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Spatial and temporal patterns of snowmelt refreezing in a Himalayan catchment

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Seasonal snow contributes significantly to the annual runoff in the Himalaya and both timing and volume are important for downstream users. In polar regions, meltwater refreezing within snowpacks has been well-studied. While the conditions in the Himalaya are considered favorable for refreezing, little is known about refreezing in this region, hindering a complete understanding of seasonal snowmelt dynamics. In this study, we simulated refreezing with the seNorge (v2.0) snow model for the Langtang catchment in the Nepalese Himalaya covering a 5-year period. Thereby, we aim to improve our understanding about how refreezing varies in space and time and to provide a framework for future snow modeling studies. The first part of this study focuses extensively on developing meteorological forcing data, which were derived from an unique elaborate network of meteorological stations and high-resolution meteorological simulations. The snow model was validated against in-situ snow observations and snow cover satellite data. In the second part of this study, we analyze the spatial and temporal refreezing patterns, and attempt to identify possible driving factors. The results show that the annual average refreezing amounts to 122 mm (21% of the total melt). We found that the magnitude of refreezing varies strongly in space depending on elevation and aspect. In addition, there is a strong seasonal altitudinal variability related to air temperature and snow depth, with most refreezing during the early melt season. We also found a substantial intra-annual variability, which mainly results from fluctuations of snowfall, highlighting the importance of using multi-year time series in refreezing assessments. Daily refreezing simulations decreased by 84% (to an average 19 mm year^{-1}) compared to hourly simulations, emphasizing the importance of using sub-daily time steps to capture diurnal melt-refreeze cycles. Climate sensitivity experiments revealed that refreezing is highly sensitive to future changes in air temperature, as a temperature increase of 2°C leads to a refreezing decrease of 35%. We conclude that including refreezing with a sub-daily temporal resolution is highly relevant for understanding snow dynamics in the current and future climate of the Himalaya.