Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2018-38-AC3, 2018

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Quantification of Drainable Water Storage Volumes in Catchments *and* in River Networks on Global Scales using the GRACE and/or River Runoff" *by* Johannes Riegger

J. Riegger

riegger@iws.uni-stuttgart.de

Received and published: 20 September 2018

< I carefully read the manuscript and comments from M. Bierkens and A. Gunter. They both raise important questions on the actual applicability of the proposed method. I found a few points in the manuscript that need more deepening. For that reason, I suggest that the paper could be considered for publication after review. Please find my comments below.

-> I would like to thank the referee very much for his helpful comments especially with respect to very important references.

Below you find my respond to his comments in detail.

< 1. As pointed out by M. Bierkens, the abstract should be significantly shortened. I also recommend that the author avoid the use of concepts or terms in the abstract that are not properly explained. For example, it is not clear in the abstract alone, what the runoff- storage relationship (P.1, L. 17) is. It is also not clear what phase shift (P.1, L. 20) is being referred to. I also suggest that the Introduction should be rewritten, focusing on a clear statement of the issue the author is trying to address, a comprehensive literature review on what has been done before, and a simple description of how the problem will be tackled. Details on the technique should be reserved for the following sections.

-> The abstract will be revised according to the recommendations.

< 2. My feeling is that there is a general lack of recent and appropriate literature in the field. For example, in the abstract, the author states: "A possible reason for the observed phase shift might be found in the river network storage, which so far has not been addressed separately in the R-S relationships." Also, in the introduction: "Very little attention is given so far to the storage volume of renewable water resources participating 5 in the dynamic water cycle driven by precipitation P, actual evapotranspiration ETa and river runoff R." Many modeling studies have been performed towards a better understanding of surface water storage (SWS) and dynamics. The impact of SWS on the terrestrial water storage variability is evaluated globally in Getirana et al. (2017a). In that study, the authors use Noah-MP, accounting for a detailed computation of the water and energy balances, including groundwater recharge, and an advanced river routing scheme, accounting for river and floodplain dynamics using the local inertia formulation.

-> I am very grateful for the literature links to recent investigations. Obviously my literature alarm did not work very well.

-> It is very interesting to see that complementary work has been done in parallel with very similar results and conclusions using totally different approaches namely high performance distributed models on the one hand and a simple conceptual, top down model on the other hand.

-> The publications listed are very helpful to position the Cascaded approach presented here in the context of river routing investigations and Surface Water Storage. Especially the water budget investigations for 14 different LSMs (Getirana et al. (2014)) are very helpful as they allow to sort in the results of the Cascaded Approach into those of the LSMs (Getirana et al. (2014), Fig. 14). With a Nash-Sutcliffe (NS) coefficient of 0.74 and a correlation (c) of 0.90 (with respect to the mean seasonal cycle) compared to an NS of 0.58 and a c of 0.84 for the best LSM the Cascade Storage approach outperforms the LSMs. Yet, this is mainly seen as the result of the quality of recharge data taken from the water balance using GRACE and river runoff as the use of moisture flux divergence for this purpose leads to much worse results. This limits the approach to a lumped description of basins on global scales due to the resolution limits of GRACE. Yet, with improvements in the spatial resolution of gravity satellites the number of catchments which can be described by this approach will tremendously increase (P24 L26-28).

-> However, the Cascaded Storage approach was never intended to compete with the LSMs providing spatial distributions of water budget variables, but instead to enable a purely data driven determination (and forecast) of river discharge from GRACE as well as absolute, drainable storage volumes for catchments and river networks in a simple, lumped approach directly from satellite data (i.e. in general from GRACE and additional remote sensing data). No detailed information on vegetation, soil etc., complex flow processes nor detailed hydraulic information for river routing like roughness, cross section, gradient or backwater effects is needed. Of course, the simplicity and accuracy of this approach is payed by the lack of the spatial information within the catchment. However, spatial distributions within catchments are difficult to be evaluated locally anyway.

< In page 5, the author states: “Even though global hydrological models comprise a number of storages like soil, surface water, groundwater etc. some of them show considerable phase shifts between the calculated and measured runoff and an underestimation of the signal amplitudes (Güntner et al., 2007, Chen et al., 2007, Schmidt et al., 2008, Werth et al., 2009, Werth et al., 2010).” There are very well known reasons for these issues to happen, and the references used to support that statement are somehow outdated (8-11 years old). Recent developments on hydrological modeling, in particular, river routing schemes have successfully dealt with phase shifts and amplitude ratios in both Amazon and globally (Getirana et al., 2014, 2017b; Luo et al., 2017; Paiva et al., 2013; Yamazaki et al., 2011, 2012, 2014; Siqueira et al., 2018).

-> I am very grateful for these references !

-> It is interesting to see that totally different approaches, a sophisticated bottom up and a simple conceptual top-down approach lead to similar results. The average river network storage contribution of 50% calculated here is equal to the 50% by Papa et al. (2013) and close to the 41% by Getirana et al. (2017a).

-> Getirana et al. (2017a) also confirm that the large Surface Water Storage SWS in the Amazon basin increases the simulated TWS toward a better match with GRACE. It also confirms that adding SWS improves the phase agreement with GRACE. They come to the conclusion that SWS (called river network storage here) is a major component of Total Water Storage TWS and they emphasize the importance of integrating adequate river routing schemes and the consideration of SWS when composing or decomposing TWS.

-> This consistency with the Cascaded storage approach institutes new possibilities for investigations on the hydraulic time constant of river networks and on the relationship between flood areas, volumes, river runoff and calculated river network mass in general. This possibly provides deeper insights into river hydraulics i.e. routing schemes and the mass-, area-, and level- relationships of flooded areas (P24 L23-25).

< I strongly suggest that the author better contextualize the study pointing out what the contribution is, considering what has already been done.

-> The recommended references certainly help to further sharpen the intention of the Cascaded storage approach and its benefits in the context of parallel investigations. All aspects that turned up with these references will be integrated into the revise publication.

< 3. It is common sense to use the term runoff for the surface or total runoff generated by a land surface model, usually given by mm/d or mm/s, which is the rate of water flowing to the river network, while streamflow is used for the river discharge, usually in m3/s. The former is either simulated by LSMs or estimated from the spatial distribution of the latter, which can be observed at gauge stations. Sometimes, in the text, I get confused with what the author is referring to. For example, in the abstract, the author refers to "observed runoff", while it should be "observed streamflow". I suggest that the author make a proper use of these terms and clarify when runoff and streamflow are used.

-> The expression "Runoff R" (here in mm/month) is used here as general expression for the drainage density i.e. the drainage rate per area for the respective catchment as it is needed for a comparison with mass density (Eq2) and for the mass balance equation Eq 4. "River Discharge" denoted as Q (Eq1) is used for the streamflow (i.e. in m3/s) measured at gauging stations. "River runoff" is thus given by river discharge divided by the catchment area.

-> Runoff is not generally used as a synonym for overland flow or flow in the river network, yet is specified by an index C for the catchment and R for the river network system. Catchment runoff in this paper conceptionally comprises all contributions to catchment drainage whether this is overland flow or groundwater flow, as due to the climatic and hydraulic conditions of the full Amazon basin upstream Obidos these flows cannot be separated in the measurements.

-> This would be different for boreal or seasonally dry regions (P16 L22-24) where contributions of overland and groundwater flow can be distinguished by their dynamic response. Disregarding the phase shift catchment and river runoff are of the same mean values.

-> The manuscript will be checked for consistency and revised for a clear description.

Minor comments

< 1. In the paper, the application of the technique is limited to the Amazon, and I think that using the term "global scales" in the title is a bit of an overstatement. I suggest the removal of that term from the title.

-> The expression "Global scales" in the title is used to indicate that the approach is limited to catchment areas well above 200000 km2 due to the spatial resolution of GRACE and to the structure length of moisture flux divergence.

-> The approach is neither limited to the Amazon basin nor to fully humid catchments. This has already been shown by Riegger & Tourian 2014 for boreal regions, for which the uncoupled storage was quantified by means of remote sensing (MODIS snow coverage). As already mentioned (P16 L25-30) the challenge for seasonally dry or monsoonal catchments, where soil moisture plays a major role in the annual cycle, is to quantify the uncoupled storage compartments by other means of remote sensing like satellite soil moisture, water level altimetry etc.

-> Thus, even though the application of the scheme is evaluated on the Amazon basin for a simplified start (no consideration of time dependent uncoupled storage), it is not limited to this specific catchment. The approach – as formulated here - can be applied to all fully humid tropical catchments.

-> Applications with time dependent uncoupled storage are more complex and need the integration of remote sensing data as shown in Riegger and Tourian, (2014) for boreal catchments (P5 L7). For this case additional lumped information (snow coverage from MODIS) can be used for a separation of coupled and uncoupled snow / ice storages leading to a reasonable accuracy of total mass estimations (NS=0.37 and correlation=0.69 for Lena w.r.t. mean seasonal cycle)), which is in the range of LSM performances. The re-formulation with the Cascaded storage approach is under work. Further developments and investigations for monsoonal catchments as mentioned in the outlook are proposed for funding.

-> Of course the quantification of uncoupled storage compartments by remote sensing is a real challenge at the moment, yet the perspectives to apply this method on a global coverage are quite promising.

< 2. “Cascaded” will be defined

< 3. w.r.t. means with respect to

< 4. “semi / arid” – Do you mean, semi-arid, or semi-arid and arid? -> means semi-arid and arid

< 5. “Surface water, the river network and temporarily inundated areas” – what differentiates surface water from river network and temporarily inundated areas? It seems to me that the latter two are part of the former.

-> Surface water in this context means the storage related to overland flow not including the river network and inundated areas. Isolated surface water bodies are not considered here. Inundated areas which are not isolated are assigned to the river network system. So to be clear, overland flow storages should be mentioned here instead of possibly misleading surface storages.

-> The text will be checked and revised for a clear description.

< 6. GIEMS means “Global Inundation Extent from Multi-Satellites”

< 7. “Observations of inundated areas in river networks provided by the GIEMS project (Prigent et al, 2007, Paiva et al., 2013) indicate a considerable contribution of river

network storage for the Amazon Catchment” – Getirana et al. (2012) provide the actual water storages in rivers and floodplains in the Amazon basin.

-> Thanks ! This was a very useful hint.

< 8. Paiva et al. (2013) is not a GIEMS reference

-> Sorry, that might have been mixed up in the text. Paiva et al., (2013) describe a quite sophisticated modeling approach for the Amazon basin including the hydrodynamic modeling of backwater effects. It is interesting that they come to an average surface water contribution (corresponding to river network storage here) of 56%, which is close to the value determined here.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2018-38, 2018.