# Investigation of the Atmospheric Boundary Layer Thermodynamics on the Base of Microwave Remote Sensing

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## Introduction

Temperature profiles through the atmospheric boundary layer (ABL) are important in studying the energy balance near the ground surface and in validating satellite remote sensing retrievals. For continuous measurement of atmospheric temperature during the last several years different microwave remote sensing instruments were used: multichannel (Westwater 1993; Ware and Solheim 2000) and single-channel scanning radiometers (Troitsky et al. 1993; Westwater et al. 1999). Multi-channel instruments can measure temperature profiles up to about 7 - 10 km in contrast with the single-channel scanning instruments with the altitude limit at about 0.6 - 1 km. But single-channel instruments have the advantage of accuracy and vertical resolution at low-altitudes (Kadygrov and Pick 1998).

This paper presents the results obtained during several field campaigns in 1991-2000 by using the MTP-5 instrument – an angular scanning radiometer operated at a center frequency of 59.6 GHz, with a sensitivity of 0.03K at 1 sec integration time, a cycle time of 120 sec for one temperature profile measurement, and an accuracy of 0.5K up to the altitude 600 m (Kadygrov and Pick 1998; Westwater et al. 1999).

## Results of Measurements

Recognizing that thermal radiation fluxes are a major component of atmospheric models, mobile radiometric systems MTP-5 were used for atmospheric boundary layer thermodynamic investigation at different regions (in a mountains valley, on an island coast, and in the Arctic).

During the field phase of the Mesoscale Alpine Program (MAP) during August - October 1999, the MTP-5 was deployed in the Riviera Valley in southern Switzerland (Weber et al. 2000). One of the scientific objectives of MAP is to investigate the structure and evolution of ABL in complex terrain and its effect on alpine weather systems. A total of 7231 temperature profiles were obtained, including 2441 with the temperature inversion. Figure 1 presents the temperature time-height cross sections and some statistical parameters of temperature inversion. Profiles with temperature inversion were estimated for temperatures different across inversion (Max Inv., [c], left scale) and height of inversion base (Height [m], right scale). Continuous measurement gave a good possibility for estimation of temperature inversion in mountain region. Figure 2 presents, on the basis of MTP-5 data, the difference in temperature inversion dynamic inside the mountain valley and above the flat surface. Specific features of temperature inversion in mountain regions show that the temperature inversion starts from fast reduction of ground-based temperature at about 16:00 local time and big day-night temperature variations near the ground surface.

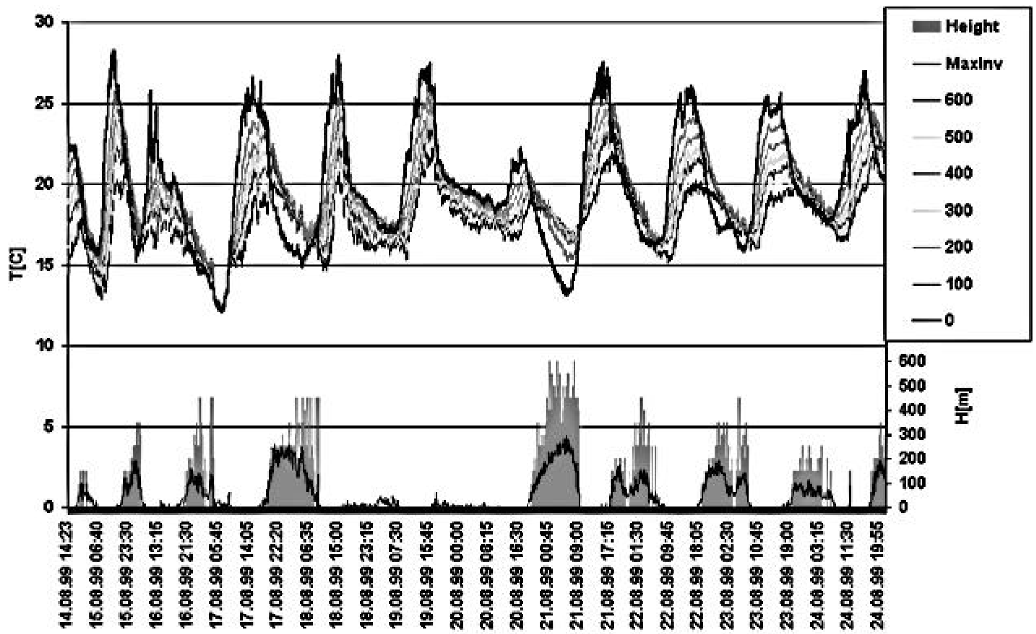


**Figure 1**. Temperature time-height cross sections and temperature inversion parameters derived from MTP-5, August 14-24, 1999.

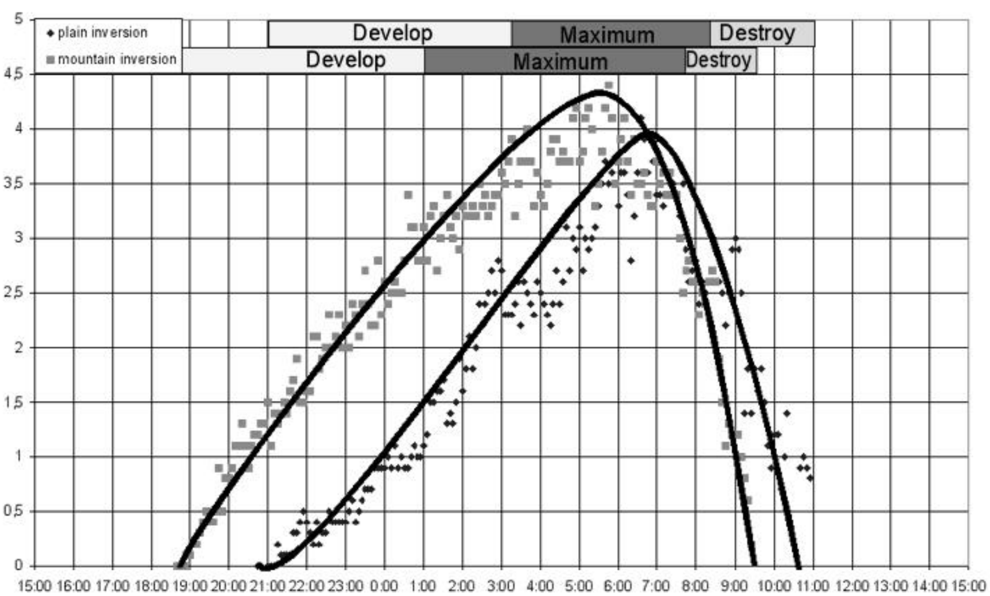


**Figure 2**. Differences in temperature inversion dynamic for flat surface and for mountain region.

During December 1999 and January-February 2000, the MTP-5 was installed at the Russian meteorological station Val at the north part of Sakhalin Island (Kadygrov et al. 2000). About 13,000 temperature profiles were obtained during the observation period. The measurement was provided as a part of the project "Clarification of the actual condition of sea ice in the Sea of Okhotsk and its role in the climate system" (sponsored by CREST – Core Research for Evolutional Science and Technology, Japan). During the field phase of the project, two types of field observations were conducted to investigate the marine atmospheric boundary layer and snow clouds over the Sea of Okhotsk. One involved research aircraft observations above the Sea of Okhotsk to measure cloud characteristics, radiation balance, and meteorological parameters of marine atmospheric boundary layer. The other involved ground-based onsite observations of atmospheric boundary layer thermodynamics. Table 1 shows the statistical distribution of the temperature inversion top during the period of observation, and Table 2 shows statistical parameters of the duration of temperature inversion. Figure 3 shows the result of the calculation of potential temperature gradient ($\Delta\theta$):$\Delta\theta(z) = \theta(z)-\theta(z-\Delta z)$, where $\Delta z = 50$ m. $\Delta\theta$ is positive when the atmosphere is stable, and negative when the atmosphere is unstable. Figure 4 shows the temperature at altitude 300 m and near surface (2 m) for the period of observation December 1-31 1999. Figure 5 shows the same data but for the period February 1-27, 2000. In December there were several warm air fronts, and no ice formation near the north part of the Sakhalin Island coast. In February there were stable, cool temperatures at all altitudes (except for some warming during February 15-19, 2000) and ice formation was observed on the coast of north Sakhalin Island.

**Table 1**. Statistical distribution of the temperature inversion top.

| **Height[m]** | **50** | **100** | **150** | **200** | **250** | **300** | **350** | **400** | **450** | **500** | **550** | **600** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of profiles | 0 | 0 | 9 | 25 | 63 | 92 | 169 | 74 | 254 | 262 | 546 | 1609 | 3103 |
| **%** | **0** | **0** | **0.29** | **0.81** | **2.03** | **2.96** | **5.45** | **2.38** | **8.19** | **8.44** | **17.6** | **51.9** | **100** |

**Table 2**. Statistical parameters of the duration of temperature inversion.

| **Duration [h]** | **<8** | **<10** | **<12** | **<14** | **<16** | **<18** | **<20** | **<22** | **<24** | **>24** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | 71 | 3 | 3 | 5 | 9 | 2 | 2 | 0 | 0 | 2 | **97** |
| **%** | 73.2 | 3.1 | 3.1 | 5.2 | 9.3 | 2.1 | 2.1 | 0.0 | 0.0 | 2.1 | **100** |

Continuous measurement of atmospheric boundary layer temperature profiles was provided by an MTP-5 from a special scientific train, which crosses the territory of Russia from the west to the east side and from the south to the north (1999 – 2000, TROICA Project – Transcontinental Observations of the Chemistry of the Atmosphere) and covers thousands of kilometers (Golitsyn et al. 2000). The purpose of the experiment is to study sources, transportation, and transformation of gaseous and aerosol species in the atmosphere over Eurasia. A special carriage-laboratory was equipped with different instruments: gas-analyzers for measuring surface concentration of $O_3$, CO, $CO_2$, NO, $NO_2$, and $CH_4$; instruments for measuring direct solar radiation; an MTP-5 for measuring ABL temperature profiles; and devices for measuring spectral and mass concentration of aerosol. Some results of the measurements are shown in Figure 6. Information about the dynamic of temperature inversion was very useful for investigating gas emission and aerosol distribution.

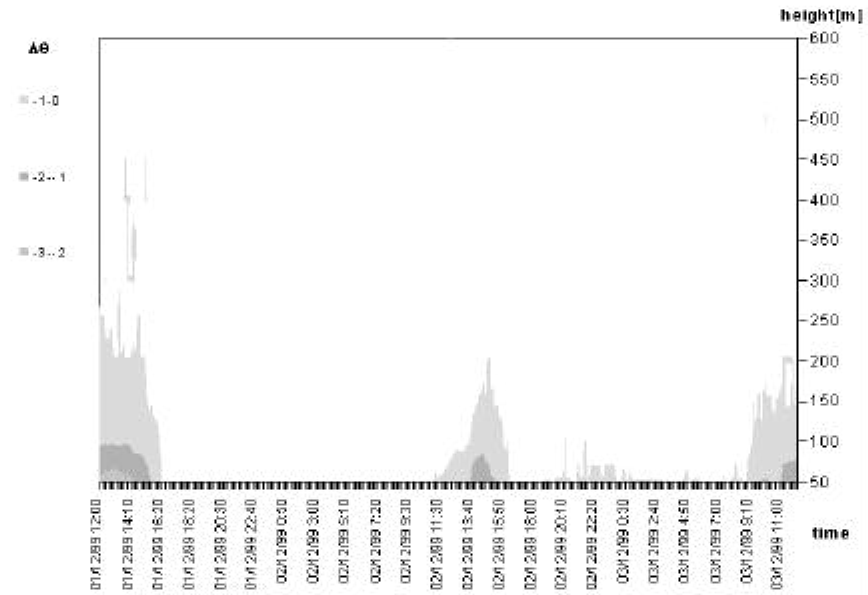


**Figure 3**. Calculated from MTP-5 data the potential temperature gradient (01.12÷03.12.1999).

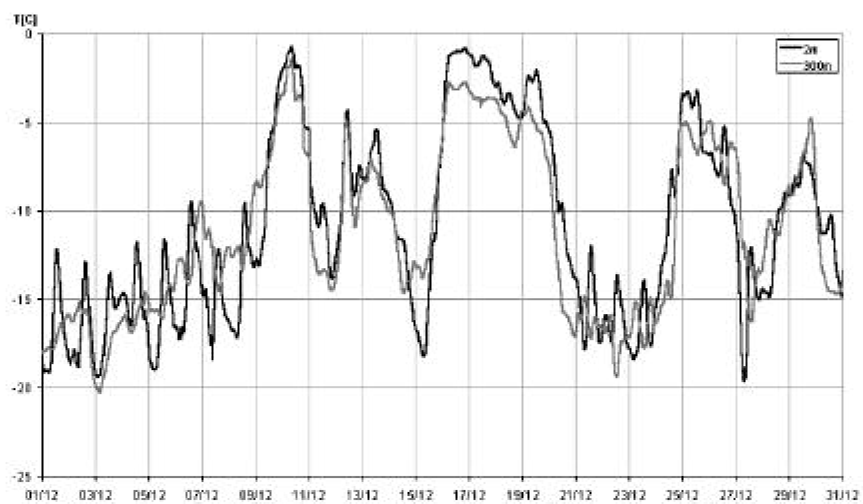


**Figure 4**. The temperature at altitude 300 m and near surface (2 m) for the period of observation December 1-31, 1999.

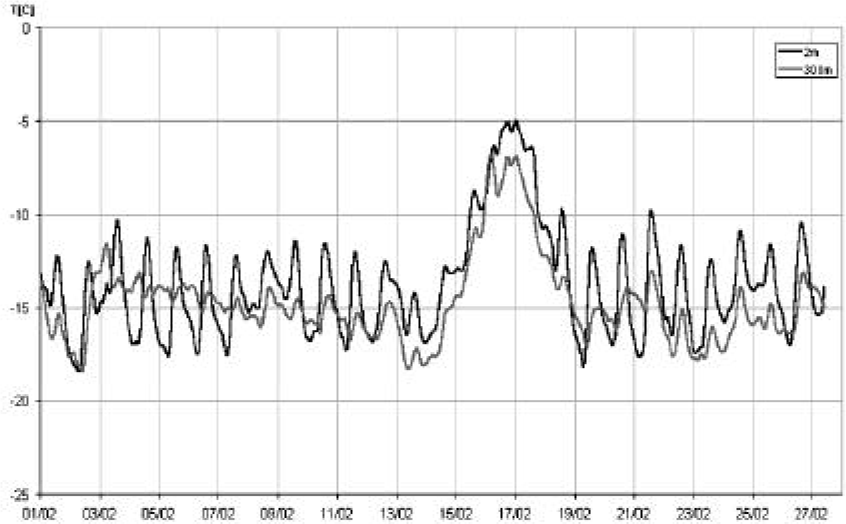


**Figure 5**. The temperature at altitude 300 m and near surface (2 m) for the period of observation February 1-27, 2000.

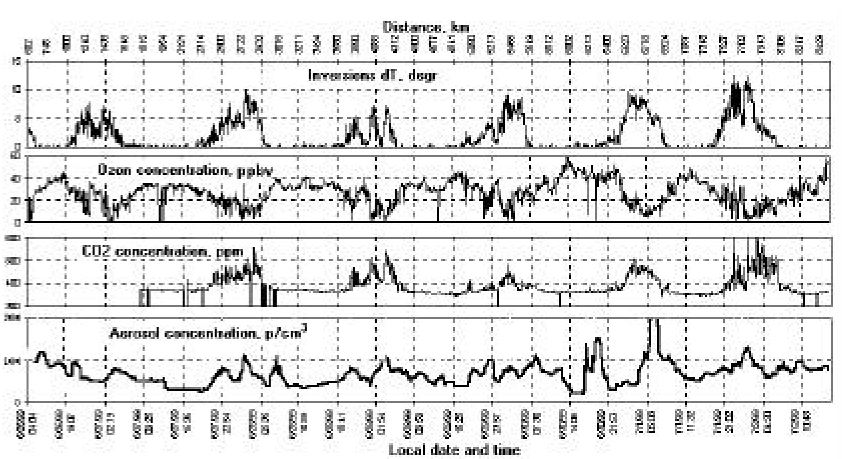


**Figure 6**. Some data from the TROICA Project.

Simultaneous measurement of ABL temperature profiles over the central and north (Dolgoprudny) part of Moscow city began January 1, 2000, by using the two MTP-5 instruments. The measurement was provided as a part of WMO pilot project GURME (Global Urban Research Meteorology and Environment, WMO report, 1999). The distance between two MTP-5 instruments is about 15 km and measurements of ABL temperature profiles provided simultaneously each 15 min. One of the scientific objectives of such measurements is to determine the influence of a big urban area on the boundary layer parameters. Analysis of the temperature profile variations (0÷600 m) at Dolgoprudny and Moscow during February 15-22, 2000, indicated that the first empirical orthogonal function (EOF) (97.9 percent, 98.3 percent of the total variance, respectively) shows the warming at Moscow in the 0÷300 m and cooling in the 300÷600 m layer compared to temperature variations at Dolgoprudny (Figure 7). The behavior of the first EOF expansion coefficient at Dolgoprudny lags by about 30 min with that at

Moscow, which can be caused by transport processes. A more detailed analysis will be done at the beginning of 2002 using the EOF and SVD (single value decomposition) analysis when more data is collected (dataset will include continuous simultaneous measurement of ABL temperature profiles during 2000-2001).

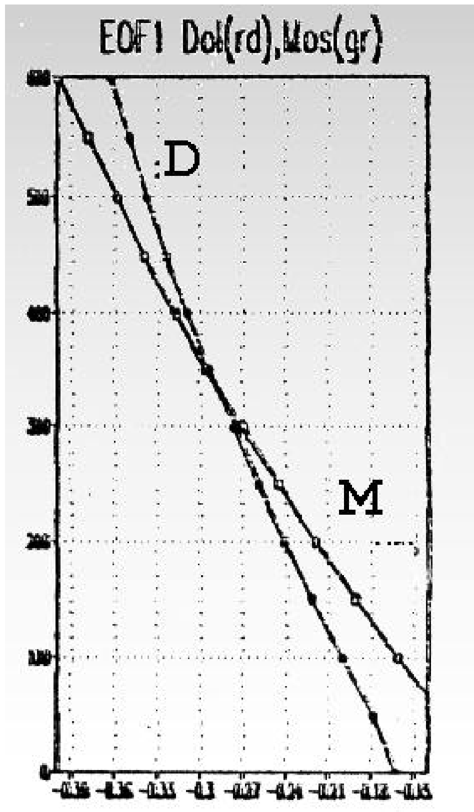


**Figure 7**. Analysis of the temperature profile variations (0÷600 m) at Dolgoprudny and Moscow during February 15-22, 2000.

## Summary and Discussion

The advantage of microwave remote sensing of ABL temperature profile by using a single-channel radiometer can provide permanent, unattended measurements at practically all meteorological conditions. At the same time, one sufficient disadvantage of the method was clarified. This disadvantage is a low accuracy rate of the temperature profile retrieval in the case of a temperature inversion lifted over the surface at a height of more than 100 m. An example of such a situation is shown in Figure 8 (comparison of radiometric data with radiosonde data at Barrow, Alaska). Sometimes (for Barrow, within January-April) the lifted temperature inversion can be very narrow (less than 100 m), and indications of this type of inversion are problematic for passive remote sensing. In this situation, which is not common but can take place in the Arctic coast, one solution is to overlap the disadvantage mentioned above by possibly using information from an active microwave channel as a backup to the passive one. The information can be from the microwave radar with wavelengths of 3 mm or 8 mm.

The other solution is to use once-daily radiosonde data in addition to the continuous measurement of ABL temperature profile by the single-channel microwave radiometer.

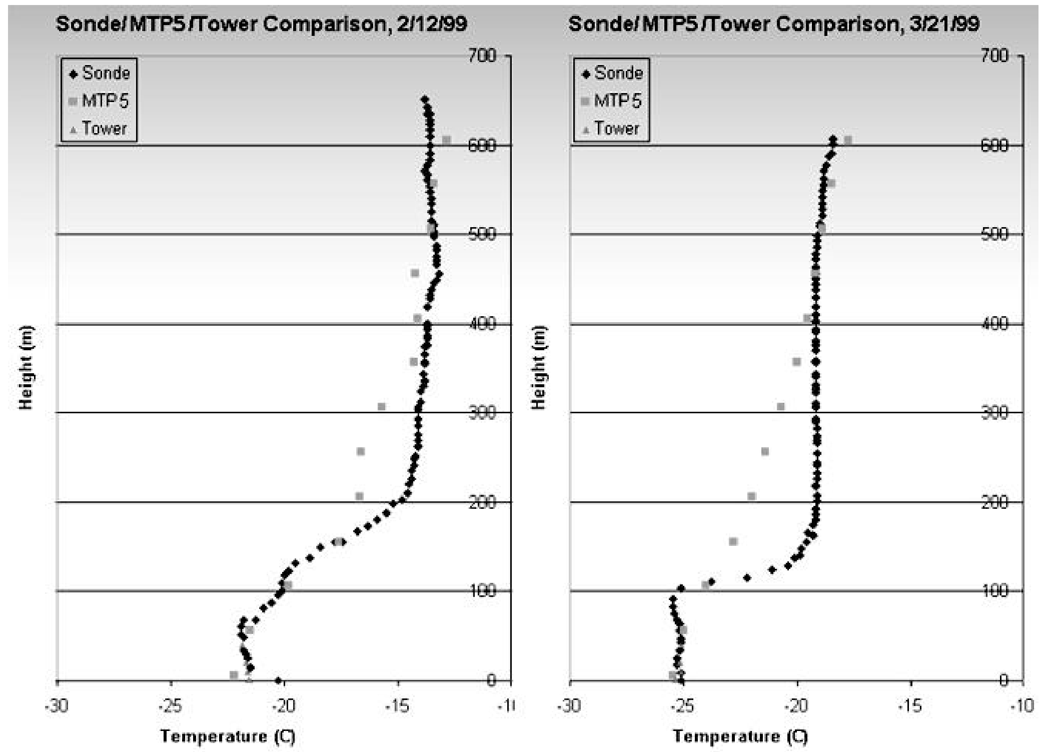


**Figure 8**. Comparison of radiometric data with radiosonde data at Barrow, Alaska.

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## References

Golitsyn, G. S., I. G. Granberg, A. V. Andronova, et al., 2000: Features of fine aerosol distribution over Russian territory and their influence on human health: Abstr. of II Intern. Conference "Air pollution and water resources at the region of Caucasus Mineral Waters," Kislovodsk, October 8-14, 2000, Maks Press, Moscow, pp. 34-35.

Kadygrov, E. N., and D. R. Pick, 1998: The potential for temperature retrieval from an angular-scanning single-channel microwave radiometer and some comparison with in situ observations. *Meteorological Application*, **5**, 393-404.

Kadygrov, E. N., E. Miller, Y. Fujiyoshi, and M. Wakatsuchi, 2000: Investigation of atmospheric boundary layer thermodynamics at the Sakhalin Island by using a microwave temperature profiler. In *Proc. of SPIE Symp.: Microwave Remote Sensing of the Atmosphere and Environment II*, Sendai, Japan, SPIE Vol. 4152, pp. 310-318.

Troitsky, A. V., K. P. Gaikovich, V. D. Gromov, E. N. Kadygrov, and A. S. Kosov, 1993: Thermal sounding of the atmospheric boundary layer in the oxygen band center at 60 GHz. *IEEE Trans. on Geoscience and Remote Sensing*, **31**(1), 116-120.

Ware, R. H., and F. S. Solheim, 2000: Microwave profiling of atmospheric temperature, humidity, and cloud liquid water. In *Proc. of SPIE Symp.: Microwave Remote Sensing of the Atmosphere and Environment II*, Sendai, Japan, SPIE, Vol. 4152, pp. 292-302.

Weber, H., M. W. Rotach, E. Kadygrov, V. Kadygrov, and E. Miller, 2000: The thermal structure of the atmospheric boundary layer in an Alpine valley: Results of continuous remote sensing measurements and comparison with radiosonde data. In *Int. Radiation Symp.: Current problems in atmospheric radiation, (IRS'2000)*, Abstract, St.-Petersburg, Russia, pp. 234-235.

Westwater, E. R., 1993: Ground-based microwave remote sensing of meteorological variables. In *Atmospheric Remote Sensing by Microwave Radiometry*, J.W.S. Inc., Ed. M.A. Janssen, Ch. 4, pp. 145 213.

Westwater, E. R., Y. Han, V. Irisov, V. Leuskiy, E. N. Kadygrov, and S. A. Viazankin, 1999: Remote sensing of boundary layer temperature profiles by a scanning 5-mm microwave radiometer and RASS: comparison experiments. *J. of Atm. and Ocean. Tech*., **16**(7), 805-818.

WMO Report TD N 1014. WMO-RA-II/RAV.GAW Urban Research Meteorology and Environment (GURME) Workshop (Beijing, China, November 1-4, 1999).