Response to Referee #1's comments on hess-2021-580:

General Comment: *The manuscript presents a stochastic approach to generate an ensemble of reference rainfall scenarios (giving a desired rainfall amount P, rainfall duration D and return period T). This approach is based on multi-fractal theory, which is parsimonious and easy to apply. While this research topic is generally relevant for the readership of HESS, there is still a bit of issue which needs to be addressed. Please find the attached comments. Those comments should be addressed before considering publishing this article.*

Response: We thank the referee for meticulously reviewing our manuscript and providing several constructive suggestions. We are especially grateful for the referee's positive feedback. In this document we provide our detailed response to the referee's supplementary comments and also mention how we plan to address these issues in a future version of this manuscript.

Supplementary Comments:

Comment 1: *L7: research gap is not clear.*

Reply: It should be noted that this paper addresses the research gap between standard procedures for defining reference precipitation and the strong multi-scale intermittency of precipitation. It therefore proposes a procedure designed to tackle multi-scale intermittency head-on, based on extreme non-Gaussian statistics and scaling behaviour over a wide range of scales. The aim of this paper is that the baseline precipitation scenarios simulated by this procedure can be used as more realistic inputs into hydrological models for applications such as the optimal design of stormwater management infrastructure, including green roofs.

We will incorporate the above explanation in the abstract to make the research gap that we address clearer right in the beginning of the paper.

Comment 2: *L21-23: it is not clear to me why 'uniform rainfall or … for such purposes' directly leads to the conclusion 'stochastic simulation of reference rainfall events is necessary'. At least one sentence (to discuss the lack of measurement data …) is missing.*

Reply: We agree to improve the corresponding text. The sentence 'Uniform rainfall … for such purposes' will be shifted to the beginning of L57, whereas L21-24 will be replaced by

'Rainfall is quite commonly considered to be a stochastic variable due to the fact that rainfall process is complex and strongly dependent on initial conditions. There have been several studies/attempts to stochastically produce rainfall time series and space-time fields as listed here.'.

Comment 3: *L23: Does it refer to several types of single-site stochastic rainfall models or space-time models? Event-based simulation or continuous simulation? Please clarify.*

Reply: When we mention several model types in the beginning of L23 we refer to all these classes. To make this clearer, we will replace L23 by 'There have been several studies/attempts to stochastically produce rainfall time series and space-time fields as listed here. Simple point processes …'.

Comment 4: *L25: This paragraph is describing 'several types of stochastic rainfall models', but I am confused about why a model related to river discharge is described in detail. I get the point that one module in this 'Hydrogram model' is to generate hyetograms. If it is the case, I am wondering whether it is better to directly state that one of those types is the Monte Carlo method instead of the 'Hydrogram model'.*

Reply: We agree, and will replace L25-27 with ', and Monte Carlo method. All these four models are purely temporal.'

Comment 5: *A general comment on this whole paragraph (L38) & Table 1: The idea of creating this table looks good. However, more references would be needed. The latest one mentioned in this 'literature-based assessment' is in 2004, which is almost 20 years ago. In references for several model types for example in hybrid processes-based models, all references mentioned were published 20 years ago. Although those reference papers mentioned by the authors are very useful, it is necessary to update the reference list.*

Reply: We will add more recent references in this part and in Table. 1 following the referee's suggestion.

Comment 6: *L38: does it refer to spatial rainfall field or spatially averaged rainfall time series?*

Reply: For the sake of better clarity we will replace L38 with '1) Non-Homogeneity: Spatial Heterogeneity – rainfall is extremely variable with spatial location, especially at small

spatial scales and Temporal Heterogeneity or Intermittency – rainfall time series at a single spatial location is extremely variable with time, especially at small time scales'.

Since more than one query of the referee seems to be regarding space-time vs. time modelling, we will clarify that:

i. this dichotomy is not as strong as usual for multifractal models because a time multifractal can be seen as a time cut of a space-time multifractal
ii. the aim of the present study is focused over a fixed (and rather small) space extension such as a building roof
iii. the large scale deployment of rainfall-runoff management technologies would instead require space-time models, obtained with the help of new and rather limited developments (see (i)).

Comment 7: *L38: Does 'modelling approaches' refers to those modelling approaches for getting a realistic rainfall field for most hydrological applications or specifically for sizing storm-water management infrastructures?*

Reply: It refers to those modelling approaches (mentioned above from L23-36) for getting a realistic rainfall field for most hydrological applications (one such application is the designing of rain-water management infrastructures).

Comment 8: *L40: All these characteristics are '… makes the simulations physically relevant/realistic' while 'physically based' is specifically mentioned again in the second criteria 'Physically-based – the simulations rely on physical principles. What's the difference between these two? At least, the meaning of 'simulations rely on physical principles' in the second criteria need to be clarified.*

Reply: For improving clarity, we will replace 'physically relevant/realistic' by 'realistic' in L38. The term "physically-based" simply implies that these rainfall models represent the underlying process (at least abstractly) using physically meaningful parameters. This term is used in a slightly more generalized framework, because it is stochastic rather than deterministic, with fractional rather than integer derivatives.

Comment 9: *L56: The research gap is not ever mentioned until now. It would be much better to clearly state it in the manuscript.*

Reply: We will do this as mentioned in our reply to Comment 1 of the referee.

Comment 10: *L57: Single-site or multi-sites or spatial-temporal rainfall field or something else? please clarify.*

Reply: At present we simulate reference rainfall time series scenarios for different conurbations so single-site for three different sites (we will clarify this in L57). However, the advantage of the proposed simulation procedure is that since it is based on UM framework it can be easily extended in future to simulate spatio-temporal rainfall fields as well.

Comment 11: *L59-61: Ok. this seems to be the research aim, which gives me the impression that the authors are implying that: Using any existing stochastic rainfall models, it is NOT possible to "simulate reference rainfall ensembles characterized by P, D, T while exhibiting temporal variability and intermittency close to that of observed rainfall data". If my impression is correct, the authors were taking this as a research gap. However, this gap was not discussed or mentioned in the introduction section. I suggest revising the whole section and adding more essential information to it to make this introduction section easier to follow.*

Reply: Yes, as mentioned in our reply to Comment 1 of the referee we will modify the abstract.

Comment 12: *L78: resolution (space and time)?*

Reply: Just time.

Comment 13: *L120: are TM analysis and DTM analysis newly developed in this study? This is not clear to me.*

Reply: No, these are standard multifractal statistical analysis techniques and we have cited the corresponding papers in L120 and L136. However, this study uses a slightly modified iterative DTM procedure (also already existing) as explained in Appendix A. We felt it would be a bit more convenient for readers unacquainted with these analysis techniques if we added brief explanations here.

Comment 14: *L170: Is scale-symmetry able to be represented by other model types? From Table 1 in this manuscript, at least the Radar-based method can represent this, which can directly give us a space-time field. Why choose the multifractal theory instead of a radar-based*

method (see Pegram's paper as mentioned by the authors)? It will be helpful to justify the choice and include this discussion (probably in the introduction section).

Reply: The procedure proposed here needs only observational rainfall time series (not very data demanding) and is computationally simpler and parsimonious compared to the Radar-based bead method of Pegram. The current procedure can also be directly extended to obtain space-time fields as well. Furthermore, the idea of space-time complexity in the UM framework is somewhat more generalized than it is in the Radar-based bead model (spatial complexity and temporal complexity are dealt with separately rather than together). We will add a brief discussion about the Radar-based bead model and why we prefer the UM cascade model over it in the introduction section.

Comment 15: *L172: The authors mention that these types of models can be considered as a bridge between purely statistical and purely physical models. I am wondering whether these features have been in this cascade model used in this study: seasonality (or different types of storm event).*

Reply: As mentioned in L168-171, this statement was made in the context of the UM cascade model using the physical concepts of energy transfer from large scales to small scales by random breakup of eddies to abstractly represent atmospheric processes underlying rainfall production. Statistical analysis of observed rainfall in the three conurbations chosen by this study did not display any significant seasonality, but there was a clear evidence of a strong synoptic maximum with corresponding changes in scaling behaviour. This required some elaboration of the UM cascade process to guarantee good agreement between observed and simulated rainfall over the full range of time scales, thereby reproducing well the statistics of different storm types (either convective or stratiform).

Comment 16: *L176: It seems that the study presented here is to simulate temporal rainfall as the author mentioned in the abstract, but 'rainfall fields' convey a message that a time varying spatial field is generated. Not entirely sure if this word is widely used when time series is generated. If not, please change this word.*

Reply: We used the term field in a more generalized context since a time series can be considered as a one-dimensional field. However, for the sake of better clarity we will use 'rainfall time series' instead as suggested by the referee.

Comment 17: *L180: Does it always refer to temporal resolution?*

Reply: Yes.

Comment 18: *L225: Ok, I can see that these metrics might be useful. Besides these, I am wondering whether the autocorrelation of simulated events is well reproduced. This feature plays a critical role in dominating a catchment response to a rainfall event. In addition, since this approach is proposed for hydrological applications, I am wondering whether it is much more convincing to feed those simulated scenarios into a hydrological model (event-based) for better validating this approach?*

Reply: The Codimension Comparison Metric (CCM) already takes care of this issue and more. Autocorrelation or its inverse Fourier transform i.e. spectral density are generally just second order statistics. Comparing the scaling moment function $K(q)$ for $q = 2$ of observed and simulated rainfall is the same as comparing their respective spectra and therefore their autocorrelation. The CCM compares $c(\gamma)$ instead of $K(q)$ however they are just the Legendre transforms of each other.

It is true that the proposed approach is for hydrological applications such as designing green roofs for rain-water management, however, we need observational data of not only rainfall but also discharge from the green roof to validate the entire hydro-meteorological modelling approach. We are still working on setting up experimental green roof prototypes and monitoring protocols for this purpose, and the referee's query can only be addressed via a separate publication in the future.

Comment 19: *L280: Has the author developed/improved a novel method in this study. Please clarify it.*

Reply: Yes (as mentioned in our reply to referee's comments 1 and 11). Even though several earlier studies have attempted to simulate rainfall using a Universal Multifractal (UM) approach, we are unaware of UM-based studies that have proposed procedures to simulate reference rainfall scenarios. We will add this explanation in the beginning of L280.

Comment 20: *Figure 6 and Figure 7: these two figures are not informative. Please consider simplifying/redesigning these or moving them into the appendix*

Reply: We feel the referee is referring to Figures 7 and 8. If so, we agree and will move them into the appendix.