Patchy Snow Cover on Debris-Covered Glaciers

Alex Winter-Billington[1,3], Ruzica Dadić[1,2], R. Dan Moore[3], Gerald Flerchinger[4], Patrick Wagnon[5], Argha Banerjee[6]

[1]Te Herenga Waka – Victoria University of Wellington; [2]WSL Institute for Snow and Avalanche Research; [3]University of British Columbia; [4]USDA Northwest Watershed Research Center; [5]Institut des Géosciences de l'Environnement (IGE); [6]IISER Pune

1. INTRODUCTION

Glacier ice melt beneath a layer of rock debris depends strongly on the debris' thickness; other sources of prediction uncertainty remain poorly constrained. Using observations from monsoonal North Changri Nup glacier (NCN) and the physically based model SHAW-Glacier, Winter-Billington et al. (2022) showed that predictions of sub-debris melt were more sensitive to the rain–snow threshold wet bulb air temperature than to all other physical parameters combined. Further, it appeared that patchy snow cover masked the expected relation between melt and debris thickness in the observational data. Here are some outcomes of part 2 of the study, in which this hypothesis was tested.

2. OBJECTIVE

Characterise the sensitivity of sub-debris melt to the combined effects of spatially variable debris thickness and spatially and temporally heterogeneous (patchy) snow cover.

3. DATA AND METHODS

We conducted a 'virtual experiment' using SHAW-Glacier to simulate patchy snow cover overlying a debris layer. With on-site meteorological data, we created nine synthetic precipitation–snow deposition scenarios by crossing three values of the rain–snow partition wet-bulb air temperature, $T_{p,w}$, and three snow deposition cases: (wind) Scour, Neutral and Enhanced Deposition. SHAW-Glacier was run hourly for each scenario with a 500-member Monte Carlo ensemble to estimate parameter uncertainty. Predicted ice melt was evaluated against observations at NCN (presented in Winter-Billington et al., 2022), while model outputs of debris temperature, moisture content, *SWE*, and snowmelt were analysed statistically and graphically to understand the underlying processes.

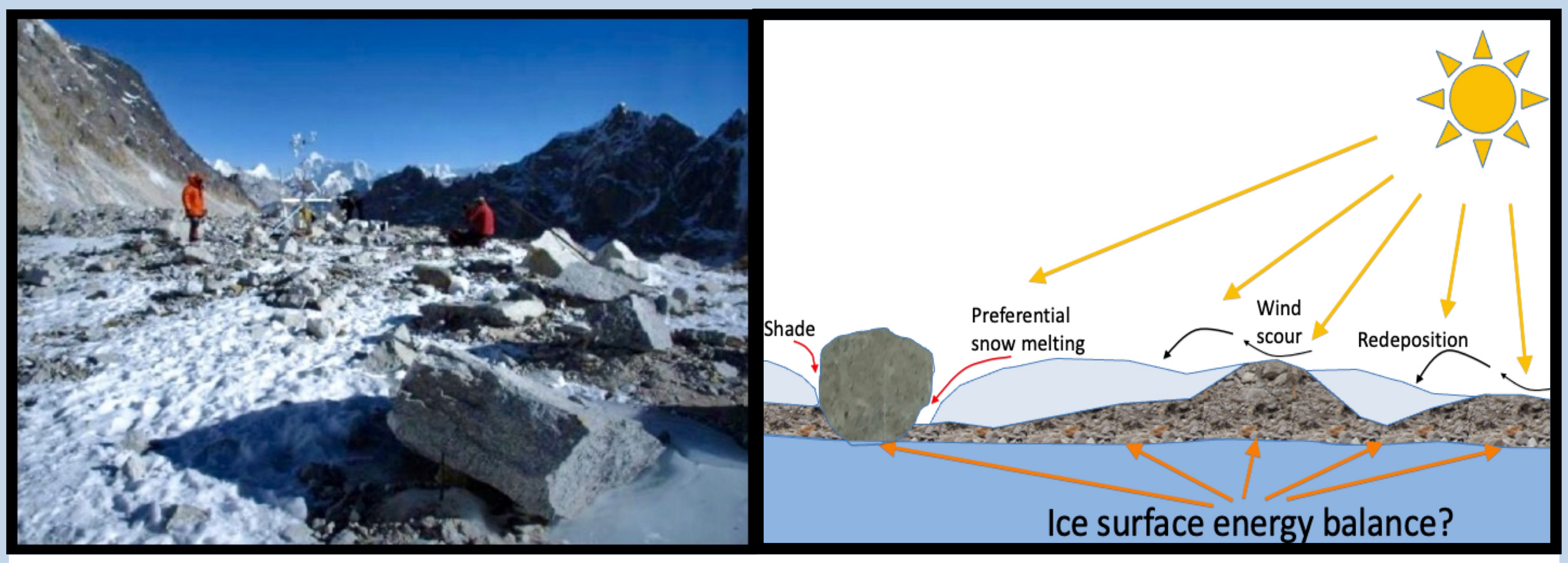

Fig. 1. Left: Patchy snow cover in the study area on North Changri Nup, Nepal. Right: Schematic illustrating the problem of spatially heterogeneous debris thickness and patchy snow cover.

4. RESULTS

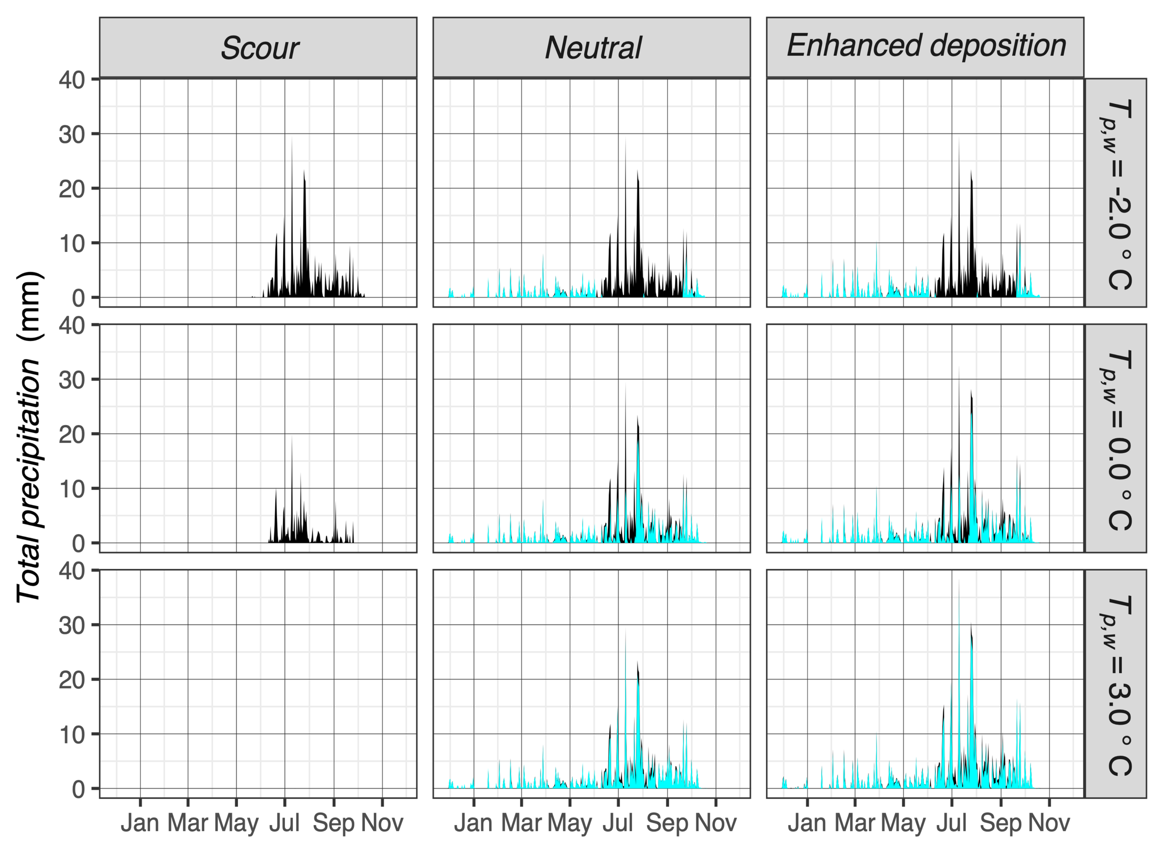

Fig. 2. Synthetic precipitation input data used to simulate spatially heterogeneous snow cover, representing nine 'patches' in the study area. Black is rain and blue is snow.

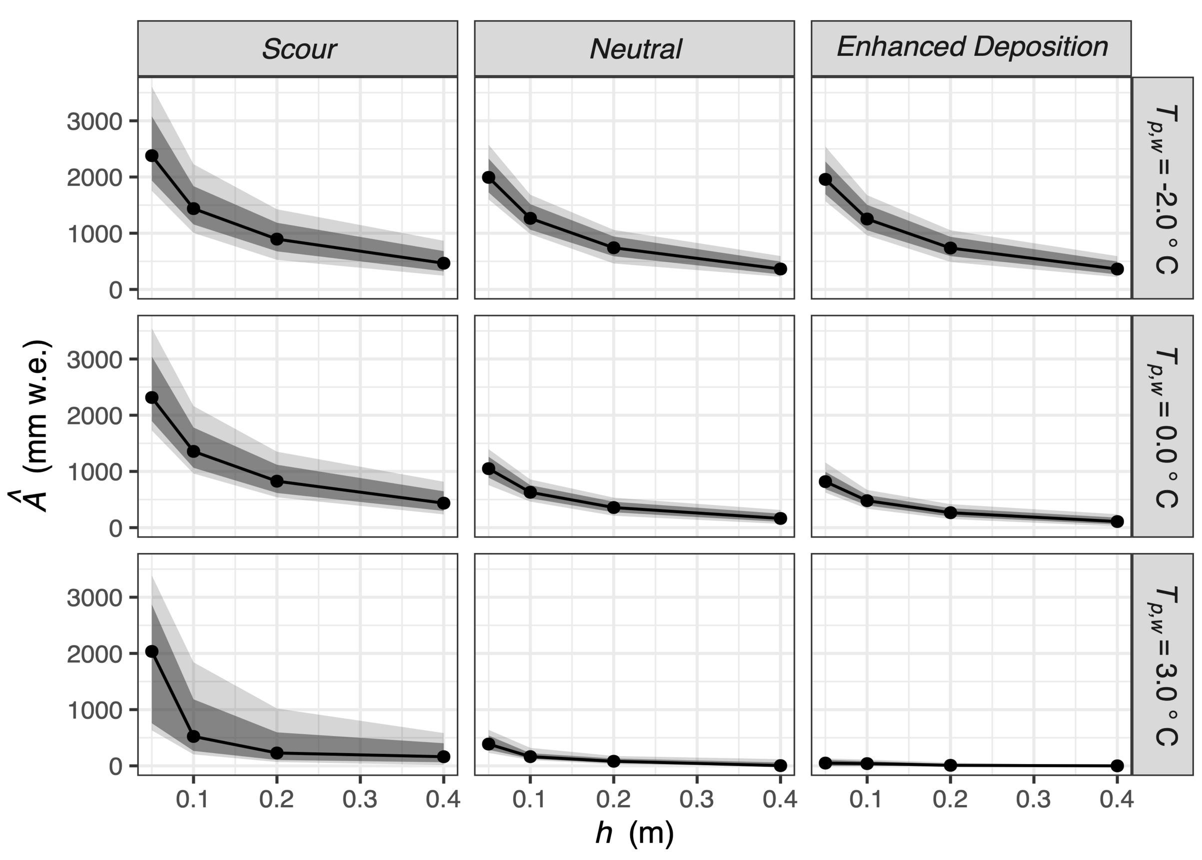

Fig. 4. Annual melt (y-axis) simulated using four values of debris thickness (x-axis) and the nine synthetic precipitation time series. Dark grey is 95 %, and light grey 100 %, of the predicted values.

The virtual experiment (Fig. 2) showed (Figs. 3 and 4):

1) decreased melt with increasing snowfall,
2) increased melt with increasing rainfall,
3) decreased sensitivity of melt to debris thickness with increasing snowfall,
4) decreased sensitivity of melt to debris thickness with increasing rainfall,
5) decreased surface temperature and increased debris-ice interface temperature with increasing rainfall (Fig. 5).

The positive relation between rainfall and sub-debris melt was consistent across simulations, and sensitive to physical parameter values.

Further (not shown):

- Simulated debris-ice temperature profiles exhibited the "zero-curtain effect" (Hinkel & Outcalt, 1994), and isothermal conditions at 0 °C when snow cover was present;
- isothermal conditions prevented the debris from falling below 0 °C on cold nights, suggesting that latent heat fluxes contributed to the energy budget in the debris layer.
- *SWE* was inversely related to debris thickness: warm, thick debris initially melted snow, delaying the accumulation of a snow pack.

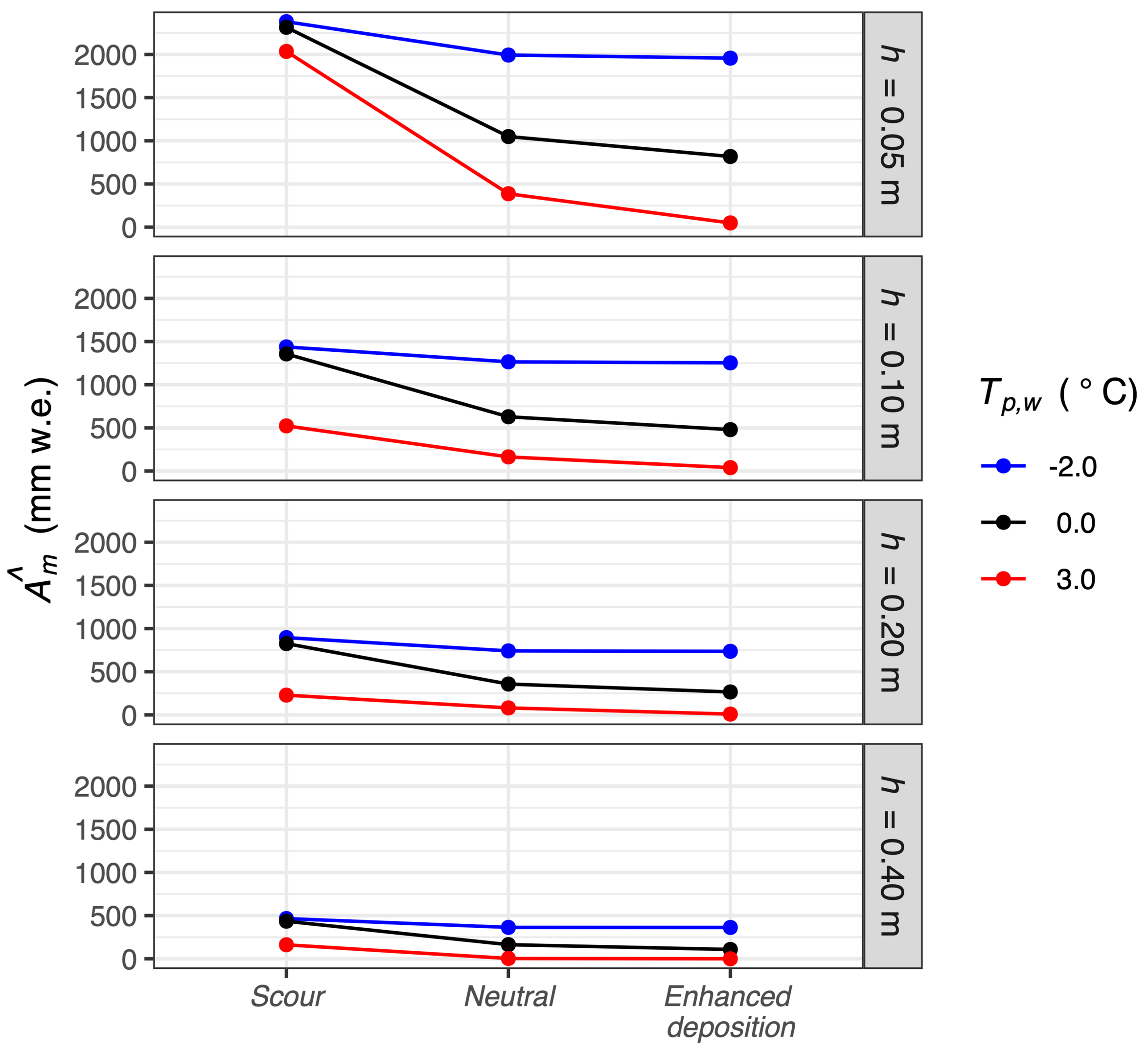

Fig. 3. Annual sub-debris ice melt (y-axis), predicted using four values of debris thickness, *h* (rows), three snow distribution scenarios (x-axis), and three values of $T_{p,w}$ (colours).

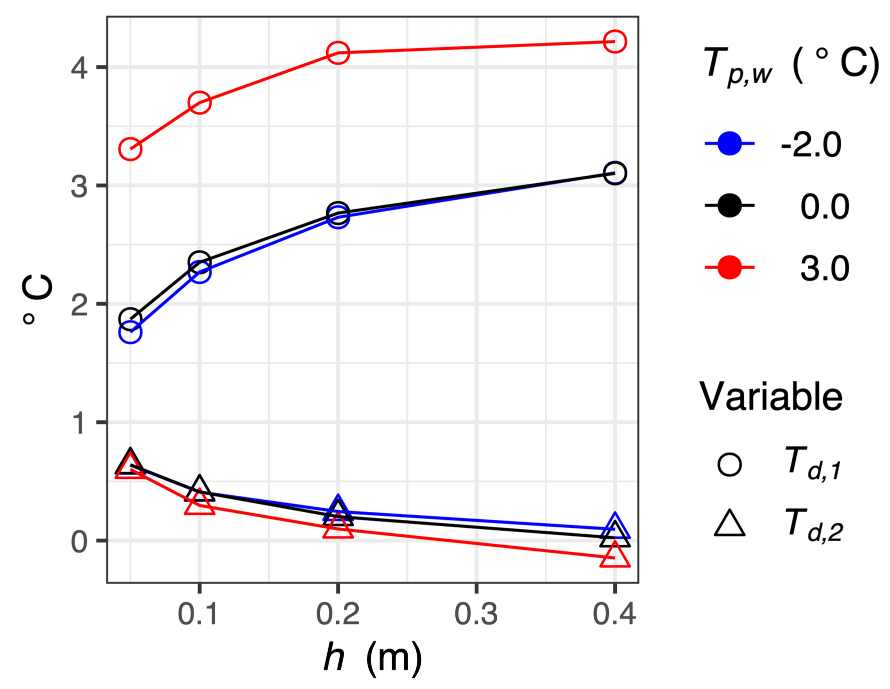

Fig. 5. Temperature of the top, T_{d1}, and bottom, T_{d2}, nodes in the debris layer, simulated for each value of $T_{p,w}$ under the Scour scenario.

5. KEY FINDINGS

- The apparent insensitivity of sub-debris melt to debris thickness on NCN can be explained by patchy snow cover.
- Uncertainty in predictions of melt due to patchy snow cover approximately equals that due to debris thickness.
- The relation between sub-debris melt and debris thickness varies with meteorological conditions.
- Heat advection by water in the debris, during snow melt and rain, may be key to accurate predictions of melt.

6. NEXT STEPS

- Quantify the occurrence of patchy snow cover on debris-covered glaciers using on-site time lapse photography and satellite imagery.
- Evaluate the advection of heat by water percolating through a debris layer on glaciers in different climates by observation and modelling with SHAW-Glacier.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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