We would like to thank Anonymous Referee #1 for providing us with constructive comments on the submitted manuscript. We believe that the input that will help improve the manuscript significantly. We would also like to thank the reviewer for acknowledging the improvement of the present manuscript compared to the previously submitted HESS16. The reviewer's comments (shown in italics) have been addressed point-by-point.

Anonymous Referee #1
Received and published: 7 May 2017

Papadimitriou et al. submitted the manuscript "The effect of GCM biases on global runoff simulations of a land surface model" to Hydrology and Earth System Sciences as a revised version of the manuscript "Hotspots of sensitivity to GCM biases in global modeling of mean and extreme runoff" (doi:10.5194/hess-2016-547 (hereafter called as HESS16)). Main focus of the manuscript is the assessment of GCM biases to the impact model JULES and runoff. Compared with the HESS16 version, this manuscript is presented much clearer and consistent and many of the referee suggestions were considered. I therefore acknowledge the authors for carefully revising the manuscript. However, there are a few issues that needs to be addressed before publication.

Major

RC1. In all the analyses, the ensemble mean (of 3 GCMs) is shown, but it would be very informative to see exemplarily the behavior of the single GCMs within the focus of the study. This also affects the question about the reason to select the specific 3 GCMs out of CMIP5. For example, I am surprised to see the huge difference of "Raw – WFDEI" for Rs and Rl in Fig 4. When I am interpreting the Rs color values correct, the ensemble GCM are > 50 W m-2 higher for nearly complete South America (and the other way around for Rl). Is that consistent among the GCMs?

AC1. To give an insight into the behavior of each ensemble member, we estimated the spatial averages of the raw input variables for each single GCM over the study regions. This information, along with the respective ensemble mean and WFDEI values is summarized in a Table added in the Supplement of this paper (Table S2) and also in the following pages of this reply. The authors believe that this information can help clarify the source of possibly large biases presented in Figure 4.

Specifically on the example given by the reviewer, concerning the initial biases of Rs and Rl in Figure 4, an examination of values for the AMZ region can provide some relevant answers. Comparison of the single GCM values with WFDEI (for AMZ) indicate that: for Rl the initial biases are relatively consistent among the 3 GCMs, while for Rs, IPSL has the largest contribution to the ensemble mean initial bias , as its difference from WFDEI is double compared to the other two GCMs. A note on the color interpretation of Figure 4 mentioned by the reviewer: "Raw-WFDEI" for Rs is in the greatest value class (>50 W/m^2) for the northern part of South America and in the second greatest class (25 to 50 W/m^2) for central South

America. For Rl, most of South America falls into the second greatest underestimation class (-25 to -50 W/m^2).

The selected GCMs have participated in the ISIMIP Fast Track experiment. The 3 GCMs cover the full range of the climate sensitivity along the 5 Fast Track experiment models, hence it was decided to limit the ensemble to 3 members due to the large number of runs needed for the experiment conducted in this study.

RC2. I realize the range of the raw GCM range in Fig. 6, esp. for Congo. In order to see the effect of bias correction, please consider drawing also results for the bias corrected GCM runs. Sure, this adds another color, but this figure can also be redrawn showing e.g. with 3 red lines for each raw GCM and 3 green lines for each bias corrected GCM. This would provide the reader a much more visual interpretation of the effect of bias correction to discharge seasonality and could be an added value of the overall study.

AC2. The bias corrected results are not presented in Figure 6 for the sake of visual clarity, as bias corrected results are very close to each other and to the WFDEI results, and their values are almost indistinguishable. Following the reviewer's indication, a new figure has been produced to include the bias corrected results and is presented below. However, the authors feel that the new figure does not provide substantial new information due to the almost indistinguishable behavior of the 3 bias corrected GCMs -and it is also more difficult to interpret- and suggest that the previous version of the figure should remain in the manuscript.

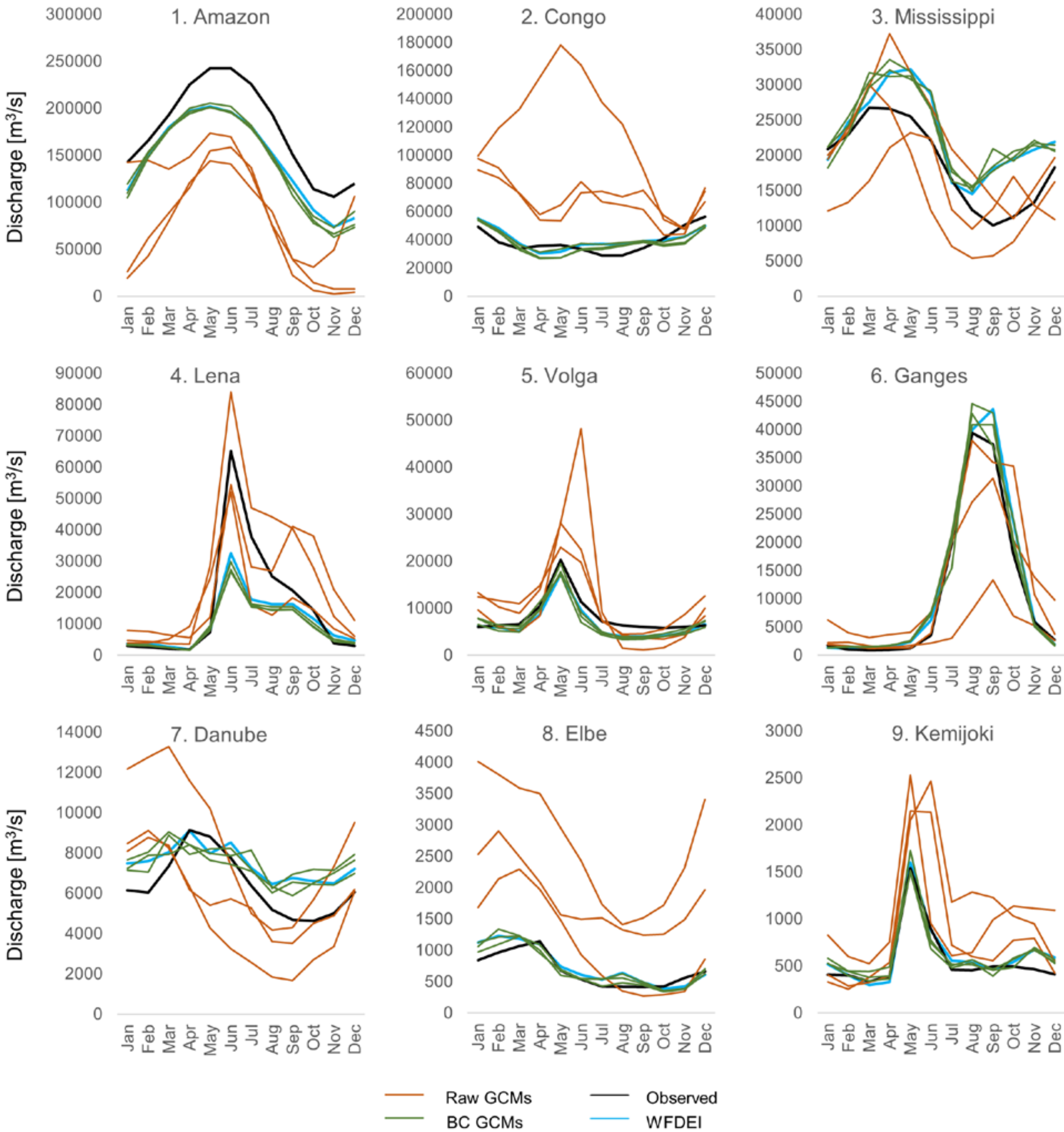

Figure 6. Discharge seasonality [m^3/s] derived from the period 1981-2010 for 9 study basins. Each panel shows observed discharge (GRDV measurements) compared to JULES' simulated discharge from WFDEI data, raw GCM data and bias corrected GCM data.

Table S 1. Values of input variables, for each GCM (GFDL, IPSL and MIROC), the ensemble mean (Ens.Mean) and WFDEI data, spatially averaged for 24 Giorgi regions.

	P [mm/day]					**T [K]**				
	GFDL	*IPSL*	*MIROC*	*Ens.Mean*	*WFDEI*	*GFDL*	*IPSL*	*MIROC*	*Ens.Mean*	*WFDEI*
NEU	2.61	2.30	2.53	2.48	2.43	277.90	277.15	281.16	278.74	279.50
MED	1.44	1.08	1.44	1.32	1.56	288.73	287.57	290.13	288.81	288.26
NEE	1.71	1.67	1.79	1.72	1.67	274.42	274.15	277.89	275.49	276.75
NAS	1.59	1.66	1.78	1.68	1.25	267.91	269.70	270.71	269.44	267.53
CAS	0.92	0.79	1.36	1.02	0.93	284.84	284.00	287.60	285.48	285.79
TIB	1.36	1.05	1.99	1.47	0.63	274.44	271.79	273.20	273.14	275.70
EAS	2.96	2.88	2.96	2.94	2.57	286.26	285.73	288.39	286.79	284.48
SEA	8.77	6.74	6.80	7.44	6.96	299.45	299.15	298.99	299.19	299.21
NAU	2.97	1.37	3.46	2.60	1.65	297.80	297.47	298.36	297.87	297.40
SAU	1.79	1.60	2.28	1.89	1.28	289.28	286.59	287.49	287.79	290.68
SAH	0.22	0.06	0.35	0.21	0.15	297.02	294.15	296.73	295.97	298.18
WAF	4.60	2.92	4.02	3.85	2.86	298.65	298.50	299.70	298.95	300.57
EAF	2.15	1.52	2.87	2.18	1.99	297.86	297.14	298.09	297.69	298.99
EQF	2.87	3.34	2.80	3.00	2.67	295.21	295.47	295.61	295.43	296.00
SQF	3.33	3.18	2.79	3.10	3.04	295.89	295.95	296.37	296.07	295.96
SAF	2.37	1.62	2.20	2.06	1.27	291.60	290.33	290.83	290.92	290.89
WNA	1.92	1.88	2.32	2.04	1.49	282.01	282.41	284.29	282.90	282.96
CNA	2.48	2.11	2.12	2.23	2.62	283.22	283.91	286.66	284.59	284.58
ENA	3.53	3.49	3.77	3.60	3.20	286.57	287.57	289.45	287.86	282.26
CAM	3.43	2.17	2.22	2.60	2.84	295.70	295.89	297.40	296.33	295.32
AMZ	3.57	3.55	4.06	3.72	5.32	297.74	297.44	297.66	297.61	297.94
CSA	2.37	1.71	2.20	2.09	2.83	291.79	290.06	291.07	290.97	290.61
SSA	2.58	2.76	2.70	2.68	2.57	281.71	278.10	279.75	279.85	281.32
SAS	3.61	2.94	4.76	3.77	3.75	296.89	296.78	297.21	296.96	296.36
	Rl [W/m2]					**Rs [W/m2]**				
	GFDL	*IPSL*	*MIROC*	*Ens.Mean*	*WFDEI*	*GFDL*	*IPSL*	*MIROC*	*Ens.Mean*	*WFDEI*
NEU	298.76	289.91	313.39	300.69	295.33	106.90	113.95	105.91	108.92	115.03
MED	325.96	306.36	328.73	320.35	314.19	194.08	207.62	202.13	201.27	199.11
NEE	283.96	268.51	293.05	281.84	286.82	113.46	130.74	131.76	125.32	113.86
NAS	255.12	250.35	261.36	255.61	245.13	115.27	125.07	132.40	124.24	117.66
CAS	294.43	276.17	300.68	290.43	295.95	208.62	212.39	224.00	215.01	204.59
TIB	254.00	226.63	239.74	240.12	239.85	193.41	203.32	238.30	211.68	216.40
EAS	330.69	311.34	329.96	324.00	310.11	175.70	203.77	197.67	192.38	171.51
SEA	412.92	398.55	404.30	405.26	415.89	217.69	235.62	220.55	224.62	194.56
NAU	375.94	353.13	375.57	368.22	357.89	245.74	275.31	245.39	255.48	248.10
SAU	330.27	314.19	326.86	323.77	326.54	197.93	190.86	185.11	191.30	216.98
SAH	337.31	309.98	339.92	329.07	337.15	262.15	275.38	277.74	271.75	264.56

WAF	384.32	363.56	388.70	378.86	392.92	230.64	281.46	240.12	250.74	231.51
EAF	371.89	347.30	372.53	363.91	384.45	251.09	292.60	247.54	263.74	237.33
EQF	372.31	356.07	365.27	364.55	377.08	240.21	278.16	231.80	250.05	232.56
SQF	378.02	362.43	370.00	370.15	373.27	234.04	268.65	237.10	246.60	223.85
SAF	344.64	323.67	334.37	334.23	321.71	217.70	237.28	219.01	224.66	232.14
WNA	296.89	293.37	302.39	297.55	281.30	196.70	183.22	195.71	191.87	205.10
CNA	311.69	298.60	310.79	307.03	308.70	178.09	198.56	207.13	194.59	185.28
ENA	339.03	327.43	341.57	336.01	305.46	171.46	189.71	187.69	182.95	164.46
CAM	377.27	360.63	370.16	369.35	366.67	229.89	252.57	248.63	243.70	229.00
AMZ	386.81	370.84	385.43	381.03	410.20	236.57	276.72	229.83	247.71	195.18
CSA	345.94	327.65	331.53	335.04	336.63	213.80	221.64	223.21	219.55	210.34
SSA	306.49	300.96	309.79	305.75	296.61	143.79	119.23	129.33	130.78	149.19
SAS	376.44	362.65	375.76	371.62	373.47	232.43	252.54	230.45	238.47	207.03
	H [kg/kg]					**Ps [HPa]**				
	GFDL	*IPSL*	*MIROC*	*Ens.Mean*	*WFDEI*	*GFDL*	*IPSL*	*MIROC*	*Ens.Mean*	*WFDEI*
NEU	0.0051	0.0048	0.0066	0.0055	0.0055	995.14	994.72	992.99	994.28	983.13
MED	0.0075	0.0075	0.0087	0.0079	0.0076	981.06	979.10	980.40	980.19	958.26
NEE	0.0042	0.0041	0.0054	0.0046	0.0045	998.58	997.13	995.35	997.02	994.48
NAS	0.0031	0.0036	0.0042	0.0037	0.0033	966.94	964.29	964.13	965.12	955.25
CAS	0.0044	0.0044	0.0057	0.0048	0.0055	900.50	896.25	899.36	898.70	893.06
TIB	0.0033	0.0034	0.0042	0.0036	0.0034	735.65	728.50	736.90	733.68	734.45
EAS	0.0090	0.0089	0.0108	0.0096	0.0078	974.67	969.55	973.25	972.49	947.43
SEA	0.0176	0.0178	0.0186	0.0180	0.0176	1000.13	1001.34	1003.18	1001.55	977.85
NAU	0.0121	0.0117	0.0140	0.0126	0.0096	991.65	994.78	994.03	993.49	978.92
SAU	0.0079	0.0068	0.0081	0.0076	0.0071	1004.23	1001.10	1002.27	1002.53	988.15
SAH	0.0061	0.0055	0.0068	0.0061	0.0061	965.67	965.58	966.70	965.98	955.18
WAF	0.0132	0.0123	0.0145	0.0133	0.0124	982.76	982.58	982.96	982.77	970.86
EAF	0.0113	0.0112	0.0130	0.0118	0.0122	939.81	936.28	940.58	938.89	928.97
EQF	0.0126	0.0135	0.0132	0.0131	0.0131	927.28	923.68	927.22	926.06	897.12
SQF	0.0134	0.0136	0.0144	0.0138	0.0123	964.04	963.95	964.50	964.16	924.14
SAF	0.0104	0.0094	0.0104	0.0101	0.0077	970.87	970.37	970.88	970.71	909.10
WNA	0.0059	0.0062	0.0074	0.0065	0.0051	908.11	909.20	907.96	908.42	867.44
CNA	0.0071	0.0067	0.0078	0.0072	0.0071	970.30	967.75	964.45	967.50	967.64
ENA	0.0092	0.0097	0.0113	0.0101	0.0068	1005.31	1003.65	1001.77	1003.58	986.35
CAM	0.0135	0.0136	0.0147	0.0140	0.0122	983.62	983.88	982.98	983.49	928.03
AMZ	0.0135	0.0140	0.0158	0.0144	0.0158	969.59	970.66	970.49	970.25	956.50
CSA	0.0100	0.0091	0.0096	0.0096	0.0095	976.00	975.62	973.88	975.17	935.84
SSA	0.0060	0.0047	0.0057	0.0055	0.0050	997.59	994.17	993.09	994.95	957.83
SAS	0.0134	0.0136	0.0152	0.0141	0.0132	965.75	965.46	965.67	965.63	932.59
	W [m/s]									
	GFDL	*IPSL*	*MIROC*	*Ens.Mean*	*WFDEI*					

NEU	5.50	4.47	4.10	4.69	3.64
MED	4.02	3.99	4.32	4.11	3.17
NEE	3.61	2.93	3.01	3.18	3.56
NAS	3.57	3.46	3.85	3.63	3.05
CAS	2.85	3.64	4.33	3.61	3.27
TIB	2.46	3.98	5.50	3.98	3.49
EAS	4.54	4.39	4.18	4.37	3.15
SEA	5.09	3.75	3.89	4.24	1.83
NAU	4.48	3.93	4.24	4.22	4.24
SAU	6.46	6.87	7.14	6.83	4.16
SAH	3.59	4.12	4.53	4.08	4.33
WAF	2.84	2.54	3.12	2.83	2.77
EAF	2.95	3.23	3.85	3.34	3.24
EQF	3.08	2.75	3.19	3.01	2.68
SQF	3.82	3.55	4.01	3.79	2.49
SAF	5.15	5.40	5.78	5.44	3.79
WNA	3.88	3.50	4.78	4.05	3.06
CNA	3.29	3.28	3.34	3.30	3.90
ENA	5.22	4.72	4.46	4.80	2.86
CAM	4.48	3.89	4.55	4.31	2.50
AMZ	2.91	2.73	2.10	2.58	1.71
CSA	4.68	4.83	5.11	4.87	3.24
SSA	7.94	7.90	8.54	8.12	5.14
SAS	4.31	3.56	3.13	3.67	2.49

RC3. Structural, the paper misses a clear separation between "Results" and "Discussion". For example, section "The model evaluation. . ." at page 11 reads for me like a discussion (finding out reasons for performance of the model). Please move to discussion part. Another example is Page 13 section starting with "First.." – the authors itself write that they discuss. Please avoid that in a results section. Similar difficulties I have with P15, section starting with "The variation..". You could also consider to have a joint "Results and discussion".

AC3. The reviewer's concerns on the structures issues are valid. Thus, following the reviewer's suggestion, "Results and Discussion" is a joint version in the revised manuscript. This option was preferred because reviewer #2 suggested that our discussion on runoff sensitivities to specific humidity should take a more prevalent role in the manuscript and that supplementary figures regarding this section should be included in the manuscript.

Minor

RC4. P5, l16: "been used in the BCIP": Could you please write some essentials of the intercomparison results? This is especially of importance, as it seems that the method is only applied in studies by the authors of this manuscript.

AC4. Beyond the aforementioned studies of the authors that make use of the bias correction methodology, MSBC has also been used in the framework of ECLISE FP7 and HELIX FP7 projects. In the latter, the methodology is used to adjust biases in a range of climate variables such as radiation (rlds, rsds), temperature (tas, tasmax, tasmin), wind, precipitation and specific humidity.

The BCIP project aims to address a number of topics and bias adjustment related gaps in use of climate information. To this time, the comparison has been narrowed to precipitation, mean temperature, maximum and minimum temperature (pr, tas, tasmax, tasmin). As a first stage of comparison, methods are assessed for their ability to reproduce mean values of the observational dataset, as well as lower and upper percentiles (1^{st}, 5^{th}, 95^{th} and 99^{th} percentiles) and the 20-year return period, on data from two RCMs. While the project is still ongoing, a first set of results can be found in Nikulin et al. (2015). Relevant presentation slides, presenting the remaining bias in mean precipitation for the two RCMs, can be accessed with the link below.

http://www.meteo.unican.es/files/posters/20150415_EGU2015_BCIP_GN.pdf

The MSBC methodology is found to perform well in all metrics, comparing to the other methodologies, ranking it high in performance. Respective comparison for the remaining bias in mean and the high/ low percentiles of the four variables and two RCMs are available upon demand. A representative comparison of the remaining bias in temperature and precipitation at mean and 99^{th} percentile is shown for DJF and JJA periods in the figure below.

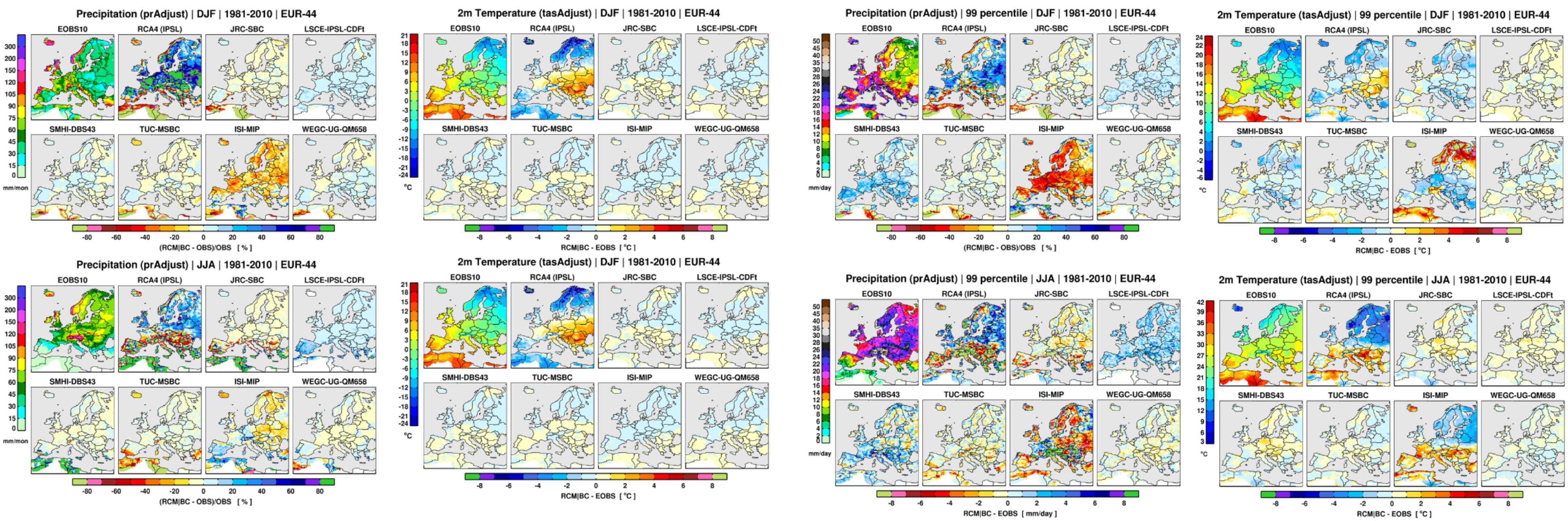

Figure R 1. Comparison of the remaining bias in temperature and precipitation at mean and 99th percentile for DJF and JJA periods, using different bias correction methods.

RC5. P5, l28: could you somehow describe "edge segments" e.g. by a percentile? Otherwise it reads a bit vague.

AC5. As it is described in the methodology section, the bias adjustment method partitions the data CDF into discrete segments and applies a quantile mapping correction to each segment, achieving a better fitted transfer function. The optimal number of the segments is estimated by Schwarz Bayesian Information Criterion to balance between complexity and performance. Additionally the upper and lower CDF segments (Segments 1st and 5th in Figure R1, for an example of an optimum 5 segments) are explicitly corrected using the average difference between the reference period of the raw model data and the observations (ΔT). As the number of segments is not predefined, there are not fixed percentile values to define the "edge" segments. The description of the methodology in the revised manuscript has been enriched. However, technical details are not described in depth as they are beyond the main focus of the study. A detailed assessment of the methodology along with a full technical description of the method has just been submitted for consideration in Earth System Dynamics-Discussion (http://www.earth-syst-dynam-discuss.net/esd-2017-53/) in Grillakis et al. (2017).

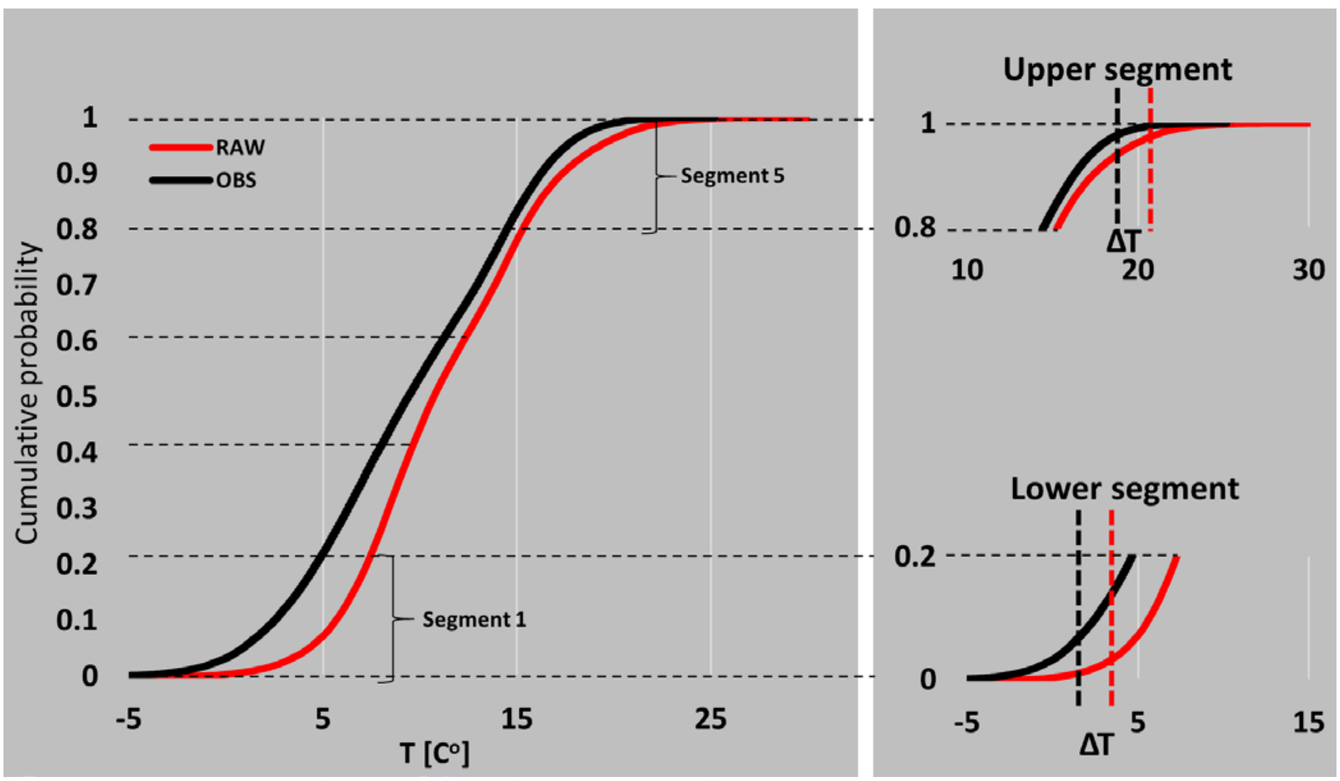

Figure R 2. Edge segments of the CDFs in a theoretical example of 5 segments and the ΔT correction applied to them (borrowed and modified from (Grillakis et al., 2017)).

RC6. P8, l7: what is meant by median value? Of each grid cell in a specific region? Please specify.

AC6. Median values of change (median|ΔRF|) and sensitivity (median|S|) are derived by considering the values of all land grid boxes and for all the experiments (apart from temperature). This way, |ΔRF| and |S| of each grid box and each experiment are compared against the same value.

The clarification is added to the revised manuscript.

RC7. P11 section starting with "The shown persistent. . .": Although interesting, it is a bit vague and could be supported by citing common papers (e.g. Coxon et al. (2015) for discharge uncertainty). Please either move the last sentence "We believe. . ." to discussion and discuss it properly or just delete it. It is too speculating without providing reasons for this statement.

AC7. Following the reviewer's indications, relevant references were added to support this section and the last sentence was deleted.

RC8. P12, l12: please check the statement, that global LSMs are calibrated (the sentence reads so).

AC8. In this sentence, we did not want to state that LSMs are calibrated, but rather highlight that tuning of their parameters would be a very complicated and time consuming task, which is done for specific applications and locations. Thus, even if the model parameters are tuned for a specific application and location, there are still going to exist regions of lower performance at the global scale. However, because the statement about LSM calibration is confusing and does not help the message we are trying to communicate in this part of the paper (that the global nature of the model does not allow top performance for all the regions), this part of the sentence was deleted in the revised manuscript.

RC9. P16, l15: I cannot see terrain elevation in Fig. 11, so the statement cannot be made (strictly speaking).

AC9. The statement was replaced with the following sentence in the revised manuscript: "The highly affected areas mainly correspond to regions with high mountain ranges."

RC10. Please go carefully through the reference list. A quick look on it shows a lot of inconsistencies. For example: first reference – Journal name is missing – and why are you citing the discussion paper and not the final version? Check consistency of Giorgi and Bi. Check if everywhere a doi is provided, check if upper/lower case is consistent, Hattermann et al 2016 is published since a while (please update citation), and what does "Submitted in this special issue" should mean? N/a in Maraun 2012? What are "and Ohters" in Nikulin et al?, Journal / doi for Oki and Sud? I did not check if all references are listed in the reference list / in the manuscript.

AC10. In the revised manuscript, the reference list has been thoroughly checked and the inconsistencies have been corrected.

RC11. Figure 7: I am a bit sceptic to consider a NSE > 0 as "good". In many studies, this is the case of e.g. > 0.5 or 0.7. It is absolutely not necessary to provide color hues to indicate how good or bad a model performs, it hinders (me) for an objective look at the table (in fact, it is a table with colored cells). Please convert to a real table for more clarity.

AC11. The value of zero for NSE is set as an arbitrary limit to characterize the model behavior as "acceptable", rather than "good". In our case, the lower value of NSE for the run forced with WFDEI data is 0.24. The reviewer's considerations are valid regarding basin scale hydrological applications, especially when these are conducted with basin scale, calibrated models. However, in the case of global modelling the evaluation metrics can have looser thresholds, as it is unrealistic that the model will have such a good performance (NSE>0.5 or 0.7) for many different basins, run with the same model configuration which is "tuned" on land processes rather than strictly on runoff representation-. Most global scale hydrological evaluations avoid using the NSE index and employ metrics such as the RMSE and the correlation coefficient (e.g. Blyth et al., 2011; Hattermann et al., 2017). In the studies that the NSE metric is used, it is not unusual to encounter negative values of this evaluation index (e.g. MacKellar et al., 2013; Zulkafli et al., 2013). In our evaluation, we employ three different metrics, in addition to the visual inspection of the annual cycles, in order to have a multi-faceted assessment of model performance.

Following the reviewer's indication, the colored table presented in figure form was converted to a real table, added to the tables of the manuscript (as Table 3).

RC12. Figure 11: Please consider other colors to distinguish ECII and ECI for better visualization.

AC12. The authors considered the reviewer's suggestion but concluded that the color hues of ECI and ECII are distinguishable and do not necessarily need alterations in order to be understood by the reader. Moreover, the color hues were carefully selected to reflect the relationship between the change and sensitivity. In more detail, a warm tone was selected for the high change category and a grey tone for the low change category. Then, the saturation of each tone increases for the high sensitivity category (resulting to dark orange for ECI and dark grey for ECIII).

Supplement:

RC13. Table S1 is not referred from the main manuscript, please also provide station name. Fig. S3 – what does the red color mean? Please indicate in figure caption. Figs S4-S10 are not mentioned in the main manuscript. To my knowledge, a supplement should support the main paper, and that are interesting figures, but without referencing it in the main paper, they are unconnected and lost with just the figure caption.

AC13. The station name was added to the information provided in Table S1. In Fig. S3, the red color indicates the selected focus regions, which are also included in the main body of the manuscript. A relevant explanation is added to the legend of the figure. Following the reviewer's indications, all the tables and figures presented in the Supplement are referenced in the manuscript.

Technical

RC14. P1, l26: please be consistent: either Global Hydrological Model or global hydrological model, not global Hydrological Model.

AC14. The inconsistency in the text is revised to "Global Hydrological Model".

RC15. P3, l29: check if Penman (1948) is the correct citation for Penman-Monteith approach (isn't it Monteith 1965?)

AC15. The reviewer is correct. The reference has been changed in the revised manuscript.

RC16. P5, l 4 (the two sentence starting with "The WFDEI". . .): I feel this information is not required for the manuscript. Consider to shorten it.

AC16. The sentence is shortened in the revised manuscript.

RC17. P6, l31: please be as specific as possible in naming the variables. Is it net shortwave radiation, or downward shortwave / longwave (which I am sure is meant?)

AC 17. All the radiation components refer to downward radiation. Relevant clarifications were added to the manuscript.

RC18. P12, l26: please insert a blank between number and unit. Same at l30 (5mm)

AC18. Corrections have been made in the revised manuscript.

RC19. P16, l6: to which section are you referring to?

AC19. To text was referring to Section 2.8 (Categorization of individual bias effects). The correct reference is added in the revised manuscript.

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