ACOUSTIC PULSE PROPAGATION THROUGH STABLY STRATIFIED LOWER ATMOSPHERE

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1. INTRODUCTION

There are several problems in atmospheric acoustics, which require taking into account the influence of both the mean stratification and fluctuations of wind speed and temperature on acoustic signal propagation through atmosphere. These problems include a location of various acoustic sources in the atmosphere, a prediction of sound levels from pulse and noise sources, and acoustic remote sensing of the atmosphere. To solve them one needs to parameterize the statistical characteristics of wind speed and temperature fluctuations for calculating a statistics of the parameters of acoustic signals such as travel time, duration and arrival angles.

It is necessary to note that the parameterization of turbulence statistics in stably stratified atmospheric boundary layer (ABL) is still a problem, since these characteristics at high Richardson numbers can not be described by means of the existing similarity theories, most of which are based on the assumption about the turbulence as being locally homogeneous and stationary. It is recognized now that different types of instabilities of internal gravity waves (IGWs) may be a source of a small-scale turbulence and meso-scale eddy structures (such as “cat eyes”, “filaments”, “banks” and others) in stable ABL (Gossard and Hooke, 1975). Such turbulence coexists and continuously interacts with the IGWs, so the statistical properties of the IGWs affect the statistics of turbulence in stably stratified ABL.

The IGWs itself induce meso-scale wind speed and temperature fluctuations in stable ABL with the periods from a few minutes to a few hours. Their horizontal scales are ranging from hundred metres to a few km. These fluctuations cause fluctuations of the parameters of acoustic signals propagating through ABL, such as travel time, amplitude, duration, and the angles of arrival of the acoustic signals. To obtain statistics of the parameters of acoustic signals one needs to know a form of the frequency-wavenumber spectrum of the wind speed and temperature fluctuations induced by IGWs. Such a need motivated our study of the effects of meso-scale wind speed fluctuations associated with IGWs on the statistical characteristics of the parameters of the acoustic pulses in stable ABL. Below we describe experimental and theoretical results of this study.

2. MEASUREMENT OF ACOUSTIC TRAVEL TIME FLUCTUATIONS.

To measure meso-scale wind speed and temperature fluctuations we used an acoustic pulse sounding method. This method is some kind of acoustic tomography of stable ABL based on the existence of an acoustic wave guide near ground surface due to formation of the temperature inversion and vertical wind shear.

The field experiment was conducted in August 2002 at the base of the Institute of Atmospheric Physics near Zvenigorod. For sounding of the ABL we used a special acoustic pulse generator and four receivers placed on the ground at different distances from the generator. The stratification of the ABL was controlled by Doppler Sodar, Temperature Profiler and meteorological mast with the acoustic anemometers mounted at the heights of 6 m and 56 m above ground surface.

Acoustic pulses of stable form were generated due to detonation of the air-propane mixture with the repetition period of 30sec. One of the acoustic pulses at a distance of 20m from the generator is shown in the upper part of Fig.1. When propagating in the acoustic wave guide the initial signal “splits” at a distance of 2.6 km into a set of arrivals A, B, C, and D, as seen in Fig.1. Such evolution of the pulse wave form with distance was earlier explained theoretically.

For each signal radiated at the moment t we measured the time interval $\Delta T(t)$ between the arrivals (A) and (D) with the accuracy of 2 msec . By measuring temporal variations of this interval $\delta T(t)= \Delta T(t)-\Delta T_0$ relative to its initial value ΔT_0 we were able to calculate the temporal variations $(\delta c_{eff})(t)$ of the effective sound speed $c_{eff}=c+V_e$ averaged over the selected ray trajectory connecting the source and each receiver. Here c is the sound speed and V_e is the projection of the wind velocity along the radius-vector directed from the source to the receiver. The main contribution to the travel time fluctuations comes from some portion of the ray trajectory near its turning point.

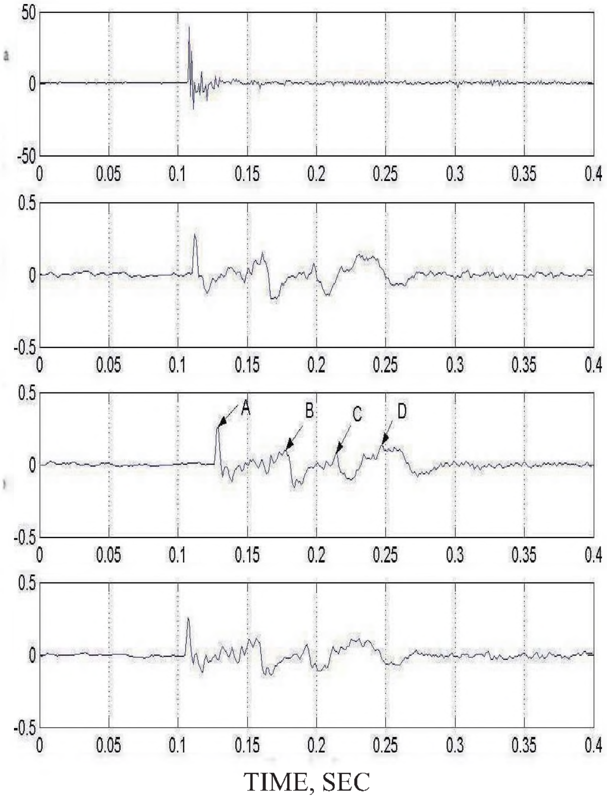

Fig.1. One of the acoustic signals recorded near the source at a distance r=20m (top), and far from the source at r=2550m (Vertical axis is an acoustic pressure in Pa). The signal was received by a 5-m triangle array of receivers. A,B,C, and D are different arrivals of the signal.

3. RESULTS AND DISCUSSIONS.

The temporal fluctuations of the pulse travel time measured in the night hours of August 13, 2002 by a 200-m triangle array are shown in Fig.2. For these time series we have calculated the coherences K_{ij} and the corresponding phase spectra φ_i- φ_j between the pairs of receivers i and j of a triangle array, where i,j=1,2,3. The calculated coherences showed a low-frequency peak ~ (0.7÷0.98) within a low frequency interval (0.6÷1.7) 10^{-3} Hz (the corresponding periods are between 10 min and 28 min). Within the same frequency interval the sum of phase differences was close to zero, and this fact indicated a wave like character of the observed low-frequency fluctuations. Only those frequencies were selected, for which the condition $\Sigma\varphi\approx 0$ was met. Beside a low-frequency peak this condition was also met for the frequencies 6.7 10^{-3} Hz (period 2.5 min) and 1 10^{-2} Hz (period 1.5 min). Thus, there existed a number of dominant frequencies, for which all the coherences reached maxima.

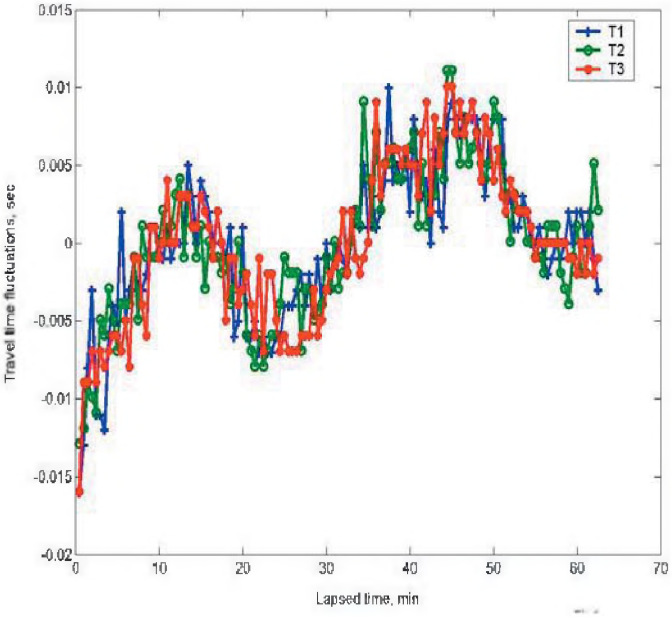

Fig.2. Temporal fluctuations $\delta T(t)$ (vertical axis) of the pulse travel time measured on August 13, 2002 (22:40-22:50) by a 200-m triangle array R1-R3.

For the obtained dominant frequencies we have estimated (by using phase spectra at a triangle array) the horizontal phase velocities V_p of the observed fluctuations and their direction of propagation. The value of V_p as found decreases from 5.5 m/s at a period of 28min to about 2m/s at a period of 8min. The obtained periods and phase velocities are typical for the internal waves often observed in stably stratified ABL. The corresponding horizontal wave lengths of these fluctuations $\lambda= V_p /f$ decrease from 8.6 km at a period of 28 min to 960m at a period of 8min. At shorter period (2.5 min) the wavelength $\lambda\approx$270m.

Within the range of periods (2.5 ÷10)min the observed fluctuations are likely induced by the trapped IGWs in the wave guide formed near ground surface by the mean stratification of the Brunt-Väisäla frequency and wind speed in stable ABL. This was clearly seen from the vertical profiles (not shown here) of BV-frequency, and wind speed in the lower 400-m atmospheric layer. The same dominant periods were also found in the frequency auto-spectra of travel time fluctuations obtained during the period of measurements (August 9-August 13, 2002). Despite a temporal variability of the obtained experimental spectra their average power law decay was close to the predicted theoretical power law $\varepsilon\ \omega^{-2}$, where ε is the mean rate of wave energy input from the random internal wave sources.

REFERENCES

GOSSARD, E.E., AND W.H. HOOKE (1975) “WAVES IN THE ATMOSPHERE,” *ELSEVIER, AMSTERDAM*, 456 PP.