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Near-surface snow physics data from a dog-sled traverse expedition in the northwest Greenland ice sheet during 2018 spring

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Abstract: In the northwest Greenland ice sheet, in-situ measurements of near-surface snow physical conditions, which can be used to estimate surface mass balance, are crucially lacking. Herein, we performed a glaciological field traverse expedition with a traditional Greenlandic dog-sled to obtain in-situ near-surface snow density and stratigraphy data in 2018 spring. We succeeded in obtaining these data from snow pits at four locations. Moreover, we observed the spatial variability of snow density at the SIGMA-A site. These data are in the easy-to-read excel format.

1. Background & Summary

The significant snow and ice mass losses from the Greenland ice sheet (GrIS) since the 2000s have been attributed mainly to the accelerated reduction of the surface mass balance (SMB)[1-2]. Although the ice-sheet-wide SMB has been estimated using polar regional climate models[3-6] in recent years, the value of in-situ SMB and related snow/ice measurements is still high because they are the only ground truth of the changing snow/ice physical conditions and can be used for the evaluation of these models. Therefore, several international data-collection programs have been launched: Historical in-situ SMB data from the stake measurements at 46 sites over the GrIS have been compiled[7]. The SMB and snow on sea ice working group (SUMup) dataset, a standardized dataset of Arctic and Antarctic observations of SMB components, has been developed[8]. Also, 200-point surface snow density data from firn cores and snow pits on the GrIS have been archived[9].

Locations of the in-situ measurements in the above-mentioned datasets show regionally unequal features. One problem is that the measurements of near-surface snow physical conditions crucially lack in the northwest GrIS, wherein mass loss has accelerated since 2005[10]. Although the present-day mass loss from the northwest GrIS can be attributed mainly to the ice discharge[2], the importance of SMB in this area is increasing in response to the rapid modulation of the surrogate atmospheric conditions. It has been demonstrated that increased early summer cloudiness in the northern GrIS enhances atmospheric warming through increased downwards longwave heating, which has triggered a rapid snowline retreat, causing early bare ice exposure, amplifying runoff[11].

Herein, we attempted to collect near-surface snow physics data in the northwest GrIS during the spring of 2018. Since 2012, we have conducted in-situ near-surface atmospheric and glaciological measurements in the area[12-17]. When we proceeded to the inland area, we always used helicopters[12, 17]. However, in the present study, we tried to utilize a traditional Greenlandic Dog-sled to conduct multi-point snow pit measurements on the GrIS. The advantages of using a dog-sled on the GrIS are that the expedition will be less affected by weather conditions than by the use of a helicopter, Greenlandic dogs are well trained to prevent attacks by polar bears[17], and the expedition is absolutely zero-emission. Herein, we present near-surface snow physics data, including snow density and stratigraphy obtained during the expedition. These data are available in the excel file format.

2. Location (or Observation)

Since 2012, some parts of our research activities in the study area have been conducted in the collaborative framework of the 'Snow Impurity and Glacial Microbe effects on abrupt warming in the Arctic' (SIGMA) project[12]. In the following section, we call the present dog-sled expedition as the 'SIGMA-Traverse 2018' Our special Greenlandic dog-sled team was developed by T. Yamasaki and consisted of 13 Greenlandic dogs. The initial weight of the dog-sled with all the loads (except for the body weights of the participants: M. Niwano, T. Yamasaki, and S. Yamaguchi) at the departure time was almost 500 kg. This kind of scientific traverse expedition using a dog-sled in the northwest GrIS is the second challenge after the one[18], which undertook a glaciological traverse expedition focusing on water vapor and aerosols in 2000.

Figure 1 shows the study area and the route of SIGMA-Traverse 2018. Table 1 indicates the expedition itinerary. On 6 April 2018, we left Siorapaluk for the SIGMA-A site (78°30' N, 67°38' W, 1490 m a.s.l.)[12, 13, 15, 17]. In the first two days, we climbed up the Meehan Glacier and then reached the main ridge of the GrIS on 9 April. On the way to SIGMA-A, it took four days and we conducted two snow pit measurements focusing on snow density profile and snow stratigraphy at the ST2 and ST3 sites. After the five-day travel, we reached SIGMA-A on 10 April. We stayed five nights at the site and conducted the maintenance of the SIGMA-A automated weather station (AWS) as well as a snow pit measurement in the same manner as that conducted at ST2 and ST3. Also, multi-point near-surface snow density measurements to acquire spatial variability of snow density were carried out on the last day at SIGMA-A. On the return trip, one snow pit measurement was performed at ST4. As seen in the annual SMB map presented by a recently conducted SMB model inter-comparison[19], ST2, ST3, SIGMA-A, and ST4 are located above the equilibrium line. A previous study[9] reported that the number of measurements conducted at elevations ranging from 1000 to 1750 m a.s.l. is relatively small; therefore, our measurement data (obtained at 912–1490 m a.s.l.) are valuable.

3. Methods

The depth of each snow pit, with the cross-sectional area of 1.5 m^2 approximately (Fig. 2), ranged from 1.3 to 2.0 m. Throughout the measurements, we mainly used a box-type density cutter (e.g., ref. 20); however, a cylinder-type density cutter (e.g., ref. 20) was used for extremely hard snow. For the (manual/visual) snow stratigraphy measurements, we followed the international snow classification method[21].

4. Data Records

We tried to determine the bottom boundaries for the latest annual layers at each snow pit, which we defined as the snow layers accumulated after the previous summer. With the information, measured SMBs of the latest annual layers as of the measurement dates are obtained (Table 2). For this purpose, we referred to the surface meteorological data from SIGMA-A AWS[22] (Fig. 3a) and the measured snow stratigraphy (Fig. 3b). At the four snow pits except for ST4, we found two evident thin ice layers less than 2 cm thick in the top 1.2 m snowpack. Around 1 July 2017, the measured surface height with respect to 1 January 2017 was approximately 0.3 m, whereas it became approximately 1.1 m in early April 2018 (indicated with two solid blue lines in Fig. 3a). In the SIGMA-A snow pit, an ice layer (upper one of the two ice layers) was found at 0.79 m below the surface; therefore, we determined the snow layer above the ice layer to be the latest annual layer at SIGMA-A. Because two ice layers were additionally observed in the near-surface snow at ST2 and ST3 (Fig. 3b), we determined the latest annual layers in the same manner as that applied to SIGMA-A. At ST4, we could not find an ice layer near the surface (Fig. 3b); however, two extremely hard melt forms were measured under two different depth hoar layers. Therefore, we set the bottom of the latest annual layer above the upper extremely hard melt form layer.

The easy-to-read excel format dataset contains eight sheets as follows:

1. "Contact_Point": Information of the lead author of the data is indicated
2. "Position_Summary": Locations and elevations of ST2, ST3, SIGMA-A, and ST4 are listed.
3. "Grain_Shape_Notation": Definitions of snow grain shapes are introduced.
4. "ST2_08-04-2018": Near-surface profiles of snow grain shape and density from ST2 measured on 08 April 2018 are indicated. For both properties, top and bottom depths of snow layers which

pertain to measured values are specified together. Also, a boundary of annual layers is highlighted. SMB for the latest annual layer is indicated together.

5. "ST3_09-04-2018": Same as ST2_08-04-2018 but contains data from ST3 measured on 09 April 2018.
6. "SIGMA-A_11-04-2018": Same as ST2_08-04-2018 but contains data from SIGMA-A measured on 11 April 2018.
7. "SIGMA-A_14-04-2018": Eight near-surface snow density data measured at SIGMA-A on 14 April 2018 are included. These values are for top 0.05, 0.1, and 0.5 m, respectively. Values for average, standard deviation, and coefficient of variation are indicated together.
8. "ST4_15-04-2018": Same as ST2_08-04-2018 but contains data from ST4 measured on 15 April 2018.

5. Technical Validation

The uncertainties of snow density measurements due to the density cutter method might be approximately 9 %, as reported by a previous study[20]. Furthermore, the snow density measurements involve uncertainties due to spatial variability. Therefore, we measured the spatial variability of the near-surface snow density by digging eight independent snow pits around SIGMA-A on 14 April 2018 (Table 3). Evidently, the variability becomes smaller in the lower layers (1.2 % for the top 0.5 m snow) than the surface layers (7.4 % for the top 0.05 m). Also, these values are still lower than the uncertainty involved in the measurement technique.

6. Competing interests

The authors declare no competing interests.

7. Figures

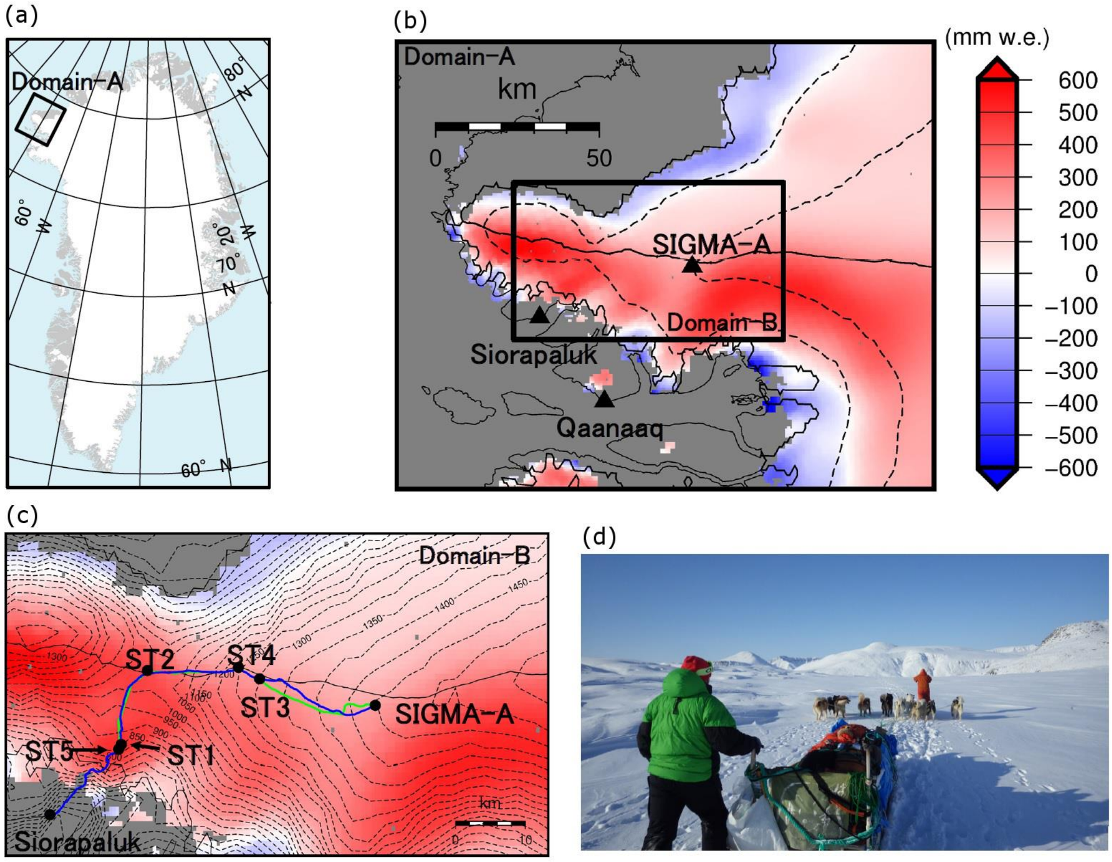

Figure 1. The Study area of the SIGMA-Traverse 2018. (a) A map showing entire Greenland, (b) northwest area (Domain-A) indicated in (a), (c) northwest GrIS (Domain-B) indicated in (b). In (b) and (c), accumulated SMB (mm w.e.) with respect to 1 August 2017 on 15 April obtained from the NHM-SMAP v1.00 calculation[5] is depicted together to show regional characteristics of SMB from 2017 to 2018. Dashed lines in (b) indicate surface elevation at 1000 and 1500 m, and the contour interval of dashed lines (surface elevation) in (c) is 50 m. (d) A scene of the expedition walking down near the termination of the GrIS (top of the Meehan Glacier) in the return trip.

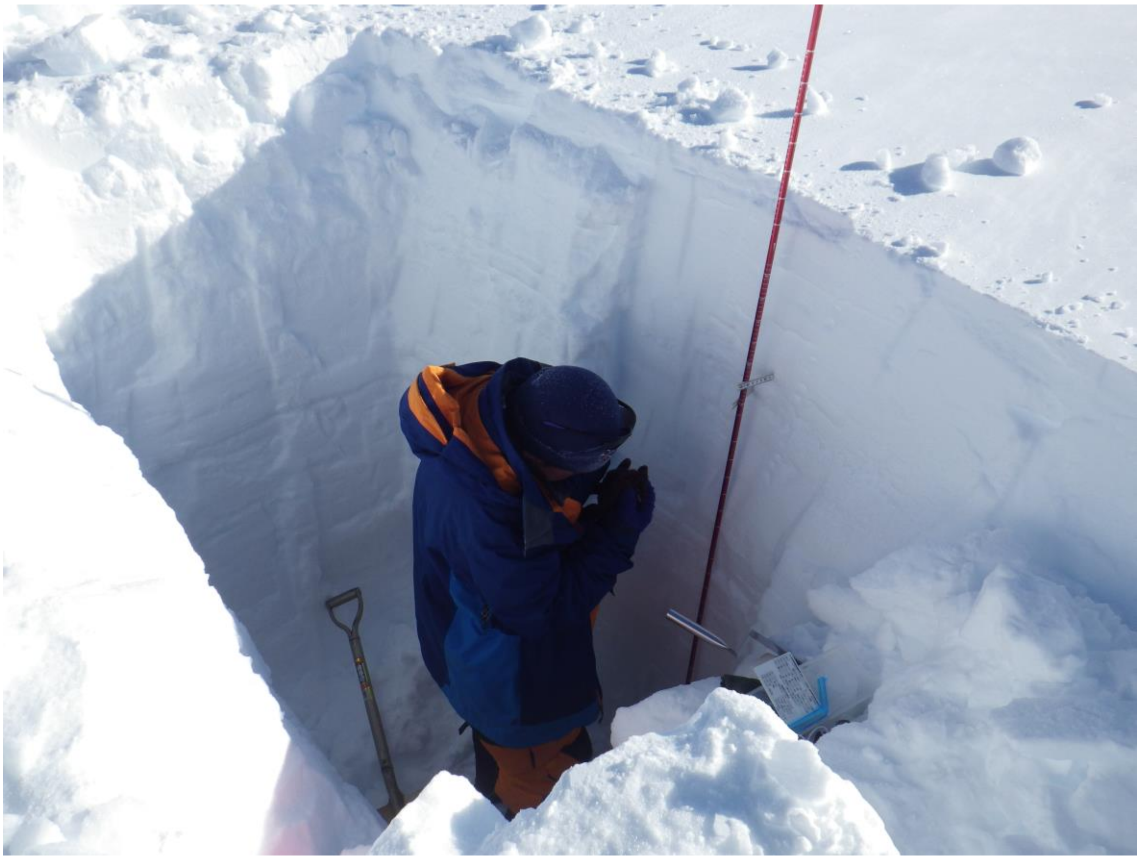

Figure 2. View of the snow pit work carried out on 11 April 2018 at SIGMA-A.

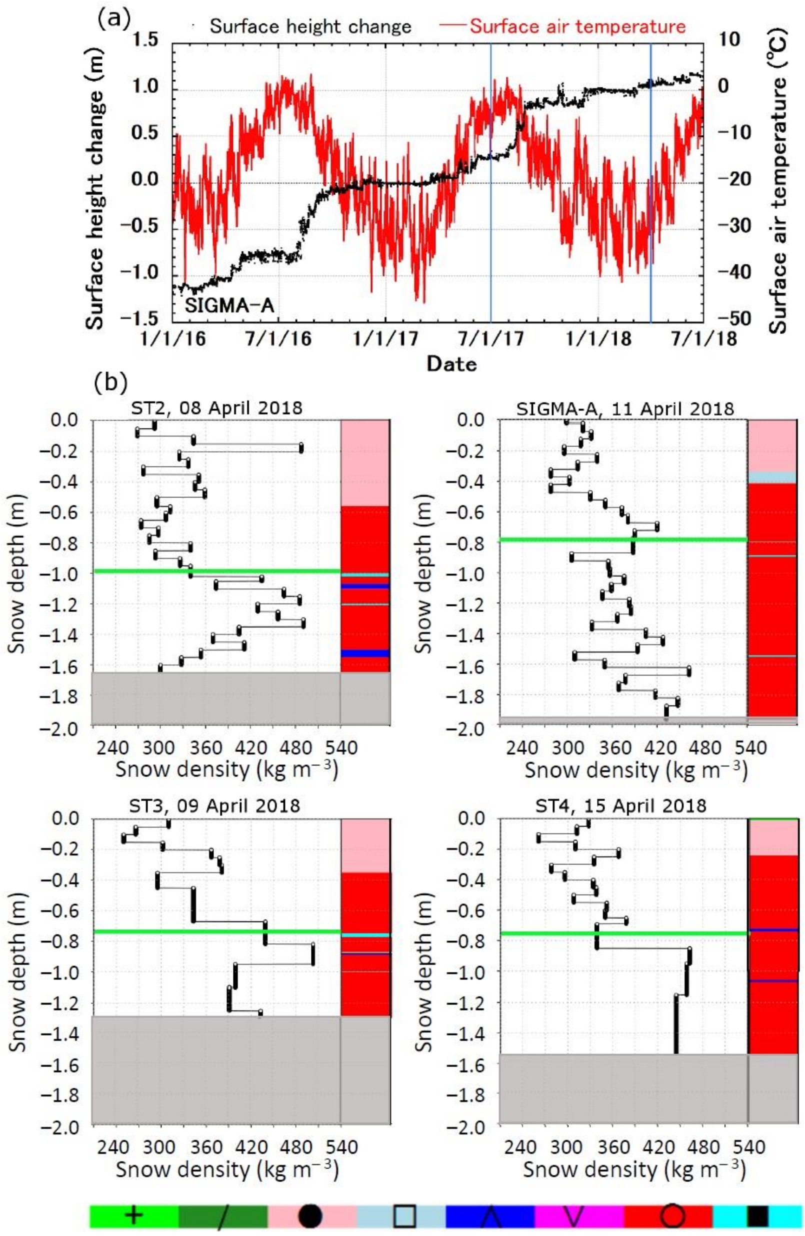

Figure 3. Surface meteorological and glaciological measurement data during SIGMA-Traverse 2018. (a) Temporal evolution of hourly surface air temperature and surface height change with respect to 1 January 2017 at SIGMA-A from 1 January 2016 to 1 July 2018 measured with the AWS. Blue solid lines indicate 1 July 2017 and 1 April 2018, respectively. (b) Measured near-surface snow density (solid black lines) and snow grain shape profiles (colors). Green solid lines indicate estimated boundaries for annual layers. Characters and colors indicating snow grain shape (bottom of the figure) follow the international definition[21]. In sequence from the left, they denote precipitation particles, decomposing and fragmented precipitation particles, rounded grains, faceted crystals, depth hoar, surface hoar, melt forms, and ice layer.

8. Tables

Table 1. Itinerary of SIGMA-Traverse 2018.

Date	Departure place	LON (°W)	LAT (°N)	Altitude (m a.s.l.)	Place of arrival	Travel record	Field measurements
06 April 2018	Siorapaluk	70.63	77.79	12	ST1	Moving distance: 24.9 km	-
07 April 2018	-	-	-	-	-	Remaining in place due to bad weather	-
08 April 2018	ST1	70.04	77.93	919	ST2	Moving distance: 14.7 km	Snow pit measurement
09 April 2018	ST2	69.83	78.09	1162	ST3	Moving distance: 25.2 km	Snow pit measurement
10 April 2018	ST3	68.75	78.09	1288	SIGMA-A	Moving distance: 28.1 km	-
11 April 2018	-	-	-	-	-	-	AWS maintenance and snow pit measurement
12 April 2018	-	-	-	-	-	No activities due to bad weather	-
13 April 2018	-	-	-	-	-	-	AWS maintenance
14 April 2018	-	-	-	-	-	-	Multipoint surface density measurements and AWS maintenance
15 April 2018	SIGMA-A	67.63	78.05	1490	ST4	Moving distance: 33.6 km	Snow pit measurement
16 April 2018	-	-	-	-	-	Remaining in place due to bad weather	-
17 April 2018	ST4	68.96	78.11	1242	ST5	Moving distance: 37.6 km	-
18 April 2018	ST5	70.02	77.94	986	Siorapaluk	Moving distance: 26.7 km	-

Table 2. Measured SMBs for the latest annual layers at ST2, ST3, SIGMA-A, and ST4, respectively. Each measurement date is indicated together.

Site	ST2	ST3	SIGMA-A	ST4
Date	08 April 2018	09 April 2018	11 April 2018	15 April 2018
SMB (mm w.e.)	323	253	265	241

Table 3. Statistical information of average snow density for the top 0.05, 0.1, and 0.5 m obtained from eight snow pit measurements conducted at the SIGMA-A site on 14 April 2018.

Depth (m)	Average (kg m^{-3})	Standard deviation (kg m^{-3})	Coefficient of variation (%)
0-0.05	304	22	7.4
0-0.1	307	16	5.1
0-0.5	319	4	1.2

Author contributions

MN planned and led the SIGMA-Traverse 2018 expedition. MN, TY, and SY conducted the expedition. SY and MN performed snow pit measurements. TY developed a special dog sled team consisting of 13 Greenlandic dogs for this expedition and prepared related logistics. TA processed the SIGMA-AWS data and supported the logistics of the expedition. MN prepared the manuscript and its relevant data with contributions from all co-authors.

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Data Citations

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