Application of Microwave Radiometry for Urban Heat Island Study

E. N. Kadygrov[1], **E. A. Vorobeva**[1], **I. N. Kuznetsova**[2],
V. V. Folomeev[1], **and E. A. Miller**[1]

[1] Central Aerological Observatory, Russian Federation
[2] Hydrometeorological Centre of Russia, Russian Federation

Abstract— Last decade or so for temperature profiling in atmospheric boundary layer were used passive microwave radiometers with the frequencies in molecular oxygen absorption band. One of the widely used instrument was MTP-5H — A single channel an angular-scanning microwave temperature profiler. MTP-5 was developed in 1990–1992 by the scientists from several leading institutions of Russia. For studying urban heat island in Moscow region, three passive microwave radiometers (MTP-5H) were used. These devices worked simultaneously for continuous measurements of atmospheric boundary layer temperature profile up to 600 m. In this report, quantitative parameters of Moscow urban heat island (UHI) will be presented.

1. INTRODUCTION

The numbers of researches dedicated to the UHI study considerably increased in recent years. This investigations show that anthropogenic stress in the form of powerful sources of gas and aerosol pollutants as well as water vapor and supplemental heat sources can greatly influence the intensity and the form of the environment response in the large industrial cities and megalopolises. These factors lead to special climate formation in megalopolis. For study of UHI ordinary were used near-surface data from meteorological stations at the city and in suburb. As a result, the fundamental factors of the UHI formation were formulated (Oke, 1977).

Nevertheless, it is clear that UHI is one of the atmospheric phenomena, which requires further study. For this study it is necessary to have a representative data on the vertical thermal structure over the cities. Usually for this purpose balloon-borne instrumentation (such as free and tethered sounding balloons or constant volume free balloons), aircraft techniques and facilities, tower sensors were used. But these devices are costly and cannot provide continuous measurements. So during last two decades or so, atmospheric boundary layer (ABL) observations have been enhanced by remote sensing techniques.

Our technology was based on using passive microwave remote sensing or radiometric method. These passive techniques involve measurements of radiation emitted from the atmosphere, instead of detection of scattered energy due to natural or artificial atmospheric targets. One of the advantages of microwave radiometric device includes the possibility to provide measurements in practically all weather conditions in urban area. It also allows continuous unattended measurements, which provide long time series and time-height cross sections.

For the investigation of UHI in Moscow were used three passive microwave radiometers simultaneously. This simultaneous measurement had two objectives. The first was to determine a Megacity impact to the ABL parameters which led to creation of UHI. The second objective was to investigate the ABL stability and its influence a radiation balance near the ground surface.

2. MEASUREMENTS AND INSTRUMENT DESCRIPTION

During 2000–2009, three microwave temperature profiles (MTP-5H) were used simultaneously in Moscow region for continuous measurements of the atmospheric boundary layer (ABL) temperature profile. One MTP-5H was installed in the center of Moscow city. The second in the north part of Moscow (Dolgoprudny), and the third about 50 km west ward from the Moscow city center (Zvenigorod). The relative position of the devices is shown on Figure 1.

Zvenigorod town has little industry, low traffic intensity and due to topography good air ventilation. So it can be considered as an undisturbed rural site. In Dolgoprudny, radiosond data is also obtained.

The temperature profiles were obtained "round-the-clock" every 5 minutes up to altitude of 600 m with a 50 meters grid. MTP-5H microwave radiometer is single channel solid state Dicke-type super heterodyne receiver (radiometer). The working frequency is ~ 60 GHz. The radiometer has sensitivity of 0.04 k for integration time of 1 second. The antenna is a scalar horn with beam-width of about 6° and has low response outside the main lobe. The MTP5 is self calibrating angular scanning single-channel microwave radiometer. The specifications of MTP-5H is shown on Figure 2.

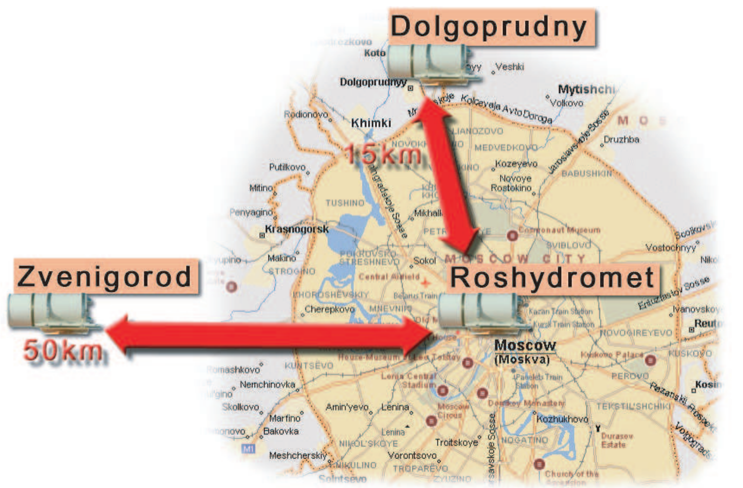
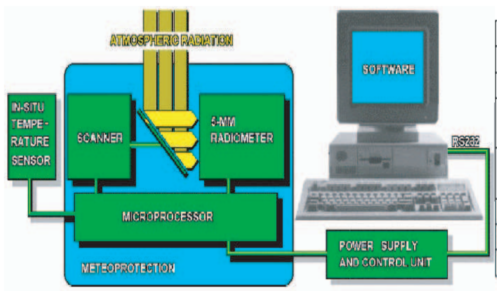


Figure 1: The relative position of three microwave temperature profiles (MTP-5H).



MTP5	H-Hursh
Altitude range	600 m
Height resolution	50 m - 100 m
Maximum rate of mesurements	120 sec
Accuracy of temperature profile retrieval	0,2 – 0,5 K
Weight	20 kg
Power consumption	max 60 W nominal 20 W
Outside temperature range	-40 °C - +40 °C

Figure 2: Specifications of MTP-5H instruments.

Calibration of the receiver is achieved by 0.1°C temperature control and a switched internal noise generator. A one point absolute calibration is achieved either by viewing an external target or by knowing the emission temperature in the horizontal direction.

3. RESULTS

The examples of data obtained by radiometers is shown on Figure 3.

The results show that the strongest response of the temperature on the urban influence was observed in the near surface layer of the atmosphere. As were shown by the measurements, the whole 600 m layer was convective unstable at that time. The stability of ABL leads to an increase of pollution and moisture in Moscow and blocks cooling in the evening. The heat absorbed by the buildings and asphalt roads also acts to retain warmth. As a result of these factors, the cooling in the suburbs happens faster.

It is evident that at nights and in the mornings even under the relatively clean conditions, the large city affects the thermal field. But the level of the urban heat dome is not high. The upper boundary of the dome goes approximately up to 300 m. The largest temperature gradients were fixed between the city and its suburb (1.5–3.5°C) inside the lowest atmospheric layer (0–100 m). In the afternoon (from 12:00 up to 18:00) the concentrations of pollutants and water vapor in the urban air decreased to the levels with week influence on the thermal processes in ABL and UHI decreased. The temperature difference between Moscow and Zvenigorod in the layer 0–100 m did not exceed 1°C. An intensification of UHI near the ground was observed after 18:00. An increase of city-suburb difference was observed after 21:00 in the layer 0–100 m. Diurnal spread of the temperature difference in the layer 300 m did not exceed 1.0°C (0.1–1.0°C). It was equaled 0.7°C in the layer 600 m (−0.5–+0.2°C). Under the high polluted conditions (July 20, 2002) nocturnal and morning (0:00 to 9:00) city-suburb difference inside the layer 0–100 m was from 2.6 to 8.2°C. The UHI was conserved and its top reached 600 m in the afternoon, but its intensity even in the lowest layer of the atmosphere rarely exceeds 1–2°C. Our studies confirmed that UHI is observed generally at night.

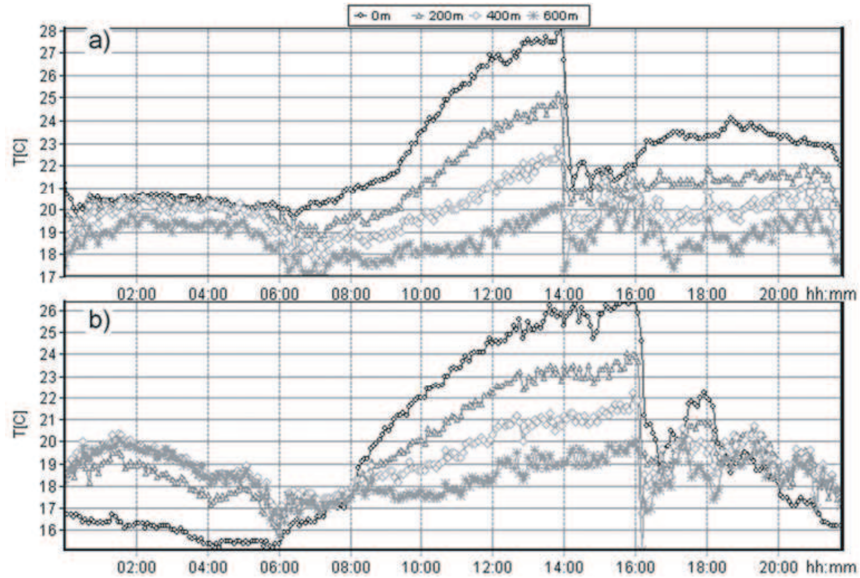
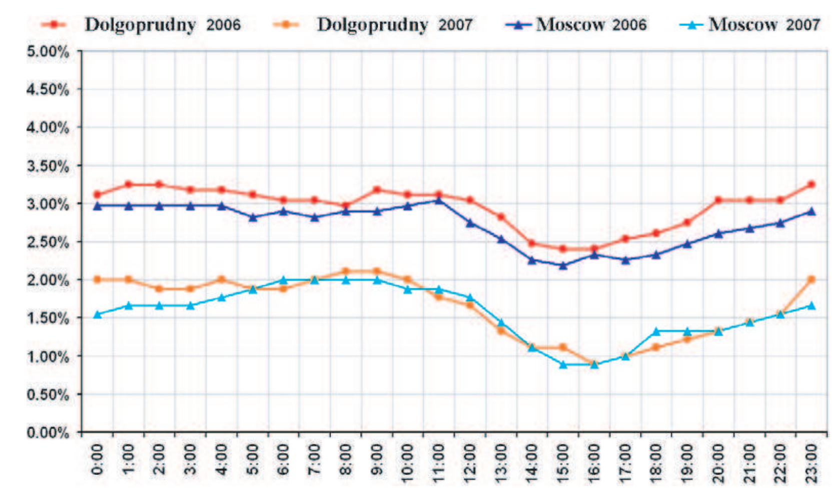
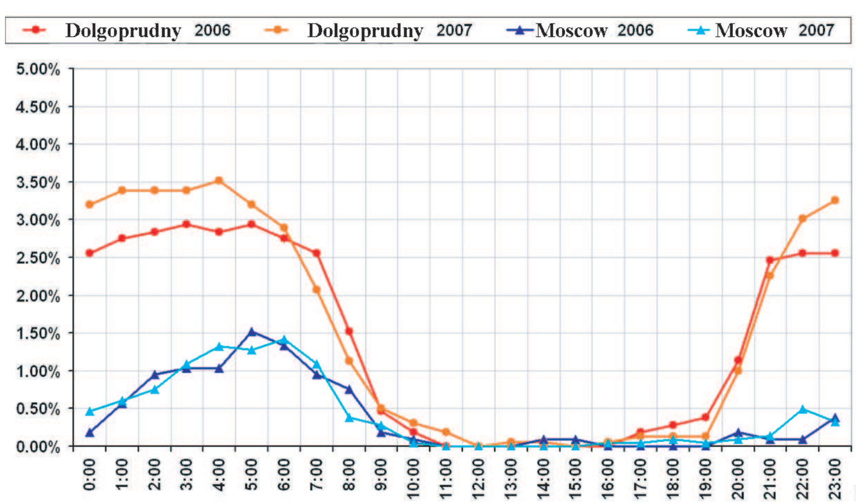


Figure 3: Temperature variations at different heights during the atmospheric front passage. (a) Moscow, (b) Zvenigorod. June 20, 2001.



(a)



(b)

Figure 4: The diurnal distribution of inversions. For Dolgoprudny & Moscow. (a) Winter period, (b) summer period 2006–2007.

It was also calculated features of vertical temperature gradient for each 100 meters above the city and above suburb at two seasons (summer, winter). It was also calculated parameters of temperature inversions in city center and in suburb and its seasonal variations (Figure 4).

The Figure 4 shows that amount of inversions in winter in Moscow and Dolgoprudny is very close. The abrupt difference in the quantity of inversions for two winters 2007 and 2006 is explained by very warm winter months in 2007. But for summer season in 2007 and 2007, it can be seen appreciable distinction in frequency of cases and in time, when inversion was formed. At nights, a quantity of inversions in Dolgoprudny in winter and in summer is very close. While in the center of Moscow in summer, this quantity is two times smaller than in winter months. In summer, inversions is very rare in both places. The similar results were obtained by the authors for 2001. The maximum difference between the city and its suburb is in summer. It is probably connected with the differences in underlying surface characteristics.

4. CONCLUSIONS

Continuous temperature profiles observations in atmospheric boundary layer on the basis of stationary and mobile microwave profilers allow to obtain unique data and to investigate the UHI over the big cities. And its clear that remote sensing in studying UHI is very efficient.

Two types of UHI were identified on the basis of the temperature profile measurements: The warmer dome of the urban heat at all levels, and low warmer dome in combination with the lens of the cold air above it. The lens of cold, placed under the dome is a result of both radiation balance deformation in more humid and polluted urban air and more active mixing processes in more unstable urban air.

UHI exists not only under the conditions accompanied by the elevated pollution levels, but also under that one when relatively clear air does not accumulate urban polluting outbreaks.

The most pronounced UHI is observed in the morning and at night. The accumulation of the pollutants and water vapor in the urban air occurs this time and UHI reaches its maximal intensity. During the day, the UHI is broken down or remains only in the low 300 meters.

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