Borehole and active-layer monitoring in the northen Tien Shan (Kazakhstan)

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The Zhusalykezen Mountain pass (43°05'N, 76°55'E, 3330 m a.s.l.) is located within the discontinuous permafrost area of the Transili Alatau Range (frontal range of northern Tien Shan). The location is close to the city of Almaty, and therefore offers an opportunity for geocryological and ecological investigations of the natural system and systems affected by human activities.

The Upper Pleistocene and Holocene moraines from the mountain descend into the nearby valleys. Vegetation cover is dominated by Kobresia. Mean annual, January and July air temperatures at the elevation 3300 m a.s.l. are -3.5°C, -13.7°C and 6.7°C, respectively. The maximum annual precipitation is about 1000 to 1100 mm. The snow cover develops in October. By the beginning of June, the thickness of snow cover varies from 1 to 5 cm up to 100 to 120 cm, relative to topography and wind activity.

Depending on geomorphology and microclimatic conditions, the thickness of permafrost varies from 10 to 15 m to 80 to 90 m on the northern slopes and is absent on the southern slopes. Temperatures of permafrost vary from –0.1°C to –0.45°C. There are 10 thermometric boreholes located on different slopes and aspects within an area of 3 km^2. Active layer thickness is determined by temperature measurements made in boreholes from 3 m up to 70 m in depth. Several CALM sites are located near a mountain pass. Initial results of the Circumpolar Active Layer Monitoring were reported previously (Brown et al. 2000).

Ground temperatures up to 25 m in depth have been measured since 1973 (Gorbunov and Nemov 1978). Both interpolation of temperature measurements and excavations in the moraines revealed active-layer thickness in the late summer for 1973 and 1974 (Table. 1). The table includes mean active-layer thickness during 1974-1977 for C1(K0) and C2(K1) sites. The average increase in mean annual air temperature for the last 100 years in the central part of Transili Alatau Range has been 0.02°C/yr. The average ten-year temperature for 1991-2000 has increased by 0.3°C in comparison with 1981-90. The greatest increase of temperature for the same period has been mean winter (0.4°C), maximum winter (0.9°C) and minimum summer temperature (0.5°C). The warmest years for the last decade of the 20th century were 1997, 1998 and 1999, when

Table 1. Active-layer thickness near Zusalykezen Mountain pass for 1973-1977.

Excavations	Altitude	Depth of pits and boreholes	Active layer thickness
	m a.s.l.	m	m
Pits			
No 1	3337	6.0	4.5
No 2	3334	4.0	4.0
No 4	3334	4.3	3.5
No 5	3337	9.3	4.0
No 10	3336	9.0	3.8
No 12	3334	4.2	3.7
Boreholes			
C1 (K0)	3337	25.0	3.2
C2 (K1)	3328	14.0	3.4
C3a	3337	10.3	4.3
C7	3334	11.7	3.5
C11	3335	13.0	3.7

mean annual air temperature was higher than the long-term average temperature by 1.1°C, 1.49°C and 0.93°C, respectively. Analysis of meteorological conditions for summer time has shown that the summer temperatures and precipitation figures are currently rising (Figure. 1).

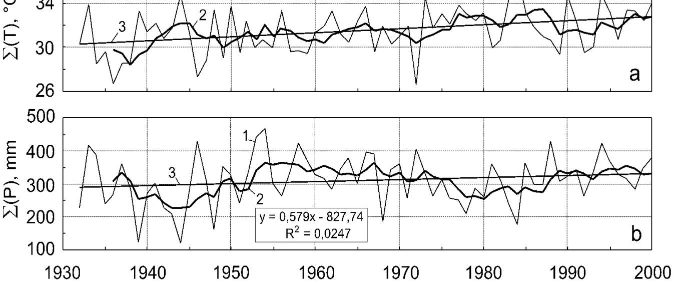

Figure 1. Air temperatures (a) and precipitation (b) for the summer time (Central Transili Alatau Range, 2500 m a.s.l.). 1 – annual, 2 – five-year average, 3 – linear trend.

Thus, climatic processes during the 20th century and especially during the last two decades have a great influence on the contemporary thermal state of permafrost. Geothermal observations indicate permafrost warming in the northern Tien Shan for the last 30 years. The permafrost temperatures increased during 1973 - 2002 from 0.2 to 0.3°C for undisturbed systems, and up to 0.6°C of those affected by human activities.

In accordance with interpolation of borehole temperature data, active-layer thickness showed a significant increase during the last 30 years from values of 3.2 to 3.4 m in the 1970s to a maximum of 5.2 m.

The average active-layer thickness for all measured sites increased by 23% in comparison with the early Seventies. But compared with the thawed depths for the new CALM sites (K0, K1, C7) the increase is much greater at 42%. For example, at the CALM K1 site during 1974-1977, the average active-layer thickness was 3.4 m and maximum value of 3.5 m. During 1990-2000 at the same site the average active-layer thickness was 4.85 m with a maximum value of 5.2 m. At the CALM site K0, the average and maximum active-layer thickness were 3.2 m and 3.3 m for 1974-1977 and 4.8 m and 5.1 m during 1990-2000.

As mentioned earlier, 1998 was the warmest year on record in Transili Alatau since 1964. As a result, in the following year the ground temperature at a depth of 4.6 m had increased significantly. For example, the average temperatures at 4.6 m were -0.2, 2.24, 0.10, 0.06 and 0.04 in 1998, 1999, 2000, 2001, and 2002, respectively. This deep penetration of seasonal thawing into the ground initiated the appearance of a residual thaw layer deeper than 5 m at the CALM K1 site. Normally seasonal freezing penetrates from 4.5 to 5.2 m.

Using data obtained from boreholes, geologic and geomorphologic data, and knowledge about the extent of snow cover and vegetation, an attempt was made to calculate spatial distribution of active-layer thickness for Zhusalykezen Mountain pass area. An area of 1.5x2 km^2 near the mountain pass was selected for the computations of depth of seasonal thaw. The deterministic model (Marchenko 2001) with regular grid spacing of 50x50 m was used for computation. Figure 2 shows the calculated spatial changes in active-layer thickness within selected areas.

Because in high mountain areas permafrost is one of the dominant factors affecting slope stability, knowledge about tendencies of active layer development is of great interest. Model calculations of active-layer thickness allow for the assessment of surface processes, landscape dynamics and natural hazards.

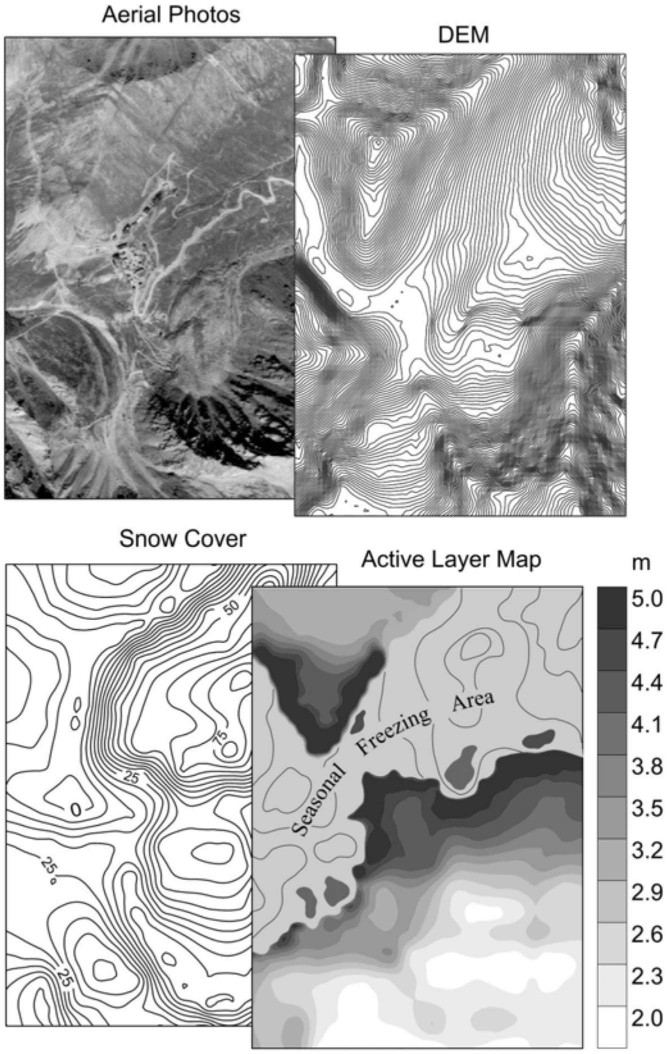

Figure 2. Computed active-layer thickness distribution for Zhusalykezen Mountain pass area using complex data.

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