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.

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We firstly would like to acknowledge the insightful comments and suggestions provided by Referee 2. Followings are the responses (A) based on the comments (Q):

Q1: Are GRACE observations averaged across the basin, or are they assimilated as gridded data? If the latter then how were horizontal error correlations taken into account?

A1: GRACE TWS are calculated and assimilated at the model grid scale (1 km). The GRACE observation error is assumed to be 20 mm and horizontal observation er-

ror correlations are not considered. This will be stated more clearly in the revised manuscript.

Q2: GRACE observations are assimilated once every 5 days and, if I understand correctly, no smoothing is applied. Are any temporal discontinuities seen in model state variables or related fluxes (e.g., ET, runoff) due to this episodic application of increments? None are obvious in the time series presented in the paper, but it would be useful for the authors to comment on any artefacts that do exist or to discuss how this was avoided.

A2: The referee is correct, GRACE observations are assimilated once every 5 days and no smoothing is applied. Like any land surface assimilation application, the update results in discontinuities as mass in added or removed from the state. However, as the referee remarks, these are not large enough to be obvious in the time series presented. On the other hand, if we updated once a month and applied the entire increment on one day, we would expect to see more significant artefacts or temporal discontinuities. Discussion of this will be added to the revised manuscript for clarity.

Q3: GRACE products are now distributed with gridded error estimates, and a method for estimating basin-wide error using these estimates is provided on the GRACE Tellus website. How does the error calculated from these estimates compare to the 20 mm estimate used in this study?

A3: The total error (measurement and leakage errors, no correlation) derived from the GRACE Tellus website was 25.78 mm, averaged over our study region, but are based on solutions using a different processing of the CSR RL05 data. The recent study from Dahle et al. (2014) suggested monthly error levels of 15 mm for the GFZ RL05 solutions (at ~330 km spatial resolution), so we feel that the 20mm errors used for this study remain a reasonable choice. (Please also see the response A6 in Referee 1). This will be stated more clearly in the revised manuscript.

Q4: Also related to the question of GRACE errors: did the authors perform any sen-

sitivity study by varying the GRACE error estimate? Figures 5,7, and 8 indicate that the DA run copy falls very close to GRACE, suggesting that the observations were weighted very heavily in the EnKF update. Is this optimal? A higher GRACE error estimate would relax the DA simulations back towards OL, and it would be interesting to see how this affects metrics of simulation performance.

A4: As stated in the response A6 in Referee 1, we feel that the 20 mm observation error value was realistic as it was suggested by several independent assessments e.g., Klees et al. (2008), Wahr et al. (2006), Schmidt et al. (2008) and it also had been applied in previous GRACE assimilation studies (Zaitchik et al, 2008; Houborg et al, 2012). Our philosophy here was to set the GRACE errors to realistic values determined from independent studies, so that the solutions were not guided towards any particular outcome. The fact that the 20mm errors led to improvements in the groundwater and streamflow estimates suggest that the error levels were reasonable. That said, we do recognize that improvements could be made with respect to the GRACE error characteristics that may improve solution performance, but this is a topic of future work.

Q5. I am confused by the authors' comments regarding adjustment for "dry snow." Why, exactly, does this need to be corrected for in the GRACE observations?

A5: The snow component is small averaged over our study area (approximately 2%, except over the Alp which is approximately 7% respected to SM+UZ+LZ in winter), and so our defined TWS from OpenStreams-wflow does not include the dry snow component (this is stated in Page 11843, Line 25-27). To reconcile GRACE to OpenStreams-wflow TWS, we then removed the dry snow component from GRACE before the assimilation process. This will be stated more clearly in the revised manuscript.

Additional References:

Schmidt, R., Flechtner, F., Meyer, U., Neumayer, K. -H, Dahle, Ch., Koenig, R., and Kusche, J.: Hydrological Signals Observed by the GRACE Satellites, Surv. Geophys., 29, 319 - 334, doi:http://dx.doi.org/10.1007/s10712-008-9033-3, 2008.

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