We would like to thank Anonymous Referee #2 for providing us with constructive comments on the submitted manuscript. We believe that the input that will help improve the manuscript significantly. The reviewer's comments (shown in italics) have been addressed point-by-point.

Anonymous Referee #2
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General comments:

This paper examines the impact of bias correction on global uncoupled land-surface model (LSM) simulations using GCM data as inputs. They step through an observation-based simulation, and two GCM simulations using raw GCM inputs and a bias correction simulation that corrects all seven variables required to run an LSM that solves the surface energy balance. They find the bias correction scheme removes nearly all bias from all seven variables and the subsequent LSM simulations closely match the observation-based simulation.

They then step through six simulations where they remove bias correction from one variable at a time (e.g. precipitation or temperature) to examine the impact of bias correction for that specific variable. Findings highlight that precipitation and temperature are the most important variables to bias correct, as expected. However, radiation is also found to have high sensitivity and should be corrected as well. Surface pressure and wind speed generally have little impact and can almost always be neglected. I appreciate the literature review to place the sensitivities found here in the context of other studies.

Extra time is spent examining humidity, as extreme sensitivity across higher latitudes in the northern hemisphere is found in the LSM (JULES in this paper). They attribute the extreme sensitivity to reduced ET in high humidity environments, and direct condensation and deposition of water vapor into the snowpack in these regions.

Overall, this paper is logically organized and generally easy to follow. I think it will be ready for publication in HESS after the authors address my comments.

Comments:

RC1. The specific humidity discussion is much needed to explain the extreme sensitivities in the JULES model. I believe it should be expanded in the main text, with the figures in the supplemental material moved to the paper. Additionally, examination of relative humidity for supersaturated conditions should be done for an example grid cell or the entire Northern European region.

Figure S.4 and the discussion in Section 4.4 imply that the raw GCM runs are too humid and have supersaturated conditions in high latitudes in the northern Hemisphere. I'm a bit surprised by this, thus it is worth checking in more detail by looking at relative humidity over a larger spatial region in the raw GCM output.

What GCM data are used to force JULES? That is a key detail I cannot find in the paper. Was it the lowest sigma level of the GCM, or the 10-m/2-m diagnosed variables from the GCM? It is possible (although maybe not likely) that the issue could stem from the use of JULES while the GCMs use a different LSM and that mismatch could be at the root of these results.

Finally, some detailed examination of how JULES treats vegetation and snowpack versus the LSMs in the GCMs may also give some insight into this issue. These regions are primarily boreal forest, which are sometimes difficult areas to model in winter, particularly surface fluxes into/out of the snowpack (e.g. Chen et al. 2014). Is it possible to distinguish between condensation and deposition in the JULES output? That may give additional insight into JULES behavior.

AC1. Figures S4, S5 and S6 of the Supplementary material were combined in one Figure showing 3 plots of latitudinal means and were transferred to the main manuscript, after the reviewer's suggestion (Figure 11, shown below). We would prefer to leave the other two relevant figures (showing the seasonality of snowmass and the difference in long term means of water fluxes respectively) as Supplementary figures, in order to keep a proper number of figures (already 11) in the main manuscript.

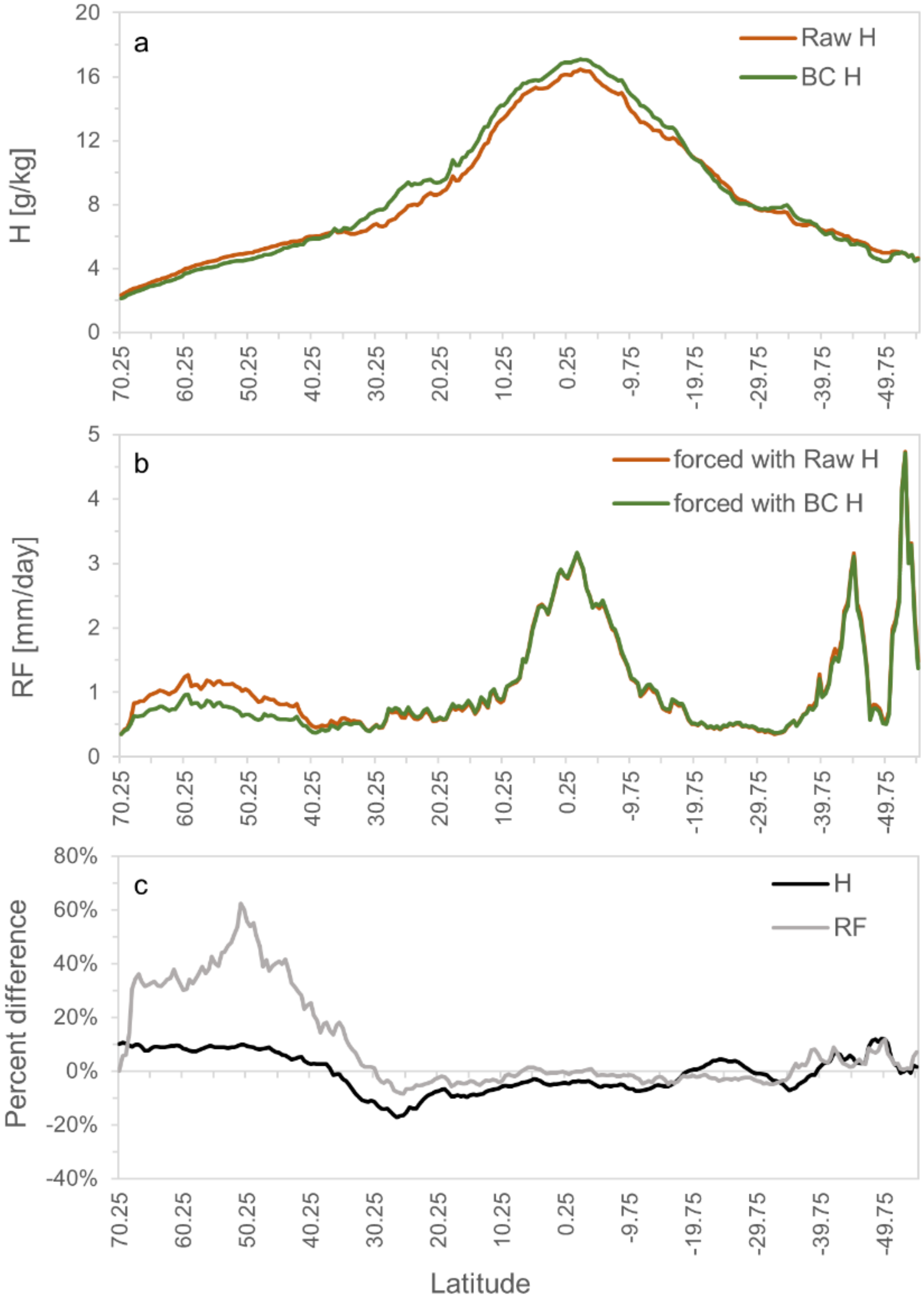
a
Raw H
BC H
H [g/kg]
20
16
12
8
4
0
70.25
60.25
50.25
40.25
30.25
20.25
10.25
0.25
-9.75
-19.75
-29.75
-39.75
-49.75
b
forced with Raw H
forced with BC H
RF [mm/day]
5
4
3
2
1
0
c
H
RF
Percent difference
80%
60%
40%
20%
0%
-20%
-40%
Latitude

Figure 1. a. Latitudinal means of raw and bias corrected specific humidity [g/kg], b. Latitudinal means of JULES' runoff forced with raw and bias corrected specific humidity [mm/day], c. Percent differences of the latitudinal means in a (H) and b (RF). The latitudinal means are calculated from the 1981-2010 period.

The reviewer suggested an investigation of relative humidity for supersaturated conditions. From the input specific humidity H, we estimated the respective relative humidity (this transformation also requires temperature T and surface pressure Ps as input to the Clausius-Clapeyron equation). Then we calculated the fraction of time (based on a daily timestep) that supersaturated conditions occur, for the historical period 1981-2010. The estimation was performed for a) the WFDEI H, T, Ps, b) the raw H, T, Ps, c) the bias corrected H, T, Ps and d) for a combination of data corresponding to the NobcH run (raw H combined with bias corrected T and Ps). The results are presented in the following figure, which has been added to the Supplement of the paper:

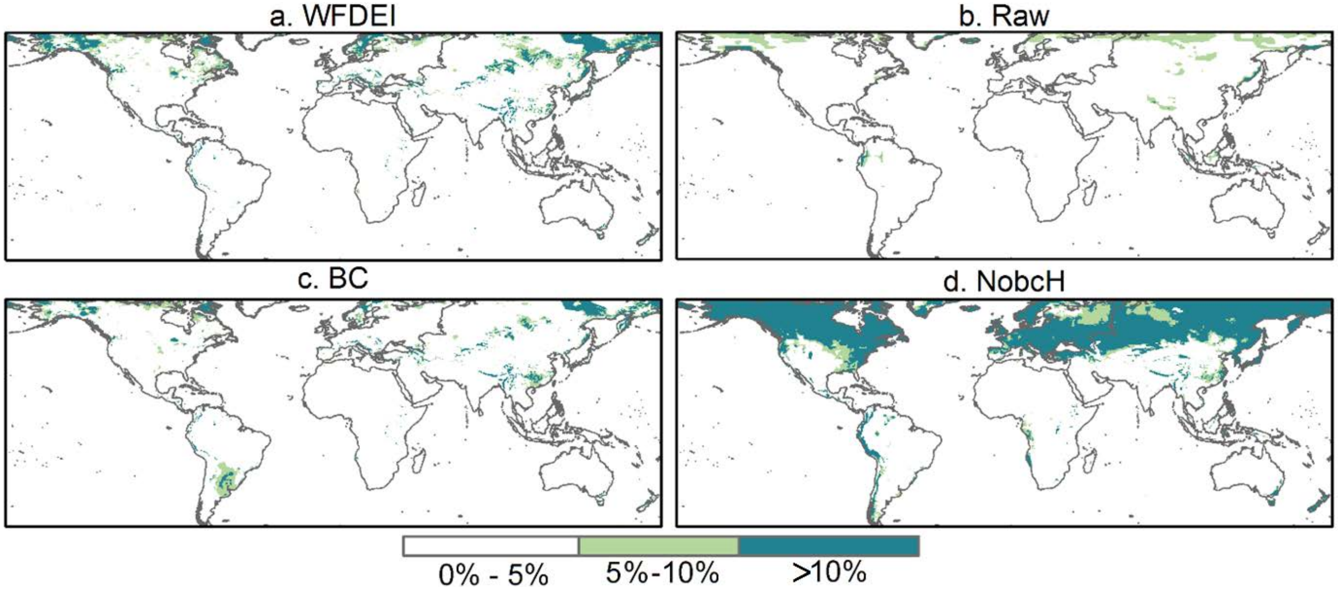

Figure S 1. Fraction of time under supersaturated air conditions (Relative humidity>100%), calculated from specific humidity H, temperature T and surface pressure Ps for: a. WFDEI data, b. Raw GCM data, c. BC GCM data and d. data corresponding to NobcH (raw H, BC T and BC Ps). Calculations are based on the historical period 1981-2010.

Firstly, this analysis reveals that supersaturated conditions are present in all three sets of datasets (WFDEI, Raw and BC). Is also worth noting that supersaturation was observed both in cases with daily temperature above and below 0^{o}C. Secondly, the NobcH calculation has a pattern of supersaturated conditions over the northern latitudes, corresponding to the high sensitivity regions discussed in the relevant section of the manuscript (Section 4.4). Thus, the high runoff sensitivity over the high latitude regions is not a result of supersaturated conditions in the raw GCM H and it rather stems from: 1) raw GCM H being higher than

BC H and 2) the calculation of relative humidity within JULES, done by combining raw GCM H with bias corrected T and Ps.

This inconsistency strengthens the argument for the need of bias correction of more forcing variables -in addition to P and T. Specific humidity is a variable that is often left uncorrected, a practice that could possibly result to runoff overestimations in the northern latitudes based on our findings, in cases that hydrological models which account for deposition and condensation are used.

A discussion on these findings is added to the relevant section in the manuscript.

The GCM data used to run JULES are described as “near surface” fluxes, which typically refers to 2 m above ground. On the consideration of the reviewer about the issues possibly stemming from the use of JULES while the GCMs use other LSMs, we think that this as an unlikely implication. JULES, as most LSMs, is designed to run both online with GCMs and offline, using GCM output data as forcing. Moreover, this would question the widely used practice of the scientific modelling community of forcing GHMs and LSMs with GCM output data in order to perform impact assessments.

The supersaturated conditions revealed in Figure S6 result from the interaction of atmospheric only variables (specific humidity, temperature and surface pressure). The JULES model performs a respective calculation prior to calculating the water and energy fluxes. In the presence of supersaturated conditions in the model, water vapor transitions to liquid (condensation) or ice (deposition), depending on temperature. As supersaturated conditions here result from the combination of raw H with bias corrected T and Ps, we believe that a comparison of vegetation and snow models used in the LSM of the GCM, although interesting, cannot add relevant information to our analysis. The reviewer’s point on the difficulty for modelling the snow dominated boreal forest regions is an important issue, which will particularly affect the sensitivity of GHMs and LSMs for these regions. In our single model study, we cannot assess possible sensitivities of other models. However, our study highlights the importance for special focus on the snow dominated boreal forest in future studies that will assess sensitivities of multiple models, due to the complex interactions between vegetation, snow and energy and radiation fluxes in the aforementioned regions.

RC2. Discussion in sections 3.1 and 3.2 can be shortened to make room for the expanded discussion of the specific humidity biases. These add little value to the paper in my opinion.

AC2. The authors tried to shorten these sections but it was not easy to leave out much of the presented content. The discussion of the results in sections 3.1 and 3.2 was requested by reviewer#1 during our previous submission of the manuscript, so we cannot substantially shorten these parts. Moreover, we believe that the results are discussed quite briefly and it is due to the number of examined variables that the sections increase in length.

RC3. The bias correction procedure needs more detail discussed. The authors mention the issues of keeping variables physically consistent when performing bias correction across many variables. However, they do not discuss the basic checks that are still necessary and should be performed when bias correcting many variables. For example, limiting humidity to prevent supersaturation conditions in the bias corrected fields when correcting temperature and specific humidity.

AC3. A number of essential parameter checks were performed along with the bias adjustment of the variables, such as prevention of unrealistic values (e.g. negative values to positively constrained variables) and the avoidance of extreme values well beyond or below the historical record of WFDEI. As the bias correction was limited to the historical period, this was a trivial task, as transfer functions were not extrapolated to a projection period. The bias adjustment for each calendar month aided the physical consistency of the bias adjusted variables, as it adjusts the seasonality in a coherent way according to the observational dataset that is used.

The issue of humidity supersaturation was also investigated in the bias correction stage. As it is discussed and shown in previous comment, supersaturation is a rare occurring state, which however exists in both raw climate model data and the WFDEI observational dataset, many of the times in cases where mean daily temperature exceeds 0^{o}C. Masaki et al., (2015) also report supersaturation even at temperatures over 0^{o}C, mainly in cases of raw GCM data. Additionally, WFDEI meteorological forcing, which is explicitly developed for hydrological purposes, has been included to the ISIMIP2b (Frieler et al., 2016) protocol without any notation about humidity treatment prior to its use. Considering these, it was decided to avoid treating the supersaturation cases in the WFDEI and the raw and bias corrected datasets, as it is inherent in data. Nonetheless, as discussed in the answer of the first comment of the reviewer, runoff sensitivity to specific humidity biases is driven by the combination of bias adjusted temperature and raw specific humidity.

References:

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Masaki, Y., Hanasaki, N., Takahashi, K. and Hijioka, Y.: Propagation of biases in humidity in the estimation of global irrigation water, Earth Syst. Dynam, 6, 461–484, doi:10.5194/esd-6-461-2015, 2015.