1 Experimental Design

1.1 Background

Efficient collection of snow depth and density data is critical to a successful snow measurement campaign. Since snow is spatially and temporally variable, snow properties must be measured over an extensive area within a short period of time. Often, researchers aim to collect snow data at the end of the winter season, when accumulation is at a maximum and melt has not yet begun. This window of time is narrow, which makes it difficult to obtain data over a large study area. Therefore, it is advantageous for researchers to gain insight into the minimum amount of data needed to find reliable interpolations as well as the most efficient way to collect this data.

The number of snow depth and density data collected during this project far exceeds the that of most snow accumulation studies (c.f. ??) and utilizes non-traditional sampling designs (Shea and Jamieson, 2010). By using subsets of this extensive data set, we hope to better understand the spatial extent and sampling frequency that result in accurate estimates of distributed winter surface mass balance.

1.2 Methods

To investigate the effect of sample size and distribution on WSMB estimates, data subsets are selected and LR, SK and RK are used to find the distributed SWE field on each glacier. Subsets that are likely to be used in future snow survey campaigns are selected. Five main sampling designs are chosen:

1. Centreline transect (Figure 1)
2. Centreline and four transverse transects (Figure 2)
3. Centreline and three transverse transects (Figure 3)
4. Hourglass transects (Figure 4)
5. Hourglass and circle transects (Figure 5)

The measured locations in the accumulation area of each glacier are then added to each subset resulting in a total of ten sampling designs. Within each subset, sample sizes of 10 to 100 (maximum 50 for centreline) equally spaced points are selected and the three interpolation methods are used to estimate WSMB. SWE values from all eight density options are separately used for subset interpolation. Further details are described in Appendix 1.3.

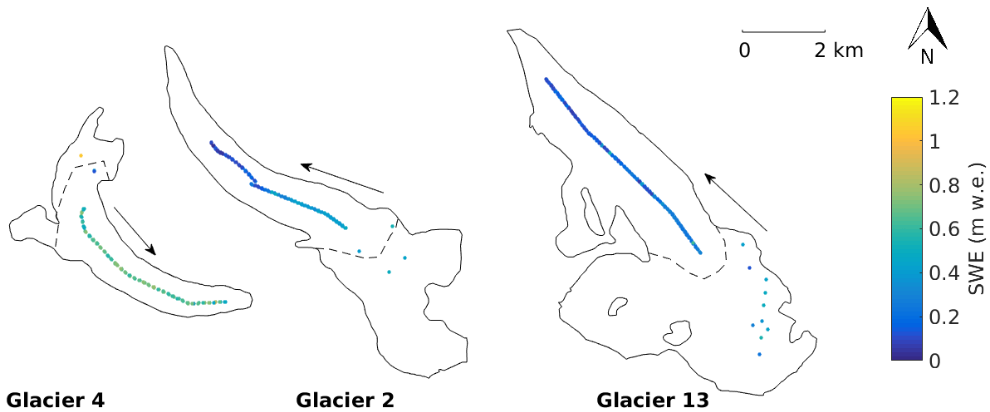

Figure 1: Centreline sampling design with accumulation area points as a subset of all measured locations. Dashed line is the approximate location of the ELA and arrow shows glacier flow direction.

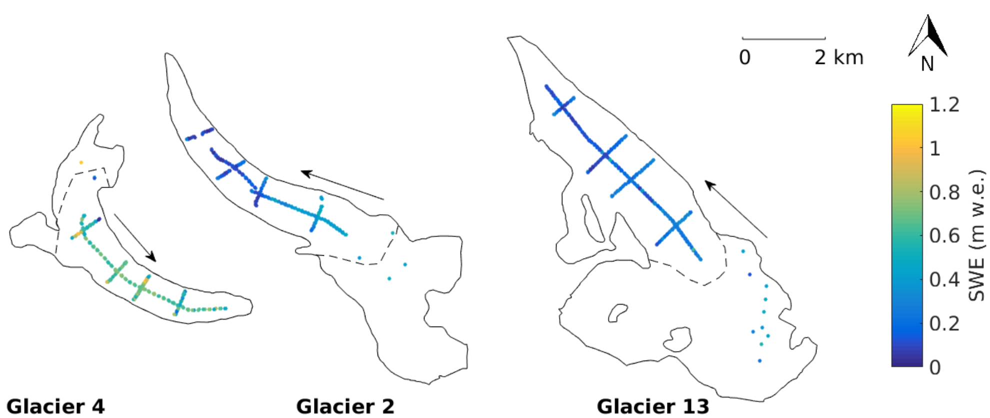

Figure 2: Centreline and four transects sampling design with accumulation area points as a subset of all measured locations. Dashed line is the approximate location of the ELA and arrow shows glacier flow direction.

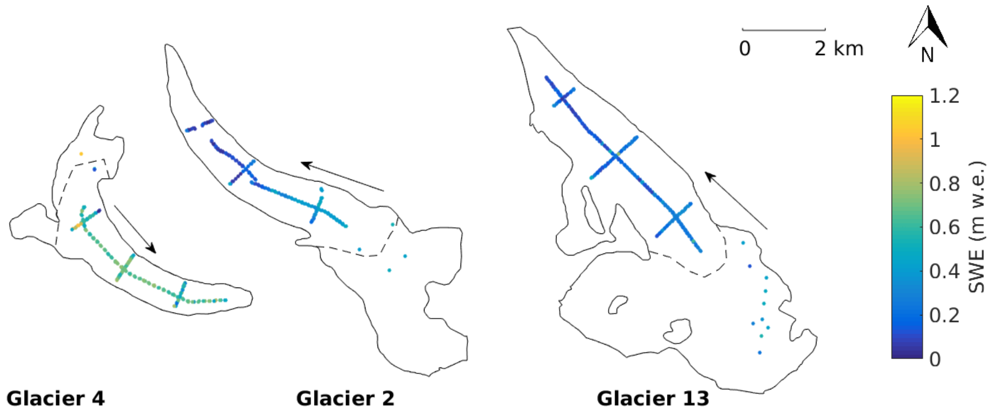

Figure 3: Centreline and three transects sampling design with accumulation area points as a subset of all measured locations. Dashed line is the approximate location of the ELA and arrow shows glacier flow direction.

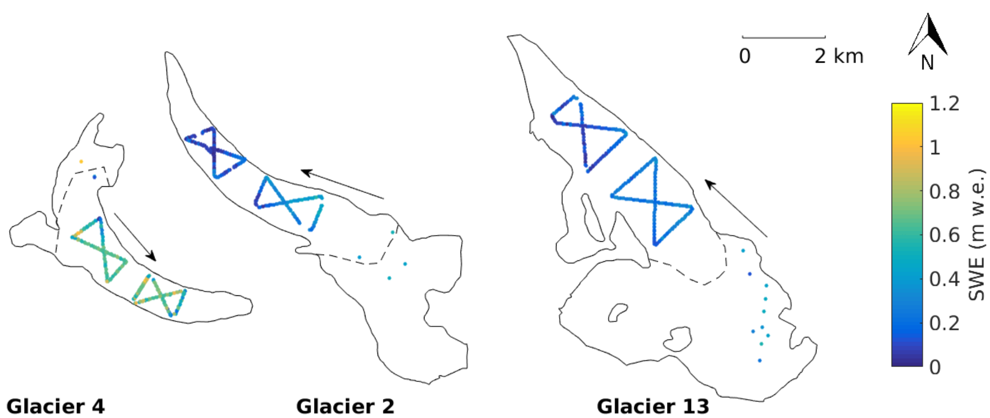

Figure 4: Hourglass sampling design with accumulation area points as a subset of all measured locations. Dashed line is the approximate location of the ELA and arrow shows glacier flow direction.

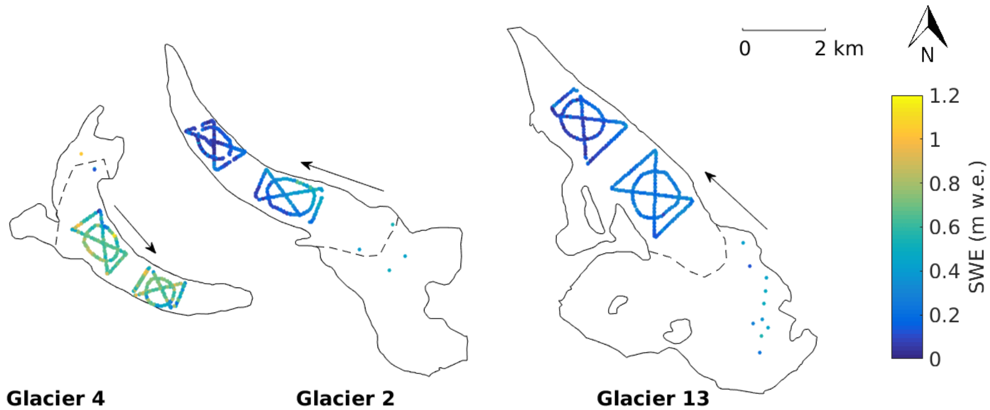

Figure 5: Hourglass and circle sampling design with accumulation area points as a subset of all measured locations. Dashed line is the approximate location of the ELA and arrow shows glacier flow direction.

1.3 Results

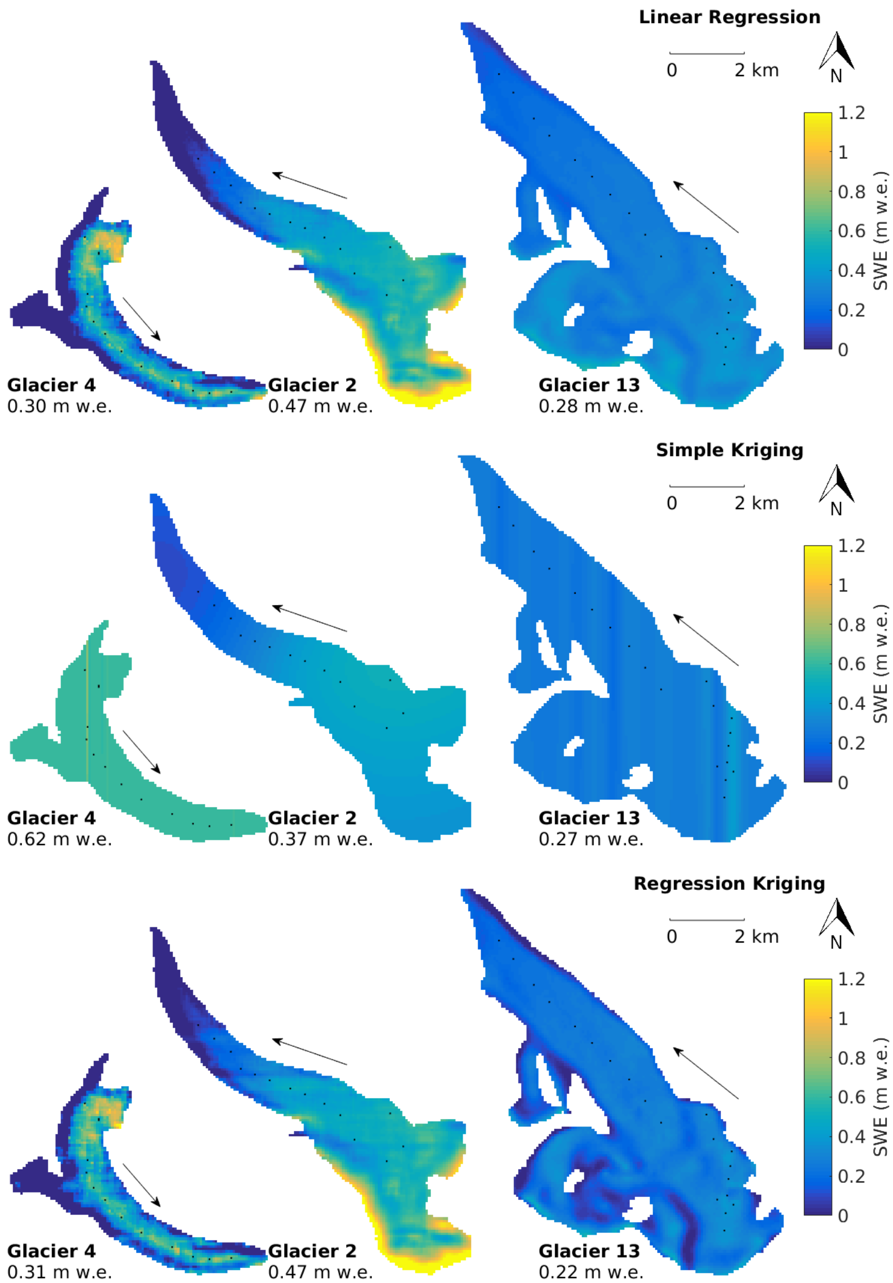

Figure 6: Distributed winter surface mass balance found using linear regression (MLR) (top), simple kriging (middle) and regression kriging (BMA) (bottom) on centreline subset data ($n = 10$). Arrows indicate glacier flow direction and black dots show snow depth sampling locations.

References

Shea C and Jamieson B (2010) Star: an efficient snow point-sampling method. *Annals of Glaciology*, **51**(54), 64–72 (doi: 10.3189/172756410791386463)

APPENDIX - Experimental design software

The experimental design component of this study examines the estimated WSMB using data subsets. Subsets are chosen based on the survey design component (e.g. centreline, hourglass) and a chosen sample size. Then, LR, SK and RK are used to find a glacier-wide distribution of SWE. This process is completed in the MATLAB script 'BalanceDesign.m'.

1. SWE values at all measurement locations are estimated using one of the density options (S1, F1, S2, F2, S3, F3, S4, F4).
2. The author-made function 'DataSubset.m' is used to select all points that are a part of the chosen design subset (e.g. centreline, hourglass, etc.). The selection is made based on the sampling point classification that was determined in the sampling design (Sections **??**). For example, only points that are classified as 'UM' and 'LM' are included in the 'centreline' subset. Measurement locations that happen to fall along on the centreline but are a part of another sampling design subset, such as the hourglass, are not included. The corresponding topographic parameter values for each sampling subset location are then selected.
3. The author-made function 'ObsInCell.m' then takes the average SWE value of multiple measurement values within a single DEM cell. The result is one SWE value with a set of topographic parameters for each DEM cell where subset measurements are available.
4. Then, the author-made function 'SortNSelect.m' orders the data by the cell number (origin at NW corner of DEM and increasing in the eastward and southward directions) and selects n number of between the first and last point. The data are selected based on an equally spaced index vector that spans the length of the subset, not on the actual location of the data points, because data were collected in equally spaced intervals along a subset transect. The number of points ranged from 10

to 100 in increments of 10 for all subsets, expect for centreline subset where the range was from 10 to 50 points in increments of 5 points because of small subset length.

5. Estimation of distributed SWE is then completed using the author-made functions 'LinearRegression.m' for linear regression (LR), 'KrigingR_G.m' for simple kriging (SK) and 'RegressionKriging.m' for regression kriging (RK). Each function uses its respective interpolation method to calculate a distributed SWE field and returns regression coefficients for LR and RK.