Dear Editor and Reviewers,

Thank you for your detailed comments and suggestions about our manuscript entitled “Dealing with non-stationarity in sub-daily stochastic rainfall models”.

To capitalize on your propositions of improvement, we suggest to thicken the validation and discussion parts of our manuscript. To this end, we consider to modify the plan of the paper as detailed hereafter. The content of the new sections is introduced together with our point-by-point responses to the comments of the reviewers.

Hoping that our responses answer your concerns, and that our propositions of improvements will fulfil your expectations,

Best regards,

Lionel Benoit, Mathieu Vrac and Gregoire Mariethoz.

General overview of the proposed changes:

Considering the comments and recommendations of the reviewers, we plan to add some material to the validation and discussion parts of our paper. The guidelines of the paper will be amended as follow:

1. Introduction
2. Overview of rainfall space-time patterns observed in radar images
3. Assessing rain statistics stationarity from radar images
   3.1. Extracting space-time information from radar images
   3.2. Classification of radar images based on rainfall space-time statistics
4. Validation and application
   4.1. Stochastic rainfall model
   4.2. Detection of rainfall non-stationarity in a controlled setting
   4.3. Impact of rainfall non-stationarity on stochastic modelling of an actual dataset
   4.4. Seasonality of rain type occurrence [new material]
   4.5. Sensitivity of the rain typing approach to the size of the calibration dataset [new material]
5. Discussion [now separated from the conclusion]
   5.1. Model dependence of rain typing [new material]
   5.2. Consequences of non-stationarity on sub-daily stochastic rainfall modelling [new material + part of the current conclusion section]
6. Conclusion

The new sections will be written and the others amended to answer the concerns of the referees as detailed hereafter. In the following RC denotes a reviewer comment and AR denotes our response to the comment.

Responses to the comments of Reviewer #1:

RC: My comments are mostly minor, except for one major issue that I encourage the Authors to address: in the case study the Authors present their results based on only 10 realizations. Likely, more

than 10 realizations are needed in order to quantify the natural (stochastic) variability in rainfall and to statistically identify the mean signal of the rainfall.

AR: We agree with this comment. In the revised version of the paper, we will assess our method based on a set of 50 realizations instead of 10 in the current version.

RC: [2 26] ". 'space' is used in this paragraph with two different meanings. First, in relation to the domain ("the question of stationarity in space is not addressed here because we focus on regional to local areas", and then in relation to the structure of rainfall within the domain ("The proposed framework relies on the classification of radar images based on their space-time features"). I found it to be a bit confusing.

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [3 18] "…small enough to ensure spatial stationarity". The study area is characterized with a complex terrain, as seen from the figure illustrating the domain. What are the height differences and how do you know for sure that stationarity is preserved in space? To check spatial stationarity one must have a very long (>30 years) observation set. I suggest using one of MeteoSwiss gridded product (e.g. HiresD) which is freely available to check if the assumption of spatial stationarity is valid.

AR: We agree that spatial stationarity is an important question, which is linked to the nature of the terrain, but also to the size of the area of interest. However, in the present study, we choose to focus on the temporal non-stationarity of rainfall statistics. We therefore consider the size of the target area as a setting of our method, and the stationarity of rainfall within this area as a prerequisite modelling assumption. The choice of the size of the target area (and the related question of spatial non-stationarity) therefore depends on the targeted application and, in turn, it depends on the stochastic rainfall model that is being applied (and for which we are looking for stationary periods). That is why this question of the size of the study window and the stationarity of rainfall within the area of interest will be discussed in details in the new section "5.1 Model dependence of rain typing" in light of the specific stochastic rainfall model used in the present study.

RC: [3 20] The Alps mask and bias rainfall estimates from the weather radar over some areas in Switzerland. How good are the rainfall estimates from the Swiss weather radar system for this region?

AR: We agree that the quality of available radar data is uneven depending of the area of interest, and therefore depending on the problem being addressed. Therefore, this issue will also be discussed in the new section "5.1 Model dependence of rain typing."

RC: [Figure 1] Please also add a scale bar in plot (a). I suggest adding an arrow indicating the advection direction and speed (i.e. using arrow length) in plot (c).

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [5 2] "This change in the space-time features is very rapid and takes place in less than 30 min". Very interesting. If the changes are so rapid, why not using the weather radar data from MeteoSwiss at 5-min resolution? Results should be more robust. I guess data at 5-min resolution was not available for this study, but this is a point (of using higher temporal resolution data) you might want to later discuss.

AR: Exactly, we used 10-min resolution data because 5-min resolution data were not available to us. We will add a sentence in the new version of our manuscript to make this point more clear.

RC: [5 16] “Quantile 80% of rain intensities“. Why 80%? Why not 95% or even 99% to explicitly account for extreme rainfall intensities? Please give the reason for choosing the 80th quantile.

AR: The idea is to characterize high rain intensities, but the value of 80% is arbitrary. Note that estimating a robust 99% quantile requires an amount of data that we do not have necessarily in one single radar image cropped over a 60 x 60km^2 area. We will add a comment in the manuscript to precise it.

RC: [5 18] “…and applied here in the context of rain fields occurring at mid-latitudes under a temperate climate”. Does it matter for which climate it is applied for?

AR: You are right, it does not matter at this point. The climate of the study area matters to interpret the rain types that are obtained and their frequency of occurrence (cf new section 4.4. and conclusion), but not for the selection of the space indices. We will delete this sentence from ‘and applied here…’.

RC: [5 19] “They are computed based on binary images representing rain masks“. I suggest adding a reference here to Fig. 2.

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [5 21] “clusters”. It seems that sometimes ‘clusters’ are used and sometimes ‘cells’ are used to describe the same rainfall features. Please be consist.

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [6 26] “…we adopt an approach based on a Gaussian Mixture Model classifier (GMM)”. Why? Using GMM for clustering is one option, but other methods to cluster data are available. Please give the reason to favorite GMM on other methods. Also - I guess the build-in Matlab functions were used?

AR: We adopted the GMM classifier because this framework allows for a consistent automatic selection of the number of clusters through a model selection approach based on the BIC criterion. In addition, this framework does not require any assumption about the joint distribution of the data used for classification, which is useful in the present case since we do not have prior information about the distribution of the rain indices. We will add a sentence to further justify our choice in the new version of the paper.
Regarding the implementation, we used build-in Matlab functions fitgmdist and cluster. We forgot to mention that. We will specify it in the next version.

RC: [8 4-5] A repetitive. Consider deleting.

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [8 5] “In addition, it can be desired to avoid noisy successions of rain types”. This sentence is not clear to me.

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [Table 1] “Type 3” is missing.

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [10 8] "…convective rains (Type 1), thunderstorm-related heavy showers (Type 2), and stratiform rains (Type 3)". Why not following the same types you are presenting in Figure 1? I was confused at first reading as I had in mind that the rainfall types presented in Figure 1 are the one that will be discussed and presented throughout the paper. And - I would interpret both types 1 and 2 as convective events, characterized with high intensity rainfall and associated with thunderstorm, but one is more correlated in space than the other. I found the names given to type 1 and 2 a bit misleading.

AR: To avoid confusion, in the revised version of our manuscript, we will try to identify rain types by numbers only, and not using names that refer to physical properties. The reference to the nature of the rain generation processes (e.g. convective, thunderstorm , stratiform, etc.) will be confined to the introductive sections 1. and 2., as well as to the discussion of the physical meaning of the rain types identified in new section "4.4 Seasonality of rain type occurrence".

RC: [11 2] "synthetic images". At 1-km and 10-min, right?

AR: Yes, you are right.

RC: [11 3] "Results show that the proposed method can consistently detect the prescribed rain types and their temporal evolution, for all realizations". Please support this statement with some numbers. How good are the results? Looking at the figure, it seems close to 100% fit.

AR: We agree with this comment. We will modify our manuscript accordingly.

RC: [12 2] "10 realizations". I recommend increasing the number of realizations (to 30, or even 50) to better account for the natural (stochastic) variability of climate. Examining the results in Figure 6 - the signal of under/overestimating will be clearer with more realizations plotted.

AR: You are right, we will perform 50 realizations instead of 10 to assess our method.

RC: I am missing some discussion on […] the sensitivity of the results depending on the threshold (10% and 60 min) that you were using.

AR: This will be discussed in the new section: "5.1 Model dependence of rain typing".

RC: I am missing some discussion on […] discussing if the 6 rainfall types that were automatically chosen are really differ (physically and statistically) from each other - or if some rainfall types could have been consider as the same one to reduce the number of types, etc.

AR: This will be discussed on an annual basis in the new section "4.4 Seasonality of rain type occurrence".

RC: The discussion part should be "thicken" and should be separated from the conclusion part.

AR: Agree. The discussion will be a section by itself, and it will be thicken by the addition of a new sub-section "5.1 Model dependence of rain typing". The second part of the discussion, entitled "5.2 Consequences of non-stationarity on sub-daily stochastic rainfall modelling" will encompass the discussion part of the current "Discussion and conclusion" section as well as additional comments about the impact of the observed rainfall non-stationarity on stochastic rainfall experiments.

RC: [15 21-25] In this context, I would like to mention three of our previous studies (Peleg and Morin, 2012, 2014; Peleg et al., 2015) in which we follow the framework suggested here, i.e. we classified rainfall types based on climate variables taken from re-analysis data (rainfall statistics are therefore based on rainfall images from a weather radar that are linked to different synoptic

conditions/systems), used the statistics to train a sub-hourly distributed rainfall generator to simulate rainfall at high-resolution (5-min and 250-m) for both present and future climates (linked to GCMs). I believe that some parts of the analysis presented in these papers (e.g. cluster analysis of rainfall types, extracting space-time statistics from radar images to train rainfall generators) is also relevant here.

AR: Thank you for this comment and for sharing your previous studies. We will further discuss the future work part in comparison with the papers you mention.