Climate variations and changes in extreme climate events in Russia

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Abstract
Daily temperature (mean, minimum and maximum) and atmospheric precipitation data from 857 stations are used to analyze variations in the space–time distribution of extreme temperatures and precipitation across Russia during the past six decades. The seasonal numbers of days (N) when daily air temperatures (diurnal temperature range, precipitation) were higher or lower than selected thresholds are used as indices of climatic extremes. Linear trends in N are calculated for each station for the time period of interest. The seasonal numbers of days (for each season) with maximum temperatures higher than the 95th percentile have increased over most of Russia, with minimum temperatures lower than the 5th percentile having decreased. A tendency for the decrease in the number of days with abnormally high diurnal temperature range is observed over most of Russia. In individual regions of Russia, however, a tendency for an increasing number of days with a large diurnal amplitude is found. The largest tendency for increasing number of days with heavy precipitation is observed in winter in Western Siberia and Yakutia.

Keywords: climatic extremes, daily temperature, precipitation, regional and seasonal features

1. Introduction

Research on the frequency of extreme meteorological values and climatic events is one of the most important problems in studying climatic change. The idea is that global warming shows up, among other things, in the increasing number of extreme events, such as droughts, floods, long-lasting abnormally high and abnormally low air temperatures, destructive tropical cyclones, etc. This provokes grave concern in the world community. Studying climate and weather extremes is declared to be one of the major activities of the World Meteorological Organization.

IPCC experts regularly meet to coordinate investigations of climate extremes. Since even a moderate change in the mean can give rise to a relatively large change in the probability of rare extremes and the climate of different regions of the world varies over wide limits, it is required that the change in regional mean and extreme characteristics be studied in more detail. One of the first meetings (Asheville, NC, USA, 1997) held to coordinate investigations in different countries and to obtain comparable results recommended using temperature indices that reflect the extreme character of the climate (Folland et al 1999).

Here index 1 is used to denote daily, monthly, seasonal and annual values of maximum, minimum and mean air temperature above or below the 2, 5, 10, 90, 95 and 98% distribution intervals. These indices have been used in studies by many scientists from different countries. Domonkos (2001) studied long periods (several weeks) of extremely low and extremely high temperatures over the territory of Hungary. The 5% interval of the temperature distribution was used as a threshold value. Yan et al (2001) used 10 and 90% intervals as threshold values to determine three periods in the change of temperature extremes: the decrease in warm extremes in the
late 19th century, the decrease in cold extremes in the first half of the 20th century, and the increase in warm extremes starting from the 1960s. The previous decrease and the current increase in warm extremes prevail in summer, and a tendency for the decrease in cold extremes in winter is observed throughout the period in question. The analysis of the time series of daily air temperatures for some of the European and Chinese stations that have the longest series made the authors conclude that abnormally high temperatures in winter are increasing to a greater extent than abnormally low temperatures, i.e. the temperature variability decreases in winter and increases in summer.

Another study that employs this index was conducted for Australia and New Zealand. Plummer et al (1999) analyzed the series of daily precipitation totals from 379 Australian stations for the period 1910–1995. The value of the 99% interval was used as a threshold to determine the extreme character of daily precipitation totals. Calculations were also made with the threshold 25.4 mm/day (one inch). The calculations were made for individual parts of Australia (northwest, northeast, southwest and southeast) and for the whole of the country. The heaviest rain was found to be recorded in summer and in fall in the north of Australia. The south of the country exhibits a uniform seasonal distribution. An increased value of the 99% interval was recorded in most of the seasons and the parts. For the whole of Australia, a slight 5% increase in the annual number of days with precipitation more than 25.4 mm was recorded.

Jones et al (1999) used in their article definite temperatures, apart from the values of the 90 and 10% intervals, as threshold values to study the change in the frequency of temperature extremes over the British Isles. For the winter season, the number of days and the sum of degree days with temperatures below 0 °C were determined, while for the summer, these were determined with temperatures above 20 °C.

The same threshold value to study temperature extremes in northern and central Europe was chosen by Heino et al (1999) and the extreme character of precipitation was studied by using the number of days with precipitation higher than or equal to 10 mm. The authors considered another index that was recommended in Folland et al (1999), i.e. the difference between annual maximum and minimum temperatures (DTR). The studies revealed the decrease in the daily temperature amplitude and in the number of frosty days (with temperatures below 0 °C), while the series of daily precipitation maxima and the number of days with precipitation more than 10 mm exhibit no great changes.

This work is built on previous investigations of extreme climate in Russia (Gruza et al 1999). In this paper, the change in daily temperatures and precipitation extremes in Russia are studied for the two periods, 1951–2006 and 1977–2006.

2. Data

To analyze variations in the space–time distribution of extreme temperatures and precipitation at individual Russian stations for the last few decades, daily temperature (mean, minimum and maximum) and atmospheric precipitation data are used. A daily data set has been prepared at the RIHMI-WDC (Obninsk, Russia).

The Russian Institute for Hydrometeorology Information (RIHMI-WDC) is responsible for creating and maintaining the State Hydrometeorological Data Holding. The observations from the Russian meteorological stations come regularly to the Data Holding’s archives. The number of active stations varies with time. The maximum number of the stations was recorded in the 1980s (more than 2000). Currently, there are about 1500 active stations in Russia.

In creating historical meteorological series, particular attention is to be given to data quality control and elimination of data inhomogeneity (NCDC 2005). There are different reasons for data inhomogeneity in Russia. On the one hand, this is due to the change in the observation procedure (change in observation frequency). Data homogeneity is also disturbed by the change in meteorological data processing procedures (e.g. introduction of wetting corrections into precipitation observations), instrumental change and displacement of meteorological stations.

Meteorological data sets are subject to the first automated control while these are prepared to be archived at the RIHMI-WDC (Veselov 2002). Visual screening for time-dependent biases and quality control routines further reduced the number of stations used for our analyses to 530 for the period 1951–2006, and to 857 stations for the period 1977–2006.

3. Method

The total number of days for each season when daily air temperatures (diurnal temperature range, precipitation) were found to be higher or lower than some of the fixed limiting values was used in this case as an index of climatic extremes. To this end, daily values for each month for the time period of interest (1951–2006) were arranged in order of magnitude, and 5 and 95% percentiles were defined for each station on a monthly basis. All values falling within the intervals ranging from the lowest percentile to the 5th percentile and from the 95th percentile to the highest percentile for the time period of interest were considered as daily extremes. The number of days, N, when daily temperatures, diurnal temperature range or precipitation were within the above-mentioned intervals was determined for the seasons of each year (Gruza et al 1999).

Linear trends for the number of days were calculated for each station for the time period of interest. Any trend analysis is a simplistic way to describe what has happened on average during the period under consideration. Linear trend analysis gives a mean rate of this change. It cannot be extrapolated and does not deliver the entire picture if there is a nonlinearity. There are always nonlinearities and this is always an approximation.

Each point estimate of trends for most climatic variables for the past 30–50 years is condemned to be statistically insignificant because of ‘weather noise’, a high level of micrometeorological variability and, sometimes, due to nonlinearities of climatic changes. Outliers in these fields
4. Results

4.1. Temperature regime

Seasonal and regional features in variability of temperature extremes are notable against the background of the increase in mean annual air temperature averaged over the Russian territory (Figure 1). Figures 2–5 show a space distribution of coefficients of the linear trend in the numbers of days with abnormally high air temperature for the four seasons for the period 1951–2006. In winter and spring, the tendency for the increase in the number of days with extremely high temperatures is prevailing over the Russian territory. In summer and in fall, the areas with negative coefficients of the linear trend are found in central and northern regions of Russia and in central European Russia, respectively. In Western Siberia, the tendencies for abnormally high air temperatures are prevailing. In southeast Russia, the number of days with extremely high air temperatures increases in all the seasons.
Figure 6. Linear trend coefficient (days/10 years; 1%–5% significance level) in the time series of days with abnormally high air temperatures in winter (December–February). Time period 1977–2006.

Figure 7. Linear trend coefficient (days/10 years; 1%–5% significance level) in the time series of days with abnormally high air temperatures in summer (June–August). Time period 1977–2006.

Summer extreme temperatures contribute to the increase in the number of fires in this region (Groisman et al. 2007). Exceptions include the decreased number of days with high temperatures recorded in Chukotka, in winter, and in Yakutia, in fall. For the period 1977–2006 (figures 6 and 7), higher coefficients of the linear trend are recorded in the numbers of days with abnormally high air temperatures. At the same time, the area in which where the tendency for the smaller number of such days is recorded increased in winter and decreased in summer.

In the past decades, the temperature regime has become less extreme in terms of abnormally low air temperatures (figures 8 and 9). It is in the territory of European Russia alone where the tendency for an increased number of days with extremely low air temperatures is found in the north of the territory in winter and in the west in fall. In the period 1977–2006, the winter space distribution of the linear trend coefficients in the time series of abnormally low temperatures exhibited areas of positive values in Chukotka, the south of Western Siberia and central European Russia (figures 10 and 11). This fact deserves particular attention, since the number of days with abnormally low air temperatures is increasing against the background of the mean air temperature rise in central European Russia.

Negative tendencies prevail in the space distribution of linear trend coefficients in the series of the number of days with an abnormally large diurnal amplitude of air temperature (figures 12 and 13). However, the central and northwestern regions of European Russia experience an increased number of days with a large diurnal amplitude. Higher extremeness of temperature conditions, which appears as large diurnal air temperature differences, is also recorded in the Amur Region and the Khabarovsk Territory. In the spring–summer season, the number of days with a large diurnal amplitude increases in the east of Chukotka. The peculiar features of the space distribution of the linear trend coefficients in the time series of the number of days with a large diurnal amplitude of air temperature are also typical for the period 1977–2006, with the...
values derived being larger in magnitude. Thus the tendency for the increased number of days with a large diurnal amplitude is found against the background of the lower change in diurnal air temperatures in individual regions of Russia.

4.2. Precipitation regime

The character of variability in the number of days with extremely large daily precipitation over Russia is different. An increasing number of days with precipitation exceeding the 95% percentile in winter is found at stations in the north of European Russia and in Siberia for both periods (figures 14 and 15). Negative linear trend coefficients in the time series of the number of days with heavy precipitation are only observed at individual stations in eastern and European Russia (for 1977–2006). In spring, precipitation conditions are found to be more extreme in the Urals and Western Siberia for the two periods, and in southern and eastern Yakutia for the period 1977–2006. In summer, no significant linear trend coefficients were found for the period 1951–2006. According to the data for the period 1977–2006, a reduced number of days with heavy precipitation was found in the south and southwest of European Russia, the north of Western Siberia, in Chukotka, and the southern Far East. Individual stations in Western Siberia show a tendency for an increase. According to the 1977–2006 data, the fall season is characterized by higher extremeness related to heavy precipitation over most of Asian Russia (figure 16).

5. Conclusions

Research on extreme climate characteristics made it possible to reveal regional and seasonal features in the change of extremeness of temperature and precipitation conditions. The number of days with abnormally low air temperatures that is increasing against the background of the mean air temperature rise deserves particular attention and further
investigation. The tendency for an increased number of days with extremely low air temperatures is found in European Russia in the north of the territory in winter and in the west in fall. In the period 1977–2006, the winter space distribution of the linear trend coefficients in the time series of abnormally low temperatures exhibited areas of positive values in Chukotka, the south of Western Siberia and central European Russia.

The tendency for an increased number of days with a large diurnal amplitude is found against the background of the lower change in diurnal air temperatures in individual regions of Russia (section 4.1—figures 12 and 13).

Linear trend coefficients derived from the data for the past 30 years in the series of the number of days with extreme temperatures increased as compared with those for the period 1951–2006. According to the 1977–2006 data, the fall season is characterized by higher extremeness related to heavy precipitation over most of Asian Russia (section 4.2).

In this paper, linear trend analysis is a first step to report what has happened. We give the mean rate of changes for the period in question in one number (mean slope, i.e., linear trend). This mode of presentation for linear trends does not yet deliver statistically significant estimates but might show a pattern of changes. Further study of homogeneity of the daily data may be necessary to obtain greater detail concerning recent trends in extremes.

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