EXPERIMENTAL INVESTIGATION OF THE FEASIBILITY OF MEASUREMENT OF THE STRUCTURE CHARACTERISTIC OF TEMPERATURE FIELD OF THE ATMOSPHERE BY ACOUSTIC METEOROLOGICAL STATION

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The results of experimental investigation of the feasibility of measurement of the structure characteristic of the air temperature by acoustic meteorological station are presented. It is shown that the turbulent state of the atmosphere can be determined quite accurately with the help of the precision acoustic meteorological station.

Turbulent air inhomogeneities engender random spatiotemporal structure of the refractive index field of the atmosphere. This structure undergoes local dynamic perturbations attendant to changes in the current weather situation. Therefore, the results of many investigations performed with the use of optical devices can be well–grounded exclusively in the case in which the atmospheric turbulence is taken into account in data processing.

In the wide range of spatial frequencies of permittivity fluctuations the only characteristic of this process is the parameter

$$C_T^2 = C_\varepsilon^2 / C_{\varepsilon T}^2 \qquad (1)$$

referred to as the structure characteristic of temperature fluctuations,[1] where $C_;^2$ is the structure characteristic of permittivity fluctuations, and $K_{\varepsilon T} = 2{\cdot}10^{-6} <P>\times$ $\times <T>^{-2} (77.6 + 0.584\,\lambda^{-2})$ is constant at the fixed pressure $<P>$, wavelength λ, and temperature $<T>$.

The objective of this experiment is the investigation of the feasibility of measurement of the structure characteristic of temperature with the help of an acoustic meteorological station.

The relation between the structure characteristics of permittivity and refractive index fluctuations is also well–known

$$C_\varepsilon^2 = 4\,C_n^2 \,. \qquad (2)$$

In this way we can determine the structure characteristic of temperature fluctuations by means of calculation of the structure characteristic of the refractive index fluctuations

$$C_T^2 = C_n^2 \left[\frac{10^6\,T^2}{79\,P} \right]^2 , \qquad (3)$$

where

$$C_n^2 = \frac{1}{0.344}\, K^{-7/6}\, L^{-11/6}\, \sigma_{IR}^2 \,. \qquad (4)$$

Having measured the relative variance of the intensity fluctuations for the spherical wave $\sigma_{IR}^2 = \dfrac{<I^2>}{<I>^2} - 1$ and by substituting the values of the wave number K and the measurement path length L into Eq. (4) and the atmospheric pressure P and the temperature T into Eq. (3), we can determine the value of C_T^2 sufficiently accurately.

It also can be determined by means of the direct measurements of the temperature pulsations since the structure constant of the random temperature field is

$$C_T^2 = D_T(r)\, r^{-2/3} \,, \qquad (5)$$

where $D_T(r)$ is the structure function of the random temperature field

$$D_T(r) = <[T(r_1 + r) - T(r_1)]^2> \,. \qquad (6)$$

Accepting a hypothesis of "frozen" turbulence, Eq. (6) can be written down in the form

$$D_T(\mathbf{v}\tau) = <[T(r_1 + \mathbf{v}\tau) - T(r_1)]^2> \,, \qquad (7)$$

where **v** is a three–dimensional vector of the wind velocity.

In such a manner by measuring the temperature inside a bounded volume at the regular intervals τ, we can determine the value of $D_T(r)$ and, by substituting it into Eq. (5), finally obtain the value of the structure constant of temperature fluctuations C_T^2.

Several types of acoustic anemorhumbothermometers and meteorological stations[2,3] were designed and produced by the author. A block diagram of the last model of the acoustic meteorological station is shown in Fig. 1.

In September of 1992 the field experiment was performed. The structure characteristic of temperature field of the atmosphere was measured by the optical method and with the use of the direct measurement of temperature pulsations. An experimental setup is shown in Fig. 2.

An LG–52 helium–neon laser with a wavelength of 0.6328 μm was utilized as a source of a spherical wave in optical measuring device. A plane mirror 100 mm in diameter was used as a reflector to ensure complete interception of the light beam. A photomultiplier FÉU–79 equipped with an interference filter and input diaphragm 0.2 mm in diameter surved as a detector.

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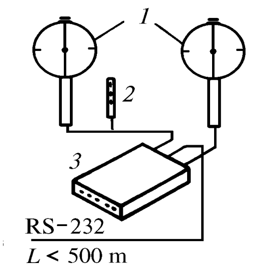

FIG. 1. A block diagram of the three–component two–level acoustic meteorological station: 1) acoustic three–component sensor, 2) humidity gauge, and 3) resident computer and pressure gauge.

Four acoustic meteorological sensors located on different sections of the optical measurement path were utilized for direct measurements of the temperature pulsations. Two of them, measuring the temperature of air in a volume, were positioned at the center of the path at altitudes of 2 and 6 m, and had a measurement frequency of 7 Hz. Two other sensors were positioned at the ends of the path and had a measurement frequency of 1 Hz and four times less accuracy. The synchronous recording of information was performed on a modified multiprocessor measuring complex[4] under various meteorological conditions over the course of 120 minutes.

Two realizations providing most comprehensive idea of the entire range of temperature fluctuations were selected from a large number of realizations. Results of calculation of the structure characteristic of temperature pulsations are shown in Figs. 3 and 4.

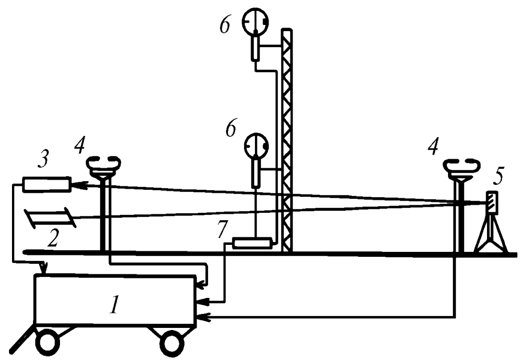

FIG. 2. The experimental setup: 1) transportable multiprocessor recording complex, 2) helium–neon laser, 3) photomultiplier with pre–amplifier, 4) acoustic anemorhumbothermometer, 5) flat mirror, and 6 and 7) intellectual acoustic meteorological station.

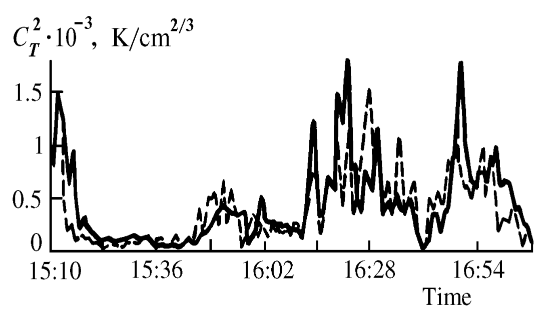

FIG. 3. Structure characteristic of temperature pulsations for moderate and strong temperature fluctuations. Solid line shows the data of the optical measurement and dashed line – the data of the acoustic measurement.

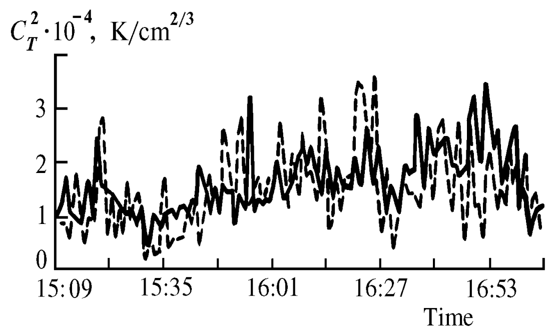

FIG. 4. Structure characteristic of temperature pulsations for weak temperature fluctuations. Solid line shows the data of the optical measurement and dashed line – the data of the acoustic measurement.

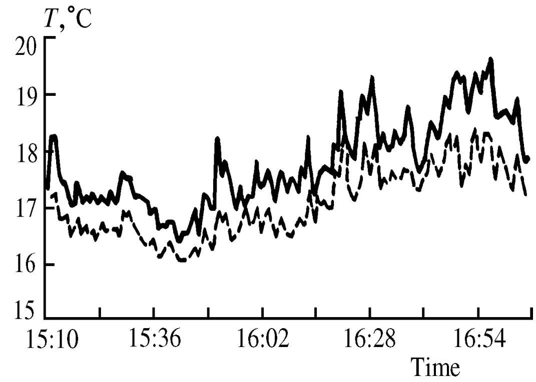

FIG. 5. Local temperature for realization shown in Fig. 3. Solid line denotes the temperature at an altitude of 2 m *and dashed line – at an altitude of* 6 m.

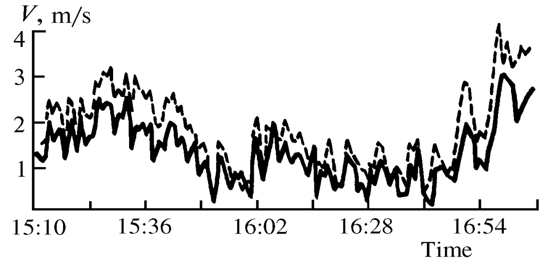

FIG. 6. The resultant modulus of the wind velocity for realization shown in Fig. 3. Solid line denotes the wind velocity at an altitude of 2 m *and dashed line – at an altitude of* 6 m.

Results shown in Fig. 3 were obtained under conditions of well–developed cumulus cloudiness. The minima in C_T^2 coincide with the time when the Sun was screened by clouds and from 15:31 to 15:47 it was slightly raining. The maxima were found at the time when the Sun shone through breakes in clouds. The distributions of the temperature and resultant modulus of the wind velocity V at that time are shown in Figs. 5 and 6, respectively.

These data were taken from the two acoustic sensors of the intellectual meteorological station positioned at the centre of the optical path. The first sensor was located at an altitude of 2 m and the second was placed 4 m higher. The instantaneous values of temperature used for C_T^2 determination were taken from the lower sensor. Spread of the values of C_T^2 obtained by means of direct measurements of temperature and that obtained by means of measuring the intensity fluctuations of a laser beam is explained by the fact that the temperature of air was measured locally while the intensity fluctuations were measured on 100–m path, i.e., spatial averaging took place in the last case. The cross–correlation coefficients is 0.74.

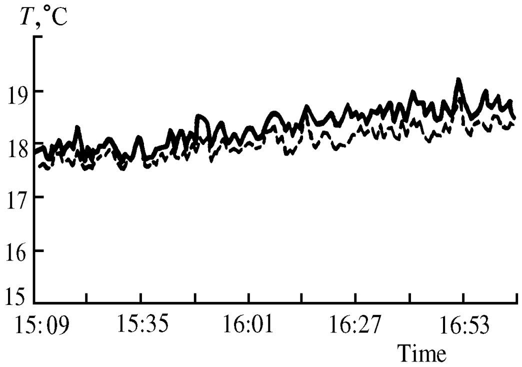

FIG. 7. Local temperature for realization shown in Fig. 4. Solid line denotes the temperature at an altitude of 2 m *and dashed line – at an altitude of* 6 m.

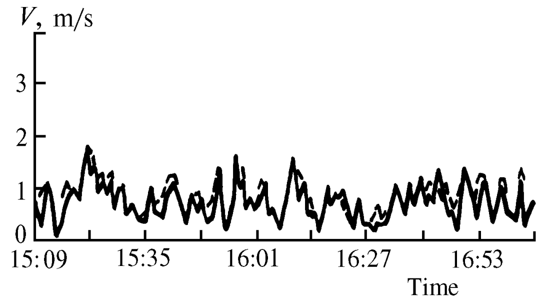

FIG. 8. The resultant modulus of the wind velocity for realization shown in Fig. 4. Solid line denotes the wind velocity at an altitude of 2 m *and dashed line – at an altitude of* 6 m.

The temporal behavior of C_T^2 under calm cloudy weather conditions calculated from the data of the same sensors as in the above–described experiment are shown in Fig. 3. The temporal behavior of temperature and resultant modulus of the wind velocity for this realization are shown in Figs. 7 and 8, respectively. In the both first and second cases we can see a good agreement between the values of C_T^2 measured by the principally different methods.

The accuracy of the temperature measurement by the acoustic meteorological station is equal to 0.05°C and the error of the measurement of the intensity of the laser beam was less than 0.1%. The variance of temperature fluctuations was derived from $N = 100$ readings with a sampling frequency of 1.6 Hz. Since the normalized random error in calculating the variance was equal to[5]

$$\varepsilon(\sigma_T^2) \approx \frac{1}{\sqrt{N}}\,, \qquad (8)$$

the measurement error of the structure constant of temperature fluctuations must be less than 10% in this experiment.

In conclusion it should be noted that in most atmospheric situations the measurement of the structure characteristic of the temperature field of air by the acoustic meteorological station ensures accuracy sufficient for applied research.

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