Influence of forest fires on the transport and transformation of atmospheric admixtures over Lake Baikal

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The conditions of dynamics and transformation of minor atmospheric gases over Lake Baikal are considered based on experimental data and numerical simulation. An event of the spread of a smoke plume from a forest fire at the northwestern shore of Lake Baikal is analyzed. It is shown that powerful sources of nitrogen oxides as forest fires increase the nitrogen dioxide concentration by an order of magnitude and the nitrogen oxide concentration by 1 to 3 orders of magnitude.

Introduction

A fire can be considered as a sort of uncontrollable reactor, chemical transformations in which occur with atmospheric emissions of huge, proportional to the fire scale, amount of various products of combustion, pyrolysis, and thermal-oxidative degradation. Fires cause colossal economical and ecological damages. Combustion products include harmful and toxic substances, such as carbon monoxide, various hydrocarbons, in particular polyaromatic, nitrogen oxides, sulfur dioxide, sulfuric acid, soot, hydrogen sulfide, prussic acid, formaldehyde, vanadium pentoxide, and other toxicants.

Because of the advection and diffusion, these substances can be transported to tens and hundreds kilometers. It is important to determine how these pollutants spread in the atmosphere. The solution of this problem through instrumental investigations, especially, in field experiments, involves considerable difficulties. Fires appear suddenly, and it is extremely difficult to predict them and to be prepared for them. Once a fire appears, all efforts are aimed at its liquidation, and there is no time for any instrumental measurements and investigations. It should be noted that the series of physical and chemical characteristics of the environment, obtained with the aid of specialized instrumentation, are significantly discrete in space and time. A serious problem is the separation of processes of some scale from those of other scales. Because of superposition of various processes, it is impossible to estimate the contribution from each of them separately based on measurements.

The aim of this work was to study the distribution of nitrogen compounds and other minor gases over the open part of Lake Baikal during forest fires.

1. Methods of investigation

A 310A chemiluminescent gas analyzer (manufactured by OPTEK, St. Petersburg) was used to measure the nitrogen dioxide and monoxide concentrations over Lake Baikal in the period from July 26 until August 6 of 2005 during the cruise of the *Vereshchagin* Research Vessel (Fig. 1).

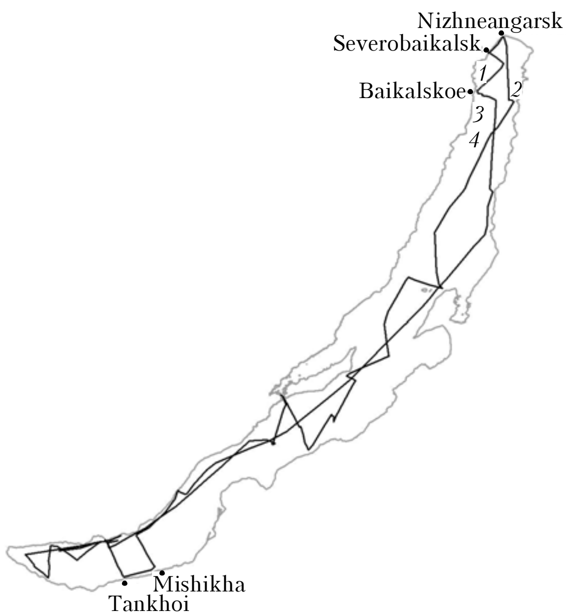

Fig. 1. Cruise of *Vereshchagin* RV in the period of field investigations from July 26 until August 6 of 2005: Cape Slyudyanskii (*1*); Cape Turali (*2*); Cape Krasnyi Yar (*3*); Cape Kotelnikovskii (*4*).

The measurements were carried out and the results were recorded continuously. The air was sampled at a height of 3 m above the water surface to avoid the possible influence of exhausts from the vessel diesel.

To analyze the distributions of the studied gases, the measured data were supplemented with the results calculated using modern nonstationary spatial mathematical models, describing the processes of formation of the concentration fields and the transformation of aerosols and gases, produced in the atmosphere during fires. Such models have been developed both in Russia and in foreign countries.[1–7]

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In this work, we used a nonlinear nonstationary spatial mathematical model of the Eulerian type.[8] The model was applied earlier to study the processes of transport and transformation of aerosol and gas components, emitted by industrial plants situated in the region of Southern Baikal and in the valley of River Angara.[9,10] The comparison of the results of numerical simulation with the data of instrumental measurements has shown a satisfactory quantitative agreement.[11]

2. Measurement results and numerical experiments

The measurements have shown that over Baikal area, in its open part, the concentrations of nitrogen dioxide and monoxide varied only slightly: the nitrogen dioxide concentration ranged from 4 to 8 μg/m^3, while the nitrogen monoxide concentration did not reach 1 μg/m^3. Closer to the shore, where the influence of shore sources and diesel exhausts of the vessel became significant, the nitrogen dioxide concentration increased by an order of magnitude, while the nitrogen monoxide concentration increased by 1 to 3 orders of magnitude. As the vessel went offshore at about several tens of meters, the concentrations of nitrogen dioxide and monoxide decreased quickly and reached their values which are ordinary for the Baikal area: 4–8 μg/m^3 for nitrogen dioxide and less than 1 μg/m^3 for nitrogen monoxide. Thus, the nitrogen dioxide concentration equal to 4 μg/m^3 can be considered as a background one.

In Northern Baikal before the beginning of fires, the NO_2 concentration equal to 4–6 μg/m^3 prevailed. As RV went 16 km to the east from Cape Slyudyanskii (northern lake hollow) on August 2, the heavy smoke was observed on the slopes of Baikalskii Ridge with the smoke plume spreading to the lake area. The maximum concentration of nitrogen dioxide reached 59 μg/m^3, and that of nitrogen monoxide of 162 μg/m^3. The smoke plumes from the fires of August 2 were still visible at a distance to 16 km to the south from Cape Slyudyanskii. In the morning of August 3 at the center of the Baikalskoe–Turali sector, the concentrations of the measured ingredients began to increase and dropped to the maximum values of 38 μg/m^3 (nitrogen dioxide) and 78 μg/m^3 (nitrogen monoxide). The nitrogen dioxide concentrations higher than 8 μg/m^3 were observed along a 20-km route in the center of Northern Baikal (20 km to the east from Cape Krasnyi Yar – 25 km to the east from Cape Kotelnikovskii); then, further to the south, the concentrations decreased to 6 μg/m^3.

We have carried out mathematical simulation of the processes of transport and transformation of combustion products in the region of Northern Baikal. To find the coordinates of the centers of forest fires, we used the real-time space images, available on the site geol.irk.ru.

The processes of transport of minor gases were simulated in the zone with the area of 250×300 km and the height of 5 km above the Lake Baikal surface. The time step and the horizontal step were, respectively, 150 s and 1 km. The vertical step was defined in the following way: 50 m up to the height of 200 m, 100 m from 200 m up to 700 m, 300 m up to 1000 m, 500 m in the range of 1000–2000 m, and then 1000 m. The initial concentrations were taken to be: 0.93 kg/m^3 for molecular nitrogen N_2, 0.297 kg/m^3 for molecular oxygen O_2, $7 \cdot 10^{-4}$ kg/m^3 for water vapor H_2O, 10^{-7} for molecular hydrogen H_2, $6 \cdot 10^{-8}$ for ozone O_3, and $8 \cdot 10^{-10}$ kg/m^3 for nitrogen dioxide (NO_2).

The coefficients of turbulent diffusion were calculated with the use of equations of the semiempirical theory of turbulence. The block of chemical reactions, taken into account in the numerical experiments, was presented in Ref. 8. In contrast to Ref. 8, the calculations were made with the rate constant of the reaction R27 (photochemical dissociation of nitrogen dioxide) equal to $7.8 \cdot 10^{-4}$ s^{-1}. The intensity of all the sources of emission of nitrogen dioxide, formed during forest fires in the Northern Baikal region, was 6 kg/s, while that for nitrogen monoxide was also 6 kg/s.

Figure 2 shows the distributions of the surface concentrations of various nitrogen compounds, calculated by the model. The wind flow had the north-north-west direction and the speed of 5 m/s. The comparison of the calculated and measured concentrations of nitrogen monoxide and dioxide has shown a satisfactory agreement between them.

The second series of the experiments consisted in the study of the influence of meteorological characteristics on the transport and transformation of minor gases. The variable parameters were the wind direction and speed and the initial value of the water vapor concentration. The calculated results have shown that the varying initial concentration of water vapor exerts a significant influence on the concentration of atmospheric minor gases. As the water vapor concentration in the atmosphere changes by an order of magnitude, the concentrations of OH and HO_2 also change by an order of magnitude, the concentration of HNO_4 changes sevenfold, the concentration of HNO_2 varies fivefold, and the concentration of HNO_3 changes fourfold. The decrease of the speed of the northwestern wind (to 3 m/s) leads to the increasing concentrations of the most atmospheric minor gases. The southwestern and southeastern winds favor cleaning of the atmosphere over Baikal; they cause the decrease in the concentrations of the main pollutants; the concentrations of hydrogen radical OH^- and HO_2^-, to the contrary, increase up to their background values.

Conclusions

Thus, our investigations have shown that, in the presence of powerful sources of emission of nitrogen oxides, during forest fires, the concentration of nitrogen dioxide increases by an order of magnitude, while the concentration of nitrogen monoxide increases

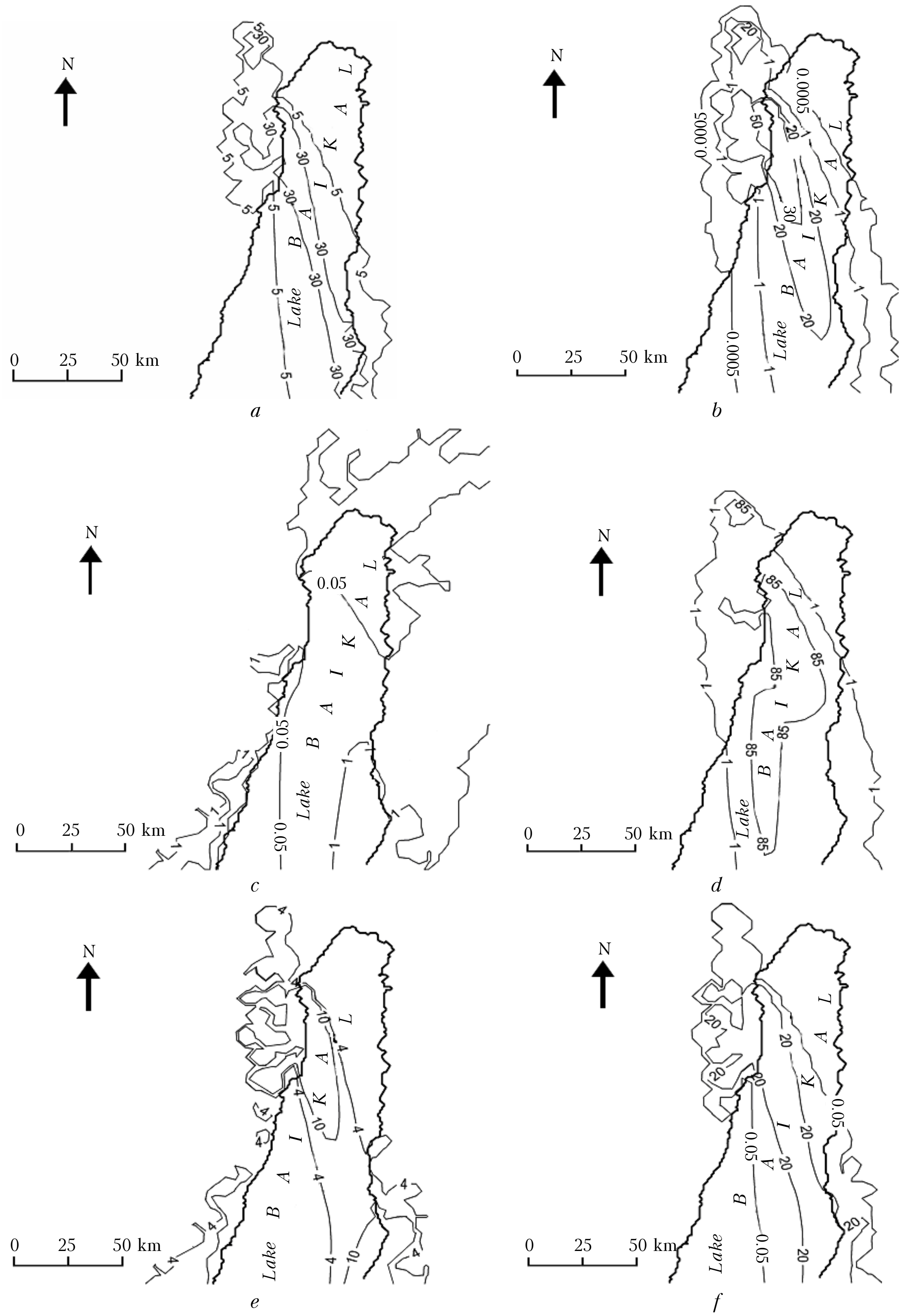

Fig. 2. Isolines of the calculated surface concentrations in the region of Northern Baikal, in μg/m^3, for nitrogen dioxide (*a*); nitrogen monoxide (*b*); nitrate ions, in ng/m^3 (*c*); nitrite ions, in pg/m^3 (*d*); nitrogen trioxide in gas phase (*e*); dinitrogen pentoxide (*f*).

by 1 to 3 orders of magnitude. Even in the case of small-area forest fires, the intensity of emissions of nitrogen monoxide exceeds the intensity of the total emission from all sources located in a small town (for example, Baikalsk).

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