SOME ASPECTS OF A TECHNIQUE FOR AIRBORNE NEPHELOMETRIC STUDIES OF THE TROPOSPHERIC AEROSOL ON A REGIONAL SCALE

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In this paper we discuss in detail some aspects of a technique for airborne studies of submicron aerosol using a nephelometric device. In particular, we analyze possible deviations of measured number density and size–spectrum from actual ones that can occur at aerosol sampling and transportation to scattering volume. We also present in this paper results of intercalibration measurements, which confirm the validity of estimations of the calibration uncertainties. These results also show that the value of the coefficient in the relation between the angular and integral characteristics of light scattering has been chosen correctly.

INTRODUCTION

Atmospheric aerosol is an inherent component of the atmosphere and plays an essential role in formation of its optical properties. At present great bulk of data is available on aerosol optical and microphysical characteristics, principal processes of its generation and transformation in all the altitude range where the presence of particles can affect on the optical properties of the atmosphere.[1–5]

At the same time, the strong spatial and temporal variability of aerosol properties and their connection with all the atmospheric processes cause the necessity of a more detailed study of all the variety of states in order to improve the dynamic models of optical characteristics that are necessary for solving problems of weather and climate forecast and for estimating the efficiency of systems operating through the atmosphere in the optical wavelength range.

In terms of "aerosol weather and climate" the low troposphere, where more than 80% of particles are concentrated, is the most complex subject for study. It is just the altitude range where the majority of sources of particles, aerosol producing vapors, and the main processes determining aerosol sink occur.[1] The low troposphere is characterized by the strongest spatiotemporal variability of almost all parameters under the effect of a complex of geophysical, synoptic, and meteorological factors.

These were the main reasons for a large–scale experiments started at the Institute of Atmospheric Optics in 1986 under the "VERTICAL" program.[6]

This paper that opens the planned series of publications on the analysis of the nephelometric data obtained during 1986–88 from the airborne laboratory is devoted to the consideration of some aspects of a measuring technique and formation of the bulk of the data obtained.

We have paid special attention to the technique problems because of the following reasons. Further development and improvement of the dynamic models of atmospheric aerosol requires now a more comprehensive study of the factors that determine the variability of aerosol characteristics. At present a lot of research groups deal with measurements of different parameters. The number of publications devoted to atmospheric aerosol is steadily increasing.

Nevertheless, omitting some methodological aspects, false interpretation of the role of particles of different size in optical effects or, what is most frequent, not enough statistical reliability of the data and unreasonable extension of the results obtained at one geographical site to the regional level often lead to the false conception on the random variability of aerosol states that cannot be taken into account and predicted. In another extreme case, the same reasons lead the authors of some publications to wrong conclusions about the existence of well pronounced relationships between aerosol characteristics and that or another atmospheric factor. These circumstances are the obstacle for the development of optical and microphysical models of atmospheric aerosol.

Submicron particles of tropospheric aerosol (they are the particles that are accessible for study with the nephelometer we used) have a long lifetime. Therefore, their state and variability are subject to the action of the atmospheric processes of a wide range of spatial and temporal scales (from local up to the regional ones, at least).

To study the atmospheric phenomena of a regional scale, it is necessary either to perform measurements in a lot of sites or to use of mobile means that are capable of observing large areas during a relatively short time. Taking into account the fact that it is impossible to understand the processes of variability of submicron aerosol fraction without data on their three–dimensional distribution we chose an airborne laboratory to make such observations.

INSTRUMENTATION AND TECHNIQUE PROBLEMS

In order to study the aerosol optical characteristics, we have developed an airborne nephelometric setup based on the photoelectric nephelometer FAN which is capable of measuring the coefficient of directed light scattering at the angle of 45° and at several wavelengths in the visible spectral range.[7] Meteorological parameters of the atmosphere (temperature and relative humidity) were measured simultaneously during all the flights.

The nephelometer was installed inside an aircraft. This makes no limits to the work at daytime. The main advantage of the used arrangement over the airborne nephelometers with an open working volume is the possibility of a direct

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action on aerosol. This makes it possible to increase the information capacity of the experiment and to study the effect of meteorological parameters on its optical properties.

However, in this case a number of difficulties can arise because of possible distortions of the characteristics of air under investigation at sampling and transportation to the scattering volume.

In the airborne setup samples to be analyzed were collected continuously by direct airflow. Here the principle technique moment is to satisfy the isokinetic condition. To do this, it is necessary to satisfy a number of requirements to the geometry of the collecting device.[10] The sampling device we used was made of a thin–walled tube with inner diameter of 10 mm placed in the forepart of the aircraft infront of the propellers at a distance about 30 cm from the fuselage, i.e., in the undisturbed zone. The radius of the collecting tube curvature was chosen so that to avoid the inertial sedimentation of particles with the size $d \le 10$ μm on its walls.

Possible changes of the particles number density when moving along the collection path are connected firstly with their diffusion and sedimentation on the walls, and secondly with the inertial settling on the wall bends that are not completely avoided in the construction of the air transport path. Estimates made according to Refs. 11 and 12 show that the loss of particles of submicron size did not exceed 1% but it can reach ten per cent for the particles with the size $d \ge 10$ μm.

An essential reason that also can decrease the information capacity of the experiment relative to the coarse–fraction particles is connected with the small scattering volume used in the setup.

For the suggested arrangement of the measurement setup the aerosol drying is unavoidable in the air transport path due to the difference between air temperature outside and inside the aircraft (it was decreased by heat–isolation), and immediately in the working volume where the nephelometer chamber was additionally heated by a lamp. It should be noted that in our experiment we can take account of the drying effect when processing data, because we recorded hygrograms[7] (the dependence of scattering coefficient on relative humidity f up to ~ 90–95%) during each measurement cycle at different altitudes. The meteorological parameters (temperature and relative humidity) of air outside the aircraft and immediately in the scattering volume were recorded simultaneously with nephelometric measurements. The true values of the scattering coefficient *in situ* were reconstructed on this basis.

When working in the wide altitude range where the contribution from aerosol particles into light scattering can be comparable to or only a fraction of the molecular scattering, the problem of calibration of the device in the absolute units becomes a principal moment that provides obtaining reliable data on the variability of optical characteristics. To calibrate the nephelometer, we developed a technique based on recording the scattering coefficients of clear air at different altitudes.[7] To provide better accuracy and reliability of this technique, we calibrated the device by the molecular scattering of pure gases under laboratory conditions. The gases He, N_2, CO_2, Ar, Kr, and Xe whose scattering coefficients are known[13] were used as working substances. Calibration results are shown in Fig 1*a* where x axis is the ratio of the molecular scattering coefficient of a gas to that of N_2, and y axis is the nephelometric signal. Thus, the scale of the device was calibrated in absolute units, and the nephelometric chamber background was determined. The sensitivity of determining the aerosol scattering coefficient was ~ 10–15% of the molecular scattering at a given altitude.

The next problem that should be discussed is the transition from the directed light scattering coefficient μ(45°) measured by the nephelometer to the volume scattering coefficient σ since it is the parameter that is necessary for the majority of scientific and applied problems. Taking into account close correlation[14,15] between μ(45°) and σ, one can estimate the scattering coefficient by the formula

$$\sigma = K\,\mu(45^\circ)\,. \qquad (1)$$

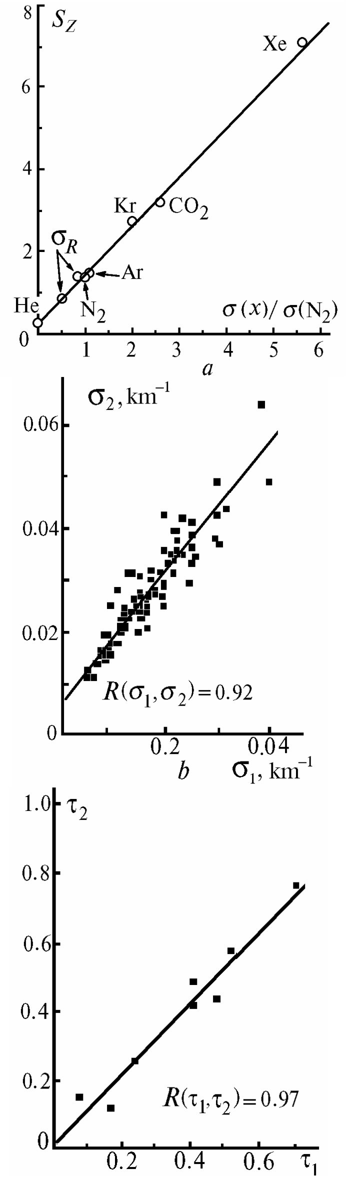

FIG. 1. Calibration of the nephelometric setup by the molecular scattering from pure gases (σ_R *is the scattering coefficient of the clear air at pressure of* 760 *and* 400 mm Hg*) (a); intercalibration of an analog of the airborne setup (*σ_1*) with the nephelometer SNU of the Institute of Atmospheric Physics (*σ_2*) by the ground-based measurements of the scattering coefficient (R is the correlation coefficient) (b); comparison of the values of the atmospheric optical thickness measured from the ground (*τ_2*) and obtained by integrating the vertical profile of the scattering coefficient in the altitude range up to* 5 km *(*τ_1*) (c).*

It should be noted that the choice of the specific value of the transition constant does not distort the measured parameter dynamics but in each particular case can lead to the systematic error in determining σ. The analysis of a great bulk of experimental and calculational data[14–17] shows that the average K value for the majority of atmospheric hazes and wide lognormal size distributions is equal to 7.5. For our data processing we used the value K equal to 9. The experience of calibration with ground–based measurements of the extinction coefficients[15,18] showed that the loss of some contribution of the coarse–dispersed particles in measurements by nephelometric method leads to underestimating of the value of the scattering coefficient by 10–20%. Therefore, the choice of the transition constant greater than the mean value by 1.1–1.2 times is quite reasonable. The sets of complex experiments carried out at the Institute of Atmospheric Optics (Tomsk) and Institute of Atmospheric Physics (Moscow) in Odessa (1987) and Dushanbe (1989) made it possible to calibrate different devices including our airborne nephelometric setup. In these experiments we performed simultaneous measurements with different nephelometric setups,[19] airborne sounding of the vertical profile of aerosol scattering coefficient, and ground–based measurements of the vertical optical thickness of the atmosphere.[19,20] The results of comparison presented in Figs. 1*b* and *c* show a good agreement of the data that is indicative of the correctness of the calibration and choice of the constant for transition from angular to integral scattering characteristics.

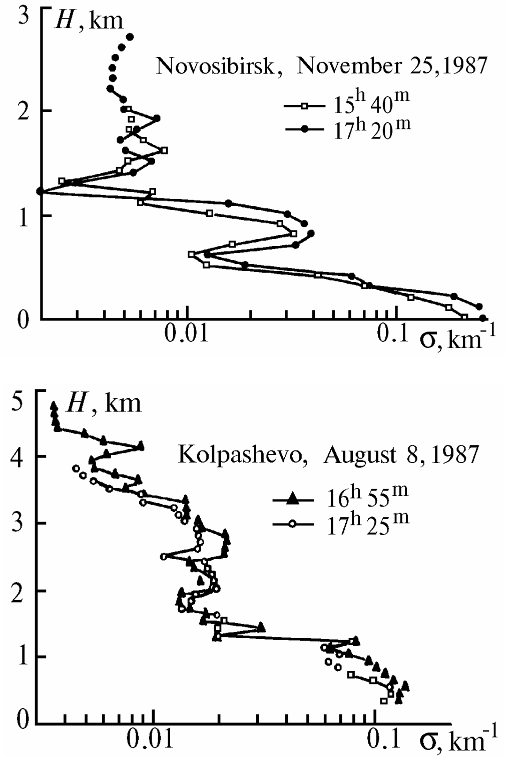

FIG. 2. Vertical profiles of the scattering coefficient obtained under the stable synoptic conditions in a 1–hour *interval.*

A problem arises due to small scattering volume, on how much would the measured optical parameters be characteristic of the given observation conditions and could they be extended to larger volumes of air. When processing the data, we always had the possibility to assess the stability of the atmospheric optical situation, since in each flight we recorded the spatial variability of the nephelometric signal during a few minutes.

In spite of small scattering volume, our results showed that practically under all stable synoptic and meteorological conditions only insignificant variations of the scattering coefficients were observed. This shows that the optical properties of submicron aerosol are essentially uniform over space. To illustrate this fact, the data on vertical profile of the aerosol scattering coefficient are presented in Fig. 2. The profiles were obtained at taking off and landing the aircraft in approximately 1 hour under the stable meteorological conditions (when only weak variations of meteorological parameters were observed).

DISCUSSION OF THE BULK OF DATA OBTAINED OVER WEST SIBERIA

The vertical profiles were recorded continuously during taking off and landing (or its imitation) the aircraft. The time of recording of a single profile within the altitude range up to 5 km was about 30–40 min. In data processing the standard digitizing was made every 100 m of altitude. In situations when noticeable peculiarities occurred in the altitude behavior of the parameters measured, digitizing was performed at higher spatial resolution, and maxima and minima of the profiles measured were shown on the altitude grid of 50 m increment. Some of the profiles was synthesized from the data obtained in the same flight during ascends and descends between working horizontal levels. Such paths were from 500 m to 2 km long, and the period between them was from 30 min to 1 hour. Separate paths were sewn in one profile if synoptic situation, aerosol and meteorological parameters were almost unchanged during the flight (aircraft flew about 200 km during that time).

Thus, the bulk of data on 602 vertical profiles was compiled for the West Siberia region. The profiles were measured during all seasons under various meteorological and synoptic conditions. The geography of flights and the number of data obtained over each site are shown in Fig. 3.

Since the subject of our study was aerosol processes that are characteristic of the region as a whole, we excluded, when forming the bulk of data, data obtained directly over cities and big industrial centers. Of course, we could not completely avoid the anthropogenic effect. By this we mean the impact of a populated area that can be considered as the local aerosol source on the parameter measured, rather than the circumstance that it makes some contribution to the formation of the average regional background. Particular effect can be expected the data obtained in the near–ground atmospheric layer, because the majority of data were obtained at taking off and landing in airports where the influence of the neighboring city can be essential. Let us note that the main features of vertical stratification of the aerosol scattering coefficient obtained over different geographical sites under the conditions of common stable air mass are close to each other. This is illustrated by Fig. 4 where the vertical profiles obtained in the common air mass are shown. Differences mostly observed in the near–ground layer are evidently caused by the local sources, including the anthropogenic ones.

A problem inevitably arises in the analysis of geophysical processes and phenomena on how representative are data obtained during a short time. Moreover, the peculiarities of instrumentation and technique of measurements in the atmosphere can shift a set of observational data toward some kind of weather conditions. In particular, the photometric measurements of the atmospheric optical characteristics using natural sources and lidar sounding of the atmosphere are conducted under conditions of small cloud amount (as a rule, in anticyclones). Therefore, a great number of other situations remain out of consideration.

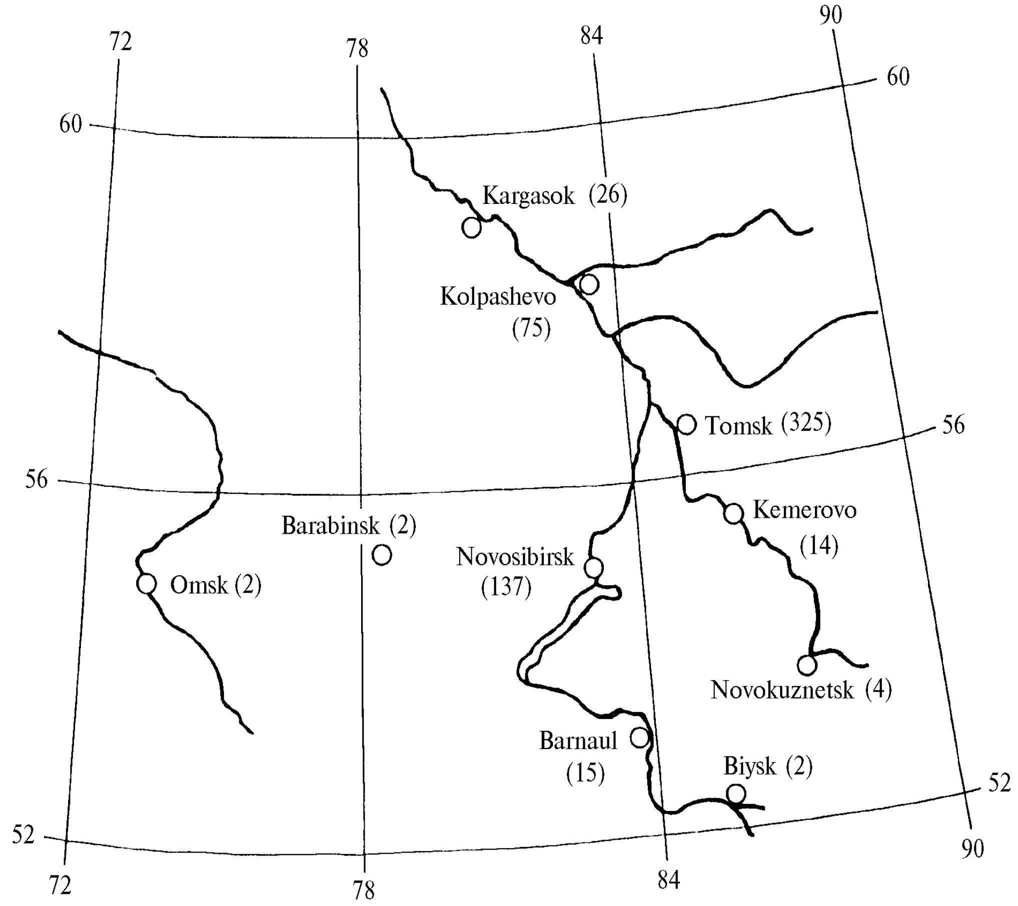

FIG. 3. Geography of the airborne laboratory flights over West Siberia region in 1986–88 and the number of the data obtained (in parentheses).

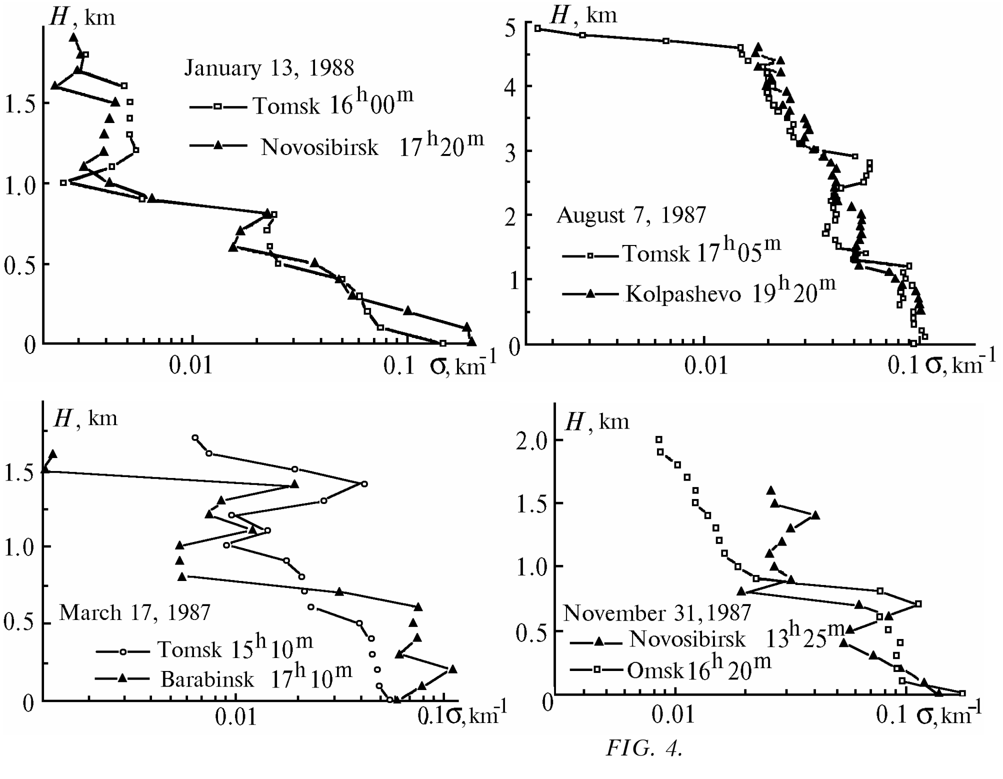

FIG. 4.

The airborne sounding makes it possible to avoid the aforementioned limitations. When planning the experiment we aimed at covering by measurement flights all the variety of atmospheric conditions and providing the maximum possible regularity and duration. The exception was the rather rare events of dense fogs, powerful thunder storms, and heavy winds.

Nevertheless, the main bulk of data analyzed in this paper were obtained during 2.5 years at different frequency of observations for different synoptic and meteorological situations. Therefore, before making analysis of the aerosol characteristics observed it is necessary to assess the geophysical significance and the quality of the experimental data. Since this is a key question while there are no data of long–term observations of vertical profiles of aerosol characteristics for this region, let us try to assess representativeness of the bulk of data on hand from the standpoint of the standard meteorological and synoptic parameters.

The analysis was carried out with use of an information–retrieval system[21] that allows to find and arrange the data sets according to the criteria given beforehand.

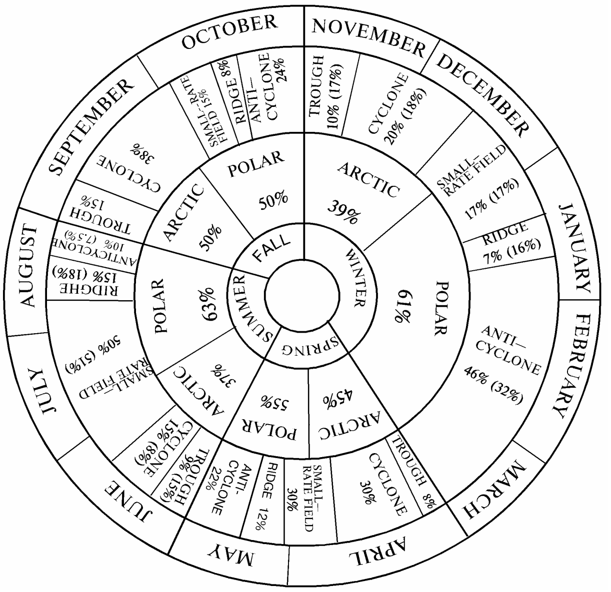

FIG. 5. Comparison of the statistical weights of air masses and pressure field types in the bulk of data analyzed with the mean long–term values.

The whole bulk of data was divided into seasonal sets according to the climatic definition of the seasons that are characteristic of the region under investigation.[22] Within each season the data were classified with respect to the type of air mass, pressure field, and weather conditions. The events of atmospheric fronts were isolated, for each season, into a separate set (their fraction was 25% of the total number of events). The diagram of dividing into seasons and the statistical weights of synoptic attributes are shown in Fig. 5. The data[22] of long–term observations on the number of events determined by different pressure field types are presented in parentheses. The number of the atmospheric conditions determined by polar continental air in West Siberia, is, according to average long–term data, 59–62% for each season.[22] It well agrees with our data presented in Fig. 5. The analyzed portion of different pressure field types also agrees with the average long–term data. Obviously, one can explain some small differences in the compared statistical weights by the circumstance that, as distinct from Ref. 22, we have isolated the front events into a separate set in each season.

Analogously we have compared vertical profiles of measured meteorological parameters with the average long–term data of aerological sounding.[23] The average vertical profiles of temperature are shown in Fig. 6*a*, for all seasons, and the profiles of specific humidity are shown in Fig. 6*b*. The data of aerological sounding averaged over the stations situated in the region under investigation (Aleksandrovskoe, Barabinsk, Novosibirsk, and Omsk) are shown by crosses.

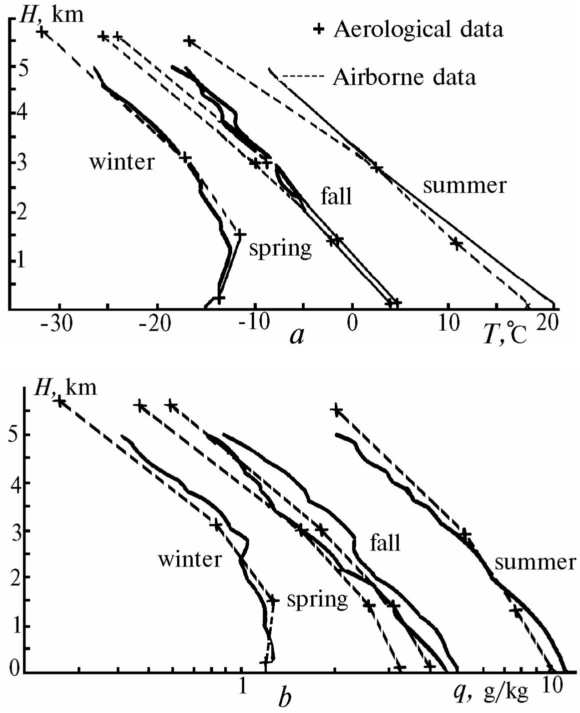

FIG. 6. Comparison of the data on season–average profiles of temperature (a) and specific humidity (b) obtained in our experiment with average long–term aerological data.

Good agreement of the analyzed synoptic and meteorological characteristics of the atmosphere during the period of our observations with the climatic average for our region allows us to hope that the bulk of data obtained on the optical parameters of submicron aerosol and the factors of its variability discussed in the papers reflect the most general features that are characteristic of the region as a whole.

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