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Precipitation Uncertainty Hampers the Understanding of Glacier Response in High Mountain Asia

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High Mountain Asia (HMA) provides crucial water resources to more than 1.5 billion people and accurate quantification of high elevation precipitation in this region is essential for understanding the hydrological cycle, patterns of ongoing climatic change, and water resource management. This is particularly the case in high elevation, glacierised catchments where the interplay of complex cryospheric and atmospheric processes limits our understanding of current and future water resource availability. Moreover, the role of precipitation and snow accumulation is critical for the health of glaciers which represent both an important freshwater storage and hydrological buffer to drought conditions, but also pose an increasing hazard to downstream populations through potential lake-damming and outburst floods. In both present-day and future modelling scenarios, precipitation at both macro and local scales generate some of the greatest uncertainties in glacier response to climate, and in few places are these hydroclimatic complexities better demonstrated than in HMA.

We explore the variability of precipitation estimates across several of the latest regional gridded products with high spatial (≥ 10 km) and temporal (hourly) resolution and provide a specific focus over glacierized areas of HMA. Given the common temporal window of 2001-2019, we find substantial disagreement between precipitation products in terms of i) their annual and seasonal magnitudes, ii) the fraction of precipitation occurring during the summer/monsoon period, iii) the decadal difference of precipitation sums, iv) the inter-annual correlation to station observations, v) diurnal precipitation frequency and, vi) dependence on elevation and topographic complexity. Biases of precipitation amounts against in-situ station data can exceed +400% in steep mountainous areas of the Himalaya and errors between products are 23-120% greater over glacierized areas relative to the HMA-wide mean.

When forcing an energy balance model over select glaciers, annual mass balances can disagree by up to 8 m w.e. (1.5 m w.e.) over a single year without (with) bias correction to local observations, propagating into highly distinct long-term trends of estimated glacier health. The high variability of glacier response at the catchment scale relates to spatial patterns of precipitation occurrence due to orographic effects and the resolution and physical process representation of different products. Differences in the surface energy balance of glaciers is, however, most strongly linked to the sub-daily timing of precipitation events and resultant temperature-driven phase of precipitation in different seasons.

We discuss the implications of process representation by different precipitation products and the uncertainty attached to their application in models of glacier energy and mass balance. We also highlight the role of elevation-dependent temperature changes over HMA during the last decades and the implications for changing precipitation phase as a key driver of regionally distinct patterns of glacier mass balance.