ARTICLE

Main Characteristics of Dust Storms and Their Radiative Impacts: With a Focus on Tajikistan

Sabur.F.Abdullaev[1*]   Irina.N.Sokolik[2]

1. Physical-Technical institute Academy of Sciences of Republic of Tajikistan, Ayni str.299/1, Dushanbe,ZIP-734063, Tajikistan
2. School of Earth and Atmospheric Sciences Georgia Institute of Technology, Atlanta, 311 Ferst Drive Atlanta, GA 30332-0340, USA

ABSTRACT

Dust storms are commonly occurring phenomena in Tajikistan. The known aridity of the region is a major factor in promoting numerous dust storms. They have many diverse impacts on the environment and the climate of the region. The classification of dust storms and synoptic conditions related to their formation in Central Asia are discussed in the content of their diverse impact. We address dust optical properties that are representative of the region. Dust storms significantly reduce visibly and pose a human health threads. They also cause a significant impact on the radiative regime. As a result, dust storms may cause a decrease in temperature during daytime of up to 16℃ and an increase in temperature during night time from up to 7℃ compared to a clear day.

1. Introduction

Tajikistan is situated in the global dust belt on the way of transport routes of dust from some major dust sources like the Aralkum desert of the desiccating Aral Sea, the Kyzyl-Kum and Karakum deserts east of the Caspian Sea, the Iranian Dasht-e-Kavir and Dasht-e-Lut deserts and the deserts in Afghanistan, Sahara and Taklamakan desert [1-4] (Figure 1). Therefore, Tajikistan is frequently affected by severe dust events every year (from April untill November) and is a net accumulator of dust. Tajikistan is a country with a dry climate and benefits from its water resources in the mountainous Pamir region, which are stored in a large part in glaciers. Furthermore, Central Asia and especially Tajikistan are highly affected by climate change. For example, the dramatic glacier shrinking took place in the last decades, which has also an effect on the water resources of Tajikistan and the whole Central Asian area. Since the trans-regionally important rivers as Amu Darya and Syr Darya are fed by glacier melt water, which were originally feeding the Aral Sea, which now became itself a strong dust source [1-4]. On the other hand, deposited dust itself can accelerate glacier

Corresponding Author:
Sabur.F.Abdullaev,
Physical-Technical institute Academy of Sciences of Republic of Tajikistan, Ayni str.299/1, Dushanbe,ZIP-734063, Tajikistan;
Email: sabur.f.abdullaev@gmail.com

DOI: https://doi.org/10.30564/jasr.v2i2.352

1

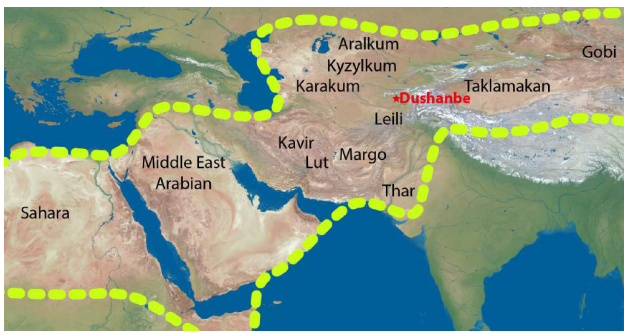melt by altering the glacier's surface albedo [3].

Figure 1. Geographical map with desert regions (black text), dust belt (bright green dotted line), measurement site in Dushanbe, Tajikistan (red text) highlighted (http://naturalearth.springercarto.com, adapted) [4]

It should be noted that in the period up to 1990th (September 20, 1989 to October 15, 1990), predominantly strong dust storms with the subsequent precipitations were observed. These dust storms had a duration of 6-8 hours and were accompanied by a decrease in the horizontal visual range down to 50 meters [5,6].

After 1990s, the duration of dust hazes increased to 3 to 8 days (sometimes for a week). They often created a pulsating change in the range of the horizontal visibility, and, most importantly, were not accompanied by a precipitation. In the summer-autumn period of 2001 dust hazes reached the record frequency. It occurred almost daily with 29 days of dust haze stay in Dushanbe city between July-August. On November of 2007 (from 8 to 24), the dust haze covered the whole territory of southern Tajikistan. Sometimes, the horizontal visibility was less than 200-500 m. In August 2008 (from 4 to 15), and August of 2009 (from 25 to 29), pulsating dust episodes were observed, causing a deterioration of the horizontal visual range down to 200 meters. Often after prolonged dust haze episodes, dust particles were deposited on the ground without any precipitation. These deposits result in very high pollution levels in the surface layer [6]. Thus, it is important to study dust storms in Tajikistan that provide the motivation for this work. The goal of this paper is to provide a comprehensive characterization of dust storms in Tajikistan by linking the environmental conditions, dust properties, and dust diverse impacts.

Aerosol plays an important role in the formation of weather and climate, both regionally and globally. Aerosol is frequently generated by dust storms (DS) in the atmosphere of the arid zone. The fine particle fraction (with a diameter<1 μm) may be transported with the air flow far enough away from the source and it may remain long time in the atmosphere. Atmospheric dust is the aerosol, which significantly absorbs solar radiation and also interact with

thermal radiation [7]. The extent of the observed effects is determined by the microphysical properties of dust particles, namely, by their complex refractive index, particle size distribution, shape, density, and their total concentration in the atmosphere that all control the dust optical properties and dust radiative impacts.

The fine particle fraction (with a diameter <1 μm) may be transported with the air flow far enough away from the source and it may remain long time in the atmosphere. Atmospheric dust is the aerosol, which significantly absorbs solar radiation and also interact with thermal radiation [7]. The nature of the observed effects is determined by the microphysical properties of dust particles, namely, by their complex refractive index, particle size distribution, shape, density, and their total concentration in the atmosphere that all control the dust optical properties and dust radiative impacts.

Depending on the concentration of dust and its vertical profile, time, and duration of the residence of dust in the atmosphere, it may have diverse effects on the air temperature and the land surface vegetation [7-12]. For particle sizes of the order of a few micron or less, which determine the opacity of the dust storms or dusty haze, the visible radiation is absorbed stronger than thermal [11,13]. Therefore, in the afternoon we can expect a decrease in the surface temperature under dusty atmosphere conditions, and at night - a warming in the comparison with normal conditions, since the thermal radiation from the surface will be partially absorbed by a dusty atmosphere and reradiated back. Dust can increase the albedo of the system [8-11].

One of the effective way of determining the optical characteristics of atmospheric aerosol is a photo metric method of direct and diffuse solar radiation. Currently, the most advanced system in the automation of the measurement efficiency of obtaining data and global coverage is network of AERONET aerosol observations (http://aeronet.gsfc.nasa.gov) [14]. In Dushanbe, the study of the AOT (aerosol optical thickness) of atmosphere using the AERONET program was held in July 2010 in the regular mode measurements by the AERONET network with the support of collaborators from the United States, France, and Portugal [13].

For this research the data were taken from the archive of Agency on Hydrometeorology of Tajikistan and website www.r5.ru.

https://rp5.ru/Weather_in_Dushanbe ;
https://rp5.ru/Weather_in_Termez ;
https://rp5.ru/Weather_in_Repetek ;
https://rp5.ru/Weather_in_Bayramaly ;
https://rp5.ru/Weather_in_Qurghonteppa_(airport) ;

2. Classification of Dust Storms and Synoptic Conditions Related to Their Formation in Central Asia

A dust storm is a phenomenon of strong gusty winds that bring into the air large amounts of dust, sand and other particles that are then suspended in the air, causing a decrease in a horizontal visibility down to from 1-2 km to several hundred meters [12,15]. In Central Asia (CA), the main centers of dust storms are the Kyzylkum desert and the Karakum desert. In Tajikistan, dust storms occur most frequently in southern valleys of the Lower Kafirnigan, Vakhsh, Kyzyl-Su, and Yakhsu [16].

A dusty haze is a phenomenon, in which solid particles are suspended in the air and the horizontal visibility is limited to 2-4 km. Dust particles can travel hundreds and even thousands kilometers from the point of their initiation during dust storms. In the case of the turbulent state of the atmosphere, dust can be transported to the heights of 3-4 km, and more. The thickness of the layer of dust haze depends on the wind speed and the vortex structure. Ascending air currents lead to dust haze being lifted up to 5-7 km.

The initiation and spread of dust storms depend on the following two conditions: the presence of suitable materials (dust, sand) and strong winds, which capable to carry particles horizontally and vertically. Favorable conditions for dust storm are created by prolonged dry periods, the presence of loess soils in the foothills, loose sand in the desert, and frequent gales. In Tajikistan, especially the strong dust storm or the so-called "Afghan" occurs in warm seasons (June-September).

The Kyzyl-Kum Desert, Karakum Desert and Aral-Kum are known local sources of dust in the Central Asian region.

The Kyzylkum Desert is the 11th largest desert in the world. Its name means "red sand" in Uzbek and Kazak languages. The desert is located in Central Asia in the flood plain between the rivers Amu Darya and Syr Darya, and is divided between Kazakhstan, Uzbekistan, and Turkmenistan. The desert occupies about 298000 square kilometers.

The Karakum Desert) occupies about 70%, or the 350000 km^2 area of Turkmenistan. The desert located to the east of the Caspian Sea, with the Aral Sea in the north and the Amu Darya River and the Kyzylkum desert in the north-east. The Murghab River and Tedjen River flow from Hindu Kush Mountains in the south and through the desert, providing water for irrigation purposes. The largest irrigation canal in the world is the Karakum Canal that crosses the desert.

An additional source of dust, the Aral Sea, arose in the last quarter of the last century. During the hot season (June-September), the surface is heated by the solar radiation. The moisture evaporates and the upper layer of soil is converted into a friable mass of sand, which is capable of moving by winds, and transferring the fine material from the surface into the atmosphere. Strong winds, especially in the summer, often form dust storms. Note that dust, salt, and sand storms cause extensive ecological and economic damages, especially to the vegetation, agricultural lands, and industrial facilities. They also pose a serious health thread.

It is advisable to consider first not the genetic classification of dust storms (DS), which is rather difficult, but a classification according to some external features. From the point of view of the duration of dust storms and visibility, they [17] propose the following main types:

(1) Short-term dust storms with a relatively small deterioration in the visibility. Their duration often does not exceed several minutes, very often these are dust storms caused by purely local wind features.

(2) Short-term dust storms with a strong deterioration in the visibility. The duration of these dust storms are the same as the first type, but they can cause a drop in the visibility to one kilometer, and sometimes less than a kilometer (to 100 - 200 m) [17].

(3) Long-lasting and pulsating dust storms with a relatively small deterioration of the visibility (2-4 or more kilometers) [17]. Dust storms can last for several hours or even days and are generated by stable pressure fields with large horizontal gradients. Particularly dangerous and difficult the dust storms with pulsating visibility.

(4) Long-lasting severe dust storms with a large deterioration of the visibility (1 - 2 km or less). These are the most dangerous dust storms when you consider that they usually have a greater vertical power [17].

(5) Dusty or sandy storms drifts represent the phenomenon of the transfer of dust and sand in a layer not more than 2 m from the soil surface. In general, dust drifting in its pure form is extremely rare [17].

Dust storm (dust haze) leads to a decrease in the horizontal visibility range. To determine the degree of a reduction of the horizontal visibility range, weather conditions with a relative humidity of less than 50% were chosen, which is typical of the situation associated with DH in Tajikistan. Figure 2 shows the frequency of the horizontal visibility range (in%) is less than 1 km and 10 km in Dushanbe for the period 1950-2014. As one can see, after the 1970s, aerosol pollution associated with dust storms prevails in the atmosphere.
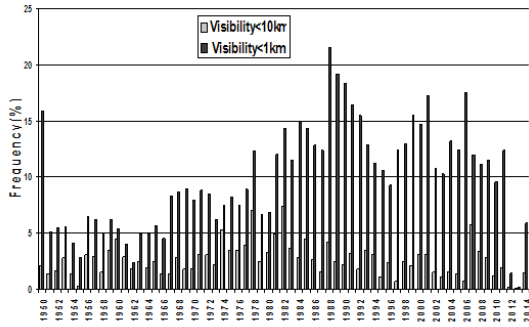
Figure2. The frequency of repeat ability of the horizontal visibility range (in%) is less than 1 km and less than 10 km in Dushanbe city for the period 1950-2014

A long rainless period of summer months in Central Asia and in the foreign territory adjacent to it leads to a strong degradation of the soil surface, as a result of which DS can occur even at low wind speeds (7-10 m / s). If the air mass, moving over the Central Asian deserts, loses contrast in the surface air layer and atmospheric fronts pass through the territory of Tajikistan in a weakened form, then dust storms do not occur. However, dust, reaching a vertical height of 5 km (Figure 3) [5], even from remote sources of DS, can be brought into the territory of Tajikistan in the form of the dust haze (DH) from the desert zone (Figure 4) [5].
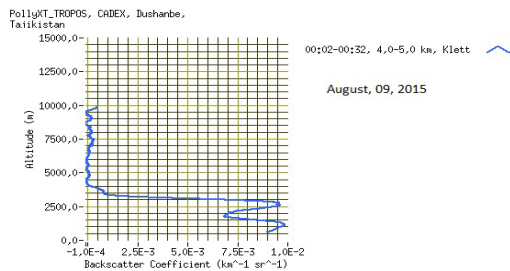

Figure 3. The vertical profile of the back scatter coefficient recorded using the Lidar complex Polly XT - TROPOS during the dust haze period of August 9, 2015 as part of the CADEX project
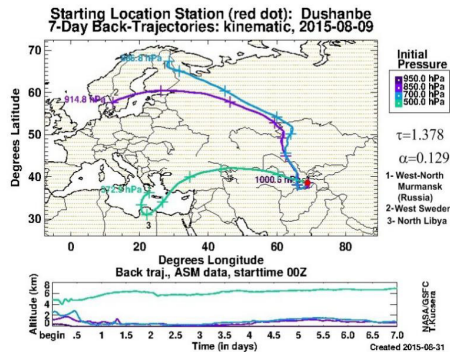

Figure 4. The back trajectory of air masses during the formation of DH

In the case of intense invasions of cold air with the rapid mixing of atmospheric fronts, strong winds arise, causing DS and DH both outside Tajikistan and in its valleys along the route of the air flow. Orography features also contribute to the strengthening of winds in the south-western regions of Tajikistan, and the DS capacities in this zone are associated with the large reserves of loess soils and light gray soils (1000 square kilometers desert). Dust storms invade Tajikistan mainly from the south of the country (Ayvadzh village), while the invasion through a narrow gorge in the south of the republic framed by low mountains (altitude 1100 m) creates an aerodynamic effect, the speed of the invasion can sometimes reach 25-30 m/sec, extending to Dushanbe. Since the Dushanbe city is covered from all sides by mountains, the dust haze may exist for a long time [5].

The Dushanbe city is located at an average elevation of 821 m above sea level, in the intermountain Gissar valley, surrounded from the north by the Gissar ridge, and from the south by the low Rangon mountains. The valley is open only from the western and eastern sides by narrow intermountain passes. The orographic isolation of the valley contributes to the increase of the air circulation, as a result of which windless weather prevails here and, accordingly, a stagnation of pollutants occurs [1-3].

One of the main factors causing the air stagnation is the anticyclonic circulation, which causes the development of powerful retention layers — the inversion layer, when the temperature rises with the height, or the is other mal layer, when the temperature in a certain surface layer remains constant. Inversions that have the most significant effect are formed on clear and cloudy nights due to the cooling of the surface air layer. In addition, during the winter period, the arctic front plays a role of the retaining layer, which penetrates into the valley and sharply cools the surface layer of the air at an altitude of 1-1.5 km.

As a result of these phenomena, there is a retention and accumulation of pollutants. Such substances include: particulate matter (dust, combustion products) and harmful gases (CO, ground-level ozone, NOx, etc.).

Some episodes of the dust haze for the period 2010-2015 are shown in Table 1 and Table 2, indicating the aerosol optical thickness (AOT) (at λ= 1020, 500 and 340 nm), water vapor amount (W, cm), Angstrom parameter $\alpha(\lambda)$, fine and coarse and total fractions of AOT at 500 nm, the number of measurements per day (N), the value of the daytime cooling and nighttime warming, as well as the mass concentration of particle matter less than 10 mm (PM10) for these days. For comparison, these characteristics are given for particularly clear days of this series [6].

Table 1. Some episodes of the dust haze for the period 2010-2012

Date	τ			W(cm)	$\alpha(\lambda)$	AOT (500nm)			N	dT_d	dT_n	PM10($\mu g/m^3$)
	1020nm	500nm	340nm			Total	Fine	Coarse				
06/14/2010	1.876	1.795	1.866	2.369	0.025	1.787	0.168	1.619	6	-2.6	3.3	748
08/23/2010	2.533	2.775	2.878	2.605	0.12	2.77	0.479	2.291	25	-1.3	4.2	1156
08/24/2010	0.846	0.934	0.959	1.41	0.1	0.932	0.151	0.781	16	-5.2	2.3	389
10/02/2010	*0.03*	*0.053*	*0.07*	*0.431*	*0.553*	*0.052*	*0.021*	*0.031*	*59*			*22*
10/13/2010	1.446	1.528	1.571	2.02	0.073	1.527	0.218	1.309	8	-2.3	5.2	637
10/22/.2010	1.037	1.084	1.081	0.762	0.033	1.084	0.147	0.938	43	-12.2	5.4	452
01/21/2011	2.136	2.32	2.538	1.097	0.17	2.318	0.447	1.87	2	-2.8	6	967
01/30/2011	1.299	1.334	1.437	1.155	0.095	1.334	0.195	1.139	2	-2.8	5.5	556
03/06/2011	1.323	1.356	1.452	1.07	0.087	1.354	0.196	1.158	1	-2.5	6.8	565
03/23/2011	0.714	0.704	0.739	0.872	0.214	0.706	0.076	0.63	8	-1.8	1.2	293
08/08/2011	1.602	1.749	1.818	2.031	0.103	1.75	0.305	1.445	33	-3.8	1.1	729
08/26/2011	1.766	1.994	2.093	2.641	0.149	1.995	0.42	1.575	37	-4.4	1.6	831
10/06/2011	2.68	2.661	2.623	1.428	0.027	2.665	0.271	2.394	11	-4.3	3.7	1109
10/07/2011	1.415	1.4	1.416	1.578	0.011	1.401	0.129	1.272	36	-6.1	0.5	583
10/08/2011	0.862	0.896	0.947	1.537	0.068	0.896	0.125	0.771	30	-5.7	0.3	373
11/30/2011	*0.03*	*0.069*	*0.11*	*0.52*	*1.427*	*0.557*	*0.452*	*0.104*	*11*			*29*
05/16/2012	1.857	1.856	1.932	2.174	0.031	1.854	0.207	1.647	2	-4.5	1.6	773
07/13/2012	0.947	1.072	1.115	1.406	0.133	1.07	0.218	0.852	64	-2.8	0.8	447
08/25/2012	0.886	0.989	1.048	1.905	0.136	0.987	0.179	0.808	48	-6	3.6	412
12/21/2012	*0.021*	*0.058*	*0.094*	0.718	1.685	0.12	0.104	0.015	18			24

Table 2. Some episodes of dust haze for the period 2013-2015

Date	τ			W(cm)	$\alpha(\lambda)$	AOT_500nm			N	dTd	dTn	PM10($\mu g/m^3$)
	1020nm	500nm	340nm			Total	Fine	Coarse				
02/07/2013	*0.018*	*0.047*	*0.071*	*0.291*	*1.562*	*0.114*	0.103	0.011	9			*20*
02/09/2013	2.506	2.539	2.694	1.211	0.059	2.534	0.325	2.209	1	-3.4	3.3	1058
02/27/2013	1.774	1.959	2.132	0.929	0.186	1.955	0.401	1.554	1	-11.2	9.3	816
03/01/2013	1.17	1.129	1.162	0.879	0.016	1.129	0.096	1.033	2	-14.4	6.3	470
03/22/2013	1.487	1.423	1.429	0.87	0.036	1.42	0.098	1.323	12	-1.4	3	593
05/19/2013	0.581	0.633	0.686	1.902	0.108	0.632	0.099	0.533	25	-6.5	4.6	264
07/05/2013	0.333	0.451	0.585	1.942	0.55	0.448	0.146	0.302	32	-1.9	2.9	188
08/01/2013	0.509	0.795	1.053	2.586	0.684	0.789	0.359	0.431	2	-5.9	0.9	331
08/07/2013	0.35	0.489	0.645	2.209	0.518	0.486	0.169	0.317	35	-2.7	1.5	204
11/05/2013	1.254	1.306	1.349	1.551	0.075	1.305	0.185	1.12	1	-2.2	7.2	544
11/23/2013	0.865	1.062	1.253	0.991	0.367	1.06	0.312	0.749	1	-1.8	1.6	443
07/02/2014	1.393	1.516	1.619	2.275	0.122	1.516	0.243	1.273	50	-4.6	3.4	632
07/25/2014	0.565	0.644	0.708	1.493	0.149	0.644	0.117	0.527	60	-2.9	2	268
07/26/2014	0.449	0.537	0.627	1.679	0.233	0.536	0.119	0.417	58	-3	0.6	224
07/30/2014	0.505	0.655	0.803	2.185	0.367	0.654	0.187	0.466	30	-6.5	6.2	273
08/15/2014	0.941	1.055	1.123	1.481	0.141	1.054	0.196	0.858	11	-7.6	4.6	440
09/28/2014	1.021	1.1	1.138	1.749	0.074	1.1	0.162	0.938	36	-5	3.2	458
11/19/2014	1.047	1.209	1.387	0.961	0.412	1.206	0.287	0.92	5	-4.8	3.8	504
11/20/2014	0.488	1.25	1.791	1.311	1.285	1.239	1.116	0.123	2	-8.9	0.8	521
12/27/2014	0.017	0.045	0.067	0.298	1.333	0.382	0.049	0.333	8			*19*
01/01/2015	*0.088*	*0.161*	*0.23*	*0.418*	*0.942*	*0.078*	*0.033*	*0.045*	*14*			*67*
07/06/2015	1.106	1.208	1.247	1.655	0.088	1.208	0.204	1.004	27	-5	7	503
07/21/2015	1.112	1.253	1.357	2.441	0.171	1.252	0.241	1.011	33	-7	3	522
08/09/2015	1.212	1.378	1.43	1.383	0.129	1.377	0.28	1.097	54	-5	6	574

The high values of AOT, PM10 and low values of the Angstrom parameter indicate the presence of the dust. The duration of dust in the atmosphere of Dushanbe due to the city's relief is alarming[6]. Table 1 and Table 2 present episodes of pure dust cases ($\tau \geq 0.4$; 0.2) and some data of the clean atmosphere ($\tau < 0.2$; 1.5). In the spring, the Iranian branch of the polar front begins to shift to the north and passes through Central Asia. At this time, temperature

contrasts at the front reach their maximum value, which leads to an increase in the intensity of cyclones. The cyclonic activity in the southern areas of Central Asia, including Tajikistan, causes a pronounced early spring (March - April) maximum in the precipitation [13,14,17,18].

In the valleys of Tajikistan, the dust haze may be a result of the dust storm. This dust haze is delayed by the high mountains more than 2000 m high and lasts from a few days up to a several weeks. Over the last 20-30 years, a number of dust haze events in Tajikistan has increased. In addition, the haze may come from other areas: from the southwest, and south (from April till November every year). The wind that brings it has received a local name of "Afghan". The "Afghan" is of a gray color, reminiscent of fog or haze. The name of the "Afghan" has no scientific evidence as most dust invasions of Tajikistan have a long-term source such as the Sahara deserts east of the Caspian Sea, the Iranian Dasht-e-Kavir and Dasht-e-Lut deserts, the Aralkum desert of the desiccating Aral Sea, the Kyzyl-Kum and Karakum and the deserts in Afghanistan, and Taklamakan desert. The Afghans call this dust invasions "Shuravi" (mean dust come from Soviet Union) as the dust invasions enter Afghanistan through the desert zone of Uzbekistan [5].

Besides the "Afghans", in rare cases that occur (ones every 5-10 years), a dust haze can be transferred from the east of the Taklamakan Desert (China). As a result, the glaciers and snowfields are painted by the light orange color. The local name of this dust haze is "Chinese". This type of dust haze is observed in springs (March - April). This dust haze reaches eastern Tajikistan, and very rarely, once in 20-30 years, it carries over to western Tajikistan. Dust storms in the Taklamakan desert occur on the southern periphery of a strong anticyclone centered in the region of the Lake Balkhash [5].

3. The Number and Duration of Dust Haze Episodes

The bulk of the Central Asian dust storms develops over its lowland area, where the most favorable conditions occur. However, the distribution of dust storms in different parts of Central Asia is extremely uneven. It varies greatly and depends on the place of the origin, the type of synoptic processes, seasons and local topography.

The Figure 5 shows the number of days with the dust haze in Termez, Shaartuz, Kurgan-Tube, and Dushanbe in the period between 2000 and 2014. The average annual number of days with the dust haze in Dushanbe is 12, with seven of which having a strong dust haze, when the visibility is less than 2 km.
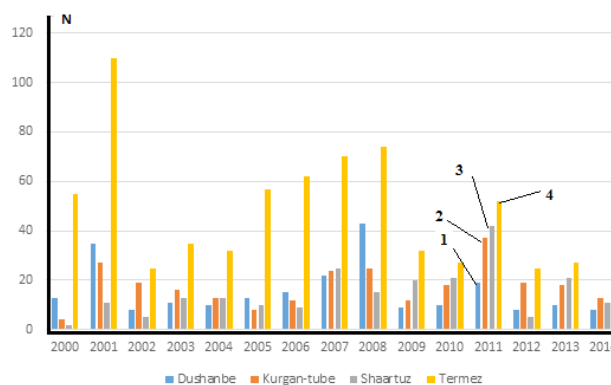

Figure5. The number of episodes of the dust hazes during the 2000-2014 period at stations: Dushanbe (1), Kurgan-tube(2), Shaartuz(3), and Termez (4)

In the early 1990s, short term dust hazes that lasted 5-7 hours were very strong. In the later part of the 1990s, dust hazes sometimes lasted several weeks, with a visibility of less than 2 km. For example, in 2001, dust hazes reached the record frequency, with an almost daily occurrence in Dushanbe between June and August. There was 29 days continuously dust haze stay in the atmosphere of Dushanbe between July to August 2001.

Our studies [19-22] have confirmed that a dust haze leads to a daytime cooling of air by 3-8°C and a nighttime warming by 2-5°C compared with a clear weather condition. Between November 12 - 20th of 2007, the dust haze covered the whole territory of southern Tajikistan. Sometimes, the horizontal visibility was less than 200-500 m. It should be noted that in the period from September 20, 1989 to October 15, 1990, predominantly strong dust storms with the subsequent precipitations were observed. These dust storms had a duration of 6-8 hours and were accompanied by a decrease in the horizontal visual range down to 50 meters. After 1990s, the duration of dust hazes increased to 3 to 8 days. They often created a pulsating change in the range of the horizontal visibility, and, most importantly, were not accompanied by a precipitation event. In the summer-autumn period of 2001, November of 2007 (from 5 to 24), August 2008 (from 4 to 15), and August of 2009 (from 25 to 29), pulsating dust episodes were observed with a deterioration in the horizontal visual range down to 200 meters. Often after prolonged episodes of the dust haze, dust particles were deposited on the ground without any precipitation. These deposits result in very high pollution levels in the surface layer.

Figure 6 shows the results of our analysis of the duration of dust haze episodes. The trend in the number of dust episodesis similar for all stations. The duration of the dust haze over 2005-2014 was uneven in its nature,

showing a varying dust activity with time.

A seasonal change in the duration of episodes of the dust haze for each observation point (Figure 6) shows some peculiar features. Months of the clean atmosphere or "dusty" months remain overlap for each meteorological station. These features are consequence of station geographical locations. The maximum duration of the dust haze for all meteorological points was observed in the summer time [19-22]. Durations of the dust haze in Dushanbe are more than in other sites because the city is surrounded by heals and mountains.
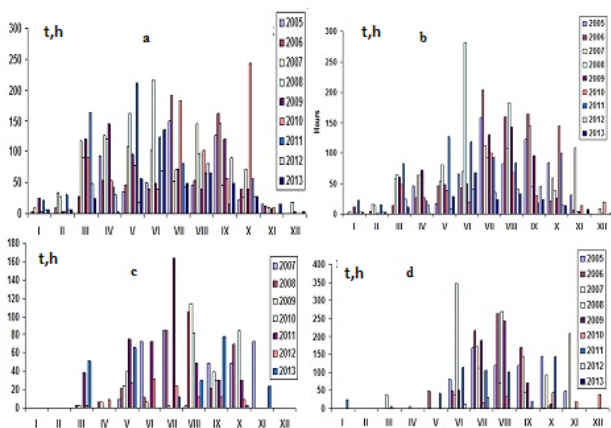

Figure6. Duration of dusty haze episodes (in hours) in the period 2005-2014 at four stations by month: Termez (a); Shaartuz (b); Kurgan-Tube (c); and Dushanbe (d)

During the instrumental observations 1961-2013, we have found an increase in a decade the mean annual temperature of 0.7-1.2°C in the lowland areas of Tajikistan. A temperature increase (about 0.1-0.7°C) was observed in the southern regions of the country. In the mountains of central Tajikistan, Rushan, and the lowland of the Zarafshan, there was a small reduction of temperature of 0.1-0.3°C.

In large cities, the growth of the temperature was especially significant and reached 1.2-1.9°C, an effect that is clearly associated with the urbanization (building heating, roads, buildings, the impact of transport, businesses, etc.).

Figure 7 shows the dynamics of the average annual temperature in Dushanbe for the last 60 years. Our analysis of the meteorological data indicates a trend of an increase in the mean annual air temperature. Over 60 years for the Kurgan-Tube (elevation 426 m) an increase was 1.9°C, for Dushanbe (803 m), - 1.72°C, for Haramkul (2800 m) - 1.33°C, for the glacier Fedchenko (elevation 4169 m) - 0.73°C. In 1997, the widely observed increase in the average annual temperature was 1-2°C, in 1999 it was 1.2-2.1°C, and in 2000, it was 1.5°C over the long-

term average temperature. These increases have a significant impact on the state of glaciers and water resources of the region.
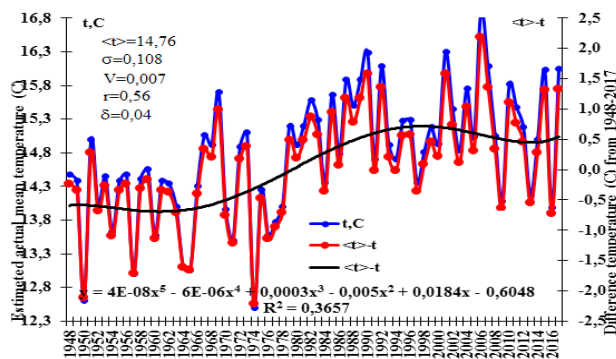

Figure 7. Dynamics of changes in mean annual surface air temperatures in Dushanbe

The highest temperatures were observed in 1990, 1992, 2001, 2006 and 2007. Figure 7 shows that for these years the mean annual temperature was always greater than 16°C. The period between 1950 and 1974 was the coldest of the last century. Most recently, the coldest winter was during 2007-2008. It was the coldest winter of the last 25 years, with the seasonal mean temperature dropping to -5°C, which is significantly lower than the average for 60 years. Since the end of the 1970s over the whole of Tajikistan, a lot of the forest area was cut, creating favorable conditions for the development of semi-arid areas in the country. The reconstruction of forests will take several decades [16].

The increase of air temperature on the plain regions of Tajikistan constituted, on the average, 0.1-0.2°C in a decade. The biggest increase for the 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 (Figure 8). An insignificant increase of temperature in Khujand is most likely related to the development of irrigation and building of the Kayrakkum water reservoir. The increase of the annual mean temperature in mountainous areas constituted 0.3-0.5°C in the 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 decrease of temperature (-1.1°C) during this period is noted in the kettle of the Bulunkul Lake, which could be related to the characteristic features of climate in the Eastern Pamir [3].
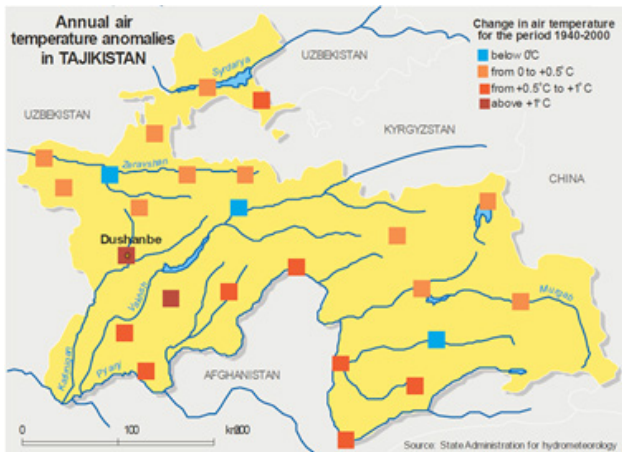
Figure 8. Annual air temperature anomalies in Tajikistan for the period 1940-2000 [3]

An analysis of the meteorological data for the last thirty years shows that around the 1980s, Tajikistan observed strong dust storms, especially in September 1989 and October 1990 that were 7 to 11 hours long. Over the last thirty years, observed dust hazes typically last 4 to 15 days, and are accompanied by a pulsating change in the visibility, typically ending without a rain. Several strongest dust hazes occurred in the summer-autumn of 2001 (dust stays in the atmosphere for 29 days during July-August 2001), November (5 to 24) of 2007 and August (from 4 to 15) of 2008, August of 2010, and July-August of 2011. They pulsed with the horizontal visibility range down to 200 meters. After the dust haze ends, the rainfall does not occur and sub-micron dust particles remain in the atmosphere in the surface layer for a long time [5].

The climate warming in the next 50 years could lead to a global climate catastrophe. Under climate warming, arid zones in Tajikistan may experience drought and expansion of desert areas (desertification areas), which may lead to more frequent dust storms (or dust hazes) in the Central Asia region. Especially dangerous, the effect of warming could be on the glaciers, which are the main sources of fresh water in the region.

4. Aerosol Characteristics of Dust Storms in Tajikistan

The climatic effects of aerosol are primarily determined by the complex refractive index of the particles $m=n-i\kappa$, which determine the ratio between absorption and scattering radiation by particles [9,11,23-26]. These aerosol characteristics affect the dust optical properties and hence dust radiative impacts.

Several methods are used to determine the real and imaginary parts of the refractive index of dust aerosol. They can be divided into two groups [24]. The first group includes methods for determining the real, n, and imaginary, κ, parts based on measurements of optical and radiative characteristics of aerosol in the atmosphere by applying the inverse solution of problems [27]. The second group includes methods that involve the analysis of dust aerosol samples. These methods, in turn, can be classified as follows: modeling techniques, by using the modeling of known refractive indices of the main components of substances [9,11]; methods of the diffuse reflection, which is based on the theory of Kubelka – Munka [28,29]; the Kramers-Kronig method [30-36]; and diffuse transmission methods [36-38].

A characteristic feature of the first group of methods is that they allow to identify some of the effective value of the imaginary part of dust aerosol present in real atmospheric conditions [24]. For example, [39] describes a method for determining κ for atmospheric dust with respect to the direct and diffuse solar radiation reaching the Earth's surface. It is assumed that the particles are spherical and the size distribution of particle is precisely known, in particular, [40] use the Jungle distribution type. A determination result of is highly dependent on the choice of the surface albedo. In a slightly modified form, the method is used in [41], where for Saharan aerosol was obtained the values of κ=0.0029; 0.008; 0.018, respectively, for λ=0.61; 0.468; 0.375 m, assuming that . The size distribution of the particles was determined experimentally.

Methods of the second group are associated with a number of technical difficulties encountered in their implementation. In addition, a potential drawback of these measurements may be that the selection and preparation of aerosol samples are distorted that affect measured optical characteristics [24]. The first approach of the second group classification discussed above found its development in [26,42,43]. It is based on an assumption that the effective refractive index of the material can be modeled by considering it as a mechanical mixture of compounds, which is established from the chemical analysis of aerosol samples. In particular, Andronova, Zhukovsky and Mandibles [42] describes a model of the aerosol chemical composition, which most closely matches the composition of the samples taken in the steppe and desert zones. Given values of are for the relative humidity of 18-25%, Andronova, Zhukovsky and Mandibles [42] showed that for this model of arid aerosol, an increase in the proportion to free water leads to a smoothing of the spectral variation of $n(v)$ and $\kappa(v)$; values of $n(v)$ in the visible region is reduced from n=1.65 when the relative humidity f = 18 ...25% to n=1.382, f = 75 ...85% [24].

Different approaches exist for estimating n and κ, consequently, κ, using R. Authors of [28,41] present a com-

monly used approach, based on the Kubelka-Munk theory. According to this theory, one does not need any prior information on the properties of the particle sample. Data for κ, obtained in these studies are presented in [23].

Another approach to define m from the measured reflection is the Kramers-Kronig relations, developed in [30]. The essence of the method is as follows: the measured reflection spectrum $R(v)$ (v - frequency) is used to calculate the phase shift $\Theta(v_0)$ using the dispersion relations

$$\Theta(v_0) = -v_0/\pi \int_0^\infty lnR(v)/(v^2-v_0^2)dv \quad (1)$$

This method allows to define the complex amplitude reflection coefficient

$$r(v_0) = R(v_0)^{0.5} exp(i\Theta(v_0)) \quad (2)$$

Then, using the Fresnel formulas one can determine the complex refractive index $m(v_0)$ and, therefore, determine the characteristics of $n(v_0)$ and $\kappa(v_0)$ [24]. To determine the optical constants of dust aerosol, we use the infrared spectrum (IR), where the diffuse transmittance is usually applied. In general, these methods differ in the preparation of the samples. The most widely used method is preparing tablets of KBr [31,42,44]. In this method, the dust aerosol powder mixed with KBr or other alkali metal halide, is compressed into a tablet form. The essential requirements of this approach are: a limit on the size of the particles of the substance ($r < \lambda$), where λ is the wavelength, and the proximity of the refractive index of the alkali metal halide to the index of the refraction of the analyzed material in the transparency window.

An application of the method on a KBr tablet to the study of dust aerosol has yielded spectra of n and κ in the IR [31,44]. The values of the real part were calculated by the Fresnel formulas based on the found range of κ. A slightly modified version of the method was used to determine the optical constants of the samples of soil and dust [44]. The average value of κ for eight different types of dust is presented in [23,24].

In September of 1989, on the territory of Tajikistan, the Soviet-American complex experiment was held to study the lifting of dust, chemical, microphysical, and optical properties of dust aerosol and its impact on local weather conditions and climate [45]. The experiment took place in the framework of the Soviet-American agreement on the environmental protection plan for the Working Group VIII. In addition, experiments were conducted in the Karakum Desert, based in the Repetek sand-desert reserve in 1970. They provided the important data on the profile of solar and thermal radiation. More detailed studies of the optical characteristics of dust were carried out during the

Global aerosol-radiation experiment (GAREKS) in 1977 and 1979 [46].

Golitsyn [45] describes the objectives and the plan of the conducted experiment that took place in the south of Tajikistan in the fall of 1989, see Figure 11. The objectives included the study of the characteristics of dust aerosol and its impact on the radiative fluxes, and consequently on the local weather conditions and climate. Synoptic conditions during the experiment were described in [47]. During the experiment, a satellite observation [48] and airborne sensing [49] were also conducted. The study on the deposition of dust showed that in Shaartuz, 10-30 dust storms were observed per year, and measured average annual values of the intensity of deposition of dust aerosol were 206-617 g/(m^2 year).

The model of deposition and transport of desert dust for the Valley of the Kafirnigan River (Figure 9) was constructed using the results of the study of the dust storm that occurred on September 16 and 20, 1989 in Shaartuz [45]. In [50], an analysis is presented of the temperature in the atmosphere surface layer in September 1989 during the Soviet-American experiment, showing that there is a marked cooling of the air under the dust haze layer. Experimental evidences suggest that the decrease in temperature and amplitude of its diurnal oscillations coincide with a decrease in the visibility range. A significant increase in the optical thickness during the dust storm was observed [51].

The result of dust microphysical studies were presented in [45]. This study reported that in the arid zone of Shaartuz, the particle size distribution in the range of 0.1-2 microns can be approximated by the Young's distribution, and in the range of 2-20 microns, it can be represented by the lognormal distribution. Results of the measurement of the optical thickness of the atmospheric aerosol obtained by the Soviet and American experiments are shown in [45].

Figure 9. Scheme of the Kafirnigan valley in the southwest of Tajikistan, 1, 2, 3, - ground station data collection: Shaartuz, Esanbay, Dushanbe, respectively, 4-Kurgan-Tube, 5-Termez, 6-Repetek, 7-Bayramali

The altitude range of transport of arid aerosol largely depends on the source of the dust, and on the set of atmospheric processes. It is believed that the transcontinental transport of dust from the Taklimakan Desert occurs just under tropopa use layer (~ 10 km) [38,52]. Over Japan Asian dust aerosols observed in a wide range of heights from 6 to 10 km [43].

5. Temperature Effects of Dust Storms in Southern Tajikistan

In this section, we analyze changes in surface air temperatures during a dust haze event in the atmosphere over Dushanbe, Shaartuz, and Esanbay, in September 1989. We also present quantitative estimates of the cooling of the air that reduces the amplitude of the daily temperature fluctuation with the reduction of the horizontal visibility range. For these estimates, measurements of the direct solar radiation, taken by an actinometer, and the attenuation coefficient of air photoelectric aerosol turbidity (by using photoelectric aerosol Nephelometer (PhAN) are being used.

Golitsyn and Shukurov [10] studied the effects of dust on the temperature using the example of dust storms in the south-western region of Tajikistan. Their study focused on the relationship between the temperature of the surface air layer and the horizontal visibility S_m, based on the data from five weather stations - Ayvaj, Shaartuz, Kurgan-Tube, Sanglok, and Dushanbe, which are located in the direction of south-to-north, similar to the movement of the air in the periods of dust storms. A distance from Ayvaj to Dushanbeis about 250 km. The data are from 10 days of strong dust hazes, which occurred in theJuly-August1976, 1979, 1980, and 1984 with the vertical thickness of the dust layer reaching 1.2-2.5 km, S_m values ranged from 0.2 km to 10 km.In the daily course often, almost in all cases,there was a decrease of temperature during the daytime, and an increase in the temperature at night in comparison with clear conditions. The temperature was measured 8 times a day, every 3 hours(Moscow time: GMT+3, day startswith00 hours).

All analysis gave the same results: a reduction in average daily temperature with decreasing S_m. This fact suggested the possibility to consider a dust haze as a natural analogue of the smoke haze in the study of climate effects of nuclear war fires[53-55].

Our study describe a detailed analysis of the temperature data obtained at the meteorological stations: Dushanbe, Shaartuz, and Esanbay. We investigated actinometrical atmospheric transparency P_a by aerosol, the attenuation coefficient in the atmospheric boundary layer σ_a, km⁻¹

and temperature effects for each episode of the dust haze. During the experiment, there were only two episodes of dust: the moderate haze during September 16-18, 1989 (the 1st episode) and the thick haze on September 20-21, 1989 (the 2nd episode). Synoptic conditions during the experiment described in [47]. The values of the average daily drop of the temperature (ΔT) and the amplitude of the temperature oscillations (ΔT_A) in its daily course were evaluated only for the 1st day of the dust haze on 20 September. The results of measurements air temperature t (° C) (see Figure 11), actinometrical transparency of the atmosphere in aerosol (P_a) and the attenuation coefficient σ_a, as well as obtained from these data values of the aerosol optical thickness of the atmosphere, $\tau_a=-lgP_a$ and σ_a, are shown in Figure 12.

Figure 10 (a) dots denote: I –values t, measured at the meteorological station Dushanbe; II-value t, which could be realized in 09 hours on September 20 in the absence of the dust haze; III-value t which could only be realized due to the arrival of the cold air mass. The envelope line of I held on the maximum t in the non-dust days 15, 19, and 28 September; the envelope-line II-done with the minimum night t in the non-dust days of 25 and 28 September; the envelope line III-done with maximum daily values of t in clear days25 and 28 September; the vertical dashed line IV is in the period 09 hours, close to the time of the invasion of the cold air mass in the range of Dushanbe; poly line V-conducted by the values t measured in the term of09 hours to determine the day with a maximum turbidity of the air.

The solid vertical lines denote the beginning and end of the precipitation event. Oblique dashed line shows a designated intervals maximum t, day at 12 and 15 hours and the minimum in 00 hours and 03 hours. Due to the lack of value of t, 15 and 21 h points are joined by a dotted line.

As can be seen from Figure 10, the main features in the behavior of day and night, ºC, when the dust haze agreement with the data [10] days, temperature values t fall due to the general weakening of the solar radiation in the visible and infrared radiation emitted from the earth surface caused by dust hazes. The absolute values of the daytime cooling of the air are higher than its night time warming. The same result can be seen for meteorological stations Shaartuz and Esanbay.
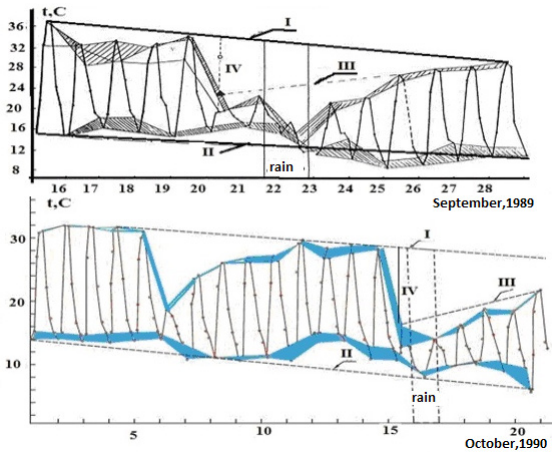
Figure10. Variations surface air temperature in Dushanbe during the dust storms: a - in September 1989, b - in October 1990

During the second episode of the dust storm, with the arrival of the cold air mass between the 06 and 09 hours on September 20, within 09 hours according to Figure 10, the temperature was reduced by about 10^0 (Figure 10 shows the difference in t, $^{\circ}$C, levels 3 and point 1 of the envelope). This finding is consistent with the data [56]: the intrusion of the cold air on the territory of Tajikistan(Weather data in Ayvaj) 02 hours on September 20, causes a sharp decrease in the air temperature.

The line I (Figure 11) indicates amonotonic decrease in t, $^{\circ}$C from 15 to 29 September by about 10°C, which in overall agree with many years of average data on the temperature in this period by about 6°C.

Thus, the analysis of the results showed that for the first dust episode(September 17) daytime temperature dropped relative to the line 1 is for Dushanbe - 2.4°C, for Shaartuz - 5.5 $^{\circ}$C, and for Esanbay-5 $^{\circ}$C. The nighttime temperature is increased relative to the line II, respectively 2°C, 3°C, and 1.3°C.

For the second dust episodeon September 20, the daytime temperature dropped to the line I is14 $^{\circ}$C for Dushanbe, 11°C for Shaartuz, and12.4°C for Esanbay. The night temperature increased relative to the line II of the2.4°C, 3°C and 2°C, respectively.

Figure 11(dots) denotes 1 - P_a values of the transparency of the atmosphere, according to solar radiation measurements (angular height of the Sun on September 15-20 was 53°, the number of air masses, respectively, m=1.2). Dots 2 show value of S_m,calculated as $S_m=3.9/\sigma_a$. Dots 3 show values of the optical thickness of the atmosphere in aerosol conditions obtained from the relationship; Dots 4 show values of σ_a.

As noted above, σ_a was measured on September 17 and 20, the rest of the values σ_a reconstructed from the σ_a

comparison with τ_a the values measured at noon on September 15-19. The numerical values of these quantities are given in Table 1, indicating the value of the mean-square deviation and relative errors.

The value of P_a, σ_a, and τ_a refer to the effective wave length λ=0.5μm. Evaluation of the vertical thickness of 1 dusty haze of the 1 st episode of the ratio $\tau_a=\sigma_a L$ gives L=0.9 in the direction of the sun.This result is consistent with the conclusion of [10], if we consider that Dushanbeis located at a height H=0.821 km above sea level.
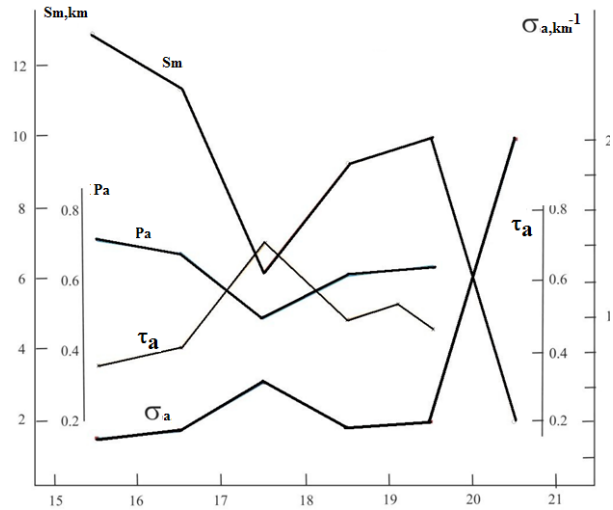

Figure 11. Diurnal variation of different optical parameters of the atmosphere during the first and the second dust episodes: S_m – horizontal visibility, σ_a - back scattering coefficient, P_a – transparence of atmosphere, τ_a- aerosol optical thickness (on the X axis - days, September 1989)

As can be seen from Figure 11 and Table3 the value of S_m in the period of the 1stepisode of the dust varied in a range from 6.3 km to 13 km, which is consistent with the assessment of the values of S_m for the 1st episode at the meteorological station, in which S_m=*4-10*km . According to measurements with PhAN, a value of September 20 is 2 km, which gives the value of S_m=2km. However, according to all meteorological stations(Shaartuz, Esanbay, and Dushanbe), as noted in [57], the values of S_m fall to 0.5 km.

The data processing procedure is somewhat different from that used in [10]. However, the average daily temperature for the for $t_d = \sum_{i=1}^{6} t_i / 6$ 06 - 21 hours period and average night $t_n = \sum_{i=1}^{2} t_i / 2$ for the period 00 and 03 hours, then everyday, starting from September 15to September 20, inclusive, were determined by the total temperature $t_c=t_d+t_n$. The further procedure of the data processing is shown in Figure 14,where the straight lines 1 and 2 are plotted as envelopes according to the values ofat noon on

September 19and15, on midnight on September 15 and 18 in the clear day.

Table 3. The mean values of P_a, τ_a, σ_a (km^{-1}) .The columns are standard deviations for the P_a and τ_a . The relative errors of σ_a and P_a . S_m for 17 and 20 September 5% for σ_a, S_m 15, 16, 18, September. The values of Δ_T, K and ΔT_a, K obtained by the envelope method.

N	Day	P_a	$\dfrac{\delta P_a}{10^3}$	τ_a	$\delta\tau_a\,10^3$	σ_a	S_m	ΔT,°K	ΔT_A,°K
1	09/05/89	0.70	7	0.35	1	0.305	12.8	0	13.6
2	09/16/89	0.67	9	0.40	1	0.330	11.8	0.9	9.6
3	09/17/89	0.49	3	0.71	5	0.616	6.3	2.2	6.4
4	09/18/89	0.62	30	0.48	4	0.400	9.8	2.1	9.0
5	09/19/89	0.63	20	0.47	4	0.380	10.3	0.4	12.2
6	09/20/89	-	-	-	-	2.00	1.95	6.7	2.8

Lines shown on Figure 12 were drawn from the values of the daily average temperature t_d and the night average temperature t_n , values ΔT,°K ,are the daily cooling temperature under a layer of haze estimated as $\Delta T = \Delta T_d + \Delta T_n$, where ΔT_d is the difference between the values t_d and $t_{skirting}$ envelope on the line1 (see explanatory notes to). ΔT_n is the difference of values between t_n and $t_{skirting}$ on the envelope line 2 values, ΔT_n is defined as the temperature difference between noon and midnight smoothed lines 1 and 2 (envelope method discussed in further details in [50]).

The Figure 12 presents the main results of this analysis. Dots denote the 1-values T. These values are assigned to each episodeasa dust-to-one in general; 2-values of ΔT,°K ,according to the present study-prepared by the method of envelopes (see interpretation of Figure14).

The results of this study confirm the main conclusions of [10], the system decrease in T ,at the earth's surface and the amplitude of the diurnal oscillations with decreasing S_m .
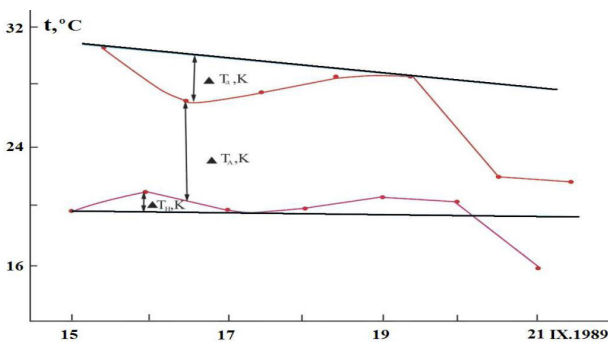

Figure12. Explanation of the definition of the envelope method ΔT value and ΔT_A at the different S_m.

Taking into account the data of this work and that of [10], it can be argued that values of ΔT , ΔT_A and S_m have a fairly definite relationship in the range of S_m minimal to

S_m=12km . When $S_m > 12$ values ΔT are negligible and close to ΔT_A during clean days.

It should be noted that in October 1990,two episodes of the strong dust storm(October 6, 1990 and October 15, 1990) were observed. Dust storms led to a sharp decrease in the daily temperature and a warming in the night temperature. Meteorological visibility reached 0.5 - 1 km. The moderate dust haze on October 12, 1990, led to a decrease in the daily temperature and an increase in the night temperature.

When comparing the amplitude of the temperature of the clean day before the dust storm and the clean day after the dust storm, we obtain the night warming up to 8 ^{0}C and the daytime cooling to -16^{0}C (Figure 13a). When comparing the amplitude of the temperature of the clean day before dust haze and clean day after the dust haze, we obtain some night warming up to 4^{0}C , and the daytime cooling to 3^{0}C (Figure 13b).
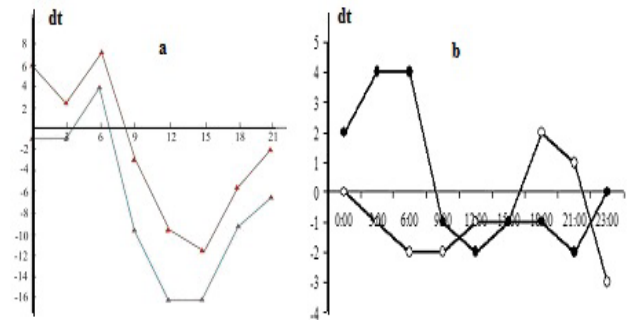

Figure 13. Comparison of the amplitude of the temperature of the clean day before the dust storm and clean day after the dust storm (September 20,1989) (a): Comparison of the amplitude of the temperature of the clean day before the dust haze and the clean day after the dust haze (August 09,2015) (b)

6. The Temperature Effect of Dust Aerosol during a Dust Haze Event in the South of Tajikistan

The data on meteorological parameters of the atmosphere were obtained from the site http://www.rp5.ru. For the analysis of the meteorological data, we collected the data in the period from November 8 to November 21, 2007,when there were a few interesting dust episodes. The values of ΔT and ΔT_A , the average daily temperature drop sand the amplitude of the oscillations in its daily course, were evaluated for all episodes of November 08 to November 21, 2007 (see Figure14).

The results of temperature measurements and measurements of the aerosol scattering coefficient, σ_a , and obtained from these data values of the aerosol optical depth

$\tau_a=-lgP_a$ and σ_a shown in Table 2, the temperature settings are shown in Table 3. P_a is the aerosol transparency of the atmosphere.
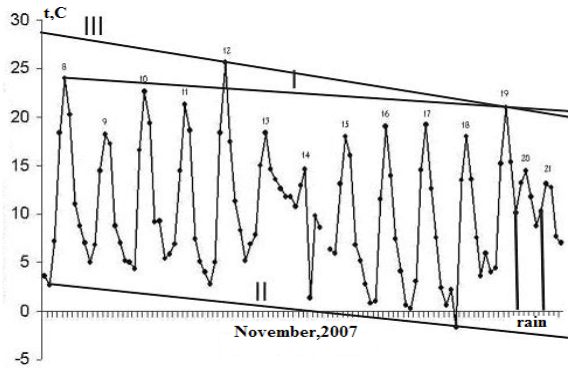

Figure 14. Variations in the surface air temperature in Dushanbe during the dust haze in November 2007

Values of σ_a were measured on November 8 and 12, the rest of the values reconstructed from the measured values of σ_a and τ_a in the afternoon of November 9, 10, 13...21. The value σ_a for dust episodes that occurred on November 9, 13, 14, 15 and the data, τ_a on these days were measured. The values of S_m , km, calculated from the data σ_a with the ratio of $S_m=3.9/\sigma_a$ from the measured values of the aerosol scattering coefficient, σ_a. Evaluations of the vertical thickness of the dust haze in the first episode give L=1.9 km in the direction of the Sun.

Figure 14 shows the line I, which is computed with maximum temperatures of the clean days of November 8 and 19; the line II is computed with a minimum night temperature in the clean days of November 8 and 18; the line III is computed with maximum daily values of the air temperature in the clean days of November 12 and 19; the vertical line represents the time 08 hours, close to the time of the invasion of the cold air mass within the Dushanbe. The solid vertical lines denote the beginning and end of precipitation.

Table 4. The mean values of P_a, τ_a and σ_a km^{-1} and temperature settings.

Days	S_m	σ_a	τ_a	P_a	$\langle t_n\rangle$	$\langle t_d\rangle$	ΔT_1	t_{md}	t_{mn}	ΔT_2
11/08/07	51	0.07	0.1	0.93	5.62	17.45	11.83	24	8.8	15
11/09/07	0.5	7.82	-	-	7.6	14.15	6.55	18.2	7	11
11/10/07	2	1.95	1.8	0.17	7.9	15.75	7.85	22.6	9.3	13
11/11/07	4	0.97	0.9	0.41	5.97	15.3	9.33	21.3	5.1	16
11/12/07	51	0.07	0.1	0.87	7.46	16.6	9.14	25.6	8.3	17
11/13/07	0.5	7.82	-	-	9.58	17.45	7.87	18.4	13	5.8
11/14/07	0.5	7.82	-	-	10.5	9.92	-0.58	14.6	8.6	6
11/15/07	0.2	19.6	-	-	6.13	13.27	7.14	18	5.2	13
11/16/07	2	1.96	1.8	0.17	3.8	13.7	9.9	19	4.1	15
11/17/07	4	0.97	0.9	0.41	3.43	12.35	8.92	19.2	2.4	17
11/18/07	4	0.97	0.9	0.41	3.5	10.9	7.4	18	3.6	14
11/19/07	4	0.97	0.9	0.41	8.3	14	5.7	21	13	7.8
11/20/07	10	0.39	0.4	0.7	10.23	11	0.77	13.1	7	6.1
11/21/07	51	0.07	0.1	0.93	9.75	14.75	5	20.4	16	4.4

*
_____

Note: S_m - horizontal visibility range

σ_a- aerosol scattering coefficient

τ_a - aerosol optical thickness

P_a- transparency of the atmosphere

$\langle t_n\rangle$ - average daytime temperature

$\langle t_d\rangle$ - average night time temperature

t_{md} - midday temperature

t_{mn} - midnight temperature

As can be seen in Figure 15, the main features in the behavior of the daytime and nighttime temperatures in the dust haze correspond to the data of [10], i.e., daily temperature drops due to the general weakening of the solar radiation by the dust haze in the visible and infrared radiation.

Absolute values of the day time cooling of the air are more than the absolute value of nighttime warming. The same result can be seen from measurements of air temperatures at the meteorological station in Termez (Uzbekistan).

Line 1 (Figure 15) indicates amonotonic decrease in the temperature from November 8 to November 21 of about 3.1°K. For all episodes of the dust haze, the analysis of the results is shown in Table 4.

The data processing procedure is somewhat different from that used in [10]. However, as in [10], we determined the average daily temperature $t_d=\sum_{i=1}^{4}t_i/4$ in the period from 08 to 17 hours and average night $t_n=\sum_{i=1}^{4}t_i/4$ for the period from 20 to05 hours. Then everyday, beginning from November 8 to November 21, we determined the total temperature $t_s=t_d+t_n$. The further procedure of the data processing is shown in Figure 17, where the straight lines 1 and 2 are shown as envelopes according to the values at noon's on November 8, 21, and t_n -at midnight on November 11 and 17.

Lines 1 and 2 were drawn from the values of day t_d and night t_n .The values of ΔT , which are daily cooling temperatures under the haze layer were estimated as $\Delta T=\Delta T_d+\Delta T_n$, where ΔT_d is the difference between the values t_d and t_{env} shown by the line 1 , ΔT_n is the difference between the quantities t_d and t_{env}, shown by the line 2.The values ΔT were determined as the difference between the temperature at noon and at the midnight. Numerical values of T and T_A are shown in Table 5.

Figure 15 and Table 5 present the main results of this analysis. The points marked 1 give ΔT values obtained by

the 1st data processing method of comparing the total daily temperatures.

Table 5. Average values of temperature parameters

Days	$\langle t_n \rangle$	$\langle t_d \rangle$	T_1	t_{md}	t_{mn}	T_2	ΔT_1	ΔT_2	$T(K)$	$T_A(K)$
08/11/2007	5.62	17.45	12	24	8.8	15	0	2.5	2.5	-2.5
09/11/2007	7.6	14.15	6.6	18.2	7	11	-5.76	1.2	-4.6	-6.96
10/11/2007	7.9	15.75	7.9	22.6	9.3	13	-1.15	4.2	3.05	-5.35
11/11/2007	5.97	15.3	9.3	21.3	5.1	16	-2.3	0	-2.3	-2.3
12/11/2007	7.46	16.6	9.1	25.6	8.3	17	2.7	2.3	5	0.4
13/11/2007	9.58	17.45	7.9	18.4	12.6	5.8	-2.3	10.8	8.5	-13.1
14/11/2007	10.5	9.92	-0.6	14.6	8.6	6	-8.1	3.46	-4.6	-11.6
15/11/2007	6.13	13.27	7.1	18	5.2	13	-4.61	2.3	-2.3	-6.91
16/11/2007	3.8	13.7	9.9	19	4.1	15	-3.1	1.5	-1.6	-4.6
17/11/2007	3.43	12.35	8.9	19.2	2.4	17	-2.7	0	-2.7	-2.7
18/11/2007	3.5	10.9	7.4	18	3.6	14	-3.5	1.92	-1.6	-5.42
19/11/2007	8.3	14	5.7	21	13.2	7.8	0	12.3	12.3	-12.3
20/11/2007	10.23	11	0.8	13.1	7	6.1	8.1	6.54	14.6	1.56
21/11/2007	9.75	14.75	5	20.4	16	4.4	0	16.15	16.2	-16.2

Note: $\Delta T_1 = t_{md} - t_{env}$; $\Delta T_2 = t_{md} - t_{env}$

Dust storms and haze events are the essential meteorological factors in Central Asia. An average annual number of days with haze events in Dushanbe is about 15-20, with seven days of a strong haze when visibility values becomes less than 2 km. The year of 2001 is the record. During that year, in the period from June to August, the weak haze in Dushanbe was almost daily. A number of days with the moderate to severe haze in the period from June to November was 29 days. Note that in the summertime, there is a cooling of the air by 3-8 degrees compared with clear weather days [58,59].
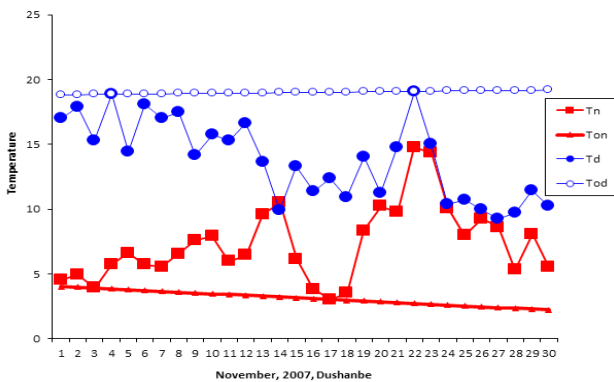

Figure 15. Explanation of the variables defined by the envelope $\Delta T(K)$ and $\Delta T_A(K)$ for various S_m

In 2007, during the study period from November 8 to November 21, there were a few days of dust haze events of various magnitudes. A detection processes brought a dust haze resulting in a drop of the visibility range from 10 km to 0.2 km (see Figure 17). Our analysis of several episodes of the dust storm (dust haze) shows that for an average dust haze (S_m=8-10km) , the amount of the daily cooling of the air temperature at all studied stations is on average ΔT=2°K , in the case of strong dust storm (S_m<1-2km) is ΔT=4.5°K . (Figure 18)
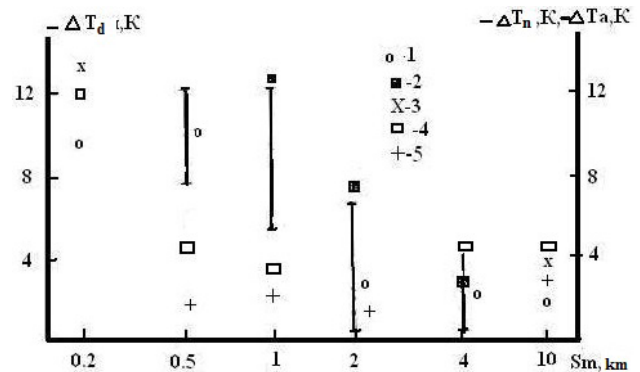

Figure 16. Comparison of the $\Delta T(K)$ depending on the range of visibility S_m

The absorption by dust particles in the infrared range is especially important in the area of a transparency window of 8-13 μm , where dust and main atmospheric gases significant absorbs the thermal radiation. This is precisely the wavelength region where the distribution function of the Planck thermal radiation has a maximum for common terrestrial temperatures. Therefore, the loss of heat in the space of the thermal radiation emitted by the soil is reduced due to the presence of dust particles (the course fraction), having strong absorption bands in this spectral range near 10 μm. In this case, almost all the energy of the absorbed particles of the solar and thermal radiation is converted to heat of the air. At the night, the heat absorbed by dust particles (especially, by course fraction), transfers to the air and heats it. As a result, the total daytime air temperature in a dusty atmosphere is lower than in a clean day and the nighttime temperature is a bit higher than in a clean night. The particle size distribution function has a bimodal character with maximum in the range of 0.5-10 and 0.05-0.5 microns (Figure 17). One can see the difference between clear and dust haze days, although the distribution of particles is always bimodal. During the invasion of the dust haze, particles of the coarse fraction predominate. The proportion of the coarse fraction gradually increases with increasing aerosol optical thickness in case of the dust intrusion and low values of the Angstrom parameter indicate the presence of coarse particles.
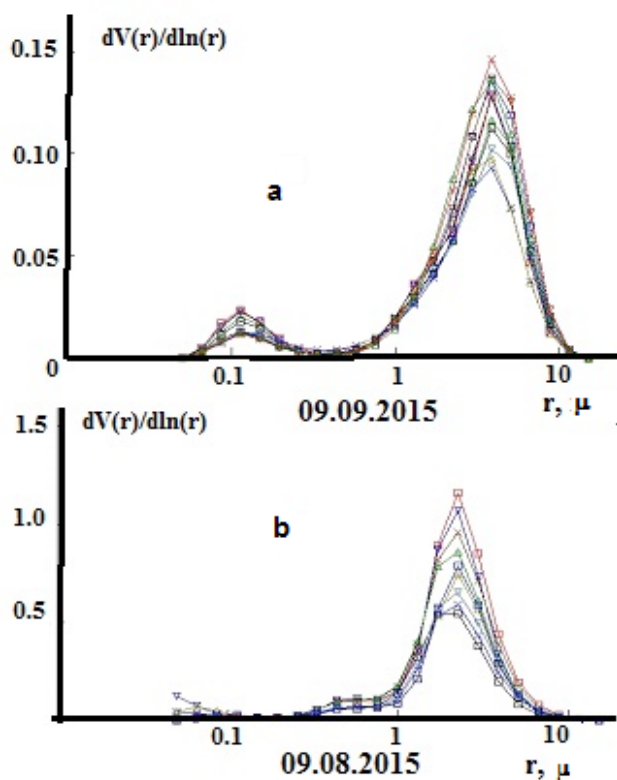
Figure 17. Changes in the size distribution function of aerosol particles in the atmosphere of Dushanbe city: a - in the usual situation (09/09/2015); b – case dust haze (08/09/2015)

Dust particles can participate in two events, leading to opposite changes in the temperature. We can identify the critical parameters that determine the transition from one effect to another. Figure 18 shows the dependence of the average daily air temperature in dusty and clean atmospheres on the concentration of dust (based on our experimental results).

To clarify the role of dust aerosol in the long-term changes of the air temperature, it is necessary to analyze and separate the contributions of aerosols in the greenhouse and anti-greenhouse effects. This can be achieved by using decades-long measurements of air temperatures at various meteorological stations in Tajikistan. A trend of the mean annual temperature is different for the measurement points located at different altitudes. Figure 18 shows an increase in the mean annual temperature over 100 years at altitudes ranging from 426 m (Kurgan-Tube) to 4260 m(Fedchenko). The higher the observation point above sea level, the less of the warming effect is observed.In the arid zone, where Tajikistan is located, dust particles are constantly present in the atmosphere with a background value of about 100 mg/m³.The greater is the height of the observation point, the lower is the concentration of the

background aerosol and dust.

Studies [50,58] have reported the effect of dust storms on the temperature regime of the atmospheric boundary layer and found that dust storms lead to a decrease in the air temperature at the surface layer of the atmosphere, but an explanation of the effect of the dusty haze on the temperature regime of the surface layer is not yet available.For the further clarification of the influence of the dusty haze on the temperature regime of the surface layer, we studied data on temperature changes obtained at meteorological stations in Dushanbe, Termez, Bayramali, and Repetek for the period 2005-2010 and for the Kurgan-Tube for the 2008-2010 year.
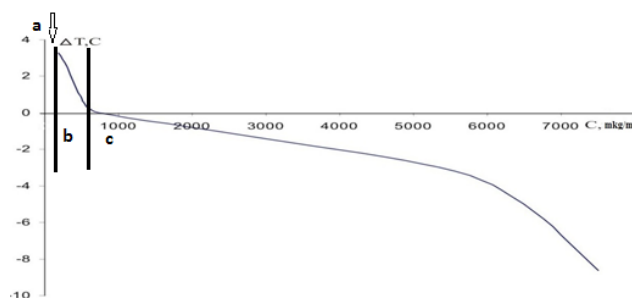

Figure 18. The dependence of the average daily air temperature shifts on the concentration of dust aerosol(a – back round; b- dust haze and c-dust storm).

In the study of temperature measurements during a few months at Dushanbe, Termez, Bayramali, Repetek and Kurgan-Tube we detected the exceeding value of the night warming and the daily cooling.This fact suggests that, under certain weather conditions in the surface layer of the dust haze warming occurs.Such a mechanism could proceed as follows: in the presence of a dusty haze in the surface layer of the atmosphere, when the transparency of the atmosphere P>0.3 and the concentration of dust particles is less than 170 μg/m³, the absorption in the infrared region of the spectrum occurs [15].At the nighttime, the heat is absorbed by the aerosol particles and the surface of the soil.Thus, there is some heating of the surface layer of the atmosphere at nights.

The portion of the line above the x-axis in Figure 19 corresponds to the greenhouse effect due to the presence of the atmospheric dust haze.The curve, which is below the x-axis, corresponds to the anti-greenhouse effect during the dust storm. An intersection with the x-axis at the almost linear section allows one to define a critical value of the concentration corresponding to the transition from the greenhouse to the anti-greenhouse effect, which is 750 μg/m³.

Figure 19 shows the intensity of the direct solar radi-

ation as a function of aerosol concentration. At low concentrations of dust aerosol(less than 160 μg/m^3), which is almost always present in the atmosphere,dust does not contribute to the greenhouse effect, because the level of the heat transfer from the heated particles is at the level of the thermal noise in the air.
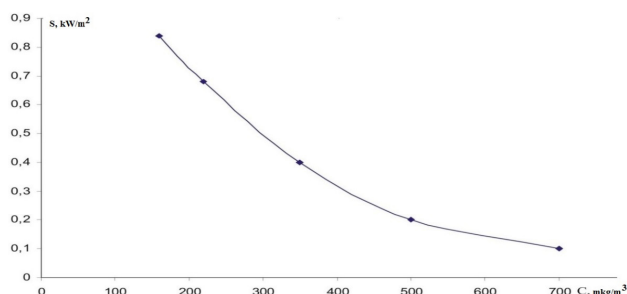

Figure 19. The dependence of the intensity of the direct solar radiation at the surface on the aerosol concentrations.

If the total contribution of the nighttime warming exceeds the total contribution of the daytime cooling, the dusty haze contributes to the greenhouse effect, and vice versa. If the total contribution of the nighttime warming is less than the total contribution of the daytime cooling, the dusty haze contributes to the anti-greenhouse effect. In the study of the temperature data, we found the both effects may occur in the arid (Termez, Bayramali and Repetek), and insub-aridzones (Dushanbe, Kurgan-Tube).

Figure 20a shows a typical example of the behavior of average night and average daily temperatures during a month.The corresponding data for the thermal effects of the dust storm for the same month are shown in Figure 20b. Envelopes lines for average daily temperatures were constrained by the maximum values of daily maximum temperature, under an assumption of an absence of a dusty haze. The envelope lines of average nighttime temperatures are made for minimum nighttime temperatures. Value of the daytime cooling was defined as the difference between the average daytime temperature and the envelope of the line drawn by the maximum values of the maximum daytime temperature(in the absence of a dusty haze). Figure 20c shows the aerosoloptical depth (Dushanbe, August 2010)
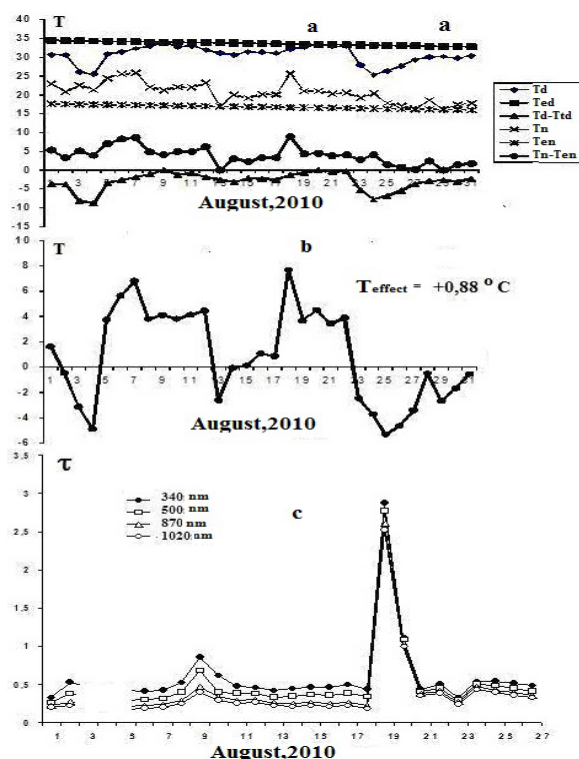

Figure 20. a - air temperature, b - average daily temperature differences due to dust, c –aerosol optical depth (Dushanbe, August 2010)

The magnitude of the night warming was defined as the difference between the temperature and the envelope averaged night line drawn for the minimum night temperature (assuming the absence of a dusty haze). The total value of these differences determines the effect dusty haze on the temperature during a month.

To determine the patterns of influence of dust aerosol on the temperature regime of the surface layer, we studied data on air temperatures, obtained from meteorological stations in Dushanbe, Termez, Bayramaliand Repetek for the period 2005-2011years, and Kurgan-Tube for the 2008-2011.

Table 6 AND Table 7 SHOW THE final results of the processing of the data on the thermal effects, averaged for each month of observation.

Table 6. Changing the daily average values of the temperature effect (^{o}C) for Kurgan-Tubeand Dushanbe

Kur-gan-Tube	2005	2006	2007	2008	2009	2010	2011
V				3.01	-0.36	3.47	-0.6
VI				3.92	0.06	-2.25	-0.58
VII				0.12	2.24	2.71	0.26
VIII				4.43	0.32	1.07	0.01

IX				0.68	0.33	1.71	-0.71
X				0.71	-0.27	-0.86	
XI				0.98	0.25	-5.95	
Dushanbe	2005	2006	07	2008	2009	2010	2011
V	-2.1	-1.8	-1.23	-0.91	-0.84	-2.4	-2.75
VI	-0.5	-0.54	-2.57	-0.19	-0.64	-1.91	-0.59
VII	1.6	1.56	1.78	0.86	0.05	-2.05	-1.28
VIII	1.1	1.05	0.54	0.24	-0.06	0.88	-0.36
IX	1.2	0.51	-0.84	0.84	-0.95	-1.72	0.17
X	-1.2	1.266	-1.04	3.4	-1.15	-0.73	
XI	-2.6	-0.278	-0.95	-1.92	0.89	-1.42	

The analysis shows that the previously powerful dust storms, such as the September 20, 1989, and October 15, 1990, led to a sharp decrease in the daytime air temperature and an increase in nighttime temperatures. In general,this process clearly led to a sharp decrease in temperature in the lower atmosphere.

Comparing the heat haze effect in cities located in a very narrow range of the south-eastern part of Central Asia,one can discover an interesting pattern. In Dushanbe, Termez, Bayramali, and Repetek the positive thermal effect was observed in 45% of the total number of months that were followed, in the Kurgan-Tubein the last 2 years a positive effect was observed in 85% of the number of months.The average monthly value of the temperature effect, which characterizes the average change in the temperature associated with the dusty air, for Dushanbe (-0.15 ° C), Termez (-0.23 ° C), Bayramali (-0.35 ° C), Repetek (-0.0065 °) and for Kurgan-Tube (+ 0.35° C) is different.

To determine the reasons for differences in the magnitude of the thermal effect of the air caused by dust, we analyzed the geographical and physical features of the observation locations Repetek (38°34N.,63°11'E. elevation185 m), Bayramali (37°36'N.,62°11'E., elevation 241 m) and Termez (37°36'N.,62°11'E., elevation 302m) are in the arid zone in the open countryside. Dushanbe (38°33'N.,68°47'E., elevation 821 m) and Kurgan-Tube (37°50'N.,68°47'E., elevation 430 m) are located in mountainous areas, with blowing winds hindered by the mountains surrounding the valley, where these cities are located (Figure 9).

From the change in the scattering coefficient, one can derive the height of several diffusion layer switch different aerosol concentrations over the various points of the city.Sudden changes in aerosol concentrations correspond to changes in temperature of these layers.

Table 7. Changes of the daily average values of the temperature effect (° C) for Termez, Bayramali, and Repetek.

Termez	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
V	0.7	-0.36	0.76	-0.33	-0.73	2.11	0.96	0.44	0.64	-1.91
VI	-0.4	-1.49	-0.08	-1.87	0.02	1.8	-0.65	-0.38	-0.58	-2.67
VII	0.9	1.65	0.62	0.6	-0.02	-1.27	-1.07	0.2	0.18	-1.16
VIII	1	1.13	-0.39	0.01	0.05	-1.12	-0.55	0.02	0.08	-0.16
IX	-0.8	-1.67	-0.07	-1.83	-0.35	2.28	-0.34	-0.4	0.31	-1.97
X	-1	-0.85	-1.62	-1.09	-1.45	0	-0.56	-0.94	-0.94	-1.21
XI	-1.3	0.98	-0.68	0.42	1.46	-1.73	-0.69	-0.22	-0.22	

Bayramali	2005	2006	2007	2008	2009	2010	2011
V	0.6	-1.35	-0.26	-1.81	-1.55	-1.45	-1
VI	-2.7	0.44	-1.21	-1.65	1.06	-1.07	0.82
VII	-0.9	2.33	-0.38	0.16	1.3	2.8	0.24
VIII	-1.6	0.53	-0.11	-0.33	0.38	-3.4	1.2
IX	1	2.061	-0.15	-0.14	0.11	1.15	0.03
X	2.4	-0.07	-1.54	-3.36	0.76	4.65	
XI	-1.7	-0.62	-2.54	-2.2	0.59	-4.66	

Repetek	2005	2006	2007	2008	2009	2010	2011
V	2	0.07	4.02	1.84	-1.97	-1.87	-0.74
VI	1.2	-1.05	1.01	-0.52	1.14	1.66	0.09
VII	0.6	1.32	-1	-0.44	0.48	-0.59	0.52
VIII	-0.2	0.43	-1.07	-0.84	0.01	-0.16	0.39
IX	1	1.29	-1.62	-1.01	0.44	-0.91	-0.45
X	0.3	-0.13	0.68	-3.99	-2.26	-0.62	
XI	-3.1	-0.47	0.78	-0.15	0.89	-4.75	

During a dust storm in the surface layer of the atmosphere, the total content of aerosol increases by more than an order of magnitude. Figure 21 shows typical profiles of the scattering coefficient obtained in Dushanbe [60]. Above the inversion layer, the scattering coefficient is about 10 times less than under the inversion layer (the scattering is shown by a family of curves 2 in Figure 21). In this layer,the absolute value increases as compared with a pure atmosphere average by an order of the magnitude (depending on the capacity of the dust removal).

This leads to a static situation, when the dust rises into the air and for a long time it does not settle and, thus, stabilizes the state of dust. This stabilization occurs by increasing the inversion layers that inhibit the spread of dust in the vertical direction and leads to a uniform mixing. A formation of diffusion layers with different concentrations of dust was recorded in 1989, through airborne measurements over Dushanbe [60] (Figure 21). In period of Soviet-American experiments, a change in high-rise temperature (T) and the light scattering coefficient, which is proportional to the concentration of the aerosol, were observed[60].
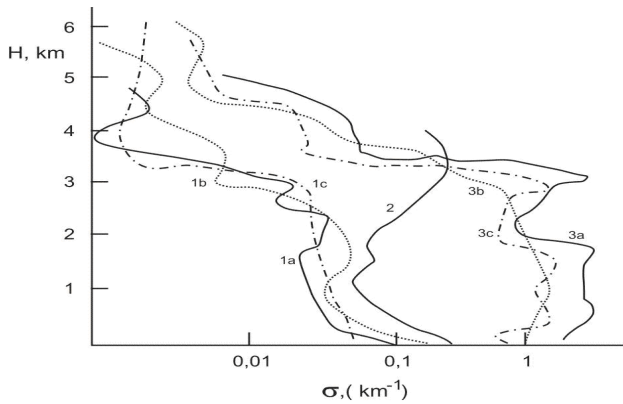
Figure 21. Vertical profiles of the scattering coefficient at a wavelength of λ=0.52μm of Dushanbe: 1a, and in c, are for background conditions; 2 is during the dusty haze on September 16, 1989; and 3a, and in c, are during a dust storm on September 21, 1989 [60].

The results of the temperature effect of dust aerosols for five stations located along the path of the dust storms in the period 2005 to 2011 indicates that 41% of the dust aerosol event contributes to the greenhouse effect, and in 59% of the cases contributing to the anti-greenhouse effect.

The temperature inversion (temperature above the inversion layer above1-1.5°C) at an altitude of 3400m (for Dushanbe) becomes more pronounced and has a locking action on the distribution of the aerosol up. Above the inversion layer,the scattering coefficient is only three times greater than the one for a pure atmosphere.The altitude of the temperature inversion for Kurgan-Tube increased more significantly than in Dushanbe.

During dust storms, the developed turbulent mode provides lower-level temperature inversion supporting a good mixing of the aerosol. At a height of H= 1400m, well below the inversion layer, the scattering coefficients are practically constant [60]. The formation of diffusion layers, which are characteristic of the dust haze, is often observed in the arid zones of Central Asia.

7. Conclusions

Tajikistan is located in the global dust belt on the way of transport routes of dust from some major dust sources like the Aralkum desert of the desiccating Aral Sea, the Kyzyl-Kum and Karakum deserts east of the Caspian Sea, the Iranian Dasht-e-Kavir and Dasht-e-Lut deserts and the deserts in Afghanistan and Sahara, and Taklamakan desert in China. Therefore, Tajikistan is frequently affected by severe dust events every year (from April until November) and is a net accumulator of dust. Tajikistan is a country with a dry climate and benefits from its water resources in

the mountainous Pamir region, which are stored in a large part in glaciers. Furthermore, Central Asia and, especially Tajikistan, is strongly affected by climate change. For example, the dramatic glacier shrinking took place in the last decades, which has also effected water resources of Tajikistan and the whole Central Asian region. On the other hand, deposited dust itself can accelerate glacier melt by altering the glacier's surface albedo.

Arid zones of Tajikistan are constantly exposed to the presence of dust particles that a result of dust storm and dust haze events, spreading over the thousands of kilometers. The strengthening of dust storms offset that leads to the distribution dust particles throughout the territory of Central Asia,causing the following consequences:a significant deterioration of public health and other living organisms: 50% reduction in bees and other beneficial insects; a reduction of direct solar radiation; significant weakening of the process of photo synthesis in the vegetation; change the melting regime of glaciers; territorial expansion of desert areas and soil degradation; and the quantity and quality of agricultural products.

In this manuscript, we have analyzed the classification of dust storms and synoptic conditions related to their formation in Central Asia. An analysis of the meteorological data for the last thirty years shows that around the 1980s, Tajikistan observed strong dust storms, especially in September 1989 and October 1990 that were 7 to 11 hours long. Over the last thirty years, observed dust hazes typically continues 4 to 15 days, and are accompanied by a pulsating change of the horizontal visibility, typically ending without rain. Several strongest dust hazes occurred in the summer-autumn of 2001, November (5 to 24) of 07 and August (from 4 to 15) of 2008, August of 2010, and July-August of 2011. They decreased the horizontal visibility range down to 200 meters. After the dust haze ends, the rainfall does not occur and sub-micron dust particles remain in the atmosphere in the surface layer for a long time.

Analyses of the number and duration of dust haze episodes in the period 2005-2014 at four stations: Termez and Shaartuz deserts; Kurgan-Tube rural and Dushanbe urban site show increasing the number and duration of dust haze episodes in 2001.

A comparison of the amplitude of the temperature of the clean day before the dust storm and the clean day after the dust storm was performed, revealing the night warming up to 8 ℃ and the daytime cooling to -16 ℃. Comparisons of the amplitude of the temperature of the clean day before the dust haze and the clean day after the dust haze, revealed some night warming up to 4 ℃, and the daytime cooling to -3 ℃.

We studied the duration of the dusty haze at selected stations: Termez (Uzbekistan), Dushanbe (Tajikistan), determining the seasonal and annual variations of the dust haze using the database of meteorological parameters for Dushanbe (2000-2012), Bayramali and Repetek (2005-2012), Termez (2005-2014), Kurgan-Tube (2008-2012.). The results of the variation of surface temperature during the last century for Tajikistan was analyzed. The results of a detailed analysis of the temperature effect of dust aerosols at five stations, which are located in two neighboring states on the way of transportation of dust storms in the period 2005 to 2012, indicate that 41% of the dust event contributes to the greenhouse effect, and in 59% of the cases contributing to the anti-greenhouse effect.

The study of dust storms should be conducted in different world dust sources to comparatively examine the strength of the sources in terms of the dust flux emission, the initial height of dust plumes that controls the ability of dust plumes to be transported over long distances.

Dust optical properties and its radiative impacts vary from the source-to-source. For instance, the ability of dust to absorb sunlight strongly depends on the presence of certain minerals (e.g., iron oxides). The mineralogical composition varies from one dust emitted area to another. Thus, the world wide sources will need to be well-documented.

The diverse impacts of dust, including the radiative impact, the impact on vegetation, as well as, the adverse impact on human health will need to be examine in the synergistic fashion.

Acknowledgments

References

[1] Makhmadaliev, B.; Novikov, V. The First National Communication of the Republic of Tajikistan to the United Nations Framework Convention on Climate Change; Dushanbe, Tajikistan, 2002.

[2] Makhmadaliev, B.; Kayumov, A.; Novikov, V.; Mustaeva, N.; Rajabov, I. The second national communication of the Republic of Tajikistan under the United Nations framework convention on climate change; Dushanbe, 2008.

[3] Kayumov, A.; Novikov, V. Third National Communication of the Republic of Tajikistan under the United Nations Framework Convention on Climate Change. 2014.

[4] Hofer, J.; Althausen, D.; Abdullaev, S.F.; Makhmudov, A.N.; Nazarov, B.I.; Schettler, G.; Engelmann, R.; Baars, H.; Fomba, K.W.; Müller, K. Long-term profiling of mineral dust and pollution aerosol with multiwavelength polarization Raman lidar at the Central Asian site of Dushanbe, Tajikistan: case studies. Atmospheric Chemistry and Physics 2017, 17, 14559.

[5] Nazarov, B.I.; Abdullaev, S.F.; Maslov, V.A. Dynamic processes during dust incursions in Central Asia Irfon: Dushanbe, 2016.

[6] Nazarov, B.I.; Abdullaev, S.F.; Maslov, V.A. Atmospheric aerosol of Central Asia.; Donish: Dushanbe, 2017.

[7] Zuev, V.E. Atmospheric Transparency in the Visible and the Infrared; Israel Program for Scientific Translations;[available from the US Department of Commerce, Clearinghouse for Federal Scientific and Technical Information, Springfield, Va., 1970.

[8] Kondratyev, K.Y. Climate and aerosol. Trudy GGO 1976, 3-36.

[9] Ivlev, L.S. The chemical composition and structure of atmospheric aerosols; Leningrad State University: Leningrad, 1982: 368.

[10] Golitsyn, G.S.; Shukurov, A.K. Temperature effects of dust aerosol as exemplified by dust storms of Tadzhikistan. In Proceedings of Doklady- earth science sections. Silver Spring MD: 46-49.

[11] Ginzburg, A.S.; Sokolik, I.N. The transmission and reflection of light by a homogeneous layer of an absorbant aerosol. Akademiia Nauk SSSR Fizika Atmosfery i Okeana 1989, 25: 954-959.

[12] Goody, R.M. Atmospheric Radiation [Russian translation], 1966.

[13] Romanov, N.N. Dust storms in Central Asia; Tashkent, 1960: 198.

[14] Bugaev, V.A.; Georgia, V.A.; Kozin, B.M. Synoptic processes in Central Asia; Tashkent, 1957: 67.

[15] Abdullaev, S.F. The impact of global climate change and adaptation measures to climate change. In Nature and Us: Questions of environmentally sustainable development in Tajikistan, Dushanbe, 2009: 155-184.

[16] Nazarov, B.I.; Abdullaev, S.F. Aerosol pollution under arid and mountainous areas of Tajikistan. In Proceedings of International Expert Meeting on the environment: 60-62.

[17] Karetnikova, K.A. Synoptic conditions for the occurrence of the "Afghans" and some of the features of this phenomenon. Journal of Geophysics 1985, 5: 36-80.

[18] Dzhorzhdio, V.A. In Guide to short-term weather forecasts, Tashkent, 1954: 73-77.

[19] Abdullaev, S.F.; Nazarov, B.I.; Sharifov, D.M. Modeling of transport process and distribution of arid aerosol. In Proceedings of XIII Joint International Symposium "Atmospheric and ocean optics. Atmospheric physics.", Tomsk, Russia.

[20] Nazarov, B.I.; Salikhov, D.K.; Abdullaev, S.F. The description of moving of atmospheric particles in the near earth layer. In Proceedings of Russian-Canadian Workshop Modeling atmospheric dispersion of weapons agents, Moscow: 137-139.

[21] Nazarov, B.I.; Abdullaev, S.F.; Maslov, V.A. Laws of dusty haze - the number of episodes and duration. In Proceedings of Problems of modern physics, Dushanbe; pp. 65-68.

[22] Abdullaev, S.F.; Nazarov, B.I.; Madvaliev, U. Climate change in condition of arid and of high mountain regions of Tajikistan. In Proceedings of XVIIth International Energy and Environment Fair and Conference, Istanbul: 277-278.

[23] Dovgalyuk, Y.A.; Ivlev, L.S. Physics of Water and Other Atmospheric Aerosols, 1998.

[24] Sokolik, I.N.; Andronova, A.; Johnson, T.C. Complex refractive index of atmospheric dust aerosols. Atmospheric Environment. Part A. General Topics 1993, 27: 2495-2502.

[25] Kondratyev, K.Y.; Moskalenko, N.I.; Pozdnyakov, D.V. Atmospheric aerosols.; Gidrometeoizdat: Leningrad, 1983: 224.

[26] Bohren, C.F.; Huffman, D.R. Absorption and scattering of light by small particles; John Wiley & Sons: 2008.

[27] Herman, B.M.; Browning, R.S.; De Luisi, J.J. Determination of the effective imaginary term of the complex refractive index of atmospheric dust by remote sensing: The diffuse-direct radiation method. Journal of the Atmospheric Sciences, 1975, 32: 918-925.

[28] Lindberg, J.D.; Laude, L.S. Measurement of the absorption coefficient of atmospheric dust. Applied optics, 1974, 13: 1923-1927.

[29] Lindberg, J.D.; Gillespie, J.B. Relationship between particle size and imaginary refractive index in atmospheric dust. Applied optics, 1977, 16: 2628-2630.

[30] Hale, G.M.; Holland, W.E.; Querry, M.R. Kramers-Kronig analysis of relative reflectance spectra measured at an oblique angle. Applied optics, 1973, 12: 48-51.

[31] Volz, F.E. Infrared optical constants of ammonium sulfate, Sahara dust, volcanic pumice, and flyash. Applied Optics 1973, 12: 564-568.

[32] Volz, F.E. Infrared absorption by atmospheric aerosol substances. Journal of Geophysical Research, 1972, 77: 1017-1031.

[33] Volz, F.E. Infrared optical constants of aerosols at some locations. Applied optics 1983, 22: 3690-3700.

[34] Darmenova, K.; Sokolik, I.N.; Darmenov, A. Characterization of east Asian dust outbreaks in the spring of 2001 using ground-based and satellite data. In J. Geophys. Res., AGU: 2005, 110: D02204.

[35] Sakai, T.; Nagai, T.; Nakazato, M.; Mano, Y.; Matsumura, T. Ice clouds and Asian dust studied with lidar measurements of particle extinction-to-backscatter ratio, particle depolarization, and water-vapor mixing ratio over Tsukuba. Applied Optics 2003, 42: 7103-7116.

[36] Liu, Z.; Sugimoto, N.; Murayama, T. Extinction-to-backscatter ratio of Asian dust observed with high-spectral-resolution lidar and Raman lidar. Applied Optics 2002, 41: 2760-2767.

[37] Iwasaka, Y.; Shi, G.; Trochkine, D.; Matsui, A.; Kim, Y.; Yamada, M.; Nagatani, T. Processes of Background KOSA Outbreak. Proceedings of the EMEA 2005 in Kanazawa, 2005, Intern. Sympos. on Environmental Monitoring in East Asia—Remote Sensing and Forests, 2005, 20-36.

[38] Uno, I.; Eguchi, K.; Yumimoto, K.; Takemura, T.; Shimizu, A.; Uematsu, M.; Liu, Z.; Wang, Z.; Hara, Y.; Sugimoto, N. Asian dust transported one full circuit around the globe. Nature Geoscience, 2009, 2: 557.
DOI: 10.1038/NGEO583

[39] Andronova, A.V.; Minashkin, V.M. Study microphysical and optical characteristics of dust aerosols of different regions of the USSR. Izvestiya Acad.Sci., Atmos. and Oceanic Physics 1989, 25: 40-44.

[40] Ivlev, L.S. Aerosol atmospheric model. Problems of Atmospheric Physics 1969, 8: 125-160.

[41] Kortum, G. Reflectance Spectroscopy: Principles Methods, Applications; New York, 1969.

[42] Andronova, A.V.; Zhukovsky, D.A.; Mandibles, V.F. Chemical and microphysical characteristics of aerosols on the measuring sites and Shaartuz Esanbay. In Soviet-American experiment on arrid aerosol, SPA "Typhoon": St. Petersburg, 1992.

[43] Zuev, V.E.; Ivlev, L.S.; Kondratyev, K.Y. The new findings of aerosols. Izvestiya USSR Acad.Sci., Atmos. and Oceanic Physics 1973, 9: 371-385.

[44] Patterson, E.M.; Gillette, D.A.; Stockton, B.H. Complex index of refraction between 300 and 700 nm for Saharan aerosols. Journal of Geophysical Research, 1977, 82: 3153-3160.

[45] Golitsyn, G.S. Soviet-American experiment on arid aerosol; NGO "Typhoon": St. Petersburg, 1992: 208.

[46] Kondratyev, K.Y.; Jvalev, V.F. First Global Experiment PIGAP "Aerosol and climate"; Gidrometeoizdat: Leningrad, 1976: 239.

[47] Krapivtseva, G.M.; Krivchikova, T.V.; Shukurov, A.K. On the synoptic conditions during the period of Soviet-US dust experiment in Tajikistan in September 1989. In Soviet-American experiment on arid aerosol, Hydrometeoizdat: St.Petersburg, 1993: 20-24.

[48] Mack-Cynon, D. Satellite data on dust storms in Tajikistan. In Soviet-American experiment on arid aerosol, Hydrometeoizdat: St.Petersburg, 1993: 25-26.

[49] Belan, B.D.; Kabanov, D.M.; Panchenko, M.V. Aircraft sounding of atmospheric parameters in the dust experiment. In Soviet-American experiment on arid aerosol, Hydrometeoizdat: St.Petersburg, 1993: 26-28.

[50] Golitsyn, G.S.; Shukurov, A.K.; Abdullaev, S.F.; Nazarov, B.I. On the surface are cooling due too dust atmospheric turbidity. In Soviet-American experiment on arid aerosol, Hydrometeoizdat: St.Petersburg, 1993: 67-78.

[51] Shukurov, A.K.; Nazarov, B.I.; Abdullaev, S.F. On optical depth ratios of dust aerosol in visible and infrared spectra regions. In Soviet-American experiment on arid aerosol, Hydrometeoizdat: St.Petersburg, 1993: 83-88.

[52] Eguchi, K.; Uno, I.; Yumimoto, K.; Takemura, T.; Shimizu, A.; Sugimoto, N.; Liu, Z. Trans-pacific dust transport: integrated analysis of NASA/CALIPSO and a global aerosol transport model. Atmospheric Chemistry and Physics, 2009, 9: 3137-3145.

[53] Cess, R.D.; Potter, G.L.; Ghan, S.J.; Gates, W.L. The climatic effects of large injections of atmospheric smoke and dust: A study of climate feedback mechanisms with one-and three-dimensional climate models. Journal of Geophysical Research: Atmospheres 1985, 90: 12937-12950.

[54] Budyko, M.I.; Golitsyn, G.; Israel, Y.A. Global climate catastrophe; Gidrometeoizdat: Leningrad, 1986: 160.

[55] Thompson, S.L.; Schneider, S.H.; Golitsyn, G.S.; else, S.b. Environmental Consequences of Nuclear War. Environment, 1986, 28.

[56] Alperovich, L.I.; Latifov, S.; Mamchenko, T.B. Determining the optical constants of dispersive media in the infrared region. Colloid Journal , 1984, 46: 999-1001.

[57] Nazarov, B.I.; Abdullaev, S.F.; Maslov, V.A. Influence of dust storms on climate change. In Proceedings of International Conference "Problems of modern physics.", Dushanbe: 50-54.

[58] Nazarov, B.I.; Abdullaev, S.F.; Maslov, V.A. Studies of Temperature Effects of Dust Storms. Izvestiya. Atmospheric and Oceanic Physics, 2010, 46: 475-481.

[59] Abdullaev, S.F.; Nazarov, B.I.; Maslov, V.A. Some results of the aerosol influence of air pollution on climate change. In Proceedings of International Conference "Problems of modern physics.", Dushanbe: 40-44.

[60] Pachenko, M.V.; Terpugova, S.A.; Bodhaine, B.A.; Isakov, A.A.; Sviridenkov, M.A.; Sokolik, I.N.; Romashova, E.; Nazarov, B.; Shukurov, A.; Chistyakova, E.I. Optical investigations of dust storms during USSR-US experiments in Tadzhikistan, 1989. Atmospheric Environment, Part A. General Topics 1993, 27: 2503-2508.