Response to reviewers

Reviewer: 1 (RC1)

Reviewer comments in 'black', our responses to each comment in 'blue'.

General Comments:

This manuscript analyzes lake-level changes across 232 lakes in High Mountain Asia from 2010 to 2024 using CryoSat-2 and ICESat-2 data. The results show heterogeneous lake-level changes across HMA, with overall increases in the Tibetan Plateau lakes and declining tendencies in the Himalaya. The authors further examine correlations between lake-level changes and ERA5-Land precipitation, temperature, and evaporation to interpret possible hydroclimatic controls. While the dataset and regional synthesis are useful, the manuscript's current scientific contribution is somewhat limited by a largely descriptive analytical framework. The conclusions regarding climatic drivers, cryospheric buffering, and regional mechanisms are not fully supported by the current analyses. The study would benefit from more robust attribution framework, and a more explicit statement of its novelty relative to previous HMA lake-level studies.

Author's response: We thank the reviewer for taking your time to review our manuscript and for providing thoughtful and constructive comments. Your comments have been very helpful in strengthening and improving our study. We agree that the initial version did not sufficiently distinguish the contribution of the present study from previous regional assessments and mechanistic interpretations of the relationships between lake water level changes and climate variables. We substantially revised the manuscript by clarifying the scientific contribution of our study, moderating the interpretation of climate-lake water level relationships, expanding the discussion of uncertainties associated with the climate data and altimetry analysis, and distinguishing more clearly between the findings of the present study and interpretations based on previous literature. We also revised the Abstract, Introduction, Methods, Results, Discussion, and Conclusions to improve the clarity, scientific rigor, and presentation of the manuscript. The detailed responses to each comment are provided below.

Specific Comments:

1. **About innovation.** The broader finding on the rising lake-level in the central Tibetan Plateau and declining tendency in the southern Tibetan Plateau/Himalayan region is already well established in the literature. The authors state that the majority of previous studies are confined to the Tibetan Plateau. While existing studies have either extended the analysis to high-elevation lakes above 2500 m a.s.l. (e.g., Zhang et al., 2020) or to glacial lakes across the entire HMA (e.g., Wang et al., 2025). It is useful that the manuscript extends the lake-level record to 2010–2024, however a 15-year period does not necessarily provide a clear advantage for assessing long-term trends. The manuscript should more explicitly state the knowledge gap, not only in terms of "more lakes and longer time series," but new process understanding. For example, does the study reveal post-2018 acceleration or deceleration in lake-level changes? Or does it identify regional differences that were not captured by previous TP- or HMA-wide studies?

Wang Y, Zheng D, Zhang G, Carrivick JL, Bolch T, et al. (2025). Patterns and change rates of glacial lake water levels across High Mountain Asia. National Science Review, 12(3): nwaf041.

Zhang, G., Yao, T., Xie, H., Yang, K., Zhu, et al. (2020). Response of Tibetan Plateau lakes to climate change - Trends, patterns, and mechanisms. Earth Science Reviews, 208

Author's response: We agree that the general pattern of rising lake levels across much of the central and northern Tibetan Plateau and declining lake-level trends in parts of the southern Tibetan Plateau and Himalaya has been documented in previous studies. And extending the observational record to 2024 by themselves, does not constitute sufficient scientific advances. We have revised the manuscript to clarify the main contribution of this study with more detailed characterization of the spatial/temporal heterogeneity and persistence in lake water level changes underlying the broad regional patterns of lake level change across High Mountain Asia (HMA) within a common observational and analytical framework.

We provide a spatially consistent assessment of lake-level variability for 232 large lakes across three geographic subregions of HMA using CryoSat-2 observations from 2010–2023 and ICESat-2 observations from 2018–2024. The extended observational record enables us to examine the temporal evolution of lake-level trends by comparing pre-2018 (2010–2017) and post-2018 (2018–2023) periods. These analysis reveals that the broad regional patterns comprise both persistent trends and substantial temporal shifts: 117 lakes (50.4%) maintained increasing trends in both periods, 38 lakes (16.4%) maintained declining trends, while 77 lakes (33.2%) changed the direction of their trends, including 52 lakes (22.4%) transitioning from declining to increasing levels and 25 lakes (10.8%) transitioning from increasing to declining. The median lake-level trend increased from +0.034 m/yr before 2018 to +0.095 m/yr after 2018, although this temporal evolution differed substantially among regions. The Tibetan Plateau showed a shift toward more positive trends, whereas western HMA shifted toward weaker or more negative trends, while Himalayan lakes retained negative median trends in both periods. We analysed statistical association of catchment-scale climate variations to examine whether these distinct lake level trajectories are with different climate variables, while avoiding attribution of individual water-balance contributions beyond what can be supported by the analysis. Together, these results demonstrate that the well-established regional patterns of lake level change across HMA mask substantial temporal evolution and spatially variability. By resolving changes in the persistence, acceleration, and reversal of lake-level trends within a consistent observational framework, the present study complements previous Tibetan Plateau-wide and HMA-wide assessments and provides new insight into the recent evolution of lake water level changes. We expanded the discussion to place our findings in the context of recent studies, including findings from Zhang et al. (2020) and (Wang et al., 2025) in the revised manuscript.

2. **About mechanistic interpretation.** The manuscript relates lake-level trends to ERA5-Land temperature, precipitation, and evaporation trends. This provides a reasonable first-order analysis, but the Discussion often moves from correlation to mechanistic interpretation. For example, the authors suggest that lake expansion on the Tibetan Plateau is mainly associated with increased precipitation, that glacierized catchments reflect cryospheric buffering, and that declining Himalayan lakes indicate precipitation sensitivity and reduced meltwater buffering. These interpretations are plausible, but correlation analyses alone are not sufficient to infer dominant mechanisms. Lake -level change integrates catchment runoff, direct precipitation over the lake, evaporation, groundwater exchange, glacier and snow melt, and possible outlet

dynamics. The authors should therefore either moderate the mechanistic language or strengthen the analysis, for example by introducing a simple lake water-balance framework to guide interpretation.

Author's response: We agree that correlations between lake level trends and ERA5-Land climate variables cannot by themselves establish the dominant mechanisms controlling lake level changes. As lake water level variability reflects the integrated effects of contributing hydrological components of catchment water balance. We revised the manuscript to clearly distinguish between statistical associations supported by our results and process-based attributions based on previous studies. We revised the discussion on positive/negative relationship between lake level trends and climate variables presented as a statistical association with the importance of variability, rather than as a direct estimate of contribution to lake level change.

Our catchment-scale analysis shows precipitation variability as the climate variable most consistently associated with de-seasoned lake trends, with a significant positive correlation ($r = 0.42$, $p < 0.001$) except for lakes within glacierised catchments such as endorheic basins in Tibetan Plateau (Jiang et al., 2020; Zhang et al., 2017a; Zhang et al., 2017b). Although this statistical relationship does not by itself quantify the relative contributions of precipitation to lake level change. When compared with individual lake water level time series derived from satellite altimetry and in situ measurements, our estimates show strong agreement with previous studies (Lei et al., 2022; Zhang et al., 2019; Zhang et al., 2017b). The recent modest deceleration in growth rates observed in the ICESat-2 record (2018-2024) coincides with the decline in precipitation in our ERA5-Land analysis post-2021, suggesting the interannual precipitation variability as potential contributor to recent changes in lake level trajectories (Fig. S2). Lake expansion on Tibetan Plateau in recent decades have been attributed to precipitation, evaporation (Biskop et al., 2016; Yang et al., 2017), Snow and ice melt (Zhang et al., 2017b) ground Water (Lei et al., 2022). The increasing precipitation trend observed at meteorological station on Tibetan Plateau during 1978 to 2013, except in parts of the southeast (Zhang et al., 2017a), is broadly consistent with the spatial pattern of lake water level changes (Fig. 2).

We similarly revised the discussion of Himalayan lakes to avoid attributing declining lake levels to precipitation deficits based on the correlation analysis. For lakes in glacierised catchments, we revised the weak correlations with contemporaneous ERA5-Land temperature, precipitation, and evaporation variables indicate that lake level variability cannot be directly explained by these variables alone and may involve delayed or nonlinear hydrological responses. The potential role of snow and glacier melt is discussed as a plausible interpretation supported by previous process-based studies, rather than as a mechanism demonstrated by results of our study. We also revised the limitations to clarify the correlations between lake level trends and individual climate variables should be interpreted as statistical associations. We hope these revisions provide an appropriate interpretation of the lake water level variations and climate variables while retaining its value as a first-order assessment.

3. **About uncertainty.** The climate-driver analysis is based on ERA5-Land temperature, precipitation, and evaporation. Reanalysis data, especially precipitation, is highly uncertain in high-mountain regions, and this uncertainty directly affects the interpretation of correlations between climate variables and lake-level changes. The authors should discuss this limitation more explicitly. If possible, comparison with another precipitation product would strengthen the analysis.

Author's response: We agree that, although ERA5-Land provides consistent spatial and temporal coverage across HMA, its performance in high-elevation regions with complex topography is subject to uncertainties due to coarse spatial resolution, sparse ground observations, and systematic biases in the representation of precipitation. We have therefore expanded the discussion of ERA5-Land uncertainties and their implications for interpreting the climate variables and lake water level relationships. Previous evaluations indicate that ERA5-Land generally reproduces the broad spatial and temporal patterns of precipitation and temperature over the Tibetan Plateau, although systematic biases remain, particularly in precipitation estimates (Wu et al., 2023). Comparison with observations from 28 meteorological stations in the Qilian Mountains during 1980–2 018 showed that ERA5-Land captured the spatial patterns and temporal trends of monthly precipitation and temperature, while systematically overestimating precipitation amounts (Li et al., 2022). Over the eastern Tibetan Plateau, ERA5-Land reproduced the broad spatiotemporal evolution of regional rainfall events, with spatial correlations exceeding 0.8, although biases remained in rainfall characteristics (Hu and Yuan, 2021). Evaluations across the Tibetan Plateau similarly indicate that ERA5-Land captures broad precipitation and temperature patterns and their variability, while systematic regional biases persist (Wu et al., 2023). Given these uncertainties, in the revised manuscript the absolute magnitudes of ERA5-Land precipitation and evaporation trends with caution.

4. **About Discussion.** The discussion of glacier melt and permafrost contribution mainly relies on previous studies. Some statements on glacier-melt buffering and permafrost-related contributions cannot be directed supported by the lake-level and climate-correlation analyses. The manuscript should make clearer which process interpretations are directly supported by this study and which are inferred from prior literature.

Author's response: We agree with the reviewer's suggestion and revised the discussion to more clearly distinguish between results directly supported by our analysis and process-based interpretations based on previous studies. Our analysis shows that lakes within glaciated catchments exhibit rising water levels, while correlations with contemporaneous ERA5-Land temperature, precipitation, and evaporation are generally weak and statistically non-significant ($r < 0.17$). The observed weak correlations indicate that lake level variability in these catchments cannot be directly explained by the climate variables and may involve hydrological processes with delayed or nonlinear responses. The seasonal correlations identified for Gozha Lake are discussed as potential indications of the influence of snow storage and the timing of snow and ice melt, rather than as direct evidence of their contribution to lake water level change.

To place our findings in a broader cryosphere context, we now discuss previous lake-catchment scale studies that have quantified contributions from glacier mass loss, ground-ice melt, and permafrost degradation to lake storage changes on the Tibetan Plateau and across HMA (Wang et al., 2022; Zhang et al., 2024). These studies provide estimates of cryosphere melt contributions to lake storage changes in individual catchments, supporting the plausibility of cryosphere related contributions to the rising lake levels. However, the relative importance of these processes likely varies among lakes and cannot be resolved from our regional correlation analysis alone. Similarly, the increase in median growth rates from 0.028 m yr^{-1} during the CryoSat-2 period to 0.096 m yr^{-1} during the ICESat-2 period is presented as a possible indication of enhanced meltwater contributions under sustained warming, rather than as direct evidence of increasing glacier melt contributions. We acknowledge that process-based investigation using lake water balance modelling and independent observations of glacier, snow, and permafrost change is required to quantify these contributions.

5. **About regional classification.** The manuscript groups lakes into Tibetan Plateau, Himalaya, western HMA, and glacierized catchments, however, the criteria are not described explicitly. In particular, "glacierized catchments" overlap spatially with the other regions. It is not clear whether these are treated as an independent category or a cross-cutting classification.

Author's response: Thank you for pointing out the missing explanation on classification. We now include a description to clarify the regional classification in the Materials and Methods section. For regional analysis, we use HMA boundaries from Bolch et al. (2019) and group the lakes into three geographic subregions, the Tibetan Plateau, Himalaya, and western HMA. We merged the subregions located within the Tibetan Plateau and western HMA. In addition to the geographic classification, we analyzed water level variations of lakes located in glacierised catchments based on the presence of glaciers within the contributing lake catchment. Lakes in glacierised catchment classification is therefore a cross-cutting classification rather than a separate geographic region. Lakes within glacierised catchments can occur within the Tibetan Plateau, Himalaya, or western HMA and may therefore belong simultaneously to one geographic region and the glacierised catchment group.

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