Snow composition as a method for studying aerosols

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The month-averaged chemical composition of snow in various zones and subzones of Western Siberia is presented and the amount of salts and solid particles deposited per unit area (km^2) is calculated. Main sources of salts and directions of geochemical flows are determined.

Air masses form the most powerful, variable and mobile substance-energy factor on the Earth. Huge amounts of solid, liquid, and gaseous (sorbate) for the most part finely dispersed substances (aerosols) are transported by air. Their typical representatives are soot and other products of organic burning, volcanic exhalations, substances of cosmic origin, salts, metal oxides, acids, particles of loess and other loose rocks, etc.[1]

Water vapor is one of the most important components of the aerial transportation. Other aerosols can serve condensation nuclei for water vapor. Significant amounts of soluble and insoluble solid, liquid, and gaseous admixtures are transported with clouds. Then, hundreds and even thousands of kilometers far from the source, the atmosphere is "washed out" by solid and liquid precipitations. Deposition of the aerial particles takes place also along the path of the air mass transfer. Some aerosols deposit through dry sedimentation when the wind flow energy decreases at a mechanical geochemical barrier (as the relief type changes from a plain to hills and mountains, or the plant cover changes from open steppe areas to forests).[2] These processes are most pronounced for directed geochemical flows, when a constantly oriented transfer of air masses takes place.

Just these conditions exist at the territory of Western Siberia. The plain character of the relief, prevalence of southern and western winds (occurrence up to 70% and higher) allow the transport of dust and salt components from arid regions of Kazakhstan and Central Asia. As the wind flow energy decreases, these substances deposit mostly in central part of the Barabinskaya plain – the inner sink region. Here the local redistribution of the air-transported material at the terminals of its accumulation on the evaporation and alkali geochemical barriers favors salinization of these areas.[3,4]

To reveal the qualitative and quantitative composition of the transported aerosol material, we studied the chemical composition of atmospheric precipitations (liquid and solid) in various natural zones of Western Siberia: from Salekhard in the north (forest-tundra) to Kulunda in Altaiskii Krai (steppe). At the reference sites located mostly within the Novosibirsk Region, monthly summarized samples were collected at weather stations and hydroposts. In route missions along planned profiles and a grid of points, rain and snow sampling was conducted both during the whole period of snow or rain falling or in some time intervals from the beginning to the end of precipitation. Snow samples were collected in early and late winter from the entire snow depth both from interval to interval and as a whole.[4]

Sampling in the winter period is most representative, in our opinion, since it excludes fluctuations in the chemical composition of precipitation caused by local surface sources, since the soil surface in winter is covered by snow.

The analytically determined chemical composition of snow in different natural subzones of Western Siberia is given in Table 1.

However, these data allows us to judge only the tendency (direction) of the halogeochemical processes in the winter period, since we believe that no less than ten samples on characteristic landscapes in every subzone (we have from 4 to 14) are needed for the sufficient representativeness. To be noted are the following peculiarities of salt accumulation in the snow cover (based on analysis of Table 1):

1. Zonal latitude distribution.
2. Wavy character of occurrence (cyclicity) of some ion contents and total mineralization from the north to the south, which is associated, in our opinion, with peculiarities of functioning of natural systems in the winter period.
3. An increased concentration of all salt ions in forest-tundra as compared to subzones located southward, up to the northern forest-steppe subzone. This circumstance is likely connected with the income of salts from the Arctic Ocean.
4. With the distance from the ocean, these indices decrease roughly up to the boundary of the central-southern taiga (11 mg/dm^3), to the south of which they increase again. We explain this behavior by the income of salt aerosols from the saline arid and semiarid territories with prevalence there of southern and western winds.[4]
5. The above-said is clearly seen from the data for the northern forest-steppe. The salt composition of snow is determined here by calcium and magnesium carbonates and sodium chlorides, as well as an

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increased content of potassium ions. In this subzone the concentration of the salt components in snow is most significant (up to 40 mg/dm^3).

6. To the south of the northern forest-steppe we again see the salt concentration decrease. This is connected with a weaker effect on these territories of air masses from the arid territories of Kazakhstan and Central Asia, decrease of the wind flow energy, and insignificant income of salt from Baraba saline lakes and soils, since the occurrence of northern winds is low.

7. Comparison of old and fresh snow in the southern forest-steppe subzone suggests that possible sources of salts other than winter precipitations and snow storm transport exist there, which will be considered below.

8. Increased concentrations of nitrogen-containing ions (nitrates, ammonium) were observed in snow before the beginning of snow melting. In fresh snow they were usually low, which confirms the concept of the presence of other their sources.

High pollution of snow cover in industrial zones and big cities is attributed to heat and energy production industry and to domestic waste. Concentration of salt components is high even in fresh snow due to continuous presence of aerosols (gas, smoke, soot, etc.) in their atmosphere (see Table 2).

Snow cover is polluted tens of kilometers far from industrial centers. This is seen in winter aerial photographs and in our airborne observations. Polluted areas have an oval shape elongated in the prevalent wind direction (southwest–northeast).

Thus, the salt composition of the snow cover includes the components fallen with winter precipitations coming as a result of snowstorm transport and dry sedimentation, including industrial emissions. The pH value of snow water not subjected to evaporation concentration is 6.2–7.2; sometimes the fresh snow pH is 5–6; and several cases of pH = 3–3.5 were observed in the forest-steppe zone, which is likely associated with the industrial acidification.

The calculations of the salt components in snow and its chemical composition in the main natural zones are given below in Table 3.

Analysis of the data presented in Table 3 confirms the above theses (# 2). The northern regions are subject to the effect of the ocean, while the forest-steppe zone is under the effect of aerial transfer from arid regions. We see an intense metamorphization and transformation of the snow chemical composition up to the type III, which is characterized by prevailing concentration of chloride ion over sodium (appearance of $MgCl_2$ in the salt composition).

Table 1. Chemical composition of snow in different natural zones of Western Siberia, mg/dm^3

Natural zone, sampling site, number of samples	NO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	NH_4	Mineralization
Forest-tundra, Salekhard suburbs, 6 samples	1.8	8.3	2.5	2.6	2.3	0.6	1.4	0.9	0.6	21.0
Northern–central taiga, north of Khanty-Mansiisk, 4 samples	0.7	4.9	1.2	1.7	1.3	0.4	0.8	0.4	0.3	11.7
Central taiga, Strezhevoi–Aleksandrovsk, 10 samples	0.3	4.1	1.8	1.5	1.2	0.2	1.0	0.3	0.5	10.9
Central–southern taiga, Kolpashevo, 6 samples	0.6	5.0	1.8	2.3	1.6	0.3	1.3	0.7	0.2	13.8
Southern taiga–subtaiga, south of Tomsk and Tyumen Regions, 5 samples	1.9	6.2	1.8	3.6	2.2	0.6	1.2	1.0	0.4	18.9
Northern forest-steppe, northeast of Lake Chany, 8 samples	3.3	16.1	2.9	6.4	4.8	1.2	2.5	2.0	0.4	39.6
Southern forest-steppe, southeast of Lake Chany, 14 samples	3.6	10.1	2.7	6.2	4.7	0.7	1.8	1.6	0.2	31.6
Kolochnaya steppe, Karasuk plain, 7 samples	3.8	8.8	2.5	6.0	4.9	0.6	1.5	0.8	0.3	29.2
Southern forest-steppe, fresh snow	trace	7.3	2.0	2.9	2.2	0.7	0.5	0.4	0.1	16.1

Table 2. Chemical composition of snow in towns of the Novosibirsk Region, mg/dm^3

Sampling site	NO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	Mineralization
Novosibirsk, center	N.a.	40.7	12.2	18.3	15.8	2.0	8.0	1.1	98.1
Berdsk, industrial center	N.a.	102.5	5.7	51.4	46.5	4.9	2.3	3.5	216.8
Iskitim, industrial zone	2.5	129.4	7.1	15.9	36.1	4.9	2.3	5.1	200.8
Novosibirsk, industrial zone, fresh snow	5.6	140.3	4.3	16.3	45.1	4.6	2.3	1.2	219.7

Table 3. Salt content and type of snow water chemism for natural zones of Western Siberia, t/km^2

Zone, subzone	Mean	Limits	Formula of chemical composition (by O.A. Alekin)
Forest-tundra	1.7	1.2–2.1	H–Cl II Ca, Na
Northern – central taiga	1.3	1.0–1.6	H–S–Cl II Ca, Na
Southern taiga	1.7	1.3–2.1	H–S II Ca, Mg
Forest-steppe	2.7	2.0–3.5	H–S II–III Ca, Mg, Na
Steppe	1.3	1.0–1.6	H–S II Ca, Mg

No clear regularities have been found in the content of solid dust particles in snow. At abundant snowfall, the amount of salts in fresh snow is from 1 to 5 g/m^2, which corresponds to 1–5 t/km^2. Late in winter the snow cover accumulates from 10–15 to 35 t/km^2 of solid particles, which largely reflect the snowstorm transfer. Long-range and super-long-range transfer aerosols do not exceed 50% of the total amount. Thus, it should be concluded that snow contains up to 15–17 g/m^2 of solid aerosols corresponding to a 0.01 mm layer. This amount is 10–30 times lower than that transported in the warm period.

Summarizing the above-said, it is important to note that even for short geological periods (for example, the 10 thousands years long Holocene) the income of dissolved salts and solid particles can be significant. If we conditionally assume that deposition of these components was uniform during the Holocene, then the aerosol transport only in winter months is responsible for 150–170 thousand tons of solid particles and up to 50 thousand tons of dissolved salts per 1 km^2. This makes up a layer more than 10 cm thick. With allowance for transport in the warm period, the thickness of aerial Holocene depositions may be up to 1–3 m, which is confirmed in the loess thickness in China.[5]

The huge amount of transported salts – 100–150 thousand tons per 1 km^2 could transform Western Siberia into a salt desert in the absence of the inverse process. However, on local closed-sink areas under the conditions of difficult water exchange the salination process is in progress provided the evaporation exceeds the precipitation total.

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References

1. S.J. Rasool, ed., *Chemistry of the Lower Atmosphere* (Plenum Press, New York, 1972).
2. N.F. Glazovskii, *Current Salination in Arid Zones* (Nauka, Moscow, 1987), 192 pp.
3. V.A. Kazantsev, Pochvovedenie, No. 12, 16–25 (1990).
4. V.A. Kazantsev, *Problems of Pedohalogenesis* (Nauka, Novosibirsk, 1998), 280 pp.
5. Z. Kukal, *Rychlost Geologickych Procesu*; *Rate of Geological Processes* [Russian translation] (Mir, Moscow, 1987), 246 pp.