Comparison of air composition over industrial cities of Siberia

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Using a mobile control station we have studied the air quality in 11 Siberian cities from Irkutsk to Novosibirsk in winter and summer periods. The results obtained show that modern industrial city in winter is not only an island of "heat" but also the island of pollutants. The concentrations of admixtures are much higher at the center of most cities than in their outskirts. An exception is ozone, which, evidently, dies in industrial emissions at the center and recovers on the periphery. In summer, the effect of local circulation substantially weakens, and the difference between parameters measured in the city center and on its periphery is not always observed.

Introduction

Assessing the scope of problems concerning the state of the atmosphere over Siberian cities, we should note the following. It is typical feature of Siberian cities that the quality of the atmosphere significantly depends on the climate conditions. During more than half a year, stable atmospheric stratification dominates over Siberia with temperature inversions, favoring accumulation of pollutants of different origin in the lower atmospheric layers, where people live and ecosystems function.

In addition to severe climatic conditions, modern industrial cities experience increasingly intensifying effect of anthropogenic factors on the environment and human beings. These effects come through the environmental pollution, alteration of characteristics of the earth's surface and hydrological and hydrothermodynamic regimes of the atmosphere, etc. Urban conditions give rise to distinct mesoclimates favoring accumulation of pollutants; while urbacenoses proceed under extreme, evolutionarily "inappropriate" conditions and represent special and poorly understood type of ecosystems. In this case, natural and anthropogenic systems (power-generating and industrial objects, traffic, etc.) interact very closely. There is serious disparity between ever growing chemization of all industries and low level of the general chemical knowledge even at the level of responsible decision making: e.g., until so for incomplete technologies are still used that have no final stages of rational waste utilization. Therefore, there is a considerable potential risk of anthropogenic catastrophes which, in turn, may trigger ecological catastrophes through emissions of heat, moisture, and toxic admixtures.

It also should be kept in mind that the cities are not closed systems. They can both disperse pollutants to the surrounding territories and receive them from outside.

All these issues are related to the ecological safety and quality of life. At present, there are no doubts that there is a close correlation between environmental state and human health, ability of work, and life span.

General degradation of ecologic situation in Siberian cities leads to increase of products of elevated toxicity in human organs and tissues, influencing the functioning of the organism as a whole and producing metabolic disturbance. As a result, the exotoxicosis is supplemented with toxicosis caused by internal imbalance of metabolic processes (endotoxicosis). There take place a failure of the compensatory mechanisms and, in particular, accumulation of foreign products of proteolysis of albumens, leading in turn to breakdown in immune system and enhanced risk of the development of many pathologic processes.

Lack of fundamental medical knowledge in the field of endotoxicosis and absence of deep insight into the real biochemical and physiological processes hamper efficient expert diagnostics of pathologic states caused by the increased anthropogenic load.

The approach to estimating the ecologic risk based on normative documents, which is widely used throughout Russia for all industrial activities, has been out of date and provides no solution for

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strategically superior problem, namely prevention of ecologically hazardous situations and mitigation of their possible consequences. One of the reasons is the delay in getting basic knowledge in the field of the ecological chemistry and related sciences that are needed for solving urgent ecological problems. Many basic and applied studies, performed Russian scientists in concrete fields of knowledge, are well within worldwide avenues and compete with foreign developments both in the research level, approaches, and the problems solved. However, there is deficiency in the interdisciplinary studies, which are required for a complex solution of such problems.

Studies of the regularities of formation and transformation of air pollution fields in big industrial centers have most rapidly been developed in recent 10–15 years. It has long been considered that on days with moderate wind, the city is well blown, and increased background of air pollution is observed only in regions close to industrial activity zones or along the admixture plumes. To determine the future arrangement of new industries, the climatic wind rose was used. In this case, new enterprises are to be located outside the city on its leeward side. It was assumed that, for such an arrangement, the emissions will be blown out by wind, and the enterprises will produce minimum effect on the atmosphere of the city. Modern theoretical data on specific features of the aeration of big industrial centers show that this is a dangerous mistake.[1–3]

When city is viewed from illuminator of an aircraft, even in the presence of strong wind it is easily seen that the emissions from elevated sources (plant stacks) propagate downwind and off the city. At the same time, the city is overcast with haze, indicating that aerosol admixtures are primarily accumulated within city boundaries.

If the city is observed for a few days without precipitation, such as in anticyclone, it can be seen that the urban haze during this time changes color from whitish to dirty black. This shows that the admixtures emitted on the territory of the city have not been blown out from the city but transformed in the course of the chemical, photochemical, condensation, and coagulation processes. Data of aircraft surveys over cities show[4,5] that accumulation of admixtures takes place not only in the near-ground layer but also in the layers above it, spreading in some periods through the entire depth of the atmospheric boundary layer. Within traditional frameworks, this situation with the "cap" of pollutants over the city cannot be explained.

Concentration of industrial objects on a restricted territory, such as the territory of a modern city, leads to the fact that within the city boundaries there takes place the emission of a large amount of different admixtures that usually are not observed under natural conditions. They include the chemical compounds at different phase states and of different origin, extra thermal energy, electromagnetic emissions of different types, etc. As a result, the city becomes "island of heat", which has been known sufficiently long ago.[6] Usually, the city is built on an elevated terrain; therefore, its territory has orographic nonuniformities, and it is generally located on the coast of a large water basin what makes a temperature contrasts at the boundary between land and water. Together, these factors create local circulation in the city surroundings.[2,3]

It is a specific feature of the local urban circulation that in the shadow of the city there appear return air flows along the directions opposite to the main flow, observed on the windward side.[2] This return circulation, in some sense, locks the industrial emissions on the territory of the city, over which the haze forms, consisting of gaseous and aerosol species and referred to as the pollution "cap". It is a characteristic feature of this circulation that it keeps over the city not only under weak wind but under conditions of moderate intensity wind as well. It breaks up during the passage of atmospheric fronts over the city. After their passage, the circulation recovers within a day.

Calculations show[1–3] that the area of the zone, encompassed by the local circulation, depends on the scales of the city and on the number and power of the enterprises therein. The pollutants within the circulation zone are accumulated, but not infinitely.

Since the air temperature inside thus formed urban atmospheric column is higher than in the atmosphere outside the city, the air starts lifting. Data from Ref. 6 show that first the admixture column is vertical, and then, under the impact of the main flow, it inclines. It levels off horizontally at a considerable distance from the city and travels near the upper boundary of the atmospheric boundary layer. The height of this layer depends on the season; it is separated from the free atmosphere by the blocking layer.[7]

From the aforesaid it follows that there are contradictions between traditional concepts of the formation of pollution field in the region of industrial center, actually observed admixture distribution, and theoretical prediction of the presence of specific local circulation, determining the regularities of admixture behavior in the urban atmosphere.

The purpose of this paper was experimental determination of the effect of local air circulation on air composition of industrial cities of Siberian region. We consider summer period and compare the obtained results for different seasons; the winter period was extensively studied in Ref. 8.

Methods of observations and sites

In our studies we have used an AKV-2 mobile station, developed at the Institute of Atmospheric Optics SB RAS. The instrumentation of the station[9] provides measurements of: (1) air temperature and humidity, wind speed and direction, total solar radiation; (2) aerosol disperse composition in two size ranges: 0.4–10 μm by use of a modernized A3-6 particle counter in 12 channels, and from 3 to 200 nm with a diffusion spectrometer of aerosol in 8 channels; and (3) concentrations of NO, NO_2, O_3, SO_2, CO, and CO_2. For determination of aerosol chemical composition, we used the method of deposition of samples on filters of the AFA type with the subsequent analysis using analytical instrumentation.

In principle, the AKV-2 station differs little from analogous stations created in many regions. The main difference is that, the rechargeable battery and a 12V DC to 220 V AC voltage converter used, the station provides for measurements not only during stops but *en rout* measurements as well.

The possibility of conducting *en rout* measurements with the mobile AKV-2 station has made it possible to pass from *en rout* observations to the areal ones. This, in turn, provides the possibility of using modern software packages of mapping air admixtures on the territory of a concrete city. We have validated this method in Tomsk in July 2005. Figure 1 presents the routs of the station AKB-2; they were selected to encompass the central part of the city and its periphery.

Figure 2 presents the concentration field of nitrogen oxide over the territory of Tomsk. This pattern was constructed as a result of two-hour trip of the mobile station over the territory of the city. Similar maps were also constructed for other measured parameters.

Figure 2 depicts the problems with automobile traffic in the city. The NO concentration is maximum at crossroads of the main highways and decreases away from them. It should be noted that the NO distribution almost one-to-one coincides with the distribution of CO, also of "automobile engine" origin.

It was established quite long ago that the precipitation clear the air from admixtures.[10] To address this process, in August 2005 with the use of the mobile station, we have surveyed Tomsk during precipitation. The measurement scheme was the same as in the previous case.

The obtained data showed that this process is non-unique (Figs. 3 and 4).

Automobile exhausts have the strongest effect on the *en rout* readouts of CO content. Elevated CO concentrations are observed at crossroads of the main city highways. However, depending on weather conditions and time of measurements, the concentration levels may substantially vary. In the second case (on August 26) the measurements were conducted in drizzle; and under these conditions the CO was intensively washed out from the atmosphere, and its concentration was found to be minimum even under conditions of heavy traffic.

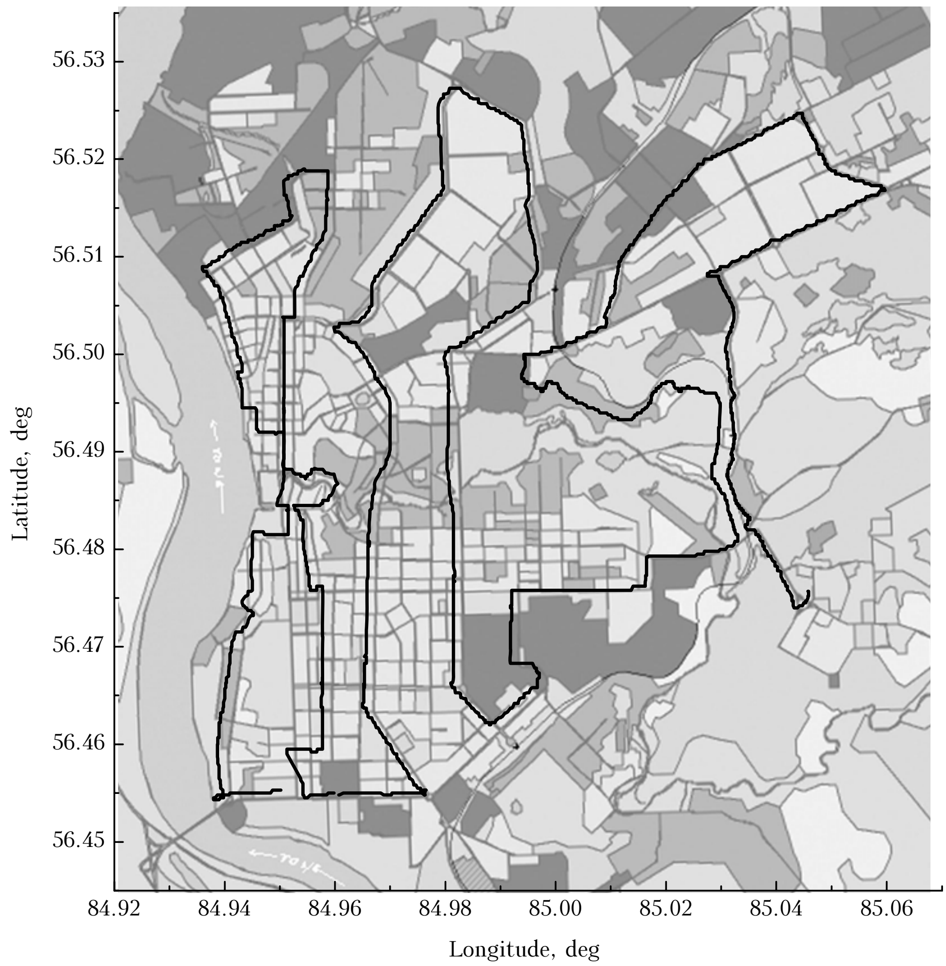


Fig. 1. Tracks of the mobile station in Tomsk on July 7, 2005.

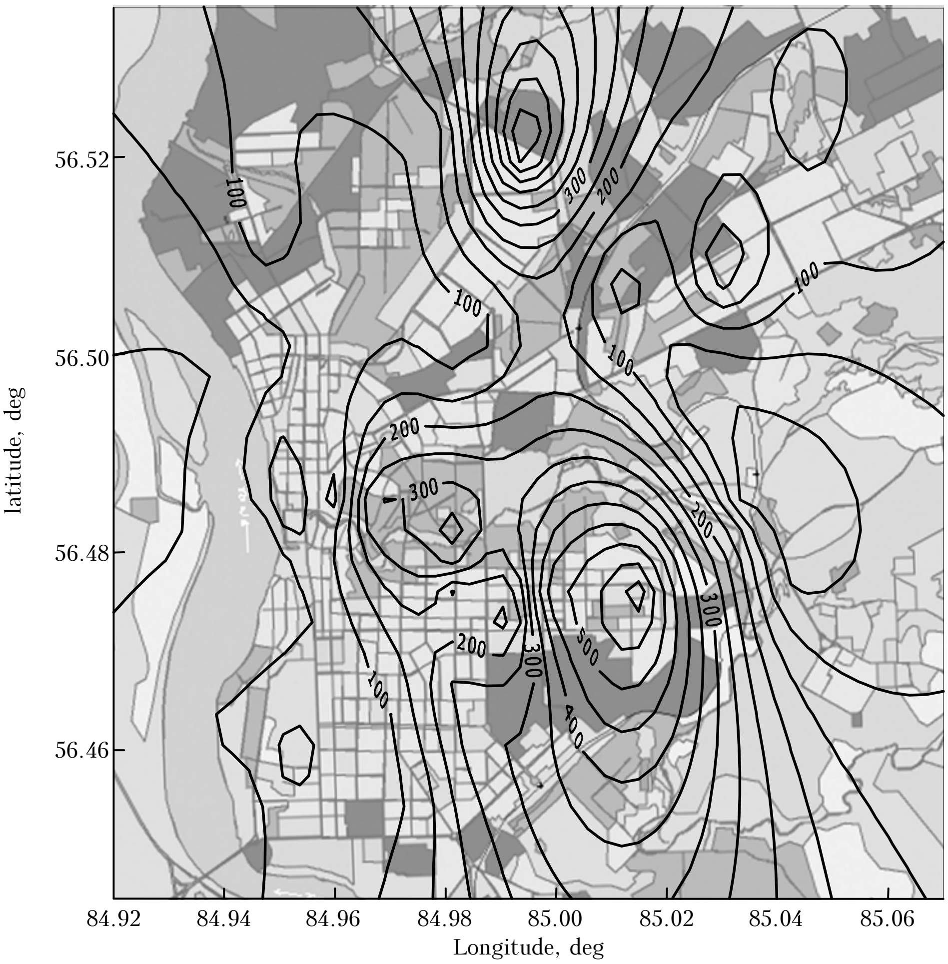


Fig. 2. Distribution of nitrogen oxide concentration (μg/m^3) over Tomsk territory.

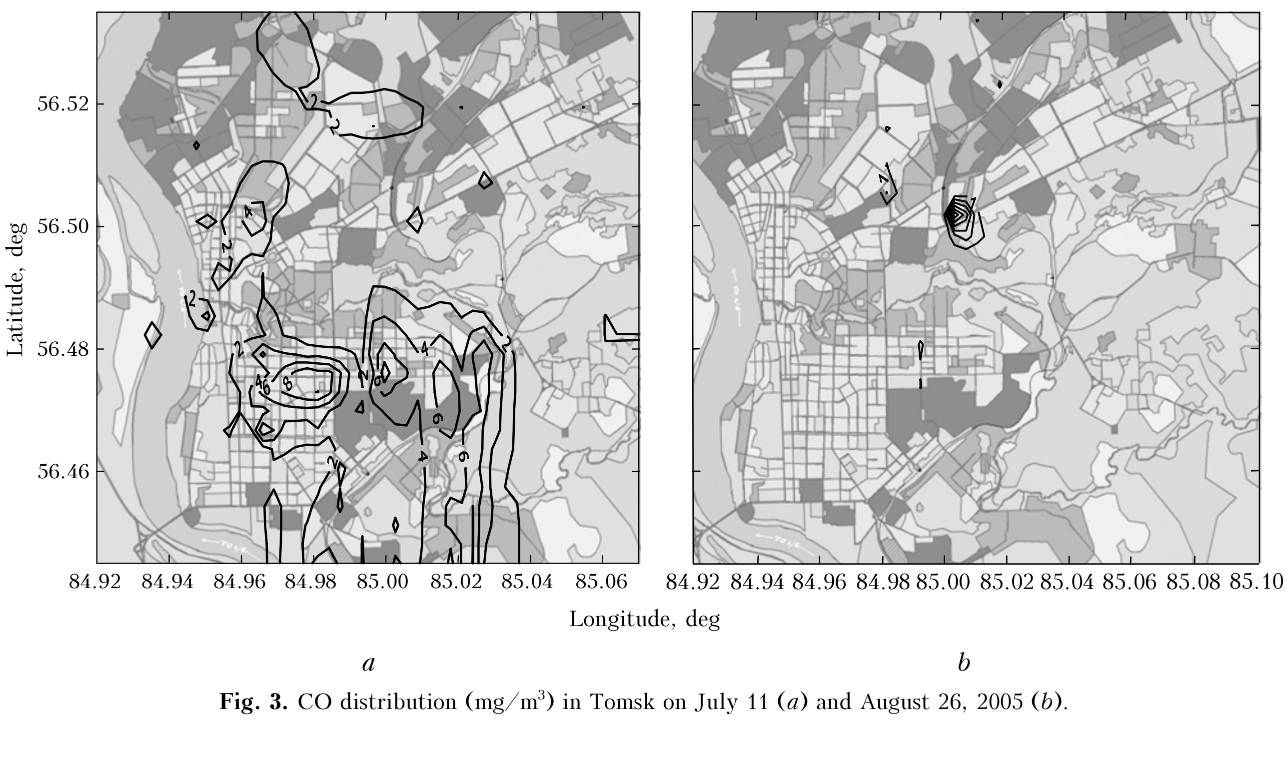
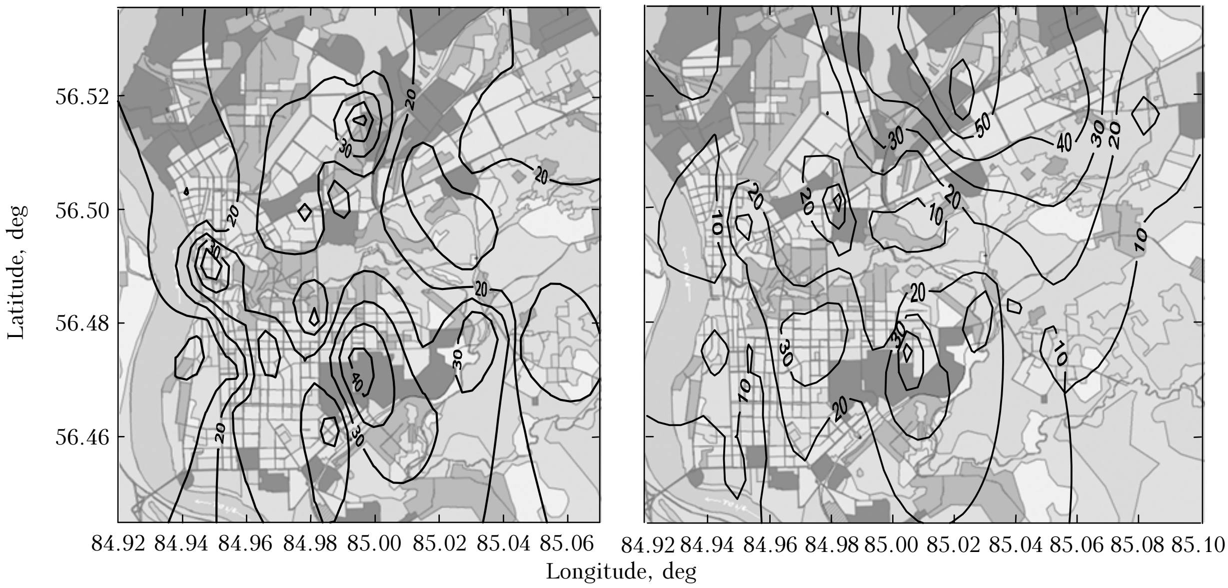


Fig. 3. CO distribution (mg/m^3) in Tomsk on July 11 (*a*) and August 26, 2005 (*b*).



a *b*

Fig. 4. Distribution of nitrogen dioxide (μg/m^3) in Tomsk on July 11 (*a*) and August 26, 2005 (*b*).

The NO_x species are integral part of the engine exhausts. At the same time NO concentrations are several times larger than concentrations of NO_2 in the immediate vicinity of the traffic. Our measurements in both cases showed the presence of a substantial region of air pollution by NO_x in the central part of the city. The minimum values were observed near Tom River and in the vegetated valley of Ushaika River, as well as in the region of Akademgorodok.

Seemingly, the process of air cleaning depends significantly on the solubility of gases. The carbon oxide, sulfurous anhydride, and ozone are very effectively washed out from the atmosphere. On the contrary, nitrogen oxides weakly respond to precipitation.

For comparing the air composition in other cities, the measurements were conducted in February–March, 2004 and in August, 2005 along the route depicted in Fig. 5.

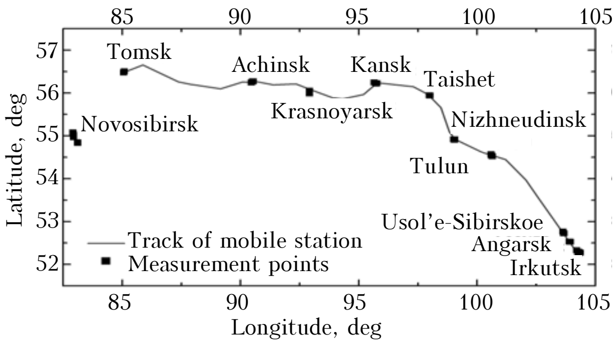


Fig. 5. The route of the mobile station in February–March, 2004.

In addition to the continuous observations during the station motion, in Angarsk, Usol'e-Sibirskoe, Tulun, Nizhneudinsk, Taishet, Kansk, Krasnoyarsk, and Achinsk, we have conducted measurements during stops at the city entry, near center, and at the exit. These observations were aimed at estimating the contribution of urban circulation to admixture accumulation on the city territory and to the change of thermodynamic regime. Figure 6 illustrates the positions of the stops in Achinsk. In other cities, the measurements were made using this same scheme.

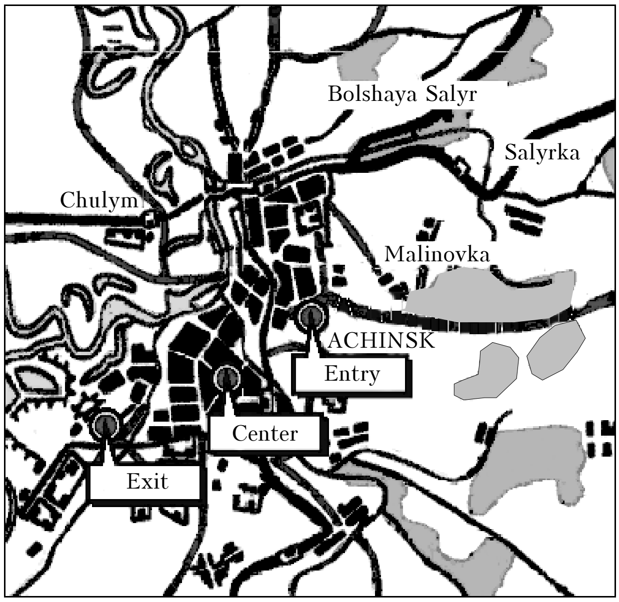


Fig. 6. Scheme of measurement sites in Achinsk on February 29, 2004 (07:00–11:00 LT).

Measurements

The measurement data obtained in all of the above-mentioned cities have revealed the presence of admixture accumulation processes and change of the thermodynamic regime on their territory. Of course, there is no ideal correspondence with theory. Nonetheless, certain general regularities do exist.

Let us turn to Fig. 7, which presents the gas and aerosol concentrations, temperature, and relative humidity in Achinsk.

It is seen that in the central part where usually admixtures are accumulated, the SO_2, NO_2, CO, and *NS* concentrations are a several times higher than in the city periphery. On the contrary, the ozone content in center is much lower. This is normal, having in mind that the ozone is not injected to air by enterprises and engines, but rather is formed from admixtures immediately in the atmosphere.[11] Given the high aerosol concentration, ozone molecules O_3 start to interact with aerosol particles and are destructed.

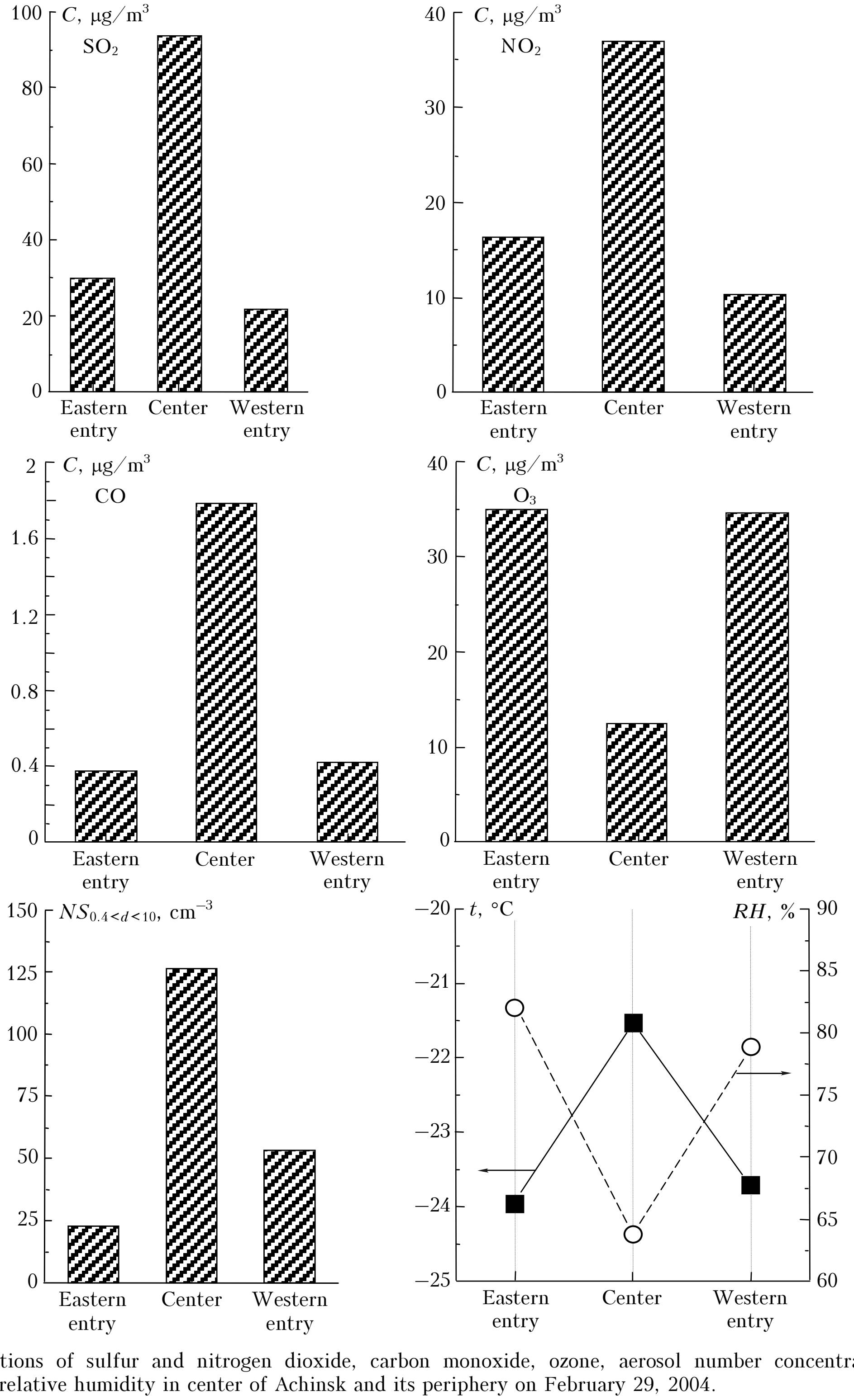


Fig. 7. Concentrations of sulfur and nitrogen dioxide, carbon monoxide, ozone, aerosol number concentration (*NS*), air temperature, and relative humidity in center of Achinsk and its periphery on February 29, 2004.

Data on air temperature show that it is 2.5°C higher at the center than in the eastern/western periphery of the city.

The relative humidity deserves a special note. The point is that it is still unclear whether it is normally higher in the city or outside it. Oke[12] argues that the city has additional water vapor sources: enterprises, untight communications, motor vehicles. On the other hand, he also shows that in winter time the snow is removed from the city streets, and much of its territory is covered with asphalt. Therefore, the natural source in the form of surface evaporation is less effective here. Therefore, knowing the relationship between absolute and relative humidity at a fixed air temperature,[10] it is possible to draw the following conclusion. If with the increase of air temperature at the center of the city the relative humidity proportionally decreases, this indicates that there are no additional sources of water vapor. Otherwise, in the case of proportional covariation, the water vapor sources are present. Returning to Fig. 7, we see that in Achinsk there took place a proportional decrease of relative humidity. Therefore, the city has no additional moisture sources.

The plots analogous to those in Fig. 7 have been made for all cities in which we have carried measurements for both summer and winter periods. Their analysis would occupy too much space; therefore, we compiled the tables containing the differences between parameters at city center and its periphery:

$$\Delta X = X_c - X_p.$$

From this formula it is clear that any quantity with plus (minus) sign will have higher value at the center (on the periphery) of the city.

Wintertime data are given in Table 1, and summertime data in Table 2. It should be noted that, in contrast to winter, summertime measurements were conducted twice in most of the cities, on the way to and back.

Table 1. Differences in admixture concentrations and meteorological quantities between the centers and peripheries of Siberian cities in February–March, 2004

City	t, °C	RH, %	CO, mg/m^3	O_3, μg/m^3	SO_2, μg/m^3	NO_2, μg/m^3	NS, cm^{-3}	Note
Irkutsk	1.74	−9.5	0.23	−29.4	35.4	29.1	6.9	
Angarsk	0.13	0.8	0.30	−22.9	23.0	12.2	10.3	
Usol'e-Sibirskoe	0.78	8.9	−0.36	22.7	−49.9	−20.0	−2.5	Suburbs in industrial zone
Tulun	0.90	2.9	0.21	−7.5	34.2	15.9	8.5	
Nizhneudinsk	−0.48	0.7	0.04	−10.8	6.8	0.3	3.6	
Taishet	−1.27	8.3	2.32	−16.2	11.6	3.3	50.8	Smog
Kansk	1.57	−8.8	−0.03	13.1	−24.5	−9.3	−11.3	Suburbs in industrial zone
Krasnoyarsk	6.80	2.2	−0.18	−1.5	63.0	7.8	4.5	Smog
Achinsk	2.19	−15.1	1.36	−22.1	71.9	26.7	73.2	
Novosibirsk	1.65	0.3	0.35	−39.9	77.5	29.8	10.7	
Akademgorodok, Novosibirsk	0.56	7.9	−0.07	−1.1	34.3	17.4	0.3	

Table 2. Differences in admixture concentrations and meteorological quantities between the centers and peripheries of Siberian cities in August, 2005

City	t, °C	RH, %	CO, mg/m^3	O_3, μg/m^3	SO_2, μg/m^3	NO_2, μg/m^3	NO, μg/m^3	Date
Angarsk	−0.6	6.4	2.5	−29	−6.1	33	260	08.11
Usol'e-Sibirskoe	0.2	−4.6	−1.2	34	−5.0	−12	−11	08.08
Usol'e-Sibirskoe	4.0	−16.6	−3.8	1	3.8	12	−18	08.11
Tulun	−0.3	2.2	0.1	9	4.0	0.3	26	08.07
Tulun	0.0	3.2	0.1	−10	3.9	2.4	28	08.11
Nizhneudinsk	−0.6	−3.0	0.1	9	−3.0	0.4	2	08.07
Nizhneudinsk	−0.5	2.4	1.1	−7	4.0	2.2	0	08.11
Taishet	0.1	5.2	0.1	−17	7.2	2.6	57	08.07
Taishet	−0.4	−4.0	−0.2	−2	−3.0	3.2	9	08.11
Kansk	0.3	4.3	0.2	−14	−14.0	10.8	−16	08.06
Kansk	−0.1	−10.5	0.1	12	−2.9	1.4	−40	08.12
Krasnoyarsk	1.0	−6.0	0.2	−1	3.2	4.0	28	08.05
Krasnoyarsk	1.5	−9.9	0.1	7	−9.8	2.4	10	08.12
Achinsk	−1.2	0.7	0.2	2	–	−14	−150	08.06
Achinsk	1.8	−7.6	0.1	−1	–	5.3	27	08.12
Mariinsk	1.9	−12.1	0.3	20	–	−3.9	3	08.05
Mariinsk	−0.2	−1.4	0.1	11	1.1	−4.0	1	08.13
Novosibirsk	−0.1	3.5	0.2	−14	0.9	9.0	111	07.01

From data of Table 1 it is seen that in most cases the air temperature is higher at the center than on the periphery of the city (9 out of 11 cities). It is also seen that, the bigger the city, the larger the temperature difference. Obviously, in this situation the number of enterprises, motor vehicles, and heat leakage from buildings are important.

The relative humidity varies from city to city in a wide range. Nonetheless, from Table 1 we can conclude that on the territory of eight out of eleven cities, there are additional sources of water vapor.

Carbon monoxide in the city is mainly produced by automobile engines. Naturally, its density is higher in the central part of the cities. This is reflected in Table 1. Exceptions are Usol'e-Sibirskoe where the peripheral point turned out to be near industrial zone, and Krasnoyarsk, in which the measurements at the center were conducted at nighttime. Seemingly, the peripheral measurements were carried out in period of a heavier traffic. The difference in Kansk and Novosibirsk Akademgorodok is close to the measurement error of these parameters.

As was already noted above, ozone in the central part of the cities suffers destruction in fresh emissions and frequently recovers to the periphery. From Table 1 it is seen that this pattern is observed in nine cities out eleven under consideration. Two cities, in which the background points undergo impact of the industrial zone, the pattern is reverse.

Sulfur and nitrogen dioxide, whose sources are emissions of different origin, typically have increased concentration at the city centers and decreased concentrations towards the periphery. Exceptions, again, occur for two cities in which the background measurements were conducted in industrial zone.

Concentration of particles with $d \geq 0.4$ μm is presented in the last column of Table 1. Data in this column also demonstrate increased values in the central part of the cities and decreased values in the periphery, of course, with the exception of the cases when the background was measured in the region of industrial zone.

Thus, the industrial emissions and automobile exhausts in most of the industrial cities of Siberia in winter turn out to be the source of increased admixture concentrations in the atmosphere of the cities. Moreover these pollutants do not disperse, but even are accumulated.

From Table 2 it follows that, in contrast to winter period,[8] in summer the differences in concentrations and meteorological quantities between the city center and periphery are much more variable. The main interseasonal difference is the absence of a stable regularity in the distribution of the differences, which was the case for winter. Obviously, this is due to better dispersal of the contaminants from the atmosphere of this region in summer.

Data on chemical composition of aerosol particles can be taken from Table 3. It presents, in relative units, the excess of concentration of some elements and ions X_c over the background level X_p:

$$\partial X = (X_c - X_p)/X_p.$$

From data of Table 3 it is seen that, in most of the cases, the urban samples have 2–3 times more chemical elements than the background samples. Sometimes, the excess in some elements or species may reach orders of magnitude; for instance, this is the case for Si in Irkutsk, Al in Achinsk, and Ca in Usol'e-Sibirskoe.

It is worthy to note that the above results were obtained during a single wintertime study and, as such, they do not reflect the entire spectrum of possible situations.

In addition to the study of inorganic aerosol fraction, in cities of Irkutsk–Cheremkhovsk industrial zone (Irkutsk, Angarsk, and Usol'e-Sibirskoe) we also deposited the aerosol samples on "Whatman 41" fiber glass filters for determination of polycyclic aromatic hydrocarbons (PAHs), the aerosol microcomponents and superecotoxicants of the first danger class.[13]

Immediate quantitative chemical analysis for determination of ion-elemental composition and content of polyaromatic hydrocarbons was performed after completion of the expedition at the stationary laboratories of Irkutsk Limnological Institute (PAH, hydrocarbonate-anion) and Tomsk State University (elements and other ions).

The total concentrations of priority PAHs in aerosol of the cities varied from 20 to 30 ng/m^3 (Table 4). At the same time, the concentration of benz(a)pyrene did not exceed the maximum permissible concentration (MPC) measuring 1 ng/m^3. Increased total PAH concentrations in aerosol were revealed in the industrial zone of Irkutsk (Novo-Lenino) and Usol'e-Sibirskoe. The benz(a)pyrene concentration in these regions exceeded maximum permissible concentration by factors of 7 and 2.5 respectively. In earlier studies,[13] in Irkutsk, total concentrations of twelve PAHs in different regions of the city in winter ranged from 25 to 300 ng/m^3, while benz(a)pyrene concentrations ranged from 0.8 to 30 ng/m^3. Data of Russian Hydrometeorological Agency[14] suggest that whereas in 1996 the annually average benz(a)pyrene concentrations were 6.5 MPC in Irkutsk, 6 MPC in Angarsk, and 2.8 MPC in Usol'e-Sibirskoe, in 2002 in Irkutsk and Usol'e-Sibirskoe they increased to 10.4 and 6.2 MPC, respectively, and only in Angarsk it decreased to 2.8 MPC.[15] Such a dynamics agrees with the data obtained during our expedition.

The PAH concentrations, as well as the percentage relation between them are determined by the place of aerosol sampling, i.e., by locations of pollution sources. Among the identified PAHs in the public green space and industrial zones of Angarsk, the predominating species are phenanthrene, pyrene, and fluoranthene, whose total amount reaches 80% of the mass of the detected PAHs (Fig. 8).

Similarity of the percentage relations of PAHs in aerosol, collected in these two regions, indicates pollution transport from industrial to inhabited zone of Angarsk.

Table 3. The relative excess of content of ions and elements in composition of aerosol particles, sampled in the central and peripheral parts of Siberian cities

City	Si	Ca	Al	Mg	Ti	Fe	Mn	B	Cu	Ni	V	Cr	Cl^-	SO_4^{2-}	NO_3^-	NH_4^+
Irkutsk	88.8	–0.3	3.9	8.8	13.3	23.8	33.5	25.4	0.8	22.5	0.7	0.4	2.8	–	19.0	10.5
Angarsk	–	0.7	9.5	0.5	1.2	9.6	–0.8	–1.0	–0.2	–0.6	–0.4	2.5	–	–	–	–
Usol'e-Sibirskoe	0.4	20.1	1.3	2.5	3.4	2.9	6.5	–0.7	3.5	9.6	3.9	–1.0	0.9	–0.8	–1.3	1.0
Tulun	9.1	0.3	0.7	9.5	1.2	1.2	10.2	–	3.5	–1.0	1.6	1.7	–0.5	3.7	2.0	7.4
Nizhneudinsk	5.4	2.6	4.6	2.7	3.3	3.4	2.8	–	–0.6	–0.5	1.2	–	18.3	–	–	–1.0
Kansk	22.6	0.1	–	1.0	–	–	–	–	1.1	1.2	–	1.2	0.9	4.4	2.1	1.0
Achinsk	1.2	23.4	37.4	9.4	2.0	1.6	46.6	–1.0	0.6	–1.0	9.3	6.3	1.0	6.3	0.1	7.7
Novosibirsk	3.3	3.0	5.3	6.0	2.5	2.2	6.3	0.4	0.6	–1.0	0.1	9.8	0.1	0.2	10.9	1.4

N o t e . Dash means absence of element/ion in the background sample.

Table 4. Levels of PAH concentration in aerosol (ng/m^3) of cities of Irkutsk Region, sampled on February 26, 2004

PAH	Sampling region				
	Irkutsk, Akademgorodok	Irkutsk, Novo-Lenino	Angarsk, industrial zone	Angarsk, inhabited zone	Usol'e-Sibirskoe, inhabited zone
Phenanthrene	1.1	15.0	15.8	12.6	16.8
Anthracene	0.14	1.4	< 0.001	0.53	1.2
Fluoranthene	3.1	10.2	14.4	6.7	23.9
Pyrene	2.4	7.3	7.9	3.8	13.8
Benzo(a)anthracene	1.2	4.7	0.7	< 0.001	2.3
Chrysene	2.3	4.8	1.6	< 0.001	4.6
Benzo(b)fluoranthene	2.6	5.7	1.2	1.6	4.2
Benzo(k)fluoranthene	0.21	7.3	0.94	< 0.001	3435
Benzo(e)pyrene	2.2	4.0	0.87	0.75	2.6
Benz(a)pyrene	**0.31**	**7.2**	**0.58**	**0.53**	**2.7**
Perylene	0.29	1.3	< 0.001	< 0.001	< 0.001
Indeno(1,2,3-c,d)pyrene	2.8	9.7	1.3	1.2	4.0
Dibenzo(a,h)anthracene	0.6	< 0.001	< 0.001	< 0.001	< 0.001
Benzo(g,h,i)perylene	2.4	8.9	1.4	1.7	3.3
Total PAH	**21.6**	**87.5**	**46.7**	**29.4**	**82.7**

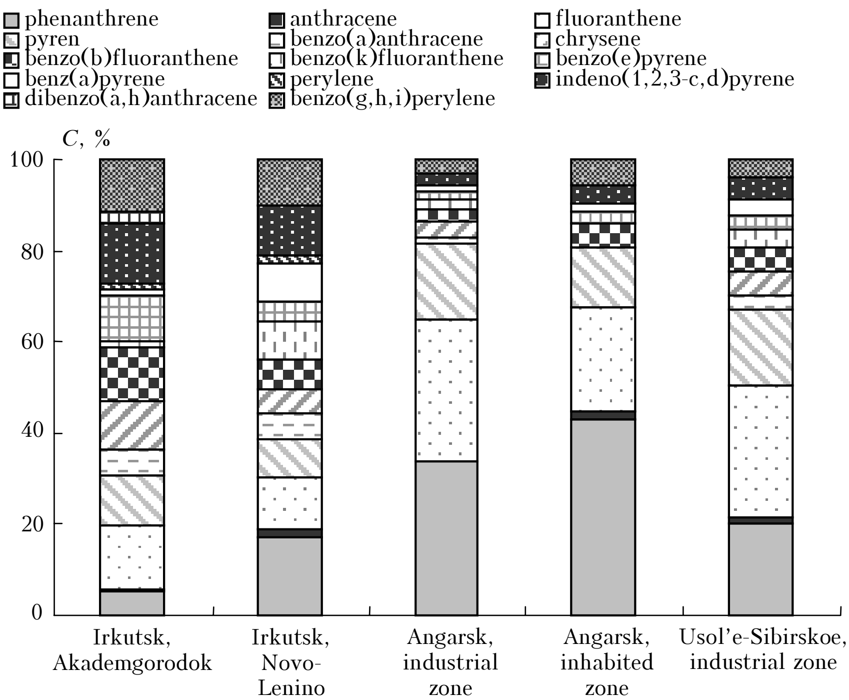


Fig. 8. Percentage relation between individual PAHs in aerosol samples, collected in the cities of Irkutsk industrial zone.

The regions of Akademgorodok and Novo-Lenino in Irkutsk distinctively have high contents of benzo(g,h,i)perylene and indeno(1,2,3-c,d)pyrene, which are indicators of air pollution by motor transport.[16] The main PAH sources in the region of Novo-Lenino are medium-power boilers using fuel-bed method of coal combustion, as well as private sector with stove heating,[17] characterized by fuel undercombustion, signified by high content of benz(a)pyrene in aerosol samples from this region.

Conclusion

The experimental studies conducted have revealed that in winter in the industrial cities of Siberia the existing specific local circulation favors creation of specific fields of admixture distribution. The admixture concentration is higher in the central city parts and decrease toward the periphery. This same is also true for thermodynamic air characteristics.

In summer, owing to more effective atmospheric ventilation, the effects of local circulation substantially weaken. As a result, the distinct admixture accumulation in the central parts of the cities may not always be noticed.

References

1. V.V. Penenko and A.E. Aloyan, *Models and Methods for Environmental Protection Problems* (Nauka, Novosibirsk, 1985), 256 pp.
2. V.V. Penenko and M.G. Korotkov, Atmos. Oceanic Opt. **11**, No. 6, 492–496 (1998).
3. V.V. Penenko and E.A. Tsvetova, Atmos. Oceanic Opt. **15**, Nos. 5–6, 370–376 (2002).
4. B.D. Belan, Atmos. Oceanic Opt. **6**, No. 2, 124–135 (1993).
5. B.D. Belan, V.K. Kovalevskii, D.V. Simonenkov, G.N. Tolmachev, and T.M. Rasskazchikova, Atmos. Oceanic Opt. **9**, No. 6, 476–483 (1996).
6. G.E. Landsberg, *Urban Climate* (Gidrometeoizdat, Leningrad, 1983), 248 pp.
7. B.D. Belan, Atmos. Oceanic Opt. **7**, No. 8, 558–562 (1994).
8. B.D. Belan, G.A. Ivlev, V.A. Pirogov, E.V. Pokrovskii, D.V. Simonenkov, N.V. Uzhegova, and A.V. Fofonov, Geografia i Prirodnye Resursy, No. 1, 152–157 (2005).
9. M.Yu. Arshinov, B.D. Belan, D.K. Davydov, G.A. Ivlev, A.V. Kozlov, D.A. Pestunov, E.V. Pokrovskii, D.V. Simonenkov, N.V. Uzhegova, and A.V. Fofonov, Atmos. Oceanic Opt. **18**, No. 8, 575–580 (2005).
10. L.T. Matveev, *Atmospheric Physics* (Gidrometeoizdat, Saint Petersburg, 2000), 360 pp.
11. B.D. Belan, Atmos. Oceanic Opt. **9**, No. 9, 754–773 (1996).
12. T.R. Oke, *Climates of Boundary Layer* (Gidrometeoizdat, Leningrad, 1982), 360 pp.
13. A.G. Gorshkov and I.I. Marinaite, Atmos. Oceanic Opt. **13**, No. 10, 899–902 (2000).
14. *Governmental report on the environmental state in Irkutsk Region,* State Committee for environmental protection in Irkutsk Region, State Committee of Ecology of Russia, Administration of Irkutsk Region (Public Corporation Oblmashinform, Irkutsk, 1999), 320 pp.
15. *Governmental report on the environmental state in Irkutsk Region,* Main Authority of Natural Resources and Environmental Protection of Ministry of Natural Resources of Russia in Irkutsk Region (Irkutsk, 2004), 327 pp.
16. A.R. Suzdorf, S.V. Morozov, L.I. Kuzubova, N.N. Anshits, and A.G. Anshits, Khimia v Interesakh Ustoich. Razvitia **2**, Nos. 2–3, 511–540 (1994).
17. E.V. Molozhnikova, *"Treatment of environmental pollution by aerosols in problems of development of energy systems,"* Author's Abstract of Cand. Phys.-Math. Sci. Dissert., Irkutsk (2003), 24 pp.