Organic and inorganic carbon in atmospheric aerosols over Yakutia

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This paper analyzes the results of geochemical monitoring of gases and aerosols in the near-surface atmosphere, which has been carried out by researchers from the Permafrost Institute, Russia, and Hokkaido University, Japan, since 1993. The carbon concentrations in atmospheric aerosol were measured at atmogeochemical stations located at the Laptev Sea coast (near Tiksi) and in the Central Yakutia (near Yakutsk). As a result, the monitoring yielded long-term data series on the chemical composition of atmospheric gases and aerosols for the areas with different climate (the nearly arid, continental climate at Yakutsk and the humid, maritime climate in Tiksi) and with different, both quantitatively and qualitatively, anthropogenic impact.

Geochemical monitoring of gases and aerosols in the surface atmosphere has been conducted by the Permafrost Institute SB RAS, Russia, and the Hokkaido University, Japan, since 1993. The distribution of carbon in atmospheric aerosols is studied at atmogeochemical stations located at the coast of Laptev Sea (near Tiksi) and in Central Yakutia (near Yakutsk).

The atmospheric aerosol is sampled with systems, consisting of a set of selective filters, through which the atmospheric air is blown by pumps at a fixed flow rate. Two types of the filters 47 mm in diameter are used: Teflon filters (Sumitomo Fluoropore AF07P) for water-soluble substances and quartz fiber filters (Palluflex 2500 QAT-UP) for carbonaceous particles. The atmospheric aerosols passed through the impactor with the pore diameter of 2 μm are sampled at each filter with a pump characterized by the air flow rate of 5 liter/min. Filters are replaced every 30 days. The flow rate through the filters is controlled with a flowmeter.

After sampling, several disks of 1 cm in diameter are cut out from the filters. A half of the disks is used for determination of the total carbon content. Another one half is heated in an electric furnace at 300°Ñ in air for 30 min in order to remove organic carbon and then it is analyzed for elemental carbon. The difference between total carbon and elemental carbon gives the content of organic carbon.

Carbon is determined using a combination of a NC analyzer (Sumitomo Chemical Industry Inc., Model NC-80) and a gas chromatograph (Hitachi Inc., Model 163 FID) with a nickel catalytic methanizer and a flame-ionization detector. The detection limit of the analytical methods used is 1 μg of carbon.[1]

As a result, many-year monitoring yielded the data on the chemical composition of gases and aerosols in regions characterized by different climate (nearly arid, continental climate in Yakutsk and humid, maritime climate in Tiksi) and different, both quantitatively and qualitatively, anthropogenic impact has been obtained.

It has been found that carbon is the dominant component of aerosols in Yakutia: the total content of elemental and organic carbon usually makes up to 60–70% of the total amount of atmospheric aerosols in Central Yakutia and 50–90% in the Arctic zone.

The parameters of the distribution of organic and inorganic carbon in the surface atmosphere near Yakutsk and Tiksi are given in Table 1.

Table 1. Concentration of organic and inorganic carbon in the surface atmosphere near Yakutsk and Tiksi, μg/m³

Concentration	TAC	EC	OC	OC/EC
		Yakutsk		
Max	42.0	16	29	
Min	0.57	0.14	0.45	
Average	11.0	3.2	5.8	1.81
Number of samples	58	58	58	
		Òiksi		
Max	3.0	1.7	2.0	
Min	0.39	0.064	0.22	
Average	1.3	0.34	0.67	1.97
Number of samples	60	60	60	

Notes. TAC – is the total concentration of atmospheric aerosol; EC denotes elemental carbon; and OC stands for organic carbon.

The content of the most aerosol components (Na^+, Ca^{2+}, Mg^{2+}, NH_4^+, SO_4^{2-}) and elemental carbon is higher in the winter atmosphere. The content of organic carbon is relatively uniform during a year. For example, near Yakutsk the content of the most aerosol components and elemental carbon in the winter urban atmosphere exceeds the summer values by 1.5–3.5 times (Table 2).

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Table 2. Average total concentration of aerosols, organic and inorganic carbon in the surface atmosphere near Yakutsk, μg / m³

Season	TAC	EC	OC	ΣC	OC / EC	*n**
Summer (June–Aug)	16.8	3.0	6.7	9.7	2.23	13
Winter (Nov–March)	17.9	5.2	7.2	12.4	1.38	28
Winter / summer	1.1	1.7	1.1	1.16	–	–

* *n* is the number of samples.

The concentration of organic and inorganic carbon in the surface atmosphere near Tiksi is also subject to significant variation during a year. The content of elemental carbon in aerosols is much higher in winter atmosphere of the coastal region and considerably (2.1 times) exceeds the summer concentrations. Somewhat lower accumulation is characteristic of organic carbon (Table 3).

Table 3. Average content of organic and inorganic carbon in the surface atmosphere near Tiksi, μg / m³

Season	TAC	EC	OC	ΣC	*n*
Summer (June–Aug)	1.20	0.09	0.81	0.90	15
Winter (Nov–March)	2.03	0.19	1.11	1.30	25
Winter / summer	1.7	2.1	1.4	–	–

In some years (August 1996, June–July 1998) the carbon concentration increases by 2 to 3 times in summer period (Table 4) because of the forest fires, covering significant territories. Thus, in June 1998, 337 forest fires were detected on the territory of Yakutia, about $2.1 \cdot 10^6$ m³ wood was burnt and damaged.[2] In these periods, the OC / EC ratio changes toward even higher prevalence of organic carbon. For example, in August 1996, in the period of intense forest fires, the OC / EC ratio near Yakutsk was 2.64.

The effect of forest fires, most of which arise in the taiga zone of Yakutia, leads to a insignificant increase of the carbon concentration in atmospheric aerosols of tundra – near Tiksi, at the distance about 1 000 km.

The calculations performed by specialists of the Institute of Cosmophysics SB RAS (Yakutsk) using the technique proposed by Canadian investigators[3] showed that forest fires in Central Yakutia in 1999, when more than $97 \cdot 10^6$ t of forest biomass were burnt (Fig. 1), emitted a great amount of greenhouse gases into the atmosphere: $73 \cdot 10^6$ t CO_2, $4.8 \cdot 10^6$ t CO, and $0.4 \cdot 10^6$ t CH_4 (Table 5).

The fire areas, calculated emission of carbon into the atmosphere, and the carbon content in atmospheric aerosols at the stations of Yakutsk and Tiksi in the period of 1994–1999 are given in Table 6.

The comparison of calculated data on the carbon emission into the atmosphere[2] and the observed carbon content in atmospheric aerosols at the station Yakutsk indicates the existence of a functional relation between the parameters compared (Fig. 2), but this relation is not observed in the data on the aerosol content obtained at the station in Tiksi.

In the atmosphere of Central Yakutia the local transport of sedimentary material and anthropogenic emissions prevails and the effect of forest fires is considerable, while at the coast of Laptev Sea, the prevailing mechanism is the long-range and global atmospheric transport.[1]

Table 4. Average concentration of organic and inorganic carbon in atmospheric aerosols in summer (June–August), μg / m³

Station	Period	ΣC	OC	EC	OC / EC
Yakutsk	Without fires (*n* = 6)	5.52	3.37	2.15	1.57
	With fires (*n* = 7)	12.40	8.95	3.45	2.59
	Fires / no fires	2.25	2.66	1.60	–
Tiksi	Without fires (*n* = 8)	0.82	0.57	0.24	2.37
	With fires (*n* = 7)	2.29	1.21	1.08	1.12
	Fires / no fires	2.79	2.12	4.50	–

Table 5. Fire areas and emission of greenhouse gases at the territory of Yakutia[2]

Year	Fire area, 10^6 ha	CO_2 (C), 10^6 t	CO (C), 10^6 t	CH_4 (C), 10^6 t
1995	0.12	2.1 (0.57)	0.2 (0.09)	0.011 (0.008)
1996	2.5	46.0 (12.54)	4.3 (1.84)	0.43 (0.32)
1998	1.1	19.0 (5.18)	1.8 (0.77)	0.17 (0.13)
1999	3.9	73 (19.91)	4.8 (2.06)	0.40 (0.30)

Table 6. Fire area, calculated emission of carbon into the atmosphere, and carbon content in atmospheric aerosols

Year	Area, 10^6 ha	Rainfall, mm	Emission of C, 10^6 t	Summer content of C in aerosols, μg / m³	
				Yakutsk (*n* = 13)	Tiksi (*n* = 15)
1994	–	200	–	5.6	0.6
1995	0.12	109	0.67	3.3	1.0
1996	2.5	162	14.7	7.6	1.6
1997	–	190	–	–	1.3
1998	1.1	115	6.08	12.0	0.7
1999	3.9	190	22.3	36.1	0.7

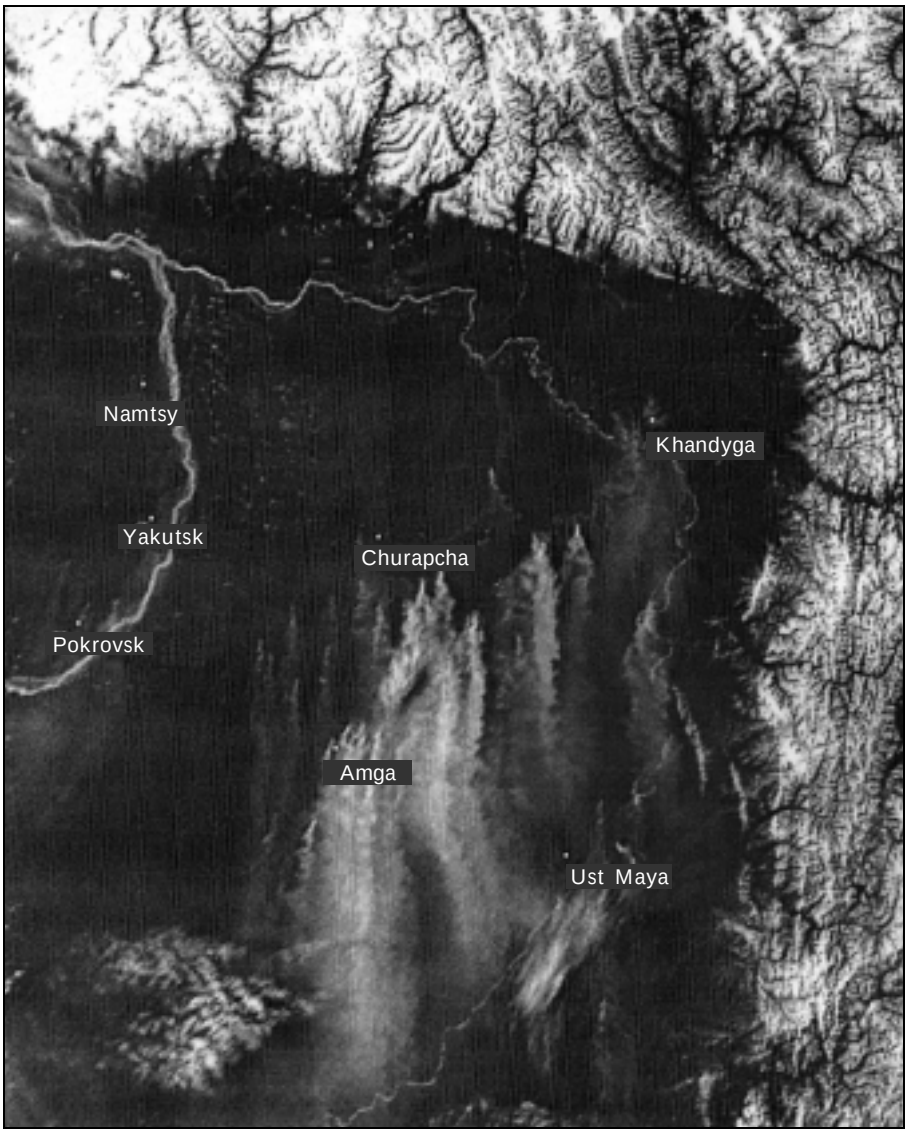

Fig. 1. Large forest fires in Lena–Aldan interfluve in Yakutia (May, 1999) from NOAA space data.

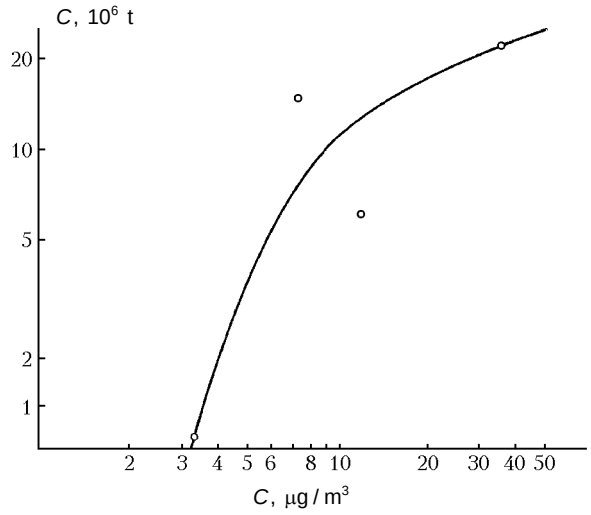

Fig. 2. Atmospheric emission of carbon vs. carbon content in atmospheric aerosol at the station in Yakutsk.

American[4] and Japanese[5] investigators studied the composition of atmospheric aerosols in the environment of the USA and Japan: in big cities, industrial regions, suburbs, and background areas (Table 7).

The total carbon and the elemental carbon concentrations in Yakutsk are roughly at the same level as in the American cities (Pleasanton, Luray) and in Japan (Sapporo, Kanto). The background content of total and elemental carbon at the Hachijo-jima and Chichi-jima islands in the Pacific Ocean (Japan) exceeds somewhat the corresponding values observed at the coast of Laptev Sea of the Arctic Ocean (Tiksi). Thus, we can conclude that in the background regions the elemental carbon concentration amounts to 0.3–1.4 $\mu g/m^3$ (about 6–20% of the total aerosol mass).

The maximum concentrations of total and elemental carbon ever observed in Yakutsk (May 1999) were 36.1 and 7.1 $\mu g/m^3$, respectively, and the amount of organic carbon in this period was 29.0 $\mu g/m^3$.

Table 7. Average concentrations of carbon in aerosols (μg / m³) in the USA,[4] Japan,[5] and Russia

Location	Date	C_{tot}	EC	EC / TAC
		USA		
		Big cities		
New York	Feb 10–Mar 06, 1972	33.1	13.3	0.09
Washington	June 9–28, 1972	11.6	6.5	0.11
Denver	Nov 08–Dec 20, 1978	15.8	5.4	0.06
		Suburbs		
Warren	1979–1980	12.3	3.7	0.06
Pleasanton	Aug 13–Sep 05, 1972	9.6	3.2	0.03
		Industrial towns		
Abbeville	Aug 05–Sep 11, 1979	12.5	1.7	0.04
Luray	July 14–Aug 15, 1980	9.4	1.7	–
		Japan		
		Big cities		
Kanto, Tokyo suburb	1982	5–18	2–10	0.06–0.16
Sapporo	1982	4–19	3–8	0.09–0.23
		Background territories		
Hachijo-jima	1981	1.2–3.2	0.6–1.4	
Chichi-jima	1981	0.8–2.5	0.4–1.3	
		Russia		
		(our data)		
Yakutsk	1993–1999	9.0	3.2	0.03
Tiksi		1.01	0.34	0.26

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