Microwave Remote Sensing Investigation of the Atmospheric Boundary Layer Thermal Regime Above an Urban Area

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Introduction

During 2000-2002, three microwave temperature profilers (MTP-5) were used simultaneously in the Moscow region for continuous measurements of the atmospheric boundary layer (ABL) temperature profile. One MTP-5 was installed in the center of Moscow city, the second in the north part of Moscow (Dolgoprudny), and the third about 50 km westward from the Moscow city center (Zvenigorod experimental site). The MTP-5 instrument is an angular-scanning single-channel microwave radiometer that can provide temperature profile measurements every 10 minutes within the altitude range 0 - 600 m with an accuracy 0,5°C (Kadygrov and Pick 1998; Kadygrov et al. 1998; Westwater et al. 1999).

The simultaneous measurements had three main scientific objectives. The first was to determine a Megacity impact to the ABL parameters, which led to creation of a so-called "heat island" (Kondratiev and Matveev 1999; Golitsin et al. 2002). The second objective was to investigate the ABL stability and its influence on a radiation balance near the ground surface. For that reason, the collection of continuous data about ABL temperature profiles in different synoptical situations was provided. The third objective was to compare the simultaneous ABL temperature profiles in Zvenigorod and Dolgoprudny where radiosonde data was obtained. Note that all preceding climatological dataset about temperature inversion in the entire Moscow region was based on radiosonde data obtained in Dolgoprudny. For this reason, the comparison of ABL temperature profiles from two sites separated by only tenths of kilometers seems to be very interesting.

Analysis of Simultaneous Remote Sensing Data

The data collected using simultaneous remote sensing of ABL temperature profiles have shown essential differences in thermal regime between the center of a big city and the suburb. In general, the annual average ABL condition in the central part of Moscow is close to unstable (adverse conditions), and deterioration of the vertical exchange conditions has a brief disposition. The monthly averaged temperature gradients in Moscow city center are presented in Tables 1 and 2 as a function of local time (on the base of MTP-5 data).

The data show that the atmosphere has unstable temperature stratification during the night and in the early morning, both in the layer 0-100 m (Table 1) and in the layer 0-300 m (Table 2). Thermal turbulence is at minimum between 3 and 6 o'clock on the morning. Based on the MTP-5 data, it was experimentally confirmed that the influence of a big city microclimate is comparable to the influence of large-scale meteorological processes during a number of synoptic situations. Within such events, the heating from anthropogenic sources dominates radiation cooling of the lowest atmospheric layer.

Simultaneous remote sensing observations at the three points gave detailed quantitative parameters of temperature inversion, ABL stability, and the differences in stability between the center of the urban area and the more outlying locations. Based on the MTP-5 data, the recurrence of temperature inversion for the central part of Moscow was calculated (Table 3).

Table 1. Monthly averaged temperature gradients (°C/100 m) in the layer 0-100 m in the center of Moscow city.

Time (h)	October	April	January	July 2000	July 2001
0	-0.54	-0.55	-0.75	-0.57	-0.67
3	-0.41	-0.31	-0.77	-0.49	-0.29
6	-0.34	-0.22	-0.78	-0.44	-0.12
9	-0.43	-0.75	-0.81	-0.88	-1.24
12	-0.99	-1.44	-0.97	-1.09	-1.67
15	-1.10	-1.71	-1.04	-1.37	-1.90
18	-0.87	-1.50	-0.92	-1.29	-1.55
21	-0.59	-0.87	-0v95	-1.02	-1.24

Table 2. Monthly averaged temperature gradients (°C/100 m) in the layer 0-300 m in the center of Moscow city.

Time (h)	October	April	January	July 2000	July 2001
0	-0.48	-0.53	-0.51	-0.54	-0.70
3	-0.35	-0.30	-0.54	-0.42	-0.35
6	-0.25	-0.15	-0.56	-0.30	-0.13
9	-0.27	-0.47	-0.58	-0.68	-0.97
12	-0.76	-1.16	-0.70	-0.91	-1.38
15	-0.93	-1.37	-0.80	-1.12	-1.52
18	-0.80	-1.24	-0.71	-1.04	-1.22
21	-0.60	-0.86	-0.73	-0.89	-1.07

Table 3. Recurrence of temperature inversion (%) in Moscow city center.

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Climate (radiosonde)	49	43	36	35	36	34	35	38	38	33	41	42
MTP-5 **2000-2001**	32	18	35	57	32	23	10 (2000г) 35 (2001г)	29	27	35	20	3

Remote sensing data differs noticeably from radiosonde data, particularly during wintertime–from November up to February. The recurrence of inversion for that time was less than 17-39% with respect to climatological data. In contrast, the April recurrence was 20% more than that calculated from climatological data.

As mentioned above, climatological data for Moscow city center were calculated on the basis of radiosonde data from the Dolgoprudny aerological station. Therefore, the first reason for inversion recurrence differences may be the urban heat island influence (big difference between surface-atmosphere exchange in the center and in the north part of Moscow). The second reason is that those radiosondes are normally released at 02:30 am local time. However, most of the temperature inversions in April began after that time and so were not detected by the radiosonde data.

During simultaneous remote sensing measurements, differences were indicated in thermal regime of ABL in Dolgoprudny and in Zvenigorod station. Figure 1 presents temperature fields in Moscow city center, in Dolgoprudny, and in Zvenigorod for an anticyclone environment (July 23, 2001). Figure 2 presents the parameters of temperature inversions for the same places and within the same time. The temperature inversions were indicated at all three observation points during the night. The deepest was about 6°C in Zvenigorod, 3.5°C in Dolgoprudny, and 1.0 - 1.5°C–in Moscow; the respective inversion heights were 470 m, 370 m, and 300 m. Dissipation of inversion begins first in Moscow, then occurs in Dolgoprudny, and then in Zvenigorod.

The quantitative parameters of the Moscow heat island are unknown in city climate understanding. Heat island parameters and its seasonal and daily variations were ascertained during anticyclone conditions. The data indicated two main types of heat islands. The specific parameters of the first type were as follows:

- The heat dome top has an altitude up to 600 m.

- The ABL temperature in the city is higher than in the suburb. This type of heat island was indicated mostly in the cold season or in all seasons with high cloud density or in warm seasons during cloudless nights.

The specific parameters of the second type of heat island were as follows:

- The heat dome top has an altitude up to 300 m.

- Above this altitude, the temperature in the suburb is higher than in the city center.

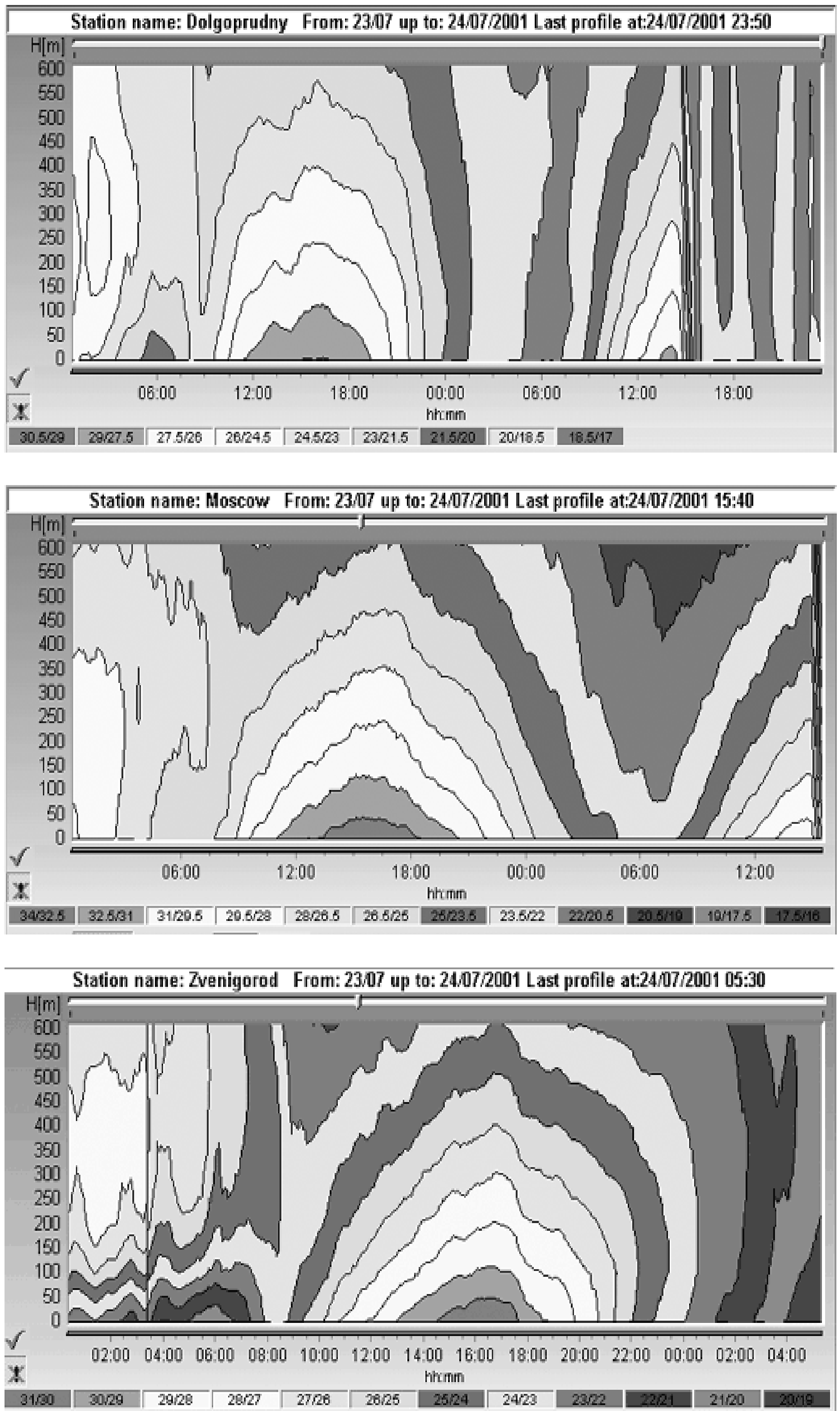

Figure 1. Temperature field in Dolgoprudny, Moscow, and Zvenigorod (July 23, 2001).

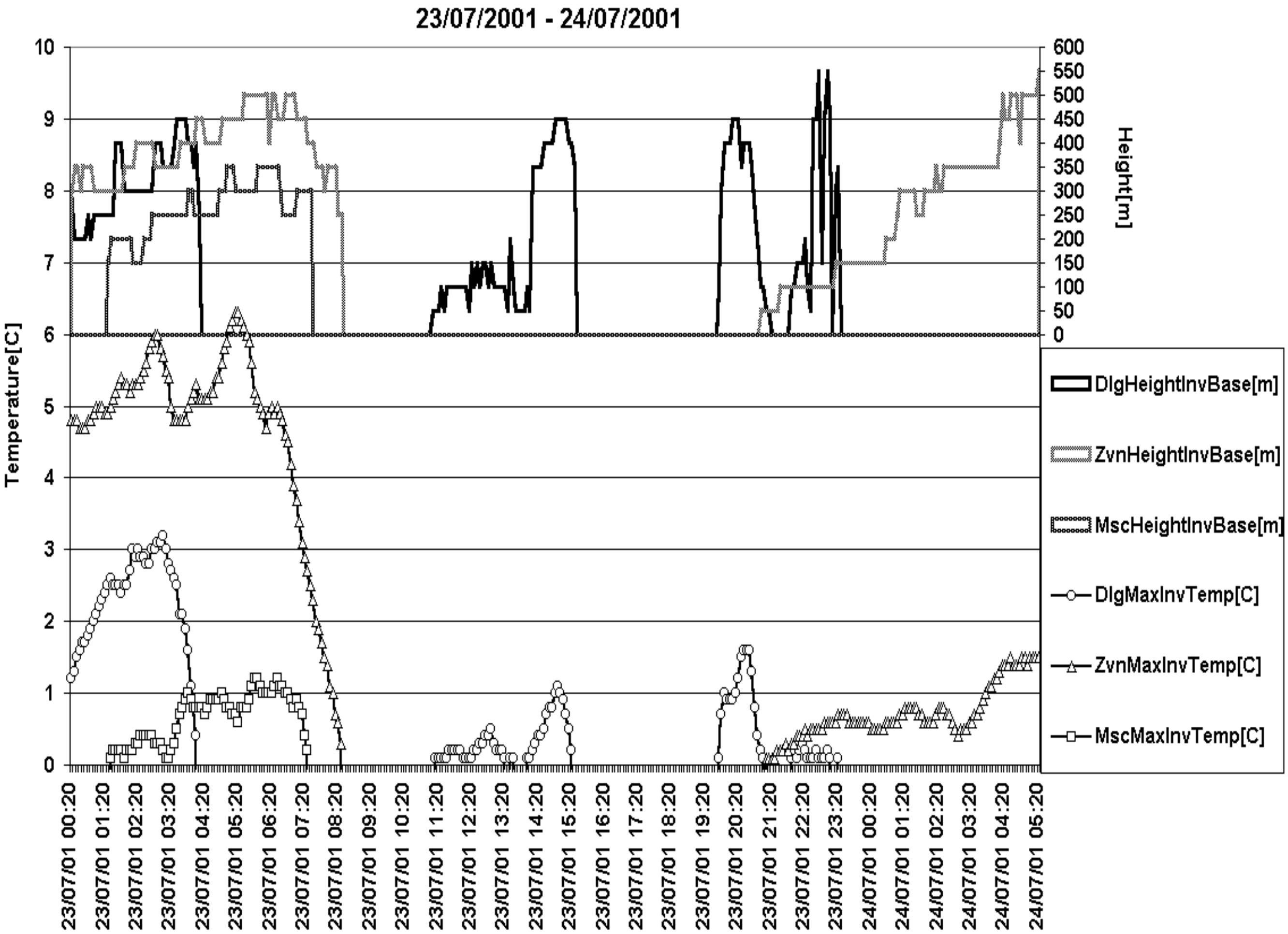

Figure 2. Parameters of temperature inversion in Moscow, Dolgoprudny, and Zvenigorod (July 23-24, 2001).

This type of heat island is formed mostly by convective processes. One explanation for that type of heat island could be that

- The bottom part of the ABL in the city heats faster because of turbulence exchange.
- The top part of the ABL cools faster due to mixing with cold air from the highest altitudes.

The extent to which the city heat island influences the suburb ABL is very dependent on wind speed and wind directions. It was observed that the ABL thermal regime in Dolgoprudny resembles that for Moscow city center more closely than that for Zvenigorod. Figure 3 presents some typical temperature profiles resulting from remote sensing in Dolgoprudny and in Zvenigorod in comparison with the radiosonde data obtained in Dolgoprudny.

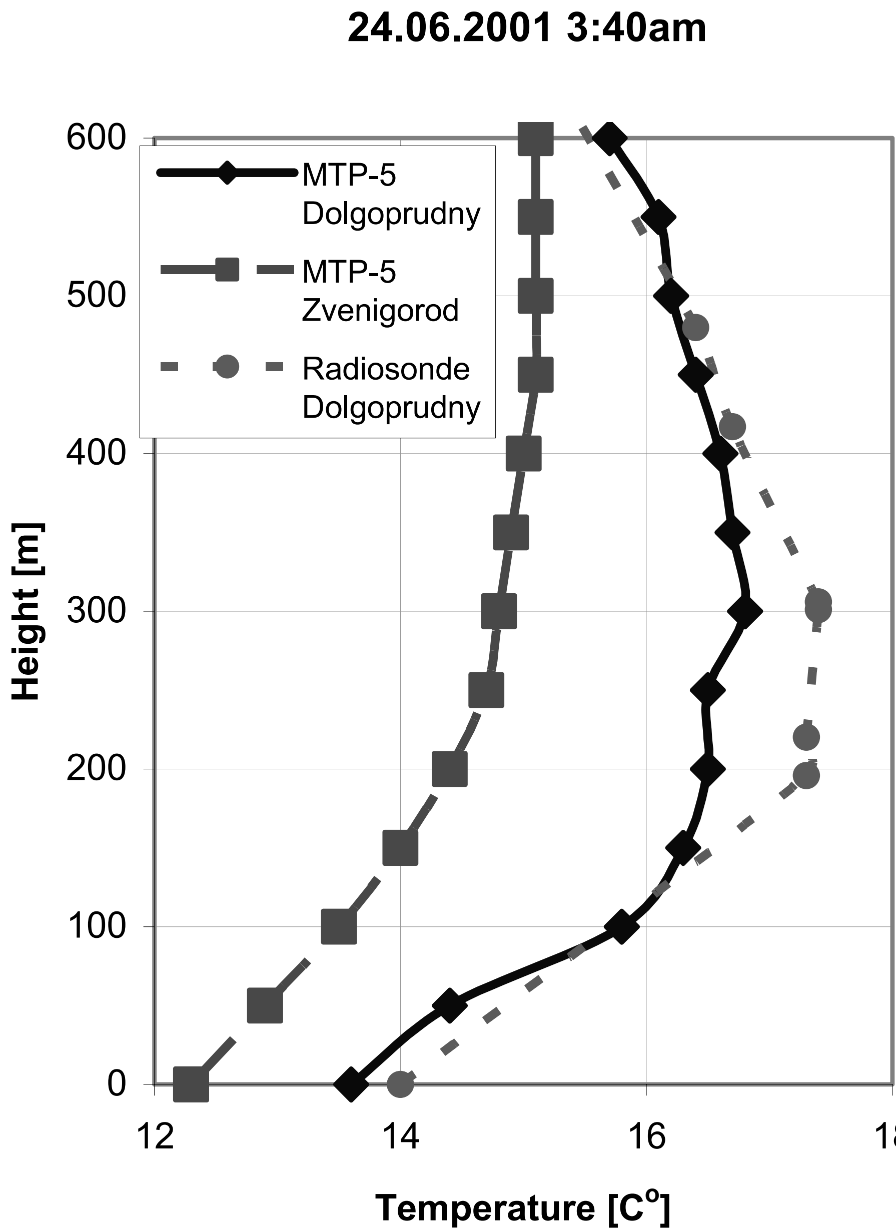

Figure 3. Comparison of ABL temperature profiles in Dolgoprudny and in Zvenigorod (June 24, 2001).

Conclusions

The results of simultaneous remote sensing measurements of ABL temperature profiles can be summarized as follows:

- For the first time, quantitative parameters were obtained for the heat island in the ABL of Moscow Megacity for different seasons and various synoptic conditions.

- Continuous data about ABL stability for different synoptic conditions are very useful for studying the energy balance near the ground surface. This was confirmed during Atmospheric Radiation Measurement (ARM) intensive operational period, which was carried out on the Zvenigorod experimental site in March-April 2002;

- It was detected that radiosonde data obtained in Dolgoprudny are not fully representative for determining ABL parameters on the Zvenigorod experimental site because of the influence of the Moscow Megacity heat island.

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