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CHANGES IN SEASONAL AND ANNUAL HIGH-FREQUENCY AIR TEMPERATURE VARIABILITY IN THE ARCTIC FROM 1951 TO 1990

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ABSTRACT

A detailed analysis of intraseasonal (within season) and interannual (between years) temperature variability for the whole Arctic for the period 1951–90 is provided. For this purpose four temperature variables were used: average (TMEAN), maximum (TMAX) and minimum (TMIN) temperatures, and the diurnal temperature range (DTR). The source data for the analysis were the daily TMAX and TMIN for ten stations representing almost all climatic regions in the Arctic. The methods of calculation of temperature variability were mostly taken from Plummer (1996; *Australian Meteorological Magazine* **45**: 233). Thus the results presented for the Arctic can be fully compared with existing results for the other parts of the world (China, the former USSR, the USA and Australia).

Regional trends in intraseasonal and interannual temperature variability were mixed and the majority of them were insignificant. Trends in intraseasonal variability were positive in the Norwegian Arctic and eastern Greenland and negative in the Canadian and Russian Arctic. Small increases in interannual variability for all temperature variables were observed annually in the Norwegian Arctic and eastern Greenland, and in the Canadian Arctic. These were largely a result of increases in winter and transitional seasons respectively. On the other hand, opposite tendencies, both on a seasonal and an annual basis, occurred in the Russian Arctic. Statistically significant negative trends in intraseasonal variability were noted mainly in the Canadian Arctic, whereas such trends in interannual variability were noted mainly in the Russian Arctic.

The absence of significant changes in intraseasonal and interannual variability of TMEAN, TMAX, TMIN and DTR is additional evidence (besides the average temperature) that in the Arctic in the period 1951–90 no tangible manifestations of the greenhouse effect can be identified.

KEY WORDS: Arctic; high-frequency air temperature variability; intraseasonal and interannual variability; time series analysis

1. INTRODUCTION

The current state of knowledge concerning the changes in air temperature variability (hereinafter referred to as temperature variability) in recent decades, in a global sense, is not satisfactory. The data and analyses that exist are poor and not comprehensive. Such a situation is a result of the fact that up till now most investigations conducted in the field of climate change studies were focused on the analysis of the mean quantities. Meanwhile, as has recently been shown by Katz and Brown (1992), extreme climatic events are more sensitive to climatic changes than their mean values. This means that if global climate change is a real phenomenon, its change should be first detected and most clearly revealed in the behaviour of the extreme climatic events. The importance of including changes in daily variability in climate change studies also results from the fact that significantly greater socio-economic and environmental impacts are associated with changes in climatic extremes and variability than with mean quantities (e.g. Karl *et al*., 1997). In recent years a growing

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number of papers have dealt with the problem of time-dependent changes of variability. The majority of them focused on air temperature (e.g. Parker *et al.*, 1992, 1994; Karl *et al.*, 1995; Plummer, 1996; Przybylak, 1996, 1999, 2000a; Michaels *et al.*, 1998; Jones, 1999; Collins *et al.*, 2000; Moberg *et al.*, 2000). Our knowledge during the last decade has grown significantly, but it is still far from complete. Therefore, the second report of the IPCC (Houghton *et al.*, 1996), based on all available results, concluded that '... temperature shows no consistent, global pattern of change in variability. ... On regional scales there is clear evidence of changes in some extremes and climate variability indicators. Some of these changes have been toward greater variability; some have been toward lower variability.' The third IPCC report (Houghton *et al.*, 2001) generally confirms the conclusion presented in the second report, although it underlines the growing evidence suggesting a decrease in the intraseasonal and intra-annual temperature variability, whereas interannual variability shows either an increase or no trend.

The pattern of changes in temperature variability in recent decades (say the last four or five decades), on a global scale, is rather inconsistent with climate model projections, which suggest that in a warmer climate a decrease in high-frequency temperature variability should occur (analogous to the decrease in variability observed from the poles to the tropics, and from winter to summer). For this period, and especially after 1975, when the second phase of contemporary global warming is occurring, the decreasing trend in temperature variability should be very clear. In reality, we rather observe mixed and insignificant changes (e.g. see figure 1 in Karl *et al.* (1995), figure 4 in Plummer (1996), figures 4, 5 and 8 in Moberg *et al.* (2000) or figures 2–7 in Przybylak (2000a)). More recently Collins *et al.* (2000) have found that most Australian stations studied revealed decreasing trends in maximum, minimum and mean temperature variability from 1957 to 1996. Many of these declines were found to be significant. However, trends of variability indices (inter-daily differences and standard deviation) averaged for all-Australia were not significant.

It is widely recognized that polar regions are more sensitive to climate changes than is the rest of the Earth. Thus, taking into account earlier remarks, one can state that detection of the coming global climate changes should be observable at their earliest stage by analysing tendencies in climate variability and the occurrence of extreme events in these regions. Meanwhile, this problem for the Arctic is less investigated than for the rest of the globe. Generally, only Przybylak (1996, 1999, 2000a) has investigated tendencies in temperature variability for the Arctic in the period 1951–90 using two measures of daily temperature variability, i.e. standard deviation (Przybylak, 1996) and inter-period differences (Przybylak, 1999, 2000a).

The main aim of this study is to present the results concerning changes in mean seasonal and annual intraseasonal (within season) and interannual (between years) temperature variability for the three Arctic climatic regions.

2. STUDY AREA, DATA AND METHODS

The study area includes the Arctic, where its southern boundary is taken after *Atlas Arktiki* (Treshnikov, 1985) (figure 1).

The source data for the analysis were the daily maximum (TMAX) and minimum (TMIN) temperatures for ten stations (see figure 1) representing the majority of the climatic regions in the Arctic distinguished by the authors of *Atlas Arktiki* (Treshnikov, 1985). Most of the stations' data (except those from stations located in the Russian Arctic) cover the period 1951–90. A detailed list of sources of data used is given by Przybylak (1996, in press). The daily average temperature (TMEAN) was calculated from the arithmetic average of the daily TMAX and TMIN. The diurnal temperature range (DTR) was computed by subtracting the daily TMIN from the daily TMAX. The daily averages were computed using this method just because such a method was also used by Karl *et al.* (1995) and Plummer (1996). Also, other calculations, including the choice of statistical measures of high-frequency temperature variability, were conducted according to the suggestions provided in the papers mentioned, and in Plummer's paper in particular. Thus, most results presented here for the Arctic can be fully compared with the existing results for the other parts of the world (China, the former USSR, the USA and Australia).

Changes in intraseasonal and interannual temperature variability were calculated. The methods of calculation of temperature variability were mostly taken from Plummer (1996). Temperature variability is defined as the

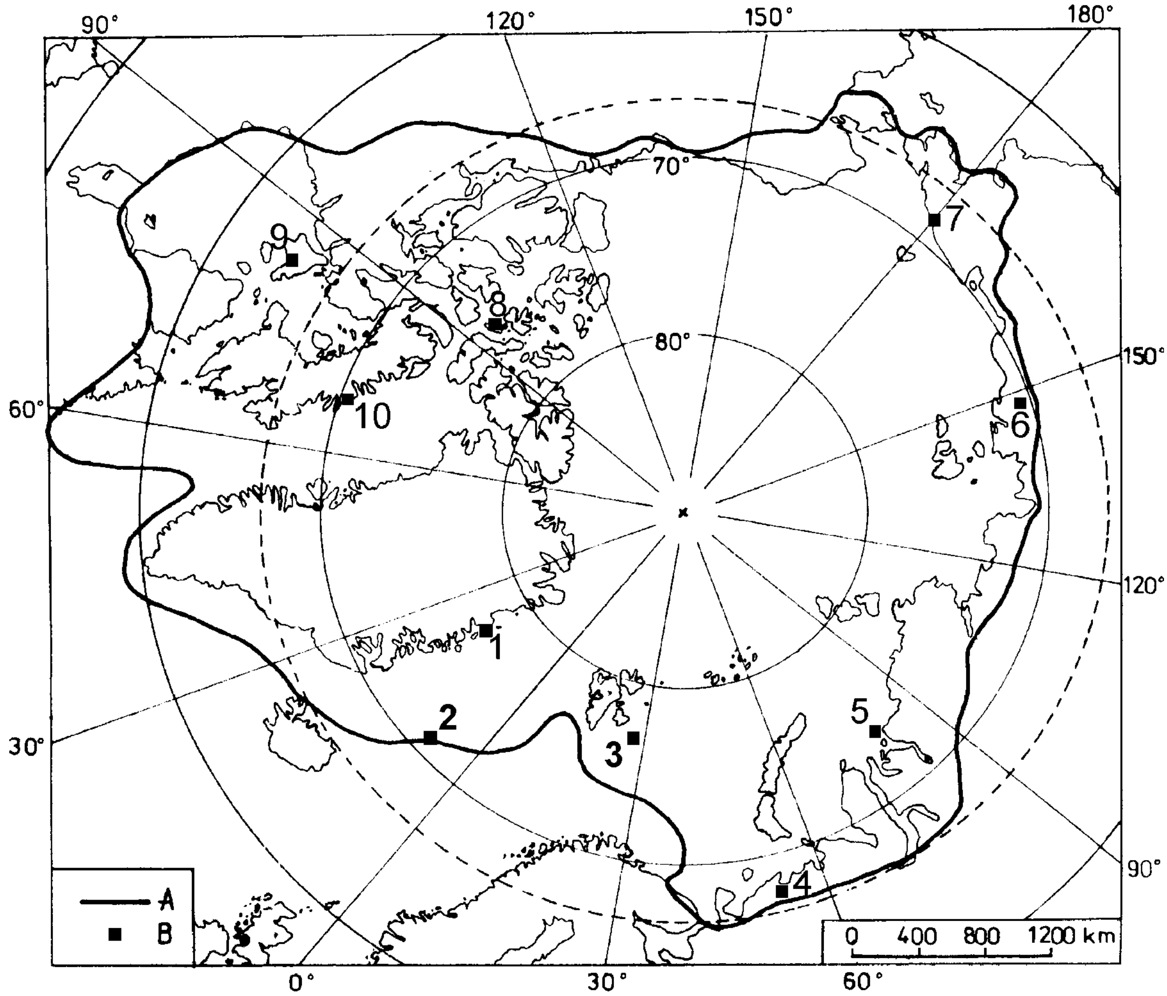

Figure 1. Location of Arctic meteorological stations used: (A) the border of the Arctic after *Atlas Arktiki* (Treshnikov, 1985); (B) meteorological stations — (1) Danmarkshavn ($H = 11$ m); (2) Jan Mayen ($H = 10$ m); (3) Hopen ($H = 6$ m); (4) Naryan-Mar ($H = 7$ m); (5) Ostrov Dikson ($H = 20$ m); (6) Chokurdakh ($H = 48$ m); (7) Mys Shmidta ($H = 7$ m); (8) Resolute A ($H = 67$ m); (9) Coral Harbour A ($H = 64$ m); (10) Clyde A ($H = 25$ m)

mean of a series of values defined by the absolute value of the difference in temperature between two adjacent discrete time series. According to Karl *et al.* (1995), such a definition is less prone to confounding the effect of high- and low-frequency variability as in the case of standard deviations. For each variable, daily anomalies were calculated by subtracting the long-term daily mean values (1951–90) from their respective actual daily values. In this way the influence of seasonal cycle of air temperature was removed.

The intraseasonal variability was calculated on a number of different time-scales: 1, 2, 5, 10 and 30 days. The 1 day time scale represents day-to-day variability. Seasonal averages were calculated by averaging the absolute differences between consecutive daily anomalies of temperature. The intraseasonal differences relative to the 2 to 30 day time intervals were calculated for each season by using overlapping running differences. For example, for the 10 day time scale, averages of the daily temperature anomalies were calculated for days 1 to 10, days 2 to 11, days 3 to 12, etc. Then the absolute differences between these consecutive average values were computed and were subsequently averaged for each season. Seasons are defined as December to February (DJF), March to May (MAM), June to August (JJA) and September to November (SON). The averages of the four seasonal values were used to find an annual average.

Interannual variability was calculated by taking the absolute value of the difference of the seasonal mean temperature anomaly from one year to the next. On the other hand, the annual value was calculated by averaging the four seasonal means, providing none was missing. Plummer (1996) has shown that interannual temperature variability calculated in the traditional way (i.e. as an absolute difference between mean annual values of temperature) can, in some cases, mask a large variability, which occurs in particular seasons. Such situations occur when interannual changes between mean seasonal temperatures are high, while mean annual temperatures are similar to each other. For more details explaining the method of calculating the inter-period differences and interannual variability see Plummer (1996).

Calculations according to the methods presented were conducted for each station. In the next step, areally averaged temperature variabilities (intraseasonal and interannual) for three Arctic regions (the Norwegian Arctic and eastern Greenland, the Canadian Arctic and the Russian Arctic) were calculated using simple mathematical averaging. The statistical significance of the linear trends was assessed using the Kendall-tau non-parametric test (Kendall and Gibbons, 1990).

3. RESULTS AND DISCUSSION

3.1. Intraseasonal temperature variability

Climate model simulations (e.g. Houghton *et al*., 1990, 1992, 1996; Karl *et al*., 1995 and references cited therein; Mearns *et al*., 1995; Zwiers and Kharin, 1998) indicate that in a warmer climate (e.g. due to rising concentration of greenhouse gases) a decrease in high-frequency temperature variability should be observed. Przybylak (1999) found that this is true also for the Norwegian Arctic, where in the cold decade (1960s) the temperature variability in two individual stations analysed (Jan Mayen and Hopen) was higher than in warmer decades (1950s and 1980s). However, trends in high-frequency temperature variability in these stations were mixed and insignificant. This behaviour of temperature variability from 1951 to 1990 is consistent with minor changes in mean air temperature in this period in the Norwegian Arctic (see Przybylak, 1996, 1997, 2000b). Przybylak (2000a) has shown the results concerning intraseasonal variability averaged for the whole year and for the three Arctic regions. In the present paper the analysis is further extended to the four seasons (DJF, MAM, JJA and SON). The limited space of the paper does not allow the presentation of graphical documentation of the four calculated temperature variables. Therefore, owing to the generally high similarity of the results (see figure 2 or Przybylak (1999) and (2000a)) the focus will be on the TMEAN.

Analysing mean annual high-frequency temperature variability, Przybylak (2000a) found that, of the four variables studied, TMAX and DTR had the greatest day-to-day variability (see also figure 2). For the longer time scales (5 days and more) the highest temperature variability was noted for TMAX and TMIN. On the other hand, DTR clearly had the lowest variability. Differences in mean absolute seasonal and annual values of inter-period TMEAN (figures 3–6) and other variables (not shown), as well as their range of changes in time, decrease when the time scale of averaging intervals increases. This tendency is most clear for the DTR. Of the four temperature variables analysed, the TMAX is most sensitive to high-frequency temperature variability.

3.1.1. The Norwegian Arctic and eastern Greenland. In the Norwegian Arctic and eastern Greenland, where cyclonic activity is the greatest in the Arctic, the high-frequency temperature variability is the lowest, particularly in autumn and summer. For some readers such a result may be surprising, but the reason for this is the fact that the cyclonic activity here is more stable than in other regions. In addition, open sea waters, which cover a great part of this region, also result in a drop in temperature variability. In turn, in areas covered by sea ice, such an effect may also be connected with the positive trend in the direction of the earlier (spring) and later (autumn) snow-melt onset dates observed from 1979 to 1998 (Drobot and Anderson, 2001). These earlier and later snow-melts should exert a particular influence on the temperature variability of late spring, summer, and early autumn. The intraseasonal temperature variability increased northwards and eastwards of this region due to the decreasing frequency of cyclones and the increasing frequency of anticyclones. The more frequent changes of these opposite kinds of baric systems here cause rapid changes in wind directions,

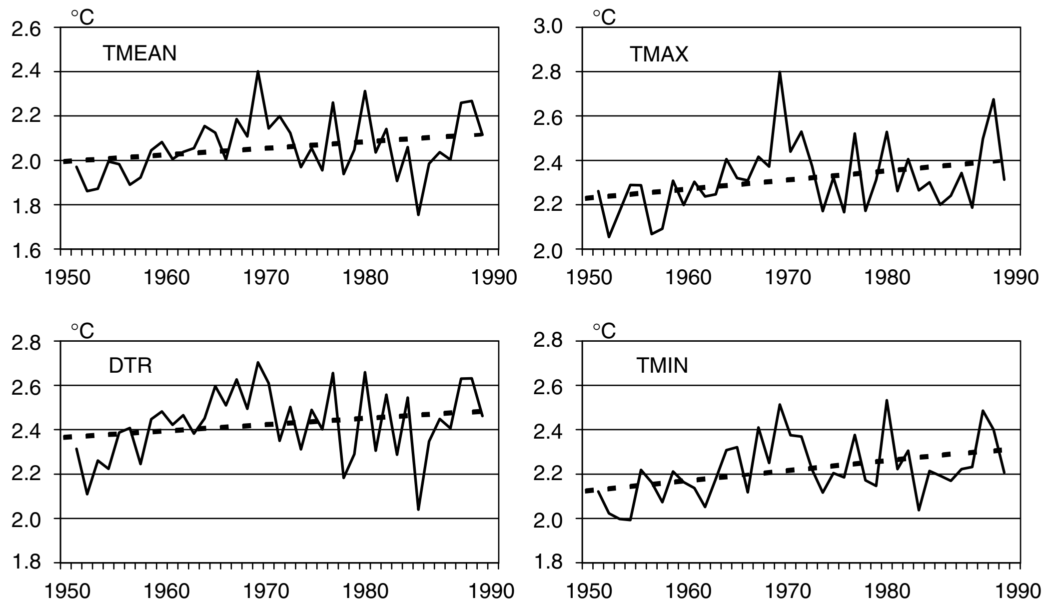

Figure 2. Variations (solid lines) and trends (dashed lines) of TMEAN, DTR, TMAX, TMIN for the Norwegian Arctic and eastern Greenland, 1951–90

e.g. from the southern sector to the northern sector or *vice versa*. As a result, advections of warm and humid air masses are replaced by advections of cold and dry air masses and *vice versa*. Sea-ice cover, occurring here almost throughout the year, also enhances temperature variability.

Annual mean values of day-to-day TMEAN variability are slightly above 2 °C and for longer time-scales (5 to 30 days) are lower than 1 °C (figure 3). Clearly, the highest TMEAN variability for all time scales analysed is noted in winter. For example, day-to-day temperature variability oscillates around 3 °C. The 5 day averaged differences range from 1 to 1.5 °C and the 30 day variability oscillates around 0.3 °C (figure 4). It is also worth noting that year-to-year changes of the high-frequency variability are also the highest in this season and exceed 1 °C (for the 1 day time scale), 0.6 °C (for 5 day time scale) and 0.3 °C (for 10 day time scale). High-frequency temperature variability in summer and its year-to-year changes are significantly the lowest (see figure 4). For example, day-to-day temperature variability is almost three times lower than in winter and two times lower than in spring and ranges from 1.1 to 1.2 °C. It is very interesting to note that temperature variability is higher in spring than in autumn. The reasons for these observations are difficult to determine without detailed investigation, including atmospheric circulation changes in particular.

Trends in areally averaged intraseasonal variability for the Norwegian Arctic and eastern Greenland for all temperature variables are slightly positive for the annual mean values (Table I and figure 3). For seasonal values the trends are also weak, and, though they are of mixed sign, the majority of them are positive (Table I and figure 4). Positive values clearly dominate in autumn and, particularly, in winter. In spring, positive values are still present for TMEAN and TMIN, but only for time scales by less than 10 days. In summer, decreasing trends dominate for all temperature variables, except the DTR for time scales of longer than 1 day. Only for two cases were trends statistically significant, both concerning TMIN. For annual values the day-to-day changes were significant, and for summer values changes in the 10 day differences. This behaviour of the temperature variability in the Norwegian Arctic and eastern Greenland is consistent with trends of mean temperature in the period studied. Przybylak (1996: figures 26 and 27) found decreasing trends for winter, autumn and annual values, and increasing trends for two other seasons. Thus, decreasing/increasing trends in mean temperatures relate to increasing/decreasing trends in temperature variability. In both kinds of temperature characteristics the trends are insignificant.

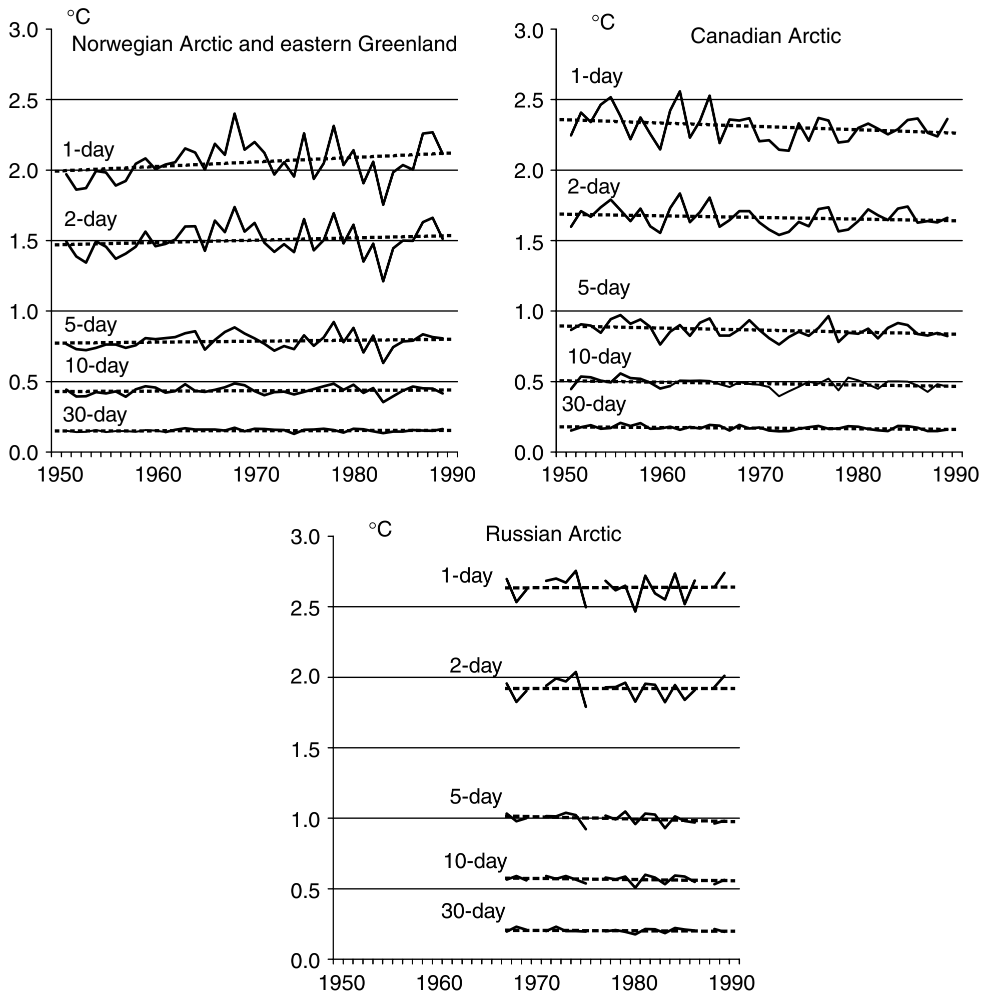

Figure 3. Variations (solid lines) and trends (dashed lines) of the mean regional annual absolute differences in daily average temperatures calculated for various averaging intervals, 1951–90

3.1.2. The Canadian Arctic. Areally averaged intraseasonal temperature variability in the Canadian Arctic is mostly higher than in the Norwegian Arctic and eastern Greenland (see figure 3 and compare figures 4 and 5). This situation is also true for other variables analysed (not shown). This is clearly seen for summer and autumn, whereas during the two other seasons the differences in variability are small. Intraseasonal temperature variability (on all time scales) averaged for spring, winter and for the year was clearly higher in the 1950s and in the first part of the 1960s. Later on, the variability was significantly lower. On the other hand, the variability in summer and autumn throughout the whole period was, broadly speaking, similar. The range in year-to-year changes of intraseasonal variability in both regions mentioned is similar.

Contrary to the results obtained for the Norwegian Arctic and eastern Greenland, in the Canadian Arctic a large decrease in intraseasonal temperature variability occurred in spring, winter and for values averaged yearly. For the annual values, statistically significant decreasing trends were observed for the TMIN and DTR (Table I). This is evident for all time scales. The most pronounced decreasing trends were noted in winter, especially for the 5 and 10 day time intervals. For these time scales all temperature variables studied were statistically significant. For shorter and longer time scales a significant decrease in variability is observed mainly for the DTR. In spring, the statistically significant decreasing trends for all time scales were found only for DTR and for the shorter time scales (1 and 2 days) for TMIN. All variables also show

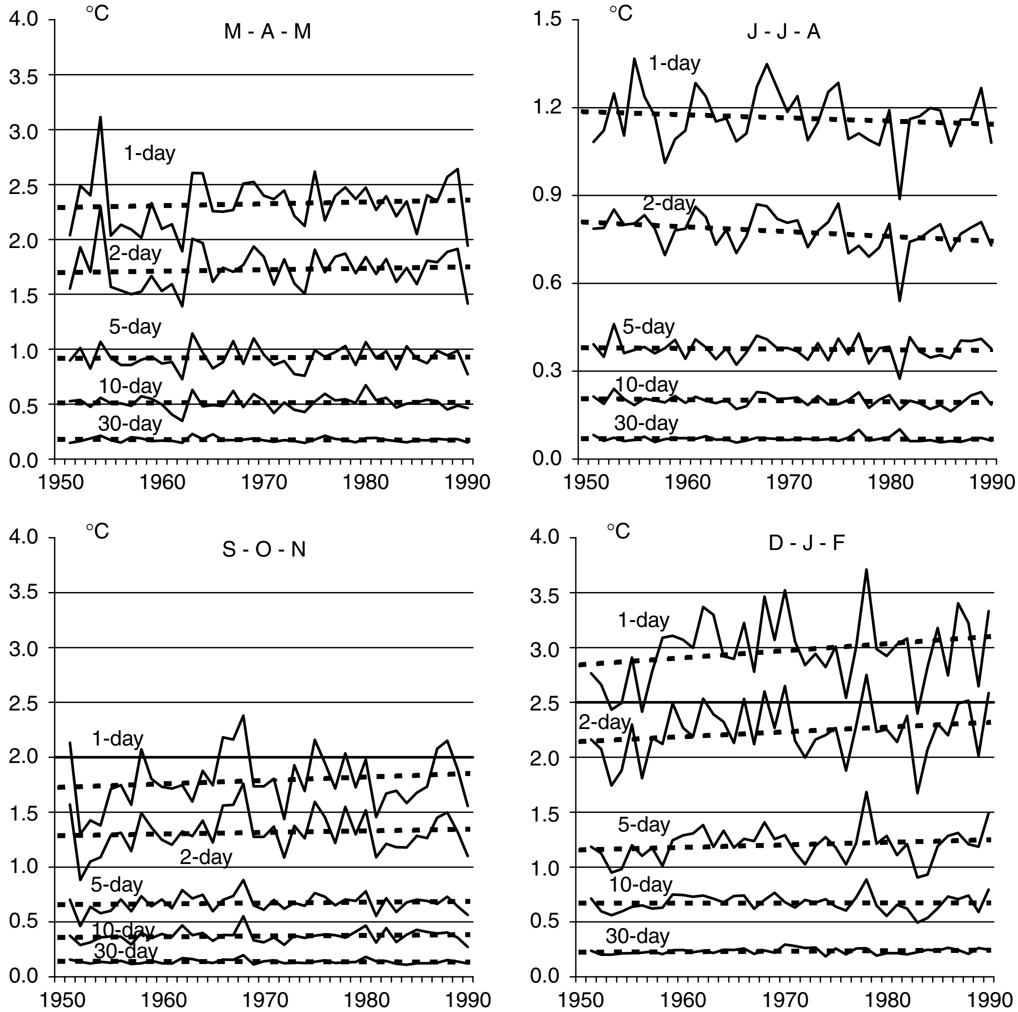

Figure 4. Variations (solid lines) and trends (dashed lines) of the mean seasonal absolute differences in daily average temperatures for the Norwegian Arctic and eastern Greenland, calculated for various averaging intervals, 1951–90

significant decreases for the 30 day time scale. In two other seasons, the trends in intraseasonal variability were mixed and generally not statistically significant. In summer, TMAX and TMIN experienced opposite trends in variability. However, only trends in intraseasonal TMIN high-frequency variability were statistically significant. In autumn, TMEAN variability was characterized by weak increasing trends (Table I and figure 5), whereas DTR was characterized by decreasing trends, which, except for the 5 and 10 day time intervals, were statistically significant. TMAX and TMIN intraseasonal variability had the same signs of trends within each individual time scale, but the signs changed depending on the length of the averaging interval. In conclusion, one can say that, in the Canadian Arctic, decreasing trends of intraseasonal temperature variability prevailed from 1951 to 1990. Many of them were also statistically significant. Thus, these results seem to agree with the theoretical expectations of changes of high-frequency temperature variability in a warmer world. However, as results from the investigation made by Przybylak (1996, 1997, 2000b) demonstrate, most of the Canadian Arctic in the period studied was characterized by a small decrease in air temperature. Thus, in the Canadian Arctic we should rather observe no trend or a small increase in temperature variability. Such behaviour was observed only in summer and autumn. The discrepancy exists for two other seasons between the two characteristics of temperature analysed. The question arises as to whether the relationship between mean

Table I. Sign of the trend for various measures of daily temperature variability and values of trends (°C per 10 years) statistically significant at least at the level of 0.05[a]

Element	MAM			JJA			SON			DJF			Year		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1 day															
TMEAN	+	−0.0627	+	−	+	+	+	+	−	+	−	−	+	−	+
TMAX	−	−	+	−	+	+	+	−	−	+	−0.0938	−	+	−	+
TMIN	+	−0.1465*	+	−	−0.0792*	+	+	−	−	+	−	−	0.0376	−0.0917*	−
DTR	−	−0.1325*	+	−	−	+	+	−0.0707	−	+	−0.1549*	−	+	−0.1025*	−
2 day															
TMEAN	+	−	+	−	+	+	+	+	−	+	−	−	+	−	+
TMAX	−	−	+	−	+	+	+	+	−	+	−	−	+	−	−
TMIN	+	−0.0724*	−	−	−0.0268	+	+	+	−	+	−	−	+	−0.0416*	−
DTR	−	−0.0779*	+	+	+	+	+	−0.0383	−	+	−0.1153*	−	+	−0.0586*	−
5 day															
TMEAN	+	−	−	−	−	+	+	+	−	+	−0.0529	−	+	−	−
TMAX	−	+	+	−	+	+	+	0.0231	−	+	−0.0649	−	+	−	−
TMIN	+	−	−	−	−0.0135	−	+	+	−	+	−0.0545	−	+	−0.0234*	−
DTR	−	−0.0363*	+	+	+	+	+	−	−	+	−0.0456	−	+	−0.0232*	−
10 day															
TMEAN	−	−	−	−	−	−	−	+	+	+	−0.0306	−0.0474	+	−	−
TMAX	−	+	+	−	+	−	+	+	−	−	−0.0365	−	+	−	−
TMIN	+	−	−	−0.0038	−0.0072	−	+	+	+	−	−0.0307	−0.0597	+	−0.0128*	−
DTR	−	−0.0179*	−	+	+	−	+	−	−0.0167	+	−0.0202*	−	+	−0.0104*	−
30 day															
TMEAN	−	−0.0131*	+	−	−	−	−	+	−	+	−	−	+	−0.0460	−
TMAX	−	−0.0097	+	+	+	−	+	−	−	+	−	−	+	−	−
TMIN	−	−0.0168*	+	−	−	−	−	−	−	+	−	−	+	−0.0063*	−
DTR	−	−0.0047*	+	+	+	−	+	−0.0029	−	+	−0.0066*	−	+	−0.0035*	+
Interannual															
TMEAN	−	+	−	−	+	−0.4914*	−	+	−	+	−	−	+	+	−
TMAX	−	+	−	−	−	−0.5742*	+	+	−	+	−	−	+	+	−
TMIN	−	+	−	−	+	−0.3455	−	+	−	+	−	−	+	+	−0.4631*
DTR	−0.1214	+	−	−	+	−	+	−	−	+	−	+	+	+	−

[a] TMEAN: average daily temperature; TMAX: maximum daily temperature; TMIN: minimum daily temperature; DTR: diurnal temperature range. (1) Norwegian Arctic and eastern Greenland; (2) Canadian Arctic; (3) Russian Arctic. Asterisk indicates trends statistically significant at the level of 0.01.

temperature and its high-frequency variability is different here than in the Norwegian Arctic and other parts of the world and, if so, why. The answer requires more investigations based on longer series of high-resolution data, which simultaneously will be characterized by more clear trends in average temperature. Such conditions up till now have not been fulfilled.

3.1.3. The Russian Arctic. The availability of the daily TMAX and TMIN from the Russian Arctic is limited. Therefore, in the present paper the results are presented for the period 1967–90. Unfortunately, even for this short period gaps exist for some seasons. Thus, an estimate of intraseasonal temperature variability trends may not be fully reliable. Nevertheless, some general conclusions can be drawn.

The Russian Arctic, in particular its central and eastern parts, has a similar climate to that of the Canadian Arctic (Przybylak, 1996, 2000b). Both these areas have a high degree of thermic continentality exceeding 60% (see figure 3 in Ewert (1997)) and are characterized mainly by anticyclonic activity. Thus, intraseasonal temperature variability and its change over time should here be roughly similar to the previously described variability for the Canadian Arctic. Analysis of Table I and figures 3, 5 and 6 generally confirm this statement, although in the case of seasonal trends differences may be noted. However, we must remember that the trends,

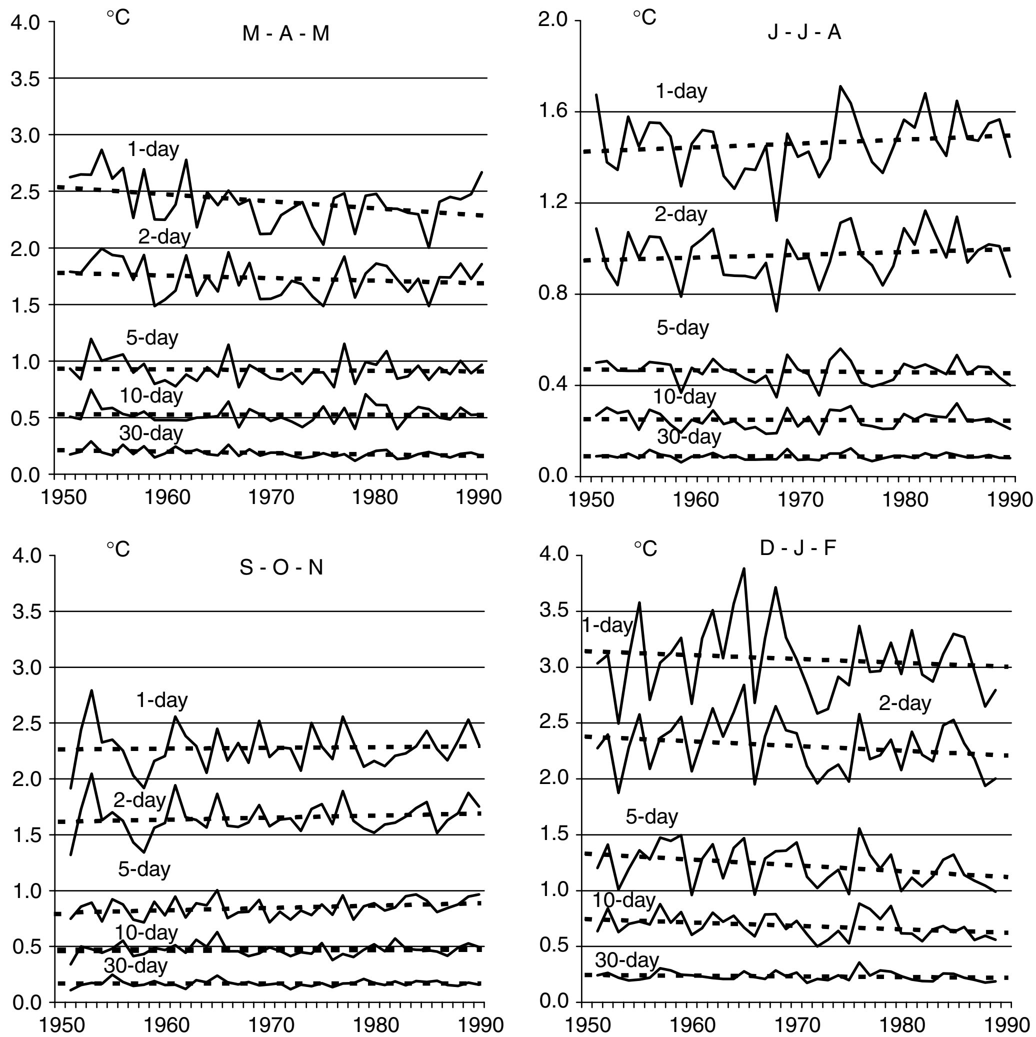

Figure 5. Variations (solid lines) and trends (dashed lines) of the mean seasonal absolute differences in daily average temperatures for the Canadian Arctic, calculated for various averaging intervals, 1951–90

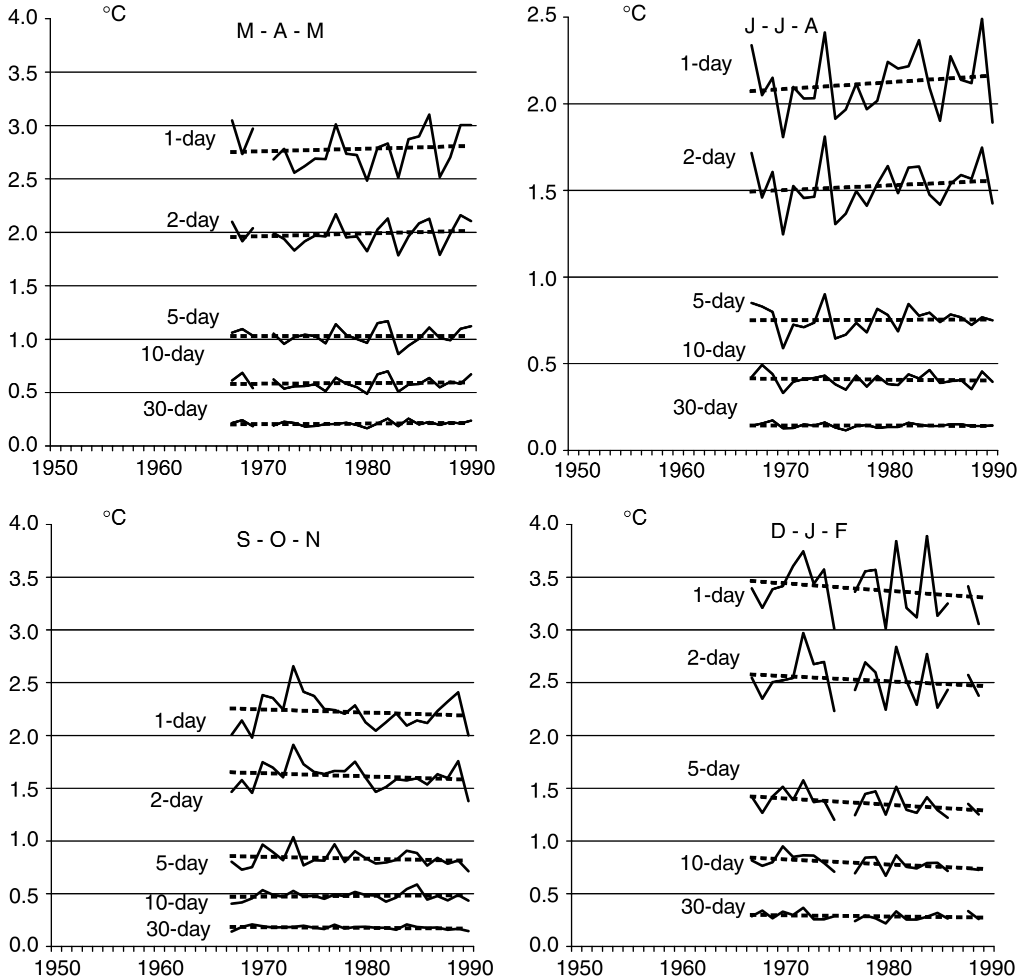

Figure 6. Variations (solid lines) and trends (dashed lines) of the mean seasonal absolute differences in daily average temperatures for the Russian Arctic, calculated for various averaging intervals, 1967–90

due to the different periods, are not fully comparable. It is also well seen that the temperature variability in the Russian Arctic is higher than in the Canadian Arctic. The differences are especially large for summer (compare figures 6 and 5). For example, the day-to-day TMEAN variability in the Russian Arctic is higher than 2 °C, whereas in the Canadian Arctic it is between 1.3 and 1.6 °C. The best correspondence between signs of trends in variability between these two climatic regions exists for winter and for the annual values. On the other hand, a large number of discrepancies occur in the transition seasons (see Table I). The majority of the trends in the Russian Arctic, particularly in autumn and winter, are negative. In the two other seasons, mainly in the shortest time intervals, increasing trends dominate in intraseasonal temperature variability. However, except for three cases, all trends are not statistically significant.

The relationships between trends in mean air temperature and its intraseasonal variability in the Russian Arctic are consistent with theoretical expectations of their behaviour in a warmer climate for all seasons (except spring).

3.2. Interannual temperature variability

3.2.1. Mean. This kind of temperature variability was significantly more often investigated than the intraseasonal variability described earlier. For the Arctic, the first detailed investigations of this problem, using three different indices of variability (average deviation, standard deviation and year-to-year average changes), including a presentation of spatial distributions of the standard deviations σ of the mean seasonal and annual temperatures for the period 1951–90, were carried out by Przybylak (1996). Before the tendencies in the interannual temperature variability are presented, it is useful to describe in brief the main results of this earlier work.

Of the four seasons, clearly the winter temperature has highest σ (see figure 7 and table 11 in Przybylak (1996)). In this season in the Arctic one can distinguish three areas with the highest variability ($\sigma > 2.5\,^{\circ}$C): (i) the Barents and Kara seas; (ii) the south-eastern part of the Canadian Arctic and the southern part of Baffin Bay; and (iii) Alaska. The main reason for the high winter temperature variability is the fact that the TMEAN of this season is influenced mainly by the atmospheric circulation, which is very changeable on a year-to-year basis. This conclusion also confirms the fact that the three regions with the highest values of σ (listed above) are situated in the parts of the Arctic characterized by the most vigorous cyclonic activity (e.g. Serreze *et al.*, 1993). On the other hand, in the regions where anticyclonic activity dominates (most of the Russian Arctic, the Arctic Ocean and the northern part of the Canadian Arctic) the weather and climate is more stable and

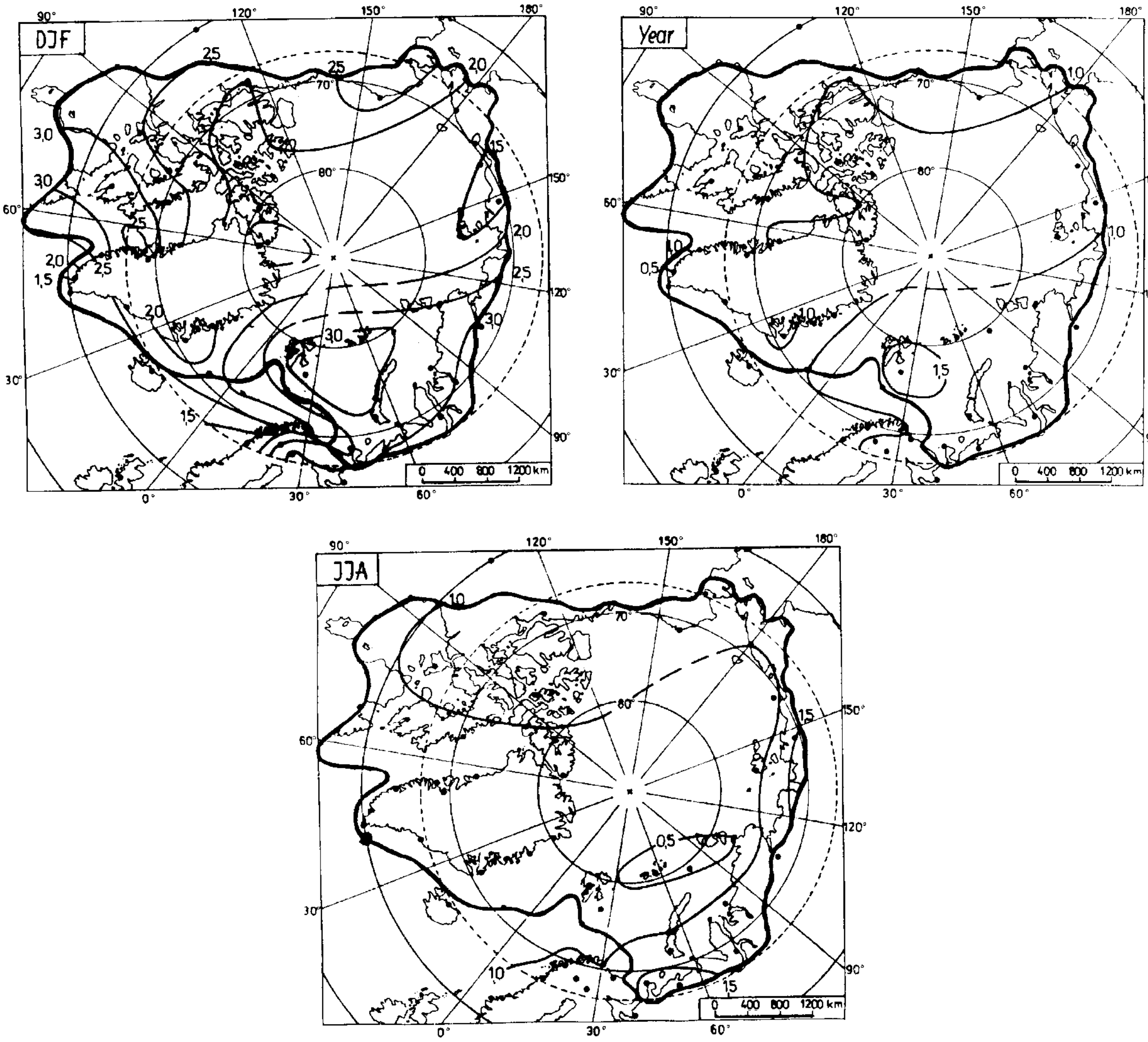

Figure 7. Spatial distributions of the standard deviations of mean winter (DJF), summer (JJA) and annual (Year) air temperatures in the Arctic, 1951–90 (after Przybylak 1996)

σ values range from 1.5 to 2.0 °C. In spring and autumn (not shown), the patterns of σ distribution in the Arctic are similar to that of winter; however, values of σ are significantly lower and range from 1 to 2.5 °C. Most areas of the Arctic (mainly the Canadian Arctic, Baffin Bay and the southern parts of the Norwegian and Russian Arctic) show greater σ in spring than in autumn. The variability of summer temperature in 1951–90 is significantly the lowest (figure 7) and σ rarely exceeds 1.5 °C. This happens only in the central part of the Russian Arctic. The most stable year-to-year summer temperature occurred in the region spreading from Zemlya Frantsa Josifa to Taymyr Peninsula ($\sigma < 0.5$ °C). According to Przybylak (1996) there are, at least, two reasons for the low variability of the summer temperature: (i) weak atmospheric circulation, and (ii) the stabilizing effect of snow and ice melting, which uses significant amounts of energy coming to the Arctic surface both by radiational and advectional means. Annual TMEAN in the Arctic is influenced mainly by the winter temperature, and therefore the spatial distribution of its variability is roughly similar to that noted for winter (figure 7). Generally, values of σ of the annual TMEAN are 1.0–1.5 °C lower than those for winter. The highest variability is noted in the area between Spitsbergen, Zemlya Frantsa Josifa and Novaya Zemlya. These values of σ are in good correspondence with the analogous calculation conducted for different latitudinal zones for the period 1951–80 (Aleksandrov *et al.*, 1986).

Przybylak (1996) also found similar results to those presented above for σ of TMAX and TMIN.

3.2.2. Trends. Current general circulation models do not give similar simulations of the behaviour of interannual temperature variability with enhanced concentrations of CO_2. Both decreases and increases of this variability are simulated (Plummer, 1996).

3.2.2.1. The Norwegian Arctic and eastern Greenland: In the Norwegian Arctic and eastern Greenland, interannual variability of TMEAN is greatest in winter (up to 5–6 °C), although it most often ranges between 2 and 3 °C (figure 8). Large variability is also noted for spring and autumn. Clearly the lowest variability can be seen for summer TMEAN (generally below 1 °C). Such seasonal patterns are also generally characteristic of other variables (not shown). In the case of TMAX and TMIN, the magnitude of variability is similar to that observed for TMEAN, whereas the DTR has a roughly two times lower variability. In cold seasons (from autumn to spring) TMIN has a slightly higher interannual variability than TMAX. On the other hand, in summer the opposite relationship occurs.

In the Norwegian Arctic and eastern Greenland the trends in interannual variability of annual TMEAN, calculated both on the basis of data from individual stations (Przybylak, 1999) and areally averaged data, are slightly positive and not statistically significant (Table I, figure 8). This was a result of positive trends noted for the winter TMEAN. In the other three seasons, small decreases in variability were observed, in particular in spring and summer (see figure 8). With two exceptions (for trends of TMAX and DTR in autumn), the rest of the variables show generally similar patterns to that presented for TMEAN (see Table I). A statistically significant decrease in variability was only noted for mean spring DTR.

3.2.2.2. The Canadian Arctic: As in the case of the intraseasonal temperature variability, the interannual variability is also higher in the Canadian Arctic in comparison with the Norwegian Arctic and eastern Greenland (compare figures 9 and 8). This conclusion is also true of other variables (not shown), except the DTR for autumn, winter and spring. For more details see Przybylak (2000b). Signs of trends in the variability of seasonal TMEAN, TMIN and DTR in the Canadian Arctic in comparison with the Norwegian Arctic and eastern Greenland are opposite (Table I). On the other hand, tendencies in variability of annual averages are the same. All trends are, however, weak and insignificant.

It is worth adding that, in the Canadian Arctic, the interannual variability of seasonal (especially autumn) and annual temperature averages show a clear rhythm between peaks representing the highest and lowest values. The length of rhythm is equal to 4–6 years after 1970, and slightly longer prior to 1970. It is likely that this rhythm is related to the El Niño–southern oscillation (ENSO). Przybylak (2000b) found that the climatic influence of ENSO on the Arctic is greatest in the Canadian Arctic. This rhythm is also clearer after 1970, when a significant increase in the intensity of ENSO is noted.

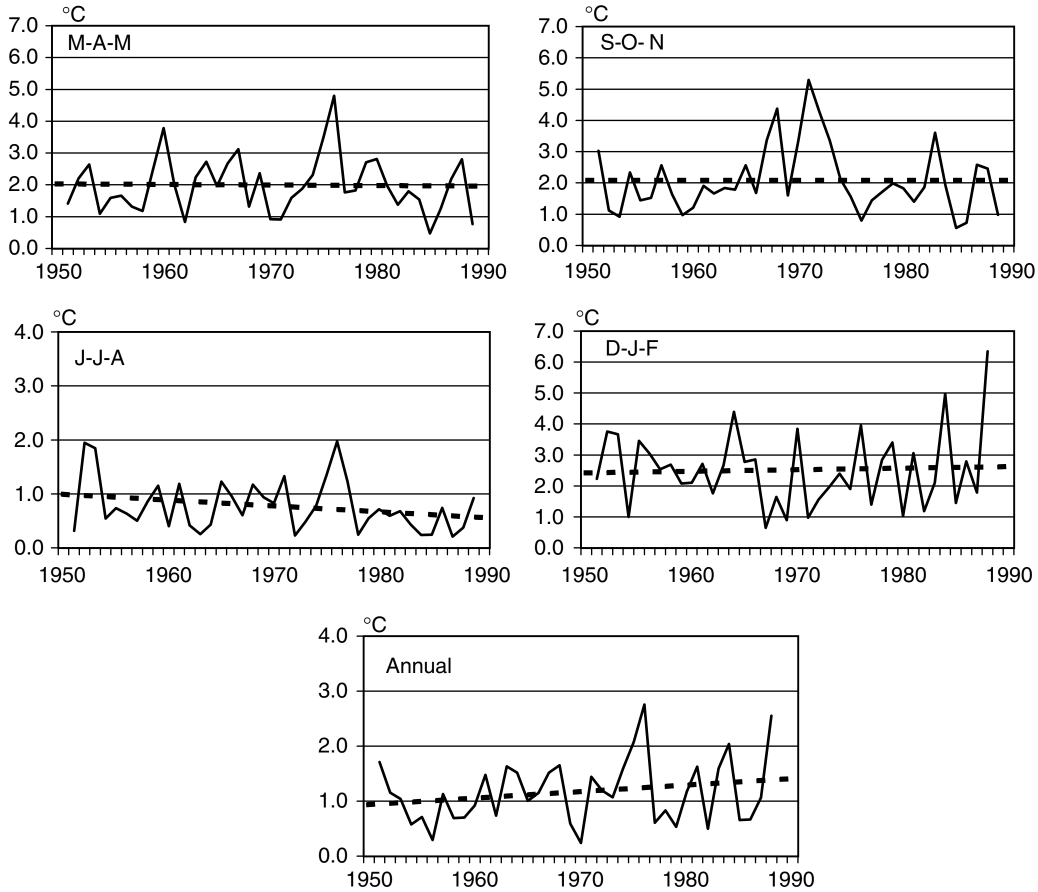

Figure 8. Interannual variability of the mean seasonal and annual temperatures (solid lines) and its trends (dashed lines) for the Norwegian Arctic and eastern Greenland, 1951–90

3.2.2.3. The Russian Arctic: The magnitudes of interannual variability of mean seasonal and annual temperatures in the Russian Arctic are roughly similar to those observed in the Canadian Arctic (compare figures 10 and 9). Such relations were noted for all temperature variables studied. The magnitude of interannual variability, similar to the intraseasonal variability, also decreased in recent decades (except the DTR for winter). However, the decreases in variability for summer (TMEAN, TMAX and TMIN) and annual (only TMIN) temperature variables were statistically significant (see Table I).

Przybylak (1996, 1997), in analysing the σ of mean winter, summer and annual temperature variables in running decades for almost the same set of stations as used in the present paper, found generally similar results (see his figure 15 and figure 12 respectively).

4. CONCLUSIONS AND FINAL REMARKS

Regional trends in annually averaged intraseasonal variability of all temperature variables studied from 1951 to 1990 were positive in the Norwegian Arctic and eastern Greenland and negative in the Canadian and the Russian Arctic. The majority of them for all four temperature variables analysed and five different time scales (1, 2, 5, 10 and 30 days) were not statistically significant. Statistically significant decreases in high-frequency variability for all averaging periods were observed only in the Canadian Arctic in the case of TMIN and the DTR (Table I). Trends in intraseasonal temperature variability averaged for seasons are also

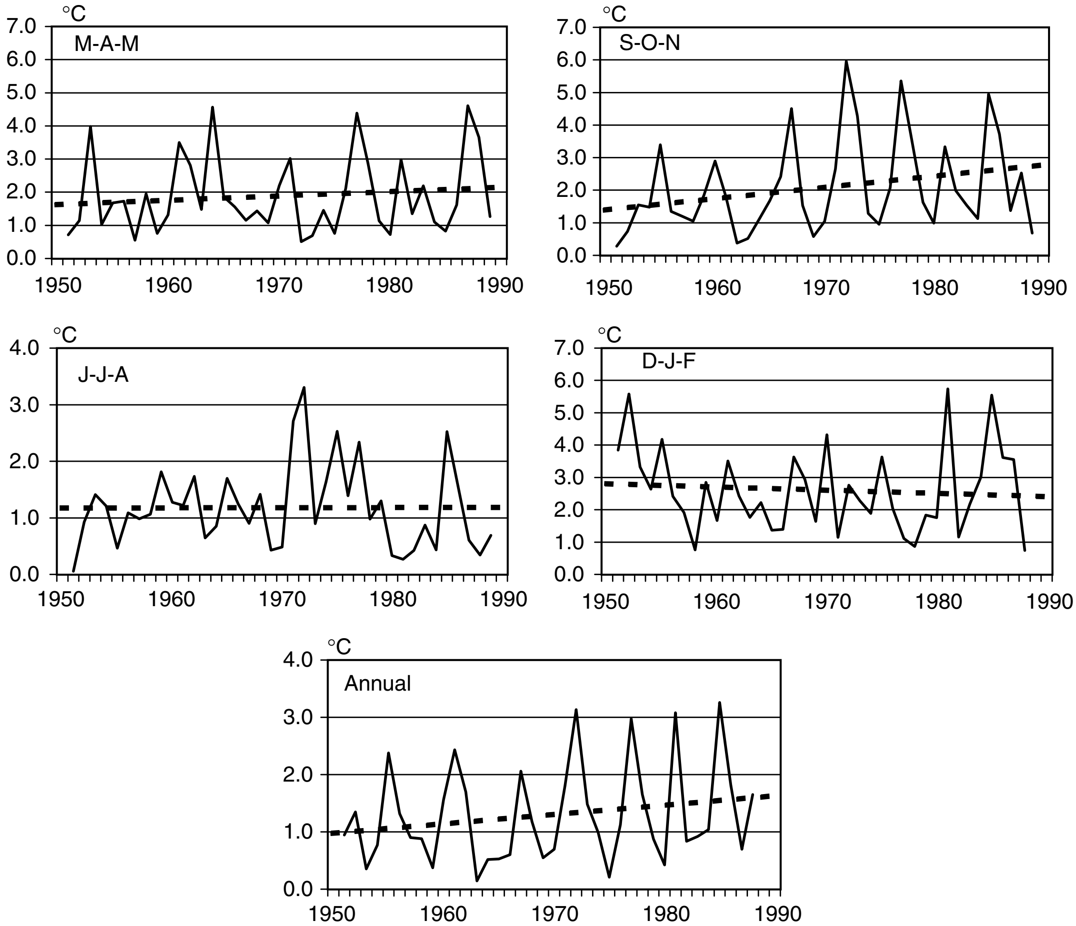

Figure 9. Interannual variability of the mean seasonal and annual temperatures (solid lines) and its trends (dashed lines) for the Canadian Arctic, 1951–90

weak and rarely significant. Opposite signs of trends between summer, on the one hand, and autumn and winter, on the other hand, are very often noted. However, this relation is mainly observed for the shortest time intervals (up to 5 days). As in the case of annual values, statistically significant trends in intraseasonal variability were observed (with small exceptions) in the Canadian Arctic. These weak and mixed trends in intraseasonal temperature variability in the Arctic are also consistent with small changes in mean temperature observed here in the period studied.

Interannual temperature variability in the Arctic, similar to intraseasonal variability, does not show the same tendency in the period studied. Even within each Arctic region analysed here (excluding the Russian Arctic), signs in interannual temperature variability change from season to season. Statistically significant trends were noted only in the Russian Arctic for mean summer (TMEAN, TMAX and TMIN) and annual (only TMIN) temperature variability.

In conclusion, one can say that trends in both the intraseasonal and interannual temperature variability of the temperature variables studied do not show any significant changes. Thus, this aspect of climate change, as well as trends in average seasonal and annual values of temperature investigated earlier (Przybylak, 1996, 1997, 2000b), proves that, in the Arctic in the period 1951–90, no tangible manifestations of the greenhouse effect can be identified. The possible reasons for the lack of occurrence of the contemporary phase of global warming (after 1975) in the Arctic are presented by Przybylak (1996, 2000b).

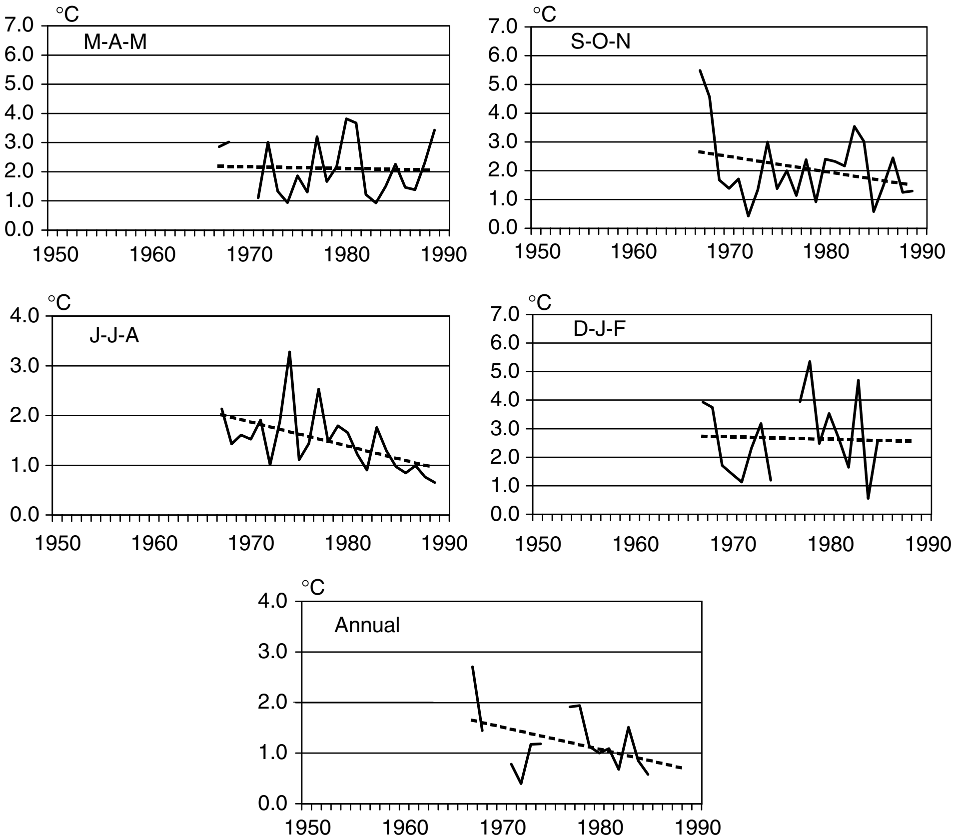

Figure 10. Interannual variability of the mean seasonal and annual temperatures (solid lines) and its trends (dashed lines) for the Russian Arctic, 1967–90

I should also stress here that the sets of long-term high-resolution temperature data for the Arctic are limited due to both the general sparse network of stations and unavailability of data, particularly in digital form. The last problem mainly concerns obtaining the data from Greenland and the Russian Arctic. When long and more complete daily temperature series are available (especially for the Russian Arctic) the analysis should be repeated in order to improve knowledge about long-term changes in intraseasonal and interannual temperature variability.

A more recent analysis of mean seasonal and annual air-temperature trends in the Arctic (Przybylak, in press) shows that in the mid-1990s there occurred quite a large rise in air temperature. The areally averaged annual air temperature for the whole Arctic for the last 5 year period of the 20th century was the warmest since 1950 (1.0 °C above the 1951–90 average). Thus, it is possible that the inclusion of data from the 1990s may alter to some degree the results presented in this paper.

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