Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-269-AC3, 2016

Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Evaluating the hydrological consistency of satellite based water cycle components" *by* O. López et al.

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Received and published: 26 July 2016

Author Introduction. We thank the anonymous reviewer for their insightful comments on our manuscript. We have attempted to address these points in the responses below.

Comment 1. The study focuses on four "relatively simple" catchments. But what's so simple about these catchments? The runoff fraction is definitely not negligible (see Figure 2). The snowfall fraction in some of them is quite high (e.g., precipitation in the Aral Sea and Colorado catchments is composed of about 15% snowfall). The Niger catchment and maybe others have extensive wetlands which store and evaporate large amounts of water. Some of the catchments (e.g., the Colorado one) are also littered with reservoirs. All these factors contribute considerably to the total water storage and thus should be explicitly accounted for in such a study (as recognized by the authors

at the end of the paper on page 17).

Author response. We agree that these are not "ideal" catchments to explore our approach. Unfortunately, the requirements for a candidate basin that would yield the most useful results to the study made the selection of basins difficult: a basin that is large enough so that its mass changes can be detected by GRACE satellites, yet with a lack of complicating factors contributing to the hydrological balance (see additional response to another reviewer). Ultimately, we compromised to "relatively simple", since in comparison to many other basins, the hydrological processes in arid and semi-arid environments are somewhat better defined. In terms of water storage (either in reservoirs, wetlands or as snow), this should not be a major issue as GRACE is able to detect large changes in mass irrespective of their source. Of course, in this case the problem lies when the mass loss is not accounted for by evaporation. This was recognized in the text as one of the challenges in both the Aral Sea and Colorado River basins and remains a problem in large scale evaporation retrievals.

Comment 2. "We selected four basins as focus regions of study: the Colorado River basin in North America, Niger basin in Africa, Aral basin in Asia and the Lake Eyre basin in Australia (Figure 1)." Given the amount of hydrological data and computing resources available these days, why did you decide to focus on such a small sample of catchments?

Author response. As noted above, the major limitation was the size requirement due to the coarse resolution of GRACE data. This need, coupled with the limitation of a "relatively" simple hydrological system, limited the options for basin selection. However, even an analysis focusing on these four basins provides a good initial framework for assessing the utility of the approach. While the approach could be extended to include all candidate basins globally, our preference was to focus on a selected number that we could reasonably characterise to explore the potential. We would note that there are numerous examples in the literature of analysis of GRACE products and other data being examined over just a single basin. Future work can certainly expand the technique to other basins and climate types.

Comment 3. Why are three products considered for evaporation and only one for precipitation? The differences among products are probably even larger for precipitation than for evaporation. Other viable precipitation products include WFDEI, MSWEP, and GPCC.

Author response. The choice for a single precipitation product (as well as only one GRACE product) was intentional, as the study focused on a desire to explore the quality of a number of competing satellite evaporation products. The method was originally targeted as an evaluation tool for these large-scale retrievals. We sought to determine whether differences in evaporation, while constraining the variability in other hydrological components, could be detected by the method. The GRACE CSR product was chosen as it is the most commonly used of the three official products. In terms of precipitation, GPCP was chosen due to its global coverage, temporal extent and extensive use in the literature. However, we can certainly expand the analysis to include other precipitation products. So far, we have seen that the conclusions of the study are not altered when using the PERSIANN dataset (Hsu et al., 1997) (see preliminary results in Figure 1 below for inclusion as supplementary material).

References

Hsu, K.-l., Gao, X., Sorooshian, S. and Gupta, H. V.: Precipitation estimation from remotely sensed information using artificial neural networks, Journal of Applied Meteorology, 36(9), 1176-1190, 1997.

Comment 4. Why did you use simulated rather than observed runoff? NOAH is an uncalibrated model which means its simulated runoff contains biases.

Author response. This seems to be a misunderstanding. Neither simulated nor observed runoff were explicitly included in the evaluation of hydrological consistency. Simulated runoff from GLDAS-NOAH was plotted in Figure 2 only to review the as-

sumption of a 'relatively' simple water cycle in arid and semi-arid regions. As was noted in addressing the first comment, this was not always the case for the chosen study basins and the implications of this were described in the Discussion section. We will ensure that this point is more clearly articulated in the relevant text.

Comment 5. The study concludes that there is little consistency among the different hydrological variables in the catchments. This is really not a novel result. Previous (global-scale!) papers have arrived at similar conclusions for evaporation (e.g., Miralles et al., 2016, HESS, cited in the paper) and precipitation (e.g., Herold et al., 2015, GRL). What new lessons we can learn from this paper?

Author response. While a number of global evaporation (and precipitation) evaluation papers have recently been published (including McCabe et al. 2016), they do not seek to compare consistency with related hydrological variables, but instead focus largely on an assessment against point-scale observations and/or inter-product variability. Our approach is designed to see whether within these varying products there is one (or more) that are at least consistent with other related hydrological variables (in this case, P and dS). This is a major distinction to past work. Importantly, many of these recent evaporation assessment papers explicitly identify the problems of employing a traditional point-scale evaluation approach and the need to explore alternative assessment techniques (such as that developed here).

As such, we propose a quite different method for assessment based on the concept of hydrological consistency. As referenced in the introduction (and elsewhere in the paper), a limited number of water budget studies, ranging from individual basins (Pan et al., 2008; Sheffield et al. 2009) to global scale studies (Sahoo et al., 2011, Pan et al., 2012), have shown large errors in water budget closure: but have done so with a focus entirely on the temporal scale and invoking the use of a hydrological model. Some of these studies (Sahoo et al, 2011; Pan et al., 2012) sought to constrain the water balance by using a merged product or data assimilation approach, but did not evaluate hydrological consistency of the individual products. This is what is explored in our work. The motivation behind this study was to take a step back and determine whether a first order hydrological agreement could be achieved in these relatively simple environments. As was found, the challenge on how to do this remains, raising some important questions on both product quality and also the techniques we use to evaluate global products. We will attempt to better articulate these issues and other novel aspects.

References

McCabe, M. F., Ershadi, A., Jimenez, C., Miralles, D. G., Michel, D. and Wood, E. F.: The gEWEX landFlux project: Evaluation of model evaporation using tower-based and globally gridded forcing data, Geoscientific Model Development, 9(1), 283-305, doi:10.5194/gmd-9-283-2016, 2016. Pan, M., Wood, E. F., WÃ³jcik, R. and McCabe, M. F.: Estimation of regional terrestrial water cycle using multi-sensor remote sensing observations and data assimilation, Remote Sensing of Environment, 112(4), 1282-1294, doi:http://dx.doi.org/10.1016/j.rse.2007.02.039, 2008. Pan, M., Sahoo, A. K., Troy, T. J., Vinukollu, R. K., Sheffield, J. and Wood, E. F.: Multisource estimation of long-term terrestrial water budget for major global river basins, Journal of Climate, 25(9), 3191-3206, doi:10.1175/JCLI-D-11-00300.1, 2012. Sahoo, A. K., Pan, M., Troy, T. J., Vinukollu, R. K., Sheffield, J. and Wood, E. F.: Reconciling the global terrestrial water budget using satellite remote sensing, Remote Sensing of Environment, 115(8), 1850-1865, doi:http://dx.doi.org/10.1016/j.rse.2011.03.009, 2011. Sheffield, J., Ferguson, C. R., Troy, T. J., Wood, E. F. and McCabe, M. F.: Closing the terrestrial water budget from satellite remote sensing, Geophysical Research Letters, 36(7), doi:10.1029/2009GL037338, 2009.

Comment 6. The abstract is very poor. Only the last sentence can be considered results/discussion/conclusions. The previous sentences (with the exception of maybe the second to last sentence) are all introduction. It is not even mentioned how many catchments have been examined. Stick to one or maybe two sentences introduction.

Author response. We will review the abstract, and if necessary, iterate to present a clearer description of the work and key results.

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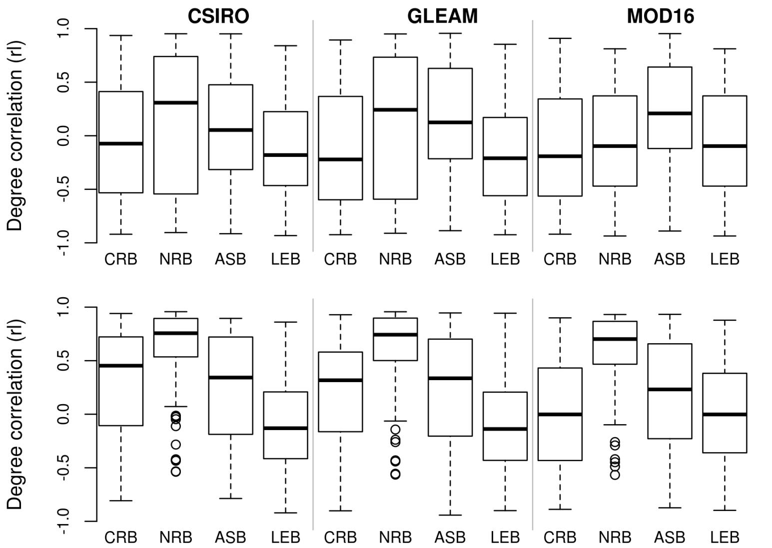

Figure S1. Top: average degree correlation statistics per study region and evaporation product. Bottom: GRACE data were shifted by two months to match the phase with P-E anomalies. The boxplots show the first, second (median) and third quartiles. Outliers, defined as data outside the 1.5 inter-quartile range (IQR) whiskers below or above the first and third quartiles are shown as circles. This figure represents a summary of the analysis using the PERSIANN product as precipitation. **The results are very similar to those in Figure 8.**

Fig. 1. Supplementary Figure 1