Arctic Report Card 2008

Tracking recent environmental changes

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

Warming (red) and mixed (yellow) signals

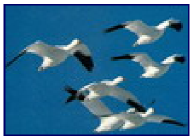
There continues to be widespread and, in some cases, dramatic evidence of an overall warming of the Arctic system.

Atmosphere

5° C temperature increases were recorded in autumn

Sea Ice

Near-record minimum summer sea ice extent



Biology

Fisheries and marine mammals impacted by loss of sea ice

Ocean

Observed increase in temperature of surface and deep ocean layers

Greenland

Records set in both the duration and extent of summer surface melt

Land

Permafrost temperatures tend to increase, while snow extent tends to decrease

October 2008

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Atmosphere

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Summary

Autumn temperatures are at a record 5º C above normal, due to the major loss of sea ice in recent years which allows more solar heating of the ocean. Winter and springtime temperatures remain relatively warm over the entire Arctic, in contrast to the 20th century and consistent with an emerging global warming influence.

The year 2007 was the warmest on record for the Arctic, continuing a general, Arctic-wide warming trend that began in the mid-1960s (Fig. A1).

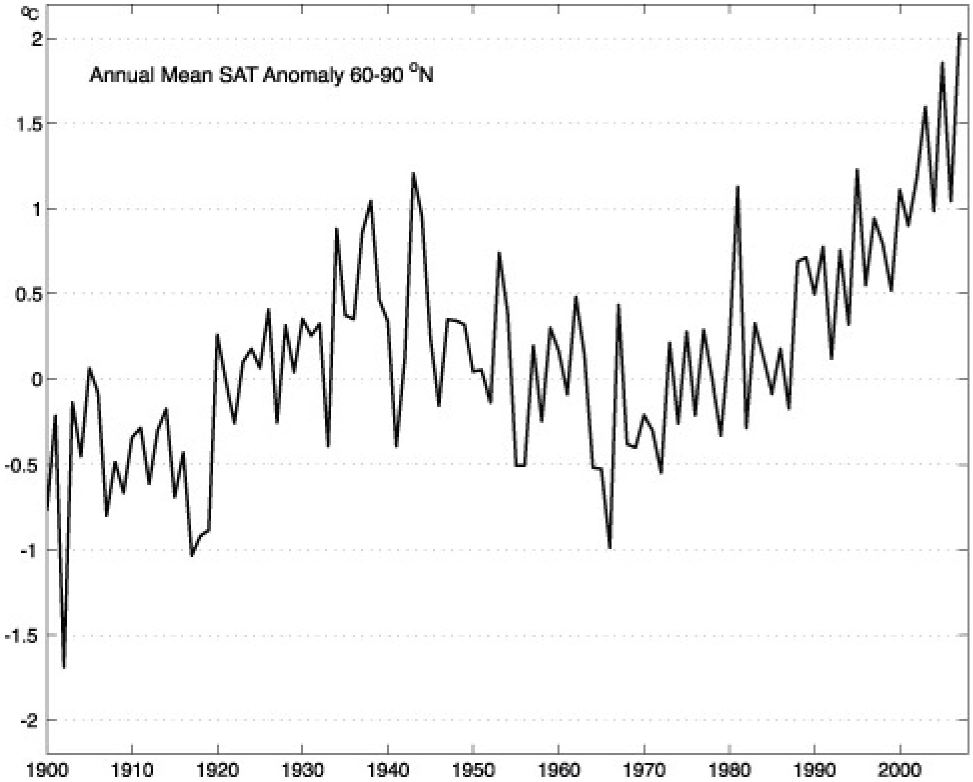

Figure A1. Arctic-wide annual averaged surface air temperature anomalies (60°–90°N) based on land stations north of 60°N relative to the 1961–90 mean. From the CRUTEM 3v dataset, (available online at www.cru.uea.ac.uk/cru/data/temperature/. Note this curve does not include ship observations.

The summers of 2005 through 2007 all ended with extensive areas of open water (see sea ice section). This allowed extra heat to be absorbed by the ocean from solar radiation. As a result ice freeze-up occurred later than usual in these years. Surface air temperature (SAT) remained high into the following autumns, with warm anomalies above an unprecedented +5° C during October and November across the central Arctic (Fig. A2).

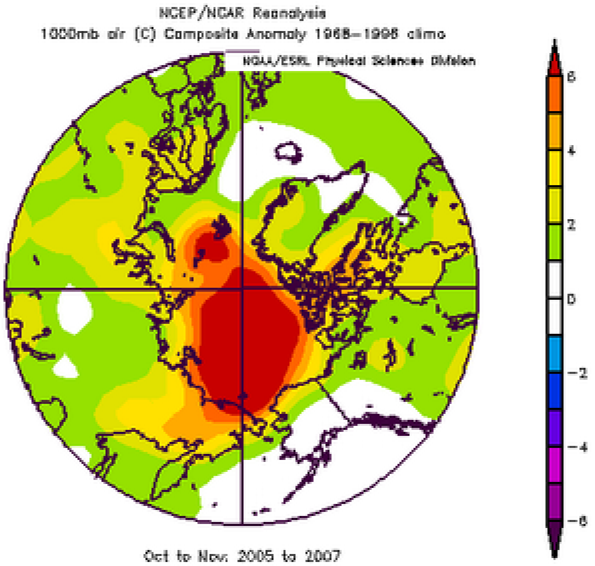

Figure A2. Near surface air temperature anomaly map for October and November for recent years with a reduced sea ice cover, 2005–2007. Data are from the NCEP – NCAR reanalysis through the NOAA /Earth Systems Research Laboratory, generated online at www.cdc.noaa.gov.

The major retreat of sea ice extent during the summer of 2007 was set up by sustained winds blowing from the North Pacific across the North Pole (Fig. A3). These winds contributed to sea ice advection toward the Atlantic sector. Additionally, the advection of warm moist air into the central Arctic contributed to melting sea ice, especially in the Pacific sector. The near record minimum sea ice extent in 2008 was nearly the same as in 2007, but the causes were different. The wind pattern in 2007 was unusually constant throughout the summer, while in 2008 the winds were more variable. Summer winds in 2007 appear to be a once in a decade event, while the atmosphere had less of a contribution to sea ice loss in 2008.

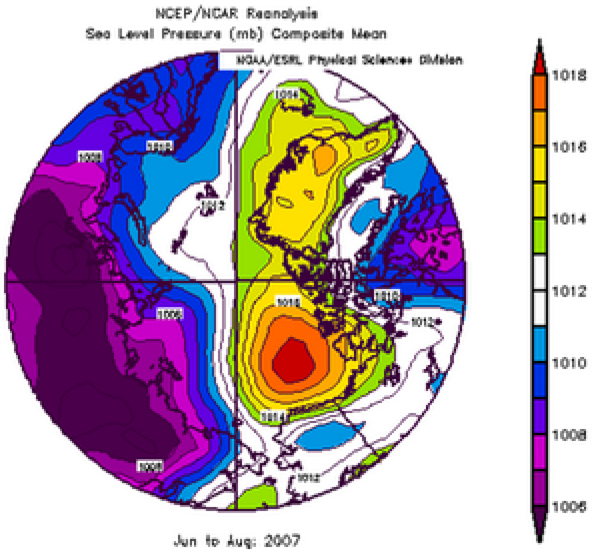

Figure A3. Sea level pressure field for summer 2007. This map has the same orientation as Figure A2. Purple/Blues regions have low pressure and orange regions have high pressure. Winds tend to blow parallel to the contour lines so the flow is from north of Bering Strait across the North Pole. Data are from the NCEP – NCAR reanalysis.

Winter and spring air temperatures in 2007 and 2008 continue the nearly Arctic-wide extent of positive SAT anomalies, similar to the early years of the twenty-first century (Fig. A4). These years contrast with the twentieth century in which positive and negative SAT anomalies were more spatially distributed. This Arctic-wide background SAT anomaly of greater than +1°C is consistent with projections from IPCC climate models (Chapman and Walsh 2007). Exceptions were the Bering Sea and western Alaska, which experienced a third consecutive cold winter. The Barents Sea continues to be a hot spot, which began in 2006.

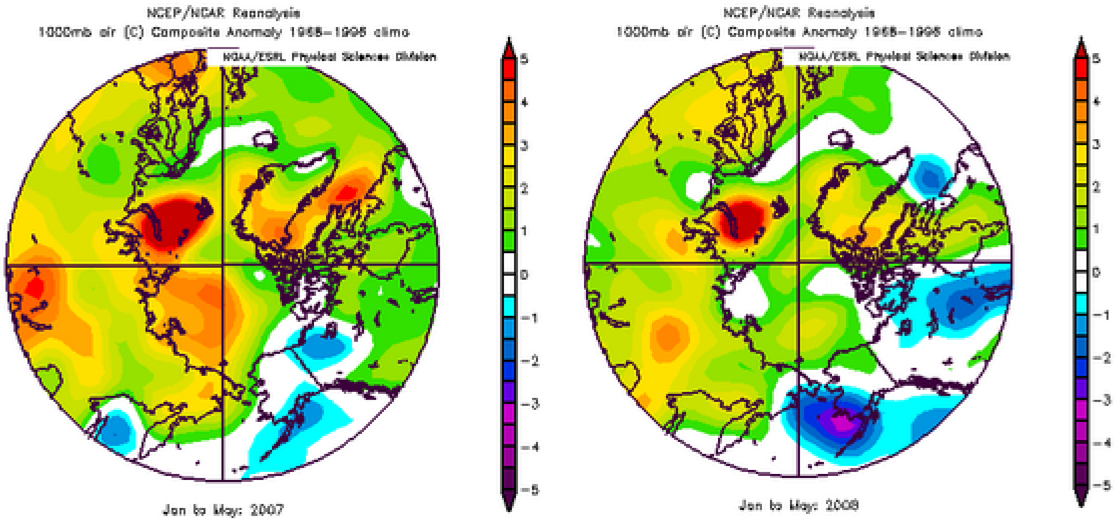

Figure A4. Near surface air temperature anomalies for January–May 2007 and 2008. Data are from the NCEP – NCAR reanalysis.

The climate of the Arctic is influenced by repeating patterns of sea level pressure (SLP) that can dominate individual months or can represent the overall atmospheric circulation flow for an individual winter and spring. The main pattern is known as the Arctic Oscillation (AO) circulation regime, widely considered the main source of Arctic climate variability during the twentieth century. A second pattern influences the Pacific sector of the Arctic, known as the Pacific North American (PNA) pattern. A positive period of the AO has lower sea level pressure over the central Arctic, brings warmer temperatures to Eurasia, and helps to export sea ice into the Atlantic. In 2007 and 2008 the AO returned to a strongly positive wintertime index value for the first time in more than a decade, but its value was still lower than the large positive values of the early 1990s (Fig. A5).

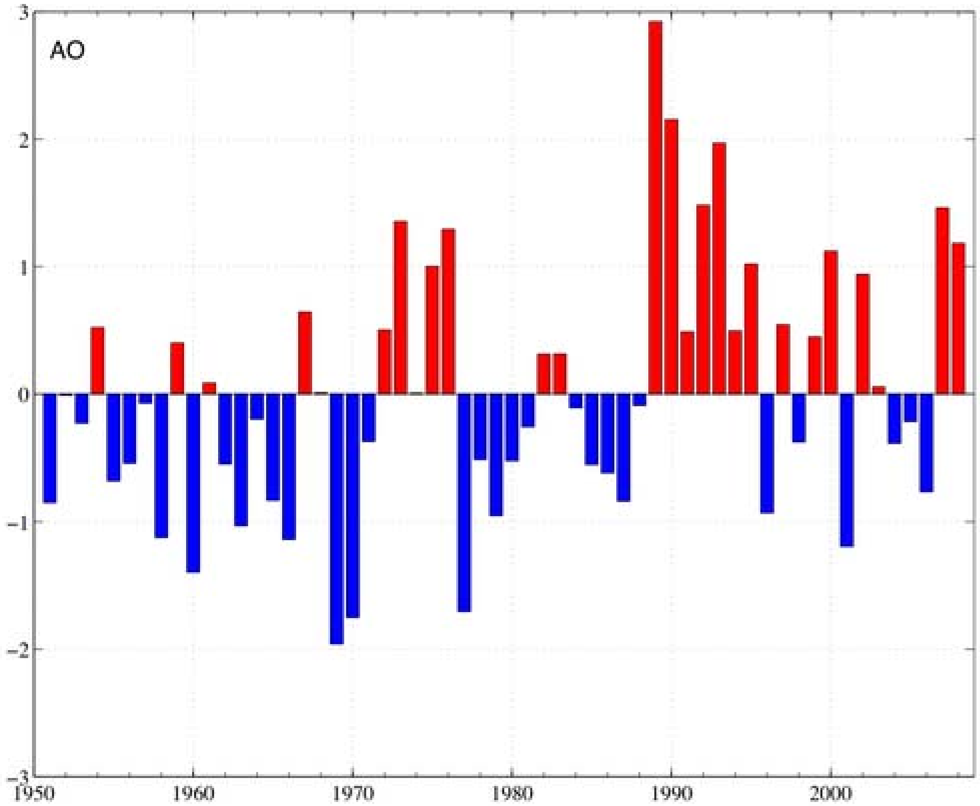

Figure A5. The extended winter (DJFM) Arctic Oscillation index, 1950 to 2008 (based on data available online at www.cpc.ncep.noaa.gov).

The actual SLP anomaly patterns for both 2007 and 2008 have minimums over western Eurasia (Fig. A6). These patterns contrast with that of the canonical positive AO, where the lowest anomalies are centered over Iceland and the central Arctic. The geostrophic wind pattern associated with the 2007 SLP anomaly field brought air flow from western Russia toward the North Pole, with a positive (warmer) SAT anomaly maximum over the northern Barents Sea (A4). 2008 actually has a “dipole” pattern of SLP anomalies with extensive high pressure over Arctic Canadian and low pressure on the Siberian side, giving decidedly non-AO regional impacts in the Pacific sector.

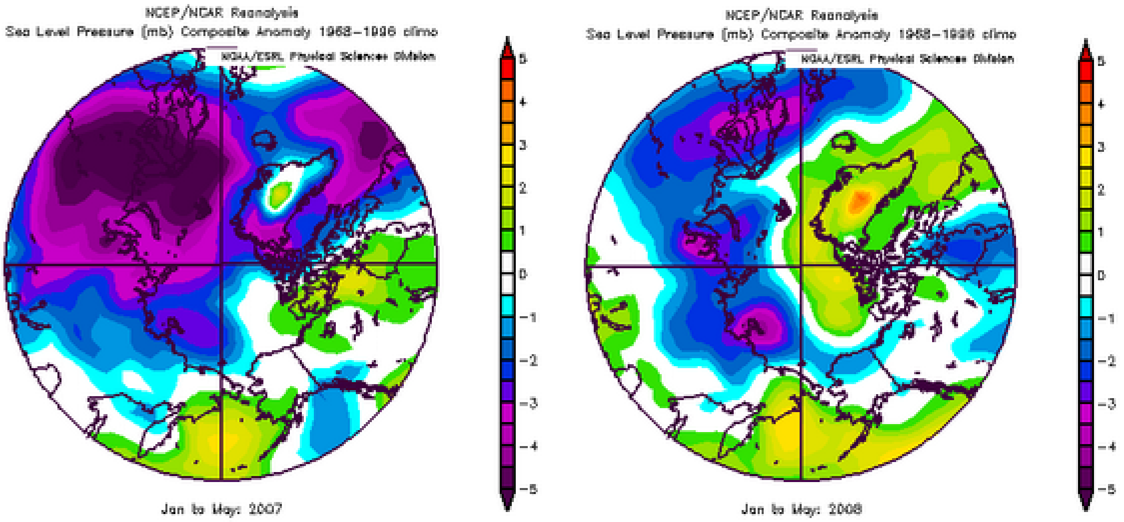

Figure A6. SLP anomaly pattern for (left) Jan–May 2007 and (right) Jan–May 2008. Note the extensive Arctic-wide areas of low SLP in winter and spring, which project onto a positive AO index. Data are from the NCEP – NCAR reanalysis Anomalies are relative to a 1968–96 climatological period.

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Sea Ice Cover

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[4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

New! Monthly Sea Ice Outlook from SEARCH/Arcus

Summary

The continued significant reduction in the extent of the summer sea ice cover is a dramatic illustration of the pronounced impact increased global temperatures are having on the Arctic regions. There has also been a significant reduction in the relative amount of older, thicker ice.

Extent and thickness

Satellite-based passive microwave images of the sea ice cover have provided a reliable tool for continuously monitoring changes in the extent of the Arctic ice cover since 1979. During 2008 the summer minimum ice extent, observed in September, reached 4.7 million km^2 (Fig. S1, right panel). While slightly above the record minimum of 4.3 million km^2, set just a year earlier in September 2007 (Fig. S1, left panel), the 2008 summer minimum further reinforces the strong negative trend in summertime ice extent observed over the past thirty years. At the record minimum in 2007, extent of the sea ice cover was 39% below the long-term average from 1979 to 2000. A longer time series of sea ice extent, derived primarily from operational sea ice charts produced by national ice centers, suggests that the 2007 September ice extent was 50% lower than conditions in the 1950s to the 1970s (Stroeve et al. 2008). The spatial pattern of the 2008 minimum extent was different than in 2007. The 2007 summer retreat of the ice cover was particularly pronounced in the East Siberian and Laptev Seas, the Beaufort Sea, and the Canadian Archipelago. In 2008, there was less loss in the central Arctic, north of the Chukchi and East Siberian Seas and greater loss in the Beaufort, Laptev and Greenland Seas.

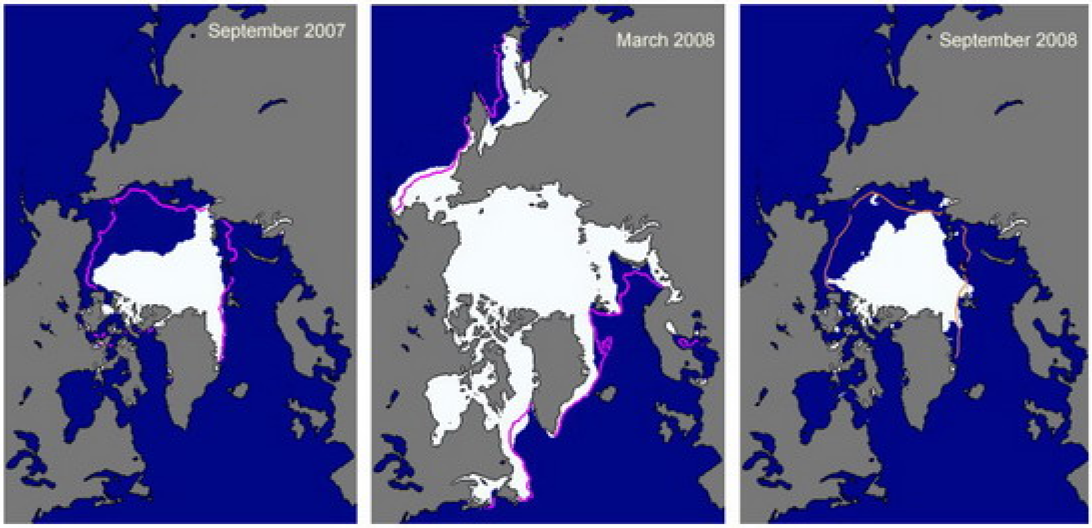

Figure S1. Sea ice extent in (left) September 2007, (center) March 2008 and (right) September 2008, illustrating the respective winter maximum and summer minimum extents. The magenta line indicates the median maximum and minimum extent of the ice cover, for the period 1979–2000. The September 2007 minimum extent marked a record minimum for the period 1979–2008. [Figures from the National Snow and Ice Data Center Sea Ice Index: nsidc.org/data/ seaice_index.]

The annual maximum sea ice extent typically occurs in March. In March 2008, the maximum ice extent was 15.2 million km^2 (Figure S1, center panel). This marked a second year of slight recovery in winter ice extent from the record minimum of 14.4 million km^2 for the period 1979–2008, which was observed in 2006.

For comparison, the mean monthly ice extent for March and September, for the period 1979–2008, is 15.6 and 6.7 million km^2, respectively.

The annual variation of the extent of the Arctic sea ice cover in 2007 and 2008, relative to past years, is shown in Fig. S2. As explained in Comiso et al. (2008), the 2007 Arctic ice cover was comparable to the 2005 ice cover through mid-June but then began a more precipitous decline. In 2008, the rapid decline did not begin until mid-August. Five-year averages from 1980 through 2004 show a general decrease in the Northern Hemisphere sea ice extent throughout the seasonal cycle, with this pattern being especially strong in the late summer and early fall. The 2007 ice extent rebounded with a rapid early autumn growth, albeit with an exceptionally slow recovery in the Chukchi and Barents Seas. By early November 2007, the ice extent conditions were comparable to those observed in recent years, while remaining well below the long-term (1979–2007) average.

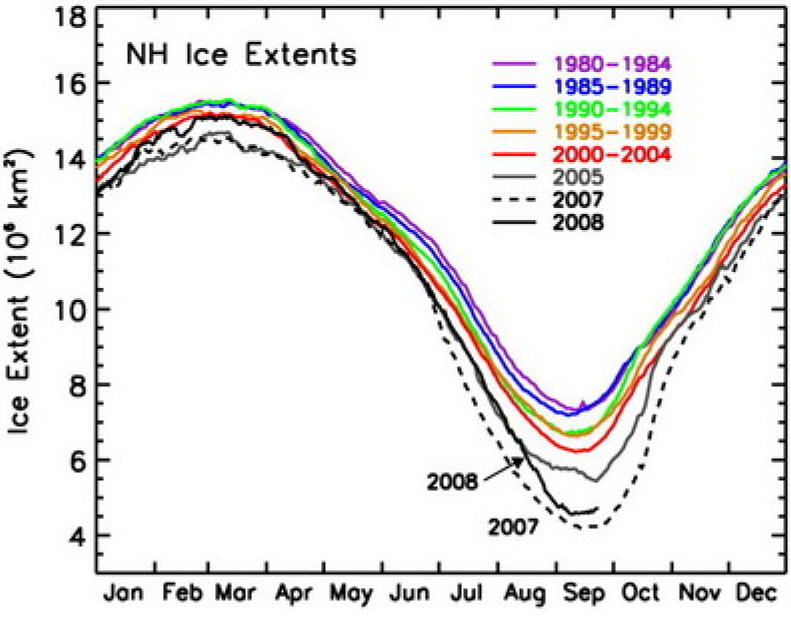

Figure S2. Daily ice extents 2005, 2007, and 2008, and averaged over the 5-yr periods 1980–84 through 2000–04. Values are derived from satellite passive microwave data from NASA's SMMR and the Department of Defense's SSM/I. (Adapted from Comiso et al. 2008.)

Figure S3 shows the time series of the anomaly in ice extent in March and September for the period 1979–2008. Both winter and summer have a negative trend in extent: –2.8% decade^{-1} for March and –11.1% decade^{-1} for September. The seasonality of the observed ice retreat, with a great rate of reduction of the summer extent versus winter extent, is consistent with model projections (e.g. Stroeve et al, 2007).

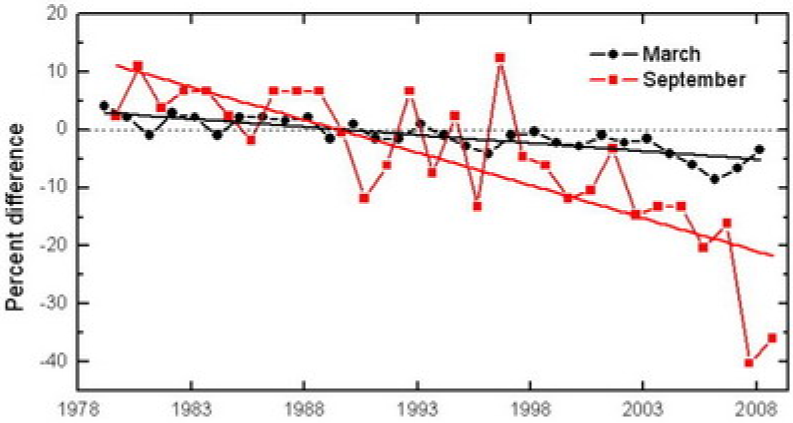

Figure S3. Time series of the difference in ice extent in Mar (the month of ice extent maximum) and Sep (the month of ice extent minimum) from the mean values for the time period 1979–2007. Based on a least squares linear regression, the rate of decrease for the Mar and Sep ice extents was –2.8% and –11.1% per decade, respectively.

Ice thickness is intrinsically more difficult to monitor. With satellite-based techniques (Laxon et al. 2003; Kwok et al. 2004, 2007) only recently introduced, observations have been spatially and temporally limited. This said available data from a variety of sources consistently indicate a net thinning of the Arctic sea ice cover. Data from submarine-based observations indicate that over the period of available records, 1975 to 2000, the annual mean thickness of the ice cover declined from a peak of 3.71 m in 1980 to a minimum of 2.46 m in 2000, a decrease of 1.25 m (Rothrock et al. 2008). Satellite-derived estimates of sea-ice age and thickness, combined to produce a proxy ice thickness record for 1982–2007, also indicate the ice has thinned significantly between 1982 and 2007 (Maslanik et al. 2007). Helicopter-borne and ice-based electromagnetic measurements indicate a reduction of modal and mean sea ice thicknesses in the region of the North Pole of up to 53 and 44%, respectively, between 2001 and 2007 (Haas et al., 2008). In contrast to the central Arctic, measurements of the seasonal and coastal ice cover do not indicate any statistically significant change in thickness in recent decades (Melling et al. 2005; Haas 2004; Polyakov et al. 2003). This observation indicates that the thinning of the ice cover is primarily the result of changes in the characteristics of the perennial ice.

Seasonal versus perennial ice

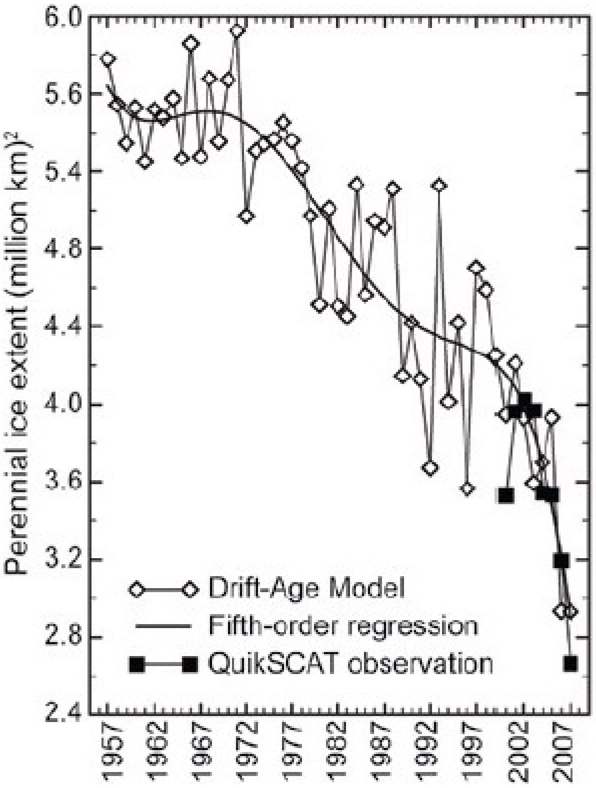

Figure S4. Time series of area of perennial sea ice extent in March of each year estimated by the Drift-Age Model and observed by QuikSCAT satellite scatterometer within the model domain. In each year, the model result was an average over March, and the satellite observation was on the spring equinox (21 Mar). (Adapted from Nghiem et al. 2007)

The Arctic sea ice cover is composed of perennial ice (the ice that survives year-round) and seasonal ice (the ice that melts during the summer). Consistent with the diminishing trends in the extent and thickness of the cover is a significant loss of the older, thicker perennial ice in the Arctic (Fig. S4). Data from the NASA QuikSCAT launched in 1999 (Nghiem et al., 2007) and a buoy-based Drift-Age Model (Rigor and Wallace, 2004) indicate that the amount of perennial ice in the March ice cover has decreased from approximately 5.5 to 3.0 million km^2 over the period 1958–2007. While there is considerable interannual variability, an overall downward trend in the amount of perennial ice began in the early 1970s. This trend appears to coincide with a general increase in the Arctic-wide, annually averaged surface air temperature, which also begins around 1970 (see Fig. A1). In recent years, the rate of reduction in the amount of older, thicker perennial ice has been increasing, and now very little ice older than 5 yr remains (Maslanik et al. 2007).

Many authors have recently acknowledged that a relatively younger, thinner ice cover is more susceptible to the effects of atmospheric and oceanic forcing (e.g. Gascard et al., 2008; Stroeve et al., 2008; Kwok, 2007; Ogi and Wallace, 2007; Maslanik et al., 2007; Serreze et al., 2007; Shimada et al., 2006). In the face of the predictions for continued warming temperatures (Christensen et al., 2007), the persistence of recent atmospheric (Comiso et al., 2008; Kwok, 2008) and oceanic circulation patterns (Steele et al. 2008; Polyakov et al. 2007), and the amplification of these effects through the ice albedo feedback mechanism (Perovich et al., 2008), it is becoming increasingly likely that the Arctic will change from a perennially ice-covered to an ice-free ocean in the summer.

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Ocean

A. Proshutinsky[1], J. Morison[2], I. Ashik[3], E. Carmack[6], I. Frolov[3], J. C. Gascard[4], M. Itoh[5], R. Krishfield[1], F. McLaughlin[6], I . Polyakov[7], B. Rudels[8], U. Schauer[9], K . Shimada[5] , V. Sokolov[3], M. Steele[2], M.-L. Timmermans[1], and J. Toole[1]

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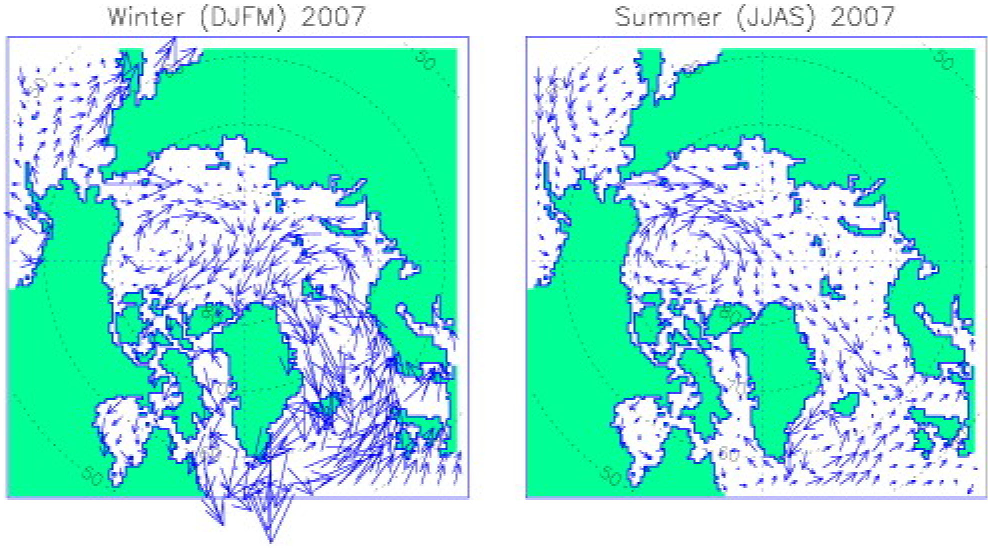
Summary

In general, the Arctic Ocean continued to warm and freshen in 2007 under the influence of unusual atmospheric forcing and continued dramatic sea ice melt. These changes were accompanied by an unprecedented rate of sea level rise.

Surface circulation regime

The circulation of the sea ice cover and ocean surface layer are closely coupled and are primarily wind-driven (Proshutinsky and Johnson, 1997). Data from satellites and drifting buoys indicate that the entire period of 2000–2006 has been characterized by an anticyclonic (clockwise) circulation regime due to a higher sea level atmospheric pressure over the region north of Alaska, relative to the 1948–2005 mean, and the prevalence of anticyclonic winds (Figure O1). Under these conditions, the clockwise circulation pattern in the Beaufort Sea region (the Beaufort Gyre) tends to be relatively strong. Conversely, in the cyclonic regime the clockwise circulation pattern in the Beaufort Sea region weakens, and the flow across the basin, from the Siberian and Russian coasts to Fram Strait (the Transpolar Drift), shifts poleward. The cyclonic pattern dominated during 1989–1996; the anticyclonic pattern has prevailed since 1997. The dominance of the anticyclonic regime during the last decade of 1997–2007 is consistent with the Arctic Oscillation (AO) index which fluctuated about zero, indicating a relatively low level of influence from the Atlantic on these Arctic processes (Rigor et al., 2002) .


Winter (DJFM) 2007

Summer (JJAS) 2007

Figure O1. Circulation patterns of the simulated upper-ocean wind-driven circulation in (left) winter and (right) summer of 2007. Updated following Proshutinsky and Johnson (1997)

Water temperature and salinity

Marginal Seas

Sea Surface Temperature (SST) trends over the past 100 yr in the Arctic marginal seas (White, Kara, Laptev, East Siberian, Chukchi, and Beaufort) were analyzed by Steele et al. (2008). They found that many areas cooled up to ~0.5°C decade^{-1} during 1930–65 as the AO index generally fell (see Fig.A.5), while these areas warmed during 1965–95 as the AO index generally rose. Warming is particularly pronounced since 1995, and especially since 2000 when the AO index exhibited relatively low and fluctuating values. Summer 2007 satellite-derived data indicate that SST anomalies were up to 5°C in ice-free regions (Fig.O2).

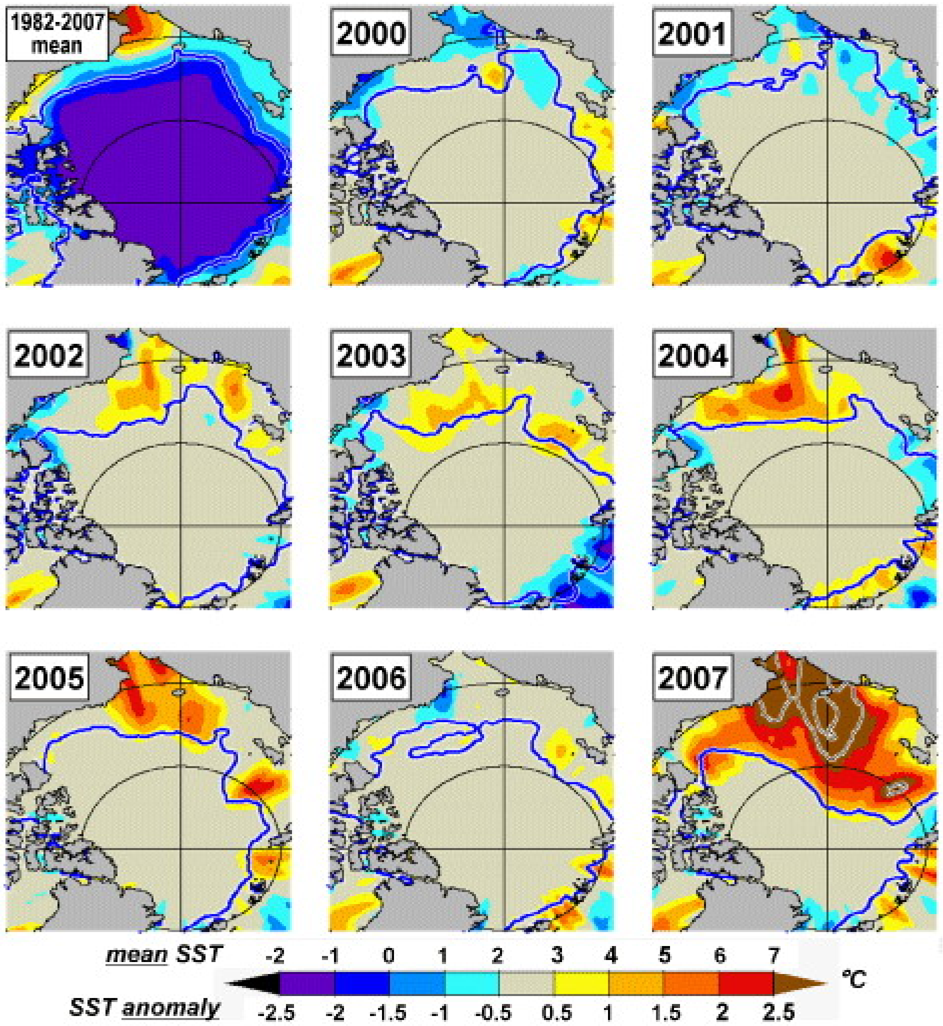


Figure O2. (top left) Mean satellite-derived summer (Jul–Aug) SST (Reynolds et al. 2002) and anomalies from this mean over 2000–07. Latitudes 70° and 80°N and longitudes 0°/180° and 90°E/270°E are shown. For 2007, extra contours for 3° and 4°C are provided. Also shown is the Sep mean ice edge (blue contour) for each year (from Steele et al. 2008)

Long-term (1930–95) salinity trends (Steele and Ermold 2004) show that since 1930, the White Sea has gained freshwater while the East Siberian Sea has lost it, consistent with river discharge trends over this period. Over the past 20 yr, increases in both river discharge and direct precipitation can explain observed salinity decreases in the White Sea, but not in the Kara Sea. Salinity trends in the Laptev Sea and East Siberian Sea indicate that ocean circulation plays a dominate role in these areas, where in recent years freshwater has been diverted eastward along the coast, rather than northward toward the deep ocean. Polyakov et al. (2008) confirmed these results and extended the data analysis up to 2003. The result shows that the freshwater content trend in the Siberian Seas (upper 50-m layer) for the period 1920–2003 is 29 ± 50 km^3 decade^{-1}. In 2007, all expeditions working in the marginal seas (I. Polyakov et al. 2007, personal communication) indicated an unusual freshening of the surface layer due to an extreme rate of sea ice melt.

Central Arctic (Nansen, Amundsen, and Makarov basins)

In spring 2007 near surface salinities at the North Pole (NP) were increased by about 1 unit and the Atlantic Water (AW) core temperature was increased by 0.5°C, respectively, above pre-1990s climatology. Data collected since 2000 at the North Pole Environmental Observatory (NPEO , http://psc.apl.washington.edu/northpole/) indicate that in 2000 and 2001 the spring salinities in the upper 150 m near the pole and in the northern Makarov Basin were elevated 1–2 units above climatology and temperatures in the AW core along the Lomonosov Ridge were elevated 1°–2°C. These conditions were nearly the same as observed in 1993 (Morison et al. 2000). In spring of 2004 and 2005, NP region hydrographic conditions largely returned to climatology (Morison et al. 2006). In spring of 2006, temperature and salinity anomalies near the NP region began to move away from climatological norms, again, repeating their behavior in spring of early 2000–03. The 2007 International Polar Year expansion of NPEO airborne surveys, combined with observations of the Switchyard project (W. Smethie 2007, personal communication), yielded a springtime section across 90°W–90°E. Results from this survey were consistent with the NP data, a further indication that in 2007 upper-ocean salinity structure and Atlantic Water temperatures in the central Arctic Ocean moved away from climatological norms, with increased salinity and temperature.

Atlantic Water enters the Arctic Ocean through the Barents Sea and Fram Strait, where it transitions from surface water to water of intermediate depth. The Atlantic Water temperature increase can be partially explained by other observed changes in the AW layer circulation. The first evidence of strong warming within the AW layer was found in the Nansen Basin in 1990 (Quadfasel et al. 1991). Positive AW anomalies of up to 1°C were carried along the continental margins into the Arctic Ocean interior (Woodgate et al. 2001; Schauer et al. 2002). Schauer et al. (2004) and Polyakov et al. (2005) have also shown that since the late 1990s, AW temperature has increased. Polyakov et al. (2007) and Dmitrenko et al. (2008) found that the 2000–05 Atlantic Water warming along the Siberian continental slope has propagated as a series of several AW warm impulses that penetrated into the Arctic Ocean through Fram Strait in 1999–2000 with a mean speed of 2.5 cm s^{-1}. The 2007 results suggest one of these pulses has reached the central Arctic Ocean. Preliminary reports from the summer hydrographic surveys in the central Arctic (U. Shauer et al. 2007, personal communication) indicate that, relative to 2004–05, in the Nansen and Amundsen Basins the temperature of the Atlantic Water core increased by approximately 0.5°C, and the thickness of this layer increased by 100–150 m mostly due to the propagation of a warming signal into the deeper ocean layers. In the Makarov Basin, no changes in the parameters of the Atlantic Water layer were detected. In contrast to the NPEO springtime results, in all basins the summer surface salinity was 1–2 units less than in 2003–05. It is speculated that the decrease in salinity in these regions is related to the extent of the massive sea ice melt in 2007.

Canada Basin and Beaufort Gyre

The 2007 Canada Basin and the Beaufort Gyre summer conditions exhibited very strong freshening relative to 2006 and previous years of observations (Richter-Menge et al. 2006). Data collected as part of the Beaufort Gyre Environmental Observatory (BGEO, www.whoi.edu/beaufortgyre/index.html) show that in 2000–07, the total freshwater content in the Beaufort Gyre has not changed dramatically relative to climatology (although the absolute maximum was observed in 2007), but there was a significant change in the freshwater distribution (Fig. O3(c,d)). The center of the freshwater maximum shifted toward Canada and significantly intensified relative to climatology. This region of the Beaufort Gyre is much fresher than 30 yr ago.

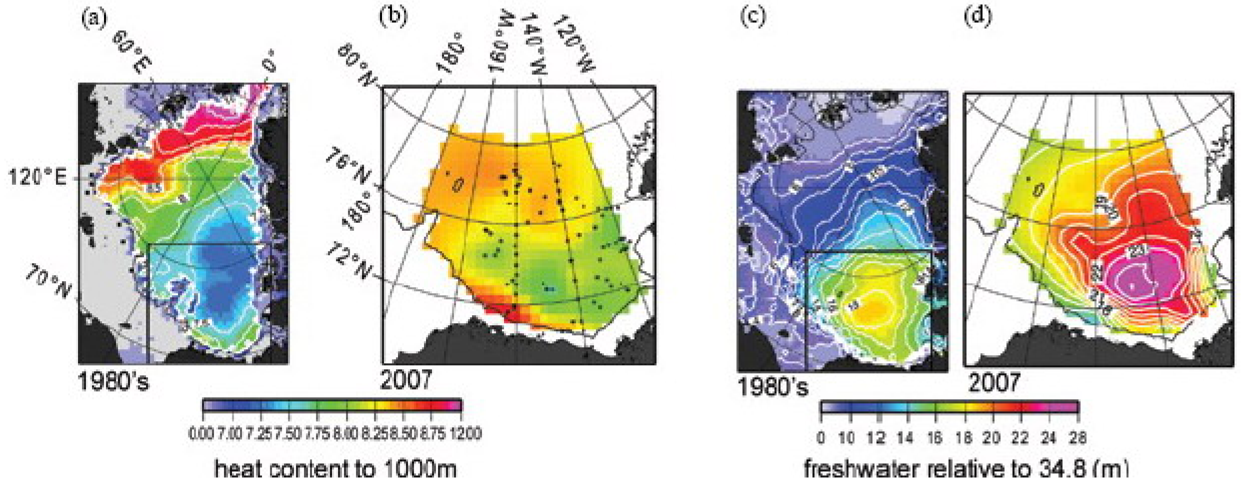


Figure O3. (a), (c) Summer heat (1 x 1010 J m^{-2}) and (right) freshwater (m) content in the Arctic Ocean based on 1980s climatology (Timokhov and Tanis 1997). (b), (d) Heat and freshwater content in the Beaufort Gyre in 2007 based on hydrographic survey (black dots depict locations of hydrographic stations). For reference, the Beaufort Gyre region is outlined in black in panels a and c. The heat content is calculated relatively to water temperature freezing point in the upper 1,000-m ocean layer. The freshwater content is calculated relative to a reference salinity of 34.8.

Significant changes were observed in the heat content of the Beaufort Gyre (Fig. O3(a,b)). It has increased relative to the climatology, primarily because of an approximately twofold increase of the Atlantic layer water temperature (Shimada et al. 2004). In the late 1990s, Atlantic Water with temperatures as much as 0.5°C warmer than previous records was observed in the eastern Canada Basin (McLaughlin et al. 2004). These observations signaled that warm-anomaly Fram Strait waters, first observed upstream in the Nansen Basin in 1990, had arrived in the Canada Basin, and confirm the cyclonic circulation scheme. The 2007 observations manifested that these processes are still in progress and the AW layer warming signal propagated farther east. The surface layer water in the Beaufort Gyre also accumulated a significant amount of heat in 2007, due to the significant retreat of the ice cover causing its exposure to the direct solar heating. This was similar to the conditions observed in the regions free of ice in the Amundsen, Nansen, and Makarov Basins.

Sea Level

Figure O4 contains sea level (SL) time series from nine coastal stations having representative records for the period of 1954–2007 in the Siberian Seas (from the Arctic and Antarctic Research Institute data archives). There is a positive SL trend along Arctic coastlines of 1.94 ± 0.47 mm yr $^{-1}$ for 1954–89, after correction for Glacial Isostatic Adjustment (GIA). This compares to an estimated rate of 1.85 ± 0.43 mm yr^{-1} along the Arctic coastlines over the same period, based on 40 Arctic coastal stations available at the time (Proshutinsky et al. 2004). The addition of 1990–2007 data increases the estimated rate of SL rise for the nine stations in the Siberian Seas, beginning in 1954, to 2.61 ± 0.45 mm yr^{-1} (after correction for GIA). The rate of 2.61 ± 0.4 mm/yr is considerably larger than the rate of 1.94 ± 0.47 mm/yr. Both estimates are higher than the sea level rise rate for the global ocean estimated by the Intergovernmental Panel on Climate Change (IPCC) as ~1.8 mm/yr, for 1961 to 2003 (IPCC, 2007). Note the time period included in our estimate (1954–2007) is longer than the IPCC period (1961–2003) and that the sea level in the Arctic rose significantly during 2000–2007.

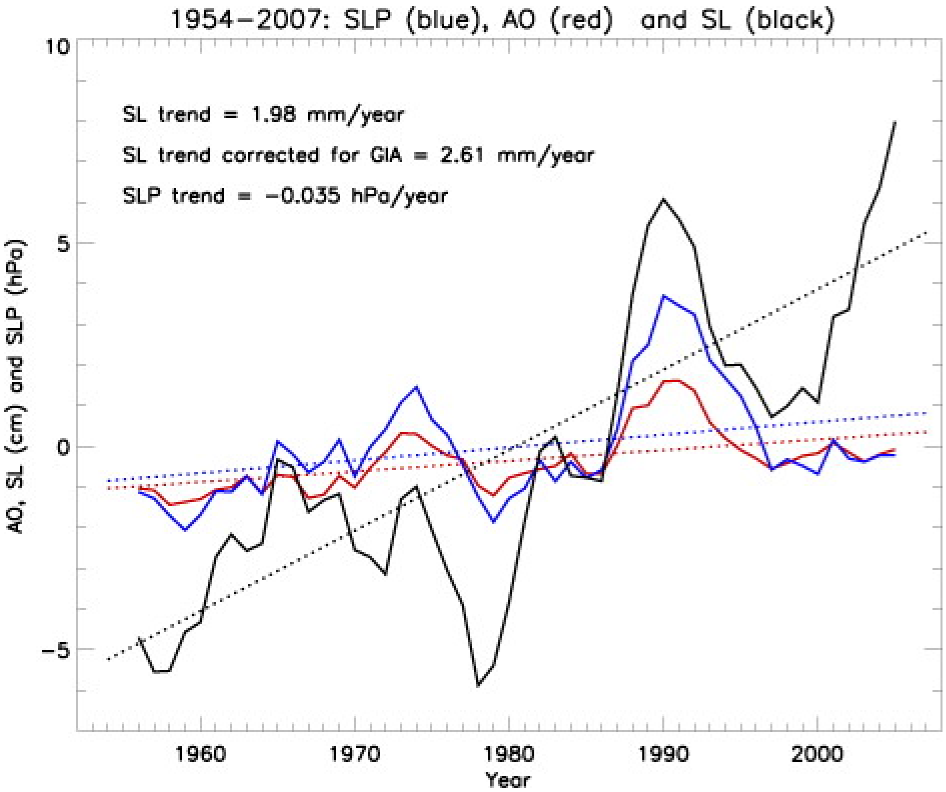


Figure O4. Five-year running mean time series. The black line is the annual mean sea level at nine tide gauge stations located along the Kara, Laptev, East Siberian, and Chukchi Sea coastlines. The red line is the annual mean AO index anomaly multiplied by 3. The blue line is the sea level pressure at the North Pole (from NCAR – NCEP reanalysis data) multiplied by –1.

From the beginning of the record until 1996, SL correlates relatively well with the time series of the AO index and SLP at the North Pole (Fig.O4). In contrast, from 1997–2007 SL generally increased despite the relatively stable behavior of AO and sea level pressure, indirectly indicating that after 1996 something other than the inverted barometric effect dominated sea level rise in the region. Among possible candidates are ocean expansion due to heating, freshening, and wind-driven effects.

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Land

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Summary

Land-based observations, while widely ranging, reflect the effects of a general warming trend. For instance, there was an increase in the relative greenness of the Arctic region, consistent with warming soil and air temperatures, earlier snow melt, and the expansion of shrubs and tree line to the north. Permafrost continues to warm, however the rate of warming in the 2000s is significantly slower than in the 1990s. There is a continued tendency for a decrease in the snow cover of the Northern Hemisphere in the months of April through October. Glaciers are shrinking in most of the world. The amount of river discharge to the Arctic Ocean is increasing.

Vegetation

Evidence of widespread changes in vegetation in northern latitudes comes from trends in terrestrial greennessas detected by the Normalized Difference Vegetation Index (NDVI) derived from the NOAA AVHRR satellites (Myneni et al. 1997; Zhou et al. 2001; Lucht et al. 2002; Jia et al. 2003; Goetz et al. 2005; Bunn et al. 2007). During the 1981–2005 period of observation, about 6% of the circumpolar tundra area experienced an increase in NDVI and about 1% experienced a decrease (Fig.L1; Bunn et al. 2007). The positive trends in NDVI in tundra areas have been strongest in North America. For example, in the tundra region south of 70°N (the region of the Arctic with a consistent AVHRR record from 1982 to 2005) the rate of change in NDVI is +0.58% yr^{-1} over the North American Arctic compared to +0.34% yr^{-1} over the Eurasian Arctic (Jia et al. 2007). Forested areas experienced a slight decline over the same period: NDVI declined in 6% of the forested area versus an increase in 4% of the area.

Figure L1. Spatial distribution of trends in May to Aug photosynthetic activity across the northern high latitudes from 1981 through 2005. Significant positive trends in photosynthetic activity are shown in green, and negative trends are shown in rust. (From Bunn et al. 2007.)

Vegetation responds relatively quickly to warming temperatures by growing more vigorously and densely. Over a longer time span, changing climate alters vegetation type. Land cover on much of the Alaska North Slope, for example, is transitioning from tundra to shrubs (Wang and Overland 2004). Recent vegetation dynamics observations across the Arctic also indicate that, in general, shrubs have become more abundant and taller. A study in northern Alaska (Tape et al. 2006) showed that both larger and smaller shrub species have increased in size, abundance and extent over the last 50 years. As well as increasing in size and filling in empty patches, the shrubs were colonizing new areas (Figure L2).

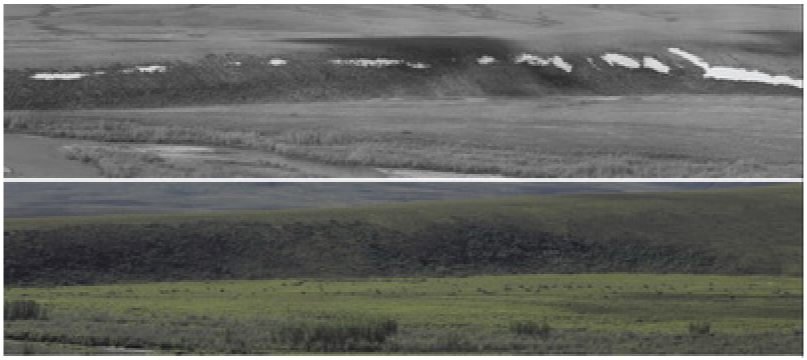

Figure L2. Large shrubs have colonized a river terrace that was virtually free of large shrubs in 1949. The new shrubs are more than 2 m high. In the foreground are poplar trees. Photo from the Chandler River located at 68° 25.14' N, 161° 15.24' W: 7/4/1948 and 7/29/2001. (Tape et al. 2006).

Changes in land cover, vegetation density, and other factors are reflected in NDVI. Overall, increasing NDVI is consistent with warming soil and air temperatures, earlier snow melt, and the expansion of shrubs and tree line to the north.

Permafrost

Observations show a general increase in permafrost temperatures during the last several decades in Alaska (Osterkamp and Romanovsky 1999; Romanovsky et al. 2002; Osterkamp 2003; Romanovsky et al. 2007a), northwest Canada (Couture et al. 2003; Smith et al. 2005), Siberia (Pavlov 1994; Oberman and Mazhitova 2001; Romanovsky et al. 2007b; Pavlov and Moskalenko 2002), and northern Europe (Isaksen et al. 2000; Harris and Haeberli 2003). Permafrost temperature records uninterrupted for more than 25 yr have been obtained by the University of Alaska Fairbanks along the International Geosphere-Biosphere Programme Alaskan transect, which spans the entire continuous permafrost zone in the Alaskan Arctic. All of the observatories show a substantial warming during the last 20 yr (Fig. L3). 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 2005). These data also indicate that the increase in permafrost temperatures is not monotonic. During the observational period, relative cooling has occurred in the mid-1980s, in the early 1990s, and then again in the early 2000s. As a result, permafrost temperatures at 20-m depth experienced stabilization and even a slight cooling during these periods. Permafrost temperature was relatively stable on the North Slope of Alaska during 2000–07. However, 2007 data show a noticeable increase in the temperature at 20-m depth by 0.2°C at the two northernmost sites of Deadhorse and West Dock. Permafrost temperature did not change significantly at the other North Slope sites. This may indicate a new wave of permafrost warming similar to the warming that started in 1994 (Fig. L2), which also started at the Deadhorse and West Dock sites and only later appeared at the interior sites.

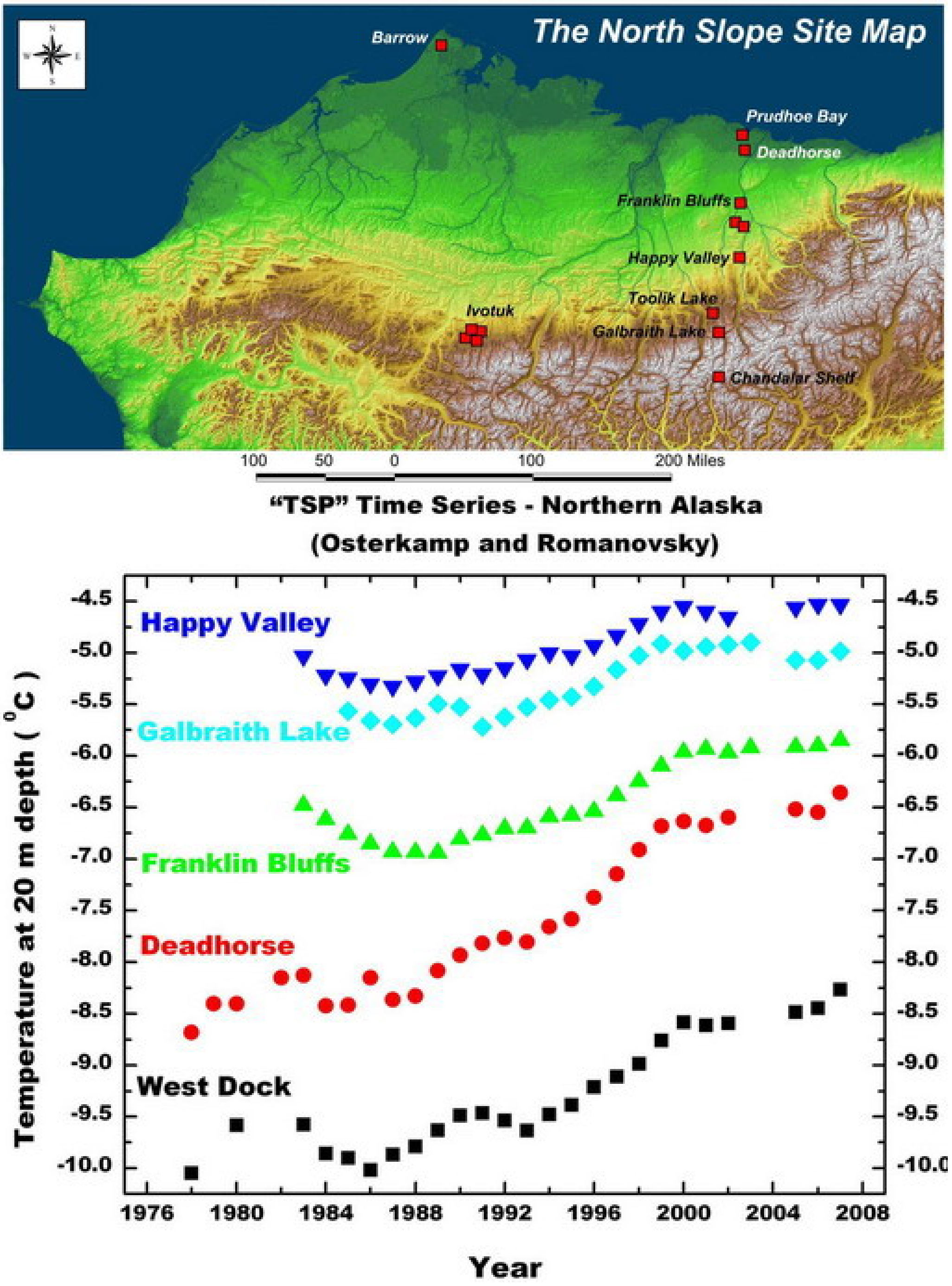

Figure L3. (top) Location of the long-term University of Alaska permafrost observatories in northern Alaska. West Dock is at Prudhoe Bay. (bottom) Changes in permafrost temperatures at 20-m depth during the last 25 to 30 yr (updated from Osterkamp 2003).

Snow extent

Northern Hemisphere snow cover extent has a mean maximum of approximately 47 million km^2, typically occurring in February. The minimum usually occurs in August and is less than about 1 million km^2, most of which is snow on glaciers and perennial snow fields. As a result, snow cover is the land surface characteristic responsible for the largest annual and interannual differences in land surface albedo. Snow covers a much smaller area in the Southern Hemisphere, approximately 2% of the global total, and plays a relatively small role in global climate. A time series of snow extent in the Northern Hemisphere, beginning in 1978 and derived from two sources, is presented in Fig. L4. There is a consistent decreasing trend in snow cover in the months of April through October, with the strongest seasonal signal occurring between April and August. Data derived from NOAA snow charts (Robinson and Frei 2000; Frei and Robinson 1999; Ramsay 1998; NOAA/NESDIS/ OSDPD/SSD 2006) indicate a statistically significant decreasing trend of –2.1% decade^{-1} (Brodzik et al. 2006). Snow cover data derived from passive microwave imagery (Armstrong and Brodzik 2001; Armstrong et al. 2005a,b) show a decreasing trend of –0.7% decade^{-1}, although it is not significant at the 90% level. Both time series show similar inter-annual variability and consistently indicate Northern Hemisphere maximum extents exceeding 40 million km^2. The western United States is among the regions with the strongest decreasing trends, supporting Groisman et al. (2004) and Mote et al. (2005) results using in situ observations. Shallow snow cover at low elevations in temperate regions is the most sensitive to temperature fluctuations and hence most likely to decline with increasing temperatures (Lemke et al. 2007, 343–346).

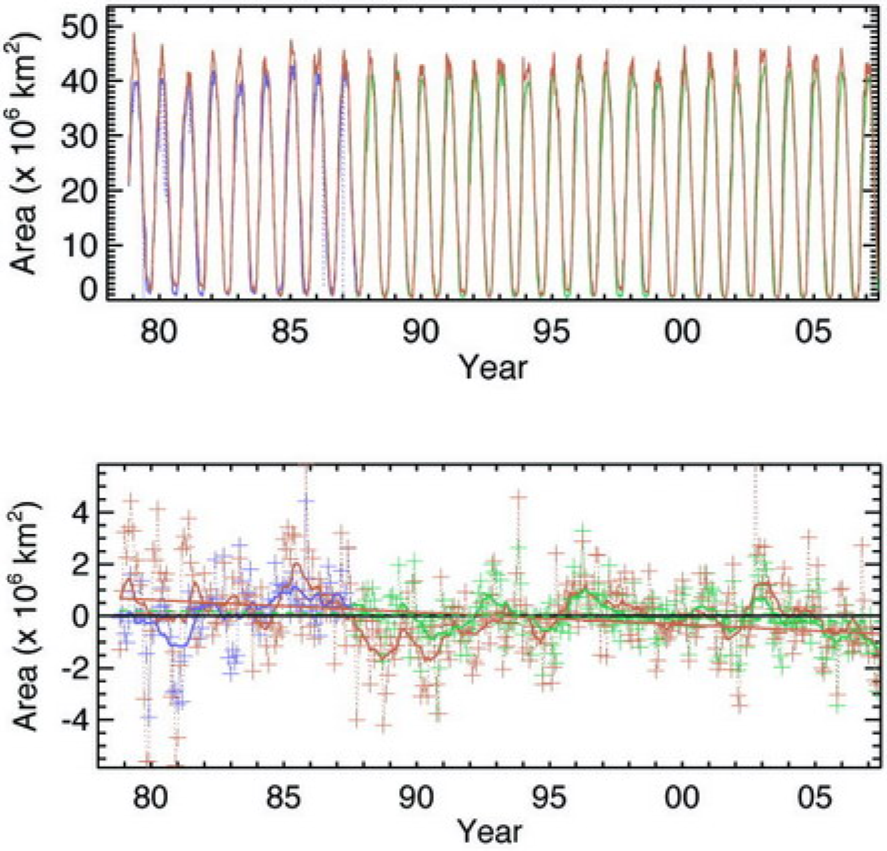

Figure L4. (top) Time series of Northern Hemisphere snow covered area derived from passive microwave (purple/green) and NOAA snow charts (orange), and (bottom) snow covered area departures from monthly means, 1978–2007.

For the Northern Hemisphere winter of 2006–07, the microwave data indicate negative departures from the long-term mean (1978–2007) for every month except October and February, with an average negative departure for the winter months (November through April) of approximately 0.7 million km^2. For the calendar year of 2007, the NOAA data indicate an average snow cover extent of 24.0 million km^2, which is 1.5 million km^2 less than the 38-yr average and represents the third least extensive snow extent for the period of record.

Glaciers

Glaciers and ice caps, excluding those adjacent to the large ice sheets of Greenland and Antarctica, can be found on all continents except Australia and have an estimated total area between 512 and 540 × 103 km^2. The complicated and uncertain processes that control how fast glaciers move make it difficult to use changes in the areal extent of glaciers as a straightforward indicator of changes in climatic conditions. Mass balance measurements, or the difference between the accumulation and ablation, are a more direct method to determine the year-to-year "health" of a glacier. Changes in mass balance correspond to changes in glacier volume. These measurements are typically obtained from less than about 0.2% of the world's glaciers. Researchers have measured mass balance on more than 300 glaciers since 1946, with a continuous record for about 40 glaciers since the early 1960s (e.g., Cogley 2005; Kaser et al. 2006). These results indicate that in most regions of the world, glaciers are shrinking in mass. From 1961 to 2005, the thickness of "small" glaciers decreased approximately 12 m, or the equivalent of more than 9,000 km^3 of ice (Dyurgerov and Meier 2005; online at http://nsidc.org/sotc/glacier_balance.html). Recent mass loss of glaciers, ice caps, and ice sheets is estimated to be 0.58 mm Sea Level Equivalent (SLE) per year between 1961 and 2005 and 0.98 mm SLE per year between 1993 and 2005 (Dyurgerov and Meier 2005; online at http://nsidc.org/sotc/sea_level.html). In contrast to the two major ice sheets, Greenland and Antarctica, the network of small glaciers and ice caps, although making up only about 4% of the total land ice area or about 760,000 km^3, may have provided as much as 60% of the total glacier contribution to sea level change since the 1990s. This acceleration of glacier melt may cause 0.1 to 0.25 m of additional sea level rise by 2100 (Meier et al. 2007). The greatest mass losses per unit area are found in Patagonia, Alaska, and northwest United States/southwest Canada. However, because of the corresponding large areas, the biggest contributions in total to sea level rise come from Alaska, the Arctic, and the Asian high mountains.

River discharge

Overall, the twenty-first century to date is characterized by an increased level of river discharge to the Arctic Ocean (www.R-ArcticNet.sr.unh.edu). The mean 2000–06 discharge from six of the largest Eurasian rivers (North Dvina, Pechora, Ob, Yenisei, Lena, and Kolyma) was 127 km^3 (7%) higher than long-term mean over the period 1936–99 (Fig. L5). The largest Siberian rivers, Yenisey and Lena, provided more than 70% of this increase. Preliminary 2007 estimates of annual discharge to the Arctic Ocean from the Russian rivers have been made using near-real-time data (http://RIMS.unh.edu). These estimates indicate a relatively high annual discharge for the six largest Eurasian rivers, possibly achieving a new historical maximum in 2007 for total discharge to the Arctic Ocean over the 1936–2007 observational period. The mean annual discharge to the ocean over 2000–06 from the five largest North American rivers was about 6% (30 km^3) greater than the long-term mean over 1973–99. The historical annual maximum was observed for the summary discharge in 2005 (Fig. L5). However, the relatively short discharge time series for North America (37 yr) and the significant unmonitored land area does not support conclusions with the same reliability as for Eurasia.

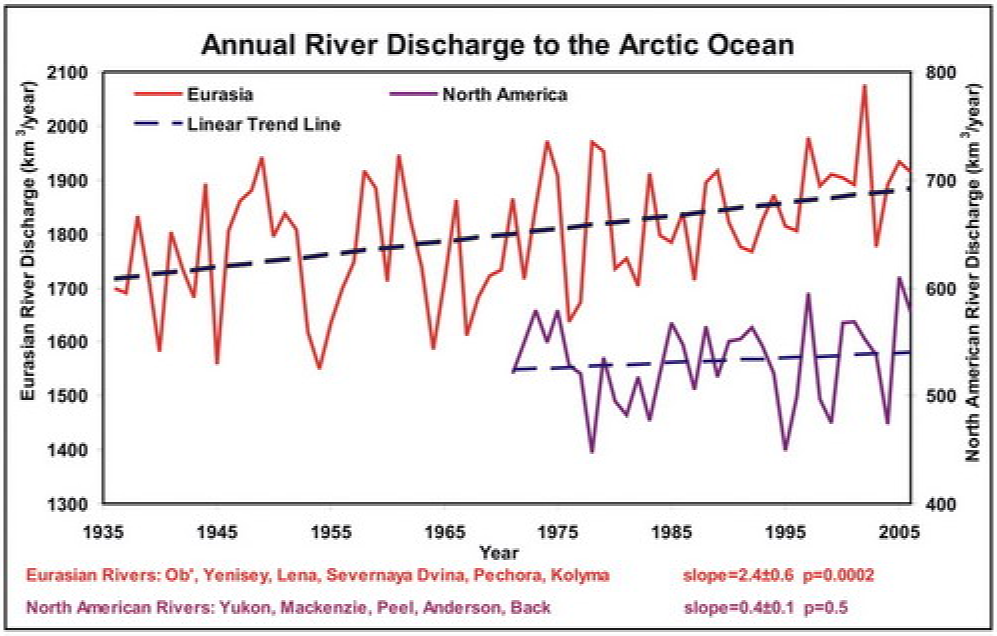

Figure L5. Total annual discharge to the Arctic Ocean from the six largest rivers in the Eurasian pan-Arctic for the observational period 1936–2006 (updated from Peterson et al. 2002) (red line) and from the five largest North American pan-Arctic rivers over 1973–2006 (purple line). The least squares linear trend lines are shown as dashed blue.

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Greenland

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Summary

Warming has continued around Greenland in 2007, culminating in record setting (since 1970s) melt area and amplified absorption of solar radiation. Greenland's largest glacier, among a majority of others, continued its retreat. The ice sheet lost at least 100 cubic km (24 cubic miles) of ice, making it one of the largest single contributors to global sea level rise.

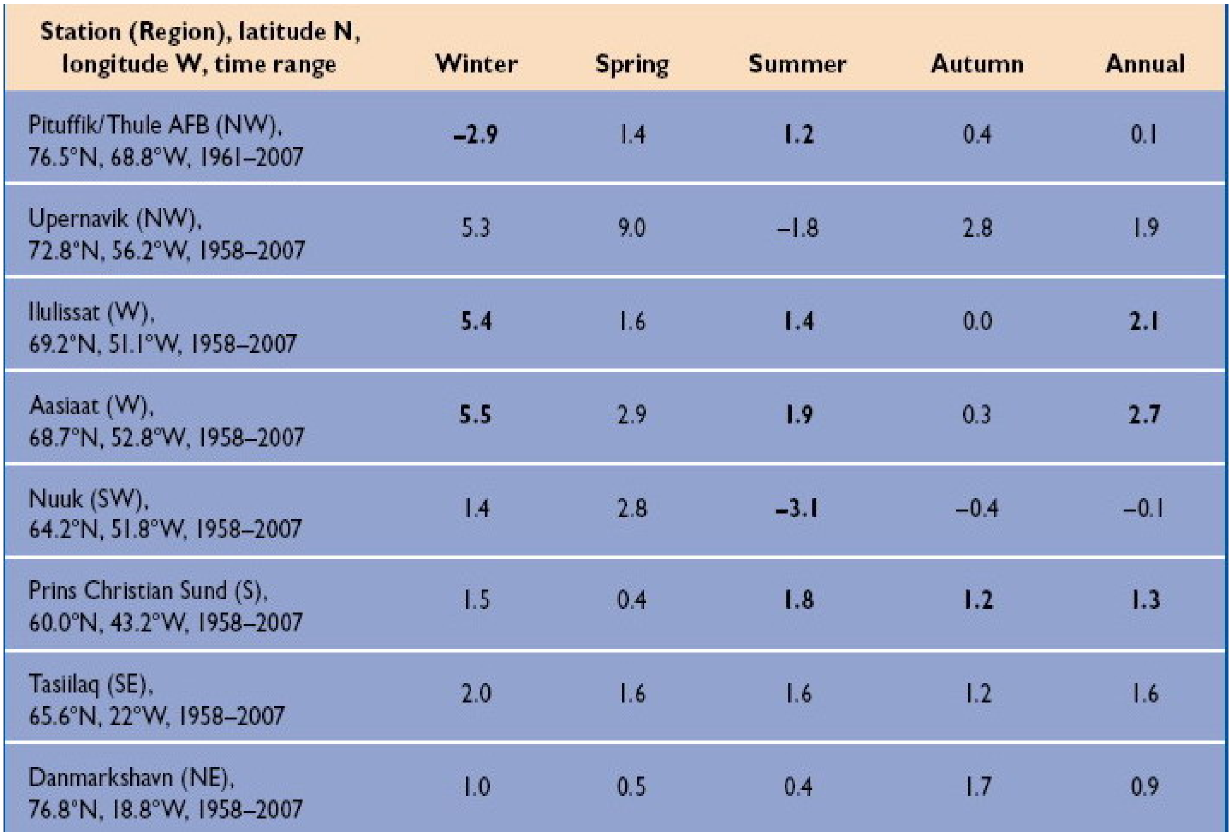
Overview

Greenland climate records indicate regional warming in 2007, with statistically significant positive (warm) annual temperature anomalies in the 1.3° to 2.7°C range for coastal stations and 1.3°C for the inland ice sheet with respect to 1971–2000 averages. Seasonal temperature anomalies were largest in winter but not positive in every season. Upper air temperatures indicate lower- to midtropospheric warm anomalies in all seasons above sounding stations surrounding Greenland. Noteworthy are western and southern locations where midtropospheric anomalies exceed those observed at the surface. Ice sheet surface melt duration anomalies were up to 53 days longer than the 1973–2000 average, based on passive microwave remote sensing. MODIS-derived surface albedo anomalies in 2007 versus the 2000–07 period were persistently negative, consistent with extensive surface melting. Greenland's largest glacier continued its recession, with ice flushing out from an embayment thought to have been ice filled since at least the onset of the Little Ice Age. The overall ice sheet mass budget was likely in mass deficit by at least 100 $km^3\ yr^{-1}$.

Coastal surface air temperatures

Warm (positive) anomalies predominated in 2007, relative to the last 50-yr period (1958–2007), when the most reliable continuous surface air temperature records are available from a collection of stations around the island (Cappelen et al. 2007, 2008). Exceptions included an anomalously cold winter at Pittufik (northwest), an unusually cold summer and autumn at Nuuk (southwest), and an anomalously cold summer at Upernavik. The Z-scores exceeding ±1.0 or ±2.0 indicate anomalies exceeding the most common 66% or 95% of the observed cases, respectively (Table G1). At Upernavik (northwest) the spring temperature was the warmest in the past 50 yr, and at Nuuk (southwest) the summer temperature was the coldest in the past 50 yr. The only anomalies that were significant annually, that is, with Z-scores ≥1.0, were warm anomalies for 2007 annual means.

Table G1. Greenland station surface air temperature anomalies by season, 2007 vs 1971–2000. Anomalies are in °C. Bold values indicate values that meet or exceed 1 Z-score.



Station (Region), latitude N, longitude W, time range	Winter	Spring	Summer	Autumn	Annual
Pituffik/Thule AFB (NW), 76.5°N, 68.8°W, 1961–2007	**–2.9**	1.4	**1.2**	0.4	0.1
Upernavik (NW), 72.8°N, 56.2°W, 1958–2007	5.3	9.0	–1.8	2.8	1.9
Ilulissat (W), 69.2°N, 51.1°W, 1958–2007	**5.4**	1.6	**1.4**	0.0	**2.1**
Aasiaat (W), 68.7°N, 52.8°W, 1958–2007	**5.5**	2.9	**1.9**	0.3	**2.7**
Nuuk (SW), 64.2°N, 51.8°W, 1958–2007	1.4	2.8	**–3.1**	–0.4	–0.1
Prins Christian Sund (S), 60.0°N, 43.2°W, 1958–2007	1.5	0.4	**1.8**	**1.2**	**1.3**
Tasiilaq (SE), 65.6°N, 22°W, 1958–2007	2.0	1.6	1.6	1.2	1.6
Danmarkshavn (NE), 76.8°N, 18.8°W, 1958–2007	1.0	0.5	0.4	1.7	0.9

Upper air temperatures

Upper air sounding data available from the Integrated Global Radiosonde Archive (Durre et al. 2006) indicate for Greenland in 2007 a continued pattern of lower- to midtropospheric warming and lower-stratospheric cooling, consistent with trends since 1964 (Box and Cohen 2006). In the lower troposphere at the 850-hPa level (1.1–1.5-km altitude), for example, annual temperature anomalies were between +0.6° and +1.5°C at sites surrounding the island, relative to the 1971–2000 average. Seasonal anomalies were largest in winter with up to +8.1°C at 1,000 hPa at the Aasiaat/Egedesminde sounding site, with smaller positive anomalies elsewhere in almost all seasons. At the upper limit of mandatory observational levels, (20 hPa, in the lower–mid stratosphere), –11.6°C anomalies are evident. Large lower-stratospheric temperature anomalies are not necessarily abnormal given the relatively large observed temperature variability due in part to much lower atmospheric mass (e.g., Christy and Drouilhet 1994) and given the fact that mid-stratospheric anomalies tend to mirror lower troposapheric anomalies (e.g., Liu and Schuurmans, 1990; Wong and Wang, 2000). Summer anomalies above southern Greenland balloon launching sites at the 850 and 600-hPa levels were between +0.2° and +1.3°C.

Greenland ice sheet melt extent

Passive microwave observations indicate summer 2007 (June–August) Surface Melt Duration (SMD) was greater than any other observed summer since records began in 1973 (Mote 2007).

The ice sheet area undergoing surface melt was 60% greater in 2007 than the next highest year (1998). Summer 2007 had 20 days more melt than average (1973–2000) across nearly all of the regions that exhibit melting. Up to 53 more days of melting than average was observed for elevations in the 2,000- to 2,400-m above sea level range between the north and south domes of the ice sheet (Fig. G1).

Ice sheet precipitation, evaporation, and meltwater runoff

Polar MM5 climate data assimilation model runs spanning 50 yr (1958–2007), calibrated by independent in situ ice core observations (Bales et al. 2001; Mosley-Thompson et al. 2001; Hanna et al. 2006) and ablation stakes (van de Wal et al. 2006), indicate that year 2007 precipitation and accumulation was not abnormal despite a +10 km^3 $decade^{-1}$ positive total precipitation trend over the 1958–2007 period. Surface water vapor fluxes were within an insignificant inter-annual range. In accordance with a +1.3°C year 2007 annual mean temperature anomaly, the fraction of precipitation that fell as rain instead of snow, surface meltwater production, and meltwater runoff were well above the 1971–2000 mean (Table G2). Due to abnormally large mass loss by meltwater runoff despite normal snow accumulation, melt and more frequent rainfall darkened the snow and ice surface (Fig. G2).

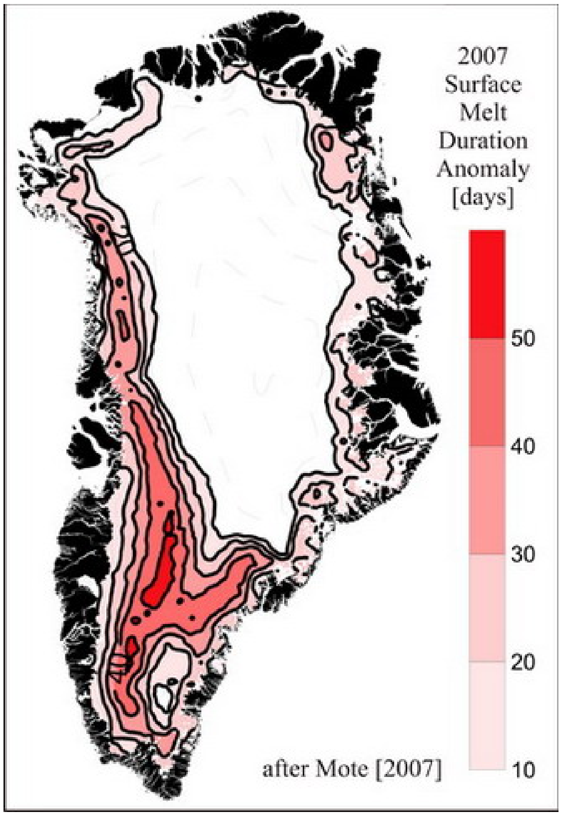


Figure G1. Surface melt duration departure from average for summer (Jun–Aug) 2007 from SSM /I; units are days. The average is based on the summers from 1973 to 2000 (excluding 1975, 1977, and 1978). Only departures >10 days are included. (Figure after Mote 2007)

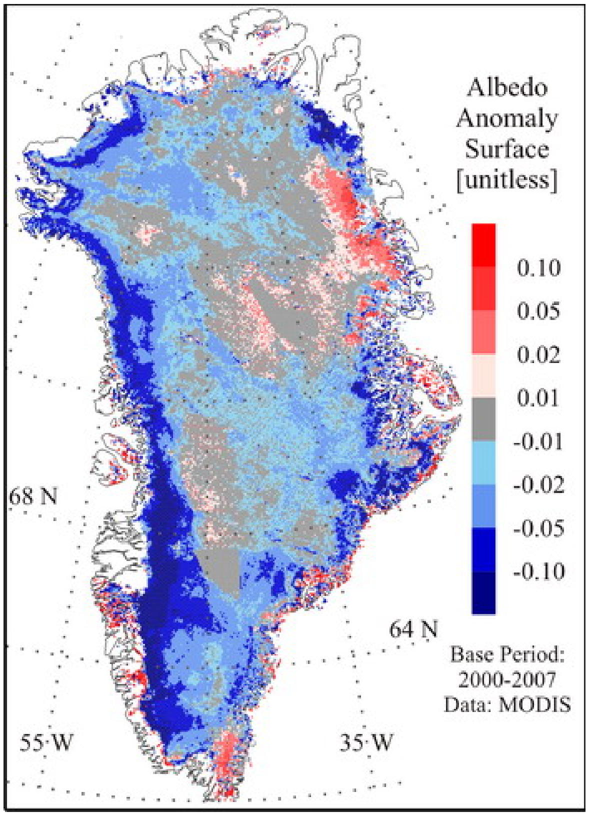
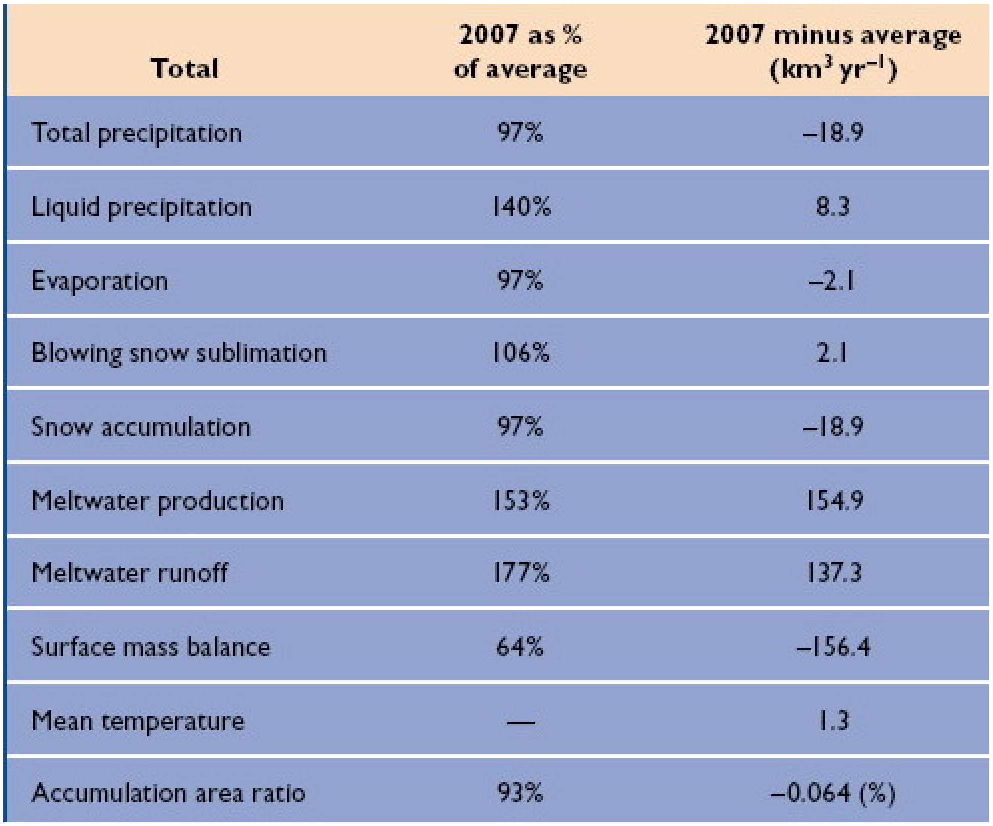


Figure G2. Albedo anomaly (unitless) for 8–23 Aug (days 220–235) 2007 vs the 2000–07 average (from algorithm based on Liang et al. 2005).

Table G2. Greenland ice sheet surface mass balance parameters: 2007 departures from 1971–2000 average (adapted from Box et al. 2006).



Total	2007 as % of average	2007 minus average ($km^3\ yr^{-1}$)
Total precipitation	97%	–18.9
Liquid precipitation	140%	8.3
Evaporation	97%	–2.1
Blowing snow sublimation	106%	2.1
Snow accumulation	97%	–18.9
Meltwater production	153%	154.9
Meltwater runoff	177%	137.3
Surface mass balance	64%	–156.4
Mean temperature	—	1.3
Accumulation area ratio	93%	–0.064 (%)

Glacier changes

The terminus of Greenland's largest glacier, the Jakobshavn's Isbrae near the town of Ilulissat, retreated 0 to 500 m in 2007 (Fig. G3), continuing a retreat that began summer 2001 with a dramatic 11-km floating ice collapse (Weidick and Bennike 2007). The large ice lagoon called Tissarissoq at the south side of the fjord was flushed of ice by the end of the summer, ice-free probably for the first time since at least the onset of the Little Ice Age (ca. 0.4–0.1 ky BP). It is possible that Tissarissoq was ice-free before that time during the medieval warm period (ca. 1.1–0.5 ky BP).

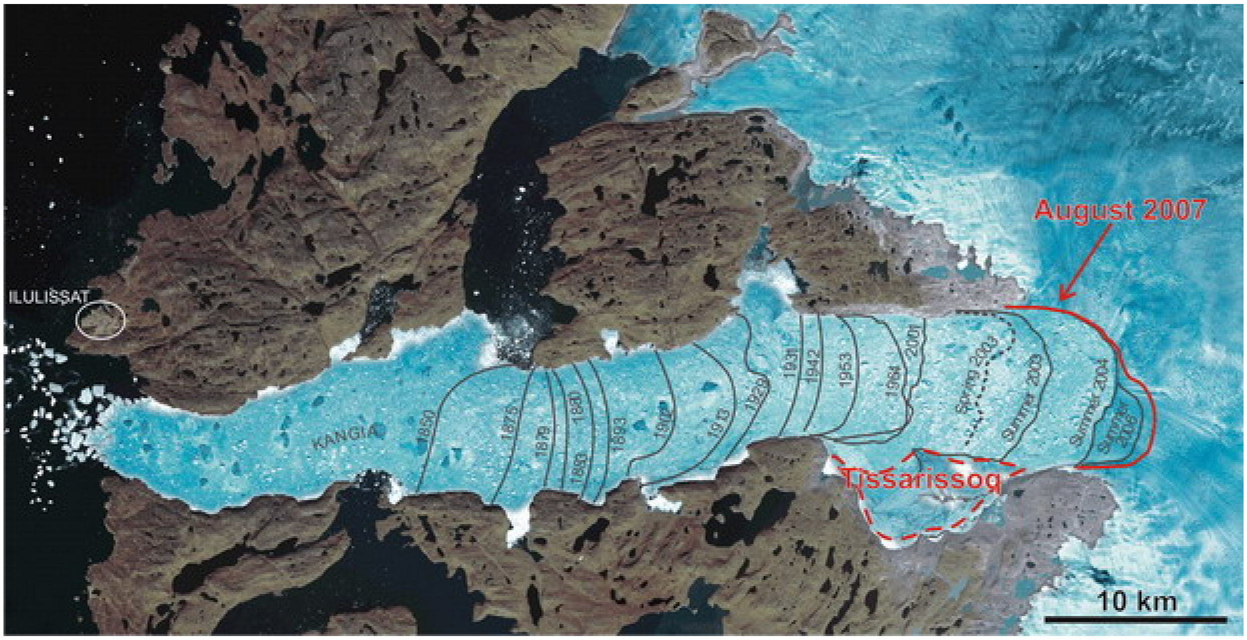


Figure G3. Front position of the Ilulissat (Jakobshavn Isbrae) glacier in 2007 and earlier years, based on Weidick and Bennike (2007). The image mosaic is from Jun 2003 Landsat and ASTER images.

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Biology

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Summary

Changes to Arctic wildlife populations and habitats, although mixed, present some cause for concern. Recent observations of key marine mammal populations indicate impacts to their populations and habitats may continue for some time. 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 in some other sub-populations. With the record summer sea ice retreats of 2007 and 2008, walruses, in some regions of the Arctic, were forced to haul out along shores in unusually large numbers, triggering increases in trampling deaths in response to increased terrestrial disturbance. Long term impacts to this walrus re-distribution are also expected as habitats are unable to sustain the needs of concentrated walrus populations into the future. Recent estimates of wild caribou and reindeer indicate that these populations may be entering a period of declining numbers, with populations that have previously been increasing at a steady rate now showing signs of either peaking or beginning to decline. Most goose populations are experiencing increasing numbers. For some species found in the Barents Sea, near record warm water conditions are close to the limit of their adaptive capabilities.

Given the threats (both observed and predicted) facing northern species and their habitats, there is justifiable cause for concern, particularly with regard to small or declining populations, as well as for those for which information is insufficient. For example, the lack of trend information for Arctic Char, which some northern communities greatly depend on, represents a significant knowledge gap. Another area of concern is the Barents and Bering Seas which are both experiencing ecosystem re-organizations which result in greater uncertainty for the future status of stocks. Consequently, there is a need to increase monitoring of these ecosystems for continuing change.

State of Wild Reindeer Herds

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Rangifer (wild reindeer and caribou) herds across the circumpolar north have long been characterized by periods of abundance and periods of scarcity. Recent population estimates indicate we may be entering a period of declining numbers. Populations that have been increasing at a steady rate since the early to mid 1970's are either showing signs of peaking or beginning to decline. Figure R1 shows the current status of selected *Rangifer* (the major migratory herds and herds being monitoring as part of the CircumArctic *Rangifer* Monitoring and Assessment (CARMA) Network.

- Two of the largest herds, which had been stable, have shown a decline based on current counts. The Western Arctic Herd dropped 25% to 377,000 animals between 2003 and 2006. The Taimyr Herd in Russia is estimated at 750,000 animals, down from a high of 1,000,000 animals in 2000.
- In the Ungava Peninsula of Canada the George River (385,000, decreasing) and the Leaf River Herd (628,000, increasing) were last counted in 2001 and, thus, recent trends are not available. At that time, however, the total population of caribou in the Ungava had declined from about 1.13 million in 1994. Managers believe the 2 herds are a meta-population with no marked genetic differentiation between the two herds.
- The Porcupine Caribou Herd was one of the first herds to decline, dropping from a high of 178,000 in 1989 to 123,000 in 2001. Repeated attempted to provide a current estimate of the herd have failed.
- In the central barrens of Northwest Territories and Nunavut herds have declined by as much as 80% in the last 5 years. These dramatic declines have local agencies and user communities preparing for resource shortages in the near future.
- See: http://www.nwtwildlife.com/NWTwildlife/caribou/newsreleasesept06.htm), and (http://www.arcticpeoples.org/2007/02/03/canadas-disappearing-caribou/)
- Other herds in Russia are also in decline with the exception of the Chukotka herd, a herd that has increased greatly since declines in the domestic reindeer industry following the collapse of the Soviet Union. There is some speculation that domestic stock may have augmented wild reindeer population in the region.
- A number of herds have been photographed for population estimates in 2007 and 2008 but the final values have not been reported. These include; Beverly, Qamanirjuaq, Central Arctic, Teshekpuk Lake and Lena-Olenyk.

Although many predicted that herds would not continue to expand, 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 CARMA Network (http://www.rangifer.net/carma/) 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 over the next 4 years.

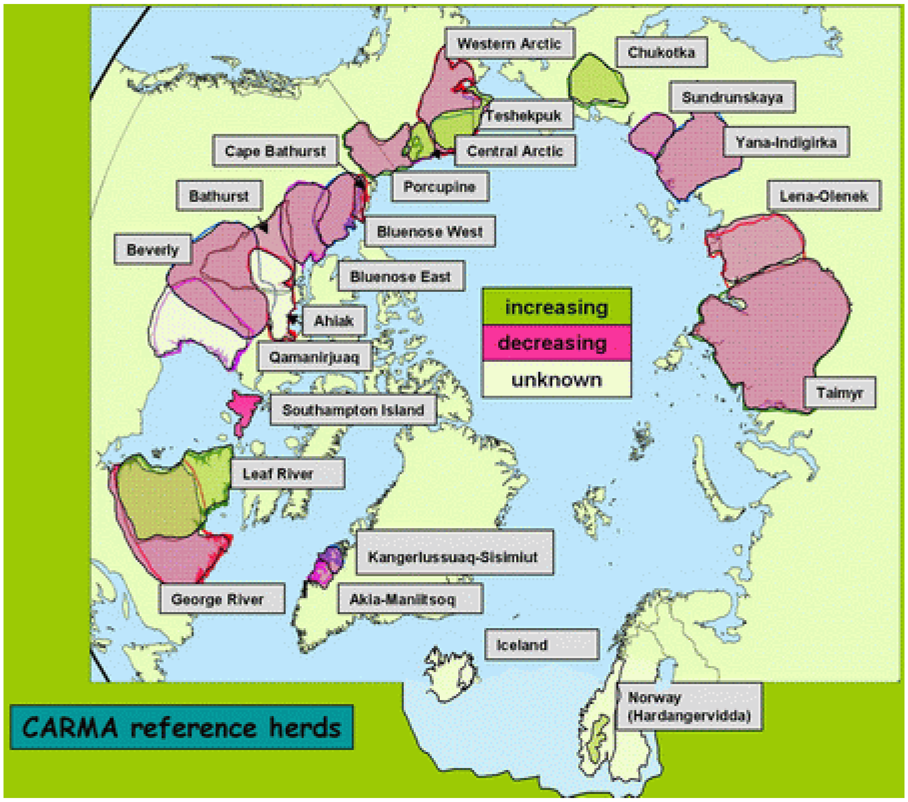

Figure R1. Current status of the main migratory herds across the circumpolar north.

Additional Information:

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Goose Populations

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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 organisation 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).

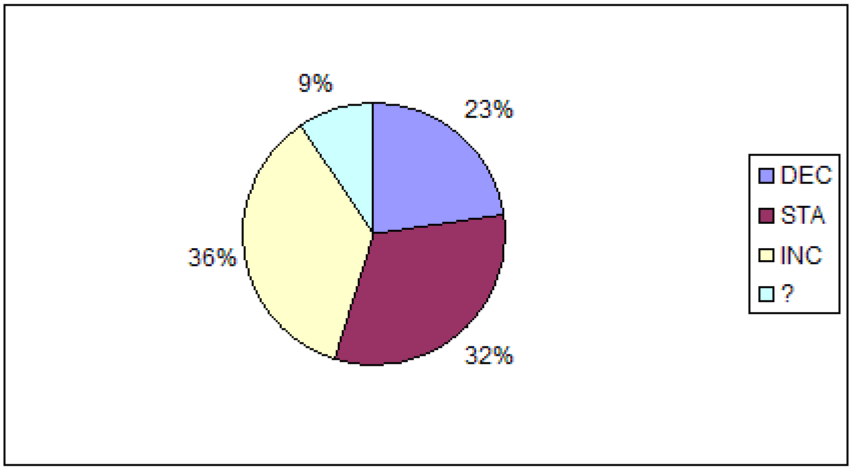

Figure E1. Trends in 47 Arctic Geese populations (Wetlands International, 2006). DEC - population decreasing; STA - population stable; INC - population increasing; ? - unknown

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Marine Mammals

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U.S. Marine Mammal Commission

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. See photo credits at end of essay.

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 (Fig. M1). 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. Table 1 (below) 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 2, below).

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. 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 (Table 2, below). A recent special publication of Ecological Applications provides a comprehensive review of the likely impacts of climate change on Arctic marine mammals [37].

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. 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 [38,39]. 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. The immediate impact of this redistribution was an increase in trampling deaths as walruses on shore stampeded in response to terrestrial disturbances [40]. 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.

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 increased predation by polar bears and arctic foxes [41], 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 [42,43]. 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 [35]. Of course, in addition to environmental impacts, reduced sea ice will make the Arctic more accessible 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.

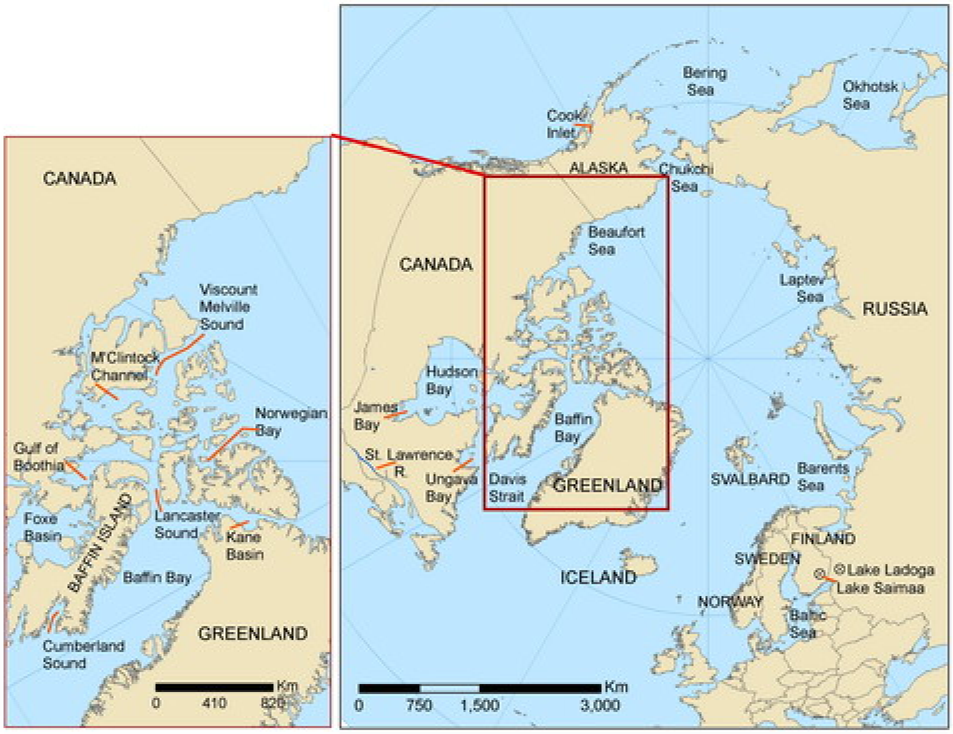

Figure M2. Map of the Arctic with place names referred to in the text or in Table 1.

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	1
	E. Canada-W. Greenland	6,300	2002-2004	increasing	2,3
	Svalbard	unknown	—	unknown	4
	Okhotsk Sea	unknown	—	unknown	4
Beluga whale	Cook Inlet	380	2000	declining	5
	Eastern Bering Sea	18,100	1989–1991	unknown	6
	Bristol Bay	1,600	2000	increasing	6,7
	Eastern Chukchi Sea	3,700	1992	stable	4,6
	Eastern Beaufort Sea	39,300	1999	stable	6,8
	Foxe Basin	1,000	1983	unknown	9
	Western Hudson Bay	25,000	1978 & 1987	unknown	10,11
	Southern Hudson Bay	1,300	1987	unknown	9
	James Bay	7,900	2001	unknown	9
	St. Lawrence River	1,100	1997	stable	12
	Eastern Hudson Bay	1,200	2001	declining	13
	Ungava Bay	<50	2007	unknown	14

	Cumberland Sound	1,500	2001	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	9
	11 additional stocks	unknown	—	unknown	
Narwhal	Canadian High Arctic	70,000	2002–2004	unknown	16,18
	Northern Hudson Bay	3,500	2000	unknown	19
	Eastern Baffin Island	15,000	1993	unknown	
	West Greenland	2,000	1998–1999	unknown	18,20
	East Greenland	>1,000	1980–1984	unknown	18,21
Ringed seal[a]	Arctic subspecies	~2.5 million	1970s	unknown	22
	Baltic Sea subspecies	5,000–8,000	1990s	mixed	23
	Lake Saimaa subspecies	280	2005	increasing	24
	Lake Ladoga subspecies	3,000–5,000	2001	unknown	25
	Okhotsk Sea subspecies	>800,000	1971	unknown	22
Bearded seal[b]	Bering-Chukchi Seas	250–300,000	1970s	unknown	26
	Canadian waters	190,000	1958-1979	unknown	27
	Atlantic and Russian Arctic	unknown	—	unknown	
	Okhotsk Sea	200–250,000	1968–1969	unknown	26
Walrus[c]	Bering-Chukchi Seas	~201,000	1990	unknown	28
	Atlantic subspecies	18–20,000	2006	mixed	29,30,31,32
	Laptev Sea	4,000–5,000	1982	unknown	33
	Other regions	unknown	—	unknown	
Polar bear	Chukchi Sea	2,000	1993	unknown	34
	Southern Beaufort Sea	1,500	2006	declining	34
	Northern Beaufort Sea	1,200	1986	stable	34
	Viscount Melville Sound	220	1992	increasing	34
	McClintock Channel	280	2000	increasing	34
	Norwegian Bay	190	1998	declining	34
	Lancaster Sound	2,500	1998	stable	34
	Gulf of Boothia	1,500	2000	stable	34
	Foxe Basin	2,200	1994	stable	34
	Western Hudson Bay	940	2004	declining	34
	Southern Hudson Bay	1,000	1988	stable	34
	Baffin Bay	2,100	1998	declining	34
	Davis Strait	1,700	2004	unknown	34
	Kane Basin	160	1998	declining	34
	Barents Sea	3,000	2004	unknown	34
	Laptev Sea	4,000–5,000	1993	unknown	34
	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.

Table M2. Key Arctic marine mammal species ecology

Species	**Primary Diet** [35]	**Relationship with Sea Ice Habitat** [36]
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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The information summarized here was collected through the hard work of countless Arctic researchers whose contributions to this report far outweigh the author's own. Kit Kovacs, Randy Reeves, and their colleagues in the Pinniped and Cetacean Specialist Groups of the International Union for Conservation of Nature (IUCN) provided invaluable help by identifying key sources of information for Arctic marine mammal stocks. Joselyd Garcia compiled the information presented in Table 1, and Mina Innes produced Figure 2. This report was improved by comments on earlier versions by Mike Cameron, Mike Gill, Bob Gisiner, Kit Kovacs, Kristin Laidre, Jim Overland, Tim Ragen, Jackie Richter-Menge, Randy Reeves, Michael Svoboda, and anonymous reviewers.

Photo Credits for collage of Marine Mammals in Figure 1:

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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Fisheries in the Bering Sea

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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).

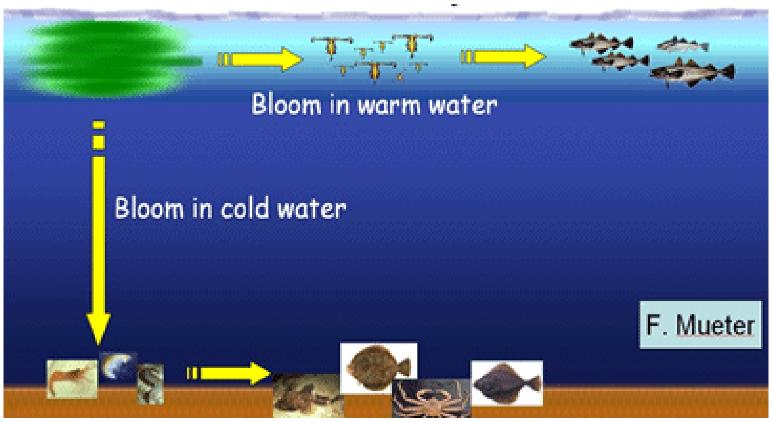

Figure F1. Bering Sea Ice shifting from Benthic to Pelagic Pathway

An indicator of this shift is the observed multi-year persistence of change. Summer bottom water temperatures of the southeast Bering Sea were warm from 1996–2005 (except for 1999) (Figure F2), due to sea ice leaving the region earlier in the spring. Pollock expanded their range northward during these years. Since 2005, the Bering Sea has been relatively cold, with more sea ice in the winter. In 2008, the winter sea ice extent in the Bering Sea was at a near record maximum and bottom water temperatures were at a near record minimum. Cold water species such as Arctic cod have returned toward the south. At present Bering Sea climate change and ecosystem response are more characterized by natural variability in terms of large multi-year warm and cold periods than by an emerging global warming trend.

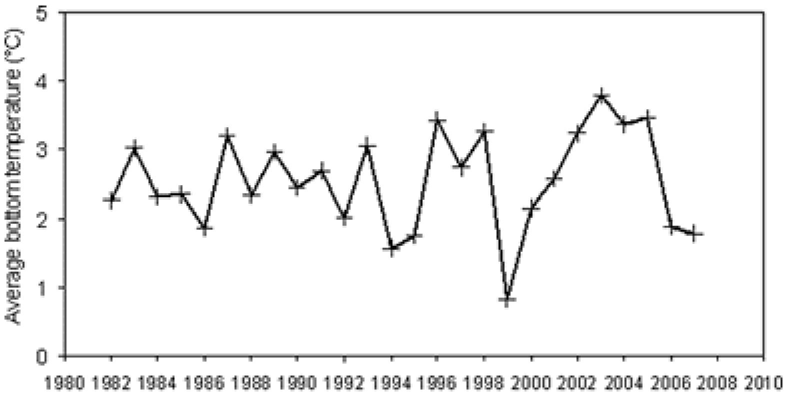

Figure F2. Southeast Bering Sea summer ocean bottom temperatures. From NOAA, P. Stabeno (TBP).

Pollock are currently a major economic resource for the Bering Sea (Figure F3). Warm temperatures and lack of sea ice tend to favor pollock, which has had one of highest biomass for any large marine ecosystem at the expense of bottom-living fish and crab and walrus, which feed on bottom dwelling clams. The biomass for pollock in the Bering Sea and the number of new fish added each year (called recruitment) are shown in Figure F4. These data imply that the status of pollock stocks may be more complicated than a simple temperature relationship. Winters of 2006, 2007 and 2008 were of cold or average temperature, which typically contributes to less favorable conditions. Pollock recruitment, however, began to decrease before the return of these cold temperatures. It is suggested that after almost a decade of warm temperatures, the food supply for pollock shifted to less favorable species and that pollock predators, such as arrowtooth flounder, became well established. Although there was a large year class in 2006, given the present low biomass, the recent shift in water temperatures, low abundance of food, high abundance of predator species, and the unknown timing of future climate events, the future status of pollock is uncertain.

Figure F3. Walleye Pollock. Photo from the NOAA AFSC

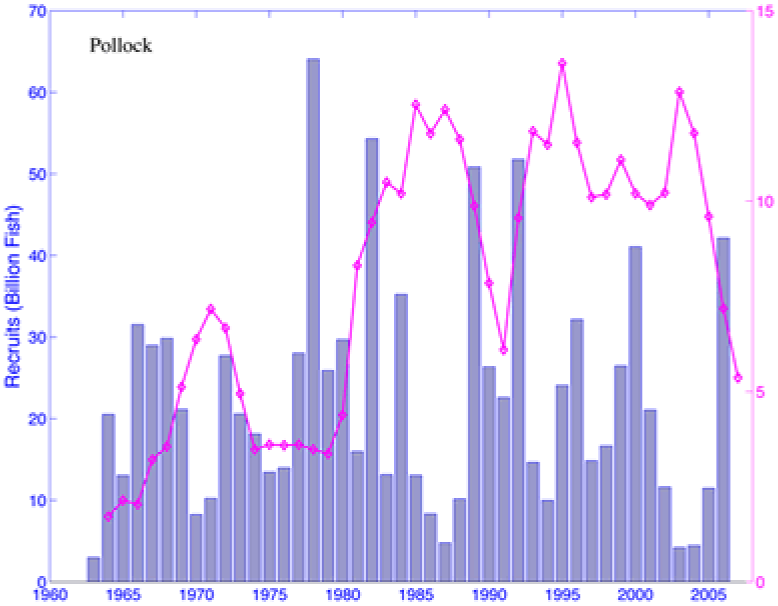

Figure F4. Bering Sea Pollock. Diamonds indicate biomass, and vertical bars indicate recruits to the population each year. From the NOAA/NMFS SAFE report

Marine mammals are major consumers of fish and other species in the Bering Sea ecosystem and may have been impacted by climate shifts. The number of new fur seal pups (Figure F5) added to the population on St. Paul Island (in the Pribilof Islands) (Figure F6), shows a decrease after the 1970s and another more recent decrease after 1998. Although it is difficult to assign direct causes to the declines, there was a climate shift in the North Pacific Ocean in 1977, and, since then, a general sustained warming.

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 extreme warm temperatures in future years, which will continue the negative impact on Arctic and bottom species, while favoring sub-Arctic species such as salmon.

Figure F5. Northern fur seal Callorhinus ursinus. From the NOAA Photo Library.

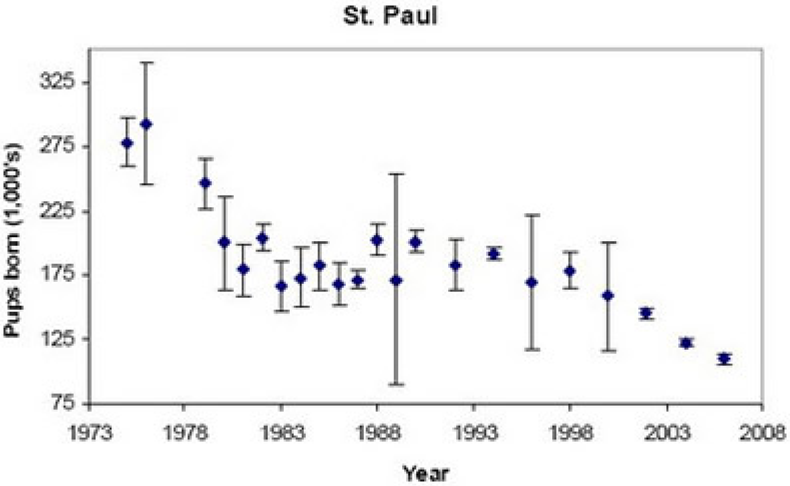

Figure F6. Northern fur seal Callorhinus ursinus pups born on St. Paul, 1975–2006. Error bars are approximate 95% confidence intervals. From NOAA NMFS AFSC

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

North Pacific Groundfish Stock Assessment and Fishery Evaluation Reports (from NOAA / AFSC).

Fisheries in the Barents Sea

The following information is taken from
the Joint PINRO/IMR report on the state of the Barents Sea ecosystem 2006
Stiansen, J.E and A.A. Filin (editors)

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

The Barents Sea, north of the Scandinavian Peninsula is shown, with the prevailing warm and cold current directions, in Figure B1. Temperature in the Barents Sea has been above normal in recent years, and is currently close to an all-time high, rivaling temperatures of 1937–1938, for the periods where observations are available.

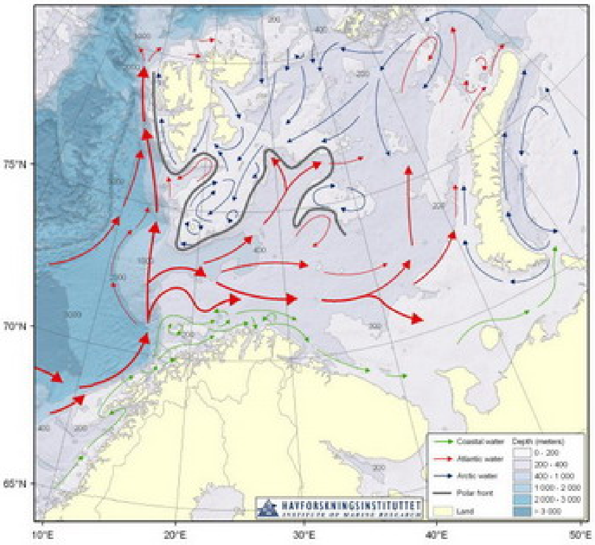

Figure B1. The main features of the circulation and bathymetry of the Barents Sea. From PINRO/IMR report.

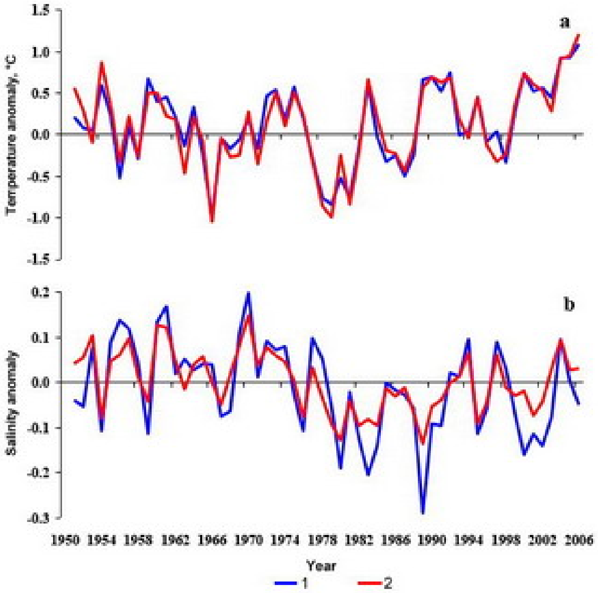

Figure B2. Mean annual temperature (a) and salinity (b) anomalies in the 0–200 m of the Kola section in 1951–2006. 1 – coastal waters, 2 – the offshore current. From PINRO/IMR report.

Ocean temperature history for the Kola section, directly north of the Scandinavian Peninsula, averaged over 0–200 m depth, shows temperatures of 1 °C above the long term mean (Figure B2). Although this increase may not seem very large, it has the potential to cause significant changes in the ecosystem. For some of the species found in the Barents Sea, recent temperature conditions are probably close to the limit of what they can adapt to, and even a small temperature change may lead to a northward increase of their distribution area. Changes in distribution of species could also cause changes in species overlap and hence predator-prey interactions.

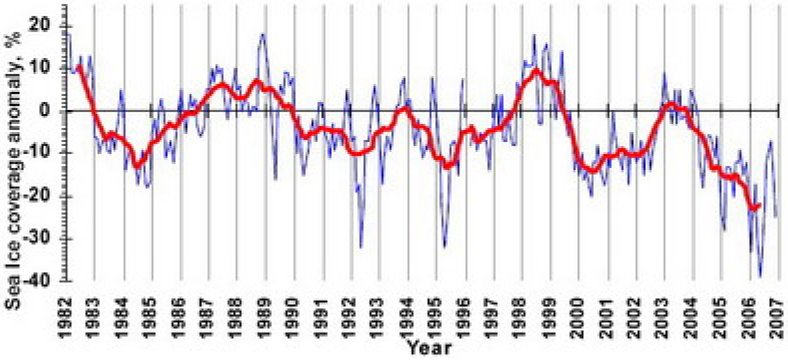

Figure B3. Anomalies of mean monthly ice extent in the Barents Sea in 1982–2006. A blue line shows monthly values, the red one – 11-month moving average values (Anon., 2007). From PINRO/IMR report.

Temperature is not the only relevant factor in this context. The reasons for increases in temperature may be an increased inflow of Atlantic water, or a higher temperature of the water flowing into the Barents Sea. For example, during the winter of 2006, the volume transport of Atlantic Water into the Barents Sea was the highest recorded since the observations started in 1997. Increased inflow leads to increased abundance of nutrients and planktonic organisms, which may enhance growth and survival for the fish species. The winter ice cover in 2006 was the lowest observed since 1970 (Figure B3).

The abundance of cod (Figure B4, blue area) appears to be stable in recent years and warmer temperatures are assumed to be favorable for this species. Caplin (Figure B5, blue area) are at historically low levels and, as a more cold water species, are expected to move north and east. Complicated relationships between cod, capelin and euphausiids (small shrimp) have been demonstrated. Predation on euphausiids by cod decreased the food supply for capelin and reduced the capelin feeding and possibilities for stock recovery. At the same time predation on euphausiids by capelin reduces the food supply for both adult and juvenile cod. Thus both climate change and the internal species dynamics of the ecosystem, as well as fishing pressure, impact future fishing conditions.

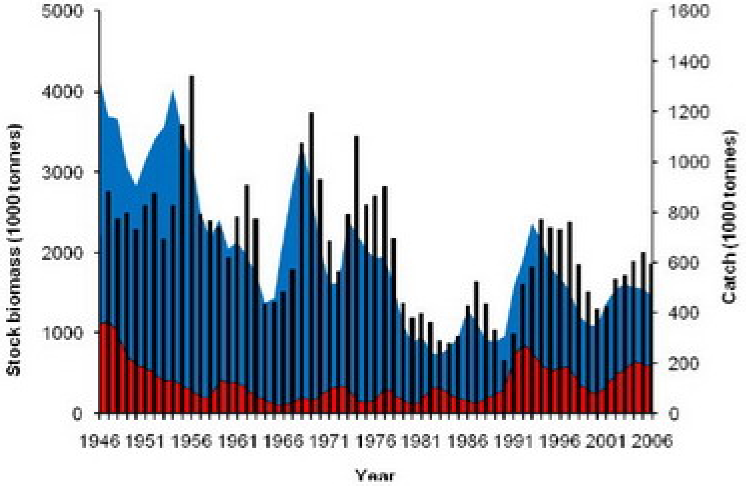

Figure B4. Northeast Arctic cod, development of spawning stock biomass (red area), total stock biomass (age 3 and older, blue area) and landings (columns). From PINRO/IMR report.

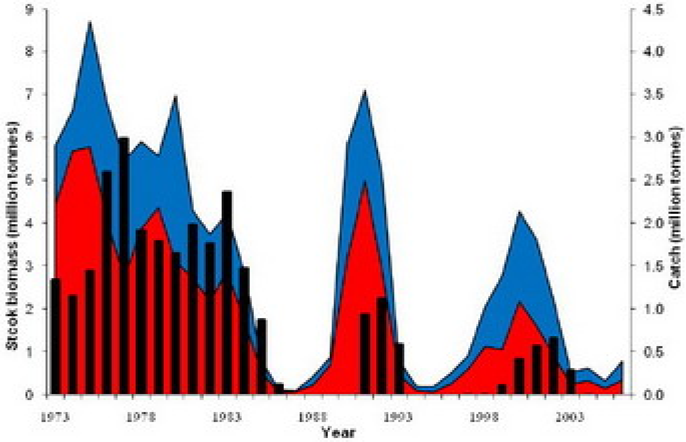

Figure B5. Barents Sea capelin. Total stock (blue area) and maturing component (red area) during autumn, and total landings (columns), 1973–2006. From PINRO/IMR report.

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Stiansen, J.E and A.A. Filin (editors), Joint PINRO/IMR report on the state of the Barents Sea ecosystem 2006, with expected situation and considerations for management. IMR/PINRO Joint Report Series No. 2/2007. ISSN 1502-8828. 209 pp. Contributing authors in alphabetical order: Aglen, N.A. Anisimova, B. Bogstad, S. Boitsov, P. Budgell, P. Dalpadado, A.V. Dolgov, K.V. Drevetnyak, K. Drinkwater, A.A. Filin, H. Gjøsæter, A.A. Grekov, D. Howell, Å. Høines, R. Ingvaldsen, V.A. Ivshin, E. Johannesen, L.L. Jørgensen, A.L. Karsakov, J. Klungsøyr, T. Knutsen, P.A. Liubin, L.J. Naustvoll, K. Nedreaas, I.E. Manushin, M. Mauritzen, S. Mehl, N.V. Muchina, M.A. Novikov, E. Olsen, E.L. Orlova, G. Ottersen, V.K. Ozhigin, A.P. Pedchenko, N.F. Plotitsina, M. Skogen, O.V. Smirnov, K.M. Sokolov, E.K. Stenevik, J.E. Stiansen, J. Sundet, O.V. Titov, S. Tjelmeland, V.B. Zabavnikov, S.V. Ziryanov, N. Øien, B. Ådlandsvik, S. Aanes, A. Yu. Zhilin.

The State of Char in the Arctic

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Introduction

The char species complex is made up of approximately 20 closely related taxa. Char 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.

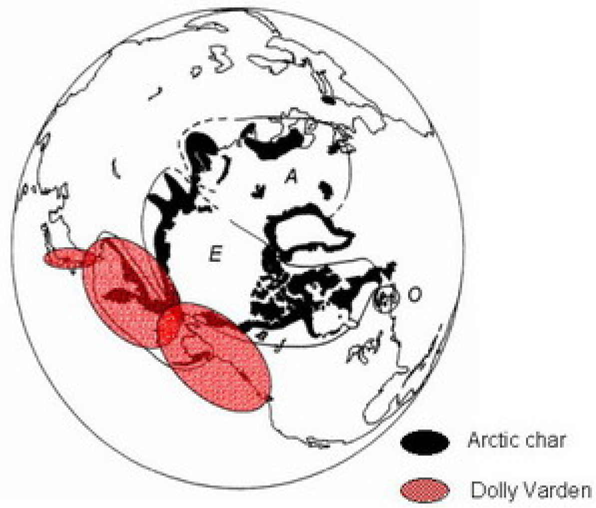

Figure C1. Global distribution of Arctic char and Dolly Varden.

Arctic Char are the most northerly distributed freshwater fish species and occur in suitable habitats in all Arctic countries. 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.

Status of Char in Northern Canada

Arctic char in the Northwest Territories has been ranked as Secure (not at risk of extinction or extirpation and not likely to become so in the foreseeable future) with the exception of the populations in the Hornaday and Kuujjua rivers which have been ranked as Sensitive (not at risk of extinction or extirpation but may require special attention or protection to prevent them from becoming at risk) (Working Group on General Status of NWT Species 2006). In Nunavut, Arctic char has been ranked as Sensitive (Canadian Endangered Species Conservation Council 2006). Dolly Varden in the Northwest Territories has been ranked as Sensitive (Working Group on General Status of NWT Species 2006) and is currently being assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Future updates will document the status of char in other Arctic countries as information becomes available.

Populations of both Arctic char and Dolly Varden inhabiting different systems have been shown to be genetically distinct (Reist 1989; Everett et al. 1998; Reist 2001; Rhydderch 2001; Bernatchez et al. 2002; Kristofferson 2002; among others) and are subject to different levels of biological (e.g., natural habitat change such as that caused by earthquakes) and anthropogenic (e.g., fisheries) stressors, thus summarizing population trends in a meaningful manner is a substantial endeavour. Furthermore, few long-term data sets exist for single populations or stock complexes and those that do deal exclusively with the effects of exploitation on population structure (Power et al. 2000). Prior to 2000, there had not been any Canadian studies that examined relationships between changes in stock characteristics and environmental variables. The first Canadian study of its kind examined a 20 year data set on Nain, Labrador char populations (Power et al. 2000). A similar recently conducted study examined a 15 year data set from the Hornaday River in the Northwest Territories (Chavarie 2008). Both studies found that environmental variables, including precipitation and temperature, influenced population characteristics such as mean length. Chavarie (2008) concluded that environmental changes predicted by climate change scenarios will significantly impact Hornaday River Arctic char and will likely affect other northern Arctic char populations.

As noted above, northern char population trends represent a significant gap in our knowledge of this species. To that end a char monitoring network is being developed within Canada and internationally as part of the International Polar Year (IPY) project Climate Variability and Change Effects on Char in the Arctic (Project Lead:Dr. James Reist, Fisheries and Oceans Canada;

http://www.ipy.org/index.php?ipy/detail/arctic_biodiversity_of_chars/). This network will also contribute to the Circumpolar Biodiversity Monitoring Program (CBMP) of the Arctic Council.

Threats to Northern Char Populations

Potential threats to northern char populations include over-harvesting, habitat degradation/disruption, climate change, invasive species, and pollution among others. Perhaps the most urgent of these is climate change which is predicted to exacerbate existing stressors (ACIA 2005; Reist et al. 2006a). For example, rising temperatures may increase the level of contaminants, such as mercury, in Arctic freshwaters negatively affecting the health of the fish and the ecosystems they inhabit (ACIA 2005; Reist et al. 2006b). Their wide distribution, high level of diversity and significance to northern aquatic ecosystems make chars ideal for studying the effects of ecosystem change.

Knowledge Gaps

In order for char to be used to monitor Arctic change and attribute cause(s) to that change, several obstacles must be overcome. These include:

1. Char biodiversity and geographically wide distribution: As noted previously, this is one aspect of char biology that makes them ideal for studying effects of ecosystem change. However, it is also problematic as their high level of diversity creates difficulties in interpretation of results. Chars occur in rivers, lakes, and seasonally in the sea. Their diversity includes adaptations to all of these environments and to moving between freshwater and marine systems. In freshwater, different species are adapted to specific habitat types (e.g., lakes versus rivers). Each species, and in some cases population, is also inherently diverse. This includes differences such as anadromy versus freshwater residency and diversity of forms in some situations (e.g., ecological types within many lakes). These diverse forms may be seen as size variants, morphological variants, ecological forms or some combination of the above. A key component in our understanding is therefore to develop basic knowledge of the range and geographic distribution of this diversity to provide a baseline for future comparisons and thus for documenting change.
2. Role(s) of char(s) in the ecosystems: The roles performed by chars, how these change with life history, and how these differ among char forms are keys to understanding any observed changes and addressing consequences of the changes.
3. Indicators to monitor: What are the best parameters to monitor for chars to document short-term change, medium-term change and long-term change in both the chars and their supporting ecosystems? How best should such monitoring be developed in the long-term?
4. Char responses to stressors: Is most of the observed variation genetically based (and therefore can only shift in small increments over longer time frames) or is it environmentally driven and thus can we expect rapid char responses to rapid changes in stressors and environments? What surprises may exist concerning local responses of chars and how may we best prepare for such?

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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].

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About the Report Card

The Arctic Report Card is introduced as a means of presenting clear, reliable and concise information on recent observations of environmental conditions in the Arctic, relative to historical time series records. Issued annually, it provides a method of updating and expanding the content of the *State of the Arctic Report*, published in fall 2006, to reflect current conditions. Some of the essays are based upon articles in the BAMS State of the Climate in 2007.

Material presented in the Report Card is prepared by an international team of scientists and is peer-reviewed by topical experts of the Climate Experts Group (AMAP) of the Arctic Council. The audience for the Arctic Report Card is wide, including scientists, students, teachers, decision makers and the general public interested in Arctic environment and science. The web-based format will facilitate future timely updates of the content.

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