

Authors' response to Referee #1

For clarity, authors' responses are presented by blue colour.

We have answered all the comments of the reviewer 1. Answers are attached to this revision note. Along with the answers we are also explaining all the changes we have done.

This is an interesting article investigating and bias-correcting the long-term reanalysis of precipitation over South Korea. Different combination of transfer function and wet frequency adjustment methods are applied to correct the precipitation time series. Explicit analysis was done and detailed results were shown. The manuscript is well presented, however, there are still spaces to improve.

(Response) Thank you for the comments.

General comments:

1. QM based methods are fundamental tool for bias correction of climate variables. However, Many similar studies have been done. It is also quite normal to take the combination of different transfer functions to describe CDF for different quantiles. Thus, the contribution of this paper to the scientific progress is low.

(Response) The composite distribution based on the quantile mapping approach has been recently employed to describe the distinctive feature of CDF over different quantiles, especially for the correction of climate change scenarios (Gutjahr and Heinemann, 2013; Nyunt et al., 2016; Smith et al., 2014; Volosciuk et al., 2017). However, the bias correction of the reanalysis data using the composite distribution has not been explored sufficiently. It appears that only a very limited number of studies have investigated the validity of the different transfer function method for the multi-decadal reanalysis data (Teng et al., 2015; Vrac and Naveau, 2007), but not for century-long reanalysis such as ERA-20c. From this perspective, the composite distribution addresses the context of the bias correction to facilitate the improved transfer function, particularly new for the reanalysis (or numerical weather prediction data).

Moreover, the previous studies have applied QM approaches to gauged catchments, where a statistical relationship between the observed and modelled can be established. However, the suggested QM algorithm in this study can significantly reduce the systematic error associated with daily precipitation, which has not been improved in regional-scale studies, over the spatio-temporally limited rainfall observation network. More specifically, this study first explored the

ERA-20c data and corrected them in 603 grid points using dozens of gauging stations over South Korea for the reference period 1973-2010. This QM approach can also be applied to the whole of the 20th century (1900-2010) without synthesizing the corresponding observation, albeit the study has been carried out in South Korea for the reference period. Thus, we believe that the methodology used in this study is novel and contributes positively to the hydrological community.

2. Also, the title of this manuscript highlights the "Contribution of Bias Correction to the Reduction of Uncertainty", but it is not well explored in this paper.

(Response) As indicated, this study mainly focused on the bias correction of ERA-20c daily precipitation, and we considered that the century-long dataset could contribute to the reduction of the uncertainty in hydrological analysis where a limited number of observations were generally given. In this study, we only explored the uncertainty range for three different periods. Thus, we changed the title of this manuscript to “Exploring the Long-Term Reanalysis of Precipitation and its Bias Correction using a Composite Gamma-Pareto Distribution Approach over South Korea” upon your comments. We will further explore the uncertainty reduction in using the long-term reanalysis data in the next study.

3. Unlike the temperature, bias correction of precipitation is more challenging due to the fact of spatial/temporal heterogeneity and zero inflation. The bias correction should take care of all the four cases: (0,0), (0,1), (1,0) and (1,1), where 0 denotes a dry day and 1 indicates a wet day. It is not clear how the authors did for these four different cases.

(Response) Thanks for good comments. It is expected that the temporal correlation of ERA-20c daily precipitation would be high enough to compare the rainfall sequences. However, it has been acknowledged that the temporal correlation is relatively low to directly compare the rainfall sequences (Poli et al., 2013). In our study, for instance, the range of Pearson's correlation coefficients is from 0.22 to 0.46 (mean : 0.40) for the daily precipitation sequences between the raw ERA-20c and weather stations over South Korea for the reference period (1973-2010). Thus, we used the ERA-20c data in the context of simulation data which is similar to the climate change scenarios during the reference period.

4. The authors proposed a new framework for bias correction in un-gauged area by using the IM-PCM method to interpolate the parameter of transfer functions. To my opinions, the contour mapping technique could bring large uncertainties and biases. Even the results are validated, but it is based on the average of all the 48 stations. The study of spatial impacts of this technique on the bias correction is still missing.

(Response) This study evaluated the IM-PCM method by employing a leave-one-out cross validation framework over 48 weather stations for the reference period and the overall error estimation results were described in the manuscript for both the extreme and mean. For a more specific analysis in each weather station in the context of cross validation, we generated a map showing the spatial errors in both annual maximum series (AMS) rainfalls and mean. The AMS errors were illustrated by root-mean-square-error (RMSE) and Nash-Sutcliffe efficiency (NSE) in Figure r1. For the mean, we further evaluated the IM-PCM method by estimating the relative error between the observed and modelled in Figure r2. As shown in the figures, for the AMS rainfalls, gpQM95 and gpQM99 generally perform well except for a few stations. Most stations showed NSE over 0.8 and RMSE less than 30mm. For the mean daily rainfall, the relative errors are generally below 10%.

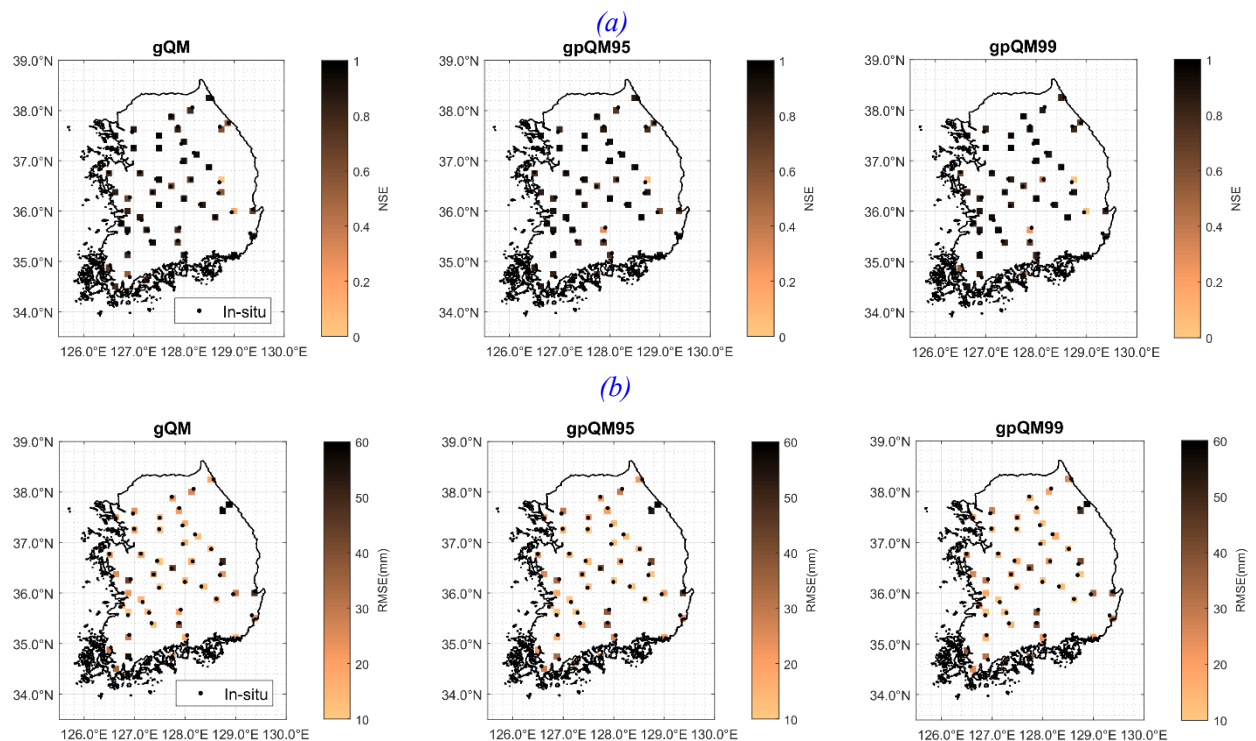


Figure r1. Cross validation results of the IM-PCM for the annual maximum series rainfall of the bias corrected data by QM approaches (gQM, gpQM95 and gpQM99) over 48 grid points. (a) Nash-Sutcliffe efficiency (NSE) and (b) root-mean-square-error (RMSE).

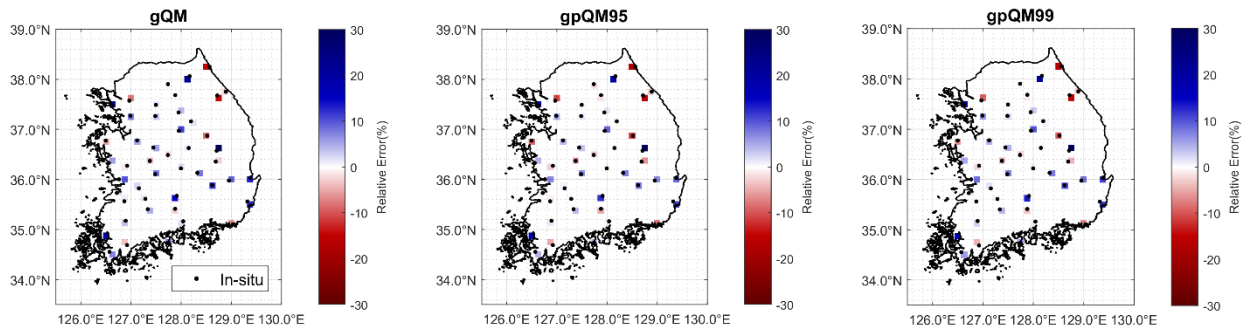


Figure r2. Relative error of the bias-corrected mean rainfall by QM approaches (gQM, gpQM95 and gpQM99) in 48 grid points compared with the corresponding in-situ.

5. It is not clear that how the authors set the calibration and validation period. It seems the complete study period is used for both calibration and validation.

(Response) The main objective of this study is to correct the modelled data with the limited observation network. For this purpose, instead of temporally dividing the data into calibration and validation periods, we employed a leave-one-out cross validation scheme for the calibration and validation during the reference period to fully use the available data.

Specific comments:

Page 4, Line 5: "but not bias correction issues" -> "but not bias correction technique issues"

(Response) We have changed the sentence.

Page 4, Line 11: In addition to linear scaling, local intensity, power transformation, and quantile mapping, there are also there sophisticated method for bias correction, e.g. copula-based technique.

(Response) Thank you for the references. The literature review on the previous studies for bias correction has been changed as follows:

(Page 4, Line 9) "The underlying concepts for the bias correction approach vary from a simple delta change or mean bias correction to a quantile mapping (QM) or a multivariate approach based on the copula-based technique (Laux et al., 2011; Mao et al., 2015; Maraun, 2016; Maraun and Widmann, 2018; Teutschbein and Seibert, 2012)."

Page 5, Line 9: "Comparatively little attention has been given to the bias correction of the reanalysis data" is not correct. There is no clear clue for this.

(Response) There exist several studies on the bias correction of reanalysis, but it is rare to explore bias correction for century-long data such as ERA-20c. In this context, we have described that "Comparatively little attention has been given to the bias correction of the reanalysis data", but it needs to be described more specifically. Thus, we have changed the line to "Comparatively little attention has been given to the bias correction of the century-long reanalysis data like ERA-20c".

Page 10, Line 20: "(TH4). The frequency" -> "(TH4), the frequency"

(Response) Thank you for the comment. We have changed the typos.

Page 16, Line 9: It is not clear if all the TH are tested together with gQM or not?

(Response) All evaluations were based on the gQM along with the THs. We have clearly stated the explanation as follows:

(Page 16, Line 10) "This study examined four different thresholds (TH1, TH2, TH3, and TH4) for adjustment of the wet-day frequency of ERA-20c daily precipitation through an experiment with the gQM approach in terms of both the mean and extreme values".

Page 17, Line 13: "TH4 performs the best with 0.755 for NSE". It is a bit confuse to me, as the TH only affects the wet frequency of the time series. How it affects the extreme correction? This needs to be explained in more detail.

(Response) A cut-off threshold influences on the number of valid data in a given time series. To be more specific, the low threshold allows a relatively large number of data in the QM algorithm, while the high threshold reduces the number of valid data. Because the quantiles of extremes rely on the number of sample data in a given fitting curve, the threshold value affects the extreme correction based on the QM scheme. This explanation has been included in the revised manuscript.

Page 17, Line 20: It is not clear if the TH4 is take for gpQM tests.

(Response) Thank you for the comment. Yes, gpQM approaches have been performed with TH4. We have clearly stated the explanation as follows:

(Page 18, Line 1) “Here, after adopting TH4 as a lower threshold, the 95th or 99th quantiles have been considered as upper thresholds for the correction of extremes (gpQM95 and gpQM99)”.

[Reference]

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