The effect of snow and soil on the ground thermal regime in steep bedrock slopes

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Motivation

Snow and soil demonstrate high spatial heterogeneity in mountain environments. This in turn impacts the spatial distribution of permafrost on a very localized level. Additional considerations for permafrost distribution in mountain environments include elevation, aspect, and slope. We can use these factors to predict where permafrost is, and we can use these predictions to help people in recreation and infrastructure building and maintenance. This poster presents preliminary understandings of the impacts ground and snow conditions have on mean annual air temperature and surface offset, in combination with elevation, aspect, and slope.

Figure 1: Joffre Peak, BC. Landslide occurred May 2019 on the north side of the slope. Heterogeneity of mountain environments can be seen, with bare rockfaces, snow, and vegetation. Permafrost thaw was a contributing factor to the landslide. Joffre Peak is part of a larger region of recreation, including hiking and climbing.

Modelling

These models were driven in GEOtop using ERA5 reanalysis climate driving data from Joffre Peak over 40 years from 1980 to 2022. Temperatures were modelled at 10cm depth, representing the ground surface temperature. The factors represented in Fig 2 combine for 504 simulations, with the majority coming from ground conditions and snow.

Modelling of snow variability is not as straight forward as modelling of slope, aspect, and elevation. The main obstacle is that GEOtop deposits snow without considering slope. This allows for two scenarios that cannot exist outside of simulations:

1. Snow of the same volume deposited on a horizontal and sloped surface will vary in thickness (Fig 3a) despite the same precipitation data.
2. Snow does not adhere to steep slopes (>55°-60°)[1,2] outside of simulation. Snow depth can be adjusted using a snow correction factor (Fig 3b).

For this modelling, simplified snow correction factors of a low snow, variable snow, and high snow were selected (Table 1).

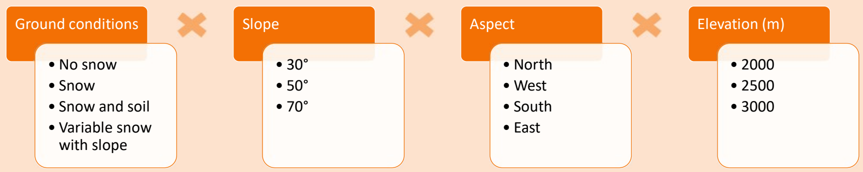
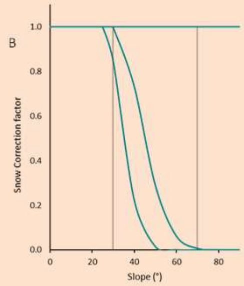


Figure 2: 4 factors explore variability. For each factor, the different modelled conditions are shown

Figure 3a: snow (white) depth (orange line) varies with increasing slope (black line) for the same volume of snow.



3b: snow correction factors can be calculated using exponential functions dependent on site-specific factors. Final snow depth will be the product of snow depth at 0° and the correction factor. Slopes between 30-70° are most affected by the snow correction factor.[3]

Slope (°)	Low Snow	Variable Snow	High Snow
0	0.7	1	1.2
10		1	
20		1	
30		0.9	
40	…	0.7	…
60		0.3	
70		0.1	
80		0.05	
90	0.7	0	1.2

Table 1: Snow correction factors used in simulations

Results

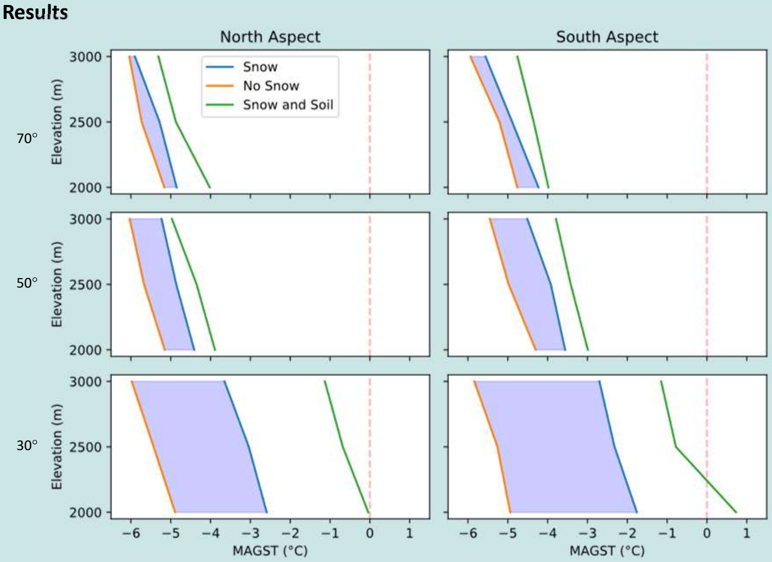


Figure 4: Mean annual ground surface temperatures for multiple scenarios. Blue regions represent variable snow conditions. Generally, there is cooling with increasing slope, warming with increasing snow and soil cover, and a warmer south aspect compared to a north aspect. Snow and soil have the largest impacts at lower slope angles.

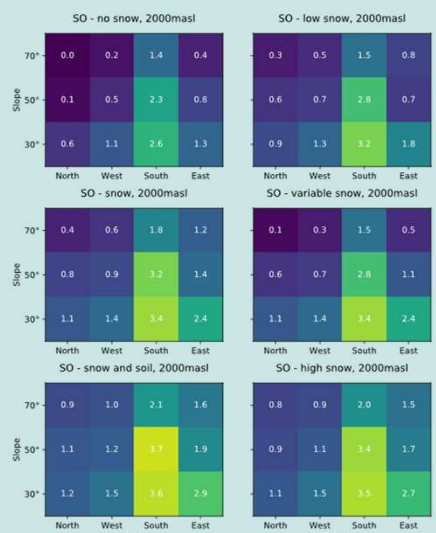


Figure 5: Heat maps of surface offsets (°C) for scenarios at 2000m. Surface offsets increase with snow, and snow and soil. The impacts of variable snow on surface offsets are more significant with increasing slope.

Key Takeaways

- Soil in combination with snow has a significant and modellable effect on the ground thermal regime
- Snow variability must be accounted for on a local level when modelling the ground thermal regime

Next Steps

1. Adjust snow correction factors to capture the temperature variabilities that snow creates
2. Modify soil characteristics to account for latent heat of water contained in soil
3. Run the simulations for other locations in the mountains of Western Canada to capture impacts of continentality and latitude
4. Compare modelled data to observational data

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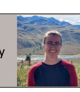

References and Acknowledgement

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2. Ishikawa, M. and T. Sawagaki, GIS-simulation of the spatial distribution of snow cover and observed ground temperatures in the Daisetsu Mountains, Japan. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography, 2001. 55(4): p. 212-218.
3. Pogliotti, P., Influence of snow cover on MAGST over complex morphologies in mountain permafrost regions. PhD Thesis. 2011

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