

3

Climate Change Trends and Scenarios

3.1. Methodology

The analysis of climatic change was primarily focused on the study of changes in surface air temperature, precipitation, snow cover, and extreme hydrometeorological events occurring in the territory of Tajikistan during 1961-1990, and throughout the period of instrumental observation.

Research work on climate change included:

Description of local climate and processes forming it;

Detailed analysis of climatic conditions for the period of 1961-1996 (recommended by WMO as a basis period);

Identification of climate change trends;

Comparison of climatic norms of the base period with the results of leading global climate models (GCMs);

Development and analysis of climate change scenarios assuming a doubled atmospheric CO₂ concentration (2xCO₂) for the period up to 2050.

Nearly 30 meteorological stations located in various climatic zones and altitudes ranging from 300 to 4,200 masl were selected to conduct the analysis.

The development of climate scenarios was conducted together with the Climate Change Center of Azerbaijan using the data received from 10 representative meteorological stations. Modeling was based on the outputs of leading models (GCMs), such as HadCM2, CCCM, GISS, GFD3, UK-89 using climate data for 1961-1990. At almost all stations, the best results regarding temperature and precipitation were with the HadCM2 model.

To fully consider all factors that have an impact on the climate, GCMs include physical processes related to irradiation, photochemistry, thermodynamics, evaporation, condensation, etc. In equilibrium models CO₂ concentration is constant, equal to 1xCO₂, 2xCO₂, 4xCO₂, etc. In dynamic models, CO₂ concentration constantly changes, for instance 1% per annum.

Climate change scenarios were generated by MAGICC-SCENGEN software and based on GHG concentrations in the atmosphere. The resolution of climate modelling was 0.5° latitude and longitude. This software considers 4 basic regions; Tajikistan is included to the Asian region.

National experts have pointed out that the resolution of global climate models does not fully correspond to the complexity of climatic conditions in Tajikistan, where altitude zonation of the climate and precipitation are characteristic and the climate is dependant on the form of landscape. Thus, GCMs cannot be used for high reliability local climate modeling.

3.2. Factors determining the weather and climate in Tajikistan

The climate in Tajikistan is determined by three main factors: solar irradiation, atmospheric circulation, and form of the landscape.

Surface solar irradiation depends on cloud cover, sandstorms, haze, fog, etc. The input of solar irradiation is determined by the processes of global circulation which is mainly a planetary factor. In the complex mountain conditions of Tajikistan atmospheric circulation incurs significant changes, forming local peculiarities. That is why weather and climate in this zone are mostly formed by land surface and atmospheric circulation.

The types of atmospheric circulation in Central Asia, and particularly in Tajikistan, are diverse: cyclonic, anti-cyclonic, frontal and local (mountain-valley, breeze, etc.).

The cyclonic circulation takes place in low-pressure zones, and is characterized by a turbulent anti-clockwise movement of the air from bottom to top. While rising upwards, the air mass expands and cools down adiabatically ($1^{\circ}\text{C}/100\text{ m}$ of altitude), and saturates with moisture. Thus, a formation of vast cloud systems and rainfalls constantly occur in the cyclones.

Anti-cyclonic circulation occurs in high-pressure zones, and is characterized by a turbulent clockwise movement of the air from top to bottom. As a result, air mass warms up adiabatically ($1^{\circ}\text{C}/100\text{ m}$ of altitude). The warming of air leads to an abrupt decrease of the relative humidity, which in turn, leads to a dissipation of cloud systems, and favors fair weather without rainfall.

Depending on the type of weather, synoptic processes in Central Asia can be classified into four main categories:

A. Cyclonic circulation. There are three basic types of cyclones: the South-Caspian, the Murgab and the Upper-Amudarya. The latter causes snow precipitation throughout Tajikistan, including southern hot lowlands.

B. Cold wave intrusions. According to the areas of origin and direction of movement, cold intrusions are subdivided into three types: western, northwestern, and northern. The most extreme weather deterioration occurs when intrusions follow at the rear of cyclones. Northwestern cold intrusions in the dry season form sandstorms and haze. Northern cold intrusions in the summertime often cause unstable weather on the northern and northeastern slopes of the Turkestan and Zeravshan ranges.

C. The group of synoptic processes causing unstable weather. Three types of processes belong to this group: confining cyclones, wave activities, and the southwestern and southern peripheries of anti-cyclones. Wave-activities are typical for highland areas; they take place in cold frontal partitions. Such a process can continue from several days to one week, accompanied by significant rainfall. When an influx of arctic air masses occurs along the southeastern periphery of anti-cyclones relating to western and northwestern humid intrusions, it is accompanied by widespread rainfall in the winter and springtime.

D. The group of synoptic processes conditioning fair weather. The following processes belong to this group: southwestern peripheries of the Siberian anti-cyclone, thermal depressions, small-gradient fields of decreased or increased air pressure. Thermal depression is typical only for the summer season, and is characterized by very hot hazy weather. In 2000-2001, it played a major role in forming a long-lasting drought in Tajikistan.

3.3. Air temperature

The air temperature in Tajikistan is formed under the influence of different factors. The temperature of the warm period of the year is steadier, whereas in the cold period it depends on the prevalence of intruding air masses from the north or south, as well as their frequency. In the former, the winters are cold, and in the latter, they are warm.

Taking into account the diversity of the climate conditions in Tajikistan, a number of areas with similar geographical conditions have been earmarked to describe the thermal condition of the territory.

Wide valleys and plains at a height of up to 1,000 m are primarily agricultural and cotton growing areas. They cover the southwest part of the republic, Gissar, Vakhsh, lowland Kafirnigan and the Kulyab valley, as well as the Ferghana valley and neighboring districts of the Sogd region.

The summer heats are characteristic to wide valleys and plains when the summer thermal depression is dominant. In summer, clear and hot weather is characteristic, during which the maximum temperature can reach between +43°C and +47°C. The monthly mean temperature of the hottest month (July) lies between +28°C and +30°C (fig. 3.1).

In winter, Tajikistan is under the influence of the Siberian anticyclone. The cold period of the year is characterized by the intrusion of cold arctic air, during which air temperature can be as low as -24°C to -30°C on some days, even in the extreme south of the republic. The monthly mean temperature in the coldest month (January) essentially remains around 0.3-2.5°C, while in the northern part of the republic (Khujand) it falls to 0.3°C below zero (tab. 3.1).

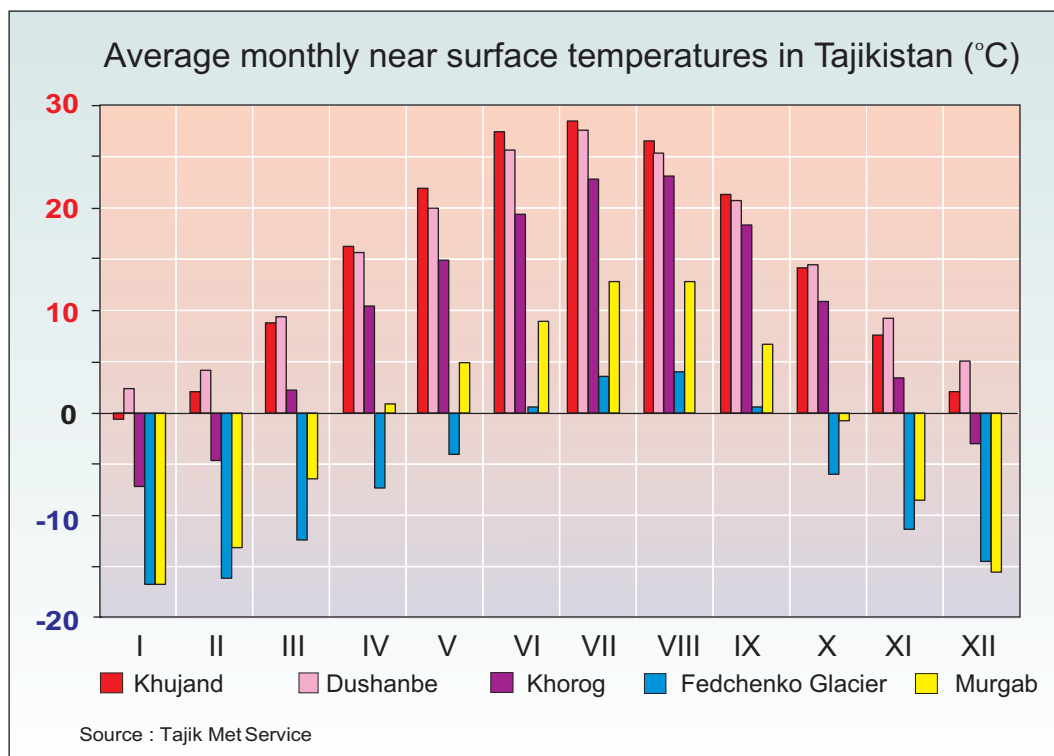


Fig. 3.1.

Table 3.1.

Climatic indicators of air temperature

Station	Altitude (masl)	Average		Absolute average		Absolute		Amplitude	Duration of period	
		Jan	July	Min	Max	Max	Min		>0°	<0°
Wide valleys and plains										
Aivaj	318	1.8	31.4	-2.4	38.8	46	-22	68	365	0
Khujand*	410	-0.3	28.4	-4.2	36.2	46	-26	72	322	43
Dushanbe*	803	2.1	27.1	-2.8	35.2	43	-27	70	365	0
Transition zone										
Faizabad	1,215	0.3	26.7	-2.8	32.3	41	-21	62	346	19
Khorog*	2,075	-7.1	22.6	-11.7	30.1	38	-27	65	258	107
Madrukasht	2,236	-4.3	18.4	-8.3	25.9	36	-22	58	258	107
Mountain regions										
Ishkashim	2,523	-8.5	19.6	-12.9	26.7	35	-28	63	190	175
Karakul	3,930	-18.2	8.4	-23.2	14.8	24	-46	70	146	219
Fedchenko*	4,169	-17.0	3.5	-19.5	8.5	16	-34	50	0	365

Source: Tajik Met Service

* - revised data

Frequent fluctuations in winter temperature above and below 0°C are typical to this zone. On average the last spring frost for the majority of areas disappears at the end of March, and the first autumn frost starts in the second half of October. The most continuous frost-free periods for the low valleys of Southwest Tajikistan are typically 260 days.

Zeravshan valley and the mountainous areas of Central Tajikistan and Western Pamir form a transitional area from valleys to areas of high altitude up to 2,500 m. As in the previous case, cloudless and dry, but cooler, weather persist here in the summer. For this zone, a consecutive decline in temperature is characteristic, depending on the altitude.

The landscape has a major influence on air temperature. The temperature on the open slopes and mountain passes in the winter months is much higher than in the valleys and closed depressions where strong cooling occurs. During the summertime the opposite occurs.

The mean temperatures in January fluctuate within a wide range: from -1°C in the lower reaches of the Zeravshan valley to -7°C in the mountains of Central Tajikistan. Western Pamir is distinct by quite higher temperatures. Thus, the monthly mean temperature in Kalai-Khum in January is 0.2°C. The absolute minimum reaches -34°C in Tavildara.

The hottest month of the year is July, when the monthly mean temperature changes from 25°C in the Zeravshan valley to 18°C in the mountains of Central Tajikistan. The absolute maximum reaches between +36°C and +40°C.

The first frost is observed in the late October and the final spring frost occurs in the second half of April. The frost-free period in valleys averages to 200 days, decreasing to 150 days at the altitude of 2,500 masl.

The high-altitude areas above 2,500 m include Central and Eastern Pamir, and mountain ranges. The climate of these areas is continental. Rarefied atmospheric conditions in high altitude areas, although causing increased solar irradiation, at the same time cause heat loss. Therefore, temperature fluctuations between winter and summer and from day to night are significant and increase in the east (tab. 3.1).

Eastern Pamir has distinctively severe climatic conditions. Winter is long and cold here. The monthly mean temperature in January ranges from -14°C to -26°C . The absolute minimum is extremely low and reaches -63°C (Bulunkul Lake). Summer is short and cool. The July mean air temperature does not exceed $+15^{\circ}\text{C}$ (Irkht). The absolute maximum varies between $+20^{\circ}\text{C}$ (Fedchenko Glacier) and $+34^{\circ}\text{C}$ (Irkht).

The longest frost-free period has had a duration of 111 days (Irkht), and in a number of the coldest areas (Shaimak, Karakul, Bulunkul, Fedchenko Glacier) there is no frost-free period at all.

3.3.1. Changes in air temperature

The greatest changes in the climate, particularly in air temperature, have taken place in the areas affected by human intervention into environment: urbanization, land development, reservoir construction, etc.

Thus, general warming in the 1930-40s, as a whole, has not had an effect on the climate change in the republic. In the following decade, a decrease in air temperature was observed, and the mid-1950s was one of the coldest times throughout the instrumental observation period of Tajikistan. At that time, air temperature on average was $1-1.5^{\circ}\text{C}$ lower than normal.

In light of the fact that significant changes in the climate were beginning to be observed since the 1950-60's, as stated by IPCC, and considering that comprehensive meteorological observations had been carried out in Tajikistan during this period, climate change research reviewed every aspect of the annual and seasonal air temperature change for that time.

During 1961-1990, an increase of $0.7-1.2^{\circ}\text{C}$ in the mean annual air temperature was observed in the wide valleys of Tajikistan. To a lesser degree, an increase in temperature by $0.1-0.7^{\circ}\text{C}$ had taken place in mountainous and high-altitude areas (fig. 3.2). A small decline in temperature by $0.1-0.3^{\circ}\text{C}$ was recorded only in the mountains of Central Tajikistan, Rushan and the lower reaches of Zeravshan. In large cities, the growth of near surface temperature was especially significant and reached $1.2-1.9^{\circ}\text{C}$ (fig. 3.3) that is obviously associated with urbanization (construction of roads, buildings, transport, industry, etc.).

In the zones with irrigated agriculture, such as the newly irrigated Yavan valley, the temperature tended to decrease, especially in summer. In the south (Shaartuz) and north (Khujand) of the republic, the mean annual air temperature has remained the same, which is conditioned by local factors (land development, construction of water reservoir).

During 1961-1990, the warmest year was 1971, when the mean annual air temperature exceeded the norm by $0.7-0.8^{\circ}\text{C}$ everywhere. The following year of 1972 was the coldest in this period, when the negative deviation of the temperature was 2°C from valley to foothill zones, and $1-1.3^{\circ}\text{C}$ at high altitudes. Eastern Pamir was an exception, where the coldest year was 1965, when the mean air temperature was $1.2-3.4^{\circ}\text{C}$ lower than normal.

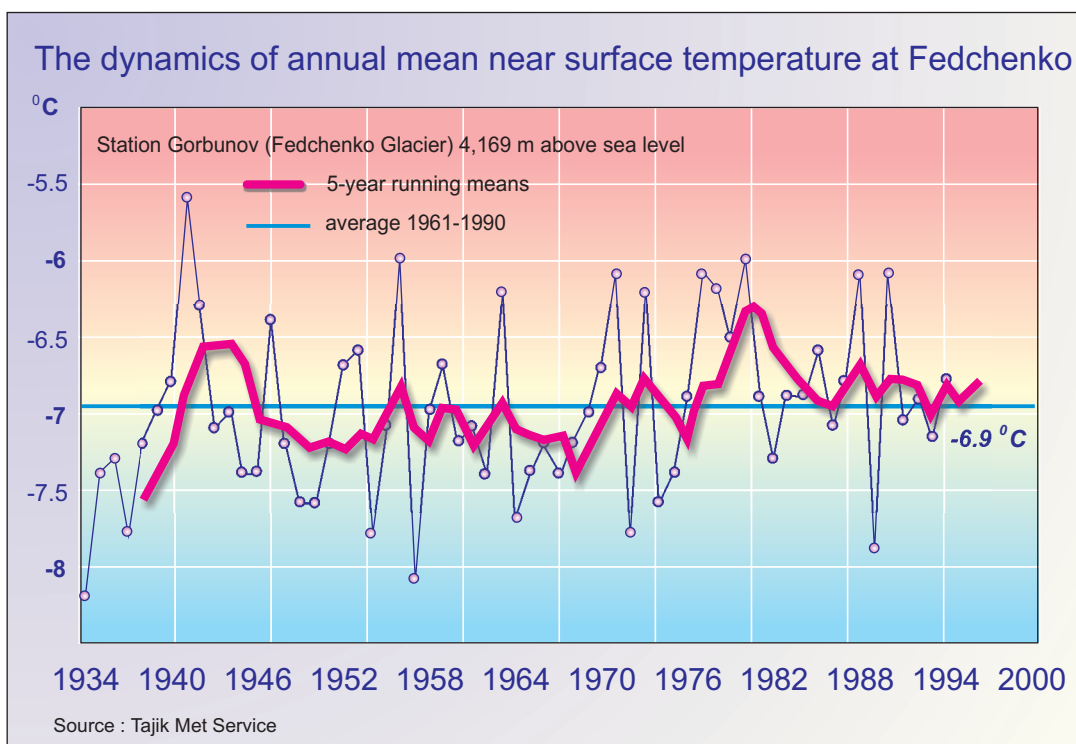


Fig. 3.2.

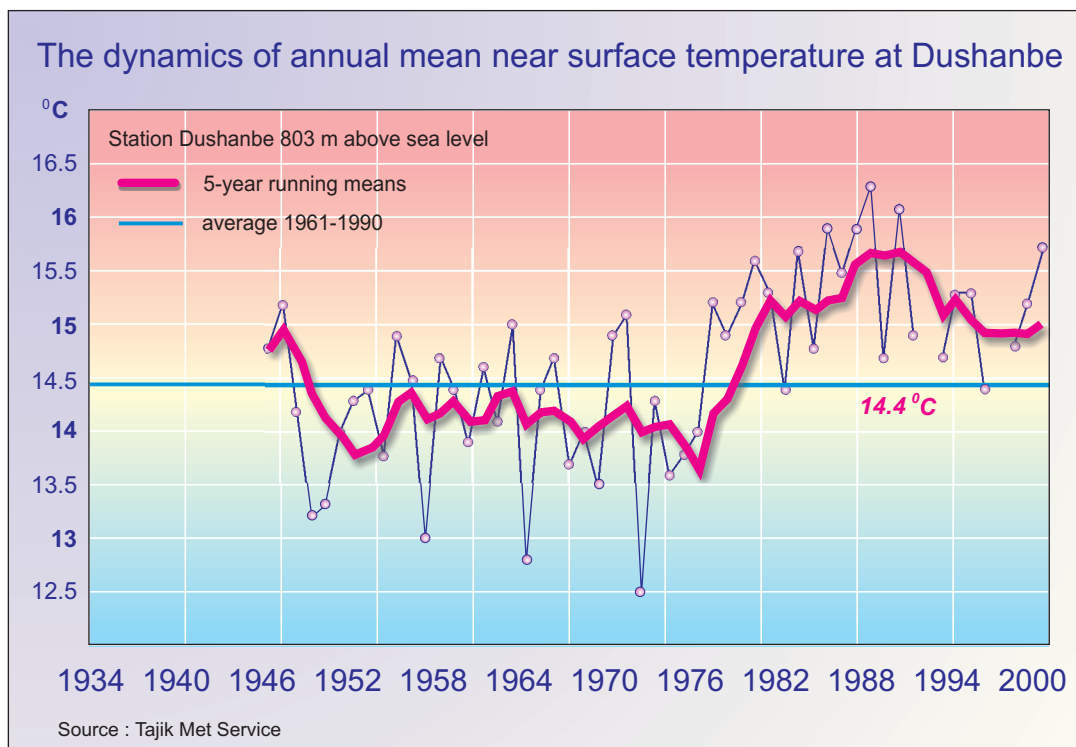


Fig. 3.3.

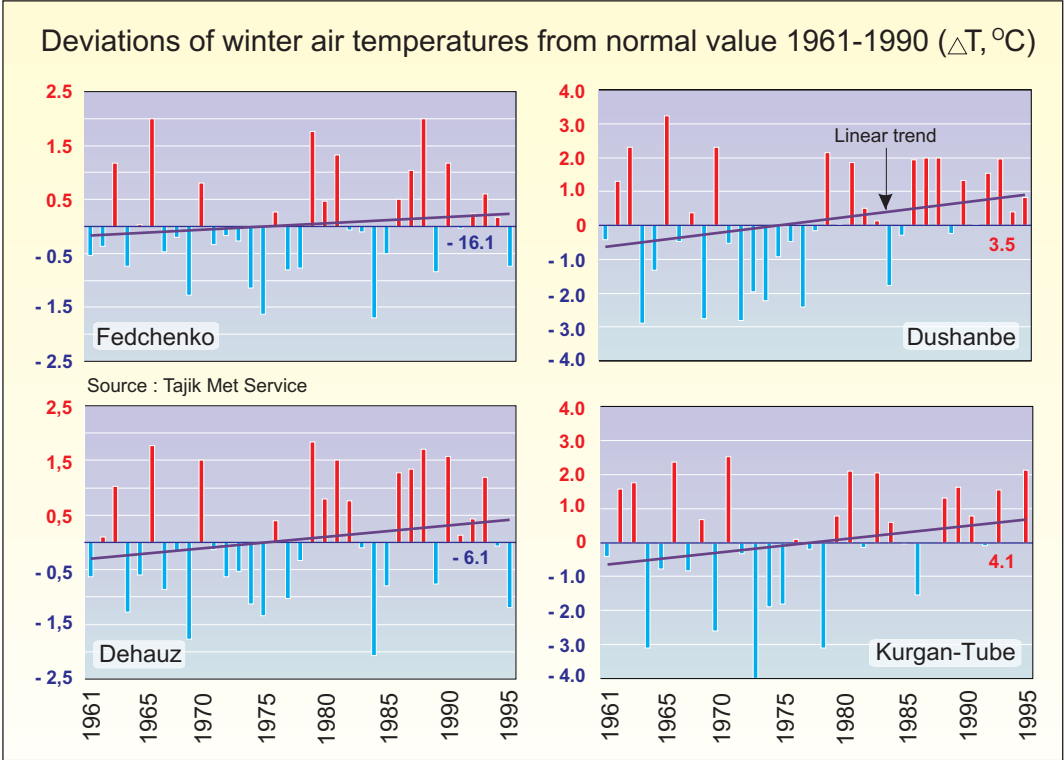


Fig. 3.4.

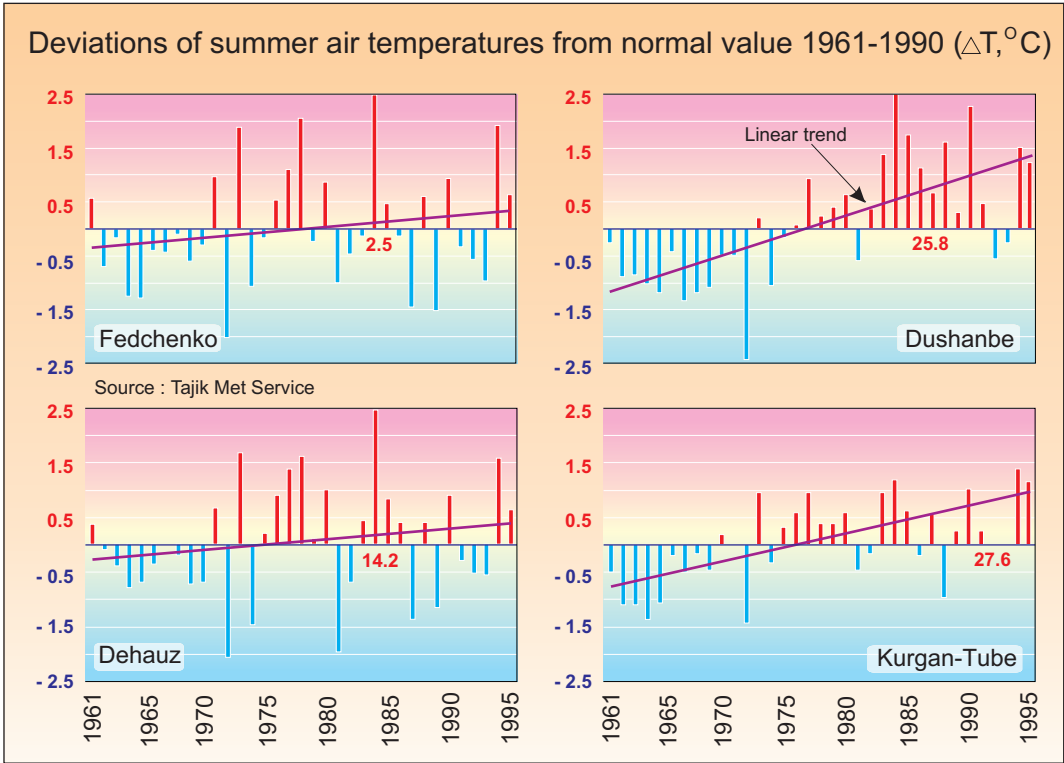


Fig. 3.5.

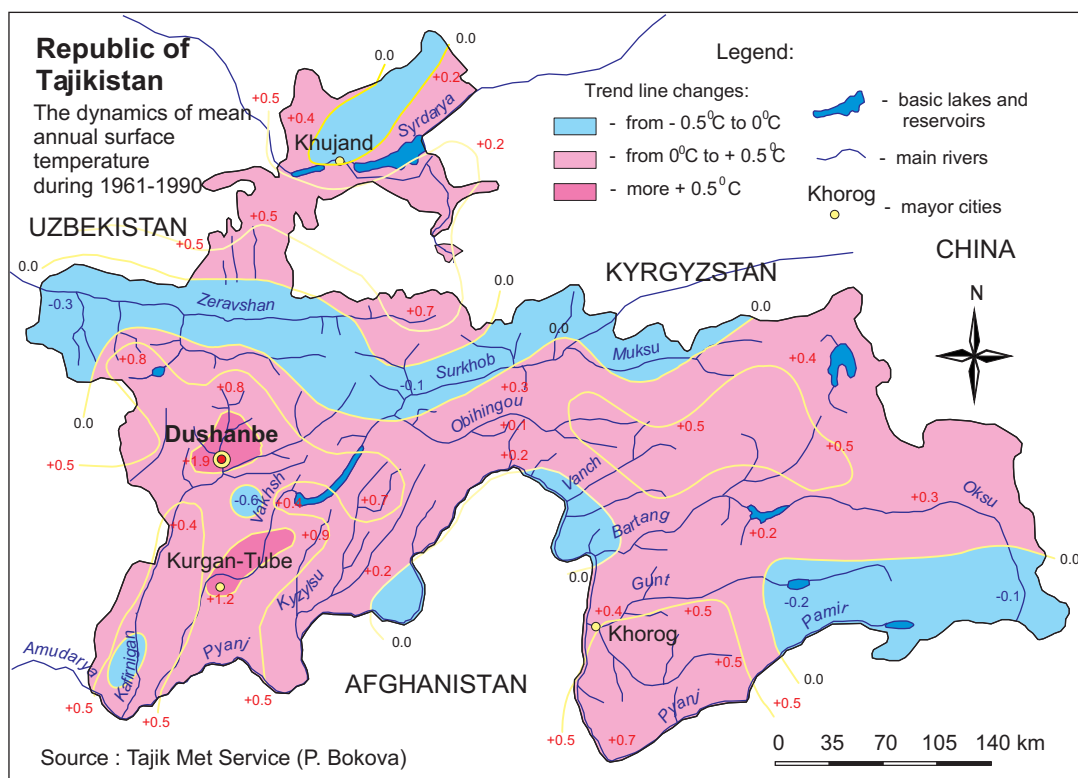


Fig. 3.6.

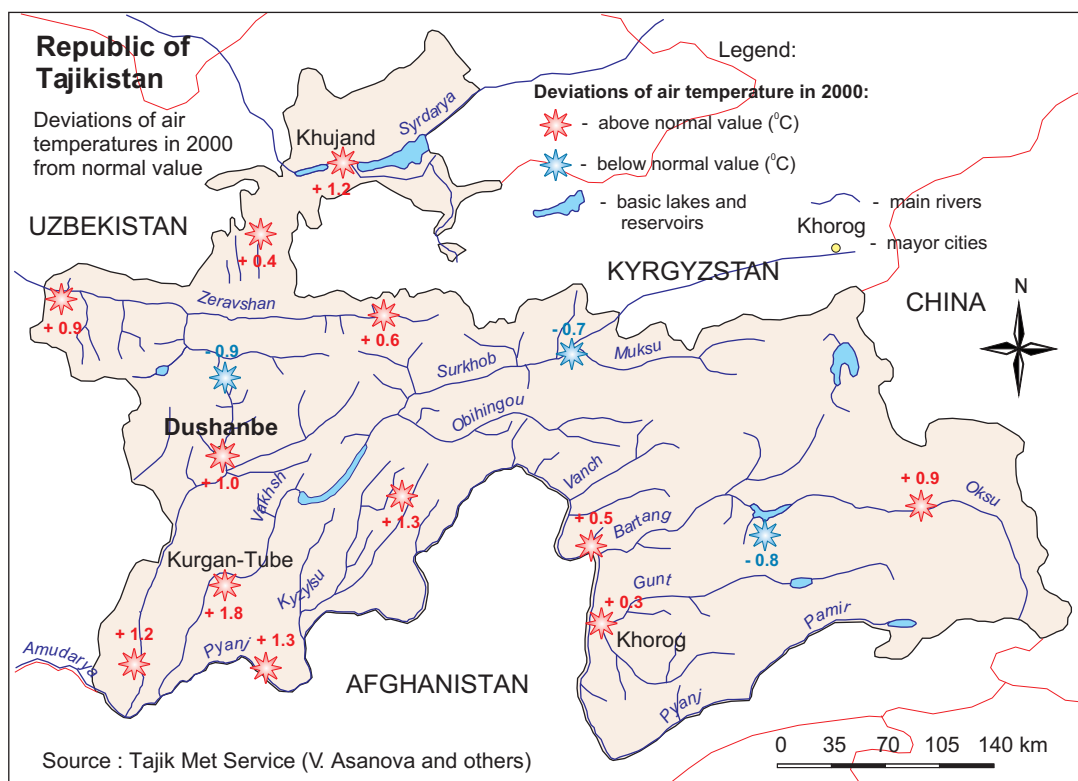


Fig. 3.7.

The warmest period was observed between 1977 and 1984, and in lowland areas until the 1990s. The temperature at this time exceeded norm by 0.6-1.6°C.

During the period under investigation, the greatest increase in temperature observed for the autumn and winter seasons were by 0.6°C in the valleys and by 0.7°C in the mountains. In the spring and summer seasons the rise of air temperature all over the republic has averaged between 0.1°C and 0.4°C.

The winter period was characterized by an increase in temperature, except for the lower reaches of the Zeravshan, Kulyab and Yavan valleys and Eastern Pamir, where it has decreased by 0.1°C to 0.4°C. The greatest increase in the winter air temperature was observed in Dehauz, Faizabad and Maikhura, as well as in large cities (fig. 3.4).

The spring temperatures in Tajikistan, in general, tend to increase in lowlands, mountains and high-altitude areas by somewhere between 0.2°C and 0.7°C. In a number of foothill areas, irrigated valleys and certain areas of the Pamirs a temperature decline of 0.1°C to 0.7°C has been observed.

Maximum annual temperatures in Tajikistan are usually observed in the summer. It is established that absolute maximum temperatures rise steadily. In lowlands and foothill areas, tendencies of increasing summer temperatures by 0.2-0.8°C are common place (fig. 3.5). In the mountains of Central Tajikistan a small decrease in air temperature by 0.4°C, and by 0.3°C in the south of the republic (Shaartuz) has been observed.

In the republic, particularly in the south and the east of the country, the autumn temperatures average a significant growth of 0.8-1.2°C. Central Tajikistan is probably an exception, as in a number of areas a downward trend has been observed.

The map (fig. 3.6.) shows the information on air temperature change tendencies during 1961-1990. Since the 1990s, the volume of meteorological observation programmes in Tajikistan has decreased considerably. Nevertheless, available data asserts that the 1990s appear to be the warmest decade throughout the period of instrumental observations in Tajikistan, particularly in 1997 and 2000 (fig.3.7).

3.4. Precipitation

Two zones basically determine atmospheric precipitation in the territory of Tajikistan. The dry climate zone covers the valleys of Southwest and Northern Tajikistan, the foothills of the Turkestan range, as well as the extensive high-altitude area of Eastern Pamir (50-300 mm per year). The rest of the territory is classified as a zone of insufficient humidity (up to 900 mm). Exceptions are the windward southern slopes of Gissar range, where a damp climate zone prevails (above 1,800 mm).

The observed distinctions in the distribution of annual precipitation (tab. 3.2) in the territory of the republic are caused, essentially, by the land surface features. The Gissar range resists western and south-west humid air masses and the largest amount of precipitation in the republic (Sioma, Haramkul) at more than 1,500 mm, falls on its southern slopes.

Table 3.2.

Mean annual precipitation in Tajikistan (mm)

Murgab (3,576 m)	Khorog (2,075 m)	Dehauz (2,564 m)	Kalaihumb (1,279 m)	Dushanbe (803 m)	Tavildara (1,616 m)	Haramkul (2,800 m)
75	281	315	502	640	922	1,521

Source: Tajik Met Service

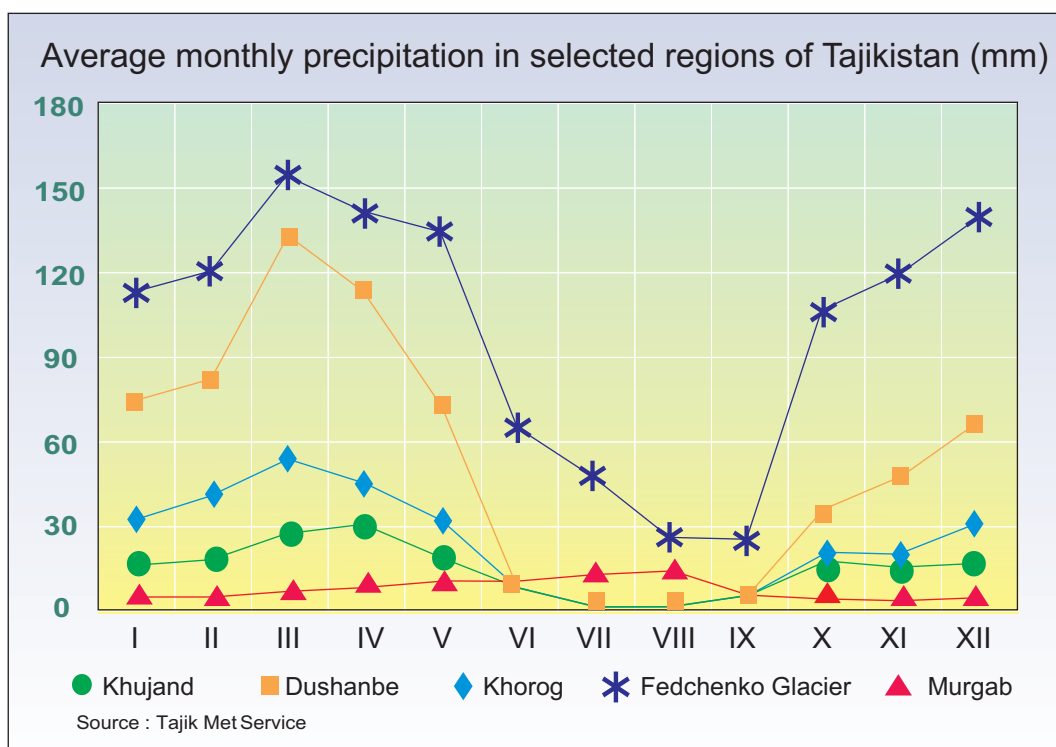


Fig. 3.8.

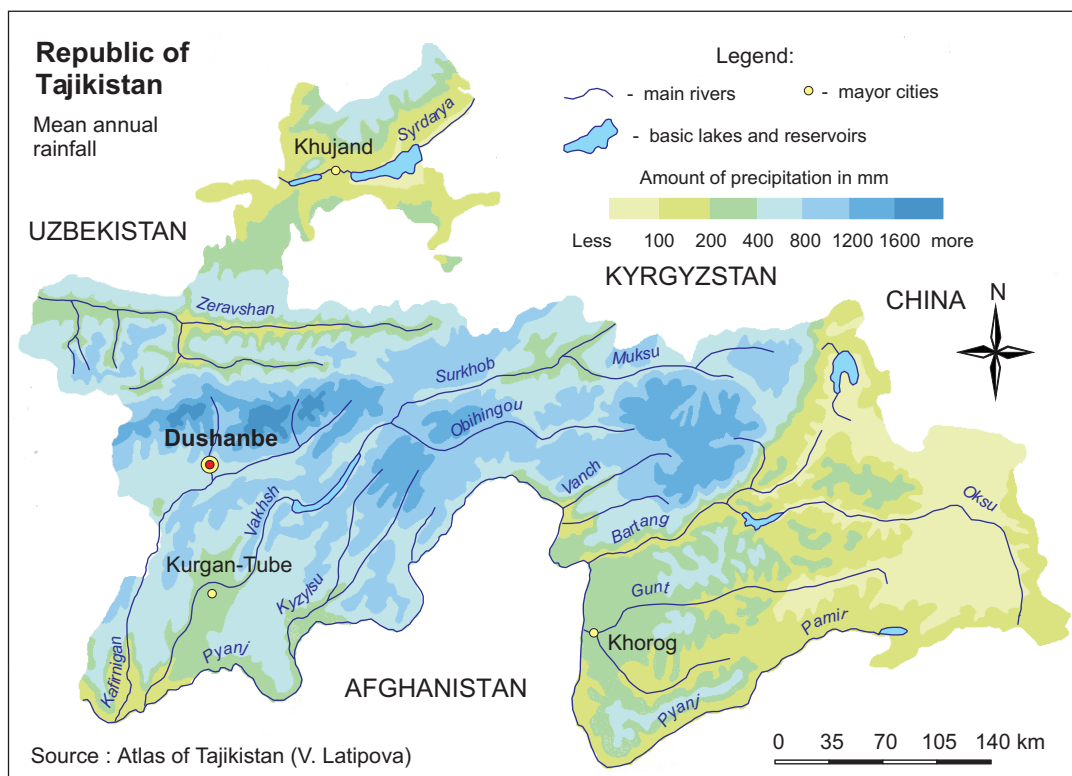


Fig. 3.9.

In spite of the fact that the slopes of all mountain ranges are well-humidified, internal areas of the extensive mountain massifs of Tajikistan, especially deep closed depressions, closed and narrow valleys among mountains, receive little precipitation. For example, in the Surkhob River valley the precipitation is 3 times less than that at the same altitude of the southern slopes of the Gissar range. It is dry in the valley of the Zeravshan River, where the annual precipitation totals between 190 - 340 mm. It is very dry also in southern Tajikistan, where annual precipitation does not exceed 150 - 200 mm (fig. 3.8).

Annual precipitation distribution in various areas of Tajikistan is not uniform. For most of the territory, the precipitation is lowest in the summer months. The maximum precipitation occurs in March to April in the valleys and foothills, and in April to May in high-altitude areas.

The maximum period of rainfall in most of the territory varies within the range of 30-100 mm per month; in some areas within the range of 200-300 mm. In the north of Tajikistan and Eastern Pamir, the precipitation maximum decreases to 12-20 mm per month. The months of minimum precipitation all over the territory usually does not exceed 5 mm, and only in some high-altitude areas reaches 10-20 mm per month (fig. 3.9).

In the foothills of Tajikistan, 15-20% of the annual precipitation falls in the form of snow. The quantity of hard precipitation increases up to 50-70%, with the altitude mounting, and reach the maximum of 85-90% in the Pamirs, including Fedchenko Glacier (100%).

The number of days with precipitation of 0,1 mm and more in the plains vary within the range of 50-80 days, in the foothills 80-100 days, up to about 125 days as the altitude heightens. The least number of days with precipitation is observed in Eastern Pamir - 50 days only.

3.4.1. Changes in precipitation pattern

Atmospheric precipitation is primarily determined by land surface peculiarities and atmospheric circulation. The height and orientation of mountains remarkably affect the strengthening of the cyclone precipitation.

The basic amount of atmospheric precipitation over the territory of Tajikistan is brought in by air masses from the Arctic and Atlantic Ocean, Mediterranean Sea, and the Indian Ocean. The amount of atmospheric precipitation manifests great variability from year to year with the occurrence of very drought-prone or wet periods.

The comparison of abnormal amounts of precipitation with the reoccurrence of latitudinal and longitudinal types of atmospheric circulation indicate the formation of excess precipitation under longitudinal currents, while the deficit of precipitation is observed under the latitudinal currents of air masses.

In 1961-1990, within the mountains of Central Tajikistan, as well as in the valleys of southwest and northern Tajikistan, foothills of Turkestan range and high-altitude areas of Eastern Pamir, a reduction in the amount of annual precipitation of 1-20% has been observed. In the foothills and mountains of the Khatlon region, the reduction in precipitation averages between 6-22% (fig. 3.10).

In Karategin and Darvaz, from the altitude of 1,500 m and higher, the amount of precipitation has increased by 14-18%. In Western Pamir, the increase of precipitation is 12-17%. The greatest increase in precipitation (36%) has been observed on Fedchenko Glacier (fig. 3.10).

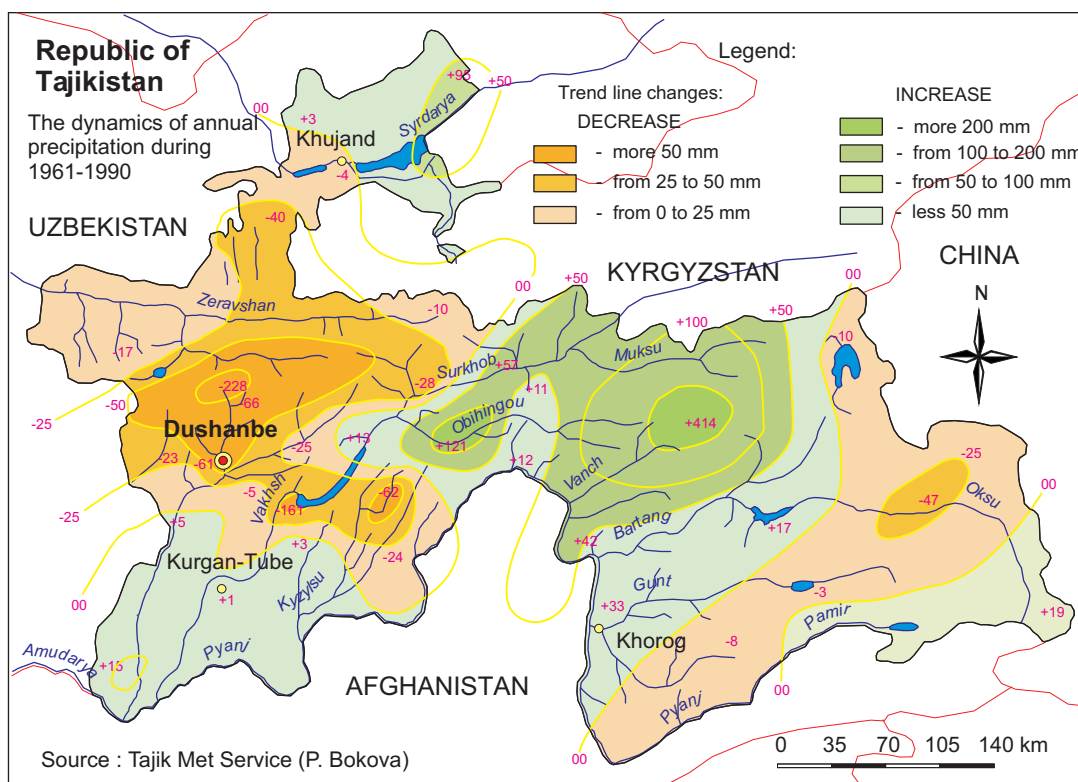


Fig. 3.10.

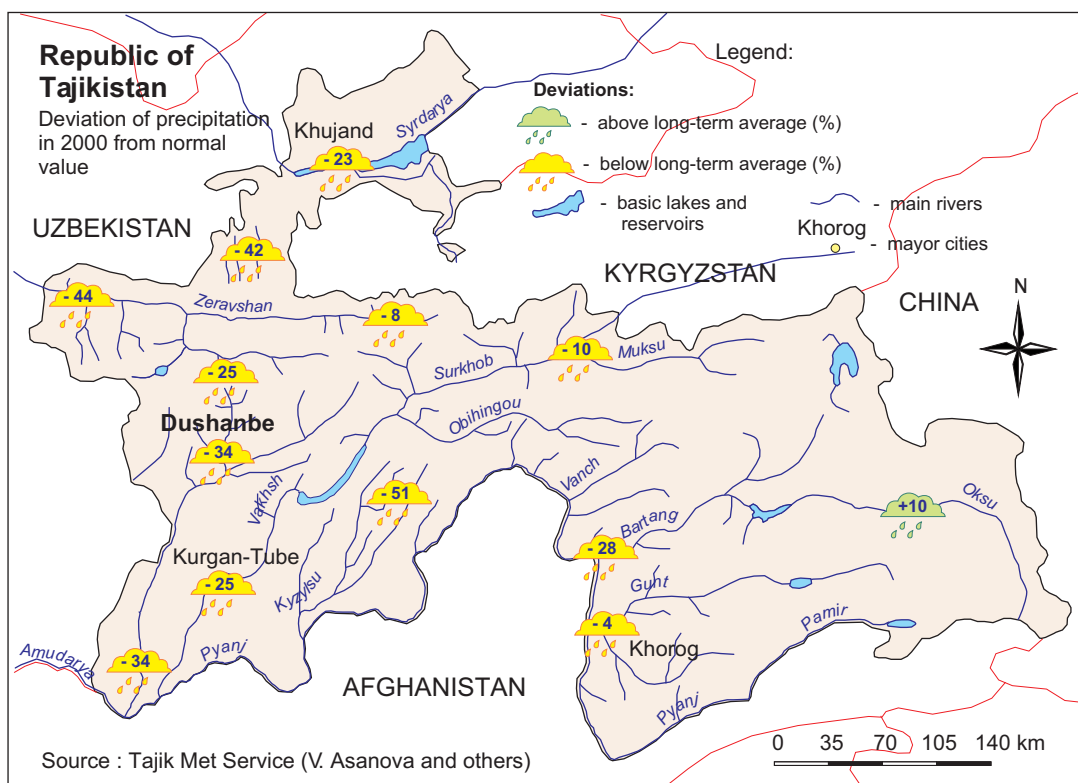


Fig. 3.11.

Overall, the most humid or dry periods were not actually observed during the years 1961-1990. In valleys, there is essentially an alternation between short wet and dry periods. In abnormally humid years, the amount of precipitation exceeds the norm by 50-65%, in Khujand by 60-100%, and in the Kulyab region by 30%. In the driest years, the deficit of precipitation is on average 35-50% below the norm.

Significant annual deviations of precipitation are observed in the mountains. Here, negative deviations are around 10-20% whereas positive changes range from 10-20% in Dehauz up to 50-100% in Murgab. In abnormally humid years, the precipitation ranges from 50 to 100% above average in the upper reaches of Zeravshan and Western Pamir, and sometimes to more than 150% in Eastern Pamir.

Research shows that the precipitation during the cold period of 1961-1990 had increased in the plains and foothill valleys. A small increase in precipitation had occurred in the upper reaches of the Zeravshan River and in Western Pamir. The greatest increase in precipitation (29%) during the cold period was observed on Fedchenko Glacier. In Eastern Pamir, during the same cold period a drastic precipitation reduction was observed, which was likely to have been caused as a result of shading of this area by the mountain ranges.

The warm period is characterized by uneven temporal distribution of precipitation. It is characteristic of this period for the highest levels of precipitation to fall in April and the beginning of May, then drastically reduce; in valleys, precipitation is rarely observed from July till September.

In the warm period of 1961-1990, the lowlands and foothills observed a drastic reduction in precipitation by 6-57%, and the upper reaches of the Zeravshan River by 6%. A remarkable reduction in precipitation during the warm period was experienced in Eastern Pamir (70%). During the same period in higher regions of the same territory (above 1,500 masl), the amount of precipitation increased from 9% to 36%. On Fedchenko Glacier, the precipitation increased by 44%.

The lowlands suffer from lack of rainfall as well as excessive rainfall more often than the mountains. During drier years, precipitation is 30-70% lower than average, and during wetter years precipitation can be 200% and more above average.

The most arid years in Tajikistan throughout the period of instrumental observation were 1944 and 2000, when a precipitation deficit of 30-70% was observed all over the territory, except for high-altitude depressions (fig. 3.11). Unusual drought was reported in Tajikistan during these years. The most humid year was 1969, when precipitation was 1.5 times above the long-term average.

3.5. Changes in snow stock

The depth and duration of snow cover vary considerably over the territory of Tajikistan.

In the southern areas of the republic (Gissar, Vakhsh, Kulyab and low Kafirigan valleys) and in the northern plains, consistent snow cover is absent in 90% of winters, and in 15% of winters snow cover is not formed at all. Snow cover in the Pamirs stockpiles at elevations between 3,500-4,000 masl and perpetually replenishes itself.

In the mountains, the distribution of snow cover depth is closely connected to land surface peculiarities and atmospheric precipitation. The snow cover reaches greater depths in the areas of maximum precipitation. So, on the southern slopes of the Gissar range, at the

area surrounding the Haramkul meteorological station, the maximum depth of snow can exceed 2.5-3 m, while at the same time the average decadal snow depth in Eastern Pamir reaches 4-5 cm, and the maximum is 20 cm (fig. 3.12).

In many areas, as the altitude grows, the depth of snow cover increases. The average biggest decadal snow depth at the altitude of 1,500 masl reaches 40 cm, while at the altitude of 1,850 masl it increases up to 90 cm, and at the altitude of 2,800 masl to 250 cm (Haramkul).

The height of snow cover varies from year to year and can considerably deviate from the long-term average. For example, at the Anzob pass, where the average height of snow cover is 169 cm, its maximum reaches 264 cm, but minimum - 92 cm.

Mean monthly distribution of the number of days with snow cover in Tajikistan is scattered. In the south of the country and in the Ferghana valley (in the north), the snow cover is less than 20 days annually. To the north and south from the Ferghana valley, in Gissar valley and in Karategin and Darvaz districts the number of days with snow cover gradually increases following the altitude zonation, and reaches a maximum of 244 days at the Anzob pass. In Western Pamir, the number of days with snow cover varies depending on the altitude from 40 to 160 days. In Eastern Pamir, the number of days with snow cover ranges between 40 - 90 days.

For analyzing changes in snow stock in Tajikistan, instrumental observation data received from 17 climate stations was reviewed, including data on the accumulation of greatest snow stocks, snow depth, temperature, and water content in snow.

Water content in the snow bed was taken as the basic characteristic of the snow cover, because this value, combined with snowmelt intensity, determines stream flow in the rivers, magnitude of maximum flow, humidity content in the soils, etc.

In the low-altitude zone up to 1,000 masl, which occupies about 17% of the total territory of the republic, consistent snow cover is not formed; snow falls sporadically and melts quickly. As a rule, the greatest depth of snow in this zone occurs at the end of January and beginning of February and reaches 20-25 cm high. The water content in fresh snow cover is very small and does not exceed 5-10 mm. On average, the number of days with snow cover over the winter period in the south of the republic does not exceed 15-30 days, and in the north, it continues up to 50-60 days.

In the mid-altitude zone of 1,000-2,000 masl, occupying about 11% of the total area of the republic, steady snow cover begins to lie from mid-December until mid-March, and in certain years, there is no formation of constant snow cover at all. The average number of days with constant snow cover, in various areas ranges within 85 to 100. The biggest snow stocks occur in the second half of February.

At the altitudes of 2,000-3,000 masl, occupying about 12% of Tajikistan's territory, constant snow cover is formed at the end of November and beginning of December, and melts, as a rule, at the end of March and beginning of April. Depending on the location, the number of days with snow cover averages between 100 to 135 days. Practically everywhere in this zone, the maximum snow stock is observed at the end of February and beginning of March.

In the high-altitude zone between 3,000 to 4,000 masl, occupying about 50% of the total area of Tajikistan, the accumulation of the biggest snow stocks takes place at the end of March and beginning of April. Constant snow cover is not formed everywhere at these heights. In the Eastern Pamir, the snow can fall throughout the year

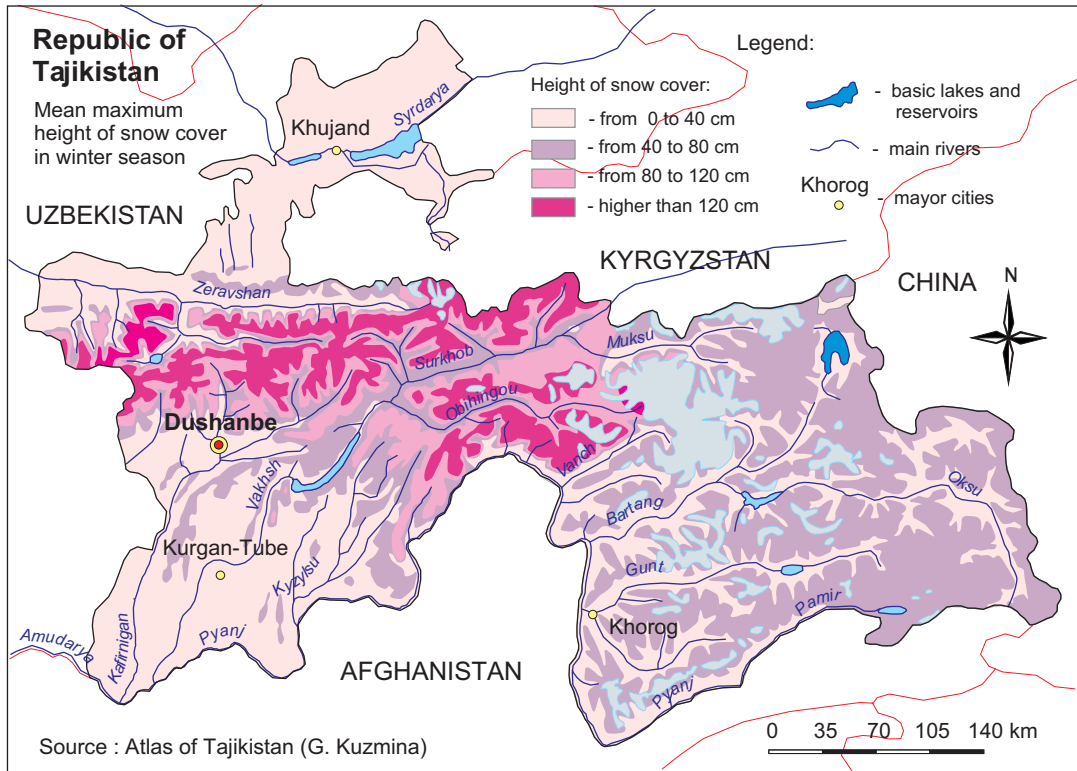


Fig. 3.12.

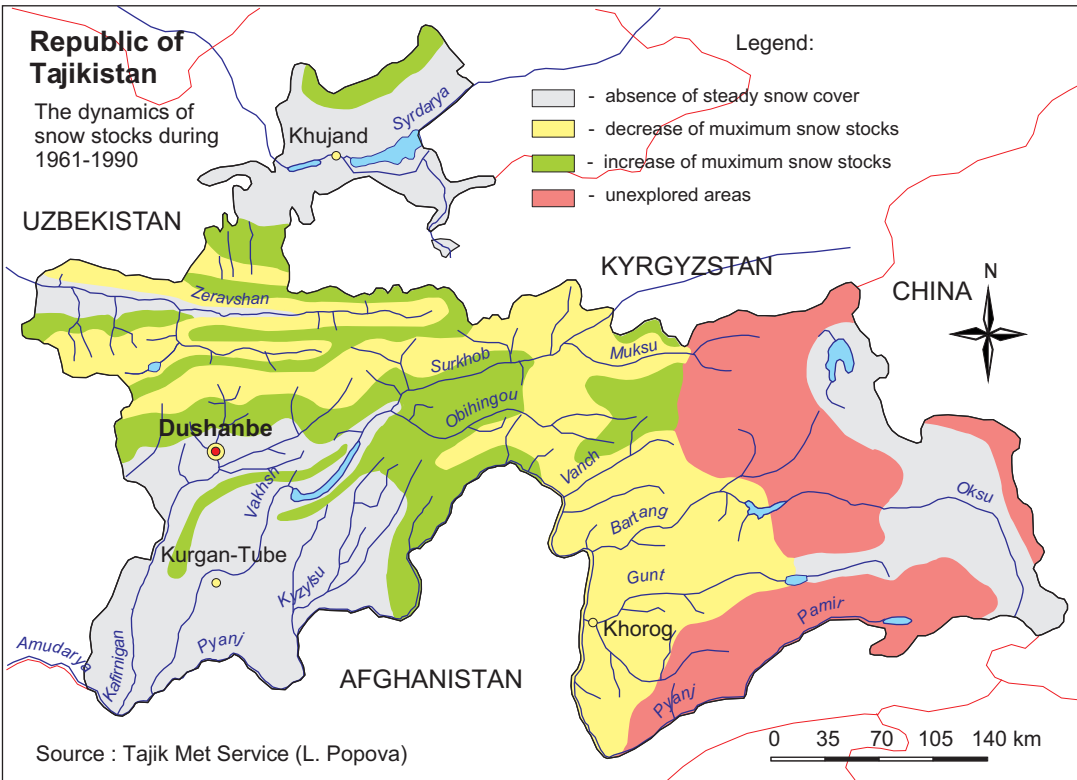


Fig. 3.13.

but in view of climate aridity and small amount of precipitation, the snow cover is less permanent and is quickly blown away. The average number of days with steady snow cover in this zone considerably decreases eastwards from 245 days in Gissarrange to 45 in Eastern Pamir.

In the zone above 4,000 masl, occupying around 10% of the territory of the republic, maximum snow stocks begin in the middle of May, and steady snow cover persists perpetually. Glaciers and permanent snowfields cover most of this high-altitude zone.

It has been observed that each type of winter in Tajikistan, in terms of snowfall, corresponds to certain characteristics of atmospheric processes. So, winters with less snow are characterized by the prevalence of anticyclone circulation near the ground. In winters with medium snowfalls, there is an alternation of anticyclone circulation and southern cyclones accompanied by cold intrusions with insufficiently humid air masses. In winters with high snowfalls, the cyclone activity with frequent humid cold intrusions prevails. The number of winters with small snow stocks exceeds by 1.5-2 times the number of winters with high snow stocks.

Winters with the highest rates of snowfalls were reported in 1949-1950 and 1964-1965, when snow stock exceeded long-term averages in 1.5-2 times over 50% of the territory. The winter in 1969 manifested particularly high rates of snowfalls, when throughout the territory of the republic the rates were 2-2.5 times above normal. The winters with low rates of snowfall were in 1955-1963. Beginning from 1964 to 1984, there has been an alternation between winters in terms of snowfall rates. For the period of 1985 to 1990, at elevations of 3,000 masl, snow stocks decreased.

The analysis of changes in water contents in the snow throughout instrumental observation, and separately for the period of 1961-1990s, shows an average increase of 35% in foothills and medium-height mountainous areas of the republic with altitudes of up to 2,000 masl (fig. 3.13). On the contrary, in the zone from 2,000 to 3,500 masl, an overall reduction in maximum snow stock of 35% on average has been observed.

However, the tendency of declining snow stocks in the zone above 2,000 masl is not uniform everywhere. The increase in snow stocks has been observed in mountainous areas of the Khatlon Region (Sanglok, 2,230 masl) and on Fedchenko Glacier (4,169 masl). It is necessary to note that on Fedchenko and in Sanglok since the 1960s, the snow stocks have been in decline.

3.6. Extreme weather events

The study of processes resulting from climate change is based not only on the analysis of air temperature, precipitation and snow cover, but also on extreme weather events (high and low temperatures, sandstorms, heavy snowfall and rainfall, floods, mudflows, avalanches, hailstone falls).

High temperatures. The zone of an adverse thermal regime (equal to and higher than 40°C) covers the entire plain areas of the republic. On the basis of the analysis of observational data, an upward trend of 30% in the number of days with temperature above 40°C has been identified in almost all the plains of the republic. In 1984, a period of 48 days with temperatures above 40°C (fig. 3.14) was observed in Shaartuz. The least number of days with temperatures above 40°C was observed in 1972.

Low temperatures. Daily mean temperatures of air equal and below -10°C are also considered dangerous weather events. The least average number of days in one year with low temperatures is observed in the territory's plains (0.2-0.8 days), although in some years this number increases up to 5-15 days. The greatest reoccurrence of low temperatures is observed in mountainous areas, especially in low depressions, mountain passes, and tops of high mountain ranges. In foothill areas, the average number of days with low temperature changes from 6 to 16 days, and in some years, between 25 and 80 days. In general, the number of days within one year with a daily average temperature below -10°C shows a downward trend by 30-50 % (fig. 3.15).

Heavy snowfall and rainfall. Intense precipitation is one of the most dangerous hydrometeorological events in terms of its consequences. The average number of days with intense precipitation in the republic is insignificant and varies from 0.1 to 6 days per year. In some areas, intense precipitation does not occur at all. In some years, for example in 1969, the number of semidiurnal intense precipitation exceeded the average value by 3.5-5.5 times. The maximum number of days with intense precipitation is accounted for mainly in spring months and in summer months in high-altitude areas. During 1961-1990, the number of days with intense hard precipitation tended to reduce. The change in the number of days with intense liquid precipitation is ambiguous. For example, in the Kulyab valley the number of days with intense liquid precipitation increased by 1.5 times. In the area of Dushanbe city, a downward trend of 1.5-2 times was observed.

Hail. Hailstones frequently cause damage to agriculture. The centre of most hail events is located along the Gissar range, primarily in the foothills. The number of days with hail grows as the altitude increases. At the same time, the maximum reoccurrence of hail ranges from 0.7-1 days in lowland areas to 4-8 days in high altitudes. Gissar valley is known for its large frequency of hail events, where the number of days with hailstone averages to 1.9-3.5 days per year. In 1961-1990, the number of days with hailstone in lowland and foothill areas decreased by 60-80%. In mountainous areas, the occurrence of hail has not changed, and in some areas has increased.

Floods. One of the consequences of heavy rainfall is high flood waters, which are observed frequently in the foothills and mountainous areas of Tajikistan at the altitudes of up to 2,000 masl. In high-altitude areas, floods can result from a break-through in temporary lakes. As a rule, high floodwaters are of a short-term nature, but cause huge damage to settlements and the national economy. During the period under research, the highest number of disastrous floods was observed in 1969, 1970, 1985 and 1988. The southeast slopes of Gissar range, northern slopes of Turkestan range and southern slopes of Kuramin range are the areas with greatest flood activity, particularly in the basins of Yakhsu, Varzob, Vakhsh, and Obihingou rivers. As a whole, during 1961-1990, an increase of 50-60% in the number of days with disastrous floods was observed. Between 1991-2000, several disastrous floods were experienced in the republic in 1993 and 1998, which destroyed many sites (Ragun hydropower station dam under construction, roads, houses in Khatlon and Sogd regions) and huge damage was caused.

Avalanches. Basic conditions for the formation of avalanches are slopes with a gradient of $30-50^{\circ}$, snow cover more than 30 cm, and relevant meteorological conditions. In Tajikistan's conditions, the major reason of avalanches is fresh snow formation (60-70%). The biggest recurrence of avalanches has been reported on the slopes with a northern exposition. Most avalanches are observed in February and March. The biggest number of days with avalanches was indicated in 1978, when mass avalanches occurred in all highland areas. It caused traffic jams; many communication and power supply systems were damaged. In 1969, extraordinary avalanche activities were indicated in the Western

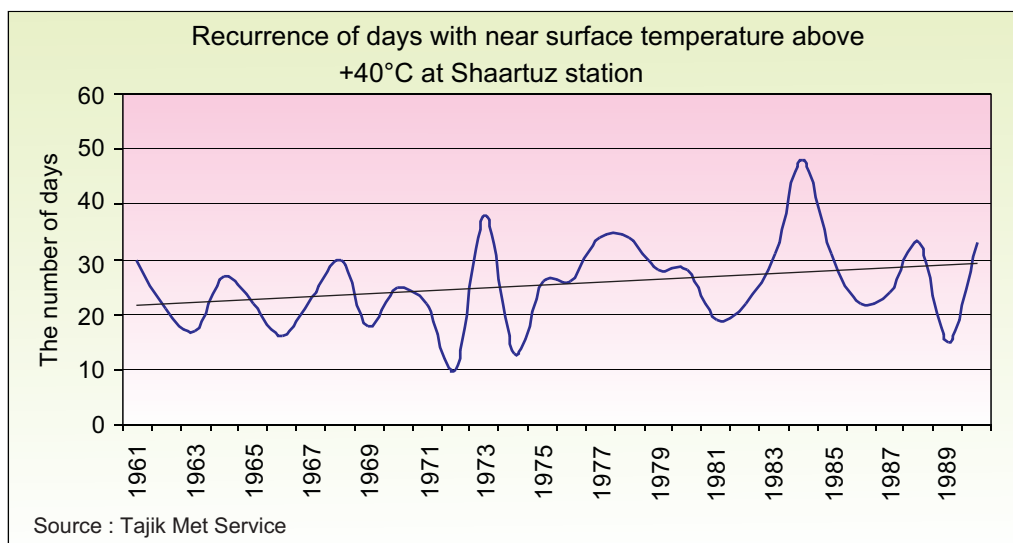


Fig. 3.14.

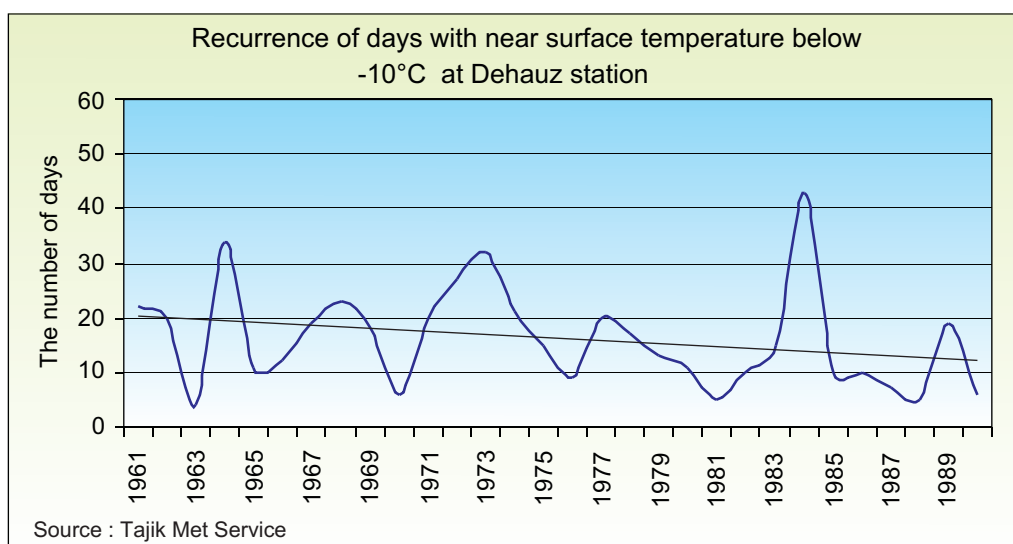


Fig. 3.15.

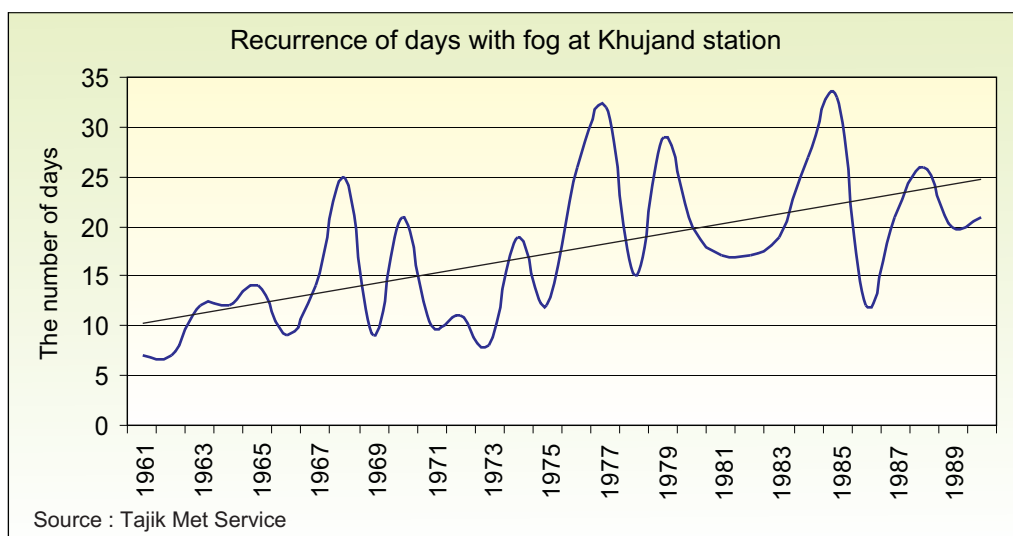


Fig. 3.16.

Pamir. The number of days with avalanches exceeding twice the average was indicated in 1976, 1984 and 1987. In the period of 1961-1990, there was a trend towards an increase of days with avalanches by 50-70%.

Fogs, lasting for more than 24 hours, with a visibility of 50 meters and less, are considered especially dangerous. However, it is a rare phenomenon in Tajikistan. Fogs start in November, reach their peak in December-January, and end in March. The exception is highland areas in the zones of cloud formation, where fogs are permanent. In most areas, total duration of fog does not exceed 50-70 hours a year. On the mountain passes, duration of fogs increases to 1,200 hours a year. Normally, fogs continue for 3-5 hours. In the period of 1961-1990, the number of days with fog increased by 20-50%. In the area of Khujand city, the number of days with fog increased by 80% (fig. 3.16).

Sandstorms are divided into local and frontal types. In the first case, these phenomena cover small areas with dry sandy soils and moderate winds. Such phenomena are frequent in the south of the country. Frontal sandstorms that accompany cold-wave intrusions, rush upwards along the valleys of Kafirnigan and Vakhsh. At the same time a strong wind (18-20 m/sec) along with sandstorm blow for several hours. The biggest number of days with sandstorms is observed in the south of the country and reaches 14 days a year. In the period of 1961-1990, there is a trend towards a reduction in the number of days with sandstorms by 1.5-2 times. However, in the late 1990s, the number of days with sandstorms has increased.

3.7. Climate change scenarios

Several leading global climate models such as: HadCM2, CCCM, GISS, GFD3, UK89 were used to study the possible scenarios of climatic changes in Tajikistan. Modeling was based on the climate data of 1961-1990 received from 10 representative meteorological stations of Tajikistan. The accuracy of reproducing real climate in the models was checked by comparing the results of projections based on the current concentration of CO₂ with real climate data.

All the models tended to underestimate temperature values when compared to the real climate. The model HadCM2 was the most consistent for temperature analysis, except for Khorog area. The reproduction errors by HadCM2 range from 1 to 5°C. Errors in climate reproduction by other models for plain areas reaches significant values. The GISS model can be applied in the transition zone from valleys to mountains as it underestimates the temperature in warm periods and overestimates it in cold periods. Other models underestimate temperature by 8-10°C. For high-altitude areas (above 2,500 m), the models closest to real temperatures are UK-89 and HadCM2. For other climate models the deviation of temperature from real climate ranges from -7°C to +16°C.

All models essentially underestimate precipitation when compared with the actual climate. In lowlands, HadCM2 is appropriate to some extent. In the area of Kurgan-Tube this model is acceptable in the cold period of the year, and in the warm period the models GFD3 and CCCM approach real values. In the area of Kulyab, UK-89 provides a satisfactory description of precipitation. For the mountain areas of Central Tajikistan, good results are also given by UK-89. For the arid zone along the Turkestan range, HadCM2 provide the closest data. The areas of Western Pamir are described by near actual values using GFD3 and HadCM2. The models CCCM and HadCM2 are more acceptable for the areas of Eastern Pamir, showing insignificant deviations for July-September.

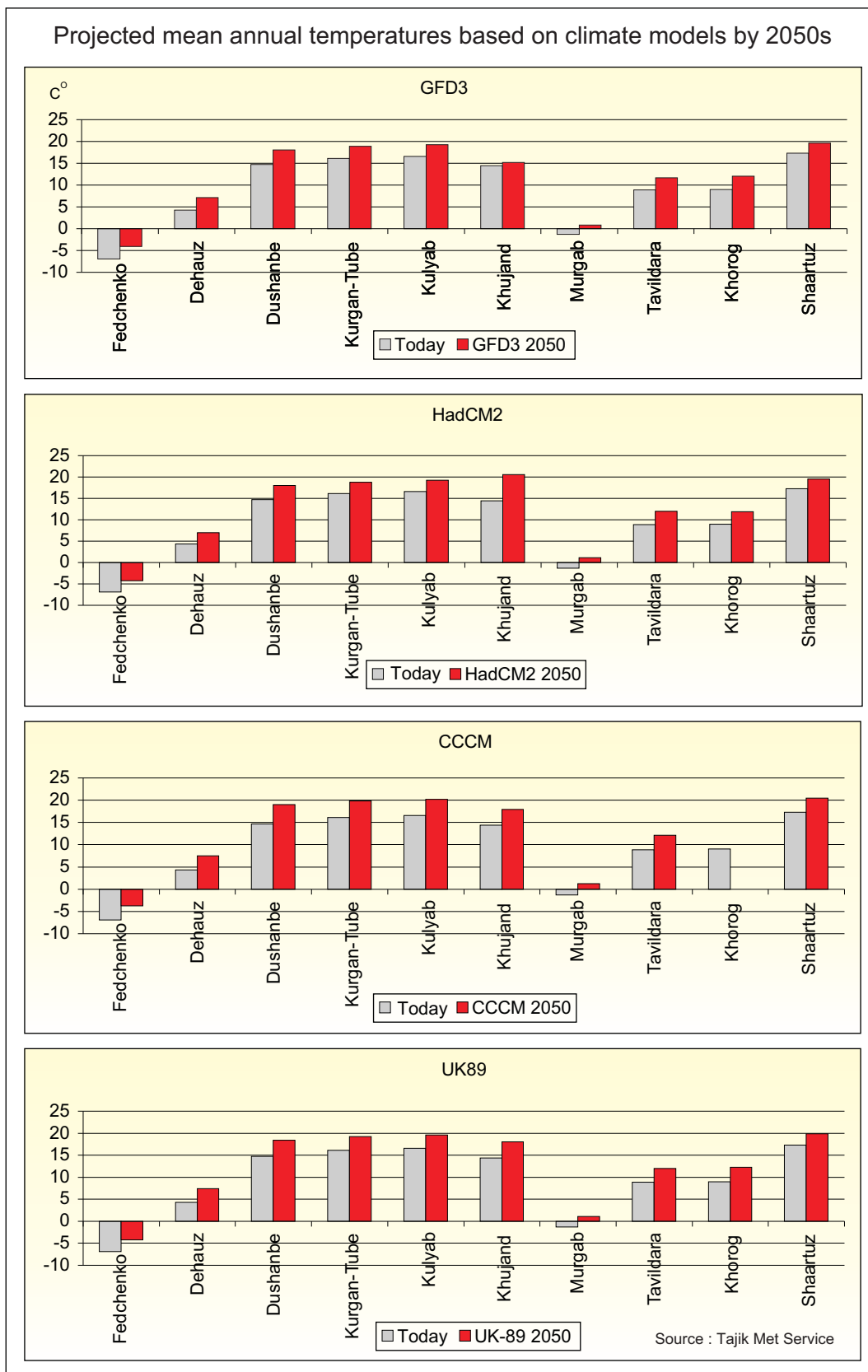


Fig. 3.17.

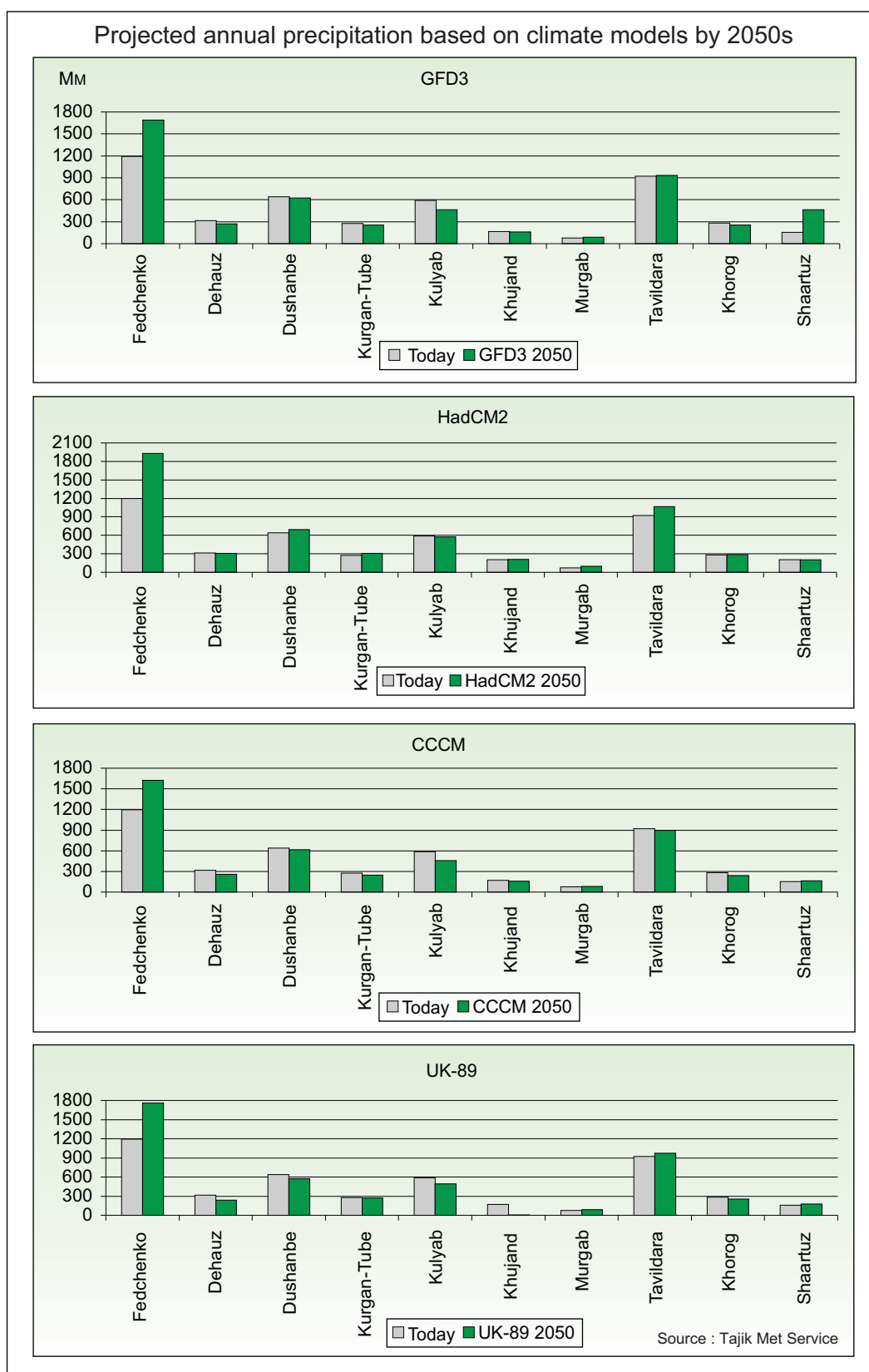


Fig. 3.18.

On the basis of the models selected, climate change projections were prepared for the period until 2050s, when $2\times\text{CO}_2$ is expected. The modeling of mean annual temperature scenarios in Tajikistan shows that the interval of expected changes ranges between 1.8-2.9°C. Mean monthly temperature change varies considerably within the models. Thus, according to CCCM the greatest increase in temperature is expected in February-March at the stations of Dushanbe, Kurgan-Tube, Kulyab and Shaartuz, which will reach 4.7-4.9°C. At the same time, HadCM2 shows minimum increase and in summer period - maximum increase of 1.9-2.3°C (fig. 3.17).

According to the models, the change and variability in precipitation for the period until 2050s are even greater than the changes in air temperature. According to UK-89 and HadCM2 models, an increase of 3-26% is expected in most of the regions of the republic is projected. Based on CCCM and GFD3, a decline of precipitation by 3-5% and more is expected (fig. 3.18). There is also significant difference in the seasonal precipitation projections. According to HadCM2, a maximum increase in precipitation of 41-69% is expected in July. Based on CCCM, at the same period the biggest reduction in precipitation of 16-21% is expected.