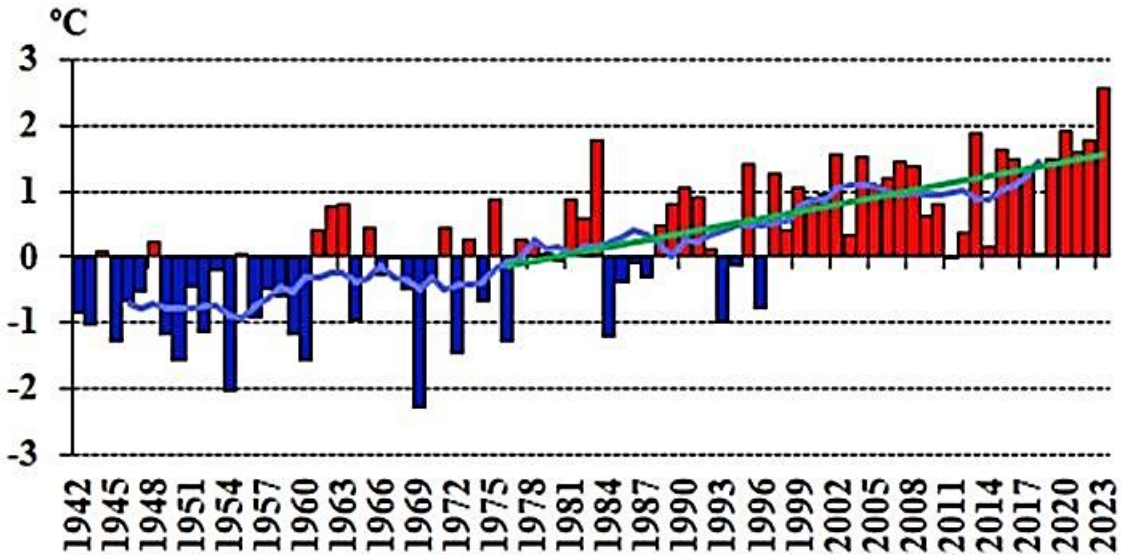
MINISTRY OF ECOLOGY AND NATURAL RESOURCES OF THE REPUBLIC OF KAZAKHSTAN

REPUBLICAN STATE ENTERPRISE "KAZHYDROMET"

SCIENTIFIC RESEARCH CENTER

ANNUAL BULLETIN OF MONITORING STATUS AND CLIMATE CHANGE OF KAZAKHSTAN: 2023



ASTANA, 2024

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SHORT SUMMARY

Climate features in 2023

In general, 2023 was the warmest year for the globe during the period of instrumental observations. The global average annual temperature in 2023 was approximately 1.45±0.12 °C above the baseline level of 1850-1900, used as an approximation of pre-industrial levels.

The year 2023 on average for the territory of Kazakhstan took a record 1st place in the ranked downward series of mean annual air temperatures since 1941, the anomaly of mean annual temperature (deviation from the long-term average for the period 1961 1990) amounted to +2.58 °C. The year was record warm in almost all regions of Kazakhstan, except Zhambyl, Pavlodar and North-Kazakhstan regions, where 2023 was among the 5% of extremely warm years (rank 2), on average in the regions of air temperature anomalies ranged from +2.11 °C to +3.46 °C. Extremely high annual temperatures were recorded according to the data of most weather stations in the country. The share of the country area with anomalies above the 80th percentile was 99%. According to 186 weather stations data, the year 2023 was extremely warm (90 and 95% extremes were recorded), including 111 stations - the warmest year since 1941, with record temperature anomalies ranging from +1.46 to +3.92 °C. The abnormally warm seasons were spring (+2.97 °C – the fourth magnitude in a row after 2020 (+3.84 °C), 2008 (+3.77 °C) and 2016 (+3.09 °C), summer (+1.90 °C – the third magnitude in a row after the summer of 1998 (+2.23 °C) and 2012 (+2.03 °C) and autumn (+3.27 – record warm autumn, the previous record was +2.45 °C and was recorded in 1971).

In many regions of Kazakhstan, the warmest months were March and November. The record warmest months were July and November (rank 1) with anomalies of +2.45 °C and +5.77 °C, respectively. Previous maximum air temperature anomalies were observed in July 1998 (+1.86 °C) and November 2010 (+4.51 °C). Extremely warm (5% extremes) were March with an anomaly of +6.45 °C (rank 3) and the month of October with an anomaly of +3.44 °C (rank 4). The mean monthly temperature of June month in 2023 was among the ten warmest months for the period since 1941 with an anomaly of +1.68 °C.

The daily maximum temperature in 2023 exceeded 35 °C and even 40 °C over the entire territory of Kazakhstan (except for high mountain areas). In 2023, 24 meteorological stations participating in climate monitoring of Kazakhstan updated or reached the values of absolute maximums, located mainly in the northern and eastern regions, as well as in the western region. The highest air temperature in 2023 was recorded at station Karatobe in West Kazakhstan region: +46.0 °C. In the western and southern regions, the total duration of all heat waves was more than 30, in some places more than 60 days. As a consequence of high air temperatures for a significant part of the warm period of the year, especially in the western and southern regions of Kazakhstan, there was an acute need for cooling of premises to maintain a favorable temperature.

The daily minimum air temperature in 2023 below minus 30 °C was observed in the north of the western region, in the northern, eastern, central and southeastern regions, and below minus 40 ° C - mainly in the northern and northwestern regions of Kazakhstan. In 2023, the daily minimum temperature records were updated at four meteorological stations in the western and southern regions of Kazakhstan. The lowest air temperature in 2023 was recorded in the MS Kos-Expired Aktobe region: minus 42.7 °C.

The layer of precipitation for 2023 on average over the territory of Kazakhstan amounted to 359.4 mm (113.1 % of the norm). On average over the territory of most regions annual precipitation amounts were within ±20 % of the norm. A significant deficit of precipitation (up to 25 57 %) was observed in the south of Kostanay region, in the south-western and southern regions of the country. From seasons autumn with significant excess of moisture practically on the whole territory of the country (except for southern and south-western regions) stands out. 149,1 % of norm - the maximum value in a number of observations since 1941 - fell in autumn season in Kazakhstan as a whole, besides it is necessary to single out "dry" spring, especially in Turkestan (53 % of norm) and Kostanay regions (56 % of norm) - the sixth spring among the "driest".

In 2023, on average over the territory of Kazakhstan most of the year there was an excess of precipitation (from January to March and from August to December). Extremely wet (5% extremes) were two months of 2023: September (193.7 % of the norm, rank 2) and August (175.8 % of the norm, rank 4); and very wet (10% extremes) were October (151.8 % of the norm, rank 7) and December (155.5 % of the norm, rank 7). Precipitation deficit was observed from April through July months. In April, the average precipitation amounted to 79.3 % of the norm, in July - 71.5 % of the norm. Two months were extremely dry: May 60.2 % of the norm (the eighth driest month) and June 59.2 % of the norm (the third driest month). From April to July, the precipitation deficit was observed over much of the territory of Kazakhstan. At some stations monthly precipitation minimums were updated, at other stations - monthly maximums. According to data of many stations in the western, central and southern regions precipitation was absent for at least a month.

Climate change in Kazakhstan

A steady increase in the average annual air temperature is observed in all regions of Kazakhstan. The average increase in the average annual air temperature in Kazakhstan is 0.36 °C every 10 years. On average, for the territory of individual regions, the growth rate ranges from 0.25 ° C/10 years (Karaganda region) to 0.56 °C/10 years (West Kazakhstan region). In all seasons except winter, the temperature increase is statistically significant.

All trends in the average annual and seasonal precipitation in Kazakhstan are statistically insignificant. Over the past 48 years, there has been a slight trend towards an increase in annual precipitation (by 1.7 mm/10 years), mainly due to precipitation in the spring season, when the increase in some western, northern and central regions is 8-18%/10 years. In the autumn period, precipitation decreases almost throughout the territory of Kazakhstan, in some western and southern regions by 4-12%/10 years. In the summer season, precipitation also decreases almost throughout Kazakhstan, in some western and southern regions by 5-7%/10 years.

The analysis of trends in extremes of surface air temperature and precipitation showed that for the period 1961 - 2023.:

− there is a steady increase in the number of summer days with temperatures above 30 °C, as well as tropical nights with temperatures above 20 °C, especially noticeable in the south, south-west and west of the republic;

− everywhere there is an increase in the number of heat waves in the warm season, the total and maximum duration of heat waves, as well as the duration of heat waves in general for the year;

− there is a reduction in heat deficit (the need for heating) in the cold season and an increase in cold deficit in the warm period (the need for air conditioning), especially in the south-west and west of the republic;

− everywhere there is a steady increase in the period of active vegetation with an average daily temperature above 10 °C, as well as the sum of active temperatures for this period;

− the number of days with frosts and severe frosts below minus 20 °C is reduced;

− there have been no significant changes in the characteristics of the extreme precipitation regime in most of the territory of the republic.

The observed increase in the frequency and duration of periods with high air temperatures in the warm season leads to negative consequences not only for the human body and animals, but also for transport infrastructure due to deformation of the road surface, for urban conditions and recreation areas, for the energy industry, as there is a need for additional energy generation for cooling premises.

An increase in surface temperature leads to a shortening of the period with negative temperatures, as a result, precipitation is more likely to fall in liquid form. This, in turn, can affect snow accumulation during the cold season. In mountainous areas, both the area and the period of precipitation in solid form are decreasing, which affects glacial systems.

An increase in surface temperature during the cold season leads to a decrease in the need for thermal energy generation. Reducing the number of days with frosts, on the one hand, leads to a positive effect on public health, on the other hand, heat waves during the cold season can lead to the formation of ice on the roads when the cold weather returns.

An increase in the length of the growing season in those areas where this is combined with an increase in precipitation and a reduction in the maximum duration of the rainless period (in some northern and southeastern regions) improves conditions for crop production.

In some areas, an increase in the maximum daily precipitation has been recorded, which can lead to an increased risk of destruction of the roadway and storm water systems in settlements, landslides and mudslides in mountainous areas.

INTRODUCTION

Climate is a natural resource that is vital for determining the directions of development of many sectors of the economy and the health of the population of any state. Meteorological information collected, managed and analyzed by national hydrometeorological services helps users of this information, including decision makers, to plan any activity taking into account current climatic conditions and observed climate changes. The use of up-to-date meteorological and climate information helps to reduce risks and damage and optimize socio-economic benefits. Monitoring of the climate system is carried out by national, regional and international organizations in coordination with the World Meteorological Organization and in cooperation with other environmental programs.

The study of the regional climate and the constant monitoring of its changes is one of the priorities of the national hydrometeorological Service of Kazakhstan RSE "Kazhydromet". Since 2010, Kazhydromet has been issuing annual bulletins to provide reliable scientific information about the regional climate, its variability and change. Taking into account the geographical location of Kazakhstan and its vast territory, the observed changes in climatic conditions in various regions of the Republic can have both negative and positive effects on biophysical systems, economic activity and the social sphere. Consideration of climatic conditions and assessment of their changes are necessary to identify potential consequences and take timely and adequate adaptation measures, ultimately, to ensure the sustainable development of Kazakhstan.

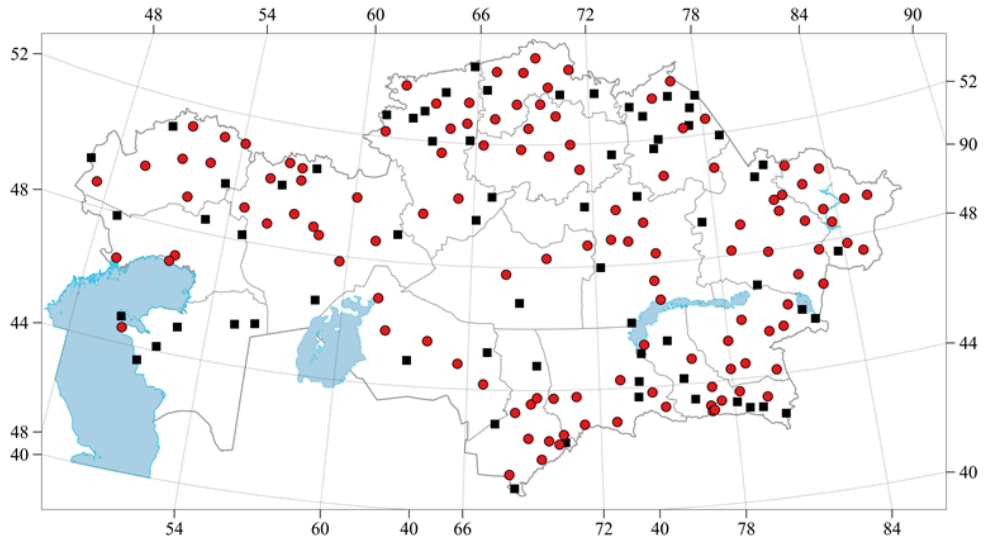
This issue of the bulletin describes the climatic conditions observed in 2023, including an assessment of the extremes of temperature and precipitation regimes, and provides historical information on changes in surface air temperature and precipitation that have occurred since 1941. This issue of the bulletin also contains estimates of climate change over a shorter period – since the mid-1970s of the last century, when, according to many experts, global climate change has become more intense, especially in the Northern Hemisphere. Appendices 3 and 4 show maps of the distribution of average long-term values of air temperature and precipitation for the period 1961-1990, averaged by season and per year.

The initial data. Data from the Republican Hydrometeorological Fund of RSE "Kazhydromet" are used to prepare the bulletin:

1) the series of average monthly air temperatures and monthly precipitation amounts, while about 120 weather stations have homogeneous series since 1941 and their data are involved in the generalization of information on the territory of the regions and in Kazakhstan as a whole, since 1961, there are about 190 such stations, and their data were used to assess climatic norms for the period 1961-1990., to assess anomalies and trends in a particular point;

2) the series of daily maximum and minimum air temperatures and daily precipitation since 1961 (about 190 weather stations).

The network of meteorological stations used for climate monitoring is shown on the schematic map below.

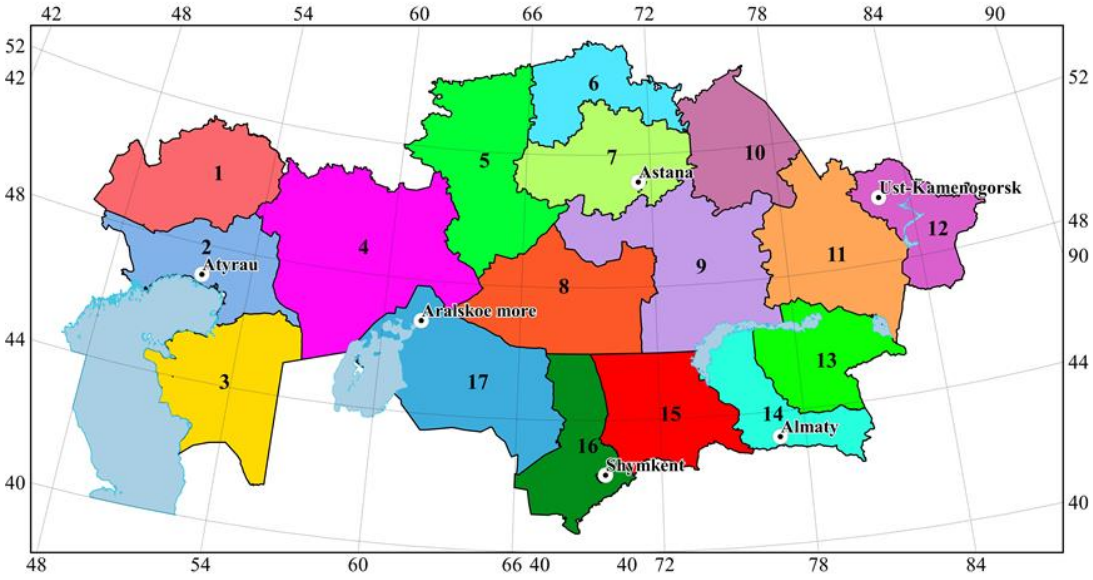


Network of meteorological stations in Kazakhstan used for climate monitoring (stations used for averaging over the area of regions are shown in red circles)

The main approaches and methods. The "norm" in the bulletin refers to the average annual value of the considered climatic variable for the period 1961 - 1990. Temperature anomalies are calculated as deviations of the observed value from the norm. Precipitation anomalies are usually considered both in deviations from the norm (similar to air temperature) and as a percentage of the norm. As additional characteristics of anomalies, indicators based on the distribution function (probability of non-excess, which characterizes the frequency (in %) of occurrence of the corresponding anomaly value in a series of observations) and ordinal statistics (ranks, i.e., ordinal numbers in an ordered series of values relative to other numbers in the dataset) are used, periods for evaluating these statistics are specifically specified in every case.

Linear trend coefficients determined by the least squares' method are used as an estimate of changes in climate characteristics over a certain time interval. The measure of trend materiality is the coefficient of determination (D), which characterizes the contribution of the trend component to the total variance of the climate variable over the period under consideration (as a percentage).

The assessment of trends in surface air temperature and precipitation, the average values of anomalies of meteorological variables are given both according to data from individual stations and on average for the territory of Kazakhstan as a whole and for 17 of its administrative-territorial regions. The average values of anomalies of meteorological variables for the territory are calculated by averaging station data on anomalies. The borders of the administrative-territorial regions of Kazakhstan are shown on the schematic map below.



1	West Kazakhstan region	10	Pavlodar region
2	Atyrau region	11	Abai region
3	Mangystau region	12	East Kazakhstan region
4	Aktobe region	13	Almaty region
5	Kostanay region	14	Zhetysu region
6	North Kazakhstan region	15	Zhambyl region
7	Akmola region	16	Turkestan region
8	Ulytau region	17	Kyzylorda region
9	Karaganda region		

The scheme of administrative-territorial division of the Republic of Kazakhstan

To assess the temperature and precipitation regime in a particular year and its changes since 1961, climate indices recommended by the World Meteorological Organization are used and contribute to the "detection" (mathematically) of significant climate change, including the characteristics of extremes. Some indexes are based on fixed uniform thresholds for all stations, while others are based on thresholds that may vary from station to station. In the latter case, the thresholds are defined as the corresponding percentiles of the data series. The indices also allow us to assess the impact of the current climate and its changes on various aspects of socio-economic conditions in the studied region. There are indices reflecting the potential impact on human health, on energy generation needs in different seasons, on agrometeorological conditions, on transport infrastructure, on the extremity of hydrometeorological conditions, etc.

Responsible for the issue: Head of the Department of Climate Research T.A. Tillakarim. Leading researchers Smirnova E.Yu., Aktayeva G.S., Medetova A.K., Amanulla E.E. and leading engineers Abdolla N.S., Turumova G.E. also participated in the preparation of the bulletin.

1 OVERVIEW OF GLOBAL CLIMATE CHANGE AND ITS STATUS IN 2023

For more than 30 years, the World Meteorological Organization (WMO), through the Commission on Climatology and in cooperation with its members, has been issuing an annual report on the state of the climate, in response to concerns expressed in 1993 about projected climate change. The annual Global Climate report identifies indicators of the climate system, including greenhouse gas concentrations, rising land and ocean temperatures, rising sea levels, melting ice and retreating glaciers, as well as extreme weather events. It also highlights the impact on socio-economic development, migration and displacement, food security and terrestrial and marine ecosystems. Global climate indicators provide a broad view of climate change on a global scale, covering atmospheric composition, energy changes, and the response of land, ocean, and ice. These indicators are closely interrelated. For example, an increase in the content of CO2 and other greenhouse gases in the atmosphere leads to an energy imbalance and, thus, to a warming of the atmosphere and the ocean. Ocean warming, in turn, leads to an increase in sea level, to which is added the melting of ice on land in response to an increase in atmospheric temperature. Together, the indicators create a coherent picture of global warming, which affects all parts of the Earth's system.

There are clear links between key climate indicators as a physical system and cascading risks for most of the 17 Sustainable Development Goals. Thus, monitoring global climate indicators, as well as the risks and consequences associated with them, is crucial for achieving the Sustainable Development Goals by 2030.

Key provisions on the state of the global climate in 2023:

The report of the World Meteorological Organization (WMO) on the state of the global climate in 2023 indicates that once again records have been broken and, in some cases, left far behind in terms of greenhouse gases, surface temperatures, ocean heat content and acidification, sea level rise, Antarctic Sea ice cover and glacier retreat. The World Meteorological Organization (WMO) in its report published that 2023 was the warmest year in the history of observations by a very large margin.

The **average annual global surface temperature** in 2023 was 1.45 ± 0.12 °C above the average temperature for the pre-industrial period 1850-1900. (Figure 1.1). The transition from the La Niña-related cooling (lasted from mid-2020 to early 2023) to the warming of El Niño by mid-2023 is clearly reflected in the temperature increase compared to last year. Given that El Nino usually has the greatest impact on global temperatures after reaching a peak, it is expected that 2024 may turn out to be even hotter. Six international datasets used for global temperature monitoring and analysis place 2023 among the warmest years on record in the world, and all six datasets show that the global temperature in each month from June to December 2023 set new monthly records. July and August were the two hottest months on record globally. The previous warmest years in the entire history of observations were recognized as 2016 (strong El Nino) and 2020 with an average annual air temperature of 1.29±0.12 °C and 1.27±0.13 °C above the temperature of the pre-industrial era, respectively. Also, all six data sets show that the average value for the last ten years, from 2014 to 2023, were the warmest years in the history of instrumental observations since 1850 and the average decennial global temperature exceeded by 1.20±0.12 °C the average temperature of 1850-1900 (Figure 1.1). The long-term increase in global temperature is caused by an increase in the concentration of greenhouse gases in the atmosphere.

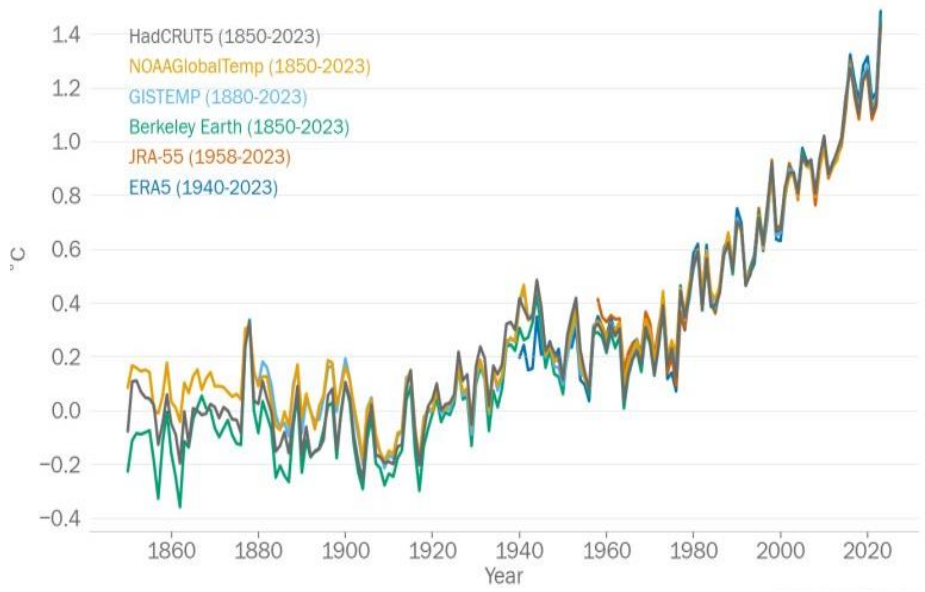


Figure 1.1 – Anomalies of the global average annual air temperature relative to pre-industrial conditions (1850-1900) from six sets of global temperature data (1850-2023)
Source: Met Office, United Kingdom of Great Britain and Northern Ireland; Copernicus Climate Change Service (C3S); Climate Data Repository (CDS), 2023

The observed concentrations of the three main greenhouse gases — carbon dioxide, methane and nitrous oxide — reached record levels in 2022. CO2 levels are 50% higher than in the pre-industrial era, which leads to heat retention in the atmosphere. The long lifetime of CO2 means that temperatures will continue to rise for many years to come.

In 2022, the molar fractions of **greenhouse gas concentrations** reached new highs: carbon dioxide or carbon dioxide (CO2) – 417.9 ppm ± 0.2 or 150% of the pre–industrial level, methane (CH4) – 1923±2 parts per billion (ppb) or 266% of the pre-industrial level and nitrous oxide (N2O) - 335.8± 0.1 ppb or 124% of the pre-industrial (1750) level. Real-time data from a number of specific locations show that concentrations of greenhouse gases, CO2, CH4 and N2O, continued to rise in 2023.

The global average sea surface temperature (TPM) in 2023 reached record values starting in April, and the records of July, August and September were broken by a particularly large margin. Exceptionally high temperatures were recorded in the eastern part of the North Atlantic, the Gulf of Mexico and the Caribbean, in the North Pacific Ocean, as well as in vast areas of the Southern Ocean, where widespread marine heat waves were observed.

Global mean sea level continued to rise in 2023, reaching a new all-time high for the existence of satellite altimetry (1993-2023), reflecting the ongoing warming of the ocean (thermal expansion), as well as the melting of glaciers and ice sheets. The rate of increase in global average sea level more than doubled between the first decade (1993-2002) of satellite observations, when sea level rose by an average of 2.13 mm per year and the last decade (2014-2023), where global average sea level rose by an average of 4.77 mm per year.

The ocean's heat content in 2023 reached a new record high in the entire history of observations. The rate of ocean warming has increased especially strongly in the last two decades. The average daily coverage of the world's oceans by a marine heat wave was 32%, which is much higher than the previous record, 23% in 2016. By the end of 2023, conditions that contributed to heat waves were observed in most of the world's oceans between 20 ° south and 20 ° C. since the beginning of November. Of particular note are the large-scale marine heat waves in the North Atlantic, which

began in the spring in the Northern Hemisphere, peaked in September and continued until the end of the year. At the end of 2023, a wide band of severe and extreme marine heat wave formed throughout the North Atlantic with temperatures 3 °C above average.

The Mediterranean Sea has been almost completely engulfed by strong and severe sea heat waves for the twelfth year in a row. Ocean acidification has increased as a result of carbon dioxide uptake.

Glaciers. The global set of reference glaciers has experienced the largest ice loss in the entire history of observations (since 1950), caused by extreme melting in both western North America and Europe.

In 2023, the area of Antarctic Sea ice turned out to be the lowest in the entire history of observations: its maximum length at the end of winter was 1 million km2 less than in the previous record year, which is equivalent to the area of France and Germany combined.

Glaciers in the European Alps have experienced an extreme melting season. The annual mass loss of Swiss glaciers in 2022-2023 was the second largest in the entire history of observations (from 1950 to the present) and amounted to 4.4% of the remaining ice volume. Together with a record 5.9% mass loss in 2021-2022, Swiss glaciers lost about 10% of their remaining volume in just two years.

In 2023, a record loss of glacier mass occurred in the western part of North America (from 1965 to the present), its rate was five times higher than the figures recorded in 2000-2019. According to some estimates, glaciers in western North America lost 9% of their volume in 2020 over the period 2020-2023.

Significant negative mass balances are explained by the fact that the winter snow cover was below average, followed by intense spring heat, which led to early ice exposure on most glaciers and ice fields in southwestern Canada.

The Greenland Ice Sheet continued to lose mass in the 2022-2023 hydrological year. This summer was the warmest in the history of observations at the Greenland Summit station, with temperatures 1.0 °C above the previous record. Satellite data on the extent of melting indicate that the ice sheet has experienced the third largest cumulative melting volume of all time (1978-2023), after the extreme melting seasons in 2012 and 2010.

Snow cover. The total area of snow cover in the Northern Hemisphere from January to April 2023 was close to the long-term average (1991-2020) and amounted to 16.74 million km2, which is the eighth lowest since 1967 and 1.47 million km2 below the long-term average, but the spring heat wave in northwestern North America caused widespread melting snow. The area of snow cover in North America in May 2023 was the lowest in the entire history of observations (1967-2023) and amounted to 7.47 million km2, which is about 1.57 million km2 (17%) below the long-term average.

One of the most significant in terms of the number of victims of extreme events is the floods that occurred due to the Mediterranean cyclone, locally dubbed "Storm Daniel", in the month of September. In the initial stage, the storm caused heavy rains in Greece, southern Bulgaria and parts of Turkey, in the next stage, the storm caused significant flash floods in Spain, which negatively affected grain production. The heaviest precipitation fell in the Thessalian region of Greece north of Athens, where 760 mm fell in Zagora Pelion on September 5, and 1096 mm in 5 days from September 4 to September 8, while 329 mm fell in Bulgaria on September 4-5 in 16 hours. The storm then

remained inactive for several days in the eastern Mediterranean, and then struck again as heavy rain in northeastern Libya on September 10 and 11. Heavy rains hit the coast and nearby mountains: on September 10-11, 414 mm fell in 24 hours in Al-Bayda. Intense rains have led to severe flooding in the region. The worst effects were noted in the city of Derna (about 50 km east of Al-Bayda), where most of the central part of the city was destroyed as a result of flooding, aggravated by the destruction of two dams. At least 4,700 confirmed deaths in Libya are linked to flooding, and 8,000 people are still missing (as of December 15). Another 19 people died in Greece and Bulgaria.

Tropical cyclone Freddy in February-March became one of the longest-lived tropical cyclones in the world. The main consequences of "Freddy" were associated with floods during landfall in Mozambique and Malawi, as a lot of precipitation fell (up to 672 mm during the storm in Mozambique). Some areas of Mozambique and Malawi have not yet recovered from the storms of 2022. Malawi was particularly hard hit, with at least 679 people killed and more than 659,000 displaced, while another 165 people died in Mozambique. Casualties were also reported in Madagascar and Zimbabwe, and in the sea off Mauritius.

In 2023, there were many significant heat waves in different parts of the world. Some of the most significant were in southern Europe and North Africa, especially in the second half of July, where there was a strong and exceptionally prolonged heat wave. Extreme heat in the second half of July moved from southern Europe to southeastern Europe, and in late August and early September, the heat swept west-central Europe. During these events, temperature records were set in many places in southern France, northern Spain and western Switzerland. Record high temperatures in Europe were recorded in the Sardinian resorts of Lotzorai and Jerzu (Italy), where on July 24 the temperature reached 48.2 °C, on August 23 the Brera Observatory in Milan recorded an average daily temperature of 32.98 °C, which was the highest in the entire history of observations, since 1763, in Tirana (Albania) (43.0 °C on July 25). Record high temperatures were also recorded in North Africa: in Tunisia (Tunisia) (49.0 °C on July 24), Agadir (Morocco) (50.4 °C on August 11) and Algeria (49.2 °C on July 23).

In 2023, extremely high air temperatures were combined with exceptionally dry conditions, which provoked extensive forest fires in different parts of the world. The largest fire ever observed in the European Union was an extensive forest fire observed in northeastern Greece in late August and early September (both on the mainland and on the islands), which burned 96,000 hectares.

The wildfire season in Canada has surpassed all previous records. Significant fire activity began in late April, spread during a very warm and dry May, and continued throughout the summer and early autumn. The total area burned per year in the country amounted to 14.9 million hectares, which is more than seven times higher than the long-term average (1986-2022) and significantly exceeds the previous record seasonal figure of 6.7 million hectares in 1989.

The deadliest wildfire of the year occurred in Hawaii, on the western side of the island of Maui. Extreme weather conditions, low humidity and strong gusty winds, combined with the previous drought, contributed to the development and rapid spread of severe fires. The area of Lahaina, which was largely destroyed, suffered the most: more than 2,200 buildings were destroyed. A mandatory evacuation of 7,500 people was announced throughout the area. At least 100 people died, which is the largest number of victims of wildfires in the United States in more than 100 years. Wildfires of this intensity and rate of spread are extremely rare in the tropics.

Prolonged **drought** in 2023 persisted in northwestern Africa and parts of the Iberian Peninsula, as well as in central and southwestern Asia, and intensified in many areas of Central America, northern South America and the southern United States. Among the most significant drought zones was the area of subtropical South America, concentrated in the north of Argentina and Uruguay. In most of northern and central Argentina, between 20 and 50% of precipitation fell from January to August, with precipitation in some regions falling below average for the fourth year in a row. In eight states of Brazil, the minimum amount of precipitation in the last 40 years fell from July to September.

Source: Report «The state of the Global climate in 2023», WMO-No. 1347 permanent link *https://library.wmo.int/idurl/4/68835*

2 AIR TEMPERATURE

In 2023, the average annual average air temperature anomaly in Kazakhstan was +2.58 °C relative to the long-term average value for the period 1961-1990. (5.4 °C), this is a record value among the warmest years in the history of observations since 1941, and was 0.66 °C higher than the previous record in 2020. Since the 1960s, every subsequent decade in Kazakhstan has been warmer than the previous one. The average annual value of air temperature over the last decade 2014-2023. It was +6.82 °C and exceeded the climatic norm by 1.42 °C, this is a record value among positive decadal anomalies, the previous warmest decade was in 2013-2022 with an anomaly of +1.33 °C. The last five years of 2019-2023 were also the warmest with an average annual air temperature of +7.30 °C, which exceeded the climatic norm by 1.87 °C.

Table 2.1 shows the lists and ranks of the ten warmest years on average across the Globe and across Kazakhstan (according to the terrestrial network). Each year, which is included in the 10 warmest years for the Globe and for Kazakhstan, has its own fill color, which allows us to judge the coincidences in the rank that fell into both lists of the warmest years. The six warmest years in Kazakhstan were included in the list of the ten warmest years for the Globe. The years 2023 and 2020 turned out to be record warm both in Kazakhstan and around the globe.

Table 2.1 – The warmest years in the history of observations on the Globe (since 1850) and in Kazakhstan for the period 1941-2023 and the corresponding anomalies of the average annual surface air temperature averaged over the territory of Kazakhstan. The anomalies are calculated relative to the period 1961-1990

Rank	The globe	Kazakhstan	The anomaly of the average annual temperature (Jan.-Dec.), averaged over the territory of Kazakhstan, °C
1	**2023**	**2023**	2,58
2	2020	2020	1,92
3	2016	2013	1,89
4	2019	2022	1,78
5	2017	1983	1,76
6	2022	2015	1,64
7	2015	2021	1,58
8	2021	2002	1,55
9	2018	2004	1,53
10	2014	2019	1,50

Figure 2.1 shows a ranked series of average annual surface air temperature anomalies averaged by weather stations in Kazakhstan for the period from 1941 to 2023. Globally, all 10 extremely warm years occur in the current century. In Kazakhstan, this feature is also well traced, with the exception of 1983, which ranks fifth in the rank of the warmest years.

2.1 Air temperature anomalies in Kazakhstan in 2023

On average, the average annual air temperature in Kazakhstan continues to rise. The year 2023, with an air temperature anomaly of 2.58 °C, took 1st place in a descending series of average

annual temperatures since 1941 and became one of the ten warmest years. Of the ten warmest years, nine are in the 21st century (Figure 2.1).

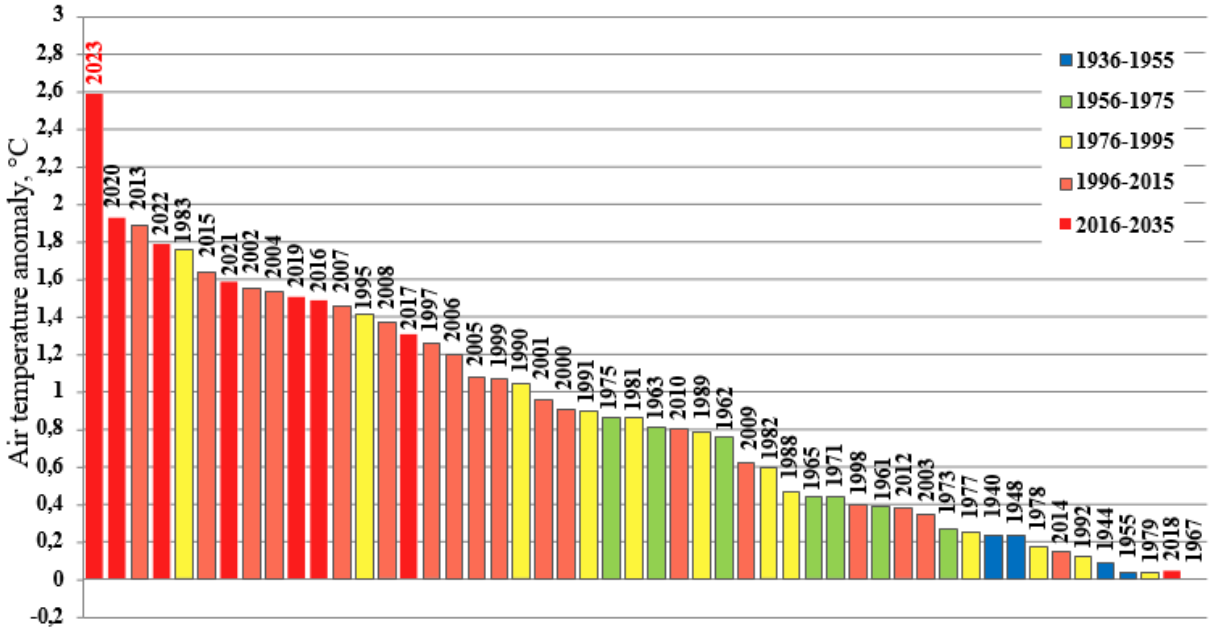


Figure 2.1 – A ranked series of positive anomalies of average annual (January-December) surface air temperatures averaged over the territory of Kazakhstan (according to 121 weather stations) for the period 1941-2023. The anomalies are calculated relative to the base period of 1961-1990

Table 2.2 shows the average annual and seasonal air temperature anomalies averaged by regions and in Kazakhstan as a whole, Table 2.3 shows the anomalies of the average monthly air temperature. For each anomaly value, the probabilities of not exceeding them are given, calculated from data for the period 1941-2023, as well as standard deviations for 1961-1990. (Table 2.2). In Tables 2.2 and 2.3, temperature values above the 95th or below the 5th percentile (respectively, warm and cold extremes) are highlighted in bold and color.

The anomalies of the average annual air temperature in 2023 throughout the territory of Kazakhstan were positive and significantly higher than the climatic norm for 1961-1990. (Figure 2.2, above). Especially warm conditions were observed throughout Kazakhstan, however, the focus with the highest positive values of temperature anomalies (more than 3.0-3.9 ° C, with a probability of not exceeding 95%) was observed in the western, southwestern regions, in the south of Aktobe and Ulytau regions, in Kyzylorda and in the north of Turkestan regions, as well as locally in the Eastern-Kazakhstan, Pavlodar, Akmola, Kostanay and North Kazakhstan regions (Figure 2.2, below). In the rest of the territory, air temperature anomalies were in the range of 2.0-2.9 °C, except for the mountainous regions of the south, south-east and east of the republic, where air temperatures exceeded the norm by 1.5-1.9 °C.

The year was record warm (Table 2.2) in almost all regions of Kazakhstan, except Zhambyl, Pavlodar and North Kazakhstan regions, where 2023 was among the 5% of extremely warm years (rank 2), on average, air temperature anomalies ranged from +2.11 °C to +3.46 °C.

Extremely high annual temperatures (5% extremes) It was noted at 183 weather stations in Kazakhstan, where temperature anomalies reached +3.9 °C, including 111 weather stations located

in the western, central, southern, southeastern and eastern regions. 2023 was the warmest year since 1941. Only 3 weather stations located in the south of Kazakhstan in Turkestan and Zhambyl regions The year 2023 was among the 10% of extremely warm years, this is the fifth value among the warmest years (Figure 2.2, bottom).

Year

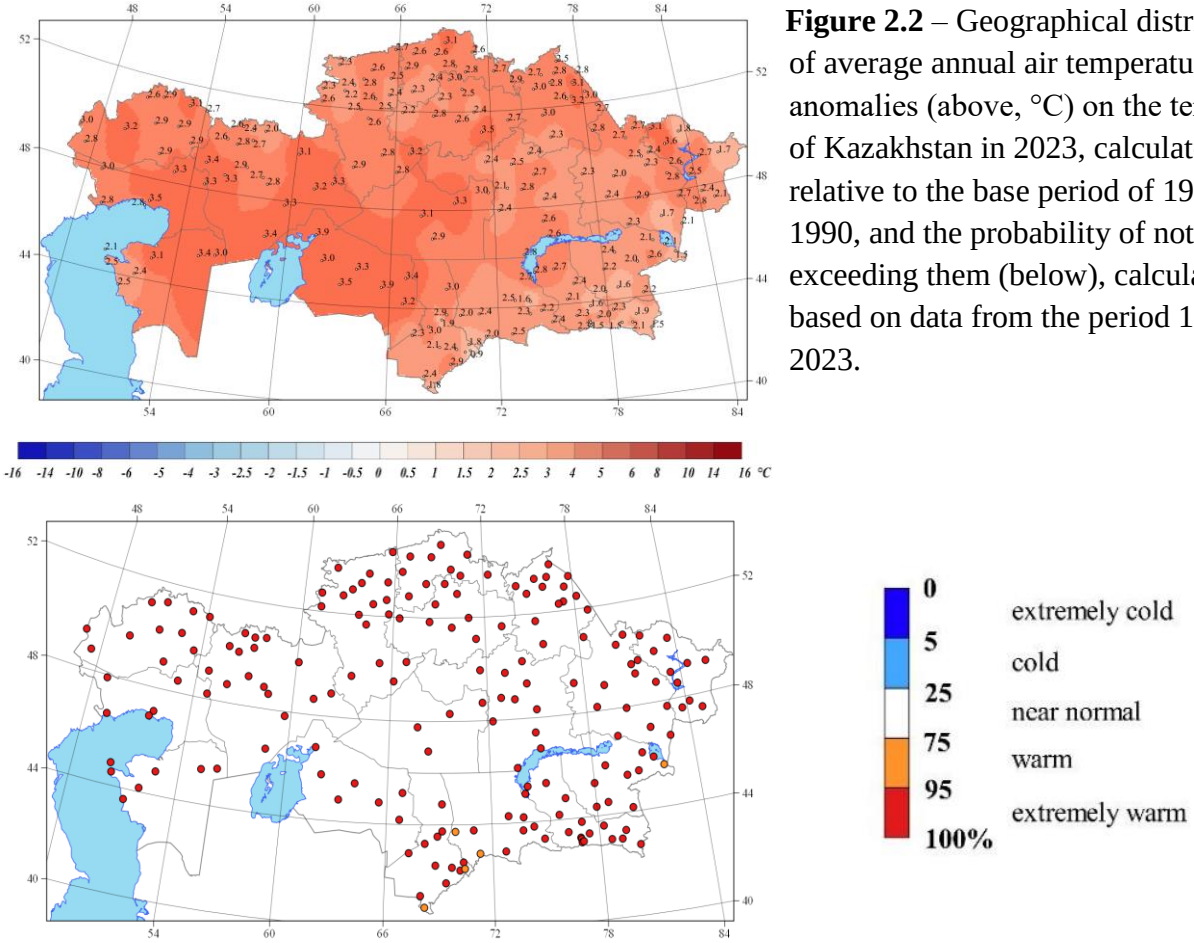


Figure 2.2 – Geographical distribution of average annual air temperature anomalies (above, °C) on the territory of Kazakhstan in 2023, calculated relative to the base period of 1961-1990, and the probability of not exceeding them (below), calculated based on data from the period 1961-2023.

In 2023, the average monthly air temperatures averaged over the territory of Kazakhstan were above the climatic norm (1961-1990) in all months of the year (Figure 2.3). The warmest months were March and November. July and November were the warmest months on record (Rank 1) with anomalies of +2.45 °C and +5.77 °C, respectively. The previous peaks of the air temperature anomaly were observed in July 1998 (+1.86 °C) and November 2010 (+4.51 °C). Extremely warm (5% extremes) were March with an anomaly of +6.45 °C (rank 3) and October with an anomaly of +3.44 °C (rank 4). The average monthly temperature of June in 2023 entered the top ten warmest months since 1941 with an anomaly of +1.68 °C. In September, January and May, the positive anomaly of the average monthly air temperature ranged from 0.58 to 1.05 °C (Table 2.3). The smallest positive anomaly was observed in September (+0.58 °C).

The spatial distribution of seasonal air temperature anomalies in 2023 across the territory of Kazakhstan is shown in Figure 2.4.

Table 2.2 – Regionally averaged average annual (January-December) and seasonal air temperature anomalies in 2023: vT – deviations from the long–term average for 1961-1990, °C; P(t≤T2022) – probability of non-excess (in parentheses), calculated from data for the period 1941-2023 in %; s - the mean square deviation in °C for the period 1961-1990.

Region	Year		Winter		Spring		Summer		Autumn	
	vT (P)	**s**	**vT (P)**	**s**	**vT (P)**	**s**	**vT (P)**	**s**	**vT (P)**	**s**
Kazakhstan	**2,58 (100)**	0,86	0,56 (51)	2,44	**2,97 (96)**	1,28	**1,90 (98)**	0,65	**3,27 (100)**	1,16
Abai	**2,42 (100)**	1,07	0,55 (52)	2,74	1,56 (72)	1,47	**2,02 (98)**	0,77	**3,60 (100)**	1,50
Almaty	**2,13 (100)**	0,75	-0,06 (43)	2,24	1,74 (74)	0,96	**2,24 (100)**	0,66	**2,90 (100)**	1,02
Akmola	**2,65 (100)**	1,07	0,61 (59)	2,84	2,86 (90)	1,85	**2,02 (98)**	1,04	**3,76 (100)**	1,51
Aktobe	**2,90 (99)**	0,94	0,64 (55)	2,50	**4,70 (100)**	1,90	1,69 (94)	0,93	**2,92 (99)**	1,40
Atyrau	**3,02 (100)**	0,82	0,93 (57)	2,40	**4,29 (100)**	1,56	2,03 (93)	0,85	**3,16 (100)**	1,20
East Kazakhstan	**2,50 (100)**	1,11	1,45 (67)	2,72	1,73 (77)	1,59	**1,90 (96)**	0,84	**3,12 (100)**	1,52
Zhambyl	**2,26 (100)**	0,87	-0,23 (35)	2,87	2,48 (89)	1,00	**2,15 (100)**	0,81	**3,24 (100)**	1,18
Zhetysu	**2,11 (100)**	0,79	-0,07 (43)	2,46	1,62 (73)	1,04	**1,94 (99)**	0,63	**3,04 (100)**	1,13
West Kazakhstan	**2,94 (100)**	1,06	1,53 (65)	2,74	**4,83 (100)**	2,01	1,41 (74)	1,22	**2,93 (100)**	1,27
Karaganda	**2,50 (100)**	0,85	-0,04 (45)	2,45	2,18 (84)	1,31	**1,90 (99)**	0,80	**3,65 (100)**	1,37
Kostanay	**2,61 (99)**	1,06	0,51 (55)	2,75	**3,75 (99)**	1,91	1,48 (87)	1,07	**3,24 (99)**	1,50
Kyzylorda	**3,46 (100)**	0,91	1,57 (61)	2,85	**4,75 (100)**	1,28	**2,25 (98)**	0,95	**3,29 (100)**	1,21
Mangystau	**2,48 (100)**	0,75	0,77 (54)	1,88	**3,17 (100)**	1,35	2,00 (84)	0,86	**2,97 (100)**	1,16
Pavlodar	**2,64 (100)**	1,16	0,85 (56)	3,15	2,49 (85)	1,73	**1,92 (98)**	0,94	**3,76 (100)**	1,62
North Kazakhstan	**2,62 (100)**	1,16	1,35 (67)	2,94	3,04 (91)	1,87	1,68 (90)	1,17	**3,67 (100)**	1,53
Turkestan	**2,35 (100)**	0,79	-0,33 (34)	2,60	**3,30 (99)**	0,86	**2,06 (99)**	0,85	**2,92 (100)**	1,10
Ulytau	**3,11 (100)**	0,97	0,09 (52)	2,71	3,56 (94)	1,42	**1,99 (98)**	0,92	**3,83 (100)**	1,46

Notes: 1. for the Mangystau region, the assessment was carried out only according to MS Fort Shevchenko;

2. Values above the 95th or below the 5th percentile (respectively, warm and cold extremes) are highlighted in bold and bright color;

3. Values above the 90th or below the 10th percentile are highlighted in pale color;

4. The average temperature anomalies in Kazakhstan were obtained by averaging the data of 121 stations.

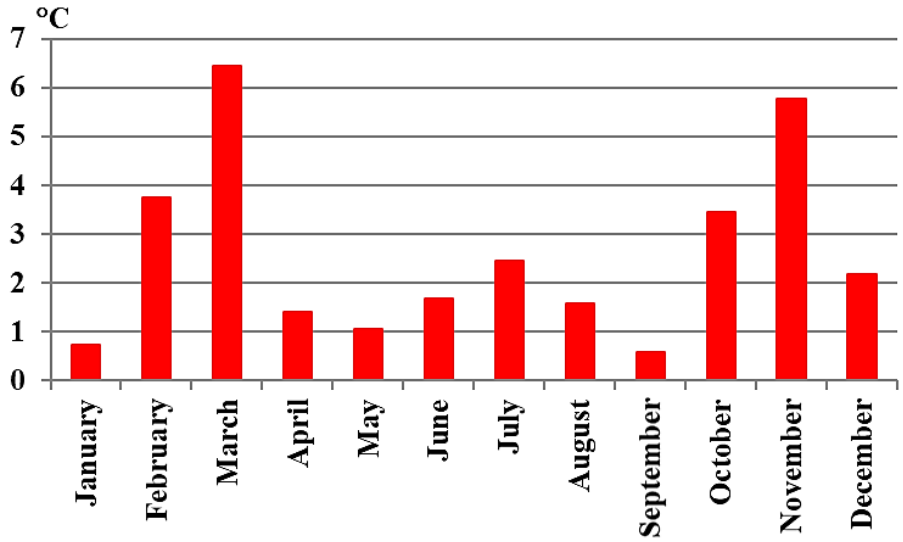


Figure 2.3 – Average monthly air temperature anomalies averaged over the territory of Kazakhstan in 2023, calculated relative to the average for the period 1961-1990.

In the winter of 2022/23 (December 2022 – February 2023), the average air temperature in Kazakhstan was 0.56 °C above the climatic norm (rank 41, Table 2.2). The warmest winter season remained the winter of 2019/2020 with an anomaly of +5.54 °C, and the coldest winter season was 1969 with an anomaly of -8.2 °C. In the winter season of 2022/2023, negative temperature anomalies were observed in the central, southeastern part of the country, mainly close to normal (from -0.1 to -1.1 °C). Temperature regions significantly below normal were formed in the mountainous regions of the south of Turkestan and Zhetysu regions (from -1.7 to -2.6 °C, Figure 2.4). Zones with positive air temperature anomalies occupied the western, northern regions (up to 2.1 °C in the far northwest and far north), the northeastern region (up to 1.4 °C), in the Kyzylorda region (from 1.1 to 2.0 °C). The most significant excess of the climatic norm was observed in the territory of the East Kazakhstan region and the border areas with it (with anomalies from +2.1 ° C to +3.4 ° C). In the rest of the country, the air temperature was about normal.

Cold winter conditions were observed at the Shuyldak meteorological station (Turkestan region), located in a mountainous region of the southern region of Kazakhstan, the lowest seasonal temperature was recorded here, which entered 10% of extremely low anomalies with a value of -2.3 °C (Figure 2.4). At 6 weather stations located in mountainous areas of the south and south-east of Kazakhstan, there were low seasonal temperatures corresponding to the "cold" gradation (10-25 percentile). Moderately abnormally warm winter season conditions (75-95 percentile) were observed at 2 weather stations in the East Kazakhstan region: Ust-Kamenogorsk and Ulken Naryn.

In December 2022, on average, the temperature anomaly in Kazakhstan was below the norm for the period 1961-1990 by 2.79 °C (rank 66, Table 2.3). Almost the entire territory of the country (with the exception of the extreme western regions, where the air temperature anomaly was +0.0-0.9 °C) occupied an area with negative air temperature anomalies with a probability of non-compliance of less than 25% (Figure 2.5). Temperatures significantly below normal were recorded in several regions: in the south of the Aktobe region and the surrounding area (by 3.2-4.7 °C), in the central region, as well as the southern Baltic region (by 4.1-7.0 °C), in the northeastern region (by 3.2-5.3 ° C). In the rest of the territory, negative air temperature anomalies were in the range of 1.2-3.6 °C (Figure 2.5).

Table 2.3 – Regionally averaged average monthly air temperature anomalies in 2023: **vT** – *deviations from the average for 1961-1990*, °C; ***P (t≤T2022)*** *– probability of non-excess (in parentheses), calculated from data for the period 1941-2023 and expressed in %*

Region	12 (2022)	1	2	3	4	5	6	7	8	9	10	11
Kazakhstan	-2,79 (21)	0,72 (46)	3,74 (77)	6,45 (98)	1,41 (77)	1,05 (70)	1,68 (89)	2,45 (100)	1,58 (80)	0,58 (62)	3,44 (96)	5,77 (100)
Abai	-3,72 (17)	1,17 (62)	4,13 (82)	5,36 (89)	-0,27 (33)	-0,45 (37)	1,89 (87)	2,67 (99)	1,51 (85)	0,56 (65)	3,91 (99)	6,33 (100)
Almaty	-3,02 (20)	-1,59 (24)	4,42 (82)	4,99 (95)	0,39 (48)	-0,11 (38)	2,59 (98)	2,70 (99)	1,46 (87)	0,26 (50)	3,74 (99)	4,71 (100)
Akmola	-2,70 (24)	2,06 (71)	2,41 (68)	5,69 (95)	0,90 (61)	2,00 (77)	1,11 (79)	3,10 (99)	1,88 (79)	0,90 (63)	3,50 (95)	6,89 (100)
Aktobe	-2,31 (26)	0,96 (49)	3,28 (72)	8,85 (99)	3,46 (91)	1,79 (80)	1,45 (74)	1,83 (88)	1,77 (74)	0,45 (55)	2,71 (89)	5,61 (100)
Atyrau	-2,17 (22)	1,53 (49)	3,37 (67)	7,77 (100)	3,23 (93)	1,87 (89)	1,37 (70)	1,50 (83)	3,20 (90)	1,50 (83)	2,87 (87)	5,07 (100)
East Kazakhstan	-2,66 (16)	1,94 (71)	5,03 (93)	6,28 (96)	-0,40 (30)	-0,66 (37)	2,09 (90)	2,10 (95)	1,53 (84)	-0,09 (44)	3,88 (99)	5,55 (99)
Zhambyl	-2,76 (24)	-2,87 (13)	4,90 (77)	5,67 (96)	0,90 (66)	0,86 (65)	2,56 (96)	2,63 (99)	1,31 (80)	0,39 (59)	4,01 (99)	5,27 (100)
Zhetysu	-3,81 (20)	-1,16 (29)	4,75 (85)	5,18 (94)	0,38 (48)	-0,70 (33)	1,98 (93)	2,64 (100)	1,25 (82)	0,21 (51)	3,91 (99)	4,94 (98)
West Kazakhstan	-0,01 (52)	0,95 (46)	3,63 (71)	9,30 (100)	3,04 (89)	2,13 (83)	0,79 (61)	0,90 (68)	2,60 (82)	1,24 (80)	2,54 (80)	5,01 (99)
Karaganda	-4,44 (21)	0,67 (55)	3,66 (79)	4,43 (88)	1,20 (68)	0,89 (61)	1,34 (83)	3,00 (99)	1,34 (70)	0,11 (48)	3,71 (98)	7,13 (100)
Kostanay	-2,31 (30)	1,50 (60)	2,33 (67)	6,62 (96)	2,43 (84)	2,22 (84)	0,70 (63)	2,57 (96)	1,16 (68)	0,54 (54)	3,03 (91)	6,16 (99)
Kyzylorda	-3,38 (20)	2,84 (70)	5,28 (76)	8,46 (99)	3,30 (91)	2,50 (89)	2,34 (88)	2,80 (96)	1,64 (78)	0,54 (60)	3,28 (96)	5,98 (100)
Mangystau 1	-1,40 (24)	1,30 (50)	2,40 (63)	6,30 (100)	2,30 (89)	0,90 (71)	1,30 (71)	1,60 (82)	3,20 (85)	1,40 (76)	2,40 (77)	5,10 (100)
Pavlodar	-3,72 (20)	4,44 (89)	1,82 (60)	6,80 (98)	-0,28 (35)	0,94 (61)	1,48 (82)	2,44 (95)	1,78 (79)	1,34 (76)	3,52 (94)	6,40 (99)
North Kazakhstan	-1,77 (32)	3,10 (80)	2,69 (71)	5,33 (95)	1,61 (78)	2,11 (83)	0,54 (63)	2,94 (98)	1,56 (76)	1,63 (85)	3,47 (95)	5,94 (98)
Turkestan	-2,78 (23)	-2,39 (12)	4,18 (72)	6,63 (100)	1,71 (85)	1,57 (78)	2,84 (100)	2,66 (99)	0,67 (68)	0,24 (55)	3,43 (96)	5,12 (100)
Ulytau	-4,67 (18)	1,27 (59)	3,70 (76)	6,53 (94)	2,30 (83)	1,87 (80)	1,40 (77)	3,03 (100)	1,50 (74)	0,43 (56)	3,73 (96)	7,30 (100)

Notes: 1. for the Mangystau region, the assessment was carried out only according to MS Fort Shevchenko;

2. values above the 95th or below the 5th percentile (respectively, warm 95% and cold 5% extremes) are highlighted in bold and bright color.

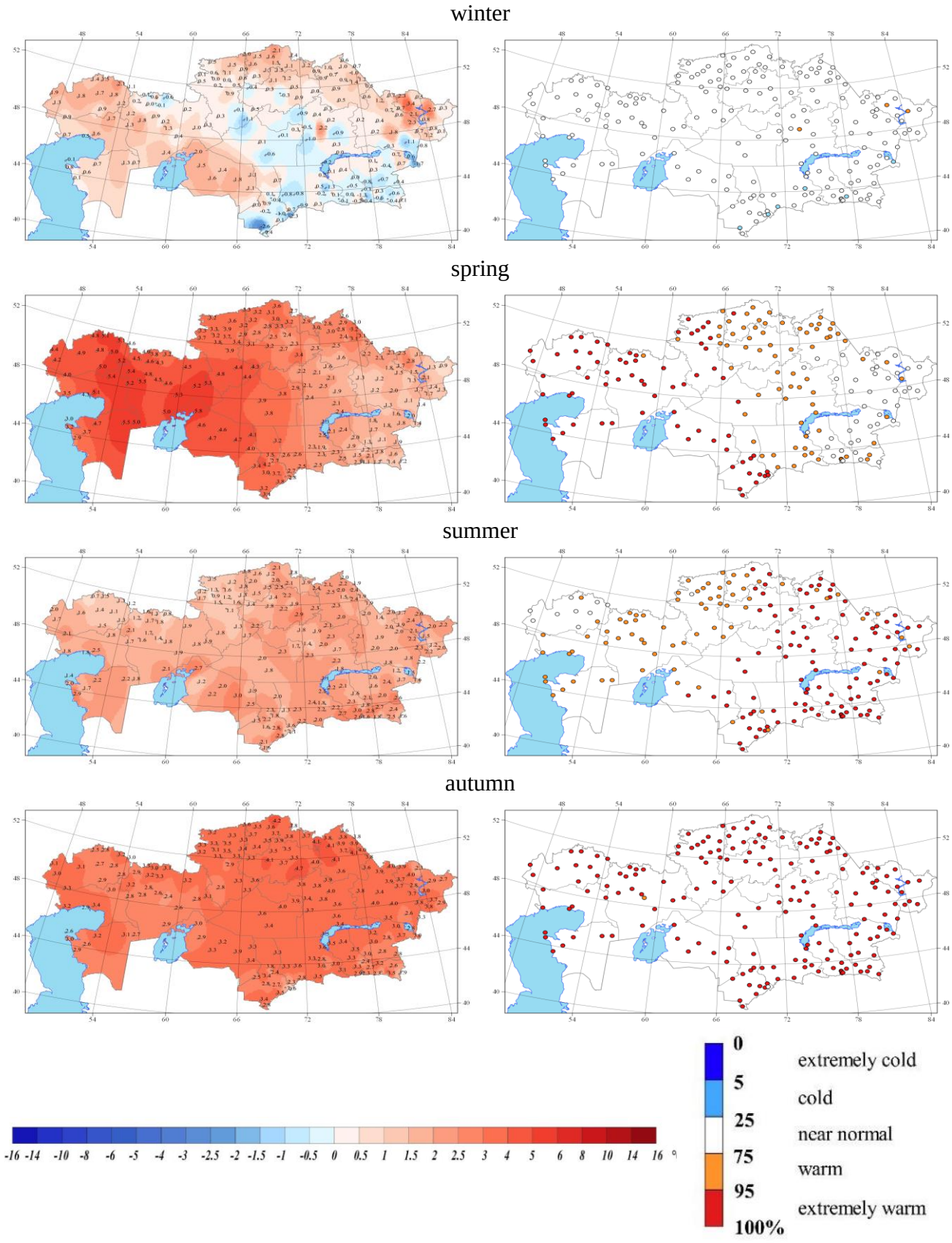


Figure 2.4 – Spatial distribution of the air temperature anomaly (°C) in 2023, calculated relative to the base period of 1961-1990, and the probability of non-exceeding air temperature values in 2023, calculated based on data from the period 1961-2023.

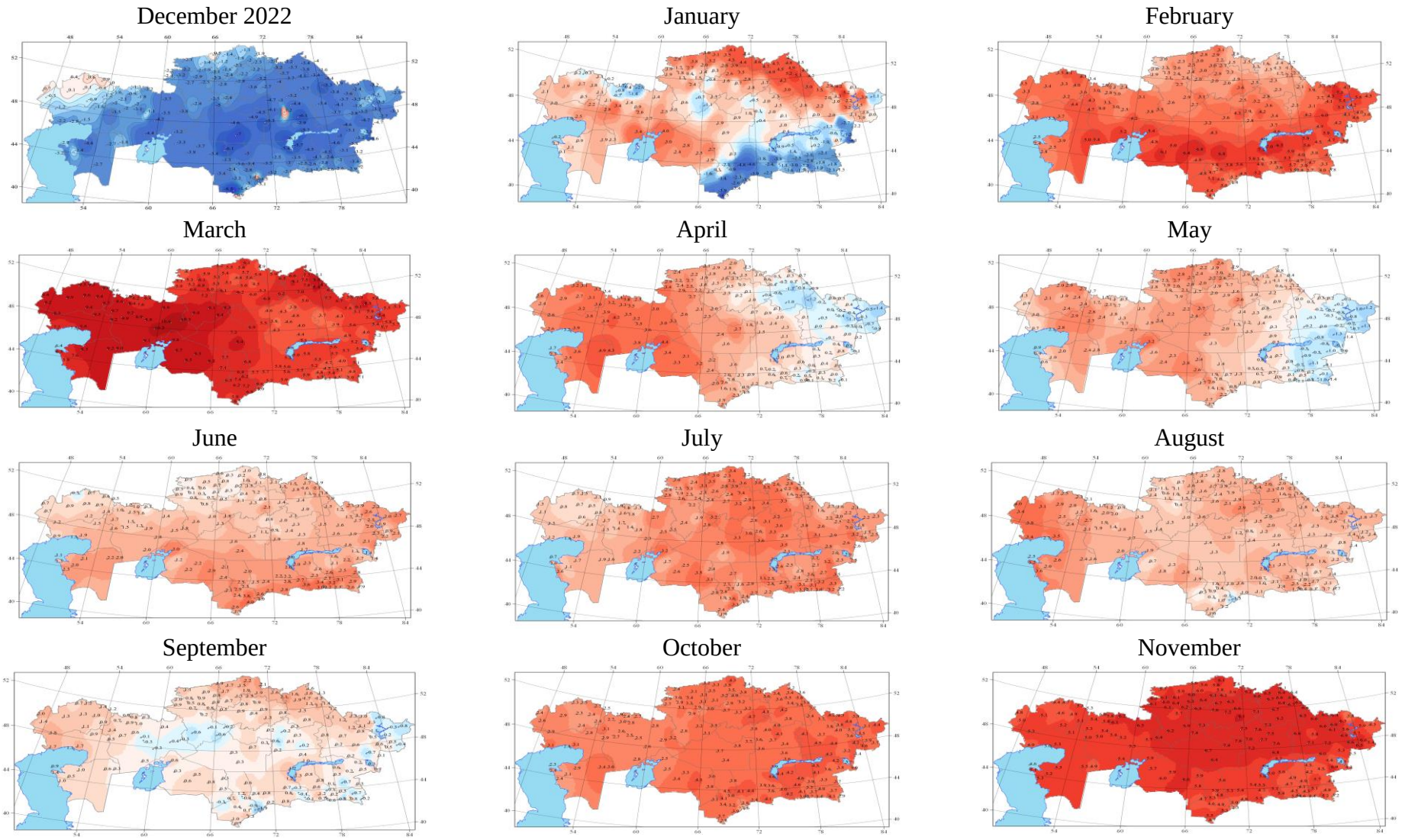


Figure 2.5 – Spatial distribution of the anomaly of the average monthly air temperature (°C) in 2023, calculated relative to the base period of 1961-1990.

In January 2023, the average air temperature anomaly in Kazakhstan was 0.72 °C higher than the average annual value for the period 1961-1990. (Table 2.3). The northern, eastern (with the exception of the extreme eastern regions), western (with the exception of the northern regions of the Aktobe region), southwestern and central regions occupied areas with positive air temperature anomalies (Figure 2.5). Temperatures significantly above normal were recorded in several regions: a large focus with the most significant positive anomalies (+3.0-5.3 °C) covered the northern and eastern parts of the country; another focus of significant positive anomalies (+2.4-4.0 °C) was located in the northern Aral Sea region and Kyzylorda region. The southern, southeastern part of the country, as well as the northern part of Aktobe region, in places in the south of Kostanay region, in the west of Karaganda region and in the far east of East Kazakhstan region were occupied by areas with negative air temperature anomalies (Figure 2.5). The temperature range was significantly below the climatic norm in the south and southeast with anomalies from -1.4 to -6.5 °C.

Extremely cold conditions were observed in January in the foothill and mountain stations of southern Kazakhstan: at two weather stations in Turkestan region (Shuyldak and Zhetysai) and three weather stations in Zhambyl region (Taraz, Khantau, Saudakent), air temperature anomalies entered 5 or 10% of extremely cold Januaries. At MS Kishkenekol (North Kazakhstan region), the air temperature anomaly entered 10% of extremely high temperatures.

In February, the average air temperature anomaly in Kazakhstan was higher than the climatic norm and amounted to 3.74 °C (rank 20, Table 2.3). Extremely warm February was in the East Kazakhstan region (the average anomalies in the territory amounted to +5.03 °C). Positive air temperature anomalies were observed throughout the country, which increased from the north and northeast to the west, south and east, reaching maximum values from +4.5 to +5.8 °C, in places exceeding +6.1-7.3 °C. Temperatures near and slightly above normal (from 1.0 to 2.0 °C) were observed in the north-east of the country, as well as in the north of Kostanay and Akmola regions. Air temperature anomalies ranging from +2.1 to +4.9 °C were observed mainly in the central, western regions of Kazakhstan and in the North Kazakhstan region, eastern and southeastern, southern and southwestern parts of the country, temperature anomalies ranged from +3.1 to +5.9 °C, in places up to +6.8–7.3 °C (Figure 2.5).

Among the extreme features of the winter months, it should be noted that temperatures are significantly higher than the climatic norm in February in the south, south-east and east of Kazakhstan. At 7 weather stations located in these regions, temperature anomalies entered 5% or 10% of extremely high temperatures. Moderately abnormally warm conditions were observed at 40% of meteorological stations located in the east, southeast, south, central and western parts of the country (Figure 2.5).

Spring in Kazakhstan was extremely warm, the average air temperature anomaly in the country was +2.97 °C – this is the fourth warmest spring (probability of non–exceeding 96%, Table 2.2). The warmest spring season since 1941 was the spring of 2020 with an anomaly of +3.84 °C, and the coldest spring period - spring 1960 with an anomaly of -4.26 °C. It was extremely warm in the northern, western, southern and central regions of Kazakhstan. The values of positive air temperature anomalies increased from the eastern and southeastern regions (where it was about 0.9-1.7 °C) to the northern and western regions, reaching maximum values of 5.0-5.8 °C. The record warm spring was in 5 regions of Kazakhstan, located in the west, south-west of the country: the average air temperature anomalies of the spring season in the territory of West Kazakhstan, Aktobe, Atyrau, Mangystau and Kyzylorda regions were +4,83, +4,70, +4,29, +3,17 and +4.75 °C, respectively. The values of the

average temperature anomalies in the Kostanay and Turkestan regions were 5% extremely high: +3.75 and 3.30 °C, respectively. The average for the territory of three more regions: Air temperature anomalies in North Kazakhstan, Akmola and Ulytau entered 10% of the extremely high ones.

Extremely high seasonal air temperatures were observed at 72 meteorological stations in Kazakhstan – above the 95th percentile, including 38 MS, located in the western region and the Kyzylorda region, the highest seasonal temperatures since 1941 were recorded (Figure 2.4)

In March, the average air temperature anomaly in Kazakhstan was higher than the climatic norm and amounted to 6.45 °C (rank 3 with a probability of non-exceeding 98%, Table 2.3). It was extremely warm almost throughout the country (Figure 2.5), only in the Karaganda and Abai regions conditions were moderately abnormally warm (probability of non-exceeding 88-89%). It was record warm in the territory of 4 regions (West Kazakhstan, Atyrau, Mangystau, Turkestan), where temperature anomalies on average in these territories were in the range of 6.30–9.30 °C. The average anomalies in the rest of the regions were 5 and 10% extremely high. The most significant and large heat source was observed in the western, southwestern regions and in the south of Kostanay region, where air temperature anomalies ranged from +6.2 to +10.6 °C (Figure 2.5).

At 118 meteorological stations of the republic, air temperature anomalies were 5 and 10% extremely high, and monthly temperature records were recorded at 29 weather stations located in the regions of the western region and south Turkestan region (Appendix 1).

In April, the air temperature anomaly averaged over the territory of Kazakhstan was 1.41 °C (rank 20 with a probability of not exceeding 77%, Table 2.3). The western half of the territory of the republic, the southwestern, central and northern regions covered a zone of positive temperature anomalies, the values of which increased from the central regions to the north and west from 1.0 to 4.9 °C (Figure 2.5). In many areas in the west, in the Kyzylorda and Turkestan regions, April entered 5 and 10% of the extremely warm months. Thus, April became extremely warm for 3 regions: Aktobe, Atyrau and Kyzylorda, where temperature anomalies on average in these territories were in the range of 3.23–3.46 °C. Negative anomalies near and slightly below the norm from 0.1 to 1.4 ° C covered the Pavlodar, East Kazakhstan and Abai regions, as well as mountainous areas of the Almaty region. The most significant negative anomalies (up to minus 1.4 °C) were observed in the far east in the mountainous region.

In April, extremely warm conditions (above the 90th percentile) developed for 15 weather stations located in the western and southern regions.

In May, the average air temperature anomaly in Kazakhstan was 1.05 °C (rank 26, Table 2.3). Most of the country was in the zone of positive anomalies: the entire western, northern, northeastern, central and southern parts of the country. The values of the temperature anomaly increased from the southeastern part of the country to the west, reaching maximum values ranging from +2.4 to +2.9 °C (Figure 2.5). According to 8 weather stations located in the west of the country, as well as in the Kyzylorda region, may entered 10% of the extremely warm months. Negative anomalies covered the eastern and southeastern territories of the country: East Kazakhstan, Abai, Zhetysu and the southeastern part of the Almaty region. The most significant negative anomalies (up to minus 1.4 °C) were observed in the mountainous regions of Almaty and Abai regions. At 2 weather stations in the Almaty region, the air temperature values were included in 10% of the lowest temperatures observed in the month of May.

Summer, as well as spring, was extremely warm in almost the entire territory of Kazakhstan, except for West Kazakhstan, Mangistau and Kostanay regions. On average, the temperature anomaly of the summer season in the country was extremely high and amounted to +1.90 °C – this is the third value among the warmest summer seasons with a probability of not exceeding 98%. The warmest summer season remains the summer of 1998 with an anomaly of 2.23 °C, and the coldest summer season is the summer of 1947 with an anomaly of -1.93 °C. The magnitude of positive air temperature anomalies gradually increased across the country from the northwestern regions, where it was about 1.1-1.8 ° C, to the southeastern regions, where it reached 2.0-3.0 °C. Temperature anomalies were on average record in the territory of 2 regions of the southern region of Kazakhstan: Zhambyl (+2.15 °C) and Almaty (+2.24 °C) regions. In the territory of 9 regions located in the central, southern, southeastern and eastern regions of Kazakhstan, air temperature anomalies were included in 5% of extremely high anomalies (probability of non-exceeding 96-99%) with values from 1.90 °C for East Kazakhstan and Karaganda regions to 2.25 ° C for Kyzylorda region. In 3 more regions located in the western and northern regions, air temperature anomalies entered 10% of extremely high anomalies with values from 1.68 °C (North Kazakhstan region) to 2.03 °C (Atyrau region). Temperatures above the climatic norm within the "heat" gradation were observed in West Kazakhstan, Kostanay and Mangystau regions, their anomalies were +1.41, +1.48 and +2.00 °C, respectively.

Extremely high seasonal air temperatures were observed at 105 meteorological stations in Kazakhstan – above the 95th percentile, including at 28 MS, the highest seasonal temperatures since 1941 were recorded in the southern, southeastern, eastern and central regions (Figure 2.4). At another 30 weather stations, air temperature anomalies were included in 10% of extremely high seasonal anomalies.

In June, the average air temperature anomaly in Kazakhstan was 1.68 °C (rank 10, Table 2.3). The record heat in June was in the territory of the Turkestan region, the anomaly of the average monthly air temperature in the territory averaged +2.84 °C. In 4 more regions (Almaty, Zhambyl, East Kazakhstan and Zhetysu), the average air temperature anomalies in the territory entered 5% or 10% of extremely high anomalies with values from +1.98 °C for Zhetysu region to +2.59 °C for Almaty region. Positive anomalies were observed in almost the entire territory of the republic, with the exception of a small area in the far northwest with negative anomalies up to minus 0.3 °C. Anomalies within ± 1 °C near the norm were observed in the western part of West Kazakhstan and Atyrau regions, in the northern part of Aktobe, Kostanay, Akmola and North Kazakhstan regions (Figure 2.5). The values of positive air temperature anomalies in the range of 3.0–4.0 °C were observed in the mountainous regions of the southern and southeastern region. It was extremely warm at 46 weather stations located in the south of Ulytau, Abai and East Kazakhstan regions, as well as in the southern regions (Almaty, Zhetysu, Turkestan and Zhambyl) - 90% and 95% extremes were noted, of which 4 weather stations were record warm.

The month of **July** was record-breaking hot: the average air temperature anomaly in Kazakhstan was 2.45 °C (rank 1, Table 2.3). Air temperature anomalies in the range of 0.5-1.3 °C (about normal) were observed mainly in the West Kazakhstan region and nearby areas of the border regions (Figure 2.5), and the average temperature anomaly in the region was 0.9 °C. It was moderately abnormally warm in 3 more regions of the western region of the country, the magnitude of positive anomalies was in the range of 1.1-2.7 °C. Foci of maximum positive anomalies with values of +2.6–3.6 °C were noted in Central, northern, northeastern Kazakhstan, in the Aral Sea region and the

eastern part of the Kyzylorda region, as well as in mountainous areas of the south and south-east of the country (Figure 2.5). Record–breaking anomalies of the average monthly air temperature on average in the territories of the regions - Ulytau (+3.03 °C) and Zhetysu (+2.64 °C). In 11 more regions, air temperature anomalies on average in their territory were 5% extremely high: for 6 regions, July became the second warmest month since 1941, with an average temperature anomaly in the territory of these regions ranging from +2.63 °C (Zhambyl region) to +3.10 °C (Akmola region); for the North Kazakhstan region with an average air temperature anomaly of +2.94 °C, July became the 3rd warmest month; on the territory of Kostanay and Kyzylorda regions, temperature anomalies averaged +2.57 °C and 2.80 °C, respectively (rank 4 with a probability of not exceeding 96%, Table 2.3); and for the regions of eastern Kazakhstan: Pavlodar (+2.44 °C) and East Kazakhstan (+2.10 °C), The month of July became the fifth warmest month (95% probability of non-exceeding). At 141 weather stations located in the northern, eastern, central, southern regions and in the eastern part of the Aktobe region, air temperature anomalies entered 5 or 10% of extremely high temperatures, of which new records of average monthly air temperature were recorded at 25 weather stations (Appendix 1).

In August, the average monthly air temperature averaged over the territory of Kazakhstan was 1.58 °C higher than the climatic norm (Table 2.3). The western half of the territory of the republic and the northeastern part of the country covered a zone of positive anomalies, the values of which increased to the west from +1.3 to +4.0 °C (Figure 2.5). It was extremely warm (10% extremes) in the Atyrau region, the values of the air temperature anomaly averaged +3.2 °C. In the south of Turkestan and Zhambyl regions, as well as in the mountainous and foothill areas of Almaty and Zhetysu regions, air temperatures were mainly within ± 1 ° C, about normal. The most significant negative anomalies (up to minus 1.5 °C) were observed at the Shuyldak weather station in the Turkestan region. In August, extremely warm conditions developed in the western part of the Northern Balkhash region and in some mountainous and foothill areas of the east and southeast, where 5 and 10% extremes were recorded at 11 meteorological stations.

Autumn on the territory of the republic was record warm, the temperature anomalies averaged across the country amounted to 3.27 °C. (Table 2.2). The previous warmest autumn season since 1941 was the autumn of 1971 with an anomaly of +2.45 °C, and the coldest autumn period was the autumn of 1976 with an anomaly of -3.56 °C. The anomalies of the average seasonal temperature were on record in the territory of 15 regions on average, the anomalies ranged from +2.90 °C to +3.83 °C. In 2 more regions, air temperature anomalies were included in 5% of extremely high anomalies with values from +2.92 °C for Aktobe region to +3.24 °C for Kostanay region (rank 2, with a probability of not exceeding 99%). Throughout the country, air temperature anomalies were about 2.5 °C and above, with the exception of some stations in Aktobe, Turkestan, Almaty and East Kazakhstan regions. The foci of maximum positive anomalies (4.0-4.7 °C) occupied the extreme northern, northeastern regions, in places in East Kazakhstan, Abai, Karaganda and Ulytau regions. At 184 meteorological stations in Kazakhstan, extremely high seasonal air temperatures were observed, above the 95th percentile, of which 138 meteorological stations recorded record high seasonal temperatures since 1941. At 2 more weather stations, air temperature anomalies were included in 10% of extremely high anomalies, and only at the Shuyldak weather station (Turkestan region), the average seasonal air temperature was about normal.

The month of **September** was about the climatic norm: the average monthly air temperature averaged over the territory of Kazakhstan was 0.58 ° C higher than the climatic norm (Table 2.3). Temperature anomalies in September throughout the territory of Kazakhstan were mainly in the range of 1.0 °C (Figure 2.5). The maximum positive anomalies were observed in the far west, north and northeast, where they reached 1.7-2.2 °C. Negative anomalies, within the normal range, were observed in the northern Aral Sea region, in the south of the Kostanay region, in the Karaganda region and in the foothill and mountainous regions of the south, south-east and east of the country.

At 6 weather stations located in the North Kazakhstan and Pavlodar regions, air temperature anomalies entered 10% of extremely high temperatures. And in the mountainous region of the south Turkestan region, extremely cold conditions were observed, 5 and 10% extremes were recorded

In October, the average monthly air temperature anomaly in Kazakhstan was 3.44 °C (rank 4, probability of non-exceeding 96%, Table 2.3). It was extremely warm throughout Kazakhstan, except in the western region, where conditions were moderately abnormally warm and the values of the air temperature anomaly in the range of 2.1-3.0 ° C and corresponded to the 77-89 percentile. Air temperatures above the climatic norm were observed throughout the country. An extensive heat source was formed in the eastern half of Kostanay and Kyzylorda regions, in the northern, central, eastern and southern regions of the country, where air temperature anomalies were more than 3.0 ° C. October turned out to be especially warm in the southern Baltics and the south of the Almaty region, in the eastern part of the Kazakh small-scale forest and in places in the eastern, northern and southern regions, the values of temperature anomalies here ranged from +4.0 to +4.7 °C (Figure 2.5). As a result, October became the second warmest month for East Kazakhstan, Abai, Zhetysu, Almaty and Zhambyl regions, and for Karaganda region - the third warmest month (Table 2.3).

At 81 weather stations located in the central, eastern and southern regions, air temperature anomalies entered 5% of extremely high temperatures, including record maximum values of the average monthly air temperature were set at 8 MS. Previous record highs were mainly observed in October 1997. Temperatures above the 90% percentile were recorded at 40 weather stations in the country, located in the northern and northeastern parts of the country.

The month of November was record-breaking hot: the average monthly air temperature averaged over the territory of Kazakhstan was 5.77 °C above the climatic norm (rank 1, Table 2.3). The anomalies of the average monthly air temperature were on record in the territory of 11 regions located in the central, southeastern, western and southern regions of Kazakhstan with temperature anomalies in the range of 4.71–7.30 °C. In 6 more regions located in the northern, eastern, and southeastern parts of the country, air temperature anomalies entered 5% of extremely high anomalies with values from +4.94 °C for the Zhetysu region to +6.40 for the Pavlodar region. The focus of more significant positive anomalies (with an anomaly up to +7.8–8.1 °C) occupied the entire Central Kazakhstan (Figure 2.5).

November in the whole country was record warm, almost the entire territory of the country was extremely warm, 95% extremes were recorded at 97.9% of stations (including 52.4% recorded record values, Appendix 1). 2 more weather stations recorded air temperatures above the 90% percentile.

For the purpose of monitoring the extreme values of climatic parameters that are most significant for specific sectors of the economy and the social sphere, the WMO Climatology

Commission has developed the ClimPACT software product (www.climpact-sci.org), which allows calculating a set of specialized climate indices based on the daily values of maximum and minimum air temperature and precipitation. The following are the indices that are most indicative of the degree of temperature extremes in 2023.

In 2023, the warm period of the year is characterized by the fact that the maximum daily temperature in most of Kazakhstan exceeded 30 and even 35 ° C (with the exception of the high-altitude areas of the southeast and east). ***The number of days when the maximum daily air temperature exceeded 30 ° C*** increases from north to south. In the northern, northeastern, eastern, central, northeastern parts of the Ulytau region and in the northern part of the western regions, the number of days when the maximum daily air temperature exceeded 30 °C (index Txge30) ranged mainly from 18 to 70 days (Figure 2.6), and in mountainous areas of the south-East and east from 0 to 14 days. In other regions of the country, the number of days with temperatures above 30 ° C ranged from 80 to 120 days, the maximum number of such days was in the south of the Turkestan region – 130 days.

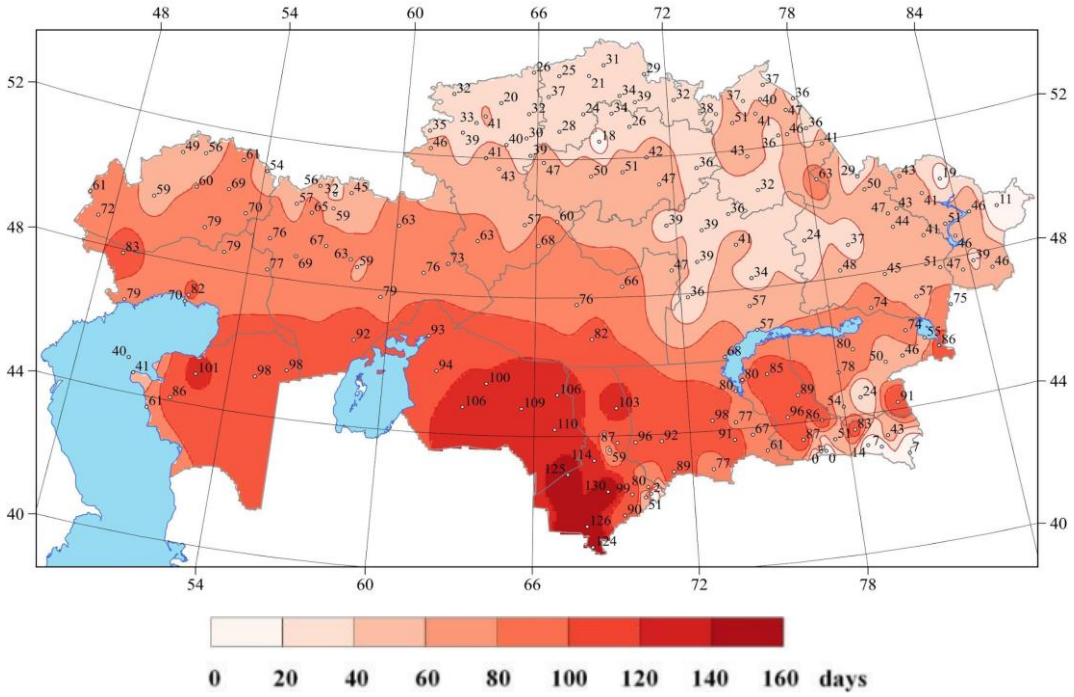


Figure 2.6 – The number of days in 2023 when the maximum air temperature exceeded 30 °C *(index Txge30)*

One of the indicators of extreme temperature conditions in the warm season is the total duration of all heat waves. The heat wave/heat wave takes the case when, for six or more consecutive days, the excess heat coefficient has a positive value (HWF/EHF index, Figure 2.7). In Kazakhstan, the HF/UHF index varies in the northern, eastern and central regions within 8-20 days. The index values increase in the south and west directions. As a result, the total duration of all heat waves in the western regions was 24-42 days, in the southern regions – 33-63 days.

In 2023, in most of the western and southern regions (with the exception of mountainous regions) of the country, as well as in some areas of the Ulytau and Abai regions, Pavlodar, East Kazakhstan and Kostanay regions, ***the daily maximum air temperature (TXx index)*** exceeded 40 °C, in West Kazakhstan, Mangystau, Kyzylorda and Turkestan regions in some places, the daily

maximum air temperature exceeded 45 °C (Figure 2.8). In other regions, the values of the TXx index ranged from 35-39 °C, and in the mountainous regions of the south, southeast and east - within 24-36 °C.

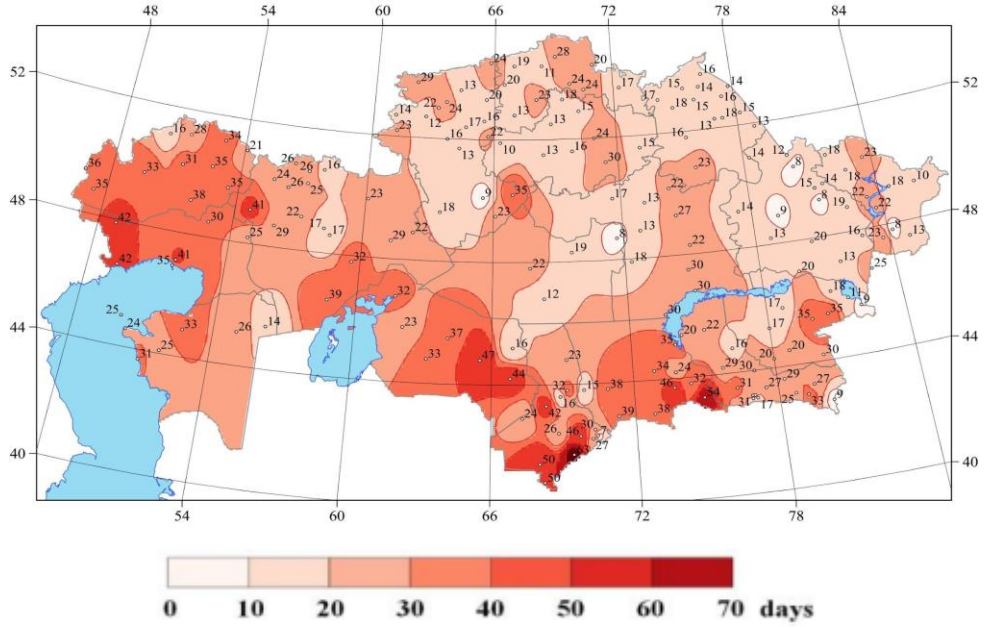


Figure 2.7 – Total duration of heat waves during the warm period in 2023 (*HWF/EHF index,* day)

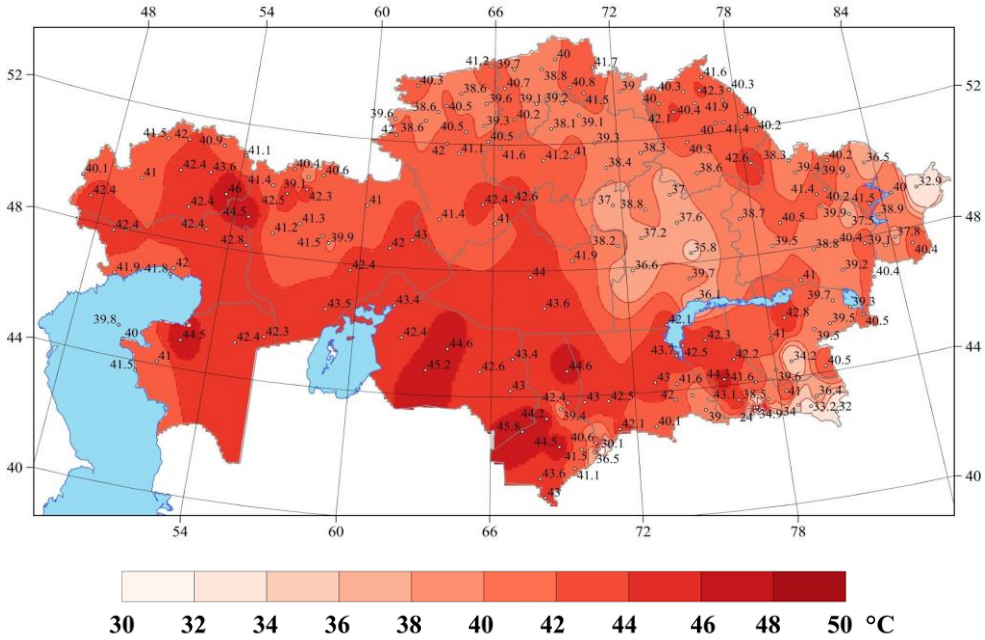


Figure 2.8 – Values of the maximum daily air temperature (°C, *index TXx*) recorded in 2023

As a result of this increased background temperature in the summer months, the values of the previous absolute daily maxima of air temperature were updated at some weather stations in 2023 (highlighted in red, Figure 2.9). The values of absolute maxima recorded from the moment of the station's opening to 2023 are shown in blue. In 2023, the values of absolute maxima were reached or exceeded at 24 weather stations participating in climate monitoring in Kazakhstan: the largest excess was recorded at MS Fedorovka at +2.7 °C (42.3 °C); and the smallest at 3 weather stations: MS

Ganyushkino at +0.0 °C (41.9 °C); MS Uil at +0.0 ° C (44.5 °C); MS Shchuchinsk at +0.0 ° C (39.1 °C). Most of the record air temperature values in 2023 were recorded in the northern and northeastern parts of Kazakhstan. On the territory of Kazakhstan, most of the highest air temperature values (absolute maxima) were recorded in July 1983, when air temperatures reached +49...+50 °C at some weather stations in the Turkestan region (MS Turkestan, Shayan, Arys, Tasty), as well as in July 1995, when the air temperature at MS Kyzylkum it rose to +51.0 °C.

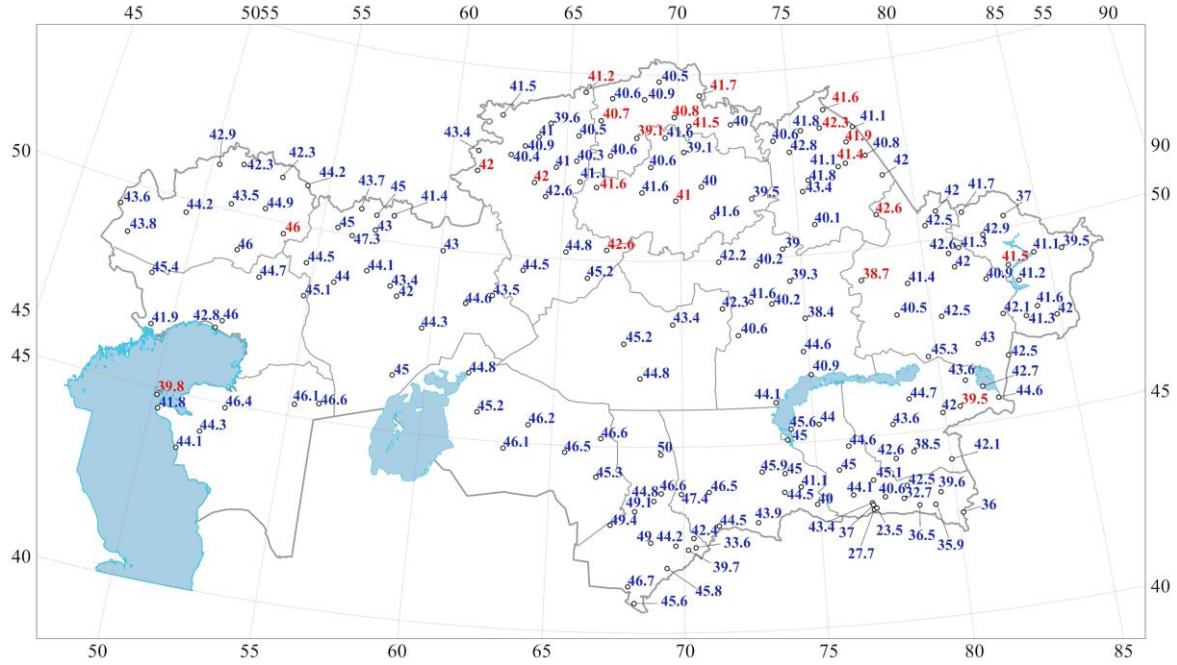


Figure 2.9 – The values of the absolute maximum air temperature (° C) recorded from the beginning of the opening of the weather station to 2023. If the record value of the maximum daily air temperature is recorded in 2023, this value is marked in red

On the recommendation of WHO, an index has been introduced ***characterizing the number of days when the daily minimum temperature does not fall below 20 °C (index TR, "tropical night")***, since at such night temperatures the human body does not have time to rest from the daytime heat. In most of the southern and western regions, the number of days with high night temperatures was the highest. In Turkestan, Kyzylorda and Zhambyl regions, the ***TR index*** values held for more than 44-79 days, in Mangystau and southeastern Atyrau regions - for more than 62-69 days, and in some places for more than 80 days (Figure 2.10). The minimum number of tropical nights, or their absence, was observed in the northern, central, southeastern, eastern and mountainous regions of Kazakhstan.

As a result of high air temperatures, a significant part of the warm season, especially in the western and southern regions of Kazakhstan, there was an urgent need to maintain a favorable temperature in the premises, i.e. air conditioning. In this case, a threshold of 23 °C was adopted as a favorable temperature, exceeding which means a shortage of cold (CDDcold23 index, Figure 2.11). The maximum shortage of cold was observed in Mangystau, Kyzylorda and Turkestan regions, where the index values were 500-620 and even 728 degree-days in places.

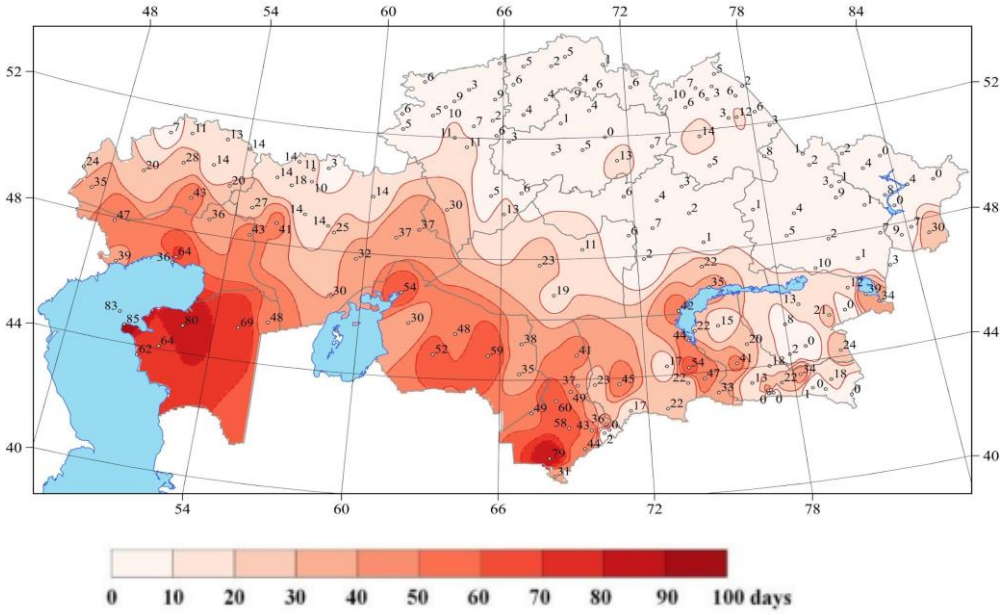


Figure 2.10 – The number of days when the daily minimum temperature is above 20 °C in July 2023 *(TR index)*

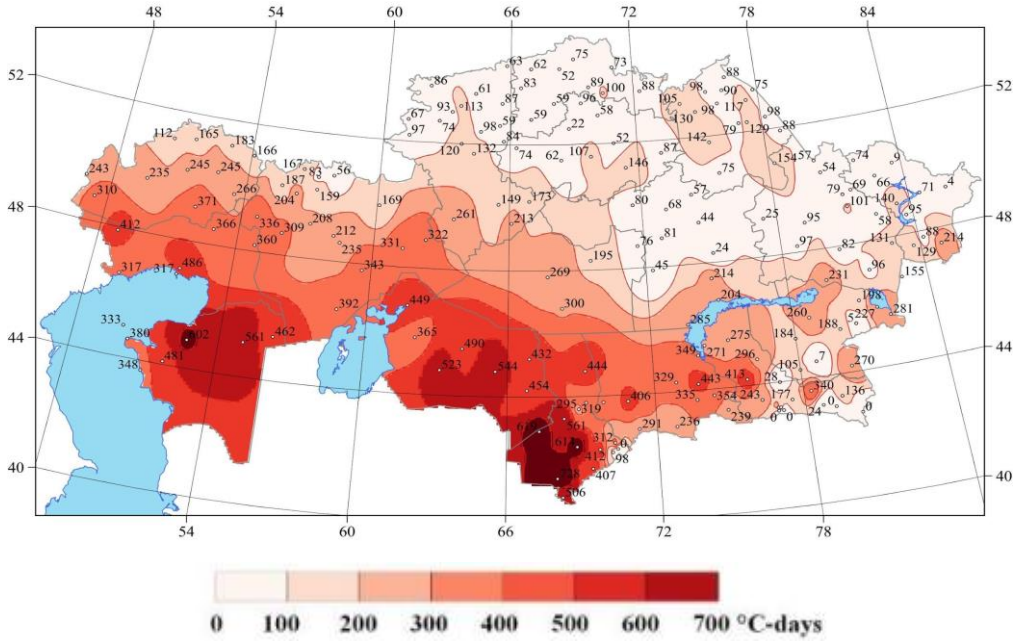


Figure 2.11 – Cold deficit degree-day) observed in 2023 *(CDDcold23 index*

In January 2023, usually the coldest month of the year, significant negative anomalies were observed in the northern, in places in the north-western and north-eastern, as well as in the eastern, eastern central and south-eastern regions of Kazakhstan and the ***daily minimum air temperature*** *(TNn index*, Figure 2.12) fell below minus 35-40 here °C, in places below 41 °C.

In January 2023, usually the coldest month of the year, significant negative anomalies were observed in the northern, in places in the north-western and north-eastern, as well as in the eastern, eastern central and south-eastern regions of Kazakhstan and the ***daily minimum air temperature*** *(TNn index*, Figure 2.12) fell below minus 35-40 here °C, in places below 41 °C.

Figure 2.13 shows the absolute minima of air temperature recorded since the opening of the weather station. In Kazakhstan, absolute lows of air temperature below minus 50 °C were recorded at 2 stations – in January 1931 at MS Shaganatty/Oryol settlement (minus 54.2 ° C) and in January 1893 on the MS Astana (minus 52 ° C). Air temperatures below minus 45 °C were observed mainly in the northern and eastern regions of Kazakhstan. In 2023 Daily minimum temperature records have been updated at four weather stations: in the west of Kazakhstan at MS Kos-Expired (-42.7 °C) and in the south – at MS Kogaly (-36.4 °C), MS Tasaryk (-28.3 °C) and MS Shuyldak (-29.3 °C). In 2023, air temperatures below minus 30 °C were observed in the northeast of West Kazakhstan and the north of Aktobe regions, in the northern, northeastern, eastern and central parts, in Zhambyl, Almaty and Zhetysu regions; the lowest air temperature in 2023 was noted in the MS Kos-Expired Aktobe region: minus 42.7 °C.

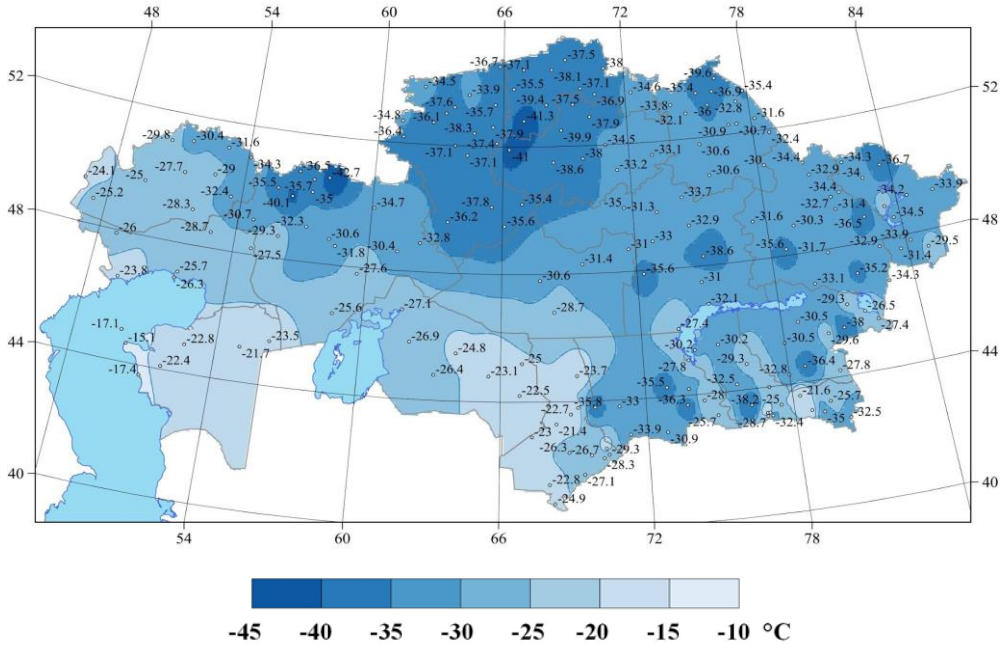


Figure 2.12 – Values of the daily minimum air temperature (°C) registered in 2023 (*indexTNn*)

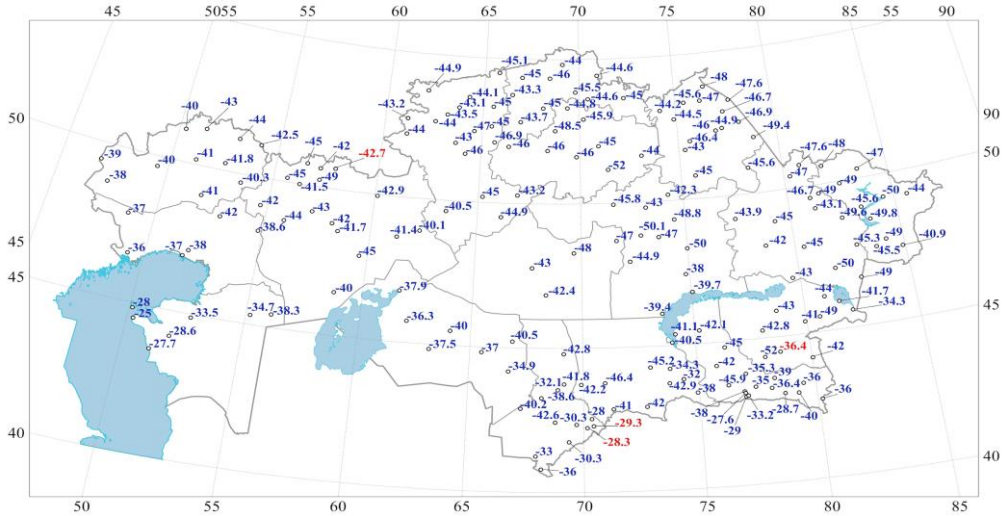


Figure 2.13 – Values of absolute minima of air temperature (°C) recorded from the beginning of the opening of the weather station to 2023. If the record value of the minimum daily air temperature is recorded in 2023, this value is marked in red

2.2 Changes in air temperature observed in Kazakhstan

Figures 2.14–2.15 show time series of average annual and seasonal surface air temperature anomalies averaged over the territory of Kazakhstan and administrative regions and their 11-year moving averages for the period 1941-2023, as well as linear trends in air temperature over the period 1976-2023. The anomalies are calculated relative to the base period of 1961-1990. Linear trends provide visual information about the gradual increase in average annual and seasonal surface air temperatures over the past decades. Table 2.4 presents estimates of air temperature changes for the period 1976-2023: the linear trend coefficient characterizing the average rate of change of the air temperature anomaly over the time interval under consideration; and the coefficient of determination showing the contribution of the trend to the overall variance of the time series.

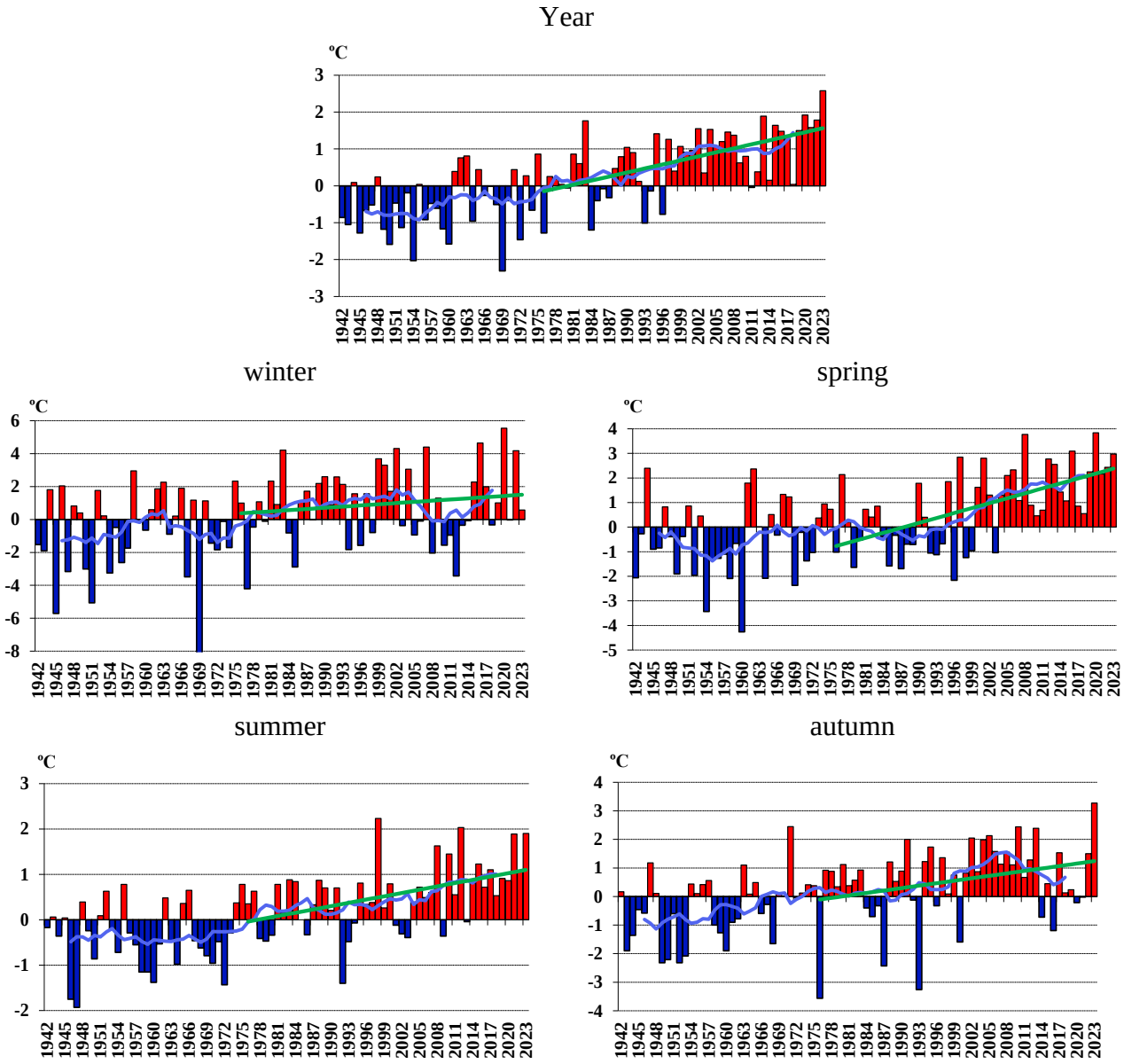


Figure 2.14 – Time series of anomalies of annual and seasonal air temperatures (°C) averaged over the territory of Kazakhstan for the period 1941-2023. The anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2023 is highlighted in green. *The smoothed curve is obtained by an 11-year moving average*

On average, in the territory of Kazakhstan for the period 1976-2023, the increase in the **average annual** air temperature is 0.36 ° C every 10 years, the contribution to the overall temperature variability is 34% (Figure 2.14, Table 2.4). On average, in the territory of all regions of Kazakhstan in the period 1976-2023, there was also a steady increase in the average annual air temperature – the coefficients of determination are in the range of 13-57%, trends are significant at the 5% level (Figure 2.15, Table 2.4). It is warming at a faster rate in the western, southwestern and southern regions of Kazakhstan (from 0.47 °C/10 years to 0.56 °C/10 years), at a slower rate in the central, northeastern, eastern and southeastern regions (from 0.25 °C/10 years to 0.30 °C/10 years).

On average, the trend towards warming of the winter season in Kazakhstan is 0.24 °C/10 years (Table 2.4), but it should be noted that the trend describes only about 2% of the total variance and is insignificant at the 5% level. Winter temperature trends were positive in all regions on average across their territory, but trends mainly explain up to 5% of the variance of the series and are statistically insignificant. The most noticeable growth rate of winter temperature by 0.34-0.50 °C / 10 years was observed in the western, southwestern and southern regions of Kazakhstan - in Aktobe, West Kazakhstan, Atyrau, Mangystau, Kyzylorda and Turkestan regions, where the coefficient of determination is 4-13%. In West Kazakhstan, Atyrau and Mangystau regions, the trend describes 7, 9 and 13% of the total variance, respectively, and is statistically significant at the 5% level. According to several stations in the far west and far south, this trend is stable (Figure 2.16). A fairly extensive area remains on the territory of Kazakhstan, where there is a tendency for temperature to decrease – this is in the center and northeast (up to -0.1 ° C /10 years), in the mountainous region of the east and southeast (up to -0.4 °C / 10 years) Kazakhstan.

In December 2022, there are no stable trends in changes in average monthly temperatures. In most of the territory of Kazakhstan, the trends are positive, the maximum values of the East Kazakhstan region (up to 0.53-0.82 ° C / 10 years), and in the west (up to 0.39 ° C / 10 years). In the southern half of Kazakhstan, there are several foci with a tendency to decrease in air temperature, up to a maximum of 0.58 ° C/10 years in the southern and southeastern regions of the republic (Figure 2.17).

In January, the region with a tendency to lower air temperature occupied a vast territory of the central, northern, northeastern and eastern parts of the republic, with a maximum rate of up to 0.32-0.63 ° C/10 years, the temperature decreases in the eastern region and in the south of the Abai region (Figure 2.17). In the west and south, maximum positive trends were noted - up to 0.33-0.60 ° C/10 years. Although the values of the angular coefficient for December and January temperatures are quite high, but due to the large interannual temperature variability in these months, the contribution of the trend component to the overall variance is insignificant. There are no statistically significant temperature trends.

In February, there is a tendency for air temperature to rise throughout Kazakhstan with maximum values in the western regions, Kyzylorda, Turkestan regions and in the western part of the Southern Baltic region (0.81–1.21 °C/10 years). And only in the south of the Abai region remains an area of mild cooling, in the center of this region the cooling rate reaches -0.1 ° C / 10 years. Statistically significant air temperature growth rates in February were observed at 65 weather stations located in the western, southern and southeastern regions of the republic, as well as in the city of Astana (Figure 2.17).

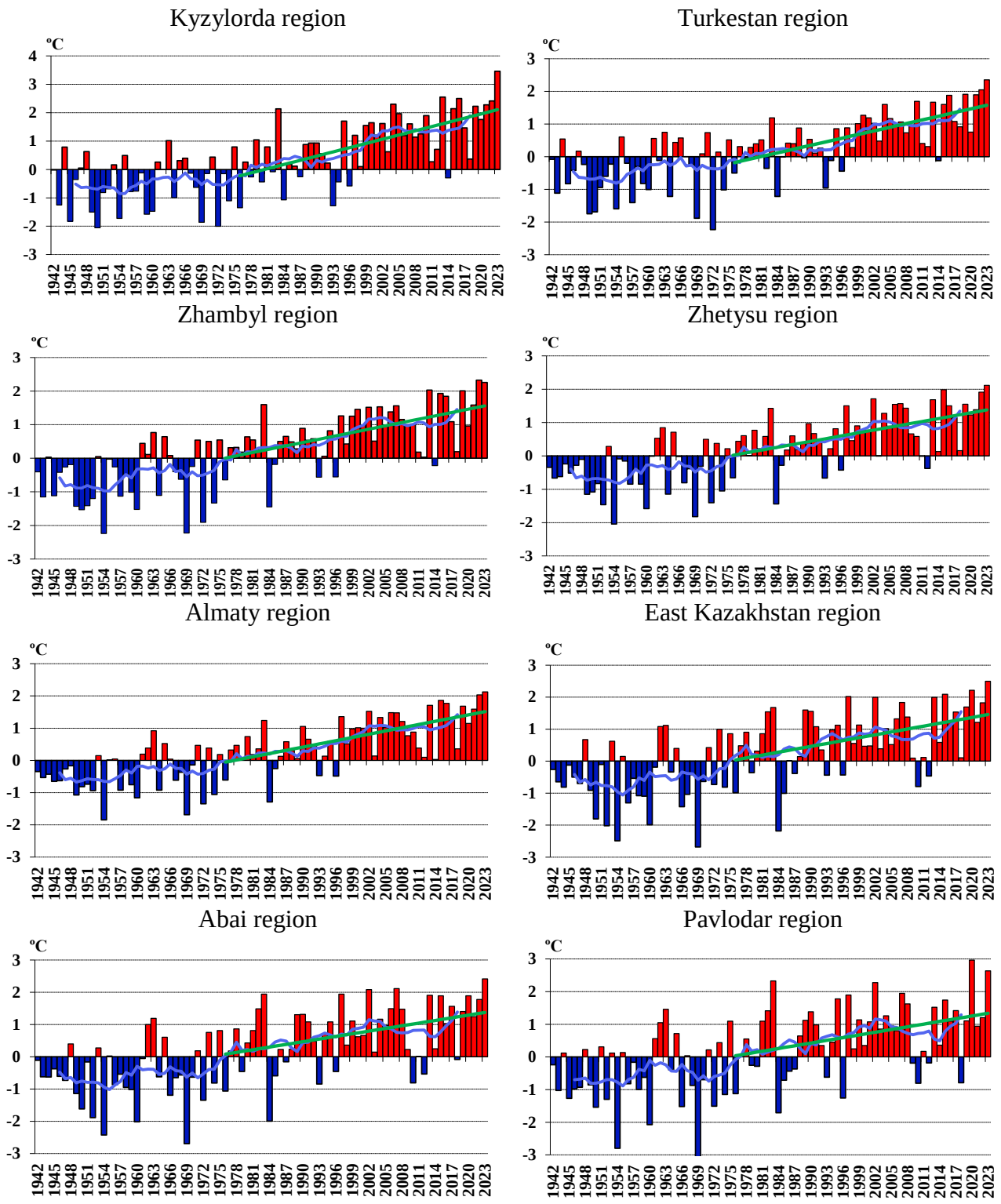


Figure 2.15 – Time series of anomalies of annual air temperatures (°C) averaged across the regions of Kazakhstan for the period 1941-2023. The anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2023 is highlighted in green. *The smoothed curve is obtained by an 11-year moving average. Sheet 1*

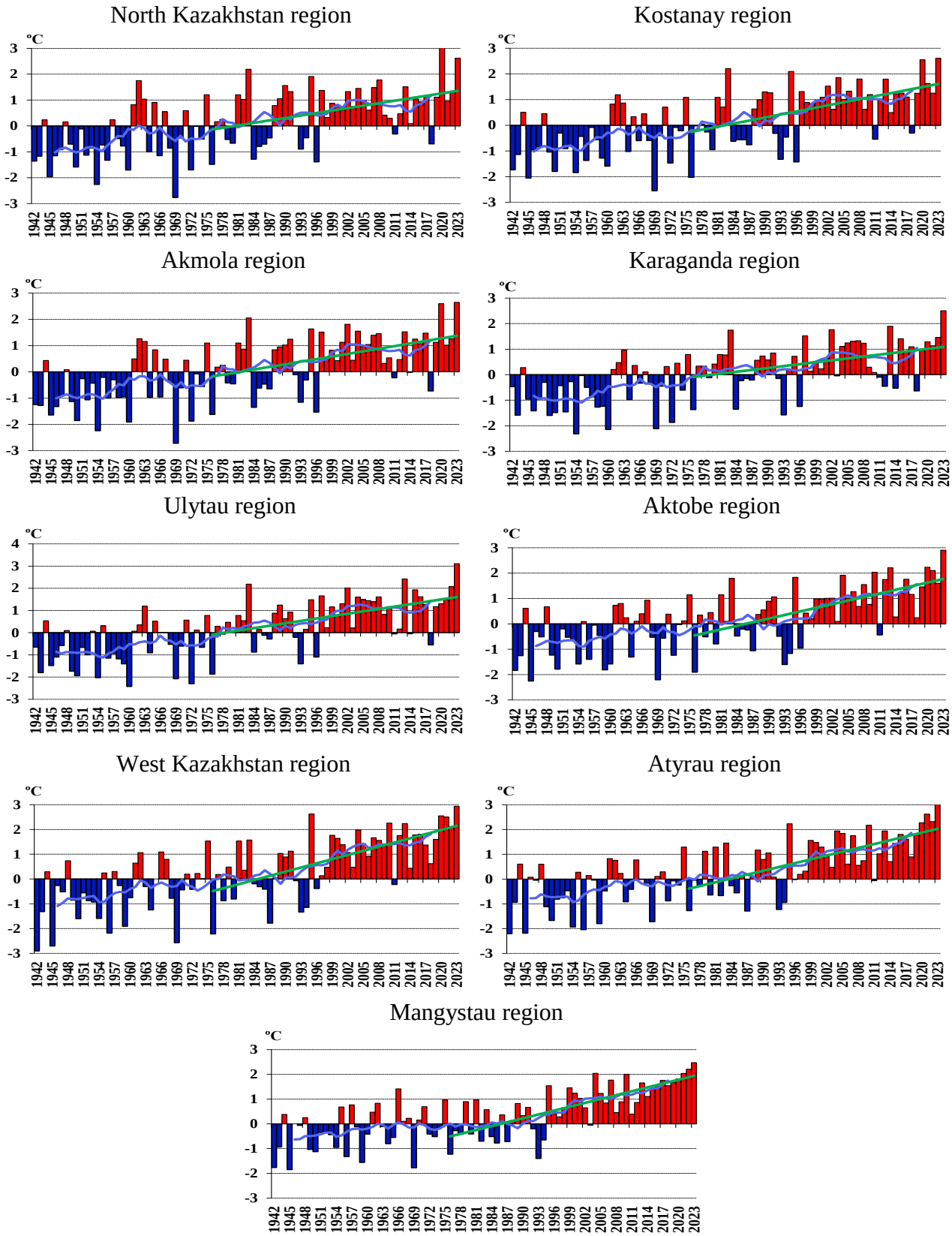


Figure 2.15 – Time series of anomalies of annual air temperatures (°C) averaged over the regions of Kazakhstan for the period 1941-2023. The anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2023 is highlighted in green. *The smoothed curve is obtained by an 11-year moving average. Sheet 2*

In the spring season, the most intense warming trend is observed in all regions of Kazakhstan (Table 2.4). The range of the average rate of air temperature increase in the regions is from 0.45 °C/10 years (Mangystau region) to 0.91 °C/10 years (Kyzylorda region) with 21-41% of the explained dispersion. The foci of the most intense warming are observed in the eastern part of Mangystau, the southeastern part of Aktobe, Kyzylorda, Ulytau, Pavlodar, Abai regions (0.73-1.01 °C/10 years), Figure 2.16. The lowest rate of warming in the spring period is observed in the coastal part of the Caspian Sea, in the mountainous and foothill regions of the south, southeast and Zhaysan (Zaisan) basin, the extreme northern and northwestern regions (0.43-0.59 ° C / 10 years). The trends are statistically significant at all weather stations in the country. On average, the rate of air temperature increase in Kazakhstan was 0.67 °C/10 years (the contribution of the trend component was 35%). Trend estimates are significant at the 1% level.

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 1976-2023.

Region	Year		Winter		Spring		Summer		Autumn	
	a	**D**	**a**	**D**	**a**	**D**	**a**	**D**	**a**	**D**
Kazakhstan	**0,36**	34	0,24	2	**0,67**	35	**0,24**	21	**0,29**	9
Abai	**0,27**	16	0,05	0	**0,70**	31	**0,17**	12	0,18	3
Almaty	**0,33**	39	0,23	3	**0,65**	38	**0,27**	28	0,19	6
Akmola	**0,33**	21	0,19	1	**0,69**	25	0,07	1	**0,35**	7
Aktobe	**0,47**	37	0,38	4	**0,68**	22	**0,37**	16	**0,42**	13
Atyrau	**0,51**	44	**0,50**	9	**0,58**	27	**0,52**	40	**0,42**	16
East Kazakhstan	**0,30**	18	0,13	1	**0,66**	27	**0,21**	14	0,20	4
Zhambylskaya	**0,33**	32	0,26	3	**0,65**	36	**0,24**	24	0,17	3
Zhetysu	**0,29**	27	0,15	1	**0,63**	32	**0,23**	24	0,15	3
West Kazakhstan	**0,56**	42	**0,50**	7	**0,63**	22	**0,57**	29	**0,48**	20
Karaganda	**0,25**	15	0,11	1	**0,69**	30	0,05	1	**0,13**	1
Kostanay	**0,40**	27	0,26	2	**0,66**	21	0,20	5	**0,44**	13
Kyzylorda	**0,50**	40	0,42	4	**0,91**	41	**0,35**	29	**0,29**	8
Mangystau	**0,52**	57	**0,45**	13	**0,45**	25	**0,64**	54	**0,51**	25
Pavlodar	**0,28**	13	0,04	0	**0,71**	29	0,08	1	0,28	5
North Kazakhstan	**0,32**	18	0,16	1	**0,59**	21	0,08	1	**0,42**	11
Turkestan	**0,37**	44	0,34	5	**0,61**	37	**0,29**	25	**0,22**	7
Ulytau	**0,36**	24	0,20	1	**0,83**	34	**0,16**	7	0,22	3

* a – linear trend coefficient, °C/10 years

** D – coefficient of determination, %

***statistically significant trends at the 5% level are highlighted in bold

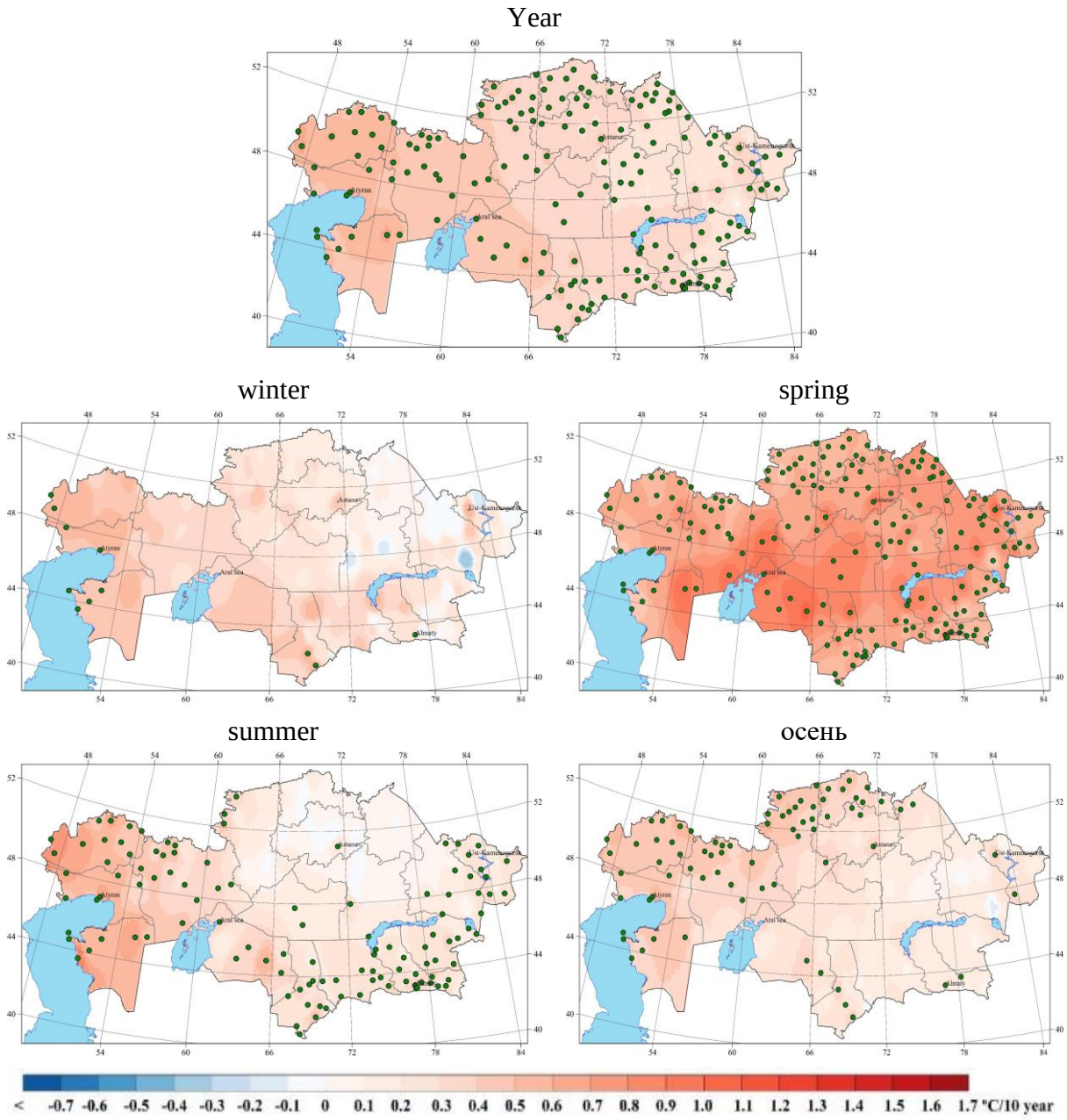


Figure 2.16 – Spatial distribution of the values of the linear trend coefficient of the average annual and seasonal surface air temperature (°C/10 years) calculated from observations for the period 1976-2023.

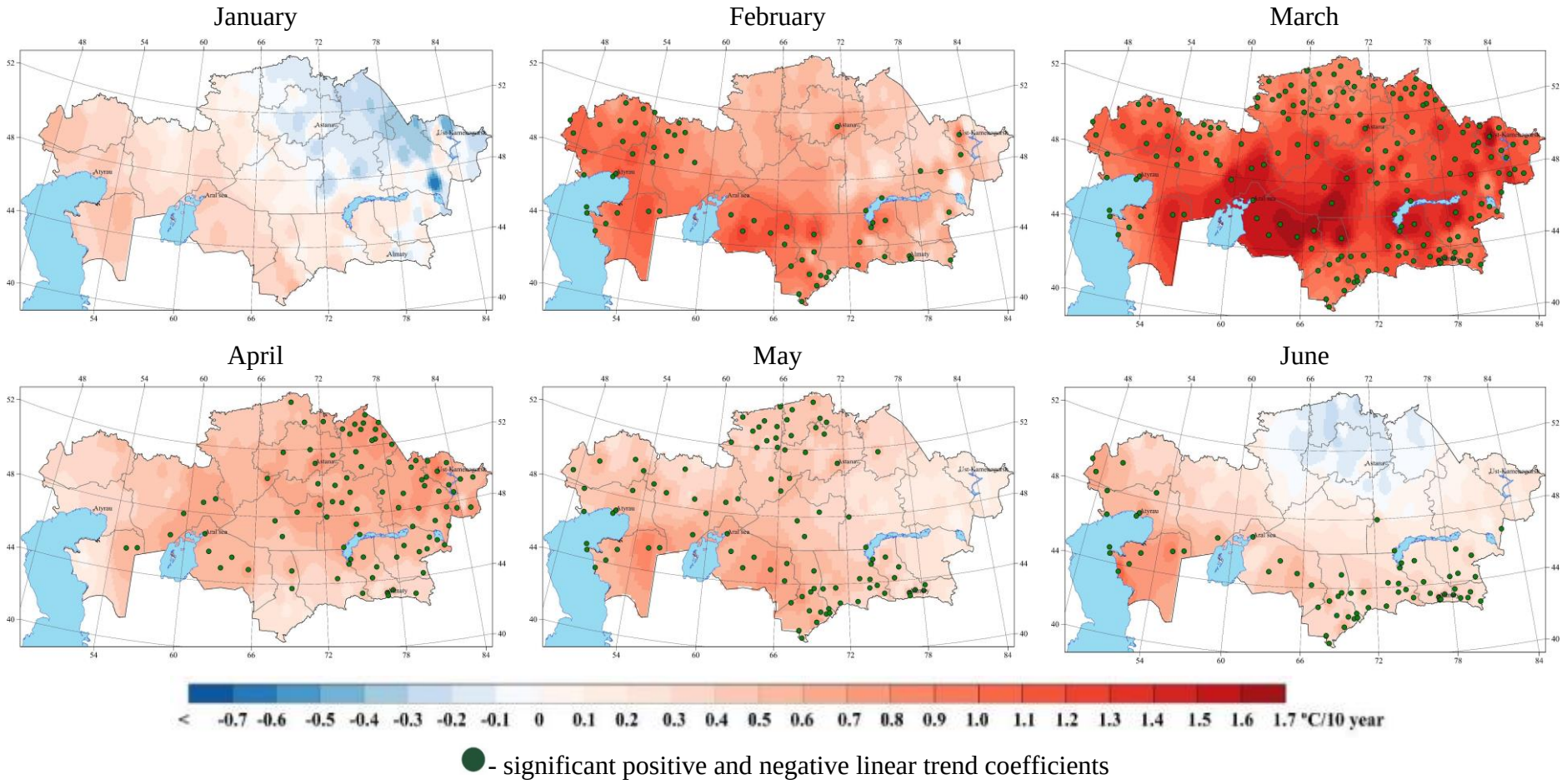


Figure 2.17 – Spatial distribution of the values of the linear trend coefficient of the average monthly surface air temperature (°C/10 years), calculated from observations for the period 1976-2023. *Sheet 1*

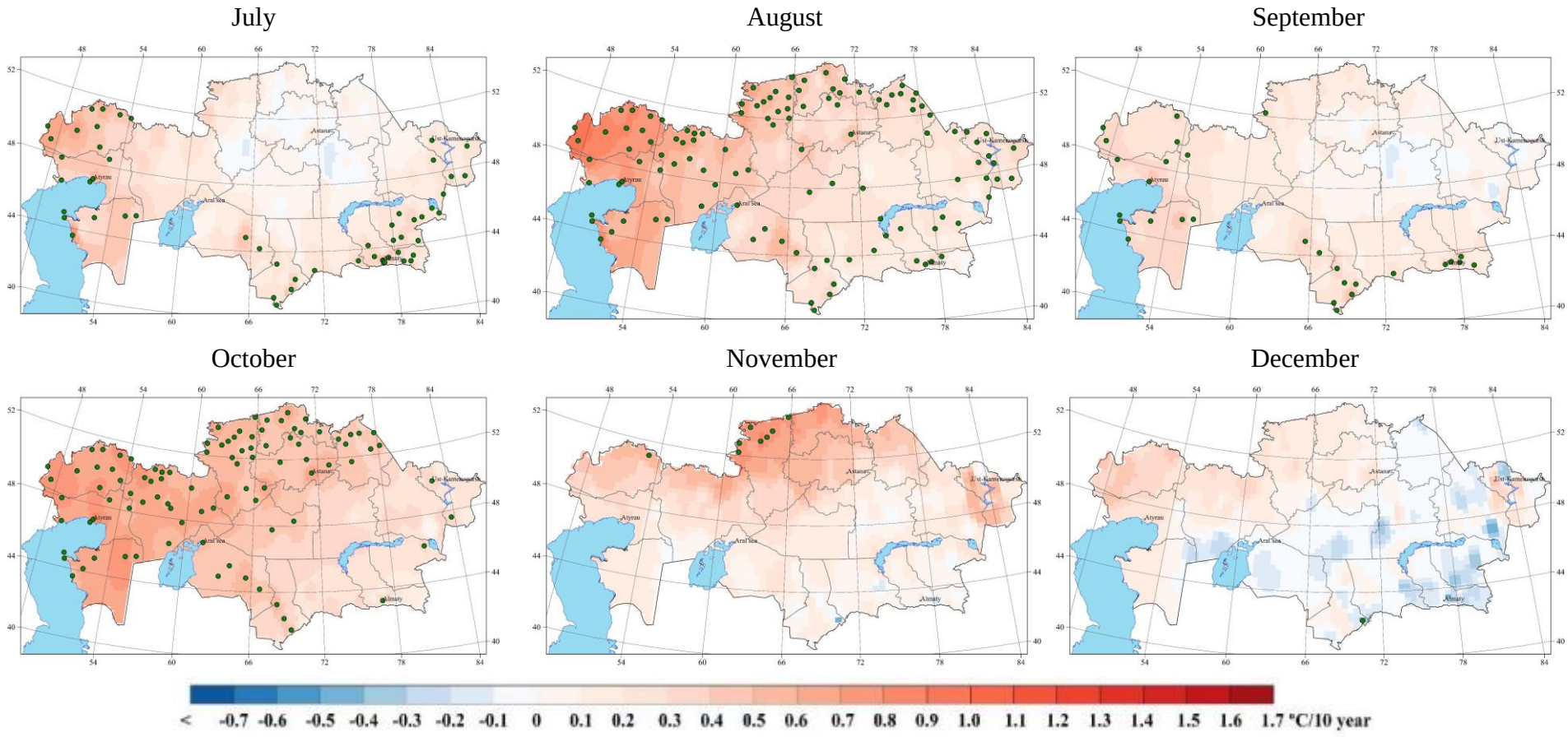


Figure 2.17 – Spatial distribution of values of the linear trend coefficient of the average monthly surface air temperature (°C/10 years) calculated from observations for the period 1976-2023. *Sheet 2*

According to all stations, the highest and statistically significant rate of increase in air temperature in the spring period was noted in *March* (by 0.72-1.76 °C/10 years), Figure 2.17. *In April and May,* the trend of a significant increase in air temperature was also observed throughout the republic. In April, statistically significant growth rates were observed mainly in the eastern part of the Karaganda region, in the eastern region of the country and in the southeast from about 70 ° C. d (in the range from 0.35 to 0.91 ° C / 10 years), in May – in the opposite part (north, northwest, west, southwest and south) of the republic (in the range from 0.36 to 0.87 ° C / 10 years).

In summer, the average air temperature in Kazakhstan increases by 0.24 °C/10 years (determination coefficient 21%, Table 2.4). The most significant rate of increase in air temperature is observed in the western regions – by 0.32–0.89 ° C / 10 years. Less intense warming is observed in the southern and southeastern regions of Kazakhstan, where summer air temperatures tend to rise by 0.18-0.29 °C/10 years (Figure 2.16). Trends here describe from 15 to 53% of the time series variance. There are practically no trends in the northern, northeastern and central regions (0.0-0.1 ° C /10 years) - the share of the trend component in the total variance of the series in these regions is almost zero, although a positive trend sign remains. In some areas of the central region, there are areas where, on average, over the period 1976-2023, the temperature even decreased and the rate of cooling in these areas reaches - 0.1 ° C / 10 years.

In June and *July*, a slight cooling trend is observed in the northern, northeastern and central regions (up to a maximum of 0.30 °C/10 years, Figure 2.17). In some western, southwestern, southern and southeastern regions of the country, statistically significant rates of increase in surface air temperature by 0.27-0.82 ° C/10 years were observed. *In August*, statistically significant positive trends in air temperature in the range from 0.17 to 0.95 °C/10 years were observed in most regions of Kazakhstan. The highest rate of air temperature increase in the month of August is observed in the western region.

In autumn, the warming trend is observed in all regions of Kazakhstan. On average, the seasonal temperature in Kazakhstan increases by 0.29 °C/10 years (determination coefficient 9%, Table 2.4). The most significant rates of temperature increase are observed in the western and northern regions – by 0.35-0.51 ° C /10 years, while the proportion of variance explained by the trend is 7-25%. In the central, some southern and eastern regions, there are practically no warming trends – although the trend sign is positive, but the share of the trend component in the total variance of the series is no more than 5%. It should be noted that during the period 1976-2023. in the autumn period, the average rate of warming increased slightly in all regions and on average across the country, as well as trends became statistically significant at a 5% level in the whole country and in three more regions: Akmola, Kyzylorda and Turkestan. In the extreme south of Turkestan and Abai regions, there has been a slight tendency for air temperature to drop to -0.1 ° C/10 years. It should also be noted that in summer, the maximum and significant trends were observed in the western, southern and southeastern regions, and in autumn - in the western and northern regions (Figure 2.16). That is, in the western regions of the country, significant climate warming was observed in all seasons of the year.

In September, warming occurs in most of the territory of the republic, in some southern and western regions of the country there were statistically significant rates of increase in surface air temperature by 0.21-0.49 ° C /10 years (Figure 2.17). In the central and some eastern regions, there are practically no trends, although the trend sign is positive, but the share of the trend component in the total variance a row of no more than 4%. In some areas of the eastern and central regions, foci

with a slight cooling to -0.1 ° C /10 years were observed. *In October,* warming occurred throughout Kazakhstan, statistically significant positive trends in air temperature in the range from 0.41 to 0.85 ° C / 10 years can be traced in the western and northern regions, in places in the south – in the Kyzylorda and Turkestan regions. In November, positive trends (in the range of 0.21-0.85 ° C/10 years) covered the northern half of Kazakhstan, including the eastern region, but in most cases, they are insignificant, and only at Aksai weather stations (West Kazakhstan region) and 7 weather stations (Arshalinsky district, Zhitikara, Karabalyk, Kostanay, Mikhaylovka, Presnogorkovka, Rudnyi) In Kostanay region, the trend is statistically significant at the 5% level. *In November,* the area where warming was practically absent (0.0-0.1 ° C/10 years), there were also some areas with negative trends (from -0.0 to -0.43 ° C/ 10 years), covered the southern, southeastern and central regions of the country, only at the Shuyldak weather station in the Turkestan region the most significant negative trend is observed, but statistically insignificant (-0.43 °C/10 years).

2.3 Trends in surface air temperature extremes

Not only does the average level of air temperature and precipitation change, but other characteristics of the regimes of these basic elements of the climate, including the frequency and intensity of extremes, also change. Thus, climate change can affect almost all spheres of human activity, physical and chemical processes in the biosphere.

A correct assessment of such impacts of climate change should have a pronounced regional, and even local character, since both climate change and vulnerability of systems, as well as adaptation opportunities, significantly depend on the physical, geographical, economic and demographic characteristics of the regions, which in this regard have their own specifics.

An increase in air temperature leads to shifts in the timing of phenological events in plants and animals, the boundaries of plant zones, mainly to the north and upwards in mountainous areas, as well as changes in the structure of ecosystems.

An increase in the duration of the growing season (*GSL index*, Figure 2.18) by 1-5 days/10 years is observed throughout the republic. A statistically significant increase of 3-5 days/10 years can be traced according to the data of most stations in West Kazakhstan, Aktobe, Kyzylorda, Turkestan, Zhambyl, Almaty, Zhetysu, Ulytau, Abai and East Kazakhstan regions. Here and further in the figures, red or green circles highlight the points according to which the trend coefficients are statistically significant at the 5% level. In the northern and northeastern regions, the increase in the duration of the growing season is mostly statistically insignificant.

In addition to an increase in the duration of the growing season, a statistically significant increase in the sum of temperatures during the growing season is observed throughout Kazakhstan (*GDDgrow10 index*, Figure 2.19). In the southern and western parts of the country, the increase in the sum of temperatures is significantly higher than in the northern part. The largest and statistically significant increase, by more than 80-degree days/10 years, can be traced according to the data of most stations in the southwestern part of West Kazakhstan, Atyrau, Mangystau, Kyzylorda, Turkestan, Zhambyl and Almaty regions.

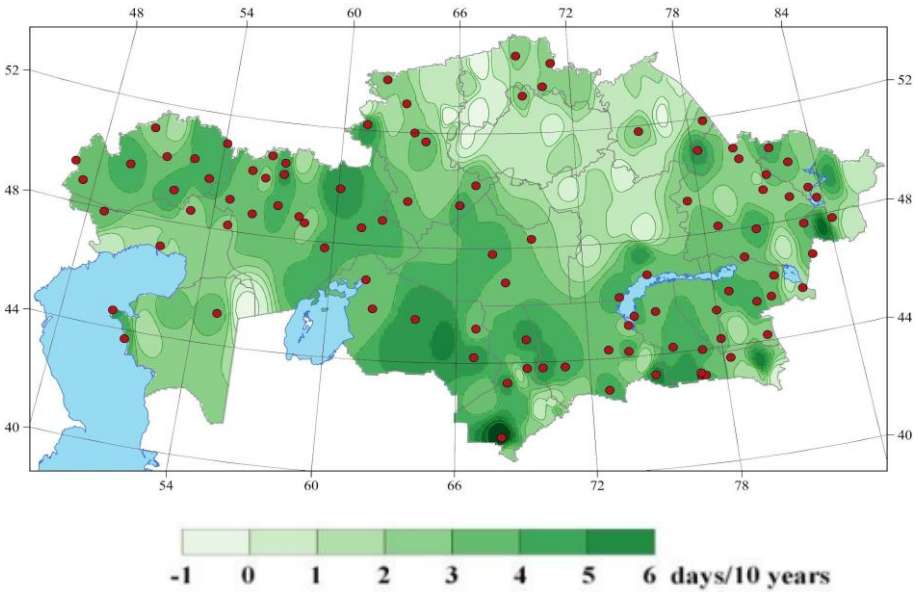


Figure 2.18 – The rate of change in the duration of the growing season (day/10 years) in the period 1961-2023 (*GSL index*)

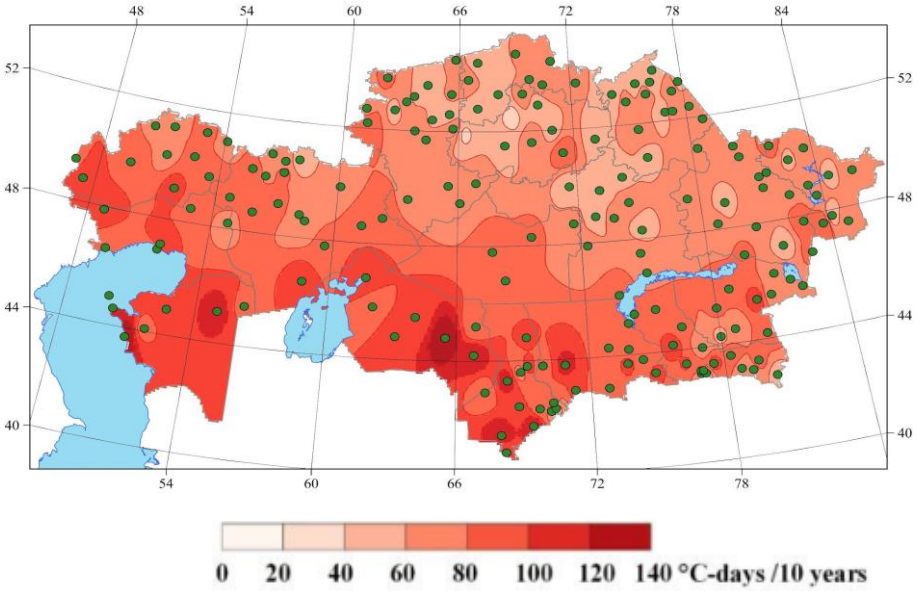


Figure 2.19 – The rate of change in the sum of temperatures during the growing season (degree days/10 years) in the period 1961-2023 (*GDDgrow10 index*)

Not only does the average air temperature rise, but the frequency of high summer temperatures also increases. In the conditions of hot and dry summers in the western and southern regions of Kazakhstan, this has a negative impact not only on vegetation, but also on the human body and animals. For example, the number of days with temperatures above 30 °C is increasing almost everywhere, especially noticeably in the western and southern regions of the republic – by 4-7 days in 10 years (Figure 2.20). The highest rate of increase in the recurrence of high summer temperatures was observed at the Aktau meteorological stations (7.5 days/10 years, Mangystau region) and Aral Tenizi (6.8 days/10 years, Kyzylorda region). A statistically insignificant negative trend in the recurrence of hot days was observed at the stations of North Kazakhstan, Akmola and Karaganda regions.

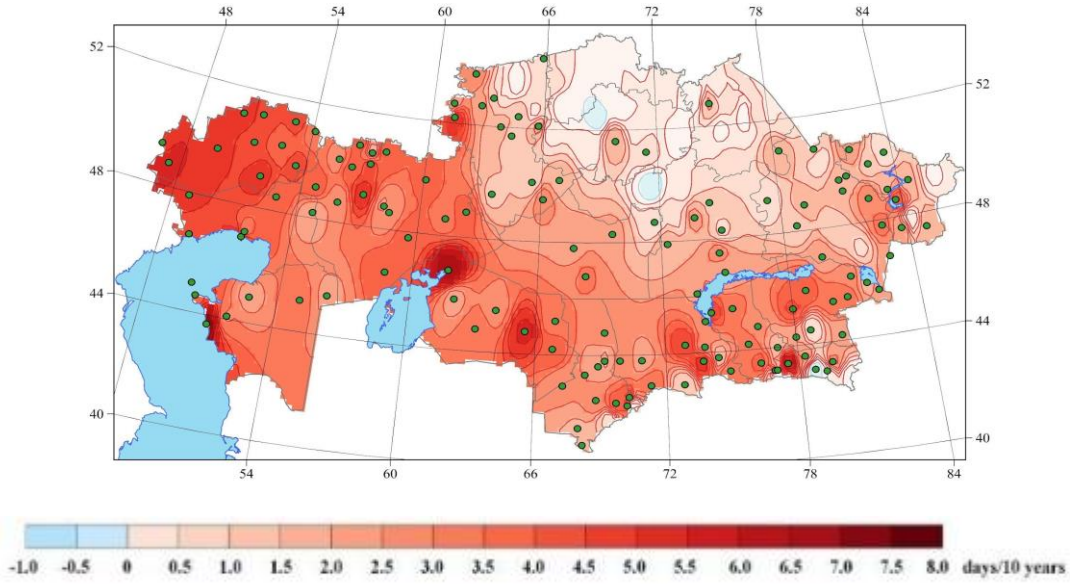


Figure 2.20 – The rate of change in the number of days when the maximum daily temperature is equal to or above 30 °C (day/10 years) in the period 1961-2023 (*index TXge30*)

Рисунок 2.20 – Темпы изменения количества суток, когда максимальная суточная температура равна или выше 30 °С (сутки/10 лет) в период 1961-2023 гг. (*индекс TXge30*)

In most of the territory of the republic, there is a statistically significant positive trend in the total duration of all heat waves during the warm period (a heat wave is 3 or more days in a row when the excess heat coefficient has a positive value, the *HWF/EHF index*, Figure 2.21). The most significant positive trend (more than 6-9 days/ 10 years) was observed at meteorological stations located in the western and southern regions.

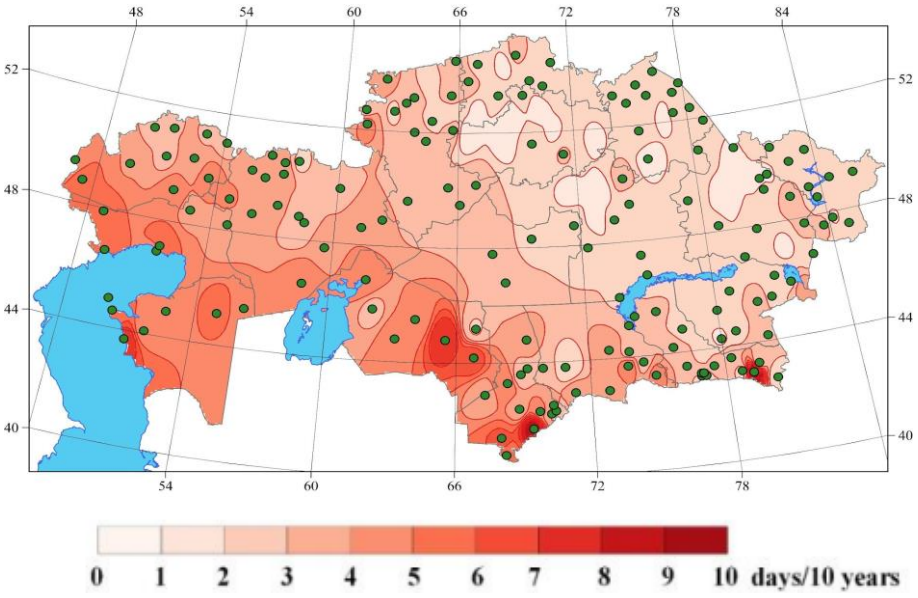


Figure 2.21 – The rate of change in the total duration of heat waves during the warm period (day/10 years) in 1961-2023 (HWF/EHF index)

Almost the entire territory of the republic shows a statistically significant positive trend in the number of individual heat waves during the warm period (*HWN index*, Figure 2.22). At stations in the southern and southwestern regions, there are one more such waves on average every 10 years.

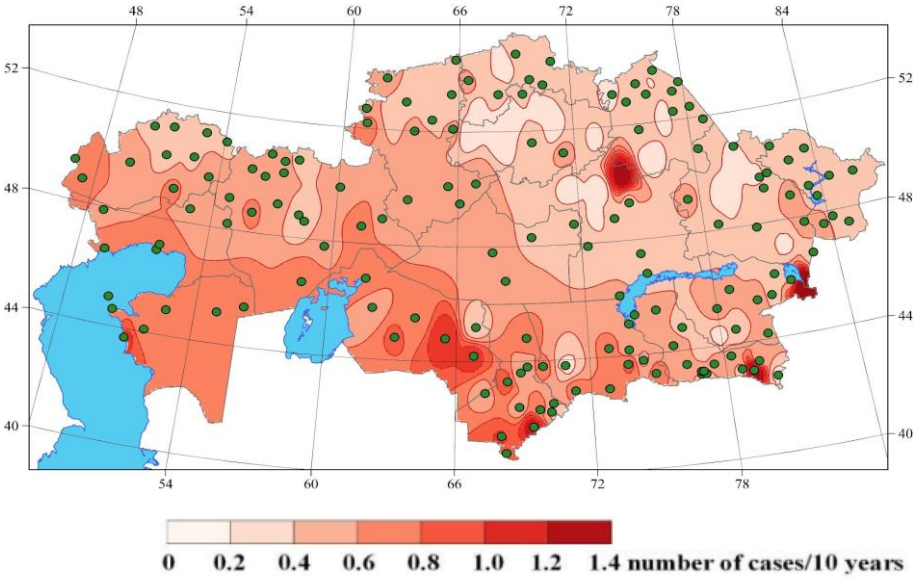


Figure 2.22 – The rate of change in the number of heat waves during the warm period (number of cases/10 years) in 1961-2023 (*HWN index*)

The *duration of the maximum heat wave during the warm period* increases everywhere (*HWD index*, Figure 2.23), in the western and southern regions the wave lengthens by more than one day on average every 10 years.

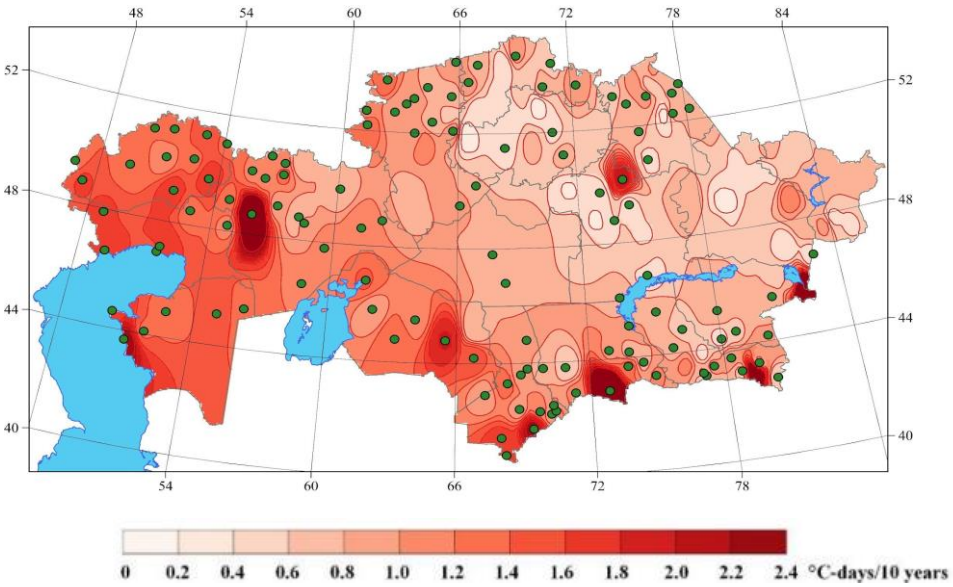


Figure 2.23 – The rate of change in the maximum duration of heat waves during the warm period (day/10 years) in 1961-2023 (*HWD index*)

An increase in air temperature in all seasons of the year leads to an increase in *the total duration of heat waves over the year* (when, for at least 6 consecutive days, the daily maximum air temperature was above the 90th percentile, *WSDI index*) throughout the republic (Figure 2.24). In the northern regions and in some central, southern and eastern regions, the increase is 1-3 days / 10 years. The most significant increase (by 3-6 days/10 years) is observed in the western half of the country.

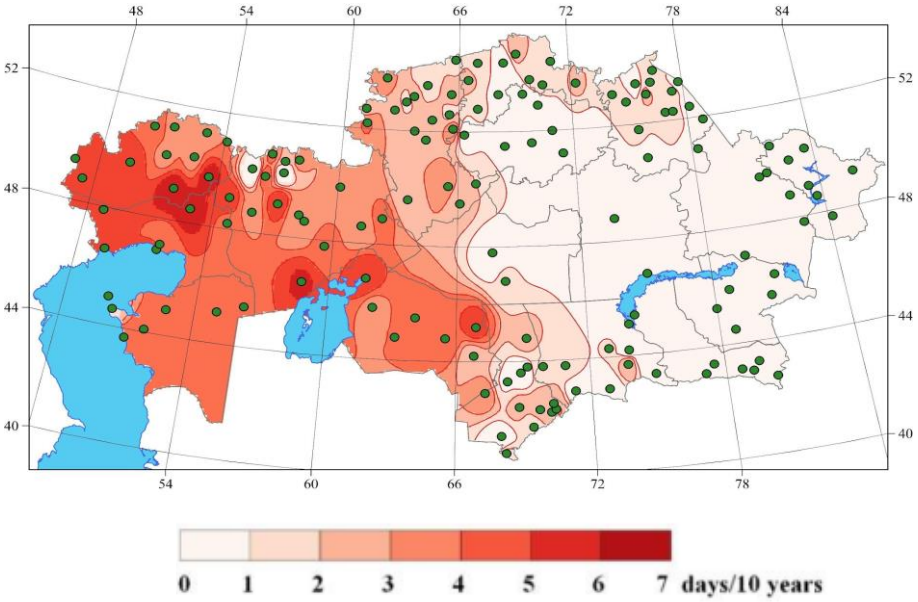


Figure 2.24 – The rate of change in the total duration of heat waves per year (day/10 years) in the period 1961-2023 (*WSDI index*)

The consequence of an increase in air temperature in most months of the warm season is an increase in *cold deficiency*, or the need to maintain a favorable temperature in the room, in this case a threshold of 23 ° C is adopted (*CDDcold23 index*, Figure 2.25). Only in the north and northeast of the republic there are small areas with some decrease in cold deficiency. In the rest of the country, there is an increase in cold deficit, in the western regions, in the south-west and south, the rate of increase in cold deficit is more than 10 °C every 10 years. The maximum increase in cold deficiency is observed in Atyrau, Mangystau, Kyzylorda, Turkestan regions (30-50 °C/10 years).

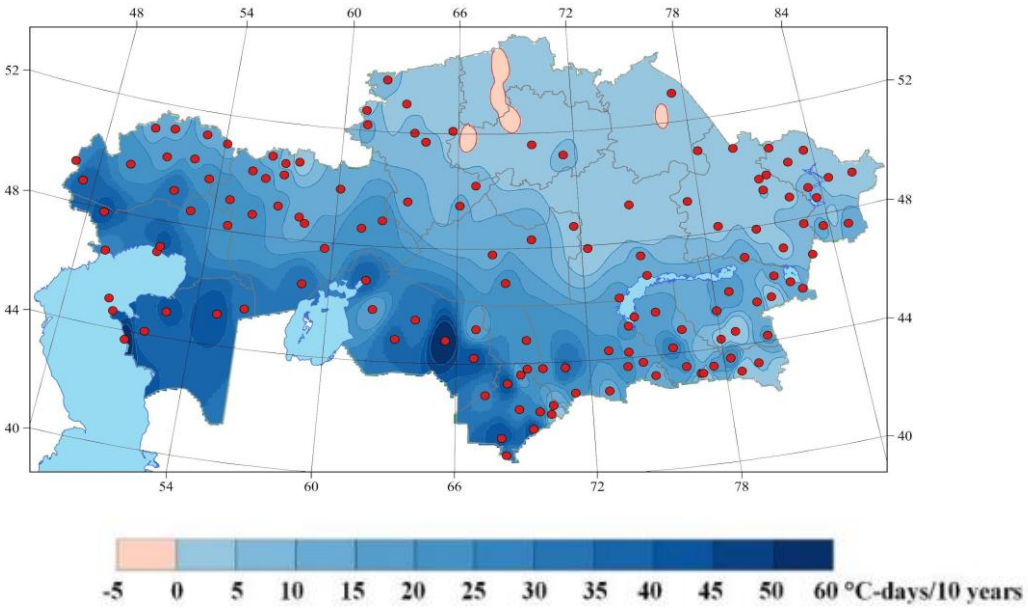


Figure 2.25 – The rate of change in cold deficit (degree days/10 years) in the period 1961-2023 (*CDDcold23 index*)

In many regions of Kazakhstan, the value of the daily minimum temperature is increasing, in about half of the cases at a faster pace than the increase in the daily maximum. Figure 2.26 shows the

change in *the number of days when the minimum temperature is ≥ 20 °C* (*TR index*, *the number of tropical nights*). Over the past more than 60 years, Kazakhstan has mainly seen an increase in the number of such days, as much as possible in Atyrau and Mangystau regions by 4-8 days/10 years, as well as by 6-7 days/ 10 years at some stations of Kyzylorda and Turkestan regions. Thus, the conditions for night rest of the human body from the daytime heat are significantly deteriorating here, which, as shown above, is also increasing.

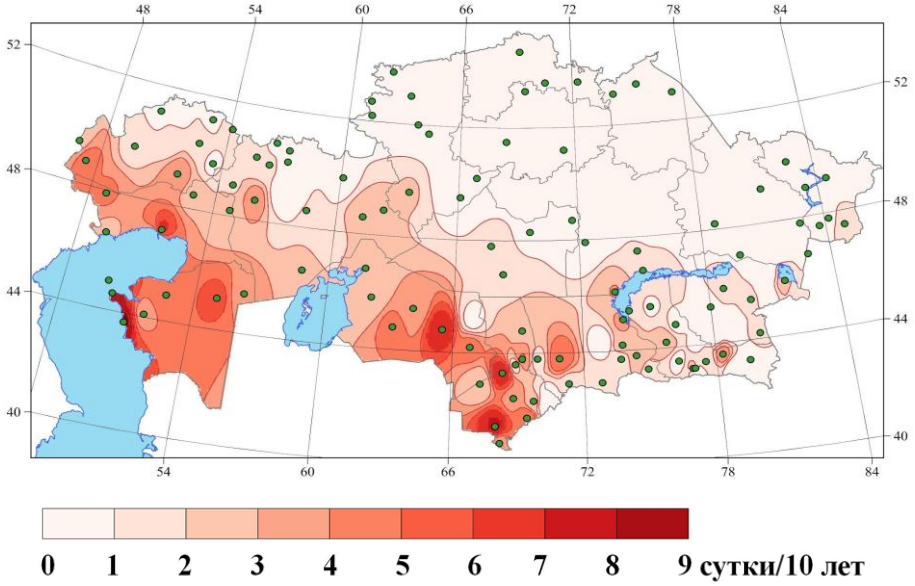


Figure 2.26 – The rate of change in the number of tropical nights (day/10 years) in the period 1961-2023 (*TR index*)

As a result of the increase in air temperature, the number of days per year decreases throughout Kazakhstan when the *daily minimum temperature is equal to or falls below 0 °C* (day with frost, *FD0 index*, Figure 2.27) and below minus 2 °C (severe frosts, *TNltm2 index*, Figure 2.28). The rate of reduction varies across the territory, in basically, from 2 to 4 days / 10 years, in some places the reduction rate is higher than 5-6 days in 10 years.

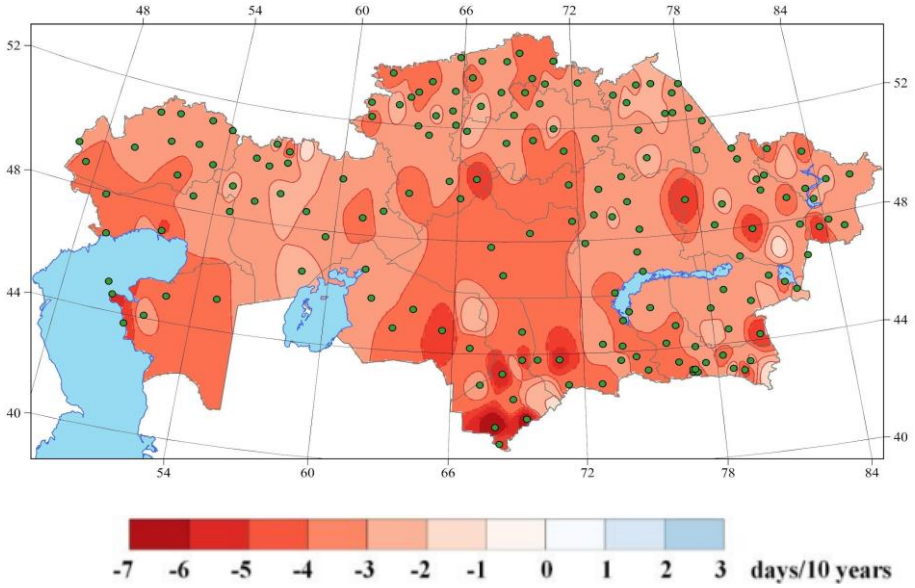


Figure 2.27 – The rate of change in the number of days with frost (day/10 years) in the period 1961-2023 (*index FD0*)

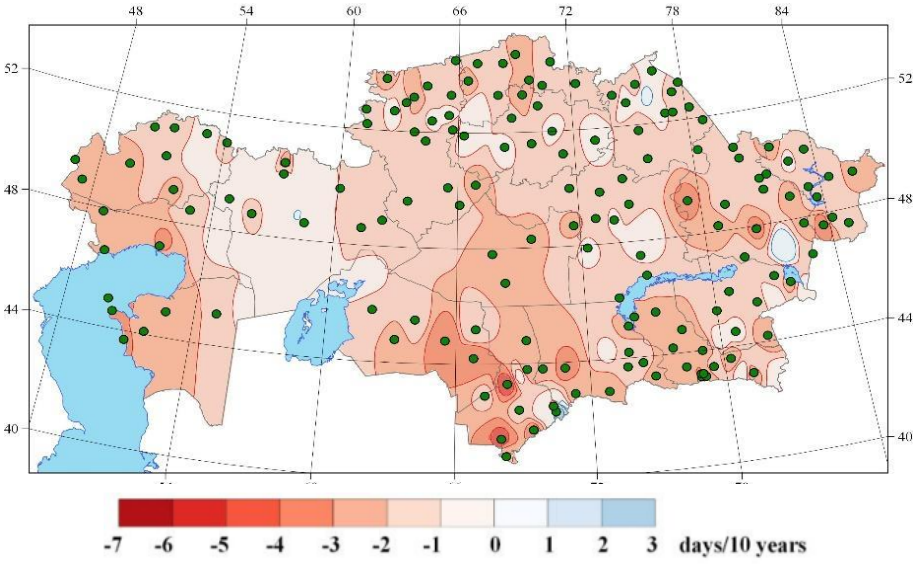


Figure 2.28 – The rate of change in the number of days with severe frosts (day/10 years) in the period 1961-2023 (*TNltm2 index*)

On the territory of the republic, the *number of days with very severe frosts* is almost everywhere decreasing (when the daily minimum air temperature is below minus 20 °C, *TNltm20 index*, Figure 2.29). 2-3 days / 10 years) significantly reduce the number of such days in the north-western, central and south-eastern regions. In some areas of the East Kazakhstan region, the frequency of days with very severe frosts decreases at a more significant rate - by 4-5 days / 10 years.

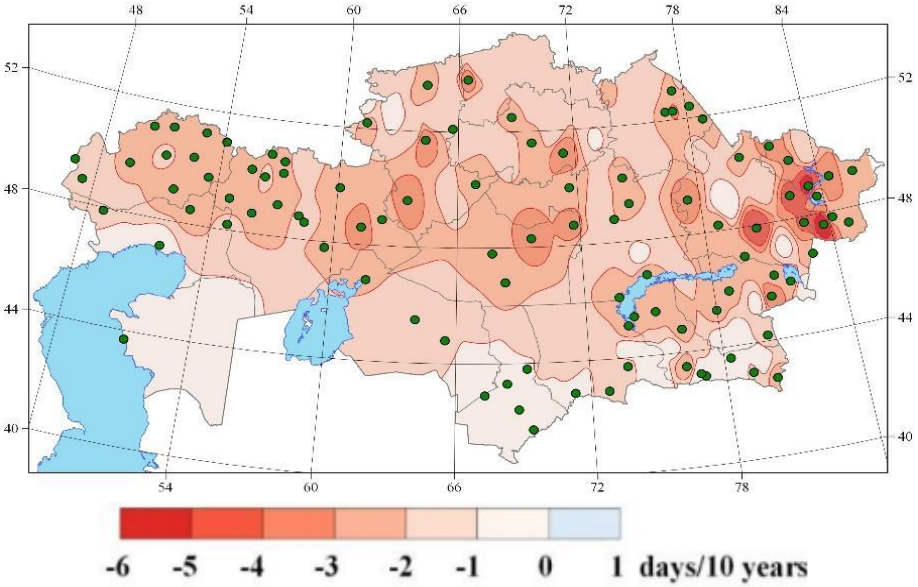


Figure 2.29 – The rate of change in the number of days with very severe frosts (day/10 years) in the period 1961-2023 (*TNltm20 index*)

Reducing the number of days with negative temperatures leads to a widespread reduction in *heat deficit during the cold season* (*HDDheat23 index*, Figure 2.30). Here, the temperature of 23 °C is taken as the threshold value of the air temperature, which is desirable to maintain indoors. In most of the territory of Kazakhstan, the range of heat deficit reduction is in the range of 60–100-degree

days for every 10 years. The reduction of heat deficit in most of the northern and eastern parts of the central regions is up to 40-degree days for every 10 years, but in some areas of these regions there is no reduction in heat deficit. In places in various regions, mainly in the western, southwestern and some areas of the eastern regions of Kazakhstan, this reduction is the largest and amounts to 140–160-degree days/10 years.

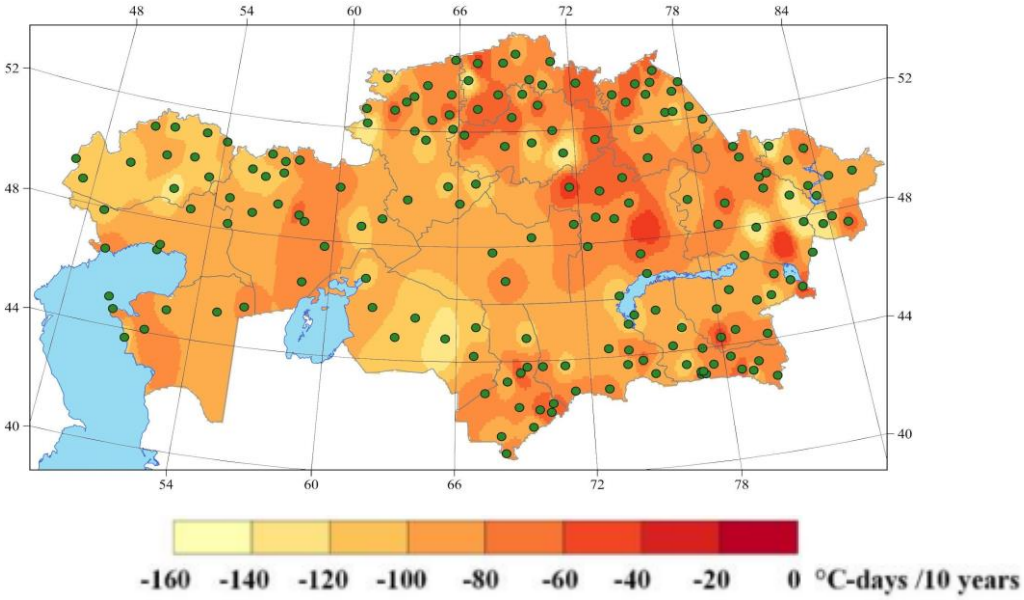


Figure 2.30 – The rate of change in heat deficit (degree days/10 years) in the period 1961-2023 (*HDDheat23 index*)

3 ATMOSPHERIC PRECIPITATIONS

Data on monthly and daily precipitation totals at about 190 meteorological stations from the Republican Hydrometeorological Fund of RSE 'Kazhydromet' were used to describe climatic conditions observed in 2023, including assessment of extremes of precipitation regime and climate change assessment. Annual, seasonal and monthly precipitation amounts are expressed in mm, or expressed as a percentage of the 1961-1990 norm. Table 3.1 presents values of anomalies of annual and seasonal precipitation amounts, Table 3.2 presents values of anomalies of monthly precipitation amounts observed in 2023 and averaged over the whole territory of Kazakhstan and its regions. For each anomaly value, the probabilities of non-exceedance calculated for the period 1941 - 2023 are given. The probability of non-exceedance characterizes the frequency of occurrence of the corresponding value of the anomaly in a series of observations. Precipitation anomalies, which occupied the first or the last five years in the descending ranked series, are highlighted in bold.

3.1 Anomalies of precipitation on the territory of Kazakhstan in 2023

In 2023, the average annual precipitation for the territory of Kazakhstan was close to the norm and amounted to 113.1 % of the norm, or 359.4 mm (rank 16, probability of non-exceedance of 81%). The deficit of precipitation was experienced in Zhambyl and Kyzylorda regions, where the average annual precipitation totals for the region were 85 and 87 % of the norm with a probability of non-exceedance of 25 and 36 %, respectively. Maximum exceeded the annual norm of precipitation on average in Atyrau region - by 50 % of the norm, but the average layer of precipitation was only 225.5 mm, the year was included in the 10 % of extremely wet. The amount of precipitation in two more regions was included in the 10% of extremely wet years on average for the territory of West Kazakhstan (131 % of the norm) and Kostanay (126 % of the norm) regions (Table 3.1).

In most of the territory of Kazakhstan for 2023 precipitation fell either near the norm or more than the norm (Figure 3.1). Foci of maximum precipitation relative to the norm were located in the western and northern regions (140-176 % of the norm), in mountainous areas of East Kazakhstan region (120-146 % of the norm). The greatest deficit of annual precipitation amounts was experienced in some areas in the south of Kostanay region, in most of Kyzylorda region, in the south-west of Turkestan region and in the south-east of Zhambyl region, where 43-71 % of normal precipitation fell, also small centers of precipitation deficit were observed in the west of Mangistau region, locally in Akmola, Abai, Almaty regions (73-85 % of normal).

At the meteorological station Korday (Zhambyl region) a new minimum of annual precipitation of 278.2 mm was established with the previous minimum of 301.2 mm in 2021, at MS Kyzylkum (Turkestan region) the year was in the 5% of extremely dry, and at MS Ereimentau (Akmola region) the year was in the 10% of extremely dry (Figure 3.1). According to data from 33 stations located in the western, north-western, central and eastern regions, the year was extremely wet: 17 stations recorded 5% extremes, of which 2 stations set record values of maximum annual precipitation totals: 497.9 mm at MS Zheleznodorozhnyi (Kostanay region) with the previous maximum of 473.6 mm in 1963, 577.4 mm at the Kamenka MS in the West Kazakhstan region, the previous maximum was 503.7 mm in 1956 (Annex 1); 16 MS recorded extremely high (10% extremes) for these regions precipitation.

Table 3.1 - Regionally Averaged Annual (January-December) and Seasonal Precipitation Anomalies in 2023:: **vR** – *deviations from the long-term averages for 1961–1990, in mm/season;* ***P(r≤R$_{2022}$)*** *– non-exceedance probability (in parentheses), calculated using data for the period 1941–2023, in %;* ***RR*** – ratio of R_{2023} to the norm, in %

Region	Year		Winter		Spring		Summer		Autumn	
	vR (P)	RR	vR (P)	RR	vR (P)	RR	vR (P)	RR	vR (P)	RR
Kazakhstan	41,7 (81)	113,1	2,7 (53)	104,2	-18,5 (13)	78,8	-4,6 (41)	94,8	**38,9 (100)**	**149,1**
Abai	54,3 (82)	118,9	15,6 (73)	127,1	-8,0 (41)	88,2	-7,2 (37)	91,7	**45,0 (98)**	**159,8**
Almaty	-11,0 (48)	97,7	-15,8 (14)	75,5	-34,2 (25)	80,8	-17,8 (31)	87,1	21,6 (78)	121,4
Akmola	82,2 (86)	125,3	7,4 (64)	115,5	-12,0 (28)	82,7	-19,5 (30)	85,0	**70,1 (98)**	**189,6**
Aktobe	75,0 (87)	128,5	2,8 (56)	104,7	5,0 (56)	107,7	-8,2 (45)	87,8	**47,2 (96)**	**165,3**
Atyrau	75,3 (92)	150,1	9,8 (69)	131,2	11,6 (64)	130,7	-7,9 (45)	80,7	**48,2 (97)**	**219,2**
East Kazakhstan	85,5 (89)	121,7	21,8 (86)	135,0	-4,6 (42)	95,0	-19,5 (25)	84,7	**81,8 (100)**	**173,6**
Zhambyl	-45,1 (25)	85,2	-12,3 (26)	83,2	-42,1 (18)	64,7	-7,4 (30)	80,7	-12,6 (40)	82,9
Zhetysu	14,6 (59)	103,8	-0,7 (45)	99,1	-18,8 (32)	84,1	-17,9 (31)	80,5	27,0 (86)	126,9
West Kazakhstan	86,4 (90)	130,7	0,2 (58)	100,4	0,7 (46)	101,3	19,6 (79)	124,6	40,7 (92)	151,9
Karaganda	49,9 (89)	119,6	12,6 (82)	124,9	-18,1 (17)	71,9	-3,9 (41)	94,9	**47,8 (100)**	**177,3**
Kostanay	76,0 (91)	126,2	-7,1 (36)	85,4	-26,4 (6)	55,7	24,5 (76)	122,8	**58,2 (100)**	**178,8**
Kyzylorda	-17,9 (36)	87,3	2,4 (46)	106,1	-21,0 (18)	57,1	-2,3 (46)	87,7	-3,9 (48)	88,2
Mangystau 1	22,5 (78)	115,8	-5,9 (36)	75,4	21,6 (86)	146,3	-11,3 (50)	67,3	7,5 (76)	120,1
Pavlodar	28,9 (62)	109,9	4,3 (64)	109,7	-17,3 (15)	68,5	-4,2 (41)	96,5	32,2 (93)	144,5
North Kazakhstan	59,6 (78)	116,9	4,4 (60)	109,2	-14,6 (24)	77,8	-25,7 (28)	83,2	**62,1 (97)**	**171,3**
Turkestan	-8,9 (37)	98,0	-1,6 (41)	98,9	-78,1 (6)	53,3	24,5 (86)	200,9	6,1 (64)	106,5
Ulytau	14,1 (67)	106,5	-3,3 (57)	93,8	-7,5 (48)	87,4	-4,4 (46)	91,8	19,5 (86)	139,1

Notes: 1. for the Mangystau region, the assessment was carried out only based on Fort Shevchenko meteorological station;

2. values above the 95th or below the 5th percentile (wet 95% and dry 5% extremes, respectively) are highlighted in bold and bright color;
3. values above the 90th or below the 10th percentile are highlighted in pale color;
4. the mean precipitation anomalies were obtained by averaging data from 121 stations across the Republic of Kazakhstan.

On average for the territory of Kazakhstan winter and summer periods, during which on average in the country fell 66 mm and 83 mm, which is 104.2 % and 94.8 % of the climatic norm for the season, respectively; spring period of 2023 on the moisture regime was characterized by the presence of a deficit of precipitation in general for the season and fell 68.8 mm of precipitation or 78.8 % of the norm (this is the 11th driest spring); and in autumn, 118 mm fell on average over the territory of the country, which is 149.1 % of the climatic norm and the season took the first place in the ranked series of observations from the wettest to the driest season since 1941. (Table 3.1).

Figure 3.1 shows the spatial distribution of annual and seasonal precipitation in 2023, expressed as a percentage of normal for the period 1961-1990, and gives the probabilities of not exceeding annual and seasonal precipitation in that year.

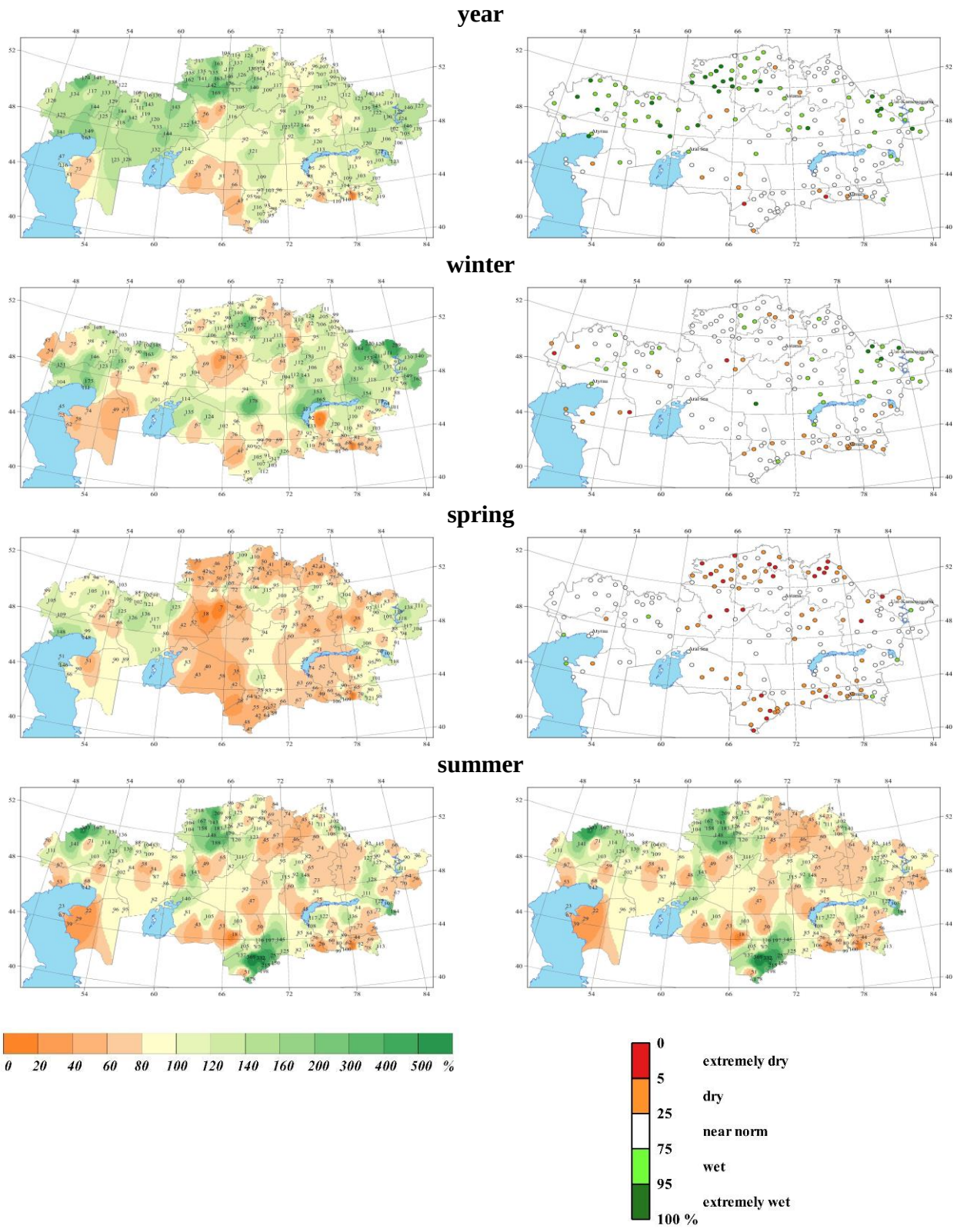


Figure 3.1 – Geographical distribution of annual and seasonal precipitation in 2023, expressed as a percentage of the norm (on the left), and the probability of non-exceedance (on the right), calculated for the period 1961–2023. Sheet 1

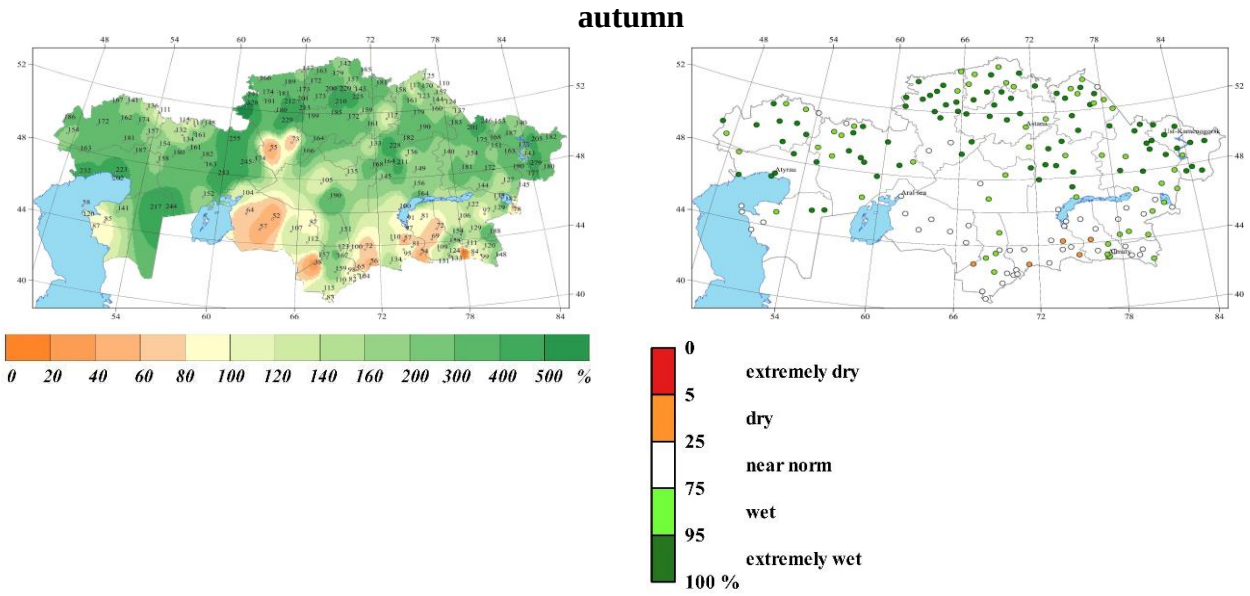


Figure 3.1 – Geographical distribution of annual and seasonal precipitation in 2023, expressed as a percentage of the norm (on the left), and the probability of non-exceedance (on the right), calculated for the period 1961–2023. Sheet 2

Figure 3.2 shows the intra-annual distribution of precipitation in 2023 averaged over the territory of Kazakhstan, as well as the long-term average monthly precipitation for the period 1961-1990.

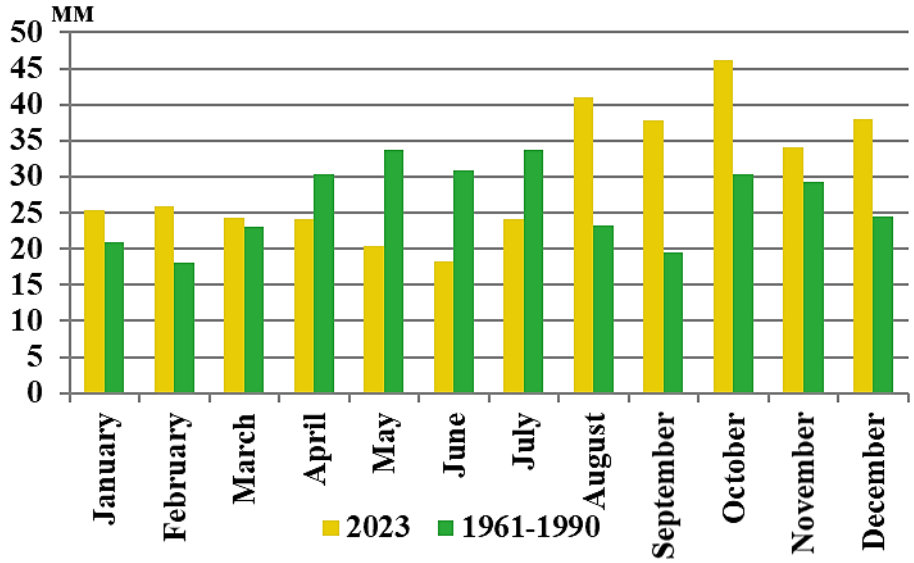


Figure 3.2 – Territory-averaged monthly precipitation sums in Kazakhstan in 2023 and their norms, calculated for the period 1961–1990

In 2023, on average, there was an excess of precipitation in Kazakhstan for most of the year (from January to March and from August to December, Figure 3.2). Two months of 2023 were extremely wet: September, when the average precipitation in Kazakhstan was 37.8 mm or 193.7 % of the climatic norm, which corresponds to the 98th percentile (this is the 2nd wettest month, the record value was recorded in 1946). and the amount of precipitation was 37.9 mm) and August month, when on average 40.9 mm of precipitation or 175.8 % of the norm fell in the country (rank 4, probability of non-exceedance of 96 %), and very wet, included in the 7 wettest months (10 %

extremes) were October (46.1 mm - 151.8 % of the norm) and December (37.9 mm - 155.5 % of the norm). Precipitation deficit was observed from April to July. In April, the average amount of precipitation was 24.1 mm (or 79.3 % of the norm), in July - 24.2 mm (or 71.5 % of the norm) with a probability of non-exceedance of 28 % and 17 %, respectively. Two months were extremely 'dry': May 60.2 % of the norm or 20.35 mm (among the eight driest months) and June 59.2 % of the norm or only 18.3 mm (among the three driest months, as little precipitation in June fell in 1955 (13.1 mm - 42.5 % of the norm) and 1975 (16.7 mm - 54.1 % of the norm).

In winter 2022/2023 (December 2022-February 2023), on average over the territory of Kazakhstan, the amount of precipitation during the winter period was about the norm (Table 3.1) and amounted to 104.2 % of the norm (rank - 39, empirical probability 53 %). In most of the country precipitation was more than 80 % of the norm (Figure 3.1). Excess precipitation (more than 120 % of normal) was observed in the eastern part of the country (136-259 % of normal), in the northern regions (124-181 % of normal), in Northern Pribalkashie (133-171 % of normal) and in the Caspian Lowland and some areas of the northern part of the western region (123-163 % of normal).

According to data from 10 meteorological stations located in the eastern and central regions, the amount of precipitation for the winter period entered the 5 and 10 % of extreme wet, of which 3 meteorological stations in the eastern region: Shalabai, Dmitrievka, Leninogorsk recorded record values of maximum precipitation for the winter period (120.2 mm, 103.2 mm and 137.8 mm), the previous values (115.8 mm, 82.2 mm and 134.1 mm) were recorded in 1966, 1992 and 2017, respectively. The largest centres of significant precipitation deficit were observed in the south of Kostanay region (30-73 % of the norm), in Mangistau region, in the extreme west, north-east, south and south-east of the country (45-77 % of the norm). According to 8 meteorological stations located in the west, south of Kostanay region and in the south-east, the winter season was among the 5 and 10 % of the driest years.

In December 2022 was characterised mainly by precipitation deficit, relative anomalies of precipitation averaged over the territory of Kazakhstan amounted to 60 % of the norm for the period 1961-1990 or 9.7 mm below the norm (probability of non-exceedance of 13 %, Table 3.2). A significant precipitation deficit of less than 60 % of the norm was observed over most of the country, covering the western half of the country, southern, south-eastern regions, and most of the northern, central and eastern regions.

Precipitation less than 20 % of the norm fell over a large area of Mangistau region and southern region, in some areas of the south of Kostanay region. According to data from 25 MS located in these regions, December was among the 5 and 10 per cent of extremely dry months. A new minimum of monthly precipitation was observed at MS Kuigan, when during the whole month there was no precipitation, the previous record of the minimum value of precipitation was recorded in 1965 - 1.0 mm (Annex 2). In most of the north-eastern and eastern and central regions of the country, as well as locally in the foothills and in the region of Ulytau precipitation was about normal or significantly above normal (Figure 3.3).

Table 3.2 – Regionally averaged monthly precipitation anomalies in 2023, calculated as deviations from the long-term mean values for 1961–1990 (in mm), *and the probability of non-exceedance (in parentheses), calculated using data for the period 1941–2023 and expressed in %*

Region	12 (2022)	1	2	3	4	5	6	7	8	9	10	11
Kazakhstan	-9,7 (13)	4,5 (78)	7,8 (81)	1,2 (56)	-6,3 (28)	-13,5 (9)	**-12,6 (3)**	-9,6 (17)	**17,7 (96)**	**18,3 (98)**	15,7 (92)	4,8 (74)
Abai	-8,0 (23)	**16,9 (95)**	6.7 (84)	14,4 (87)	-0,5 (45)	**-22,0 (4)**	-16,7 (7)	-20,5 (7)	29,9 (93)	**29,8 (100)**	21,7 (93)	-6,6 (31)
Almaty	-15,5 (6)	2,3 (63)	-2,6 (31)	-4,0 (42)	-6,5 (45)	-23,7 (18)	**-37,5 (2)**	-2,7 (42)	22,5 (90)	17,9 (92)	6,1 (73)	-2,4 (52)
Akmola	-2,4 (37)	2,5 (69)	7,2 (85)	6,3 (75)	4,8 (68)	-23,0 (6)	-10,7 (24)	-23,8 (14)	15,0 (76)	**44,1 (100)**	6,3 (80)	19,7 (93)
Aktobe	-9,3 (24)	3,9 (69)	8,2 (84)	-0,4 (40)	3,3 (64)	2,1 (50)	-9,7 (29)	3,4 (65)	-1,9 (52)	14,1 (85)	**24,6 (97)**	8,4 (82)
Atyrau	-10,6 (6)	-5,3 (15)	**25,7 (98)**	-8,9 (10)	16,9 (92)	3,5 (54)	-4,7 (45)	-3,8 (50)	0,6 (60)	11,2 (87)	**29,1 (96)**	7,9 (85)
East Kazakhstan	1,6 (59)	14,7 (93)	5,5 (78)	15,3 (86)	1,7 (43)	-21,7 (25)	**-26,5 (1)**	-18,1 (18)	25,1 (89)	**48,8 (100)**	27,0 (92)	6,1 (68)
Zhambyl	-17,8 (9)	-1,3 (48)	6,8 (68)	-3,1 (46)	-17,4 (24)	-21,6 (12)	**-16,7 (2)**	-4,9 (36)	14,2 (93)	0,6 (60)	-0,8 (60)	-12,4 (26)
Zhetysu	-9,7 (20)	9,9 (84)	-0,9 (36)	5,5 (68)	-10,2 (32)	-14,2 (31)	-22,5 (9)	-16,5 (20)	21,1 (90)	20,8 (93)	17,7 (84)	-11,5 (31)
West Kazakhstan	-13.5 (21)	-3,8 (47)	**17,5 (96)**	-8,5 (24)	3,5 (63)	5,7 (63)	-1,1 (57)	**35,1 (96)**	-14,4 (21)	-7,8 (35)	**34,9 (96)**	13,6 (87)
Karaganda	-1,0 (47)	6,6 (80)	7,0 (85)	6,2 (76)	-6,0 (30)	-18,3 (12)	**-18,2 (3)**	**-21,5 (4)**	**35,7 (97)**	**20,4 (98)**	**25,9 (97)**	1,5 (62)
Kostanay	-9,3 (19)	-2,1 (46)	4,3 (79)	2,5 (58)	**-16,1 (3)**	-12,9 (19)	-2,6 (52)	-14,8 (28)	**41,8 (98)**	21,0 (91)	14,9 (91)	**22,3 (98)**
Kyzylorda	-8,5 (15)	2,6 (57)	8,4 (82)	-6,9 (25)	-12,0 (15)	-2,1 (50)	-6,0 (21)	-2,6 (47)	6,3 (87)	-3,4 (42)	4,2 (78)	-4,7 (43)
Mangystau 1	-8,2 (30)	-4,5 (10)	6,8 (86)	-8,3 (42)	18,1 (85)	11,8 (90)	-14,6 (12)	-7,5 (32)	10,8 (87)	14,9 (89)	0,5 (57)	-7,9 (30)
Pavlodar	3,3 (58)	5,9 (86)	-4,8 (26)	8,3 (81)	-2,5 (41)	**-23,1 (0)**	-8,1 (30)	-14,7 (24)	18,6 (86)	25,1 (92)	3,0 (71)	4,1 (70)
North Kazakhstan	-5,4 (34)	0,7 (62)	9,1 (89)	11,3 (86)	**-19,6 (2)**	-6,3 (36)	17,9 (81)	**-42,1 (2)**	-1,5 (53)	23,4 (90)	12,7 (86)	**26,0 (97)**
Turkestan	-35,3 (10)	8,7 (63)	25,0 (84)	-29,5 (10)	-28,0 (18)	-20,6 (20)	**-10,0 (1)**	-0,5 (67)	**35,1 (100)**	-3,0 (54)	6,9 (74)	2,2 (60)
Ulytau	-3,1 (40)	-9,0 (26)	8,9 (84)	11,9 (86)	-12,3 (19)	-7,1 (50)	-12,9 (7)	-11,1 (25)	19,7 (90)	10,9 (93)	4,5 (81)	4,1 (70)

Notes: 1. for the Mangystau region, the assessment was carried out only based on Fort Shevchenko meteorological station;
2. values above the 95th or below the 5th percentile are highlighted in bold and bright color;
3. values above the 90th or below the 10th percentile are highlighted in pale color;
4. the mean precipitation anomalies were obtained by averaging data from 121 stations across Kazakhstan.

In January, the distribution of precipitation over the territory was uneven, on average over the territory of Kazakhstan the amount of precipitation was 121.7 % of the norm (rank 19, Table 3.2). Strong deficit of precipitation was observed in Mangistau region (15,1 % of norm - the ninth driest January in the series of observations), and extremely wet in the whole territory was in Abay (193,1 % of norm) and East Kazakhstan region (179,4 % of norm), it is the 5th and 6th wettest January. In most

of Kazakhstan there was an excess of moisture, precipitation was about or much more than normal. In the eastern regions the amount of precipitation exceeded the norm by 1.5-3.9 times, in the northern, northern part of the western regions, Aral Sea region, southern and south-eastern regions - by 1.2-2.3 times, in the north-eastern and eastern part of the central regions - by 1.3-1.9 times (Figure 3.3). The largest amount of precipitation (118 mm) fell at MS Ashchysay (Turkestan region), which was 155.4 % of the norm.

Extremely humid conditions and 5% and 10% extremes were observed at 17 MCs located mainly in the east and north-east, centre, south and west, including 3 MCs (Shalabai, Dmitrievka and Leninogorsk) located in Abay and East Kazakhstan regions set records of monthly maximum precipitation (68.5 mm, 43.2 mm and 59.7 mm) their previous records (54.5 mm, 34.1 mm and 58.5 mm) were set in 1947. , 1971 and 1940, respectively (Appendix 2). In January, there were two large centres with a strong deficit of precipitation: one centre covered the entire territory of Mangistau region, the Caspian lowlands and the western half of West Kazakhstan region (7-63 % of the norm), the second centre was located in the western half of the central region (23-65 % of the norm). Small local zones with precipitation less than 70 % of the norm and even 30 % of the norm were observed in mountainous areas of the south and south-east, in the north and north-western part of the Abai region. The least precipitation (0.8 mm) during the month fell at meteorological stations Aktau and Fort-Shevchenko (Mangistau region), which amounted to 7.3 and 22.4 % of the norm. On the territory of West Kazakhstan and Mangistau regions at some stations January month entered 5 and 10 % of extremely dry.

February was wet, with average monthly precipitation of 143.4 % of the norm or 7.8 mm above the long-term average (rank 16, probability of non-exceedance 81 %, Table 3.2). In most parts of the country precipitation was much higher than the norm (Figure 3.3). In the West Kazakhstan and Atyrau regions it was extremely wet, the average moisture content over the territory was 202 and 392 % of the norm (with a probability of non-exceedance of 96 and 98 %) this is the fourth and second wettest February, respectively.

Precipitation exceeded the norm 1.3-4.9 times in the western regions, 1.3-3.2 times in the northern and central regions and the Turanian Lowlands, 1.2-2.9 times in the mountainous region of the south, Southern Pribalkashie and in some areas of the eastern region. (Figure 3.3). The most significant excess of the norm was observed at the Atyrau MS (485.1 % of the norm) in the Atyrau region. The highest amount of precipitation (173.2 mm) fell at MS Shuyldak (Turkestan region), which was 232.5 % of the norm. At 27 meteorological stations located in different regions of the country, moisture conditions were characterised as humid and extremely humid (90 and 95% extremes). At MS Atyraui Saryshagan were established new maximum monthly precipitation (49.0 mm and 29.2 mm), their previous values (41.7 mm and 21.0 mm) were recorded in 1952 and 1993, respectively (Annex 2).

Strong deficit of precipitation (less than 70 % of the norm) was in the north-eastern region (35-72 % of the norm), in mountainous areas of the south-east and east (47-70 % of the norm) and locally in the central part of the country and in the south of Kostanay region (48-67 % of the norm).

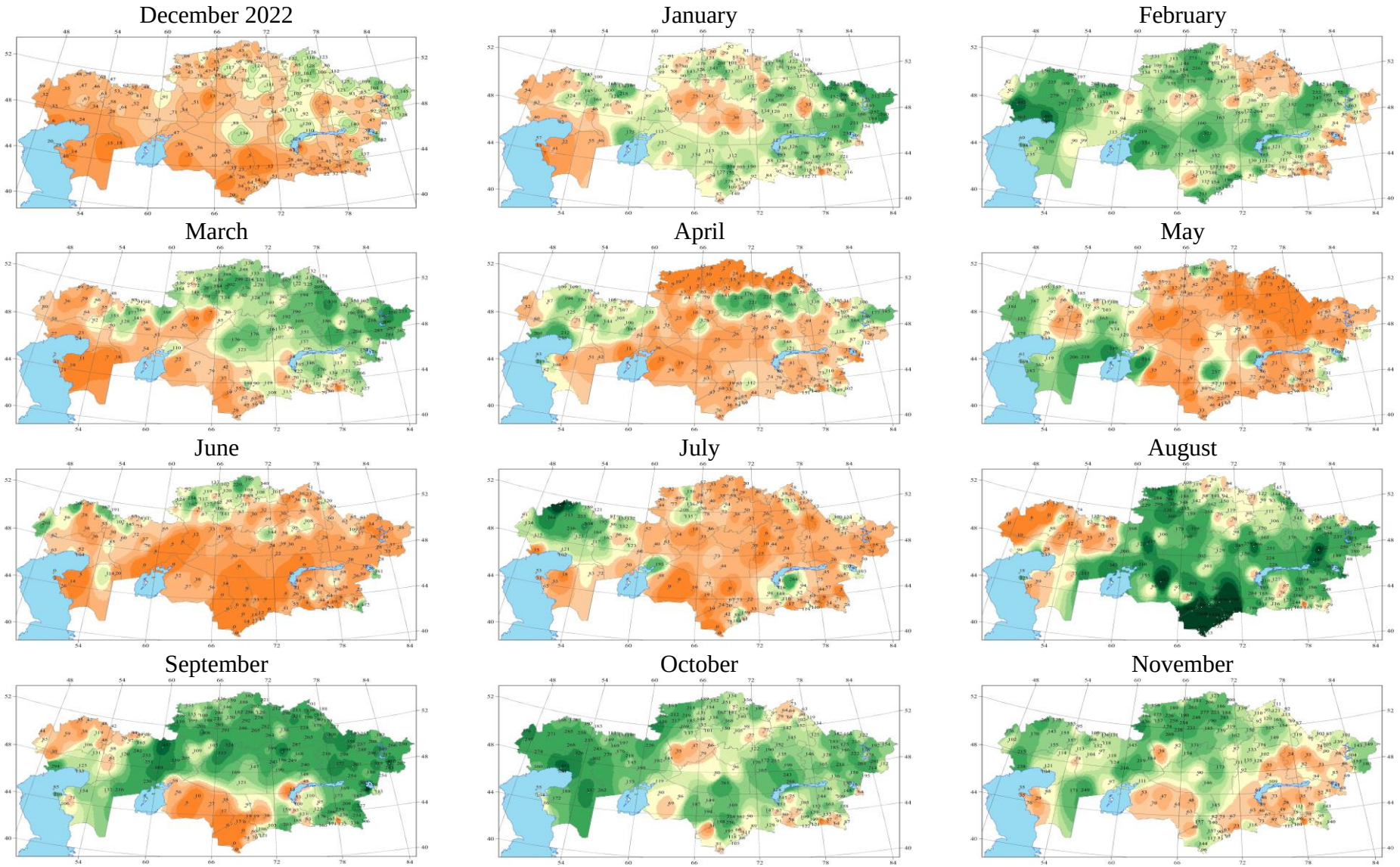


Figure 3.3 – Spatial distribution of monthly precipitation in 2023
(As a percentage of the norm, calculated relative to the baseline period 1961–1990)

In spring, precipitation averaged 78.8 % of the norm with a probability of not exceeding 13 % (or the driest spring in the series of observations, Table 3.1). Extremely dry was observed on average in Kostanay (56 % of the norm) and Turkestan (53.0 % of the norm) regions - the sixth driest spring in the series of observations since 1941. Mangistau region received significantly higher than normal precipitation - 146 % of the norm. A significant deficit of spring precipitation was observed over most of the country - less than 76 % of the norm (Figure 3.2). A significant deficit of seasonal precipitation amounts was observed in the south of the Kostanay region (7-52 % of the norm), a strong deficit of precipitation was observed in the northern, north-eastern, central, southern regions and in some places in the western parts of the country (28-67 % of the norm). At MS Amangeldy (Kostanay region) a new minimum of seasonal precipitation was set at 3.6 mm, the previous minimum precipitation was 6.4 mm in 2021. According to data from 21 weather stations located in the northern regions: Kostanay, North Kazakhstan, Akmola and Pavlodar, in the eastern (Abay, East Kazakhstan) and southern (Turkestan and Zhambyl) regions it was extremely dry (5% extremes were recorded).

Excess precipitation was observed in most of the western region of the country and in mountainous areas of the eastern region, as well as in the central part of the country. Pockets of significant precipitation during the spring season were observed in western regions of Atyrau, central regions of Aktobe and East Kazakhstan regions (121-148 % of the norm, Figure 3.2).

In March, the average amount of precipitation over the territory of Kazakhstan was 105.3 % of the norm for the period 1961-1990 (Table 3.2). The distribution of precipitation was uneven. Excess precipitation, mainly above the norm, was observed in the northern, central, eastern and south-eastern parts of the country, as well as in the northern part of the Aktobe region (Figure 3.3), the amount of precipitation exceeded the norm by 124-350 % of the norm. In the northern, eastern and eastern part of the central regions of Kazakhstan, two large centers with significant excess moisture were observed. At 14 meteorological stations located in these parts of the country, it was extremely humid and 5 and 10 % extremes were recorded. The Atyrau and Turkestan regions were very dry, averaging 24.2 and 53.1 % of normal (10 % extremes) - the ninth driest month in the series of observations, respectively. Significant precipitation deficit (less than 60 % and even below 40 % of the norm) was observed almost everywhere in the western region, in the south of Kostanay region, in Kyzylorda and Turkestan regions, as well as in the north-western part of Pribalkashye and mountainous regions of the south of the country (Figure 3.3). According to the data of 10 MS located in Mangistau and Turkestan regions, as well as in the south of Kostanay region, March month was included in the 5 and 10 % of extremely dry, of which a new minimum of monthly precipitation (0.8 mm) was established at MS Amangeldy in Kostanay region, the previous value of 0.9 mm was observed in 1951 (Annex 2).

In April, the average amount of precipitation over the territory of the country was 79.3 % of the norm (rank 60, probability of non-exceedance 28 %, Table 3.2). Precipitation deficit (1-73 % of the norm) was observed over most of the territory of Kazakhstan, the most significant (less than 30 % of the norm and even 10 %) in the north and north-east, western part of the central region and Turan lowland (Figure 3.3). According to data from 32 MS located in North Kazakhstan, Pavlodar, Kostanay, northern Akmola and Kyzylorda regions, it was extremely dry (5 and 10 % extremes were recorded), including updated records at 4 meteorological stations in the northern region. According to three meteorological stations of Kostanay region: MS Sarykol, MS Karasu and MS Mikhaylovka records of minimum monthly precipitation were set (0 mm, 0.3 mm and 0.3 mm), their previous records (0.23 mm, 0.7 mm and 0.8 mm) and were recorded in 1963, 1991 and 1963, respectively. At

MS Mikhailovka in Pavlodar region precipitation was absent during the whole month, the same case was observed in 1997 (Annex 2). Pockets of significant precipitation (160-275 % of the norm) were observed predominantly in most of Akmola and southern Pavlodar regions, in the western part of the country, as well as in East Kazakhstan and bordering Abai regions and in the north of Pribalkashye. A strong excess of moisture was observed in Atyrau region, the average precipitation in the territory was 228.0 % of the norm, which corresponds to the 92nd percentile. At 7 meteorological stations in Akmola, Pavlodar and Atyrau regions, moisture conditions were extremely humid (5 and 10 % extremes were recorded).

In May, as well as in April, precipitation deficit was observed on the most part of the territory of Kazakhstan, on average over the territory of the country precipitation amounted to 60.2 % of the norm or 13.5 mm below the long-term average and moisture conditions are characterized as extremely dry (10% extreme, Table 3.2). Precipitation deficit (2-64 % of the norm) was observed in the northern, eastern, central, southern regions and in some places in the western region. A strong deficit of precipitation on average over the territory was observed in the Pavlodar region - 14.1 % of the norm or 3.78 mm (record dry month, the previous record of minimum monthly precipitation was recorded in 1955.), Abai - 28.3 % of the norm with a probability of non-exceedance of 4%, Akmola - 32.3 % of the norm with a probability of non-exceedance of 6%, Karaganda and Zhambyl regions average precipitation amounted to 38.4 and 41.9 % of the norm, which corresponds to the 12th percentile, respectively. In May, record precipitation minimums were set at 7 MSs (Annex 2): at 2 MSs in Akmola region (Astana, Ereimentau) and at 4 MSs in Pavlodar region (Shaldai, Aktogay, Bayanauyl, Krasnoarmeika); at Shaldai MS in Pavlodar region precipitation was absent throughout the month. According to data from 37 meteorological stations, moisture conditions were extremely dry (5 and 10 % extremes were recorded, Figure 3.3). In May in some regions of western oblasts, Priaralie, in the north of North Kazakhstan and Turkestan oblasts, north-west of Pribalkashye, as well as in some foothill areas of the south-east and east precipitation exceeded 130 % of the norm. In places in the west, south-west, north and south more than 160 and even 300 % of the norm (Figure 3.3). In 2 MSs (Kazaly and Fort-Shevchenko) May was among the 10 % of the wettest months. The most significant amount of precipitation (333.7 % of the norm) fell in the Kazaly MS (Kyzylorda region), which totaled 30.7 mm, 10.6 mm above the long-term average.

In summer, the average amount of precipitation over the territory was 94.8 % of the norm (rank - 49, probability of non-exceedance 41 %, Table 3.1). Three centers of excessive moistening were observed during the summer period - in the northern part of West Kazakhstan region (141-303 % of the norm), northern half of Kostanay region (143-209 % of the norm), south-eastern part of Turkestan and adjacent to it part of Zhambyl region (178-369 % of the norm). A significant exceedance of the norm by 1.8 times was also observed at MS Zhalanashkol (Zhetysu region). In 9 MSs located in the above regions, 5% extremes (extremely wet) were recorded, including the record seasonal amount of precipitation at the Kamenka MS (Figure 3.2). Precipitation deficit zones were observed in all regions (44-77 % of the norm), with severe precipitation deficits in the south-eastern part of Zhambyl, south-south-east of Kyzylorda and west of Mangistau regions (18-39 % of the norm). The amount of precipitation falling into the gradation ‘extremely dry’ (5% extremes) was recorded at 4 meteorological stations located in Zhambyl, East Kazakhstan, Pavlodar and Akmola regions.

Significant deficit of monthly precipitation totals remained in most regions during two summer months - June and July, and taking into account April and May - during 4 consecutive months (Figure 3.3). **In June**, a significant precipitation deficit was observed over most of Kazakhstan, with the average precipitation amounting to 59.2 % of the norm (the 4th driest month, Table 3.2). A significant deficit of precipitation was observed in Turkestan, Zhambyl, Karaganda, East Kazakhstan and Almaty regions, on average over the territory their amount was 12.0 % of the norm, 14.6 % of the norm, 29.6 % of the norm, 34.8 % of the norm and 39.6 % of the norm (5 % extremes), respectively. In Ulytau and Zhetysu regions, the month was among the 10 % driest Junes (Table 3.2). In West Kazakhstan, Aktobe and in some mountainous and foothill regions of the republic the prevalence of precipitation deficit over excess is noticeable. In June, 21 meteorological stations located mainly in Turkestan, Kyzylorda and Karaganda regions set records of minimum precipitation (Annex 2), of which 16 stations had no precipitation throughout the month. In 27 MSs located in different regions of the country, it was extremely dry (5 and 10% extremes were recorded (Figure 3.3). Excess moisture in June was observed in the northern regions (120-234 % of the norm), in mountainous and foothill areas of the south-east of the country (161-172 % of the norm), as well as in places along the northern and western border of western Kazakhstan (102-206 % of the norm), Figure 3.3. Extreme excess precipitation (90 and 95 % extremes) was observed locally at 4 MS in the northern region of the country.

In July, as well as in June, a strong deficit of precipitation remained in most of the territory of Kazakhstan, the average amount of precipitation was 71.5 % of the norm or 9.6 mm below the multiyear average (Table 3.2). Extremely dry (5 % extremes) was on the territory of Karaganda and North-Kazakhstan regions, on average on their territory the amount of precipitation was 29.7 % and 33.6 % of the norm (the fifth and third driest July in the series of observations since 1941), respectively. The entire southern part of the country (with the exception of the Southern Pribalkashye regions, where precipitation was 81-264 % of the norm), the Caspian Lowland, central and eastern regions of Kazakhstan and almost the entire territory of the northern region of the country were in the zone of severe precipitation deficit (less than 60 % of the norm), and sometimes extreme (less than 40 % of the norm and even 20 % of the norm) and record precipitation deficit (less than 6 % of the norm). At 6 meteorological stations located in the Turkestan, Kyzylorda and Karaganda regions were established record minimum precipitation (Annex 2), of which at 5 MS precipitation was absent throughout the month. According to data from 25 meteorological stations located in the northern, eastern, central and south-eastern regions, moisture conditions were characterized as extremely dry (5 and 10% extremes were recorded). In July, precipitation within 80-164 % of the norm was recorded in some areas of the north, north-east, east, Alakol depression, in Atyrau region and in the north of Aktobe region. Precipitation was significantly above the norm in South Pribalkashye, in Northern Priaralie (195-264 % of the norm) and in West Kazakhstan region (216-606 % of the norm, Figure 3.3). At the Kamenka MS the most significant and record amount of precipitation for the month fell 203 mm, the previous record - 133.1 mm, which was noted in 1959 (Annex 2). According to data from 5 meteorological stations located in the West Kazakhstan and Almaty regions, in July, moisture conditions were extremely wet - 5 and 10% extremes were observed.

In August in the northern, eastern, central, south-eastern, southern and eastern part of south-western regions of the country excess precipitation prevailed, on average over the territory of Kazakhstan monthly precipitation amounted to 175.8 % of the norm or 41 mm with a probability of non-exceedance of 96 % (the fourth wettest month in the series of observations since 1941, Table

3.2). In most of the territory of these regions, precipitation exceeded the norm by 1.5-6.0 times, and in the southern half of Turkestan and Zhambyl regions - by 7-28 times (Figure 3.3). In August, record precipitation maximums were set at 8 MSs (Annex 2). According to 58 meteorological stations, August 2023 was extremely wet (5% and 10% extremes were recorded). As a result, on average over the territory of the regions, record wetness was in Turkestan region (897.7 % of the norm) and extreme wetness (5 and 10 % extremes) was observed in 7 regions (Kostanay region (rank 2) and Karaganda region (rank 3), Ulytau, Abai, Zhetysu, Almaty, Zhambyl), where the average moisture content was from 173.8 to 300.4 % of the norm. Zones of significant precipitation deficit (less than 40 % of the norm and even 10 % of the norm) were observed in many regions of western Kazakhstan (Figure 3.3). At MS Chapaevo and Urda, located in the West Kazakhstan region, no precipitation was observed during the whole month - these are record values.

In autumn, the average layer of precipitation over the territory of Kazakhstan was 149.1 % of the norm or 117.9 mm - this is a record amount of precipitation for the season (rank 1), the previous record was observed in 1965 (148 % of the norm or 117.2 mm). Practically on the whole territory was extremely wet, except for the south of Kostanay region and southern part of Kazakhstan. On average over the regions, record wetness was in Kostanay, East Kazakhstan and Karaganda regions, and extreme wetness (5% extremes) - in Akmola and Abai regions (the 2nd wettest autumn since 1941), in Atyrau and North Kazakhstan (rank 3), Aktobe (rank 4) regions (Table 3.1, Figure 3.2). At 81 MSs located in the western, northern, central and eastern regions, 5% extremes were recorded, including record values at 27 meteostations. At 20 MSs of Kazakhstan it was very humid, 10% extremes were recorded.

Precipitation deficit (less than 80 % of the norm) was observed in the south of Kostanay region (55-73 % of the norm), in the western half of Kyzylorda region (52-64 % of the norm), at the southern junction of Kyzylorda and Turkestan regions (38 % of the norm), Zhambyl and Almaty regions (54-72 % of the norm) and in some other small areas across Kazakhstan (Figure 3.2). In 5 MS located in the south of the country there was a significant deficit of precipitation - less than 25 % of the norm.

In September, as well as in August, a significant excess of moisture was observed in most of the country. September was extremely wet - on average over the territory of Kazakhstan precipitation amounted to 193.7 % of norm (rank 2 with probability of non-exceedance of 98 %). Record wetness was in the East Kazakhstan, Akmola and Abai regions, with an average of 244.3-276.2 % of the norm (Table 3.2). In 82 MS located in the eastern part of Aktobe and Mangistau regions, northern, central, eastern and south-eastern regions were extremely wet (5 and 10 % extremes were recorded), including 10 MS with record values of maximum monthly precipitation (Figure 3.3, Annex 2). At the same time, a strong precipitation deficit was observed in the northern part of the western region and in the south of the country (less than 50 % of the norm, and in the south even less than 15 % of the norm). Five meteorological stations in the Turkestan region (Arys, Aschysai, Zhetysai, Kyzylkum, Shardara) did not receive precipitation during the whole month.

In October, the situation of excessive moisture continued practically on the whole territory of the country, the average amount of precipitation on the territory of the Republic was 151.8 % of the norm (rank 7, probability of non-exceedance of 92 %, Table 3.2). In the western (145-452 % of the norm), northern (130-338 % of the norm), central, eastern and south-eastern (146-288 % of the norm) regions, as well as in the eastern part of Kyzylorda, Turkestan and in the south of Ulytau regions (149-261 % of the norm) excessive precipitation was observed (Figure 3.3). Two

meteorological stations in the West Kazakhstan region recorded record maximum monthly precipitation: MS Karatobe (61.5 mm), the previous record was set in 2004 and was 58.1 mm, MS Zhanybek (79.3 mm), the previous record was 73.7 mm in 1954 (Annex 2). At 58 meteorological stations located in the western, northern, eastern, central and south-eastern regions, moisture conditions were characterized as extremely humid (90 and 95% extremes). In October, small zones with precipitation deficit (31-79 % of norm) were observed in the southern part of Kostanay region, north-eastern and some areas of southern regions of the country (Figure 3.3).

In November, excessive moisture is observed in most of the territory of Kazakhstan, on average over the territory of Kazakhstan precipitation was 116.5 % of the norm (probability of not exceeding 74 % of the norm). In the western (143-265 % of the norm), northern (127-336 % of the norm), central, some eastern regions and in the Turkestan region (139-180 % of the norm) excessive precipitation was observed (Figure 3.3). In the North Kazakhstan (202.8 % of the norm) and Kostanay (196.6 % of the norm) regions, November was among the 50 % of the wettest months. According to 6 MS located in the western and northern regions of the country records of maximum monthly precipitation were set (Annex 2). At 30 meteorological stations located in the western, northern and western part of the central regions, moisture conditions were characterized as extremely humid (90 and 95% extremes were recorded). Precipitation deficit, in some places strong was observed in several foci: in the western part of Mangistau region (29-76 % of the norm); practically on the whole territory of Kyzylorda region (47-70 % of the norm) and a large focus occupying the territory of Zhambyl, Almaty, Zhetysu, Abai and south-eastern part of Karaganda regions (24-74 % of the norm), 4 meteorological stations in these areas were extremely dry (Figure 3.3).

To assess the extremes of precipitation in 2023, climate change indices recommended by the World Meteorological Organization were assessed. Below is an analysis of some of the most representative precipitation indices and peculiarities of distribution of their values over the territory of Kazakhstan in 2023.

Figure 3.4 presents the values of absolute maximum daily precipitation recorded from the beginning of the weather station opening to 2023 (shown in blue).

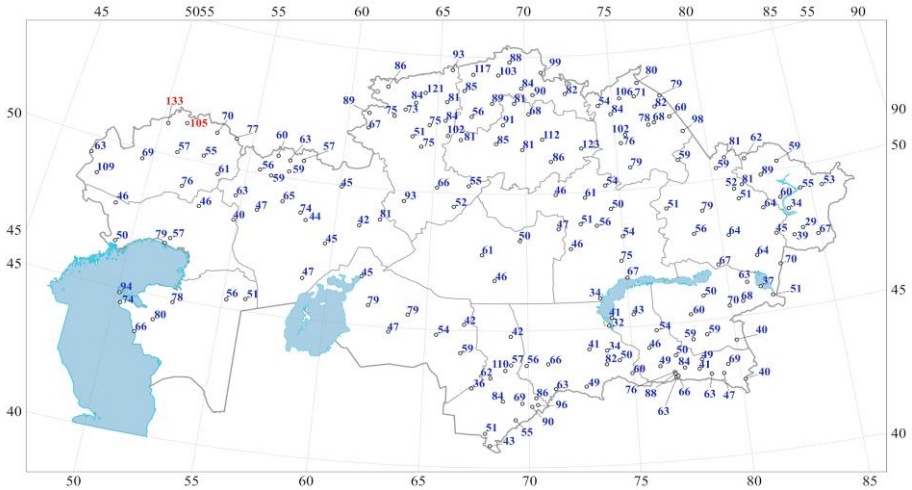


Figure 3.4 – Absolute maximum daily precipitation (in mm), selected for the period from the opening of the meteorological station until 2023. If the record daily precipitation was recorded in 2023, the value is marked in red

The values of daily precipitation maximums that overlapped the previous absolute maximum in 2023 are shown in red. In 2023, the value of the absolute maximum of precipitation was exceeded at two meteorological stations in Kazakhstan: at MS Kamenka 133.4 mm fell during the day, the previous maximum was in 28 July 1959 and was 66.5 mm and at MS Uralsk, where 104.7 mm fell during the day, the previous maximum of daily precipitation was observed on 25 July 1992 and was 79.3 mm.

The daily maximum precipitation, selected based on data for 2023 (***Rx1day index***), was 10-30 mm over most of the territory of Kazakhstan (Figure 3.5). The highest daily maximum precipitation was observed in the north-west of the country (105-133 mm), in the northern part of the Karatau Ridge (84 mm, Tur. In the north, north-east and in the foothill and mountainous regions of the south and south-east it was more than 30-40 mm in some places, in Karaganda region more than 50 mm in some places. The lowest maximum daily precipitation (less than 10 mm) was observed in the south-western part of Mangistau region, in the south of Kyzylorda region and in the sands of Saryesik Atyrau (Almaty region)

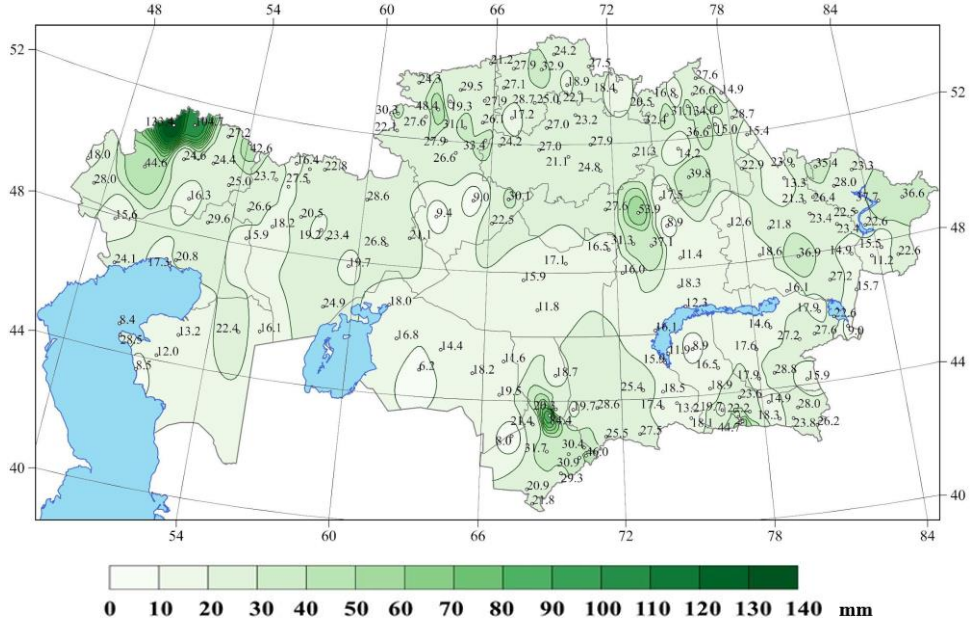


Figure 3.5 – Daily maximum precipitation in 2023 *(Rx1day index)*

In 2023, ***the share of very heavy precipitation*** (when daily precipitation is equal to or greater than the 95th percentile, r95ptot index) in annual precipitation over most of Kazakhstan was less than 20 per cent (Figure 3.6). The greatest contribution of very heavy precipitation (more than 40-50%) was observed in the north-eastern part of Mangistau region, as well as in places in the north of West Kazakhstan, Kostanay, in mountainous areas of the south-east and Turkestan regions. In different regions of Kazakhstan daily precipitation did not reach the 95th percentile.

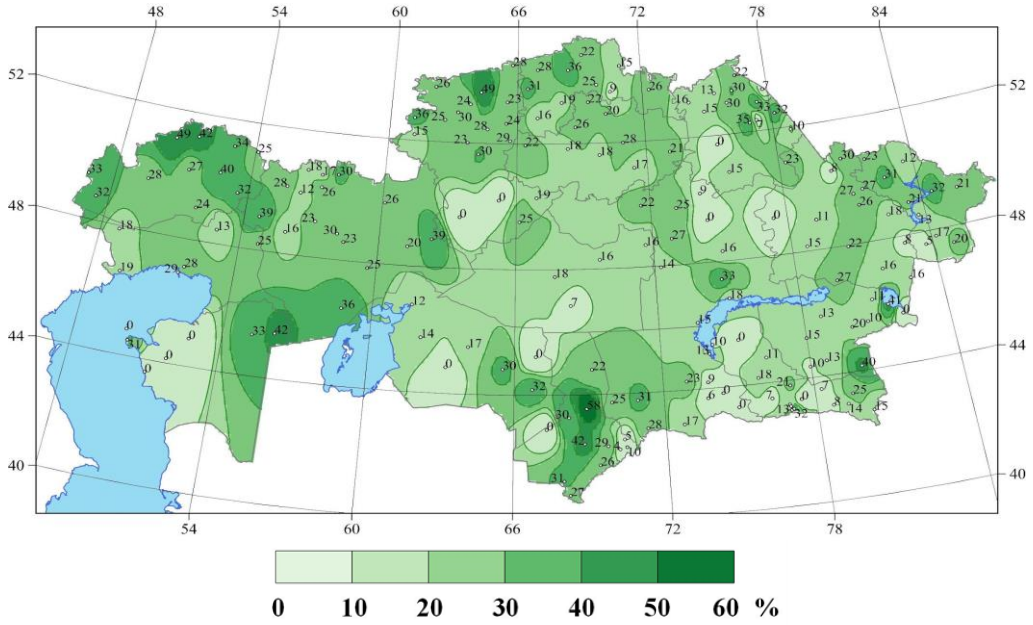


Figure 3.6 – Share (in %) of extreme daily precipitation in the annual total precipitation for 2023 (*индекс r95ptot*)

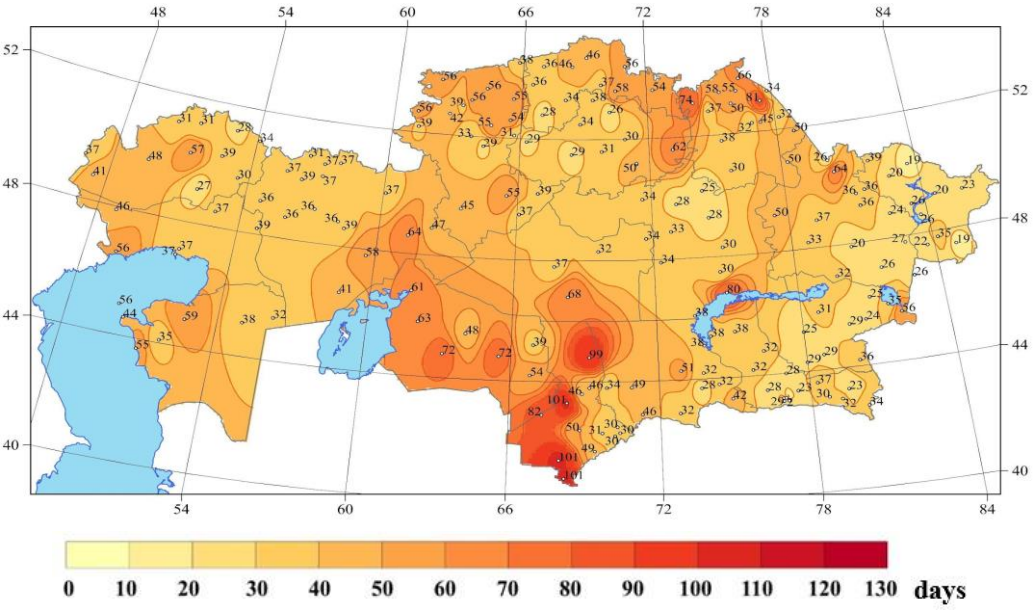


Figure 3.7 – Maximum duration of the dry spell in 2023, in days (CDD index)

In the arid climate of Kazakhstan, the CDD index is very important, which shows the ***maximum duration of the rainless period***, *when the daily amount of precipitation was less than 1 mm*. In 2023, in most of the territory of the country, the maximum continuous duration of the rainless period was 20-50 days. The longest duration of the dry period was observed in the Turkestan, Kyzylorda, Pavlodar, north-east Abay regions, in the northern Pribalkashye - more than 70 days (Figure 3.7). The maximum duration of the rain-free period was recorded in the Turkestan region at several meteorological stations: MS Turkestan, Shardara, Zhetysai (101 days without precipitation), MS Tasty (99 days without precipitation), MS Akkum (82 days without precipitation), in the Karaganda and Pavlodar regions - at MS Balkash and Uspenka (80 and 81 days without precipitation, respectively). The shortest duration of the rain-free period (19 days) was observed at MS Leninogorsk and MS Zaisan in the East Kazakhstan region.

3.2 Observed changes in the amount of precipitation

Linear trends in the series of monthly, seasonal and annual precipitation totals were estimated from data of the 121st station.

Time series of anomalies of annual and seasonal precipitation totals for the period 1941-2023, 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 precipitation regime (Table 3.3, Figures 3.8 and 3.9). Annual precipitation on average over the territory of Kazakhstan decreased in the 1960s and 1970s, in the last 40-year period long-period trends were absent, there was an alternation of short periods with positive and negative anomalies of precipitation.

In the period 1976-2023 trends in the average over the territory of Kazakhstan relative anomalies of annual and seasonal precipitation amounts are practically absent - the share of the trend component in the total variance of the series, mainly does not exceed 3%, the positive sign of the trend is observed for winter, spring and annual precipitation amounts, for summer and autumn - negative (Table 3.3, Figure 3.8).

Table 3.3 – Characteristics of the linear trend of seasonal and annual precipitation anomalies (% of the norm per decade), averaged over the territory of Kazakhstan and its oblasts for the period 1976–2023

Region	Year		Winter		Spring		Summer		Autumn	
	a	D	a	D	a	D	a	D	a	D
Kazakhstan	0,5	0	0,7	0	2,1	2	-0,4	0	-0,7	0
Abai	1,4	1	0,7	0	0,4	0	3,2	2	0,7	0
Almaty	0,4	0	1,5	0	0,5	0	-0,8	0	1,1	0
Akmola	3,5	6	**8,1**	**10**	1,5	1	2,1	1	3,6	2
Aktobe	-1,2	1	-1,6	0	5,1	3	-5,3	3	-3,7	3
Atyrau	3,3	3	7,3	5	**17,5**	**14**	-7,7	4	-1,9	0
East Kazakhstan	0,9	1	1,9	1	1,2	0	-0,2	0	1,2	0
Zhambyl	-1,6	1	-1,3	0	-1,3	0	0,9	0	-3,8	2
Zhetysu	1,2	1	4,1	2	2,6	1	-0,9	0	-1,0	0
West Kazakhstan	0,0	0	-3,1	3	**10,5**	**13**	-5,0	3	-0,6	0
Karaganda	0,6	0	0,6	0	-1,3	0	3,7	2	-2,1	1
Kostanay	-0,3	0	-1,0	0	5,5	5	-2,1	1	-2,3	1
Kyzylorda	-4,7	6	-0,4	0	-2,9	1	-6,4	1	**-11,5**	**15**
Mangystau 1	-5,0	5	5,7	2	-10,8	7	-4,8	1	-4,6	1
Pavlodar	1,3	1	1,0	0	2,6	1	0,9	0	1,2	0
North Kazakhstan	2,0	2	2,8	1	**8,1**	**9**	-0,3	0	0,5	0
Turkestan	0,3	0	-0,1	0	1,0	0	2,9	0	-1,4	0
Ulytau	0,5	0	-3,3	3	2,8	1	3,5	1	-0,9	0

* a – linear trend coefficient, % of the norm per decade;

** D – coefficient of determination, %;

*** - statistically significant trends are highlighted in bold.

In most regions, the trends of both increase and decrease in annual precipitation are insignificant, the coefficient of determination is 3 % and less. In Akmola region, the rate of increase

in annual precipitation was about 3.5 norm/10 years with a coefficient of determination of 6 %. In Kyzylorda and Mangistau regions, precipitation decreased at a rate of 4.7 and 5.0 % of the norm/10 years with a coefficient of determination of 6 % and 5 %, respectively (Table 3.3, Figure 3.9). On average for the territory of Kazakhstan in the period 1976 - 2023, there is a slight tendency to increase the annual amount of precipitation by 0.5 % of the norm/10 years (Table 3.3).

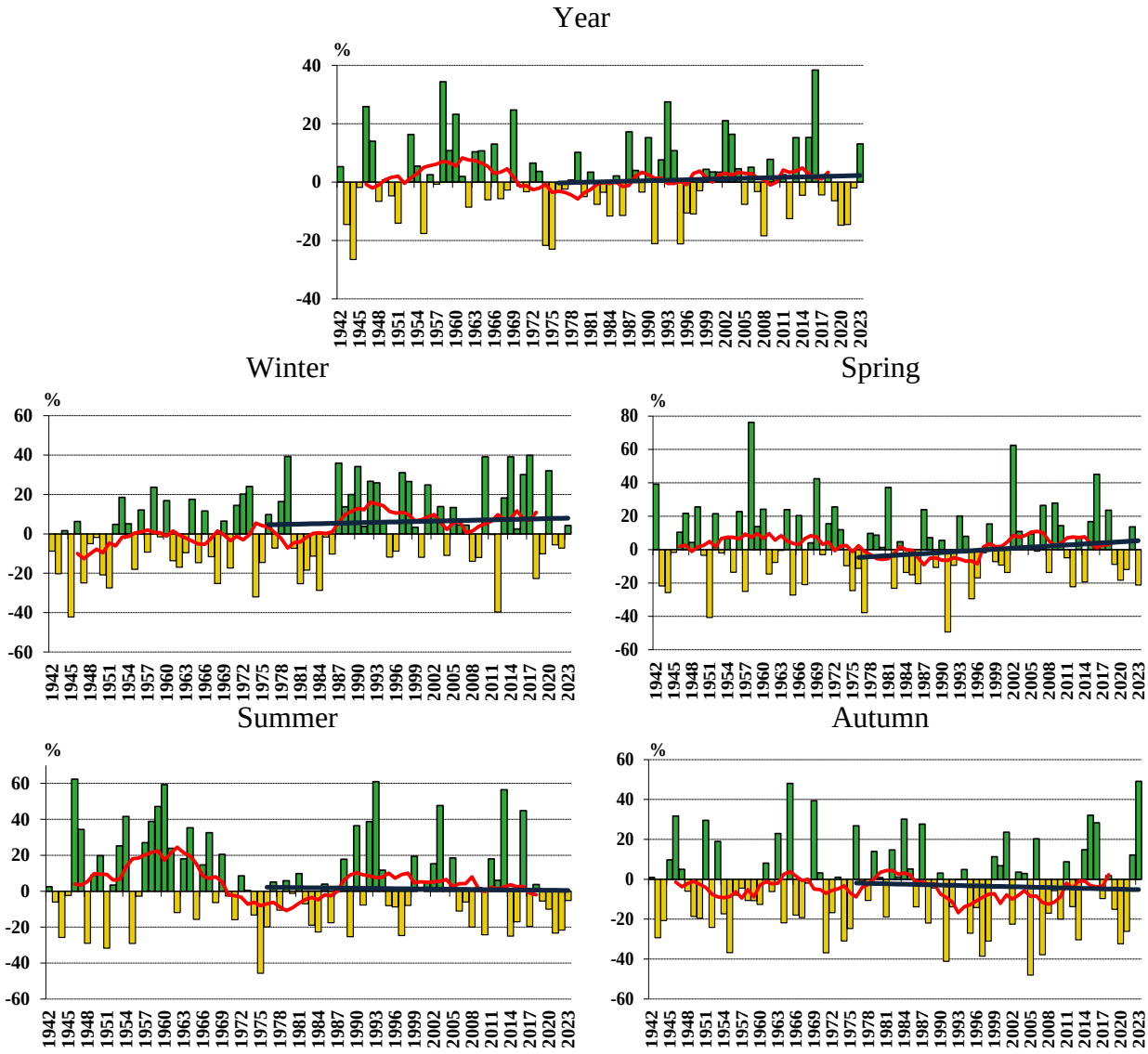


Figure 3.8 – Time series of anomalies of annual and seasonal precipitation sums (%), spatially averaged over the territory of Kazakhstan for the period 1941–2023. Anomalies are calculated relative to the baseline period 1961–1990. The linear trend for the period 1976–2023 is shown in black. *The smoothed curve is obtained using an 11-year moving average*

In the winter period in average for Kazakhstan the trends of relative anomalies of seasonal precipitation amounts slightly increased - by 0.7 % of the norm/10 years. The most significant trends of precipitation increase are observed in Akmola region - by 8.1 % of the norm/10 years (coefficients of determination are 10 %), Atyrau region - by 7.3 % of the norm/10 years (coefficient of determination is 5 %), Mangistau and Zhetysu regions - by 5.7 and 4.1 % of the norm/10 years (coefficients of determination are 2 %), respectively (Table 3.3, Figure 3.9). The tendency to increase precipitation in Akmola region is statistically significant. A noticeable decrease in precipitation on

average over the territory is noted in West Kazakhstan and Ulytau regions - by 3.1 and 3.3 % of the norm/10 years, respectively (coefficients of determination are 3 %).

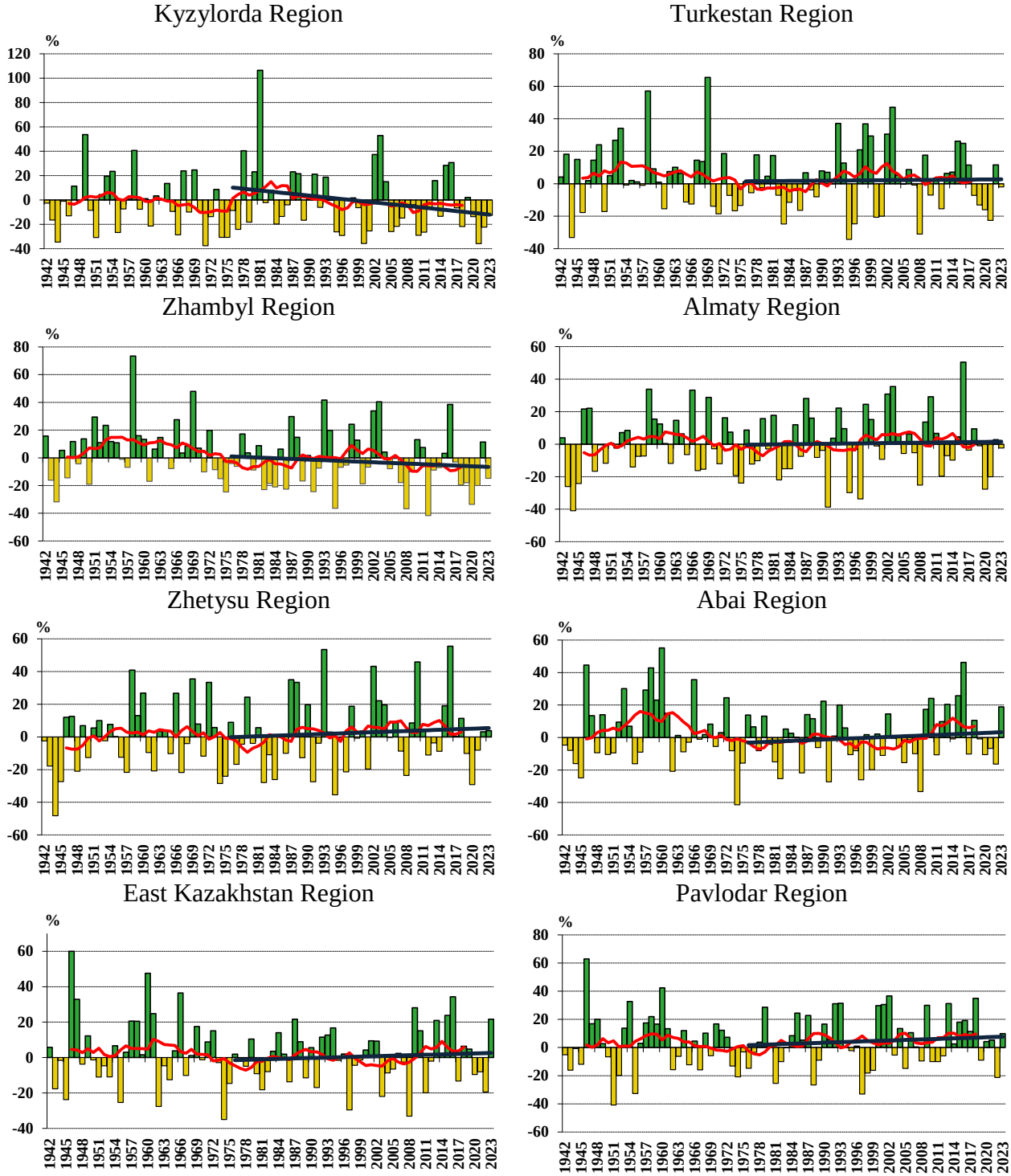


Figure 3.9 – Time series of anomalies of annual precipitation sums (%) for the period 1941–2023, spatially averaged by oblasts of Kazakhstan. Anomalies are calculated relative to the baseline period 1961–1990. The linear trend for the period 1976–2023 is shown in black. *The smoothed curve is obtained using an 11-year moving average. Sheet 1*

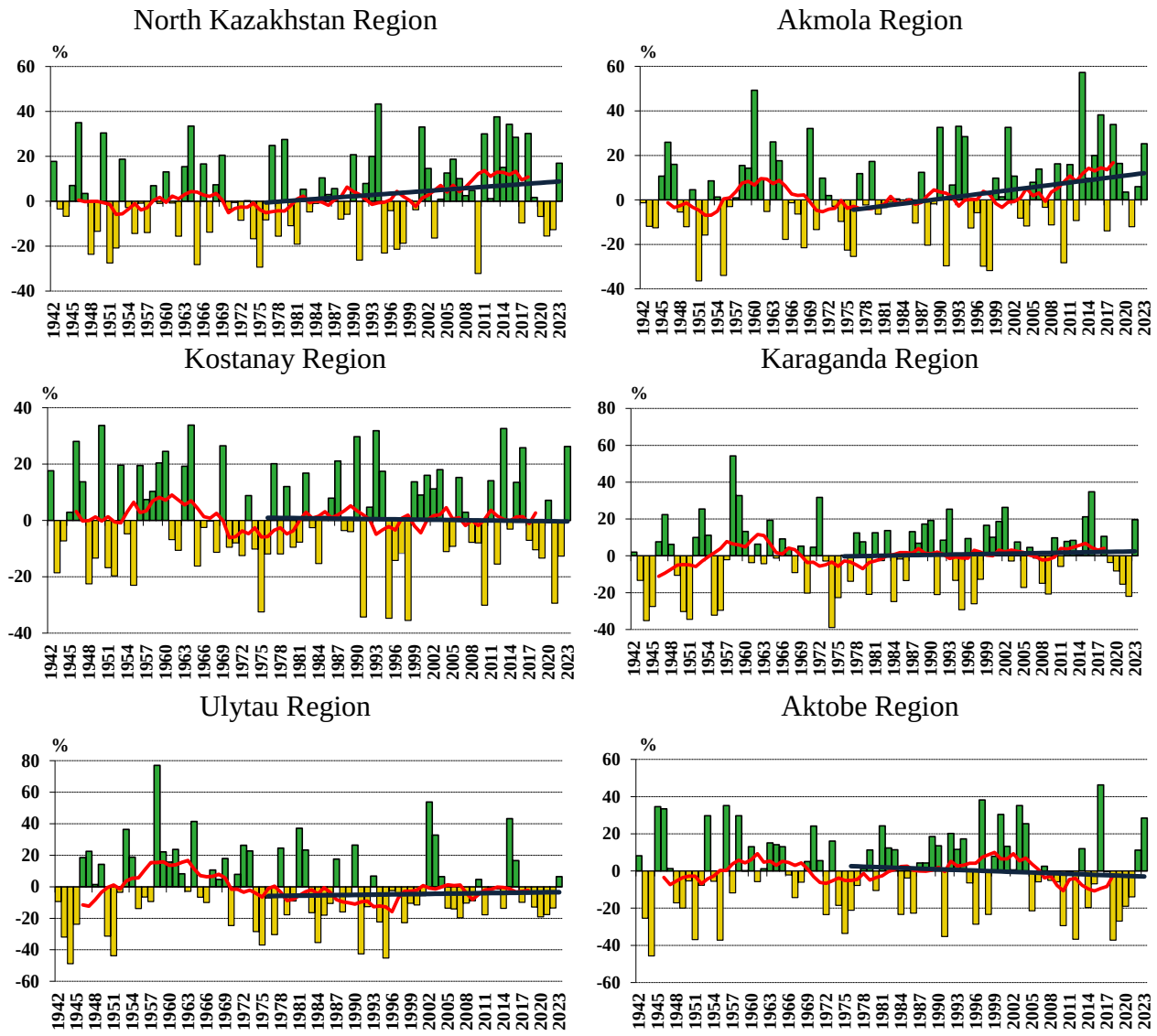


Figure 3.9 – Time series of anomalies of annual precipitation sums (%) for the period 1941–2023, spatially averaged by oblasts of Kazakhstan. Anomalies are calculated relative to the baseline period 1961–1990. The linear trend for the period 1976–2023 is shown in black. *The smoothed curve is obtained using an 11-year moving average*. *Sheet 2*

Average ***spring*** precipitation in Kazakhstan increased slightly - by 2.1 % of the norm every 10 years. On the territory of most regions the trends in precipitation are positive, but also insignificant. The highest rate of precipitation increase was observed in the western (West Kazakhstan and Atyrau regions) and northern (Kostanay and North Kazakhstan regions) regions of the republic - by 5.5-17.5 % of the norm/10 years with coefficient of determination 5-14 % (Table 3.3, Figure 3.9). These trends are statistically significant, except for Kostanay region. The greatest contribution to the increase in precipitation in the spring season is in March, when stable statistically significant trends are observed almost throughout Kazakhstan. The decreasing trend of spring precipitation is observed in the south-west, south of Kostanay region, in Kyzylorda, Zhambyl and Karaganda regions, in South Pribalkashye, here statistically significant trends of decreasing precipitation are observed at some stations. A noticeable statistically significant trend of decreasing precipitation by area is observed in the Mangistau region - by 10.8 % of the norm/10 years with a coefficient of determination of 7 %.

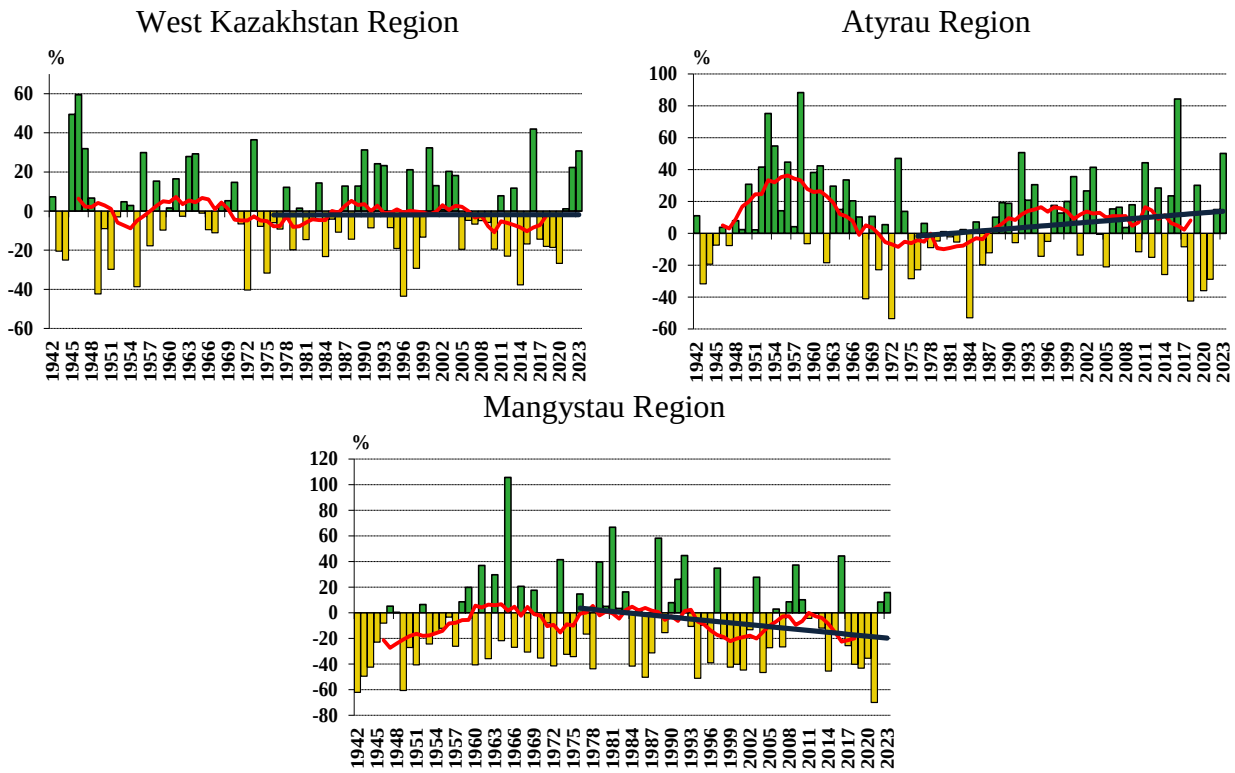


Figure 3.9 – Time series of anomalies of annual precipitation sums (%) for the period 1941–2023, spatially averaged by oblasts of Kazakhstan. Anomalies are calculated relative to the baseline period 1961–1990. The linear trend for the period 1976–2023 is shown in black. *The smoothed curve is obtained using an 11-year moving average*. *Sheet 3*

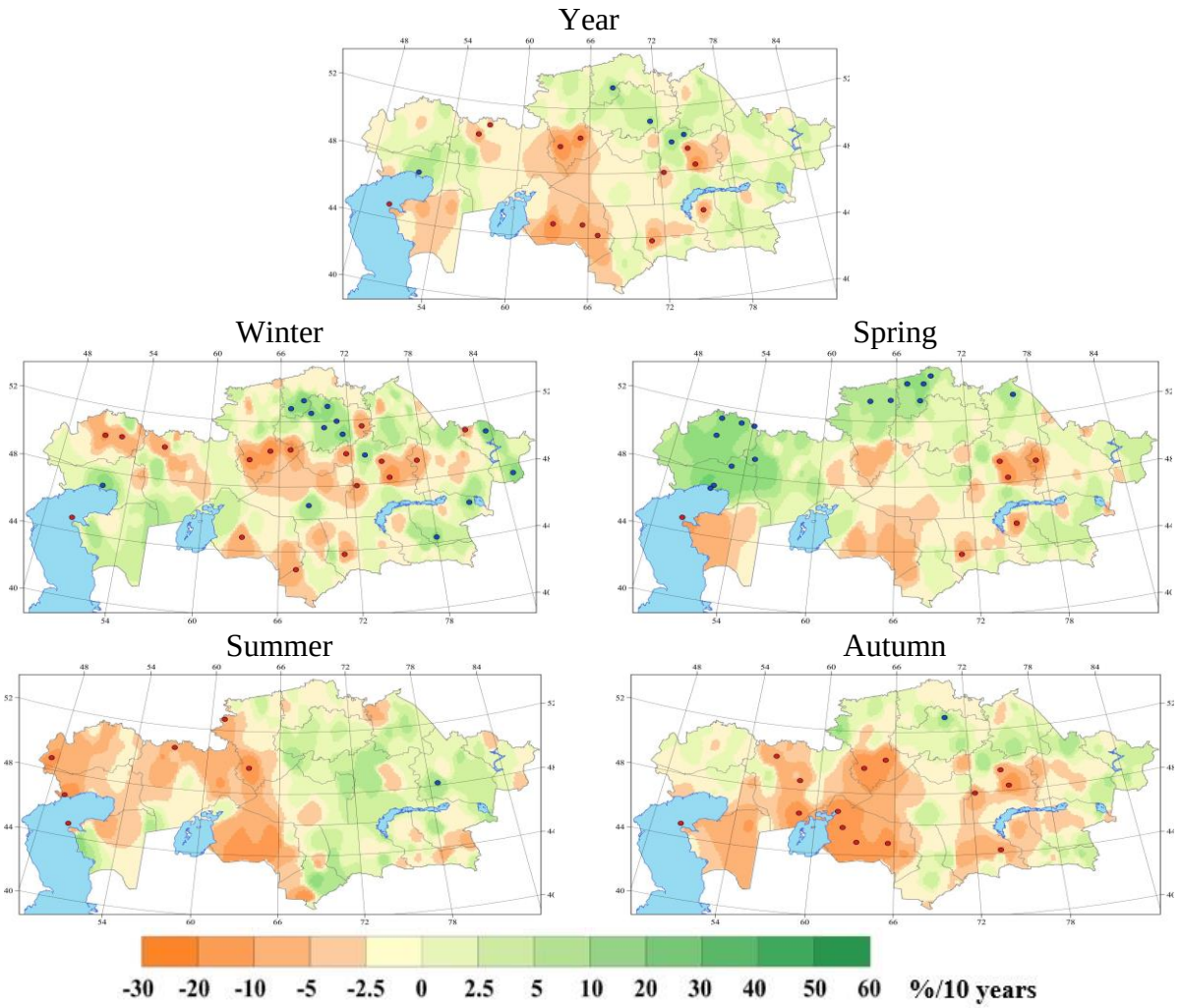
In summer, trends in the amount of seasonal precipitation in all regions of Kazakhstan are weakly expressed, as the share of the trend in the total dispersion is insignificant and does not exceed 4 %. The most significant tendencies to decrease in precipitation are in Atyrau region - by 7.7 % of norm/10 years (coefficient of determination is 4 %), Kyzylorda region - by 6.4 % of norm/10 years (coefficient of determination is 1 %), Aktobe and West Kazakhstan regions - by 5.3 and 5.0 % of norm/10 years (coefficients of determination are 3 %) and Mangistau region - by 4.8 % of norm/10 years (coefficient of determination is 1 %) (Table 3. 3, Figure 3.9).

In autumn in most regions, the trends in precipitation during the autumn season are negative. The most significant precipitation reduction rates are observed in Mangistau and Kyzylorda regions - by 4.6 and 11.5 % of normal/10 years, respectively, with coefficient of determination of 1 and 15 %, respectively. The trend of precipitation decrease in Kyzylorda region is statistically significant (Table 3.3, Figure 3.9).

More detailed information on the nature of changes in precipitation regime in Kazakhstan is provided by spatial distribution of linear trend coefficient values of annual, relative anomalies of seasonal and separately for each month precipitation amounts (% of normal/10 years) presented in Figures 3.10 and 3.11. Estimates were obtained from station time series of annual, seasonal and monthly precipitation anomalies for the period 1976-2023.

There is a patchiness in the direction of change in seasonal and monthly precipitation (Figures 3.10 and 3.11). **In winter**, a significant increase in precipitation was recorded in several regions - in the north (mainly in Akmola region), south-west, south-east and east (by 9-17 % of the norm /10

years). February was the main contributor to this increase (Figure 3.11). Statistically significant tendency to decrease seasonal precipitation is observed in the north-western and central regions, in the south of Kyzylorda and Zhambyl regions and is within 7-12 %/10 years.



significant positive and negative values of the linear trend coefficient are highlighted in green (increase in precipitation) and red (decrease in precipitation)

Figure 3.10 – Spatial distribution of the linear trend coefficient values of annual and seasonal precipitation sums (% per decade), calculated for the period 1976–2023

In December, decreasing trends in precipitation were observed in the northern and north-western parts, in the eastern part of central Kazakhstan, as well as in the southern and south-eastern half of Kazakhstan (Figure 3.11). Significant downward trends in precipitation were observed at some meteorological stations in the north of West Kazakhstan and south of Kostanay regions (by 10-15 % of the norm /10 years), in central and eastern regions (by 9-15 % of the norm /10 years), in the southern region (by 12-18 % of the norm /10 years).

In January, decreasing precipitation trends are observed in the north of the western region, in the central region, in the north-east, some small pockets in the north and in the mountainous regions of the south, south-east (Figure 3.11). Statistically significant trends of decreasing precipitation are observed at some stations in the central and western part of the country within 10-12 %norm/10 years.

Increasing trends of precipitation are observed in some regions of the north (by 15-17 %/10 years), in the eastern region, in the south and south-east of the country (13-22 % of the norm/10 years).

In February, an increase in precipitation is observed almost throughout Kazakhstan, but there are several large centres where there is a tendency to decrease precipitation: in the southern region - the western part of Mangistau, southern part of Kyzylorda, northern part of Turkestan and Zhambyl regions, as well as southern Pribalkashye; in the central region - the southern part of Kostanay region and the area of the Kazakh Shallow Soil. Statistically significant tendency to increase monthly precipitation is observed in the northern and south-eastern regions, as well as in places in the eastern and central parts of the country in the range of 11-27 %/10 years. Zones with statistically significant tendencies to decrease precipitation are noted at some stations located in the Kazakh Shallow Soil, in the north in East Kazakhstan, south of Kostanay and west of Mangistau regions - 16-21 % of the norm for each 10 years (Figure 3.11).

In spring, a steady statistically significant increase in the amount of seasonal precipitation is observed in the western (by 10-25 % of the norm/10 years) and northern (by 8-13 % of the norm/10 years) regions of the country. There are no statistically significant trends in the southern half of Kazakhstan, except for small areas where precipitation decreases significantly (Figure 3.10).

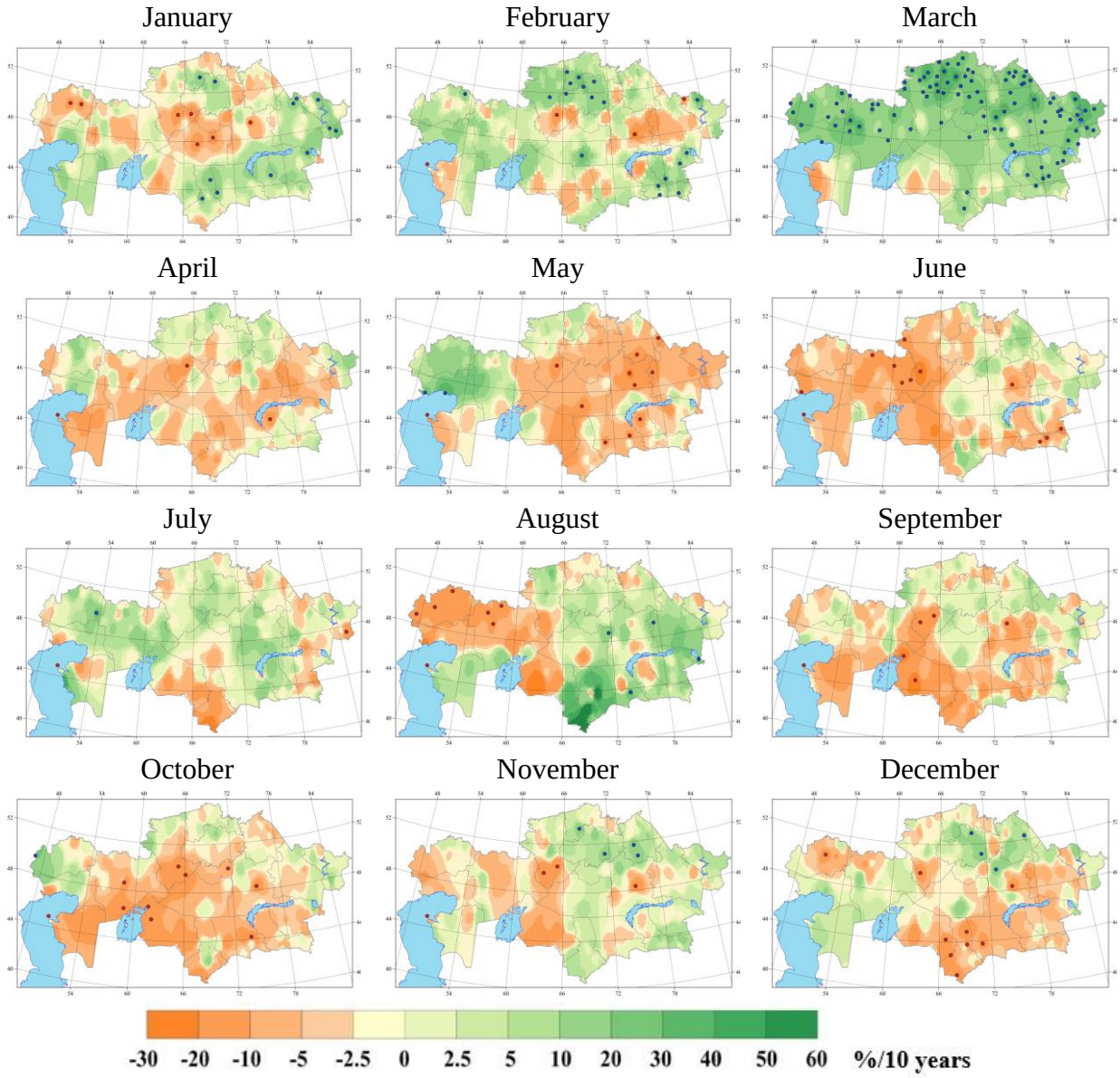
Among spring months, **March** stands out, when a statistically significant increase in monthly precipitation totals is recorded over most of Kazakhstan: in the northern (by 16-43 % of the norm/10 years), western (by 11-34 % of the norm/10 years), southern, mainly southern Turkestan, Almaty and Zhetysu regions by 11-23 % of the norm/10 years, central and eastern (by 13-37 % of the norm/10 years) regions of the country (Figure 3.11).

In April on the territory of Kazakhstan the tendency to decrease of monthly precipitation amounts prevails, two large centres are observed - one centre is located in the direction from south-west to north-east, trends in this zone are statistically insignificant, except for values on MS Kulaly Island and MS Amangeldy, where the amount of precipitation decreases by 34.0 and 15 % of the norm/10 years, respectively; the second centre, covers part of the southern and central regions, the regions of Pribalkash and Alakol, as well as the region of Abay; stable trends in this centre are also absent, except for MS Aul-4, where the rate of decrease in precipitation is 15 % of the norm/10 years. Zones of precipitation increase are observed to the north of the Caspian Sea, covering the West Kazakhstan region, in the northern and north-eastern regions, as well as in the foothill areas of the south-east and east of the country. There are no statistically significant trends in the increase of precipitation.

In May in most of the eastern half and south-west of the country there is a tendency to decrease precipitation. According to data from 7 meteorological stations located in the north-eastern and central parts of the country and in the south of Kostanay region, as well as 3 meteorological stations in the southern regions and one meteorological station in Mangistau region, the downward trend in monthly precipitation is statistically significant. Trends of increasing precipitation are observed in several regions - in the north-west, west and some areas in the south of Kazakhstan. Statistically significant trends of increasing precipitation are observed only at some stations in the coastal part of the Caspian Lowland within 27-37 % of normal/10 years (Figure 3.11).

In summer, an extensive region of precipitation decrease covers the western half of the territory of the Republic (up to -16 % of the norm/10 years in the Caspian and Turanian lowlands),

with statistically significant trends in seasonal precipitation recorded at some stations in this region. The tendency for the increase of summer precipitation is noted in the coastal part of the Northern Caspian Sea, in the south, east and north of Lake Balkash (up to 16 % of the norm/10 years). Trends of both signs are rarely statistically significant (Figure 3.10).



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

Figure 3.11 – Spatial distribution of the linear trend coefficient values of monthly precipitation (% per decade), calculated for the period 1976–2023

In June, most of the western half of Kazakhstan, the central part of the Kazakh Shallow Basin and the south-eastern region are in the zone of precipitation decrease (Figure 3.11). The most significant and statistically significant trends of decrease in monthly precipitation by 11-24 % of normal/10 years are observed at 12 meteorological stations located in the Caspian Sea region, in the eastern part of Aktobe and western part of Kostanay regions, in the centre of Karaganda region and

in mountainous and foothill areas of the southeast. Increasing precipitation trends are observed over most of the eastern region of Kazakhstan, but there are no statistically significant precipitation trends.

In July, most of the country shows increasing trends in precipitation (Figure 3.11), but there are small pockets in different parts of the country where decreasing precipitation is recorded. The most significant tendencies to increase precipitation are observed in the West Kazakhstan, Aktobe, central region, Zhambyl and Almaty regions by 10-23 % of the norm/10 years, and in the east of the country - by 7-12 % of the norm/10 years. At the same time, a statistically significant trend of precipitation increase is noted only at the Karatobe MS (West Kazakhstan region) by 21 % of the norm/10 years. A noticeable decrease in precipitation over the territory of Kazakhstan is noted in Kyzylorda and Turkestan regions - by 6-26 % of the norm/10 years, in Ulytau region - by 1-7 % of the norm/10 years, in some places in the western, north-western and eastern regions. Statistically significant trends of decreasing precipitation over the territory of Kazakhstan are practically absent, except for two meteorological stations: MS Zaisan (13 % of the norm/10 years, coefficient of determination 13 %) and MS Kulaly island (24 % of the norm/10 years, coefficient of determination 12 %).

In August, as well as in June, precipitation decreasing trends are observed everywhere in the western half of the country (except for Mangistau region). Statistically significant decreasing precipitation trends were recorded only at 7 meteorological stations located in the northern part of West Kazakhstan and Aktobe regions, and in the western coastal part of Mangistau region and amounted to 11-20 % of normal/10 years (Figure 3.11). Trends to increase precipitation are observed in Mangistau region (by 3-13 % of the norm/10 years), in most of the eastern half of Kazakhstan (by 3-25 % of the norm/10 years), trends in these zones are statistically insignificant, except for values at 6 meteorological stations located in the central, southern and southeastern regions, where precipitation increases by 16-75 % of the norm/10 years.

In autumn, most of the territory was in the zone of negative trends in precipitation (Figure 3.10). Precipitation totals for the autumn season significantly decreased according to many meteorological stations in Mangistau, Aktobe, southern part of Kostanay, Kyzylorda regions, in some places in central and southern regions. In these regions at some stations there is a significant (at the level of 5 %) decrease in precipitation within 8-21 % of the norm/10 years, with the coefficient of determination being 9-41 %. Tendencies to increase precipitation are observed in the north, east, mountainous and foothill regions of the southeast (Figure 3.10).

In September, downward trends in the amount of precipitation are recorded in most parts of the country. The most significant precipitation reduction rates are observed in Mangistau, in some areas of Aktobe, south of Kostanay, Karaganda, Kyzylorda regions, in the southern and south-eastern regions (by 5-16 % of normal/10 years), but at most stations the trends are statistically insignificant. Statistically significant trends are noted only at 6 meteorological stations located in the south of Kostanay, Kyzylorda and Karaganda regions, where the rate of precipitation decrease is in the range of 16-24 % of the norm/10 years, with the share of variance explained by the trend being 9-15 %. In some western, northern, eastern, central and south-eastern regions there is a weak tendency to increase precipitation (Figure 3.11).

In October, as well as in September, on the territory of Kazakhstan, mainly weak trends were observed, both in the direction of increasing and decreasing precipitation. On the most part of the

territory of the country there is a decrease in the amount of precipitation (Figure 3.11). In the south-western, central and southern regions, statistically significant precipitation reduction rates of 10-27 % of normal/10 years are observed, with a coefficient of determination of 8-28 %. The most significant rates of precipitation decrease are observed in the Kulaly Island MS (Mangistau region). In some areas in the extreme west, north and east, trends of increasing precipitation are practically absent, the share of the trend component in the total dispersion of the series is not more than 3 %. The most significant rates of increase in precipitation are observed in the extreme west and north-west of the country (6-14% of the norm/10 years), and statistically significant increase in precipitation only at MS Zhanybek (West Kazakhstan region) by 25 % of the norm/10 years, with the share of variance explained by the trend is 12 %.

In November, the decreasing trends of precipitation were mainly observed in the western half of Kazakhstan, the Kazakh Shallow Basin and some areas of the southern region. At most stations the trends are statistically insignificant. Statistically significant trends were observed only at 4 meteorological stations located in these regions, where the rate of precipitation decrease was in the range of 16-23 % of the norm/10 years, with the proportion of variance explained by the trend being 12-27 %. A stable trend of the most significant decrease in precipitation is observed at MS Aktogay (Karaganda region) by 19 % of the norm/10 years, with the share of variance explained by the trend being 27 %. Trends to increase in precipitation are observed in most of the northern, north-eastern, western part of the central, mountainous and foothill areas of the eastern and southern regions of Kazakhstan. At most stations in these regions, the trends are mostly statistically insignificant, except for values at 4 meteorological stations located in the northern and north-eastern regions, where a significant tendency to increase precipitation by 13-18 % of normal/10 years is observed, with a coefficient of determination of 9-15 % (Figure 3.11).

Annual precipitation amounts decrease significantly in some north-western, central and southern regions (by 6-12 % of the norm/10 years), and increase significantly only according to data from a few stations in the northern, north-eastern part of the central regions (by 4-8 % of the norm/10 years, Figure 3.10).

3.3 Trends in precipitation extremes

Figure 3.12 shows the change in the maximum duration of the rain-free period when daily precipitation was less than 1 mm (CDD index). For the territory of Kazakhstan, weak trends are noted, both in the direction of decrease and in the direction of increase of the dry period by 1-4 days/10 years. Trends are mainly insignificant, except for some stations in the northern, north-eastern and eastern part of the central regions, where a statistically significant decrease of such period was recorded; and in the south-western region, Priaralie and some mountainous areas of the south-eastern region, an increase in the maximum duration of the dry period by 1-6 days/10 years was recorded.

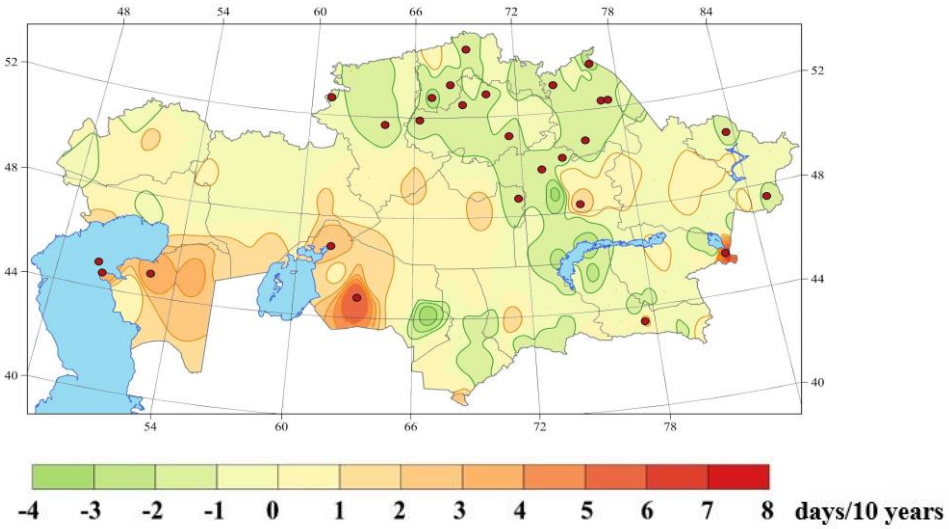


Figure 3.12 – Rates of change in the maximum duration of the dry spell (days per decade) for the period 1961–2023 (CDD index)

ANNEX 1

RECORD VALUES OF AVERAGE MONTHLY AIR TEMPERATURES SET IN 2023

№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C	№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C
	February, 2023				24	Chapaevo	West Kazakhstan	5,5	5,4 (2020)
1	ZhetysayNature Reserve	East Kazakhstan	-13,6	-14,2 (1998)	25	Atyrau	Atyrau	8,6	7,3 (2020)
	March, 2023				26	Ganyushkino	Atyrau	7,7	6,7 (2020)
1	Zhosaly	Kyzylorda	8,0	7,9 (2008)	27	Karabau	Atyrau	7,0	6,1 (2020)
2	Arys	Turkestan	12,7	12,5 (2008)	28	Novyi Ushtegan	Atyrau	7,9	6,9 (2020)
3	Zhetysay	Turkestan	14,4	13,9 (2008)	29	Peshnoy	Atyrau	6,8	6,2 (2020)
4	Kazygurt	Turkestan	13,3	13,0 (2008)		**June, 2023**			
5	Kyzylkum	Turkestan	12,3	12,2 (2008)	1	Kordai	Zhambyl	22,8	22,5 (2008)
6	Tasaryk	Turkestan	10,2	9,6 (2008)	2	Kazygurt	Turkestan	27,3	26,9 (2021, 2001)
7	Turkestan	Turkestan	13,1	12,6 (2008)	3	Shardara	Turkestan	29,4	29,0 (2022, 2021)
8	Shardara	Turkestan	13,1	12,8 (2008)	4	Shymkent	Turkestan	27,5	26,9 (2021)
9	Shymkent	Turkestan	13,3	12,9 (2008)		**July, 2023**			
10	Karaukeldy	Aktobe	5,2	4,7 (2008)	1	Bektauata	Karaganda	26,8	26,3 (1974)
11	Martuk	Aktobe	1,7	1,2 (2008)	2	Besoba	Karaganda	22,8	22,5 (1974)
12	Novoalekseevka	Aktobe	3,1	2,8 (2008)	3	Karaganda	Karaganda	23,9	23,8 (1974)
13	Uil	Aktobe	5,4	4,8 (2020, 2008)	4	Kyzyljar	Karaganda	27,0	26,5 (1974)
14	Aktau	Mangystau	9,9	8,9 (2020)	5	Korneevka	Karaganda	22,777	22,0 (1974)
15	Beineu	Mangystau	9,6	9,3 (2008)	6	Saryshagan	Karaganda	27,4	27,0 (2015)
16	Kyzan	Mangystau	10,3	9,3 (2008)	7	Zhanaarka	Ulytau	24,9	24,5 (1974, 1940)
17	Tushchibek	Mangystau	10,2	9,4 (2008)	8	Aksuat	Abai	24,9	24,7 (2021)
18	Fort-Shevchenko	Mangystau	9,6	8,9 (2020)	9	Aktogay	Abai	27,2	27,0 (1965)

№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C	№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C
19	Kulaly Island	Mangystau	7,8	7,3 (2020)	10	Ayagoz	Abai	23,7	23,6 (1974)
20	Zhanibek	West Kazakhstan	6,4	5,5 (2020)	11	Barshtatas	Abai	24,6	24,5 (1974)
21	Zhalpaktal	West Kazakhstan	6,2	5,8 (2020)	12	Kaynar	Abai	22,1	21,6 (1974)
22	Taipak	West Kazakhstan	6,1	6,0 (2020)	13	Karauyl	Abai	23,8	23,5 (1965)
23	Urda	West Kazakhstan	7,7	6,6 (2020)	14	Astana	Akmola	24,9	24,3 (2012)
15	Kokshetau	Akmola	24,1	23,5 (1998, 1989)	12	Aktobe	Aktobe	3,0	2,7 (2010)
16	Uspenka	Pavlodar	24,6	24,5 (1965)	13	Ayakkum	Aktobe	5,3	3,8 (2010)
17	Aul №4	Almaty	27,8	27,7 (2021)	14	Irgiz	Aktobe	3,3	2,5 (2010)
18	Kuigan	Almaty	27,6	27,3 (2005)	15	Karabutak	Aktobe	2,5	1,6 (2013)
19	Zharkent	Zhetysu	27,6	27,2 (1956)	16	Martuk	Aktobe	2,9	2,5 (2010)
20	Sarkand	Zhetysu	25,6	25,3 (1965)	17	Mugodzharskaya	Aktobe	2,6	2,1 (2013)
21	Shymkent	Turkestan	30,0	29,7 (2019)	18	Novoalekseevka	Aktobe	3,2	3,1 (2010)
22	Moyinkum	Zhambyl	28,9	28,5 (2019)	19	Nura	Aktobe	4,1	2,1 (2010)
23	Tole Bi	Zhambyl	28,2	27,9 (1956)	20	Temir	Aktobe	3,0	2,8 (2010)
	October, 2023				21	Uil	Aktobe	4,3	4,2 (2010)
1	Chiganak	Zhambyl	12,8	11,9 (1997)	22	Shalkar	Aktobe	3,8	2,7 (2010)
2	Usharal	Zhetysu	12,0	11,8 (1997)	23	Emba	Aktobe	3,3	2,4 (2010)
3	Ushtobe	Zhetysu			24	Ilyinsky	Aktobe	3,3	3,1 (2010)
4	Kegen	Almaty	7,4	6,6 (1997)	25	Kos-Istek	Aktobe	1,8	1,2 (2010)

№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C	№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C
5	Bakanas	Almaty	13,1	12,8 (1997)	26	Rodnikovka	Aktobe	1,4	1,2 (2013, 2010)
6	Tugyl	East Kazakhstan	8,7	8,1 (1946, 1945)	27	Aksu-Ayuly	Karaganda	1,5	-1,2 (2010)
7	Shar	East Kazakhstan	7,7	7,4 (1997)	28	Aktogay	Karaganda	0,8	-2,3 (2010)
8	Ust-Kamenogorsk	East Kazakhstan	8,8	8,5 (1945)	29	Balkhash	Karaganda	3,3	1,9 (1994)
	November, 2023				30	Bektauata	Karaganda	3,9	1,3 (2013)
1	Aksay	West Kazakhstan	3,1	2,9 (2010)	31	Besoba	Karaganda	1,7	-1,1 (2010)
2	Chingirlau	West Kazakhstan	2,9	2,8 (2010)	32	Zharyk	Karaganda	2,5	0,3 (2010)
3	Karabau	Atyrau	5,2	5,1 (2010)	33	Karaganda	Karaganda	2,5	0,0 (2010)
4	Peshnoy	Atyrau	6,6	6,4 (2010)	34	Kertindy	Karaganda	2,2	0,1 (2010)
5	Aktau	Mangystau	11,5	10,2 (2010)	35	Kyzyltau	Karaganda	2,2	0,0 (1947)
6	Beineu	Mangystau	7,7	6,8 (2010)	36	Korneevka	Karaganda	1,2	-0,7 (2010)
7	Kyzan	Mangystau	9,0	8,0 (2010)	37	Saryshagan	Karaganda	4,0	2,9 (1994)
8	Sam	Mangystau	6,7	5,7 (2010)	38	Zhetykonur	Ulytau	4,7	2,7 (2010)
9	Tushchibek	Mangystau	9,2	8,7 (2010)	39	Zhanaarka	Ulytau	2,8	0,1 (2010)
10	Fort-Shevchenko	Mangystau	11,4	10,6 (2010)	40	Zhezkazgan	Ulytau	3,6	0,9 (2010)
11	Kulaly Island	Mangystau	9,4	9,3 (2010)	41	Kyzyljar	Ulytau	3,4	0,9 (2010)
42	Aktogay	Abai	3,4	2,4 (1994)	71	Aul №4	Almaty	4,1	4,0 (1994)
43	Ayagoz	Abai	1,1	-0,5 (2006, 1994)	72	Kegen	Almaty	1,7	1,6 (1947)
44	Barshtatas	Abai	1,5	0,0 (1994)	73	Kogaly	Zhetysu	3,8	3,5 (1988)
45	Dmitrievka	Abai	0,6	-0,4 (2013, 2010)	74	Aul T. Ryskulova	Turkestan	10,3	9,8 (1988)

№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C	№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C
46	Zhalgyztobe	Abai	0,9	0,2 (2013)	75	Ashysay	Turkestan	8,6	7,8 (1947)
47	Kaynar	Abai	0,2	-1,7 (2010)	76	Tasaryk	Turkestan	8,6	7,9 (1988)
48	Karauyl	Abai	1,2	0,2 (2010)	77	Turkestan	Turkestan	9,1	7,9 (2004, 1971)
49	Semipalatinsk	Abai	1,7	0,9 (2010)	78	Sholakorgan	Turkestan	7,4	6,2 (1980)
50	Shalabay	Abai	1,0	0,6 (2010)	79	Kazygurt	Turkestan	10,7	10,2 (2004)
51	Shar	Abai	1,1	-0,1 (2013)	80	Shardara	Turkestan	11,6	10,4 (1974)
52	Akkol	Akmola	-0,2	-0,5 (2013)	81	Shymkent	Turkestan	10,8	10,3 (1988)
53	Astana	Akmola	2,2	0,3 (2013)	82	Tasty	Turkestan	6,2	4,3 (1994, 1971)
54	Atbasar	Akmola	0,8	-0,4 (2013)	83	Zhetysay	Turkestan	11,0	10,8 (2004)
55	Balkashino	Akmola	-0,7	-1,1 (2013)	84	Kyzylkum	Turkestan	8,3	8,0 (1971)
56	Ereymentau	Akmola	1,0	-0,5 (2013, 2010)	85	Aral Sea	Kyzylorda	5,7	3,9 (2010)
57	Zhaltyr	Akmola	1,0	0,0 (2013)	86	Zhosaly	Kyzylorda	6,2	4,2 (1947)
58	Torgai	Kostanay	2,9	1,7 (2013)	87	Kazaly	Kyzylorda	6,2	4,8 (1947)
59	Amangeldy	Kostanay	2,7	1,0 (2017, 2010)	88	Kyzylorda	Kyzylorda	7,8	6,0 (2010)
60	Arkalyk	Kostanay	1,9	0,3 (2013)	89	Shieli	Kyzylorda	8,5	6,7 (1947)
61	Ekidin	Kostanay	3,7	1,3 (2017)	90	Karak	Kyzylorda	6,9	4,8 (1971)
62	Bayanaul	Pavlodar	1,3	0,7 (2010)	91	Zlikha	Kyzylorda	6,5	5,3 (1947)
63	Sharbakty	Pavlodar	-0,2	-0,3 (2010)	92	Kordai	Zhambyl	6,4	5,9 (1994)
64	Ekibastuz	Pavlodar	1,4	0,8 (2010)	93	Moyinkum	Zhambyl	6,6	6,0 (1980)
65	Krasnoarmeyka	Pavlodar	0,4	0,1 (2013)	94	Uyuk	Zhambyl	6,8	6,7 (1980)
66	Shaldai	Pavlodar	0,4	-0,2 (2010)	95	Saudakent	Zhambyl	7,2	6,9 (1980)
67	Ulken Almaty	Almaty	1,6	1,0 (1988)	96	Shokpar	Zhambyl	7,8	7,2 (1980)

№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C	№	Name of Meteorological Station	Region	Maximum Air Temperature, °C	Previous Record High Air Temperature, °C
68	Kyrgyzsay	Almaty	6,0	5,7 (1980)	97	Chiganak	Zhambyl	5,0	4,6 (1994, 1980)
69	Kuigan	Almaty	4,3	4,0 (1994)	98	Khantau	Zhambyl	8,6	8,0 (1988)
70	Mynzhilki	Almaty	-1,7	-2,5 (2007)					

ANNEX 2

RECORD VALUES OF MONTHLY PRECIPITATION, SET IN 2022

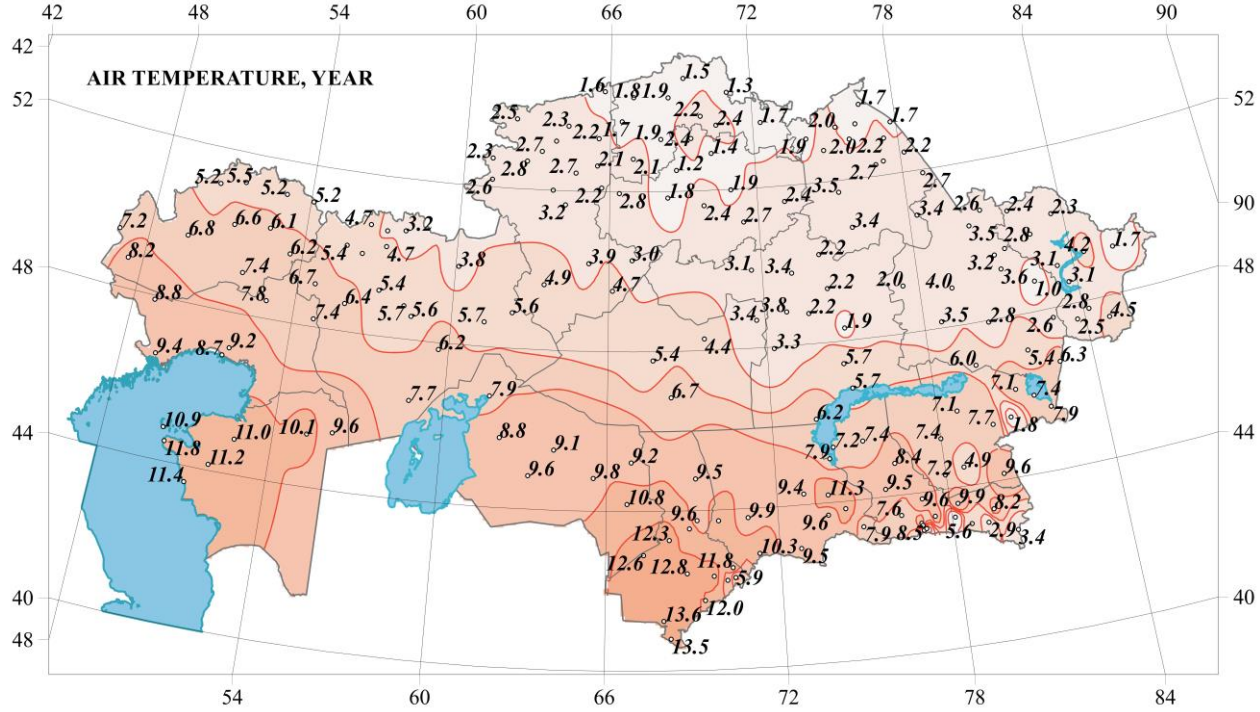
№	Name of the meteorological station	Region	Maximum amount of precipita-tion, mm	Previous maximum precipitation, mm	Minimum amount of precipitatio, mm	Previous minimum rainfall, mm
	January, 2023					
1	Kuigan	Almaty			0	1,0 (1965)
2	Leninogorsk	East Kazakhstan	59,7	58,4 (1940)		
3	Dmitrievka	Abai	43,2	34,1 (1971)		
4	Shalabay	Abai	68,5	54,3 (2013)		
	February, 2023					
1	Atyrau	Atyrau	49,0	41,7 (1952)		
2	Saryshagan	Karaganda	23,8	21,0 (1993)		
	March, 2023					
1	Amangeldy	Kostanay			0,8	0,9 (1951)
	April, 2023					
1	Karasu	Kostanay			0,3	0,7 (1991)
2	Mikhaylovka	Kostanay			0,3	0,8 (1963)
3	Sarykol	Kostanay			0,0	0,2 (1963)
	May, 2023					
1	Astana	Akmola			0,6	0,7 (1955)
2	Ereymentau	Akmola			0,6	3,7 (1955)
3	Aktogay	Pavlodar			0,7	2,2 (1991)
4	Bayanaul	Pavlodar			4,4	6,9 (1974)
5	Krasnoarmeyka	Pavlodar			2,3	2,4 (1974)
6	Shaldai	Pavlodar			0,0	1,0 (2021)
	June, 2023					
1	Almaty, Kamenskoe Plato	Almaty			16,2	26,2 (1995, 1994)
2	Almaty, UHMS	Almaty			2,8	3,0 (1955)
3	Samarka	East Kazakhstan			2,7	5,3 (1945)
	July, 2023					
1	Kamenka	West Kazakhstan	203,1	133,1 (1959)		
2	Karaganda	Karaganda			2,6	5,0 (2019)
	August, 2023					
1	Karaganda	Karaganda	90,0	88,5 (2018)		
2	Aksu-Ayuly	Karaganda	109,0	94,6 (1943)		
3	Zheleznodorozhny	Kostanay	93,0	75,3 (1969)		
4	Kostanay	Kostanay	102,4	101,1 (2012)		
5	Shuyldak	Turkestan	108,4	62,2 (2020)		
6	Arys	Turkestan	36,5	19,3 (2009)		

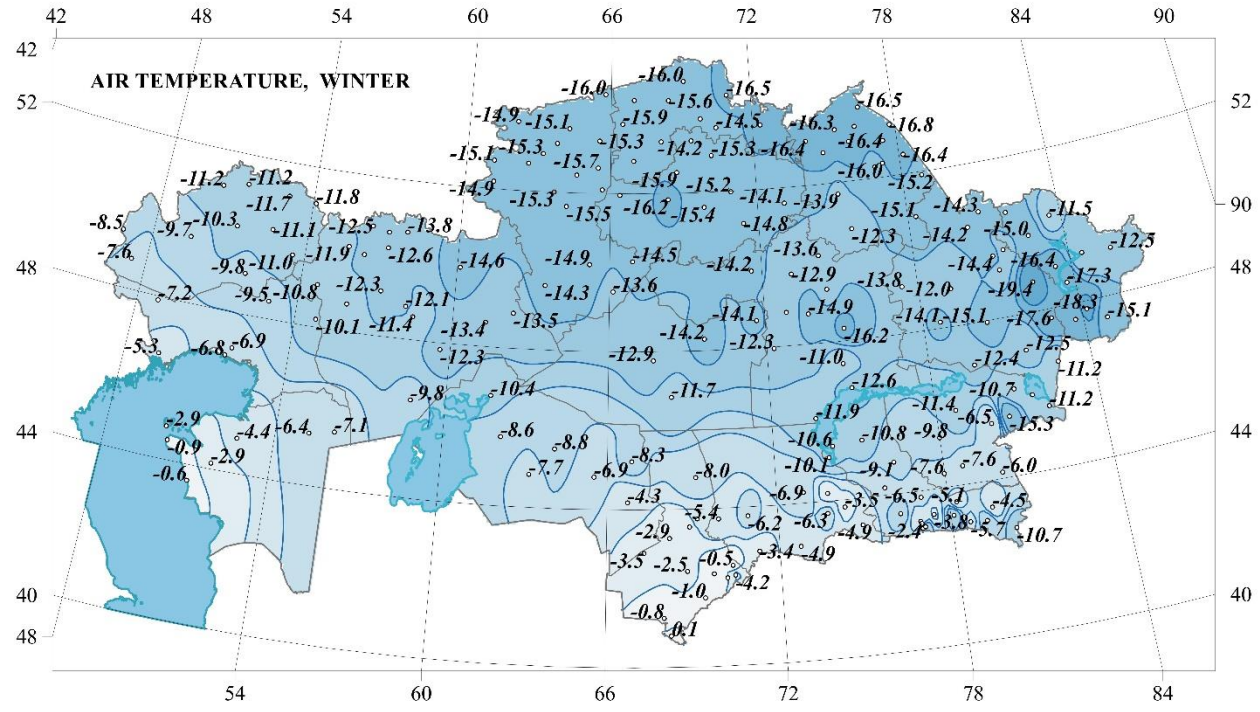
Continuation of Appendix 2

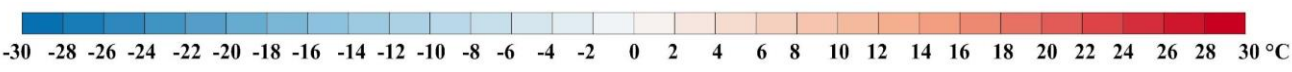
№	Name of the meteorological station	Region	Maximum amount of precipita-tion, mm	Previous maximum precipitation, mm	Minimum amount of precipita-tion, mm	Previous minimum rainfall, mm
7	Shymkent	Turkestan	81,3	39,5 (1949)		
8	aul T. Ryskulova	Turkestan	73,5	45,5 (1954)		
	September, 2023					
1	Balkashino	Akmola	79,9	67,7 (1952)		
2	Karabutak	Aktobe	63,1	57,1 (1996)		
3	Dmitrievka	Abai	92,5	59,7 (1970)		
4	Shar	Abai	56,7	55,2 (1975)		
5	Semipalatinsk	Abai	64,7	59,9 (1946)		
6	Samarka	East Kazakhstan	83,5	74,8 (2017)		
7	Karaganda	Karaganda	90,0	66,2 (1987)		
8	Korneevka	Karaganda	68,3	57,7 (1987)		
9	Zholboldy	Pavlodar	67,6	59,6 (2001)		
10	Ekibastuz	Pavlodar	52,0	49,1 (1965)		
	October, 2023					
1	Zhanibek	West Kazakhstan	79,3	73,7 (1964)		
2	Karatyube	West Kazakhstan	61,5	58,1 (2004)		
	November, 2023					
1	Kamenka	West Kazakhstan	96,0	87,4 (1965)		
2	Karasu	Kostanay	57,1	57,0 (1963)		
3	Kostanay	Kostanay	55,2	54,0 (1946)		
4	Zhitikara	Kostanay	67,9	55,0 (1955)		
5	Kushmurun	Kostanay	55,5	55,0 (1963)		
6	Timiryazevo	North Kazakhstan	54,9	45,0 (2002)		
	December, 2023					
1	Astana	Akmola	61,8	56,0 (1991)		
2	Balkashino	Akmola	76,9	62,5 (2016)		
3	Nura	Aktobe	48,7	48,7 (2004)		
4	Karasu	Kostanay	47,6	47,6 (1963)		
5	Pavlodar	Pavlodar	45,4	45,3 (2004)		
6	Ruzaevka	North Kazakhstan	57,6	55,8 (2016)		
7	Petropavlovsk	North Kazakhstan	58,4	56,9 (1989)		

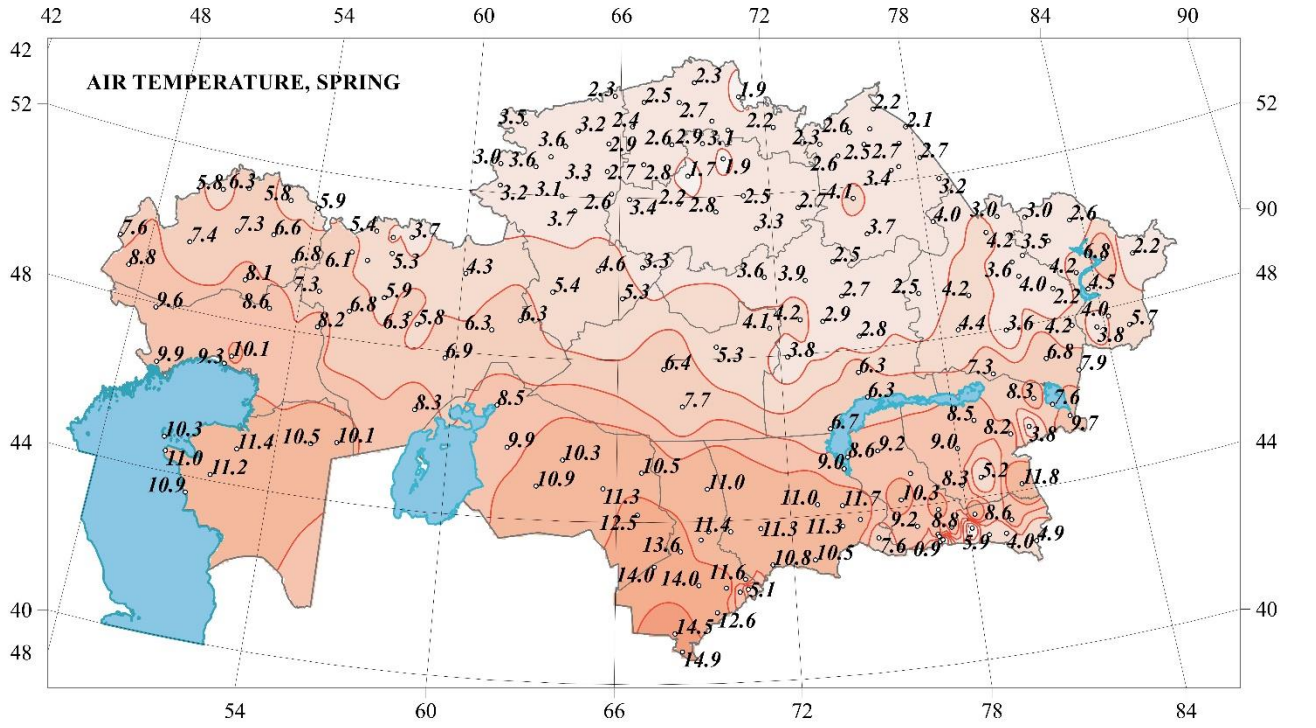
ANNEX 3

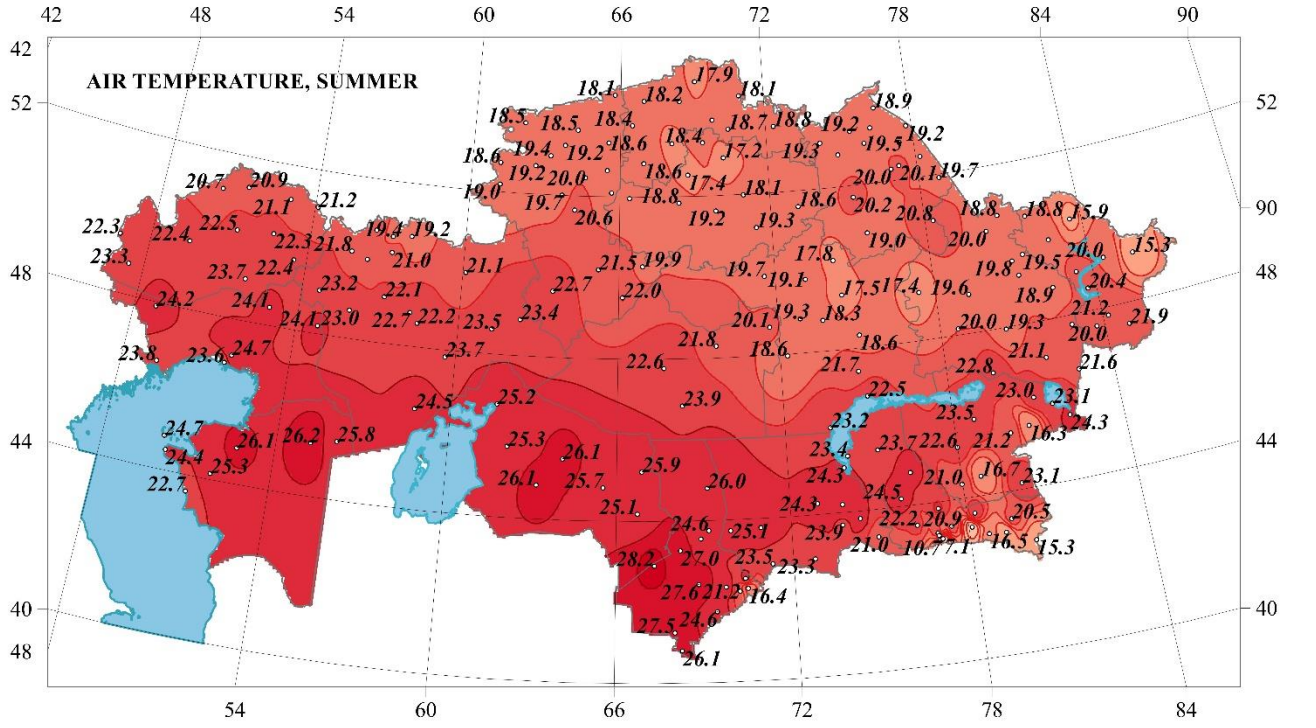
SPATIAL DISTRIBUTION OF AVERAGE ANNUAL AND AVERAGE SEASONAL AIR TEMPERATURES ACROSS THE TERRITORY OF KAZAKHSTAN, CALCULATED FOR THE PERIOD 1961–1990

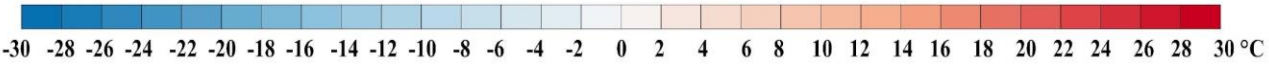


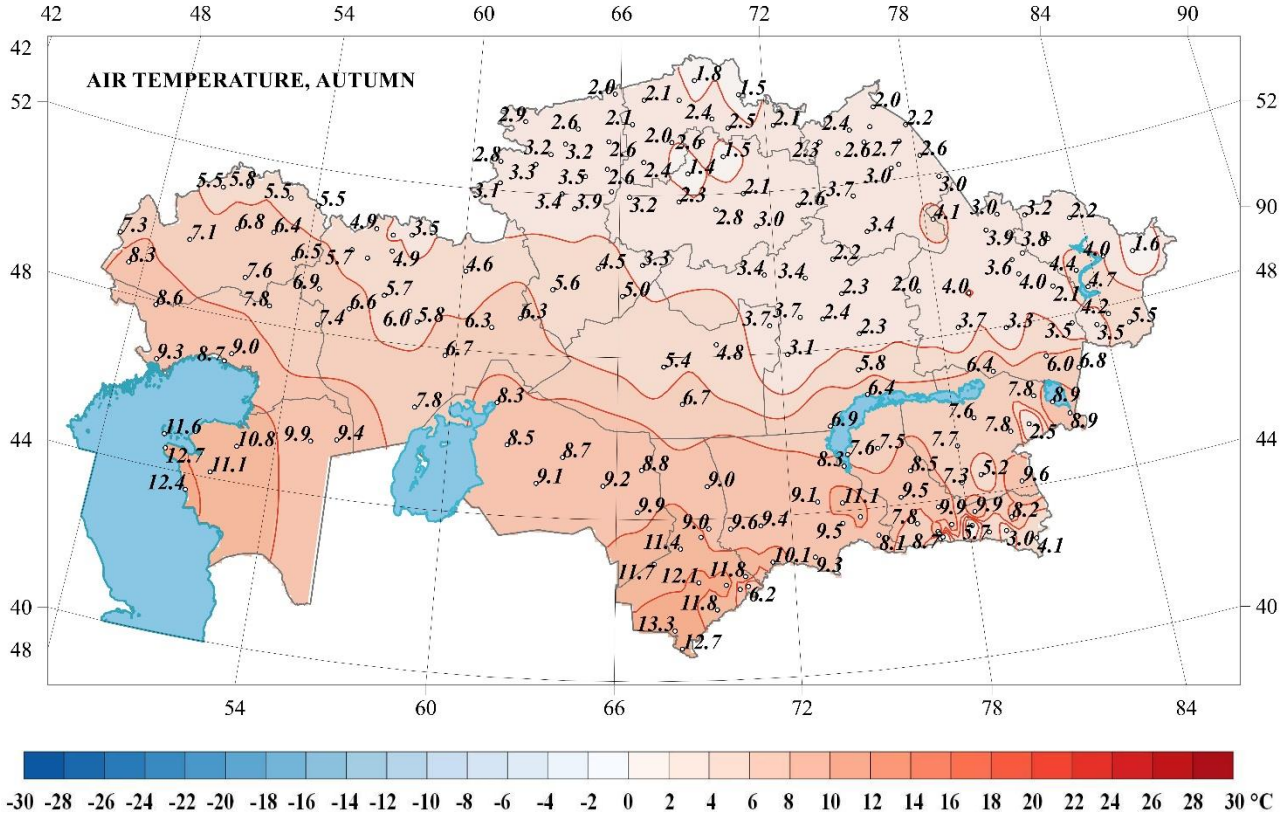





AIR TEMPERATURE, SPRING
42
48
54
60
66
72
78
84
90
52
44
40

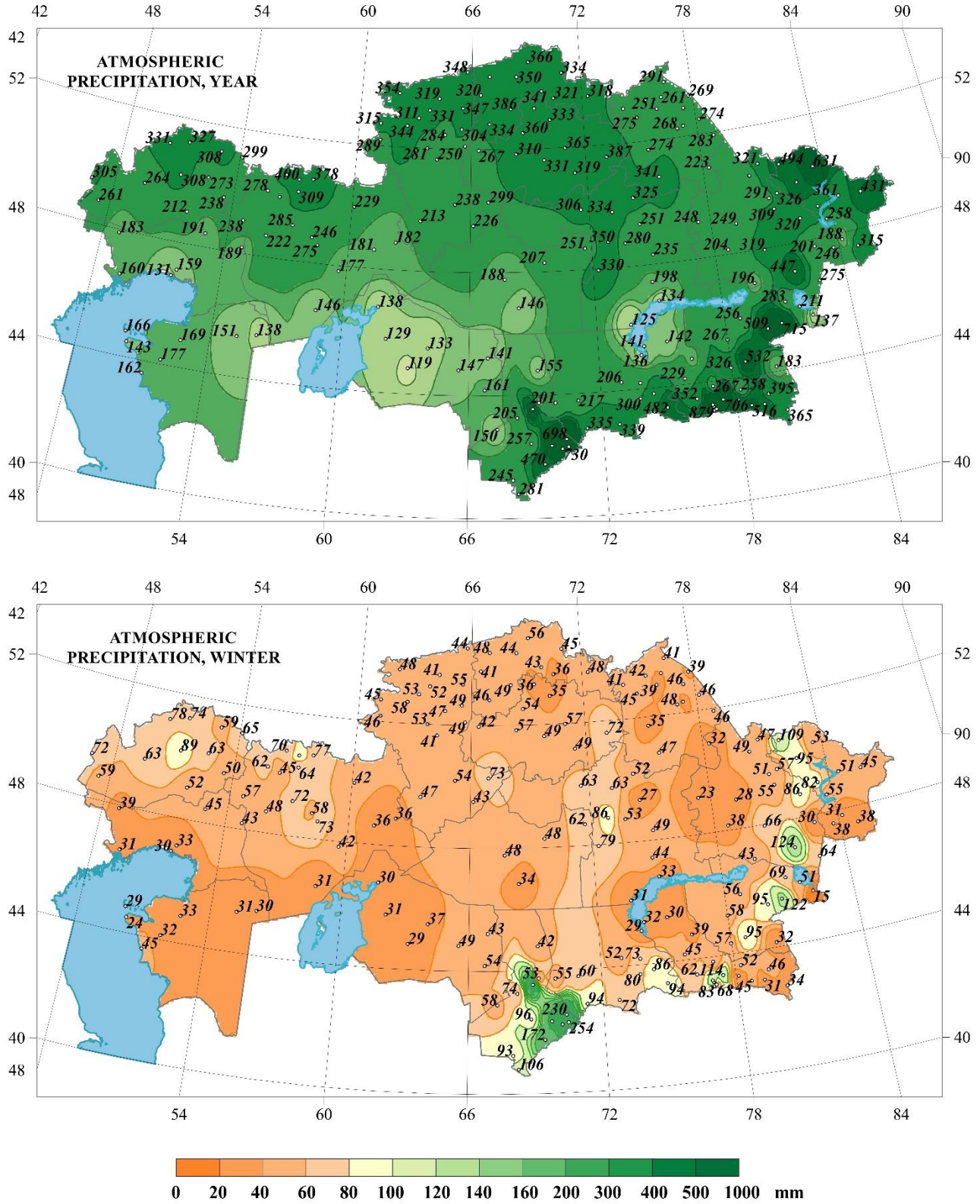

AIR TEMPERATURE, SUMMER
42
48
54
60
66
72
78
84
90
52
44
40

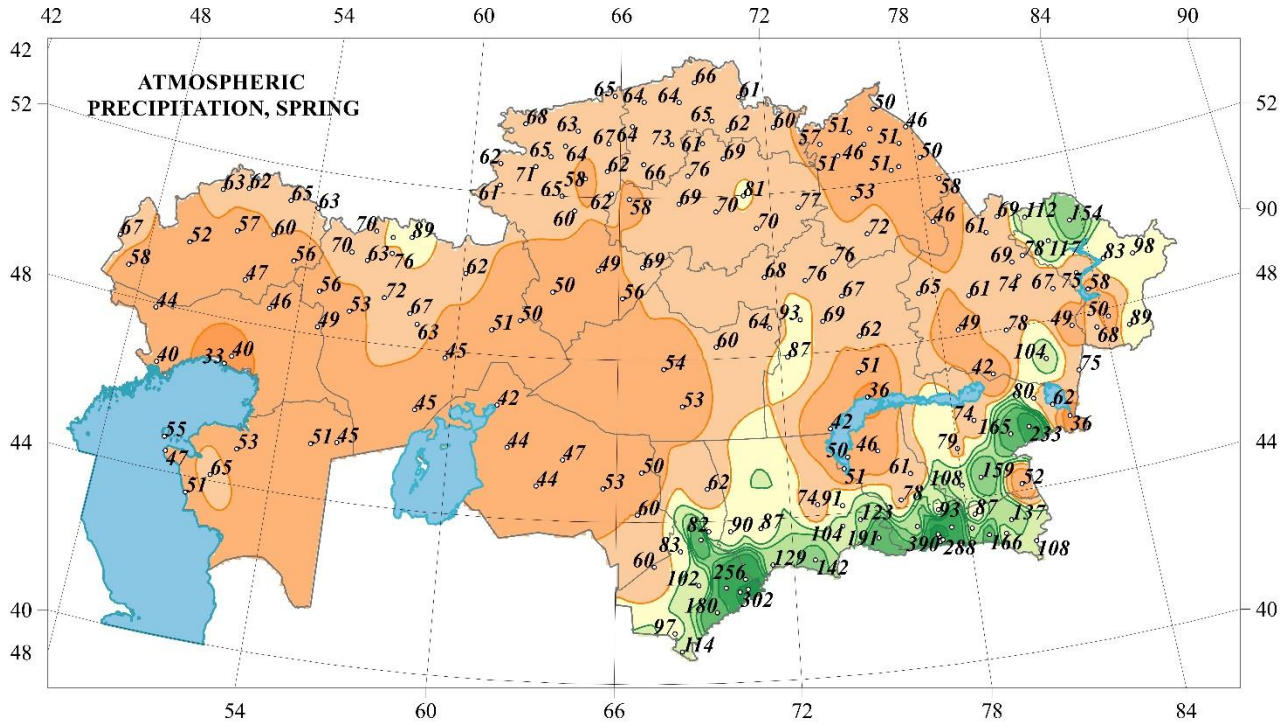

-30 -28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 °C

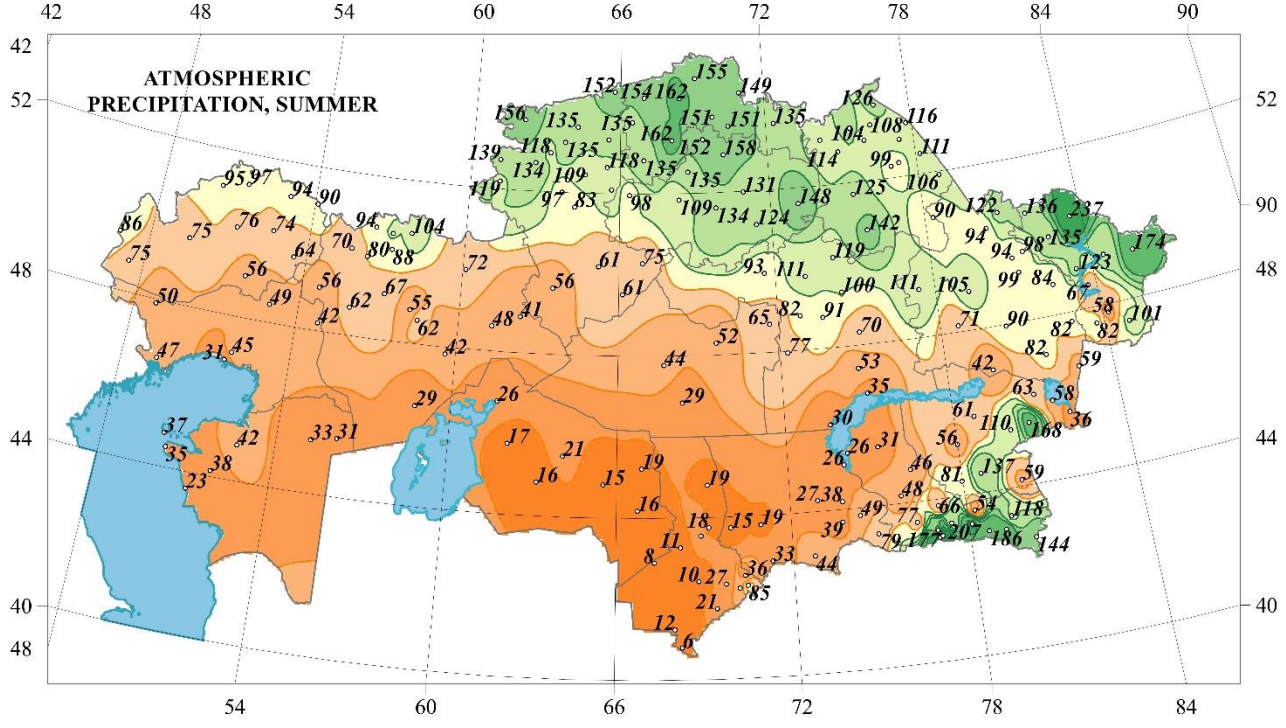

AIR TEMPERATURE, AUTUMN
42
48
54
60
66
72
78
84
90
52
48
44
40
-30 -28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 °C

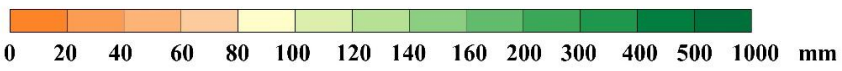
ANNEX 4

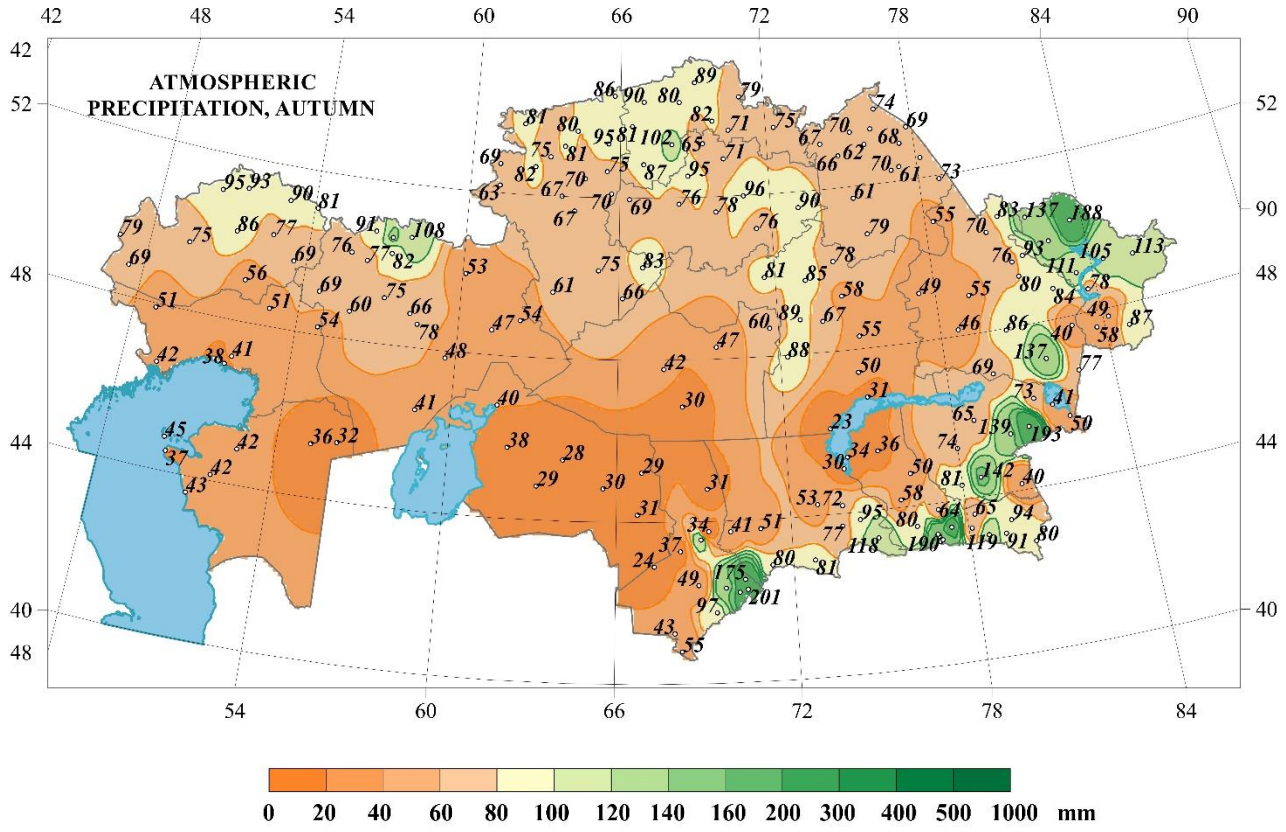
SPATIAL DISTRIBUTION OF ANNUAL AND SEASONAL PRECIPITATION SUMS ACROSS THE TERRITORY OF KAZAKHSTAN, CALCULATED FOR THE PERIOD 1961–1990




ATMOSPHERIC
PRECIPITATION, SPRING


ATMOSPHERIC
PRECIPITATION, SUMMER


0 20 40 60 80 100 120 140 160 200 300 400 500 1000 mm


ATMOSPHERIC
PRECIPITATION, AUTUMN
42
48
54
60
66
72
78
84
90
52
48
44
40
0 20 40 60 80 100 120 140 160 200 300 400 500 1000 mm

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