Discussion of “Wetting and drying trends in the Land-Atmosphere Reservoir of large basins around the world” (manuscript number: hess-2023-172) —Reviewer 2

Juan F. Salazar[1], Ruben D. Molina[1], Jorge I. Zuluaga[2], and Jesus D. Gomez-Velez[3]

[1]GIGA, Escuela Ambiental, Facultad de Ingeniería, Universidad de Antioquia, Calle 70 No. 52-21, Medellín, Colombia.
[2]SEAP/FACom, Instituto de Física, Facultad de Ciencias Exactas y Naturales, Universidad de Antioquia, Calle 70 No. 52-21, Medellín, Colombia.
[3]Environmental Sciences Division & Climate Change Science Institute, Oak Ridge National Laboratory, 1 Bethel Valley Road, Oak Ridge, TN, 37830, USA

Correspondence: Juan F. Salazar (juan.salazar@udea.edu.co)

This document presents comments by Reviewer 2 (blue font) and our responses (black font).

Comment R2-1

The authors introduce the concept of the Land-Atmosphere Reservoir (LAR), which explicitly considers land-atmosphere interactions such as moisture recycling when computing a basin water budget. The LAR is in contrast to traditional approaches that assume atmospheric processes as external effects. Based on the LAR concept, the authors study long-term storage trends of the six largest river basins using river discharge data from HYBAM and GRDC and meteorological data from ERA5 reanalysis, and find a contrasting latitudinal trend, with tropical basins getting wetter and temperate basins getting drier. The study is interesting, and the topic is suitable for publication in the Hydrology and Earth System Sciences. However, I have some comments that should be addressed before publication.

Thank you. We greatly appreciate your constructive comments and suggestions. Please find our responses below and note that they include new results that shed light on the mechanisms behind the trends and their latitudinal contrast.

Comment R2-2

Is there any reason why the authors apply the LAR only to the largest basins? Given that GRDC and ERA5 data are available globally, a similar analysis could be conducted for other basins (with different sizes and climatic conditions) with relatively little effort.

In principle, the LAR dynamics can be studied at any scale (i.e., for any basin size). No theoretical limitation exists, including that Local Moisture Recycling (LMR) can occur at any basin.

However, there are theoretical and practical reasons for focusing on the largest basins. Whereas the LAR is crucial for understanding large basins, it might be unnecessary for small basins where external factors (e.g., large-scale wind patterns) largely impose precipitation. If so, LMR is possibly negligible, and therefore, the traditional LR framework is a parsimonious representation that works well without the complications of including the atmosphere in the control volume for the water budget computations.

That is why we focused on the largest basins on Earth, where LMR involves water amounts comparable in magnitude to other fluxes in the basin's water budget. Table 1 in the submitted manuscript shows that, for the studied basins, LMR represents between 23% and 47% of precipitation, which is comparable to evapotranspiration and river discharge in the same basins.

In contrast, we do not expect that LMR represents such a significant fraction of precipitation in small basins. This means that using the LAR for studying small basins should not produce significantly different results than the traditional LR. Hence, the LAR is crucial for studying large basins but not strictly necessary for small ones. What the limiting scale is is an intriguing question for future research.

Finally, studying small basins through the LAR lens is limited by the availability of atmospheric convergence estimates at the same scale. One could obtain these estimates with high-resolution atmospheric models, but they are not widely available, such as reanalysis data for large basins.

The revised manuscript will include this discussion about the applicability of the LAR framework at different scales. In future studies, we plan to use the LAR framework for more basins and look forward to other scientists doing that, too.

Comment R2-3

The authors applied the LAR concept to show the long-term trends in the large basins (e.g. Figs. 3 and 4). Is there something we can learn here that we didn't know from previous studies using the traditional approaches? I would like to see more detailed analysis and discussion in this aspect.

One of our study's key ideas is that applying the LAR framework to study large basins can yield substantially different results than the traditional LR approach. In other words, the LAR allows us to learn lessons that would not be possible by using the LR, e.g., by modeling large basins from the traditional perspective of catchment hydrology. For instance, the trends in water storage for the LAR are related to but not equivalent to trends in TWS. This allows results such as the one for the Amazon basin, where the LAR trend exceeds the trends in TWS obtained from GRACE data by around one order of magnitude.

The main reason for these differences between the LAR and LR approaches is that the latter does not include LMR as an internal mechanism of a complex basin system, which is critical in some basins like the Amazon where around 30% of precipitation is internally (i.e., within the LAR) recycled.

Our following response includes new results comparing TWS anomalies from GRACE and our estimates of water storage change in the LAR. This comparison shed light on the relationship between the LAR and LR. They are related but are not the same, especially in large basins where LMR plays a prominent role. Please continue this discussion in our subsequent response.

Comment R2-4

The paper has no in-depth explanation about physical mechanisms behind the revealed long-term trends of the basins. For instance, why do we see the contrasting wetting and drying trends between the tropical and temperate basins? Why has the trend in the Congo basin changed since 2000?

We hypothesize that the latitudinal contrast in the trends is caused mainly by land-atmosphere exchanges and atmospheric processes currently affected by climate change. Compared to high-latitudes, the low-latitude atmosphere is thicker and wetter, and its warming due to climate change increases its capacity to hold water. This is consistent with an increased capacity of the low-latitude LAR to store water.

Before continuing, please note that we are using “low-latitude” and “high-latitude” basins instead of “tropical” and “temperate” basins, following a good suggestion by Reviewer 1.

High-latitude basins are warming, too, due to climate change. However, in such basins, the increased capacity of the atmosphere to hold water does not compensate for surface water losses due to snow and ice melting, leading to glaciers retreat and permafrost thawing. We hypothesize that high-latitude basins are losing more water due to these surface processes than they can gain due to atmospheric warming.

Low-latitude glaciers are also retreating —they tend to disappear—, but they are concentrated in high-altitude mountains, and their size is too small to govern the storage dynamics in large basins like the Amazon, Congo, and Parana. In contrast, snow and ice dynamics are much more significant in high-latitude basins.

Motivated by your comment (and a similar Reviewer 1’s comment), we will include the following two figures into the revised manuscript. They show, for each of the studied basins, a comparison between $d(S_L + S_A)/dt$ based on our Equation (2) and dS_L/dt estimated from two different GRACE products. These new figures show three ideas we want to highlight. First, there is a high correlation between the LAR storage change estimated with our Equation (2) and the LR storage change obtained from GRACE. Although the LAR and LR storages are not the same, they are related, and therefore, this correlation between time series obtained from substantially different sources helps validate our results.

Second, there are two types of basins, as illustrated in Figure 1. In a basin like the Amazon, storage variations in the LAR are wider in amplitude than the corresponding variations in the LR. In contrast, in the Ob basin, LAR storage variations largely coincide with LR storage variations. Our interpretation is that, in the first type of basins, land-atmosphere exchanges and atmospheric processes play a more prominent role in the storage dynamics than in the second type, where TWS largely controls these dynamics.

Third, low-latitude basins pertain to the first type, whereas high-latitude basins are closer to the second type. This lends additional support to our hypothesis about the latitudinal contrast in the trends because, from this perspective, low-latitude basins seem more sensitive to atmospheric changes (e.g., warming due to climate change) than high-latitude basins that are more sensitive to changes in terrestrial water (e.g., snow and ice loss).

So far, we have not found a sound hypothesis for the trend change in the Congo River basin. The data shows such a change, but the explanation needs a more specific study of this basin, which might motivate future research.

The revised manuscript will include these new results and discussion.

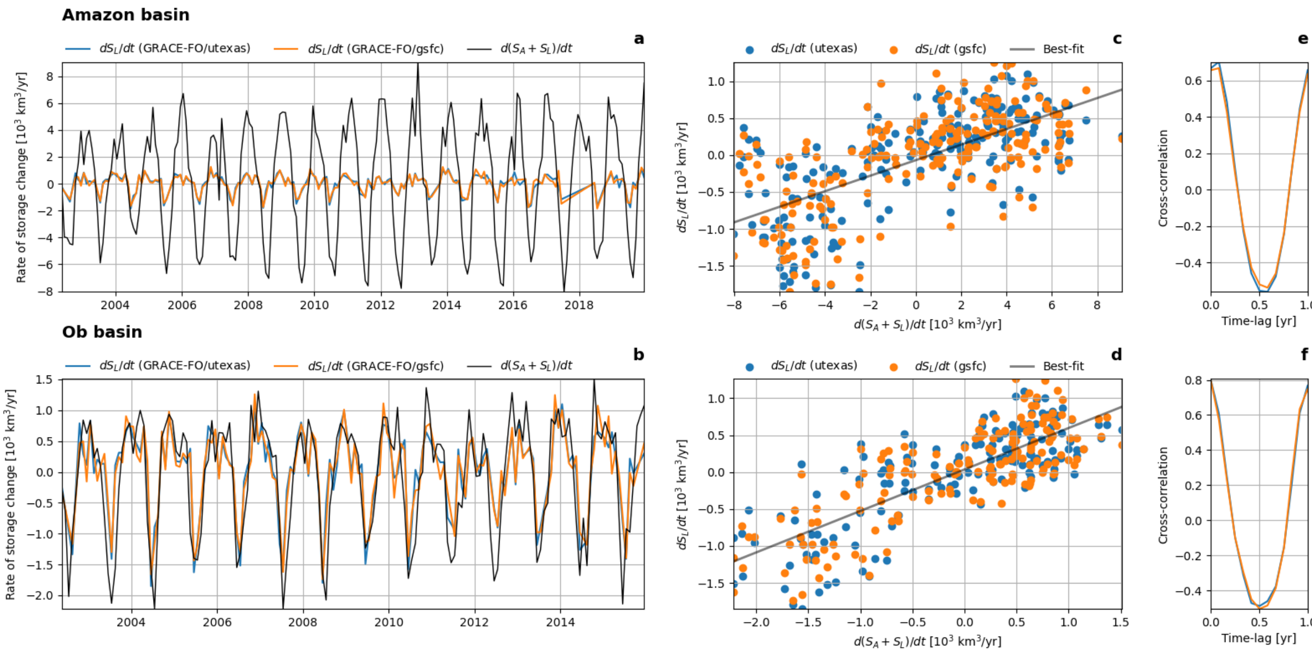

Figure 1. Comparison between the storage dynamics in the LAR and LR. **a,b** Rate of storage change in the LAR ($\mathrm{d}(S_A + S_L)/\mathrm{d}t$) from Equation (2), and the corresponding estimates for the LR ($\mathrm{d}S_L/\mathrm{d}t$) based on two different GRACE products: GRACE University of Texas and GRACE GSFC, for the Amazon and Ob basins. **c,d** Scatter plot, and **e,f** cross-correlation for different time lags between the LAR and LR time series.

Comment R2-5

Just as a minor suggestion, Fig. A9 to 14 and Fig. A15 to 20 can be combined into a figure, respectively, to avoid too many figures.

Thank you, the revised manuscript will combine these figures as suggested.

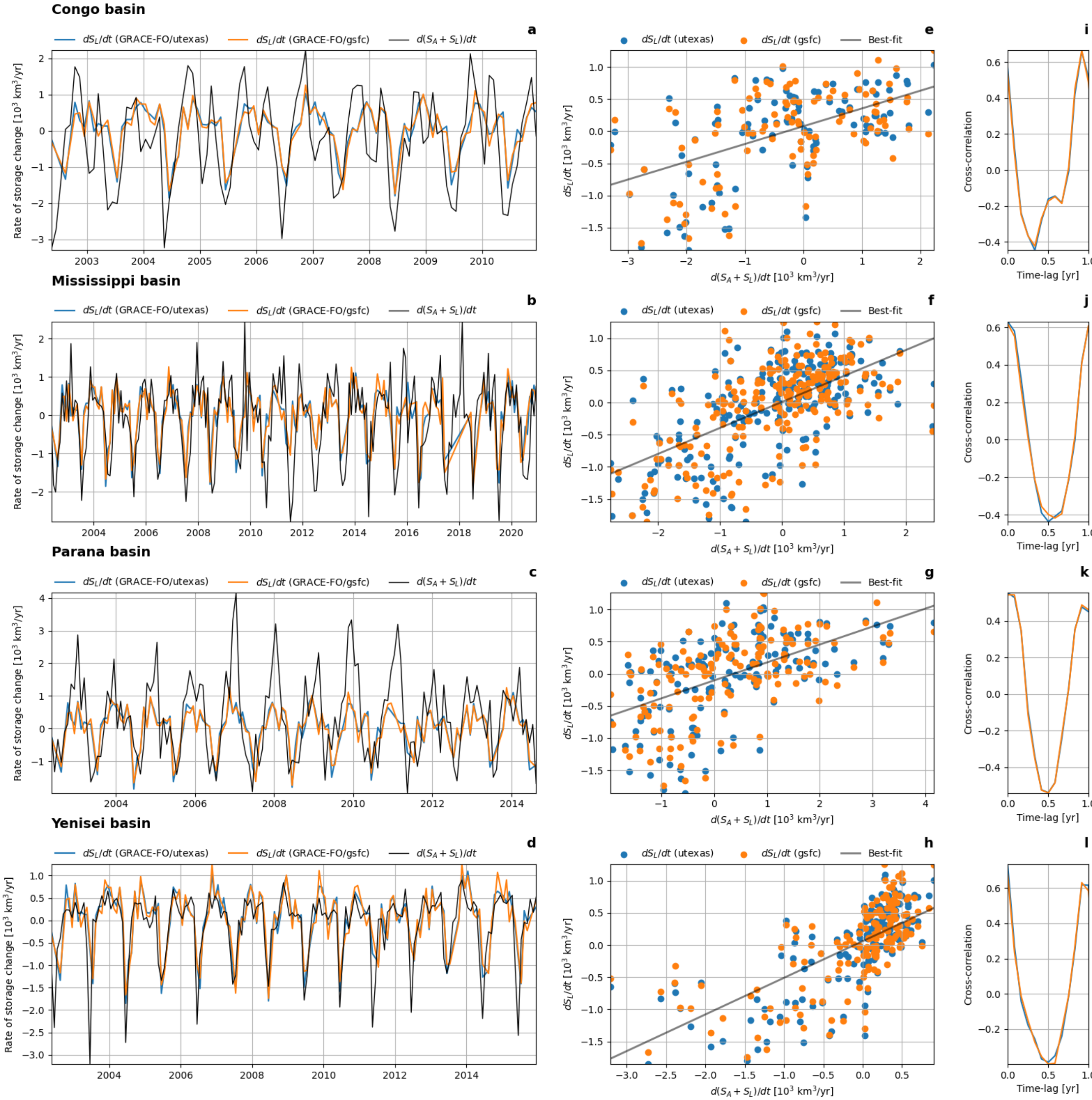

Figure 2. Same as Fig. 1, but for the Parana, Congo, Mississippi, and Yenisei basins.