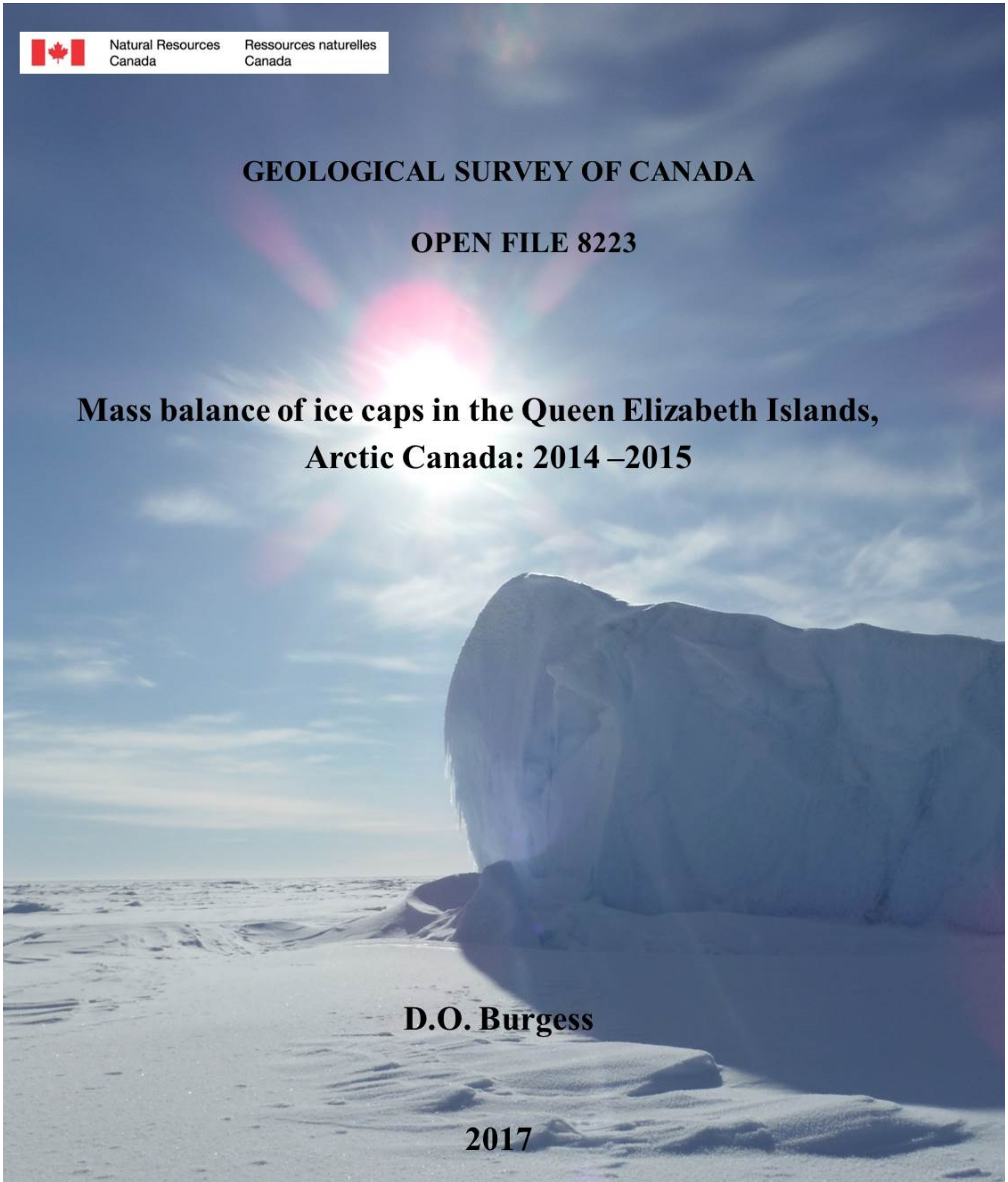
Natural Resources Canada / Ressources naturelles Canada



GEOLOGICAL SURVEY OF CANADA

OPEN FILE 8223

Mass balance of ice caps in the Queen Elizabeth Islands, Arctic Canada: 2014 –2015

D.O. Burgess

2017

Celebrating 175 yrs

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doi:10.4095/300231

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Recommended citation
Burgess, D.O., 2017. Mass balance of ice caps in the Queen Elizabeth Islands, Arctic Canada: 2014 –2015; Geological Survey of Canada, Open File 8223, 38 p. doi:10.4095/300231

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ABSTRACT

In-situ glacier mass balance surveys were conducted by Natural Resources Canada in April/May 2016 across the Devon, Meighen, South Melville, and Agassiz Ice Caps, Queen Elizabeth Islands. Survey results indicate significantly negative values over all ice caps in the 2014-2015 mass balance year with Meighen and Melville Ice Caps experiencing the fourth most negative mass balance year on record thinning by -115 and -89 cm respectively while the Devon Ice Cap, which thinned by -39 cm, experienced the sixth most negative year on record. After the relatively cool summers of 2013 and 2014, extremely negative mass balance values for 2014-2015 are more consistent with the post-2005 trend during which melt rates of high Arctic glaciers have been 3-5 times more negative than the long-term (1960-2013) average. The *climatic* net mass balance measurements from the Agassiz and Devon (NW) Ice Caps indicated an increase of the Equilibrium Line Altitude by 300 m and 400 m respectively relative to the long-term means. Associated water equivalent mass loss of 0.68, 0.052, and 0.053 Gt for the Devon (NW), Meighen, and South Melville Ice Caps respectively indicate a net ***positive*** contribution to global sea-level rise from these three sites for the 2014-2015 balance year.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

TABLES PAGE

FIGURES

1. INTRODUCTION

At ~105,000 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. The Government of Canada has been measuring the mass balance of reference glaciers in the Queen Elizabeth Islands (QEI) annually since the early 1960's. This multi-decadal time series which spans elevations from sea-level to 1800 m a.s.l. provides a robust indicator of climate trends where meteorological observations are otherwise sparse. In addition, the *in-situ* measurements of glacier mass balance provide calibration and validation to remote sensing measurements of glacier mass change as well as input to regional and hemispheric scale climate dynamic models aimed at predicting the response of Canada's glaciers to future climate change. Results from the *in-situ* glacier mass balance monitoring program conducted by Natural Resources Canada are thus critical to assessing the impact of freshwater flux from Canada's glaciers on global and regional sea-level rise, ocean ecosystems and circulation patterns, 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 4 reference glaciers in the QEI during April/May, 2016 under research licence numbers 0200216R_M (Nunavut Research Institute) and 15790 (Aurora Research Institute). Results from this work are disseminated to:

i) Northern communities through reports and engagement activities,

ii) Government of Canada in support of Sector Level Programs [M&L], Parks Canada, and National Climate Change Assessments [ECCC,CCIAD],

iii) Peer-reviewed publications, and

iv) International organizations (*World Glacier Monitoring Service [WGMS], National Oceanographic and Atmospheric Administration [NOAA], American Meteorological Society [AMS], and American Geophysical Union [AGU]*). Dissemination of data and assessments of glacier change to the *WGMS* (http://wgms.ch/) helps fulfill Canada's commitments to the United Nations Framework Convention on Climate Change (http://unfccc.int/essential_background/convention/items/6036.php) where it is used for global glacier and climate change studies (eg. Intergovernmental Panel on Climate Change, https://www.ipcc.ch/). Contributions to all organizations (*WGMS*, *NOAA*, *AMS*, *AGU*) supports Canada's commitment to internationally co-operative agreements (eg. United States Arctic Research Commission and Arctic Executive Steering Committee, 2016) aimed at understanding changes occurring in the Arctic and their global consequences.

2. STUDY SITES

Devon Ice Cap (75.4N, 82.6W)

Occupying approximately 14,000 km^2 of eastern Devon Island, Nunavut, the Devon Ice Cap is located in the Southeast sector of the QEI (Figure 1). The elevation of the Devon Ice Cap 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 et. al., 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; Gardner, et. al., 2011; Millan et. al., 2017). Surface mass balance measurements on Devon Ice Cap began in 1960 along the Northwest transect (Figure 2) which spans nearly the entire elevation range (0 – 1800 m a.s.l.) of the ice cap. Results from this program indicate that mass balance of the Northwest basin of the Devon Ice Cap, herein after called Devon (NW), 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 Devon (NW) Ice Cap has thinned by an average of ~7 m across the Northwest basin since 1960 with 50% of the thinning occurring since 2005 (Figure 3b).

Meighen Ice Cap (79.9N, 99.1W)

The Meighen Ice Cap is a small 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. – Figure 4) of the 3 reference glaciers, the Meighen Ice Cap has maintained a cumulative mass balance profile similar to that of the Devon (NW) Ice Cap (Figure 3b). Precipitation on the Meighen Ice Cap ranges from 10 – 30 cm w.e. which comes mainly in the form of snow with additional contributions from rime due to advection of super-cooled water droplets from the near-by Arctic Ocean. Alt (1979) attributed summer fog events to suppression of melt across the Meighen Ice Cap to explain frequent positive balance years with ice-cap wide ablation rarely exceeding 50 cm w.e. in any given summer prior to 2005. The long-term average net balance of -16 cm w.e. a^{-1} (Table 1) has thinned the Meighen Ice Cap by ~8 m since 1960 (Figure 3b) with 50% of the thinning having occurred after 2005. Predominately negative mass balance since 1960 coincides with a reduction in areal extent of the Meighen Ice Cap by 34% resulting in a total area of 60 km^2 in 2012.

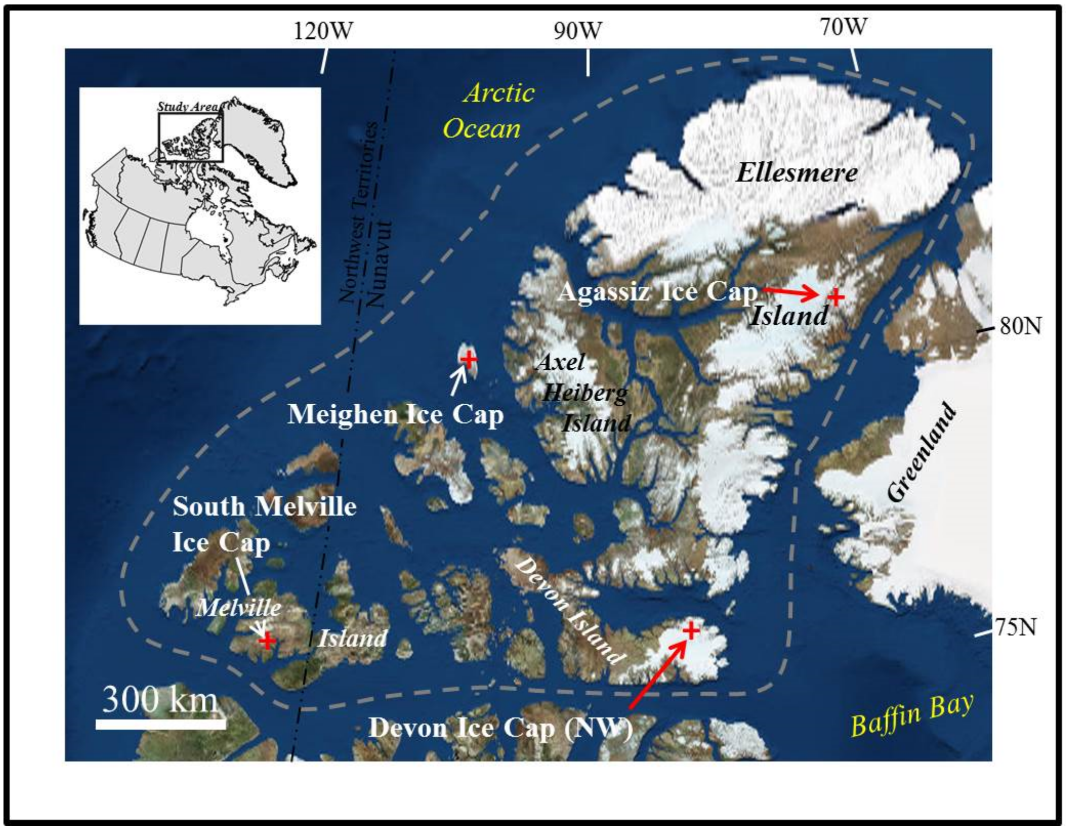

Figure 1. Location of the 4 glacier reference sites (red crosses) maintained by Natural Resources Canada in the Queen Elizabeth Islands, Arctic Canada. Inset shows study area map location within Canada.

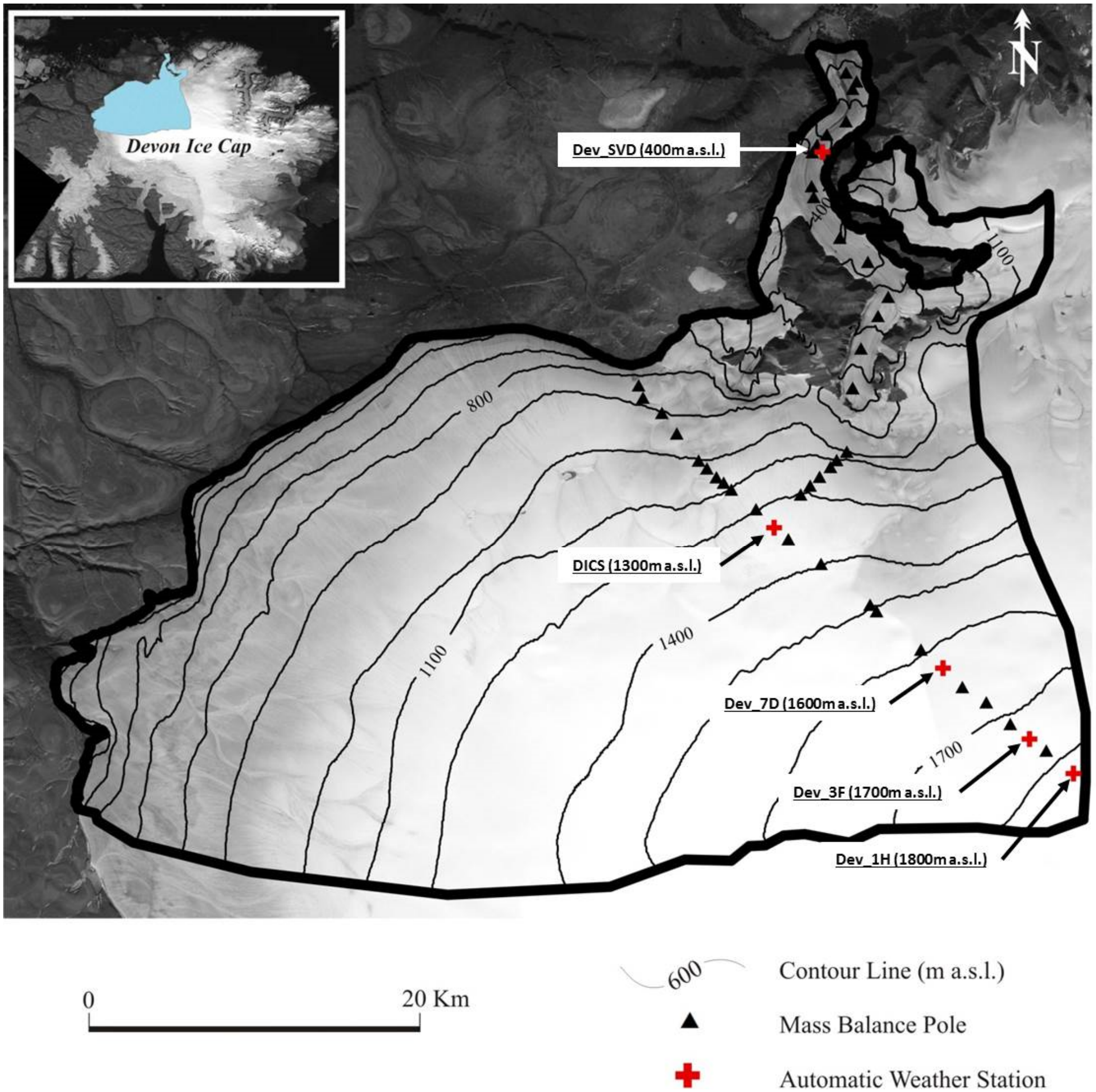

Figure 2. Mass balance poles and automatic weather stations along the Northwest transect of the Devon Ice Cap, Nunavut. The inset indicates the location and extent of the Northwest basin (shaded blue). The background image is a LandSat ETM$^+$ satellite scene acquired in July, 2000.

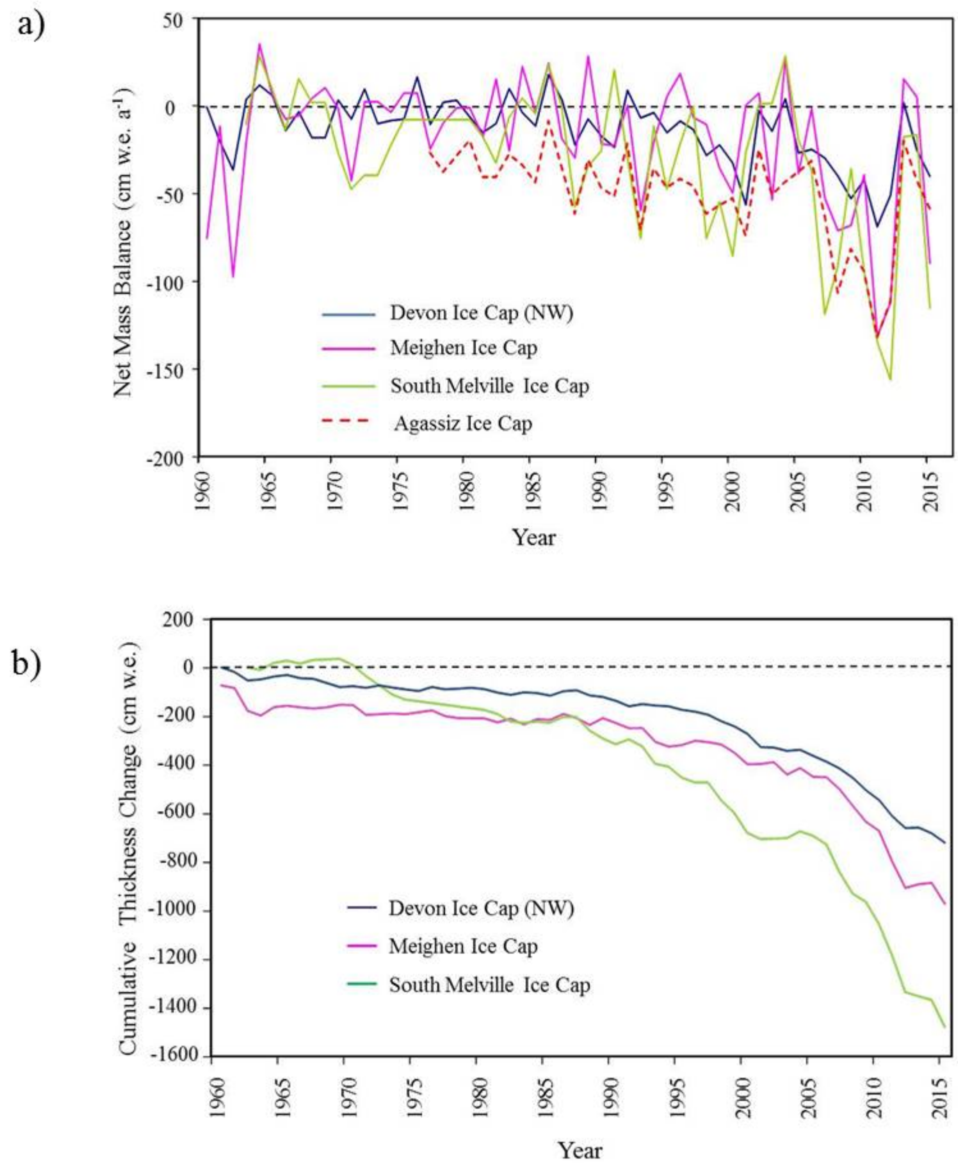

Figure 3. Annual mass balance (a) and cumulative thickness change (b) profiles for long-term glacier monitoring sites in the Queen Elizabeth Islands. Mass balance profile for the Agassiz Ice Cap was not included in (b) as it represents climatic net balance only.

South Melville Ice Cap (75.5N, 114.9W)

The South Melville Ice Cap is the most southerly of three small (~40 km^2 in 2012) stagnant ice caps located on west Melville Island, Northwest Territories (Figure 1). The South Melville Ice Cap occupies elevations between 500 and 720 m a.s.l. (Figure 5) and is surrounded by non-glacierized peaks of the Blue Hills which extend to >900 m a.s.l. to the east and south of the ice cap. The South Melville Ice Cap 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 South Melville Ice Cap maintained a slightly negative average mass balance of -16 cm w.e. yr^{-1} with ~1 out of 4 years experiencing positive balance values. Since 2005 however, mass balance of the South Melville Ice Cap has been ~5 times more negative than the 1963-2004 period, and has thinned by ~8 m accounting for 50% of the total amount thinned (~15 m) since measurements began in 1963 (Figure 3b). By 2012, ice margin retreat has resulted in areal shrinkage by 27 km^2, or 40% of its 1960 area, with newly exposed bedrock throughout the interior regions accounting for ~3 km^2 of total area loss of the South Melville Ice Cap.

Agassiz Ice Cap (80.7N, 72.9W)

The Agassiz Ice Cap is located along the northern ranges of the Arctic Cordillera, occupying ~19,000 km^2 of northern Ellesmere Island with maximum ice cap elevations extending to ~2000 m a.s.l. The ice cap loses ~ 0.3 Gt of ice mass per year through calving flux discharge from 8 main tidewater terminating glaciers (van Wychen et al., 2013), however the primary mode of ablation from the Agassiz Ice Cap is through surface melt and runoff in response to summer warming. A surface mass balance monitoring network was established in 1976 with dedicated transects to sample the accumulation and ablation zones separately. The upper most transect (Nipple Ridge) extends ~7 km southwards from the upper weather station and provides information on snow water equivalent variability across the accumulation zone of the Drambuie Glacier basin (Figure 6). A second transect extends ~25 km east-northeast from the upper weather station along the centerline of the Drambuie Glacier basin down to 700 m a.s.l.. Since measurements began, summer ablation along the Drambuie glacier transect has averaged ~34 cm w.e. a^{-1} with winter accumulation along the Nipple ridge line averaging ~ 13 cm w.e. over the entire period of record.

3. METHODS

Glacier mass balance surveys are conducted annually between early April and late May on the Devon (NW), Meighen, South Melville, and Agassiz Ice Caps. The monitoring network on Devon (NW) Ice Cap consists of 38 aluminum poles (drilled 1 – 4 meters into the ice cap surface) with the main transect extending from the ice cap summit region (~1800 m a.s.l.) to the terminus of the Sverdup Glacier (100 m a.s.l.), and a second arm extending from the main transect at Devon Ice Cap Station (DICS; ~1300 m a.s.l.) to the near stagnant western margin at ~500 m a.s.l. (Figure 2). 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. Mass balance measurements on the Agassiz Ice Cap are collected at 12 mass balance poles located 1 – 2 km apart along the Drambuie glacier (1500 and 700 m a.s.l) and at 9 pole locations along Nipple ridge.

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 2015 and 2016 provide information needed to calculate net balance for the late summer 2014 to late summer 2015 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 2014 – 2015 balance year are included in the Appendix.

Currently, mass balance pole measurements along the Drambuie Glacier are not averaged across elevation bands for the entire basin as is the case for measurements from the other 3 sites. The plotted mass balance profile for the Agassiz Ice Cap (Figure 3a) is thus biased towards more negative values as most of the basin-wide accumulation is not included in the calculations as the basin boundaries have yet to be defined and the transect does not extend to the lowest part of the ablation zone. Recent progress towards resolving both of these limitations will allow water equivalent mass loss for the entire Drambuie Glacier basin to be calculated for the 2015-2016 mass balance year. The signal from the Agassiz ice cap is thus a *climatic* signal which is interpreted in terms of the annual *equilibrium line altitude* (ELA;. the elevational boundary separating the zone of ablation from the zone of accumulation) relative to the long-term mean.

Meteorological data collected from on-ice Automatic Weather Stations (AWS) at all monitoring sites are 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. The 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 Canada (Edmonton) CR800 data loggers on all stations except the Devon Sverdrup which is equipped with a CR1000. All data loggers are downloaded during each annual site visit.

In spring 2016, the Sverdrup Glacier (Dev_SVD) and Devon Ice Cap Station (DICS) on Devon Ice Cap (Figure 2) were equipped with data telemetry via the Iridium^{TM} satellite communications constellation. Data services provided by Campbell Scientific Canada (Edmonton) include web-page postings of image and data plots (http://dataservices.campbellsci.ca/sverdrup/index.php), and a password protected ftp site to access data needed to calculate near real-time estimates of net mass balance for the Devon NW glacier basin. Post melt season data retrieved from the Sverdrup and Ice Cap Station sites were used to calculate 2015-2016 real-time mass balance results for the Devon NW glacier basin. Results were reported as 'preliminary values' to the various data repositories (i.e. WGMS and NOAA) and will be validated from field measurements during the spring 2017 field campaign.

Figure 4. 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. Contours plotted at 10 m intervals.

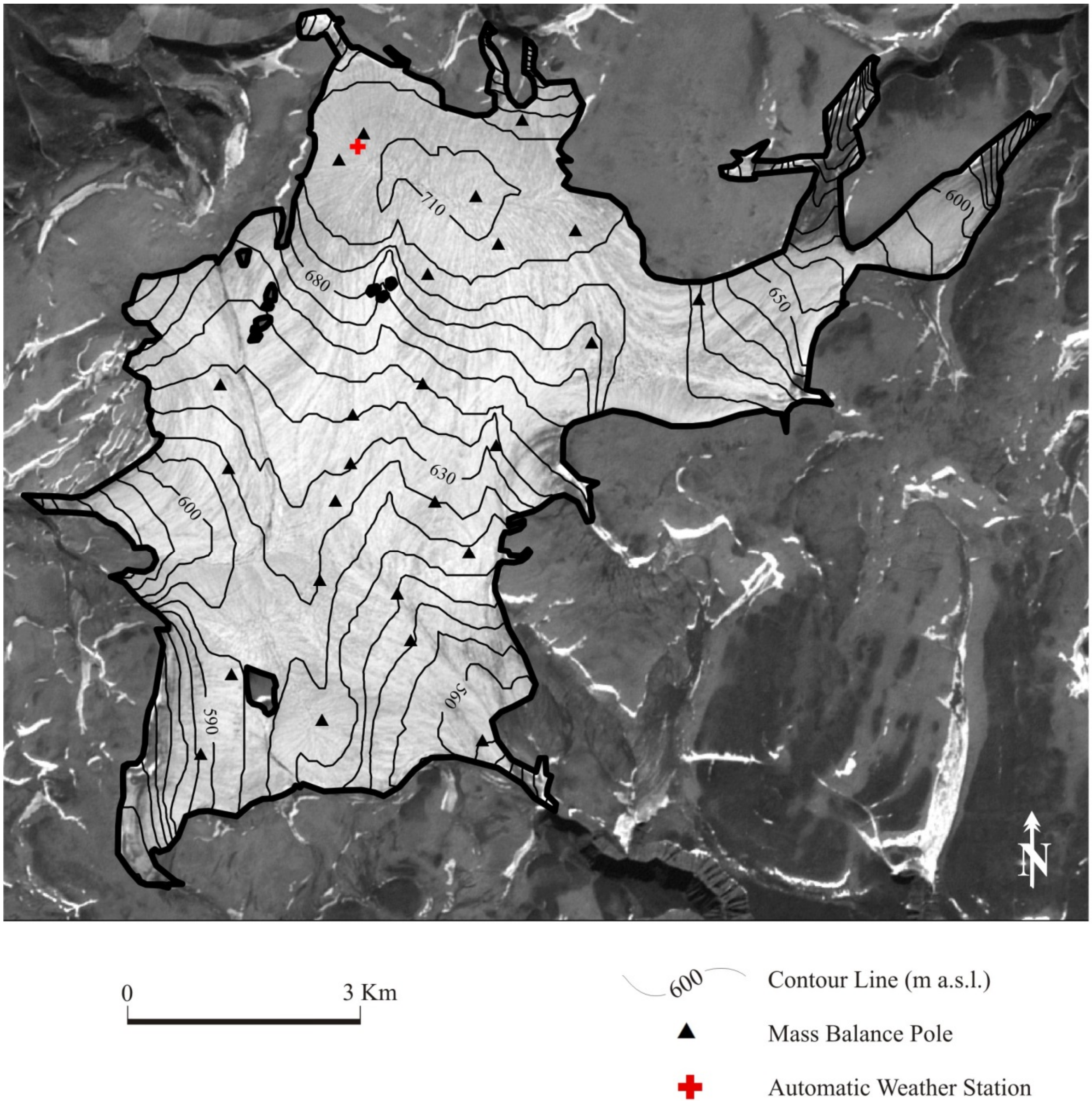

Figure 5. Location of mass balance pole network and automatic weather stations on the South Melville Ice Cap, Nunavut. Background is a LandSat ETM$^+$ satellite image acquired in July, 1999. Contours plotted at 10 m intervals.

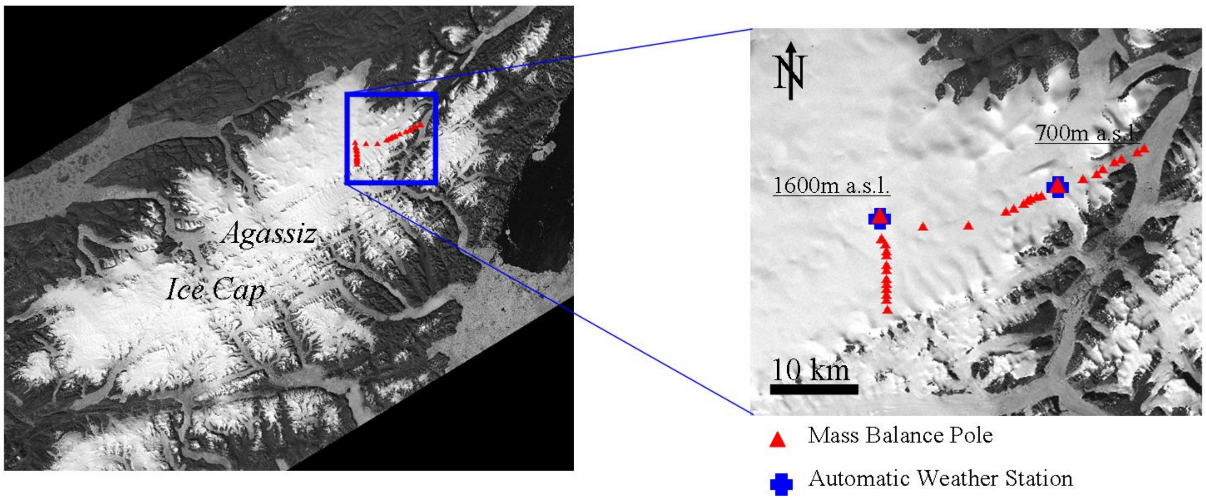

Figure 6. Location of mass balance pole network and automatic weather stations on the Agassiz Ice Cap, Nunavut. Background is a LandSat ETM^{+} satellite image acquired in July, 1999. The Nipple ridge and Drambuie glacier transects extend southwards and east-northeast from the upper AWS (1700 m a.s.l.) respectively.

4. RESULTS

Results from the 2016 surveys in the Canadian high Arctic field surveys indicated significantly negative values for all ice caps in the 2014-2015 mass balance year. Net mass balance across the Devon (NW) averaged -40 cm w.e. making it the 6th most negative year on record with thinning of almost 4 times greater than the long-term mean (Table 1). Enhanced summer warmth resulted in thinning of the terminus region (0-100 m a.s.l.; see Figure 7) by ~50 cm in excess of the long-term average, and positioned the 2014-2015 ELA ~400 m higher than the long-term mean. As a consequence, the accumulation area of Devon (NW) was limited to 20% of the entire basin area (Figure 8) while the remaining 80% the basin shed 0.68 Gt through melting and run-off of the previous winter snow pack to the ocean.

Average net balance for the Meighen Ice Cap of -89 cm w.e. in 2014-2015 was the fourth most negative mass balance year on record and five times more negative than the long-term average of -17 cm w.e. a^{-1} (Figure 9). The ice cap experienced negative balance across its entirety with an average of ~ 80 cm w.e. thinning at the summit region increasing to -120 cm w.e. along most of the ice cap margin (Figure 10). Persistent thinning and retreat of the Meighen Ice Cap margin has resulted in the permanent loss of four long-term mass balance poles, all of which were located along the northern margin. Ablation across the entire ice cap resulted in a total loss of 0.052 Gt of mass from the Meighen Ice Cap (Table 1) through melting of the previous winter snowpack and glacier ice, and run-off directly to the Arctic Ocean.

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

* The ELA anomaly for the Devon Ice Cap is relative to the 1960-2013 time period whereas the anomaly for Agassiz Ice Cap is relative to the 1977-2015 time period.

Site	Net Balance 2014-2015 (cm w.e.)	Long-Term Average Net Balance (cm w.e. a^{-1})	Equilibrium Line Altitude Anomaly* (m)	Total Mass Change in 2014-2015 (Gt)
Devon Ice Cap (NW)	-40	-14	+400	-0.68
Meighen Ice Cap	-89	-17	N/A	-0.052
Melville Ice Cap	-115	-29	N/A	-0.053
Agassiz Ice Cap	-58	-41	+300	N/A

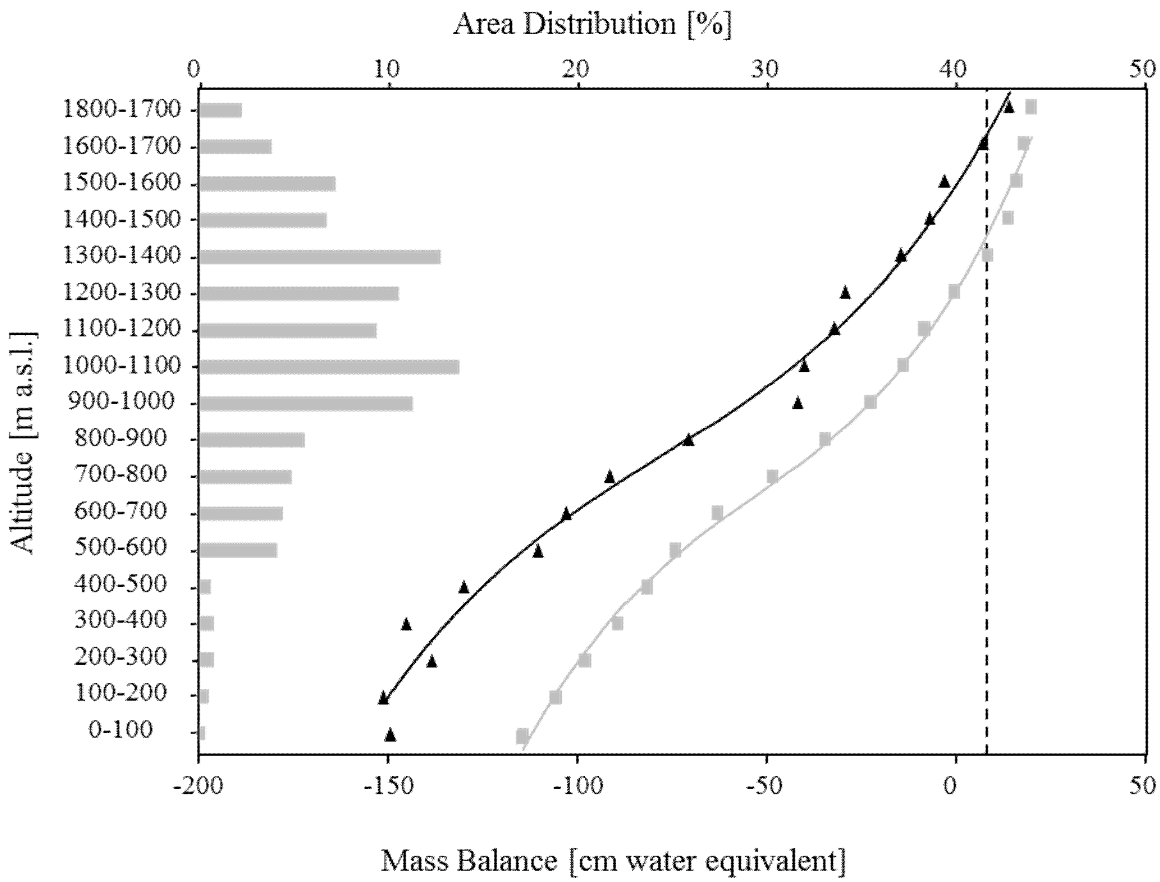

Figure 7. Net mass balance values for the 1961-2013 average (gray) and the 2014-2015 balance year (black) plotted as a function of elevation for the Northwest sector of Devon Ice Cap. Trend lines are 3rd order polynomials with r^2 values of 0.98 and 0.99 for the long-term and 2014-2015 balance years respectively.

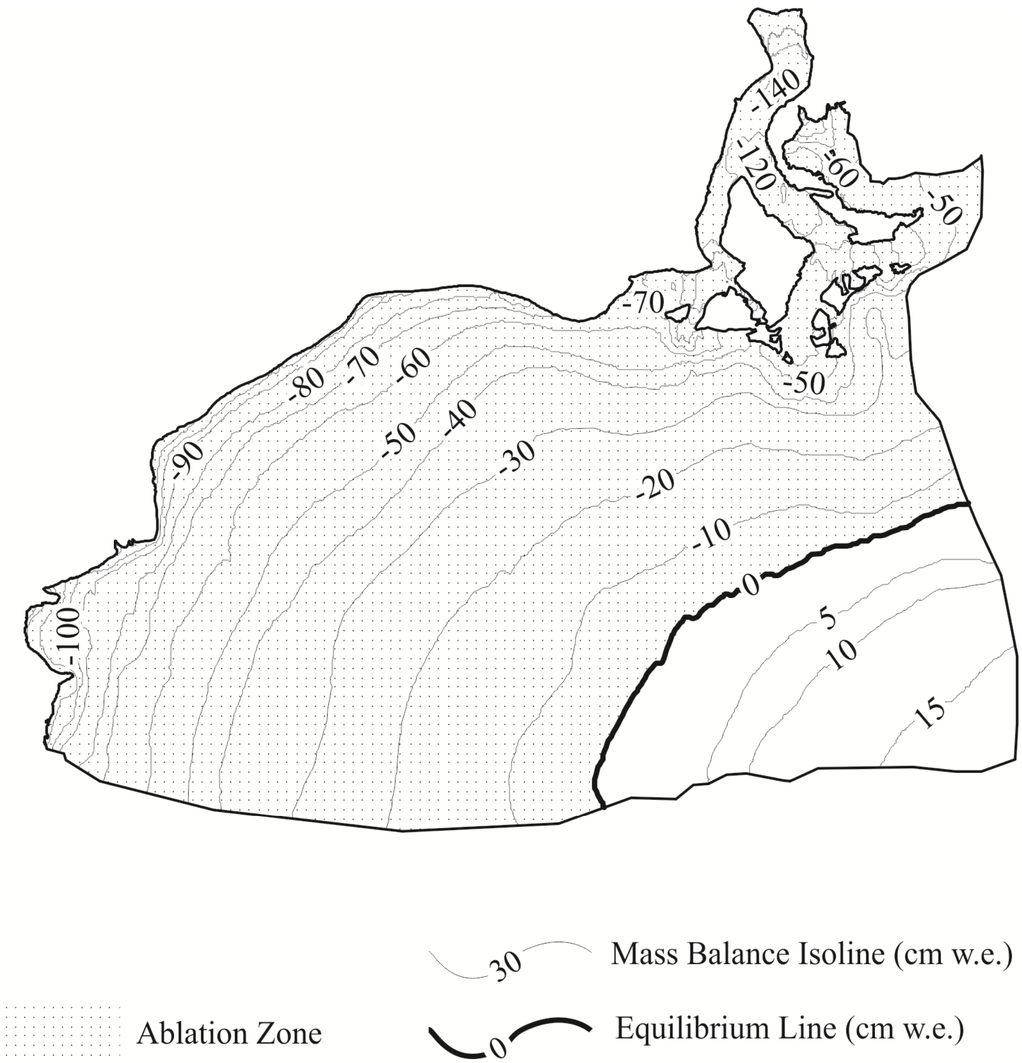

Figure 8. Net surface balance for 2014-2015 across the Devon (NW) Ice Cap, Nunavut modeled from a 3rd order polynomial of the original pole values as a function of elevation.

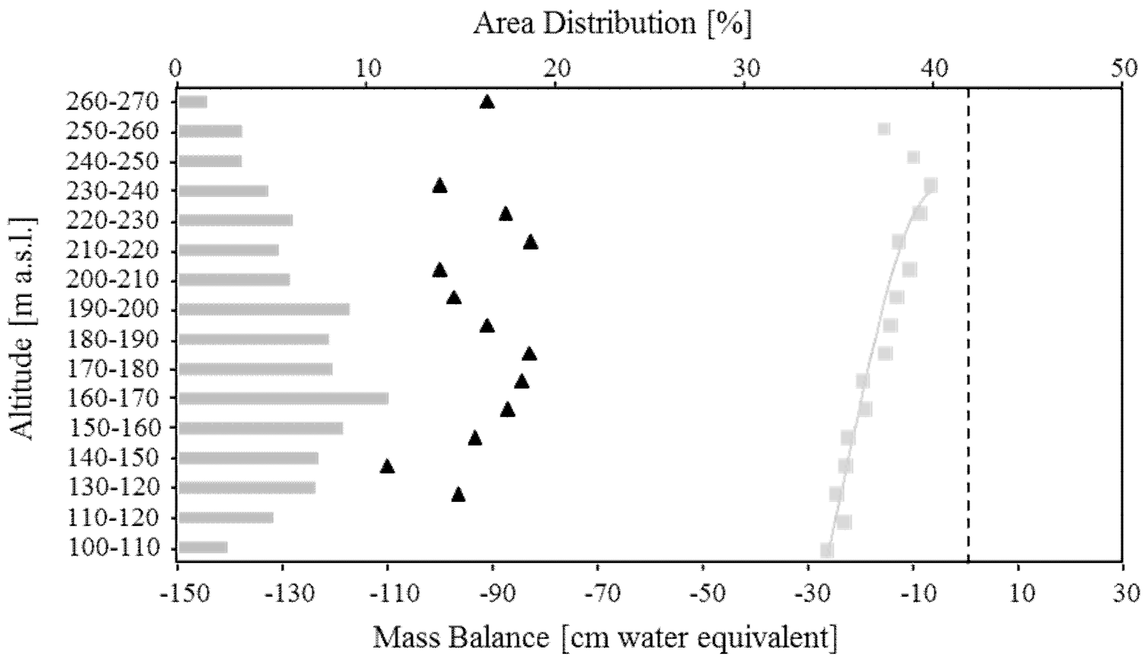

Figure 9. Net mass balance values for the 1960-2013 average (gray) and the 2014-2015 mass balance year (black) plotted as a function of elevation for the Meighen Ice Cap, Nunavut. The long-term trend line indicates a strong positive relationship between net mass balance and elevation (r^2=0.82) whereas the relationship for 2014-2015 balance year exhibited no trend.

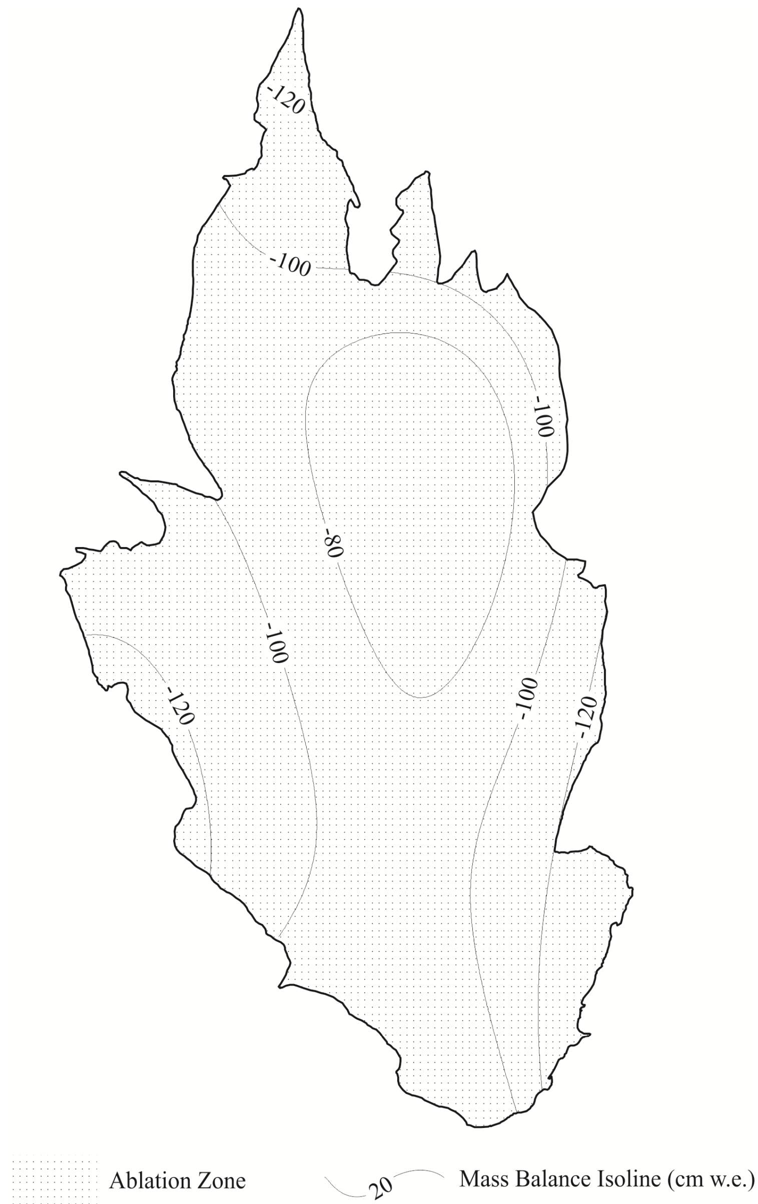

Figure 10. Interpolated spatial pattern of 2014-2015 net surface mass balance across the Meighen Ice Cap, Nunavut.

With an average net mass balance of -115 cm w.e. (Figure 12), the South Melville Ice Cap experienced the highest melt rate of the 3 sites in this study (Table 1), and the 4th highest melt year of the 55 year period of record. The South Melville Ice Cap experienced net mass loss across the entire ice cap surface with minimum melting occurring in the central region, increasing towards the north and south margins (Figure 11). Due to persistently high melt rates (<1 m a^{-1}) since the mid-2000's, the South Melville Ice Cap has become more fragmented as the ice cap has thinned, exposing increasingly larger areas of the underlying bedrock. Changes in the local surface energy balance and heat advection from the exposed bedrock areas (Jiskoot and Mueller, 2012) are likely to become increasingly important as positive feedback effects that accelerate the ongoing melting of the South Melville Ice Cap.

Results from the 2016 mass balance surveys on the Agassiz Ice Cap indicate an increase of the 2014-2015 ELA by ~300 m relative to the long-term average (Table 1). This *climatic* signal indicates unusually warm temperatures at high elevations across the Drambuie Glacier basin which have significantly increased the area from which mass loss due to melting and runoff to the Arctic Ocean has exceeded accumulation for the 2014-2015 balance year.

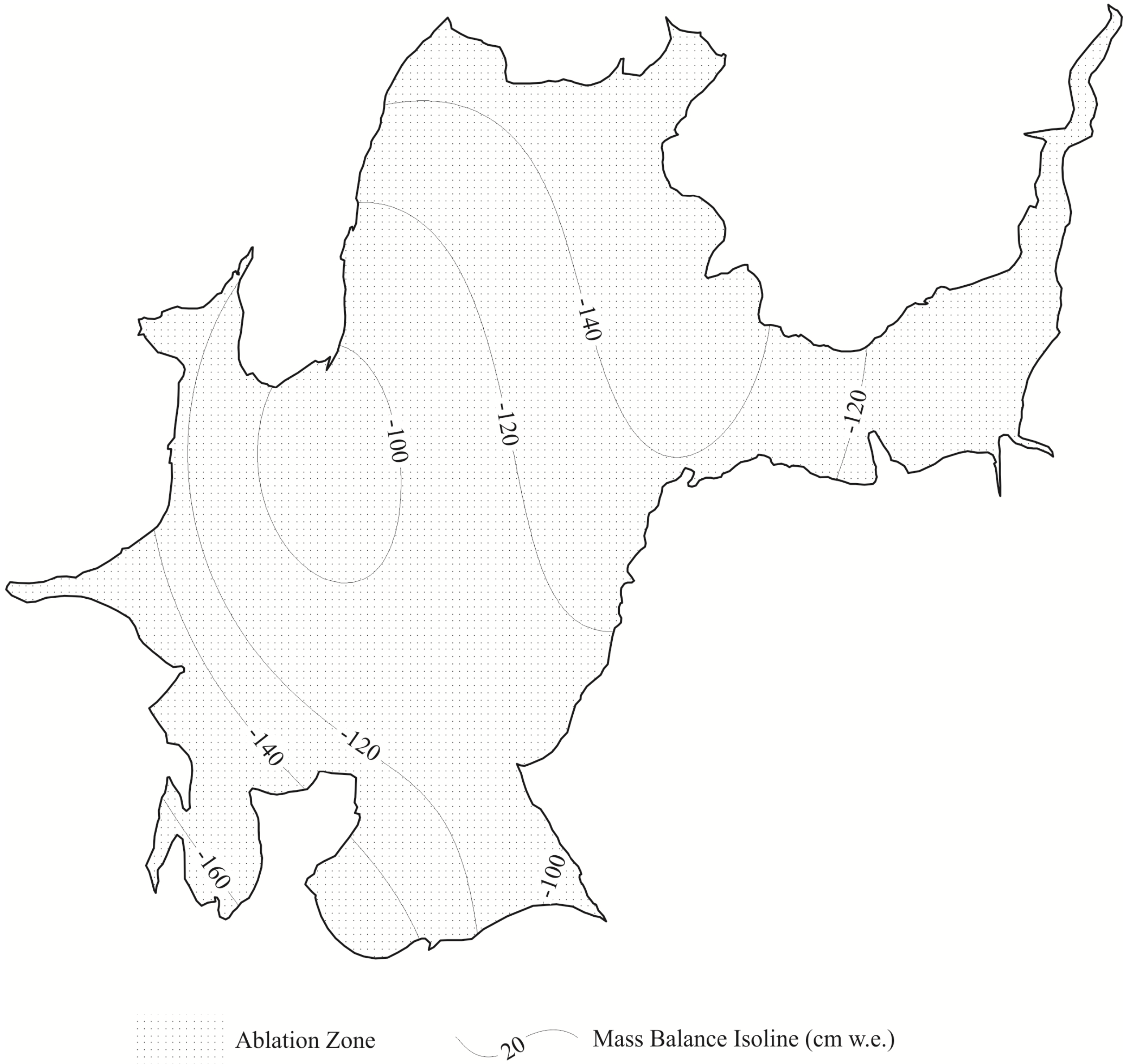

Figure 11. Interpolated spatial pattern of the 2014-2015 net surface mass balance for the South Melville Ice Cap, Northwest Territories.

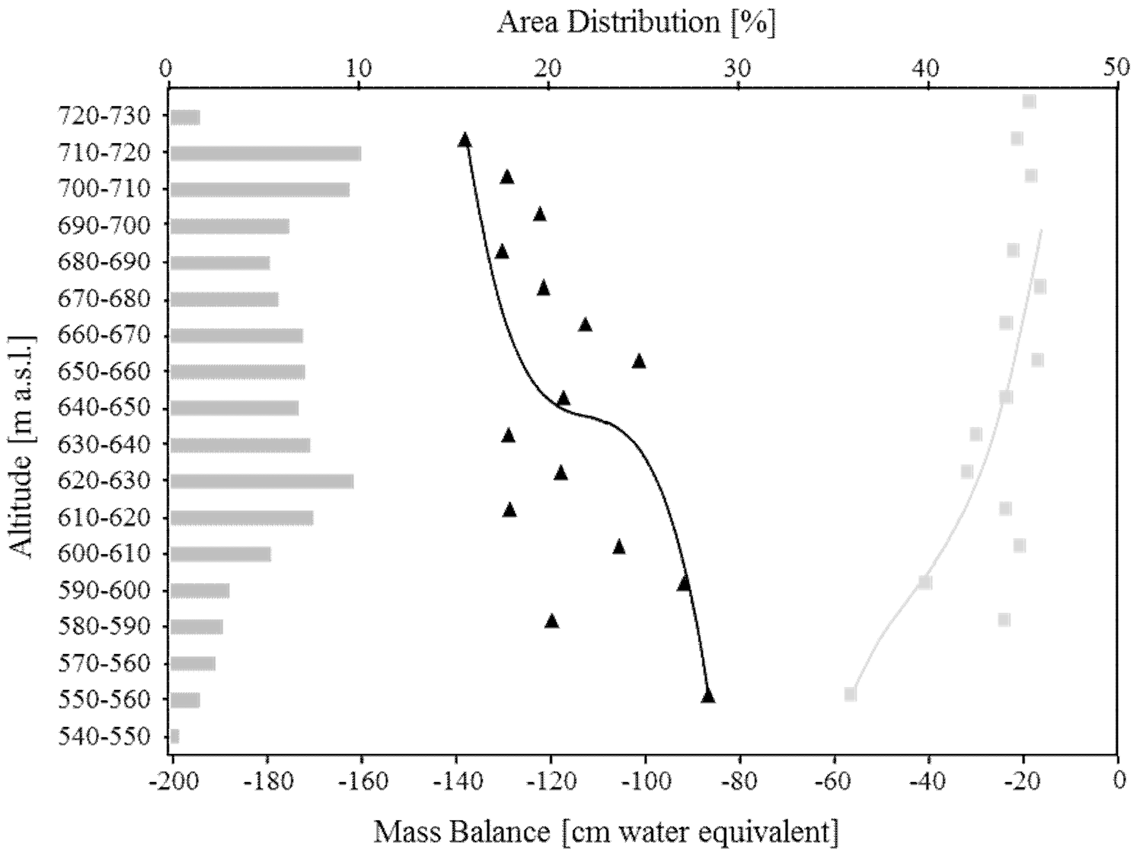

Figure 12. Net mass balance values for the 1963-2013 average (gray) and the 2014-2015 balance year (black) plotted as a function of elevation for the South Melville Ice Cap, Northwest Territories. Trend lines are 3rd order polynomials with r^2 values of 0.49 and -0.52 for the long-term and 2014-2015 balance years respectively.

5. SUMMARY

Results from glacier mass balance surveys conducted by NRCan in the spring of 2016 indicate strongly negative net mass balance values across the ice caps in the Queen Elizabeth Islands for the 2014-2015 balance year. Net mass losses from the Devon (NW), Meighen, and Melville Ice Caps were four to six times higher than the long term average. Significant increases of the ELA across the Agassiz and Devon (NW) Ice Caps of 300 m and 400 m respectively, indicate that above average temperatures that prevailed across the QEI during the summer of 2015 (Jeffries et. al., 2015) extended throughout nearly the entire elevational range of the larger ice caps. The total water equivalent volume change for the Devon (NW), Meighen, and South Melville Ice Caps for the 2014-2015 mass balance year was -0.68 -0.052, and -0.053 Gt respectively resulting in a net ***positive*** contribution to sea-level rise from these sites. After the relatively cool summers of 2013 and 2014 (Burgess, 2014, 2016), extremely negative mass balance values during the 2014-2015 mass balance year indicate a return to unusually high melting that has prevailed across the Canadian high Arctic since 2005 (Sharp, et. al., 2011).

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 006-16). Glacier mass balance surveys were conducted across the Queen Elizabeth Islands under research licence numbers 0200216R_M (Nunavut Research Institute) and 15790 (Aurora Research Institute). 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, Geological Survey of Canada.

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APPENDIX

Table A1. Mass balance pole values for Devon Ice Cap, 2014 -2015 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2014-2015 Net Balance (cm w.e.)	2014-2015 Winter Balance (cm w.e.)	2014-2015 Summer Balance (cm w.e.)
H	75.3691	-82.6702	1829	14	14	0
FH	75.3807	-82.7280	1769	14	14	0
F	75.3863	-82.7634	1737	16	16	0
EF	75.3941	-82.8040	1707	14	14	0
E	75.4049	-82.8550	1687	16	16	0
DE	75.4125	-82.9056	1663	8	11	-3
D	75.4220	-82.9473	1638	6	13	-8
K	75.4312	-82.9941	1592	-5	13	-18
ML	75.4505	-83.0889	1507	0	9	-9
M	75.4538	-83.1032	1491	-3	16	-19
N / OM	75.4741	-83.2083	1398	-10	11	-21
O	75.4866	-83.2776	1363	-12	13	-24
DICS	75.4923	-83.3081	1300	-20	0	-20
DVT1	75.5016	-83.3476	1297	-17	6	-23
DVT2	75.5115	-83.4010	1202	-35	5	-40
DVT6	75.5148	-83.4170	1197	-29	12	-41
DVT7	75.5175	-83.4331	1152	-41	8	-49
DVT8.1	75.5219	-83.4533	1121	-28	17	-45
DVT9	75.5258	-83.4712	1103	-47	6	-53
DVT10.2	75.5395	-83.5195	1050	-45	14	-59
DVT10.4	75.5498	-83.5521	1001	-22	28	-50
DVT11	75.5575	-83.5931	962	-45	14	-58
DVT12	75.5637	-83.6034	931	-57	12	-69
DSG92	75.5151	-83.2367	1283	-38	10	-49
DSG91	75.5253	-83.1958	1239	-29	10	-39
DSG91B	75.5289	-83.1835	1198	0	9	-9
DSG9	75.5334	-83.1627	1102	-44	10	-54
DSG73	75.5668	-83.1553	831	-70	12	-82
DSG72	75.5878	-83.1411	768	-92	13	-105
DSG70	75.6051	-83.1077	675	-112	7	-119
DSG6	75.6152	-83.0877	622	-93	18	-112
DSG53	75.6331	-83.1335	460	-127	24	-151
DSG52	75.6451	-83.1935	499	-133	11	-143
DSG51	75.6661	-83.2520	388	-125	6	-131
DSG5	75.6714	-83.2576	369	-146	9	-155
DSG4A	75.6934	-83.2496	312	-157	10	-167
DSG4AWS	75.6906	-83.2423	315	-154	5	-159
DSG3	75.6988	-83.2298	292	-151	12	-163
DSG2	75.7060	-83.1900	231	-125	9	-134
DSG1	75.7232	-83.1788	179	-157	13	-169
DSG1B	75.7270	-83.1712	157	-146	8	-154
DSG0	75.7316	-83.1936	137	-150	8	-158

Table A2. Mass balance pole values for Meighen Ice Cap, 2014 -2015 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2014-2015 Net Balance (cm w.e.)	2014-2015 Winter Balance (cm w.e.)	2014-2015 Summer Balance (cm w.e.)
8	80.01736991	-99.10659992	124	-96	22	-118
35b	79.97885993	-99.32126993	130	-110	20	-129
11	80.00511993	-99.27430999	143	-86	18	-104
18	79.99963783	-99.04853127	152	-100	23	-122
12	80.00537993	-99.24731992	153	-82	13	-95
13	80.00352996	-99.20496994	156	-75	13	-88
30	79.96215999	-99.05919992	160	-118	17	-135
17a	79.99973992	-99.09186998	160	-73	12	-85
34a	79.97228994	-99.05678996	160	-97	12	-109
14	80.00060996	-99.15687994	172	-71	11	-82
16a	79.99965996	-99.10300995	175	-70	15	-85
35a	79.97715991	-99.23530991	179	-97	13	-110
15	79.99927992	-99.12095997	183	-81	13	-94
34	79.98048996	-99.09960992	185	-95	17	-112
29	79.96156999	-99.08951995	200	-100	14	-114
35	79.97606666	-99.15599992	213	-75	11	-86
20	79.97325998	-99.14029995	216	-73	14	-86
24	79.95960996	-99.18488991	220	-96	15	-111
28	79.96251991	-99.10550994	220	-86	13	-100
21	79.96849998	-99.14689994	222	-69	12	-81
27	79.96238655	-99.11872275	231	-97	16	-113
25	79.96069995	-99.16249992	240	-73	16	-89
26	79.96115995	-99.13360993	240	-130	13	-142
31	79.93688998	-99.12118996	268	-91	13	-104

Table A3. Mass balance pole values for Melville Ice Cap, 2014 -2015 balance year.

Pole ID	Latitude	Longitude	Elevation (m a.s.l.)	2013-2014 Net Balance (cm w.e.)	2013-2014 Winter Balance (cm w.e.)	2013-2014 Summer Balance (cm w.e.)
MV1	75.391830	-114.949090	553	-86	22	-109
3	75.406470	-114.979190	581	-119	21	-140
7	75.411700	-114.984250	590	-63	25	-88
4	75.398000	-115.019330	606	-147	14	-161
8	75.416000	-114.952200	608	-109	34	-143
11	75.421780	-114.966370	620	-125	13	-139
5	75.403370	-115.058383	621	-159	34	-193
10	75.413500	-115.018110	621	-137	20	-157
10Wood	75.422170	-115.010190	623	-113	19	-132
13	75.426370	-115.002860	631	-108	23	-131
14	75.427820	-114.938650	635	-168	12	-180
15	75.435540	-115.059060	636	-101	14	-115
16	75.431750	-115.001140	641	-90	14	-104
18	75.431670	-114.970030	650	-112	17	-129
28	75.439000	-114.894890	676	-130	12	-142
L5	75.449760	-115.015450	690	-114	20	-134
22	75.447000	-114.966130	696	-117	15	-133
27	75.451340	-114.900420	703	-155	17	-172
17	75.460000	-115.003500	708	-141	15	-156