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Hydrology and Earth System Sciences Discussions
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Interactive comment on "Precipitation bias correction of very high resolution regional climate models" *by* D. Argüeso et al.

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We thank all the reviewers for their suggestions, remarks and discussion, which has definitely strengthened and improved this paper. We consider that the manuscript is now easier to follow as well as more rigorous.

All three reviewers are generally positive and highlighted that the manuscript is well written and concise. They also believed that the manuscript has potential influence in the field. Two major concerns are shared by most of the reviewers: a) The fact that the model could still produce fewer days than the station observations and thus the problem is not completely solved but reduced and b) the selection of the parameters. We paid especial attention these two issues both in our replies and the revised version

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of the manuscript. We also tried to address all remarks by the reviewers.

Reviewer comments are here repeated in **boldface**. Our replies to the reviewer follow in normal typeface.

This study by Argüeso et al. presents an enhancement for bias correction of RCM simulation. It reviews the respective state of the art approaches and proposes a new technique to circumvent or reduce a methodological inherent problem of histogram equalization approaches which occurs if the model simulation features fewer rainy days than the observation by application on station time series. The article is well written and concisely structured. However, the main methodological problem that occurs if the uncorrected RCM features less rainy days than the observation is not solved by this approach but circumvented. As the paper, nevertheless, proposes a new way to implement station data in the correction process, I would suggest to accept this manuscript after some minor remarks.

1) The authors should discuss the theoretical possibility that although the applied method works in the shown study case, also observed station data could feature more rainy days than the RCM simulations.

We agree with the reviewer that the validity of the assumption must be discussed. Indeed, the model is producing less precipitation than the recorded in the stations in region 5, and thus there are limitations in the applicability of our method. We have acknowledged such limitations in the text and used region 5 as an example of them. Accordingly, we also acknowledge that the method we proposed reduced the problem considerably, but there are still situations in which the problem we called attention to is not completely resolved.

2)Is this WRF simulation driven by re-analysis data?

Yes. This WRF simulation is driven by NNRP reanalysis 1 as stated in section "2.1

Model description".

3)The authors seem to apply their methodology on the entire time span between 1990 and 2009. However, it is strongly recommended to use a split sample evaluation, as without the skill of the results can in fact just be judged as test for the correct technical implementation of the method. If this is the case, could the authors discuss why the correction is not nearly perfect? Does the remaining errors stem from the seasonally applied correction?

The use of separate periods is generally advisable when calibration and validating a method. However, this paper is focused on an issue that is becoming increasingly likely in the upcoming regional climate simulations and the aim is to suggest a method to reduce its impacts. We have clarified this in the text.

Despite the fact that a single period was selected in this study to present our method, a perfect match in the comparison we performed cannot be expected. Different causes might explain the differences between these two datasets, which are actually very small in most of the domain, except region 5 (Figure 5 e-h and m-p, and Figure 6 in the manuscript). In this region, the model is especially dry and the assumption of a wetter model in terms of wet-day frequency is not fulfilled. As a consequence, the correction of the model rainfall in this region is not accurate. However, in the rest of the domain, the comparison between corrected model estimates and observations shows a very good agreement. The fitting is performed using a theoretical distribution and thus it might explain why the corrected and the observed datasets are slightly different. Some of the comparisons were made on a region-by-region basis or comparing each station with the nearest grid point, which was not exactly the way they were corrected (5 nearest stations with inverse distance squared weighting and regionalisation). This could definitely have a contribution in the differences.

The seasonal application of the method actually improves the correction. We have tested annual and monthly timescales and they were worse than the seasonal ones for different reasons. At monthly timescales, the fitting to a gamma distribution tends to be less accurate because in some regions the number of rain days is very small. As for the annual timescale, there are features of precipitation that vary seasonally and are not taken into account (see also comment 4). In our opinion, the main possible sources of disagreement between the corrected model outputs and the observations are those mentioned above.

4)The approach to use 5 stations instead of the one nearest to the model grid cell in general should strongly reduce the spatial scale problem between gridded model results and observational station data. However, the network density strongly differs within the study region (e.g. region 3 is very sparsely covered) which may have an impact on the correction. Could the authors discuss this issue e.g. in respect to small scale summer convective systems which could only inïňĆuence one of the observational stations due to their small spatial extension.

It is true that a dense good quality network is required to apply this method and that sparsely covered areas are likely to be corrected less accurately. But this is an intrinsic limitation to bias correction, which strongly relies on observational data availability. For instance, the use of gridded observations are also subjected to this limitation, because the information is generally coming from the same set of observations.

The way the method is designed, it does not correct the occurrence of a rainfall event in a given day, but the probability of a particular intensity. In this respect, the method incorporates the small scale summer convective systems that might influence only one station at a time due to their small spatial extension, but statistically affect all of them equally over the 20-yr period. Also, the application of the method to seasonal timescales also helps to differentiate between characteristics of the dominant precipitation throughout the year.

5)Referring to the latter remark no. 4, why did the authors not average, or take into account more grid cells from the RCMs considering the issue of effective

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resolution of RCMs and the issue that the exact location of precipitation cells in the RCM cannot be expected.

In line with comment 4, the correction is made on the cumulative probability distribution function and thus individual precipitation cells is not targeted in this study, which is aimed at a correct statistical representation of the rainfall events. A particular precipitation event might not be located correctly, but we expect the corrected model outputs to correctly represent the climatology in each of the grid points.

6)Why do the authors "only" apply seasonal correction, as e.g. Figure4 indicates strong intra-annual variations of the climatologies on monthly scale. Would the performance of the method be still stable if the correction process is applied on smaller time scales?

As mentioned in comment 3, other timescales were also explored and as the reviewer correctly suggested, the fitting towards a gamma distribution at monthly timescales is unstable due a relatively small sample of rain days in certain areas, especially at the tail of the distribution.

7)The authors use the AWAP precipitation data set for the regionalization. However it is not shown if the patterns of the AWAP and the then evaluated GHCN rain gauge data show similar patterns on daily scale (on seasonal scale those patterns are shown in Figure 5). This issue may also inïňĆuence the applied averaging-penalization. Following the suggestion by reviewer 1, we provided additional comparison between AWAP and GHCN at monthly timescales (climatology). Despite the fact that further evaluation of AWAP daily precipitation and comparison between AWAP and GHCN spatial patterns would be interesting, it remains beyond the scope of this manuscript. An evaluation of the gridded observations was provided in previous studies (Jones et al. 2009, King et al. 2013). Furthermore, AWAP was used for temporal and spatial completeness reasons to identify areas with similar precipitation regimes. The regionalisation method is partly designed to keep only the main modes of variability and the small differences should not have a major effect on the borders of the regions. Also, various numbers of stations and different penalisation values were tested to provide a sensitivity test which showed minimal impact on the choice of these parameters, which implies that the method is not very sensitive to the location of the borders either.

8)How were the used factors and numbers (0.5 penalization factor, 5 stations used for the correction process, wet-day limit of 0.0 mm/d) determined?

The wet-day limit was chosen to include as many rain days as possible. To that purpose, days with any precipitation amount were considered as rain days (the gauge precision made this threshold equivalent to 0.1 mm/day). Also, Berg et al. (2012) found no sensitivity to the wet-day definition within the range 0-1 mm/day using a similar histogram equalisation method. This has been added to the text.

Regarding the parameters of the bias correction method, both reviewers 1 and 2 also commented on this issue. We have quoted here the reply to reviewer 1:

We carried out a sensitivity analysis to determine the impact of the choice of both the penalization parameter and the number of nearest stations. Ten possible combinations of these two parameters were selected and their performance was investigated. In particular, three values of the penalisation parameter (0.1, 0.5 and 0.9) and three values of the number of stations (3, 5 and 7) were examined, which yield 9 possible combinations. An additional configuration using a single nearest station is also included (penalisation does not apply in this case).

The bias correction was applied 50 times for each of the parameter configurations removing 10% of the stations each time as a means of perturbing the corrected solutions and thus studying the method sensitivity to these choices. Figure 1 (in this comment) illustrates the results of this sensitivity analysis through two different statistical measurements. Corrected WRF outputs were compared with GHCN (each station with the nearest grid point) on seasonal timescales and the mean absolute error (MAE) is cal-

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culated averaging over all stations and all seasons to generate a boxplot including the 50 realisations of the bias correction for each of the parameter configurations. The pattern correlation is also calculated to measure the spatial pattern similarity between corrected WRF outputs and AWAP, and also represented using a boxplot.

The seasonal MAE shows that the choice of the parameter has a minor impact on the results and all possible configurations give a similar value (8 mm/month), including the use of a single station, for which penalisation does not apply. However, the analysis of the pattern correlation reveals that in this particular case, the spatial structure is better represented using more than a single station, showing a very slight decay with larger penalisation values. The stability of the method with respect to the parameters is probably enhanced by the network density and the inverse distance weighting, which tends to give much larger importance to closer stations. In this particular case, we have chosen a moderate number of stations and penalisation in order to provide a test of the method. The sensitivity test suggest that different choices should not significantly affect the results, although this is likely dependant on the characteristics of the region and the network and thus different values might be more suitable under different conditions.

We have included a sentence on the manuscript to mention that the method was found to be slightly sensitive to the choice of the parameters, except that the use of several stations is generally preferred to improve the spatial structure of precipitation climatology.

9)Concerning the results, it would be nice to have some plot dealing with the pdf characteristics between 0 mm/d and 5 mm/d that the actual skill of the proposed enhancement at lower intensities can be seen more easily. We created a plot similar to Figure 7 (probability distribution), but zooming into the range 0-10 mm/day following the reviewer's suggestion (Figure 2 in this comment). Although we agree this plot could be interesting, we do not think it adds significant value to Figure 7 and mostly duplicates the information already provided.

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10)Concerning the comparison of bias patterns after correction in Figure 5, some obvious and interesting differences exist. I.e. just regarding the lower coastline region in study region 4 where the observational net is quite dense and the topography should be rather neglectable. Why do in the station data corrected results error remain up to 50 mm/month? Out of 362 stations there are very few where the difference is larger than 40 mm/month (both negative or positive). To be specific 6 in DJF, 6 in MAM, 4 in JJA and 10 in SON, most of them located in region 5, which has already been identified as a problematic area. All seasons considered, only 3 of them are located in region 4.

Although the method is probably subjected to some limitations, this very low rate of high errors suggest that the specific conditions (or even deficiencies) of particular stations might also play a role. Nonetheless, there is also a larger number with more moderate differences and these might be attributed to various causes such as the comparison performed (as mentioned in comment 3), the fitting towards theoretical functions or the local topography (which is not always smooth along the coast), among others.

11)Page 8150, line 5: Change: "However, the number of days tends to decrease with resolution. . ." to "However, the respective number of days tends to decrease with increasing resolution. . ." Corrected

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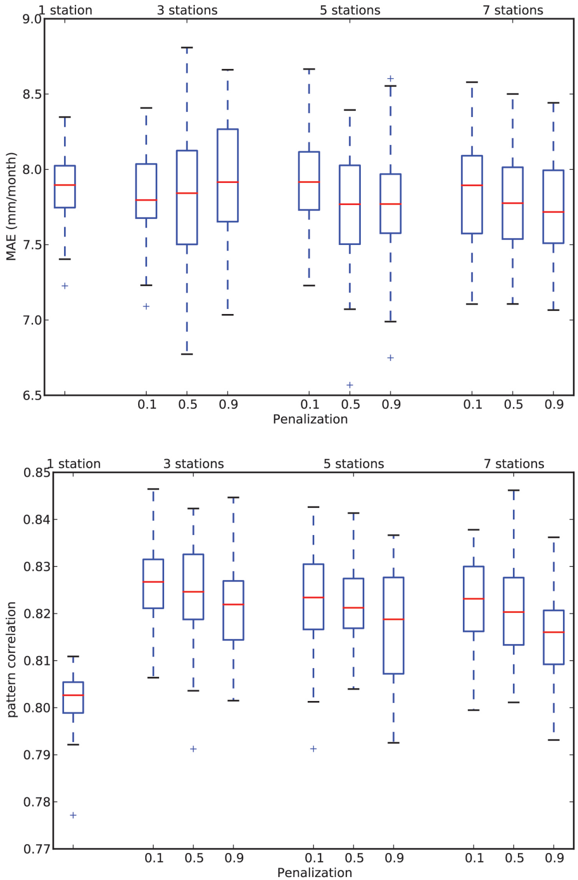

Fig. 1. Top: Seasonal MAE between the 50 perturbed realisations of each bias correction conïňAguration and GHCN. Bottom: as top but for pattern correlation and using AWAP as reference

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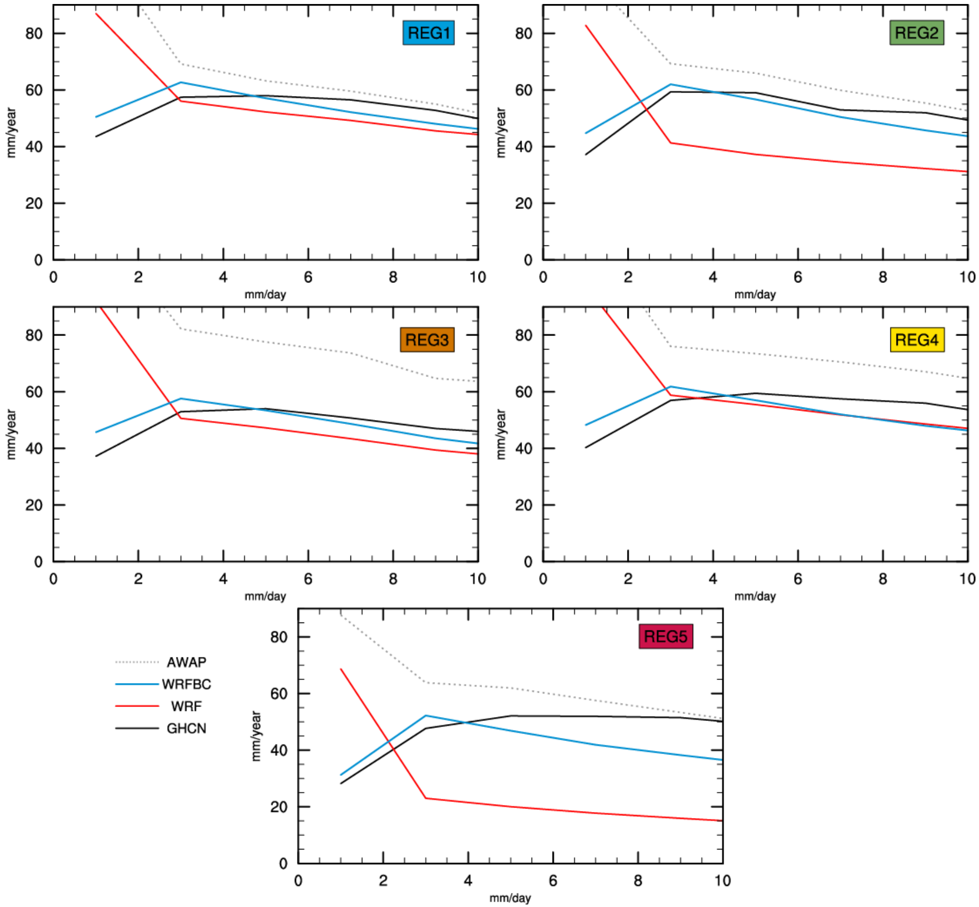

Fig. 2. Contribution to annual precipitation from different-intensity rainfall events in the 5 regions for AWAP, WRF (corrected and non-corrected) and GHCN, limited to the range 0-10 mm/day.

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