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Comparison of Atmospheric Circulation in the Area of Spitsbergen in 1920–1950 and in the Modern Warming Period

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Abstract—The results of studying the temporal variability of atmospheric circulation in the Western Arctic (the Norwegian and Barents seas) are presented. The daily dataset of Girs–Vangengeim E, W, and C circulation forms for the period of 1891–2016 is used to describe atmospheric circulation. Special attention is given to the estimation of differences in weather conditions during the modern period of warming (1985–2015) and in the period of the first Arctic warming (1920–1950). For the cold (November–March) and warm (April–October) seasons, the trends in the frequency of occurrence of the circulation forms are determined. The occurrence of the number of consecutive days with the same atmospheric circulation form which can be considered as a characteristic of weather stability during the analyzed period of warming, is computed for both seasons. The prevalence of the E circulation form during the warm season is typical of both periods. The modern period of warming in the study area, as compared to the period of the first warming, is characterized by an increase in the occurrence of the C circulation form with a short duration. It is found that the current climate regime is characterized by an increase in surface air temperature against a background of less stable weather conditions.

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INTRODUCTION

The climate change is most clearly manifested in polar regions. The great number of scientific publications not only investigate possible reasons for these climate changes but also search possible ways for the adaptation to observed and predicted changes [1, 2, 9, 18, 23].

The present study considers temporal variations in the characteristics of atmospheric circulation in the area of Spitsbergen located in the zone of the most intensive heat and moisture exchange between the Arctic and the middle and tropical latitudes. The atmospheric circulation makes essential contribution to the formation of long-term variability [3, 23]. The modern warming in the area of the archipelago is most clearly manifested: an increase in surface air temperature [14, 20] and glacier melting [19, 21] has been registered here in the recent decades. The cases when stable fast ice is not formed in the archipelago fjords in winter became more frequent [12, 22, 24, 27].

One of the climate research directions in the Arctic regions is the analysis of observational data from the weather station network. Such analysis is most often associated with the investigation of spatiotemporal variations in monthly mean values of surface air temperature or monthly total precipitation [13, 20, 26]. An essential reason for such preference is the relative availability of these kinds of observations. The analysis of variations in other meteorological parameters, in particular, in wind speed is rare. There are several papers dealing with the study of wind speed variations in the area of Spitsbergen based on the analysis of observational data from weather stations as well as reanalysis data [25].

The time series of surface air temperature detect two periods of the warming: the first one, in the 1920s–1950s, and the second one, from 1975 till now.

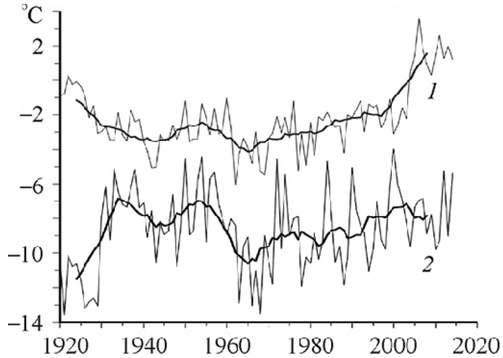

Fig. 1. The temporal variability of average surface air temperature for (*1*) the warm (April–September) and (*2*) cold (October–March) seasons and the 11-year moving averages (the heavy lines) for Longyearbyen (Spitsbergen).

The interannual variations in surface air temperature in Longyearbyen (Spitsbergen) presented in Fig. 1 may be an example of manifestation of both periods of the warming in the study area.

These two periods characterized by the surface air temperature rise as compared to the previous years can be considered as climatic regimes with comparable mean values but with different weather conditions (stable or unstable). The present study provides the comparative assessment of weather conditions both during the warming in the 1920s–1950s and during the current warming. The assessment is based on a simple characteristic of atmospheric circulation implemented in the Girs–Vangengeim classification of atmospheric circulation forms. The change in the frequency of occurrence of severe weather events like strong wind may be an additional estimate of differences in weather conditions during the analyzed periods of the warming.

OBSERVATIONAL DATA AND INFORMATION FOR THE ANALYSIS

The atmospheric circulation was analyzed using the daily dataset of Girs–Vangengeim atmospheric circulation forms developed in the Arctic and Antarctic Research Institute (AARI) and covering the period from 1891 till now. According to the classification, the atmospheric circulation for the Atlantic part of the Arctic comes to three types: western (W), eastern (E), and meridional (C) [6, 8].

The circulation type is determined using the direction of the main air mass transport. The western circulation pattern is characterized by the intensification of westerlies, when the zonal movement of cyclones from the Atlantic Ocean to the east is registered. The eastern circulation is formed either when the westerlies are broken by the invasion of anticyclones developing in continental air from the east or northeast or when strong stationary anticyclones develop over the continent. The meridional circulation is characterized by the disturbance of westerlies as a result of the invasion of continental Arctic air to the north of Scandinavia and by the formation of the meridional high-pressure zone through Scandinavia to the central part of Europe [7, 10].

Earlier the epochs were distinguished using data on the frequency of W, E, and C forms during a year, on the annual background of the distribution of air pressure and air temperature anomalies in the Northern Hemisphere [8, 17]. Many studies (including the above ones) which deal with the problems of climate change and atmospheric circulation and are based on the Girs–Vangengeim classification, utilized data on the number of days with one or another circulation pattern for every month and did not examine the intramonthly variability. Some studies provided the comparison of variations in surface air temperature with interannual variability of atmospheric circulation forms. A connection was revealed between the surface air temperature rise and the prevalence of W and E forms and between the air temperature decrease and the dominance of C and E forms [5]. It was also revealed that the NOA index variations and the W form are interrelated with total precipitation. It is noted that an increase in the NAO index and in the frequency of the W form favors an increase in total precipitation in the south of Western Siberia [4]. Based on the exceeding of normals of the frequency of one type for the period of 1973–2006, the following epochs were distinguished: the epoch of the E form (1973–1984), the transition period with the prevalence of the E form and with the W type frequency growth (1985–1990); W + C (1991–2006) [4].

Table 1. The average frequency of circulation forms for the cold and warm seasons during the first and current warming

Form	1920–1950		1985–2015	
	Cold season	Warm season	Cold season	Warm season
C	50(15)	44(17)	38(12)	48(14)
W	67(17)	59(19)	65(13)	63(21)
E	65(18)	80(25)	80(14)	71(18)

Note: The confidence intervals obtained using the *t*-test are given in brackets.

The studies of possible changes in the frequency of strong winds in the area of Spitsbergen are complicated by the absence of routine meteorological observations of wind speed covering both analyzed periods. For this reason, the 3-hour meteorological observations of 10-m wind speed from Vardo (Norway), Bear Island (Barents Sea), the Tikhaya Bay (Hooker Island), and the Ernst Krenkel Observatory (Heiss Island) stations were used for the analysis (the last two stations are located on Franz Josef Land). As meteorological observations were conducted at the Tikhaya Bay station in 1929 to 1960, the observations at this station in 1930–1950 were used for the analysis, and the period of 1985–2015 was estimated using the nearby Ernst Krenkel Observatory station. Thus, the single time series was composed of observational data of the above two stations. Meteorological observations directly on Spitsbergen could not be used. Observational data from Vardo and Bear Island stations were obtained at the Norwegian Meteorological Institute website (www.met.no), data for the Ernst Krenkel Observatory station were taken in the All-Russian Research Institute of Hydrometeorological Information–World Data Center (Obninsk, www.meteo.ru), and data for the Tikhaya Bay station were obtained in the Arctic and Antarctic Research Institute (www.meteo.ru). The analysis of data on wind speed covers a significant time period, when the instruments for its measurement were changed at weather stations. The comparison of wind speed measured with anemorumbometers and weathervanes showed the overestimation of wind speed by weathervanes [11]; to reduce this speed to the speed measured with an anemorumbometer, the correcting coefficient (0.88) was applied.

RESULTS AND DISCUSSION

The analysis of atmospheric circulation features during the period of the first and current warming was carried out for a conditional winter (November–March) and summer (April–October); such division is caused by the essential difference in the intensity of interlatitude exchange during the cold and warm seasons [3]. In case of the western circulation form (W), the cyclones move from west to east in the middle and high latitudes, and the interlatitude exchange is weakened. In the high latitudes, the temperature regime is considerably affected by the radiative cooling which favors the formation of the negative anomaly of air temperature and surface air pressure in the study area.

The position of upper-level ridges and troughs in the pressure field in case of the meridional circulation form (C) facilitates cold advection in the eastern part of upper-level ridges and warm advection in the western part; the negative air temperature anomaly is formed in the area of Spitsbergen due to cold advection. The distribution of upper-level ridges for the eastern circulation form (E) being opposite to the C form leads to the opposite distribution of warm and cold advection zones, and the positive anomaly of air temperature is formed in the study region.

The results of the previous studies indicate a trend towards a decrease in the number of days with the meridional (C) and western (W) circulation types and a significant increase in the number of days with the eastern (E) type in the cold season (November–April) during the period from 1891 till now. In summer (March–October), there is a trend towards an increase in the number of days with the C and E types due to a significant decrease in the frequency of days with the W form [16].

The frequency of occurrence (the number of days with a specific circulation form) was calculated for each season and for each circulation form for every year of the period of 1920–1950 and for the period of 1985–2015 characterizing the modern warming. The results are presented in Table 1. The temporal variations for each circulation form during the analyzed periods and the linear trends are shown in Fig. 2. As follows from Table 1, the highest frequency in 1920–1950 is observed for the E circulation type (80 days

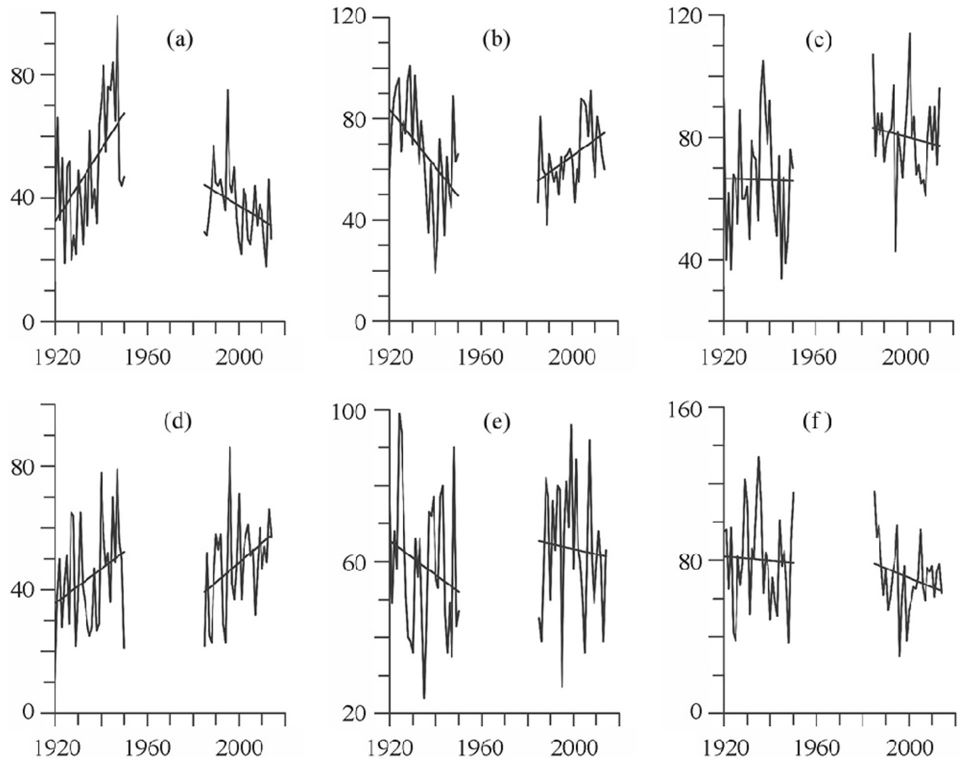

Fig. 2. The temporal variability of the frequency (days) of circulation forms over the periods of the first (1920–1950) and modern (1985–2015) warming for (a, b, c) the cold and (d, e, f) warm seasons. (a, d) C form; (b, e) W form; (c, f) E form.

per season); the respective values for the W and C forms are 59 and 44 days. The average values of the frequency insignificantly differ for the periods of the warming; besides, the trends during the period of the warming have the same sign for each circulation form. Both periods of the warming during the warm season are characterized by the increase in the frequency of the C form (Fig. 2d) and by the decrease in the frequency of W and E forms (Figs. 2e and 2f) during 30 years.

During the cold season, there are differences in the frequency of circulation types between the first and current periods of the warming. The most probable circulation type was W (67 days) for the first period of the warming and E (80 days) for the period of the current warming. As a result, under the prevalence of the W type during the first period of the warming, the westerlies intensify and the meridional exchange weakens, whereas the meridional air exchange intensifies during the period of the current warming. The trends in the frequency of C and W circulation forms have different directions. The frequency of the C type increases during the first period of the warming and decreases during the modern period (Fig. 2a); the opposite pattern is observed for the W form (Fig. 2b).

The calculation of the duration of one or another circulation type during the certain number of consecutive days allows assessing how stable or unstable weather conditions were. Such estimate may be an indirect characteristic of the duration of the natural synoptic period proposed by B.P. Mul'tanovskii [15]. Figure 3 presents the frequency of duration for each circulation form during several days. Three gradations of duration were chosen for the analysis: short (1–5 days), medium (5–10 days), and long (>10 days). As clear from the presented figure, the frequency of short periods of circulation type existence with the duration of 1–5 days increased during the period of the current warming. Hence, the number of long periods of existence decreased for each of three circulation forms. Such changes mostly affected the frequency of the C form. Hence, in the period of the modern warming climate is characterized by frequently changing synoptic conditions and, thus, by the less stable weather pattern as compared to the period of the first warming.

The prevalent cyclone trajectories and the spatial field of surface air pressure and air temperature anomalies correspond to each circulation type. The above results indicating a change in weather conditions imply a possible variation in the frequency of severe weather events in the analyzed region. To clarify this issue, the probabilities of occurrence of such hazardous phenomenon as strong wind were estimated using observational data from some weather stations. The wind speed increase up to 15 m/s and more should be

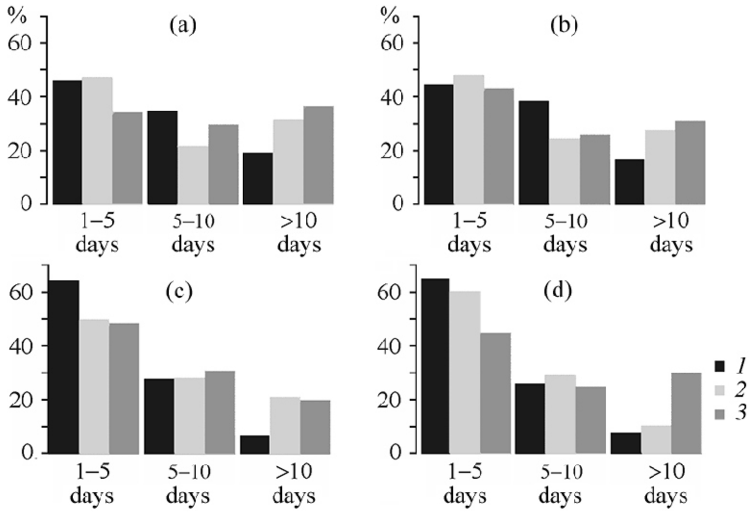

Fig. 3. The frequency (%) of circulation forms revealed during the periods of (a, b) 1920–1950 and (c, d) 1985–2015 for (a, c) the cold and (b, d) warm seasons for the following gradations: short (1–5 days), medium (5–10 days), and long (>10 days). (*1*) C form; (*2*) W form; (*3*) E form.

Table 2. The frequency (%) of cases with strong wind at different weather stations in the cold and warm seasons during the 1920–1950 and 1985–2015 periods of the warming

Weather station	1920–1950		1985–2015	
	Cold season (November–March)	Warm season (April–October)	Cold season (November–March)	Warm season (April–October)
Tikhaya Bay (since 1930)	10.5(3.7)	3.4(1.8)	–	–
Krenkel Observatory	–	–	9.0(3.1)	3.8(2.3)
Vardo	15.7(6.9)	3.3(1.9)	4.8(2.3)	0.9(0.8)
Bear Island	10.2(5.3)	7.4(3.1)	7.3(3.7)	1.8(1.7)

Note: The confidence intervals obtained using the Wilcoxon are given in brackets.

considered as the most hazardous for the area of Spitsbergen. The frequencies of weather conditions with 10-m wind speed exceeding 15 m/s were computed for each period of warming. The calculations were performed for cold and warm seasons, the results are presented in Table 2.

As follows from the table, the occurrence of strong wind during the cold season is by several times higher than in the warm season. According to observations at weather stations located in the southern and central parts of the study area, the period of the current warming is characterized by the decreasing frequency of cases of strong wind as compared to the first period of warming. In the northern part (the observations on Franz Josef Land), differences between the periods are insignificant.

CONCLUSIONS

The analysis revealed differences between circulation patterns during the periods of the first and modern warming. The frequencies of duration of each circulation form insignificantly differ in the warm season during the periods of the first and current warming. The highest frequency of occurrence was found for the E circulation type. During the cold season, the highest frequencies for the first and modern periods of the warming were obtained for the W and E circulation forms, respectively.

The climate regime in the warm and cold seasons of the modern warming is mostly realized as a regime with the short and, hence, frequently changing periods with a certain circulation type. The frequent change of circulation patterns does not favor the formation of significant anomalies of surface air temperature and air pressure and, hence, the formation of conditions for strong wind.

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