Impact of the urban area of Tomsk on the temperature–humidity regime of air

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We analyze the measurement data obtained during complex experiments conducted in summer 1997, 2000, and in the fall of 1999 in two localities, namely, in Tomsk and Kireevsk. Analysis has shown that the direct inflow of the anthropogenic heat into the urban atmosphere is not a primary source of formation of the so-called heat island. The local air circulation causes, to a greater extent, the formation of the pollution cap above the city.

Nowadays the anthropogenic impact on the environment becomes stronger. The vast populated areas where great amount of anthropogenic admixtures are emitted impose the strongest effect. One of the pollution, namely, the extra thermal energy, is caused by two factors: direct emission of the waste heat from industrial enterprises and transfer of energy and additional absorption of solar energy by anthropogenic admixtures accumulated in the urban atmosphere. Mechanisms of thermal pollution are too complicated, and the role of each of them changes during a day and a year as well.

The problem of thermal effect of a megalopolis is discussed for a long time.[1–4] The experiments on studying thermal pollution of the atmosphere of a relatively small city with the population about 500 thousand people is described in this paper.

To study the urban effect on meteorological conditions, we carried out field experiments in summer of 1997 and 2000, and in the fall of 1999. The idea of these experiments was the following. Automated meteorological stations were installed in Kireevsk settlement of Tomsk Region and in Akademgorodok. They performed synchronous hourly measurements. First, the stations were placed together at one site for intercalibration. The transition coefficients were calculated from the comparison of thus obtained results, what allowed us to exclude the differences in absolute values.

Besides, analysis of synoptic conditions during the experiments was carried out from near-ground and height maps kindly presented by Tomsk Hydrometeorological Center. The time of fronts passages across the observation sites was determined using the maps, and the cases were selected when both sites were in the same air mass. As the south-west transfer prevails in our region, air masses passed over Kireevsk (which is a background station) and then come across Tomsk to Akademgorodok. The plots of diurnal behavior of the differences in temperature, relative humidity, and specific pressure of water vapor between two sites were constructed for each of the periods (Fig. 1).

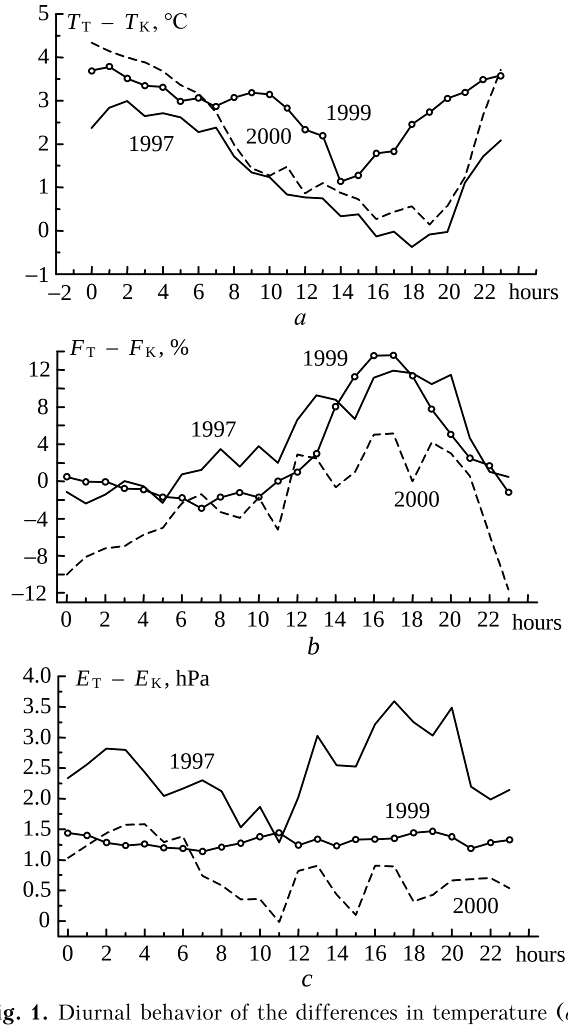

Fig. 1. Diurnal behavior of the differences in temperature (*a*), relative humidity (*b*), and the specific pressure of water vapor (*c*).

It is seen that there is difference between the parameters measured in both sites, that changes during a day. The nighttime maximum of the temperature difference is most likely caused by the peculiarities of air circulation over the city, resulting from which the pollution cap is formed.[4,5] As a result, cooling of air over the city occurs slower. Both these factors affect the thermal pollution at night. At night direct emission of heat is less intense because of not that heavy traffic, but heat disappears slower because of the closed local circulation. The second factor is the anthropogenic emission itself that leads to the greenhouse effect.

Minimum values of $T_T - T_K$ observed in the daytime are caused by the fact that the pollution cap in the daytime produces two effects. On the one hand, the pollution accumulated over the city decreases the net flux of radiation whilst, on the other hand, it favors heating of air under the effect of direct emission of heat. Such a combination leads to the fact that heating of air over a city and in its environments during daytime become practically equal. If there was no additional direct heating in the daytime, air temperature should be greater in the environments of the city, and the city should be a cold island. Really, temperature excess in Kireevsk was 11.2% for all time of observations, and 7.8% in summer. Then it follows that air temperature in the city is higher for longer time, and, on the average, the city is a heat island.

Regardless the fact that daily amplitude of the differences in the parameters under study in fall is less than in summer, their diurnal behavior is also observed, but the time of minimum values onset is displaced.

No diurnal behavior of the difference in the specific pressure of water vapor in fall was observed. This season is the time of snow cover formation, which leads to equalization of the conditions of evaporation in the city and its environments, but in the city, there are more sources of water vapor, and the difference in e is positive during a day.[2]

We also have studied the effect of wind direction on the diurnal behavior of the differences in temperature and humidity in Tomsk and Kireevsk. The following plots of the diurnal behavior of this parameters present the results of summer expeditions (greater statistical provision): for all the data arrays; for the cases with east component of the wind, when the air coming to Akademgorodok has not entered into the city; for the cases with west component of the wind, when the air coming to the TOR station has come across the city in one or another degree; for the cases with south-west component of the wind, when the air coming to the station has crossed practically all the city (Fig. 2). It was finally obtained that, independently of the wind direction, the daytime values of the differences in temperature tend to minimum, and the curves practically approaches each other, and in the nighttime maximum difference is observed near midnight. Differences in relative humidity and specific pressure of water vapor are less at east wind at any time of a day than at west wind, that is most likely caused by some decease of the effect of the city on the water content.

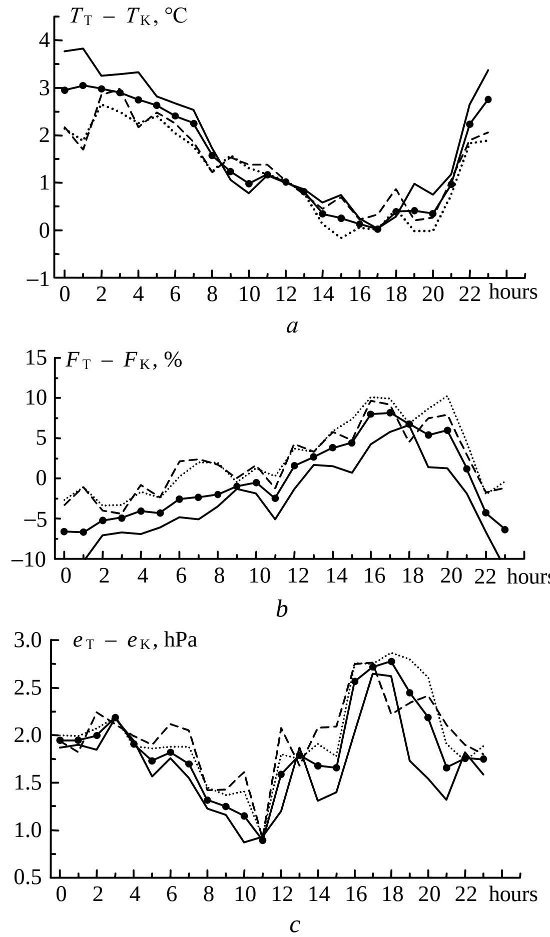

Fig. 2. Diurnal behavior of the differences in temperature (*a*), relative humidity (*b*), and the specific pressure of water vapor (*c*) at different wind directions: (•–•–•) without the account for the wind direction; (········) at the westerly component; (——) at the easterly component; (- - - - -) at the south-west component.

As one can isolate the effect of the city only in the case of homogeneous air mass, let us consider in a more detail the results obtained at the absence of fronts of any type. The mean values of the parameters under study for different years, standard deviations, extreme values, and the number of cases are shown in the Table.

It is seen from the Table that mean differences between temperatures in Tomsk and Kireevsk in summer either do not exceed 2°C or are close to that, and in the fall they approach to 3°C. The increase of the mean values in fall occurs due to the decrease of the daily amplitudes. Maximum values of the differences in the nighttime in fall are close to that in summer, while minimum values are 1°C greater.

Mean differences in both relative humidity and specific pressure of water vapor for the period of observations strongly change from year to year, and one can say nothing about their seasonal values.

Table

Parameters	1997 (August)		1999 (October–November)		2000 (July–August)	
	totally	without fronts	totally	without fronts	totally	without fronts
$T_T - T_K$ (mean)	1.00	1.47	2.94	2.86	1.98	2.22
σ	1.24	0.75	0.90	0.73	4.91	4.91
Limits of variations	−5.0–9.5	−2.7–6.3	−7.8–9.5	−7.8–8.4	−6.4–8.4	−2.5–8.4
Number of cases	559	273	683	416	724	565
$F_T - F_K$	4.18	3.48	3.16	2.47	−4.36	−3.06
σ	14.0	7.99	18.24	10.18	26.45	26.44
Limits of variations	−26.9–43.9	−19.4–25	−32.8–40.3	−14.9–30.6	−42–31.7	−42–21.9
Number of cases	526	256	682	416	616	288
$e_T - e_K$	2.10	2.45	1.41	1.30	1.49	0.79
σ	1.13	0.05	0.85	0.12	0.69	0.89
Limits of variations	−4.8–9.2	−1.79–7.5	−1.56–6.23	−1.56–2.93	−3.18–5.27	−2.57–4.46
Number of cases	523	256	681	414	612	283

Individual values of the differences in temperature in Tomsk and Kireevsk varied in a wide range during the experiments, and, as is seen from the Table, the limits of variations of the parameters are reduced if take into account fronts.

Apart from the mean values of the parameters and the limits of variation, their frequency of occurrence in different ranges is of great interest. We have constructed the plots of the frequency of occurrence of temperature difference with the step of 0.5°C, relative humidity with the step of 5%, specific pressure of water vapor with the step of 0.3 hPa using full data array of the experiments and for isolated periods of observations as well (Fig. 3).

Frequency of occurrence of different intervals ΔT is shown in Fig. 3*a* for all time of the observations and for summer and fall periods separately. It is seen that the main maximum of the frequency of occurrence of the temperature difference between Tomsk and Kireevsk in summer lies in the range 5–5.5°C, while the total period of observation is characterized by the presence of two almost equal maxima in the ranges 0–0.5 and 2–2.5, and one additional maximum in the range 4.5–5°C. Temperature difference between Tomsk and Kireevsk greater than 5°C is observed in the nighttime in the cases when weather conditions have been determined by a small-rate field or anticyclone. In these cases, the pollution cap over the city reaches its maximum development. When analyzing the relationships between the frequencies of occurrence of different temperature differences during all time of the observations and in the fall of 1999, the difference in distributions is well seen. As the amplitude of diurnal behavior is lower in the fall, it is natural that the difference between the values is smaller, and mainly varies in small number of ranges. The distribution in fall approaches the normal one with the well-pronounced maximum in the range 2.5–3°C.

It is seen in Fig. 3*b* that repeatability of different ranges of differences of relative humidity ΔF has practically single-mode behavior both for all periods of the observations and in summer. The most often observed values ΔF lie in the range 0–5%. The maximum frequency of occurrence in the fall is displaced to the range from 0 to −5%. As relative humidity depends mainly on temperature, and in fall the city is warmer during practically all time, relative humidity is lower there in this time.

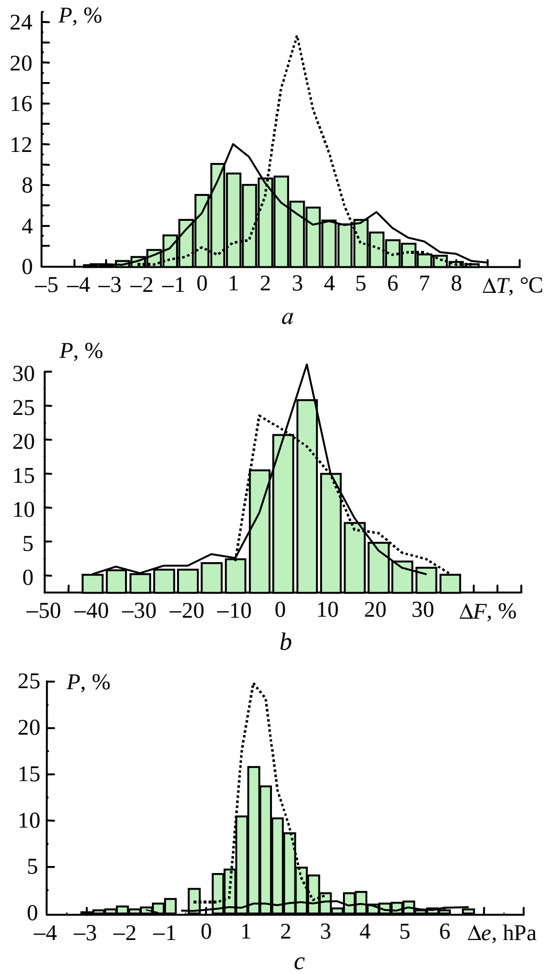

Fig. 3. Frequency of occurrence of different ranges of differences in temperature, relative humidity, and specific pressure of water vapor in Tomsk and Kireevsk: [box] − all time; ——− summer; - - - - - − fall.

Figure 3*c* shows the relationship between the frequencies of occurrence of different ranges of differences in the specific pressure of water vapor Δe for all period of observations for summer and fall. It is seen from Fig. 3*c* that the behavior of the frequency of occurrence of Δe in summer is smooth. In fall the maximum frequency of occurrence lies in the range 1–1.5 hPa, because the difference in the specific pressure of water vapor in the city and its environments during a day varies, on the average, within these limits. The result obtained does not contradict those in Ref. 2.

Although the island of heat over a city exists independently of season, diurnal behavior of ΔT is an evidence of the fact that direct emission of heat into the atmosphere from the urban area is not the priority heat source, because temperature in the city at night is significantly higher, as it was mentioned in Ref. 2. At the same time, based on data from Fig. 2, one can notice that, as Akademgorodok is situated in the outskirts of the city of Tomsk, diurnal behavior of ΔT at east winds should be smoothed, and difference in temperatures at the station and out of the city should approach zero. However this does not happen. In our opinion, the observed diurnal behavior confirms the hypothesis on the significant contribution of the pollution cap to the formation of the heat island over the city.

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References

1. A.M. Vladimirov, Yu.N. Lyakhin, L.T. Matveev, and V.G. Orlov, *Protection of Environment* (Gidrometeoizdat, Leningrad, 1991), 424 pp.
2. Yu.L. Matveev and N.A. Merkur’eva, Atmos. Oceanic Opt. **10**, No. 10, 739–743 (1997).
3. L.T. Matveev, Meteorol. Gidrol., No. 5, 22–27 (1979).
4. V.V. Penenko and M.G. Korotkov, Atmos. Oceanic Opt. **11**, No. 6, 492–496 (1998).
5. B.D. Belan, Atmos. Oceanic Opt. **9**, No. 4, 293–295 (1996).