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DIURNAL TEMPERATURE RANGE IN THE ARCTIC AND ITS RELATION TO HEMISPHERIC AND ARCTIC CIRCULATION PATTERNS

RAJMUND PRZYBYLAK*
Department of Climatology, Nicholas Copernicus University, Torun, Poland

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ABSTRACT

The changes of atmospheric circulation patterns in the Northern Hemisphere and in the Arctic for the period 1939–1990 were investigated. For this purpose, the seasonal and annual frequencies of occurrence of W, E and C macrotypes according to the Vangengeim–Girs typology and groups of synoptic processes in the Arctic (A, B, W, G, D and K) according to the Dydina classification have been computed.

Spatial and seasonal patterns of the mean diurnal temperature range (DTR) in the Arctic are presented, based on the data from 33 Arctic stations for the period 1951–1990.

The relationships between the DTR in the Arctic and the atmospheric circulation changes in the Northern Hemisphere and in the Arctic have been investigated. The seasonal mean DTR for each macrotype of circulation and group of circulation was calculated using daily data from ten Arctic stations for the period 1951–1990. These stations represent all climatic regions and subregions identified by the authors of *Atlas Arktiki* (1985. *Glavnoye Upravlenye Geodeziy i Kartografiy*, Moskva, p. 204). In addition, the correlation coefficients between DTR in the Arctic and both the North Atlantic Oscillation Index (NAO) and the Zonal Index (ZI) have been computed.

Statistically significant changes of atmospheric circulation in the Northern Hemisphere (mainly in low and moderate latitudes) since the mid-1970s, which are also reported by other researchers, have been confirmed. In the Arctic, the atmospheric circulation has also undergone changes in recent decades; however, these changes are significantly smaller.

Both the annual and the seasonal mean DTR values have been found to be the highest in the centre of the southernmost parts of the Canadian and Russian Arctic and the lowest in the Norwegian Arctic. Based on the seasonal means, four types of annual course of the DTR in the Arctic have been identified.

The results pertaining to the relationship between DTR and atmospheric circulation provide some evidence that, in recent decades, both the large-scale changes of the atmospheric circulation in the Northern Hemisphere and its changes in the Arctic have led to the damping of the cool half-year DTR in the Arctic. Copyright © 2000 Royal Meteorological Society.

KEY WORDS: Arctic; diurnal temperature range; spatial changes; atmospheric circulation changes; time series analysis

1. INTRODUCTION

During the 1990s a large number of studies concentrated on the analysis of fluctuations of daily maximum and minimum air temperature, as well as on the diurnal temperature range (DTR). The first well-known studies were published by Karl *et al*. (1991, 1993). They showed that during the period 1951–1990, over 37% of the global landmass, the increase of minimum temperature was two to three times greater than that of maximum temperature. As a result, a marked decrease in DTR was noted. More recently, new analyses were conducted by Horton (1995) and Easterling *et al*. (1997). The datasets used in these analyses covered approximately 42% and 54% of the global landmass, respectively. The results obtained are

* Correspondence to: Department of Climatology, Nicholas Copernicus University, Danielewskiego 6, PL 87-100 Torun, Poland; e-mail: rp11@geo.uni.torun.pl

generally consistent with the findings of Karl *et al.* (1991, 1993). Most other studies which examined this problem for smaller areas also found a decrease in the DTR (see Brázdil *et al.*, 1995, 1996; Dessens and Bücher, 1995; Jones, 1995a; Kaas and Frich, 1995; Plummer *et al.*, 1995; Türkes *et al.*, 1996; Przybylak, 1997). However, some regions of the world reveal no significant trends: for example, Austria (Böhm and Auer, 1994); the Czech Republic (Brázdil *et al.*, 1994); the Nordic countries (Kaas and Frich, 1995); India (Kumar *et al.*, 1994); the Alpine region (Weber *et al.*, 1994); some parts of the Arctic, mainly the Canadian Arctic (Przybylak, 1997); and, the Antarctic (Jones, 1995b). Some studies even show a significant increase in the DTR (Poland: Niedźwiedź and Ustrnul, 1994; the North Sea region including the British Isles: Horton, 1995).

Przybylak (1997) found a significant decrease in the DTR in most of the Arctic, except for some parts of the Canadian Arctic. In that study, spatial and temporal changes in extreme air temperatures in the Arctic were examined over the period 1951–1990. The main objective of the present work is to determine the causes of the damping in the DTR in recent decades. The definite answer to this question is still open, but the majority of researchers assume, based both on observations and on modelling studies, that the most probable influencing factor is an increase in cloudiness (see Plantico *et al.*, 1990; Frich, 1992; Henderson-Sellers, 1992; Karl *et al.*, 1993, 1995; Dessens and Bücher, 1995; Hansen *et al.*, 1995; Jones, 1995a; Plummer *et al.*, 1995; Salinger *et al.*, 1995; Przybylak, 1997). However, it is still unknown what causes the increase in the cloud cover.

Using the monthly averages of DTR and cloudiness in the Arctic over the period 1951–1990, Przybylak (1997) found that the most important factor which influenced the decrease in the DTR during the warm half-year was an increase in cloudiness. However, in the cool half-year the dominant variable damping the DTR was day-to-day temperature change, which is governed mainly by the atmospheric circulation.

Atmospheric circulation plays a crucial role in shaping the climate of the Arctic, especially during the cool half-year when the incoming solar radiation is low or even non-existent (polar night) (see Przybylak, 1996). In the Arctic, and in other regions, every change in climate must be directly or indirectly connected with changes in atmospheric circulation. Atmospheric circulation determines the size of different climatic variables, such as cloud cover, air humidity, snow cover, wind speed, non-periodical day-to-day changes of air temperature, which significantly influence the DTR (see, for example, Figure 8 in Karl *et al.*, 1993).

For this reason, in order to estimate if the current changes of atmospheric circulation could cause the observed decrease in the DTR, the present study examines the relationship between atmospheric circulation and the DTR in the entire Arctic, as defined in *Atlas Arktiki* (1985). In such an investigation, more reliable results can be obtained by using daily data because, as noted by Robinson *et al.* (1995), some important information regarding climate diagnostics and climate change detection are lost when monthly or longer averages are used. To my knowledge, up until now, such detailed analyses have been very rarely performed. Reviewing the literature, one can only find some short notes in which authors made statements about the possibility that changes in atmospheric circulation could also cause a decrease in DTR (for example, Karl *et al.*, 1993, 1995; Horton, 1995; Kaas and Frich, 1995; Mearns *et al.*, 1995; Easterling *et al.*, 1997; Przybylak, 1997). More comprehensive studies were only published by Niedźwiedź (1987) and Przybylak (1992), who investigated the relationships between different types of atmospheric circulation and daily DTR in Hornsund (Spitsbergen). Przybylak (1992) found that all mean monthly DTR (except May) were higher when the anticyclonic situations occurred. In the cool half-year, the highest DTR was linked to air masses coming from the northern sector. In turn, in summer the highest DTR occurred when air masses came from the southern and eastern sectors. Przybylak (1992) also reported that the influence of different circulation types on the DTR could be clearly seen in Hornsund, mainly in the cool half-year.

Based on these findings one can conclude that certain changes in the atmospheric circulation (i.e. lower frequency of advection of air masses from the North, or lower frequency of transition of air masses coming from northern and southern sectors), occurring especially during the cool half-year, could cause a decrease in the DTR in Spitsbergen. In the present study, similar analyses are performed for ten Arctic stations, using two different catalogues of circulation types and DTR for the period 1951–1990.

2. DATA AND METHODS

In the first part of this paper, the mean seasonal and annual spatial distributions of the DTR in the Arctic over the period 1951–1990 are presented in order to give the climatic background of this variable. For this purpose the mean monthly data of the DTR were used from 33 Arctic and seven sub-Arctic stations (Figure 1). In comparison with my previous work (Przybylak, 1997), an additional 12 stations have been included in the analysis. All data come from national meteorological institutes (Danish Meteorological Institute, Norwegian Meteorological Institute and Canadian Climate Centre) or other institutions (Arctic and Antarctic Research Institute at St. Petersburg and National Climatic Data Center at Asheville). The quality control of the extreme air temperature series, from which the DTR series were computed, had been performed earlier by Przybylak (1996, 1997).

Atmospheric circulation plays an essential role in the formation of the climate of the Arctic, especially during the polar night. As is well-known, the role of circulation in the formation of climate is much greater at the Arctic than at lower latitudes. Therefore, the main section of this work is preceded by an analysis of the atmospheric circulation variability in the period 1939–1990. The relationship between atmospheric circulation and the DTR was established using synoptic climatological methods. For this purpose, one must rely on the catalogue of the daily synoptic types of atmospheric circulation

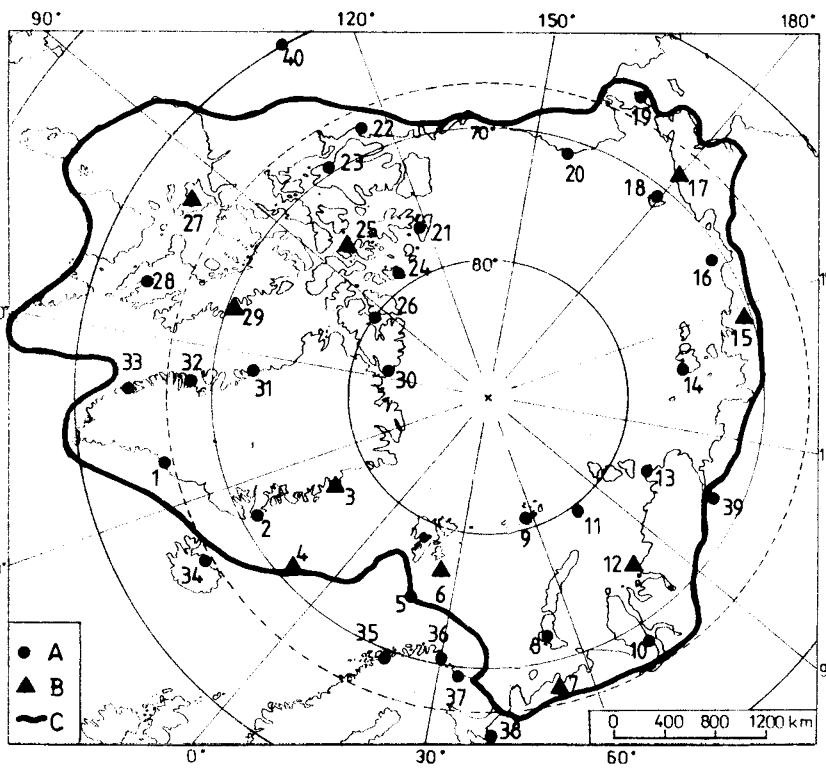

Figure 1. Location of meteorological stations used. Key—A and B: stations with mean monthly DTR data used; B: stations with daily DTR data used; C: the border of the Arctic after *Atlas Arktiki (1985)*; 1: Angmagssalik (height above sea level, H = 35 m); 2: Kap Tobin (H = 41 m); 3: Danmarkshavn (H = 11 m); 4: Jan Mayen (H = 10 m); 5: Björnöya (H = 15 m); 6: Hopen (H = 6 m); 7: Naryan-Mar (H = 7 m); 8: Malye Karmakuly (H = 46 m); 9: Polar GMO E.T. Krenkelya (H = 20 m); 10: Mys Kamenny (H = 7 m); 11: Ostrov Vize (H = 18 m); 12: Ostrov Dikson (H = 20 m); 13: GMO E.K. Fedorova (H = 13 m); 14: Ostrov Kotelny (H = 10 m); 15: Cokurdah (H = 48 m); 16: Ostrov Chetyrekhstolbovoy (H = 6 m); 17: Mys Szmidta (H = 7 m); 18: Ostrov Vrangel (H = 3 m); 19: Nome (H = 11 m); 20: Barrow (H = 4 m); 21: Mould Bay (H = 15 m); 22: Coppermine (H = 24 m); 23: Cambridge Bay (H = 27 m); 24: Isachsen (H = 25 m); 25: Resolute A (H = 67 m); 26: Eureka (H = 10 m); 27: Coral Harbour A (H = 64 m); 28: Iqaluit A (H = 34 m); 29: Clyde A (H = 25 m); 30: Alert (H = 63 m); 31: Upernavik (H = 63 m); 32: Jakobshavn (H = 47 m); 33: Godthab (H = 20 m); 34: Akureyri (H = 27 m); 35: Tromsö (H = 10 m); 36: Vardo (H = 15 m); 37: Murmansk (H = 46 m); 38: Arkhangelsk (H = 13 m); 39: Khatanga (H = 24 m); 40: Forth Smith A (H = 203 m)

encompassing both (i) the Northern Hemisphere and the period 1951–1990 and (ii) the whole Arctic and the period 1951–1990. Only the catalogue published by Dydina (1982, updated) meets the above criteria. Other published classifications of the daily synoptic types for the Arctic either cover only small parts of the Arctic (for example, Canadian Arctic: Bradley and England, 1979; Spitsbergen: Niedźwiedź, 1987; Niedźwied, 1993) or cover only a short time span (for example, 1973–1981: Barry *et al*., 1986). Dydina (1982) simultaneously gives on the one hand a catalogue of the macrotypes of atmospheric circulation for the Northern Hemisphere according to the Vangengeim–Girs typology, and on the other an independent catalogue of synoptic processes occurring in the Arctic.

Vangengeim (1935, 1948) and then Girs (1948, 1971, 1981) constructed the classification of flow patterns for the Northern Hemisphere. The types of hemispheric flow pattern distinguished by these authors are characterized by the different geographical position of troughs and ridges, as well as by the size of amplitude of waves in the upper westerlies (Figure 2). They reflect a zonal (W) and meridional (C and E) character of circulation. For further details about this classification, please see Barry and Perry (1973) and *Atlas Arktiki* (1985).

Vangengeim was the first meteorologist who in 1928–1930 began to investigate the relationships between atmospheric circulation and weather in the Arctic using synoptic climatological methods (Dolgin, 1970). This research was further developed by his followers at the Arctic and Antarctic Research Institute in St. Petersburg. Among them was Dydina, who began working on this problem in the 1950s. She constructed the classification of typical synoptic processes occurring in the Arctic using the

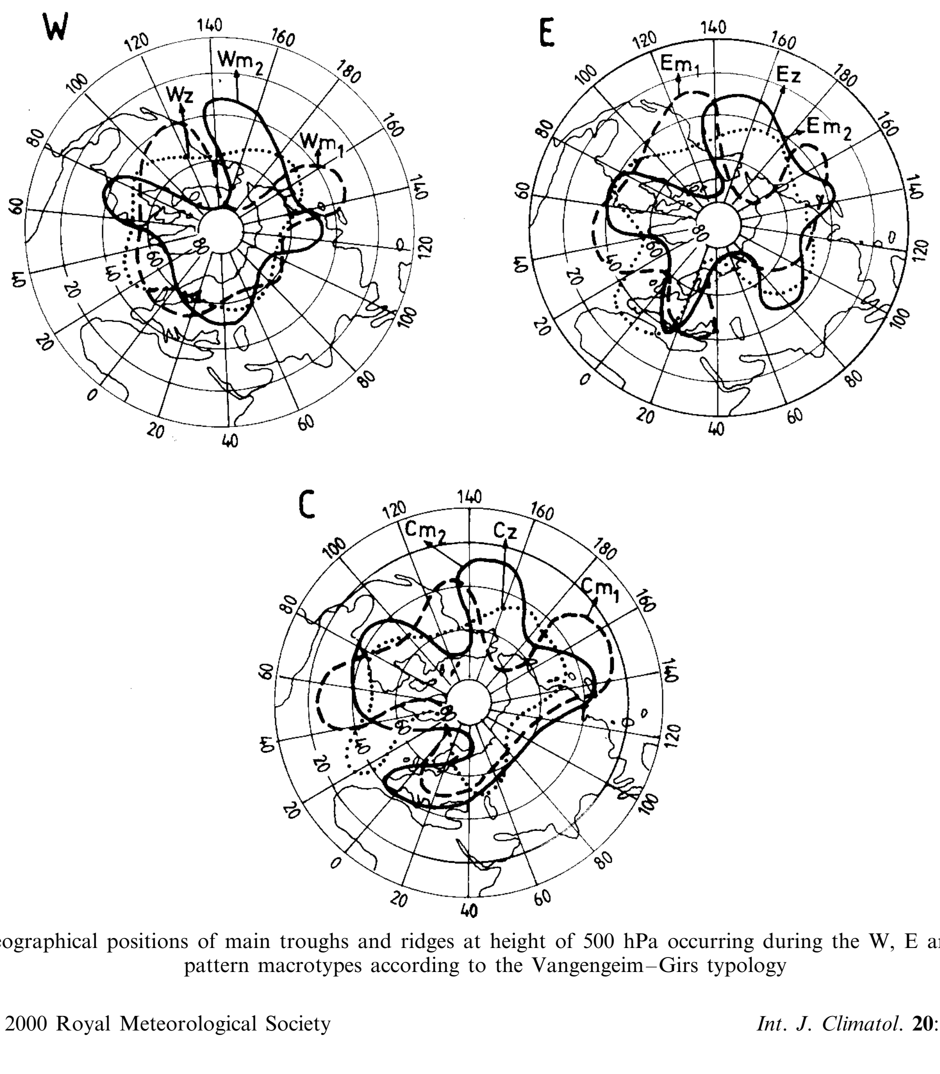

Figure 2. Geographical positions of main troughs and ridges at height of 500 hPa occurring during the W, E and C circulation pattern macrotypes according to the Vangengeim–Girs typology

analysis of the elementary synoptic processes, first for the period 1939–1953 (Dydina, 1958) and later for the period 1939–1968 (Dydina, 1982). Different types of synoptic processes in the Arctic were distinguished, taking into account: (i) the similarity of location of isobaric fields and their kinematic characteristics in the Arctic, and (ii) the significant similarity of these fields in the middle latitudes. Based on these principles, Dydina (1964, 1982) found 16 major synoptic types and nine additional ones. In the next step, by using some general features of location of isobaric fields only in the Arctic, she classified all these types into six groups of synoptic processes in the Arctic: A, B, W, G, D and K. These groups have the following characteristics (also see Figure 3 and *Atlas Arktiki*, 1985):

Group A—development of cyclonic activity over greater part of the Arctic, except the Canadian Arctic Archipelago where anticyclones prevail;
Group B—development of anticyclonic activity over most of the Arctic;
Group W—development of cyclonic and anticyclonic activity over western and eastern parts of the Arctic, respectively;
Group G—the synoptic processes of this group are opposite to group W;
Group D—development of cyclonic activity over Kara and Lapteev Seas or to the north of them; anticyclones occur to the west and to the east of the area of cyclonic activity;
Group K—the synoptic processes of this group are opposite to group D.

A team of meteorologists working at the Arctic and Antarctic Research Institute, particularly Dydina (1958, 1964), has identified the relationships between different types (groups of types) of circulation and the most important elements of weather in the Arctic. Dydina also found significant connections between the types of synoptic processes in the Arctic and the macrotypes of atmospheric circulation in the Northern Hemisphere. The results obtained allowed for the production of a medium range weather forecast for the Arctic and its parts. Later, Dydina (1982 and references therein) published a number of studies concerning this problem.

Dydina's classification of synoptic processes in the Arctic is very well-known among Russian meteorologists and climatologists, and has been accepted by leading Russian experts investigating different environmental problems in the Arctic. For example, in both the *Atlas Okeanov: Polarnyj Severnyj Okean* (Gorshkov, 1980) and the *Atlas Arktiki* (1985), the atmospheric circulation in the Arctic is depicted using the synoptic processes identified by Dydina.

The subjective character of this classification is its main weakness, and some researchers are sceptical as to the authenticity of Dydina's types and groups of synoptic processes in the Arctic. However, the accuracy of Dydina's classification using 'objective' synoptic typing techniques (principal component and cluster analyses) was confirmed by Vanda (1978) and Vanda and Lyamzin (1978). They obtained statistically significant relationships (Chuprov coefficient of correspondence 0.633) between the groups of synoptic processes in the Arctic identified by Dydina and the groups of atmospheric circulation distinguished by them as a result of the above mentioned 'objective' method of classification. This allows us to state that Dydina's classification does have an objective character to a significant degree. The validity of this classification was also confirmed by good results obtained in operational weather forecasts for the Arctic. I too decided to use Dydina's classification because in my earlier work (Przybylak, 1994, 1996) the relationships between air temperature and precipitation in the Arctic on one the hand, and atmospheric circulation on the other, were established using her catalogue of synoptic processes.

In order to find the relationship between atmospheric circulation and DTR, daily DTR data from ten Arctic stations for the last few decades has been used (in Figure 1 they are marked as triangles). The data come from the same sources as the monthly data. Each of these stations represents a different climatic region or subregion according to *Atlas Arktiki* (1985). In addition, the relationship between changes of the atmospheric circulation in middle latitudes represented by the Zonal Index (herein ZI, the difference of the sea level pressure between 35°N and 65°N) and the North Atlantic Oscillation Index (herein NAO, the difference of the sea level pressure between Lisbon and Stykkisholmur, Iceland), according to Hurrell (1995), and the DTR in the Arctic, have been examined for the winter period (defined as the period from December to March).

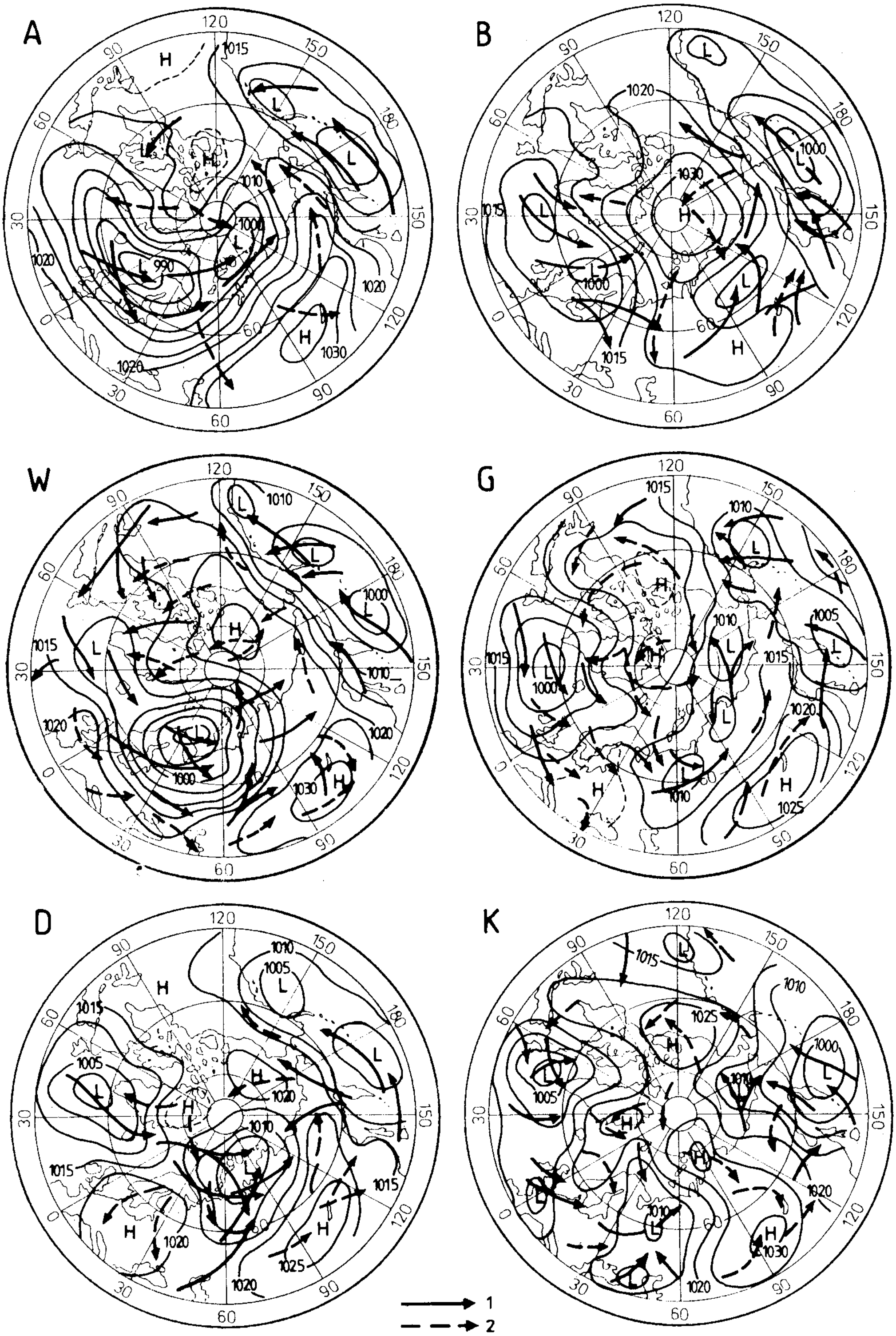

Figure 3. Examples of synoptic situations for particular groups of atmospheric circulation (A, B,W, G,D and K) according to the typology of Dydina (1982). Key—1: tracks of cyclones; 2: tracks of anticyclones; H: anticyclone; and L: cyclone

Standard climatological methods have been used in the analysis. The isolines describing the spatial distribution of seasonal and annual DTR in the Arctic were drawn using simple mathematical interpolation. As we know, there are no long-term series of maximum and minimum temperatures for the inner part of Greenland and the Arctic Ocean. However, since the temporal and spatial variability of air temperature over the Arctic Ocean is one of the smallest in the Arctic region (see Figure 14 in Przybylak, 1996), it was decided to present the probable results of the analysed variables for this area on the basis of data from the neighbouring stations. Such analysis would not be feasible for Greenland because of great topographical differences occurring there.

The variability of atmospheric circulation was examined using running means and linear trends. In order to establish the influence of atmospheric circulation on the DTR, the mean seasonal DTR for each analysed macrotype (W, C and E), and group (A, B, W, G, D and K) of atmospheric circulation, was computed. For comparative purposes, the mean seasonal DTR was also calculated. Linear correlation coefficients were computed between the mean winter DTR and both the ZI and the NAO indices. The statistical significance of the mean seasonal DTR differences, occurring between different groups of circulation in the Arctic and macrotypes of circulation over the period 1951–1990, was estimated using the Student's t test.

3. RESULTS AND DISCUSSION

3.1. Changes in atmospheric circulation patterns

According to research conducted by Alekseyev *et al.* (1991), the advection of warmth from the lower latitudes supplies more than 50% of the annual heat supply to the Arctic climatic system. Most of this warmth (95%) is transported by atmospheric circulation, with the remainder (5%) being transported by ocean circulation. During the polar night, only these two fluxes of warmth reach the Arctic and protect it from significant radiation cooling. Based on this, and on the fact that the change of the synoptic processes is about 1.5 times faster in the Arctic than in middle latitudes (Vangengeim, 1952, 1961), it can be concluded that the climate of the Arctic is significantly more sensitive to the atmospheric circulation variability than is the climate in both middle and low latitudes. Thus, without examining the atmospheric circulation variability, it is impossible to properly assess the causes of the changes in air temperature (including the DTR) and other climatic elements in the Arctic.

The mean frequency of the E macrotype, both annual (48%) and seasonal (from 41% in autumn to 52% in summer), was the greatest during the period 1939–1990. Two other macrotypes, W and C, occurred with much lower annual frequency (each with 26%). In winter and autumn, the W macrotype occurred with greater frequency than the C macrotype, while in spring and summer the opposite situation occurred (Figure 4). Table I shows the variability in the absolute frequency of occurrence of the circulation macrotypes in different seasons and for the year. It can be seen that the greatest variability is in winter and autumn, and the lowest is in spring and summer. The most stable macrotype (except spring) is the C macrotype and the least stable is the E macrotype.

During the period under study, group W occurred with the greatest frequency (28%) and group G with the lowest frequency (7%) (Figure 4). During the year, group W clearly dominates in winter (39%) and autumn (30%), and slightly dominates in spring (26%). In summer its frequency is much lower (16%), and is only slightly higher than the frequency of group G (14%), which on an annual basis is the most rarely occurring group of circulation. It is worth mentioning that in summer the differences between frequencies of the analysed groups of circulation are the lowest. This means that in this season the synoptic processes are the least stable. Groups of atmospheric circulation which are characterized by the dominance of cyclonic activity over the greater part of the Arctic (for example, A) have a higher variability of the frequency of occurrence than those groups characterized by anticyclonic activity over this part of the Arctic (for example, B). The annual courses of this variability are opposite: Group A has the greatest variability in winter and autumn, while group B has the greatest variability in spring and summer (Table I).

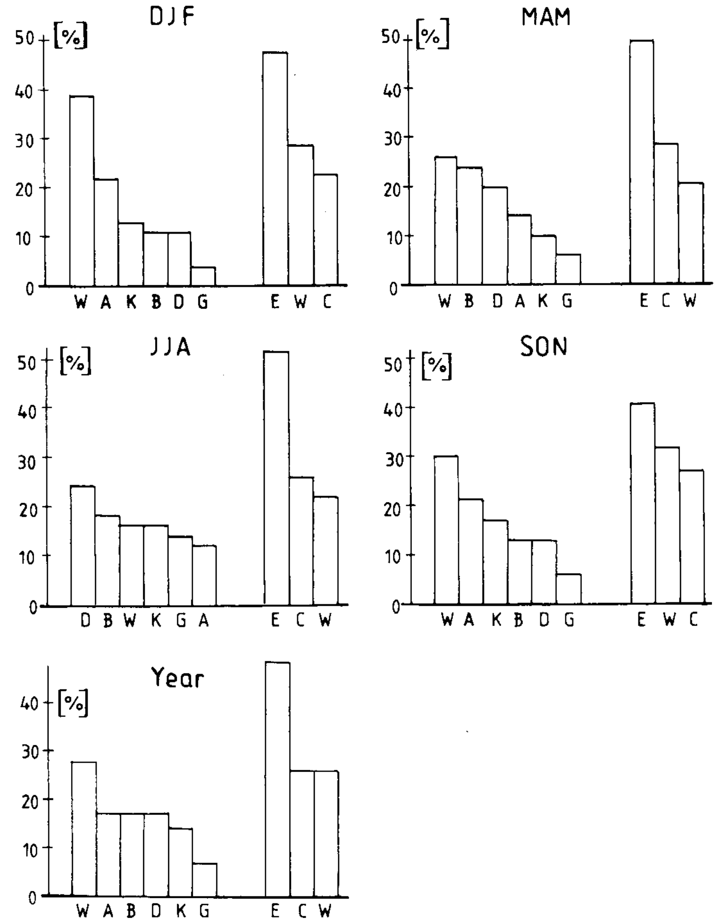

Figure 4. Arrangement of the circulation groups in the Arctic (A, B, W, G, D and K) and macrotypes of circulation (W, C and E) according to the seasonal and annual occurrence frequency (in %) over the period 1939–1990

The frequency of the W macrotype decreased until the mid-1970s, when subsequently a rapid increase can be observed. Such behaviour was found both in the annual (Figure 5) and seasonal (not shown; see Przybylak, 1996) frequencies. The increase in the frequency of occurrence of this macrotype is clearly visible especially in winter and in spring. The frequency of the C macrotype shows a steady decrease until the mid-1970s, and then there is no observable trend. The course of frequency of the E macrotype is roughly opposite to the frequency of the W macrotype (Figure 5). Based on the above analysis, it can be clearly seen that the great change in atmospheric circulation in the Northern Hemisphere occurred in the mid-1970s. After that time, a statistically significant increase in the frequency of occurrence of the W macrotype and a decrease of the E macrotype were observed in winter, spring and for the year (see Table II, period 1976–1990).

The long-term trends of frequency (period 1951–1990) of the analysed macrotypes were statistically significant, mainly in spring and summer. Large changes occurring especially in the wintertime atmospheric circulation are also confirmed by some other indices describing atmospheric circulation (for example, ENSO, NAO, ZI and North Pacific—area-weighted mean sea level pressure over the region 30°N–65°N, 160°E–140°W) mainly over ocean basins in both low and middle latitudes (see, for example, Trenberth and Hurrell, 1994; Hurrell, 1995, 1996; Houghton *et al.*, 1996; Hurrell and van Loon, 1997). In the Arctic, a statistically significant increase of synoptic activity in the years 1952–1989 was also observed by Serreze *et al.* (1993).

Table I. Mean seasonal and annual absolute occurrence frequency (m) of circulation macrotypes (W, C and E) and groups of circulation in the Arctic (A, B, W, G, D and K) and their S.D.s for the period 1939–1990

Season	Parameter	Macrotypes of circulation			Groups of circulation in the Arctic					
		W	C	E	A	B	W	G	D	K
December–February	m	25.6	20.4	43.7	19.7	9.5	35.4	3.2	10.2	11.6
	S.D.	12.5	11.1	15.4	10.0	8.8	10.2	4.1	7.2	6.8
March–May	m	19.6	26.4	46.0	12.5	22.3	24.2	5.7	18.6	8.8
	S.D.	10.1	10.6	15.4	9.4	9.8	8.6	5.2	7.0	5.6
June–August	m	20.6	24.0	47.4	10.7	16.7	15.0	13.0	21.7	14.8
		11.6	10.9	14.0	9.0	10.7	8.5	7.3	7.2	7.3
September–November	m	29.4	24.2	37.3	18.8	11.8	27.7	5.4	11.8	15.6
	S.D.	12.3	12.0	14.7	10.2	6.5	8.5	4.8	6.0	9.2
Year	m	95.5	95.0	174.7	61.8	60.3	102.8	27.3	62.4	50.8
	S.D.	25.4	25.3	38.0	23.6	20.1	19.9	11.7	15.8	17.7

The seasonal and annual frequencies of occurrence of most circulation groups defined by Dydina show no significant trends in recent decades (Table II, Figure 6). In the period 1951–1990, statistically significant changes in annual frequency were revealed in groups D (increase) and K (decrease). In the last 15 years (1976–1990) only group A shows a statistically significant increase of frequency. By contrast, group B reveals a large decrease of frequency. A comparison of annual (Figure 6) and seasonal (not shown; see Przybylak, 1996) courses of the frequency of occurrence of the analysed groups reveals a high similarity between groups G, D and K. The greatest differences were observed for groups A and B.

In conclusion, it can be stated that in the Arctic the change of the atmospheric circulation in recent decades is significantly smaller than in lower latitudes of the Northern Hemisphere. Such a situation is both understandable and appropriate because the 'roots' of the atmospheric circulation variability in the Arctic are mainly located in the middle latitudes (especially in the areas covered by Icelandic Low, Siberian High, Aleutian Low and Canadian High).

3.2. Spatial and seasonal patterns of the mean DTR in the Arctic

The highest mean annual DTR values (> 8°C) occur over the continental parts of the Canadian and Russian Arctic, which are located far from the Atlantic and Pacific oceans (Figure 7). The lowest DTR values (< 5°C) are observed in the Norwegian Arctic, particularly in those areas which are not covered by sea ice. Slightly higher DTR (5–6°C) can be observed in the region spreading from the Norwegian Arctic to Alaska, which encompasses almost all the islands located there (from Spitsbergen to Ostrov Vrangel). Probably one of the main factors causing this is a very strong and changeable cyclonic activity occurring there which brings high cloudiness. Its influence on lowering the DTR is noted mainly in the warm half-year. The opposite is true for the cold half-year. As a result, as mentioned above, as well as some other regions which are also strongly influenced by atmospheric circulation (the western and northern parts of the Russian Arctic and the western coastal parts of Greenland), the highest DTR occur in winter (Figure 8).

In winter, the highest DTR are noted in the southern continental parts of the Arctic (> 8°C), and the lowest in the southern Norwegian Arctic as well as in the west coast of Greenland (Figure 8). In the central Arctic the DTR is equal to about 7°C.

In spring, the differentiation of the DTR is significantly higher than in winter and reaches more than 7°C (in winter only 4°C). The highest values (> 9°C) occur in the centre of the southernmost parts of the Canadian and Russian Arctic (characterized by the greatest degree of the continentality of the climate in the Arctic; see Marsz, 1995), and the lowest values occur in the Norwegian Arctic and the western coast of Greenland (< 6°C).

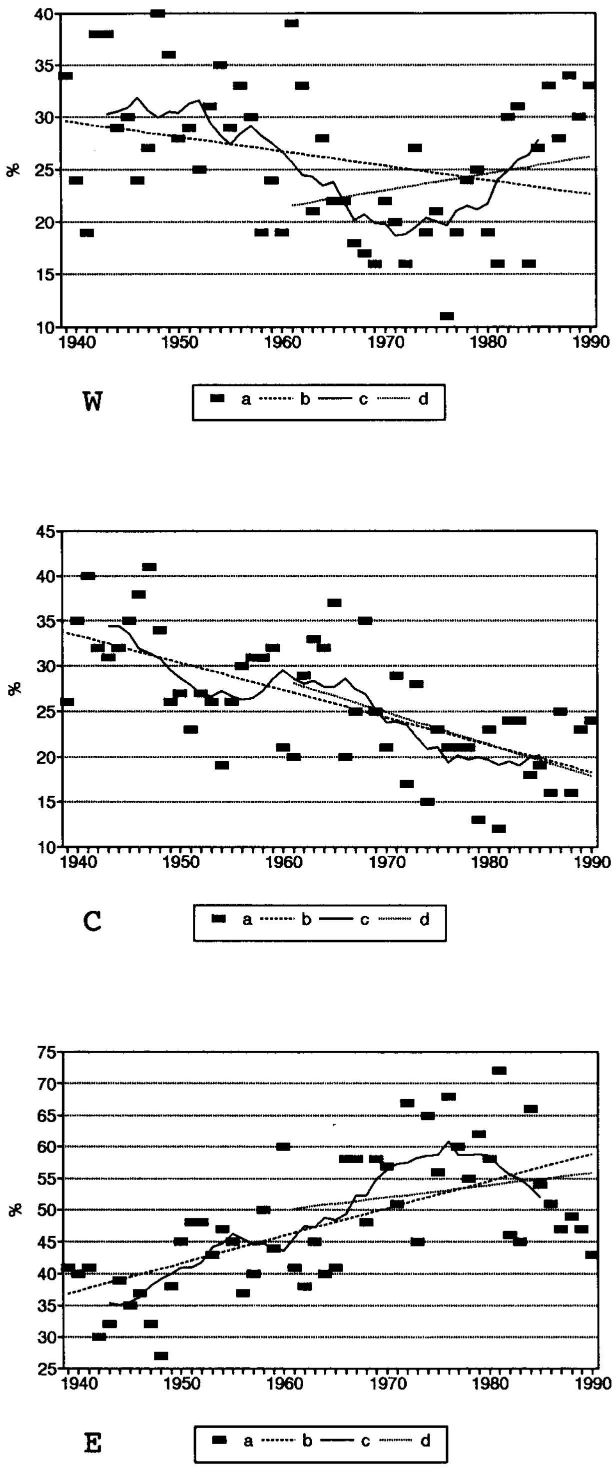

Figure 5. Course of the seasonal and annual occurrence frequency (in %) of the circulation macrotypes W, C and E and their trends over the period 1939–1990. Key—a: year-to-year course; b: linear trend over the period 1939–1990; c: 10-year running mean; d: linear trend over the period 1961–1990

Table II. Trends of seasonal and annual absolute occurrence frequency (number of cases/10 years) of circulation macrotypes (W, C and E) and groups of circulation in the Arctic (A, B, W, G, D and K) for the periods 1951–1990, 1961–1990 and 1976–1990

Season	Period	Macrotypes of circulation			Groups of circulation in the Arctic					
		W	C	E	A	B	W	G	D	K
December–February	1951–1990	1.16	0.26	−1.43	−0.03	1.57	−2.41	1.07	1.10	−1.30
	1961–1990	5.79*	−5.37*	−0.41	−2.16	1.14	−1.00	1.31	−0.39	1.11
	1976–1990	21.61**	1.79	−23.54*	−4.25	−3.54	9.64	1.18	−5.61	2.43
March–May	1951–1990	−0.03	−3.73∼*	3.76**	0.00	−2.05	0.54	1.02	1.00	−0.51
	1961–1990	0.78	−3.82*	3.04	−1.16	−2.07	1.45	1.87	1.37	−1.46
	1976–1990	2.56	1.64	−12.75*	10.21	−14.57*	−3.18	6.14	−2.18	3.57
June–Augusr	1951–1990	−3.44*	−2.08	5.52***	1.70	0.12	−2.49*	−0.25	2.73**	−1.82
	1961–1990	−2.70	−1.36	4.07	1.75	0.57	−2.44	0.01	2.72*	−2.84
	1976–1990	1.15	−4.14	−2.93	3.21	−6.29	4.68	1.43	−2.14	−0.89
September–November	1951–1990	0.78	−3.09*	2.32	2.01	0.64	0.31	−0.40	−0.04	−2.52*
	1961–1990	1.55	−1.68	0.14	1.31	−0.81	1.64	0.08	0.56	−3.12
	1976–1990	0.13	5.89	−9.25	17.0*	−4.54	−11.57*	−4.07	0.46	2.71
Year	1951–1990	−1.54	−8.90**	10.44*	3.26	0.22	−3.29	1.36	4.79*	−6.36*
	1961–1990	5.96	−13.22**	7.28	−0.60	−1.56	0.71	3.65	4.50	−6.69*
	1976–1990	44.32**	4.86	−49.32**	31.00*	−31.00	1.18	3.79	−10.96	5.86

* Trends statistically significant at the 0.05 level.
** Trends statistically significant at the 0.01 level.
*** Trends statistically significant at the 0.001 level.

In summer, the mean DTR are lower than in spring but the differences between the highest (> 10°C) and the lowest (< 3°C) values are the same. The exceptionally low DTR is present in the Norwegian Arctic and the northwestern part of the Russian Arctic, where it drops below 3–4°C (Figure 8).

In autumn, the differentiation of the mean DTR in the Arctic is getting smaller (4–5°C). Again, as in other seasons, the highest DTR are in the centre of the southernmost parts of the Canadian (> 8°C) and the Russian (> 6°C) Arctic and the lowest are in the Norwegian Arctic (< 4°C) (Figure 8).

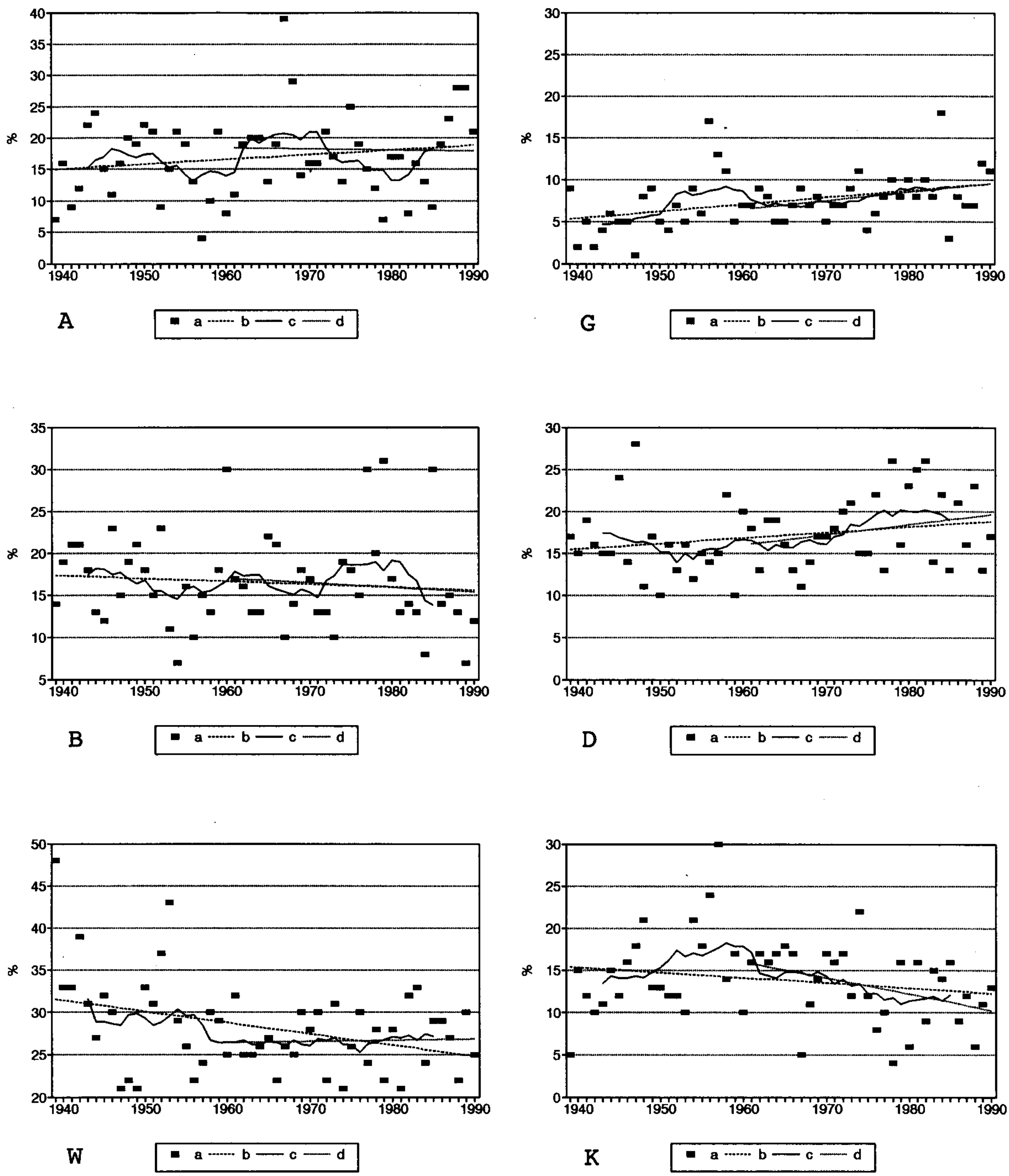

Figure 6. Course of the annual occurrence frequency (in %) of the circulation groups (A, B, W, G, D and K) in the Arctic and their trends over the period 1939–1990. Key as in Figure 5

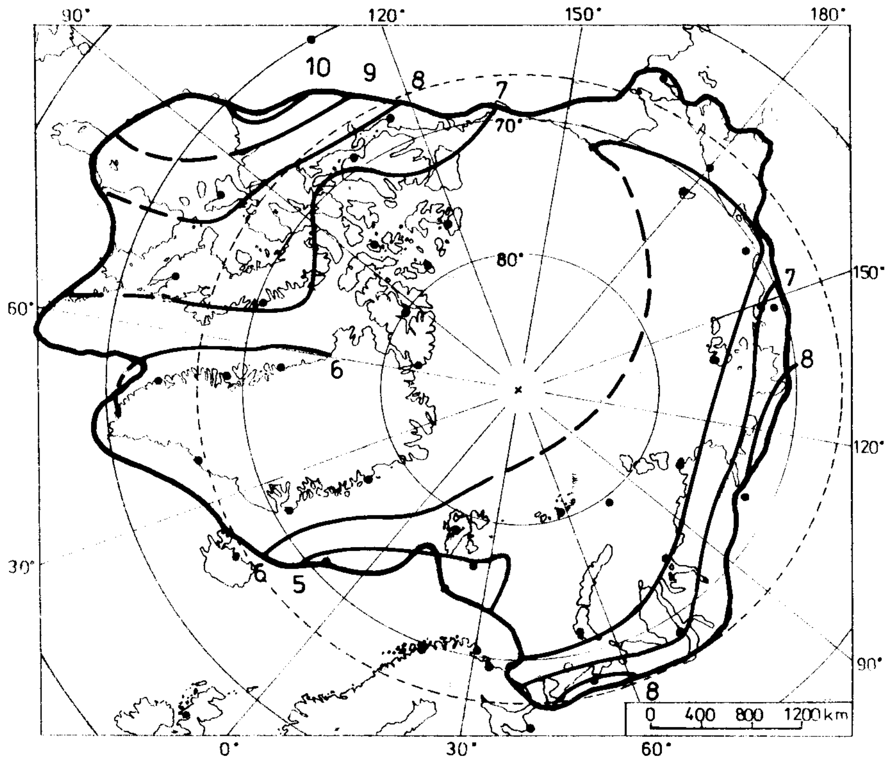

Figure 7. Spatial distribution of the mean annual DTR (in °C) in the Arctic over the period 1951–1990. Key—dashed lines denote probable course of the isolines

Based on the seasonal means, it is possible to distinguish four types of annual course of this variable in the Arctic (see Figure 9(a)):

(i) maximum DTR in winter and minimum in summer,
(ii) maximum DTR in spring and minimum in autumn,
(iii) maximum DTR in winter and minimum in autumn,
(iv) maximum DTR in summer and minimum in autumn.

The first two types clearly dominate in the Arctic (Figure 9(a)). From the 33 analysed stations, the first type occurred in 14 stations (42.4%) and the second in 11 stations (33.3%). The third and fourth types were present in four (12.1%) and three (9.1%) stations, respectively. Only the DTR at the station 'Eureka' has a different pattern. The maximum DTR in winter and minimum in summer occur mostly in the Norwegian Arctic as well as in the western and northern parts of the Russian Arctic, and the northern part of the Canadian Arctic (Figure 9(a)). Most likely, this pattern is also present in central Arctic. It is worth mentioning that these areas are either under a very intense influence of atmospheric circulation (great frequency of cyclones) or are situated around the North Pole, where the daily contrast of the incoming radiation is the lowest in the Arctic and cyclonic activity, although weaker, is still present (see Serreze and Barry, 1988 or Serreze *et al.*, 1993).

The second type in the annual course of the DTR (the highest values in spring and the lowest in autumn), which is almost equally as frequent as the first, occurs in those parts of the Arctic where cyclonic activity is weak and the daily contrast of solar forcing is the highest (southern parts of the Canadian and Russian Arctic, northern Alaska and some parts of Greenland; see Figure 9(a)). Ohmura (1984) gives a more detailed explanation of the causes of this kind of annual course of the DTR. Ohmura's findings are based on the examination of heat balance on Axel Heiberg Island (Canadian Arctic) in the summers of 1969 and 1970. This type in the scientific literature is known as the 'Frame' type. The occurrence of the

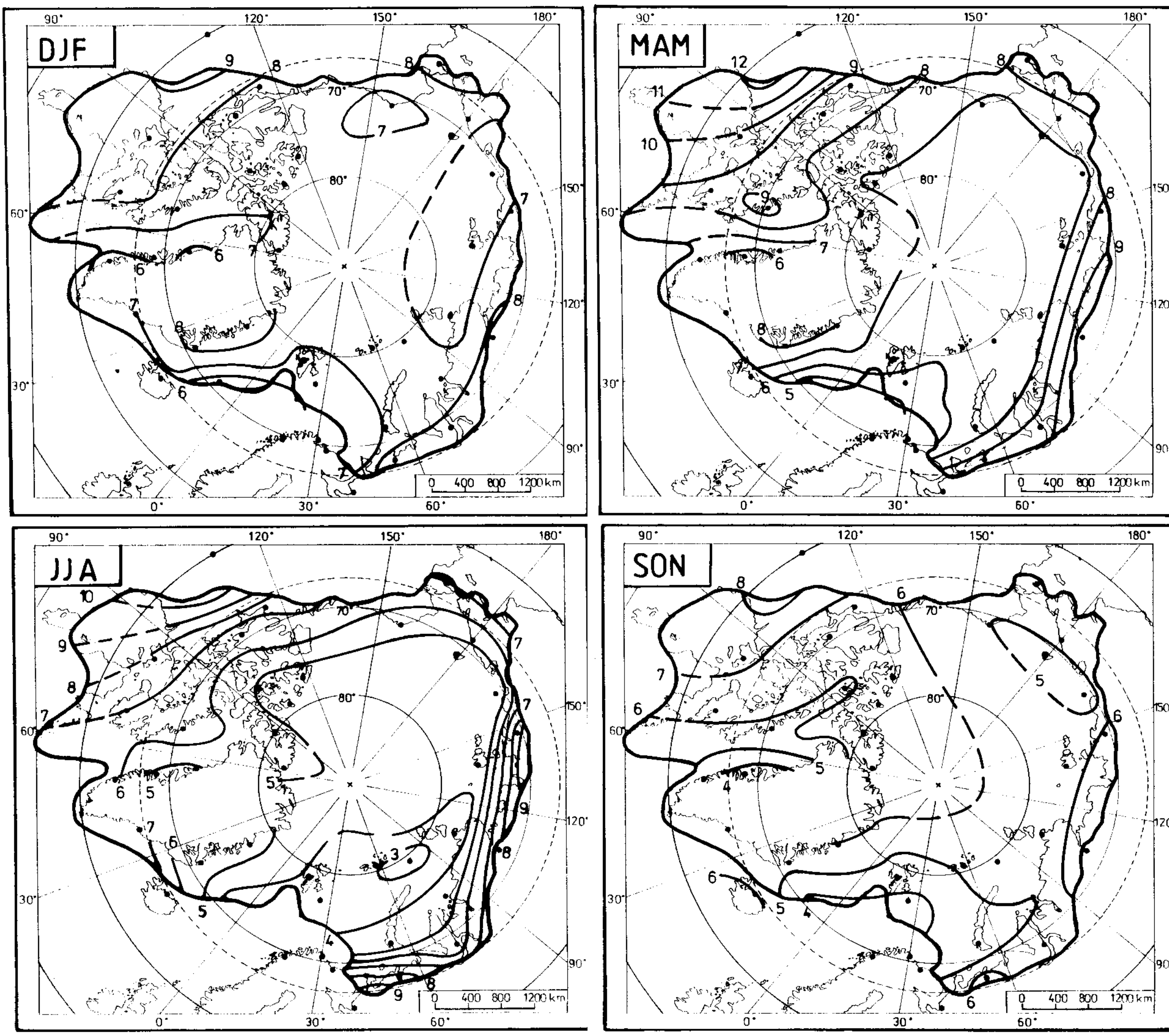

Figure 8. Same as Figure 7, but for winter (December–Febrauary), spring (March–May), summer (June–August) and autumn (September–November)

third and fourth types of annual course at stations located in various isolated parts of the Arctic can be related to the specific local conditions (radiation and atmospheric circulation).

According to the monthly means of the DTR, the highest values occurred most often in April (63.6% of the stations) or February (18.2%) and the least in September (62.1%) or October (16.7%) (see Figure 9(b)).

3.3. Relations between DTR and atmospheric circulation

As mentioned in the Introduction, only a few researchers have suggested the possibility that the observed decrease in the DTR could be caused by changes in atmospheric circulation. There are two main ways in which atmospheric circulation influences the DTR: direct and indirect. In the first (direct), the atmospheric circulation largely controls the day-to-day changes of air temperature. In the situation when the sun is located low over the horizon (higher latitudes and the northern parts of the middle latitudes in winter), this is the most important factor influencing the DTR (see Figure 8 in Karl *et al.*, 1993).

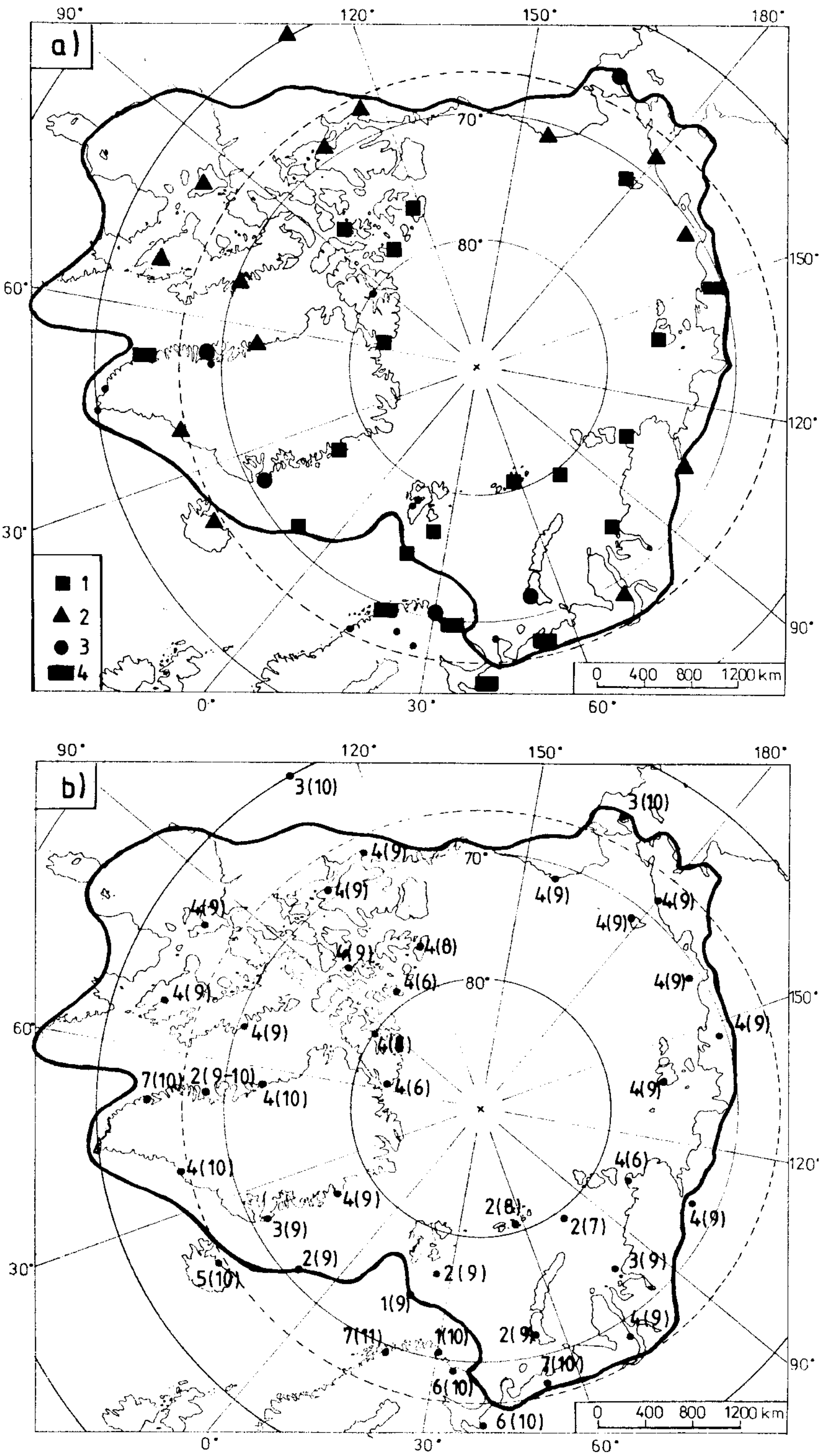

Figure 9. Annual courses of the DTR in the Arctic based on their seasonal a) and monthly b) means from the period 1951–1990. a) Key—1: maximum of the DTR in winter and minimum in summer; 2: maximum of the DTR in spring and minimum in autumn; 3: maximum of the DTR in winter and minimum in autumn; and 4: maximum of the DTR in summer and minimum in autumn. b) First number denotes the month with the highest mean DTR and the second (in parentheses) denotes the month(s) with the lowest mean DTR

Table III. Mean seasonal DTR (in °C) in the Arctic for each analysed macrotype of circulation (W, C and E) over the period 1951–1990

Season	Station	DAN[a]	JAN	HOP	NAR[b]	DIK[b]	CZO[b]	SZM[b]	RES	COR	CLY
December–February	W	8.0	5.2	6.2	8.6	6.6	6.9	7.2	7.1	8.1	7.6
	C	8.8	5.8	7.4	9.5	6.9	7.0	7.0	7.1	8.3	7.7
	E	8.8	4.9	6.3	8.6	7.6	7.3	7.1	7.3	8.4	7.5
March–May	W	8.0	4.9	5.9	8.8	7.1	8.6	7.6	6.9	9.5	9.3
	C	8.1	4.8	6.1	8.3	6.7	8.8	7.3	6.9	9.5	9.5
	E	8.0	4.2	5.5	8.8	7.0	8.5	7.3	7.2	9.9	9.1
June–August	W	5.6	3.5	2.9	8.5	4.9	8.8	6.0	4.8	7.9	6.6
	C	5.9	3.9	3.2	7.7	4.6	8.9	6.3	5.0	7.5	6.5
	E	5.5	3.6	3.1	9.3	4.3	8.9	5.6	5.0	8.2	6.8
September–November	W	6.1	3.7	3.3	6.2	5.0	6.5	5.7	6.0	7.0	5.8
	C	6.4	4.3	4.1	6.4	5.0	5.8	5.3	5.6	7.1	5.8
	E	6.3	3.7	3.7	6.5	5.1	6.3	5.3	5.9	7.4	5.9

DAN: Danmarkshavn; JAN: Jan Mayen; HOP: Hopen; NAR: Naryan-Mar; DIK:Ostrov Dikson; CZO: Cokurdah; SZM: Mys Szmidta; RES: Resolute A; COR: Coral Harbour A; CLY: Clyde A.
[a] Data for the period 1955–1990.
[b] Data for the period 1967–1990.

Baranowski (1968) and Przybylak (1992) arrived at such a conclusion based on measurements of the DTR in Hornsund (Spitsbergen). Recently Kaas and Frich (1995) also found that in the stations Nuuk (Greenland) and Tromsö, the 'DTR is probably determined more by the cyclonic activity than by diurnal radiation processes'.

The second influence of atmospheric circulation on the DTR is indirect. Its change markedly alters some climatic elements (for example, cloudiness, humidity, wind speed) or sulphate aerosols loading which are also important mechanisms causing the changes in the DTR (see, for example, Karl *et al*., 1993, 1995; Hansen *et al*., 1995; Easterling *et al*., 1997). Karl *et al*. (1995) stated that the increase in cloud amount over much of the mid and high latitudes is at least partly related to the changes in atmospheric circulation. The second cause of the increase in cloudiness could be the rise of anthropogenic sulphate aerosol loading (see Karl *et al*., 1993, 1995; Hansen *et al*., 1995, 1997; Przybylak, 1997) which enhances cloud optical thickness, albedo and/or lifespan.

In the Arctic, as mentioned earlier, the climate is very sensitive to changes in atmospheric circulation, especially in the cool half-year. Thus, in the process of seeking the causes of the recent DTR decrease in the Arctic (see Przybylak, 1997), it is necessary to investigate this climatic factor. The influence of cloudiness on the DTR is explained in Przybylak (1999).

Based on the catalogue describing the macrotype of circulation for each day according to the Vangengeim–Girs typology and the group of synoptic processes in the Arctic according to Dydina (1982) on the one hand, and using the daily DTR for ten Arctic stations on the other, the seasonal mean DTR for all these circulation characteristics (Tables III and IV) was computed. For comparison purposes, the seasonal means of the DTR for all the analysed data (Table IV) are also presented. They allow for the calculation of the anomalies of the DTR connected with a given macrotype or group of circulation in the studied part of the Arctic.

The analysis of Table III allows us to conclude that, in the period 1951–1990, in most parts of the Arctic, mainly over the areas with intensive cyclonic activity, the highest DTR was connected with the meridional macrotypes of circulation. This was especially clearly visible in winter and less in autumn. In spring, the differentiated influence of the analysed macrotypes of circulation was evidently the lowest. In the spring season in as many as four stations the highest DTR occurred even during the W macrotype. Based on these results and taking into account the recent changes (after 1975) in atmospheric circulation, especially in winter (rapid increase of frequency of W macrotype, and decrease of E macrotype; Table II and Figure 5), one can conclude that the observed large-scale changes in atmospheric circulation in the Northern Hemisphere could have led to the decrease in the cool half-year DTR in the Arctic in recent decades.

In addition, the reliability of the above conclusion was also checked using other indices of atmospheric circulation (ZI and NAO). The correlation coefficients between mean winter (defined here as December–March) values of indices and the DTR taken from 33 Arctic stations for the period 1951–1990 were computed. The correlation is clearly stronger between the NAO index (than ZI) and the DTR in the Arctic. In both cases, however, most stations show negative correlations, with the exception of the Kara Sea region and a small part of the western Canadian Arctic. The DTR in ten Arctic stations have statistically significant correlations with the NAO index and only three with the ZI index. The highest correlation occurs in the Norwegian Arctic and inner parts of the Russian and Canadian Arctic, as well as in Greenland. Since about the mid-1970s, the NAO index during winter has changed to a predominantly positive mode, with the highest values (since 1864) occurring in the late 1980s (Hurrell, 1995). Similar behaviour is also shown when using the ZI index. Kożuchowski (1993) found that ZI values in the late 1980s were the highest of the 20th century. Thus, these characteristics of the atmospheric circulation also confirm the previous conclusion.

Table IV. Mean seasonal DTR (in °C) in the Arctic for each analysed group of circulation (A, B, W, G, D and K) over the period 1951–1990

Season	Station	DAN[a]	JAN	HOP	NAR[b]	DIK[b]	CZO[b]	SZM[b]	RES	COR	CLY
December–February	A	8.8	5.8	7.0	8.4	7.7	6.9	7.1	7.4	8.3	7.6
	B	8.7	4.8	6.2	10.3	6.9	7.8	6.3	7.7	8.6	7.7
	W	8.2	5.3	6.4	8.3	6.8	7.2	7.1	7.1	8.2	7.6
	G	8.8	4.2	6.3	9.2	7.6	6.5	8.7	7.3	8.8	7.4
	D	9.4	4.8	7.1	10.1	7.6	7.5	7.4	6.9	8.0	7.5
	K	8.5	4.9	5.9	8.1	6.8	6.5	6.9	7.2	8.2	7.5
	Mean	8.6	5.2	6.5	8.8	7.2	7.1	7.1	7.2	8.3	7.6
March–May	A	8.3	5.1	6.8	8.4	7.9	9.3	8.1	7.5	9.8	9.8
	B	7.7	4.0	5.3	8.5	6.2	8.2	6.9	7.0	9.4	9.0
	W	8.1	5.0	5.9	8.5	7.2	8.6	7.2	7.1	10.0	9.0
	G	7.9	3.8	5.3	9.1	6.6	8.5	8.3	6.8	9.4	9.8
	D	8.0	4.3	5.7	9.1	7.0	8.8	7.4	6.9	9.6	9.1
	K	8.2	4.5	4.9	8.1	6.7	7.6	7.8	7.2	10.2	9.8
	Mean	8.0	4.5	5.7	8.7	6.9	8.6	7.4	7.1	9.7	9.2
June–August	A	6.1	3.9	3.1	9.2	4.3	9.8	6.9	5.0	8.1	6.5
	B	5.0	3.6	2.9	7.8	4.1	7.7	4.9	4.8	7.6	6.6
	W	5.6	3.8	3.0	9.2	5.0	8.4	4.8	5.0	8.1	7.0
	G	5.6	3.5	3.2	8.1	3.9	8.8	6.9	5.2	8.1	6.5
	D	5.6	3.5	3.2	8.7	4.0	9.7	5.2	4.7	7.9	6.9
	K	5.9	3.6	3.1	10.1	5.8	8.2	6.5	5.2	8.1	6.5
	Mean	5.6	3.6	3.1	8.8	4.5	8.9	5.8	4.9	8.0	6.7
September–November	A	6.4	4.1	4.1	6.2	4.6	6.2	6.0	5.9	7.1	5.9
	B	6.2	3.6	3.5	6.4	5.1	6.4	4.7	5.6	7.2	5.8
	W	6.3	4.1	3.8	6.5	5.3	6.3	5.1	6.2	7.5	6.0
	G	6.0	3.4	3.6	6.4	4.4	6.5	6.3	5.4	7.0	5.6
	D	6.2	3.6	3.9	6.9	5.2	6.1	4.9	5.7	6.9	5.8
	K	6.2	3.6	3.0	6.1	5.1	6.0	5.8	5.9	7.0	5.7
	Mean	6.3	3.8	3.7	6.4	5.0	6.2	5.4	5.9	7.2	5.8

DAN: Danmarkshavn; JAN: Jan Mayen; HOP: Hopen; NAR: Naryan-Mar; DIK:Ostrov Dikson; CZO: Cokurdah; SZM: Mys Szmidta; RES: Resolute A; COR: Coral Harbour A; CLY: Clyde A.

[a] Data for the period 1955–1990.

[b] Data for the period 1967–1990.

Table V. Values of the Student's t-test of winter (December–February) and spring (March–May) DTR differences at Jan Mayen occurring between different groups of circulation in the Arctic (A, B, W, G, D, K) and macrotypes of circulation (W, C, E) over the period 1951–1990

	Groups of circulation in the Arctic						Macrotypes of circulation		
	December–February								
March–May	A	B	W	G	D	K	W	C	E
A		5.00***	3.24**	7.05***	4.84***	4.87***	3.67***	0.00	6.20***
B	6.31***		2.78**	2.45*	0.00	0.48	2.13*	5.01***	0.58
W	0.54	8.24***		5.25***	2.67**	2.46*	0.72	3.24**	3.45***
G	6.45***	1.37	7.60***		2.40*	3.01**	4.63***	7.06***	3.45***
D	4.33***	2.46*	5.16***	3.16**		0.47	2.05*	4.85***	0.56
K	2.86**	3.17**	2.97**	3.74***	1.18		1.75	4.88***	0.00
W	1.03	6.58***	0.67	6.47***	4.01***	2.22*		3.68***	2.35*
C	1.64	6.72***	1.50	6.40***	3.74***	1.80	0.68		6.46***
E	5.37***	2.13*	7.19***	2.90**	0.89	2.00*	5.47***	5.51***	

* DTR differences statistically significant at the 0.05 level.
** DTR differences statistically significant at the 0.01 level.
*** DTR differences statistically significant at the 0.001 level.

Easterling *et al.* (1997), when analysing the relations between changes of the westerly index calculated from the cold ocean–warm land pattern and the DTR over the region 60°W–90°E, 30°N–80°N, found that the recent increase in westerly flow is associated with a decrease in DTR over northern Europe and Russia. Consequently, those findings support the results presented here for the Arctic. Based on the above results, I cannot agree with the statement made by Horton (1995) that 'An increased westerly flow may have increased the apparent DJF diurnal range by increasing the frequency and intensity of air mass transitions (fronts)'. It concerns the area from the British Isles to central Europe. Moreover, it is well-known that the increase in frequency of westerly inflow into Europe evidently causes the rise of the oceanicity of the climate, which is a factor much more important than increased frequency and intensity of air mass transitions.

The changes of atmospheric circulation within the Arctic are characterized here by the frequency of occurrence of circulation groups according to Dydina (1982). Table IV shows the mean seasonal DTR for ten Arctic stations for each analysed group of circulation over the period 1951–1990. One can see that in the Arctic there sometimes exist great differences in the mean seasonal values of DTR computed for the analysed groups of circulation. The values of DTR connected with the given groups of circulation will differ depending on the region of the Arctic and the season of the year. This means that the situation in which the individual group of circulation gives the highest (lowest) DTR in the whole Arctic and in all seasons did not happen. This significantly obscures the relations between these two characteristics. To overcome this problem, for each season and for each analysed station three groups of circulation with the lowest DTR were chosen. Later on such groups were determined based on both the greatest number of stations in which the lowest DTR occurred in the same groups and the lowest mean DTR (from ten stations) for each season but for the whole Arctic. These two methods have given very similar results. The following arrangement of the groups of circulation generating the lowest DTR in the Arctic is presented according to their mean seasonal values: winter—groups K, W and G; spring—groups B, K and G; summer—groups B, D and G; and autumn—groups K, B and G. The first group in each season is characterized by the lowest DTR and so on.

To estimate the statistical significance of the mean seasonal DTR differences, occurring between different groups of circulation in the Arctic and macrotypes of circulation over the period 1951–1990, the Student's t test was utilized. Computations were performed for each station; however, in the interest of brevity, the results are presented for only two stations: Jan Mayen and Coral Harbour A (Tables V, VI,

Table VI. Values of the Student's t-test of summer (June–August) and autumn (September–November) DTR differences at Jan Mayen occurring between different groups of circulation in the Arctic (A, B, W, G, D, K) and macrotypes of circulation (W, C, E) over the period 1951–1990

	Groups of circulation in the Arctic						Macrotypes of circulation		
	June–August								
September–November	A	B	W	G	D	K	W	C	E
A		2.71**	0.89	3.48***	3.92***	2.80**	3.92***	0.00	3.21**
B	4.10***		1.95	0.95	1.10	0.00	1.10	3.12**	0.00
W	0.00	4.48***		2.79**	3.21**	2.02*	3.20**	1.02	2.37*
G	4.64***	1.33	4.91***		0.00	0.98	0.00	3.95***	1.14
D	4.04***	0.00	4.41***	1.31		1.15	0.00	4.64***	1.44
K	4.41***	0.00	4.90***	1.39	0.00		1.15	3.25***	0.00
W	3.89***	0.97	4.44***	2.21*	0.95	1.08		4.64***	1.43
C	1.75	6.11***	1.94	6.21***	6.02***	6.64***	6.39***		3.95***
E	3.89***	0.97	4.45***	2.21*	0.95	1.08	0.00	6.40***	

* DTR differences statistically significant at the 0.05 level.
** DTR differences statistically significant at the 0.01 level.
*** DTR differences statistically significant at the 0.001 level.

VII and VIII). The first station represents the region of the Arctic with a strong maritime climate, high cyclone frequencies and low DTR values, and the second represents those with the opposite conditions (strong continental climate, high anticyclone frequencies and high DTR values) (see Figure 8). Comparison of the number of statistically significant DTR differences at Jan Mayen (Tables V and VI) and Coral Harbour A (Tables VII and VIII) shows the significantly greater role of atmospheric circulation in shaping the DTR in the Atlantic region of the Arctic than in the Canadian Arctic, especially in winter. In the winter season at Jan Mayen as much as 75% of all the DTR differences are statistically significant at least at the 0.05 level, while in Coral Harbour A only 13.9% are statistically significant. On the other hand, in summer the analogical values are quite similar and are equal to 47.2% and 38.9%, respectively.

Table VII. Values of the Student's t-test of winter (December–February) and spring (March–May) DTR differences at Coral Harbour A occurring between different groups of circulation in the Arctic (A, B, W, G, D, K) and macrotypes of circulation (W, C, E) over the period 1951–1990

	Groups of circulation in the Arctic						Macrotypes of circulation		
	December–February								
March–May	A	B	W	G	D	K	W	C	E
A		1.12	0.58	1.44	1.39	0.47	1.09	0.00	0.62
B	1.89		1.58	0.51	2.11*	1.42	1.92	1.11	0.81
W	0.99	3.46***		1.78	1.01	0.00	0.61	0.56	1.44
G	1.35	0.00	2.22*		2.21*	1.67	2.04*	1.43	1.20
D	0.93	1.06	2.24*	0.71		0.85	0.48	1.36	2.10*
K	1.40	3.02**	0.77	2.37*	2.23*		0.49	0.46	1.08
W	1.35	0.51	2.70**	0.35	0.50	2.56*		1.06	1.97*
G	1.43	0.55	2.93**	0.36	0.54	2.66**	0.00		0.59
E	0.54	3.24**	0.70	1.93	1.87	1.22	2.39*	2.65**	

* DTR differences statistically significant at the 0.05 level.
** DTR differences statistically significant at the 0.01 level.
*** DTR differences statistically significant at the 0.001 level.

Table VIII. Values of the Student's t-test of summer (June–August) and autumn (September–November) DTR differences at Coral Harbour A occurring between different groups of circulation in the Arctic (A, B, W, G, D, K) and macrotypes of circulation (W, C, E) over the period 1951–1990

	Groups of circulation in the Arctic						Macrotypes of circulation		
	June–August								
September–November	A	B	W	G	D	K	W	C	E
A		2.59**	0.00	0.00	1.09	0.00	1.06	3.28**	0.61
B	0.43		2.70**	2.67**	1.79	2.66**	1.74	0.60	4.13***
W	2.12*	1.34		0.00	1.14	0.00	1.11	3.44***	0.65
G	0.40	0.72	2.07*		1.13	0.00	1.10	3.41***	0.64
D	0.96	1.25	3.07**	0.39		1.12	0.00	2.58**	2.26*
K	0.49	0.85	2.63**	0.00	0.48		1.09	3.39***	0.63
W	0.54	0.91	2.96**	0.00	0.53	0.00		2.49*	2.16*
C	0.00	0.46	2.40*	0.42	1.06	0.55	0.62		5.34***
E	1.72	0.94	0.63	1.74	2.76**	2.28*	2.62**	2.00*	

* DTR differences statistically significant at the 0.05 level.
** DTR differences statistically significant at the 0.01 level.
*** DTR differences statistically significant at the 0.001 level.

Analysis of the statistically significant DTR differences in all stations (not shown) reveal that the greatest number of them in all seasons, except summer, occurred in the Atlantic region of the Arctic, especially in its western and central parts (mostly > 50%). During summer, this characteristic is the highest in the central and eastern parts of the Russian Arctic (about 70%). The lowest number of statistically significant DTR differences was present in all seasons, mainly in the Canadian Arctic (below 40%). Also, in spring and autumn the DTR differences are very rarely significant in regions of the Arctic represented by the stations Danmarkshavn and Narjan-Mar (below 20%).

In the annual cycle, the majority of analysed stations (six, located mainly in Russian and Canadian Arctic) reveal the most significant DTR differences in summer. Other stations representing the region of the Arctic with the greatest influence of atmospheric circulation most frequently exhibit statistically significant DTR differences in winter or spring.

Based on the above results, it can be clearly observed that the relationships between both the groups of circulation in the Arctic (per Dydina) and macrotypes of circulation (per Vangengeim-Girs) on the one hand and the DTR in the Arctic on the other are strong, and in many cases statistically significant. Simultaneously, it has been shown that these relations are spatially and seasonally differentiated in the Arctic.

What is the influence of changes in atmospheric circulation in the Arctic on the DTR? To answer this question, we must check what the trends of the seasonal frequency of the above listed groups of circulation in recent decades are. Such computations for the periods 1951–1990, 1961–1990 and 1976–1990 are presented in Table II. In addition, the courses of the annual frequency of occurrence of days with particular circulation groups in the Arctic and their linear trends are shown in Figure 6. Przybylak (1997) showed that the decrease of the DTR in the Arctic was greatest in the period 1961–1990 (see Table III and Figure 7 of that paper). Therefore, this period was taken into account when looking for relations with atmospheric circulation. In winter and summer, all three groups of circulation (besides group W in winter) giving the lowest mean DTR in the Arctic show an increasing trend of their frequency in this period (Table II). It is evident, from Table II, that the tendency of the frequency of occurrence of group W in winter changed rapidly in the mid-1970s. Since that time a significant increase is noticeable. It is also very important to add that all these groups (excluding group G) are simultaneously characterized by the greatest seasonal frequency of occurrence (see Figure 4). Thus, one can conclude that the described changes in atmospheric circulation in the Arctic in winter and summer could explain to some degree the observed decrease in the DTR. In winter, probably more important is the direct influence of circulation on the DTR (through the increase of non-periodical changes of day-to-day air temperature), while in summer the indirect influence could be more important (through, for example, increase of cloudiness which in this season is the most important factor decreasing the DTR). In spring, the character of the influence of atmospheric circulation on the DTR is not clear and depends on the above-mentioned methods which we chose for finding the three groups with the lowest DTR (in first/second/method two groups giving the lowest DTR show the increasing/decreasing/trend of their frequency). In autumn, changes in atmospheric circulation should lead to an increase of the DTR. It is worth noting that in autumn the area of the Arctic where the decrease in DTR occurred was the smallest (see Przybylak, 1996). Serreze *et al.* (1993) showed statistically significant increases in cyclone activity north of 65°N over the period 1952–1989 for winter, spring and summer. Their more recent results (Serreze *et al.*, 1997) for the cold season (October–March) suggest that this upward tendency continued until 1992/1993. They also found statistically significant increases in anticyclone activity, but for spring, summer and autumn. This means that the relative increase (decrease) of cyclone activity in relation to anticyclone activity in the analysed period occurred in winter (autumn). Przybylak (1992) found that in Hornsund (Spitsbergen), in all months (except May), the mean DTR is much lower during cyclonic than during anticyclonic synoptic situations. In the winter months, these differences are highest and exceed 1°C. Thus, the changes of Arctic synoptic activity found by Serreze *et al.* (1993) confirm the accuracy of the results presented here.

4. CONCLUSIONS

Significant changes in atmospheric circulation in the Northern Hemisphere (mid and low latitudes) have been occurring since the mid-1970s. From that time, a marked increase of the frequency of the W macrotype (zonal type) and the decrease of the E macrotype (meridional type) can be observed (Figure 5). This is consistent with the changes of atmospheric circulation in other regions of the world characterized by very well-known indices (for example, ENSO, NAO or ZI). The variability analysis of the frequency occurrence for groups of synoptic processes in the Arctic (according to Dydina, 1982) allows for the conclusion that in the Arctic the change of atmospheric circulation in recent decades (Figure 6) is significantly smaller than in the lower latitudes of the Northern Hemisphere.

The highest mean annual DTR values occur in the centre of the southernmost parts of the Canadian and Russian Arctic (characterized by the greatest degree of the continentality of the climate in the Arctic), and the lowest occur in the Norwegian Arctic (characterized by the greatest degree of the oceanicity of the climate in the Arctic; see Marsz, 1995). The annual and seasonal spatial patterns of the DTR are roughly similar (see Figures 7 and 8). Based on the seasonal means, four types in the annual course of the DTR were distinguished. However, the first two types (maximum of the DTR in winter and minimum in summer, and maximum in spring and minimum in autumn) clearly dominate in the Arctic (about 75% of the analysed stations) (see Figure 9). According to the DTR monthly means, the highest values most often occurred in April (63.6%) and the lowest in September (62.1%).

The results obtained concerning the relationship between the DTR and atmospheric circulation show that both the large-scale changes in atmospheric circulation in the Northern Hemisphere and its changes in the Arctic have led to the damping of the cool half-year DTR in the Arctic in recent decades. The analysis of the correlation coefficients computed between mean winter DTR in the Arctic and both NAO and ZI indices also confirms this conclusion. It is worth noting that the observed changes in atmospheric circulation are consistent with the DTR changes occurring in the Arctic (see Przybylak, 1997).

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REFERENCES

Alekseyev, G.W., Podgornoy, I.A., Svyaszczennikov, P.N. and Khrol, W.P. 1991. 'Features of climate formation and its variability in the polar climatic system atmosphere–sea ice-ocean', in Krutskikh, B.A. (ed.), *Klimaticzeskij rezym Arktiki na rubeze XX i XXI ww.*, Gidrometeoizdat, Sankt-Peterburg, pp. 4–29 (in Russian).

Atlas Arktiki, 1985. *Glavnoye Upravlenye Geodeziy i Kartografiy*, Moskva, p. 204.

Baranowski, S. 1968. 'Thermic conditions of the periglacial tundra in SW Spitsbergen', *Acta Univ. Wratisl.*, **68**, 1–73 (in Polish).

Barry, R.G., Newell, J.P., Schweiger, A. and Crane, R.G. 1986. *Empirical and modeled synoptic cloud climatology of the Arctic Ocean*, Final Report to Climate Research Program NASA NAG 5-417, CIRES, p. 103.

Barry R.G. and Perry A.H. 1973. *Synoptic Climatology. Methods and Application*, Methuen & Co. Ltd., London, p. 555.

Böhm, R. and Auer, J. 1994. 'A search for greenhouse signal using daytime and nighttime temperature series', in *Climate Variations in Europe*, *Proceedings of the European Workshop on Climate Variations* held in Kirkkonummi, Finland 15–18 May, pp. 141–151.

Bradley, R. and England, J. 1979. 'Synoptic climatology of the Canadian High Arctic', *Geogr. Ann.*, **61A**, 187–201.

Brázdil, R., Machu, R. and Budiková, M. 1994. 'Temporal and spatial changes in maxima and minima of air temperature in the Czech Republic in the period of 1951–1993', in Brázdil, R. and Kolar, M. (eds), *Contemporary Climatology*, Brno, pp. 93–102.

Brázdil, R., Budíková, M., Auer, I., Böhm, R., Cegnar, T., Fasko, P., Gajić Capka, M., Lapin, M., Niedźwiedź, T., Szalai, S., Ustrnul, Z., Weber, R.O. and Zaninović, K. 1995. 'Trends of maximum and minimum daily temperatures in Central Europe', in *Proceedings of the International Conference on Past*, *Present and Future Climate*, Helsinki 22–25 August, pp. 222–225.

Brázdil, R., Budíková, M., Auer, I., Böhm, R., Cegnar, T., Fasko, P., Lapin, M., Gajić Capka, M., Zaninovic, K., Niedźwiedź, T., Ustrnul, Z., Szalai, S., Weber, R.O. 1996. 'Trends of maximum and minimum daily temperatures in central and southeastern Europe', *Int. J. Climatol.*, **16**, 765–782.

Dessens, J. and Bücher, A. 1995. 'Changes in minimum and maximum temperatures at the Pic du Midi in relation with humidity and cloudiness, 1882–1984', *Atmos. Res.*, **37**, 211–228.

Dolgin, I.M. 1970. 'Founders of Arctic synoptic methodology', *Meteorol. Gidrolog.*, **5**, 105–110 (in Russian).

Dydina, L.A. 1958. 'About principles of long-term weather forecasts for the Arctic', *Trudy ANII*, **215**, 32–34 (in Russian).

Dydina, L.A. 1964. *Macro-circulation Method of the Weather Forecasts for 3–10 Days for the Arctic*, Gidrometeoizdat, Leningrad, p. 391 (in Russian).

Dydina, L.A. 1982. *Specific Features of Synoptic Processes Development in the Arctic Area and their Utilisation in Medium-term Forecasts*, Gidrometeoizdat, Leningrad, p. 224 (in Russian).

Easterling, D.R., Horton, B., Jones, P.D., Peterson, T.C., Karl, T.R., Parker, D.E., Salinger, M.J., Razuvayev, V., Plummer, N., Jamason, P. and Folland, Ch.K. 1997. 'Maximum and minimum temperature trends for the globe', *Science*, **277**, 364–367.

Frich, P. 1992. 'Cloudiness and diurnal temperature range', in *Proceedings of 5th International Meeting on Statistical Climatology*, 22–26 June, Toronto, Canada, pp. 91–94.

Girs, A.A. 1948. 'Some aspects concerning basic forms of atmospheric circulation', *Met. Gidr.*, **3**, 9–11 (in Russian).

Girs, A.A. 1971. *Many Years Fluctuations of Atmospheric Circulation and Long-term Hydrometeorological Forecast*, Gidrometeoizdat, Leningrad, p. 279 (in Russian).

Girs, A.A. 1981. 'Some forms of atmospheric circulation and their utilisation in forecasts', *Trudy AANII*, **373**, 4–13 (in Russian).

Gorshkov, S.G. (ed.) 1980. *Military Sea Fleet Atlas of Oceans: Northern Ice Ocean*. Ministry of Defense, Russia, p. 184 (in Russian).

Hansen, J., Sato, M. and Ruedy, R. 1995. 'Long-term changes of the diurnal temperature cycle: implications about mechanisms of global climate change, *Atmos. Res.*, **37**, 175–209.

Hansen, J., Sato, M., Lacis, A. and Ruedy, R. 1997. 'The missing climate forcing', *Phil. Trans. R. Soc. Lond. B*, **352**, 231–240.

Henderson-Sellers, A. 1992. 'Continental cloudiness changes this century', *GeoJournal*, **27**(3), 255–262.

Horton, B. 1995. 'The geographical distribution of changes in maximum and minimum temperatures', *Atmos. Res.*, **37**, 101–117.

Houghton, J.T., Meila Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K. (eds) 1996. *Climate Change 1995: The Science of Climate Change*, Cambridge University Press, Cambridge, New York, Melbourne, 572 pp.

Hurrell, J.W. 1995. 'Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation', *Science*, **269**, 676–679.

Hurrell, J.W. 1996. 'Influence of variations in extratropical wintertime teleconnections on Northern Hemisphere temperature', *Geophys. Res. Lett.*, **23**, 665–668.

Hurrell, J.W. and van Loon, H. 1997. 'Decadal variations in climate associated with the North Atlantic Oscillation', *Clim. Change*, **36**, 301–326.

Jones, P.D. 1995a. 'Maximum and minimum temperature trends in Ireland, Italy, Turkey and Bangladesh' *Atmos. Res.*, **37**, 67–78.

Jones, P., 1995b. 'Recent variations in mean temperature and diurnal temperature range in the Antarctic', *Geophys. Res. Lett.*, **22**, 1345–1348.

Kaas, E. and Frich, P. 1995. 'Diurnal temperature range and cloud cover in the Nordic countries: observed trends and estimates for the future', *Atmos. Res.*, **37**, 211–228.

Karl, T.R., Kukla, G., Razuvayev, V.N., Changery, M.J., Quayle, R.G., Heim, R.R. Jr, Easterling, D.R. and Fu, C.B. 1991. 'Global warming: evidence for asymmetric diurnal temperature change', *Geophys. Res. Lett.*, **18**, 2253–2256.

Karl, T.R., Jones, P.D., Knight, R.W., Kukla, G., Plummer, N., Razuvayev, V.N., Gallo, K.P., Lindesay, J., Charlson, R.J. and Peterson, T.C. 1993. 'A new perspective on recent global warming: asymmetric trends of daily maximum and minimum temperature', *Bull. Am. Meteorol. Soc.*, **74**, 1007–1023.

Karl, T.R., Knight, R.W., Kukla, G. and Gavin, J. 1995. 'Evidence for radiative effects of anthropogenic sulphate aerosols in the observed climate record', in Charlson, R.J. and Heintzenberg, J. (eds), *Aerosol Forcing of Climate*, Wiley, Chichester, pp. 363–382.

Kożuchowski, K. 1993. 'Variations of hemispheric zonal index since 1899 and its relationship with air temperature', *Int. J. Climatol.*, **8**, 191–199.
Kumar, R.K., Kumar, K.K. and Pant, G.B. 1994. 'Diurnal asymmetry of surface temperature trends over India', *Geophys. Res. Lett.*, **21**, 677–680.
Marsz, A.A. 1995. *Index of Oceanicity as a Measure of Climatical Interaction in the System Ocean–Atmosphere–Continents*, Wyzsza Szkola Morska, Gdynia, p. 110 (in Polish).
Mearns, L.O., Giorgi, F., McDaniel, L. and Shields, C. 1995. 'Analysis of variability and diurnal range of daily temperature in a nested regional climate model: comparison with observations and doubled CO_2 results', *Climate Dyn.*, **11**, 193–209.
Niedźwiedź, T. 1987. 'The influence of the atmospheric circulation on the air temperature in Hornsund region (Spitsbergen)', in *Proceedings of XIV Polar Symposium: Actual Research Problems of Arctic and Antarctic*, Lublin, Poland, May 7–8, pp. 174–180 (in Polish).
Niedźwiedź, T. 1993. 'Long-term variability of the atmospheric circulation over Spitsbergen and its influence on the air temperature', in *Proceedings of XX Polar Symposium*, Lublin, Poland, pp. 17–30.
Niedźwiedź, T. and Ustrnul, Z. 1994. 'Maximum and minimum temperatures in Poland and the variability of atmospheric circulation', in Brázdil, R. and Kolar, M. (eds), *Contemporary Climatology*, Brno, pp. 420–425.
Ohmura, A. 1984. 'On the cause of "Fram" type seasonal change in diurnal amplitude of air temperature in polar regions', *J. Climatol*, **4**, 325–338.
Plantico, M.S., Karl, T.R., Kukla, G. and Gavin, J. 1990. 'Is recent climate change across the United States related to rising levels of anthropogenic greenhouse gases?', *J. Geophys. Res.*, **95**, 16617–16637.
Plummer, N., Lin, Z. and Torok, S. 1995. 'Trends in the diurnal temperature range over Australia since 1951', *Atmos. Res.*, **37**, 79–86.
Przybylak, R. 1992. 'The thermic and humidity relations against a background of the circulations conditions in Hornsund (Spitsbergen) in the period 1978–1983', *Dok. Geogr.*, **2**, 1–105 (in Polish).
Przybylak, R. 1994. 'Thermic characteristic of groups and macrotypes of atmospheric circulation in the Atlantic region of the Arctic over the period 1951–1990', *Probl. klimatol. polarnej*, **4**, 105–118 (in Polish).
Przybylak, R. 1996. *Variability of Air Temperature and Precipitation over the Period of Instrumental Observation in the Arctic*, Uniwersytet Mikolaja Kopernika, Rozprawy, p. 280 (in Polish).
Przybylak, R. 1997. 'Spatial and temporal changes in extreme air temperatures in the Arctic over the period 1951–1990', *Int. J. Climatol.*, **17**, 615–634.
Przybylak, R. 1999, 'Influence of cloudiness on extreme air temperatures and diurnal temperature range in the Arctic over the period 1951–1990', *Pol. Polar Res.*, **20** (in press).
Robinson, D.A., Leathers, D.J., Palecki, M.A. and Dewey, K.F. 1995. 'Some observations on climate variability as seen in daily temperature structure', *Atmos. Res.*, **37**, 119–131.
Salinger, M.J., Allan, R., Bindoff, N., Hannah, J., Lavery, B., Leleu, L., Lin, Z., Lindesay, J., MacVeigh, J.P., Nicholls, N., Plummer, N. and Torok, S. 1995. 'Observed variability and change in climate and sea level in Oceania', in *Proc. GREENHOUSE '94* (in press).
Serreze, M.C. and Barry, R.G. 1988. 'Synoptic activity in the Arctic Basin, 1979–85, *J. Climate*, **1**, 1276–1295.
Serreze, M.C., Box, R.G., Barry, R.G. and Walsh, J.E. 1993. 'Characteristics of Arctic synoptic activity, 1952–1989', *Met. Atmos. Phys.*, **51**, 147–164.
Serreze, M.C., Carse, F. and Barry, R.G. 1997. 'Icelandic low cyclone activity: climatological features, linkages with the NAO, and relationships with recent changes in the Northern Hemisphere circulation', *J. Climate*, **10**, 453–464.
Trenberth, K.E. and Hurrell, J.W. 1994.' Decadal atmosphere–ocean variations in the Pacific', *Clim. Dyn.*, **9**, 303–319.
Türkes, M., Sümer, U.M. and Kilic, G. 1996. 'Observed changes in maximum and minimum temperatures in Turkey', *Int. J. Climatol.*, **16**, 463–477.
Vanda, Ju.A. 1978. 'Investigation of the relationship between numerical and synoptic typing of atmospheric processes in the Arctic', *Trudy AANII*, **349**, 124–131 (in Russian).
Vanda, Ju.A. and Lyamzin, O.M. 1978. 'About problem of typing of synoptic processes using cluster analysis', *Probl. Arkt. Antarkt.*, **53**, 21–26 (in Russian).
Vangengeim, G.Ya. 1935. *Application of Synoptic Methods to the Study and Characterization of Climate*, Gidrometeoizdat, Moskva, p. 112 (in Russian).
Vangengeim, G.Ya. 1948. 'Specific features of atmospheric circulation in different epochs and climate fluctuations', *Trudy II Vsesojuznogo Geogr. Sjezda*, **39** (in Russian).
Vangengeim, G.Ya. 1952. 'Bases of the macrocirculation method for long-term weather forecasts for the Arctic', *Trudy ANII*, **34**, 1–314 (in Russian).
Vangengeim, G.Ya. 1961. 'Degree of the atmospheric circulation homogeneity in different parts of Northern Hemisphere under the existence of main macrocirculation types W, E and C', *Trudy AANII*, **240**, 4–23 (in Russian).
Weber, R.O., Talkner, P. and Stefanicki, G. 1994. ' Asymmetric diurnal temperature change in the Alpine region', *Geophys. Res. Lett.*, **21**, 673–676.

