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POLLUTION OF THE AIRBASIN OF AN INDUSTRIAL CENTER

Abstract. *A study of air qualities has been done in 11 Siberian cities from Irkutsk (easternmost) to Novosibirsk (westernmost) in winter and summer with a mobile measurement station. It is shown that in winter a modern industrial city is not only a "heat island", but also a "pollution island". Admixtures concentration in centers of most cities is much higher than in their periphery. The exception is ozone, which is apparently destroyed by industrial emissions in the center and replenished in the periphery. In summer the local circulation is considerably weakened, and the difference between the parameter values for the center and periphery not always remains.*

Keywords: *industrial center, urban, suburban, heat island, air pollution, mobile measurement station.*

1 Introduction

Research of patterns of air pollution field formation and transformation in large industrial centers has been thriving for the last 10–15 years. It has been considered for a long time that a city is well ventilated on a regular day with moderate wind, and increased concentration of air pollution is observed only near the industrial areas or along the trail of contaminants' distribution.

Present day theories prove it's a dangerous mistake [8–10]. A lot of studies show that the polluting admixtures produced in the city territory are not transferred outside but are furthermore transformed by various processes.

As a result of combining such factors as industrial objects accumulation in limited space, orography, artificial and natural reservoirs etc., a local circulation arises in city areas [9,10].

The peculiarity of urban local circulation is the arisal of returned airflows leeward of the city opposite to the main airflow. This returned air circulation "locks" industrial emissions in the city area.

A haze consisting of gases and aerosols appears above the city. It is called "pollution cap". A peculiar characteristic of such a circulation is that it persists not only with a light wind but with a moderate one too. It is disrupted by atmospheric fronts but is renewed within 24 hours.

Thus, an "urban column" forms above the city. Since the air temperature inside the column is higher than that of the city surroundings, the air begins to rise. At the beginning the urban column has a vertical shape and then under the influence of the main airflow it begins to bend [5]. At a considerable distance from the city it becomes horizontal and spreads near the upper edge of the atmosphere's border layer. This layer is separated from the free atmosphere by an inhibiting layer and its height depends on the season.

The purpose of this paper is experimental determination of the local air circulation effect on air composition of the industrial cities of Siberian region. This paper considers summer period and compares the obtained results with the data for other seasons. The winter period was extensively studied in [6].

2 Data and methodology

For this research we have used the AKV-2 mobile station developed by the Institute of Atmospheric Optics SB RAS. The station's equipment provides measurements of the following: air temperature and humidity; wind speed and direction; total solar radiation; NO, NO_2, O_3, SO_2, CO, CO_2 concentration; aerosol disperse composition in two ranges: 0,4-10 μm by use of the modernized AZ–6 counter in 12 channels and 3–200 nm with the diffusion aerosol spectrometer in 8 channels. The accuracy of all given measurements by the AKV–2 station has been described in detail in [1].

For the aerosol chemical composition determination we have used the method of deposition of samples on AFA type filters with subsequent analytical analysis. In general, the AKV–2 station doesn't differ much from similar ones created in many regions. The main distinction is a rechargeable battery and a 12V DC to 220V AC voltage converter which allows for measurements not only at stops but also en route.

The possibility of conducting en route measurements with the AKV–2 mobile station has allowed us to proceed from route based observations to the areal ones. This, in turn, allows the use of modern software packages for air admixtures mapping on the territory of a specific city. We had validated this method in Tomsk in July 2005 [4].

For comparing the air composition in other cities measurements had been made in February–March, 2004 and in August, 2005 along the route depicted in Fig. 1. En-route measurements had been made in every large industrial city.

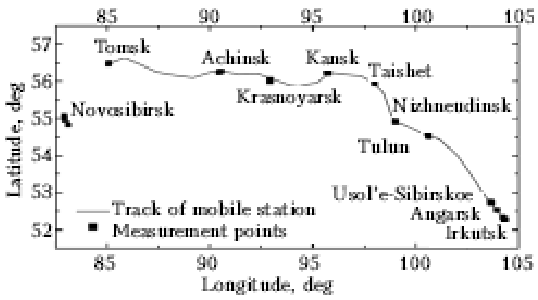

Fig. 1 Mobile station route in February–March, 2004.

In addition to the continuous observations during the station movement, in the cities of Angarsk, Usol'e–Sibirskoe, Tulun, Nizhneudinsk, Taishet, Kansk, Krasnoyarsk and Achinsk we had conducted measurements during stops at entry, near the city center and at the exit. This is classical approach.

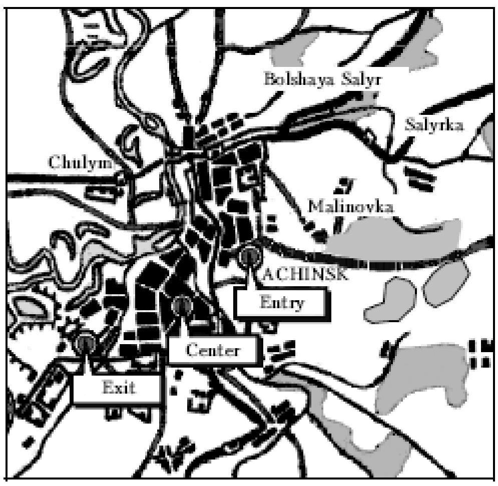

Fig. 2 Scheme of measurements sites in Achinsk on February 29, 2004 (07:00–11:00 LT).

These observations had been made to estimate the contribution of urban circulation to admixture accumulation in the city territory and to the change of thermodynamic regime. The main feature of this method is the necessity to make the measurements in all three points as close to simultaneity as possible, which was successfully accomplished. Figure 2 shows the positions of stops in Achinsk. In other cities the measurements had been made using the same scheme.

3 Results and discussion

The measurement data obtained in all of the above-mentioned cities has revealed presence of admixture accumulation processes and changes in the thermodynamical regime in their territory. Naturally, the correspondence with the theory is not ideal. Nonetheless, certain general regularities do exist.

Figure 3 shows values of the gas and aerosol concentrations, temperature and relative humidity in Achinsk. One can see that in the city center where the admixtures are usually accumulated the SO_2, NO_2, CO and NS concentrations are several times higher than in the city periphery. On the contrary, the ozone concentration is much lower there. It is a regular occurrence, granting that the ozone is not released into the atmosphere by industries and car engines but is rather formed there from different admixtures [2]. Given a high aerosol concentration, the ozone molecules start to react with aerosol particles and are destroyed.

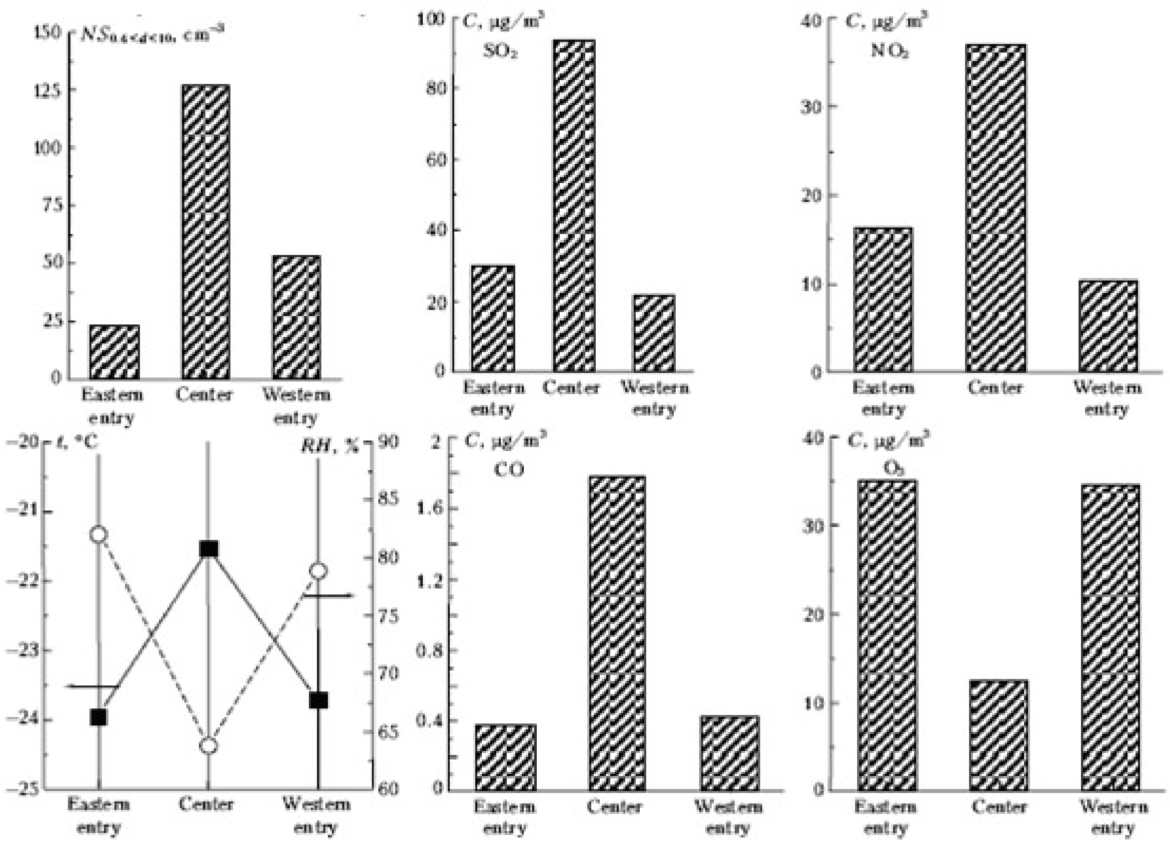

Fig. 3 Concentrations of sulfur and nitrogen dioxide, carbon monoxide, ozone, aerosol number concentrations (NS), air temperature and relative humidity in the center and periphery of Achinsk on February 29, 2004.

The air temperature data shows that in the city center it is 2.5°C higher than in the eastern/western periphery.

The relative humidity deserves a special note. There is no agreement among the scientists about whether it is normally higher in the city or outside it. Oke [7] argues that the city had additional vapor sources such as industries, untight communications and motor vehicles. On the other hand, he also points out that in winter snow is removed from the city streets and much of the surface is covered with asphalt thus lowering surface evaporation, which is a natural source of moisture. Therefore, knowing the relation between the absolute and relative humidity at a fixed air temperature [6], the following conclusion can be made. If with an increase of air temperature at the city center the relative humidity proportionally decreases, it shows that there are no additional vapor sources. In case of a proportional covariation, additional vapor sources are present. Returning to Fig. 3, one can see that a proportional relative humidity decrease took place. Therefore, the city has no additional sources of moisture.

Plots similar to those on Fig. 3 have been made for all the cities where we have made measurements both for the summer and winter periods. It would take too much space to analyze them all, so we have compiled the data into tables containing the differences between the parameters at city center and periphery:

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

Therefore, if a value is positive (negative), it is higher in the center (on the periphery) of the city. Data for winter and summer is given in Tables 1 and 2 respectively. It should be noted that in contrast to winter, summertime measurements had been made twice in most of the cities: the second time on the way 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, μ/m^3	SO_2, μ/m^3	NO_2, μ/m^3	NS, sm^{-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	Surbub 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	Surbub 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, μ/m^3	SO_2, μ/m^3	NO_2, μ/m^3	NS, sm^{-3}	Note
Angarsk	-0.6	6.4	2.5	-29	-6.1	33	260	11.08
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	11.08
Tulun	-0.3	2.2	0.1	9	4.0	0.3	26	07.08
Tulun	0.0	3.2	0.1	-10	3.9	2.4	28	11.08
Nizhneudinsk	-0.6	-3.0	0.1	9	-3.0	0.4	2	07.08
Nizhneudinsk	-0.5	2.4	1.1	-7	4.0	2.2	0	11.08
Taishet	0.1	5.2	0.1	-17	7.2	2.6	57	07.08
Taishet	-0.4	-4.0	-0.2	-2	-3.0	3.2	9	11.08
Kansk	0.3	4.3	0.2	-14	-14.0	10.8	-16	06.08
Kansk	-0.1	-10.5	0.1	12	-2.9	1.4	-40	12.08
Krasnoyarsk	1.0	-6.0	0.2	-1	3.2	4.0	28	05.08
Krasnoyarsk	1.5	-9.9	0.1	7	-9.8	2.4	10	12.08
Achinsk	-1.2	0.7	0.2	2	-	-14	-150	06.08
Achinsk	1.8	-7.6	0.1	-1	-	5.3	27	12.08
Mariinsk	1.9	-12.1	0.3	20	-	-3.9	3	05.08
Mariinsk	-0.2	-1.4	0.1	11	1.1	-4.0	1	13.08
Novosibirsk	-0.1	3.5	0.2	-14	0.9	9.0	111	01.07

The data in Table 1 shows that in most cases air temperature in the city center is higher than at its periphery (9 out of 11 cities). It also shows that the bigger the city, the larger the temperature difference. Apparently, it is influenced by the number of industries and vehicles as well as by heat leakage from buildings. Relative humidity varies from city to city in a wide range. Nonetheless, from the data in Table 1 we can draw a conclusion that there are additional sources of vapor in the territory of 8 out of 11 cities.

Carbon monoxide in the cities is produced mainly by car engines. Its density is naturally higher in the central part of a city. This is reflected in Table 1. Exceptions are Usol'e Sibirskoe where the peripheral measurement point turned out to be near an industrial area and Krasnoyarsk where the measurements at the city center had been conducted at nighttime. It also appears that the peripheral measurements had been made at the time of heavier road traffic. The difference in Kansk and Novosibirsk Akademgorodok is close to the measurement error value for this parameter.

As noted above, ozone suffers destruction in the central part of a city and is quickly replenished from the periphery. Table 1 shows that this pattern is observed in 9 out of 11 cities. It is reversed in the two cities where the background points had been influenced by industrial areas.

The source of sulfur and nitrogen dioxides are emissions of different origin, therefore, their concentration is typically higher in the city center and lower at the periphery. Once again, exceptions occur when the background is measured close to industrial areas.

The data for concentration of particles with $d \geq 0,4$ μm is shown in the last column of Table 1. This data also shows increased values in the city center and lower ones at the periphery with the same two exceptions.

Thus, in most of Siberian industrial cities in winter emissions from industries and cars cause increased admixture concentrations in their atmosphere, which are apparently not dispersed but accumulated.

From the data in Table 2 we draw a conclusion that in contrast to winter period the values for concentrations and meteorological quantities vary much more in summer. The main difference is that there is no stable pattern in the distribution of differences between the city center and periphery which was the case in winter [3]. It is apparently due to better dispersing quality of the region's atmosphere in summer.

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

	Si	**Ca**	**Al**	**Mg**	**Ti**	**Fe**	**Mn**	**B**
Irkutsk	88.8	-0.3	3.9	8.8	13.3	23.8	33.5	25.4
Angarsk	-	0.7	9.5	0.5	1.2	9.6	-0.8	-1.0
Usol'e-Sibirskoe	0.4	20.1	1.3	2.5	3.4	2.9	6.5	-0.7
Tulun	9.1	0.3	0.7	9.5	1.2	1.2	10.2	-
Nizhneudinsk	5.4	2.6	4.6	2.7	3.3	3.4	2.8	-
Kansk	22.6	0.1	-	1.0	-	-	-	-
Achinsk	1.2	23.4	37.4	9.4	2.0	1.6	46.6	-1.0
Novosibirsk	3.3	3.0	5.3	6.0	2.5	2.2	6.3	0.4
	Cu	**Ni**	**V**	**Cr**	**Cl**	**SO^2_4**	**NO_3**	**NH^+_4**
Irkutsk	0.8	22.5	0.7	0.4	2.8	-	19.0	10.5
Angarsk	-0.2	-0.6	-0.4	2.5	-	-	-	-
Usol'e-Sibirskoe	3.5	9.6	3.9	-1.0	0.9	-0.8	-1.3	1.0
Tulun	3.5	-1.0	1.6	1.7	-0.5	3.7	2.0	7.4
Nizhneudinsk	-0.6	-0.5	1.2	-	18.3	-	-	-1.0
Kansk	1.1	1.2	-	1.2	0.9	4.4	2.1	1.0
Achinsk	0.6	-1.0	9.3	6.3	1.0	6.3	0.1	7.7
Novosibirsk	0.6	-1.0	0.1	9.8	0.1	0.2	10.9	1.4

Data on chemical composition of aerosol particles is given in Table 3. It presents the excess of certain elements and ions concentration (X_c) compared to the background level (X_p) in relative units:

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

Data in Table 3 shows that in most cases the urban samples contain 2–3 times more chemicals than the background ones. At times, the excess of a certain element or compounds can reach orders of magnitude. Examples are Si in Irkutsk, Al in Achinsk and Ca in Usol'e Sibirskoe.

It must be noted that the given data has been obtained during a single wintertime study, therefore it does not reflect the whole spectrum of possible situations.

4 Conclusion

Our experimental studies have revealed that the existing specific local circulation favors creation of specific fields of admixture distribution in industrial cities of Siberia in winter. The admixture concentration is highest in the city center and decreases toward the periphery. The same applies to the air termodynamical qualities. In summer due to better dispersing quality of the atmosphere the local circulation effects are considerably weakened. As a result, admixture accumulation in central parts of cities is not always distinct.

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Загрязнение воздушного бассейна промышленного центра

Аннотация. *С помощью мобильной станции проведено обследование качества воздуха в 11 городах Сибири от Иркутска до Новосибирска в зимний и летний периоды. Показано, что современный промышленный город в зимний период является не только «островом тепла», но и островом загрязнений. Концентрации примесей в центре большинства городов значительно выше, чем на периферии. Исключение составляет озон, который, очевидно, гибнет в выбросах предприятий в центре и восстанавливается на периферии. В летний период действие локальной циркуляции значительно ослабляется и не всегда сохраняется разница между параметрами, измеряемыми в центре города и на периферии.*

Ключевые слова: *индустриальный центр, остров тепла, загрязнение атмосферы, передвижные станции.*