Separation of a contribution coming from city to variations of thermodynamic characteristics of the air in Tomsk as an example

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An attempt is undertaken to separate out the contribution of a city to variations of thermodynamic characteristics of the air, using two sites situated on the windward and leeward sides of the city of Tomsk. At the sites, two towers are installed, each carrying identical systems for measurements of the air humidity and temperature, wind speed and direction at four heights: 10, 20, 30, and 40 m. Both of the systems have been operated synchronously since July 2004. Tentative monitoring data, indicating the scale of Tomsk as a heat island, are presented.

The majority of the Earth's population now lives in cities, and the tendency to the growth of urban population becomes stronger and stronger. Therefore, the problem of air quality at such territories becomes increasingly urgent. The concentration of industrial plants, heavy traffic, and buildings with life support systems on a limited area inevitably modifies the environment. It was found that such a concentration leads to formation of a heat island in the city.[1] As known, an urban heat island, characterized by the increased surface temperature with respect to background rural data, is the most obvious result of urbanization. The main causes leading to the formation of an urban heat island is the additional heat release in a city, different humidity characteristics and surface roughness, and different albedo of the urban and rural areas.[2] Recently, different investigators have noticed the vertical structure of the urban development, which favors the heating of the surface atmosphere through the heat accumulation in city "canyons" and in buildings.[3]

In this connection, it is of particular interest the measurement of anthropogenic heat fluxes and their spatial distribution. Data averaged over different city districts are usually lower than 100 W/m^2 [Ref. 1]. However, under conditions of a megalopolis, the additional anthropogenic heating can increase significantly and play an important role in forming the temperature conditions of the urban environment, especially, at night and in winter.

The study of a heat island over Tomsk also revealed its significant effect on the urban atmosphere.[4] Further investigations have shown that this is characteristic of many Siberian cities.[5]

Since the data in Refs. 4 and 5 were obtained during short research missions it was worth organizing the monitoring of such processes. Thus, we have started this monitoring, using the following technique.

The Institute of Atmospheric Optics has two measurement sites. One of them – Basic Experimental Site (BES) – is situated in the Academic Campus (56°29′N, 85°04′E; 170 m above sea level). Another one, the background site is situated near the village of Kireevsk, about 60 km west of the city on the shore of the Ob River (56°25′N, 84°04′E; 80 m above sea level). These sites are mapped in Fig. 1.

It can be seen that, at the prevailing west-to-east transport, the air passes first through the background site, then through Tomsk, and only then it comes to BES.

Both of the sites employ identical automated systems for measurement of meteorological parameters in the surface atmosphere. The systems are Unzha-2 cable-stayed towers, equipped with air temperature and humidity sensors and M-127 electromechanical anemometers at four levels (Fig. 2) (the design feature of these measurement systems are described in Refs. 6–8). The M-127 serial anemometers are used as sensors of wind speed and direction. They are installed at the heights of 10, 20, 30, and 40 m above the ground on remote holders in the southern and northern directions. This arrangement allowed us to take into account perturbations of airflows by the tower frame. The electronic sensors of temperature and humidity are installed at the same heights. The appearance of one of the measurement systems is shown in Fig. 2.

Based on the many-year experience of operating the automatic measuring system of the TOR station,[9] we have developed and fabricated an electronic recording system on the basis of a PIC16F877 microcontroller for data collection and input into the computer (see Fig. 3).

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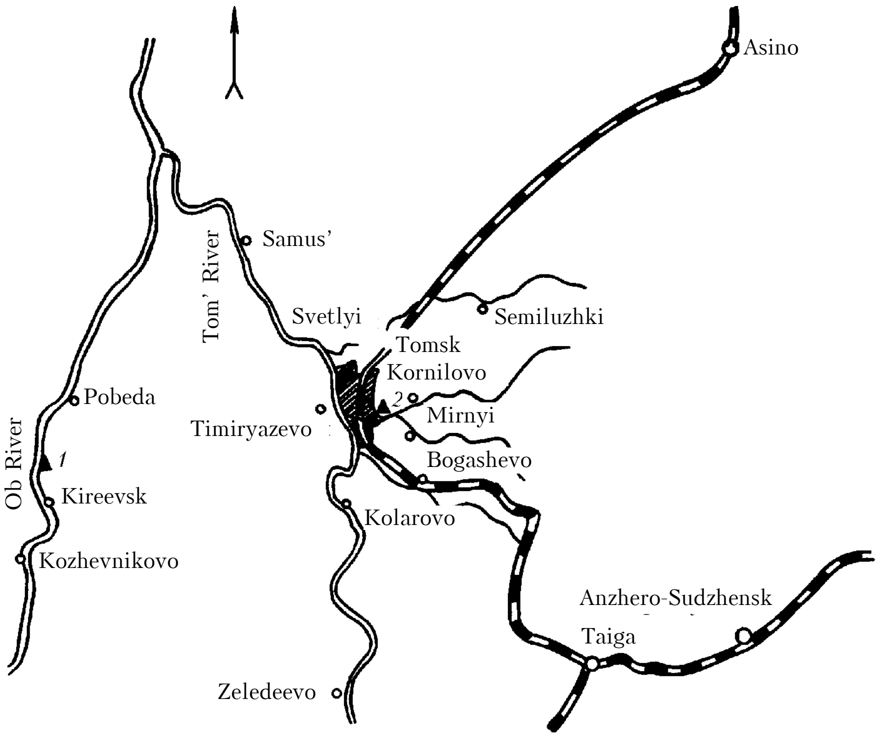

Fig. 1. Map of the IAO measurement sites: background site (*1*), BES (*2*).

Fig. 2. The appearance of measurement systems.

Due to the original technical design of the measurement system, we succeeded in avoiding intermediate analog-to-digital and digital-to-analog conversions of signals when determining the wind speed and direction. However, the main advantage of this system consists in the application of a single system for recording pulses from anemometer, which is certainly advantageous for drawing the real pattern of the wind field as a whole. The calculated errors of measurement of the airflow speed and direction, introduced by the electronics (besides the errors of the anemometers themselves), do not exceed 5% at the wind speed of 50 m/s and amount to only 0.1% at 1 m/s [Ref. 10].

The analog outputs of the temperature and humidity sensors were connected to the system by use of a 1-bit ADC built in the microcontroller. A controller was also used for thermal stabilization of the case housing the instrumental block. Changing the main parameters of measurements and information processing, it was possible to obtain the instantaneous profiles of meteorological parameters of the surface atmosphere, as well as to calculate the fluxes of heat, humidity, and momentum in the monitoring mode.

The scheme of control over measurements and processing of the obtained information is shown in Fig. 3.

The data obtained are transmitted through the radio channel into the computers at each of the sites. After the primary processing and creation of files for each measurement, the data are transmitted to the data collection center at the Institute of Atmospheric Optics (by the fiber optics channel from BES and by the radio telephone channel from the background site).

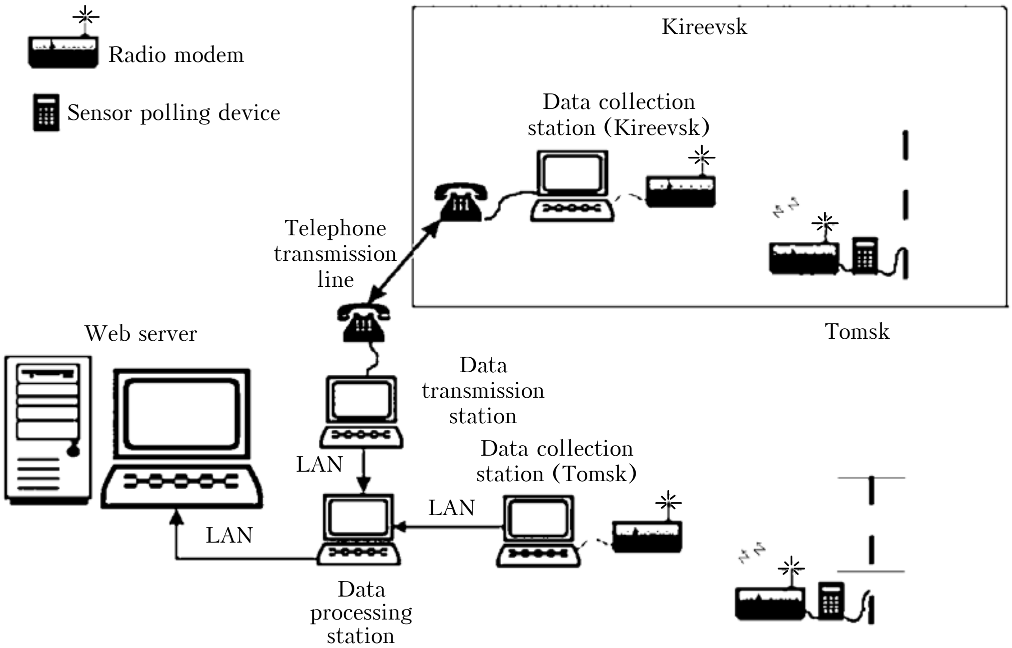

Fig. 3. Schematic of control over measurements and processing of information obtained by spatially distributed measurement systems.

The measurement systems were put into operation in July 2003 at BES and in July 2004 at the background site. Below we present the first results of monitoring organized in this way.

The diurnal behaviors of the averaged differences of temperature ($T_u - T_r$) and relative humidity ($U_u - U_r$) at different levels in the surface atmosphere are shown in Fig. 4.

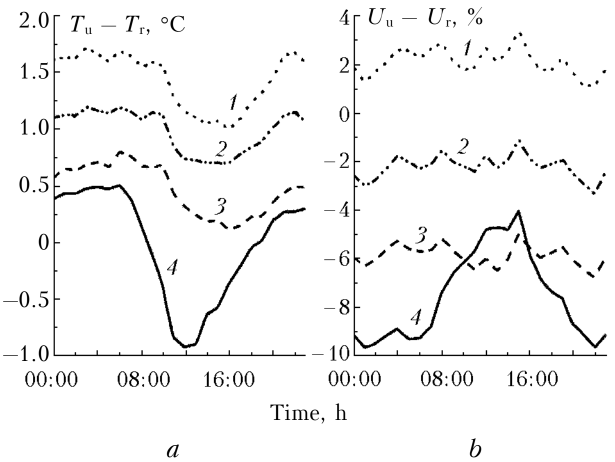

Fig. 4. Diurnal behaviors of the averaged differences of temperature and relative humidity between the urban (u) and rural (r) sites at different measurement levels: $\Delta T1$ (*1*), $\Delta T2$ (*2*), $\Delta T3$ (*3*), and $\Delta T4$ (*4*) (*a*); $\Delta U1$ (*1*), $\Delta U2$ (*2*), $\Delta U3$ (*3*), and $\Delta U4$ (*4*) (*b*).

It can be seen that the average temperatures in the close vicinity of Tomsk for the considered period generally exceeded those observed at the background (rural) site, while the comparison of the daytime and nighttime values shows that the latter are at least 0.5°C higher. It can also be seen that the temperature differences between the urban and rural sites decrease with height. If at the height of 10 m the difference varies for 24 hours from 1.7 to 1.2°C, then at the 40-m level above the ground it varies from 0.5 to –0.8°C. Possibly, the level of influence of the urban heat island on the vertical stratification of the atmosphere in the period of measurements was just near this height (40 m). However, this assumption calls for more detailed observations. This hypothesis is supported only by the dynamics of the internal mixing layer.[11]

The relative humidity is higher in the suburbs at the lower level and behaves almost neutrally for 24 hours (Fig. 4). At the upper levels (at 20, 30, and 40 m), it becomes higher at the background site, which can be explained by the lower temperature of air at this site with the constant absolute water vapor content.[5]

The parameterization of the data obtained in terms of temperature intervals has revealed the varying configuration of the urban heat island (Fig. 5). At positive or slightly negative temperatures, its influence on Tomsk outskirts is determined by the air mass incoming direction. For the Academic Campus, this influence almost vanishes at the south-eastern direction of air mass motion. However, for temperatures below –10°C, the influence of anthropogenic heating increases significantly at any measurement level regardless of the wind direction, while for temperatures below –20°C the difference already exceeds 2°C. Thus, we have observed the formation of a “heat cap” over the city, which covered vast suburban regions.

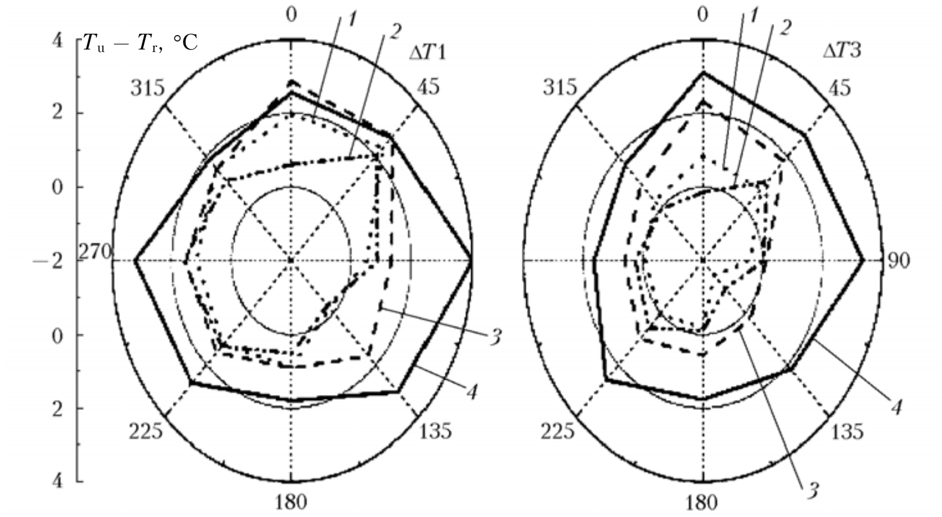

Fig. 5. Distribution of temperature differences between the urban (u) and rural (r) areas at the 1st and 3rd measurement levels for different directions of air mass inflow: $T_u - T_r > 0$°C (*1*), 0–10°C (*2*), 10–20°C (*3*), $T_u - T_r < -20$°C (*4*).

These data are in a good agreement with the results on the anthropogenic heating of the urban environment with respect to the rural one, obtained by different authors. Note that under conditions of a city center the temperature and humidity differences are even larger with respect to not only rural, but also to suburban values. The investigations with the IAO mobile station in the city of Krasnoyarsk in winter have shown that the temperatures at the central part of the city exceeded those in remote urban districts by up to 7°C [Ref. 5].

Figure 6 shows the distribution of the mean wind speed at the upper levels of the towers in Tomsk and Kireevsk. These levels are chosen because the neighboring forest is higher than 20–25 m and, consequently, it influences the results measured at the three lower levels.

It can be seen from Fig. 6 that the wind velocity is much higher over the urban territory than over the rural one, and the difference increases in nighttime. It is possible that the diurnal behavior of the wind velocity is affected by the breeze from Ob River, when it is not covered by ice. In daytime the direction of this breeze coincides with that of the main transport, while at night it is opposite. But, even the breeze cannot explain such a large difference. To check whether it is a measurement error or not, the data of both sensors of the wind velocity V_S (K) and V_N (K) at the height of 40 m for the background site are shown in Fig. 6. It can be seen that the readouts of these sensors agree accurate to the measurement errors.

Thus, already the first obtained data are indicative of the marked contribution of the city to the variations of thermodynamic characteristics of the air.

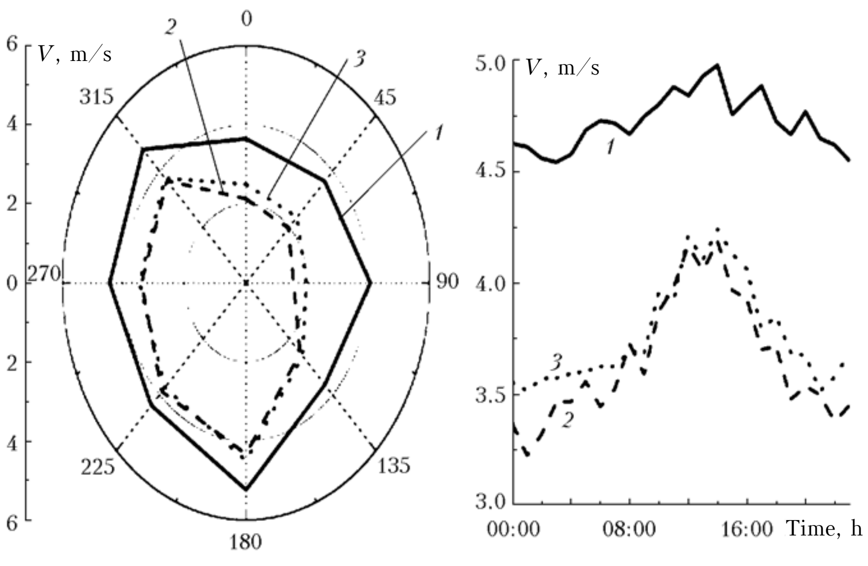

Fig. 6. Direction and time distributions of the mean wind velocity at upper measurement levels in the city of Tomsk (T) and the village of Kireevsk (K): V_S4 (T) (*1*); V_S4 (K) (*2*); V_N4 (K) (*3*).

In the future, it is planned to additionally equip both measuring systems with devices for measurement of the gas and aerosol composition of air, which will allow us to perform the combined assessment of the city influence on the air quality.

Acknowledgments

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