Response to Review

Reviewer #CC1:

With the rapid development of satellite remote sensing technology, a large number of datasets related to water cycle variables have been produced, providing important opportunities for more accurately revealing hydrological variation processes within watersheds. However, many datasets on precipitation, evapotranspiration, runoff, and water storage change are observed or modeled independently, and contain certain uncertainties. This leads to poor physical consistency among the datasets, often manifested as non-closure of the water balance. It is therefore crucial to obtain consistent datasets.

This paper addresses the limitations of existing water balance closure correction methods that fully allocate water imbalance residuals, which may lead to negative corrected values. The authors propose a method based on partially closed water balance correction, which effectively resolves the issues of accuracy loss and negative values inherent in current methods. This approach demonstrates important innovation and research value. To help the authors further improve the manuscript, I have the following suggestions:

Response: Thank you for your careful review. These comments are very helpful for us to improve the manuscript. We really appreciate your time and efforts. The point-to-point responses were given after individual comments.

- It is recommended that the authors provide a more detailed explanation in the introduction regarding the sources of water balance residuals (including errors, unmeasured components, and biases). This would better clarify the irrationality of fully allocating the residuals based solely on observational errors in existing closure methods, as well as the underlying reason why this can easily lead to negative values.

Response: Thank you for your constructive suggestion. We apologize for not clearly explaining the sources of water imbalance errors in our manuscript. These errors primarily stem from the estimation errors of budget components (errors in remote sensing and reanalysis products of budget components), systematic biases, and the omission of unmeasured components. However, existing BCC methods typically assume that all of ΔRes arises from estimation errors and then redistribute it according to estimation errors. In the revised manuscript, we have provided a more detailed description of the principles behind existing BCC methods, the main uncertainty sources causing water imbalance error, and the limitations of existing BCC methods that fully redistribute the water imbalance error. The following sentence has been added to the revised manuscript:

"Existing BCC methods redistribute the entire ΔRes error among water budget components to enforce strict water budget closure. This redistribution is typically guided by the relative uncertainties of the individual components, based on the assumption that the entire residual error originates from observational or modeling errors in these datasets. However, this assumption overlooks the fact that ΔRes is not solely the result of measurement or estimation errors in P, ET, Q, or TWSC. Rather, it is a composite residual that also reflects contributions from systematic biases and the omission of unmeasured components. These include deep groundwater exchanges that may cross basin boundaries, snow and glacier storage changes (particularly in high-altitude or high-latitude regions), and anthropogenic influences such as irrigation withdrawals, reservoir operations, and inter-basin water transfers. Because existing BCC methods do not explicitly account for these additional sources of imbalance, forcing strict closure by allocating the entire ΔRes to the measured components can introduce unrealistic uncertainties. As a result, the application of existing BCC methods—despite their goal of improving internal consistency — often leads to limited improvements, or, in some cases, even a decline in the accuracy of the corrected hydrological datasets.".

- In the methods section, the authors propose a stepwise iterative approach to find an optimal balance point for allocating residuals, which is a sound strategy. The condition for terminating the iteration is the emergence of negative values in the water cycle variables. While it is easy to understand how precipitation, evapotranspiration, and runoff can become negative, water storage change inherently includes both positive and negative values. Therefore, the authors are advised to clearly explain how the termination condition is defined for water storage change.

Response: Thank you for your careful review. We apologize for not clearly explaining the termination condition for the iterative adjustment of terrestrial water storage change (TWSC). We consider it inappropriate to continue redistributing the water imbalance error to TWSC if its sign changes after applying the existing BCC method—specifically, if TWSC shifts from a positive to a negative value, or vice versa. Such a change indicates that the correction applied to TWSC may be unreasonable. This is because GRACE satellite observations of TWSC are generally regarded as reliable, and the primary purpose of BCC methods is to improve the internal consistency among precipitation, evapotranspiration, runoff, and TWSC. A reversal in the sign of TWSC during the correction process suggests a potential overcorrection, and further adjustments should therefore be terminated. We have added the following sentence to the revised manuscript:

"During the iterative correction process, if any of the water budget components (P, ET, and Q) becomes negative, the redistribution of water imbalance error to that component is immediately suspended. In subsequent iterations, redistribution is recalculated to ensure that only components with physically meaningful positive values receive the imbalance correction. For example, if ET becomes negative in a given iteration, the imbalance is subsequently redistributed to P, Q, and TWSC only, in accordance with Equation 33. For TWSC, if a sign reversal occurs during iteration (i.e., from positive to negative or vice versa), the redistribution of the water imbalance error to TWSC is suspended in the following iteration.".

- The paper demonstrates that applying existing water balance closure correction methods may reduce the accuracy of water cycle variables. Although this is an important finding, it is recommended that the authors add a discussion on the underlying reasons for this issue.

Response: Thanks for your constructive suggestion. We believe that the reduced accuracy of the corrected datasets resulting from existing water budget closure correction (BCC) methods may be due to the following reasons: 1) Most existing BCC methods estimate errors in budget components without incorporating independent observational data. Inaccurate error estimates for a single budget component can propagate through the redistribution process, biasing the redistribution of the water imbalance error to other budget components and ultimately reducing the accuracy of all budget components (Abolafia-Rosenzweig et al., 2021). Incorporating high-quality observational data into the error estimation process is therefore essential to improve the robustness of BCC methods; 2) Existing BCC methods are limited by the assumption that the entire water imbalance error can be fully attributed to estimation errors in budget components. These methods enforce water budget closure by completely redistributing the water imbalance error among the budget components. However, this residual may also arise from systematic biases and unmeasured processes, rather than solely from component-level estimation errors. In this study, we propose an iterative optimization approach that seeks a more balanced redistribution of water imbalance error, aiming to minimize both the errors introduced into individual budget components and the remaining water imbalance error. This method significantly improves the accuracy of the corrected datasets. Future research could further enhance this approach by integrating it with physically based hydrological or land surface models, offering a promising pathway toward greater physical realism and internal consistency in corrected water budget datasets; 3) Observational datasets themselves often do not strictly satisfy water budget closure due to inherent measurement limitations and sampling errors. This introduces uncertainty when using these datasets to validate the accuracy of BCC-corrected results. For example, even if the corrected datasets more closely approximate the true values of individual components, the absence of ground-truth observations presents a fundamental challenge for objectively assessing the validity of these corrections. Future studies should prioritize the development of more objective and physically grounded evaluation metrics to better assess the performance of BCC-corrected datasets. We have discussed these issues and potential solutions in the revised manuscript as follows:

"Several factors may contribute to this reduction in accuracy. First, most existing BCC methods estimate errors in budget components without incorporating independent observational data. These methods then redistribute water imbalance errors based on these internally estimated uncertainties (Section 3.2). However, the absence of observational constraints undermines the reliability of the estimated component errors, which in turn leads to a suboptimal and potentially biased allocation of the imbalance. As previously noted, inaccurate error estimates for a single variable can propagate through the redistribution process, biasing the residual redistribution to the remaining budget components and ultimately lowering the accuracy of all water budget components (Abolafia-Rosenzweig et al., 2021). Incorporating high-quality observational data into the error estimation process is therefore essential to improve the robustness of BCC methods; Second, existing BCC methods are limited by their assumption that the entire water imbalance error can be fully attributed to errors in the measured budget components. These methods enforce water budget closure by completely redistributing the water imbalance error among the budget components, yet this residual may also stem from systematic biases and unmeasured processes—not just estimation errors of measured budget components. In this study, we propose an iterative optimization approach that seeks a balanced redistribution of the ΔRes, aiming to minimize both the errors introduced to individual budget components and the remaining ΔRes. This method significantly improves the accuracy of the corrected datasets. Future research may further enhance this framework by integrating it with physically based hydrological or land surface models, which could provide a promising pathway toward more physically consistent and realistic water budget estimates; Third, the observational datasets themselves often fail to strictly satisfy water budget closure due to measurement limitations and sampling errors. This introduces uncertainty when using these datasets to validate the accuracy of BCC-corrected estimates. For instance, even if the corrected datasets more closely approximate the true values of budget components, the lack of ground-truth observations presents a fundamental challenge for objectively evaluating the effectiveness of these corrections. Future work should prioritize the development of more objective and physically grounded evaluation metrics to assess the accuracy of BCC-corrected datasets. Although this challenge lies beyond the scope of the present study, addressing it will be critical for advancing the reliability of water budget assessments.”.

- Some minor formatting issues should be carefully checked. For example, multiple terms and abbreviations are used throughout the paper. It is suggested that the full name along with the abbreviation be given at first mention, with the abbreviation used thereafter.

Response: Thank you very much for your careful review. We have thoroughly revised the manuscript to ensure that all abbreviations are spelled out in full when first introduced, with the corresponding abbreviations provided in parentheses. Thereafter, only the abbreviations are used consistently throughout the text.

- The axis labels in Figures 12–15 should be formatted consistently with the other figures. They should not be bolded.

Response: Thank you very much for your careful review. We have changed the axis labels in Figures 12–15 from bold to regular font. We have also checked all the figures to ensure consistency.

Reference:

Abolafia-Rosenzweig, R., Pan, M., Zeng, J., & Livneh, B. (2021). Remotely sensed ensembles of the terrestrial water budget over major global river basins: An assessment of three closure techniques. Remote Sensing of Environment, 252, 112191. https://doi.org/10.1016/j.rse.2020.112191