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Spatiotemporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas in Alaska for the period from 2017 to 2019

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Abstract: This is the third report of the annually recurring, continuous measurements of the fiber-optic DTS (distributed temperature sensing) system using Raman-scattering optical time domain reflectometry, implemented at a research site in the interior of Alaska (Poker Flat Research Range). This is the last portion of the measurement (called “Loop1”), which started in 2012, resumed in 2017 after the one-year intermission due to the sensor cable failures, and terminated indefinitely in 2019. In this period, a fiber-optic cable sensor was deployed across the landscape to measure temperatures at high spatiotemporal resolution (0.5-meter and 30-minute intervals) horizontally across the different land surface cover types. It also had four sub-sections where the cable sensor was set in coil configurations (1.2 m high), installed vertically half below and half above the ground. The total cable

ran 1.9 km for this period of measurements, within which about a 1.4 km section covered horizontal surface paths. This dataset contains the measurements from September 23, 2017 to September 6, 2019 (372 observation days). Due to potential deterioration of the measurement quality because of occasional partial and total interruptions, and of the occasional DTS equipment malfunctioning, this period of data is archived separately from the previous datasets.

1. Background & Summary

This dataset updates the previous ones[1,2] and concludes the Loop1 measurement conducted from 2012 to 2019; the period consists of three distinct periods dissected by two substantial intermissions, that is, from 2012 to 2014[1], from 2015 to 2016[2], and from 2017 to 2019 (this dataset). As described in the section 5 of this paper and in the previous accompanying papers[1,2], the continuity, extent, and overall quality of the measurement along the sensor cable is vulnerable to external direct physical disturbances, such as those from animals. In addition, the extensive operation of another Loop measurement (Loop2) was initiated in 2017 using two channels of the DTS equipment other than those used for Loop1. These factors likely induced occasional unstable performance with potentially deteriorated quality of the Loop1 DTS measurement for this period. Comprehensive evaluations of the measured data across the whole periods are required in terms of relative attributions of the changes in ambient background and the internal factors of the DTS system, however, it is beyond the scope of this paper.

2. Location

The Poker Flat Research Range (65.12°N; 147.49°E, 210 meters above mean sea level) is a facility managed by the University of Alaska Fairbanks, located about 50 km northeast of Fairbanks in the interior of Alaska (Fig. 1). The area is in a discontinuous permafrost zone.

3. Methods

The cable sensor was initially installed in 2012 over 2.7 km long, of which surface paths (six horizontal sections) cover 2.0 km and the five vertical sections coiled around PVC pipes[1] cover 0.7 km (Figure 2). Both the end part of the horizontal section (ca. 300 m) and the fifth tube (total of ca. 100 m) were damaged by attacks from wild animals and discarded in 2015[2], and further damaged in 2017. For this period, the total cable ran 1.9 km, within which about a 1.4 km section covered horizontal surface paths. See Figures 2 and 3 for the horizontal section locations from 1 to 5. The version Ver.4.1.36 of the software “DTS Configurator” was used from 2017 to 2019, which ran on the

Windows 7 operating system.

The general explanations of the measurement methods were provided in the previous papers[1,2] in terms of the physical principles, the equipment, and the fiber-optic cable sensors of the DTS measurements, together with further details of the software specifications and the source of the validation data[3].

4. Data Records

This entry is a new quality-controlled dataset covering the period from 2017 to 2019, compiled from three separate data entries archived at the Arctic Data archive System as described below (#3). The dataset consists of three different types of files, that is, two attribution files, one quality-controlled temperature data file, and original output files.

1. Attribution files.

(1) Temporal information (1 file)

A comma-separated-value text file with entities of [data number, year, month, day, hour, minute, second, and date] (Table 1).

The number of stored items is 17256. Here, the date denotes the elapsed date, with the fraction of a day, from January 1, 2017, beginning at noon, Alaska Standard Time.

Filename: TemporalData_Loop1_2017_2019.csv.

(2) Locational information (1 file)

A comma-separated-value text file with entities of [data number, longitude, latitude, section number, section information, observation number in the section] (Table 2, Figure 3).

The number of stored items is 3871. Note that only the first half of the data was retained because of the lower quality of the data in the second half for this period of the measurement as described in section 5 below.

Filename: SectionData_Loop1_2017_2019.csv.

2. Quality-controlled temperature data file (1 file)

An unformatted binary (4-byte float) data file only of the temperature [°C] data, extracted from the quality-controlled output files (i.e., checked for no missing or inappropriate values, as described in section 5).

It has the (location, time) dimension as described above in #1. The file is in the size of 267,191,904 bytes (= 3871 x 17256 x 4). See Figure 4 for coverage of the successful, quality-controlled data in time and space.

Filename: Loop1_temperature_2017_2019.dat

3. Original output files

This new dataset is compiled from the three previously registered original trace files (the data

citations #2-4):

(1) A20190625-002 “Spatio-temporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas at Alaska in 2017” (https://ads.nipr.ac.jp/dataset/A20190625-002)

(2) A20190625-003 “Spatio-temporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas at Alaska in 2018” (https://ads.nipr.ac.jp/dataset/A20190625-003)

(3) A20191021-001 “Spatio-temporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas at Alaska in 2019.” (https://ads.nipr.ac.jp/dataset/A20191021-001)

A trace file is produced by the “DTS Configurator” software in text (ASCII) format with the file name convention “dtsout1-YYYYMMDD00N000.tra”, where YYYY, MM, and DD are the year, month, and day of the data production, and N is the order of products in the same day. The first 117 lines are header information on the measurement settings. Each observation output starts with “[Trace.xxx],” where xxx denotes the number of consecutive measurements and ends with temporal information when the output was produced.

Each line of output has the following entries separated by a semicolon: “Number; distance [meter]; temperature [°C]; original DTS signal [-]; loss of signal [dB]”

Data example:

[Trace.4069]
0;0;16.0011787414551;-8.26901149749756;-0.348246369759242
1;0.5;13.5141181945801;-8.3326940536499;-0.32830130259196
2;1;10.4333248138428;-8.41308689117432;-0.334304012854894
3;1.5;9.35385322570801;-8.44165992736816;-0.34427952170372
(omission)
31;15.5;-2.62263703346252;-8.77354717254639;-0.381170624494553
32;16;-1.57275438308716;-8.74331474304199;-0.383834759394328
33;16.5;-1.42903351783752;-8.7391939163208;-0.3812262515227
34;17;-2.39346647262573;-8.76692867279053;-0.374911000331243
(omission)
9319;4659.5;-2.73332405090332;-8.77674770355225;-10.7754872004191
9320;4660;-1.58336901664734;-8.74361896514893;-10.7812287648519
9321;4660.5;-1.27457284927368;-8.73476982116699;-10.8274384816488
9322;4661;-2.59927845001221;-8.77287197113037;-10.7515415827433
(omission)
9344;4672;10.2049369812012;-8.41911506652832;-11.2823729197184

9345;4672.5;9.34458446502686;-8.4419059753418;-11.3449542999268
9346;4673;9.33199691772461;-8.44224071502686;-11.3502987543742
Date.Year;2017
Date.Month;11
Date.Day;5
Time.Hour;0
Time.Minute;2
Time.Second;3

5. Technical Validation

We have taken the same measures to assure the technical quality of the measurements and the compiled data: 1) calibration of the measured temperature of the cable sensor, 2) comparison of the DTS measurement with another observation (namely, the JICS tower observations[3]. cf. Figure 5[1]), and 3) removal of the failed observations due to breaks or inappropriate fusion of the cables. Please refer to the previous paper[2] for the details. Figure 5 shows the daily mean values on the selected days. After five years of operation, the DTS equipment started to function unstable, and the loss of signal became prominent in the latter half of the measurement. Thus, this period of measurement is archived separately from the previous datasets and retains only the first half of the go-back-and-forth measurements in the quality-controlled dataset. However, the original measurement data are also provided as stated in section 4 3. Original output files.

6. Usage Notes

It should be noted that, as a nature of time domain reflectometry, each measured value at a point does not necessarily indicate the point-wise temperature at the corresponding point but rather averaged temperature along the intervals that contain the point.

7. Competing interests

There are no competing interests in this study.

8. Figures

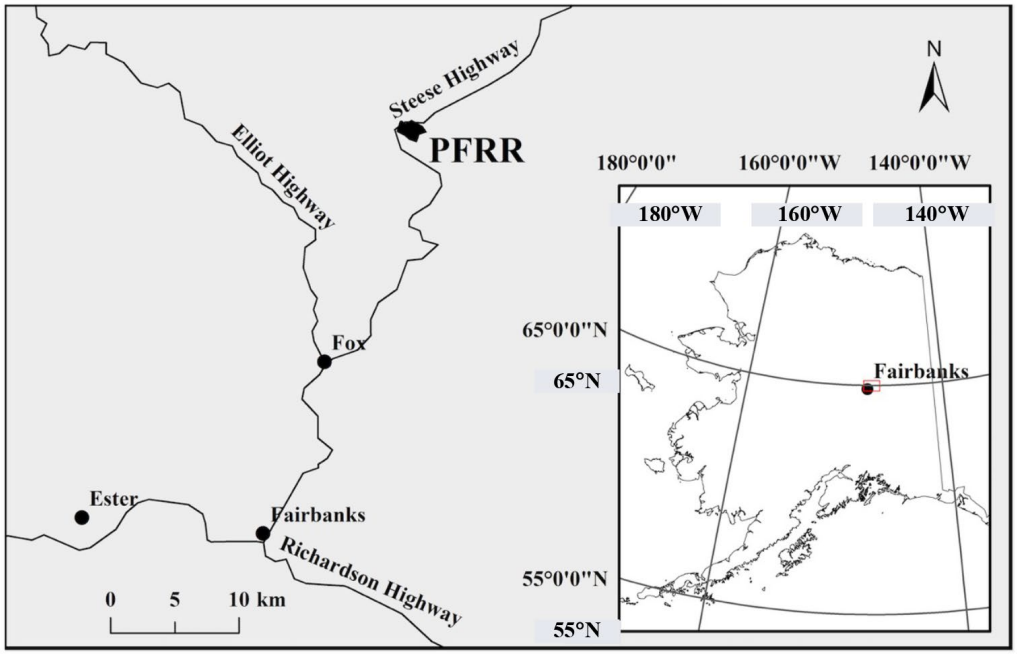

Figure 1. Location of the DTS system installed at the Poker Flat Research Range (PFRR; University of Alaska Fairbanks). [Reproduced from Saito *et al.* (2018)]

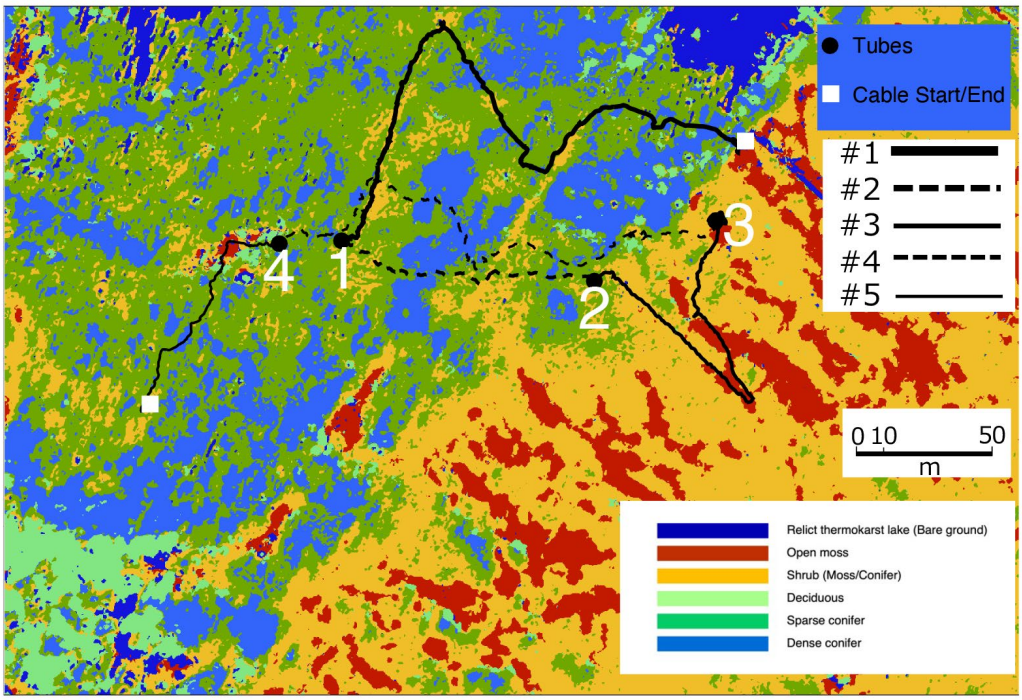

Figure 2. Installation information of the Loop1 fiber-optic cable from 2017 to 2019 at Poker Flat Research Range. Horizontal sections of the cable sensor are delineated by different lines. Numbers in white denote the tube sections. Colors show the surface cover types.

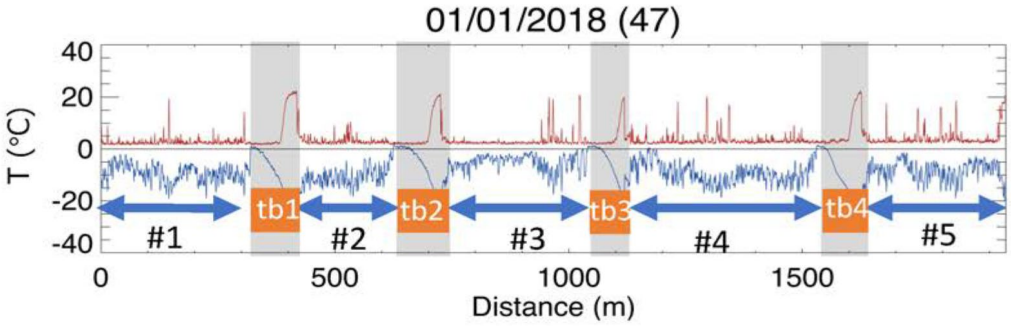

Figure 3. Daily summary of the DTS observations on January 1, 2018. The daily average is shown in blue, and the range is in red. Sectioning of the cable for inter-tubes (#1 to #5) and tubes (tb1 to tb4) are also shown. The figure in round parentheses in the figure title denotes the number of successful observations on the day.

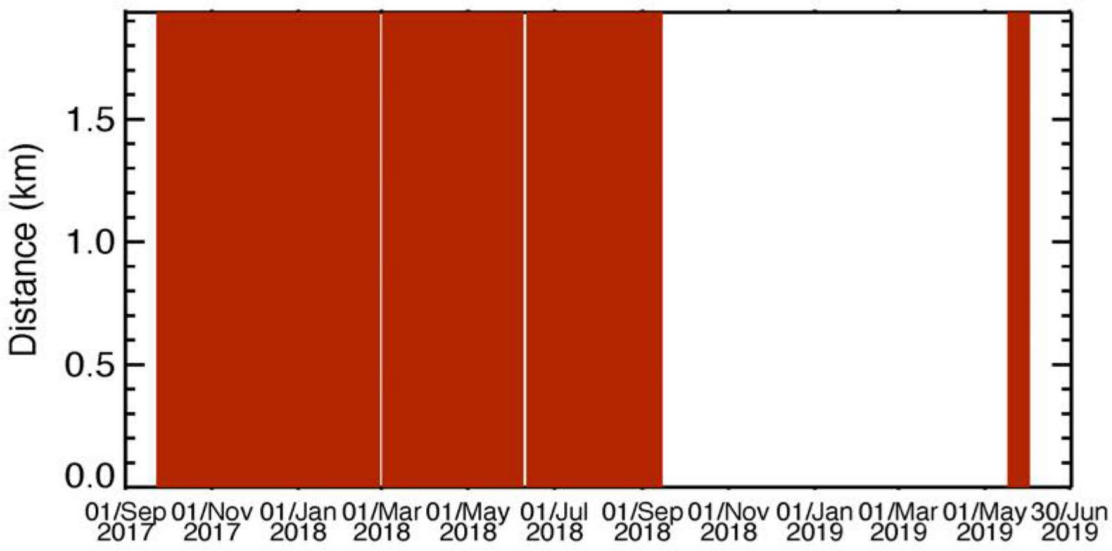

Figure 4. Dates and locations of the successful observations by Distributed Temperature Sensing (DTS) system from 2017 to 2019. Successful observations are shown in red.

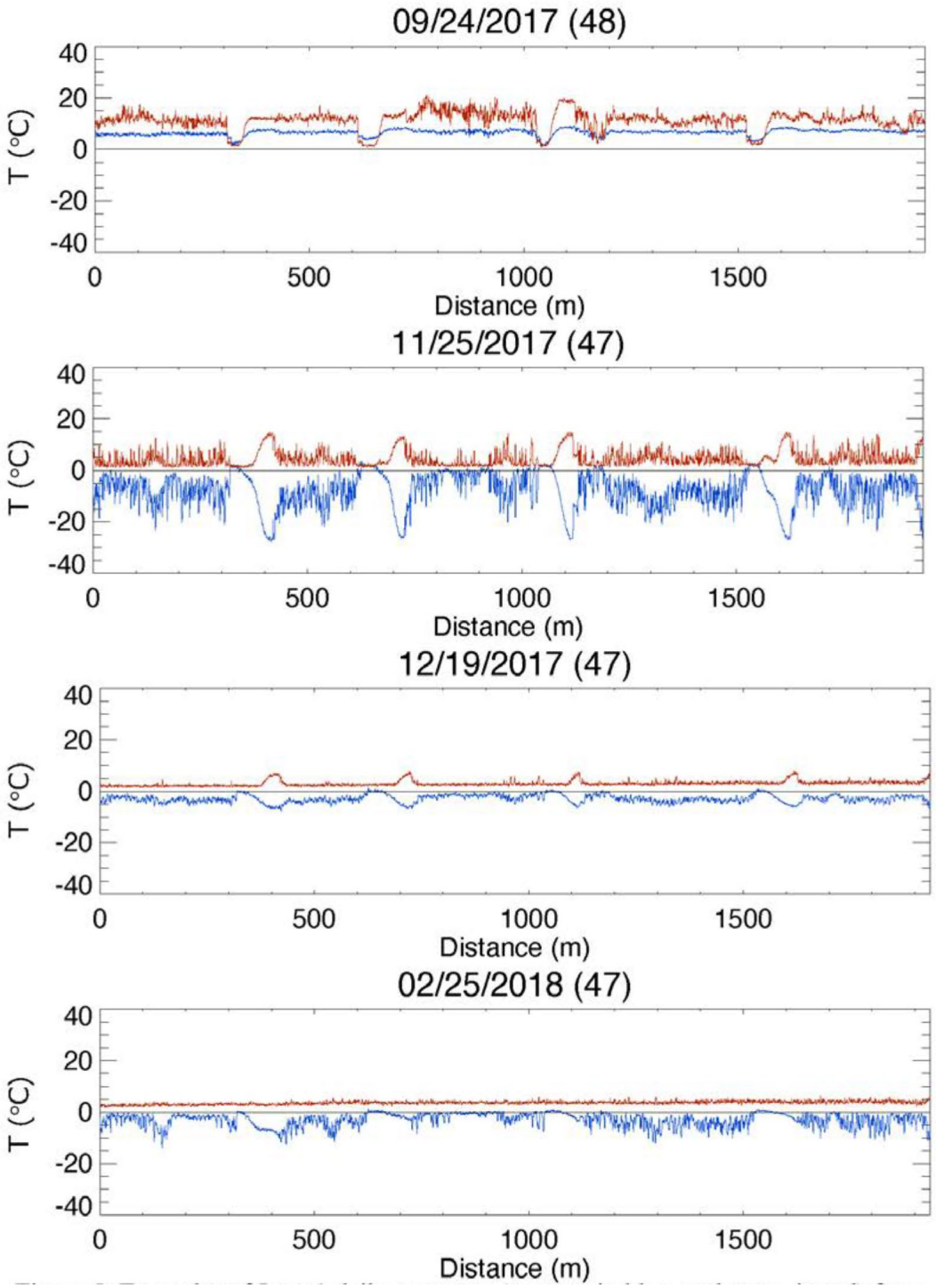

Figure 5. Examples of Loop1 daily summary (average in blue, and range in red) from 2017 to 2019. The figure in round parentheses in the figure title denotes the number of observations on the day.

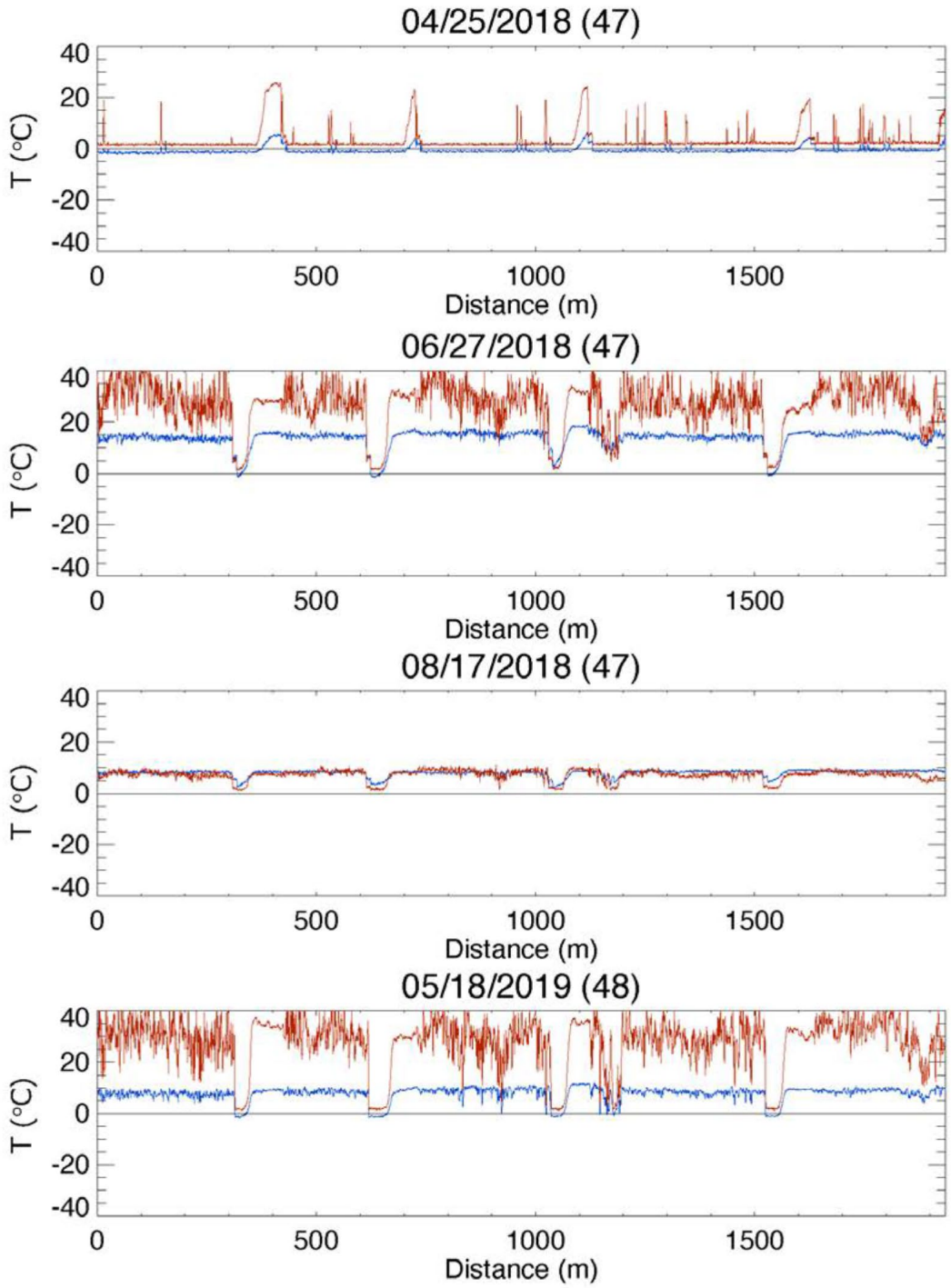

Figure 5. (Continued)

9. Tables

Table 1. The data structure of the temporal information file.

1	Temporal Information							
2	#	Year	Month	Day	Hour	Minute	Second	Date
3	0	2017	9	23	15	2	29	265.126725
4	1	2017	9	23	15	32	29	265.147558
5	2	2017	9	23	16	2	29	265.168391
6	3	2017	9	23	16	32	29	265.189225
7	4	2017	9	23	17	2	29	265.210058
8	5	2017	9	23	17	32	29	265.230891
9	6	2017	9	23	18	2	29	265.251725
10	7	2017	9	23	18	32	29	265.272558
11	8	2017	9	23	19	2	29	265.293391
12	9	2017	9	23	19	32	29	265.314225
13	10	2017	9	23	20	2	29	265.335058
14	11	2017	9	23	20	32	29	265.355891
15	12	2017	9	23	21	2	29	265.376725

(omission)

17245	17242	2019	6	1	23	31	15	881.480035
17246	17243	2019	6	2	0	1	15	881.500868
17247	17244	2019	6	2	0	31	15	881.521701
17248	17245	2019	6	2	1	1	15	881.542535
17249	17246	2019	6	2	1	31	15	881.563368
17250	17247	2019	6	2	2	1	15	881.584201
17251	17248	2019	6	2	2	31	15	881.605035
17252	17249	2019	6	2	3	1	15	881.625868
17253	17250	2019	6	2	3	31	15	881.646701
17254	17251	2019	6	2	4	1	15	881.667535
17255	17252	2019	6	2	4	31	15	881.688368
17256	17253	2019	6	2	5	1	15	881.709201
17257	17254	2019	6	2	5	31	15	881.730035
17258	17255	2019	6	2	6	1	15	881.750868
17259								
17260								
17261								

Table 2. The data structure of the locational information file.

1	Section Information: f1(Start=>Tube1, forward), tb1(Tube1, forward),					
2	f2(Tube1 = > Tube2, forward), tb2(Tube2, forward), ..., f5(Tube4 = > End, forward),					
3	r5(End = > Tube4, backward), rb4(Tube4, backward), f4(Tube4 = > Tube3, backward), ...					
4	#	Longitude	Latitude	Section #	Section Info	Obs # in section
5	0	-147.489868	65.124063	1	f1	1
6	1	-147.489865	65.124055	1	f1	2
7	2	-147.489858	65.124050	1	f1	3
8	3	-147.489858	65.124048	1	f1	4
9	4	-147.489860	65.124048	1	f1	5
10	5	-147.489864	65.124051	1	f1	6
11	6	-147.489863	65.124055	1	f1	7
12	7	-147.489857	65.124059	1	f1	8
13	8	-147.489852	65.124062	1	f1	9
14	9	-147.489849	65.124066	1	f1	10
15	10	-147.489847	65.124070	1	f1	11
16	11	-147.489846	65.124074	1	f1	12

(omission)

3868	3863	-147.497889	65.122576	5	f5	600
3869	3864	-147.497890	65.122574	5	f5	601
3870	3865	-147.497890	65.122571	5	f5	602
3871	3866	-147.497891	65.122568	5	f5	603
3872	3867	-147.497891	65.122565	5	f5	604
3873	3868	-147.497888	65.122561	5	f5	605
3874	3869	-147.497885	65.122558	5	f5	606
3875	3870	-147.497882	65.122555	5	f5	607
3876	3871	-147.497882	65.122555	5	r5	1
3877	3872	-147.497885	65.122558	5	r5	2
3878	3873	-147.497888	65.122561	5	r5	3
3879	3874	-147.497891	65.122565	5	r5	4
3880	3875	-147.497891	65.122568	5	r5	5
3881	3876	-147.497890	65.122571	5	r5	6
3882	3877	-147.497890	65.122574	5	r5	7
3883	3878	-147.497889	65.122576	5	r5	8

(omission)

7737	7732	-147.489849	65.124066	1	r1	611
7738	7733	-147.489852	65.124062	1	r1	612
7739	7734	-147.489857	65.124059	1	r1	613
7740	7735	-147.489863	65.124055	1	r1	614
7741	7736	-147.489864	65.124051	1	r1	615
7742	7737	-147.489860	65.124048	1	r1	616
7743	7738	-147.489858	65.124048	1	r1	617
7744	7739	-147.489858	65.124050	1	r1	618
7745	7740	-147.489865	65.124055	1	r1	619
7746	7741	-147.489868	65.124063	1	r1	620
7747						
7748						
7749						

Author contributions

K. Saito initiated, designed, and supervised the entire project; procured the sets of equipment, negotiated the use of PFRR, led the deployment of the cable sensor, and performed the calibrations, programming, and measurements of the DTS system. G. Iwahana and R. Busey contributed to installation of the DTS equipment. GI, H. Nagano, and H. Ikawa contributed to maintaining DTS measurement. GI conducted land cover classification for the site and generated figures of geographical information. RB supervised the technical aspects of the project. All the authors contributed to the final manuscript with input, suggestions, and editing.

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References

1. Saito, K., Iwahana, G., Ikawa, H., Nagano, H. and Busey, R. C. Links between annual surface temperature variation and land cover heterogeneity for a boreal forest as characterized by continuous, fibre-optic DTS monitoring. Geosci. Instrum. Method. Data Syst. 2018, 7 (3), p. 223–234. https://doi.org/10.5194/gi-7-223-2018.
2. Saito, K., Iwahana, G., Ikawa, H., Nagano, H. and Busey, R. Spatiotemporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas in Alaska for the period from 2015 to 2016. Polar Data J. 2023, 7, p. 58–71. https://doi.org/10.20575/00000049.
3. Nakai, T. et al. Characteristics of evapotranspiration from a permafrost black spruce forest in interior Alaska, Polar Sci. 2013, 7 (2), p. 136–148. https://doi.org/10.1016/j.polar.2013.03.003.

Data Citations

1. Saito, K., Iwahana, G., Ikawa, H., Nagano, H., and Busey, R. Spatiotemporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas in Alaska for the period from 2017 to 2019. 1.00, Japan, Arctic Data archive System (ADS), 2024. https://doi.org/10.17592/001.2023101901.
2. Saito, K., Iwahana, G., Ikawa, H., Nagano, H., and Busey, R. Spatio-temporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas at Alaska in 2017. 1.00, Japan, Arctic Data archive System (ADS), 2024. https://doi.org/10.17592/001.2019062502.
3. Saito, K., Iwahana, G., Ikawa, H., Nagano, H., and Busey, R. Spatio-temporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas at Alaska in 2018. 1.00, Japan, Arctic Data archive System (ADS), 2024. https://doi.org/10.17592/001.2019062503.
4. Saito, K., Iwahana, G., Ikawa, H., Nagano, H., and Busey, R. Spatio-temporally continuous temperature monitoring using optical fibers (Loop1) in the internal forest areas at Alaska in 2019. 1.00, Japan, Arctic Data archive System (ADS), 2024. https://doi.org/10.17592/001.2019102101.