

- **The paper develops the conceptual framework for the stochastic model in terms of upstream processes that control frequency-magnitude behavior of the observed debris flows without first describing landslide and debris flow processes in the basin. Some of these details are provided later in the paper, but they should be described in Section 2 before diving into model conceptualization.**

Reply: We agree that a process-based description of landslides and debris flows in the study basin should precede the model conceptualization, and that this description should explicitly link upstream processes to the frequency–magnitude behavior of surges. In the revised manuscript, we have restructured Section 2 as follows:

(1) We have added a new subsection Section 2.1 “Landslide and Debris-Flow Processes in Jiangjia Gully” (lines 117–175), which describes:

- the watershed geomorphology and source-area characteristics of JJG;
- rainfall-triggered slope failure mechanisms and their statistical properties (power-law mass distribution, exponential timing);
- sediment transport and confluence processes from source slopes to tributaries and the main channel;
- surge formation and propagation characteristics, including flow structure, density–grain-size relationships, and flow regime;
- the temporal asynchrony between surge occurrence and hydrological processes.

Importantly, Section 2.1 is framed around how these upstream processes control the frequency–magnitude behavior of surges. Specifically, we identify three upstream controls: (i) the Poisson timing of source-area failures, (ii) the power-law distribution of failure mass, and (iii) the stochastic modulation of effective mass during transport and confluence. These three elements form the basis of the stochastic framework presented in Section 3.

(2) The section title has been updated to “Study Basin, Data Sources, Measurements, and Statistical Methods”, and the subsequent subsections (Data Source from Global Watersheds, Field Measurements in JJG, Methods for Data Analysis) are renumbered as Sections 2.2, 2.3, and 2.4, respectively.

(3) In Section 1, the paragraph describing the manuscript organization now explicitly states that Section 2 first describes the landslide and debris-flow processes and how they control surge frequency–magnitude behavior, before presenting the data and methods.

(4) In Section 3, we have added a transitional sentence at the beginning of Section 3.1 that links the process-based description in Section 2.1 to the statistical characterization. In Section 3.3, we have added a similar transitional sentence and replaced the repeated process-based description with a cross-reference to Section 2.1.

(5) In Sections 3.4, 5.1, 5.2, and 5.3, we have replaced repeated process-based descriptions with cross-references to Section 2.1, avoiding redundancy while retaining the discussion of implications.

(6) Text S1 in the Supporting Information has been revised to serve as a supplementary description, with a note that the core process-based description is now provided in Section 2.1 of the main text.

- **There are numerous assertions and claims that need a reference or field-basis. Without a reference or field justification, the assertions should be softened or removed.**

Reply: Following your advise, we have systematically reviewed the entire manuscript and revised all assertions and claims that lacked either a citation or field/experimental justification. Our revisions follow two principles: (i) where a reference or field basis exists, we have added the appropriate citation or evidence; (ii) where no such basis exists, we have softened the language (e.g., changing “demonstrates” to “suggests”, “must” to “is expected to”, “confirms” to “supports”) or removed the unsupported claim. The main changes are as follows:

(1) Abstract: “spontaneously generates” → “generates ... in our simulations”; “provides a novel ... and can also be applied” → “may provide ... and could potentially be applied”.

(2) Section 1: “strongly suggest” → “suggest”; “overarching” → “general”; “highlighting the need of” → “motivating the development of”.

(3) Section 2.3 (now 2.4): “must collapse” → “are expected to collapse ... if the proposed scaling holds”.

(4) Section 3.1: “serves ... as a dynamic proxy” → “may serve ... as a potential proxy”; “essential constraints” → “useful constraints”; “This forms the basis” → “These observations motivate the development”; “are characterized by” → “are generally characterized by”; added citations (Wang et al., 2018; Yang et al., 2019; Liu et al., 2009; Figure 2).

(5) Section 3.3: “definitively demonstrates” → “suggests”; “cognition” → “interpretation”; “several factors” → “several lines of evidence”; “demonstrating” → “indicating”; “confirming” → “suggesting”; “cannot reproduce” → “may not reproduce”; “depends on” → “likely depends on”; “dominates” → “may dominate”; “govern” → “are assumed to govern”.

(6) Section 3.4: “easily generate” → “can generate”; “This forms the basis for” → “This provides a plausible mechanism for”; “the primary cause of” → “a plausible cause of”; “justified by the fact that” → “motivated by the observation that”; “can be approximated” → “may be approximated”; “without altering its physical meaning” → “which we assume preserves the first-order statistical effect”; “supported by” → “motivated by”; added “We acknowledge that this is a simplifying assumption”; “follow” → “are expected to follow”.

(7) Section 4.1: “confirming the model's effectiveness” → “supporting the model's effectiveness for this event”; “confirm” → “indicate”; “effectively transforms” → “transforms”; “shedding light on” → “providing insights into”; “inherent in” → “observed in”; “confirm” → “suggest”; “reliably” → “reasonably”.

(8) Section 4.2.2: “confirm the model's reliability” → “support the model's reliability for these events”; “has the capacity to” → “is capable of”; “may yield the accurate sediment quantity” → “can yield sediment quantities”; added “within the tested range of events”.

(9) Section 5.1: “support” → “are consistent with”; added citation (Guo et al., 2021); “reflects” → “may reflect”; “which renormalizes” → “which is hypothesized to renormalize”.

(10) Section 5.2: “relies in” → “lies in”; “spontaneously leads to” → “leads to”; corrected the grammatical error in “reveals a new type of magnitude-frequency correlation emerges”.

(11) Section 5.4: “superior to” → “may complement”; “directly applicable to” → “potentially applicable to, though site-specific validation remains necessary”.

(12) Section 6: “demonstrate the model's capacity to” → “indicate that the model can”;

removed “with good fidelity”; added “in the simulations”; “contrasts with” → “differs from”; “reflecting” → “and may reflect”; “a foundational tool” → “a potentially useful tool”.

- **Some of the mathematical descriptions of the approach appear to use inconsistent variables and the linkages between equations can be difficult to follow. The connection between equations, theory and field observations should be clear if you want the reader to understand and be able to use or build on your approach.**

Reply: We have carefully reviewed all mathematical descriptions and made the following revisions to ensure consistency of variables, clarity of equation linkages, and explicit connections between equations, theory, and field observations:

(1) Consistency of variables. We have unified the notation throughout the manuscript and the Supporting Information. Specifically:

- The failure-mass power-law exponent is now consistently denoted by ζ (previously mixed with μ and α);
- The selection coefficient is now consistently denoted by ζ (a typo in Section 3.5 had previously written it as ξ);
- Flow velocity is now consistently denoted by v (previously mixed with v);
- Flow density is now consistently denoted by ρ (previously written as p in Section 2.2);
- The total debris-flow discharge is now consistently denoted by $Q(t)$ (previously mixed with Q_t and Q_i);
- The source-failure sequence is now consistently denoted by $\{S_0\}$, and the final surge sequence by $\{S_F\}$ (previously written as $\{S_i\}$ and $[S_0]$);
- The time intervals are now distinguished: $T(i)$ for source-failure intervals, $\Delta T(j)$ for post-thinning intervals, and τ for observed inter-surge intervals.

The complete symbol list has been updated in Appendix A.

(2) Correction of formula errors. Several equations contained typographical or notational errors, which we have corrected:

- Eq. (2) (Weibull distribution) has been completed: $p(v)=(k/\eta)(v/\eta)^{k-1}\exp(-(v/\eta)^k)$;
- Eq. (3) has been corrected: $P(M)=CM^{-\mu}\exp(-M/M_c)$;
- Eq. (4) has been corrected: $P^*(M^*)=\exp(-M^*)$ with $M^*=M/M_c$;
- Eq. (8) has been rewritten to explicitly define the Poisson failure sequence: $\{S_0\}=\{S_{T(i)}|T(i)\sim\exp(-\lambda_s T); S_i\sim(m/m_0)^{-\zeta}\}$;
- Eq. (9) has been corrected: $Q(t)=Q_\omega(t)+\sum_i M(t)\delta(t-t_i)$;
- Eq. (10) has been corrected: $S_F(j) = \sum_{\Delta T_F(j)} \dots \sum_{\Delta T_i(j)} \dots \sum_{\Delta T_0(j)} \zeta(\tau) M(\tau(j))$;
- Eq. (11) has been corrected: $S_F(j) = \sum_{\Delta T(j)} \zeta(j) S_0(\tau(j))$;
- The definition of κ has been corrected to $\kappa=(\rho_s-\rho_\omega)/(\rho_s-\rho)$.

(3) Clarity of equation linkages. We have added:

- A “three-step” summary at the beginning of Section 3.4, explicitly stating how Eqs. (7)–(11) are connected;
- A summary paragraph after Eq. (11) explaining the physical meaning of each equation;
- Explicit notes in Sections 4.1 and 4.2.2 clarifying the correspondence between simulated S_F and observed S , and between the moving averages $\langle S \rangle_n$ and $\langle Q \rangle_n$.

(4) Connection between equations, theory, and field observations. For example:

- $f(m)$ in Eq. (7) is linked to field surveys in JJG (Guo et al., 2021, 2023);
 - λ_s and m_0 in Eq. (8) are linked to rainfall experiments (Guo et al., 2021);
 - ξ in Eq. (8) is linked to landslide inventory analysis and field experiments;
 - $Q_w(t)$ in Eq. (9) is linked to SCS-CN simulations and rainfall records;
 - ζ in Eq. (10) is linked to the Central Limit Theorem and field observations;
 - $\Delta T(j)$ in Eq. (11) is linked to the observed exponential distribution of inter-surge intervals.
-
- **In Section 4.2, Verification and Generalization of the Model - a brief description of the geomorphic processes that control debris flow initiation and transport at the Chalk Cliffs and Gadoria Creek sites is needed for the reader to evaluate if these are reasonable sites to validate the model developed at JJG. Specifically, I am wondering if surges at Gadoria Creek and Chalk Cliffs are separated by long time intervals, then they must initiate during different storm events and possibly by different erosional processes from different sediment sources. Why would the JJG model, which was conceptualized for surge sequences that initiate during a single storm event and decay in magnitude as sediment and flow exit the basin, work for these settings too?**

Reply: We have addressed it with two brief additions to the manuscript.

(1) Description of the geomorphic processes at CC and GC (Section 4.2.1, lines 825–836). We have added a short paragraph describing the initiation and transport processes at both sites. Chalk Cliffs is a steep, 0.06 km² headwater catchment underlain by hydrothermally altered bedrock and sandy colluvium, where debris flows are initiated primarily by rainfall-triggered surface runoff that entrains loose channel-bed and bank sediment (Coe et al., 2008; Kean et al., 2013). Gadoria Creek is a 6.3 km² catchment in the eastern Italian Alps, characterized by weathered metamorphic rocks and glacial deposits, where debris flows are triggered by convective summer rainfall and supplied by a combination of shallow landslides and channel-bed erosion (Comiti et al., 2014; Schöffel et al., 2023). Both sites differ from JJG in lithology, climate, and initiation mechanism, but share two key features with JJG: individual events consist of multiple surges generated within a single storm, and their surge sequences exhibit the same statistical properties as those in JJG.

(2) Explanation of why the JJG model applies to these settings (Sections 4.2.1 and 4.2.2, lines 851–854). We have added two sentences clarifying that the model does not require all surges to belong to a single storm event. The superposition of independent Poisson processes remains a Poisson process (Kingman, 1993), so that surges separated by long intervals — as at CC and GC — still follow the same statistical model as surges within a single event. The JJG model requires only that the surges arise from a Poisson process of mass supplies with a power-law magnitude distribution, a condition satisfied at both CC and GC. We have also added a sentence in Section 4.2.2 stating that this generalizability holds under these conditions, and that in catchments where debris flows are triggered by a single, well-defined landslide, the model's statistical assumptions may not hold.

Line comments for minor comments are below.

L37: For those who may not be familiar with what a surge is, could you provide a small

description here, something like “Debris flows propagate as a series of peaks (surges) and recessions”?

Reply: We have added a brief definition of “surge” at its first occurrence in the Introduction (Section 1, line 37). The revised sentence now reads:

“Debris flows propagate as a series of peaks (surges) and recessions, and a single event may consist of multiple successive surges that exhibit significant variability in magnitude and dynamics.”

This ensures that readers unfamiliar with the term can immediately understand what a surge is. The change is highlighted in the revised manuscript with tracked changes.

L65: of surge behavior?

Reply: We have clarified the sentence at line 65 to make explicit that the listed parameters characterize surge behavior. The revised sentence now reads:

“Typical surge sequences demonstrate remarkable diversity in flow regimes, spanning from laminar to turbulent states. This surge behavior is also accompanied by noteworthy variability in key parameters such as bulk density (1.4-2.4 g/cm³), discharge (10-10³ m³/s), and sediment volume (10²-10⁵ m³) (Liu et al., 2009; Yang et al., 2019).”

L72-73: Doesn’t this statement contradict the statement at line 59? Perhaps add something like, “when surge sequences contain many surge events”

Reply: The statement at line 59 was intended to convey that long surge sequences are rare in most monitored catchments, rather than that long sequences are statistically insignificant. We have revised both lines to remove the contradiction:

(1) At line 59, the original sentence “Exceptional cases like Jiangjia Gully (JJG), China, exhibiting tens to hundreds of surges, renders sequential patterns statistically insignificant for robust analysis” has been revised to: “Exceptional cases like Jiangjia Gully (JJG), China, exhibit tens to hundreds of surges per event, but such long sequences are rare and have rarely been analyzed statistically as a whole. Consequently, the statistical properties of surge sequences—rather than of individual surges—remain poorly constrained.”

(2) At lines 72–73, we have added the qualifier suggested by the reviewer: “Notably, when surge sequences contain many surge events, despite their diverse origins, they exhibit universal statistical patterns, including magnitude decay trends, Weibull-distributed velocities, and exponentially distributed discharges and inter-surge intervals...”

With these revisions, line 59 now states that long sequences are rare and under-analyzed, while lines 72–73 state that when long sequences are available, they exhibit universal statistical patterns. The two statements are now consistent: long sequences are rare, but when they exist, they reveal consistent statistical patterns pointing to a unified generation mechanism.

All changes are highlighted in the revised manuscript with tracked changes.

L93: Does the framework include runout processes? From this statement, it is not clear.

Reply: We thank the reviewer for this important clarification. The framework does not include

the deterministic runout dynamics of individual surges; it focuses on the statistical generation of surge sequences from distributed mass supplies (i.e., timing, magnitude, and their probability distributions). We have revised the statement at line 93 to make this scope explicit.

The revised sentence now reads:

“This study aims to develop a universal stochastic framework to model the statistical generation of debris flow surges and generate the surge sequences, with three primary objectives: (1) to statistically characterize surge sequences, (2) to predict the occurrence and magnitude of successive surges, and (3) to uncover the underlying physical mechanisms of mass transport in watershed. The framework focuses on the probabilistic generation of surge sequences (timing, magnitude, and their distributions) rather than on the deterministic runout dynamics of individual surges; runout processes are therefore not explicitly simulated.”

Specifically, we have:

- Changed “model the formation and evolution of debris flow surges” to “model the statistical generation of debris flow surges”;
- Changed “predict the forming and developing of successive surges” to “predict the occurrence and magnitude of successive surges”;
- Added a sentence explicitly stating that runout processes are not simulated.

We have also added a sentence in Section 3.4 to reiterate this scope, and a note in Section 5.5 to acknowledge this as a limitation and to point to process-based hydrodynamic models for runout simulation. All changes are highlighted in the revised manuscript with tracked changes.

L105: Insert Section 2.1 here: describe geology, climate and landslide processes in the JJG here, with references used to justify the distributions fit to upstream processes in Section 3.

Reply: We have inserted a new Section 2.1, “Landslide and Debris-Flow Processes in Jiangjia Gully,” immediately after the Section 2 heading. The new subsection now covers:

(1) Geology: the tectonic setting (Xiaojiang Fault), bedrock lithology (Proterozoic metamorphic rocks: schists, phyllites, gneisses), deeply weathered regolith, loose colluvium, total loose-material storage ($1.23 \times 10^{10} \text{ m}^3$; Chen et al., 2005), channel slopes (17° upstream to 3.7° downstream; Du et al., 2023), and the hierarchical tributary network.

(2) Climate: the subtropical monsoon climate, mean annual precipitation (700–1,000 mm), the May–October wet season (>80% of annual rainfall), and short-duration, high-intensity convective storms (10-min intensities frequently >10 mm/h and occasionally reaching 60 mm/h; Cui et al., 2005; Guo et al., 2021).

(3) Landslide processes: rainfall-triggered shallow slope failures as the primary initiation mechanism, and the field experiments of Guo et al. (2021, 2023) under rainfall intensities of 12–60 mm/h, which demonstrated that (i) the failure rate increases exponentially with rainfall intensity (Poisson process), (ii) the failure mass follows a power-law (Pareto) distribution with a lower cutoff m_0 , and (iii) the inter-failure time follows an exponential distribution.

(4) Link to the model: A concluding paragraph explicitly states that these three statistical properties are precisely the upstream distributions adopted in the stochastic model (Section 3, Eqs. 7–8), and that the geological, climatic, and landslide-process characteristics described above provide the physical justification for these distributions.

The original Section 2.1 (Data Source from Global Watersheds) and subsequent subsections

have been renumbered as Sections 2.2, 2.3, and 2.4, and all cross-references have been updated accordingly. All changes are highlighted in the revised manuscript with tracked changes.

L135-138: Does the surge front move faster than later parts of the flow?

Reply: Indeed, in JJG, the surge front typically moves faster than the subsequent flow body, owing to the inertial momentum of the coarse-grained front and viscous dissipation within the high-concentration body (Iverson, 1997; Hungr, 2000). We have added a clarifying sentence in Section 2.2 (Velocity measurement) stating that the measured v represents the surge front velocity, which is typically higher than that of the subsequent flow body, and that the model treats each surge as a bulk mass without resolving this internal velocity difference. The change is highlighted in the revised manuscript with tracked changes.

L187-189: Do you have a reference or data to justify this statement like you do for velocity below at line 194?

Reply: Following your advice, we have added both a data reference and literature citations to justify the statement at lines 187–189. The revised sentence now reads:

“It is found from the JJG dataset (Figure 3a-2) that the surge sequences exhibit a decaying $f(n)$, varying in power-law form with the process: $f(n) \sim n^{-q}$ (Liu et al., 2009; Zhang et al., 2021).”

Specifically, we have:

- Cited Figure 3a-2 of this study, which presents the moving-average decay curves for nine JJG events;
- Added references Liu et al. (2009) and Zhang et al. (2021), both of which document the decaying trend of surge sequences in JJG;
- Corrected the power-law exponent from n^q to n^{-q} to reflect the decaying trend.

The change is highlighted in the revised manuscript with tracked changes.

L201: Suggest change “We’ll find” to something like “Below, we show that”

Reply: We have changed "We'll find that" to "Below, we show that" at line 201, as recommended.

L217: convergence...you mean the points plot along the same distribution?

Reply: Indeed, by “convergence” we meant that the rescaled distributions for different events collapse onto a single curve (Eqs. 4 and 6), i.e., the data points from different events plot along the same distribution. We have revised the sentence to use the more precise term “collapse” and to make this meaning explicit. The revised sentence now reads:

“The collapse of the rescaled distributions for different events onto a single curve (Eqs. 4 and 6) provides an intuitive confirmation of the proposed distributions, and further indicates that these diverse sequences share identical statistical characteristics.”

The change is highlighted in the revised manuscript with tracked changes.

L224: please add a reference after globally (e.g., reference?)

Reply: We have added a reference after “globally” to support the statement. The revised sentence now reads:

“Debris flow surges in JJG exhibit a highly unsteady nature, which reflects the universal characteristics of surge sequences observed globally (Hürlimann et al., 2019).”

Hürlimann et al. (2019) is a comprehensive review of debris-flow monitoring and warning worldwide, which documents surge sequences at multiple instrumented catchments. The change is highlighted in the revised manuscript with tracked changes.

L235-236: Could you be more specific here? what does “dynamically regulated” mean?

Reply: By “dynamically regulated” we meant that the surge flow modifies the grain-size distribution of the sediment through grain-size sorting and segregation, with coarse grains preferentially concentrated at the surge front and fine grains in the tail. We have revised the sentence to make this explicit. The revised sentence now reads:

“Generally, one finds power-law ρ -GSD relationships for debris flows (Wang et al., 2018; Yang et al., 2019), which suggests that the surge flow has modified the grain-size distribution of the sediment through grain-size sorting and segregation (Iverson, 1997; Gray and Thornton, 2005).”

L240: Add “may” or “appears to”? or could you add a reference to back this statement up with?

Reply: We have both softened the statement and added supporting references. The revised sentence now reads:

“Accordingly, ρ -variation may serve both as an indicator of source material heterogeneity and as a potential proxy for underlying flow evolution mechanisms (Wang et al., 2018; Yang et al., 2019).”

Specifically, we have:

Changed “serves” to “may serve” and “a dynamic proxy” to “a potential proxy”, to reflect the level of support available;

Added references Wang et al. (2018) and Yang et al. (2019), which document the ρ -GSD relationships in debris flows and support the interpretation of ρ -variation as an indicator of source heterogeneity and flow evolution.

L254: Are “generally” consistent, or add explanation of the 070724 debris flow

Reply: We have both softened the statement and added an explanation for the 070724 event. The revised sentence now reads:

“The features of surge sequences across different events are generally consistent, including the decay trend of discharge (Fig. 3a-2), the probability distributions of Q , S , v , and τ (Fig. 3a-3,4,5), and the similarity between surge groups within a single event (Fig. 3b). One exception is event 070724, whose moving-average decay is weaker than that of the other events (Fig. 3a-2); this event has a relatively short sequence and a lower proportion of high-magnitude surges, which likely

accounts for its deviation.”

Specifically, we have:

- Changed “are consistent” to “are generally consistent” to acknowledge that not all events are identical;
- Added a sentence explaining that event 070724 is an exception, and attributing its weaker decay to its shorter sequence and lower proportion of high-magnitude surges.

L262: Replace with “large rivers”? Not sure what great means...you like the rivers?

Reply: We agree that “great rivers” is ambiguous, and we have replaced it with “large rivers” as suggested. The revised sentence now reads:

“For instance, we find that in many hydrographic processes in large rivers (e.g., the Yellow River), the fluctuation of flood discharge presents like a white noise series ($H \sim 0$), with decaying exponent $q \sim 0$.”

L263: Do you have a previous publication or know of a study to add here as a reference?

Reply: We have added additional references to support the statement at line 263. The revised sentence now reads:

“Therefore, the observed power-law decaying indicates significant inter-surge correlations between surges, consistent with the Hurst exponent ($H > 0.5$) reported for most sequences (Liu et al., 2008; Zhang et al., 2021; Liu et al., 2017).”

Specifically, we have added:

Liu et al. (2008) — “Decaying of discharge of intermittent debris flow” (Journal of the Graduate School of the Chinese Academy of Sciences), which documented Hurst exponents greater than 0.5 for surge sequences in JJG;

Liu et al. (2017) — “Fluctuation of sediment transport by viscous debris flow in Jiangjia Gully” (Journal of Sediment Research), which similarly reported long-range correlation in surge sequences.

L267: replace “are” with “exhibit”?

Reply: We have replaced “are” with “exhibit” and changed “long-range correlation” to “long-range correlations” to match the plural subject. The revised sentence now reads:

“In fact, data in JJG show that the sequences exhibit long-range correlations in that the auto-correlation coefficient obeys a power-law decay, $C_{\text{auto}}(n) \sim n^{-\beta}$, with exponent β between (0.35, 0.69), and the correlated range n varies from 0.10 to $0.70N$, N being the total number of surges.”

We have also corrected “data ... shows” to “data ... show” for subject-verb agreement. The change is highlighted in the revised manuscript with tracked changes.

L272: not sure what this means, is it needed?

Reply: We agree that the sentence was not essential to the argument. We have removed it from the revised manuscript. The surrounding text now reads:

“This behavior contrasts markedly with white noise sequences, which inherently converge toward a steady-state condition characterized by $q = 0$. Therefore, the observed power-law decaying indicates significant inter-surge correlations between surges, consistent with the Hurst exponent ($H \approx 0.90$) reported for most sequences (Zhang et al., 2021).”

L273: Some points are slightly off the curve...what about “very well” or something similar, instead of “perfect” and provide a statistical measure that describes that fit, like the Chi-Square or K-S statistic

Reply: We agree that “perfectly” was too strong, and we have replaced it with “very well”. We have also added a statistical measure of the goodness of fit, using the Kolmogorov–Smirnov (K-S) statistic already reported in Section 3.6 and Table S2. The revised sentence now reads:

“The rescaled curve $P^*(M) = \exp(-M^*)$ fits the observed distributions very well (Fig. 4a-3), with Kolmogorov–Smirnov (K-S) statistics of $D < D_{0.05}$ for all analyzed events (Table S2), demonstrating the robustness and consistency of the distribution.”

L273: This should be Fig. 3a-3

Reply: We have corrected the figure reference from “Fig. 4a-3” to “Fig. 3a-3” at line 273.

L277: Such as, could you give an example of what you mean with an (e.g.,....) or directly in the sentence?

Reply: We have added specific examples in the sentence at line 277. The revised sentence now reads:

“While power-law distributions are common in natural phenomena such as landslide size distributions (e.g., Guzzetti et al., 2002), flood magnitudes (e.g., Bowers et al., 2012), and earthquake magnitudes (e.g., Hergarten, 2002), the exponential modification suggests distinct underlying mechanism for its emergence.”

L293: Replace “in the gentle channel of slope” with “when slope is”

Reply: We have replaced “in the gentle channel of slope” with “when the channel slope is” as recommended. The revised sentence now reads:

“However, the high C_s may significantly modify the critical Fr for onset of roll wave (or flow instability), particularly when the channel slope is less than several degrees ($< 5^\circ$ in the mainstream channel of JJG).”

L300: Could you add a quick statement here to explain why this would be the case in terms of your observed debris flow behavior? Requirements for a Poisson process include event independence and the return interval of different surge time intervals remain consistent with time....why would these characteristics be true for your dataset?

Reply: We have added a brief statement explaining why the JJG observations satisfy the two

key requirements of a Poisson process. The revised text now reads:

“...Our results therefore indicate that surges constitute a Poisson process, representing the most fundamental class of stochastic point processes. This is consistent with the two key requirements of a Poisson process: the surges originate from independent, randomly distributed slope failures (Guo et al., 2021, 2023), and their inter-surge intervals remain statistically consistent over time (Fig. 3a-5).”

Specifically, event independence is supported by the fact that surges originate from randomly distributed, independent slope failures across the watershed (Guo et al., 2021, 2023), and stationarity is supported by the observation that the inter-surge intervals within a given event show no systematic trend over time (Fig. 3a-5). The change is highlighted in the revised manuscript with tracked changes.

L301: I don't really see clustered groups of high- ρ surges in 2b

Reply: We agree that the clustering of high- ρ surges is more evident in the long sequence (Fig. 2a) than in the short sequence (Fig. 2b). We have revised the sentence to cite only Fig. 2a. The revised sentence now reads:

“As observed in the long sequence (Fig. 2a), high- ρ surges tend to occur in clustered groups with relatively short intervening intervals.”

L319: Would be helpful to clearly state that N is surge number, both in this caption and in the text

Reply: We have added a clear definition of N both in the caption of Figure 3 and in the main text:

(1) In the caption of Figure 3: “In all panels, N denotes the surge number (i.e., the sequential index of each surge within an event).”

(2) In the main text (Section 3.2): “Throughout, N denotes the surge number, i.e., the sequential index of each surge within an event.”

L323: Why not just use S ?

Reply: In this sentence, we use M as a generic symbol for the magnitude variable, since the unified distribution applies to both Q and S . To avoid confusion, we have added a clarification: “Here M denotes the magnitude variable, i.e., either Q or S .” If the reviewer prefers, we could instead use S directly when discussing sediment volume; however, we have retained M because the distribution is presented as a unified one for both Q and S (Fig. 3a-3).

L330: Delete “that”.

Reply: done.

L346: Suggest replacing surges with “surge intermittency”

Reply: We have replaced “surges” with “surge intermittency” at line 346, which more accurately describes what is being modeled as a Poisson process. The revised sentence now reads:

“The exponential distribution of these inter-surge intervals indicates that surge intermittency can be modeled as a Poisson process (Krishnan, 2015).”

We have also checked other similar statements in the manuscript and made consistent revisions where appropriate.

L352: Replace perfectly with “well” or similar word and provide statistical metric that describes that fit, like the Chi-Square or K-S statistic

Reply: We have replaced “perfectly” with “well” and added a statistical measure of the goodness of fit using the Kolmogorov–Smirnov (K-S) statistic already reported in Tables S2 and S3. The revised sentence now reads:

“Comparing with the power-law distribution that describes the heavy tail with a roll over in small events, as in the case of earthquakes and landslides, the new distribution fits the data well over the entire range, as illustrated by the curves (Fig. 3, 6, 7, 8). The goodness of fit is confirmed by Kolmogorov–Smirnov (K-S) tests, with $D < D_{0.01}$ for the majority of analyzed events (Tables S2 and S3).”

L363: At this point in the paper, there has been little presentation of rainfall patterns or debris flow processes in the basin. I would add those observations before this statement or summarize observations from another paper.....or change “Our observations collectively indicate” to “We hypothesize”

Reply: We have changed “Our observations collectively indicate” to “We hypothesize” at line 363, as recommended. In addition, we have added a new Section 2.1 (Landslide and Debris-Flow Processes in Jiangjia Gully) that describes the geology, climate, and landslide processes in the basin, providing the observational basis for this statement. The revised sentence now reads:

“We hypothesize that spatial and temporal variations in rainfall patterns, distributed source areas, diverse transport pathways (including tributaries and channel connections), and episodic erosion and sediment incorporation processes interact to initiate scattered processes of mass supplies and thereby surges.”

L407: This is a nice figure of the model conceptualization. It would greatly benefit from a description of the landslide and debris flow processes observed in the basin added to Section 2.

Reply: We have added a new Section 2.1 (Landslide and Debris-Flow Processes in Jiangjia Gully) that describes the geology, climate, and landslide processes in the basin. To make the connection to Figure 4 explicit, we have also added a sentence at the end of Section 2.1 stating that the process-based description corresponds directly to the three components of the conceptual model shown in Figure 4: source processes (rainfall-triggered slope failures), inter-processes (bank and bed erosion, sediment entrainment), and confluence (cascading transport from sources to the main channel). In addition, we have added a note in the caption of Figure 4 pointing readers to Section

2.1 for the underlying observations. The changes are highlighted in the revised manuscript with tracked changes.

L423: Could you explain why the Dirac delta function is necessary? To limit inputs to a single point in the model?

Reply: Yes — the Dirac delta functions are used to localize each slope failure to a single point in space ($r=r_i$) and time ($t=t_i$), i.e., to treat each failure as an instantaneous point source of mass. This is consistent with the field observation that individual slope failures in JJG occur as discrete, localized events rather than as spatially distributed or temporally continuous supplies (Guo et al., 2021, 2023). We have added a clarifying sentence after Eq. (7). The revised text now reads:

“...where $\delta(x)$ is the Dirac delta function, and $f(m)$ represents the probability density distribution of failure mass m . Here the Dirac delta functions localize each failure to a single point in space and time, treating each slope failure as an instantaneous point source of mass, consistent with the discrete nature of source-area failures observed in JJG (Guo et al., 2021, 2023).”

L424-427: This would be helpful as background information about landslide processes in the basin, in Section 2

Reply: We agree that the description of landslide processes belongs in Section 2 as background information. We have added a new Section 2.1 (Landslide and Debris-Flow Processes in Jiangjia Gully) that describes the geology, climate, and landslide processes in the basin, including the power-law failure-mass distribution and exponential failure-time interval observed in JJG (Guo et al., 2021, 2023). To avoid duplication, we have shortened the corresponding description in Section 3.4 to a brief statement referring readers to Section 2.1. The revised text in Section 3.4 now reads:

“...where $\delta(x)$ is the Dirac delta function, and $f(m)$ represents the probability density distribution of failure mass m . As described in Section 2.1, field observations and experiments in JJG show that the failure mass follows a power-law distribution, $f(m) \sim m^{-\zeta}$, and the failure time interval follows an exponential distribution. Consequently, the occurrence of failures is described as Poisson process...”

L430: The exponent ζ is not explained in the text, is it related to the Pareto distribution?

Reply: ζ is the Pareto exponent (also referred to as the power-law exponent) of the failure-mass distribution. We have added an explicit explanation after Eq. (8). The revised text now reads:

“...incorporating a size cutoff m_0 to prevent divergence in the integral. The exponent ζ is the Pareto exponent (also referred to as the power-law exponent) of the failure-mass distribution, and it controls the relative frequency of small versus large failures: larger ζ corresponds to a steeper distribution with fewer large failures, while smaller ζ corresponds to a heavier tail with more frequent large failures.”

L438-440: Could you list the reference for this, and move or at least mention first in Section 2.

Reply: We have (i) added supporting references and (ii) moved the statement to Section 2.1. Specifically:

(1) In Section 2.1 (Landslide and Debris-Flow Processes in Jiangjia Gully), we now state: “Field investigations indicate that approximately 30% of the source-area failure mass effectively contributes to the surge fronts (Guo et al., 2021, 2023; Iverson et al., 2011), while the remainder is deposited or temporarily stored along the transport pathway.”

(2) In Section 3.4, we have shortened the corresponding description to a brief statement referring readers to Section 2.1: “As described in Section 2.1, field investigations indicate that approximately 30% of the source-area failure mass effectively contributes to the surge fronts, consistent with observations in other regions (e.g., 20–40% in the Oregon Coast Range; Iverson et al., 2011).”

This ensures that the statement is supported by references and is first presented in Section 2, while avoiding duplication in Section 3.

L451: and this type of intermittent failure behavior has been observed in the JJG?

Reply: Intermittent failure behavior has been directly observed in JJG. Field experiments and monitoring show that source-area failures occur as discrete, randomly timed events, with failure mass following a power-law distribution and inter-failure times following an exponential distribution (Guo et al., 2021, 2023). We have added a clarifying sentence to make this explicit. The revised text now reads:

“Additionally, intermittent failures, acting as on/off processes, are the primary cause of self-similarity when a large number of these sources are aggregated into surges (Cox, 1984; Embrechts & Maejima, 2002; Willinger et al., 1997). Such intermittency has been directly observed in JJG, where source-area failures occur as discrete, randomly timed events (Guo et al., 2021, 2023).”

L453: Suggest changing the section title to something like “Basin interprocesses and hydrographs” to help the read follow your conceptualization of moving from upstream processes in this section to the confluence in the next section.

Reply: We have changed the title of Section 3.4 (2) from “Inter-processes and hydrographs” to “Basin interprocesses and hydrographs”, as recommended. This makes it clearer that this subsection describes the basin-scale intermediate processes linking the upstream source-area failures (Section 3.4 (1)) to the confluence into surges (Section 3.4 (3)). The change is highlighted in the revised manuscript with tracked changes.

L454: Replace “The” with “Typically”?

Reply: We have added “Typically,” at the beginning of the sentence to make the statement more cautious, while retaining “the” to preserve the specific reference. The revised sentence now reads:

“Typically, the inter-processes linking slope failures to surges involve bank and bed erosion, as well as sediment entrainment within the main channel and its tributaries.”

L456-457: Suspended sediment is often estimated as a simple function of the hydrograph but I can't think of one paper that estimated debris flow discharge in this way....could you list a reference here to help readers like me?

Reply: The assumption that debris-flow discharge equals water discharge multiplied by a coefficient has been used in several studies. We have added supporting references at lines 456–457. The revised sentence now reads:

“...leading to the common assumption that debris-flow discharge equals water discharge multiplied by a constant coefficient, i.e., $Q_f = \kappa Q_w$ (e.g., Gong et al., 2021; Guo et al., 2025).”

Specifically:

- Gong et al. (2021) estimated debris-flow discharge as $Q_{DF} = Q_w \cdot (1/(1-c_v)) \cdot D_C$, where Q_w is the water discharge, c_v is the solid concentration, and D_C is a blocking coefficient.
- Guo et al. (2025) proposed a $Q_d - Q_w$ relationship and found that at high discharge, $Q_d = kQ_w$ with $k=1.75$.

These references support the use of a linear coefficient relating debris-flow discharge to water discharge.

L459: Coefficient K is an important parameter later in the paper and perhaps deserves a better description here.

Reply: We agree that κ deserves a clearer description at its first appearance. We have revised the sentence to include:

- (1) The definition of κ as the discharge ratio of debris flow to water, $\kappa = Q_f / Q_w$;
- (2) The expression $\kappa = (\rho_s - \rho_w) / (\rho_s - \rho)$ with all symbols defined (ρ_s = solid grain density, ρ_w = water density, ρ = bulk density);
- (3) A note that this expression only describes the material composition, not the transport capacity of water;
- (4) A forward reference explaining that κ varies dramatically across surges and is therefore treated as a random variable later in Section 3.4 (2).

The revised sentence now reads:

“...leading to the common assumption that debris-flow discharge equals water discharge multiplied by a constant coefficient, i.e., $Q_f = \kappa Q_w$ (Gong et al., 2021; Guo et al., 2025). Here κ is the discharge ratio of debris flow to water, defined as $\kappa = Q_f / Q_w$. In practice, κ is often related to the flow density through $\kappa = (\rho_s - \rho_w) / (\rho_s - \rho)$, where ρ_s is the solid grain density (2,650 kg/m³), ρ_w is the water density (1,000 kg/m³), and ρ is the bulk density of the debris flow. This expression, however, only describes the material composition of a given flow and does not capture the transport capacity of water. However, observations in JJG show that hydrographic processes do not synchronize with the sediment processes; and κ varies dramatically across surges within a sequence, which is why we later treat it as a random variable (Section 3.4 (2)) rather than a constant.”

L459: Could you provide a reference for this equation?

Reply: The assumption that debris-flow discharge equals water discharge multiplied by a coefficient has been used in several studies. We have added supporting references. The revised

sentence now reads:

“...leading to the common assumption that debris-flow discharge equals water discharge multiplied by a constant coefficient, i.e., $Q_f = \kappa Q_w$ (Gong et al., 2021; Guo et al., 2025).”

L464: Hard to tell which bars are the hydrograph.

Reply: We have revised Figure 5 to make the hydrograph more clearly distinguishable from the bars. Specifically:

- (1) The simulated hydrographs are now plotted as thick solid curves (red and blue), while rainfall records are shown as colored bars and debris-flow surges as gray bars;
- (2) A legend has been added inside each panel to clearly label each element;
- (3) The caption of Figure 5 has been revised to explicitly state: "In each panel, the colored bars represent rainfall records from different gauges, the gray bars represent debris-flow surges, and the solid curves represent simulated hydrographs (CN=80 and CN=90)."

These changes make it easy for readers to distinguish the hydrograph from the bars.

L469: There is a lot of information in these plots. The acronyms are not explained. Which color is precipitation?

Reply: We have revised Figure 5 and its caption to address all three points:

- (1) Acronyms explained: The caption now states that the colored bars represent rainfall records from different gauges (LJYK, BYS, MYP, and GCZ), with a reference to Figure 1a-1 for gauge locations.
- (2) Color coding clarified: The caption now explicitly states: “In each panel, the colored bars represent rainfall records from different gauges, the gray bars represent debris-flow surges, and the solid curves represent simulated hydrographs (CN=80 and CN=90).” This directly answers the reviewer’s question about which color represents precipitation — the colored bars represent rainfall.

L474-475: This information would also be great to have in Section 2, with a reference or perhaps this is your own observation? You could bring it up again here to justify equation 9.

Reply: We thank the reviewer for this suggestion. We have addressed it in two places:

- (1) In Section 2.1, we now describe the temporal asynchrony between surges and hydrological processes, and explicitly state that this observation is based on our own analysis of the JJG monitoring data (Figure 5). The revised text reads: “Comparisons of surge sequences with rainfall records and simulated hydrographs (Figure 5) show that surges do not consistently align with either rainfall peaks or water discharge peaks (Guo et al., 2023). This asynchrony is observed for two representative events (080705 and 130607; Figure 5), and is a direct consequence of the fact that surges are generated by discrete, randomly distributed source-area failures rather than by continuous water discharge. This observation is based on our own analysis of the JJG monitoring data (Figure 5).”
- (2) In Section 3.4 (2), we now refer back to this observation to justify Eq. (9). The revised text reads: “As described in Section 2.1, the surges of two debris flow events (080705 and 130607) do

not consistently align temporally with either the recorded rainfall or the hydrographs (Fig. 5). This asynchrony motivates the formulation of Eq. (9): the total debris-flow discharge consists of a continuous background water discharge $Q_w(t)$ plus discrete mass supplies $M(t)$ from randomly distributed source-area failures, so that the sediment supply cannot be determined by the hydrograph alone.”

L477: act as

Reply: We have changed the verb phrase at line 477 to "act as" as recommended. The revised sentence now reads: "...which act as randomly distributed supplies...".

L483-484: Does K satisfy the normal distribution? Is there a field or theoretical justification for this statement, if not, could you add a reference?

Reply: The Normal approximation for κ is justified by the Central Limit Theorem: $\kappa = Q_d/Q_w$ integrates the cumulative effects of multiple independent sub-processes (runoff generation, pore-pressure diffusion, bank and bed erosion), each of which contributes additively to the discharge ratio. As these sub-processes are statistically symmetric and additive, their cumulative effect approaches a Normal distribution (Krishnan, 2015). This is further supported by the statistical analysis of JJG debris-flow discharge by Hong et al. (2015), which used Chi-square and Kolmogorov–Smirnov tests to characterize the probabilistic properties of discharge. We have revised the sentence to make this justification explicit and to add the supporting references. The revised text now reads:

“This is motivated by the fact that $\kappa = Q_d/Q_w$ varies dramatically across surges within a sequence and can be approximated as Normally distributed, as a consequence of the Central Limit Theorem: κ integrates the cumulative effects of multiple independent sub-processes (runoff generation, pore-pressure diffusion, bank and bed erosion), each of which contributes additively to the discharge ratio (Hong et al., 2015; Krishnan, 2015). We therefore reduce the role of the hydrograph to a standard Gaussian process $N(0,1)$, which preserves the first-order statistical effect of hydrological processes on sediment mobilization.”

L493-494: Is this true? The CDFs in Figure a3 and a5 do not look symmetric.

Reply: The reviewer is correct that the CDFs in Figures 3a-3 and 3a-5 are right-skewed and not symmetric in shape. Our statement was intended to mean that the contributing sub-processes are statistically symmetric in the sense that there is no inherent preference for any specific process — not that the resulting distribution of κ or of the surge magnitudes is symmetric. We have revised the sentence to make this distinction explicit. The revised text now reads:

“The assumption of a Gaussian distribution is further supported by the fact that all inter-processes are unbiased — i.e., there is no inherent preference for any specific process — and additive in magnitude, with each process contributing to the surge discharge. Here 'symmetric' refers to the absence of bias among the contributing sub-processes, not to the shape of the resulting distributions (which can be right-skewed, as in Fig. 3a-3 and 3a-5).”

L499: At the confluence, cascading processes move from

Reply: We have revised the sentence to use the structure “At the confluence, cascading processes move from ...”. The revised sentence now reads:

“At the confluence, cascading processes move from sources to tributaries and then to the main stream, incorporating both intra-watershed failures and sediment contributions as simplified in the inter-processes.”

L501: In the confluence

Reply: We have added the article “the” so that the phrase now reads “In the confluence”. The revised sentence now reads:

“In the confluence, hydrological processes play a crucial role in integrating and directing mass supplies from multiple sources.”

L502-503: A description of debris flow initiation processes in the JJG along with comparison with debris flow initiation processes elsewhere would bolster statements like this

Reply: We have addressed it in two places:

(1) In Section 2.1, we have added a comparison between the initiation processes in JJG and those in other regions. Specifically, we note that JJG debris flows are primarily initiated by rainfall-triggered source-area slope failures, in contrast to runoff-generated debris flows observed elsewhere (e.g., Chalk Cliffs, USA; Coe et al., 2008; Kean et al., 2013), where surface runoff entrains loose channel-bed and bank sediment. We also explain that in JJG, the transport and confluence processes serve primarily to integrate and modulate the mass supplied by source-area failures, rather than to generate new sediment by runoff erosion.

(2) In Section 3.4 (3), we now refer back to Section 2.1 and include a brief comparison with runoff-generated debris flows. The revised text reads: "As described in Section 2.1, in JJG the mass supply is dominated by discrete source-area failures, and the role of hydrological processes at the confluence is primarily to integrate and modulate these supplies rather than to generate new sediment by runoff erosion — a key difference from runoff-generated debris flows (e.g., Chalk Cliffs; Coe et al., 2008; Kean et al., 2013)."

These additions provide the process-based context and comparison needed to support the statements in Section 3.4 (3).

L507: Do these occur in the JJG? Please describe in Section 2.

Reply: Yes — these intermediate processes are directly observed in JJG. We have added a brief description in Section 2.1, noting in particular that damming-breaching cycles are frequently observed at tributary junctions, where temporary blockage by landslide debris or coarse sediment is followed by sudden release, producing episodic surges (Cui et al., 2005; Guo et al., 2023). The change is highlighted in the revised manuscript with tracked changes.

L515: DeltaT_0 is not explained in the text, it looks like this is interval of the first surge sequence? I'm not familiar with the three dot notation, what do those represent?

Reply: We have added explanations for both ΔT_0 and the ellipsis notation. The revised text now reads:

“...where $S_F(j)$ denotes the mass of the j -th surge in the final sequence in the main channel, $\mathbf{M}$ is the mass vector from the source-failure sequence $\{\mathbf{S}_0\}$, $\Delta T_i(j)$ is the j -th interval in the source-failure sequence (i.e., the interval between successive failures at the source), $\Delta T_i(j)$ represents the j -th interval in the sequence of the i -th order intermediate processes, and $\Delta T_F(j)$ for the final surge sequence. The ellipsis indicates that all intermediate orders are included.”

Specifically:

- $\Delta T_0(j)$ is the j -th interval in the source-failure sequence, i.e., the interval between successive failures at the source;
- $\Delta T_i(j)$ is the j -th interval in the sequence of the i -th order intermediate processes (e.g., tributary channels);
- $\Delta T_F(j)$ is the final interval between surges in the main channel;

L519-521: Could you rewrite this sentence, explicitly stating how one could interpret the cascading processes from use of equation 10?

Reply: We have rewritten the sentence to explicitly state how Eq. (10) can be interpreted. The revised text now reads:

“Equation (10) describes a sequential filtering of the source-failure mass: at each order of the channel network, the mass supplied during interval $\Delta T_i(j)$ is multiplied by a selection coefficient $\zeta(\tau)$ representing the fraction retained and transferred downstream. The nested summations thus trace how the source-failure mass is progressively selected and integrated across successive orders, with $S_F(j)$ representing the cumulative mass contributing to the j -th surge in the main channel.”

L525: What does "thinning" mean in this sentence. Why is $\mathbf{M}$ excluded from equation 11?

Reply: We thank the reviewer for these questions. We have clarified both points:

(1) “Thinning”: In this context, “thinning” refers to a standard operation on a Poisson process in which each event is independently retained with probability ζ and removed with probability $1-\zeta$, so that the retained events themselves form a new Poisson process with reduced intensity (Kingman, 1993). We have made this explicit in the revised text.

(2) Why $\mathbf{M}$ is replaced by $\mathbf{S}_0$ in Eq. (11): In Eq. (10), $\mathbf{M}$ is the mass vector drawn from the source-failure sequence $\{\mathbf{S}_0\}$. In the simplified Eq. (11), we use $\mathbf{S}_0$ directly because $\mathbf{M}$ and $\mathbf{S}_0$ represent the same source: the mass supplied by source-area failures. The simplified equation therefore does not distinguish between the mass vector and the source-failure sequence.

The revised text now reads:

“Mathematically, this can be reduced to a thinning—here “thinning” refers to a standard operation on a Poisson process in which each event is independently retained with probability ζ and removed with probability $1-\zeta$, so that the retained events themselves form a new Poisson process with reduced intensity (Kingman, 1993)—from $\{\mathbf{S}_0\}$ to $\{\mathbf{S}_F\}$, i.e.,

$$S_F(j) = \sum_{\Delta T(j)} \zeta(j) S_0(\tau(j)) \quad (11)$$

where $S_F(j)$ is the mass of the j -th final surge, $S_0(\tau(j))$ is the mass supplied from the source-failure sequence during the interval $\tau(j)$, and $\zeta(j)$ is the selection coefficient for that interval; here M in Eq. (10) is replaced by S_0 because M is itself the mass vector drawn from the source-failure sequence $\{S_0\}$ ”

L533: Are you referring to lambda_s here?

Reply: Yes — we are referring to λ_s , the intensity parameter of the exponential distribution for inter-surge intervals. To avoid confusion with the Poisson intensity λ of source-area failures, we have made this explicit in the revised text. The revised sentence now reads:

“The distribution has typical parameter $\lambda_s \sim 1/\langle\tau\rangle$, where λ_s is the intensity parameter of the exponential distribution for inter-surge intervals (distinct from the Poisson intensity λ of source-area failures), and $\langle\tau\rangle$ is the average inter-surge interval, typically on the order of 10^2 seconds.”

L540: Which coefficient, the selecting factor coefficient zeta?

Reply: The coefficient referred to here is the selection coefficient ζ (the selecting factor introduced in Eq. 10). We have made this explicit in the revised text. The revised sentence now reads:

“In this simplification, we employ one single selection coefficient ζ to integrate the cascading collection of mass sources, where the mass supplies occurring within time interval $\Delta T(j)$ are supposed to contribute to the j -th surge, with a selecting factor $\zeta(j)$ at the period, which is generated by a Gaussian process $N(0, 1)$.”

L548-552: This text seems to describe the approach used in equations 7 and 8...move there? But the variable used here do not quite match the variables in equations 7 and 8, can you check that variable names are correct?

Reply: Upon review, we believe this text describes the Gaussian assumption for the selection coefficient ζ used in Eqs. (10) and (11), rather than the source-failure description in Eqs. (7) and (8). We have therefore kept it in place but corrected the variable names:

- “ $T(j)$ ” has been corrected to “ $\Delta T(j)$ ” to match Eq. (11);
- The selection coefficient has been explicitly denoted as “ ζ ”;
- The redundant phrase “trades detailed mechanistic representation for operational feasibility” has been removed, leaving only “prioritizes operational feasibility over detailed mechanistic understanding”.

The revised text now reads:

“In this simplification, we employ one single selection coefficient ζ to integrate the cascading collection of mass sources, where the mass supplies occurring within time interval $\Delta T(j)$ are supposed to contribute to the j -th surge, with a selecting factor $\zeta(j)$ at the period, which is generated by a Gaussian process $N(0, 1)$. This assumption is supported by the Central Limit Theorem, which posits that the cumulative effects of multiple independent sub-processes tend to converge toward a normal distribution. Furthermore, this approach prioritizes operational feasibility over detailed mechanistic understanding, a common trade-off in modeling complex systems.”

L550: what does intensity mean here, rainfall intensity?

Reply: The “intensity” referred to here is the Poisson intensity, i.e., the expected number of events per unit time in the Poisson process, not the rainfall intensity. In the context of the thinning operation, the retained events form a new Poisson process with a reduced Poisson intensity (Kingman, 1993). We have clarified this in the revised text. The revised sentence now reads:

“Mathematically, this can be reduced to a thinning—a standard operation on a Poisson process in which each event is independently retained with a certain probability, so that the retained events themselves form a new Poisson process with a reduced Poisson intensity (i.e., a lower expected rate of events per unit time; Kingman, 1993)—from $\{S_0\}$ to $\{S_F\}$, i.e., ...”

We have also clarified the meaning of λ_s at the end of the paragraph: "The distribution has typical parameter $\lambda_s \sim 1/\langle\tau\rangle$, where λ_s is the intensity parameter of the exponential distribution for inter-surge intervals (distinct from the rainfall intensity I_R and the Poisson intensity λ of source failures), and $\langle\tau\rangle$ is the average inter-surge interval, typically on the order of 10^2 seconds.”

L553-556: This section appears to describe how landslide-derived sediment volumes are determined, using a an approach described by Guo et al. (2021). if that is correct, I suggest moving it to section 3.4, before the "

Reply: We agree that the description of how landslide-derived sediment volumes are estimated belongs with the model parameters rather than interrupting the mathematical formulation. We have moved this paragraph from Section 3.4 (3) to the end of Section 3.5 (Model Parameters), where it now serves as a supplementary note on the estimation of the effective mass contribution. The revised text in Section 3.5 now reads:

“...A first-order simulation for an ungauged catchment therefore requires only the source-area extent, local rainfall intensity, and an order-of-magnitude estimate of m_0 and ξ . Field investigations indicate that approximately 30% of the source-area failure mass effectively contributes to the surge fronts (Guo et al., 2021, 2023; Iverson et al., 2011), which serves as an overall estimation for the potential debris-flow magnitude but is not treated as a model parameter.”

L557: Is m_0 used in equation 8? if it is or is used somewhere else, please remind the reader where m_0 is used and its importance.

Reply: m_0 is used in Eq. (8), where it appears explicitly in the term $(m/m_0)^{-\xi}$ as the lower cutoff (scale parameter) of the failure-mass distribution. It represents the minimum failure mass considered in the model, and it controls the smallest mass that can contribute to a surge. We have added a clarifying explanation after Eq. (8). The revised text now reads:

“...incorporating a size cutoff m_0 to prevent divergence in the integral. Here m_0 is the lower cutoff (scale parameter) of the failure-mass distribution in Eq. (8), representing the minimum failure mass considered in the model; it is calibrated from field surveys or regional landslide inventories (Section 3.5). The exponent ξ ...”

L558: Where is x_i used? Could you describe which equation this parameter belongs to?

Reply: We thank the reviewer for this question. ζ is used in Eq. (8), where it appears in the term $(m/m_0)^{-\zeta}$ as the Pareto exponent (power-law exponent) of the failure-mass distribution. We have made this explicit in the revised text. The revised sentence now reads:

“The exponent ζ also appears in Eq. (8), in the same term $(m/m_0)^{-\zeta}$, and is the Pareto exponent (also referred to as the power-law exponent) of the failure-mass distribution; it controls the relative frequency of small versus large failures: larger ζ corresponds to a steeper distribution with fewer large failures, while smaller ζ corresponds to a heavier tail with more frequent large failures.”

L576: This statement seems odd. Why couldn't a stochastic model could be used to produce a single, randomly generated debris flow surge? Perhaps better to say something like "Implemented as described above, our stochastic model produces a surge sequence rather than individual surges"

Reply: We agree that the original statement was imprecise — a stochastic model can indeed be used to generate a single surge; it is our particular implementation that produces a sequence. We have adopted the reviewer's suggested wording. The revised sentence now reads:

“Implemented as described above, our stochastic model produces a surge sequence rather than individual surges.”

L581-586: Since this is a standard test, can you state that you use a conservative significance level and cite a reference rather than describe the approach here?

Reply: We agree that the K–S test is standard and does not require a detailed description in the main text. We have therefore condensed the description to two sentences and replaced the detailed methodological exposition with references. The revised text now reads:

“To validate the simulation results, we employ the Kolmogorov–Smirnov (K–S) test, a standard non-parametric test for distributional similarity (Berger et al., 2014; Zhang et al., 2025). We adopt a conservative significance level of $\alpha=0.01$, corresponding to $D_{0.01}=1.63/n$ (Massey, 1951), to minimize false negatives. The null hypothesis that the simulated and observed distributions are identical is rejected when $D>D_{0.01}$ (i.e., $p<0.01$); otherwise, the simulation is considered to adequately capture the statistical characteristics of the surge sequence.”

L598: It is not clear how you determined unique parameter values for each debris flow event. I'm assuming they are based on measurements and site characteristics. Could you add a few sentences that gives an overview of how you used field data and observations to select the parameter values?

Reply: We have added a brief overview of how the four parameters are determined from field data and site characteristics. The revised text now reads:

“the four parameters are determined as follows: (i) λ is computed from the source-area extent A_i (delineated from DEM/remote sensing; Section 2.1) and the event rainfall intensity I_R recorded by the rain gauges, using $\lambda(A_s)=\sum(A_i/A_E)\lambda_E$ and the experimentally calibrated relation $\lambda_E\sim\exp(k_T I_R)$ (Guo et al., 2021); (ii) m_0 is estimated from field surveys of typical source scars and regional

landslide inventories (Section 3.5); (iii) ξ is taken from the rainfall-dependent relation $\xi \sim \exp(-k_p I_R)$ calibrated from rainfall experiments in JJG (Guo et al., 2021, 2023); and (iv) ζ is drawn from a standard Gaussian distribution $N(0,1)$, requiring no site-specific calibration”

L615: should this be $P(S_F)$?

Reply: since the model simulates the final surge mass sequence S_F , the probability distribution should be denoted as $P(S_F)$. We have corrected the notation. The revised sentence now reads:

“Simulations were conducted in MATLAB (Zhang et al., 2025), with model performance assessed against three criteria: correspondence in (1) the overall decaying tendency, (2) the timing of decay onset, and (3) the resulting probability distribution $P(S_F)$ (Eq. 3).”

L622: What does “sequence features” mean?

Reply: By “sequence features” we meant the key statistical features of the surge sequence, namely the decaying trend, the magnitude distribution, and the inter-surge timing. We have made this explicit in the revised text. The revised sentence now reads:

“The simulations confirm that the key statistical features of the surge sequence—namely, the decaying trend, the magnitude distribution, and the inter-surge timing—can be reproduced by the cascading random processes (Fig. 4).”

L627-629: This paragraph appears to be describing the validation approach, which you also describe at L 608 to 615. Can you combine the two or at least put them together?

Reply: We agree that the validation approach was described in two separate places, which made the manuscript unnecessarily repetitive. In the revised manuscript, we have combined the two descriptions into a single, consolidated validation subsection.

Specifically, we have moved the description of the validation approach from Section 4.1 to Section 3.6 (Model Test). Section 3.6 now presents, in one place:

(i) the three validation criteria, i.e., (1) the overall decaying tendency, (2) the timing of decay onset, and (3) the resulting probability distribution $P(S_F)$;

(ii) the comparison target, i.e., simulated and observed sediment mass S_F rather than fluid discharge Q_f ;

(iii) the MATLAB implementation;

(iv) the Kolmogorov–Smirnov (K–S) test used to quantify the distributional similarity between simulated and observed data.

Accordingly, the repeated paragraph in Section 4.1 has been deleted. Section 4.1 now begins with a brief transition sentence referring to Section 3.6 and proceeds directly to the simulation results for the JJG events, without repeating the validation methodology. We believe this restructuring makes the validation logic clearer and the manuscript more compact.

L659-660: Here, a brief description of the geomorphic processes that control debris flow initiation and transport is needed for the reader to evaluate if these are reasonable sites to apply the model developed at JJG

Reply: We agree that the original text did not provide enough information on the geomorphic processes controlling debris-flow initiation and transport at Chalk Cliffs (CC) and Gatria Creek (GC). In the revised manuscript, we have added a brief description for each site (Lines 1014-1031). For Chalk Cliffs, we now note that the catchment is dominated by steep, unchanneled hollows and a thin, highly erodible sandy regolith, and that surges are generated mainly by episodic runoff-driven entrainment along the channel rather than by discrete slope failures. For Gatria Creek, we now note that steep hillslopes and extensive colluvial deposits supply sediment through both shallow landslides and channel-bed erosion, with local damming–breaching cycles at tributary junctions. We have also added a closing sentence explaining that these similarities, together with the contrasting initiation and transport processes, make CC and GC suitable for testing whether the JJG-derived model remains valid across different geomorphic settings.

L668-673: I think you could just say that you use really long time intervals between surge events to define the surge sequence at these sites.

But if surges at these sites are separated by long time intervals, they must initiate during different storm events and possibly by different erosional processes and sediment sources. Why would the JJG model, that was conceptualized for surge sequences that initiate during a single storm event and decay in magnitude as sediment and flow exit the basin, work for these settings too?

Reply: We agree that the original text did not clearly explain why a model developed for within-event surge sequences at JJG can be applied to sites where surges are separated by long time intervals.

In the revised manuscript, we have made two small but important clarifications in the “event sequence” paragraph of Section 4.2.1. First, we now state explicitly that for catchments such as CC and GC, where a single storm produces only a few surges, the event-level sequence — i.e., the chronological sequence of debris-flow events separated by long time intervals — is used as a statistically equivalent object for testing the model. Second, we now clarify that the JJG model does not require all surges to originate from a single storm. Its core assumptions are that mass supply is a Poisson process, failure mass follows a power-law distribution, and cascading transport preserves the Poisson nature of the sequence. Because the superposition of independent Poisson processes remains a Poisson process (Kingman, 1993), surges separated by long intervals still follow the same statistical model as surges within a single event, provided that mass supplies remain intermittent and power-law distributed in magnitude. We also clarify that the decaying trend is a within-event feature reflecting finite sediment supply, whereas the properties actually validated are the magnitude distribution and the inter-surge timing, which are preserved in both within-event and event-level sequences. Finally, we have added an explicit statement of the model’s applicability limits: it is expected to hold where surges arise from intermittent, Poisson-like mass supplies with a power-law magnitude distribution, and may not hold where debris flows are triggered by a single, well-defined landslide or by continuous hydrological processes.

L687: Since you just created this model, can you actually look up its parameter values? Please be more specific and perhaps mention how those parameter values are used to derive the critical parameters you describe in Section 3.5.

Reply: We agree that the original text was too general and did not specify how the model parameters can be constrained from available data, nor how these values are used to derive the critical parameters in Section 3.5.

In the revised manuscript, we have rewritten this part of Section 5.2 to provide a specific, parameter-by-parameter description of the data sources and typical ranges. Specifically:

(i) The Poisson intensity λ is obtained from the source-area extent A_s delineated from DEM or remote sensing, the event rainfall intensity I_R recorded by local rain gauges, and the experimentally calibrated relation $\lambda_E \sim \exp(k_T I_R)$, with k_T taken from Guo et al. (2021). The watershed-scale intensity follows from the additivity of the Poisson process, $\lambda(A_s) = \sum (A_i/A_E) \lambda_E$.

(ii) The Pareto cutoff m_0 is estimated from regional landslide inventories or field surveys of typical source scars, typically in the range of 10^1 – 10^3 m³ for shallow rainfall-induced failures.

(iii) The Pareto exponent ζ is taken from the narrow range reported for rainfall-induced shallow landslides (approximately 1.0–2.5), and can be refined using the rainfall-dependent relation $\zeta \sim \exp(-k_P I_R)$ calibrated from JJG rainfall experiments (Guo et al., 2021, 2023).

(iv) The selection coefficient ζ is drawn from $N(0,1)$ and requires no site-specific calibration.

We have also added an explicit statement that these values are used in Section 3.5 to derive the critical parameters (λ , m_0 , ζ , ζ), which control the Poisson timing of source failures, the power-law distribution of failure mass, and the stochastic modulation of effective mass during transport and confluence. We further clarify that λ and ζ are event-specific because they depend on local rainfall intensity, whereas m_0 and the distributional form of ζ are relatively insensitive to specific events and can be adopted from regional ranges.

L759: This information should be included in the description of Table 1 so that the reader understands how unique parameter values were determined for each site.

Reply: We agree that the parameter-determination information was only given in the main text and was not included in the description of Table 1, which made it difficult for readers to understand how the event-specific parameter values in the table were obtained.

In the revised manuscript, we have added a separate paragraph directly below the caption of Table 1 (and above the table), describing how each parameter value was determined. The paragraph specifies: (i) the Poisson intensity λ from the source-area extent A_i and the event rainfall intensity I_R using $\lambda(A_i) = \sum (A_i/A_E) \lambda_E$ and $\lambda_E \sim \exp(k_T I_R)$ (Guo et al., 2021); (ii) the Pareto cutoff m_0 from field surveys of typical source scars and regional landslide inventories; (iii) the Pareto exponent ζ from $\zeta \sim \exp(-k_P I_R)$ calibrated from JJG rainfall experiments (Guo et al., 2021, 2023); and (iv) the selection coefficient ζ from a standard Gaussian distribution $N(0,1)$, which requires no site-specific calibration. The paragraph also explains the meaning of the rainfall-intensity columns (I_R -VL, I_R -IL, I_R -ILB, I_R -VA, I_R -VB) and clarifies the distinction between the Pareto exponent ζ and the selection coefficient ζ .

In the main text of Section 4.1, we now provide only a brief summary and refer the reader to the paragraph below Table 1 for details, avoiding duplication between the text and the table.

L771: watershed-level landslides?

Reply: We thank the reviewer for this comment, which we interpret as asking how the source-area Poisson assumption is transferred to the watershed scale, and whether watershed-level landslides also satisfy the Poisson and power-law assumptions used in the model.

In the revised manuscript, we have added a short clarification in Section 4.1. Specifically, the Poisson assumption is formulated at the source-area scale, where individual slope failures occur as independent, randomly timed events. Because the superposition of independent Poisson processes remains a Poisson process (Kingman, 1993), the watershed-scale failure sequence is also Poisson, with intensity $\lambda(A_s) = \sum_i \lambda(A_i)$, where A_i denotes the individual source areas. Similarly, for the heavy-tailed Pareto distributions adopted here, the superposition of independent source-area failures remains approximately power-law in the tail, because the largest events dominate the aggregate mass. This provides the basis for representing the watershed-level landslides as a single Poisson process with a power-law magnitude distribution in the model. We have also cited Kingman (1993) to support the additivity property of the Poisson process.