Supplement of Geosci. Model Dev., 12, 4443–4467, 2019
https://doi.org/10.5194/gmd-12-4443-2019-supplement

Geoscientific
Model Development
Open Access

Supplement of

Improving permafrost physics in the coupled Canadian Land Surface Scheme (v.3.6.2) and Canadian Terrestrial Ecosystem Model (v.2.1) (CLASS-CTEM)

Joe R. Melton et al.

Correspondence to: Joe R. Melton (joe.melton@canada.ca)

1 Impact of the de Vries (1963) thermal conductivity parameterization

The Exp. *deVries thermal cond.* has a smaller average MAE of 0.287 m than *SoilGrids+Moss* (0.472 m, Main Figure 3). Comparing the spatial patterns of ALT for *deVries thermal cond.* with *SoilGrids+Moss* shows generally deeper ALTs with a large loss of permafrost in the southern zones of the PD in eastern Russia (Main Figure 2 and Figure S5). Global simulated PA drops from 17.9 to 16.2 Mkm^2. In winter simulations at seven sites in the South Saskatchewan River Basin (SSRB), MacDonald (2015) found the de Vries (1963) soil thermal conductivity formulation to outperform the Côté and Konrad (2005) soil thermal conductivity parameterization in CLASS-CTEM through improvements in both simulated soil moisture and snow. However, the de Vries (1963) formulation neglects the effect of ice on soil thermal conductivity (see equations A7 - A10). As the thermal conductivity of liquid water (0.57 W m^{-1} K^{-1} at 5 °C) is much lower than that of ice (2.24 W m^{-1} K^{-1} at -4 °C), it is surprising that this formulation performs as well as it did both in our simulations against the GTN-P ALT observations, and for the SSRB runs conducted by MacDonald (2015). This neglecting of the thermal conductivity difference between liquid water and ice could be the cause of a dampened soil temperature annual cycle as deeper soil layers are slower to cool in the *deVries thermal cond.* simulations compared to *SoilGrids+Moss* (Figure S12). We do see an increase in wMAE at the GTN-P borehole sites (Main Figure 4) demonstrating that this parameterization does indeed degrade model performance as would be anticipated.

2 Impact of driving meteorological dataset

When the meteorological forcing dataset is CRUJRA55 instead of CRUNCEP, the MAE of both *SoilGrids+Moss* and *Pel16+Moss* improves further to 0.415 m and 0.404 m, respectively, with two fewer cells ISPF (The spatial differences between the *Pel16+Moss* and *SoilGrids+Moss* simulations with CRUNCEP and CRUJRA55 are shown in Figure S11). The CRUNCEP meteorological forcing dataset generally produces deeper ALTs for much of Eurasia than simulations forced with CRUJRA55 with some shallower ALTs in Alaska and the Yukon. While CRUNCEP and CRUJRA55 share a common climatology (CRU), it is likely their differences in sub-monthly variability leads to significant differences in simulated PA and ALTs. This result is in line with Beer et al. (2018) who used artificially manipulated climate datasets to show that soil temperature can be 0.1 to 0.8 °C higher when climate variability is reduced in the model forcing data.

Table S1. GTN-P ALT sites used in the CLASS-CTEM evaluation. The mean ALT is calculated by first taking the mean of the sampling grid for each observation in time and then taking the mean across all observation times at each site. The standard deviation (SD) at each site is calculated across the sampling grid. The mean SD is then the average SD of the sampling grid across all observation times.

	Name	Latitude (°N)	Longitude (°W)	Obs. period	Mean obs./yr	Mean ALT (m)	Mean SD over ALT grid (m)
1	Cape Chukochii R13a	70.08	159.92	2000 - 2015	0.94	0.41	0.09
2	Taglu Grid	69.37	-134.95	1998 - 2008	1.27	0.99	0.22
3	Mt Rodinka PLOT	68.75	161.50	2003 - 2015	1.00	0.99	0.14
4	Mt Rodinka Control Site	68.73	161.40	2003 - 2015	1.00	1.35	0.11
5	Urengoy GAS FIELD GP5	66.32	76.91	2008 - 2014	1.14	0.77	0.41
6	Vaskiny Dachi 2	70.30	68.88	2007 - 2015	1.00	0.70	0.12
7	Mt Rodinka Burn Site	68.72	161.53	2003 - 2015	0.77	1.53	0.09
8	Barrow	71.32	-156.60	1995 - 2015	1.52	0.36	0.08
9	Panteleekha River	68.42	161.22	1996 - 1996	1.00	0.45	0.12
10	Tiksi	71.58	128.78	1997 - 2000	1.25	0.42	0.11
11	Chukochya River	69.49	156.99	1996 - 2015	0.65	0.44	0.06
12	Betty Pingo	70.28	-148.87	1995 - 2015	1.43	0.52	0.17
13	Cape Rogozny	64.78	176.97	1994 - 2015	1.05	0.50	0.05
14	Zackenberg ZEROCALM 2	74.47	-20.50	1996 - 2010	9.27	0.63	0.13
15	Chandalar Shelf	68.07	-149.58	1996 - 2015	0.90	0.36	0.09
16	Old Man	66.45	-150.62	1996 - 2015	0.85	0.40	0.04
17	Franklin Bluff	69.68	-148.72	1996 - 2015	1.00	0.62	0.15
18	Alexandria Fiord	78.88	-75.92	1996 - 2001	0.67	0.57	0.07
19	North Head Grid	69.72	-134.46	1998 - 2008	1.00	0.47	0.08
20	Lousy Point Grid	69.22	-134.29	1998 - 2008	1.00	0.56	0.13
21	Wickersham	65.27	-148.05	1972 - 2015	0.93	0.47	0.08
22	Allaiha	70.56	147.43	2004 - 2015	1.00	0.47	0.08
23	Talnakh	69.43	88.47	2008 - 2015	1.25	0.95	0.21
24	Igarka	67.48	86.44	2008 - 2017	1.10	0.76	0.32
25	Happy Valley 1km	69.10	-148.50	1995 - 2015	1.52	0.44	0.09

Table S1. continued

26	West Dock 1ha	70.37	-148.55	1996 - 2015	1.00	0.31	0.07
27	Marre Sale	69.72	66.75	1995 - 2015	1.00	1.10	0.33
28	Segodnya Pingo	69.09	158.90	1996 - 2015	0.70	0.51	0.12
29	Talnik	67.33	63.73	1998 - 2015	2.50	1.29	0.27
30	Zackenberg ZEROCALM 1	74.47	-20.50	1996 - 2010	7.87	0.71	0.07
31	Malchikovskaya Channel	68.52	161.43	1996 - 2015	1.45	0.54	0.10
32	Ivotuk	68.48	-155.74	2000 - 2014	0.87	0.52	0.11
33	Konkovaya River R15a	69.41	158.45	1996 - 2015	0.70	0.35	0.07
34	Kuropatochya River R12a	70.92	156.63	1996 - 1996	1.00	0.37	0.09
35	Bykovsky Cape Plakor	71.79	129.42	2001 - 2014	0.86	0.33	0.06
36	Ayach	67.58	64.18	1996 - 2015	1.55	0.80	0.11
37	Vaskiny Dachi 1	70.28	68.89	2007 - 2015	1.00	0.70	0.09
38	Khomus2	69.98	153.58	2005 - 2005	1.00	0.54	0.09
39	Plosky Tolbachik 1	55.75	160.29	2003 - 2012	1.10	0.69	0.27
40	Betty Pingo WET	70.28	-148.92	1995 - 2015	1.48	0.41	0.05
41	Kougarok	65.46	-164.63	1999 - 2015	0.71	0.57	0.11
42	Norman Wells Grid	65.19	-126.47	1998 - 2008	1.18	0.46	0.12
43	Bolvansky	68.29	54.51	1999 - 2015	1.65	1.09	0.17
44	Kruglaya	64.63	176.97	2010 - 2015	1.00	0.45	0.07
45	Happy Valley 1ha	69.17	-148.83	1996 - 2015	0.80	0.40	0.08
46	Tuymada	62.01	129.66	2008 - 2015	1.12	2.02	0.08
47	Imnavait Creek MAT	68.61	-149.31	1995 - 2015	1.52	0.45	0.09
48	Lavrentiya	65.60	171.05	2000 - 2012	3.46	0.65	0.10
49	Bykovsky Cape Alas	71.78	129.40	2004 - 2015	0.92	0.31	0.07
50	Sagwon Hills MNT	69.44	-148.67	1995 - 2015	1.62	0.58	0.12
51	Mt Rodinka Station	68.70	161.55	2003 - 2015	1.00	0.77	0.14
52	Pearl Creek	64.90	-147.80	1969 - 2015	1.00	0.64	0.08
53	Atqasuk	70.45	-157.40	1995 - 2015	1.33	0.48	0.19
54	Andryushkino	69.17	154.43	2005 - 2015	1.55	0.38	0.11
55	Toolik 1km	68.62	-149.60	1995 - 2015	1.43	0.48	0.12

Table S1. continued

56	Deadhorse	70.17	-148.47	1996 - 2015	0.95	0.65	0.08
57	Yubileynoe 3 DRY	65.95	75.87	2007 - 2007	1.00	0.23	0.04
58	Betty Pingo MNT	70.28	-148.89	1995 - 2014	1.55	0.38	0.08
59	Samoylov	72.37	126.48	2002 - 2015	7.50	0.48	0.06
60	Toolik MAT	68.62	-149.62	1995 - 2015	1.52	0.45	0.10
61	Yubileynoe 2 DRY	66.01	75.78	2007 - 2007	1.00	0.27	0.08
62	Most	56.91	118.28	2013 - 2014	1.00	0.49	0.08
63	Belenkiy	56.76	118.19	2013 - 2014	1.00	0.54	0.14
64	Fort Simpson Grid	61.89	-121.60	1999 - 2008	1.00	0.90	0.24
65	Lorino	65.54	-171.63	2010 - 2012	1.00	0.47	0.11
66	Bykovsky Cape	71.78	129.42	2015 - 2015	1.00	0.34	0.05
67	Plosky Tolbachik 2	55.76	160.32	2004 - 2012	1.00	0.56	0.04
68	Kuropatochya River R12b	70.92	156.63	1996 - 1996	1.00	0.27	0.08
69	Kashin Island	68.23	53.85	2010 - 2015	1.50	0.74	0.19
70	Rengleng River Grid	67.80	-134.13	1998 - 2008	1.18	0.78	0.13
71	Khomus1	69.98	153.58	2005 - 2005	1.00	0.51	0.09
72	Talnik	67.33	63.73	1999 - 2015	2.24	0.58	0.14
73	Konkovaya River R15b	69.41	158.45	1999 - 2015	0.71	0.45	0.06
74	Akhmelo Channel	68.81	160.99	1996 - 2015	0.95	0.52	0.08
75	Cape Chukochii R13b	70.08	159.92	1999 - 2015	1.00	0.43	0.06
76	Willowlake River Grid	62.70	-123.06	2001 - 2008	1.00	0.81	0.19
77	Alazeya River	69.32	154.97	1998 - 2015	0.78	0.51	0.09
78	West Dock 1km	70.37	-148.56	1995 - 2015	1.43	0.50	0.12
79	Yubileynoe 2 WET	66.01	75.78	2007 - 2007	1.00	0.28	0.04
80	Mountain Dionisiya	64.57	177.20	1996 - 2015	0.95	0.55	0.10
81	Yubileynoe 3 WET	65.95	75.87	2007 - 2007	1.00	0.35	0.03
82	UNISCALM	78.20	15.75	2011 - 2015	1.00	1.03	0.06
83	Yakutskoe Lake	69.85	159.49	1999 - 2015	0.82	0.46	0.06

Table S1. continued

84	Neleger	62.32	129.50	2008 - 2015	1.00	1.24	0.10
85	Lake Glukhoe	68.80	160.96	1996 - 2015	0.95	0.85	0.16
86	Svyatoy Nos Cape	72.86	141.01	2001 - 2001	1.00	0.38	0.04
87	Parisento	70.12	75.58	1992 - 1995	0.75	0.91	0.31
88	Bonanza Creek	64.75	-148.00	1990 - 2015	0.96	0.71	0.11
89	Vaskiny Dachi 3	70.30	68.84	2007 - 2015	1.00	1.13	0.13
90	Imnavait 1km	68.50	-149.50	1995 - 2015	1.48	0.52	0.10
91	Nadym Grid	65.33	72.92	1997 - 2016	1.25	1.35	0.48
92	Urengoy GAS FIELD GP15	67.48	76.70	2008 - 2015	1.00	0.84	0.15
93	Reindeer Depot Grid	68.68	-134.15	2000 - 2008	1.11	1.10	0.10
94	Council	64.84	-163.71	1999 - 2015	0.71	0.57	0.33
95	Lake Akhmelo	68.83	161.03	1996 - 2015	0.95	0.97	0.16
96	Galbraith Lake	68.48	-149.50	1996 - 2015	0.90	0.53	0.09
97	Tolbachinsky Pass	55.89	160.54	2006 - 2015	0.90	0.47	0.02

Table S2. GTN-P permafrost temperature (borehole) sites used in the CLASS-CTEM evaluation.

	Name	Latitude (°N)	Longitude (°W)	GTN-P site number	Permafrost zone	Number of observations
1	Chevak	61.54	-165.60	746	Continuous	45
2	Smith Lake 4	64.87	-147.86	619	Discontinuous	964
3	Circle	65.82	-144.07	752	Discontinuous	105
4	Tobolsk aerologicheskaya	58.15	68.18	1670	None	1079
5	Belenkiy	56.76	118.19	1835	Continuous	34
6	Kerak	57.98	125.50	686	Discontinuous	99
7	Bayandai	53.10	105.53	1674	Isolated	1536
8	Rubtsovsk	51.50	81.22	1666	None	1403
9	Ust	65.45	52.17	1699	None	954
10	Karam	55.33	107.50	1676	Sporadic	990
11	Olkhon	53.23	107.44	1135	Sporadic	82
12	Nadym Pingo	65.30	72.89	178	Discontinuous	169
13	Franklin Bluffs dry b	69.67	-148.72	103	Continuous	691
14	Mould Bay	76.23	-119.30	1108	Continuous	24
15	Ishim	56.13	69.52	1605	None	1550
16	ILU2007	69.22	-51.10	535	Discontinuous	213
17	Taiga	56.07	87.62	1663	None	565
18	Vologda Molochnoe	59.28	39.87	1648	None	579
19	Svobodnyi	51.45	128.12	1623	None	1546
20	Russkaya Polyana	53.83	73.83	1610	None	1089
21	Onega	63.90	38.12	1658	No	1225
22	Berezovo	63.93	65.05	1639	Sporadic	1090
23	Komsomolsk	51.08	137.03	1693	Sporadic	1248
24	Nozhovka	57.08	54.75	1637	None	808
25	Deadhorse 2 new instrumentation	70.16	-148.47	88	Continuous	699

Table S2. continued

26	Turukhansk	65.78	87.95	1652	Discontinuous	1369
27	Boguchany	58.42	97.40	1704	Isolated	1567
28	Saranpaul	64.28	60.88	1638	Discontinuous	1070
29	Smith Lake 3	64.87	-147.86	618	Discontinuous	1134
30	West Dock 1 surface	70.37	-148.55	118	Continuous	436
31	Sagwon MNT	69.43	-148.67	116	Continuous	1021
32	Kupino	54.37	77.28	1620	None	1253
33	Vyazemskaya	47.55	134.82	1689	None	1627
34	Rodino	52.50	80.20	1705	None	1396
35	West Dock 1 surface	70.37	-148.55	118	Continuous	1061
36	Irkutsk obs grass	52.28	104.30	1653	Sporadic	1589
37	Tyumen	57.15	65.50	1647	None	1642
38	Eniseisk	58.45	92.15	1657	None	1356
39	Smith Lake 2	64.87	-147.86	620	Discontinuous	991
40	Bikin	46.80	134.27	1694	None	1061
41	Ivotuk 3	68.48	-155.74	65	Continuous	39
42	Anderson	64.35	-149.20	845	Discontinuous	90
43	Makushino	55.25	67.30	1697	None	1350
44	Barnaul agricst	53.33	83.70	1673	None	1358
45	Tura	64.17	100.07	1641	Continuous	1092
46	Yartsevo	60.25	90.23	1642	Isolated	1500
47	Banks Island	73.22	-119.56	1107	Continuous	478
48	Salmon Lake	64.91	-165.05	1191	Discontinuous	185
49	Azarova	56.90	117.58	54	Continuous	52
50	Franklin Bluffs dry be	69.67	-148.72	104	Continuous	280

Table S2. continued

51	Bomnak	54.72	128.93	1696	Discontinuous	1064
52	Irkutsk obs bare soil	52.28	104.30	1695	Sporadic	244
53	Tolstovka Amurskaya agrexpst	50.17	127.92	1687	None	1629
54	Kamen	53.80	81.33	1622	None	1391
55	Isil	54.90	71.27	1649	None	1627
56	Ivdel	60.68	60.43	1631	None	839
57	Eletskaya	67.17	64.17	1645	Sporadic	619
58	Erbogachen	61.27	108.02	1654	Continuous	1331
59	Anaktuvuk Pass	68.15	-151.72	833	Continuous	44
60	Tashtyp	52.80	99.88	1671	Continuous	1521
61	Solyanka	56.17	95.27	1682	None	1340
62	Ivotuk 4	68.48	-155.74	74	Continuous	316
63	Howe Island 1 b	70.32	-147.99	93	Continuous	568
64	Tatarsk	55.20	75.97	1661	None	842
65	Khanovey	67.29	63.65	1184	Continuous	29
66	Slavgorod	53.97	78.65	1665	None	1476
67	Troitsko	62.70	56.20	1698	None	983
68	Bogotol	56.23	89.58	1617	None	1176
69	Last Bridge	65.39	-164.66	1188	Continuous	60
70	Olkhon	53.23	107.44	1118	Sporadic	138
71	Sidorovsk	66.67	82.33	1678	Discontinuous	1380
72	Rhonda Basin	66.57	-164.48	1185	Continuous	49
73	Shimanovskaya	51.98	127.65	1624	None	857
74	Franklin Bluffs surface	69.66	-148.72	106	Continuous	1131
75	Ambler	67.08	-157.87	780	Continuous	57

Table S2. continued

76	Olkhon	53.23	107.44	1136	Sporadic	82
77	Nadym ND3 4	65.31	72.86	176	Discontinuous	116
78	Belenkiy	56.76	118.19	224	Discontinuous	192
79	Leushi	59.62	65.78	1643	None	1061
80	Sterlitamak	53.62	55.98	1616	None	1135
81	Mould Bay	76.23	-119.30	1108	Continuous	1304
82	Franklin Bluffs dry ib	69.67	-148.72	105	Continuous	1103
83	Krasnoyarsk expfield	56.00	92.88	1655	None	1447
84	Barabinsk	55.37	78.40	1662	None	1046
85	Minusinsk expfield	53.70	91.70	1656	None	1119
86	Tulun agro	54.60	100.63	1686	Isolated	1591
87	Kolpashev	58.30	82.90	1659	None	1187
88	Syktyvkar 1	61.67	50.85	1672	None	969
89	Rhonda Upland	66.56	-164.46	1186	Continuous	79
90	Howe Island 1 ib	70.32	-147.99	94	Continuous	104
91	Ust	65.97	56.92	1614	None	1387
92	Zima railst	53.93	102.05	1677	Isolated	1109
93	Kosh	50.02	88.68	1707	Discontinuous	938
94	Aldan D	57.53	124.53	692	Discontinuous	80
95	Khomutovo	52.50	104.33	1685	None	1052
96	Kotkino	67.02	51.20	1611	Sporadic	496
97	Happy Valley 1 b	69.15	-148.85	95	Continuous	380
98	Nadym ND3	65.31	72.86	175	Discontinuous	246
99	Franklin Bluffs dry b	69.67	-148.72	103	Continuous	447
100	Biisk zonalnaya	52.68	84.95	1621	None	1349

Table S2. continued

101	Ivotuk 4	68.48	-155.74	74	Continuous	51
102	Ivotuk 3	68.48	-155.74	65	Continuous	245
103	Happy Valley 1 ib	69.15	-148.85	110	Continuous	441
104	Ust	61.80	57.92	1675	None	603
105	Poliny Osipenko	52.42	136.50	1690	Sporadic	1535
106	Tunka	51.73	102.53	1668	Continuous	1588
107	Olkhon	53.23	107.44	1840	Sporadic	36
108	Ushelistiy	56.54	118.48	227	Continuous	94
109	Ivotuk 3	68.48	-155.74	65	Continuous	140
110	Skovorodino	54.00	123.97	1612	Sporadic	854
111	Tomsk	56.43	84.97	1660	None	697
112	Nadym PiCla	65.31	72.89	177	Discontinuous	49
113	Franklin Bluffs wet b	69.66	-148.72	107	Continuous	310
114	Mary s Igloo East	65.11	-164.70	1190	Discontinuous	160
115	Kazachinskoe expfield	57.75	93.18	1681	None	569
116	Kargopol	61.50	38.95	1627	None	1216
117	Deadhorse 1 surface	70.16	-148.47	87	Continuous	972
118	Shitkino	56.37	98.37	1669	None	1038
119	Tarko	64.92	77.82	1606	Discontinuous	1003
120	Howe Island 1 ib	70.32	-147.99	94	Continuous	512
121	Kalachinsk	55.03	74.58	1644	None	1163
122	Nadym ND2	65.31	72.89	174	Discontinuous	160
123	Banks Island	73.22	-119.56	1107	Continuous	385
124	Olkhon	53.22	107.45	1137	Sporadic	70
125	Belenkiy	56.76	118.19	1116	Continuous	231

Table S2. continued

126	Vikulovo	56.82	70.62	1646	None	1295
127	Mould Bay	76.23	-119.30	1108	Continuous	1092
128	Konosha	61.00	40.17	1700	None	659
129	Srednii Vasyugan Vasyuganskoe	59.22	78.23	1684	None	1169
130	Khoseda	67.08	59.38	1701	Discontinuous	933
131	Ivotuk 4	68.48	-155.74	74	Continuous	508
132	Erofei Pavlovich	53.97	121.93	1651	Sporadic	814

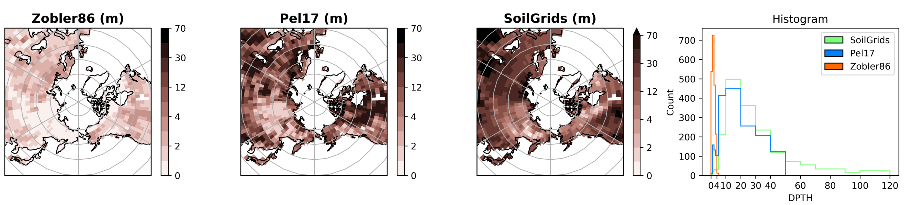

Figure S1. Comparison of soil permeable depth datasets from Zobler86 (Zobler, 1986), Pel16 (Pelletier et al., 2016), and SoilGrids (Shangguan et al., 2017).

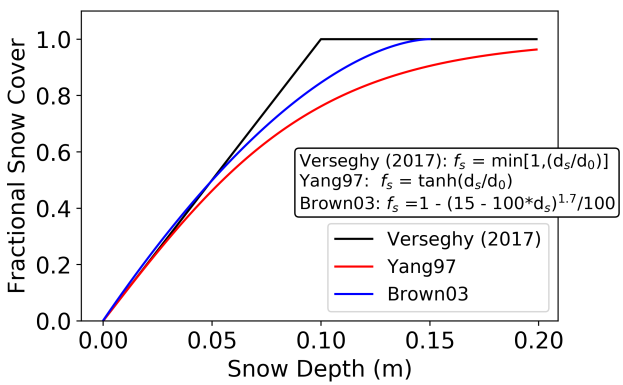

Figure S2. Snow cover as a function of snow depth for the CLASS-CTEM linear relation (Verseghy, 2017), the hyperbolic tangent form of Yang et al. (1997), and the exponential relationship proposed by Brown et al. (2003)

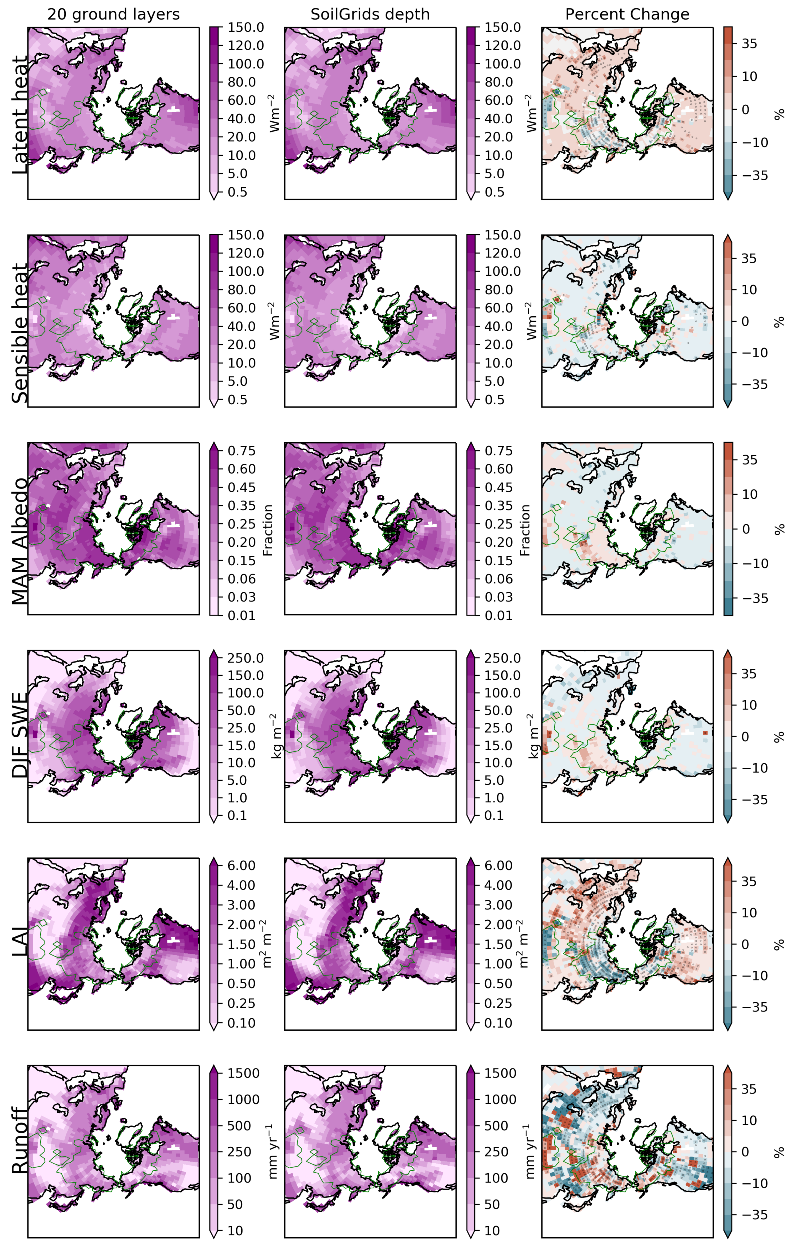

Figure S3. Comparison of mean annual latent and sensible heat flxues, spring (March, April, May; MAM) total surface albedo, winter (December, January, February; DJF) snow water equivalent (SWE), mean annual leaf area index (LAI) and total runoff. Positive percent change values indicate that the '20 ground layer' experiment has higher values of a quantity than the *Base model* while negative values indicate the opposite. The green polygon indicates regions of permafrost simulated by that experiment. The green polygon on the percent change plots is the permafrost region from the *20 ground layers* experiment. Dots indicate grid cells that are statistically significant (independent two-sample t-test p level < 0.05). The left column shows the results from the Exp *20 ground layer* while the middle column shows the *SoilGrids depth* experiment.

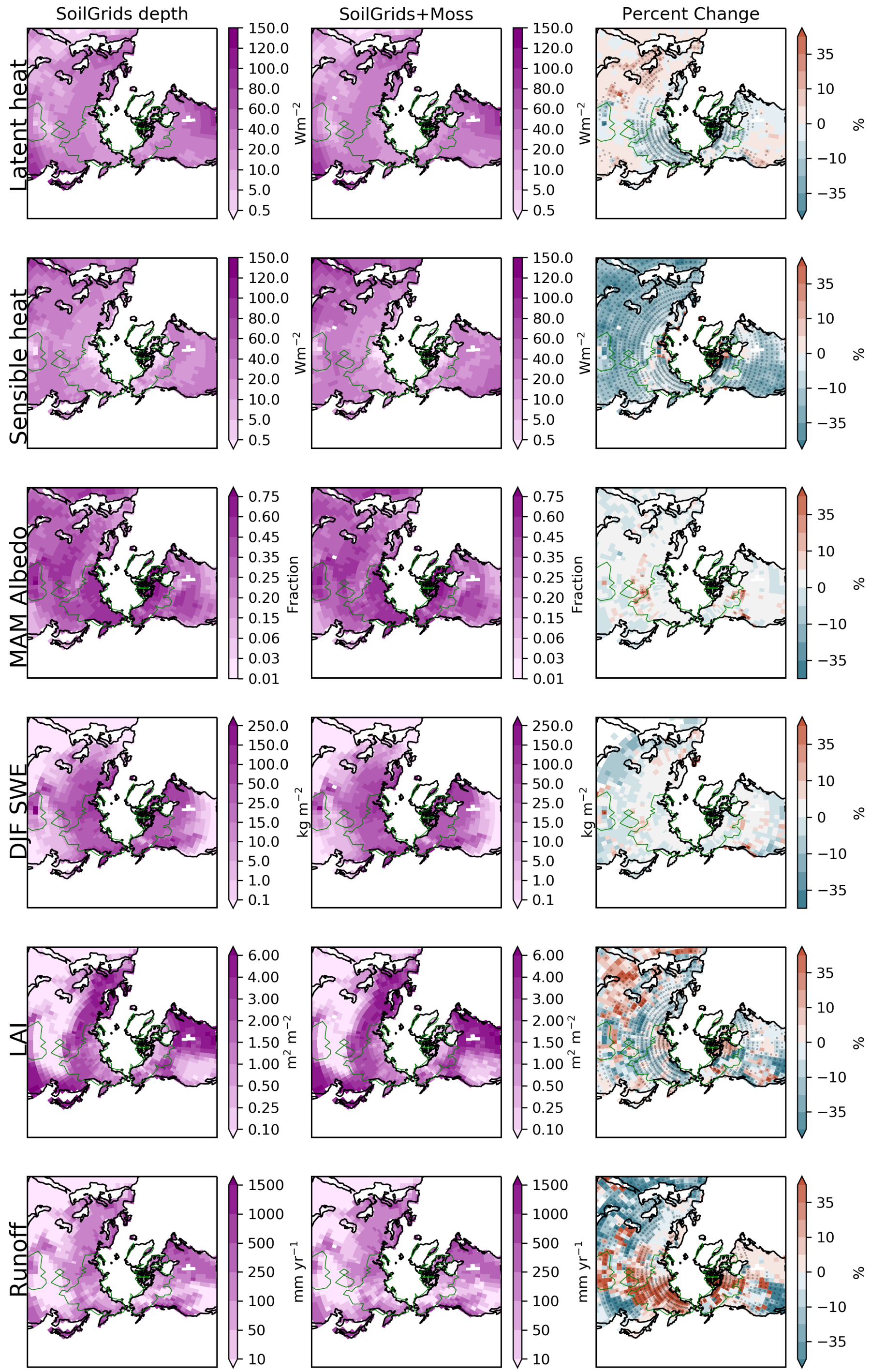

Figure S4. Same as Figure S3 but for experiments *SoilGrids depth* and *SoilGrids+Moss*

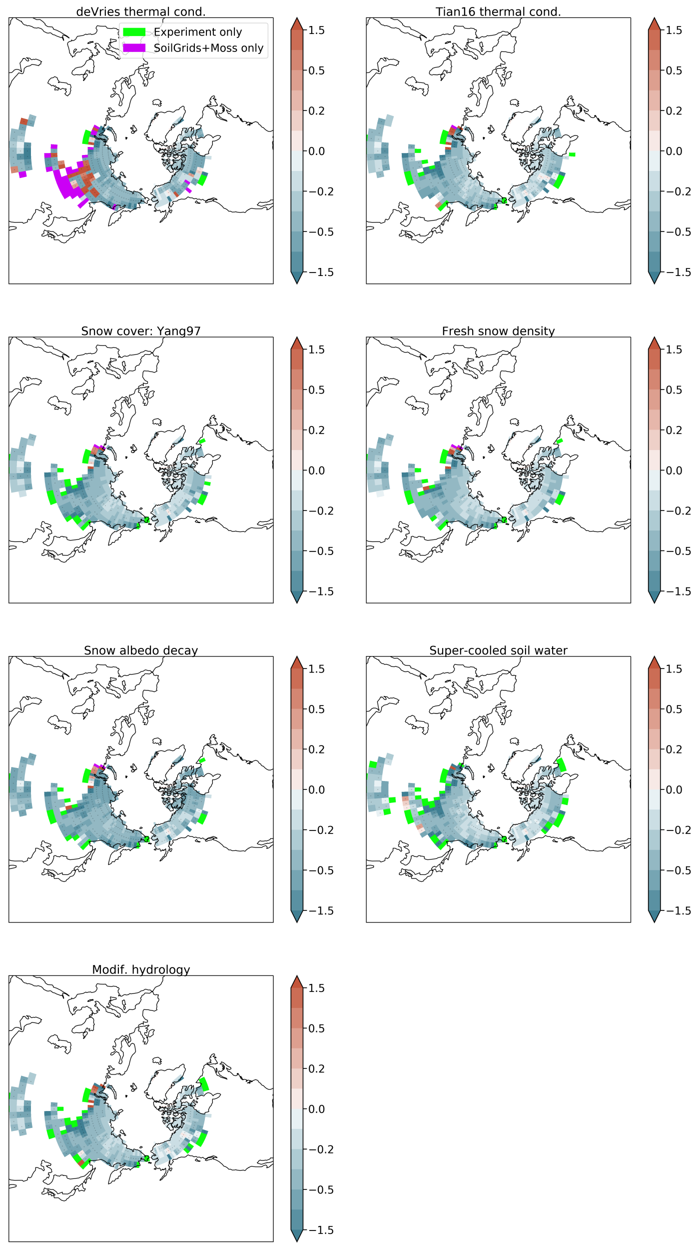

Figure S5. Differences (meters) between the *SoilGrids+Moss* simulated ALT and the ALT simulated by the alternative parameterization experiments (based on the model setup of *SoilGrids+Moss*, see Main Table 1). Negative values indicate that ALTs of the experiment are deeper than in *SoilGrids+Moss* while positive values indicate shallower ALTs. Since permafrost free soils have an undefined ALT, model grid cells that have permafrost in only the experiment are green while cells that have permafrost only in the *SoilGrids+Moss* simulation are purple. Dots indicate grid cells that are statistically significant (independent two-sample t-test p level < 0.05).

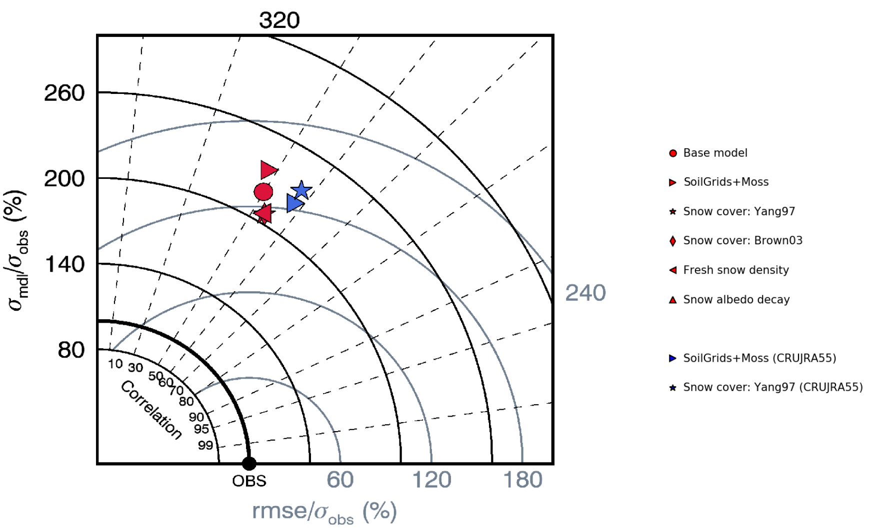

Figure S6. Taylor diagrams for winter (DJF) SWE compared to Blended-5 for the period spanning January 1981 to December 2010. Blended-5 is a multi-dataset SWE product developed by Mudryk et al. (2015) that combines five observation-based SWE datasets. Exp. *Snow albedo decay* is outside the plot boundaries. This plot shows anomaly correlation coefficient as well as ratio of standard deviations and root mean square error normalized by the standard deviation from observations. Values shown correspond to the centroid over the values obtained for every grid cell northward of 45°N, with climatological SWE > 4 mm to avoid regions of ephemeral snow.

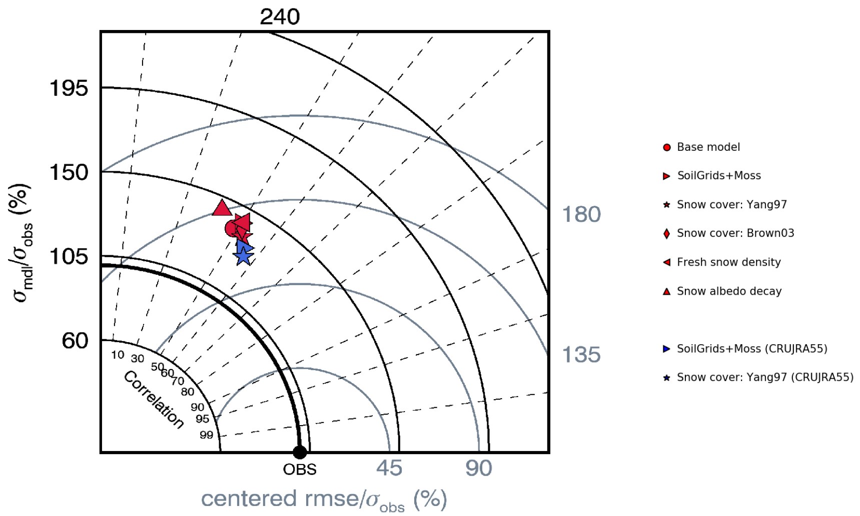

Figure S7. Taylor plot of total spring albedo (AMJ) compared to MODIS MCD43C3 white-sky albedo (MODIS Adaptive Processing System, NASA, 2016) for the period spanning February 2000 to December 2013. The Taylor plot shows the anomaly correlation coefficient (polar coordinates), ratio of standard deviations (y axis) and root mean square error (RMSE) normalized by the standard deviation from observations (x axis). Values shown correspond to the centroid over the values obtained for every grid cell northward of 45°N.

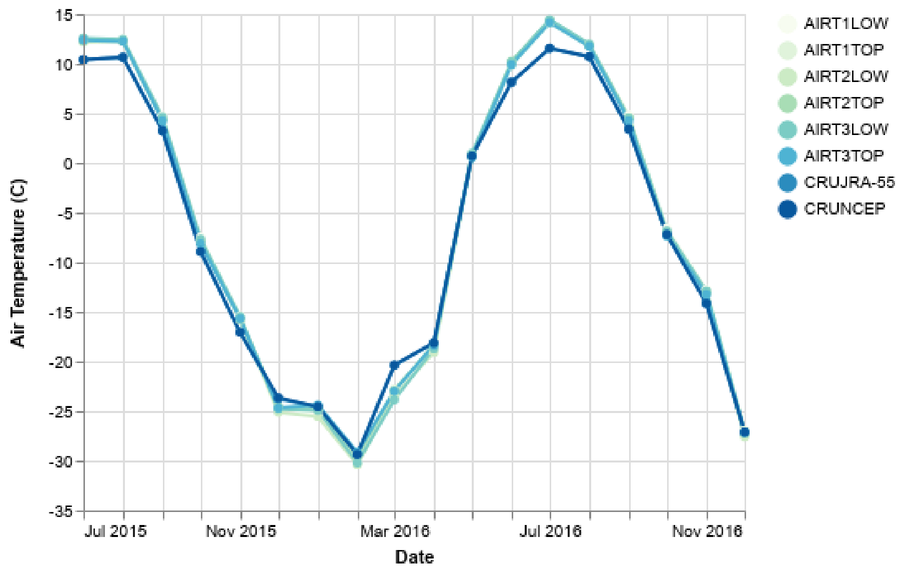

Figure S8. Mean monthly 2 m air temperature at Lac de Gras sites from meteorological stations as part of the Slave Province Surficial Materials and Permafrost Study (SPSMPS) (Gruber et al., 2018) and reanalysis meterological datasets CRUNCEP (Viovy, 2016) and CRUJRA55 (Harris et al., 2014; Kobayashi et al., 2015)

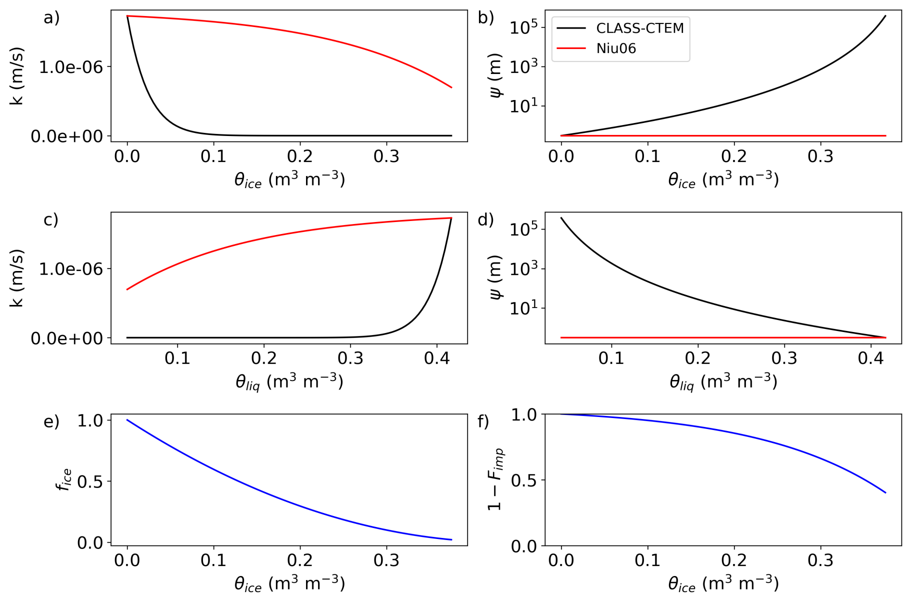

Figure S9. Soil hydraulic conductivity (a,c) and matric potential (b,d) for a soil with sand and clay content by weight of 40% and 20%, respectively, with a maximum saturation level of 95%. The Zhao and Gray (1997) f_{ice} and the Niu and Yang (2006) $(1 - F_{imp})$ parameters are shown in plots e and f, respectively.

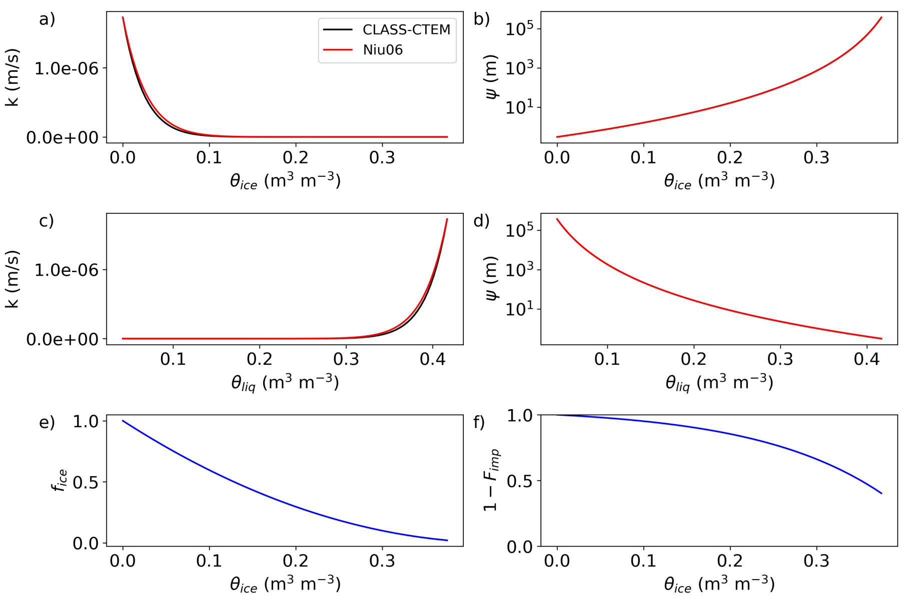

Figure S10. Same as Figure S9 but the θ_{ice} term is removed from the numerator of equations B6 and B7.

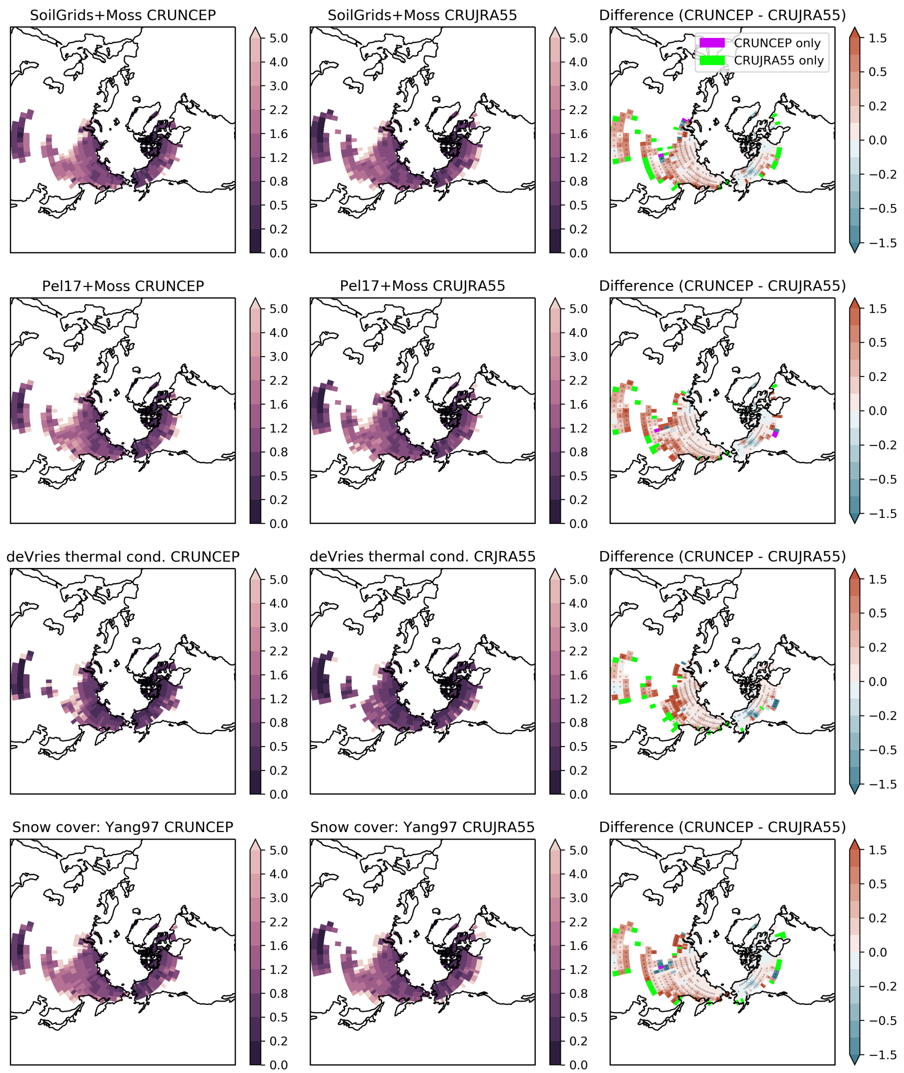

Figure S11. ALTs for experiments *SoilGrids+Moss*, *Pel16+Moss*, *deVries thermal cond.*, and *Snow cover: Yang97* using the CRUNCEP meterological forcing dataset (left column), CRUJRA55 meteorological forcing dataset (middle column), and their difference (right column). Dots indicate grid cells that are statistically significant (independent two-sample t-test p level < 0.05).

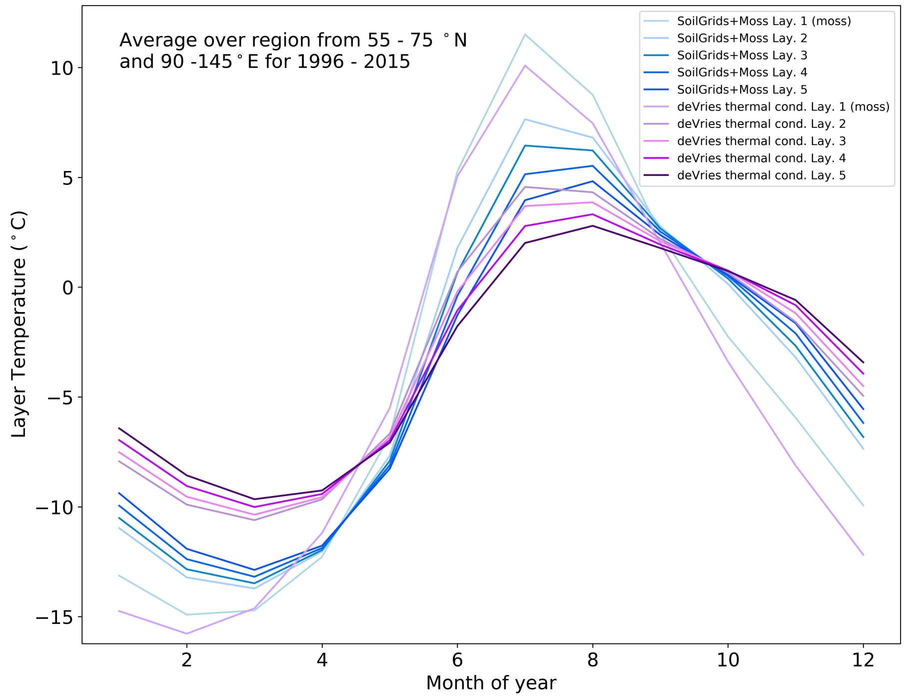

Figure S12. Mean monthly soil temperature over a permafrost region in eastern Siberia for the top 5 ground layers for the *SoilGrids+Moss* and *deVries thermal cond.* experiments. The first layer is moss in both simulations.

References

Beer, C., Porada, P., Ekici, A., and Brakebusch, M.: Effects of short-term variability of meteorological variables on soil temperature in permafrost regions, The Cryosphere, 12, 741–757, 2018.

Brown, R. D., Brasnett, B., and Robinson, D.: Gridded North American monthly snow depth and snow water equivalent for GCM evaluation, Atmosphere-Ocean, 41, 1–14, https://doi.org/10.3137/ao.410101, 2003.

Côté, J. and Konrad, J.-M.: A generalized thermal conductivity model for soils and construction materials, Can. Geotech. J., 42, 443–458, https://doi.org/10.1139/t04-106, 2005.

de Vries, D.: Thermal properties of soils, Physics of Plant Environment, 1963.

Gruber, S., Brown, N., Stewart-Jones, E., Karunaratne, K., Riddick, J., Peart, C., Subedi, R., and Kokelj, S.: Air and ground temperature, air humidity and site characterization data from the Canadian Shield tundra near Lac de Gras, Northwest Territories, Canada, v. 1.0 (2015-2017), http://www.cen.ulaval.ca/nordicanad/dpage.aspx?doi=45561XD-2C7AB3DCF3D24AD8, https://doi.org/10.5885/45561XD-2C7AB3DCF3D24AD8, accessed: 2018-11-13, 2018.

Harris, I., Jones, P. D., Osborn, T. J., and Lister, D. H.: Updated high-resolution grids of monthly climatic observations–the CRU TS3. 10 Dataset, Int. J. Climatol., 34, 623–642, 2014.

Kobayashi, S., Ota, Y., Harada, Y., Ebita, A., Moriya, M., Onoda, H., Onogi, K., Kamahori, H., Kobayashi, C., Endo, H., Miyaoka, K., and Takahashi, K.: The JRA-55 Reanalysis: General Specifications and Basic Characteristics, Journal of the Meteorological Society of Japan, 93, 5–48, https://doi.org/10.2151/jmsj.2015-001, 2015.

MacDonald, M. K.: The Hydrometeorological Response to Chinook Winds in the South Saskatchewan River Basin, Ph.D. thesis, University of Edinburgh, 2015.

MODIS Adaptive Processing System, NASA: MODIS/Terra+Aqua Albedo 16-Day L3 Global 0.05Deg CMG V005, title of the publication associated with this dataset: MODIS/Terra+Aqua Albedo 16-Day L3 Global 0.05Deg CMG V005, 2016.

Mudryk, L. R., Derksen, C., Kushner, P. J., and Brown, R.: Characterization of Northern Hemisphere snow water equivalent datasets, 1981-2010, Journal of Climate, 28, 8037–8051, 2015.

Niu, G.-Y. and Yang, Z.-L.: Effects of Frozen Soil on Snowmelt Runoff and Soil Water Storage at a Continental Scale, J. Hydrometeorol., 7, 937–952, https://doi.org/10.1175/JHM538.1, 2006.

Pelletier, J. D., Broxton, P. D., Hazenberg, P., Zeng, X., Troch, P. A., Niu, G., Williams, Z. C., Brunke, M. A., and Gochis, D.: Global 1-km Gridded Thickness of Soil, Regolith, and Sedimentary Deposit Layers, https://doi.org/10.3334/ORNLDAAC/1304, 2016.

Shangguan, W., Hengl, T., Mendes de Jesus, J., Yuan, H., and Dai, Y.: Mapping the global depth to bedrock for land surface modeling, J. Adv. Model. Earth Syst., 9, 65–88, https://doi.org/10.1002/2016MS000686, 2017.

Verseghy, D.: CLASS – The Canadian land surface scheme (v. 3.6.2), Climate Research Division, Science and Technology Branch, Environment Canada, 2017.

Viovy, N.: CRU-NCEP Version 8, title of the publication associated with this dataset: CRU-NCEP version 8, 2016.

Yang, Z.-L., Dickinson, R. E., Robock, A., and Vinnikov, K. Y.: Validation of the snow submodel of the Biosphere–Atmosphere Transfer Scheme with Russian snow cover and meteorological observational data, J. Clim., 10, 353–373, 1997.

Zhao, L. and Gray, D. M.: A parametric expression for estimating infiltration into frozen soils, Hydrological Processes, 11, 1761–1775, https://doi.org/10.1002/(SICI)1099-1085(19971030)11:13<1761::AID-HYP604>3.0.CO;2-O, https://onlinelibrary.wiley.com/doi/abs/10.1002/%28SICI%291099-1085%2819971030%2911%3A13%3C1761%3A%3AAID-HYP604%3E3.0.CO%3B2-O, 1997.

Zobler, L.: A world soil file for global climate modelling, title of the publication associated with this dataset: NASA Technical Memorandum 87802, 1986.