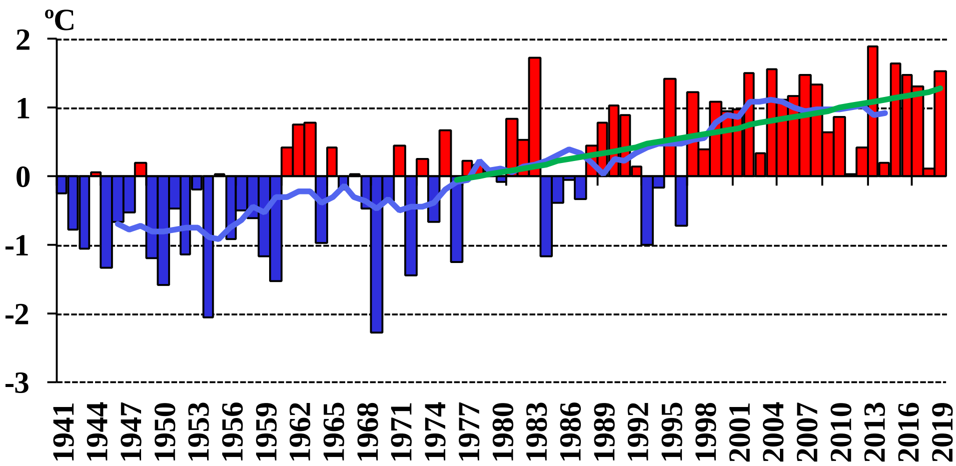
Ministry of Ecology, Geology and Natural Resources of the RK

Republican State Enterprise "Kazhydromet"

Scientific Research Center

ANNUAL BULLETIN OF MONITORING OF THE CLIMATE STATE AND CLIMATE CHANGE IN KAZAKHSTAN: 2019



Nur-Sultan, 2020

CONTENT

SHORT SUMMARY

Climate features in 2019

In general, for the Globe, 2019 entered the ten warmest years for the period of instrumental observations (18502019), taking 2nd place. The global average temperature in 2019 was about 1.1 ± 0.1 °C above the 1850–1900 baseline used as an approximation to pre-industrial levels.

The average annual air temperature in 2019, on average in Kazakhstan, was 1.55 °C above the climatic norm. This is the fifth value in the ranked series of average annual air temperature anomalies for the observation period since 1941. The annual amount of atmospheric precipitation in 2019 was 92% of the norm (294.2 mm).

The air temperature of ***the winter season*** (December 2018-February 2019) in most of the territory of the republic was around the norm, the average anomaly in Kazakhstan was +1.14 °C. Extremely warm (the probability of not exceeding 96-99 %) was in January in the Zhambyl and Turkestan regions. In general, throughout the territory of the republic, the amount of precipitation was 92 % of the climatic norm or 58.1 mm. A significant deficit of precipitation (the probability of not exceeding 2-5 %) was noted at the stations of the Aktobe, Kostanay, Karaganda and Zhambyl regions. Winter in these areas has entered 10 % of the extremely dry winter seasons. At some stations of the West Kazakhstan and Pavlodar regions, the absolute minimum and maximum seasonal values were covered.

The spring air temperature was above normal in many regions of the republic. The average air temperature in Kazakhstan during this period exceeded the climatic norm by +2.25 °C with a probability of no more than 91 %. The amount of precipitation in the spring season on average in Kazakhstan was 81.5 mm (96% of the norm, the probability of not exceeding 33 %). The largest amount of atmospheric precipitation fell in the Atyrau region (236 % of the norm, the probability of not exceeding 94 %). The absolute maximum and minimum values of seasonal precipitation have been updated at two meteorological stations of the Karaganda region.

The summer season of 2019 was relatively warm in most of the territory of Kazakhstan. The average air temperature in the republic was 0.97 °C above normal (92-nd percentile). In the southern regions, the average seasonal temperatures were significantly above normal, mainly due to the consistent hot weather in July. Atmospheric precipitation during the summer period was 80.7 mm (86 % of the norm, the probability of not exceeding 30 %). Lack of moisture (30-60 % of the norm, the probability of not exceeding 10-25%) was observed in most of the territory of the republic. At MS Aktogay (Karaganda region) the absolute minimum amount of precipitation in the summer season has been updated.

The autumn air temperature on average in Kazakhstan exceeded the climatic norm by 0.26 °C. In Aktobe region, significant below zero air temperature anomalies were noted in the range from –1.1 °C to –1.7 °C with a probability of less than 25 %. Atmospheric precipitation for the entire season fell 65.6 mm (82 % of the norm, the probability of not exceeding 32 %). The wettest was in the northern regions. Extremely dry recorded in Turkestan and West Kazakhstan regions (the probability of not exceeding 1-2 %). The absolute minimum and maximum seasonal values were covered at some stations in Akmola, Kostanay, West Kazakhstan and Zhambyl regions.

Climate change in Kazakhstan (1976-2019)

On average across the territory of Kazakhstan for the period 1976-2019 an increase in the average annual air temperature is 0.31 ºC every 10 years. The highest growth rates are observed in spring (0.60 ºC/10 years), the lowest in winter (0.11 ºC / 10 years). All the obtained air temperature trends, except for the winter season, are statistically significant. Also, in the period from 1976 to 2019. there is a tendency towards an increase in the annual amount of atmospheric precipitation by 4.3 mm/10 years. In all seasons, except for autumn, the amount of atmospheric precipitation increases by 1.9-3.2 mm/10 years. A statistically significant change in the amount of precipitation was noted only in spring.

Trends in extremes of surface air temperature showed that for the period 1976–2019:

- there is a steady increase in the number of days with temperatures above 35 °C and nights with temperatures above 20 °C, especially in the south, southwest and west of the republic;
- everywhere there is an increase in the total duration of heat waves and a reduction in the total duration of cold waves;
- everywhere there is a steady increase in the number of days with an average daily temperature above 10 °C;
- in the west, north and south of the republic, the number of days with daytime frosts decreases, when the daily maximum air temperature is below 0 °C;
- in many regions, the number of days with severe frosts is significantly reduced, when the daily minimum air temperature is below minus 20 °C;
- there is a decrease in the deficit of heat during the cold season and an increase in the deficit of cold in the warm season, especially in the southwest and west of the republic;
- in most of the territory of Kazakhstan, there is a decrease in the maximum values of daily precipitation in the year;
- the share of extreme precipitation in the annual amount of precipitation changes, mostly insignificantly;
- there are weak statistically insignificant positive and negative trends in the maximum duration of the rainless period.

INTRODUCTION

Climate is a natural resource, which is vitally important for the well-being, health and prosperity of the population of any state. Meteorological information collected, managed and analyzed by the National Hydrometeorological Services helps users of this information, including persons, which makers decisions to plan any activity taking into account modern climatic conditions and observed climate changes. Using of current meteorological and climate information helps reduce risks and damage and optimizes social and economic benefits. Climate system monitoring is carried out by national, regional and international organizations, coordinated by the World Meteorological Organization and in cooperation with other environment programs.

Studying of the regional climate and regular monitoring of its changes are the priority tasks of the National hydrometeorological service of Kazakhstan "Kazgydromet". Since 2010 the "Kazgydromet" makes release of annual bulletins for providing reliable scientific information about regional climate, its variability and change. Due to a geographical location of Kazakhstan and its vast territory, observed changes in climate conditions in various regions of the Republic can have both a negative and positive impact on biophysical systems, on economic activity and the social sphere. Taking into account of the climate conditions and the assessment of their changes are necessary for identification of the potential consequences and introducing timely and adequate adaptation measures, and, as the result, for ensuring sustainable development of Kazakhstan.

This edition of the bulletin describes the climatic conditions observed in 2019, including an assessment of the extremes in temperature and precipitation, and provides historical information on changes in surface air temperature and an amount of precipitation since 1941. Also, this release of the bulletin contains climate change estimates for the shorter period from the middle of 1970s years, when according to many experts, global climate change has become more intense, especially in the Northern Hemisphere. Annex 1 and 2 show the maps of the distribution of seasonal and annual air temperatures and rainfall, averaged over the period 1961-1990.

Initial data. Bulletin is based on data of the National Hydrometeorological Fund of "Kazhydromet":

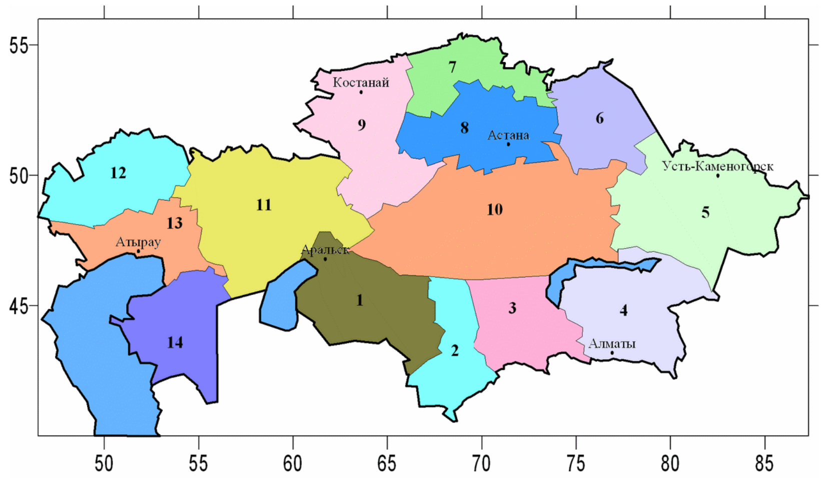
1) time series of monthly mean air temperature and monthly precipitation total from 1941 to 2019: data of more than 200 weather stations were used to assess climate averages for 1961-1990 and more than 190 weather stations data to assess tendencies in temperature and precipitation;

2) time series of daily maximum and minimum air temperatures and daily precipitation totals from 1961 to 2019 (from more than 90 weather stations).

The main approaches and methods. In this bulletin, the "norm" is the climate variable averaged for the period 1961-1990. Temperature anomalies are calculated as deviations of the observed value from the norm. Anomalies of an amount of precipitation can be considered as in deviations from the norm (similar to air temperature), and as a percentage of the norm. The probability of not exceeding characterizes a frequency (in %) emergence of the corresponding value of anomaly in the time series of observations.

As assessment of changes in climate characteristics for a certain time interval the coefficients of linear trends are used, which are determined by the least squares method. The coefficient of determination (R2) represents the strength of a linear trend and characterizes the contribution of the trend to the total variance of the climate variable for the considered time period (in percent).

Assessment of tendencies surface air temperature and amount of precipitation is carried out according to individual stations and on average for 14 regions of Kazakhstan. Averages for the territory anomalies of meteorological variables are calculated by averaging of station data on anomalies. The borders of the regions are given on the schematic map below.



1 – Kyzylorda region.
2 – Turkestan region.
3 – Jambyl region.
4 – Almaty region.
5 – East Kazakhstan region.
6 – Pavlodar region.
7 – North Kazakhstan region.
8 – Akmola region.
9 – Kostanay region.
10 – Karaganda region.
11 – Aktobe region.
12 – West Kazakhstan region.
13 – Atyrau region.
14 – Mangystau region.

Scheme of administrative-territorial division of the Republic of Kazakhstan

To assess the extreme temperature and precipitation in 2019 and its changes since 1961, climate change indices recommended by the World Meteorological Organization were used. Some indices are based on fixed unified threshold values for all stations, others based on threshold values that can vary from station to station. In the latter case, the threshold values are defined as the corresponding percentiles of the data series. The indices allow us to evaluate many aspects of climate change, such as, for example, changes in the intensity, frequency and duration of the manifestation of extremeness in air temperature and rainfall.

The Bulletin was prepared by the experts of Climate Research Department:

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1 REVIEW OF GLOBAL CLIMATE CHANGES and ITS CONDITIONS in 2019

More than 25 years, the World Meteorological Organization (WMO) publishes the annual Statement about condition of global climate in order to provide authoritative scientific information on global climate and significant weather and climate events occurring around the world. These publications complement the assessment reports are issued by the Intergovernmental Panel on Climate Change (IPCC) every six to seven years.

The World Meteorological Organization will continue to follow closely climate variability and change and their impact. An information portal is being set up to allow indicators of the state of the climate to be tracked.

Briefly about the condition of global climate in 2019:

- the global mean temperature for 2019 was 1.1±0.1 °C above pre-industrial levels;
- global atmospheric mole fractions of greenhouse gases reached record levels;
- the year 2019 saw low sea-ice extent in both the Arctic and the Antarctic;
- the ocean absorbs around 90% of the heat that is trapped in the Earth system by rising concentrations of greenhouse gases. Ocean heat content, which is a measure of this heat accumulation, reached record high levels again in 2019;
- in 2019, the global mean sea level reached its highest value since the beginning of the high-precision altimetry record (January 1993).

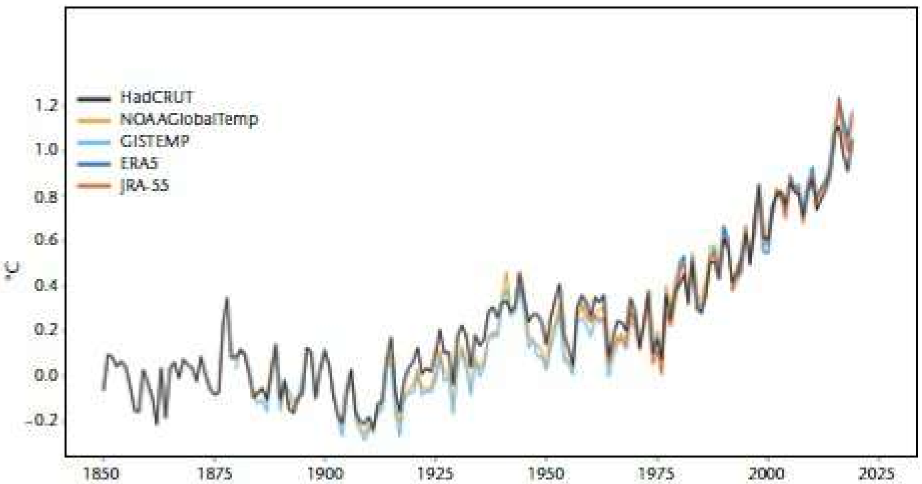


Figure 1.1 – Anomalies of the global average in comparison with the basic period of 1850-1990 within five global datasets. *Source: UK Met Office Hadley Centre*

Preliminary results for 2019, based on a subset of glaciers, indicate that the hydrological year 2018/2019 was the thirty-second consecutive year of negative mass balance, with an ice loss in excess of 1 m w.e. Eight out of the ten most negative mass-balance years have been recorded since 2010. The cumulative loss of ice since 1970 amounts to over 23 m w.e.

The year 2019 also saw numerous major heatwaves. Amongst the most significant were two heatwaves that occurred in Europe in late June and late July. The first one reached its maximum intensity in southern France, where a national record of 46.0 °C (1.9 °C above the previous record) was set on 28 June at Verarge (department of Hérault). It also affected much of western Europe. The second one was more extensive, with national records set in Germany (42.6 °C), the Netherlands (40.7 °C), Belgium (41.8 °C), Luxembourg (40.8 °C) and the United Kingdom

(38.7 °C). The heat also extended to the Nordic countries, where Helsinki had its highest temperature on record (33.2 °C) on 28 July. At some long-term stations, records were broken by 2 °C or more, including Paris, where a temperature of 42.6 °C, at the main Montsouris observatory on 25 July, was 2.2 °C above the previous record set in 1947, and Uccle (near Brussels), whose 39.7 °C was 3.1 °C above the previous record. In total, Australia's seven hottest days on record occurred in 2019. High temperatures reached the far south of the continent: 30.8 °C at Rio Grande (Argentina, 53.8° S), on 4 February, is believed to be the southernmost recorded instance of a temperature of 30 °C.

Consistent with a warm year globally and an overall warming trend, extreme cold was less common than extreme heat. One area of below-average temperature for 2019 was North America. The year's most significant cold spell was in late winter in central North America. This started with an intense cold wave in the United States Midwest in late January, including an Illinois state record of −38.9 °C at Mount Carroll on 31 January, followed by very persistent cold through February and early March in inland western areas on both sides of the United States-Canada border. February mean temperatures were more than 15 °C below normal in places, including Great Falls (Montana), whose monthly mean of −17.9 °C was 15.3 °C below normal and more than 5 °C below the previous record.

While temperatures were near or above average, very heavy winter and early spring precipitation led to an unusually heavy snowpack in many parts of the European Alps. More than 300 cm of snow fell in parts of the Austrian Alps between 4 and 15 January, whilst spring snowfalls led to a record-high snow depth for 1 June of 270 cm at Weissfluhjoch (Switzerland, 2540 m elevation), although very hot weather in June led to that snow melting by early July, close to the normal start of the snow-free period. Numerous avalanches were reported throughout the region during the heaviest snowfall periods.

Unusually dry conditions in relation to long-term means for 2019 were observed in Australia and western Indonesia and surrounding countries. Also, southern Africa, Central America and parts of South America received abnormally low precipitation amounts. Large areas with unusually high precipitation amounts were observed in the Central United States, Northern Canada, northern Russia, South-west Asia, northern China and eastern Africa.

Regular flooding occurred during the Indian summer monsoon season, particularly in western and northern India and neighbouring countries. The Islamic Republic of Iran was badly affected by flooding in late March and early April, with the Shiraz region being the worst affected. During the event, 24-hour rainfall totals were as high as 188 mm. At least 76 deaths were reported as well as severe economic losses. A tropical low brought extreme rainfall and associated flooding in northern Queensland (Australia) in late January and early February. The flooding and associated unusually cool weather led to heavy livestock losses. Total economic losses were estimated to be in the order of US$2 billion. Persistent heavy rainfall affected a large part of the central United States in late 2018 and the first half of 2019. The 12-month rainfall averaged over the contiguous United States for the period July 2018 to June 2019 (962 mm) was the highest on record. Total economic losses from flooding in the United States, in 2019, were estimated at US$20 billion, with especially acute episodes on the Missouri River in March, and the Arkansas River in late May and early June. Very wet conditions affected parts of South America in January.

There was major flooding in northern Argentina, Uruguay and southern Brazil, with losses in Argentina and Uruguay estimated at US$2.5 billion.

Drought affected many parts of south-east Asia and the south-west Pacific in 2019. Exceptionally dry conditions prevailed from mid-year onwards in Indonesia and neighbouring countries; Singapore had its driest July to September on record. April–July rainfall in Yunnan province of China was the lowest since 1961. Long-term drought conditions, which had affected many parts of inland eastern Australia in 2017 and 2018, expanded and intensified in 2019, particularly in the second half of the year, which saw Australia’s driest spring (November and December) on record.

2 AIR TEMPERATURE

On average in Kazakhstan, the average annual air temperature anomaly was +1.55°with a relatively average long-term value for the period 1961-1990 (5.74 ° C) and was 1.44 °C higher than in 2018. Average annual air temperature for the last decade 2010-2019 was +6.69 °C and exceeded the climatic norm by 0.95 °C, this is the second largest positive decade anomaly after the record warm decade 2000-2009. The warmest ten-year period in Kazakhstan with an anomaly of +1.11 °C is the period 2000-2009.

The ranks of the ten warmest years on average for the Globe (according by the land network) and across Kazakhstan are presented in table 2.1. Each of the ten warmest years for the globe has been assigned own color fill, which makes it easy to judge, that whether this year is among the warmest years for Kazakhstan. The four warmest years in Kazakhstan were included in the list of the ten warmest years for the globe, 2019 was included in this list.

Figure 2.1 shows the ranged series of the annual mean surface air temperature anomalies, which averaged according to 124 meteorological stations of Kazakhstan for the period from 1941 until now. On a global scale, all extremely warm years are accounts for on the last 20 years. This feature in Kazakhstan also well traced with the exception of 1983, which takes the second place in the rank of the warmest years, and 1995, which has also entered ten the warmest years.

Table 2.1 - Ten of the warmest years in the history of observations for the Globe (since 1850) and in Kazakhstan (since 1941) and corresponding annual mean surface air temperature anomalies averaged over the territory of Kazakhstan. Anomalies calculated relatively for the period 1961-1990.

Rank	Earth	Kazakhstan	Average annual temperature anomaly (Jan-Dec), averaged over the territory of Kazakhstan, ° C
1	2016	2013	1,89
2	2019	1983	1,72
3	2017	2015	1,66
4	2015	2004	1,56
5	2018	2019	1,55
6	2014	2002	1,51
7	2010	2007	1,49
8	2005	2016	1,49
9	2013	1995	1,43
10	2006	2008	1,35

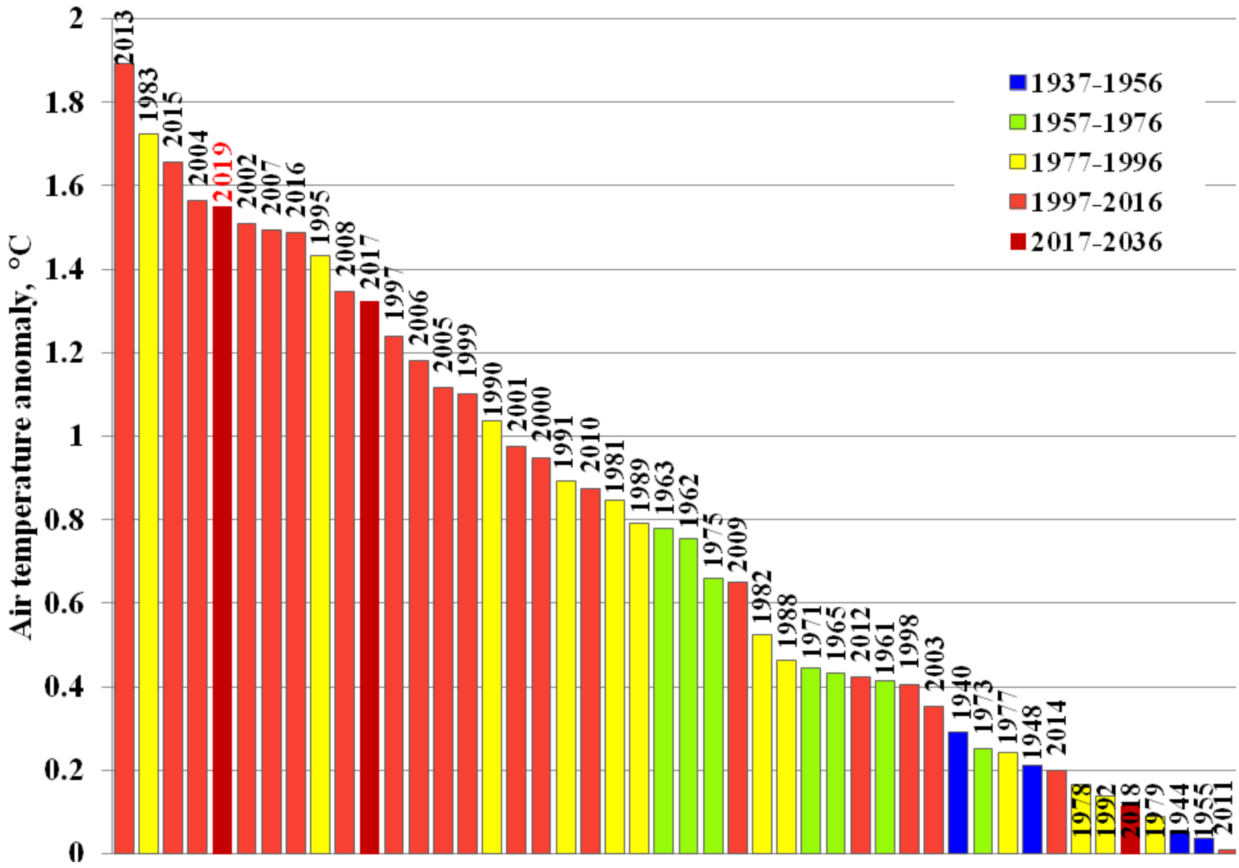


Figure 2.1 - Ranged series of the 45 largest of positive annual mean surface air temperature anomalies (Jan-Dec) averaged over the territory of Kazakhstan (according to 124 weather stations) for the period 1941-2018. Norms calculated relatively to the base period of 1961-1990.

2.1 Air temperature anomalies in 2019

In 2019, the average surface air temperature anomaly (January-December) over the territory of the Republic has taken 5th place by descending order of anomalies since 1941 (table 2.1).

Table 2.2 the average annual and seasonal air temperature anomalies averaged over regions and across Kazakhstan as a whole, and table 2.3 shows the mean monthly air temperature anomalies observed in 2019. For each anomaly, the probabilities of their non-exceeding are calculated based on data for the period 1941-2019, as well as the standard deviation for 1961-1990. (table 2.2). In tables 2.2 and 2.3, temperatures above the 95th or below the 5th percentile (extremes of high and low temperatures, respectively) highlighted in bold and bright colors.

In most of the country's territory, the annual average air temperature anomalies were positive (table 2.2; figure 2.2). Significant above zero air temperature anomalies within 1.13, 1.58 ºC, the probability of not exceeding which was more than 75 % were observed in all regions of Kazakhstan. The centers of extremely positive anomalies (96-100 %) of air temperature traced in the southern and southwestern regions of the republic. Areas with negative mean annual air temperature anomalies were’t observed. The annual average air temperature averaged over the territory of Kazakhstan was significantly higher than the climatic norm - by 1.55 ºC, which is higher than the standard deviation (0.85 ºC). At several meteorological stations in the south and southwestern part of Kazakhstan, the absolute maximums of average annual air temperatures were updated.

The air temperature of the winter season (December 2018, February 2019) in most of the territory was close to norm, positive anomalies were traced in the extreme south and southwest (Figure 2.2). The average air temperature anomaly in the republic was +1.14 ˚C (table 2.2).

Significant positive air temperature anomalies (above 3 ºC and the probability of not exceeding which was more than 91 %), averaged over the territories of the regions observed in Zhambyl and Turkestan regions (table 2.2). Minor below zero anomalies of the average seasonal air temperature (in the range from –0.90 ºC to –0.08 ºC) were noted in Karaganda, Kostanay, Pavlodar and North Kazakhstan regions (table 2.2). Within the winter season extremely warm was in January in Zhambyl and Turkestan regions, where anomalies were above 5 ºC with a probability of not exceeding 97-98 % (table 2.3).

Cold spots (the probability of not exceeding 22-25 %, figure 2.2)were observed only at the meteorological stations Karauyl (-1.7 ˚C) and Leninogorsk (-1.6 ˚C) in the East Kazakhstan region. The centers of extreme positive anomalies with a probability of not exceeding 96-99 % traced in the Turkestan region at the stations Arys, Kazygurt, Turkestan, Shardara (4.9 ˚C, 4.4 ˚C, 4.1 ˚C, respectively) and in the Zhambyl region at the Uyuk station (4.3). The absolute maximums and minimums of the winter season temperature have not been updated.

Spring 2019 in many regions of the republic the air temperature was above normal. The average air temperature anomaly in the spring season over the territory of the Republic wasb+2.25 ˚C by 91 % probability of not exceeding. Negative mean seasonal temperature anomalies were not observed at any station (figure 2.2). Average air temperature anomalies for the territories of Akmola, Aktobe, Atyrau, Zhambyl, Kyzylorda and Turkestan regions were significantly higher than the norm - by 2.19-3.02 ˚C (table 2.2). Extremely hot spots were’t found within the spring season. In May, it was cold in the East Kazakhstan region (anomaly minus 1.51 ˚C, table 2.3). The historical highs and lows of the average monthly air temperature among the spring months have’t been updated.

Table 2.2 – Regionally averaged annual mean (January-December) and seasonal air temperature anomalies in 2019: vT - deviations from the long-term average for 1961–1990 (°C), P(t≤T2019) – probability of non-exceedance (in brackets), calculated according to the data for the period 1941-2019 (%;) s – standard deviation (ºC) for the period 1961-1990

Region/region	Year		Winter		Spring		Summer		Autumn	
	vT (P)	**s**	**vT (P)**	**s**	**vT (P)**	**s**	**vT (P)**	**s**	**vT (P)**	**s**
Kazakhstan	**1,55(96)**	**0,85**	1,14(64)	2,44	2,25(91)	1,26	0,97(92)	0,64	0,26(53)	1,14
Almaty	1,58(94)	0,77	1,37(65)	2,36	2,01(89)	0,99	**1,45(96)**	**0,63**	0,43(55)	1,07
Akmola	1,23(84)	1,08	0,21(48)	2,84	2,06(83)	1,84	0,16(58)	1,04	0,35(51)	1,52
Aktobe	1,47(88)	0,94	1,40(70)	2,51	3,02(93)	1,91	0,88(75)	0,92	-0,50(34)	1,40
Atyrau	1,78(93)	0,82	2,88(82)	2,40	2,25(92)	1,55	1,26(79)	0,85	-0,07(47)	1,20
East Kazakhstan	1,53(91)	1,07	0,09(48)	2,71	2,31(88)	1,51	0,73(76)	0,79	0,52(55)	1,50
Zhambyl	**2,08(100)**	**0,85**	3,33(91)	2,84	2,31(91)	0,99	**1,81(97)**	**0,83**	0,24(50)	1,16
West Kazakhstan	1,62(85)	1,06	1,10(61)	2,74	2,75(88)	2,01	0,72(62)	1,22	0,48(66)	1,27
Karaganda	1,11(82)	0,90	-0,13(44)	2,56	1,42(78)	1,35	-0,86(83)	0,85	-0,11(41)	1,41
Kostanay	1,27(88)	1,06	-0,08(46)	2,76	2,41(85)	1,92	0,79(78)	1,09	0,10(48)	1,49
Kyzylorda	**2,20(96)**	**0,90**	2,79(79)	2,87	3,01(91)	1,21	1,64(92)	0,93	0,03(43)	1,19
Mangystau *	**1,94(96)**	**0,76**	2,79(86)	2,26	2,04(84)	1,25	1,97(84)	0,91	0,14(45)	1,15
Pavlodar	1,13(80)	1,16	-0,90(34)	3,15	1,67(71)	1,73	-0,19(60)	0,94	0,69(55)	1,62
North Kazakhstan	1,11(83)	1,16	-0,19(46)	2,94	1,88(84)	1,86	-0,22(47)	1,17	0,78(60)	1,53
Turkestan	**1,92(100)**	**0,79**	3,40(93)	2,60	2,19(92)	0,86	**1,44(96)**	**0,85**	0,18(48)	1,10

Notes: 1. for the Mangystau region, an assessment has been carried out since 1960;
2. values above the 95th or below the 5th percentile (respectively, warm and cold extrema) are shown in bold and bright colors.

Table 2.3 - Regionally averaged mean monthly air temperature anomalies in 2019: **vT**-*deviations from the average for 1961-1990,°C; P (t≤T2019) is the probability of not exceeding (in brackets) calculated according to the data for the period 1941-2019. and expressed in %*

Region/region	12 (2018)	1	2	3	4	5	6	7	8	9	10	11
Kazakhstan	-1,43 (29)	2,81 (84)	2,00 (66)	5,00 (94)	1,26 (75)	0,49 (64)	0,17 (60)	1,60 (97)	1,15 (76)	-0,19 (38)	3,05 (96)	-2,09 (28)
Almaty	-1,10 (38)	3,20 (88)	1,89 (59)	4,49 (91)	2,04 (88)	-0,52 (34)	0,17 (50)	2,27 (97)	1,93 (93)	1,21 (75)	1,49 (75)	-1,41 (37)
Akmola	-2,43 (26)	2,00 (67)	1,07 (57)	5,01 (91)	0,82 (61)	0,36 (52)	-2,31 (11)	1,28 (85)	1,52 (75)	-0,72 (28)	4,34 (96)	-2,56 (28)
Aktobe	-0,51 (46)	2,76 (75)	1,94 (62)	6,04 (92)	1,03 (66)	2,00 (84)	1,75 (76)	1,65 (85)	-0,75 (28)	-2,42 (7)	3,83 (94)	-2,89 (24)
Atyrau	0,62 (61)	3,49 (78)	4,54 (80)	4,20 (92)	0,80 (67)	1,76 (84)	3,39 (92)	0,80 (69)	-0,42 (30)	-1,14 (15)	3,33 (91)	-2,40 (25)
East Kazakhstan	-3,07 (17)	2,15 (73)	1,05 (53)	5,81 (92)	2,63 (85)	-1,51 (24)	-0,76 (26)	0,54 (69)	2,41 (98)	1,06 (75)	2,17 (88)	-1,65 (34)
Zhambyl	0,55 (56)	5,23 (97)	4,08 (75)	5,22 (94)	1,25 (78)	0,45 (60)	0,58 (62)	3,01 (100)	1,84 (92)	0,95 (66)	1,95 (84)	-2,19 (29)
West Kazakhstan	-0,27 (51)	1,08 (47)	2,54 (66)	4,46 (84)	1,39 (67)	2,38 (87)	2,68 (80)	0,14 (53)	-0,67 (29)	-1,82 (11)	4,26 (97)	-0,98 (44)
Karaganda	-3,13 (21)	1,26 (62)	1,44 (65)	3,66 (84)	1,05 (70)	-0,44 (37)	-1,04 (20)	1,84 (94)	1,77 (82)	-0,28 (37)	3,22 (94)	-3,26 (20)
Kostanay	-2,50 (30)	1,69 (61)	0,53 (50)	5,14 (89)	0,72 (60)	1,38 (73)	-0,68 (38)	1,94 (89)	1,12 (70)	-1,54 (12)	3,86 (96)	-2,02 (28)
Kyzylorda	-0,89 (38)	5,20 (91)	4,05 (65)	6,48 (92)	0,83 (62)	1,71 (84)	1,45 (80)	3,13 (100)	0,33 (53)	-0,31 (34)	3,20 (96)	-2,79 (17)
Mangystau *	0,41 (59)	4,09 (88)	4,03 (83)	4,03 (89)	0,11 (47)	2,04 (86)	4,25 (94)	1,67 (83)	-0,01 (38)	-0,23 (30)	3,57 (91)	-2,96 (5)
Pavlodar	-4,03 (16)	0,86 (55)	0,47 (47)	4,73 (87)	0,96 (55)	-0,69 (30)	-2,62 (10)	0,58 (75)	2,61 (94)	0,10 (51)	4,11 (97)	-2,16 (28)
North Kazakhstan	-2,74 (26)	2,20 (71)	-0,01 (48)	4,65 (89)	0,18 (52)	0,82 (58)	-2,24 (11)	0,71 (78)	0,85 (65)	-0,64 (32)	4,06 (96)	-1,10 (39)
Turkestan	1,17 (67)	5,26 (98)	3,74 (71)	4,79 (94)	0,50 (60)	1,27 (78)	0,04 (52)	3,10 (100)	1,18 (79)	0,35 (56)	2,58 (88)	-2,37 (24)

Notes: 1. for the Mangistau region, an assessment has been carried out since 1960;
2. values above the 95th or below the 5th percentile (respectively, warm and cold extreme points) are shown in bold and bright colors.

Summer 2019 was warm in the most regions of Kazakhstan, in the northern part of the country the average seasonal temperatures were around the norm (figure 2.2). Extremely high average seasonal air temperatures (the probability of not exceeding 96-97 %) observed in Almaty, Zhambyl, Turkestan regions (table 2.2). At a number of stations located in the southern half of Kazakhstan reached historical maximums of the average monthly air temperature (in the range from +24.0 to +32.1˚C). As a result, July in Almaty, Zhambyl, Kyzylorda, Turkestan regions entered 5% of the hottest summer months (table 2.3). In August, the absolute maximum air temperature was reached at MS Terekty (+23.0 ˚C, East Kazakhstan region) and Aksengir (+25.0 ˚C, Almaty region). At the same time, the average air temperature over the territory of the East Kazakhstan region was extremely high with the probability of not exceeding 98 % (table 2.3).

Summer temperature absolute minimums have not been updated. The air temperature anomaly averaged over the territory of Kazakhstan for the summer season of 2019 was +0.97 ˚C (92nd percentile, table 2.2).

The air temperature of the autumn season in the country was close to normal, with the exception of the Aktobe region, where significant below zero air temperature anomalies were recorded in the range from -1.1 ˚C from to -1.7 ˚C with the probability of less than 25 % (figure 2.2). Minor below zero air temperature anomalies averaged over the territories of the regions were observed in Aktobe (–0.50 ºC), Atyrau (–0.07 ºC), Karagandy (–0.11 ºC) regions (table 2.2). The average air temperature of the autumn season of 2019 exceeded the climatic norm by 0.26 ˚C. Historical extremes of air temperature among the autumn months have not been updated at any weather station.

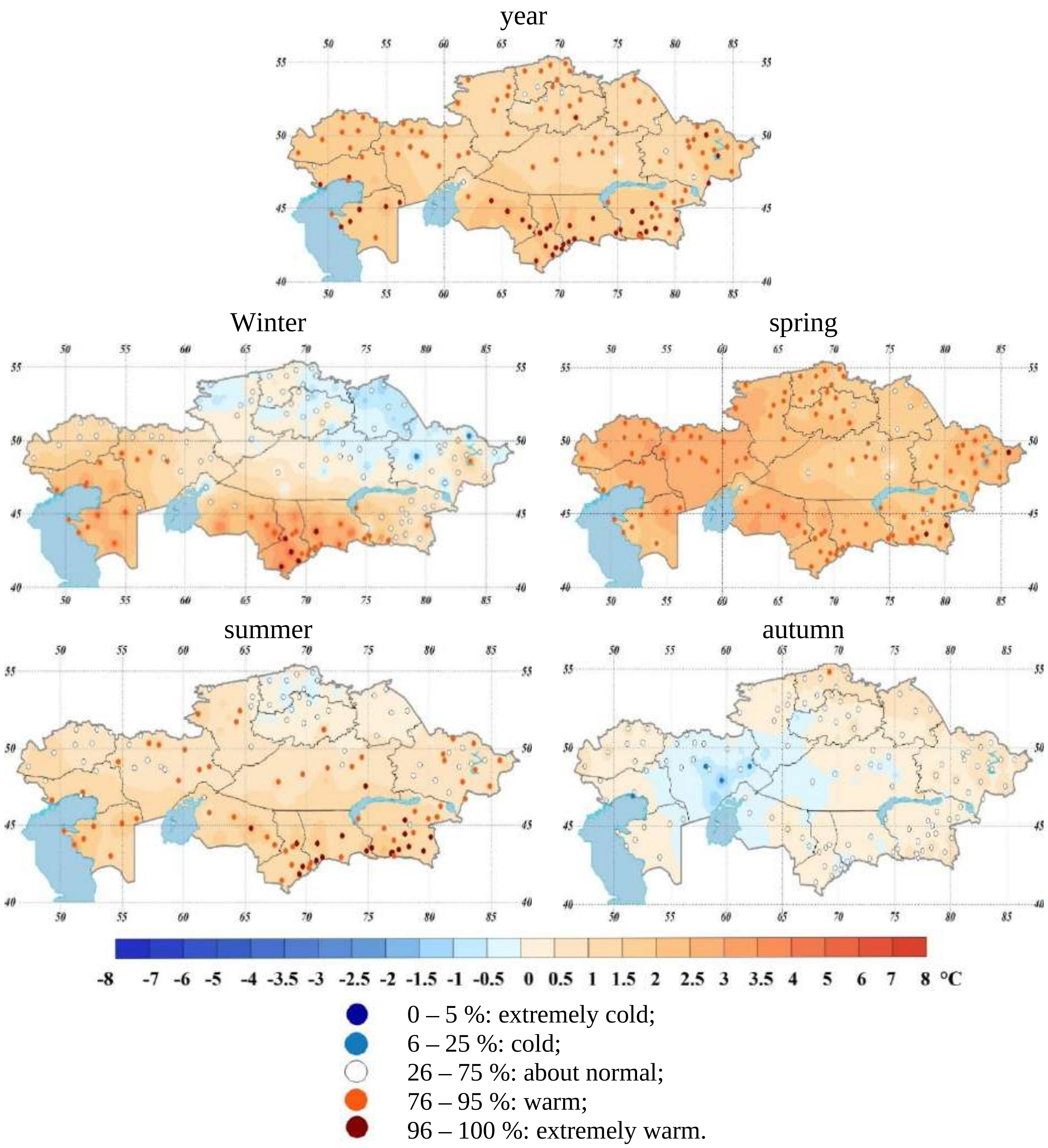


Figure 2.2 - Spatial distribution of air temperature anomalies (°C) in 2019 calculated relatively for basic period of 1961–1990, and the probabilities of not excess of air temperature

For monitoring the extreme values of climatic parameters, that are most significant for specific sectors of the economy and social sphere, the WMO Commission on Climatology developed the ClimPACT software product, which allows calculating a set of specialized climate indices. Based on the data of daily values of maximum, minimum air temperature and atmospheric precipitation at meteorological stations in Kazakhstan for the period since 1961, the following climatic indices were calculated:

- TXx, maximum of the daily maximum air temperature (°C);
- TNn, minimum of daily air temperature minima (°C);
- DTR, daily amplitude of air temperature (°C);
- SU25, the number of hot days with temperatures above 25 °C (days);
- TR, or tropical nights, the number of days when the daily minimum is above 20°C (days);
- SU35, the number of hot days with temperatures above 35 °C (days);
- TX90p, percentage of warm days with daily maximum air temperatures above the 90th percentile;
- TN10p, percentage of days when the minimum temperature was below the 10th percentile (cold nights);
- WSDI, duration of heat waves, or number of days on which for at least 6 consecutive days the daily maximum air temperature was above the 90th percentile (days);
- CSDI, duration of cold waves, or sum of days when the daily minimum air temperature was below the 10th percentile for at least 6 consecutive days (days);
- WSDI10, duration of heat waves, or number of days when the daily maximum air temperature was above the 90th percentile for at least 10 consecutive days (days);
- GSL, duration of the growing season or the period between the first date when the average daily temperature of the five days was ≥ 5° C, and the last date, when the average daily temperature of the five-day period was ≤ 5 °C (days);
- TM10a, the number of days with an average daily temperature above 10 °C (days);
- GDDgrow10, the sum of active air temperatures above 10 °C (°C);
- ID, number of days with daytime frosts (days);
- FDm20, number of days with severe frosts (days);
- Hddheat18, heat deficit (°C days);
- Cddcold23, cold deficit (°C days);
- CSDI3, duration of short cold waves, or sum of days when at least 3 consecutive days the daily minimum air temperature was below the 10th percentile (days);
- FD0, number of days with night frosts (days);
- RX1day, maximum amount of precipitation in 1 day (mm);
- CDD, duration of rainless periods, there was no precipitation (days);
- CWD, duration of precipitation periods, or number of days with at least 6 consecutive days when precipitation was equal or greater than 1 mm (days);
- R95pTOT, share of extreme daily precipitation in annual precipitation (%).

These selected indices make it possible to assess the impact of climatic factors on sectors such as health, water resources, agriculture and energy.

Daily maximum air temperature in 2019 (TXx index). Figure 2.3 shows the values of the absolute maximum air temperature recorded from the beginning of the opening of the meteorological station until 2019.The values of the daily maximum air temperature observed in 2019 are shown in blue, and the values of the absolute maximums values recorded since the opening of the station to 2018 are shown in red. In 2019, the absolute maxima were exceeded at two stations in Kazakhstan: MS Emba by +0.1 ˚C (43.4 ˚C) and MS Peshnaya by +0.3 ˚C (41.1 ˚C).

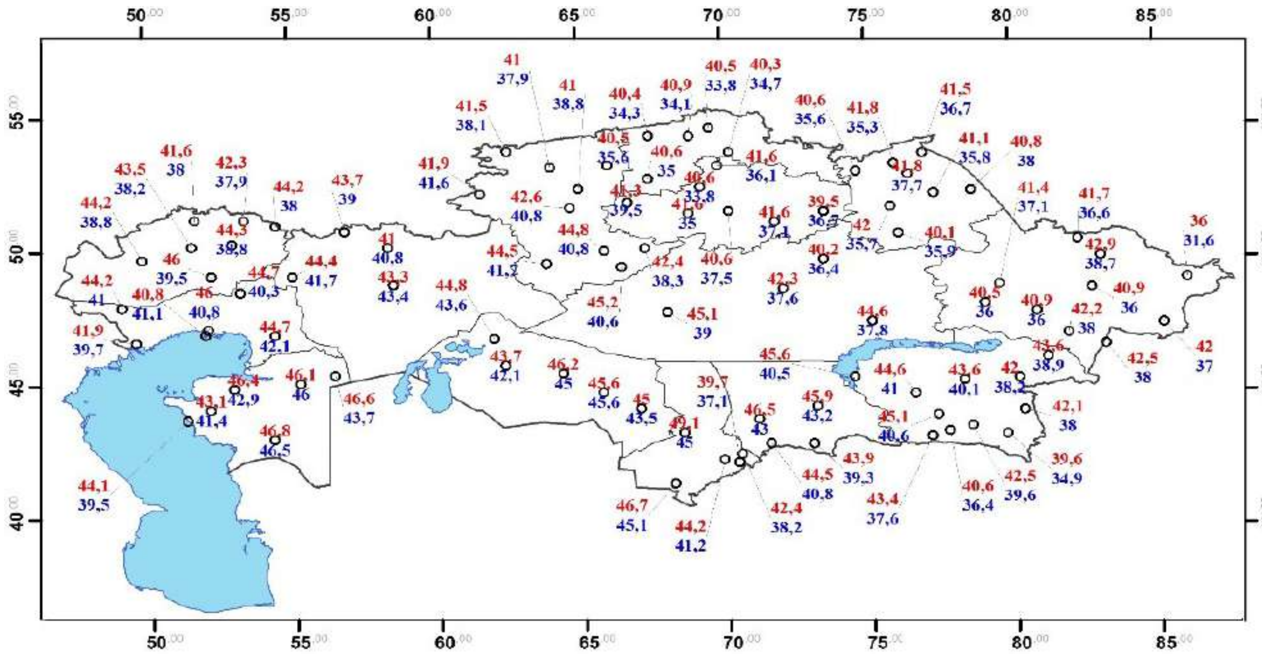


Figure 2.3 – Values of the absolute maximum air temperature (˚C) registered from the beginning of the opening of the meteorological station until 2018 (*shown in red*) and the maximum values of the daily air temperature (˚C) observed in 2019 (*shown in blue*)

Most of the highest air temperatures (absolute maximums) in Kazakhstan were recorded in July 1983, when at some meteorological stations of the Turkestan region the air temperature reached +49...+ 50 °C (MS Turkestan, Shayan, Arys, Tasty), as well as in July 1995, when the air temperature at MS Kyzylkum rose to +51 °C.

Further, figure 2.4 shows the absolute minimum air temperature (TNn index) recorded from the opening of the meteorological station to 2018 (in red), and in blue – the values of the minimum air temperature in 2019. In Kazakhstan, the absolute minimum temperature is below minus 50 °C recorded at 2 stations in January 1931 at the MS Shaganat (–54 °C) and in January1893 at MS Nur-Sultan (–52 °C). In 2019, as in 2018, the records of daily minimum temperatures were not updated. Air temperatures below minus 30 °C were observed mainly in the northern regions of Kazakhstan.

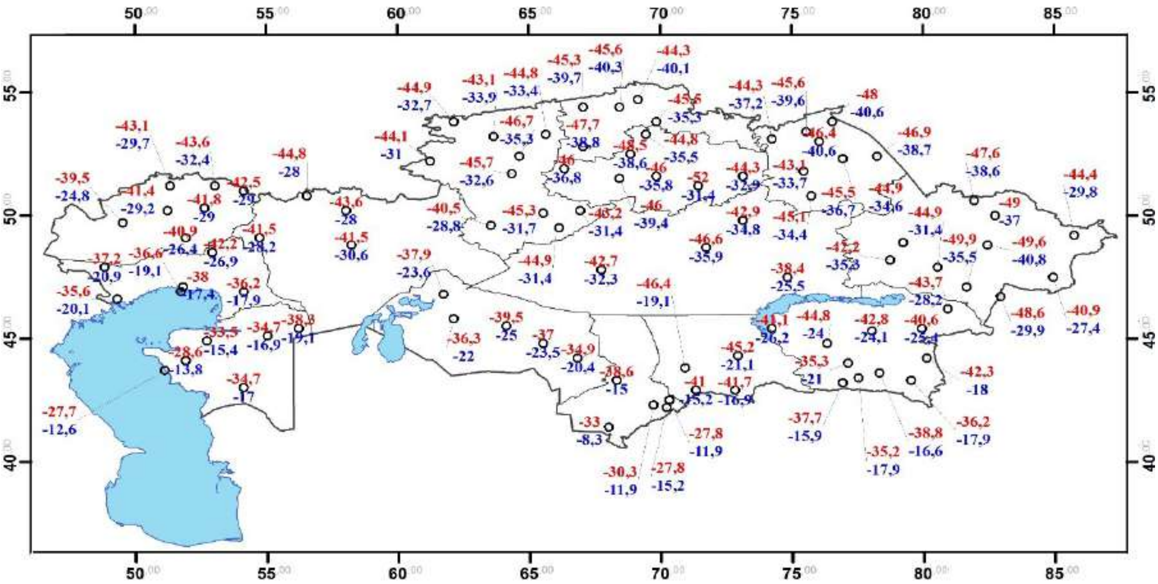


Figure 2.4 - The values of the absolute minimum air temperature (˚C) registered from the beginning of the opening of the meteorological station until 2018 (*shown in red*) and the minimum values of daily temperature (˚C) observed in 2019 (*shown in blue*)

Amplitude of daily air temperature (DTR index) shows the difference between the highest and lowest air temperature values during the day. Figure 2.5 shows the spatial distribution of the air temperature daily amplitude value over the territory of Kazakhstan in 2019. The daily amplitude in the territory of Kazakhstan in 2019 ranges from 9 ºC to 16 ºC. The largest daily amplitude (in some places up to 15-16 ºC) is observed in Kyzylorda, Turkestan, Zhambyl, Almaty and East Kazakhstan regions. In other regions of the country the daily amplitude is 10-12 ºC.

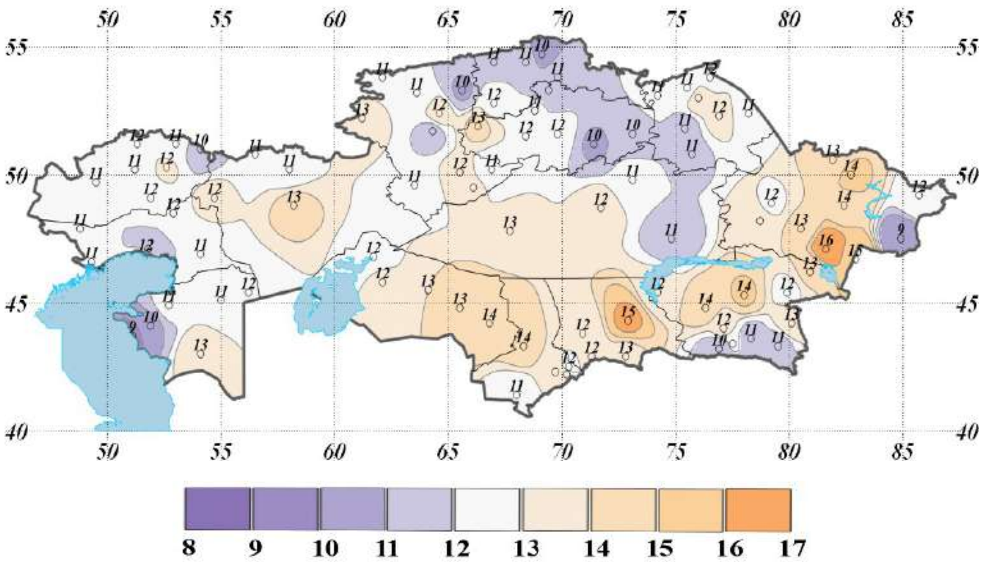


Figure 2.5 - Spatial distribution of the air temperature daily amplitude values (ºC) over the territory of Kazakhstan in 2019 (DTR index)

Information on the number of days with high air temperatures – above 25 ºC and 35 ºC is important (fig. 2.6 and 2.7). ***The number of days with temperatures above 25 ºC*** increases from north to south and southwest, which illustrates the air temperature zonal distribution. The maximum number of such days in 2019 was observed in Turkestan (MS Shardara 158 days a year), Kyzylorda (128 – 145 days a year), Mangystau (123 – 152 days a year) regions. The minimum number of days with air temperatures above 25 ºC (less than 50 days per year) was observed at stations in the North Kazakhstan and Akmola regions and at mountain stations in the south and southeast. For example, at the MS Katon-Karagay, this number of days was observed 35 days a year.

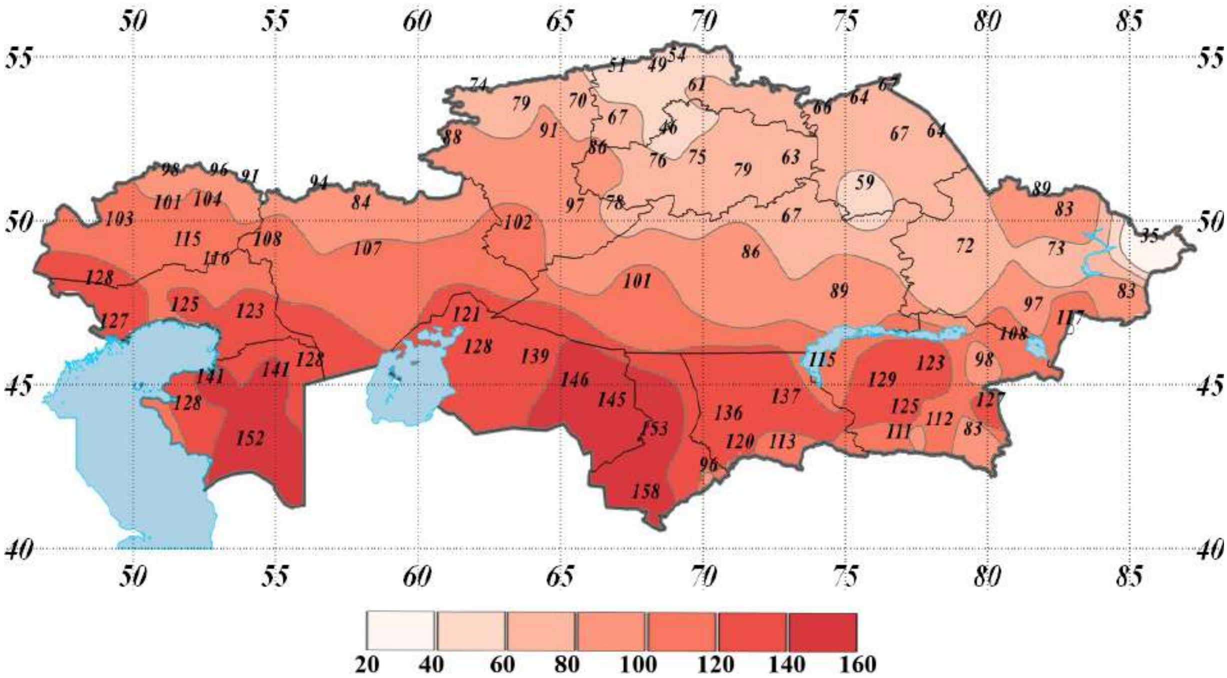


Figure 2.6 – Number of days with air temperature above 25 ºC in 2019 (Su25 index)

The number of days with an air temperature above 35 ºC, or hot days, in 2019 in the northern regions of the republic were observed extremely rarely (fig. 2.7 a), only 2 – 5 days a year, which is confirmed by the probability of non-exceeding (fig. 2.7 b). In the east of the country, there were also few such days – from 3 to 13 days a year. In the south and south-west of Kazakhstan, the number of hot days ranged from 40 to 67 days a year, that is, approximately 1.5 – 2 months a year, the probabilities of non-exceeding range from 76 % to 100 %.

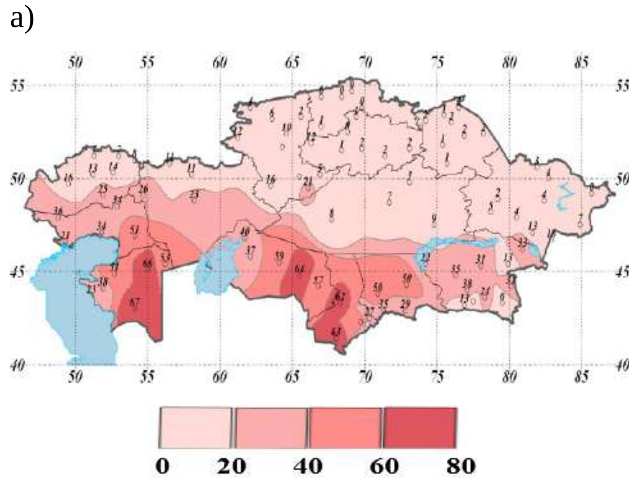


Figure 2.7 – The number of days with an air temperature above 35 ºC (a, Su35 index) and the probability of its non-exceeding (b) in 2019. Probabilities are calculated for the period 1961 - 2019

Figure 2.8 shows the number of days in 2019***, when the daily minimum air temperature was above 20 ºC (or the tropical nights index)***. In 2019, the maximum number of tropical nights was observed in Turkestan (38 – 74 days), Kyzylorda (28 – 56 days), Mangystau (47 – 66 days a year), Atyrau (20-59 days) regions. In some northern and mountainous regions the daily minimum did not exceed 20 ºC.

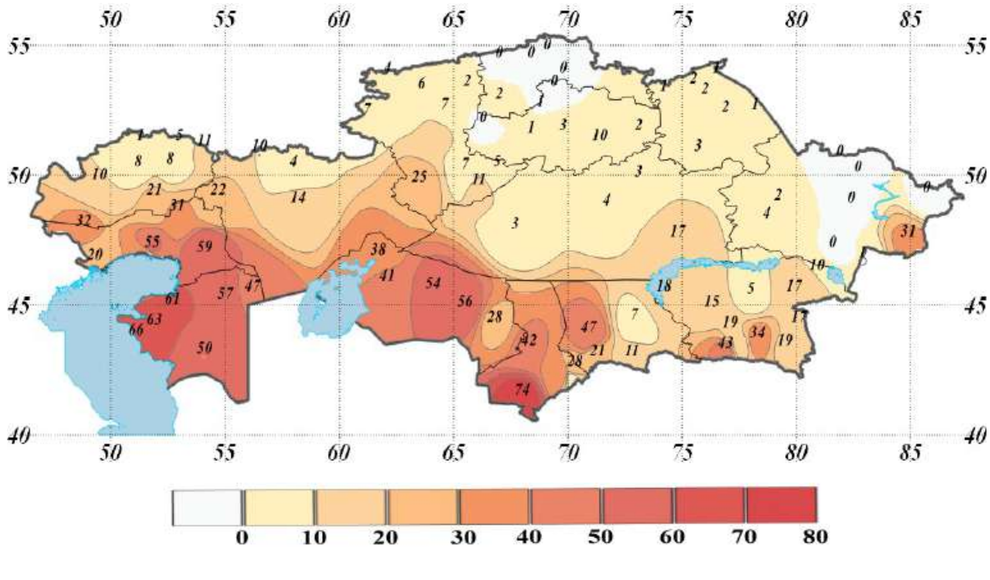


Figure 2.8 – Number of days when the daily minimum air temperature was above 20 ºC in 2019 (TR index)

Percentage of warm days with daily maximum air temperatures above the 90th **percentile**(Tx90p index) in 2019 across the territory of Kazakhstan ranged from 0 % to 32 % (figure 2.9 a). Most of these days (20 – 32 % of cases) were observed in Kyzylorda, Aktobe, Mangystau and West Kazakhstan regions. In all other regions of the country, the percentage of warm days ranged from 11 % to 19 % of cases per year. The regularities in the distribution of the values of this index over the territory of Kazakhstan are largely consistent with the distribution of the number of hot days and the duration of heat waves.

Percentage of colder days or when the daily minimum air temperature was below the 10th percentile(index Tn10p) in most of the territory of Kazakhstan did not exceed 15 % of cases (figure 2.9 b).

a) b)

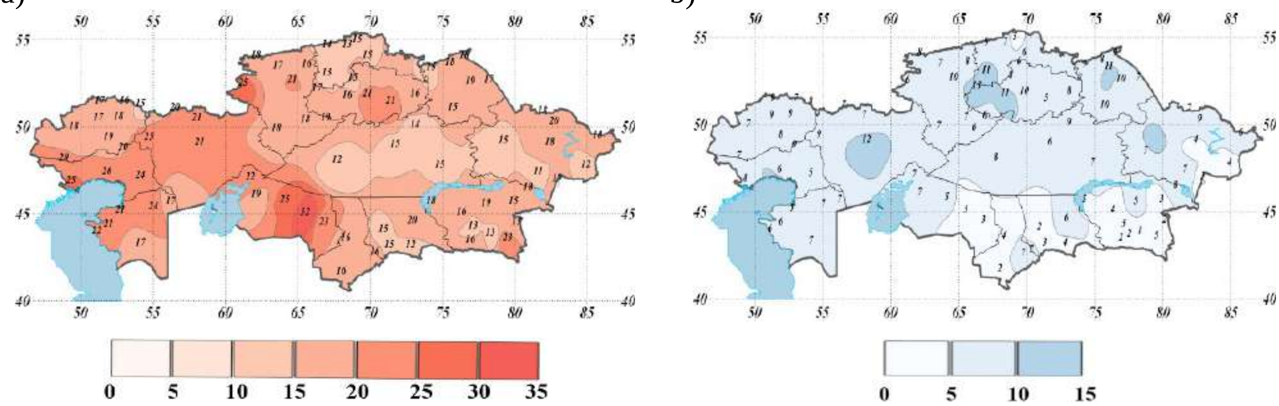


Figure 2.9 – Percentage of cases in 2019 when the daily maximum temperature was above the 90th percentile (Tx90p index, a) and the daily minimum temperature was below the 10th percentile (Tn10p index, b). Percentiles are calculated for the period 1961 – 1990.

The number of days when at least 6 consecutive days the daily maximum air temperature was above the 90th percentile (WSDI index) is taken as a heat wave. In 2019, the maximum total duration of heat waves was observed in Kyzylorda (22 – 37 days), Aktobe (32 – 38 days), Kostanay (22 – 32 days), Mangystau (24 – 35 days), West Kazakhstan (30 – 38 days) regions (figure 2.10 a). In Almaty, Zhambyl regions and the central part of Karaganda region the heat waves were’t observed. In other regions, heat waves were observed for about 10 – 25 days.

a) b)

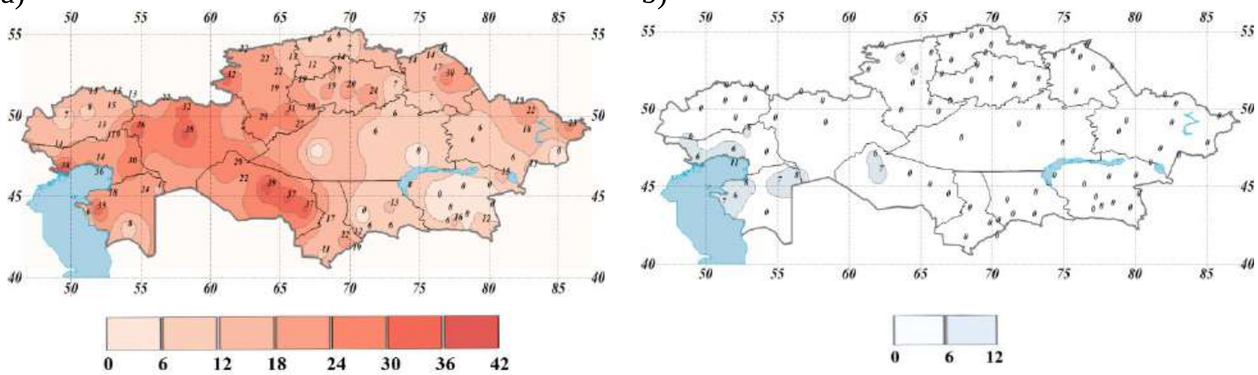


Figure 2.10 – The total sum of days in 2019, when at least 6 consecutive days the daily maximum air temperature was above the 90th percentile (a, WSDI index) and at least 6 consecutive days the daily minimum air temperature was below the 10th percentile (b, CSDI index). Percentiles are calculated for the period 1961 – 1990.

The number of days when, at least 6 consecutive days, the daily minimum air temperature was below the 10th percentile (CSDI index) was taken as a cold wave. There were practically cold waves on the territory of the republic was’t observed (figure 2.10 b), only in Mangystau and West Kazakhstan regions the total duration of cold waves was 6 – 11 days.

Figure 2.11 shows the distribution of ***the total duration of heat waves when at least 10 consecutive days the daily maximum air temperature was above the 90th percentile*** (WSDI10 index) in 2019. Longer heat waves in the republic are observed less often, but the effect of such waves may be more strong. Prolonged heat waves were observed mainly in Kyzylorda and Turkestan regions (10 – 23 days/year).

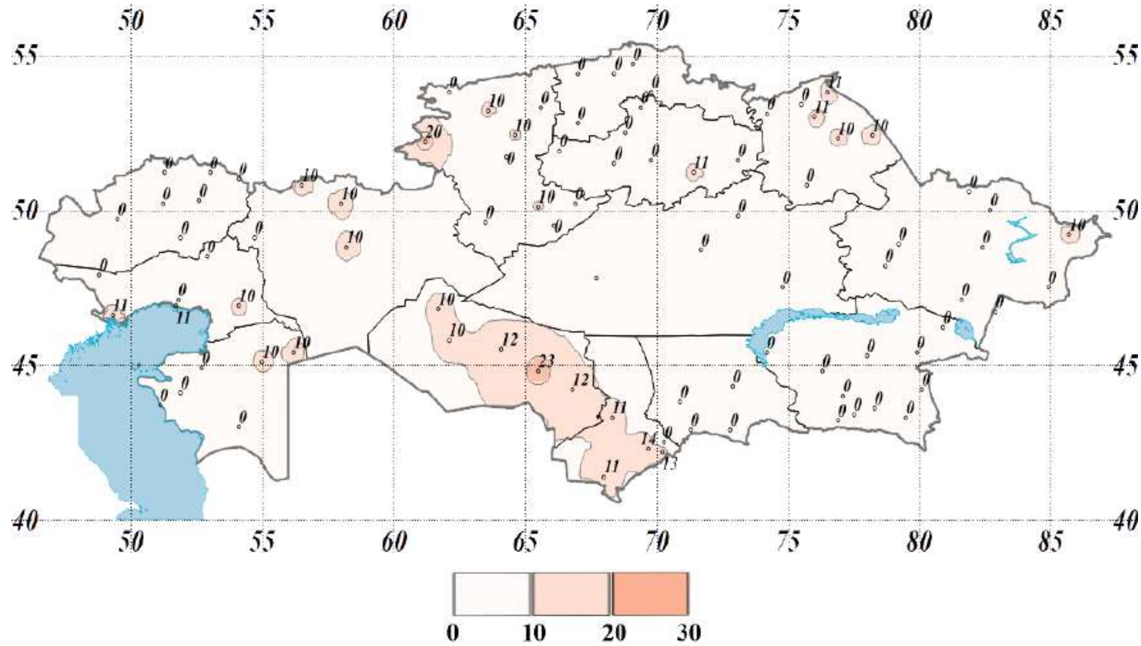


Figure 2.11 – Total sum of days in 2019 with at least 10 consecutive days the daily maximum air temperature was above the 90th percentile. Percentiles are calculated for the period 1961 – 1990 (WSDI10 index)

GSL Index defines the duration of the growing season of plants as the period between the first date when the average daily temperature of the five-day period was ≥ 5 °C, and the last date when the average daily temperature of the five-day period was ≤ 5 °C. Figure 2.12 shows the spatial distribution of the duration of the growing season in 2019. In 2019, the shortest growing season was 145 – 192 days in the northern regions of the republic. In the southern half of Kazakhstan, the growing season lasted more than 220 days, in the extreme south – more than 260 days, the maximum was observed at the Shardara meteorological station and amounted to 311 days a year.

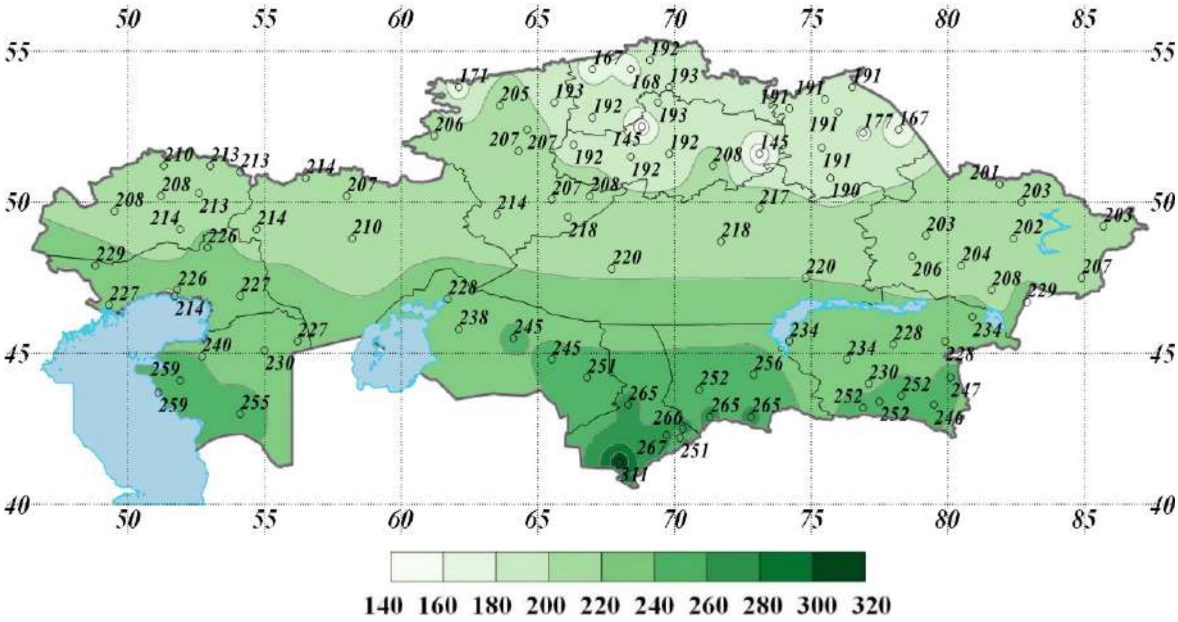


Figure 2.12 – Duration of the growing season (days) in 2019
(GSL index)

On the territory of Kazakhstan, a stable transition of air temperature through 5 °C in 2019 began from February 23rd in the extreme south according to the data MS Shardara to May 2nd in the north of the republic according to the MS Petropavlovsk (figure 2.13 a).

a) b)

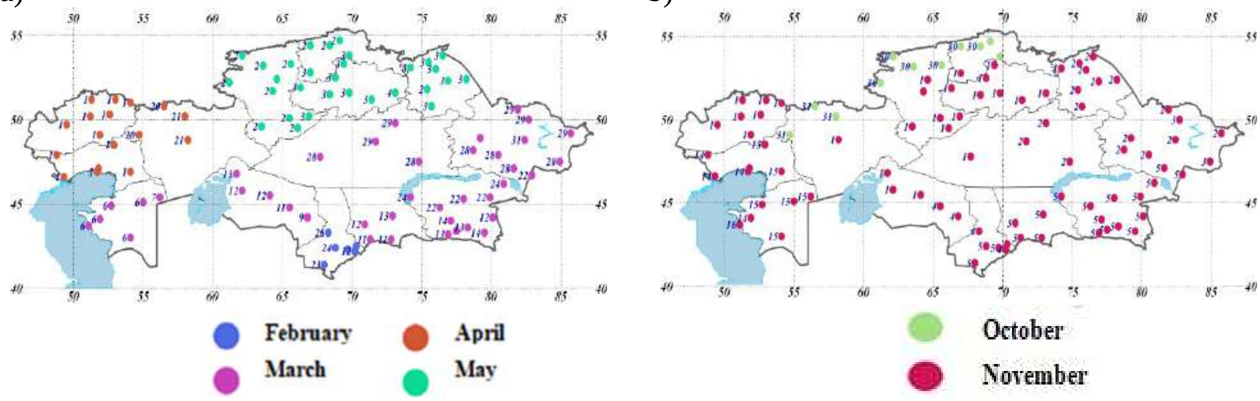


Figure 2.13 – Transition dates of air temperature through 5 °C in spring and autumn 2019

The stable transition through 5 °C in the autumn of 2019, practically throughout the entire territory of Kazakhstan (figure 2.13 b), begins at the beginning of November, only at several stations of the Aktobe, Kostanay and North Kazakhstan regions, a steady transition begins 1 – 2 days earlier, that is, in end of October.

The TM10a index characterizes the number of days with an average daily temperature above 10 ℃ (figure 2.14 a). In 2019, in the southern regions of such days were observed from 190 days to 246 days, in the northern and central regions of the republic – from 126 days to 180 days, in the east – from 147 days to 196 days, in the northwest – from 171 days to 190 days, in the southwest – from 194 days to 214 days.

Figure 2.14 (b) shows the spatial distribution of the active air temperature sums ***for the period with an average daily temperature above 10 °C (GDDgrow10 index)***. In 2019, the sums of such temperatures increases from north to south from about 1000 °C to over 3000 °C. The maximum sum of temperatures (3034 °C) observed at the southern MS Shardara. The minimum amounts were recorded in mountainous areas, for example, in the east of the republic at the MS Katon-Karagay, it was 753 °C, this station is located at an altitude of 1081 m above sea level.

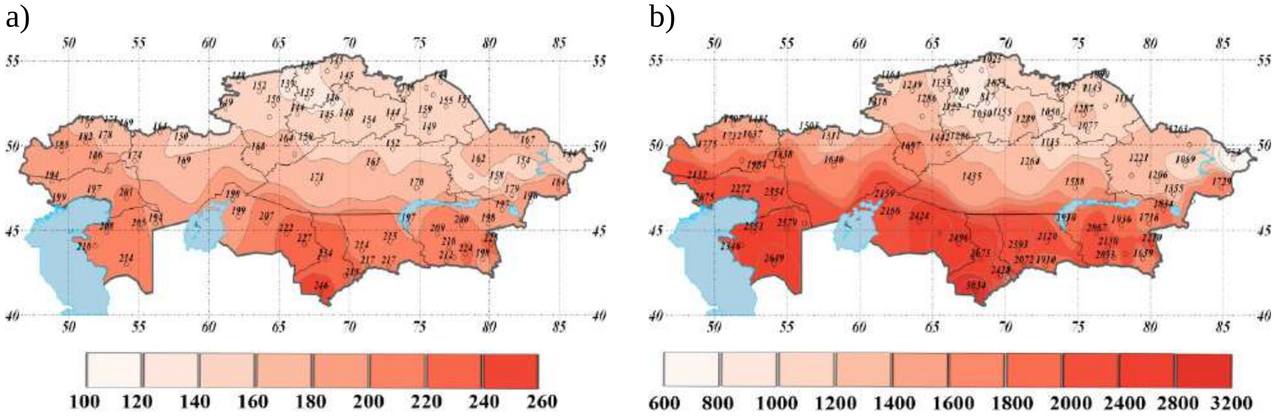


Figure 2.14 – Number of days with average daily temperature above 10 ˚C (a, index TM10a), as well as the sum of active air temperatures above 10 °C (b, GDDgrow10 index) in 2019.

Figure 2.15 shows ***the number of days with frost, when the daily maximum air temperature was below 0 ° C (ID index)***. Due to the geographical location, the northern regions in the winter months are characterized by temperatures, when daily maximums often drop below 0 °C, in 2019 there were from 100 days to 130 days of such days. In the southern regions, daily maximums in the winter months are mainly positive, the number of days with daily temperature maximums below 0 °C varies from 2 days to 50 days.

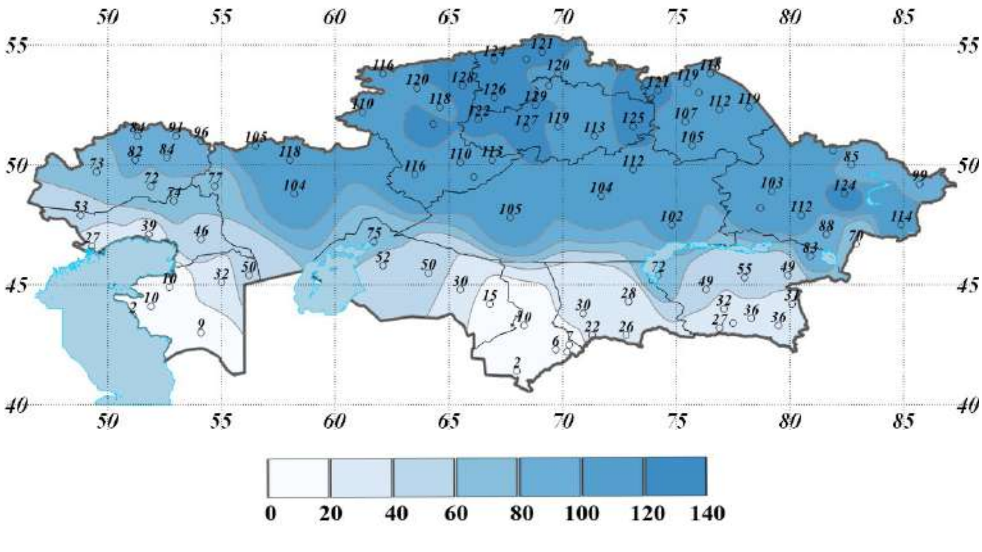


Figure 2.15 – Number of days with daytime frosts in 2019 (ID index)

The number of days with severe frosts, when the minimum air temperature was below 20 °C (FDm20 index) in Kazakhstan in 2019 is shown in the figure 2.16. In the southern regions of the country, such days were either not observed, or there were no more than 15 days, in the northern regions of Kazakhstan, the number of such days ranged from 30 days to 40 days, in some places 50 to 60 days.

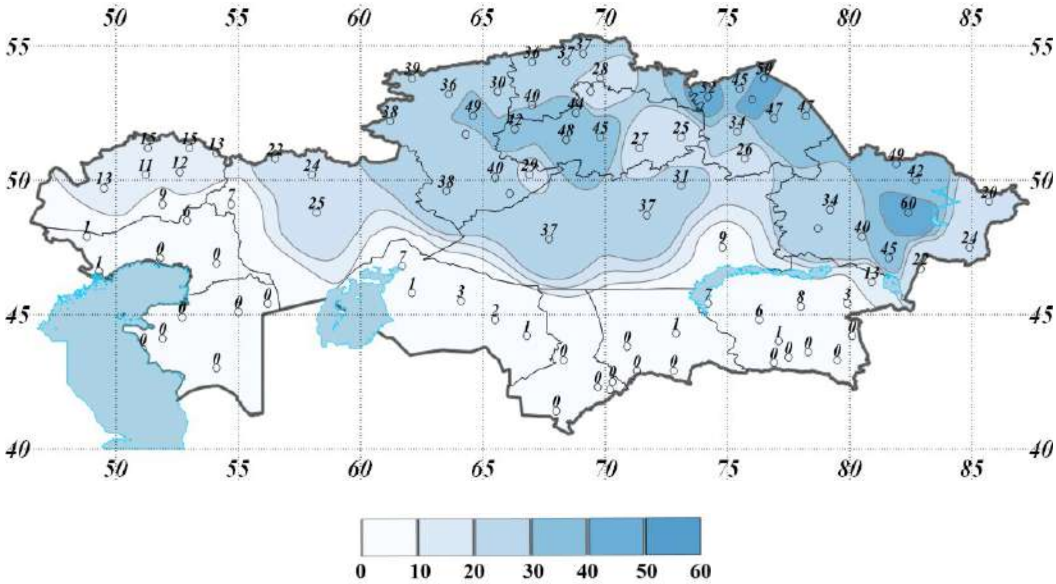


Figure 2.16 – The number of days with severe frosts in 2019 (FDm20 index)

Heat Deficiency Index (Hddheat) shows the sum of the differences between the comfortable temperature (here the temperature is taken as + 18 ºC) and the average daily outside air temperature (fig. 2.17). In the north, the heat deficit ranges from 4000 °C to 6000 °C, in the south – from 2000 °C to 3200 °C, in other regions – from 3200 °C to 4000 °C.

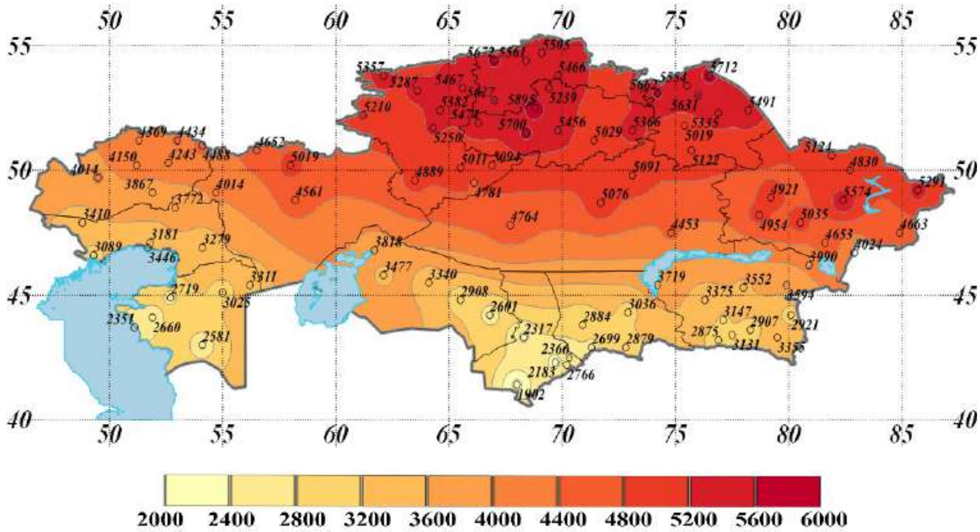


Figure 2.17 – Heat deficit (°C/days) in the cold season in 2019 (Hddheat18 index)

Cold deficit index (cddcold23) shows the sum of the differences between the comfortable temperature in the warm season (here the temperature is + 23 ºC) and the average daily outside air temperature (figure 2.18). In the southern regions, the sum of the excess of comfortable temperatures ranges from 400 °C to 600 °C, in the northern and eastern regions of the republic this figure does’t exceed 100 °C, and in other regions – from 100 °C to 400 °C.

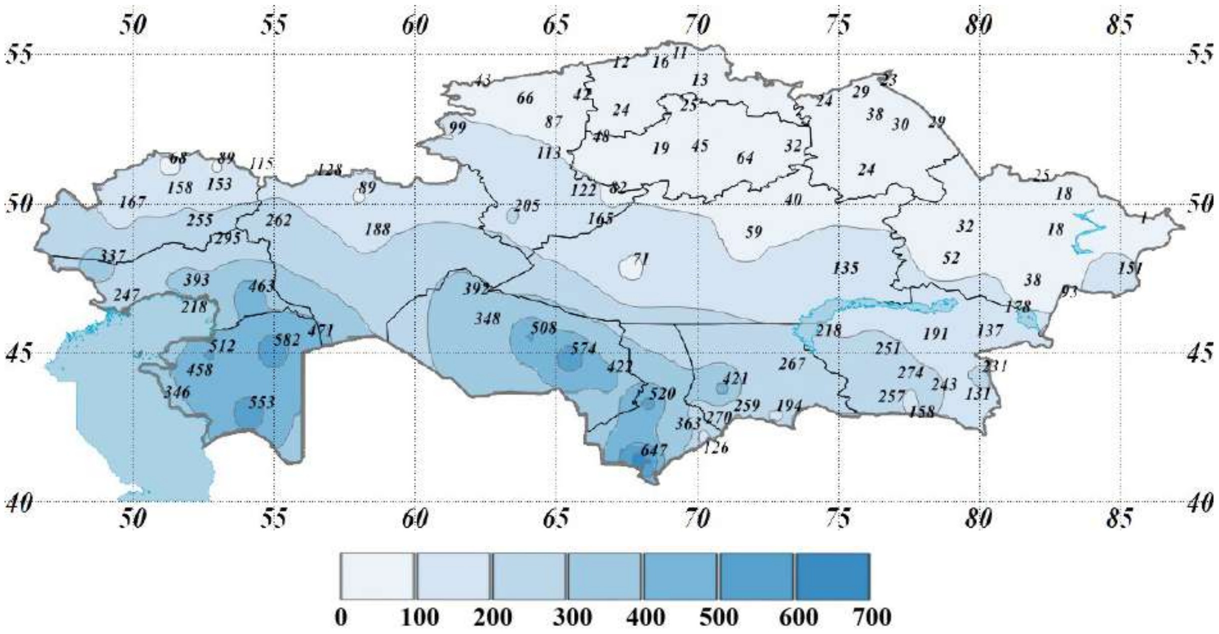


Figure 2.18 – Cold deficit (°C/days) in the warm season in 2019 (Cddcold23 index)

2.2 The observed changes of the air temperatures

Figures 2.13 - 2.14 are shown the time series of averaged over the territory of Kazakhstan and administrative regions of the annual mean and seasonal anomalies of surface air temperatures over the period 1941 - 2019, also linear trends of air temperature change over the period 1976 - 2019. Anomalies are calculated relatively for the basic period of 1961 - 1990. Linear trends gives evident information about the gradual increase in annual mean and seasonal surface air temperatures over the last decades. Table 2.4 presents changes in air temperature over the period 1976 2019: the linear trend coefficient characterizing the average rate of change air temperature anomaly; and the coefficient of determination, and the determination coefficient showing trend contribution for the total variance.

On average across the territory of Kazakhstan for the period 1976 2019 increasing in the average annual air temperature is 0.31 ºC every 10 years. The highest growth rates are observed in the spring (0.60 ºC/10 years), the lowest in winter (0.11 ºC/10 years). The contribution of the trend to the total variance of average annual temperatures is 25 %, for other seasons from 0 % in winter to 26 % in spring. In all seasons, except for winter, the temperature increasing is statistically significant (table 2.4).

More detailed information on the change in the average annual, seasonal and monthly air temperature (in ºC/10 years) across the territory of Kazakhstan for the period 1976 2019. is presented in the figures 2.21 - 2.22.

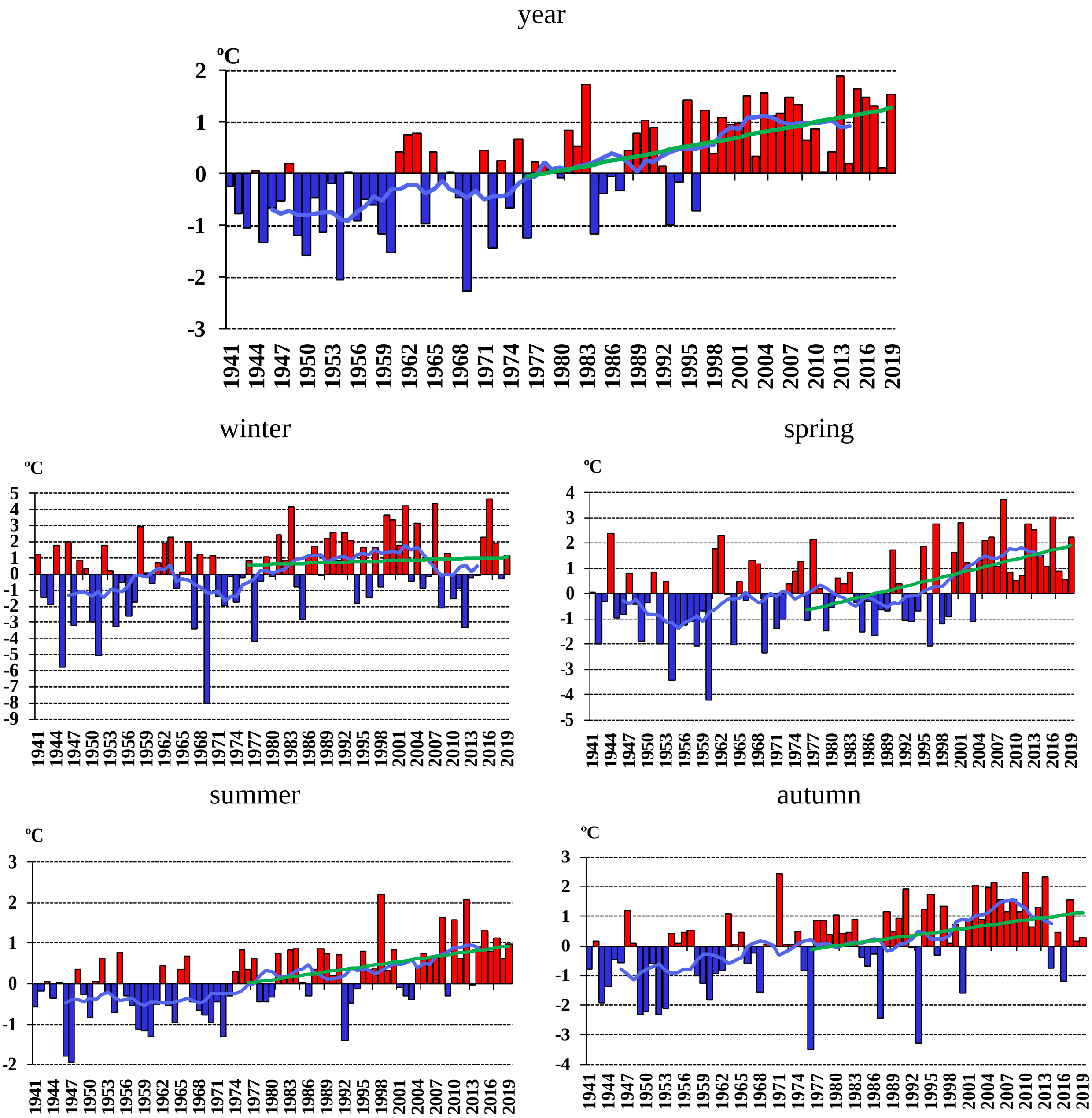


Figure 2.13 – Time series of anomalies of annual and seasonal air temperatures (ºC), averaged over the territory of Kazakhstan for the period 1941 - 2019. Anomalies are calculated relatively to the base period of 1961–1990. Linear trend during 1976-2019 is highlighted in green color. *Smoothed curve is received by the 11th sliding averaging*

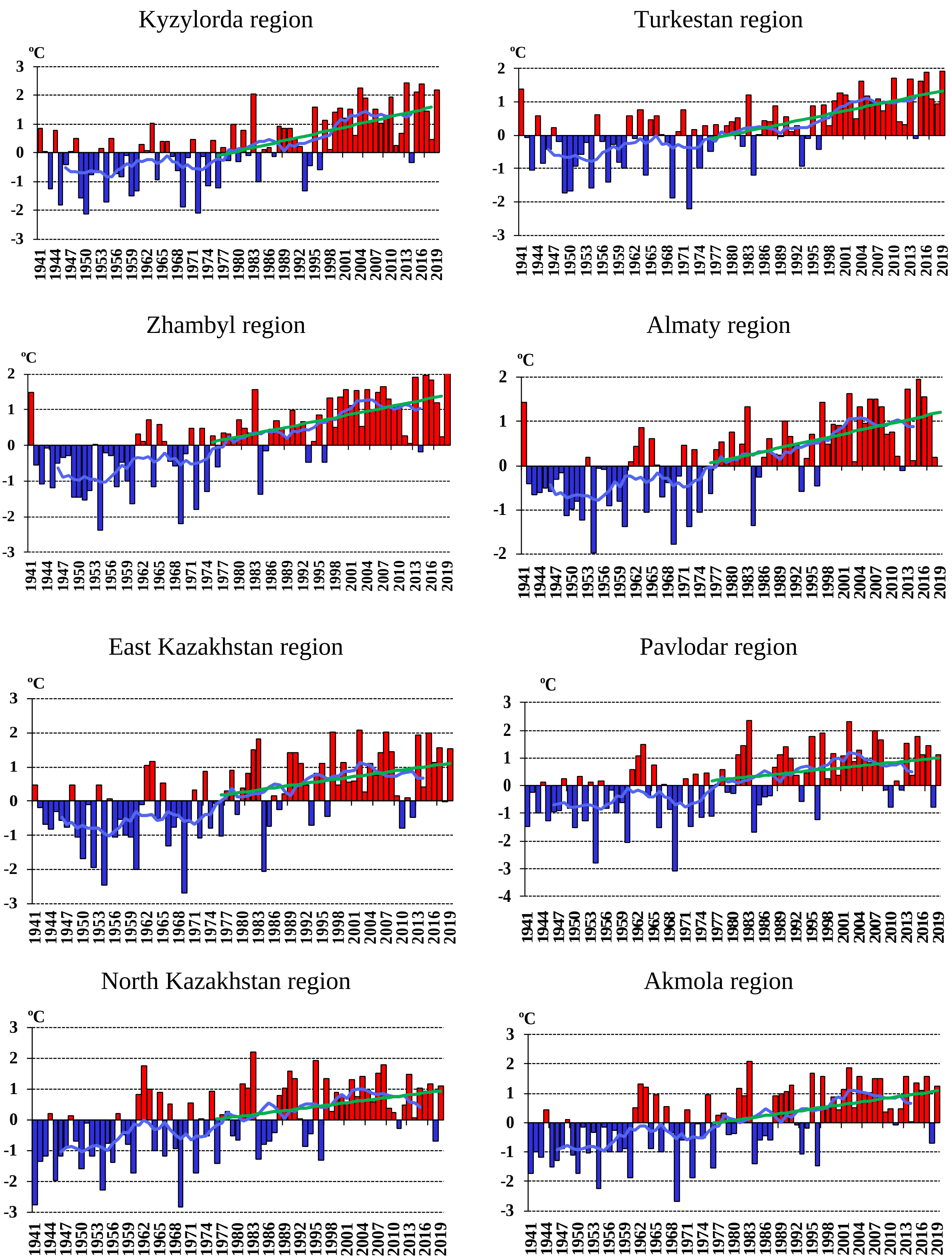


Figure 2.14 – Time series of anomalies of annual air temperatures (ºC), averaged over the regions of Kazakhstan for the period 1941 - 2019. Anomalies are calculated relatively to the base period of 1961–1990. Linear trend during 1976-2019 is highlighted in green color. *Smoothed curve is received by the 11th sliding averaging, Sheet 1*

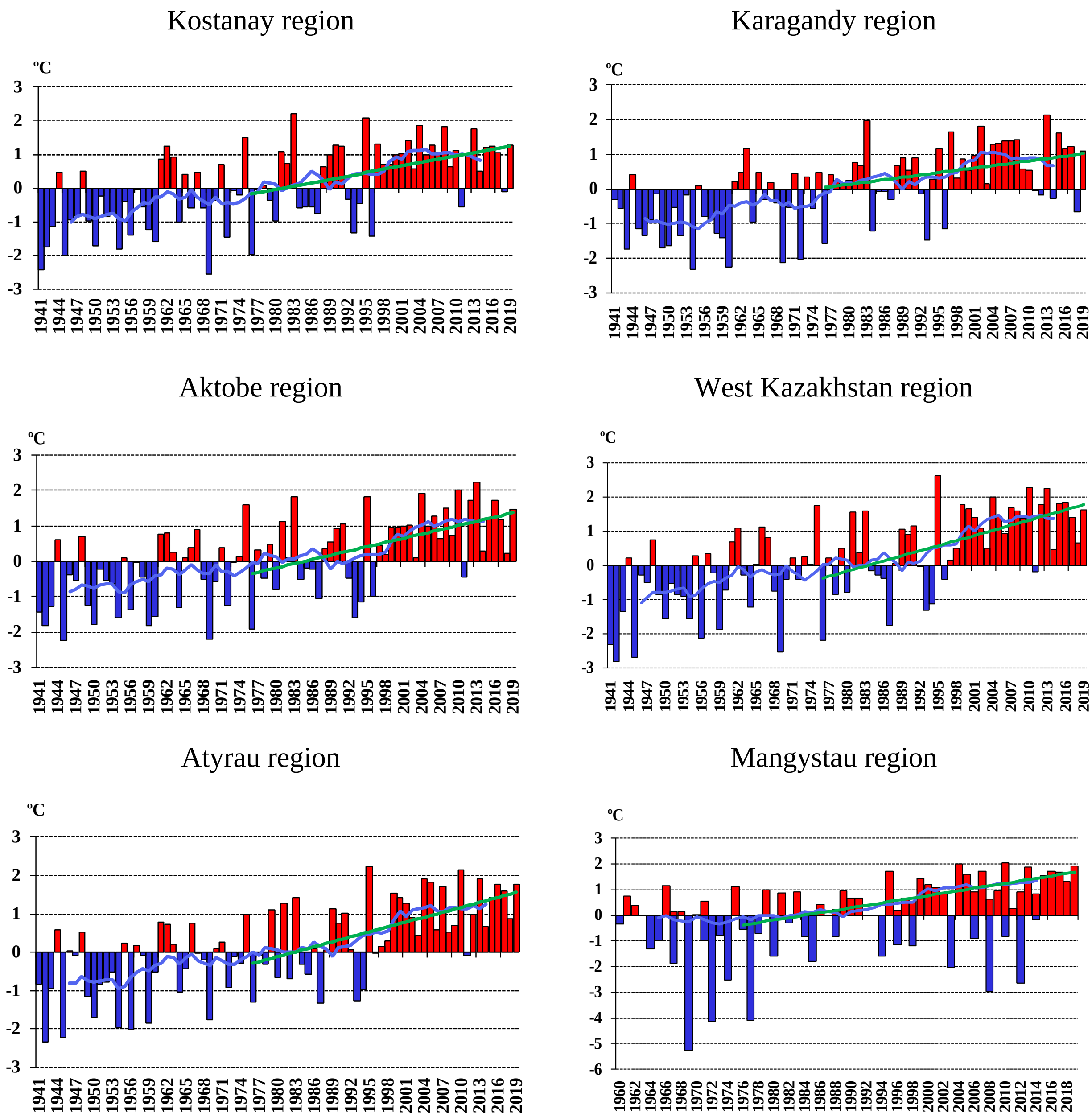


Figure 2.14 – Time series of anomalies of annual air temperatures (ºC), averaged over the regions of Kazakhstan for the period 1941 - 2019. Anomalies are calculated relatively to the base period of 1961–1990. Linear trend during 1976-2019 is highlighted in green color.
Smoothed curve is received by the 11th sliding averaging, Sheet 2

Averaged across the territory of Kazakhstan for the period 1976-2019 increasing the average annual air temperature is 0.31 ºC every 10 years. The highest growth rates are observed in the spring (0.60 ºC/10 years), the lowest – in the winter (0.11 ºC/10 years). The contribution of the trend to the total variance of average annual temperatures is 25 %, for other seasons – from 0 % in winter to 26 % in spring. In all seasons, except for winter the temperature increasing is statistically significant (table 2.4).

More detailed information on the change in the average annual, seasonal and monthly air temperature (in ºC/10 years) across the territory of Kazakhstan for the period 1976-2019 presented in the figure 2.15-2.16.

Table 2.4 – Characteristics of the linear trend of surface air temperature anomalies, averaged over the territory of Kazakhstan and its regions for the period 1976 – 2019.

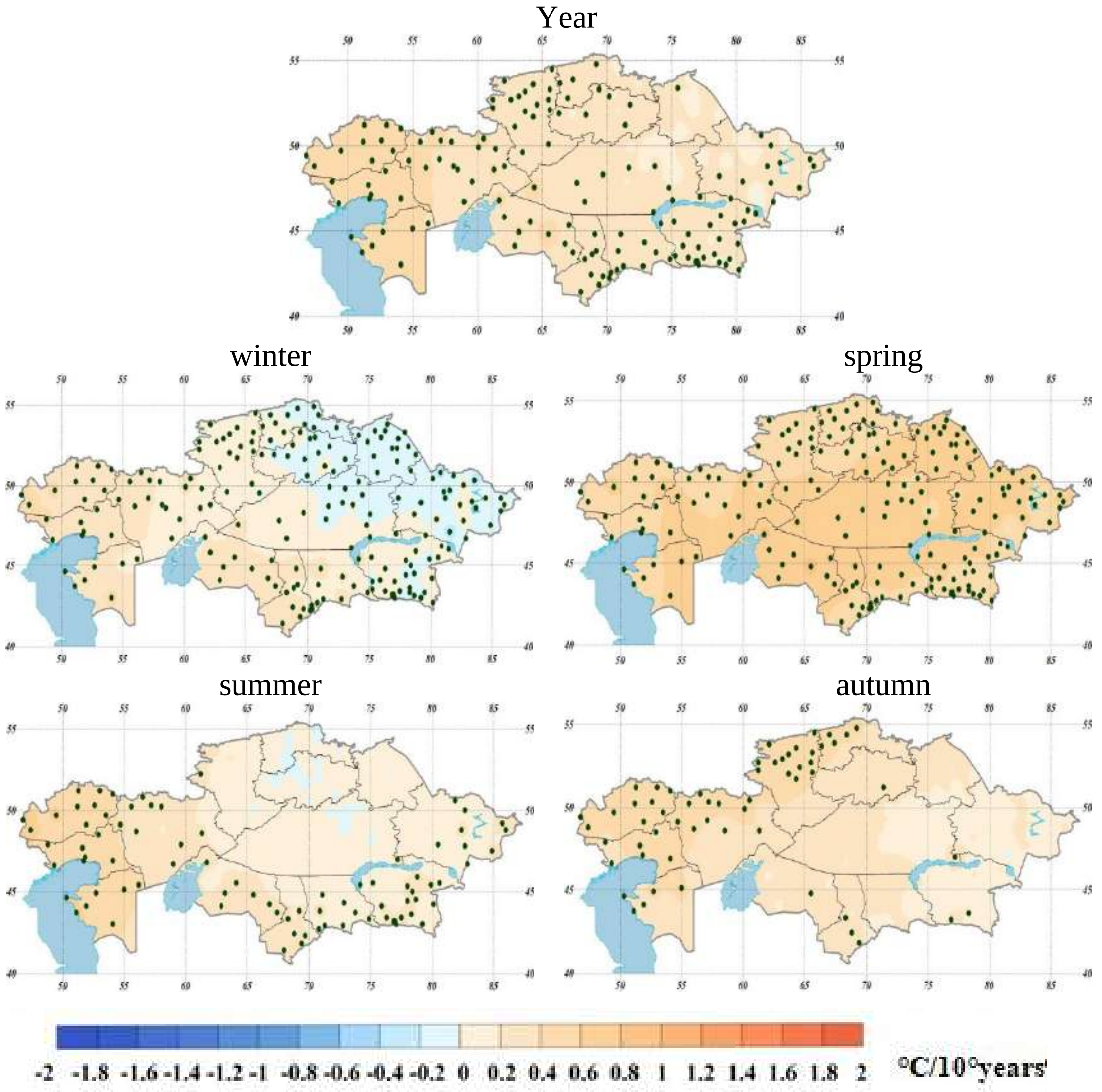
Region / region	Year		Winter		Spring		Summer		Autumn	
	a*	**R^2	a	R^2	a	R^2	a	R^2	a	R^2
Kazakhstan	0,31	**25**	0,11	0	0,60	**26**	0,21	**15**	0,29	**8**
Almaty	0,27	**21**	0,08	0	0,59	**27**	0,21	**18**	0,19	**5**
Akmola	0,26	**12**	0,02	0	0,61	**19**	0,00	0	0,34	**6**
Aktobe	0,40	**26**	0,22	1	0,60	**15**	0,31	**10**	0,42	**11**
Atyrau	0,43	**32**	0,36	4	0,48	**18**	0,45	**31**	0,38	**12**
East Kazakhstan	0,22	9	-0,09	0	0,62	23	0,16	8	0,16	2
Zhambyl	0,30	**25**	0,18	1	0,60	**27**	0,21	**16**	0,20	**5**
West Kazakhstan	0,50	**32**	0,37	3	0,56	**16**	0,53	**22**	0,46	**15**
Karaganda	0,23	**10**	0,00	0	0,68	**23**	0,02	0	0,16	2
Kostanay	0,34	**18**	0,08	0	0,56	**14**	0,15	2	0,50	**13**
Kyzylorda	0,42	**29**	0,29	2	0,79	**31**	0,27	**18**	0,28	**7**
Mangystau	0,48	**46**	0,34	**5**	0,58	**27**	0,57	**40**	0,37	**11**
Pavlodar	0,19	**6**	-0,14	0	0,62	**22**	0,03	0	0,24	3
North Kazakhstan	0,22	9	-0,04	0	0,45	12	-0,01	0	0,42	9
Turkestan	0,34	**36**	0,29	3	0,55	**27**	0,23	**15**	0,25	**8**

* a – coefficient of the linear trend, ºC/10 year
** R^2 – determination coefficient, %
***«in bold font» has highlighted statistically significant tendencies

Trends of average annual temperature all territory of Kazakhstan were positive and statistically significant (figure 2.15–2.16). Faster warming is in the western regions of Kazakhstan (0.33 - 0.50 ºC/10 years), the lowest warming rate (0.19 - 0.34 ºC/10 years) is observed in the north-eastern part of the republic, as well as in the south mountainous regions (0.22 - 0.27 °C/10 years).

In winter, the highest rate of increasing in air temperature was noted in the southern and western regions: from 0.22 to 0.37 ºC/10 years. In East Kazakhstan, Pavlodar, North Kazakhstan regions, there has been a weak trend towards decreasing in temperature: from - 0.04 to-0.14ºC/10 years (table 2.4). In January, in the vast territories of the north, north-eastern part of the republic the negative trend of air temperature change ranged from 0.14 to - 0.59 ºC/10 years. Statistically significant negative air temperature tendencies in January were observed at the stations Urzhar (East Kazakhstan region, –0.86 ºC/10 years), SCFM Borovoe (Akmola region, –1.07 ºC/10 years). A significant positive trend was noted only at the MS Kazygurt – 074 ºC/10 years. In February, on the territory of all Kazakhstan, there was the tendency of air temperature increasing: from 0.11 to 0.74 ºC/10 years(figure 2.16).Statistical reliable growth rates of air temperature in February observed at the stations of Mangystau region: Akkudyk (0.82 ºC/10 years) and Fort-Shevchenko (0.75 ºC/10 years). In December, decreasing in air temperature from 0.01 to 0.07 °C/ 10 years was observed in the north-eastern and southern regions of the Republic. It should be noted that in the foothill and mountainous regions of the extreme east, as well as in the western regions, positive trends in air temperature change from 0.12 to 0.45 ºC/10 years were recorded. All the obtained trends in air temperature changes in December are statistically insignificant.

In spring, the most intense and statistically significant warming from 0.38 to 0.79 ºC/10 years is observed throughout Kazakhstan. All trends in the average temperature for the spring season are statistically significant (figure 2.15). The highest rate of increase in air temperature was noted in March (from 0.66 to 1.82 ºC/10 years). In April, statistically significant growth rates (from 0.44 to 1.82 ºC/10 years) are traced to the east of 70 ºE, in May - to the south of 50 N. (from 0.36 to 0.82 ºC/10 years, figure 2.16).



● significant positive and negative linear trend coefficients

Figure 2.15 – Spatial distribution of the values of the linear trend coefficient of the average annual and seasonal surface air temperature (°C/10 years) calculated according to observations during 1976 – 2019

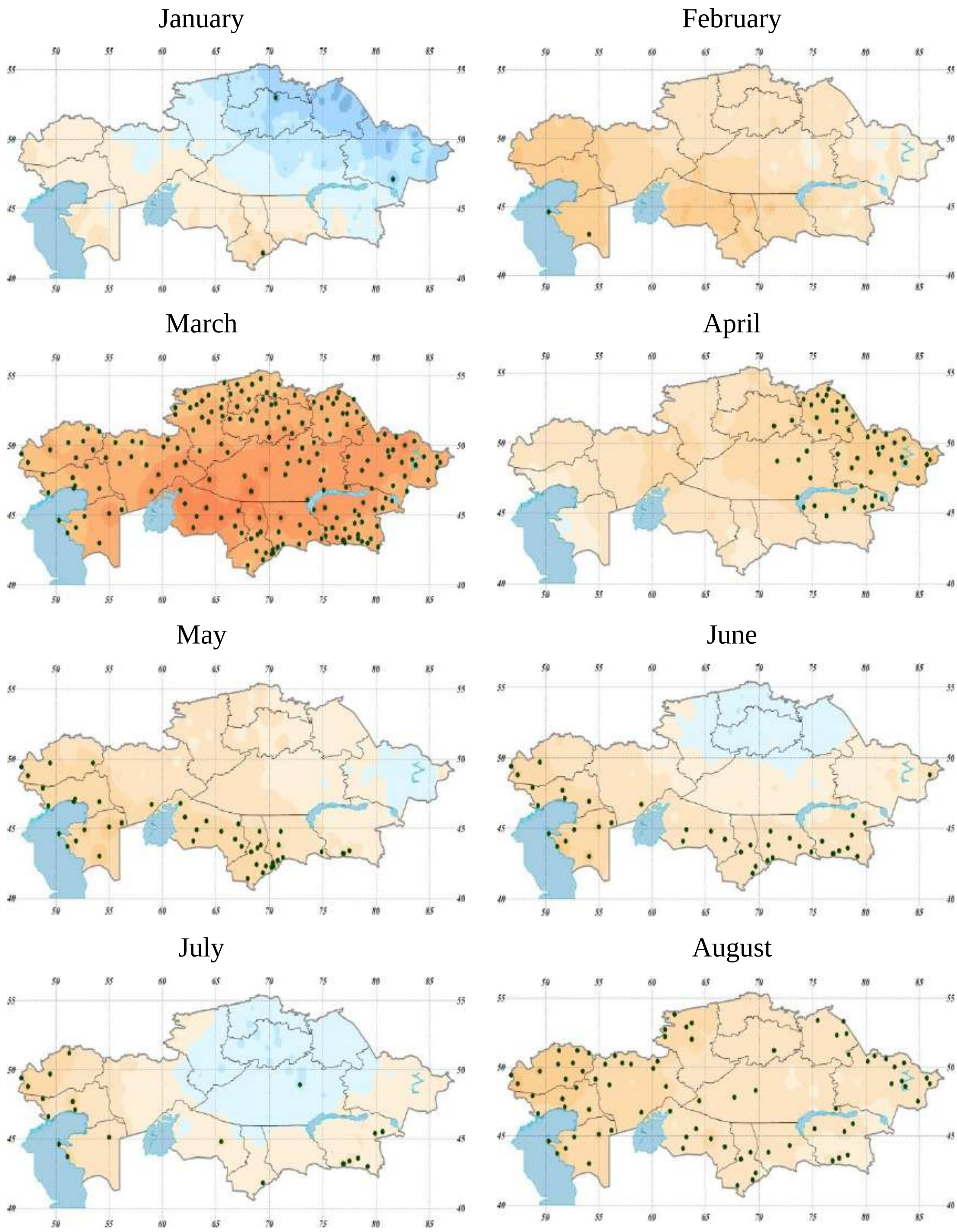
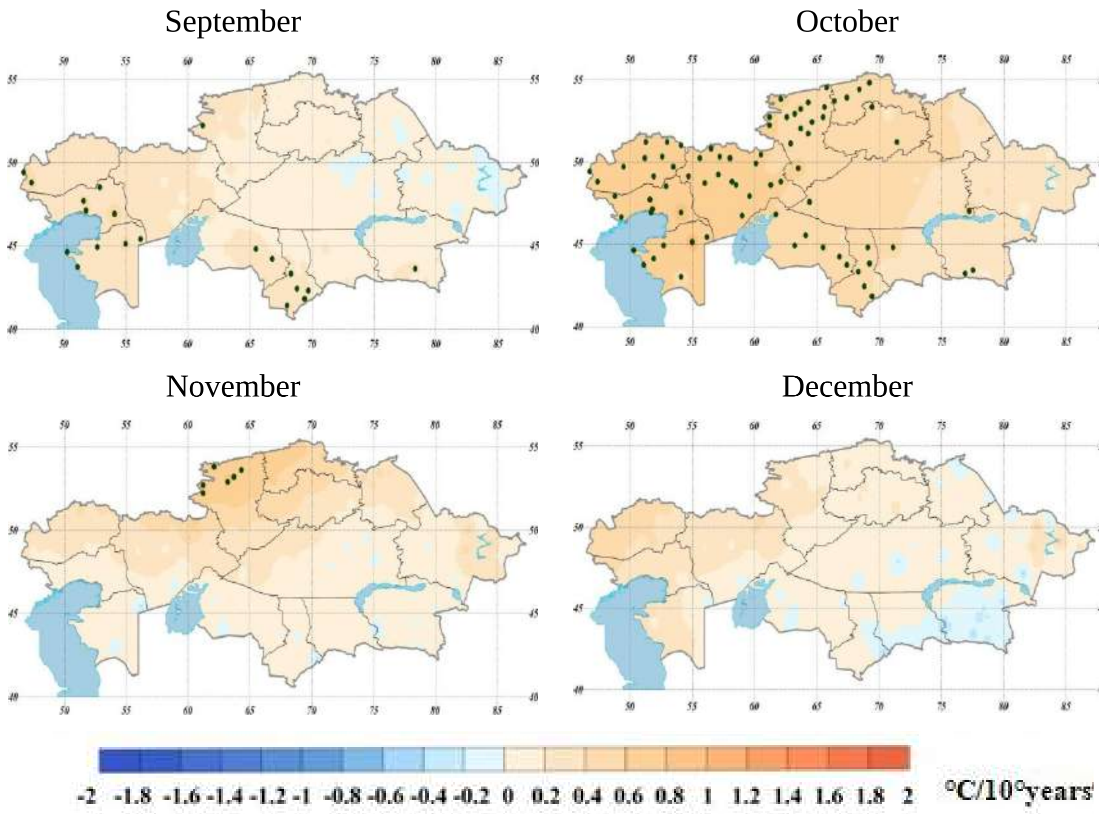


Figure 2.16 – Spatial distribution of linear trend values of coefficient mean monthly surface air temperature (°C/10 years), calculated according to observational data by the period 1976 – 2019 *Sheet 1*



- significant positive and negative linear trend coefficients

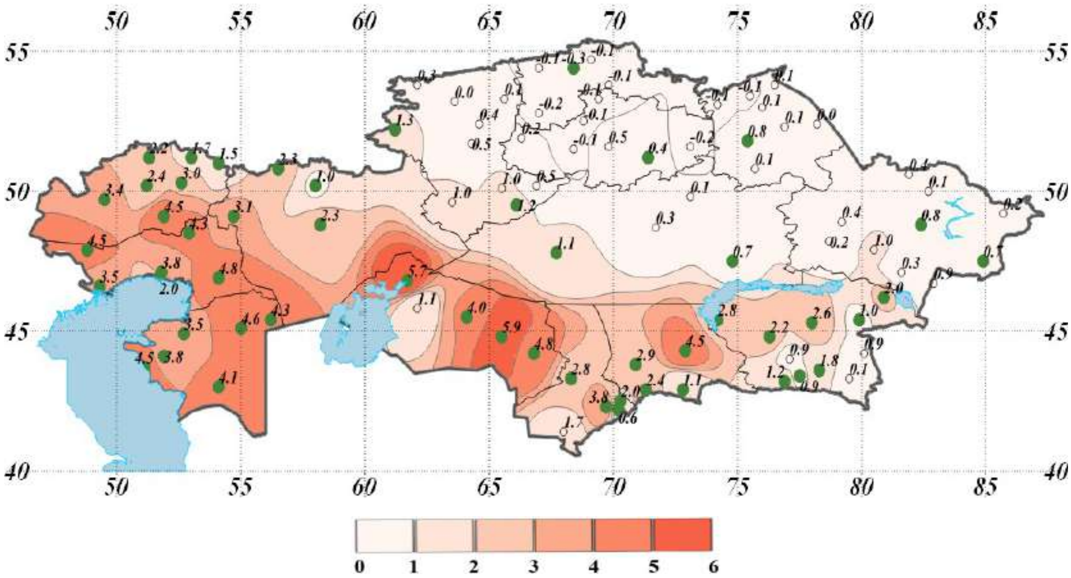
Figure 2.16 – Spatial distribution of linear trend values of coefficient mean monthly surface air temperature (°C/10 years), calculated according to observational data by the period 1976 – 2019 *Sheet 2*

In the summer, stable positive trends observed in the east, as well as in the southern and western regions of the Republic (from 0.15 up to 0.92 ºC/10 years). In the central and northern regions of Kazakhstan tendencies in the air temperature changes were statistically insignificant and ranged from –0.11 to 0.33 ºC/10 years, with the exception of MS Zhitikara in Kostanay region, where the increasing in the air temperature was statistically significant and amounted to 0.36 ºC/10 years (figure 2.15). In June and July a slight cooling is observed in the northern and central regions (by 0.01 ... 0.33 ºC/10 years). A statistically significant negative trend was noted only at the MS Zharyk in Karaganda region (-0.33 ºC/10 years). In August, in the most regions of Kazakhstan statistically significant positive trends of the air temperature are noted from0.24 to 0.89 ºC/10 years.

In autumn, over the past 4 decades, a steady increase in air temperature was noted in the north-west, west and south of the Republic (from 0.28 up to 0.64 ºC/10 years). The main contribution was made by the months of September and October, when the statistically significant positive trend in air temperature was 0.24-0.52 ºC/10 years and 0.25-0.91 ºC/10 years, respectively. In August, the centers showed statistically insignificant negative trends in surface air temperature in Karaganda, Pavlodar, East Kazakhstan regions (from-0.01 to-0.22 ºC/10 years, figure 2.16).

2.3 Tendencies in the extremes of surface air temperature

In many regions of Kazakhstan, there is a statistically significant positive trend of an increasing the number of days when the air temperature was above 35 °C, these are Kyzylorda (4-6 days/10 years), Atyrau, Mangystau (3-5 days/10 years) regions, as well as in some areas of Zhambyl, West Kazakhstan, Aktobe and Almaty regions (1-2 days/10 years). The trends in the rest of the republic are also positive, but statistically insignificant (figure 2.23).

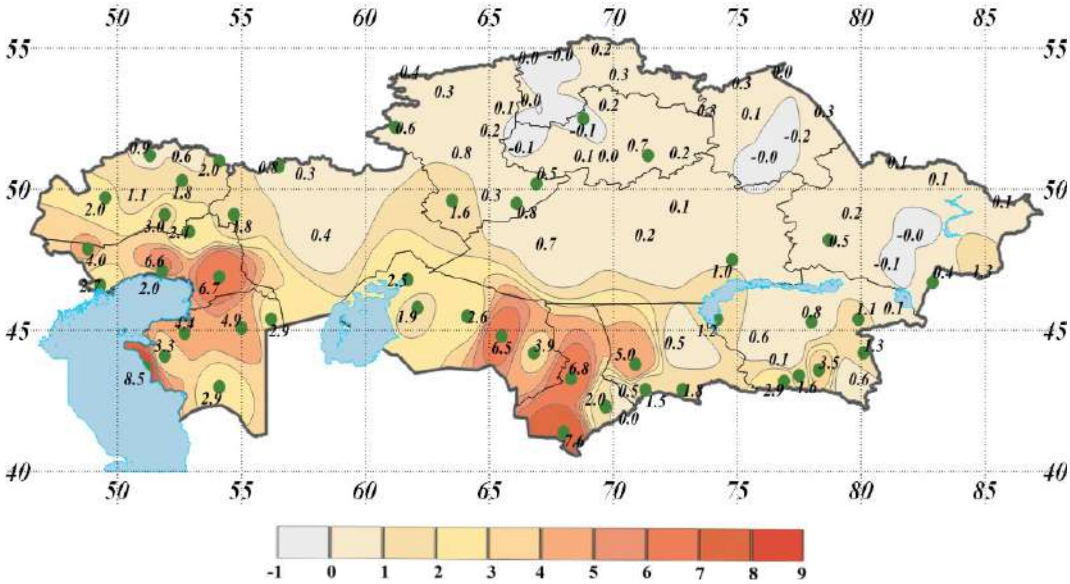


●- significant negative and positive coefficients of the linear trend

Figure 2.23 - Spatial distribution of the linear trend coefficient of the number of days with air temperature above 35 ºС (days/10 years), calculated for the period 1961 to 2019 (index SU35)

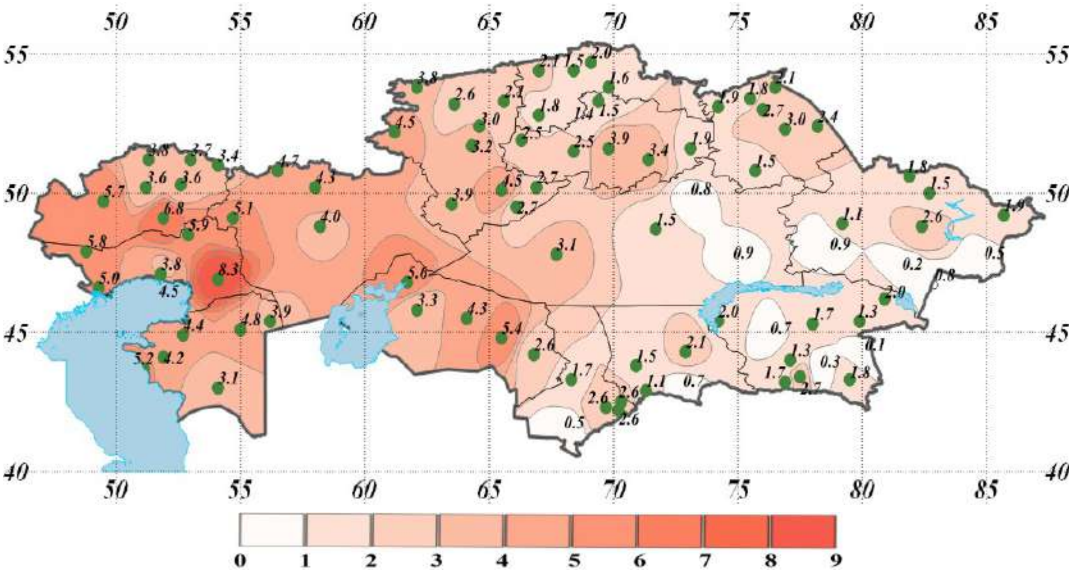
Figure 2.24 shows the spatial distribution of the coefficients of the linear trend of the number of days when the minimum temperature is ≥ 20 ***℃ (TR index, number of tropical nights),*** calculated for the period 1961 to 2019. Over the past more than 40 years in Kazakhstan, increasing in the number of such days has been observed: in the Atyrau and Mangystau regions by 5-7 days/10 years, as well as by 5-8 days/10 years at some stations in the Turkestan and Kyzylorda regions. In the rest of the territory of the republic the significant changes in the number of days with a minimum temperature of ≥ 20°C was't observed.

Total duration of heat waves per year (when, for at least 6 consecutive days the daily maximum air temperature was above the 90th percentile, the WSDI index) increases throughout the republic (figure 2.25), and this increasing is statistically significant. The most significant increasing (by 4-8 days/10 years) is observed in the western regions of the country, as well as in the Kyzylorda region. In some central, southern and eastern regions of the country the increasing are statically insignificant.



●- significant negative and positive coefficients of the linear trend

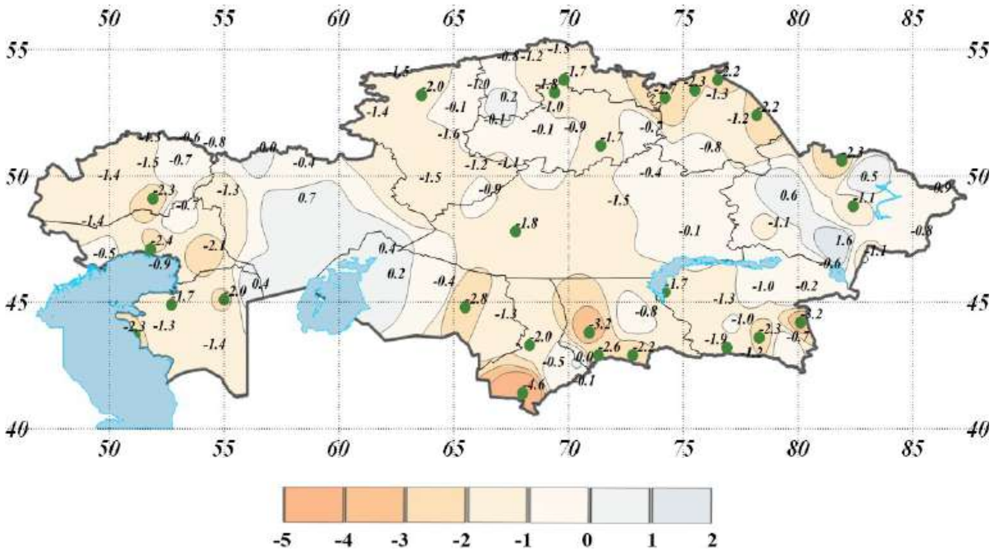
Figure 2.24 – Spatial distribution of the linear trend coefficient of the number of days when the minimum temperature ≥ 20˚C (days/10 years) calculated for the period 1961-2019 (TR index)



●- significant negative and positive coefficients of the linear trend

Figure 2.25 – Spatial distribution of the linear trend coefficient of the total duration of heat waves (days/10 years) for the period 1961-2019 (WSDI index)

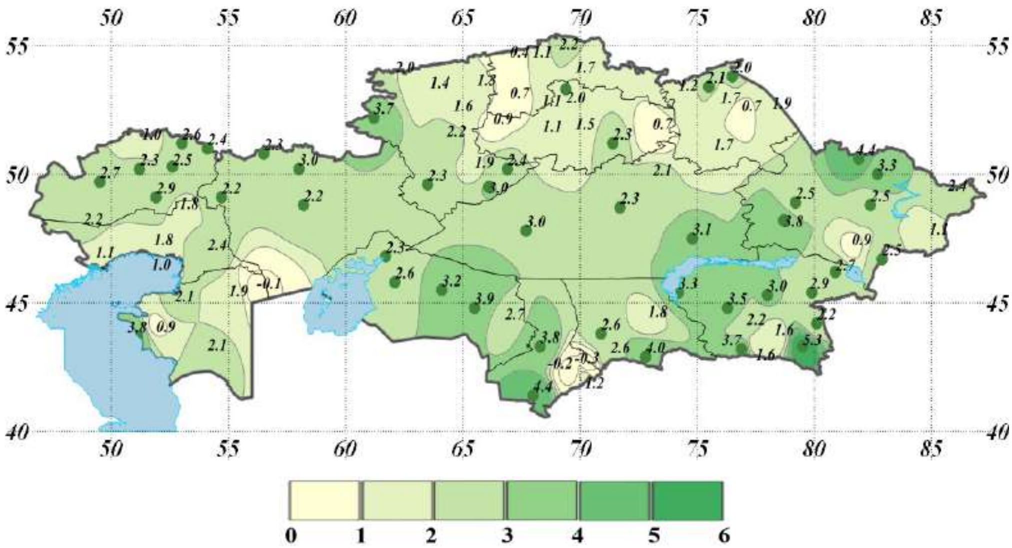
Figure 2.26 shows the distribution of the linear trend coefficient of the total duration of short cold waves when at least 3 consecutive days the daily minimum air temperature was below the 10th percentile (CSDI3 index), calculated for the period 1961-2019. In most of the territory of Kazakhstan is observed the decreasing in the total duration of short cold waves by 1-2 days/10 years, in some places the decreasing is more significant. According to the data of individual stations are noted the slight increasing in the total duration of cold waves.



●- significant negative and positive coefficients of the linear trend

Figure 2.26 – Spatial distribution of the linear trend coefficient of the total duration of short cold waves (days/10 years) for the period 1961 – 2019 (CSDI3 index)

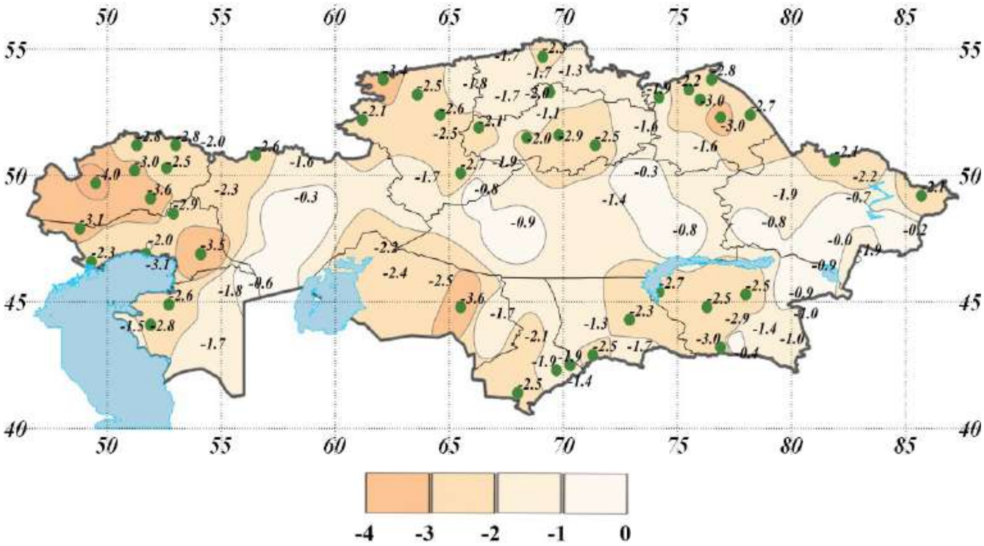
In general, across the territory of the Republic is observed increasing in the duration of the growing season (GSL index) by 2-5 days/10 years (figure 2.27). Statistically significant increasing by 3-5 days/10 years is traced according to the data of most stations in the West Kazakhstan, Aktobe, Kyzylorda, Turkestan, Zhambyl, Almaty, Karaganda and East Kazakhstan regions. In the northern regions of the country increasing in the duration of the growing season is mainly statistically insignificant.



●- significant negative and positive coefficients of the linear trend

Figure 2.27 – Spatial distribution of the linear trend coefficient of the duration of the growing season (days/10 years) for the period 1961 – 2019 (GSL index)

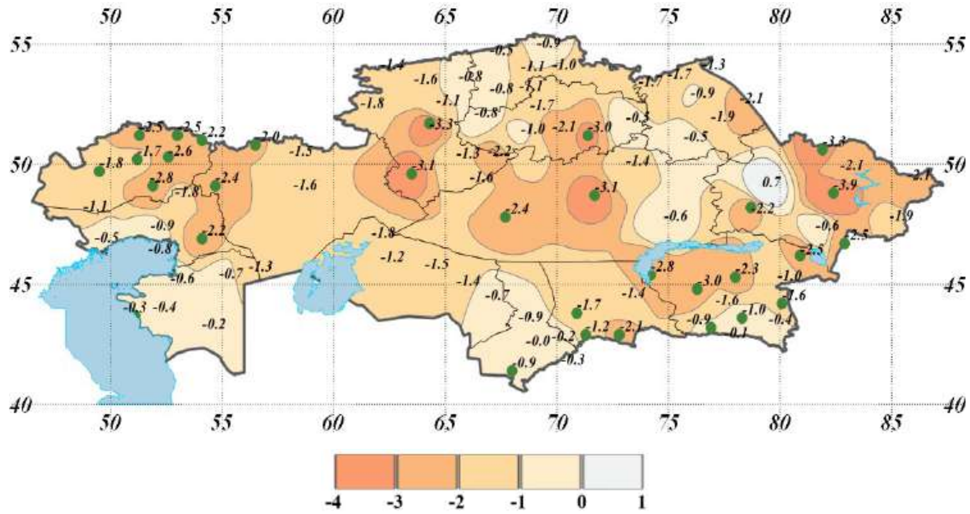
Significant statistical reduction (3-4 days/10 years) ***in the number of days with daytime frost when the daily maximum temperature is below 0 ℃ (***ID0 index) is observed in most of the western, southern and northern regions of Kazakhstan.



●- significant negative and positive coefficients of the linear trend

Figure 2.28 – Spatial distribution of the linear trend coefficient of the number of cases with a daily maximum air temperature below 0˚C (days/10 years) for the period 1961 2019 (index ID0)

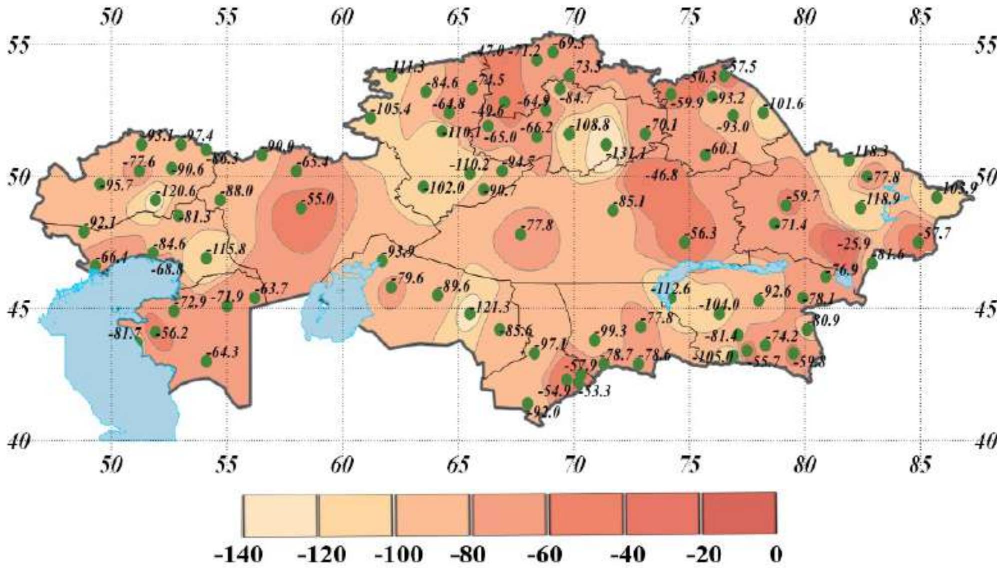
On the territory of the republic ubiquitously the number of days ***with severe frosts decreases by 1–3 days/10 years (when the daily minimum air temperature is below minus 20 °C, index FDm20)***, decreasing by 3-4 days/10 years is observed at some stations of the West Kazakhstan, East Kazakhstan, Kostanay, Karaganda and Almaty regions.



●- significant negative and positive coefficients of the linear trend

Figure 2.29 – Spatial distribution of the linear trend coefficient of the number of days in a year with severe frosts (when the daily minimum air temperature is below minus 20 °C) for the period 1961 – 2019 (index FDm20)

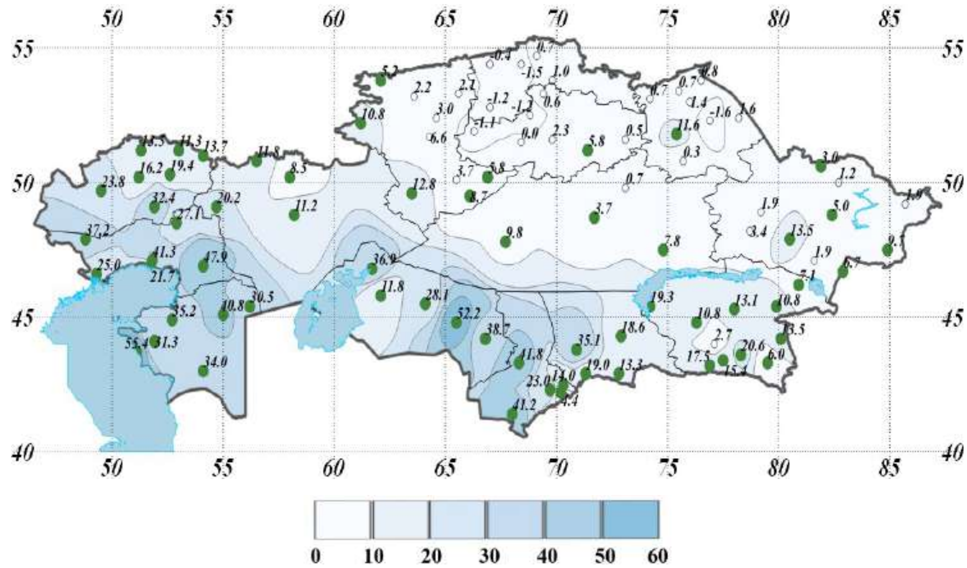
Figure 2.30 shows the spatial distribution of the coefficients of the linear trend of heat deficit (hddheat18 index), calculated for the period from 1961 to 2019. Throughout the country is observed a significant reduction in heat deficit from 20 °C–days/10 years to 140 °C–days/10 years. The maximum reduction is observed at MS Nur-Sultan (131 °C–days/10 years), MS Kyzylorda (121 °C–days/10 years), MS Kulsary (116 °C–days/10 years), MS Taipak (121 °C–days/10 years).



●- significant negative and positive coefficients of the linear trend

Figure 2.30 – Spatial distribution of the linear trend coefficient for heat deficit (°C–days/10 years) for the period 1961 – 2019 (index hddheat18)

The spatial distribution of the linear trend coefficients of ***the cold deficit (cddcold23 index)***, calculated for the period 1961 – 2019, is shown in figure 2.31. On the territory of the country, from the north to the southwest, there is an increase in the cold deficit from 10 to 60 °C–days every 10 years. The maximum increasing in the cold deficit is observed in Atyrau, Mangistau, Kyzylorda, Turkestan regions (by 3050 °C–days/10 years).



●- significant negative and positive coefficients of the linear trend

Figure 2.31 – Spatial distribution of the coefficient of the linear trend of the cold deficit (°C–days/10 years), calculated for the period 1961 – 2019 (index cddcold23)

3 Precipitation

3.1 Anomalies of precipitation in Kazakhstan in 2019

Figure 3.1 shows the intra-annual distribution of the amount of atmospheric precipitation for 2019, spatially averaged over the territory of Kazakhstan, as well as the average long-term monthly rainfall for the period 1961-1990. The greatest amount of the precipitation in 2019 fell in April (39.5 mm, 125% of the norm), June (36.8 mm, 108 % of the norm) and December (27.5 mm, 114 % of the norm). In May, July, October and November, was below the climatic norm by 27-38 %.

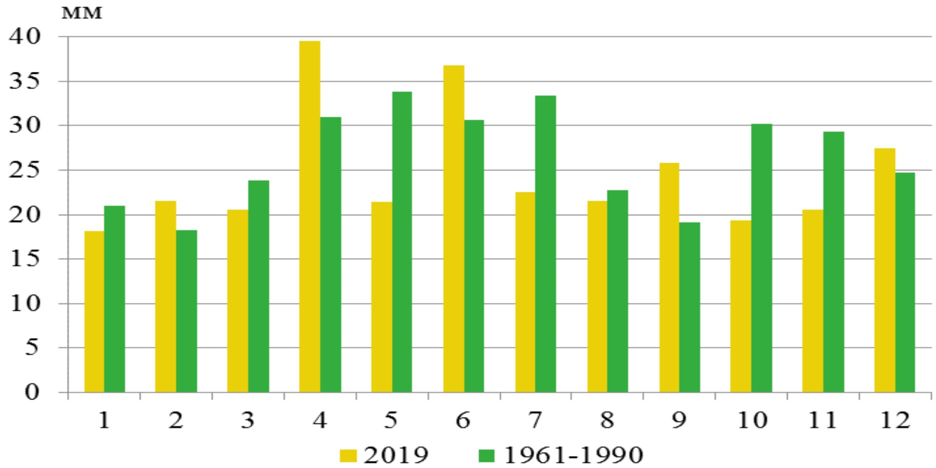


Figure 3.1 - Monthly precipitation in 2019 and norms for the period 1961-1990, averaged over the territory of Kazakhstan

Further presented values of the annual and seasonal precipitation anomalies (table 3.1), as well as the monthly precipitation anomalies (table 3.2), observed in 2019 and averaged over the whole territory of Kazakhstan and its regions. For each value of the anomaly are given the probabilities of non-exceedance, calculated for the period 1941-2019. Probability of non-exceedance shows the percentage frequency of particular anomaly in the observation record. Precipitation above 95th or below the 5th percentile is shown in bold.

Figure 3.2 shows the territorial distribution of the annual and seasonal precipitation amount in 2019, expressed as a percentage of the norm for the period 1961-1990, and also shows the probabilities of not exceeding the annual and seasonal precipitation amounts in a given year.

On average in the territory of Kazakhstan the annual amount of precipitation in 2019 was 92 % of the norm (294.2 mm). The amount of precipitation varies from 76% (Aktyubinsk region) to 117 % of norm (Atyrau region). It was extremely dry (probability of not excess of 0-5 %) was at some stations of the Aktobe, Kostanay, Karaganda and Zhambyl regions. The absolute maximums and minimums in 2019 have not been updated (figure 3.2, table 3.1, 3.2).

Table 3.1 - Regionally averaged annual and seasonal anomalies in precipitation in 2019: **vR** deviations from the long-term average for 1961-1990, mm; **P (r≤R2019)** is the probability of not exceeding (in brackets) calculated according to the data for the period 1941-2019 and expressed in %; **RR** - relationship of **R_{2019}** to normal, expressed in%

Region	Год			Зима			Весна			Лето			Осень		
	vR	**P**	**RR**	**vR**	**P**	**RR**	**vR**	**P**	**RR**	**vR**	**P**	**RR**	**vR**	**P**	**RR**
Kazakhstan	-23,0	21	92	-5,7	35	90	-7,2	33	96	-5,8	30	86	-13,0	32	82
Almaty	-21,9	50	96	9,7	58	114	-31,0	28	79	5,7	52	103	-11,4	50	86
Akmola	48,1	79	114	-1,2	47	100	6,0	65	108	-19,5	32	86	41,1	94	154
Aktobe	-68,3	11	76	-19,1	23	69	-14,0	20	83	-21,0	23	68	-29,4	11	61
Atyrau	27,7	69	117	-7,2	21	77	54,3	94	236	3,0	62	108	-12,0	24	71
East-Kazakhstan	-0,9	55	98	-13,0	32	83	-7,4	41	91	13,6	65	112	-9,5	46	88
Zhambyl	-61,4	14	80	-20,1	16	73	-8,8	44	92	-9,4	26	87	-30,0	14	59
West-Kazakhstan	-52,3	20	82	6,7	71	110	1,0	47	103	10,8	57	104	**-43,1**	**2**	**45**
Karagandy	-25,0	29	88	-9,6	34	83	-14,6	28	80	-20,3	25	70	3,9	64	99
Kostanay	-31,1	32	87	-20,2	10	60	-7,8	29	86	-18,5	26	79	6,4	66	109
Kyzylorda	-2,8	61	99	10,1	74	121	5,4	67	115	-12,9	11	33	-17,7	12	47
Mangystau*	-55,8	40	94	0,1	55	108	-29,1	79	133	-11,1	20	62	-18,6	42	87
Pavlodar	-26,6	28	91	-11,4	15	74	-6,2	33	89	-17,0	28	89	-7,8	37	89
North-Kazakhstan	8,8	55	102	-8,3	34	83	-7,6	32	89	1,0	47	101	12,4	74	113
Turkestan	-57,0	20	88	-3,9	33	91	-1,6	48	103	-4,6	30	73	**-59,8**	**1**	**34**

Notes: 1. for the Mangistau region, an assessment has been carried out since 1960;
2. values above the 95th or below the 5th percentile are shown in bold and bright colors.

Winter 2018/2019. In general, throughout the territory of the republic, the amount of precipitation amounted to 92 % of the climatic norm or 58.1 mm (Figure 3.2, Tables 3.1, 3.2). It was dry in Aktobe, Kostanay, Pavlodar, Zhambyl, Atyrau and regions, where precipitation during the winter period was 59-77 % of the norm with a probability of not exceeding 10-23 %. A significant deficit of precipitation (the probability of not exceeding 2-5%) was noted at the stations of the Aktobe, Kostanay, Karaganda and Zhambyl regions. In January, it was extremely dry in Atyrau and Pavlodar regions (the probability of not exceeding 3 %). Winter in these areas has entered 10 % of the extremely dry winter seasons. At some stations of the West Kazakhstan and Pavlodar regions, the absolute values were overlapped (Table 3.3).

Spring. The amount of precipitation in the spring season on average in Kazakhstan was 81.5 mm (96% of the norm, the probability of not exceeding 33%). The largest amount of atmospheric precipitation fell in the Atyrau region (236% of the norm, the probability of not exceeding 94%), where April was extremely humid (with the probability of not exceeding 100%). At two meteorological stations in the Karaganda region, the absolute values of precipitation were updated (Table 3.4).

Table 3.2 - Regionally averaged mean monthly precipitation anomalies in 2019: vT-deviations from the average for 1961-1990, mm; ***P(r≤R***$_{2019}$***)*** is the probability of not exceeding (in brackets) calculated according to the data for the period 1941-2019. and expressed in %

Region	12 (2018)	1	2	3	4	5	6	7	8	9	10	11
Kazakhstan	-6,2 (23)	-3,0 (34)	3,3 (66)	-3,5 (32)	8,6 (75)	-12,3 (10)	6,3 (61)	-10,7 (8)	-1,2 (47)	6,7 (87)	-10,8 (16)	-8,7 (17)
Almaty	-3,9 (34)	-0,6 (51)	14,2 (87)	**-21,8 (5)**	8,8 (69)	-18,1 (23)	21,9 (87)	-23,7 (10)	7,5 (69)	14,4 (91)	-18,5 (32)	-7,2 (38)
Akmola	-8,0 (14)	-3,9 (39)	10,6 (93)	12,4 (85)	10,9 (80)	-17,3 (12)	8,8 (62)	-27,6 (14)	-0,9 (52)	**33,8 (98)**	-0,1 (60)	7,3 (83)
Aktobe	-9,1 (24)	-8,5 (25)	-2,1 (38)	4,0 (62)	-2,2 (52)	-15,8 (8)	**-19,2 (3)**	0,7 (56)	-2,5 (52)	0,9 (67)	-13,5 (21)	**-16,8 (5)**
Atyrau	1,6 (58)	**-8,0 (3)**	-0,9 (39)	-5,3 (28)	**28,4 (100)**	31,1 (92)	-3,7 (47)	3,1 (69)	3,7 (66)	-1,7 (61)	4,4 (65)	**-14,7 (3)**
East-Kazakhstan	-11,7 (7)	2,6 (64)	-3,6 (38)	**-13,7 (1)**	3,5 (50)	2,8 (61)	26,3 (88)	-12,0 (25)	-0,5 (52)	-1,5 (53)	-6,3 (50)	-1,7 (44)
Zhambyl	-10,8 (28)	-6,1 (37)	-3,4 (34)	-4,9 (43)	18,2 (82)	-22,2 (12)	3,1 (56)	-7,9 (25)	-4,5 (32)	5,2 (75)	-29,2 (7)	-6,0 (41)
West-Kazakhstan	7,5 (80)	0,3 (64)	-1,2 (50)	10,8 (78)	1,0 (55)	-10,8 (11)	-10,1 (29)	15,2 (80)	-4,9 (47)	-2,4 (52)	-12,0 (17)	**-28,6 (0)**
Karagandy	-7,3 (20)	-9,9 (17)	7,4 (83)	-2,2 (46)	4,0 (64)	-16,4 (14)	6,1 (66)	-17,7 (11)	-8,7 (34)	6,0 (82)	0,1 (67)	-2,1 (53)
Kostanay	-10,1 (16)	-9,3 (20)	-1,0 (44)	6,3 (70)	1,5 (48)	-15,7 (14)	-1,2 (52)	-23,3 (15)	5,9 (58)	11,0 (83)	-2,9 (50)	-1,4 (52)
Kyzylorda	-0,2 (53)	3,9 (56)	6,7 (73)	**21,3 (98)**	-5,7 (44)	-9,5 (14)	-5,5 (12)	-4,5 (35)	-2,9 (35)	-0,6 (70)	-8,0 (29)	-9,1 (21)
Mangystau*	0,4 (55)	1,6 (50)	1,0 (66)	1,9 (64)	15,5 (84)	-1,4 (47)	-11,7 (8)	0,2 (55)	0,4 (62)	0,3 (69)	-8,5 (18)	2,0 (61)
Pavlodar	-5,6 (17)	**-12,0 (3)**	6,3 (87)	-3,8 (29)	15,2 (89)	**-17,6 (5)**	29,5 (87)	-25,1 (10)	-21,4 (10)	2,7 (52)	-3,3 (56)	-7,3 (33)
North-Kazakhstan	-4,6 (35)	-6,5 (30)	3,0 (73)	4,0 (67)	1,9 (56)	-13,4 (23)	4,3 (55)	-8,9 (41)	5,7 (60)	25,6 (92)	-2,7 (53)	-10,4 (21)
Turkestan	-11,8 (30)	2,7 (51)	4,6 (47)	-16,2 (32)	39,9 (92)	-25,3 (14)	4,5 (53)	-4,8 (44)	-4,2 (20)	-1,9 (55)	-29,1 (7)	-28,9 (17)

Notes: 1. for the Mangistau region, an assessment has been carried out since 1960;
2. values above the 95th or below the 5th percentile are shown in bold and bright colors.

Table 3.3 - Stations with updated absolute values of precipitation (mm) for the winter in 2019

Region	Station	Absolute maximum in 2019	Absolute minimum in 2019	Previous absolute value
West Kazakhstan	Zhanybek	121,1		114,9 (2010)
Pavlodar	Lozovaya		19,8	20,1 (1981)
East Kazakhstan	Kainar		3,9	4,4, (1974)

Table 3.4 – Stations with updated absolute values of precipitation (mm) for the spring in 2019

Region	Station	Absolute maximum in 2019	Absolute minimum in 2019	Previous absolute value
Karagandy	Balkash	109,2		89,7 (1972)
	Aktogay		10,7	10,8 (2006)

Summer. On average, 80.7 mm of atmospheric precipitation fell across the territory of the republic (86 % of the norm, the probability of not exceeding 30 %). Deficit of precipitation (30-60 % of the norm, the probability of not exceeding 11-25 %) was observed in Kyzylorda, Mangystau, Aktobe and Karaganda regions. It was extremely dry in June in the Aktobe region (the probability of not exceeding 3 %). In the northeast, southeast, as well as in the central part of the republic, the probability of not exceeding the amount of precipitation was 10-25 %. At MS Aktogay (Karaganda region), the absolute minimum of precipitation in the summer season has been updated (Table 3.5).

Table 3.5 – Stations with updated absolute values of precipitation (mm) for the summer in 2019

Region	Station	Absolute maximum in 2019	Absolute minimum in 2019	Previous absolute value
Karagandy	Aktogay		15,8	18,0 (1945)

Autumn. Atmospheric precipitation for the entire autumn season fell 65.6 mm (82 % of the norm, the probability of not exceeding 32 %). The wettest was observed on the territory of Kostanay, North Kazakhstan and Akmola regions, where the amount of precipitation was 109 %, 113 % and 154 % of the norm, respectively. September was extremely precipitation for Akmola oblast (probability of not exceeding 98 %). The driest was observed in the south and west of the republic (34-47 % of the norm). Extremely dry recorded in the Turkestan and West Kazakhstan regions (the probability of not exceeding 1-2 %). Absolute precipitation values have been updated at several stations (Table 3.6)

Table 3.6 – Stations with updated absolute values of precipitation (mm) for the autumn in 2019

Region	Station	Absolute maximum in 2019	Absolute minimum in 2019	Previous absolute value
Akmola	Shchuchinsk	162,4		132,7 (1945)
Kostanay	Dievskaya	117,3		116,6 (1984)
West Kazakhstan	Karatobe		20,8	29,2 (2005)
Zhambyl	Uyuk		4,4	7,0 (2005 г.)

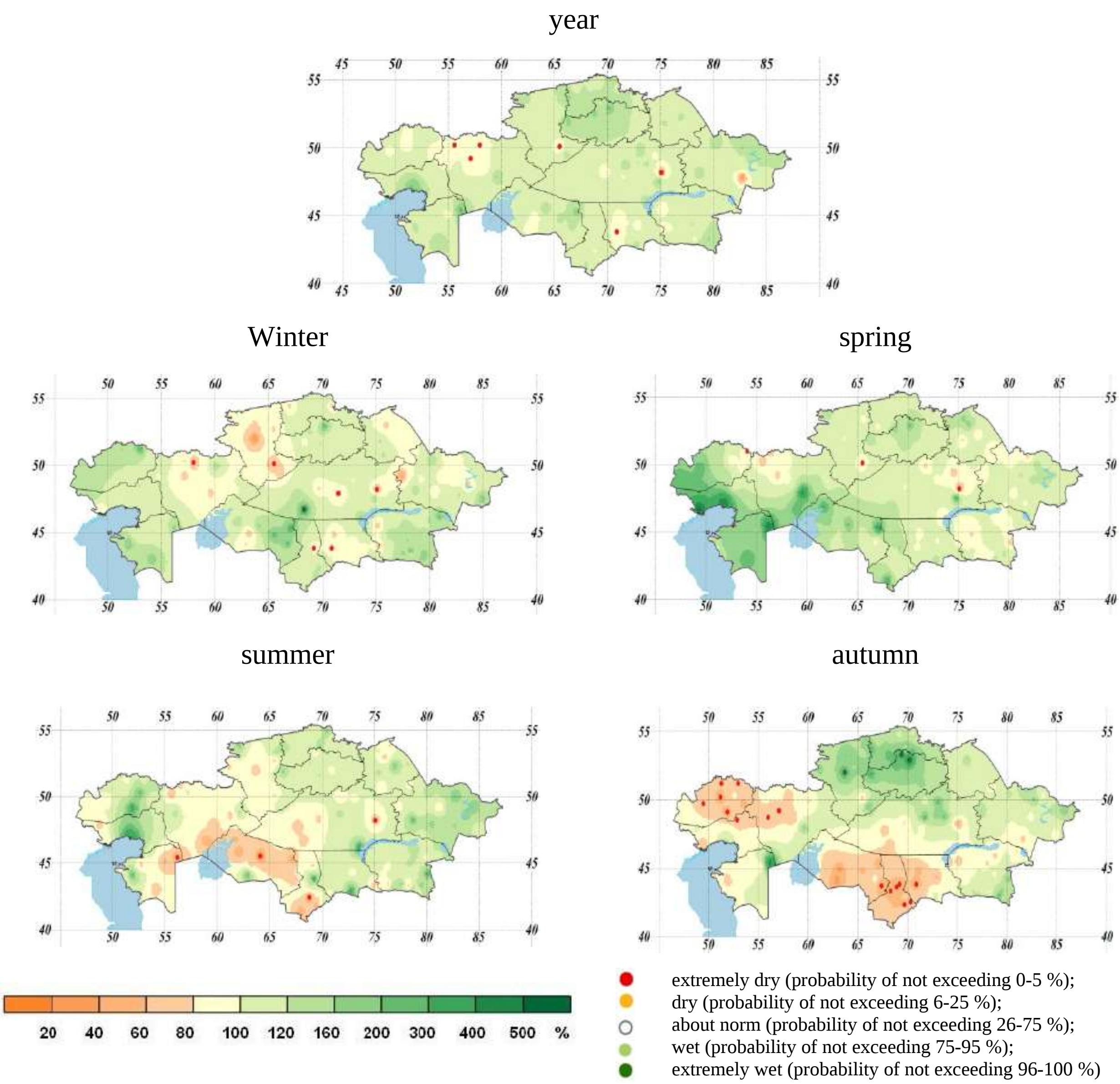


Figure 3.2 - Precipitation in 2019 as % of the norm 1961 – 1990 and probability of not exceeding in 2019 calculated according to the period 1941 – 2019

To assess precipitation extremes in 2019 experts used Indexes of climate change proposed by the World Meteorological Organization. The analysis of the most representative indexes and their distribution throughout Kazakhstan in 2019 are presented below.

Maximum of daily precipitation in 2019(index Rx1day). Figure 3.3 shows absolute maximum daily precipitation, since the beginning of records to 2018 (in red color) and daily maximum observed in 2019 (in blue color). In 2019 the absolute maximum of daily precipitation has not been updated at any weather station in Kazakhstan.

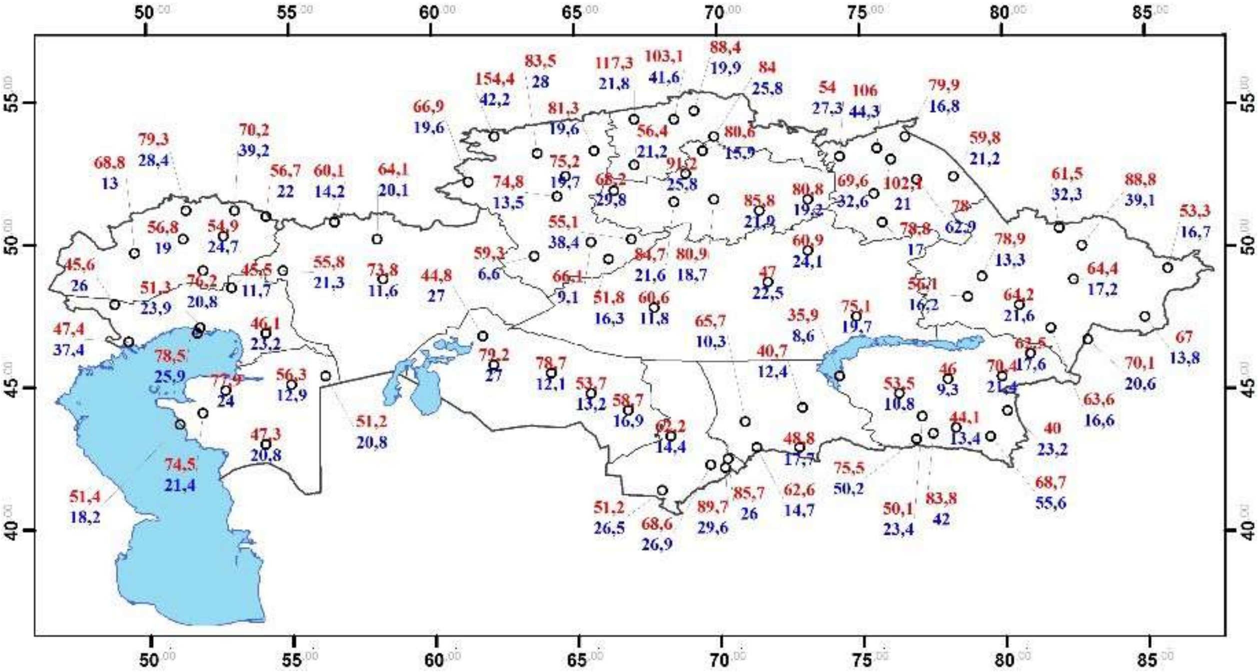


Figure 3.3 – Absolute maximum of daily precipitation, since the beginning of records until 2018 (in red) and the daily maximum in 2019(in blue), mm

Figure 3.4 shows the share of the amount of precipitation that fell per day with an extremely high amount of precipitation (more than the 95th percentile) in the total precipitation for the whole of 2019. The R95 and PRPTOT indices were used for the calculation. The R95 precipitation index shows the amount of precipitation in excess of the 95th percentile, the PRPTOT index shows the amount of precipitation in a year. The largest share of extreme precipitation was observed at meteorological stations in the western region of the country – Sam (64 %), Atyrau (63 %) and Kulsary (52 %). At some stations of Akmola, Karaganda, Pavlodar and East Kazakhstan regions, the share of extreme precipitation is also quite high and amounts to 32 – 42 %.

The CDD index which represents the ***maximum length of time when precipitation was less than 1 mm*** and it is very important for the arid regions of Kazakhstan (Figure 3.5).

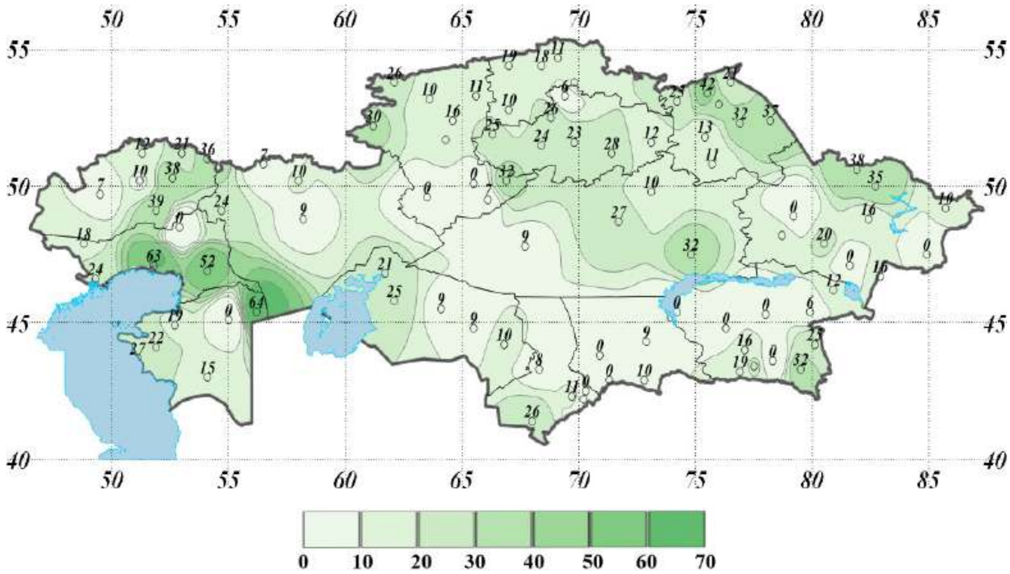


Figure 3.4 - Percentage share of extreme precipitation in the annual total in 2019. Extreme precipitation is the sum of daily precipitation exceeding 95th percentile

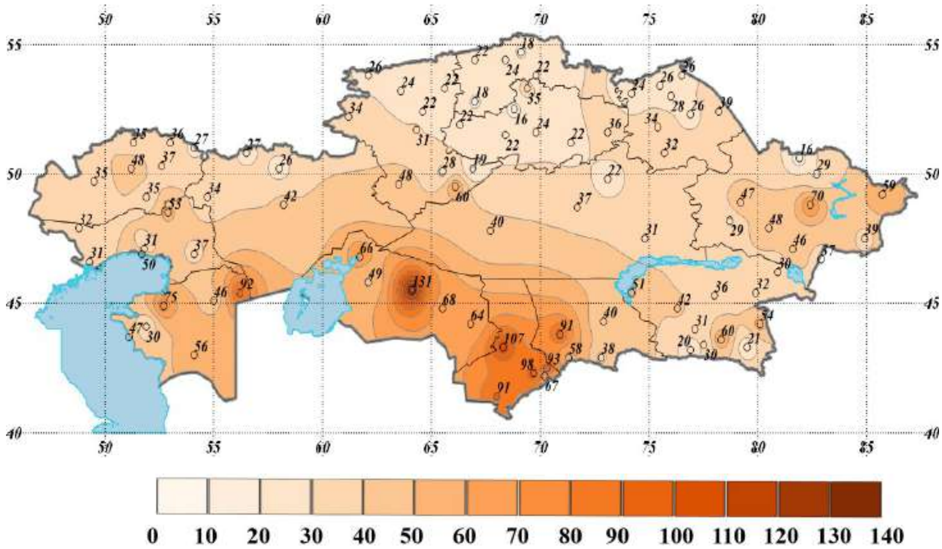


Figure 3.5 – Maximum duration of the rainless period (in days) in 2019

In 2019, the largest maximum duration of the rainless period is observed in the southwest of the republic (Figure 3.5). At some meteorological stations in this region, the duration of the period without precipitation was 91 – 131 days/year. The longest rainless period was recorded at MS Turkestan and MS Zhusaly of Kyzylorda region (107 and 131 days/year), respectively. The shortest duration of the rainless period (16 - 34 days/year) was noted in the north of Kazakhstan.

The results of calculating ***the maximum duration of the rainy period*** in 2019, when the amount of precipitation was equal to or more than 1 mm (CWD index), are presented in

Figure 3.6. The maximum duration of the period with precipitation in 2019 was 2-8 days. The longest rainy period (6-7 days) was observed in the northern and eastern regions of the country, as well as in the MS Uralsk (West Kazakhstan) and the MS village of Turara Ryskulova (Zhambyl region) - 6 and 8 days, respectively.

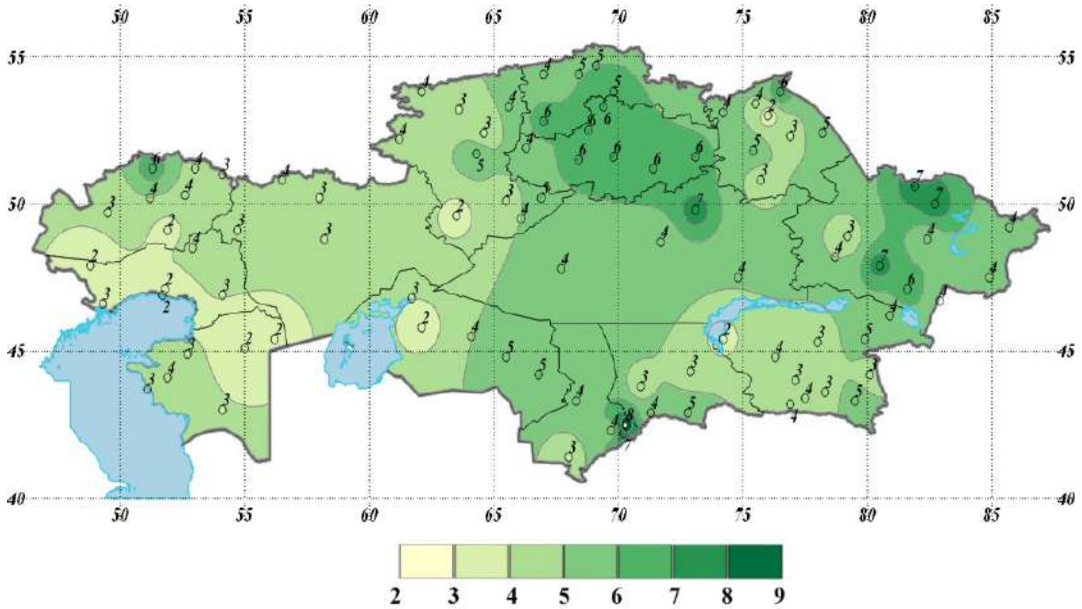


Figure 3.6 – Maximum duration of the period (in days) in 2019, when the amount of precipitation was equal or greater than 1 mm

3.2 Observed changes in precipitation in Kazakhstan Наблюдаемые изменения количества осадков

In contrast to air temperature, the change in precipitation in the territory of Kazakhstan during the study period is more colorful picture. Linear trends in monthly, seasonal and annual precipitation were estimated from 121 stations.

Time series of annual and seasonal precipitation anomalies for the period 1941 - 2019, calculated relative to the base period 1961 - 1990 and spatially averaged over the territory of Kazakhstan and regions give a general idea of the nature of modern changes in the regime of atmospheric precipitation. Over the past decades, there has been an alternation of short periods with positive and negative precipitation anomalies (Figures 3.7 and 3.8).

On average in Kazakhstan in the period 1976 - 2019 there is a tendency for an increase in the annual amount of atmospheric precipitation by 4.3 mm/10 years (table 3.7). A positive trend in the average amount of precipitation over the territory of the regions (from 1.6 to 14.1 mm/10 years) was noted in most cases. In Zhambyl, Mangistau, Aktobe, West Kazakhstan and Kyzylorda regions, there is a decrease in annual precipitation by 1.6-5.4 mm/10 years. A statistically significant increase in annual precipitation was found only in the north of Kazakhstan, where the trend contributed to the total variance of 7 %. In all seasons, there is a tendency towards an increase in the average amount of atmospheric precipitation over the territory of the Republic from 1.9 mm/10 years to 3.2 mm / 10 years, with the exception of autumn, where there is a negative trend in the amount of precipitation (1.3 mm / 10 years). A statistically significant change in the amount of precipitation was only in spring (Figures 3.7, 3.8; Table 3.7).

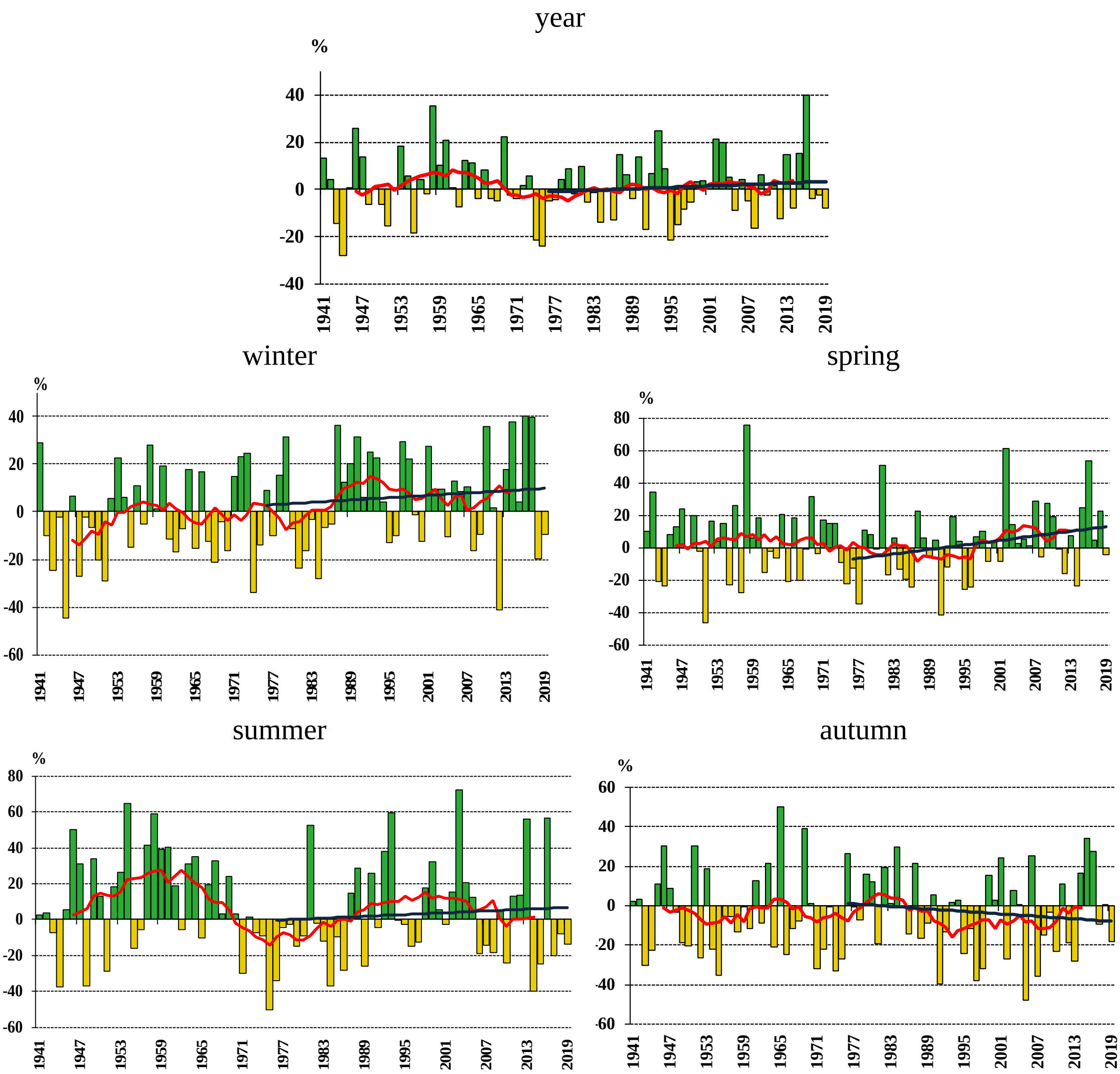


Figure 3.7 - Time series and linear trends of annual and seasonal precipitation anomalies (in %) for the period 1941-2019, spatially averaged over the territory of Kazakhstan and its regions. Anomalies are calculated relatively for the base period 1961 - 1990. Linear trend for the period 1976 to 2019 highlighted in black. *Smoothed curve is received by the 11 years sliding averaging*

Spatial distribution of the linear trend coefficient values for annual, seasonal and monthly rainfall (%/10 years) calculated for the period 1941-2019 and presented in figures 3.9 and 3.10 provides more detailed information on the nature of changes in precipitation regime in Kazakhstan.

According to individual weather stations, there is observed a spotting in distribution of the sign of changing in annual and seasonal precipitation (Figure 3.9-3.10).

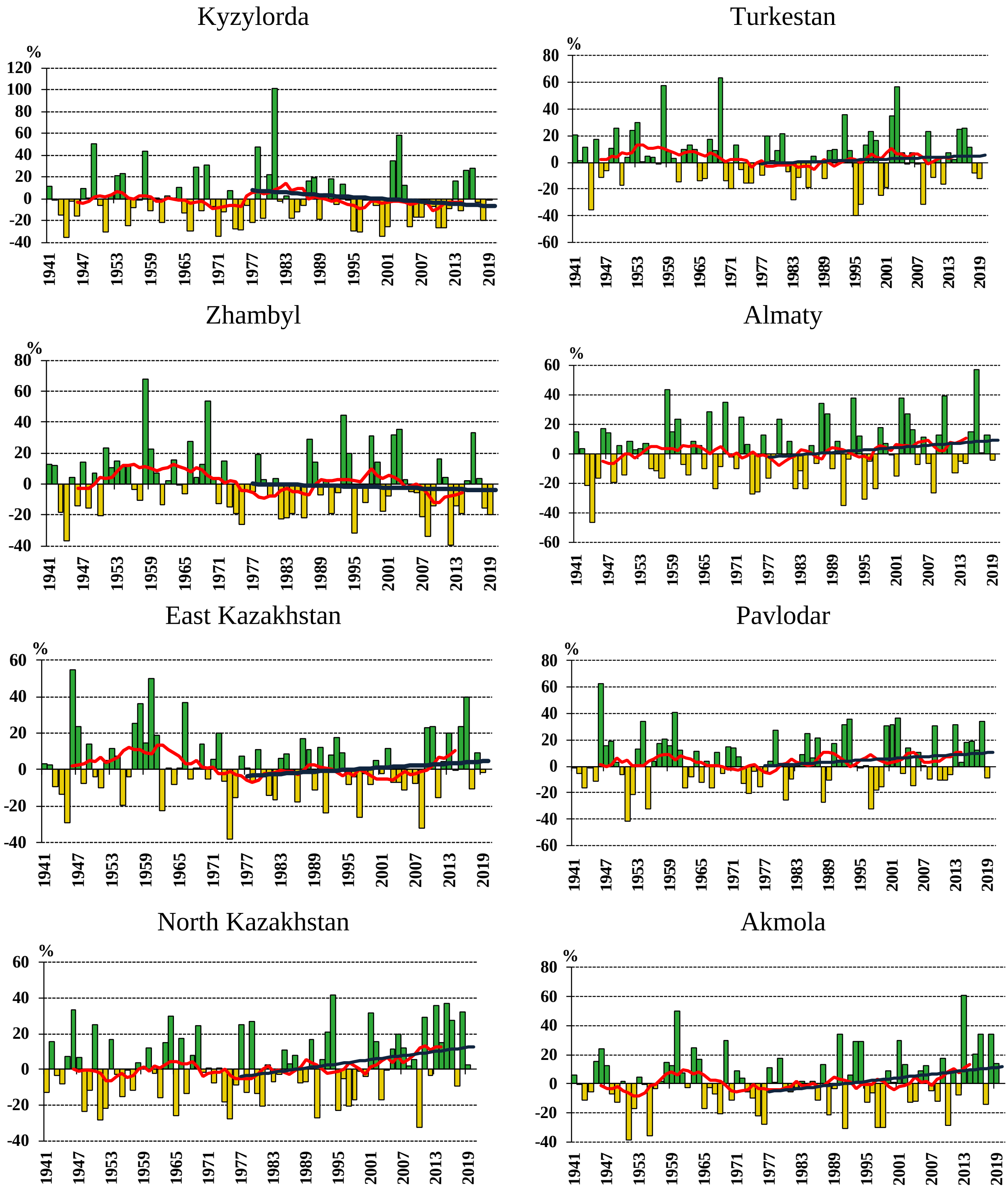


Figure 3.8 - Time series of annual precipitation anomalies (in %) for the period 1941-2019, spatially averaged over Kazakhstan regions. Anomalies are calculated relatively for the base period 1961 - 1990. Linear trend for the period 1976 - 2019 highlighted in blue. *Smoothed curve is received by the 11 years sliding averaging. Sheet 1*

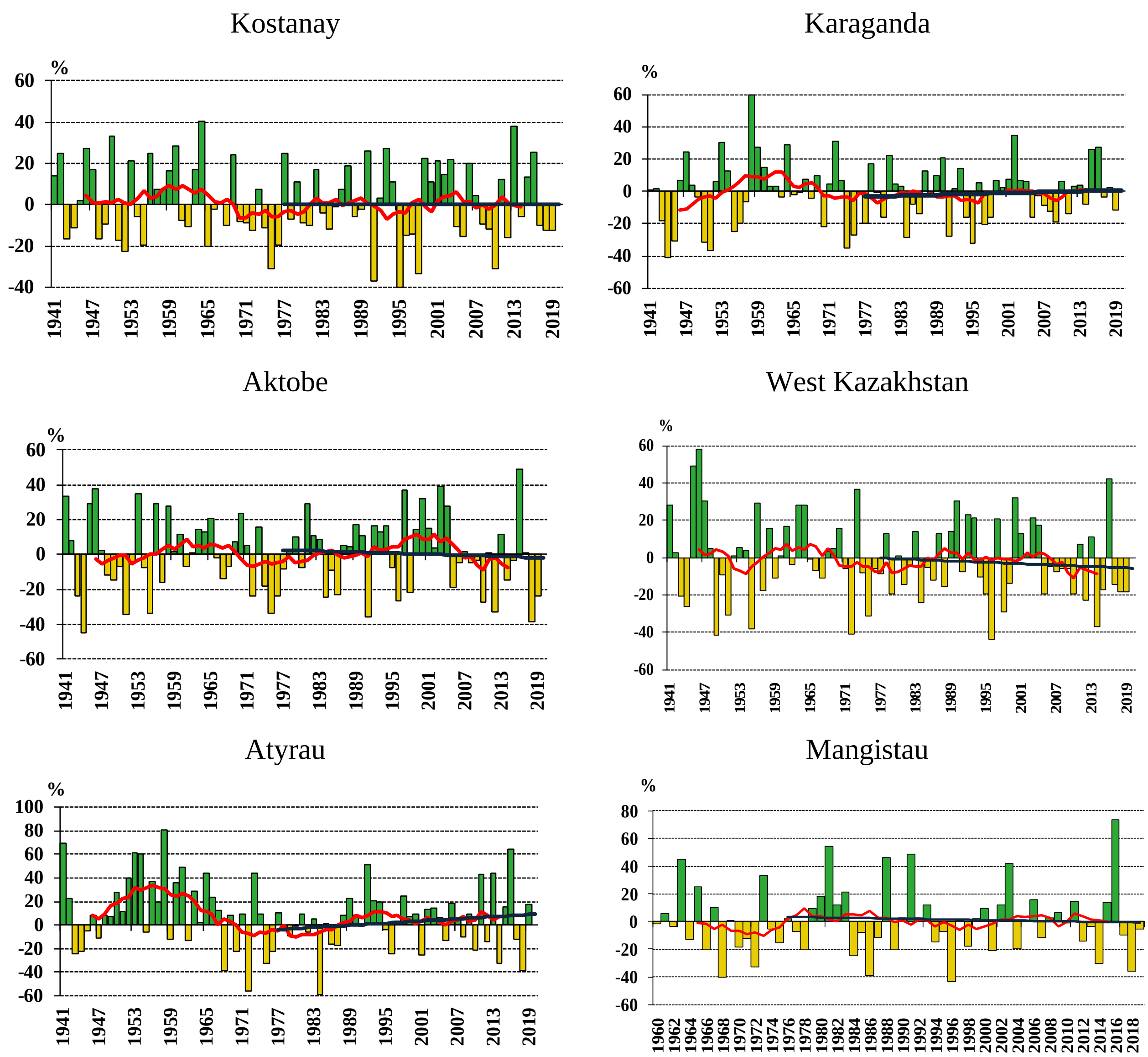


Figure 3.8 - Time series of annual precipitation anomalies (in %) for the period 1941-2019, spatially averaged over Kazakhstan regions. Anomalies are calculated relatively for the base period 1961 - 1990. Linear trend for the period 1976 - 2019 highlighted in blue. *Smoothed curve is received by the 11 years sliding averaging. Sheet 2*

Annual precipitation trends over most of Kazakhstan were generally positive but insignificant. A steady increase in the amount of precipitation can be traced at some meteorological stations in the north-east of the republic (4-13%/10 years). A statistically significant decrease in the amount of precipitation (7-31%/10 years) was noted at the stations of the Kostanay, Karaganda and Zhambyl regions.

Stable positive trends in ***winter*** are observed in the northeast (4 7% / 10 years), southeast (4 9% / 10 years) and southwest (7 12% / 10 years) of Kazakhstan.

In spring, the growth rate of precipitation throughout the territory of Kazakhstan is 1-26%/10 years. Positive statistically significant trends (4-14%/10years) were noted mainly in the northwest of the republic. At a faster pace (4-21%/10 years) precipitation increases in March.

Table 3.7 – Characteristics of linear trend (mm/10 years, %/10 years) of seasonal and annual precipitation anomalies averaged over the territory of Kazakhstan and its regions for the period 1976-2019. Anomalies are calculated relatively for the base period 1961-1990

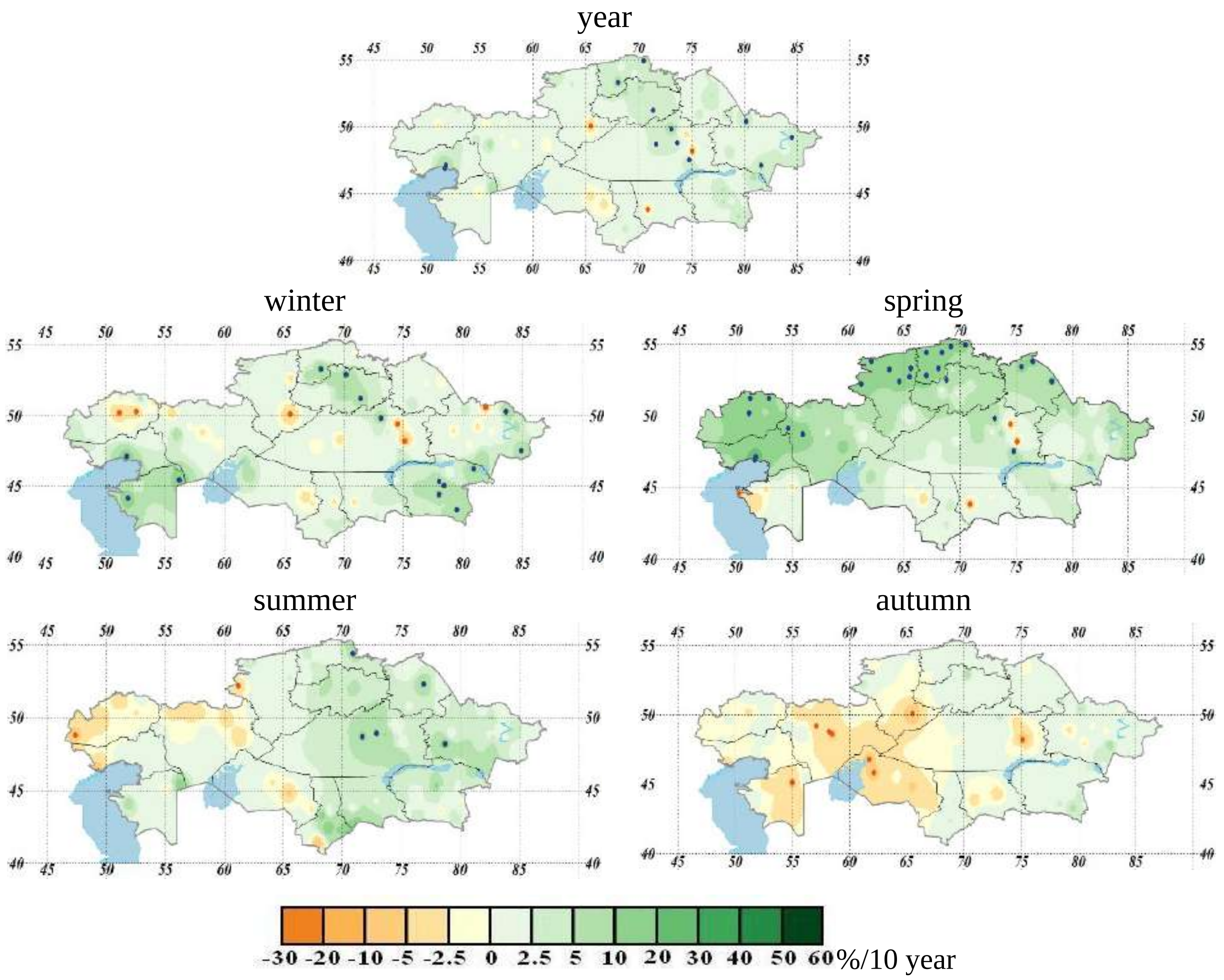
Region	Unit of measure	Year		Winter		Spring		Summer		Autumn	
		*a	**R^2	a	R^2	a			*a	**R^2	A
Kazakhstan	мм	4,3	2	0,9	1	3,2	**5**	1,5	1	-1,3	1
	%	1,0		1,6		4,6		1,6		-2,1	
Almaty	мм	10,5	3	4,4	**6**	2,8	1	2,7	1	0,8	0
	%	2,7		6,6		2,2		2,5		1,2	
Akmola	мм	13,6	**7**	3,1	**6**	3,5	4	6,2	3	0,6	0
	%	4,0		6,8		4,9		4,7		0,9	
Aktobe	мм	-3,2	1	-1,0	0	5,1	**5**	-3,4	2	-4,4	7
	%	-1,1		-1,5		8,4		-4,7		-5,9	
Atyrau	мм	4,8	3	2,6	**6**	7,2	**15**	-3,0	3	-1,6	1
	%	3,0		7,8		18,2		-6,4		-3,8	
East Kazakhstan	мм	5,9	2	0,2	0	3,2	3	3	2	-0,3	0
	%	1,9		0,8		3,6		3,7		0,0	
Zhambyl	мм	-1,6	0	0,8	0	-2,6	1	2,2	1	-1,7	1
	%	-1,0		1,0		-2,5		5,4		-2,9	
West Kazakhstan	мм	-3,6	1	-2,8	**5**	6,1	**12**	-4,5	4	-2,2	1
	%	-1,2		-3,7		10,5		-5,8		-2,7	
Karaganda	мм	3,7	1	-0,5	0	1,3	1	4,9	**6**	-2,0	2
	%	0,9		-2,2		2,0		6,5		-3,9	
Kostanay	мм	1,6	0	-1,4	1	7,3	**19**	-0,3	0	-4,0	**6**
	%	0		-2,7		11,4		-0,5		-5,1	
Kyzylorda	мм	-5,4	3	-0,8	1	-8,0	0	-7,8	0	-3,4	**9**
	%	-3,4		-0,5		-1,0		-4,7		-9,9	
Mangistau	мм	-1,6	0	3,4	**11**	-3,6	4	0,7	0	-1,6	2
	%	-1,0		10,5		-6,7		2,5		-4,5	
Pavlodar	мм	6,9	3	-0,3	0	5,0	**11**	2,7	1	-0,2	0
	%	2,4		-0,6		9,4		2,6		-0,4	
North Kazakhstan	мм	14,1	**7**	0,6	0	9,1	**23**	4,3	1	0,2	0
	%	3,9		1,2		13,8		2,8		0,1	
Turkestan	мм	6,7	1	2,7	1	3,1	1	1,8	1	-1,1	0
	%	1,4		1,0		1,8		6,5		-0,2	

Notes: * a – linear trend coefficient, %/10 years, mm10 years;
** R^2 – coefficient of determination, %
*** statistically significant trends are highlighted in bold

In summer, in the western region of the republic, negative trends in precipitation amounted to 0.1-12 %/10 years, but the trends are mostly insignificant, with the exception of MC Zhetykonur and Urda, where a significant decrease in precipitation amounted to

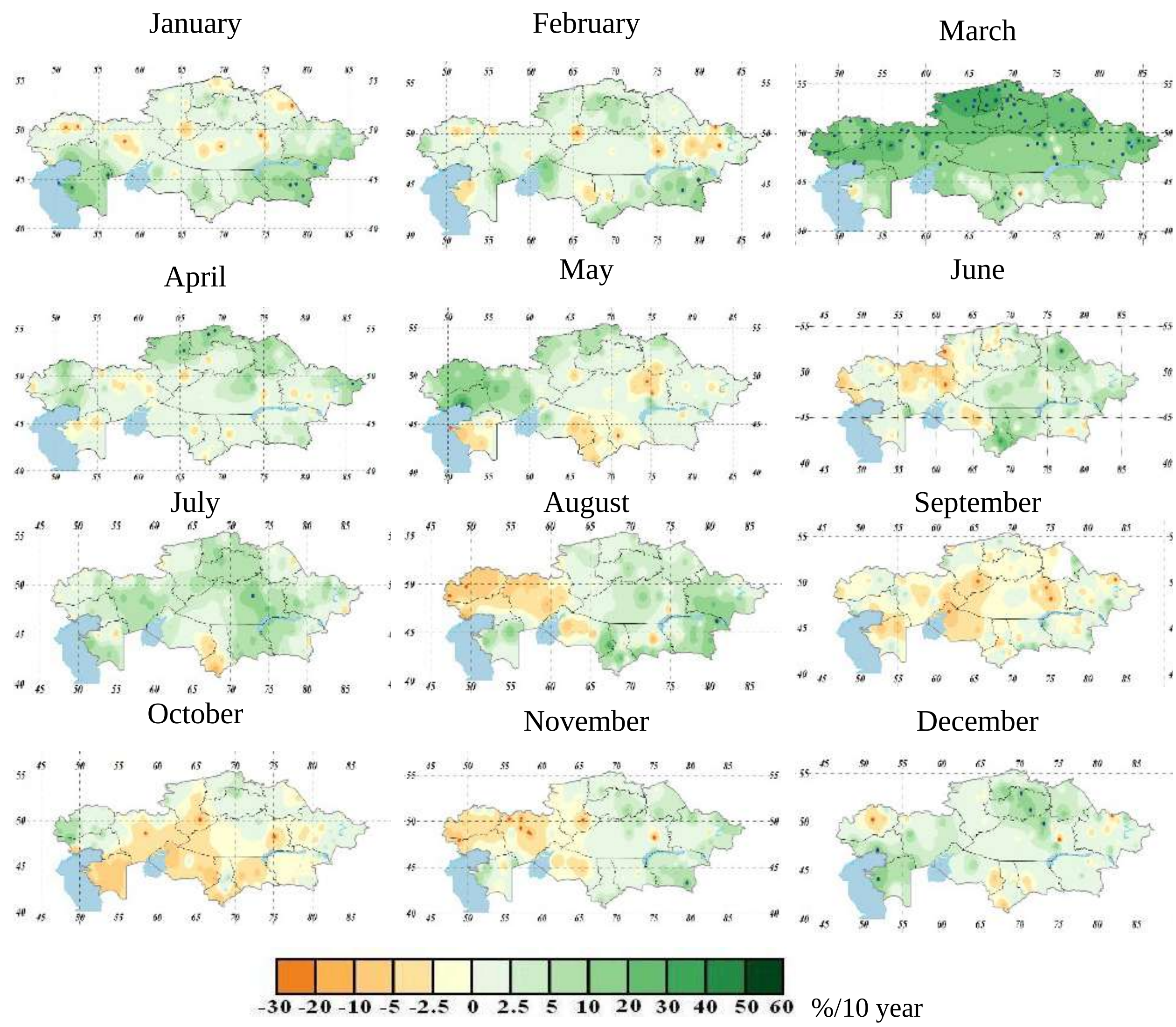
4-5 % / 10 years. At several meteorological stations in North Kazakhstan, East Kazakhstan, Karaganda and Pavlodar regions, the steady positive trend of the summer season was 4-6%/10 years.

In autumn, a negative trend can be traced in most of the territory of Kazakhstan (1-21 %/10 years). The statistically significant values of the decrease in the amount of precipitation at some stations were 6-31 %/10 years. A weak positive trend in the amount of precipitation (1-6 %/10 years) is noted in the southeast, north east and central part of the republic. All obtained trends are insignificant.



significant positive and negative values of the linear trend coefficient are highlighted in red and blue

Figure 3.9 – Spatial distribution of the linear trend coefficient values of annual and seasonal precipitation (%of the/10 years) calculated for the period 1976-2019



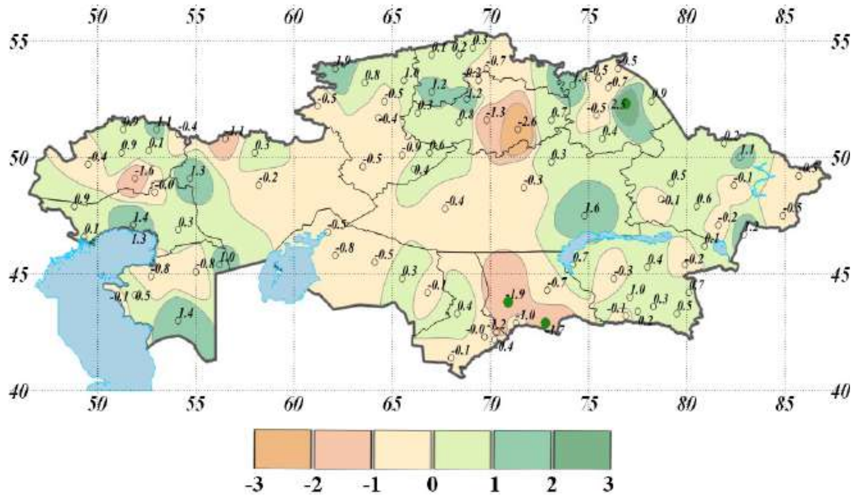
significant positive and negative values of the linear trend coefficient are highlighted in red and blue

Figure 3.10 – Spatial distribution of values of the linear trend coefficient of monthly precipitation (%/10 years), calculated for the period 1976-2019

3.3 Trends in precipitation extremes

Trends in precipitation extremes were analyzed for the period 1976 to 2019 on basis of the most indicative indices proposed by WMO.

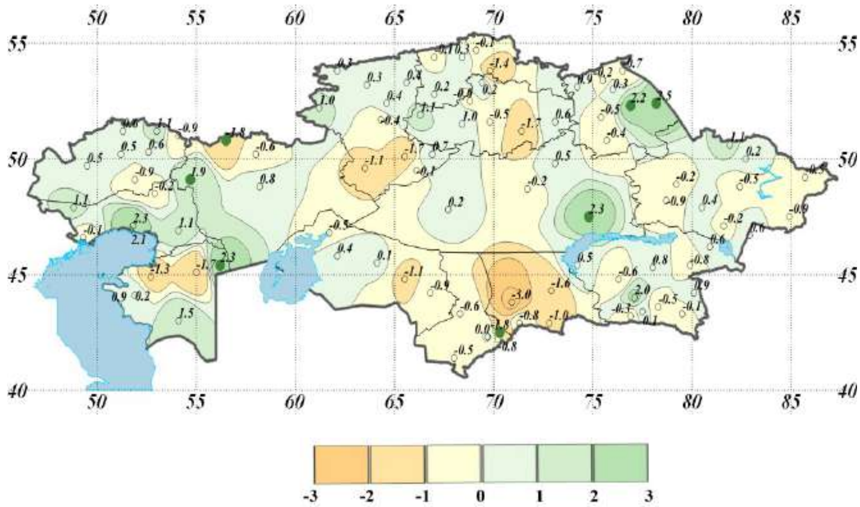
In most of the territory of Kazakhstan, there is a decrease in the ***maximum daily precipitation*** by 1.0-2.6 mm/10 years (Rx1day index, Figure 3.11), which is mainly statistically insignificant. At MS Uyuk (Zhambyl region), a steady decrease in the maximum daily amount of precipitation by 1.9 mm/10 years was noted. A significant increase in the maximum daily precipitation by 1.7 mm/10 years and 2.5 mm / 10 years was noted at MS Kulan (Zhambyl region) and MS Pavlodar, respectively.



●– significant positive and negative values of the linear trend coefficient

Figure 3.11 - Spatial distribution of the linear trend coefficient of maximum in the year values of daily precipitation (mm/10 years) calculated for the period 1961 - 2019(index Rx1day).

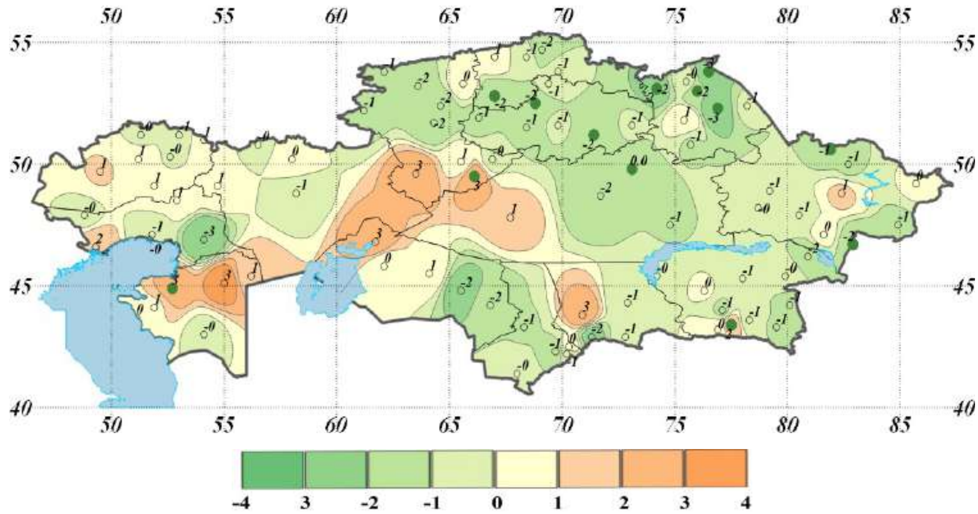
Analysis of trend in ***share (%/10 years) of extreme precipitation in annual precipitation (R95pTOT index)*** showed that in Kazakhstan as a whole there were insignificant statistically insignificant trends, both its decrease and increase by 0.01 - 2.0 % for 10 years (Figure 3.12). At MS Bektauata (Karaganda region), Pavlodar and Sharbakty (Pavlodar region), Uil (Aktobe region), Sam (Mangistau region), a steady increase in the share of extreme precipitation in the annual amount was 1.9 2.5 % every 10 years. A statistically significant decrease in the share of extreme precipitation in the annual amount was recorded at MS Martuk (Aktobe region) and the village of Turara Ryskulov (Turkestan region) by 1.8 % every 10 years.



●– significant positive and negative values of the linear trend coefficient

Figure 3.12 – Spatial distribution of the linear trend coefficient of the share (%/10 years) of extreme precipitation in annual precipitation amounts calculated for the period 1961 - 2019 (index R95pTOT).

In the conditions of the arid climate of Kazakhstan, the CDD index (***the maximum duration of the rainless period when the daily precipitation was less than 1 mm***) is very important. Figure 3.13 shows the spatial distribution of the linear trend coefficient of the maximum duration of the rainless period (days/10 years), calculated for the period from 1961 to 2019. On the territory of Kazakhstan, weak tendencies were noted, both downward and upward by 1-3 days / 10 years. The trends are mostly insignificant, except for some stations in the northern and northeastern regions.

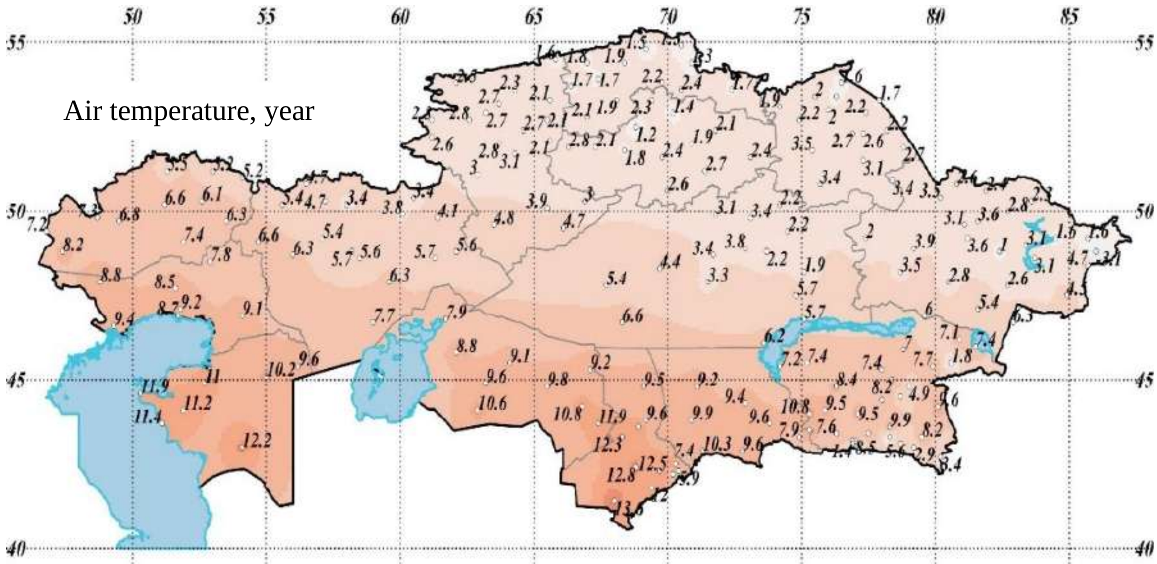


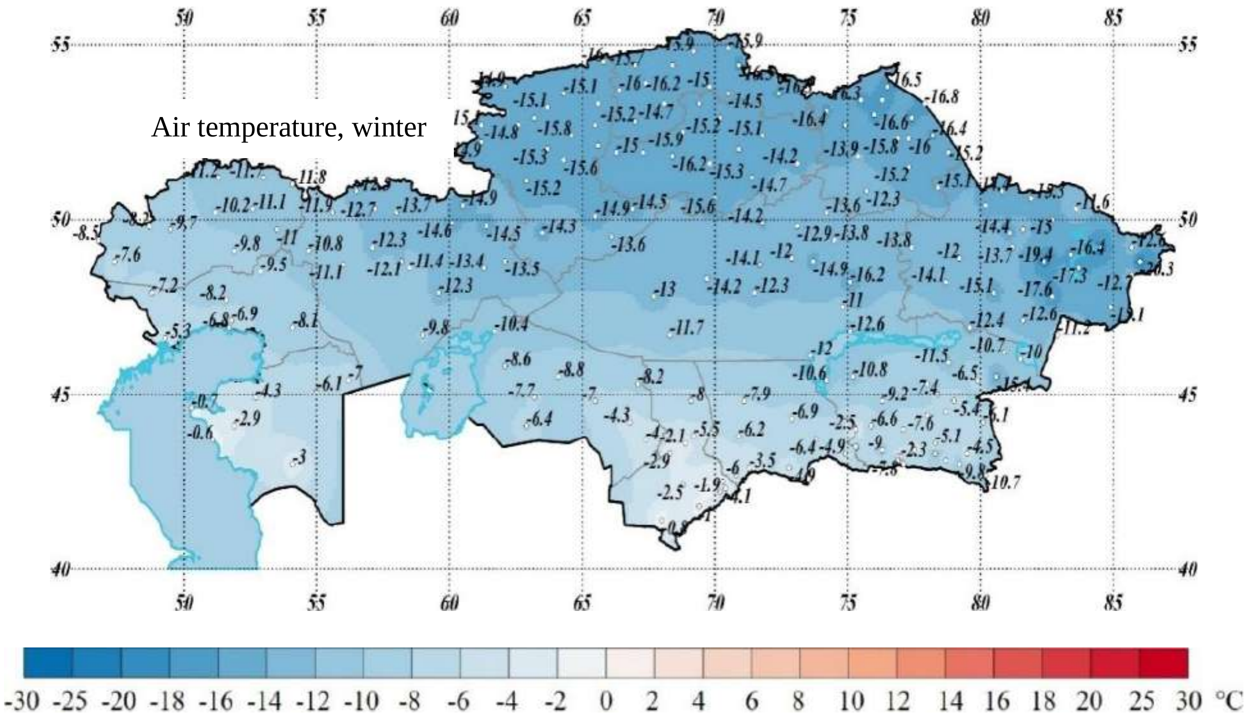
●– significant positive and negative values of the linear trend coefficient

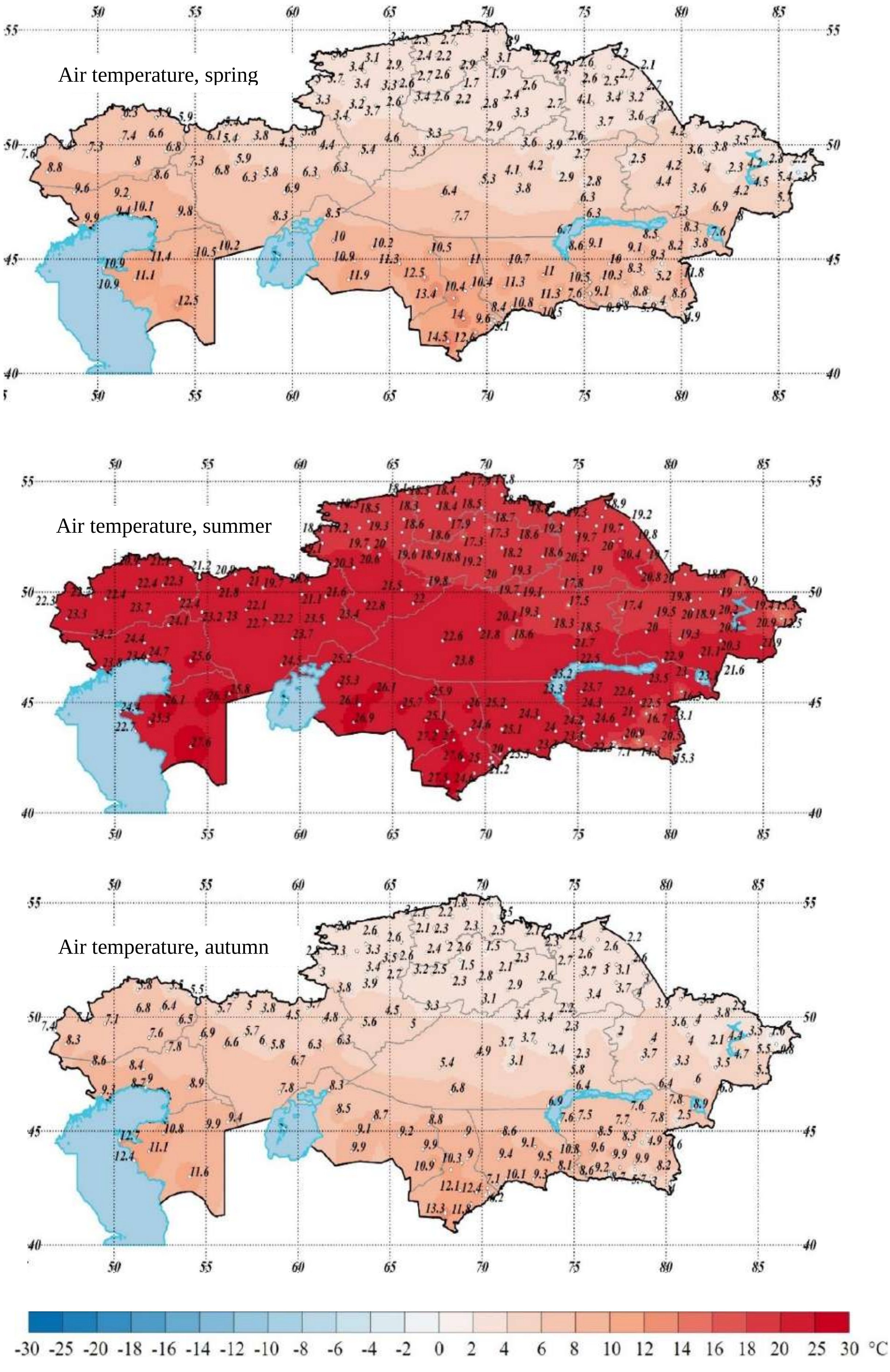
Figure 3.13 – Spatial distribution of the linear trend coefficient of maximum duration of the no rainless period (days/10 years) calculated for the period 1961 – 2019 (index CDD).

ANNEX 1

SPATIAL DISTRIBUTION OF ANNUAL MEAN AND MEDIUM-SEASON AIR TEMPERATURES IN KAZAKHSTAN, CALCULATED FOR THE PERIOD 1961-1990

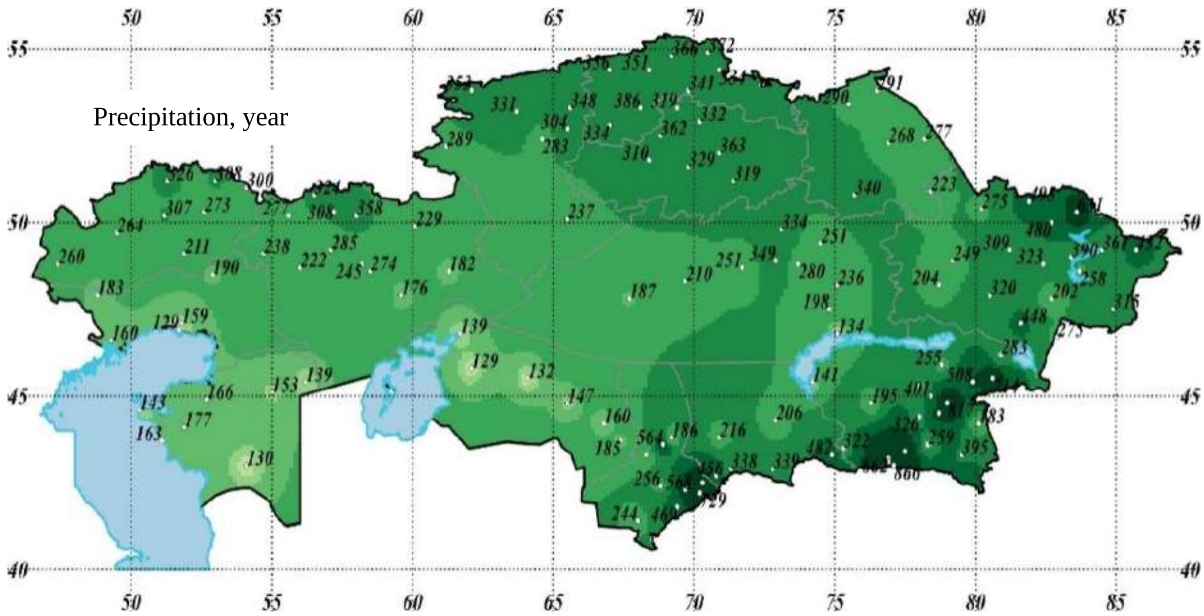


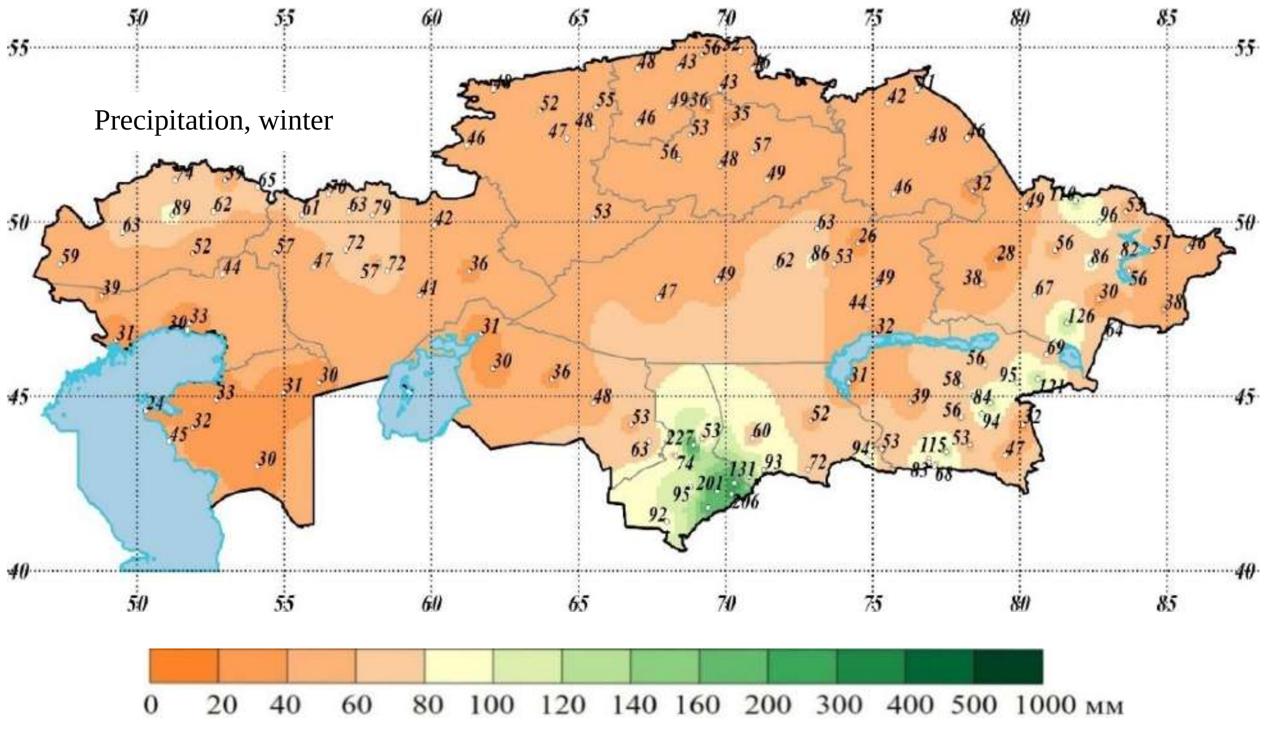


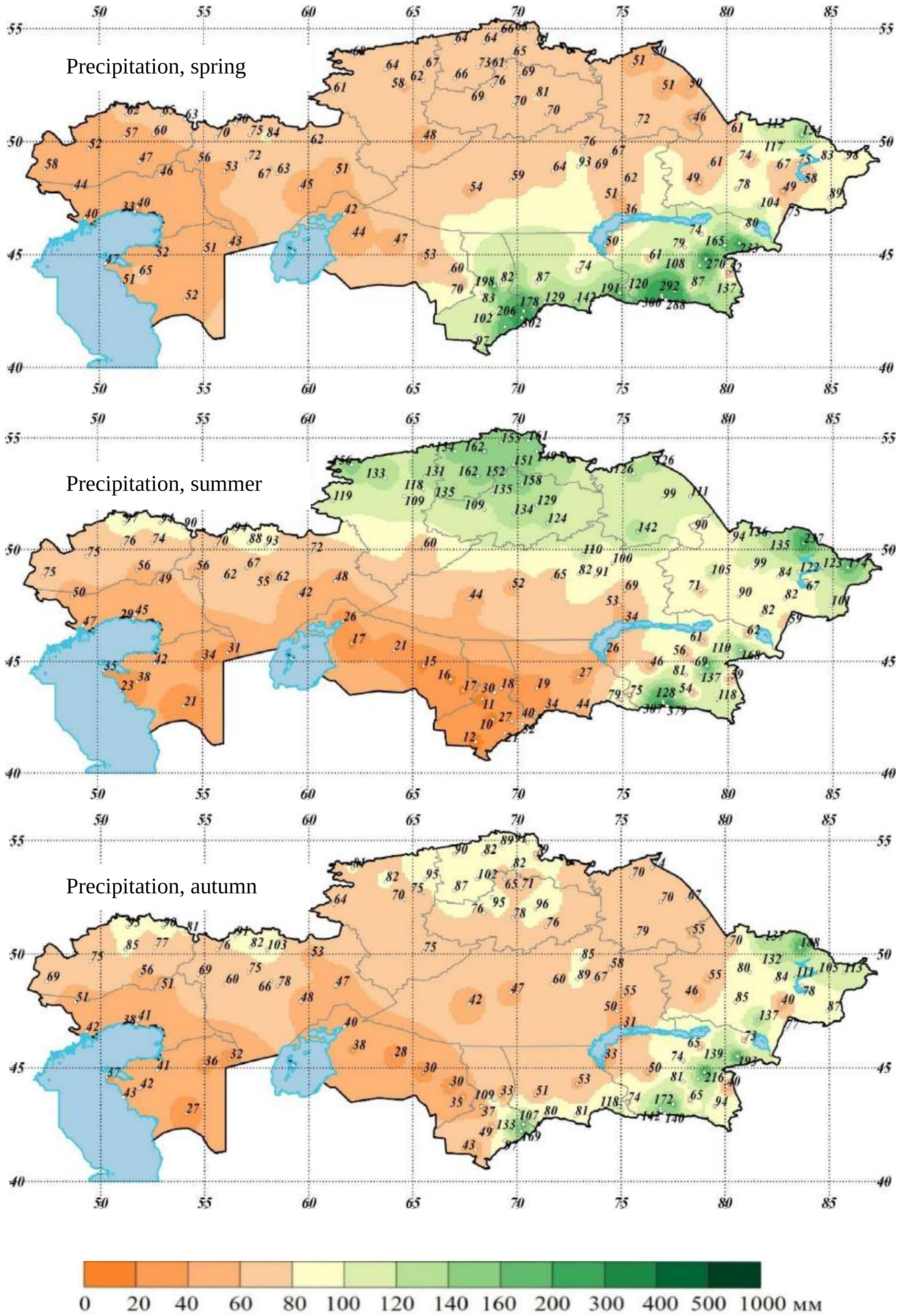

Air temperature, spring
Air temperature, summer
Air temperature, autumn
-30 -25 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 25 30 °C

ANNEX 2

SPATIAL DISTRIBUTION OF ANNUAL AND SEASONAL SUM OF PRECIPITATION IN KAZAKHSTAN, CALCULATED FOR THE PERIOD 1961-1990






Precipitation, spring
Precipitation, summer
Precipitation, autumn
0 20 40 60 80 100 120 140 160 200 300 400 500 1000 мм