GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L18504, doi:10.1029/2006GL027341, 2006

Abrupt decline in the Arctic winter sea ice cover

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Received 23 June 2006; revised 18 August 2006; accepted 24 August 2006; published 30 September 2006.

[1] Although the Arctic perennial ice cover has been on a rapid decline, the winter ice cover had been unexpectedly stable. We report and provide insights into a remarkable turn of events, with the observation of record low ice extent and area during the winters of 2005 and 2006. Negative ice anomalies in these years are prevalent in the peripheral seas but are most dominant in the eastern Arctic basin where the perennial ice becomes even more vulnerable to further decline. Overall, the winter ice anomalies correlate well with surface temperature anomalies and wind circulation patterns. Since historical satellite data indicate a positive trend in winter temperatures and a negative trend in the length of seasonal ice growth period, it is likely that the winter ice cover will continue to retreat in the near future. Results suggest that the expected warming impact of greenhouse gases is becoming apparent in the Arctic during the dark winter months. **Citation:** Comiso, J. C. (2006), Abrupt decline in the Arctic winter sea ice cover, *Geophys. Res. Lett.*, *33*, L18504, doi:10.1029/2006GL027341.

1. Introduction

[2] Before 2005, the maximum extent of the Arctic winter sea ice cover as observed from satellite data has been changing modestly with the trend being negative but only about −1.5% per decade. In contrast, the Arctic perennial ice area has been declining at a rapid rate of about −10% per decade [*Comiso*, 2006a]. The trend for the entire hemisphere and for all season has been modest as well being between −2 to −3 % per decade [*Bjorgo et al.*, 1997; *Parkinson et al.*, 1999]. The rapid change in the perennial ice cover, which is ice that survives at the end of the melt period, provides an intriguing signal of a warming Arctic. The perennial ice consists mainly of multiyear ice floes that have been the mainstay of the Arctic sea ice cover. The rapid decline of the ice enhances the ice-albedo feedback which in turn could accelerate the melt process [*Comiso and Parkinson*, 2004]. Although the ice was already observed to be on a rapid decline before this time [*Comiso*, 2002] the persistently low values from 2002 to 2005 had led to speculations that the sea ice cover might have reached the tipping point [*Lindsay and Zhang*, 2005] as the impact of ice-albedo feedback starts to dominate. Also, it led to postulates of a linear decline and a departure from what would be expected from the Arctic Oscillation [*Overland and Wang*, 2005]. Meantime, a near term recovery of the perennial ice cover is not apparent since surface temperature has been increasing [*Comiso*, 2006a] while the ice cover in 2006 appears to be following the 2005 ice pattern.

[3] The large difference in the trends for winter maxima and summer minima was puzzling in light of the fact that greenhouse warming is supposed to be most prominent in winter [*Shindell et al.*, 1999] especially in the Arctic where long wave radiation dominates during the dark winter months. The moderate trend is also consistent with trends in surface temperatures inferred from infrared satellite radiances during approximately the same period in winter as shown by *Serreze and Francis* [2006] who also asserted that the Arctic may be in a state of preconditioning, setting for larger changes in the years to come. In 2005, however, the winter ice cover maximum was observed to be the lowest during the satellite era and preceded the record lowest perennial ice cover during the same year. In 2006, the winter ice cover maximum was even lower than that of 2005. As in 2005, an abnormal ice retreat in the eastern region is also observed in the spring of 2006 and the seasonal trend suggests that the perennial ice area in 2006 will be anomalously low as well. In light of patterns of warming in the Arctic as has been reported recently [*Comiso*, 2006a], these changes in the winter ice cover requires detailed study and evaluation.

2. Trends in the Mid-Winter and End-of-Summer Ice Cover

[4] Two sea ice parameters that have been useful in quantifying the state of the sea ice cover are the extent and area and especially, their maximum and minimum values. Ice extent is defined as the sum of the ice covered areas with at least 15% ice concentration while ice area is the integral sum of areas actually covered by sea ice. The ice maximum extent and area provide information about available ocean surface area that is thermodynamically conditioned for ice formation during the growth season. They are in part affected by the influence of wind that causes the transport or advection of the ice cover towards the relatively warmer south. Declines in winter ice maxima would mean northward advances of the −2.0°C sea surface temperature (SST) isotherm and therefore a warmer ocean in the region. On the other hand, the ice minimum reflects the efficiency of atmospheric and oceanic heat at melting the ice cover during the summer period. A negative trend in ice minima thus means a positive trend in oceanic and atmospheric temperatures, assuming that the percentage of ice advected out of the Arctic basin [*Kwok et al.*, 2004] is taken into consideration. The ice minimum data have been used to quantify the extent and area of the perennial ice cover [*Comiso*, 2002] which is the thick component of the Arctic ice cover.

[5] Analyses of passive microwave satellite data from 1978 to the present indicate significant declines in maximum

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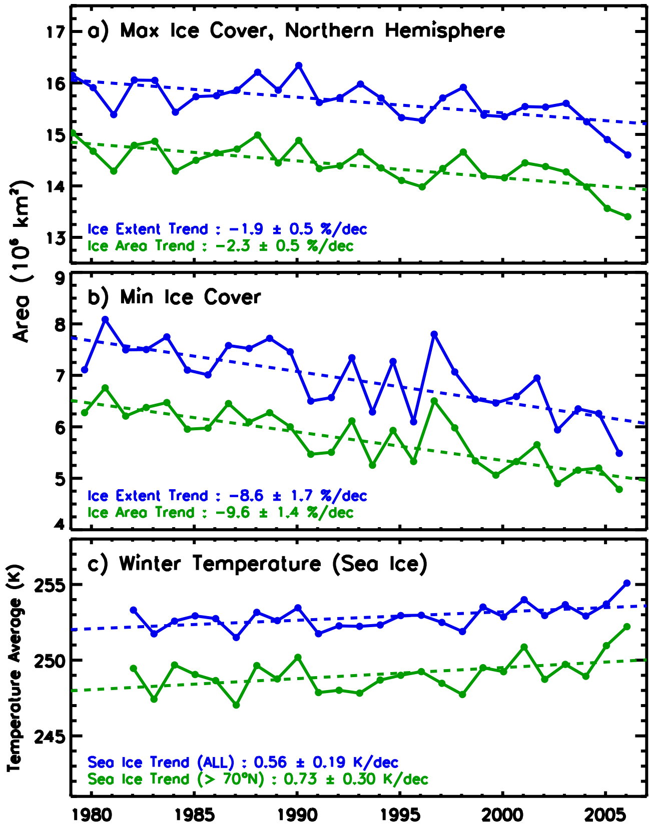

Figure 1. Arctic extent and area derived from satellite passive microwave (SMMR and SSM/I) data during (a) ice extent maxima from 1979 to 2006, (b) ice extent and area minima from 1979 to 2005 and surface temperatures derived from AVHRR data during (c) winter (DJF) from 1981 to 2006. The trends are as indicated with the error listed being the statistical uncertainty associated with yearly variability.

and minimum ice extents and areas (Figure 1) but the minimum values have been changing about 5 times faster than maximum values. In Figure 1a, the maximum values for 2005 and 2006 stand out as significantly lower than average values and part of a monotonic decline that started in 2003 for ice extent and 2001 for ice area. The maximum extent and area observed during the satellite era were at their highest at 16.2×10^6 km^2 in 1990 and 15×10^6 km^2 in 1979, respectively, while the corresponding values for averages from 1979 to 2005 are 15.6 and 14.4×10^6 km^2. The maximum extents and area in 2005 are significantly lower at 14.9 and 13.5×10^6 km^2, respectively, while the corresponding values for 2006 are even lower at 14.6 and 13.4×10^6 km^2. But even with the inclusion of 2005 and 2006 data, the resulting trends in winter maximum extent and area of about −1.9 % and −2.5% per decade, respectively, are still low compared to −8.6 % and −9.6% per decade for the minimum extent and area (Figure 1b). The rapid decline of the perennial ice cover is still not well understood and may be associated with the observed reductions in average thickness in the 1990s as reported previously [*Rothrock et al.*, 1999; *Wadhams and Davis*, 2000]. The latter may have been caused by longer melt period which has been increasing at 15 days per decade [*Comiso*, 2006a; *Belchansky et al.*, 2004], abnormal loss of thick ice through Fram Strait [*Kwok et al.*, 2004] or higher percentages of the thinner second year ice [*Comiso*, 2002, 2006b].

[6] Using surface temperatures derived from satellite infrared AVHRR data during clear-sky conditions [*Comiso*, 2003], yearly winter averages (Figure 1c) over all sea ice covered area (blue line) and over sea ice area north of 70°N (green line) provide the means to assess the overall effect of longwave radiation on the surface. As discussed previously, temperatures derived from AVHRR data may not represent the true surface temperature averages because of no data during cloudy conditions [*Comiso*, 2003]. The presence of clouds alters the radiation balance and causes surface temperatures over cloud-covered areas to be different from those in cloud free areas. Studies of limited data during SHEBA (1997 to 1998), however, indicated biases of only about 0.4°C during winter months [*Comiso*, 2003]. The effect of interannual changes in cloud fraction is a concern but in part fortuitously minimized during the data processing. In particular, retrieved temperature data had to be normalized to be consistent with in situ (or station) data in order to take into account calibration inconsistencies of data from the 5 different AVHRR sensors used for the historical record. The trends in the AVHRR temperature data are thus mainly consistent with trends in the in situ data that are not biased by cloud masking.

4. Discussion and Conclusions

[15] Overall, the maximum ice extent and area of sea ice in the Arctic have been relatively stable until 2005 and 2006 when the values were about 6% lower than average for each year. This phenomenon, which is correlated with surface temperature, is occurring in peripheral seas but primarily in the eastern part of the Arctic basin near the North Pole, where the perennial ice cover, which has been declining rapidly, becomes even more vulnerable. The ice anomaly in the eastern region is in part caused by wind-induced advection of the perennial ice to the western region. Significant delay in the onset of freeze-up appears to be reflected in the winter ice data of 2005 and 2006 in part because of abnormally warm temperatures. Recent reports of increasing length of the melt period (of 15 days per decade) over the sea ice region [e.g., *Comiso*, 2006a; *Belchansky et al.*, 2004] means a shortening of the growth period (in the seasonal region) that will likely cause a continuation in the decline of the extent of the winter ice maxima in the near future.

[16] The distribution of clear-sky surface temperatures in the Central Arctic in 2005 and 2006 exhibits a pattern of warming in winter that may in part reflect the warming effect of increasing atmospheric greenhouse gases. Progressively increasing surface temperatures in the Arctic basin in winter since 1998 suggests that the impact of long wave radiation during winter months is becoming more apparent. Ice-albedo feedback effects and increasing atmospheric greenhouse gases would serve to accelerate the warming and also the downward trend in the winter ice cover. The abnormally low winter ice maximum extent and area and enhanced surface temperatures in 2005 and 2006, as reported in this paper, may just be the beginning of these trends which have been more apparent in other seasons. The decade of change, suggested by *Serreze and Francis* [2006] may have actually arrived.