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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Improving estimates of water resources in a semi-arid region by assimilating GRACE data into the PCR-GLOBWB hydrological model" *by* N. Tangdamrongsub et al.

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I read the manuscript by Tangdamrongsub et al. with an interest. The manuscript addresses important methodological issues of GRACE data assimilation into hydrological models. There are, however, serious issues in the methodological implementation of this paper (especially the treatment of the observation vector in Eq. (7)). I also found a number of examples in which previous studies are not correctly referred (in terms of the details of methodology). My very relevant previous work on modeling errors of GRACE TWS changes is ignored. I believe that the following comments are important to be addressed by the authors prior to the publication of the manuscript in a prestigious journal like HESS.

Major comments on methodology:

1) Treating observations as random variable

l. 368 and matrix D in Eq. (7): Burgers et al. (1998) showed that it is necessary to consider the observations as random variable, i.e. that not only an ensemble of predicted model states but also an ensemble of observations has to be considered when calculating the update of each model ensemble member. Perturbations for the observations can be drawn from the error covariance matrix R. Otherwise, the error statistics of the updated model ensemble are underestimated (i.e. not correctly treated). In a correct implementation, matrix D does not contain N identical columns as described in l. 368. This should be fixed or at least discussed by the authors. In addition, it is not possible to draw random errors from the full error covariance matrix of GRACE TWS changes on a 0.5x0.5 degree grid, since the matrix has a rank deficiency. This is a critical issue and should be addressed by the authors as well.

l. 507-508: The standard deviations of the EnKF results are however underestimated, since the observation vector was not treated as a random variable in Eq. (7). Therefore, the error statistics of the updated model states are not correct. This should be fixed or at least discussed.

l. 588-589: This might change after correctly estimating the updated model ensemble spread by generating perturbations for the observations (revising Eq. (7)).

2) Characteristics of error covariance matrices

Eq. (8): Since both error covariance matrices (from the model and the observations) have a rank-defect due to (1) the fact that usually the number of model states is much larger than the number of model ensemble members and (2) GRACE cannot actually resolve TWS changes on a 0.5x0.5 degree grid, the inverse in Eq. (8) does not exist. This should be pointed out and a reference to sections 5.2.1 and 5.2.2 might be provided that describe how the authors deal with this issue.

l. 251: GRACE observations are highly correlated on such a fine spatial resolution (similar to the above comment). Did the authors investigate this? Was this the reason to use a maximum correlation length for the observation error covariance matrix?

l. 414-415: If I understand it correctly, the error correlation length is set to 250 km and TWS changes outside of this radius are assumed to not be correlated to the center grid cell. Is this reasonable? It would be helpful to investigate the correlations of points with longer distances to verify this choice. Does the "local" error covariance matrix have a full rank?

Fig. 7: In the main text (l. 414-415), it is explained that a correlation length of 250 km is used (approx. four to five 0.5x0.5 degree ($\sim$50kmx50km at the equator) grid cells in each direction from the center grid cell). In Fig. 7, it is shown that only the neighboring grid cells are considered. Please clarify.

l. 419: Since the neighboring 0.5x0.5 degree grid cells are highly correlated, it is not reasonable - based on the GRACE error characteristics - to apply the EnKF without spatial error correlations on such a fine scale. A statement would be helpful to the reader.

l. 726-727: But: The authors do not use the full error covariance matrix as directly calculated from the observations. Instead a maximum correlation length of 250 km is assumed, and thus a part of the information within the full error covariance matrix is neglected. Therefore, the statement might be misleading.

Major comments on citation of previous works:

3) Zaitchik et al. (2008)

l. 90-91: That seems to be incorrect. Zaitchik et al. (2008) used an ensemble Kalman smoother (EnKS) approach to partition the monthly update increment (based on comparing monthly means of modeled and observed TWS changes) equally to each day of the month. GRACE TWS changes are only assimilated once per month and not every

10 days.

4) Forman et al. (2012)

l. 95: This work adapts the method as proposed in Zaitchik et al. (2008) to a snow-dominated basin.

l. 98: Please also consider the disadvantage of computational costs: The method has some computational drawback since the model has to be evaluated twice over the same month.

5) Forman et al. (2013)

l. 106: In Forman et al. (2013), the authors did not use correlated errors for the data assimilation. They investigated for which spatial resolution errors of GRACE TWS changes might be considered as uncorrelated. According to these investigations, they assumed white noise for (sub-)basin averaged TWS changes from GRACE.

6) Girotto et al. (2016)

l. 89-95: In this work, the authors performed an analysis of introducing the update increments completely at the beginning of a month, the end of a month or equally distributed over all days of a month. This is worth to be mentioned along with the other citations.

7) Schumacher et al. (2016)

l. 39-40 and l. 106-108: A first analysis of assessing the effect of considering or neglecting spatial error correlations of GRACE TWS changes was performed in Schumacher et al. (2016) in form of a synthetic experiment, for which one of the authors of this HESSD manuscript was the editor and should therefore be very familiar with the work. It seems that the paper is methodologically the closest related to the analysis presented here and, therefore, should be cited and discussed. Findings should be compared to the findings in the published paper.

l. 577: This was also seen and discussed in Schumacher et al. (2016). The authors should compare their results with the findings in this paper, since the objective of both papers is to understand the effect of considering spatial error correlations of GRACE TWS changes on hydrological data assimilation results.

l. 715-718: The authors should add something like "in agreement with the recommendation in Schumacher et al. (2016)."

l. 719-724: The findings in the HESSD manuscript allow for a clearer conclusion on improvements when error correlations of GRACE TWS changes are taken into account. What might be the reason for this? Differences in the study set up? Localization of model / observation error covariance matrices?

l. 729: A reference to Schumacher et al. (2016) would strengthen this statement, since the HESSD manuscript is not the only study that concludes a benefit / more realistic GRACE data assimilation approach if implementing GRACE error correlations.

l. 752-753: Schumacher et al. (2016) should be added to the list of references.

l. 755: Alternative methods have been investigated in Schumacher et al. (2016), namely a square root analysis scheme (SQRA) and the singular evolutive interpolated Kalman filter (SEIK). Especially the application of the SEIK filter showed promising results. A citation would support the authors expectation that alternative methods, e.g. the particle filter, would improve the data assimilation performance.

Minor comments:

l. 583: "truth", i.e. to the independent measurements of individual water compartments. These measurements are also subject to uncertainties and not "true" values.

l. 756: "true" -> better "full" (true is difficult since often unknown / poorly known)

References:

Burgers, G., P.J. van Leeuwen and G. Evensen (1998). Analysis scheme in the

ensemble Kalman filter. Mon Weather Rev, 126:1719–1724. doi:10.1175/1520-0493(1998)126<1719:ASITEK>2.0.CO;2.

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Schumacher, M., J. Kusche and P. Döll (2016). A Systematic Impact Assessment of GRACE Error Correlation on Data Assimilation in Hydrological Models. J Geod, 90(6): 537–559. doi:10.1007/s00190-016-0892-y.

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