Influence of meteorological conditions on the spreading and transformation processes of aerosol and gas components in the Lake Baikal region

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ABSTRACT

Using a numerical simulation we investigated the influence of synoptic conditions on the spreading and transformation of sulphur, nitrogen and other minor gas species' compounds in the region of Lake Baikal. Emission sources included the enterprises and motor transport of the Irkutsk-Cheremkhovo industrial complex, Slyudyanka and Baikalsk, Ulan-Ude, Selengisnk, and Gusinoozersk..

Keywords: measurement of meteorological characteristics, concentration, Baikal region, statistical analysis, numerical model.

1. INTRODUCTION

Results of experimental and theoretical investigations indicate that meteorological conditions have a pronounced effect on the transport, diffusion and transformation processes of pollutants in the atmosphere. It is therefore important to quantify the characteristics of this influence.

The favorable conditions for accumulation of pollutants in the Baikal region and Lake Baikal's water body are created in the winter and summer seasons in low-gradient fields of increased and decreased pressure. The transport of pollutants from local pollution sources and motor transport in the winter season, in conditions of increased recurrence of surface and elevated temperature inversion due to significant amounts of fuel burnt at heat-generating enterprises of the Irkutsk-Cheremkhovo industrial center. In the summer months, unlike the winter season, the intensity of mobile cyclogenesis is significantly lower compared with winter, but the role of convection is large. Besides, in summer, with the increased solar irradiation, there is an increase of the rate of photochemical reactions in the atmosphere, with the production of more toxic chemical compounds. Curiously, at the present time it is in summer that over a given territory the trend component of the increase in ground pressure manifests itself, which indicates some enhancement of the anti-cyclogenesis and an attenuation of wind, contributing to a weaker spreading of pollutants in the atmosphere. If such a trend continues, the concentrations of sulphur- and nitrogen-containing pollutants can increase during the warn season over the territory under consideration.

2. METHODS OF RESEARCH AND RESULTS

To estimate the possible changes we carried out an analysis of the meteorological characteristics for the summer period 1994-1995 using data from hydrometeorological stations located in the Angara and Baikal region and examined different synoptic situations in this region.

The nonlinear nonstationary spatial Euler model [1] was used to investigate the spreading and transformation processes of sulphur, nitrogen and other minor gas species' compounds in the region of Lake Baikal for different synoptic

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situations. Emission sources included enterprises and motor transport of the Irkutsk-Cheremkhovo industrial center, Slyudyanka, Baikalsk, Ulan-Ude, Selenginsk, and Gusinoozersk; the respective total capacities are taken from [2-4]. The spreading processes of pollutants were modeled for the region with the area 500x250 km^2 and 5 km altitude above the surface of Lake Baikal. The time and horizontal steps were 150 s, and 5 km, respectively; the vertical steps were specified as follows: before 350 m altitude, they were 50 m, followed by 150, 1000, 1500, and 2000 m. The initial concentration of molecular nitrogen [N_2], molecular oxygen [O_2], water vapor [H_2O], and molecular hydrogen [H_2] was taken to be 0.93, 0.297, $2.23x10^{-4}$, and 10^{-7} kg/m^3, respectively. It was assumed that in the air there is a constant presence of hydrogen peroxide H_2O_2, and its concentration, 10^{-9} kg/m^3, does not change in space and over time. The coefficient of turbulent diffusion were calculated using the relations from semiempirical theory of turbulence [1].

The meteorological characteristics of the first group of numerical simulations corresponded to an enhancement of the anticyclone in the southern part of the Baikal region, and the second series showed the antiwestward directed transit of a deep cyclone through the study region. At the altitude of the leading flow (3 km), at the time of anticyclone enhancement antinorthward directed meridional flows were dominant; zonal and southern flows dominated during the transit of the cyclone. The rate of gravity settling was taken to be 0.5 cm/s in calculating the density of mass flow of suplhates, nitrates and nitrites (dry settling).

To estimate the contribution of emissions from each group of enterprises (Irkutsk-Cheremkhovo industrial center, Slyudyanka and Baikalsk, Ulan-Ude, Selenginsk, Kamensk, and Gusinoozersk) to pollution of the southern part of the lake during the cyclonic and anticyclonic circulations we carried out model calculations with active emission sources of the aforementioned industrial complexes separately. Results are presented in the table. The first column of the table lists the groups of emission sources (ICh - Irkutsk-Cheremkhovo industrial center, SU - industrial complexes of Selenginsk and Ulan-Ude, and SB - enterprises and motor transport of Slyudyanka and Baikalsk) provided that the other groups discharge no pollutants at a given time. The second to seventh columns contain calculated values of the contributions from the aforementioned groups of sources to pollution of South Baikal with inorganic acids during the cyclonic and anticyclonic circulations.

Table 1

Contribution from the individual groups of emission sources
of sulphur and nitrogen compounds to pollution of Lake Baikal with acids

Group of sources	Contribution to pollution of the southern part of Baikal, %					
	for cyclonic circulation			for anticyclonic circulation		
	H_2SO_4	HNO_3	HNO_2	H_2SO_4	HNO_3	HNO_2
ICh	34	23	23	81	66	38
SU	27	24	4	0	2	0
SB	39	53	73	19	32	72

Thus during the anticyclonic circulation the contribution from the Irkutsk-Cheremkhovo industrial complex to pollution of the hollow of South Baikal with inorganic acids is the largest; the contribution from emission sources of Slyudyanka and Baikalsk is less significant, and the greatest contribution is made by enterprises and motor transport of Slyudyanka and Baikalsk; a somewhat smaller contribution corresponds to the Irkutsk-Cheremkhovo industrial complex, and the emission sources in the valley of the Selenga river is still smaller.

Fig. 1 presents the distributions of the calculated concentration values of sulphur and nitrogen compounds at the underlying surface of the Lake Baikal region for July 4, 1994 at 14 hours local time, during the transit of a warm sector of a deep cyclone traveling in the antiwestward direction. maximum values of concentrations of primary gaseous pollutants (SO_2 and NO_2) are observed near the emission sources (Fig. 1a, 1c), and extreme values of concentrations of secondary pollutants are somewhat shifted upstream and are maximal in the piedmont area of the Eastern Sayan mountains (Fig. 1b, 1d, 1f).

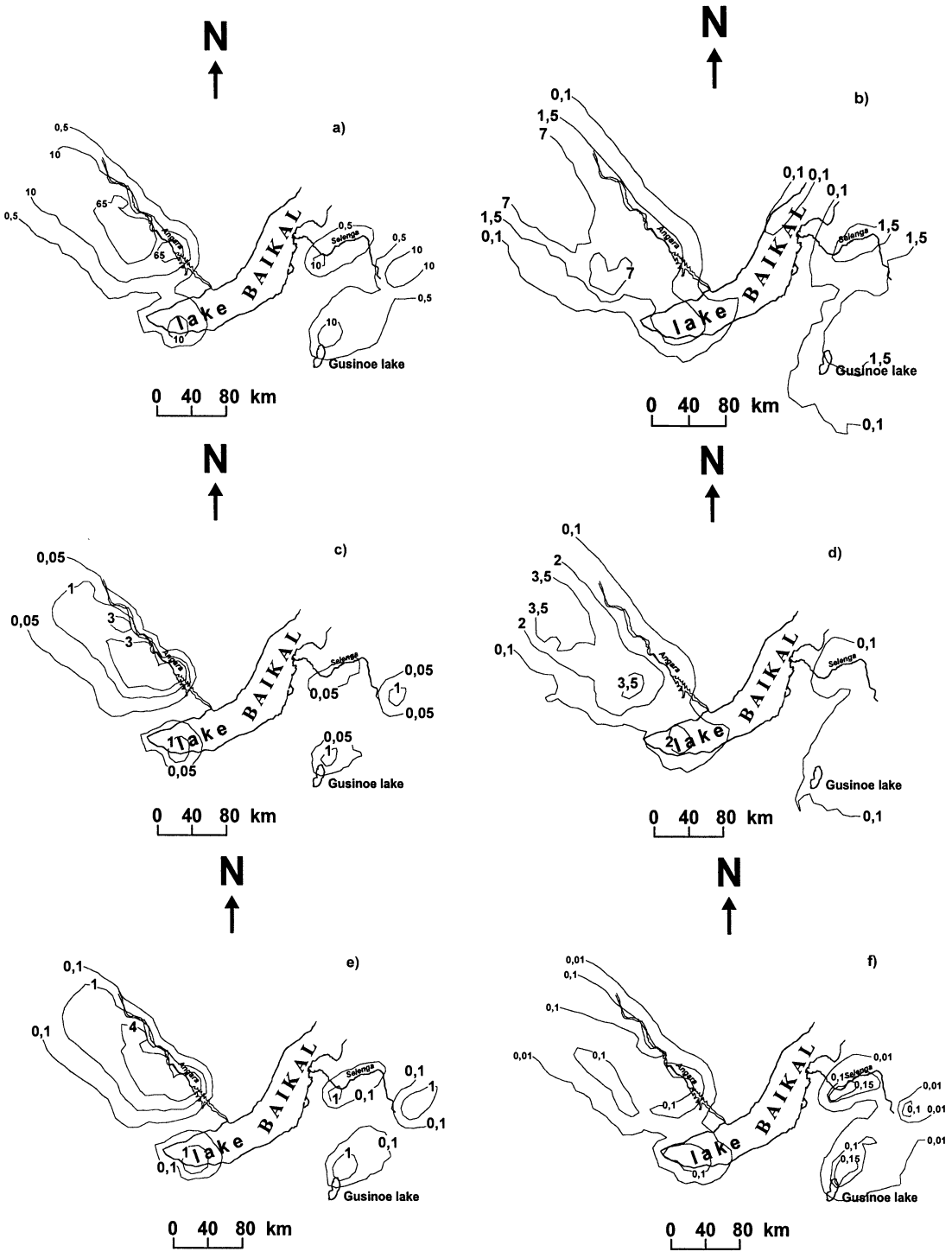

Figure 1. Contours of the calculated surface concentrations of sulphur and nitrogen compounds for the cyclonic circulation in the Lake Baikal region, in $\mu g/m^3$: a) concentration contours for SO_2; b) H_2SO_4; c) NO_2; d) HNO_3; e) NO; f) HNO_2.

Fig. 2 illustrates the distribution of the calculated concentrations for some of the minor gas species of the atmosphere at the underlying surface of the selected territory for July 21, 1994 at 14 hours local time, during the anticyclonic circulation. The ingredients (SO_2 and NO_2) that are being discharged into the atmosphere, interact most intensively with hydrogen radicals, OH and HO_2; near the emission sources the concentrations of these radicals are therefore minimal.

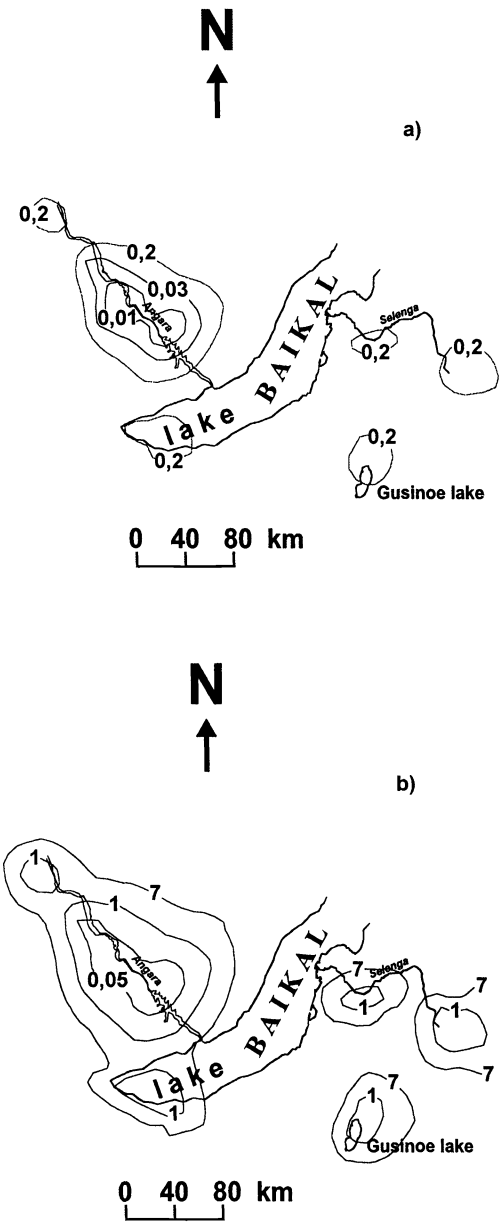

Figure 2: Contours of the calculated surface concentrations of radicals, OH and HO_2, for the anticyclonic circulation in the Lake Baikal region, in ng/m^3: a) concentration contours for OH; b) HO_2

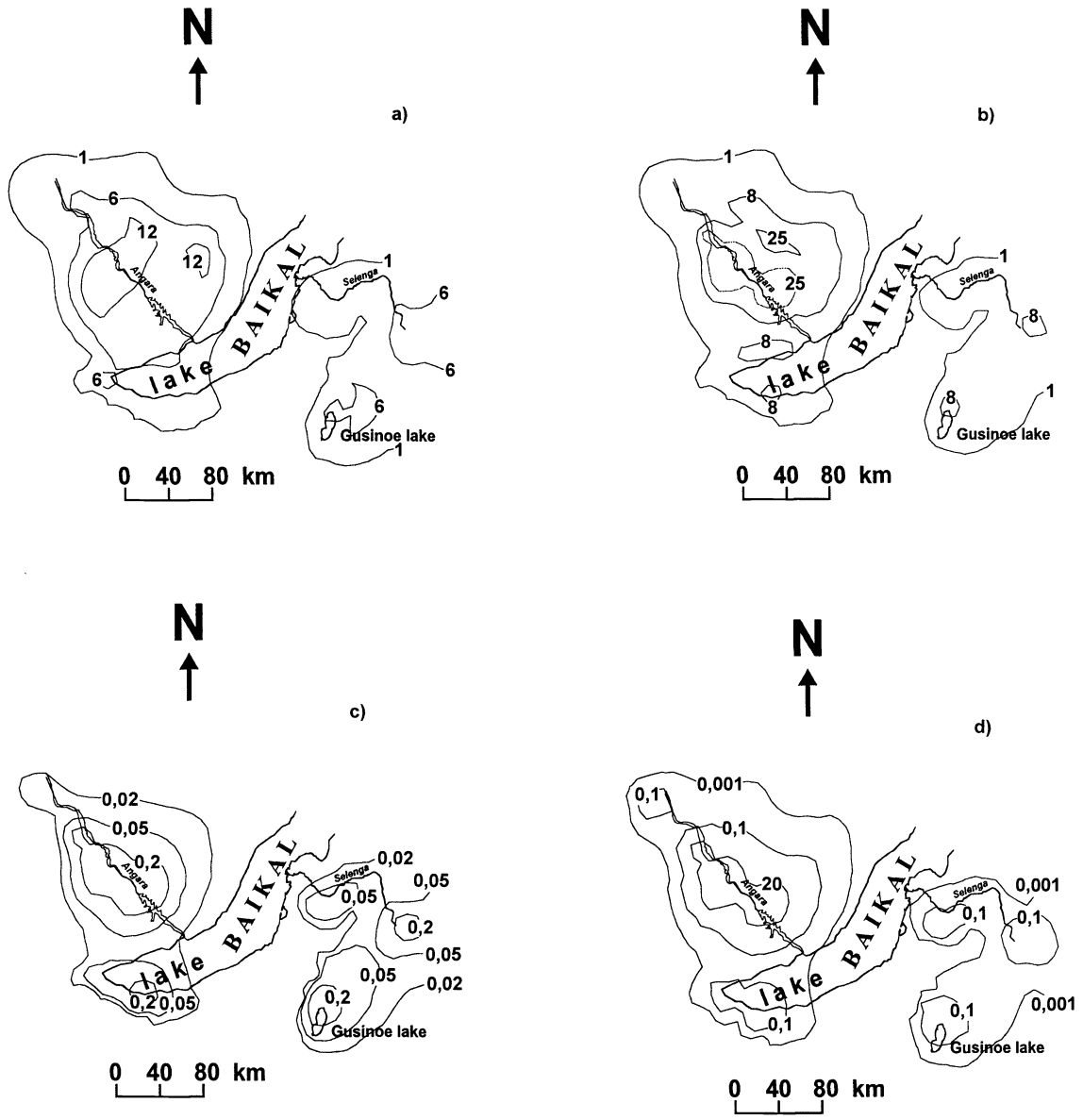

Figure 3: Contours of the calculated surface concentrations of nitrogen and atomic oxygen O (^{3}P) compounds for the anticyclonic circulation in the Lake Baikal region, in ng/m^3: a) concentration contours for HNO_4; b) NO_3; c) O(^{3}P); d) N_2O_5.

Fig. 3 presents the contours of the calculated concentration values of nitrogen and atomic oxygen O (^{3}P) compounds. On the order of magnitude, the calculated concentration values of minor gas species correspond to observed values of these same components in other regions.

4. CONCLUSIONS

Thus during the anticyclonic circulation the contribution from the Irkutsk-Cheremkhovo industrial complex to pollution of the hollow of South Baikal with inorganic acids is the largest; the contribution from emission sources of Slyudyanka and Baikalsk is less significant, and the greatest contribution is made by enterprises and motor transport of Slyudyanka and Baikalsk; a somewhat smaller contribution corresponds to the Irkutsk-Cheremkhovo industrial complex, and the emission sources in the valley of the Selenga river is still smaller.

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