Arctic Report Card: *Update for 2010*

Tracking recent environmental changes

Return to previous Arctic conditions is unlikely

Record temperatures across Canadian Arctic and Greenland, a reduced summer sea ice cover, record snow cover decreases and links to some Northern Hemisphere weather support this conclusion


Arctic Report Card 2010

🟥 Atmosphere 🟨 Biology 🟥 Greenland
🟥 Sea Ice 🟨 Ocean 🟨 Land

Red boxes: Consistent evidence of warming.
Yellow boxes: Many indications of warming.

Atmosphere
Arctic climate is impacting mid-latitude weather, as seen in Winter 2009-2010

Sea Ice
Summer sea ice conditions for previous four years well below 1980s and 1990s

Ocean
Upper ocean showing year-to-year variability without significant trends

Land
Low winter snow accumulation, warm spring temperatures lead to record low snow cover duration

Greenland
Record setting high temperatures, ice melt, and glacier area loss

Biology
Rapid environmental change threatens to disrupt current natural cycles

October 2010

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Oct 13, 2010

Executive Summary

October 19, 2010

Overview

The Arctic Report Card (www.arctic.noaa.gov/reportcard/) tracks recent environmental changes throughout the Arctic, and is updated annually. In 2010, it is clear that the Arctic is experiencing the impacts of a prolonged and amplified warming trend, highlighted with many record-setting events. Not surprisingly, the impact of this warming is most evident in the dramatic losses that have been observed in the ice covers that define the region. Since the loss of these ice covers serves to further feed the warming trend, the expectation is that warming will continue. This makes it increasingly unlikely (at least for the foreseeable future) that the Arctic will return to conditions that were considered normal in the later part of the 20th century. Instead, it is very likely that Arctic climate warming will continue and we will continue to see records set in years to come.

Highlights for 2010

In 2010, there was continued widespread and, in some cases, dramatic effects of a warming Arctic, where deviations from the average air temperature are amplified by a factor of two or more in the Arctic relative to lower latitudes. As the air temperature increases, ice (which presents a bright, white, highly reflective surface) melts, revealing darker ocean and land surfaces that absorb more solar energy during a summer season when the sun never sets. This causes more heating, which causes more melting, continuing a cycle that contributes to *Arctic amplification*. In 2010, there were some dramatic examples of the effects of this cycle.

Record warm air temperatures were observed over Greenland in 2010. This included the warmest year on record for Greenland's capital, Nuuk, in at least 138 years. The duration of the melt period on Greenland's inland ice sheet was exceptional, being 1 month longer than the average over the past 30 years, and led to an extended period of amplified summer melt. All of the additional melt water very likely contributing to a faster rate of crevasse widening. Glacier loss along the Greenland margins was also exceptional in 2010, with the largest single glacier area loss (110 square miles, at Petermann glacier) equivalent to an area four times that of Manhattan Island. There is now no doubt that Greenland ice losses have not just increased above past decades, but have accelerated. The implication is that sea level rise projections will again need to be revised upward.

The record warm air temperature in 2010 extended over the Canadian Arctic. Coupled with a longer melt season, these conditions caused a continued increase in the rate of ice mass loss from other smaller glaciers and ice caps in the Canadian Arctic.

The combination of warm spring air temperatures and low winter snow accumulation led to a new record minimum in springtime snow cover duration over the Arctic. The warming air temperatures also played a major role in the observed increases in permafrost temperatures around the Arctic rim, the increase in river discharge to the Arctic Ocean, and the increase in the greenness of Arctic vegetation.

The September 2010 Arctic sea ice extent was the third smallest of the past 30 years. This continues an ongoing trend, with the four smallest September ice extents having occurred in the past four years. Eight of the ten lowest summer minimums have occurred in the last decade. The amount of older, thicker multiyear ice was the third smallest ever, and there was a notable loss of multiyear in the Beaufort Sea, north of Alaska. Looking at the geographical distribution of ice extent we see that both the Northern Sea Route and the Northwest Passage were ice-free in September.

The changes in the extent and duration of the sea ice cover are also strongly linked to changes in the Arctic Ocean surface temperatures. Observations show that the distribution of summer surface temperatures reflects the speed and location of the retreat of the summer sea ice cover.

It is also apparent that changes in sea ice conditions and, more broadly, changes in the physical environment are impacting local populations and ecosystems. The biological essays in the 2010 Arctic Report Card highlight the inherently fluctuating nature of Arctic ecosystems. For instance, Barents Sea harvested fish stocks continue to fluctuate, and there are indications that these changes may be linked to sea temperatures and the associated fluctuations in sea ice cover. With the expectation of continued warming air temperatures, Arctic species that have adapted to the Arctic environments are expected to be displaced by the encroachment of more southerly (sub-Arctic) species and ecosystems. Gaining a better understanding of how the Arctic's living resources are responding to these environmental changes is essential to develop effective conservation and adaptation strategies.

One final highlight from the 2010 Arctic Report Card that illustrates the impact of Arctic change on populations, is the link that scientists have identified, and are still trying to explain, between changes in the Arctic and severe cold weather in December 2009 and February 2010 in eastern North America, northern Europe and eastern Asia.

While we see somewhat direct relationships between warming and ice cover melt, it is more difficult, due to the complex nature of ecosystems, to predict and understand how these biological systems are and will respond to this amplified warming trend. This final point helps emphasize the fact that the Arctic is an inherently complicated system.

Acknowledgements

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Atmosphere

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Summary

While 2009 showed a slowdown in the rate of annual air temperature increases in the Arctic, the first half of 2010 shows a near record pace with monthly anomalies of over 4°C in northern Canada. There continues to be significant excess heat storage in the Arctic Ocean at the end of summer due to continued near-record sea ice loss. There is evidence that the effect of higher air temperatures in the lower Arctic atmosphere in fall is contributing to changes in the atmospheric circulation in both the Arctic and northern mid-latitudes. Winter 2009-2010 showed a new connectivity between mid-latitude extreme cold and snowy weather events and changes in the wind patterns of the Arctic; the so-called Warm Arctic-Cold Continents pattern.

The annual mean air temperature for 2009 over Arctic land areas was cooler than in recent years, although the average temperature for the last decade remained the warmest in the record beginning in 1900 (Fig. A.1). The 2009 average was dominated by very cold temperatures in Eurasia in February (the coldest of the decade) and December, while the remainder of the Arctic remained warm (Fig. A.2). The spatial distribution of annual temperature anomalies for 2009 has a pattern with values greater than 2.0°C throughout the Arctic, relative to a 1968–96 reference pefriod (Fig. A.3). These anomalies show the major feature of current Arctic conditions, where there is a factor of two (or more) amplification of air temperature relative to lower latitudes.

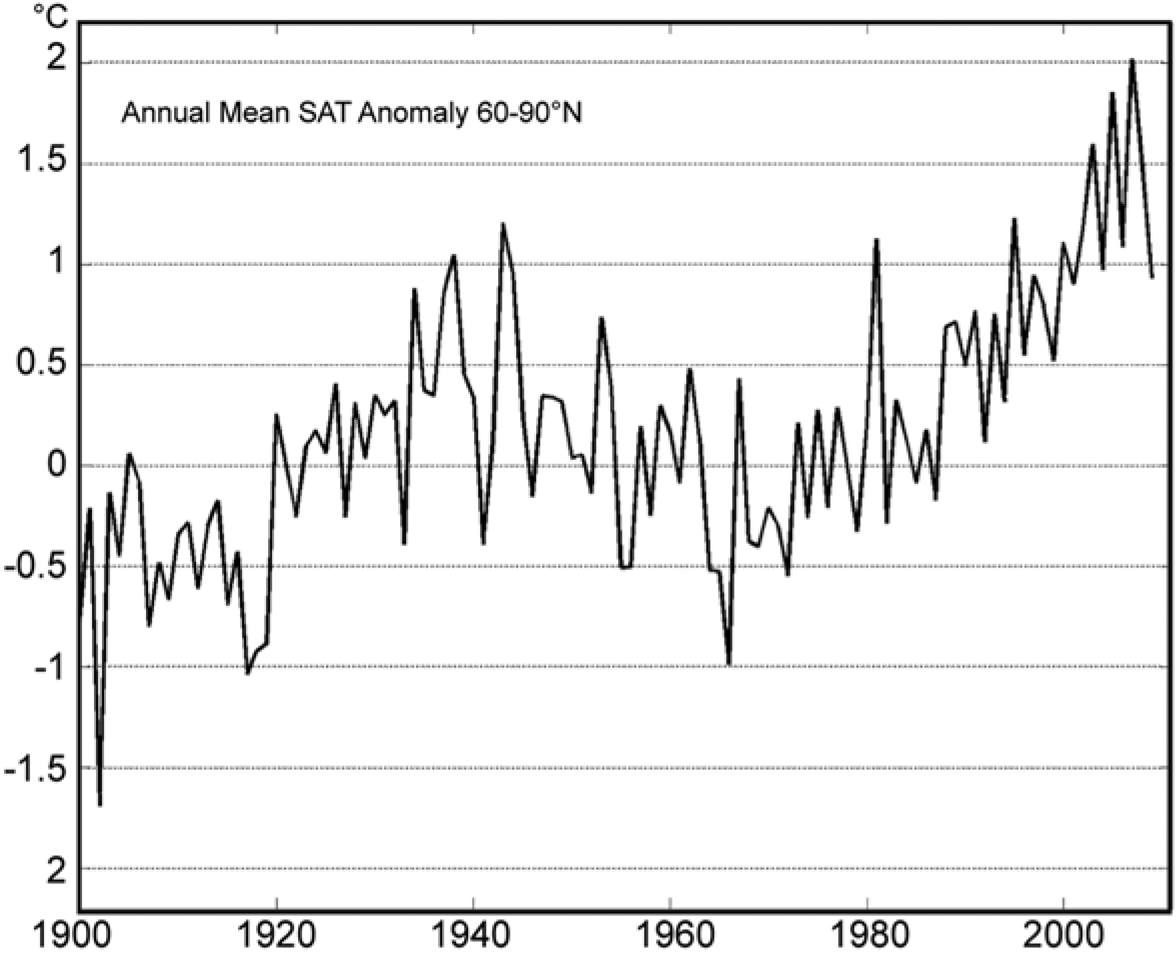

Figure A.1. Arctic-wide annual average surface air temperature anomalies relative to the 1961–90 mean, based on land stations north of 60°N from the CRUTEM 3v dataset, available online at www.cru.uea.ac.uk/cru/ data/temperature/. Note this curve does not include marine observations.

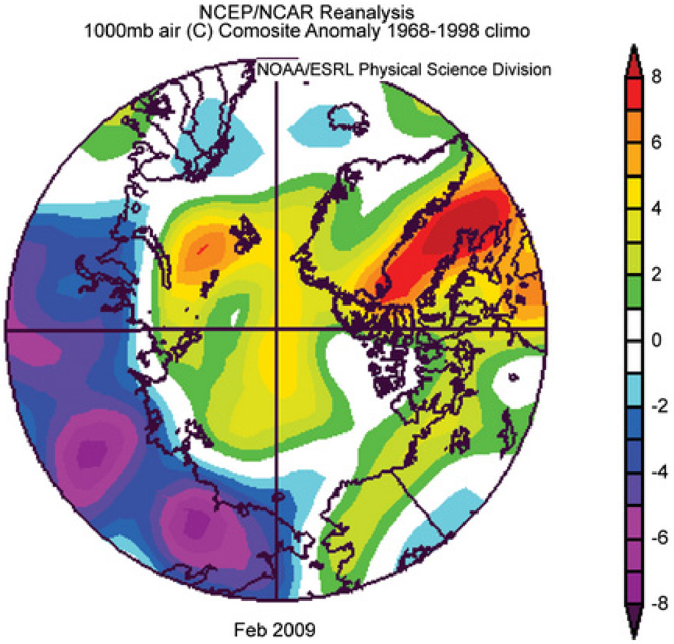

Figure A.2. Near-surface (1000 mb) air temperature in °C anomalies for February 2009. Anomalies are relative to the 1968–96 mean, according to the NCEP–NCAR reanalysis through the NOAA /Earth Systems Research Laboratory, generated online at www.cdc.noaa.gov.

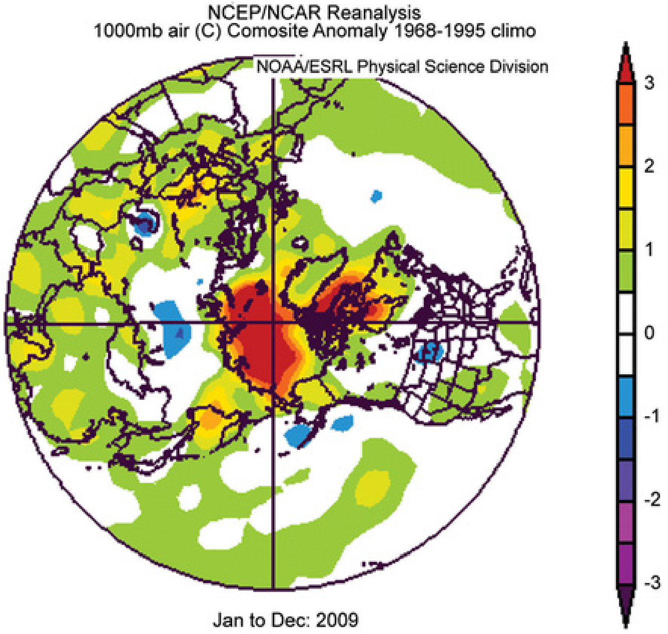

Figure A.3. Near-surface (1000 mb) annual air temperature in °C anomalies for 2009 over the northern hemisphere relative to 1968–96 mean according to the NCEP–NCAR reanalysis through the NOAA / Earth Systems Research Laboratory, generated online at www.cdc.noaa.gov. Arctic amplification of air temperature anomalies are a factor of two or more relative to lower latitudes.

The first 7 months of 2010 achieved a record high level of global mean air temperature, but this could moderate for the rest of the year due to La Niña influences. The warmest temperature anomalies for the Arctic in the first half of 2010 were over northeastern Canada (Fig. A4).

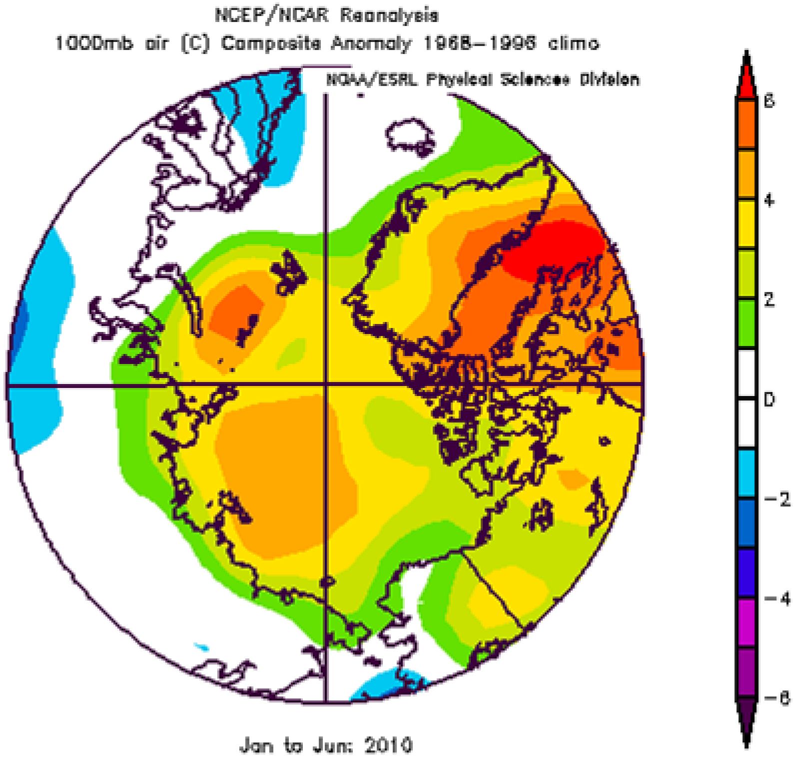

Figure A.4. Air temperature for the first half of 2010 showing anomalies of over 4°C over northeastern Canada.

While 2009 and 2010 did not meet or exceed the record minimum sea ice extent set in 2007, the summer sea ice cover remains relatively small. As noted in the Arctic sea ice section, September 2009 had the third lowest minimum sea ice extent relative to the period when observations began in 1979. The minimum sea ice extent in 2010 is similar to 2008, and lower than 2009. Nearly the same atmospheric conditions have existed in the summers of 2008, 2009 and 2010, helping to drive the characteristics of the summer sea ice season.

Summer 2007 atmospheric conditions were extraordinary and helped lead to the record low ice extent in September 2007. This involved the development of a new climatic wind pattern, the Arctic Dipole Anomaly (DA) which has southerly wind flow from the Bering Strait across the North Pole and persisted throughout the summer of 2007. In May and June of 2009 and 2010, the DA was present again, helping to initiate rapid summer ice loss. Although ice extent at the end of June 2010 was in fact slightly lower than that observed at the same time in 2007, in July the sea level pressure (SLP) pattern shifted back to a more typical low pressure region over the central Arctic Ocean (Figure A5). This shift created conditions that significantly slowed the rate of ice loss during mid-summer 2010. As a result of the increased within-summer atmospheric variability in 2009 and 2010, we did not meet or exceed the record minimum sea ice cover extent set in 2007. However, these conditions have still resulted in a four year sequence of extremely low sea ice extent years.

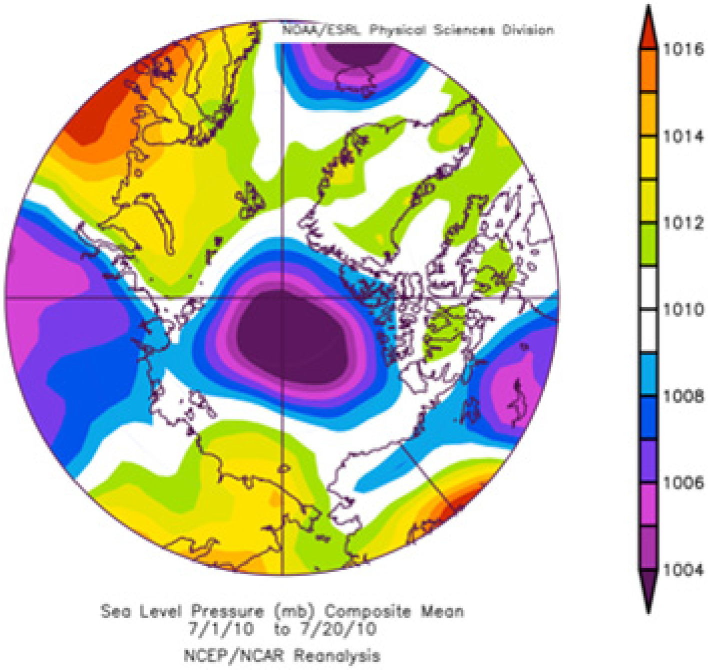

Figure A.5. Map of sea level pressures (SLP) for 1-19 July 2010 showing low SLP over the central Arctic Ocean, a pattern that brought cooler and cloudier conditions and slowed the rate of sea ice loss.

Although 2009 did not have a record sea ice minimum in September, there were still extensive regions of open water in the Chukchi, East Siberian Laptev, and Kara Seas (see sea ice section, Fig. I2), which allowed extra solar and longwave radiation to be absorbed by the ocean (see ocean section, Fig. O1). The heat accumulated in the ocean can be released back to the atmosphere the following autumn, impacting temperatures in the lower troposphere (Fig. A6) and creating consequences for regional and far field wind patterns through large scale atmospheric teleconnections patterns (Overland and Wang 2010).

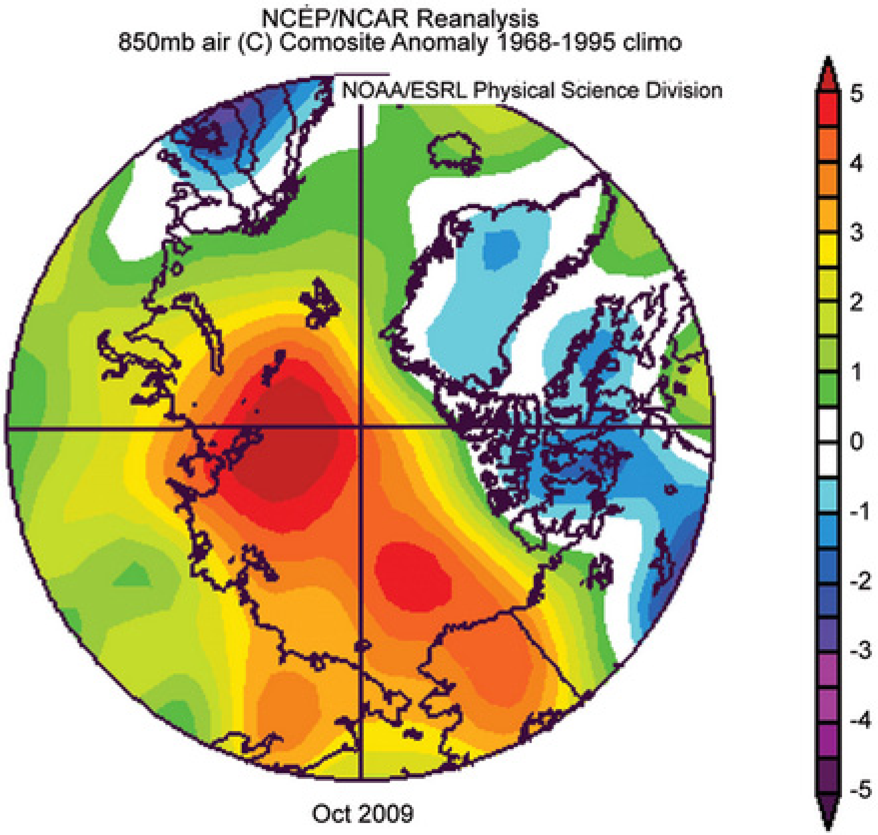

Figure A.6. Lower tropospheric (850 hPa) air temperature in °C anomalies for October 2009 relative to the 1968–96 mean according to the NCEP–NCAR reanalysis through the NOAA /Earth Systems Research Laboratory, generated online at www.cdc.noaa.gov.

Winter 2009-2010 showed a major new connectivity between Arctic climate and mid-latitude severe weather, compared to the past. Figure A7a shows normal early winter atmospheric conditions with low geopotential heights of constant pressure surfaces over the Arctic (purples). These fields indicate the tendency of wind patterns: winds tend to blow counter clockwise around the centers of lower heights, parallel to the height contours. In Figure A7a for example, winds tend to blow from west to east, thus separating cold arctic air masses from the regions further south.

In December 2009 (Fig. A7b) and February 2010 (Fig. A7c) we actually had a reversal of this climate pattern, with higher heights and pressures over the Arctic that eliminated the normal west-to-east jet stream winds. This allowed cold air from the Arctic to penetrate all the way into Europe, eastern China, and Washington DC. As a result, December 2009 and February 2010 exhibited extremes in both warm and cold temperatures with record-setting snow across lower latitudes. Northern Eurasia (north of 50° latitude to the Arctic coast) and North America (south of 55° latitude) were particularly cold (monthly anomalies of -2°C to -10°C). Arctic regions, on the other hand, had anomalies of +4°C to +12°C. This change in wind directions is called the Warm Arctic-Cold Continents climate pattern and has happened previously only three times before in the last 160 years.

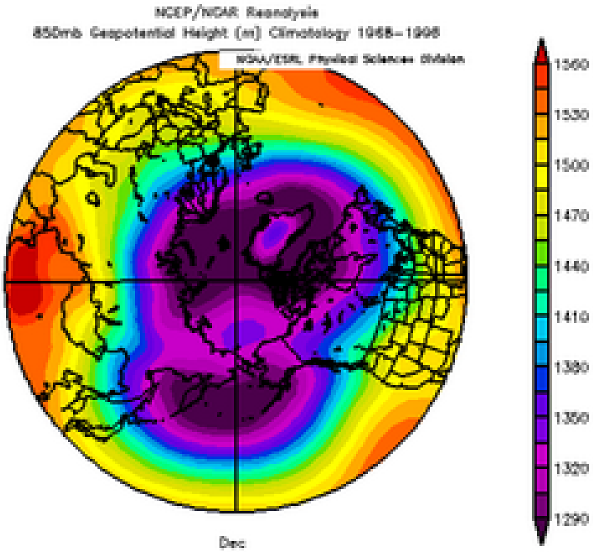

Figure A.7a. The climatological 850 mb geopotential height field for December, over the period 1968-1996. Low heights over the Arctic are representative of the polar vortex of westerly winds. Data are from the NCEP–NCAR Reanalysis through the NOAA/Earth Systems Research Laboratory, generated online at www.cdc.noaa.gov.

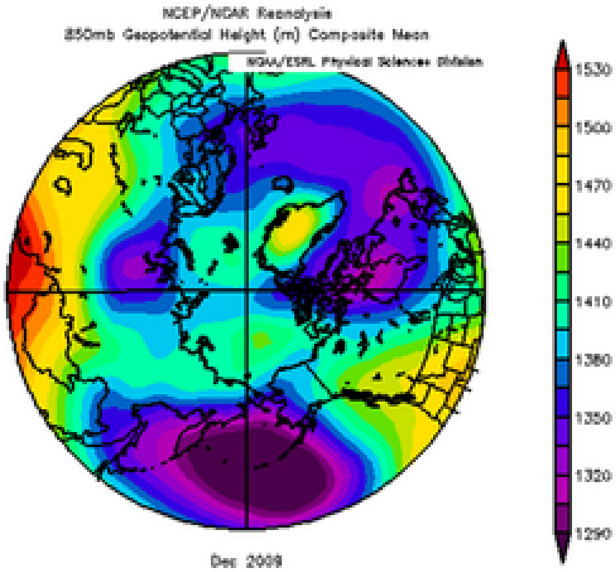

Figure A.7b. Similar to Figure 7a, but for the observed 850 mb geopotential height field in December 2009. Note the near reversal of the pattern with the maximum heights now residing over the Arctic. Air streamlines follow the height contours, showing a connection between the Beaufort Sea region and the eastern United States and that the westerly flow into Europe is strongly displaced to the south. The normal region of the Icelandic Low is at a near maximum under these conditions.

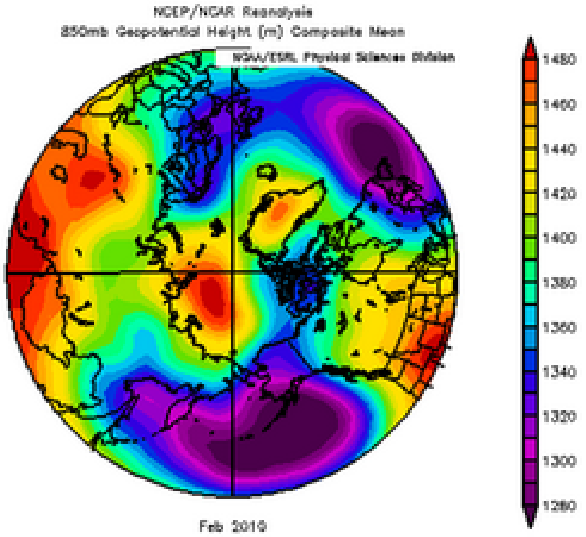

Figure A.7c. The 850 mb geopotential height field for February 2010. Again note the anomalous height maxima over the Arctic, the southward displacement of streamline into Europe and the northerly streamline into eastern Asia. Again the Icelandic Low location has a High.

While individual weather extreme events cannot be directly linked to larger scale climate changes, recent data analysis and modeling suggest a link between loss of sea ice and a shift to an increased impact from the Arctic on mid-latitude climate (Francis et al. 2009; Honda et al. 2009). Models suggest that loss of sea ice in fall favors higher geopotential heights over the Arctic. With future loss of sea ice, such conditions as winter 2009-2010 could happen more often. Thus we have a potential climate change paradox. Rather than a general warming everywhere, the loss of sea ice and a warmer Arctic can increase the impact of the Arctic on lower latitudes, bringing colder weather to southern locations.

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Sea Ice Cover

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October 15, 2010

***Monthly Sea Ice Outlook* from SEARCH/Arcus**

Highlights:

- September minimum sea ice extent is third lowest recorded
- Loss of thick multiyear ice in Beaufort Sea during summer

Sea ice extent

Sea ice extent is the primary parameter for summarizing the state of the Arctic sea ice cover. Microwave satellites have routinely and accurately monitored the extent since 1979. There are two periods that define the annual cycle and thus are of particular interest: March, at the end of winter when the ice is at its maximum extent, and September, when it reaches its annual minimum. Maps of ice coverage in March 2010 and September 2010 are presented in Figure I1, with the magenta line denoting the median ice extent for the period 1979–2000.

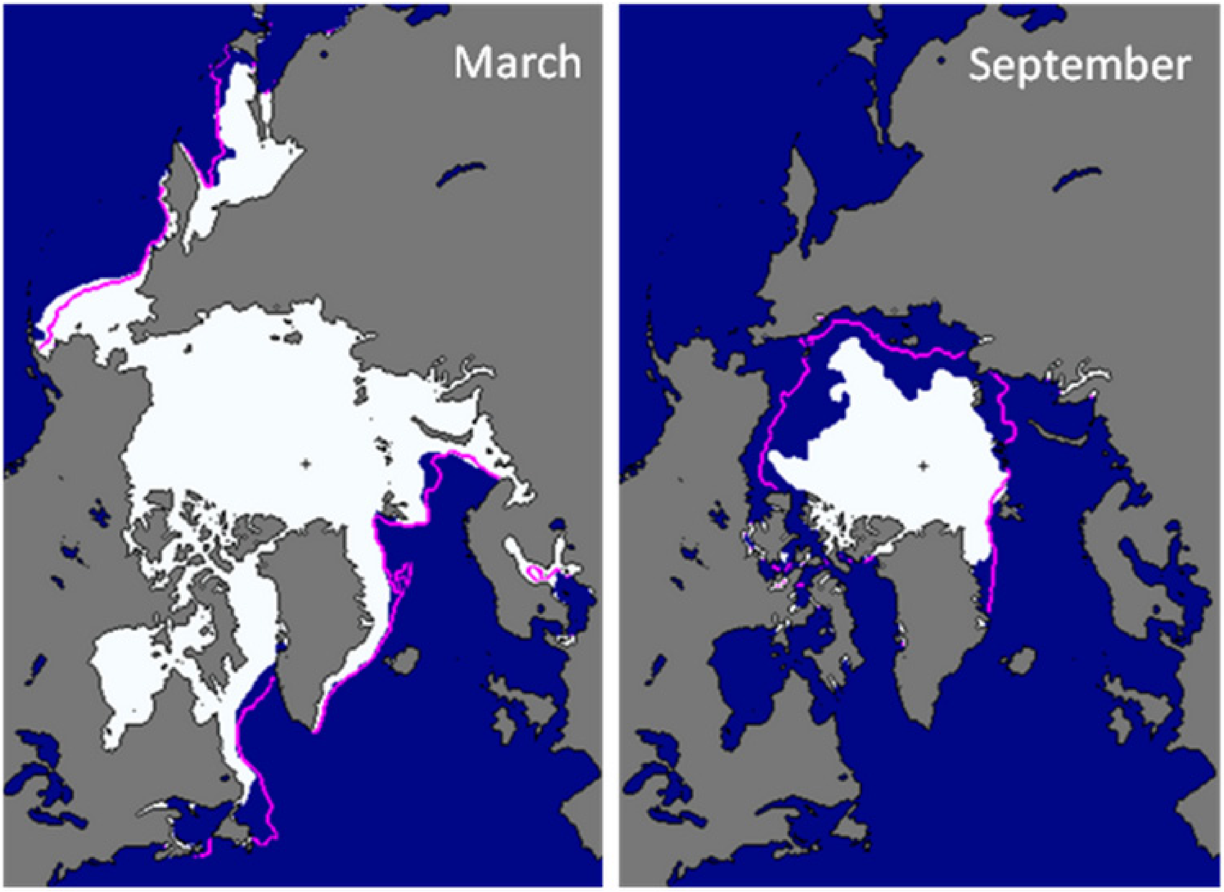

Figure I1. Sea ice extent in March 2010 (left) and September 2010 (right), illustrating the respective monthly winter maximum and summer minimum extents. The magenta line indicates the median maximum and minimum extent of the ice cover in the given month for the period 1979–2000. (Figures from the National Snow and Ice Data Center Sea Ice Index: nsidc.org/data/seaice_index.)

On September 19, 2010 sea ice extent reached a minimum for the year of 4.6 million km^2. The 2010 minimum is the third-lowest recorded since 1979, surpassed only by 2008 and the record low in 2007. Overall, the 2010 minimum was 31% (2.1 million km^2) lower than the 1979-2000 average. The last four summers have experienced the four lowest minimums in the satellite record, and eight of the ten lowest minimums have occurred during the last decade. Surface air temperatures through the 2010 summer were warmer than normal throughout the Arctic, though less extreme than in 2007. A strong atmospheric circulation pattern set up during June helped push the ice edge away from the coast. However, the pattern did not persist through the summer as it did in 2007 (see the Atmosphere Section for more details).

The March 2010 ice extent was 15.1 million km^2, about 4% less that the 1979–2000 average of 15.8 million km^2. Winter 2010 was characterized by a very strong atmospheric circulation pattern that led to warmer than normal temperatures. The yearly maximum sea ice extent occurred on March 31. This was the latest date for the maximum ice extent observed in the 30 year satellite record and was due primarily to late ice growth in the Bering Sea, Barents Sea, and the Sea of Okhotsk.

The time series of the anomalies in sea ice extent in March and September for the period 1979–2009 are plotted in Figure I2. The anomalies are computed with respect to the average from 1979 to 2000. The large interannual variability in September ice extent is evident. Both winter and summer ice extent exhibit a negative trend, with values of -2.7 % per decade for March and -11.6% per decade for September over the period 1979-2010.

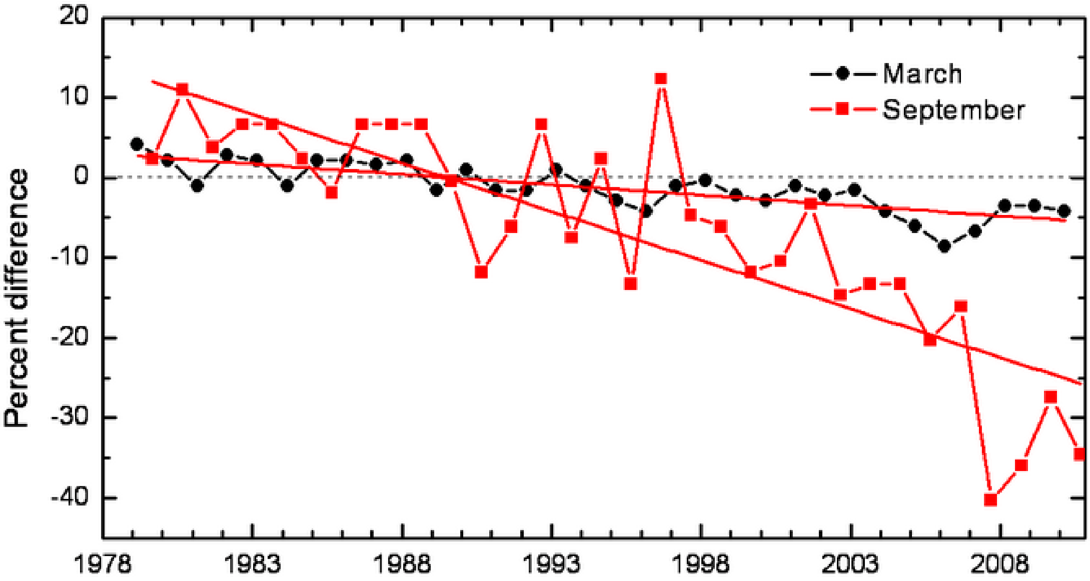

Figure I2. Time series of the percent difference in ice extent in March (the month of ice extent maximum) and September (the month of ice extent minimum) relative to the mean values for the period 1979–2000. Based on a least squares linear regression for the period 1979-2009, the rate of decrease for the March and September ice extents is –2.7% and –11.6% per decade, respectively.

Sea ice age

The age of the ice is another key descriptor of the state of the sea ice cover, since older ice tends to be thicker and more resilient than younger ice. Satellite observations can determine the age of the ice by tracking ice parcels over several years. This method has been used to provide a record of ice age since the early 1980s. Figure I3 shows sea ice age derived from tracking ice parcels for the first week of March 1988 (a), 2008 (b), 2009, (c) and 2010 (d). The panels illustrate the substantial loss in the oldest ice types within the Arctic Basin in recent years compared to the late 1980s.

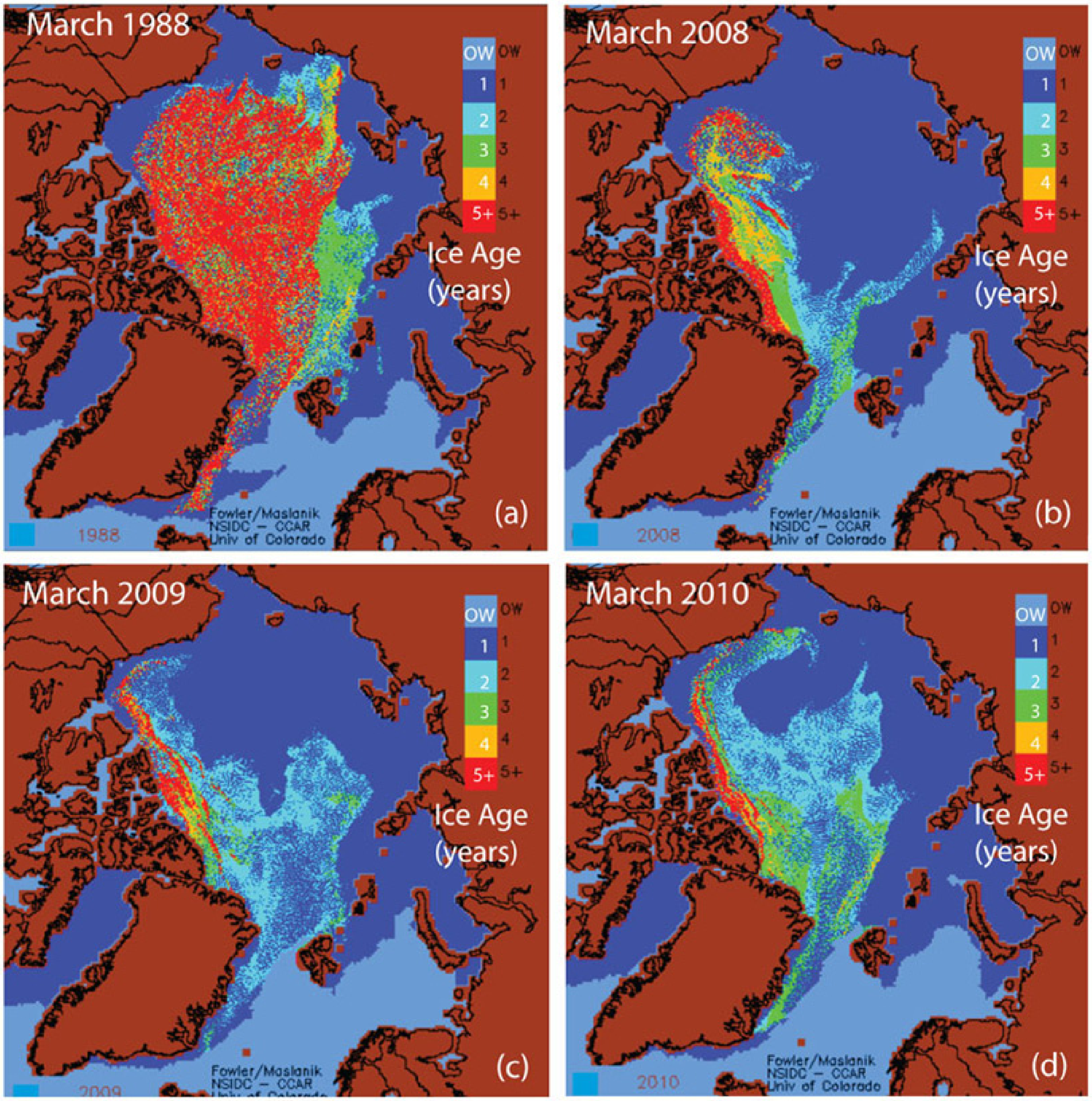

Figure I3. Sea ice age derived from drift tracking of ice floes for the first week of March in a) 1988, b) 2008, c), 2009, and d) 2010. The panels illustrate the substantial loss in the oldest ice types within the Arctic Basin in recent years compared to the late 1980s. (Figure courtesy of National Snow and Ice Data Center, J. Maslanik and C. Fowler).

Following the summer melt of 2007, there was a record low amount of multiyear ice (ice that has survived at least one summer melt season) in March 2008. Since then there has been a modest increase in multiyear ice in 2009 and again in 2010. Even with this increase, 2010 had the third lowest March multiyear ice extent since 1980. A strong atmospheric circulation pattern during winter 2010 kept most of the 2-3 year old ice in the central Arctic. However, it also moved a lobe of older ice types from the region of old thick ice north of the Canadian Archipelago into the Beaufort Sea and the Chukchi Seas. Despite being old and presumably relatively thick, this area of ice did not survive the summer melt period (Figure I4).

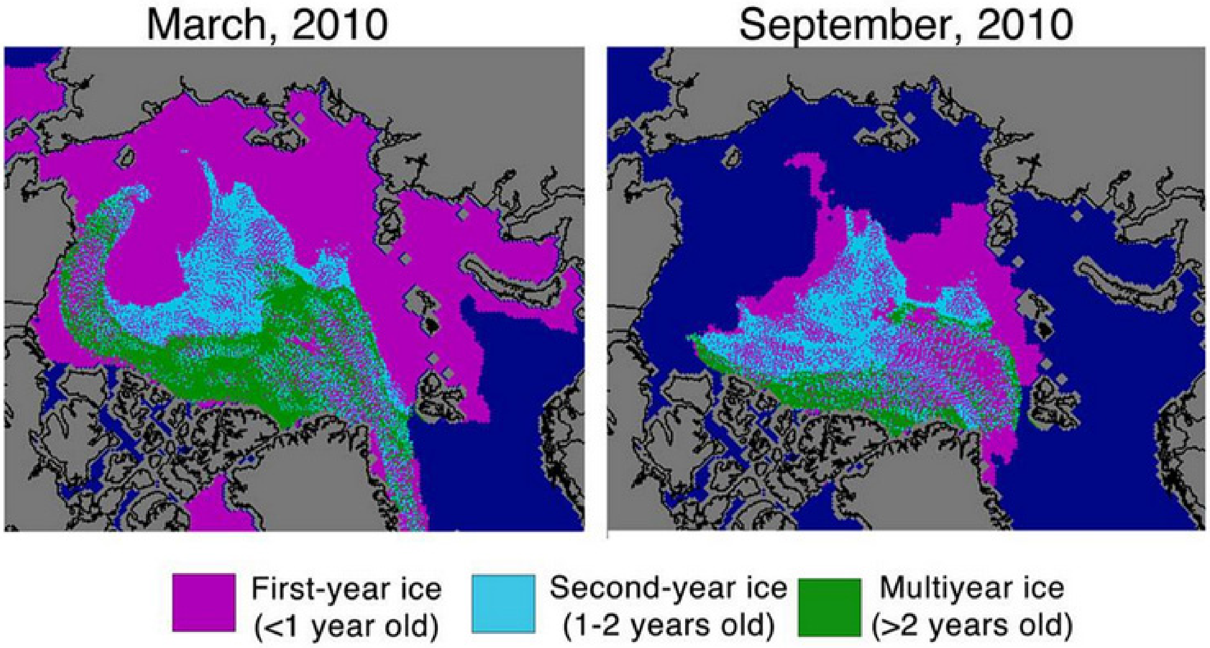

Figure I4. Map showing age of the sea ice in March and September 2010. Note the loss of multiyear ice in the Chukchi and Beaufort Seas in summer 2010. (Figure courtesy of National Snow and Ice Data Center, J. Maslanik and C. Fowler).

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Ocean

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October 18, 2010

Summary

In 2009 the annual wind-driven Arctic Ocean circulation regime was cyclonic for the first time since 1997. This regime significantly influenced the characteristics of the sea ice cover and ocean: maximum upper ocean temperatures in summer 2009 continued to decline relative to the historical extreme warm conditions observed in summer 2007; surface-layer waters in the Arctic Ocean in 2009 remained much fresher than in the 1970s and were comparable to 2008 conditions; and the sea level along the Siberian coastline significantly decreased relative to 2008. An interesting change in ocean geochemistry was observed in the Canada Basin. The combination of an increase in the amount of melt water from the sea ice cover and CO2 uptake (acidification) in the ocean caused the surface waters of the Canada Basin to become corrosive to calcifying organisms.

Circulation

In 2009, the annual wind-driven ocean circulation regime can be characterized as cyclonic (counterclockwise), with a Beaufort Gyre that is significantly reduced in strength and a Transpolar drift that is effectively nonexistent (Fig. O.1). This is the first time that an annual cyclonic circulation regime has been observed in the Arctic since 1997. The anticyclonic circulation regime that persisted through 2008 lasted at least 12 years instead of the typical 5–8 year pattern [as reported in Proshutinsky and Johnson (1997), who analyzed statistics of Arctic circulation regimes between 1948 and 1989]. The climatological seasonal cycle of the Arctic has anticyclonic ice and ocean circulation prevailing in winter and cyclonic circulation in summer. Since 2007, this seasonality has changed dramatically. In 2007, both summer and winter circulations were very strongly anticyclonic (Fig. O.1, top panels) and resulted in the unprecedented reduction of the Arctic Ocean summer sea ice cover. In 2008, the winter circulation was anticyclonic but the summer circulation was unusual with a well-pronounced Beaufort Gyre and a cyclonic circulation cell north of the Laptev Sea (Fig. O.1, middle panels). In 2009 (Fig. O.1, bottom panels), the circulation reversed relative to climatology in both winter and summer: it was anticyclonic in summer (instead of cyclonic) and cyclonic in winter (instead of anticyclonic). These wind-driven conditions significantly influenced the characteristics of the sea ice cover, oceanic currents, ocean freshwater and heat content observed during 2007–09.

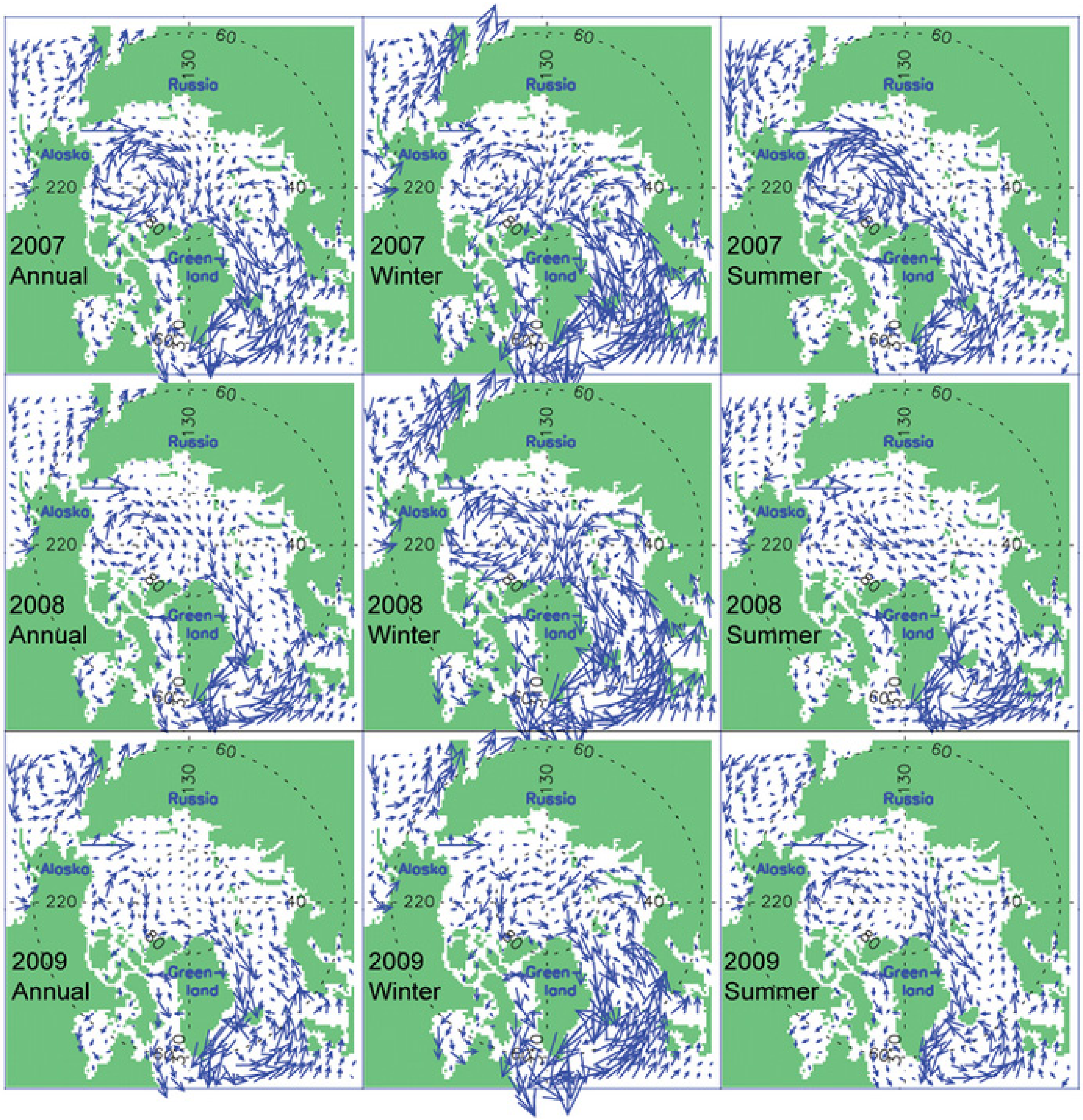

Figure O.1. Simulated circulation patterns of the upper-ocean wind-driven circulation in 2007 (top), 2008 (middle) and 2009 (bottom). Annual, winter, and summer circulations are shown in the left, center, and right panels, respectively.

Water temperature and salinity

Maximum upper ocean temperatures in summer 2009 continued to decline since the historical extreme in summer 2007 (Fig. O.2). This tendency is strongly linked to changes in the characteristics (e.g., pace and location) of the summer sea ice retreat and their effect on local atmospheric warming (Steele et al. 2010, manuscript submitted to J. Geophys. Res.). Surface warming and sea ice reduction in the Canada Basin has also been accompanied by the widespread appearance of a near-surface temperature maximum at 25–35 m depth due to penetrating solar radiation (Jackson et al. 2010). As described in the Arctic atmosphere section, the heat accumulated in the surface and near-surface layers of the ocean can be released back into the atmosphere in the fall—a cycle that is likely to influence sea ice conditions in the future.

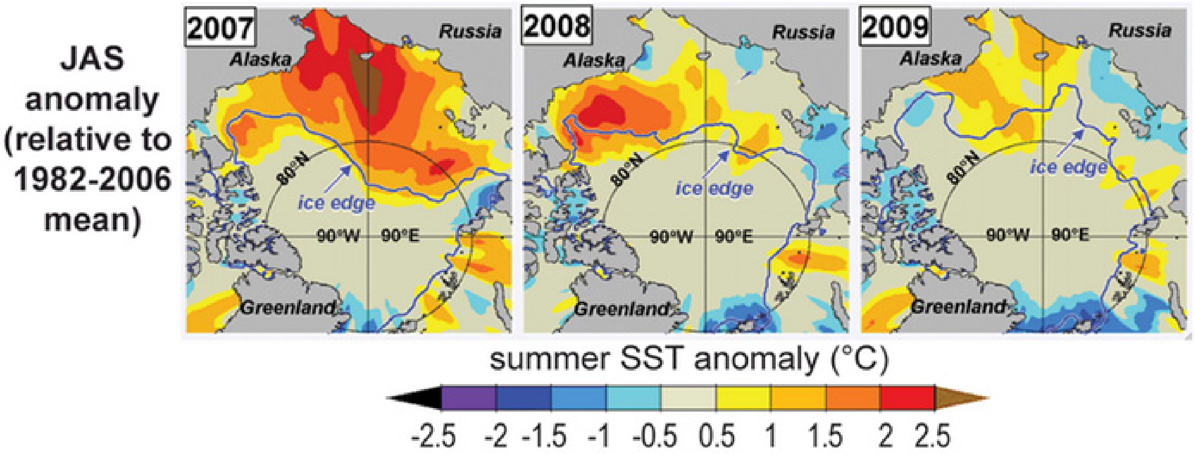

Figure O.2. Satellite-derived summer (JAS) sea surface temperature (SST) anomalies (Reynolds et al. 2002) in 2007 (left), 2008 (middle), and 2009 (right) relative to the summer mean over 1982–2006. Also shown is the Sep mean ice edge (thick blue line).

Surface-layer waters in the Arctic Ocean in 2009 remained much fresher than in the 1970s (Timokhov and Tanis 1997, 1998). In the Beaufort Gyre, freshwater content in 2009 (Fig. O.3) was comparable to the 2008 freshwater conditions, with the exception of the southwest corner of the Canada Basin. In this region, the freshwater accumulation was increased relative to 2008 by approximately 0.4 km^3 under enhanced Ekman pumping and sea ice melt in this region. In total, during 2003–09 the Beaufort Gyre (Proshutinsky et al. 2009) has accumulated approximately 5000 km^3 of freshwater (from 17 300 km^3 in 2003 to 22 300 km^3 in 2009), which is 5800 km^3 larger than climatology of the 1970s (Timokhov and Tanis 1997, 1998).

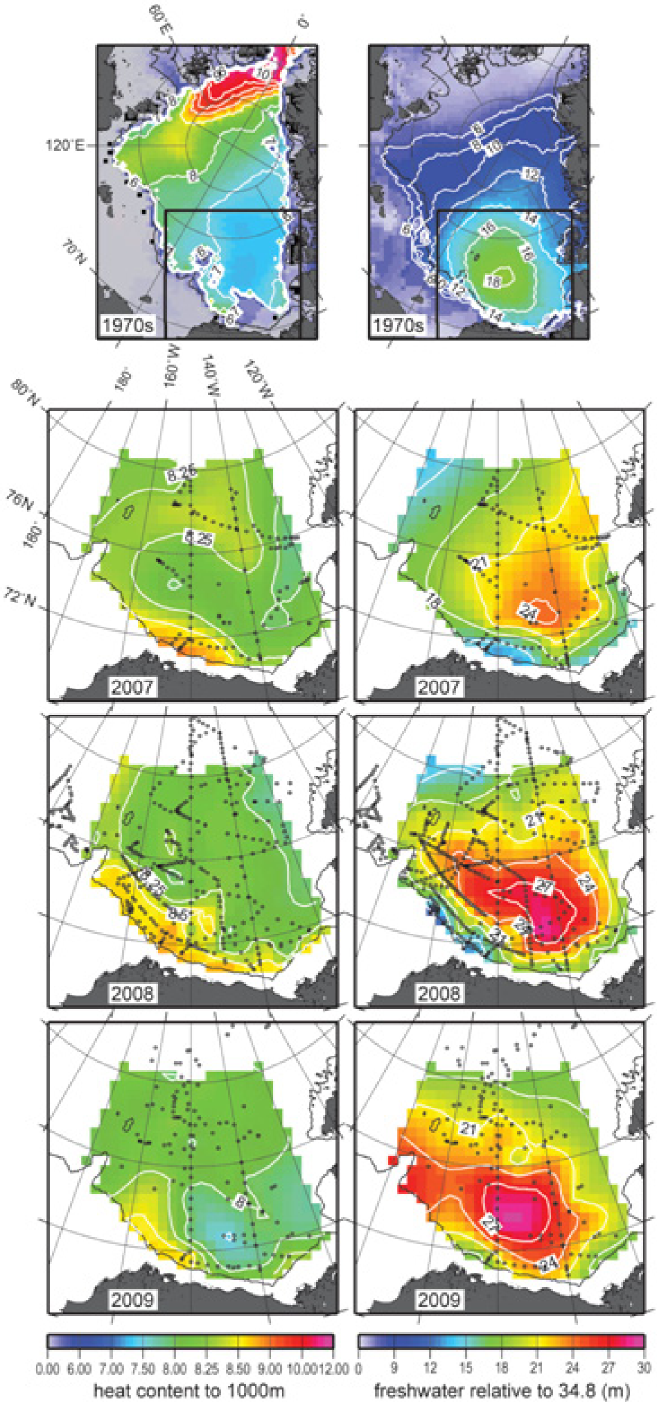

Figure O.3. Summer heat (1×10^{10} J m^{-2}) (left) and freshwater (m) content (right) in the 1970s, 2007, 2008, and 2009. The top two panels show heat and freshwater content in the Arctic Ocean based on 1970s climatology (Timokhov and Tanis 1997, 1998). The bottom six panels show heat and freshwater content in the Beaufort Gyre based on hydrographic surveys (black dots depict locations of hydrographic stations). For reference, this region is outlined in black in the top panel of each column. The heat content is calculated relative to water temperature freezing point in the upper 1000m ocean layer. The freshwater content is calculated relative to a reference salinity of 34.8.

Hydrographic surveys conducted in 2007–09 summer (Fig. O.3) in the Canada Basin indicate that in 2007 and 2008 there were two shallow temperature maximums in the upper Pacific water layer. However, in 2009, the heat content in this layer was reduced.

Atlantic Water layer maximum temperature anomalies for 2007–09 (Fig. O.4) were calculated relative to the 1970s (Timokhov and Tanis 1997, 1998; Polyakov and Timokhov 1994). The 2007–09 Atlantic Water layer data were derived from ship-based and Ice-Tethered Profiler (ITP) instruments. In 2007–09, the temperature anomalies were generally higher on the Eurasian side of the Lomonosov Ridge, reaching a maximum of up to 1.5°C along the Eurasian Basin boundaries. Warming was less pronounced in the Canada Basin. There was little to no temperature anomaly (<0.1°C) at the southeast boundary of the Canada Basin or in the basin boundary regions adjacent to Greenland and the Canadian Archipelago. Negative (cooling) temperature anomalies were detected in the vicinity of Nares Strait. Considering 2009 data alone, the warming pattern remained similar with the major difference being that maximum temperature anomalies along the Eurasian Basin boundaries were lower (<1.0°C).

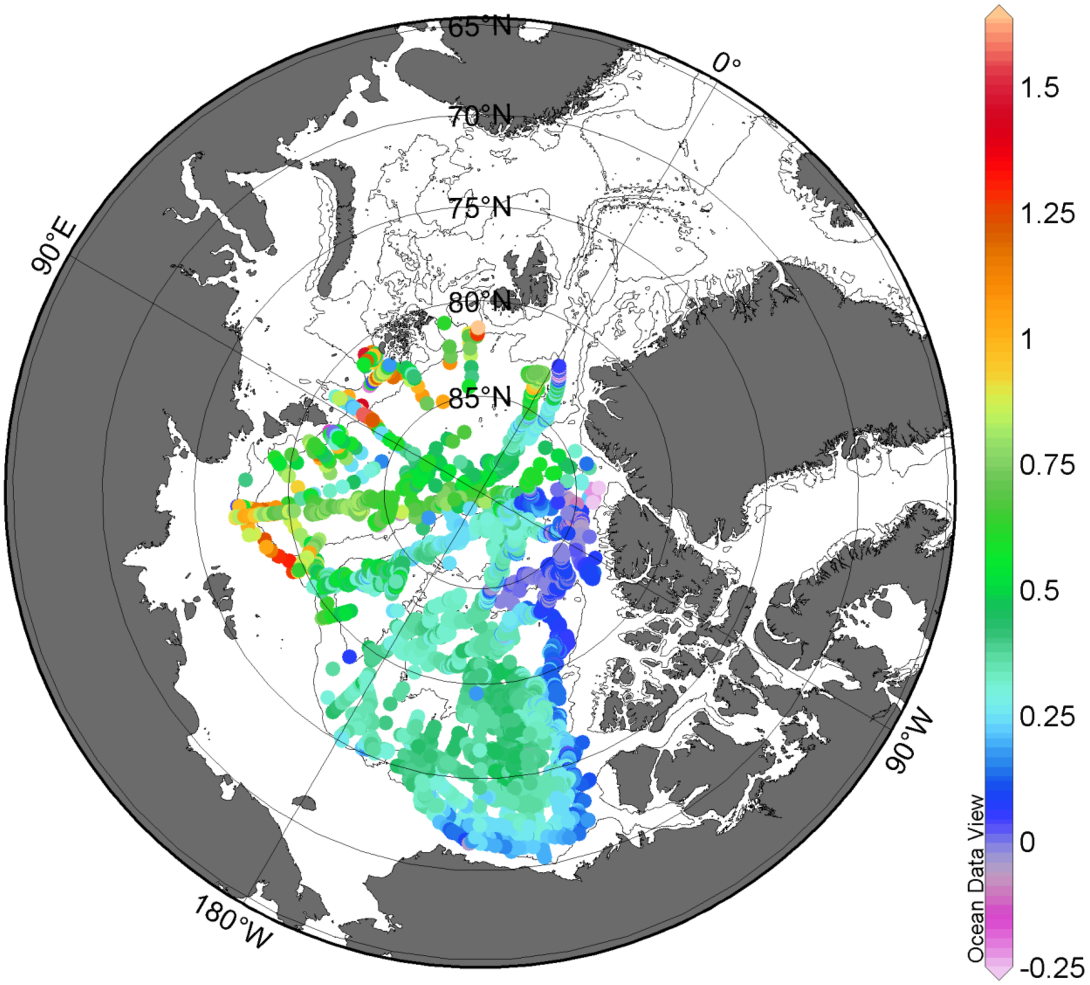

Figure O.4. 2007–09 Atlantic water layer temperature maximum anomalies relative to climatology of Timokhov and Tanis (1997, 1998). Black solid line delineates 250 and 2500 meters depth contours.

The characteristics of the Atlantic Water layer discussed above are regulated by the Atlantic water parameters in the Fram Strait (Fig. O.5), where the Atlantic water inflows to the Arctic Ocean. After reaching a maximum in 2006, the temperature of Atlantic water in Fram Strait decreased until 2008. In 2009, Atlantic water temperature and salinity in the northern Fram Strait started to rise again, returning to their long-term means. The late winter of 2008 and early spring of 2009 were also characterized by a higher Atlantic water volume inflow with the West Spitsbergen Current as compared to 2005–07 (Fig. O.5).

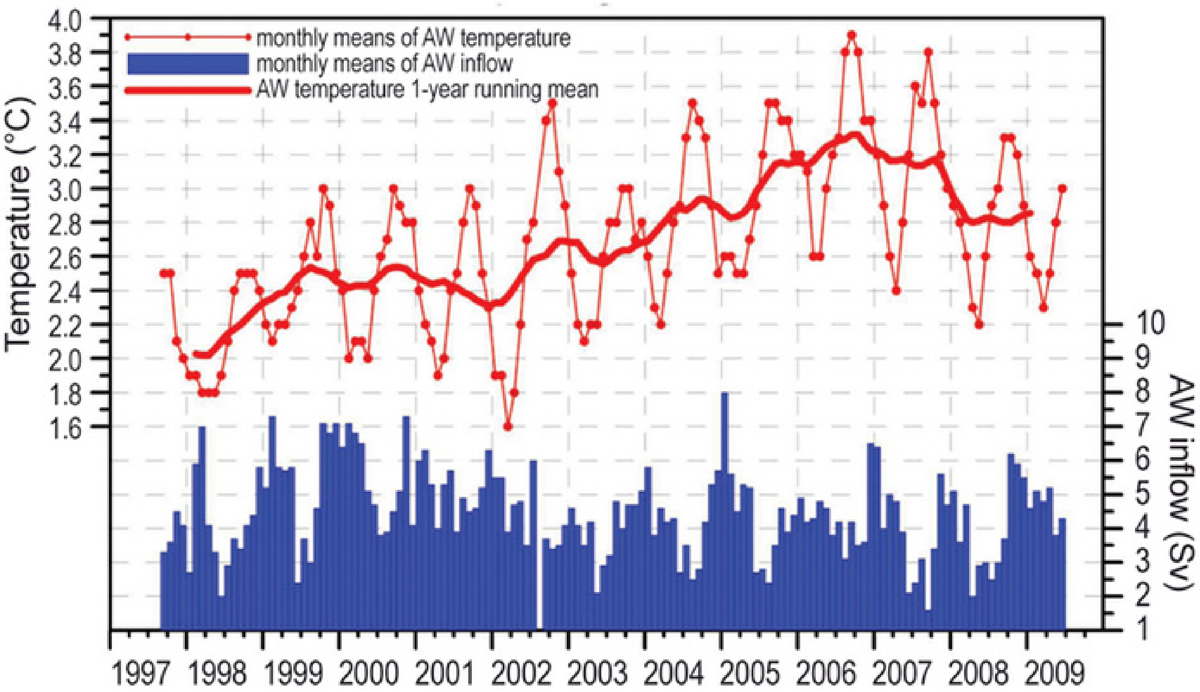

Figure O.5. Mean temperature of Atlantic water (AW, defined with TAW >1°C) and the AW volume inflow in the West Spitsbergen Current, northern Fram Strait measured by the array of moorings at 78°50'N.

The Bering Strait is another important gateway to the Arctic Ocean. Preliminary analysis of mooring data from the Bering Strait does not suggest a repeat of the very high heat fluxes from 2007 (Woodgate et al. 2010). Temperatures in 2008 were generally cooler than in 2007, reaching only 2°C–3°C in near-bottom temperature, compared to 4°C–5°C in 2007. Similarly, by the time of mooring turn-around in 2009, water temperatures were about a degree colder than the same month (August) in 2007. These cooler temperatures are more in agreement with temperatures of 2000–06 in the strait.

An interesting change in ocean geochemistry was observed in the Canada Basin in 2008 and 2009. The input of sea ice meltwater, in combination with CO2 uptake and global ocean acidification, caused the surface waters of the Canada Basin to become corrosive to calcifying organisms in the upper layer in 2008 (Yamamoto-Kawai et al. 2009). This is the first deep basin observation of aragonite undersaturation in surface waters. In 2009 the areal extent of surface waters unsaturated in aragonite, a form of calcium carbonate produced by marine organisms, increased. The increased stratification and decrease in upper-layer nutrient concentrations has also resulted in an increase in the number of picoplankton and a decrease in nanoplankton. Shifts such as these may alter the food web in the future (Li et al. 2009).

Sea level

Figure O.6 shows sea level (SL) time series from nine coastal stations in the Siberian Seas, having representative records for the period of 1954–2009 (Arctic and Antarctic Research Institute data archives). In 2009, the SL along the Siberian coastline has significantly decreased relative to 2008. This caused a slight reduction in the estimated rate of SL rise for the nine stations over the period, to 2.57 ± 0.45 mm yr^{-1} (after correction for glacial isostatic adjustment, GIA). The changing SL rise tendency may be due to the substantial change in the wind-driven ocean circulation regime (less anticyclonic, as described in section 5c1) and/or due to steric effects associated with the reduction of surface ocean warming and freshening rates (section on Water temperature and salinity, above). Ocean cooling and salinification both result in sea level decrease.

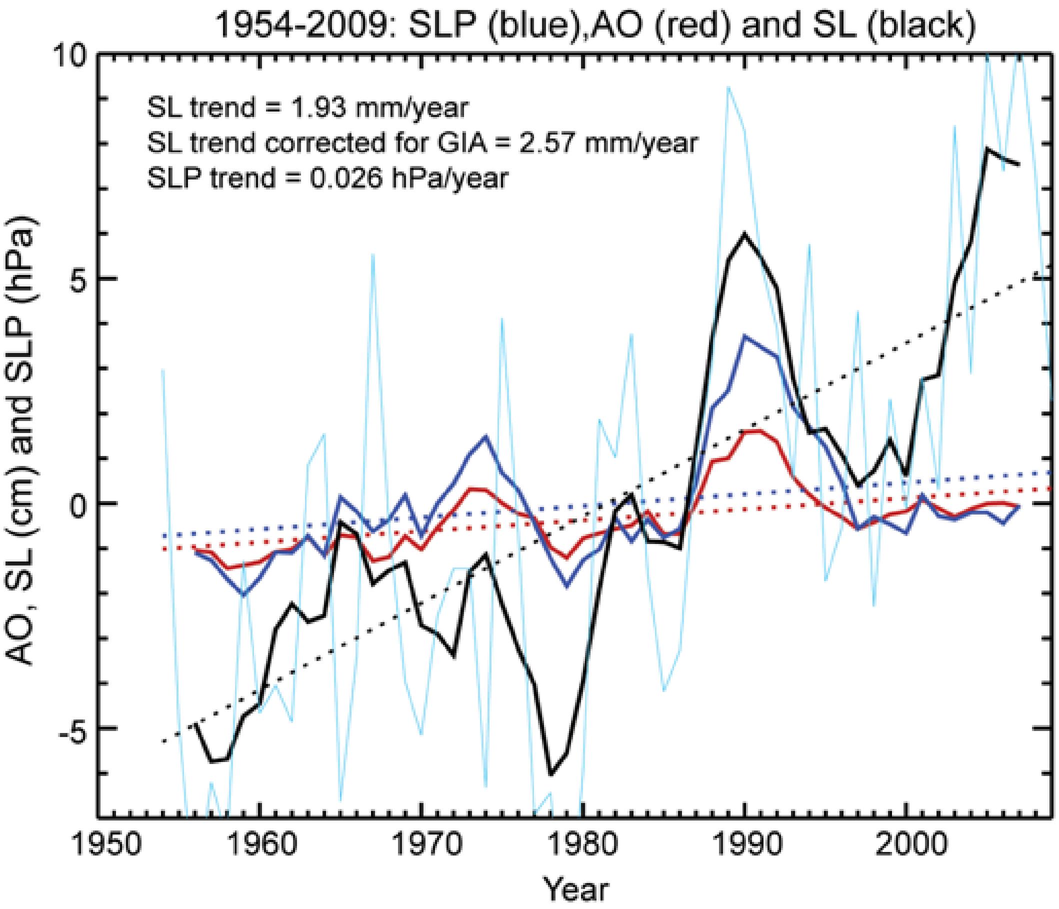

Figure O.6. Five-year running mean time series of: the annual mean sea level at nine tide gauge stations located along the Kara, Laptev, east Siberian, and Chukchi Seas' coastlines (black line); anomalies of the annual mean Arctic Oscillation (AO) Index multiplied by 3 (red line); sea surface atmospheric pressure at the North Pole (from NCAR–NCEP reanalysis data) multiplied by -1 (dark blue line); annual sea level variability (light blue line). Dotted lines depict estimated trends for SL, AO, and SLP.

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Land

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October 19, 2010

Summary

Observations of land-based changes in the Arctic cover a wide spectrum, including variations and trends in vegetation, permafrost, river discharge, snow cover, and mountain glaciers and ice caps. In general, these observations present further evidence of the impact of a general, Arctic-wide warming trend that is accompanied by high variability from year to year and region to region. They also illustrate the connectivity between various elements of the Arctic system, with conditions being linked to atmospheric circulation patterns, sea ice conditions, and ocean surface temperatures.

Highlights:

- A combination of low winter snow accumulation and warm spring temperatures created a new record low spring snow cover duration over the Arctic in 2010, since satellite observations began in 1966.
- 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.
- Observations show a general increase in permafrost temperatures during the last several decades in Alaska, northwest Canada, Siberia and Northern Europe, with a significant acceleration in the warming of permafrost at many Arctic coastal locations during the last five years.
- The greatest changes in vegetation are occurring in the High Arctic of Canada and West Greenland and Northern Alaska, where increases in greening of up to 15% have been observed from 1982 to 2008.
- In the Eurasian river drainage basins, the correlation between increased river discharge and decreased summer minimum sea ice extent (over the period 1979-2008) is greater than the correlation between precipitation and runoff, suggesting that both rivers and sea ice were responding to changes in large-scale hemispheric climate patterns.

Vegetation

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October 18, 2010

Summary

The greatest percentage greening changes are occurring in the High Arctic of Canada and West Greenland and Northern Alaska, where increases of up to 15% have been observed from 1982 to 2008. A few ground-based studies indicate that the observations of greening trends detected from space are consistent with changes detected in tundra biomass. At present it is not clear if the greening associated with disturbances (e.g. landslides, fires, thawing permafrost) has increased or if the disturbance are sufficiently large in area to contribute to the global changes.

The vegetation report in the 2009 update of the Arctic Report Card documented recent trends in tundra summer greenness and correlations with coastal sea-ice and summer land temperatures, as observed from earth-orbiting satellites. These observations of changes in vegetation were interpreted from variations in the annual maximum Normalized Difference Vegetation Index (MaxNDVI), which is an indicator of the photosynthetic capacity of the vegetation. Increases in the NDVI generally correspond to positive changes in the tundra biomass, whereas negative trends indicate a loss of green plant biomass. During the studied period of satellite observations (1982-2008) Arctic sea ice within 50-km of the coast retreated by a circumpolar average of over 25%, tundra land temperatures within the 50-km coastal strip increased an average of 5 ˚C (24% increase), and the MaxNDVI increased 5%. Absolute MaxNDVI changes were by far the greatest in the northern Alaska/Beaufort Sea area (0.09 AVHRR NDVI units or a 14% increase) (Fig. V1, left), whereas the percentage changes have been highest in the Baffin Bay, Beaufort Sea, Canadian Archipelago and Davis Strait areas (10-15% changes) (Fig. V1, right) (Bhatt et al., 2010).

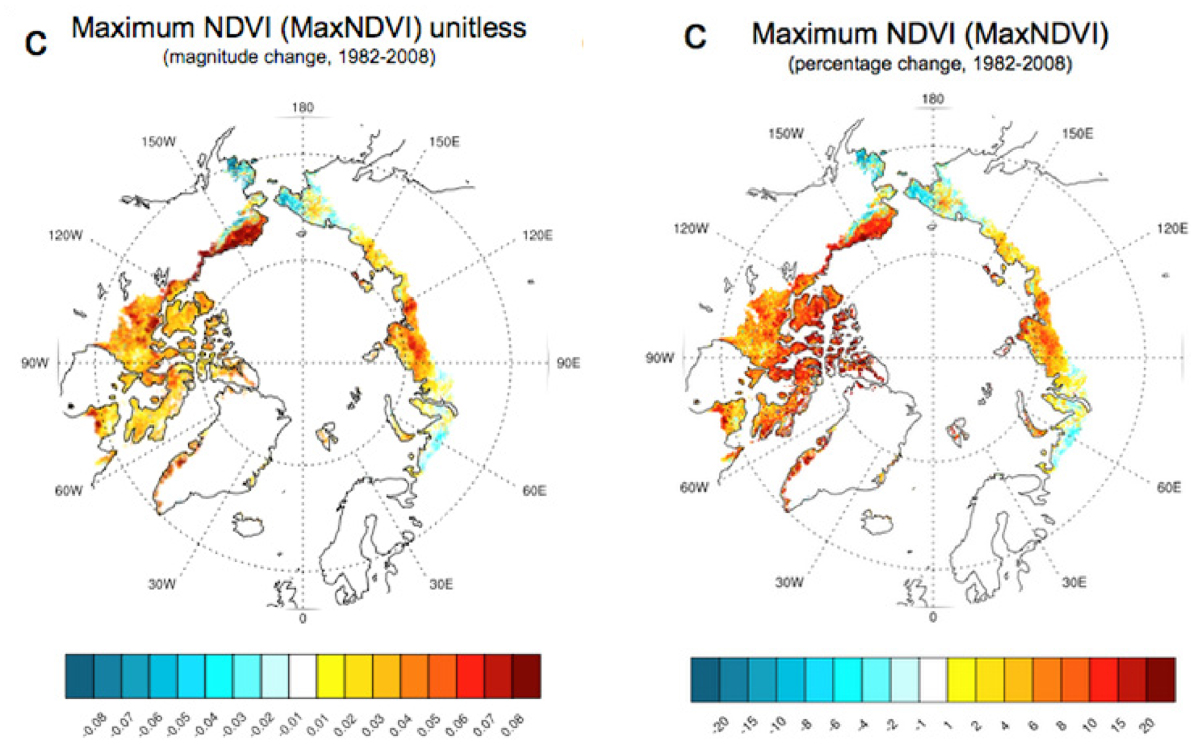

Figure V1. Magnitude (left) and percentage (right) change of maximum NDVI (MaxNDVI) from 1982 to 2008 for the circumpolar arctic tundra region. Colors show changes only within the area north of the Arctic tree line. Color scales are not linear (Bhatt et al., 2010).

The greening trends observed in the satellite data are now supported by quantitative, long-term in situ vegetation measurements from the International Tundra Experiment (ITEX) and the Back to the Future (BTF) projects. As in the satellite measurements, the most evident changes appear to be occurring first in the sparsely vegetated areas of the far North. A study of plots at Alexandra Fiord, Ellesmere Island is the first to demonstrate significant changes in above and below ground biomass over the last 25-30 years (Hill and Henry, 2010, accepted; Hudson and Henry, 2009) (Fig. V2). In addition, there has been a change in the relative abundance of species with an increase in the dominant species over this same time period. The changes in the tundra plant communities are most likely in response to the increase in air temperature over the past 35 years of between 0.6-1.0°C/decade, with the strongest increases seen in the winter temperatures. The increases in biomass also correspond with longer growing seasons, with extensions into the late summer, and with deeper active layers (depth of summer soil thawing). In another far-north Canada study, repeat photographs of permanent vegetation study plots 46 years after their initial installation near the Lewis Glacier, Baffin Island, document rapid vegetation changes along the margins of large retreating glaciers (Johnson et al., 2009; Webber and Tweedie, personal communication, 2009).

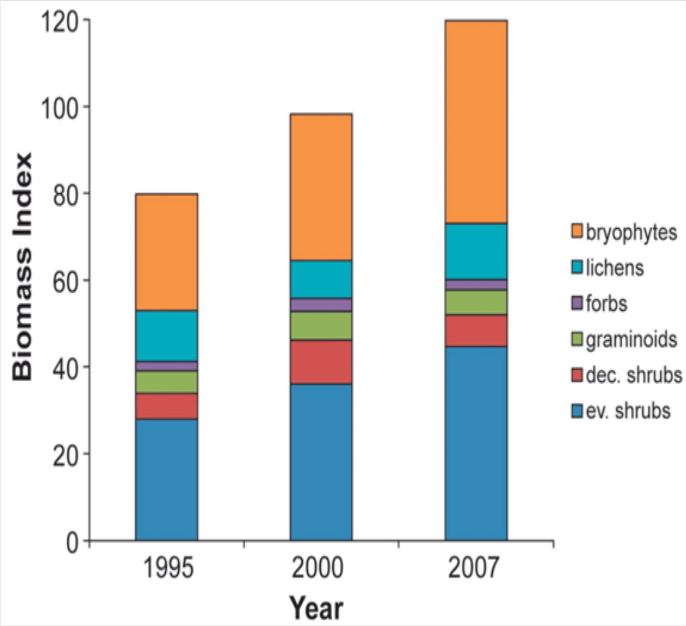

Figure V2. Above ground biomass index by plant functional type for 18 permanent vegetation plots at Alexandra Fiord, Ellesmere Island, Canada, in 1995, 2000, and 2007. Values were the mean number of living tissue hits per plot using the point intercept method. Total live vegetation, bryophytes, and evergreen shrubs increased significantly over the period at $p = 0.05$ (Hudson and Henry, 2009).

Further south, in the more lush tundra near Toolik Lake, a detailed analysis of a 22-year record (1989-2008) of tundra vegetation structure and composition from a set of 156 permanent monitoring plots indicates a general increase in above ground biomass (Gould and Mercado-Diaz, 2008). Over the last two decades the relative abundance of vascular vegetation increased by 16%, while the relative abundance of nonvascular vegetation decreased by 18%. The canopy height, as well as the extent and complexity of the canopy have been increasing over time with the amount of horizontal surface having multiple strata increasing from about 60% to 80%.

The frequencies of landslides, thermokarst features (irregular land surfaces formed in permafrost regions by melting ground ice), and fires have been noted in several areas of the Arctic (Jones et al., 2009; Kokelj et al., 2009; Lantz, 2008; Lantz and Kokelj, 2008; Walker et al., 2009; Leibman and Kizyakov, 2007; Ukraientseva, 2008). Warmer soil temperatures, thawing permafrost, more abundant water, and increased nutrients on these disturbed features result in pronounced greening.

Tundra fires have been predicted to increase with warming summer temperatures. In late summer 2007, the Anaktuvuk River fire near the University of Alaska's Toolik Lake Field Station burned almost 1000 km^2. It is the largest known fire to occur in northern Alaska and offered an opportunity for detailed analysis of the changes to the tundra energy and nutrient balance (Liljedahl et al., 2007) and spectral properties (Rocha and Shaver, 2009) . The burning itself released ~1.9M tonnes of carbon to the atmosphere, which was about 30% of the carbon stock within the vegetation and active layer of this area (M.C. Mack unpublished data).

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Permafrost

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Summary

Observations show a general increase in permafrost temperatures during the last several decades in Alaska (Romanovsky et al., 2002; Romanovsky et al., 2007; Osterkamp, 2008; Smith et al., 2010), northwest Canada (Couture et al., 2003; Smith et al., 2005 and 2010), Siberia (Oberman and Mazhitova, 2001; Oberman, 2008; Drozdov et al., 2008; Romanovsky et al., 2010a), and Northern Europe (Isaksen et al., 2000; Harris and Haeberli, 2003; Christiansen et al., 2010). During the last five years, the warming of permafrost has significantly accelerated at many Arctic coastal locations in these regions.

Most of the permafrost observatories in Alaska show a substantial warming during the 1980s and 1990s. The detailed characteristic of the warming varies between locations, but is typically from 0.5 to 2°C at the depth of zero seasonal temperature variations in permafrost (Osterkamp, 2008). However, during the last 9 years, permafrost temperature has been relatively stable on the North Slope of Alaska (Smith et al., 2010). There was even a slight decrease in the Alaskan Interior during the last 3 years. Only coastal sites in Alaska still show continuous warming (e.g. Fig. P1), especially during the last three to four years. The data from the 2010 field season may indicate that, in Alaska, the observed warming trend observed along the coast has started to propagate southward towards the northern foothills of the Brooks Range (Fig. P2).

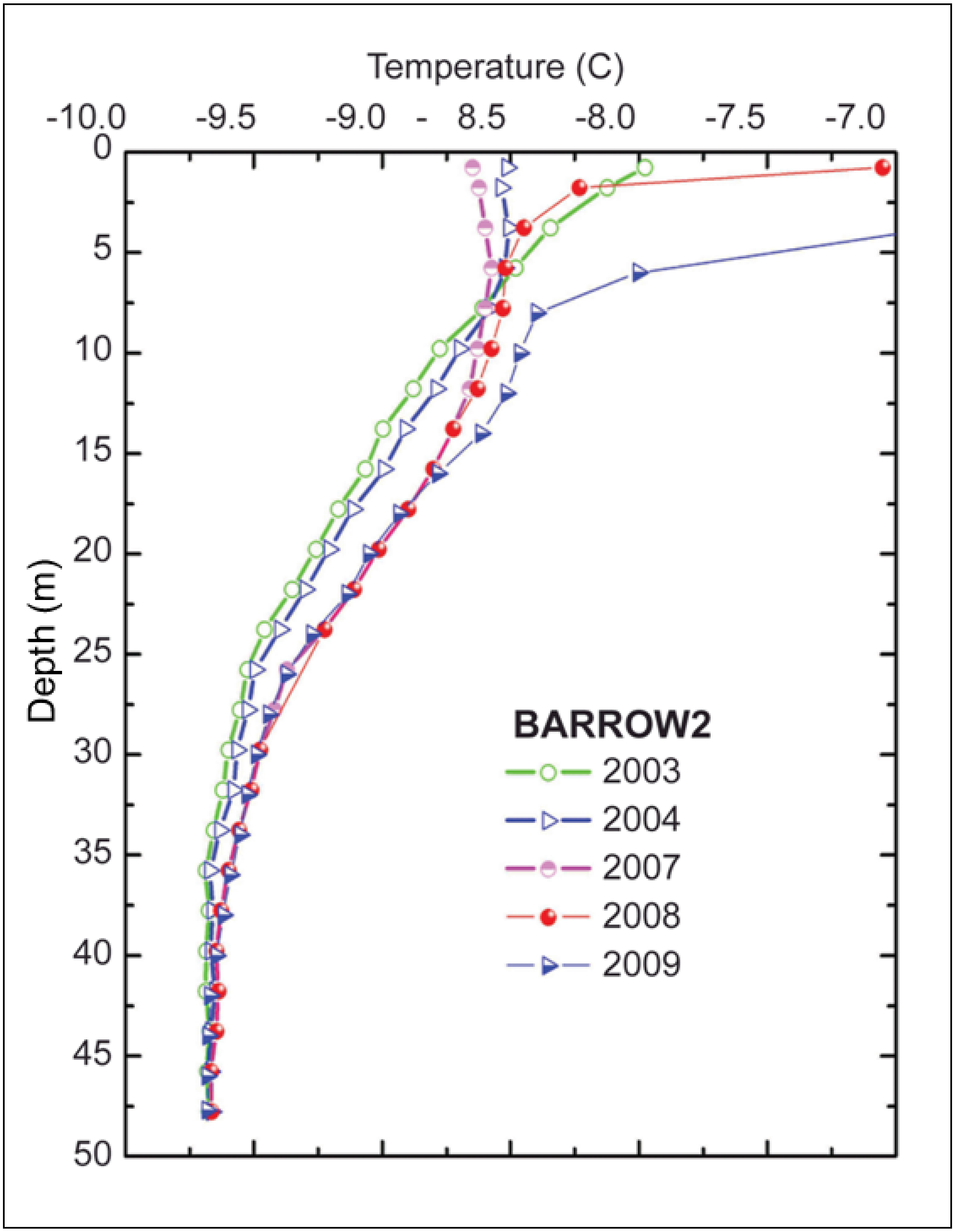

Figure P1. Changes in permafrost temperature between 2002-2009 at different depths at the Barrow Permafrost Observatory, which lies along the northern coast of Alaska.

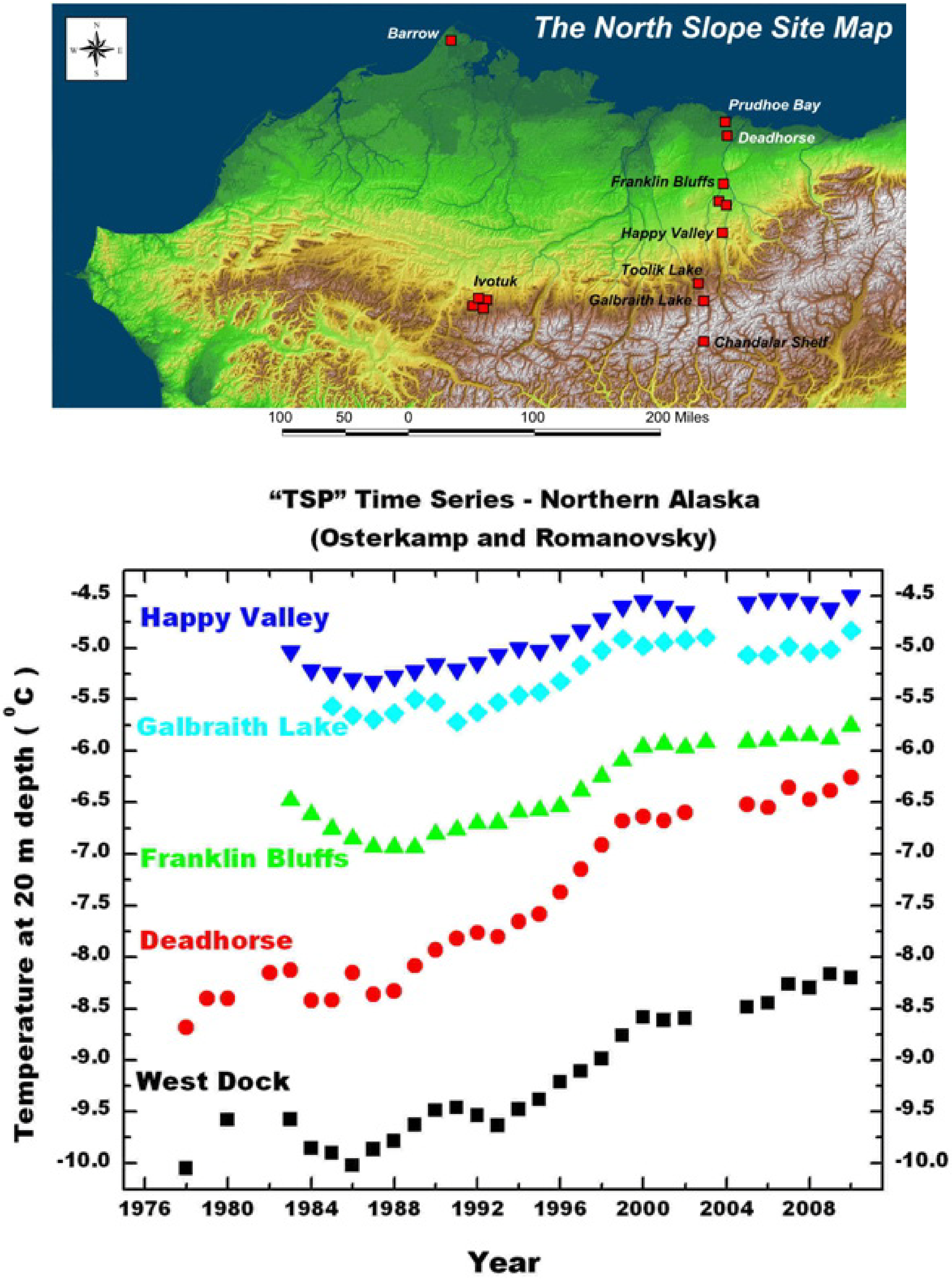

Figure P2. Top: Location of the long-term University of Alaska permafrost observatories in northern Alaska. Bottom: Changes in permafrost temperatures at 20 m depth during the last 27 to 32 years (updated from Osterkamp, 2003).

Permafrost temperature has increased by 1 to 2°C in northern Russia during the last 30 to 35 years. A common feature for Alaskan, Canadian, and Russian sites is more significant warming in relatively cold permafrost than in warm permafrost in the same geographical area (Romanovsky et al., 2010b). An especially noticeable permafrost temperature increase in the Russian Arctic was observed during the last three years – the mean annual permafrost temperature at 15-m depth increased by more than 0.35°C in the Tiksi area and by 0.3°C at 10-m depth in the European North of Russia.

The last 30-years of increasing permafrost temperatures have resulted in the thawing of permafrost in areas of discontinuous permafrost in Russia (Oberman, 2008; Romanovsky et al., 2010a). This is evidenced by changes in the depth and number of taliks (a layer of year-round unfrozen ground that lies in permafrost), especially in sandy and sandy loam sediments compared to clay. A massive development of new closed taliks in some areas of the continuous permafrost zone, resulting from an increased snow cover and warming permafrost, was responsible for the observed northward movement of the boundary between continuous and discontinuous permafrost by several tens of kilometers (Oberman and Shesler, 2009).

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River Discharge

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October 19, 2010

Summary

There is an increasing trend in river discharge to the Arctic Ocean from both Eurasia (over 1936-2008) and North America (over 1970-2008).

Annual river discharge to the Arctic Ocean from the major Russian rivers in 2008 was 2078 km^3 (Fig. R1). In general, river discharge shows an increasing trend over 1936-2008 with a rate of annual change of 2.9 ± 0.4 km^3/year. An especially intensive increase in river discharge to the ocean was observed during last 20 years when sea ice extent in the Arctic Ocean began decreasing (Fig. R1). Interestingly, the correlation between Eurasian river discharge and sea ice extent over 1979-2008 is R = -0.72, or greater than the correlation between precipitation (Willmot et al., 1996) and runoff in these Eurasian drainage basins (R= 0.54). This suggests that both rivers and sea ice were responding to changes in large-scale hemispheric climate patterns (Shiklomanov and Lammers, 2009).

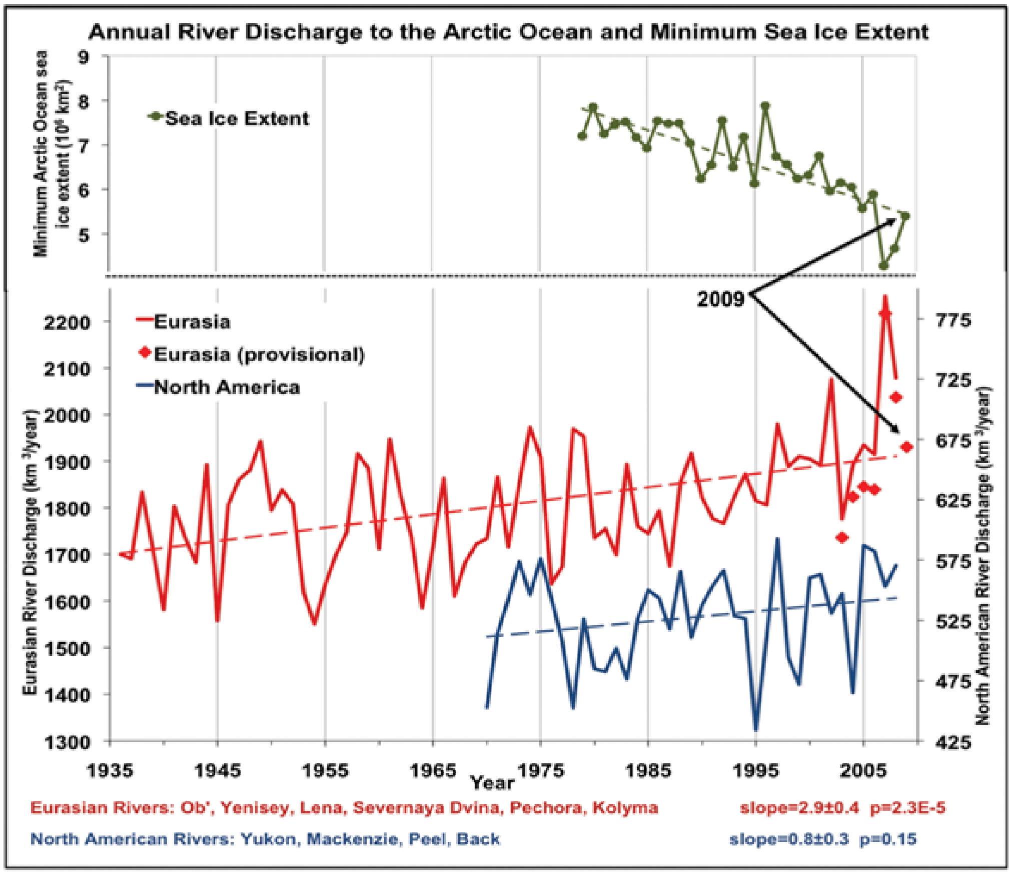

Figure R1. Total annual river discharge to the Arctic Ocean from the six largest rivers in the Eurasian Arctic for the observational period 1936-2008 (updated from Peterson et al., 2002) (red line) and from the four large North American pan-Arctic rivers over 1970-2008 (blue line). The least squares linear trend lines are shown as dashed lines. Provisional estimates of annual discharge for the six major Eurasian Arctic rivers, based on near real time data from http://RIMS.unh.edu, are shown as red diamonds. Upper green line shows the September (minimum) sea ice extent in the Arctic Ocean over 1979-2009 from NSIDC (http://nsidc.org/data).

There is also an increasing tendency in river discharge to the Arctic Ocean from North America (Fig. R1). The mean annual discharge to the ocean over 2000-2008 from the 4 large North American Arctic rivers was 6% (31 km^3) greater than the long-term mean from 1970-1999.

Official river discharge data are usually processed and published with some delay. This gap is related to discharge calculation techniques that take into account diverse flow conditions and ambiguous relationships between measured water stage (water level) and estimated river discharge. Cold regions, with long periods of ice cover, present the most difficult conditions for reliable discharge estimates in near real-time (Shiklomanov et al., 2006). However, in cooperation with Russian partners, we developed a method to estimate river discharge from the most important Russian monitoring sites in near real-time using provisional stage measurements and river ice data (http://RIMS.unh.edu). Provisional estimates for the 2009 annual river discharge to the Arctic Ocean from the six Russian rivers was greater than the long-term mean over 1936-2008 but much smaller than discharge in 2007 and 2008 (Fig. R1). Taking into account that the provisional estimates over 2003-2007 show a tendency to underestimate the annual observed values within an error of ± 2-4%, we anticipate the total discharge of six largest Eurasian rivers in 2009 being in the range 1930-1970 km^3.

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Terrestrial Snow

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October 18, 2010

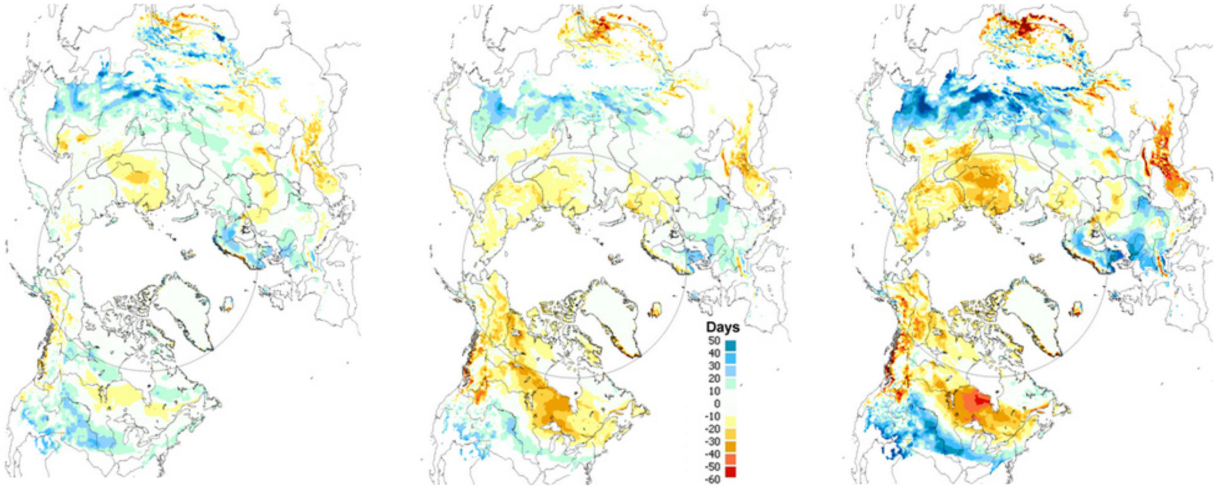
2009/10 Summary

A combination of low winter snow accumulation and warm spring temperatures created a new record low spring snow cover duration (SCD) over the Arctic in 2010, since satellite observations began in 1966. The 2009/10 winter was characterized by an atmospheric circulation pattern that contributed to cold, dry conditions and below-average snow accumulation over large areas of Siberia, but to enhanced snowfall in the eastern Canadian Arctic. Atmospheric circulation conditions in March and April helped pull warm southerly air into the western North American Arctic, which contributed to early snow melt.

Overview

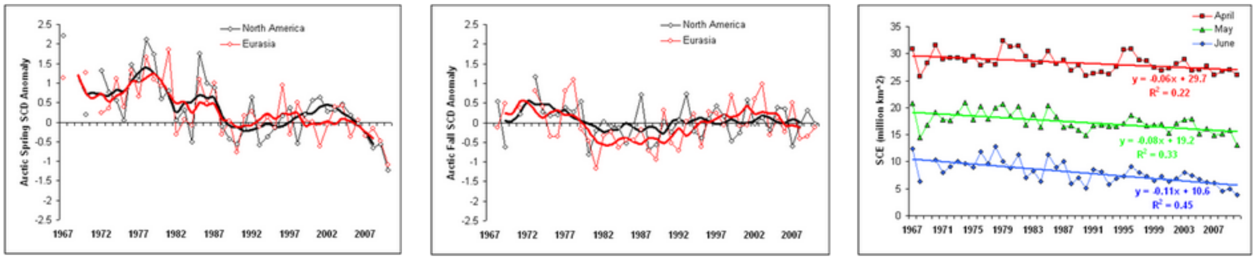
Reliable information on snow cover across the Arctic and sub-Arctic is needed for climate monitoring, for understanding the Arctic climate system, and for the evaluation of snow cover and (associated feedbacks) in climate models. Monitoring snow cover across the Arctic region is complicated by strong local controls on snow cover, frequent cloud cover, and large gaps and biases in surface observing networks. Therefore, it is beneficial to consider multiple sources of snow information (for example, from satellite observations, analyses of surface measurements, and output from atmospheric reanalysis) both to address the uncertainties associated with individual datasets, and to understand how various snow cover related variables are inter-related. These variables include snow cover extent (SCE: *the area covered by snow*), snow cover duration (SCD: *how long snow is on the ground*), and snow water equivalent (SWE: *the amount of liquid water stored in the form of snow*).

SCD was computed separately for the first (Fall) and second (Spring) halves of the snow year to provide information on changes in the start and end dates of snow cover (Fig. S1). A new record low spring SCD was observed over both the North American and Eurasian sectors of the Arctic during 2010 (Fig. S2a) continuing the trend to earlier spring snow melt over the Arctic identified from multiple datasets by Brown et al. (2010). Fall SCD (or snow cover onset date) continues to show no sign of any trends (Fig. S2b). Northern Hemisphere spring SCE, for months when snow cover is confined largely to the Arctic (Fig. S2c), continue to show decreasing trends previously linked to the poleward amplification of SCE sensitivity to warming air temperatures (Dery and Brown, 2007).



(a) fall (b) spring (c) complete snow season

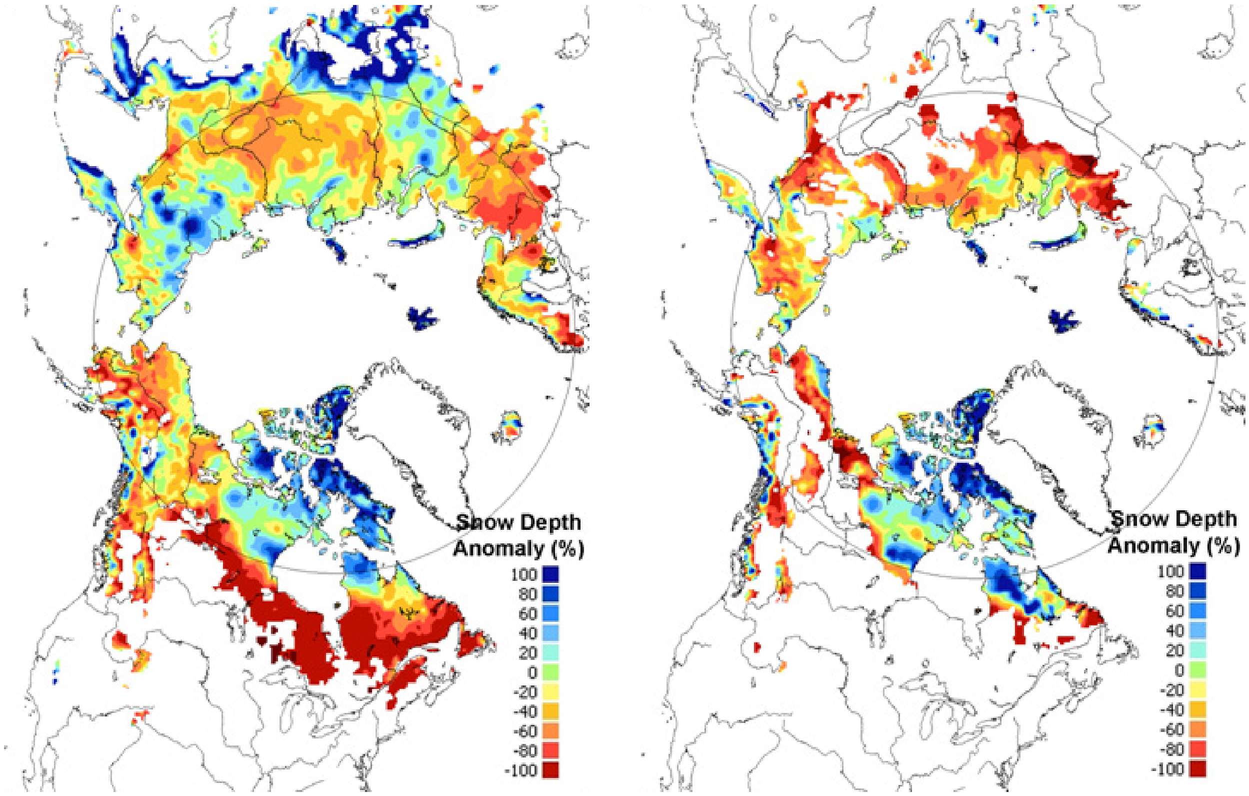
Figure S1. Snow cover duration (SCD) departures (with respect to 1998-2010) from the NOAA IMS data record for the 2009/10 snow year: (a) fall; (b) spring; (c) complete snow season.



a b c

Figure S2. Arctic seasonal snow cover duration (SCD) anomaly time series (with respect to 1988-2007) from the NOAA record for (a) the second (spring) and (b) first (fall) halves of the snow season. Solid lines denote 5-yr moving average. (c) Monthly Northern Hemisphere snow extent from the NOAA record for April, May and June, 1967-2010. Solid lines denote linear trends. These data were computed from the NOAA snow extent data record maintained at Rutgers University (http://climate.rutgers.edu/snowcover/).

Spatial patterns of fall, spring, and seasonal SCD anomalies for 2009/10 are shown in Fig. S1. Negative (shorter duration) spring SCD anomalies were evident over much of the Arctic land area in 2010 (with the exception of Scandinavia). Early spring melt was particularly strong over sub-Arctic Canada and Alaska. Mean monthly snow depth anomalies for April and May 2010 from the Canadian Meteorological Centre (CMC) global snow depth analysis (Brasnett, 1999) are shown in Fig. S3. The pre-melt Arctic winter snowpack is characterized by unusually shallow snow over Alaska, central Siberia, and western Russia with positive (deeper snow) anomalies over the eastern Canadian Arctic and eastern Eurasia. Large areas of the Eurasian Arctic show snow depth anomalies getting more negative from April (Fig. S3a) to May (Fig. S3b), illustrating an early and rapid snow melt across this region. This melt in the Eurasian sector is consistent with warm air temperature anomalies in this region during these two months.



a

b

Figure S3. Mean monthly snow depth anomaly (% of 1999-2009 average) from the CMC snow depth analysis for (a) April and (b) May 2010.

A multi-dataset Arctic SWE time series, derived for 1999 through 2010, indicate that regionally average April SWE anomalies (the month of maximum accumulation) were positive (more liquid water in the form of snow) in North America, and near normal in Eurasia (Fig. S4). Taken together with the early spring snow melt that characterized much of the Arctic in 2010, this is consistent with a more dynamic snowmelt regime (see Francis et al., 2009), and illustrates the potentially disconnected nature of SWE and SCE anomalies in the Arctic. .

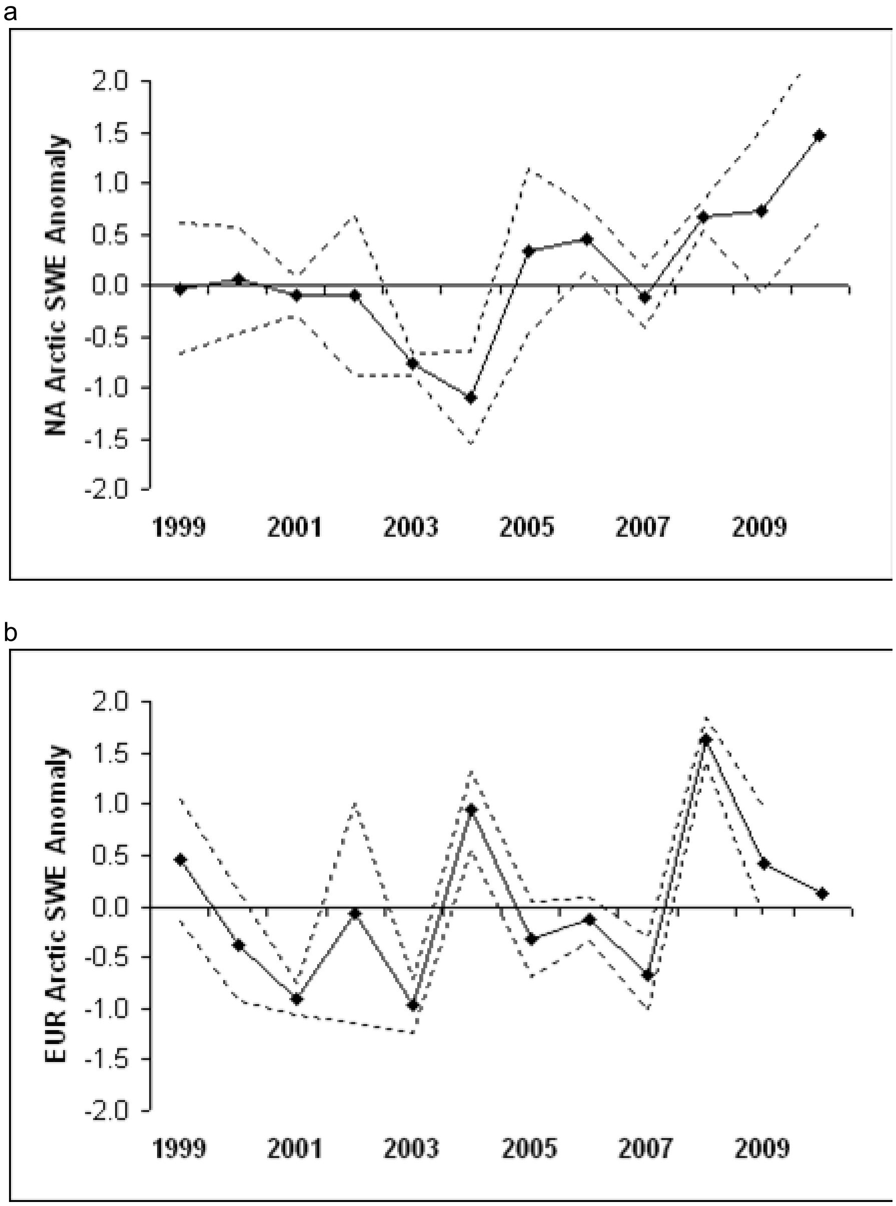


Figure S4. Multi-dataset time series of mean Arctic April snow water equivalent (SWE) anomalies (relative to 1999-2009 period) for (a) North America; (b) Eurasia. Dashed lines denote +/- 1 standard error from the mean multi-dataset anomaly (solid line). The datasets include two independent satellite derived datasets (Pulliainen, 2006; Derksen et al., 2010), estimates from the CMC dataset, and the ERA-interim reanalysis.

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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.

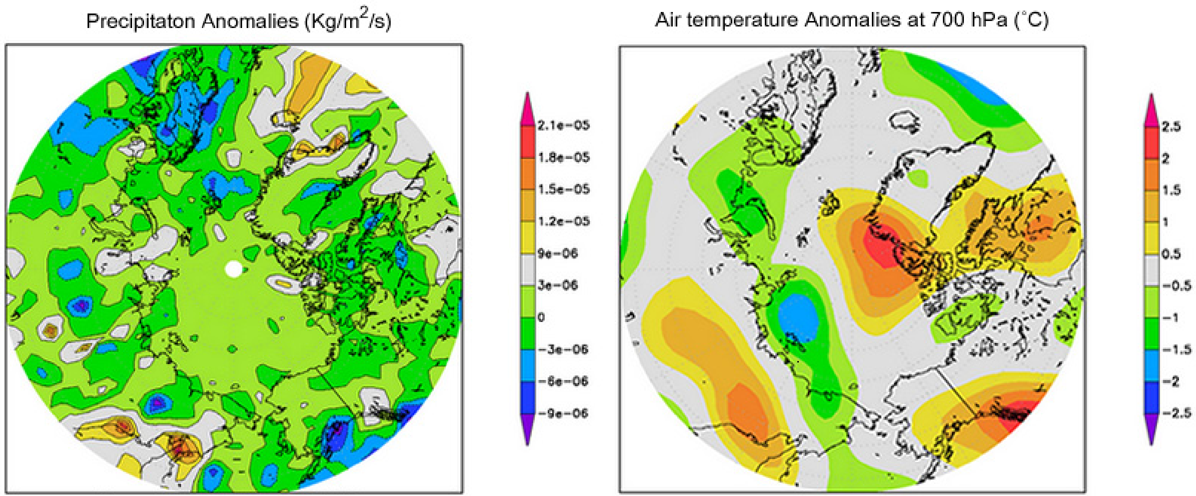
The surface mass balance (snowfall minus meltwater runoff) of around 20 glaciers in the Arctic is measured annually. The Russian Arctic islands are not included in this data set because no measurements are currently being made there. The data that are available show an overall trend of increasing mass 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		

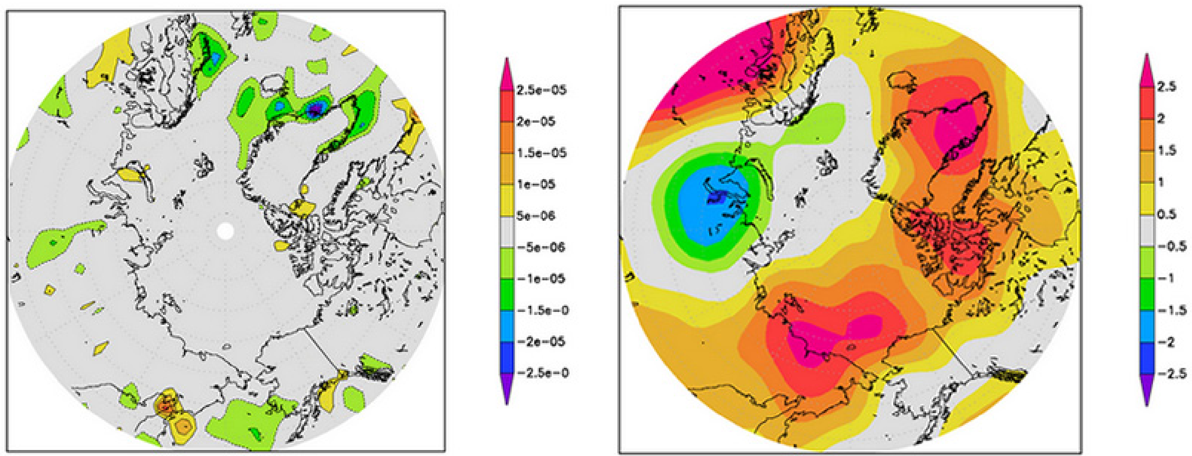
Table G1. Measured annual net surface mass balances of glaciers in Alaska, the Canadian Arctic, Iceland and Svalbard for 2007-2008, for the Canadian Arctic for 2008-2009. Mass balance data for glaciers in Alaska, Svalbard, and Iceland are from the World Glacier Monitoring Service; those for Arctic Canada 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.



a) Winter (September 2008-May 2009)

b) Summer (Jun - Aug 2009)



c) Winter (September 2009-May 2010)

d) Summer (Jun - Aug 2010)

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.

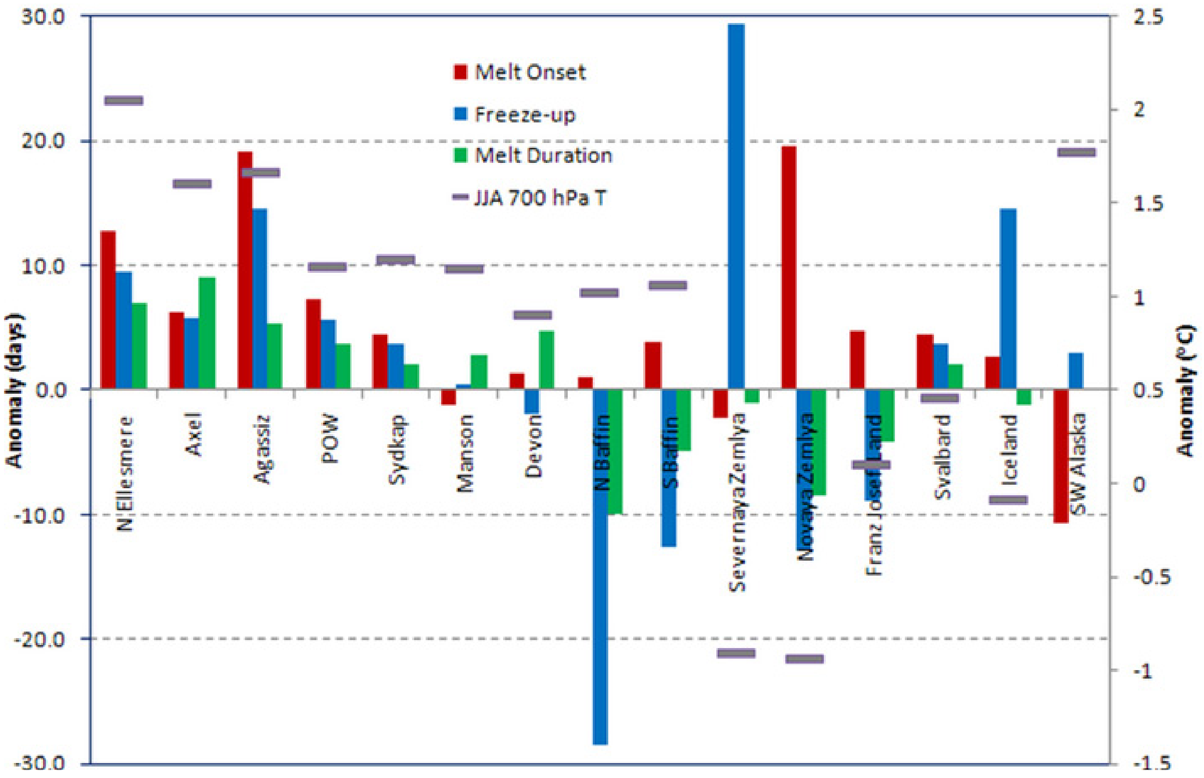


Figure G2. Anomalies in 2009 melt season duration and the dates of melt onset and freeze-up (relative to 2000-2004 climatology) derived from SeaWinds scatterometer on QuikScat, and anomalies in summer (June-August) 2009 air temperature (K) at 700 hPa in the NCEP/NCAR Reanalysis relative to a 1948-2008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

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Greenland

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Summary

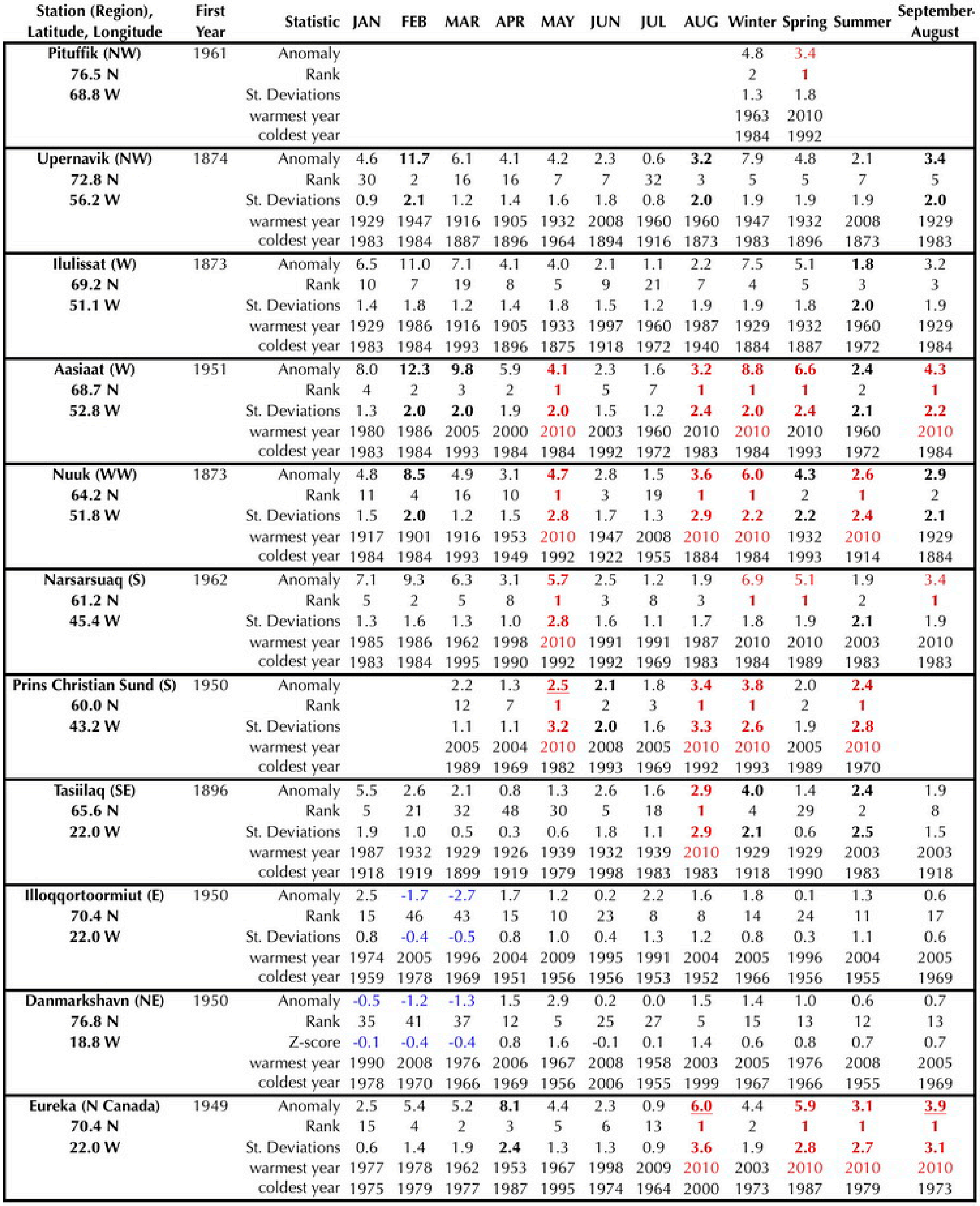
Greenland climate in 2010 is marked by record-setting high air temperatures, ice loss by melting, and marine-terminating glacier area loss. Summer seasonal average (June-August) air temperatures around Greenland were 0.6 to 2.4°C above the 1971-2000 baseline and were highest in the west. A combination of a warm and dry 2009-2010 winter and the very warm summer resulted in the highest melt rate since at least 1958 and an area and duration of ice sheet melting that was above any previous year on record since at least 1978. The largest recorded glacier area loss observed in Greenland occurred this summer at Petermann Glacier, where 290 km^2 of ice broke away. The rate of area loss in marine-terminating glaciers this year (419 km^2) was 3.4 times that of the previous 8 years, when regular observations are available. There is now clear evidence that the ice area loss rate of the past decade (averaging 120 km^2/year) is greater than loss rates pre-2000.

Coastal surface temperatures

A clear pattern of exceptional and record-setting warm air temperatures is evident at long-term meteorological stations around Greenland (Table GL1). For instance:

- Nuuk (64.2°N along Greenland's west coast): Year 2010 summer, spring, and winter 2009/2010 were the warmest on record since record keeping began in 1873.
- Aasiaat (69.0°N along Greenland's west coast): It was the warmest month of May and August, and the warmest winter, spring, 2nd warmest summer and the warmest year (July 2009-August 2010) since record keeping began in 1951.
- Narsarssuaq (61.2°N in southern Greenland): It was the warmest month of May, and the warmest winter, spring and the warmest year (July 2009-August 2010) since record keeping began in 1951.
- Thule AFB, Pituffik (76.5°N along Greenland's west coast): It was the warmest spring (March-May) on record, which began in 1961.

Table GL1. 2010 Greenland station surface air temperature anomalies by season, relative to 1971–2000.



Station (Region), Latitude, Longitude	First Year	Statistic	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	Winter	Spring	Summer	September-August
Pituffik (NW)	1961	Anomaly									4.8	3.4		
76.5 N		Rank									2	**1**		
68.8 W		St. Deviations									1.3	1.8		
		warmest year									1963	2010		
		coldest year									1984	1992		
Upernavik (NW)	1874	Anomaly	4.6	**11.7**	6.1	4.1	4.2	2.3	0.6	**3.2**	7.9	4.8	2.1	**3.4**
72.8 N		Rank	30	2	16	16	7	7	32	3	5	5	7	5
56.2 W		St. Deviations	0.9	**2.1**	1.2	1.4	1.6	1.8	0.8	**2.0**	1.9	1.9	1.9	**2.0**
		warmest year	1929	1947	1916	1905	1932	2008	1960	1960	1947	1932	2008	1929
		coldest year	1983	1984	1887	1896	1964	1894	1916	1873	1983	1896	1873	1983
Ilulissat (W)	1873	Anomaly	6.5	11.0	7.1	4.1	4.0	2.1	1.1	2.2	7.5	5.1	**1.8**	3.2
69.2 N		Rank	10	7	19	8	5	9	21	7	4	5	3	3
51.1 W		St. Deviations	1.4	1.8	1.2	1.4	1.8	1.5	1.2	1.9	1.9	1.8	**2.0**	1.9
		warmest year	1929	1986	1916	1905	1933	1997	1960	1987	1929	1932	1960	1929
		coldest year	1983	1984	1993	1896	1875	1918	1972	1940	1884	1887	1972	1984
Aasiaat (W)	1951	Anomaly	8.0	**12.3**	**9.8**	5.9	**4.1**	2.3	1.6	**3.2**	**8.8**	**6.6**	**2.4**	**4.3**
68.7 N		Rank	4	2	3	2	**1**	5	7	**1**	**1**	**1**	2	**1**
52.8 W		St. Deviations	1.3	**2.0**	**2.0**	1.9	**2.0**	1.5	1.2	**2.4**	**2.0**	**2.4**	**2.1**	**2.2**
		warmest year	1980	1986	2005	2000	2010	2003	1960	2010	2010	2010	1960	2010
		coldest year	1983	1984	1993	1984	1984	1992	1972	1983	1984	1993	1972	1984
Nuuk (WW)	1873	Anomaly	4.8	**8.5**	4.9	3.1	**4.7**	2.8	1.5	**3.6**	**6.0**	**4.3**	**2.6**	**2.9**
64.2 N		Rank	11	4	16	10	**1**	3	19	**1**	**1**	2	**1**	2
51.8 W		St. Deviations	1.5	**2.0**	1.2	1.5	**2.8**	1.7	1.3	**2.9**	**2.2**	**2.2**	**2.4**	**2.1**
		warmest year	1917	1901	1916	1953	2010	1947	2008	2010	2010	1932	2010	1929
		coldest year	1984	1984	1993	1949	1992	1922	1955	1884	1984	1993	1914	1884
Narsarsuaq (S)	1962	Anomaly	7.1	9.3	6.3	3.1	**5.7**	2.5	1.2	1.9	6.9	5.1	1.9	3.4
61.2 N		Rank	5	2	5	8	**1**	3	8	3	**1**	**1**	2	**1**
45.4 W		St. Deviations	1.3	1.6	1.3	1.0	**2.8**	1.6	1.1	1.7	1.8	1.9	**2.1**	1.9
		warmest year	1985	1986	1962	1998	2010	1991	1991	1987	2010	2010	2003	2010
		coldest year	1983	1984	1995	1990	1992	1992	1969	1983	1984	1989	1983	1983
Prins Christian Sund (S)	1950	Anomaly			2.2	1.3	2.5	**2.1**	1.8	**3.4**	**3.8**	2.0	**2.4**	
60.0 N		Rank			12	7	**1**	2	3	**1**	**1**	2	**1**	
43.2 W		St. Deviations			1.1	1.1	**3.2**	**2.0**	1.6	**3.3**	**2.6**	1.9	**2.8**	
		warmest year			2005	2004	2010	2008	2005	2010	2010	2005	2010	
		coldest year			1989	1969	1982	1993	1969	1992	1993	1989	1970	
Tasiilaq (SE)	1896	Anomaly	5.5	2.6	2.1	0.8	1.3	2.6	1.6	**2.9**	**4.0**	1.4	**2.4**	1.9
65.6 N		Rank	5	21	32	48	30	5	18	**1**	4	29	2	8
22.0 W		St. Deviations	1.9	1.0	0.5	0.3	0.6	1.8	1.1	**2.9**	**2.1**	0.6	**2.5**	1.5
		warmest year	1987	1932	1929	1926	1939	1932	1939	2010	1929	1929	2003	2003
		coldest year	1918	1919	1899	1919	1979	1998	1983	1983	1918	1990	1983	1918
Illoqqortoormiut (E)	1950	Anomaly	2.5	-1.7	-2.7	1.7	1.2	0.2	2.2	1.6	1.8	0.1	1.3	0.6
70.4 N		Rank	15	46	43	15	10	23	8	8	14	24	11	17
22.0 W		St. Deviations	0.8	-0.4	-0.5	0.8	1.0	0.4	1.3	1.2	0.8	0.3	1.1	0.6
		warmest year	1974	2005	1996	2004	2009	1995	1991	2004	2005	1996	2004	2005
		coldest year	1959	1978	1969	1951	1956	1956	1953	1952	1966	1956	1955	1969
Danmarkshavn (NE)	1950	Anomaly	-0.5	-1.2	-1.3	1.5	2.9	0.2	0.0	1.5	1.4	1.0	0.6	0.7
76.8 N		Rank	35	41	37	12	5	25	27	5	15	13	12	13
18.8 W		Z-score	-0.1	-0.4	-0.4	0.8	1.6	-0.1	0.1	1.4	0.6	0.8	0.7	0.7
		warmest year	1990	2008	1976	2006	1967	2008	1958	2003	2005	1976	2008	2005
		coldest year	1978	1970	1966	1969	1956	2006	1955	1999	1967	1966	1955	1969
Eureka (N Canada)	1949	Anomaly	2.5	5.4	5.2	**8.1**	4.4	2.3	0.9	**6.0**	4.4	**5.9**	**3.1**	**3.9**
70.4 N		Rank	15	4	2	3	5	6	13	**1**	2	**1**	**1**	**1**
22.0 W		St. Deviations	0.6	1.4	1.9	**2.4**	1.3	1.3	0.9	**3.6**	1.9	**2.8**	**2.7**	**3.1**
		warmest year	1977	1978	1962	1953	1967	1998	2009	2010	2003	2010	2010	2010
		coldest year	1975	1979	1977	1987	1995	1974	1964	2000	1973	1987	1979	1973

*Anomalies are in °C, with respect to the 1971–2000 base period. Bold values indicate values that meet or exceed 2 standard deviation2 from the mean. Red characters indicate a record setting year. The winter value takes December from the previous year.

Warming was greatest in Winter (December-February), with temperatures 3.8°C to 8.8°C above the 1971-2000 baseline. The only cooler-than-normal air temperatures were in the winter in east Greenland and are not statistically significant. Winter warming is relevant to increased summer melt because warmed snow or ice volumes require less heat to be brought to the melting point. Under these conditions, melt onset occurs earlier than normal and the snow cover duration is shorter. This leads to a lower average albedo earlier in the summer, allowing for a greater absorption of solar energy, more melting and higher temperatures, especially on land once snow cover is completely melted and exposes bare (dark) land. The "ice-albedo" feedback, responsible for amplified warming in the high latitudes is clearly operating here. A pattern of "polar amplification" of warming has been evident in surface air temperature records for decades (Hansen and Lebedev, 1987).

Atmospheric circulation anomalies

The NCEP/NCAR reanalysis data indicate warm airflow from the south over the southwestern part of the Greenland ice sheet (Fig. GL1).

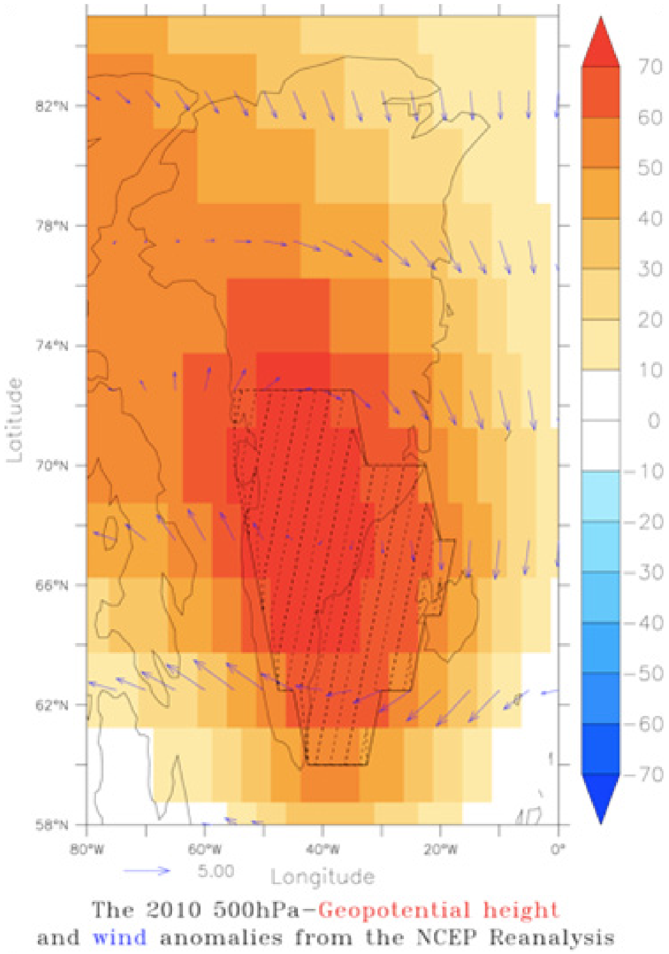


Figure GL1. The geopotential height and wind anomalies for JJA 2010 (referenced to the 1971–2000 mean) at 500 hPa from the NCEP/NCAR Reanalysis. Areas where geopotential height anomalies were at least twice the 1971–2000 standard deviation are hatched. The blue arrows represent wind vector anomalies, with scale indicated by the blue arrow below the plot.

Surface melt extent and duration

The area and duration of melting on the ice sheet continued to expand in 2010, as compared with past years via daily passive microwave satellite remote sensing observations (Mote, 2007). April to mid-September (18 September) 2010 had about an 8% more extensive melt area than 2007, when the previous record maximum melt extent was observed (Figure GL2). The 2010 melt extent through mid September was 38% greater than the 1979-2007 average, and the June to August extent was 26% greater than average. .

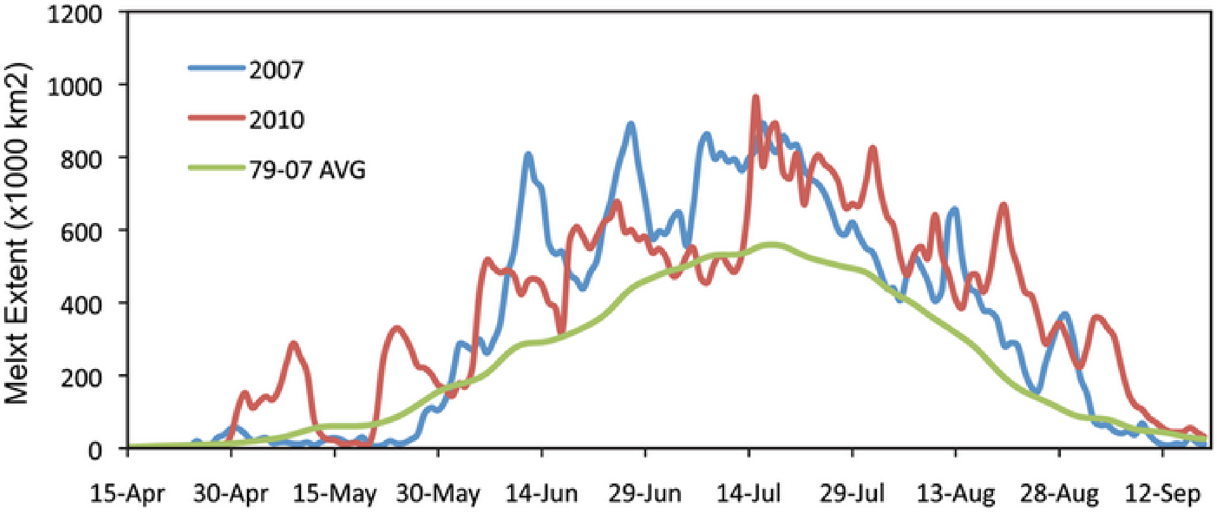


Figure GL2. Time series of Greenland melt extent derived from passive microwave remote sensing from 2010 (red), 2007 (blue) and the 1979-2007 average (green), after Mote (2007).

Abnormal melt duration was concentrated along the western ice sheet (Figure GL3), consistent with anomalous warm air inflow during the summer (Figure GL1) and abnormally high winter air temperatures which led to warm pre-melt conditions. The melt duration was as much as 50 days greater than average in areas of west Greenland that had an elevation between 1200 and 2400 meters above sea level. In May, areas at low elevation along the west coast of the ice sheet melted up to about 15 days longer than the average. NCEP/NCAR Reanalysis data suggest that May surface temperatures were up to 5°C above the 1971–2000 baseline average. June and August also exhibited large positive melting day anomalies (up to 20 days) along the western and southern ice sheet. During August temperatures were 3°C above the average over most of the ice sheet, with the exception of the northeastern ice sheet. Along the southwestern ice sheet, the number of melting days in August has increased by 24 days over the past 30 years.

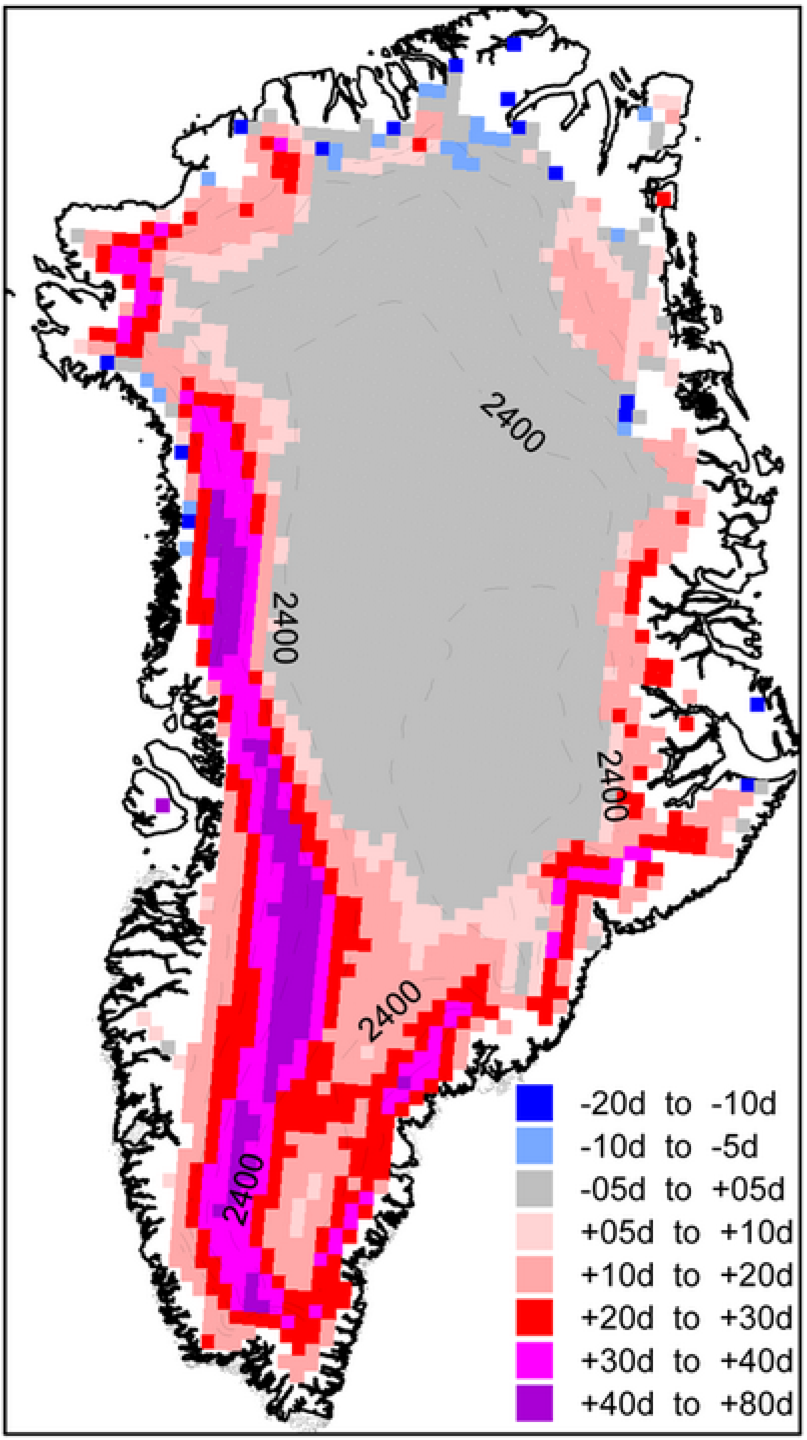


Figure GL3. Difference (days) in summer 2010 melt duration compared to 1979-2007 mean, after Mote (2007). The 2400 m elevation contour is included to illustrate higher elevations of melting over the southern ice sheet.

In May, areas at low elevation along the West coast of the ice sheet melted up to about 15 days longer than the average; June and August also show large positive melting day anomaly values (up to 20 days) along the West and South regions of the ice sheet. NCEP/NCAR Reanalysis data suggest that May surface temperatures were up to 5°C above the average. During August temperatures were 3°C above the average over most of the ice sheet, with the exception of the northeast ice sheet. Along the South-West portion of the ice sheet, the number of melting days in August has increased by 24 days over the past 30 years.

In-situ observations from the K-Transect

Ice sheet surface mass balance from September 2009-2010 was by far the lowest since 1990, when routine measurement began along an elevation transect of in-situ observations located near Kangerlussuaq at 67°N on the western flank of the ice sheet (van de Wal et al. 2005). Averaged over the 150-km long elevation K-transect, from 340 to 1500 meters above sea level, the surface mass balance was highly significant at 2.7 standard deviations below the 1990-2010 average. The altitude of the snow line (the extent of the melt of the winter snow cover) was higher than ever, with a very early onset of the melt season that continued until the beginning of September. Surface albedo values at the weather stations dropped below average and air temperatures in summer were above average.

Marine-terminating glacier area changes

Marine-terminating glaciers are of particular interest because they represent the outlets through which the ice can move most quickly and in the largest quantities out to the sea, contributing to rising average global sea levels and drawing down the inland ice reservoir. Glacier front ice area loss is also of concern because it is associated with reduced flow-resistance, which leads to accelerated ice loss from the inland ice.

Daily surveys of Greenland ice sheet marine-terminating outlet glaciers, from cloud-free Moderate Resolution Imaging Spectroradiometer (MODIS) visible imagery (http://bprc.osu.edu/MODIS/), indicate that in the past year Greenland glaciers collectively lost an area of 419 km^2. This is more than 3 times the loss rates of the previous 8 years, 2002-2009, which was 121 km^2/year (Figure GL4). 7/10 of this year's loss came from the 290 km^2 ice island detachment from Petermann glacier in far northwest Greenland (see: http://bprc.osu.edu/MODIS/?p=69). Glacier ice area loss elsewhere (i.e. outside the Petermann Glacier) remained near the 121 km^2/year rate observed during the past decade. There is now clear evidence that the ice area loss rate of the past decade is greater than loss rates pre-2000.

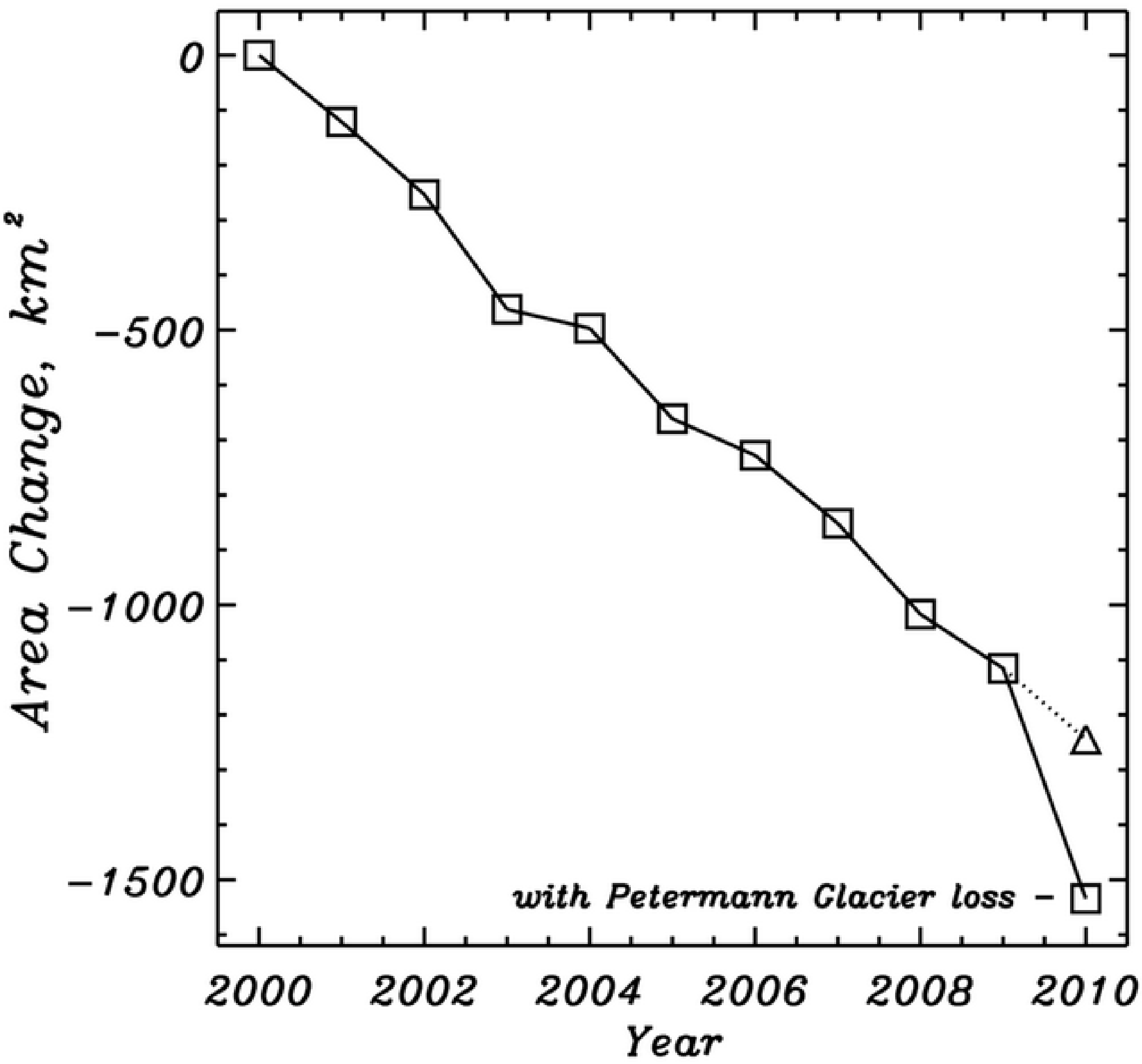


Figure GL4. Cumulative net annual area changes for the 35 widest marine-terminating glacier outlets to the Greenland ice sheet. Year 2010 net area changes are shown with and without the Petermann glacier loss. The trend without the Petermann loss is illustrated by the triangle in year 2010.

A number of other large outlet glaciers also lost significant amounts of ice area: Zachariae Isstrøm in northeast Greenland lost 43 km^2; Humboldt glacier in northwest Greenland lost 20 km^2; Ikertivaq glacier in Southeast Greenland lost 15 km^2; and the 5 glaciers that empty into Upernavik glacier bay in northwest Greenland lost 14 km^2.

Since 2000, the net area change of the 35 widest marine-terminating glaciers is -1535 km^2; equivalent to an ice area loss 17.5 times the size of the 87.5 km^2 Manhattan Island. The total effective glacier length change has been, on average, -1.7 km since year 2000. While the overall area change indicates the largest observed retreat, 7 of 35 glaciers did advanced in 2010 relative to 2009. The largest glacier advances were at Ryder and Storstrømmen glacier, each advancing 4.6 and 4.2 km^2, respectively. Land-terminating glaciers are not part of our survey but most certainly lost a much smaller area because they are so much slower-moving than marine-terminating glaciers.

Precipitation and surface mass balance

The balance between snowfall gain and meltwater loss is positive for any healthy ice mass. In 2010, the MAR regional climate data assimilation model simulated that the ice sheet surface mass balance was 90% less positive than normal (Table GL2); the lowest net mass accumulation rate since 1958 when data to drive the model become available (Figure GL5). This condition reflects a very heavy melt year combined with below normal ice sheet snow accumulation. The high melt rate in 2010 was a consequence of:

- a warmer winter favoring an earlier melt season onset because the snowpack is relatively warm and, thus, can reach its melting temperature more quickly.
- a drier winter favoring less snow pack and thus an earlier appearance of a darker surface (e.g. bare ice or the previous year summer snow surface), which has a lower surface albedo.
- a very warm summer.
- a summer with less snowfall than normal (-20%), impacting the surface albedo which was low during the whole melting season in 2010.

The temperature and precipitation anomalies are very likely the result of regional circulation anomalies illustrated in Figure GL1. The main anomalies occur along the south-western margin where the number of days with bare ice was higher than normal. Compared to Summer 2007, where melt anomalies took place in both ablation and percolation zones (Tedesco et al., 2008), most of melt anomalies of this summer took place in the bare ice zone.

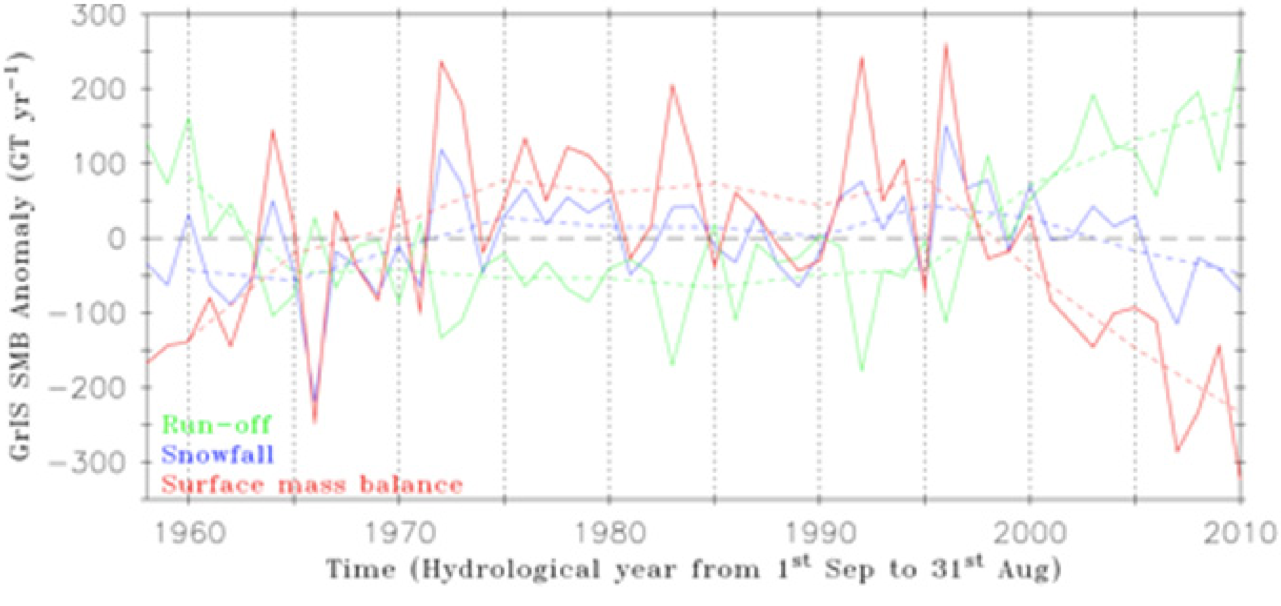


Figure GL5. Time series of hydrological year (1 Sep to 31 Aug) mean surface mass balance (SMB) component anomalies simulated by the regional climate MAR model (Fettweis et al., 2010). The differences between the SMB time series and the snowfall minus run-off time series are attributed to rainfall and sublimation/evaporation.

Table GL2. Greenland ice sheet surface mass balance and near-surface temperature anomalies simulated by the regional climate MAR model.

2010 anomaly referenced to	Total SMB (GT)	Total Snowfall (GT)	Total Runoff (GT)	Winter Snowfall (GT)	Winter Air Temperature (K)	JJA Air Temperature (K)
Period	1st Sep to 31st August	1st Sep to 31st August	1st Sep to 31st August	1st Sep to 30th April	1st Sep to 30th April	1st Jun to 31st Aug
1971-2000	-383 GT (-93%)	-94 GT (-15%)	290 GT (+124%)	-48 GT (-10%)	2.5	2.4
1991-2000	-392 GT (-93%)	-119 GT (18%)	271 GT (+107%)	-70 GT (-14%)	2.3	2.2
2001-2010	-159 GT (-84%)	-48 GT (-8%)	109 GT (+26%)	-35 GT (-8%)	1.2	1

Anecdotal Data

A long-term resident of Greenland wrote on 4 February, 2010: "we don´t have snow, we don´t have the cold" ... "This weather this year is really different, in 30 years that I live in Ilulissat [69.0°N along Greenland's west coast], that is the first year in this conditions. We have lot of dog sledding tourists, but we cannot do the tour, too much ice on the hills and dangerous to drive by sled." ... "no snow at all". Later, the same source remarked of "10-12 days of" continuous "heat wave" like weather, in June, with "a lot of blue skies".

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Biology

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October 15, 2010

Summary

The contribution of Arctic wildlife to global biodiversity is substantial. The region supports globally significant populations of birds, mammals and fish. For example, over half of the world's shorebirds and 80% of the global goose population breed in Arctic and sub-Arctic regions. Many of these populations experience natural and often dramatic cycles in abundance, switching from periods of growth and decline. Dramatic changes (e.g., sea-ice loss) in the Arctic's ecosystems have occurred, are predicted to continue over the next century, and may disrupt these natural cycles. Changes in physical attributes of the Arctic (e.g. increasing air temperatures, decreasing sea ice extent) are expected to result in winners and losers. Arctic species that have adapted to these extreme environments are expected to be displaced by the encroachment of more southerly (sub-Arctic) species and ecosystems. Understanding how the Arctic's living resources are responding to these changes is essential in order to develop effective conservation and adaptation strategies.

The biological components of the 2010 Arctic Report Cards highlight the inherently fluctuating nature of Arctic ecosystems and provide some insight into how Arctic ecosystems and the biodiversity they support are responding to changing environmental conditions. Dramatic declines in many wild caribou and reindeer populations over the past two decades and the dramatic increases in goose populations over the same period appear to be moderating. Barents Sea harvested stocks continue to fluctuate and these changes may be linked to sea temperatures and the associated fluctuations in sea ice cover. The Arctic Species Trend Index, released in 2010 and drawing on 965 populations of 306 Arctic and sub-Arctic vertebrate species across the Arctic, has been relatively stable since 1970. However, there are significant variations between groups and species, and geographic areas. Populations of vertebrate high arctic species declined 26% between 1970 and 2004. Low and sub-Arctic species have fared better over this time period: the low Arctic species index, largely dominated by marine species, has experienced increasing abundance (although the result is largely biased by pelagic data from the Bering Sea), while the sub-Arctic index (reflecting mostly terrestrial and freshwater species) has declined since the mid-1980s, resulting in no overall change over the 34 year period. These observed trends are largely consistent with current predictions regarding the response of Arctic wildlife to changing environmental conditions in the Arctic, caused by both natural and human-caused change. Given the predicted dramatic changes in the Arctic over the next century (e.g. from climate change), it is becoming increasingly important to invest in improved monitoring in this remote area to understand how these systems are changing and thereby facilitate more effective and timely conservation and adaptation actions.

State of Wild Reindeer Herds

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Summary

Rangifer (wild reindeer and caribou) herds across the circumpolar north have long been characterized by periods of abundance and periods of scarcity. Populations that have been increasing at a steady rate since the early to mid 1970's peaked and most have declined, some rapidly (Bluenose West, Cape Bathurst, Bathurst, Beverly), although two Alaskan coastal herds continued to increase (Teshekpuk Lake and Central Arctic Herds). Counts in 2009 indicate that some herds may be stabilizing although it is far too early to report a trend. Figure C1 shows the current status of selected *Rangifer*, the major migratory herds and herds being monitored as part of the CircumArctic Rangifer Monitoring and Assessment (CARMA) Network (see note on CARMA in the last paragraph of this article).

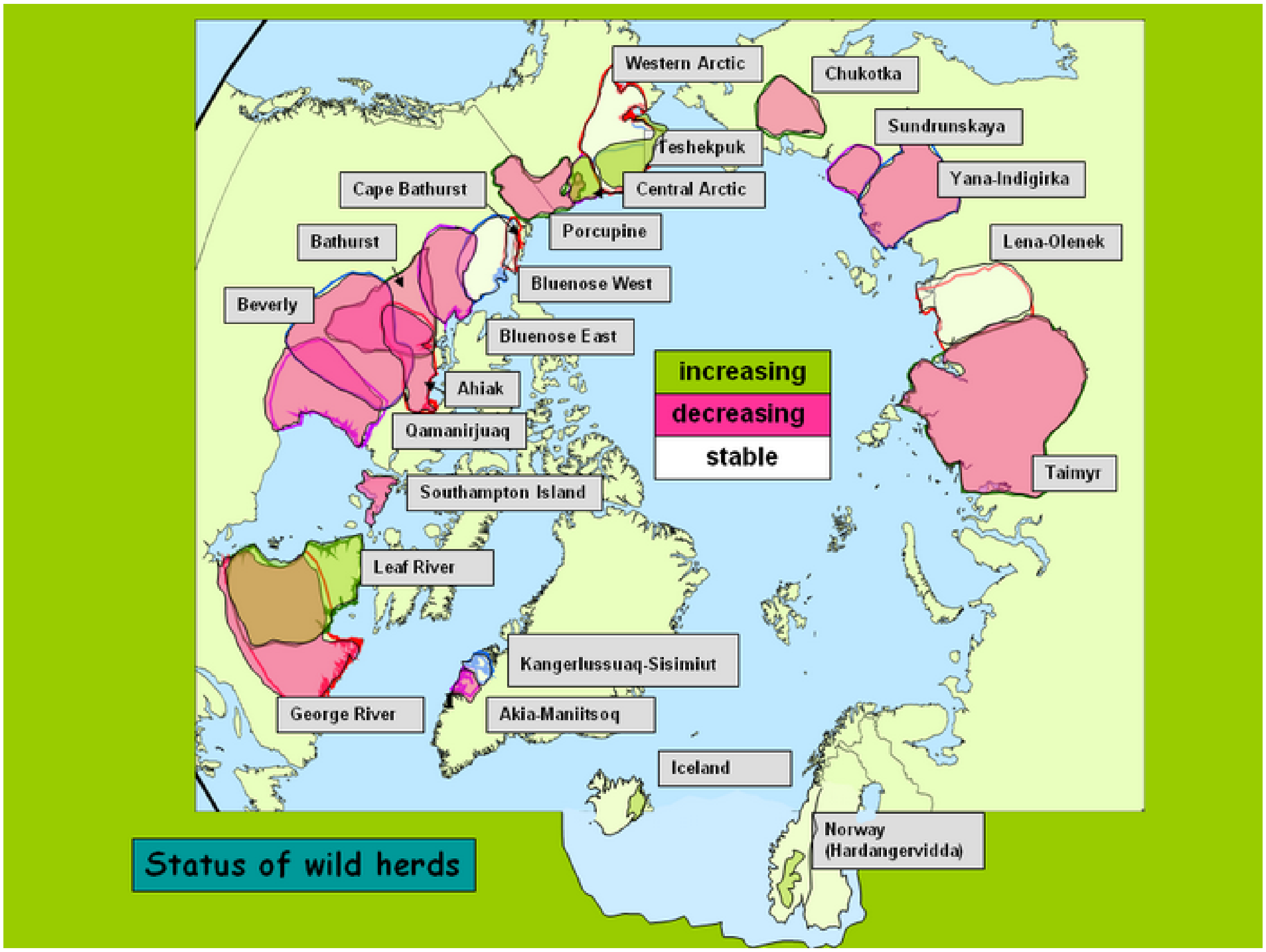

Figure C1. Current status of the main migratory herds across the circumpolar north.

- East of the Mackenzie Delta, counts of the Cape Bathurst and the Bluenose West Herds indicate stable abundance from 2006 to 2009.
- The Western Arctic herd count in 2009 indicated 401,000 caribou, compared to 377,000 in 2007, although considered stable between the two counts.
- A 2009 count of the Lena-Olenyk herd in Russia resulted in 95,000 animals reversing a declining trend since 2001.
- In the summer of 2010 photographic population estimates were made of the Bluenose East, the George River and the Porcupine Herd but results are not yet available.
- Although the map indicates that the Leaf River herd is increasing, no counts have been made since 2001 and an attempt to count in 2010 failed.

It is still too early too declare that the recent declines are leveling off, but the halt of further declines in the last few years is welcome news to boards and agencies managing the herds involved. Most feel the general declines that the north experienced and continue to experience are part of a natural cycle possibly exacerbated by harvesting, and the increasing human presence on the ranges. However, during this population scarcity, many are concerned that the increased threats of climate change, increased industrial expansion in the north and the increased sophistication and mobility of harvesters will require more careful monitoring and analysis of population response.

The CircumArctic *Rangifer* Monitoring and Assessment (CARMA) Network (http://www.carmanetwork.com/display/public/home) was formed in response for a need to cooperate and coordinate monitoring efforts across the north. The Network is taking advantage of the International Polar Year initiative to increase its monitoring and assessment activities.

Additional Information:

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Marine Mammals

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NOAA Fisheries Service

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No new updates for 2010

Figure M1. Marine mammals found in the Arctic. Clockwise from the upper left: Beluga whales, Narwhal, Ringed seal, Walrus, Bowhead whale, Bearded Seal, and center, Polar Bear.

A variety of marine mammals can be found in the Arctic at least seasonally. Seven species are present in the Arctic year-round and are often associated with sea ice—bowhead whale, beluga whale, narwhal, ringed seal, bearded seal, walrus, and polar bear. All seven of these species are important top predators within Arctic marine ecosystems. As such they may serve as sentinels of Arctic climate change, with changes in their status reflecting ecosystem-wide perturbations[1]. Table M1 summarizes current knowledge regarding the abundance and trends of these species. Unfortunately, abundance estimates are not available for one or more populations of most species, and trends are unknown for even more populations. Further, some of the available estimates are based on data from the 1990s or earlier and, therefore, are out of date. It is clear, even from this limited information, that several populations of Arctic marine mammals are quite small (e.g., Ungava Bay and Cook Inlet belugas, Lake Saimaa ringed seals, and several stocks of polar bears each have 400 or fewer animals), and this raises concerns about the potential impact of catastrophes such as oil spills or disease outbreaks. Also, all species with sufficient data exhibit mixed population trends, with some populations of each species increasing while others are stable or declining. The available data are not sufficient for an analysis of trends by region (e.g., to highlight regions within which populations of several species are all increasing or all declining). However, it is likely that species within a region will exhibit different trends because they occupy very different ecological niches, ranging from the bowhead whale that filters zooplankton out of the water to the polar bear that hunts seals on the sea ice (Table M2).

A comprehensive assessment of the status of Arctic marine mammals must consider current population demography and dynamics as well as the resistance or resilience of each species to current and projected threats. Arctic marine mammals appear to be in a tenuous position—they are adapted to life in seas that are at least seasonally ice-covered, and the extent of summer ice cover is rapidly diminishing[41]. These species are long-lived and reproduce slowly and, although they have persisted through ice ages and interglacial periods in the past, it is unclear how quickly they can adapt to rapid changes in habitat. The impacts of reduced sea ice vary depending on the ecological relationship between each species and sea ice[41] (Table M2). A recent special publication of Ecological Applications provides a comprehensive review of the likely impacts of climate change on Arctic marine mammals[42], and other reviews discuss impacts of climate change on marine mammals broadly at a global scale[43] and in more detail for the North Atlantic Arctic[44].

Although assessment of future impacts is by its very nature speculative, currently observed impacts on polar bears and walruses indicate that Arctic marine mammals will almost certainly be affected by the predicted changes in Arctic marine ecosystems [45]. Reduced sea ice has already been implicated in lower body condition and reduced survival of polar bears in western Hudson Bay, and similar impacts are likely elsewhere as sea ice breaks up earlier and bears are forced to fast on shore longer [46,47]. The record sea ice retreat of 2007 caused Pacific walruses to haul out along the shores of Alaska and Russia in unusually large numbers and in new locations [48]. The immediate impact of this redistribution was an increase in trampling deaths as walruses on shore stampeded in response to terrestrial disturbances [48]. Over the long-term, walruses could deplete nearshore benthic resources if they are forced to use land haul-out sites exclusively in the future. Similar shifts in the seasonal distribution of all Arctic marine mammals are likely. For example, species that are strongly tied to sea ice habitats, such as the polar bear and ringed seal, may be limited in the future to areas with sea ice refugia (e.g., summer sea ice is predicted to persist longer in the Canadian Arctic Archipelago than elsewhere), whereas sub-Arctic or migratory species may be able to access areas where sea ice had previously excluded them[41]. Further, species or populations that either migrate with the sea ice edge or make forays to the ice edge from coastal areas may have to travel farther and expend more energy as the summer sea ice edge retreats farther from the coast and from the location of the winter ice edge [49,50].

In addition to the more obvious impacts that changes in the distribution and quality of habitat will have on the distribution of Arctic marine mammals, early spring rains could cause ringed seal lairs to collapse, exposing their pups to hypothermia and increased predation by polar bears and arctic foxes [51], and it has been suggested that increased variability in sea ice and weather conditions could result in more frequent ice entrapments of narwhals and belugas [52,53]. Further, changes in the seasonality of ice retreat could result in changes in the timing and location of phytoplankton blooms (e.g., associated with the melting ice edge or in open water following ice retreat), which in turn could influence both the total amount of primary production and the allocation of that production among pelagic and benthic food webs [39]. Of course, in addition to environmental impacts, reduced sea ice will make the Arctic more accessible for some species (e.g., gray whales[1]) and for human activities, some of which could impact marine mammals (e.g., oil spills, habitat alteration, prey removals, contaminants, and ship strikes). Also, all of these species are harvested for subsistence, with varying degrees of regulation among populations and regions.

Given the threats (both observed and predicted) facing marine mammals, there is justifiable cause for concern regarding populations that are small or declining, as well as those for which information is insufficient. Expanded and accelerated research and monitoring efforts will be necessary to detect changes in the status of Arctic marine mammal populations and to identify the causes of those changes in time to allow developing problems to be addressed [54,55,56].

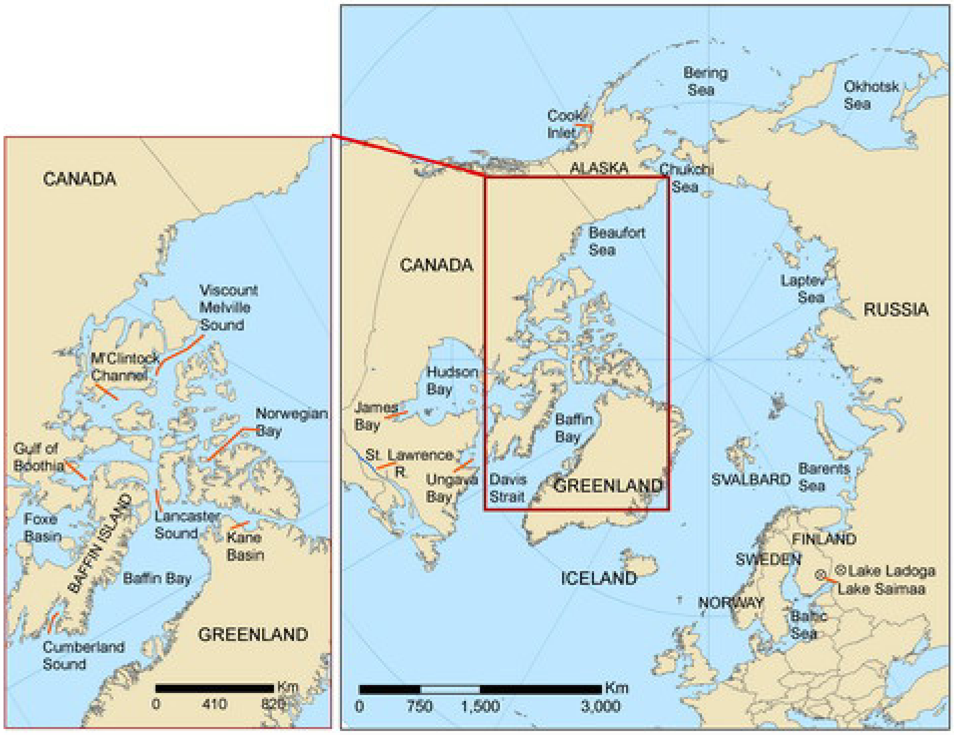

Figure M2. Map of the Arctic with place names referred to in the text or in Table M1.

Table M1. Current abundance and trends of Arctic marine mammal species. Information on abundance, trends, and most recent data (year) are summarized by biological stock, except for ringed seals, bearded seals, and walruses, whose stock structure is unknown (see table footnotes). Figure M2 indicates the locations of place names referred to here. Citation numbers refer to literature cited.

Species	Stock	Abundance	Year	Trend	Citation(s)
Bowhead whale	Bering-Chukchi-Beaufort Seas	10,500	2001	increasing	2
	E. Canada-W. Greenland	6,300	2002–2004	increasing	3,4
	Spitsbergen	unknown	—	unknown	5
	Okhotsk Sea	<400	1979	unknown	5
Beluga whale	Cook Inlet	380	2007	stable	6
	Eastern Bering Sea	18,100	2000	unknown	7

	Bristol Bay	3,300	2005	increasing	6
	Eastern Chukchi Sea	3,700	1989–1991	unknown	6
	Eastern Beaufort Sea	39,300	1992	unknown	6
	Foxe Basin	1,000	1983	unknown	8
	Western Hudson Bay	57,300	2004	unknown	9
	Southern Hudson Bay	1,300	1987	unknown	10
	James Bay	4,000	2004	unknown	11
	St. Lawrence River	1,200	2005	stable	12
	Eastern Hudson Bay	4,300	2004	declining	13
	Ungava Bay	<50	2007	unknown	14
	Cumberland Sound	1,500	1999	increasing	15
	E. High Arctic-Baffin Bay	21,200	1996	stable	16
	West Greenland	7,900	1998–1999	unknown	17
	3 stocks in Okhotsk Sea	18–20,000	1987	unknown	18
	11 additional stocks	unknown	—	unknown	
Narwhal	Canadian High Arctic	>60,000	2002–2004	unknown	19
	Northern Hudson Bay	3,500	2000	unknown	20
	West Greenland	2,000	1998–999	unknown	21,22
	East Greenland	>1,000	1980–1984	unknown	21,23
Ringed seal[a]	Arctic subspecies	~2.5 million	1970s	unknown	24
	Baltic Sea subspecies	5,000–8,000	1990s	mixed	25
	Lake Saimaa subspecies	280	2005	increasing	26
	Lake Ladoga subspecies	3,000–5,000	2001	unknown	27
	Okhotsk Sea subspecies	>800,000	1971	unknown	24
Bearded seal[b]	Bering-Chukchi Seas	250–300,000	1970s	unknown	28
	Canadian waters	190,000	1958–1979	unknown	29
	Atlantic and Russian Arctic	unknown	—	unknown	
	Okhotsk Sea	200–250,000	1968–1969	unknown	28
Walrus[c]	Bering-Chukchi Seas	~201,000	1990	unknown	30
	Atlantic subspecies	18–20,000	2006	mixed	31,32,33,34
	Laptev Sea	4,000–5,000	1982	unknown	35
	Other regions	unknown	—	unknown	
Polar bear[d]	Chukchi Sea	2,000	1993	unknown	36
	Southern Beaufort Sea	1,500	2006	declining	36
	Northern Beaufort Sea	1,200	1986	stable	36
	Viscount Melville Sound	220	1992	increasing	36
	McClintock Channel	280	2000	increasing	36
	Norwegian Bay	190	1998	declining	36
	Lancaster Sound	2,500	1998	stable	36
	Gulf of Boothia	1,500	2000	stable	36
	Foxe Basin	2,200	1994	stable	36
	Western Hudson Bay	940	2004	declining	36
	Southern Hudson Bay	1,000	1988	stable	36
	Baffin Bay	2,100	1998	declining	36
	Davis Strait	1,700	2004	unknown	36
	Kane Basin	160	1998	declining	36
	Barents Sea	2,700	2004	unknown	37
	Laptev Sea	4,000–5,000	1993	unknown	36
	3 other stocks	unknown	—	unknown	

[a] Ringed seal stock structure unknown; information summarized for five recognized subspecies.
[b] Bearded seal stock structure unknown; information summarized for geographic regions.
[c] Walrus stock structure unknown; information summarized for Atlantic subspecies and geographic regions for Pacific subspecies.
[d] Recent analysis of genetic, ecological and life history data from Canadian polar bears suggests that their stock structure may need to be revised [38].

Table M2. Key Arctic marine mammal species ecology

Species	**Primary Diet** [39]	**Relationship with Sea Ice Habitat** [40]
Bowhead whale	Zooplankton (filter feeder)	Forage in productive marginal ice zone
Beluga whale	Diverse fishes and invertebrates	Refuge from predation? Access ice-associated prey
Narwhal	Ice-associated and benthic fishes (deep diver)	Forage in areas of very dense ice
Ringed seal	Diverse fishes and invertebrates	Resting and nursing platform Access ice-associated prey
Bearded seal	Benthic invertebrates	Resting and nursing platform Access to benthic foraging grounds
Walrus	Benthic invertebrates	Resting and nursing platform Access to benthic foraging grounds
Polar bear	Seals (primarily ringed) and other marine mammals	Hunting platform

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Bowhead: Julie Mocklin, National Marine Mammal Lab, AFSC, NMFS, NOAA
Beluga: Laura Morse, National Marine Mammal Lab, AFSC, NMFS, NOAA
Narwhal: Kristin Laidre, University of Washington
Ringed seal: Brendan P. Kelly, University of Alaska Southeast
Bearded seal: Ian Stirling, Environment Canada
Walrus: Ian Stirling, Environment Canada
Polar bear: Ian Stirling, Environment Canada
Collage created by Tracey Nakamura, NOAA/PMEL

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Murres

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Introduction

The two species of murres (N. America)/guillemots (Europe), *Uria lomvia* (Thick-billed Murre) and *U. aalge* (Common Murre), both have circumpolar distributions, the former breeding in Arctic and Subarctic regions, from northern Norway, Iceland, Newfoundland and the Aleutian Islands to the High Arctic, while the latter is predominantly a Subarctic and Boreal species breeding from California, the Gulf of St. Lawrence and northern Spain to the northern Bering Sea, Labrador and Bjornoya (Bear Island). In winter, *U. lomvia* occurs mostly in Arctic waters, while *U. aalge*, although overlapping extensively with *U. lomvia*, is found predominantly in subarctic and temperate waters (Figs. 1 and 2). They are among the most abundant seabirds in the northern hemisphere, with both species exceeding 10 million adults (Gaston and Jones 1998).

Figure 1. St. Lawrence Island, Bering Sea, Alaska (Lisa Sheffield).

Figure 2. Murres on St. Lawrence Island, Bering Sea, Alaska (Lisa Sheffield).

Murres feed from coastal to pelagic waters, taking a wide range of small fish (<50 g) and invertebrates, including annelids, pteropod and cephalopod molluscs, and mysid, euphausiid, amphipod and decapod crustacea. Common Murres generally feed more on fish than Thick-billed Murres (Gaston and Jones 1998, Anker-Nilssen et al. 2000). Adults of both species weigh about 1 kg, can remain under water for up to 4 min and dive regularly to depths >100 m, reaching a maximum depth of ~150 m. Their diving capacity, when combined to their typical foraging radius of up to100 km from the colony, means that murres sample a relatively large volume of the marine environment around their colonies (Falk et al. 2000, Elliott et al. 2008).

Murres have proven useful indicators of environmental change in studies of population trends (Gaston et al. 2009), nestling growth (Barrett 2002, Gaston et al. 2005) and nestling diet (Osterblom et al. 2001). They breed in very large colonies of up to 1 million birds on mainland cliffs or offshore islands. In most places, they lay their eggs in the open, making breeding adults simple to count. Consequently, their population trends are relatively easy to assess and this, allied to their abundance and widespread distribution, makes them ideal subjects for circumpolar environmental monitoring. In addition, being robust birds and returning annually to the same breeding sites, they are useful platforms on which to deploy depth and temperature recorders, GPS and geolocator tags. These devices have greatly amplified the value of the birds for environmental monitoring.

Status and Trends

The sensitivity of murre populations to changes in environmental conditions has been demonstrated on a hemispheric scale in recent studies by the Seabird Working Group of CAFF (C-Bird). Irons et al. (2008) combined population trend data from around the Arctic with information on surface sea temperature (SST) and decadal-scale oscillations, to show that both species of murre showed negative population trends where there was a large change in SST, either warmer or cooler. Colony growth was most often positive where conditions remained relatively stable (Fig. 3). More specifically, the northern species, *U. lomvia*, exhibited highest population growth where conditions warmed moderately. *U. aalge* showed highest rates of increase where things cooled moderately. In the context of global warming, this result suggests that not only the direction but the magnitude of change may be important in determining outcomes and that Common and Thick-billed Murres may not necessarily react in the same way to a given temperature change.

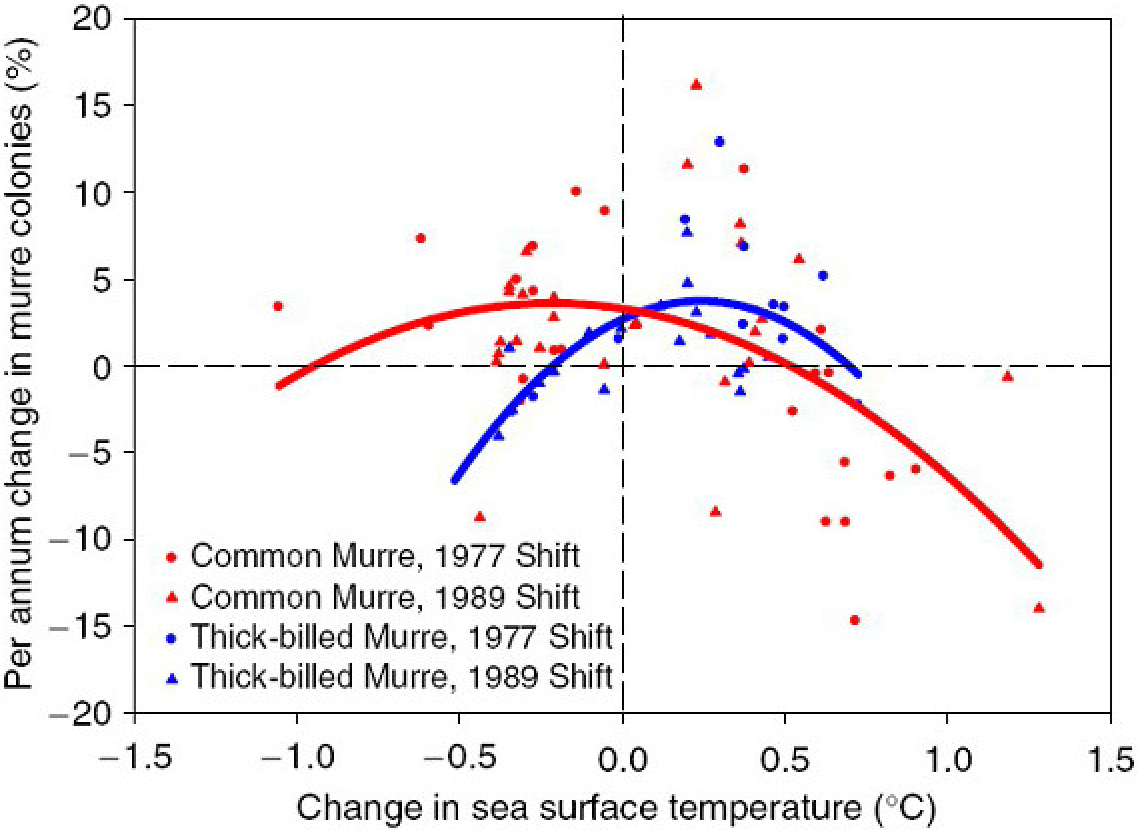

Figure 3. Relationship between per annum change in the size of murre colonies during the 12 years after the1977 climatic regime shift and during 9 years after the 1989 shift, and changes in sea surface temperatures around the colonies from one decadal regime to the next. Population data are from 32 Common and 21 Thick-billed Murre colonies, encompassing the entire circumpolar region. As 10 sites supported both species, 43 different study areas were represented. Quadratic functions were fitted to the data (Thick-billed Murres P=0.002, df=27, r2=0.370; Common Murres P<0.001, df=48, r2=0.280). Reprinted from Irons et al. 2008.

Both species have shown substantial variation in regional population trends since the 1970s. A comparison of the period from 1977-1989, when Sea Surface Temperatures (SST) in the North

Pacific were generally above normal and those in the North East Atlantic generally below normal, with the period from 1989-1999 when the situation reversed, showed that populations in the North Pacific were generally decreasing during the earlier decade and increasing subsequently (Fig. 4, Irons et al. 2008). Conversely, those in the eastern Atlantic showed more variable trends. However, several European colonies were affected by widespread collapse of fish stocks in the 1980s (Vader et al. 1990). Those European colonies not affected by fish-stock collapses mostly increased up to 1989, but increases were less general between 1989-1999. Only a few colonies, principally those in the eastern Canadian Arctic, have shown consistent increases in population and no colonies have shown persistent downward trends (C-bird unpubl. data). Subsequent to 1999, regional trends have been less clear. Populations of both species in the Barents Sea have begun to recover from earlier declines related to fish stock collapse (Barrett et al. 2006). Those in Alaska and in the Canadian Arctic have been stable overall since the 1990s (Dragoo et al. 2008, Gaston et al. in press).

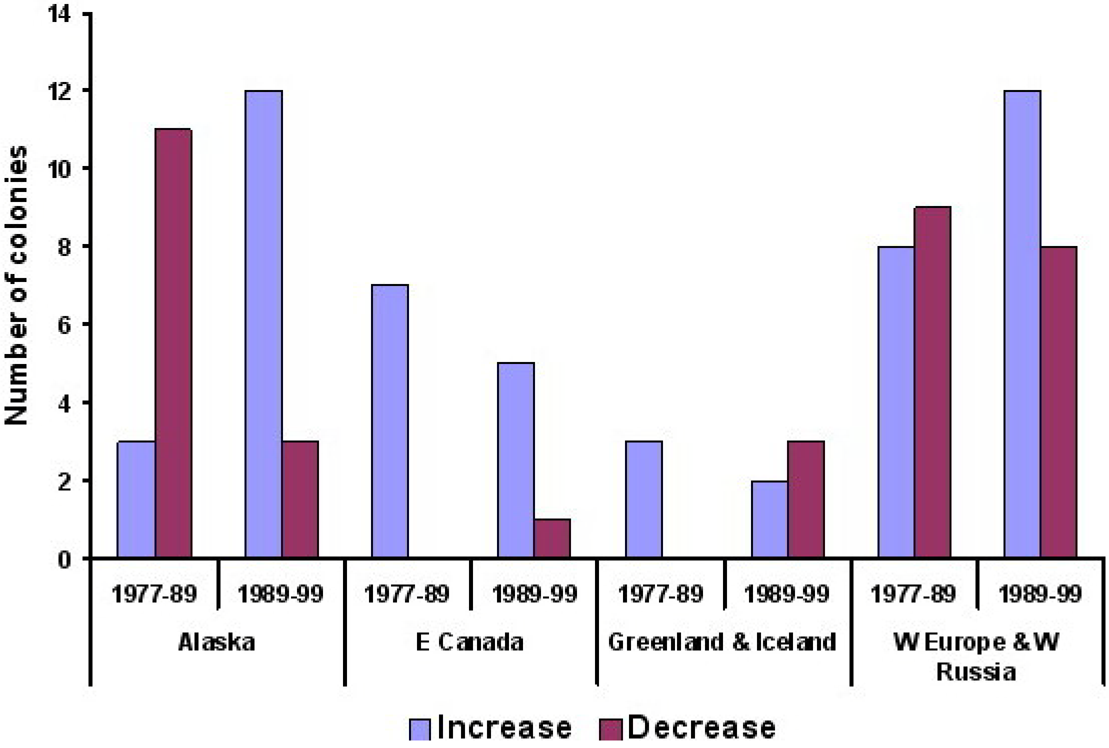

Figure 4. Number of Common and Thick-billed Murre colonies increasing or decreasing during 1977-1989 and 1989-1999.

Threats

Murres, both adults and eggs (especially lomvia), are harvested by aboriginal people and by local communities in many Arctic jurisdictions. These activities are not thought to have much impact on populations except in West Greenland, where some colonies have been substantially reduced by harvesting of adults while breeding (CAFF). Both species are highly susceptible to oiling and they are often the most numerous species killed by oil spills. They are frequently drowned in gill-nets, especially when these are set overnight (Melvin et al. 1999): hundreds of thousands were killed in salmon gill-nets off West Greenland in the 1960s (Tull et al. 1972).

Although currently abundant, with few populations showing cause for alarm, climate change will pose a future problem and range contraction appears likely in the longer-term.

Knowledge Gaps

Despite substantial research and monitoring on the two species, information is generally inadequate to quantify changes in murre feeding ecology and food availability, or changes in mortality due to oil pollution, commercial fisheries, and hunting. In 1996, the Circumpolar Seabird Group reviewed conservation issues affecting murres, and produced an *International Murre Conservation Strategy and Action Plan* to guide future international conservation efforts. The plan proposed action to assess the threats to murres from harvests, and commercial and industrial activities. The Plan also recommended further research to address the potential effects of global climate change on murre populations.

* **Note:** On "murres" vs "guillemots". We think the use of murres is preferable because guillemot does not exclude *Cepphus* spp. when used as a collective noun.

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Fisheries in the Bering Sea

J. Overland

NOAA, Pacific Marine Environmental Laboratory, Seattle, WA

October 5, 2009
Conditions in 2010 remain similar to those in 2009

With warm sea temperatures during 2000 to 2005, the Bering Sea was showing indications that Arctic species that require the presence of sea ice were being replaced by sub-Arctic species that don't require sea ice. This is shown schematically in the Figure F1 as a shift of the biological energy pathway that favors bottom animals (Benthic) to one favoring species that live closer to the ocean surface (Pelagic).

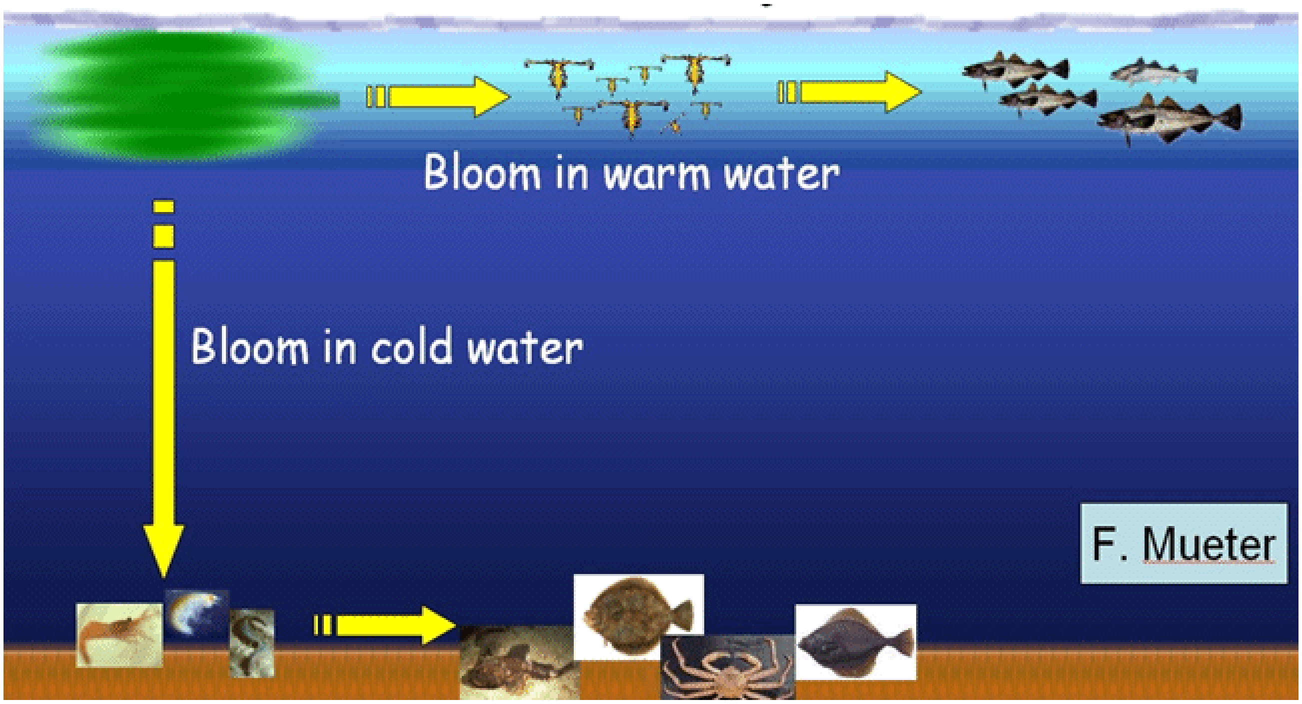

Figure F1. Bering Sea Ice shifting from Benthic to Pelagic Pathway.

However since 2005, the Bering Sea has been relatively cold with more sea ice in the winter and spring than normal. In 2008 and 2009, the winter sea ice extent in the Bering Sea was at a near record maximum, not seen since the early 1970s, and ocean temperatures were at a near record minimum (Figure F2). Under these conditions, cold water species, such as Arctic cod, have returned toward the south. At present Bering Sea climate change and ecosystem response are more effectively characterized by natural variability with multiple years of warm and cold temperatures, than by an emerging global warming trend or by an influence from the major summer sea ice losses in the Arctic Ocean proper.

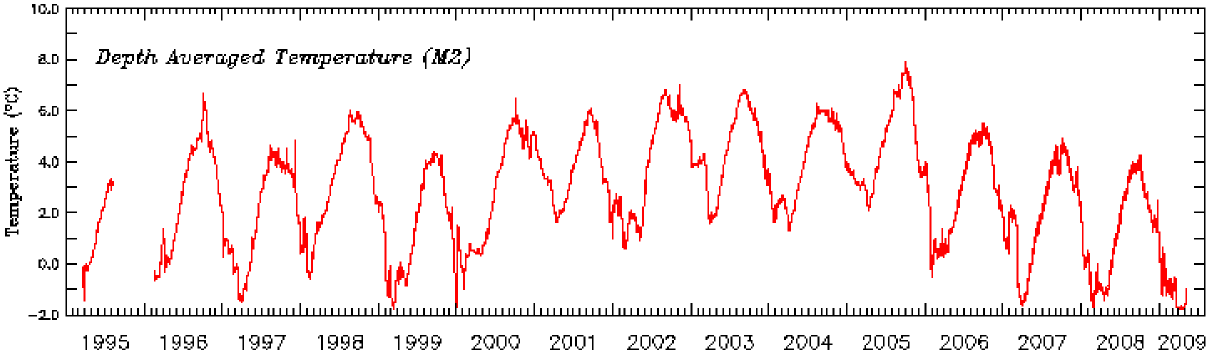

Figure F2. Southeast Bering Sea summer ocean bottom temperatures. From NOAA, P. Stabeno.

Pollock are a major economic resource from the Bering Sea. Warm temperatures and lack of sea ice have tended to favor pollock in the recent past, creating one of highest biomass for any large marine ecosystem throughout the world. The biomass for pollock in the Bering Sea and the number of new fish added each year (called recruitment) are shown in Figure F3. In recent years pollock recruitment has been low, with the decrease beginning before the return of the cold temperatures (Figure F2). The Bering Sea pollock population is now in collapse. It is suggested that during the end of the warm period (2003-2005), the normal food supply for pollock shifted to less favorable species and that pollock predators, such as arrowtooth flounder, became well established. With the recent shift to a cold period, the favorable food supply for pollock returned to the Bering Sea, but it was less available due to the presence of sea ice. Further, the continued presence of arrowtooth flounder as a predator on pollock remained a negative factor.

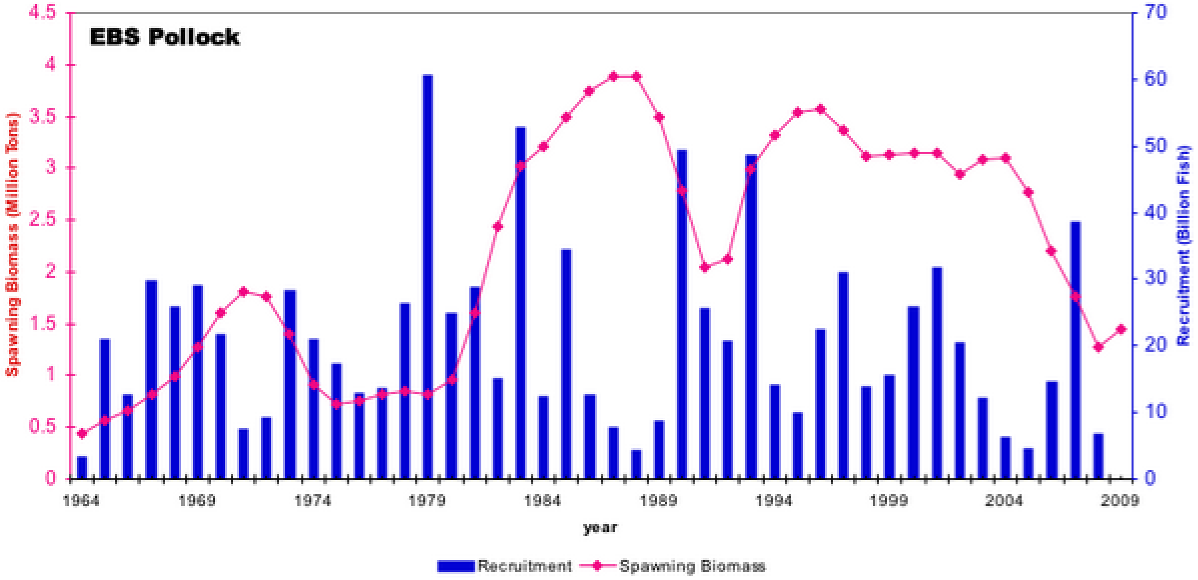

Figure F3. Bering Sea Pollock. Diamonds indicate biomass, and vertical bars indicate recruits to the population each year. From the NOAA/NMFS SAFE report.

Bering Sea temperatures respond both to global warming and large natural variability. While the Bering is cold at present we anticipate a swing back to average temperatures in the coming winter due to El Niño conditions. By 2020 or before, we anticipate a swing back to prolonged warm temperatures. This scenario would continue the negative impact on Arctic and bottom species, such as crab, while favoring sub-Arctic species such as salmon.

Reference

Stock Assessment and Fishery Evaluation Report (SAFE Report) from NOAA / AFSC.

Status of the Barents Sea Ecosystem

Norwegian Institute of Marine Research
http://www.imr.no/tokt/toktomtaler/okosystemtoktet/toktdagbok_2010/fremdeles_lave_temperaturer_i_barentshavet/nb-no

Abstracted by J. Overland, NOAA, Pacific Marine Environmental Laboratory

October 14, 2010

Summary

The stocks of capelin, Northeast Arctic cod and haddock are all increasing. Stocks of shrimp and saithe have decreased in recent years. All five stocks are harvested in a sustainable manner and have full reproductive capacity. The stock of polar cod is at a high level. The stocks of Greenland halibut, golden redfish, deep-sea redfish and coastal cod are at low levels. In a long-term perspective, the water masses are warm, although on average, not as warm as in 2006 (Figure BA1).

The temperature goes down in the Barents Sea

The downward trend in sea temperature that has been observed in the Barents Sea since 2006 continues. Preliminary data from ecosystem cruises shows that the southwestern parts of the ocean are still slightly warmer than average, but colder than in 2009. The biggest change is in the area outside of northern Svalbard, where temperatures in some areas are more than 3°C lower than the year before. There is much ice north of Svalbard, although elsewhere in the Arctic ice cover is low (see Sea Ice section).

Atlantic water flowing into the Barents Sea from the south has great influence on sea temperatures. The inflow of this water is measured in a fixed oceanographic section, Fugløya Bear Island, which crosses the entrance to the Barents Sea. Since the record warm year in 2006, there has been a gradual decline in temperatures in the Atlantic waters, and this year's research shows that this persists (Figure BA1). Still, the temperature is above average, but only by about 0.3°C, and this is the lowest that has been measured since 2001. Climate variability in the ocean area is large, and the decline that is now observed is consistent with natural climate fluctuation.

Sea temperatures are measured at all stations around the Barents Sea. The data from the southwestern Barents Sea suggest the same as average: Slightly colder than the previous year, but still above the long-term average.

Ecosystem expeditions cover the areas west and north of Svalbard, and it is in these areas that the largest changes have recently been observed. In 2009, in Atlantic waters off the northern part of Svalbard, temperatures were recorded up to about 7.5°C (Figure BA1), while this year's cruise shows maximum temperatures of about 4.5°C in the same area indicating a significant decline in sea temperature in these areas.

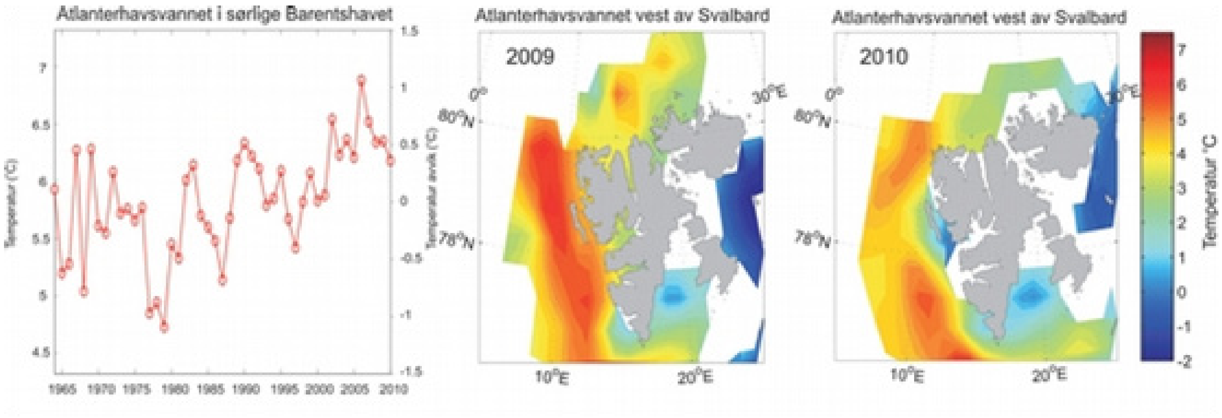

Figure BA1. The left figure shows the temperature in the Atlantic water flowing into the Barents Sea in the south. Vertical axis on the left side of the figure shows the temperature, while the axis on the right side of the figure shows the temperature deviation from the mean of the 30-year period 1977-2006. The two figures on the right show temperatures at 100 meters depth, measured in 2009 and 2010.

Ice conditions

In 2010, much ice was be found in the area north of Svalbard at the end of summer, but it is also the only place with a lot of ice relative to the mean (Figure BA2). For most of the Arctic, the minimum summer sea ice extent was much less than average (see the Sea Ice summary for more details). Sea ice position is largely dependent on wind direction. West wind results in ice moving southward, and in the last few weeks of September there was an extensive concentration of ice in the area north of Svalbard. The relatively large amount of ice in this area is likely an indication of frequent west winds and lower temperatures.

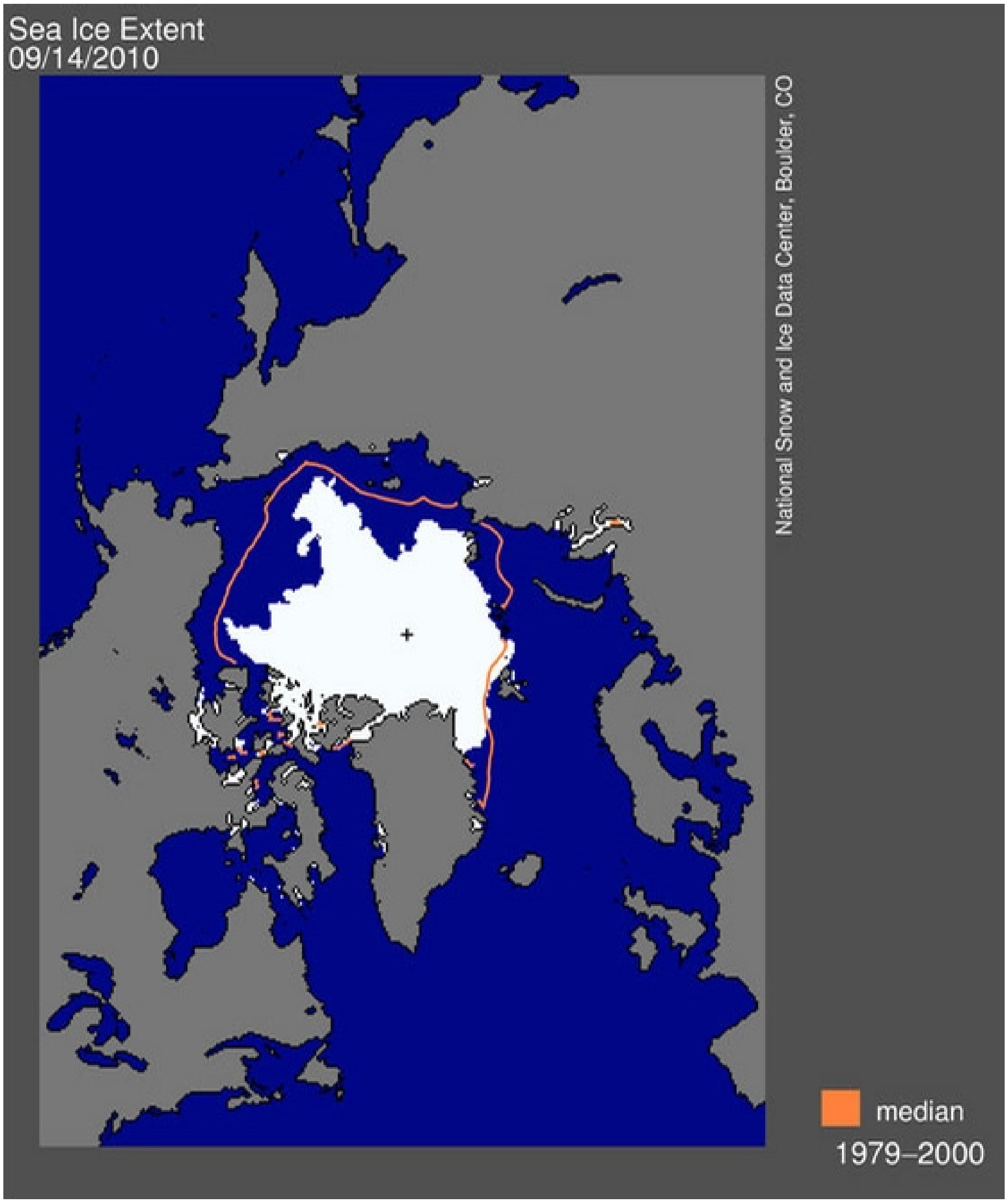

Figure BA2. Distribution of sea ice on 14 September 2010, close to the time of minimum ice extent for 2010. The orange line shows the average from 1979-2000 on the date shown. A figure derived from the National Snow and Ice Data Center, and daily updates can be seen http://nsidc.org/arcticseaicenews/.

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http://www.imr.no/tokt/toktomtaler/okosystemtoktet/toktdagbok_2010/fremdeles_lave_temperaturer_i_barentshavet/nb-no

The State of Char in the Arctic

C. D. Sawatzky and J. D. Reist

Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, MB

October 15, 2009
No new updates for 2010

Introduction

Arctic Char are the most northerly distributed freshwater fish species and occur in suitable habitats in all Arctic countries. They are widely distributed throughout the circumpolar north (Figure C1) from northernmost areas south to temperate regions (e.g., Switzerland, Italy) (Johnson 1980), with a latitudinal distribution of approximately 40°N to 84°N.

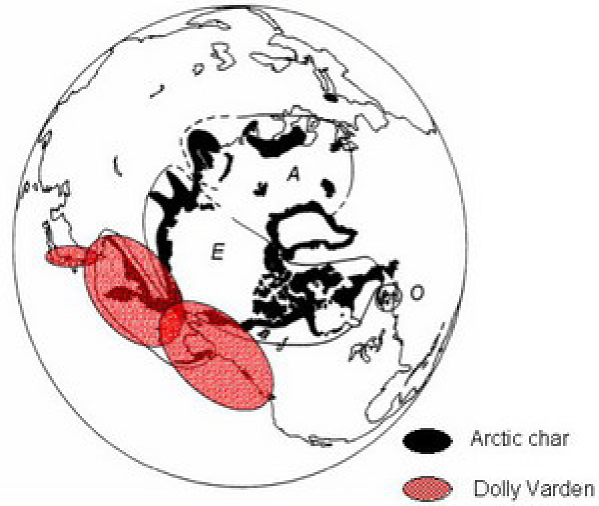

Figure C1. Global distribution of Arctic char and Dolly Varden.

The two most widely distributed groups are Arctic char (*Salvelinus alpinus*), a diverse primarily lake-adapted group (Figure C2), and Dolly Varden (*Salvelinus malma*), primarily a river-adapted group (Figure C3). Both occur as anadromous (sea-run) and freshwater resident forms. They are important components of northern aquatic ecosystems and are economically (subsistence food, commercial and sport fisheries) and culturally significant to northern communities (Conservation of Arctic Flora and Fauna 2001), particularly in Canada. For example, Arctic char made up approximately 45% by number of the top 15 species harvested in Nunavut between 1996 and 2001 (Priest and Usher 2004). The majority of the Canadian commercial Arctic char catch is taken in Nunavut fisheries at Rankin Inlet, Cambridge Bay, Pelly Bay and Nettilling Lake (DFO 2006).

Figure C2. An example of morphological diversity in Arctic char on a regional scale; these fish were sampled from one lacustrine and one marine site in northern Labrador, Canada. Photo by Wendy Michaud.

Figure C3. Adult male anadromous Dolly Varden char in spawning condition captured in the Firth River, Yukon Territory, Canada. Photo by Jim Johnson.

Formal Status Assessments by Conservation Organizations

Several regional and/or national organizations conduct formal status assessments to conserve biodiversity; examples include the International Union for the Conservation of Nature (IUCN http://www.iucn.org/) based in Europe and Natureserve (http://www.natureserve.org/) based in North America. These are supplemented by formal assessment groups in many countries; e.g., in Canada the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, http://www.cosewic.gc.ca/). All conduct assessments of various taxa (species or taxonomic units below species) according to established criteria and based upon the best available information. Summaries are shown in Figure C4 for IUCN assessments.

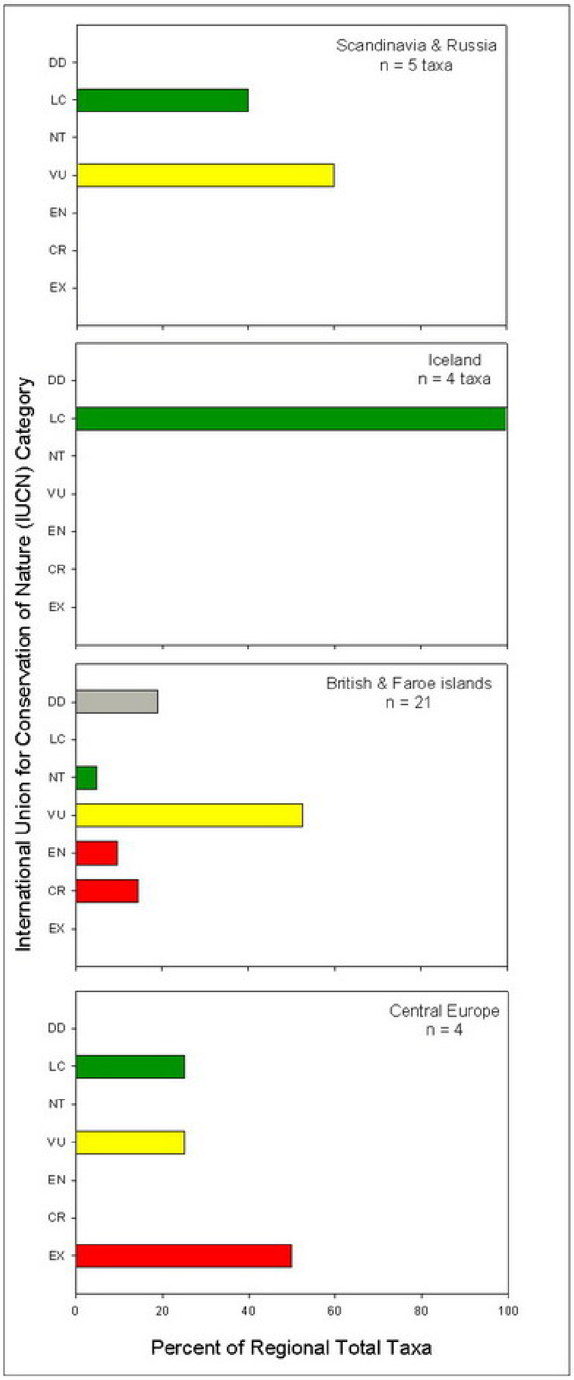

Figure C4. Percentages of European Char Taxa assessed at different levels of risk by IUCN criteria (http://www.iucn.org/; accessed 8 August 2009) for different regions. Note that there is much disagreement regarding the taxonomy used by IUCN, numbers of taxa are small, and assessments tend to be biased towards 'stressed' taxa. Colors indicate different groups of threat levels: gray – information lacking (DD = data deficient), green – assessed at minimal concern (LC = least concern, NT = near threatened), yellow – assessed at increased concern (VU = vulnerable), and, red – assessed at high concern (EN – endangered, CR – critically endangered, EX – extinct). Southern areas exhibit higher percentages of yellow and red threat groups.

Natureserve rankings are not plotted, and taxonomy is not comparable with that used by IUCN (i.e., North American species tend to represent multiple sub-specific taxa). For the five recognized species-level taxa in North America rankings are as follows:

- Southern (non-arctic) – three species are secure and one vulnerable (global rankings);
- Northern (Arctic) – one species is secure.

Natureserve rankings for sub-specific taxa (i.e., components of the above) provide additional understanding as follows:

- Within the continental USA, five of five distinct population groupings of bull char (*S. confluentus*, vulnerable as a species) rank as critically imperiled (n=1) or imperiled (n=4); assessment for 3-4 groups in Canada is underway;
- One southern taxon (*S. alpinus oquassa*) of the Arctic char complex is imperiled in southern Canada and northeastern United States (Natureserve = imperiled, COSEWIC = under assessment; northern Arctic char populations are secure);
- One southern taxon (*S. fontinalis timageamensis*) found in central Ontario of the brook char group is critically imperiled (Natureserve; COSEWIC = endangered);
- The southern taxon (*S. malma lordi*) of the Dolly Varden group is secure throughout its range (southern Alaska, British Columbia to Washington), and the northern taxon (*S. malma malma*) is secure throughout Alaska, however, it appears to be stressed in northwestern Arctic Canada (COSEWIC assessment underway; two of five anadromous populations stressed).

Conclusions

Virtually all stressors which are known to affect fish populations generally have been documented as affecting chars, a group which appears to be particularly susceptible to both local (e.g., exploitation) and pervasive (e.g., climate change) stressors as well as individual and cumulative effects of stressors. From the evidence presented above southern populations (or taxa) of chars, particularly the wider group related to Arctic char, appear to be at greater risk overall as evidenced by higher levels of conservation concern (i.e., more acute conservation status) and by greater percentage of extirpations particularly in Europe. Trends appear to be similar for North America. Two inescapable conclusions thus result: 1) southern populations of chars, particularly those isolated in lakes or requiring unperturbed river habitats, are at acute risk and given their probable evolutionary history represent an irreplaceable component of biodiversity of the Arctic char group; and, 2) southern populations are useful proxies of potential future effects and issues facing northern chars. Accordingly, appropriate care in addressing conservation, management, and stressors of both chars and their ecosystems is required particularly as wide-reaching changes occur throughout the north.

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Additional Resources

Selected Recent Publications on Trends in Canadian Populations of Arctic Char

Dempson, J.B., Shears, M., Furey, G., and Bloom, M. 2004. Review and status of north Labrador Arctic charr, *Salvelinus alpinus*. Canadian Science Advisory Secretariat (CSAS) Research Document 2004/070: 46 p. [available from: http://www.dfo-mpo.gc.ca/Library/284126.pdf; accessed: 24 July 2008].

DFO [Department of Fisheries and Oceans]. 2004a. Cambridge Bay Arctic char. Canadian Science Advisory Secretariat (CSAS) Stock Status Report 2004/10: 15 p. [available from: http://www.dfo-mpo.gc.ca/Library/284796.pdf; accessed: 24 July 2008].

Tallman, R. 2005. Stock assessment report on Kipisa Arctic char. Canadian Science Advisory Secretariat (CSAS) Science Advisory Report 2005/028: 14 p. [available from: http://www.dfo-mpo.gc.ca/csas/Csas/status/2005/SAR-AS2005_028_E.pdf; accessed: 24 July 2008].

Selected Recent Publications on Trends in Canadian Populations of Dolly Varden

DFO [Department of Fisheries and Oceans]. 2001. Rat River Dolly Varden. DFO Science Stock Status Report D5-61: 15 p. [available from: http://www.dfo-mpo.gc.ca/Library/264842.pdf; accessed: 24 July 2008].

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Goose Populations

M.J.J.E. Loonen[1], C. Zöckler[2], B. Ebbinge[3]

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March 20, 2008
Update is in progress and will be available in Spring 2011

Since the 1970's, many goose populations have gone through an impressive increase in size. In the last decade, the global goose population almost doubled from 12.5 million birds (Madsen et al. 1996) to a current total of 21.4 million (Wetlands International, 2006). Most of these population increases have coincided with large range extensions within the Arctic, but also into temperate regions. Changing agricultural practices have resulted in new, abundant and high quality food sources for wintering geese (Van Eerden et al. 1996, Fox et al. 2005). This has occurred while hunting pressure has decreased through improved legislative protection, a decline in the ratio of hunters per 1000 geese and the establishment of refuge areas.

Goose populations are intensively monitored. Population estimates are based on simultaneous counts in wintering areas, often supplemented with data on nesting densities, ring recoveries and sightings of colour-marked individuals. Wetlands International (www.wetlands.org) is the organization which compiles all population data with help of its Goose Specialist Group (www.geese.nl/gsg).

Geese are common in many parts of the Arctic. All Arctic populations are migratory and their annual migration routes and stop over places involve a large proportion of the Northern Hemisphere, including almost all countries in North America, Europe and North, Central and East Asia. Goose populations have a direct and significant influence on Arctic ecosystems as exemplified by recent impacts on tundra vegetation due to expanding populations and via the role played by goslings and eggs as a food source for predators in the Arctic.

The most recent review of water bird populations (Wetlands International, 2006) considers several Arctic goose populations as declining. The declines are widely distributed across all flyways indicating a possible link to phenomena acting on a circumpolar scale. Figure E1 depicts the overall distribution of trends within Arctic goose populations. For nine percent of the population, there is no or insufficient information on trends. Thirty-six percent of the populations are still increasing, thirty-two percent are stable, but twenty-three percent are declining – a proportion slightly higher than compared with ten years ago (Madsen et al. 1996).

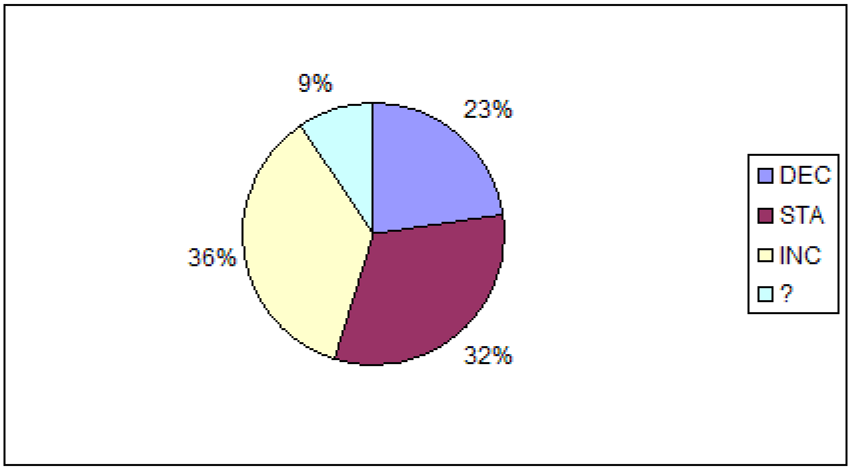

Figure E1. Trends in 47 Arctic Geese populations (Wetlands International, 2006). DEC - population decreasing; STA - population stable; INC - population increasing; ? - unknown

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Arctic Wildlife

The Arctic Species Trend Index: A Barometer for Arctic Wildlife

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Introduction

Dramatic changes (e.g., sea ice loss) in the Arctic's ecosystems are predicted to occur over the next century (ACIA 2005). Understanding how the Arctic's living resources, including its vertebrate species, are responding to these changes is essential in order to develop effective conservation and adaptation strategies. Arctic species that are adapted to these extreme environments are expected to be displaced, in part, by the encroachment of more southerly species and ecosystems (Post *et al* 2009). Since Arctic ecosystems are characterized by low species diversity, they are at heightened risk of experiencing dramatic changes. The loss of a single species could have dramatic and cascading effects on an ecosystem's state and function (Post *et al* 2009). The current, mostly, single species approach to monitoring, with a bias towards charismatic species over functional species, limits our ability to detect and understand critical changes in the Arctic's ecosystems. A broader and more integrated approach is needed to facilitate a better understanding of how biodiversity is responding to a changing Arctic, and how these changes might reflect or counter global biodiversity trends.

For the first time, an index that provides a pan-Arctic perspective on trends in the Arctic's living resources is available. The Arctic Species Trend Index (ASTI), like the global Living Planet Index (LPI), illustrates overall vertebrate population trends by integrating vertebrate population trend data of an appropriate standard (Collen *et al* 2009) from across the Arctic and over the last 34 years (with 1970 as the baseline[1]). An increasing index indicates that, overall, more vertebrate populations in the Arctic are increasing than decreasing. Whereas a decreasing index, indicates the opposite situation. This index not only allows for a composite measure of the overall trajectory of Arctic vertebrate populations, but can be disaggregated to investigate and display trends based on taxonomy, biome, region, period and other categories. These disaggregations will facilitate the identification of potential drivers of these trends. Over time, tracking this index will help reveal patterns in arctic wildlife response to growing pressures, thereby facilitating a better predictive ability on the trajectory of arctic ecosystems.

Status and Trends

A total of 965 populations of 306 species (representing 35% of all known Arctic vertebrate species) were used to generate the ASTI. In contrast to the global LPI (Loh *et al* 2008), whose overall decline is largely driven by declines in tropical vertebrate populations, the average population of arctic species rose by 16% between 1970 and 2004. This pattern is very similar to the temperate LPI (Loh *et al* 2008) and is consistent in both the North American and Eurasian

Arctic. The overall increasing trend in the Arctic is thought to be partly driven by the recovery of some vertebrate populations (e.g., marine mammals) from historical overharvesting (George *et al* 2006) as well as from recent changes in environmental conditions both inside (e.g. Bering Sea Pollock (Overland 2008)) and outside (e.g. Lesser Snow Geese (Abraham *et al* 1997)) of the Arctic, resulting in dramatic increases in some species' populations. This increasing trend, however, is not consistent across biomes, regions or groups of species.

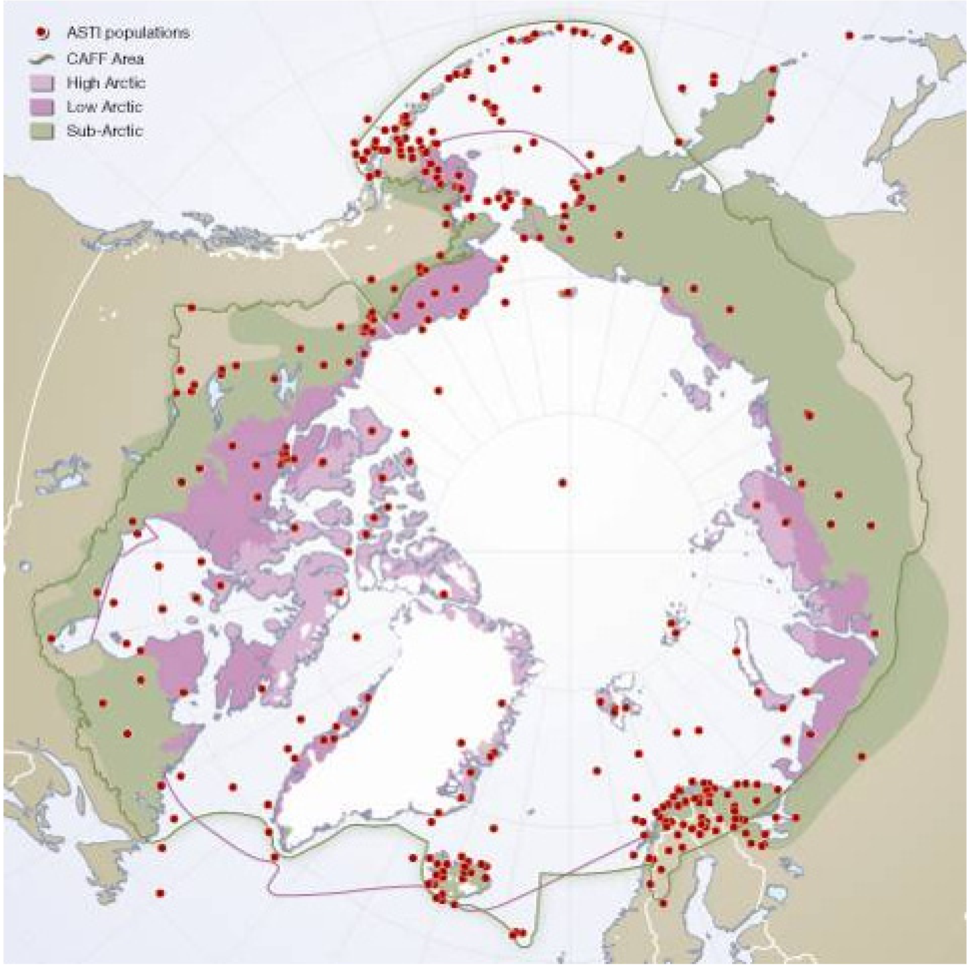

Figure W1. Location of datasets in the Arctic Species Trend Index.

Populations in the High, Low and Sub-Arctic boundaries (map in Figure W1), for instance, show markedly different trends. High Arctic vertebrate abundance has experienced an average decline of 26%. Despite an initial growth period until the mid-1980s, Sub Arctic populations (mostly terrestrial and freshwater populations) have, on average, remained relatively stable (-3% decline) whereas Low Arctic populations, largely dominated by marine species, show an increasing trend (+46%). This pattern may reflect, to some extent, varying and predicted responses [ACIA 2005; Post *et al* 2009) to changing pressures such as climate change and harvest patterns, but may also reflect natural, cyclic patterns for some species and populations. Regardless, caution is needed in interpreting these results.

The High Arctic has experienced the greatest increases in temperature to date and even greater temperature increases are expected, resulting in further loss of sea ice extent and range contraction of high arctic ecosystems and species (ACIA 2005; Anisimov *et al* 2007). However, 34 years is too limited a time series to attribute these environmental changes to declining trends in High Arctic vertebrates. For example, wild barren-ground caribou and reindeer herds are known to naturally cycle over long time periods. Recent, largely synchronous declines across the Arctic are thought to be natural and in part, responsible for the declining High Arctic index. However, declines in other species populations, such as lemmings in Greenland, Russia and Canada, may be, in part, the beginning of a negative response to a dramatically changing system. In contrast, increasing trends in Low Arctic populations are biased by dramatically increasing fish populations in response to changing marine conditions (Overland 2008) and recovering marine mammal populations (George *et al* 2006) in the eastern Bering Sea. More data are needed in other arctic marine systems before an accurate picture regarding arctic marine vertebrate population trends can be developed.

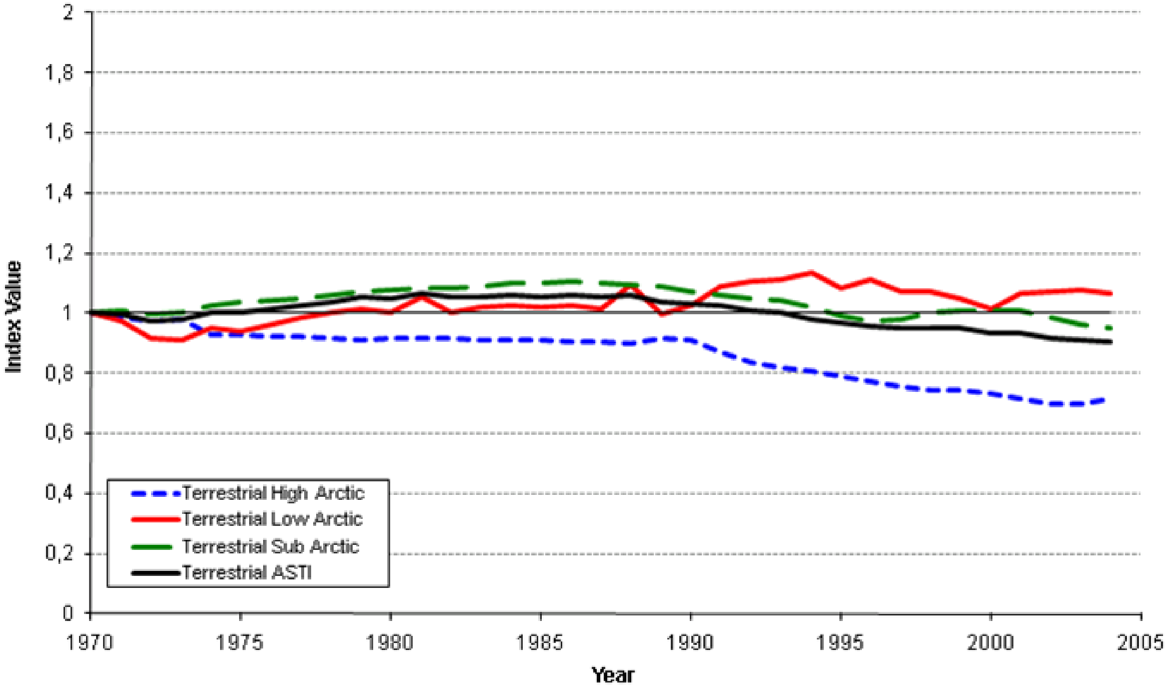

Figure W2. Index of terrestrial species disaggregated by Arctic boundary for the period 1970-2004. (High Arctic, n=25 species, 73 populations; Low Arctic, n=66 species, 166 populations; Sub Arctic, n=102 species, 204 populations)

Divergent patterns are also observed between the different biomes (marine, freshwater, terrestrial). Whereas the freshwater and marine indices increase over the time period (52% and 53% respectively), the terrestrial index shows an overall decline of 10% despite increasing in the late 1970's to mid-1980's. The data behind the freshwater index is currently too sparse (51 species, 132 populations) to fully reflect the circumpolar freshwater situation, and whilst the marine index is robust (107 species, 390 populations), it is largely driven, as is the Low Arctic index, by an overweighting of population data from the eastern Bering Sea. The moderate decline in the terrestrial index (-10%) is largely a reflection of declines (-28%) in terrestrial High Arctic populations (mostly herbivores (e.g. caribou, lemmings), whereas terrestrial Low Arctic populations (e.g. Lesser Snow Geese (Abraham *et al* 1997)) have increased by 7% and Sub Arctic populations have declined (-5%) slightly (Figure W2). Terrestrial Low Arctic population increases are driven, in part, by dramatically increasing goose populations, but may also reflect ecological response to climatic changes whereby species with more southerly distributions are responding favourably to these climatic changes (Post *et al* 2009). This northward movement of southern species (e.g. Red Fox (Killengreen *et al* 2006) coupled with increasing incidence of severe weather events in the High Arctic (Post *et al* 2009; Miller *et al* 2003) and changing tundra vegetation (Sturm *et al* 2001; Wahren *et al* 2005) may explain, in part, the declines in terrestrial High Arctic populations and the expected negative impact on herbivorous species.

The major arctic taxa (birds, mammals and fish) also exhibit divergent trends. Birds, which comprise 52% of the ASTI populations, are revealing a very flat trend overall (-2%), whereas mammal populations increased fairly steadily (+33%) over the same time period. The fish index experienced the greatest increase (+96%), but, again, this is primarily driven by marine fish population increases in the Eastern Bering Sea. Within the bird taxa, freshwater birds have increased dramatically (+43%) and is largely a reflection of increases in some waterbird populations, likely in response to stricter hunting regulations and land-use changes on their wintering grounds (Drent *et al* 2007). The terrestrial bird index, despite a doubling in the numbers of geese, has experienced a moderate decline (-10%) over the past 34 years, whereas marine birds, although fluctuating, have remained relatively steady (-4%). An analysis of migrant versus non-migrant birds showed an increasing trend for non-migrants (+20%) and a slight decline (-6%) for migrants, although there was no significant differences between the two groups. However, the slight decline in migrant birds would have likely become a more significant decline if the increasing geese populations were not included and we were able to include shorebird population trend data derived from non-Arctic survey sources[2]. Declines in migrant shorebirds to date is mostly regarded as a response to pressures (land-use changes, etc.) found on wintering and stop-over sites (Stroud *et al* 2006; Piersma *et al* 2001; Niles *et al* 2009), but expected changes to arctic breeding habitat as a response to climate change may also become a factor in the long-term, as most High Arctic species and populations would be at risk (Post *et al* 2009; Meltofte *et al* 2007).

While the ASTI offers some initial insight into recent trends in Arctic vertebrate populations, and notwithstanding the over-representative sample of Arctic vertebrate species, careful interpretation of the ASTI is required, as it does not yet adequately represent all populations, taxa, biomes and regions. The large number of Bering Sea populations in the Marine index and the recent recovery of marine mammal populations from historical overharvesting illustrate how the index can be influenced and reveals the shortcomings that a restricted timeline of biodiversity change presents. While rapid, human-induced changes in Arctic ecosystems are already likely resulting in winners and losers among arctic species and populations (Post *et al* 2009), more data coverage and longer-time series are needed to give an accurate, unbiased picture. Despite the limited time series for the index, the large and diverse collection of data in the index, representing a multitude of taxa across regions, biomes and longitudes does allow some insight into potential responses to human-induced pressures, outside of natural variation. This index will improve with the scale, number and breadth of contributions and future analyses will be more robust in their messages.

Endnotes

[1] 1970 was used as the baseline as pre-1970 data in the ASTI was limited making trend results uncertain for years preceding 1970.

[2] Population trend data derived from non-arctic surveys were not included in the analyses.

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Addendum

At the time this PDF file was created, the *Arctic Report Card: Update for 2010* was still undergoing final edits and revisions. The most recent and correct information can be found on the Arctic Report Card website, http://www.arctic.noaa.gov/reportcard/.