Supplementary information for the manuscript *"Water content of firn at Lomonosovfonna, Svalbard, derived from subsurface temperature measurements"*

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1 Empirical data and visualization tools

The empirical data used in the present study and the relevant technical descriptions are available online at the Pangaea database Marchenko2019PT. Depths of sensors installed on T-strings are shown in Figure S1. The earlier installed T-strings were scanned at uneven in time intervals: 1 h before August 1, 3 h from August 1 to November 1, 12 h from November 1 to April 1 and 1 h after April 1. Later T-string was scanned every 1 h.

Two visualization tools (apps) for producing interactive plots of the temperature values in the time-temperature axes (`plotTvst.mlapp`) and in the temperature-depth axes (`plotTvsZ.mlapp`) are available through GitHub. Users can choose T-strings for which the data is to be shown, zoom in and out within the temperature and depth/time axis. To run the apps `*.mlapp` files have to be in the same folder with the data file `LF_Temp.mat` and the auxiliary function `water00_preprocess.m`. In case the Matlab software is not available one can install Matlab runtime Matlab runtime. The empirical data visualized through the above described apps was subjected to the below described calibration routine, however no interpolation and low-pass filtering in time is applied. Also the positive values are not reset to 0 °C.

2 On the uncertainty in temperature data and post-processing routines

As any empirical data our temperature measurements are subject to uncertainty that originates from different phenomena. In the present section we would like to highlight several points that are deemed important in the context of firn water content quantification.

The temperature tolerance of the BetaTHERM 100K6A1iA thermistors applied in the 2014 installation is 0.1 °C in the temperature range from 0 to +70°C (datasheet). In the following field season we used Amphenol MC65F103A thermistors with 0.15°C temperature tolerance reported for the T range from 0 to 50°C (datasheet). The above given values for temperature errors can be expected to be further increased as in most cases the measured temperature is negative and due to the influence of such additional uncertainty sources as: the difference between nominal and actual resistance of the reference resistors, errors in the voltage measurement by the data logger, additional resistance of the copper leads and contacts at the relay multiplexers and data logger, conversion of resistance to temperature, etc.

In order to minimize the systematic errors readings from individual thermistors were calibrated by applying offsets defined as the mode (most frequent value) during the time period, when the temperature is close to 0 °C. The subjective decision whether data from a sensor is to be calibrated as described above or not was taken based on the following criteria: presence and duration of the time period when readings stay at a level that can be interpreted as the natural threshold of 0 °C, sharpness of the transition from the warming phase and towards the cooling trend that precede and follow the period with stable T readings.

The offsets applied to data from individual sensors (variable `T.off`) and the percentage of all values that are equal to the calibration offset (variable `T.off_fraction`) are contained in the file `W_data.mat` available through GitHub along with the computer codes used in the present study. Figure S2A provides a summary on the calibration offsets applied to the raw data. Comparing the values (ca -0.15 — 0.20 °C) with the assumed ice melt temperature $T_0 = -0.03$ °C used within the firn water quantification routines it becomes obvious that calibration may have a serious influence on the results. Having that in mind we did not apply the calibration to readings from several sensors that lacked signs of reaching the ice melt temperature.

Furthermore, data from several thermistors was excluded from the analysis (empty makers in Figure S1). This applies to sensors that returned positive values that can be hardly expected in firn at the depth of several meters. Additional information on the phenomena is provided in the following chapter. Figure S2B illustrates the influence of the calibration and omitting sensors returning positive temperature on the temperature values used for the firn water content quantification.

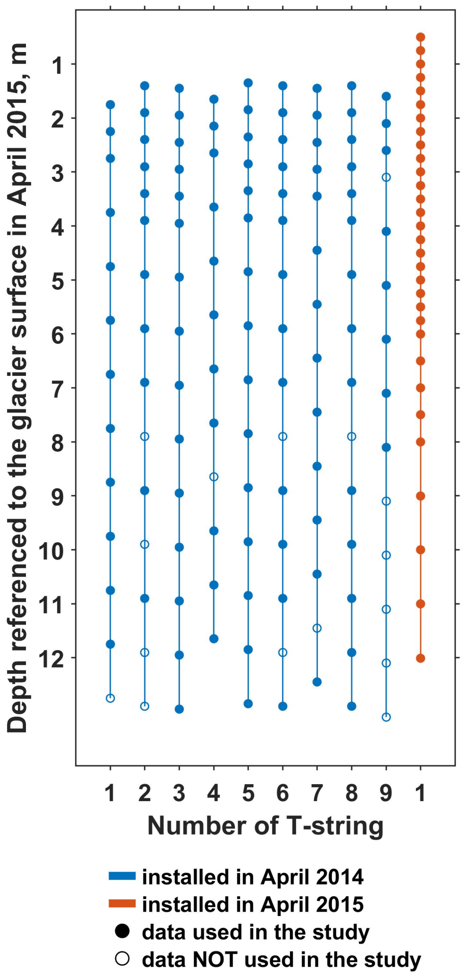

Figure S1: Depths of sensors on thermistor strings installed in April 2014 (blue) and 2015 (red). Data from sensors shown by empty markers was not included in the study.

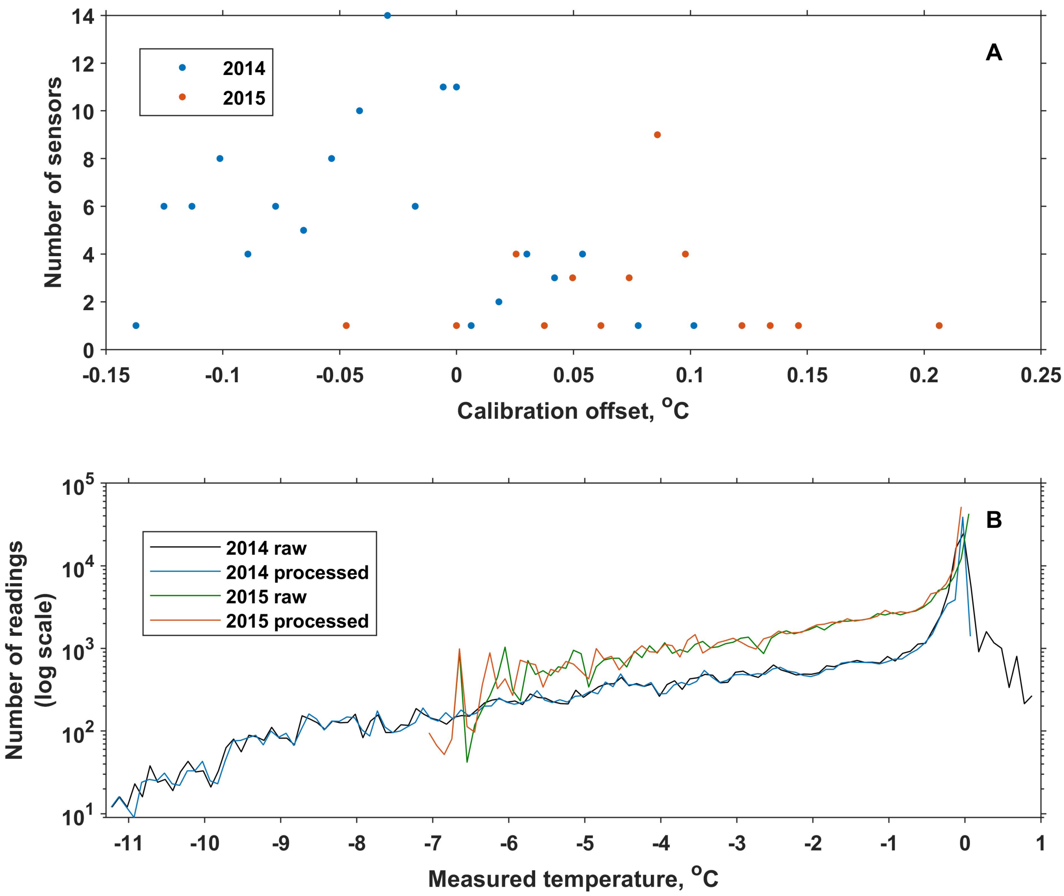

Figure S2: A: calibration offsets applied to readings from individual sensors, B: histograms of raw and processed temperature measurements. Note: here the "processed" data has undergone the calibration routine and some sensors were excluded, no interpolation and low-pass filtering in time is applied.

3 On the phenomena of positive measured subsurface temperature values

As it is apparent from the empirical data (Figure S2B), multiple thermistors exhibit significantly positive temperature values. The majority of positive values are concentrated near 0 °C, but values as high as 0.8 °C are observed. Most of these empirical data series from individual T-strings show a distinctive plateau around 0 °C after or before periods with positive temperature measurements. Some sensors lack that pattern.

While it is hard to admit that at Lomonosovfonna (1200 masl) positive temperature values are possible in glacier firn at the depth of several meters, we also have to respect the fact that the corresponding data series show a consistently evolving signal and its magnitude is larger than the temperature tolerance of the sensors (see part 2 of the Supplement). Furthermore the temperature values returned by the "misbehaving" sensors during cold periods do not look unlogical when compared with the neighbouring sensors that never reach above 0 °C.

The suggested possible cause of the positive temperature measurements is leaking of water through the electrical isolation of the sensors. The soldered contacts between the sensor leads and the cable lead are isolated by thin heat shrink tube along with self-amalgamating tape and another layer of thicker heat shrink tube, both going all around the multileaded cable.

If we assume that a measured resistance ($R_1 = 332.62$ kOhm) expected from the sensor at 1 °C is the total resistance of two resistors connected in parallel: the sensor at 0 °C ($R_0 = 351.02$ kOhm) and the water film that goes around it (R_w), then an accordance with the Kirchhoff's and Ohm's laws:

$$\frac{1}{R_1} = \frac{1}{R_0} + \frac{1}{R_w},$$

yielding $R_w = 6345.450$ kOhm, which is almost 20 times larger than R_1 and R_0. Thus, while a perfect electrical isolation should create a "resistor" with infinite resistance, in our case at temperate conditions and for some sensors we have parallel resistances not lower than $Rw = 6345.45$ kOhm. It is notable that data from the T-string installed at the same field site in 2015 has much less positive values and their magnitude is lower, which allows to speculate about possible shortcomings of the T-string manufacturing technology. If the above assumption corresponds to what has happened in reality, then the problem is only relevant for measured values that are close to 0 $°C$, since the resistance of the frozen water film dramatically increases once it gets frozen.

Other possible reasons for occurrence of the positive temperature readings are heating of the sensors due to penetration of solar radiation through the snow, conductive heating along the multileaded cable, failures of hardware other than disturbance of the electrical isolation of the sensors. The first two hypothesis can be ruled out since they assume a negative dependence of the amount and magnitude of the positive measured temperature values on depth, which is not observed. We analysed the dependence of the fraction of positive T readings from individual sensors on the corresponding number of the port on the data logger wiring panel. No links between the two parameters were found. One further option is drift in the resistance-temperature curve for some of the sensors, which is, however, not likely according to the manufacturer.

References

[Marchenko and others, 2019] Marchenko S, Pohjola VA and Pettersson R (2019) Subsurface temperature at Lomonosovfonna, Svalbard, April 2012-2016 (doi: 10.1594/PANGAEA.902613)