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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Data assimilation of GRACE terrestrial water storage estimates into a regional hydrological model of the Rhine River basin" *by* N. Tangdamrongsub et al.

Anonymous Referee #1

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General comments:

The manuscript at hand presents results of an assimilation approach to include GRACE terrestrial water storage (TWS) data into a hydrological model using an ensemble Kalman filter. The study investigates the effect of a varying quality of climate forcing data (by introducing both a global and a regional data set) and the impact of model calibration by using both a calibrated and a non-calibrated version of the model. The authors find that after data assimilation the modeled TWS agrees better to GRACE then the open-loop model output and that the modeled groundwater estimate fits significantly better to in-situ gorundwater observations. However, the improvement of

streamflow estimates appears to be only modest. In my opinion, the manuscript is of good quality and the presentation of the study is convincing. I especially like the differentiation between different types of input data and model versions, as this results in a valuable insight into the benefit of data assimilation in data sparse regions. However, there are some issues in the paper that do not become completely clear to me. I therefore suggest publication of the manuscript in HESS after some modifications. Furthermore, I would like to thank the authors for sharing their very interesting research!

Specific comments:

Abstract and Conclusions: While in the results section, the authors realistically describe the benefit of the GRACE data assimilation on the results (and also the limit of this benefit in case of streamflow data) the abstract and the conclusions appear comparably optimistic. (I agree with reviewer Sylvain Ferrant on this.). However, I think that in their comment published on November 15th, the authors settle this matter. Altogether, I think after the suggested modifications they represent a realistic assessement of how GRACE can help to improve the model.

Page 11841: You cite Güntner et al. (2008) for satellite altimetry. However, this paper is not really about altimetry and quite significant progress has been made in recent years regarding the accuracy of radar altimetry and its applicability to inland surface water bodies. I therefore suggest to reference a more recent state of the art publication on this topic.

Page 11847, lines 17ff: It is not entirely clear to me what the impact of GLDAS is here. If you use soil moisture from GLDAS to determine groundwater variations from the measurements, is this really an independent observation of groundwater? How meaningful is this observation after mixing it with GLDAS? Or do you rather validate against the soil moisture compartment of GLDAS? Please discuss this issue with a bit more detail.

Chapter 4.1: How did you set up your ensemble Kalman filter procedure? Did you use

an available software package (such as, for example, DART)? Or did you implement the procedure individually?

Chapter 4.2: It does not become clear to me how you use the GRACE observations. Do you use them as a basin mean averaged over the Rhine catchment? Or did you calculate the GRACE TWS values on some grid?

Page 11849, lines 14ff: I do not really understand how the vertical distribution of the GRACE information into the soil moisture (SM) and the groundwater compartments (LZ and UZ) works. If I understand correctly, SM is adjusted first and if this storage reaches its upper or lower limit, the rest of the increment is applied to LZ and UZ (?). However, I would assume that the information about the distribution of the increment among the different model compartments can be obtained directly from the Kalman filter itself? Should this information (given a reasonable ensemble model covariance matrix, see also my question regarding Chapter 4.3 below) not be provided by the Kalman gain matrix? Please give some more details on this and why you chose to carry out the vertical distribution the way you do.

Page 11849 lines 21/22: You apply an observation error of 2cm for your GRACE TWS observations. This appears to be a rather simplistic assumption. First of all this number disregards the recent improvements of GRACE accuracy (Klees et al. 2008 used RL04 data). Furthermore, the Klees et al. refer to this accuracy for river basins above 1 million km2, which is significantly larger than the Rhine. Have you performed any kind of error propagation to test whether this assumption is valid for your test area? Or did you carry out any tests on how different GRACE error estimates would affect your assimilation results?

Page 11850: lines 5ff: In your "non-calibrated" case, you set each parameter value to its mean value over the whole basin. This way, on average the non-calibrated and the calibrated cases agree. Is this really the case in data sparse regions? I would assume that even the mean value of the non-calibrated parameters might differ quite

significantly from the mean value of the calibrated parameters. Therefore, I believe that setting the mean values equal is over-optimistic and not a necessary assumption. I would expect that your results might show the positive impact of GRACE in data sparse regions even better, if you would not assume a "correct" mean value for the parameters.

Chapter 4.3: How do the model uncertainties enter the Kalman filter algorithm? Do you determine a full empirical ensemble covariance matrix with the dimensions of all of the model grid cells and the three model compartments? Or do you use only the variances? Please give a few more technical details on your approach.

Additional references: Quite recently, there have been additional studies on assimilating GRACE data into hydrological models (see full references below). First of all, Forman and Reichle (2013) discuss the effect of spatial aggregation of GRACE TWS estimates before assimilating them into a hydrological model. And Eicker et al. (2014) discuss the introduction of the full GRACE error structure into the assimilation procedure. (A more detailed treatment of the GRACE error from the product itself is an issue you also mention as topic for future research in your conclusions). I would suggest that you include references to those new studies in your manuscript.

References:

Forman BA, Reichle R (2013) The spatial scale of model errors and assimilated retrievals in a terrestrial water storage assimilation system. Water Resour Res 49:7457–7468. doi:10.1002/2012WR012885

Eicker, A., Schumacher, M., Kusche, J., Döll, P., Müller Schmied H. (2014) Calibration/Data Assimilation Approach for Integrating GRACE Data into the WaterGAP Global Hydrology Model (WGHM) Using an Ensemble Kalman Filter: First Results, Surveys in Geophysics, Volume 35, Issue 6, pp 1285-1309, doi:10.1007/s10712-014-9309-8

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