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Hydrology and Earth System Sciences
Discussions

Interactive comment on "An evaluation of the importance of spatial resolution in a global climate and hydrological model based on the Rhine and Mississippi basin" *by* Imme Benedict et al.

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We thank anonymous referee #2 for reading and commenting on our manuscript. We will reply on the major and minor comments which are raised.

(A) Spatial scale of the simulations

A1. Reviewer: I ask the authors to explain in more details how the remapping between the GCM and GHM is done, and in particular to discuss if this step provides climate simulations at a resolution high enough to enable them to capture the hydrological processes relevant for their study.

Response: First, we use closest distance spatial interpolation to remap the GCM variables to the resolution of the GHM. Second, we agree with the reviewer that the resolution of the high-resolution GCM cannot capture all relevant local hydrological processes, which is indeed a limitation of this study. We would like to emphasize that within this study we are interested in the impact of resolution of global models on hydrology. A resolution of 25 by 25 km is already at the high-end of state-of-the-art for global climate models and higher resolutions are hardly feasible, computationally, on a global scale.

A2. Reviewer: Explicitly acknowledge that there is no bias correction applied on the GCM simulations before they are used for hydrological modelling.

Response: For clarification, we will add to the experimental set-up that no bias correction is performed.

(B) Increasing resolution of the GCM

B1. Reviewer: Not convinced about the author's explanation that E-OBS shows underestimations of precipitation in the Italian Alps. It is my impression that those red/orange grid cells reflect errors in the model simulations at high resolution, and illustrate that increasing model resolution does not immediately lead to improved simulations.

Response: We do think that there is an underestimation of precipitation over the Alps in the E-OBS dataset. This is confirmed by Osnabrugge et al., 2017 (figure 4) who found large differences between EOBS and HYRAS (precipitation dataset from German Meteorological Service) in the Alpine area. More specifically, they found higher values for HYRAS compared to EOBS at the locations (Italian Alps) where we find an overestimation of EC-Earth compared to EOBS. Other studies also indicate that EOBS underestimates precipitation in the Alpine region (Turco et al., 2013;). Finally, it should be noted that no under catch correction is applied in EOBS (Prein and Gobiet, 2016). We will include the above mentioned references in the manuscript to verify the underestimation of precipitation in the Alps in the EOBS dataset. Besides, topography is extremely important for orographic precipitation. And we do agree that with the T799 resolution not all Alpine structure will be well captured, which we will include in the result section. Again, we would like to emphasize that the goal of this paper is to study the impact of horizontal resolution of global models, where the impact of changes in large-scale atmospheric drivers of precipitation is the most important effect.

B2. Reviewer: I suggest that they provide evidence from other studies that further reducing the resolution will provide the better precipitation simulations in the Mississippi basin or similar areas.

Response: The study from Liu et al. (2016) provides convection-permitting simulations with the Weather and Research Forecast model (WRF) over the USA for current and future climate. This model shows overall good performance capturing the seasonal precipitation climatology, except for a summer dry bias. In particular, snow is well simulated compared to snow observations (SNOTEL) (Liu et al., 2016). In these same simulations hourly precipitation from Mesoscale Convective Systems (MCSs) was detected and compared with radar-based precipitation estimates (Prein et al., 2017). They conclude that the convection-permitting simulations are able to capture the main characteristics and in particular the propagation of the MCSs (Prein et al., 2017). Above mentioned references will be included in the manuscript.

B3. Reviewer: More details are needed to explain how the GCM was adapted to run at higher resolution, especially for the land-use products.

Response: EC-Earth is based on IFS cy31r1. An extensive description of the model and it's land-surface characteristics can be find in the cited paper describing the simulations (Haarsma et al., 2013), describing the model (Hazeleger et al., 2010, 2012) and in the documentation of IFS (ECMWF, IFS Documentation Cy31r1, 2006). The input climate fields (i.e. land-surface characteristics) can be found in the documentation, they are similar for both resolutions and interpolated to the requested target resolution, in this case either T159 or T799. The land-use products are based on the Global Land

Cover Characteristics (GLCC) data (which are derived from Loveland et al., 2000). We will include the reference to the IFS documentation (ECMWF, IFS Documentation Cy31r1, 2006).

B4. Reviewer: Although I recognize the importance of getting large-scale processes right, is it necessary to run a climate model over the entire planet on a 25km grid to capture them adequately?

Response: We would like to emphasize the importance of running a GCM at high resolution (T799 instead of T159), for better representing large-scale circulation. Previous studies show that the large-scale circulation patterns significantly improve when the resolution increases from T159 to T511 (Jung et al., 2011) and from T159 to T799 (van Haren et al., 2015). The study of Jung et al. (2011) also shows that increasing the resolution of a GCM from T1279(∼16 km) to T2047(∼10km) leads to relative small changes. Moreover, teleconnections, in particular from the tropics, are important for weather regimes in mid-latitudes. A biased background state will affect extremes (e.g. Henderson et al., 2017). That is why we argue that running a convection-permitting model with the T159 GCM as boundary conditions is not the perfect design for future experiments. The literature mentioned above shows evidence that running a convection-permitting model with boundary conditions from the high-resolution GCM (T799) is a much better design for future experiments than downscaling from current global climate models, which we will include as an outlook in the manuscript. However we also like to stress that this study is focussed on global models and that we can only give an outlook on the use of convection-permitting models.

(C) Increasing resolution of the GHM

C1. Reviewer: Explain how the remapping of the hydrological parameters to the high resolution was done and discuss whether the results of Melsen et al. (2016) are truly transferable to your study.

Response: We remap the parameters from the low to the high resolution using the resample statement in PCRaster (Karssenberg et al., 2010). We will include a reference to the W3RA documentation for the list of parameters which are resamples from low (~50 km) to high (~5 km) resolution. To validate this approach of resampling the parameters towards the high resolution we refer to Melsen et al. (2016), who concludes that parameters are to a large extent transferable between different spatial scales. They base this conclusion on a sensitivity study of parameter transferability over resolution (~50, 10,5 & 1 km) and time for the Thur basin in Switzerland. Although the catchment in their study is much smaller than the basins in this study, the change of spatial resolution from 50 to 5 km is comparable.

C2. Reviewer: Because horizontal transport was switched off in the GHM this makes it difficult to assess the gains of increased resolution, which should be made more explicit and better discussed.

Response: There is no lateral redistribution of water between grid cells in both resolutions of W3RA. It is also not common to have a groundwater flow component in a global-scale model, although it has been implemented in some (de Graaf et al., 2015). We mention in the discussion that lateral groundwater becomes more and more important at higher resolutions, starting from 1 km (van Dijk, 2010; Bierkens et al., 2015; Wood et al., 2012). This sentence was meant as an outlook for future experiments but does not corresponds with our simulations, which we should clarify. In addition, there is horizontal transport of runoff via the routing module which is run after the hydrological model run. We will clarify this in our experimental set-up.

C3: Reviewer: Change table 3 and 4 to barplots.

Response: See Figure 1 and Figure 2.

C4: Reviewer: I wonder how close GHMs are to replace calibrated catchment-scale hydrological models, for example by computing the NSE.

Response: For specified catchment studies, we advise to use calibrated catchment-

scale models. However, the purpose of this study was to test the sensitivity of discharge to the resolution of a global hydrological model. For interpretation we have chosen to analyse to large catchments. For the Rhine we can compare our model results of ERA-Interim and W3RA with model results of ERA-Interim and HBV (Photiadou et al., 2011). For the discharge at Lobith, Photiadou et al. (2011) obtained a Nash-Sutcliff efficiency (NSE) of -0.54. The NSE for our simulations are shown below. For the Mississippi we are not aware of a catchment-scale hydrological study with ERA-Interim forcing to compare our results.

NSE:

T799 + 0.5°: -0.51

T799 + 0.05°: -0.49

T159 + 0.5°: -0.78

T159 + 0.05°: -0.72

Minor comments

If we do not discuss the minor comment stated by the reviewer it means that we agree with the reviewer and we will adapt this in the manuscript.

* Reviewer: Please explain why six simulations of five years were run instead of a single simulation of 30 years. Please also explain how the six members differ.

Response: The GCM experiments were at first hand performed for multiple research questions, like the impact of climate change on teleconnection responses to specific tropical sea surface temperature patterns (Haarsma et al., 2013). Namely, similar experiments for present climate (2002-2006) are also performed for future climate (2094-2098). These research questions motivated the larger ensemble approach of shorter runs. We will add in the manuscript that the research questions discussed in this paper could also be studied with a fewer longer runs.

In this study we use 5-year 6-member ensemble simulations from 2002-2006. A 10-year spin-up run at the low resolution (T159) was made, followed by a 9 month run (from January to October) spin-up run at the desired resolution. The 6 member ensemble was made by taking the atmospheric state of one of the first 6 days of October as initial state for each member. After this spin-up the spread in the atmospheric state was sufficient to treat the 6 runs as independent members (PhD thesis Ronald van Haren, page 65). For this extensive explanation on the difference between the six members we refer to Haarsma et al. (2013).

* Reviewer: Difficult to jump back and forth between Rhine and Mississippi.

Response: We understand the comment on jumping back and forth between the Mississippi and Rhine. At first hand, we decided this set-up as want to compare the two different basins. Nevertheless, as the anonymous referee #1 also suggests to first discuss the Rhine and then the Mississippi we will do so if we get the opportunity to revise the manuscript.

* Reviewer: Was the spin-up (i.e. the period not used in the validation phase) of 1 or 5 years?

Response: The spin-up period was 6 years (5 +1 year). We will make this more clear in the revised manuscript. A validation of the spin-up is shown in the reply to referee number 1. âĂČ

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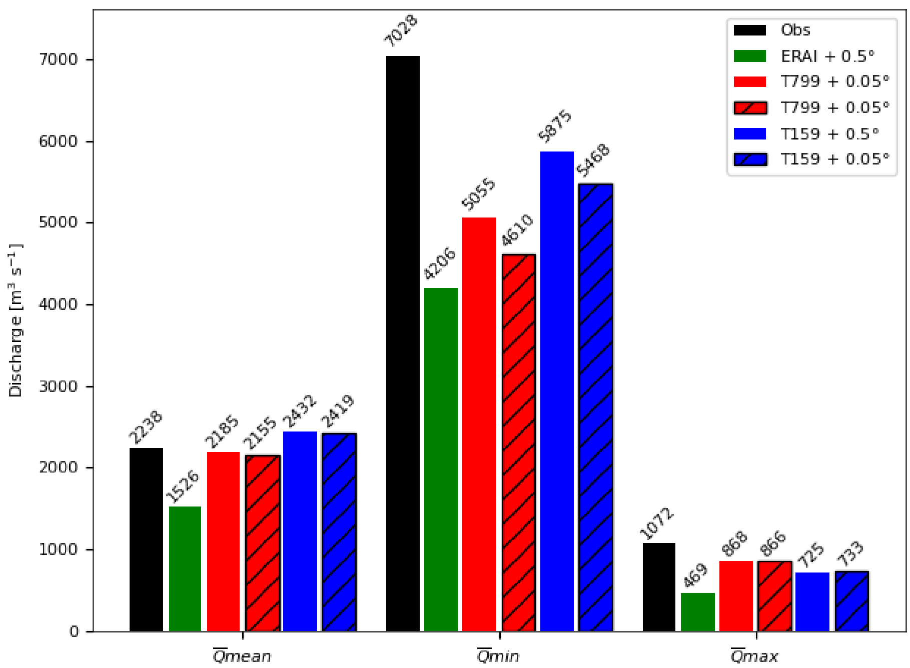

Fig. 1. Discharge measures (Qmean, Qmin and Qmax) for the observations and different model runs (0.5° and 0.05° W3RA GHM runs) with different forcing data (ERAI, EC-Earth T799 and T159) at Lobith.

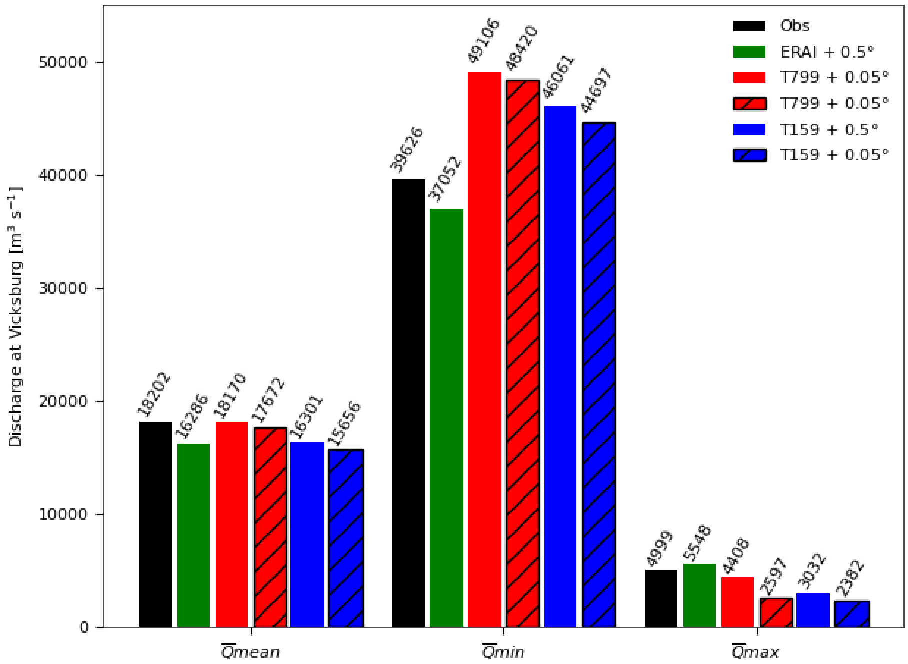

Fig. 2. Discharge measures (Qmean, Qmin and Qmax) for the observations and different model runs (0.5° and 0.05° W3RA GHM runs) with different forcing data (ERAI, EC-Earth T799 and T159) at Vicksburg.