Review of HESS Manuscript

'Effects of climate model radiation, humidity and wind estimates on hydrological simulations'

by I. Haddeland, J. Heinke, F. Voß, S. Eisner, C. Chen, S. Hagemann, F. Ludwig

Dear Authors, dear Editor,

I have reviewed the aforementioned work. First, take my apologies for the long time it took me to respond, this was due to the fact that in the course of the review, my focus went beyond the paper to the underlying topic of bias correction in climate modeling and climate chance studies in general. Due to this, I am also in the somewhat uncomfortable situation that I comment not only on the direct aspects of the article, but also on its basic assumptions. I should also add that I am a hydrologist, not meteorologist by education and profession, so maybe some of my comments appear like an outside rather than inside view on the topic.

I have structured my review as follows: First, I will comment on the proposed paper, and then on bias correction in general, followed by conclusions.

Comments on the paper

Scope: The proposed article is well within the scope of HESS.

Summary: The paper analyses the impact of output of global circulation models (GCMs) other than precipitation (P) and temperature (T) on simulations of evaporation (E) and runoff (Q) by global hydrological models (GHMs) on global scale and for several large river basins. Namely the influence of radiation (R), humidity (H) and wind (W) is analyzed by comparing E and Q based on the raw GCM output vs. E and Q produced with R, H and W multiplicatively bias-corrected with the reference /baseline meteorological data (WFD reanalysis data, Weedon et al. 2011). In the study, P and T are always used in bias-corrected form (correction with WFD according to Piani et al. 2010). In the course of this analysis, the usefulness of bias-correcting meteorological forcings other than P and T and its effect on hydrologic projections is addressed.

The major findings of the study are

- R, H and W have especially in energy-limited areas large effects on the simulation of the terrestrial water balance (E, Q). Hence, input from GCMs that differ in this respect lead to differing water balance simulations.

- In such regions, a multiplicative bias correction of R, H and W with the baseline forcing data reduces the bias between GHM output and the related baseline results.

- Applying the bias correction with parameters from the control period to future GCM projections has relatively little impact on the climate change signal (i.e. the relative changes in E, Q between the control and projection period), but on the absolute values (i.e. both the control and projection period are subject to comparable absolute changes).

- Compared to bias correcting P and T, the influence of bias correcting R, H and W is smaller.

Overall ranking: If one accepts bias corrected GCM output as a suitable base for climate change studies, the work can be accepted with **minor revisions**. The proposed revision is explained below.

The paper contributes to the field of climate change and its influence on the terrestrial water cycle, a topic of ongoing and intense research activity. The interesting and novel aspect is that not only, as commonly done, parts of the GCM output (P and T) are bias corrected to make them suitable for further use, but also the other hydrologically relevant fields R, H and W. The study is well rooted in previous studies but with respect to the new aspects of the paper it is sufficiently self-contained. The state of research in the field is documented in the literature overview. The paper is well structured and easy to read.

The authors apply a very simple bias correction method, which multiplicatively adjusts, separate for each calendar month, grid point and field (R, H, W) the mean GCM field value with the mean baseline field value (WFD). This adjustment ratio is applied to daily values. This method has deficits as it a) leads to temporal field inconsistencies from one month to the next and b) does not correct the higher moments of the distribution like the method proposed by Piani et al. (2010). So I suggest using this method also for the correction of R, H and W, which would make the method of bias correction consistent throughout all fields (P, T, R, H, W) in the study.

However, the entire study is based on the concept of GCM bias correction. I am not convinced that this is a suitable approach for climate change studies, as I will explain below.

Comments on bias correction in climate change studies

The output (here: fields of P, T, R, H, W) of current-day GCMs is biased (here: systematic, non-random errors) to a degree that it cannot be used for climate change studies directly (i.e. related to the fields themselves) or indirectly (i.e. as input for further models such as GHMs). This seems generally acknowledged in the climate change community (see e.g. Piani et al. (2010), Hagemann et al. (2011), or the proposed paper).

The usual way out of this is to apply a bias correction, i.e. the GCM output (simulations and projections) is corrected towards the 'true' fields. These are often represented by global reanalysis data, e.g. the WATCH dataset (Weedon et al. 2011). The correction parameters are determined during an observed period of time and applied on this and the projection period. A multitude of bias correction approaches has been developed, such as the delta change method, multiple linear regression, analog methods, local intensity scaling, quantile mapping. An overview can be found in Hagemann et al. (2011) or Themeßl et al. (2011). In the following, I will list the steps of an advanced statistical BC method as proposed by Piani et al. (2010) and used in the proposed article. With the help of this example, I hope to make my general points of critique clearer.

The procedure:

- Match the resolution of the GCM and baseline data, typically through downscaling.
- Exclude outliers, if necessary exclude further values with upper or lower cutoff limits
- Order the remaining values of both the GCM and baseline fields by magnitude
- Plot the ordered baseline vs. GCM values. This is the empirical transfer function
- Fit a low-parameter curve to the empirical transfer function. This is the transfer function which is applied for bias-correcting the GCM fields.

The transfer functions are determined separately for

- Each calendar month (and subsequently temporally interpolated to avoid discontinuities at the end of the month
- Each grid point
- Each variable (P, T, etc.)
- In addition, the type of transfer function (linear, power law, exponential tendency to a slope) varies spatially (selected according to fit best with the least number of parameters)

What does applying of such a bias correction method mean?

- The GCM fields are not suitable to be used directly (otherwise the bias correction would not be used)
- The bias structure of the GCM fields are a function of time, space and meteorological variable. Within the range of values of each meteorological variable, the bias spreads in a non-uniform way through the entire distribution (otherwise simpler correction techniques would suffice). In short, the bias structure is complex. In my eyes this complexity is a direct result of the complex

nature of hydro-meteorological atmospheric and land-surface process interactions. This means that the best (and in my eyes only) way to reduce this bias is to improve the process descriptions of the GCMs.

- Despite its complexity, the bias structure of the GCM fields shows patterns, e.g. a positive bias in the number of wet days, inabilities to produce extreme events etc. (Piani et al. 2010). This pattern-like nature of the error can be seen as a chance rather than a problem, as it may point to specific deficits of process descriptions in the GCMs and thus offers the possibility of targeted improvement.

- The bias correction of extreme values not included in the GCM output during the simulation period requires an extrapolation of the transfer function beyond the range of observed values. That means, for example, that GCM rainfall can potentially be bias-corrected beyond physical limits.

- The bias correction may affect the relative magnitude of values among grid cells and months, (i.e. for example a temperature gradient from one grid cell to the next could be flipped).

- The bias correction alters the spatiotemporal covariance structure of a GCM field by altering the temporal covariance structure within and between months (the temporal autcorrelation is only invariant under linear transformations) and the spatial covariance structure between grid cells. This destroys the main advantage of dynamic models (the GCMs) i.e. to create thermodynamic fields with an auto correlation structure and spatial correlation structure that is consistent with atmospheric physics. From a hydrological point of view, changes in the covariance structure may strongly affect hydrological functioning whenever non-linear processes are involved, e.g. surface runoff generation, macropore flow initiation, etc.

- The bias correction affects the correlation among different fields. This issue is also discussed by Piani et al. (2010) with respect to the space-time averaged statistical relationship among fields. They present this matter as subject of ongoing scientific debate where it is not yet clear whether observed field correlations remain stable (and are thus applicable) to changing climatic conditions.

Conclusions

All the points I have raised concerning bias correction are well known in the climate change community. Hagemann et al. (2011) state '… it is rather difficult to judge whether the impact of the bias correction on the climate change signal leads to a more realistic signal or not'. While they conclude that '…the issue of bias correction will be of interest within the next years, even though it is desirable that this will no longer be necessary in the longterm perspective', I think using bias correction to tune the output of GCMs to mask their obvious errors leads to nowhere: Its application, irrespective of the quality of the method used, means to accept the common underlying assumptions of bias correction:

- A GCM with such obvious deficiencies that bias correction is necessary is nevertheless suitable to predict (the sometimes subtle) effects of climate change.

- The bias is temporally and spatially stationary, i.e. the bias correction parameterized in the past can be used for the future and bias corrections at one place can be used there in the future, even if climate change has altered the local hydrometeorological conditions.

- The links and feedbacks between the meteorological states and fluxes (P, T, H, etc.) are not of key importance, i.e. the resulting fields can be corrected after, not during modeling the related processes. However, as Seneviratne et al. (2006), cited in Hagemann et al. (2011) point out 'For Europe, land–atmosphere coupling is significantly affected by global warming and is itself a key player for climate change, thereby highlighting the importance of soil moisture–temperature feedbacks (in addition to soil moisture–precipitation feedbacks) for regional future climate changes.'

I understand and admit that these points are not directly linked to the proposed study in particular and hence I feel uneasy to make the authors pay for the reservations I have with methods that are state of the art in the climate change community by stating that I do not accept the underlying assumptions of their study. However, I would also feel uneasy to leave these points unmentioned.

Irrespective of the editors decision if and how he considers this review, I would like to encourage HESS to stimulate an open debate on the issue of bias correction in climate change modeling.

Yours sincerely,
Uwe Ehret

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