

Interactive comment on “Addressing the assumption of stationarity in statistical bias correction of temperature” by Manolis G. Grillakis et al.

Anonymous Referee #1

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Review on Grillakis et al 2016

General Summary:

The authors present a bias correction method that is intended to address the assumption of stationarity in statistical bias correction. The idea behind the presented method is to disaggregate "stationary" and "non-stationary" components of the model-based time series that are to be bias-corrected, in order to preserve the original signal of the model for the "non-stationary" components. The authors show that this method does what it is designed to do, i.e. it preserves the trend signal of the original model but largely reduces biases relative to an observational dataset. However, I believe that there are a number of problems to this approach, both conceptually and technically, as

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well as methodological inconsistencies, which I will outline below. Due to these, I do not think that this manuscript could be published in its present state.

Major comments:

1. Conceptual issues and added value to previous literature

a) "stationarity of biases" vs. "preservation of trends"

The authors state in the abstract a generality about bias correction techniques, namely that "various methodologies have been developed, their majority assumes that the statistical characteristics of the biases between the modeled data and the observations remain unchanged in time." (l. 27-29) and further state that they would develop "a method to overcome the assumption of stationarity and its drawbacks". (l. 30-31) These statements are mirrored multiple times in the manuscript. However, the authors' method does NOT address the issue of biases that are (or could be) changing over time (or in a changing climate) due to changing feedbacks, changing climatic patterns, etc. Quite to the contrary, the authors' method assumes a quite strict stationarity of the biases that are being corrected by their method (i.e. through a normalisation procedure that normalises yearly time series to the reference period, where only "stationary" (i.e. "stationarised") parts are being bias corrected); and non-stationary parts of the time series are not accounted for. This preserves the trend (as intended by the authors), but ultimately would fall short if "statistical characteristics of the biases" would change over time (see Boberg and Christensen, 2012, NCLIM, for an example of temperature-dependent biases, where due to non-stationarities in biases one might NOT want to preserve the original trend).

Therefore, I believe the statements made in the paper regarding a "stationarity of biases" vs. "preservation of trends" could lead to a severe misconception among the readers, and I believe a substantial revision/clarification of these statements and discussion (including title) would be necessary to emphasize that the aim of the

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authors was to develop a trend-preserving bias correction technique, rather than a technique that addresses the "assumption of stationarity in statistical bias correction of temperature" (title). See e.g. Maraun (2016) for a more thorough discussion, including implicit assumptions, of using a "trend-preserving" bias correction vs. "state-dependent biases" (where one would expect time-dependency in the biases).

b) Previous work on trend-preserving bias correction

The authors motivate their study with an example of a model-based and observed time series, where a statistical bias correction method (quantile mapping) induces an additional warming signal of 1.5°C by the end of the century due to the shape of the transfer function. However, the fact that bias correction can change the trend signal is not new, and in fact has been highlighted in a number of publications (see e.g. Maraun 2016 for a discussion). Moreover, several papers have investigated the issue raised in detail, and various methodologies to preserve trends have been developed. Unfortunately, the authors do not even refer to previous papers that already developed tools to address this issue (except for Hempel et al., 2013, ESD). For example, see:

Li H, Sheffield J, Wood E., *J Geophys Res.*, 2010.

Maurer, E.P. and D.W. Pierce, *Hydrol. Earth Syst. Sci.*, 2014.

Pierce D, Cayan D, Maurer E, Abatzoglou J, Hegewisch K., *J Hydrometeorol.*, 2015.

Maraun D, *Curr. Clim. Change Rep.*, 2016.

2. Technical implementation of non-stationarity module (NSM) of bias correction and underlying assumptions of NSM

In their manuscript, the authors separate "stationary" and "non-stationary" components of the time series by transforming each annual time series to the reference period using a transfer function (calibrated for each year separately). However, several implicit assumptions, choices, and potential in-consistencies seem to underlie this procedure, which to my mind are not or only very shallowly addressed in the present manuscript.

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For example:

a. The procedure seems to be prone to conceptual in-consistencies that need to be addressed: For example, consider the following case: Imagine you want to bias-correct a climate model that has very strong positive biases in summer due to land-atmosphere feedbacks that take off in the warmest, say, 30 days in each summer, and small biases for other seasons (a scenario that is not uncommon for regional climate models). Further, imagine a volcano goes off in any one particular year, leading to inter-annual variability in the climate system and a cold year without these hot 30 summer days. If I understand the procedure correctly, this unusually cold year without hot ("biased") days would still be bias-corrected following the reference period (i.e. "stationarized" time series), and thereby potentially large, unwanted side effects would be introduced.

b. The proposed method (BC-NSM) seems to underestimate variability on the annual time scale (Fig. 2c). I wonder whether this issue stems from the in-consistency outlined in (a), but in any case it seems to be a methodological problems that needs to be addressed.

c. Why is the "recalibration" (Eq. 1 - Eq.3) performed on the annual time scale? How would it look like if this stationarity/non-stationarity separation would be conducted on other time scales? (for example for each season separately?) Regarding this point, the authors loosely refer to the annual cycle as the most dominant frequency of variation in the climate system, but for example in tropical regions this assumption does not necessarily hold. While I understand that a year seems to be an obvious choice, it is subjective, and any of such choices will be (to some degree) prone to in-consistencies as outlined in (a).

d. Why is the separation being done in an additive way? (Eq. 2) While this seems to be a reasonable choice at first sight, it is clearly subjective, and to me it is not at all evident why climatic time series could be separated into "stationary" and "non-stationary" components in an automated and additive way (given this is done on an annual basis, and not by subtracting **long-term** trends, etc.).

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e. The procedure is not sufficiently explained, and relevant sections seem to be very hastily written. For example, out of 3 equations, two appear to be wrong (wrong subscripts in Eq. 2, Eq. 3 does not make sense unless $S_i^{NS} = 0$). Furthermore, the reader is left to guess how exactly the transformations and methodology is implemented ("using linear functions instead of gamma functions", l. 192-193). If the authors would decide to move forward with their manuscript, I believe that the readability of the manuscript would benefit greatly from a substantial rewriting and a better illustration of the procedures.

3. Comprehensive evaluation of procedure and comparison to previous trend-preserving bias correction methods

As stated already above, a couple of "trend-preserving" bias correction methods already exist in the literature, which the authors tend to ignore (with one exception, see above). However, given that the authors' intention is to present a novel methodology, it would be crucial to see how a new method compares to established methods. Is there a large gain in performance compared to "less intrusive" methods, i.e. those that only preserve the trend (Hempel et al., 2013, ESD) or trends in individual quantiles (Li et al., 2010 JGR)? If not, what is the added value of yet another post-processing step? Furthermore, to my mind it would be crucial to explore how yet another additional bias correction step (in the form of a "pre-postprocessing") would change statistical properties of the data. For example, I get the impression that BC-NCM reduces the variance on annual time scales (Fig. 2c). Is this an artefact that stems from the method or does it only appear to do so? For example, it might be beneficial to compute power spectra of the model data, observations, and the bias-corrected data in order to see how the various transformations distort or change variability at different frequencies (and both for the calibration and validation period).

Minor comments:

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l. 65-67 I do not believe that this is always the case. Climate models are indeed also tuned to specific variables.

l. 92 typo: flawed

l. 96-99 A change in the model trend is not in all conceivable cases unwanted. See discussion above or Maraun (2016).

l. 122-125: As described above, it is unclear to me why a change above or below the annual periodicity should distinguish between a stationarity and non-stationarity process. I would advise the authors to make their reasoning more clear here.

l. 132 / Fig. 1: Generally, the transfer function for bias correction is a function of the modelled data, i.e. $f(x_{mod})$. Wouldn't it be more natural to put the model data on the x-axis?

l. 132/Fig. 1: It seems that in your example, you've bias-corrected to station data? This induces a scale-mismatch, and I wonder whether this scale mismatch might contribute to the fact that the trend change is so large. The induced changes in the trend are not as large in Fig. 5, are they? Would it change if the bias correction is conducted on a seasonal basis?

l. 161/162 Sentence not understandable. Please rephrase.

l. 168 each year's data

l. 192/193 Why linear here? Please be specific.

l. 197 "The bias correction methodology modification has been already used in the Bias Correction Intercomparison Project..." - but by modification you do not mean the BC-NSM in this paper, do you?

l. 215 Has the data quality of the observations been assessed? One might expect that observations-related uncertainties are largest in the early period, therefore using the first 50 years for validation might not be an ideal choice.

l. 221 This statement is trivial in that it does reconstruct the initial raw data time series by construction, doesn't it?

l. 234-237: I do think that BC-NSM underestimate variability in annual averages. Given that inter-annual variability is very important for climate impacts (for example in

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the carbon cycle), I would consider this is something that is crucial to get right.

I. 339-341: I do agree that this is the case for statistical bias correction, but biases can also be overcome by using bias correction scheme that preserve the physics (e.g. ensemble-resampling methods, Sippel et al., 2016, ESD).

References:

Boberg, Fredrik, and Jens H. Christensen. "Overestimation of Mediterranean summer temperature projections due to model deficiencies." *Nature Climate Change* 2.6 (2012): 433-436.

Hempel, S., et al. "A trend-preserving bias correction—the ISI-MIP approach." *Earth System Dynamics* 4.2 (2013): 219-236.

Maraun, Douglas. "Bias Correcting Climate Change Simulations—a Critical Review." *Current Climate Change Reports* 2.4 (2016): 211-220.

Maurer, Edwin P., and David W. Pierce. "Bias correction can modify climate model simulated precipitation changes without adverse effect on the ensemble mean." *Hydrology and Earth System Sciences* 18.3 (2014): 915-925.

Li, Haibin, Justin Sheffield, and Eric F. Wood. "Bias correction of monthly precipitation and temperature fields from Intergovernmental Panel on Climate Change AR4 models using equidistant quantile matching." *Journal of Geophysical Research: Atmospheres* 115.D10 (2010).

Pierce, David W., et al. "Improved Bias Correction Techniques for Hydrological Simulations of Climate Change." *Journal of Hydrometeorology* 16.6 (2015): 2421-2442.

Sippel, Sebastian, et al. "A novel bias correction methodology for climate impact simulations." *Earth System Dynamics* 7.1 (2016): 71.

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