GEOLOGICAL SURVEY OF CANADA

OPEN FILE 7692

**Mass balance of the Devon (NW), Meighen, and South Melville
ice caps, Queen Elizabeth Islands for the 2012-2013 balance year**

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2014

Canada

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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, 2014. Survey results indicate positive net balance values for the Devon (NW) and Meighen ice caps (+2 and +17 cm w.e. respectively), while the South Melville ice cap experienced slightly negative mass balance (-18 cm w.e.). Results from these glacier surveys are indicative of relatively cool conditions that prevailed across this region during the summer of 2013. Associated water equivalent volume change for the Devon (NW), Meighen, and South Melville ice caps in 2012-2013 was 0.04, 0.01, and -0.009 Gt respectively resulted in a net negative contribution to global sea-level rise from these 3 sites for the 2012-2013 balance year.

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1.   INTRODUCTION

At ~100,000 km^2 in area, glaciers and ice caps in the Canadian high Arctic collectively represent the largest single 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, 2014 under research licence numbers 0200214R-M (Nunavut Research Institute) and 15412 (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

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 period of increasingly negative mass balance (Figure 3a), particularly after 2005 during which period the melt rates have been ~4 times greater than the long-term average (Sharp, et al., 2011). The cumulative mass balance time series indicates that the DIC has thinned by an average of ~6 m across the Northwest basin since 1960 (Figure 3b).
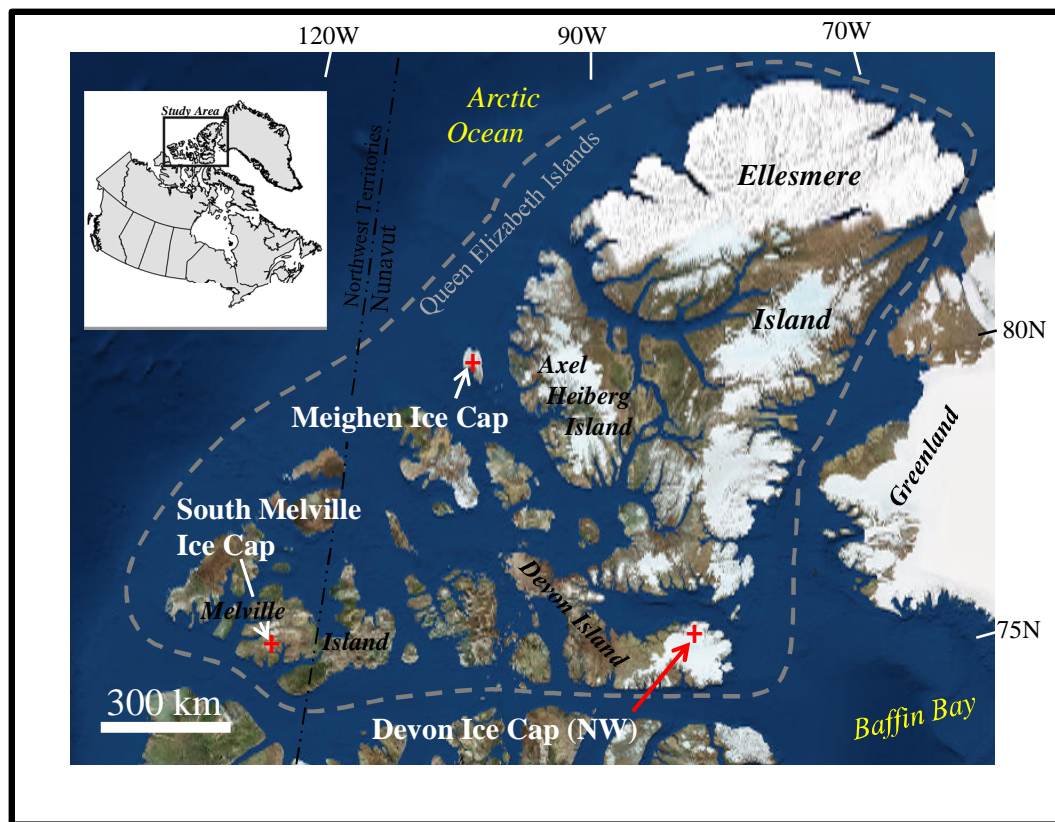
Figure 1. Location of 3 glacier reference sites (red crosses) maintained by Natural Resources Canada in the Queen Elizabeth Islands, Arctic Canada. Inset shows study area map location within Canada
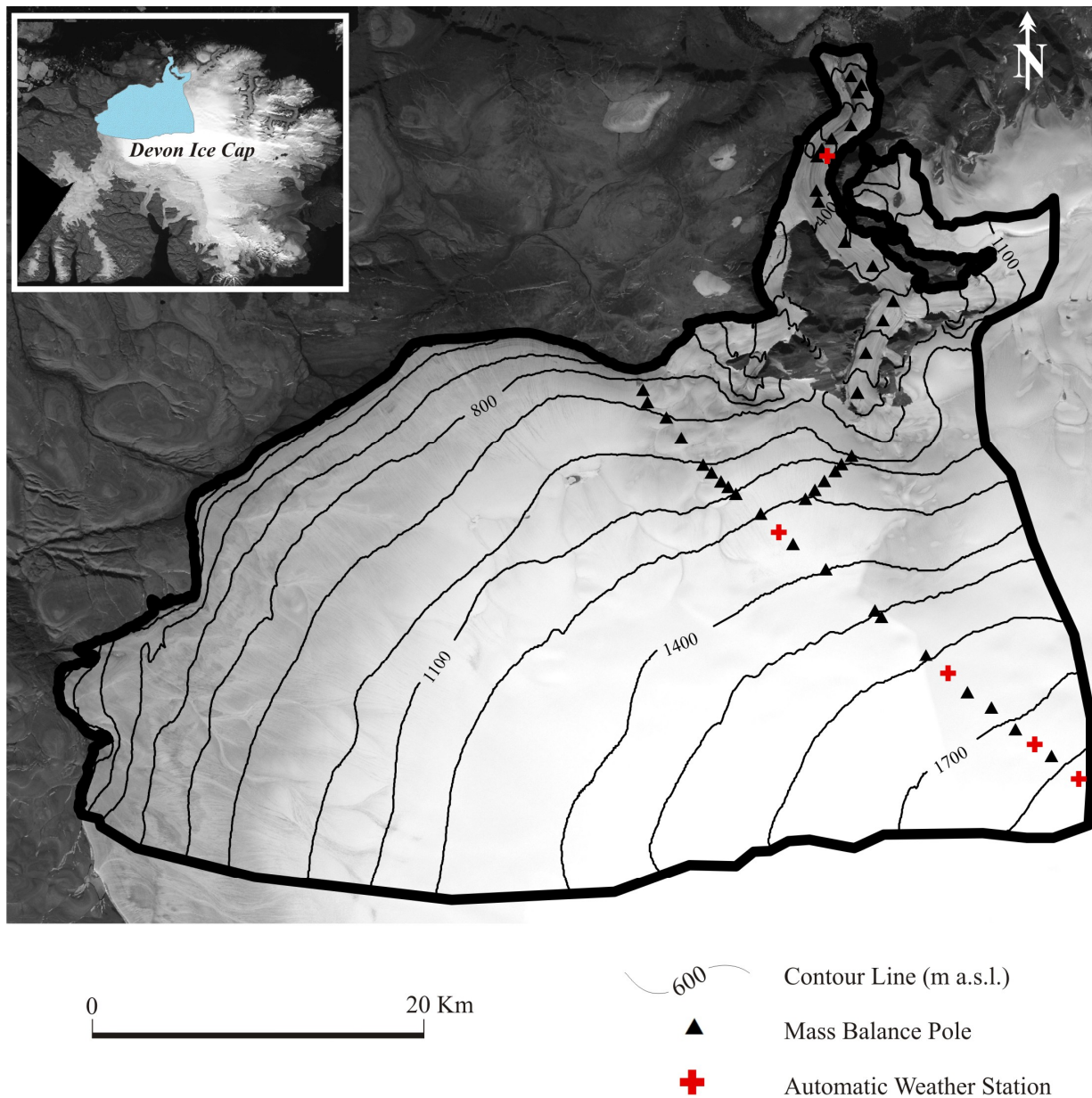
Figure 2. Location of mass balance pole network and automatic weather stations in the Northwest sector of the Devon Ice Cap. Background is a LandSat ETM[+] satellite image acquired in July, 2000. Inset in top left indicates the location of the Northwest sector (shaded blue) within the ice cap.
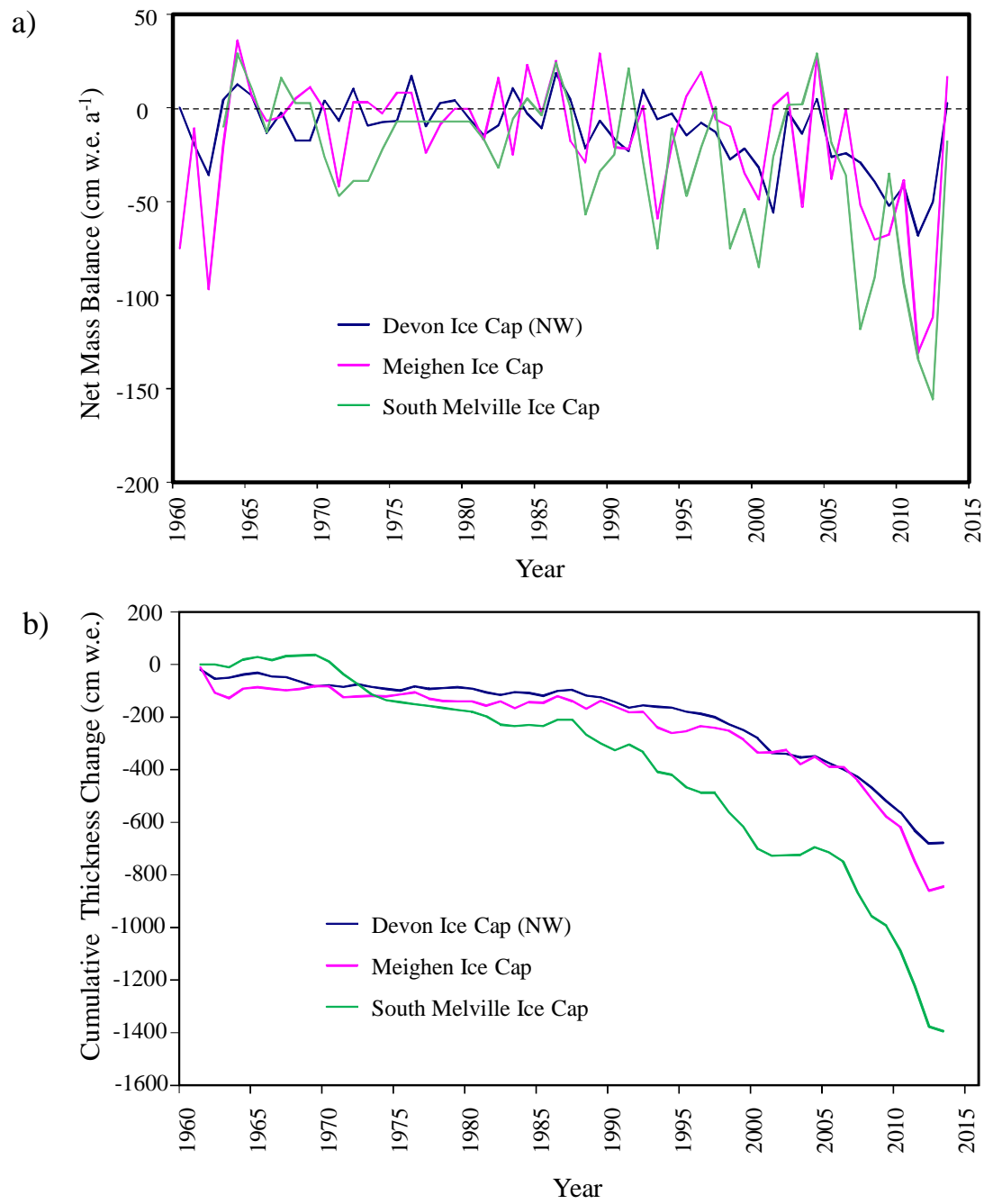
Figure 3. Long-term annual (a) and cumulative (b) net mass balance profiles for the Devon(NW), Meighen, and South Melville Ice Caps.

Meighen Ice Cap

The Meighen Ice Cap (MIC) is small (92 km^2 in 1960) stagnant ice cap located on Meighen Island in the northwest sector of the QEI, Nunavut (Figure 1). Despite being located at the lowest elevation range of the 3 reference glaciers (ie. 100-250 m a.s.l. – see Figure 5), 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 -15.9 cm w.e. a^{-1} (Table 1) has thinned by ~8 m between 1960 and 2013 (Figure 3b) and reduced its area through margin retreat by 34% between 1960 and 2012.

South Melville Ice Cap

The South Melville Ice Cap (SMIC) is the most southerly of 3 small (~67 km^2 in 1960) 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 and long-term average of 50 cm w.e. a^{-1} mass due to summer melting. Ablation due to summer melting has doubled since 2005. Results from surface mass balance measurements on the SMIC (established in 1963) indicate a significantly negative mass balance in the early to mid 1960's, shifting to the prevailing trend of increasingly negative values since 2005 (Figure 3a). The average net mass balance of the SMIC has been -27.4 cm w.e. a^{-1} (Table 1) which has led to a cumulative thinning of ~14 m since 1963 (Figure 3b). Vertical wastage 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	Average Net Balance 2012-2013 (cm w.e.)	Long-Term Average Net Balance (cm w.e. a^{-1})	Total Mass Change in 2012-2013 (Gt)
Devon Ice Cap (NW)	2	-13	+0.04
Meighen Ice Cap	17	-16	+0.01
Melville Ice Cap	-18	-27	-0.009

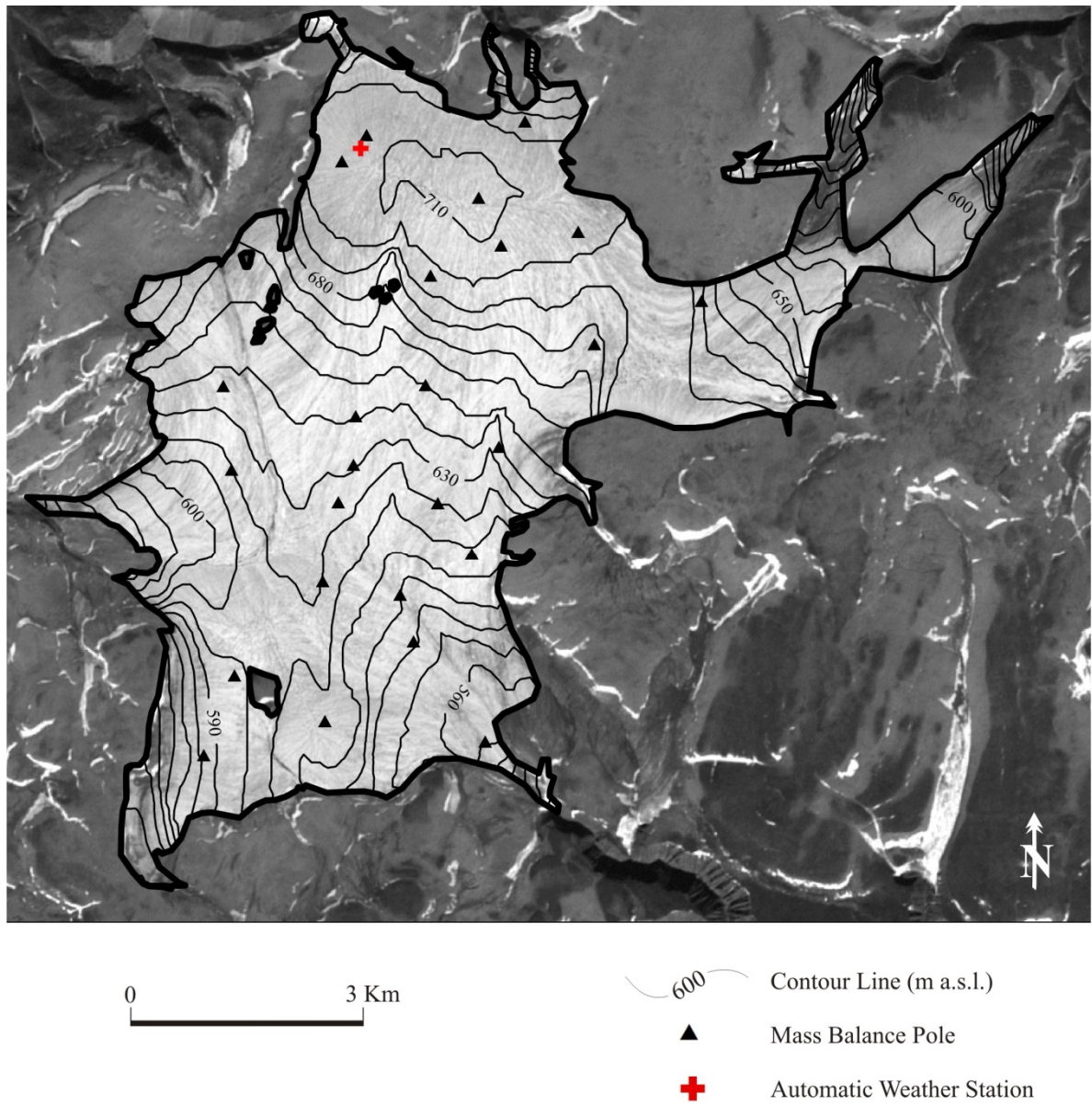Figure 4. Location of mass balance pole network and automatic weather stations on the South Melville Ice Cap, Nunavut. Background is a LandSat ETM$^+$ satellite image acquired in July, 1999.

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-ice conditions to synoptic scale climate models. AWS's measure ambient air temperature and relative changes in height of the snow/ice cap surface at 1 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 2013 and 2014 provide information needed to calculate net balance for the late summer 2012 to late summer 2013 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 2012 – 2013 balance year are include in the Appendix.

4.   RESULTS

The 2012-2013 average net balance across the DIC_NW of +2 cm w.e. (long-term mean of -13 cm w.e – see Table 1) was the 14th most positive year on record. While net accumulation above 1600 m a.s.l. for the 2012-2013 balance year agreed well with long-term average values (Figure 6), net thinning below 1600 m a.s.l. was significantly lower. Maximum melt rates of -77 cm w.e. near the terminus of the Sverdrup Glacier in the 2012-2013 balance year were ~50 cm w.e. less negative than the long-term average, and the mass balance gradient (ie. mass change as a function of elevation) below the ELA was lower in 2012-2013 (-0.8 kg m^{-2} a^{-1} m^{-1}) compared with the long term mean gradient of (-0.92 kg m^{-2} a^{-1} m^{-1}). In 2012_2013 the equilibrium-line altitude (ELA) was ~300 m lower than the long-term mean (Figure 7) resulting in an accumulation area ratio (AAR) of 78%. Overall, the DIC_NW increased in mass by +0.04 Gt of ice during the 2012_2013 balance year which is in sharp contrast to the long-term average rate of -0.21 Gt ice lost from this basin annually.

 The 2012-2013 average net balance across the MIC of +17 cm w.e. (long-term mean of -16 cm w.e – see Table 1) was the 7th most positive year on record. The spatial pattern of surface mass balance across the ice cap ranged from ~30 cm w.e. at the highest elevations of the south-

Figure 6. Net mass balance values for the 1961-2013 average (gray) and the 2012-2013 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 2012-2013 balance years respectively.

Figure 7. Map of the 2012/2013 net surface mass balance for the Northwest sector of Devon Ice Cap, Nunavut.

central regions, to minimum values of ~0 cm w.e. along the western margin (Figure 8). Relatively high values of surface mass balance (ie. 15-20 cm w.e.) were maintained along the eastern margin. The anomalously cool summer of 2013 may explain why the horizontal pattern of surface mass balance is not consistent with earlier observations by Patterson (1969) who indicated a trend of higher melting along the eastern margin than the west. Despite the apparent discrepancy in the pattern of net mass balance across the MIC, a moderately strong relationship with elevation was maintained for the 2012-2013 balance year (Figure 9). In terms of mass change, the MIC gained 0.01 Gt of ice during the 2012-2013 balance year in contrast with the long-term mass loss rate of -0.012 Gt a^{-1}.

The 2012-2013 net balance averaged across the SMIC of -18 cm w.e. was slightly less negative than the long-term mean of -27 cm w.e. (Table 1). While both the long-term and the 2012-2013 balance year values exhibit a moderate relationship between net mass balance with elevation (Figure 10), the spatial pattern of net balance across the ice cap (Figure 11) suggests that the surface balance was also controlled as a function of distance from the ice cap margin. In terms of mass change, the SMIC lost -0.009 Gt of ice during the 2012-2013 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 2014 by Natural Resources Canada under research licence numbers 0200214R-M (Nunavut Research Institute) and 15412 (Aurora Research Institute). Results from this work provide information on the state-of-health of the Devon, Meighen, and South Melville ice caps for the 2012-2013 balance year. While the annual long-term average mass balance value for all 3 reference glaciers was negative, the Devon and Meighen ice caps in 2012-2013 experienced positive balance values of 2 and 17 cm w.e. respectively. Mass balance for South Melville ice cap (2012-2013) of -18 cm w.e. was only slightly less negative than the long-term average of –27 cm w.e. Associated water equivalent volume change for the Devon(NW), Meighen, and South Melville ice caps was 0.04, 0.01, and -0.009 Gt respectively resulting in a net *negative* contribution to global sea-level rise from these 3 sites for the 2012-2013 balance year. Overall, glacier mass balance values in the Queen Elizabeth Islands for 2012-2013 were in sharp contrast to the recent trend of strongly negative balance over the past 10 years (Sharp et al. 2011) reflecting the relatively cool conditions that prevailed across this region during the summer of 2013.

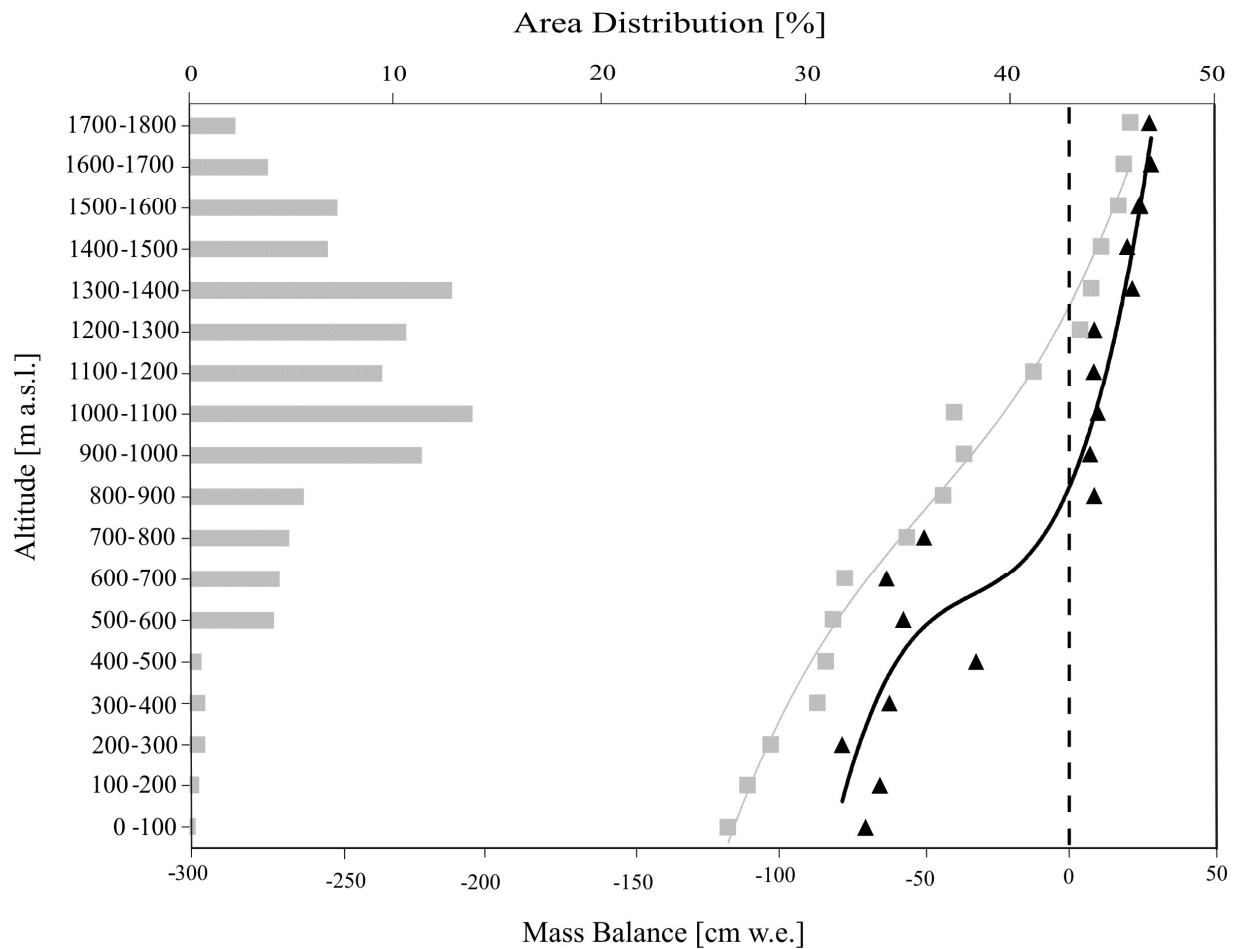Figure 8. Map of the 2012/2013 net surface mass balance for the the Meighen Ice Cap, Nunavut.
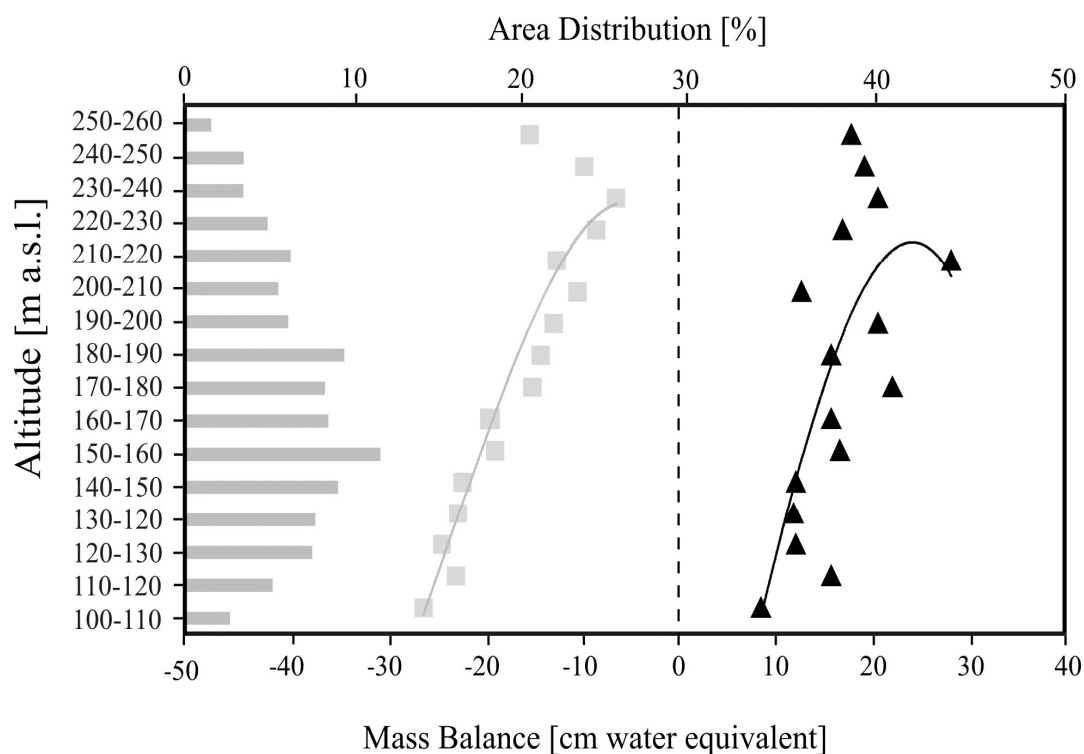
Figure 9. Net mass balance values for the 1960-2013 average (gray) and the 2012-2013 balance year (black) plotted as a function of elevation for the Meighen Ice Cap, Nunavut. Trend lines are 3rd order polynomials with r-squared values of 0.82 and 0.47 for the long-term and 2012-2013 balance years respectively.

Figure 10. Net mass balance values for the 1963-2013 average (gray) and the 2012-2013 balance year (black) plotted as a function of elevation for the South Melville Ice Cap, Northwest Territories. Trend lines are 3rd order polynomials with r-squared values of 0.49 and 0.51 for the long-term and 2012-2013 balance years respectively.

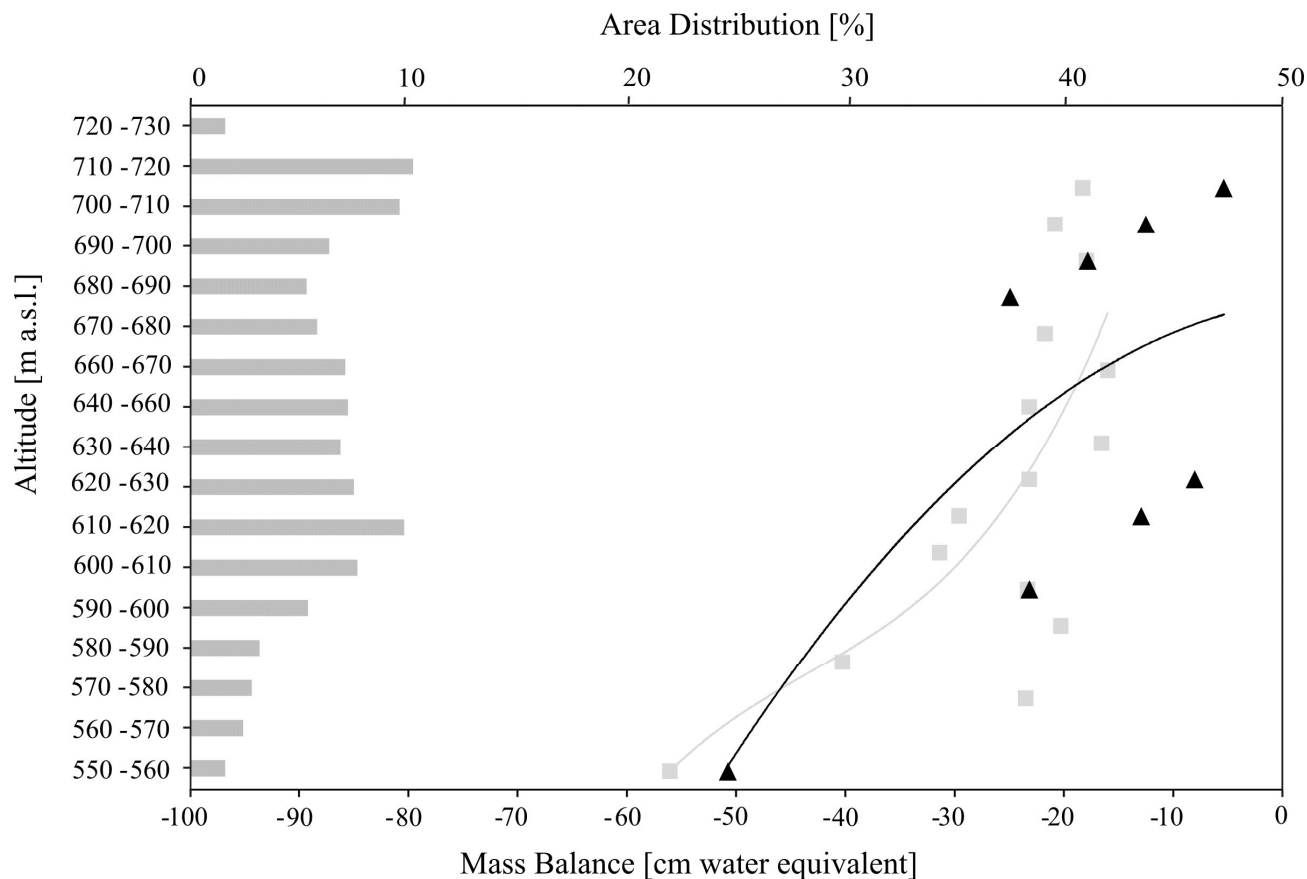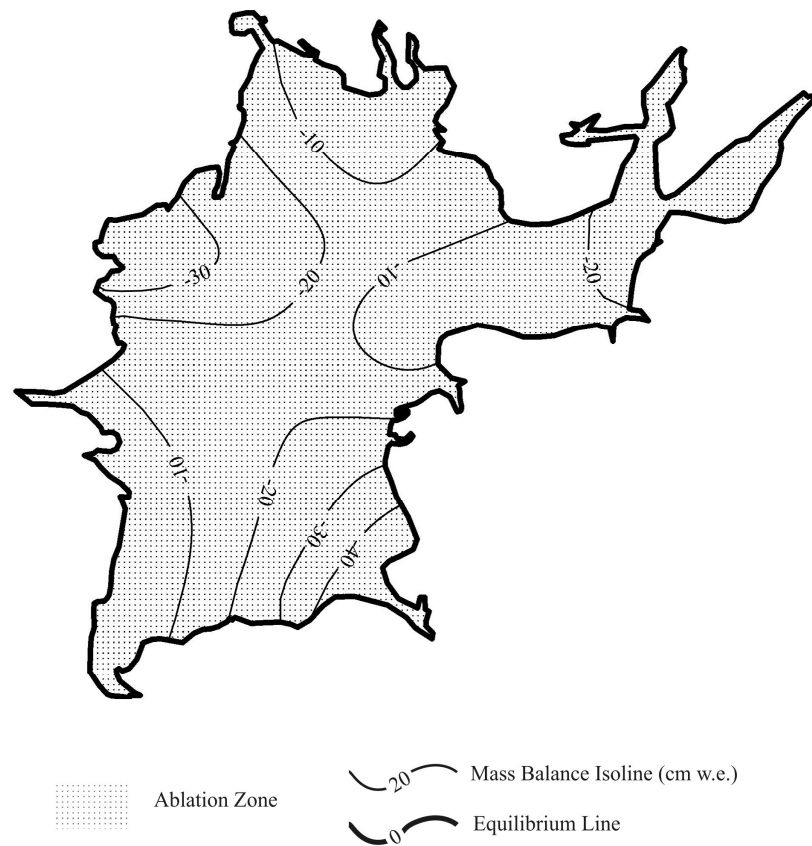Figure 11. Map of the 2012/2013 net surface mass balance for the South Melville Ice Cap, Northwest Territories.

6. ACKNOWLEDGMENTS

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APPENDIX

Table A1. Mass balance pole values for Devon Ice Cap, 2012-2013 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2012-2013 Net Balance (cm w.e.)	2012-2013 Winter Balance (cm w.e.)	2012-2013 Summer Balance (cm w.e.)
H	75.3691	-82.6702	1829	22.8	23.2	3.6
FH	75.3807	-82.7280	1769	24.0	23.3	4.7
F	75.3863	-82.7634	1737	34.8	20.1	18.7
EF	75.3941	-82.8040	1707	28.4	22.1	10.3
E	75.4049	-82.8550	1687	27.6	18.2	13.4
DE	75.4125	-82.9056	1663	27.2	20.7	10.5
D	75.4220	-82.9473	1638	20.4	16.9	8.5
K	75.4312	-82.9941	1592	19.0	19.7	4.3
ML	75.4505	-83.0889	1507	15.5	17.6	3.9
M	75.4538	-83.1032	1491	24.5	19.3	11.2
N / OM	75.4741	-83.2083	1398	21.5	21.3	6.2
O	75.4866	-83.2776	1363	18.0	19.1	4.9
DVT2	75.5115	-83.4010	1202	8.4	13.9	0.5
DVT7	75.5175	-83.4331	1152	14.4	17.0	3.4
DVT9	75.5258	-83.4712	1103	1.8	9.2	-1.4
DVT10.2	75.5395	-83.5195	1050	17.4	28.0	-5.6
DVT11	75.5575	-83.5931	962	7.2	19.3	-7.1
DVT12	75.5637	-83.6034	931	6.6	19.8	-8.2
DSG91	75.5253	-83.1958	1239	7.2	18.8	-6.6
DSG91B	75.5289	-83.1835	1198	10.2	13.9	1.3
DSG9	75.5334	-83.1627	1102	8.4	13.9	-0.5
DSG73	75.5668	-83.1553	831	-36.5	8.9	-42.4
DSG72	75.5878	-83.1411	768	-63.2	5.2	-65.4
DSG6	75.6152	-83.0877	622	-51.6	5.5	-55.1
DSG53	75.6331	-83.1335	460	-25.8	10.7	-34.5
DSG52	75.6451	-83.1935	499	-38.3	14.9	-51.2
DSG51	75.6661	-83.2520	388	-61.4	7.3	-68.7
DSG5	75.6714	-83.2576	369	-59.6	11.8	-71.5
DSG3	75.6988	-83.2298	292	-73.9	3.0	-76.8
DSG2	75.7060	-83.1900	231	-60.5	8.3	-68.8
DSG1	75.7232	-83.1788	179	-60.5	9.7	-70.2
DSG1B	75.7270	-83.1712	157	-77.4	7.0	-84.4
DSG0	75.7316	-83.1936	137	-81.0	6.0	-87.0

Table A2. Mass balance pole values for Meighen Ice Cap, 2012-2013 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2012-2013 Net Balance (cm w.e.)	2012-2013 Winter Balance (cm w.e.)	2012-2013 Summer Balance (cm w.e.)
5	80.0308	-99.2034	106	8.4	22.4	-14.0
8	80.0174	-99.1066	120	15.6	19.7	-4.1
9	80.0187	-99.1581	132	8.4	16.2	-7.8
11	80.0051	-99.2743	143	7.8	16.2	-8.4
13	80.0035	-99.2050	156	20.4	20.6	-0.2
14	80.0006	-99.1569	172	21.6	19.7	1.9
17a	79.9997	-99.0919	160	15.6	19.3	-3.7
18a	79.9733	-99.1403	216	32.4	19.5	12.9
21	79.9685	-99.1469	222	24	19.6	4.4
21a	79.9618	-99.3144	139	18.6	24.2	-5.6
23	79.9617	-99.2095	206	21.6	17.1	4.5
28	79.9625	-99.1055	213	23.4	17.8	5.6
29	79.9616	-99.0895	191	20.4	18.2	2.2
30	79.9622	-99.0592	152	12.6	18.7	-6.1
31	79.9369	-99.1212	252	27	16.8	10.2
32	79.9311	-99.1150	253	8.4	16.7	-8.3
33a	79.9187	-99.1073	208	8.4	15.9	-7.5
34	79.9805	-99.0996	177	22.2	17.2	5.0
34a	79.9723	-99.0568	145	16.2	19.0	-2.8
35a	79.9772	-99.2353	182	15.6	17.9	-2.3
35b	79.9789	-99.3213	135	8.4	18.8	-10.4
38	79.9348	-99.1616	238	1.2	16.6	-15.4

Table A3. Mass balance pole values for Meilville Ice Cap, 2012-2013 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2012-2013 Net Balance (cm w.e.)	2012-2013 Winter Balance (cm w.e.)	2012-2013 Summer Balance (cm w.e.)
1	75.3918	-114.9491	553	-50.7	13.3	-64.0
3	75.4065	-114.9792	581	-27.6	17.9	-45.5
5	75.4034	-115.0584	621	-8.0	25.6	-33.6
8	75.4160	-114.9522	608	-23.1	21.2	-44.3
10	75.4135	-115.0181	621	-17.8	18.7	-36.5
14	75.4278	-114.9386	635	-8.0	19.2	-27.2
22	75.4470	-114.9661	696	-17.8	19.2	-37.0
23	75.4554	-114.9437	716	-5.3	21.0	-26.3
25	75.4498	-114.9345	707	-11.6	19.5	-31.1
27	75.4513	-114.9004	703	-16.0	20.0	-36.0
L5	75.4498	-115.0155	690	-24.9	19.0	-44.0
AWS	75.4613	-114.9950	707	-13.4	23.2	-36.5