CONSIDERATION OF THE EXCESS TURBULENT ATTENUATION IN SODAR MEASUREMENTS OF THE STRUCTURAL CHARACTERISTIC OF THE TEMPERATURE FLUCTUATIONS

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The iterative algorithm is proposed that allows one to consider acoustic signal losses due to the excess turbulent attenuation in the interpretation of sodar measurements of the structural characteristic of the temperature fluctuations. Some experimental results are presented.

Nowadays monostatic sodars are widely used to measure the structural characteristic of the temperature fluctuations C_T^2. However, the problem of quantitative estimation of C_T^2 is still at the stage of methodical studies. A comparison of sodar data with *in situ* measurements has shown that the standard deviation may be as great as 40% within the 30–500-m altitude range, whereas the maximum deviation may reach 100% (with allowance for the surface temperature and relative humidity). We believe that the above-indicated discrepancy in the sodar and *in situ* measurements is caused primarily by the excess turbulent attenuation of an acoustic signal when it propagates along a path to a sounded volume and backward to a receiver. In the present paper, the iterative algorithm has been proposed that allows one to consider acoustic signal losses due to the excess turbulent attenuation. The algorithm has been implemented for interpreting measurements of C_T^2 with the Zvuk–1 sodar. The sodar design was described in detail in Ref. 1. The sodar specifications are presented below.

Sensing range, m 500
Operating frequency f, Hz 1650–1850
Transmitted electric power P_0, W 65
Acoustic pulse repetition period, s 4; 6
Acoustic pulse duration τ, ms 150
Effective area of the receiving antenna A, m^2 .... 0.5

The structural characteristic of the temperature fluctuations was determined as follows. From the equation of monostatic sounding

$$P(z) = P_0\gamma_1\,\gamma_2\,\sigma_\pi(z)(c\tau/2)(A/z^2)L(z) \tag{1}$$

the acoustic backscattering cross section $\sigma_\pi(z)$ was found, where $P(z)$ is the power of the acoustic signal coming from altitude z, γ_1, and γ_2 characterize the efficiency of the electric energy conversion into the acoustic energy and *vice versa*, c is the sound speed in air, and $L(z)$ considers the signal attenuation on paths to the scattering volume and backward to the receiver. The structural characteristic of the temperature fluctuations $C_\mathrm{T}^2(z)$ was determined from the formula

$$C_\mathrm{T}^2(z) = 1.35\cdot 10^2\,\sigma_\pi(z)T^2\,\lambda^{1/3}, \tag{2}$$

where $\lambda = c/f$ is the acoustic radiation wavelength and T is the surface air temperature.

The iterative algorithm was constructed in the following way.[2] The first iteration of the structural characteristic of the temperature fluctuations $C_\mathrm{T}^{2(1)}(z)$ was calculated from acoustic sounding equation (1) without considering the excess turbulent signal attenuation on the sounding path, that is, for $L(z) = 1$.

The first iteration $C_\mathrm{T}^{2(1)}(z)$ was then used to calculate the excess turbulent signal attenuation

$$L(z) = \exp\left\{-2\Delta z\sum_{i=1}^{N}\left[\beta_\mathrm{v}(z_i) + \beta_\mathrm{T}(z_i)\right]\right\}, \tag{3}$$

where $\Delta z = 8$ m is the altitude resolution of the sodar, z_i is the current altitude of the sounded volume, N is the number of strobe pulses of length Δz between the transmitter and the sounded volume, $\beta_\mathrm{v}(z)$ is the coefficient of scattering by turbulent wind inhomogeneities, and $\beta_\mathrm{T}(z)$ is the coefficient of scattering by turbulent temperature inhomogeneities. For $L_0^2 \gg \lambda^2$, where L_0 is the outer scale of the atmospheric turbulence, the scattering coefficients are given by the following expressions[3]:

$$\beta_\mathrm{v}(z) = 9.542\,\frac{C_v^2(z)}{C^2}\,\frac{L_0^{5/3}(z)}{\lambda^2}, \tag{4}$$

$$\beta_\mathrm{T}(z) = 0.3596\,\frac{C_\mathrm{T}^2(z)}{T^2}\,\frac{L_0^{5/3}(z)}{\lambda^2}. \tag{5}$$

In calculating the scattering coefficients from Eqs. (4) and (5), $C_\mathrm{T}^{2(1)}(z)$ was taken as $C_\mathrm{T}^2(z)$. Because we did not measure the vertical profile of the structural characteristic of the wind velocity fluctuations, it was approximated with the use of the empirical relation

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$$C_{\mathrm{v}}^2(z) = C_{\mathrm{v}_0}(0.04 + 0.33 z^{-2/3}), \tag{6}$$

suggested by Brown and Clifford[4] for daytime convection. Here, the structural characteristic of the wind velocity fluctuations in the surface atmospheric layer C_{v_0} was measured with micropulsation sensors described in detail in Ref. 5.

In calculating the scattering coefficients from Eqs. (4) and (5), the outer scale of the atmospheric turbulence was given by the expression[6]

$$L_0(z) = \left(\frac{C_{\mathrm{T}}^2(z)}{2.8\gamma_a^2}\right)^{3/4}, \tag{7}$$

where γ_a is the adiabatic temperature gradient.

By substituting the calculated factor of the turbulent attenuation into Eq. (1), we obtained $\sigma_\pi(z)$ and by substituting it into Eq. (2), we obtained the second iteration of the structural characteristic of the temperature fluctuations $C_{\mathrm{T}}^{2(2)}(z)$. With the use of $C_{\mathrm{T}}^{2(2)}(z)$, we calculated the turbulent attenuation factor and by substituting it into Eq. (1), we calculated $\sigma_\pi(z)$. The third iteration $C_{\mathrm{T}}^{2(3)}(z)$ was then calculated with the use of $\sigma_\pi(z)$ and so on, until the difference between the current and previous values of $C_{\mathrm{T}}^2(z)$ became less than the preset error value. The iteration process terminated when next iterations started to diverge. The iterations were calculated sequentially for each strobe pulse $i = 1, \ldots, N$.

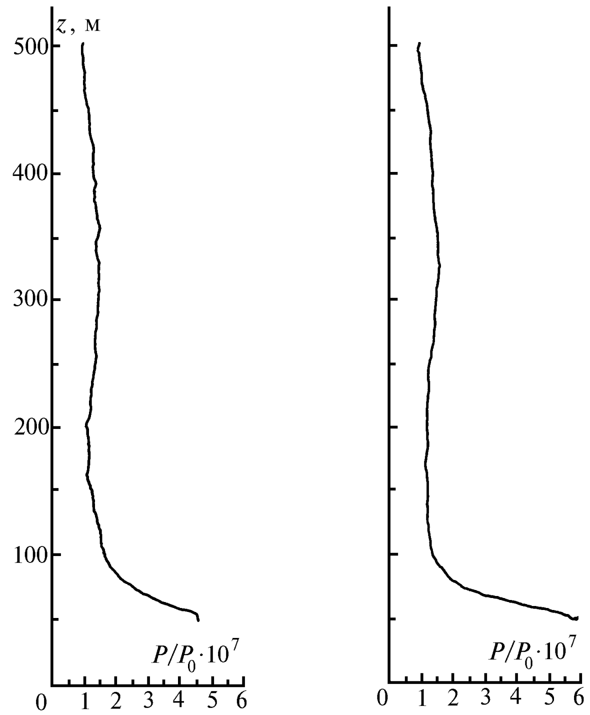

FIG. 1. Vertical profiles of sodar signals. The measurements started at 16 h, *Tomsk LT. The signals were averaged over* 10-min *periods. The normalized signal power is plotted on the abscissa.*

Figure 1 shows the vertical profiles of the normalized acoustic signal power for two successive sodar measurement runs started at 16 h, Tomsk LT, and averaged over 10-min periods. The measurements were performed in summer. Figure 2 shows the vertical profiles of C_{T}^2 for successive measurement runs (curves *1–4*) normalized by the value of C_{T}^2 for $z_i = 48$ m. The dependence $C_{\mathrm{T}}^2(z) \sim z^{-4/3}$ typical of the daytime convection is also shown in Fig. 2.

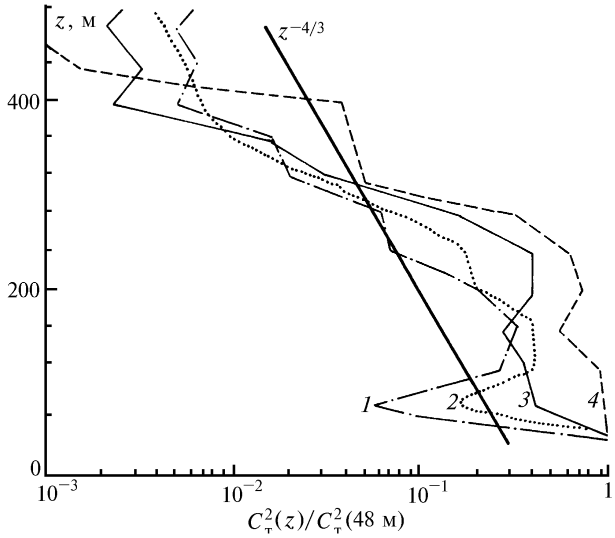

FIG. 2. Vertical profiles of C_{T}^2 derived from the data of acoustic sounding considering the excess turbulent signal attenuation.

The results of comparing demonstrate that the derived profiles of C_{T}^2 obey the law $z^{-4/3}$ to altitudes as great as 300 m. Above 300 m, a faster rate of C_{T}^2 decrease was repeatedly observed.

The magnitude of the correction for the turbulent attenuation given by the formula

$$\delta C_{\mathrm{T}}^2(z_i) = \frac{C_{\mathrm{T}}^{2(k)}(z_i) - C_{\mathrm{T}}^{2(1)}(z_i)}{C_{\mathrm{T}}^{2(k)}(z_i)} \cdot 100\%, \tag{8}$$

where $C_{\mathrm{T}}^{2(k)}(z_i)$ is the final kth iteration of C_{T}^2, is illustrated by Table I.

TABLE I.

z_i, m	80	104	144	208	256	304	352	400	480
$\delta C_{\mathrm{T}}^2(z_i)$, %	2.8	5.15	8.97	11.3	14.83	25.18	41.11	84.11	92.4

It is seen that the contribution of the excess turbulent attenuation increases as the sounding altitude increases. It reaches 25% for $z_i = 304$ m and 92.4% for $z_i = 480$ m. These results clearly indicate the necessity of consideration of the excess turbulent signal attenuation in sodar measurements of C_{T}^2.

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