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SHORT SUMMARY

Climate features in 2021

In general, for the Globe, 2021 entered the top five or seven warmest years for the period of instrumental observations. The global average annual temperature in 2021 was about 1.11±0.13 °C above the baseline 1850-1900 level used as an approximation of pre-industrial levels.

On average in Kazakhstan, the average annual air temperature in 2021 was 1.58 °C higher than the climatic norm for the period 1961-1990. And this is the fifth value in the ranked series of the warmest years for the period 1941-2020. For five regions of Turkestan, Mangystau, West Kazakhstan, Aktobe and Kyzylorda regions, 2021 was among the 5 % of extremely warm years with anomalies from + 1.89 °C to + 2.28 °C, for the Atyrau region the year was a record warm - the average for the territory of the anomaly was +2.63 °C. Extremely high annual temperatures were recorded according to most weather stations in the western, southwestern and southern regions of the country. According to 19 weather stations in the western and southern regions, 2021 was the warmest year since 1941, record temperature anomalies ranged from +1.4 to +3.2 ºC.

In many regions of Kazakhstan, the period from May to August was extremely hot. Witha certain maximum temperature in 2021 exceeded 30 and even 35 C° throughout the territory of Kazakhstan (with the exception of the highlands). In 2021, at eight weather stations involved in monitoring the climate of Kazakhstan, the values of absolute maximums were updated. In the western and southern regions, the total duration of all heat waves was more than 50, in some places more than 60 days. As a consequence of high air temperatures, a significant part of the warm period of the year, especially in the western and southern regions of Kazakhstan, there was an urgent need to cool the premises to maintain a favorable temperature.

The precipitation layer for 2021 on average in the territory of Kazakhstan amounted to 271.5 mm (86 % of the norm). On average, in the territory of most regions, annual precipitation amounts were in the range of ±20 % to the norm. The deficit of precipitation (up to 30-40 %) was observed in the western, southern and central regions of the republic. A strong deficit of precipitation (up to 70 %) was observed in the Mangystau region.

The average rainfall in Kazakhstan was below normal for most of the year. Two months were extremely dry: May, in which the average layer of precipitation was about 45 % of normal, and April, when 58 % of the norm fell. A significant deficit of precipitation was also observed in January (23 %) and from June to December (13-34 %). Two months were extremely wet - February (185.8 % of the norm) and March (191.6 % of the norm). From April to October, most of the territory of Kazakhstan experienced a deficit of precipitation. At some stations, monthly precipitation minimums have been updated, at others - monthly highs. According to 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. On average, in Kazakhstan, the increase in the average annual air temperature is 0.32 ºC every 10 years. On average, for the territory of individual regions, the growth rate is in the range from 0.23 ºC/10 years (Karaganda region) to 0.54 ºC/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. There is a weak trend towards an increase in annual precipitation (by 1.1 mm/10 years), mainly due to the precipitation of the spring season, when the increase in some western and northern regions is 10-20 %/10 years. In the autumn period, the amount of precipitation decreases almost throughout the territory of Kazakhstan, in some western and southern regions by 4-13 %/10 years.

Analysis of trends in surface air temperature extremes and precipitation showed that for the period 1961 to 2021:

– there is a steady increase in the number of summer days with temperatures above 25 °C and 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, and the duration of heat waves in the whole year increases;

– There is a reduction in heat deficit (the need for heating) in the cold period of the year and an increase in the shortage of cold 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 with severe frosts below minus 20 °C is reduced;

– there have been no significant changes in the characteristics of the extremity of the 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 period of the year leads to negative consequences not only for the human body and animals, but also for the transport infrastructure due to the deformation of the road surface, for the conditions of the urban environment and recreation areas, for the energy industry, as there is a need for additional energy production for cooling the premises.

An increase in surface temperature leads to a reduction in the period with negative temperatures, as a result, precipitation often falls in liquid form. This, in turn, can affect snow accumulation in 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 in the cold period of the year 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 in the cold period of the year can lead to the formation of black ice on the roads when the cold returns.

Increasing the length of the growing season in areas where this is combined with an increase in rainfall and a reduction in the maximum duration of the rainless period (in some northern and south-eastern regions) improves conditions for crop production.

The increase in the maximum daily rainfall recorded in some areas may lead to an increased risk of destruction of the roadway and stormwater systems in settlements, landslide and mudflow manifestations 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 change. The use of relevant meteorological and climate information helps to reduce risks and damage and optimize socio-economic benefits. Monitoring of climate change the system is implemented 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 constant monitoring of its changes is one of the priority tasks of the national hydrometeorological service of Kazakhstan RSE "Kazhydromet". Since 2010, RSE "Kazhydromet" has been issuing annual bulletins to provide reliable scientific information about the regional climate, its variability and change. Taking into account the geographical position 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, on economic activities and the social sphere. Taking into account climatic conditions and assessing their changes are necessary to identify potential impacts 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 2021, including an assessment of the extremity of temperature and precipitation regimes, and provides historical information on changes in surface air temperature and precipitation that have occurred since 1941 of the last century. This issue of the bulletin also contains estimates of climate change for a shorter period - from the mid-1970s of the last century, when, according to many experts, global climate change has become more intense, especially in the Northern Hemisphere. Annexes 2 and 3 provide maps of the distribution of average long-term values of air temperature and precipitation for the period 1961-1990, averaged by seasons and per year.

Initial data. To prepare the bulletin, the data of the Republican Hydrometeorological Fund of the RSE "Kazhydromet" are used:

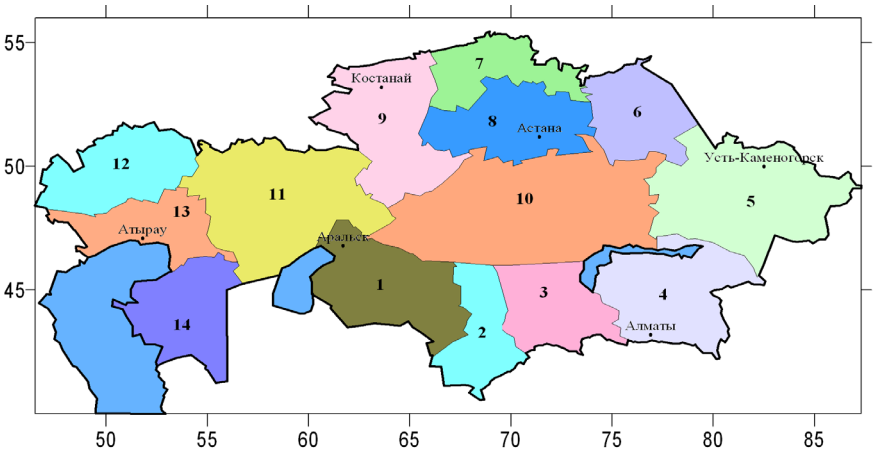
1) time series of average monthly air temperatures and monthly precipitation amounts, while about 120 weather stations have had homogeneous series since 1941 and their data are involved in summarizing information on the territory of the regions and in Kazakhstan as a whole, since 1961 there have been 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) series of daily maximum and minimum air temperatures and daily precipitation since 1961 (about 190 weather stations).

Basic approaches and methods. The "norm" in the bulletin refers to the long-term average value of the climate variable under consideration for the period 1961-1990. Temperature anomalies are calculated as deviations of the observed value from the norm. Anomalies in the amount of precipitation are 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 (the probability of non-increase, which characterizes the frequency (in %) of the appearance of the corresponding value of the anomaly in a series of observations) and ordinal statistics (ranks, i.e. serial numbers in an ordered series of values relative to other numbers in the data set) are used, the periods for estimating these statistics are specifically specified in each case.

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



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

Scheme of administrative-territorial division of the Republic of Kazakhstan

To assess the 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" (mathematical) of significant climate change, including extreme characteristics. Some indices are based on fixed uniform threshold values for all stations, others on threshold values that can vary from station to station. In the latter case, thresholds are defined as the corresponding percentiles of the data series. The indices also make it possible to assess the impact of the current climate and its changes on various aspects of socio-economic conditions in the region under study. There are indices that reflect the potential impact on human health, on the needs for energy generation in different seasons, on agrometeorological conditions, on transport infrastructure, on the extremity of hydrometeorological conditions, etc.

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1 OVERVIEW OF CHANGES IN THE GLOBAL CLIMATE AND ITS STATUS IN 2021

It has been 29 years since the World Meteorological Organization issued the first state of the climate report in 1993 in response to concerns then expressed about projected climate change. The annual State of the Global Climate Report identifies indicators of the climate system, including greenhouse gas concentrations, rising land and ocean temperatures, rising sea levels, melting ice and glacier retreat, and extreme weather events. It also notes 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 land, ocean and ice responses. These indicators are closely interrelated. For example, an increase inCO_2 and other greenhouse gases in the atmosphere leads to an imbalance of energy and thus to a warming of the atmosphere and ocean. Ocean warming, in turn, leads to sea level rise, to which is added the melting of ice on land in response to rising atmospheric temperatures. Together, the indicators create a consistent picture of global warming that affects all parts of the earth's system.

Clear links can be seen between key climate indicators as a physical system and cascading and risks for most of the 17 Sustainable Development Goals. Thus, monitoring global climate indicators and their associated risks and impacts is critical to achieving the Sustainable Development Goals by 2030.

Key provisions on the state of the global climate in 2021:

The average annual global temperature in 2021 was 1.11 ± 0.13 °C above the pre-industrial average temperature 1850-1900 (Figure°1.1). This is a less significant anomaly than in some recent years, due to the influence of La Niña conditions at the beginning and end of the year. The six datasets used in the analysis place 2021 between the fifth and seventh warmest years on record in the world, and all six show that the last seven years, from 2015 to 2021, were the seven warmest years on record.

In 2020, the molar **fractions of greenhouse gas concentrations** reached new highs: 149 % carbon dioxide (CO_2), 262 % methane (CH_4) and 123 % nitrous oxide (N_2O) from pre-industrial (1750) levels, respectively.

Global average sea level reached a new all-time high in 2021, rising by an average of 4.5 mm per year between 2013 and 2021.

In Greenland, an exceptional melting occurred in mid-August, and the first recorded rain fell at Summit Station, the highest point of the Greenland ice sheet, located at an altitude of 3,216 m.

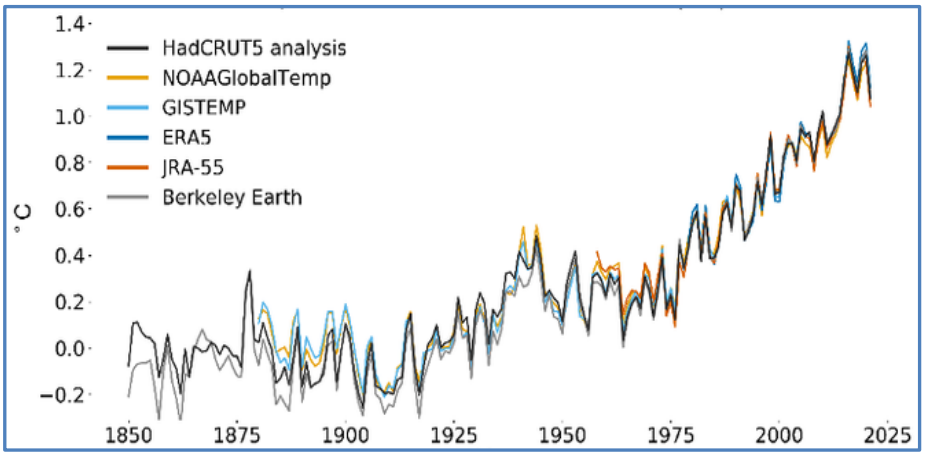

Figure 1.1 – Anomalies in global average annual temperature relative to pre-industrial conditions (1850-1900) from six global temperature datasets (1850–2021)

Source: Met Office, United Kingdom of Great Britain and Northern Ireland

The Antarctic **ozone hole** reached a maximum area of 24.8 million km^2 in 2021. This unusually deep and large ozone hole was caused by a strong and stable polar vortex and colder-than-usual conditions in the lower stratosphere.

Exceptional **heatwaves** broke records in western North America and the Mediterranean. In Death Valley in California, temperatures reached 54.4 °C on July 9, which corresponds°to a similar value to 2020 as the highest recorded in the world since at least the 1930s, and in Syracuse in Sicily, temperatures reached 48.8 °C.

Hurricane Ida was the most significant of the season in the North Atlantic, hitting land in Louisiana on August 29, and was the strongest in the state's history with economic damage in the United States estimated at $75 billion.

In China's Henan province, **flooding** caused numerous casualties and $17.7 billion in economic damage, and Western Europe experienced one of the worst floods on record in mid-July, an event linked to economic losses in Germany exceeding $20 billion.

The drought affected many parts of the world, including parts of Canada, the United States, the Islamic Republic of Iran, Afghanistan, Pakistan, Turkey, and Turkmenistan. In Canada, severe drought caused projected wheat and rapeseed production levels to be 35 to 40 percent below 2020 levels, while in the United States, Lake Mead levels on the Colorado River fell 47 m below normal full stock levels in July – the lowest level on record.

2 AIR TEMPERATURE

In 2021, on average in Kazakhstan, the average annual air temperature anomaly was +1.58 °C relative to the long-term average value for the period 1961-1990. (5.4 °C) and was 0.34 °C lower than in 2020. Since the 1960s, every subsequent decade in Kazakhstan has been warmer than the previous one. The average annual air temperature over the last decade of 2012-2021 was +6.61 °C and exceeded the climatic norm by 1.19 °C, this is a record value among positive decade anomalies, the previous warmest decade was in 2001-2010 with an anomaly of +1.09 °C. The last five years of 2017-2021 was also the warmest with an average annual air temperature of +6.69 °C, which exceeded the climatic norm by 1.27 °C.

Table 2.1 shows the lists and ranks of the ten warmest years on average across the Globe (according to the terrestrial network) and across Kazakhstan. 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 of those included in both lists of the warmest years. The five warmest years in Kazakhstan were included in the list of the ten warmest years for the Globe. The year 2020 turned out to be extremely warm both in Kazakhstan and in the whole globe.

Table 2.1 – The warmest years in the history of observations on the Globe (since 1850) and in Kazakhstan for the period 1941-2021 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	Anomaly of the average annual temperature (Jan.-Dec.), averaged over the territory of Kazakhstan, °C
1	**2020**	**2020**	1,92
2	2016	2013	1,89
3	2019	1983	1,76
4	2017	2015	1,64
5	2015	2021	1,58
6	2021	2002	1,55
7	2018	2004	1,53
8	2014	2019	1,50
9	2010	2016	1,48
10	2005	2007	1,46

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 2021. 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 third in the rank of the warmest years.

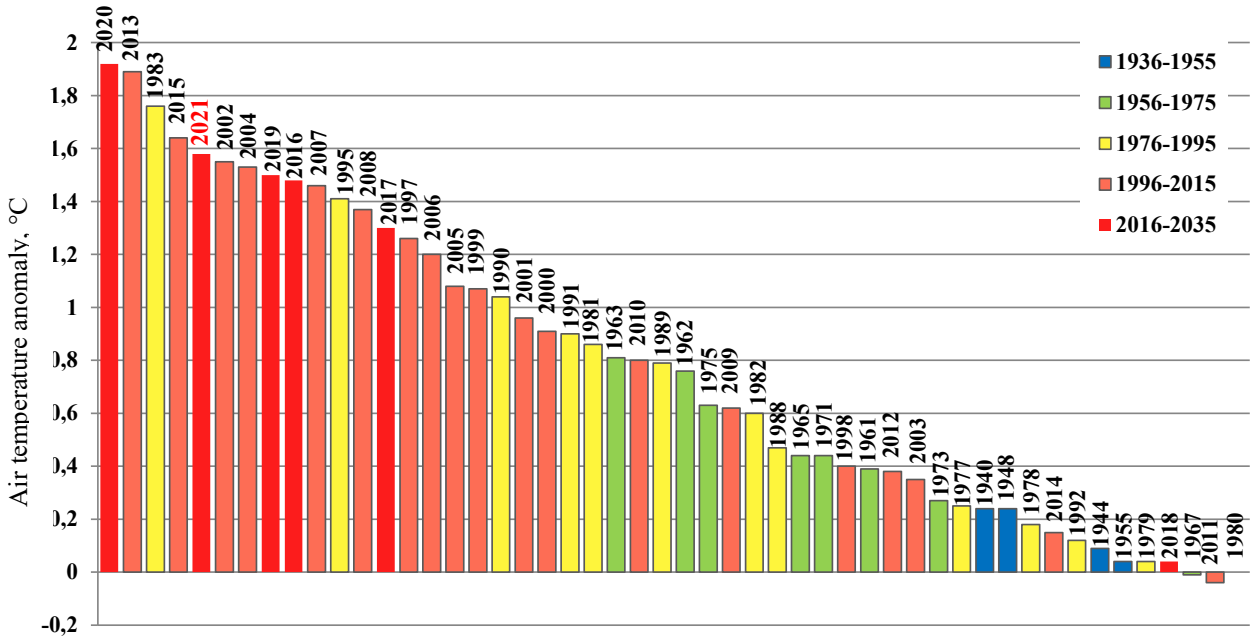

Figure 2.1 – A ranked series of positive anomalies of average annual (January December) surface air temperatures averaged over the territory of Kazakhstan (according to 121 weather stations) for the period 1941-2021. Anomalies are calculated relative to the base period of 1961-1990.

2.1 Anomalies of air temperature on the territory of Kazakhstan in 2021

The year 2021 in Kazakhstan ranked 5th in the descending series of average annual temperatures since 1941 (Table 2.1).

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 1941-2021, as well as standard deviations for 1961-1990. (table 2.2). In Tables 2.2 and 2.3, the temperature values above the 95th or below the 5th percentile (respectively, warm and cold extremes) are highlighted in bold and color.

The year was record warm (Table 2.2) for the Atyrau region (the average anomaly in the territory is +2.63 °C). For Turkestan, Mangystau, West Kazakhstan, Aktobe and Kyzylorda regions, 2021 was among the 5% of extremely warm years (with anomalies +1,89, +2,04, +2,50, +2,10 and +2.28 °C, respectively). Average anomalies in the territory of Zhambyl, Kostanay and Almaty regions were included in 10% of extremely high anomalies: +1.58, +1.63 and 1.49 °C, respectively. On the territory of the other regions, the average anomalies in the territory are within 0.94 1.24 °C.

Table 2.2 – Regionally averaged average annual (January-December) and seasonal air temperature anomalies in 2021: **vT** – *deviations from long–term averages for 1961- 1990, ºC; P (t≤T2021) - probability of non-excess (in parentheses), calculated from data for the period 1941-2021 in %; s is 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	**1,58 (95)**	**0,86**	-0,03 (46)	2,44	2,16 (86)	1,28	**1,89 (98)**	**0,65**	-0,02 (40)	1,16
Almaty	1,49 (91)	0,76	0,31 (48)	2,33	1,80 (81)	0,99	**1,41 (96)**	**0,63**	-0,19 (35)	1,06
Akmola	1,02 (75)	1,07	-0,62 (35)	2,84	2,16 (84)	1,85	1,10 (89)	**1,04**	-0,05 (40)	1,51
Aktobe	**2,10 (98)**	**0,94**	0,39 (51)	2,50	2,23 (80)	1,9	**3,41 (98)**	**0,93**	-0,04 (48)	1,4
Atyrau	**2,63 (100)**	**0,82**	0,96 (59)	2,40	**2,60 (95)**	**1,56**	**3,99 (100)**	**0,85**	0,38 (58)	1,2
East Kazakhstan	1,23 (83)	1,08	-0,08 (46)	2,71	2,11 (83)	1,52	0,77 (79)	0,79	0,10 (48)	1,5
Zhambyl	1,58 (94)	**0,87**	0,29 (46)	2,87	1,61 (79)	1,00	**1,77 (98)**	**0,81**	-0,36 (38)	1,18
West Kazakhstan	**2,50 (98)**	**1,06**	0,20 (49)	2,74	2,36 (84)	2,01	**4,27 (99)**	**1,22**	0,67 (69)	1,27
Karaganda	1,24 (86)	0,88	-1,07 (31)	2,51	2,39 (88)	1,32	1,02 (93)	**0,83**	-0,45 (36)	1,39
Kostanay	1,63 (93)	1,06	-0,06 (46)	2,75	2,41 (85)	1,91	**2,44 (96)**	**1,07**	0,07 (48)	1,5
Kyzylorda	**2,28 (96)**	**0,91**	-0,28 (40)	2,85	3,41 (91)	1,28	**3,05 (100)**	**0,95**	-0,38 (33)	1,21
Mangystau[1]	**2,04 (99)**	**0,75**	0,80 (55)	1,88	2,00 (94)	1,35	**3,13 (99)**	**0,86**	0,37 (53)	1,16
Pavlodar	0,94 (71)	1,16	-1,21 (31)	3,15	2,34 (85)	1,73	0,19 (59)	0,94	0,19 (49)	1,62
North Kazakhstan	0,95 (75)	1,16	-1,13 (33)	2,94	2,17 (88)	1,87	1,22 (90)	1,17	0,24 (46)	1,53
Turkestan	**1,89 (99)**	**0,81**	1,37 (59)	2,57	1,61 (80)	0,93	**2,32 (100)**	**0,85**	-0,12 (44)	1,12

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-3rd 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. Average temperature anomalies on the territory of Kazakhstan were obtained by averaging the data of 121 stations.

Anomalies of the average annual air temperature in 2021 were positive throughout Kazakhstan (Figure 2.2, above). In most of the eastern half of the republic, temperatures exceeded the norm by 1.0 - 2.0 °C, and only in some central, northern, northeastern and mountainous regions – by 0.6-0.9 °C. In the western, southwestern and extremely southern regions, anomalies were in the range of 2.0 - 3.2 °C, the probability of non-exceeding anomalies in these regions was higher than 95%, which corresponds to the characteristic of temperature conditions as "extremely warm" (Figure 2.2, below). According to 19 weather stations in the southern and western regions, 2021 was the warmest year since 1941.

Table 2.3 – Regionally averaged average monthly air temperature anomalies in 2021: ***vT*** – *deviations from the average for 1961-1990, °C; P (t≤T2021) – the probability of non-excess (in parentheses), calculated from data for the period 1941-2021 and expressed in %*

Region	12 (2020)	1	2	3	4	5	6	7	8	9	10	11
Kazakhstan	-3,60 (16)	-0,32 (31)	3,82 (80)	1,01 (61)	1,31 (74)	**4,14 (100)**	1,22 (84)	1,57 (94)	**2,89 (100)**	0,15 (48)	0,23 (40)	-0,43 (50)
Almaty	-4,12 (16)	-0,86 (30)	**5,89 (98)**	2,19 (74)	0,65 (54)	**2,59 (98)**	0,52 (59)	**2,37 (98)**	1,38 (86)	2,11 (94)	-1,39 (10)	-1,30 (40)
Akmola	-2,18 (28)	-1,56 (29)	1,83 (65)	0,19 (51)	0,90 (61)	**5,40 (100)**	-0,25 (54)	0,45 (73)	3,13 (94)	-1,56 (16)	1,49 (65)	-0,09 (50)
Aktobe	-4,19 (13)	2,36 (68)	3,02 (74)	-0,52 (48)	1,83 (78)	**5,37 (100)**	**4,25 (98)**	1,20 (78)	**4,76 (99)**	-0,86 (25)	1,26 (63)	-0,51 (48)
Atyrau	-4,37 (9)	4,27 (86)	2,90 (64)	0,63 (53)	2,90 (91)	**4,27 (100)**	**3,97 (96)**	**2,70 (95)**	**5,27 (100)**	-0,17 (35)	0,70 (50)	0,57 (65)
East Kazakhstan	-2,79 (20)	-2,40 (20)	4,90 (91)	2,27 (74)	1,39 (69)	2,66 (93)	-0,81 (26)	1,66 (94)	1,49 (83)	0,18 (53)	0,07 (36)	0,04 (50)
Zhambyl	-4,07 (16)	-1,24 (23)	6,16 (93)	1,07 (60)	0,61 (53)	**3,14 (96)**	1,50 (84)	**2,34 (98)**	1,51 (86)	2,01 (93)	-1,73 (9)	-1,40 (39)
West Kazakhstan	-5,25 (6)	3,60 (75)	2,23 (63)	0,24 (49)	1,78 (74)	**5,05 (100)**	**4,36 (95)**	2,51 (89)	**5,99 (100)**	-1,01 (26)	1,78 (73)	1,24 (73)
Karaganda	-5,54 (11)	-1,65 (24)	3,99 (80)	0,97 (58)	2,03 (80)	**4,16 (100)**	-0,31 (36)	1,16 (88)	2,19 (91)	-0,30 (38)	-0,14 (31)	-0,90 (44)
Kostanay	-2,29 (31)	0,20 (38)	1,92 (65)	0,32 (53)	1,13 (63)	**5,81 (100)**	1,98 (84)	0,81 (74)	**4,50 (98)**	-1,07 (16)	1,74 (68)	-0,44 (49)
Kyzylorda	-6,44 (10)	0,52 (48)	5,12 (75)	1,44 (60)	3,28 (93)	**5,50 (100)**	**3,30 (96)**	2,16 (94)	**3,74 (100)**	0,50 (58)	-0,32 (26)	-1,38 (43)
Mangystau[1]	-3,00 (9)	3,50 (91)	1,90 (56)	0,10 (45)	3,00 (94)	2,90 (94)	2,80 (89)	1,80 (85)	**4,90 (100)**	0,30 (48)	0,10 (40)	0,70 (70)
Pavlodar	-2,46 (26)	-3,24 (23)	2,06 (61)	1,52 (64)	1,02 (56)	**4,46 (98)**	-1,28 (29)	-0,10 (59)	1,90 (84)	-1,42 (15)	1,04 (56)	0,94 (61)
North Kazakhstan	-0,89 (44)	-2,30 (29)	-0,23 (45)	-0,04 (49)	0,51 (58)	**5,99 (100)**	-0,11 (51)	0,40 (73)	3,39 (94)	-1,16 (21)	1,93 (69)	-0,01 (51)
Turkestan	-3,28 (20)	1,76 (59)	5,62 (91)	0,62 (58)	0,58 (60)	**3,64 (98)**	**2,47 (99)**	**2,23 (96)**	**2,24 (98)**	**2,34 (95)**	-1,40 (11)	-1,26 (39)

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.

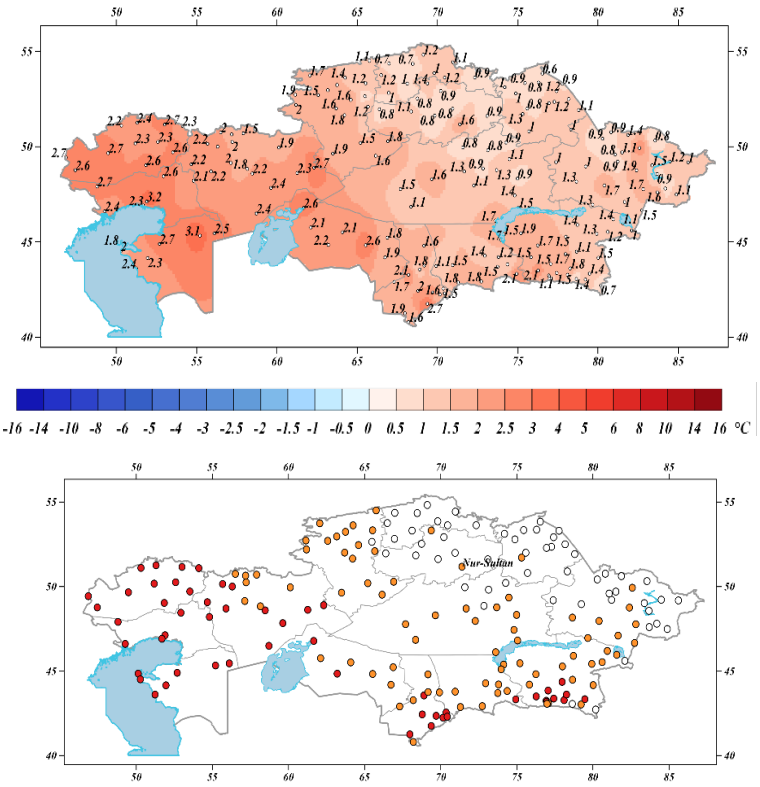

Figure 2.2 – Geographical distribution of average annual air temperature anomalies (above, °C) on the territory of Kazakhstan in 2021, calculated relative to the base period of 1961-1990, and the probability of not exceeding them (below), calculated according to the data of the period 1961-2021.

The territorial distribution of seasonal air temperature anomalies in 2021 across the territory of Kazakhstan is shown in Figure 2.3.

In the winter of 2020/21, the average air temperature in Kazakhstan was only 0.03 °C below the norm for the period 1961-1990. (Table 2.2). The winter of 2019/2020 remained the warmest winter season. Zones with positive air temperature anomalies occupied the western regions (up to +1.4 °C in the extreme west), the western part of the Kostanay region (up to +0.8 °C), the extreme southern regions (up to +2.6 °C) and some areas in the east (up to +2.0 °C, Figure 2.3). In the rest of the territory, temperatures were below normal, mostly by no more than 1 °C. Negative anomalies reached 1.0 1.6 °C in the extreme northern regions, 1.1 1.3 °C in the eastern surroundings of Balkhash region, 2.1 °C in the south of the East Kazakhstan region. The cold center with the most significant temperature anomalies (up to minus 3.4 °C) was located in the central regions of Kazakhstan**.**

Low seasonal temperatures corresponding to the 10-25 percentiles were observed at 25 weather stations in Kazakhstan located in the northern, central and southeastern regions of Kazakhstan.

In December 2020, on average, the temperature anomaly in Kazakhstan was 3.60 °C lower than normal for the period 1961-1990 (Table 2.3). The values of the anomalies averaged over the territory of the regions lie in the range of minus 0.89 – minus 5.54 °C with a probability of not exceeding 6 44%. Temperature regions significantly below normal were formed in the western, southwestern, central regions and in the southeastern Baltic region (up to minus 5.0 ° C and below). In the extreme northern regions, air temperatures were about normal with anomalies ranging from minus 0.7 to plus 0.3 °C.

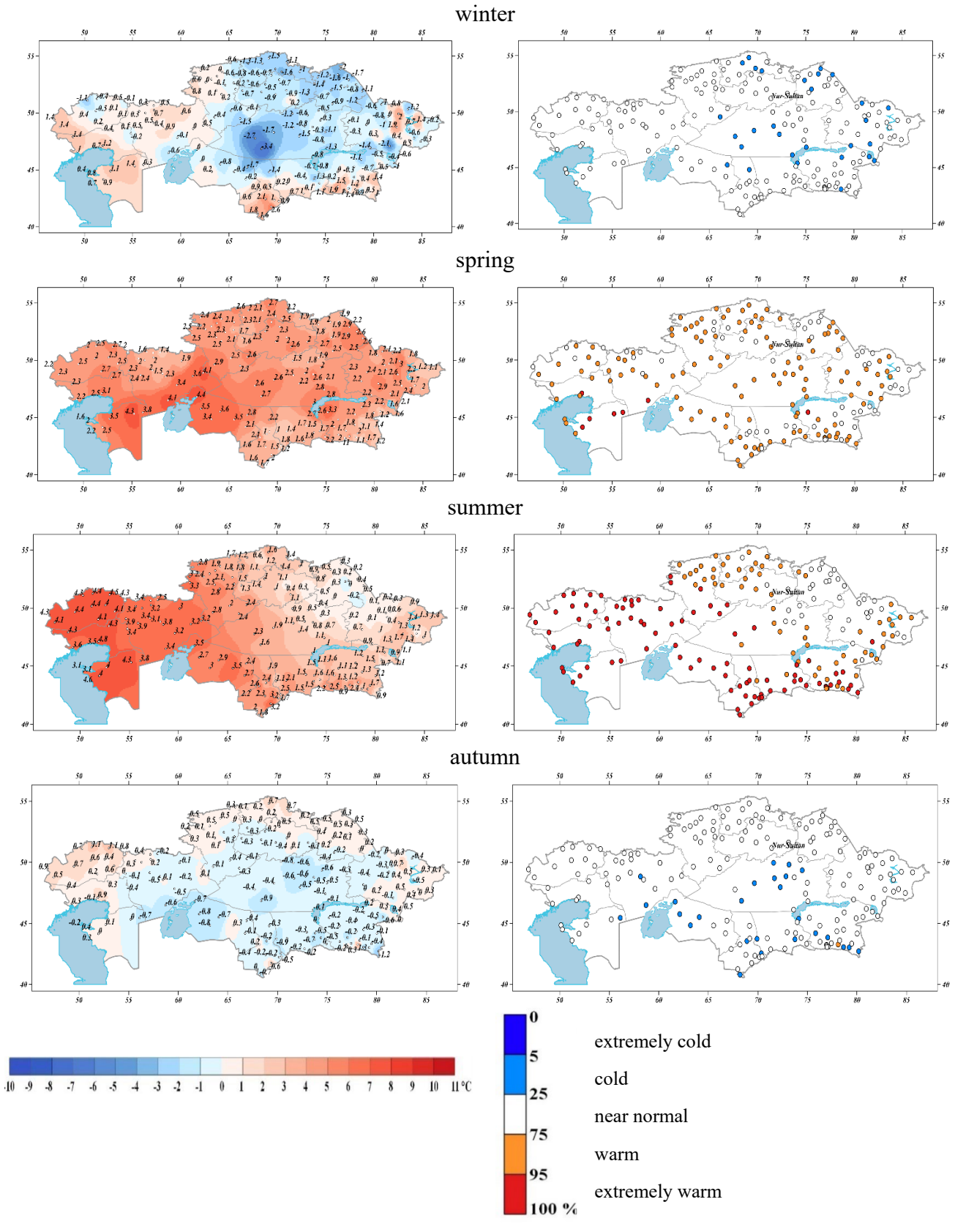

Figure 2.3 – Spatial distribution of the air temperature anomaly (°C) in 2021, calculated relative to the base period of 1961-1990, and the probability of not exceeding the air temperature values in 2021, calculated according to the data of the period 1961-2020.

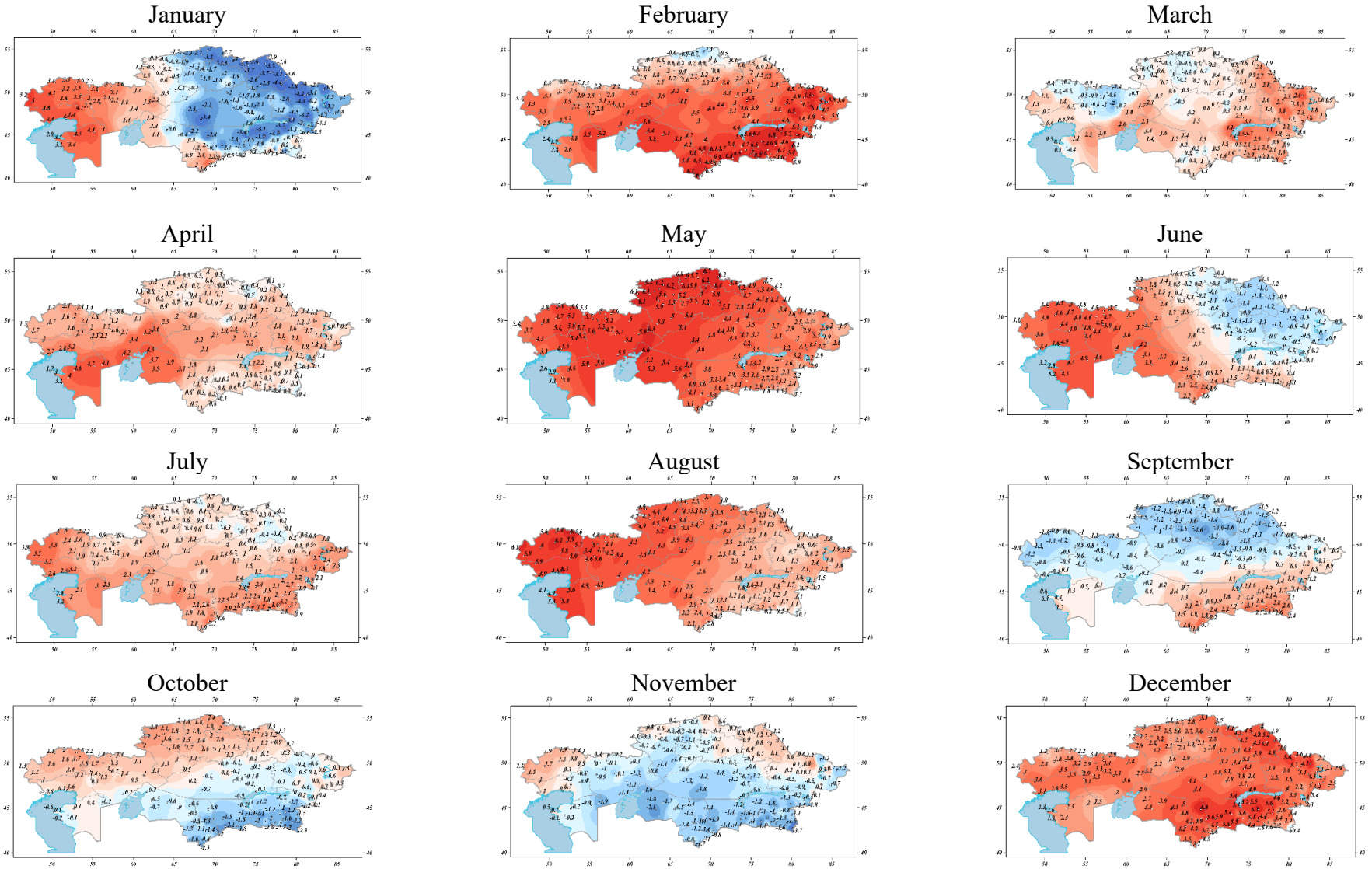

Figure 2.4 – Spatial distribution of the anomaly of the average monthly air temperature (°C) in 2021, calculated relative to the base period of 1961-1990

In January 2021, the average air temperature anomaly in Kazakhstan was 0.32 °C lower than the average annual value for the period 1961-1990. The eastern half of the country (with the exception of the extreme southeastern regions) was occupied by an area with negative air temperature anomalies (Figure 2.4). Temperatures significantly below normal were recorded in several regions: in the northern (by 2.5 3.9 ° C), in the eastern (in places by 3.0 4.4 ° C), in the central (by 2.5 3.4 ° C), as well as in the southern Baltic (by 3.0 3.7 ° C). In the western half of the republic, air temperature anomalies were positive and their values increased in a westerly direction, reaching 5.2 °C in the extreme western region. The focus of elevated temperatures was also in the southern half of the Turkestan region with an anomaly of up to 3.6 °C.

In February, the average air temperature anomaly in Kazakhstan was higher than the climatic norm and amounted to 3.82 °C. It was extremely warm on the territory of the Almaty region, the air temperature anomaly was 5.89 °C (the probability of not exceeding 98%), the average air temperature anomalies in the Zhambyl, Turkestan and East Kazakhstan regions were included in 10% of extremely high anomalies: +6.16, +5.62 and 4.90 °C, respectively (Table 2.3). Positive anomalies were observed in almost the entire territory of the republic, with the exception of a small area in the far north with negative anomalies up to 1.1 °C (Figure 2.4). The values of positive anomalies increased from north to south and south-east, reaching maximum values of 5.5 - 6.5 °C, sometimes exceeding 7-8 °C. Temperatures in these regions entered 5% of extremely warm February. New records of average monthly air temperature were recorded at 6 weather stations in the southern region.

In spring, the average temperature anomaly of the spring season in Kazakhstan was +2.16 °C (Table 2.2, Figure 2.3). Republic and exceeded 1.0 °C. The values of the average anomalies in the territory were extremely high in Atyrau (+2.60 °C with a probability of not exceeding 95%), the average air temperature anomalies in the Mangystau and Kyzylorda regions were 10% extremely high: +2.00 and 3.41 ° C, respectively. Air temperature anomalies in the entire territory of the republic exceeded 1.0 °C. Foci of significant anomalies, more than 3 ° C, are located in the south of Atyrau and east of Mangystau regions (up to 4.3 ° C), in the northern Aral Sea region and in the north of Kyzylorda region (up to 4.1 4.4 °C), in places in the western Baltic region (up to 3.3 °C). MS Kyzan recorded the highest seasonal temperature since 1941 – plus 14.9 °C.

In March, it was warm in most of the territory (Figure 2.4), the average temperature anomaly in Kazakhstan was 1.01 °C (Table 2.3). Temperatures in the range ± 1 °C near normal were observed in the northwest and southwest, in the northern, central and some southern regions of the country. The northern part of the Aktobe region was occupied by an area with negative temperature anomalies up to 2 °C. The maximum positive anomalies reached: 1.8 °C in the far west; 2.6 °C in the Aral Sea region; 4.1 °C in the western Baltic region; 2.8 2.9 °C in the southeast, east and northeast of the country.

In April, the air temperature anomaly averaged over the territory of Kazakhstan was 1.31 °C. In the entire territory of the country, except for the northeast and the mountainous part of the extreme southeast, temperatures were above the climatic norm (Figure 2.4). Temperatures near normal were in the north, east, in the southern regions and in some areas of the western part of the country. Foci of heat with a temperature anomaly within 3.1 4.7 °C occupied the territories of Mangystau, the south of Aktobe and the western part of Kyzylorda regions, 95-97% extremes were recorded at 8 weather stations.

May was record warm: the average air temperature anomaly in Kazakhstan was 4.14 °C (rank 1). It was also record warm on the territory of 8 regions (West Kazakhstan, Atyrau, Aktobe, Kyzylorda, Kostanay, Karaganda, Akmola and North Kazakhstan), where temperature anomalies on average in these territories were in the range of 4.16–5.99 □C. The average anomalies on the territory of the remaining regions were 5 and 10% extremely high. Temperatures above the climatic norm by 6.0 °C or more were observed in the north of the Kostanay region, in the territory of the North Kazakhstan region and in the Northern Aral Sea region (Figure 2.4). New record values of the average monthly air temperature were set at 82 weather stations, at 73 weather stations air temperature anomalies entered 5% of extremely high temperatures.

The summer was extremely warm in almost the entire territory of Kazakhstan. On average, the temperature anomaly of the summer season in Kazakhstan was extremely high and amounted to 1.89 °C (rank 3 with a probability of not exceeding 98%, Table 2.2). The warmest summer season remains 1998 with an anomaly of 2.23 °C. Anomalies were on average on the territory of 3 regions of the western and southern regions of Kazakhstan (from +2.32 °C with Turkestan region to +3.99 °C with Atyrau region). In 6 more regions, air temperature anomalies were included in 5% of extremely high anomalies with values from +1.41 °C for the Almaty region to +4.27 °C for the West Kazakhstan region.

Air temperatures were higher than normal by more than 1.0 °C in most of the territory. The exceptions were the north-eastern part of the Karaganda and north-western part of the East Kazakhstan regions, as well as the Pavlodar region, where air temperatures were about the climatic norm. The magnitude of positive anomalies increased from east to west, exceeding 3 °C in the western regions of Kazakhstan and in places in the south in Turkestan and Kyzylorda regions. The maximum values of anomalies were noted in West Kazakhstan (up to 4.4 °C), Atyrau (up to 4.8 °C) and Mangystau (up to 4.6 °C) regions. According to about 30% of stations in Kazakhstan, the temperatures of the summer season exceeded the 95th percentile. Record high seasonal temperatures have been recorded at 27 weather stations since 1941.

In June, the average temperature anomaly in Kazakhstan was 1.22 °C (Table 2.3). The western half of the territory of the republic and the south-eastern regions were covered by a zone of positive anomalies, the values of which increased to the west from 1.0 to 5.2 °C (Figure 2.4). In many areas in the west, in the Kyzylorda and Turkestan regions, June entered 5% of the extremely warm months. Negative anomalies covered the eastern territories of North Kazakhstan, Akmola, Karaganda and Almaty regions, the entire territory of Pavlodar and East Kazakhstan regions. The most significant negative anomalies (up to minus 1.4 °C) were observed at the junction of Akmola and Pavlodar regions. At 40 weather stations, air temperature anomalies entered 5% of extremely high temperatures, at 2 weather stations (Shymkent and Shardara MS, Turkestan region), new record values of the average monthly air temperature were set.

In July, the air temperature anomaly averaged over the territory of Kazakhstan was 1.57 °C (rank 4 with a probability of non-exceeding 94%, Table 2.3). Extreme heat (5% extremes) was in Atyrau, Turkestan, Zhambyl and Almaty regions, where the average temperature anomalies in the territory amounted to 2.23 2.70 ° C (Table 2.3). The foci of maximum positive anomalies (3.0 -3.5 °C) occupied the extreme western and south-eastern regions, in places in the Mangystau and East Kazakhstan regions. Temperatures slightly above normal (up to 1.0 °C) were observed in the north-

west and in the northern regions, including the northern parts of the Karaganda and East Kazakhstan regions. Temperatures below normal (by a maximum of 0.3- 0.4 °C) were observed in places in North Kazakhstan, Akmola and Pavlodar regions.

August was record-breaking hot: the average monthly air temperature averaged over the territory of Kazakhstan was 2.89 °C higher than the climatic norm (rank 1, Table 2.3). The anomalies of the average monthly air temperature were record-breaking on average in the territory of 4 regions of the western and southern regions of Kazakhstan (from +3.74 °C in the Kyzylorda region to +5.99 °C for the West Kazakhstan region. In 3 more regions, air temperature anomalies were included in 5% of extremely high anomalies with values from +2.24 for the Turkestan region to +4.76 °C for the Aktobe region. With the exception of small areas in the south and east of Kazakhstan, the air temperature was above normal by more than 1.0 °C (Figure 2.4). The values of the anomaly increased from west to east and in the western half of Kazakhstan everywhere exceeded 4 °C. Here, at many weather stations, the air temperature values fell within 5% of the highest temperatures observed in August. In the western regions of Aktobe, Atyrau and Mangystau regions and throughout the entire West Kazakhstan region, anomalies exceeded 5 °C, in places 6 °C. Record maximum values of the average monthly air temperature were set at 30 weather stations in the western and south-western regions. The previous highs were observed mainly in August 2016.

In autumn, the average air temperature in Kazakhstan was about normal (the anomaly was minus 0.02 ° C, Table 2.2). The temperature anomalies of the autumn season throughout the republic were mainly within ±1 °C (Figure 2.3). The maximum positive anomalies were observed in the extreme northwest, where they reached 1.1 °C. Foci of maximum negative anomalies with values of 0.5 - 0.8 °C were noted in the Aral Sea region and in Central Kazakhstan (up to minus 0.9 °C).

In September, the average temperature anomaly in the country was 0.15 °C. The average temperature in the Turkestan region with an anomaly of 2.34 ° C was 5% extremely high, in the Zhambyl and Almaty regions – 10% extremely high with anomaly values of 2.01 and 2.11 ° C, respectively. In the extreme southern regions of these regions, air temperatures were 2.5 - 3.7 °C above normal (Figure 2.4). At 17 weather stations, air temperature anomalies entered 5% of extremely high temperatures. Temperatures below normal by more than 1 °C were observed in the north-western (maximum 1.3 °C) and northern regions (maximum 1.5 1.7 ° C). The most significant negative anomaly (-2.3 °C) was observed at the Zhaltyr weather station (Akmola region).

In October, the average air temperature in Kazakhstan was about normal with an anomaly of 0.23 ° C (Table 2.3). Positive temperature anomalies exceeding 1.0 °C were observed in the western and northern regions, as well as in the far east. The values of anomalies increased to the north, reaching 2.0- 2.3 °C in the extreme northwestern and northern regions (Figure 2.4). In Mangystau, Kyzylorda, Karaganda and East Kazakhstan regions, as well as in the northern regions of Turkestan, South Kazakhstan, Almaty regions, the average monthly temperature was about normal (anomalies ± 1 ° C). In the southern regions of Turkestan, South Kazakhstan, Almaty regions, the average monthly temperature was below normal, in some places by 1.5- 2.5 °C. At 28 meteorological stations in the southern region (mainly in mountainous and foothill areas), extremely low monthly air temperatures were observed – below the 10th percentile. At MS Zhetysai (Turkestan region), the air temperature entered 5% of extremely low temperatures.

In November, the anomaly of the average monthly air temperature in Kazakhstan was about normal (anomaly minus 0.43 ° C, Table 2.3). In the northern half of Kazakhstan, air temperatures were mostly within ± 1 °C near normal (Figure 2.4). Foci of more significant positive anomalies occupied the extreme western regions (with an anomaly of up to 1.5- 1.9 °C) and the eastern ones in the Pavlodar region (with an anomaly of up to 1.2 °C). The values of negative anomalies increased to the south, reaching 1.9- 2.1 °C in some areas of the Kilorda, Zhambyl and Almaty regions. At MS Narynkol (Almaty region), the average monthly air temperature entered 5% of extremely low temperatures (-7.1 °C with an anomaly of 3.7 °C)

For the purposes of monitoring the extreme values of climatic parameters that are most significant for specific sectors of the economy and social sphere, the WMO Climatology Commission has developed a ClimPACT software product that allows calculating a set of specialized climate indices based on daily values of maximum and minimum air temperature and precipitation. Below are the indices that are most indicative of the degree of extreme temperature conditions in 2021.

In 2021, the warm period of the year is characterized by the fact that the daily maximum temperature exceeded 30 and even 35 ° C throughout Kazakhstan (with the exception of high-altitude areas). In the northern, north-eastern and western parts of the Karaganda region, the number of days when the maximum daily air temperature exceeded 30 °C (index TXge30) was mainly from 30 to 80 days (Figure 2.5), in the rest of the territory – from 80 to 120 days, the maximum number of such days was in the south Turkestan region – 141 days.

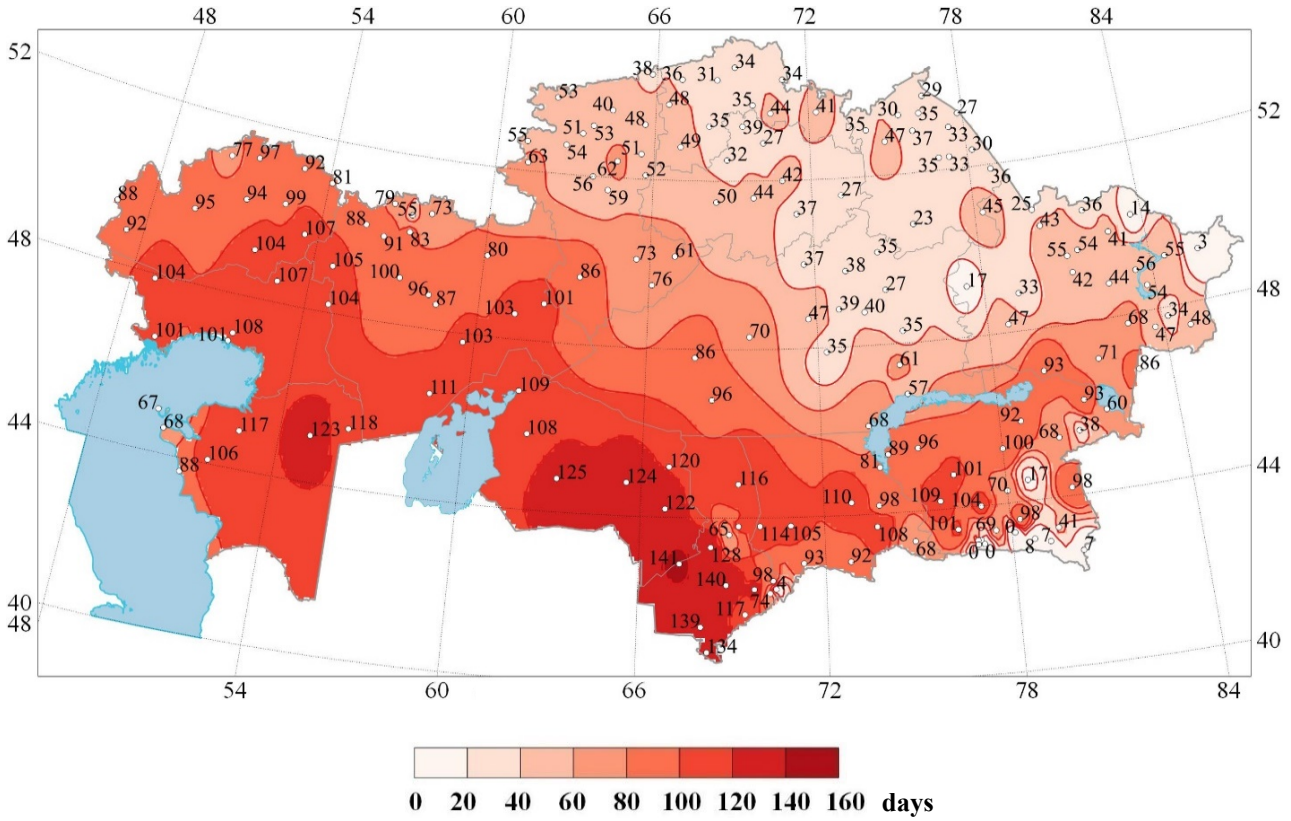

Figure 2.5 – The number of days in 2021 when the maximum air temperature exceeded 30 °C (index TXge30)

In the period from May to August 2021, in many regions of Kazakhstan there was a very ***high percentage of days when the maximum daily temperature exceeded the values of the 90th percentile (*TX90p index).** For example, in May and August, according to most stations in the western half of Kazakhstan, the daily maximum air temperature was above the 90th percentile for more than 50% of the days (Figure 2.6). The minimum proportion of extremely warm days (less than 10%) was recorded in the foothill and mountainous southeastern regions.

As another characteristic of the extreme temperature regime in the warm period of the year is the total duration of all heat waves (for a heat wave, the case is taken when the excess heat coefficient has a positive value for 6 or more days in a row, the HWF/EHF index, Figure 2.7). In the western and southern regions, the total duration of all heat waves was more than 50, in some places more than 60 days.

In 2021, in the northern, north-eastern regions, in the western part of the Karaganda region, the ***daily maximum air temperature (index TXx)*** was 36-40 °C (Figure 2.8). In other regions, with the exception of mountainous areas, it was above 40 °C, and in some western and southern regions it exceeded 45 °C.

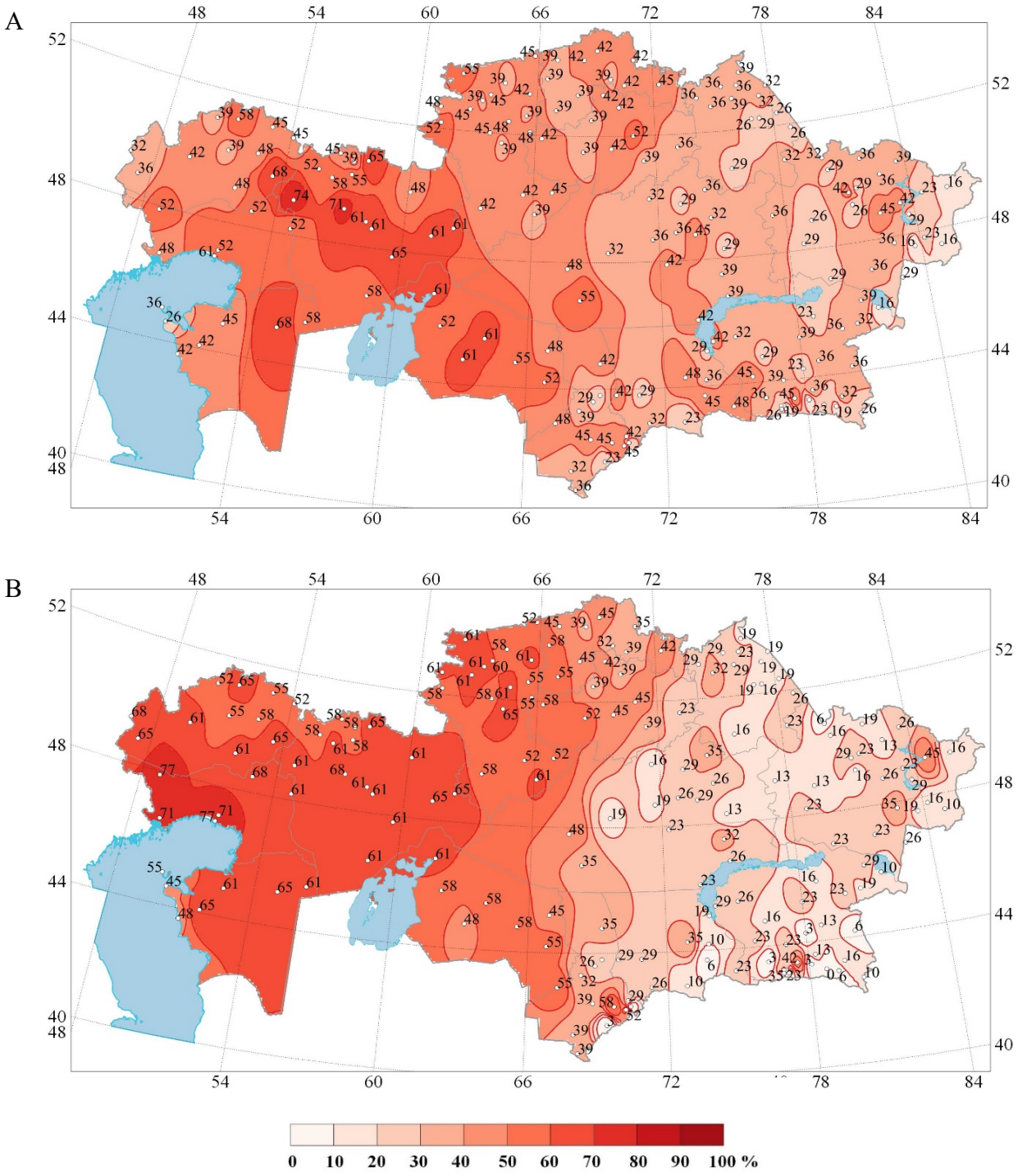

Figure 2.6 – Percentage of days when the maximum daily temperature in May (A) and August (B) 2021 was above the 90th percentile (TX90p index)

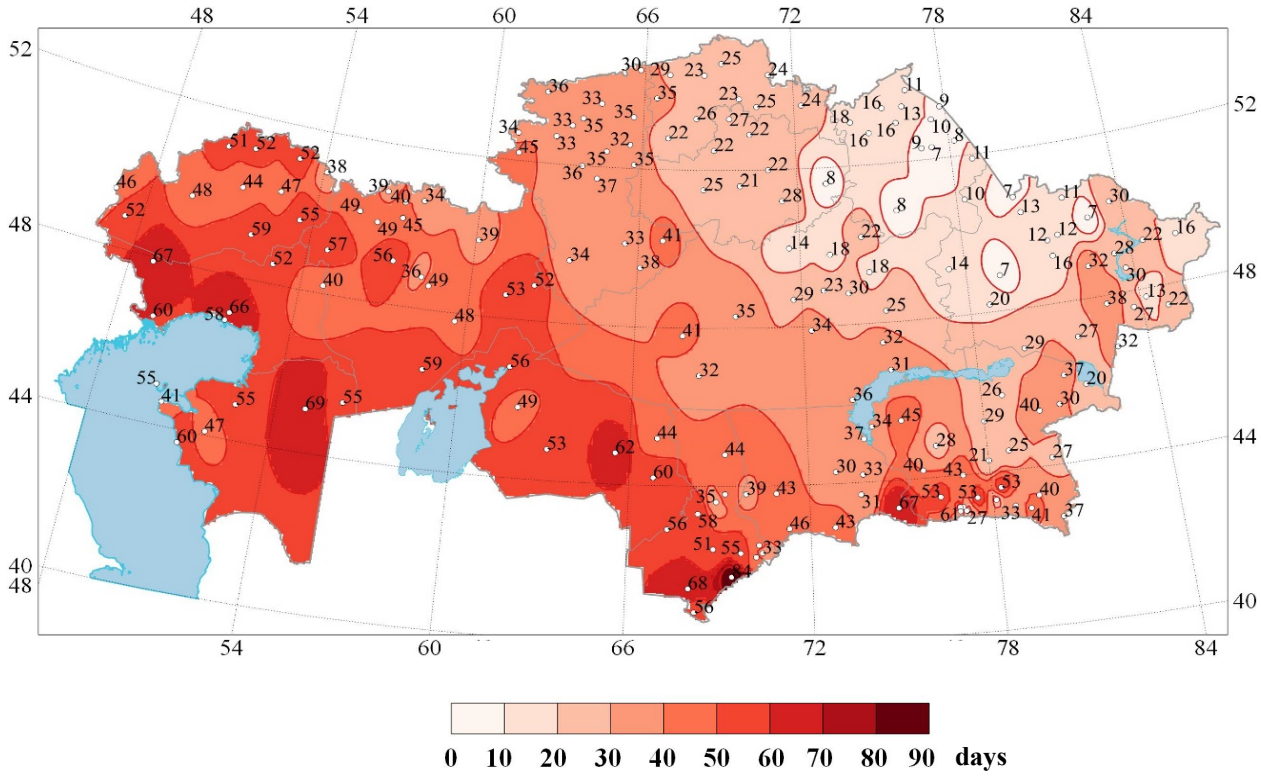

Figure 2.7 – Total duration of heat waves during the warm period in 2021 (HWF/EHF index, day)

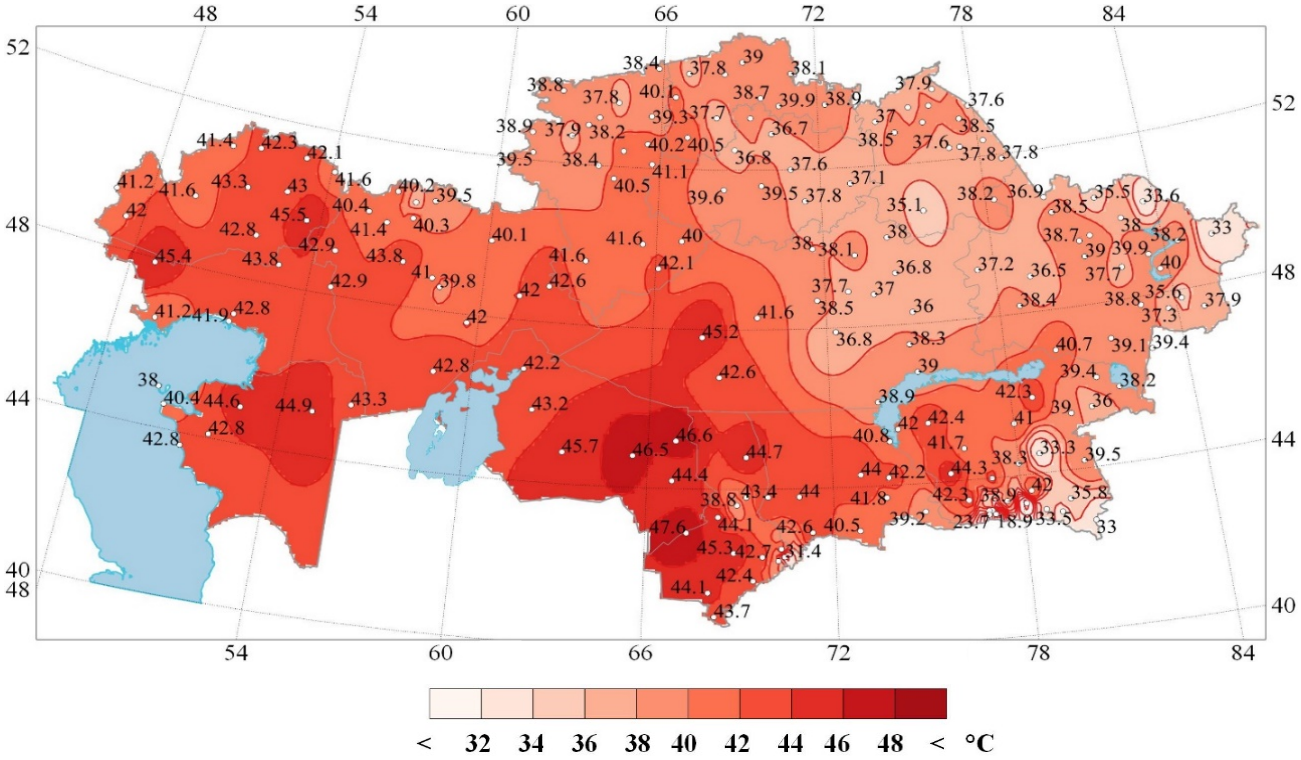

Figure 2.8 – Values of the maximum daily air temperature (°C) recorded in 2021

As a result of such an increased background temperature in the summer months, the values of the previous absolute daily maxima of air temperature were updated in 2021 at some MS (highlighted in red, Figure 2.9). The values of absolute maxima recorded from the moment of the station's opening to 2021 are shown in blue. In 2021, the values of absolute maxima were exceeded at eight weather stations participating in climate monitoring in Kazakhstan: MS Zlikha to 0.9 °C (46.6 °C); MS Kyzylorda to 0.9 °C (46.5 °C); MS Karatobe to +1.7 °C (45.5 °C); MS New Ushtagan to 0.6 °C (45.4 °C); MS Zhezkazgan to 0.1 °C (45,2 °C); MS Uralsk to +0,7 °C (42,3 °C); MS Zheleznodorozhny to 0.5 °C (41,1); MS Shokpar to +0,3 °C (41,1 °C). Most of the highest air temperature values (absolute maxima) in Kazakhstan were recorded in July 1983, when the air temperature reached +49...+50 °C at some weather stations of the Turkestan region (MS Turkestan, Shayan, Arys, Tasty), as well as in July 1995, when the air temperature rose at MS Kyzylkum up to +51 °C.

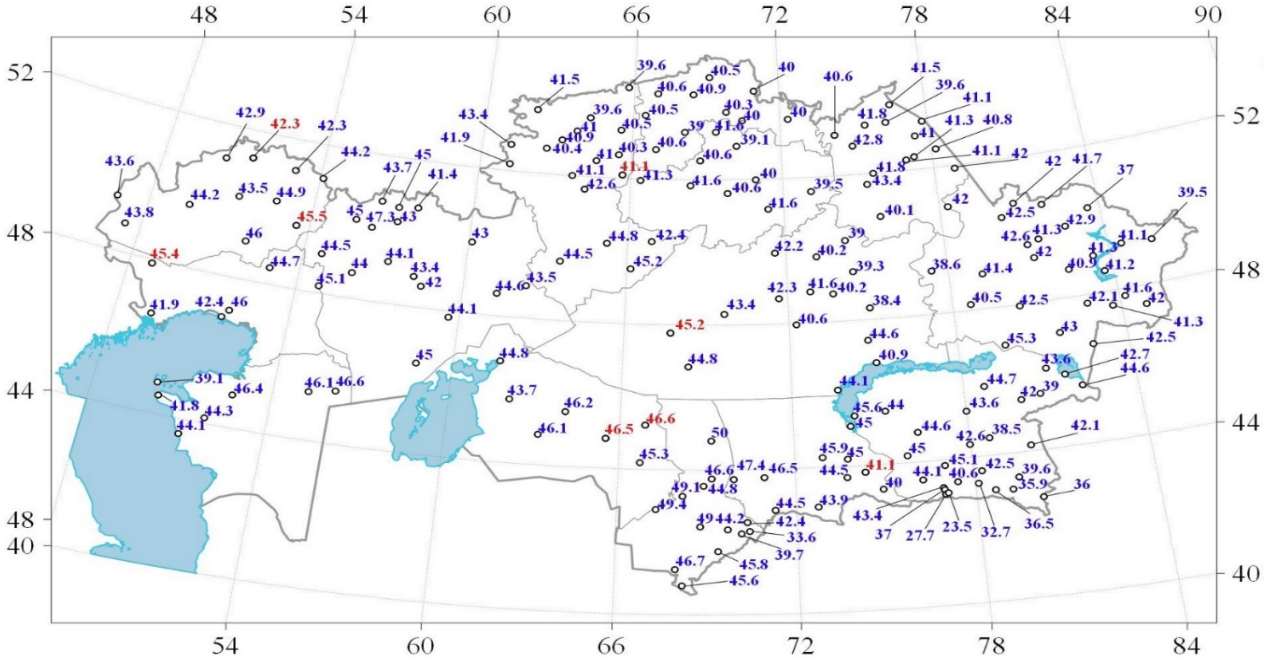

Figure 2.9 – Values of absolute maxima of air temperature (°C) recorded from the beginning of the opening of the weather station to 2021. If the record value of the maximum daily air temperature is recorded in 2021, this value is marked in red

By the recommendation of WHO, an index has been introduced that characterizes ***the number of days when the daily minimum temperature does not fall below 20 ° C (TR index, "tropical night")***, since at such night temperatures the human body does not have time to rest from the heat of the day. Since the summer was extremely hot in the western and southern regions, high night temperatures lasted for more than 30 to 40 days, in most of the Atyrau, Kyzylorda and Turkestan regions – more than 50 to 60 days, in Mangystau – more than 80, and in some places more than 90 days (Figure 2.10). The minimum number of tropical nights, or their absence, was observed in the northern, central, south-eastern and mountainous regions of Kazakhstan.

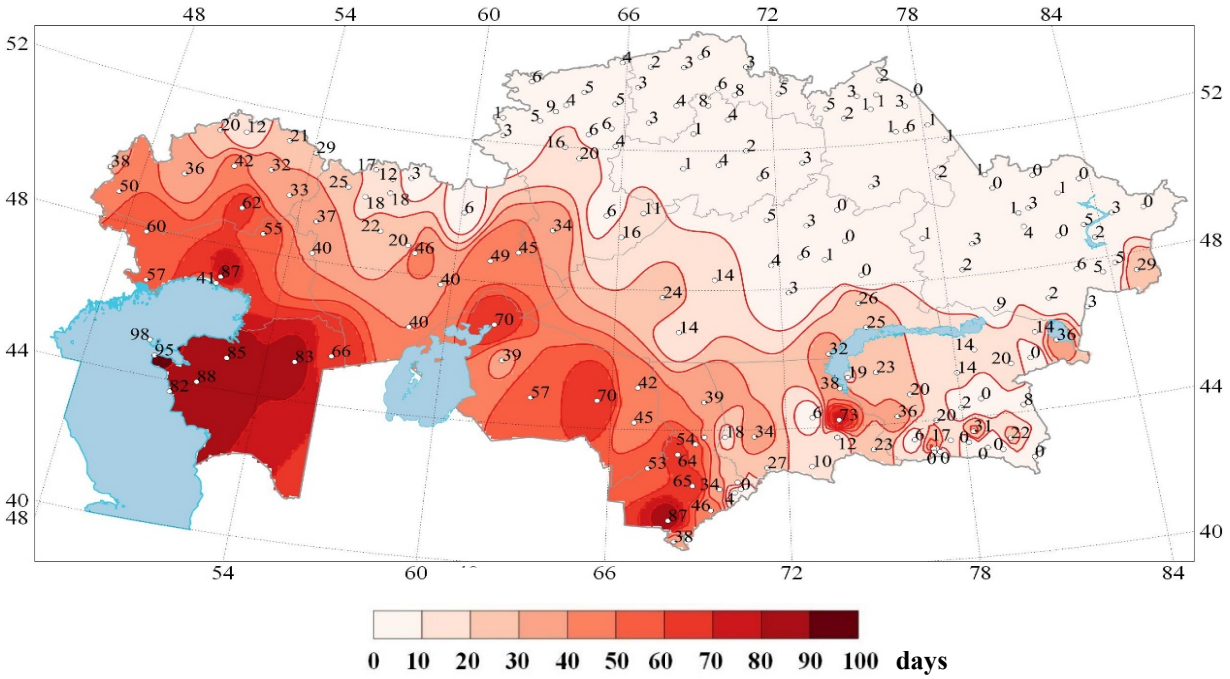

Figure 2.10 – The number of days when the daily minimum temperature is above 20 ° C in July 2021 (TR index)

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. 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 cold deficit was observed in Atyrau, Mangystau, Kyzylorda, Turkestan regions, where it is 600 and even 700 degree-days in places.

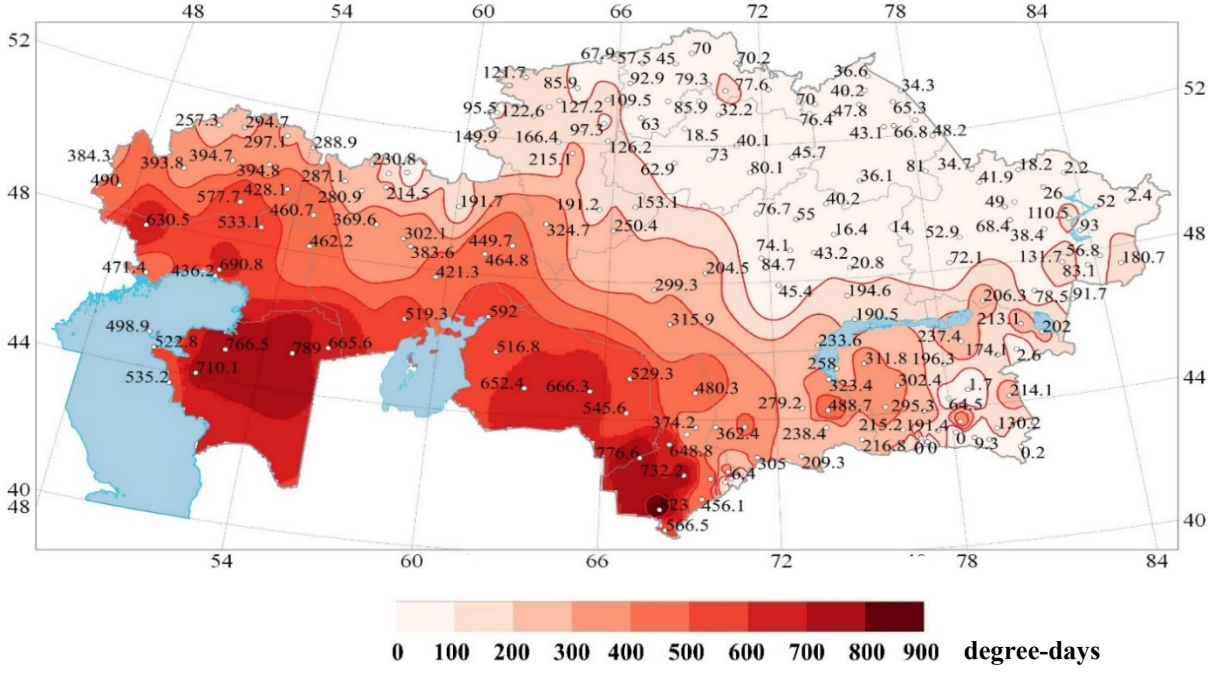

Figure 2.11 – Cold deficit (degree-days) observed in 2021 (CDDcold23 index)

In January 2021, usually the coldest month of the year, significant negative anomalies were observed in the northern and northeastern regions of Kazakhstan and ***the daily minimum air temperature (TNn index,*** Figure 2.12) fell below minus 35-40 ° C, in some places below 43 °C.

Figure 2.13 shows the absolute minima of air temperature recorded since the opening of the weather station. In Kazakhstan, absolute minimums of air temperature below minus 50 ° C were recorded at 2 stations – in January 1931 at MS Shaganatty/Orlovsky settlement (-54 ° C) and in January 1893 on MS Nur-Sultan (-52 ° C). Air temperatures below minus 45 °C were observed mainly in the northern and eastern regions of Kazakhstan. In 2021, no new records of the daily minimum temperature were recorded.

На рисунке 2.13 представлены абсолютные минимумы температуры воздуха, зафиксированные с момента открытия метеостанции. В Казахстане абсолютные минимумы температуры воздуха ниже минус 50 °С отмечены на 2 станциях – в январе 1931 г. на МС Шаганатты/Орловский посёлок (-54 °С) и в январе 1893 г. на МС Нур-Султан (-52 °С). Температуры воздуха ниже минус 45 °С наблюдались в основном, в северных и восточных регионах Казахстана. В 2021 г. новых рекордов суточной минимальной температуры не зафиксировано.

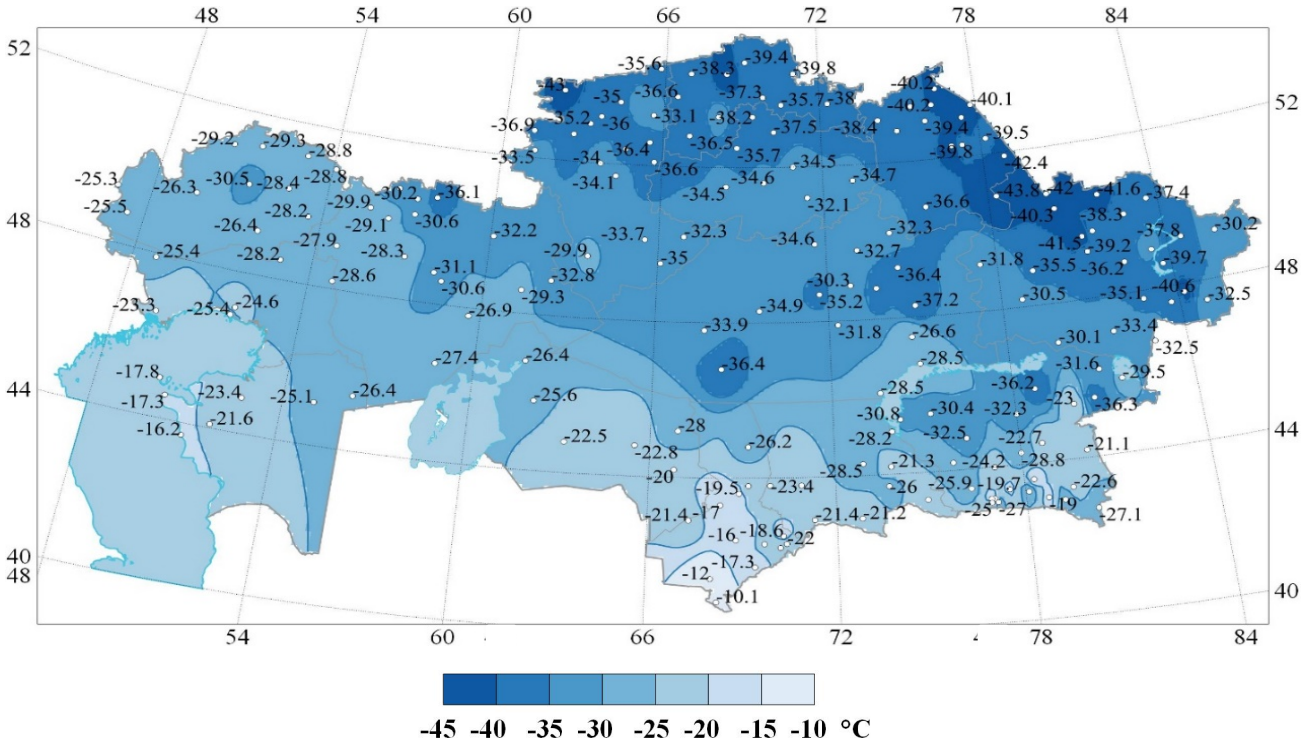

Figure 2.12 – Values of the daily minimum air temperature (°C) registered in 2021

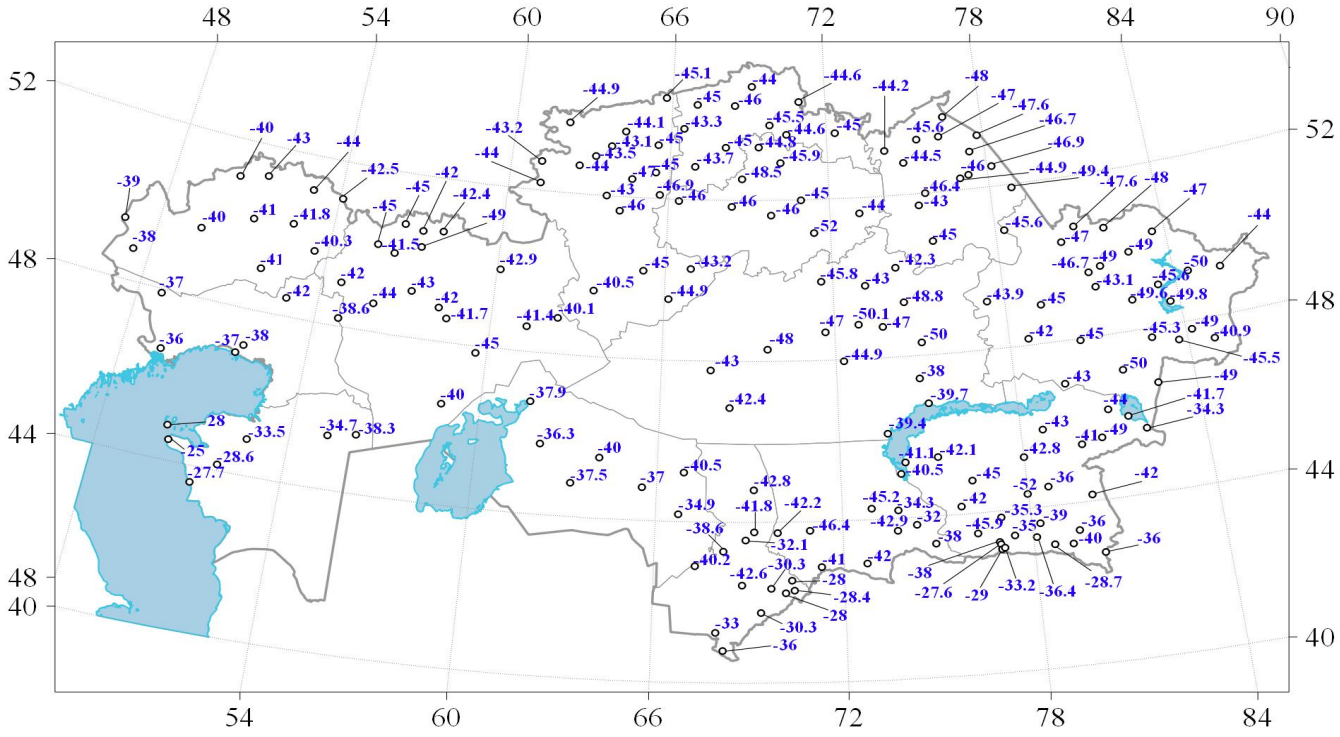

Figure 2.13 – Values of absolute minima of air temperature (ºC) recorded from the beginning of the opening of the weather station to 2021. If the record value of the minimum daily air temperature is recorded in 2021, this value is marked in red

2.2 Changes in air temperature observed on the territory of 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 1941-2021, as well as linear trends in air temperature changes for the period 1976-2021. 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 – 2021: 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 trend's contribution to the overall variance of the time series.

On average, over the territory of Kazakhstan for the period 1976-2021, the increase in the **average annual** air temperature is 0.32 °C every 10 years, the contribution to the overall temperature variability is 27% (Figure 2.14, Table 2.4). On average, in the territory of all regions of Kazakhstan in the period 1976-2021, a steady increase in the average annual air temperature is also observed – the coefficients of determination are in the range of 10-38%, trends are significant at the 5% level (figure 2.15, table 2.4). It is warming at a faster pace in the western and southwestern regions of Kazakhstan (from 0.44 °C/10 years to 0.54 °C/10 years), at a slower pace – in the central, northern and eastern regions (from 0.23 ° C/10 years to 0.29 ° C/10 years).

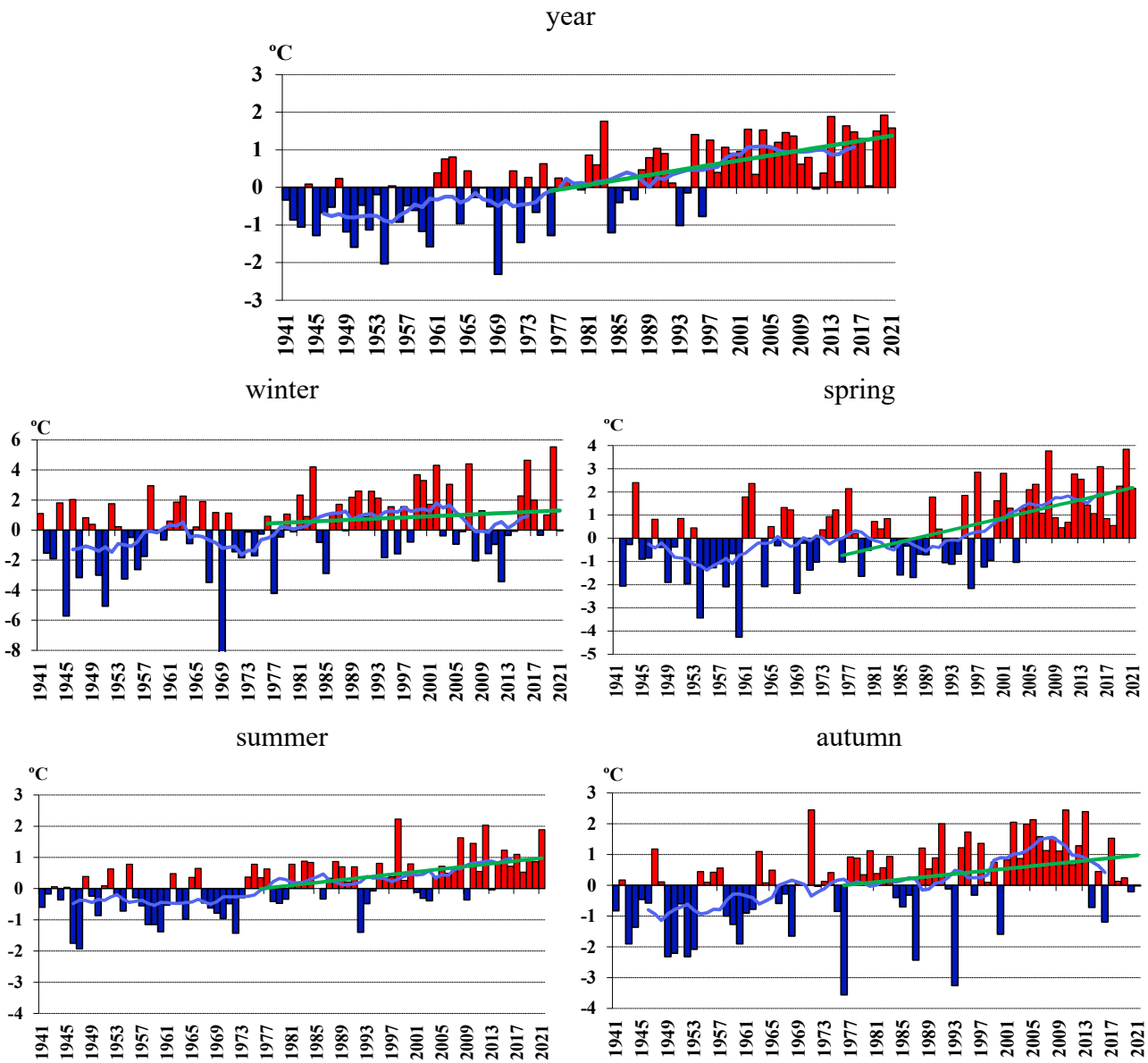

Figure 2.14 – Time series of anomalies of annual and seasonal air temperatures (°C) averaged over the territory of Kazakhstan for the period 1941-2021. Anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2021 is highlighted in green. *The smoothed curve is obtained by an 11-year moving average*

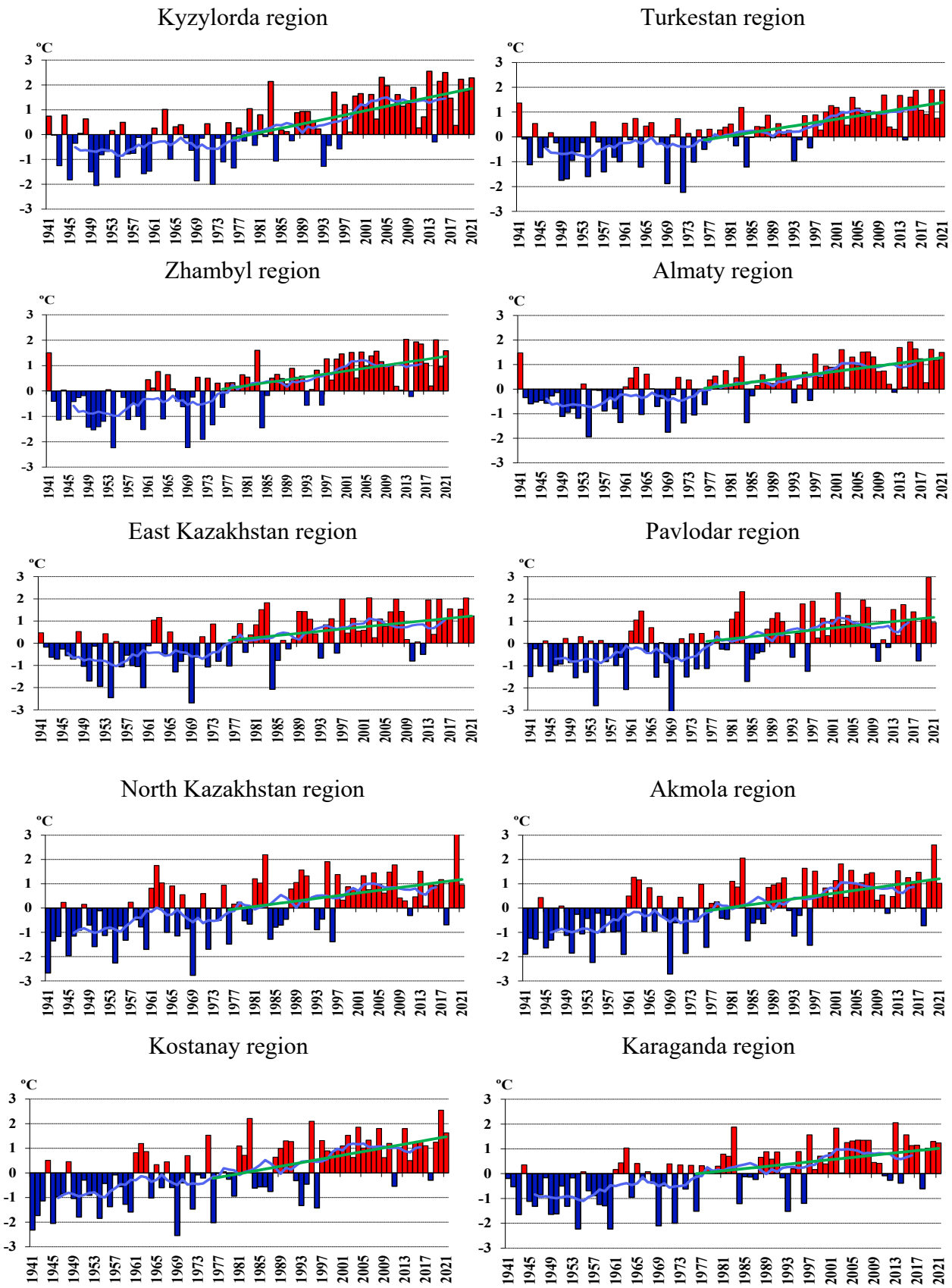

Figure 2.15 – Time series of anomalies of annual air temperatures (°C) averaged across the regions of Kazakhstan for the period 1941-2021. Anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2021 is highlighted in green. *The smoothed curve is obtained by an 11-year moving average. Sheet 1*

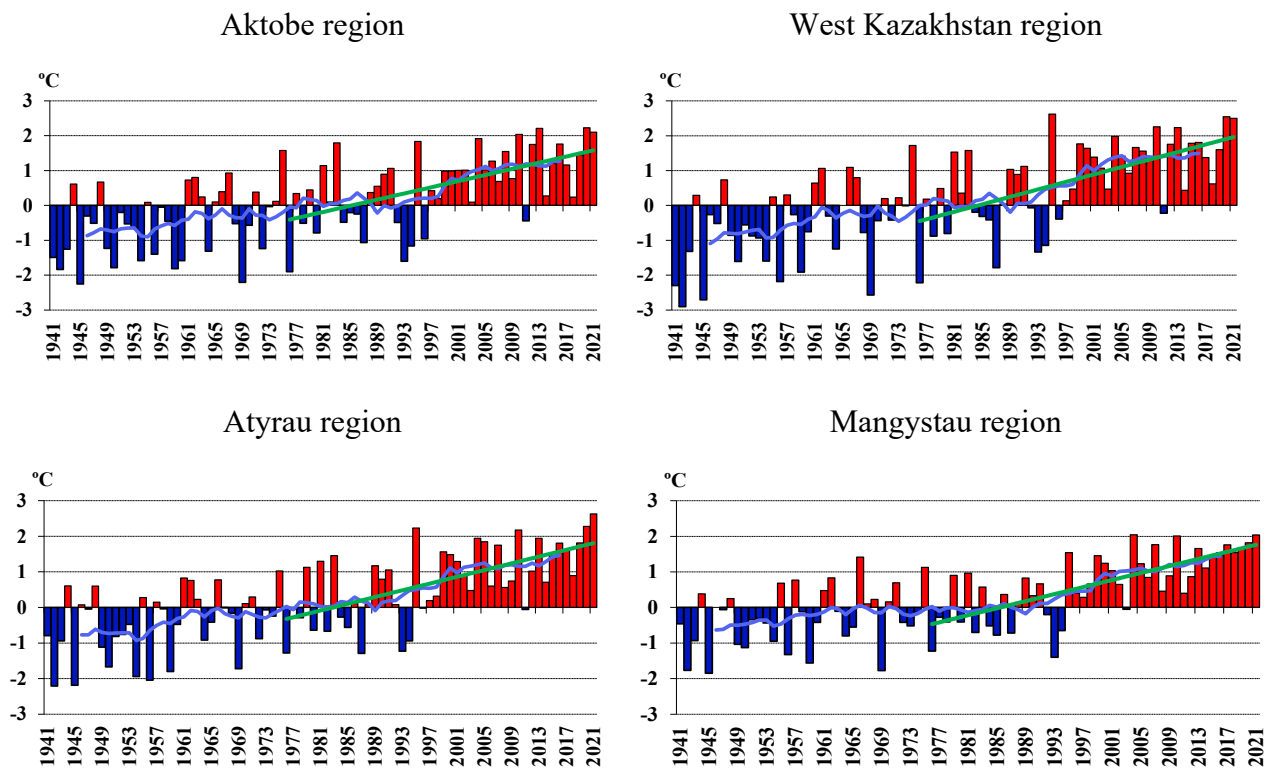

Figure 2.15 – Time series of anomalies of annual air temperatures (°C) averaged across the regions of Kazakhstan for the period 1941-2021. Anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2021 is highlighted in green. *The smoothed curve is obtained by an 11-year moving average. Sheet 2*

On average, the **winter** season warming trend in Kazakhstan is 0.19 °C/10 years (Table 2.4), but it should be noted that the trend describes only about 1% of the total variance and is insignificant at the level of 5%. The trends of average winter temperatures in the regions were positive, except for Pavlodar, and mainly explain up to 3% of the variance of the series and are statistically insignificant. The most noticeable warming, by 0.33 - 0.47 °C/10 years, was observed in the western region of Kazakhstan (in the West Kazakhstan, Atyrau, Mangystau regions), as well as in the Turkestan region, where the coefficient of determination is 5-11%. According to several stations in the far west, this trend is stable (Figure 2.16). On the territory of Kazakhstan, there is a fairly extensive area where there is a tendency to lower temperatures – this is the center, northeast and east of Kazakhstan.

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 1976-2021.

Region	Year		Winter		Spring		Summer		Autumn	
	a	**D**	**a**	**D**	**a**	**D**	**a**	**D**	**a**	**D**
Kazakhstan	0,32	**27**	0,19	1	0,65	**31**	0,22	**17**	0,22	5
Almaty	0,28	**27**	0,16	1	0,62	**32**	0,22	**21**	0,10	1
Akmola	0,29	**16**	0,14	1	0,69	**23**	0,03	0	0,28	5
Aktobe	0,44	**32**	0,33	3	0,65	**20**	0,37	**14**	0,36	**9**
Atyrau	0,47	**38**	0,45	**7**	0,53	**23**	0,52	**38**	0,35	**11**
East Kazakhstan	0,24	**12**	0,03	0	0,67	**27**	0,15	**9**	0,11	1
Zhambyl	0,29	**25**	0,21	2	0,62	**31**	0,21	**18**	0,07	1
West Kazakhstan	0,54	**37**	0,47	5	0,61	**20**	0,59	**28**	0,43	**15**
Karaganda	0,23	**12**	0,07	0	0,71	**28**	0,04	0	0,06	0
Kostanay	0,37	**23**	0,20	1	0,65	**19**	0,19	4	0,41	**10**
Kyzylorda	0,44	**33**	0,34	3	0,87	**36**	0,33	**24**	0,20	4
Mangystau[1]	0,50	**52**	0,42	**11**	0,43	**22**	0,65	**51**	0,45	**20**
Pavlodar	0,24	**10**	-0,03	0	0,72	**27**	0,04	0	0,21	3
North Kazakhstan	0,28	**14**	0,08	0	0,58	**18**	0,04	0	0,38	**8**
Turkestan	0,34	**38**	0,33	5	0,57	**31**	0,26	**20**	0,15	3

* a – linear trend coefficient, ° C/10 years
** D is the coefficient of determination, %
***statistically significant trends at the 5% level are highlighted in bold

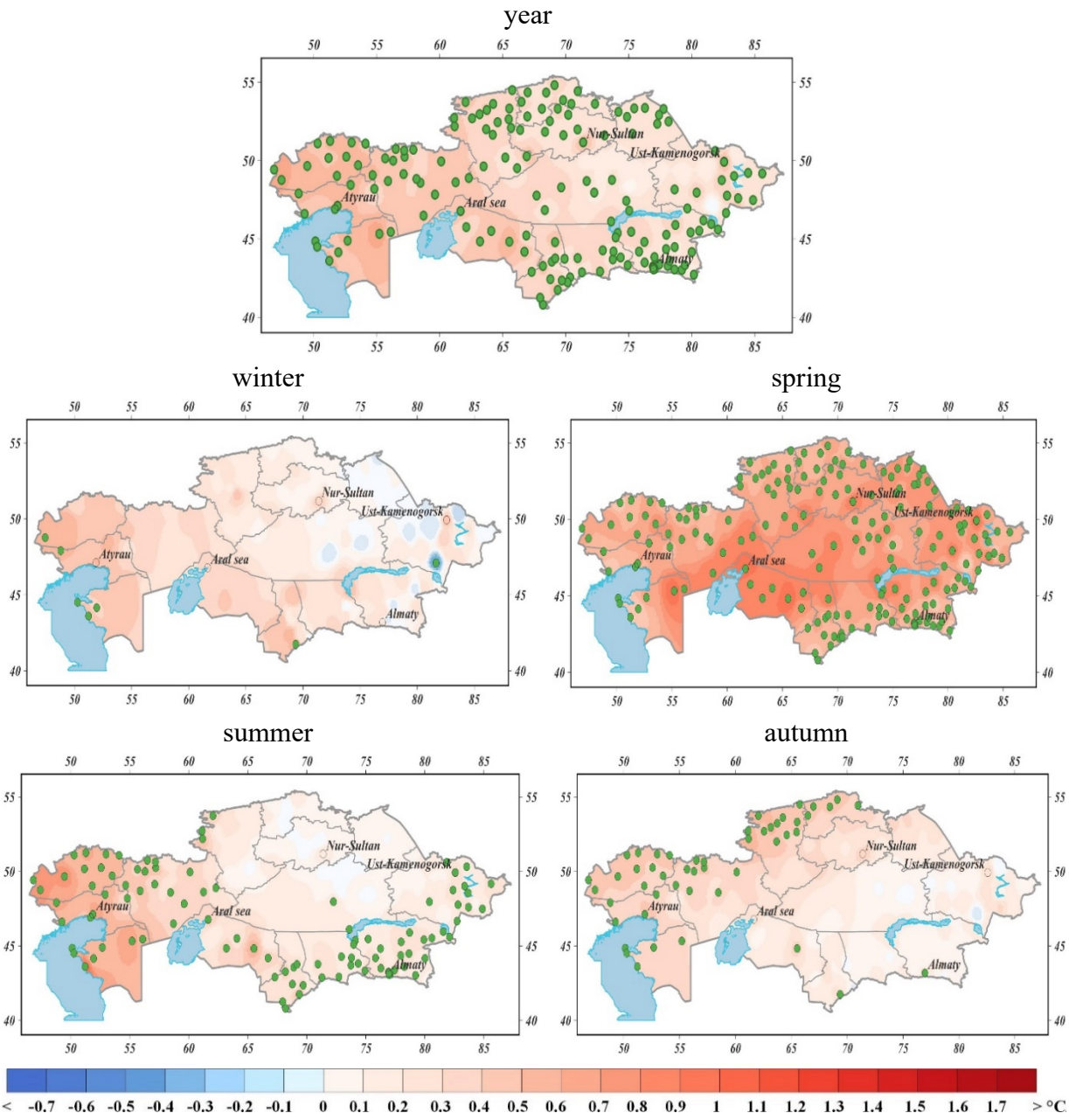

Figure 2.16 – Spatial distribution of values of the linear trend coefficient of the average annual and seasonal surface air temperature (°C/10 years) calculated from observations for the period 1976-2021.

There are no stable trends in the change of average monthly temperatures in December. In most of the territory of Kazakhstan, the trends are positive, the maximum values are in the west (up to 0.42 ° 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 0.50 ° C /10 years in the southern and southeastern regions of the republic.

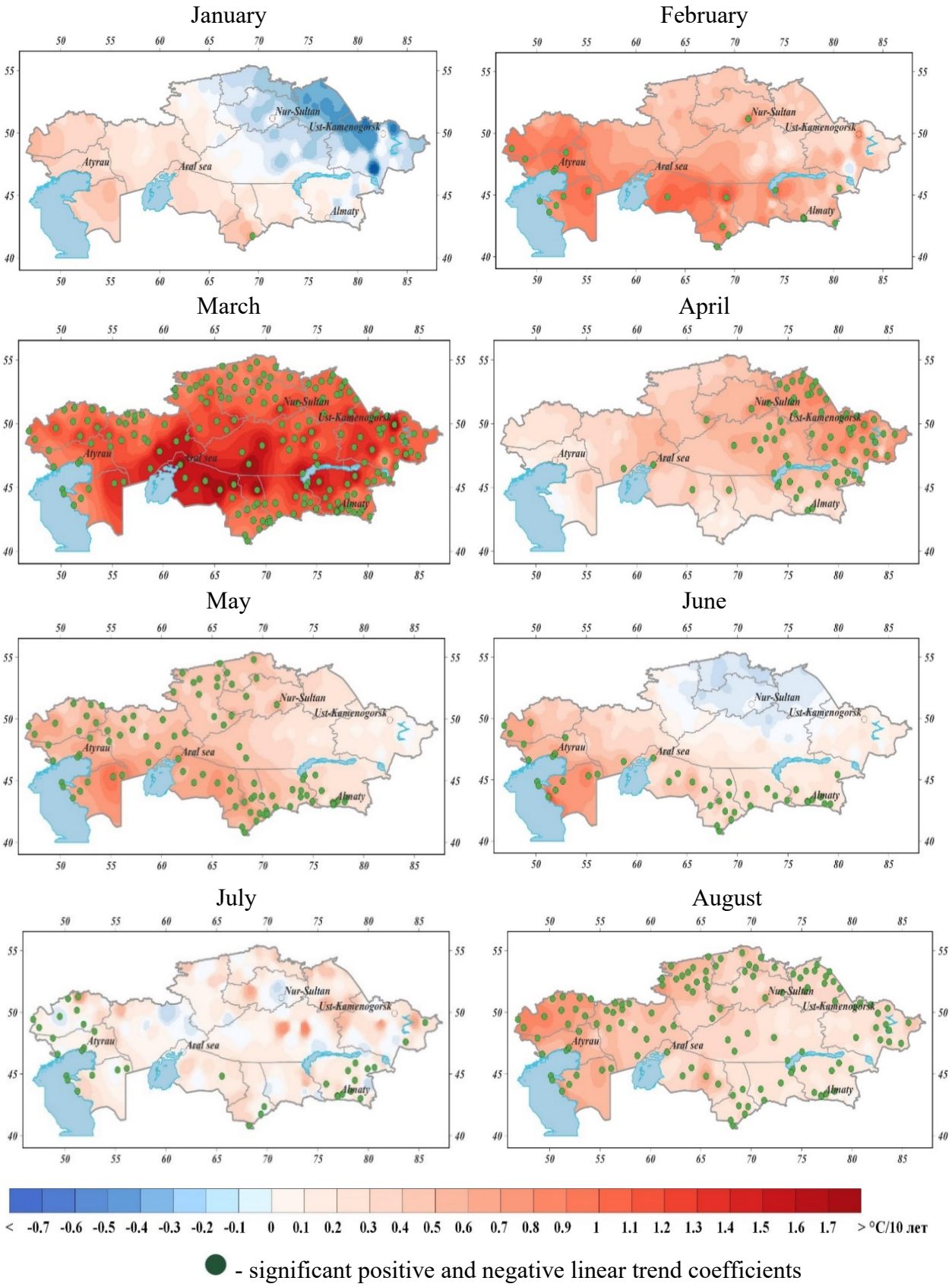

Figure 2.17 – Spatial distribution of values of the linear trend coefficient of the average monthly surface air temperature (°C/10 years) calculated from observations for the period 1976-2021. *Sheet 1*

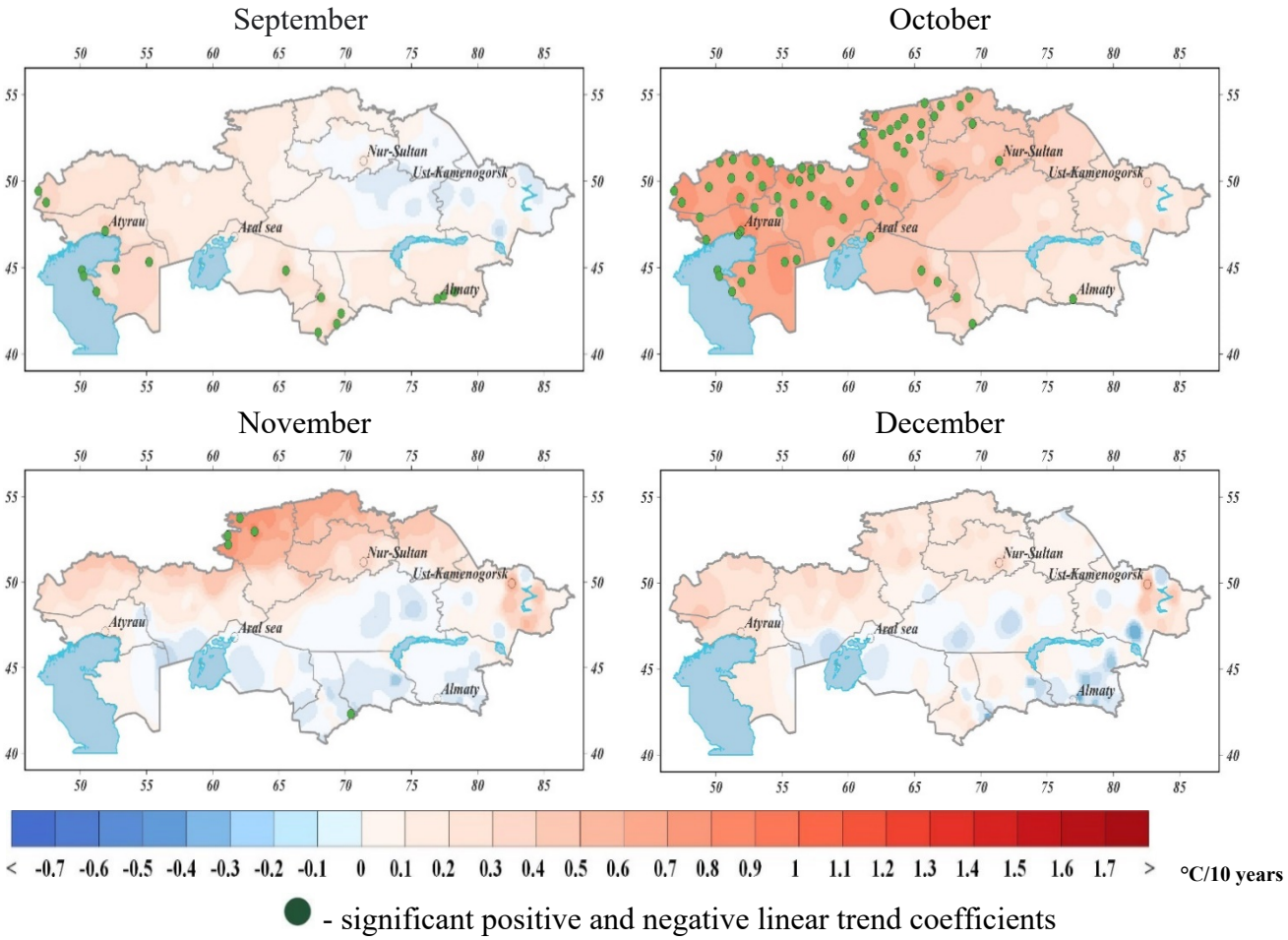

Figure 2.17 – Spatial distribution of values of the linear trend coefficient of the average monthly surface air temperature (°C/10 years) calculated from observations for the period 1976-2021. *Sheet 2*

In January, the region with a tendency to decrease in air temperature occupied a vast territory of the central, north and north-eastern parts of the republic, the temperature decreases at a maximum rate of up to 0.60-0.75 °C /10 years in the north-eastern regions (Figure 2.17). In the west and south, maximum positive trends were noted – up to 0.40-0.55 °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. A statistically significant positive trend in temperature was observed only at MS Kazygurt (0.72 °C/10 years, Turkestan region). In February, there is a tendency to increase air temperature throughout Kazakhstan with maximum values in the western regions of 0.80–1.14 °C /10 years. Statistically significant air temperature growth rates in February were observed at 21 stations in the western and southern regions of the republic.

In the **spring** season, the most intense warming trend is observed in all regions of Kazakhstan (Table 2.4). On average, the air temperature in Kazakhstan increased by 0.65 °C/10 years (the contribution of the trend component is 31%). The range of the rate of air temperature increase in the regions is from 0.40 °C /10 years (Almaty region) to 0.97 °C/10 years (Kyzylorda region) at 10.42% of the variance explained by the trend. The foci of the most intense warming are observed in the

eastern part of the Mangystau region, in the Kyzylorda, Karaganda and Pavlodar regions (0.73 0.97 °C/10 years), figure 2.16. Trends are statistically significant at all weather stations of the country.

The highest and statistically significant rate of increase in air temperature in the spring period according to all stations was noted in March (by 0.69 to 1.72 °C/10 years), figure 2.17. In April and May, the temperature also increased throughout the republic. In April, statistically significant growth rates are traced mainly to the east from about 70 ° C (in the range from 0.29 to 0.98 °C/10 years), in May – in the opposite part of the republic (in the range from 0.23 to 0.96 °C/10 years).

In summer, on average in Kazakhstan, the air temperature of the summer season increases by 0.22 °C/10 years (determination coefficient of 17%, Table 2.4). The most significant rate of increase in air temperature is observed in the western regions – by 0.37–0.65 °C/10 years. Less intense warming is observed in the southern and southeastern regions of Kazakhstan, where the air temperatures of the summer season tend to increase by 0.22-0.26 °C/10 years. Trends here describe from 14 to 51% of the variance of time series. There are practically no trends in the northern and central regions – the share of the trend component in the total variance of the series is almost zero, although the positive trend sign remains.

In June and July, a slight cooling trend is observed in the northern and central regions (up to a maximum of 0.30 °C/10 years, Figure 2.17). In August, statistically significant positive trends in air temperature in the range from 0.22 to 0.88 °C/10 years are observed in most regions of Kazakhstan. The highest rate of growth of the average monthly air temperature is observed in the western region.

In autumn, the average seasonal temperature in Kazakhstan increases by 0.22 °C/10 years (determination coefficient of 5%, Table 2.4). Trends in the average temperature in the regions are also positive. The most significant rates of temperature increase are observed in the western and northern regions – by 0.28 0.45 °C/10 years, while the proportion of variance explained by the trend is 5-20%. In some northern, central, southern and eastern regions there are practically no trends, the share of the trend component in the total variance of the series is no more than 5%. If in summer the maximum and significant trends were observed in the western, southern and southeastern regions, then in autumn - in the western and northern regions (figure 2.16). That is, in the western regions, significant climate warming was observed in all seasons.

In September, warming occurs in most of the territory of the republic, in some southern and western regions of the country, statistically significant rates of increase in surface air temperature by 0.24 to 0.48 °C/10 years were observed (figure 2.17). In the eastern regions, there are pockets with a slight cooling. In October, warming occurred throughout Kazakhstan, statistically significant positive trends in air temperature in the range from 0.44 to 0.86 °C/10 years can be traced in the western region, in the north and in places in the south. In November, positive trends covered the northern half of Kazakhstan, including the eastern region, with statistically significant trends at four weather stations in Kostanay region (in the range of 0.72-0.85 °C/10 years).

2.3 Trends in surface air temperature extremes

Not only the average level of air temperature and precipitation change, but also other characteristics of the regimes of these basic elements of the climate change, including the frequency and intensity of extremes. 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 regions that have their own specifics in this regard.

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.

On the territory of the republic, there is an increase in the duration of the growing season (GSL index, figure 2.18) by 2-5 days/10 years. 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, Karaganda and East Kazakhstan regions. In the northern regions, the increase in the duration of the growing season is mostly statistically insignificant.

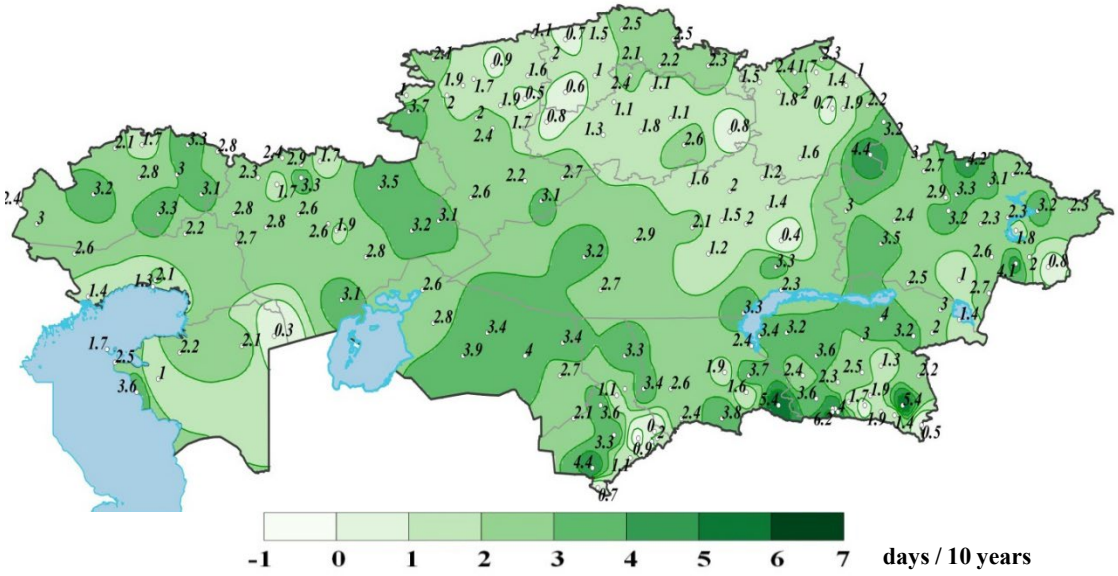

Figure 2.18 – Spatial distribution of the coefficient of the linear trend of the duration of the growing season (day/10 years) calculated for the period 1961 to 2021 (GSL index)

In addition to the increase in the duration of the growing season, in the southern half of the territory of Kazakhstan there is a statistically significant increase in the sum of temperatures during the growing season (GDDgrow10 index, Figure 2.19). The increase in the sum of temperatures during this period in the southern part of the territory is significantly higher than in the northern part. The largest and statistically significant increase, by more than 60 degree days / 10 years, can be traced according to the data of most stations in Atyrau, Mangystau, Kyzylorda, Turkestan, Zhambyl and Almaty regions.

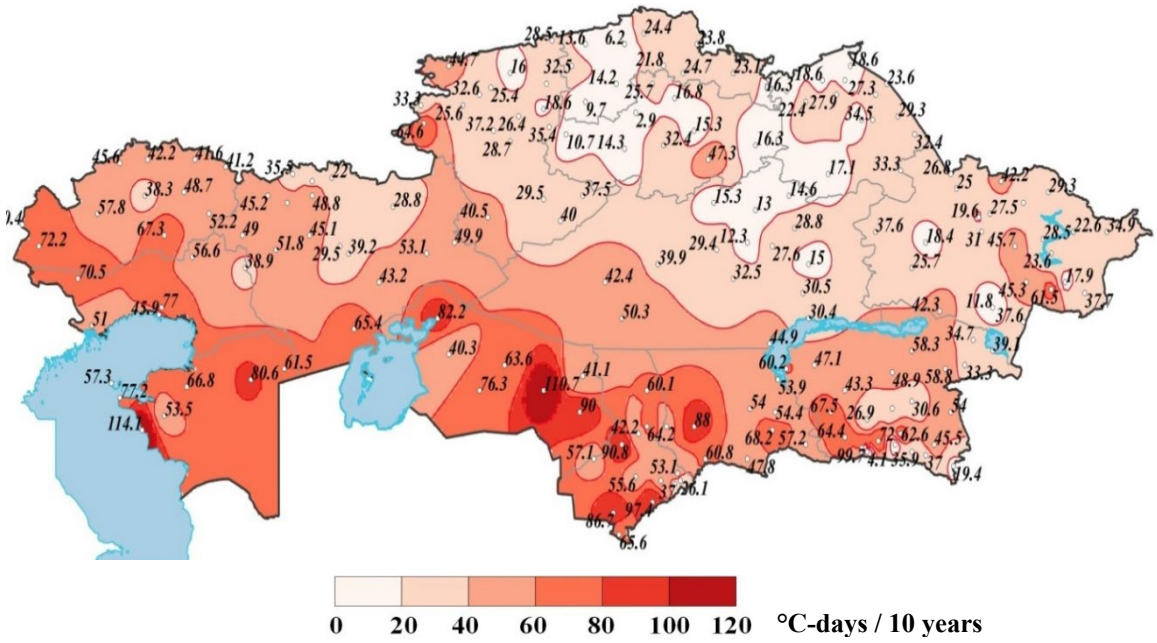

Figure 2.19 – Spatial distribution of the coefficient of the linear trend of the sum of temperatures during the growing season (°C-days/10 years), calculated for the period 1961-2021 (GDDgrow10 index)

Not only the average air temperature increases, but the frequency of high summer temperatures 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 noticeable 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 frequency of high summer temperatures was observed at the Aktau meteorological station (7.6 days/10 years, Mangystau region). At the stations of the North Kazakhstan and Akmola regions, a statistically insignificant negative trend in the frequency of hot days was observed.

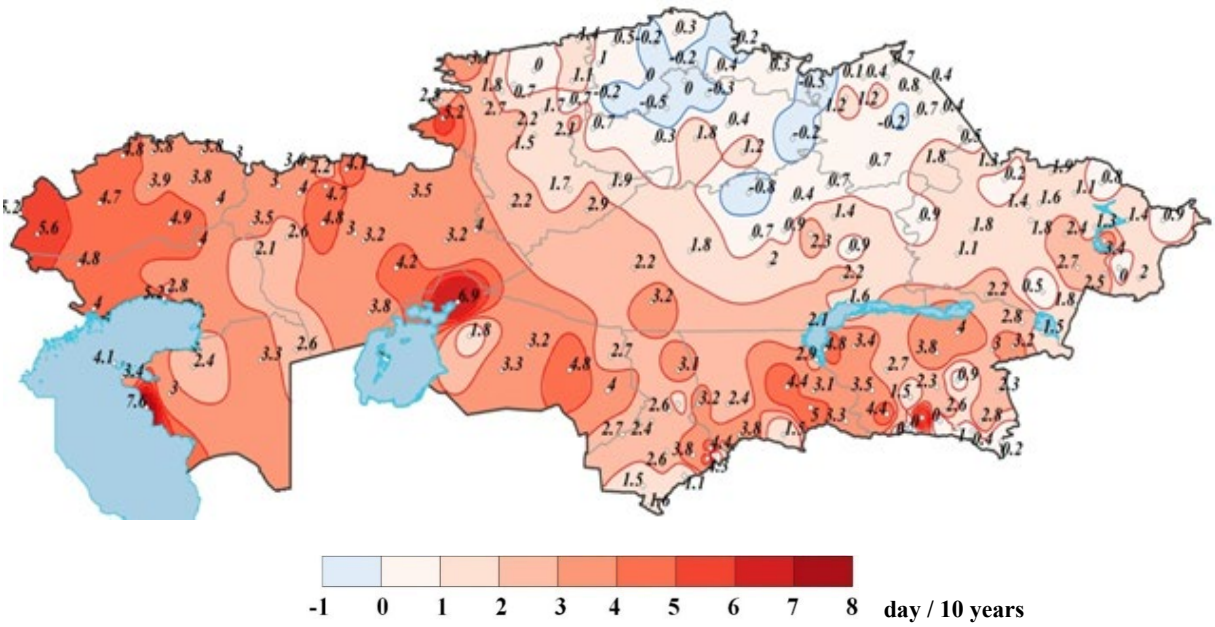

Figure 2.20 – Coefficients of the linear trend of the number of days when the maximum daily temperature is equal to or above 30 °C (day/10 years), calculated for the period 1961 to 2021 (index TXge30)

In most of the territory of the republic, there is a 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 greatest significant positive trend (more than 6-9 days/10 years) was observed at the stations in Almaty and Mangystau regions.

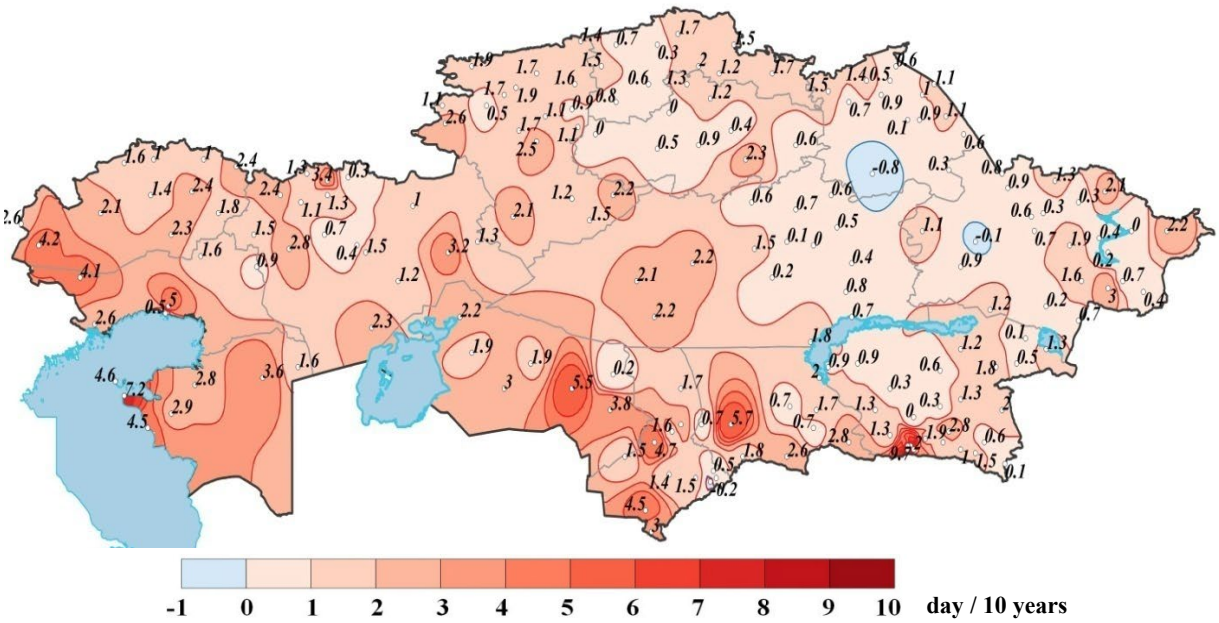

Figure 2.21 – Spatial distribution of the linear trend coefficient of the total duration of heat waves in the warm period (day/10 years), calculated for the period 1961-2021 (HWF/EHF index)

A significant positive trend in the number of individual heat waves during the warm period is observed almost throughout the entire territory of the republic (HWN index, figure 2.22). The greatest trend (by 1.5-2.0 cases/10 years) was observed at the stations of Turkestan and Almaty regions.

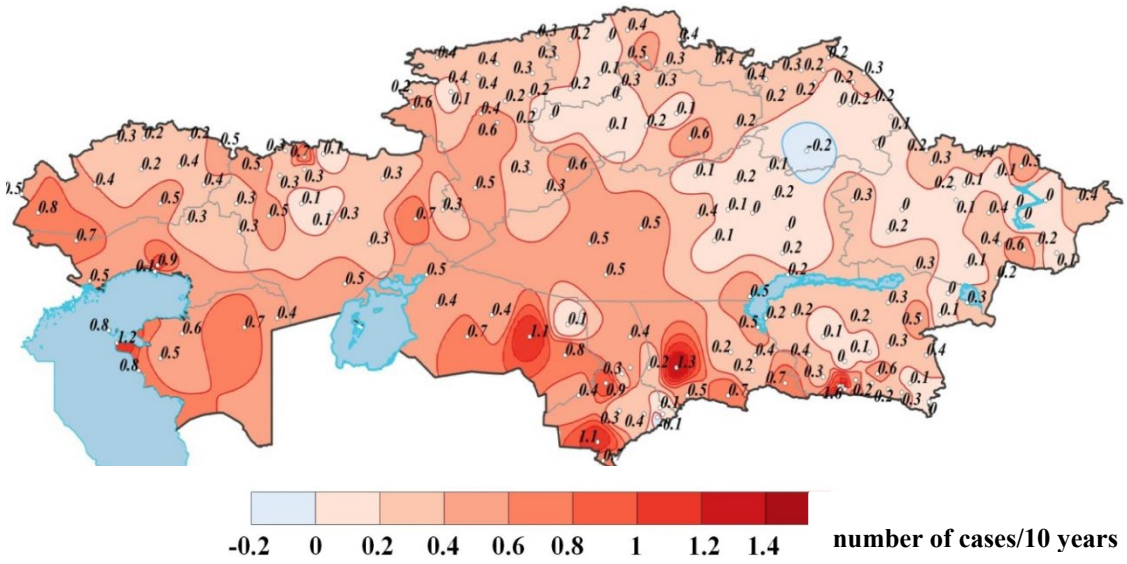

Figure 2.22 – Spatial distribution of the linear trend coefficient of the number of heat waves in the warm period (number of cases/10 years) calculated for the period 1961-2021 (HWN index)

In the western and southern regions, the duration of ***the maximum heat wave*** increases ***during the warm period*** (HWD index, figure 2.23). The most significant positive trend was observed at the MS New Ushtagan Station (1.3 days/10 years, Atyrau region).

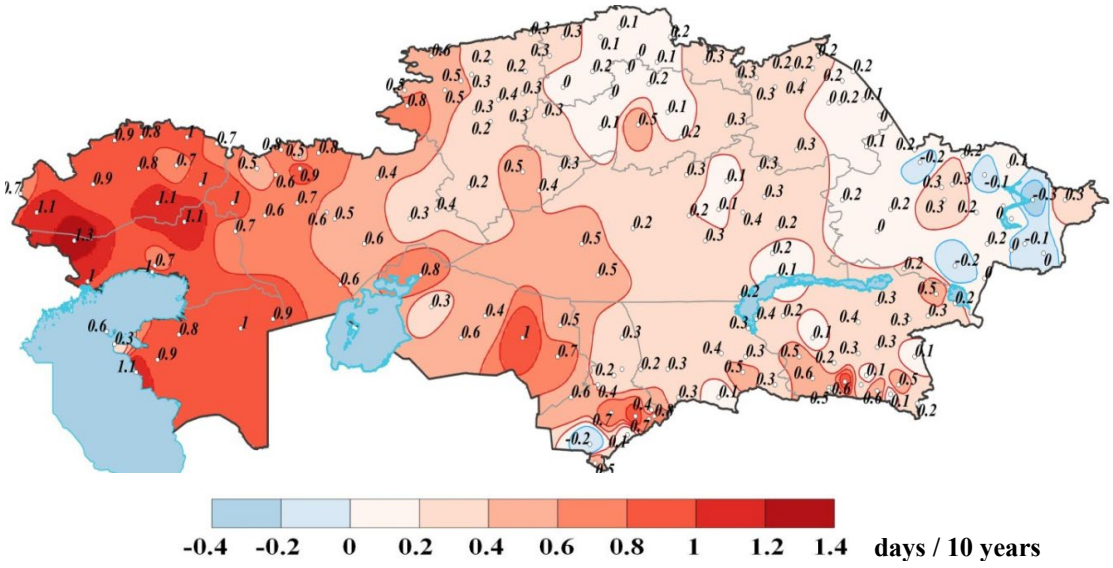

Figure 2.23 – Spatial distribution of the linear trend coefficient of the maximum duration of heat waves in the warm period (day/10 years), calculated for the period 1961 to 2021 (HWD index)

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, the WSDI index) throughout the republic (Figure 2.24). The most significant increase (by 4-7 days/10 years) is observed in the western half of the country, as well as in the northern regions and in some central, southern and eastern regions (by 1-3 days/10 years).

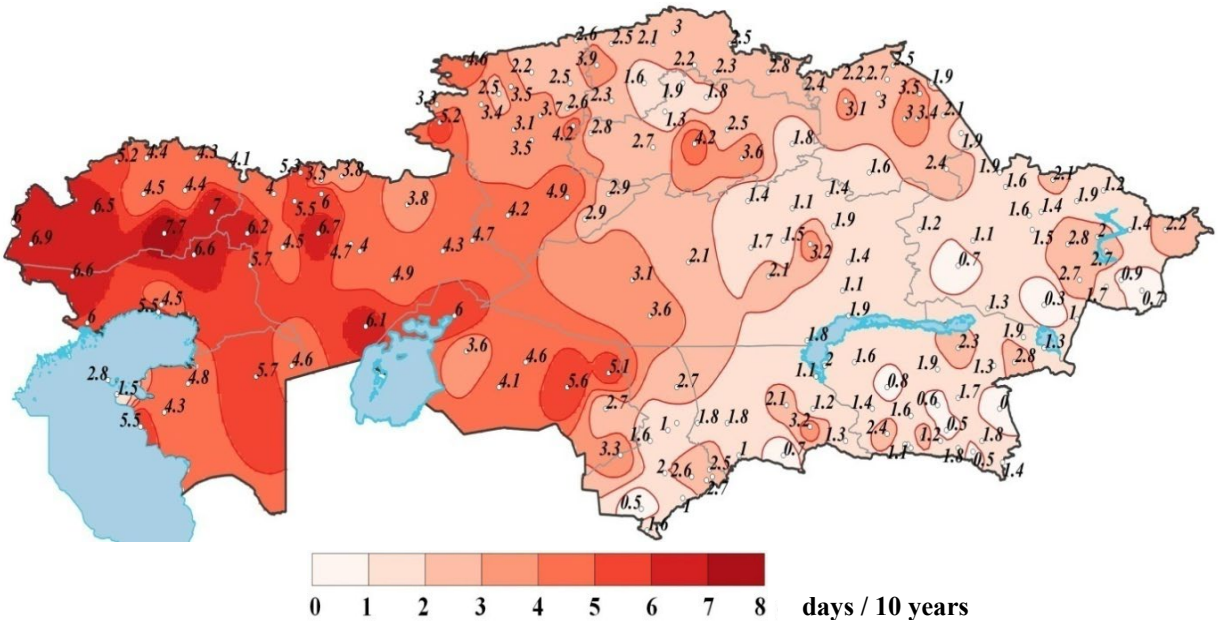

Figure 2.24 – Spatial distribution of the linear trend coefficient of the total annual duration of heat waves (day/10 years) calculated for the period 1961-2021 (WSDI index)

The consequence of an increase in air temperature in most months of the warm season is an increase in *the shortage of cold*, 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 of the republic, there are small areas with a slight decrease in the shortage of cold. In the rest of the country, there is an increase in cold deficit, in the western regions, in the southwest and south, the rate of increase in cold deficit is more than 10 °C every 10 years. The maximum increase in cold deficit is observed in Atyrau, Mangystau, Kyzylorda, Turkestan regions (30-50 °C/10 years).

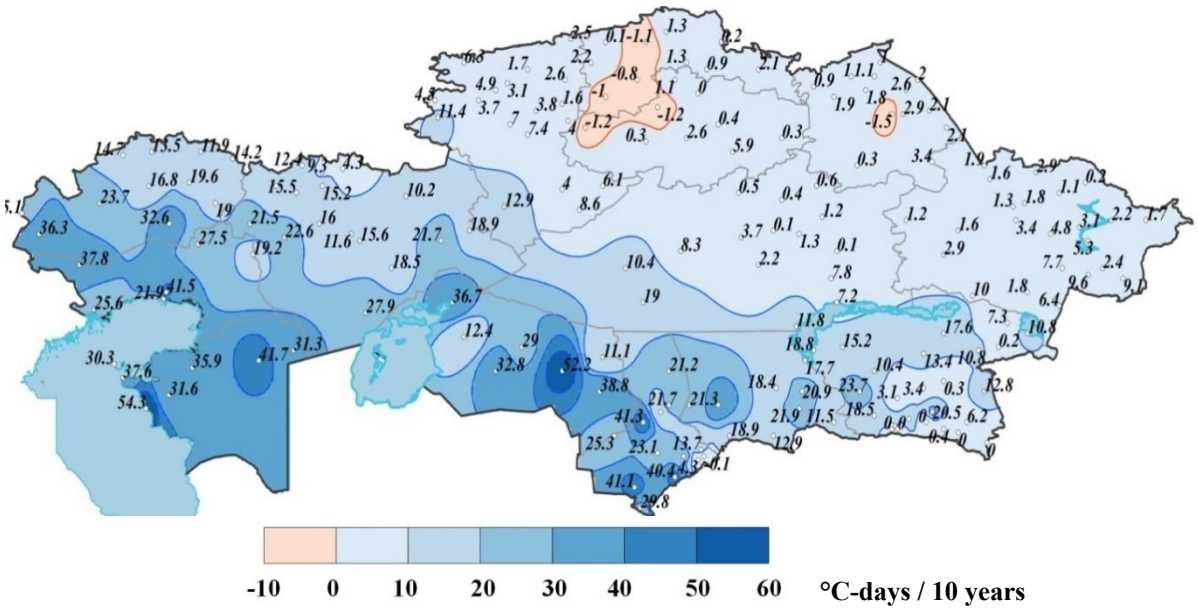

Figure 2.25 – Spatial distribution of coefficients of the linear trend of cold deficit (°C days/10 years) calculated for the period 1961 to 2021 (CDDcold23 index)

Figure 2.26 shows *the change in the number of days when the minimum temperature is ≥ 20 ℃ (TR index, the number of tropical nights)*. Over the past more than 40 years, Kazakhstan has mainly seen an increase in the number of such days: in Atyrau and Mangystau regions by 4 8 days / 10 years, as well as by 5-7 days / 10 years at some stations of the Kyzylorda, Turkestan regions. Thus, the conditions for night rest of the human body deteriorate here from the daytime heat, which, as shown above, also increases. There were no significant changes in the number of days with a minimum temperature of ≥ 20 °C in the rest of the republic.

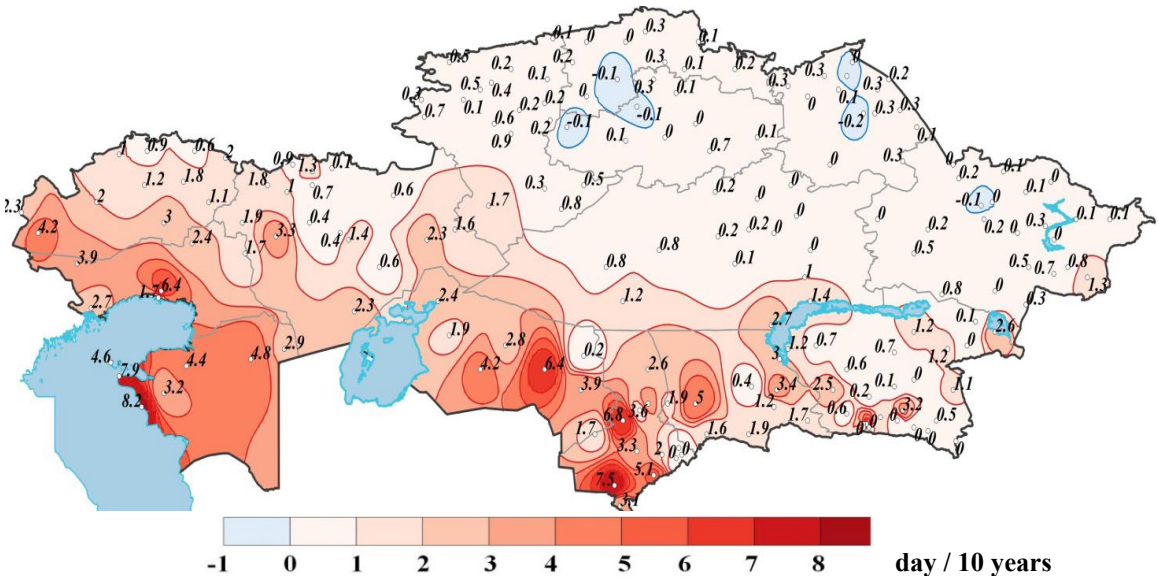

Figure 2.26 – Spatial distribution of the linear trend coefficient of the number of tropical nights (day/10 years) calculated for the period 1961-2021 (TR index)

As a consequence of the increase in air temperature, *the number of days per year* decreases throughout the territory of Kazakhstan *when the daily minimum temperature is equal to or falls below 0 °C* (a 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 from 1 up to 7-8 days/10 years. The greatest reduction of the day with frosts and severe frosts was observed at the stations of the Almaty and Turkestan regions.

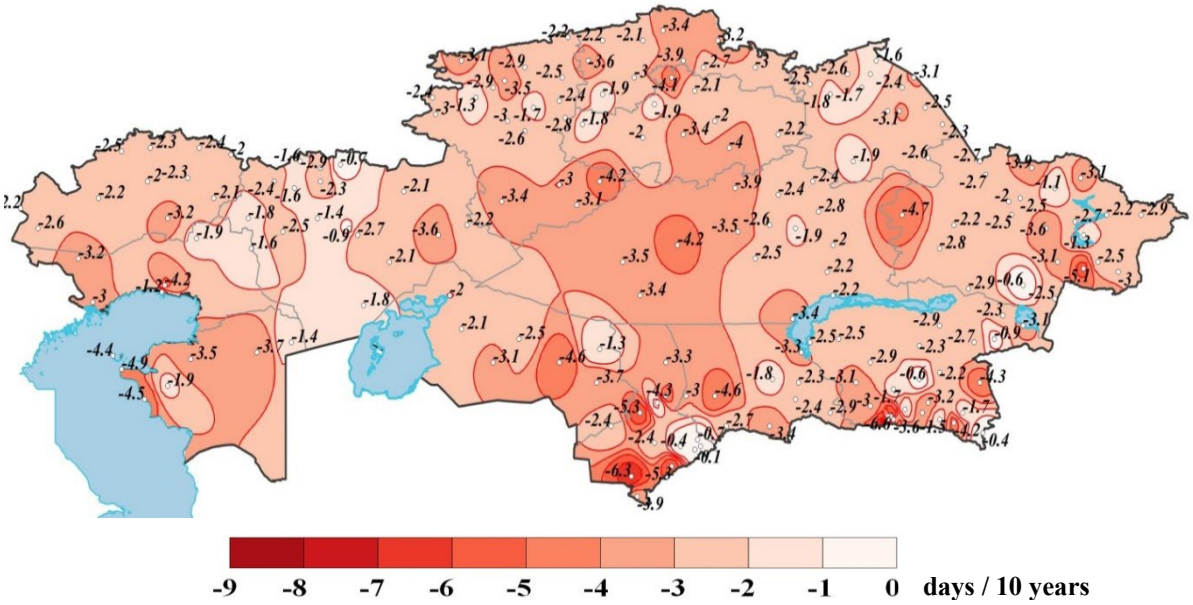

Figure 2.27 – Spatial distribution of the linear trend coefficient of a day with frost (days/10 years) calculated for the period 1961-2021 (index FD0)

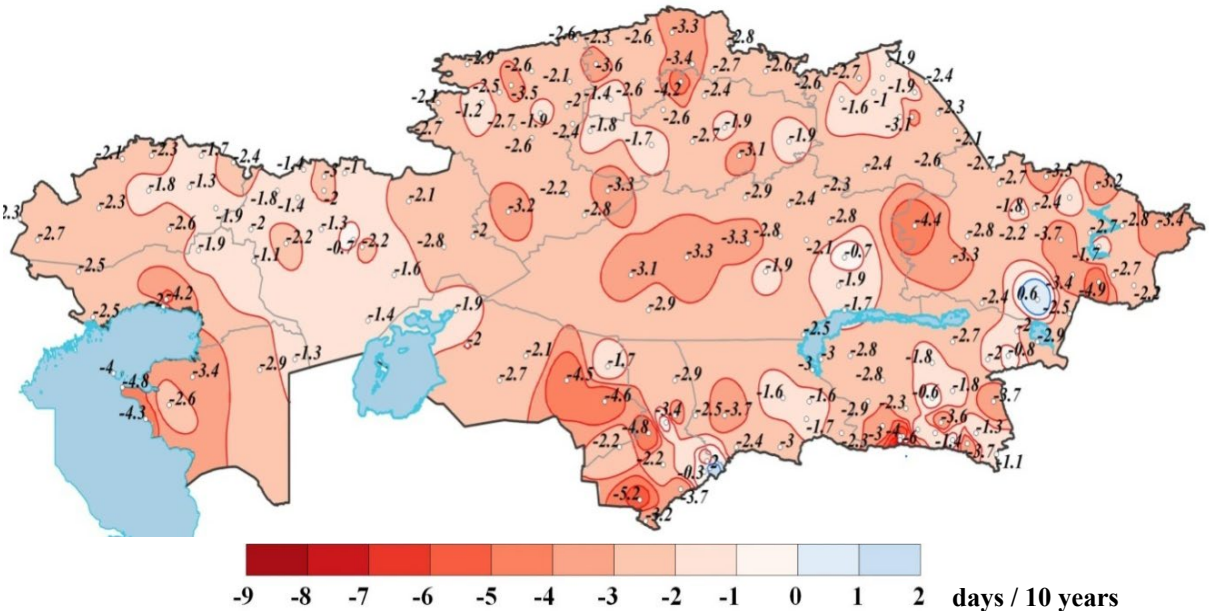

Figure 2.28 – Spatial distribution of the coefficient of the linear trend of severe frosts (days/10 years) calculated for the period 1961 to 2021 (TNltm2 index)

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). Reductions of 3-5 days / 10 years are observed at some stations in West Kazakhstan, East Kazakhstan, Kostanay, Karaganda and Almaty regions.

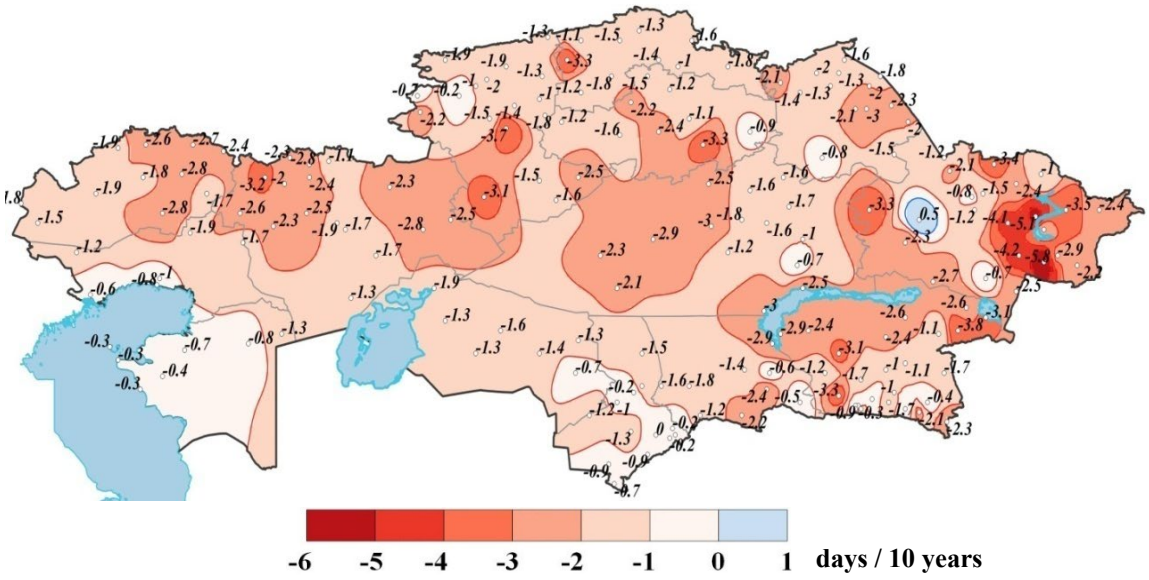

Figure 2.29 – Spatial distribution of the linear trend coefficient of very severe frosts (days/10 years) calculated for the period 1961-2021 (TNltm20 index)

Reducing the number of days with negative temperatures leads to a widespread reduction in heat deficit in the cold period of the year from 27 to 161 degree days/10 years (HDDheat18 index, Figure 2.30). Here, the temperature of 18 °C is taken as the threshold value of the air temperature, which is desirable to maintain indoors. The maximum reduction (by 161 degree days/10 years) is observed at MS Ulken Almaty in Almaty region, at MS Akzhar (East Kazakhstan region) It was 142 degree-days /10 years, for MS Nur-Sultan (Akmola region) and MS Timiryazevo (North Kazakhstan region) - for 136° degree–days/10 years.

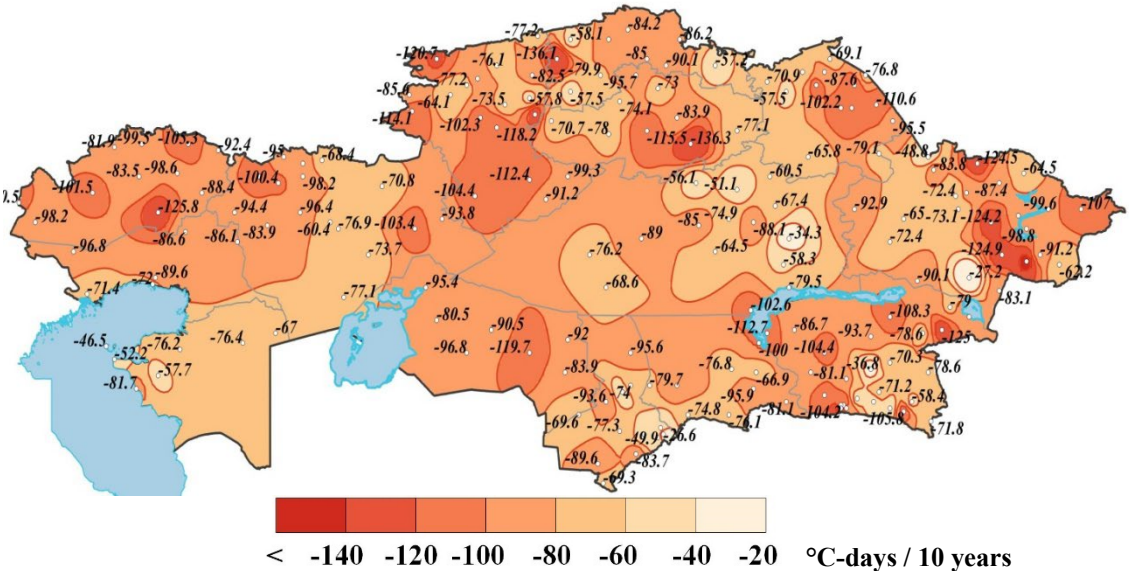

Figure 2.30 – Spatial distribution of the coefficient of the linear trend of heat deficit (°C-days/10 years) calculated for the period 1961 to 2021 (HDDheat18 index)

3 ATMOSPHERIC PRECIPITATION

3.1 Anomalies of precipitation on the territory of Kazakhstan in 2021

In 2021, the average annual precipitation on the territory of Kazakhstan amounted to 85,5 % of the norm, or 272 mm (rank 73, the probability of non-exceeding 10 %). Table 3.1 shows the values of anomalies of annual and seasonal precipitation amounts observed in 2021 and averaged over the whole territory of Kazakhstan and its regions. For each anomaly value, the probabilities of non–excess calculated for the period 1941-2021 are given. The probability of not exceeding characterizes the frequency of occurrence of the corresponding anomaly value in a series of observations. Precipitation above the 95th or below the 5th percentile is highlighted in bold. Figure 3.1 shows the territorial distribution of annual and seasonal precipitation in 2021, expressed as a percentage of the norm for the period 1961-1990, and also shows the probabilities of non-excess of annual and seasonal precipitation amounts in a given year.

Table 3.1 - Regionally averaged average annual (January-December) and seasonal precipitation anomalies in 2021: **vR** – *deviations from long–term averages for 1961–1990, mm/season;* ***P(r≤R2021)*** *- probability of non-excess (in parentheses), calculated from data for the period 1941-2021 in %;* ***RR*** *-the ratio of* R_{2021} to the norm in %

Region/region	Year		Winter		Spring		Summer		Autumn	
	vR (P)	RR	vR (P)	RR	vR (P)	RR	vR (P)	RR	vR (P)	RR
Kazakhstan	-46,2 (10)	85,5	-3,6 (41)	94,4	-10,5 (27)	88,0	-20,5 (11)	76,7	-20,6 (15)	73,9
Almaty	-65,6 (20)	84,9	8,1 (57)	111,8	-9,8 (40)	93,4	-35,6 (11)	69,5	-32,1 (20)	68,1
Akmola	-39,1 (20)	88,0	20,1 (85)	142,2	-17,0 (15)	75,4	-48,4 (6)	62,8	0,1 (56)	100,1
Aktobe	-36,7 (28)	86,1	-1,9 (48)	96,8	-21,1 (16)	67,1	-9,4 (41)	86,1	-12,9 (41)	82,1
Atyrau	-43,4 (7)	71,1	-5,4 (27)	82,7	-13,7 (15)	63,6	**-28,1 (5)**	**30,9**	-10,8 (30)	73,3
East Kazakhstan	-24,8 (26)	92,6	-0,8 (50)	98,7	-17,0 (26)	78,6	-4,6 (42)	95,6	-10,8 (43)	88,2
Zhambyl	-60,8 (12)	80,0	-12,5 (25)	83,0	4,8 (62)	104,0	-23,9 (8)	37,3	-32,6 (15)	56,0
West Kazakhstan	3,5 (57)	101,2	-4,2 (51)	93,7	27,2 (81)	146,9	-22,0 (30)	72,3	-20,7 (30)	73,7
Karaganda	-38,7 (22)	84,1	-20,1 (11)	60,7	-9,7 (37)	84,5	-11,9 (33)	83,1	-8,4 (41)	85,7
Kostanay	-85,3 (6)	70,6	12,5 (83)	125,6	**-31,1 (2)**	**47,9**	-52,8 (6)	50,8	-27,9 (8)	62,2
Kyzylorda	**-50,7 (1)**	**64,1**	**-18,1 (3)**	**54,6**	-10,1 (35)	79,3	-13,1 (15)	31,4	**-24,7 (1)**	**25,7**
Mangystau[1]	**-100,0 (0)**	**29,9**	-13,3 (15)	44,6	**-41,2 (1)**	**11,8**	-27,8 (15)	19,7	-19,0(16)	49,1
Pavlodar	15,3(56)	105,2	-1,5 (53)	96,7	-19,0 (12)	65,5	29,9 (72)	124,8	2,3 (57)	103,2
North Kazakhstan	-54,8 (18)	84,5	20,7 (86)	143,8	-19,1 (12)	70,9	-22,4 (31)	85,3	**-38,3 (2)**	**56,0**
Turkestan	**-98,7 (6)**	**77,4**	**-56,4 (2)**	**62,6**	12,5(58)	107,4	-18,5 (10)	23,8	-46,0 (13)	51,1

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 (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. Average precipitation anomalies were obtained by averaging the data of 121 stations of the Republic of Kazakhstan.

In 2021, a significant deficit in annual precipitation amounts was observed in the Mangystau region, where on average only 29,9 % of the norm fell – the minimum value since 1941, and in the Kyzylorda region, where 64,1 % of the norm fell – this is the second rank among the driest years (Table 3.1). On average, the precipitation deficit in the western, northern, central and southern regions (Atyrau, Kostanay, North Kazakhstan, Akmola, Karaganda, Turkestan, Zhambyl, Almaty) was about 20-40%. Precipitation about normal fell in West Kazakhstan, Aktobe, and Pavlodar and East Kazakhstan regions.

On average, in the territory of Kazakhstan in the winter of 2021, precipitation was about normal, in spring, summer and autumn – below normal and amounted to 88,0 %, 76,7 %, 73,9 % of the norm, respectively (Table 3.1).

Figure 3.1 shows the intra-annual distribution of precipitation in 2021, averaged over the territory of Kazakhstan, as well as the average long – term monthly precipitation for the period 1961 - 1990.

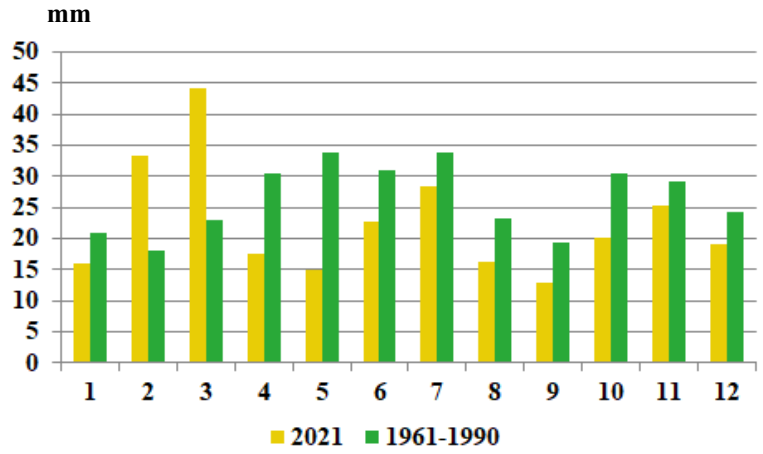

Figure 3.1 – Monthly precipitation amounts averaged over the territory of Kazakhstan in 2021 and their norms calculated for the period 1961-1990

For most of the year, the average amount of precipitation in Kazakhstan was below normal (Figure 3.1). Two months were extremely dry: May, in which the average precipitation layer was only 15 mm of precipitation (or about 45 % of the norm, the probability of non-exceeding 1 %, Table 3.2); and April, when 17,5 mm of precipitation fell (58 % of the norm, the probability of non-exceeding 10 %). A significant shortage of precipitation was also observed in January (23 %) and from June to December (13-34 %). The two months of 2021 were extremely wet – February, when an average of 33,5 mm of precipitation fell across the country (185,8 % of the norm), and March, when the average layer of precipitation in Kazakhstan was 44,3 mm (191,6 % of the norm). The probability of not exceeding the precipitation amounts in both months was 98 %.

The greatest deficit of annual precipitation amounts was experienced by the eastern regions of the Mangystau region, the Aral Sea region and the south of the Kostanay region, where less than 40 % of the precipitation norm fell (Figure 3.2).

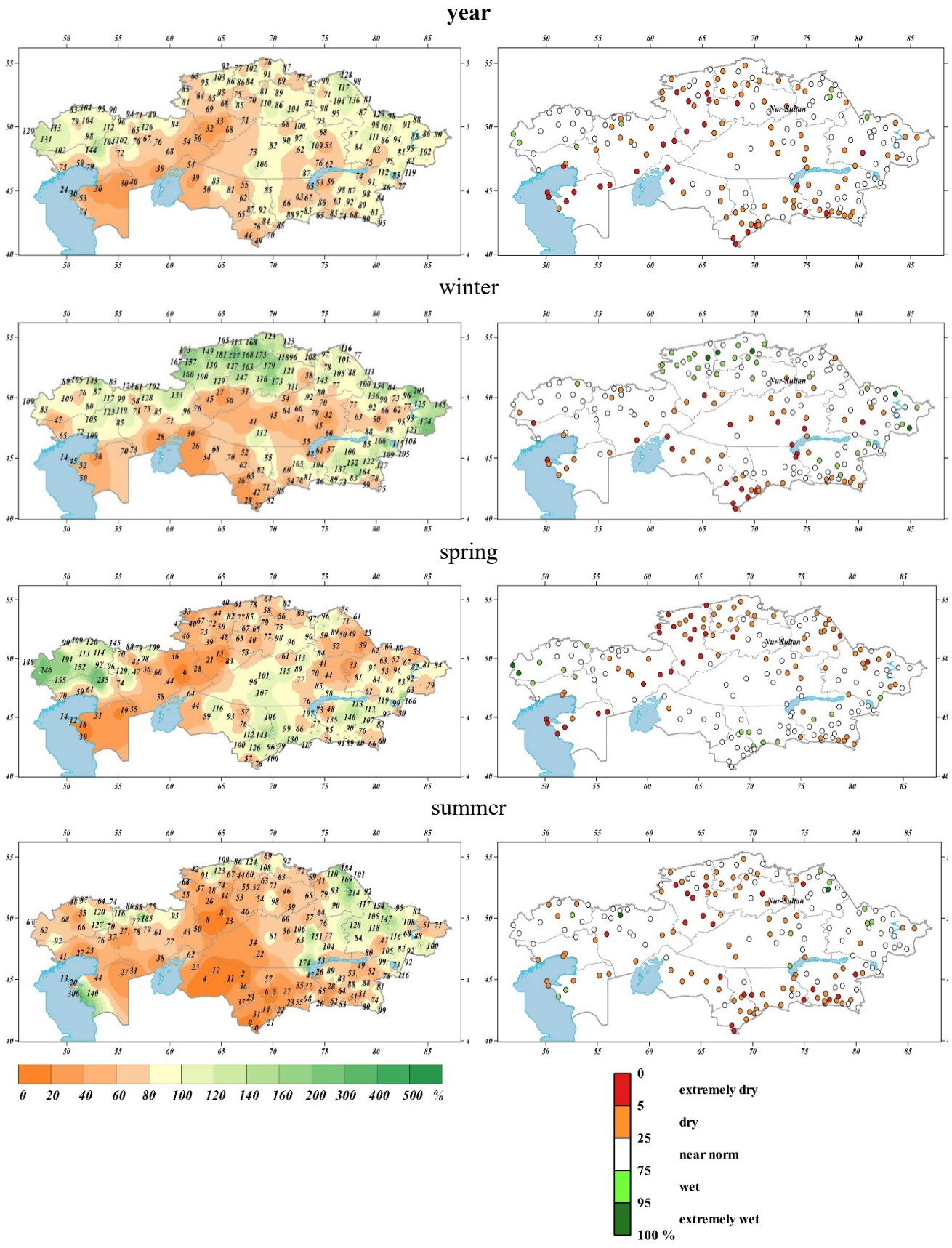

Figure 3.2 – Geographical distribution of annual and seasonal precipitation in 2021, expressed as % of the norm (left), as well as the probability of not exceeding it (right), calculated for the period 1961 – 2021. *Sheet 1*

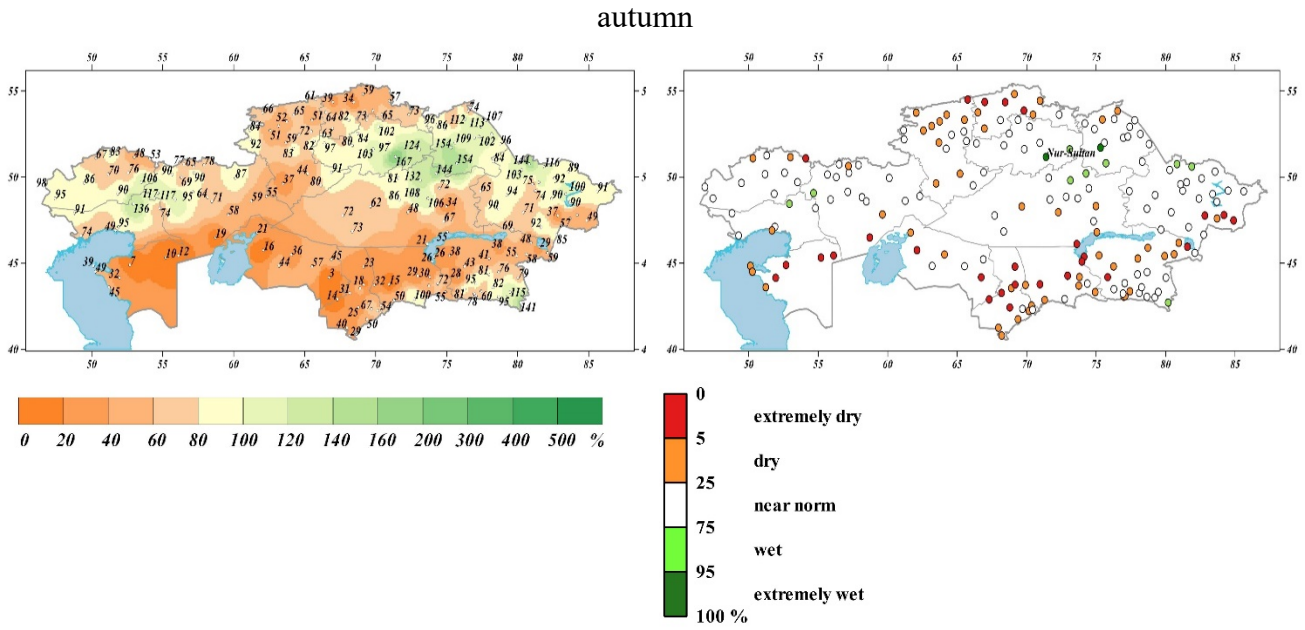

Figure 3.2 – Geographical distribution of annual and seasonal precipitation in 2021, expressed as % of the norm (left), as well as the probability of not exceeding it (right), calculated for the period 1961 – 2021. *Sheet 2*

At 7 weather stations (Figure 3.2), new minimums of annual precipitation were established: 301,2 mm at MS Kordai in Zhambyl region with a previous minimum of 303,9 mm in 1991; 138,3 mm at MS Zhetysai in Turkestan region (the previous minimum was 154,4 mm in 1995); 78,8 mm at MS Amangeldy in Kostanay region (the previous one was 121,5 mm, 2019.); 55 mm on MS Sam (previous 67,6 mm, 1984), 50,1 mm on MS Kyzan (previous 63,2 mm, 1972), 45,5 mm on MS Beineu (previous 68,1 mm, 2018) and a total of 42,6 mm of precipitation on MS Fort-Shevchenko in Mangystau region (previous minimum in 1942 was 54,0 mm).

In the winter of 2020/2021 (December 2020 – February 2021), the average amount of precipitation in winter in Kazakhstan amounted to 94,4 % of the norm (rank 48, Table 3.1). There was a severe shortage of precipitation in Turkestan and Kyzylorda regions (on average, 63 and 55 % of the norm, respectively), where the amount of precipitation it was below the 5th percentile. It was very dry in the Karaganda and Mangystau regions, where precipitation was 40 % less than normal (probability of non-excess of 11 %) and 55 % less than normal (probability of non-excess of 15 %), respectively. Record values of the minimum amount of precipitation for the winter season were recorded at 5 weather stations of the above-listed regions (Figure 3.2). In Kostanay, North Kazakhstan and Akmola regions, the average humidification in the territory was from 126 to 144% of the norm (with a probability of non-exceeding 83 to 86 %). On MS Timiryazevo (North Kazakhstan region), a record amount of precipitation was recorded in winter – 92,4 mm, the previous value was 85,3 mm (2001).

The foci of a significant shortage of precipitation in winter were distributed throughout the republic as follows: the south-western regions received humidification of only about 40-50 % of the norm (in places only 14 %); in the south of Kostanay region, in most central regions, in the western Lake Balkhash region and in the west of East Kazakhstan region – within 40-60 % of the norm; in

the Aral Sea region, in the south of the Kyzylorda and Turkestan regions, precipitation fell significantly less than the norm – less than 30 %, Figure 3.2. More than the norm of precipitation fell: in the north-west – in places 120-130 % of the norm; in the northern regions – significantly more than the norm (up to 160-180 %, in some places up to 230 % of the norm); in mountainous areas in the east (up to 170-200 % of the norm); and in most of the territory of the Almaty region (in some places up to 150 % of the norm).

Table 3.2 – Regionally averaged monthly precipitation anomalies in 2021, calculated as deviations from the long-term average values for 1961-1990, (in mm), and *the probability of non-excess (in parentheses), calculated from data for the period 1941-2021 and expressed in %*

Region	12 (2020)	1	2	3	4	5	6	7	8	9	10	11
Kazakhstan	**-14,2 (3)**	-4,8 (23)	**15,5 (98)**	**21,2 (98)**	-12,9 (10)	**-18,8 (1)**	-8,1 (20)	-5,4 (33)	-7,1 (27)	-6,6 (18)	-10,2 (17)	-3,9 (42)
Almaty	-16,5 (7)	-3,6 (40)	**28,1 (98)**	**35,5 (95)**	-24,5 (17)	-20,8 (20)	-16,7 (17)	-13,0 (26)	-5,8 (32)	-16,4 (6)	1,2 (67)	-16,9 (16)
Akmola	-7,0 (18)	2,1 (68)	**24,9 (98)**	16,2 (91)	-15,3 (8)	-18,0 (11)	-20,1 (7)	-21,6 (21)	-6,7 (47)	6,6 (63)	-16,3 (13)	9,8 (86)
Aktobe	-15,2 (12)	-10,0 (21)	**23,3 (98)**	7,7 (73)	-9,4 (30)	**-19,4 (2)**	-11,3 (26)	19,7 (90)	**-17,8 (0)**	-5,2 (47)	-19,6 (10)	12,0 (87)
Atyrau	-10,1 (7)	-5,2 (17)	9,8 (88)	-2,4 (40)	-3,5 (43)	-7,9 (18)	-7,7 (28)	-8,9 (22)	**-11,5 (0)**	-3,2 (47)	-9,1 (17)	1,5 (66)
East Kazakhstan	-9,8 (17)	-0,4 (50)	9,5 (86)	**20,4 (96)**	-13,5 (8)	-24,0 (8)	8,0 (65)	-12,6 (22)	0,0 (50)	-12,1 (15)	-4,5 (56)	5,8 (70)
Zhambyl	-19,9 (7)	-7,8 (16)	15,2 (85)	**47,3 (97)**	-17,2 (23)	-25,3 (7)	**-16,0 (2)**	-6,8 (23)	-1,1 (55)	**-9,6 (3)**	-4,9 (52)	-18,1 (10)
West Kazakhstan	-15,5 (12)	-2,7 (51)	14,1 (90)	19,2 (92)	13,3 (85)	-5,3 (28)	5,3 (72)	-4,8 (41)	**-22,6 (1)**	2,6 (60)	**-19,9 (5)**	-3,3 (60)
Karaganda	**-12,4 (5)**	-7,9 (21)	0,2 (60)	12,7 (88)	-9,4 (18)	-13,0 (25)	-3,0 (42)	-2,8 (46)	-6,0 (36)	-1,8 (50)	-9,5 (28)	3,0 (65)
Kostanay	-11,2 (12)	-1,3 (48)	**25,0 (100)**	2,5 (58)	-13,4 (11)	**-20,1 (3)**	**-24,7 (5)**	-5,4 (51)	**-22,7 (0)**	-2,8 (50)	-17,4 (7)	-7,7 (33)
Kyzylorda	**-13,9 (0)**	-3,0 (32)	-1,2 (40)	11,5 (92)	-11,4 (18)	-10,2 (7)	**-7,8 (3)**	-1,7 (60)	-3,6 (25)	-3,7 (38)	**-12,2 (3)**	-8,7 (12)
Mangystau[1]	-9,9 (12)	**-5,3 (0)**	1,9 (68)	-10,7 (31)	**-15,5 (0)**	-15,0 (21)	-8,1 (52)	**-10,9 (0)**	**-8,8 (0)**	0,7 (65)	-10,1 (16)	-9,6 (18)
Pavlodar	-2,2 (30)	-5,7 (35)	6,5 (86)	14,4 (91)	-12,9 (6)	**-20,5 (1)**	11,5 (57)	2,9 (56)	15,4 (82)	1,7 (50)	-5,0 (51)	5,6 (76)
North Kazakhstan	-5,5 (33)	5,1 (80)	**21,1 (97)**	6,9 (77)	-7,9 (25)	-18,1 (12)	-21,2 (16)	0,6 (58)	-1,8 (52)	-12,0 (16)	-20,1 (10)	-6,1 (42)
Turkestan	**-39,9 (3)**	-24,0 (11)	7,5 (50)	**58,9 (97)**	-23,0 (20)	-23,4 (16)	-8,1 (10)	-6,2 (40)	-4,1 (27)	-7,0 (6)	-9,9 (53)	-29,1 (16)

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 (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. Average precipitation anomalies were obtained by averaging the data of 121 stations of the Republic of Kazakhstan.

December 2020 was characterized mainly by a shortage of precipitation, the precipitation averaged over the territory of Kazakhstan amounted to 42 % of the norm for the period 1961-1990. or 14,2 mm below the norm (rank 77, the probability of not exceeding 3%). In most parts of the country there was a significant shortage of precipitation – less than 60 % of the norm. Precipitation of less than 20 % of the norm fell on a significant area of the south-western, central and southern regions of the country (Figure 3.3). Across the country, except for some northern regions and the West Kazakhstan region, there were areas where it was extremely dry. New monthly precipitation minima (1,8 mm, 1,2 mm, 1,2 mm and 1,0 mm) were established on the MS Mynzhilki, Nura, Kishkenekol and Turkestan, their previous values (2,7 mm, 1,7 mm, 1,4 mm and 1,4 mm) were noted in 1967, 1976, 1974, 1999, respectively (Appendix 1). On MS Beineu, Kyzan and Shirik-Rabat, precipitation was not observed throughout the month. Above normal precipitation fell in Pavlodar and East Kazakhstan regions. **In January**, the average amount of precipitation in Kazakhstan amounted to 76,8% of the norm (rank 62, Table 3.2). Precipitation deficit was observed in most of the country, the most significant (less than 10% of the norm) – in the Mangystau region and in the Aral Sea region. According to data from more than 30 MS located in the west, in the southern and central part of the country, it was extremely dry: 5 % extremes were recorded at 19 stations, of which no precipitation was observed during the month at 4 MS Tasaryk, Shymkent, Shardara (Turkestan region) and Fort Shevchenko (Mangystau region) (Appendix 1). Precipitation of more than 120 % of the norm was observed mainly in the north and east, as well as in some areas of the southern part (Karatau) of the country (Figure 3.3). In January 2021, it was extremely humid for 5 MS located in the above-listed areas. **February** was extremely humid – the average amount of precipitation in Kazakhstan was 185,8 % of the norm (rank 1, Table 3.2). In most of the territory of the western region, precipitation exceeded the norm by 1,5-3,3 times (Figure 3.3), in the northern regions, the most significant excess of the norm was observed at MS Timiryazevo (554 % of the norm) in the North Kazakhstan region. According to data from more than 50 MS located in the western, northern regions, as well as in East Kazakhstan and Almaty regions, February entered 5 % of the extremely wet, of which record values were set at 14 MS (Appendix 1). Some districts of Kyzylorda, Turkestan, Karaganda and East Kazakhstan regions experienced a shortage of precipitation. The least precipitation (2,8 mm) during the month fell on MS Balkash and Saryshagan, which amounted to 34,4 and 34,1% of the norm, respectively.

In spring, the average precipitation layer on the territory of Kazakhstan amounted to 88 % of the norm (rank 59, Table 3.1). A strong precipitation deficit was observed in the Mangystau region (12 % of the norm is the second driest spring in a series of observations) and in the Kostanay region (48 % of the norm is the third driest spring in a series of observations). Significantly higher than normal precipitation was received by the West Kazakhstan region – 147 % of the norm.

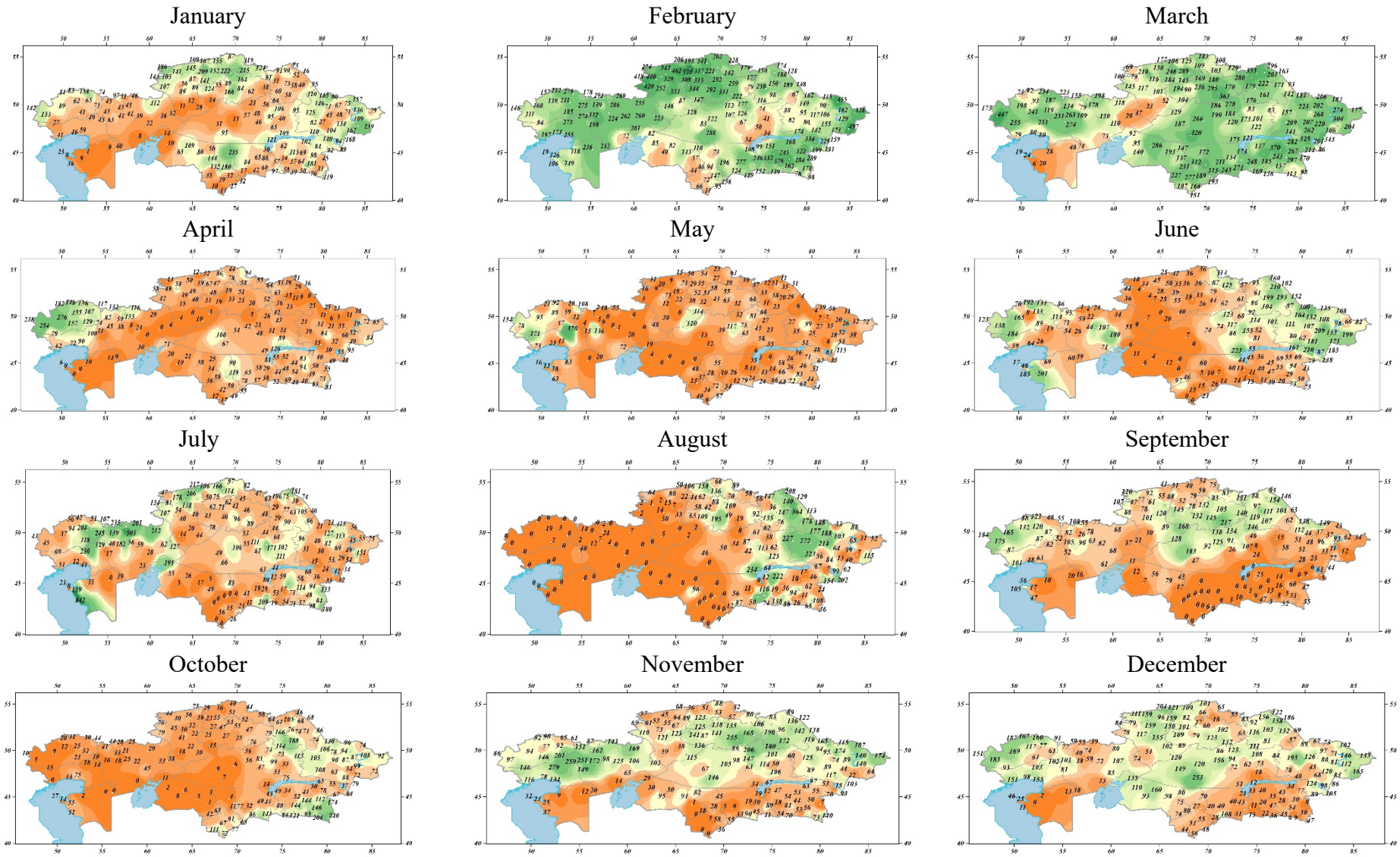

Figure 3.3 – Spatial distribution of monthly precipitation in 2021 (in % of the norm calculated relative to the base period of 1961-1990)

A shortage of spring precipitation, as well as winter precipitation, was observed in most of the territory of Kazakhstan (Figure 3.1). In the south-west of the country, precipitation was less than 20 % of the norm and humidification conditions are characterized as extremely dry (5% extremes were noted). It was dry and extremely dry in most of the Aktobe region (40-60 % of the norm, in the east of the region less than 10% of the norm) and in the Kostanay region (20-50 % of the norm, in some places less than 20 % of the norm). In the North Kazakhstan region and in the western half of the Akmola region, the amount of precipitation was about 60-80 % of the norm. Another zone with a shortage of precipitation occupied the eastern regions of the Karaganda region (40-80 % of the norm), the southern regions of the Pavlodar region and the northern regions of the East Kazakhstan region (40-60 % of the norm). Small areas with precipitation less than 80 % of the norm are also noted in other areas of the southern half of Kazakhstan. The hearth with precipitation of more than 120 % of the norm is located in the West Kazakhstan region and in the north of the Atyrau region, in some places more than 230-240 % of the norm of precipitation fell here.

March, as well as February, was extremely humid – on average, precipitation in Kazakhstan amounted to 191,6 % of the norm or 21,2 mm higher than the long-term average (rank 2, Table 3.2). In most parts of the country, precipitation fell significantly more than normal (Figure 3.3). In some western regions, the amount of precipitation exceeded the norm by 2,5-4,5 times, in the northern, central, southern and eastern regions – by 2-3,5 times. The largest amount of precipitation (235 mm) fell on Shymkent MS, which was 274 % of the norm. At 39 MS, located in the south, southeast, east, northeast, center, 5 % extremes were recorded, including record values were set at 6 MS (Appendix 1). Precipitation of less than 80 % of the norm was observed in the Mangystau region (in places less than 10 % of the norm), at the junction of the Aktobe and Kostanay regions and in some other small areas across Kazakhstan. The least precipitation fell on Aktau MS (1,2 mm), which was 6,3 % of the norm. **In April and May**, on average, the precipitation layer over the country amounted to 57,6 % of the norm and 44,5 % of the norm (the second extremely dry May after 1957), respectively (Table 3.2). During these months, precipitation deficit was observed almost throughout Kazakhstan, with the exception of certain areas in the west, south, center and east of the republic, precipitation fell about normal, in some places more than 120 % (Figure 3.3).

In April, it was extremely dry according to 25 MS located in the Mangystau region, in the south of Aktobe and Kostanay regions and in the east. On MS Shar (East Kazakhstan region) and MS Sharbakty (Pavlodar region) a record minimum precipitation was set (1,2 mm and 0 mm, respectively), their previous records (1,3 mm and 0,7 mm) were in 1967 and 1997 (Appendix 1). At 7 MS located in different parts of the country, precipitation was absent throughout the month. On 3 MS of the West Kazakhstan region (MS Urda, Zhanybek, Zhalpaktal), an extremely large amount of precipitation was recorded for these areas. The most significant amount of precipitation (83 mm) fell on MS Aschisai in Turkestan region, which amounted to 136 % of the norm. According to data from about 50 MS, May was included in 5 % of the driest months (Appendix 1), precipitation was absent at 13 weather stations located in different parts of the country throughout the month. Some of them had no precipitation during April-May. Records of minimum precipitation were set at 6 weather stations (Aktobe, Kostanay, Akmola, Pavlodar and Almaty regions).

In summer, the shortage of precipitation, as well as in winter and spring, continued to be felt in most of the territory of Kazakhstan and even intensified in many regions. As a result, the average amount of summer precipitation in Kazakhstan was 23 % below normal (Table 3.1). A significant shortage of precipitation was noted in the Atyrau region, on average in the territory their amount was only 31 % of the norm (5 % extreme). In Akmola, Kostanay, Zhambyl and Turkestan regions, the season was in 10 % of the driest summer seasons (Table 3.1). In some places in the western regions precipitation was less than 30 % of the norm, in the south of Kostanay and in some places in Kyzylorda, Turkestan regions even less than 10 % of the norm. In the extreme south of the Turkestan region, precipitation was absent throughout the summer season. In most parts of Pavlodar, East Kazakhstan regions, and the east of Karaganda region, precipitation was about normal (± 20 %) with small pockets where precipitation significantly exceeded the norm (150-215 % of the norm). Small areas with seasonal precipitation above normal are also noted in the north- and south-west, and in the far north of the republic (Figure 3.1).

A significant deficit of monthly precipitation amounts persisted in most regions throughout the summer months, and taking into account April and May – for 5 consecutive months (Table 3.2, Figure 3.3). This is primarily Mangystau and all the southern regions, most of the territory of the northern and central regions. **In June and July**, in many areas of western, northern, central and southern Kazakhstan, precipitation was less than 40, in some places less than 10 % of the norm. In Kostanay, Kyzylorda and Zhambyl regions, June, and in Mangystau July were in 5 % of the extremely dry months (Table 3.2). In June, record precipitation lows were set for 9 MS (Appendix 1), precipitation was absent for 5 MS throughout the month. In July, precipitation was absent for 9 MS. On MS Amangeldy, precipitation was absent for 3 months in a row – from April to June. Precipitation of more than 120 % of the norm was observed in June in the east and north-east of the country, as well as in some areas of central and western Kazakhstan. In July, more than 120 % of normal precipitation fell in some southwestern, western, northwestern and northern regions and in other parts of Kazakhstan. In places in the south-west, north-west and north, the amount of precipitation was more than 160 and even 200 % of the norm, so the conditions of July here are characterized as humid and extremely humid. A record amount of precipitation fell on Aktau and Aktobe MS in a month (52.2 and 149.4 mm), their previous records were 45.5 and 136.9 mm, which were recorded in 1995 and 1941, respectively (Appendix 1).

In August, the catastrophic situation with a shortage of precipitation continued in many regions in the western half of Kazakhstan, where in August there was either no precipitation (at about 50 weather stations), or less than 10-20 % of the norm fell (Figure 3.3). Many regions of the eastern half of the republic also did not receive additional moisture – in some central, south-eastern and eastern regions, precipitation fell less than 20 % of the norm. According to 73 weather stations, August 2021 was extremely dry. August was the driest on average in the Aktobe region since 1941, in Atyrau since 2007, in Kostanay since 1976 and in the Mangystau region since 2017, the average amount of precipitation in Kazakhstan was 30,3 % below normal (Table 3.2). Precipitation above the norm, in some places more than 200 % of the norm, fell in the north-east of the country, also in some northern regions and the Lake Balkhash region (Figure 3.3). The most significant amount of precipitation (364 %) fell on MS Krasnoarmeyka (Pavlodar region), which amounted to 118,0 mm.

Record precipitation maximums were set at two MS and record precipitation minimums were set at 60 weather stations (Appendix 1).

In autumn, the average amount of precipitation in Kazakhstan amounted to 74 % of the norm (Table 3.1). A strong shortage of precipitation was observed in the Kyzylorda region – 26 % of the norm with a probability of not exceeding 1 % (the second driest autumn in a series of observations since 1941) and in the North Kazakhstan region – 56 % of the norm with a probability of not exceeding 2 % (also the second driest autumn in a number of observed areas). In autumn, the southern half of Kazakhstan, the extreme north-western regions, Kostanay and North Kazakhstan regions were in the zone of significant precipitation deficit (Figure 3.1), where humidification conditions are characterized as dry and in places extremely dry (5% extremes). In Mangystau region, less than 10 % of the norm fell in places, in the Aral Sea region and in the east of the Kyzylorda region – less than 20 % of the norm. Small pockets where precipitation exceeded the norm by more than 20 % were located in the north-east of Atyrau region (up to 136 % of the norm), at the junction of Akmola, Karaganda and Pavlodar regions (up to more than 140-160% of the norm),

In September and October, the average amount of precipitation in Kazakhstan was about 66 % of the norm (Table 3.2), but a shortage of precipitation remained in most of the country (Figure 3.3). In September, in most regions of the southern half of the republic, including the east, as well as in the far north, precipitation was less than 50 % normal. In the south-western and southern regions and in the area of Lake Balkhash, precipitation fell less than 20 % of the norm, no more than 20 weather stations had no precipitation throughout the month. In October, precipitation in most of the republic was less than 40 % of the norm, in most western, southern and central regions – less than 20 % of the norm. According to 14 weather stations located in various parts of the country, it was extremely dry (5 % extremes were recorded). There was no precipitation on MS Ayakkum, Beineu, Sam, Ganyushkino, Karak throughout the month.

In September, precipitation in the range of 80-120 % of the norm was recorded in some areas of northwestern, northern, central and northeastern Kazakhstan. Precipitation was significantly higher than normal in the extreme western regions (more than 140-180 % of the norm) and in the central part of the country, where precipitation was even more than 200 % of the norm. The most significant amount of precipitation in September fell on MS Nur-Sultan (52,6 mm), which amounted to 217,4 % of the norm (5 % extreme). In October, precipitation of more than 120 % of the norm was received by some areas in Pavlodar, East Kazakhstan and Almaty regions, as well as in the south of the country (Figure 3.3). A significant excess of precipitation (5 % extremes) was observed at the meteorological stations of MS Bayanauyl (Pavlodar region), Kegen, Assy and Narynkol (Almaty region). A record amount of monthly precipitation fell on MS Narynkol (68,5 mm), the previous record was set in 1987 and was 67,2 mm (Appendix 1).

In November, the average amount of precipitation in Kazakhstan amounted to 86,7% of the norm (Table 3.2), but the distribution of precipitation across the territory was uneven. In the southern half of Kazakhstan, with the exception of some and mainly foothill and mountainous areas, there was a shortage of precipitation, which increased to the south. Thus, less than 20 % of the norm of precipitation fell in some areas of the Mangystau region, in the south of the Aktobe, Kyzylorda and Turkestan regions, 5 % extremes were observed in places in the Zhambyl and Almaty regions.

MS Shieli (Kyzylorda region) and MS Assy (Almaty region) had a record low amount of precipitation for the month of November (0,2 mm and 1,9 mm), their previous records were 0,46 mm and 2,6 mm, which were recorded in 1960 and 1988, respectively (Appendix 1). On MS Shardara, Kyzylkum, Zhetysai in the Turkestan region, precipitation was absent throughout the month.

Many regions in the northern half of the republic received precipitation either near or above normal (with the exception of the extreme northwestern and northern regions, where precipitation was 38-80 % of normal). Precipitation of more than 120 % of the norm was observed in some regions of the western regions, where in places precipitation exceeded the norm by 1,5-2,5 times. The region at the junction of Akmola, Karaganda and Pavlodar regions received 1,5-2 precipitation norms. The maximum excess of precipitation was observed in the extreme eastern foothill and mountainous regions of the East Kazakhstan region, where the monthly precipitation amounted to 188-234 % of the norm (Figure 3.3). According to the data of 8 MS in November it was extremely humid – there were 5 % extremes.

To assess the extremes of precipitation in 2021, climate change indices proposed by the World Meteorological Organization were evaluated. Below is an analysis of some of the most significant precipitation indices and the distribution of their values across the territory of Kazakhstan in 2021.

Figure 3.4 shows the values of absolute maxima of daily precipitation recorded from the beginning of the opening of the weather station to 2021 (shown in blue). The values of daily precipitation maxima that exceeded the previous absolute maximum in 2021 are highlighted in red. In 2021, the value of the absolute maximum was exceeded at one meteorological station in Kazakhstan: 58,9 mm fell on MS Aktobe per day, the previous maximum was in 1984 and was 58,6 mm.

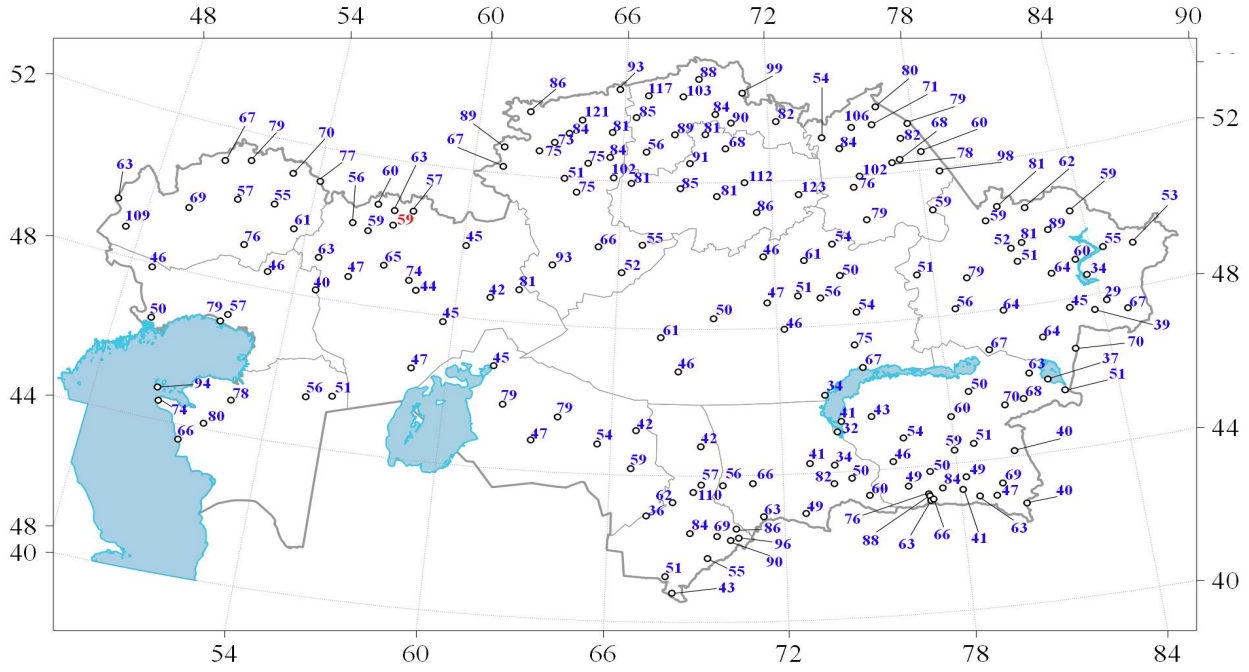

Figure 3.4 – The absolute maximum of daily precipitation (mm), selected for the period from the beginning of the opening of the weather station to 2021. If the record daily precipitation is recorded in 2021, the value is marked in red

The daily maximum of precipitation, selected according to data for 2021 ***(index Rx 1 day)***, was 10-20 mm in most of the territory of Kazakhstan (Figure 3.5). The maximum daily precipitation was observed in the north-west, north-east and in the foothill and mountainous areas of the south was more than 40 mm in places, in the northern regions and in the foothill and mountainous areas of the south-east – more than 50-60 mm.

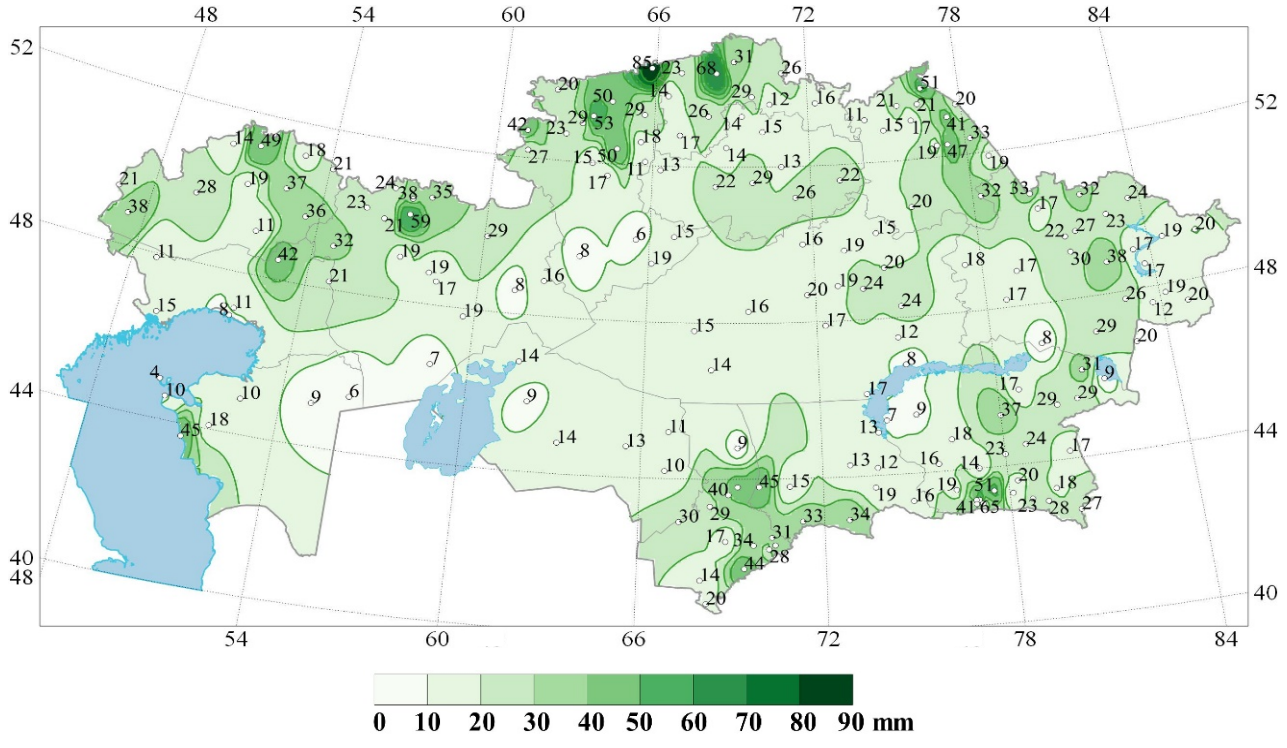

Figure 3.5 – Daily maximum precipitation in 2021 (Rx1day index)

In 2021, the **share of very heavy precipitation** (when the daily precipitation is equal to or greater than the 95th percentile, the r95ptot index) in the annual precipitation in most of the territory of Kazakhstan was less than 20 % (Figure 3.6). The largest contribution of very heavy precipitation (more than 40-50 %) was noted in the north of Aktobe, Kostanay, North Kazakhstan and Pavlodar region. In various regions of Kazakhstan, the daily precipitation did not reach the 95th percentile.

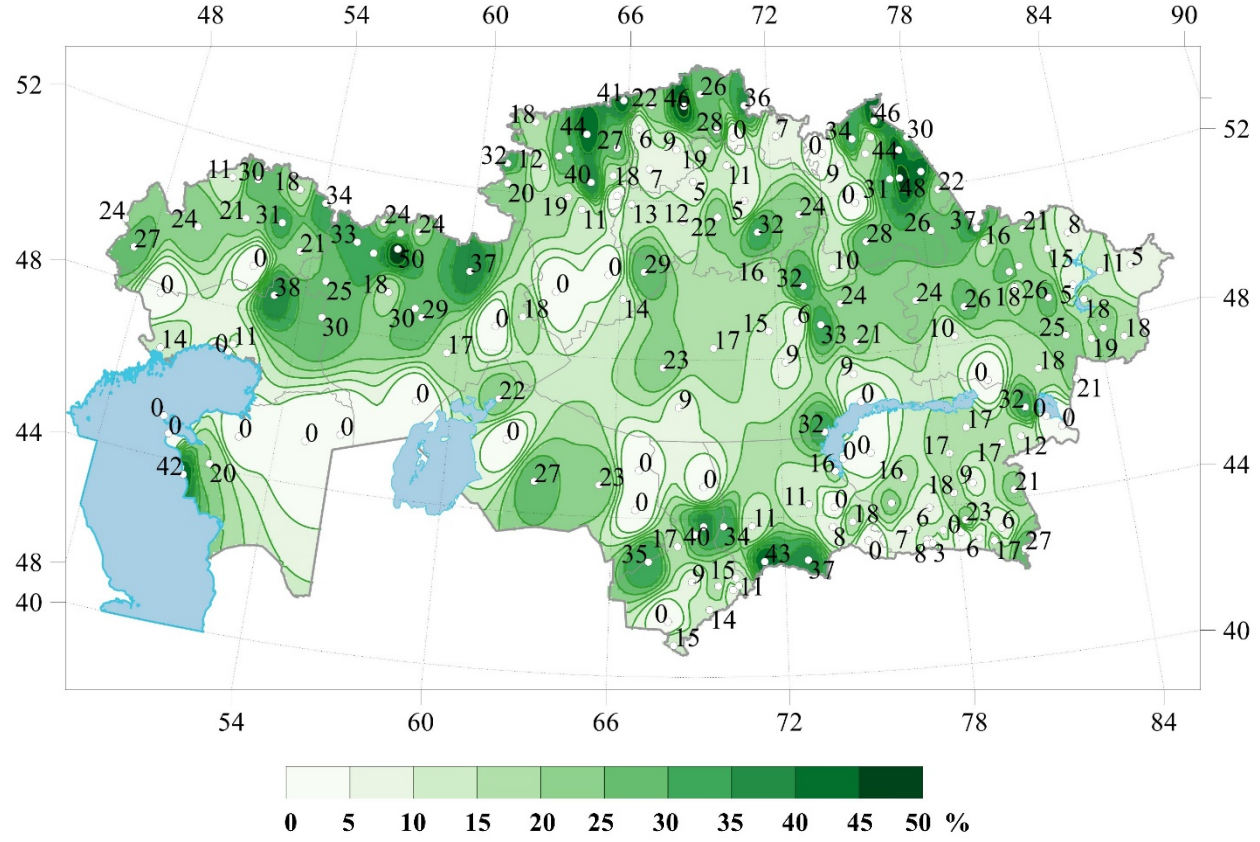

Figure 3.6 – The share (in %) of extreme daily precipitation in the annual precipitation amount for 2021 (r95ptot index)

In the conditions of the arid climate of Kazakhstan, the CDD index is very important, which shows ***the maximum duration of the rainless period*** *when the daily precipitation was less than 1 mm*. In 2021, in most of the territory of the republic, the maximum continuous duration of the rainless period was 20-60 days. The longest duration of the rainless period was observed in the Kyzylorda and Turkestan regions – more than 120 days (Figure 3.7). In the Kyzylorda region, the maximum duration of the rainless period is recorded on MS Karak (209 days without precipitation), in the Turkestan region – on MS Sholakkorgan (170 days without precipitation). The shortest duration of the rainless period (15 days) was noted at MS Leninogorsk in the East Kazakhstan region.

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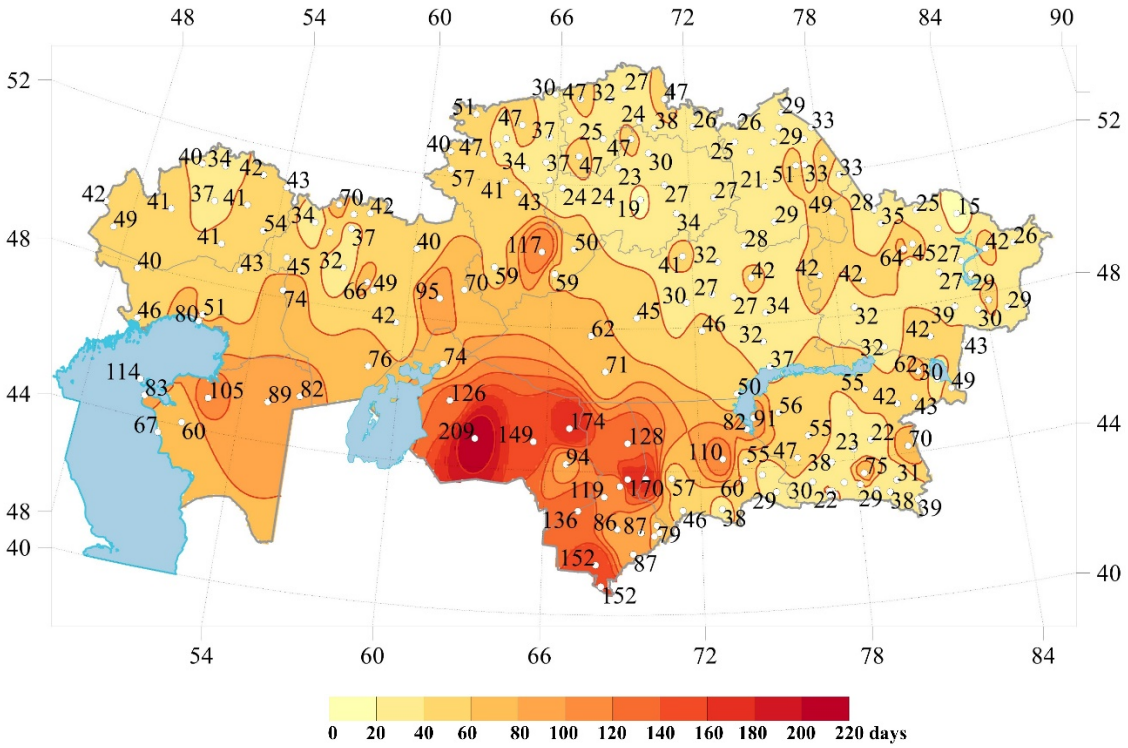


Figure 3.7 – Maximum duration of the idle period in 2021, day (CDD index)

3.2 Observed changes in precipitation

Linear trends in the series of monthly, seasonal and annual amounts of atmospheric precipitation were estimated according to the data of the 121 stations.

Time series of anomalies of annual and seasonal precipitation totals for the period 1941-2021, calculated relative to the base period of 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 3.7, Figures 3.8 and 3.9). The annual precipitation on average on the territory of Kazakhstan decreased in the 1960s and 1970s, in the last 40-year period there were no long-period trends, there was an alternation of short periods with positive and negative anomalies in the amount of precipitation.

In the period from 1976 to 2021, trends in the average annual and seasonal precipitation amounts in Kazakhstan are practically absent – the share of the trend component in the total variance of the series does not exceed 3 %, a positive trend sign for winter, spring, autumn and annual precipitation amounts, for autumn – negative (Table 3.7, Figure 3.8).

In most areas, the trends towards both an increase and a decrease in the amount of annual precipitation are insignificant, the coefficient of determination is 3 % or less. In the Akmola region, the rate of increase in precipitation was about 3 % of the norm/10 years with a determination coefficient of 5 %. In the Kyzylorda and Mangystau regions, precipitation decreased at a rate of 4,7 % of norm/10 years with a determination coefficient of 5,8 % (Table 3.7, Figure 3.9). On average in Kazakhstan in the period 1976-2021 there is a slight tendency to increase the annual amount of precipitation by 0,3 % of the norm /10 years (Table 3.7).

Table 3.7 – Characteristics of the linear trend of the anomaly of seasonal and annual amounts of precipitation (% of the norm/10 years) averaged over the territory of Kazakhstan and its regions for the period 1976-2021.

Region	Year		Winter		Spring		Summer		Autumn	
	a	**D**	**a**	**D**	**a**	**D**	**a**	**D**	**a**	**D**
Kazakhstan	0,3	0	1,3	1	2,7	3	0,4	0	-2,8	3
Almaty	0,8	0	5,3	5	1,0	0	0,4	0	-1,4	0
Akmola	3,3	5	**9,0**	**10**	3,6	3	2,7	1	0,4	0
Aktobe	-2,6	3	-2,1	1	5,1	2	-5,7	3	**-6,8**	**10**
Atyrau	2,2	1	6,4	4	**16,6**	**12**	-7,0	3	-5,3	3
East Kazakhstan	1,1	1	1,2	0	1,5	0	2,7	2	-0,7	0
Zhambyl	-1,9	1	0,0	0	-1,9	1	2,4	0	-4,8	3
West Kazakhstan	-1,6	1	-4,0	5	**9,2**	**10**	-5,9	4	-3,8	3
Karaganda	0,7	0	-0,7	0	0,6	0	5,2	4	-3,6	2
Kostanay	-0,7	0	-1,2	0	**8,6**	**11**	-2,2	1	**-5,9**	**9**
Kyzylorda	-4,4	5	-0,5	0	-1,7	0	-5,3	1	**-12,6**	**16**
Mangystau	-6,8	8	7,4	3	**-13,6**	**10**	-4,2	1	-9,1	6
Pavlodar	2,1	2	1,4	1	5,3	4	2,2	1	0,4	0
North Kazakhstan	2,4	3	3,9	2	**11,2**	**17**	0,6	0	-1,7	1
Turkestan	0,1	0	0,7	0	1,8	1	2,9	0	-3,6	1

* a – linear trend coefficient, %norm/10 years;

** D – coefficient of determination, %;

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

In winter, on average, precipitation in Kazakhstan increased slightly – by 1,3 % of the norm/10 years. The most significant trends towards an increase in precipitation are in the Akmola region – 9,0 % of the norm/10 years (determination coefficients is 10 %), and in the Almaty region – by 5,3 % of the norm/10 years (determination coefficients is 5 %). A noticeable decrease in precipitation is observed in the West Kazakhstan region - by 4,0 % of the norm/10 years (the coefficient of determination is 5 %).

In spring, Kazakhstan's average precipitation of the spring period increased slightly – by 2,7 % of the norm every 10 years. On the territory of most regions, precipitation trends are positive, but also insignificant. In the West Kazakhstan and Atyrau regions of the western region, in the Kostanay and North Kazakhstan regions of the northern region of the republic, precipitation increased at a very high rate – by 9,2-16,6% of the norm/10 years with a determination coefficient of 10-17 %. The greatest contribution to the increase in precipitation of the spring season falls on the month of March, when stable statistically significant trends are observed almost throughout the territory of Kazakhstan.

In summer, there were practically no trends in precipitation in all regions of Kazakhstan, since the contribution of the trend to the overall dispersion was insignificant and did not exceed 4 %.

In autumn, precipitation trends are negative in most regions. The most significant rates of precipitation decrease are observed in Aktobe, Kostanay, Mangystau and Kyzylorda regions – by 5,9-12,6% of the norm/10 years with a determination coefficient of 6-16 %.

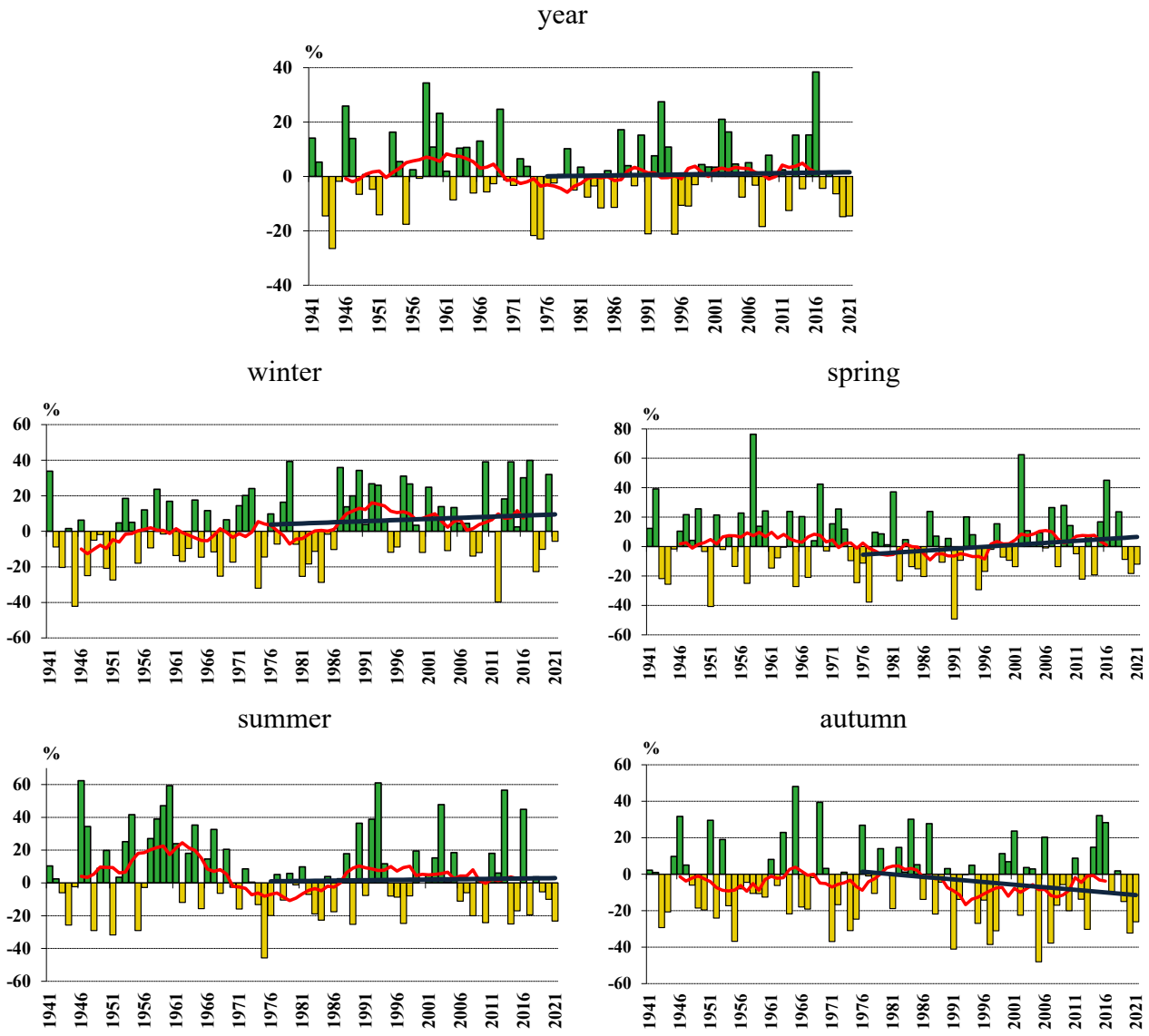


Figure 3.8 – Time series of anomalies of annual and seasonal precipitation amounts (%) spatially averaged over the territory of Kazakhstan for the period 1941-2021. Anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2021 is highlighted in black. *The smoothed curve is obtained by an 11-year moving average*

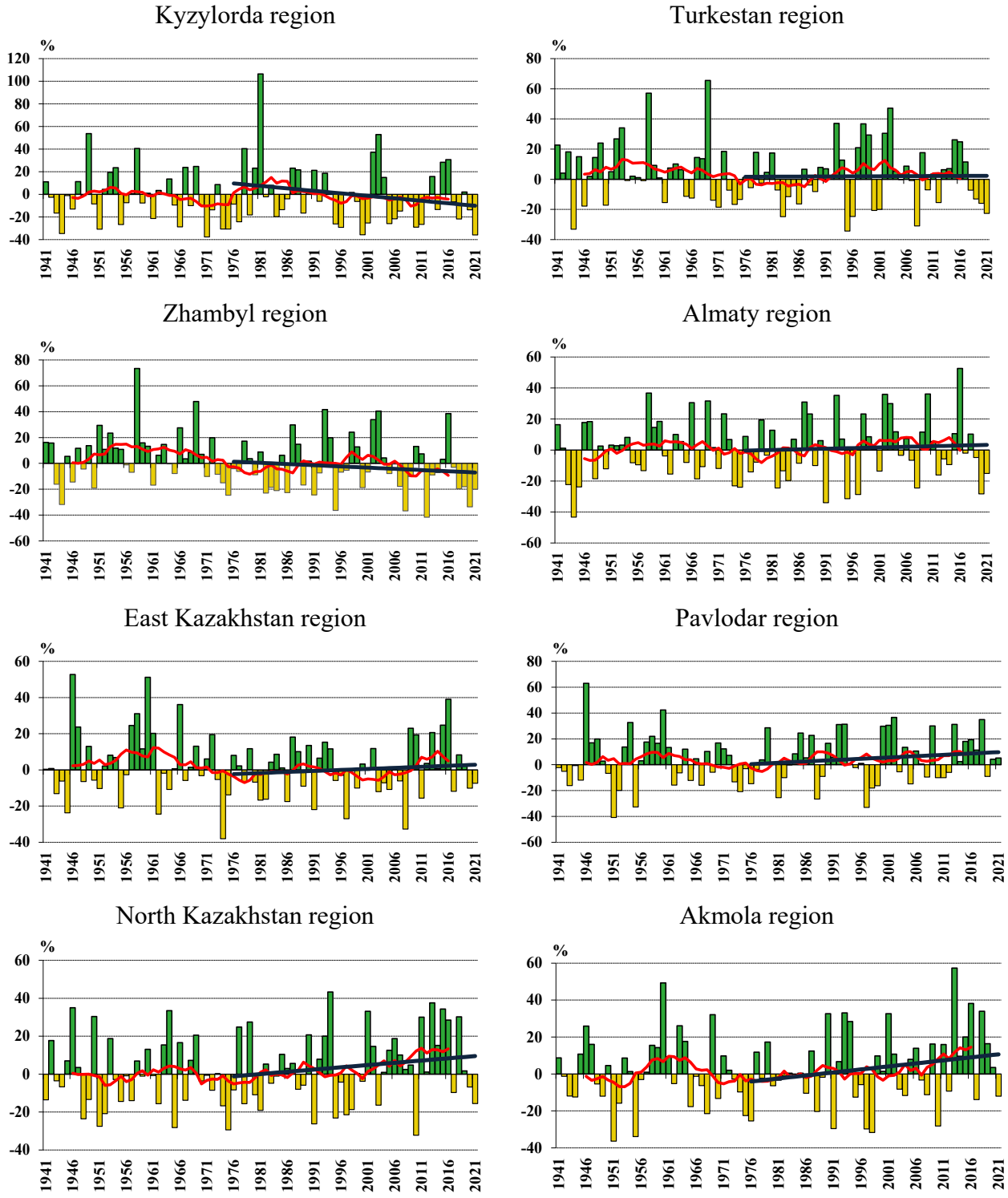


Figure 3.9 – Time series of anomalies of annual precipitation amounts (%) for the period of 1941-2021, spatially averaged across the regions of Kazakhstan. Anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2021 is highlighted in black. *The smoothed curve is obtained by an 11-year moving average. Sheet 1*

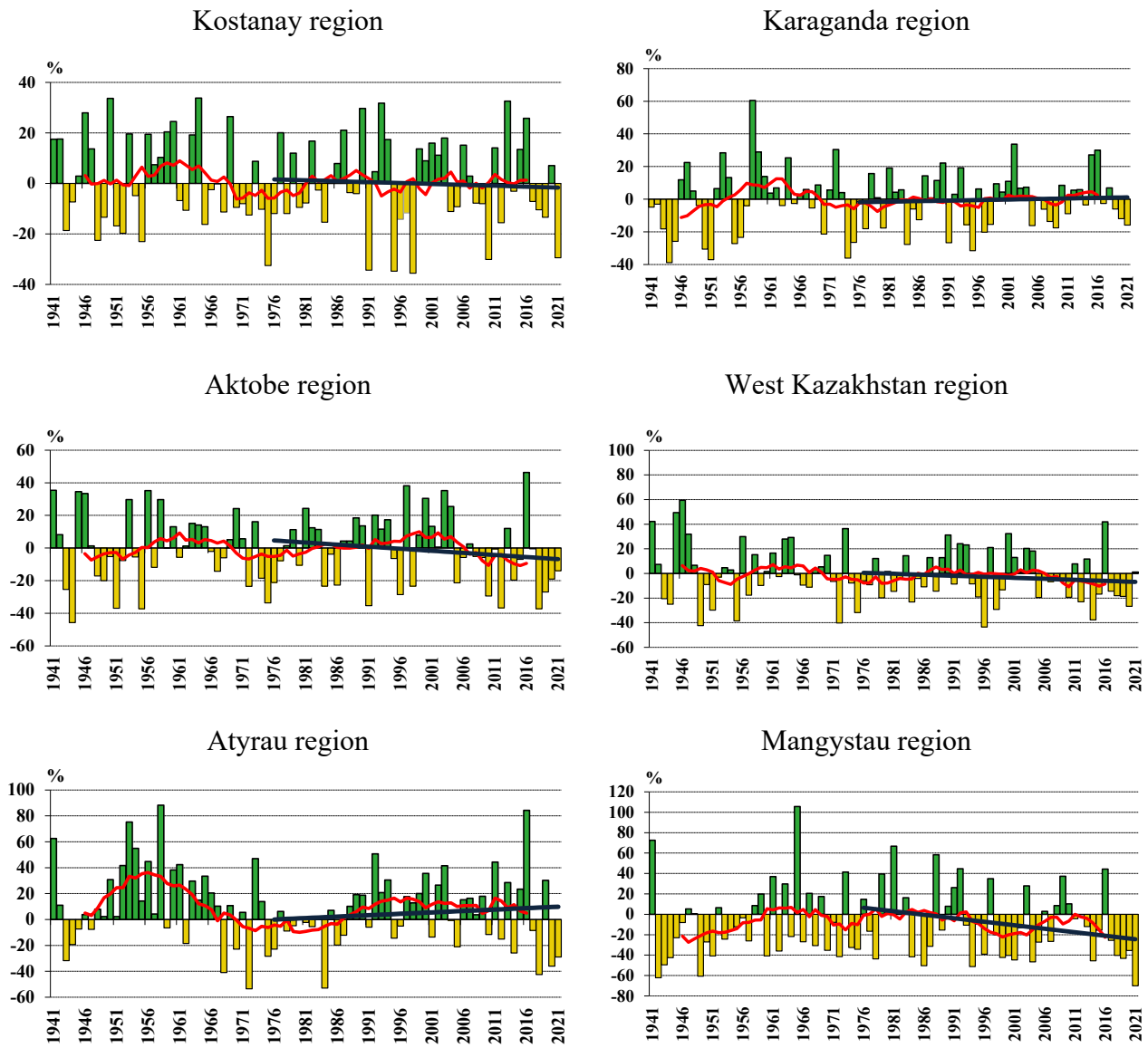
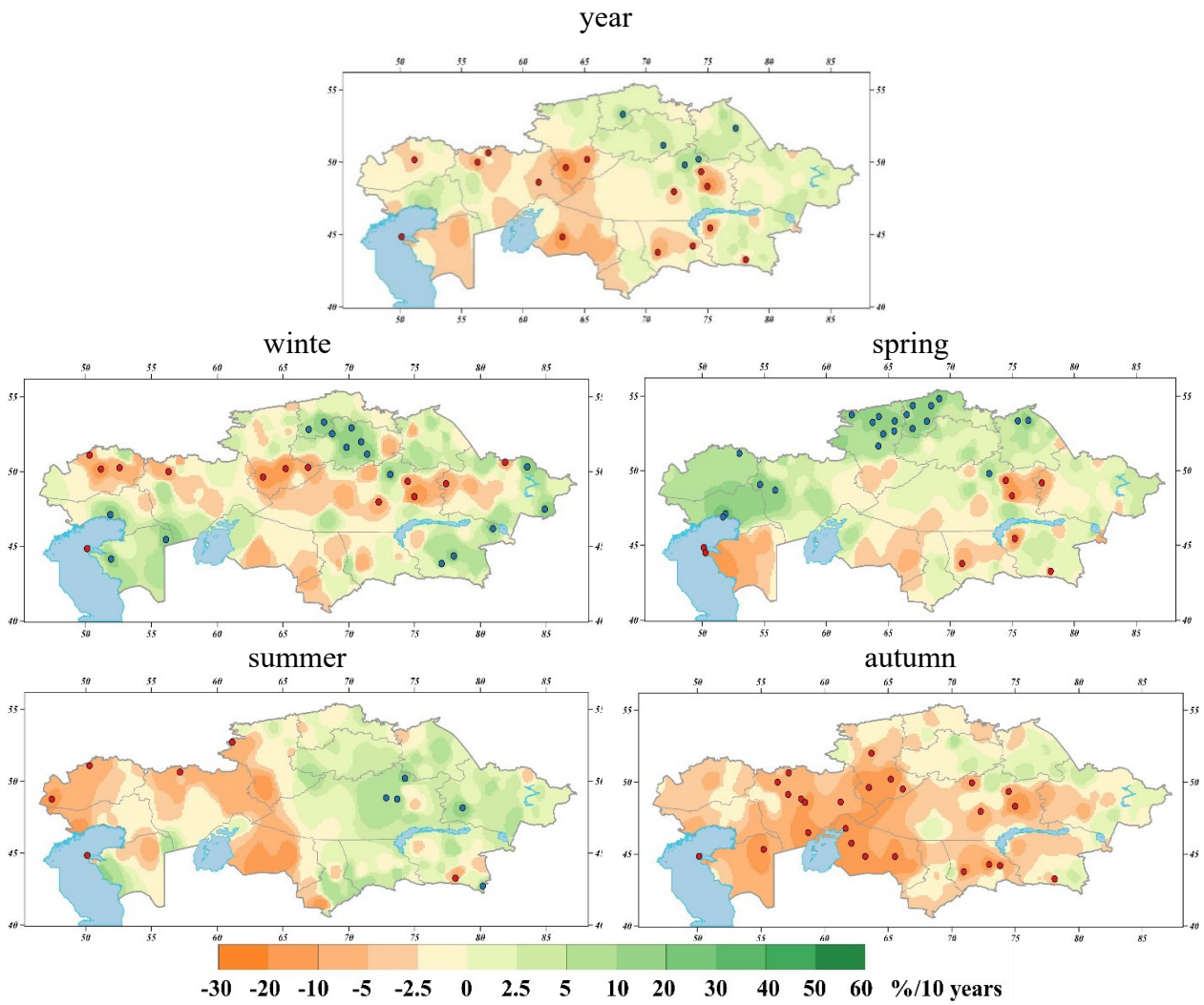


Figure 3.9 – Time series of anomalies of annual precipitation amounts (%) for the period of 1941-2021, spatially averaged across the regions of Kazakhstan. Anomalies are calculated relative to the base period of 1961-1990. The linear trend for the period 1976-2021 is highlighted in black. *The smoothed curve is obtained by an 11-year moving average. Sheet 2*

More detailed information about the nature of changes in the precipitation regime in Kazakhstan is provided by the spatial distribution of the values of the linear trend coefficient of annual, seasonal and separately for each month precipitation amounts (%/10 years) presented in Figures 3.10 and 3.11. Estimates are obtained from station time series of annual, seasonal and monthly precipitation anomalies for the period 1976-2021.

On the territory of the republic, there is a spotting in the direction of changes 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, southwest and southeast (by 10-15 % of the norm/10 years). The main contribution to this increase was made by February (Figure 3.11). A significant downward trend is also observed in the north-western and central regions within 10-15 %/10 years. **In spring**, a significant increase in precipitation amounts is observed in the western and northern regions (by 2,7 % of the norm/10 years, the contribution to the variance is 3 %). There are no trends in the

southern half of Kazakhstan, with the exception of small areas where precipitation decreases significantly. Among the spring months, March stands out, when a significant increase in monthly precipitation amounts is recorded in most of the territory of Kazakhstan (in some places by 30-40 % on average for every 10 years). **In summer**, the western half of the republic's territory is in the zone of precipitation decrease, the eastern half is in the zone of increase, but the trends of both signs are rarely statistically significant. **In the autumn months**, most of the territory is in the zone of negative trends in precipitation. Precipitation amounts for the autumn season decreased significantly according to many stations in Aktobe, Kostanay, Kyzylorda regions, in places in the central and southern regions (by a maximum of 15-20 % of the norm/10 years). As a result, according to most stations, these changes are statistically insignificant (Figure 3.10), **annual** precipitation amounts decrease significantly in some northwestern, central and southern regions (by 6-12 % of the norm/10 years), and significantly increase only according to several stations in the northern region (by 6.8 % of the norm/10 years).



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

Figure 3.10 – Spatial distribution of values of the linear trend coefficient of annual and seasonal precipitation amounts (%/10 years) calculated for the period 1976-2021.

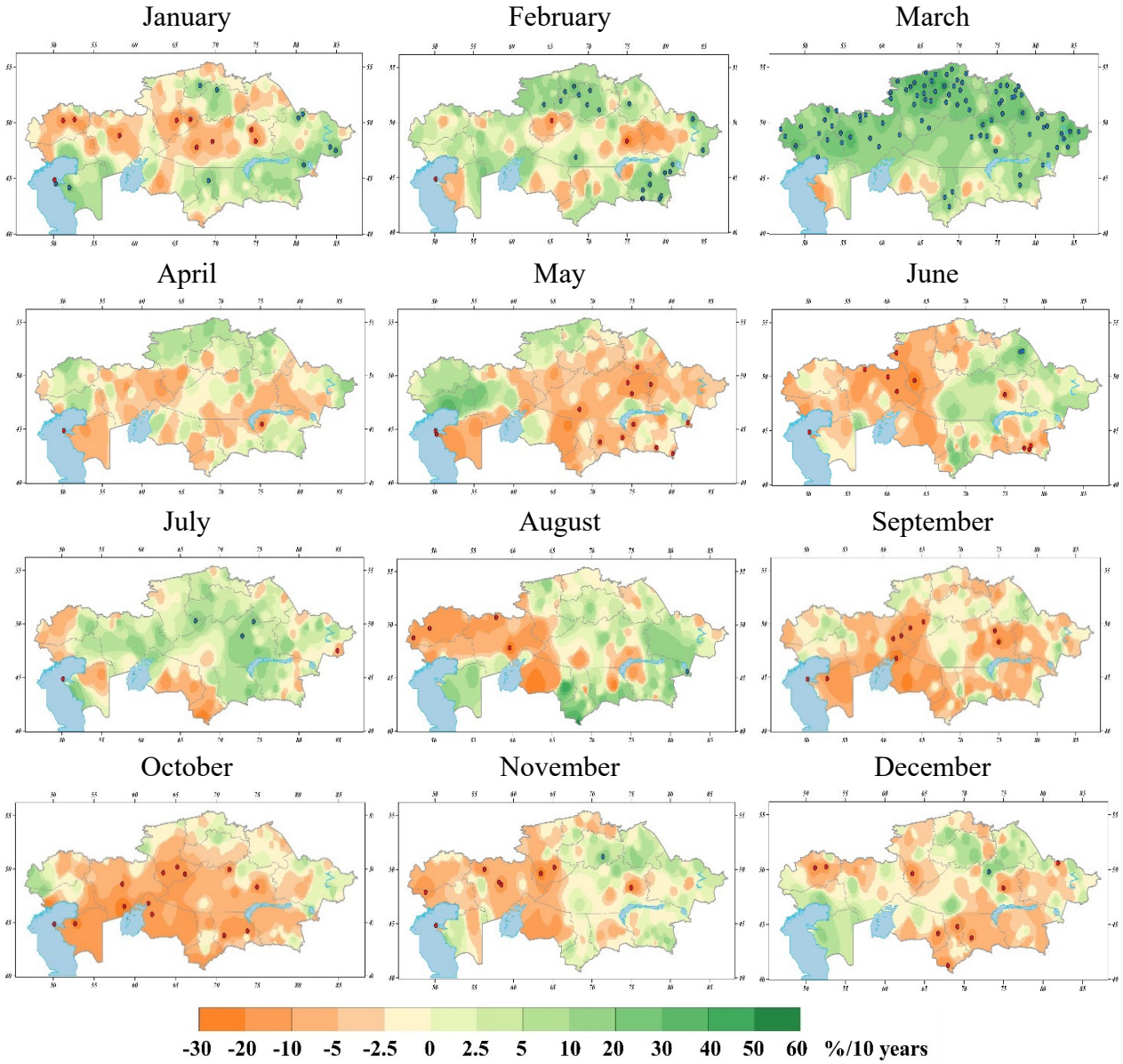


Figure 3.11 – Spatial distribution of values of the linear trend coefficient of monthly precipitation (%/10 years) calculated for the period 1976-2021.

3.3 Trends in precipitation extremes

Figure 3.12 shows the change in *the maximum duration of the waterless period when the daily precipitation was less than 1 mm* (CDD index). On the territory of Kazakhstan, there are mainly weak trends, both in the direction of decreasing and increasing the rainless period. The exception is some northern, northeastern and central regions, where a decrease in such a period by 1-3 days/10 years is recorded.

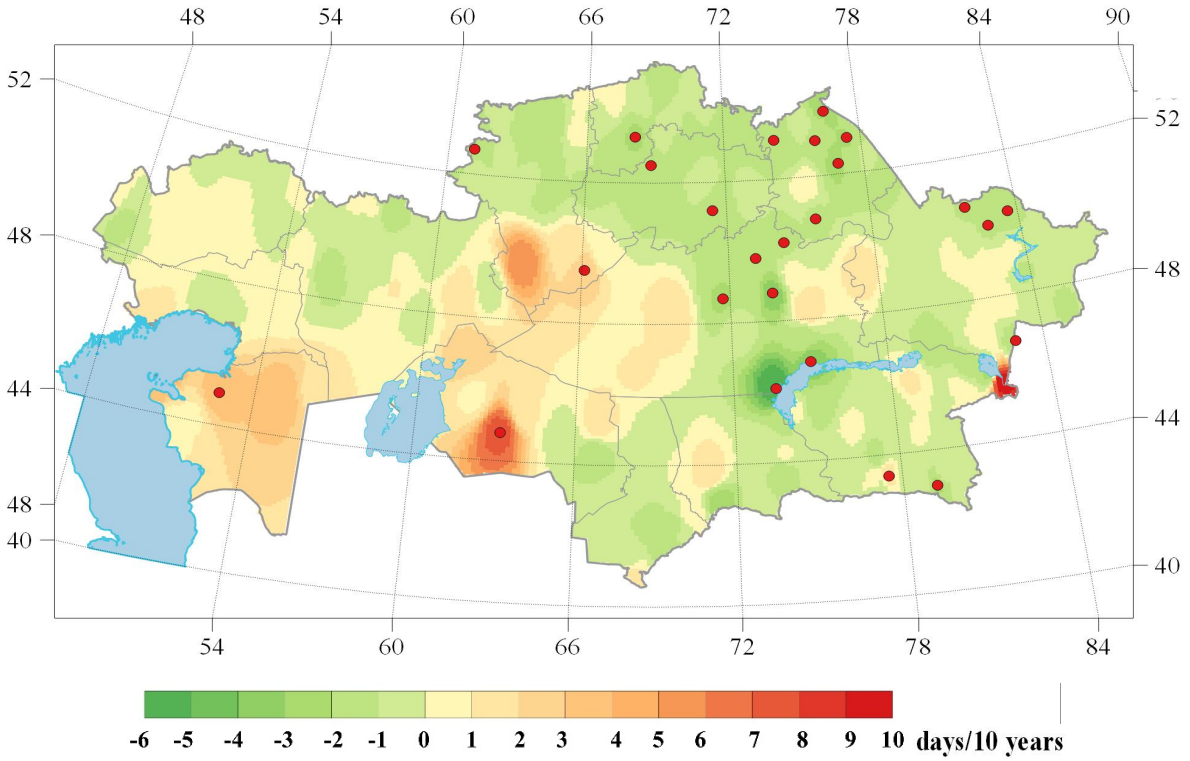


Figure 3.12 – The rate of change in the maximum duration of the idle period (days/10 years) in the period 1961-2021 (CDD index)

ANNEX 1

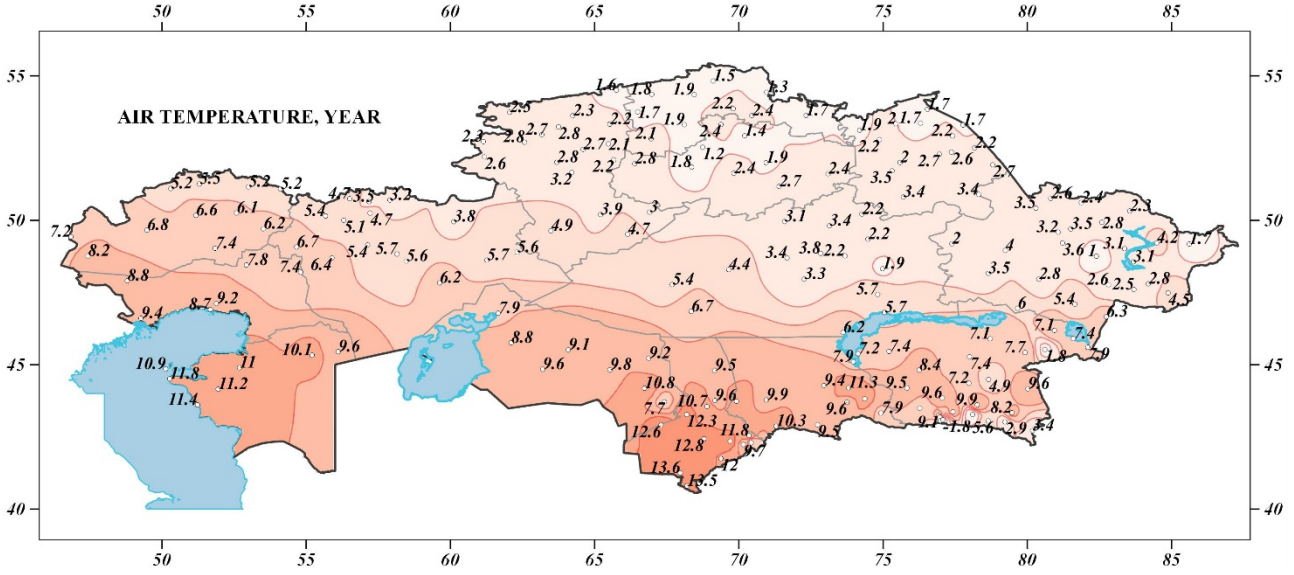
RECORD MONTHLY RAINFALL IN 2021

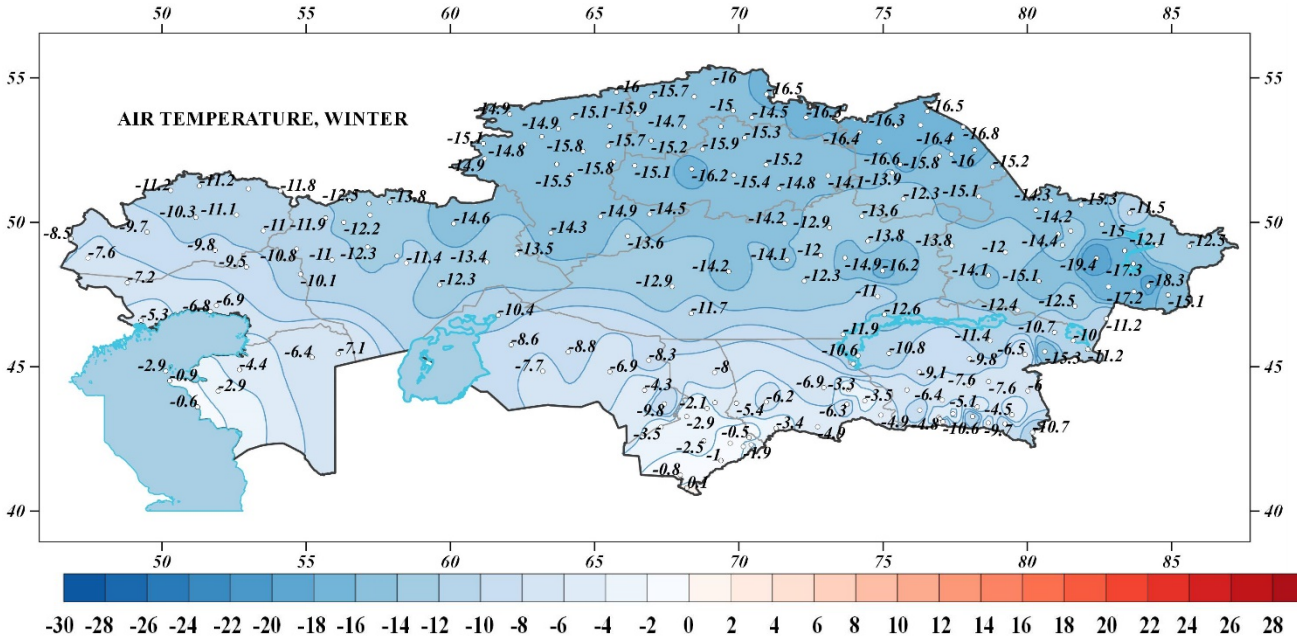
№№ pp	Name MS	Region	Maximum precipitation, mm	Previous maximum precipitation, mm	Minimum precipitation, mm	Previous minimum precipitation, mm
	December 2020					
1	Nura	Aktobe			1,2	1,70 (1976)
2	Mynzhilki	Almaty			1,8	2,70 (1967)
3	Kiskenekol	North Kazakhstan			1,2	1,40 (1974)
4	Turkestan	Turkestan			1,0	1,40 (1999)
	February 2021					
1	Esil	Akmola	33,7	28,60 (2001)		
2	Zhaltyr		46,7	44,76 (1958)		
3	Mugodzharskaya	Aktobe	49,8	48,06 (1944)		
4	Ucharal	Almaty	61,1	54,05 (1941)		
5	Leninogorsk	East Kazakhstan	63,3	52,50 (1966)		
6	Zaisan		47,2	46,76 (1958)		
7	Tobol	Kostanay	62,0	60,10 (1985)		
8	Mikhaylovka		35,2	31,60 (2001)		
9	Karamendi		35,6	31,00 (1985)		
10	Kostanay		45,5	40,00 (2007)		
11	Sarykol		62,4	54,70 (2008)		
12	Kushmurun		37,8	31,80 (2001)		
13	Timiryazevo	North Kazakhstan	62,1	34,30 (1966)		
14	Yavlenka		37,9	29,40 (1966)		
	March					
1	Nur-Sultan	Akmola	52,3	48,30 (2008)		
2	Ushtobe	Almaty	86,0	75,40 (1958)		
3	Saudakent	Zhambyl	90,8	69,08 (1956)		
4	Urda	West Kazakhstan	72,0	62,57 (1946)		
5	Yertis	Pavlodar	39,0	34,80 (2010)		
6	Sholakkorgan	Turkestan	68,0	62,27 (1956)		
	April					
1	Sharbakty	Pavlodar			0,0	0,70 (1997)
2	Shar	East Kazakhstan			1,2	1,30 (1967)

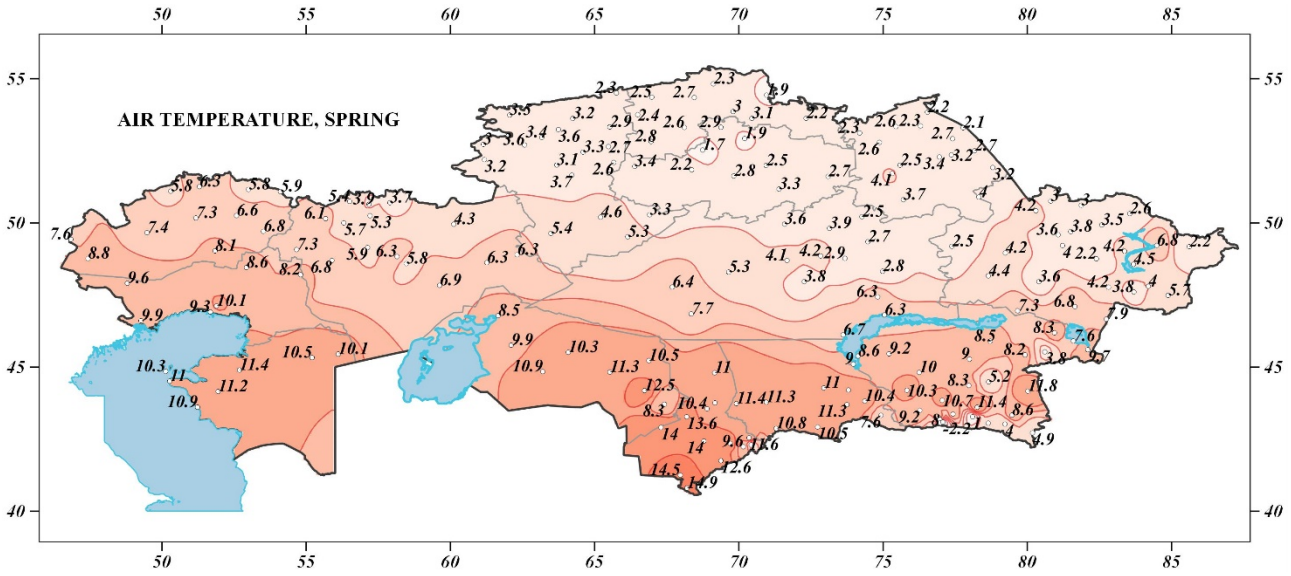
№№ pp	Name MS	Region	Maximum precipitation, mm	Previous maximum precipitation, mm	Minimum precipitation, mm	Previous minimum precipitation, mm
	May					
1	Aktobe	Aktobe			0,0	0,40 (2010)
2	Karabutak				0,0	0,60 (2019)
3	Aul N4	Almaty			0,0	0,45 (1955)
4	Amangeldy	Kostanay			0,0	0,60 (1991)
5	Shaldai	Pavlodar			1,0	2,00 (1974)
	June					
1	Dievskaya	Kostanay			1,1	3,70 (1998)
2	Karamendi				1,8	1,90 (1975, 1955)
3	Tole bi	Zhambyl			0,3	0,60 (1984)
	July					
1	Aktau	Mangystau	52,2	45,50 (1995)		
2	Aktobe	Aktobe	149,4	136,94 (1941)		
	August					
1	Krasnoarmeyka	Pavlodar	118,0	84,20 (1985)		
2	Uspenka		103,9	102,60 (1991)		
1	Arkalyk	Kostanay			0,4	1,20 (1953)
2	Arshalinsky z/svh.				0,7	1,50 (2007, 1971)
3	Jitikara				0,5	1,00 (2008)
4	Rudnyi				0,6	4,00 (2004)
5	Tobol				0,4	2,90 (1966)
6	Zhanybek	West Kazakhstan			0,0	0,12 (1951)
7	Kos-Istek	Aktobe			0,0	0,70 (2007)
	October					
1	Narynkol	Almaty	67,4	67,20 (1987)		
	November					
1	Shiely	Kyzylorda			0,2	0,46 (1960)
2	Assy	Almaty			1,9	2,60 (1988)
	December, 2021					
1	Zhetykonur	Karaganda	32,9	31,70 (2015)		
1	Balkash	Karaganda			1,6	1,61 (1965)
2	Bektauata				2,7	2,99 (1965)

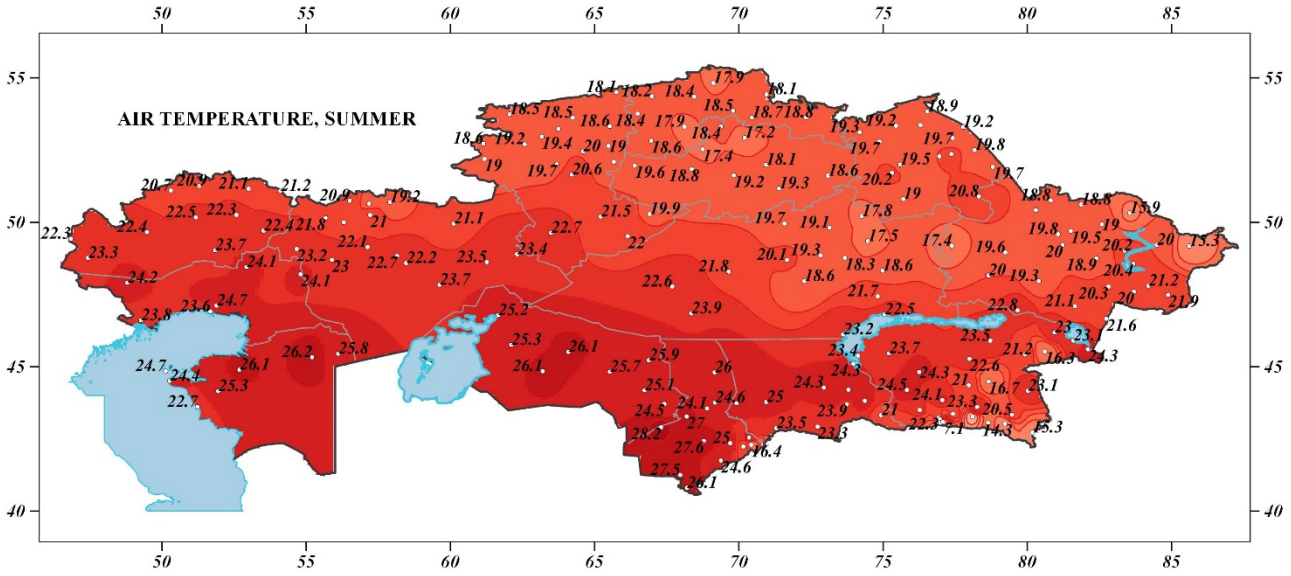
ANNEX 2

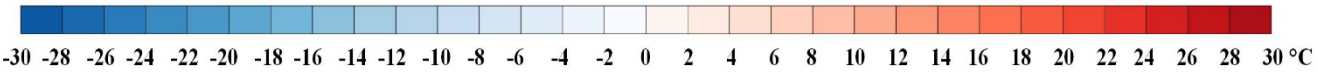
SPATIAL DISTRIBUTION OF AVERAGE ANNUAL AND AVERAGE SEASONAL AIR TEMPERATURES ON THE TERRITORY OF KAZAKHSTANON, CALCULATED FOR THE PERIOD 1961–1990






AIR TEMPERATURE, SPRING


AIR TEMPERATURE, SUMMER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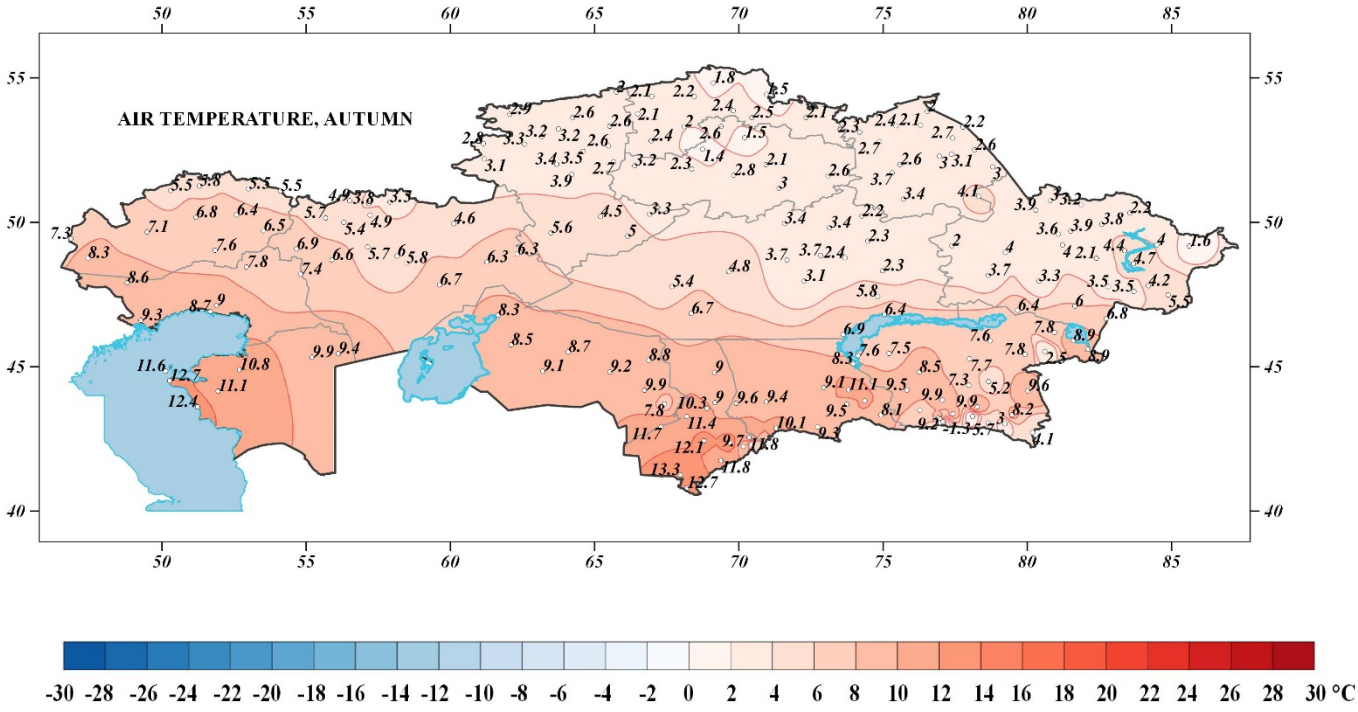
AIR TEMPERATURE, AUTUMN
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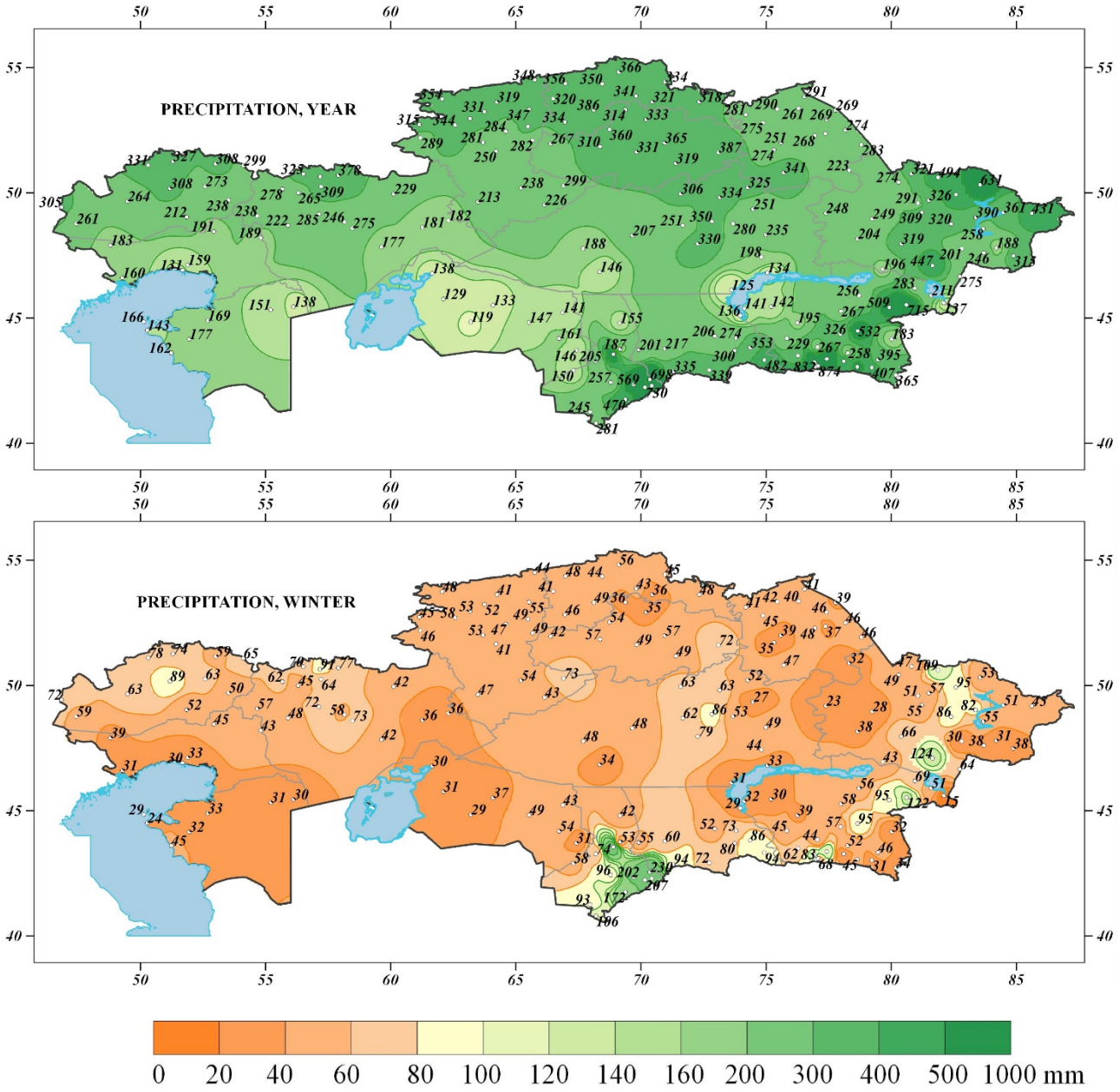
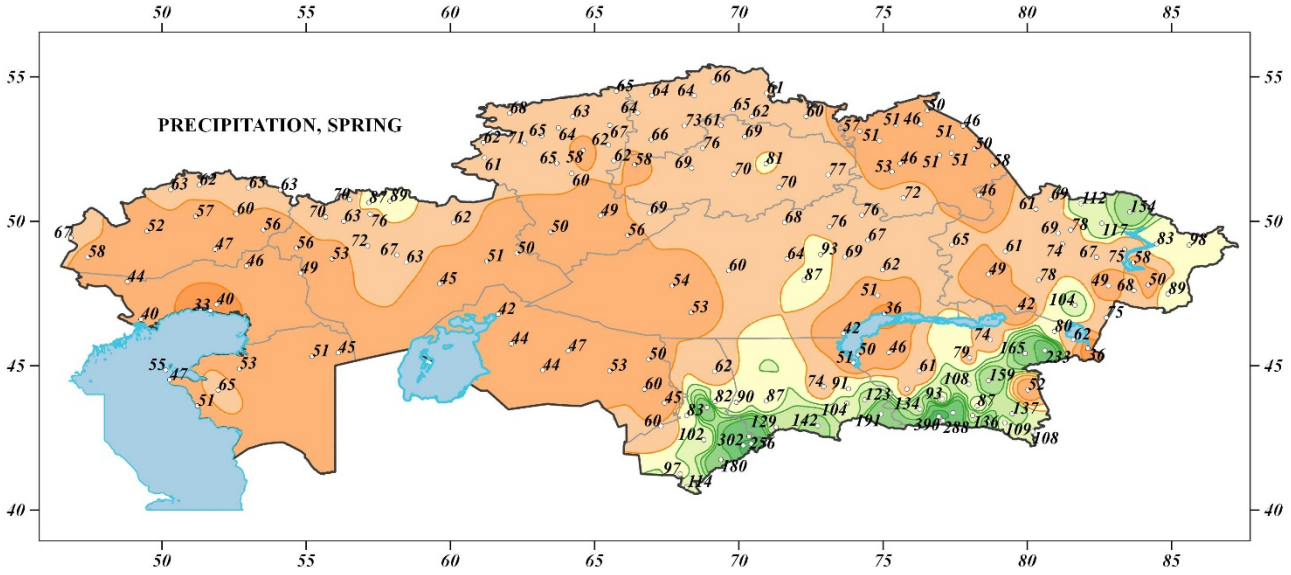
ANNEX 3

SPATIAL DISTRIBUTION OF ANNUAL AND SEASONAL AMOUNTS OF PRECIPITATION ON THE TERRITORY OF KAZAKHSTAN, CALCULATED FOR THE PERIOD 1961-1990




PRECIPITATION, SPRING
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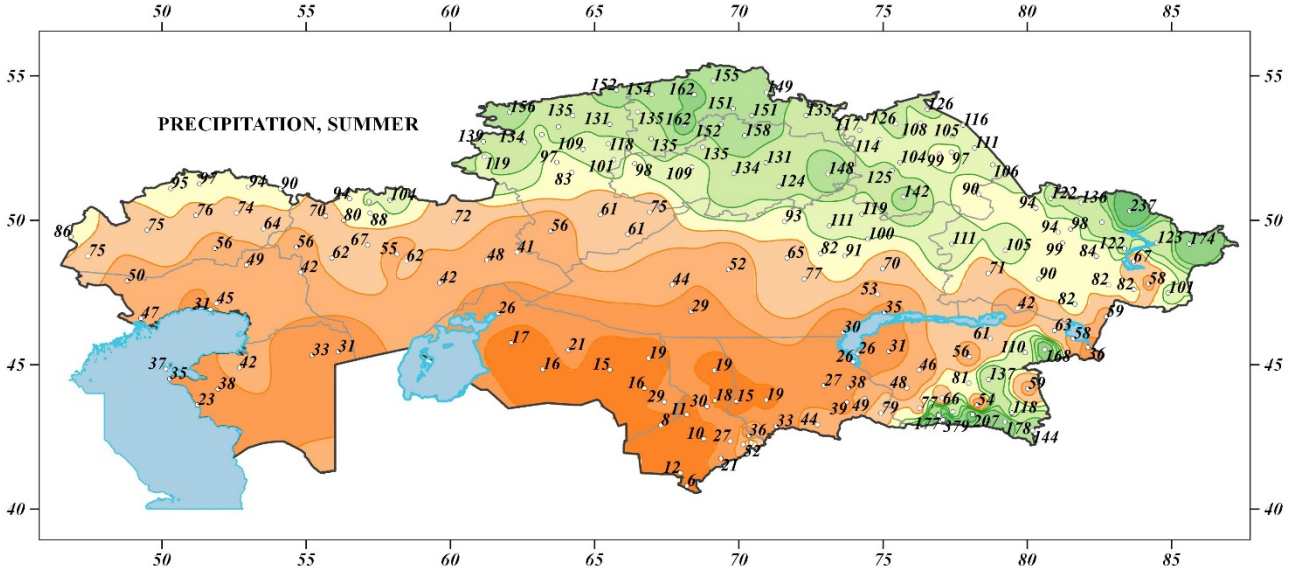
PRECIPITATION, SUMMER
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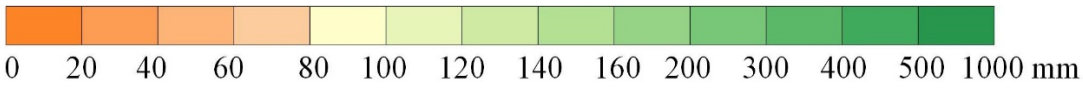
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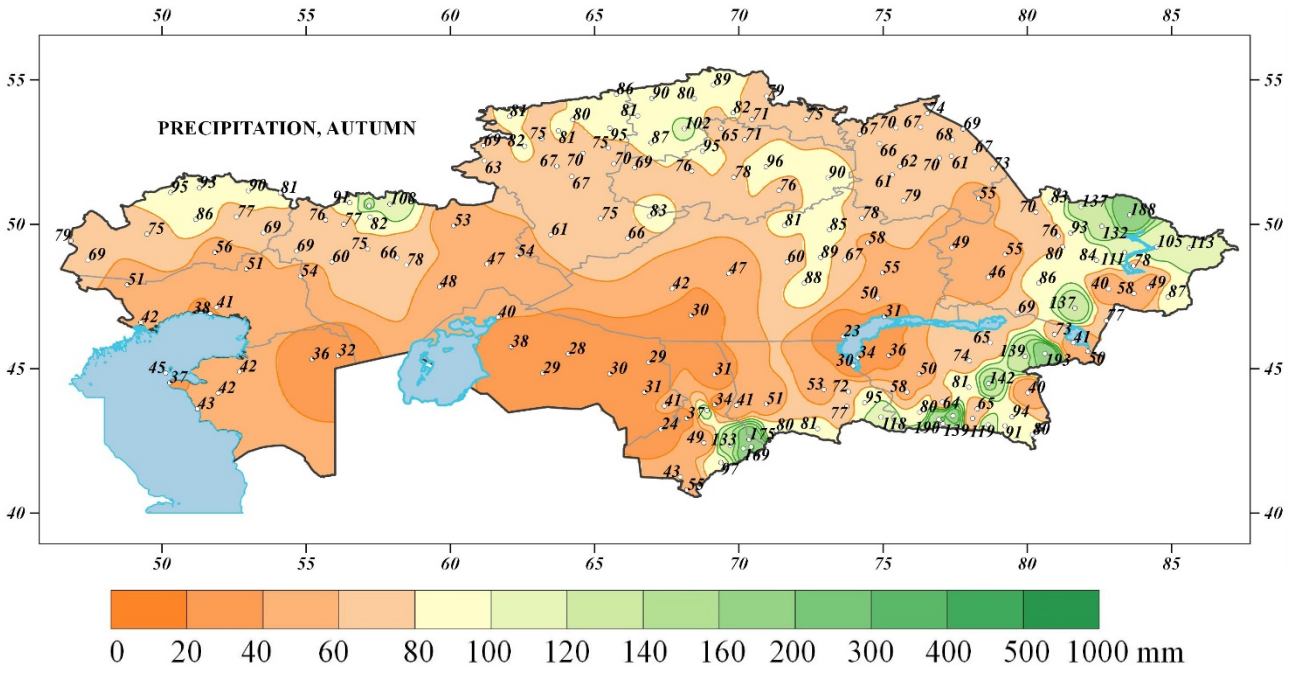
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