Dear Editor,
please find enclosed a revised version of the manuscript entitled “Stochastic downscaling of precipitation in complex orography: a simple method to reproduce a realistic fine-scale climatology”.

We wish to thank the reviewers for their very constructive comments and for their positive opinion on our manuscript. The points which have been raised also gave us the opportunity to discuss in deeper detail some features of the downscaling method, which we didn’t examine in depth in the previous version.
A comment by one of the reviewers, in particular, led us to investigate more in detail the performance of the method in space and time. Following this input, we implemented a small modification in the smoothing method used (Gaussian weights instead of constant weights), as fully documented in the new version of the paper, which provides a better signature in terms of spatial power spectra, further improving the method. Consequently we repeated all downscaling realizations and we updated the figures in the manuscript accordingly, but this has not led to any significant differences in the figures and in our qualitative results compared to the previous version. Please see also our reply to reviewer #1 for details.

We also introduced a discussion on the use of different values of the coefficient γ, a free parameter of the downscaling procedure, used in the final nonlinear transformation of the downscaled field (see section 3.1). The use of different values of this parameter allows to improve the agreement between the standard RainFARM method and the verification datasets, and thus to isolate the improvements arising from the suggested modification to RainFARM which takes into account precipitation climatology.
In response to reviewer #2, we also improved the description of the datasets which we used at the beginning of section 2.4.

The detailed answers to the Reviewers’ comments are reported below in bold italic.

Best regards,
Silvia Terzago and co-authors

Reviewer #1

"The paper presents the application of a precipitation downscaling technique for climatological purposes. It is based on the Rainfall Filtered AutoRegressive Model (RainFARM). The rainfall downscaling algorithm (RaiFARM) is modified in order to account for realistic precipitation patterns generated by complex topography. The conclusions of the work are interesting, and the topic is suitable for publication in Natural Hazard and Hearth System Science. The paper is well written and clear. The improvement of the methodology proposed here allows for applying the RainFARM approach also to climatological predictions. It would be interesting to see how the modified RainFARM behaves in space-time."

We thank the reviewer for his very positive comments. His request to further investigate the behavior of the method in space and time has led us to introduce a small improvement in the downscaling procedure, using Gaussian (instead of constant) weights for the smoothing step discussed in section 3.1. In fact, this modification provides a better agreement in terms of spatial power spectra between the downscaled fields and the original reference fields.
In order to highlight the performance of the method in space we enclose in fig. R01 a comparison of the spatial power spectra for the perfect model experiment discussed in section 4.1. As shown in the figure, the spatial power spectra reconstructed at small scales with the RainFARM method agree well with those of the reference fine-scale data, particularly when the modified method discussed in this manuscript is used. The modified method appears to be able to capture an additional orographic signature in the spatial spectrum which the original method, by definition, could not represent.
For illustration we also enclose, in fig. R02, a comparison of spatial snapshots of the downscaled fields with the original data for a specific time frame (05 Jan 1980, as an example). This comparison shows qualitatively how the modification suggested in this paper, which is able (see figs. 2f-g in the manuscript) to reduce remarkably the biases in the climatology of precipitation, does not visibly affect the individual downscaled fields at a given instant in time. The figure also illustrates the advantage of using a smoothing kernel as discussed in section 3.1, compared to precipitation conservation based on box-averages which shows box-like artefacts (Fig. R02b).

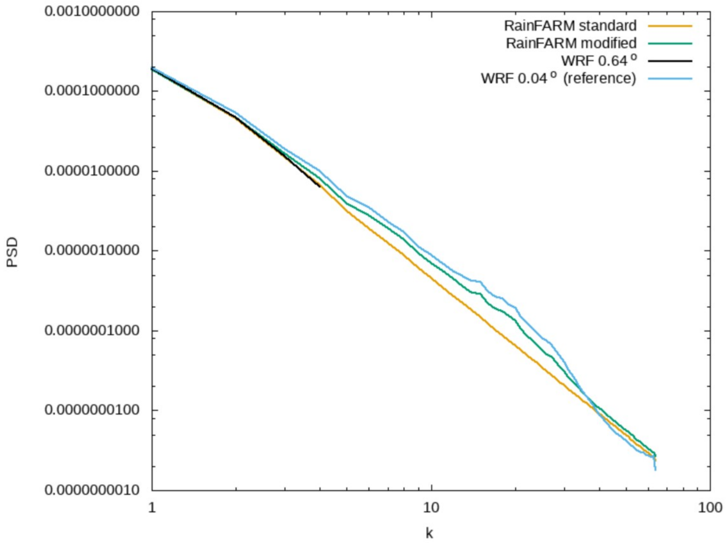

Figure R01. Spatial power spectra of the WRF precipitation fields. Precipitation downscaled with the standard RainFARM (orange), with the modified RainFARM (green), the reference (cyan), and the large-scale aggregated WRF field (black).

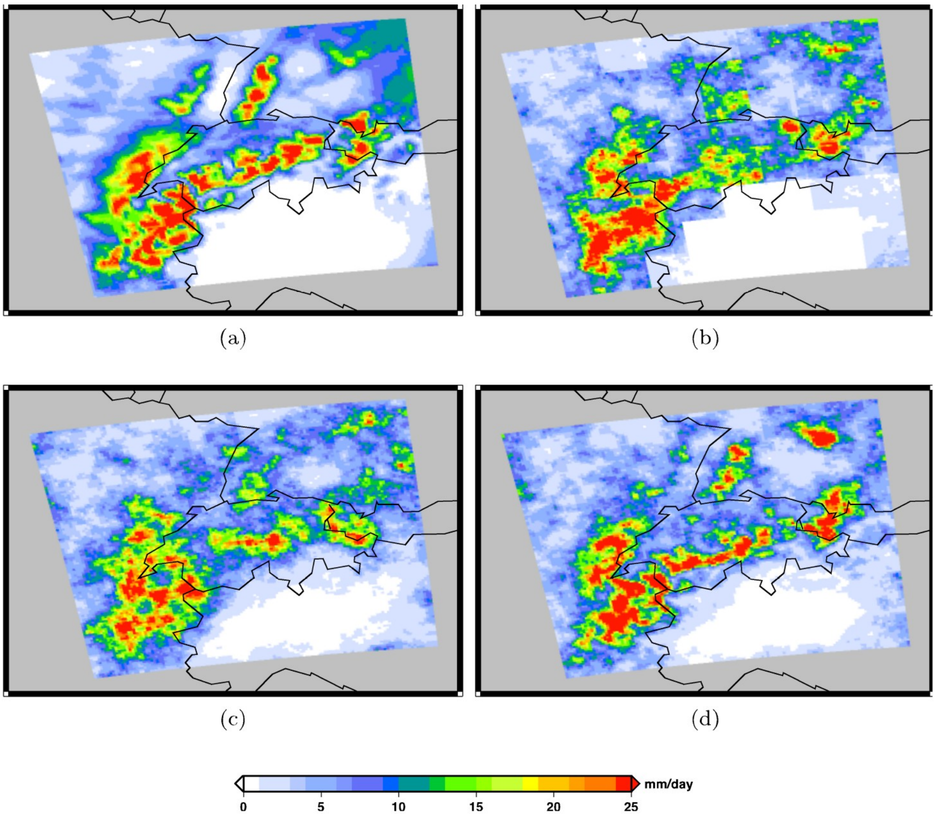

Figure R02. Snapshots of precipitation fields at a specific date (5 Jan 1980) for a) WRF reference at 0.04° spatial resolution; downscaled fields with b) the standard RainFARM method with box-averaging; c) the standard RainFARM method with gaussian smoothing; d) the modified RainFARM method with improved climatology discussed in the manuscript.

Reviewer #2

The paper is well written, the structure is clear (and as it should be) and the authors mention the necessary and useful references. The only two points, which I would recommend to improve, is

1) ***to say a little bit more about the improvements by their method in the different seasons. Often, in winter, spring and fall the improvement is larger than in summer. Have the authors made a similar experience and can they show how the improvement of the downscaling depends on season?***

The spectral slopes used by the RainFARM downscaling methods have indeed been computed separately for each month of the year (12 slopes in total), implying that the spectral properties of the large scale field (slightly variable month by month) are reproduced also in the downscaled fields. So, both the standard and the modified downscaling methods should take into account the seasonal cycle of precipitation. Following the suggestion of the reviewer we evaluated the performances of the standard and modified RainFARM methods for different seasons. We expanded figure 4 in the manuscript adding 4 new panels (d-e) which show the performances of the downscaling in the different seasons for low-precipitation gridpoints, which exhibit the most interesting behavior in our opinion. The new panels are now commented in the manuscript, in Section 4.2.
The same plots for high precipitation gridpoints (reported in Fig. R03 for completeness) reveal small differences among the different seasons.

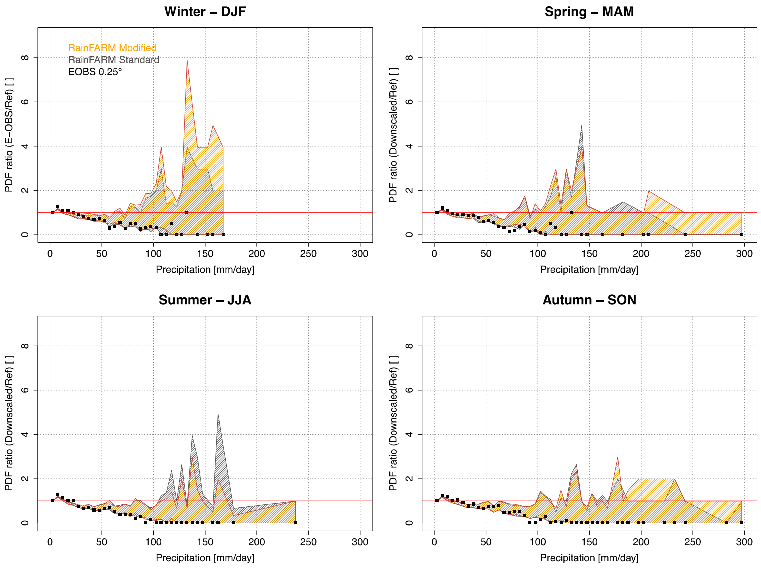

Figure R03. Ratio between the PDF of E-OBS downscaled precipitation and the PDF of the station observations, for high precipitation grid-points. The standard (gray) and the modified (orange) RainFARM methods are compared for different seasons (DJF, MAM, JJA, SON).

> ***2) To discuss shortly the inflation topic. There was somewhat a discussion about this topic in the last years. Typically, in a gridded model, small precipitation amounts are over-estimated, large precipitation amounts under-estimated. This underestimation of large precipitation events in the original gridded field leads to an inflation of the downscaled precipitation which may be a problem. It would be a good idea when the authors could explain how they tackled this problem.***

As a stochastic downscaling method, RainFARM actually is well suited to address directly the inflation problem. In fact, by reconstructing (through extrapolation in spectral space) the missing small scale variability of a smoother large-scale field, RainFARM effectively reintroduce the missing variance due to small-scale fluctuations by adding small-scale random fluctuations. This is similar to what suggested originally by von Storch (1999), but RainFARM does so by introducing perturbations which reconstruct a realistic spatial correlation of the precipitation fields. Additionally, an optional tuning of the final nonlinear transformation (typically, of the exponent of an exponential) in the RainFARM method may allow to obtain downscaled fields capable of reproducing even better the observed precipitation PDF, while at the same time maintaining a correct correlation structure. As also discussed in the original paper describing RainFARM (Rebora et al 2006; https://doi.org/10.1175/jhm517.1) and in subsequent papers (e.g. D'Onofrio et al., 2014) the RainFARM downscaled fields present a good reproduction of a wide range of statistical measures of observed precipitation. The modification suggested in this paper, which modifies locally the downscaled precipitation, further allows to achieve a better agreement in terms of climatology and, as we show, in terms of precipitation PDFs and an even better reproduction of the spatial correlation structure of the fields (see our reply to reviewer #1 and fig. R01), with improved RMSE compared to the reference fields.

Additionally: A question about the used stations: In the text, the authors say that they used also the stations of the daily gauges, but in Fig. 1 there are only the automated ones. Perhaps, the authors should explain this a little bit clearer.

Thank you very much for this useful comment, we have now better characterized the datasets which we used in the manuscript. We considered the daily precipitation dataset (parameter rka150d0) provided by MeteoSwiss (https:/gate.meteoswiss.ch/idaweb). This dataset includes a large number of stations, both manual and automated ones, providing time series of different temporal lengths and covering different periods. We checked the continuity of these time series and we retained only those providing at least 80% data over a common time period, i.e. 1981-2010. We ended up with 59 stations, and all of them are automated stations, as the reviewer correctly states. We better clarified this in the manuscript in Section 2.4.