Responses to reviewers' comments

We appreciate the constructive comments from Reviewers #4 and #5. In the revised manuscript, we have incorporated changes (highlighted in blue) to address all comments presented below in *italics*. Our responses to each comment are provided in **bold.**

Reviewer #4

1. I have reviewed the manuscript and the previous reviewers' comments. In my opinion, the authors have addressed the main scientific concerns sufficiently, and the revised manuscript is now acceptable for publication subject to minor technical corrections.

*I recommend **acceptance subject to technical corrections**. The only correction I suggest is that the authors should moderate any remaining over-assertive wording in the title, abstract, and conclusion regarding the "reconciliation" or "alignment" between GRACE-derived groundwater storage anomalies and piezometric observations. Given the limited number of observation wells, the small basin size relative to the GRACE footprint, and the uncertainties associated with the residual groundwater-storage approach, the wording should emphasize "assessment," "comparison," or "consistency evaluation" rather than implying a full quantitative reconciliation.*

This is a technical wording issue and does not require further scientific revision. After this correction, I support publication of the manuscript.

R1: Thank you for the comment. We have carefully reviewed the final version of the manuscript and ensured that no over-assertive wording remains, including in the title, abstract, and conclusion.

Reviewer #5

2. This study examines the limitations of GRACE-derived groundwater storage estimates in the coastal Lower Kutai River Basin, Indonesia, which has a catchment area of approximately 23,000 km². The study compares GRACE-based terrestrial water storage (TWS) estimates from multiple products with different spatial resolutions and evaluates the potential influence of ocean leakage on inland GRACE grids. It also investigates whether ENSO-related signals are detectable in GRACE-derived TWS and groundwater storage estimates, and assesses the plausibility and limitations of GRACE-derived groundwater storage changes using limited piezometric data.

Overall, the study is valuable, with clear objectives and a well-structured methodology. The results generally support the stated objectives. However, I recommend minor revisions to further improve the quality of the manuscript before acceptance. My minor comments are provided below:

R2: Thank you for the positive review. Our responses to each of the specific comments are provided below.

3. It is suggested that, in addition to the temporal comparison shown in Figure 4 between the storage components, ΔSMS from Noah LSM, ΔSWS from WGHM, and the computed plausible ΔGWS, and GRACE derived TWS, the authors include spatial maps of these components. These maps would help identify the spatial dominance and relative contribution of each storage component to GRACE derived TWS changes across the study area. They would also enable readers to better visualize the dominant storage processes in different regions and would strengthen the interpretation and validation of the spatial variability of the storage components.

R3: We agree that visualising the data as grid-based maps would help identify the spatial dominance and relative contribution of each storage component (ΔTWS, ΔSMS, ΔSWS, and ΔGWS). However, we did not compute ΔGWS using grid-based values from each storage component (ΔTWS, ΔSMS, and ΔSWS). Instead, we used ensemble mean or spatially averaged values to comply with the recommended caution when using GRACE data as neighboring grid cells are not independent (Dahle et al., 2025; Vishwakarma, 2020). The term "mean" has been added to Figure 4 and Table 1 captions. We consider that the plot in Figure 4, the example presented in Table 1, and the descriptions in lines 321-327, 406-412, and 61-620 are sufficient to demonstrate the dominant contribution of soil moisture storage changes (ΔSMS) to ΔTWS compared to ΔSWS.

Lines 321-327: In the study area, water storage components derived from the GLDAS and WGHM datasets exhibit distinct contributions to mean ensemble ΔTWS. Among these components, soil moisture storage changes (ΔSMS) play the most dominant role with values ranging from -28.8 to 5.5 cm (Table S4 and Fig. S13). In contrast, surface water storage changes (ΔSWS) derived from the Noah LSM and WGHM datasets are comparatively smaller, ranging from -5.3 to 5.5 cm (Table S4, Fig. S4). Canopy water anomalies (ΔCW) are negligible with values ranging from -0.02 to 0.01 cm (Table S4,

Fig. S14). The very low ΔCW values indicate that canopy water variations have an insignificant influence on overall water storage changes, whereas small ΔSWS values suggest that surface water contributes minimally to ΔTWS in the study area.

Lines 406-412: Fig. 4 shows that when ΔSMS values from Noah LSM are more negative than ΔTWS values from GRACE JPL (0.5°), GRACE ΔGWS becomes anomalously high and vice versa. For example (Table 1), during the wet season, ΔTWS in March 2008 was 1.9 cm, whereas ΔSMS was 5 cm and ΔSWS was 3.6 cm. The computed ΔGWS of -6.7 cm is implausible unless intense and widespread groundwater abstraction has occurred. Conversely, in September 2015 when precipitation was zero, ΔTWS was -8.6 cm, ΔSMS was -22.5 cm, and ΔSWS was -4.1 cm. Despite the overall water deficit, the computed ΔGWS was 18 cm, an implausible gain unless significant regional groundwater inflow into the GRACE grid occurred. These examples highlight computational uncertainty in ΔGWS estimation, particularly when specific dataset combinations are used.

Line 614-620: As discussed in Section 3.2, ΔSMS exerts the most substantial influence on ΔTWS in this study, whereas ΔSWS contributes minimally, and ΔCW contributions are negligible (Table S4). Because ΔGWS is computed as a residual, any discrepancy between ΔTWS and ΔSMS directly affects ΔGWS estimations (Arifin et al., 2025; Shamsudduha and Taylor, 2020). A key observation in Fig. 4 highlights that when ΔSMS values are lower than ΔTWS, ΔGWS estimates become anomalously high. It emphasizes the importance of obtaining reliable root zone soil moisture estimates as it represents the hydrologically active layer that exchanges water with both the atmosphere and the underlying unsaturated zone (Gao et al., 2024).

2. Given the limited availability of in situ groundwater level observations in the study area, it is recommended that the authors include additional global groundwater storage products to support the validation of GRACE derived groundwater storage estimates. In addition to WaterGAP or WGHM groundwater data, products such as the Global Gravity based Groundwater Product and PCR GLOBWB 2 could be considered. Including these datasets would provide an independent comparison and help improve confidence in the reliability and spatial consistency of the estimated groundwater storage variations.

R4: We did not include either G3P or PCR-GLOBWB 2 in our study. However, we included two groundwater storage changes (ΔGWS) products for comparison with our results: the Global Land Water Storage 2.0 (GLWS 2.0) and GLDAS 2.2 datasets. The

results shown in Figure 6 indicate that the magnitude of plausible ΔGWS computed in this study is smaller than those derived from both GLWS 2.0 and GLDAS 2.2. However, as also shown in Figure 8, the limited ΔGWS estimates derived from piezometric observations suggest that the ΔGWS estimated in this study shows better agreement with the magnitude of piezometer-based ΔGWS. Nevertheless, reliable storage coefficients from a dense piezometric network are still required to further validate this comparison.

3. The supplementary section contains approximately 29 figures. It is suggested that the authors consider reducing the number of supplementary figures, where possible, and retain only those that are directly relevant to the study objectives and necessary for supporting the main findings. This would improve the clarity and focus of the supplementary material.

R5: Thank you for this comment. We agree that the number of supplementary figures is relatively large. We have carefully reviewed the manuscript and decided to reduce the number of figures in the supplementary file from 29 to 24.

References

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