EGU25-10423, updated on 16 Apr 2026
https://doi.org/10.5194/egusphere-egu25-10423
EGU General Assembly 2025

Reconstructing the water balance of selected glacierized catchments in High Mountain Asia since 1970

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In High Mountain Asia (HMA), declines in water stored in glaciers and seasonal snowpacks have been widespread in recent decades. Changes are however highly heterogeneous, with glaciers in the Pamirs experiencing near-neutral mass balance while fast rates of mass loss are observed in the Southeastern Tibetan Plateau. Modeling can provide an understanding of mass balance seasonality and mountain hydrology at a spatial and temporal resolution not achievable by observations, and validated simulations can extend over long time scales. Quantifying the water balance at high elevations requires the estimation of snowfall amounts, which is challenging due to uncertainties in reanalysis products and rare precipitation measurements. Differences in accumulation regimes and precipitation decadal variability complicate the assessment of precipitation phase change and its role in glacier and snow mass changes under warming conditions.

In this study, we leverage in-situ hydro-meteorological observations and climate reanalysis to run a mechanistic, highly resolved land-surface model and reconstruct snow and glacier mass changes since 1970 at three benchmark glacierized catchments with contrasting climatic conditions in HMA. The catchments cover areas between 100 and 200 km2, span elevations ranging from 2000 to 6000 m a.s.l., and are located in the Northwestern Pamir (Kyzylsu), Nepalese Himalayas (Trambau-Trakarding) and Southeastern Tibetan Plateau (Parlung No.4). The land-surface model is run at hourly and 100 meters resolution, and its performance is evaluated using in-situ snow depth, surface albedo, remotely sensed snow cover and multi-decadal geodetic glacier mass balance.

At all sites, we find declining trends in snowfall, snow depth and glacier mass balance between 1970 and 2023. A decline in the snowfall to total precipitation ratio was found at all sites (-0.005,

-0.005 and -0.03 decade-1 at Kyzylsu, Trambau-Trakarding and Parlung No.4 respectively), but was only pronounced at the Southeastern Tibetan site. The decadal variability in precipitation amount, rather than phase, controls most of the snowfall and glacier mass changes, although the shift in precipitation type from snowfall to rainfall had a substantial contribution to the recent snowfall decline at Parlung No.4 (30% of the snowfall decrease between 1970-1999 and 2000-2023), where we simulate the most rapid glacier mass loss, in agreement with regional assessments of geodetic mass balances. Glacier mass loss has only been marked at Kyzylsu since 2018, following a near-neutral mass balance period characteristic of the Pamir-Karakoram Anomaly. Positive runoff trends were found at Parlung No.4 (+6%/dec) and Trambau-Trakarding (+2%/dec), but not at Kyzylsu (-2.5%/dec) where the recent increase in ice melt only partially compensated for reduced precipitation and for a relative increase in evapotranspiration. Future simulations should assess how snowfall, glacier mass balance and runoff trends will evolve as climate warming strengthens in these catchments.