Ice Physics and the Natural Environment

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Climatic Changes in the Mountain Glacier Area of Pamir

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1 Introduction

Atmospheric changes in Central Asia during the 20th century [i, ii] are influenced by the amount of dust storms [iii] and other climatic parameters. The arid zones generate enormous quantities of dust particles which undergo transformation, transport and sedimentation, significantly affecting the climate and other aspects of the natural environment.

The high mountain ranges of Tyang-Syang and Pamiro-alai form an orographic basin open to air flow from the southwest. Mountain ranges rising 5000 to 6000 m above sea level in the eastern and northern parts of Central Asia form a barrier preventing southwestern air masses from penetrating further. These conditions are typical for this area of Tajikistan. Air masses coming into this region are formed over the western part of the continent.

When dust storms develop in the deserts of Middle Asia and break into the mountain country of Pamiro-Alai the dust load in the convective layer of the troposphere increases. Meteorological stations record dust haze during these episodes (Fig. 1).

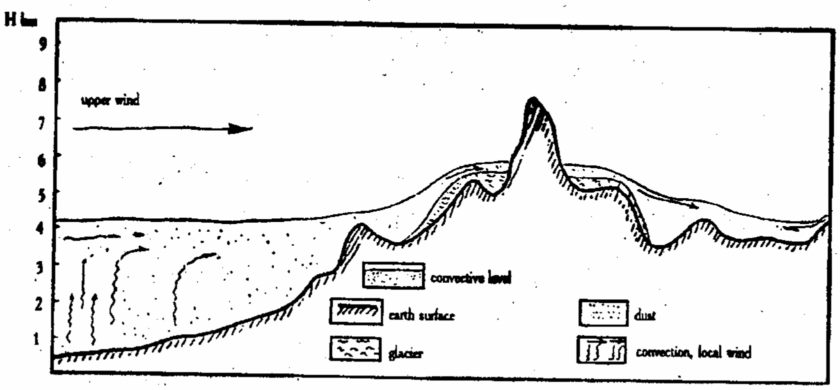

Fig. 1. Transport of aerosol.

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Haze caused by dust storms is often transported over large distances through the lower troposphere. The vertical extent of the haze layer may reach 3 to 4 km. Particle number densities at 1.5 m may reach 8.4 cm^{-3}.[iv] Haze penetrates far to the east along the river valleys, but it is rarely observed in the Pamir Mountains (3–6 days/yr).[v] Annual trends show that the highest number of days with haze occurs during July to October and the lowest during winter. While the average duration of a haze episodes does not exceed 40 hr/yr in the north, that figure increases to 200–400 hr/yr in the Central Valley, and it grows to 500–600 hr/yr in the extreme south. The annual duration of haze in Pamir varies from 4 to 40 hr/yr.

2 Background: Glacial Geography of Pamir

Glaciers and snow cover are a major component of the natural environment of Tajikistan. The general area of glaciation covers more than 8000 km^2, or 6% of Tajikistan. More than 400 km^3 of fresh water are stored in the glaciers, eight times the annual flow of all rivers in Tajikistan. Over 1000 glaciers have an surface area of more than 1.5 km^2 each. Sixteen glaciers are more than 16 km long. Central-Pamir is the largest glaciated region of Tajikistan. The general area of glaciers reaches 2500 km^2, or about one third of the entire glaciation of Tajikistan. Glaciers of the Central-Pamir have different sizes. The longest are Fedchenko and Grumm-Grdgimailo. Another major glacial region is Zeravshan, covering an area more than 556 km^2.

Fedchenko, the longest mountain glacier in the world, is located in the northern part of Pamir and was discovered in 1878 by V.F. Oshanin. The Gorbunov Meteorological station is located in the middle part of the Fedchenko glacier, at a height of 4169 m. The glacier covers an area of 651.7 km^2; the length of the main hanger is 77 km; and the volume of ice in the glacier is 136.5 km^3. Fedchenko glacier is feed by 49 tributary glaciers of various sizes. The region surrounding the Fedchenko glacier contains 100 glaciers, with a general area of 824.1 km^2, and a volume of 144.4 km^3. The highest point of the glacier is 7.0 km, and the lowest is 2.9 km. The average height of the firn line on the main glacier is about 4.7 km. Seismic measurements indicate a thickness of 800–900 m. The flow velocity ranges from 0.6 to 0.9 m/day, with an average speed of 0.73 m/day. The fastest movement was observed in June and July. Movement in the firn zone is slower, 0.6 m/day. In the glacier tongue the speed drops to 0.4 m/day or less.

Mountaineers first visited the remote Pamir firn-glacial plateau in 1957. Glaciological research was conducted in 1976–77 by members of the Institute of Geography of the Academy of Science, USSR. The plateau is located in an interval of heights between 5400–6000 m, covered by snow fields and high-altitude glaciers, reaching a height of 7495 m at Communism Peak. In the central part of the plateau the thickness of firn and ice can reach 300 m[vii]. The discharge of ice from the northern boundary of the plateau occurs by "calving" of ice blocks every 15 to 20 minutes. Blocks as large as 100 tons break off once every 2 to 3 days. The resulting ice avalanches flow downward to the ablation area of Fortambek glacier, where huge avalanche cones form. These avalanches constitute the total loss of ice mass for the plateau.

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The Zeravshan glacier belongs to the largest glaciers of Central Asia. It is not connected to other significant units of glaciation of Pamir-Alay. The system of the Zeravshan glacier consists of 21 glaciers with an area of 132.6 km^2 and an ice volume of about 15 km^3. The area of the main flow is 38.7 km^2; the length is 27.8 km, with an average width of 1.6 km. The average slope of the surface is about 8 degrees. Seismic data from 1962 show an average thickness of ice of 200 m. At an elevation of 2810 m the tongue of the Zeravshan glacier is the lowest in that region. The average height of the firn line is 4000 m. The highest point is Piramidalniy peak with an altitude of 5510 m. [viii]

Regular surveys of the terminus of the Zeravshan glacier, taken by members of hydrographical service of Tajikistan, show that in the last years glacier decay has been rapid. In some years the glacial tongue receded by up to 100 m.

3 Climate Change

In Tajikistan's mountainous region, long-term meteorological data were recorded at stations situated 300 to 4200 m above sea level. From these data we can estimate climatic change in the middle troposphere. About 80 meteorological stations (60–70 years of observations) are situated on the mountain slopes. Kurgan-Tube (426 m above sea level), Dushanbe (803 m above sea level) and the Fedchenko Glacier stations (Gorbunova, 4169 m above sea level) are located in the valleys, which are open to air flow from the west. The Kharamkul station (2800 m above sea level) has its own orographic conditions and is sometimes influenced by northerly air flow. Data from these stations provide long periods of vertical profiles.

4 Air Temperature

An analysis of the annual air temperature data from 1929 to 1993 shows a positive temperature trend at all levels (Fig. 2). The Kurgan-Tube temperature increase is 1.9°C/100 years. At 803 m above sea level the temperature increase is 1.72°C/100 years. Data from the Kharamkul station show a temperature increase of 1.33°C/100 years. A temperature increase of 0.7°C/100 years is found at 4169 m above sea level. The data show that troposphere warming decreases with elevation, leading to increased vertical gradients of temperature (Table 1). The vertical gradient increases by 3.3% per 70 years between levels 1 and 4. This should reduce the stability of the atmosphere and result in a stronger vertical mixing.

Monthly temperature changes are different throughout the year, but a warming tendency is shown in every month except in February (Fig. 3). The highest temperature increase occurred in the last half of the year at the Kurgen-Tube and Dushanbe stations. In Dushanbe, the greatest warming occurred in November and reached 7.3°C. In addition, Duarte Maria Luz (1993)[vi] showed that, in the summer period (1962–1965), air temperature in the troposphere has an upward trend at tropical and middle

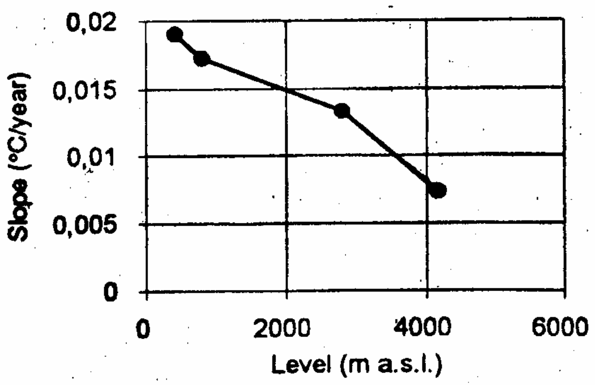

Fig. 2. Trend of annual air temperature.

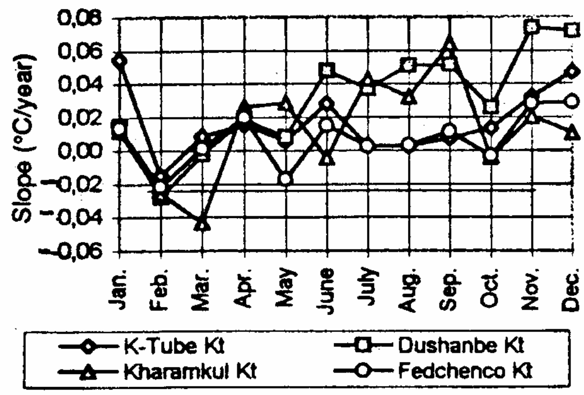

Fig. 3. Trend of monthly air temperature

Table 1. Vertical temperature gradient between different levels.

Station	H(m)	No of level	Delta of level	Gradient (°C/100 m) 1926 year	1996 year	%
Kurgan-Tube	426	1	1-2	-0,31	-0,34	9,7%
Dushanbe	803	2	2-3	-0,60	-0,62	3,3%
Kharamkul	2800	3	3-4	-0,68	-0,71	4,4%
Fedchenco	4169	4	1-4	-0,60	-0,62	3,3%

latitudes. Warming was very slight at the high-mountain stations in summer, but in November and December the temperature rose by 2.8°C.

5 Precipitation

A positive tendency is also found in annual precipitation. The trend increases with elevation above sea level (Fig. 4). The rate of precipitation increase at the lowest station (Kurgen-Tube) was 4.6 mm/100 years; at the second station the increase is 64.7 mm/100 years, at Kharamkul it was 181.6 mm/100 years, and at the highest

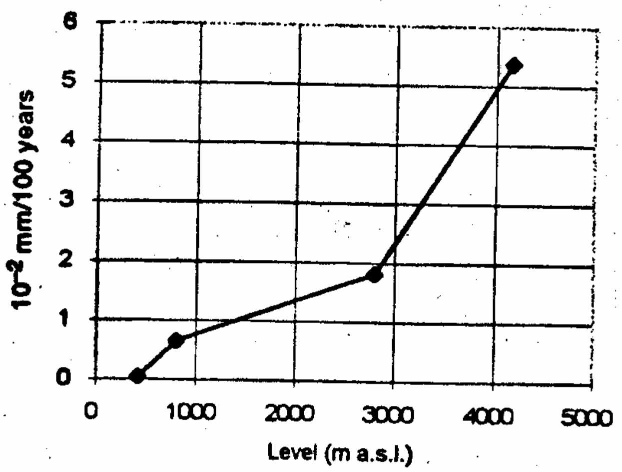

Fig. 4. Annual precipitation trend.

station (Fedchenko) the precipitation increase was 536.8 mm/100 years (Table 2). The percentage increase of precipitation was greater at the high elevations than in the low valleys.

Monthly changes of precipitation varied throughout the year. The monthly increase was lowest for all stations in June (Fig. 5).

Table 2. Trend of annual precipitation change per 100 years on different levels.

Station	H(m)	No of level	Precipitation (mm)			
			1900 year	2000 year	%	Delta P (mm)
Kurgan-Tube	426	1	287,8	292,5	1,6%	4,7
Dushanbe	803	2	632,0	696,7	10,2%	64,7
Kharamkul	2800	3	1 267,9	1 449,5	14,3%	181,6
Fedchenco	4169	4	1 027,6	1 564,4	52,2%	536,8

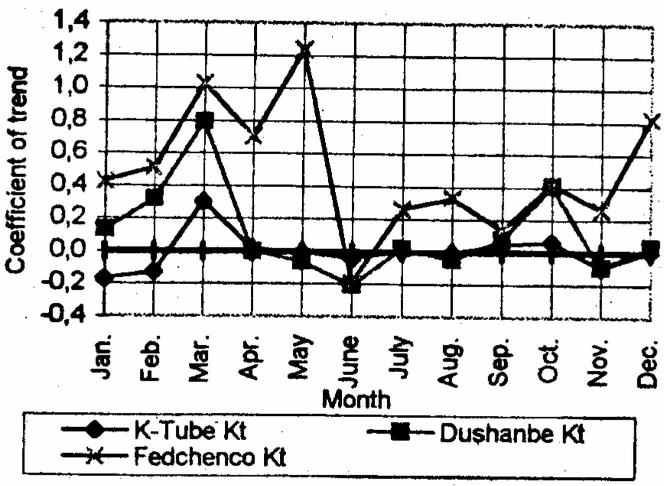

Fig. 5. Trend of monthly precipitation.

6 Conclusion

Analysis of these data allows us to draw some conclusions about climatic changes in Tajikistan and their connection to the changes of the global climate. (a) Annual air temperatures show a steady increase at all levels from 400 to 4000 m (a.s.l.). (b) The rate of air temperature increase on the plain stations is greater than in the high mountains. (c) The vertical gradient of temperature increases with time and leads to increased atmospheric mixing. (d) The cold half of the year warms up more than the warm half. (e) Precipitation increases in mountain areas more than in the valleys. (f) Precipitation increases more in the cold half of the year than in the warm half. (g) In valleys, a reduction in precipitation occurs in May, and all stations show a reduction in June. (h)Climate warming has caused of some of Pamir's glaciers to recede.

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