SOUND TRAVEL TIME FLUCTUATIONS CAUSED BY ATMOSPHERIC GRAVITY WAVES

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1. Introduction

Atmospheric gravity waves (AGWs), generated from various random sources (wind shear instabilities, jet streams, meteofronts, orography, convection), significantly contribute to the power spectrum of the mesoscale wind speed and temperature fluctuations in the atmosphere. The temporal scales of wave-associated fluctuations in the lower atmosphere may range from 1 min to several hours, whereas spatial scales are between hundred meters and several dozens of kilometers (Gossard and Hooke, 1975).

Despite an important role of AGWs in formation of a turbulent regime in the middle atmosphere and the stable atmospheric boundary layer (ABL) (Einaudi & Finnigan, 1993; Otte&Wyngard, 2001), the statistics of wave-associated wind speed and temperature fluctuations is poorly understood till now. The AGWs also cause the variations of refraction index for acoustic waves, propagating in the atmospheric wave ducts at long distances from their sources. To predict the mean square values of phase and amplitude fluctuations of acoustic waves one needs to know a form of the power spectrum of the mesoscale wind speed and temperature fluctuations in the atmospheric wave duct. Particularly, this is necessary for the acoustic sounding of stable ABL, acoustic source detection, and prediction of low-frequency sound levels from various explosive and noise sources.

Although a theory of sound propagation through an atmosphere with locally isotropic and homogeneous turbulence is well developed by now (Tatarskii, 1971), there is still a problem to describe the influence on sound propagation of energy-containing mesoscale atmospheric fluctuations, caused by AGWs. Such fluctuations are substantially anisotropic and inhomogeneous in space, and nonstationary in time, and their 4D frequency-wavenumber spectrum, needed for sound propagation modeling, is generally unknown to us.

In this paper the calculations of statistical characteristics of sound travel time fluctuations caused by AGWs are presented. These calculations are used to interpret the experimental data on the statistics of acoustic pulse travel time fluctuations in stable ABL.

2. Model of sound travel time fluctuations induced by AGWs.

The small-scale AGWs, which are often observed in stable ABL with the echo-records of sodars (Kjellaas *et al.* 1974), have rather low horizontal speeds, usually less than 10m/s. Therefore, for such waves are of great importance the effects of advection by the larger scale AGWs which are trapped within stably stratified layers of the lower troposphere, but penetrate down to the ABL (Gossard and Hooke, 1975).

The effects of advection of small-scale waves by a nonstationary wind induced by an entire spectrum of waves was taken into account in the models of AGW spectrum developed in recent works (Chunchuzov, 2002; Hines 2001). The strong nonlinear interactions between AGWs are shown to lead to the universal form for the high-wavenumber tail of the AGW spectrum. The 3D spectrum of both temperature and horizontal wind speed fluctuations decays with a wavenumber k as k^{-5}, whereas 1D vertical wavenumber spectrum takes a universal k_z^{-3}-form (Chunchuzov, 2002). Based on the obtained spectral forms the vaiances, frequency spectra and structure functions of sound travel time fluctuations have been calculated. The frequency spectrum normalized by the Brunt-Vaisaala (BV)-frequency N and the mean square value of travel time fluctuations $<\delta\tau^2>$ is shown in Fig. 1.

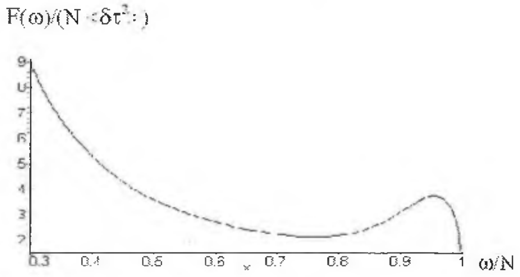


Fig. 1.The normalized frequency spectrum of sound travel time fluctuations caused by AGWs .

This spectrum decays with an increase of frequency ω as ω^{-2}, but when ω approaches the local value of BV-frequency N(z) at a height z the spectrum exhibits a local maximum (or "shoulder") due to in-phase interference at ω ~ N between incident and reflected gravity waves. Prediction of the spectral peak near N is consistent with the existence of a dominant period of 8 min in the experimental frequency spectra and coherences of acoustic pulse travel time fluctuations in the stable ABL (next section).

3. Measurements of acoustic pulse travel time fluctuations in stable ABL.

Several field experiments on acoustic pulse sounding of stable ABL have been carried out near Zvenigorod (Russia). One case of measurements of travel time of acoustic pulses, generated by a detonation of the air-propane mixture with a repetition period of 1min, is shown in Fig.2. To estimate the horizontal coherences, the speeds and scales of the observed wind speed fluctuations in stable ABL we have placed two acoustic reseivers at the same distance of 2.6 km from a pulse source, but along different azimuths relative to the mean wind speed direction.

The 1.5-h time series of the fluctuations of the pulse travel time $\delta\tau$ are shown in Fig.2 along with the fluctuations of the effective sound speed C_{eff} (measured by the anemometer at a height of 56 m), and atmospheric pressure P (measured by microbarograph) . For these time series, obtained at the three different points 2.6 km apart, the calculated auto-spectra and the coherences are shown in Fig. 3

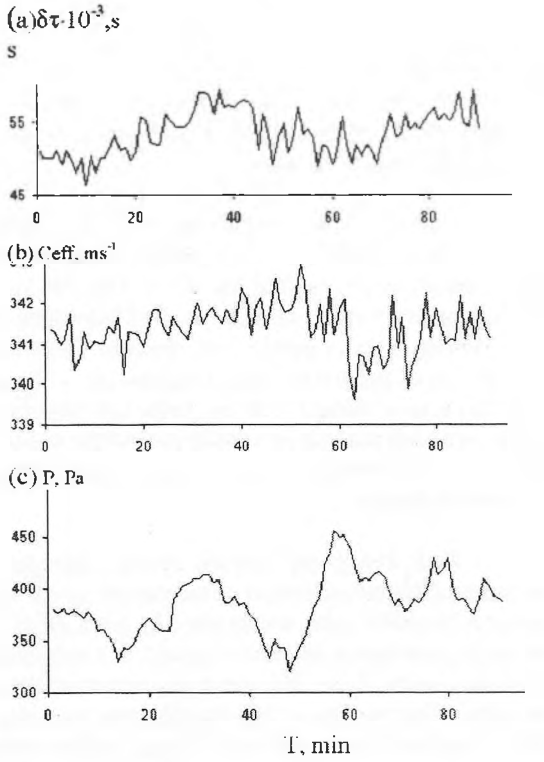
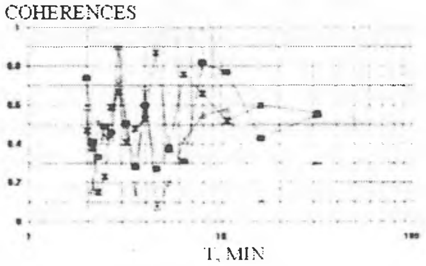


Figure 2. The time series of travel time fluctuations T, effective sound speed Ceff and atmospheric pressure P during October 10, 1995, obtained at the three points 2.6 km apart. a) T; b) Ceff at z=56 m ; c) P.



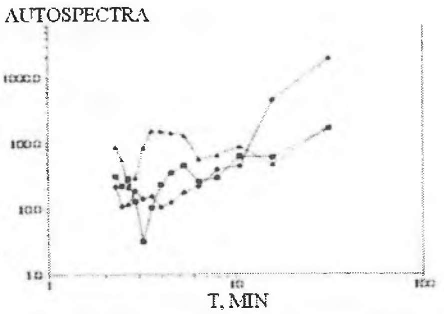


Figure 3. Coherences and Autospectra for the time series shown in Figure 2.

In Fig.3 the obtained autospectra tend to decrease with an increase of period T, but have a broadband maximum ("shoulder") between 5 min and 10 min. As follows from the theoretical model of AGW spectrum in section 2 such a maximum may arise due to contribution to the observed wind fluctuations from the trapped gravity wave modes in the lower atmosphere. The appearance of the "shoulder" in the frequency spectra of travel time and wind speed fluctuations in stable ABL shows that AGWs significantly contribute to the observed fluctuations. This is also confirmed by a presence of the peak of coherences at T≈ 8-10 min seen in Fig.3. For T ranging from 8 to 10 min the sum of the phase differences between each pair of three receivers is close to zero, and this also indicates that such fluctuations are likely caused by AGWs. The intrinsic frequencies of the observed AGWs are close to the typical BV-frequency values (~ $2\cdot10^{-3}$ Hz) in the troposphere, where the mean temperature lapse rate is about 6° C per 1 km. Therefore, we suggest that observed AGWs may be trapped in stable layers of lower troposphere, where a profile of N(z) has a typical maximum value close to $2\cdot10^{-3}$ Hz (Gossard and Hooke, 1975). The estimated from the phase spectra horizontal phase speed and wavelength λ are about 7m/s and 3.4 km, respectively.

4. References

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