Processes of Transportation and Sedimentation of Dust Aerosol

Alexander Finaev

Institute of Geology, Academy of Sciences, Rudaki pr. 33, 734025 Dushanbe, Tajikistan

Abstract

Loess-soil sediments are the good indicators of palaeoclimate change on the continents. The thickest sediments are in China and Tajikistan. The estimation of loess accumulation rate is the important characteristic in study of loess. This rate is determined during the research of loess sections.

So climate, geographical situation, relief, surrounding territories and early researches give possibilities for creating of sediment formation model from precipitated atmospheric aerosol.

The results of calculation were presented at the conferences in Krasnoyarsk (Lomov and Finaev, 1994) and in Garmisch-Partenkirchen (Finaev, 1995). In this article the basis and 3-D model for such accounts are given. The comparison of modelling results and factual data of loess sections shows good connection between these two independent approaches.

The present article describes logic and technique for estimation of aerosol transportation and sedimentation processes in Tajikistan.

1. Introduction

The arid zones of the globe generate enormous quantities of dust particles, which then go through various processes of transformation, transportation and sedimentation. Such cases not only affect the climate in the extreme, but also influence other processes of natural environment forming. Loess-soil sections contain considerable geologic information, which characterizes palaeoclimatic fluctuations (Dodonov et al., 1999).

The thickest loess-soil depositions of Central Asia are situated in Southern Tajikistan. The reasons for such depositions are geographical position of this area, location of mountain ranges and climate. The simulation of loess formation processes is important for comprehension and confirmation of hypothesis about loess formation from precipitated aerosol. Climatic data of actual observations are used for simulation. The period of these observations covers only the last century. The results of simulation were represented on the conferences (Lomov and Finaev, 1994; Finaev, 1995).

2. The basis and modelling logic

Specific features of dust aerosol transportation and precipitation are provided by combination of physic-geographical and climatic conditions. The highest mountain ranges of Tyang-Syang and Pamir-Alai, organised into a certain “curtain” system, form voluminous orographic niches opened for penetration of air masses from the southwest. Mountain ranges of 5000 - 6000 m a.s.l. in the eastern and northern parts of Middle Asia form a barrier preventing these southwest air masses from penetrating any further. Thus air is stagnated in the lower troposphere. That is why dust storms developing in the deserts of Middle Asia and breaking into the mountain country of Pamir-Alai move the dust in the lower convective layer of the troposphere, particularly in the valleys. Aerosol gradually precipitates to underlying surface, while meteorological stations make records of dust haze during these episodes (Fig. 1) (Finaev, 1988, Dodonov et al., 1999).

Favourable conditions for the development of dust storms occur in the deserts of Middle Asia during the summer and fall seasons. At this period lack of precipitation in combination with soil overdrying and scanty vegetation cover cause the deflation processes, even if wind speed is faint. Haze rises up into the air by the dust storms and hangs there even after the episode is over. Then it is transported to large distance by air streams through the lower troposphere. Coarse particles raised into the air precipitate quickly back to ground, while the fine ones remain suspended for some time, producing the haze. Visibility then may fluctuate from 4-10 up to 2-4 km. The vertical extent of the haze layer may reach 3-4 km. Concentration of dust particles in the air makes 8,4 per cm^3 (Ivanov and Finaev, 1987). The number of days with haze increases southward. There are up to 10 such days annually recorded in Northern Tajikistan, 20-27 days/year in Gissar Valley and 40-70 days at the extreme south. Haze penetrates far to the east along the river valleys (up to 26 days with haze are annually recorded in Gharm). Haze is rarely observed in Pamir Mountains (only 3-6 days/year) (Climate of the USSR. Handbook, 1970). As for the annual trends, the maximum number of days with haze is recorded in July-October, and the minimum is during the winter.

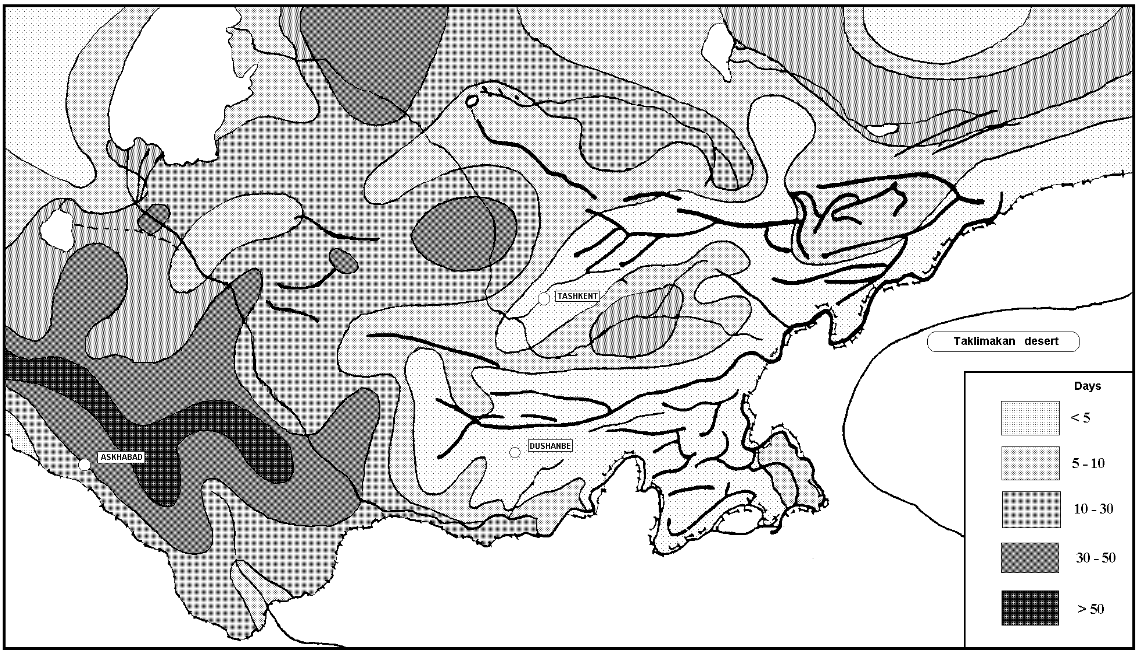


Fig. 1: Duration of dust storm of Central Asia.

The duration of haze episodes also increases southward as well as the number of hazy days. The average duration of a haze episode does not exceed 40 hr/yr in the north, increases to 200-400 hr/yr in Gissar Valley, and further grows to 500-600 hr/yr in the extreme south. The annual cumulative duration of haze in Pamir varies from 4-8 to 30-40 hr/yr. As for Fedchenko Glacier haze is an extremely rare event there. It is observed only once every 25 years or so, and its duration is 0,4 hr/yr. The annual trend of haze duration is similar to that of the number of hazy days (Fig. 2), (data from Handbook “Climate of the USSR”, 1970).

The maximum of haze in July (Shaartuz) and in August (Dushanbe) is connected with amplification of storms and convection above dry soil during maximal solar heat. The maximum of haze in October is connected with the beginning of cyclonic activity above dry surface. On Fedchenco glacier the maximum of haze is in June. At this time level of convection reaches maximal height and dusty air distributes to high-mountainous districts. In winter period the soil is getting moist and the level of convection reduces. That is why in spite of the wind during the cyclonic activity the amount of haze reduces too.

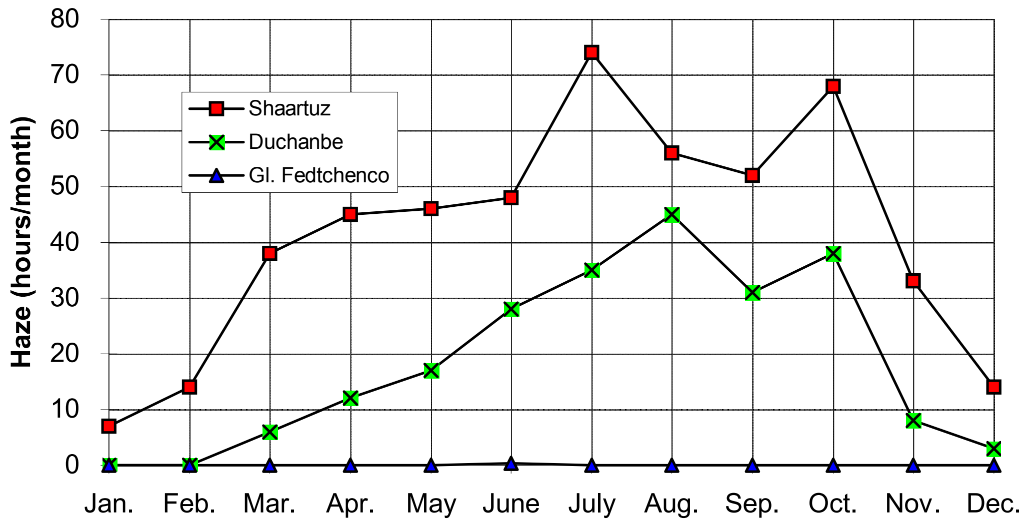


Fig. 2: Duration of dust haze (hours/month).

Research of aerosol (Finaev, 1987b; Soviet-American experiment for research of arid aerosol, 1992) and glacier dust sediments (Anokhin, 1978) showed that aerosol is distributed in convective layer as high as convection level. Basic mass of aerosol consists of particles more then 25 mkm. These particles are marked on all levels of convection thickness and in glaciers, which are situated at the same height.

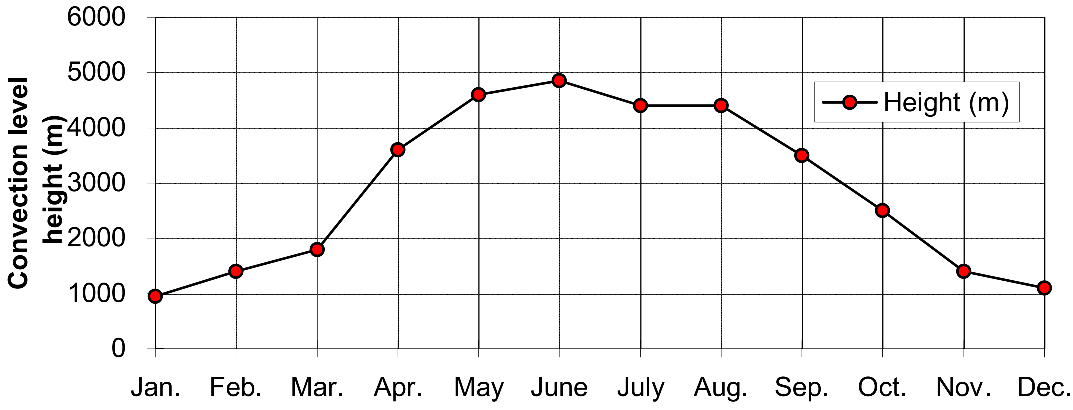


Fig. 3: Height of convective level. (Finaev, 1987a; 1994).

Finaev (1987a; 1994) determined average monthly height of convection level. The maximal height of it is recorded in June (Fig. 3). The warm up of ground and convective streams increase in this month. So, average annual aerosol distribution map (Fig. 4) was calculated base on these data. The scale of grid for map calculation was 10x10 km.

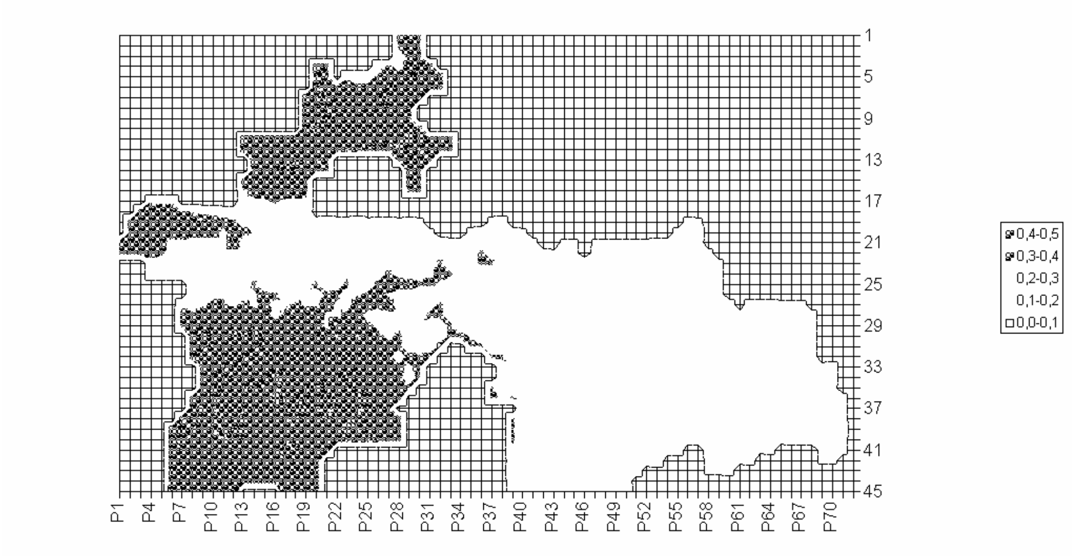


Fig. 4: Aerosol penetration (average annual); 0-0,3 - clean air; 0,3-0,5 - dust pollution.

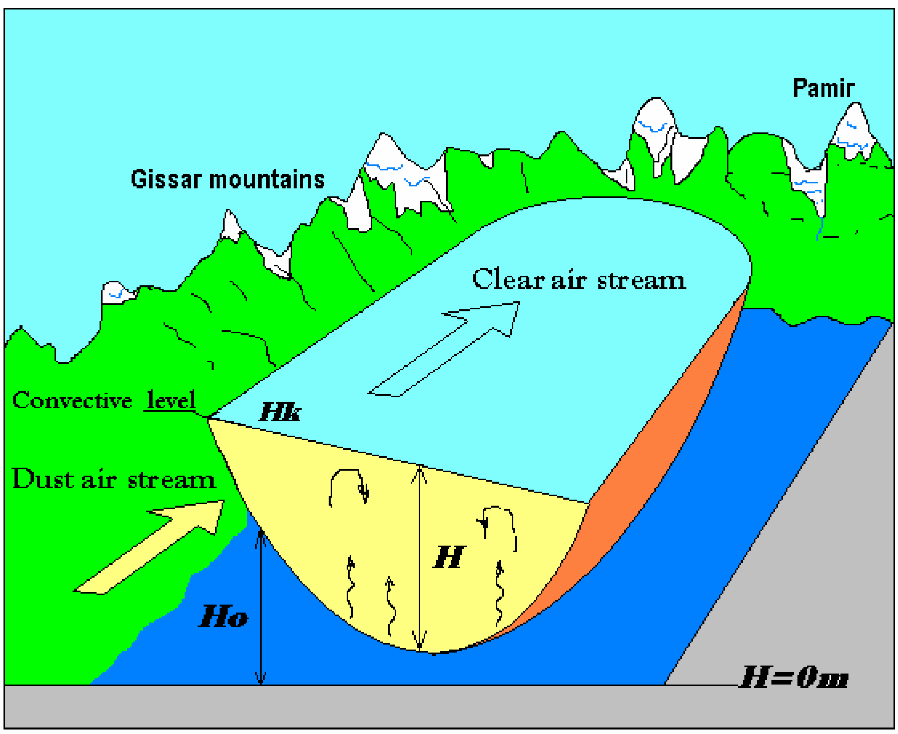
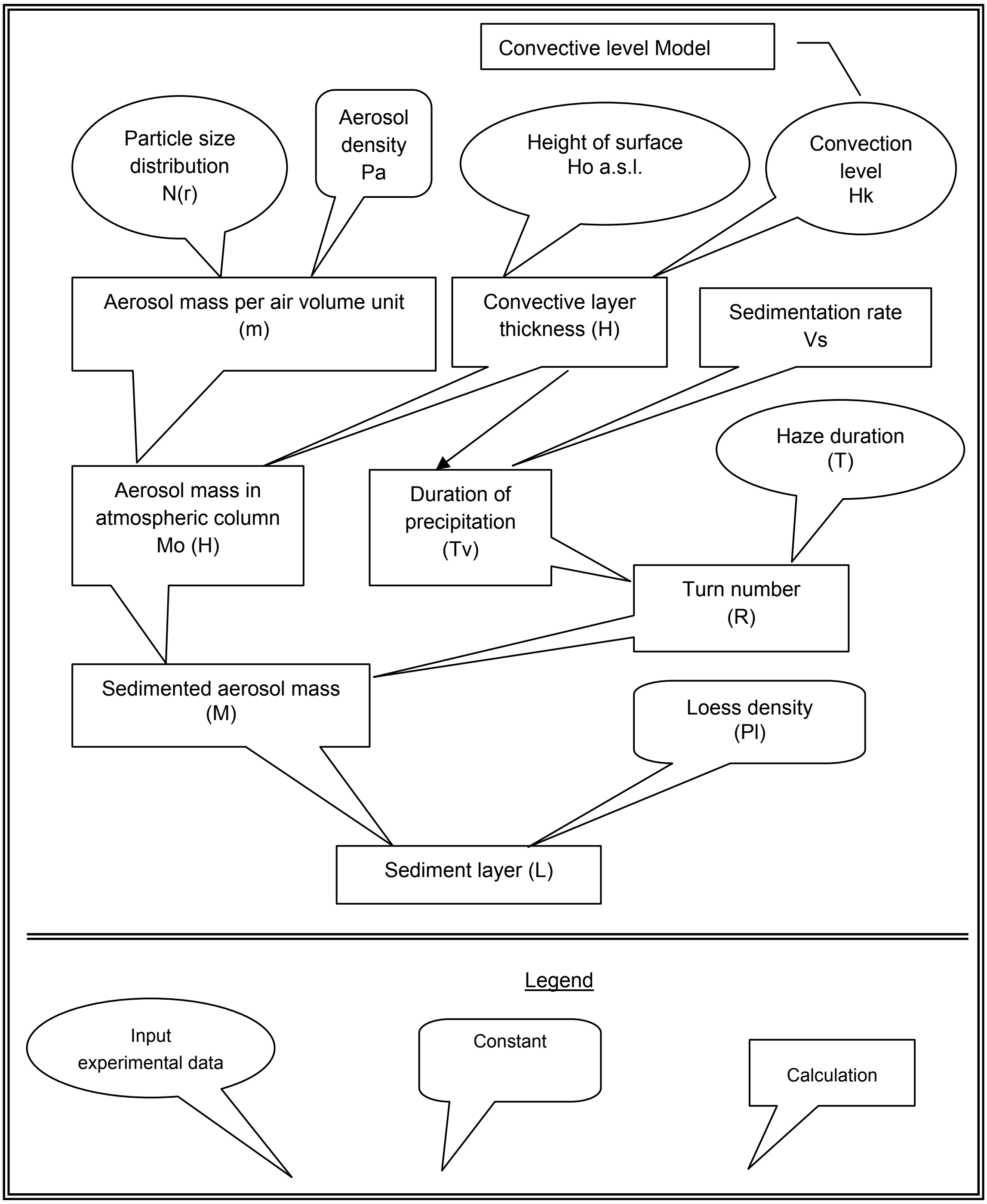


Figure 5: Diagram of dust material accumulation model.



The analysis of available materials showed basic processes and mutual links, which happen in this region during transportation and precipitation of aerosol.

Fig. 6: Sediment layer model.

Thus, model stimulation logic is rather simple. It is necessary to estimate the amount of precipitated aerosol from an individual vertical column of air. Height of column is limited by ground surface and top border of convective layer. Time of precipitation depends on the size of particle. The influence of wind vertical vector is not taken into account. The duration of process action is limited by the time of haze observation at meteorological stations.

3. Calculation technique

Based on facts described above, it is possible to show the processes of aerosol transport as sedimentation as next (Fig. 5). During dust storms in Middle Asian desert dust aerosol is distributed throughout the troposphere almost uniformly up to the top of convective layer (speed of both horizontal and vertical eddy fluxes reaches tens of meters per second then). The air mass loaded with aerosol enters Tajikistan area and fills closed valleys lying below that convective layer. Meeting the barrier of mountain ranges the air stagnates, its eddy weakens, and aerosol starts to precipitate to ground. Part of this air mass overflows the ridges. To substitute it new portions of dusty air arrive. A continuous feeding of the area by dusty air masses occurs during such dust episodes. That explains the total duration of haze. Based on the facts, logic and scheme of model given above we can calculate the amount of precipitated aerosol (Fig. 6).

The mass of aerosol in air volume unit is readily calculated:

$$m = 4/3 P_i P_a \int_{r_1}^{r_N} r^3 N(r) dr ,$$

where *m* - is the mass of aerosol per air volume unit, P_i= *3.14*..., *Pa* - is the aerosol density, *r* - is the particle radius, *N(r)* - is the number of *r* - particles.

The total aerosol mass in dust-loaded atmospheric column is:

Mo = m H,

where *H* - is the depth of the convective layer above given surface. It is expressed as difference between the upper level of convection *(Hk)* and the underlying surface a.s.l. *(Ho)*:

H = Hk - Ho.

Precipitation time *(Tv)* is calculated as:

Tv = H/V,

where V - is free fall speed for an aerosol particle of r radius. It is found from the Stokes formula:

V = 2/9 r2g (Pa - Pw)/w

where $g = 978.049(1 + 0.0052834 \sin^2(F) - 0.000006 \sin^2(2F))$ - is the acceleration of gravity at latitude *F*, *w(20°C) = 18.1x10-5 Poise (g/cm s)* - is air viscosity at the temperature of 20°C, *Pa* - is the aerosol particle density (taken for quartz: = 2.65 g/cm^3). *Pw* - is the density of air *(Pw= 0.0012928 g/cm^3)*.

It is necessary to note that meteorological stations record the duration of haze to cover the whole period of dusty air mass action, but it is not the time of aerosol precipitation from air column. The time of precipitation may be shorter than the total time. Therefore, the whole period of haze may be used to characterise the number of dusty columns from which aerosol precipitates. That characteristic may be called the "number of turns" (R):

R = T / Tv,

where *T* - is the duration of haze over some period (month, year). Then the mass of aerosol *(M)* precipitated per area unit in given territory will make:

M = m H R .

It is then easy to calculate the thickness of the formed soil layer *(L)*:

L = M / Pl

where Pl - is the density of loess (1.35 g/cm^3). The important point of this calculation is the estimation of convection level height where aerosol is spread. Figure 5 shows the change of convection level height during the year (Finaev, 1987a; 1994).

Data set used for model:

N(r) - function of particles size distribution. For Central Asian aerosol it was determined in Soviet-American experiment on arid aerosol research (1992) and by Ivanov and Finaev (1987).

Ho - surface height a.s.l. - average height of grid cell in scale 10x10 km. Relief map.

Hk - top border of convective layer. Depends on season. Was determined according to the model of Finaev (1994).

T - haze duration. (Climate of the USSR. Handbook, 1970).

4. Results

The actual data on periodicity and duration of dust haze (Climate of the USSR. Handbook, 1970) combined with the actual data of surface height above sea level were used as the basis for calculations of the rate of aerosol precipitation in Tajikistan according to the technique described above. Variability of the convective layer thickness during the year was also calculated. It changed from 950 m above sea level in January up to 4850 m in June. Calculations of precipitated thickness were made for each month separately at every station recording haze episodes. Meteorological station height above sea level (Ho) and average annual thickness of dust sediments (L) are given in table 1. The analysis of table data shows that sediment thickness depends on the station height, local climatic features and on the distance from dust storm regions. Sediment thickness during the year varies from 0.04 mm/yr to 0.683 mm/yr. The averaged accumulation rate on the surface is 0.2 mm/yr. Almost the same data were obtained in loess section for the early Holocene (0.17 to 0.26 mm/yr.) (Lomov, 1991).

Shackleton et al. (1995) showed that loess accumulation rate in Karmaidan section varies from 0,05 to 0,22 mm/yr. The calculation of sedimentation rate on Faizabad station, which is situated in Karmaidan section area, makes 0,22 mm/yr. The rate of sedimentation on Kangurt, Kulyab and Khovaling points are 0,207, 0,338 and 0,273 mm/yr accordingly (Tab. 1). Accumulation rate of Daraikolon loess section, which is situated in the same district, makes 0,11-0,31 mm/yr and depends on loess horizon (Dodonov et al., 1999). For the first and the second pedocomplexes loess accumulation rate is 0,31 mm/yr, and the average rate per 0,8 million years is 0,25 mm/year. The average sedimentation rate of dust particles on three stations of the area mentioned above makes 0,27 mm/yr.

The model allows us to estimate the distribution of sedimentation rate according to the height of terrain (Fig. 7). While the simulation of this profile there was used tab. 1, however points of Northern Tajikistan were excluded. They do not suit the conditions. The scattering of points can be estimated by polynomial of the sixth order with coefficient of correlation R^2=0,86. The polynomial curve shows that the dust material accumulation processes occur to the height of 2600 m. Accumulation rate varies from 0,3 up to 0,2 mm/yr at heights of 900-1600 m. It corresponds to the experimental data obtained on Karmaidan and Daraikolon sections, which are in the range of these heights. The increase of sedimentation rate on 3000-4200 m shows accumulation in eastern part of East Pamir. The transport of aerosol in this district is caused by Taklimakan desert (Western China).

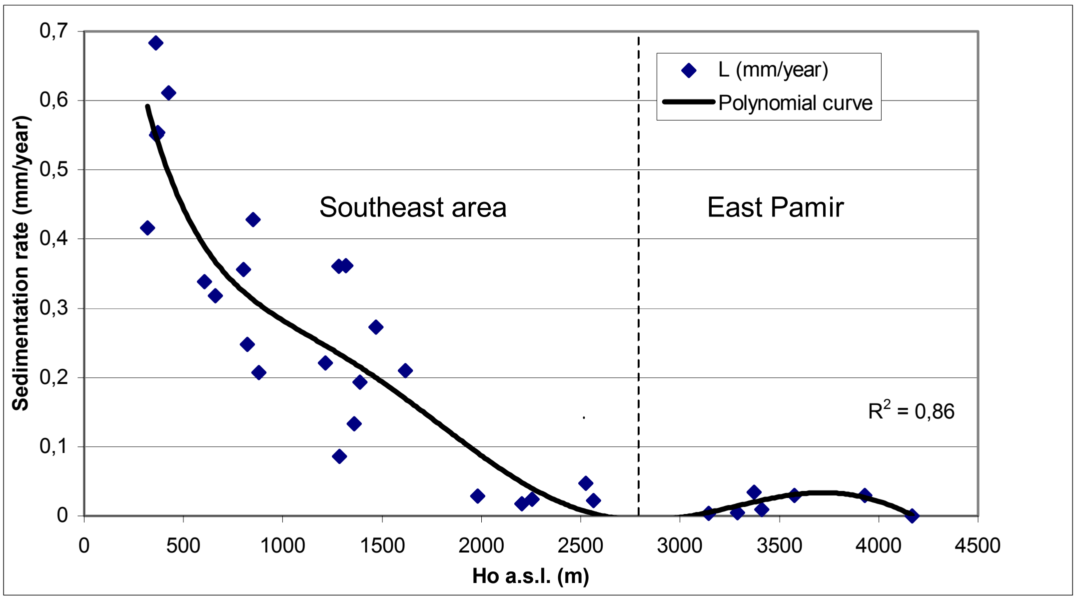


Fig. 7: Sedimentation rate (mm/year).

Table 1: Thickness of precipitated aerosol layer
L (mm/year) average annual.

Station	Ho a.s.l., m	L, mm/yr.
Aivadzh	318	0,416
Anzob Pass	3373	0,034
Gharm	1316	0,362
Ghushary	1359	0,133
Danghara	660	0,318
Dekhauz	2564	0,022
Dzhaushanghoz	3410	0,009
Dushanbe, agro	803	0,356
Dushanbe, city	822	0,248
Iol	1283	0,361
Irkht	3290	0,005
Iskanderkul	2204	0,018
Isfara	841	0,017
Ishkashim	2524	0,047
Kalai-Khum	1284	0,086
Kanghourt	879	0,207
Karakoul	3930	0,030
Koulyab	604	0,338

Station	Ho a.s.l., m	L, mm/yr.
Kourgan-Tyube	426	0,611
Fedchenko Glacier	4169	0,0004
Leninabad	410	0,041
Madroushkent	2254	0,024
Mourgab	3576	0,030
Obi-Gharm	1387	0,193
Parkhar	369	0,554
Pendzhikent	1015	0,036
Pyandzh	362	0,683
Roushan	1981	0,029
Sanghiston	1522	0,014
Tavil-Dora	1616	0,210
Oura-Tyube	1004	0,044
Faizabad	1215	0,221
Khovaling	1468	0,273
Shaartuz	363	0,550
Shakhrinau	852	0,428
Shakhristan Pass	3143	0,004

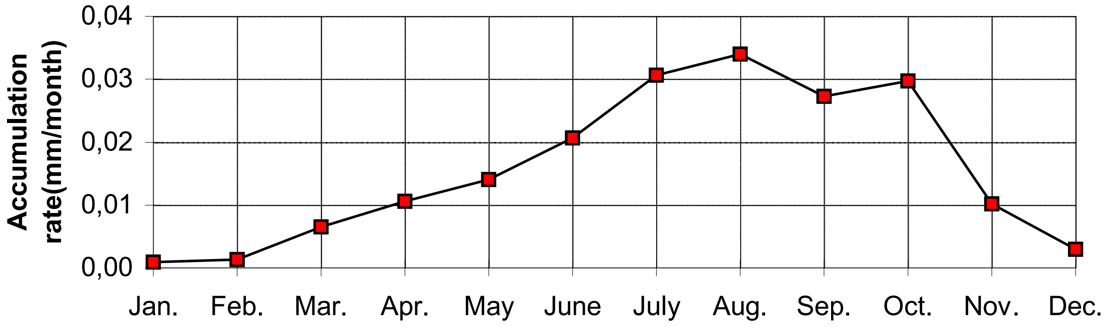


Fig. 8: The average monthly accumulation rate (mm/month).

The annual trend of dust material accumulation is not homogeneous and depends on climate fluctuation. Fig. 8 shows average monthly accumulation rate over all stations.

Based on these results it is quite easy then to make annual sedimentation thickness map, which is shown on Fig. 9. The thickest layer is in the southwest of the territory. The area of East Pamir is influenced by aerosol stream from Taklimakan dessert. The actual distribution of loess soils is shown on Fig. 10 (map was made according to the data of Prof. S.P. Lomov). The comparison of model and actual maps showes good correlation though there are differences. They are connected to erosive processes, which had happened during geologic period of loess formation. The erosion processes changed sedimentation structure in valleys of southern areas. There are many powerful rivers that washed away the surface sediments.

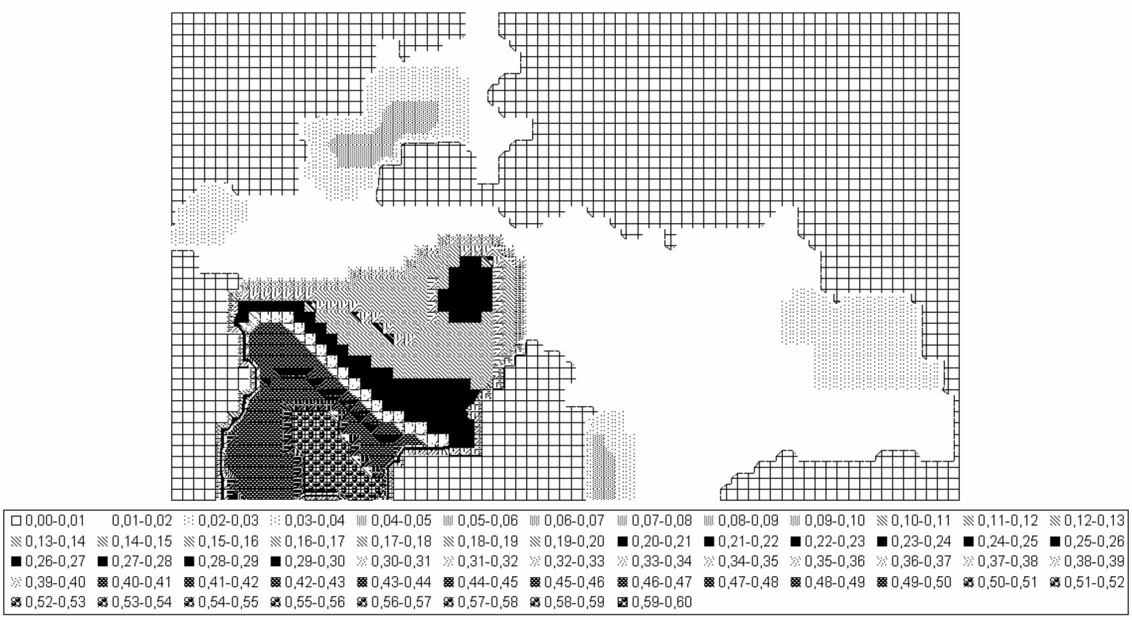


Fig. 9: Distribution of ac contradistinction cumulated sediments (mm/year).

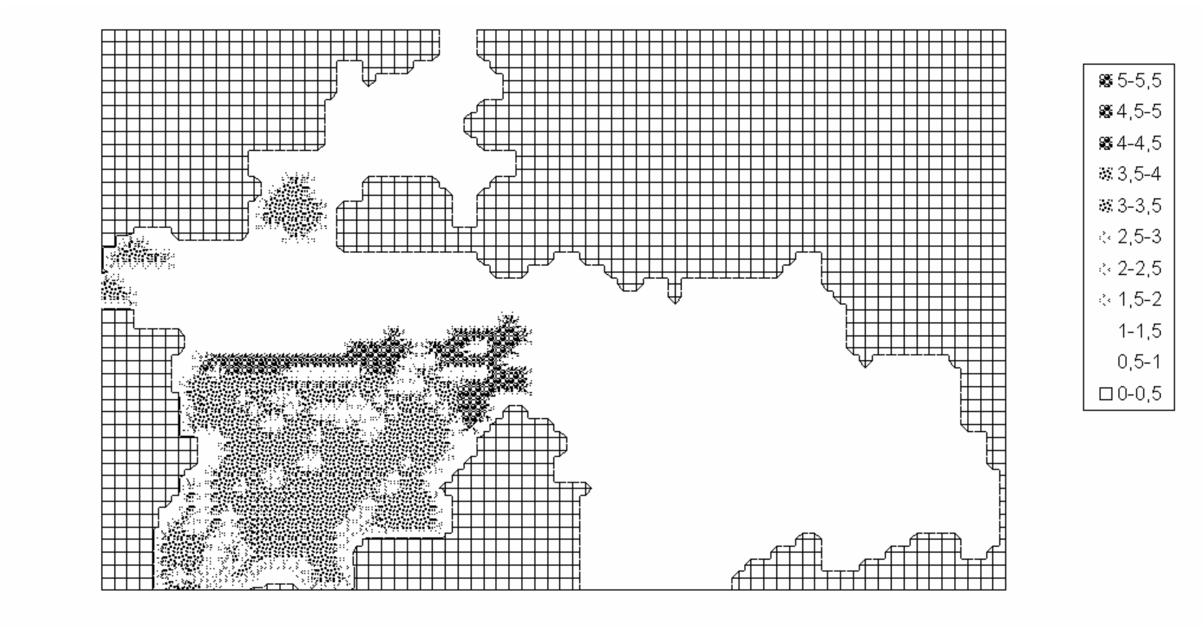


Fig. 10: Distribution of loess soils.
0-1 - without loess; 1-3 - bottomland and waterlogged soil; 3-4 - loess;
4-5,5 - palaeoloess fragments.

5. Conclusion

Deflation processes of Middle Asia deserts and dust deposits of mountain ranges of Tyang-Syang and Pamir-Alai are united in one system due to physic-geographical and climatic condition.

The analysis of these conditions helped to simulate aerosol deposits thickness. The model demonstrates that the highest accumulation rate is typical for the southern areas and reaches 0.5-0.6 mm/yr. The average accumulation rate of dust over the whole Tajikistan is 0.2 mm/yr. This sedimentation rate correlates with data from loess sections of the early Holocene.

Analysis of geographical and climatic data and the results of different researches allowed us to make 3D model of dust particles sedimentation in loess formation region.

6. Acknowledgments

Financial support for the author's participation at the Workshop "Pamir and Tian-Shan: Glacier and Climate Fluctuations during the Pleistocene and Holocene" in Bayreuth, Germany, was provided by the German Research Foundation (DFG).

7. References

Anokhin Yu.A., Voronskaya G.N., Kasakov Yu.E., Kislov B.V., Nikolishin I.Ya., Nosdrukhin V.K. (1978): Ledniki kak obékti izucheniya dinamiki atmosfernih zagryaznenii (The Glacier as an Object of Studies of Atmospheric Pollution Dynamics). Materiali Glaciologicheskih Issledovaniy 34, 192-197 (in Russian).

Dodonov A.E., Sheckleton N.J., Zhou L.P., Lomov S.P., Finaev A.F. (1999): Loess-soil stratigraphy Quaternary Middle Asia: geochronology, correlation and evolution of palaeo environment. Stratigraphy. Geological correlation. V. 7, № 6, 66-80.

Finaev A.F. (1987a): Vertikalniy profil' koefficienta pogloscheniya atmosferi v gornih rayonah Sredney Azii (Vertical Profiles of the Atmospheric Extinction Coefficients in the Mountain Areas of Middle Asia). Red. "Izv. Ac. Nauk Tadj. SSR. Otdel. Biol. Nauk." Dushanbe. 10 p. Deposit. VINITI 3.09.87. No 6479-B87 (in Russian).

Finaev A.F. (1987b): Otcenka terndov aerosolnogo zagrazneniya v Tajikistane (Estimation of the Trends of Aerosol Pollution in Tajikistan). Red. "Izv. Ac. Nauk. Tadj. SSR. Otdel. Biol. Nauk." Dushanbe. 8 p. Deposit. VINITI 3.09.87. No 6480-B87 (in Russian).

Finaev A.F. (1988): Radiacionnii regim territorii Tajikskoi SSR (Radiation Regime over the Territory of the Tajik SSR). Autoreferat. Dissert. Cand. geograph. Nauk. Leningradskii Gosudarstvennii Hydrometeorologicheskii Institut. 24 (in Russian).

Finaev A.F. (1994): Vertikalnii profil' rasseyannoi radiatcii I godovoi hod visoti konvektivnogo sloya (Vertical profile of diffuse radiation and year motion of the convection layer height). Izvestiya Akademii Nauk. Otdelenie Nauk o Zemle, 3 (in Russian).

Finaev A.F. (1995): Processes of transportation and sedimentation of dust aerosol. In book: Global Analysis, Interpretation, and Modelling: First Science conference 25-

29 September 1995, Garmisch-Partenkirchen. IGBP Secretariat of Germany in Berlin, 22.

Ivanov V.A., Finaev A.F. (1987): Koncentratciya i raspredelenie po razmeram aerozolya v gornih dolinah (Concentration and Size Distribution of Aerosols in Mountain Valleys). Trudi Glavnoi Geofizicheskoi Observatirii, 507, 121-125 (in Russian).

Klimat SSSR. Spravotchnik. Oblachnost' i Atmosfernie Yavleniya (1970): (Climate of the USSR. Handbook. Cloudiness and Atmospheric Phenomena). Issue 31.). Part V., 214 (in Russian).

Lomov S.P. (1991): Evolutciya serih i korichnevih pochv v techenii Holocena (Evolution of Grey and Brown Soils During the Holocene). Conferenciya Tajikskogo Sel'skohozaistvennogo Instituta (in Russian).

Lomov, S. and Finaev, A. (1994): Otcenka Processov accumulacii lessov v Tajikistane. (Estimation of the Processes of Loess Accumulation in Tajikistan). In Book: Palaeo ecology and settling of ancient people in North Asia and America. Short content of reports of International symposium. Krasnoyarsk, 166 – 168 (in Russian).

Shackleton N.J., An Z., Dodonov A.E., Gavin J., Kukla G.J., Ranov V.A. and Zhou L.P. (1995): Accumulation rate of loess in Tajikistan and China: Relationship with Global Ice Volume Cycles. Quaternary Proceedings, 4, 1-6.

Sovetsko-Amerikanskii experiment po issledovaniu aridnogo aerosolya. Tajikistan, Sentjabr' 1989. (1992): (Soviet-American experiment for research of arid aerosol. Tajikistan, September 1989.) S-Peterburg, Hydrometeoizdat (in Russian).