Research of the Optical, Radiative, and Meteorological Characteristics of the Boundary Layer Based on Remote Sensing Data Obtained During the 1996 Intensive Observing Period in Tomsk

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Introduction

The mean values of the radiation balance of the earth's surface, the atmosphere, and the earth-atmosphere system as a whole are well established. However, this does not apply to the parameters of local areas of the earth's surface and the atmosphere above them. The radiation balance of such local objects experiences considerable variations depending on the spatiotemporal distribution of cloud and aerosol fields, including their physical and optical properties, as well as on the meteorological and synoptic situation. Thus, the radiation balance depends, in particular, on the cloud fraction, the shape of the clouds, their height, and the morphology of the cloud boundaries. The radiation balance is also influenced by the atmospheric transmission and the stratification of aerosol, which in its turn is determined by the thermodynamic regime of the atmosphere.

The study of interrelations among these numerous factors is only feasible based on the data from statistically significant simultaneous observations of the key atmospheric parameters. It is evident that the use of remote sensing techniques is most promising for making such observations.

Experiment

In our recent measurement campaign to study the optical and meteorological properties of the lower troposphere, we used different measurement facilities, among which are a scanning aerosol lidar “Loza-3”; a deltaplane equipped with a nephelometer and temperature, humidity, and solar radiation sensors; and an acoustic sensing complex involving a sodar and an acoustic meteostation.

The scanning aerosol lidar “Loza-3” (Balin et al. 1993) measured the vertical structure of the aerosol scattering coefficients up to 3-km height with spatial resolution of 7.5 m. In the presence of cloud fields, the lidar also measured the height of the cloud low boundary, along with the in-depth profile of the scattering coefficient within a cloud. In order to provide a possibility of studying the spatiotemporal behavior of the cloud low boundary height, the measurements have been conducted in two modes of the lidar operation. In the first mode, the lidar scanned the atmospheric volume under study in a vertical cross section to acquire information on the spatial distribution of the cloud height. The scanning provided one degree angular resolution. In the second mode, the lidar was operated along a preset direction to provide data on the dynamics of the cloud height from a time series of lidar responses from clouds. Data arrays thus obtained were then processed using correlation and spectral analysis.

On some days, the deltaplane flew over the measurement site at heights up to 3 km under clear sky conditions and up to the cloud boundary otherwise. In this measurement campaign, we have managed to collect data on the fine structure of the optical, radiative, and meteorological parameters of the atmosphere along a vertical direction. We also obtained information on the horizontal inhomogeneities of these parameters along paths up to 20 km in length.

The acoustic complex measured some meteorological and turbulent characteristics of the ground and boundary atmospheric layers. To study the characteristics of the ground layer, we used an acoustic meteostation that enabled us to make *in situ* measurements of the instantaneous temperature values and the three mutually orthogonal components of wind velocity. In addition, it measured mean values of temperature, wind speed, humidity, pressure, and the full set of statistical characteristics of these parameters. Data arrays thus formed allow us to infer standard parameters of the atmospheric turbulence in the ground layer (up to 67 parameters). Based on the Monin-Obukhov theory, we were able to predict vertical behavior, within the ground layer, of the profiles of such meteorological and turbulent characteristics as temperature and wind velocity, as well as of their structure constants, coefficients of turbulent exchange for heat and wind velocity, the rate of the turbulent energy dissipation, the outer scale of turbulence, and so on. The sodar has been used to study the boundary layer (Krasnenko 1986). It enables us to collect information on the type of atmospheric stratification, on mixing layer height, on the structure characteristic of the temperature field, and on the wind velocity profile up to 600 m.

Meteorological Situations During the Measurements

Let us now briefly present a description of the meteorological and synoptic conditions characteristic of the period during which the measurements were conducted, i.e., from August 28 until October 11, 1996 (daytime, from 0800 till 2000, local time).

Figure 1 sets out the distributions of the cloud height and cloud fraction as constructed using the data of 154 sessions of observations performed every two hours. As follows from these data and from the diagram in Figure 2 we had clear sky conditions only in 13% of observations. During the rest of the observations, there were clouds and in 68%, we could observe clouds of different types. However, the probability of observing one and the same combination of cloud forms is too low. The highest frequency of occurrence is characteristic of combinations of the upper level clouds (Cl) with the clouds of the other types. The frequency of occurrence of the cloud fraction value closely correlated with their type. Thus, in the case of St and Sc clouds, we observed the overcast most frequently. It so happened that clouds of these types prevailed during the period of the measurement campaign; the total percentage of the overcast is 60% of all the observations.

In fact, such a situation with the cloud cover is very typical for Western Siberia during the fall. This period is characterized by frequent changes of air masses, among which the polar and moderate air masses dominate. One additional and important factor of the radiation balance variation is the atmospheric transmission below clouds. This atmospheric property is, to a great extent, determined by the spatiotemporal structure of aerosol fields. In order to interpret the shape of the profiles of the aerosol scattering coefficients, one has to have information on the atmospheric temperature stratification and wind profiles. The percentage of the types of the atmospheric temperature stratification occurring during the campaign period, as inferred from standard classification, is shown in Figure 3. Their time variation is shown in Figure 4.

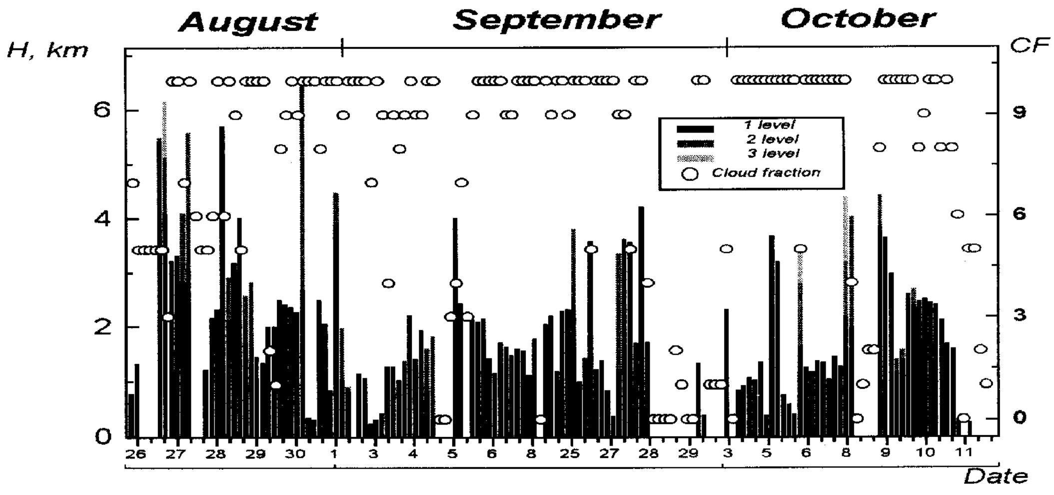

Figure 1. Distribution of cloud height and cloud fraction (CF) over the measurement period.

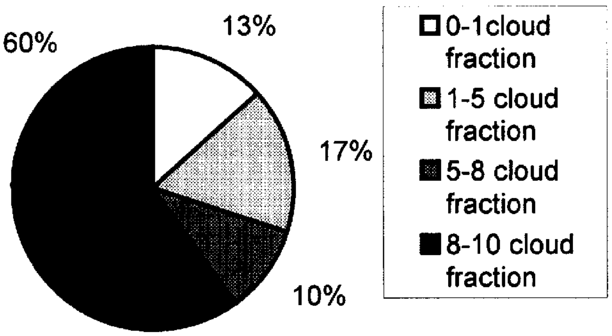

Figure 2. Frequencies of occurrence of the cloud fraction.

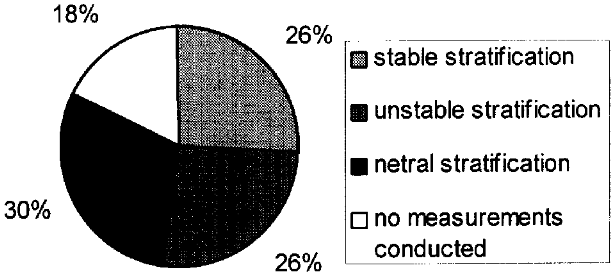

Figure 3. Classification of the stability of the atmospheric boundary layer observed in the period from September 23 until October 11, 1996 (during the day from 8 a.m. till 8 p.m.)

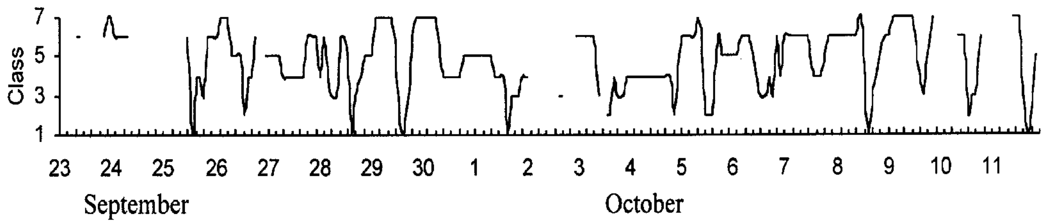

Figure 4. Classes of the atmospheric stability as inferred from the sodar data.

As is seen from the data presented in these figures, the percentages of stable and neutral stratifications were approximately equal— about 30% each. Stable stratification normally prevailed at night; starting with the sunrise and till noon, the temperature inversion layer gradually ascends and destructs. In the evening hours, the stable stratification again forms in the atmosphere. The temporal variation of the stratification surely does not favor the accumulation of the aerosol in the boundary layer of the atmosphere. This circumstance is well seen in the behavior of the mixing layer height (see Figure 5), which is strongly influenced by the dynamics of the convective turbulence fluxes. As analysis of the entire experimental material has shown, the period of observations during this campaign may, on the whole, be characterized by low wind speed and moderate intensity of turbulence, including the fluxes of heat and momentum.

Results

The radiation balance behavior recorded during the entire measurement period agrees well with the known diurnal behavior showing negative values of the balance at

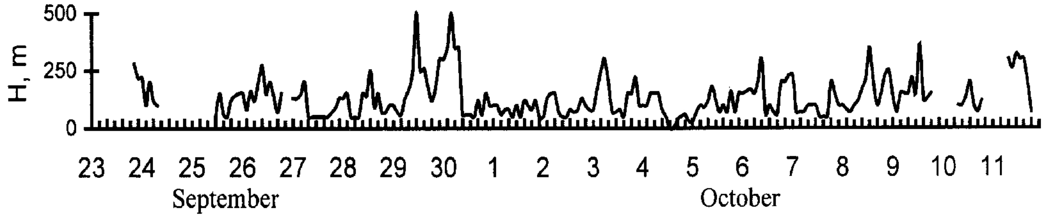

Figure 5. The height of the mixing layer as estimated from sodar data.

night-time and positive maximum at daytime. Also, the absolute values of the balance decrease in the presence of clouds both at night and day. Joint analysis of the vertical distribution of the aerosol scattering coefficients and data on the atmospheric stratification and radiation parameters enabled us to reveal the following facts. Under conditions of unstable stratification, the aerosol vertical distribution exhibits a monotonic fall off of the aerosol scattering coefficients with the increasing height, similar to the temperature height behavior (see Figure 6).

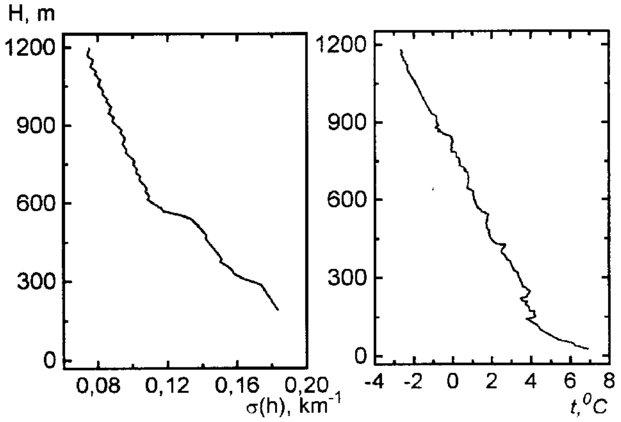

Figure 6. Height distributions of the aerosol scattering coefficient under unstable stratification.

In the majority of cases, such vertical distributions have been observed in the continental polar air masses with a low gradient field of enhanced pressure.

Under conditions of stable stratification, the aerosol scattering coefficient has practically neutral height distribution up to the height of a temperature inversion.

In the case of a neutral stratification, aerosol layers often occur in the atmosphere, which is confirmed by the radiation parameters of the atmosphere. As seen from Figure 7, almost all essential changes in the aerosol density with height agree well with the increase, at these same heights, in the intensity of the downwelling and upwelling radiation, as well as in the net solar radiation flux and radiation balance. This behavior is characteristic of all the synoptic situations taking place during the measurement campaign as, in particular, in the moderate continental air mass presented by the data in Figure 7. Such positions of the aerosol layers under conditions of neutral stratification of the atmosphere may be caused by the jet streams formed in the air which is demonstrated by the altitude behavior of the horizontal component of wind velocity set out in the right-hand portion of the figure at heights of 150 and 350 m. The scattering coefficient within clouds varied from 10 to 30 km^{-1} and that conforms with the values for the types of clouds observed.

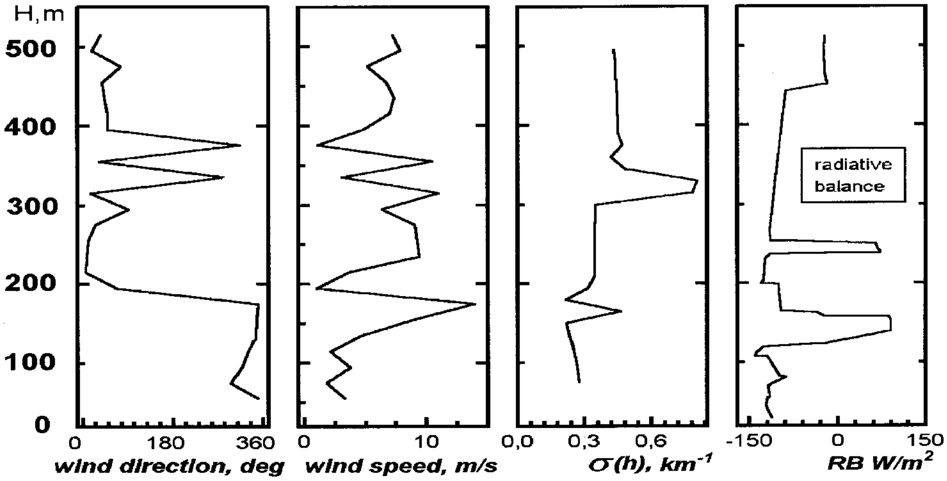

Figure 7. Height distribution of the wind direction and speed, scattering coefficient of atmosphere, radiative parameters recorded in one session of observation.

In situations with continuous cloudiness, we managed to reveal the spatial scales characteristic of the variations in the low boundary of the clouds from time series of spatially resolved vertical cross-sections obtained with the lidar by applying the technique of spectral analysis of the data set. According to our data, the scales vary from hundreds of meters to several kilometers. Moreover, we have noticed that the main characteristic scale tends to decrease during a day with decreasing cloud height.

Conclusions

The combined measurements of the radiative, meteorological, and optical parameters of the atmosphere conducted synchronously enabled us to reveal the basic features in the variation of atmospheric parameters in different synoptic situations. Further investigations are needed in order to confirm the reproducibility and validity of the regularities observed during that measurement campaign.

References

Balin Y. S., and I. A. Razenkov, 1993: Laser Monitoring of Aerosol Pollution of Air Basin of Industrial Centers. *Atmos. Oceanic Optics,* **6**, p. 104114.

Krasnenko N. P., 1986: *Acoustic Sounding of the Atmosphere.* Nauka, Novosibirsk (Russia).