it also introduced additional sources of uncertainty related to sensor response, baseline correction, and frequency-dependent amplitude scaling.

Over the past few years, the expansion of the local strong-motion network and the collection of high-quality accelerograms, together with data from neighboring countries, enabled the compilation of a comprehensive dataset suitable for independent model development. Sufficient strong-motion data coverage enables a reassessment of ground-motion models. This provides an opportunity to test whether the previously observed hybrid model features were due to data heterogeneity or reflect genuine regional behavior.

This study presents a new generation of regional ground-motion models for Georgia and the surrounding Caucasus, derived exclusively from homogeneous strong-motion observations. A two-stage classical regression analysis (the same method as in the previous study, Jorjiashvili et al., 2022) is applied to separate magnitude and distance dependencies and to quantify both inter-event and intra-event variability. Particular attention is given to the influence of fault mechanism and local site class, defined according to Eurocode 8 shear wave velocity in the upper 30m depth (V_{s30}).

For the study, several parameters were selected, such as peak ground acceleration (PGA) and 5%-damped pseudo-spectral accelerations (SA) over a broad period range (0.01-10 s). Second, to assess how the exclusion of broadband data affects amplitude levels and variability compared to previous hybrid models. Third, to provide improved estimates of inter-event (τ) and intra-event (σ) standard deviations, which are critical for hazard assessment (Han, 2020; Jorjiashvili et al., 2016).

2. Dataset and data processing

The data used in the present study were compiled exclusively from the Georgian strong-motion network and selected high-quality recordings from adjacent regions of the Caucasus gathered within recent years. It represents a significant update to the dataset used in the earlier hybrid ground-motion model (Jorjiashvili et al., 2022), which combined broadband and accelerometric observations. The new dataset excludes broadband recordings to ensure full frequency-response and amplitude-scaling compatibility, providing a homogeneous basis for GMMs (Shengelia et al., 2019, 2020).

1600 three-component accelerograms from shallow crustal earthquakes with magnitudes $3.5 \leq M_w \leq 7.0$ and hypocentral distances up to 300 km were used for the study. Events were recorded between 2017 and 2025 by 39 seismic stations equipped mainly with Güralp CMG-5T and Nanometrics Titan SMA strong-motion accelerometers operated by the Institute of Earth Sciences and National Seismic Monitoring Centre at Ilia State University and collaborating agencies in neighboring countries.

In addition, data recorded in Georgia and the surrounding area in the 1990s by the old strong-motion (SMACH, SM-1) network were used. 662 records of 14 stations were used from this network (Smit et al., 2000). The use of these data was important because several significant events during instrumental periods were recorded, including the M6.9 Racha earthquake in 1991, which had many aftershocks (all of which were included in the study). This earthquake is mentioned separately because it was the biggest event recorded by the Georgian network within the instrumental period. Most of the recordings in this study come from the Georgian strong-motion network, managed by the Institute of Earth Sciences and the National Seismic Monitoring Centre at Ilia State University. To improve coverage near the

borders and include more moderate-to-large earthquakes, a limited number of additional recordings from neighboring countries were added. These countries are Armenia (A0 network by the National Survey for Seismic Protection, NSSP), and Azerbaijan (AB network by the Republican Seismic Survey Center, RSSC). These recordings were taken from international seismic databases, such as the Engineering Strong Motion Database (ESM) and EarthScope/IRIS. The foreign data make up only a small part of the dataset and were mainly used to improve regional coverage and sampling. All data used in this study are publicly available at <https://ds.iris.edu/> and <https://esm-db.eu/>.

Figure 1a shows the map of epicenters and seismic networks used in the study for both datasets. Figure 1b shows the distribution of data by epicentral distance, magnitude, and depth. Figure 1c shows data distribution by hypocentral distance and magnitude for each dataset.

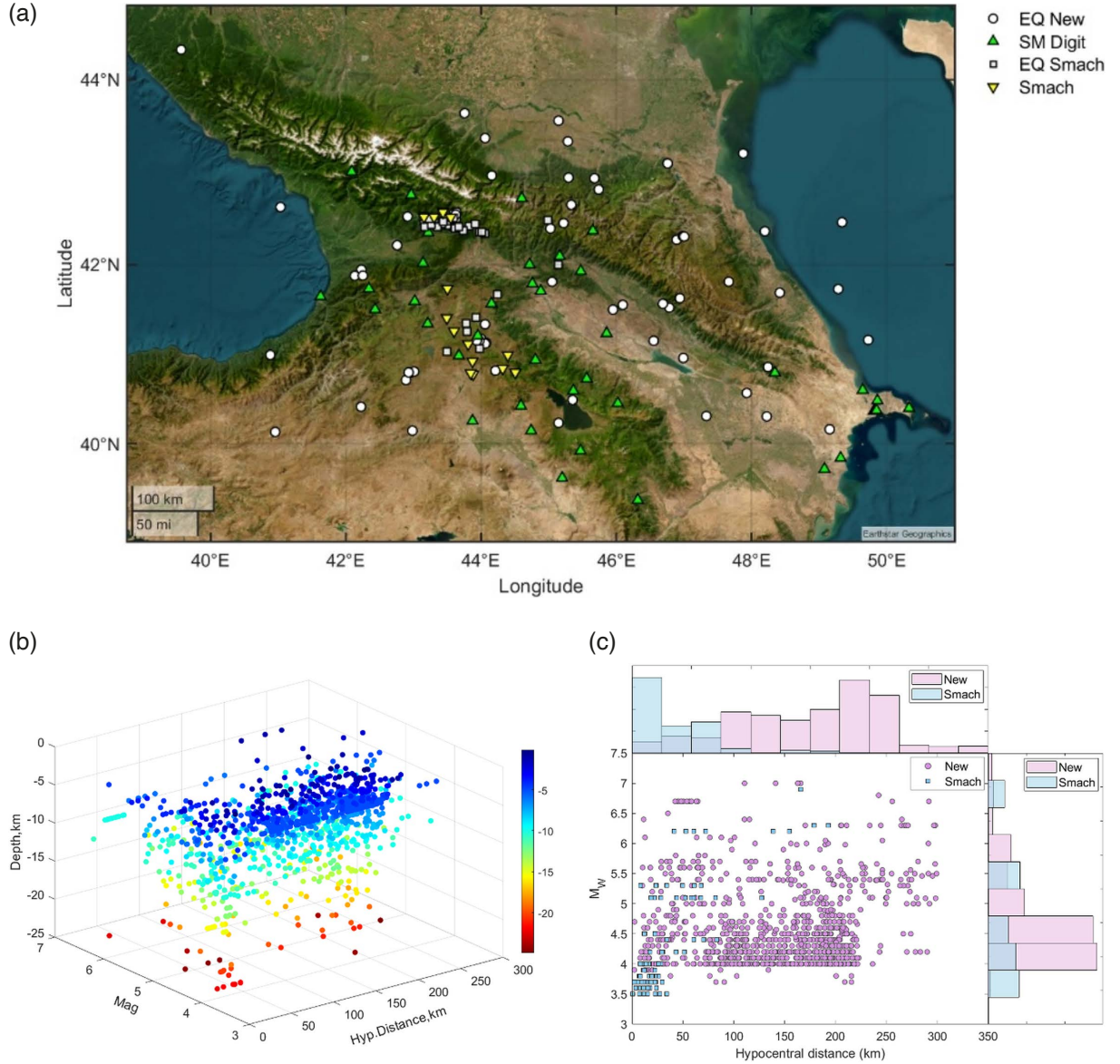


Figure 1. (a) Map of seismic network and epicenters used in the study. (b) Data distribution by hypocentral distance, magnitude, and depth. (c) Data distribution by hypocentral distance and magnitude for each dataset. The pink color corresponds to new data, and the blue color corresponds to old Smach data.

Each earthquake is featured by moment magnitude, focal depth, fault mechanism (thrust, strike-slip, or normal), and hypocentral distance (Fig. 2a, Fig. 2c, Table 1). Earthquake source parameters, including hypocentral location, focal depth, and moment magnitude (M_w), were obtained primarily from the catalog of the Institute of Earth Sciences and National Seismic Monitoring Centre (IES-NSMC), supplemented where necessary by information from international

seismic agencies and repositories, including EarthScope/IRIS and ESM. For larger earthquakes, M_w values and focal mechanism solutions were verified using published moment-tensor solutions and regional seismotectonic studies. Faulting mechanisms were assigned based on available focal mechanism solutions and previous regional studies (e.g., Tan and Taymaz, 2006; Triep et al., 1995; Adamia et al., 2011; Philip et al., 2014). Earthquakes for which reliable focal mechanism information was unavailable were classified as “undefined”.

Site conditions at recording stations were estimated using the average shear-wave velocity in the upper 30 m (V_{s30}), derived primarily from geophysical prospecting surveys conducted at or near the station locations. For most stations, V_{s30} values were obtained using seismic refraction measurements and related site investigations conducted during station installation and subsequent site characterization studies. Stations were classified according to Eurocode 8 site classes: A ($V_{s30} > 800$ m/s), B ($360 \leq V_{s30} \leq 800$ m/s), and C ($180 \leq V_{s30} < 360$ m/s) (European Commission, 2004). Sites with $V_{s30} < 180$ m/s were not represented in the dataset (Fig. 2b, Fig. 2d, Table 1).

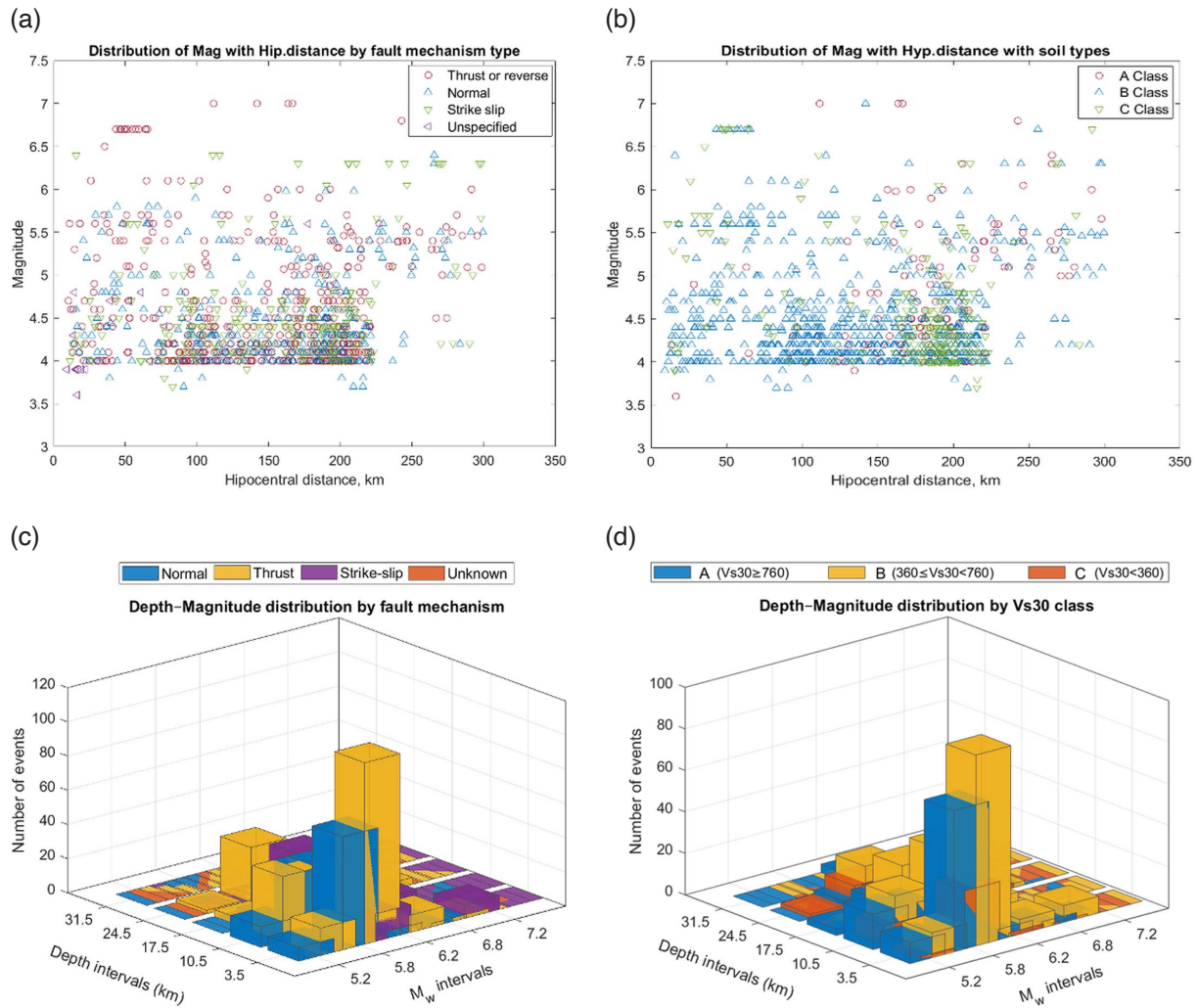


Figure 2. Distribution of earthquake source and site characteristics in the compiled dataset. (a) Relationship between moment magnitude (M_w) and hypocentral distance for different faulting mechanisms. (b) Relationship between moment magnitude (M_w) and hypocentral distance for different Eurocode8 site classes. (c) Three-dimensional distribution of earthquake magnitudes and focal depths according to faulting mechanism. (d) Three-dimensional distribution of earthquake magnitudes and focal depths according to site class (V_{s30}).

Waveform processing followed established strong-motion analysis procedures consistent with those applied in earlier regional studies (e.g., Jorjiashvili et al., 2022). All records were visually inspected to identify possible clipping and low-quality waveforms. Records exhibiting insufficient signal-to-noise ratios were excluded from analysis. Baseline correction and cosine tapering were applied prior to filtering. To determine appropriate filter corner frequencies,

each accelerogram was padded with zeros, and its Fourier amplitude spectrum was examined. Signal-to-noise ratio (SNR) estimates were evaluated individually for each record following the approach of Ambraseys et al. (2005) and Malagnini et al. (2000). Based on the spectral characteristics and SNR analysis, record-specific band-pass filters were selected and applied using Butterworth filters. Peak ground acceleration (PGA) and 5%-damped pseudo-spectral accelerations (SA) were then computed for both horizontal components, and the larger value was retained for subsequent regression analysis (Akinci et al., 2014; Kalkan et al., 2004; Sung et al., 2025).

Table 1. Distribution of data by faulting mechanism and site class according to Eurocode 8. Rows correspond to fault types, and columns correspond to site classes.

F_Type/S_Class	A	B	C	Total	Total in %
Thrust	133	686	195	1014	45
Normal	82	462	156	700	31
Strike-slip	42	336	124	502	22
Undefined	16	24	6	46	2
Total	273	1508	481	2262	
Total in %	12	67	21		

3. Methodology

3.1 Functional form of the proposed ground-motion model

Ground motion prediction coefficients were estimated using a two-stage regression analysis proposed by Joyner and Boore (1993, 1994), with a functional form similar to that of a previous hybrid model (Jorjiashvili et al., 2022). Such a form was chosen because it was also shown during the evaluation of the previous model to reflect the attenuation characteristics of the Caucasus region very well. In the first stage of the regression, event-specific amplitude factors and parameters controlling the distance dependence of motion were assessed; in the second, magnitude terms were derived. Faulting mechanism and local soil conditions were also included. This approach allows separate evaluation of the magnitude, distance, and site contributions to GMMs, ensuring model stability. It also allows assessing intra-event and inter-event variability separately.

We developed a model to predict peak ground acceleration (PGA) and 5%-damped pseudo-spectral acceleration (SA) using the following general functional form:

$$\log Y = c_1 + c_2 M + c_3 \log \left(\sqrt{R^2 + c_4^2} \right) + c_5 R + F_{fault} + F_{site} + \varepsilon. \quad (1)$$

In this equation, Y represents the ground-motion parameter being predicted (PGA or SA), M is the moment magnitude, R is the hypocentral distance, c_i are the regression coefficients, and ε is the residual term for the model's random variability.

We described the total residual variability as a combination of inter-event and intra-event components:

$$\varepsilon = \sqrt{\tau^2 + \phi^2}, \quad (2)$$

τ and ϕ are the standard deviations for inter-event and intra-event variability.

We used a linear term to scale for magnitude, which gave stable regression results for all magnitudes in the dataset and showed that ground-motion amplitudes usually increase with earthquake size. Distance attenuation was modeled with both logarithmic geometrical spreading and linear anelastic attenuation terms. The logarithmic term mainly controls how ground motion decreases near the source, while the linear term accounts for energy loss farther away. We included a pseudo-depth coefficient, c_4 , to stabilize predictions at short distances and avoid unusual results near the source. Faulting-style effects were modeled using categorical dummy variables for thrust, normal, strike-slip, and undefined focal mechanisms (variables F_T , F_N , F_S , and F_U):

$$F_{fault} = c_6 F_T + c_7 F_N + c_8 F_S + c_9 F_U, \quad (3)$$

where $F_T = 1$ for thrust fault earthquakes, $F_N = 1$ normal fault earthquakes, $F_S = 1$ for strike-slip fault earthquakes, and $F_U = 1$ for all other types of faults.

This setup lets the regression account for systematic differences in energy release from different tectonic processes in the region. Site amplification effects were modeled using the average shear-wave velocity in the top 30 meters (V_{S30}). Site conditions were classified according to Eurocode 8 categories and introduced relative to a reference rock condition:

$$F_{site} = c_{10} \log \left(\frac{V_{S30}}{V_{ref}} \right), \quad (4)$$

where $V_{ref} = 750$ m/s corresponds to the reference rock condition adopted in this study.

In Eq. (1-4), coefficients c_1 – c_{10} were obtained via regression analysis. GMMs were obtained using the two-stage regression method proposed by Joyner and Boore (1993, 1994). This method was designed to decouple magnitude and distance dependence. In the first stage, only the distance dependence and site effects were considered, along with the intra-event variability, while in the second stage, the magnitude dependence and faulting mechanism were considered, along with the inter-event variability. All regressions were processed periodically to determine the coefficients of the two stages, and then residuals were analyzed (Jorjashvili et al., 2010).

Unlike earlier models for the region that used both broadband and accelerometric data, our study uses only accelerometric recordings and applies a magnitude-dependent weighting scheme during regression.

3.2 Magnitude-Based Weighting Scheme

One of the challenging aspects of this study was the limited number of large-magnitude records ($M \geq 6$), despite the region's high potential for active faults to produce earthquakes with $M \geq 7$. Therefore, a magnitude-dependent weighting approach was adopted to reduce the influence of the large number of small-magnitude records in the GMM regression. Because smaller events dominate the dataset but contribute less to the overall scaling of ground motion, this weighting method helps balance the regression by giving greater influence on moderate and large earthquakes, which better constrain the attenuation and magnitude-scaling terms. Following Akkar and Kale (2015), a piecewise-linear weight function was used, given by the following formula:

$$w(M) = \begin{cases} a_1, & M < M_1 \\ a_1 + (a_2 - a_1) \frac{M - M_1}{M_2 - M_1}, & M_1 \leq M \leq M_2, \\ a_2, & M \geq M_2 \end{cases} \quad (5)$$

where base weight $a_1 = 1$, high-magnitude weight $a_2 = 6$, lower break magnitude $M_1 = 4.5$, and upper break magnitude $M_2 = 6.2$. To achieve a more uniform contribution of small to moderate earthquakes to regression analysis, the function was adjusted to begin at $M_1 = 4.5$. This approach addresses the issue of fewer large events by increasing their influence on model coefficients. Weighted and unweighted magnitude distributions were examined to confirm that the weighting procedure effectively increases the relative contribution of $M_w \geq 6$ earthquakes.

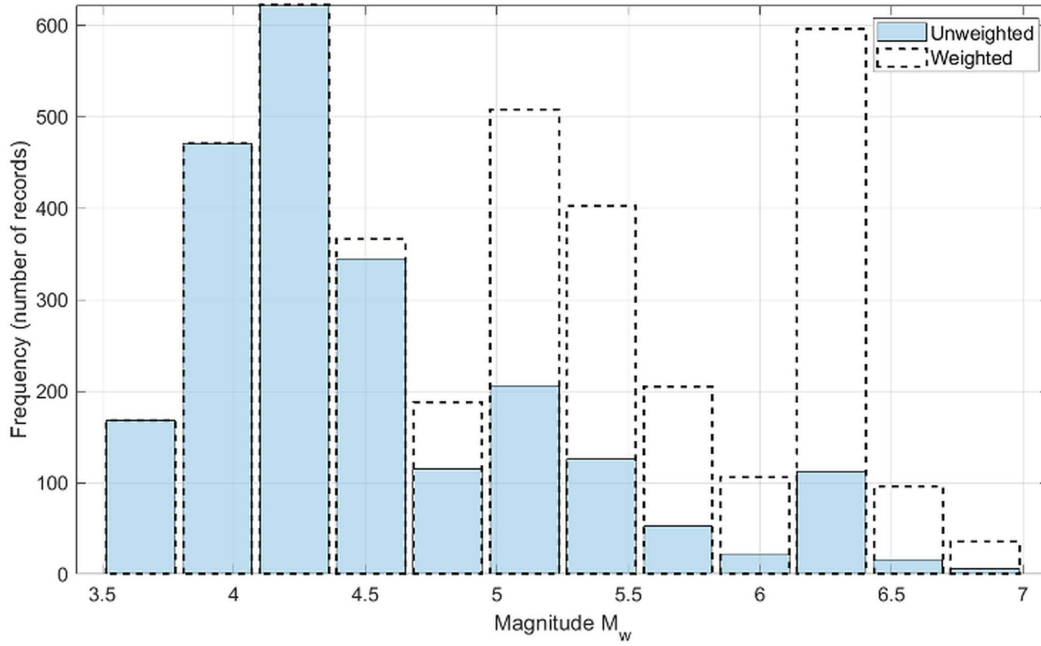


Figure 3. Data frequency changes after weighing techniques.

Such a technique balances the near-field data with lower magnitude and the far-field data with higher magnitudes. This procedure ensures that the regression analysis captures both the distance decay of moderate events and the saturation effects of strong earthquakes, forming a robust empirical foundation for the new GMMs presented in this study. The weighting procedure does not change the number of independent accelerograms, which stays at 2262. Magnitude-dependent weights were applied by proportionally replicating observations based on their assigned weights. This approach gives more influence to records from moderate to large magnitude events in the regression. Thus, the weighted regression dataset contains 3882 observations derived from the original 2262 independent accelerograms (Fig. 3). Ground motion prediction coefficients were estimated by a two-stage regression analysis proposed by Joyner and Boore (1993, 1994), using the same functional form as in a previous hybrid model (Jorjashvili et al., 2022). The same functional form was chosen because it was also shown during the evaluation of the previous model to reflect the attenuation characteristics of the Caucasus region very well. In the first stage of the regression, event-specific amplitude factors and parameters controlling the distance dependence of motion were assessed; in the second, magnitude terms were derived. Faulting mechanism and local soil conditions were also included. This approach allows separate evaluation of the magnitude, distance, and site contributions to GMMs, ensuring model stability. It also allows assessing intra-event and inter-event variability separately.

4. Results and discussion

4.1 Regression results and model coefficients

GMMs in the presented study, as it was mentioned above, were obtained via a two-stage regression analysis. In Appendix 1 the regression coefficients for PGA and SA are listed for both horizontal and vertical components. We also calculated summary statistics for each regression coefficient. These statistics show how stable and variable the model parameters are (Table 2).

The regression coefficients show stable and physically consistent results for both PGA and spectral acceleration (SA). The magnitude-scaling coefficient (c_2) is positive for both horizontal and vertical components, indicating increasing ground-motion amplitudes with earthquake size. The logarithmic distance coefficient (c_3) remains negative across all periods, while the linear distance coefficient (c_5) is generally negative, confirming the expected attenuation of ground motion with distance. The distance-smoothing parameter (c_4) shows moderate period-dependent variation but remains stable for both horizontal and vertical components.

Fault-type coefficients (c_6 - c_9) exhibit greater variability than the magnitude and distance terms, which is expected because fault-mechanism effects are generally less constrained. The site coefficient (c_{10}) remains consistently negative across all periods, indicating a stable site-response effect relative to the reference rock condition. The variability terms (τ , φ , and σ) are also stable for both horizontal and vertical components. Overall, the coefficients demonstrate physically reasonable scaling behavior and attenuation characteristics for the proposed ground-motion model.

Table 2. Descriptive statistics of the model coefficients (c_1 - c_{10}) with standard deviations estimated for PGA and spectral acceleration periods.

Parameter	PGA		SA							
	Horiz.	Vertical	Horizontal				Vertical			
	Values	Values	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
c1	-2.2790	-2.5880	-3.6548	1.3795	-5.5010	-1.5830	-3.6323	1.2955	-5.4060	-1.6840
c2	0.4540	0.4590	0.5376	0.0807	0.4360	0.6560	0.5260	0.0750	0.4370	0.6360
c3	-1.1210	-1.1330	-1.0731	0.2716	-1.5660	-0.7350	-1.1210	0.2370	-1.5730	-0.8410
c4	4.6130	4.3250	4.2489	0.8721	2.1980	5.8570	4.1404	1.1779	2.1180	5.9940
c5	-0.0025	-0.0030	-0.0013	0.0025	-0.0051	0.0033	-0.0009	0.0026	-0.0049	0.0034
c6	0.0070	0.0530	0.0165	0.0085	0.0007	0.0280	0.0143	0.0049	0.0050	0.0230
c7	-0.0150	-0.0090	-0.0058	0.0883	-0.1770	0.1531	-0.0112	0.0470	-0.0900	0.0840
c8	0.0050	0.0060	0.0413	0.0625	-0.0750	0.1368	0.0316	0.0308	-0.0180	0.0976
c9	-0.0220	-0.0180	0.0156	0.0512	-0.0780	0.1002	0.0063	0.0232	-0.0300	0.0568
c10	-0.3840	-0.3720	-0.3892	0.0258	-0.4210	-0.3240	-0.3792	0.0135	-0.4000	-0.3500
τ	0.1870	0.1940	0.2186	0.0280	0.1730	0.2640	0.2153	0.0204	0.1820	0.2430
φ	0.2810	0.2840	0.2999	0.0389	0.2410	0.3770	0.3011	0.0304	0.2610	0.3580
σ	0.3375	0.3442	0.3711	0.0469	0.3027	0.4462	0.3703	0.0352	0.3209	0.4302

4.2 Model Behavior and Physical Characteristics

In this section, model's behavior, physical characteristics and comparisons with previous hybrid models are presented.

Figures 4a and 4b show how the new strong-motion-based GMM predicts PGA curves for magnitudes M5, M6, and M7. As the magnitude increases, ground motions also rise, but they become weaker as the hypocentral distance grows. This shows that the model responds well to changes in both magnitude and distance. Compared to the previous hybrid model, the new GMM gives slightly lower amplitudes and a stronger decrease, especially at medium and large distances. This result is expected because the model uses a consistent, strong-motion dataset and does not include acceleration records from broadband sources.

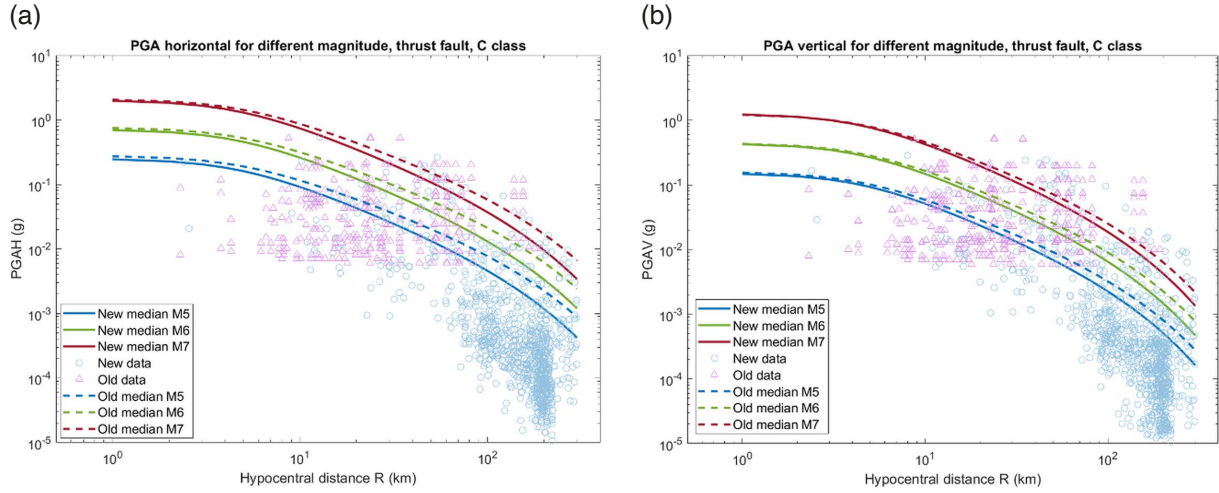


Figure 4. Prediction curves for PGA with different earthquake magnitudes, thrust fault type, and soil class C using the new strong-motion dataset and Smach data: (a) horizontal component; (b) vertical component.

Figure 5a shows how the faulting mechanism affects PGA attenuation for an M6 earthquake under Site Class C conditions. Thrust-fault events produce the highest predicted ground motions, while strike-slip and normal faulting produce lower values. The differences among the three mechanisms are moderate, but the results align with the usual observation that compressional tectonic regimes cause stronger shaking than extensional ones. The small gap between the curves suggests that while the faulting mechanism is a secondary source of variability in the regional dataset, it can still be detected. In this figure is shown that thrust fault events generate the highest ground motions, followed by strike-slip and normal mechanisms, which do not show a big difference between them. This trend aligns with global observations (Boore et al., 2014; Si and Midorikawa, 1999) and confirms the expected higher stress drops in compressional regimes in the Caucasus. The small separation among fault-type curves suggests that mechanism effects, while detectable, are moderate within the regional dataset.

Figure 5b shows how site conditions affect PGA predictions for an M6 thrust-fault earthquake. The model gives the highest amplitudes for Site Class C (soft soil), lower values for Site Class B (stiff soil), and the lowest for Site Class A (rock sites). The gaps between the curves show how near-surface geology influences ground-motion amplification, with softer soils yielding higher PGA values than rock sites at all distances. The consistent ordering

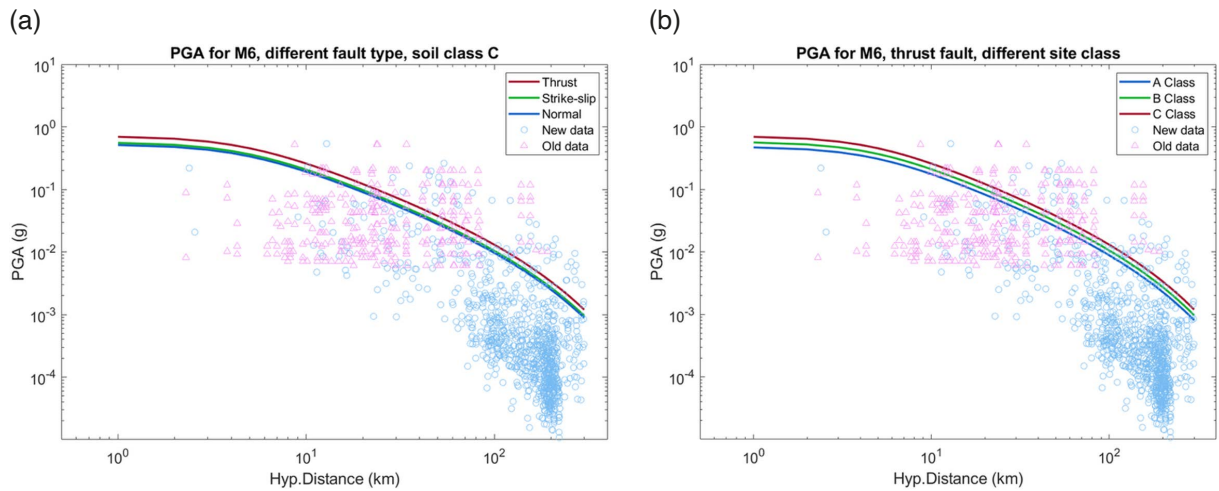


Figure 5. Predicted curves for PGA with M6. (a) Effect of faulting mechanism for Site Class C, showing predictions for thrust, strike-slip, and normal faulting. (b) Effect of site conditions for a thrust-fault earthquake, showing predictions for Site Classes A, B, and C. Open circles and triangles denote recordings from the new strong-motion dataset and the historical SMACH dataset, respectively.

of the curves indicates that the model captures the expected site-response effects and provides predictions for all site classes in the dataset.

Figures 6a and 6b show the variation in spectral acceleration (SA) with periods of 0.01 to 10s for thrust-fault events, and site class C for the horizontal and vertical components, respectively. Both models capture the typical increase of SA up to 0.2-0.3 s, followed by a gradual decay at longer periods. The new GMM yields slightly lower amplitudes in the short-period range (<0.3 s) and closer agreement with the hybrid model at intermediate and higher periods (0.3-10 s).

This reduction at high frequencies may also be attributable to a more homogeneous dataset and improved signal processing that minimizes broadband bias. Overall, the new model preserves the same spectral shape and magnitude scaling, confirming that the region's attenuation characteristics remain consistent with previous findings.

Comparison of the SA curves shows that, despite differences in amplitude, both models present similar spectral shapes and consistent scaling with distance. Figure 7a shows that the difference between the new and old GMMs increases with increasing distance. At 1 km, the two models are very close and show similar spectral shapes with only small amplitude differences. As the distance increases (5-10 km), the old model starts to produce significantly higher SA values than the new model. This gap continues to increase, and at 20-30 km the difference between the

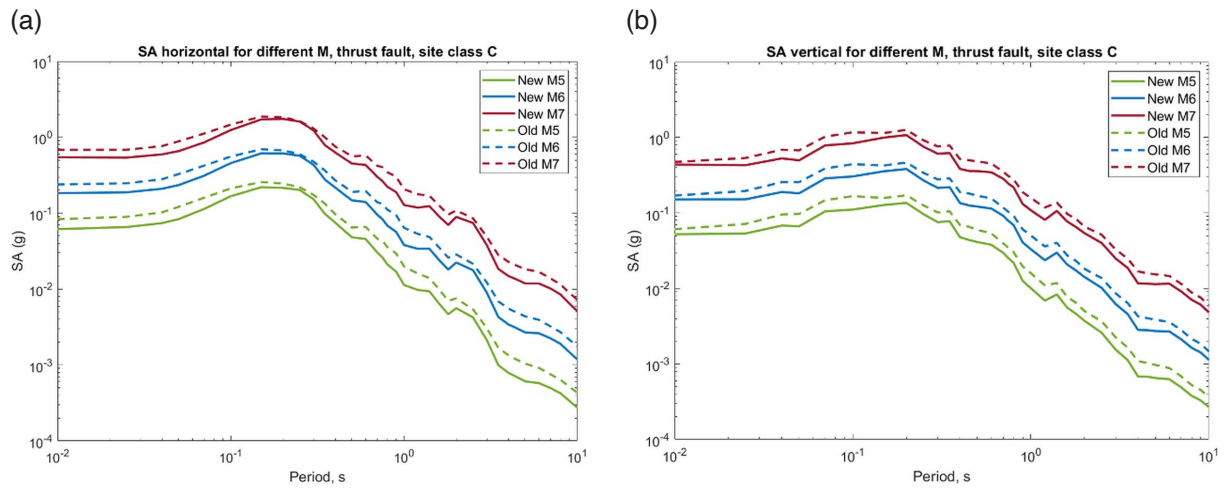


Figure 6. Prediction curves for SA with different earthquake magnitudes at a hypocentral distance of 10 km. (a) horizontal component; (b) vertical component.

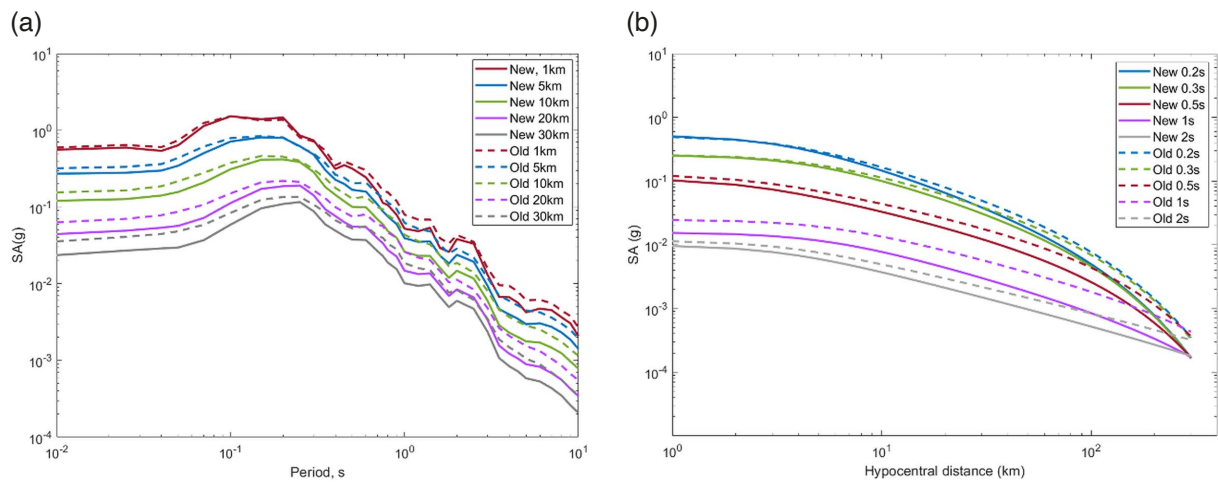


Figure 7. (a) Comparison of spectral acceleration (SA) new and old GMMs for M6, thrust fault, and site class C. Curves are shown for hypocentral distances of 1, 5, 10, 20, and 30 km. Solid lines represent the new GMMs and dashed lines represent the old model. (b) Distance attenuation of SA for selected periods (0.2, 0.3, 0.5, 1, and 2 s) for the new and old GMMs. Solid lines represent the new model, and dashed lines represent the old model.

models becomes most pronounced, especially at short and intermediate periods. Thus, the new GMM predicts systematically lower spectral accelerations than the old model, and the gap progressively widens with increasing hypocentral distance.

Figure 7b illustrates how the new and old GMMs differ in their predictions of SA decay as a function of distance for several key time periods (0.2, 0.3, 0.5, 1, and 2 s). For all periods studied, the new model shows lower SA amplitudes than the old one, and the magnitude of this difference clearly depends on the distance. At short distances, the predictions of both models are relatively similar, with only small differences between the curves. As the distance increases, the difference between them also increases: the old model maintains higher amplitudes over the entire distance range, while the new model decays more rapidly. This increasing difference is evident in both short and long time periods, though it is most noticeable in intermediate periods. Despite differences in amplitude, the general shapes of the decay curves are consistent across periods, indicating that both models follow similar functional forms but differ primarily in amplitude scaling.

Figure 8 compares the newly developed PGA model with several models for an M6 thrust fault and site class C. The comparison models were selected based on their coverage of the area. All models used for comparison are either derived specifically for the Caucasus region or use Caucasus data alongside data from other European countries. Across the full distance range, the curves display similar overall shapes, but the amplitude levels differ substantially among the models. At short distances (<10 km), most previous models predict relatively high PGA values and cluster closely together, with Ambraseys et al. (2005) generally producing the highest amplitudes and Smit et al. (2000) the lowest. The reason for the higher values in Ambraseys et al. (2005) may be the inclusion of stronger earthquakes in Europe than in the Smit et al. (2000) study, which may be due to the limited data used. The new model obtained in the present study falls within the general envelope at close distances, though slightly below the older models.

To provide a quantitative comparison, PGA values were extracted from the models at representative hypocentral distances of 10, 50, and 100 km for an Mw 6 thrust-fault earthquake with Site Class C conditions. At 10 km, the proposed model predicts a PGA of 0.259 g, compared with 0.283 g, 0.332 g, 0.438 g, and 0.201 g predicted by Jorjiashvili et al. (2022), Akkar et al. (2014), Ambraseys et al. (2005), and Smit et al. (2000), respectively. At 50 km, the corresponding PGA values are 0.038 g, 0.050 g, 0.070 g, 0.072 g, and 0.036 g, while at 100 km they are 0.013 g,

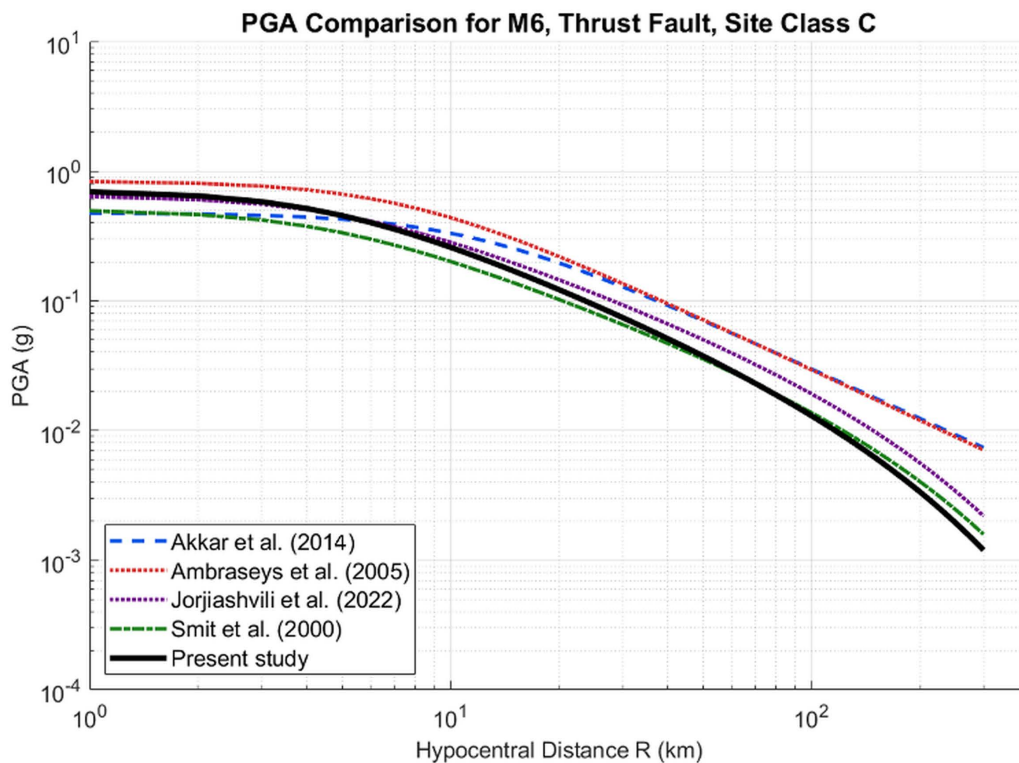


Figure 8. Comparison of PGA curves for M6, thrust fault and site class C. The figure shows predictions from Akkar et al. (2014), Ambraseys et al. (2005), Jorjiashvili et al. (2022), Smit et al. (2000), and the present study.

0.019 g, 0.030 g, 0.029 g, and 0.014 g. These results confirm that the proposed model predicts systematically lower amplitudes than the 2022 hybrid model, Akkar et al. (2014), and Ambraseys et al. (2005), while remaining closest to the model of Smit et al. (2000). The differences become more pronounced with increasing distance, reflecting the stronger attenuation characteristics of the new model.

As distance increases, the divergence between the models becomes more evident. The old GMMs attenuate more slowly, consistently maintaining higher PGA levels, whereas the present study shows a more rapid decay. This results in noticeably lower predicted PGA values at intermediate and large distances (>20–30 km). Compared with the closest previous model (Jorjiashvili et al., 2022), the new model continues to attenuate more rapidly, suggesting differences in path attenuation or in magnitude-scaling behavior in the updated dataset, better network coverage, or the use of homogeneous sensors in the present study.

Overall, the comparison shows that while the new model retains the same physical trend and functional form as existing GMMs, it predicts systematically lower PGA values, especially at larger distances, indicating a stronger attenuation rate than that of previously published models.

4.3 Residual Analysis and Model Performance Evaluation

One of the main parts of the study was an uncertainty and error analysis to assess the reliability of the models obtained. In this section, some statistics, comparisons, and analyses are given.

Figure 9 shows the standardized residuals of the proposed weighted PGA model as functions of moment magnitude, hypocentral distance, and Vs30. When you look at each plot, the points are mostly scattered around the zero line, and none of the points are in a clear direction. There is no steady increase or decrease. It looks mostly random, suggesting the model lacks strong trends in these parameters. The amount of scatter is also quite similar across the range, so the model's behavior appears stable across all the data we used.

We tested how well the proposed weighted ground-motion model performs by examining standardized residuals for magnitude, hypocentral distance, and site condition (Fig. 9). We also examined how using magnitude-dependent weighting and limiting the dataset to distances of up to 200 km affected the results (Figs. 9 and 10).

Figure 9 shows the standardized residuals for the final weighted model. The residuals are evenly distributed around zero across all magnitudes (Fig. 9a), indicating that the magnitude-scaling term captures how PGA depends on earthquake size. There is no clear trend as magnitude increases, so the weighting scheme does not seem to introduce any significant magnitude-based bias.

The residuals for hypocentral distance (Fig. 9b) also stay close to zero. There is more scatter at larger distances, which is expected because of attenuation and assignment, but there is no clear sign of overprediction or underprediction. The residuals remain stable near the 200 km cutoff, indicating that this limit does not introduce significant bias into the regression results.

Figure 9c shows the residuals plotted against Vs30. The residuals stay close to zero for all site conditions in the dataset. There is no clear trend in Vs30, which suggests that the site-amplification term properly accounts for local soil effects.

Figure 10 illustrates how the average standardized residuals for both weighted and unweighted models vary with magnitude and hypocentral distance. In both cases, the residuals mostly stay near zero, showing that the models fit the observed data well. The weighted regression gives similar residual trends as the unweighted model, so weighting does not change the model's overall predictions.

Figure 10a shows that the average residuals remain close to zero in most magnitude ranges. At higher magnitudes, they exhibit small deviations because there are fewer recordings, increasing uncertainty.

Figure 10b shows how the residuals vary with distance. Both models slightly underestimate the observations at very short distances and show positive residuals at intermediate distances. Beyond approximately 150–200 km, the residuals return close to zero, suggesting that the attenuation term remains stable over this distance range. Overall, the weighted model reduces systematic effects related to magnitude while preserving a residual pattern similar to that of the unweighted model.

Figure 11 compares the predictive performance of the 2022 model, the new model with the expanded strong-motion database, and the final weighted model. In all cases, the predicted PGA values follow the general trend of the observations. The scatter around the 1:1 line decreases from the 2022 model to the final weighted model.

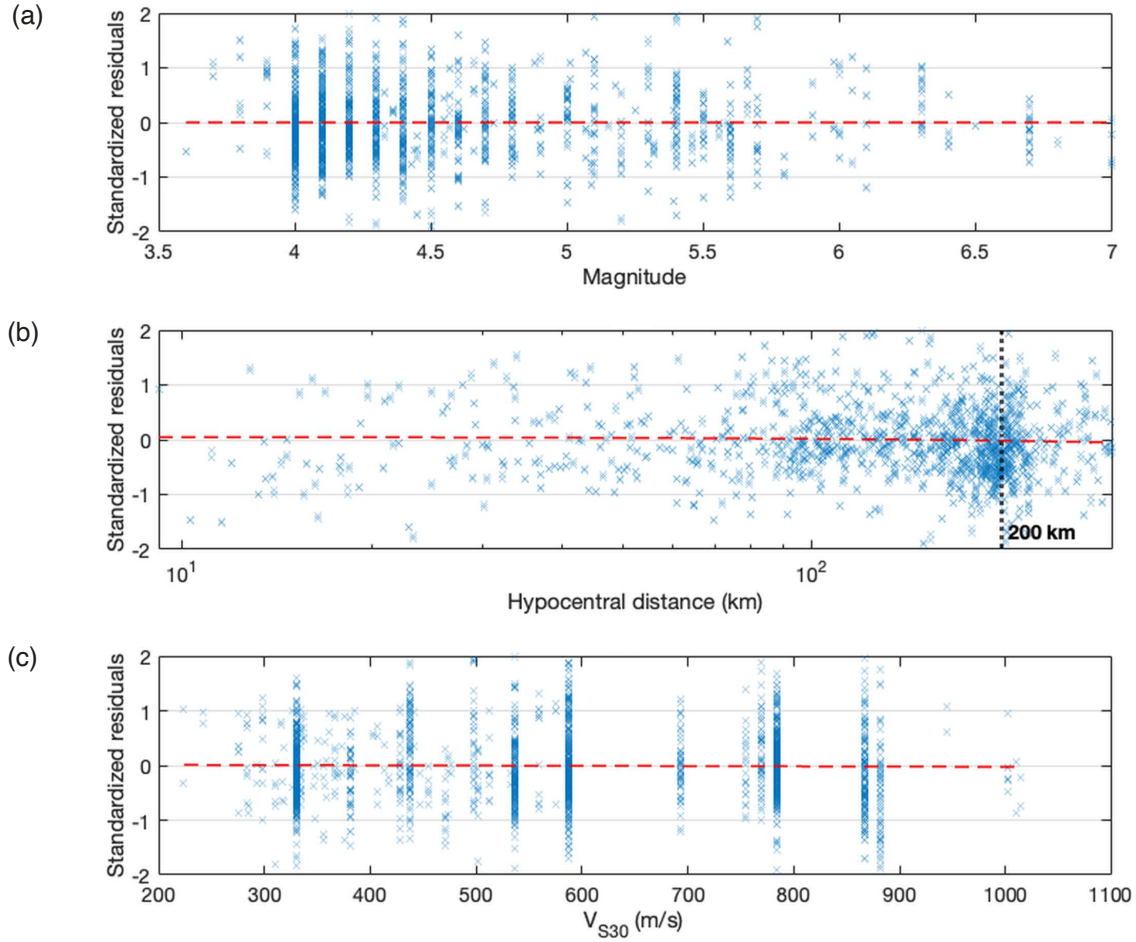


Figure 9. Standardized residuals of the proposed weighted PGA model plotted against: (a) moment magnitude; (b) hypocentral distance, and (c) site condition (V_{S30}). The red dashed line indicates the zero-residual level, while the vertical dotted line in panel (b) marks the 200 km distance threshold.

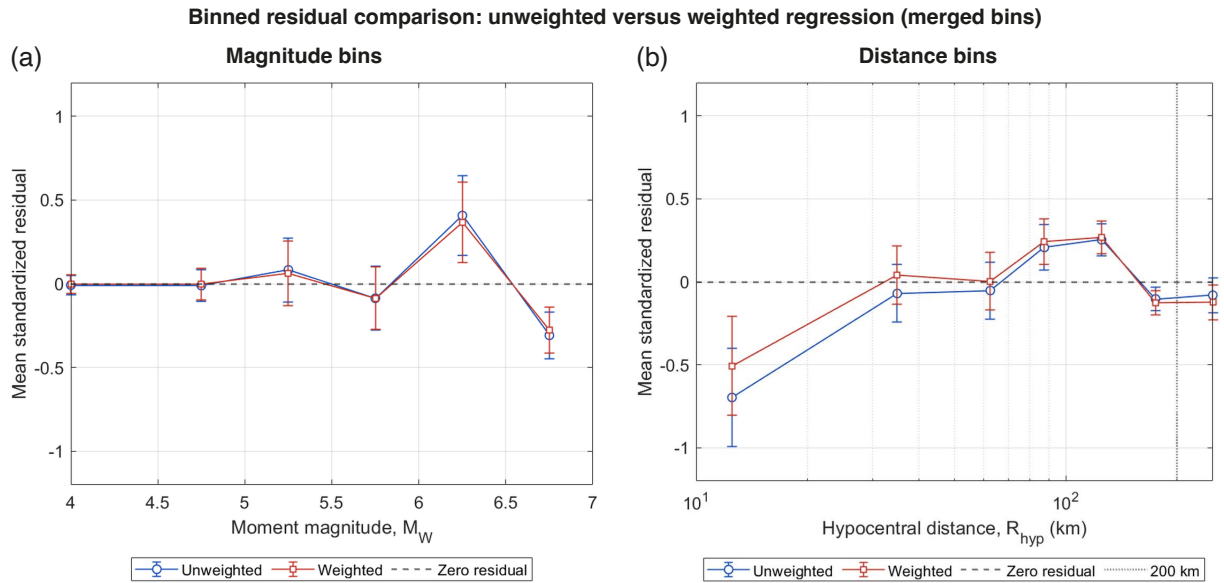


Figure 10. Comparison of binned mean standardized residuals obtained from the unweighted and weighted regressions. (a) Residuals as a function of moment magnitude. (b) Residuals as a function of hypocentral distance. Error bars represent one standard deviation within each bin. The horizontal dashed line indicates zero residual, while the vertical dotted line in panel (b) marks the 200 km distance threshold.

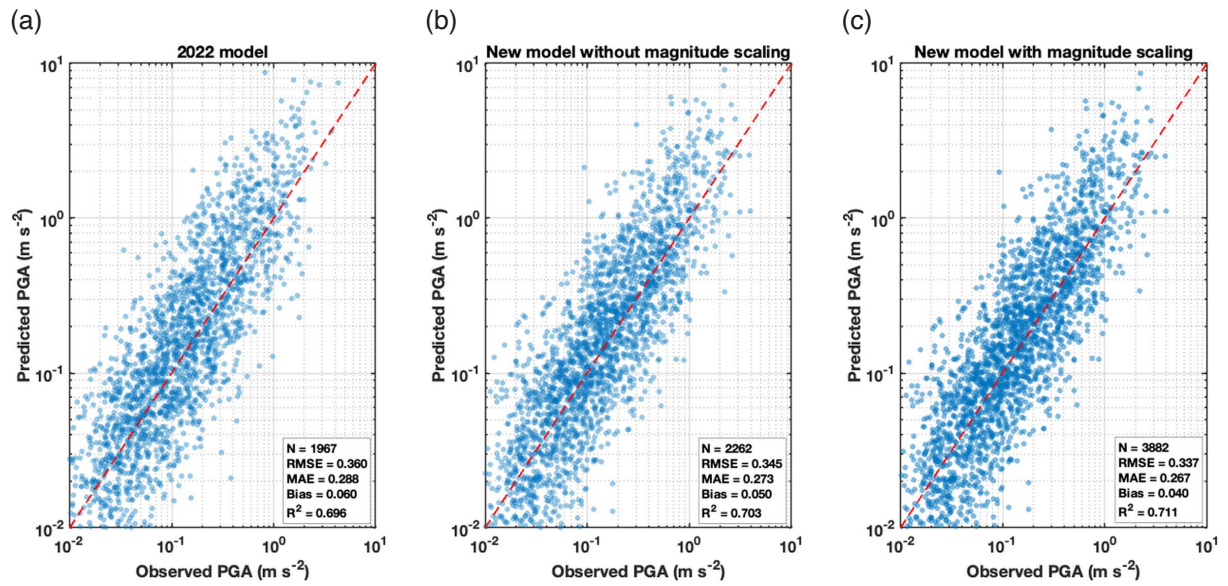


Figure 11. Comparison between observed and predicted PGA values for three generations of ground-motion models. (a) The previously published 2022 hybrid model based on strong-motion and broadband data. (b) The new model developed from the expanded strong-motion database without magnitude-dependent weighting. (c) The final weighted model incorporating magnitude-dependent scaling in the regression. The red dashed line represents the 1:1 agreement line. Statistical performance measures, including the number of records (N), root mean square error (RMSE), mean absolute error (MAE), bias, and coefficient of determination (R^2), are shown in each panel.

The 2022 model has an RMSE of 0.360, an MAE of 0.288, a bias of 0.060, and an R^2 of 0.696. The new model without magnitude-dependent weighting improves these results, lowering the RMSE to 0.345, the MAE to 0.273, the bias to 0.05, and increasing the R^2 to 0.703. The final weighted model shows lower RMSE (0.337), MAE (0.267), and bias (0.040), together with a higher R^2 (0.711), within its respective calibration dataset. However, because the three models were calibrated and evaluated using datasets with different numbers of observations, these performance metrics are not strictly directly comparable and should be interpreted with caution. The comparison indicates that both the expansion of the strong-motion database and the introduction of magnitude-dependent weighting are associated with modest changes in the performance metrics. The weighted model shows lower prediction errors within its respective calibration dataset; however, because the models were evaluated using datasets with different numbers of observations, these differences should not be interpreted as a strictly controlled comparison of predictive performance. Together with the residual analysis, the results indicate that magnitude-dependent weighting provides a stable regression solution while increasing the influence of the relatively sparse moderate-to-large magnitude observations.

The inter-event (τ), intra-event (σ), and total standard deviations are plotted in Fig. 12 for SA. All components are smaller in the new GMM than in the 2022 model across most periods. The total standard deviation decreases by about 10-15%. Both inter-event (τ) and intra-event (σ) decrease in the new model (solid) compared to 2022 (dashed). However, τ values show more reduction than σ (about 15-20%). This can be caused by the better event sampling (many stations per event). Lower σ values result in less path/site heterogeneity and reduced noise from mixed networks. In total, lower values of the total standard deviation can be obtained due to homogeneous sensors and less noise mismatch. The ratio $\sigma > \tau$ remains typical and stable for both models. The minimum variability occurs around 0.1-0.3 s, consistent with other regional and global GMMs (Akkar et al., 2014 (a, b); Boore et al., 2014; Jorjiashvili et al., 2010).

Table 3. Summary of the predictive performance metrics for the 2022 model, the new unweighted model, and the final weighted model. RMSE and MAE show how much the predictions differ from actual values. Bias measures the average difference between observed and predicted results. R^2 shows how much of the variance in the data the model explains.

Metric	2022 Model	New Model (No Weighting)	New Model (Weighted)
N	1967	2262	3882
RMSE	0.360	0.345	0.337
MAE	0.288	0.273	0.267
Bias	0.060	0.050	0.040
R^2	0.696	0.703	0.711

Note: N denotes the number of observations used in each regression. For the weighted model, $N = 3882$ represents the weighted regression observations generated by proportional replication of the original 2262 independent accelerograms; it does not represent 3882 independent records.

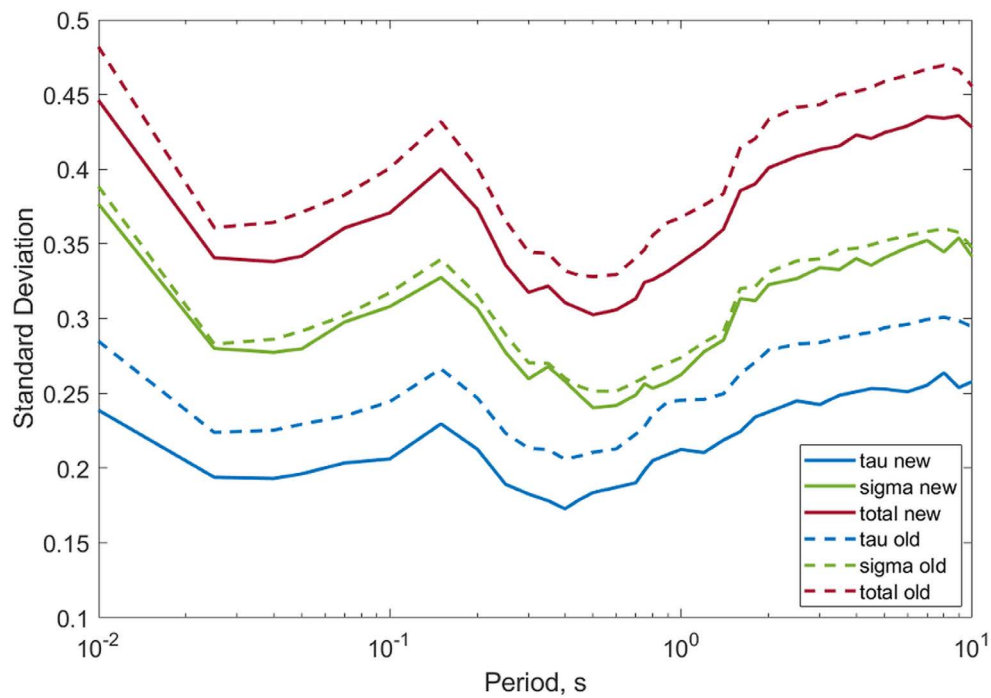


Figure 12. Standard deviation differences between the GMMs obtained in the present study and the 2022 hybrid model.

5. Conclusions

This manuscript presents updated GMMs for Georgia and the surrounding Caucasus region based exclusively on strong-motion recordings. The new models were developed using 2262 high-quality accelerograms from shallow crustal earthquakes. The homogeneous dataset (free of broadband-to-acceleration conversions) improves the reliability of amplitude scaling and attenuation characteristics.

A key refinement in this study was the application of magnitude-dependent weights in the regression. This adjustment increased the contribution of the few large events and reduced the excessive influence of the many smaller ones. With this balance, the magnitude scaling became more uniform, and the regression coefficients remained stable across the full range of magnitudes. The approach also produced smoother attenuation curves and clearer distance-decay patterns, while reducing residual scatter. Overall, the modification improved the stability of the regression and strengthened the physical reliability of the derived GMMs.

It should be noted that comparing the regression coefficients of the present model with those of the previous hybrid model reveals a noticeable change in the coefficient that represents the linear distance-decay term. For PGA, the change is from -0.0023 in the 2022 hybrid model to -0.0025 in the present model, indicating slightly faster attenuation with increasing distance. This result is reasonable because the new GMM is based only on strong-motion recordings, avoiding the additional uncertainty introduced by mixed broadband and accelerometric data.

The obtained results confirm that the new GMMs reproduce the main regional attenuation features identified in the previous hybrid model (Jorjiashvili et al., 2022) with several important improvements. Predicted PGA and SA amplitudes are slightly lower at short distances and short periods (<0.3 s), reflecting the removal of broadband amplitude bias and enhanced signal consistency. The regression analysis demonstrates stable magnitude and distance scaling, with the fault mechanism and site effects remaining significant contributors to ground-motion variability.

Residual analyses showed that the proposed model gives stable predictions across the full range of magnitudes, distances, and site conditions in this study. Standardized residuals are mostly centered around zero and do not show clear trends with magnitude, hypocentral distance, or V_{s30} . This suggests that the chosen functional form captures the main factors affecting ground-motion variability. The magnitude-dependent weighting scheme resulted in lower RMSE, MAE, and bias and a higher coefficient of determination (R^2) within its respective regression dataset. However, because the models are associated with different numbers of regression observations, these differences should be interpreted with caution. Together with the residual analysis, these results indicate that the weighting procedure provides stable model behavior without introducing an evident systematic bias.

A major improvement of the new model is the reduction of aleatory variability. Both inter-event and intra-event standard deviations decreased significantly (primarily inter-event deviations, which decreased by about 15-20%) compared with the 2022 hybrid model, primarily due to better network coverage, homogeneous sensors, and reduced path/site heterogeneity. The ratio $\sigma > \tau$ remains consistent with other regional and global models (Akkar et al., 2014; Boore et al., 2014; Si and Midorikawa, 1999), indicating robust model performance.

Overall, the newly developed GMMs provide a more stable, region-specific, and physically consistent representation of ground motions in the Caucasus. These models are recommended for seismic hazard assessment and engineering applications in Georgia and adjacent areas, and they form a reliable foundation for the next generation of probabilistic seismic hazard maps in the region.

Data availability statement. All data used in the study were obtained from the Institute of Earth Sciences and National Seismic Monitoring Centre (<http://ies.iliauni.edu.ge>) under Ilia State University, and access can be obtained upon special request to the institute. Requests for access to these data should be made via e-mail: earthscience@iliauni.edu.ge. All data used in the study can also be obtained from the IRIS Data Management Center (<https://ds.iris.edu>) and the Engineering Strong-Motion (ESM) database (<https://esm-db.eu>).

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Appendix A.

Table A1. Coefficients and errors obtained by regression analysis. PGAH is the horizontal component of PGA; PGAV is the vertical component of PGA; SAH is the horizontal component of SA; SAV is the vertical component of SA. τ is the inter-event error, σ is the intra-event error, and ε is the total error.

Intensity	T, s	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	τ	σ	ε
PGAH	0	-2.279	0.454	-1.121	4.613	-0.0025	0.007	-0.015	0.005	-0.022	-0.384	0.187	0.281	0.3375
PGAV	0	-2.588	0.459	-1.133	4.325	-0.003	0.053	-0.009	0.006	-0.018	-0.372	0.194	0.284	0.3442
SAH	0.01	-2.215	0.474	-1.478	3.762	-0.002	0.007	-0.077	-0.021	-0.031	-0.412	0.239	0.377	0.4462
SAH	0.025	-2.215	0.458	-1.37	3.398	-0.0023	0.009	-0.06	-0.013	-0.026	-0.388	0.194	0.28	0.3408
SAH	0.04	-2.021	0.453	-1.467	4.392	-0.002	0.008	-0.06	-0.013	-0.028	-0.388	0.193	0.278	0.3382
SAH	0.05	-1.846	0.448	-1.565	4.456	-0.0016	0.009	-0.057	-0.011	-0.03	-0.392	0.196	0.28	0.3419
SAH	0.07	-1.682	0.438	-1.566	3.542	-0.002	0.008	-0.066	-0.019	-0.04	-0.395	0.204	0.298	0.3607
SAH	0.1	-1.583	0.436	-1.463	3.609	-0.0029	0.003	-0.113	-0.043	-0.06	-0.376	0.206	0.308	0.3708
SAH	0.15	-1.741	0.447	-1.228	4.22	-0.0043	0.002	-0.135	-0.063	-0.07	-0.389	0.23	0.328	0.4002
SAH	0.2	-1.961	0.454	-1.062	3.4	-0.0048	0.003	-0.152	-0.068	-0.068	-0.379	0.213	0.307	0.3733
SAH	0.25	-2.011	0.451	-0.989	5.602	-0.0051	7E-04	-0.177	-0.075	-0.078	-0.385	0.189	0.278	0.3359
SAH	0.3	-2.251	0.453	-0.921	4.218	-0.005	0.004	-0.129	-0.049	-0.061	-0.411	0.183	0.26	0.3177
SAH	0.35	-2.509	0.453	-0.876	3.969	-0.0047	0.014	-0.005	0.0208	0.0021	-0.408	0.178	0.268	0.3219
SAH	0.4	-2.645	0.462	-0.882	5.029	-0.0042	0.011	-0.054	-0.004	-0.015	-0.408	0.173	0.258	0.3108
SAH	0.45	-2.924	0.475	-0.798	2.786	-0.0042	0.014	-0.029	0.0117	-5E-04	-0.392	0.179	0.249	0.3065
SAH	0.5	-3.131	0.486	-0.735	2.198	-0.0042	0.015	-0.021	0.0242	0.0079	-0.375	0.184	0.241	0.3027
SAH	0.6	-3.087	0.488	-0.798	3.634	-0.0033	0.019	0.045	0.0542	0.0355	-0.342	0.187	0.242	0.306
SAH	0.7	-3.312	0.498	-0.795	4.057	-0.0029	0.021	0.0735	0.0742	0.0516	-0.324	0.19	0.249	0.3134
SAH	0.75	-3.317	0.503	-0.867	5.701	-0.0023	0.025	0.1291	0.1059	0.0781	-0.33	0.199	0.257	0.3244
SAH	0.8	-3.509	0.511	-0.833	4.409	-0.0022	0.027	0.1531	0.1242	0.0923	-0.337	0.205	0.254	0.3261
SAH	0.9	-3.623	0.524	-0.877	5.253	-0.0016	0.028	0.1501	0.1309	0.0965	-0.346	0.209	0.257	0.3317
SAH	1	-3.813	0.527	-0.89	5.234	-0.0013	0.028	0.1531	0.1368	0.1002	-0.374	0.213	0.263	0.3378
SAH	1.2	-4.024	0.543	-0.836	4.565	-0.0012	0.026	0.1171	0.1142	0.0809	-0.379	0.211	0.278	0.3486
SAH	1.4	-4.219	0.561	-0.765	3.487	-0.0012	0.022	0.045	0.0742	0.0465	-0.382	0.219	0.286	0.3599

Ground-Motion Models for the Caucasus

Intensity	T, s	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	τ	σ	ε
SAH	1.6	-4.312	0.575	-0.881	5.857	-0.0004	0.022	0.042	0.0776	0.044	-0.387	0.225	0.314	0.3856
SAH	1.8	-4.589	0.589	-0.844	4.225	-0.0003	0.022	0.0375	0.0801	0.0408	-0.409	0.234	0.312	0.3902
SAH	2	-4.575	0.601	-0.845	3.298	-0.0003	0.016	-0.048	0.0359	0.0032	-0.41	0.238	0.323	0.4008
SAH	2.5	-4.794	0.622	-0.857	2.912	-0.0001	0.014	-0.089	0.02	-0.01	-0.411	0.245	0.327	0.4085
SAH	3	-4.986	0.625	-0.959	4.732	0.0007	0.019	-0.017	0.0634	0.0242	-0.399	0.243	0.334	0.413
SAH	3.5	-5.297	0.633	-1.029	4.607	0.0012	0.027	0.0855	0.1242	0.0739	-0.392	0.249	0.333	0.4155
SAH	4	-5.459	0.638	-1.007	3.469	0.001	0.028	0.081	0.1242	0.0733	-0.392	0.251	0.34	0.4229
SAH	4.5	-5.501	0.642	-1.045	3.775	0.0012	0.027	0.066	0.1209	0.069	-0.402	0.253	0.336	0.4205
SAH	5	-5.393	0.645	-1.2	5.173	0.0019	0.026	0.042	0.1101	0.0601	-0.41	0.253	0.341	0.4244
SAH	6	-5.433	0.656	-1.251	4.595	0.0022	0.021	-0.018	0.0709	0.0311	-0.419	0.251	0.348	0.4289
SAH	7	-5.45	0.656	-1.3	4.289	0.0025	0.018	-0.033	0.0525	0.02	-0.419	0.256	0.352	0.4353
SAH	8	-5.388	0.651	-1.396	4.789	0.003	0.017	-0.041	0.0375	0.0121	-0.421	0.264	0.345	0.4341
SAH	9	-5.396	0.642	-1.444	4.665	0.0032	0.017	-0.026	0.0384	0.0164	-0.414	0.254	0.354	0.4358
SAH	10	-5.36	0.636	-1.511	5.655	0.0033	0.017	-0.02	0.0384	0.0191	-0.414	0.258	0.342	0.428
SAV	0.01	-2.841	0.461	-0.85	4.107	-0.0045	0.006	-0.05	-0.012	-0.026	-0.396	0.239	0.358	0.4302
SAV	0.025	-2.157	0.453	-1.485	4.365	-0.0019	0.006	-0.05	-0.008	-0.022	-0.373	0.197	0.281	0.3432
SAV	0.04	-1.941	0.445	-1.535	4.694	-0.0018	0.008	-0.027	0.0025	-0.014	-0.372	0.189	0.285	0.3418
SAV	0.05	-1.872	0.437	-1.572	4.032	-0.0018	0.009	0.009	0.0217	-0.002	-0.374	0.198	0.294	0.354
SAV	0.07	-1.684	0.437	-1.573	4.47	-0.0024	0.008	-0.023	0.005	-0.016	-0.368	0.203	0.309	0.3698
SAV	0.1	-1.7	0.439	-1.546	5.489	-0.0029	0.011	0.0015	0.0242	-0.002	-0.375	0.213	0.311	0.3772
SAV	0.15	-2	0.447	-1.193	2.308	-0.0047	0.005	-0.06	-0.018	-0.03	-0.365	0.216	0.33	0.3942
SAV	0.2	-2.135	0.449	-1.066	3.275	-0.0049	0.008	-0.048	-0.011	-0.023	-0.375	0.217	0.318	0.3843
SAV	0.25	-2.328	0.447	-0.99	5.423	-0.0047	0.01	-0.038	0.0058	-0.013	-0.393	0.196	0.289	0.349
SAV	0.3	-2.566	0.453	-0.915	4.169	-0.0048	0.013	0.009	0.03	0.0087	-0.387	0.189	0.27	0.3293
SAV	0.35	-2.509	0.452	-0.949	5.625	-0.0043	0.013	-0.005	0.0192	0.0002	-0.36	0.184	0.276	0.3314
SAV	0.4	-2.73	0.453	-0.945	4.354	-0.0037	0.016	0.0495	0.0509	0.0268	-0.381	0.182	0.265	0.3214
SAV	0.45	-2.771	0.457	-0.997	5.159	-0.0032	0.017	0.0615	0.0559	0.0349	-0.383	0.182	0.264	0.3209
SAV	0.5	-2.87	0.47	-0.998	4.949	-0.0029	0.016	0.0525	0.05	0.031	-0.382	0.197	0.277	0.3399

Intensity	T, s	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	τ	σ	ε
SAV	0.6	-2.899	0.48	-1.039	5.695	-0.0021	0.015	0.0105	0.0259	0.0115	-0.365	0.195	0.269	0.3324
SAV	0.7	-3.183	0.491	-0.908	2.118	-0.0021	0.013	-0.023	0.0133	0.0033	-0.35	0.2	0.263	0.3305
SAV	0.75	-3.198	0.493	-0.954	4.97	-0.0018	0.014	-0.011	0.0217	0.0067	-0.355	0.194	0.261	0.3252
SAV	0.8	-3.292	0.499	-0.974	5.694	-0.0015	0.015	-0.012	0.0259	0.0066	-0.359	0.201	0.264	0.3318
SAV	0.9	-3.581	0.51	-0.971	4.306	-0.0011	0.021	0.069	0.0767	0.048	-0.357	0.208	0.263	0.3349
SAV	1	-3.701	0.516	-0.99	5.449	-0.0006	0.022	0.078	0.0842	0.0537	-0.363	0.211	0.264	0.3385
SAV	1.2	-4.035	0.535	-0.937	2.472	-0.0003	0.023	0.084	0.0851	0.0568	-0.372	0.221	0.282	0.3582
SAV	1.4	-4.005	0.554	-0.994	5.994	-0.0001	0.017	-0.026	0.0317	0.0091	-0.388	0.223	0.287	0.3634
SAV	1.6	-4.371	0.57	-0.849	2.531	-0.0004	0.017	-0.023	0.0317	0.0058	-0.385	0.226	0.296	0.3721
SAV	1.8	-4.523	0.576	-0.841	2.891	-0.0002	0.018	-0.001	0.045	0.0138	-0.389	0.223	0.289	0.3651
SAV	2	-4.565	0.581	-0.925	4.688	0.0003	0.015	-0.041	0.03	-0.004	-0.394	0.23	0.303	0.3803
SAV	2.5	-4.775	0.595	-0.952	3.206	0.0007	0.018	-0.014	0.0534	0.0127	-0.386	0.233	0.309	0.3871
SAV	3	-4.976	0.603	-0.994	2.837	0.0011	0.019	0.0075	0.0659	0.0213	-0.377	0.231	0.324	0.3979
SAV	3.5	-5.13	0.611	-1.02	2.975	0.0013	0.019	0.0105	0.0659	0.0215	-0.382	0.242	0.332	0.4107
SAV	4	-5.384	0.617	-1.039	2.599	0.0016	0.023	0.0495	0.0976	0.0467	-0.385	0.243	0.332	0.4117
SAV	4.5	-5.277	0.616	-1.139	4.288	0.0021	0.02	-0.006	0.0725	0.0209	-0.39	0.239	0.339	0.4147
SAV	5	-5.198	0.622	-1.241	4.932	0.0026	0.018	-0.029	0.0617	0.0124	-0.393	0.242	0.335	0.4133
SAV	6	-5.192	0.633	-1.325	4.945	0.0029	0.014	-0.084	0.0242	-0.012	-0.396	0.243	0.337	0.4151
SAV	7	-5.211	0.635	-1.435	5.404	0.0034	0.013	-0.09	0.0092	-0.017	-0.4	0.242	0.347	0.4235
SAV	8	-5.377	0.636	-1.37	3.14	0.0031	0.013	-0.077	0.0083	-0.012	-0.394	0.241	0.349	0.4246
SAV	9	-5.379	0.635	-1.424	3.245	0.0033	0.012	-0.077	0.0008	-0.014	-0.394	0.238	0.34	0.4146
SAV	10	-5.406	0.627	-1.42	2.257	0.0031	0.011	-0.081	-0.008	-0.02	-0.392	0.224	0.328	0.397

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