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Interactive comment on "Simultaneous calibration of hydrological models in geographical space" *by* A. Bárdossy et al.

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Firstly, we would like to sincerely thank referee 2 for his thorough review of the manuscript and valuable comments. The responses to the general and specific comments are presented as below.

Main comments

1. Can eta effectively separate the dynamic and long term water balance behavior of catchments?
The water balance parameter introduced in Section 4.1 aims to isolate the dynamic and long term water balance related aspects of the hydrograph. The question is whether such a separation can be achieved by this parameter. Eta essentially corrects for water balance error (Equation 7 on Page 11233). Equation 5 on Page 11233 shows that eta achieves this by altering the estimation of actual evapotranspiration at each time step. Therefore, introducing eta is likely to alter the dynamic behavior by changing the amount of water available in the soil moisture bucket (SM in equation 5). If more water evaporates at a time step, less is available in the next time step as soil moisture and vice-versa. Moreover, this effect may increase with simulation time. This affects the eventual runoff response of the catchment that depends upon the antecedent soil moisture conditions. Thus, the parameter introduced to correct for long term water balance will also alter the dynamic behavior of the catchment. To what extent this effect is significant can be assessed by comparing the dynamic performance measures with and without eta in the model structure as introduction of eta may also affect performance criteria such as NS and GK.

Response: Yes, we found that the separation of the long term water balance and dynamic behavior of catchments could be effectively achieved by parameter η in our study. As described in section 4, parameter η regulates the available water for evapotranspiration during the calibration time period. Thus it mainly depends on the climate conditions of catchments and has only little effect on the dynamic responses of the catchments. Due to different climate conditions for different catchments, parameter η may be very different. In our study, we have also tested the simultaneously calibrated results of the HBV model with and without using parameter η in the model framework for NS performance measure. For most of the study catchments, results show that the NS values are very close for these two different structured models. But we also found that some of the catchments have relatively huge discharge volume error for the model that without using η to adjust the water balance.

2. If eta depends upon the parameter vector, can it be regionalized?
As discussed in Section 4.1 (Lines 22-23 on Page 11233), eta varies with the parameter vector. This implies that eta depends on the calibration process (which determines the parameter vectors) and associated uncertainties in climate variables and streamflow observations. This will be a challenge in its estimation for its ungauged basins.

Response: In this study, the long term discharge volumes were taken as known value to evaluate parameter η for each parameter vector. Instead of regionalizing η for ungauged basins, we suggested for the regionalization of discharge coefficients which relate discharge volumes to precipitations. We have found that the discharge coefficients show a smooth spatial behavior in the study area, regionalization of this parameter does not seem to be difficult. Afterwards, the long term discharge volumes may be calculated and the parameter η could be estimated for each common parameter set.

3. Performance assessment of transferred parameters
There are some issues related to performance assessment criteria of donor and recipient catchments that can be clarified in the text. First, if eta affects the dynamic performance measures such as NS and GK, it should also be transferred to the (assumed) ungauged catchment. However, all the experiments in the study only transfer the dynamic parameters. Second, it is unclear whether

the NS and GK measures of the donor catchment are calculated before or after eta is included in the model structure.

Response: Parameter η is a water balance related parameter and represents the available water for evapotranspiration. As described in this study, for different catchments η varies due to different climate conditions. Therefore, in all the experiments only the dynamic model parameters were considered to be transferred. For the second question, all the model performances have been shown in this paper were calculated after considering the parameter η in the model structure.

Other comments

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1. Line 6 on Page 11229: Please check this statement. Not all catchments in the MOPEX database are classified as 'reference' or minimally impacted.

Response: Thanks for your reminder, we have already checked it for our study area. We only chose the catchments that are minimally impacted by human influences in this research.

2. Section 3.4: Since several performance measures are being used, it would be helpful to know the feasible range and ideal values of each performance measure.

Response: The model calibration procedures were carried out using the ROPE algorithm (Bárdossy and Singh, 2008). This kind of parameter optimization method could obtain a pre-determined number of parameter sets that perform very similar for the model, though these parameter sets are very heterogeneous. The feasible range of model performance for all calibration and validation will be added as supplement.

3. Line 4, Page 11234: Replace parameters with 'parameter vectors'.
4. Line 12, Page 11234: Missing space after period.
5. Line 16, Page 11234: Replace weather by climate.
6. Lines 3-4, Page 11235: Replace 'the models perform differently in different catchments' with 'the model performance varies across catchments'.
7. Lines 10-11, Page 11236: Consider rephrasing to: 'Parameter vectors from other catchments generally fail to perform on catchment 15 across all three models'.
8. Lines 3 and 5, Page 11237: Replace weather by climate.
10. Lines 24-26, Page 11238: The observation that parameter vectors obtained through common calibration may outperform individual on-site calibration may also indicate the weakness of the calibration process for an individual catchment, which should ideally be able to identify the 'best' set.
11. Line 16, Page 11239: Remove 'effective'.
12. Line 19, Page 11239: 'it outperforms model', should be 'it outperforms the parameter vectors'.

Response: Thank you very much for these detailed suggestions and corrections that have been integrated in the revised version.

9. Equation 8: what does index i represent?

Response: Here index i indicate the catchment number, we have stated this in the revised paper.

13. Section 8, Page 11242: This section and associated results can potentially be removed. It is not clear whether parameter transfer between such disparate regions should be discussed with only two supporting examples.

Response: Thanks for the comments. We have received multiple comments and sug-

gestions about this section. We also have the idea that only two supporting examples seem not sufficient to discuss the parameter transfer to other continents and thus we think the numerical experiment 4 and the associated result should be removed in the revised version of our manuscript.

14. Line 7, Page 11243: What is the meaning of the term 'deepest parameter'?

Response: The ROPE algorithm (Bárdossy and Singh, 2008) was achieved based on the theory of depth function. Data depth is a method of measuring how deep (central) a given point is relative to the data set. The 'deepest parameter' represents the most central point in the whole parameter vectors.

16. Lines 17-20, Page 11243: The estimation of eta seems to be a challenge as it may be impacted by parameter interactions, observational uncertainties, etc., which cannot be ascertained due to absence of streamflow data!

Response: Yes, the estimation of parameter η requires the total discharge volume. As we discussed in section 9.3, instead of regionalizing η for ungauged basins, we suggested for the regionalization of discharge coefficients which relate discharge volumes to precipitations. At the end, we found that the discharge coefficients show a smooth spatial behavior in the study area and the regionalization of this parameter does not seem to be difficult. Afterwards, the long term discharge volumes may be calculated and the parameter η could be estimated for each common parameter set.

17. Section 10: The conclusions section can be shortened, and discussion related to the continental parameter transfer removed.

Response: We have removed the results for the German catchments and partially rewritten the conclusion in the revised paper.

18. Lines 5-11: Consider revising this text.

Response: We have revised the text to: In this study, three lumped hydrological models with three different performance measures were tested on the daily time scale. The results show that many catchments behave similar as the same dynamical parameter sets could perform reasonable for all of them. This means that hydrological behavior on the daily scale is dominated by precipitation characteristics and actual evapotranspiration. In our study area, it also indicates that the differences in catchment properties cannot be captured well by simple lumped model parameters.

19. Figure 3: Adding model names on top of the color matrices, or referring to them through labels and legend information would be helpful.
20. Figure 3: Given the scale for GK, which begins from 0.7, it seems there is not much performance variation (or is the variation from 0.7 to 0.95 significant when compared to the variation in NS from negative values to 0.8 in the sub panel above?).
21. Figure 4: Adding model names on the figure or in the legend would be helpful.

Response: Thanks for the suggestion. We have added the model names on the top of the matrices in revised paper for both Figure 3 and 4. For question 20, the GK model performance mainly focus on the water balance thus the value is not very sensitive for the study catchments. And for all the color matrices have been shown in this paper, the corresponding color bars represent the whole range of simulated model performances.

22. Figure 5: This figure would be easier to interpret if the entire feasible range of both parameters were plotted instead of the range spanning the dataset. Boxplots or histograms showing the ranges for various parameters may be more useful as several catchments can be shown in the same plot using panels. This

figure can potentially be merged with Figure 6.
23. Figure 6: See comment above, can potentially be merged with Figure 5.

Response: Thanks for the suggestions. We have merged these two figures into one in the revised paper. The reason to consider the scatterplots instead of boxplots or histograms was that the structural correlation of multi-parameters could be clearly shown with them.

24. Figure 17: This figure can potentially be removed.

Response: This figure clearly shows the smooth spatial distribution of discharge coefficients in our study area. This map indicates that for ungauged basins, the estimation of discharge coefficients might be achieved through regionalization and thus we hope to remain this figure in the manuscript.

References

Bárdossy, A. and Singh, S. K.: Robust estimation of hydrological model parameters, Hydrol. Earth Syst. Sci., 12, 1273–1283, doi:10.5194/hess-12-1273-2008, 2008.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 11223, 2015.