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Comparison of nocturnal inversion characteristics obtained by sodar and microwave temperature profiler

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Abstract. Sodar echogram is a usual means to estimate the height of temperature inversion. Our data of long-term synchronous measurements with sodar and microwave profiler in urban and rural areas showed an intricate relation between intensity of backscattering and potential temperature profiles. Qualitative relationships between echogram pattern, wind speed and temperature profiles were obtained. Distributions of temperature gradients in rural and urban measurements for summer and winter time were calculated.

1. Introduction

For description of stable boundary layer (SBL) meteorologists sometime use a simple characteristics of inversion layer - its height (IH),i.e. height where temperature profile become isothermal (below $\dfrac{\partial T}{\partial z} > 0$ and upper $\dfrac{\partial T}{\partial z} < 0$) A difference between temperature of isothermal layer and standard temperature (at 2 m height) is inversion depth. Fig. 1 shows two examples of temperature profiles (discussed below) in rural ABL for strong and weak stability (in night-time) in summer.

But turbulence study and climate or weather prediction models use a mixing height (MH) as characteristics of ABL. In acoustic sounding for that purpose a height of surface layer (in SBL) of strong backscattering of acoustic signal is used [1] (see Fig. 2). In theoretical approach dimensionless Richardson number and its critical value are used for MH determining [2]. Numerous field experiments for comparing of MH and IH were carried out but uncertainty in their closeness continue.

Currently used UHF temperature profilers permit to study this problem more carefully. Continuous measurements [3] unlike occasional ones by radiosondes allow comparing variations of MH and IH. In this paper comparison of temperature profiles and profiles of temperature gradient measured by profiler with MH observed by sodar were carried out.

2. Instrumentation and sites

Simultaneous measurements of temperature profiles by UHF profiler MTP-5 (ATTEX, Russia) and scattering intensity by sodar LATAN-3 (IAPh, Russia) were carried out in rural area at

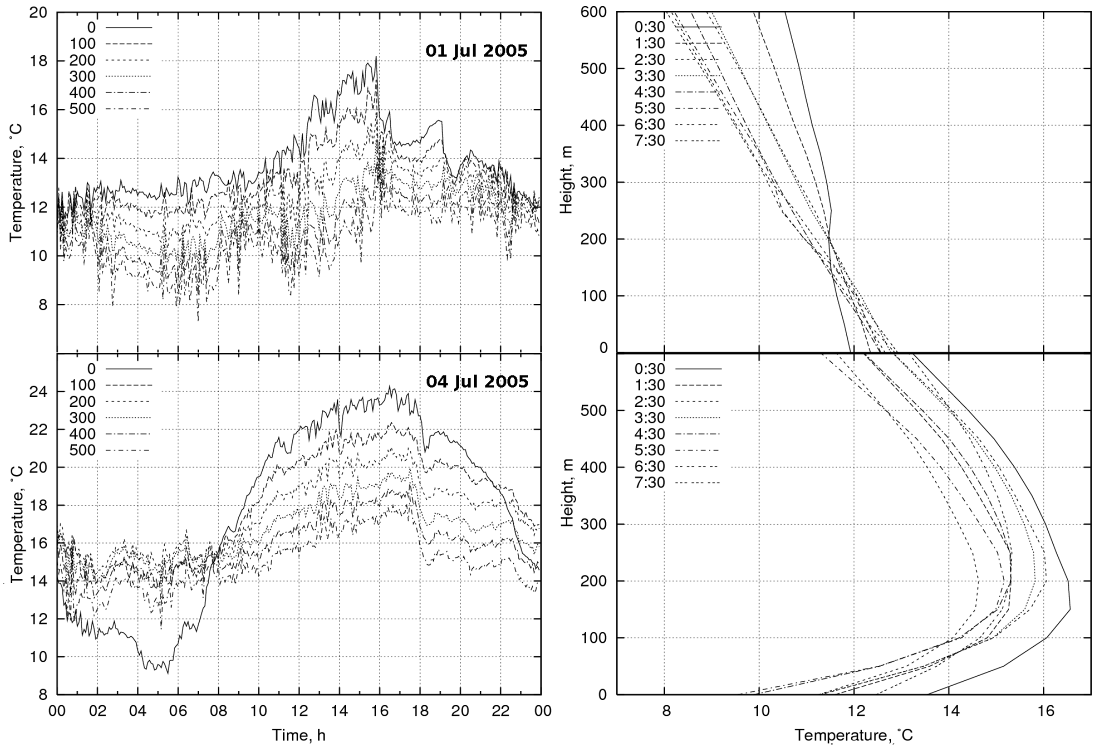

Figure 1. Diurnal course of temperature at different heights (left panel) and profiles of temperature averaged over 30 min in night-time (right panel) measured by MTP-5 profiler at rural area (ZSS of IAPh) for two cases of night ABL stability: weak (01 July 2005, above) and strong (04 July 2005, below).

Zvenigorod scientific station (ZSS) in 45 km from Moscow in July 2005. In Moscow downtown these measurements are continuous.

Profiler MTP-5 developed at the Central Aerological Observatory [4, 3] allows measuring of temperature profiles in ABL up to 600 m height. This remote instrument reconstructs temperature by inclined integral measurements so temperature profiles are smoothed but it allows easy measuring of averaged temperature lapse rate by difference at adjacent levels. Fig.1 shows examples both time series at different heights and mean vertical profiles over 30 min intervals.

LATAN-3 is Doppler mono-static three-component sodar described in [5, 6]. Examples of scattering intensity (echograms) and wind velocity profiles are presented in Fig.2 for those days like in Fig.1.

3. Methods

Observations show that height of isothermal level is not suitable for practical application due to it's not narrow and considerably grows under slightly stable stratification (see Fig.1 above).

Theoretical approach suggests two stability criterions: potential temperature gradient (lapse rate) and Richardson number. Potential temperature gradient (PTG) near surface is connected by bulk relation with IH and inversion depth: $\frac{\partial T}{\partial z} \approx \frac{\Delta T}{H}$, $\frac{\partial \Theta}{\partial z} = \frac{\partial T}{\partial z} + 1°K/100m$, where Θ - potential, T - thermodynamic temperature and ΔT - difference between surface (at standard height) temperature and temperature of isothermal layer, H - the height of inversion layer - IH.

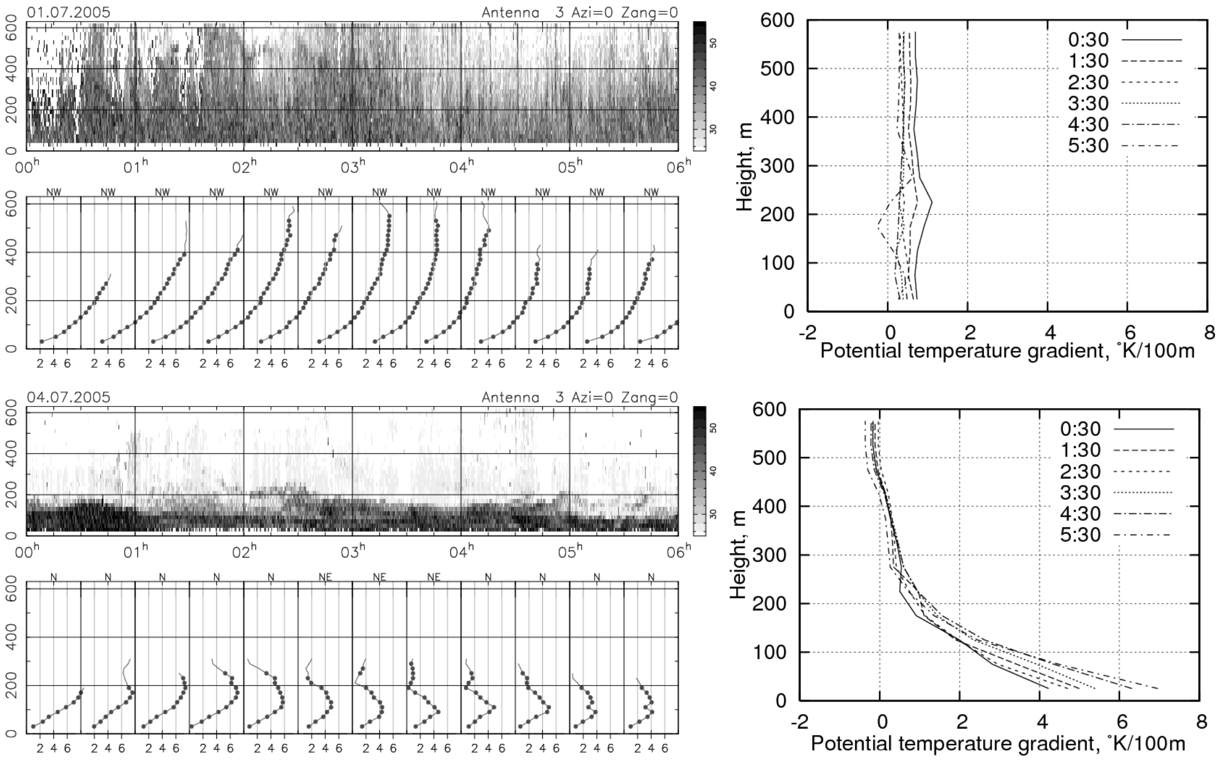

Figure 2. Echograms of acoustic sounding and wind speed profiles (left panel) measured by LATAN-3 sodar and profiles of potential temperature gradient (right panel) in night-time for those dates as in Fig.1. Gray scale on echograms is proportional of scattering intensity (C_T^2) in logarithmic units (shown on the right side). On the left side height is shown, below echograms LST is pointed, below wind profiles scale of wind speed is dislpayed as well as direction is shown above

Richardson number $Ri = \dfrac{\beta(\frac{\partial\Theta}{\partial z})}{(\frac{\partial U}{\partial z})^2 + (\frac{\partial V}{\partial z})^2}$ is dynamic criterion and preferable for MH determination. However, using of model parameters such as Richardson number is not applicable due to synoptic and stochastic variability at those heights where $\frac{\partial\Theta}{\partial z}$ or $(\frac{\partial U}{\partial z})^2 + (\frac{\partial V}{\partial z})^2$ are small. Profiler MTP-5 doesn't allow measuring of temperature gradient with sufficient accuracy above 300 m but profiles of $\frac{\partial\Theta}{\partial z}$ show that at higher levels in night-time state of atmosphere is often slightly-stable, so if we consider that $\frac{\partial\Theta}{\partial z} \approx const$ then inverse Richardson number has a minimum (and critical value) at height where wind speed has a maximum . It confirms well-known fact that MH in SBL is close to height of wind speed maximum. But Richardson number doesn't specify where maximum is reached.

Calculating of PTG by profiler measurements shows correlation of low MH by sodar data with strong stability by profiler data (see Figs. 1 and 2). Increase of stability leads to MH decrease, especially in rural area in summer time.

Calculation of MH by sodar data is carried out visually and accuracy of MH determining fluctuates near 20-100 m because of variations of top boundary of SBL and percentage of error is about 20-25%. Comparison of temperature gradients and MH was carried out when radiation

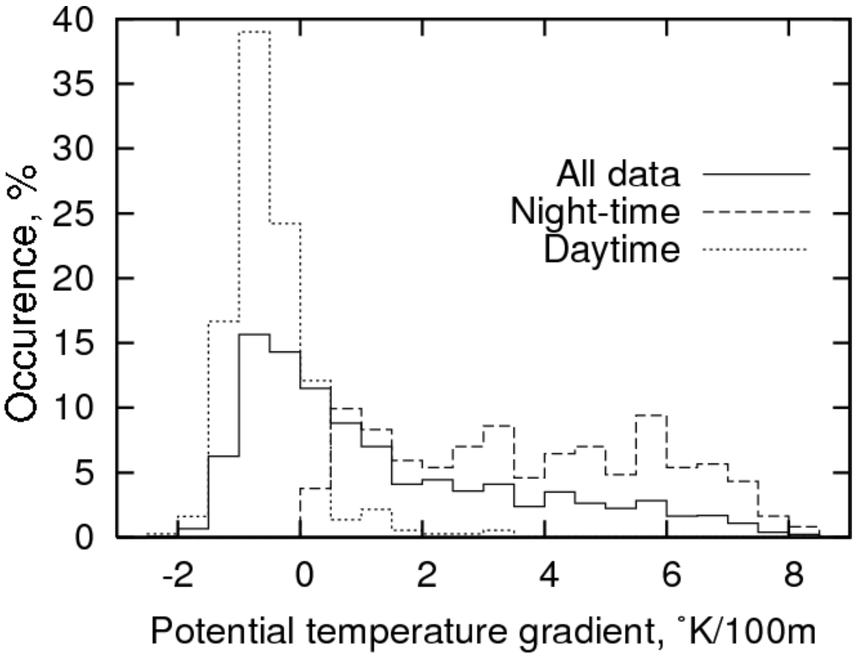

Figure 3. Distribution of PTG in the lowest part of ABL in °K/100m. 0 corresponds to dry-adiabatic temperature gradient(-10°K/km) and 1 is isothermal one.

balance generally is stable and traffic noise is insignificant. For analysis a night-time data from 0 to 6 hour of LST were selected.

For automatic measuring of MH by sodar data well-known property of acoustic backscattering in SBL may be used: above top border of SBL intensity of scattered signal decrease considerably due to neutral stratification and weak wind shear. A few algorithms were tested for determining of MH: by decreasing of intensity, by decreasing of data availability, by vertical integral of scattering intensity. All tested methods work well if height of SBL is intermediate (200 - 300 m) and discrepancy is significant under very stable or neutral stratification because of, in first case, littleness of MH and insufficiency of sodar vertical resolution, in second case, limitation of height range and fuzzy border of SBL.

4. Results

4.1. Distribution of surface temperature gradients

Difference between two lowest levels: 0 and 50 m above profiler displacement height (about 10 m) was used to calculate "surface" potential temperature gradient (sPTG). Surface value is convenient because of larger sensibility to temperature variations. This approach is alike suggested by Holzworth for convective ABL [7]. As mentioned above $\frac{\partial \Theta}{\partial z} \approx (T_{50} - T_0) * 2 + 1$. Distribution of sPTG from one month of summer measurements at ZSS site was calculated. Fig.3 shows general occurrence and depth of surface inversions in night-time for summer conditions at rural area (without urban heating influence). There is wide range of stability in summer connected with large surface radiation emission in clear nights.

Comparison of sPTG with MH by sodar for one month of continual measurements shows clear correlation between sPTG and MH in wide range of stability. This comparison permits to suggest a simple estimation of MH in rural area in middle latitudes: $H \approx 500/\frac{\partial \Theta}{\partial z}$. As Figs. 1 and 2 show if sPTG is about 1°K/100m (isothermal surface layer) then MH is about 500 m,

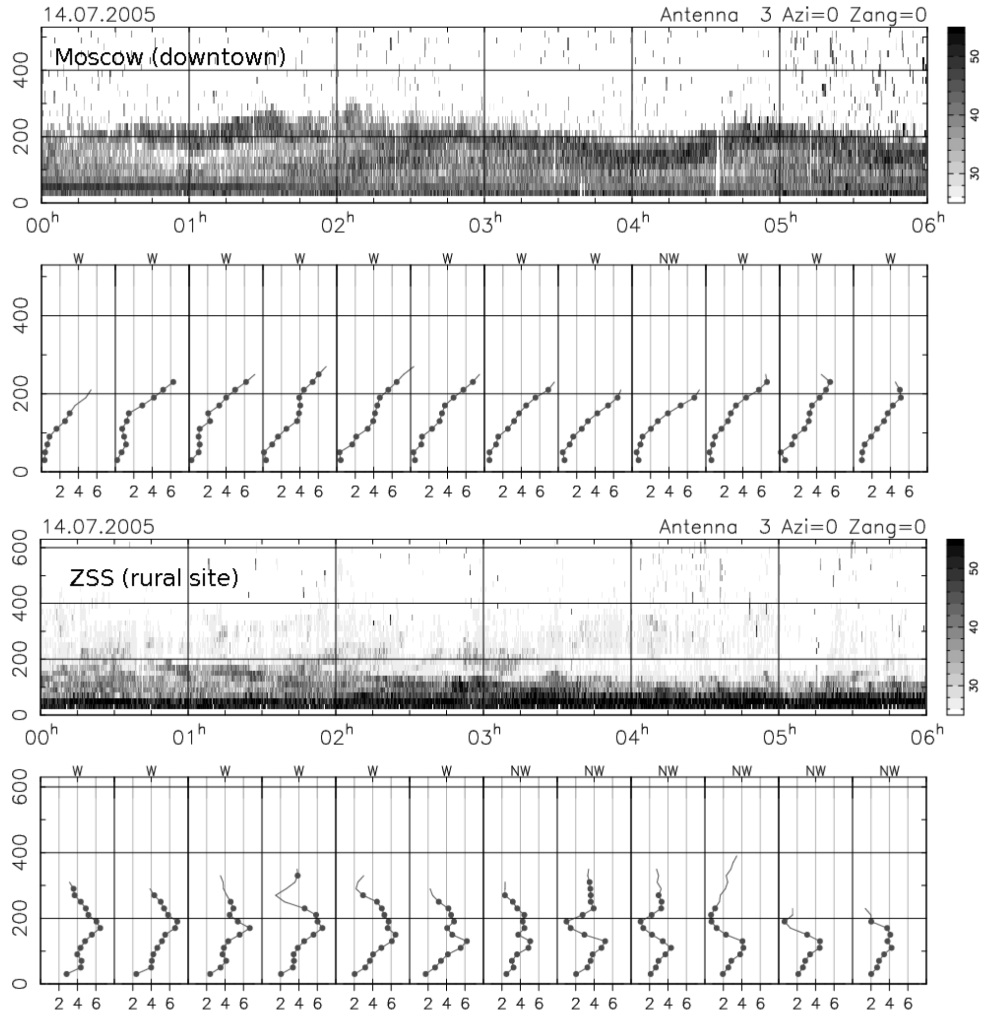

Figure 4. Simultaneous echograms and wind speed profiles in urban and rural environment. See Fig. 2 for explication.

when $\frac{\partial \Theta}{\partial z} > 5°\mathrm{K}/100m$ MH falls below 100 m. Increasing of MH often results to lesser intensity of scatter signal due to lesser PTG but scattering intensity (C_T^2) also depends on wind velocity gradient.

4.2. Comparison of urban and rural measurements

Comparison of MH by sodar data in rural area and in Moscow downtown [1, 6] shows considerable influence of urban heat island on ABL stability and MH. At night-time thickness of "surface inversion layer" by sodar measurements at urban site is sometimes larger then those at rural site sometime at 50-150 m. It amounts up to 100% of MH in rural area. One example of MH comparison by sodar echograms in urban and rural area in summer time is presented in Fig. 4. Larger MH and wind velocity maximum level is observed over urban area. Comparison of IH by profiler data shows corresponding tendency: PTG is much higher at rural areas in night-time.

In Moscow downtown surface inversions in summer nights by profiler measurements are rare due to urban heating and heat storage. Often PTG profiles have an elevated maximum (Fig. 5). Acoustic measurements show elevated or multilayer inversions with larger scattering intensity.

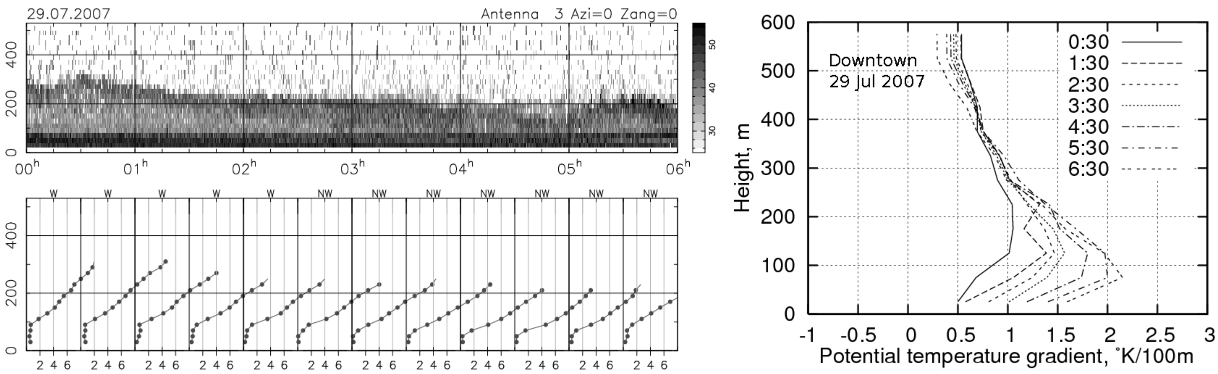

Figure 5. Comparison of MH by sodar echograms and PTG by profiler measurements for vary stable situation in urban area. (Explication is shown in Fig. 2)

The strongest stability in Moscow urban area in summer is about $2-3^{\circ}K/100m$ at 100 m level, as at rural site PTG achieves $7-8^{\circ}K/100m$ at the lowest level. The finest surface layers in Moscow downtown in summer 2007 by sodar data are about 150-200 m.

Thus if stable stratification is present outside the town and wind speed is large at top border of SBL (10-15 m/s) city heat up moved stable-stratified air mass. However, "elevated inversions" on sodar echograms determined by larger scattering intensity at the top of SBL don't correspond to height of PTG maximum. Comparison with wind profiles shows that larger scattering intensity fits to larger wind speed shear, larger turbulence mixing and so larger temperature fluctuations(C_T^2). If wind velocity is small at the top of SBL, scattering of acoustic signal is weaker for equal PTG values.

Because of PTG profiles in urban area in stable state are nonlinear, a simple relation between MH and sPTG is absent. Summer observations in June-August 2007 in Moscow downtown show

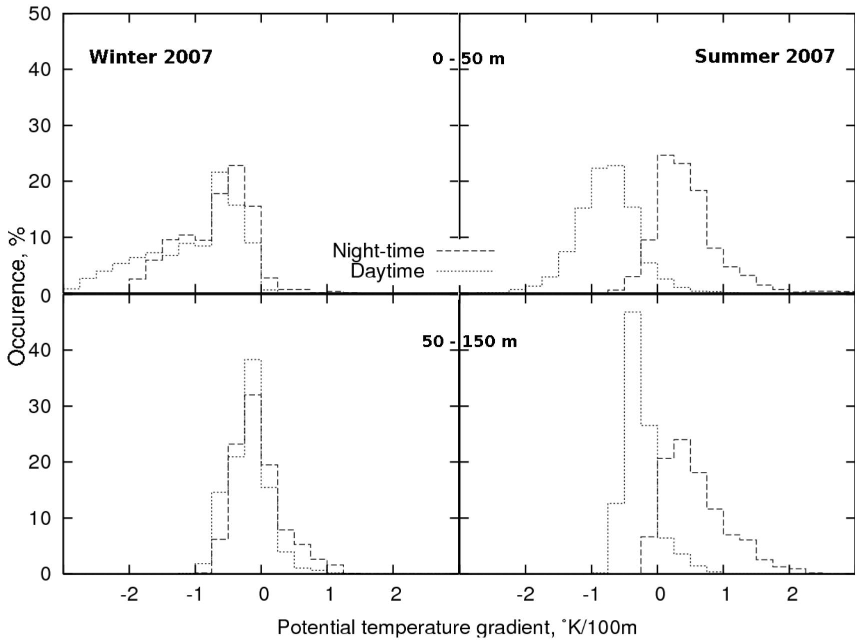

Figure 6. Distributions of PTG for cold and warm seasons at two levels: 0-50 and 50-150 m. Moscow downtown, summer and winter 2007 (December- February).

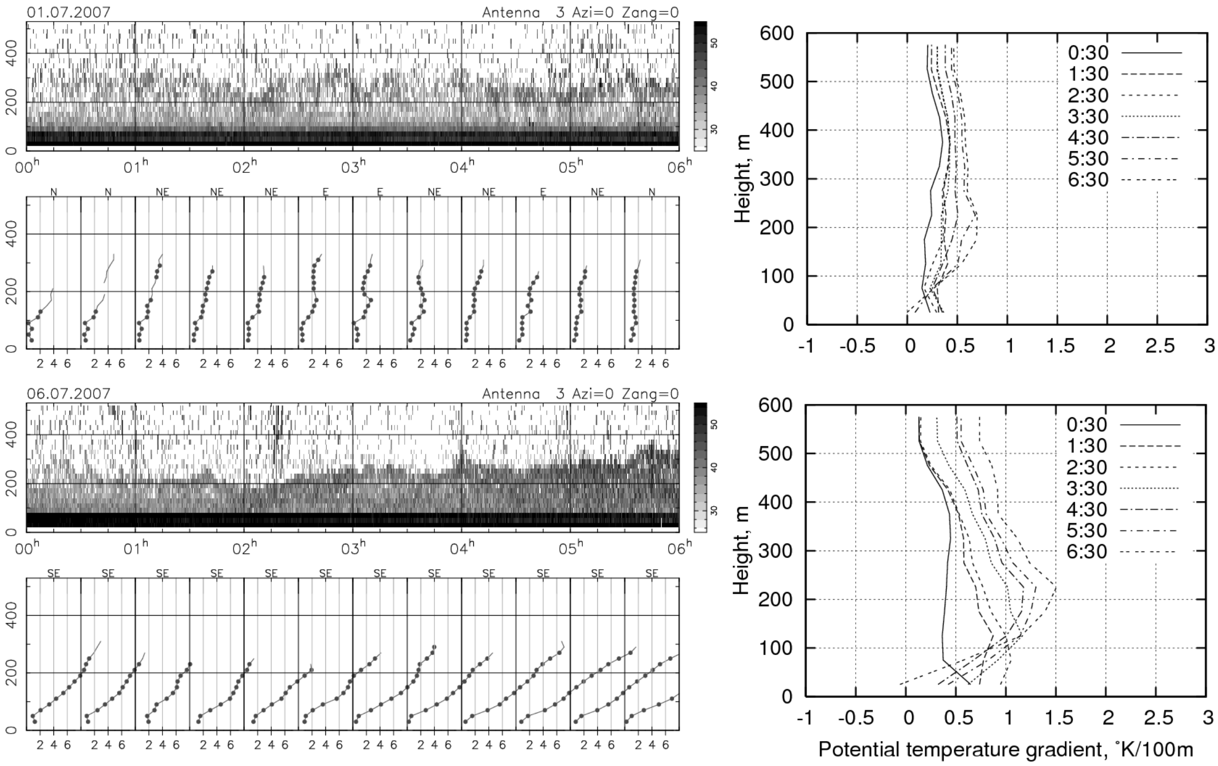

Figure 7. Comparison of echograms and wind profiles in centre of Moscow for weak and strong wind speed. At the right panels profiles of PTG are displayed.

rough empirical estimation of correlation between MH and maximum of PTG: $H \approx 400/\frac{\partial\Theta}{\partial z}_{max}$

4.3. PTG distribution in urban environment

Based on continuous measurements in 2007 distributions of PTG for different heights were calculated. Statistical analysis confirms high sensitivity of sPTG to radiation processes and heat exchange with surface and sensitivity decreases with height. Summer time allows studying different stability of ABL but statistical research demands annual generalization. Calculating and comparison of PTG distribution for summer and winter, for night and day and for different heights were carried out. This analysis demonstrates a convenient of sPTG for statistical stability description.

Fig.6 demonstrates PTG distribution for the lowest level (between 0 and 50 m) and for 100 m level (as difference between 50 and 150 m). Distributions at night-time are evidently contrasted with those at daytime as well as distributions for summer are differ from those for winter. Continuous cloudiness in winter time almost suppresses a diurnal course of PTG and urban heating displace surface inversions from urban area in winter time. Temperature lapse rate in the lowest layer of ABL has the largest diurnal and annual course.

4.4. MH and wind speed

Role of wind speed at the top of SBL in case of weak stability is very important. Small wind speed makes difficult MH determining due to fuzzy border of slightly stable ABL. Fig. 7 shows two examples of weak and strong wind speed at the top of SBL. If wind is strong top border of SBL is sharp due to larger mixing and in most cases the stable surface layer is connected with large wind shear (see Figs. 7 (bottom panel) and 2 (upper panel)).

5. Summary

Continual observations show that temperature profiler MTP-5 allows reliable measuring of averaged temperature gradient in ABL. Comparison with sodar echograms and wind profiles confirms accordance of temperature and wind measurements. The largest sensitivity for this instrument is obtained at the lowest level. Observations in rural area show wide range of stability in night SBL in summer time. Height of SBL - mixing height is surely determined only by acoustic sounding due to high sensitivity of scattered signal to mixing of "air particles". Uncertainty of MH by sodar measurements is 20-100 m. Richardson number connects MH with fast decreasing of wind speed lapse rate at the top border of SBL. Continual measurements show that MH correlates with stability of SBL measured by sPTG because of sPTG is sensible to surface thermal balance. Observations in rural area give a simple empirical estimation of MH and sPTG correspondence. Weak wind speed leads to fuzzy SBL border with lesser MH. In urban area maximum of PTG is often elevated. Empirical estimation connects MH with maximum of PTG. Distributions of PTG at urban and rural areas are differ considerably. This distribution demonstrates urban impact onto air mass.

Acknowledgments

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