Climate research in Arctic regions of Siberia

E V Maksyutova and L B Bashalkhanova
Sochava Institute of Geography SB RAS, Russia, Irkutsk

E-mail: emaksyutova@irigs.irk.ru; ldm@irigs.irk.ru

Abstract. The paper shows the impact of recent changes in air temperature and wind speed on the living conditions of human population in the Arctic regions of Siberia (to the north of 66°N and within 66-162°E). The combined effect of subzero temperatures and wind speed on the thermal status of the exposed surface of the human body was evaluated as a proxy indicator for the severity of the climate. As average monthly temperatures increase, this indicator decreases in the Arctic territories of Siberia. The dynamics of daily fluctuations of threshold values of the weather severity index from October to April from 1966/67 to 2017/2018 has been analysed for the Verkhoyansk station. We found a decrease in the number of days prohibiting and an increase in the number of days restricting a person's stay outdoors. In the more recent period from 1981/82 to 2017/18, a noticeable decrease in the number of days with prohibitive weather conditions was observed. At the same time, little variation was observed in the average number of days with restrictions in outdoor activities over longer time intervals: the difference between 1936-1964, 1966-2018, and 1981-2018 periods was less than five days.

1. Introduction
The geographical position of the Arctic regions of Siberia (66-162°E longitude) has extremely unfavourable climatic conditions for humans. The combination of excessive humidity and lack of heat contribute to the formation of Arctic deserts, tundra and forest-tundra. These landscapes are retreating in the eastern part of the territory (80-162°E longitude) to the north of the Arctic circle, being replaced with Northern taiga landscapes [1, 2]. Here, long (approximately six months) periods with lack of ultraviolet and daylight, low temperatures combined with frequent strong winds, and sharp weather and climatic contrasts influence human activities. Based on the combined effect of these factors, territories are ranked by the level of climate discomfort as very strong, severe and extremely severe.

Previous studies identified an increase in annual temperatures due to fewer days with an average daily temperature below minus 30 °C. The highest rates of annual temperature increase (up to 1.2°C over ten years) were observed in the Arctic deserts. Other territories warmed by 0.4-0.6°C over 10 years [3].

These massive temperature fluctuations in recent decades highlight the importance of assessing their impact on the living conditions in the area. Some publications [4-6] suggest a possible reduction in the frequency of the most severe conditions. At the same time, frequent and rapid temperature changes impose additional requirements for the infrastructure and compliance with policies and regulations for working outdoors.

The purpose of this work is to evaluate the dynamics of fluctuations in the number of days prohibiting and restricting human activity outdoors and quantify these changes and extreme events in the Arctic regions of Siberia.
2. Objects, data and methods
Changes in air temperature for October-April (1981-2015) in the Arctic regions of Siberia were analyzed based on observation records from 23 hydrometeorological stations [7].

The Arnoldi indicator [8] was used to quantify the combined effects of subzero temperatures and wind speed on the thermal status of the exposed surface of the human body. The impact of the weather conditions is most severe at the threshold values of this indicator: the range between 30 and 45 units is considered restrictive, and above 45 units – prohibitive for human activity outdoors. The number of days with such weather conditions is also considered. Restrictive and prohibitive conditions are associated with the risk of frostbite, reduced labor efficiency and increased likelihood of respiratory disorders and exacerbation of chronic illnesses.

The Arnoldi indicator is calculated as follows:

\[ TA = |t - t^*|, \text{ at } t^* = 2v, \]

where \( t \) - is the temperature, °C; \( v \) - wind speed, m/s.

Daily meteorological data recorded the closest to 13:00 of the local time were used to calculate TA to characterize typical workday conditions.

The dynamics of daily values of the Arnoldi indicator was analyzed for the October-April period from 1966/67 to 2017/2018 (52 years) and from 1981/82 to 2017/18 years (37 years) for the Verkhoyansk station [8]. The latter time interval is the closest to the current climatic conditions [9]. The null hypothesis was to find no significant difference between the mean values for the two-time intervals.

The change in air temperature was estimated using regression analysis to determine the statistical significance of the trend (p < 0.05) and the proportion of variance of the dependent variable explained by the model (R²). In the analysis of interannual oscillations, extreme values were identified based on the standard deviation of a series of more than 2 σ.

3. Results and discussion
Air temperature regime in the polar Siberia varies significantly across the region. The average annual temperature in the west (station Marresale, 69°43'N, 66°48'E) is much higher than in the intermountain depressions in the east (station Verkhoyansk, 67°34'N, 133°24'E). Average January temperatures vary from -48.6°C to -21.8°C.

To the west of 80°E longitude, average January temperature does not fall below -27°C, and to the east of 80°E it varies from -28°C in the Yenisei River valley (station Igarka, 67°28'N, 86°34'E) to -37°C in the Srednekolymskiy lowland and -48°C in the Yana River valley (station Verkhoyansk) [10-12].

The analysis of the temperature regime of the more recent time interval (1981–2015) has demonstrated the following. Average monthly air temperatures recorded near 13:00 of the local time decrease from -10°C in October to -25°C (station Vise, 79°30'N, 76°59'E), and -27 to -30°C (stations Golomjannyi, 79°33'N, 90°37'E and Kotelnii, 76°00'N, 137°52'E) in January-February, rising to -18°C in April. In the subarctic tundra landscapes (Dixon, 73°31'N, 80°24'E) air temperatures decrease from -7°C in October to -25°C in January-February, and reach -16°C in April. In forest-tundra landscapes to the west of 80°E, average monthly air temperatures show less contrast and vary from -4 to -5°C in October to -24 to -26°C in January and -10°C in April.

More severe conditions to the east of 80°E longitude, where forest-tundra landscapes are common, have a sharp decrease in average monthly air temperatures: from -6 to -12°C in October to -27 to -37°C in January, increasing to -8 to -16°C in April. The lowest temperatures are typical of the northern taiga: -8 to -13°C in October to -35 to -45°C in January and -6 to -12°C in April.

Changes in air temperature (average working day conditions) from October to April for the 1981-2015 period were estimated by regression analysis. In the polar regions of Siberia (except for Igarka and Dudinka stations), there are significant (p<0.05) positive temperature changes (figure 1).
highest rates of warming with a pronounced gradient to the west are observed at high latitudes, where the Arctic glacial and polar desert landscapes are common.

As a result of increasing average monthly temperatures, as well as some decrease in wind activity, there was a minor decrease in the weather severity index in the polar regions of Siberia. It does not have a significant impact on the level of climate discomfort. The lowest number of days rated as restrictive for human activity outdoors was observed in subarctic tundra and subarctic forest-tundra landscapes to the west of 80°E as well as in areas with less climate discomfort (Igarka). The increasing severity of the climate in subarctic forest-tundra landscapes to the east of 80°E is related to the wind-temperature regime in these territories [13].

The previous study [14] indicated that days with weather severity index (Arnoldi indicator) above 45 units were recorded for 1981-2015 only in Verkhoyansk. For that station, we analyzed the dynamics of the number of days rated as restrictive or prohibitive based on the Arnoldi indicator. Only small fluctuations not exceeding 3-5 days were identified for the three-time periods (table 1).

Table 1. The number of days with restrictions for working outdoors recorded at the Verkhoyansk station.

| Arnoldi indicator, units | 1936–1964 [14] | 1966–2018 | 1981–2018 |
|--------------------------|----------------|-----------|-----------|
| more than 45             | 50             | 53        | 51        |
| from 30 to 45            | 74             | 69        | 71        |

A statistically significant decrease in the number of days rated as prohibitive for human activity outdoors (Arnoldi indicator > 45 units) was found during the period from 1966/67 to 2017/2018 (figure 2). Over the shorter time interval from 1981/82 to 2017/18, the number of days rated as prohibitive also decreased significantly at a rate of -0.33 units/year ($R^2=0.11$).

Annual fluctuations in the number of days rated as restrictive show rather different dynamics. For the longer period (from 1966/67 to 2017/2018), the number of such days has a statistically significant positive trend at a rate of 0.19 units/year at $R^2=0.07$ (figure 2). In the shorter period (1981/82 to 2017/18, 37 years), the positive trend remains, but it is not statistically significant. However, the year.
to year variance increases considerably, and the number of restrictive days reaches 94, 94 and 98 in 1980/81, 1990/91 and 2011/12, respectively.

**Figure 2.** Dynamics of the number of days prohibitive (a) and restrictive (b) for human activity outdoors recorded at the hydrometeorological station Verkhoyansk: 1 – number of days per winter 2 – deviation from the mean "-σ", 3 – deviations from the mean "+σ", 4 – linear trend.

The amplitude of fluctuations in the number of prohibitive and restrictive days per year was 51 and 46 days, respectively during the long-term period (years 1966/67 to 2017/2018), and 46 and 43 days respectively during the shorter period (years 1981/82 by 2017/18).

Frequency of extreme weather conditions presents a considerable concern for the population health and economic activity. During the observation period, the number of days rated as prohibitive ranged from 26 days in 2005/06 to 77 days in 1971/72, and the number of days rated as restrictive – from 94 days in 1980/81 and 1990/91 to 98 days in 2011/12.

**4. Conclusion**

Modern climate fluctuations in the Arctic regions of Siberia have a complex effect on the living conditions of the population. While the average temperatures increase in the Arctic, the climate in the region remains severe. This is reflected in the dynamics of the number of days when weather conditions limit outdoor activity. During the observation period from 1966/67 to 2017/2018, there was a decrease in the number of days with weather conditions prohibitive for human activity outdoors, and the number of days rated as restrictive has increased. During the period from 1981/82 to 2017/18, the number of days with prohibitive weather conditions continued to decline.

Extreme weather conditions and events pose a considerable danger to life and health of the human population and place additional demands on the infrastructure and compliance with policies and regulations for working outdoors.

**References**

[1] Budyko M I 1971 *Climate and life* (Leningrad: Gidrometeoizdat) p 472
[2] Isachenko A G 2002 *Map Landscapes Ecological Atlas of Russia* (Moscow: Publishing house Map) pp 6-7
[3] Bashalkhanova L B and Maksyutova E V 2015 Climatic conditions of the human life in the northern margins of Siberia *Geography and Natural Resources* 3(36) 271-7
[4] Alekseev G V 2014 Arctic dimension of global warming *Ice and Snow* 2(54) 53-68
[5] Kattsov V M and Porfiliev B N 2012 Climate change in the Arctic: consequences for the environment and economy *Arctic: Ecology and Economy* 2(6) 66-79
[6] Vinogradova V V 2019 Universal index of thermal comfort in Russia *Izvestiya RAS Geographical series* 2 3-19
[7] Bulygina O N, Veselov B M, Razuvaev V N and Alexandrova T M Description of urgent data
array on the main meteorological parameters at the stations of Russia Certificate of State Registration of the Database № 2014620549 Income accessed online on 07th of May 2019 via http://meteo.ru/data/

[8] Arnoldi I A 1961 Hygienic issues of acclimatization of population in far North Hygienic Issues of Acclimatization of Population in far North (Moscow: Medgiz) pp 7-22

[9] Second assessment report of Roshydromet on Climate Change and its Consequences on the Territory of the Russian Federation 2014 (Moscow: Roshydromet) p 1009

[10] Handbook of climate of the USSR 1967 Vol. 17 Part II (Leningrad: Gidrometeoizdat) p 275

[11] Handbook of climate of the USSR 1966 Vol. 21 Part II. (Leningrad: Gidrometeoizdat) p 503

[12] Handbook of climate of the USSR 1967 Vol. 24 Part II (Leningrad: Gidrometeoizdat) p 398

[13] Maksyutova EV and Bashalkhanova LB 2019 Severity of the present-day climate in the Polar regions of Siberia Ice and Snow 2(59) 258-66

[14] Rusanov V I, Yakovenko E S and Stroiteleva G P 1977 Bioclimatic Atlas of Siberia and the Far East (Tomsk: Tomsk state University Press) p 106