Method and Research System for Remote Measurements of Turbulence Characteristics for the Purposes of Improving PBL Modeling

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Introduction

The thermal microwave emission of the atmosphere in the molecular oxygen absorption band centre at 60 GHz (5 mm) is forming in the skin depth about 300 m and its intensity depends on only the temperature of this layer (Gajkovich et al. 1993; Khaikin et al. 1996; Kadygrov et al. 1998). The fluctuation intensity of that emission is conditioned by turbulence pulsation of temperature and wind transfer in the 300-m depth (Gromov et al. 1992; Troitsky and Kadygrov 1996). The radiobrightness temperature fluctuation ΔT_b from the turbulence pulsation $\Delta T(h)$ can be written:

$$\Delta t_b(\nu,\theta) = \frac{1}{\cos\theta}\int_0^H \Delta T(h)\gamma_\nu(h)\cdot\exp\left[-\frac{1}{\cos\theta}\int_0^h \gamma_\nu(h)dh'\right]dh \quad (1)$$

where $\gamma_\nu(h)$ is the molecular oxygen absorption coefficient; θ is the sensing zenith angle, and ν is the frequency.

Investigations of the fluctuations of the planetary boundary layer (PBL) brightness temperature were conducted by using Dicke-type 5-mm radiometers with the band width $\Delta\nu$ = 3 GHz, sensitivity 0,03K at the 1-second integration time and antenna beam width 6°. Measurements of PBL brightness temperature were compared with measurements of brightness temperature of the microwave target with the stable temperature. Results of wind speed and direction determination were compared with radiosonde data. The measurements at 60 GHz are available in a wide range of weather conditions (dry snow, fog, weak rain, and presence of aerosol), which is important for participation in special science programs such as Arctic Haze research program.

Experimental Scheme

Three of the 5-mm single channel scanning radiometers have been involved. One of the radiometers has been used to determine atmospheric stratification (Gajkovich et al. 1993). Two other instruments worked in simultaneous mode and consequently received radiation from the several zenith angles (Figure 1). Pulsation with a period equal or less than the beginning of the meso-meteorological minimum have been of our interest.

Figure 1. View of experimental complex.

Height Spectrum Variety

Variations of brightness temperature ΔT_b caused by weak turbulence pulsation of temperature at the different altitudes of PBL can be detected with the instrumentation sensitivity about 0,03K (Kadygrov and Pick 1998). Distribution of atmospheric temperature pulsation have been usual for PBL due to average meteo-tower data $\Delta T \in [0,14\ ^{\circ}C; 0,31\ ^{\circ}C]$ and the thickness $\Delta h = 100$ m.

The measurements were carried out at various latitude zones but results were about the same: the maximum in the microwave emission spectrum of the clear atmosphere had the period about t = 4-6 min and the amplitude about 0,18K (Kadygrov and Pick 1998). If observed average wind speed was about $vx \approx 3 \div 5$ m/sec., the characteristic horizontal turbulence scale of temperature pulsation was about $Lx = vx \bullet t/2 \approx 600$ m. During the unstable stratification, this fact is connected with the dynamic-convection mode of air motion.

Analysis of observation results shows that strong spectra transformation of radio emission fluctuation had been during temperature inversion distraction. Distraction of the inversion layer leads to maximum spectra dissipation on a period of time of 4-5 min and appearance high frequency components with the period more than 30 seconds. The spectra take the usual view after the full inversion dissipation.

Simultaneous observation on two zenith angles $\theta = 0^{\circ}$, and $\theta = 60^{\circ}$, gives an opportunity to investigate turbulence spectrum of temperature on different heights. An example for those spectra (effective heights, h = 300 m and h = 150 m) is received by measurements with two radiometers. For the variety of the spectra, the height dependence of characteristic frequencies can be obtained, as shown in Figure 2.

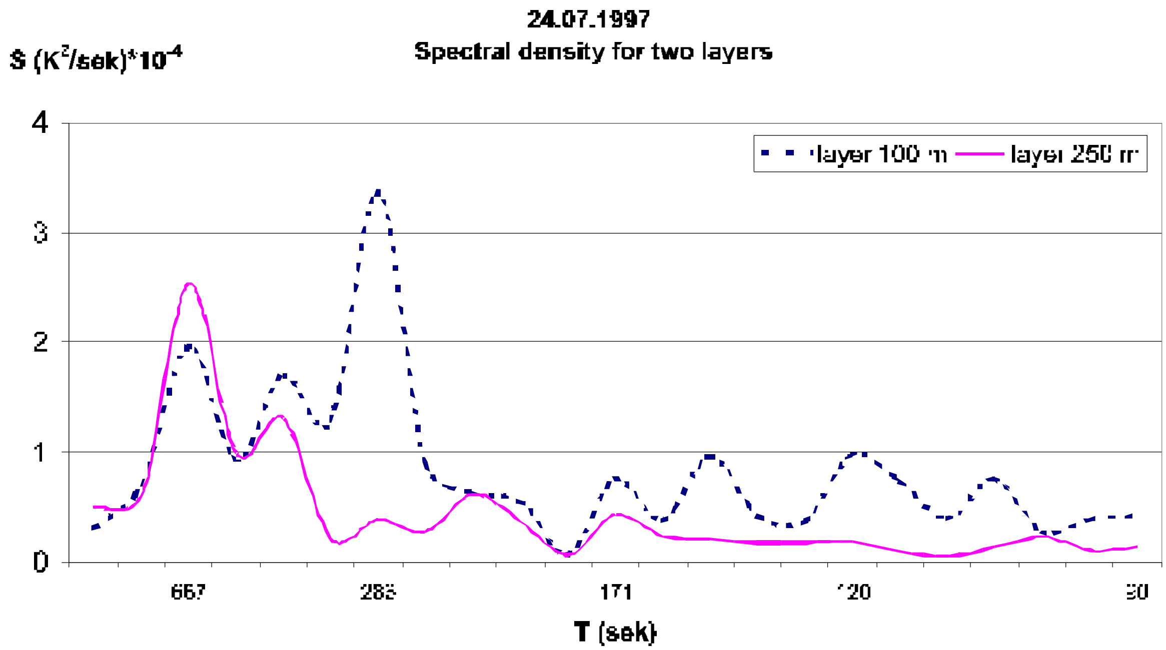

Figure 2. Spectral density of layers with different heights.

Problems of PBL Modeling

All models have to solve the problem of «non-closure» of the hydrodynamic equations for turbulent PBL. There are two main directions in modeling. First is the volume averaging under some space cell structure. Second is the assemble averaging with the necessary calculating of turbulent flux of various scales. However, the parameterization problem is the obvious one for both directions. Implementation of the modeling results is based on the identification of model parameters and constants with real experimental data obtained by in situ and remote sensing of the atmosphere. Pulsation of the intentional interval has been chosen for a priori implementation of the Taylor hypothesis for the transfer of temperature inhomogeneous between spaces of radiometric sounding.

The original method of spectra analysis obtained from the signals registered by the radiometers on different angles gave an opportunity to retrieve spectra of temperature power density fluctuation on different heights. As a result, it also gave the opportunity to obtain height dependence of the speed of dissipation of turbulent energy (ε) and wind speed and direction up to 250 m. Wind speed is one of the main meteo-elements; ε very often is used as the parameter for second-order closure models and for diffusion calculations.

Characteristics of Dynamic Processes of PBL

By using phase characteristics of the retrieved fluctuation spectra on different heights and taking into account Taylor hypothesis of the «freezing» turbulence make it possible to determine wind speed and direction height profile in PBL. The preliminary estimations have showed that the accuracy of wind speed measurements is ~1,5 m/sec. Radiometric results have been compared with radiosonde data (Figures 3 and 4).

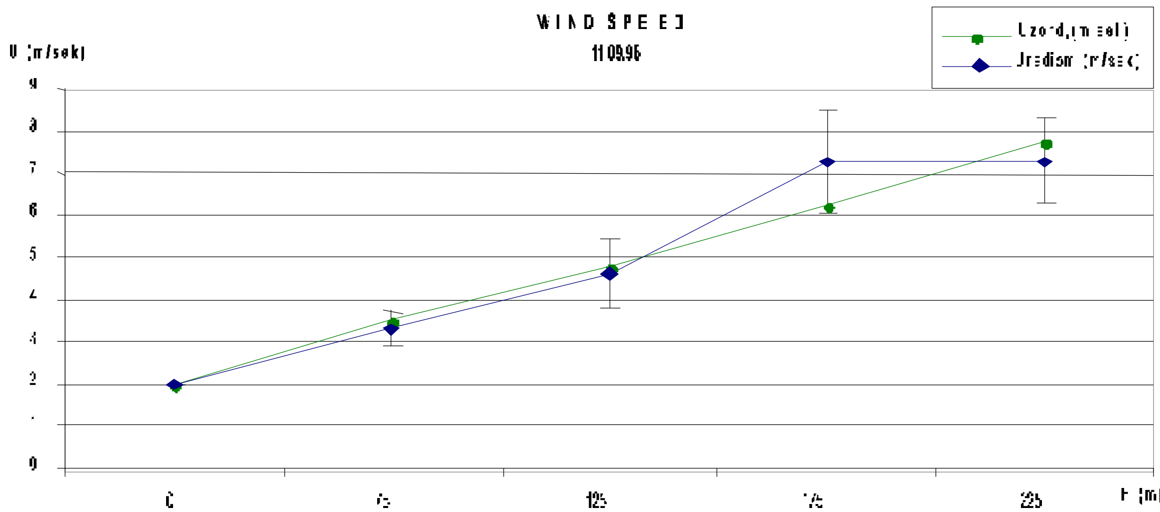

Figure 3. Comparison of radiometric and radiosonde wind speed determination.

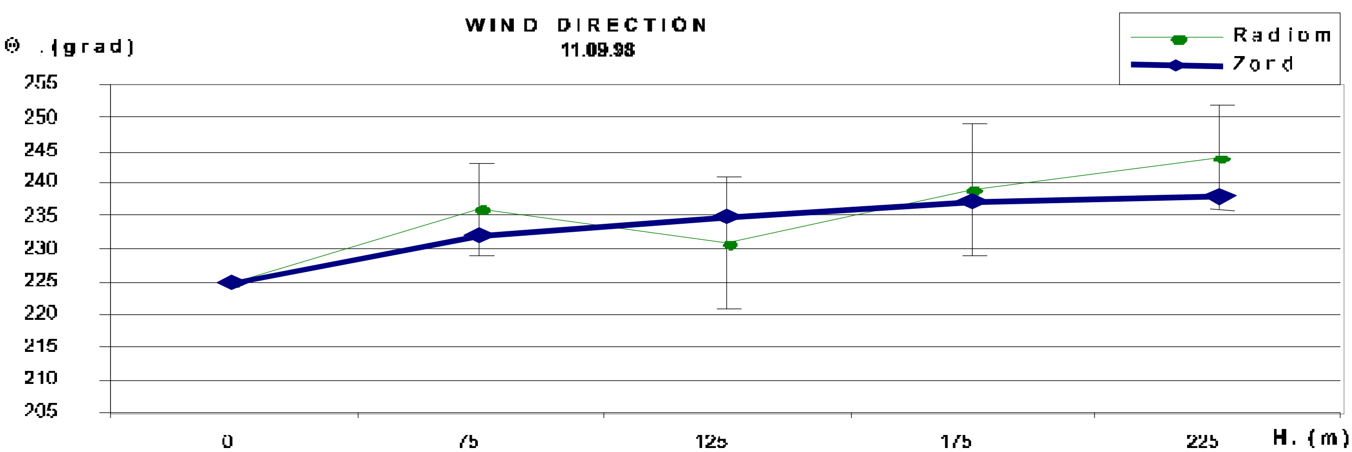

Figure 4. Comparison of radiometric and radiosonde wind direction determination.

Research of the deviation of obtained spectra from «-5/3» law gave an opportunity to recover the height dependence of the external scale for inertional interval of turbulence variations and height dependence of the speed of dissipation of turbulent energy (ε) (Figures 5 and 6).

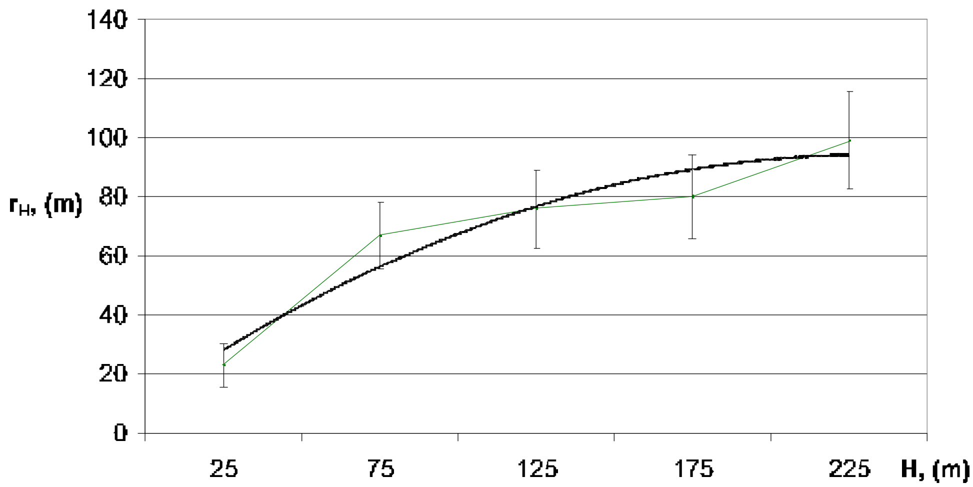

Figure 5. Height dependence of external scale (r_H) for inertional interval.

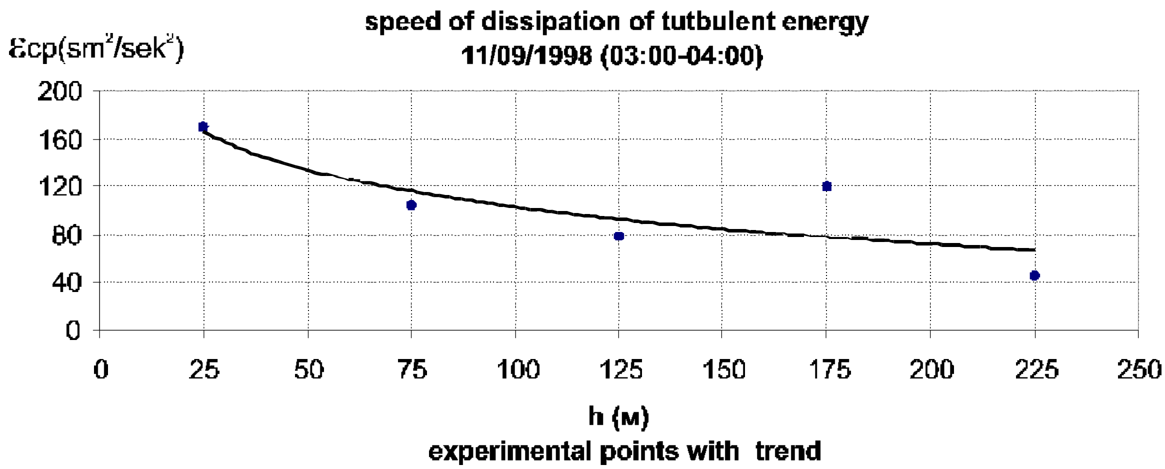

Figure 6. Height dependence of ε.

Summary

- Fluctuations of the inertional interval of the atmospheric turbulent spectrum with a time-scale of several seconds have been registered and investigated.

- The problem of height resolution of high frequency atmospheric temperature fluctuations has been solved.

- Pulsation of temperature with the amplitude of ten minus 2 power degrees and for periods of about 4-6 min have been measured and described.

- Height dependence of the external scale of inertional interval of turbulence variations and speed of turbulent energy dissipation have been recovered.

- The result of wind speed and direction determination are in good agreement with radiosonde data.

- The developed microwave remote sensing method of turbulence investigations can be applied in nonstationary conditions of hurricanes or inversion destruction.

References

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