

Response to Community Comment (CC1) by Authors

General Comment

The manuscript does not demonstrate sufficient novelty, methodological rigor, or scientific contribution to merit publication in its current form. Most findings reiterate well-established results from previous studies in the Himalaya, and the manuscript lacks a clearly articulated research gap, robust methodology, or quantitative analyses to substantiate its interpretations. Significant conceptual, methodological, and presentation issues further weaken the study.

We thank the community member for their comment and for taking the time to evaluate our manuscript. Please find our responses (in blue) in reply to comments (in black) below-

We respectfully disagree with the assertion that the study lacks novelty, methodological rigor, or scientific contribution, as it is contradicted by the evidence presented in the manuscript

The value of this study and primary aim lies in the multi-decadal velocity evolution quantified using consistent state-of-the-art methods, the integration of velocity trends with elevation-dependent mass loss, or the regional-scale synthesis across climatically and dynamically distinct Himalayan glaciers (Zankar region), which addresses a critical data gap in High Mountain Asia. The research gap is clearly articulated in the final paragraph of the Introduction, where we explicitly identify the missing link between short-term or two-epoch variability studies and long-term velocity variations, a gap our 30-year dataset is specifically designed to fill. While earlier work has reported glacier velocity changes, most studies focus on isolated glaciers, short time spans, or qualitative interpretations. In contrast, our analysis provides annual glacier velocity quantification for a long temporal period, allowing us to robustly assess long-term velocity patterns and their controlling mechanisms.

Regarding methodological rigor, the study employs a state-of-the-art methodology utilizing a multi-sensor approach, uncertainty-aware trend analysis, which are standard and widely accepted in glacier dynamics, and are explicitly detailed in Section 3. Furthermore, we have further strengthened the manuscript by explicitly reporting uncertainties (discussed in Section 3.4 and presented in Table S2), justifying methodological choices, and adding quantitative metrics to support our interpretations and a critical analysis of the data, its limitations.

We also respectfully note that identifying agreement with previous studies does not diminish scientific contribution. Rather, our results corroborate, extend, and contextualize earlier findings by placing them within a longer temporal framework and across a broader spatial domain. This synthesis is particularly valuable in the Himalaya, where long-term, consistent velocity analyses remain limited.

Our interpretations are substantiated by comprehensive quantitative analysis, including statistical assessments and critical analysis of the data generated.

Specific Comments

1. Lack of Novelty and Insufficient Contribution

The manuscript largely repeats previously published results on glacier velocity, surface elevation change, and heterogeneous glacier response in the western Himalaya (e.g., Dehecq et al., 2019; Bhambri et al., 2023; Garg et al., 2025). The conclusions on glacier thinning, deceleration, debris-cover influence, and behaviour of lake-terminating glaciers are all well documented in existing literature and are not presented with new insights, methodological improvements, or conceptual advances.

The study area (Zaskar Basin) has already been extensively analysed (Rai et al., 2012; Pandey et al., 2012; Shukla & Qadir, 2016; Rana et al., 2023; Jasrotia et al., 2023; Mandal et al., 2024). The manuscript does not convincingly demonstrate how its results expand current understanding or address an unmet research need. The authors claim earlier works cover limited time periods, but Bhushan et al. (2018) computed regional mass budgets for 1999–2014, and Rana et al. (2023) produced velocity time series from 1999–2021. It is unclear what genuinely new temporal dataset or insight the present manuscript adds.

Response:

We appreciate the community member citing relevant literature, though we must strongly refute the assertion that our work merely repeats established results or that the Zaskar Basin has been "extensively analysed" in the context of our specific contribution. Our manuscript expands current understanding through a unique, long-term dataset using state-of-the-art methodology that addresses the precise limitations of the cited works.

Our study presents a new, long-term, 30-year dataset (1992-2023) for the Zaskar glaciers. Crucially, the cited works, while valuable, rely on either yearly snapshots or single annual velocity (e.g., Bhushan et al., 2018: 2013–14; Jasrotia et al., 2024; 1999-2000 & 2019-20). Such approaches do not resolve multi-decadal trends or the spatial heterogeneity of glacier slowdown, which is critical given the non-linear and location-dependent nature of glacier dynamics. Also, Rana et al. (2023) produced a time series of velocity from 1999-2021 are factually incorrect. The study focuses on a single glacier and only for these two time periods, and not a time series dataset. Our long-term velocity time series provides critical insights into the evolution of glacier dynamics in the region.

2. Issues in the Introduction

The Introduction incorrectly implies that earlier studies provide only short-term or two-epoch comparisons. However, prior works already assess long-term glacier changes. The manuscript must clarify what additional value its stated 1992–2023 velocity record brings, especially given the absence of field validation and without clear methodological innovation.

Response:

We thank the community member for raising this point and agree that several studies have assessed long-term glacier changes in parts of the western Himalaya. However, we respectfully note that for the Ladakh/Zaskar region specifically, no previous study provides a multi-decadal glacier velocity record in detail comparable to the 1992–2023 time series

presented in this study. The studies cited and others either (i) focus on single glaciers and/or other analyses related to length and area changes, (ii) examine mass balance or surface elevation change rather than glacier velocity, or (iii) analyze velocity over limited time windows or between discrete epochs. To the best of our knowledge, no published study resolves long-term, spatially multi-glacier velocity evolution in the Zaskar Basin.

Regarding field validation, we note that the study relies on a widely used method measuring uncertainty with stable ground validation for developing satellite-based velocity products, consistent with numerous peer-reviewed glacier dynamics studies in data-sparse regions. Thus, we have clarified the limitations and strengthened the uncertainty discussion accordingly.

3. Study Area Description – Conceptual and Factual Errors

- The authors state that they selected 12 glaciers: 11 valley glaciers and one cirque glacier (G12). However, **G12 is misclassified**, as it is a well-developed compound glacier system, not a cirque glacier.
- The basis for selecting these **12 glaciers out of ~1700 in the basin** is not explained. The authors must justify:
- The total glacier count used for the basin, the criteria for choosing these specific glaciers, and how these 12 glaciers adequately represent the climatic and geometric diversity of the Zaskar region.
- **Figure 1 is confusing**, with poorly defined basin boundaries and unclear representation of which glaciers actually lie within the Zaskar Basin.
- If the goal is to derive generalizable interpretations, it is unclear why glaciers from different aspects, elevations, and climatic settings were not included.

1. Figures and Field Photographs

- Figures 1b and 1c serve no scientific purpose as presented. They lack annotations, interpretation of field features, or justification for inclusion.
- If fieldwork was performed, photographs of all studied glaciers or at least representative examples should be provided, not just two uncontextualized images.

Response:

We thank the community member for this comment. We respectfully note that the basis for selecting the 12 glaciers is already described in the manuscript and supported by the glacier attributes summarized in **Table 1**. As stated in **Section 2**, the selected glaciers span a broad range of elevations, glacier lengths and areas, debris-cover fractions, aspects, and terminus types, allowing us to examine heterogeneous dynamical responses within the Zaskar Basin. Table 1 documents these attributes for each glacier, demonstrating that the selection captures the geometric and surface-condition diversity relevant to glacier dynamics in the region. The selected glaciers, therefore, represent dynamical diversity, rather than inventory completeness, which is appropriate for the study's focus on glacier slowdown mechanisms.

Figure 1 was intended to provide geographic context for the study area and the locations of the selected glaciers. We recognise that the basin boundary and glacier identification were not

sufficiently clear in the original figure. This will be updated in the revised version of the manuscript.

Figures 1b and 1c were included solely to provide visual context of the study area and representative glacier conditions, rather than to document or interpret specific field morphologies. The manuscript does not rely on these photographs for any quantitative or qualitative analysis. We note that the study is primarily based on satellite-derived datasets, and comprehensive photographic documentation of all studied glaciers is beyond the scope of this manuscript and not required to support the analyses presented.

4. Methodological Details Are Missing or Incomplete

The manuscript lacks critical methodological information necessary to evaluate scientific reliability:

- The abstract and introduction mention “long-term velocity datasets (1992–2023)” but do not specify:
- Satellite missions used,
- Spatial/temporal resolutions,
- Coregistration procedures,
- Uncertainty estimation,
- Filtering and post-processing of displacement vectors.
- **No validation** is provided against ITS_LIVE, MEaSURES, field data, or previous studies, raising serious concerns about accuracy.
- Glacier boundary delineation and the strategy for sampling along flowlines are not described, and the location of the mentioned flowlines (e.g., Line 264) is not shown.
- The claim of assessing “drivers of velocity change” is unsupported by any physical or statistical modelling.
- The method for surface elevation change relies entirely on previously published datasets (Hugonnet et al., 2021) without explanation of why no DEM differencing was performed by the authors.

Overall, the methodological gaps are substantial and undermine confidence in the results.

Response:

We respectfully note that most of the concerns raised about methodological details do not reflect the actual content of the manuscript and are misrepresented, which is already present and addressed in the manuscript.

Satellite missions, spatial/temporal resolutions, and processing:

- Section 3 (Data and Methods) explicitly lists the satellite missions/sensors used, including the temporal coverage (1992–2023), spatial resolution of each dataset provided in detail in Supplementary section S1.
- Data Information, and the procedure for co-registration provided in section 3.2.1 (Image Correlation) and post-processing of displacement vectors.
- Filtering steps and quality control are provided in section 3.2.2 (3.2.2 Filtering Process) and
- uncertainty estimates are also described and provided in section 3.2.3 (Uncertainty Estimation) and uncertainties reported in Table S2.

Validation of data-

- The validation and quantification of velocity uncertainties was estimated based on stable ground points. Comparison with other velocity products, such as ITS_LIVE, could be added in the revised manuscript.

Glacier boundaries and flowline sampling-

- Glacier boundaries were derived from RGI V7, and the methodology for flowline delineation is also described and provided in Section 3.4.

Surface elevation change dataset-

- We rely on the Hugonnet et al. (2021) dataset because it provides high-resolution, multi-temporal, uncertainty-aware surface elevation change across the study region. Generating new DEMs was not the primary focus of this study, and using existing high-quality datasets ensures methodological consistency and allows us to concentrate on the main goal- velocity evolution.

5. Results – Conceptual Ambiguities and Incorrect Statements

- The discussion comparing median velocities among glaciers is unclear and inconsistent. For example, G12 is characterised as a cirque glacier but then attributed low velocity to “geometry and ice thickness,” despite being a well-developed compound glacier.
- Statements about lake-terminating glaciers exhibiting accelerations lack supporting analysis and do not engage with glacio-hydrological processes documented in the literature.

Response:

We respectfully note that the reviewer’s statement regarding “unclear and inconsistent” comparisons of median velocities is not supported by specific references or examples. For glacier G12, its lower velocity is explicitly attributed to its along-flowline geometry and ice thickness, consistent with the physical understanding of glacier dynamics. Also, we corrected the G12 as reported as a cirque glacier. All mean velocity comparisons are presented in **Figures 3, 4 and Table 2**.

Statements regarding the acceleration of lake-terminating glaciers are based on quantitative, spatially resolved velocity analyses, as presented in Figures 3 and 5. While the current study does not implement full glacio-hydrological modelling, we explicitly discuss these accelerations in the context of glacier geometry, terminus retreat and force balance changes, consistent with the current literature. Any causal interpretation involving glacio-hydrological processes would require further detailed modelling experiments, which are beyond the scope of this observational study.

6. Weak Analysis and Overgeneralised Interpretation

- The manuscript broadly attributes glacier deceleration to surface lowering and reduced driving stress without performing:

- Stress-balance calculations,
- Velocity–thickness scaling analyses,
- Regression between thinning and velocity change.
- Assertions regarding the influence of debris cover, glacier geometry, and lake termini remain anecdotal. No figures, quantitative assessments, or statistical metrics are provided.
- **Uncertainty estimates** for velocity and elevation change are absent, making it impossible to judge the significance of the reported trends.

Response:

We thank the community member for the comments, but we respectfully note that several statements misrepresent the manuscript.

The study does not claim to provide a complete stress-balance solution. Rather, we employ a physically interpretable framework where long-term velocity trends are evaluated relative to observed elevation change, debris cover, glacier geometry, and terminus type. Along-flowline analyses and comparative plots (Figure 3, 5, 6 and Figure S1) provide robust, quantitative evidence for the relationships between thinning and velocity change. All statistical metrics are provided based on elevation change (Figure 7), velocity trend (Figure 3 and Table 2) and correlation with different geometry factors (Figure 9). The analyses are far from anecdotal and are grounded in robust, observationally derived data. The uncertainty estimates of the velocity fields are estimated using robust methods and are reported in the supplementary material.