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Arctic air temperature change amplification and the Atlantic Multidecadal Oscillation

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[1] Understanding Arctic temperature variability is essential for assessing possible future melting of the Greenland ice sheet, Arctic sea ice and Arctic permafrost. Temperature trend reversals in 1940 and 1970 separate two Arctic warming periods (1910–1940 and 1970–2008) by a significant 1940–1970 cooling period. Analyzing temperature records of the Arctic meteorological stations we find that (a) the Arctic amplification (ratio of the Arctic to global temperature trends) is not a constant but varies in time on a multi-decadal time scale, (b) the Arctic warming from 1910–1940 proceeded at a significantly faster rate than the current 1970–2008 warming, and (c) the Arctic temperature changes are highly correlated with the Atlantic Multi-decadal Oscillation (AMO) suggesting the Atlantic Ocean thermohaline circulation is linked to the Arctic temperature variability on a multi-decadal time scale. **Citation:** Chylek, P., C. K. Folland, G. Lesins, M. K. Dubey, and M. Wang (2009), Arctic air temperature change amplification and the Atlantic Multidecadal Oscillation, *Geophys. Res. Lett.*, *36*, L14801, doi:10.1029/2009GL038777.

1. Introduction

[2] The twentieth century increase in global mean temperature has been well documented (about 0.75 K increase between 1880 and 2008) and has been attributed to a combination of natural and anthropogenic influences [*Intergovernmental Panel on Climate Change* (*IPCC*), 2007]. The global instrumental surface air temperature record has been quite well reproduced by a set of Atmosphere-Ocean General Circulation Models (AOGCMs) that are also being used to make projections of future temperature changes due to increasing concentration of atmospheric greenhouse gases. Continental scale temperature records have also been reproduced with some, though less, skill [*IPCC*, 2007, Figure 9.12]. The past climate records as well as climate model simulations have also suggested a link between Arctic and global climate change [e.g., *Polyakov et al.*, 2002; *Johannessen et al.*, 2004; *Shindell*, 2007; *Graversen et al.*, 2008; *Gillett et al.*, 2008].

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[3] The observed global mean surface temperature change since 1880 has a combination of causes including increasing greenhouse gases, variations in tropospheric anthropogenic aerosol optical depth, natural and anthropogenic surface albedo changes, variations of solar radiation, volcanic activity [*Hansen et al.*, 1996; *Stott et al.*, 2000; *Pielke et al.*, 2000; *North and Wu*, 2001; *Mishchenko et al.*, 2007; *Chylek et al.*, 2007; *Pielke et al.*, 2007; *Lean and Rind*, 2008], and variability of atmosphere-ocean circulation [*Folland et al.*, 1986; *Knight et al.*, 2006; *Baines and Folland*, 2007]. One of the robust features of the AOGCMs is the finding that the temperature increase in the Arctic is larger than the global average, which is attributed in part to the ice/snow-albedo temperature feedback. Specifically the surface air temperature change in the Arctic is predicted to be about two to three times the global mean [*IPCC*, 2007]. This robust feature of the AOGCMs has been challenged in the past [*Przybylak*, 2000; *Polyakov et al.*, 2002] as well as by a recent analysis [*Lean and Rind*, 2008] of the observed surface temperature records suggesting that the recent anthropogenic warming has been more pronounced at the lower and middle latitudes (from 45°S to 50°N) than in polar regions. Finally a recent attribution study [*Gillett et al.*, 2008] showed that the climate models reproduced well the observed Arctic warming since about 1970. However, they could not reproduce the large warming during the early part of the 20th century and the strong Arctic cooling during 1940 –1970 [e.g., *Parker et al.*, 1994]. The objective of this work is to use the surface air temperature time series to investigate observational evidence of Arctic temperature change amplification and influences of natural variability.

2. Data

[4] We utilize the Arctic surface air temperature records from 37 meteorological stations north of 64°N, with 27 of them overlapping with those used by *Overland et al.* [2004]. To explore the latitudinal variability in Arctic temperatures, we divide this region into two belts: the low Arctic (64°N–70°N) and the high Arctic (70°N–90°N). The average surface air temperature within each belt is calculated as an average of well-distributed meteorological stations having almost uninterrupted long-term temperature records. We have selected only those stations providing records up to the year 2008 that are at least 95% complete. Missing data are not interpolated. There is fairly good coverage from low Arctic land stations since about 1950 with just a few stations with continuous observations since the early 1880s. The seasonal averages and annual temperature data for individual stations (with quality control already applied) are from the NASA GISS site [*Hansen et al.*, 2006] (http://data.giss.nasa.gov/gistemp/).

[5] We calculate the low Arctic surface air temperature anomaly for 1950–2008 using temperature records from

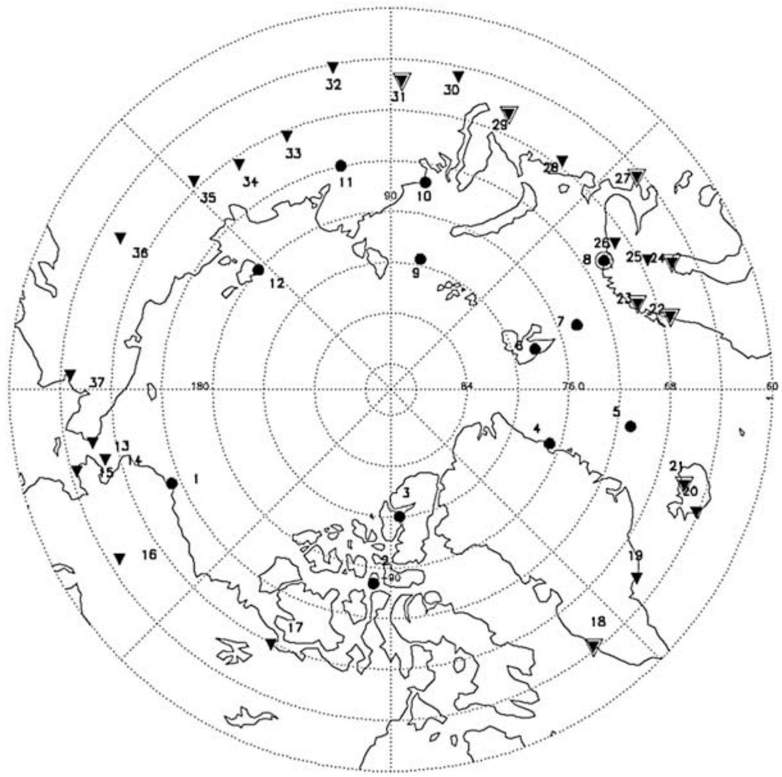

Figure 1. Map of Arctic stations (circles: 70–80°N; triangles: 64–70°N; double circles and double triangles: stations with records starting near 1880). High Arctic stations with longitude, latitude and time span of records: 1. Barrow (156.8W, 71.3N), 2. Resolute (95.0W, 74.7N), 3. Eureka (85.9W, 80.0N), 4. Danmarkshavn (18.7W, 76.8N), 5. Jan Mayen (8.7W, 70.9N), 6. Isfjord (13.6E, 78.1N), 7. Bjornoy (19.0E, 74.5N), 8. Vardo (31.1E, 70.4), 9. Vize (77.0E, 79.5), 10. Dikson (80.4E, 73.5N), 11. Hatanga (102.5E, 72.0N), 12. Kotel (137.9E, 76.0). Low Arctic stations: 13. Mys Uelen (169.8W, 66.2N), 14. Kotzebue (166.2W 66.9N), 15. Nome (165.4W, 64.5N), 16. Fairbanks (147.9W, 64.8N), 17. Coppermine (115.1W, 67.8N), 18. Nuuk (51.8W, 64.2N), 19. Angammassalik (37.6W, 65.6N), 20. Reykjavik (21.9W, 64.1N), 21 Akureyri (18.1W, 65.7N), 22. Bodo Vi (14.4E, 67.3N), 23 Tromo (19.0E, 69.5), 24. Haparanda (24.1E, 65.8N), 25. Sodankyla (26.6E, 67.4N), 26. Murmansk (33.0E, 69.0N), 27. Arkhangelsk (40.7E, 64.5), 28. Narjan–Mar (53.0E, 67.6N), 29. Salehard (66.7E, 66.5N), 30. Tarko Sale (77.8E, 64.9N), 31. Turuhansk (87.9E, 65.8N), 32. Tura (100.2E, 64.3N), 33. Olenek (112.4E, 68.5N), 34. Dzardzan (124.0E, 68.7N), 35. Verhojans (133.4E, 67.5N), 36. Zyrjanka (150.9E, 65.7N), 37. Anadyr (177.6E, 64.8N).

25 stations (Figure 1). A subset of eight stations with sufficient records (at least 1882–2008) is used to calculate lower Arctic temperature anomalies over the extended period 1880–2008. The correlation coefficient for the years 1950–2008 between un-smoothed annual temperature of the above 1950–2008 time series (calculated from all 25 stations) and 1950–2008 time series calculated using only the 8 stations having long term records is 0.94, suggesting that even the limited number of long term time series stations covering 1880–2008 represent the average temperature anomaly within the 64 to 70°N belt reasonably well.

[6] The high Arctic (70 to 90°N) temperature anomaly has been calculated for the years 1950–2008 using twelve stations (Figure 1). To estimate of the temperature changes in earlier years we have included additional stations that have full coverage for 1910–1940 or 1940–1970 periods.

3. Long Term Temperature Trends

[7] Prediction of the correct latitudinal distribution of future warming in climate models is essential for assessing the future melting of the Greenland ice sheet, Arctic sea ice and Arctic permafrost. The recent analysis [*Lean and Rind*, 2008] has raised doubts about the generally accepted assumption that future polar warming is likely to be about two to three times the mean global warming. In the following analysis we confirm that the Arctic has indeed warmed during the 1970–2008 period by a factor of two to three faster than the global mean in agreement with model predictions but the reasons may not be entirely anthropogenic. We find that the ratio of the Arctic to global temperature change was much larger during the years 1910–1970.

[8] We use the eight stations (Figure 1) with a virtually complete temperature record since the early 1880s to reconstruct the temperature history of the low Arctic, which is shown together with the mean global surface air temperature for 1880–2008 in Figures 2a and 2b. There are three distinct periods in the lower Arctic temperature record: strong warming over 1880–1940 and 1970–2008 separated by equally strong cooling from 1940–1970. The sudden changes in the Arctic temperature trends around 1940 and

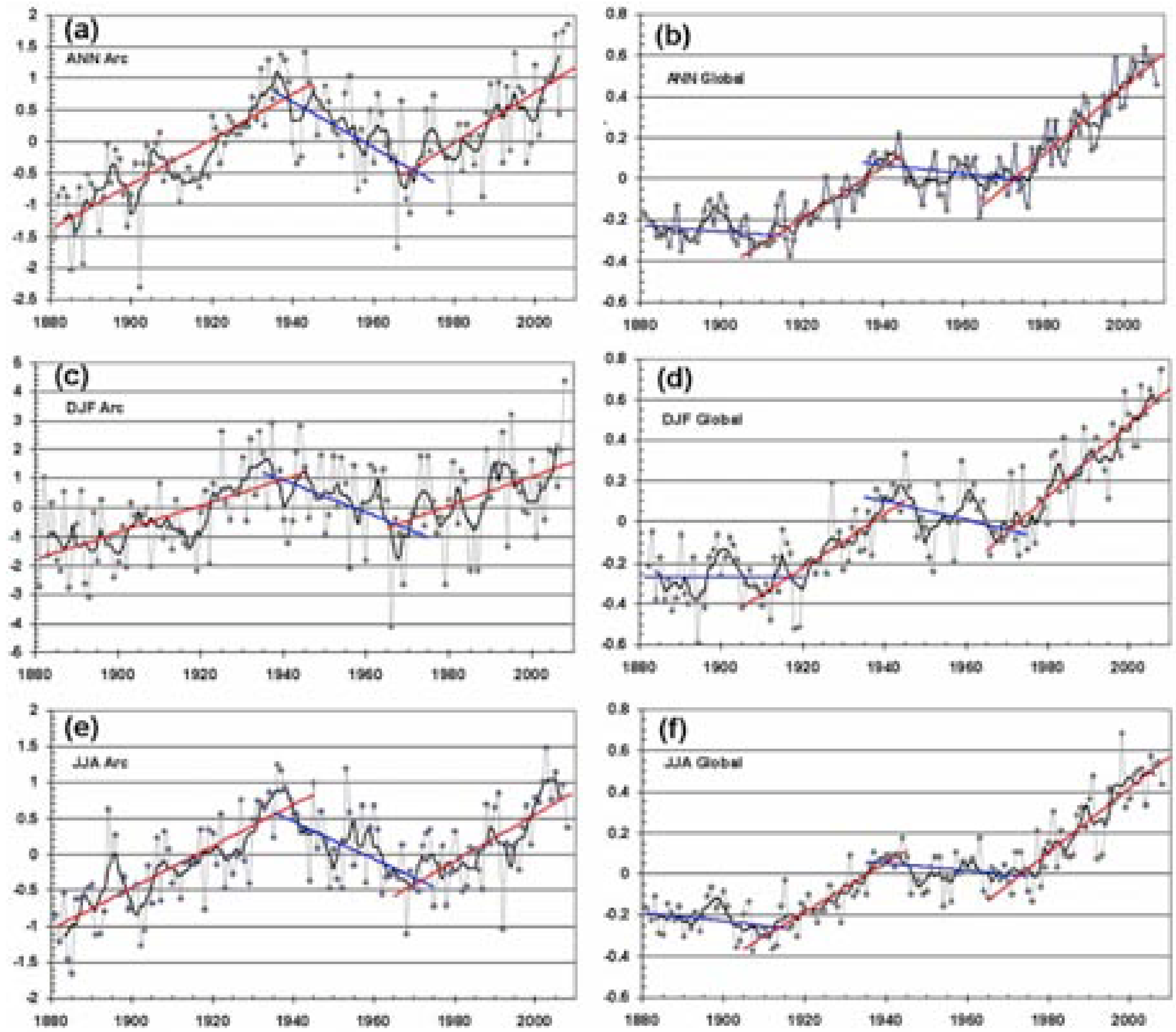

Figure 2. (a and b) Annual, (c and d) winter, and (e and f) summer Arctic and global temperature anomalies with respect to the 1910–2008 average. The heavy solid line is a 5 year running mean. The straight solid lines are the linearly regressed trends.

1970 suggest that other factors besides slowly varying concentrations of greenhouse gases and aerosols, or solar changes, could have played a significant role.

[9] The breaks in the trend of the Arctic temperature have their analogue in the mean global near surface air temperature (Figure 2). However, the Arctic breaks are much more pronounced. There is also a break in the global temperature trend around 1910, which does not appear in the Arctic temperature record. Because late nineteenth century Arctic surface air temperature estimates have errors much larger than those of recent data [*IPCC*, 2007, Figure 3.7], we limit our analysis to the years 1910–2008 where the varying Arctic and mean global temperature trends have the same sign.

[10] The rate of mean annual low Arctic air temperature increase from 1910–1940 was 0.59 K/decade compared to 0.38 K/decade from 1970–2008. The decreasing trend from 1940–1970 was −0.36 K/decade (Table 1). Varying the years when the temperature trend changes sign (i.e., 1940 and 1970 by a few years) does not make a significant difference to these slopes. The largest changes in temperature occurred during winter or autumn and smallest during the summer, suggesting the importance of seasonally-varying climate dynamics in addition to the ice/albedo feedback.

[11] The rate of increase of the mean annual global land surface air temperature (Table 1) was about 0.11 K/decade from 1910–1940 and 0.19 K/decade from 1970–2008. The cooling rate from 1940 to 1970 was −0.04 K/decade. While the warming and cooling rates of the Arctic temperature are not too different within the entire 1910–2008 time span, the mean global warming rates are considerably larger than the mean global cooling rates. Consequently the ratio of the Arctic to the global temperature change (Arctic amplification) is smaller during the warming than during the cooling periods.

[12] The ratios of the annual mean low Arctic to global temperature trends are 5.4 and 2.0 for the warming periods of 1910–1940 and 1970–2008, respectively, while ratio was around 9.0 (Table 1) during the cooling period of 1940–1970.

[13] The high Arctic (70–90°N) warmed at the rate of 0.55K/decade from 1970–2008 and at 0.76K/decade from

Table 1. Arctic Air Temperature Trends[a]

	1910–1940			1940–1970			1970–2008		
	64–70°	Globe	Ratio	64–70°	Globe	Ratio	64–70°	Globe	Ratio
ANN	0.59	0.11	5.4	−0.36	−0.04	9.0	0.38	0.19	2.0
DJF	0.83	0.13	6.4	−0.56	−0.05	11	0.38	0.20	1.9
MAM	0.48	0.11	4.4	−0.26	−0.03	8.7	0.42	0.18	2.3
JJA	0.43	0.09	4.8	−0.26	−0.05	5.2	0.30	0.18	1.7
SON	0.66	0.11	5.0	−0.36	−0.04	9.0	0.44	0.21	2.1
	1910–1940			1940–1970			71970–2008		
	70–90°	Ratio		70–90°	Ratio		70–90°	Ratio	
ANN	0.76	6.9		−0.50	12.5		0.55	2.9	
DJF	1.63	12.5		−0.72	14.4		0.58	2.9	
MAM	0.54	4.8		−0.48	16.0		0.58	3.2	
JJA	0.28	3.1		−0.14	2.8		0.31	1.7	
SON	0.63	5.7		−0.67	16.7		0.75	3.6	

[a]In each time interval the first column gives the Arctic surface air temperature trend (in K/decade), the second column the trend for the global land surface air temperature, and the third column is the ratio of the Arctic to global temperature trend (Arctic amplification). ANN stands for an annual average and seasonal data are denoted by the first letters of appropriate months. The upper half of the table provides data for the 64–70°N belt and the lower part for the 70–90°N region. Trends are calculated from appropriate averages of stations listed in Figure 1. For the high Arctic trend from 1910–1940 additional data from Upernavik, Mehaven and Alta stations and from 1940–1970 data from Vrange, Chetyr, Salauriva and Gmo stations were used. Temperature trends were determined by linear regression of the annual mean or seasonal temperature time series.

1910–1940. The Arctic amplification was 2.9 for 1970–2008 warming, suggesting that the Arctic warming is proceeding at a faster pace at the latitudes north of 70°N compared to the 64–70°N belt. This is partially due to a stronger sea ice albedo feedback at higher Arctic latitudes where the surface albedo is dominated by seasonal changes of the sea ice extent. The ratio of the high to low Arctic temperature trends is 1.4–1.5 for all three time periods. The maximum rate of warming in the high Arctic occurs again during the winter and autumn. A large autumn trend is likely related to the minimum sea ice extent that occurs in September and which has decreased at a particularly fast rate over the last two decades [*Serreze et al.*, 2007; *Comiso et al.*, 2008].

[14] The 1970–2008 ratio of the Arctic to mean global warming deduced from the observed data (2.0 for low and 2.9 for high Arctic) is consistent with the models' Arctic amplification [*Wang et al.*, 2007; *Gillett et al.*, 2008]. However, the fact that this ratio was much different during the early 20th century warming and especially during the 1940–1970 cooling suggests that there are physical processes that are not yet fully understood or properly described by the current AOGCMs.

[15] During the cooling period from 1940–1970 the Arctic amplification was around 9 for the 64–70°N belt and 12.5 for high Arctic regions (70–90°N). The large value of the Arctic amplification during the cooling period may be connected to changes in the North Atlantic ocean thermohaline circulation.

4. Atlantic Multidecadal Oscillation (AMO)

[16] The build up of atmospheric aerosols from 1940–1970s followed by their decrease since late1970s is likely one of the factors contributing towards the cooling from 1940–1970 [*IPCC*, 2007; *Chylek and Lesins*, 2008; *Shindell and Faluvegi*, 2009] and the warming since 1970s. However, there is no reason why aerosol induced cooling should be 9 to 13 times stronger in the Arctic compared to the global mean. A more plausible explanation might be found in changes in ocean thermohaline circulation. If the Atlantic Ocean were in a state producing a cold anomaly near the Arctic and a warm anomaly in the subtropical region, the Arctic may experience strong cooling while the global average temperature would be only slightly affected. This is in qualitative agreement with the observed temperature changes (Table 1). The largest ocean surface temperature changes associated with the AMO are in the higher latitudes of the Atlantic [*Parker et al.*, 2007, *Trenberth and Shea*, 2006] and are up to 1K or more in range.

[17] The ocean multi-decadal scale link with the Arctic temperature is further supported by a high correlation between the Arctic temperature and the AMO index. We use two different versions of the index: the AMO index from the NOAA site (http://www.cdc.noaa.gov/data/correlation/amon.us.long.data), which is based on de-trended SST in the North Atlantic, and the AMO of *Parker et al.* [2007] which is based on an eigenvector analysis of worldwide SST. To remove the intra-decadal scale variability we use 11 year running averages of the AMO and the Arctic temperature annual time series (Figure 3). The correlation coefficient between the annual Arctic temperature and the AMO index is 0.69 and 0.79 for the AMO as given by *Parker et al.* [2007] and NOAA, respectively.

[18] We consequently propose that the AMO is a major factor affecting inter-decadal variations of Arctic temperature and explaining high value of the Arctic to global temperature trend ratio during the cooling period of 1940–1970. A strong empirical relationship exists between the AMO and many Atlantic and worldwide climate phenomena [e.g., *Baines and Folland*, 2007; *Knight et al.*, 2006; *Chylek and Lesins*, 2008].

[19] Recent ensemble simulations of several coupled models with the late nineteenth century forcings failed to detect the observed AMO [*Knight*, 2009]. However the

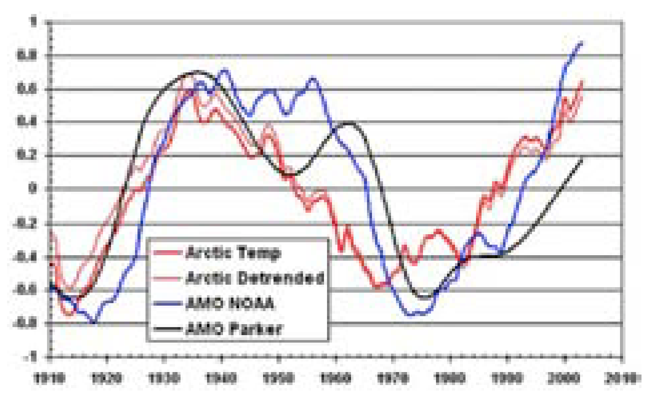

Figure 3. 11 year running average of the Arctic temperature (combined low and high Arctic stations with long term temperature records) anomaly (thin red line) with respect to 1910–2008 average, detrended anomaly (thick red line), and the AMO index anomaly. The NOAA (blue) and the [*Parker et al* [2007] (black) AMO index anomaly have been normalized to a peak value of 0.7 within 1930–1940s.

AMO has been observed earlier as a natural oscillation in some coupled models [e.g., *Delworth and Knutson*, 2000; *Latif et al.*, 2004].

5. Summary

[20] Our analysis suggests that the ratio of the Arctic to global temperature change varies on multi-decadal time scale. The commonly held assumption of a factor of 2–3 for the Arctic amplification has been valid only for the current warming period 1970–2008. The Arctic region did warm considerably faster during the 1910–1940 warming compared to the current 1970–2008 warming rate (Table 1). During the cooling from 1940–1970 the Arctic amplification was extremely high, between 9 and 13. The Atlantic Ocean thermohaline circulation multi-decadal variability is suggested as a major cause of Arctic temperature variation. Further analyses of long coupled model runs will be critical to resolve the influence of the ocean thermohaline circulation and other natural climate variations on Arctic climate and to determine whether natural climate variability will make the Arctic more or less vulnerable to anthropogenic global warming.

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