LIDAR SOUNDING OF AEROSOL VERTICAL MOTION IN THE LOWER ATMOSPHERE

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This paper proposes a technique of correlation measurement of the profile of aerosol vertical motion by means of a lidar based on the temporal correlation analysis. The results of experimental investigations are discussed.

The solution to the predicting problems on the transfer of pollution in the lower atmosphere is conventionally based on the atmospheric diffusion equation[1] that combines impurity concentration with characteristics of the three–dimensional field of wind velocity and coefficient of turbulent diffusion.

Model representations that use the near–ground and generalized meteorological data[1] are developed for the coefficient of turbulent diffusion, but profile measurements, especially the real–time ones, are more preferable for the wind velocity. The technical means of remote sensing of the atmosphere available now are capable of determining the profiles of the wind velocity with an accuracy acceptable for a lot of applications.

Active means of laser sounding, i.e., lidars that realize correlation or Doppler's principles of measuring the velocities (see, for example, Refs. 2 and 3) have here the great possibilities.

The rate of vertical motions was excluded from the consideration for many cases of the pollution transfer analysis because it is essentially less than the horizontal wind speeds. That simplified the solution of the diffusion equation. At the same time, the situations are not rare when one cannot neglect the vertical speed. Such situations are the calm conditions when horizontal speeds are small and diffusion of impurities is determined by vertical motions. Among the vertical fluxes the disordered vertical velocities describing the phenomena of the scale up to a few hundred meters and having the greatest velocities are of the most interest.

Measurement of vertical speeds in these cases can be realized by means of noncoherent aerosol lidar with vertical direction of sounding and subsequent correlation or spectral processing of signals. The traditional balloon–borne means are inefficient in such situations.

In this paper we analyze the methodical aspects for estimate of disordered vertical velocities by means of noncoherent aerosol lidar under the calm conditions.

Atmospheric aerosols involved by air flows accompany the vertical streams and are revealed in temporal and spatial fluctuations of the return signals. The calculated temporal correlation functions between the signals from different altitudes will be shifted relatively zero shift, and the shift scale is uniquely connected with the value of the vertical flux speed.

Investigations were carried out by means of the three–path lidar[2] (its block–diagram is shown in Fig. 1) satisfying the conditions of the full correlation analysis application for estimating the value of the three–dimensional wind velocity. Based on the data obtained by this lidar, the conditions were selected when the horizontal wind speeds were small (less than 0.5 m/s), and one of the paths was vertically oriented.

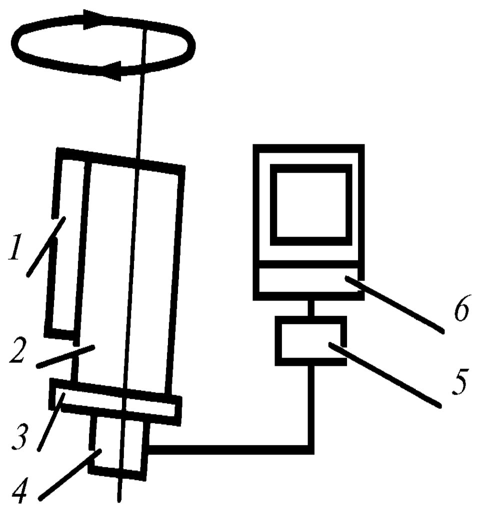

FIG. 1. Block–diagram of the correlation scanning lidar

The methodical aspects of this lidar application to sounding of the horizontal wind speed were considered in Ref. 2. The ILTI–407 commercial–type lidar *1* provided the generation of the short light pulses at the wavelength 0.53 μm with duration 15 ns. The receiving optical system *2* based on the lens objective with the diameter of 30 cm and the focal distance 620 mm was capable of recording the signal from the height about 1 km under evening conditions and 750 m under the daytime conditions. The mechanical device *3* realized scanning of the receiving–transmitting device with the frequency 0.5 Hz along the constituent of the cone without rotation of the optical system around its axis. The photoelectron block *4* provided the transformation of the optical signal into the electrical one that, in turn, was transferred to the input of the 8–bit analog–digital transformer *5* with the period of discretization 66.6 ns. The digital signal was transferred to the computer of IBM PC/AT–286 series where its preliminary processing and recording was carried out.

The signal reflected by the atmosphere was stored in the computer memory in the form of three–dimensional array F_{hjk} where h is the number of the height level, $h = 1, ..., 128$; j is the number of sounding channel, $j = 1, ..., 3$; and, k is the number of the "shot" in the given direction, $k = 1, ..., 1024$. Then two one–dimensional arrays $P_{h_1 j_1}(t)$ and $P_{h_2 j_1}(t)$ were formed from this array, where h_1 and h_2 are the fixed height levels, j_1 is the

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fixed number of the channel, $t = k f$ is the current time where f is the frequency of sending pulses in the given direction. The temporal arrays were subject for the low frequency filtration by means of the Batterwart's digital filter of the sixth order,[4] then the trend was eliminated from the smoothed time series by the method of approximation by the power polynom of the fourth order.[5] Then the Fourier transforms of the processed time series were found

$$F_1(\omega) = \sum_{k=1}^{N} P_{h_1 j_1}(t) \exp(-2\pi i k t f) ,$$

$$F_2(\omega) = \sum_{k=1}^{N} P_{h_2 j_1}(t) \exp(-2\pi i k t f) ,$$

where $\omega = 2\pi f$ is the circular frequency, i is the imaginary unity, $N = 1024$. Then the complex multiplying of the found Fourier transforms was performed

$$F_{12}(\omega) = F_1(\omega)\, F_2^*(\omega) .$$

The asterisk denotes the complex conjugation. By finding the reverse transforms of the complex product we can obtain the mutual correlation function $R_{h_1 h_2}(\tau)$

$$R_{h_1 h_2}(\tau) = \sum_{k=1}^{N} F_{12}(\omega) \exp(2\pi i k t f) ,$$

where τ is the time shift. The value of the time shift was used directly for determining the vertical component of the velocity of air flows at the heights from h_1 to h_2.

The error in the obtained values of the motion rate is generally determined by the methodical and instrumentation errors. Since this technique of measuring the vertical component is based on the algorithms for determining the horizontal component of the wind velocity, the approach proposed in Ref. 2 is quite applicable to the analysis of the measurement errors. The analysis shows that the total error of single measurement does not exceed 28–32%. However, considering that the obtained values of the vertical component were averaged over the number of the height levels between h_1 and h_2 and over three channels in order to increase the accuracy, errors in measuring did not exceed 8%.

Figure 2 presents the typical correlation functions for different levels obtained in June 1988 on the proving ground in Tomsk under conditions when the horizontal wind was less than 0.4 m/s. It is seen from the figure that as the distance between the correlated levels increases, the maximum of the correlation functions is shifted proportional to the spatial difference. Simultaneously the value of the maximum of the correlation function decreases, that is evidence of decreasing in the statistical interrelation between the dynamic atmospheric processes with the increase of the distance between levels. However the values of correlation remain high (about 0.8) even for height difference of 80 m. That notes the weak variability of aerosol structures when transferring them between the levels of obtaining the data that makes it possible to use the "frozen" condition[8] for estimating the speed of the vertical motions V. In so doing the relationship $V = \xi_0 \tau_m$ is valid, where ξ_0 is the distance between the correlated levels, and τ_m is the position of maximum of the mutual correlation function.

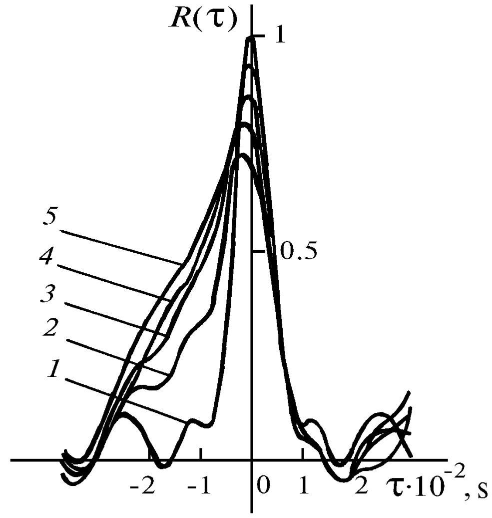

FIG. 2. Typical shape of autocorrelation functions (curve 1) and mutual correlation between levels of 300 *and* 320 m *(2);* 300 *and* 340 m *(3);* 300 *and* 360 m *(4);* 300 *and* 380 m *(5)*

The values of the vertical component of the velocity of aerosol transfer were found based on such correlation functions. The profiles of the vertical component of the velocity of aerosol motion obtained under the daytime and evening conditions on June 12, 1988 in the height range 200–800 m, respectively, are shown in Figs. 3 and 4. It is seen from the figures that the vertical speed of the aerosol in such a height range remains almost unchanged, only insignificantly increases with increasing height.

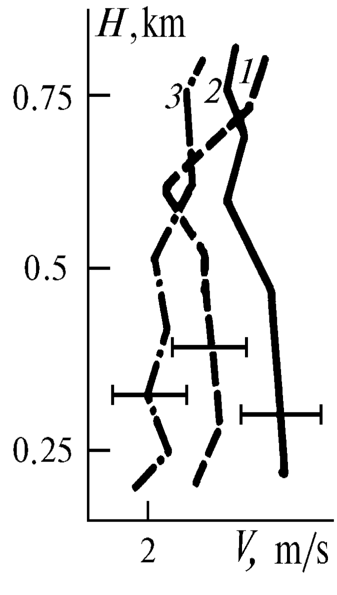

FIG. 3. The velocity of the aerosol vertical motion as a function of height under daytime conditions of sounding along three paths. Horizontal lengths indicate the confidence interval for the probability of 0.95.

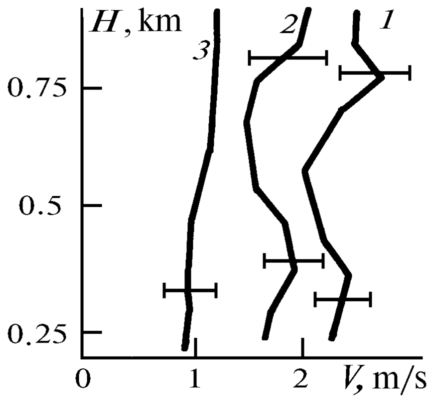

FIG. 4. The same as in Fig. 3 under evening conditions

Then the small increase of the speed of the aerosol vertical motion are related to the daytime conditions connected with stronger heating of the underlying surface under the daytime conditions of sounding and, therefore, with the increase in the intensity of convective processes in the atmosphere.

It is confirmed by the fact that in this time the raising thermal plumes were observed in the return signal of the lidar. The intensity of the fluctuations of lidar signals caused by the thermal "bubbles" of air essentially decreased in the evening. Such a situation is described in Ref. 6 where lidar investigations of the atmosphere were carried out under conditions of the disordered convection.

In conclusion let us note that the possibilities of sounding of vertical component of velocity of aerosol vertical motion by the correlation lidar are not exhausted by the described technique. Similar data can be obtained by correlation analysis not temporal but spatial realizations of the lidar signal. The purposes of further investigations will be obtaining and processing of such data.

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