Glacier Change in Arctic Canada

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WHY DO ARCTIC GLACIERS MATTER?

• Balancing the global sea level budget requires knowledge of the history of regional rates of glacier mass loss

• The Arctic is warming twice as rapidly as Earth as a whole and 54% of the world’s glacier area is in the Arctic

• 40% of the Arctic “glacier” area is in Canada – What is happening to these glaciers?

• **Key areas:** Yukon, Ellesmere I, Axel Heiberg I, Devon I, Baffin I, Labrador
Annual and 10-Year running mean of mean summer (JJA) 700 hPa air temperature over glaciated regions of northern Canada 1948-2011

Strong warming (2-3°C) since ~1990

N. Ellesmere

Devon

N. Baffin

S. Baffin

Labrador

Yukon

NCEP/NCAR R1 Reanalysis
Anomalously high geopotential height over Greenland and Canada Basin in summer results in anomalous southerly flow of warm air from NW Atlantic into west Greenland and Canadian Arctic Islands.

NCEP/NCAR R1 Reanalysis
Changes in Glacier Extent
Yukon

1958-1960: 11622 km²
2006-2008: 9081 km²

Area Loss: 2541 km²
(= 22% of 1958-60 Area)

4 glaciers grew

Source: Barrand and Sharp, GRL 2010
GLACIERS IN ARCTIC CANADA

Mostly large ice caps in North

Ice caps and valley glaciers on Baffin Island

Small glaciers in Labrador

Source: Gardner et al. Nature 2011
# Queen Elizabeth Islands 1960-2000

<table>
<thead>
<tr>
<th>Region</th>
<th>1960 Area (km²)</th>
<th>2000 Area (km²)</th>
<th>Area Change (km²)</th>
<th>Area Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.Ellesmere</td>
<td>27,556</td>
<td>26,629</td>
<td>-927</td>
<td>-3.4</td>
</tr>
<tr>
<td>Agassiz</td>
<td>21,645</td>
<td>21,366</td>
<td>-279</td>
<td>-1.3</td>
</tr>
<tr>
<td>Axel/Meighen</td>
<td>12,231</td>
<td>12,017</td>
<td>-214</td>
<td>-1.7</td>
</tr>
<tr>
<td>Pr. of Wales</td>
<td>19,558</td>
<td>19,378</td>
<td>-180</td>
<td>-0.9</td>
</tr>
<tr>
<td>S. Ellesmere</td>
<td>10,696</td>
<td>10,060</td>
<td>-636</td>
<td>-5.9</td>
</tr>
<tr>
<td>Devon</td>
<td>15,344</td>
<td>14,735</td>
<td>-609</td>
<td>-4.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>107,071</strong></td>
<td><strong>104,186</strong></td>
<td><strong>-2844</strong></td>
<td><strong>-2.7</strong></td>
</tr>
</tbody>
</table>
# Southeastern Arctic

1958/61 - 2000/01

<table>
<thead>
<tr>
<th>Region</th>
<th>1958/61 Glacier Area (km²)</th>
<th>Area Change to 2000/01 (km²)</th>
<th>Area Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bylot I</td>
<td>4859</td>
<td>- 253</td>
<td>- 5.1</td>
</tr>
<tr>
<td>N.Baffin</td>
<td>150</td>
<td>- 82.5</td>
<td>- 55</td>
</tr>
<tr>
<td>Barnes IC</td>
<td>5935</td>
<td>- 119</td>
<td>- 2</td>
</tr>
<tr>
<td>Penny IC</td>
<td>5960</td>
<td>- 113</td>
<td>- 1.9</td>
</tr>
<tr>
<td>Terra Nivea IC</td>
<td>196</td>
<td>- 44 (2010)</td>
<td>- 22.4</td>
</tr>
<tr>
<td>Grinnell IC</td>
<td>132</td>
<td>- 24 (2010)</td>
<td>- 18.2</td>
</tr>
<tr>
<td>Labrador</td>
<td>26.8 (1950)</td>
<td>-7 (2005)</td>
<td>-26.1</td>
</tr>
</tbody>
</table>
Glacier Mass Balance = Snowfall – (Runoff + Calving)
Queen Elizabeth Islands: Measured Climatic Balance

2005-2009 mean is 235 (Devon) to 402 (White) mm w.e. yr$^{-1}$ more negative than mean for 1960-2009
Changes in Equilibrium Line Altitude in the Canadian High Arctic since 2000

*ELA (2000-2009)

*ELA (1960-2009)

AAR = 0.47

AAR = 0.23

+1.5 °C JJA Mean Temperature

+220m ELA

* Average of Devon Ice Cap and White Glacier, Axel Heiberg I

D. Burgess, Geol. Survey of Canada
Regional Mass Balance Modelling
2 modeling approaches driven by output from Polar WRF running at 6km resolution forced by NCEP Final Analysis.

Climatic Balance Climatology for 2001-2008

Regional Patterns in Annual Specific Climatic Balance across QEI

- 3 rate domains: Axel/N. Ellesmere, Devon/S. Ellesmere, Agassiz/PoW (also apparent in area change data)

Ben Gready, 2012
Calving Fluxes

279 Tidewater Glaciers

Drain 48,027 km$^2$

45% of glacier area in Queen Elizabeth Islands

26 **Reference Basins** studied for annual calving fluxes (2000-2010)

Scaled to all tidewater basins

Using basin-scale calving:accumulation relationship

Jamie Davis, Gabriel Wolken, unpublished
Mass balance variability comes out of climatic balance. Calving fluxes do vary significantly in individual basins but variations seem to cancel each other out.

Bias correction deals with errors in Polar WRF default ice mask and topography.

Recent mass balance trend driven largely by changes in climatic balance.

Melt changes dominate trend.

Ben Gready, 2012
Geodetic Approaches


• DEM differencing: (CDED (1960), SPOT (2007)) (Gardner et al., 2012, TCD)
Thickness Changes

ICESat Laser Altimetry

Fall 2003 to Fall 2009

Queen Elizabeth Islands

\[ \text{Mean } dh/dt = -0.38 \text{ m/yr} \]

Geir Moholdt, in Gardner et al., 2011, *Nature*
Thickness Changes
ICESat Laser Altimetry
Fall 2003 to Fall 2009
Baffin and Bylot Islands
Mean $\frac{dh}{dt}$ = -0.69 m/yr
Geir Moholdt, in Gardner et al., 2011, Nature
Global mass trend from GRACE during 2003-2010 corrected for the effects of hydrology and glacial isostatic adjustment. A 350 km Gaussian smoothing is applied. (Jakob et al., 2012, Nature)
Table 1 | Inverted 2003–2010 mass balance rates

<table>
<thead>
<tr>
<th>Region</th>
<th>Rate (Gt yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Iceland</td>
<td>-11 ± 2</td>
</tr>
<tr>
<td>2. Svalbard</td>
<td>-3 ± 2</td>
</tr>
<tr>
<td>3. Franz Josef Land</td>
<td>0 ± 2</td>
</tr>
<tr>
<td>4. Novaya Zemlya</td>
<td>-4 ± 2</td>
</tr>
<tr>
<td>5. Severnaya Zemlya</td>
<td>-1 ± 2</td>
</tr>
<tr>
<td>6. Siberia and Kamchatka</td>
<td>2 ± 10</td>
</tr>
<tr>
<td>7. Altai</td>
<td>3 ± 6</td>
</tr>
<tr>
<td>8. High Mountain Asia</td>
<td>-4 ± 20</td>
</tr>
<tr>
<td>8a. Tianshan</td>
<td>-5 ± 6</td>
</tr>
<tr>
<td>8b. Pamirs and Kunlun Shan</td>
<td>-1 ± 5</td>
</tr>
<tr>
<td>8c. Himalaya and Karakoram</td>
<td>-5 ± 6</td>
</tr>
<tr>
<td>8d. Tibet and Qilian Shan</td>
<td>7 ± 7</td>
</tr>
<tr>
<td>9. Caucasus</td>
<td>1 ± 3</td>
</tr>
<tr>
<td>10. Alps</td>
<td>-2 ± 3</td>
</tr>
<tr>
<td>11. Scandinavia</td>
<td>3 ± 5</td>
</tr>
<tr>
<td>12. Alaska</td>
<td>-46 ± 7</td>
</tr>
<tr>
<td>13. Northwest America excl. Alaska</td>
<td>5 ± 8</td>
</tr>
<tr>
<td>14. Baffin Island</td>
<td>-33 ± 5</td>
</tr>
<tr>
<td>15. Ellesmere, Axel Heiberg and Devon Islands</td>
<td>-34 ± 6</td>
</tr>
<tr>
<td>16. South America excl. Patagonia</td>
<td>-6 ± 12</td>
</tr>
<tr>
<td>17. Patagonia</td>
<td>-23 ± 9</td>
</tr>
<tr>
<td>18. New Zealand</td>
<td>2 ± 3</td>
</tr>
<tr>
<td>19. Greenland ice sheet + PGICs</td>
<td>-222 ± 9</td>
</tr>
<tr>
<td>20. Antarctica ice sheet + PGICs</td>
<td>-165 ± 72</td>
</tr>
</tbody>
</table>

**Arctic N America** -113 Gt/yr

**All Glaciers** -149 Gt/yr

**ANA/AG** 76%

**ANA/Antarctica** 68%

**ANA/Greenland** 51%

Jakob et al., 2012, *Nature*
Comparison of Approaches: Queen Elizabeth Islands
Baffin + Bylot Islands: Geodetic Mass Balance Estimates

Gardner et al., 2012, The Cryosphere Discussions
Longer Term Perspective on Recent Warming

Ice Core Melt Layer Records from 4 sites
Penny IC Ice Core Stratigraphy 1953-2011

- Change in firnification regime
- Latent heat release from refreezing meltwater

Zdanowicz et al., 2012; JGR Earth Surface
Penny IC – 14m Temperatures

10° C warming at 14m depth 1996-2011

Zdanowicz et al., 2012; JGR Earth Surface
Old Deep Ice Core Records Extended to Present with New Shallow Cores

160 yr Records

Fisher et al., 2012

Global and Planetary Change
Longer Term Perspective
1000 – 11000 yrs

Fisher et al., 2012
Global and Planetary Change
SUMMARY

• Strong summer warming in all areas since 1990 – accelerating after 2000 in high Arctic
• Unique in > 4000 yrs – approaching early Holocene thermal maximum melt intensity
• Substantial loss of glacier area in all regions – especially high area loss rates from small glaciers and ice caps
• Accelerating mass loss driven by more negative climatic mass balance, not by increased calving
• Arctic North America now the biggest regional contributor to non-steric sea level rise after the 2 large ice sheets
Acknowledgements


NSERC, CFCAS, Federal IPY, PCSP, NSTP, CCI, NRI

Communities of Grise Fjord and Resolute Bay
Regional Mass Balance Modeling: QEI

2004-2006
+7.3 Gt/yr

2007-2009
-61 Gt/yr

Alex Gardner,
Nature 2011