Accelerated decline in the Arctic sea ice cover

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Received 8 September 2007; revised 30 October 2007; accepted 26 November 2007; published 3 January 2008.

[1] Satellite data reveal unusually low Arctic sea ice coverage during the summer of 2007, caused in part by anomalously high temperatures and southerly winds. The extent and area of the ice cover reached minima on 14 September 2007 at 4.1×10^6 km^2 and 3.6×10^6 km^2, respectively. These are 24% and 27% lower than the previous record lows, both reached on 21 September 2005, and 37% and 38% less than the climatological averages. Acceleration in the decline is evident as the extent and area trends of the entire ice cover (seasonal and perennial ice) have shifted from about −2.2 and −3.0% per decade in 1979–1996 to about −10.1 and −10.7% per decade in the last 10 years. The latter trends are now comparable to the high negative trends of −10.2 and −11.4% per decade for the perennial ice extent and area, 1979–2007. **Citation:** Comiso, J. C., C. L. Parkinson, R. Gersten, and L. Stock (2008), Accelerated decline in the Arctic sea ice cover, *Geophys. Res. Lett.*, *35*, L01703, doi:10.1029/2007GL031972.

1. Introduction

[2] The Arctic region has been a central focus of many climate change studies in recent years, both because of the large amount of change seen in the Arctic [e.g., *Comiso and Parkinson*, 2004; *Arctic Climate Impact Assessment* (*ACIA*), 2005] and because of the expectations of an amplified climate signal in the Arctic due to the ice-albedo and snow-albedo feedback effects associated with the high reflectivity of ice and snow [*Holland and Bitz*, 2003]. Among the changes in the Arctic are increasing melt areas over the Greenland ice sheet, retreating glaciers, reduced sea ice coverage, permafrost thawing, and rising surface temperatures [*ACIA*, 2005]. All the changes incorporate interannual variability but also a consistent trend toward warmer, less-icy conditions.

[3] Among the best quantified of the changes occurring in the Arctic since the late 1970s are the changes associated with the Arctic sea ice cover. This is because of the effectiveness of satellite passive-microwave imagery in monitoring the ice and the existence of satellite passive-microwave data for almost the entire period since late October 1978, when the Scanning Multichannel Microwave Radiometer (SMMR) was launched, followed by a sequence of Special Sensor Microwave Imagers (SSMI) starting in 1987. The SMMR/SSMI record has been used extensively for Arctic sea ice studies, and is the record used here for the time series analyses. Also used here are data from the Japanese Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E), launched in 2002. Although short, the AMSR-E record provides the highest-resolution satellite passive-microwave imagery available. For the years of data overlap, the SSMI and AMSR-E records provide consistent sea ice results.

[4] One of the most remarkable of the quantified changes in the Arctic is the 9–10% decline per decade in the perennial sea ice cover during the SMMR/SSMI era [*Comiso*, 2002; *Stroeve et al.*, 2007]. Perennial ice is the ice cover that remains during minimum ice extent and consists mainly of thick multiyear ice floes. These ice floes are the mainstay of the Arctic Ocean sea ice cover. The Arctic perennial ice is accompanied through much of the year by considerable additional but much younger sea ice termed seasonal ice because of not lasting through the entire year. Together, the perennial and seasonal ice constitute the full Arctic sea ice cover. The full ice cover has also been decreasing, but until recently this has been at the more modest rate of about 3% per decade [e.g., *Bjorgo et al.*, 1997; *Parkinson et al.*, 1999; *Parkinson and Cavalieri*, 2002]. We report here both that the perennial ice is showing enhanced signs of its rapid demise and that the decrease in the full ice cover has now speeded up to the point that it is experiencing the much higher retreat rates earlier reported for the perennial ice alone.

2. Summer Ice Cover in 2007

[5] The 2007 Arctic ice cover was comparable to the 2005 and 2006 ice covers through mid-June but then began a more precipitous decline (Figure 1). Five-year averages from 1980 through 2004 show a general decrease in the Northern Hemisphere sea ice extents and areas throughout the seasonal cycle, with this pattern being especially strong in the late summer/early fall (Figure 1). Each of the years after 2004 shows less ice throughout the year than any of the five-year averages going back to 1980–1984. The year 2005 had the lowest winter values, but as of July 2007, the 2007 values were well below earlier July values, placing 2007 on track for reaching a new record minimum ice extent for the years of the satellite record (Figure 1). By 14 September 2007, the ice extent and area both reached new record minima, representing a decline from the 2005 minima that is comparable in magnitude to that between 1980 and 2005. It is also apparent, however, that the ice is rebounding with a rapid early autumn growth. The rate of growth from ice minima to 23 October 2007 is 69.6×10^3 km^2/day compared to 67.6×10^3 km^2/day for the climatological average (Figure 1).

[6] The unusually low 2007 ice cover at the end of the summer melt is illustrated by the color-coded daily ice concentration map for 14 September 2007 (Figure 2). For

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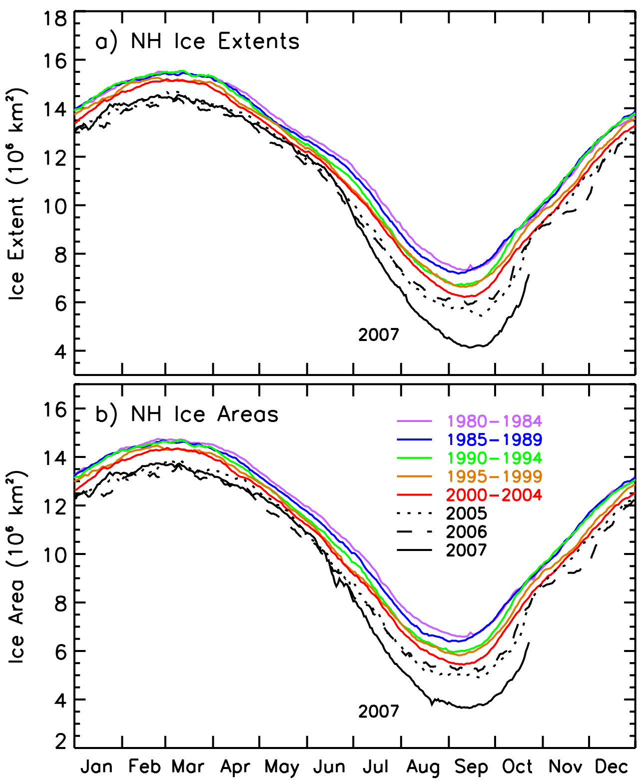

Figure 1. Daily ice extents and ice areas for 2005, 2006, 2007, and averaged over the 5-year periods 1980–1984 through 2000–2004. Values are derived from satellite passive-microwave data from NASA's Scanning Multichannel Microwave Radiometer (SMMR) and the Department of Defense's Special Sensor Microwave Imager (SSMI).

comparison, the map also includes the contour of the 2005 minimum ice edge (red contour) and the ice edge for the minimum conditions averaged over 1979–2006 (gold contour). It is apparent that much of the 2007 decline versus earlier years occurred in the extended region of the Beaufort Sea, Chukchi Sea, East Siberian Sea, Laptev Sea and Kara Sea. The contour of the ice edge during minimum extent in 2005, the year with the previous record minimum ice coverage, is considerably further south than the 2007 ice edge (dark blue in the ice concentration map) in the stretch from the Beaufort Sea to the Laptev Sea, although somewhat inside of the 2007 edge from the Greenland Sea to the Kara Sea. Overall, the 2007 summer ice exhibits a much larger anomaly than the 2005 ice (Figure 2).

[7] To gain insight into what might have triggered the accelerated sea ice decline in late June and July of 2007, we present images of monthly ice concentrations from March to August of 2007, 2005, and the 1979–2007 averages (Figure 3). These images show the temporal progression in the decay of sea ice from near peak values in March to midsummer values in August. Through May, the images for 2007 and 2005 show comparable seasonal decay. In June, distinct differences appear, specifically with a large polynya (open-water region in the midst of the ice cover) immediately north of northwestern Canada in 2005 and with a broad region of reduced ice concentrations north of Alaska and eastern Siberia (in the Beaufort, Chukchi, and East Siberian Seas) in 2007. In July, the latter of these differences expands, and by August, the expanded region of reduced ice concentrations in 2007 results in a substantial further retreat of the 2007 ice edge. The climatological averages show ice features similar to those of 2005 from March to June but with the ice edge generally somewhat further south and more diffused (on account of the averaging). In July and August, the 1979–2007 average ice cover is considerably more extensive and further south than in either 2005 or 2007.

[8] Numerical values of the 2005, 2007 and the 1979–2007 climatological monthly average ice extents, ice areas, and ice concentrations are presented in Table 1. From March to May, the monthly extents and areas in 2005 and 2007 are within 2.3% of each other, while the differences from climatology are substantially higher. In June, the 2007 ice extent is actually higher than the 2005 value by 0.17%, but the lower ice concentrations (Figure 2, Table 1) more than compensate, so that the ice areas remain lower in 2007 (Figure 1, Table 1). In July, August and September the ice extents in 2007 are lower than those of 2005 by 9%, 16% and 25%, respectively, and lower that climatology by 18%, 29% and 37%. To put the magnitude of the anomaly in a larger perspective, on 13 August 2007, the ice extent reached a new minimum of 5.43×10^6 km^2, falling below the previous 27-year record minimum of 5.44×10^6 km^2, even though on 13 August the 2007 ice cover still had over a month remaining before the normal end of the melt season. Moreover, by 8 August 2007 the ice area was also already lower, at 4.81×10^6 km^2, than the 4.90×10^6 km^2 record minimum reached on 21 September 2005. After 13 August, the ice cover continued decreasing, reaching an ice extent of 4.12×10^6 km^2 and an ice area of 3.65×10^6 km^2 by 14 September.

[9] Anomaly maps of ice concentration for 2007 versus the 1979–2007 average are presented in the fourth column of Figure 3. The images show that during March–May, much of the deviation in ice extent and area from the long-term average was due to reduced ice cover (in red and purples) in the eastern Barents Sea and the Okhotsk Sea. By June, well into the melt season around the ice edge, the negative anomalies are apparent around almost the entire ice edge; and in July 2007, the negative anomalies are prominent through almost the entire ice region south of 80°N. In August, the negative anomalies have broken through north of 80°N, although smaller areas of positive anomalies are also apparent, in the Greenland Sea and off the Taymyr Peninsula (Figure 3).

[10] Among the factors that can cause anomalously low ice is high surface temperature. High temperatures in winter can inhibit ice growth, and high temperatures in spring and summer can accelerate melt. Using satellite infrared data from 1981 to 2007 as described by *Comiso* [2006a], the last column of Figure 3 shows anomaly maps of surface temperatures in February–July 2007 versus the 1982–2007 monthly averages. We include February because of its relevance due to possible lag effects. Anomalously high temperatures in the central Arctic are apparent especially in February and April. During all months except May, the positive anomalies dominate in the central Arctic. Visually, the correlation is good between the temperature and sea ice

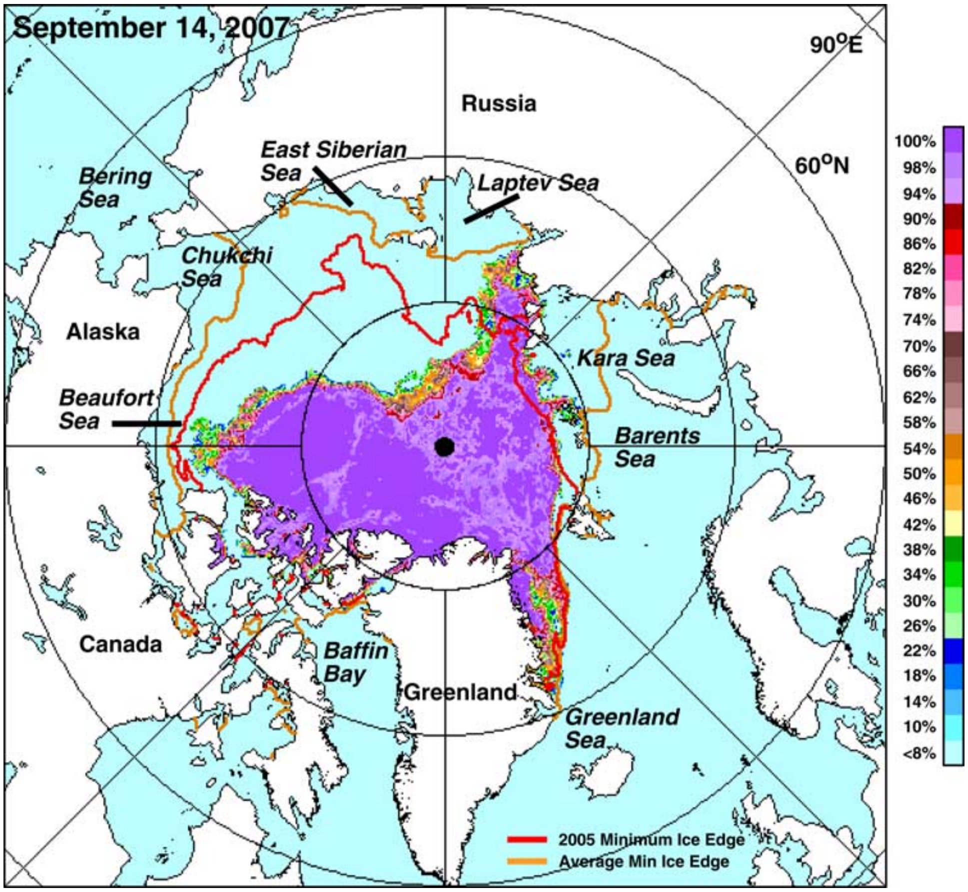

Figure 2. Daily Arctic ice concentrations from AMSR-E for 14 September 2007, when the ice cover reached its minimum extent. The gold contour represents the ice edge inferred from the average of the ice concentration maps during ice minimum extent over the period 1979–2006, while the red contour represents the ice edge during ice minimum in 2005, which was the previous record low.

anomalies (Figure 3). Another important factor in ice distributions is wind. The southerly direction of the wind in the Beaufort and Chukchi seas region in June and July (Figure 3, column 4) suggests a forcing that may have contributed to the retreat of sea ice to the north. Furthermore, the cyclonic wind pattern centered at about (140°E, 78°N) in August could foretell further sea ice retreat.

3. Accelerated Decline

[11] A topic of interest over the past several years has been the issue of why the maximum extent and area of the full Arctic ice cover have not been declining as fast as those of the perennial ice. As reported previously, the situation may be changing, since 2005 and 2006 had anomalously low winter ice cover [*Comiso*, 2006b], and 2007 does also (Figure 3). Updates of monthly anomalies of the hemispherical ice cover through September 2007 (Figure 4) show linear trends of $-3.7 \pm 0.2\%$ per decade and $-4.3 \pm 0.2\%$ per decade for ice extent and ice area, respectively. However, the rate of change in the last 10 years (blue lines) is noticeably more negative than in the first 18 years (green lines). Trends for 1996–2007 through September 2007 are $-10.1 \pm 0.7\%$/decade and $-10.7 \pm 0.8\%$/decade for ice extent and ice area, respectively, the 1996–2007 values being comparable to the rates since 1979 in the perennial ice cover which when updated to 2007 are now -10.2 ± 1.7 and $-11.4 \pm 1.6\%$/decade.

[12] In Figure 4, the last three data points, for July, August and September 2007, are so anomalously low that it became essential for us to check these points with an independent measurement, which we did by using data from the AMSR-E instrument. Both the SSM/I and the AMSR-E provided approximately the same ice extents and areas, confirming that the plummeting of the Arctic ice cover in those two months was not a function of instrumental anomaly.

4. Discussion and Conclusions

[13] The Arctic sea ice cover is influenced by a variety of factors, temperatures, winds, waves, and currents being primary among them. Warming Arctic temperatures provide a powerful forcing toward lessened sea ice coverage, but atmospheric forcing also implies that oscillations within the atmosphere are likely to be reflected in the ice cover as well. Indeed, several studies have indicated possible connections between changes occurring in the ice and such oscillatory phenomena as the Arctic Oscillation (AO) [e.g., *Thompson and Wallace*, 1998; *Wang and Ikeda*, 2000; *Rigor and Wallace*, 2004], the North Atlantic Oscillation (NAO) [e.g., *Kwok*, 2000; *Parkinson*, 2000], and periodic changes

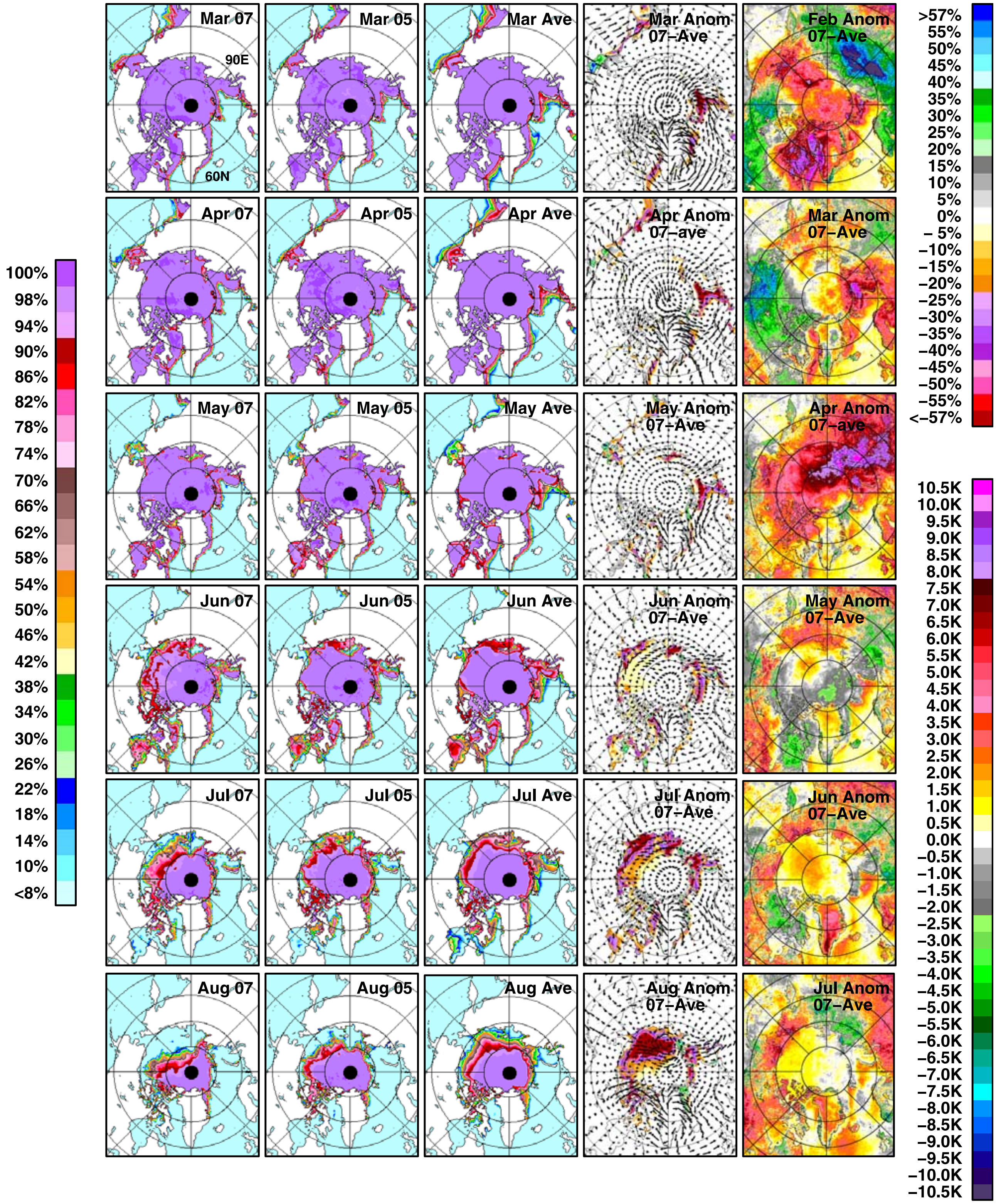

Figure 3. Monthly average sea ice concentrations, March–August, in 2007 (first column), 2005 (second column), and averaged over the years 1979–2007 (third column); 2007 ice anomaly versus the 1979–2007 average (fourth column), with 2007 winds superimposed; and the 2007 surface temperature anomaly versus the 1982–2007 average for February through July (fifth column). Left scale is for the ice concentration maps; top right scale is for the ice anomaly maps; and bottom right scale is for the temperature anomaly maps. Ice concentrations are from satellite passive-microwave SMMR and SSMI data; winds are from the National Centers for Environmental Predictions (NCEP) reanalysis data; and temperatures are from satellite infrared data from NOAA's Advanced Very High Resolution Radiometer (AVHRR).

Table 1. Monthly Ice Extents, Ice Areas, and Ice Concentrations for March–September of 2005, 2007, and the 1979 to 2007 Climatology[a]

	March	April	May	June	July	Aug	Sep
Ice Extent							
Climatology	15.19	14.47	13.11	11.78	9.70	7.50	6.83
2005	14.42	13.87	12.73	11.11	8.73	6.37	5.68
2007	14.35	13.73	12.65	11.13	7.94	5.36	4.27
%Diff (07-Cl)	−5.53	−5.11	−3.53	−5.51	−18.13	−28.51	−37.48
% Diff (07-05)	−0.49	−1.02	−0.67	0.17	−9.08	−15.82	−24.79
Ice Area							
Climatology	14.36	13.64	12.26	10.57	8.45	6.46	6.11
2005	13.59	13.11	11.82	9.77	7.48	5.39	5.03
2007	13.51	12.82	11.73	9.59	6.66	4.37	3.77
%Diff (07-Cl)	−5.93	−5.99	−4.36	−9.32	−21.22	−32.39	−38.31
% Diff(07-05)	−0.62	−2.21	−0.83	−1.87	−11.01	−18.87	−25.04
Ice Concentration							
Climatology	94.1	93.9	93.2	89.4	86.7	85.9	89.2
2005	93.8	94.2	92.5	87.5	85.3	84.4	88.4
2007	93.7	93.0	92.4	85.7	83.4	81.3	88.2
Diff (07-Cl)	−0.4	−0.9	−0.9	−3.7	−3.3	−4.6	−1.0
Diff (07-05)	−0.1	−1.2	−0.2	−1.8	−1.9	−3.1	−0.2

[a]Monthly ice extents, 10^6 km^2; Ice areas, 10^6 km^2; ice concentrations, %; climatology, Cl.

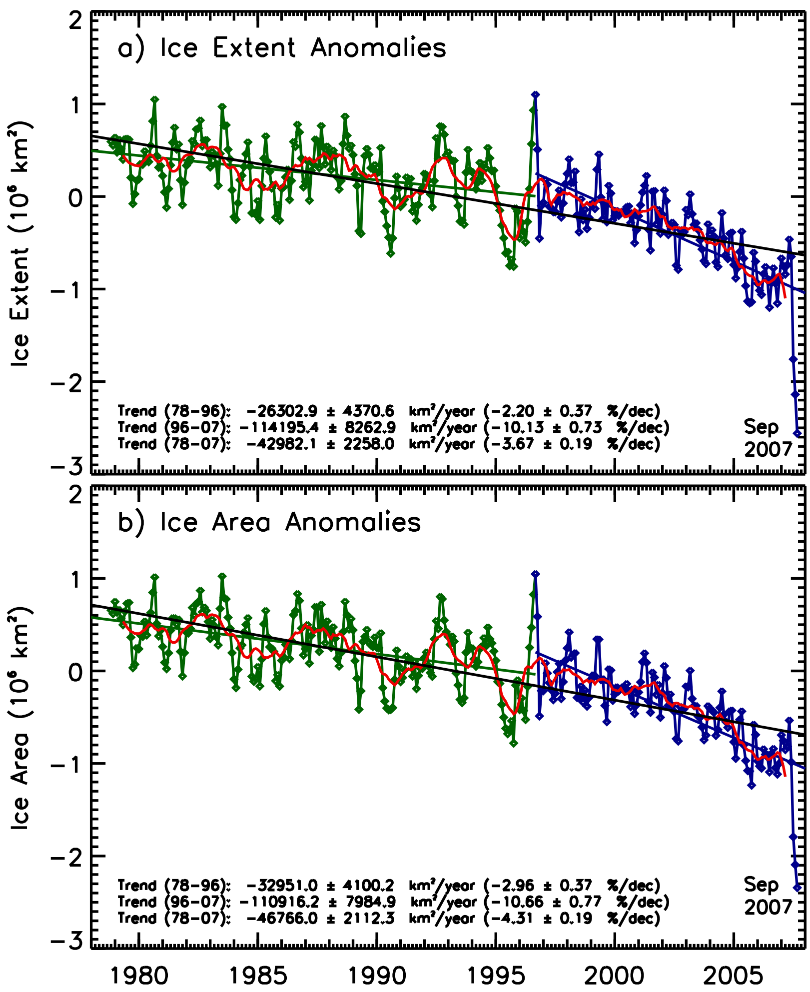

Figure 4. Monthly ice extent and ice area anomalies from November 1978 to September 2007 (green and blue), with the 12-month running average (red) and linear trend lines for the full record (black) and for 1978–1996 (green) and 1996–2007 (blue).

in wind patterns [*Proshutinsky and Johnson*, 1997]. However, the fact that over the past few years, sea ice coverage has continued, overall, to decline despite changes in the modes of the AO and NAO and in the predominant wind patterns suggests that at this point the warming conditions may be overriding the oscillations. The persistently low ice extents and areas in recent years have led to suggestions of a continuing decline and a departure from expected effects of the AO [*Overland and Wang*, 2005].

[14] Since 2002, the perennial sea ice extent and area have been consistently low, with the lowest ice coverage of the satellite era until this year occurring in 2005. The slightly higher extent and area of the perennial ice cover in 2006 versus 2005 illustrate the interannual variability within the overall downward Arctic sea ice trend. Because the perennial ice cover takes time to grow and it is usually the older floes (>2 years) that are thick enough to survive the summer melt, it would presumably require at least a few years of abnormally cold temperatures in the region for the perennial ice cover to recover to its early 1980s extent and area.

[15] Overall, our results show that a very large anomaly in the sea ice cover occurred in the Arctic during the summer of 2007. At ice minimum on 14 September 2007, the extent and area of the ice cover were 4.1×10^6 km^2 and 3.6×10^6 km^2, respectively, which are 24% and 27% less than the previous record lows of 5.4×10^6 km^2 and 4.9×10^6 km^2, both reached on 21 September 2005 and also 37% and 38% less than the climatological averages. Satellite surface temperature data indicate that the growth of sea ice was likely hindered and the retreat likely enhanced by anomalously high temperatures in previous months, especially in February and April 2007. Southerly winds, which advect warm air from lower latitudes, were prevalent during the summer, and this is also likely to have enhanced the ice retreat, through northward transport of the ice, lessened ice growth and increased melt.

[16] It is likely that the rapid sea ice decrease in 2007 is in part the result of pre-conditioning of the Arctic Ocean through abnormally low perennial ice coverage in recent years [*Serreze et al.*, 2007; *Lindsay and Zhang*, 2005]. The region of rapid retreat is approximately the same region where open water area has been abnormally high in the last decade. The satellite data show that in the Arctic basin north of 65°N, between 50°E and 290°E, the open water area has been increasing at the rate of 23% per decade while at the same time sea surface temperature has been increasing at 0.7°C per decade. It is thus a region where ice-albedo feedback has created pre-conditioning in the form of increased absorption of solar radiation.

[17] The trend for the entire ice cover (seasonal as well as perennial ice) has shifted from about −2.2 and −3.0% per decade in 1979–1996 for ice extent and area, respectively, to about −10.1 and −10.7% per decade in the last 10 years, another major shift to complement the remarkable decrease in ice coverage in 2007. The latter values are now comparable with those of perennial ice, which retreated at the rate of −10.2 and −11.4%/decade for ice extent and ice area, respectively, from 1979 to September 2007. Still, although the decreasing ice coverage might lead to an ice-free Arctic in summer sometime within the upcoming decades, in the foreseeable future the Arctic will continue to have winter ice coverage, as the Arctic surface temperatures in winter continue to remain well below freezing. Continued loss of ice in the peripheral seas, where primary productivity is known to be very high, could, however, have major consequences on the Arctic and sub-Arctic ecosystems.

References

Arctic Climate Impact Assessment (ACIA) (2005), *Arctic Climate Impact Assessment*, 1042 pp., Cambridge Univ. Press, Cambridge, U. K.

Bjorgo, E., O. M. Johannessen, and M. W. Miles (1997), Analysis of merged SSMR/SSMI time series of Arctic and Antarctic sea ice parameters 1978–1995, *Geophys. Res. Lett.*, *24*, 413–416.

Comiso, J. C. (2002), A rapidly declining perennial sea ice cover in the Arctic, *Geophys. Res. Lett.*, *29*(20), 1956, doi:10.1029/2002GL015650.

Comiso, J. C. (2006a), Arctic warming signals from satellite observations, *Weather*, *61*(3), 70–76.

Comiso, J. C. (2006b), Abrupt decline in the Arctic winter sea ice cover, *Geophys. Res. Lett.*, *33*, L18504, doi:10.1029/2006GL027341.

Comiso, J. C., and C. L. Parkinson (2004), Satellite observed changes in the Arctic, *Phys. Today*, *57*(8), 38–44.

Holland, M. M., and C. M. Bitz (2003), Polar amplification of climate change in coupled models, *Clim. Dyn.*, *21*, 221–232.

Kwok, R. (2000), Recent changes in Arctic Ocean sea ice motion associated with the North Atlantic Oscillation, *Geophys. Res. Lett.*, *27*(6), 775–778.

Lindsay, R. W., and J. Zhang (2005), The thinning of Arctic sea ice, 1988–2003: Have we reached the tipping point?, *J. Clim.*, *18*, 4879–4894.

Overland, J. E., and M. Wang (2005), The Arctic climate paradox: The recent decrease of the Arctic Oscillation, *Geophys. Res. Lett.*, *32*, L06701, doi:10.1029/2004GL021752.

Parkinson, C. L. (2000), Recent trend reversals in Arctic sea ice extents: Possible connections to the North Atlantic Oscillation, *Polar Geogr.*, *24*(1), 1–12.

Parkinson, C. L., D. J. Cavalieri, P. Gloersen, H. J. Zwally, and J. C. Comiso (1999), Arctic sea ice extents, areas, and trends, 1978–1996, *J. Geophys. Res.*, *104*, 20,837–20,856.

Parkinson, C. L., and D. J. Cavalieri (2002), A 21 year record of Arctic sea-ice extents and their regional, seasonal and monthly variability and trends, *Ann. Glaciol.*, *34*, 441–446.

Proshutinsky, A., and M. Johnson (1997), Two circulation regimes of the wind-driven Arctic Ocean, *J. Geophys. Res.*, *102*, 12,493–12,514.

Rigor, I. G., and J. M. Wallace (2004), Variations in the age of Arctic sea-ice and summer sea-ice extent, *Geophys. Res. Lett.*, *31*, L09401, doi:10.1029/2004GL019492.

Serreze, M. C., M. M. Holland, and J. Stroeve (2007), Perspective on the Arctic's shrinking sea-ice cover, *Science*, *315*, 1533–1536.

Stroeve, J., M. M. Holland, W. Meier, T. Scambos, and M. C. Serreze (2007), Arctic sea ice decline: Faster than forecast, *Geophys. Res. Lett.*, *34*, L09501, doi:10.1029/2007GL029703.

Thompson, D. W., and J. M. Wallace (1998), The Arctic Oscillation signature in the winter-time geopotential height and temperature fields, *Geophys. Res. Lett.*, *25*, 1297–1300.

Wang, J., and M. Ikeda (2000), Arctic Oscillation and Arctic Sea-Ice Oscillation, *Geophys. Res. Lett.*, *27*(9), 1287–1290.

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