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Bioclimatic conditions of the winter months in Western Kazakhstan and their dynamics in relation to climate change

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Abstract

The territory of West Kazakhstan is an intensively developing region. The main oil and gas fields are concentrated there. In addition, this region is well-known as a region of nomad cattle breeding. Both of industry and agriculture demand a lot of employees, working in the open air in wintertime. Severe winter conditions, primary very low temperatures, and strong winds characterize the region. In this work, we calculated and analyzed the spatial and temporal distributions of effective temperatures in the region and their dynamics due to the global warming in the last decades. To calculate the equivalent temperature (WCET) was used the method of OFCM 2003. Nowadays, it is known as a common method for similar studies. It was shown that in the observed region, WCET is significantly lower than the ambient temperature. Repeatability of WCET, corresponding to «increasing risk», «high risk» is high in the main part of the region. Global warming in the region results in returning extremely high temperatures of the air, decreasing repeatability of the average gradation of WCET approximately on 4%, but there is no any visible changing repeatability of extreme WCET. Obtained results can be used for planning any construction work in the open air and agriculture branches.

Keywords Wind chill · Human thermal comfort · Winter weather · West Kazakhstan

Introduction

The climate of Kazakhstan is extremely continental and dry, with high summer and low winter temperature conditions. There are winds there often; sometimes these winds are very strong (Spravochnik 2005). In Western Kazakhstan, low temperatures are caused by strengthening the ridge of the Siberian anticyclone. Usually strong winds are observed on the periphery of the ridge in the presence of cold fronts (when air masses move from the North-West, West and North (Bugaev et al. 1997).

It is known that humans perceive the environmental influences on them very differently. However, in spite of these differences, there is something in common in all living organisms. For example, it is easy to outlast frost and windless weather than not very cold, but windy weather. The presence of the wind in cold weather is perceived as a lower temperature is than the actual one. The stronger the wind, the stronger the temperature differences seem.

During the last century, many scientists tried adequately to measure the feelings of the human body in response to the air temperature, its humidity and wind speed. Epstein and others are acknowledged to have developed the most comprehensive overview of various indices (Epstein and Moran 2006; Soomere and Keevallik 2003; Van laer et al. 2014), although there are other views.

Wintertime in West Kazakhstan is characterized by low temperatures. Therefore, the most appropriate index to evaluate human outdoor comfort during cold months is wind chill equivalent temperature (Siple and Passel 1945; Dixon and Prior 1987). This index combines the effect of low temperatures and the wind speed at a moment in time. Wherein, the difference between measured air temperature and wind chill equivalent temperature (WCET) determines the heat loss under wind influence. Both of wind speed and temperature determine this loss.

No formulas for calculating the effective equivalent temperature discovered in XX century could satisfy scientists

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because the developers took into account different conditions of heat loss. So, in the beginning of XX1 century, an attempt was made to develop a unified method and a standard to calculate the WCET (OFCM 2003; Oscizevski and Bluestain 2005; Bluestain and Zecher 1999). Canadian scientists formed the basis of modern methods of WCET calculation (CWCP 2015). At the same time, other scientists tried to keep the "old" widespread methods or develop new simple methods to assess the influence of meteorological parameters on human heat loss (Shitzer and de Dear 2006; Shitzer and Tukuises 2012; Shabat et al. 2014).

It is not so easy to define the true meaning of "temperature comfort." Depending on age, region etc. for different people it will be different. In this case, a quantitative assessment is not possible. It was suggested to use a biological norm as a temperature range in which a human body can exist (Baranovska and Garbil 1998). But this criterion, also, is not good. Apart from the personal characteristics of a human body, it also might be a result of a habitat or a process of acclimatization (WHO / WMO / UNEP 1996).

It can be assumed that there was an element of subjectivity in weather conditions assessment. In the former Soviet Union and now in Russia, this problem is still in the center of attention. Analogs of (OFCM 2003) were widely used. The most significant investigation of the last several years is one containing WCET assessment in Russia Encyclopedia (2005). There is a series of high-level regional studies (Perevedentsev et al. 2009; Perevedentsev 2009). In contrast with Russian manuscripts, there is a lack of works, dedicated to the WCET problem in Kazakhstan (Beku and Nyssanbayeva 2013), even though the same methods are used in both countries (OFCM 2003).

In the whole territory, the main agricultural activity is nomad cattle breeding, and the main industrial activities are the oil and gas fields. Road transport is also well developed. Naturally, there are other sectors in industry and agriculture, playing a smaller role in the economy of the region.

One of the most important problems of our time is climate change and the assessment of these consequences on specific regions and sectors of the economy (IPCC 2013). The analysis of climate change in the region of Western Kazakhstan is not the goal of this work. However, somewhat earlier the authors of this article performed such work for the entire territory of Kazakhstan (Cherednichenko 2010, 2015; Cherednichenko et al. 2015). Based on the analysis of time series of temperature for the entire period of observations in the region, i.e., approximately from the beginning of the twentieth century. It was found that short-term climatic warming and cooling occurred earlier. Climatic extremes came not at the same time throughout the territory, but spread for several years, from 5 to 15 to 20. As a result, in the territory of Kazakhstan (it is large), it was possible to simultaneously observe a climatic temperature decrease in the northwest and an increase in temperature in the east, etc. The direction of extreme distribution was different. Since about the fifties of the last century, climatic cooling and warming occurred against the background of a general positive temperature trend. In the first years of the twenty-first century, it was noted that in the north-east of Kazakhstan, the temperature increase ceased and its decline began. The temperature dropped for 4 to 6 years, extending from the northeast to the southwest. By 2007, the climatic cooling had already covered the entire territory of Kazakhstan. The performed spectral and harmonic analysis of the time series of temperature has shown that these periodic series converge rapidly, the first three harmonics contain up to 90% of the dispersion. It is important that practically everywhere in the series of temperatures there is a "secular" harmonic containing the main part of the dispersion, the duration of which varied significantly across the territory of Kazakhstan. Approximately, at the beginning of the twenty-first century, these age-old harmonics were at their maximum. This explains the long positive temperature trend in the second half of the twentieth century and the beginning of a drop in temperature at the present time. Other authors indicate the presence of short-term climatic variations in temperature in different regions of Eurasia. Thus, in Zheng et al. (2016), based on an analysis of the tree-ring widths of the Abies furgesii from the Shennongjia area in central China, it has been shown that over the past 245 years, there have been several cases in this region of both the climatic temperature increase and its decrease. As for the current state of climatic temperature, the authors of the Climatic Research Unit (Reading, UK) have for many years already shown the temporal course of global temperature as a practically horizontal line (http://www.cru.uea.ac.uk/.). In these conditions, it is quite natural that in a particular region (ours), the temperature can drop.

Grillakis et al. (2016), using objective indices, investigated how the increase in global temperature in Europe would affect 2 °C in terms of tourism and tourist services. Works of this direction were carried out for Europe and earlier (Amelung and Moreno 2009). Even earlier (Kalkstein and Valimount 1986) estimated the summer discomfort in the USA, using climatological indices taking into account climate change. The effect of summer conditions on the living organism and methods of calculation differ markedly from the assessment of conditions in the cold period.

Many scientists think that wind indices are very useful for cold periods. In contrast to indices for warm periods, they reflect a thermal balance in human body. Naturally, such indices and more in demand in society. The main aim of this research is to use results in any national warning systems, emergency services, for regulation of working hours in the open air. This data might also be used to calculate the effect of cooling rate of various industrial objects, especially oil tubes in West Kazakhstan. Some sorts of oil must be heated, so there is a lot of special equipment for these purposes. The cooling effect might be also taken into account to construct residential houses, agricultural and industrial buildings, and livestock facilities. This way of WCET usage is the most popular in Kazakhstan.

The aim of this work was to study the dynamics of effective temperatures of the cold period in Western Kazakhstan in a changing climate, to obtain statistical characteristics of WCET, suitable for developing recommendations for potential consumers on their use.

Methodology

For WCET analysis in Western Kazakhstan, we used the observations of four weather stations Uralsk, Aktobe, Atyrau, Aktau, Kazakhstan's National Weather Service during the observation period and 50 years: from the sixties of the last century to the present. The timing of the synoptic observations, i.e., 00, 03 ... 21, 24 h of Central European time, which differs from the local time by 5 h. On these monitoring stations were conducted in strict accordance with the instructions, consistent with the requirements of the World Meteorological Organization (WMO). For our problem, we used only the temperature and wind data for the indicated 50-year period.

Station, observation of which we used, are uniformly distributed over a wide area of western Kazakhstan, but at different latitudes and in different geographical conditions (Fig. 1).

It can be seen that the station Uralsk and Aktobe are strictly continental. Aktyubinsk station is located slightly to the north from the 50° of north latitude on the western foothills of the Southern Urals. Uralsk station is located on a plane (51.5° of north latitude). It is located to the west-northwest from Aktyubinsk to 400 km away. Atyrau station is located on the northern coast of the Caspian Sea (47° of north latitude). Aktau station is situated on the eastern coast of the Sea (slightly south from 44° of the north latitude). Naturally, at Atyrau and Aktau stations, we should expect a certain influence of the Caspian Sea on WCET data.

Observations at Uralsk, Aktobe and Atyrau stations have been done for last 100 years and Aktau station was opened only in the thirties of the last century. The observations of this station, as well as Atyrau, were interrupted some times. After analyzing, however, the periods when observations were interrupted, we found that this happened in the warm part of the year, the data for which we do not use in this work. Therefore, it was possible to take the same periods of 1966–1975 and 1996–2005 for all stations as cold and warm periods in this paper. To analyze the dynamics of WCET for decades, we also used meteorological data for the last decade of 2006–2015.

WCET were calculated by a formula (OFCM 2003):

$$WCET = 13.12 + 0.6215{*}T - 11.37{*}(v{*}3.6)^{0.16} + 0.3965{*}T{*}(v{*}3.6)^{0.16} \qquad (1)$$

where T is the ambient air temperature (°C),

v-wind speed (m/s) at a height of 10 m above the ground.

The impact of solar radiation on WCET was not taken into consideration because of complexity in these assessments. To calculate heat losses of the body, is necessary to measure heat loss an average person, moving at a speed of 4.8 km/h or doing any work with the same energy consumption. He must also be dressed for the season and weather.

The question of what temperature fluctuations are considered climatic was widely discussed by the scientific community in the past decades (Gu and Philander 1995; Gruza and Ran'kova 1989; Gruza and Ran'kova 1991; Gruza and Ran'kova 2004). Most researchers agreed that the average temperature over a 10-year period can be considered climatic, and its changes in adjacent decades—climatic variations (Gruza and Ran'kova 2004).

We took data on climate change in the region from (Cherednichenko 2010, 2015; Cherednichenko et al. 2015). The analysis was carried out in accordance with statistical methods of processing using spectral and harmonic analysis, polynomial approximation methods adopted in this field, and the results themselves were subjected to rigorous examination. This allowed us to identify the climatic periods (the time interval of not less than 10 years). However, since climatic extremes on the territory of Kazakhstan do not occur simultaneously, for the stations chosen by us they were in different time intervals. This made the analysis somewhat difficult. To simplify it, and most importantly, to simplify understanding of the essence of our work, we found it possible to take the same 10-year time intervals for all stations. Therefore, our series of observations were divided into 10-year intervals. Analysis of the time series of the temperature was performed for next decades 1966–1975, 1976–1985, 1986–1995, 1996–2005, and 2006–2015. As a result of this simplification, not every time interval began to contain a climatic extreme with respect to temperature, but in general, out of five intervals, some extremes contained such extremes, and the temperature of the other periods was intermediate. In the interval 2006–2015, the maximum temperature was observed at all stations in this decade. In general, the difference in climatic temperature over a 50-year period was sufficient to study its effect on the dynamics of WCET.

Fig. 1 Region of West Kazakhstan

Results and discussion

To get a general idea of the climatic features of the region, let us first consider the distribution of the ambient temperature at the stations of the region (Table 1).

Local climatic differences in this region are critical. This is due to the fact that the region is situated in the center of the Eurasian continent, 2000 km from the Atlantic ocean, which has a softening effect on the adjoining regions, particularly in Western Europe. In the region, there is a continental climate with some softening near the Caspian Sea. The coldest months throughout the region are January and February with somewhat higher temperatures in December. The lowest temperatures occur in Aktobe; they are equal to − 14.4 and − 14.2 °C in January and February respectively. In Uralsk, which is located noticeably to the West, these temperatures were slightly higher − 12.8 and − 12.4 °C respectively). On the north coast of the Sea, the average monthly temperature was not below − 10 °C in the winter (Atyrau station), while on the east coast only in January and February were average monthly temperatures below zero. The largest annual amplitudes of the average monthly temperatures (36.9 °C) were observed at Aktobe station. They were also significant at Uralsk and Atyrau stations and equal to 35.2 and 34.8 °C, respectively. Only in Aktau it was much lower only 25.4 °C. A very shallow north part of the Caspian Sea freezes on regular basis, not less than 100 km to the South. In the summertime, it gets very hot. The deepest part of the Middle Caspian, Derbent depression, is located not far to the West of Aktau and the Sea is not frozen there. The gradual growth of differences in average monthly air temperatures in Atyrau and Aktau from zero in August to 6.8 °C in December. From January to August, this difference decreases to zero. It can be explained by the influence of the Caspian Sea.

Let us analyze the annual course of absolute extremes of temperature at all stations. The difference between the absolute maximum and absolute minimum in the same month was higher than 50 °C at Uralsk station in three winter months, at Aktobe—6 months. In Atyrau, the same dif"/>ference took place in 4 months. At Aktau station, such difference was not observed.

The modern climate temperature growth (after 1960) in the world and in the region began no later than 1970, and the significant measurements were observed only after 1975 (IPCC 2013). At different stations in the beginning of warming and cooling did not happen simultaneously

(Cherednichenko 2015). Therefore, the increase of temperature at Uralsk station started even earlier after cooling in the forties (Fig. 2a). A similar temperature trend took place in Aktobe (Fig. 2b).

In Atyrau, the climatic minimum observed in Uralsk and Aktobe in the forties was shifted to the fifties (Fig. 2c). Other climatic extremes that took place in subsequent years also shifted. At Aktau station, the southernmost in the region, during climatic minimum at northern stations in the forties and fifties there was a climatic maximum (Fig. 2d).

After this maximum, the climatic temperature changed very slightly until the nineties of the last century. In the last decade of the last century, the climatic temperature began to grow rapidly, reached a maximum at the beginning of the twenty-first century, and then it also began to decline.

The common in the time course of temperature in the region is the following:

– the presence of a positive temperature trend during the second half of the last century;
– the presence of both highs and lows on a positive trend of climatic temperature in general for an 80-year period. The time of climatic extremes varies from station to station;
– there is a pronounced trend for cooling at all stations of the region, which began at the beginning of this century, whose reality is confirmed by spectral and harmonic analysis of time series of temperature.

Maxima of climate temperature in all Kazakhstan took place in the period from 1996 to 2005 (Cherednichenko 2015). The problem of global climate change, as well as the peculiarities of climate change in the region of western Kazakhstan are not discussed in this paper.

Now, let us consider how global warming affected the characteristics of extreme temperatures in the region. It can be seen (Table 1), that at Uralsk station, an absolute temperature maximum since 1960 was updated in 5 months, at Aktobe station in 8 months, at Atyrau station in 6 months and Aktau station in 12 months. Station Aktau was organized in 1930 only. In 7 months, an absolute temperature maximum was updated after 1990. At the same time, the absolute temperature minimums were updated twice at Uralsk, Aktobe, and Atyrau stations, but only in summer and autumn months, despite the fact that global warming took place in the winter and spring months (IPCC 2013). It seems that global warming occurring in the late twentieth century manifested itself in the region through extreme temperature characteristics that are quite convincing.

WCET distribution in the cold (from 1966 to 1975) and warm (from 1996 to 2005) periods are presented in Table 2.

Probabilities of uncomfortable weather at the stations were considered. If the average temperature at Aktobe in all months was lower than at Uralsk station, the repeatability of WCET at Uralsk station was higher than at Aktobe in most months (Tables 1 and 2). In Uralsk, negative WCET were observed approximately every day in December and February. Therefore, the probability of unfavorable weather in the period from November to March differed not only among stations, but also among climatic decades chosen by us. In the warmest climatic period (1996–2005), the duration of WCET, less than zero is the same as in the cold period. Consequently, despite average WCET, the warming was not detected on extreme WCET.

Repeatability of «increasing risk», i.e., when WCET below − 27 °C, in the warm climate period at Uralsk station decreased by twice, at Aktobe station by three times. At Atyrau, the repeatability of these temperatures slightly decreased, at Aktau station it was stable at the minimum level in the whole region. All stations except Aktau were characterized by a «high risk», or when WCET below − 39 °C. In truth, the repeatability of such cases is less than 0.2 days. In general, repeatability of low and high values of WCET was not exponential (Table 2). It is necessary to study the conditions of formation of more dangerous WCET using for the analyses synoptically materials. This problem was not analyzed in this paper.

Detailed information about repeatability WCET and its changes due to the global warming in the region is given in Table 3.

The highest repeatability of WCET in the range from − 5 to − 20 °C was observed in Aktobe. Temperature below − 25 °C observed few times often in Uralsk then in Aktobe. To south repeatability of negative WCET slightly decreases and approaches its minimum in Aktau. The lower the temperature is, the faster its repeatability to the south decreases. As a result of climate warming, the repeatability of temperature range decreased at all stations. The largest decrease happened in Atyrau, it went down to 7–5%. In the region as a whole, this decrease was approximately about 4% (Table 3).

It is known, that the most significant temperature increase in most parts of the Northern Hemisphere is observed in wintertime (IPCC 2013; Climate change 2007). Therefore, we performed calculations only for the winter months. It was noticed, that in the winter global warming was more noticeable, than for the rest of cold climate period. Particularly, the repeatability of negative WCET at all stations was 1–5% lower than for the warm period, i.e., warming was stronger. In view of the similarity of the other characteristics of WCET to the data for the entire cold period, the data are not given separately for each of the winter months.

All obtained results are illustrated in the scheme (Fig. 3a), where there are integral curves of WCET distribution at Atyrau station for five successive decades.

It can be seen that significant differences were observed only for average repeatability of WCET. With the beginning of global warming, these curves of repeatability

Table 1 Medium and extreme climatic air temperatures

Station	T, °C	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Uralsk	Mean	− 12.8	− 12.4	− 5.7	7.2	15.6	20.4	22.4	20.6	14.0	5.2	− 3.0	− 9.0
	Abs. max	7	5	21	31	37	41	42	41	36	28	15	7
	Year	1948	1990	1995	1950	1996	1955	1954	2000	1944	1999	1957	1947
	Abs. min	− 43	− 40	− 35	− 19	− 7	− 1	1	1	− 7	− 19	− 33	− 35
	Year	1942	1969	1954	1963	1969	1949	1997	1976	1941	1968	1953	1955
Aktobe	Mean	− 14.4	− 14.2	− 7.4	5.9	14.9	20.2	22.5	20.3	13.5	4.5	− 4.0	− 10.9
	Abs. max	5	5	18	31	39	40	42	43	36	29	17	7
	Year	1912	1986	1944	1982	1916	1967	1984	1940	1979	1998	1981	1981
	Abs. min	− 49	− 45	− 37	− 19	− 8	− 1	4	1	− 8	− 26	− 35	− 37
	Year	1940	1917	1917	1913	1969	1926	1929	1976	1909	1976	1916	1959
Atyrau	Mean	− 9.0	− 8.4	− 1.4	10.0	18.3	23.4	25.8	23.8	17.0	8.3	0.5	− 5.5
	Abs. max	14	15	23	33	38	42	46	45	37	29	20	12
	Year	1975	1958	1914	1972	1985	1973	1911	1940	1944	1999	1974	1947
	Abs. min	− 38	− 37	− 32	− 12	− 2	2	8	5	− 6	− 16	− 30	− 34
	Year	1909	1954	1954	1898	1952	1967	1947	1973	1958	1976	1957	1933
Aktau	Mean	− 1.4	− 0.7	4.3	11.5	17.3	21.6	24.0	23.8	19.1	12.3	5.9	1.2
	Abs. max	14	16	25	31	37	41	42	41	36	31	23	15
	Year	1979	1999	1978	1975	1961	1987	1965	1999	1989	1999	1974	1980
	Abs. min	− 25	− 28	− 17	− 4	2	7	13	10	0	− 11	− 16	− 23
	Year	1964	1969	1969	1971	1966	1970	1973	1980	1973	1968	1993	1997

gradually go right towards the fewer gradations WCET, but after 2005 they return to lower temperatures of WCET. It is totally in compliance, which the climate temperature trends in the region (Cherednichenko 2015), and (Fig. 2a, d). Figure 3b shows the dynamics of WCET for the Uralsk station.

It can be seen that the peculiarities of the WCET dynamics in Atyrau are also characteristic of the Uralsk station. True, the range of changes in WCET is somewhat less, which is due to slightly smaller variations in air temperature in Uralsk. Figure 3c shows the dynamics of WCET at Aktobe station. In Aktobe, as in Uralsk, the greatest variability of WCET occurs near − 10 °C. Figure 3d shows the dynamics of WCET at the southernmost station in the Aktau region. It can be seen that the variability of WCET in Aktau is great. It is the largest among the stations whose data are involved in the analysis.

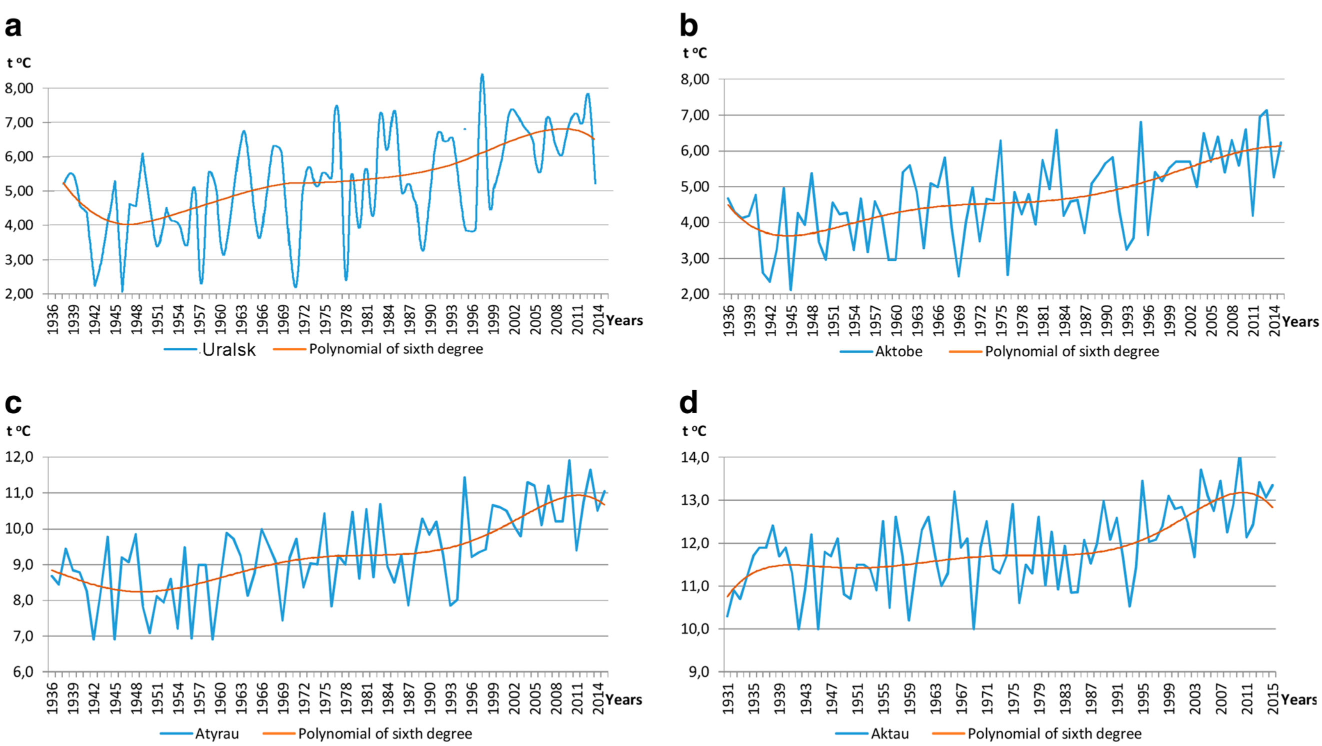


Fig. 2 The time course of the temperature in Uralsk, Aktobe, Atyrau, and Aktau approximated by a polynomial of sixth degree

Table 2 Minimum and average repeatability of WCET (number of days) in climate warm and cold periods (data of cold period in the numerator; data of warm period in the denominator)

Station	Element	Jan	Feb	March	Apr	May	Sep	Oct	Nov	Dec
Uralsk	Min WCET	−45.6/−40.9	−49.3/−40.7	−34.5/−28.1	−13.7/−18.6	−5.8/−4.7	−5.4/−5.6	−22.8/−11.6	−25.8/−34.6	−39.4/−40.4
1966–1975/1996–2005	0	30.9/30.8	28.0/28.1	27.5/27.0	4.9/7.2	0.3/0.6	0.8/0.4	9.5/6.6	23.8/22.3	30.8/30.6
	− 10	26.0/19.0	22.2/17.0	11.0/9.0	0.2/0.5			0.9/0.1	3.6/6.5	18.4/16.2
	− 20	14.3/9.0	11.2/7.1	2.6/0.9				0.1/0.0	0.1/1.5	6.0/5.9
	− 27	6.5/2.1	4.4/2.3	0.4/0.1					0.0/0.3	1.9/2.0
	− 39	0.5/0.0	0.5/0.1							
Aktobe	Min WCET	−42.2/−39.8	−36.6/−46.4	−38.0/−32.5	−18.6/−20.6	−6.3/−3.0	−5.7/−4.3	−17.2/−13.8	−33.7/−36.7	−38.1/−42.0
1966–1975/1996–2005	0	24.9/30.8	22.6/28.0	23.2/27.0	7.7/8.8	0.4/0.5	0.4/0.6	9.9/8.0	24.0/22.9	27.5/30.6
	− 10	20.1/21.5	18.3/18.1	11.4/11.4	0.4/0.8			0.8/0.3	6.9/7.4	17.8/16.3
	− 20	9.5/9.2	9.4/7.3	3.3/1.3					0.7/1.6	6.4/5.4
	− 27	2.6/2.6	2.5/2.4	0.7/0.2					0.1/0.4	1.6/1.7
	− 39	0.0/0.0	0.0/0.2							0.0/0.1
Atyrau	Min WCET	−38.5/−35.2	−39.2/−37.6	−30.0/−21.5	−13.0/−16.5	−2.8/−1.7	−3.4/−5.9	−20.5/−11.0	−33.7/−35.2	−34.2/−40.3
1966–1975/1996–2005	0	31.0/30.5	27.9/26.6	21.5/20.2	2.7/3.4	0.1/0.0	0.1/0.2	6.7/3.7	19.0/17.8	27.5/29.9
	− 10	19.2/14.9	17.8/11.8	7.7/3.0	0.0/0.1			1.0/0.0	1.6/4.1	12.1/11.2
	− 20	6.4/3.9	7.5/3.4	1.5/0.1					0.1/0.7	2.8/2.9
	− 27	2.2/0.9	2.0/0.8	0.2/0.0					0.1/0.3	0.5/0.9
Aktau	Min WCET	−30.7/−22.5	−27.7/−25.3	−23.8/−18.1	−3.9/−6.1	4.5/2.5	3.4/3.1	−7.7/−3.4	−20.9/−20.5	−26.1/−32.5
1966–1975/1996–2005	0	26.0/22.6	22.5/17.1	14.5/9.0	0.4/1.0			1.1/0.3	7.1/7.9	20.0/17.7
	− 10	8.4/4.1	7.4/3.4	2.5/0.3					0.3/0.5	4.2/3.7
	− 20	0.6/0.2	0.7/0.2	0.1/0.0					0.0/0.1	0.3/0.4
	− 27	0.1/0.0	0.0/0.0						0.0/0.0	0.0/0.1

Table 3 Repeatability of WCET in warm and cold climatic periods (number of days)

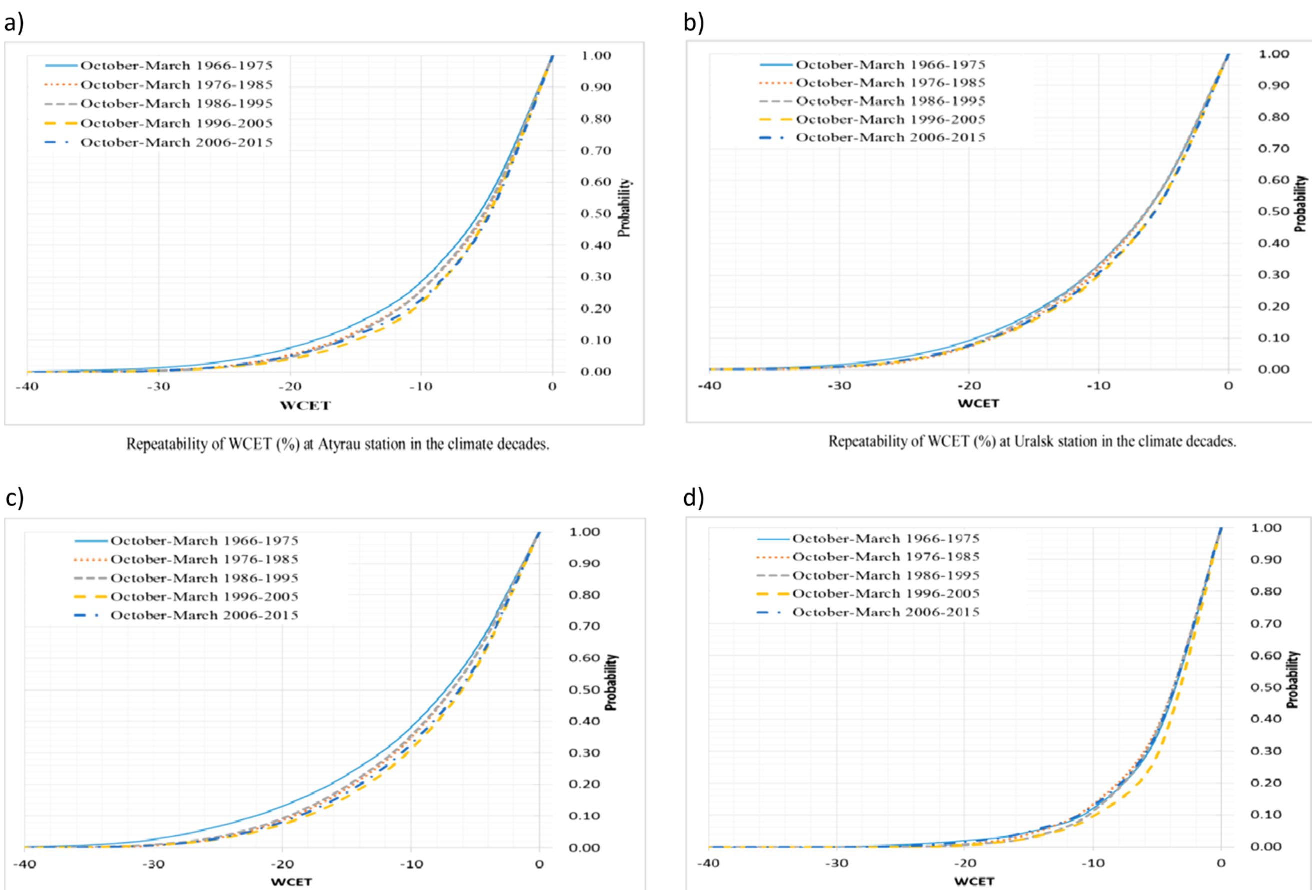
Station	Periods	Element				
		− 5	− 10	− 15	− 20	− 25
Uralsk	1966–1975	59	34	18	9	4
	1996–2005	55	30	16	7	2
Aktobe	1966–1975	62	36	20	10	3
	1996–2005	57	31	16	8	2
Atyrau	1966–1975	55	29	15	8	3
	1996–2005	48	22	10	4	1
Aktau	1966–1975	50	23	11	2	–
	1996–2005	42	16	4	1	–

Comparing the dynamics of WCET at the stations of the region, it can be seen that:

– At all stations, the cold and warm climatic periods that took place during the 50 years of meteorological observations analyzed clearly differ;
– The variability of WCET in the stations is different and it is determined by the dynamics of air temperature. The largest variability of WCET in the southern part of the region (Aktau station);
– When moving from north to south, the area of greatest variability is shifted towards higher WCET values, from − 10 °C in the north to − 5 °C in the south.

Some authors (IPCC 2013) point to the decrease of amplitude of the diurnal air course in conditions of global warming. It is necessary to analyze the diurnal course of WCET (Table 4).

Solar radiation plays a very important role in the formation of temperature regime in the region, but in winter months, its influence is not significant. At Uralsk station, the minimum WCET was observed at 03 am, and maximum ones at 12 during all months of the cold period. In cold climate period from 1966 to 1975, the minimum amplitudes of the diurnal WCET course were observed in November, December, January, and were equal to 3.9, 2.6, and 3.2 °C respectively. In February and March, they increased to 5.9 °C, to the beginning of summer it was about 10 °C and more. The sun can minimally heat open body surface in winter months because the air cools it. In warm climate period 1996 to 2005, WCET amplitudes in



Repeatability of WCET (%) at Atyrau station in the climate decades.

Repeatability of WCET (%) at Uralsk station in the climate decades.

Repeatability of WCET (%) at Aktobe station in the climate decades.

Repeatability of WCET (%) at Aktau station in the climate decades.

Fig. 3 Repeatability of WCET (%) in the climate decades

Table 4 Amplitude of the diurnal course of WCET in cold and warm climate periods

Station	Element	Jan	Feb	March	Apr	…	Oct	Nov	Dec
Uralsk	1966–1975	3.2	5.9	5.9	10.1		8.1	3.4	2.6
	1996–2005	2.9	4.5	6.5	9.5		7.7	3.9	2.8
	Amplitude difference	0.3	1.4	− 0.6	0.6		0.4	− 0.5	− 0.2
Aktobe	1966–1975	4.7	6.5	5.5	10.2		8.5	5.2	2.8
	1996–2005	3.8	5.7	7.5	8.6		7.6	3.3	2.8
	Amplitude difference	0.9	0.8	− 2.0	− 1.6		1.1	1.8	0.0
Atyrau	1966–1975	4.7	6.5	7.5	10.3		8.5	5.2	2.8
	1996–2005	3.9	5.5	7.1	8.4		8.3	4.7	2.7
	Amplitude difference	0.8	1.0	0.4	1.9		0.2	0.5	0.1
Aktau	1966–1975	3.9	1.0	5.1	6.3		5.8	4.2	3.9
	1996–2005	4.0	5.4	5.9	5.2		6.4	5.6	4.0
	Amplitude difference	− 0.1	− 4.4	− 0.8	1.1		− 0.6	− 1.2	− 0.1

November, December and January were equal to 3.9, 2.8, and 2.9 °C respectively. In February and March, they increased to 4.5 and 6.5 °C respectively. In general, the amplitude of WCET at Uralsk station was smaller only in 3 months compared with the cold climatic period. At Aktobe station, there were two cases of negative amplitude differences, whereas at Atyrau station there were no similar cases. On the other hand, at Aktau station, six cases of negative amplitude differences were observed in 7 months. All of them happened in different months. Hence, only Atyrau was characterized with an absolute reduction in the diurnal WCET amplitudes when climate temperature increased. Sometimes it happened at Aktobe and Uralsk stations, in Aktau (the southernmost station in the region) with an increase of climate temperature, WCET amplitudes also went up. It can be assumed that in the northern regions, climatic warming causes an increase in minimum daily temperatures, and in the south, an increase in the maximum daily temperatures, which also affects the amplitude of the WCET.

It is known that every person can adjust to low temperatures. Therefore, some authors try to take into account an effect of acclimatization, analyzing WCET repeatability in the coldest conditions. Usually, the role of discomfort thresholds plays 25 and 5% percentiles (Saue 2016). We used the same thresholds for our investigations. All results are given in Table 5.

WCET values, corresponding to the selected percentiles, demonstrate the significant differences due to the location of the stations and the distinction in the weather processes.

Table 5 Minimum WCET (25 and 5 percentiles)

Station	Period	Percentile	Oct	Nov	Dec	Jan	Feb	March	Apr
Uralsk	1966–1975	25	− 4.71	− 10.31	− 22.89	− 31.27	− 29.11	− 18.55	− 2.06
		5	− 11.36	− 15.99	− 31.91	− 38.96	− 39.33	− 26.90	− 7.48
	1996–2005	25	− 3.06	− 12.69	− 21.70	− 25.78	− 25.15	− 15.91	− 3.52
		5	− 7.71	− 23.33	− 33.31	− 31.16	− 35.12	− 22.34	− 10.69
Aktobe	1966–1975	25	− 4.84	− 14.19	− 24.71	− 27.00	− 27.90	− 21.40	− 4.55
		5	− 10.94	− 21.58	− 32.07	− 34.17	− 33.12	− 29.30	− 10.00
	1996–2005	25	− 3.93	− 14.21	− 21.30	− 25.99	− 25.44	− 17.27	− 4.52
		5	− 8.64	− 23.78	− 31.22	− 34.04	− 33.82	− 23.90	− 12.96
Atyrau	1966–1975	25	− 2.68	− 8.30	− 19.07	− 28.12	− 26.24	− 14.45	− 1.11
		5	− 8.03	− 14.38	− 28.46	− 40.41	− 35.21	− 24.68	− 5.47
	1995–2005	25	− 1.20	− 9.89	− 17.66	− 20.53	− 20.53	− 10.39	− 0.61
		5	− 6.23	− 20.45	− 27.53	− 29.04	− 29.50	− 16.82	− 7.37
Aktau	1966–1975	25	3.00	− 3.06	− 9.94	− 13.94	− 14.21	− 7.56	3.79
		5	− 2.68	− 8.56	− 19.44	− 19.77	− 21.26	− 16.74	− 0.03
	1996–2005	25	4.53	− 3.64	− 8.94	− 10.03	− 10.56	− 3.94	1.82
		5	0.60	− 9.44	− 19.14	− 18.44	− 18.20	− 8.94	− 1.48

The less comfortable conditions in January and February were observed at all stations. When relative threshold discomfort (5%) was about − 10 °C in winter months, the threshold of 25% was pretty much lower for the north stations (Aktobe and Uralsk). At these stations, we have the lowest threshold WCET. The threshold of 25% the first 3 months, October–December were colder in Aktobe, and the next three—in Uralsk, while April was again colder in Aktobe. The same situation occurs at the level of 5%, and also in the warm period. When comparing the WCET of warm and cold periods, it turns out that at the level of 25% in Uralsk and Aktau 2 months of the eight warm period WCET was lower than in the cold, in Atyrau and Aktau—one of the eight. At the level of 5% in Uralsk and Aktobe WCET was lower in the 3 months, and in Atyrau and Aktau—two and one, respectively. We noted the above law, that the farther from the most common WCET, the impact of global warming is weaker.

At the same time, in the cold period in Uralsk in the 25% level in 2 months was lower than the WCET «increasing risk», and at the level of 5% in the 2 months «high risk» in the 4 months «increasing risk». In Aktau, the softest terms and conditions of this level are not observed (Table 5).

Thus, if we try to define the limits of discomfort for a person in view of acclimatization, we find that it has a significant spatial variability and is important even for small areas. While the threshold of discomfort WCET <− 10 °C seems natural in November and March, and for the coastal stations—in throughout the winter for the northern stations due to the effect of acclimatization person does not take this temperature (− 10 °C) uncomfortable. Discomfort threshold is below this level.

If we agree with (Cherednichenko 2015), according to which the basic rhythm of climate variability on the territory of Kazakhstan is a century harmonic, and its maximum occurred late last and early this century, the study region should be expected gradual growth WCET repeatability values to climatic decade 1966–1975.

Conclusions

Let us state briefly the results. During the time of a positive trend in the climatic temperature, 28 cases of extremely high temperatures were updated at the stations of the region under consideration, and only 10 were extremely low. This we consider as the influence of global warming. At the same time, it can be seen that even in the context of climatic growth, extremely low temperatures in the region are possible. Comparing the dynamics of WCET at the stations of the region under the influence of a pronounced positive trend in the climatic temperature during most of the 50-year period under consideration, we obtained the following general patterns:

- At all stations, the cold and warm climatic periods that took place during the 50 years of meteorological observations analyzed clearly differ;
- The variability of WCET in the stations is different and it is determined by the dynamics of air temperature. The largest variability of WCET in the southern part of the region (Aktau station);
- When moving from north to south, the area of greatest variability is shifted towards higher WCET values, from − 10 °C in the north to − 5 °C in the south;
- The time of the onset of extreme periods and their severity at the stations under analysis is somewhat different, although a similarity in the dynamics of air temperature is observed. The warmest period for all stations is 1995–2005.

In most of the territory, the amplitude of the daily course of WCET in a warm climatic decade is less than in the cold decade. The exception is only the southernmost region (Aktau station), where in the warm climatic decade the diurnal amplitudes of the WCET even increased compared to the cold one. In northern regions, climatic warming causes an increase in minimum daily temperatures, and in the south, an increase in the maximum daily temperatures, which also affects the amplitude of the WCET. The obtained result agrees with the general trends in the amplitude of the diurnal temperature variation with warming.

Repeatability negative WCET high. At Uralsk, Aktobe, and Atyrau stations, it is close to 100%, at Aktau station it is about 85–90%. If the lowest temperature of ambient air were observed at Aktobe station, the highest repeatability of WCET below zero was observed at Uralsk station. To the South, WCET repeatability gradually decreased, especially «uncomfortable» and «increasing risk». Global climate warming has resulted in the renewal of extremely high air temperatures in the region at some stations. It has demonstrated the significant impact on WCET dynamics. As long as the temperature decreased, decreased recurrence of negative WCET. In 1995–2005 decade, it approached its minimum, on the average it was about 4%, in December, January, and February, it was 6%. In the next decade, when the climate became colder, repeatability of negative WCET increased to 1.0–1.5%. If we try to define the limits of discomfort for a person in view of acclimatization, we find that it has a significant spatial variability and is important even for small areas. Obtained results appear to be useful in some sectors of economic activity.

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