Monitoring of the soot aerosol in the atmosphere over Russia in the TROICA international experiments

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The results of measurements of the soot aerosol concentration with the help of the mobile vehiciles-laboratory in the framework of the seven TROICA (Trans-Siberian Observations into the Chemistry of the Atmosphere) many-year expedition along the Trans-Siberian railway and expeditions along the rout Moscow–Murmansk–Kislovodsk–Murmansk in spring and summer period are presented. The level of soot pollution in urban air of Russian cities is comparable with that in industrially developed countries of West Europe and USA, but substantially lower than in Beijing. The lowest values of the soot concentration in rural air were observed in summer of 1999 (0.1–1.0 μg/m^3), and the highest, caused by the smokes of peatbog fires in the European part of Russia and grass burning along the Asian part of the railway line, in autumn of 2005 (0.6–5.6 μg/m^3). Measurements at the circular railroad around Moscow were also carried out. A plume of the soot polluted air from Moscow was recorded on April 7 and 8, 2000.

Introduction

In two recent decades, the content of gaseous admixtures and aerosol particles in the atmosphere, their natural cycles and sources undergo a strong effect of human activity. Air quality in cities and industrial areas essentially decreased. Changes in the composition of the atmospheric air are observed even in remote areas everywhere. Some of these changes are global: the stratospheric ozone layer becomes thinner, the near-ground ozone concentration increases, climate becomes warmer.[1,2]

The worldwide network of stations of monitoring of the atmosphere state provides for necessary data for the study of the changes and their consequences. Unfortunately, this network is very inhomogeneous both in arrangement of stations and in the used instrumentation. Perhaps, one of the weak points is very small quantity of regular observations carried out on the territory of the former USSR, which are performed mainly at a small number of stations, for example, Voeykovo, Kislovodsk, Tomsk, Issyk-Kul. Meanwhile, power natural sources of many climatically and chemically active components of the atmosphere are situated on the territory of our country, which determine the change of the ozone content and climate of the Earth.[2–4]

In this connection, the Institute of Atmospheric Physics RAS, Russian Scientific-Research Institute of Railway Transport and Max Plank Chemical Institute (Germany) carried out 8 expeditions TROICA (Trans-Siberian Observations into the Chemistry of the Atmosphere) in 1995–2005 devoted to measurements of trace gases and aerosol concentrations, as well as radiation and meteorological parameters along the Trans-Siberian railway from Moscow to Khabarovsk (Vladivostok). The expedition in meridian direction was carried out in April–June, 2000: Moscow – Murmansk – Kislovodsk – Murmansk with long-term stationary observations in Kislovodsk and at the Kislovodsk high-mountain scientific station.

The purpose of international projects TROICA is the study of the state of the atmosphere and ecological systems on the territory of Eurasia.

The scope of the solved problems includes:

– development of the instrumentation complex and the techniques for continuous measurements of the contents of gas and aerosol components of near-ground air, radiation, and meteorological parameters;

– the study of distribution of soot aerosol over the territory of Russia, determination of its main natural and anthropogenic sources;

– the study of atmospheric pollution on the territory of railway transport, in cities and industrial regions; estimation of the intensity of different local and regional sources.

The importance of measuring the soot aerosol content in the atmosphere is as follows:

1) the soot aerosol takes part in formation of climate, because it has a great potentiality of the solar radiation absorption,

2) it is the tracer of anthropogenic pollutions,

3) it determines the level of pollution in cities and industrial regions,

4) it adsorbs unhealthy substances (for example, benz(a)pyrene) and therefore, it can have toxic and carcinogenic properties,

5) it is the catalyst of chemical reactions in the atmosphere.

Measurement technique

The air was sampled at the level of 0.3 m above the wagon roof in its front or central part. The wagon was situated at the train "head" just after the electric locomotive. The instrumentation complex

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operated in automated mode with data storage in personal computer. Measurements of the soot concentration were carried out in 7 expeditions. The aerosol samples were collected on quartz fiber filters with subsequent measurement of light absorption by the aerosol samples. The soot concentration was determined in 5 expeditions (1997–2002) continuously with a step of 1 hour by the automated sampler designed at the IAP RAS. Since 2004, the measurements were carried out with the help of the soot mass concentration meter (Aethalometer™ AE-16 designed at Magee Scientific Co, Germany) with a discreteness of 5 minutes.

Discussion of the results of measurements

Observation of soot aerosol along the Trans-Siberian railway

Continuous series of data on the soot content in the atmosphere along the Trans-Siberian railway during six expeditions TROICA are obtained. Soot concentration variations are shown in Fig. 1.

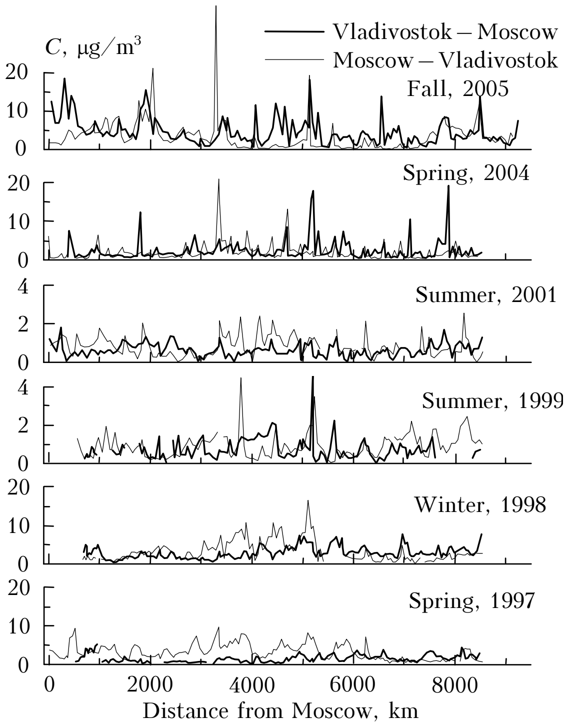

Fig. 1. Soot concentration variations along the Trans-Siberian railway.

The dates of the expeditions and the mean values of the soot concentration are presented in Table 1.

Maximal values of the soot concentration are recorded in autumn and winter, and minimal ones in summer. The soot concentration values obtained in some cities of Russia, USA, Europe, and Asia (Table 2) are close to the values obtained during observations in expeditions TROICA, but are essentially less than in Beijing.

Table 1. Dates of expeditions and mean soot concentrations

Expedition	Period of measurements	C, μg/m³
TROICA-3	April 1–7, 1997	1.8
	April 8–14, 1997	3.2
TROICA-4	February 17–26, 1998	3.0
	March 1–7, 1998	3.2
TROICA-5	June 26 – July 2, 1999	0.8
	July 3–13, 1999	0.9
TROICA-7	June 27 – July 3, 2001	0.6
	July 4–10, 2001	0.9
TROICA-8	March 19–25, 2004	2.5
	March 26 – April 1, 2004	2.1
TROICA-9	October 4–11, 2005	4.3
	October 11–18, 2005	3.5

The well pronounced seasonal behavior of the soot content in the atmosphere over Russia is observed. The large scale (500–1000 km) inhomogeneities of the soot aerosol distributions are there along the railway line in winter. They are related to the effect of synoptic and meteorological processes determining the aerosol transfer and accumulation. The areas of the Irkutsk and near Baikal regions are characterized by a greater frequency of occurrence of near-ground inversions and enhanced soot aerosol pollution, especially in the cold season, when they were affected by the vast Siberian anticyclone.

The large scale areas of pollution (about 1000 km) in spring, 1997 were caused by grass fires. The soot content in the atmosphere of South Siberia and Far East in winter and spring are twice greater than that on the European territory of Russia. The data on the content of soot aerosol in different seasons in the atmosphere over cities and rural areas are shown in Table 3.

Air in rural areas was mostly polluted by soot in fall, 2005, when peatbog fires were observed in the European part of Russia, and burnt grass smokes were observed in its Asian part. A high soot content of the burnt grass smoke was observed on the path Khabarovsk – Moscow in spring, 1997. Urban contribution of soot in autumn was 4.7 μg/m³ and was close to the winter urban one (3.4 μg/m³). The urban contribution in summer and spring was small, 0.9 and 1.6 μg/m³, respectively. The atmosphere cleaning in these cases is mainly related to the advection of the cold Arctic air.

Variations of soot aerosol in the meridian direction

Additional measurements of the soot concentration in the meridian direction were carried out (in Europe: Kislovodsk – Murmansk, 43.91–68.96°N and in Asia: Tomsk – Surgut, 56.52–61.25°N). A boat was used in the measurements on river Ob', and in Europe – the wagon-laboratory along the railway path in a quite narrow latitudinal zone.

The results of measurements along the path Moscow – Murmansk – Kislovodsk – Murmansk on April 6–9 and May 23–27, 2000 are shown in Fig. 2.

Table 2. The soot content in urban atmosphere. *C* is the mean soot concentration

Measurement place	Period of measurement	*C*, μg/m³	Ref.
USA			
8 cities	1975	5.0	[7]
26 cities	1982	3.8	[8]
Los Angeles	1959–1982	6.4	[9]
New York	1978–1980	4.2	[10]
France			
5 cities	February – April, 1985	4.6	[11]
Paris	February – April, 1985	7.9	[11]
	1989	4.6	[12]
Finland, Helsinki	November, 1996 – June, 1997	1.4	[13]
	1987	4.8	[14]
Slovenia, Leblanc	September, 1990 – February, 1991	3.6	[15]
Russia, Moscow	1985–1989, 1997	≤ 10	[16]
	1989–2005	5.1	[17]
Russia, Tomsk, Akademgorodok	1997–1998	1.3	[18]
China, Beijing	February, 1983 – February, 1984	27	[19]
	1996–1998, November	27.7	[20]
	2000–2004, November	17.5	[20]
	July, 1999 and August, 2005	11.5	[20]

Table 3. The content of soot aerosol along the Trans-Siberian railway in urban (u) and rural (r) atmosphere. *C* is the mean soot concentration. M–K – Moscow – Khabarovsk, M–V – Moscow – Vladivostok

Region	*C*, μg/m³															
	1998, winter				2005, autumn				1999, summer				1997, spring			
	M–K		K–M		M–V		V–M		M–K		K–M		M–K		K–M	
	u.	r.	u.	r.	u.	r.	u.	r.	u.	r.	u.	r.	u.	r.	u.	r.
Moscow	–	–	–	–	–	6.8	1.8	1.7	–	–	–	–	–	–	–	–
N. Novgorod	–	–	–	–	11.8	5.0	5.6	2.6	–	–	–	–	–	–	–	–
Vyatka	5.2	2.8	1.2	1.1	7.4	4.6	6.0	4.8	–	0.5	1.4	0.6	5.3	0.7	4.9	3.7
Perm	1.0	0.4	1.9	0.7	7.5	3.9	11.5	4.3	1.0	0.5	0.8	0.4	1.5	0.4	1.3	1.0
Ekaterinburg	3.2	1.4	2.3	1.2	10.5	3.6	13.3	6.8	1.0	0.5	1.3	0.4	1.3	1.0	2.4	2.0
Kurgan	–	–	2.7	1.5	–	–	–	–	1.4	0.3	0.3	0.2	3.7	1.5	4.6	2.8
Tyumen	–	–	–	–	7.7	4.0	24.1	4.2	–	–	–	–	–	–	–	–
Omsk	1.5	1.5	3.0	1.4	4.1	2.8	6.1	2.8	0.9	0.3	1.3	0.7	0.8	0.6	2.6	1.8
Novosibirsk	3.2	0.6	7.4	1.4	6.2	3.4	21.0	2.9	0.7	0.2	1.5	0.7	1.9	0.5	4.1	2.6
Krasnoyarsk	2.1	1.3	7.2	0.9	11.2	0.6	3.8	0.7	1.4	1.2	0.9	0.2	2.1	0.4	2.0	2.3
Zima	7.3	1.2	8.0	3.3	3.9	3.9	2.1	0.7	1.2	0.4	0.7	0.7	3.3	0.3	5.2	3.5
Cheremkhovo	7.1	1.2	16.5	4.0	7.3	5.6	2.6	1.0	0.9	0.7	2.0	0.7	2.4	0.3	8.2	5.3
Irkutsk	5.6	1.8	7.7	0.6	20.2	1.4	16.1	0.7	4.7	0.7	3.5	0.1	1.8	0.8	7.1	3.3
Ulan-Ude	7.0	1.8	–	0.6	4.2	3.5	8.4	0.8	2.2	0.7	0.8	0.3	3.1	0.8	4.2	1.2
Chita	4.8	2.1	3.9	0.5	6.1	2.8	1.0	0.4	1.3	0.4	1.4	0.3	2.5	0.8	7.2	1.4
Semiozernyi	7.7	1.5	1.1	0.8	–	–	–	–	0.9	0.5	1.2	–	0.9	0.8	0.5	0.5
Mogocha	–	–	–	–	7.2	3.6	0.9	0.2	–	–	–	–	–	–	–	–
Shimanovskaya	4.8	2.0	1.2	0.7	6.2	2.6	3.3	3.9	–	0.3	0.9	0.6	2.2	0.5	1.4	0.7
Belogorsk	4.2	2.2	1.2	1.2	10.0	4.8	8.6	6.6	–	–	1.0	0.6	1.0	1.0	1.3	0.8
Khabarovsk	7.7	2.5	2.7	2.2	12.8	2.3	14.9	5.3	0.7	0.3	–	1.0	3.0	1.3	–	0.7
Spassk-Dalnii	–	–	–	–	1.7	1.3	2.4	1.4	–	–	–	–	–	–	–	–
Vladivostok	–	–	–	–	8.1	3.1	–	3.4	–	–	–	–	–	–	–	–
Mean	4.8	1.4	4.7	1.4	8.1	3.5	7.7	2.8	1.4	0.5	1.4	0.5	2.2	0.7	3.7	2.0

High values of the soot concentration in both directions of the train motion headed by diesel locomotive along the path Idel' – Lodeinoe Pole were recorded. To decrease the air pollution, the wagon–laboratory was the last in the train. It was one order of magnitude greater than the mean level of the soot pollution of the atmosphere along the path Murmansk – Kislovodsk.

The enhanced soot content in atmospheric air was observed in cities and industrial centers. Variations of soot in cities along the path St. Petersburg – Kislovodsk lied in the range 0.7–3.2 μg/m³, in rural area: 0.1–0.3 μg/m³, and along the path Kislovodsk – St. Petersburg they were 1.0–4.4 and 0.5–0.8 μg/m³, respectively. The mean value of the soot concentration along the path to the north from station Idel' (64.14°N) was equal to 0.3 μg/m³ and the maximum values did not exceed 0.7 μg/m³. The mean values of the soot concentration along the path Bologoe – Povarovo were also low: 0.2 μg/m³ (April 6, 2000) and 0.7 μg/m³ (May 26, 2000).

Stationary measurements in Kislovodsk (sanatorium "Piket" and Gagarin str.) and at Kislovodsk High-Mountain Scientific Station (KHMSS) in April and

May, 2000 have shown that, after termination of the cold season, the mean soot concentration in Kislovodsk was equal to 0.4 μg/m^3 being close to the soot content level in air at the KHMSS.[21]

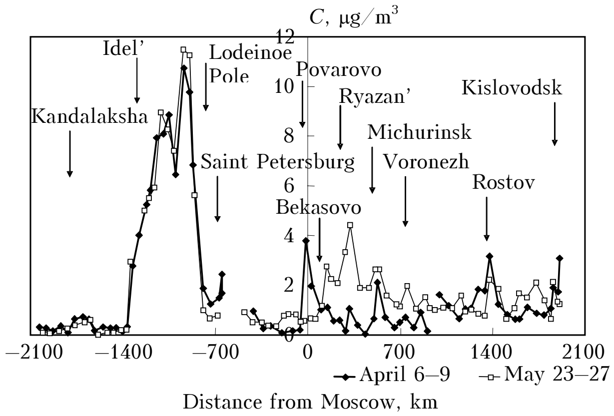

Fig. 2. Distribution of the mass concentration of soot along the railway Murmansk – Kislovodsk in April–May, 2000 (TROICA-6).

The soot content in air on a path of 800 km along river Ob' from Tomsk to Surgut on July 12–23, 1999 varied within the range 0.1–0.5 μg/m^3 at a mean value of 0.3 μg/m^3. As there are few big settlements on the boat path (in the order of the population increase: Kolpashevo, Nizhnevartovsk, Surgut, and Tomsk), and the soot was sampled at the distance no less than 70 km from them, an obtained mean value of 0.3 μg/m^3 for the soot concentration characterized the level of soot pollution of rural areas on July 12–23, 1999. Measurements of soot concentrations in expedition TROICA along the path Novosibirsk – Ekaterinburg on July 11–12, 1999 have shown values of 0.2–1.6 μg/m^3 and a mean value of 0.7 μg/m^3.

By data of Russian Hydrometeorological service the 5-day backward trajectories of air mass transfer at a level of 925 hPa (approximately 700 m above the sea level) were constructed for sites located along the boat path. Although some part of the aerosol sampling root passed through industrial regions, some noticeable anthropogenic effect on the level of the atmosphere pollution was not observed.

Plume of polluted air from the city

The soot concentration on the path of the circular railway around Moscow was also measured on April 7–8 and May 25, 2000 at station Povarovo-3 (to the north-west from Moscow) and at station Bekasovo-yard (to the south-west). According to the data of the Russian Hydrometeorological service, the wind direction on April 7–8 was southeast, therefore, high values of the soot concentration (3.8 and 2.0 μg/m^3, see Fig. 2) recorded during the standing at station Povarovo-3 and when train moving by the north-west and west parts of the circular railway (22:27–22:48 LT, April 7) and (0:24–0:41 LT, April 8) are the evidence of the presence of plume of polluted air from Moscow. Measurements carried out at the stationary site ZSS (Zvenigorod Scientific Station IAP RAS) situated to the west from Moscow, 500 m far from the circular railway on April 7 (9:24–12:00 LT) and April 8 (9:24–14:45 LT) have shown soot concentration values of 1.3 and 1.2 μg/m^3, respectively. Since these values essentially exceed the background for spring and are characteristic of polluted air, they also are the evidence of the existence of the polluted air plume from Moscow at this time.

Due to westerly wind direction on May 25 at the moment of train motion along the circular railway from station Bekasovo-yard to st. Povarovo-3 (9:54–12:50 LT), the polluted air plume from Moscow propagated to the east, so the observed soot concentrations were low (0.7 and 0.6 μg/m^3).

Comparison of the soot content measurements in urban air at SSOMAP sites and in TROICA expeditions

Measurements of the soot content in the atmosphere over the Russian cities have been regularly carried out since 1972 at the air quality monitoring network of the State Service of Observations and Monitoring of Atmospheric Pollutions (SSOMAP). In 1998, measurements were carried out in 35 cities and at 74 stations.[5] The soot concentration in air was determined using the technique described in Ref. 6. The daily mean value of the soot concentration obtained from the data of all sites was 50 μg/m^3, a single mean was 596 μg/m^3. The following maximum permissible concentrations (MPC) are accepted in Russia: a daily mean of 50 μg/m^3, a single mean (20 min) of 150 μg/m^3. According to the data of network measurements, annual mean values greater than 1 MPC were observed in 1998 in 11 cities (including Kurgan and Omsk). The maximum individual values of the soot concentration in Barnaul reach 10 MPC, in Novosobirsk – 9 MPC. Such high level of soot pollution of air in Russian cities is doubtful. Comparison of the soot concentration values (see Tables 1 and 2) obtained using the technique for collecting aerosol samples on quartz fiber filters with subsequent measurement of the light absorption by aerosol samples and the SSOMAP data of semi-quantitative determination of the soot mass concentration in atmospheric air has shown the latter to be approximately one order of magnitude overestimated.

Both methods for determining the soot concentration are used in the USA. They show the same values, and the soot mass per unit area of the standard sample is one order of magnitude lower than that in the Russian standard for determining the soot concentration.

Conclusion

The following conclusions from the results of measurements of the soot concentration in TROICA expeditions can be made.

1. The level of soot pollution of the atmosphere in Russian cities is comparable with the level of pollution of industrially developed countries of the Western Europe and the USA, but is essentially lower than that in Beijing.

2. The minimal values of soot concentrations in rural areas along the Trans-Siberian railway were observed in summer, 1999 and varied from 0.1 to 1.0 $\mu g/m^3$, and the maximal values were recorded in autumn, 2005 (0.6–5.6 $\mu g/m^3$) due to peatbog fire smokes in the European part of Russia and burnt grass along the Asian part of the railway.

3. The level of air soot pollution in rural areas between Tomsk and Surgut in July, 1999 and on Kola peninsula in April–May, 2000 was equal to 0.3 $\mu g/m^3$. The soot content in air in the rural region of Caucasus Mineral Waters in April–May, 2000 was 0.4 $\mu g/m^3$.

4. The plume of air polluted by soot from Moscow was observed on a part of the circular railway around Moscow on April 7–8, 2000.

5. It follows from comparison of the measurements at the SSOMAP stations with the data of TROICA expeditions that the SSOMAP data on the soot concentration should be decreased by approximately 10 times. It is necessary to develop a new scale of the soot mass standard for measuring the soot content in air.

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