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Hydrology and Earth System Sciences
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Interactive comment on "Precipitation ensembles conforming to natural variations derived from Regional Climate Model using a new bias correction scheme" *by* K. B. Kim et al.

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Dear Editor,

We would like to thank both reviewers for their detailed and useful comments on our paper. The constructive comments have helped to improve this article considerably.

Referee #1 (Dr. C. S. Photiadou):

1. The study is applied in a single catchment since the argument is that the regional models are used in impact studies. However, it is not demonstrated how this bias correction will influence an impact study. I am suggesting that a hydrological application

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is presented to make the bias correction stronger.

Reply:

We agree with the reviewer's comments. Based on the comment, a hydrological model is used to investigate the impact of bias correction methods.

For hydrological application, we used a conceptual hydrological model IHACRES. First, the model parameters have been optimised with the use of the observed daily precipitation, temperature and flow data. Second, the optimised parameters and the two different bias corrected precipitation data from conventional and proposed bias correction methods are then used to simulate daily flow ensembles. Finally, from this daily simulated flow data, thirty-year mean monthly flow has been estimated since the bias correction has been done on monthly basis.

Figure 1 illustrates the comparison of the spreads (5th – 95th percentile) of the flows. As expected, the spread of the monthly mean flow simulated by using conventionally bias corrected precipitation is narrower than that of the flow simulated by using proposed bias correction. This is because the conventional bias correction method uses only one observed precipitation as a reference. In order to validate whether the spread of the simulated flows are appropriate, a long period of flow data is needed. However, since we do not have long observed flow data, we used a resampling method to estimate the natural variability of the observed flow. Eleven time series of flow data is resampled on monthly basis from the daily observation data. The result shows that the spread of the resampled flow is wider than that of both simulated flows. This can be interpreted as the flow spread using the conventional bias correction method is too narrow and the proposed method is more reasonable and realistic.

2. A recent published study by Addor N. and Fischer E. M. shows the influence of natural variability on bias characterization in RCM simulations. They show that different methods of estimating natural variability give different measures, depending on the method, season, and time scale of your observation record. This in return will influence

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the bias correction. I think it will add value to the study if the authors will comment on this and then justify the procedure to generate the natural variability. For example the authors used a resampling of the 30 years by 100000 times using the parameters of the observations but did you use any maximum stopping point? The aforementioned study suggests that also the number of times one that the resampling occurs should be maximized for each case. How was the resampling procedure optimized then?

Reply:

Thanks for the suggestion. We have added the recommended reference and commented on the influence of natural variability on bias characterization in RCM simulations as follows.

There has been relevant work recently around the influence of natural variability on bias characterization in RCM simulations (Addor and Fischer, 2015). They show that different methods of estimating natural variability give different measures, depending on the method, season, and time scale of the observation record which in return influences the bias correction. Overall, they argue that observational uncertainties and natural variability need to be considered for bias correction of RCM simulations.

Regarding the optimised number of resampling, we have added the following paragraph.

In order to find the optimised number of resampling, the sensitivity analysis between the numbers of resampling and the mean value of the observed precipitation has been done. The result has showed that beyond 20,000 resampling, the mean value becomes stable. Since the running time does not take long we have resampled 100,000 times which are sufficient.

3. Fig 6a shows the probability density function of daily observed and the 11-member precipitation before any bias correction. From this figure I would say that a bias correction is not necessary.

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Reply:

It seems like the bias correction is not necessarily required given Fig 6a since the PDFs of observation and ensembles look similar. However, the quantiles (precipitation) for the same cumulative probability could be quite different in the quantile mapping process. For example, as presented in Figure 2, when the cumulative probability is 0.8, the observed precipitation is 8.1 mm/day, while uncorrected RCM ensembles precipitation ranges from 6.2 mm/day to 9.5 mm/day which are 23.5% less and 17.3% more than the observation respectively. In addition, when the cumulative probability is 0.9, the difference range becomes wider than before as described in Figure 3.

4. On the other hand, Fig. 9a shows the bias on a monthly scale; how about the bias in a daily scale? Also at page 10267, line 13, it is stated that the goal is to obtain monthly bias corrected precipitation and not daily. Explain why the preference on monthly data, why the correction is done on a daily scale instead of a monthly scale, and it is interesting to see that daily natural variability improves monthly means.

Reply:

In this study, we used daily precipitation, and bias correction has been done on monthly basis. In other words, monthly statistical properties from 1961 to 1990 are adjusted between the observed daily precipitation and simulated daily precipitation.

The reason that we have used time series of daily precipitation for bias correction is because the hydrological model, IHACRES, which we are using, requires daily precipitation for input data.

Then the issue can be the time steps for bias correction. Monthly bias correction is to match the statistical properties between observation and RCM data (daily precipitation in this study) based on monthly time period, while seasonal bias correction is to match the statistics based on seasonal time period (Figure. 4). The time steps can be monthly (12 groups), seasonal (4 groups), annual (1 group) or something else. The

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more groups we divide for bias correction, the less biased the corrected data will be. This is because if a bias correction period is shorter, temporal distribution of the time series can be considered with more details than a longer bias correction period. As a result rainfall characteristics can be matched more sophisticatedly between the observation and the simulated data. However, on the contrary, the higher the number of groups, the higher the variance will be. This is a well-known trade-off between bias and variance in mathematical modelling. What is an optimal time steps for bias correction can be another research topic. In this study, we have used monthly bias correction since normally there are reoccurring patterns on a monthly basis.

5. Also explain if the by the 11-member precipitation series you mean a mean of the 11 member.

Reply:

The "Probability density function of the 11-member precipitation time series before bias correction" in Fig. 6a's caption means not the mean of 11-member but 11 individual members. The black dashed lines in this figure represent the PDFs of each 11-member precipitation time series.

6. Page 10270 line 15: Step 4 is unclear on the "move to the centre" procedure. Please explain briefly how this is done.

Reply:

To clarify, we have revised the explanations for Step 4 as follows:

(Step 4) In Step 3, the coordinate of the centre of denormalised ensemble parameter sets is (0, 0). This coordinate is shifted to that of the observation (i.e. black dot in Figure 5 Step 4), which results in the ensemble members' parameter sets to fall into the boundary of natural variation of observations. From this, transfer functions for bias correction can be built.

7. Improve caption for Fig. 1. The grid box in red represents the entire catchment?

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Reply:

The grid box is selected, which covers most part of the Thorverton catchment. To clarify, we have revised the caption as follows:

Figure 1. Location of the Thorverton catchment (the left panel) and HadRM3 25km grid boxes (the right panel). The grid box in red is selected which covers the Thorverton catchment.

8. Fig.10 is misleading. It is stated that this plot is an example of the use of a one transfer function thus an example of the conventional bias correction. However, Fig. 7b is also a result from the conventional bias correction but has totally different behavior. Please explain if I misunderstood.

Reply:

The bias correction schemes applied in Fig. 7b and Fig. 10 are different. In Fig. 7b, each 11-member ensemble is treated individually. Therefore, different 11 transfer functions are applied to different members. However, in Fig. 10, only one transfer function (from the unperturbed member) is used to correct the entire 11 members.

9. Also maybe add at in the discussion section a paragraph on the actual results you presented and discussing the physical meaning of the proposed bias correction.

Reply:

Thanks for the suggestion. We have added the following paragraphs.

Climate model is a simplification of the reality therefore the simulated output should look like real to convince the users. However, there is a systematic error which is a result of the model structure, parameter and initial conditions. The main purpose of bias correction is to make simulated climate model output indistinguishable from the real world data series by minimising the systematic error. Ideally, after bias correction, 11 members of RCM output should look like 11 realisations from the real system, i.e.

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they should have similar spread between ensembles and real natural system. If they look obviously different from realisations they are not good representation of the real climate condition of the catchment.

Conventionally, all climate model simulations are corrected to the observation. With this scheme, the uncertainty of the model from the ensembles will be lost and as a result the 11-member ensembles will be similar to just one member. Another approach is to apply one transfer function based on unperturbed member to the rest 10 members. This will keep spread properties of ensembles but this spread may not conform to the spread from the real natural system. Therefore they do not look like as if they are drawn from the natural system.

In this study, we proposed a new scheme which overcomes the shortcomings of the aforementioned two schemes (i.e. 11 transfer functions all conformed to one observed realisation or one transfer function for 11 members which result in the bias corrected ensembles too narrow or to wide) and it is a good balance between the two.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 10261, 2015.

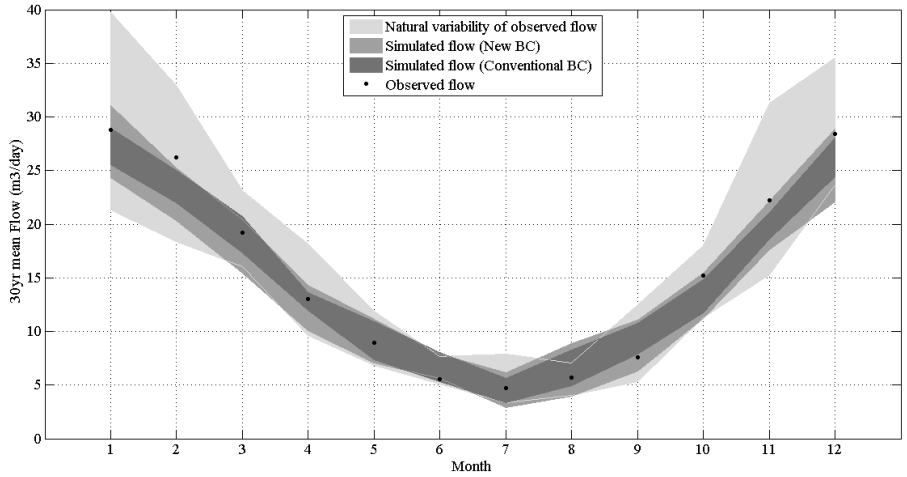

Fig. 1. Comparison of the spread of natural variability of observed flow and simulated flows.

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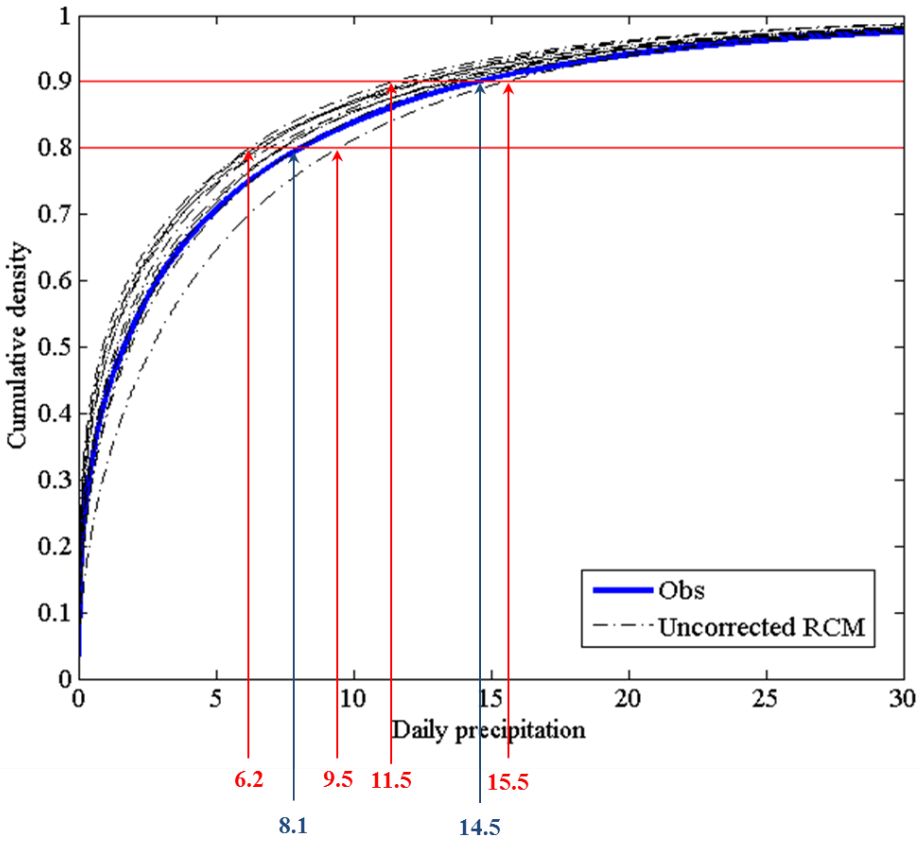

Fig. 2. CDFs of the observed and 11-member precipitation time series before bias correction.

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	CDF = 0.8		CDF = 0.9	
	Precipitation (mm/day)	Difference (%)	Precipitation (mm/day)	Difference (%)
Obs	8.1		14.5	
RCM (minimum)	6.2	-23.5	11.5	-20.7
RCM (maximum)	9.5	17.3	15.5	6.9
Total		40.7		27.6

Fig. 3. Precipitation values at CDFs are 0.8 and 0.9.

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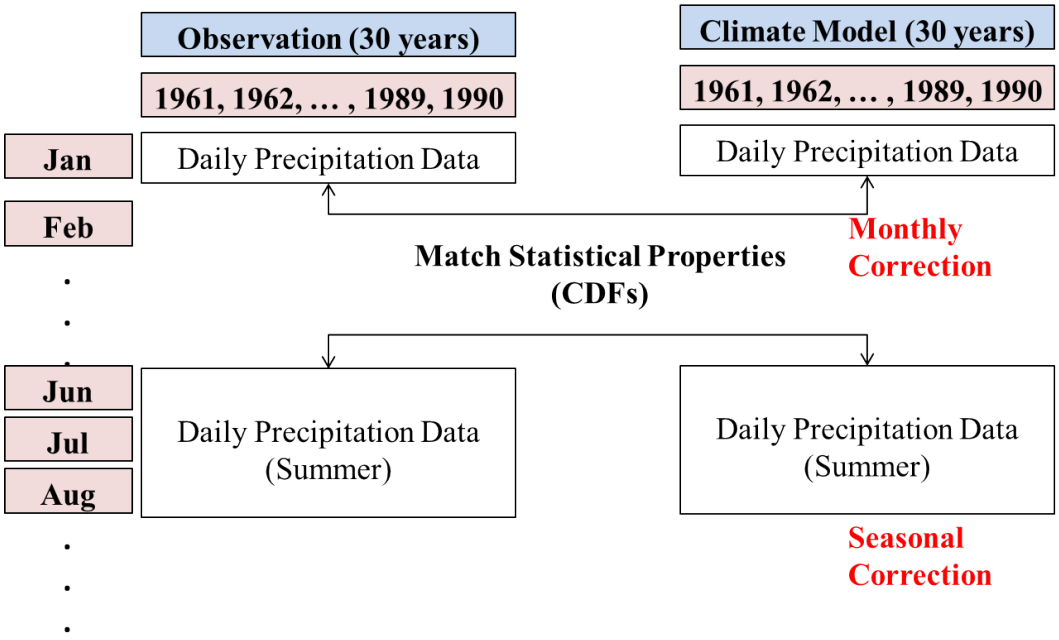

Fig. 4. Schematic of monthly bias correction and seasonal bias correction.

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