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Results
Observations

Overview

This is a document that shows the sampled and full ranges of topographic parameters and then goes into the multiple linear regression and Bayesian model averaging that was used to explain SWE with topographic parameters.

1 Topographic parameters of study sites

One method of interpolating snow water equivalent (SWE) is to relate the observed SWE with topographic parameters derived from a digital elevation model (DEM) of the study area. The imagery we were using was from the SPOT-5 DEMs and were provided at no cost by the French Space Agency (CNES) through the SPIRIT International Polar Year project (Korona and others, 2009). The DEM has a cell size fo 40x40 m. The following topographic parameters were calculated from the DEM in QGIS:

Elevation values were taken from the SPOT-5 DEMs directly.

Distance from centreline was calculated as the minimum distance between the Easting and Northing of the northwest corner of each cell and a centreline that was drawn by hand in QGIS.

Slope is the second derivative of the elevations.

Tangential Curvature represents the curvature in the direction of the contour tangent.

Profile Curvature represents the curvature in the direction of the the steepest slope.

"Northness" is defined as the product of the cosine of aspect and sine of slope (Molotch and others, 2005). A value of -1 represents a steep, south facing slope, a value of +1 represents a steep, north facing slope, and a flat surfaces yield 0.

Aspect represent what direction a slope is facing with 0° defined as north. These were calculated using Terrain Analysis in QGIS.

Sx represents wind exposure/shelter and is based on selecting a cell within a certain angle and distance from the cell of interest that has the greatest upward slope relative to the cell of interest (Winstral and others, 2002). This can be referred to as the maximum upwind slope. Negative Sx values represent exposure relative to the shelter-defining pixel, which means that the cell of interest was higher than the cell with greatest upward slope. Conversely, positive values represent sheltered cells. To determine Sx values, we use the equation

$$Sx_{A,dmax}(x_i, y_i) = \max\left[\tan^{-1}\left(\frac{z(x_v, y_v) - z(x_i, y_i)}{[(x_v - x_i)^2 + (y_v - y_i)^2]^{1/2}}\right)\right], \tag{1}$$

where A is the azimuth of the search direction, (x_i, y_i) are the coordinates of the cell of interest, and (x_v, y_v) are the set of all cell coordinates located along the search vector defined by (x_i, y_i), the azimuth (A), and maximum search distance ($d$max). Code for this calculation was provided by Adam Winstral (2016, personal communication). As done by McGrath and others (2015), we computed Sx at 5° azimuth increments for $d$max distances of 100, 200, and 300 m. These values were then correlated with observed values of SWE and the A and $d$max values with the highest correlation were used for subsequent analysis (see Table 1).

Table 1: Values of azimuth (A) and maximum search distance($d$max), which determine Sx that had the highest correlation to observed SWE.

	A (° from North)	**$d$max (m)**
Glacier 4	75	200
Glacier 2	55	200
Glacier 13	325	200

1.1 Maps of topographic parameters

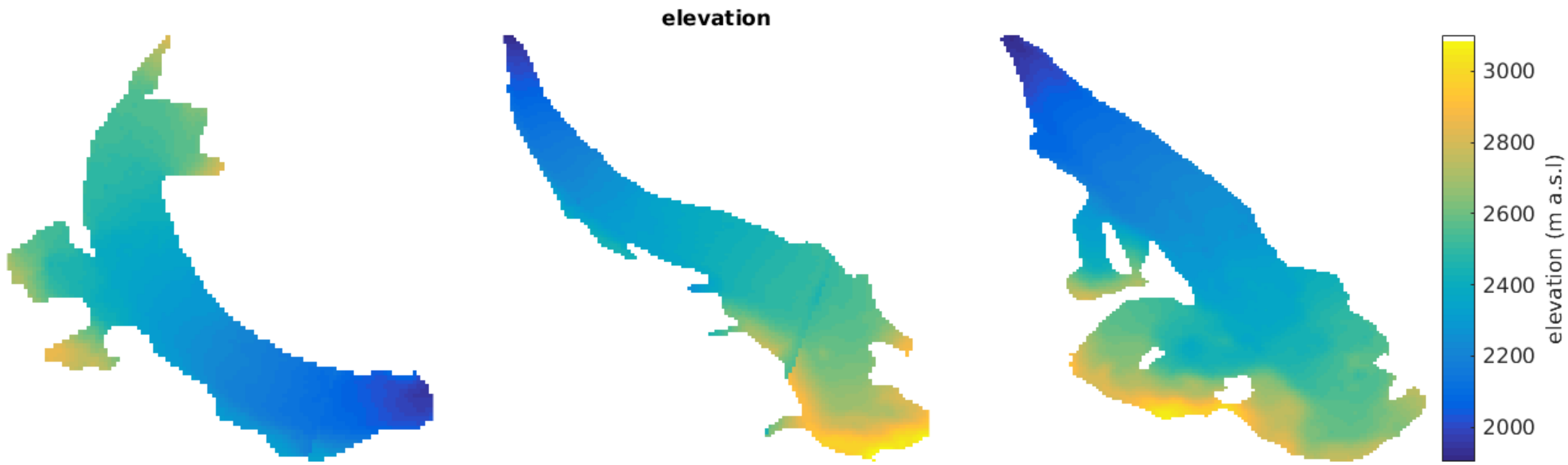

Figure 1: Values of elevation used in the topographic regressions for three study glaciers. This DEM is derived from a SPOT5 satellite image and has a grid size of 40x40 m. Subsequent topographic parameters were derived from this DEM.

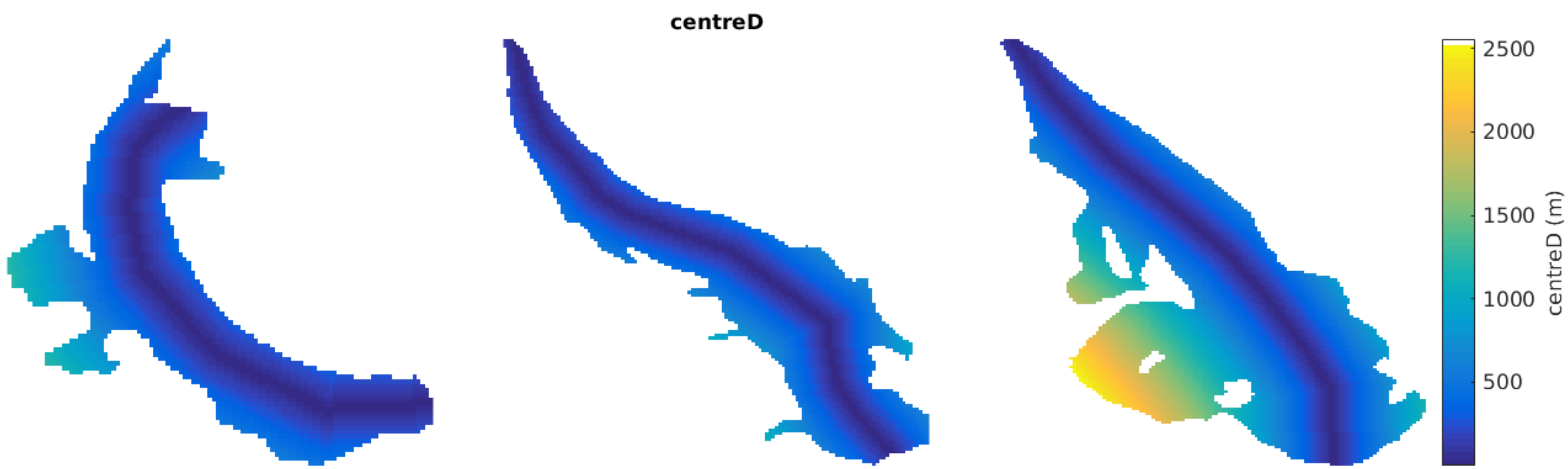

Figure 2: Values of distance from centreline used in the topographic regressions for three study glaciers. Centreline was drawn by hand in QGIS.

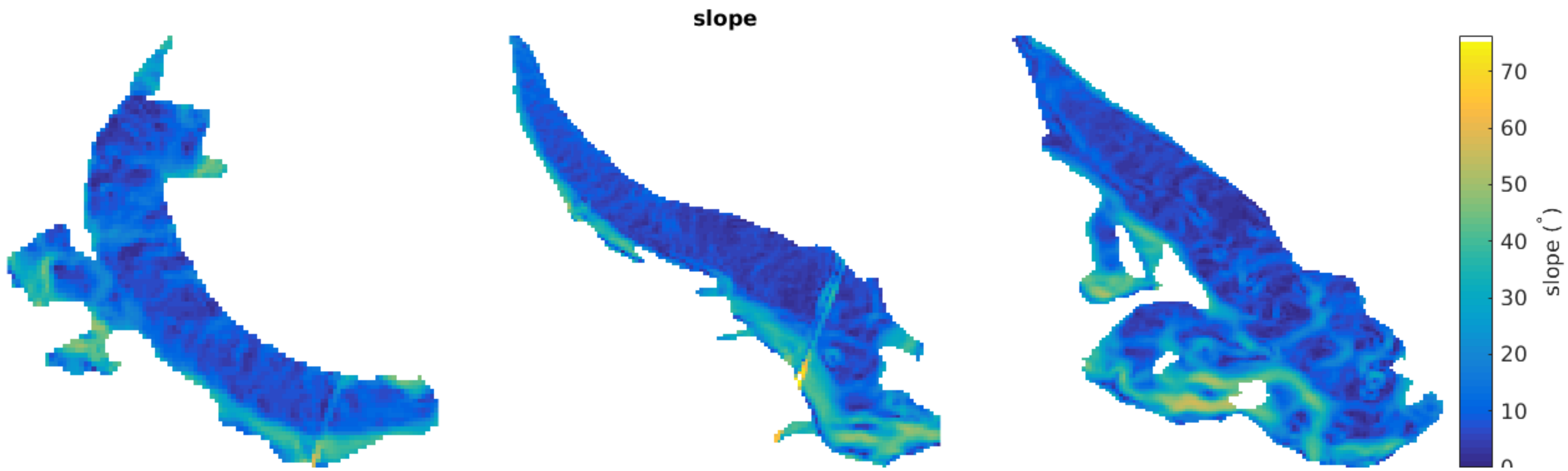

Figure 3: Values of slope used in the topographic regressions for three study glaciers. Values were derived from a SPOT5 satellite derived DEM (grid size of 40x40 m) in QGIS.

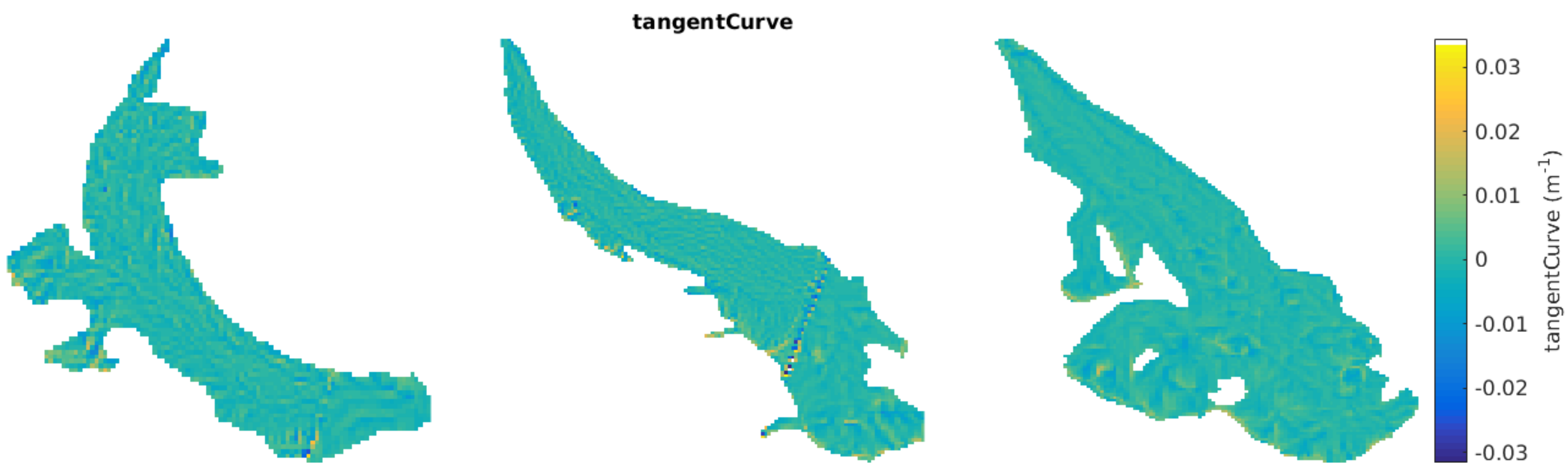

Figure 4: Values of tangential curvature used in the topographic regressions for three study glaciers. Values were derived from a SPOT5 satellite derived DEM (grid size of 40x40 m) in QGIS.

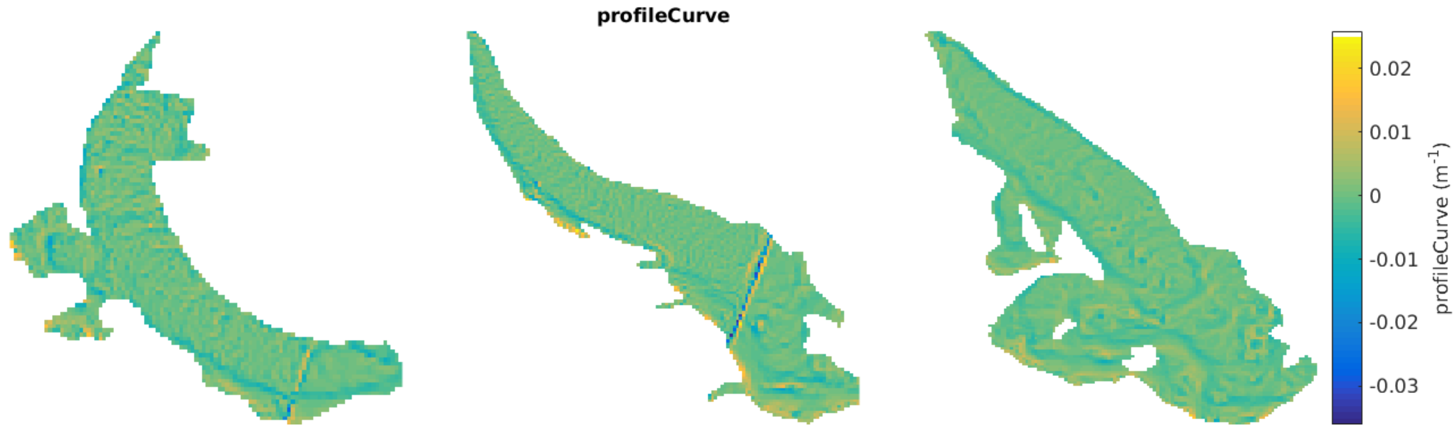

Figure 5: Values of distance from centreline used in the topographic regressions for three study glaciers. Values were derived from a SPOT5 satellite derived DEM (grid size of 40x40 m) in QGIS.

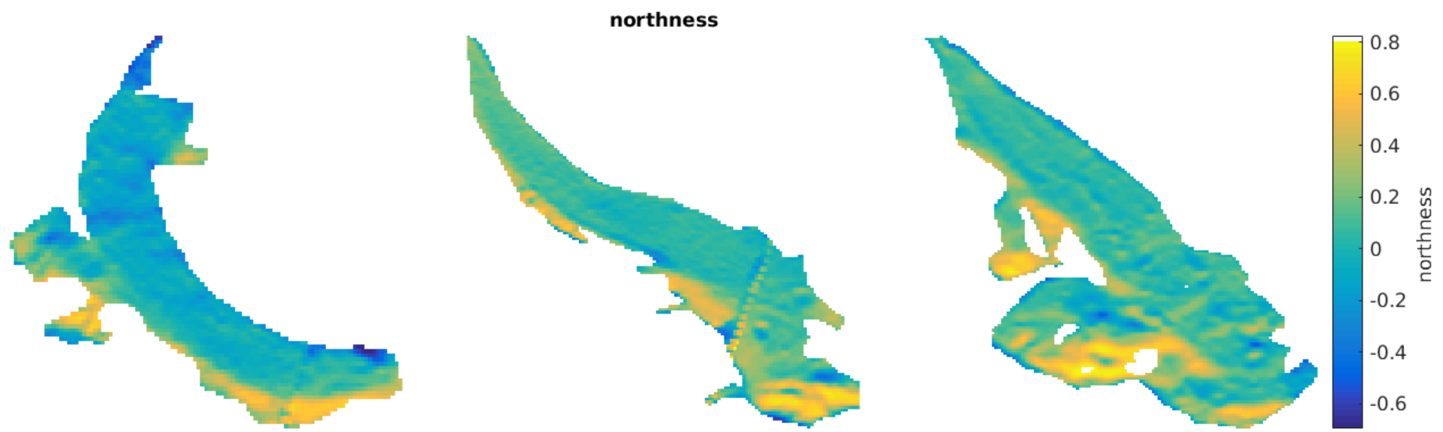

Figure 6: Values of "northness" used in the topographic regressions for three study glaciers. "Northness" is defined as the product of the cosine of aspect and sine of slope. A value of -1 represents a steep, south facing slope, a value of +1 represents a steep, north facing slope, and flat surfaces yield 0. Values were derived from a SPOT5 satellite derived DEM (grid size of 40x40 m) in QGIS.

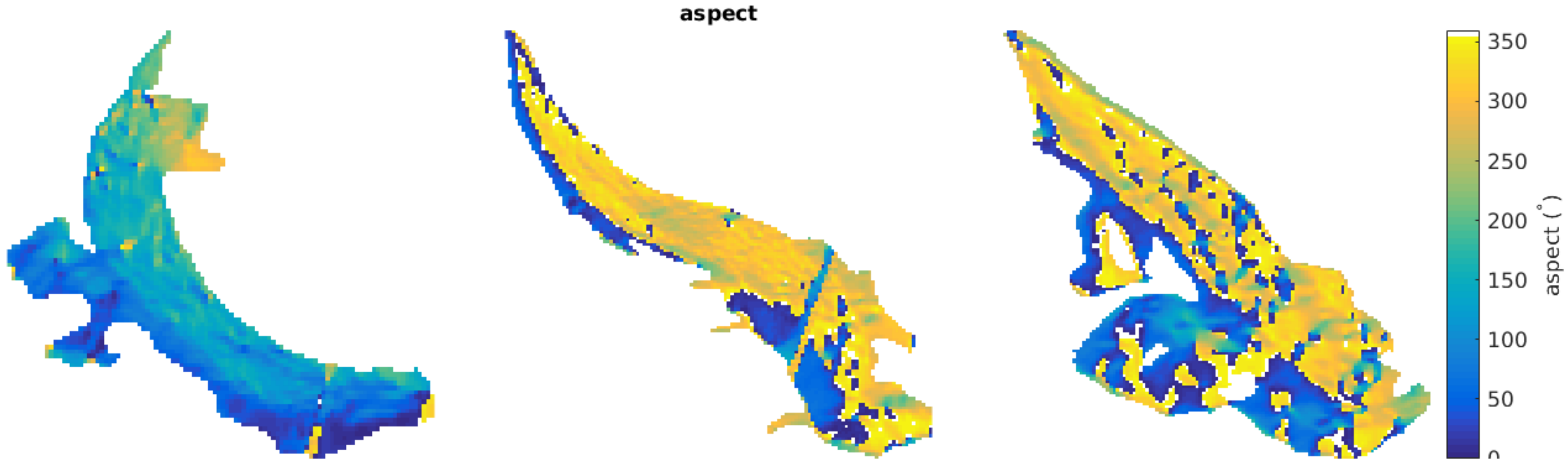

Figure 7: Values of aspect, which represent what direction a slope is facing (0° defined as north), used in the topographic regressions for three study glaciers.

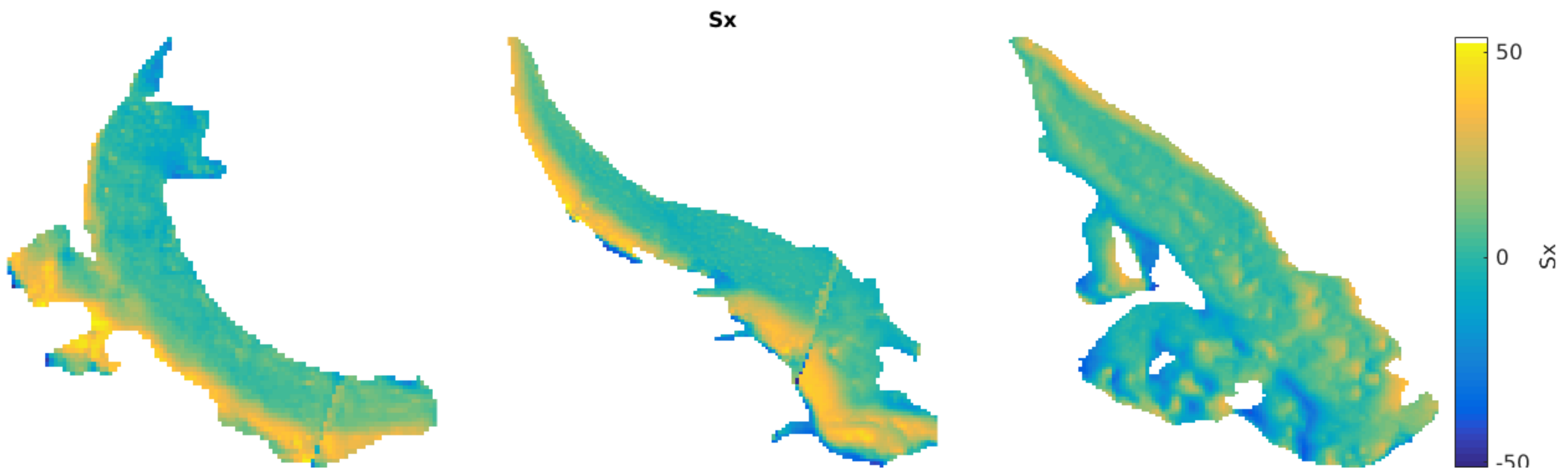

Figure 8: Values of Sx, which is a wind redistribution parameter, used in the topographic regressions for three study glaciers. See section **??** and the original paper by Winstral and others (2002) for more details on calculation .

1.2 Range of parameters sampled

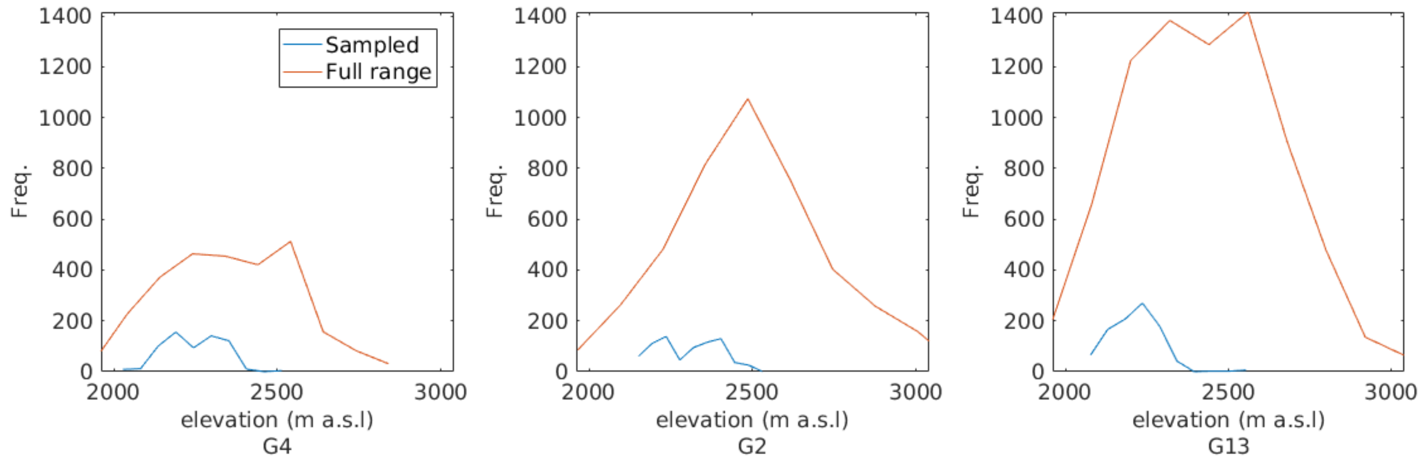

Figure 9: Range of elevation sampled as compared to total range of elevation of study glaciers.

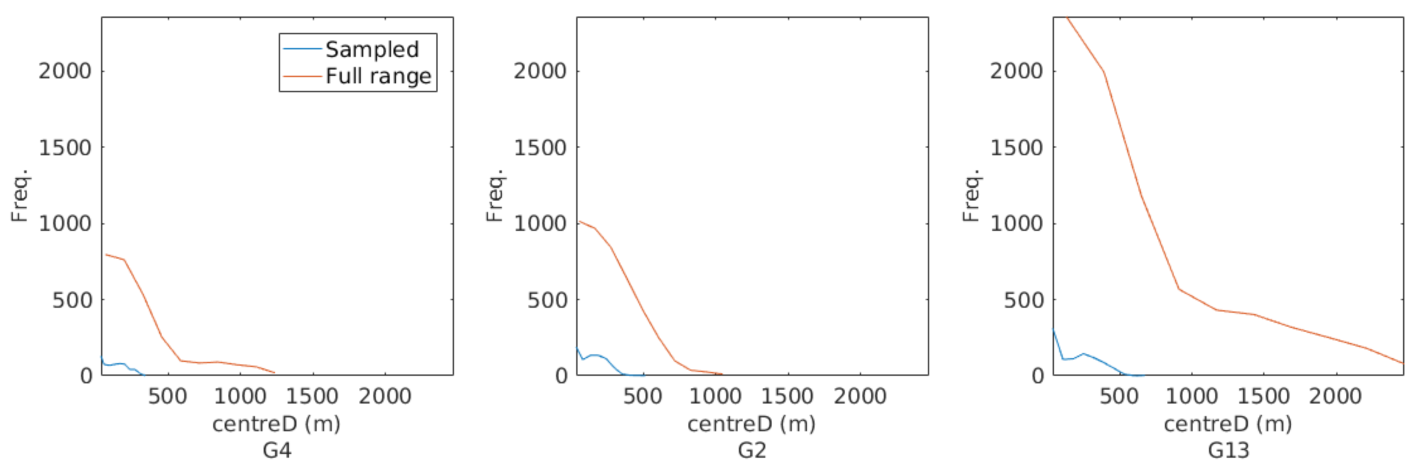

Figure 10: Range of distance from centreline sampled as compared to total range of distance from centreline of study glaciers.

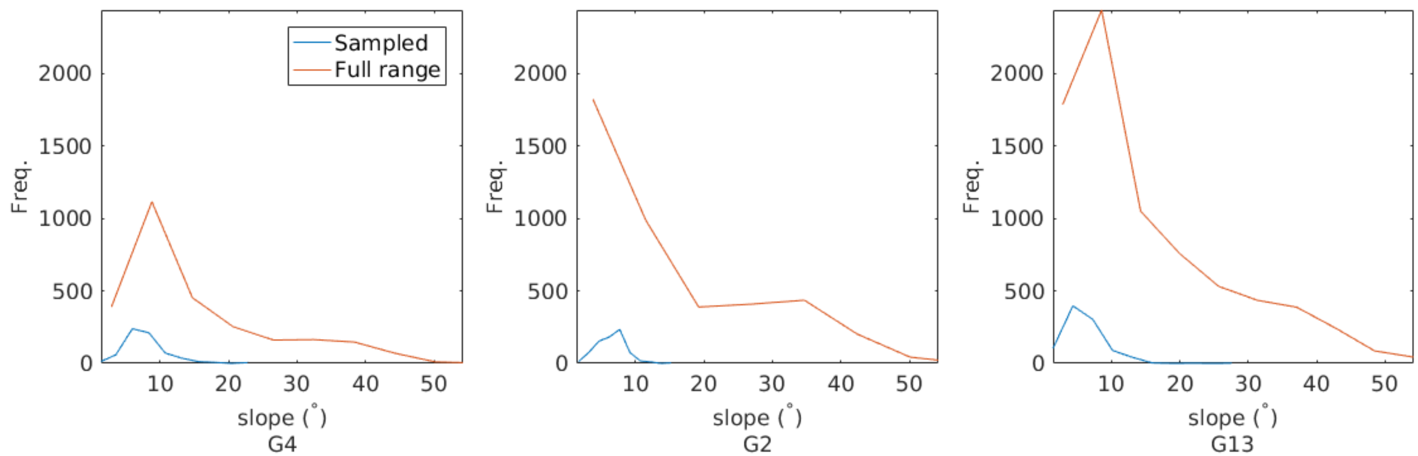

Figure 11: Range of slope sampled as compared to total range of slope of study glaciers.

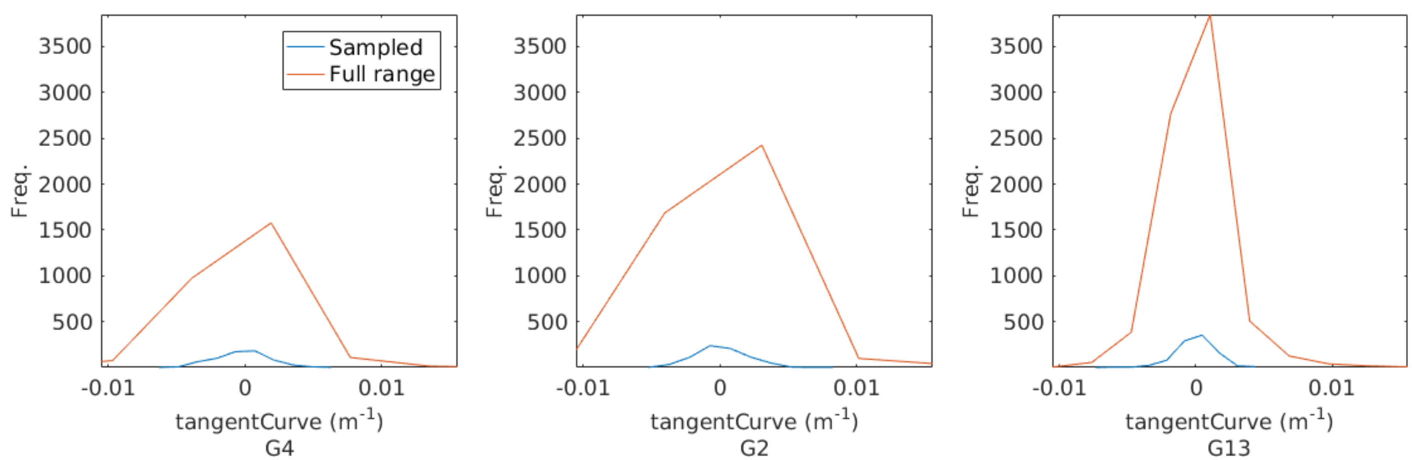

Figure 12: Range of tangential curvature sampled as compared to total range of tangential curvature of study glaciers.

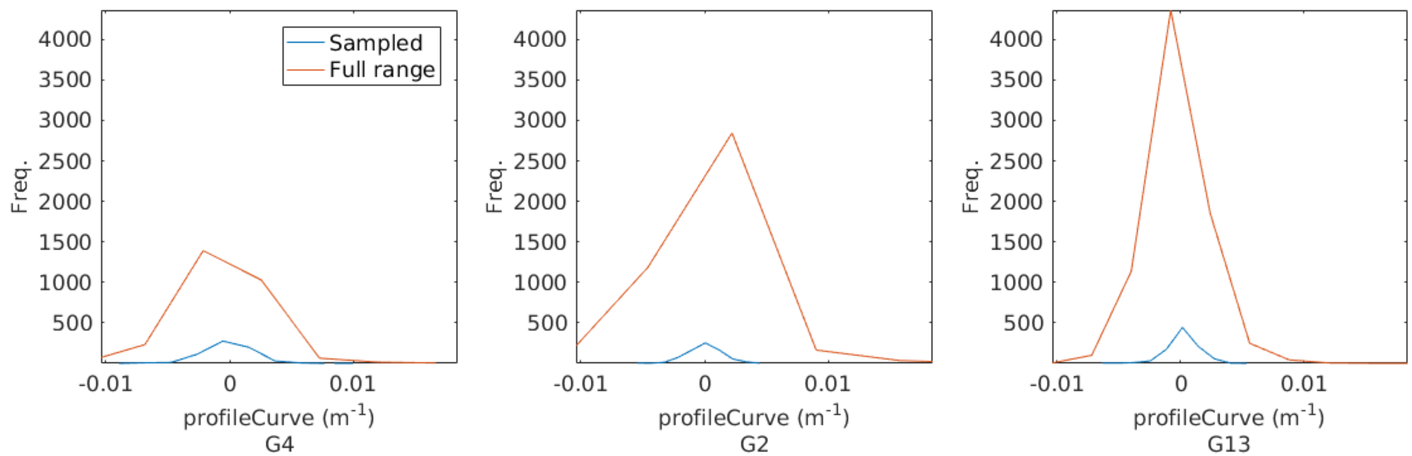

Figure 13: Range of profile curvature sampled as compared to total range of profile curvature of study glaciers.

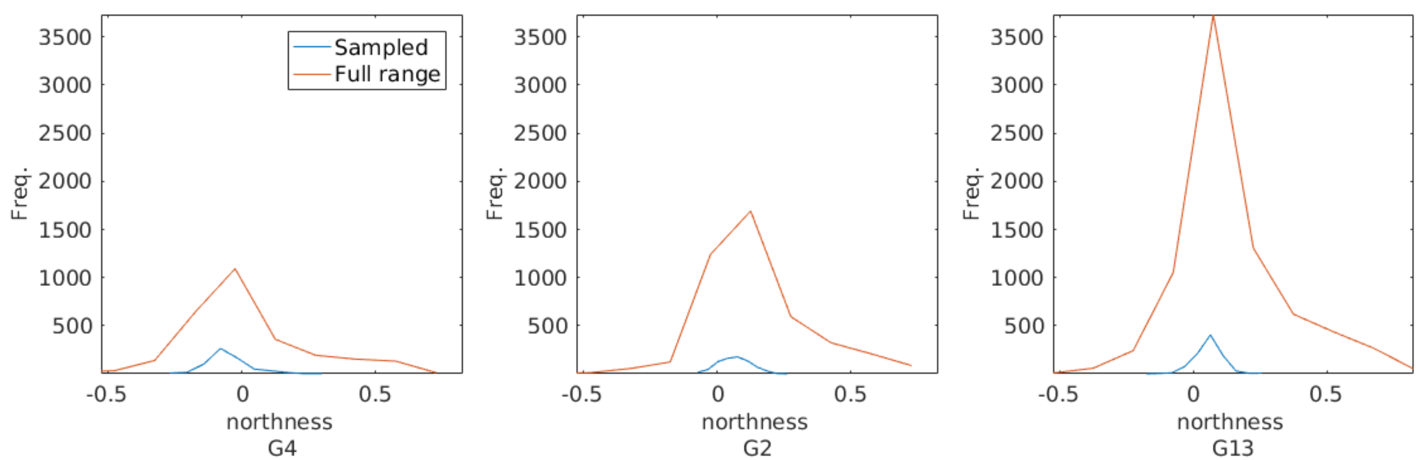

Figure 14: Range of “northness” sampled as compared to total range of “northness” of study glaciers.

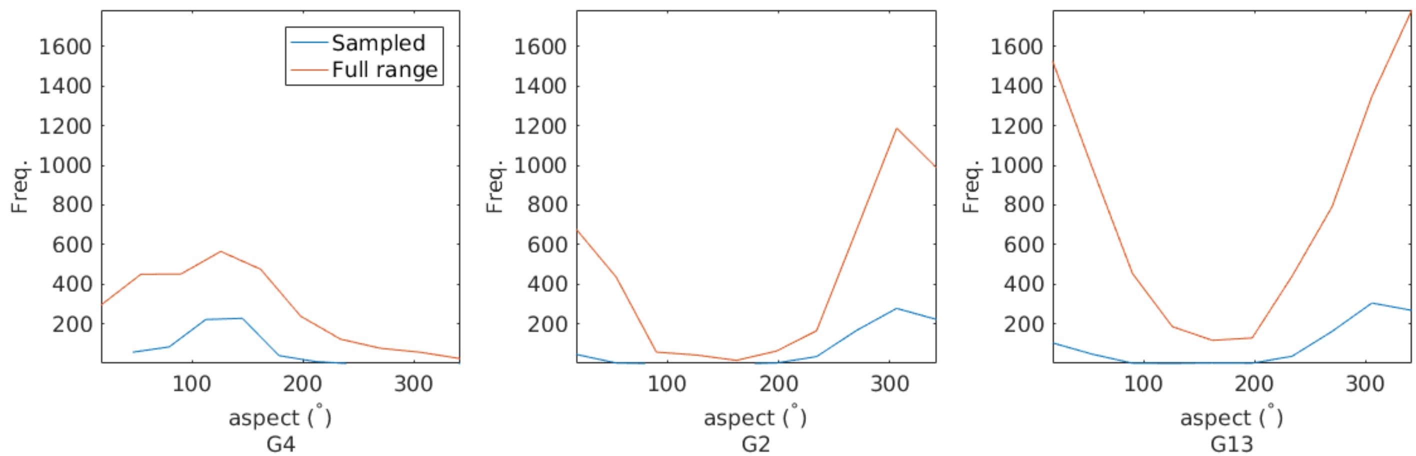

Figure 15: Range of aspect sampled as compared to total range of aspect of study glaciers.

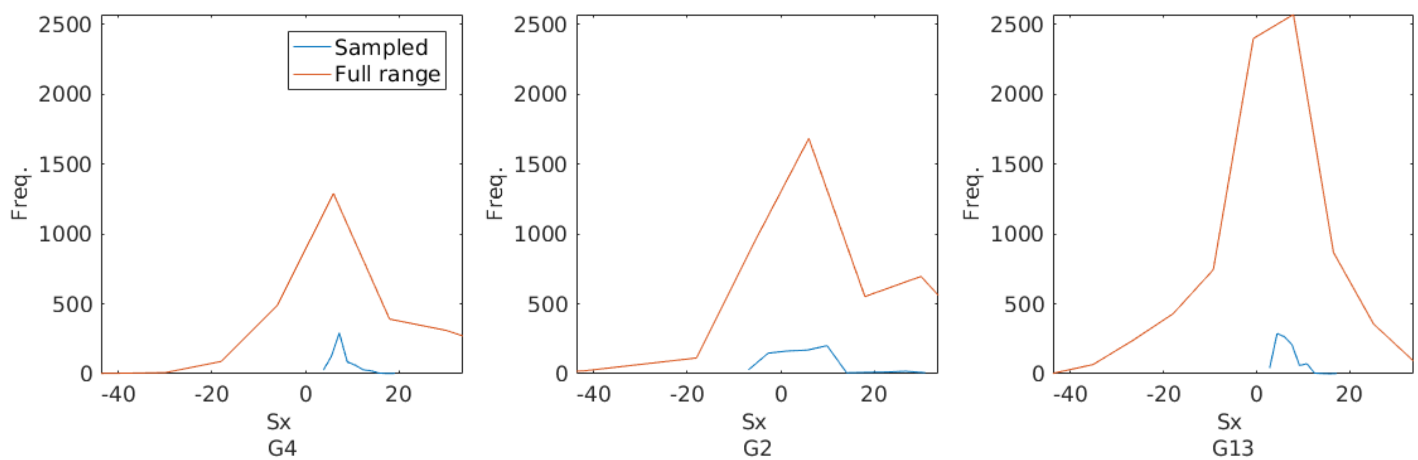

Figure 16: Range of Sx sampled as compared to total range of Sx of study glaciers.

(a) Inserting the Federal Sampler into the snow. Photo credit: C. Ariagno

(b) Weighing the Federal Sampler with snow core on the spring scale (units of cm SWE). Photo credit: G. Flowers

Figure 17: Using the Federal Sampler to measure SWE

2 Multiple Linear Regression

References

Korona J, Berthier E, Bernard M, Rémy F and Thouvenot E (2009) SPIRIT. SPOT 5 stereoscopic survey of Polar Ice: reference images and topographies during the fourth International Polar Year (2007–2009). *ISPRS Journal of Photogrammetry and Remote Sensing*, **64**(2), 204–212

McGrath D, Sass L, O'Neel S, Arendt A, Wolken G, Gusmeroli A, Kienholz C and McNeil C (2015) End-of-winter snow depth variability on glaciers in Alaska. *Journal of Geophysical Research: Earth Surface*, **120**(8), 1530–1550 (doi: 10.1002/2015JF003539)

Molotch N, Colee M, Bales R and Dozier J (2005) Estimating the spatial distribution of snow water equivalent in an alpine basin using binary regression tree models: the impact of digital elevation data and independent variable selection. *Hydrological Processes*, **19**(7), 1459–1479 (doi: 10.1002/hyp.5586)

Winstral A, Elder K and Davis RE (2002) Spatial snow modeling of wind-redistributed snow using terrain-based parameters. *Journal of Hydrometeorology*, **3**(5), 524–538 (doi: 10.1175/1525-7541(2002)003⟨0524:SSMOWR⟩2.0.CO;2)