1 The reviewer pointed out several problematic points related to the submitted paper. We found some of his
2 concerns legitimate, and therefore we suggest solution here together with reply to all comments. Nevertheless,
3 in the beginning we would like to stress, that the main topic of the submitted paper are outliers, or more
4 precisely the specific concept of 'dependence' outliers, and their influence on correlation, mainly within the
5 context of climate change impact studies where biased estimates of dependence structure may lead to serious
6 artefacts. The main idea of the paper is the method for detection of outliers in multivariate data. The
7 introduced procedure reduces the problem to the analysis of a one-dimensional plot. This is the key part of the
8 paper. We notice that this objective might be not stated clearly in the submitted version and therefore we
9 suggest to modify the paper accordingly, if we are invited to submit revised version of the paper.
10
11 **GENERAL COMMENTS**

12 Comment:
13 *"My biggest worry about the paper is that simple ideas are not explained well and that the mathematical*
14 *treatment is relatively naïve and somewhat muddled. The result is that the intercomparisons between the GCM*
15 *and RCM historical and future data are not treated straightforwardly. My biggest worry is the treatment of the*
16 *correlations between the historical and projected daily rainfall as estimated by climate models and historically*
17 *comparing correlation coefficient (cc) outputs with observations. The measured rainfall is averaged over 25 km*
18 *square areas covering catchments, some of which are of smaller dimension. The other comparisons are with the*
19 *cc modelling products of a GCM and RCM which have a foot-print of 0.11 degrees square (about 8 by 11 km at*
20 *50 degrees North). There is no figure showing this spatial mismatch, which makes it difficult for the reader to*
21 *juggle the ideas mentally to understand the consequences."*

22 Reply:
23 In order to analyse the effect of spatial discrepancy between the datasets, the resolution of the RCM model grid
24 was reduced to the half - four neighbouring model grid-boxes with resolution of 0.11 degree were combined to
25 a grid-box with resolution of 0.22 degree, whose value was calculated as the mean of the original values. The
26 time series for individual basins were derived as in the previous case - as a weighted average of grid-boxes
27 intersecting the basin with weights proportional to the intersection area. As a result of this process, the model
28 correlations moderately increased, because the spatial averaging leads to smoothing of the heterogeneous
29 process. The average increase of correlations varies in a range from 0.013 to 0.042 for individual models. This
30 increase affects model biases – the following figure compares the biases of spatial correlations for individual
31 models achieved with 0.11 and 0.22 degrees resolutions:

biases 0.11 deg. biases 0.22 deg.
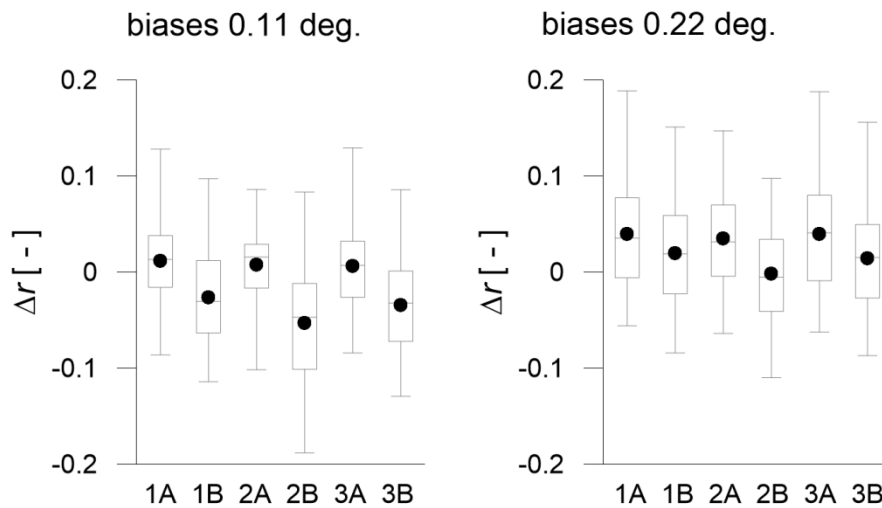
32
33 However, the resolution of 0.22 × 0.22 degrees (22.2 × 14.4 km in the study area) still differs from the resolution
34 of the observed data grid (25 × 25 km), which affects the model biases. In view of the fact, that the assessment
35 of model bias depends on the precise synchronisation of the model and observed data resolutions, we suggest
36 to remove section 4.1 from the paper. The analysis of model biases was included mainly to indicate the range of
37 possible bias in dependence structure (which is a motivation for using advanced bias-correction methods
38 considering dependence) and is not necessary, since the paper primarily deals with the effect of outliers on the
39 correlation estimates and changes of correlation in climate projections. We would therefore remove the section
40 on RCM bias. The removal would also simplify the methodology and the presentation of results and would help
41 to present our message in a more concise way. We thank to reviewer for this point.

42 Comment:
43 *"Furthermore, the confusion between correlations and covariance (the latter briefly touched on in section 4.6) is*
44 *not sensible. Covariance depends not only on correlation, which is meaningfully comparable, but also variance,*
45 *which will alter depending on scale. The statement in line 263: ' The overall result is that the covariance*
46 *structures change substantially more than correlations.' therefore comes as no surprise and is indicative of the*
47 *naivety of much of the paper's message."*

48 Reply:
49 We are aware of the difference between correlations and covariance (see line 265). All results related to the
50 changes of covariance are reduced to a short section 4.6 and all their consequences are placed in two
51 paragraphs in 4.7 (lines 285 - 294). If this results in 'confusion between correlation and covariance', we can
52 reformulate it and completely reduce all points related to covariance to a short section.
53 The fact, that the change in covariance is tightly related to the changes of variance, comes as no surprise only if
54 one knows that the correlations remain stable. It cannot be automatically expected.
55 The primary motivation for introducing the covariance was our previous paper (Hnilica et al., 2017), where the
56 methodology is based on the principal components derived from the covariance matrix (the consequences for
57 this procedure are stated in lines 285 – 288). In addition, advanced bias correction methods often consider
58 covariance structures (e.g. Mehrotra a Sharma, 2015; Mehrotra a Sharma, 2016).

59   In our opinion the results from 4.6 support the application of 'delta change method' as an alternative way for
60   deriving reasonable climate scenarios (lines 289 - 294). We found this point interesting, since the bias correction
61   methods and their increasing complexity are recently the subjects of serious criticism, for example in Ehret et al.
62   (2012) or Maraun et al. (2017).

63   Maraun, D., Shepherd, T. G., Widmann, M., Zappa, G., Walton, D., Gutiérrez, J. M., ... & Mearns, L. O. (2017).
64   Towards process-informed bias correction of climate change simulations. Nature Climate Change, 7(11), 764.
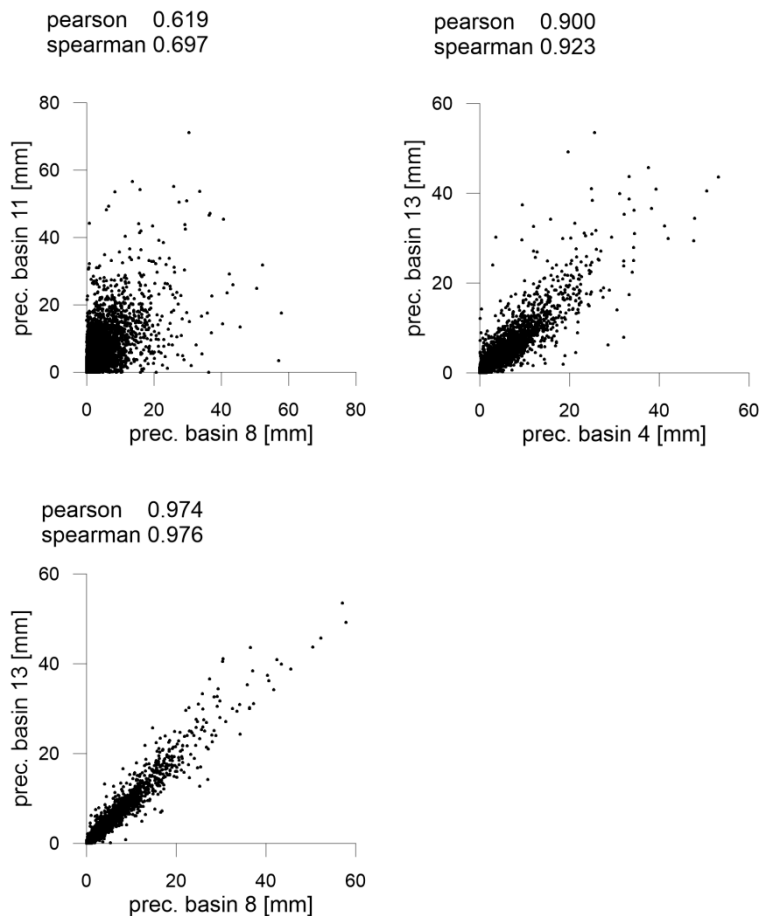
65   Comment:
66   *"Spearman correlation coefficients are used for comparison, eliminating the effect of outliers in the various time*
67   *series, which is clear from Figure 11, but rather briefly commented upon in the supporting text. However, the*
68   *declared purpose of the paper is to identify outliers and remove them so they do not contain the comparisons*
69   *between the time series, so rank correlations are not useful for this task and more usefully indicate bias in the*
70   *intercomparisons."*

71   Reply:
72   The paper deals with outliers, thus the inclusion of rank-correlations is a logical step, because one of the well-
73   known effects of rank correlations is their robustness against outliers. At the same time it was necessary to
74   point out some problematic aspects of the rank correlations for precipitation data. The rank correlations are not
75   substitute of Pearson correlations and they are not a solution of the problems with outliers.
76   The Pearson and Spearman coefficients provide different information. It is obvious, that the replacement of the
77   values by their ranks lead to some loss of information and the values of Pearson and Spearman coefficients
78   differ even for data without outliers. The three datasets differing in an intensity of the dependence between
79   variables were chosen from the simulation of the model 1A. The Pearson and Spearman correlation coefficients
80   were calculated. Only wet periods were considered, all days with any zero precipitation amounts were
81   excluded. The following figure demonstrates the results:

82

pearson 0.619
spearman 0.697

pearson 0.900
spearman 0.923

pearson 0.974
spearman 0.976

83
84
The figure shows that the Pearson and Spearman coefficients differ, and the difference depends on amount of linearity in the dependence structure.

Comment:
"Autocorrelations of the series were calculated, but included the zeros, which were pooled with the non-zero amounts in section 3 and illustrated in Figures 5 and 6. It is only in the discussion on Figure 11, in lines 251-2 where attention is drawn to the problem: "The precipitation data contain a high number of zero values which must be treated otherwise the rank correlation is distorted by severe artefacts. A possible way is to consider the correlations only for non-zero values, however this approach results into a loss of information and furthermore it is not applicable to auto-correlations. Therefore the joint (average) rank was assigned to each zero value in this study (we note that the results can differ if e.g. random rank is applied instead)." In my opinion, the inclusion of the zeros by ranks masks the problem and artificially increases the ccs. Treatments of zero and non-zero data need to be done separately; even if there are mismatches in the wet periods in the time series - there should be enough common wet days to obtain a fair comparison between the wet day sets to determine the effect of serious outliers on the serial and cross-correlation coefficients."

99　Reply:

100　In order to evaluate the effect of zero values, all results were recalculated using only non-zero pairs of data.

101　Time series from individual basins show good agreement in dry / wet periods, which is not surprising, as they

102　were derived from adjacent model grid-boxes. The exclusion of zeros leads to the loss of 35% - 55% of the data,

103　which vary in individual cases.

104　In general, the exclusion of zeros decreases both cross- and auto-correlations, whether the Pearson or

105　Spearman coefficient is used. Nevertheless, the decrease comes in both control and future periods; therefore

106　the exclusion of zeros does not affect considerably the changes of correlations. The following figure compares

107　the general overviews of changes of individual models calculated with and without zero values:
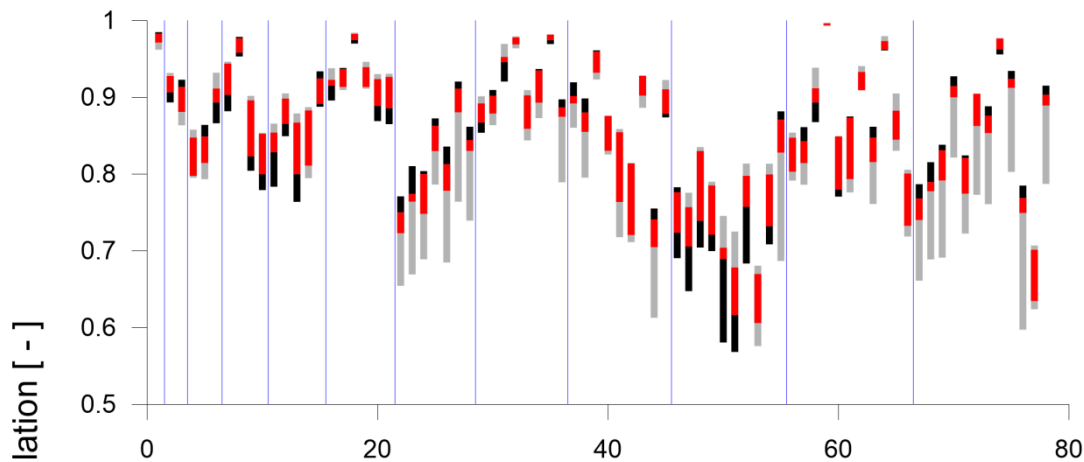
108

changes in cross-correlation

zeros included   zeros excluded
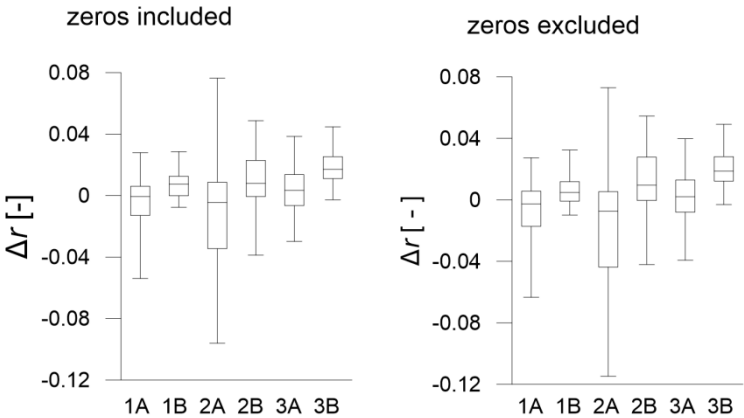
changes in lag-1 auto-correlation

zeros included   zeros excluded
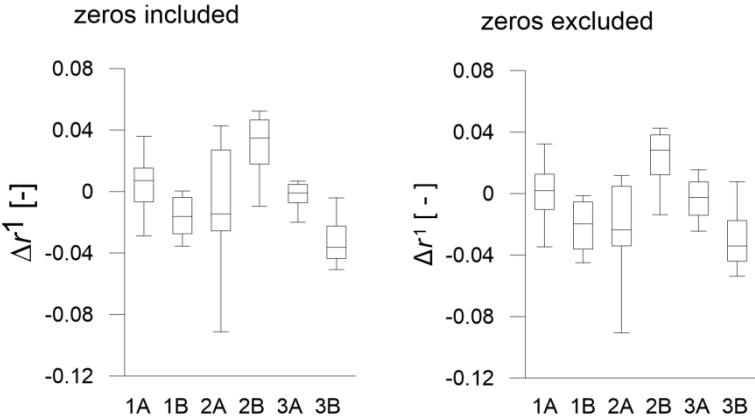
109
110

111　The exclusion of zeros does not affect considerably the analysis of significance. When the zeros are excluded,

112　the bootstrap confidence intervals from both control and future period shift down, nevertheless their overlap

113　remains similar. The following figure compares the bootstrap tests of the cross-correlations of model 2A

114　performed with and without zeros:

115

bootstrap derived confidence intervals, model 2A

zeros included

zeros excluded
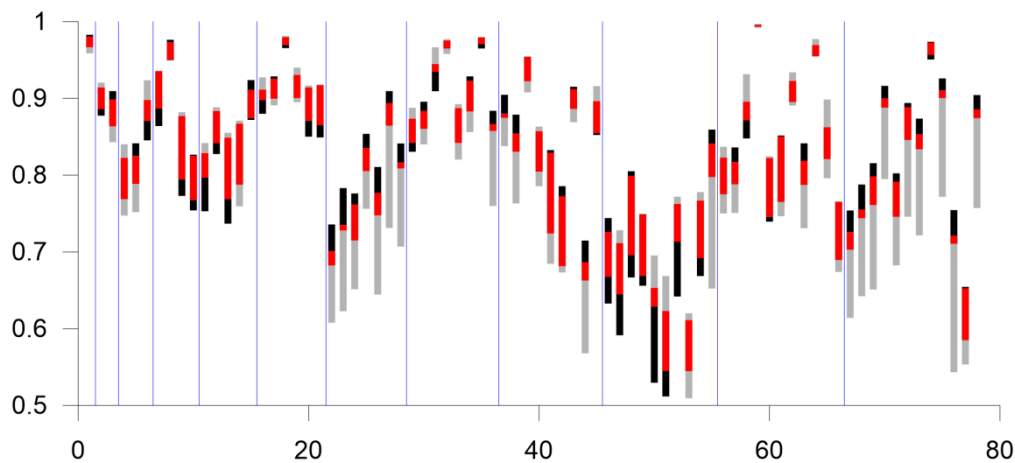
116
117
118   We note that the presence of outliers (wide confidence intervals) remains visible in the results. The exclusion of
119   zeros reduces the size of the datasets, which highlights the effect of outliers on remaining data – the intervals
120   affected by outliers widened in several cases. The effect of individual outliers is highlighted when the zeroes are
121   excluded, as seen from the next figure, which compares Fig. 8 from the submitted paper calculated with and
122   without outliers:
123

The detection of dependence outiers (model 2A, basins 6 and 8)

zeros included
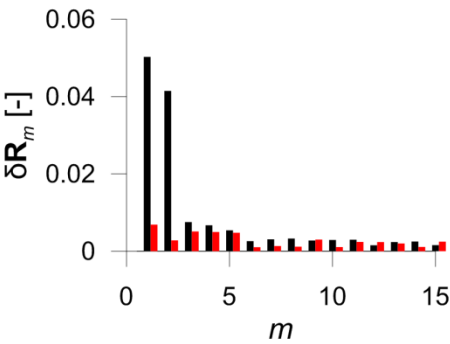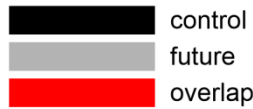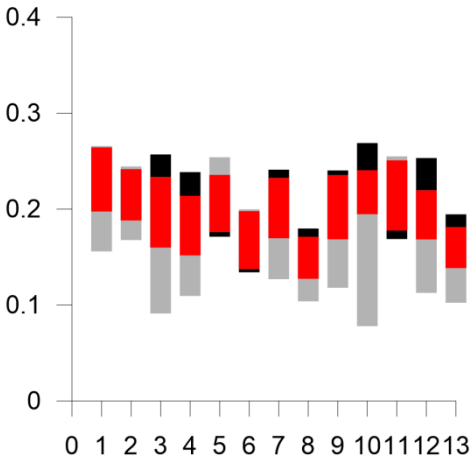

zeros excluded
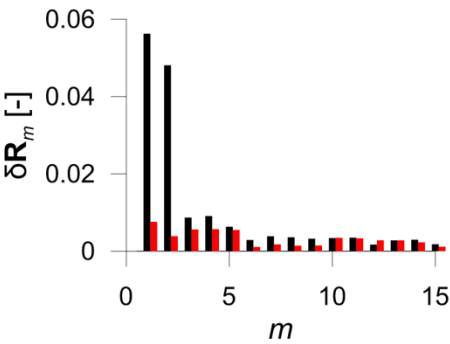
124
125
126 The next figure compares the bootstrap intervals for the lag-1 autocorrelations of the model 2A calculated with
127 and without zeros. The changes were found not much significant in the submitted paper, which remains the
128 same even for the auto-correlations calculated without zeros:
129

bootstrap derived confidence intervals, model 2A
### zeros included   zeros excluded
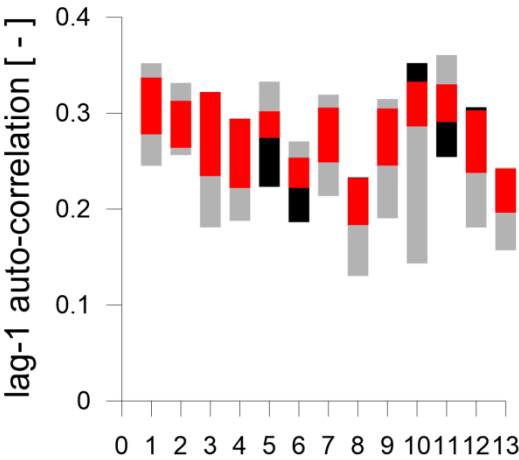
130
131
132
133 The following figure shows how the exclusion of zeros affects the rank correlations. The highest portion of
134 significant changes was found in the model 3B. This remains very similar when the zeros are excluded. In some

135 cases the control and future intervals overlap more when the zeros are excluded, but the overall result remains
136 the same:

spearman cc - confidence intervals, model 3B

zeros included

zeros excluded

pairs of basins ID

control
future
overlap
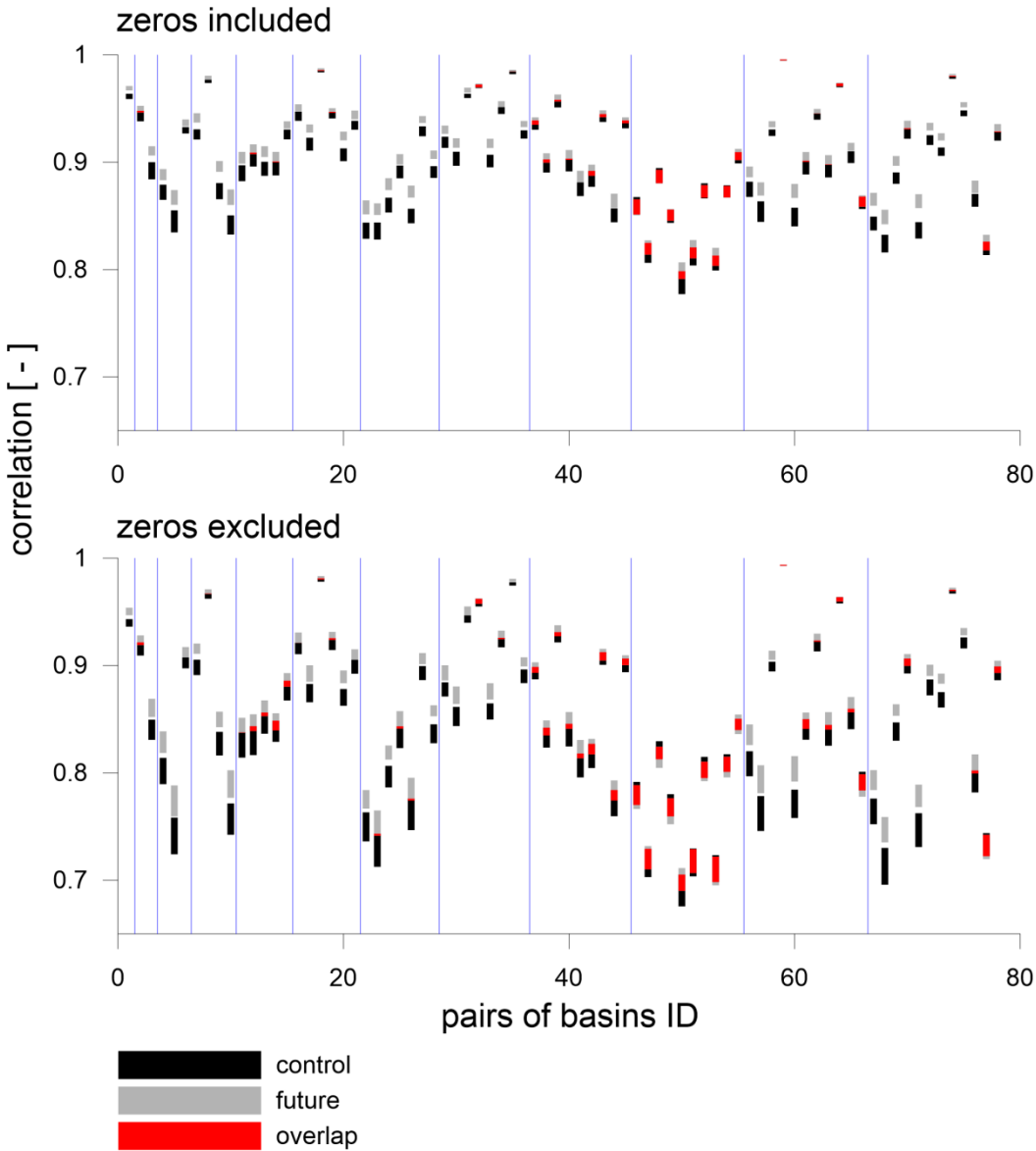
137
138
139 As a result, the exclusion of zeros affects individual correlations, but it affects considerably neither model
140 changes nor their significance. Moreover, the presence of outliers is better visible when the zeroes are
141 excluded. Therefore we suggest presenting our results using the correlations calculated without zeroes, if we
142 are invited to submit revised version of our manuscript. This modification changes neither ideas nor results of
143 our paper.

144 Comment:
145 *"Incidentally, the serial correlation coefficients should be compared both forward and backward over a few*
146 *intervals to eliminate 'drag' and find the highest cc."*

147 Reply:
148 Unfortunately, this comment is not clear to us. Could you be more specific, please?

149
150 **SPECIFIC COMMENTS**

151
152 Comment:
153 *"55: It's difficult to match table 1 and figure 1. Please consider re-labelling the links in Fig. 1 in a more orderly*
154 *pattern, South to North, perhaps as I have suggested by the blue lines on the images? "*

155 Reply:
156 We agree.

157 Comment:
158 *"Some of the areas in Figure 1 are less than 20 km across and are likely to be covered by a 25 km square Hydro*
159 *grid element - please show the grid superimposed on the basins."*

160 Reply:
161 As a result of addressing General comment 1 we suggest to remove the part on comparison between observed
162 and simulated dependence structure. Therefore the figure would be no longer necessary.

163 Comment:
164 *"99-100': 'the numbering was done according to rows of correlation matrix'. Why not use the convention of (i,j)*
165 *in each cell for row (i) and column (j)? It would save the reader from having to do arithmetic deciphering 156*
166 *numbers! Please see my partitioning of figure 4 as an alternative."*

167 Reply:
168 The intention was to assign a unique number to each cell of the matrix in order to show the results in a simple
169 plot. We think that the partitioning of the plot by blue lines is a great idea (we applied it in the previous figures
170 in this reply). We suggest to preserve the numbering of cells and to supplement the figures with the blue lines.

171 Comment:
172 *"113: In the caption of Figure 3, I do not understand the difference between bias and change in (a) & (b). Please*
173 *Insert the phrase 'Horizontal axis labelling from table 2' at the end of the figure caption"*

174 Reply:
175 The calculation of model biases is explained in lines 88 – 89 but we admit it could be done more simply.
176 Nevertheless, as stated above, we suggest removing the analysis of model biases from the paper, which will
177 simplify the methodology and the presentation of results. The Figure 3 will then contain only parts (b) and (c).
178 We agree with inserting the phrase 'horizontal axis labelling from Table 2'.

179   Comment:
180   *"116: after CCLM-4-8-17 and RCA4, please insert (A) then (B) to help the reader, as their definition is 2 pages*
181   *back"*

182   Reply:
183   We agree.

184   Comment:
185   *"124: 'range from -0.1 to 0.04.' what are the confidence limits for these statistics? 95% CLs for 78 independent*
186   *data pairs are about +/- 0.19 so I reckon that these biases are relatively negligible...!"*

187   Reply:
188   The paragraph summarises the biases of individual lag-1 autocorrelations. The significance of biases was not
189   analysed, but we think that it should be done for each bias individually using the bootstrap approach,
190   alternatively for each model individually, which means for 13 data pairs (not 78). Many of these biases are
191   probably insignificant; nevertheless, as stated above, we suggest removing of Section 4.1 from the paper.

192   Comment:
193   *"Figure 4: it would help the reader if you partitioned the elements from successive matrix rows as I have, then*
194   *add the following to the caption: The blue dividers identify the successive rows below the diagonal in the*
195   *matrix."*

196   Reply:
197   We agree, as stated above.

198   Comments:
199   *"Figure 8: to compile this figure did you visually check through 78 of these bar charts or did you devise an*
200   *algorithm to make the summary?*
201   *Figure 9: I do not understand these figures - it would help if you gave the axes labels and improve the description*
202   *in the text."*
203
204   Reply:
205   The figure demonstrates the procedure for the detection of outliers, the simplest example is considered – two
206   dimensional data (specifically the data from basins 6 and 8 from the model 2A, because these data contains
207   outliers and were plotted in Fig. 6). The plot shows the evolution of correlation structure, when 15 the most
208   noticeable outliers are removed from the data one by one. The plot is related only to these 2-dimensional data,
209   there are no 78 bar charts for analysis.
210   The Figure 9 shows the evolution of correlation structure of the model 2A, when the complete 13-dimensional
211   data are explored as a whole. We note, that the first value ($\delta\mathbf{R}_1$) in Fig. 9b is related to the day, where the
212   extreme outlier 310.1 mm was recorded in the basin 10. Therefore, the individual pairs of time series need not
213   to be analysed, the outliers are detectable from the analysis of the complete model data as a whole. Moreover,
214   the importance of individual outliers is clearly visible.
215   We apologize for the missing labels in Figure 9. The axis labels in Fig. 9 are the same as in Fig. 8. Both figures
216   depict the same process (in Fig. 8 calculated from 2-dimensional data, in Fig. 9 from 13-dimensional data). We
217   apologize for this omission. We will provide the details given above in the revised text.

218 Comment:
219 *"253-4 In these lines we find the following: ' Therefore the joint (average) rank was assigned to each zero value*
220 *in this study (we note that the results can differ if e.g. random rank is applied instead).' I do not like this*
221 *procedure - there are too many zeros in daily rainfall records, unless you have a very humid geography. What is*
222 *the proportion of dry-time? Why not calculate the binary cross correlation coefficients for wet and dry days over*
223 *a few days' lags so you can determine whether the wet periods match? Then treat the overlapping wet periods."*

224 Reply:
225 As stated above (based on addressing the general comments), the correlations were now re-calculated using
226 the overlapping wet periods only. We suggest using these zero-excluded results.

227 Comments:
228 *"261: the paragraph on 'Changes of covariance' - I do not understand the emphasis on covariance, because*
229 *differences in variance mask the dependence - that's why we use correlations! Why not compare variances and*
230 *means separately from correlations?*
231 *285:' covariance structures change considerably (even without outliers) and their changes are tightly associated*
232 *with the changes in variances.' Exactly!! See my previous remark."*

233 Reply:
234 The motivation for the introduction of covariance into the paper was stated above within the response to
235 general comments. We note that the tight relation of changes of covariance and variance cannot be
236 automatically expected. This relation becomes obvious only when the temporal stability of correlations is
237 verified.
238
239 **TECHNICAL CORRECTIONS**
240
241 We accept most of the proposed technical corrections. Therefore only the points which are formulated as a
242 question or the points that we do not agree with are discussed below:
243
244 Comment:
245 *"63: 'with 0.11 degree resolution' at this latitude that is about 11 x 8 km?"*
246 Reply:
247 Yes, in the middle of the area it is 11.1 × 7.18 km.

248 Comment:
249 *"78-82: did you exclude dry days? did you consider seasons?"*
250 Reply:
251 The exclusion of dry days was in detail analysed above and will be stated explicitly in the revised version. The
252 distinguishing between seasons was not considered, since the paper is intended as a technical note, which is
253 required a 'few pages only'. The dealing with seasons is unnecessary for the purpose of the paper; moreover it
254 would increase the extent of the paper considerably. However, it is true, that it might be necessary in real-world
255 application. We will add a note on this.

256 Comment:
257 *"110: 'individual models' in Figure 3 or 4?"*
258 Reply:
259 In Figure 3. This will be added to the text.

260 Comment:
261 *"200: ' the most outlying (multi-variate) value is found in the data' - in what alternative coordinates?"*
262 Reply:
263 The outliers are found in alternative coordinates. The construction of coordinates is explained in lines 179 –
264 189. We note that the alternative coordinates are recalculated after the removal of each outlier. We will
265 provide these details in the revised version.

266 Comment:
267 *"258: 'correlations' in Figure 11"*
268 Reply:
269 The remark about rank-correlations and non-linear relations between variables was intended in general, not in
270 particular to Figure 11.

271 Comment:
272 *"259: ' the precipitation data often show a more or less tight linear dependence' NOT to my mind in Fig 6b!!"*
273 Reply:
274 The meaning of the sentence was that the precipitation data do not show <u>nonlinear</u> relations, thus there is no
275 need to leave linear approach which is related to the Pearson correlation coefficient. Fig. 6b shows weak
276 dependence between variables, nevertheless, there is not nonlinear dependence. The sentence will be
277 reformulated.

278 Comment:
279 *"290: ' covariance is affected by a' lack of (!!) 'linear transformation. The high changes of' variance .."*
280 Reply:
281 The covariance <u>is</u> affected by a linear transformation, in particular $cov(aX, aY) = a^2 cov(X, Y)$. This is in
282 contrast to correlation, where $r(aX, aY) = r(X, Y)$. This means, that the stability of correlation together with
283 changes in covariance in climate projections can be interpreted as a linear transformation of the initial state (a
284 nonlinear transformation would change the correlations). This is why we conclude that the reasonable climate
285 scenario can be obtained by the multiplicative delta method. This approach avoids the problems of complex
286 bias correction methods (e.g. unclear effect on climate change signal).

287 Comment:
288 *"292-4: 'From this point of view a reasonable scenario of future precipitation can be obtained by the*
289 *corresponding linear transformation of observations, i.e. by the multiplicative delta method (Déqué, 2007).' In*
290 *my opinion, this is a rather weak conclusion"*
291 Reply:
292 See our previous reply.