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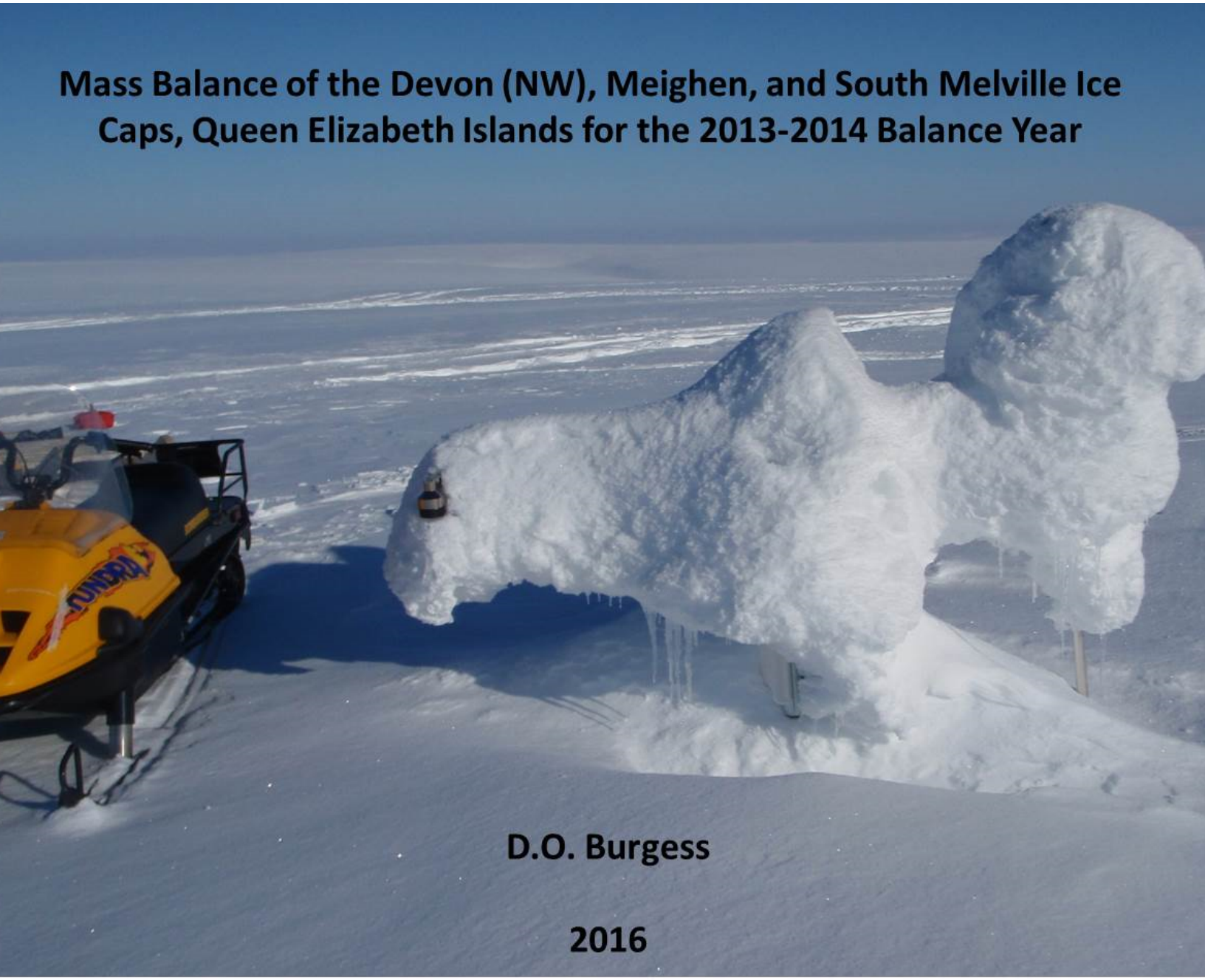
Mass Balance of the Devon (NW), Meighen, and South Melville Ice Caps, Queen Elizabeth Islands for the 2013-2014 Balance Year



D.O. Burgess

2016

Canada

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Mass Balance of the Devon (NW), Meighen, and South Melville Ice Caps, Queen Elizabeth Islands for the 2013-2014 Balance Year

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ABSTRACT

In-situ glacier mass balance surveys were conducted across the Devon, Meighen, and South Melville ice caps in the Canadian high Arctic by Natural Resources Canada during spring, 2015. Survey results indicate positive net balance value of 6 cm w.e. for the Meighen ice cap while the Devon Ice Cap and South Melville Ice Cap experienced slightly negative mass balance values of -25 and -16 cm w.e. respectively. Results from these glacier surveys are indicative of relatively cool conditions that prevailed across this region during the summer of 2014. Associated water equivalent volume change for the Devon (NW), Meighen, and South Melville ice caps was -0.418, 0.003, and -0.006 Gt respectively which resulted in a net ***positive*** contribution to global sea-level rise from these 3 sites for the 2013-2014 balance year.

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1. INTRODUCTION

At ~100,000 km^2 in area, the glaciers and ice caps in the Canadian high Arctic collectively represent the largest regional mass of ice outside of the Greenland and Antarctic ice sheets. Since the early 1960's, the Government of Canada has been measuring the mass balance of reference glaciers in the Queen Elizabeth Islands (QEI) annually. This multi-decadal time series of glacier change provides a robust indicator of climate trends across this region for a wide range of elevations (0 – 1800 m a.s.l.) where meteorological observations are otherwise sparse. *In-situ* measurements of glacier mass balance also facilitate synoptic scale assessments of glacier mass change through calibrating and validating remote sensing data, and provide input to glacier/climate models. Results from the *in-situ* glacier mass balance monitoring program conducted by Natural Resources Canada thus provides information critical to assessing the role of Canada's glaciers in global and regional sea-level rise, coastal infrastructure stability, terrain stability and water resources for industry, human consumption, and ecological needs.

The purpose of this report is to summarise results from glacier mass balance surveys conducted on 3 reference glaciers in the QEI during April/May, 2015 under research licence numbers 0200115R-M (Nunavut Research Institute) and 15621 (Aurora Research Institute). Results from this work are to be disseminated to relevant communities, and to National (*Government of Canada programs and policy and programs, Statistics Canada - EnviroStats*) and International (*World Glacier Monitoring Service, National Oceanographic and Atmospheric Administration, American Meteorological Society*) organizations.

2. STUDY SITES

Devon Ice Cap (NW)

Occupying approximately 14,000 km^2 of eastern Devon Island, Nunavut, the Devon Ice Cap (DIC) is located in the Southeast sector of the QEI (Figure 1). The elevation of the DIC ranges from sea-level where most outlet glaciers that drain the ice cap terminate, to ~1920 m a.s.l. at the ice cap summit. While the ice cap does lose some mass through ice-berg calving (Burgess and Sharp, 2005), the main form of ablation is through surface mass balance which is controlled primarily by the intensity and duration of summer melt (Koerner, 2005). Surface mass balance measurements on DIC began in 1960 along the Northwest transect which spans nearly the entire elevation range (0 – 1800 m a.s.l.) of the ice cap (Figure 2). Results from this program indicate that mass balance of the Northwest basin of the DIC has remained only slightly negative up to the mid 1990's, then shifted to a period of increasingly negative mass balance (Figure 3a), after 2005 when melt rates became ~4 times greater than the long-term average (Sharp, et al., 2011). The DIC has thinned by an average of ~7 m across the Northwest basin since 1960 with 50% of the thinning occurring since 2005 (Figure 3b).

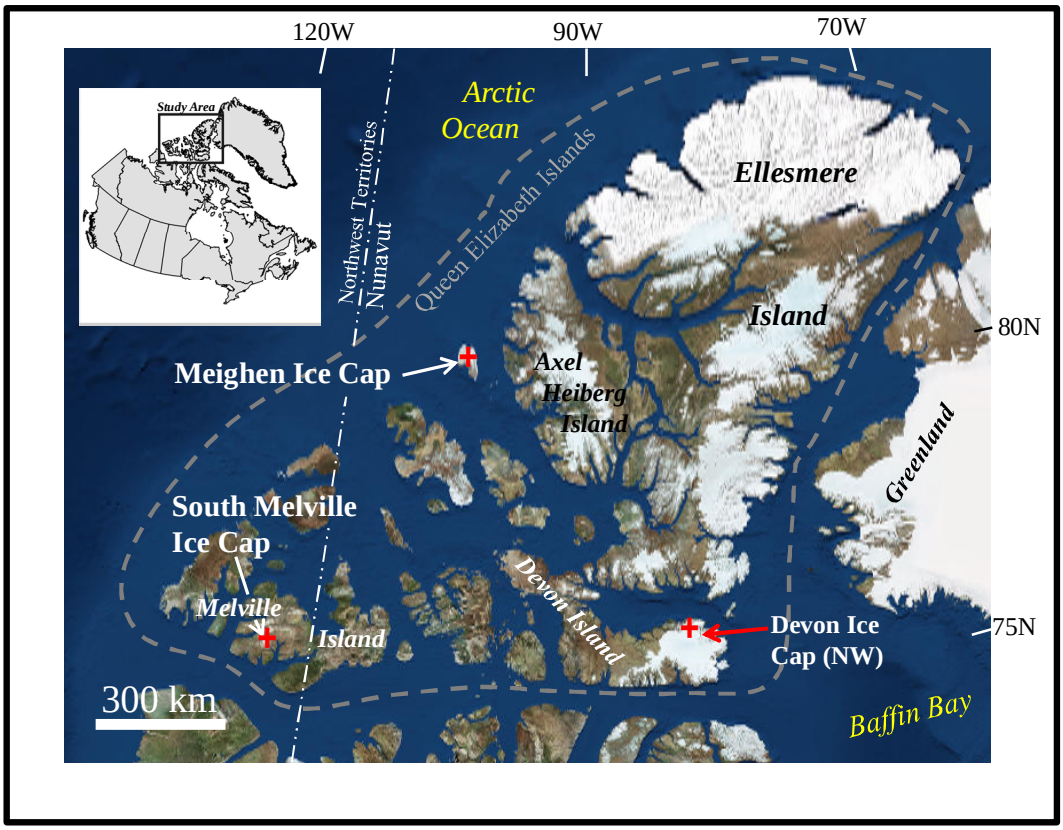

Figure 1. Location of 3 glacier reference sites (red crosses) maintained by Natural Resources Canada in the Queen Elizabeth Islands, Arctic Canada. Inset shows study area map location within Canada

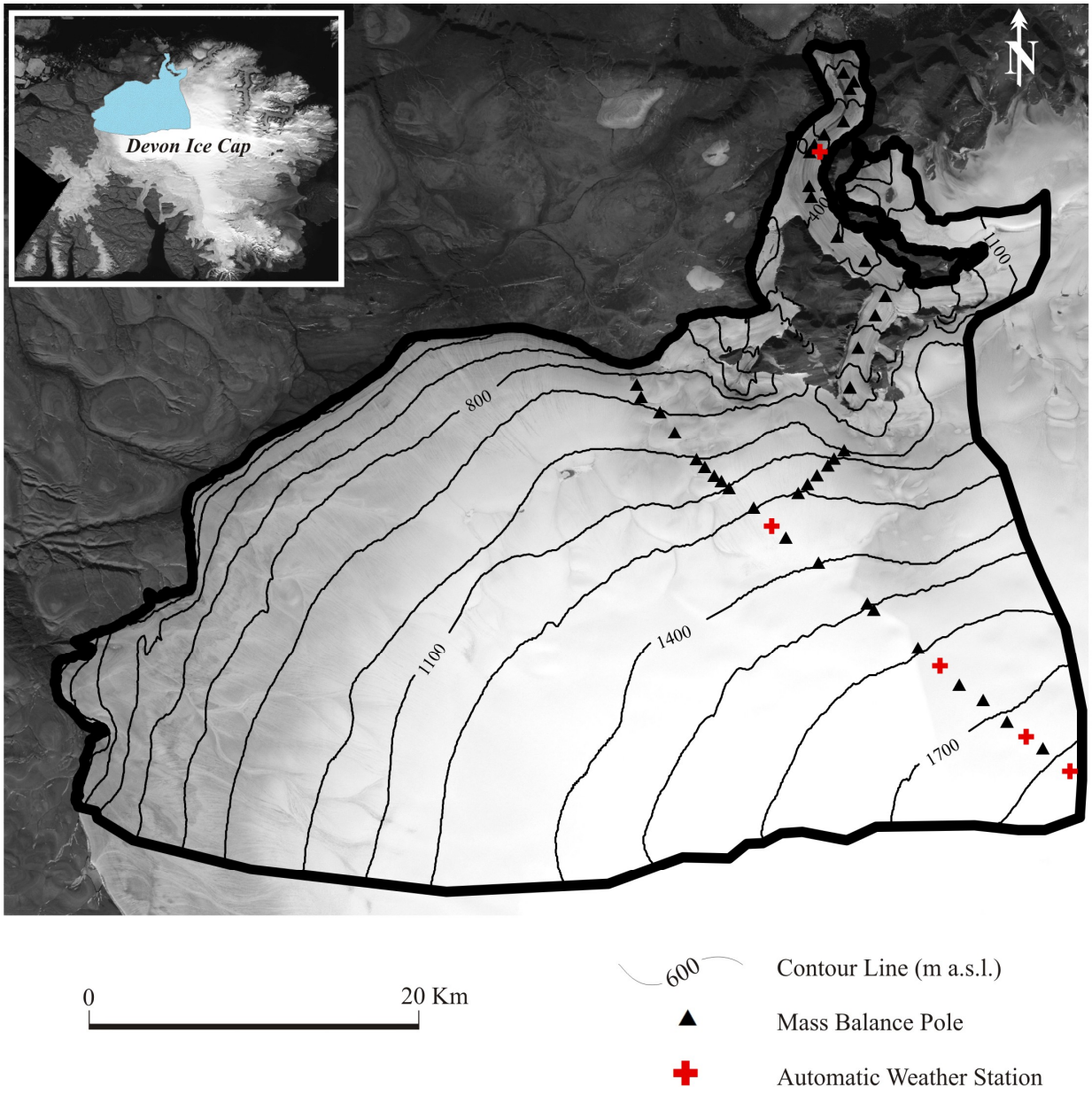

Figure 2. Location of mass balance pole network and automatic weather stations in the Northwest sector of the Devon Ice Cap. Background is a LandSat ETM^{+} satellite image acquired in July, 2000. Inset in top left indicates the location of the Northwest sector (shaded blue) within the ice cap.

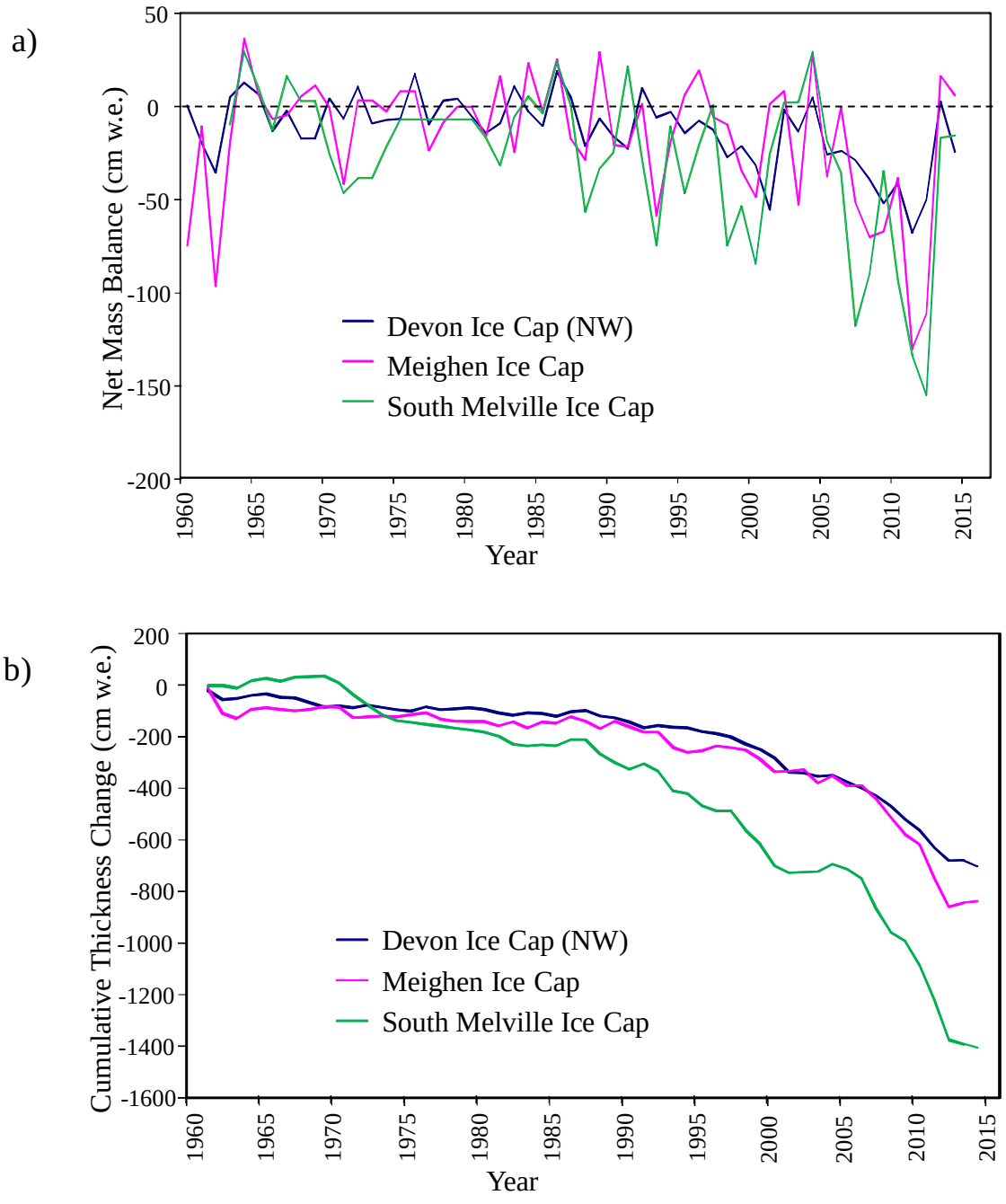

Figure 3. Long-term annual mass balance (a) and cumulative thickness change (b) profiles for the Devon (NW), Meighen, and South Melville Ice Caps.

Meighen Ice Cap

The Meighen Ice Cap (MIC) is a small (92 km^2 in 1960) stagnant ice cap located on Meighen Island in the northwest sector of the QEI, Nunavut (Figure 1). Despite having the lowest elevational range (ie. 85-270 m a.s.l. – see Figure 5) of the 3 reference glaciers, the MIC has maintained a cumulative mass balance profile similar to that of the DIC (Figure 3b). Precipitation on the MIC ranges from 10 – 30 cm w.e. which comes mainly in the form of snow, and ablation rarely exceeds 50 cm w.e. in any given summer. Alt (1979) has attributed the existence and persistence of this unusually low lying ice cap to melt-suppressing fog that would frequently inundate the ice cap from the nearby Arctic Ocean. The long-term average net balance of -16 cm w.e. a^{-1} (Table 1) has thinned the MIC by ~8 m since 1960 (Figure 3b) with 50% of the thinning having occurred after 2005. The predominately negative mass balance since 1960 coincides with a reduction in areal extent by 34% resulting in a total area of 60 km^2 in 2012.

South Melville Ice Cap

The South Melville Ice Cap (SMIC) is the most southerly of three small (~40 km^2 in 2012) stagnant ice caps located on west Melville Island, Northwest Territories (Figure 1). This ice cap is perched between 500 and 720 m a.s.l. (Figure 4) where it receives 10 – 30 cm w.e. a^{-1} precipitation mainly in the form of winter snow, and loses a long-term average of 50 cm w.e. a^{-1} mass due to summer melting. Prior to 2004, the SMIC maintained a slightly negative average mass balance of -16 cm w.e. yr^{-1} with 12 out of the 42 years experiencing positive balance values. Since 2005 however, mass balance of the SMIC has been ~5 times

more negative than the 1963-2004 period, and has thinned by ~6 m accounting for 42% of the total amount thinned (~14 m) since measurements began in 1963 (Figure 3b). Thinning has been accompanied by retreat of the margins resulting in a reduction in area of the SMIC by 27 km^2 in 2012, or 40% of its 1960 area.

3. METHODS

Glacier mass balance surveys are conducted annually between early April and late May at networks of mass balance poles at the DIC, SMIC, and MIC. Mass balance poles are 1-1/2 inch diameter, 5m long aluminum and are drilled into the ice caps between 1 and 4 meters deep leaving at least 1 m to extend above the ice cap surface. The monitoring network on DIC consists of 38 poles located entirely within the Northwest sector (Figure 2). The main transect extends from the ice cap summit region at ~1800 m a.s.l. to the terminus of the Sverdup Glacier at 100 m a.s.l., with a second arm extending from the the main transect at ~1300 m a.s.l. to the near stagnant western margin at ~400 m a.s.l. A uniform distribution of 38 and 20 poles are maintained across the Meighen and Melville ice caps respectively (Figures 4 and 5), covering the full elevation range of these ice caps.

Table 1. Average net balance values and total mass change values for 3 reference glacier monitoring sites in the Queen Elizabeth Islands, Nunavut.

Site	Net Balance 2013-2014 (cm w.e.)	Long-Term Average Net Balance (cm w.e. a^{-1})	Total Mass Change in 2013-2014 (Gt)
Devon Ice Cap (NW)	-25	-13	-0.418
Meighen Ice Cap	+6	-16	+0.003
Melville Ice Cap	-16	-27	-0.006

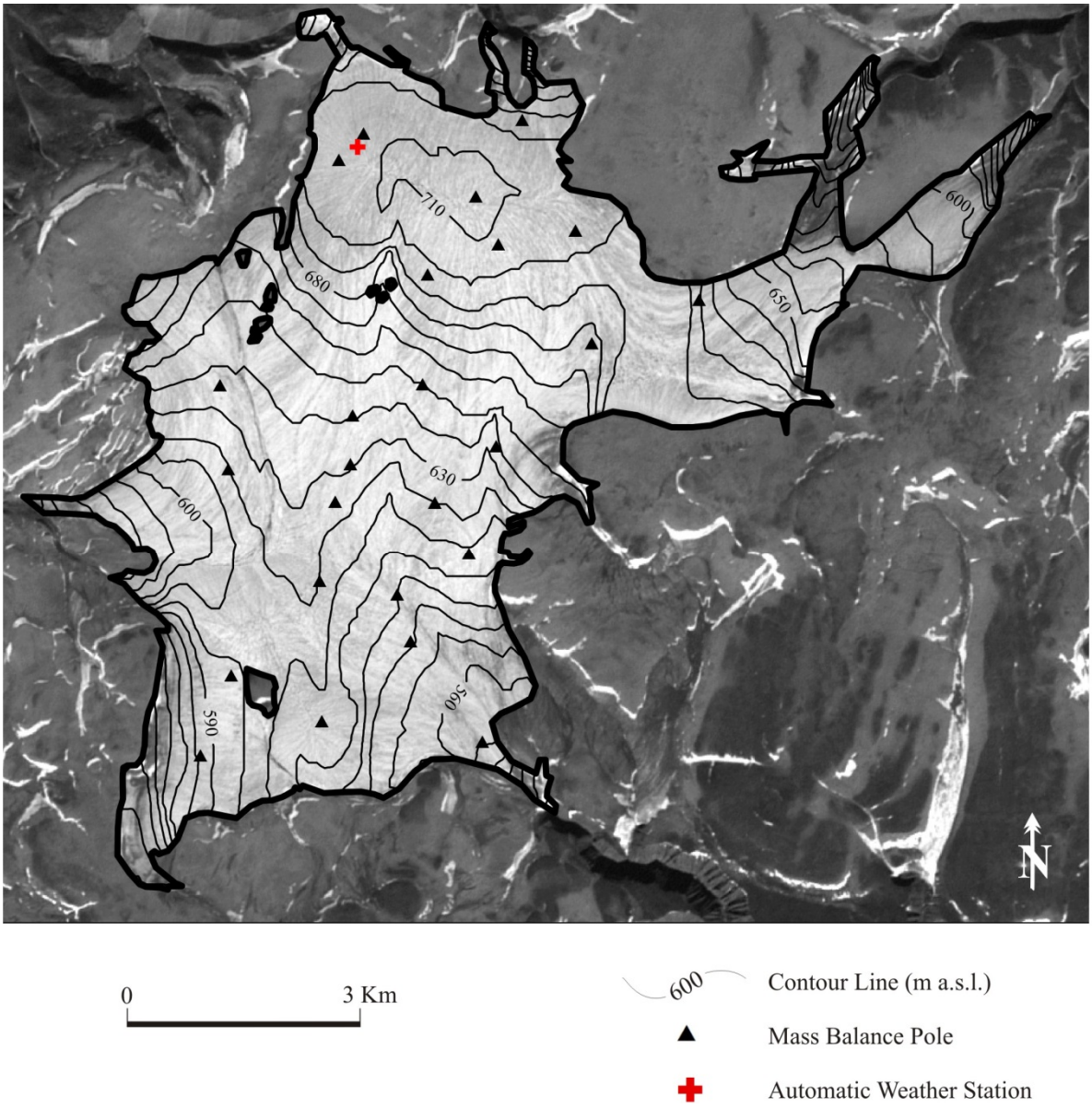

Figure 4. Location of mass balance pole network and automatic weather stations on the South Melville Ice Cap, Nunavut. Background is a LandSat ETM^{+} satellite image acquired in July, 1999.

Figure 5. Location of the mass balance pole network and automatic weather station on the Meighen Ice Cap, Nunavut. Background is a LandSat ETM^{+} image acquired in July, 1999.

Automatic Weather Station (AWS) data is used to improve the accuracy and interpretation of the mass balance values derived from the pole measurements, and for linking on-glacier conditions to synoptic scale climate models. AWS's measure ambient air temperature and relative changes in height of the snow/ice cap surface at one-minute intervals and record hourly averages. Temperature is measured using Campbell Scientific 44212 temperature probes (+/- 0.1 ^{o}C) mounted 1-2 m above the ice cap surface within R.M. Young Solar radiation shields. Snow/ice surface height is measured using Campbell Scientific SR50A Sonic Rangers (+/- 1 cm). AWS data is stored in Campbell Scientific CR800 data loggers which are downloaded during each annual site visit.

For all ice caps, glacier mass balance is derived using the *Stratigraphic System* (Cogley et al., 2011) whereby mass change of the ice cap surface over the course of one year is calculated as the water equivalent (w.e.) difference between successive annual measurements of pole length above the previous end-of-summer surface. Thus, pole measurements obtained in the spring visits of 2014 and 2015 provide information needed to calculate net balance for the late summer 2013 to late summer 2014 time interval. Winter balance is calculated as the snow water equivalency of the winter snowpack as determined from snow depth and density which are measured at regular sampling intervals across the networks. Summer balance is derived as the difference between the net and winter balance values. Average net balance is calculated a function of the net mass balance pole values and the area-elevation distribution across each ice cap or drainage basin. Pole measurements of net balance, winter balance, and summer balance for the 2013 – 2014 balance year are include in the Appendix.

4. RESULTS

The 2013-2014 average net balance across the DIC_NW was the 12th most negative year on record with a thinning rate of two times more negative than the long-term mean (Table 1) and only 30% less negative than the post-2005 average. Lower than average melt rates occurred below ~700 m a.s.l. in 2013-2014 with net thinning of -89 cm w.e. near the terminus of the Sverdrup Glacier being ~25 cm w.e. less negative than the long-term average. Higher (lower) than average melting (summer accumulation) resulted in thinning rates higher than the long term average above ~700 m a.s.l. Enhanced thinning at higher elevations on the DIC_NW positioned the 2013_ 2014 equilibrium-line altitude (ELA) ~400 m higher than the long-term mean (Figure 7) giving an accumulation area ratio (AAR) of 27%. Overall, the DIC_NW decreased in mass by -0.42 Gt of ice during the 2013_2014 balance year which is double the long-term average rate of -0.21 Gt ice lost from this basin annually.

The 2013-2014 average net balance across the MIC of +6 cm w.e. (Table 1) was the 15th most positive on record. In contrast to the long term average, there was no statistically significant relationship between net balance and elevation during the 2013-2014 balance year. Maximum net mass balance values occurred at mid elevations in the northeast sector (~170 m a.s.l.; Figure 9), and slight thinning occurring in isolated pockets along the northeast and southern margins (Figure 8).

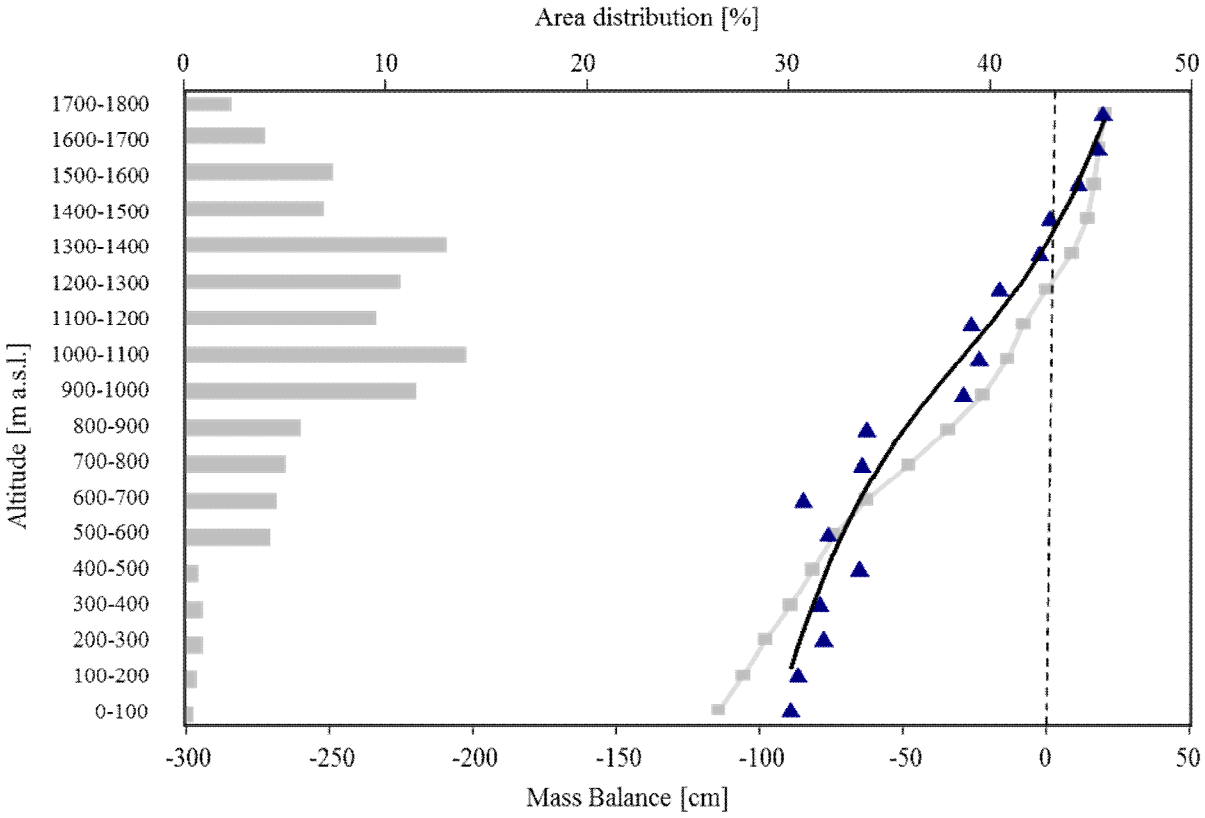

Figure 6. Net mass balance values for the 1961-2013 average (gray) and the 2013-2014 balance year (black) plotted as a function of elevation for the Northwest sector of Devon Ice Cap. Trend lines are 3rd order polynomials with r-squared values of 0.98 and 0.92 for the long-term and 2013-2014 balance years respectively.

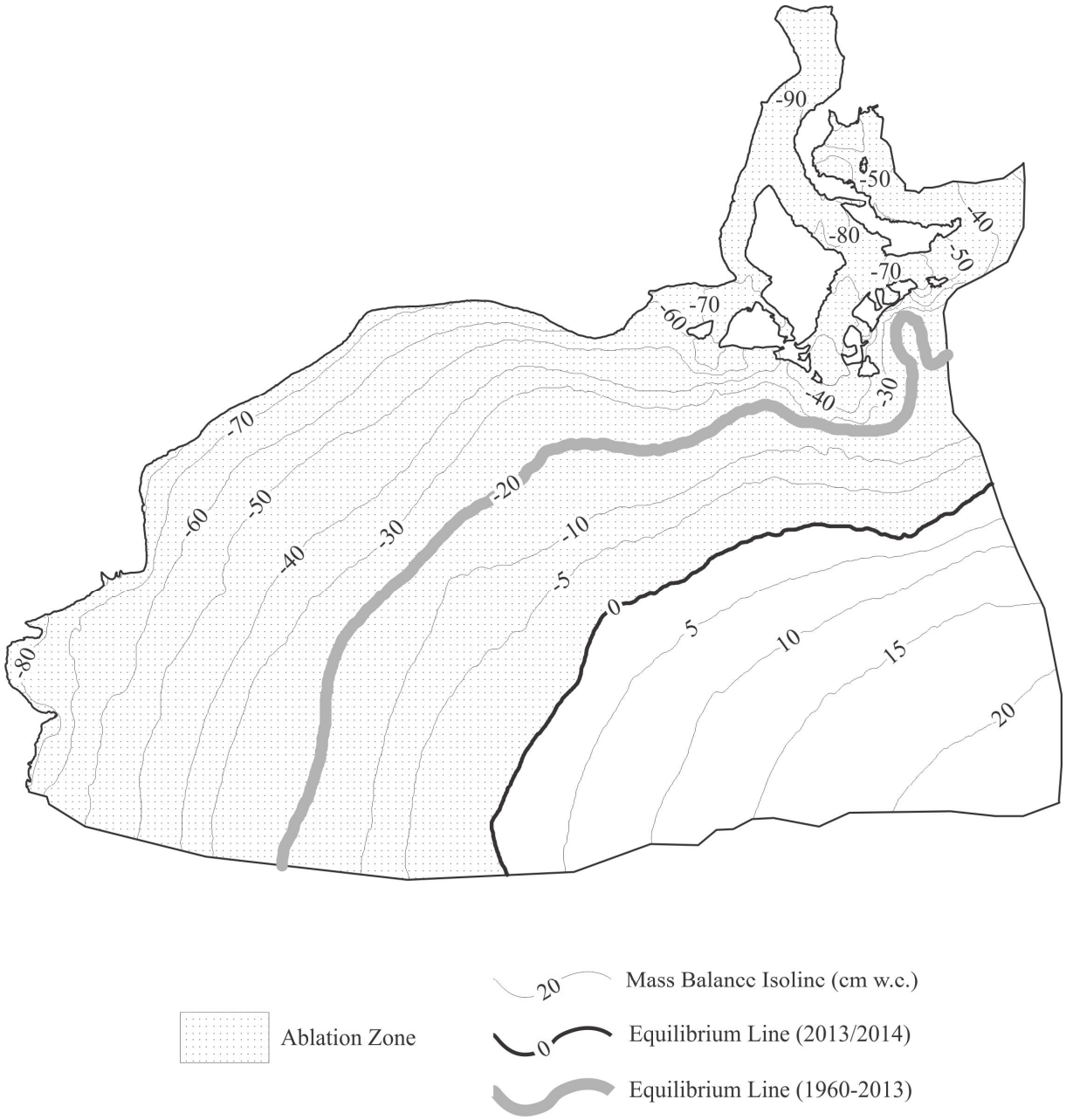

Figure 7. Map of the 2013/2014 net surface mass balance for the Northwest sector of Devon Ice Cap, Nunavut.

The most striking pattern of net surface mass balance across the MIC in the 2013-2014 balance year was relatively low net accumulation (<5 cm w.e.) along the entire western margin. While this pattern is not consistent with earlier observations (Patterson, 1969) it is consistent with the pattern of ice margin retreat which was strongest along the north and eastern sectors of the ice cap. In terms of mass change, the MIC gained 0.003 Gt of ice during the 2013-2014 balance year in contrast with the long-term mass loss rate of -0.012 Gt a^{-1}.

The 2013-2014 net balance averaged across the SMIC of -16 cm w.e. was slightly less negative than the long-term mean of -27 cm w.e. (Table 1) indicating relatively cool summer conditions over the SMIC during the summer of 2014. Maximum melt rates occurred across the southern sector of the ice cap where elevations are lowest, with moderate thinning (~ 15 cm w.e.) across the central to northern sectors and isolated pockets of apparent thickening occurred in the northeast and southeast sectors (Figure 11). Overall, there was no clear relationship between net mass balance and elevation (Figure 10) but similar to the 2012-2013 balance year, there is some indication that melt rates are enhanced near the ice cap margins. The SMIC lost -0.006 Gt of ice during the 2013-2014 balance year which is slightly less than the long-term mass loss rate of -0.12 Gt a^{-1}.

5. SUMMARY

This report summarizes results from glacier mass balance surveys conducted across the Queen Elizabeth Islands during the spring of 2015 by Natural Resources Canada under research licence numbers 0200115R-M (Nunavut Research Institute) and 15621 (Aurora Research Institute). Results from this work provide information on the state-of-health of the long-term reference glaciers of Devon, Meighen, and South Melville ice caps for the 2013-2014 balance year. While the annual long-term average mass balance value for all 3 reference glaciers was negative, the Meighen ice cap experienced anomalous growth in 2013-2014 while the South Melville and Devon (NW) Ice Caps both lost mass. The total water equivalent volume change for the Devon (NW), Meighen, and South Melville ice caps for the 2013-2014 mass balance year was -0.418, +0.003, and -0.006 Gt respectively resulting in a net ***positive*** contribution to global sea-level rise from these 3 sites for the 2013-2014 balance year. The combined net balance for all 3 reference glaciers in 2013-2014 was ~4 times less negative than the post-2005 period reflecting anomalously cool conditions that prevailed across this region in 2014 relative to the past 10 years.

Figure 8. Map of the 2013/2014 net surface mass balance for the the Meighen Ice Cap, Nunavut.

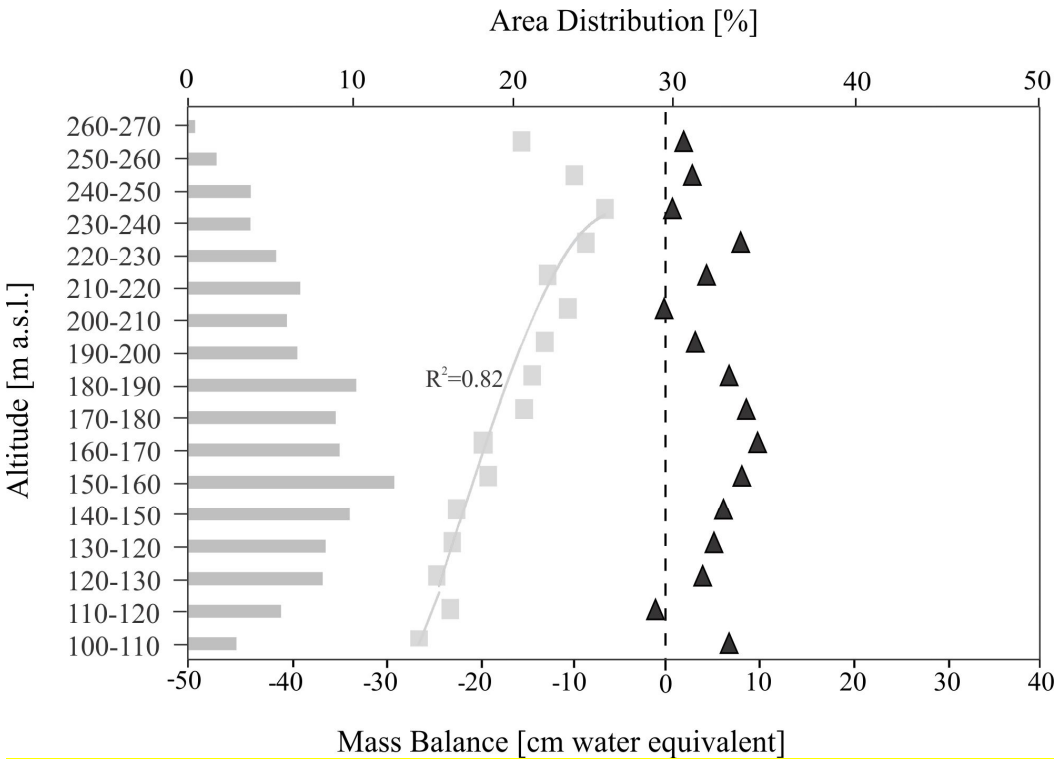

Figure 9. Net mass balance values for the 1960-2013 average (gray) and the 2013-2014 mass balance year (black) plotted as a function of elevation for the Meighen Ice Cap, Nunavut.

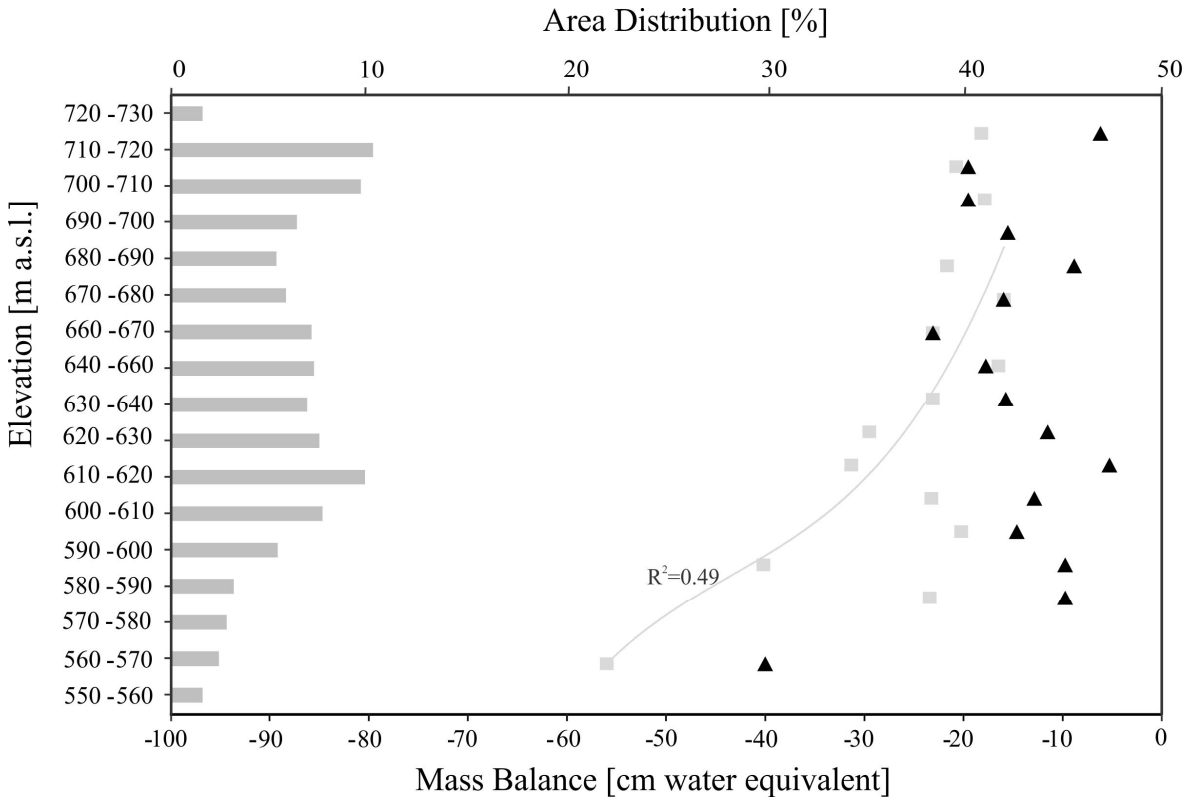

Figure 10. Net mass balance values for the 1963-2013 average (gray) and the 2013-2014 balance year (black) plotted as a function of elevation for the South Melville Ice Cap, Northwest Territories.

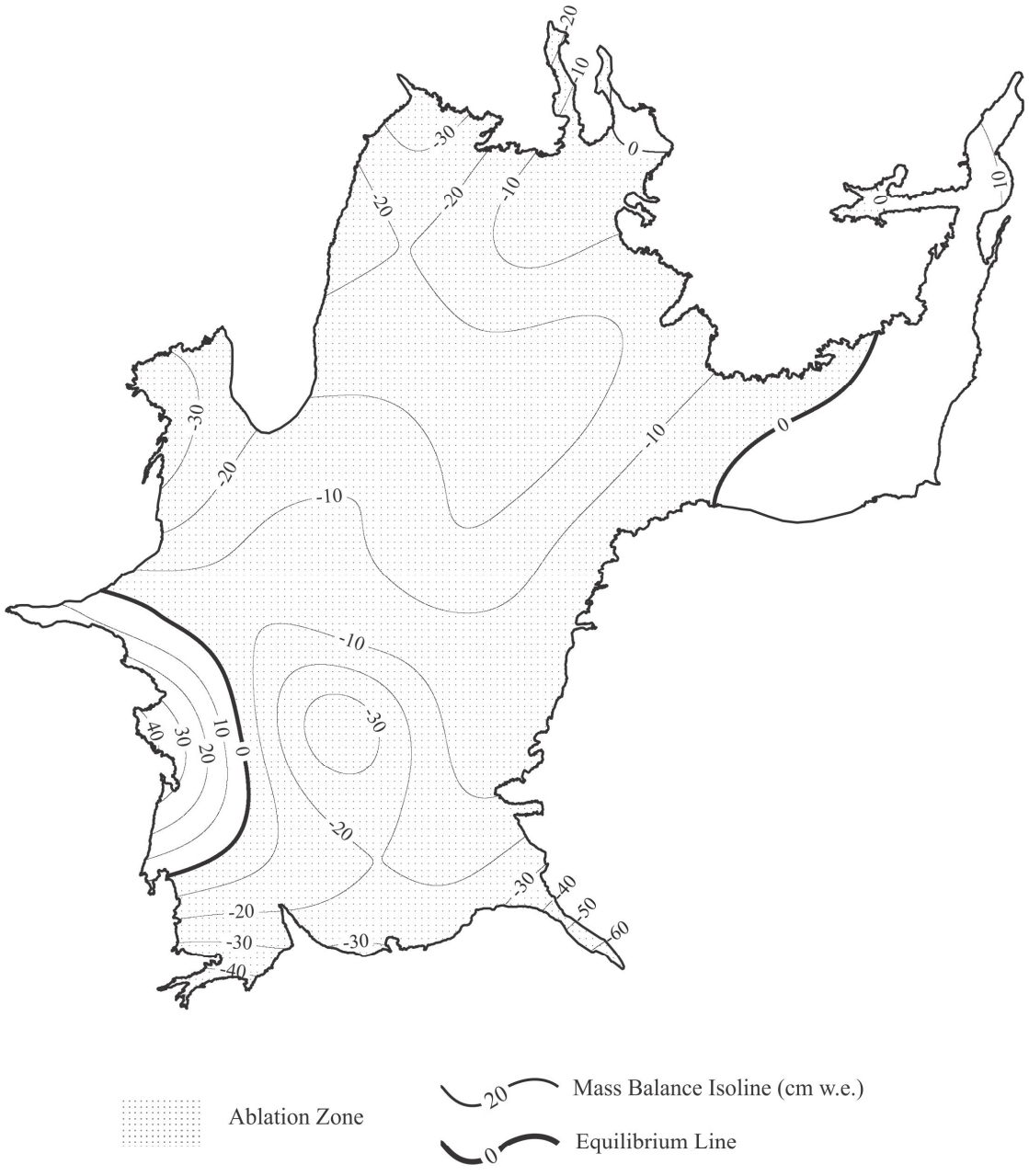

Figure 11. 2013/2014 net surface mass balance for the South Melville Ice Cap, Northwest Territories.

6. ACKNOWLEDGMENTS

This work is a contribution to the Climate Change Geoscience Program (ESS), Natural Resources Canada with logistical support provided by the Polar Continental Shelf Program (project 001-15). The communities of Grise Fiord, Ulukhaktok (Holman), and Sachs Harbor are gratefully acknowledged for their support of this program. Field assistance was provided by James Zheng, NRCan, and technical support in the field provided by Ian Milne, Campbell Scientific, Edmonton.

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APPENDIX

Table A1. Mass balance pole values for Devon Ice Cap, 2013 -2014 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2013-2014 Net Balance (mm w.e.)	2013-2014 Winter Balance (mm w.e.)	2013-2014 Summer Balance (mm w.e.)
H	75.3691	-82.6702	1829	203	193	10
FH	75.3807	-82.7280	1769	203	193	10
F	75.3863	-82.7634	1737	203	193	10
EF	75.3941	-82.8040	1707	196	186	10
E	75.4049	-82.8550	1687	200	185	15
DE	75.4125	-82.9056	1663	198	183	15
D	75.4220	-82.9473	1638	180	165	15
K	75.4312	-82.9941	1592	125	157	-31
ML	75.4505	-83.0889	1507	94	157	-63
M	75.4538	-83.1032	1491	63	158	-95
N / OM	75.4741	-83.2083	1398	-32	158	-190
O	75.4866	-83.2776	1363	-24	158	-182
ICS	75.4923	-83.3081	1343	-9	158	-167
DVT1	75.5016	-83.3476	1297	-151	201	-352
DVT2	75.5115	-83.4010	1202	-116	219	-335
DVT6	75.5148	-83.4170	1197	-169	192	-362
DVT7	75.5175	-83.4331	1152	-249	171	-420
DVT8.1	75.5219	-83.4533	1121	-267	231	-498
DVT9	75.5258	-83.4712	1103	-312	171	-482
DVT10.2	75.5395	-83.5195	1050	-142	182	-325
DVT10.4	75.5498	-83.5521	1001	-134	270	-403
DVT11	75.5575	-83.5931	962	-294	223	-517
DVT12	75.5637	-83.6034	931	-436	154	-590
DSG10	75.5104	-83.2556	1305	-89	174	-263
DSG92	75.5151	-83.2367	1283	-196	161	-357
DSG91	75.5253	-83.1958	1239	-258	165	-423
DSG91B	75.5289	-83.1835	1198	-214	171	-385
DSG9	75.5334	-83.1627	1102	-347	178	-525
DSG73	75.5668	-83.1553	831	-623	177	-800
DSG72	75.5878	-83.1411	768	-454	149	-603
DSG70	75.6051	-83.1077	675	-846	108	-953
DSG6	75.6152	-83.0877	622	-846	112	-957
DSG53	75.6331	-83.1335	460	-668	142	-810
DSG52	75.6451	-83.1935	499	-632	154	-785
DSG51	75.6661	-83.2520	388	-641	150	-790
DSG5	75.6714	-83.2576	369	-837	150	-986
DSG4A	75.6934	-83.2496	312	-837	133	-970
DSG4AWS	75.6906	-83.2423	315	-837	131	-968
DSG3	75.6988	-83.2298	292	-632	151	-783
DSG2	75.7060	-83.1900	231	-917	113	-1030
DSG1	75.7232	-83.1788	179	-908	160	-1068
DSG1B	75.7270	-83.1712	157	-819	137	-956
DSG0	75.7316	-83.1936	137	-890	155	-1045

Table A2. Mass balance pole values for Meighen Ice Cap, 2013-2014 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2013-2014 Net Balance (mm w.e.)	2013-2014 Winter Balance (mm w.e.)	2013-2014 Summer Balance (mm w.e.)
5	80.03080	-99.20345	106	72	254	-182
8	80.01737	-99.10660	124	-6	212	-218
9	80.01871	-99.15809	130	114	247	-133
10	80.00643	-99.31187	123	24	211	-187
11	80.00512	-99.27431	143	84	215	-131
12	80.00538	-99.24732	153	168	223	-55
13	80.00353	-99.20497	156	36	217	-181
14	80.00061	-99.15688	172	192	242	-50
15	79.99928	-99.12096	183			
16	79.99966	-99.10301	175	36	227	-191
17	79.99974	-99.09187	160	12	214	-202
18	79.99964	-99.04853	152	108	242	-134
20	79.97326	-99.14030	216	12	215	-203
21	79.96850	-99.14690	222	60	228	-168
21a	79.96185	-99.31441	139	18	246	-228
22	79.96199	-99.24763	178			
23	79.96168	-99.20952	206	36	248	-212
24	79.95961	-99.18489	225	120	223	-103
25	79.96070	-99.16250	240	12	204	-192
26	79.96116	-99.13361	240	72	212	-140
27	79.96239	-99.11872	231	132	219	-87
28	79.96252	-99.10551	220	66	240	-174
29	79.96157	-99.08952	191			
30	79.96216	-99.05920	160	30	253	-223
31	79.93689	-99.12119	252	12	210	-198
32	79.93114	-99.11502	253	24	206	-182
32a	79.93288	-99.11481	254			
33	79.92860	-99.10444	249	42	170	-128
33a	79.91873	-99.10731	208	-30	219	-249
34	79.98049	-99.09961	185	126	232	-106
34a	79.97229	-99.05679	160	48	229	-181
35	79.97607	-99.15600	213	54	212	-158
35a	79.97716	-99.23531	182	108	279	-171
35b	79.97886	-99.32127	135	36	207	-171
37	79.93889	-99.07332	220	144	193	-49
38	79.93481	-99.16165	230			

Table A3. Mass balance pole values for Melville Ice Cap, 2013-2014 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2013-2014 Net Balance (mm w.e.)	2013-2014 Winter Balance (mm w.e.)	2013-2014 Summer Balance (mm w.e.)
1.1	75.39183	114.94909	553	-401	178	-578
4	75.39800	115.01933	606	-196	179	-375
5	75.40337	115.05838	621	9	288	-279
6	75.39463	115.07294	635	-223	160	-382
7	75.41170	114.98425	590	-98	220	-318
8	75.41600	114.95220	608	-62	261	-323
10	75.41350	115.01811	621	-329	191	-520
10.1	75.42217	115.01019	623	-45	242	-286
11	75.42178	114.96637	620	-98	182	-280
12	75.42625	115.05664	619			
13	75.42637	115.00286	631	-116	223	-338
14	75.42782	114.93865	635	-89	195	-284
15	75.43554	115.05906	636	-205	203	-408
16	75.43175	115.00114	641	-125	199	-323
17	75.46000	115.00350	708	-196	150	-346
18	75.43167	114.97003	650	-231	180	-412
22	75.44700	114.96613	696	-205	159	-363
23	75.45543	114.94370	716	-62	163	-225
24	75.40647	114.97919	581	-98	245	-343
25	75.44983	114.93453	707	-169	165	-334
27	75.45134	114.90042	703	-160	173	-333
28	75.43900	114.89489	676	-89	192	-281
35	75.44976	115.01545	690	-223	198	-421
AWS	75.46133	114.99502	707	-249	172	-421