In-situ measurements reveal drastic intra-regional differences in glacier ablation in Ladakh

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In the present study, we report pronounced intra-regional disparities in glacier ablation between the Pensilungpa and Rulung glaciers located in western and eastern Ladakh, respectively, as evidenced by *in-situ* measurements conducted during 2023–2024. The Pensilungpa glacier exhibited the point ablation ranging significantly from –0.50 to –2.93 m w.e. a^{-1}, demonstrating substantial ablation variability. In contrast, the Rulung glacier's point ablation values range narrowly from –0.81 to –1.34 m w.e. a^{-1}, indicating uniformity. The ablation area-wide mass balances were -1.08 ± 0.28 and -0.70 ± 0.18 for Pensilungpa and Rulung, respectively. A comparative analysis reveals that Pensilungpa's ablation-area-wide mass balance was 53.5% higher than that of Rulung glacier. This significant disparity is largely attributable to the distinct altitudinal profiles of the Pensilungpa (4649–5858 m above sea level (asl)), and Rulung (5693–6232 m asl) in conjunction with variable snow inputs. Furthermore, despite the presence of substantial debris on the Pensilungpa, which typically insulates and mitigates ablation, our observations suggest that the higher temperatures at lower altitudes override the debris's insulating effects. These complex ablation patterns underscore the need for comprehensive evolutionary studies to ensure effective water resource management in the already water-stressed region of Ladakh.

Keywords: Glacier ablation, *in-situ* measurements, Ladakh, Pensilungpa glacier, Rulung glacier, trans-Himalaya.

THE global temperature rise has led to glacier decline worldwide, including in the Himalayan-Karakoram (HK) region, which is often referred to as the third pole, as it is one of the most heavily glacierised mountain regions on Earth[1]. Within the HK region, the cold-arid regions of Ladakh account for almost 50% of the glaciers of India[2]. Owing to acute aridity, most glaciers in Ladakh are small (< 0.75 km^2) and located at very high altitudes above 5200 m above sea level (asl)[3]. Despite their small size, the water stored in these glaciers supports the lives and livelihoods of the sparsely distributed population in Ladakh and eventually sustains the regional food security and socio-economic development[4]. Particularly in low precipitation years, the meltwater becomes the major source of water supply to the region[3]. Still, the Ladakh region is the least studied in terms of glaciological research.

However, there has been large spatial heterogeneity in glacier response to climate change across the Himalayan region[5]. Whilst glaciers in the monsoon-dominated eastern and central Himalaya, as well as monsoon-arid western Himalaya, are retreating, Karakoram glaciers have been stable[6]—a phenomenon termed as 'Karakoram Anomaly', which seems to be approaching its end now[7]. Ladakh region, located in the north-west of the western Himalaya, is a transition region between two distinct glaciological regimes: melting glaciers of the western Himalaya and near-stable glaciers of the Karakoram, making it a zone of interest for detailed glacier studies.

Notably, within Ladakh, there exists a high spatial heterogeneity in glacier response. Mandal *et al.*[8] investigated the mass balance of 3779 (3498 km^2) glaciers from western and eastern Ladakh and noted a marked difference in mass loss as -0.35 ± 0.07 m w.e. a^{-1} and -0.21 ± 0.07 m w.e. a^{-1}, respectively. They argued that while warming is the main driver of widespread mass loss in Ladakh, glacier size and altitudinal differences played a major role in this intraregional heterogeneity. Yet, field-based studies delving into this stark difference in glacier states do not exist. Markedly, only six glaciers have so far been surveyed in Ladakh for *in-situ* glaciological mass balance measurements. Rulung glacier (4.59 km^2) was observed for its mass balance only for two years over 1979–1981

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