

Reply to Reviewer2

General Comment 1: The authors repeatedly leave it unclear where data they show is coming from (which station or ERA5).

Response: We thank the reviewer for pointing out this important issue. In the original manuscript, the data sources for some figures and descriptions were not clearly specified, which may have made it difficult for readers to distinguish between the different data sources and their respective uses. In the revised manuscript, we have carefully checked the relevant text, figure captions, and Supporting Material and have clearly specified the data sources at the appropriate locations to avoid confusion. Specifically, the meteorological forcing data used for the glacier energy and mass balance model are mainly derived from meteorological data reconstructed using AWS1 and ERA5 data, which are then spatially distributed over the entire glacier grid using temperature and precipitation gradients. The meteorological data presented in the Results section are obtained by first spatially distributing the reconstructed data over the entire glacier grid and then calculating the glacier-wide averages. The incoming longwave radiation observed by AWS2 was used to optimize the L_{in} scheme, while AWS3 observations were used to validate the simulated albedo, sensible heat flux, latent heat flux, and L_{in} scheme. The energy fluxes and mass balance presented in the Results section are all based on model simulations and are expressed as glacier-wide averages. The snowfall, albedo, and radiation data used in the Discussion section are derived from ERA5. We have added and clarified the data sources at the relevant locations in the manuscript, and the corresponding revisions are provided below.

Revised text (L175f): The meteorological forcing data, including T_a , RH, WS, precipitation, and cloud cover, were reconstructed based on AWS1 observations and ERA5 reanalysis data and were used to drive the EBFM model. To obtain meteorological inputs for each 90×90 m grid cell across the glacier, we spatially interpolated or parameterized the meteorological variables.

L311f: We compared meteorological conditions during the TC period with those during the baseline period using glacier-wide reconstructed meteorological data, ERA5 data,

and point-based observations from AWS1 to characterize changes in meteorological conditions over the glacier.

L342f: Figure 6a shows the glacier-wide mean values of mass balance and its components derived from the model simulations during the TC period and the baseline period, including snowfall, refreezing, sublimation, and melting.

L377f: We analyzed the energy flux characteristics derived from the model simulations during the TC and baseline period.

L452f: To address this, we analyzed the spatial distributions of snowfall, cloud cover, surface albedo, S_{net} , and S_{in} during the TC period using ERA5 data, together with their daily anomalies relative to the climatological mean for the same period during 2000–2024, to identify the main area affected by TC Tauktae.

General Comment 2: The specific TC investigated never really reached the TP and based on the data shown I am wondering if this is even a signal from the cyclone or simply an above average precipitation event. It is definitely not extreme in terms of volume or duration and since the authors provide no context on how often this happens in the location (or how it may change) there is no way for the reader to eventually judge whether TCs as such are now important or irrelevant for mass balance. Since the event is short (3 days) any effect on mass balance is anyway taken with a lot of caution, considering that the ‘balance’ part is not an instantaneous process.

Response: We thank the reviewer for raising this important and helpful comment, which has helped us recognize that the original manuscript did not provide sufficient evidence demonstrating the influence of the tropical cyclone on the glacier region, making the purpose and presentation of Section 4.1 unclear. The original wording may have given the impression that we attributed these anomalous conditions to the tropical cyclone solely based on the occurrence of extreme meteorological conditions. In the revised manuscript, the newly added Section 4.1 is mainly intended to identify and verify the influence of Tauktae on the study region, while Section 4.2 focuses on characterizing the specific meteorological conditions over the glacier region during the influence period of Tauktae.

First, in Section 4.1, we conducted a combined analysis of the spatial and temporal distributions of moisture transport, cloud-top brightness temperature, and ERA5 precipitation. The ERA5 moisture flux analysis shows that moisture over the Naimona'nyi Glacier region was mainly transported from the southwest during May 18–21, 2021, which is consistent with the location of Tauktae during this period. Meanwhile, the cloud systems associated with Tauktae gradually developed toward the study region and covered the Naimona'nyi Glacier area during May 18–21. The spatial distribution of ERA5 precipitation also shows a pattern in which the precipitation area extended from the region affected by the cyclone toward Naimona'nyi Glacier. In addition, based on the reconstructed glacier-wide meteorological data, we found that precipitation, air temperature, and relative humidity during May 18–21, 2021 were all higher than their corresponding multi-year means for the same period during 2000–2024. The consistent temporal and spatial variations in moisture transport, cloud activity, precipitation distribution, and glacier-wide meteorological conditions provide multiple lines of evidence supporting the influence of Tauktae on the Naimona'nyi Glacier region. Therefore, we define May 18–21, 2021 as the main period of Tauktae influence on Naimona'nyi Glacier. The newly added Section 4.1 has been incorporated into Lines 232–291 of the revised manuscript.

In Section 4.2, we agree with the reviewer that the precipitation duration and amount during this event were not extreme. Therefore, we have removed the statements in the original manuscript describing the precipitation duration as extreme, and we no longer characterize the precipitation amount during this event as extreme. Meanwhile, we have added analyses of ERA5 precipitation, air temperature, cloud cover, and relative humidity, as well as precipitation and air temperature observations from AWS1, to further describe the meteorological variations over the glacier region during May 18–21, 2021. These revisions have been incorporated into Lines 307–329 of the revised manuscript.

We have also carefully considered the reviewer's concern regarding the influence of such a short event on glacier mass balance. Glacier mass balance results from the combined effects of accumulation and ablation and is calculated as:

$$MB = C_{en} + P_{snow} + M_{water} + E_v$$

Where mass balance (MB) consists of refreezing (C_{en}), snowfall (P_{snow}), melting (M_{water}), and sublimation/evaporation (E_v). Refreezing and P_{snow} are accumulation terms and are therefore defined as positive values, whereas M_{water} and E_v represent glacier mass loss and are therefore defined as negative values. Glacier mass balance is calculated as the sum of all mass balance components. These processes can vary on hourly or even shorter timescales. Therefore, mass balance can also respond dynamically to short-term meteorological variations. We agree with the reviewer that the short-term mass-balance response to a single tropical cyclone event lasting only four days makes a limited contribution to the overall long-term glacier mass balance. Therefore, we do not attempt to directly assess the importance of tropical cyclones for long-term glacier mass balance based on a single event. Instead, we use this event as a case study to investigate the potential influence of a tropical cyclone on glacier and to examine the meteorological and energy processes through which such an event may affect glacier mass balance. The cumulative effects of multiple tropical cyclone events may influence long-term glacier mass balance, but this requires further investigation based on more events and longer time series.

Revised text:

4.1 Identification of the influence period of tropical cyclone Tauktae on Naimona'nyi Glacier

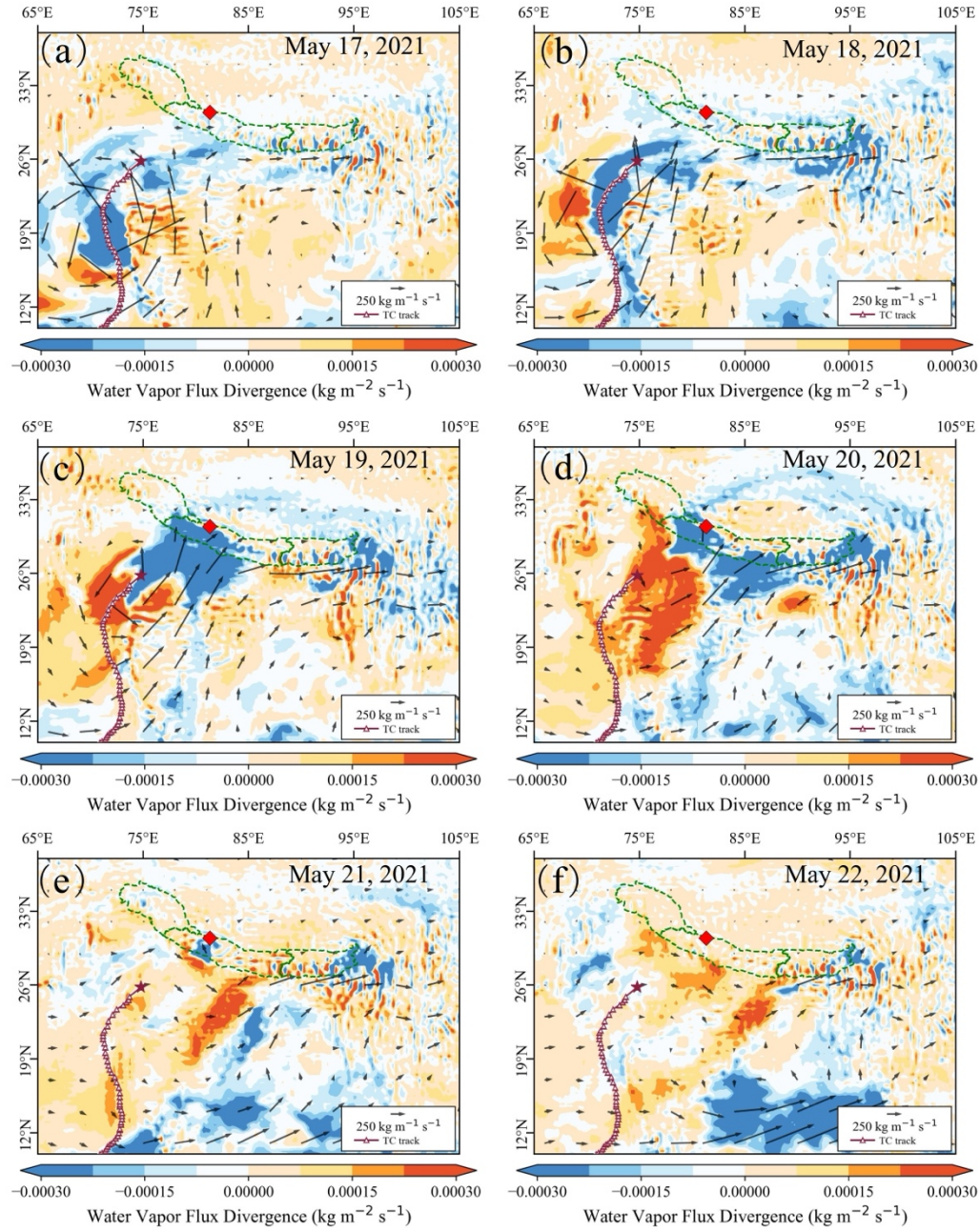


Figure 2: Daily changes in vertically integrated water vapor transport and moisture flux divergence from 17 to 22 May 2021. (a) May 17, 2021; (b) May 18, 2021; (c) May 19, 2021; (d) May 20, 2021; (e) May 21, 2021; (f) May 22, 2021. Shading indicates the integrated water vapor flux divergence ($\text{kg m}^{-2} \text{s}^{-1}$), and black arrows indicate the integrated water vapor transport (IVT), with arrow direction and length representing the direction and magnitude of IVT, respectively. The magenta curve indicates the tropical cyclone track, triangles indicate the cyclone positions along the track, and the star indicates the final position of the track. The red diamond indicates the location of

the study glacier, and the green dashed line indicates the extent of the Himalayas.

To determine whether Tauktae affected Naimona'nyi Glacier, we conducted a combined analysis of vertically integrated water vapor transport (IVT), moisture flux divergence, BT, glacier-wide reconstructed meteorological conditions, and ERA5 precipitation during May 13–25, 2021. The variations in these variables were pronounced during May 18–21. Therefore, the spatial evolution of IVT, moisture flux divergence, BT and ERA5 precipitation was examined for May 17–22, while glacier-wide meteorological conditions were presented as a complete time series for May 13–25. On May 17, 2021, TC Tauktae was located southwest of Naimona'nyi Glacier, and the IVT field showed the onset of weak moisture transport from the southwest toward the glacier. However, moisture flux divergence remained weakly negative, indicating that moisture convergence over the glacier was still weak (Fig. 2a). On May 18, IVT from the southwest toward the glacier strengthened, consistent with the location of TC Tauktae southwest of the glacier, and was accompanied by enhanced moisture convergence (Fig. 2b). During May 19–20, IVT from the southwest toward the glacier continued to intensify, while a continuous zone of moisture convergence gradually developed over and around the glacier, reaching its maximum during this period. Meanwhile, the IVT direction remained consistent with the position of TC Tauktae southwest of the glacier (Fig. 2c–d). On May 21, both the intensity of IVT and the spatial extent of moisture convergence began to decrease, although moisture convergence remained evident near the glacier (Fig. 2e). By May 22, IVT from the southwest had largely diminished, and the moisture convergence over and around the glacier had also weakened (Fig. 2f). These results suggest a possible influence of southwestward moisture transport associated with TC Tauktae on Naimona'nyi Glacier, accompanied by moisture convergence over and around the glacier.

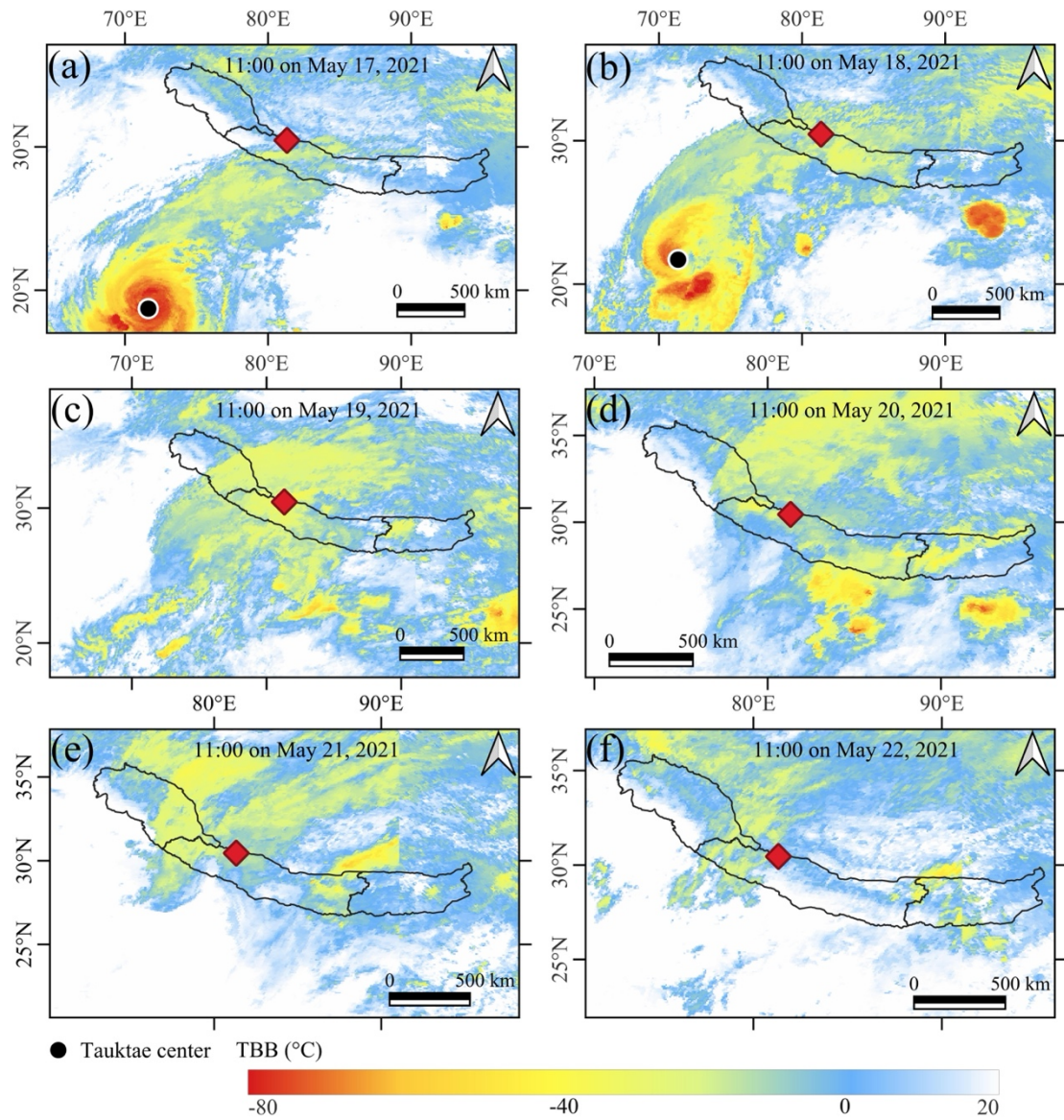


Figure 3: Cloud-top brightness temperature (BT) at 11:00 from May 17 to May 22, 2021. (a) May 17; (b) May 18; (c) May 19; (d) May 20; (e) May 21; (f) May 22. Shading indicates BT, black dots indicate the center position of TC Tauktae, black lines indicate the Himalayan region, and red diamonds indicate the location of Naimona'nyi Glacier.

Meanwhile, the spatiotemporal evolution of BT reveals the development of the cloud system associated with TC Tauktae and its expansion toward the study area. On May 17, 2021, TC Tauktae was located southwest of Naimona'nyi Glacier. On May 18, the cyclone moved further northward, while its peripheral cloud system expanded northeastward and covered Naimona'nyi Glacier. During May 19–21, as the cyclone

weakened and continued to move northward, its cloud system became increasingly fragmented and diffuse, while parts of the cold-cloud region continued to cover Naimona'nyi Glacier and its surrounding areas. By May 22, the low-BT signal over Naimona'nyi Glacier and its surrounding areas had substantially weakened (Fig 3f). ERA5 precipitation results show that on May 17, 2021, relatively heavy precipitation was mainly concentrated around TC Tauktae, with daily precipitation exceeding 30 mm, while no apparent precipitation impact was observed near Naimona'nyi Glacier (Fig S6a). On May 18, relatively heavy precipitation remained concentrated around the center of TC Tauktae, while precipitation over and around Naimona'nyi Glacier increased as the cyclone moved northward (Fig S6b). During May 19–20, the precipitation area expanded further, with relatively heavy precipitation occurring over the central and parts of eastern Himalayas (Fig S6). On May 21, the precipitation area contracted, with relatively heavy precipitation concentrated mainly near Naimona'nyi Glacier (Fig S6e). By May 22, precipitation over and around Naimona'nyi Glacier had largely dissipated (Fig. S6f).

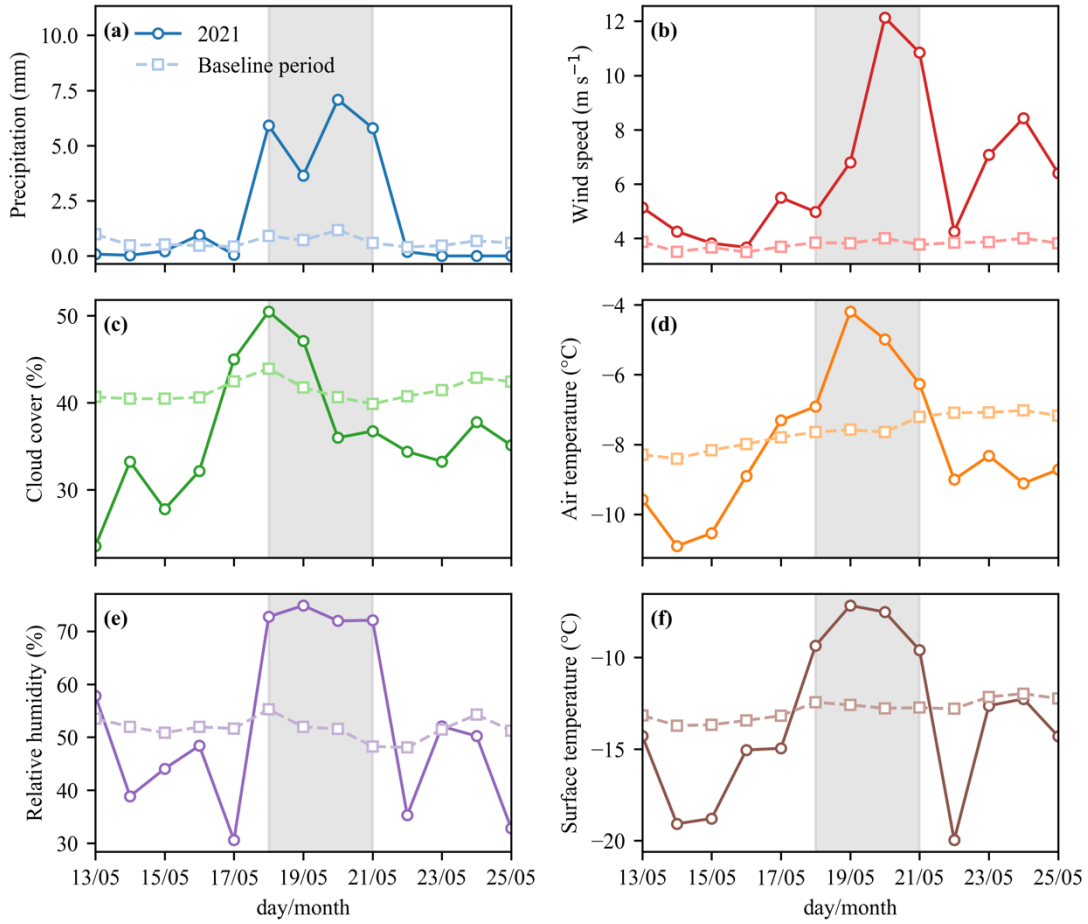


Figure 4: Daily variations in meteorological variables over Naimona'nyi Glacier from May 13 to May 25, 2021, compared with the baseline period. (a) Precipitation (mm); (b) wind speed (W s^{-1}); (c) cloud cover (%); (d) air temperature ($^{\circ}\text{C}$); (e) relative humidity (%); and (f) surface temperature ($^{\circ}\text{C}$). Solid lines with circles represent the daily variations in 2021, while dashed lines with squares represent the multi-year mean values for the corresponding days during the baseline period (2000–2024, excluding 2021). The gray shading indicates the main period associated with the influence of TC Tauktae from May 18 to May 21, 2021.

Finally, the glacier-wide reconstructed meteorological data indicate that some meteorological variables over Naimona'nyi Glacier began to deviate from the corresponding means for the same dates from 2000 to 2024 (baseline period) on May 17, 2021, with WS, cloud cover, and T_a slightly higher than the corresponding means during the baseline period (Fig. 4). During May 18–20, 2021, precipitation, T_a , RH, and

cloud cover were higher than during the baseline period (Fig 4). On May 21, 2021, although cloud cover was lower than during the baseline period, precipitation, T_a , RH, and WS remained higher than during the baseline period (Fig 4). The combined changes in IVT, moisture convergence, TC-related cloud systems, ERA5 precipitation, and glacier-wide meteorological conditions indicate that anomalous conditions over Naimona'nyi Glacier began to emerge on May 17, 2021 and became most pronounced during May 18–21, 2021. These changes were temporally and spatially consistent with the northward movement of TC Tauktae and the expansion of its associated cloud system toward the glacier. Therefore, we define May 18–21, 2021 as the main period associated with the influence of TC Tauktae (TC period) on Naimona'nyi Glacier and use this period for the subsequent analysis of its impacts.

4.2 Meteorological conditions during the tropical cyclone Tauktae influence period

We compared the mean meteorological conditions during the TC period with those during the baseline period using glacier-wide reconstructed meteorological data, ERA5 data, and point-based observations from AWS1 to characterize meteorological changes. The 90th percentile values were calculated from the corresponding data for each year, and values exceeding the 90th percentile were defined as extreme conditions. The P90 has been widely used to identify meteorological extremes (DeGaetano and Allen, 2002; Nerantzaki and Papalexiou, 2022; Schär et al., 2016). The glacier-wide reconstructed meteorological data show that mean daily precipitation during the TC period reached 5.6 mm d^{-1} , which was 4.75 mm d^{-1} higher than the baseline mean and exceeded the 90th percentile (Fig. 5a). As the event occurred in May, T_a at high elevations remained relatively low, and precipitation during both the TC period and the baseline period was dominated by snowfall. The mean RH during the TC period reached 73%, which was 21 percentage points higher than the mean during the baseline period and exceeded the 90th percentile (Fig. 5e). The mean WS was 8.7 m s^{-1} , 4.8 m s^{-1} higher than the baseline mean and above the 90th percentile (Fig. 5b). The mean cloud cover was 42.5%, 1% higher than the baseline mean (Fig. 5c). The mean T_a was $-6.0 \text{ }^{\circ}\text{C}$, $1.9 \text{ }^{\circ}\text{C}$ higher than the baseline mean and above the 90th percentile (Fig. 5d). In addition, ERA5 data at

the grid cell containing Naimona'nyi Glacier show that precipitation, cloud cover, and RH during the TC period were all higher than the baseline mean and exceeded the corresponding 90th percentile values (Fig S7). Analysis of point observations from 2014–2024 also shows that the mean daily precipitation during the TC period was higher than the baseline mean and exceeded the 90th percentile, while T_a was also higher than the baseline mean (Fig S8). Despite differences in spatial scale among the glacier-wide meteorological data, ERA5 data, and point observations, the three datasets show consistent changes in meteorological conditions. Compared with the baseline period, the TC period was characterized by enhanced precipitation over Naimona'nyi Glacier, accompanied by higher T_a , increased cloud cover, and higher RH.

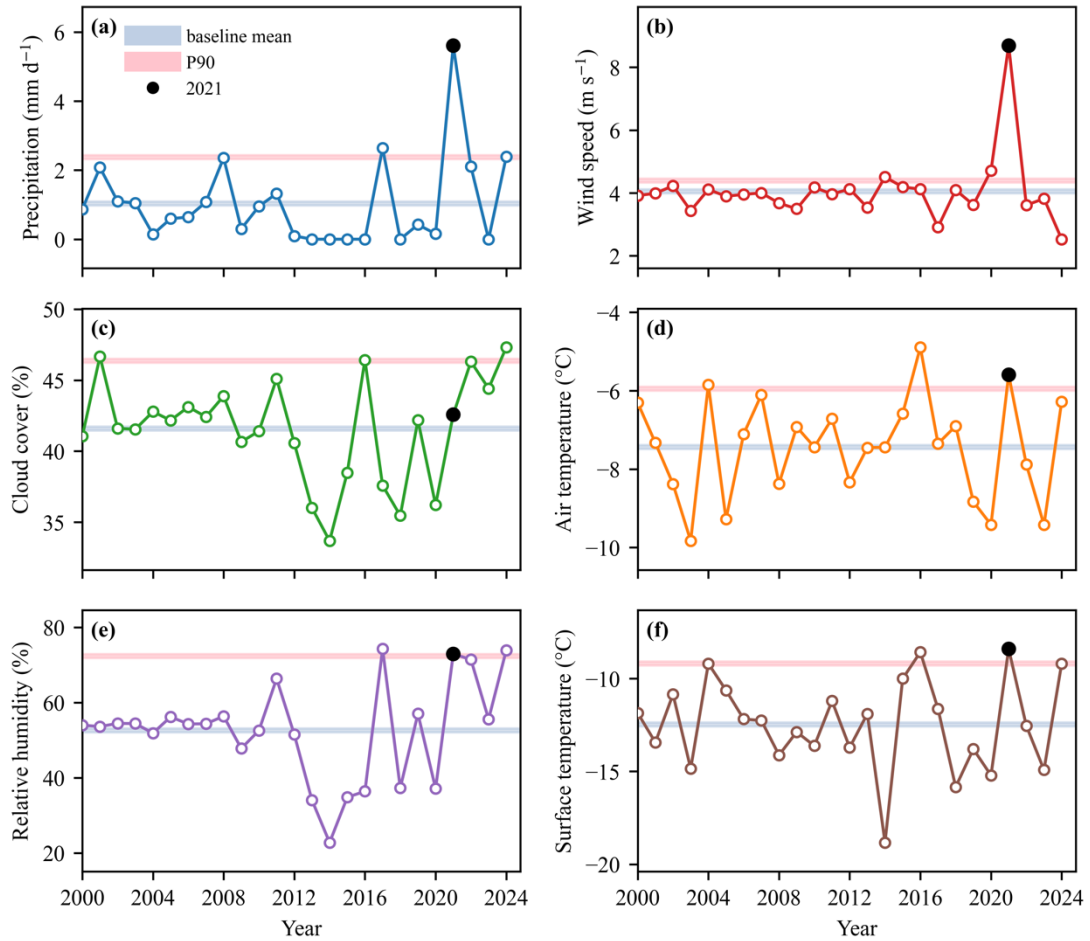


Figure 5: Interannual variability of meteorological variables during 18–21 May (2000–2024). (a) Precipitation (mm d⁻¹), (b) wind speed (WS, m s⁻¹), (c) cloud cover (%), (d) air temperature (T_a , °C), (e) relative humidity (RH, %) and (f) surface temperature (T_s , °C). All variables represent averages during May 18–21 of each year. The black

dots indicate values in 2021. The dashed black lines represent the mean of the baseline period (2000–2024).

General Comment 3: There is little to no scrutiny of the magnitude of the specific event versus the general precipitation situation in the location. While the authors mention percentiles in the text, they never show them in any figure and hence its impossible to say whether this event was in any way out of the ordinary.

Response: We appreciate the reviewer's important and helpful suggestion. We agree that reporting percentile information only in the text, without presenting it visually in the figures, made it difficult for readers to clearly assess the magnitude of the event and its anomaly relative to the general precipitation conditions in the study area. This comment also prompted us to further strengthen the comparison between the event and the long-term climatic background.

In the revised manuscript, we compare precipitation during the Tauktae-affected period of May 18–21, 2021, with the multi-year mean for the same period over 2000–2024. We have also added the corresponding percentile information to Fig. 5 to provide a more direct representation of the variation and anomaly of precipitation during the event relative to the long-term background. By presenting both the multi-year mean and percentile thresholds, readers can more clearly assess whether the precipitation during the event deviated substantially from the typical conditions for the same period and determine its relative position within the long-term precipitation distribution. These revisions also provide a more direct graphical basis for our description of the anomalous precipitation characteristics associated with the event in the main text.

General Comment 4: The Discussion rather than discussing the Results introduces completely new results (spatial analysis) and provides no discussion of the results, hence resulting in a big crucial part missing from this research.

Response: We sincerely thank the reviewer for raising this important issue. We fully agree with the reviewer's comment. After reexamining the original manuscript, we recognized that the original Discussion did not provide sufficient discussion of the main

simulation results. Following the reviewer's suggestion, we have reorganized and strengthened the Discussion section. First, the spatial analysis in the Discussion mainly uses ERA5 data to examine the spatial extent of changes in variables related to the positive mass balance anomaly, including snowfall, albedo, cloud cover, and shortwave radiation. This analysis further helps assess the potential spatial extent of the positive mass balance anomaly associated with TC Tauktae. We have therefore retained this analysis in Section 5.2 as a supplement and extension of the main results. In addition, we have added Section 5.1, which focuses on the atmospheric circulation processes that may have influenced the meteorological, energy, and mass changes identified in the results. Considering the uncertainty in whether the influence of TC Tauktae can extend across the central Himalayas and whether glaciers with different characteristics would exhibit positive mass-balance anomalies and mechanisms similar to those identified for Naimona'nyi Glacier, we have added Section 5.3. This section discusses how factors such as elevation, glacier surface type, aspect, and local environmental conditions may regulate the glacier response to TC Tauktae, and further discusses the spatial uncertainty of this response. The corresponding content has been added and revised in the Discussion section of the revised manuscript, as detailed below.

Revised text:

5.1 Uncertainty associated with the interaction between tropical cyclone Tauktae and large-scale atmospheric circulation

The spatiotemporal correspondence identified in Section 4.1 suggests that TC Tauktae contributed to the anomalous atmospheric conditions over the Naimona'nyi Glacier region. However, the influence of TC Tauktae on the Himalayas did not occur in an isolated atmospheric environment but was jointly modulated by circulation systems operating at different spatial scales, including the mid-latitude westerlies, the South Asian monsoon, and the TP vortex (Jiang et al., 2023; Li and Xiao, 2022; Lin et al., 2024; Liu and Li, 2022; Zhou et al., 2024). May is typically a transitional period during which the mid-latitude westerlies gradually weaken and the South Asian summer monsoon begins to establish. According to records from the India Meteorological Department, the southwest monsoon established over the Andaman Sea on May 21,

2021, reached Kerala on June 3, 2021, and further advanced into the northern Arabian Sea and northwestern India on June 18–19, 2021 (Bhawan and Road, 2026). Therefore, during the influence of Tauktae from May 18 to 21, 2021, the study region was still in the early stage of the gradual establishment of the South Asian monsoon. Tauktae was therefore likely an important factor contributing to the anomalous moisture input and enhanced snowfall over the Naimona'nyi Glacier region during this period. However, the gradual establishment of the monsoon circulation, the weakening of the mid-latitude westerlies, and the influence of other concurrent circulation systems cannot be completely excluded. Moreover, it remains difficult to quantitatively distinguish the relative contributions of TC Tauktae and the concurrent large-scale and regional circulations to the snowfall anomalies over the glacier. This uncertainty represents a limitation of this study in terms of mechanistic interpretation.

5.3 Spatial uncertainty in the glacier mass balance response to tropical cyclone Tauktae

Increased snowfall and surface albedo, together with the reduction in S_{in} associated with increased cloud cover, are major contributor to the positive mass balance anomaly at Naimona'nyi Glacier during the influence of TC Tauktae. Further analysis of ERA5 data shows that the anomalous signals associated with the positive mass balance anomaly, including increased snowfall, higher surface albedo, increased cloud cover, and reduced S_{net} , extend into the central Himalayas. We therefore suggest that the positive mass balance anomaly associated with TC Tauktae may have extended into the central Himalayas. However, differences in elevation distribution, surface properties, aspect, and local climatic conditions among glaciers may lead to different mass balance responses even under similar meteorological forcing (Yu et al., 2013; Zhu et al., 2018). For example, for glaciers with different elevation ranges, elevation differences may regulate the mass balance response mainly by affecting precipitation phase, rather than directly determining changes in cloud amount during the TC period. In lower-elevation glacier areas, T_a are generally higher, so precipitation associated with TC Tauktae is more likely to fall as rain, thereby reducing solid precipitation accumulation. However, increased cloud cover and the associated reduction in S_{in} radiation may still occur,

thereby suppressing ablation in these areas. Considering that low-elevation areas account for a relatively small proportion of the total glacier area, the glacier as a whole may still exhibit a positive mass balance anomaly, although the spatial distribution and magnitude of the anomaly may differ.

Glacier surface properties may further modulate this mass balance response. Debris-covered and debris-free glaciers differ in their surface energy balance and ablation processes, and debris thickness can also affect ice ablation rates. Under certain conditions, thin debris layers may enhance energy absorption at the ice surface and increase ablation, whereas thicker debris can provide greater insulation and suppress ice melt (Fugger et al., 2022; Rounce et al., 2021). However, during the influence of TC Tauktae, increase cloud cover reduced S_{in} at the glacier surface, resulting in lower energy input to the glacier overall. Therefore, regardless of the presence or absence of debris at the glacier surface, the reduction in S_{in} associated with increased cloud cover during the TC period could reduce energy input and suppress ablation. Under this common low-energy background, differences in debris cover and thickness are likely to influence the magnitude of the positive mass balance anomaly.

Glacier aspect and topographic conditions may also modulate the mass balance response to TC Tauktae (Olson and Rupper, 2019; Zhang et al., 2024). ERA5 analysis shows that the snowfall responses differed between the southern and northern slopes during the TC period. The northern slopes experienced increased snowfall and positive snowfall anomalies, whereas the southern slopes showed neither a clear increase in snowfall nor positive snowfall anomalies. Thus, the northern slopes may have received greater mass input from increased solid precipitation. Meanwhile, ERA5 indicates that both slopes experienced increased cloud cover and associated reductions in S_{in} , resulting in relatively low energy input on both slopes. Under these conditions, the combination of increased snowfall and reduced S_{in} may have produced a stronger positive mass balance anomaly on the northern slopes. Although the southern slopes showed no clear increase in snowfall, they may still have exhibited a positive mass balance anomaly through reduced S_{in} . Therefore, differences in glacier aspect may partly account for differences in the magnitude of the positive mass balance anomaly.

However, some uncertainties should be acknowledged in interpreting these results. First, not all glaciers may be affected by TC Tauktae. Regional topographic and climatic conditions may prevent some glaciers from receiving the moisture transported by TC Tauktae and its associated cloud systems, and therefore snowfall, cloud cover, and radiation conditions may show little or no significant change. In addition, among glaciers that are affected by the TC, the intensity and duration of the TC-related perturbations may also differ. These differences may be related to the distance between the glaciers and the areas of TC-related moisture transport and cloud activity, and may also be modulated by local topographic and climatic conditions. When the TC influence is weak or short-lived, changes in snowfall, albedo, and shortwave radiation over glacier areas may be limited and may even be manifested mainly as an increase in cloud cover. Under such conditions, local weather processes and other large-scale circulation systems may dominate glacier mass balance, making it uncertain whether these glaciers exhibit positive mass balance anomalies and how large these anomalies may be. This indicates that the positive mass balance anomaly and associated mechanisms identified at Naimona'nyi Glacier under the influence of TC Tauktae may have some regional relevance, but their magnitude and specific expression may vary depending on the environmental conditions of individual glaciers. Future studies should combine field observations, remote sensing data, and energy and mass balance models across glaciers with different elevations, surface types, and geographic settings to further assess the spatial variability and regional representativeness of glacier mass balance anomalies associated with TC events.

Line-by-line comments

Specific Comments 1: L46f I think this is somewhat awkward phrasing – positive mass balance is associated to all parts of the balance, it just means there is more of input than output. Consider revising to ‘Positive mass balance is often driven by positive anomalies in snowfall combined with low temperature regimes ...’

Response: We thank the reviewer for pointing out this issue. We fully agree with this

comment. The original wording was indeed not sufficiently precise. Following the reviewer's suggestion, we have revised the relevant statement as follows. The corresponding revision has been incorporated into the revised manuscript.

Revised text (L45f): Positive glacier mass balance is typically closely associated with processes such as snowfall, low air temperature, and more cloud cover.

Specific Comments 2: L68f I believe the impacts were much larger (see for example <https://rrp.unescap.org/knowledge-products/4891>) and 'traffic jams' should be removed, as its not a relevant impact. Also more precisely 'it was one of the more severe TCs in the Arabian Sea in recent years'.

Response: We thank the reviewer for the correction and helpful suggestion. We have re-examined the impacts of Tauktae and consulted the relevant information, including the material provided by the reviewer, and have further revised the corresponding description in the manuscript. We agree that the original description did not fully reflect the impacts of Tauktae, and that "traffic jams" is not a relevant impact to emphasize in this study. We have therefore removed this statement. Following the reviewer's suggestion, we have also described Tauktae more precisely as "one of the more severe tropical cyclones in the Arabian Sea in recent years." The corresponding revisions have been incorporated into the revised manuscript, as shown below.

Revised text (L67f): Tropical cyclone Tauktae formed over the Arabian Sea on May 14, 2021, and made landfall along the coast of Gujarat in western India on May 17, 2021. It was one of the more severe cyclonic events in recent years (Kannaujiya et al., 2024).

Specific Comments 3: L72f I am somewhat surprised that you find that snowfall increases were perceptible on the TP for this TC. Tauktae subsided already before the lower Himalayan foothills in India/Pakistan and while I understand that additional moisture has likely reached much higher, there should be some evidence of increased snowfall. As you have access to station data it would be prudent to show this increase or alternatively refer to studies that have shown the same. This then relates to a next comment for L273f. Here you then refer to Fig S.4, which in my view would need to

be in the main manuscript. But it requires more context – you should show more days before and after the event to show the relative scale of this additional precipitation impact. Does it really qualify as especially high for this location and season? You compare to the mean baseline, but I am not sure how that is computed – if you include 0 values there it's not surprising it quickly gets much lower on average. You should also show quantiles for that baseline. Especially as in the text you refer to the 9th percentile as well. Figure S2 suggests that this specific month was nowhere out of the ordinary, and with so little added volume of snowfall, I wonder if we can speak of a particularly heavy event at this location. I now see that you do introduce some of this in Figure 4 in the manuscript but as for Figure S4 there is no specification from which station these data are taken and again no context with respect to percentiles are given even though you do refer to those in the text.

Response: Response: We thank the reviewer for pointing out this issue and for providing this valuable suggestion. The description of snowfall associated with Tauktae in the original manuscript was not sufficiently clear and may have led readers to assume that the reported increase in snowfall was based on station observations. In fact, this information was mainly obtained from relevant news reports. Following the reviewer's suggestion, we have removed this information from the revised manuscript and replaced it with relevant published studies.

In addition, we fully agree with the reviewer that providing a longer-term temporal context and climatological reference is important for evaluating this event. Therefore, we extended the time period of the original Fig. S4 to May 13–25, 2021, and moved it to the newly added Section 4.1. This time series was used to further identify the period during which the study area was clearly affected by Tauktae. Based on this identification, we used the reconstructed glacier-wide meteorological data in Section 4.2 to analyze the meteorological changes during the influence period of Tauktae. In the revised Fig. 5, we added the climatological background for the corresponding dates during 2000–2024, together with the corresponding percentiles, providing a more complete reference for assessing the precipitation anomaly during the event. However, we also recognize that the event lasted only four days, with a mean daily precipitation

of approximately 5.6 mm d⁻¹. In terms of both the absolute precipitation amount and the total precipitation accumulated over the entire month of May, this event does not represent an exceptionally extreme precipitation event. Therefore, we have further revised the relevant descriptions in the manuscript and no longer characterize this event as an “extreme” precipitation event. Instead, we describe it as a relatively pronounced precipitation anomaly compared with the climatological background for the corresponding period in the study region.

Revised text (L69f): Although the main activity of Tauktae occurred far from the TP, North Indian Ocean tropical cyclones can influence precipitation over the TP under favorable large-scale circulation conditions through the northward propagation of associated cloud systems and long-range transport of moisture (Fan et al., 2023), potentially affecting glacier ablation and accumulation processes in the Himalayas.

Specific Comments 4: L86: Provide exact coordinates, possibly also the RGI/GLIMS ID.

Response: Response: We thank the reviewer for this helpful and specific suggestion. We agree that providing accurate geographic coordinates and a standardized glacier identifier is important for clearly locating the study glacier and improving the traceability of the study information. Following the reviewer’s suggestion, we have added the exact geographic coordinates of Naimona’nyi Glacier (30.45°N, 81.335°E) and its corresponding RGI ID (RGI60-15.09026) to the revised manuscript, allowing readers to locate the study glacier more precisely. The corresponding information has been added to the revised manuscript.

Revised text (L86f): Naimona’nyi Glacier is located in the southwestern TP (30.45°N, 81.335°E; RGI60-15.09026; Fig. 1). As one of the largest glaciers in the Mount Naimona’nyi region, it consists of southern and northern branches.

Specific Comments 5: Figure 1 In Panel (a) it would be prudent to show general glacier extents/regions (RGI or other glacier inventories). In Panel (b) more context is needed. I advise to have an ortho photo as background for topographic context and extend the

contour lines beyond the glacier. What is the colour scale? Elevation? Legends is missing!

Response: We sincerely thank the reviewer for the careful examination of Figure 1 and for these specific and helpful suggestions. We have carefully re-examined the presentation and readability of Figure 1 and made comprehensive revisions following the reviewer's recommendations. In Panel (a), we added information on the distribution of glaciers in the surrounding region, allowing readers to more clearly identify the location of Naimona'nyi Glacier within the Himalayas and Tibetan Plateau and to better understand its spatial relationship with the surrounding glacierized areas. In Panel (c), we added more topographic information and extended the contour lines beyond the glacier to provide a more complete representation of the terrain in and around the study area. We also added an orthophoto as the background, which provides a more intuitive view of the local terrain and surface features and helps clarify the spatial location of the glacier and its surrounding topography. In addition, we revised the color scale in Panel (c) and clearly indicated that it represents elevation, and we added and improved the missing legend and other relevant labels. Through these revisions, we aim to improve the completeness and readability of Figure 1 and to present the location of the study area, glacier distribution, and topographic characteristics more clearly. The corresponding changes have been incorporated into the revised Figure 1 and its caption.

Revised Figure 1:

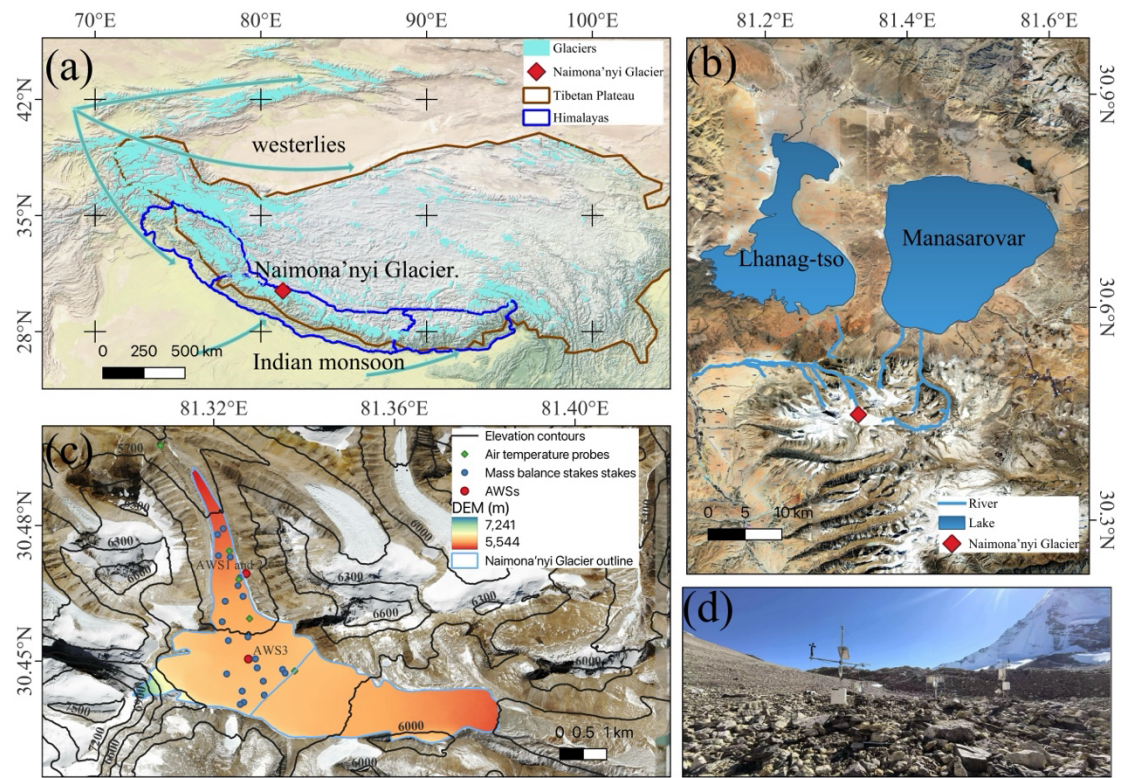


Figure 1. (a) Location of Naimona'nyi Glacier. The background map was obtained from Natural Earth. (b) Rivers and lakes surrounding Naimona'nyi Glacier. (c) Contour map showing mass balance stakes (blue circles), air temperature probes (green diamonds), and AWSs (red circles). The background imagery in (b) and (c) was obtained from Google Satellite imagery. (d) Photograph of AWS1.

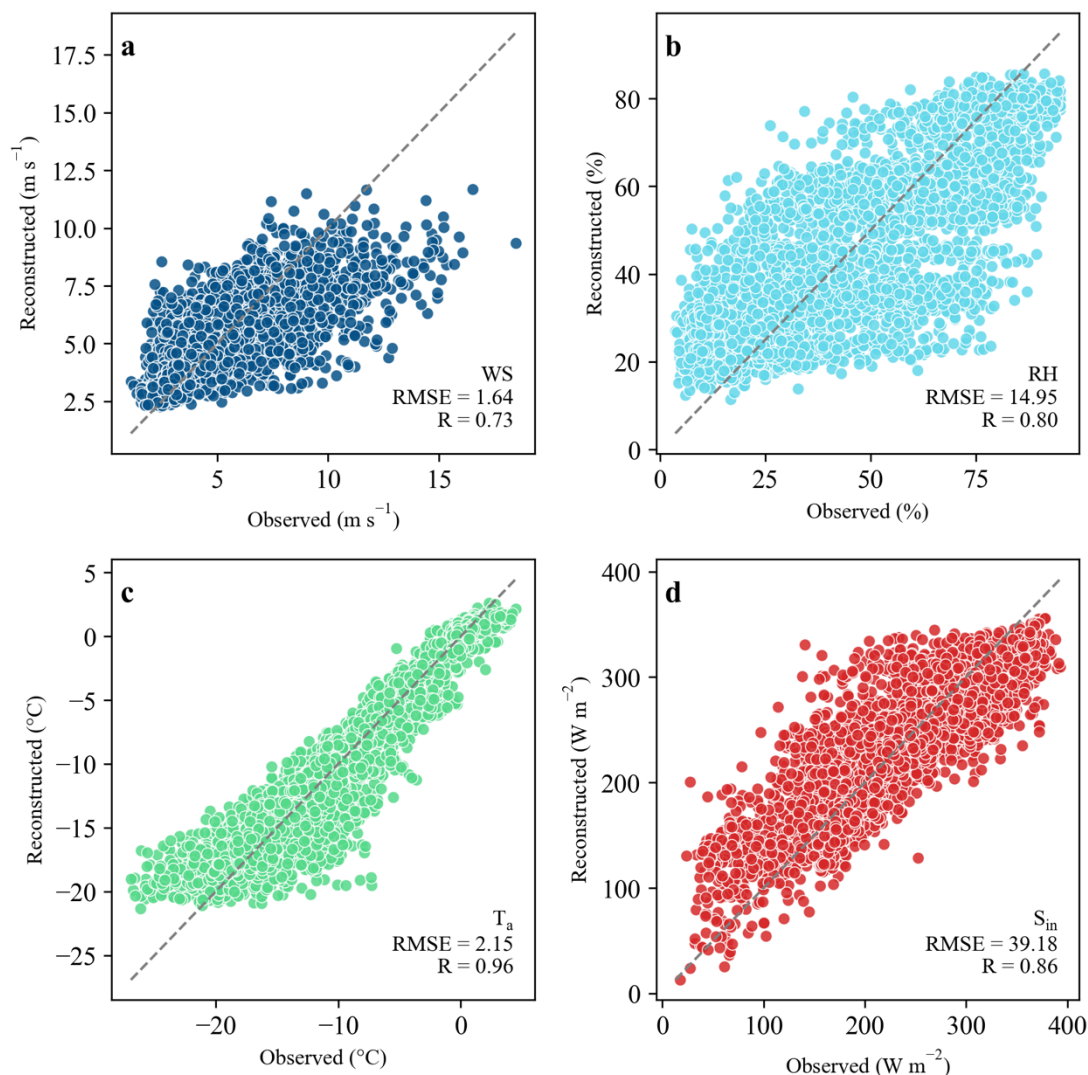
Specific Comments 6: L190f It's crucial that you note how many gaps were filled/how much data were missing and how the quality of filling was assessed. I assume that for the TC event in-situ data was available for all variables.

Response: We thank the reviewer for reminding us to provide a more complete description of the data. We acknowledge that we did not provide sufficient detail in the original description of the meteorological data. We have therefore further reviewed the temporal coverage of the observations and the data gap-filling procedure. From 19 October 2010 to 30 September 2024, the dataset mainly consists of in situ observations, with some periods of missing data and anomalous values. After removing the anomalous values. The missing records for incoming shortwave radiation, wind speed, air temperature, and relative humidity were 1,806, 3,801, 3,590, and 3,597 hours,

respectively, corresponding to 1.47%, 3.09%, 2.91%, and 2.91% of the respective observation periods. The main continuous data gap occurred from April to October 2012. To construct continuous meteorological forcing for the model, we combined AWS1 observations with ERA5 reanalysis data to fill the missing periods from 1 October 1994 to 30 September 2024. After gap filling, we evaluated the quality of the reconstructed data by comparing the reconstructed values with observations during periods with available in situ measurements and calculating statistical metrics, including R, RMSE, as shown in Fig. S3. In addition, complete in situ observations of air temperature, relative humidity, wind speed, and incoming shortwave radiation were available during the influence period of TC Tauktae. Therefore, no gap-filled data were used in the analysis of the TC Tauktae event. We have added the number and proportion of missing records, the data gap-filling method, and the quality assessment of the reconstructed data to the revised manuscript. The corresponding revision has been made at L205f.

Revised text (L205f): We reconstructed continuous hourly meteorological data from October 1994 to September 2024 using AWS1 observations and ERA5 data. First, the half-hourly meteorological observations from AWS1 were aggregated to hourly values, and anomalous values were removed, including $WS \leq 0 \text{ m s}^{-1}$, $RH < 0\%$ or $RH > 100\%$, and S_{in} exceeding the solar constant (1361 W m^{-2}). AWS1 observations covered the period from 2010 to 2024. After removing the anomalous values, 1,806, 3,801, 3,590, and 3,597 hours of data were missing for S_{in} , WS, T_a , and RH, respectively, corresponding to 1.47%, 3.09%, 2.91%, and 2.91% of the respective observation periods. The main continuous data gap occurred from April to October 2012. Subsequently, following the method of Zhu et al. (2026), we established monthly and hour-specific linear regression relationships between ERA5 data and AWS1 observations for each meteorological variable and used these relationships to reconstruct meteorological data during the missing AWS1 observation periods and before and after the AWS1 observation period.

Supplementary Figure. 3:



Specific Comments 7: L215f The model comparison should go into results, not the Data section.

Response: We sincerely thank the reviewer for this valuable suggestion. We fully agree with the reviewer that model validation and the comparison between simulated and observed results are more appropriately presented in the Results section. Considering the additional sections and figures in the revised manuscript, we have moved the detailed model validation results and related figures to the Supporting Material, while providing only a brief description and reference to these materials in the Methods section.

Specific Comments 8: L273f and Fig. S4 From which station are these data taken? Also

how do you know about the rainfall/snowfall fraction as stated in L289 when you only measure precipitation?

Response: Thank you for pointing out this important issue. We greatly appreciate the reviewer's careful examination of the data sources and the method used to determine precipitation phase. We agree that the original manuscript did not provide sufficiently clear information on the data source of Fig. S4 or on how the precipitation phase was determined, which could lead to some confusion. First, we would like to clarify that the data presented in the original Fig. S4 (now Fig. 4) are reconstructed meteorological data based on AWS1 observations and ERA5 data, and then extrapolated these meteorological variables to each glacier grid cell using the corresponding vertical gradients. The grid-cell data were subsequently spatially averaged over the entire glacier to obtain glacier-wide mean meteorological conditions. Following the reviewer's suggestion, we have further clarified the data source and calculation method of Fig. 4 in the revised manuscript.

Regarding the rainfall and snowfall fractions mentioned in L289, we also greatly appreciate the reviewer for pointing this out. The precipitation measurements at AWS1 provide only the total precipitation amount and cannot directly distinguish between rainfall and snowfall. Therefore, the snowfall fraction presented in this study was obtained using the rain–snow partitioning scheme adopted in the model. The rain–snow partitioning method and its specific parameterizations are described in Supporting Text S1, Parameterizations used in the energy and mass balance model, starting from Supporting Text S1, L129. The relevant revisions are as follows:

Revised text (L310f): We compared meteorological conditions during the TC period with those during the baseline period using glacier-wide reconstructed meteorological data, ERA5 data, and point-based observations from AWS1 to characterize changes in meteorological conditions over the glacier.

Revised text (Supporting Text S1, L129f): P_{snow} is calculated by the total daily precipitation (P) and two critical air temperature thresholds for rain (T_{rain}) and snow (T_{snow}). Within the two temperature ranges, P_{snow} was calculated from linear interpolation as the following equation:

$$P_{snow} = \begin{cases} P & T \leq T_{snow} \\ \frac{T_{rain} - T}{T_{rain} - T_{snow}} P & T_{snow} < T < T_{rain} \\ 0 & T \geq T_{rain} \end{cases}$$

Specific Comments 9: L284f Regarding the comparison to the baseline period see above – comparing to the mean of precipitation over so few days is problematic if you include dry days. Percentiles are required!

Response: Thank you for this helpful suggestion. We agree that comparing the precipitation during the Tauktae-affected period only with the multi-year mean precipitation of the baseline period may not be sufficient to fully characterize the anomaly of the precipitation event, particularly when the baseline period contains many precipitation-free days. The low mean precipitation during the baseline period reflects the generally limited precipitation during this period. we have added the 90th percentile (P90) to the original Fig. 4, now Fig. 5, to provide a more comprehensive assessment of the anomalously high precipitation associated with TC Tauktae.

Specific Comments 10: L289f This precision falls I believe well within the range of uncertainty and either it is all snowfall in any case or the numbers are too high.

Response: Thank you for pointing out this issue. The snowfall fraction reported in the original manuscript was calculated from the snowfall amount obtained using the rain–snow partitioning scheme.

At the same time, we agree with the reviewer that, although these values can be obtained from the model calculations, reporting the snowfall fraction to two decimal places does not provide meaningful additional information when the snowfall fractions for both periods are already very close to 100%. Instead, it may imply an unnecessary level of precision. We have therefore removed the specific percentage values from the manuscript and revised the relevant statement to indicate that nearly all precipitation

during both periods was snowfall. The revised text is as follows.

Revised text (L318): As the event occurred in May, Ta at high elevations remained relatively low, and precipitation during both the TC period and the baseline period was dominated by snowfall.

Specific Comments 11: L294f You do not provide evidence for this statement, required.

Response: Thank you for this thoughtful comment. We recognize that the evidence was insufficient to emphasize the distinctiveness of the TC Tauktae event based solely on the duration of intense precipitation. We fully agree with the reviewer that the difference between three and four days is too small to support a statement that the Tauktae event was markedly distinctive. Therefore, following the reviewer's suggestion, we have removed the relevant statement emphasizing the longer duration and distinctiveness of the event.

Specific Comments 12: L296f: I don't think that a difference between 3 and 4 days is significant to warrant a statement of marked distinctiveness of this event.

Response: Thank you for pointing out this issue. We agree with the reviewer that the original manuscript compared the four consecutive days of precipitation during the TC Tauktae period with the typical duration of less than three days for other intense precipitation events, and used this comparison to emphasize the longer duration of the event. This statement may have placed too much emphasis on the relatively small difference in precipitation duration. In particular, the difference between three and four days alone is not sufficient to support the distinctiveness of the event in terms of duration. Following the reviewer's suggestion, we have removed the statement regarding the longer duration of the Tauktae-related precipitation event and revised the relevant text in L296–301 accordingly.

Specific Comments 13: L405ff and Figure 8, 9 and 10 This drops as something completely new in the Discussion and should be introduced in the Results first!

Response: We sincerely thank the reviewer for pointing out this issue. We agree that, in

the original manuscript, the results shown in Figs. 8, 9, and 10 were discussed in the Discussion section, but were not introduced and presented in the Results section beforehand, making the relevant content appear somewhat abrupt in the Discussion. Following the reviewer's suggestion, we have restructured the Discussion section and reorganized the relevant content into Section 5.2, "Spatial extent of the positive mass balance response to tropical cyclone Tauktae." This section builds on the mechanisms underlying the positive mass balance response identified in Section 4.4 and further uses ERA5 data to examine meteorological and energy-balance variables closely related to these mechanisms, including snowfall, albedo, cloud cover, and shortwave radiation. By analyzing the changes in these variables during the Tauktae-affected period and their anomalies relative to the mean conditions for the same period during 2000–2024, we assess the spatial extent of the positive mass balance response associated with Tauktae. Through this reorganization, we have established a connection between the mechanisms underlying the positive mass balance response identified in Section 4.4 and the spatial extent analysis presented in Section 5.2. Thus, Section 5.2 builds on the results already presented in the manuscript to further examine and interpret the spatial extent of Tauktae's influence, thereby strengthening the logical connection between the Results and Discussion sections.

Revised text:

5.2 Spatial extent of the positive mass balance response to tropical cyclone Tauktae

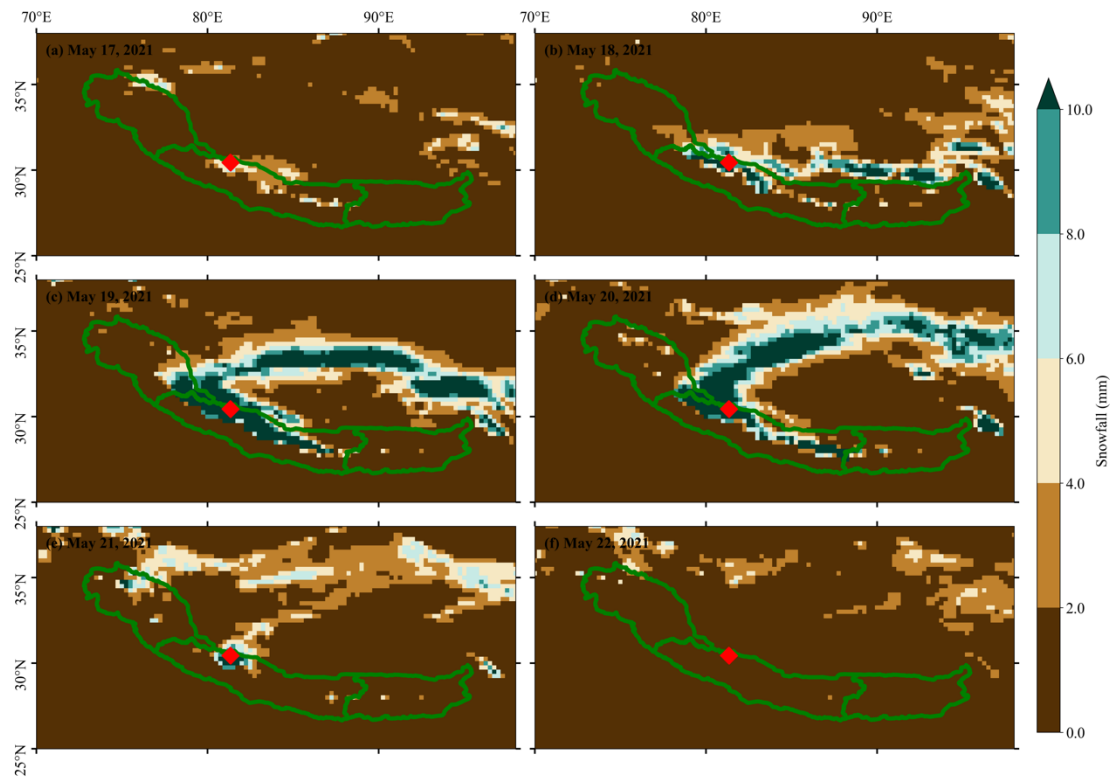


Figure 8: Spatial distribution of daily snowfall from ERA5 data o from May 17 to 22, 2021. The green solid line represents the extent and subdivision of the Himalayas. The red diamond markers indicate the location of Naimona'nyi Glacier. Panels (a)–(f) correspond to May 17–22, 2021, respectively.

During the TC period, increased cloud cover, enhanced snowfall, and the resulting increase in surface albedo were the main factors contributing to the positive mass balance response of Naimona'nyi Glacier. An important question is how far this positive mass balance response may extend spatially. To address this, we analyzed the spatial distributions of snowfall, cloud cover, surface albedo, S_{net} , and S_{in} during the TC period using ERA5 data, together with their daily anomalies relative to the climatological mean for the same period during 2000–2024, to identify the main area affected by TC Tauktac. The results show that areas of high snowfall mainly covered the central Himalayas during May 18–20 and were mainly concentrated around Naimona'nyi Glacier on May 21 (Fig. 8). From May 17–20, 2021, areas of high cloud cover occurred across the central and eastern Himalayas. On May 21, the high-cloud-cover area mainly confined to the Naimona'nyi Glacier region. On May 22, cloud cover

over the glacier further decreased (Fig S13). Areas of high surface albedo were mainly distributed over the central Himalayas during May 18–21 (Fig S14). Areas of low S_{net} and S_{in} mainly covered the central Himalayas during May 18–20; on May 21, these low-value areas contracted markedly and were mainly concentrated around Naimona'nyi Glacier, and they had largely disappeared by May 22 (Fig S15–16).

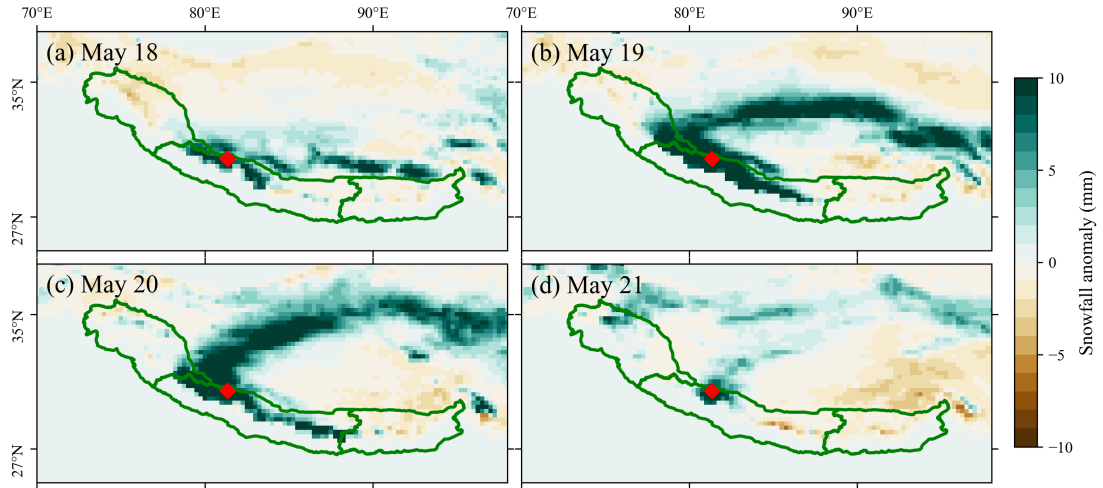


Figure 9: Daily snowfall anomalies on (a) May 18, (b) May 19, (c) May 20, and (d) May 21, 2021. Anomalies are calculated relative to the 2000–2024 climatological mean for the corresponding day of the year. The green outline denotes the Himalaya region, and the red diamond marks the location of Naimona'nyi Glacier.

Further analysis of the daily anomalies in snowfall, cloud cover, surface albedo, S_{net} , and S_{in} during May 18–21, 2021, relative to the climatological mean for the same period during 2000–2024, shows that on May 18, 2021, positive anomalies in snowfall and surface albedo were mainly concentrated over Naimona'nyi Glacier and its surrounding areas. On May 19–20, the positive anomaly areas expanded further and covered the central Himalayas (Fig. 9–10). By May 21, positive snowfall anomalies were mainly concentrated around Naimona'nyi Glacier (Fig 9), while positive surface albedo anomalies remained over the central Himalayas (Fig. 10). From May 18 to 20, 2021, positive cloud fraction anomalies were mainly distributed across the central and eastern Himalayas, while on May 21, 2021, they were largely confined to the area around the Naimona'nyi Glacier (Fig. S17). During May 18–20, S_{net} and S_{in} generally showed negative anomalies over the central and eastern Himalayas; by May 21, the negative

anomaly areas were mainly concentrated around Naimona'nyi Glacier (Fig. S18–19). Overall, the spatial distributions of the variables during the influence of TC Tauktae and their anomalies relative to the climatological background indicate that the meteorological influence of TC Tauktae extended to central and parts of the eastern Himalayas, whereas the snowfall and surface albedo perturbations closely associated with the positive mass balance response were mainly concentrated in the central Himalayas. Therefore, the positive mass balance response observed at Naimona'nyi Glacier may have extended to the central Himalayas.

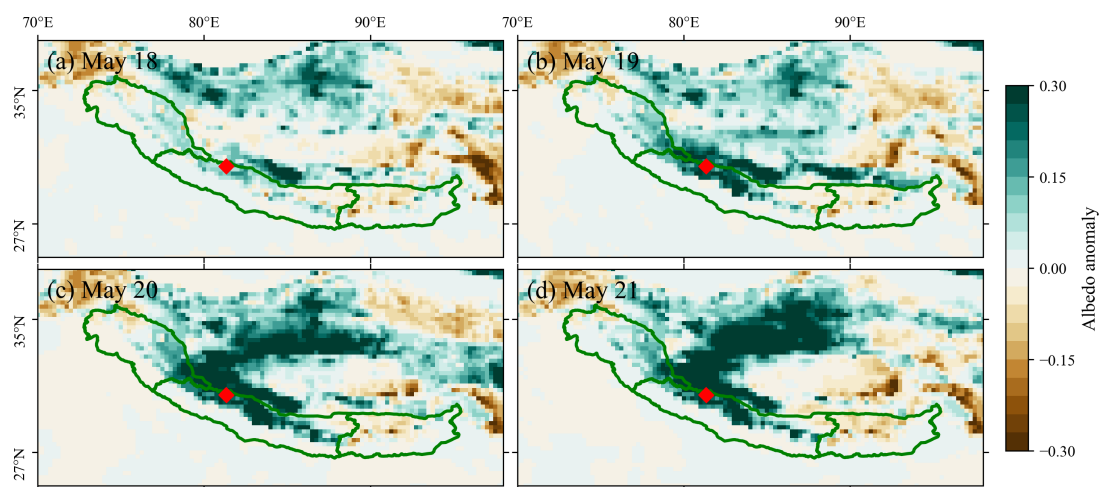


Figure 10: Daily surface albedo anomalies on (a) May 18, (b) May 19, (c) May 20, and (d) May 21, 2021. Anomalies are calculated relative to the 2000–2024 climatological mean for the corresponding day of the year. The green outline denotes the Himalaya region, and the red diamond marks the location of Naimona'nyi Glacier.

Specific Comments 14: L482f This section is material for the Introduction.

Response: Thank you for this important suggestion. We fully agree with the reviewer. The content beginning at L482 in the original manuscript mainly discussed the effects of tropical cyclones on hydrological processes, high-mountain ecosystems, and hazard risks from a general perspective, and was therefore more appropriate for the Introduction. We have thus reconsidered the purpose and content of this section and revised it accordingly. We removed the general background information from the original manuscript and instead based the revised section on our main findings regarding the impacts of TC Tauktae on Naimona'nyi Glacier. We further discuss the

potential effects of the snow accumulation and associated energy processes identified in this study on subsequent glacier ablation, runoff processes, and high-mountain hazard risks. The revised text is provided below.

Revised text (L518f):

5.4 Multiple impacts of tropical cyclones on glacierized regions

Our results demonstrate that TC Tauktae can influence the mass balance of Naimona'nyi Glacier through snowfall and associated changes in the surface energy balance. Although the positive mass balance response was mainly driven by the short-term snowfall and energy-balance changes during the TC period, the accumulated snow may continue to affect the glacier after the event. In high-altitude regions, snow deposited during the TC period can be temporarily stored in glacierized areas in solid form. During the subsequent ablation season, this snow is gradually melted and released, helping to sustain the stability of downstream river discharge, thereby partially alleviating seasonal water scarcity (Pritchard, 2019; Ultee et al., 2022). In addition, during the ablation season, deposited snow can increase surface albedo, thereby suppressing rapid glacier melt and lowering the risk of extreme meltwater events. At the same time, the snowfall associated with TC may also have adverse impacts on high-mountain ecosystems and human activities. In high-altitude pastoral regions, heavy snowfall can disrupt transportation networks and negatively affect pastoral production and livestock survival, and in some cases may even lead to livestock mortality (Li et al., 2018). In addition, anomalous snow accumulation can provide a mass source for avalanches. Snow entrainment can increase avalanche volume, while lubrication can facilitate snow movement and exacerbate avalanche hazards (Bartelt et al., 2016; Vera Valero et al., 2018; Zhuang et al., 2024). These potential effects suggest that the influence of TC events on glacierized regions extends beyond their immediate effects on glacier mass balance and may also affect hydrological processes and high-mountain hazards. Under a changing climate, studies suggest that the intensity of tropical cyclones may increase in the future (Swapna et al., 2022; Vidya et al., 2023). These findings highlight the need to further examine how TC activity may affect glacier mass balance and associated high-mountain processes over longer time scales and broader

spatial domains.