# Evaluation of bias correction methods for a multivariate drought index: case-study of the Upper Jhelum Basin

## Response to Referee 2

In their study, the authors of "Climate change projections of wet and dry extreme events in the Upper Jhelum Basin using a multivariate drought index: Evaluation of bias correction" assess the performances of several univariate (2) and multivariate (8) bias correction methods applied to climate models outputs for impact studies. The multivariate drought index SPEI is considered to evaluate the adjustments of wet and dry extreme events over the Upper Jhelum Basin, in the Western Himalaya region. Two experiments of bias correction are performed in this study: 1) the component-wise approach that consists in applying bias correction (BC) methods prior to the computation of the SPEI index, and 2) the direct approach that consists in calculating the multivariate SPEI index first, and then adjusting it using univariate BC methods. Corrections are performed to adjust daily maximum temperature, minimum temperature and precipitation from several CMIP6 GCMs, CORDEX and CORDEX-CORE RCMs with different spatial resolutions over the historical period (1986-2005). Corrections are evaluated in terms of inter-variable relationships and SPEI characteristics on the same historical period with respect to W5E5 reanalysis dataset. The authors find that the multivariate BC methods have some added value over univariate BC methods concerning the adjustment of inter-variable properties. However, both univariate and multivariate methods present similar performances for the correction of SPEI indices. The direct approach shows slightly better results than the component approach and no added value was obtained when considering high resolution products.

The article is scientifically interesting, its structure is clear and easy to follow, the results are well explained and summarized. I think this study certainly falls within the scope of the journal. However, I think there are a few minor issues that should be considered to improve the study before publication.

**Response:** We thank the referee for the time devoted to review our manuscript, and the positive feedback provided. Along the next lines, the different comments posed by the reviewer are reviewed point by point. The referee's comments are indicated in black, and the author responses in red fonts.

## General comments:

**Comment:** SPEI has been chosen to evaluate univariate and multivariate bias correction methods. In this study, the index is computed in several steps involving precipitation, Tmax and Tmin time series at different time scales. Thus, not only a good representation of the values (marginal properties) and dependence (inter-variable properties) of the variables is important for the SPEI index, but also the temporal properties. None of the multivariate BC methods used in this study are designed to adjust temporal properties. Moreover, multivariate BC methods can also deteriorate temporal properties (e.g., François et al., 2020). Consequently, it is not clear in this study whether the comparable performances of multivariate BCs with respect to univariate BCs are due to compensating effects between improvement of inter-variable properties with multivariate BC and deterioration of temporal properties at the same time. Would the same conclusions be obtained by considering other multivariate indices than SPEI, e.g., indices for which inter-variable properties are important, but not temporal ones? I think that these points (1. importance of temporal properties for SPEI, 2. inability of the implemented BC methods to adjust temporal properties and 3.

potential deterioration of temporal properties by multivariate BCs) should at least be mentioned in the discussions to provide some nuances to the conclusions of this study as explained above.

**Response:** Thank you for your comment. Temporal aspects have a role in the SPEI derived indices (since SPEI was calculated using a 30-day accumulation period at daily time step and extreme events were defined considering consecutive SPEI monthly values) and thus they might help to explain biases in SPEI indices.
To check the ability of BC methods to adjust the temporal properties of the corrected time series, we evaluated all BC methods considering several univariate indices from the EU-COST Action VALUE which are specifically related to temporal properties. More precisely, we considered the transition probability of a wet day given that the previous day was dry, the longest dry spell, the longest warm spell, the amplitude of the annual cycle and interannual variance (Maraun et al., 2019), which have not been calibrated by any of the BC methods. We found a large reduction in biases of these indices with all BC methods except for GPQM and DQM (especially for precipitation) and no clear benefit of multivariate methods (see Figures S1-S5 in the revised Supplementary Material and new Section 3.1 in the revised manuscript). Although biases in the interannual variance of temperatures are relatively high for few months, the overall performance is considered to be reasonable.
In addition to this new evaluation of univariate temporal properties, we also looked at the correlation between pairs or variables at monthly timescale and found high correlations between precipitation and temperature in the reference dataset in some parts of the domain (up to -0.54, see Fig. S7 in the revised Supplementary Material), despite the low correlations at daily scale (Fig. S1). These correlations are not present in most of the raw models but are improved after BC (except for GPQM, see Fig. S8), with no evident added value of multivariate methods. Still, we focus on daily statistics (correlation and PSS) in the main manuscript since this is when inter-variable relationships are expected to be relevant for the SPEI calculated in the present work.
We incorporated these new analyses in the revised manuscript (See highlighted text in Sect. 3.1 (page 9, lines 35:48), section 3.2 (page 10, lines 12:18) and Discussion section (page 21, lines 27:31 and page 22, lines 10:17)).

**Comment:** I really like the title which is clear, but I find the term “climate change projections” a bit misleading. The historical period 1986-2005 is only considered in the study, and thus authors are not looking into climate projections, i.e., simulations of future evolutions of the climate system. The notion of “climate change” is also misleading as the changes of the climate system are not particularly investigated in this study, not even those that could have occurred during the 1986-2005 period. I would propose to find another title for the study avoiding the words "climate change projections".

**Response:** Thanks for the comment. The reason for the name is that this work corresponds to the first part of a wider study where future climate change projections are analyzed. However, we understand that it can be misleading as it is, thus the title has been changed to “Evaluation of bias correction methods for a multivariate drought index: case-study of the Upper Jhelum Basin” in the revised manuscript.

**Comment:** In Section 4 - Discussion and conclusion: I really like the way results are summarized and discussed. However, I think it would be interesting to detail a bit more about future research by adding a few sentences. Besides investigating the robustness of results under climate change as already mentioned at the very end of the study, what are the next steps of this work? I think it would be helpful to mention a few avenues of research, as it would help to better connect this work to the research community.

**Response:** As for the future work, we had several lines at the time of submission, so we preferred to keep it general. However, we have incorporated your suggestion into the revised manuscript since the main draft of the future work has been drawn.
We incorporated this information in the revised manuscript (Discussion section, page 23, lines 1:6).

## Specific comments:

- Page 2, L21: "The use of raw GCM and RCM output for subsequent impact studies without any post processing could lead to ill-informed adaptation decisions for the foreseeable future.". Do you have any examples/references to support this sentence?
- Page 4, L20: "above/below 1". I assume you meant "above 1 and below -1"?
- Page5, Table 1 and 2, and Section 2.4: I don't understand why you detail the scenarios for the different models. As your study is focused on the 1986-2005 period, it seems that there is no particular reason to provide such details. It might be preferable to remove some parts of the text and tables mentioning information on scenarios.
- Page 5, Table 1: It might be preferable to round resolution numbers in the table.

**Response:** Many thanks for the comments. The suggested corrections have been carried out. Regarding the first comment, a few references have been added (Piani et al., 2010; Haerter et al., 2011; Argüeso et al., 2013) and the sentence has been slightly rephrased (page 2, lines 19:21).

## References:

Argüeso, D., Evans, J., and Fita, L.: Precipitation bias correction of very high resolution regional climate models, Hydrology and Earth System Sciences, 17, 4379-4388, 2013.
Haerter, J., Hagemann, S., Moseley, C., and Piani, C.: Climate model bias correction and the role of timescales, Hydrology and Earth System Sciences, 15, 1065-1079, 2011.
Maraun, D., Widmann, M., and Gutiérrez, J. M.: Statistical downscaling skill under present climate conditions: A synthesis of the VALUE perfect predictor experiment, International Journal of Climatology, 39, 3692-3703, 2019.
Piani, C., Haerter, J., and Coppola, E.: Statistical bias correction for daily precipitation in regional climate models over Europe, Theoretical and applied climatology, 99, 187-192, 2010.