Long-term variations of atmospheric general circulation in the northern hemisphere in winter season

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We present a study of the long-term variations of the near-ground pressure fields in winter inferred from NCAR/NCEP reanalysis data for middle and high latitudes of the northern hemisphere, responsible for the variations of monthly mean temperatures in Eastern Siberia. We suggest a new classification scheme to be used for Arctic pressure fields, which well reflects the influence of circulation processes on the near-ground temperature variations in Siberia. In the long-term variations of temperature, mean pressure fields, and frequency of occurrence of circulation types, one can quite clearly see the quasi-decadal variations, associated with the dynamics of Icelandic and Aleutian Lows.

Introduction

Among the main factors of climate change, there are variations of the atmospheric general circulation. Both in Russia and abroad, first general circulation studies are dated to late nineteenth – early twentieth centuries. In Russia, the general circulation studies were performed by Multanovskii in 1920s, and later on by many meteorologists (such as Vangengeim, Girs, Pogosyan, Dzedzeevskii, Budyko, among others).[1–4] However there are only few studies of the atmospheric general circulation over Eastern Siberia and its dependence on climate and weather characteristics. A motivating factor for this research has been an anomalously cold winter of 1968/69, and a subsequent rise of monthly mean winter temperatures, or the so-called global climate warming, in Eastern Siberia.

The 1970s are the years of active research into winter weather types, winter weather severity, and its linkage to human health.[5] This was also time of establishment of relationship between weather characteristics in Siberia and main circulation types; and, in particular, for Transbaikalia, the main types of synoptic processes responsible for warming were identified.[6] For Siberia and Far East, the dominating types of Kats's circulation, types of Dzerdzeevskii's atmospheric processes, etc., were considered.[7]

Unfortunately, neither model calculations, nor analysis of observation data can identify reliably the causes of variations of atmospheric general circulation. In particular, it is unclear whether these variations are a consequence of the internal instability of atmospheric general circulation or, to a greater extent, they depend on external factors, such as decrease of stratospheric ozone, increase of greenhouse gases, volcanic or solar activity, El Niño, etc.

The difficulty of analyzing lies in the absence of long-term series and incompleteness of observation data, large number of meteorological parameters, instability of atmospheric processes, etc. Against the background of transient fluctuations it is difficult to single out the long-term variations of the meteorological fields. None of the existing methods appears to be quite satisfactory for this.

To study the specific features of atmospheric general circulation, different forms of classification of atmospheric processes are used. The classification systems are many, but the majority of them are developed for limited regions. Most recognized and widespread among them are systems of classification of synoptic processes developed by Vangengeim–Girs and Dzerdzeevskii.[1,8] Their common feature is that they both characterize inter-latitudinal exchange in terms of the number and directions of arctic invasions and southern outbreaks into the middle latitudes (in the lower troposphere), and in terms of the number of altitudinal edges and troughs (in the middle troposphere), which deform the latitudinal (westward) transport dominating here.

The Vangengeim–Girs classification distinguishes three types of atmospheric circulation: westward (W), eastward (E), and meridional (C) circulations. The processes of westward type correspond to zonal atmospheric circulation; and the processes of E and C types correspond to meridional circulation with different locations of altitudinal troughs and edges. While the Vangengeim–Girs system has hemispherically wide application, this classification is performed using the main characteristics found in the Atlantic–European and Pacific Ocean sectors.

Typical schemes of circulation mechanisms, introduced by Dzerdzeevskii, are based on the relationship between circulation processes in Arctic basin and midlatitude circulation, and they are advantageous over Vangengeim–Girs classification in that they have clearer morphological features.

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The use of climatic time series and classifications of synoptic processes makes it possible to identify circulation epochs; however, their characteristics, in the form of frequency of occurrence of circulation types, are difficult to interpret in terms of pressure field of epochs; while concentrating on analysis of only characteristics of centers of atmospheric activity leads to the loss of useful information. Seemingly it would be more correct to use simultaneously both quantitative and qualitative methods of analysis to reveal of interannual variations.

One of the regions in which the specific features of atmospheric general circulation are easy to identify is Eastern Siberia, where the multiyear variations of temperature have quite large amplitude. In addition, the temperature variations in Siberia are closely related to those in Arctic, a region serving, in a certain sense, a regulator of synoptic processes in the hemisphere, particularly in winter seasons.[9–11]

Analysis of the results

To identify the circulation epochs, we used as the initial information the diurnally mean air temperatures and distributions of near-ground pressure reduced to sea-level pressure, inferred from National Centers for Environmental Predictions/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis data for period 1948–2000.

A good agreement between the initial data and *in situ* observations at meteorological stations in Irkutsk Region indicates that the former are representative and reliable. The multiyear climate variations reflect most clearly the temperature in January, most cold month of the year. Figure 1 shows a plot of the January mean temperature for southern Siberia (curve *1*), averaged over the area 50–75°N, 85–102°E, as well as the plot of retrieved temperature for the spatial location corresponding to the pole (curve *2*).

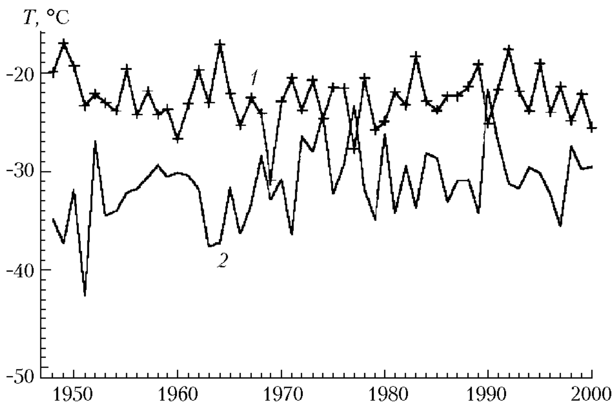


Fig. 1. Variations of January mean temperatures in the southern Siberia and at location corresponding to pole, according to NCAP/NCER Reanalysis data for period 1948–2000.

Between 1948 and 1969, in the southern Siberia there occurred a decrease of winter temperatures, followed by their increase until mid-1990s, after which the winter temperatures again decreased. For the pole, the winter temperature generally tends to grow; though, in some time periods (late 1950s – early 1960s; late 1960s – early 1970s; late 1970s – early 1980s; 1990–1998) it dropped. At the same time, the variations at the pole were generally 180° out of phase with those in Siberia, with the correlation coefficient −0.34.

Considering that correlation exists between temperature variations, it is convenient to use these plots to simultaneously identify the boundaries of the circulation epochs. Criteria of the development of new epoch may be either the presence of inflection points on the curves or substantial changes of temperature difference between the plots. Of course, the material is too limited and an additional analysis of synoptic data is required before any conclusions can be made at certain.

Based on the temperature curves (see Fig. 1), it can be hypothesized that the dynamics of atmospheric general circulation has quasi-decadal or two-decade oscillations. First characteristic time period was in 1950s and 1960s. During this period, relatively warm temperatures were observed in Siberia and quite cold ones in Arctic; in the coldest winters (1949, 1951, 1963, and 1964), the mean air temperature at the pole did not rise above −37°C. The second characteristic time period spans 1970s. During it, the mean Arctic temperatures considerably increased, and temperature curves became closer in magnitude. Lastly, in the third time period, namely 1980s and 1990s, the situation is the same as in 1950s–1960s. The temperature increases in Siberia and decreases in Arctic, in all but 1990, when it increased in Arctic and simultaneously decreased in Siberia for a short time.

While the Siberia–Arctic temperature differences differ little in the first and last time periods, the mean Siberian and Arctic temperatures appear somewhat higher than in 1950s – 1960s. Presumably, the 1950s – 1960s and 1980s – 1990s had nearly identical synoptic processes, but differed in some quantitative characteristics.

For analysis of pressure fields in the given time periods, we used the maps of near-ground pressure, reduced to the sea-level; these maps were inferred from NCAR/NCEP Reanalysis data and plotted with the resolution of 2.5×2.5°. In analysis of the maps, we assumed that the interannual variations of atmospheric general circulation could be caused by the dynamics of the main centers of cyclonic activity, namely, Icelandic and Aleutian Lows, by the resulting initiation of long thermal-pressure waves, and by change of characteristic circulations. Therefore, the data analysis included (1) immediate comparison of dynamics of centers of atmospheric activity using the maps of the mean pressure fields in different circulation epochs, and (2) analysis of the types of the circulation in these epochs.

In accordance with the above assumption, the circulation types were classified by directions of troughs of the main oceanic pressure lows at high latitudes. In contrast to the Vangengeim–Girs and Dzerdzeevskii classifications, the classification proposed here is more limited in character, because it does not consider in detail the distributions of pressure fields at midlatitudes. An additional classification criterion is the temperature regime in Siberia. We suggest to distinguish the following types of circulation:

1) merging of troughs of Icelandic and Aleutian Lows along American coast, with the Asian high-pressure ridge over the pole (America);

2) merging of troughs of these lows along Asian coast, with high-pressure system over the pole (Asia);

3) low-pressure system in the central Arctic basin when troughs of lows merge across the pole (Arctic); and

4) pressure ridge over pole, by which Asian and Canadian anticyclones merge (Ridge over Arctic).

Figure 2 shows pressure distributions characteristic of these circulation types. Solid lines show isobars below 1013 hPa level, and dashed lines those above 1013 hPa level (contour interval is 5 hPa).

In accordance with the classification accepted here, every 6 days of January from 1948 to 2000 were categorized as days with a given circulation type.

As in the temperature plots, the processes of different types have decadal-scale recurrence intervals during which atmospheric processes of specific types dominate (Table 1).

For the first two decades, January is characterized by the development of pressure ridge, leading to merging of Asian and Canadian anticyclones. At this time, extremely low temperatures were observed in polar region. In 1970s, the situation significantly changed. Intrusions of cold Arctic air have almost ceased. The Icelandic and Aleutian Lows became deeper, merging most frequently along the entire North American coast. In 1980s, there is again an increase of the number of polar outbreaks, intensification of Asian and Canadian anticyclones, and more frequent occurrence of ridges of high pressure between the anticyclones.

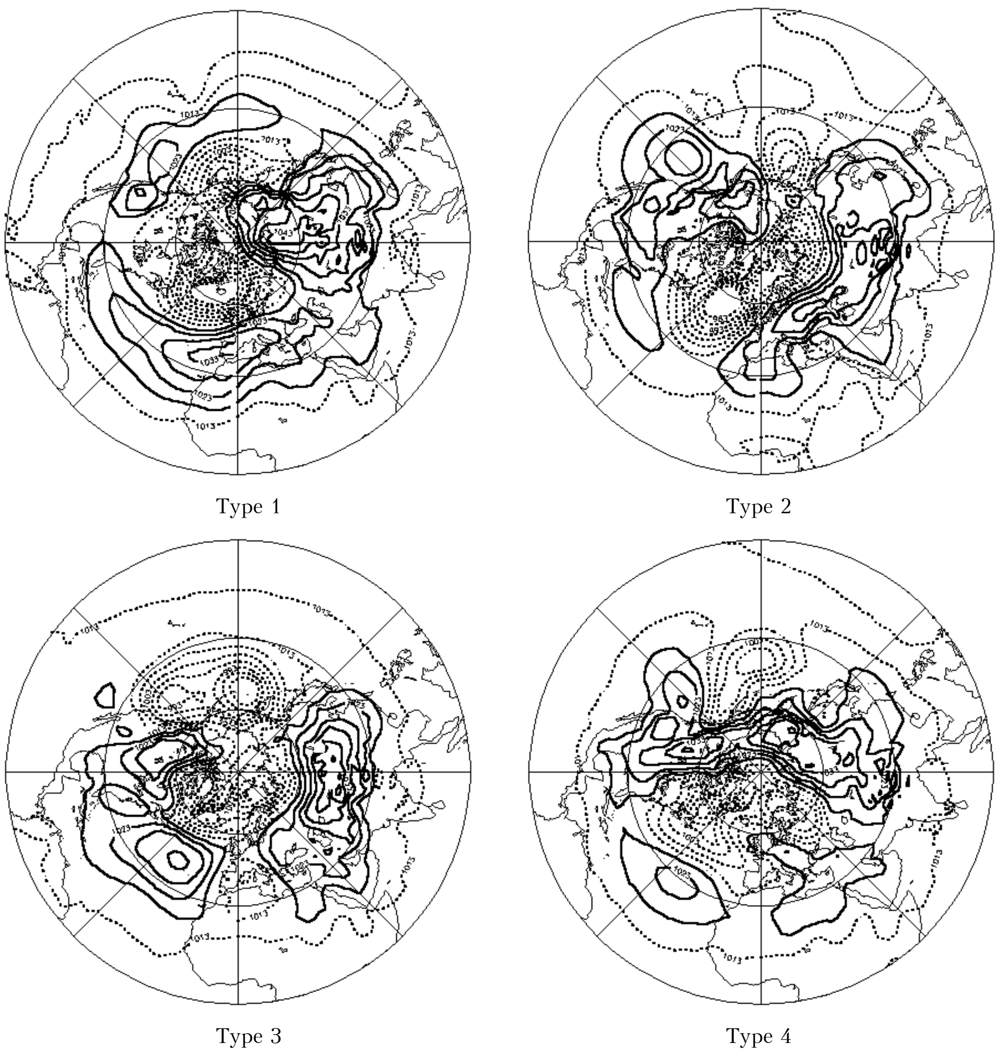


Fig. 2. Characteristic distributions of near-ground pressure fields for different circulation types.

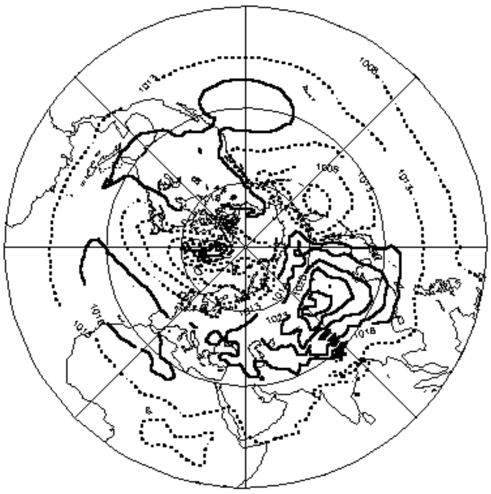
Table 1. Frequency of occurrence (%) of different circulation types over decadal time intervals

Years	America	Asia	Arctic	Ridge over Arctic
1950–1960	22	22	14	42
1960–1970	20	16	10	54
1970–1980	53	30	13	4
1980–1990	36	14	18	32
1990–2001	26	10	16	48

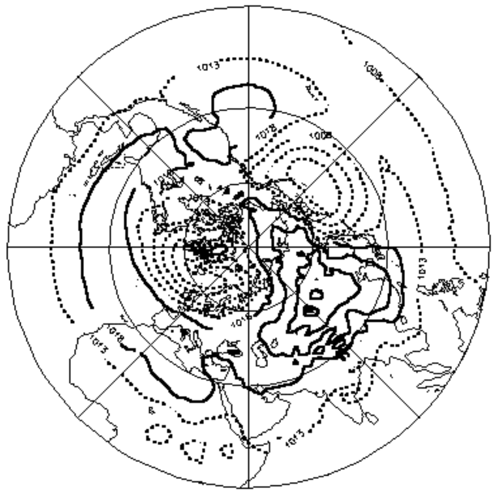
Lastly, in 1990s, there again occurs situation typical of 1950s–1960s, in which high-pressure regions dominated in the central Arctic basin.

All the types of circulation mentioned above are characteristic of all winter months, and not only of January. The fact that the frequencies of occurrence of different circulation types over 10–20-year time intervals significantly differ supports the speculation that the processes of atmospheric general circulation are cyclic in character, possibly due to Arctic variations. At the same time, all decadal periods represent separate circulation epochs, each characterized by specific frequency distribution of different synoptic processes.

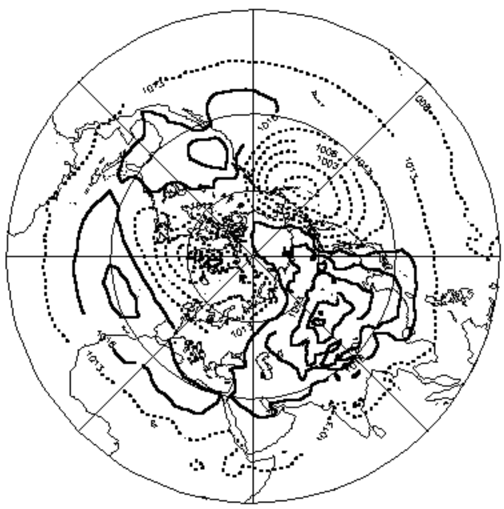
Using a classification of synoptic processes, it is possible to characterize qualitatively a circulation epoch. We expect that the difference between the epochs can be caused, in its turn, by the dynamics of centers of atmospheric activity. To estimate the pressure features of each circulation epoch, we averaged January mean pressure fields for four central years in each of the identified decadal intervals. Figure 3 presents the obtained maps of the mean fields, which characterize the long-term variations of atmospheric general circulation in winter season. In this figure the notation is the same as in Fig. 2.



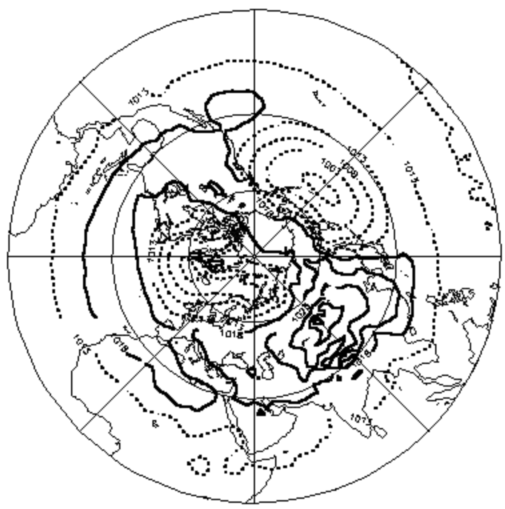
January 1954–1957



January 1974–1977



January 1984–1987



January 1994–1997

Fig. 3. January mean pressure fields in different periods.

As was expected, in accordance with the classification used here, 1970s–1980s are indeed characterized by a lower pressure over American coast. At this time, the ridge of Asian anticyclone extends far into the polar region. Merging of Canadian and Asian anticyclones is pronounced in 1990s. In 1950s–1960s, the ridge has a break along the Asian coast.

Unfortunately, more fine details in distribution of the pressure fields, such as dominating directions of troughs and ridges in Arctic basin over decadal-long time intervals, are difficult to identify by this analysis technique.

Because of the averaging procedure, east- or westward drift of trough or ridge with relatively small cross-sectional area in different time intervals leads to a spreading out of the average pattern and to a certain decrease or increase of the pressure in the central Arctic basin. The average maps resolve much better the large-scale features of pressure fields and, in particular, variations caused by migrations of activity centers and variations of their intensity. Over period considered here, the Aleutian Low shows most distinct variations. Between 1950s and 1990s, it deepened, simultaneously drifting in the eastward direction. The variations of Icelandic Low were not that well defined, being rather oscillating in character. Overall, the configurations of pressure fields were highly variable on all timescales. As a result, the forms of circulation substantially changed in the middle and high latitudes of the northern hemisphere.

The classification of synoptic processes, used here, was also found to well reflect the temperature variations both in Siberia and over the pole. The frequency of occurrence of identified circulation types, separately for most warm and most cold winters in Siberia and Arctic, is presented in Tables 2 and 3.

Table 2.Frequency of occurrence (%) of circulation types for cold winters

Region	America	Asia	Arctic	Ridge over Arctic
Arctic	13	22	17	48
Siberia	40	10	6	44

Table 3. Frequency of occurrence (%) of circulation types for warm winters

Region	America	Asia	Arctic	Ridge over Arctic
Arctic	47	15	7	31
Siberia	10	21	25	44

Despite the higher frequency of occurrence of anticyclonic weather type in the cold and warm winters, which on the whole is typical for this season at high and midlatitudes, from Tables 2 and 3 we see quite obvious dependence of the winter temperatures on large-scale features of the pressure field in Arctic. For instance, the wintertime cooling in Eastern Siberia is associated not only with the intensification of anticyclogenesis, but also with the largest separation of troughs of cyclonic activity centers from the continent. Most responsibility for Arctic cooling is shared by anticyclonic activity centers of the atmosphere. The warmest winters both in Siberia and Arctic are associated with intensification of cyclonic circulation in the Arctic basin.

Conclusion

Eastern Siberia is the region of pronounced temperature contrasts, illustrated by the fact that two successive years, 2001 and 2002, had anomalously cold and warm winters. The considerable temperature variations are determined by a combination of advective and dynamical factors, among which the circulation regime plays an important role.

The paper considers long-term variations of winter temperatures in Siberia, which were found to be closely related to Arctic temperature regime and dominated by dynamics of winter continental and oceanic centers of atmospheric activity in the northern hemisphere.

In long-term variations of thermal and circulation regimes, we found 10- and 20-year cycles, coinciding in length with the dynamics of centers of oceanic activity and Arctic oscillation, again assuming that the temperature and circulation factors are interrelated, and that this can be used for classification of pressure fields in individual regions.

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