LIDAR SYSTEM FOR INVESTIGATIONS OF CLOUDINESS IN THE DAYTIME AND NIGHTTIME

V.V. Zuev, M.I. Andreev, V.D. Burlakov A.V. El'nikov, A.V. Nevzorov, and S.V. Smirnov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

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We describe a lidar system that comprises a lidar and a videocamera. The system has been designed for studying the variability of geometry, optical properties, and phase composition of clouds. It provides for day and night observations.

Investigations of cloud formations, their morphological features, microphysical and optical characteristics and their variability in space and time, have been being carried out for many years. The observations used various techniques available: visual observations, radar sounding, aerospace survey, contact methods, photometry, IR radiometry and others. Studying of such processes as influence of clouds on the radiation and heat balance, requires vast experimental material. The instruments available for making observations must also be essentially improved.

The development of laser sensing methods for atmospheric studies made it possible investigating the cloudiness with lidars because the latter are capable of remotely acquiring data on optical characteristics of clouds as well as on their phase composition and on the lower and upper boundaries of the clouds. In this case, lidar techniques enable us to study the clouds of the upper cloud level (cirrus) through the cloud underlayer, which often screens cirrus for the ground-based observations. At present much attention is paid to the investigation of cirrus because it has been found that cirrus clouds strongly affect the atmospheric radiation processes, weather formation and climate. Depending on the optical and microphysical characteristics cirrus clouds may be responsible for the effect of temperature rise or fall.[1,2] A combined approach to investigation of the radiation and optical characteristics of cirrus clouds when using the lidar and IR radiometric techniques for measuring their properties can be very promising.[3–5]

The lidar system discussed enables us to extend the experimental investigations of clouds. The lidar system can be used for the night- and day-time measurements with high time resolution as well as for qualitative analysis of the sky condition at zenith during the measurements. The lidar is the basic part of this system. The lidar transmitter uses a diode-pumped Nd:YAG laser operating at the wavelength of 1064 nm that delivers about 150 mJ energy per pulse at the pulse repetition rate of 10 Hz. The system is operated at $\lambda = 1064$ nm because of low sky background in the near IR range what is especially important when conducting lidar observations of clouds in the daytime. Moreover, as shown in Ref. 4, the accuracy of determination of cloud boundary is higher when sounding at $\lambda = 1064$ nm than at $\lambda = 532$ nm. The lidar system has been constructed according to a single ended coaxial optical arrangement of the transmitter-receiver. The backscattered laser radiation is received using a 2.2-m-diameter mirror with the focal length of 10 m. The assembly of field stop, collimating lens, film polaroid, a narrow-band interference filter and a lens focusing the collected light onto the photomultiplier is mounted in the focal plane of the receiving mirror.

The possibility of varying the field-of-view diaphragm diameter and the receiving mirror area enables one to select the optimal signal-to-noise ratio during the day- and night-time measurements. In the night-time measurements the full area of the receiving mirror is used. In the day-time measurements the receiving area is reduced to the value equivalent to the area of a 0.3-m-diameter mirror. The field-of-view angle of the receiving system is slightly over the divergence angle of the sounding beam and equals to 0.3 mrad both for day-time and night-time measurements. The small viewing angle provides for low background illumination and enables one to reduce the contribution from multiple light scattering in a cloud into the lidar returns.[6]

The photomultiplier FEU–83 is used as a photodetector, which is cooled by the Peltier elements to the temperature about −30°C in order to decrease the thermal noise. The signals are recorded in the photon counting regime.

The lidar return signals are accumulated from 20 to 30 laser shots that provides for acquiring data in the altitude range from 0 to 12.8 km with the spatial resolution of 100 m.

The time of lidar signal accumulation, necessary for obtaining one statistically significant profile, is 3 or 4 seconds. When sounding clouds with a lidar and recording signals in the analog mode of a photomultiplier operation[3,4] this time is 0.5 min and longer.

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A videocamera is one of the lidar system components. Its viewing direction is parallel to an optical axis and it is mounted close to the focus of the lidar receiving telescope. The videocamera is intended for control of the cloud cover of the sky during lidar sounding sessions. The video records enable us to determine the horizontal dimensions of clouds, the velocity and direction of cloud motion.

To determine the phase state of cloud particles (ice crystals, water droplets or mixed type) in the clouds the depolarization degree of lidar signals, or in other words the ratio of perpendicular and parallel polarized components of the returns is measured. The film polaroid-analyzer makes it possible to conduct the measurements alternately in short time intervals of several seconds. Because of a high velocity of cloud motion (up to several tens of meters per second) and strong vertical variability of their optical density, the measurements of the depolarization degree are very approximate and bear little information. Nevertheless, the qualitative estimate of cloud phase structure is possible from these measurements. Later on we plan to replace the film polaroid for the Glan-Thompson prism and the second recording channel will be created for simultaneous measurements of both polarization components.

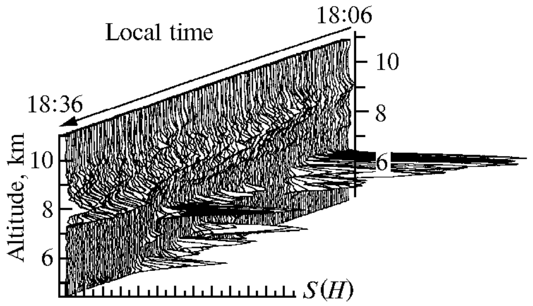

FIG 1. The variation of vertical structure of the lidar signal accumulated and corrected for the squared range (S-function) in observations of cirrus, altocumulus, and cumulus clouds on August 14, 1997, the period of measurements is from 18:06 to 18:36 LT.

The capabilities of this lidar system are demonstrated with the results shown in Fig. 1. The figure presents a fragment of a temporal behavior of the vertical lidar profiles of S-function expressed as $S(H) = (N(H) - N_{\rm backgr.}H^2)$, where $N(H)$ is the lidar return recorded, $N_{\rm backgr.}$ is the background signal including the sky background and the photomultiplier noises, H is the altitude. This fragment relates to the period of the atmospheric warm front passage over the observation point. Three types of cloudiness may be seen in the figure. The lower and middle level clouds (below 7 km) are broken clouds. In this case the optical density of the cloud cover is large. The gradual decrease of localization altitude and small optical density are typical for cloudiness at altitude higher than 7 km. The descent occurred over the observation period was about 2 km.

The visual and video observations have shown that the cloud cover over this period, the cloud fraction of 10 amounts of clouds, is conditioned by the clouds of vertical development − *Cu hum* (1 or 2 amounts of clouds), clouds of middle level − *Ac floc* (1 or 2 amounts of clouds) and clouds of upper level − *Cs fib* (10 amounts of clouds) and *Ci sp* (4 amounts of clouds). The mean velocity of cloud motion, resulting from the video data, is 9−11 m/s at 4.5−6 km altitudes for *Ac* and 11−14 m/s at 7 km altitude for *Cs* and *Ci*.

Thus the developed lidar system has made it possible to measure the dynamics of characteristics of clouds of the lower, middle and upper levels in the day- and night-time with the time resolution of several seconds.

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