RESPONSES TO REVIEWER COMMENTS

Diego Escobar

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IDD Research
Address: Av. 6 de Diciembre N30-105 y Alpallana,
Gayal 2 Building, Floor 3, Office 301, Quito,
Ecuador.
Mobile: +593 99 710 3585
Website: https://www.idd-research.org/public/

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1 COMMENT 1: Abstract and Introduction

“The abstract claims that statistical independence has been demonstrated between short-duration rainfall intensities (less than 2 hours) and daily intensities, based on a correlation coefficient of R2≤0.64. This value alone does not imply independence; it confuses basic statistical concepts and exaggerates the findings. Furthermore, the introduction invokes Noether's theorem and symmetries to justify a "probabilistic invariant", but the symmetry is never identified, so the analogy is forced.”

1.1 RESPONSE

We agree that a correlation coefficient alone does not demonstrate statistical independence in a strict statistical sense. For this reason, the manuscript has been revised to avoid such an interpretation. The result is now stated more specifically: the analyses show that the linear dependence between short-duration extreme rainfall intensities and daily intensity is weak, and that this dependence decreases systematically as duration shortens, reaching very low values at sub-hourly scales.

This behaviour has also been observed in pluviographic records from different stations. Previous analyses in Ecuador reported difficulties in establishing a consistent correlation between 24-hour maximum rainfall and short-duration rainfall, with low correlation coefficients found at stations such as Quito–Observatorio and Guayaquil–Aeropuerto (Andrade, 1997, p. 33). In particular, at Quito–Observatorio, a low degree of linear association is evident for short-duration extreme intensities, as illustrated in Fig. 1.

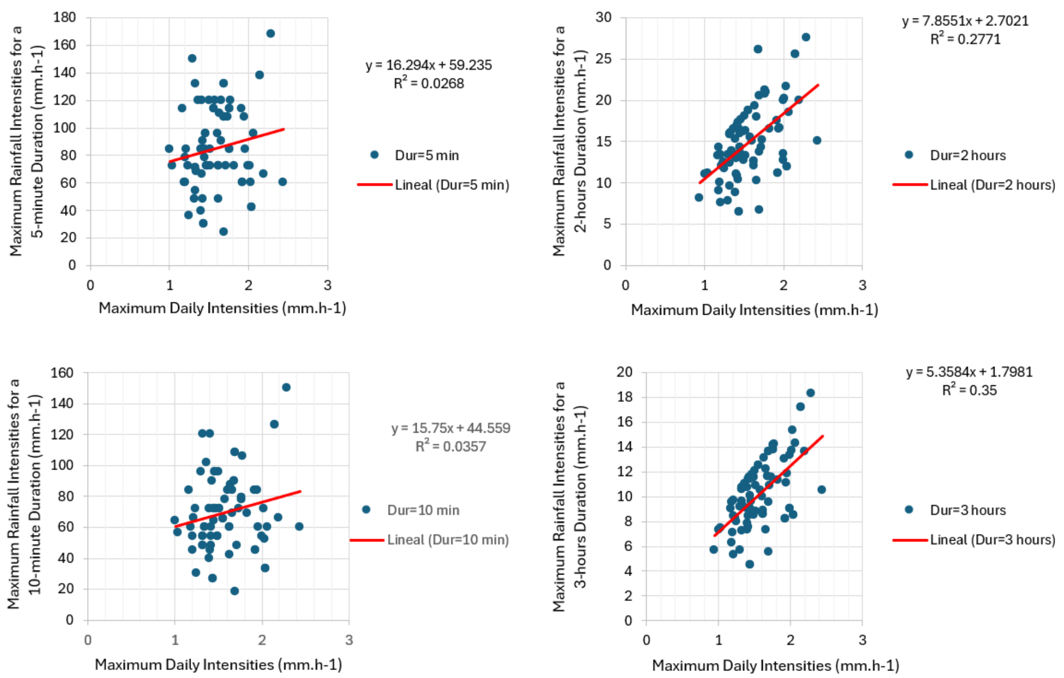

Figure 1: Comparison of maximum short-duration and daily rainfall intensities (mm·h^{-1}). Adapted from Beltrán (1995, pp. 138–139).

In the dataset analysed in this study, obtained from a stochastic simulation equivalent to 100 years using the MIT-Q model (provided in the supplementary dataset: *Correl_Intens_Med_Simu_Qobs_100años.XLS*), the coefficient of determination R^2 between daily intensity and short-duration intensities is 0.64 for 120 min, 0.50 for 60 min, 0.16 for 10 min, and 0.14 for 5 min. This systematic decrease shows that daily intensity progressively loses representativeness as an explanatory variable for short-duration extremes.

This weak correlation can be explained by the nature of storm events. The maximum intensities recorded at a station arise from storms with durations DTdifferent from 24 h and, in general, shorter. The most intense rainfall events tend to be concentrated over short time intervals. Consequently, the remaining interval between the effective event duration $DT$and the fixed 24-hour window does not represent the physical storm process, since the event has already ended. Within a given event, intensities for durations shorter than DT exhibit a high degree of coherence with their characteristic mean intensity PRE/DT. However, when intensity is expressed over a fixed temporal window of 24 h, an additional temporal component associated with the interval $(24-DT)$, which does not belong to the event itself, is implicitly introduced. This effect reduces the correspondence between daily intensity and short-duration maximum intensities. For this reason, the revised manuscript uses the terms “weak linear dependence” or “low linear association”, rather than “independence”.

Regarding the second part of the comment, we acknowledge that, in the original version of the manuscript, the reference to Noether’s theorem could be perceived as incomplete because the underlying justification was not explicitly presented.

In the revised version, it will be clarified that the PCM framework is formulated from a variational functional defined over the cumulative distribution function $P(t)$, with probability density $f(t) = P'(t)$, and solved using the Euler–Lagrange equation. The associated Lagrangian depends on $f(t)$and on the Knowledge Potential $C(t)$, but is explicitly independent of the cumulative probability function $P(t)$. As a consequence of this formulation, and in particular of this independence, the Euler–Lagrange equation leads to

$$\frac{d}{dt}\left(\frac{\partial L}{\partial f(t)}\right) = 0,$$

which implies that $\partial L/\,\partial f(t)$is constant over the domain. In the PCM formulation,

$$\frac{\partial L}{\partial f(t)} = C(t) - 1 - \ln\, f(t),$$

and, up to an additive constant, this leads to the invariant relation

$$\aleph_{\max} = C(t) - \ln\, f(t)_{\max}.$$

This result defines Maximum Certainty as a quantity that remains constant over the domain and can be interpreted as the balance between the Knowledge Potential and the information of the system.

This behaviour is analogous, in terms of variational structure, to the classical case in Lagrangian mechanics in which independence of the Lagrangian with respect to a given coordinate leads to a conserved quantity. In PCM, the independence of the Lagrangian with respect to $P(t)$ leads to the constancy of Maximum Certainty. This analogy is introduced only as an interpretative guide to the role of invariant quantities in variational formulations.

Therefore, the reference to Noether's theorem is not presented as a strict formal application, but as a general conceptual correspondence. In the revised manuscript, the wording has been adjusted to make this scope explicit, avoiding any implication of a direct application of Noether's theorem and focusing instead on the variational result derived within the PCM framework.

References cited in this response

- Andrade, L.: Utilización de modelos precipitación–escurrimiento: ventajas y limitaciones, in: *Memorias del VII Congreso Nacional de Hidráulica*, Asociación Ecuatoriana de Hidráulica, pp. 24–36, 1997.

- Beltrán Vega, F. A.: *Investigación de hietogramas críticos y evaluación del efecto de simultaneidad de tormentas en Quito*, Civil Engineering Thesis, Facultad de Ingeniería Civil y Ambiental, Escuela Politécnica Nacional, Quito, Ecuador, 200 pp., 1995.

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2 COMMENT 2: Foundations of the Maximum Certainty Principle (sections 2.1 to 2.2)

"The variational formulation of the PCM does not constitute a new principle, but rather a reformulation of the Maximum Entropy Principle (MaxEnt) with an arbitrary prior. The central functional ℵmax where C(t) is vaguely defined as a "knowledge potential", directly leads to the solution fT(t). Mathematically, this is equivalent to standard entropy maximization considering an exponential distribution, as described in Kapur (1989). More seriously, explicit Lagrange multipliers are not derived, nor is the Euler-Lagrange equation solved rigorously; it is mentioned in a circular reference that this is done in Beltrán (2023), but no demonstration is provided. The resulting truncated exponential distribution for the intra-event structure is a classic model in hydrology (Eagleson, 1978; Rodríguez-Iturbe et al., 1987), used for decades. Renaming it as the "Maximum Certainty Principle" does not represent a real methodological advance. Moreover, assuming that C(t) is monotonic and independent of elevation is physically unsustainable in the Metropolitan District of Quito (DMQ), where rainfall intensity exhibits strong altitudinal gradients between 2600 and 4555 m a.s.l., as shown in [missing reference]."

2.1 RESPONSE

2.1.1 On the alleged equivalence with MaxEnt

We do not agree that the Maximum Certainty Principle (PCM) constitutes a reformulation of the Maximum Entropy Principle (MaxEnt) with an arbitrary prior.

While MaxEnt can be formulated through a variational procedure, its objective is inferential and relies on the explicit imposition of external constraints, typically introduced through Lagrange multipliers. The resulting distribution is obtained by maximising entropy subject to these constraints.

In contrast, PCM is formulated as a variational principle in which a functional is defined over the cumulative distribution function $P(t)$, with associated density $f(t) = P'(t)$. This functional explicitly combines two components:

- the Knowledge Potential $C(t)$, and
- an information term associated with the probability density.

The solution is not obtained through constrained maximisation, but through the extremalisation of the functional, leading to the Euler–Lagrange equation and to a condition of constancy of the form

$$C(t) - \ln\, f(t) = \aleph_{\max}$$

Within this framework, the resulting function is not merely a probability distribution, but can be interpreted as an optimal trajectory in function space, associated with a state of maximum certainty of the system.

Therefore, PCM does not introduce an external prior nor solve an inference problem in the MaxEnt sense. Instead, it establishes a principle of internal balance between the Knowledge

Potential and the information content, whose solution emerges from the variational formulation itself, where the structure of the problem is embedded in the functional.

2.1.2 On the definition of the Knowledge Potential $\boldsymbol{C(t)}$

We recognise that the interpretation of $C(t)$ as a "knowledge potential" may appear abstract in its initial formulation. In the revised manuscript, it is clarified that:

- $C(t)$ is not a direct physical variable;
- it represents a modelling function describing the temporal structure of the system within the framework of the model;
- its mathematical expression depends on the type of process considered.

In this sense, $C(t)$ should be understood as a modelling construct that captures, in a simplified manner, the dominant characteristics of the process. It does not directly describe the physical state of the system, but enters the variational formulation that determines the optimal probabilistic trajectory.

Its role is analogous to that of a potential in classical mechanics: it does not determine the trajectory by itself, but defines the structure of the governing equations. This analogy refers to its role within the variational formulation and does not imply a direct physical equivalence.

In the case of storm events, the choice $C(t) = -\lambda t$ corresponds to a simplified representation of processes with characteristic temporal decay, consistent with the concentration of rainfall intensities over short durations. This choice does not aim to explicitly represent spatial effects, such as altitudinal gradients, but rather to provide a mathematically consistent description of the temporal organisation of the event.

2.1.3 On the variational derivation

We do not agree with the assertion that a rigorous derivation is not provided.

The variational derivation of PCM has been developed explicitly in previous work (Beltrán, 2022), where the functional is defined, the Lagrangian is constructed, and the Euler–Lagrange equation is applied to obtain the extremum condition and the corresponding solution.

In the manuscript, these elements were presented in a condensed form to maintain continuity of exposition, which may have given the impression of an incomplete derivation.

To improve clarity and accessibility, the revised version incorporates Appendix B: Variational derivation of the PCM formulation, where the essential steps of the derivation are presented explicitly, including the application of the Euler–Lagrange equation, thus providing sufficient detail for independent verification without relying solely on external references.

2.1.4 On the use of the truncated exponential form

We agree that the truncated exponential distribution has been widely used in hydrology to describe intra-event temporal structure (e.g. Eagleson, 1978; Rodríguez-Iturbe et al., 1987). This is explicitly acknowledged in the introduction of the manuscript, where approaches based on clustered point processes are referenced.

However, the proposed model is not limited to the use of a truncated exponential form. Within PCM, the exponential structure emerges as a particular case associated with a specific choice of the Knowledge Potential, whereas the central object of the model is the trajectory $P(t)$obtained as the solution of a variational problem.

In this sense, PCM does not define only a probability density function, but a complete temporal structure of the event, which can be interpreted as an optimal trajectory in time.

The contribution therefore does not consist in renaming an existing distribution, but in establishing a variational framework that allows the derivation and generalisation of intra-event temporal structure from internal principles of the system.

2.1.5 On the methodological contribution of PCM

PCM enables the derivation of a broad family of probability distributions depending on the form of the Knowledge Potential $C(t)$, including both classical models in hydrological literature and more complex configurations, such as multimodal structures.

The relevance of the proposed approach lies in providing a unified framework for deriving the temporal structure of rainfall events from a variational principle. This allows the temporal organisation of events to be interpreted not merely as the result of empirical time normalisation schemes (such as Huff-type approaches), but as a solution emerging from the variational formulation of the problem.

This perspective facilitates extension to different modelling contexts while maintaining conceptual coherence.

3 COMMENT 3: MIT-Q Model (sections 2.3 to 2.3.4)

"The model is calibrated with daily data from a single station (Quito-Observatory) for the period 1916-1992, completely ignoring modern high-resolution rain gauge networks (5-minute data) that have been operating in the DMQ for at least 20 years. In a context of climate change, using such old records violates the stationarity assumption and fails to adequately capture recent extreme events, especially short-duration ones. The author does not explain how sub-hourly intensities are derived from daily data, which is a serious limitation. A descriptive analysis of the pluviometric information from the Quito-Observatory station should have been performed, indicating whether the records are sub-hourly, hourly, daily, or band data. Nothing is explained about the data source; it only says "the century-old Quito-Observatory station", here and in all of Beltrán's circular references.
Furthermore, the model includes a dimensionless parameter calibrated to a value close to 10 and vaguely related to the acceleration of gravity (g). Note that in Beltrán (2023) it is stated that " la gravedad (g) induce información que obliga la conformación de patrones aleatorios preferentemente precoces", without any physical derivation justifying this relationship. The explanation of "upward pulses suppressed by gravity" is a metaphor or pseudoscience. Later, this same parameter varies between 2 and 35 depending on the station, contradicting the supposed universality of the gravitational constant.
Model validation is presented only through visual comparisons of IDF curves (Figure 5), without quantitative error metrics that show model skill, such as RMSE, BIAS, confidence intervals, or statistical tests. Validation based solely on graphical inspection is insufficient for a work that claims to provide a new methodology for extreme rainfall regionalisation."

3.1 RESPONSE

3.1.1 On the data used and their temporal resolution

The MIT-Q model is not calibrated solely using daily data, but through the integration of multiple hydrological information sources representing different temporal scales of the rainfall process. In the revised manuscript, it is clarified that the model is calibrated at the Quito–Observatorio station and validated at four nearby stations.

The calibration is based on three main components of a temporal and probabilistic nature:

- (i) official IDF curves of the Metropolitan District of Quito (DMQ);
- (ii) the annual number of rainfall events exceeding 0.1 mm, derived from climatological studies (Blandín, 1989; Pourrut and Leiva, 1989);
- (iii) the intra-event temporal structure defined through storm quartiles, obtained from pluviographic analyses (Beltrán, 1995).

In addition, the model incorporates a spatial representation of precipitation, which uses as input a raster field of annual isohyets for the DMQ, based on Pourrut and Leiva (1989) and on the hydrological study conducted for the Quito River Decontamination Plan (Fichtner–Hidroestudios, 2011). On this reference field, individual storms are generated, spatially located, and iteratively aggregated until the target spatial rainfall distribution is reproduced. In this way, the ensemble of simulated events is consistent with the observed annual spatial precipitation pattern in the DMQ.

The MIT-Q model represents individual storm events in which total duration (DT) and total precipitation (PRE) are treated as random variables. Each event covers an area determined by its duration, its spatial origin, and its velocity and direction of movement. This procedure is described in detail in the supplementary material.

The data sources used correspond to publicly available studies. In particular, the data derived from Beltrán (1995), originally available only in printed form, will be incorporated into the supplementary dataset of the revised manuscript to ensure traceability and reproducibility.

Additionally, it is important to note that the availability of rainfall records often involves a trade-off between record length and temporal representativeness. Relatively short series, even when derived from dense and high-resolution monitoring networks, may not fully capture the statistical behaviour associated with long return periods, whereas longer records, although they may not always reflect the most recent conditions, provide a more robust basis for the analysis of extremes. In this sense, both types of information play complementary roles, and their use should not be considered mutually exclusive, but rather as part of an integrated framework for the characterisation of extreme rainfall.

References cited in this response:

- Pourrut, P. and Leiva, I.: *Las lluvias de Quito: Características Generales, Beneficios y Problemática*, in: *Riesgos Naturales en Quito*, Estudios de Geografía, Vol. 2, 34–44, 1989.

- Beltrán F.: *Investigación de hietogramas críticos y evaluación del efecto de simultaneidad de tormentas en Quito*, Tesis de Ingeniería Civil, Escuela Politécnica Nacional, Quito, Ecuador, 1995.

- Fichtner–Hidroestudios: *Estudio Hidrológico. Estudios de Factibilidad y Diseños Definitivos del Plan de Descontaminación de los Ríos de Quito*, informe técnico preparado para la Empresa Pública Metropolitana de Agua Potable y Saneamiento de Quito (EPMAPS), Quito, Ecuador, 2011.

- Blandín C. : *Análisis y estudios climatológicos en Ecuador*, Instituto Panamericano de Geografía e Historia, Quito, Ecuador, 1989.

3.1.2 On the dimensionless parameter and its interpretation

References to gravity in previous work were introduced as part of a conceptual discussion and have been revised in the present manuscript to avoid unsupported physical interpretations.

In the current formulation, the relevant parameter is the burst rate λ, defined as $\lambda = \alpha_0/DT$, where $DT$is the total duration of the event and α_0 is a dimensionless model parameter obtained through calibration. In this study, $\alpha_0 \approx 10$.

This value does not imply that ten bursts are necessarily observed in each event. The number of bursts is a random variable whose realisation depends on the specific temporal configuration of each storm. The parameter $\alpha_0$defines the maximum temporal structuring capacity of the event, establishing the maximum number of internal partitions in terms of bursts.

Within the MIT-Q framework, the temporal structure of a storm is represented as a sequence of bursts whose organisation may vary between events. In a limiting case corresponding to a fully non-optimal configuration, up to α_0 bursts may occur; however, this scenario is highly improbable. Conversely, under optimal conditions, the storm manifests as a single dominant burst characterised by continuous growth of intensity followed by a smooth transition towards dissipation. In most cases, events exhibit intermediate configurations, with a number of bursts lower than α_0, depending on the stochastic realisation of the process.

Furthermore, when incorporating advection effects associated with the wind field, the parameter α_0 transforms into an effective parameter α_v, which reflects modifications in the temporal structure of storms due to displacement processes. This transformation leads to variable values of α_v, as shown in Figure 8 of the manuscript, without implying any contradiction with the original model formulation.

Therefore, α_0 does not correspond to a universal physical constant, but to a model parameter. Previous references to gravity should be interpreted as conceptual analogies and have been revised accordingly to avoid ambiguity.

3.1.3 On model calibration

In the revised manuscript, a quantitative evaluation of model performance has been incorporated for the calibration at the Quito–Observatorio station. The mean absolute percentage error (MAPE) is used, as it is particularly suitable for comparing IDF intensities across a wide range of durations.

The results show that the model exhibits low and stable relative errors for durations equal to or greater than 10 minutes, with MAPE values between 1.2% and 2.5% in the range of 10 to 240 minutes, indicating an excellent representation of the structure of the IDF curves. For longer durations (300 and 360 minutes), errors remain moderate, with values of 4.4% and 8.9%, respectively. The highest relative error occurs at the 5-minute duration, where MAPE reaches 11.5%, which is consistent with the higher variability and uncertainty associated with these temporal scales, as well as with the sensitivity of extreme intensities to small temporal variations.

Overall, these calibration results indicate that the model reproduces the temporal structure of rainfall intensities at the Quito–Observatorio station in a consistent manner.

3.1.4 On model validation

In the revised version, an additional quantitative evaluation has been incorporated using MAPE, computed from the original dataset used for calibration and validation, with explicit inclusion of error metrics in the revised analysis. For the four validation stations, considering return periods below 50 years and rainfall durations shorter than 6 hours, the results indicate that the model adequately reproduces extreme intensities in the short and intermediate duration ranges.

At Izobamba station, the model shows the best performance, with relative errors between 2.3% and 10.1% for durations between 10 and 120 minutes, a minimum of 1.7% at 300 minutes, and moderate values of 5.96%, 4.08%, and 8.93% for 180, 240, and 360 minutes.

At Iñaquito station, MAPE ranges between 5.4% and 8.4% for durations up to 180 minutes, increasing gradually to 12.2%, 18.8%, and 24.1% for 240, 300, and 360 minutes.

At La Tola station, the model shows very good agreement at 10 minutes (2.33%) and acceptable performance up to 30 minutes (6.09%–7.20%), with increasing errors at longer durations.

At DAC–Aeropuerto, the model performs well for short durations (2.38% and 7.33% at 20 and 30 minutes), but shows higher discrepancies for long durations, reaching values up to 68.1% at 360 minutes, which is associated with the lower observed intensities at these scales.

Overall, the results indicate that the model captures the structure of IDF curves consistently, particularly for short and intermediate durations, which are of primary relevance in hydrological applications.

The supplementary datasets are provided as Supplementary_Data_MITQ_Calibration_ Validation.xlsx, including a README sheet that describes the structure and contents of the data.

4 COMMENT 4: Regionalisation and Potential IDF curves (sections 2.4 to 3.1)

"The derivation of the key equation relating the parameter τ to the empirical coefficient b*b* of the INAMHI IDF curves is presented opaquely, with algebraic steps omitted. It is not clear how the expression 1−b1 is reached nor why τ is assumed constant for all durations. The introduction of the "transition storm" appears to be a mathematical artifice to join two duration regimes, without observational evidence that storms with that property exist.

The scaling factor φ(b)=b−0.237 is obtained through an empirical regression (Figure 8a), but goodness-of-fit measures are not reported nor is estimation uncertainty discussed. Most worryingly, this regression is not derived from the Maximum Certainty Principle; it is a purely empirical correction that has nothing to do with the variational functional presented in the first part of the paper.

The scaling factor maps (Figure 9) are presented as deterministic results, but no uncertainty propagation from station parameters to map cells is included. Nor is the spatial interpolation method specified. In a region with strong orographic gradients (exceeding 20%), ignoring altitude and topography is a serious omission. Note: precipitation is not random."

4.1 RESPONSE

4.1.1 On the derivation of τ and its relationship with IDF parameters

We acknowledge that, in the original version of the manuscript, not all algebraic steps leading from Eqs. (20), (22), and (23) to Eq. (25) were presented explicitly, which may hinder traceability of the derivation.

In the revised manuscript, Appendix C (Derivation of τ and its relationship with IDF parameters) has been incorporated, where this derivation is developed in detail, including the explicit formulation of the term $1 - b_1$ and all intermediate steps leading to Eq. (25).

Within this framework, the relationship between $\tau$and the parameters of the IDF curves arises from imposing consistency between the mean intensity derived from the model (Eq. 19) and the INAMHI IDF curves across different duration ranges. In this sense, $\tau$is not introduced as an arbitrary constant, but as a parameter that emerges from consistency conditions linking the temporal structure of the model with the empirical intensity–duration relationships.

Appendix C

Derivation of τ and its relationship with IDF parameters

To ensure that an optimal individual storm with precipitation PRE(mm) and duration DT(h) corresponds to an extreme event with precipitation PRE_{Tr1} and duration DT_{r1} at time t_1, the following conditions must be satisfied (subscript 1 denotes short-duration ranges and subscript 2 denotes long-duration ranges).

1. **Equality of mean intensities**

The mean intensity of the storm model must be equal to the mean intensity of the INAMHI IDF curve at t_1. Thus, Eq. (19) is equated with Eq. (21) at t_1:

$$\bar{I}(t_1) = \frac{PRE_{Tr1}}{t_1} \cdot \left(\frac{1-e^{-\alpha_{v1}\frac{t_1}{DT_1}}}{1-e^{-\alpha_{v1}}} \right)^2 = \frac{a_1 \cdot ID_{Tr}}{60^{b_1} \cdot t_1^{b_1}}, \quad \text{(C1)}$$

Solving for PRE_{Tr1}:

$$PRE_{Tr1} = \frac{a_1 \cdot ID_{Tr}}{60^{b_1} \cdot t_1^{b_1-1}} \cdot \left(\frac{1-e^{-\alpha_{v1}}}{1-e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}} \right)^2, \quad \text{(C2)}$$

2. Tangency condition (instantaneous intensity)

Tangency between the two curves at t_1 requires equality of instantaneous intensities. Substituting Eq. (C2) into Eq. (20) evaluated at t_1, we obtain:

$$I(t_1)_{tr} = 2\frac{a_1 \cdot ID_{Tr}}{60^{b_1} \cdot t_1^{b_1-1}} \cdot \left(\frac{1-e^{-\alpha_{v1}}}{1-e^{-\tau}} \right)^2 \frac{\alpha_{v1}}{DT_1} \frac{\left(1-e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}\right) e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}}{(1-e^{-\alpha_{v1}})^2} \quad ,$$

$$I(t_1)_{tr} = 2\frac{\alpha_{v_1}}{DT_1} \cdot \frac{a_1 \cdot ID_{Tr}}{60^{b_1} \cdot t_1^{b_1-1}} \cdot \frac{e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}}{1-e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}} \quad , \quad \text{(C3)}$$

This is equated with Eq. (22):

$$I(t_1)_{tr} = 2\frac{\alpha_{v_1}}{DT_1} \frac{a_1 ID_{Tr}}{60^{b_1} t_1^{b_1-1}} \frac{e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}}{1-e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}} = \frac{a_1 \cdot (1-b_1) \cdot ID_{Tr}}{60^b \cdot t^b} \quad , \quad \text{(C4)}$$

$$2\alpha_{v1} \frac{t_1}{DT_1} \cdot \frac{e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}}{1-e^{-\alpha_{v1} \cdot \frac{t_1}{DT_1}}} = (1-b_1) \quad , \quad \text{(C5)}$$

Substituting Eq. (24), evaluated at t_1, into Eq. (C5), yields:

$$2\tau_1 \cdot \frac{e^{-\tau_1}}{1-e^{-\tau_1}} = 1 - b_1 \,, \quad \text{(C6)}$$

This expression leads to Eq. (25) in the manuscript.

Note: Eq. (25) is corrected in the revised manuscript.

3. Limits of the transition storm (t_1, t_2)

The transition storm is defined by two tangency points with the INAMHI IDF curves. Therefore:

a) $\alpha_{v1} = \alpha_{v2} \,,$ (C7)

b) $DT_1 = DT_2$, From this condition, Eq. (30) is obtained, and solving for t_1:

$$t_1 = t_2 \frac{\tau_1}{\tau_2}, \tag{C8}$$

c) $PRE_{Tr_1} = PRE_{Tr_2}$

Equating the expressions for PRE_{Tr} from Eq. (C2):

$$\frac{a_1 ID_{Tr}}{60^{b_1} t_1^{b_1-1}} \cdot \left(\frac{1-e^{-\alpha_{v1}}}{1-e^{-\tau_1}}\right)^2 = \frac{a_2 ID_{Tr}}{60^{b_2} t_2^{b_2-1}} \cdot \left(\frac{1-e^{-\alpha_{v2}}}{1-e^{-\tau_2}}\right)^2, \tag{C9}$$

$$\frac{t_2^{b_2-1}}{t_1^{b_1-1}} = \frac{a_2 60^{b_1}}{a_1 60^{b_2}} \cdot \left(\frac{1-e^{-\tau_1}}{1-e^{-\tau_2}}\right)^2, \tag{C10}$$

Substituting Eq. (C8) into Eq. (C10) and solving for t_2:

$$t_2 = \frac{1}{60}\left\{\frac{a_1}{a_2} \cdot \left(\frac{1-b_1}{1-b_2}\right)^2 \cdot \left(\frac{\tau_2}{\tau_1}\right)^{b_1+1} \cdot \frac{e^{2\tau_1}}{e^{2\tau_2}}\right\}^{\frac{1}{b_1-b_2}}, \tag{C11}$$

4. Consistency between duration ranges

To apply $\boldsymbol{\alpha_{v1}}$ consistently in both short- and long-duration ranges:

At the two tangency points of Eq. (25):

$$\tau_1 = \alpha_{v1} \frac{t_1}{DT_1}, \tag{C12}$$

$\tau_2 = \alpha_{v2} \frac{t_2}{DT_2}$, for the long-duration range, with parameters α_{v2} and y DT_2. (C13)

Substituting Eq. (C8) into Eq. (C12) and solving τ_2:

$\tau_2 = \alpha_{v1} \frac{t_2}{DT_1}$, for the long-duration range, with parameters α_{v1} and y DT_1. (C14)

From Eqs. (C13) and (C14), it follows that, in the long-duration range, the value of α_{v1} obtained for the short-duration range can be used, provided that the storm duration DT_2 is replaced by DT_1.

4.1.2 On the transition storm

The transition storm is not introduced as a physically independent or directly observable event, but as a conceptual construct required to ensure continuity between short- and long-duration regimes in the IDF curves.

As described in the manuscript, in the short-duration range, maximum intensities are associated with the storm development time t_d, at which the intensity reaches its peak. Beyond this time, the event enters a dissipation phase characterised by progressively decreasing intensities.

The transition storm corresponds to a temporal configuration in which both regimes coexist: part of the duration corresponds to the development phase, while another part corresponds to the dissipation phase. This construction allows continuity to be established between intensities associated with short and long durations without requiring the existence of a distinct observable storm type.

4.1.3 On the scaling factor $\phi(b)$

The scaling factor is derived from empirical relationships obtained from 66 INAMHI meteorological stations across Ecuador. A power-law relationship was identified, with a coefficient of determination $R^2 = 0.968$ and MAPE = 1.188%. The regional relationship adopted in the study presents $R^2 = 0.968$ and MAPE = 1.285%.

We acknowledge that this relationship is obtained through empirical regression (Fig. 8a) and does not constitute a direct derivation from the Maximum Certainty Principle.

Within the proposed framework, PCM provides the temporal structure of event evolution, while the scaling factor $\phi(b)$ is introduced as an empirical extension that enables linking this temporal structure with its spatial application.

In the revised manuscript, goodness-of-fit metrics have been explicitly incorporated to support this relationship.

4.1.4 On spatial representation and uncertainty

Figure 9 does not aim to represent an independent deterministic field, but rather to express spatially the temporal scaling factor, based on the official regionalisation of isointensity zones provided by INAMHI.

The influence of altitude and topography is implicitly incorporated in the parameters of the IDF curves derived from meteorological stations, which already reflect these effects. Therefore, the results should be interpreted as a relative modification of extreme intensities based on station-derived parameters, rather than as a direct interpolation of rainfall fields.

The revised manuscript clarifies this interpretation explicitly.

5 COMMENT 5: Discussion and Conclusions

"The conclusions exaggerate the scope of the work. It is claimed that the PCM "modifies the inferential interpretation of extreme event modelling", but this is not demonstrated with concrete examples or comparisons against established methods (L-moments, maximum likelihood, two-state Poisson models). The potential IDF curves are presented as an operational contribution, but they lack independent validation with dense high-resolution networks. There is no analysis quantifying the improvement over IDF curves generated by EPMAPS or INAMHI."

5.1 RESPONSE

5.1.1 On the scope of the conclusions

It is acknowledged that the expression *"modifies the inferential interpretation of extreme event modelling"* may be excessive and has been revised in the updated manuscript to better reflect the actual scope of the work.

In the revised version, this statement has been reformulated to indicate that the Maximum Certainty Principle (PCM) provides an alternative framework for the modelling of extreme events, centred on the temporal structure of individual storms. Within this framework, PCM is consistent with the interpretation of IDF curves as envelopes of maxima and allows an explicit connection to be established between intra-event temporal structure and intensity–duration–frequency relationships.

In this sense, the proposed approach is not intended to replace established statistical methods used in extreme value analysis (such as L-moments, maximum likelihood, or Poisson-based models), but rather to offer a complementary perspective based on the temporal organisation of rainfall events.

5.1.2 On the role and validation of potential IDF curves

The MIT-Q model does not perform spatial interpolation of rainfall intensities. Instead, it generates spatial precipitation fields associated with multiple stochastic realisations of individual storm events, whose temporal structure is described through truncated exponential temporal patterns.

From these simulated fields, it is possible to sample the system response at multiple locations.

The MIT-Q simulation domain is discretised on a grid with a spatial resolution of 1 km (51 × 51 nodes), where each node acts as a virtual station capable of recording simulated pluviographs and, through extraction of maxima, generating its own IDF curve. This approach allows the spatial variability of extreme intensities to be represented beyond point-based observations, which, by their nature, may not capture local maxima.

Accordingly, the differences observed between station-based intensities and simulated values in their immediate surroundings should be interpreted as a manifestation of the spatial heterogeneity of storm events. In addition, the occurrence of higher intensities in the vicinity of existing stations indicates that extreme values may not be fully captured by point observations and may require the consideration of spatial amplification factors.

However, these estimates correspond to model-based results, and their direct validation would require observational networks with higher spatial density and sufficiently long historical records to assess extreme intensities associated with return periods on the order of 50 to 100 years. This limitation constrains the possibility of direct validation of such spatial patterns.

In this context, the incorporation of high-resolution temporal data and longer observational records represents a relevant direction for future work.

6 COMMENT 6: Appendix and Reproducibility

"The calibration and validation are insufficient for the regionalization the author seeks to justify. The Storm Information Model (MIT-Q) is calibrated at a single station (Quito-Observatory, 1916-1992) and validated only at four additional stations over approximately 2500 km^2. This control point density is extremely low to capture convective and mesoscale processes, as well as the dominant orographic effects in the Andes. The approach lacks quantitative cross-validation metrics and does not evaluate model skill using statistics such as MAE, RMSE, NSE, or MAPE, nor does it demonstrate superiority for short-duration (<2 h) extreme events, where tail behavior is critical."

6.1 RESPONSE

6.1.1 On calibration and validation in the context of regionalisation

It is acknowledged that the model is calibrated at a primary station (Quito–Observatorio) and validated at a limited number of stations within the study area. However, it is important to clarify that the MIT-Q model is not based solely on point-wise fitting, but on the generation of spatial fields of extreme precipitation derived from individual storm events.

In this framework, the validation is not restricted to direct comparison at station locations, but also involves the consistency of the simulated spatial precipitation fields with the observed large-scale distribution, as represented by annual isohyetal patterns. This constitutes a distinction from approaches based purely on interpolation or local parameter fitting.

6.1.2 On quantitative validation metrics

In the revised version, a quantitative evaluation of model performance has been incorporated using the mean absolute percentage error (MAPE), computed from the same dataset used for calibration and validation, with the explicit inclusion of error metrics in the revised analysis.

The results indicate that the model exhibits low and stable relative errors across a wide range of durations, including the short-duration interval (<2 h), which is particularly relevant for extreme rainfall analysis. In this range, MAPE values are on the order of 1.2% to 2.5% for durations between 10 and 120 minutes, indicating a satisfactory representation of extreme intensities.

These results support the ability of the model to reproduce the structure of IDF curves in the duration ranges most relevant for hydrological applications.

6.1.3 On model performance and scope

While additional metrics such as MAE, RMSE, or NSE, as well as formal cross-validation schemes, could further complement the evaluation, the results presented demonstrate that the model captures the structure of IDF relationships in a consistent manner across the stations considered.

It is also recognised that extending the analysis to denser observational networks and broader geographical domains would be beneficial, particularly in regions characterised by strong orographic gradients.

7 COMMENT 7: Overall conceptual contribution

"The work mixes a variational theory that provides no real novelty (equivalent to maximum entropy) with a storm model calibrated using obsolete data and an empirical regionalization that is not derived from the proposed principle."

7.1 RESPONSE

7.1.1 On the role of the Maximum Certainty Principle (PCM)

The role of the Maximum Certainty Principle (PCM) is to provide a variational framework for describing the temporal organisation of extreme rainfall events, from which an optimal intra-event temporal structure is obtained.

In this context, PCM is consistent with the established interpretation of IDF curves as envelopes of maxima and enables an explicit connection to be established between that interpretation and the temporal structure of individual storm events, linking the phases of development, peak intensity, and dissipation with the range of durations represented in the IDF curves.

Within this perspective, concepts such as the characteristic development time t_d, the transition towards dissipation, and the continuity between short- and long-duration regimes arise as conditions of temporal consistency between the model and the observed IDF relationships.

The so-called *transition storm* does not correspond to a specific event directly identifiable in observational records, but rather to a conceptual construct representing plausible temporal configurations of storm events. It ensures continuity between duration regimes and may be interpreted as a configuration of relatively high probability within the set of possible temporal structures.

Accordingly, PCM does not aim to explain the physical mechanisms of rainfall generation, but to provide a coherent interpretative framework for the temporal organisation of extreme rainfall intensities, facilitating its linkage with the empirical IDF relationships used in hydrological practice.

7.1.2 On the role of PCM within the proposed methodology

Within the proposed procedure, PCM is applied both in direct variational derivations and in the formulation of consistency conditions that enable its linkage with IDF curves:

- deriving the optimal temporal trajectory of the event $P(t)$and its associated probability density function;
- translating this structure into the physical domain of cumulative precipitation $Pre(t)$;
- defining the characteristic development time t_d;
- expressing the temporal structure of the event in terms of mean and instantaneous intensities;

- establishing the correspondence between the model storm function and IDF curves by imposing consistency conditions between mean intensities and characteristic durations;
- formulating the transition between short- and long-duration regimes through continuity conditions between the development and dissipation phases of the event.

In addition, the methodology has been applied to meteorological stations located in different regions of Ecuador (coastal, Andean, and Amazonian), where a consistent conceptual adaptation of the model has been observed. This suggests that, despite climatic and orographic differences, storm events share structural features in their temporal evolution associated with dissipative processes, allowing their representation within a unified variational framework.

Sincerely,

Franklin Beltrán
Jhoan Beltrán