Response to RC1:

General comments

The authors of this paper implement an extended Budyko framework for high-elevation catchments to understand the changes in water balance characteristics. Additionally, they tried to isolate the major drivers of monthly runoff variability in the region.

The overall analysis was sound and merits discussion. However, there are significant issues with the general writing of the manuscript, with many convoluted statements. My primary concerns are listed below.

Response: We sincerely thank the reviewer for the valuable and constructive comments. We appreciate the recognition of our work in applying an extended Budyko framework to high-elevation catchments and analyzing the drivers of monthly runoff variability.

In response to the reviewer's concerns regarding the quality of writing, we plan to carefully revise the manuscript to improve clarity, rephrase convoluted statements, and enhance the overall readability. We will ensure that the scientific content is communicated in a clearer and more concise manner.

A detailed response to each specific comment and a description of the planned revisions are provided below.

Specific Comments

Comments 1: The abstract needs to be more concise. The statements feel overcrowded and convoluted. Please try to split long sentences for better readability.

Response 1: We thank the reviewer for the suggestion. In response, we plan to revise the abstract to make it more concise and improve its readability. Specifically, we will split overly long sentences into shorter ones, simplify complex expressions, and restructure the abstract to better highlight the study's objectives, methods, major findings, and significance. The revised abstract will ensure that key messages are communicated more clearly and effectively to the readers.

Comments 2: How will the phase transition of precipitation (from snow to rain), influenced by a warming climate observed over high-elevation regions, affect runoff characteristics? A brief discussion on this will give more context to the results presented. Also, what about any potential glacier cover in the region?

Response 2: We appreciate the reviewer's comment regarding the phase transition of precipitation in high-elevation regions and its potential impact on runoff characteristics. As temperatures rise, precipitation is expected to transition from snow to rain, which makes runoff more sensitive to rainfall (as shown in Figure 8). Moreover, this phase transition could lead to earlier snowmelt, further altering the timing and intensity of runoff. In the revised manuscript, we will discuss the potential effects of climate-driven shifts in precipitation phase (from snow to rain) on runoff characteristics, emphasizing that such transitions could exacerbate the observed decline in runoff seasonality. We acknowledge that these changes in snow storage dynamics could lead to a decrease in runoff seasonality in the future.

Additionally, we have previously analyzed glacier distribution in the study area using glacier data from the Ice and Snow Data Center (as shown in the figure below). The glacier coverage in the region is minimal and can be considered negligible, and thus, we did not consider the impact of glaciers in this study.

Comments 3: Lines 65 to 70: Add references supporting these statements.

Response 3: We thank the reviewer for pointing this out. We will add relevant references to support the statements made in lines 65 to 70 in the revised manuscript.

Comments 4: Line 90: The line should be "A more detailed understanding of intra-annual runoff characteristics..."

Response 4: We appreciate the reviewer's comment. We will correct the sentence and revise it to: "A more detailed understanding of intra-annual runoff characteristics..." in the revised manuscript.

Comments 5: The range of altitudes in the basin has been stated multiple times in the manuscript. However, the source/reference for this information is not mentioned properly.

Response 5: We thank the reviewer for pointing this out. We will ensure that the source/reference for the range of altitudes in the basin is properly cited in the revised manuscript.

Comments 6: Section 2.1 has many convoluted sentences. Consider simplifying them. For instance, Lines 153 to 157 could be better explained with an equation rather than text. Lines 238 to 242 are not readable.

Response 6: We thank the reviewer for the valuable suggestion. In the revised manuscript, we will simplify the sentences in Section 2.1 to improve clarity and readability. For Lines 153–157, although the runoff calculation process is relatively straightforward, we will rephrase the text to make it more concise and clear, instead of introducing an additional equation. For Lines 238–242, we will rewrite and streamline the text to enhance its readability. We will carefully revise Section 2.1 according to the reviewer's advice.

Comments 7: Why is the study period chosen as 2002 to 2016? Were there any significant changes that happened in the region? Please clarify.

Response 7: We appreciate the reviewer's comment. We will emphasize the reasons for selecting the study period of 2002 to 2016 in the manuscript. Specifically, we will clarify that this period was chosen because it corresponds to the time during which consistent runoff data were available for all ten sub-basins. Furthermore, this period

allows for an evaluation of the impacts of reservoir construction and operation on hydrological processes, particularly the effects of major reservoirs such as Ertan (1999), Jinping I (2013), Jinping II (2013), Guandi (2012), and Tongzilin (2015). These developments are crucial for understanding changes in runoff patterns, and this time frame reflects the period before/after the construction of these reservoirs, enabling a thorough assessment of their influence on regional hydrology. We will revise the manuscript to explicitly highlight these reasons.

Comments 8: Some of the sub-basins chosen are nested basins. It will be good to mention them and their characteristics in the study area section.

Response 8: We appreciate the reviewer's valuable comment regarding the nested sub-basins. As pointed out, this is an important consideration. In the original manuscript, we have already listed the basic characteristics of each sub-basin in Table S2 (in the supplementary material). To provide readers with a clearer understanding of the nested sub-basins, we will move Table S2 from the supplementary material to the main text in the revised manuscript, making it more accessible. This will allow us to present information such as coordinates, basic hydrological, and meteorological data in a more intuitive manner. Additionally, we will explicitly mention the nested sub-basins and their characteristics in the " Study area and data" section, ensuring that all relevant data is easily available to readers.

Comments 9: Line 145: It is stated that the implementation of the extended Budyko framework is explained in Sect. 2.2. However, Sect. 2.2 in the manuscript is about the study area and data. Also, starting Section 2 with Study Area and Data would be better, and then move to the methodology.

Response 9: We appreciate the reviewer's comments on the structure of Section 2. We initially chose to present the methodology first because it is the key innovation of this study, while the study area was selected as a representative region. However, we understand the reviewer's concern, and in the revised manuscript, we will move the

description of the study area and data to precede the methodology section for clearer presentation of the methodology.

In the original manuscript, Section 2.1 describes the methodology, while Section 2.2 introduces the study area and data used for implementing the extended Budyko framework. In response to the reviewer's suggestion, we will add the following statement in the revised manuscript: '*In this section, the representative study area and the required data for this study are introduced in Sect. 2.1, while the theoretical framework for attributing runoff variability based on the extended Budyko is described in Sect. 2.2. Table 1 presents the variables and acronyms used in this study*'.

Comments 10: Line 248: Check the equation number. Is it 10 or 11?

Response 10: We thank the reviewer for pointing this out. We will carefully check the equation numbering in the revised manuscript, and if any error is found, we will correct it accordingly.

Comments 11: Line 281: The table number should be S2.

Response 11: We appreciate the reviewer's careful reading. We will correct the table number in the revised manuscript.

Comments 12: Include elevation information of the outlet stations in Table S2.

Response 12: Thank you for the helpful suggestion. We will add the elevation information of the outlet stations to Table in the revised manuscript.

Comments 13: The labels of the sub-basins are not clear in Figure 2. Consider making them bold/bigger. Also, provide information on the source for the DEM and snow depth data in the figure. Labelling the three figures as (a), (b), and (c) and providing a proper caption for each will bring more clarity.

Response 13: Thank you for the helpful suggestion. In the revised manuscript, we will improve the clarity of sub-basin labels in Figure 2 by increasing their font size and making them bold. We will also add the data sources for the DEM and snow depth data

directly in the figure or caption. Furthermore, we will label the three sub-figures as (a), (b), and (c), and provide detailed and informative captions for each to enhance readability and clarity.

Comments 14: Figure 3 indicates consistent negative values for total storage change across all the basins. Explain this.

Response 14: We thank the reviewer for this insightful comment. In our study, we calculated the water balance separately for ten sub-basins. In the upstream sub-basins, which are unaffected by reservoir regulation, the long-term values of ΔS fluctuate around zero, indicating that the hydrological system remains in balance under natural conditions. In contrast, the downstream sub-basins affected by reservoir operations (e.g., WLX, LG, TZL) show more pronounced fluctuations in ΔS, with a predominance of negative values (i.e., net outflow), which may be attributed to the multi-year regulatory effect of reservoirs in the study area. In addition, this pattern may be partially related to uncertainties in the methodological approach. To address this, we have independently validated the process in Section 4.2 "Uncertainties and model performance evaluations." All results indicate that reservoirs influenced by human activities are playing an increasingly important role in regulating surface water storage in alpine regions affected by climate change.

We will clarify this point further in the revised manuscript.

Comments 15: A few new results are introduced in the Discussion section, which should ideally be in the results section. For instance, the total runoff, snowmelt runoff, and the runoff contribution from reservoirs in Figure 9 are not mentioned before. Additionally, Figure 9 shows a time period from 1980 to 2017, which is beyond what was mentioned in the previous results obtained from the study. Please clarify.

Response 15: Thank you for pointing this out. Figure 9 presents a long-term analysis of the influence of snowmelt and reservoir operations on the intra-annual variability of runoff at the basin outlet. We included this figure in the Discussion section as a supplementary analysis to further explain one of our study's key findings—the role of

snowmelt and reservoirs in shaping monthly runoff. Figure 10, on the other hand, was added to independently validate the estimated storage change (ΔS) using reservoir operation data, thereby helping to assess the uncertainty of our water balance results. As both figures are intended to support and reinforce the main findings rather than introduce new directions, we plan to move them to the supplementary materials in the revised manuscript for improved clarity.

Regarding the time period shown in Figure 9 (1980–2017), we acknowledge that it differs from the primary study period (2002–2016). This extended period was selected specifically to highlight long-term trends in snowmelt reduction and to compare seasonal runoff dynamics before and after reservoir construction. This broader context helps support the interpretation of changes observed during the main study period. We will clearly explain this rationale in the revised figure caption and in the supplementary materials.

Comments 16: Lines 556-558: A hypothesis on other parts of the world may be made in the discussion part. Or this can be stated as a possible future work.

Response 16: Thank you for your comment. In the discussion section, we have already made a comparison and hypothesis regarding similar mechanisms in other parts of the world, such as snow-dominated rivers of central Europe. We will revise the manuscript to clarify that this comparison is intended as a potential avenue for future research, and will rephrase the relevant part as: "*Similar elevation-dependent mechanisms may occur in other snow-affected basins, such as Alpine-origin rivers in Europe, though further high-resolution studies are needed to confirm this.*"