Glaciers outside Greenland

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Summary

Glaciers and ice caps in Arctic Canada are continuing to lose mass at a rate that has been increasing since 1987, reflecting a trend towards warmer summer air temperatures and longer melt seasons. Ice shelf breakup is another consequence of this trend.

Shrinkage of mountain glaciers and ice caps is one of the major causes of global sea level change (Meier et al., 2007). The area of mountain glaciers and ice caps in the Arctic is over 400,000 km^2 – nearly half the global total – and these glaciers were responsible for 50-60% of the sea level rise attributed to wastage of glaciers and ice caps between 1961 and 2004 (Kaser et al., 2006).

The health of glaciers is measured using their annual mass balance – the difference between the amount of mass added to them each year by snowfall, and the amount removed by surface melting and meltwater runoff, and by calving of icebergs. Much of the high Arctic is very dry, with little inter-annual variability in annual snowfall. In these regions, year-to-year variability in mass balance arises mainly from changes in summer temperatures and surface melt rates. In more maritime regions like Alaska, Iceland, and Svalbard, snowfall is higher and more variable, so mass balance variability reflects both summer and winter conditions. In most regions, flow rates of large outlet glaciers that drain into the ocean can change suddenly, resulting in large fluctuations in the amount of mass lost by iceberg calving. As yet, these sudden changes due to ice dynamics are not well-documented, and their linkages with changes in climate are not well understood.

The surface mass balance (snowfall minus meltwater runoff) of around 20 glaciers in the Arctic is measured annually. The Russian Arctic islands are not included in this data set because no measurements are currently being made there. The data that are available show an overall trend of increasing mass loss since the early 1990s (Kaser et al., 2006) that is particularly marked in Alaska and the Canadian Arctic.

For most regions of the Arctic, direct mass balance measurements for 2008-09 are not yet available. Measurements for the 2007-08 balance year are, however, available for 20 Arctic glaciers: three in Alaska, four in Arctic Canada, nine in Iceland, and four in Svalbard (Table G1). They indicate net mass loss from 16 of the 20 glaciers, and net mass gain for two in Alaska and two in Svalbard. Field measurements in Alaska show that 2 glaciers located near the coast had very positive balances (among the 20% most positive recorded since measurements began, due to heavy winter snowfall in 2007-2008) and one in the Alaska Range had a slightly negative balance. Gravity field measurements made with the GRACE satellites show that the regional mass balance for the Gulf of Alaska glaciers was essentially zero in 2007-2008 (Table 1; pers. comm. from A. Arendt and S. Luthcke, 2010). In Iceland, the mass balances were slightly more negative than the average for the 16-17 year record, while in Svalbard they were more positive than the 20-42 year average. The annual mass balances of four glaciers in Arctic Canada were among the three most negative in the 43-48 year period of record, reflecting the impact of a very warm summer in 2008. Consistent with both summer air temperatures and measured melt duration, the annual balances of the four Canadian Arctic glaciers were also very negative in 2008-2009 (2nd most negative balance since 1961 on the Devon Island ice cap; Table G1).

Region	**Glacier**	**Net Balance 2007-8** (kg/m^2/yr)	**Net Balance 2008-9** (kg/m^2/yr)	**GRACE 2007-2008** (Gt/yr)
Alaska				
	Gulf of Alaska glaciers			-9 ±20
	Wolverine	+1300		
	Lemon Creek	+800		
	Gulkana	-181		
Arctic Canada				
	Devon Ice Cap	-388	-523	
	Meighen Ice Cap	-705	-676	
	Melville S. Ice Cap	-905	-351	
	White	-781	-580	
Iceland				
	Langjökull S. Dome	-1842		
	Hofsjökull E	-790		
	Hofsjökull N	-570		
	Hofsjökull SW	-930		
	Köldukvislarjökull	-587		
	Tungnaarjökull	-1340		
	Dyngjujökull	-24		
	Brúarjökull	-503		
	Eyjabakkajökull	-1282		
Svalbard				
	Midre Lovenbreen	-10		
	Austre Broggerbreen	-130		
	Kongsvegen	+45		
	Hansbreen	+150		

Table G1. Measured annual net surface mass balances of glaciers in Alaska, the Canadian Arctic, Iceland and Svalbard for 2007-2008, for the Canadian Arctic for 2008-2009. Mass balance data for glaciers in Alaska, Svalbard, and Iceland are from the World Glacier Monitoring Service; those for Arctic Canada were supplied by D. Burgess and J. G. Cogley). The mass balance of all Gulf of Alaska glaciers for 2007-2008 is derived from GRACE satellite gravity measurements (pers. comm. from S. Luthcke and A. Arendt).

Given the small number of both "mass balance" glaciers and situ meteorological measurements in the glaciated regions of the Arctic, we use data from the NCEP/NCAR Reanalysis to characterize climatic conditions and likely trends in mass balance in these regions. Here, we focus on winter (September-May) snowfall for 2008-9 and 2009-10, and summer (JJA) temperatures in the lower troposphere (700 hPa) for 2009 and 2010 (Fig. G1). Relative to the average for 1948-2008, winter precipitation in 2008-9 was relatively high over southeast Alaska and Iceland, and below average in southwest Alaska and southeast Svalbard. 2009 summer temperatures were unusually warm over southern Alaska, the Canadian Arctic and Svalbard, and unusually cool over Novaya Zemlya and Severnaya Zemlya. These patterns lead us to expect negative glacier mass balances (mass loss) in the Canadian high Arctic and, to a lesser extent southern Alaska and Svalbard in 2008-9, and perhaps near neutral or slightly positive balances (mass gain) in Iceland. Thus 2007-08 and 2008-09 extend a period of increasingly negative annual balances in Arctic Canada that began in 1987.

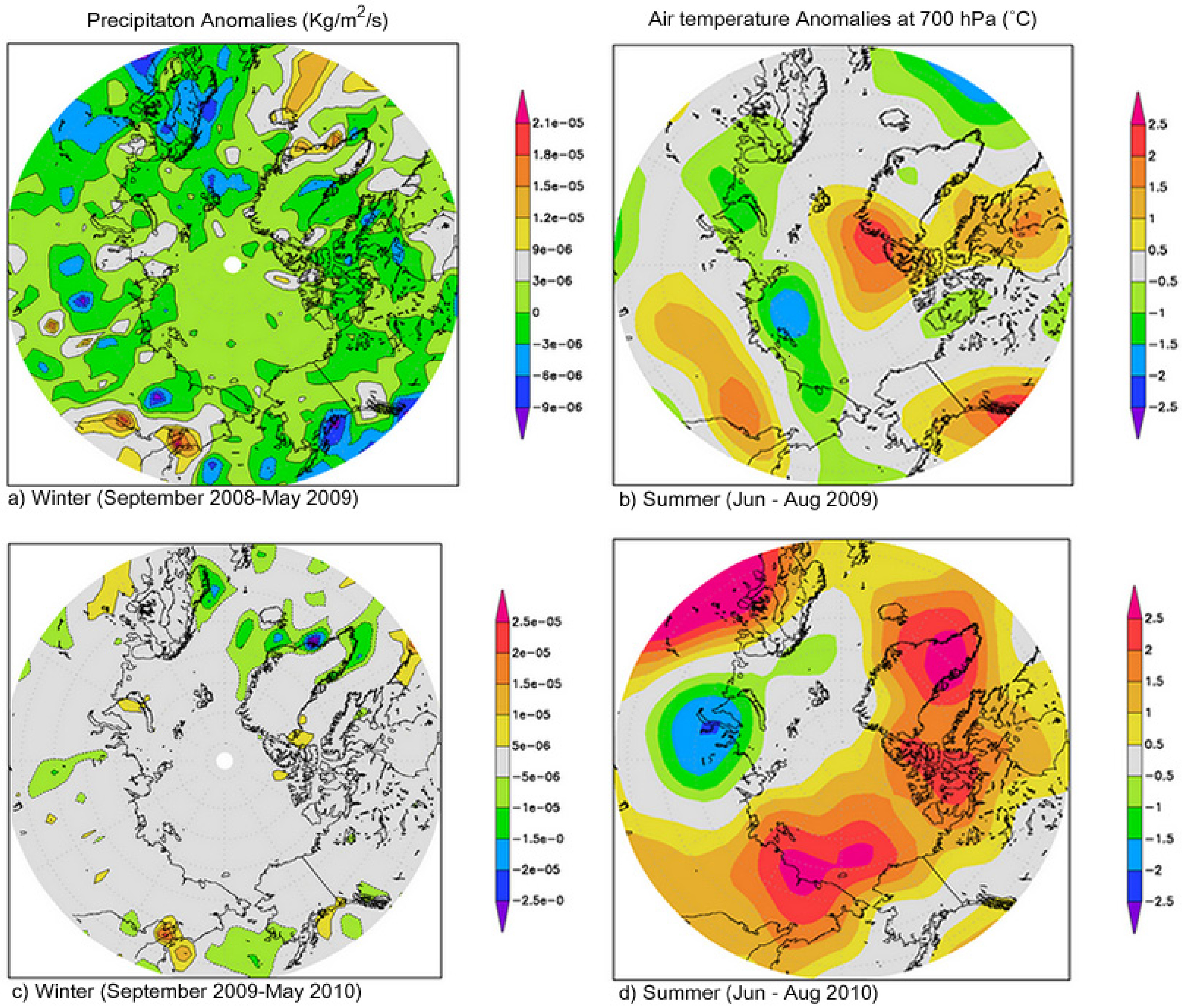

Figure G1. Anomalies (relative to 1948-2008 climatology) in: (a, top, left) winter (September 2008-May 2009) precipitation (Kg/m^2/s), and (b, top, right) summer (June-August) 2009 air temperature (˚C) at 700 hPa, (c, bottom, left) as (a), for September 2009 - May 2010, (d, bottom, right), same as (b) for June-August 2010.

To provide an independent check on the reliability of the data from climate reanalysis, we used data from the QuikSCAT satellite to determine the length of the summer melt season on larger ice caps across the Arctic (Table G2; Fig. G2). We expect that warmer summers will be associated with longer melt seasons. In 2009, melt seasons were longer than the 2000-2004 average in the Canadian high Arctic (especially on northern Ellesmere Island and Axel Heiberg Island) and Svalbard, and appreciably shorter than the average on Novaya Zemlya and Severnaya Zemlya. This is consistent with the distribution of summer air temperature anomalies from climate reanalysis. However, although summer air temperatures on Baffin Island were above the 1948-2008 average, melt season durations were shorter than the 2000-2004 average. This apparent anomaly probably arises because summers during the 2000-2004 period in this region were generally warmer than the 1948-2008 mean. The demise of QuikSCAT in October 2009 means that we are unable to determine the length of the 2010 Arctic melt season using this data source.

Region	Sub-Region	Latitude (N)	Longitude (E)	JJA 700 hPa T Anomaly	2009 Rank	Sep-May Ppt Anomaly	2009 Rank	Melt Onset Anomaly	Freeze-up Anomaly	Melt Duration Anomaly
				(deg C)	(/62)	(mm)	(/61)	days	days	days
Arctic Canada	N. Ellesmere Island	80.6 - 83.1	267.7 - 294.1	2.05	3	14.0	10	12.7	9.5	7.0
	Axel Heiberg Island	78.4 - 80.6	265.5 - 271.5	1.60	7	28	4	6.2	5.7	9.0
	Agassiz Ice Cap	79.2 - 81.1	278.9 - 290.4	1.66	8	5.5	19	19.2	14.6	5.4
	Prince of Wales Icefield	77.3 - 79.1	278 - 284.9	1.16	11	10.6	13	7.3	5.7	3.8
	Sydkap	76.5 - 77.1	270.7 - 275.8	1.20	11	-39.2	49	4.5	3.8	2.0
	Manson Icefield	76.2 - 77.2	278.7 - 282.1	1.15	11	-51.7	51	-1.2	0.5	2.9
	Devon Ice Cap	74.5 - 75.8	273.4 - 280.3	0.90	16	-8	32	1.4	-2.0	4.7
	North Baffin	68 - 74	278 - 295	1.02	11	-0.9	25	1.1	-28.5	-9.9
	South Baffin	65 - 68	290 - 300	1.06	9	20.4	18	3.9	-12.6	-4.9
Eurasian Arctic	Severnaya Zemlya	76.25 - 81.25	88.75 - 111.25	-0.91	52	45.6	9	-2.3	29.3	-1.0
	Novaya Zemlya	68.75 - 78.75	48.75 - 71.25	-0.94	50	34.1	15	19.6	-12.9	-8.4
	Franz Josef Land	80 - 83	45 - 65	0.10	30	30.1	14	4.7	-8.9	-4.2
	Svalbard	76.25 - 81.25	8.75 - 31.25	0.46	18	-49.2	47	4.5	3.8	2.0
	Iceland	63 - 66	338 - 346	-0.09	37	258.6	3	2.7	14.6	-1.2
Alaska	SW Alaska	60 - 65	210 - 220	1.77	2	29.1	25	-10.7	3.0	0.1
	SE Alaska	55 - 60	220 - 230	1.92	3	167.4	9	*	*	*

Table G2. Summer (June–August) 2009 700 hPa air temperature and winter (September 2008–May 2009) precipitation anomalies (relative to 1948-2008 climatology from the NCEP/NCAR Reanalysis) for major glaciated regions of the Arctic (excluding Greenland). For ranks, 1 = year with highest summer temperature and winter precipitation. Anomalies in melt onset and freeze-up dates and summer melt duration (days) (relative to 2000-2004 climatology) are derived from QuikScat V2 enhanced resolution scatterometer data. For melt season timing, negative anomalies indicate an earlier than normal date.

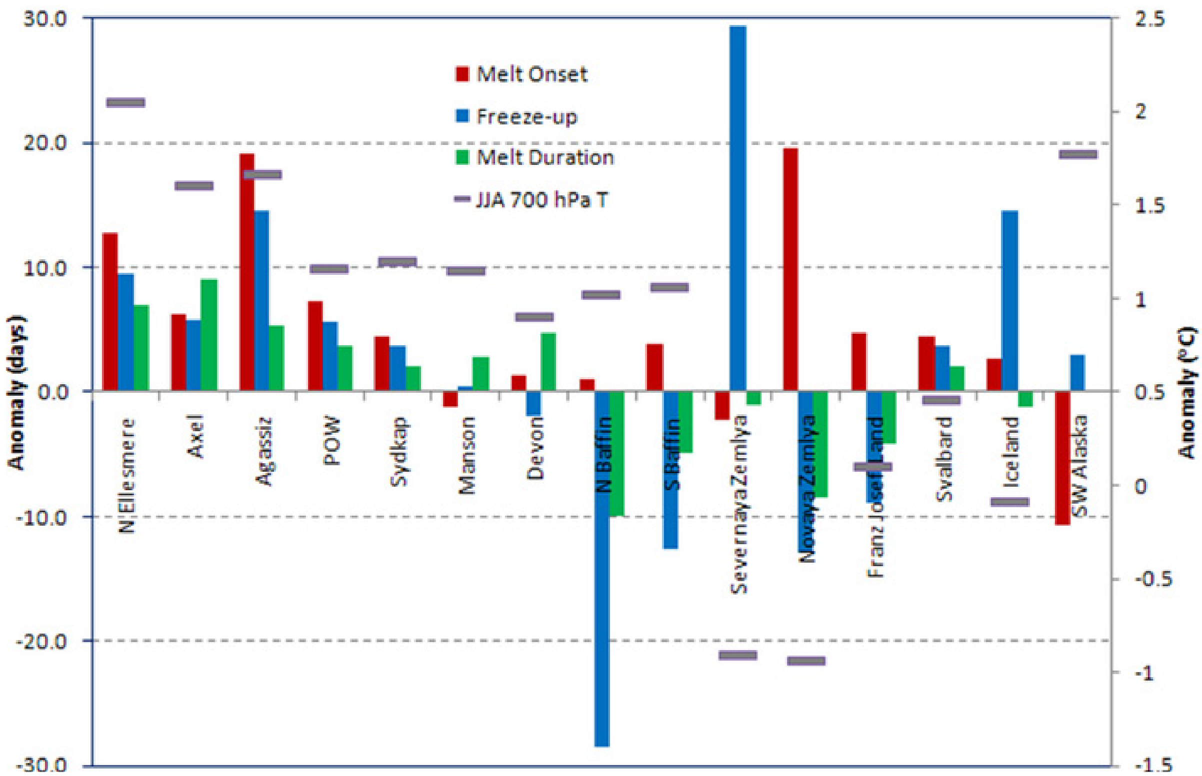

Figure G2. Anomalies in 2009 melt season duration and the dates of melt onset and freeze-up (relative to 2000-2004 climatology) derived from SeaWinds scatterometer on QuikScat, and anomalies in summer (June-August) 2009 air temperature (K) at 700 hPa in the NCEP/NCAR Reanalysis relative to a 1948-2008 climatology.

In 2009-10, winter precipitation was above average over Labrador, parts of coastal southern Alaska and Novaya Zemlya, and below average over western Iceland. Summer temperatures in 2010 were unusually warm over Iceland and the Canadian Arctic, but cooler than normal over Novaya Zemlya. On the basis of these climate conditions, it seems likely that the 2009/10 mass balances will have been anomalously positive (relative to 1948-2008) in southern Alaska, Labrador and Novaya Zemlya, but anomalously negative in the Canadian high Arctic and Iceland.

The recent period of warm summers and more negative mass balances in the Canadian high Arctic has been associated with continued breakup of the floating ice shelves that fringe northern Ellesmere Island. This phase of breakup began in 2002, and there were major calving events in 2005 and 2008. In 2010, large new fractures were first detected in the Ward Hunt Ice Shelf in Radarsat-2 images from 7 and 14 August, and breakup of the eastern part of the ice shelf was clearly underway in a MODIS image from 18 August (Fig. G3). By the end of August, some 65-70 km^2 of the ice shelf had been lost. Meanwhile, fragments of the ice islands that calved from the Ayles, Serson, Peterson, Ward Hunt and Markham ice shelves in 2005 and 2008 have drifted into the Canada Basin and the Sverdrup and Queen Elizabeth Islands and are beginning to enter the Northwest Passage via Barrow Strait.

Figure G3. MODIS image from 18 August 2010 showing the breakup of the Ward Hunt Ice Shelf, Ellesmere Island, in the region to the east of Ward Hunt Island (circled). Image from NASA.

References

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