Mobile system for atmospheric temperature profile monitoring: mobile MTP-5

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***Abstract**: Mobile system MMT -5 for investigating a spatial variability of atmospheric boundary layer temperature stratification and distribution of contaminants concentration on the territory of a big city and its suburb has been developed. The results of the measurements carried out by this system in the territory of Nijny Novgorod and its suburb during August–October 2004 are presented in this paper. The temperature profile measurements made by stationary profiler MTP-5 are used in the analysis also as a reference point. The results showed that within the city were observed 3-5 zones with different temperature stratification. The vertical and horizontal sizes of these zones depended on orography and weather conditions.*

1. Introduction

The numbers of researches dedicated to the urban heat island study were considerably increased in recent years. These investigations show anthropogenic interactions in the form of the powerful sources of pollution and water vapor and supplemental heat sources can exert a substantial influence on the intensity and form of the environment response in the large industrial cities and megalopolises. These factors lead to special climate formation in a megalopolis *(Oke 1973; Oke 1977)*. The sufficient number of the research contains information about the quantitative parameters of this phenomenon. These studies are based most frequently on near the ground surface measurements of temperature and humidity *(Duckworth and Sandberg 1954).*

Studies of ground temperature heterogeneity show that the heat island inside of the city can have heterogeneous structure so-called "multicupolas" *(Golitsyn at al 2002, Khaikine at al, 2003).* But this assumes, in turn, the three-dimensional heterogeneity of temperature profile. Thus, in the city can be observed different conditions for forming and destroying the inversions and, therefore, can be formed different prerequisites for pollution concentration increase in the atmospheric boundary layer (ABL). It is known that the successful solution of the problem of air pollution forecast is based as on the physical features of the propagation of admixtures in atmosphere and meteorological factors. Temperature atmospheric stratification is one of the most important meteorological parameters for air pollution level forecasting. For measuring the profiles of the temperature of ABL traditionally the contact temperature sensors were used, raised on the radiosondes and tethering balloons, and installed on the meteorological masts *(Garratt, 1992).* More lately appeared the remote methods, namely: lidars and radioacoustic (*Westwater, e.a., 1999*). All these methods, as a rule, are used in the stationary version.

The method of ABL temperature profiles remote measuring was developed in the Central Aerological Observatory (Roshydromet) about 15 years ago. It was created remote meteorological temperature profiler MTP–5 *(Ivanov, Kadygrov, 1994)*. The comparative tests of MTP-5 with the traditional methods of atmospheric temperature measuring showed that MTP-5 is fully acceptable for routine measurements on any National observational network *(Kadygrov and Pick 1998; Westwater et al 1999; Viazankin at al 2001, Cadeddu at al 2002)*.

Since 2000 MTP-5 is used on the network of Roshydromet. MTP-5 has a comparatively low weight (10 kg), small overall dimensions and small required power (60 W). These parameters made it possible to develop the mobile system MMTP-5 on the base of MTP-5. The investigations of space heterogeneity of atmospheric temperature stratification were carried out by this mobile system in large city Nijny Novgorod and in its suburb in August-October 2004. The measurements of temperature profiles were conducted simultaneously by MMTP-5 and by stationary MTP-5 installed on the roof of hotel “Oka” at the altitude 235 m. The special equipment installed on the mobile system MMTP-5 allowed measuring air pollution concentration. The results of temperature profile measurements and air pollution concentration in 12 points of Nijny Novgorod and its suburb (5 points) are discussed in this article.

2. The technique and equipment used in the measurements.

Two temperature profilers MTP–5 were used for investigation of ABL temperature profiles space variability in Nijniy Novgorod and its suburb. The first MTP-5 was installed on the roof of the hotel of "Oka" and the second was a mobile system MMTP-5. Common view of these devices is shown in Figure 1.

Mobile system MMTP-5

Stationary MTP-5

Fig. 1. Common view of temperature profilers.

The following equipment was installed in the mobile system MMTP-5:

- Profiler MTP-5.
- GPS system.
- Equipment for measuring the concentration of following contaminants: carbon monoxide, nitrogen dioxide, phenol, benzene, toluene, xylene, ethylbenzene, cyclohexanone, cyclohexanol**.**

Nijny Novgorod is placed on the confluence of two largest rivers of the Eastern European plain: Oka River and Volga River. Nijny Novgorod is the large industrial center occupying the area of approximately 350 km^2. The city is divided on two parts depending on the relief, namely: beyond the river part and upland part.

The upland part of the city is the watershed plateau, rugged by numerous ravines of different depth and valleys of small rivers. The altitude of plateau varies from 100 to 200 m.

Another part of the city (beyond the river) is placed between the right bank of Volga River and the left bank of Oka River. It has the altitude 70-80 m. Oka River is the boundary between the elevated and lowland city. The slopes of right bank of Oka River they are rugged by a number of large ravines. Of about ten small creeks and channels are located in the beyond the river part of the city. Swamps occupy in entire 25% of this part of the city territory.

Two meteorological stations regularly carrying out measurements of meteorological parameters are located on the territory of Nijny Novgorod. The first meteostation (M1) is located in the upland part of the city at a distance of approximately 3 km north-north-east apart from the stationary MTP-5. The second meteostation (M2) is placed in the beyond the river part of the city at a distance of approximately 2 km westward from point No 15(see fig. 2).

The places of measurements (points) were determined before beginning the measurements on the territory of Nijniy Novgorod and its suburb. The points were determined in such a way that the measurements would be carried out in the regions having characteristic landscape, orography or placed near the pollution sources. 17 points (12 in the territory of city and 5 in the suburb) were choosen taking into account these requirements. The measuring point locations in the territory of Nijny Novgorod are shown in the Figure 2a, while the measurement point locations in the suburb are shown in the Figure 2b. The point N0 is the stationary profiler MTP-5.

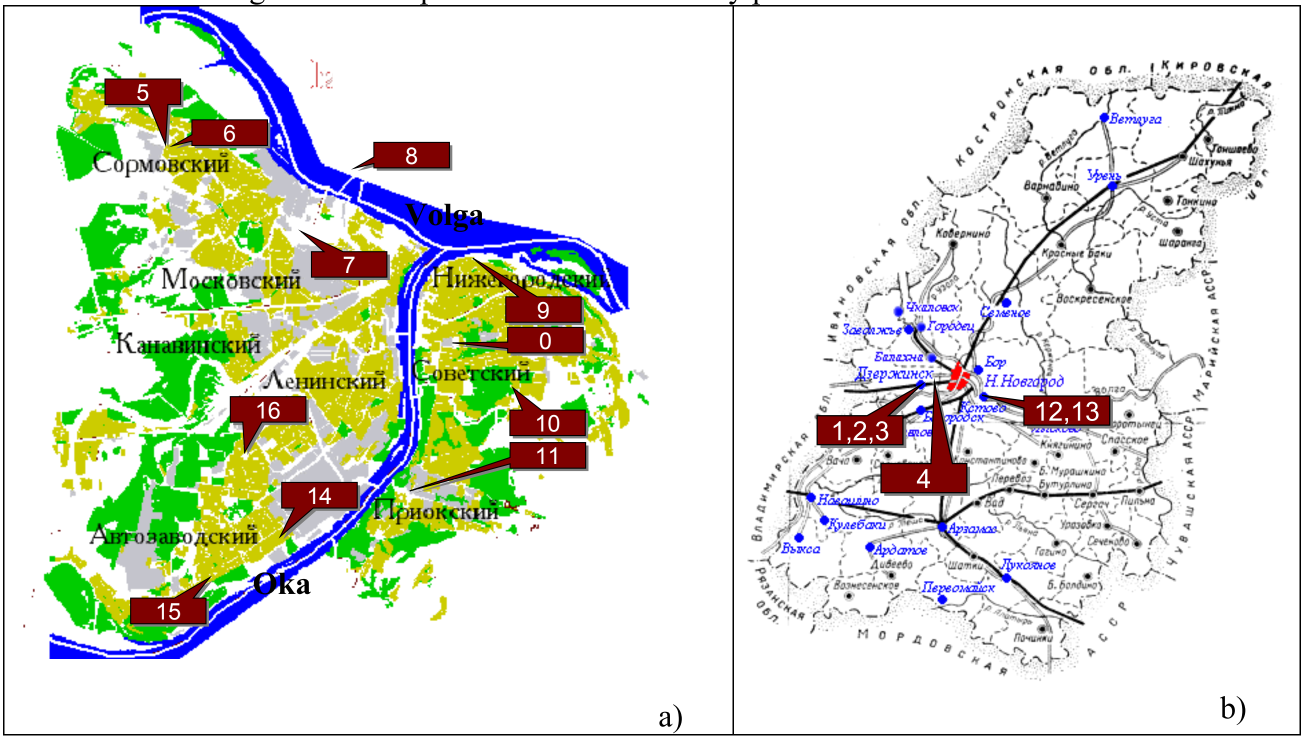

Fig. 2. Measuring point locations. a)- in Nijny Novgorod; b)- in subuarb

The altitudes of metostations M1, M2, measuring points and its distance to the stationary MTP-5 are shown in Table 1

Table 1

The measuring point's number	Altitude [m]	Distance from stationary MTP-5 [km]
0	235	0
1	98	48.1
2	102	56.2
3	105	49.3
4	89	26.2
5	92	14.2
6	92	14.2
7	80	8.0
8	75	8.6
9	155	4.5
10	160	3.5
11	184	5.5
12	80	21.7
13	130	21.2
14	86	9.5
15	85	11.7
16	86	8.7
Metostation M1	157	3.0
Metostation M2	77	13.1

The measurements were carried out on August 6, 7, September 1, and October 16, 17, 18 under weather conditions, favorable for formation and development of temperature inversions, i.e., under the stationary weather conditions at night and in the morning.

3. Results of the measurements

The changes of ground temperature measured by meteorological stations in standard terms and by MMTП-5 are shown in the Figure 3. It can bee seen that at August, 6-7 and October, 16-17 the heat island is shown brightly. Spatial heterogeneity of ground temperature is well visible. Temperature difference exceeds 2 degrees in points N1 and N3 located in center of Dzerzhinsk city and in its suburb correspondingly. The difference city-suburb exceeded 6 degrees at the distance from the city about 25 km (point N4). In same time the temperature measured by meteorological stations changed less than 1^{O}C. The significant changes of ground temperature (more than 3 degrees) are also observed during the motion through Nijny Novgorod.

For instance, at August 7 the temperature difference in points N 7 and N 9 was greater than 2.5 degree and temperature difference between points N9 and N10 was greater than 3 degree.

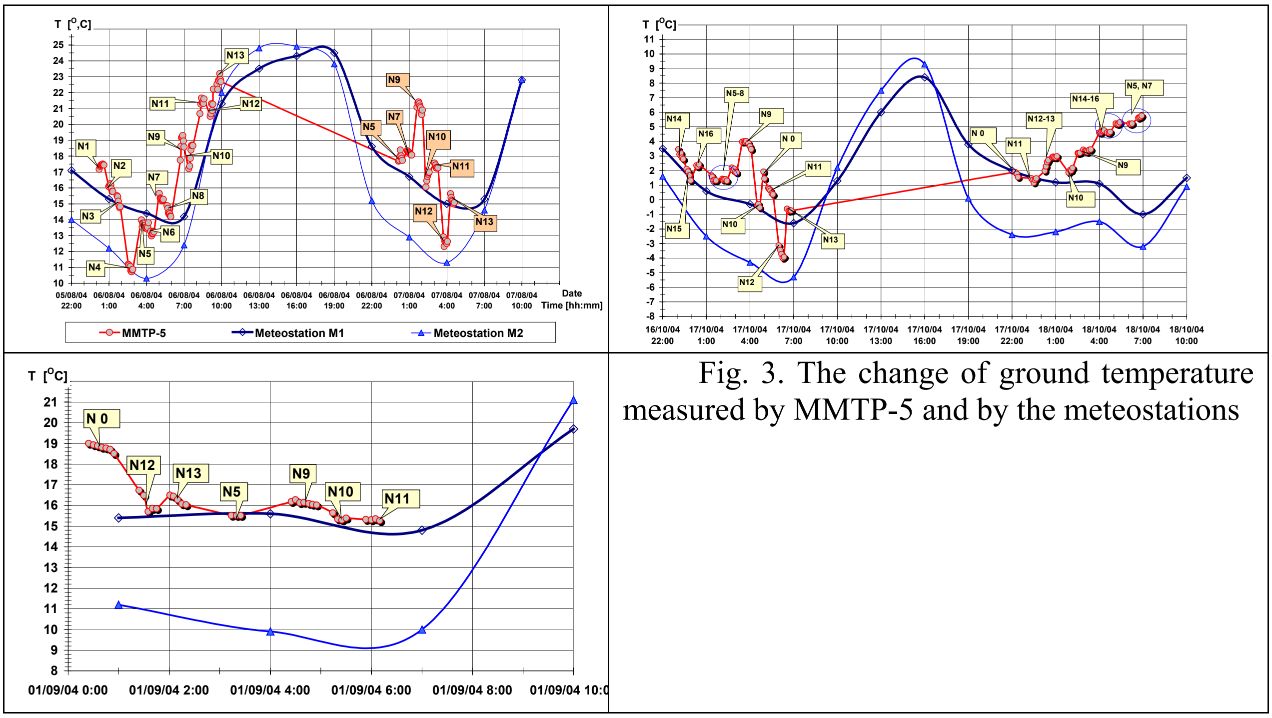

Fig. 3. The change of ground temperature measured by MMTP-5 and by the meteostations

On September 1 the ground temperature difference between the upland and beyond the river parts of the city exceeded 5 degrees as indicated by the meteostations at night and in the morning. In the same time on data MMTP-5 the ground temperature differences between the beyond the river part of the city (point 5), the suburb (point N12 and N13) and upland part (points 9-11) did not exceed 2 degrees. Approximately the same picture was observed on October 18. It is necessary to pay attention on an increase of ground temperature measured by MMTP-5 in contrast to ground temperature change on meteostations data after 3 hours in points 14-16 and points 5 and 7.

The spatial structure of temperature stratification on the city territory and its suburb was also heterogeneous. Figure 4 shows the thermograms and color field of temperatures obtained by mobile (MMTP-5) and stationary (MTP-5) profilers. It can be seen the color field obtained by stationary MTP-5 has relatively homogenous structure. Consequently the change of temperature profiles during the night and morning occurs gradually. And the color field of temperature measured by MMTP-5 differs sharply from that, obtained by stationary profiler.

As an example figure 5 shows the temperature profiles measured by mobile (in points N7 and N8) and stationary (N0) profilers. The time of the profiles obtaining in points N7 and N8 differed at less than 15 minutes. It can be seen in the figure the temperature differences for the points placed at the same height above sea level and spacing at the distance not more than 4 km exceed 1 degree at the heights more than 200 m.

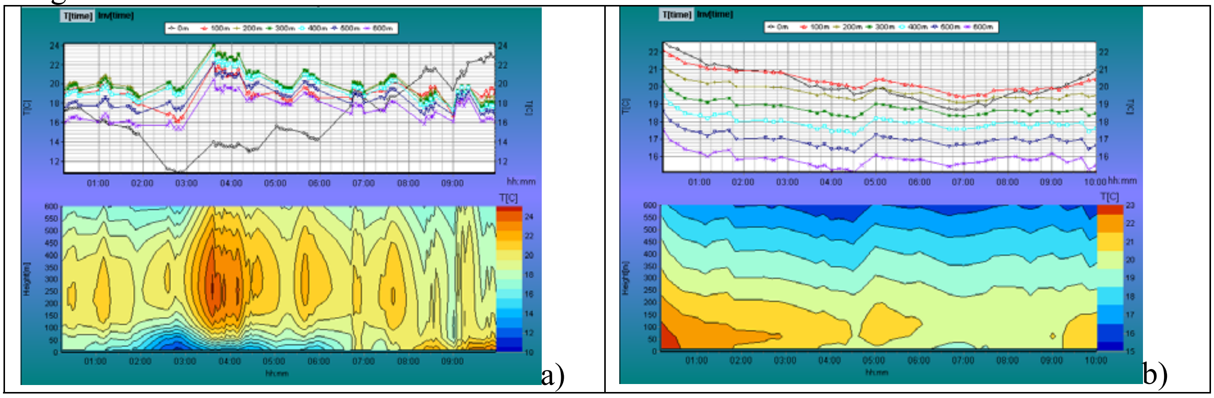

Fig. 4. Thermograms and color field of temperature, obtained by MMTP-5 (a) and MTP-5 (b). August 6, 2004 .

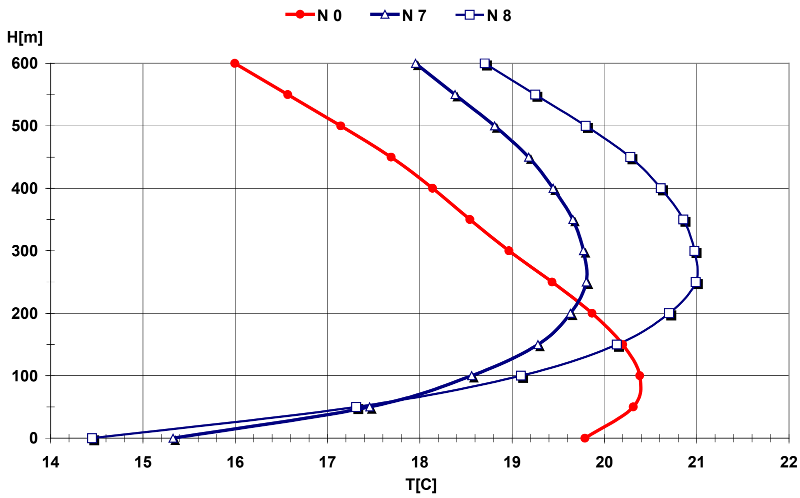

Fig. 5. Temperature profiles, obtained by MTP-5 (point N0) and MMTP-5 (points N7 and N8). August 6, 2004.

The coefficients of correlation (K_{correl}) were calculated for estimating the relations of profiles measured synchronously by mobile and stationary profilers. This parameter makes it possible to evaluate the possibility of using data obtained by stationary MTP-5 to the territory of city and its suburb. Figure 6 shows the summary dependence of K_{correl} on the distance from stationary MTP-5 for all observation days.

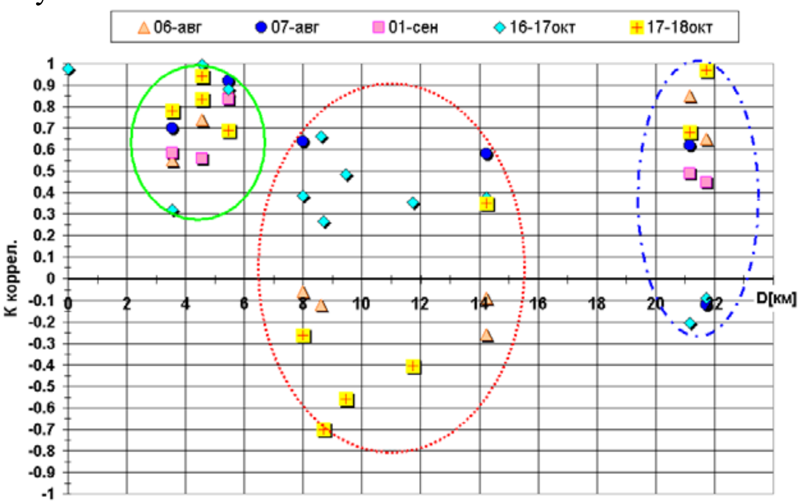

Fig. 6. Dependence of correlation coefficient from distance between stationary and mobile profilers.

On our opinion, it is possible to resolve three zones (they are shown by ovals in the figure), for which it is possible to observe a certain regularity. The steadiest correlation is observed in the first zone (D<6 km). In the second zone (7km<D<16km) K_{correl} can vary from –0.7 to +0.7 with the approximately the same probability. In the third zone (region of town Kstovo) K_{correl} was above 0,4 approximately in 70% cases. In this zone, very week relations of the profiles (K_{correl}<0) were observed also.

The calculation of K_{correl} makes it possible to estimate the zone of the representative of the data obtained by the stationary profiler MTP-5. But, as it has been mentioned above, Nijny Novgorod has clearly expressed heterogeneity of the orography and underlying surface. These factors had to have an effect on the Urban Heat Island (UHI) formation and on its spatial structure. From the data obtained, it was possible to observe the "multicupolas" of UHI under specific conditions in the city. For the evaluation this effect we calculated the synchronous temperature differences obtained at different points at the same heights relative to sea level. I.e., it was calculated temperature difference between stationary MTP-5 and mobile system at any definite point. In figures 7 and 8 are shown the color fields of temperature difference obtained at August 6 and 7, 2004 accordingly.

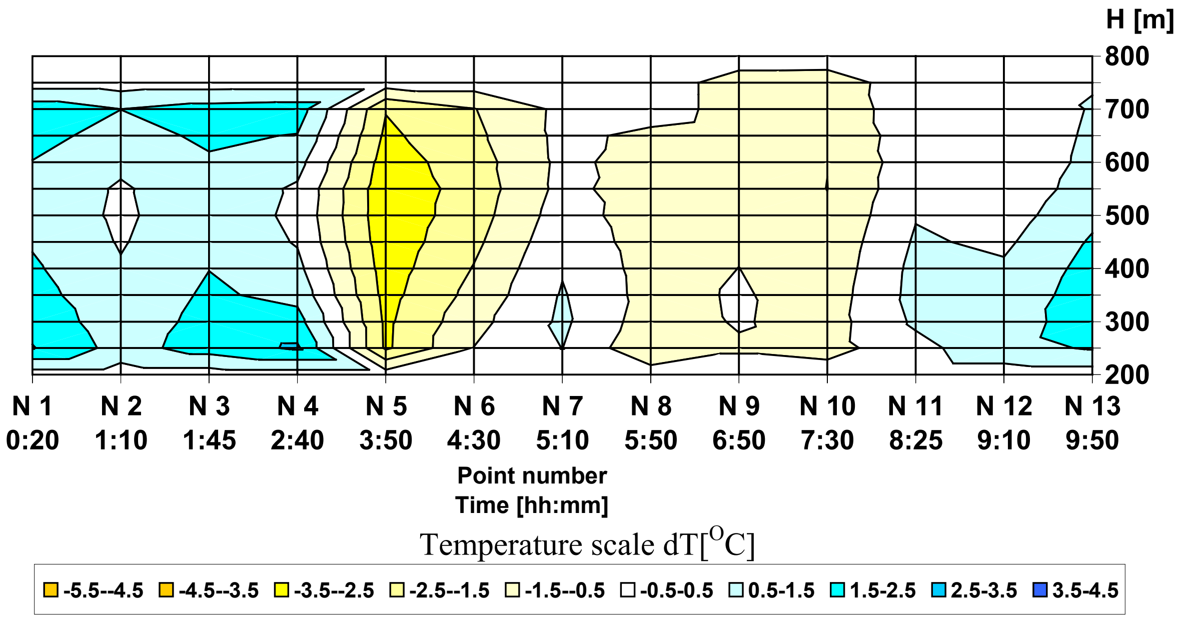

Fig. 7. Color field of temperature difference measured by MTP-5 and MMTP-5. August 6, 2004.

The measuring point's numbers and the time of the measurement are indicated on the X-axis of the figures. The altitude in meters is shown on the Y-axis. The correspondence of the temperatures difference to a color is given in the bottom of the figures. The warm color scale (nuances of yellow and brown) corresponds to the situation when the temperature in the point is greater than that measured by MTP-5. The reverse situation (temperature in the point is colder) corresponds to cold colors scale (nuances of blue and dark-blue).

Weather conditions in Nijny Novgorod were formed under the influence of an anticyclone as showed by synoptic-meteorological analysis on August 6 and 7. According to the data of radiosonde (00 UTS) at night on August 6 the week wind (< 2 m/s) was observed in entire lower 800 m layer. The wind was less than 1 m/s in the lower 500 m layer. At night on August 7 weather conditions in the lower 500 m layer were close to those observing on August 6. But in the layer 600-800 m according to radiosounding data was observed the jet stream with wind speed greater than 6 m/s. In figures 6 and 7 can be see "multicupolas", i.e. the several local zones with identical temperature difference. These zones have the form of the columns with the altitude 500-750 m and the size 3-6 km. The bars of equal temperature were observed at the altitude higher than 500 m on August 7. The jet stream observed in the layer 600-880 m could lead to such effect.

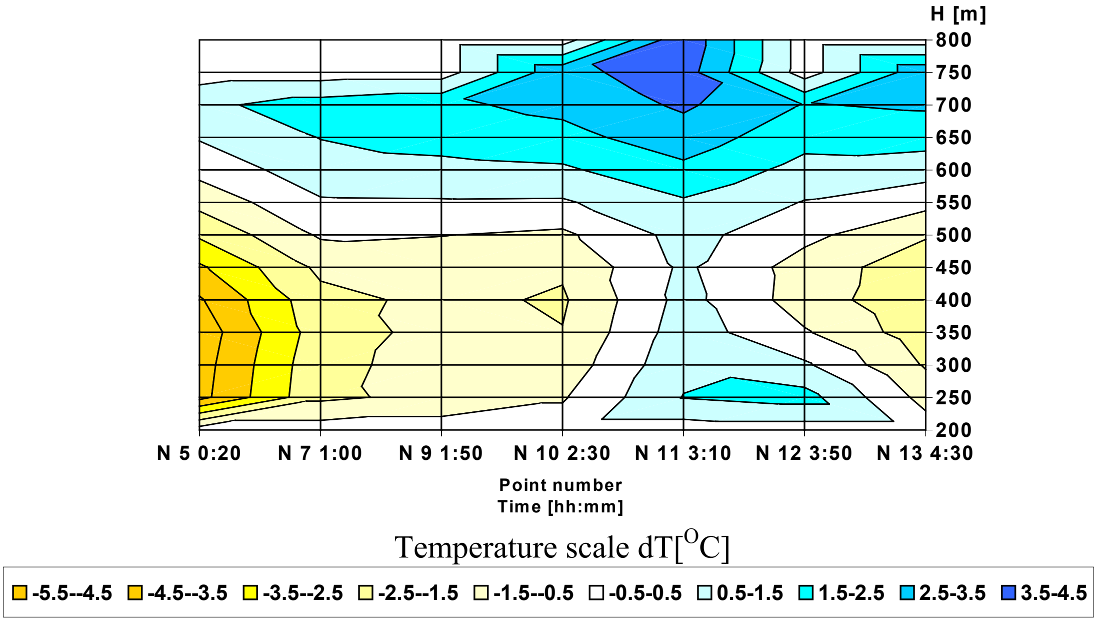

Fig. 8. Color field of temperature difference measured by MTP-5 and MMTP-5. August 7, 2004.

Weather condition on September 1 (Fig. 9) was formed under the crest of anticyclone. Wind speed from 0.5 to 2.3 m/s was observed northeastern in entire 800 m layer at night. In all observed points the temperature was colder than in the locality of the hotel "Oka". Coldest locality was near the point N 10.

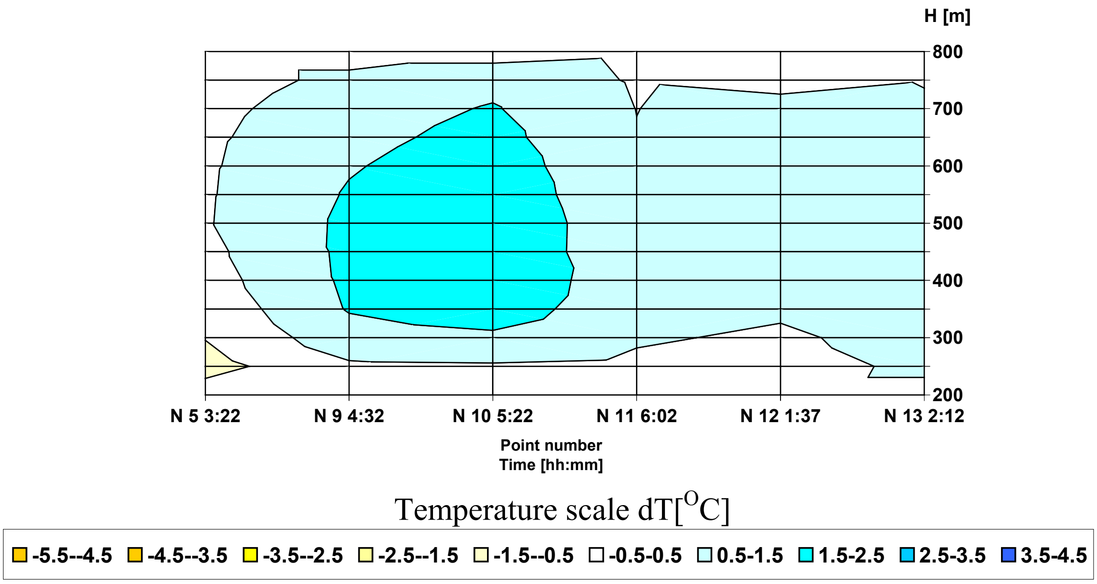

Fig. 9. Color field of temperature difference measured MTP-5 and MMTP-5. September 1, 2004.

A calm was observed near the earth surface during the night October 16-17. Weather conditions were close to those observing on August 6 and the color fields of temperature difference obtained for these days were also similar (Figure 10).

Coming cyclone caused air masses change observed at night October 17-18. A cold front passed the city in the afternoon on October 18. The significant intensification of wind with the height was observed on radiosonde data (00 UTS). Wind speed changed from 3.0 to 11.5 m/s in the height range 150 to 322 m. As it can be seen in Figure 11, these processes changed strongly the structure of color field. The warm zones were observed only up to the height 400-450 m and the cold zones were observed above.

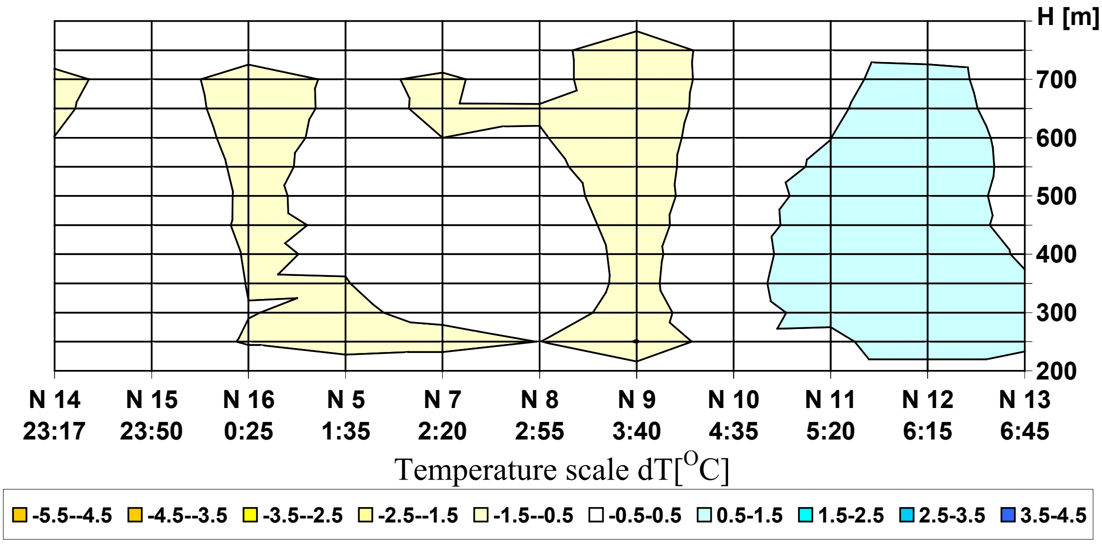

Fig. 10. Color field of temperature difference measured MTP-5 and MMTP-5. October 16-17, 2004.

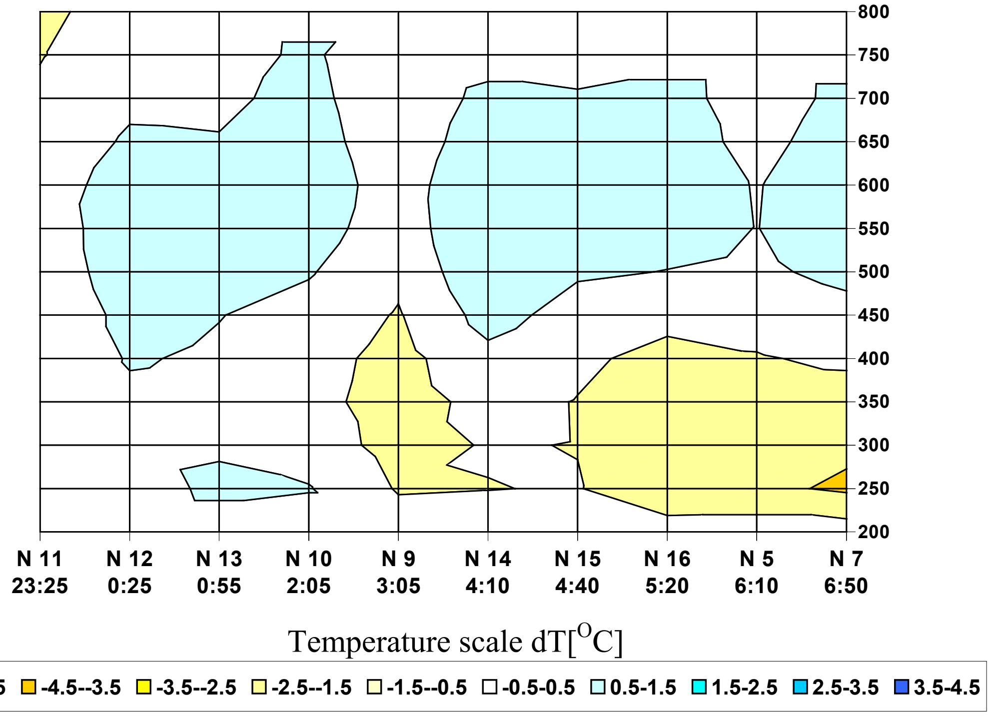

Fig. 11. Color field of temperature difference measured MTP-5 and MMTP-5. October 16-17, 2004.

As it has been marked above, the measurements of the temperature profiles at different points were accompanied by measuring of following contaminants concentration, namely: carbon monoxide, nitrogen dioxide, phenol, benzene, toluene, xylene, ethylbenzene, cyclohexanone, cyclohexanol. These measurements supplemented the standard measurements of contaminants concentration conducted by air pollution monitoring stations of Upper Volga Regional Department of Hydro Meteo Service Russia in Nijny Novgogrod. The average and maximum levels of excess of the maximal-one time limited ultimate concentration (LUC) obtained during these measurements are given in Table 1.

Table 1.

	Carbon monoxide	Nitrogen dioxide	Phenol	Benzene	Toluene	Xylene	Ethyl benzene	Cyclo-hexanone	Cyclo-hexanol
Mean	0.17	0.48	0.48	0.46	0.19	0.57	0.50	0.17	0.15
Maximum	0.52	**3.18**	**2.00**	**2.13**	0.40	**1.00**	**2.58**	0.50	0.67

The analysis of obtained data showed that although weather conditions during conducting of the measurements favored the accumulation of contaminators in the atmosphere, it was not observed systematic exceeding LUC in the entire territory of city. It was not revealed regions with the regular excess of LUC levels. At the same time the excesses of LUC level by some contaminators (with exception of nitrogen dioxide) obtained during these measurements were not measured by the air pollution monitoring stations. This result is additional confirmation of high time-spatial variability of contaminants distribution on the city area.

4. Conclusion

The measurements of temperature stratification in the Nizhny-Novgorod industrial agglomeration carried out by means of mobile and stationary temperature profilers MTP-5 showed that

- In the inspected territory it was observed 3-5 sufficiently well resolved and steady zones distinguishing by the thermal structure of ABL. These zones are coupled with the orographical features of the city. The sizes and internal structure of these zones depended on the synoptic situation.
- The zone of representative using of stationary MTP-5 data for the forecast of bad weather conditions (BWC) was determined on the basis of data obtained during these measurements. As consequent from the analysis, the data of stationary MTP-5 can be used regularly in the forecast of BWC within the radius 6-8 km. The extending of forecast to entire territory on the city and its suburb is possibly only under the specified synoptic conditions.

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