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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "The bias in GRACE estimates of continental water storage variations" *by* R. Klees et al.

R. Klees et al.

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First of all we want to thank the anonymous reviewer 2 for his comments and suggestions, which help us improving the quality of the manuscript. Some of the remarks have already been covered in the authors rebuttal to reviewer 4, see "Author comment" (AC S1836 : 'Rebuttal, anonymous reviewer 4' , Roland Klees, 22.01.2007, 13:05; (*http://www.cosis.net/copernicus/EGU/hessd/3/S1836/hessd-3-S1836.pdf*). We will refer to this rebuttal whenever necessary.

1 General comment

More emphasis could be used to show that the method really works and that it is not a single case event for using the same model for bias correction and comparison to GRACE.

The author addresses a point in our investigations, which is important: we used LEW to estimate the bias and then compared bias-corrected GRACE estimates with LEW. This could result in an overoptimistic fit of bias-corrected GRACE with LEW. We decided to repeat the complete data analysis for the CPC-LDAS model to investigate this. The main results have been included in the manuscript. The main conclusions are that indeed the bias is 'biased' towards the hydrological model used to compute it. Therefore, a comparison of bias corrected GRACE with LEW is overoptimistic if LEW was also used to compute the bias. The same happens for CPC-LDAS (i.e. CPC-LDAS is used to compute the bias; then GRACE corrected for this bias is compared with CPC-LDAS). At the same time, differences between CPC-LDAS bias estimates and LEW bias estimates are significant. However, when CPC-LDAS is used to compute the bias and bias-corrected GRACE is compared with LEW, we still obtain significant improvements, although the remaining differences are slightly larger than when LEW is used to compute the bias. Vice versa, if LEW is used to compute the bias and bias-corrected GRACE is compared with CPC-LDAS, the improvements are also significant. Therefore, we are convinced that the proposed method of bias correction works provided that some reasonable a priori information about mass variations inside the target area and in its vicinity is available. It seems to be that both CPC-LDAS and LEW allow to get good estimates of the bias.

The analysis also allows us to make some statements about the quality of CPC-LDAS relative to LEW, although it is out of the scope of the paper to make statements about the quality of LEW and CPC-LDAS. We observe that for all 4 target areas, the differences between LEW and GRACE are smaller than between CPC-LDAS and GRACE. This also holds true after bias correction, independently whether LEW or CPC-LDAS

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is used to compute the bias.

2 Specific comments:

- **The information on the GRACE data treatment is sparse:**
  As stated in the paper, we followed the standard procedure of GRACE data treatment, which is described very well in e.g. Wahr et al.,1998; Swenson Wahr, 2002). For that reason, we did not repeat the details, but preferred to make a proper reference to literature.

- **What is the effect of the neglect of the low degree coefficients (3570/10):**
  The answer to this question is included in our rebuttal to reviewer 4, see “Authors comment” (page S1843 question “Page 3570: l8”). We did not replace the degree 2 order zero coefficient by estimates provided by space geodetic data (this is sometimes done in literature), because this is problematic from a methodological point of view. The reason is the correlation among potential coefficients. Therefore, any change of one coefficient would automatically change other coefficients.

- **Effect of the GRACE errors (“the orbit weakness “, 3571/20):**
  An estimation of the GRACE errors is not trivial (among others because variance covariance matrices are not made available to the scientific community by the GRACE processing centers), and out of scope of this paper. Moreover, this information is not needed when a Gaussian filter is applied as we did in our study. It is necessary, however, for the design of a Wiener filter. Some remarks about Wiener filter and Gaussian filter and references to literature are made in the rebuttal to reviewer 4, see “Author comment” (look at page S1840 question “ 2. ; Ad 3,4” and page S1844 question “Page 3570, l28”).

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- **Partial contributions of the type-1 and type-2 errors:**
In the paper, we did not provide the results for type-1 and type-2 errors separately, simply because we want to limit the size of the paper (remember that when showing these results, the number of figures increases by a factor of 3!). Only a qualitative statement has been included in the paper (page 3562: l10-20). In the appendix to this rebuttal we show the type 1 and type 2 errors for the smallest target area, the Upper Zambezi, and for the largest target area, the Zambezi + Congo. The computations have been done for a Gaussian filter with 1000 km correlation length. As stated already in the paper, the amount of cancellation of these errors depends on the water storage variation signal inside and outside the target area (both amplitude and parity). For the smallest target area, the Upper Zambezi, the cancellation is the most significant: The amplitude of the annual type-1 error is 130 mm, the amplitude of the annual type-2 error is -60 mm, hence, the bias is 130-60 mm = 70 mm (see appendix, Figure 1). For the largest area, the Zambezi + Congo target area, the annual amplitude of the type-1 error is 30 mm, that of the type-2 error is -8 mm, which gives a total annual amplitude of the bias of 30-8 mm = 22 mm (see appendix, figure 2).

- **More details on the comparison of LEW and CPC-LDAS is needed:**
We included figures and tables in the revised version of the manuscript, which provides this information. See also paragraph 1 of this rebuttal.

- **Comparison of the results with Chen et al. (2006):**
Chen et al. (2006) have estimated the annual scaling factor between smoothed and non-smoothed water storage variations by fitting the sine year+half year function to the GLDAS model output for 4 basins around the world. The Gaussian filter with the range of the correlation lengths between 400 km and 2000 km has been used. The “Zambezi” river basin considered by the authors is quite different from the one we used (compare Figure 1 in Chen et al. (2006) and Figure 3 in our paper). We suggest that we can make an approximate comparison of the mean

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water storage variations averaged over the Zambezi and Upper Zambezi + Okavango basins (Z+UPZO) in our paper and “Zambezi” given in Chen et al .(2006). This makes it very difficult to directly compare their estimates with ours. Nevertheless, a some careful comparisons between the results they obtained and ours can be made:

- The regional hydrological model LEW has much better representation of the time variability and space distribution of the water storage in Southern Africa and, especially, in the Zambezi river basin as shown in (Winsemius et al., 2006a, 2006b). Therefore, we are confident that our bias estimates are more accurate.
- The amplitude of the water storage variation and bias estimate very much depend on the choice of the region (compare amplitudes of the 4 basins in our paper in Figure 5.). Chen et al. (2006) mentioned the reduction of the annual amplitudes caused by the filtering with Gaussian 800 km by about 25-40% what is in a good agreement with 21-35% we observed in our target areas (cf. Table 1.: [rel. bias %], p. 3583).
- We observe an underestimation of the amplitude of the water storage variation from GLDAS compare with LEW for the target area Z+UPZO (compare 100 mm of water storage variation from GLDAS given in Figure 7(d) by Chen et al. 2006 with about 127 mm of water storage variation from LEW given in Table 2.:[4],p. 3584 in our paper).
- At the same time the annual amplitude of the water storage variation from GRACE-corrected for the bias in our paper (about 133 mm) and scaled by amplitude factor in Chen et al. (2006) (about 137 mm) agree quite well. This can probably be explained by the compensation of the underestimated amplitude from GLDAS by the erroneous (larger) annual scaling factor, which cannot capture the time variability of the errors caused by the smoothing. This example shows that the method given by Chen et al. (2006) can be

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used as a proxy to recover the annual amplitudes of the water storage estimates from GRACE.

– The difference between the annual amplitude of the water storage variation over the Z+UPZO area from GRACE-corrected for the bias and non-smoothed LEW (in our paper) is about 133-127=6 mm. That is much smaller then the 137-100=37 mm (difference between GRACE-scaled and GLDAS) obtained by Chen et al. (2006). Moreover the difference between GRACE-scaled (from Chen et al. (2006) and non-smoothed LEW (from our paper) is only 10 mm. This can be seen as an indication for the weaker performance of the GLDAS model compared with the LEW model. This is also in agreement with what we found when using CPC-LDAS global hydrological model as alternative to LEW, see paragraph 1.

3 Technical corrections:

All of them will be corrected for.

4 References:

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3. Winsemius, H. C., Savenije, H. H. G., Gerrits, A. M. J., Zapreeva, E. A., and Klees, R. Comparison of two model approaches in the Zambezi river basin with regard to model confidence and identifiability, Hydrol. Earth Syst. Sci.,2006a, 10, 339-352

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5. Wahr, J., Molenaar, M. and Bryan, F. Time variability of the earth's gravity field: Hydrological and oceanic effects and their possible detection using GRACE J. Geophys. Res., 1998, 103, 30205-30230

APPENDIX

Figure 1. *Top panel:* type-1 error (E1), type-2 error (E2) and bias (E1+E2) for the Upper Zambezi area. The LEW model is used to compute the bias. *Bottom panel:* water storage estimates from LEW, GRACE and bias-corrected GRACE for the Upper Zambezi area (*http://www.lr.tudelft.nl/live/binaries/ 564ab600-7cb6-47b5-9ed1-57e41586a97b/img/e0_e1_e2_lew_g1000_UZ.jpg*).

Figure 2. *Top panel:* type-1 error (E1), type-2 error (E2) and bias (E1+E2) for the Zambezi+Congo area. The LEW model is used to compute the bias. *Bottom panel:* water storage estimates from LEW, GRACE and bias-corrected GRACE for the Zambezi + Congo area (*http://www.lr.tudelft.nl/live/binaries/ 564ab600-7cb6-47b5-9ed1-57e41586a97b/img/e0_e1_e2_lew_g1000_ZC.jpg*).

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 3557, 2006.