Evaluation of changing weather and climate comfort conditions in Russia from 1980 to 2050

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Abstract. This study examined the variations in weather and climate comfort in Russia. For retrospective analysis (1980-2015), reanalysis data were used, for the future (2020-2050) were made using calculations on the climatic model of the Marchuk Institute of Numerical Mathematics RAS. The results using the data from the RCP8.5 ("hard" scenario) suggest that in areas with a strongly continental climate winters get more comfortable, but summers get less comfortable. At the same time, there is also a tendency to smooth out and almost complete absence of a seasonal course of comfort. In regions that are characterized by a temperate continental climate there is a tendency to increase comfort in winter, a decline in autumns and springs and almost no changes in the summer. In areas with oceanic type of climate, a decrease in comfort in winters is expected, as well as in autumns and springs.

1. Introduction
Predicted and observed climate change entails an increase in the relevance of studies of the dynamics of weather and climatic conditions in specific areas. Thereby it is becoming increasingly important to study the variations of the influence of these changing conditions on the life activity in terms of the comfort of living [1,2]. Knowledge of the thermal comfort also ensures adequate warning for future extreme climate scenarios and for adequate preparation of humans and their livelihood against extreme climate conditions [3]. The consequences of the expected climate change on the living conditions can be both positive and negative. On the one hand - mitigating the severity of the climate, on the other hand- negative consequences, for example, with possible degradation of the permafrost [4].

It is proposed by the term "weather and climate comfort" – a generalized characteristic of the environment that has an impact on human health, the conditions of residence and work activity. The study of weather and climate comfort variations is mainly required for the timely assessment of adverse situations with a view to preserving human health and livelihood by taking the necessary preventive measures.

2. Materials and methods
Many attempts have been made to estimate the stress inflicted by a wide range of weather and climate conditions, or to estimate the corresponding physiological strain and to combine them into a single index. Following this concept Missenard [5] proposed in 1937 the effective temperature ($ET_m$). This
index was originally established to provide a method for determining the relative effects of air temperature and humidity on comfort. Since then some modifications were made to this basic index. For the present discussion one index, which is in daily use for many years are regarded. The effective temperature can be used to assess the environment comfort, both on a time-scale of several hours or days, and on seasonal, annual and climatic scales. It is calculated as follows:

\[
ET_m = t - 0.4(t - 10)\left(1 - \frac{f}{100}\right),
\]

where \( t \) – air temperature (°C), \( f \) – relative humidity (%).

Usually the effect on a person is considered to be a thermal sensation by the values of the effective temperature based on the categories of heat / cold load developed in [6]. In this work gradations of weather and climate comfort were developed according to the effective temperature values of the depending the criteria of physiological effects on humans in five grades: comfort - partial comfort - partial discomfort - discomfort - extreme discomfort (see the table 1).

**Table 1.** Categories of thermal sensations, physiological effect and the associated comfort sensations depending on the values of effective temperature

| \( ET_m \) (°C) | Thermal sensation | Physiological effect | Comfort sensation |
|----------------|-------------------|----------------------|------------------|
| ≥+30           | Very hot          | Incomprehensible heat| Discomfort       |
| +24..+30       | Hot               | Slightly uncomfortable| Partial discomfort|
| +18..+24       | Warm              | Comfort              | Comfort          |
| +12..+18       | Slightly warm     | Neutral              | Partial comfort  |
| +6..+12        | Slightly cool     | Neutral              | Partial comfort  |
| 0..+6          | Cool              | Neutral              | Partial comfort  |
| -12..0         | Cold              | Slightly uncomfortable| Partial discomfort|
| -24..-12       | Very cold         | Uncomfortable        | Discomfort       |
| -30..-24       | Extremely cold    | Incomprehensible cold| Extremely discomfort|
| ≥-30           | Extremely cold    | Incomprehensible cold| Extremely discomfort|


The following data were used to calculate the effective temperature values from 1980 to 2050:

- **1980-1995** – NCEP Climate Forecast System Reanalysis (CFSR) [7], spatial resolution 0.3125° x 0.3125°;
- **2000-2015** – NCEP FNL Operational Model Global Tropospheric Analyses [8], spatial resolution 1° x 1°;
- **2020-2050** – data of calculations on the climatic model of the Marchuk Institute of Numerical Mathematics RAS (RCP8.5 – "hard" scenario [9], spatial resolution 2° x 1.5°.

Calculations according to data from 1980 to 2015 are performed for completeness of analysis.

3. Results

The results of calculations from 1980 to 2050 with a step of 10 years for Russia are presented in the figures, which show the categories of weather and climate comfort according to the effective temperature index values in January (Figure 1) and in July (Figure 2) in gradations from "comfort" to "extreme discomfort". Analysis of the dynamics on that territory has revealed quite significant changes in the degree of weather and climate comfort. In general, in January (Figure 1) there is a tendency to change the degree of comfort towards comfort. This is especially evident in the central regions of the European territory of Russia, the Southern Urals and the southern regions of Siberia,
where from 1980 to 2050 the degree of comfort in the winter increased from uncomfortable to partial uncomfortable, and sometimes to partial comfort.

Figure 1. Level of weather and climate comfort for January 1980-2050.

For detailing the analysis of changes in the degree of comfort in different climatic zones, the interannual variability of the average monthly values of the effective temperature index in qualitative gradations of the comforts degree in several towns located in different climatic zones was examined: Moscow, temperate continental climate; Astrakhan, moderate strongly continental climate; Yakutsk, strongly continental climate; Murmansk, a temperate oceanic climate [10]. The results of the calculations are shown in Figure 3.
Figure 2. Level of weather and climate comfort for July 1980-2050.

According to the calculated data in Astrakhan (Figure 3) during the considered period of the 20 century, winters were “partial comfortable”, at the beginning of the 21st century (2000-2005) partial uncomfortable, and the tendency to warming began from 2010: degree of comfort began to increase. A similar dependence is observed in the summer: partial uncomfortable conditions change to comfortable ones. At the same time according to the RCP8.5 scenario in the period 2020-2050 there is a tendency to smooth seasonality. Changes in the degree of comfort in the autumns and springs in 1980-2050 were not identified. Thus, the winters become warmer (and more comfortable), and the summers get cooler and colder and, accordingly, less comfortable.
Figure 3. Level of weather and climate comfort in Astrakhan, Moscow, Murmansk, Yakutsk for January, April, July and October 1980-2050.

The same relations have been identified in Yakutsk (Fig. 3), only in this town winters become partial uncomfortable from the extremely uncomfortable by 2020. Moscow (Fig.3) is characterized by a stable preservation of partial comfortable conditions in the summer for the whole period, winters until 2020 are characterized as uncomfortable and partial uncomfortable, spring and autumn - partial comfortable and partial uncomfortable. According to scenario experiments after 2020 winters become more comfortable and on the contrary the autumns and springs get more uncomfortable.

The opposite trend is revealed in Murmansk (Fig.3) – winters get more uncomfortable. There were no extremely uncomfortable conditions in Murmansk until 2015, and 1995-2005 is a period of increasing the comfort degree to partial discomfort. Then, after 2020, according to calculations, the winters are characterized as extremely uncomfortable. The same dependencies are also observed in autumns and springs. The summers are characterized by a fairly smooth course of comfort from year to year, and conditions are defined as partial comfortable.

4. Conclusions

The results indicate that Russia is characterized by considerable heterogeneity of weather and climate comfort. Favorable (comfortable) conditions are observed only in the limited areas. This is due in large part to significant changes in air temperature, which is the determining parameter in calculating the applied effective temperature index.

The results obtained using the data from the RCP8.5 scenario suggest that in areas with a strongly continental climate, winters get more comfortable, but summers get less comfortable. At the same time, there is also a tendency to smooth out and almost complete absence of a seasonal course of comfort. In regions with a temperate continental climate, there is a tendency to increase comfort in winter, a decline in autumns and springs and almost no changes in the summer. In areas with oceanic
type of climate, a decrease in comfort in winters is expected, as well as in autumns and springs. These features can be associated with changes in the humidity regime, since it is the increase in air humidity in the cold seasons that reduces comfort.

The results may be important for the regionalization of the territory of Russia from the point of view of the livelihood comfort when planning the spatial and socio-economic development of Russia.

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