Lidar system for sounding aerosol in Surgut city under the CIS-LiNet Project

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Lidar Station of Surgut State University being one of the points of the CIS-LiNET lidar network is described. The lidar is intended for studies of the atmospheric aerosol component both in the troposphere and stratosphere. We present block-diagram of the lidar together with a brief description of the methods used for determination of aerosol backscattering characteristics. Results of its intercalibration with the lidar operated in the photon-counting mode in Tomsk are presented.

Introduction

To study regional and large-scale spatiotemporal variations of the fields of atmospheric parameters, the lidar station networks are now widely used, at which coordinated measurements are being carried out by the methods of laser sensing of the atmosphere. At the biggest network for detecting stratospheric changes (NDSC) mainly measurements of stratospheric ozone, aerosol and temperature are being conducted by means of lidars. The European aerosol lidar network (EARLINET) includes 22 lidar stations for investigation of the processes of transfer of aerosol pollutions of natural and anthropogenic origin over Europe. The processes of transfer of dust aerosol over Asia are studied at lidar stations of the AD-LiNet network.

Until recently no coordinated measurements have been conducted over the vast territory of the former Soviet Union. There were collectives and scientific schools in laser sensing of the atmosphere, which worked independently. One more lidar network of CIS countries (CIS-LiNet) was arranged at the end of year 2004 on the territory of Eurasian continent under support of International Science and Technology Center (ISTC) under the project "Monitoring of atmospheric aerosol and ozone in CIS regions by means of the network of lidar stations (CIS-LiNet)." The network united the working groups from scientific organizations of Russia, Belarus, and Kyrgyzstan.

One of the tasks of the aforementioned ISTC project is the development of the CIS-LiNet network, covering as big as possible territory of CIS. Historically, the currently operating lidar stations on the CIS territory are situated in mid-latitudes. The most northern site is Tomsk (56.5°N, 85.0°E). However, arctic and subarctic latitudes are of special interest from the standpoint of atmospheric physics and climatology. Realization of regular observations in these regions is now quite difficult because of the absence of skilled staff and technical basis. So, the first step in extending the CIS-LiNet to the north was creation of the site for laser observations of the state of the aerosol component in Surgut (61.3°N, 73.5°E) on the basis of Surgut State University (SurSU). This paper is devoted to description of the developed lidar and some results obtained with it.

1. Technical description of the lidar

The SurSU lidar created is an analog of the lidar that has been operated for a long time at the Institute of Atmospheric Optics SB RAS (IAO SB RAS), Tomsk.[1,2] The receiving-transmitting channel of the IAO SB RAS lidar consists of two channels formed by means of the beam splitter and operated in the photon counting mode. About 95% of the backscattered laser radiation flux is transmitted through the beam splitter to the channel intended to stratospheric studies. The rest 5% of the radiation backscattered from the atmosphere is reflected by the beam splitter to the second channel. This channel is used for obtaining the data on the aerosol vertical stratification in the troposphere, as close to ground surface as possible.

Operation of the tropospheric channel of the SurSU lidar is realized in current (analog) mode of PMT operation, that makes it possible more detailed tropospheric investigations, in comparison with photon counting mode, practically to the near-ground layer. The analog recording block and its software interface were developed and designed at Minsk, Institute of Physics, National Academy of Sciences of Belarus.

The block-diagram of the SurSU lidar developed is shown in Fig. 1, as well as, for comparison, the optical arrangement of the receiving part of the lidar being operated in Tomsk. The diagram of their arrangement used for intercalibration measurements in Tomsk using one laser transmitter is shown in the right-hand part of Fig. 1*a*.

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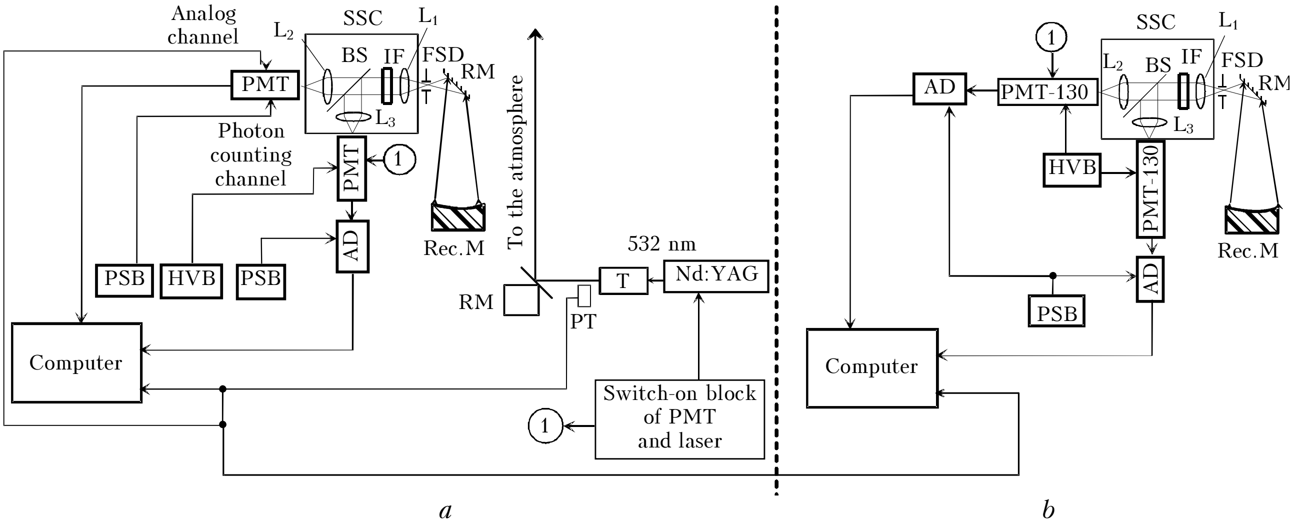

Fig. 1. Block-diagram of the lidars at measurement sites: in Surgut (*a*), in Tomsk (*b*); Nd:YAG laser; T – transmitting telescope; RM – beam folding mirrors, Rec.M. – receiving mirrors of the diameter 0.3 m; FSD – field stop diaphragms; SSC – spectral selection chambers; L_1 – collimating lenses; IF – interference filters; BS –beam splitters; L_2 and L_3 – focusing lenses; AD – amplifiers-discriminators; PT – trigger pulse generating phototransistor; HVB – high voltage supply blocks; PSB – power supply blocks.

Fig. 2. General view of the lidar complex and laser beam in the atmosphere over Surgut.

To study optical characteristics of the atmospheric aerosol, the second harmonics of a Nd:YAG laser radiation is used at the CIS-LiNet network, $\lambda = 532$ nm. This unification is necessary for carrying out intercalibration measurements of lidar instrumentation, objective comparison of the algorithms for data processing, and results of laser sensing.

The Nd:YAG laser used (model LS-2135 of LOTIS-TII) is used as a source of sounding radiation in the SurSU lidar that operates at the pulse repetition rate of 10 Hz and the second harmonics pulse energy ($\lambda = 532$ nm) of 150 mJ. This same laser was operated in intercalibration measurements in Tomsk. The diameter of the main mirror of the receiving telescope is 0.3 m (Rec.M. in Fig. 1). The distance between optical axes of the lidar transmitter and receiver is 40 cm. The divergence of the output laser beam has been decreased using the lens telescope (T) to 0.1 mrad. The diameter of the field stop diaphragm (FSD) is 1.5 mm. Transmittance of the interference filter (IF) is 60%, the transmission bandwidth at the center of the transmission maximum is 2 nm. The beam splitting mirror (BS) transmits 30% of all incident radiation to the analog receiving channel and reflects 70% to the photon-counting channel. The photomultiplier tubes used as photodetectors were: PMT-130 (photon counting mode) and PMT-84 (analog mode). Electronic control of the PMT gain is used for protecting the PMT of the photon counting channel from overload by the near-range lidar return. It is marked by figure 1 in the block-diagram.[2]

The lidar was mounted in Surgut and put into operation at the end of April 2006. The external view of the lidar and its arrangement at SurSU are shown in Fig. 2.

2. Technique for determining the optical characteristics of atmospheric aerosol

Relationship between the received signal and the optical characteristics of the atmosphere is described by the lidar equation

$$N(H) = CH^{-2}\beta_{\pi}(H)T_{\mathrm{m}}^{2}(H)T_{\mathrm{a}}^{2}(H), \qquad (1)$$

where H is the height, $N(H)$ is the recorded signal (without background), and C is the instrumentation constant;

$$\beta_{\pi}(H) = \beta_{\pi}^{\mathrm{m}}(H) + \beta_{\pi}^{\mathrm{a}}(H),$$

$\beta_{\pi}^{\mathrm{m}}(H)$ and $\beta_{\pi}^{\mathrm{a}}(H)$ are the molecular and aerosol backscattering coefficients, respectively;

$$T_{\mathrm{m}}(H) = \exp\left[-\int_{0}^{H}\alpha_{\mathrm{m}}(h)\,\mathrm{d}h\right] \text{ and } T_{\mathrm{a}}(H) = \exp\left[-\int_{0}^{H}\alpha_{\mathrm{a}}(h)\,\mathrm{d}h\right]$$

are transmissions of the atmosphere caused by, respectively, molecular ($\alpha_{\mathrm{m}}(h)$) and aerosol ($\alpha_{\mathrm{a}}(h)$) extinction, which are the sum of the total scattering and absorption coefficients. The absorption coefficients are significantly less than the total scattering coefficients, so α_{m} and α_{a} are the total scattering coefficients of molecules and aerosol, respectively. The profile of the molecular backscattering coefficient $\beta_{\pi}^{\mathrm{m}}(H)$ in Eq. (1) is assumed known either from the data of aerological sounding or based on model values.

It follows from Eq. (1) that

$$\beta_{\pi}(H) \equiv \beta_{\pi}^{\mathrm{m}}(H) + \beta_{\pi}^{\mathrm{a}}(H) = \frac{N(H)H^{2}}{CT_{\mathrm{m}}^{2}(H)T_{\mathrm{a}}^{2}(H)}. \qquad (2)$$

Thus, excess of the values $\beta_{\pi}(H)$ over $\beta_{\pi}^{\mathrm{m}}(H)$ corresponds to the values of the aerosol backscattering coefficient, i.e., $\beta_{\pi}^{\mathrm{a}}(H) = \beta_{\pi}(H) - \beta_{\pi}^{\mathrm{m}}(H)$. To determine the instrumentation constant C, the value $\beta_{\pi}^{\mathrm{a}}(H_0)$ is set *a priori* at some point H_0 on the sounding path, and calibration of the lidar signal along the sounding path is done to this point (method for calibration of lidar signal[3]). As a rule, H_0 is selected at the end of the sounding path. At vertical sounding in the troposphere, where aerosol concentration decreases with height practically exponentially, inaccuracy in setting $\beta_{\pi}^{\mathrm{a}}(H_0)$ introduces insignificant error in the aerosol backscattering coefficient determined at other heights. The method of calibration in the stratosphere, assumes the presence of a region there, where aerosol is absent, and the calibration point is selected at the minimum of the function $F(H) = N(H)H^{2}/\beta_{\pi}^{\mathrm{m}}(H)$. For a more clear presentation of the peculiarities in the vertical distribution of stratospheric aerosol, the scattering ratio is used

$$R(H) = \left[\beta_{\pi}^{\mathrm{m}}(H) + \beta_{\pi}^{\mathrm{a}}(H)\right]/\beta_{\pi}^{\mathrm{m}}(H), \qquad (3)$$

determined, according to the technique presented in Ref. 4, as

$$R(H) = \frac{N(H)H^{2}\beta_{\pi}^{\mathrm{m}}(H_0)}{N(H_0)H_0^{2}\beta_{\pi}^{\mathrm{m}}(H)T_{\mathrm{m}}^{2}(H-H_0)}. \qquad (4)$$

It follows from Eq. (4) that, ignoring inaccuracy in setting the profile of the molecular scattering and estimating the atmospheric transmission, one can present the random error in measurements in the form

$$\frac{\delta R(H)}{R(H)} = \sqrt{\frac{N(H)+N_{\mathrm{bgr}}}{\left[N(H)\right]^{2}} + \frac{N(H_0)+N_{\mathrm{bgr}}}{\left[N(H_0)\right]^{2}}}. \qquad (5)$$

3. Intercalibration of the lidar and first measurements results

Approbation of the SurSU lidar and examination of identity of the measurement data were carried out in Tomsk by means of comparison of the results of simultaneous lidar sensing of the aerosol backscattering characteristics obtained with two lidars. The profiles of the scattering ratio obtained in Tomsk on February 28, 2006 are shown in Fig. 3 as an example of the intercalibration measurements with the lidars of SurSU and IAO SB RAS in the photon counting mode.

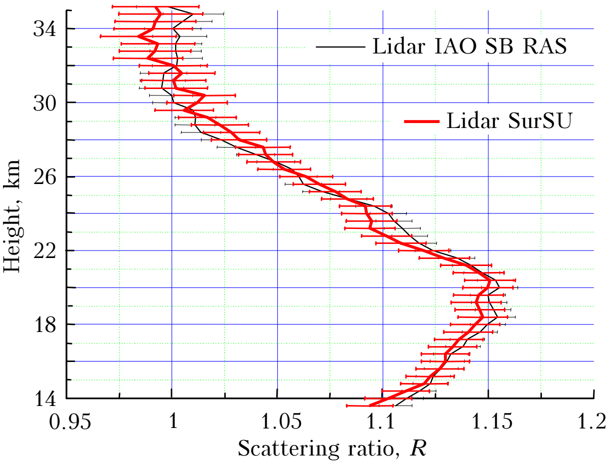

Fig. 3. Vertical profiles of the scattering ratio obtained in Tomsk on February 28, 2006 during intercalibration measurements with the lidars of SurSU and IAO SB RAS.

Accumulation of lidar signals, based on which the profiles shown in Fig. 3 were obtained, was made from 50000 laser shots. The duration of this process was approximately 1 hour 20 minutes. Spatial resolution of the profiles was 400 m.

Atmosphere during the experiments was not completely clean, cloudiness was observed at the heights of 3 and 10 km, so lidar signals from the far parts of the sounding path were additionally smoothed by sliding average over 5 points. It is seen from Fig. 3 that the aerosol vertical stratification is identical, and that $R(H)$ values coincide within the limits of random errors.

Intercalibration of the lidars of SurSU and IAO SB RAS in current (analog) mode of recording used for tropospheric investigations was also carried out in Tomsk. Its results also showed good coincidence.

The result of simultaneous sensing the vertical distribution of the aerosol component of air in the height range 1 to 30 km is shown in Fig. 4 as an illustration of the working ability of the lidar installed at SurSU.

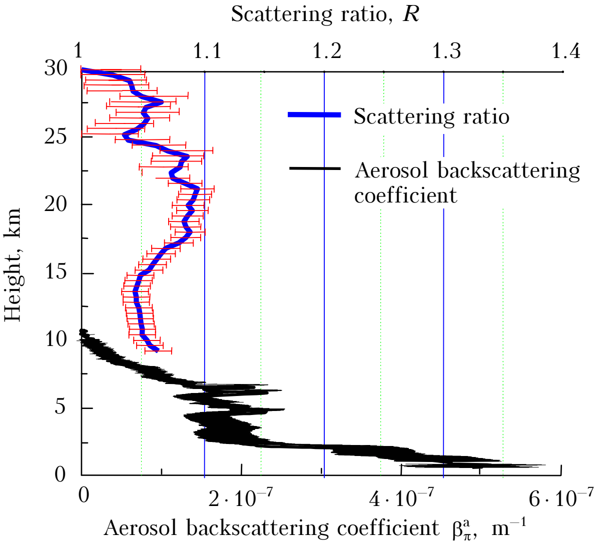

Fig. 4. Vertical profiles of the scattering ratio (top axis and upper curve) and the aerosol backscattering coefficient (bottom axis and lower curve) obtained in Surgut on April 27, 2006.

The lower profile of the aerosol backscattering coefficient was obtained from raw lidar data recorded in analog mode. The curve thickness corresponds to the value of the error in measurement taking into account all errors in reconstructing $\beta_\pi^a(H)$. The upper curve shows the scattering ratio profile obtained in the photon counting mode, also with the horizontal error bars calculated by Eq. (5). The time of accumulation of the presented profiles was approximately 40 min. The obtained results of sounding the aerosol stratification in the atmosphere are typical for the conditions of its "background" state and in the presence of mobile optically thin aerosol layers in the troposphere.

Conclusion

Thus, the lidar of Surgut State University is capable of promptly and regularly obtaining the aerosol backscattering characteristics with good accuracy practically from the mixing layer up to the heights of 30 to 35 km. The lidar is one more active site of the CIS-LiNet lidar network for observation of the state of the aerosol component of atmospheric air situated in subarctic latitudes.

Acknowledgments

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References

1. V.V. Zuev, V.E. Zuev, V.D. Burlakov, S.I. Dolgii, A.V. El'nikov, and A.V. Nevzorov, Atmos. Oceanic Opt. **16**, No. 8, 663–667 (2003).
2. V.D. Burlakov, S.I. Dolgii, and A.V. Nevzorov, Atmos. Oceanic Opt. **17**, No. 10, 756–762 (2004).
3. R. Measures, *Laser Remote Sensing* (John Wiley&Sons, New York, 1984).
4. A.V. El'nikov, V.N. Marichev, K.D. Shelevoi, and D.I. Shelefontyuk, Opt. Atm. **1**, No. 4, 117–123 (1988).