Responses to reviewer 2 (Sylvie Parey) about “R^2D^2: Accounting for temporal dependences in multivariate bias correction via analogue ranks resampling”

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General comment:

The paper handles the difficult issue of climate model bias correction extensions to tackle the adjustment of temporal, spatial and inter-variable dependency biases. Based on a previously proposed technique by the authors, named R2D2, different variants are designed and tested with one climate model simulation and one reference dataset for temperature and precipitations. The methodology is meaningfully exposed and the results are clearly commented. This constitutes an important and valuable contribution to this question of bias correction, which remains a key issue in climate impact studies. Especially, the temporal evolution of the variables is often an important feature for climate impact models, which even require a finer timestep than daily (up to hourly).

Answer:

We thank Dr. Sylvie Parey for her detailed review, compliments and constructive remarks. We tried to incorporate them in the revised manuscript.

Comment:

My main comments are the following:

- When using CDFt for the univariate bias correction of rainfall, how are no-rain days handled? This may explain the degradation in the temporal autocorrelation after 1dBC, which is not seen for temperature. The adjustment of the number of rainy days, besides that of the rainfall amount, is one of the main problems in impact studies.

Answer:

That is a relevant question since, indeed, a specific method (SSR, Vrac et al., 2016) is used to correct precipitation data and handle no-rain days. This method is now briefly detailed (lines 106-110 of the track-changes manuscript and 104-108 of the revised one) as follows:

“*A specific version of CDF-t is used to correct precipitation data. This version relies on a “Stochastic Singularity Removal” (SSR, Vrac et al., 2016) approach to manage dry time steps: first, 0’s (from both references and simulations) are randomly* *transformed to positive but very small values ($< 10^{-6}$); then CDF-t is applied onto the whole set of data (i.e., transformed data and initially positive values altogether); and the correction results are thresholded such that values $< 10^{-6}$ are put to 0."*

Moreover, this remark leads to the question of the analyses of precipitation in separating rainfall occurrences and conditional precipitation intensities given rain occurrence, at least for marginal properties. Indeed, previously (i.e., in the initially submitted article), the univariate assessments of precipitation were done without separating occurrence and intensity. Hence, the analyses for the marginal of precipitation have been redone but, this time, separating precipitation occurrences and conditional precipitation intensities given rainfall occurrence. To do so, previous figure 7 (corresponding to boxplots of relative differences of mean precipitation with respect to the mean reference precipitation) is now replaced by:

- a figure showing boxplots of the relative differences of rainfall occurrence probability with respect to that of the reference;
- and, in the same figure, the boxplots of the relative differences of the mean conditional rain intensity (given rainfall occurrence) with respect to that of the reference dataset.

Note that, for each new boxplot figure, the associated maps are also given for each season as supplementary materials.
In addition, boxplots of relative differences of the standard deviations computed from conditional precipitation intensities are also given in new figures of the supplementary materials.
To account for these changes, the text now reads (on lines 400-414 of the track-changes manuscript and lines 387-400 of the revised one):
"*For precipitation, univariate biases are investigated in separating occurrences of rainfall and conditional intensities given rainfall occurrences. Hence, Figure 7 displays, for the four seasons, boxplots of the relative differences of the probabilities of rainfall occurrence with respect to that the reference data (7(a-d)), as well as the boxplots of relative differences of the mean conditional intensities given rainfall occurrences, wrt that of the reference data (7(e-h)). The associated maps are given as supplementary materials (Figures SM21-24 for occurrence probabilities and SM25-28 for mean conditional intensities). Rainfall occurrences are defined as precipitation values > 0.1mm/day to get rid of the drizzle effect present in many climate model simulations (e.g., Dai, 2006; Kjellström et al., 2010; Teutschbein and Seibert, 2012). Generally speaking, the effects of R^2D^2 on the occurrence and conditional mean precipitation biases are similar to those observed on the mean temperature: (i) the R.1.1.0 configuration provides similar performances as BC1D; (ii) with or without time lags, and with or without adding precipitation in the conditioning, increasing the number of conditioning sites may lead to relatively higher biases, both for occurrence probability and intensity. However, including precipitation itself in the conditioning does not amplify the precipitation biases and can even reduce them depending on the season.*
Biases in standard deviations for conditional precipitation values are also given for information (Figures SM29) and coincide with results for means."

Comment:

- Section 4.2 discusses the rank association between the corrected and the raw model simulation outputs. Indeed, there is no reason why the model should reproduce the observed chronology, since it represents another sequence of variability. However, some level of correction of the model chronology may be needed (in association with the variables interdependencies for example, as treated here). The problem then is the lack of an adequate reference...

Answer:

The observed chronology (or at least the chronology of the reference dataset) is the only leverage point that we have to perform a correction of the model chronology. It is true that, as the model might behave quite differently from the reference in terms of temporality (i.e., has biases in its temporal properties), the rank association approach may not always be sufficient to fully correct the chronology-related aspects of the model, e.g., if the rank sequences of the raw model simulations are too unrealistic (i.e., too different from reference rank sequences). However, as the resampling is performed on observed rank sequences (supposed adequate), by construction, the R^2D^2 corrections including lags in the analogues will improve the temporal properties. This emphasises, nevertheless, the fact that correcting climate models that are too much biased may not be appropriate and provide non-negligible residual biases, here in the temporal properties.

Comment:

- In section 4.3.2, it is noted that "the empirical copula between temperature and precipitation is not exactly the same during the two time periods used alternatively for calibration and validation". This may be worth exploring further: how stable is the association with time? How long has the considered period to be in order to faithfully estimate the association? How can climate change alter it? This problem is properly mentioned in the discussion, but could be raised here.

Answer:

Those questions are indeed important. However, they are not specific to our suggested method and concern many methods and studies relying on dependencies of climate variables in climate change contexts. Actually, there is no clear attempt to tackle those questions in the scientific literature so far. Hence, we decided not to raise those problems in section 4.3.2, but to emphasise them as discussions in section 5.2. We believe indeed that such fundamental questions deserve to be investigated on their own, and are thus left for future works.

The following paragraph – taking up the relevant questions of the reviewer – has then be added lines 509-514 of the track-changes manuscript and lines 494-499 of the revised one):

"*Hence, the potential non-stationarity of the dependencies between climate variables (i.e., rank association) may be worth exploring further. This could be done via several questions, e.g.: how stable is the rank association with time? How long has the considered period to be in order to faithfully estimate the association? How can climate change alter it? Those questions, however, are not specific to our suggested method. They concern many methods and studies relying on dependencies of climate variables in climate change contexts. Such fundamental questions deserve to be investigated on their own, and are thus left for* *future works.*”

<u>Comment</u>:

- In the conclusion, the improvements in the temporal evolution brought by the variants of R2D2 proposed here are emphasized, but still, they do not reach the rather good level obtained with 1dBC. Hence, in many impact studies, a correct chronology of the variables is of major interest, especially if long duration occurrences of extreme conditions are of concern. This could be stated more clearly.

<u>Answer</u>:

Indeed, for temporal properties of temperature, the CDF-t 1d-BC does a good job, due to the correct auto-correlations from the raw temperature simulations. However, this is not always that clear for precipitation, depending on the season. To state this point more clearly, an additional text is now included lines 483-458 of the track-changes manuscript and lines 468-470 of the revised one):

“*For temporal properties, although the R^2D^2 variants strongly improve the initial R^2D^2 approach, they do not reach the rather good level obtained for temperature with the tested 1d-BC (due to the correct auto-correlations from the raw temperature simulations), while the results are more debatable for precipitation. In general, the main conclusions were that...*”

<u>Minor comments</u>:

<u>Comment</u>:

- p2 l36: “whose the target is the whole univariate distribution”: I would write “whose target”; the same applies to p7 l184, p9 l263

<u>Answer</u>:

All are corrected.

<u>Comment</u>:

- p4 l101: ““successive conditional”: too many quotes

<u>Answer</u>:

Corrected.

<u>Comment</u>:

- p8 l232: “as hose from the IPSL dataset” as those

Answer:

Corrected.

- 10 l302: “Finally, When adding time lags in the conditioning dimensions”: no capital letter needed for “when”

Answer:

Corrected.

Comment:

- p10 l302-303: “both for temperature and precipitation, (R.1.1.0,R.1.5.0, R.1.100.0, R.2.1.0, R.2.5.0, R.2.100.0): isn’t it rather R.1.1.1, R.1.5.1, R.1.100.1, etc... ? The same stands for the following sentence: “This is especially true, for R.2.5.0,” R.2.5.1?

Answer:

Absolutely! Thank you. This is now corrected.

Comment:

- p13 l378: “We then compare these correlation values with them from the references.” With those from the reference?

Answer:

Corrected.

Comment:

Supplementary Material:

Blank lines appear in some maps, what does it mean?

Answer:

We do not see any blank lines in the supplementary materials figures. This may come from the pdf reader of the reviewer. When zooming on the figures, some blank lines can sometimes also appear or disappear, depending on the pdf reader.

Comment:

The scales in figures 17, 18 and 19 differ, which make it difficult to compare. This is the same for the precipitation figures. It may however be difficult to use the same scale for all plots, but when possible, it’s easier for the reader.

Answer:

We are aware that similar figures for different seasons may not have the same scale. This is a choice that we made to focus on the comparison between the raw, 1d-BC and the R^2D^2 variants. Indeed, since results for some seasons might vary very little compared to other ones, imposing a common scale to all seasons considerably resulted in very uniform maps and thus reduced the possibility to compare the methods. As our goal is not to compare between seasons but rather to compare the methods conditionally on specific seasons, scales were adapted to each season. However, we believe that some comparisons between seasons can be made anyway by the interested reader.

References

Dai, A.: Precipitation Characteristics in Eighteen Coupled Climate Models, Journal of Climate, 19, 4605–4630, https://doi.org/10.1175/JCLI3884.1, https://doi.org/10.1175/JCLI3884.1, 2006.

Kjellström, E., Boberg, F., Castro, M., Christensen, H., Nikulin, G., and Sánchez, E.: Daily and monthly temperature and precipitation statistics as performance indicators for regional climate models , Climate Research, 44, 135–150, https://www.int-res.com/abstracts/cr/v44/n2-3/p135-150/, 2010.

Teutschbein, C. and Seibert, J.: Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods, Journal of Hydrology, 456-457, 12 – 29, https://doi.org/https://doi.org/10.1016/j.jhydrol.2012.05.052, http://www.sciencedirect.com/science/article/pii/S0022169412004556, 2012.

Vrac, M., Noël, T., and Vautard, R.: Bias correction of precipitation through Singularity Stochastic Removal: Because occurrencesmatter, Journal of Geophysical Research: Atmospheres, 121, https://doi.org/10.1002/2015JD024511, 2016.