Dear Vagner,

Thank you very much for your valuable comments. In this first rebuttal letter, we will only address the more significant concerns and changes to the study. Please find them below in red.

Minor text changes, figures, or language-related comments will not all be answered individually here, but we will consider them in the revised version of the manuscript.

With kind regards,

Eva Boergens (on behalf of the authors)

The study "Interannual Variations of Terrestrial Water Storage in the East African Rift Region" addresses an interesting topic and provides some valuable insights. However, several issues need to be addressed before the manuscript can be considered for publication. I recommend major revisions based on the following main points and some other minor comments presented below.

Main points:

1. The authors state that "human intervention in the form of dam management at Lake Victoria substantially contributes to the TWS variability" (lines 15-16); however, they didn't provide a clear estimation of the magnitude of this contribution. It would be interesting to see the relative contribution of natural variability and human interventions to the observed TWS fluctuations.

Thank you very much for this comment. Assessing the human versus natural contributions from the available observations alone is difficult due to the integrative nature of the gravity observation in particular, which hardly allows for separating different impacts. Instead, hydrological model simulation results could be used to compare simulations with and without human intervention. However, hydrological models explicitly adapted to the study region would be needed for such an investigation, which is unavailable to us. Following your comments and suggestions from the other reviewers, we will focus more strongly on the observed dynamics in the revised version of the manuscript and reduce the focus on their interpretation regarding the anthropogenic influence.

2. The study proposes a clustering approach to identify the East African Rift region as having similar interannual TWS dynamics. However, the justification for focusing on this specific region could be further improved by providing a stronger rationale for selecting this study area. The manuscript could highlight the East African Rift region's unique hydrological characteristics, ecological significance, or socio-economic importance.

Africa is the only continent with a net positive TWS trend over the last 22 years. We applied the cluster analysis to better identify the patterns of TWS variations at the sub-continental scale. TWS variations in Africa, in general, are not well covered in the GRACE-related literature so far. The observation that the region around Lake Victoria stands out with the strongest positive linear trend within Africa is causing our interest and provoking further investigations. Partly, this study also continues the work of Kvas et al. (2023) (to which some of the authors of this manuscript contributed), where long-term TWS trends with a higher spatial resolution were investigated, featuring the Lake Victoria region as one prominent example. In the study by Kvas et al., we can attribute the long-term trend nearly entirely to the SWS change of the lake.

We will make our reasoning clearer in the revised manuscript and add further evidence for the particular relevance of the study area for both wildlife and humans, e.g., the region's lakes have been named one of the Global 200 eco-regions for conservation by the World Wide Fund for Nature (WWF), emphasising their importance for hydrology and ecosystems (Olson and Dinerstein, 2002). The shores of Lake Victoria are densely populated (one of the world's most populated areas, according to Gridded Population of the World, GPWv4.11). The population heavily relies on the water of lakes for domestic and industrial purposes (Juma et al., 2014).

A Kvas, E Boergens, H Dobslaw, A Eicker, T Mayer-Guerr, A Güntner, Evaluating long-term water storage trends in small catchments and aquifers from a joint inversion of 20 years of GRACE/GRACE-FO mission data, *Geophysical Journal International*, Volume 236, Issue 2, February 2024, Pages 1002–1012, https://doi.org/10.1093/gji/ggad468

Olson, David M., and Eric Dinerstein. "The Global 200: Priority Ecoregions for Global Conservation." Annals of the Missouri Botanical Garden, vol. 89, no. 2, 2002, pp. 199–224. JSTOR, https://doi.org/10.2307/3298564. Accessed 17 June 2024.

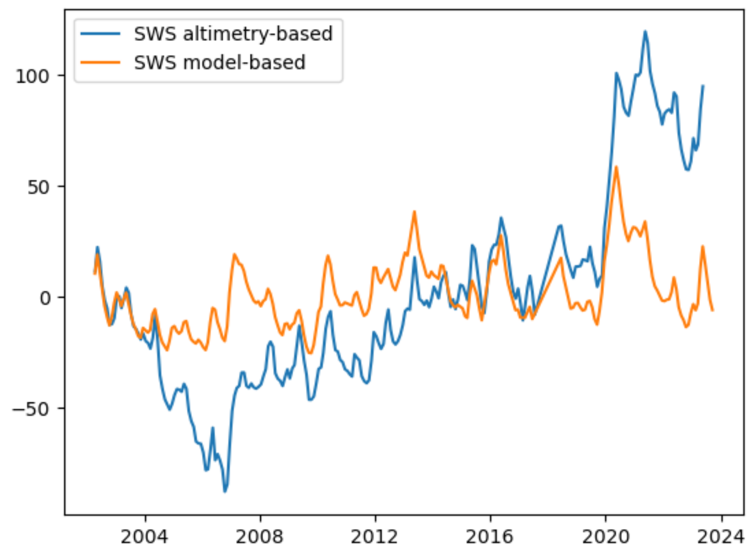
Center for International Earth Science Information Network - CIESIN - Columbia University. 2018. Gridded Population of the World, Version 4.11 (GPWv4): Population Count, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4JW8BX5. Accessed 17 06 2024

Juma, D.W., Wang, H. & Li, F. Impacts of population growth and economic development on water quality of a lake: case study of Lake Victoria Kenya water. Environ Sci Pollut Res 21, 5737–5746 (2014). https://doi.org/10.1007/s11356-014-2524-5

3. Although the study compares TWS variations with precipitation, evapotranspiration, and surface water storage in the major lakes, the analysis of the underlying drivers remains somewhat superficial. The study could provide more information about the potential mechanisms that link these factors to TWS variability in the region (e.g., land use/land cover changes, soil moisture dynamics, groundwater recharge, and human water abstractions). A more comprehensive discussion of these drivers would beef up the interpretations and conclusions of the study.

Thank you for this valuable suggestion, which aligns with the other reviewers' comments. A full analysis of the drivers of TWS variability in the region would go beyond the scope of this paper as it would need to involve comprehensive hydrological modelling, e.g., assessing the effects of land use/land cover changes. Also, in this study, we focus on geodetic observations to analyse the water storage dynamics in the region. This focus will be made more explicit in the revised version of the manuscript. Nevertheless, to investigate the drivers and contributions of the TWS changes in more detail, we performed further analyses of soil moisture and groundwater storage dynamics in relation to TWS variability and will include further results in the revised manuscript.

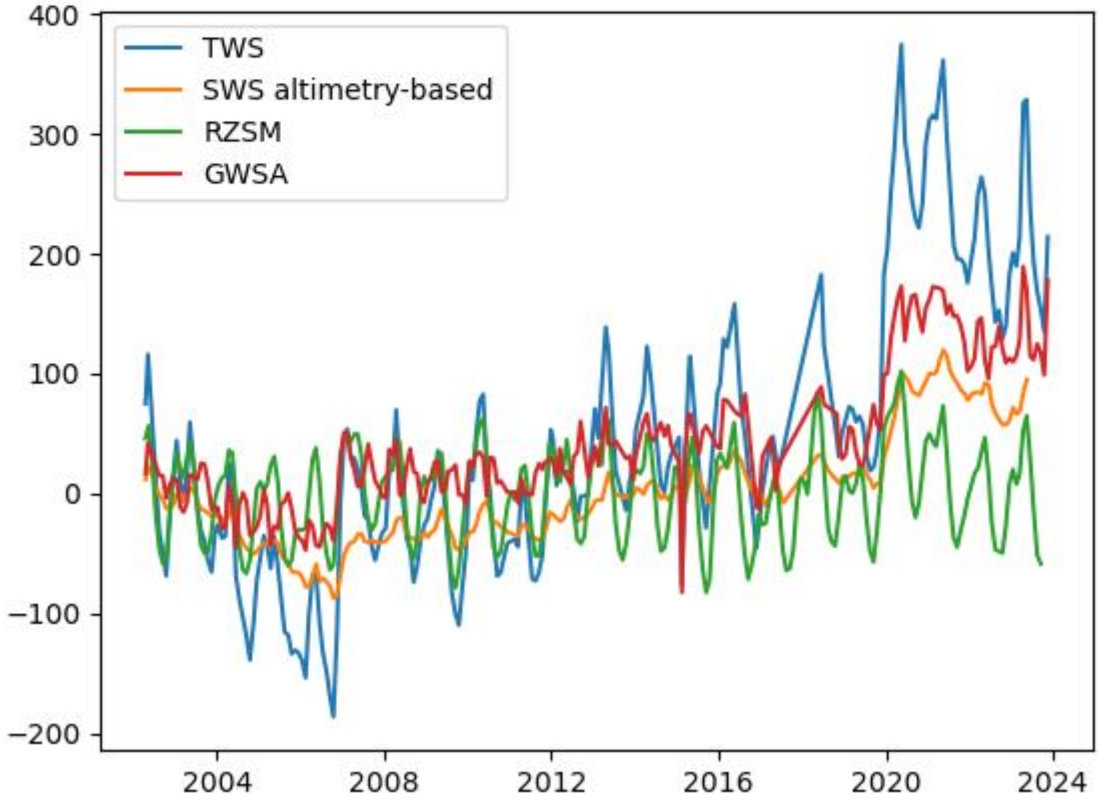
The authors of this manuscript have been part of the international consortium of the "Global Gravity-based Groundwater Product" (G3P) project funded by the EU as a Horizon 2020 project (https://www.g3p.eu/), joining several leading experts in Europe for satellite-based remote sensing of soil moisture (W. Dorigo, TU Wien), glaciers (M. Zemp, Uni Zurich), snow (K. Luojus, FMI) and mass changes with GRACE (A. Güntner, F. Flechtner, GFZ, T. Mayer-Gürr, TU Graz, A. Jäggi, Uni Bern). G3P provides groundwater storage changes as the difference between TWS and surface water storage (SWS), root zone soil moisture (RZSM), snow, and ice. The latest data set version, including all individual storage compartments, is available until 09/2023 (Güntner et al., 2024. While RZSM is satellite-based, the SWS variations are based on simulation results of the hydrological model LISFLOOD (Van der Knijff et al., 2008). However, LISFLOOD simulations of surface water storage changes are considered unreliable in the study region (cf. Prudhomme et al., 2024). In particular, despite similar dynamics and shorter time scales, the modelled SWS does not show the distinct and strong interannual variability we see in the altimetry-derived SWS of the study (see the following figure).



Thus, we computed groundwater storage variations for the present study based on our altimetry-based SWS results as GWS = TWS - RZSM - SWS(altimetry). Snow and ice can be neglected in the study region.

Side note: Our altimetry-based SWS does not include river storage variations. Based on the model's different SWS components of rivers, lakes and reservoirs, we estimate that river SWS explains roughly 10% of the seasonal SWS variations in the study area and does not show large interannual trends.

The following figure shows the area-average time series of TWS, SWS, RZSM, and GWS for the study area.



These additional data sets will allow us to discuss more on the contributions to the observed TWS signals.

Güntner, Andreas; Sharifi, Ehsan; Haas, Julian; Boergens, Eva; Dahle, Christoph; Dobslaw, Henryk; Dorigo, Wouter; Dussailant, Inés; Flechtner, Frank; Jäggi, Adrian; Kosmale, Miriam; Luojus, Kari; Mayer-Gürr, Torsten; Meyer, Ulrich; Preimesberger, Wolfgang; Ruz Vargas, Claudia; Zemp, Michael (2024): Global Gravity-based Groundwater Product (G3P). V. 1.12. GFZ Data Services. https://doi.org/10.5880/g3p.2024.001

Van Der Knijff, J. M., Younis, J., & De Roo, A. P. J. (2008). LISFLOOD: a GIS-based distributed model for river basin scale water balance and flood simulation. International Journal of Geographical Information Science, 24(2), 189–212. https://doi.org/10.1080/13658810802549154

Prudhomme, Christel, et al. "Global hydrological reanalyses: The value of river discharge information for world-wide downstream applications–The example of the Global Flood Awareness System GloFAS." Meteorological Applications 31.2 (2024): e2192.

4. The study cites some relevant literature; however, it could improve by discussing how the proposed study's findings compare to or advance previous research on TWS variability in the East African Rift region. The paper would benefit from a more thorough synthesis of the existing knowledge and a clearer articulation of this study's novel contributions.

We will add a more detailed discussion of earlier studies to the introduction and discussion part of the manuscript.

5. The study lacks a thorough assessment of the uncertainties associated with the GRACE/GRACE-FO data, the precipitation and evapotranspiration datasets, and the surface water storage estimates. It would be interesting to see a more detailed description of the potential sources of error and their implications for the results. Also, the authors could elaborate more on the limitations, such as the coarse spatial resolution of GRACE data and the lack of ground-based validation data. These limitations could be explicitly acknowledged and discussed.

We agree with the reviewer that we should add more uncertainty discussion to the manuscript. The other reviewers have also raised a similar concern. We will add more details on the data uncertainties and discuss their implications.

Unfortunately, we only have reliable uncertainties for the GRACE data set. Boergens et al. (2020, 2022) developed a covariance model for TWS data to assess the uncertainties of this study's used TWS data set. From these, the uncertainties of the STL-derived time series components can be derived via variance propagation.

Although the altimetric water level time series come with an error, these are only formal errors from the Kalman filter estimation. They can only be used for an internal comparison between different time series but not as a measure of uncertainty of the water level observations. In the manuscript, we will discuss the differences between estimates based on time-variable lake area and constant lake area for the uncertainty of the derived surface water storage.

The precipitation and evaporation data sets are provided without uncertainty assessments.

Further, we will add a more thorough discussion of the different data sets' limitations in terms of spatial and temporal resolution.

Boergens, Eva, et al. "Modelling spatial covariances for terrestrial water storage variations verified with synthetic GRACE-FO data." GEM-International Journal on Geomathematics 11.1 (2020): 24.

Boergens, Eva, et al. "Uncertainties of GRACE-Based Terrestrial Water Storage Anomalies for Arbitrary Averaging Regions." Journal of Geophysical Research: Solid Earth 127.2 (2022): e2021JB022081.

6. The current conclusion section is somewhat vague and does not fully address the broader implications of the findings for water resources management, ecosystem conservation, or climate change adaptation in the region (conditioned to the rationale for selecting the study area as per comment 2). The authors could elaborate on the potential applications of the study's findings.

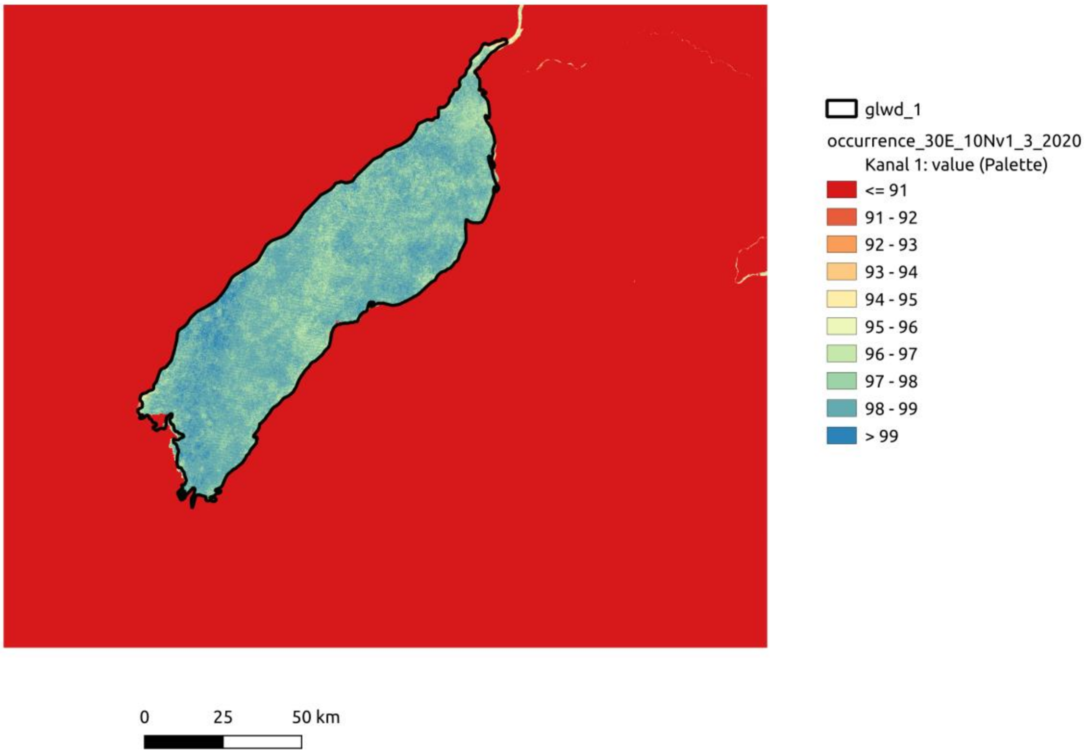
After the manuscript's revision, considering the reviewers' comments, we will thoroughly revise the conclusion section.

Minor comments:

7. Between lines 35-40, where it is "Niger Basin in West Africa," it should be "Volta Basin in West Africa" in the context of the sentence.

8. Lines 134-137: The description of the water occurrence map processing is unclear. Please provide more details on how the 95% occurrence threshold was determined and how it affects the estimation of lake surface areas.

By visually inspecting the lake's water occurrence maps and polygon outlines, we realised that even in the middle of the lake, pixels show a water occurrence of less than 100% but above 95%. See the following figure for Lake Albert. By ignoring this effect, the surface area would be underestimated.



Also, Pekel et al. (2016) documented that their water detection algorithm misses up to 5% of water pixels. That is due to partial cloud cover during the lake remote sensing observations, a particular problem in regions with regular cloud cover (such as the study region). The 95% threshold was found via a histogram of the water occurrences of pixels located clearly inside Lake Victoria (margin of 5km inside the polygon outline). In the manuscript, we will clarify the water surface processing.

Pekel, Jean-François, et al. "High-resolution mapping of global surface water and its long-term changes." Nature 540.7633 (2016): 418-422.

9. Lines 139-143: Please discuss the limitations of the surface water storage analysis based on a simplified relationship between lake level and area changes based on empirical cumulative distribution functions (ECDF). What could be the potential uncertainties it introduces in the storage estimates? For example, the monotonic and continuous relationship between lake level and area might not always be the case in reality. Lakes with complex bathymetry or irregular shorelines may exhibit non-monotonic or discontinuous relationships between level and area. However, the ECDF approach can handle outliers or anomalies in the input data more robustly than a linear regression used by Ferreira et al. (2018).

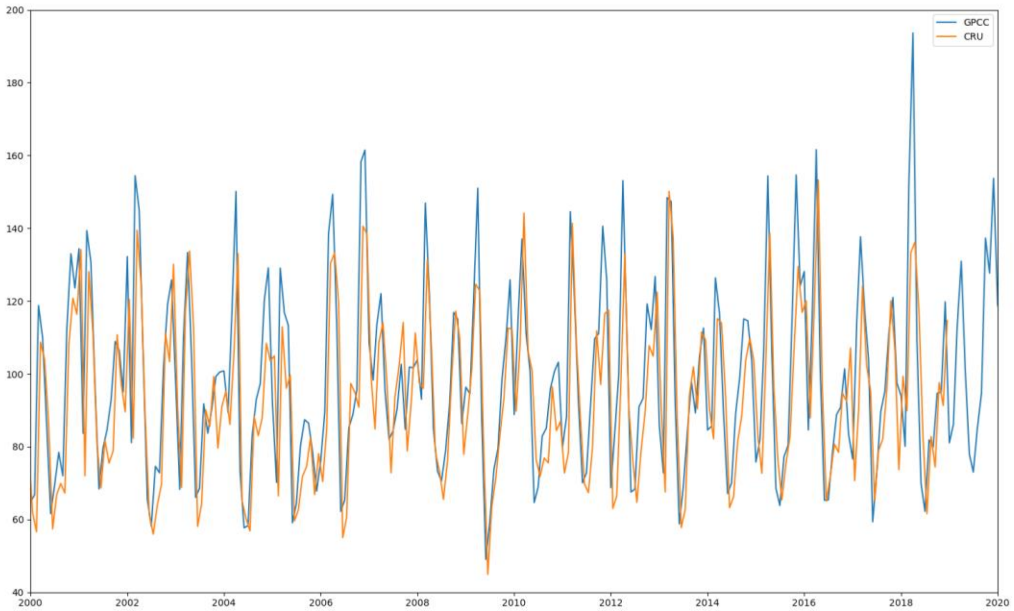
Following this comment and comments in a similar direction raised by the other two reviewers, we will add more discussion about the ECDF approach to the manuscript.

The differences in SWS for using time variable surface area or constant area are very small for the large lakes. Non-monotonic relationships between area and water level or relationships with different behaviours for rising or sinking water levels are usually only to be expected around lakes with extensive wetlands. Unfortunately, we cannot further investigate the assumption of a monotonic and continuous relationship between area and water level as we would need time-dependent area data for the lakes. However, the computation of such time series is not feasible as the mosaicking of the remote sensing scenes necessary for such big lakes is very computationally expensive. At the same time, the area change is very small compared to the total lake size.

10. Lines 240-247: The discussion of the differences between the two SPEI datasets seems speculative. Please provide more evidence to support the claim that the divergence after 2008 is caused by differences in precipitation data rather than PET estimation methods.

We compared the two precipitation data sets in the figure below (monthly time series of area-average precipitation over the study region).

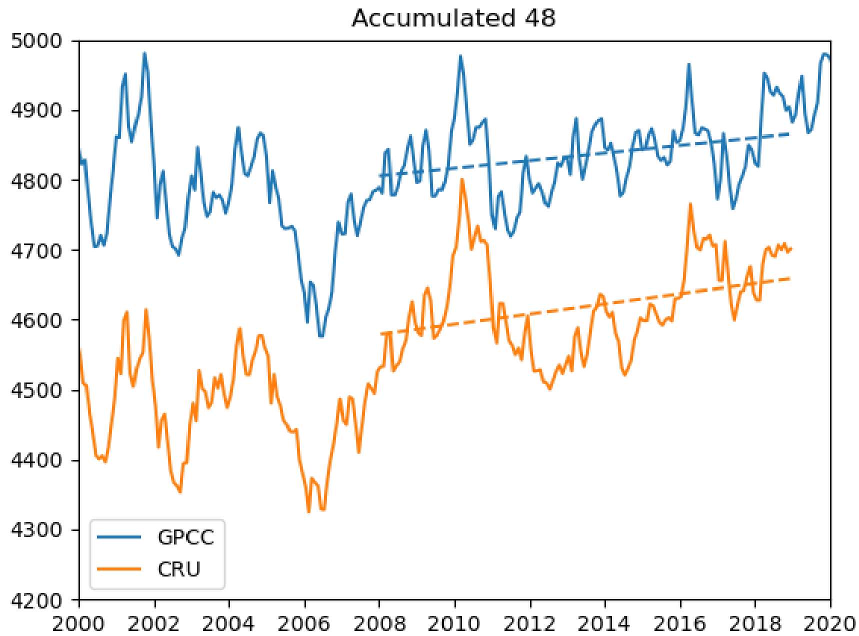
Differences between the two data sets are clearly visible: monthly maxima tend to be higher in GPCC than in CRU, and in some years, the phase of the annual signal is slightly shifted (CRU being later than GPCC).



Further, we investigate the accumulated time series (following figure) with an accumulation period of 48 months (the same period used for SPEI).

Both GPCC and CRU precipitation data sets have a positive trend since 2008 (when the two SPEI time series started to differ), but the increase in precipitation is larger for CRU (GPCC:

5.5mm/year; CRU: 7.3mm/year). This agrees well with the observed increase of SPEI (CRU-based) after 2008 and can be a reason why both SPEI data sets diverge afterwards. We cannot rule out that differences in the PET data used for the two SPEI data sets may also contribute to the SPEI differences. However, the PET data were unavailable for a direct comparison.



We will add this analysis and discussion to the manuscript.

11. Lines 290-295: The description of the Nalubaale Dam and its impact on Lake Victoria's water levels is incomplete. Please provide more information on the characteristics of the dam (e.g., operating rules) and downstream effects on the Victoria Nile and other water bodies. A study area section presenting the East African Rift Region would be useful.

After the introduction, we will add a section collecting information about the study region, including more on Lake Victoria and the Nalubaale Dam.

12. Lines 314-315: Please provide a more rigorous assessment of the data quality and its impact on the correlation analysis.

As written above, we will include an uncertainty assessment in the manuscript.

13. Lines 367-368: That concluding statement seems too broad and not fully supported by the analysis. Please refine this conclusion and provide a more nuanced interpretation of the relative contributions of natural and anthropogenic factors to TWS variability.

We will rewrite the conclusion.

14. Please revise the English since there are several issues (e.g., Line 5 shows “region region”, Line 92 shows “We analyses…”)

A thorough English language check will be done.