Spatial distribution of organic carbon in the snow cover of Baikal region

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The concentration of C_{org} and its total amount in the snow cover of the Baikal region are determined. The regions with high and low concentrations of C_{org} both in Irkutsk and on the territory under study are identified. It has been found that a significant fraction of the organic carbon comes from suspended matter.

Introduction

At present, different organic compounds have been found in the atmospheric precipitation, namely: amino acids, amines, polysaccharides, organic acids, esters, aldehydes, phenols, hydrocarbons (petroleum products), and polyaromatic hydrocarbons (PAH).[1–7] However, the content of the organic carbon (C_{org}) in atmospheric precipitation has been investigated less thoroughly. At the same time, such investigations are necessary in order to assess its atmospheric component in the formation and in the balance of organic matter of natural waters. Hence, the study of C_{org} content in the snow cover of the regions with different level of anthropogenic pollution is very urgent.

First data on the content of organic matter in atmospheric precipitation of Baikal region were obtained by K.K. Votintsev in 1951–1952.[8] It has been shown that the quantity of permanganate oxidizability (PO) of snow water varied from 1.80 to 2.52 mgO/l. In the further investigations (1976–1986)[5,7] it was determined that the many-year mean PO in the snow cover in the area of Lake Baikal remained unchanged. The content of C_{org}, which was first determined in snow water, varied from 1.0 to 13.6 mg/l, and the ratio between the PO and C_{org} is from 0.55 to 0.97. The aim of our work was to determine the concentrations of C_{org} and its spatial variations in the snow cover of Baikal region, to assess the net amount of C_{org} accumulated during the winter period, and to identify the regions with the least quantities of C_{org}.

Materials and methods

Samples of snow were taken in winters of 1996–1999 in the center of Irkutsk and in its suburbs. The samples were taken during the maximum snow accumulation (February–March) at the locations considerably removed from the pollution sources. Samples of snow were taken at two routes, namely, Bayandai–Irkutsk–Slyudyanka, Irkutsk–Listvyanka at a distance of 300–500 m from the highways as well as on the territory of Baikal–Lenskii Reserve and in the south Baikal basin (Fig. 1). Samples were taken using polyethylene bags and the area and thickness of the snow cover at the sampling site were measured. Analyses were performed in the filtered and unfiltered snow water by the methods standard in hydrochemistry of fresh waters.[9] The PO was determined in snow water except for organic carbon. Altogether 120 samples were analyzed. The error of analysis for the PO was 8 percent, for organic carbon it was 5 percent, the lower limit of detection was 0.1 mgO/l and 0.01 mg/l, respectively.

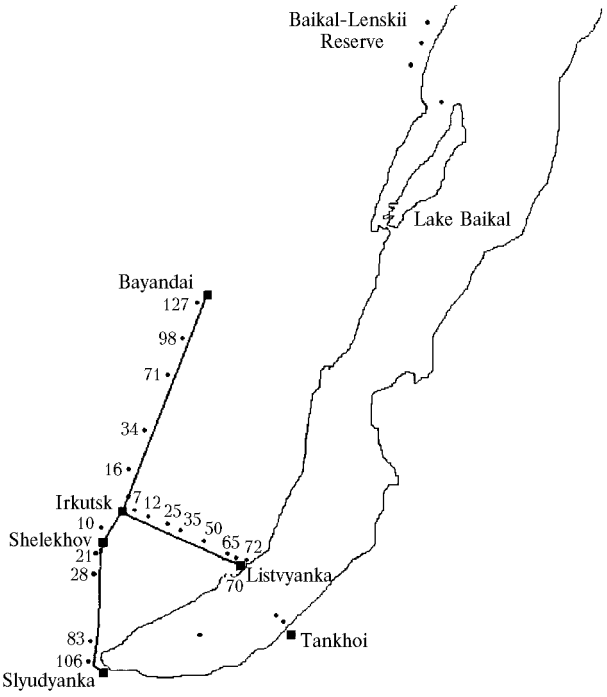

Fig. 1. The map of sampling of snow cover on the territory of Baikal region (the distance from Irkutsk is in km).

The net accumulation of C_{org} during winter period was calculated by the following formula:

$$Q = CV/S,$$

where Q is the quantity of C_{org} in the snow cover, mg/m^2; C is the determined concentration of C_{org}, mg/l; V is the volume of the entire snow sample selected, l; S is the area of sampling site, m^2.

Results and discussion

Depending on the location of the pollution sources, in Irkutsk the areas are found with different content of organic matter in the snow cover (Table 1). The low values of the total C_{org} (unfiltered samples) and PO are found in the snow cover of the districts with centralized heating (stations 5, 11, 13) remote from the center. In the center of the city (stations 1, 2, 3) and in the districts with the stove house heating the content of organic matter is high. The basic source of C_{org} in the snow cover of microdistricts with the stove house heating are solid particles (smoke, soot) formed at incomplete combustion of coal. The concentration of suspended particles in the snow cover of these districts is higher as compared with that in other districts of the city. The value of the ratio of C_{org}/C_f is 1.7–3.8. In the central part of the city and in the districts with centralized heating, where the formation of C_{org} is mainly due to the emissions from motor transport and industrial enterprises, this ratio is lower – 1.4–1.6.

The ratio of oxygen of PO to the organic carbon in unfiltered snow water varies from 1.3 to 1.9 (the average being 1.6), and in the filtered snow water it varies from 0.5 to 1.2 (the average being about 0.8) (see Table 1). From that it follows that the main amount of stable organic matter is in the solid phase.

The amount of accumulation of the total C_{org} in the snow cover of the central part of the city varied within 109–470 mg/m^2, being, on the average, 274 mg/m^2 (see Table 1). For the districts with stove heating the amount of the total C_{org} accumulated varied from 169 to 415 mg/m^2, and in the districts far from the center (stations 11, 13) the lowest amount of accumulation of C_{org}, of 106–77 mg/m^2, were observed. In the filtered samples the amount of accumulation of C_{org} was lower by 26 to 74%.

The investigations of PAH in the snow cover, carried out during the above-mentioned period and along the same routes,[6] have shown that the total C_{org} concentration is analogous to the distribution of PAH concentration. The portion of PAH in the total C_{org} in Irkutsk was about 0.2%. In the vicinity of the town of Shelekhov it increased, because of high PAH concentrations, up to 1.4–2.9%, and in the ecologically clean districts the portion of PAH was hundredths of percent (0.03–0.08). The ratio of PO/C_{org} in the unfiltered snow water is more than 1 that is indicative of a predominance of stable organic matters, one of which is PAH. In spite of the fact that C_{org} is not among the normalized indices of the environmental pollution by its amount one can judge on the level of pollution both individually and in combination with the other indices.

Of interest are the results of a comparison made between the total C_{org} concentration in the snow cover of Irkutsk and Shelekhov with the data for Angarsk and Usol'e–Sibirskoe.[7] In the snow cover of Shelekhov the amounts of C_{org} are close to the data obtained for Angarsk and Usol'e–Sibirskoe (Table 2). Table 2 shows that in the snow cover of Irkutsk the C_{org} concentrations are the highest. Based on the above C_{org} concentrations, the city of Irkutsk is the most polluted one. It has been known that Irkutsk, Angarsk, Shelekhov, and Usol'e–Sibirskoe are among the cities with high level of atmospheric pollution according to other indices.[10]

Table 1. Content of organic matter and the level of its accumulation in the snow cover of Irkutsk

Number of station	Place of sampling	PO, mgO/l	C_{org}, mg/l	PO/C_{org}	G, mg/m^2	PO, mgO/l	C_{org}, mg/l	PO/C_{org}	G, mg/m^2
		Unfiltered				Filtered			
1	Park of Parizhskoi Kommuny	10.1	11.6	0.9	470	–	–	–	–
2	Garden at the bridge across River Angara	16.6	15.7	1.0	385	–	–	–	–
3	Island of Jouth	8.8	5.7	1.5	109	1.8	3.5	0.5	**82**
4	Central Park	5.3	4.1	1.3	130	–	–	–	–
5	Park in Lisikha	2.2	3.0	1.3	117	–	–	–	–
6	The Gorkii Settlement*	8.2	5.3	1.5	169	1.8	3.2	0.6	**102**
7	Bokovo*	7.3	4.5	1.6	138	2.7	2.4	1.0	**64**
8	Novolenino*	13.6	8.6	1.6	312	4.0	4.7	0.9	**171**
9	Radishchevo*	15.6	11.5	1.4	415	3.4	3.0	1.1	**102**
10	Raduzhnyi	12.8	8.4	1.5	254	3.8	5.0	0.8	**182**
11	Solnechnyi	4.9	3.7	1.3	106	1.9	2.7	0.7	**104**
12	Akademgorodok	7.7	4.8	1.6	135	2.2	2.9	0.8	**54**
13	Dam of hydroelectric power station	1.6	2.8	0.6	77	–	–	–	–

* Districts of the city where stove heating of houses prevails.

Table 2. Content of organic matter and the level of its accumulation in the snow cover of different regions of Russia

The place of sampling	PO, mgO/l	C_{org}, mg/l	PO/C_{org}	G, mg/m^2	Data
Baikal-Lenskii Reserve	0.5–1.0	0.8–2.5	0.5–1.3	14–28	Authors' data
South Baikal	1.0–1.4	1.5–2.6	0.5–0.7	43–82	«
Irkutsk	1.6–16.6	2.8–15.7	0.6–1.6	77–470	«
Listvyanka	1.1–3.8	2.0–3.1	6–1.2	218–249	«
Slyudyanka	1.9	2.9	0.7	59	«
Shelekhov	3.1–6.2	3.0–5.5	0.6–1.2	170–215	«
Bayandai	2.4	3.0	0.8	73	«
Angarsk	–	2.3–6.0	–	–	Ref. 9
Usol'e-Sibirskoe	–	2.3–4.8	–	–	Ref. 9
Altai plains	0.4–0.6	–	–	–	Ref. 11
Central Caucasus	0.2–0.5	–	–	–	Ref. 12

When considering the variation of the C_{org} content and the PO quantity along the Slyudyanka–Irkutsk–Bayandai route, it should be noted that the concentrations of the above components decrease while moving away from Irkutsk (Fig. 2). The maximum value of C_{org} accumulation was determined in the snow cover around Irkutsk and Shelekhov. Farther along the route, the concentrations of C_{org} and PO show the alternation of districts with slight pollution and districts with the enhanced level of pollution from local sources. The PO to C_{org} ratio varied from 0.5 to 1.6. The mean values of C_{org} and PO concentrations in the snow cover as well as the C_{org} accumulation level along the route from Slyudyanka to Irkutsk are higher than those obtained along the route from Irkutsk to Bayandai.

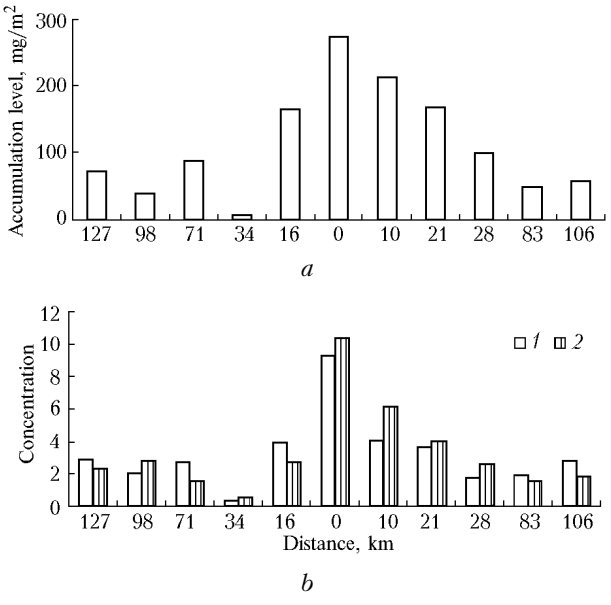

Fig. 2. Accumulation level of C_{org} (*a*) and content (*b*) of C_{org}, mg/l (*1*) and PO, mgO/l (*2*) at some points of the Bayandai–Irkutsk–Slyudyanka route.

This is because in the first section of the route we observe that the industrial emissions from Irkutsk are summed with those from Shelekhov where large industrial centers are located. In the second section the low populated areas are shown, whose contribution to the atmospheric pollution is weaker.

The concentrations of C_{org} and PO in the snow cover along the highway Irkutsk–Listvyanka are noticeably diminishing along the direction from Irkutsk to Listvyanka (Fig. 3). The local increase was observed near populated areas along the highway. The qualitative composition of organic matter in the snow cover along the highway was also inhomogeneous. The PO to C_{org} ratio varied within 0.8–1.6. The accumulation level of C_{org} along the route was distributed as its concentration. However, in the snow cover of Listvyanka, where the C_{org} content and PO value are lower than in the snow cover of Irkutsk by a factor of 2–4, large sum of C_{org} accumulation is due to the large value of water supply (see Fig. 3). In the snow cover near the astronomic station of the Institute of Solar-Terrestrial Physics (2 km from Listvyanka at 700 m height above sea level) (see Fig. 1) the concentrations of C_{org} and PO are close to those for uncontaminated regions of Russia[11]; the high C_{org} accumulation level (see Fig. 3) is also connected with large amount of water reserve. Such pattern of distribution of the organic matter was also observed in the water area of South Baikal. The C_{org} content varied within 1.5–2.6 mg/l, the PO value was 1.0–1.4 mgO/l, the PO to C_{org} ratio varied within 0.5–0.7. The C_{org} accumulation level in the snow cover was 43–82 mg/m^2. As one can see from the results, the concentration of C_{org} and PO in the snow water of the water area of South Baikal remains stable in the last decade.[5,7]

The investigations carried out in Baikal–Lenskii Reserve have shown that the content of organic matter in the snow cover of this area is lower by a factor of 4 to 9 as compared with that in Irkutsk (see Table 2). We have determined that the content of organic matter in unfiltered samples is higher by 25% as compared with that in filtered samples. On the territory of the reserve there are regions with different amounts of accumulation of organic matter in the snow cover, and, as a rule, the larger is the water supply, the larger is the amount of accumulation of organic matter, but in all cases this amount is lower than that in Irkutsk (see Table 2).

To compare the concentrations of organic matter in the snow cover of the water area of South Baikal and in Baikal–Lenskii Reserve we present the data obtained for clean regions of Altai and Central Caucasus (see Table 2). In the plain region of Altai during the period of unsettled snow cover, when a large amount of soil dust is observed in the atmosphere, the PO of snow water varied from 3.5 to 2.8 mgO/l and in the forest – from 2.6 to 0.6 mgO/l.[11]

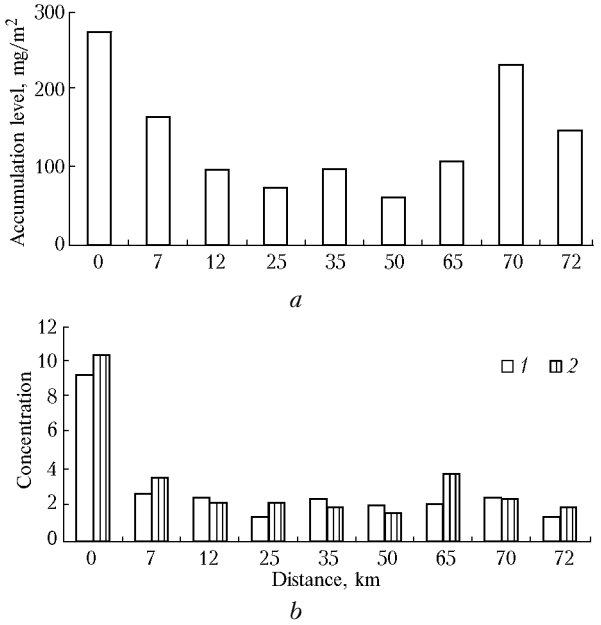

Fig. 3. Accumulation level of C_{org} (*a*) and the content (*b*) of C_{org}, mg/l (*1*) and PO, mgO/l (*2*) at points of the profile Irkutsk–Listvyanka.

In February–March, when the amount of soil dust decreased sharply, the PO of snow water decreased markedly. In the snow cover of mountain regions of the Central Caucasus the PO is much lower (see Table 2).

Thus, the PO values of the snow cover in Baikal–Lenskii Reserve are close to these obtained for the Altai snow waters during the period of stable snow cover.

Conclusion

In the snow cover of Irkutsk, the polluted and ecologically clean regions were observed based on the distribution of C_{org} concentrations and the net C_{org} accumulation. The largest C_{org} quantities are typical for the central part of the city as well as for the districts where stove heating of houses prevails.

As compared with other towns of the region the highest C_{org} concentrations were observed in the snow cover of Irkutsk.

The lowest concentrations of organic matter and the level of its accumulation in the snow cover were observed in Baikal–Lenskii Reserve. The data obtained are close to those collected in ecologically clean regions of Altai.

The results of analysis of unfiltered and filtered snow water indicate that a considerable part of C_{org} comes from the suspended matter.

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