

An aerial photograph of a vast, rugged mountain range. The foreground and middle ground are dominated by a large, light-colored glacier system with numerous crevasses and rocky outcrops. The background shows sharp, snow-capped peaks under a clear blue sky with a few wispy clouds.

**Kayumov A.**

**GLACIERS  
RESOURCES  
OF TAJIKISTAN  
IN CONDITION  
OF THE  
CLIMATE  
CHANGE**

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## INTRODUCTION

Tajikistan is situated in the mountainous part of Central Asia, between the latitudes 36°40'N-41°05'N and longitudes 67°31'E-75°14'E. The area of Tajikistan is 143.1 thousand sq. km, stretching for 700 km from the west to the east and for 350 km from the north to the south. In the north and west, Tajikistan borders with Uzbekistan and Kyrgyzstan, in the south it borders with Afghanistan and in the east - with China. The perimeter borders of the country extend to 3,000 km.

Due to specific orography and climatic conditions, Tajikistan is considered the main glacial centre of Central Asia. Glaciers are the wealth of Tajikistan, they are not only retaining water, but also regulating river flows and climate. Glaciers and permafrost are the main source of water replenishing the Aral Sea river basins. Every year the melting of snow and glaciers contribute several cub.km of fresh water to the main river basins of the country. Glaciers occupy more than 8.4 thousand sq.km, which is about 6% of the total country area. The bulk of ice cover is observed in the Pamir mountains (Fig. 1).

The largest valley glacier of the region is the Fedchenko Glacier. Its length exceeds 70 km, width - 2 km, and maximum ice thickness - 1 km. The volume of glacier itself with tributaries is 140 cub.km. It originates on 6200 masl with its terminus stretching for 2910 masl. It is estimated that Tajikistan enumerates with 8 thousand of glaciers with 7 out of them having the length of 20 km.

Rivers of Tajikistan are the main sources of water replenishing the Aral Sea. They provide neighboring areas with water for irrigation and power generation.

There are several largest river basins in the republic: Syrdarya (Northern Tajikistan), Zeravshan (Central Tajikistan), Pyandj (South-Western Tajikistan and Pamir), closed basin of the lakes of the Eastern Pamir. The largest rivers are Pyanj, Vakhsh, Syrdarya, Zeravshan, Kafirnigan, Bartang. Most of the rivers in Tajikistan are of mountainous origin.

There are 947 rivers in Tajikistan with the length more 10 km. Total river length is 28,500 km. The annual surface runoff reaches 30-45 l/sec/sq.km in highlands, whilst in lowland deserts and high mountain regions it amounts to 1 l/sec/sq.km. The annual river flow is about 53 cub.km. Most of the water resources are formed in the basins of Pyandj and Vakhsh rivers. During flood season, when snow melts intensively and heavy rainfall occurs (April-August), the rivers carry a lot of suspended solids, which can exceed 5kg/cub.m (Amudarya and Kysylsu river).

The amplitude of water fluctuation during the year in most of the rivers is not very high and varies between 0.6-2.0 m. The level of water can

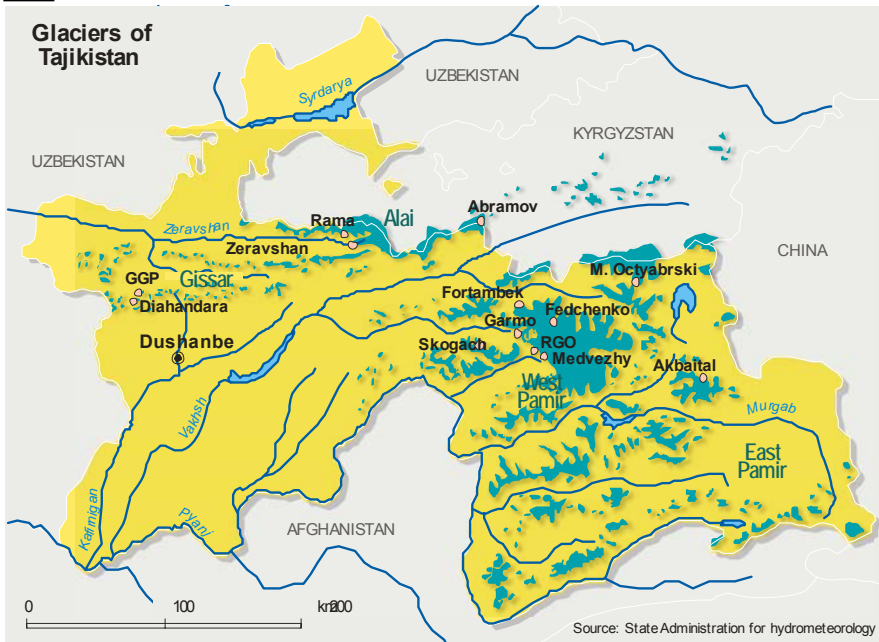


Fig. 1

significantly rise during floods in the Vakhsh, Pyanj and Obihingou rivers. Water level in flood season on the rivers Vakhsh, Pyanj and Obihingou can raise significantly.

The last decade appeared to be the warmest for the last 150 years at the global scale, and surface air temperature of our planet increased almost by 1°C. According to evaluations made by the Intergovernmental Panel on Climate Change (IPCC), such change in climate occurred and might even intensify, mostly due to anthropogenic activities. There are a number of records that during last fifty years an anthropogenic impact on climate considerably increased, largely due to emissions of greenhouse gases (GHG) into atmosphere and deforestation. During the period of 1970-2004 global emissions of greenhouse gases increased by 70%, and concentration of CO<sub>2</sub>, a major greenhouse gas, increased up to 380 ppm (in 19 century this number constituted 280 ppm). Ongoing increase of GHG emissions contributes into global warming.

Climate change has a considerable impact on the number of territories of our planet, i.e. the Arctic, the Antarctic and Central Asia. According to the data of satellite measurements, ice cover in the Antarctic Ocean has been constantly decreasing, and reached its minimum in 2005-2007. The similar trend is observed in other seas, situated closer to Tajikistan, within

the Central Asian region. The decrease in freezing period and total reduction of winter ice cover is observed in the north of the Caspian Sea during the last decade. Within the Aral Sea basin the local impact on microclimate is observed due to considerable drying of the sea, and global warming impact.

The trend towards increase of temperature is explicit in the neighboring Central Asian countries, e.g. in Uzbekistan and Kazakhstan.

The glaciers in the Central Asian mountains and in other regions of the world considerably reduced and are melting (Fig. II). As a result there is a risk that climate change might induce shortage of water (Fig. III), adversely impact ecosystems, food security and health.

The interrelation of disaster frequency and scale with climate change trends was stressed at the Dushanbe International Water Forum in June 2008. Indeed more and more large-scale sudden floods, mud flows, droughts, pest outbreaks, fires, etc. are associated with the climate change impacts.

At the global level there are research programmes, political and technical interventions on climate change mitigation established and operational, however it is far from sufficient. All nations around the world and all people should come together to save the planet. Within the context of international negotiations in Poznan and Copenhagen Tajikistan is committed to contribute to the achievement of the UNFCCC goals and

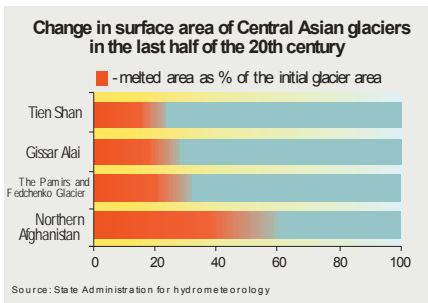


Fig. II

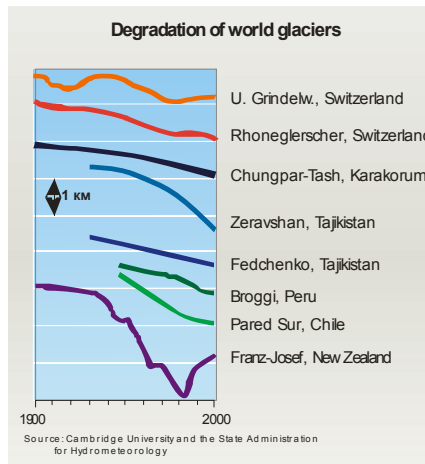


Fig. III

## **1. Climate change indicators and trends in the Republic of Tajikistan**

Results of the research show that the ground air temperature in the most districts and high altitude zones of Tajikistan is increasing, however, the change in atmospheric precipitations is uneven due to geographic and climatic diversity of the territory of the country. Analysis of the changes of mountain snow reserves reveals various trends depending on the altitude of the snow bedding.

Data from 30 stations for the period 1940-2005 and period of observation were used in studying the dynamics of ground air temperature and precipitation. The stations were selected according to orographic and climatic district groups, as well as according to altitude zones (submountain districts until 1000 masl, mountain districts from 1000 to 2500 m, high altitude areas above 2500 m). To assess changes in snow stock, the data from 15 stations was analyzed.

Glaciers may also serve as characteristic indicators for inter-annual weather variability in the mountains and long-term climatic changes. The trends and state of glaciations in Tajikistan with relation to the climate change are explored in detail in following chapters.

### **1.1. Changes in surface air temperature**

The increase of air temperature in the plain regions of Tajikistan constituted, on the average, 0.1-0.2°C in a decade. The biggest increase for 65 year period is noted in Dangara (1.2°C) and Dushanbe (1.0°C), for the rest of the territory it constitutes 0.5-0.8°C, in Khujand it is 0.3 °C (Fig. 1). Insignificant increase of temperature in Khujand is most probably related to the development of irrigation and building of the Kayrakkum water reservoir, which rendered cooling effect. The increase of annual mean temperature in the mountainous areas constituted 0,3-0,5°C in 60 year period, except separate isolated canyons where the trends are less notable or negative. The biggest increase of annual mean temperature in the mountainous zone (1.0°-1.2°C) was observed in Khovaling, Faizabad and Ishkashim. In altitudinal zones (more than 2500 masl) the increase of temperature on average constituted 0.2-0.4°C and up to 0.6°C in Djavshangoz. The fall of temperature (-1.1°C) during this period is noted in the kettle of Bulunkul Lake which could be related to the characteristic features of climate in the Eastern Pamir.

Analysis of surface air temperature changes per each month reveals a trend to warming during the cold season of the year, especially in November-December, reaching 1-3°C. The trend to temperature fall was observed at all high altitudes in February, March, May, June and October.

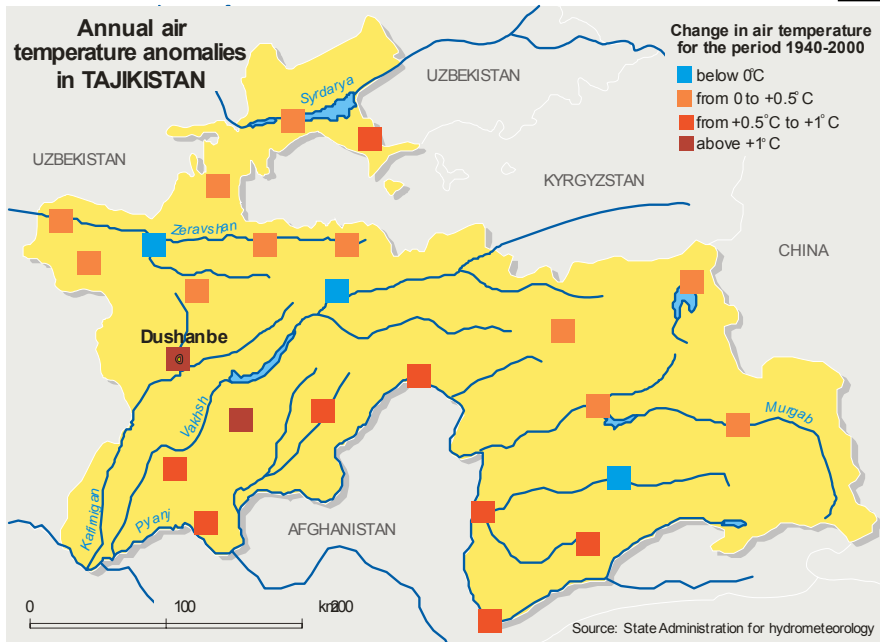
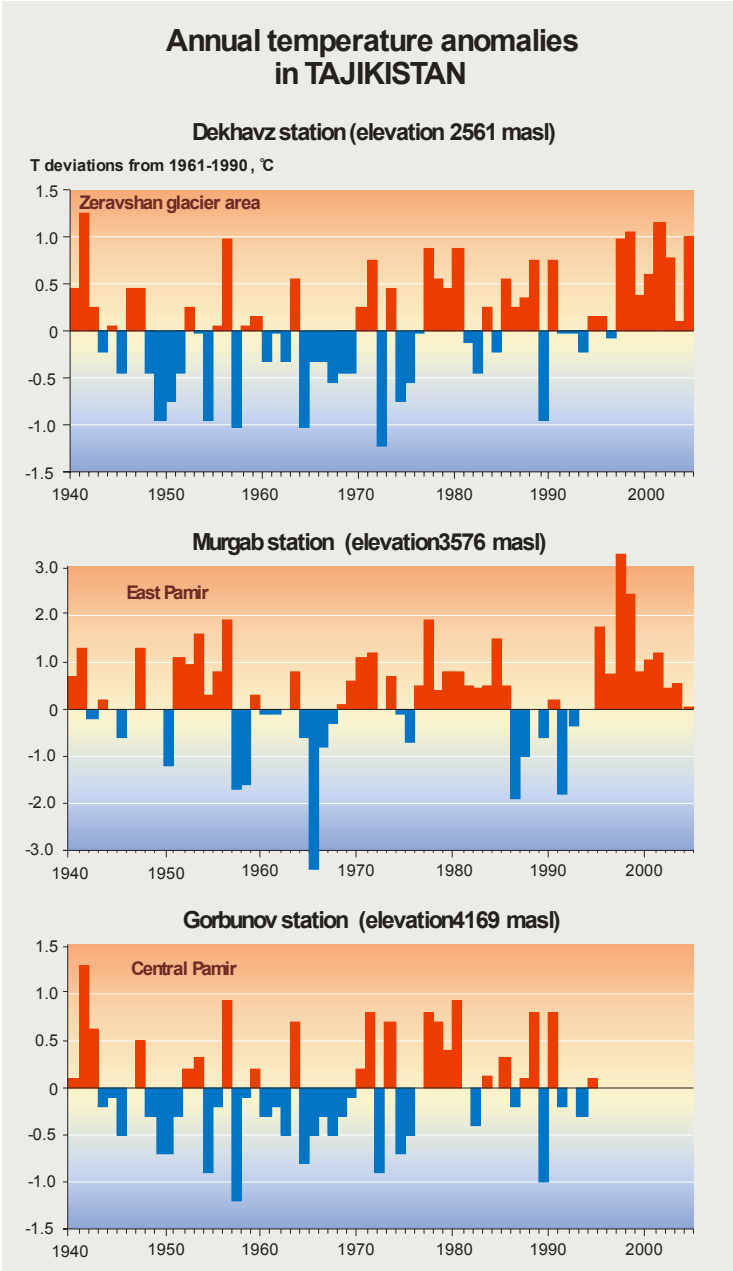


Fig. 1

In springs in some sub-mountainous and mountainous areas trend to cold spells prevails (0.1-0.2°C).

The analysis of changes of the extreme air temperatures indicated the dynamics of increase of the maximum annual and seasonal temperatures. The mean maximum temperature increased by 0.5-1.0°C. The minimum mean temperatures also increased, especially in autumn, by 0.5-2.0 °C with some exceptions in high-mountain regions (-0.1°C). In the number of areas the minimum mean temperatures decreased. Generally, the dynamics of increase of the minimum mean temperature advances the dynamics of increase of the maximum mean temperature almost everywhere (Fig. 2).

With warming of climate the duration of frost-free period increased. The stable transition above and below 0° is noted earlier in spring and later in autumn. In different areas the duration of frost-free period increased by 5-10 days. Thus, for instance, in the upper reaches of Zerafshan river (Dekhavz station) the period with temperature above 0° earlier in 1941-1960s was observed starting from the 23rd of March to the 15th of October; currently it covers the period of the 20th of March to the 20th of October.



Source: State Administration for hydrometeorology

Fig. 2



## 1.2. Changes in atmospheric precipitation patterns

The amount of atmospheric precipitations is mostly determined by the global atmospheric circulation and hydrological cycle, as well as orographic features of the area. The considerable fluctuations in time and space were detected while analyzing the changes of annual amount of precipitation; and a number of very dry and very humid periods were defined.

During the period studied the driest decade for all altitudinal zones was from 1941 to 1950. The periods of dry weather alternated with the period of humid weather up to 1990, with a trend to the increase of the amount of precipitations. After 1990 the rainiest period was in 1998-1999; and the following period of 2000-2001 was the driest one, the drought spread almost on the whole territory of the country. The irregularity and intensity of precipitations increased and this trend is expected to continue in the future. Such trend is also supported by the numerical models. Not only the amount and intensity of precipitations, but also the number of days with precipitations changed (Fig. 3).

The analysis of the annual precipitation patterns displays an insignificant increase of the annual amount (by 8% on average) on the territory up to 2500 m and insignificant reduction (by -3%) in the mountainous areas. The most considerable increase in the annual amount of precipitations occurs in summer and autumn in the area up to 2500 m (by 37-90%), mainly caused by the increase in precipitation intensity. The increase in the number of days with precipitations from 0 to 5 mm during the period under observation is registered in the Tajik part of the Fergana Valley (Khujand, by 42 days), which might be due to the impact of the Kairakkum water reservoir (moisture condensation). In general, the number of days with precipitations has decreased in the country (particularly in Iskandarkul, by 48 days).

Taking into account the mountainous relief of the territory of Tajikistan, distribution of precipitations and their long-term changes vary. Thus, the amount of precipitations in the Eastern Pamir (mountainous plateau with elevation of 4,000-6,000 masl.) reduced by 5-10%, and in Murghab by 44% (Fig. 4). The similar trend of the reduction of precipitations occurs in the southern lowland areas of the republic (Kurghan-Tyube, Shaartuz).

In the Central Tajikistan (Fedchenko, Kalaikhumb, Rasht, Faizabad, Khushyori) the precipitations increased by 5-10%. The increase of precipitation by 20% is observed in the submountain areas of the southern Tajikistan (Dangara, Kulyab). In the mountains of the northern Tajikistan (Madrushkat, Shahristan) the amount of precipitation increased by 5-30%, with exception of high mountains. In Tajik part of Ferghana valley (Istaravshan, Khujand, Isfara) there is a slight increase in precipitations,

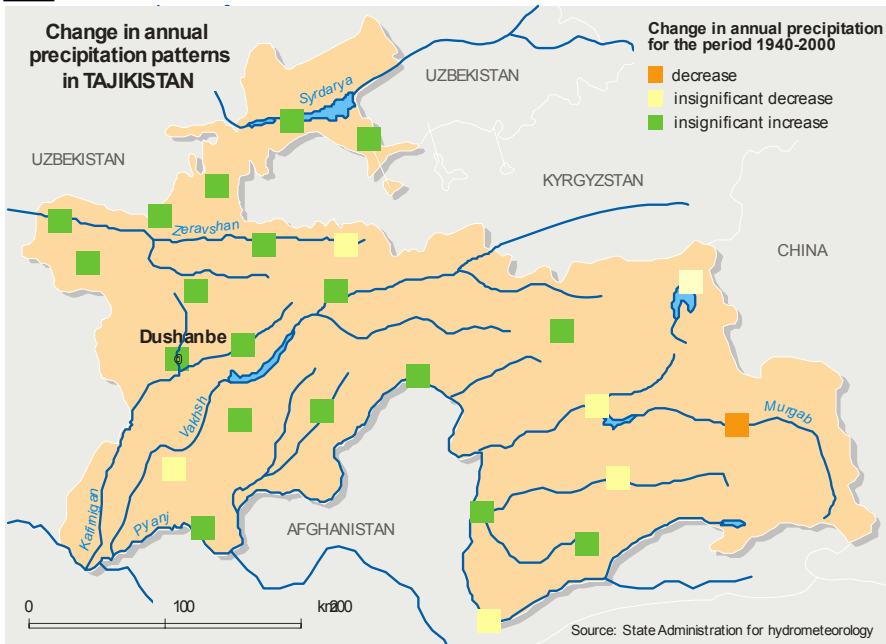


Fig. 3

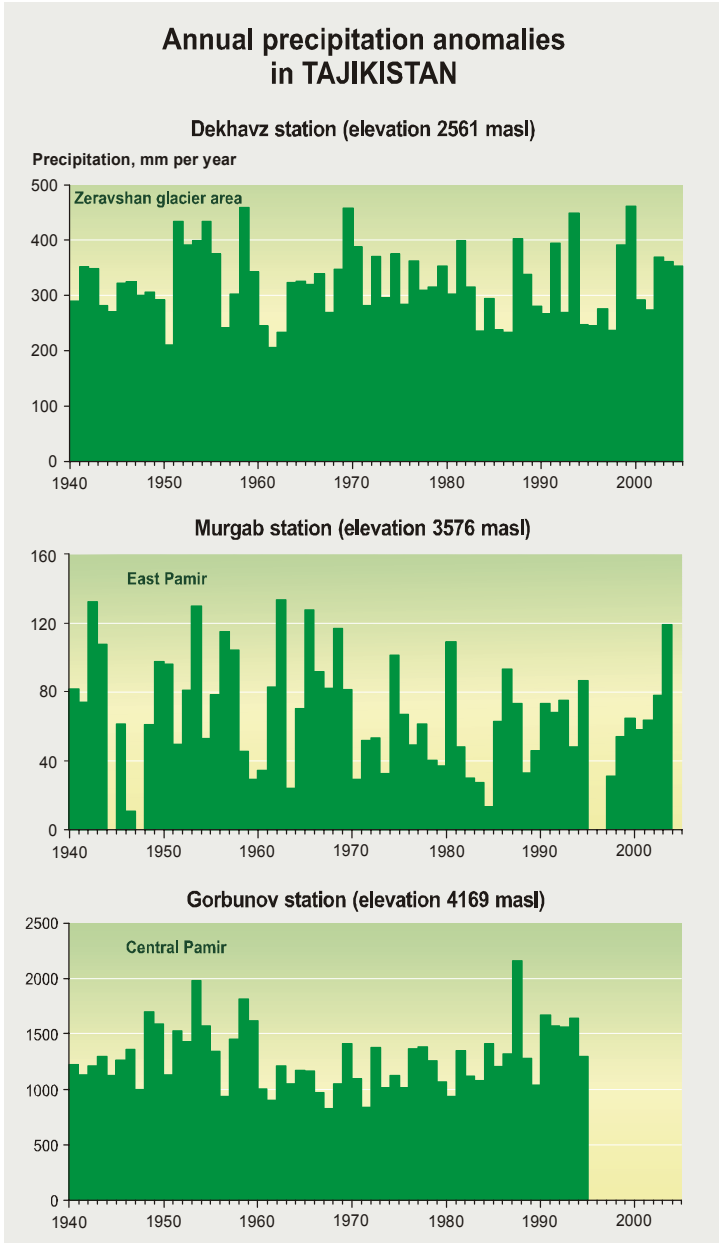
on average by 5-10%. The considerable increase, as well as the reduction of atmospheric precipitations by 30-45% is observed in the isolated mountainous areas (mountainous passes, blind canyons), where the impact of local microclimate is significant.

Extensive increase in temperature with fragmented increase and reduction of precipitations contributes to aridity of climate in many areas covered by mountainous forests and under agricultural cultivation.

### 1.3. Dynamics of snow stock

The snow stock in the conditions of mountains in Tajikistan plays a crucial role in water levels of rivers and hydrological cycle. One of the characteristics of the snow cover are reserves of water in the depth of this cover, as the snow cover, together with intensiveness of melting of snows determines the flow of water in the rivers, size of snowmelt flood and reserves of moist in the soils.

During the cold period the solid precipitations form 35-60% of their total amount in plain areas of the country; in the foothills and mountainous areas solid precipitations constitute 45-80% of their total amount, and in high mountains reaches up to 100%. There is no stable snow cover in



Source: State Administration for hydrometeorology

Fig. 4

high-mountainous zone up to 1000 m, it snows occasionally and snow melts quickly. In high-mountainous zone of 1000-2000 m the snow cover lies, mainly, from December to the middle of March (85-100 days in average). In the zone of 2000-3000 m the snow cover lies from the end of November-beginning of December till the end of March-beginning of April; the number of days with snow cover is 100-135. In the high-mountainous zone of 3000-4000 m the stable snow cover is not formed everywhere. In the Eastern Pamir it can snow in any season, but due to arid climate and small amount of precipitation the snow cover in this area melts quickly. The average number of days with snow cover in this zone decreases, as one goes to the East: from 245 days in the Gissar mountain range to 45 days in the Eastern Pamir. The zone higher than 4000 m is a zone of permanent snow and ice.

The snow stock varies greatly from year to year and it also depends on the elevation of area. The continuous period with little snow was observed in 1970-1984 (in some regions until 1900) in the high-mountainous part of river basins, while in the foothill areas, on the contrary, this period was characterized by big snow stocks. It is explained by frequent occurrence of the south-west cold air intrusions, which causes an excess amount of precipitation in the foothill areas. The winter of 2007-2008 was characterized by prevailing low surface air temperature and slow speed of seasonal warming, while general reserves of snow stock by the beginning of vegetation period constituted 60-80% for the main river basins. This situation directly affected the water availability in the rivers and subsequently, sectors of the economy (irrigation and hydropower industry).

#### **1.4. Extreme weather events and their variability**

Climate change considerably impacts not only basic climatic characteristics (temperature, precipitations, snow cover), but intensity extreme weather events as well (extreme temperatures, fogs, dust storms, haze, strong winds, heavy precipitations, thunderstorms, hail, mud flows, avalanching).

**Extremely-high temperatures.** With increase of maximum temperatures the number of days with temperature equal to +40°C or over increases (Fig. 5). The highest temperatures for the studied period were observed in the southern Tajikistan in 1944 and in 1997, when the daytime temperature was +45-47°C. The number of days with temperature equal to 40°C or over increased in the most flat areas of the country, with exception of those territories where development of land and construction of reservoirs took place.

**Dust storms and haze.** Dust storms are distributed unevenly on the

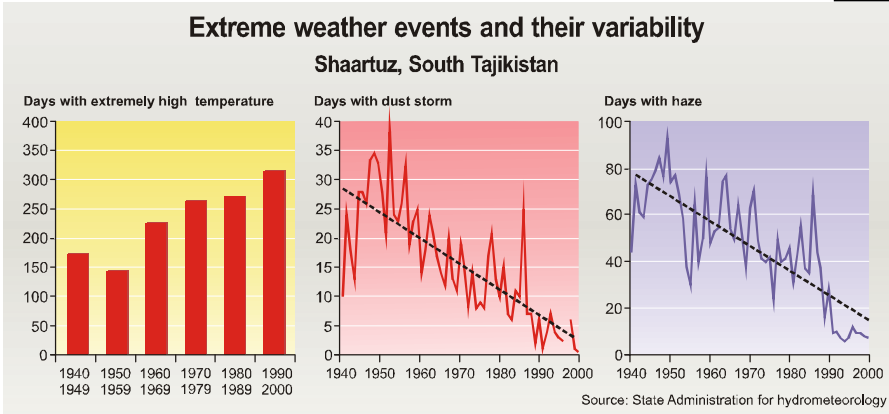


Fig. 5

territory of Tajikistan and mainly are observed in the southern deserts and semi-deserts (especially in Shartuz). Haze is most frequently observed in dry summer-autumn period. The maximum number of days with haze occurred in 1971; in Dushanbe it constituted 80 days, in Kurgan-Tyube - 94 days. In November 2007, drastic dust storm covered the southern and central parts of the country until the elevation of 3 km with the visibility rate 50-100 m. During the days with intensive dust storm precipitation of dust particles amounted to 100 thou tons per day. For the last 15 years the number of days with dust storms and haze reduced 2 times against the preceding period. This is likely caused on the one hand, by intensive development and irrigation of land prone to the dust storm formation, and on the other hand, by the reduction of the north-west fronts.

**Avalanches.** Avalanches are common phenomena in the high mountains of Tajikistan. Fearing the danger of avalanching, the traffic is stopped every winter on Dushanbe-Khujand highway, which is considered to be the most important one, as well as on the other roads. The avalanching took a toll of 46 lives during 2003-2006 (mostly local inhabitants and passengers). A number of avalanches were observed in winter of 2007-2008, when snow piles blocked the motorway connecting the central and northern Tajikistan, damaged the infrastructure and resulted in numerous fatalities. According to the expert evaluations, increase or reduction of the danger of avalanching is connected to the increase or decrease of atmospheric temperature and the amount of solid precipitation in the zone of 1500 masl. and more.

**Heavy rainfalls.** The number of days with precipitations of 5 mm and more increased in the most areas, especially in the central mountainous zones. The number of days with heavy precipitations (30 mm per day) increased in the foothill areas and Gissar valley. It should be noted that, along

with increase of rainy days (Fig. 6), the number of snowy days reduced.

**Thunderstorms.** The biggest number of days with thunder was observed in the Central (Dushanbe, 43 days in 1954) and Southern (Kurgan-Tyube, 24 days in 1963) Tajikistan. However for the last 15-25 years the number of thunderstorms considerably decreased (Fig. 6). As far as in the central and southern Tajikistan thunderclouds are often formed prior the intrusions of cold arctic air fronts, reduction of days with thunder indicates the decrease of cold winds. In the Pamir highlands thunders are very rare.

**Hails.** During the period of 1941-1970 hails rather often occurred on the whole territory of Tajikistan (Fig. 6). Hails, as large as walnuts, were observed in May 1966 in Gissar Valley, Darvaz and Karategin. Many cotton fields, agricultural crops were damaged, animals and birds died as a result of hail. Starting from 1970 the number of days with hail decreased. If during the period of 1941-1970 the average number of days with hail in Gissar Valley was 24, in 1971-1990 hailing frequency decreased almost two times and constituted 14 days. The occurrence of hails reduced even more in 1990-2005 due to the drought of 2000-2001. In general, reduction of the number of days with hailing observed is due to the decrease of cold air intrusion stimulating hail formation and hailfalls.

**Strong wind.** The densely populated territories of Tajikistan are generally characterized by mild winds; strong winds are often observed only in the bottlenecks of valleys (Khudjand). Winds at a speed 20 m/s are annually observed in the Northern Tajikistan and Eastern Pamir, southern regions of the republic (Shartuz, Nizhni Pyandj) and mountainous passes. In the Central Tajikistan such winds are observed in Faizabad. Winds at a speed 30 m/s are observed only on Anzob pass. The analysis on frequency of days with strong wind and meteorological practice show that the number of days with the

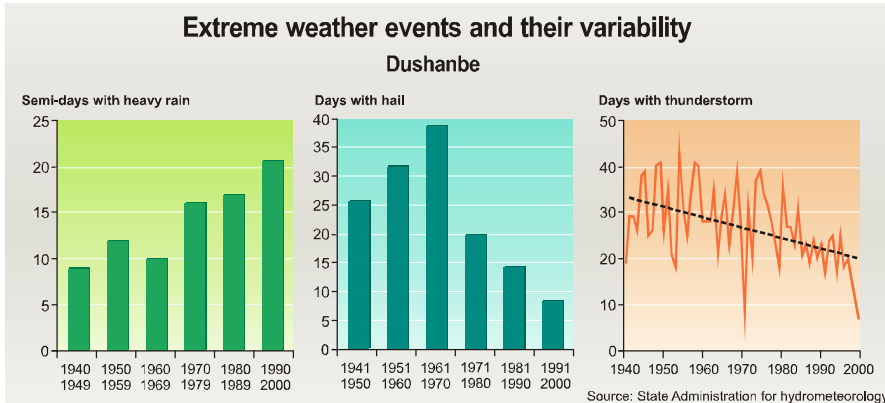


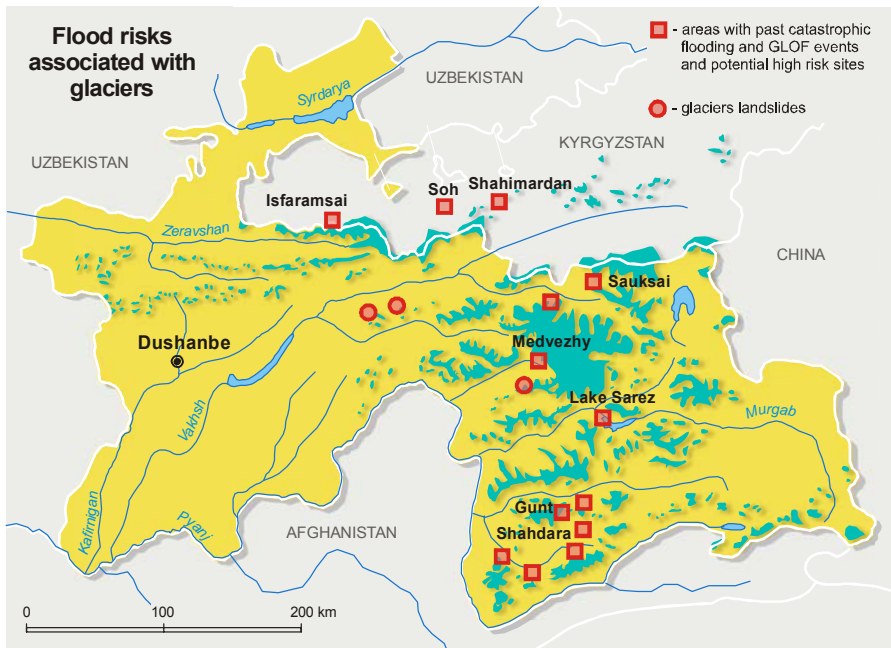
Fig. 6

western wind reduces (along with the decrease of days with dust storm), and the number days with winds of the eastern direction (east, north-east) increases.

The reduction of the number of the western and south-west winds is related to the reduction of active cold-wave intrusions. The increase of the eastern, south-east winds indicate that the number of cases with intrusion of tropical air into Tajikistan increases.

**Fogs.** Fogs are rare phenomena in Tajikistan. For the last 10-15 years there is a trend in the increase of the number of foggy days in the Tajik part of the Fergana Valley (Khujand). This is probably due to the influence of regional circular processes in the atmosphere providing for advection of warmth over radiative-chilled air.

**Mud flows and glacial lakes outburst.** According to observation data, the period of 1998-1999, along with the year 1969, was the rainiest one. The amount of mud flows occurring as a result of heavy precipitations significantly increased. The mud flows of spring 1998 destroyed 7 thousand houses and took lives of more than 130 people. There were almost no mudflows in the arid period of 2000-2001. Floods which occurred in Zerafshan river basin in 2002, 2003 and 2005 washed away houses, infrastructure, and caused human fatalities. Due to the



Source: State Administration for hydrometeorology

Fig. 7

increasing rate of summer temperatures in the mountains, there is a risk of mud flows of glacial origin because of fast melting of snow (Fig. 7). In 2001 another motion of Medvezhiy glacier was observed. It occurred without creating a glacial lake, which in the past had caused dramatic floods alongside the Vanj river. In 2007 RGO glacier considerably retreated which might have resulted in blocking the Vanj river and creation of a glacial lake. The breakthrough of the glacial lake and mud flood in Roshtkala district of Pamir in 2005 resulted in 25 human fatalities and damage to property.

### 1.5. Dynamics of aridity and droughts

Drought is one of severe meteorological phenomena and in its extreme occurrence it can cause a significant damage to property. According to evaluations the drought of 2000-2001 in Tajikistan was the most devastating natural disaster for the last decade (Fig. 8). In lowland arid regions of the Amudarya river basin (e.g. Karakalpakstan), the access to water reduced by 2 times with many agricultural field crops and households being limited the resources. This caused many catastrophic consequences to the economy and local residents. In light of climate warming, the drought assessment and regular analysis plays a crucial role in long-term prediction of the drought years and ecological cooperation. At present the greater part of the territory of Tajikistan is included into arid and scantily moistened zone. Only separate mountainous areas are situated in the moistened climate zone. Particularly arid territories of the country are the Eastern Pamir, lowland areas of Sogd Oblast and southern Tajikistan (there annual amount of precipitation is less than 100-150 mm). In summer arid conditions are

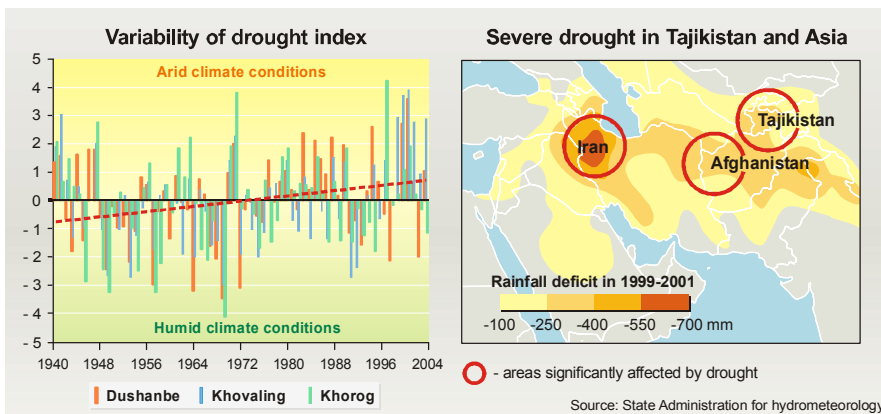


Fig. 8



predominant almost on the whole territory of the republic.

As a rule, absolute droughts are observed as separate hotbeds, and severe ones embrace big territories. During the period studied (60 years) in eight cases the droughts simultaneously covered the whole territory of the country (in 1940, 1947, 1956, 1971, 1980, 1988, 2000 and 2001). Especially severe droughts were in 1971, 2000 and 2001. In 2007 the summer and autumn period witnessed extreme lack of atmospheric precipitation, which caused soil drought. The southern regions of the country and Gissar valley, where the greatest number of years (15-19) with average and severe droughts are observed, particularly suffer from droughts. Therefore, it is prognosticated that droughts in Tajikistan will occur more intensively and frequently in future.

### **1.6. Climate change forecasts**

The previous models of the global climate change (IPCC 2001) to some extent underestimated the prognosis of the temperature increase for the perspective of 50-100 years. The most recent assessments of IPCC (2007) show that increasing global emissions of GHG will facilitate the increase of temperature for 2-6°C depending on intensiveness of emissions and geographical position of regions. Even if GHG emissions stabilized at the year 1990 level, increase of global temperature by 0.6-1°C will be unavoidable. It is considered that increase of temperature beyond 2°C will be having mainly adverse consequences for the environment and ecosystems, economy and public health.

Within the framework of the First National Communication the scenarios were elaborated on the basis of HadCM2, CCCM, GISS, GFD3 and UK- 89 global models using the reference period of 1961-1990, by 10 representative stations situated in different climatic zones and altitudinal belts of Tajikistan. Further the justification analysis of the data received with actual values for the period of 1991-2005 was carried out.

The comparative analysis of actual mean temperature for 15 years period of with model data shows that all models give conservative values. There are significant differences in precipitation forecast between actual and model parameters. The same model can reasonably prognosticate the temperature and, at the same time, give considerable inaccuracy in precipitation forecast for the same station. The key drawback of global models is their incapacity to take into consideration the local mountainous peculiarities of climate formation predominant in Tajikistan.

In order to give a more accurate evaluation of climate change trends untill 2030, with the use of modern computational modeling facilities the model ECHAM4/OPYC3 (Potsdam Institute for climate impact research, Germany) was applied. This model takes into account the response of

regional climate to global warming and the impact of two factors: fluctuations of global climatic parameters (turbulence, wind speed, temperature, atmospheric humidity, etc.) and geographical peculiarities (topography, area elevation above sea level, etc.)

According to the model ECHAM4/OPYC3 statistical estimations, the increase of mean annual temperature by 0.2-0.4°C (0.1-0.2°C in decade) is expected in most areas of Tajikistan by 2030 in comparison with the period 1961-1990,; this trend coincides with tendencies predominant in the country for the last 15-20 years. The maximum increase of temperature is expected in winter: by 2°C and higher. In some areas the reduction in precipitation can be observed (Eastern Pamir, south lowlands), whereas in others (Western Pamir) one can witness just the contrary. The different distribution of precipitation of such kind is related to

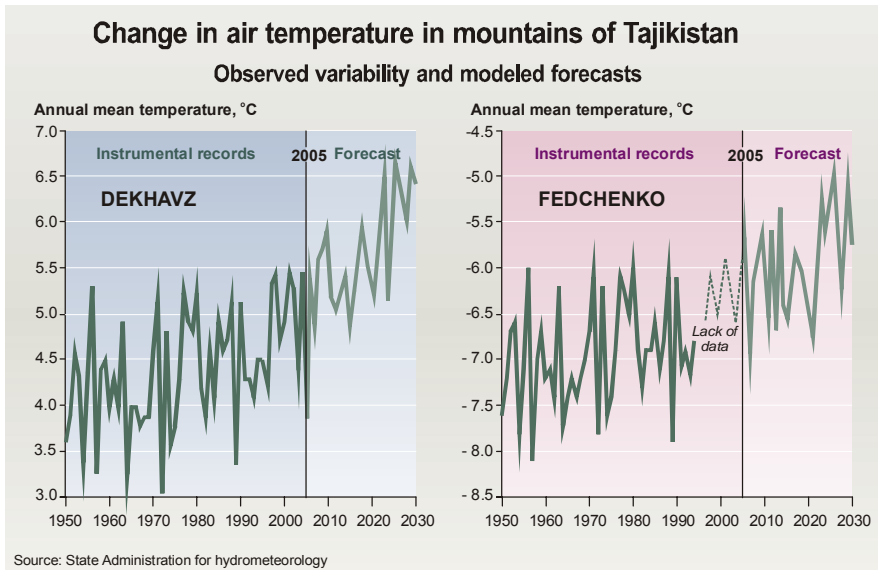


Fig. 9

the significant spatial fluctuation of atmospheric precipitation and impact of topography which intensifies it and causes more uncertainty in forecasting of precipitations expected on the territory of the republic in the long-term prospect (Fig. 9).

## 2. Impact of climate change on natural resources

### 2.1. Glaciers

Glaciers of Tajikistan occupy about 6% of the territory of the country and play an important role in forming Amudarya River, the biggest water “artery” of the Central Asia and Aral Sea Basin (Fig. 10). In the region, which is characterized by arid climatic conditions, continuous impacts of climate change may trigger the glacial volumes and water flow and availability, which plays a vital role in the water supply for the downstream regions and countries. Annually melting of the glaciers in Tajikistan brings 10-20% of water into the flow of the large rivers; during dry and hot years this number can reach 70%. Water has a crucial importance for agriculture, hydropower engineering and other economic sectors of Tajikistan. Moreover, water resources formed in Tajikistan are utilized mainly by the countries situated downstream. Therefore issues concerning the state of glaciers and water level in the rivers, and climate change impact on them, are of importance for the whole Central Asian region.

The warming rates in the high altitude areas of Tajikistan, particularly Pamir, Zeravshan and Pamir-Alai correspond to the regional and global trends and cause significant changes of glaciers, one of the most vulnerable ecosystems. The impact assessment showed that during the whole period of instrumental observations (since 1930s), the glaciations area of Tajikistan decreased by around 1/3 (Fig. 11)

**Northwest Pamir.** The system of the Fedchenko glacier lost the thinnest and side parts of its tributaries, whereas; the main accumulated

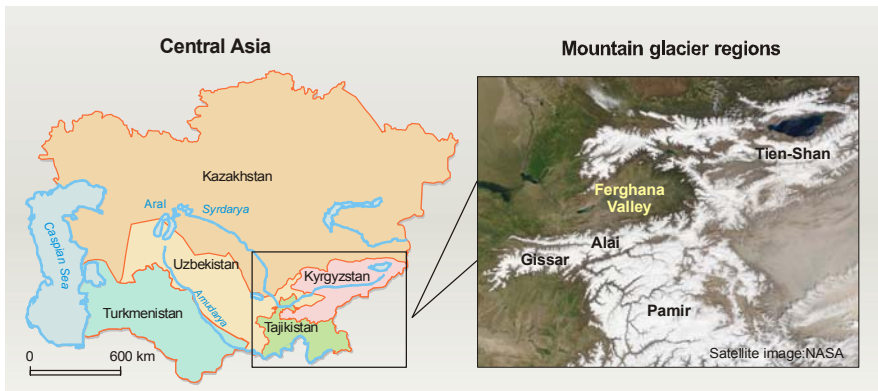


Fig. 10

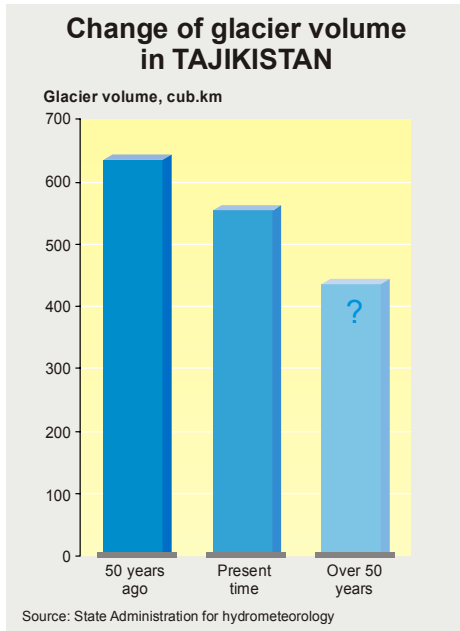


Fig. 11



Fig. 12

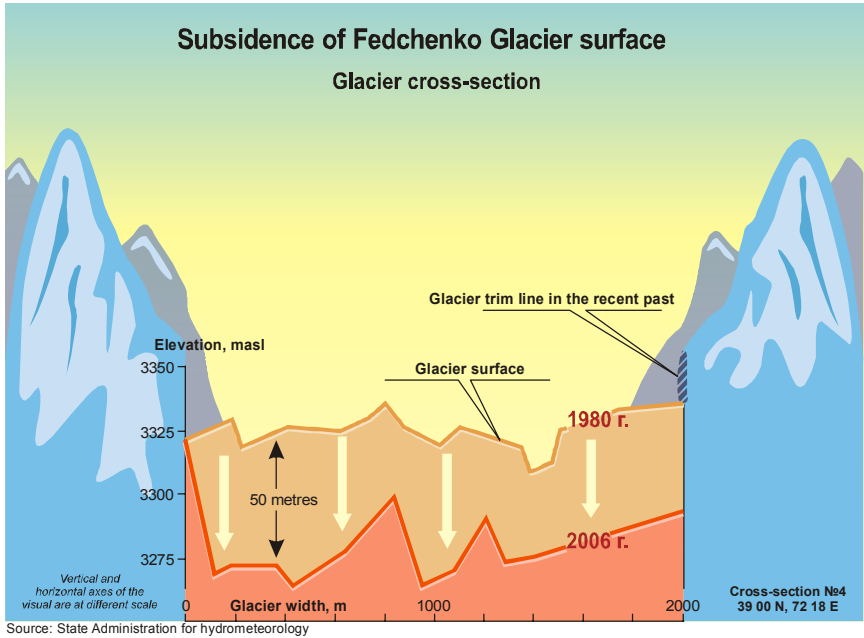


Fig. 13

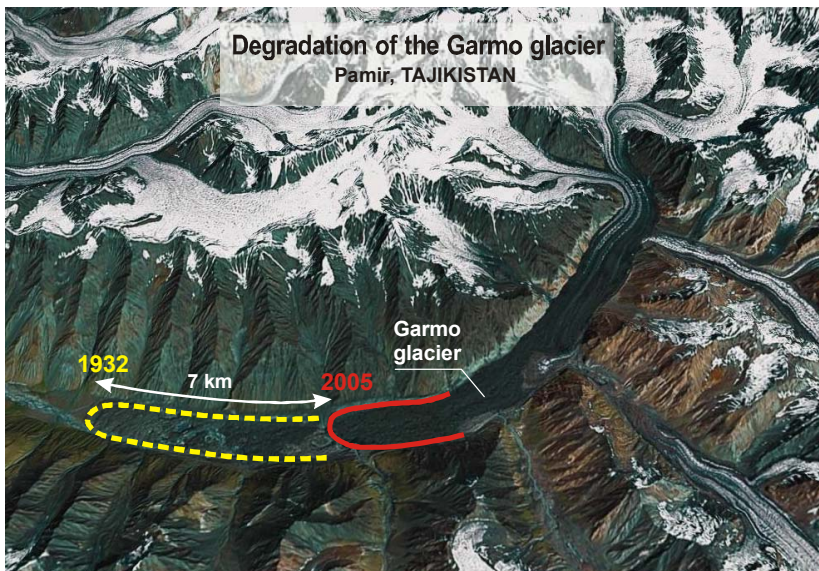
glacial mass decreases much slower (Fig. 12). Remote observations showed that within the period 1966-2000 the system of Fedchenko Glacier reduced for 44 sq.km, i.e. 6% of the total area. Later on, glaciological research of 2006 revealed that the average rate of the retreat comprised 16 m/year (Fig. 13). It is estimated that presently, the surface of the glacier in the bottom part sank for 50 meters in comparison with 1980, i.e. the glacier “growing thin”. Moreover, the terminus of the glacier retreated for 1 km since 1933. The degradation of other glaciers: Fortambek, Sugran, Mushketov also took place in the Muksu river basin; as well as glaciers in upper reaches of Sauksay and Balyandkiik. In 20th century Bolshoi Saukdara glacier where Sauksay originates from, retreated for 2 km. Almost all other glaciers in Sauksay upper reaches are of surging type that's why it is difficult to consider their degradation.

**Western Pamir.** During the last 50 years the glaciations area in the basin of Vandj river reduced by more than 25-30%. During glaciological observations in 2005 it became evident that Medvezhiy, surging glacier, retreated from Abdukagor river by 70-80 meters; its surface sank greatly, and large gaps appeared around its two protrudent ice cliffs meaning that more ice melts than comes in from the top accumulation zone of the glacier, i.e. meaning that the glacier “reduced”.

**Eastern Pamir.** In view of more severe and cold climate the glaciations degradation in the Eastern Pamir takes place less intensively than in all other mountainous areas of the country. According to the observations of 2005 Akbaital glacier tongue located not far from Akbaital pass retreated for 15 m. since 1986, and its right edge retreated for 40 meters. Average intensity of retreat constitutes, as before, 1-2 m. per year. The five small glaciers within the area of the Lake Sarez are by now completely disappeared. During the second half of the last century all glaciers of the Murghab river basin depleted by 30-40%.

**Obihingou river basin.** For the last years the Garmo glacier dramatically sank and is morained with continuum retreat , and breakage into pieces and blocks. From 1932 (when the first mapping data of the glacier occurred) to 2007 it retreated for 7 km long, which is the most significant retreat among the largest glaciers of Central Asia (retreat speed:100 m. per year). The evidence of Garmo retreat, which has been observed in the beginning of the 20th century, is shown on the Fig. 14. The Skogach glacier is significantly degrading in the bottom part, however no changes are observed in its upper reaches. Batrud glacier situated nearby retreated by approximately 1 km, and the maximum degradation rates for both glaciers were observed last years (Fig. 15).

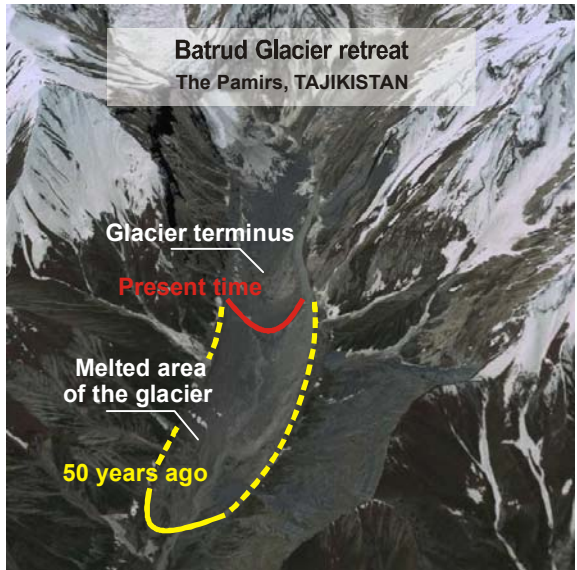
**Left bank of the Pyanj River.** On the left bank of Pyanj glaciers are situated in Afghani Badakhshan (mountain ranges of Safedi-Khirs, Kuhi-



Source: Tajik Agency on Hydrometeorology

Image: Google Earth

Fig. 14



Source: State Administration for hydrometeorology    Satellite image: Google Earth

Fig. 15

Lal, etc.), Gindikush and Vakhan mountain range. Left-bank river inflows constitute up to 15-20% of the annual flow of Pyanj. Afghanistan is situated southward of Tajikistan, therefore, degradation of glaciers in Afghanistan is more intensive. According to evaluations made in 1950s the glaciation area in Afghanistan was 4240 sq. km; by 1985 it reduced for 1000 sq. km and at present glaciations degradation exceed 50%.

**Gissar-Alai.** The Gissar-Alai glaciers vary in degradation depending on the elevation, exposition and relief; but as a whole a trend for area reduction by 1% per year is observed. In summer 2006 the glaciological expedition examined some glaciers of Gissar mountain range. It was



Photo 1. Benchmark on Zeravshan glacier

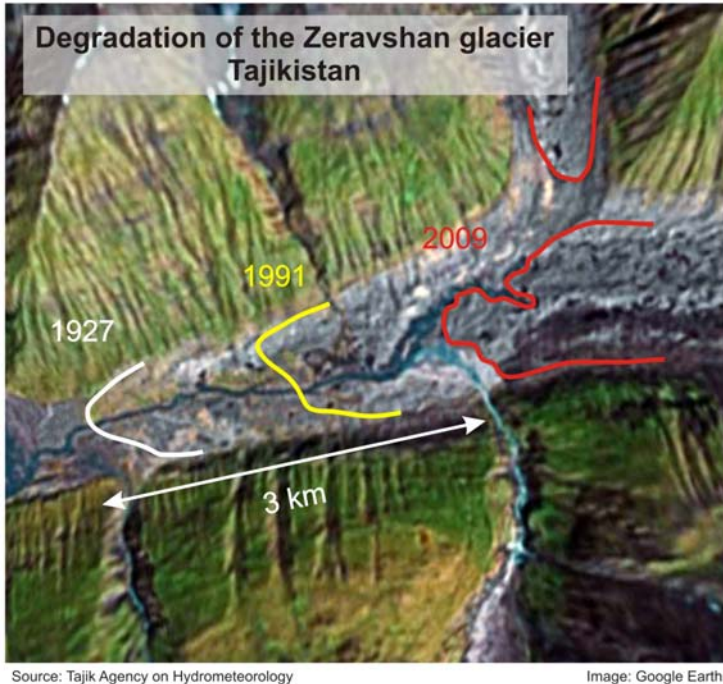


Fig. 16

found out that Yakarcha, a small glacier in Varzob tributaries, almost did not change for the last 18 years, the GGP glacier in Iskanderkul basin retreats by 3 m. per annum, and the Diahandara glacier (1 sq.km) in Karatag upper reaches totally disappeared. But Zeravshan glacier for more than 80 years has retreated on 3 km (Photo 1, Fig. 16). Only traces of moraines and dust are left instead.

If the present rate of the glaciers degradation is retained, one will witness many small glaciers of Tajikistan totally disappeared in 30-40 years. Glaciations degradation can affect mainly river regimes of Zeravshan, Kafirnigan, Karatag, Obihingou. The glacial area can reduce, in comparison with the present, by 15-20%, and water stocks by 80-100 cub.km. But still large glaciers and glacial knots will be retained. It is expected that the glacial inflow to the Pyanj, Vakhsh and generally, Amudarya River will probably increase (due to intensive melting of mountain glaciers), and then, in the long-term perspective, dramatically decrease due to the glacial deficit. Adverse impact of climate change on hydrological regime of the vital rivers of Tajikistan can have serious consequences for the definite ecological communities at local and regional scales.



Due to climate warming the freezing period will reduce in high mountainous lakes: they will freeze over later and melt earlier. Taking into account the degradation of glaciers and decrease of atmospheric precipitation the surface water flow will probably reduce and, accordingly the area of Rangkul, Shorkul, Sasikkul lakes in the Eastern Pamir can reduce as well.

Increasing rates of the glaciers and snow melting in summer is most probably continue, which will cause the risks of the glacial lake outburst in high mountains. As a result they could lead to potential mudflows and floods. Other glacial lakes, due to their natural filtrations and surface evaporation, are far likely cause any significant hazards. However, accumulation of the melting water in the body of glaciers as well as in the bottom side, increases the capacity of their retreat, collapse and degradation.

### 2.2. Water resources

The large river basins of Tajikistan differ by the elevation of water encatchment, degree of glaciations, river inflow conditions (Fig. 17). The rivers of various nutrition types have two periods in their annual flow: spring-summer overflow and autumn-winter low water. Around 60-90% of annual flow runs through during overflow period.

Upon consideration of river flow dynamics by decades the general

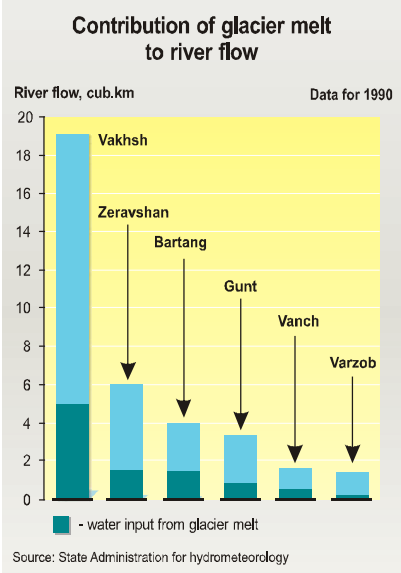


Fig. 17

trend of flow decrease was disclosed in the period of 1971-80 in the rivers of snow-ice nutrition type by 11-14% and in the rivers of snow-rain nutrition type by 8-21%. During the next decade of 1981-90 the flow volume in the rivers of ice-snow nutrition slightly decreased (by 1-10%); the flow volume in the rivers of snow-ice and snow-rain nutrition increased (by 5-25%). The average annual flow volume for the period of 1990-2000 increased in comparison with the previous decade due to increased precipitation (particularly in 1990-93 and 1998-99), air temperature and intensive melting of snow and glacial reserves. The period of 2000-2001 was characterized by the regional drought. The later decades witnessed relatively limited accumulation of snow reserves in high mountains.

Remote observations showed that since 1983 the upper stream of the Amudarya river basin had been witnessing significant decrease in atmospheric precipitation. The periods of 1992-93, 1995, 1998-99 are among a few exception cases. However, independent estimations of the Hydrometeorological services of Tajikistan and Uzbekistan made clear evidence that the increase of water availability in the Amudarya river is unlikely to link climate change processes. On the contrary, it is expected that global warming will facilitate the decrease of the river runoff by 5-15% in the long-term future.

Hydrological observations of the vital rivers of Tajikistan showed that inter-annual fluctuations of the river runoff increased with prevailing dynamics of the surface flow reduction. However, the decrease in regular hydrological observations since 1994 and data gaps for the last years make serious challenges to produce unambiguous research results on the state and rate of the water resources.

The Vakhsh river, where major hydropower plans, reservoirs and irrigation infrastructure are located, witnesses decrease of the of the water flow during the period when lesser amount of snow accumulates on glaciers; alternatively, it increases with increase in snow stock. However melting of glaciers is still more important for the Vakhsh flow than melting of snow (Fig. 18). Water flow in the Varzob river, which is most significant for Dushanbe water supply, is closely linked with snow stocks and precipitation patterns in high mountains.

Analysis of water content in rivers (Dagana station) and climatic fluctuations in the high-mountainous zone of Varzob river basin (Anzob pass station) displayed a trend to river flow reduction as a consequence of decreases in snow stock. This was especially evident in the latest decades (Fig. 19). However, in the last 5 years the water flow in the basin was stabilized, sometimes being even higher. Taking into account that the intensity of rains increased, an opposite trend is observed on Yakhsu river (south stream), which is mainly of snow-rain inflow type and is situated in the south of Tajikistan. On Yakhsu the flow increased predominantly due

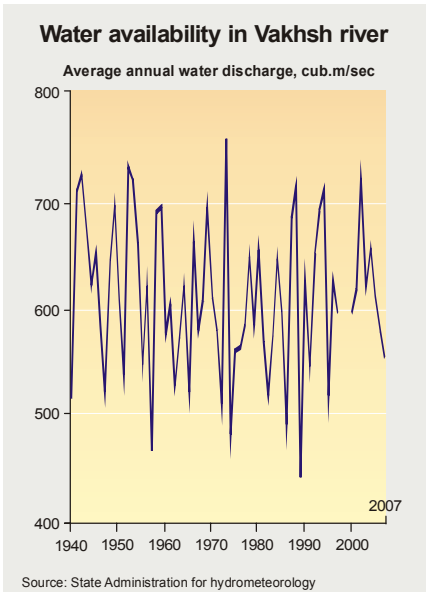


Fig. 18

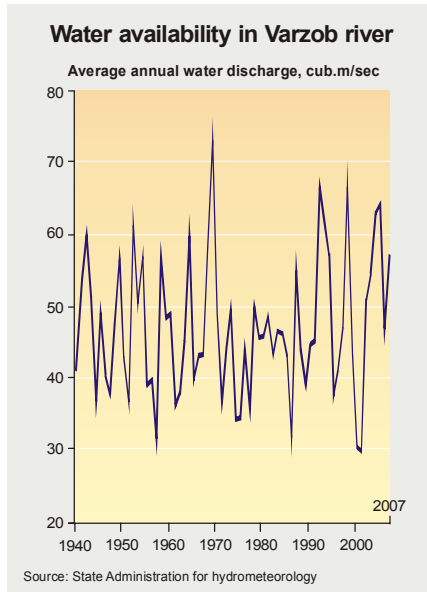


Fig. 19

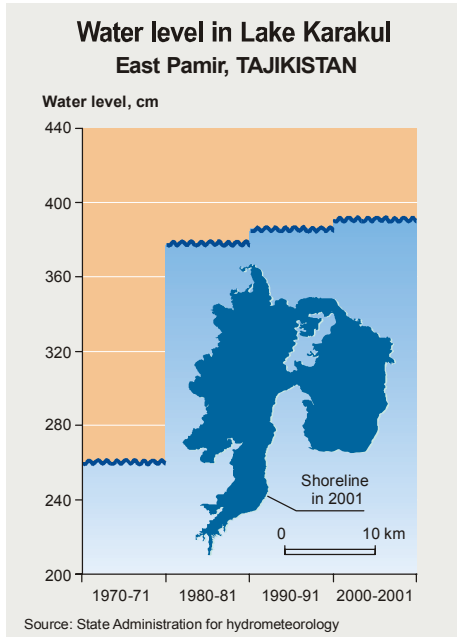


Fig. 20

to intensification of floods in spring. On the contrary, in 2008 the river flow in summer considerably reduced, resulting in water shortages experienced by farming areas in the lower reaches of the river.

Fluctuations of water level in the largest altitudinal closed Lake Karakul in Tajikistan (modern estimations of the area: 400 sq.km) are linked with climate change in the Eastern Pamir (Fig. 20). The increase of water level occurs, though precipitations reduce; such increase of water level takes place with intervals for 120 years already. The increase of water level is the result of water inflow into the lake due to the increase of atmospheric temperature in summer, melting of ice mound in the Valley of Muzkol River and glaciers. As a result of this increase of water level a peninsula in the central part of the lake was separated by a channel and turned into an island. The comparative analysis of bathymetric and cartographic lake survey indicates the increase of water level in the lake by 10 meters starting from 1880 (researches of Shemanovsky and Dankov). Since 1969, when hydrometeorological service started instrumental observations of the lake, up to 1990, the increase of the water level constituted more than 2 meters. The limited observation data for the recent years reveals the highest water level. In 1977 the area of Karakul Lake constituted 379 sq. km, and in 2007-2008 400 sq. km.

The nature and paleoclimatic investigations (samplings of bottom sediments, littoral deposits and adjoining glaciers) to determine the long-term climatic fluctuations were conducted on Karakul lake within the framework of expedition devoted to the International Polar Year in Tajikistan in July 2008.

The reduction of the area and water level is observed on small closed mountainous lakes of the Eastern Pamir: Bulunkul, Shorkul, Rangkul and Tuzkul. This fact is supported by field observation data for high mountainous ecosystems of Pamir as well lake ecosystems. Reduction and drying up of lakes has a significant impact on natural cycles. Thus migrations and breeding colonies of bar-headed geese on above mentioned lakes are observed much rarer in comparison with the past.

The level of the Lake Sarez in the mountains of the Western Pamir, containing 17 cubic km of fresh water and notorious for possible failure of its natural dam, remains stable and relatively increases in spite of the extending filtration from the lake and reduction of precipitation in the upper reaches of the basin (Fig. 21). The threat of the dam failure of the Lake Sarez is posed both by uncontrolled filtration processes and by overflow over the debris crest resulted from possible slope failure and wave formation. The highest water levels in the lake since its formation in 1911 and stabilization in the 1940s were observed in 1994 and 2005. Seemingly, melting of glaciers and increasing surface flow are the significant factors for increase of the water level (Fig. 22). For the last 50

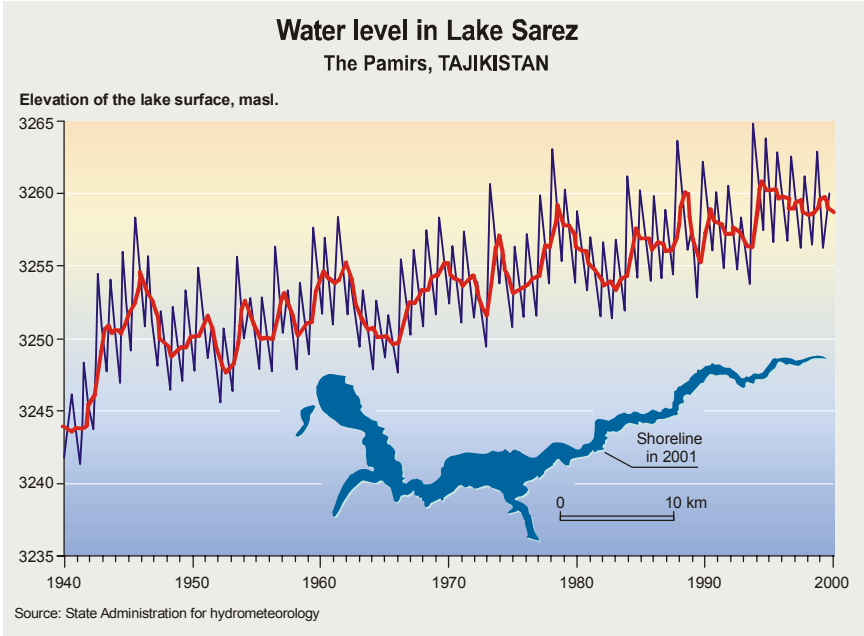


Fig. 21

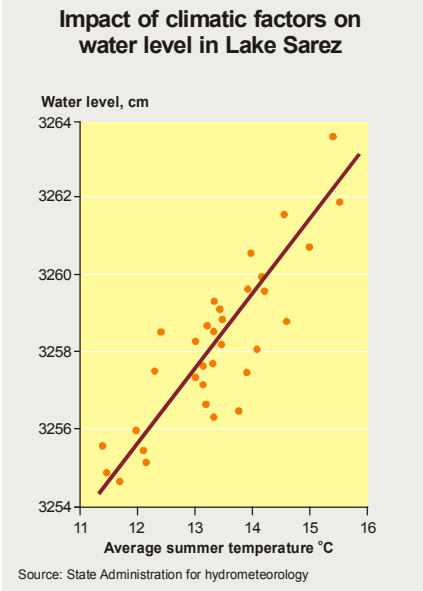


Fig. 22

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