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# Climate change in Kazakhstan during the past 70 years

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ABSTRACT

The changes of the air temperature and the precipitation in the whole territory of Kazakhstan were studied for the period from 1941 to 2011. The mean annual air temperature and the mean annual precipitation were used as the main indicators of the regional climate and the seasonal changes were analyzed for further characterizing the variation in the air temperature and precipitation. The abnormality index *K* was adopted for assessing the changing trends of the climate extremes. Our results sufficiently demonstrated increasing trends of the air temperature during the studied period (1941–2011) in Kazakhstan for all seasons. A weak decreasing trend of the annual precipitation was also detected. Accompanying the observed warming were: a dramatic increase in the daily temperature maximum, a significant increase in the number of days with the air temperature higher than 35 C, and a decreasing trend of days with the minimum daily temperature below 0 C.



## 1. Introduction

Earth's climate has been sufficiently documented to have changed both on global scale and on regional scales (Folland et al., 2001; Bengtsson et al., 2004; Gruza and Ran'kova, 2004; Shkolnik et al., 2006; Klimenko, 2011; Perevedentsev et al., 2012). Most relevant to this research is the Asian Arid Zone (35–55°N; 60–120°E) within which Kazakhstan is situated. The Asian Arid Zone is a geographic region that has been documented to be extremely sensitive to climate change during the last 100 years and is expected to be severely impacted by projected future warming (IPCC, 2007). The close association between the observed drying trend and the observed warming trend during the past 100 years further affirms the sensitivity of the Asian Arid Zone to natural and human-induced environmental changes and illustrates that this region is at high risk in the future for water resource availability and ecological security.

Climatologically, Kazakhstan is protected by the W–E striking Tianshan Mountains approximately along the 40th parallel, blocking the climatic influence of the Arabian Sea from the south and allowing the climatic dominance of the westerlies from the west (Bridgman and Oliver, 2006). The warm-season precipitation is primarily from the North Atlantic via the northward-shifted westerlies, whereas the cold-season precipitation is primarily from the Mediterranean Sea via the southward-shifted westerlies (Bothe et al., 2011). Frequent southward invasions of the polar front are the most important precipitation-promoting mechanism (Aizen et al., 2001). The cold-season climate in the study area is modulated by the interactions between the North Atlantic Oscillations (NAO) and the Siberian High. The warm-season climate is controlled by the interactions between the Asian Low occupying the interiors of Asia and the Azores High (Meeker and Mayewski, 2002).

## 2. Regional setting

Kazakhstan, situated near the center of vast Eurasian continent, is an inaccessible area for the Pacific and Indian air masses. It is on the path of westerlies that bring water vapor from the North Atlantic. However, the water influx in the air is normally extremely low after a long-distance travel. The frequent invasions of the Siberian air masses during winters make the area extremely cold. The climate in Kazakhstan is characterized by two major features: high continentality and frequent droughts.

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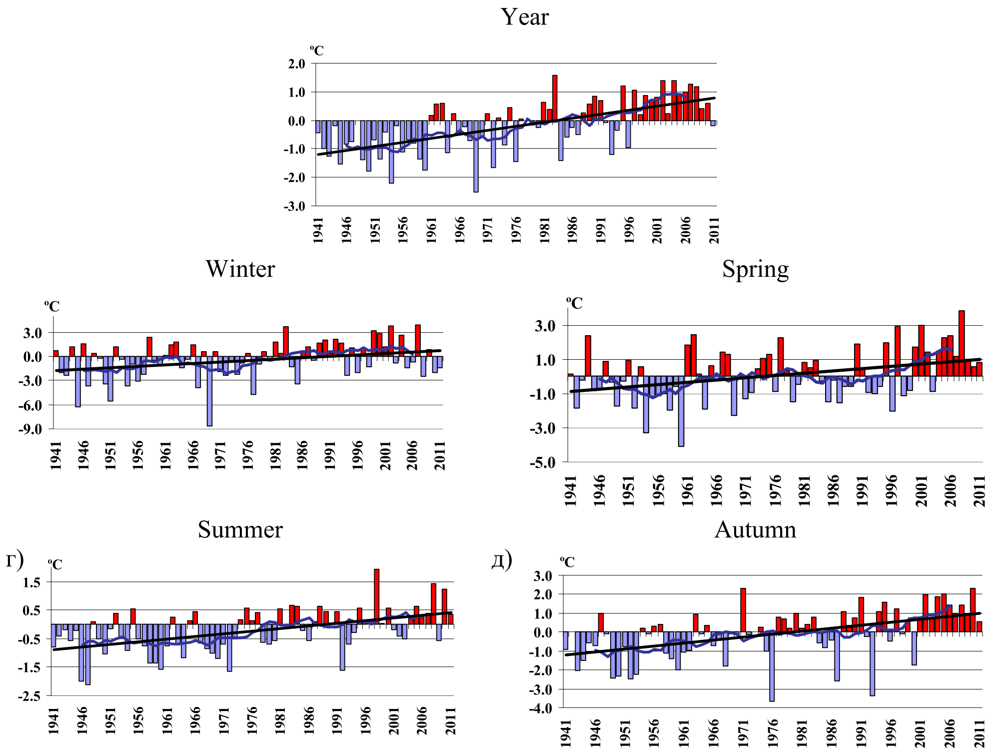


**Fig. 1.** Time series and the abnormalities of the annual and seasonal air temperatures for the period from 1941 to 2011 across Kazakhstan. The abnormalities are calculated as the deviations from the norms that are defined as the average values for period from 1971 to 2000. The fitted curve was derived using an 11-year moving averaging method.

The mean January temperature is −15 C with the minimum mean January temperature reaching −40 C. Strong snowstorms, blizzards and freezing drizzle during winters are common. The summers are fairly hot, with the maximum mean July temperature up to 40 C in the low-lying steppes and desert steppes. The mean annual precipitation is 250–350 mm in the northern regions of the country and is only 100–120 mm in the southern regions. Correspondingly, the atmospheric humidity at 1:00 pm during the hottest month (July) is about 39% in the northern regions and is only 17% in the southern regions. The climates in the Tianshan Mountains along the southeastern margin of Kazakhstan are complicated by such topographic factors as elevation, aspect, relief, and others.

## 3. Materials and methods

First, mean monthly air temperature and mean monthly precipitation from 190+ meteorological stations were obtained for the period from 1941 to 2011 to assess the monthly trends. Second, minimum and maximum daily air temperatures and mean daily precipitation from 80+ meteorological stations were obtained for the period from 1941 to 2011 to assess the daily trends. Third, the long-term mean annual values (monthly and daily) for the period from 1971 to 2000 were taken as the “norms”. The air temperature abnormalities were then calculated as the deviations of the observed values from the norms and the precipitation abnormalities were considered as the deviations from the corresponding norms. Fourth, the assessment of air temperature and precipitation tendencies was conducted for the 14 administrative regions of Kazakhstan according to the station-observed data within each one of the 14 regions. Fifth, the climate change indices introduced by the World Meteorological Organization (2013) were used for assessing the tendencies in the extremes of air temperature and precipitation.

## 4. Results and discussion

### *4.1. Temperature*

The assessment of the seasonal variations in the air temperature was carried out for the whole territory of Kazakhstan (Fig. 1) and the average rate of the temperature change (C°/10-year) was calculated for each of the 14 administrative regions (Fig. 2). Fig. 1 shows that the surface air temperature has been generally rising for the studied period (1941–2011) during all seasons. The mean annual air temperature has increased by a rate of 0.28 C°/10-year in Kazakhstan. The greatest warming occurred during the winters with an average rate of 0.35 C°/10-year and the least warming happened in summers with the average rate of 0.18 C°/10-year. The rate was 0.32 C°/10-year in autumns and 0.27 C°/10-year in springs. The trends observed in the total variance of the mean annual temperatures are statistically significant at 95% confidence level in most cases.

When the trends were examined for each one of the 14 administrative regions, a spatial pattern emerged. The mean annual air temperatures increased at a fastest rate in West Kazakhstan Province, 0.37 C°/10-year. The slowest increasing rates were found in South Kazakhstan Province, West Kazakhstan Province, Almaty Province, and Mangystau Province, ranging from 0.24 to 0.26 C°/10-year. The increasing rates were in the range of 0.28–0.31 C°/10-year in the rest of provinces. The winter-warming maximum also exhibited spatial variation. Winter warming was fastest in northern Kazakhstan and also in the Tianshan Mountains along the southeastern margin (Fig. 2). The spatial variations of the warming were not well displayed for other seasons (Salnikov, 2013).

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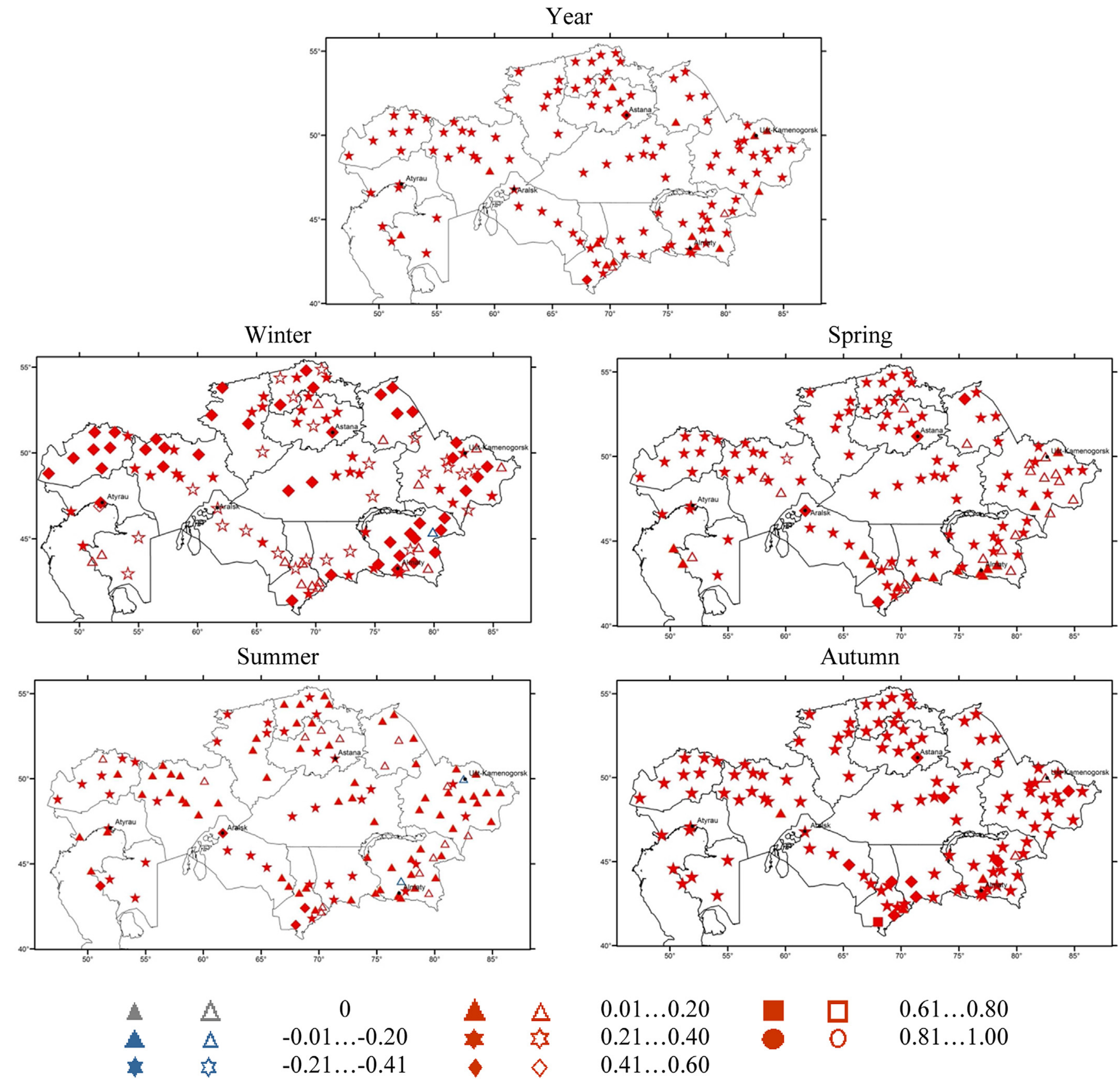


**Fig. 2.** Average rates of the surface air temperature changes (°C/10-year) calculated for the period from 1941 to 2011. Red colors represent increasing rates and blue colors decreasing rates. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

### 4.2. Precipitation

Unlike the air temperature, the tendencies or trends of the precipitation change within Kazakhstan for the studied period (i.e., 1941–2011) do not exhibit strong temporal or ubiquitous spatial patterns. Fig. 3 shows that the mean annual precipitation was relatively high between 1941 and 1971 and relatively low between 1971 and 2011, and this two-segment annual precipitation pattern resulted from a similar pattern of summer precipitation. The winter precipitation seemed to have increased slightly during the past 70 years, and no trend can be observed for autumns or springs. Spatially speaking, an insignificant increase in the annual precipitation was observed in some regions (e.g., Pavlodar, Aktobe, Karagandy, Mangystau and Almaty provinces), whereas an insignificant decrease was observed in other regions (e.g., Akmola, Jambyl, Kyzylorda, Kostanay, South Kazakhstan, West Kazakhstan, Atyrau and East Kazakhstan provinces). Those annual trends were statistically insignificant (Salnikov, 2013).

### 4.3. Extremes of air temperature

Disastrous weather phenomena were observed to have increased during the last decades. For example, summer 2012 was abnormally warm in Kazakhstan, also in neighboring Povolzhye and South Ural. The associated droughts destroyed the grain harvest in Kazakhstan and also caused forest fires in neighboring South Siberia. At the same time, catastrophic floods caused human life and property losses in Krymsk, Krasnodar Krai. The extreme warm summer (2012) was followed by an extremely frosty winter over the whole territory of Kazakhstan.

In this study, we used the abnormality index ($K$) introduced by N.A. Bagrov (Bagrov and Myakisheva, 1966) to define temperature abnormalities:

$$K = \frac{1}{N}\sum_{i=1}^{N}(\Delta T_i/\sigma_i)^2,$$

where $N$ is the number of stations, $\Delta T$ is the abnormality of the average monthly air temperature at the first station, $\sigma_i$ is its average standard deviation.

The $K$ index allows for an effective assessment of the degree of temperature abnormality and also for quantifying the duration and time distribution of the extremes. This index has been successfully used by many authors to assess the air temperatures in the territory of Kazakhstan (Muradov, 1978; Komissarova and Chernova, 1982). The calculated $K$ values from all of 90+ participating stations show that the abnormality index $K$ ranged from 1.15 (maximum) to 0.75 (minimum). The larger the $K$ value, the greater the temperature abnormality is, and vice versa. We calculated the abnormality index $K$ for January (coldest) and July (warmest) for the period from 1940 to 2011 (Fig. 4) and the statistical characteristics are illustrated in Table 1.

**Table 1**
The statistical characteristics of the calculated abnormality index ($K$) values for the period from 1941 to 2011. $K_{max}$: maximum abnormality index; $K_{min}$: minimum abnormality index, $A_k$: average abnormality index.

| Statistical characteristics | Month | |
|---|---|---|
| | January | July |
| $K_{max}$ | 9.81 (1969) | 3.35 (1960) |
| $K_{min}$ | 0.10 (1950, 1985) | 0.17 (1970, 2000) |
| $A_K$ | 8.71 | 218 |

The calculated K values for the whole territory of Kazakhstan varied greatly. For example, January $K_{max}$ was as high as 9.81 (1969) and January $K_{min}$ was as low as 0.10 (1950, 1985). And July $K_{max}$ was 3.35 (1960) and July $K_{min}$ was 0.17 (1979, 2000). As shown in Table 2, significantly negative abnormalities were observed in the first decade of the period (5 cases in 1940–1949), in the second decade (7 cases in 1950–1959), and in the decade of 2000–2009 (3 cases). Significantly positive abnormalities were observed during the decade of 1940–1949 (3 cases) and also during the decade of 1980–1989 (4 cases). The total number of cases with the extreme negative abnormalities for the entire period (1941–2011) was 26, and the total number of cases with the extreme positive abnormalities was 17. Table 2 also shows that abnormally cold January occurred 14 times and abnormally warm January 6 times during the past 70 years. Abnormally cold Julys appeared 12 times and abnormally warm Julys 11 times during the past 70 years.

**Table 2**
The case number of the temperature extremes (per decade): negative (EN) abnormalities and positive (EP) abnormalities.

| Decade | January | | | July | | |
|---|---|---|---|---|---|---|
| | Number of cases | EN years | EP years | Number of cases | EN years | EP years |
| 1940–1949 | 2 | 1940 | 1948 | 6 | 1941, 1945, 1946, 1947 | 1940, 1948 |
| 1950–1959 | 4 | 1950, 1954, 1956, 1957 | | 3 | 1950, 1957, 1959 | |
| 1960–1969 | 1 | 1969 | | 2 | 1960 | 1965 |
| 1970–1979 | 4 | 1972, 1974, 1977 | 1976 | 3 | 1972 | 1974, 1975 |
| 1980–1989 | 1 | | 1983 | 3 | | 1983, 1984, 1989 |
| 1990–1999 | 2 | 1996 | 1992 | 2 | 1994 | 1998 |
| 2000–2009 | 4 | 2006, 2008 | 2002, 2007 | 2 | 2003 | 2008 |
| 2010–2012 | 2 | 2011, 2012 | | 2 | 2010 | 2012 |
| Total | 20 | 14 | 6 | 23 | 12 | 11 |

A general increasing trend of the daily temperature maximum was observed for the whole territory of Kazakhstan. Fig. 5a shows that the eastern part and southern part of Kazakhstan experienced more dramatic increases in the daily temperature maximum, and Fig. 5b shows that the western part and southern part of Kazakhstan experienced significant increases in the number of days with the air temperature higher than 35 C. Correspondingly, a general increasing trend of the yearly heat-wave duration was also observed for the whole territory of Kazakhstan. As shown in Fig. 6, the number of yearly heat-wave days increased more in the western part (2–3 days/10-year) than in the eastern part of Kazakhstan (~1 day/10-year). A general decreasing trend of days with minimum daily temperature below 0 C was observed. The decrease was steeper in the mountainous areas of southern Kazakhstan and the number of cold days (i.e., days with the minimum daily temperature below 0 C) decreased by 5–6 days per decade. The number of cold days decreased by only 1–4 in the rest of the territory.

## 5. Conclusions

1. Increasing trends of the surface air temperature were observed in the studied period (1941–2011) in the territory of Kazakhstan for all seasons. The mean annual air temperatures increased by 0.28 C/10-year for the whole country. The greatest warming occurred during the winters, at a rate of 0.35 C/10-year, and the least warming happened in summers, with a rate of 0.18 C/10-year.
2. A weak decreasing trend (statistically insignificant) of the annual precipitation was detected, and the annual decrease was primarily accounted for by the observed decrease of summer precipitation. The rate of decrease of the annual precipitation was 0.5 mm/10-year, −0.3% per decade.
3. The calculated abnormality index $K$ values show that significantly negative abnormalities were observed in the first decade

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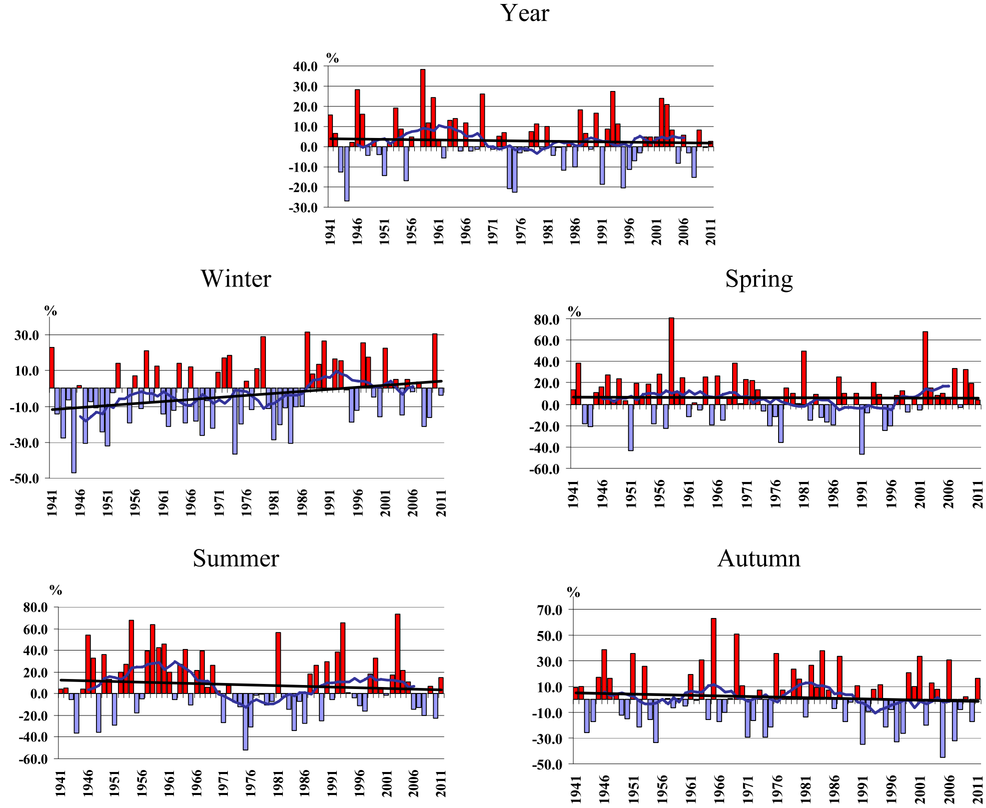


**Fig. 3.** Time series and the abnormalities of the annual and seasonal precipitation (in %) for the period from 1941 to 2011. spatially averaged over the territory of Kazakhstan and its 14 regions. The abnormalities are calculated as the deviations from the norms that are defined as the average values for period from 1971 to 2000. The fitted curve was derived using an 11-year moving averaging method.

of the observing period, in the second decade, and in the decade of 2000–2009. Significantly positive abnormalities were observed during the decade of 1940–1949 and also during the decade of 1980–1989.

4. Accompanying these changes were a dramatic increase in the daily temperature maximum, a significant increase in the number of days with the air temperature higher than 35 C, and a decreasing trend of days with minimum daily temperature below 0 C.

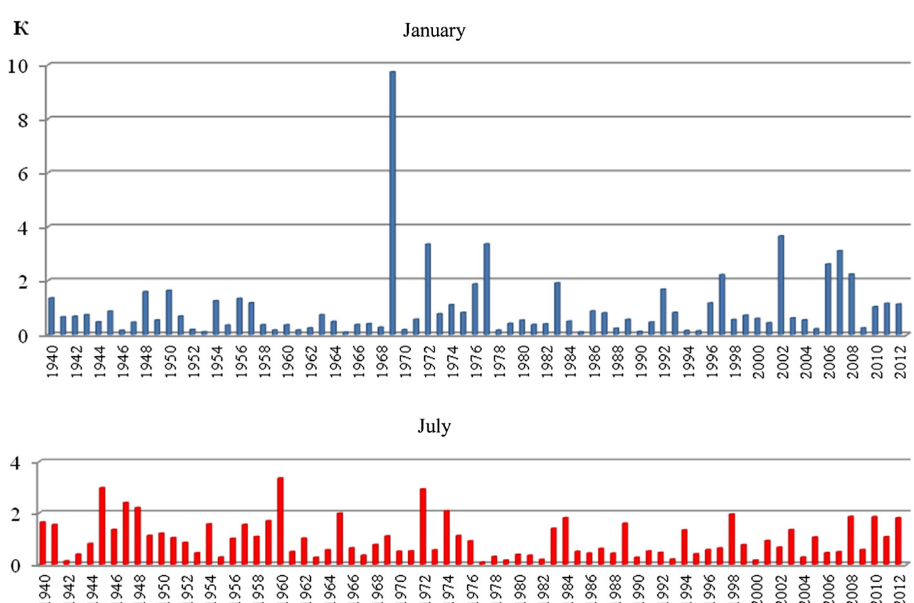


**Fig. 4.** Abnormality index *K* for the period from 1940 to 2011. Upper panel: *K* variation for January; Lower panel: *K* variation for July.

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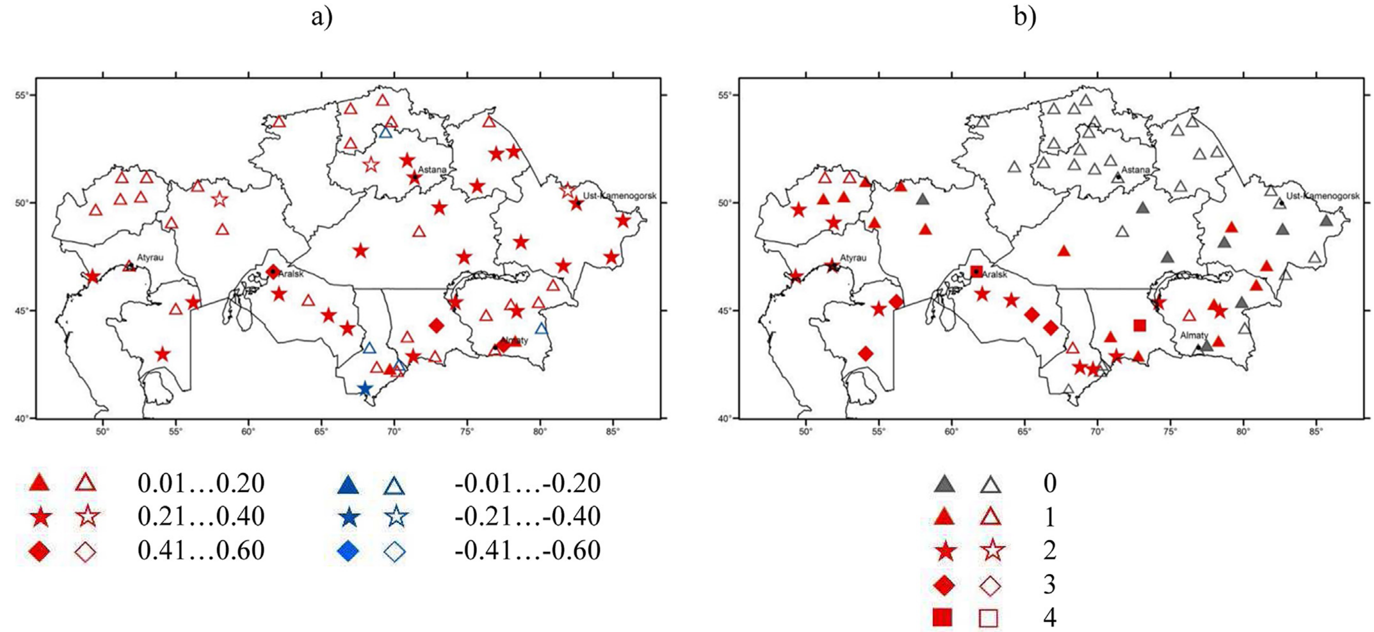


**Fig. 5.** Spatial distributions of the observed increasing rates of the daily maximum air temperature (a. C/10-year) and the number of days with the air temperature higher than 35 C (b. days/10-year) for the period from 1941 to 2011.

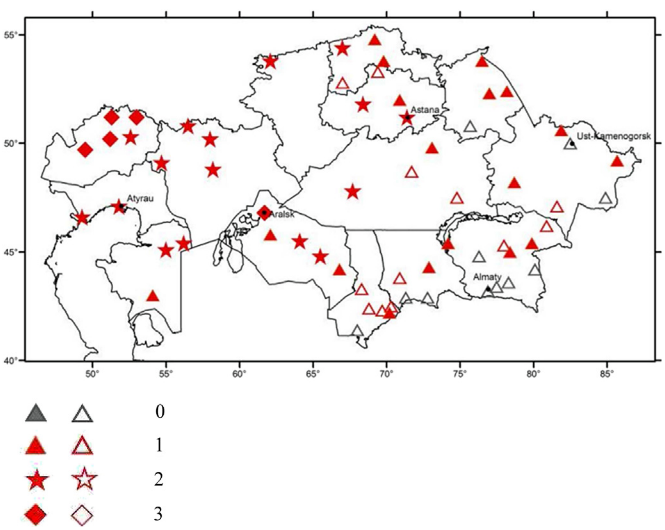


**Fig. 6.** Spatial distribution of the total duration of the heat waves (days/10-year) for the period from 1941 to 2011.

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