POSSIBILITY OF INTEGRATED STUDY OF THE SURFACE BOUNDARY LAYER BY REMOTE METHODS

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The result of integrated experimental studies of the atmospheric boundary layer, performed with the help of a Raman scattering lidar, an aerosol lidar, acoustic radar, and an airborne laboratory, are presented. The relation between the vertical distributions of the temperature, humidity, and aerosol is studied. The auto- and crosscorrelation coefficients of the parameters are found. The results presented illustrate the possibility of an integrated approach to the study of meteorological and optical parameters of the boundary layer.

The close interaction and interrelationship of the fields of meteorological quantities in the surface boundary layer (SBL)[1] make it necessary to use an integrated approach to the study of the characteristics of this layer. This approach makes it possible to determine which atmospheric process is most important in the SBL. The development of the means for laser and acoustic sounding opens up qualitatively new possibilities for studying the SBL.[2,3] To this end the experiment "Vertikal'" has been conducted, since 1986, at the Institute of Atmospheric Optics of the Siberian Branch of the Academy of Sciences of the USSR. In this experiment the standard contact methods for measuring the characteristics of the atmosphere using airborne instruments[4] and remote methods using a Raman scattering lidar (RS lidar),[5] a LOZA-4 aerosol lidar,[6] and MAL-2 acoustic radar,[3] are employed. The technical characteristics of these systems are described in Refs. 3–6.

In this paper we present some data obtained in the course of the "Vertical'" program while sounding the surface boundary layer in the region of Tomsk. These data illustrate the possibility of the integrated study of the SBL. Thus Fig. 1. shows the results of sounding obtained by the indicated methods.

One can see from Fig. la that a temperature inversion, observed both in the aircraft and lidar data, is observed in the bottom 300 meters of the SBL. The discrepancies can be explained as follows. First, the methods being compared have different vertical resolution and different time averaging. Second, the aircraft has a higher velocity component, which in the course of the measurements results in a significant horizontal averaging of the recorded characteristic. For this reason it is difficult to expect better agreement between the data than that shown in Fig. 1a.

The data on the altitude distribution of the aerosol attenuation coefficient measured with the RS-lidar and LOZA-4 lidar are compared in Fig. 1b. Both curves have the common feature that in the bottom 300 meters (the inversion layer), where the aerosol concentration is high, high values of the aerosol attenuation coefficient are observed. Above the inversion layer the value of this coefficient drops rapidly, which reflects the fact that the temperature inversion layer acts like a trapping layer. The difference in curves 1 and 2 in Fig. 1b, expressed in the fact that the layers with high values of the aerosol attenuation coefficient do not occur at the same altitude, is explained by fact that different averaging intervals and measurement methods were employed.

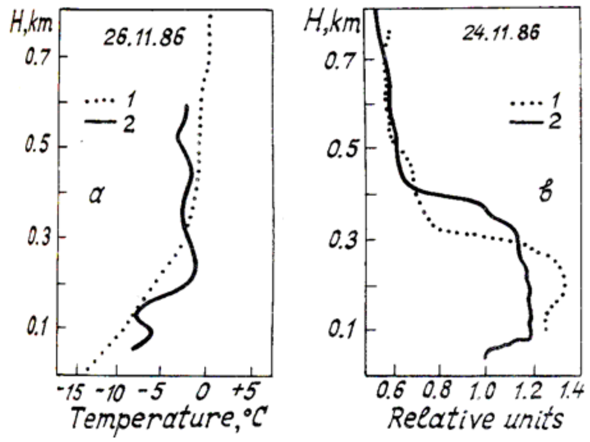

FIG. 1. The vertical distribution of the air temperature (a) according to aircraft data (1) and RS-lidar data (2) and the aerosol attenuation coefficient (b) determined with the LOZA-4 lidar (1) and the RS-lidar (2).

The stable dependence of turbulent aerosol transport in the SBL on the thermal stratification of the layer,[1] which can also be seen in Fig. 1, makes possible a qualitative comparison of the data obtained by laser and acoustic sounding.

It is well known[3] that acoustic sounding gives the general picture of the temperature stratification in the SBL. The results of combined studies of the structure of the SBL by acoustic radar and RS-lidar were presented previously in Ref. 3, and exhibited good agreement. Here, however, we shall compare the data from acoustic sounding with the data obtained with the help of the LOZA-4 lidar and presented in Fig. 2.

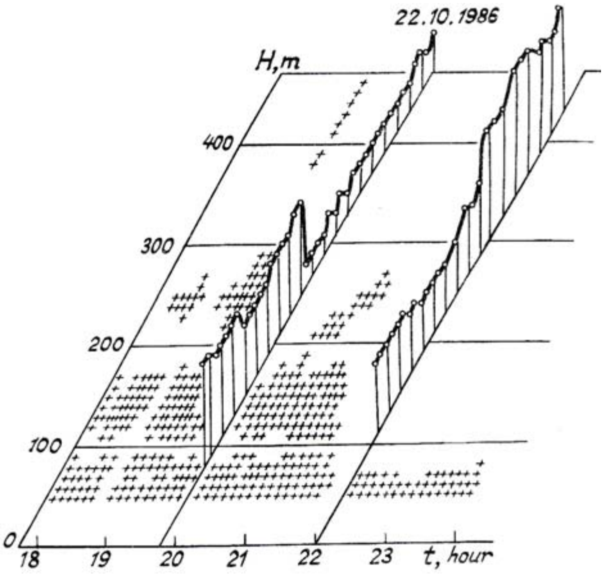

FIG. 2. The results of laser-acoustic sounding of the surface boundary layer. The facsimile recording of the acoustic signal and the profile of the inverse aerosol scattering coefficient.

Figure 2 was constructed as follows. The profile of the inverse aerosol scattering coefficient, normalized at the maximum, recorded by the LOZA-4 lidar, is superposed on a digital two-tone recording of the acoustic signal obtained after processing on a computer. Blackening (cross marks) on the facsimile trace shows increased turbulence in the temperature-inversion layer. The absence of data at the start of the trace corresponds to the "dead zone" of the acoustic radar.

One can see in Fig. 2 that the turbulent regime, which was observed in the period from 18.00 to 19.30 in the bottom 300 meters, gave rise to upward transport of aerosol from the surface layer and accumulation of aerosol in the inversion layer. The profile of the inverted aerosol scattering coefficient, obtained at 19.50, records this process in the form of high values in the layer 0–280 m and a sharp reduction in the values above this layer. In the period from 20.00 to 22.00 the turbulence in the layer 200–300 m became substantially weaker, which was reflected in the profile of the inverted aerosol scattering coefficient recorded at 22.00 h.

Thus the foregoing analysis shows that all techniques, both contract and remote, give complementary information. In addition, the quickness, with which information is obtained with the help of remote methods, makes it possible to study the dynamics of the SBL. This is already evident from Fig. 2, where one can follow well the dynamics of the turbulence in the bottom level of the atmosphere. We shall study it in greater detail using other data.

A characteristic feature of the vertical distribution of the meteorological quantities in the SBL above Western Siberia during the winter is the permanently existing temperature inversion in the layer 0–500 m. This creates exceedingly poor conditions for spreading out pollutants, especially in cities, since at the boundary of the inversion layer turbulence is suppressed, and vertical motions are, as a rule, ascending. The negative factors acting in concert give rise to accumulation of pollutants in the bottom layer.

When the inversion exists for a long time the aerosol accumulation processes are significantly more complicated. A completely different process, which is different from the obviously diurnal process, starts to develop.

We shall analyze the characteristics of this process using the data of Fig. 3, which was constructed from the results of sounding of the temperature, humidity, and aerosol with the RS-lidar. Figure 3 gives information about the so-called sing correlation according to the following principle: "+" indicates positive sign correlation ($0.5 < K \le 1$), "0" indicates an unstable correlation ($-0.5 \le K \le 0.5$), indicates a negative correlation ($-1 \le K < -0.5$).

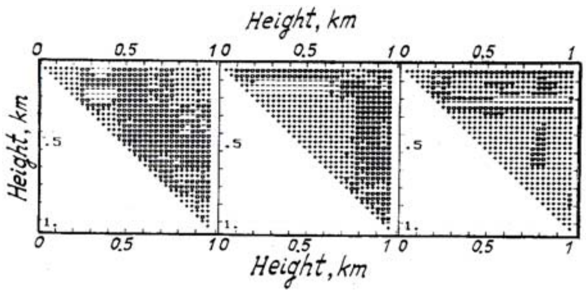

FIG. 3. Matrices of the interaltitude correlation of the temperature (a), humidity (b), and inverse aerosol scattering coefficient (c), obtained with the help of the RS-lidar. The measurement time was 2 h.

One can see from Fig. 3 that the presence of inversion in the bottom 200 meters of the atmosphere destroys the altitude correlation of the change in each parameter. Thus for air temperature and the aerosol a stable positive correlation is observed in the bottom 200 meters. Above 200 meters the autocorrelation breaks down. It is reestablished for the humidity in the layer above inversion, near 200 m, and for aerosol still higher – at 300 m. The behavior of the humidity exhibits its own peculiarities. In the inversion layer a stable negative correlation with the change in humidity in the upper layers is observed. Above the inversion layer, in the layer between 300 and 800 m, stable positive altitude autocorrelation is observed.

Similar results are also observed by averaging the aircraft data for a long period (171 profiles); they are collected in Table I. The obtained data show that for the territory of Western Siberia a temperature inversion during the winter occurs on the average in the layer up to 0.4–0.6 km; this destroys the correlation of the changes in the number density of the aerosol at different altitudes. Above 0.6 km a stable correlation is observed up to a measurement altitude of 2.2 km.

TABLE I.

The interaltitude correlation matrix for the aerosol number density in December above Western Siberia.

H,k	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2
0.0	1	0.70	0.62	0.43	0.46	0.39	0.37	0.26	0.24	0.24	0.24	0.36
0.2		1	0.75	0.46	0.45	0.37	0.38	0.32	0.38	0.26	0.27	0.35
0.4			1	0.60	0.62	0.51	0.53	0.47	0.46	0.45	0.44	0.51
0.6				1	0.81	0.73	0.68	0.71	0.68	0.71	0.71	0.78
0.8					1	0.82	0.77	0.74	0.71	0.75	0.73	0.86
1.0						1	0.82	0.78	0.77	0.74	0.74	0.74
1.2							1	0.95	0.90	0.87	0.85	0.88
1.4								1	0,98	0.97	0.98	0.99
1.6									1	0.96	0.96	0.97
1.8										1	0.98	0.98
2.0											1	0.99
2.2												1

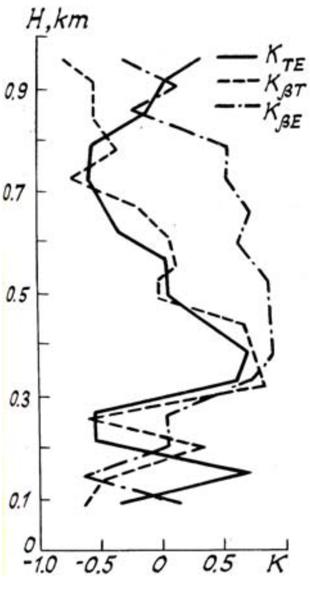

FIG. 4. The vertical distribution of the correlation coefficients of the temperature and humidity (K_{TE}), the inverse scattering coefficient and the temperature ($K_{\beta\tau}$) and the inverse scattering coefficient and the humidity ($K_{\beta E}$). E is the absolute humidity.

The presented measurements permit not only, determining the vertical distribution of the meteorological quantities in the SBL but they also permit studying the altitude correlation of the changes in each of them.

It is of less interest to study the correlation between separate quantities in the SBL.

Figure 4 show the vertical distribution of the crosscorrelation coefficients between the meteorological quantities, calculated from RS-lidar data for the same day as shown in Fig. 3.

It is obvious that in the surface inversion layer the correlation between the quantities is unstable and can change sign. Above the inversion layer there is a high positive correlation, which decreases with altitude, between the three quantities. The only exception is the correlation between the absolute humidity and the inverse aerosol scattering coefficient.

Similar results can also be obtained from aircraft data. Figure 5 shows that under spring conditions a stable negative correlation is observed between the change in the temperature and the humidity in the entire SBL. Conversely, for the correlation between the temperature and the number density of the aerosol, a stable or weak correlation, which changes from year to year, is observed in this layer.

The correlation between the aerosol number density and the relative humidity in the entire SBL is unstable.

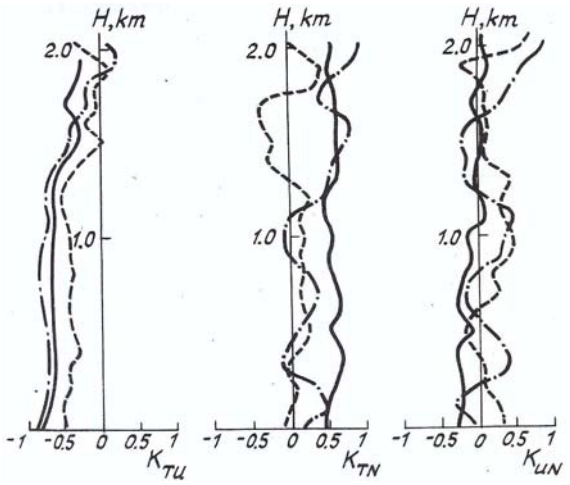

FIG. 5. The vertical distribution of the correlation coefficients in May: K_{TU} – temperature and humidity; – K_{TN} – the temperature and number density of the aerosol; K_{UN} – humidity and aerosol number density. The solid line is for 1984, the dashed line is for 1985, the dot-dashed line is for 1986. U is the relative humidity.

Summarizing this work, on the whole, we note that the results presented illustrate the possibilities of remote sounding instrumentation and the integrated approach to the study of the meteorological and optical parameters of the SBL. This will make it possible to study the SBL with much higher spatial and temporal resolution than is possible from data obtained by the standard meteorological measurements.

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