Supplementary Material

Glacier Surface Temperatures in the Canadian High Arctic, 2000-2015

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Part 1: Analysis of clear-sky observations within each 8 d period

The number of clear- sky day observations within each 8 d period was computed from the MOD11A2 Qualify Flags. The total number of clear-sky observations for all 1 km x 1 km glacier-covered pixels in the QEI were computed for each 8 d period between day 153 and day 241 for 2000-2015. LST observations are given if at least 1 clear-sky observation is available during a given 8 d period. QEI-wide (area-averaged) clear-sky day observations were then computed by averaging all ice-covered pixels within the QEI (Fig. S2; Table S1). The 16-year average number of clear-sky day observations for each 8 d period is presented in Fig. S3; the standard deviation is presented in Fig. S4.

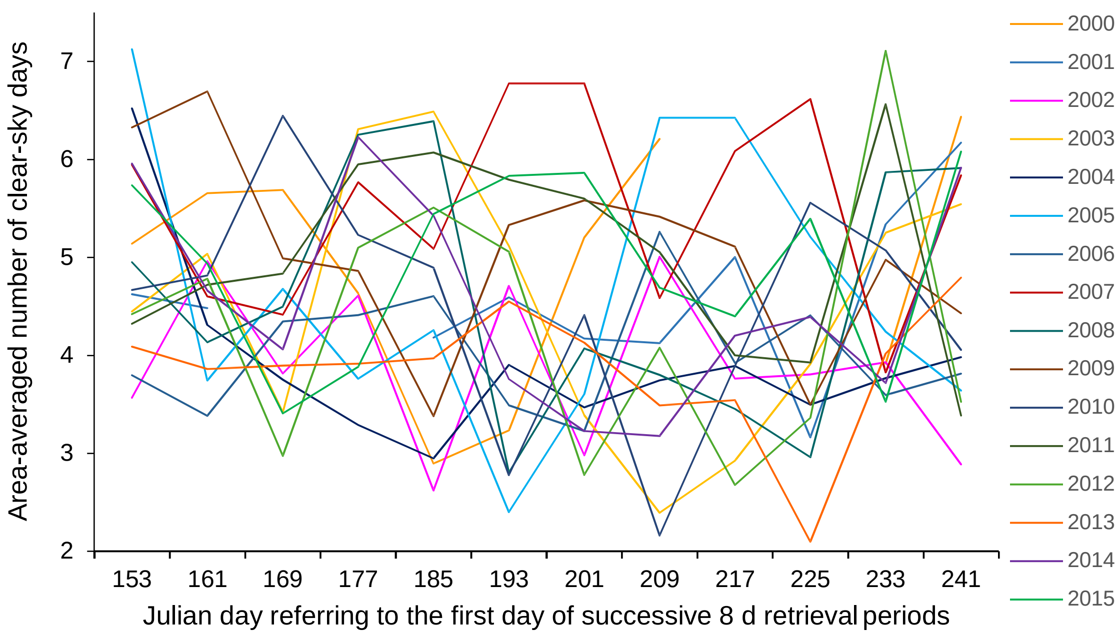

Figure S1: Mean QEI-wide (area-averaged) number of clear-sky observations within individual 8 d periods for 2000-2015.

Table S2: Mean QEI-wide clear-sky days (mean ± 1SD) within each 8 d period between 1-2 June and 28-29 August for 2000-2015

DOY	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	mean	median	stdev	variance
153	5.1 ± 1.9	4.6 ± 1.4	3.6 ± 1.7	4.4 ± 1.5	6.5 ± 1.1	7.1 ± 1.3	3.8 ± 1.5	5.9 ± 1.5	5.0 ± 1.4	6.3 ± 1.2	4.7 ± 2.0	4.3 ± 1.7	4.4 ± 1.7	4.1 ± 1.7	6.0 ± 1.3	5.7 ± 1.3	5.1 ± 1.5	4.8 ± 1.5	1.0 ± 0.3	1.1 ± 0.1
161	5.7 ± 1.6	4.5 ± 0.8	5.0 ± 1.3	5.0 ± 2.0	4.3 ± 1.3	3.7 ± 1.9	3.4 ± 1.5	4.6 ± 1.8	4.1 ± 1.7	6.7 ± 1.4	4.8 ± 1.5	4.7 ± 1.7	4.8 ± 1.2	3.9 ± 1.5	4.7 ± 1.4	4.9 ± 1.9	4.7 ± 1.5	4.7 ± 1.5	0.8 ± 0.3	0.6 ± 0.1
169	5.7 ± 1.8	no data	3.8 ± 1.9	3.4 ± 1.3	3.8 ± 1.4	4.7 ± 1.7	4.3 ± 1.5	4.4 ± 1.5	4.5 ± 1.7	5.0 ± 1.7	6.4 ± 1.6	4.8 ± 1.5	3.0 ± 1.3	3.9 ± 1.3	4.1 ± 1.6	3.4 ± 1.5	4.3 ± 1.6	4.3 ± 1.5	0.9 ± 0.2	0.8 ± 0.0
177	4.6 ± 1.5	NA	4.6 ± 1.6	6.3 ± 2.0	3.3 ± 1.6	3.8 ± 1.3	4.4 ± 1.2	5.8 ± 1.9	6.3 ± 2.0	4.9 ± 1.4	5.2 ± 1.6	6.0 ± 1.8	5.1 ± 1.9	3.9 ± 1.4	6.2 ± 1.9	3.9 ± 1.3	4.9 ± 1.6	4.9 ± 1.6	1.0 ± 0.3	1.0 ± 0.1
185	2.9 ± 1.4	4.2 ± 1.6	2.6 ± 1.4	6.5 ± 2.1	2.9 ± 1.4	4.3 ± 1.4	4.6 ± 1.4	5.1 ± 2.1	6.4 ± 1.8	3.4 ± 2.0	4.9 ± 1.7	6.1 ± 1.6	5.5 ± 1.7	4.0 ± 1.3	5.4 ± 1.5	5.4 ± 1.8	4.6 ± 1.6	4.7 ± 1.6	1.2 ± 0.3	1.5 ± 0.1
193	3.2 ± 1.3	4.6 ± 1.7	4.7 ± 1.4	5.1 ± 1.9	3.9 ± 1.4	2.4 ± 1.3	3.5 ± 1.4	6.8 ± 1.9	2.8 ± 1.1	5.3 ± 1.8	2.8 ± 1.2	5.8 ± 2.1	5.1 ± 1.7	4.6 ± 1.4	3.8 ± 1.7	5.8 ± 2.0	4.4 ± 1.6	4.6 ± 1.6	1.3 ± 0.3	1.6 ± 0.1
201	5.2 ± 1.9	4.2 ± 1.4	3.0 ± 1.4	3.4 ± 1.5	3.5 ± 1.3	3.6 ± 1.9	3.2 ± 1.7	6.8 ± 1.9	4.1 ± 1.7	5.6 ± 2.0	4.4 ± 1.3	5.6 ± 1.6	2.8 ± 1.3	4.1 ± 1.5	3.2 ± 1.5	5.9 ± 1.9	4.3 ± 1.6	4.1 ± 1.6	1.2 ± 0.2	1.4 ± 0.1
209	6.2 ± 1.7	4.1 ± 1.5	5.0 ± 1.9	2.4 ± 1.2	3.7 ± 1.6	6.4 ± 1.5	5.3 ± 2.1	4.6 ± 1.8	3.8 ± 1.5	5.4 ± 1.5	2.2 ± 1.1	5.1 ± 1.7	4.1 ± 1.6	3.5 ± 1.3	3.2 ± 1.7	4.7 ± 1.6	4.4 ± 1.6	4.4 ± 1.6	1.2 ± 0.2	1.5 ± 0.1
217	NA	5.0 ± 1.6	3.8 ± 1.3	2.9 ± 1.6	3.9 ± 1.4	6.4 ± 1.5	3.9 ± 1.2	6.1 ± 2.0	3.5 ± 1.4	5.1 ± 2.0	3.9 ± 1.2	4.0 ± 1.4	2.7 ± 1.1	3.5 ± 1.7	4.2 ± 2.0	4.4 ± 1.4	4.0 ± 1.5	3.9 ± 1.4	1.3 ± 0.3	1.6 ± 0.1
225	NA	3.2 ± 1.6	3.8 ± 1.9	3.9 ± 1.5	3.5 ± 1.6	5.2 ± 1.7	4.4 ± 1.4	6.6 ± 1.8	3.0 ± 1.2	3.5 ± 1.6	5.6 ± 2.6	3.9 ± 1.3	3.4 ± 1.5	2.1 ± 1.2	4.4 ± 2.3	5.4 ± 1.4	4.1 ± 1.6	3.9 ± 1.6	1.2 ± 0.4	1.4 ± 0.1
233	3.9 ± 1.4	5.3 ± 1.6	3.9 ± 1.6	5.3 ± 1.4	3.8 ± 1.5	4.2 ± 1.3	3.6 ± 1.6	3.8 ± 1.7	5.9 ± 1.2	5.0 ± 1.3	5.1 ± 1.5	6.6 ± 1.4	7.1 ± 1.1	4.0 ± 2.2	3.7 ± 1.5	3.5 ± 1.5	4.7 ± 1.5	4.1 ± 1.5	1.1 ± 0.2	1.2 ± 0.1
241	6.4 ± 1.2	6.2 ± 1.3	2.9 ± 1.3	5.5 ± 1.5	4.0 ± 1.8	3.6 ± 1.1	3.8 ± 1.7	5.8 ± 1.4	5.9 ± 1.4	4.4 ± 1.6	4.1 ± 1.6	3.4 ± 1.8	3.5 ± 1.5	4.8 ± 1.6	5.9 ± 1.5	6.1 ± 1.4	4.8 ± 1.5	4.6 ± 1.5	1.2 ± 0.2	1.4 ± 0.0
mean	4.9 ± 1.6	4.6 ± 1.5	3.9 ± 1.5	4.5 ± 1.6	3.9 ± 1.5	4.6 ± 1.5	4.0 ± 1.5	5.5 ± 1.8	4.6 ± 1.5	5.1 ± 1.6	4.5 ± 1.6	5.0 ± 1.6	4.3 ± 1.5	3.9 ± 1.5	4.6 ± 1.6	4.9 ± 1.6				
median	5.2 ± 1.6	4.5 ± 1.5	3.8 ± 1.5	4.7 ± 1.5	3.8 ± 1.4	4.3 ± 1.4	3.9 ± 1.5	5.8 ± 1.8	4.3 ± 1.5	5.1 ± 1.6	4.7 ± 1.5	4.9 ± 1.6	4.2 ± 1.5	3.9 ± 1.5	4.3 ± 1.5	5.2 ± 1.5				
stdev	1.2 ± 0.3	0.8 ± 0.3	0.8 ± 0.3	1.3 ± 0.3	0.9 ± 0.2	1.4 ± 0.3	0.6 ± 0.2	1.0 ± 0.2	1.3 ± 0.3	1.0 ± 0.3	1.2 ± 0.4	1.0 ± 0.2	1.3 ± 0.3	0.7 ± 0.3	1.1 ± 0.3	0.9 ± 0.2				
variance	1.5 0.1	0.6 ± 0.1	0.7 ± 0.1	1.7 ± 0.1	0.8 ± 0.0	2.0 ± 0.1	0.4 ± 0.1	1.0 ± 0.1	1.6 ± 0.1	1.0 ± 0.1	1.4 ± 0.2	1.0 ± 0.0	1.7 ± 0.1	0.4 ± 0.1	1.2 ± 0.1	0.9 ± 0.1				

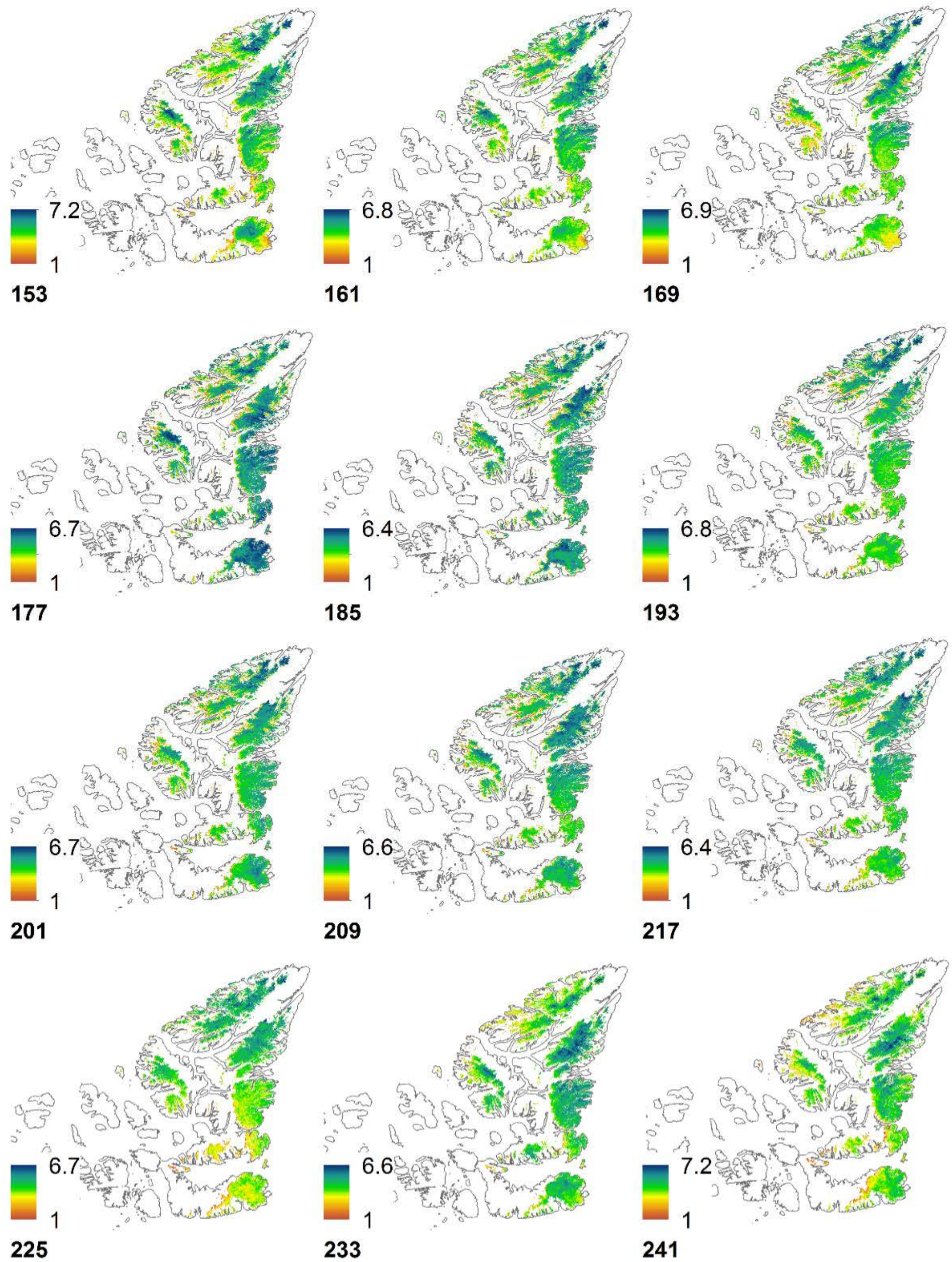

Figure S3: Mean number of clear-sky observations during each 8 d period for 2000-2015.

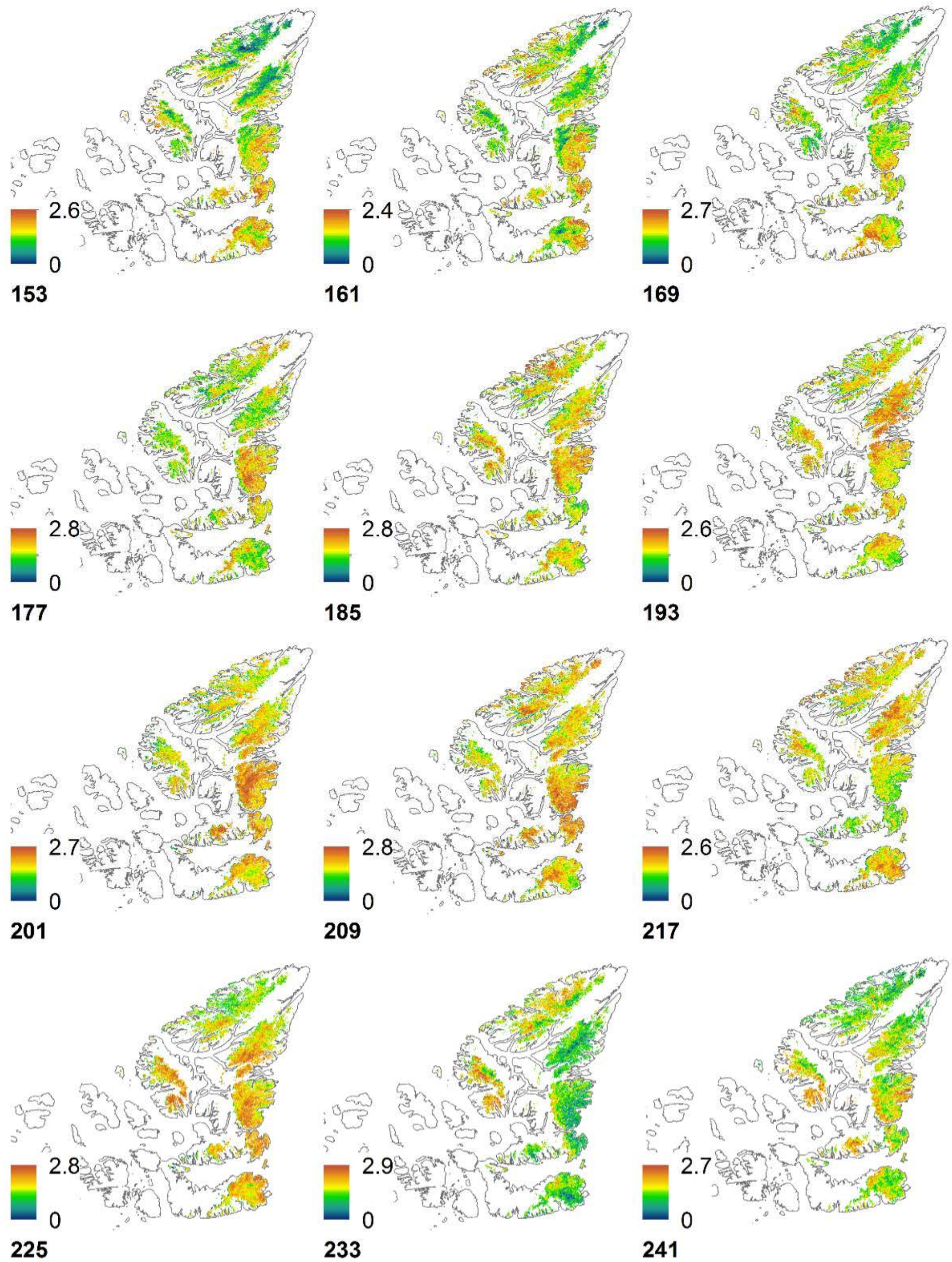

Figure S4: Standard deviation of the number of clear-sky observations during each 8 d period for 2000-2015.

Part 2: Occurrence of melt

Between 2000 and 2015, a temperature of 0°C was recorded for a small number (<1%) of pixels prior to (days 121-145) and following (days 257-273) the June-August period (Fig. S5; Table S6). The percentage of pixels experiencing a temperature >= 0°C outside the JJA period was considerably less (<1%) than during the June-August period (> 50%). In most years, we observe a step change in the percentage of pixels experiencing melt (temperature >=0°C) before and after the summer months. Given the small number of pixels experiencing melt outside of the June-August period, we restricted our analysis to the summer months (JJA). This approach facilitates comparison of data over time because it removes the need to adjust the length of the period of interest. However, the method does have limitations because changes in temperature are only monitored during the summer months. Thus, if a location already reaches the melting point regularly either prior to and/or following the JJA period, melt duration at that location would likely be underestimated. Similarly, if a location were to begin to reach the melting point outside the JJA period, this change would not be captured. The exclusion of these time periods is not believed to be significant for our study period. However, if surface temperatures continue to increase, we would also expect the length of the melt season to increase. This could warrant a revisit of the use of the JJA period to evaluate changes in glacier surface temperature.

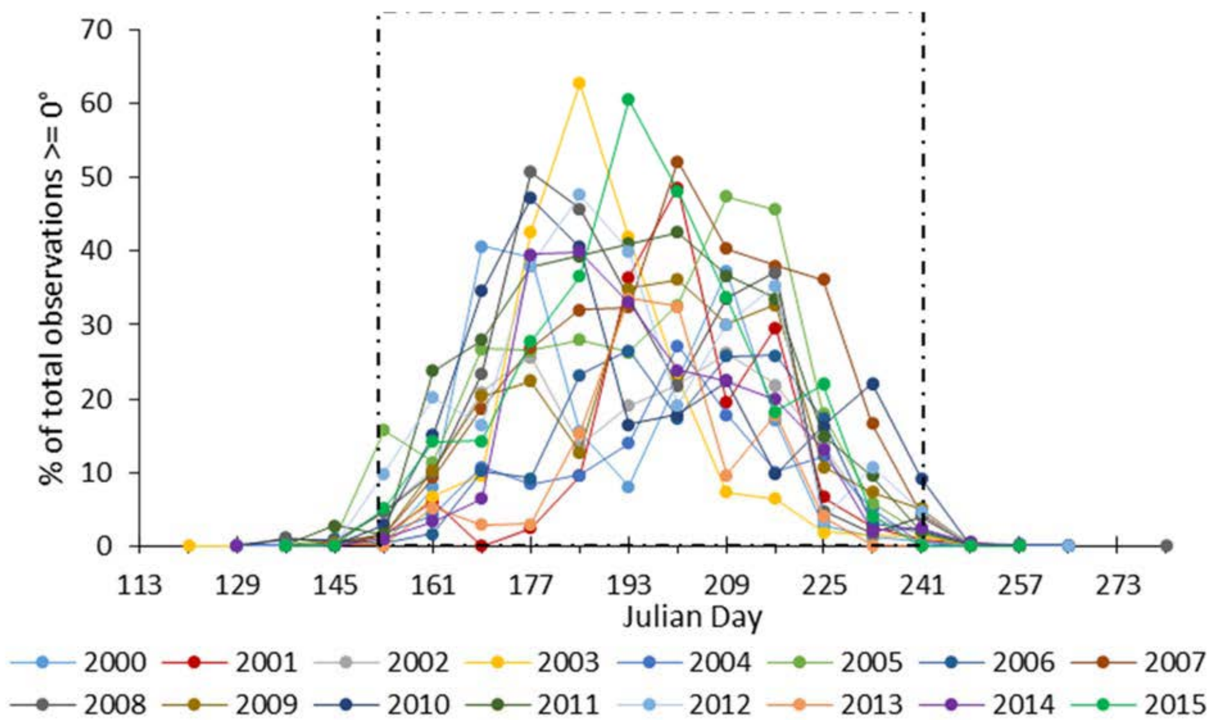

Figure S5: Percentage of observations with LST >=0°C for each 8 d observation period from day 113 – 281 for 2000 to 2015. Percentage is calculated with respect to total number of pixels with LST observations for each date. The dotted lines delineate the study period (June-August) which spans day 153 – 241.

Table S6: Percentage of observations with a value > = 0°C. Data have not been filtered to remove pixels with LST error >2°C. The number of available observations varies for each date.

	DOY	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Melt onset	113																
	121				<0.1												
	129			<0.1	<0.1	0.1		0.1		<0.1				<0.1		<0.1	
	137	<0.1	<0.1		<0.1	0.1	0.1	0.7		1.1	<0.1	<0.1	0.1	<0.1			<0.1
	145		0.4	0.8	0.1	0.2	1.0	0.9	<0.1	0.5	0.6	0.1	2.7	0.2	0.1	<0.1	0.1
June-Agust	153	0.1	1.5	4.8	0.7	1.6	15.8	0.3	1.6	4.6	1.5	2.8	1.5	9.9	0.2	1.0	5.0
	161	8.0	6.1	10.4	6.8	4.3	11.4	1.7	9.4	9.9	10.3	15.1	23.7	20.2	5.2	3.3	14.2
	169	40.7	DNE	21.0	9.6	10.7	26.7	10.1	18.7	23.4	20.4	34.6	27.9	16.5	2.9	6.4	14.3
	177	39.1	2.4	25.6	42.7	8.4	26.5	9.1	26.8	50.8	22.4	47.2	38.0	38.0	3.0	39.5	27.7
	185	15.5	9.5	13.6	62.8	9.7	27.9	23.1	32.1	45.7	12.7	40.6	39.4	47.6	15.4	39.9	36.6
	193	8.1	36.5	19.1	41.9	13.9	26.2	26.5	32.4	33.6	34.9	16.6	41.1	40.0	33.6	33.0	60.5
	201	22.6	48.7	21.8	22.9	27.2	32.7	17.4	52.2	21.8	36.1	17.8	42.6	19.2	32.5	23.9	48.3
	209	37.2	19.5	26.2	7.3	17.8	47.4	25.7	40.3	33.6	30.0	22.3	36.7	30.0	9.7	22.4	33.7
	217	17.1	29.6	21.9	6.4	10.1	45.7	25.8	38.0	37.1	32.7	9.8	33.6	35.4	17.8	19.9	18.3
	225	2.7	6.7	13.8	1.9	12.2	17.9	17.3	36.2	4.7	10.8	16.3	15.0	3.4	4.0	13.2	22.0
	233	1.2	2.6	3.9	1.5	5.1	5.9	3.0	16.6	1.6	7.4	22.0	9.5	10.7	0.1	2.1	4.1
	241	0.5	0.8	1.4	1.2	0.3	1.7	2.1	4.3	4.0	5.1	9.2	2.0	4.8	<0.1	2.4	<0.1
Freeze-up	249	0.1	0.4	0.1	0.2	<0.1	<0.1	0.4	0.3	0.1	0.2	0.2	0.1	0.2	<0.1	0.5	<0.1
	257	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	265			0.0				0.1		<0.1		<0.1		<0.1			
	273																
	281									<0.1							

Part 3: Additional supporting material

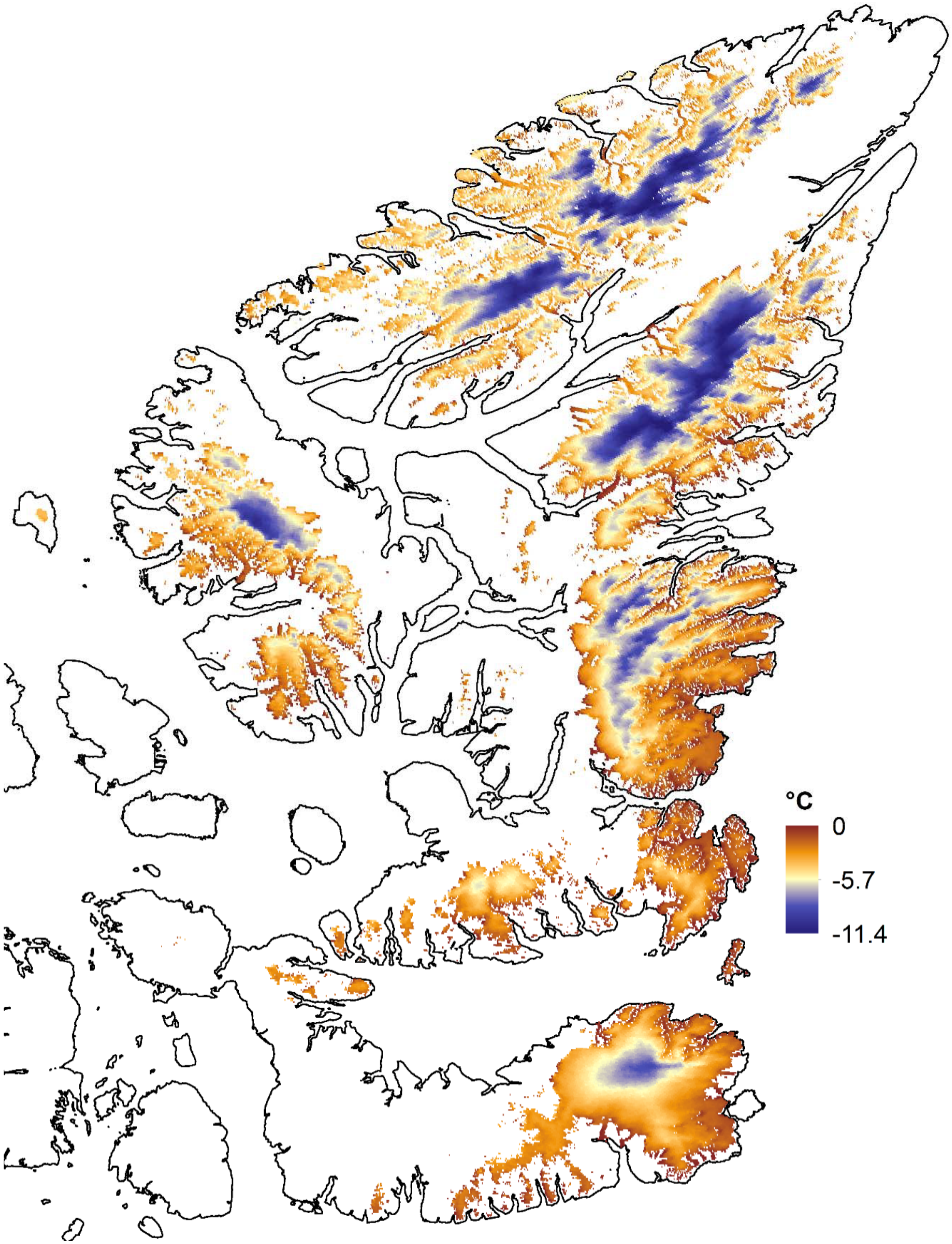

Figure S7: 16-year average clear-sky mean summer land surface temperature (°C) for glaciated regions of the Queen Elizabeth Islands for the period 2000-2015.

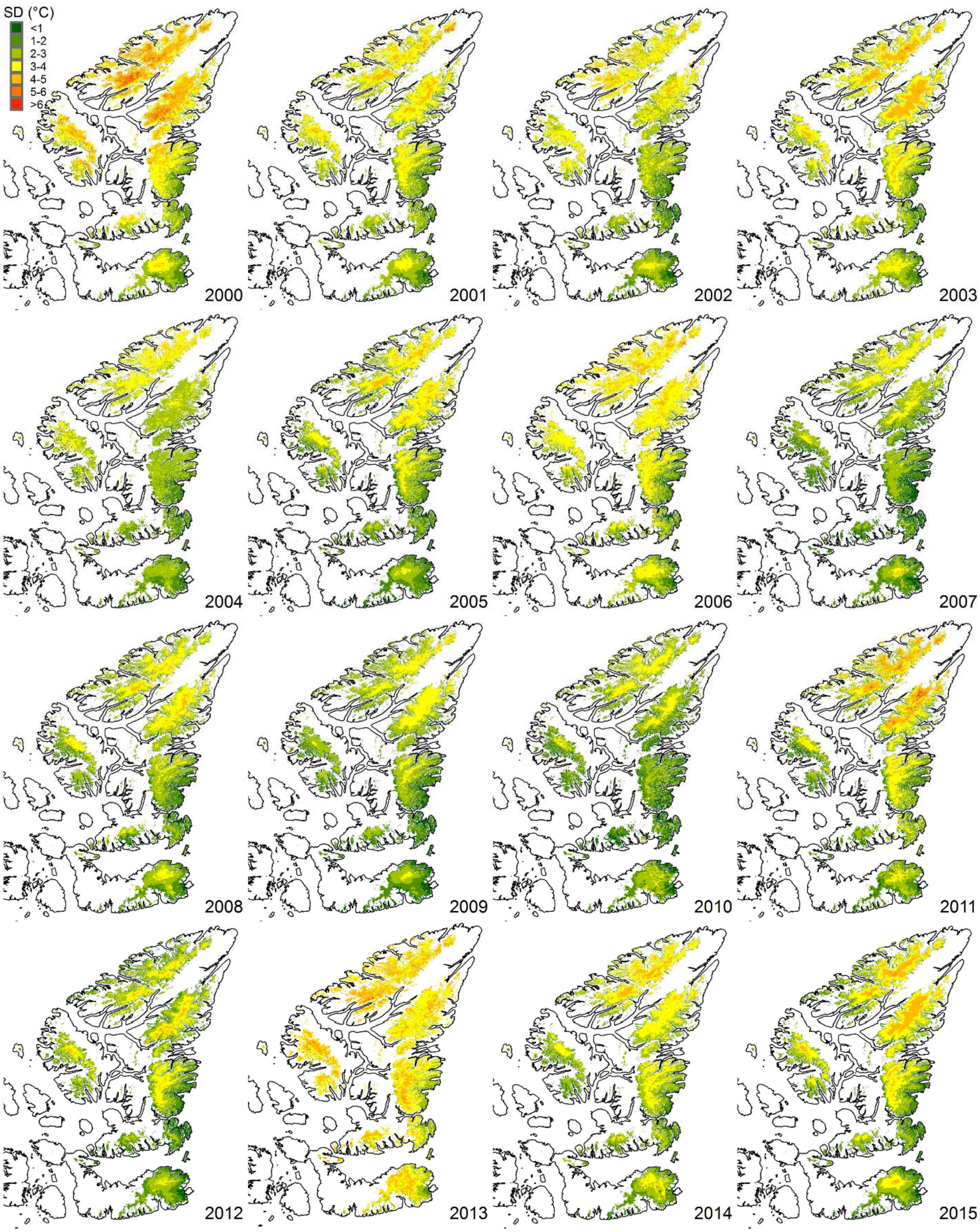

Figure S8: Standard deviation of the mean summer clear-sky land surface temperature (°C) for the Queen Elizabeth Islands.

Table S9: Location of sites used to calculate summer (June-August) 700 hPa air temperature for 2000-2015 from the NCEP/NCAR R1 Reanalysis. See Sharp and others (2011) (Section 3.3).

Region	Latitude (N)	Longitude (E)
N. Ellesmere Island	80.6 - 83.1	267.7 - 294.1
Axel Heiberg Island	78.4 - 80.6	265.5 - 271.5
Agassiz Ice Cap	79.2 - 81.1	278.9 - 290.4
Prince of Wales Icefield	77.3 - 79.1	278.0 - 284.9
Sydkap	76.5 - 77.1	270.7 - 275.8
Manson Icefield	76.2 - 77.2	278.7 - 282.1
Devon Ice Cap	74.5 - 75.8	273.4 - 280.3

Table S10: Difference between 2005-2009 and 2000-2004 average mean summer LST calculated in this study using all QEI glaciated pixels and by Sharp and others (2011) using 23 km x 23 km cell blocks (Section 4).

	Agassiz IC	Axel Heiberg I	Devon I & Coburg I	Manson IF	Northwest Ellesmere I	Prince of Wales IF	Sydkap IC
Difference in mean summer LST (°C): 2005-2009 minus 2000-2004 from Sharp and others (2011)	1.29	1.82	0.88	1.19	0.98	1.32	1.37
Difference in mean summer LST (°C): 2005-2009 minus 2000-2004 from current study	1.08	1.47	0.70	0.70	1.25	0.99	1.17
Comparison of LST difference (°C) calculated from the current study and from Sharp and others (2011)	-0.21	-0.35	-0.18	-0.49	0.27	-0.33	-0.20