Study of pollutant transport from Norilsk Mining-Metallurgical Works to Northwestern Siberia

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The observations (fall 1998) on the diurnal dynamics of the chemical composition of atmospheric aerosol and near-ground wind velocity are used to analyze the transport of pollutants from Norilsk to Northwestern Siberia. Connections between the observed concentrations of dominant substances and chemical elements and the initial emissions from the plant have been revealed. The conditions of passage of a Norilsk plume through an observation site are discussed.

Introduction

Northwestern Siberia has no significant sources of anthropogenic pollution of the atmosphere. The nearest and largest sources of atmospheric pollutants are situated hundreds and thousands kilometers away. They are located in the South and Middle Ural, on the Kola Peninsula, and in Southwestern Siberia.

Systematic long-term observations of the chemical composition of atmospheric aerosol in towns of Northwestern Siberia (Tarko-Sale, Samburg, and Krasnoselkup) provide a unique capability of studying separately the effects of the sources mentioned above on the processes of regional pollution.[1] Long-lasting situations with preferred wind directions are most interesting in this regard. Analysis of the diurnal variations of the chemical composition of atmospheric aerosols with allowance made for the wind regime allows, in some cases, determination of the specific aerosol composition and identification of pollution sources, as well as characteristic trace species and chemical elements.

Atmospheric aerosols coming from the Norilsk region are analyzed here from this point of view. The main sources of pollution of the atmosphere in Norilsk and its suburbs are non-ferrous metallurgy plants.[2] They emit more than two million tons of sulfur dioxide yearly. Overall emissions contain 96% of sulfur dioxide and from 1 to 1.5% of dust and carbon/nitrogen oxides.

Emissions of toxic arsenic, selenium, and antimony compounds, which can be transported through long distances as well, add to a negative ecological situation. Among heavy metals, copper, nickel, cobalt, zinc, and lead compounds predominate.[3] It should be noted that industrial sulfur dioxide is emitted at high altitudes in the atmosphere, and it can spread to large areas in the case of strong winds.

Atmospheric transport and chemical composition of aerosols

Continuous and long-term data records for both atmospheric aerosol composition and wind speed and direction used together allow revealing qualitative and quantitative connections with pollution sources. Taking into account the mutual arrangement of Norilsk and the observation sites (Samburg and Tarko-Sale), most interesting observation periods are those with stable northeasterly winds. In this case, knowing the distance between the source and detectors, it is possible to estimate the dynamics of aerosol arrival.

It should be noted that, for relatively small transport times (within a few days), most pollutants emitted by the plant are within the atmospheric boundary layer and uniformly mixed along the vertical.[4] In this case, provided the input parameters are properly specified, the pollutant concentration can be calculated from the equation[5]:

$$\frac{\partial S}{\partial t} + U\frac{\partial S}{\partial x} = K\frac{\partial^2 S}{\partial y^2} - \sigma S + F(x, y, t)\ , \qquad (1)$$

where S is the pollutant concentration averaged over the thickness of the atmospheric boundary layer, U is the wind speed along the x-axis, K is the coefficient of turbulent diffusion in the cross-wind direction, σ is the coefficient accounting for "dry" sedimentation of a pollutant on the Earth's surface, $F(x, y, t)$ is the function describing the locations and time dynamics of pollution sources.

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Equation (1) can be used to describe the main processes of pollutant transport and transformation on regional scale and to evaluate different scenarios of pollutant transport. Numerical simulation of the processes of atmospheric pollution with various pollutants involves significant difficulties and requires equation (1) to be appropriately adjusted to fit observation data by formulating appropriately the inverse problems.

This work is an effort in this direction. Its idea is to analyze the daily measured data on the chemical composition of atmospheric aerosol simultaneously with wind direction reports. For this purpose, we use the measurement series obtained in fall 1998 in Samburg. Northeasterly winds in this period were rather frequent. Figure 1 shows the diurnal dynamics of the concentration of substances typical for emissions from the Norilsk Works. The list of these substances includes SO_4^{2-}, Cu, Ni, Se, and Pb (Refs. 1 and 3).

The wind direction and speed were measured at a meteorological station in Tarko-Sale at the weathercock altitude. Of course, the data of aerological sensing in the atmospheric boundary layer would be more appropriate for the study, but these observations were stopped at the station since fall 1998 because of lack of funding. To get an idea on the wind directions at the altitudes of 500 or 1000 m, it is necessary to rotate the wind direction vectors shown in Fig. 1 through 20°–40° clockwise.

From Fig. 1 it follows that long northeasterly winds were observed from September 18 to 22, and from October 27 to November 4, 1998. Just in these periods we observed coordinated jumps in the concentrations of the studied substances up to quite high levels, what unambiguously points to their source.

The jump-like variations of the concentrations also indicate that the plume from the Norilsk Works has finite width and passes through the observation site in the cross direction.[5] It should be noted that, in the periods of plume passage, the nitrate concentration decreases rapidly and can reach values 100–200 times less than the sulfate concentration. A similar relation exists between the initial emissions of sulfur gas and nitrogen oxides.[2,3]

The relatively high concentrations of copper, nickel, selenium, lead, and sulfates and, conversely, low nitrate concentrations observed between October 9 and 13 point to the Norilsk pollution source as well. Short episodes on October 19 and 26 can also be attributed to aerosol emissions from the Norilsk Works.

It should be noted that the data on the near-ground wind speeds shown in Fig. 1 are fragmentary and insufficient to judge the direction of the mean aerosol transport in the mixing layer; so they are useful at the initial stages of research only. More detailed analysis can be made using maps of the spatial distribution of wind fields for the periods of observations over the studied region. This is illustrated in Figs. 2a and b. These figures show the wind velocity fields taken from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis database.

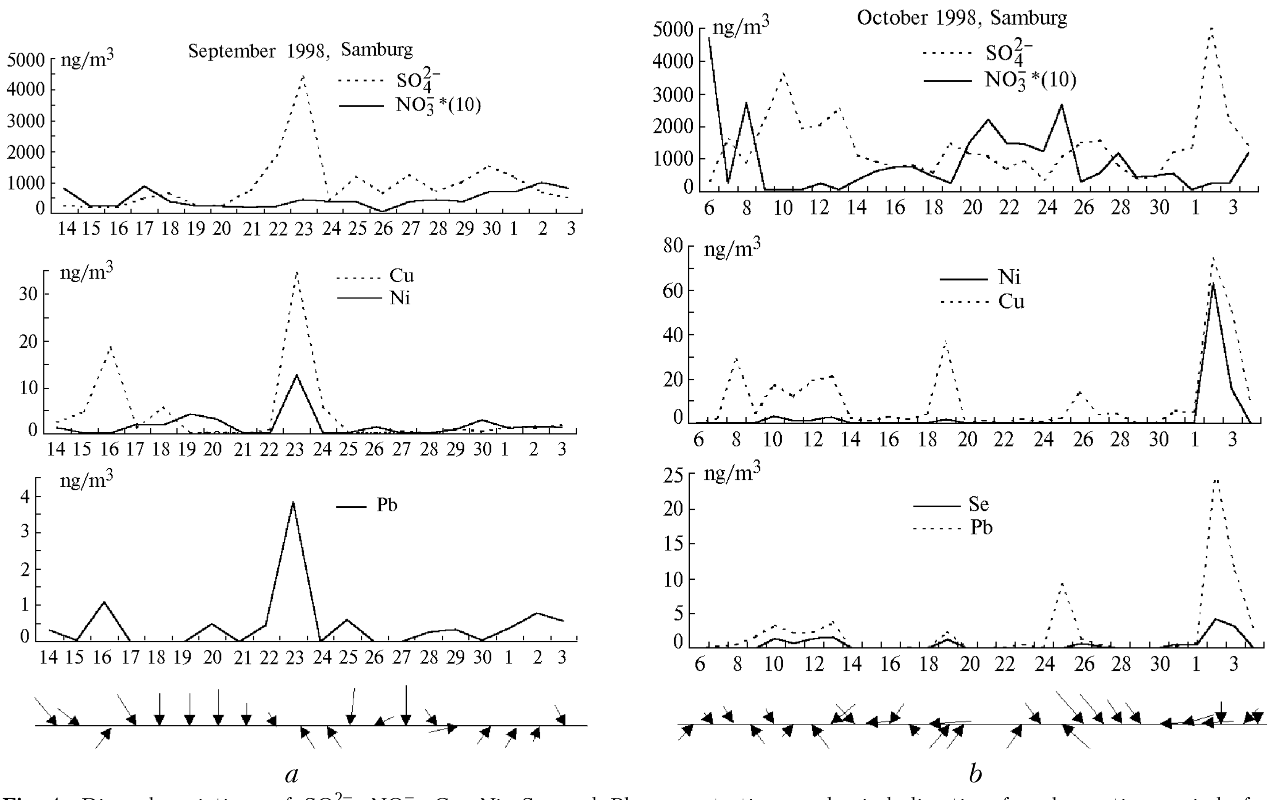

Fig. 1. Diurnal variations of SO_4^{2-}, NO_3^-, Cu, Ni, Se, and Pb concentrations and wind direction for observation periods from September 14 to October 3 (*a*) and from October 6 to November 4 (*b*), 1998.

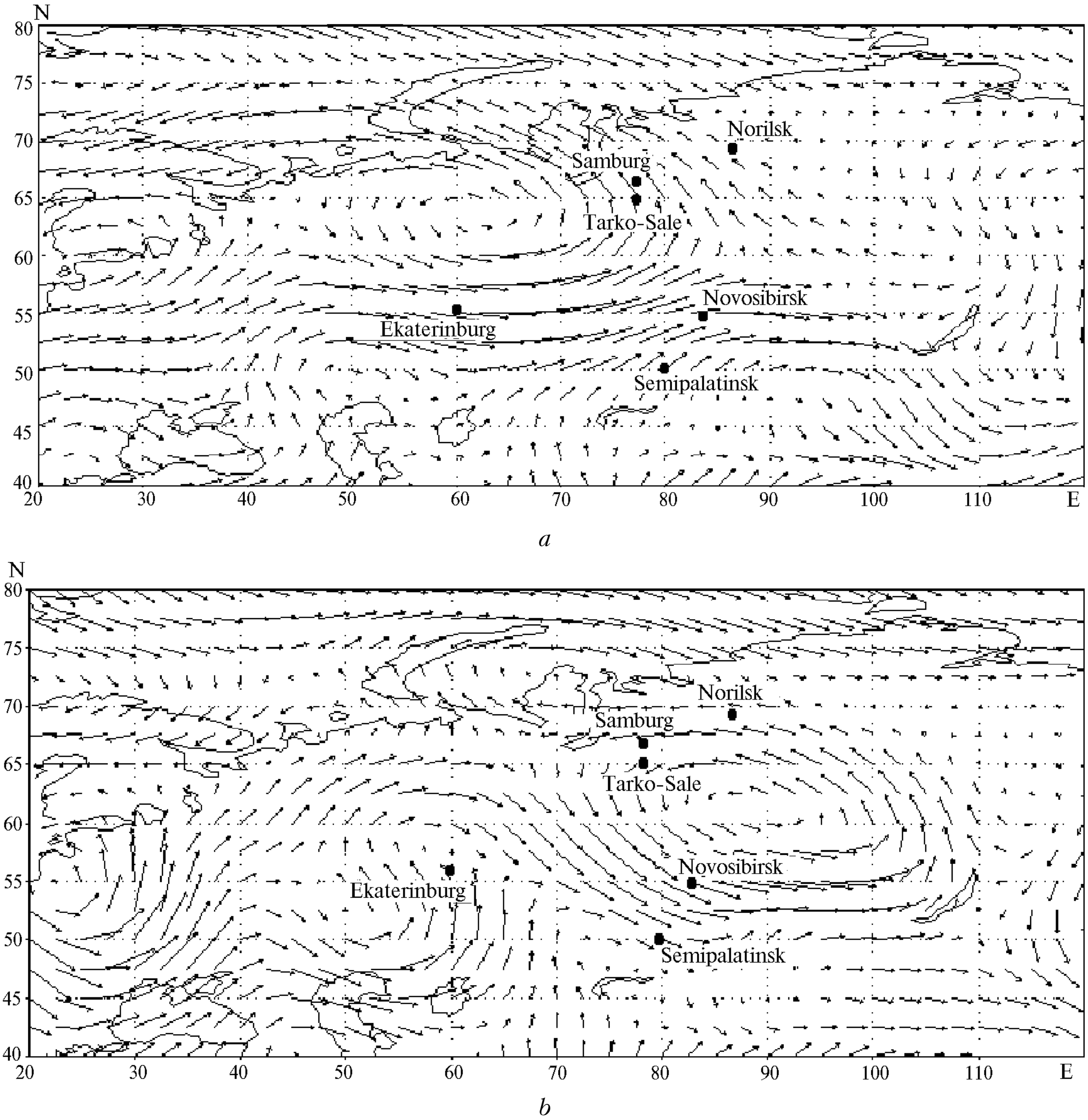

Fig. 2. Wind velocity field at 850 mb on November 1 (*a*) and November 2 (*b*), 1998.

In this period, at the observation site in Samburg we also observed a considerable increase in the concentration of SO_4^{2-}, Cu, Ni, Pb, Se and other substances typically found in Norilsk emissions. From Fig. 2*a* it follows that there was northwesterly wind over the territory between Samburg and Norilsk on November 1, 1998. This wind prevented emissions of the Norilsk Works from reaching directly the observation site. Figure 2*b* indicates that on November 2, 1998, the wind in the studied region had changed to more favorable for pollutant transport; and this fact is in correspondence with the measured high concentrations of specific atmospheric substances. For more detailed analysis of the conditions of passage of the Norilsk pollution plume, additional data on temperature, pressure, and other meteorological parameters are needed.

Conclusion

We analyzed the near-ground wind fields simultaneously with the chemical composition of atmospheric aerosols and identified some cases that emissions of the Norilsk Works were transported to Northwestern Siberia. This was deduced from the revealed connections between the observed concentrations and the initial emissions of dominant substances and chemical elements.

The presence of northeasterly winds is not generally sufficient for direct transport of pollutants emitted by the Norilsk Works to the observation sites because of the insufficient width of the emission plume. In most cases pollutants are transported by the way of the lateral drift of the plume. With more detailed meteorological information and theoretical knowledge on main physical-chemical mechanisms of transport and the structure of pollution sources, the data on the chemical composition of atmospheric aerosol allow, by formulating properly inverse problems, to construct quantitative models of regional pollution of Northwestern Siberia.

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