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Hydrology and Earth System Sciences Discussions
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Interactive comment on "Data assimilation in integrated hydrological modelling in the presence of observation bias" *by* J. Rasmussen et al.

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Thank you for your comments. We have here tried to answer these point-by-point.

-Comment: Page 8131, Lines 12-20. There have been other data assimilation studies that have focused on updating system state variables and system parameters in an integrated hydrological (groundwater-surface water) framework. These probably should be mentioned. They include:

Kurtz, W., H.-J. Hendricks Franssen, P. Brunner, and H. Vereecken (2013), Is High-Resolution Inverse Characterization of Heterogeneous River Bed Hydraulic Conductivities Needed and Possible? Hydrol. Earth Syst. Sci. 17 (10): 3795–3813. doi:10.5194/hess-17-3795-2013.

Bailey, R.T., and Baù, D. (2012), Estimating geostatistical parameters and spatially-variable hydraulic conductivity within a catchment system using an ensemble smoother. Hydrology and Earth System Sciences, 16, 287-304.

Changes: The above references have been added to the paragraph.

-Comment: Section 2.2.2 – what is the discretization of the stream network? Is it the same that is used for the aquifer? Are the groundwater and surface water processes coupled, or just linked? (linked = no iteration during the time step, just passing values between the stream model and the aquifer flow model)?

Changes: The following has been inserted into the section "The stream model network is set up using an alternating calculation scheme in which discharge and water level is calculated respectively in alternating points, and is independent from the groundwater model discretization Exchanges of water between the two processes is taken place in the groundwater model grid cells where a river branch is present.. The exchange takes place at every groundwater model time step.".

-Comment: Section 2.2.3 – spatial variability of streambed parameters (i.e. "leakage coefficient controls") has been a focus of research during the past few years, particularly in integrated hydrological modeling. How does using spatially-uniform stream model parameters influence the model results? Could this have an impact on the data assimilation results, particularly since some of the observation wells are close to the stream network and hence could be influenced by spatially-variable groundwater-surface water interactions?

Reply: The use of a spatially variable leakage coefficient would without a doubt have improved model performance and would have been preferable, but we believe it not to be feasible at the current scale and especially at the current discretization of the groundwater model. Furthermore, we believe that the current discretization is a much bigger source of error in the groundwater-stream flow interaction than the uniform parameterization of the leakage coefficient. Partly due to the errors in the groundwater-

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stream flow interaction, the observation points closest to the stream network was omitted from the assimilation as described in section 3.1.1.

Changes: None

-Comment: Page 8142, Line 18. Why choose a standard deviation of 0.6 m? Is this based on field data? Were other values tested?

Reply: The chosen value is based on the multitudes of tests and experiments that were performed before the results shown in this paper. The impact of the parameter was not deliberately tested, as the parameter did not appear to be particularly important to the estimation of bias.

Changes: The following is inserted in to the section: "The standard deviation vas chosen based on precursive testing in the synthetic test environment, that showed that this value generally led to the best estimates of bias."

-Comment: Page 8145, Lines 20-21. I am confused by this. Isn't the point of the DA methodology to estimate the parameters? (i.e. "calibrate" the model?) So then why is the model calibrated using AutoCal? I am not sure how this fits into the general aims of the study.

Reply: We believe there has been a misunderstanding. The calibrated model is only used as a reference point to compare the parameter estimation of the data assimilation algorithm.

Changes: The sentence is extended for clarification: "[the model is also calibrated using AutoCal] in order to be able to compare the parameter estimation through data assimilation with parameter estimation through more common method, such as inverse modelling"

-Comment: Section 2.4.2 – Is Hydraulic conductivity spatially-uniform throughout the catchment? Is this realistic? It seems that K should be specified as spatially-variable (ac-cording to geostatistics), and the K field should be updated using the system-

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response measurements.

Reply: As described in section 2.2.3, the parameterization of the groundwater model, including K, is based on a 3D geological model. The parameters are assigned to each unit of the geological model, and this parameterization is mapped to the 2D computational grid in a preprocessing step (built into the model code), that follows each parameter update.

Changes: Added to section 2.4.2: “Note that the estimated hydraulic conductivities are those of the geological units, that are gridded to the computational grid before further propagation of the ensemble (see section 2.2.3)”.

-Comment: Section 2.3.7 - Please provide more information regarding the “Asynchronous assimilation”. Are the daily discharge measurements averaged over the 28 days, and then the average discharge is assimilated at the update time?

Reply: The method does not average discharge, but involves saving the individual asynchronous observations and model results, and thus improving the update at the time of updating through correlation in time.

Changes: Added to the section: “The state vector is extended with model results for asynchronous observation times and the observation vector is extended with the asynchronous observations. After that, the asynchronous observations and model results are simply treated as normal model states.”

-Comment: Page 8140, Line 21. Change “hereby” to “thereby”

Changes: Changed.

-Comment: Section 3.4. A 1-year warm-up period does not seem long enough to provide a significant spread in the ensemble, given the slow travel time of groundwater. Could you please quantify the spread of the ensemble at the end of 1969, to demonstrate that enough spread occurred?

Reply: The catchment is geologically dominated by sand, and thus highly permeable. An ensemble spread therefore builds up very fast.

Changes: Added to section 3.4: “At the end of the year 1969, the spread of the ensemble of groundwater head is between 0.8 and 2.1 m (depending on the location in the catchment), which is considered sufficient for assimilation to commence.”

-Comment: In the Results section, please provide a 1:1 plot (simulated vs. observed) of groundwater head for some of the scenarios. Perhaps show a “before” and “after” plot (without and with data assimilation) to demonstrate the improvement of the hydrologic system when DA is used. Also, a plot to compare the results of the different scenarios, with the ensemble mean used for the simulated results.

Changes: 1:1 plots of groundwater head in selected observations in selected observation locations has been added, including a comparison of the base model (i.e. no DA) and SepFil and ColFil_ens200 scenarios. Plots comparing the results of different scenarios (mean of the ensemble) are already present in the paper, namely figures 5 and 8 showing head as a function of time in the synthetic test and real data tests respectively.

-Comment: Section 5: please provide conclusions, rather than just a summary of the study and discussion of results. What are the implications of the results? How can results be used in future studies, particularly in applications to real-world watershed systems?

Changes: Added to the end of the conclusion: “The study has shown that hydrological observational bias can be corrected in a data assimilation scheme and that it can improve state updating and parameter estimation. With both model- and observational bias being significant sources of error in hydrological modelling which will have a negative impact on the performance of data assimilation in hydrological models, the results provide an important advancement of application of hydrological data assimilation in large scale, integrated hydrological models.”

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