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VARIATION OF ATMOSPHERIC AEROSOL CARBON CONCENTRATION IN YAKUTIA

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Abstract

Geochemical monitoring of aerosols in the near-surface atmosphere has been carried out by the Permafrost institute, Russia, and Hokkaido University, Japan, from 1994 through 1999. Measurements of aerosol carbon concentrations in the atmosphere have been made at atmogeochemical stations located on the Laptev Sea coast (the vicinity of Tiksi) and in Central Yakutia (the vicinity of Yakutsk). Mean concentrations of elemental carbon and particulate organic carbon in Yakutsk were 3.2 μgC m^{-3} and 5.8 μgC m^{-3}, respectively, and those in Tiksi were 0.34 μgC m^{-3} and 0.67 μgC m^{-3}, respectively. Maximum concentrations of total carbon and elemental carbon observed at Yakutsk in May 1999 were 36.1 and 7.1 μg Cm^{-3}, respectively, caused by forest fires. The amount of particulate organic carbon for that period was 29.0 μgC m^{-3}.

KEYWORDS: *Atmosphere, Aerosol, Carbon, Yakutia*

1. Introduction

In IPCC report (1996), atmospheric aerosols control the global warming due to scattering and absorption of solar radiation (direct effect) and due to increase cloud albedo with increasing number of cloud droplets (indirect effect). It is, thus, important to determine global distribution of atmospheric aerosols. In the Arctic area, Staebler et al., (1999), Polissar et al., (1999), Anderson et al., (1992), Shaw (1991) and Barrie and Hoff (1985) measured chemical composition of atmospheric aerosols at Spitzbergen, Alaska and Canada. Atmospheric concentration of elemental carbon (EC) or black carbon (BC) was also measured at Alaska by Murao et al., (2004), Polissar et al., (1999) and Rosen et al., (1984). There are, however, little data available in the Siberian Arctic (Fukasawa et al., 1997).

This paper presents analysis of the results of geochemical monitoring of aerosols in the near-surface atmosphere which has been carried out by the Permafrost Institute, Russia, and Hokkaido University, Japan, from 1994 through 1999. Measurements of aerosol carbon concentrations in the

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atmosphere have been made at atmo-geochemical stations located on the Laptev Sea coast (the vicinity of Tiksi) and in Central Yakutia (the vicinity of Yakutsk), shown in Fig.1.

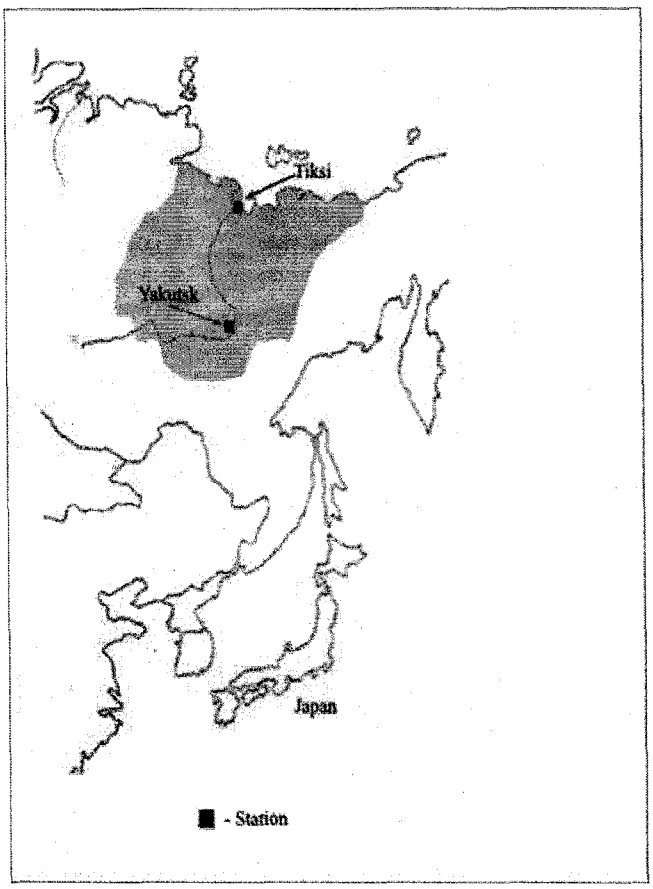

Fig.1. Map of the stations.

2. Measurement

Atmospheric aerosol samples were collected continuously for 30 days every month from 1994 through 1999 by using three kind of filters, such as Teflon filters (Sumitomo Fluoropore AF07P) for measurement of concentrations of total aerosol mass (TP) and water soluble matter, quartz fiber filters (Pallflex 2500QAT-UP) for carbonaceous particles (elemental carbon (EC) and particulate organic carbons (OC)), and Nuclepore filters (Nuclepore co., pore-size 0.4 μ m) for heavy metals. Atmospheric fine particles, less than 2 μ m in diameter, were collected on each filter passed through an Nuclepore filter of 8 μ m pore-size with a pump at a flow rate of 5 L min^{-1}.

Total aerosol mass was determined by weighing the Teflon filter on an electric balance.

Amount of aerosol carbon on the quartz fiber filters was analyzed following Ohta and Okita (1984). Several pieces of disc-shaped samples with diameter of 1 cm were cut off the filter. One half of the samples served to determine the total carbon content, and another half was heated in an electric

furnace at 300°C in air for 30 min to remove organic carbon and then used to determine the elemental carbon content. The difference between the total carbon and elemental carbon gives the amount of organic carbon.

Carbon content was determined on a combination of a NC-analyzer (Sumitomo Chemical Industry Inc., Model NC-80) and a gas chromatograph (Hitachi Inc., Model 163 FID) equipped with a nickel catalyst methanizer and a flame ionization detector. The analytical techniques permit determination of minimum of 1 μg carbon (Ohta et al., 1995).

3. Result and discussion

3.1 Concentration of carbonaceous particles in Yakutia

As a result of monitoring studies, long-term data have been obtained on the chemical composition of atmospheric aerosols for the areas with different climates (the nearly arid, continental climate at Yakutsk and the humid, maritime climate at Tiksi) and with different, both quantitatively and qualitatively, anthropogenic impact (Fig.1).

Carbon has been found to be a dominant atmospheric aerosol component in Yakutia. Elemental and particulate organic carbons normally comprise 60-70% of the total aerosol mass in Central Yakutia and 50-90% in the Arctic area.

Table 1 shows the distribution of concentration of total fine particle mass, elemental carbon and particulate organic carbons in the near-surface atmosphere at Yakutsk and Tiksi.

Table 1. Change of concentration of total fine particles (TP) (μg m^{-3}), elemental carbon (EC) (μ gC m^{-3}) and particulate organic carbon (OC) (μ gC m^{-3}), and the ratio of OC to EC (OC/EC) in the near-surface atmosphere at Yakutsk and Tiksi.

Concentration	TP	EC	OC	OC/EC
Yakutsk				
Maximum	42.0	16.0	29.0	
Minimum	0.57	0.14	0.45	
Mean	11.0	3.2	5.8	2.30
Tiksi				
Maximum	3.0	1.7	2.0	
Minimum	0.39	0.06	0.22	
Mean	1.3	0.34	0.67	1.95

The lowest carbon concentrations in atmospheric aerosols at the observation sites occur in autumn, September-October at Yakutsk and August-September at Tiksi, when total aerosol carbon (TAC) lowers to 1.5-2.0 μgC m^3 (EC : 0.3-1.0; OC : 0.8-1.5) at Yakutsk and to 0.4-1.0μgC m^3 (EC : 0.1-0.3; OC : 0.2-0.5) at Tiksi. The decrease in the carbon content of atmospheric aerosols during this season is related to the fall of autumn precipitation.

The concentrations of total aerosol carbon and of elemental carbon are higher in the winter atmosphere. The organic carbon concentration is relatively uniform throughout the year.

As shown in Table 2, in Yakutsk area, for example, the concentrations of total aerosol carbon and elemental carbon in winter are 1.3 and 1.7 times, respectively, those in summer.

Table 2. Mean concentrations of atmospheric total fine particles (TP) (μg m^{-3}), elemental carbon (EC), particulate organic carbon (OC) and total aerosol carbon (TAC) (μg C m^{-3}), and the ratio of OC to EC (OC/EC) at Yakutsk in different seasons.

Season	TP	EC	OC	TAC	OC/EC
Summer(June-August)	16.8	3.0	6.7	9.7	2.2
Winter (November-March)	17.9	5.2	7.2	12.4	1.4
Winter/Summer	1.1	1.7	1.1	1.3	

The concentrations of elemental and particulate organic carbon in the near-surface atmosphere at Tiksi also show considerable seasonal variation in Table 3. The winter concentration of elemental carbon in this coastal area is much higher (2.1 times) than the summer concentration. The content of organic carbon in winter is slightly higher (1.4 times).

Table 3. The same in table 2, but for at Tiksi.

Season	TP	EC	OC	TAC	OC/EC
Summer(June-August)	0.83	0.09	0.81	0.90	9.0
Winter (November-March)	2.03	0.19	1.11	1.30	5.0
Winter/Summer	2.4	2.1	1.4		

Average concentrations of elemental carbon and particulate organic carbon in the near-surface atmosphere are higher in the cold season both at Yakutsk and Tiksi, the most contrasting variations being observed in the polar region.

As is known, the major amounts of aerosols are delivered during long winters which distinguish the Arctic from other regions. During the winter, the entire aerosol source basins in the coastal areas of Europe, Asia and North America, as well as the sea surface are covered by snow and ice. The winter maximum of aerosol concentrations is therefore related not to local or regional sources, but to very distant (global) sources. This pattern of Arctic haze has been explained by investigations of the mineral composition of aerosols: they originate from arid regions of Europe, Africa and Asia as is also evidenced by the composition of anthropogenic pollution, and the mineral and chemical compositions (Shevchenko et al., 1999; Sirois and Barrie, 1999).

3.2 Emission of carbon in forest fires

Large-scale forest fires are one of the major sources of greenhouse gases emitted to the atmosphere (CO_2, CO, NO_x, CH_4 and others), especially in northern Asia which has an extensive cover of boreal forests. As a result of fires, huge amounts of aerosol particles are emitted into the troposphere, and occasionally to the stratosphere, in extreme cases comparable to the consequences

of volcanic activity. Gas and aerosol emission exerts a strong influence on the chemistry of the atmosphere, cloud conditions and surface energy balance, and hence, on regional and global climates.

Forest fires in Yakutia are monitored using aerial reconnaissance and the NOAA/AVHRR fire detection system as shown in Fig.2 (Solovyev and Vasilyev, 2000).

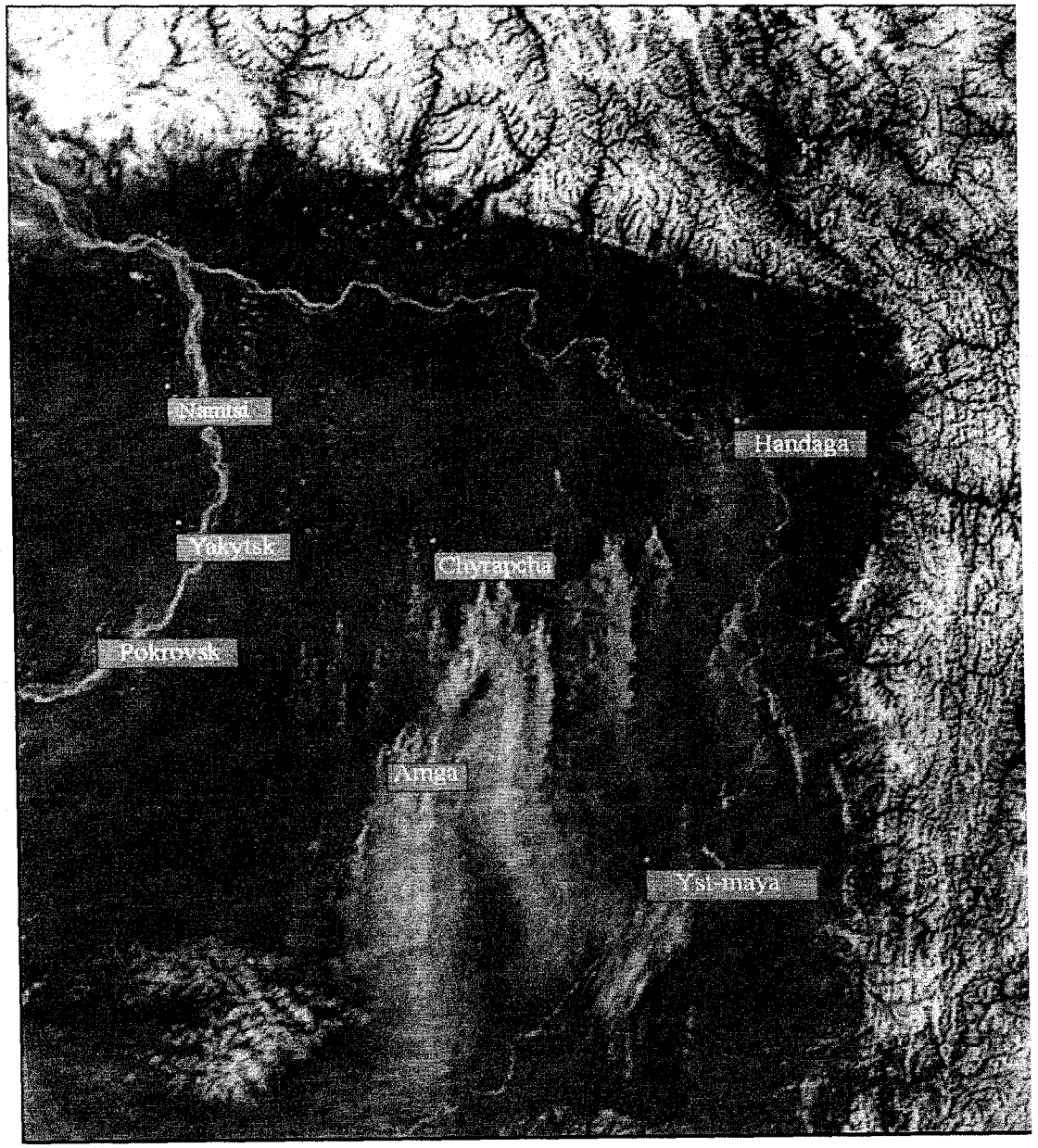

Fig.2. Large forest fires in the Lena-Amga watershed, Yakutia, in May 1999, detected from NOAA satellite.

The effect of forest fires, which occur mainly in the taiga zone of Yakutia, on greenhouse gas emi ssions is observed at large distances and leads, for example, to a notable increase in aerosol carbon concentration in the tundra zone - the Tiksi area.

A two- to three-fold increase in the summer concentrations of carbon, shown in Table 4, resulting from extensive forest fires has been observed in some years (August 1996, June-July 1998). In June 1998, for example, 337 forest fires were reported for Yakutia and approximately 2.1 million cubic meters of wood were burnt or damaged (Soloviev and Vasiliev, 2000). The OC to EC relation during these periods changes to still greater dominance of organic carbon. During the period of intensive forest fires in August 1996 the OC/EC ratio at Yakutsk was 2.64.

Forest fires which occur mainly in the taiga zone of Yakutia cause an insignificant increase in carbon concentration in the tundra atmosphere at Tiksi, at a distance of about 1,000 km.

Table 4. Mean summer concentrations (in August 1996 and June-July 1998) of aerosol carbon (μgC m^{-3}) with and without forest fires.

Station	Period	TAC	OC	EC	OC/EC
Yakutsk	Without fires	5.52	3.37	2.15	1.57
	With fires	12.40	8.95	3.45	2.59
	Fires/Clear sky	2.25	2.66	1.60	
Tiksi	Without fires	0.82	0.57	0.24	2.37
	With fires	2.29	1.21	1.08	1.12
	Fires/Clear sky	2.79	2.12	4.50	

Investigators from the Institute of Cosmophysics at Yakutsk estimated, following the method proposed in Charlson et al. (1992), that burning of 97 million tons of forest biomass by wildfires in Yakutia in 1999 (Fig.2) released large amounts of greenhouse gases into the atmosphere: 73 million tons CO_2, 4.8 million tons CO, and 0.4 million tons CH_4, as shown in Table 5.

Table 5. Fire area and greenhouse gas emission in Yakutia (Soloviev and Vasiliev, 2000)

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	73.0 (19.91)	4.8 (2.06)	0.40 (0.30)

Table 6 shows the forest fire area, estimated carbon emissions into the atmosphere, and aerosol carbon concentrations measured at Yakutsk and Tiksi stations during the period 1994-1999. The maximum concentrations of total carbon observed at Yakutsk in May 1999 was 36.1 μg Cm^{-3}, in which the amount of elemental carbon and particulate organic carbon were 7.1 μg Cm^{-3} and 29.0 μg Cm^{-3}, respectively.

Table 6. Fire area, estimated carbon emission and measured aerosol carbon concentrations

Year	Area, 10^6 ha	Carbon emission, 10^6 t	Summer concentration of aerosol carbon, μgC m^3	
			Yakutsk	Tiksi
1994	0.1	-	5.6	0.6
1995	0.1	0.7	3.3	1.0
1996	2.5	14.7	7.6	1.6
1997	0.3	-	-	1.3
1998	1.1	6.1	12.0	0.7
1999	3.9	22.3	36.1	0.7

Comparison of the estimated carbon emission (Soloviev and Vasiliev, 2000) and the measured aerosol carbon concentration at the Yakutsk station shows a functional relationship between them as in Fig.3. No such relationship has been found for the Tiksi station.

Therefore observations of aerosol carbon concentrations at the stations located in the taiga zone allow approximate estimation of the amounts of greenhouse gases emitted to the atmosphere by forest fires.

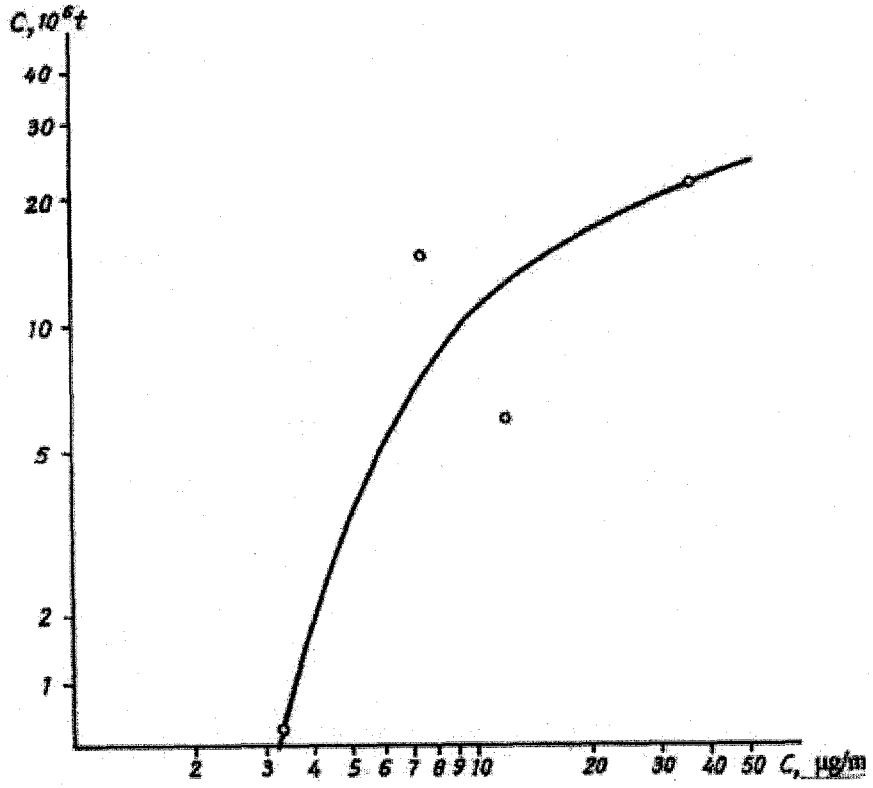

Fig.3. Relation between carbon emission and aerosol carbon concentration at Yakutsk station.

3.3 Mean ambient concentration of particulate carbon in urban and remote areas

Local transfer of deposition and anthropogenic emissions prevails, and forest fires have significant impact in the Central Yakutia atmosphere, while long-range and global tropospheric transport dominates on the Laptev Sea coast (Ohta et al., 1995). . The differences in atmospheric transport in these areas are related to climate. Central Yakutia has a predominantly anticyclonic, extremely continental climate close to arid conditions which impedes long-range atmospheric transport, while the Tiksi area has a maritime climate with mean monthly wind speeds of 4 to 6m/sec.

The U.S. (Wolff et al., 1982), Japanese (Ohta and Okita, 1984), Korean (Seung et al., 2002) and further scientists studied aerosol chemistry in various environments in urban, suburban, rural and remote (background) areas as shown in Table 7.

Table 7. Mean ambient particulate carbon concentrations (μ gC m^{-3}) in various sites

Site	Date	Total C	EC	Authors
Urban and suburban				
New York City	10.02-06.03.1972	33.1	13.3	Wolff et al., 1982
Washington, DC	9-28.06.1972	11.6	6.5	
Denver, CO	08.11-20.12.1978	15.8	5.4	
Tokyo, Kanto	1982	5-18	2-10	Ohta, Okita, 1984
Sapporo	1982	4-19	3-8	
Seoul	1999	22.5	7.3±5.9	Seung et al.,2002
Kwangju	2000	12.5	4.9±2.1	
Remote and background				
Pleasanton	1972-1980	9.8	3.2	Wolff et al., 1982
Luray	1972-1980	9.4	1.7	
Hachijo-jima	1981	1.2-3.2	0.6-1.4	Ohta, Okita, 1984
Chichi-jima	1981	0.8-2.5	0.4-1.3	
South Pole	1986-1987	NM	0.0015-0.3	Hansen et al., 1988
Barrow, Alaska, USA	1983 1988-1994 1999-2001	NM NM 0.2-1.0	0.081-0.314 0.002-0.22 0.001-0.32	Rosen et al., 1984 Polissar et al., 1999 Murao et al., 2004
Aspvreten, Sweden	1989	2.3	0.1	Zappoli et al., 1990
Russia				
Yakutsk, Sakha	1994-1999	9.0	3.2	this work
Tiksi, Sakha	1994-1999	1.0	0.34	

(NM – not measurement)

The concentrations of total particulate carbon and elemental carbon at Yakutsk are approximately the same level as those measured in the urban areas in the U.S.A. (Pleasanton, Luray) and Japan (Sapporo, Kanto).

The background concentrations of total particulate carbon and elemental carbon on the Pacific islands Hachijo-jima and Chichi-jima, Japan, are higher than those on the Laptev Sea coast (Tiksi). Further, at Barrow, Alaska the concentrations of elemental carbon were 0.081-0.314 μ gC m^{-3} in 1983 (Rosen et al., 1984) by an aethalometer measurement, 0.002- 0.22 μ gC m^{-3} from 1988 through 1994 (Polissar et al., 1999) by an aethalometer measurement, and 0.001-0.32 μ gC m^{-3} from August 1999 through June 2001 (Murao et al., 2004) with a combustion technique by Ohta and Okita (1994). Neglecting the difference of concentration levels due to different techniques, it may be concluded that the maximum concentrations of elemental carbon in the background areas is 0.3-1.4 μgC m^{-3}.

4. Conclusion

The concentrations of total and elemental carbon at Yakutsk are approximately at the same level as those measured in the urban areas in the U.S.A. (Pleasanton, Luray) and Japan (Sapporo, Kanto). The background concentrations of total and elemental carbon on the Pacific islands Hachijo-jima and Chichi-jima, Japan, are higher than those on the Laptev Sea coast (Tiksi).

Neglecting the difference of the concentration levels due to different techniques, it may be concluded that the concentration of elemental carbon in these areas is 0.3-1.4 μgC m^{-3} .

The maximum concentrations of total carbon and elemental carbon observed at Yakutsk in May 1999 were 36.1 and 7.1 μgC m^{-3}, respectively, caused by forest fires. The amount of particulate organic carbon for that period was 29.0 μgC m^{-3}.

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