Response to comments and suggestions from Reviewer 1

GENERAL

A useful set of data on snow cover is presented for 22 years, and related to temperature, precipitation, elevation and time: data on glacier decline are also presented. A loss of cover is consistent but strongest at lower elevations. Inter-year variability is greatest in winter, and least for July-September. Temperature and precipitation is taken from reanalysis data, presumably based on sparse observations and with little control for higher elevations, so the results in section 4.2 should be accompanied by precautionary warnings.

A lot of clarification is needed, and the are some inconsistencies between text, Figures and Tables. It is not always clear what is being correlated with what. Perhaps 'trend' (temporal trend) should be used more often in the place of correlation, in some passages: e.g. 'negative trends with correlations over time of …'..

Some numbers have too many decimal places. Given that some error is inevitable, more rounding should be employed.

Response: Dear reviewer, thank you so much for your thorough and detailed evaluation of the manuscript. Your careful, line-by-line examination identified several errors, omissions, and unaddressed aspects within the text, figures, and tables. I have carefully reviewed my manuscript and incorporated almost all of your comments and suggestions.

In this study, land surface temperature (LST) data at a spatial resolution of 1 km were obtained for 204 locations from MODIS Terra (MYD11A1) and Aqua (MOD11A2) products, processed via the AppEEARS platform. Precipitation data were sourced from the ERA5-Land reanalysis dataset provided by ECMWF (Hersbach et al., 2020).

I acknowledge that the coarse spatial resolution of these datasets necessitates cautious analysis and interpretation. The manuscript does not currently address the variability in topography within the 1 km resolution of the MODIS-derived LST data or the precipitation data derived from reanalysis. Nonetheless, the importance of averaging over larger spatial units remains a significant consideration and should not be overlooked. Please review the comments from Reviewers 2 and 3, where I have made an effort to provide thorough responses.

Discussion is revised and made short without repetition.

SPECIFIC

Line 110 With such relief, surely precipitation must vary more than this?

Response: We have corrected. Precipitation varied from 250 to ~ 1900 mm annually.

136-143 What effect did the cloud removal have (in biasing coverage, both spatial and temporal)?

Response:

Relying on optical remote sensing data in the Himalayan mountain region presents a major limitation. Obtaining cloud-free imagery that consistently covers the entire area and time period is a significant challenge, especially during the pre-monsoon and monsoon seasons. As a result, snow is underestimated in cloud-covered zones, which can lead to potential inaccuracies in seasonal and spatial snow cover assessments.

To overcome this challenge, we combined high-temporal-resolution eight-day composite MODIS data with high-spatial-resolution Landsat imagery, which enabled effective monitoring and seasonal analysis. This integrated approach to a greater extent compensates for the limitations of individual datasets and supports consistent long-term cryospheric assessments in cloud-prone mountain regions like the Upper Karnali Basin.

Section 4.1 text implies a graph for annual cover is necessary: only the 4 seasons are illustrated..

Response: Annual average snow cover is included in the graph.

190 Sen's slope is not defined. It seems to be the gradient of the regression line over time, so why is attribution to 'Sen' needed?

Response: Sen's slope is defined, and its importance in analyzing the trend has been highlighted (see footnote of Table 1)

207 These Fig.2 graphs are initially puzzling in that Oct-Dec shows the steepest trend line but is insignificant, while July-Sept seems flatter but has the only significant trend. This seems to relate to the lower variability of July-Sept (SD 38 cf. 212-373, Table 1).

Response: The July–September period exhibits a gentler trend line compared to October–December; however, because of its much lower interannual variability (with a standard deviation of 38.3 km² compared to 212–373 km² for other seasons, as shown in Table 1), the trend remains statistically significant. The revised manuscript now includes an explanation clarifying how variability influences the determination of significance.

Comments: Why is the correlation positive below 2000 m (Fig.7) and below 2300 m, where the T is rising (Fig.8)? Are the data so limited below 2000 m that it should perhaps be dropped? Fig. 9 shows that warmer years have less snow cover, consistently across all elevations (although<2000 m is not shown).

Response: At lower elevations (≤2000 m a.s.l.), snow cover exhibits a weak positive correlation (0.12-0.43), likely caused by occasional snowfall during short cold spells and shift between rain and snow (Pendergrass, 2020). These zones experience high year-to-year variability (CoV ~41–43%), making trends less reliable, which should be interpreted with caution. Similar elevation-sensitive variability has also been reported in other Himalayan basins (Pepin et al., 2015).

DETAILED

88 'above'

Response: Above

90 ‘within Nepal’

Response: Corrected

107 and 150 Ghimire is not in References.

Response: Reference added (Ghimire et al (2025).

118 This identifies 3 rivers , but not Kawari. Also, the upper Himla is apparently labelled ‘China Karnali’ in Table 2, but that has not been specifically located.. There should be a closer relation between map and text (and Table).

Response: Map is corrected and missing information are included, text, and table are updated and are matched with map. To clarify, Humla Karnali in Chinese territory has been labeled as Humla Karnali (China). Similarly, the downstream part of the Karnali has been labeled as Karnali (downstream).

132 delete ‘then’

Response: Deleted

134 ‘sub-basin’

Response: Corrected to sub basin.

162 Why central? not sub-glaciers. Perhaps ‘both glaciers and surrounding slopes’? Is ‘fed by’ appropriate ?

Response: Corrected as “Glacier basins are areas that include trunk and sub-glaciers, along with surrounding slopes, which are nourished by moving ice and snow.”

185 424?? Table 1 shows a July-Sept min of 169 and an annual min of 514.

Response: corrected in the result and discussion with reference to Table 1. Measures of Mean, Max, and Min, and percentiles, and sen’s slopes were included in the Table 1.

186 640.32 does not appear in the 25% row in Table 1.

Response: Corrected as in Table 1.

192 & 202 Unfortunately, Fig. 2 does not show annual averages.

Response: Annual average included in Figure 2

199-201 I am unsure what this sentence means and how it relates to Fig.2. Also it needs a verb.

Response: The unclear sentence has been revised as “Episodic snow coverage was observed in 2015, 2020, and 2022 (January–March), 2015 and 2019 (April–June), 2009, and 2021 (October–December), indicating anomalous years of high episodic heavy snowfall events”

204 Fig.2 The heading is unhelpful. I suggest the more precise ‘Annual and seasonal snow cover statistics (km2) with correlations of the trends, 2002-2024.’

Response: Corrected and caption of the figure has been revised.

204-5 Strange that Kendall’s tau does not show a negative trend like all the other correlations. Is tau appropriate here?

Response: In Table 1, Kendall’s Tau complements Sen’s Slope by indicating the statistical significance and direction of trends, especially emphasizing the significant decline in snow cover during July–September. Its inclusion enhances the robustness of trend analysis and supports key findings in the study. For April–June in Table 1, Kendall’s Tau value is positive (Tau = +0.013, $p = 0.95$). It indicates a statistically insignificant upward trend in snow cover during this season over the 2002–2024 period. This may be due to random year-to-year variation rather than a consistent long-term pattern.

210-211 Fig.3 does not show negative dominating: it is close to balance, with April-June (more negative) balancing Oct-Dec (more positive)

Response: Figure 3 has been enhanced by describing the number of locations showing positive and negative correlations. I have added another graph illustrating the annual temperature trend, which shows that approximately 70% of locations exhibit positive correlations. Although a few locations display statistically significant correlations ($p<0.1$), the overall trend remains positive.

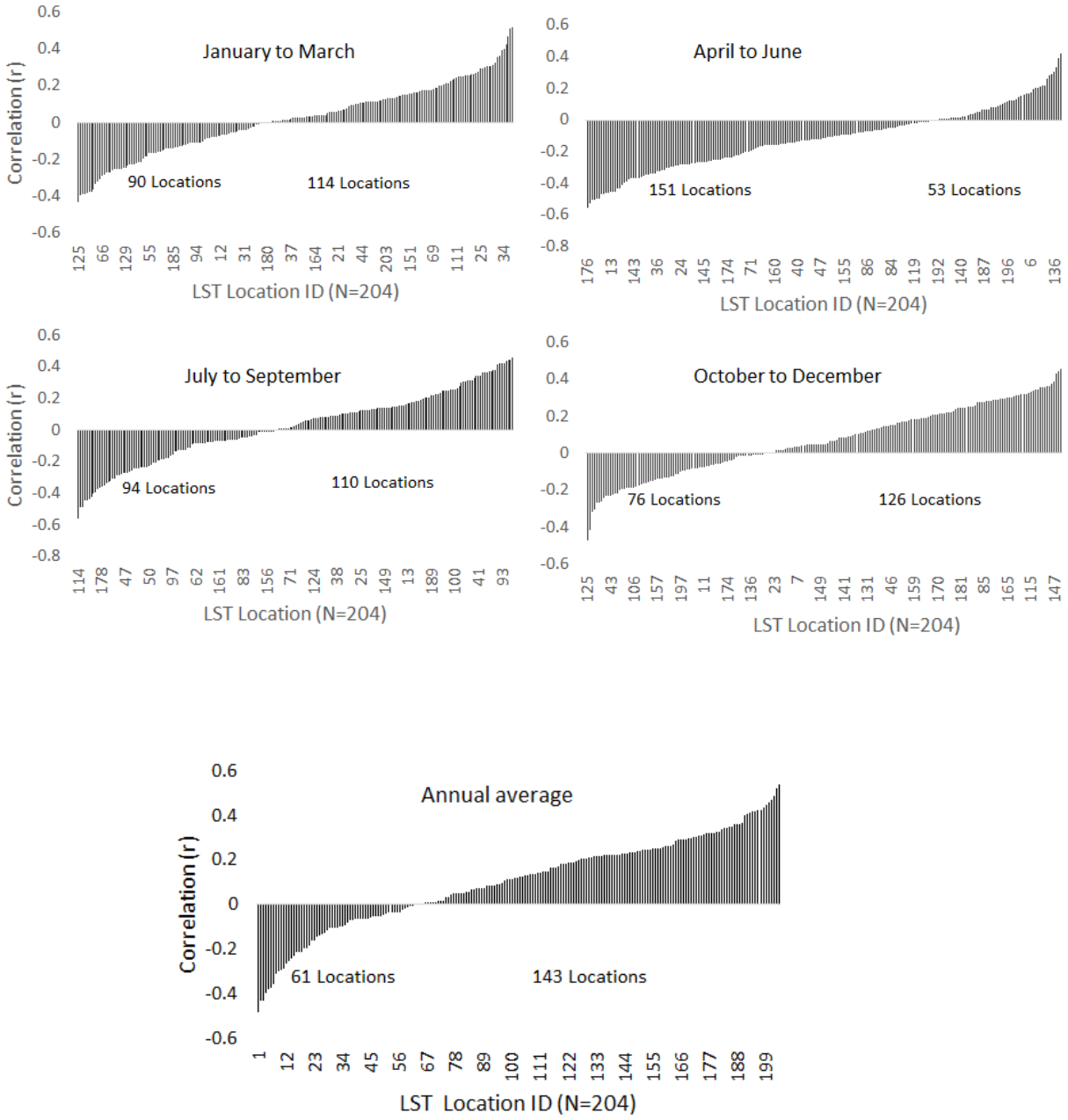


Figure 3

212 Incorrect. Fig.4 shows positive trends (probably insignificant) except for Jan-Mar. Why 'June-July'?

Response: Corrected and revised the paragraph as

"Seasonal rainfall trends from 2000 to 2024 indicate weak to moderate increases across all seasons except winter (January–March), during which rainfall exhibits a slight downward trend (R^2= 0.0144) (Figure 4). Pre-monsoon (April–June) rainfall shows a slight upward trend (R^2 = 0.0119). All these

seasons display high variability, suggesting a limited impact on snow accumulation. Monsoon rainfall (July–September) demonstrates a more noticeable increase ($R^2 = 0.0975$), primarily contributing to rainfall rather than snowfall. Post-monsoon (October–November) precipitation remains low and stable. When combined with rising temperatures, these trends indicate a shift toward rainfall-dominated precipitation, reduced snowfall, and earlier snowmelt, contributing to declining snow cover and altered hydrological regimes".

215-217 This explanation of the 204 sampled should precede 210-211.

Response: The lines (215-217) describing the sources of temperature and precipitation data have been placed before 215-217.

219 should be '-0.59 to -0.77'

Response: Corrected

222-224 More concisely 'Precipitation and temperature are negatively correlated in winter (Oct-March) and positively in the summer (April-September) half-year'.

Response: I have replaced the previous lines with the above suggested lines.

225 Fig.3 How were the 19 correlations plotted here selected from the 206 or 204) ? And perhaps the altitudes of these locations are important, explaining the wide variability / lack of spatial consistency?

Response: Figure 3 illustrates the temperature trends across various locations, which spatially range from negative to positive values. Only a few locations exhibit statistically significant trends in both directions, defined by a correlation coefficient exceeding ±0.4 and a p-value less than 0.05. In this figure, the altitudes of locations are not indicated. Given the spatial variability and inconsistency in the trends, we concur that altitude and topographic differences likely play a significant role. This aspect is further examined in Figures 7, 8, and 9, as well as Table 3, which analyze elevation-dependent warming patterns and correlations across different elevation bands. Additionally, a clarifying sentence has been added to the text to guide readers that elevation-dependent warming patterns and correlations across elevation bands will be discussed in the subsequent sections.

Fig. 4 would be improved if annual average values were connected by straight lines rather than curves: or if dots were used.

Response: Figure 4 is improved by connecting average values with straight lines. Similarly, curved line in others figures were also converted to straight line.

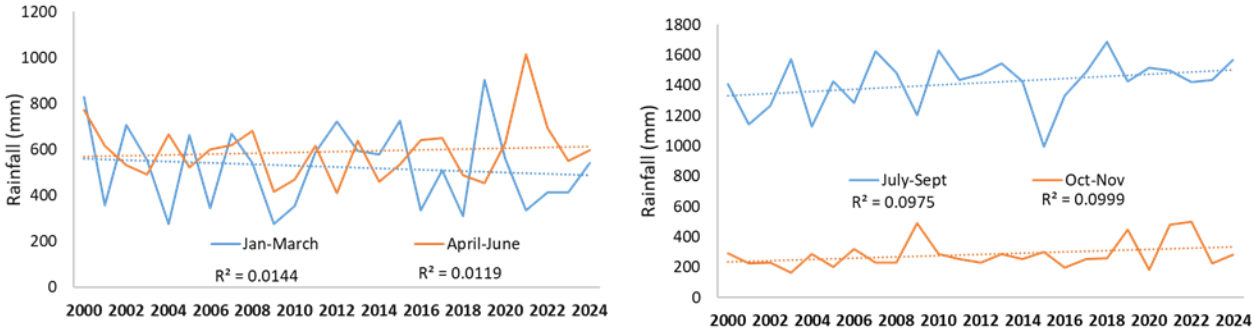


Figure 4

Fig.5 Larger numbers (on the coloured backgrounds) would clarify.

Response: Figure five improved as suggested

235 Presumably 'over the 22 years'.

Response: Included the number of years in the caption of Figure 5.

240 November?? What happened to December?

Response: Corrected

254 'the variability is strongest' is a duplication.

Response: Duplication removed

242-257 All this makes sense in terms of altitude: the lowest area (downstream) has the least and most variable snow cover, and a define decline with warming over the 22 years.

Response: The varying variability due to elevation difference and dependent warming is Figure 7,8,and 9 and explained in the upcoming sections

269 & 285 State what snow cover is being correlated WITH – i. e. time?

Response: Explained by adding a sentence, "The seasonal correlation matrices (Figure 3,4, and 5) illustrate how Landsat-derived snow cover area is statistically correlated with corresponding seasonal temperature and precipitation, rather than with time itself. This helps identify the climatic controls on snow cover dynamics across seasons."

269 'in the lowest'

Response: Revised as 'lowest'

283 delete ‘elevation’

Response: ‘elevation’ deleted

289 No: Figure 8, not 5.

Response: Corrected as Figure 8

316 delete ‘the’

Response: deleted

320-=321 What a truism! Deleted the sentence

Response: Deleted, and I agree with the statement that was so obvious and therefore hardly worth mentioning.

334 delete ‘(able’

Response: deleted

335 Too many decimal places. Drop ‘.163’ - of the order of a thousandth of a percent of the total area: surely spurious accuracy.

Response: Corrected, reduced to one decimal place.

337 Drop ‘, indicating a relative reduction in glacier coverage’ - another unnecessary truism.

Response: Deleted the obvious part of the sentence.

342 Yes, but S shows the largest absolute loss. You might also consider the relative (%) loss for each direction class.

Response: Relative (%) losses for each slope direction class have been included in the text.

343 Delete ‘Northeast (NE),’ which is repeated.

Response: Deleted the repeated ones

Fig.10: The order is illogical; these should be in rank order, e.g., NW, N, NE, E, SE, S, SW, W.

Response: Slope directions of the glacier has been put in appropriate order in fugure.

358 “May , June & July” straddles two of the seasons in the Figures.

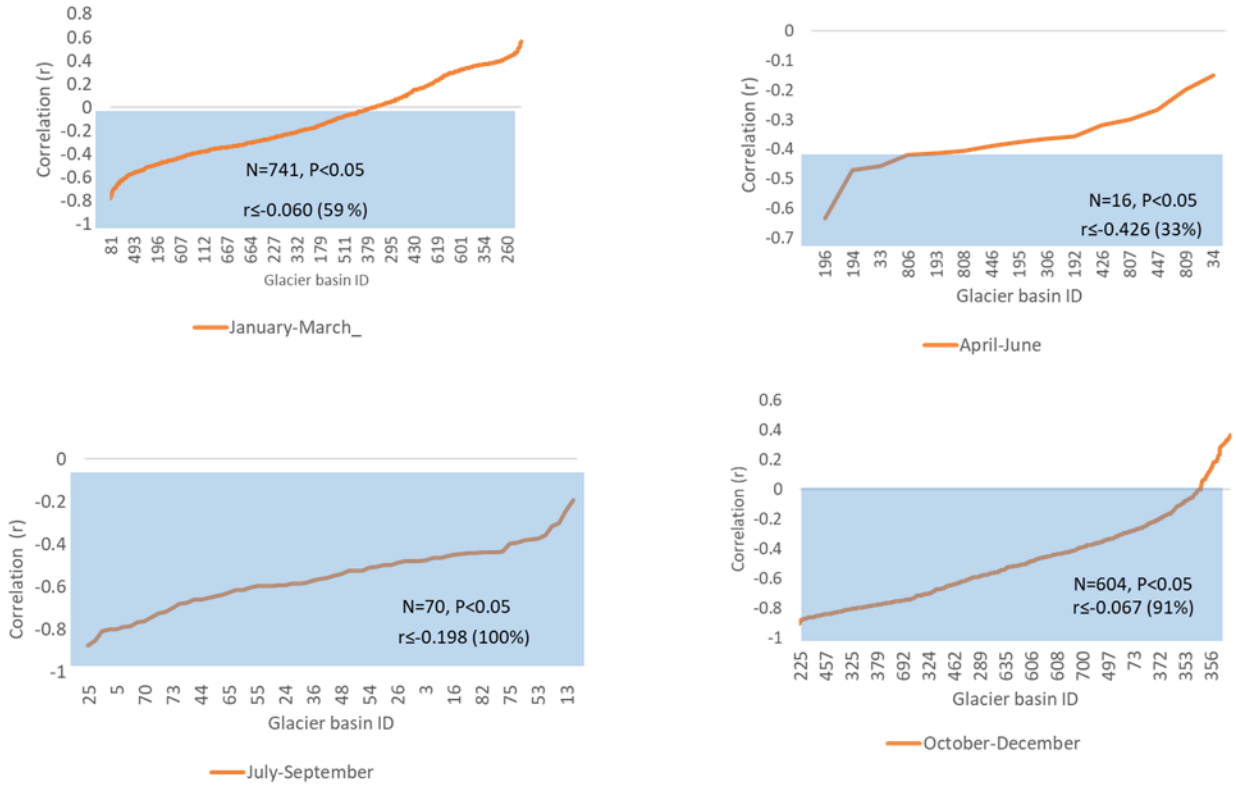
Response: Corrected as May–July

361 delete '(n='

Response: Deleted

361 "84%" is not apparent in any part of Fig.11.

Response: The whole Figure is corrected and updated and the text has been revised.



363 Fig. 11 Does the orange line relate to all basins, rather than just the selection whose IDs are given?

Response: Due to cloud cover, not all glacier basins for different seasons were analyzed. Therefore, the orange line does not represent all basins, but only cloud-free glacier basins in a given season.

369 'in the remaining basins'

Response: Corrected

415 What does "although this precipitation does not appear to facilitate snow accumulation" mean? Mean? Where is the evidence?

Response: A positive correlation between precipitation and snow accumulation does not necessarily imply a direct causal relationship whereby precipitation contributes to snow accumulation. Although these phenomena may coincide temporally, precipitation may occur in forms other than snow. In the

Upper Karnali Basin, particularly during the winter months, warmer winter temperatures associated with climate change can result in precipitation falling as rain rather than snow. Regional and global observations indicating that warming trends increase the proportion of rainfall even during seasons traditionally characterized by snowfall (e.g., Wester et al., 2019; Kraaijenbrink et al., 2021).

417 "rain instead of snow" is temperature-dependent and thus elevation-dependent.

Response: The line has been revised and has incorporated the above.

431 ? exhibits … 'less'?

Response: Corrected as "exhibits less snow cover".

432-437 duplicates 423-428. Poor editing!

Response: It was a mistake; the duplicate paragraph has been removed.

454 Yet Fig. 8 and line 293 suggest reduced warming high up.

Response:

460 'inter-annual snow cover variability '

Response: Included 'inter' in the sentence

461 3700 m ? from Fig.8.

Response: Corrected as above 3000 m

462 4100 m? "

Response: Corrected

473 'reveal'

Response: Corrected

474-475 Too many decimal places.

Response: Decimal place reduce to one or two.

528—529 Decimal places !

Response: Decimal place reduced.

571 delete one 2014

Response: deleted

589 give authors

Response: Reference deleted

595 delete “(last ….”

Response: Deleted from the reference

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Response: Will be cited