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Hydrology and Earth System Sciences Discussions

Interactive comment on "The ability of a GCM-forced hydrological model to reproduce global discharge variability" *by* F. C. Sperna Weiland et al.

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We would like to thank the anonymous reviewer for the useful comments which helped us to improve the quality of the manuscript. All comments were considered carefully and included in the text. The revised manuscript will be uploaded soon. Please, find our response to the review comments below. We retrieved all comments from the text of the anonymous reviewer and numbered them to be able to reply to each comment individually.

1) "The description of the generation of the reference climate data set is confusing, as

on the one hand, it is said that the same method was used as for the GCM data, using bias correction with CRU long-term average temperature and precipitation , while on the other hand CRU time series are mentioned. Besides, no reference to which CRU data are used for bias-correction is given":

We improved the description of the generation of the different meteorological datasets and added one additional set where the ERA-40 data is bias-corrected in exactly the same way as the GCM datasets. Both the ERA-40 and GCM datasets are bias-corrected with the CRU TS 2.1 monthly time-series by equalizing long-term average precipitation, temperature and potential evaporation. In addition the CRU TS 2.1 time-series have been downscaled, on a year by year basis, to daily values using the ERA-40 re-analysis data. This ERA-40 based dataset was already included in the submitted manuscript. A detailed motivation for the construction of the datasets is given in the last section of the introduction, for a description of the methods see section 2.4 and 2.5. The CRU CLIM 1.0 climatology was only used in the derivation of potential evaporation, since windspeed and radiation fields are not included in the monthly timeseries.

2) "There are a number of unfounded conclusions The manuscript assumes that the computed discharge obtained by a PCR-GLOBWB run driven with the reference climate is more realistic than climate models":

To our opinion the PCR-GLOBWB run based on a meteorological dataset constructed of historical datasets (e.g. ERA-40 and CRU TS 2.1) is necessary. We ran the hydrological model with this dataset in order to assess the model performance. Comparison of the PCR-GLOBWB discharge results from the model runs driven with GCM bias-corrected data against discharge observations alone would obscure the bias introduced by the hydrological model. The ERA-40 dataset can be bias-corrected on a year-by-year basis, hereby replacing the ERA-40 inter-annual variability with the CRU TS 2.1 inter-annual variability. This results in a meteorological dataset with an inter-annual and seasonal variability that best represents the observed variability as present in the CRU TS 2.1 timeseries. We realize the ERA-40 dataset does not provide a perfect representation of the climate either, however it is a global daily dataset that combines observations with what is generally considered to be one of the best weather prediction models and can thus be considered as the best possible reconstruction of recent global climate. Furthermore, although both the ERA-40 and the GCM datasets are obtained from climate / numerical weather models, the resolution of the ERA-40 reanalysis model is higher than the resolution of the GCMs (vertical resolution 60 levels, spectral resolution T159 (Uppala et al., 2005)) this is likely to improve the quality of the resulting dataset. The dataset is no longer referred to as a reference dataset and we paid more attention to the deficiencies of the ERA-40 and CRU timeseries.

3) "One of the conclusions, which is, in my opinion, unfounded is that GCM derived climate discharge quantities are overall too low (in abstract and conclusions). This is not true with respect to long-term average discharge values, where in 12 out of the 19 test basins, the ensemble average of the 12 GCM runs is closer to the observed discharge of GRDC than the discharge computed by using the reference climate (see Table 3)":

We realize we should be more careful with drawing and generalizing conclusions and we agree that GRDC should be the norm here. The bias-correction has been improved. Instead of equalizing every single year in the GCM dataset to the 30-year average CRU TS 2.1 values for rainfall, temperature and potential evaporation, the 30-year average values of the GCM timeseries and the CRU TS 2.1 are equalized by multiplying the monthly GCM values for each individual year with a correction factor that is equal to the ratio or difference between 30 year average GCM and CRU values. Hereby the inter-annual variability of the GCMs is maintained. All GCM datasets have been bias-corrected according to this method and PCR-GLOBWB has been rerun, therefore the results of our study have changed. From table 3 it can be seen that global average discharge quantities are lower in the GCM based runs than in both the GRDC observations and the PCR-GLOBWB runs based on the ERA-40 datasets. Still, indeed for 10 out of 19 basins long-term average GCM ensemble mean discharge values are closer

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to the GRDC values than the long-term average values of the run based on the CRU TS 2.1 timeseries downscaled to daily values with ERA-40 (ERA6190). However, this is more the result of a compensating effect than a result of better performance. PCR-GLOBWB overestimates discharge for 10 out of 19 basins. Amongst these basins are the Orange, Zambezi and Murray. At least for these basins, we conclude that the discharge reduction introduced by the bias-correction method (which is present in 11 out of 19 basins) compensates for the discharge overestimations present in the model.

4) "Regarding statistical high and low flows Q90 and Q10, there is no comparison at all of GCM derived results to observed values, only to the reference run. However, a comparison to observed data is necessary to form the mentioned conclusion, and should be possible, as GRDC also provides observed daily river discharge for many stations":

We have retrieved daily discharge data for all catchments where this is provided by the GRDC and used these to derive new Q10 and Q90 values

5) "Also, I do not understand what the basis is for the conclusion that intra-year variability is not well represented by GCM driven runs, "as exemplified by a limited persistence“ (in abstract). Only interannual variability of discharge is analysed, and here the conclusion (that GCM derived runs underestimate interannual variability of discharge, but is this caused by "limited persistence“?, (abstract and conclusions) appears to be well founded (and is innovative)":

As a result of the changed bias-correction method the results of the GCM based runs have changed and the conclusion above does not hold anymore. Still, by analyzing Q10, Q90 values and regime curves the influence of inter- and intra-annual discharge variability has been investigated. Here intra-annual variability stands for day-to-day and seasonal variability which both influence extreme values.

6) "Observed Lag-1 correlation of discharge is not reproduced by most GCMs (which you say on p. 705, l. 1), but neither by using the reference climate data set (which you

do not say, but show in Table 3). This may indicate that discrepancies are due to the hydrological model, and that neither the GCMs nor the reference climate data set have a comparative advantage":

Indeed, besides by discrepancies in the meteorological datasets, deviations are introduced by incomplete inclusion of reservoirs and water management measures in the model that are present in the river systems. Furthermore lag-1 correlation is influenced by temporal storage as groundwater and in reservoirs. We investigated the model performance for lag-1 correlation and only for European and Arctic basins realistic values are obtained. So indeed the conclusion that neither the GCMs nor the ERA-40 based climate dataset have a comparative advantage is correct for lag-1 correlation. Because of the large differences between modelled and observed lag-1 concentration and the difficulties in deriving both the source of these differences (meteorological forcing, hydrological model inadequacies, groundwater and reservoir storage) and the resulting hydrological meaning, we decided to leave the lag-1 correlation out of the new version of the manuscript.

7) "Often, explanations for different model results are not convincing. For example, in section 4 Conclusions, the authors write “GCM derived discharge is overall too low, as raw GCM data have too many rain days, resulting in many days with little rain from which a larger amount of rain can infiltrate or evaporate.“ Not only have GCM data too many rain days, but also ERA40 that was used to derive the reference climate data set, is known to have too many rain days":

We extended the motivation for this and other conclusions in the manuscript.

Table 3 shows that globally the discharges of the bias-corrected GCM runs and the ERACLM run are lower than both the GRDC discharge and the discharge of the ERA6190 run. In both the downscaling and bias-correction procedure precipitation quantities of all GCMs and the ERA-40 dataset have been equalized to the CRU TS 2.1 precipitation quantities. When over a 30-year period the same amount of precipitation results

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in less runoff in the GCM based runs and ERACLM run, this is a result of higher actual evaporation. The difference is present because potential evaporation and precipitation are bias-corrected in independent procedures. As a result, precipitation and evaporation that were in phase in the original model runs, may occasionally not remain in phase in the bias-corrected runs. Potential evaporation is in reality small on wet days. However, when after bias-correction potential evaporation is relatively high on a wet day, more water will evaporate and less water becomes available as runoff. In the ERA6190 run evaporation and precipitation remain in phase, because downscaling is executed for each individual year on a month-by-month basis and relative precipitation and evaporation amounts remain equal to those in the ERA6190 dataset.

8) "What is missing is a discussion of the effect of using monthly time series of CRU precipitation and temperature to correct the daily values of ERA40 as compared to bias-correcting GCM daily values by long term average monthly means, and a discussion of the differences between ERA40 and GCMs (outputs)": This is a very useful comment and we have extended the article with a discussion on the differences between the bias-correction applied to the GCM datasets and the downscaling of the CRU TS 2.1 timeseries to daily values using the ERA-40 re-analysis dataset.

The technical comments are incorporated in the revised manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 7, 687, 2010.

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Interactive Comment