First results of laser monitoring of water vapor in the troposphere at the Siberian Lidar Station

V.V. Zuev, V.D. Burlakov, S.I. Dolgii, A.V. Nevzorov, and N.E. Orlova

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

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The paper discusses the possibilities of remote laser monitoring of water vapor in the troposphere at the sensing channels of the Siberian Lidar Station (SLS) using Raman backscattering signals. We describe the UV modified sensing channel of SLS and consider the problem of efficient cutoff of the Rayleigh line wing of exciting radiation. The first profiles of water vapor vertical distribution in the troposphere obtained at SLS are presented.

The remote laser monitoring of water vapor in the troposphere is carried out with the use of the effects of differential absorption of scattered energy (DASE) within the isolated water vapor absorption line contour and the Raman scattering (RS).[1,2] The method of DASE is of maximum sensitivity but its realization is very cumbersome.[3] The RS method is simple in realization and its selectivity is very high. However, the sensitivity of this method is very limited by small cross section of the interaction. Because the value of RS cross section increases with the growth of λ of exciting radiation following the λ^{-4} law, it is more suitable to use the shortest wavelengths. On the other hand, the advancement to the region of short λ is limited by the Huggins and Hartley ozone absorption bands.

In the UV channels of the Siberian Lidar Station (SLS) an excimer XeCl laser with the wavelength of 308 nm is used. In the spectrum of backscattering signals, excited by a laser pulse at this wavelength, the signals of the Raman scattering of water vapor (at 347 nm) and nitrogen (at 331 nm) always exist, which are described by the known lidar equation[2]

$$P_{347}(H) = \eta_{347} G(H) P^0_{308} \frac{A}{H^2} \beta^r_{347}(H) T_{308}(H) T_{347}(H), \quad (1)$$

$$P_{332}(H) = \eta_{332} G(H) P^0_{308} \frac{A}{H^2} \beta^r_{332}(H) T_{308}(H) T_{332}(H), \quad (2)$$

where P^0_{308} is the laser power of an exciting pulse; $P_\lambda(H)$ denotes lidar RS signals at the corresponding λ; η_λ are the detector quantum efficiencies, $G(H)$ is the lidar overlap factor; $T_\lambda(H)$ is the spectral transmission of the atmospheric layer (0–H); $\beta^r_\lambda(H)$ is the coefficient of backward Raman scattering for water vapor and nitrogen; A is the receiving aperture area. The water vapor vertical distribution profile, as the mixing ratio ε, is determined by a simple ratio between Eqs. (1) and (2):

$$\varepsilon(H) = C_k \frac{P_{347}(H)}{P_{332}(H)} \frac{T_{332}(H)}{T_{347}(H)}, \quad (3)$$

where C_k is the calibration coefficient.

It is simple to assess that at the values of the ozone absorption cross section at $\lambda = 332$ nm less than $1 \cdot 10^{-20}$ cm^2 and the characteristic concentrations of the tropospheric ozone no more than $1 \cdot 10^{-12}$ cm^{-3}, the ratio of spectral transmissions in Eq. (3) is not too different from unity (less than 1%) for the entire thickness of the troposphere. Thus, the distorting effect of the differential absorption by the tropospheric ozone at the wavelengths of RS signals at 332 and 347 nm on the results of the determination of $\varepsilon(H)$ can be neglected.

More essential is the distortion of weak RS signals by the line wing of the Rayleigh backscattering of exciting radiation at $\lambda = 308$ nm. To suppress this line simultaneously with an effective transmission of RS signals we can use the organic solvents: amyl alcohol, ethyl acetate, *n*-butyl, and acetone. Figure 1*a* shows the measured transmission spectra of an absorbing cell 10 mm thick, filled with the corresponding solvents. It is evident that the most acceptable one for the problem being solved is acetone. Curves of the acetone transmission at different concentrations and thickness of an absorbing layer are shown in Fig. 1*b*. Thus, the use in the receiving channel of the RS signals at the wavelengths of 332 and 347 nm, a filter with the absorbing cell with acetone, makes it possible to solve the problem of suppression of the Rayleigh backscattering line wing.

The RS signals were recorded at nighttime in the pulse counting regime of the photomultiplier photocurrent with the use of the receiving aperture of 0.5-m diameter. Spectral selection of RS signals was performed using a dichroic mirror (the transmission coefficient for $\lambda_{347} = 70\%$ and the reflection factor for $\lambda_{332} = 95\%$) and interference filters with the

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following parameters: the width/transmission 3.0 nm/44% and 1.7 nm/59% at the wavelengths of 332 and 347 nm, respectively. In both channels Hamamatsu R7207-01 photomultipliers and Hamamatsu C3866 amplifiers were used.

The calibration coefficient C_k was determined by the signal ratio in the first 50 m range gate using the meteorological data of TOR station of the Institute of Atmospheric Optics SB RAS[4] located in the same building as the sounding channels of the Siberian Lidar Station.

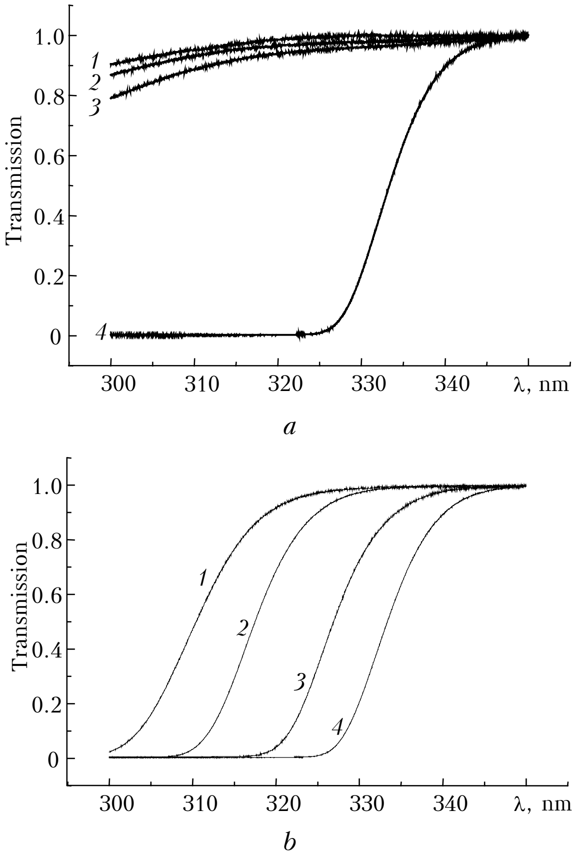

Fig. 1. Transmission spectra of some organic solvents: amyl alcohol (*1*), ethyl acetate (*2*), *n*-butyl (*3*) ; acetone (*4*) (the absorbing layer thickness is 10 mm) (*a*). Transmission spectra of acetone: aqueous solution of acetone (25%) at the absorbing layer thickness 1 mm and 10 mm (*1*, *2*), and acetone (100%) at the absorbing layer thickness 1 mm and 10 mm (*3*, *4*).

The first results of remote laser monitoring of water vapor in the troposphere, with the use of RS signals, excited by XeCl laser pulses, are given in Fig. 2. Figure 2 shows that the water vapor mixing ratio is determined practically over the entire troposphere with an acceptable accuracy. In this case the vertical resolution is 250 m and the time of signal accumulation is 17 minutes.

Figure 3 shows the sequence of water vapor vertical distribution profiles obtained on November 5, 2002 and characterizing the evolution of inverse layers both in the ground layer and at 5–6 km height. The profile was recorded every 30 minutes.

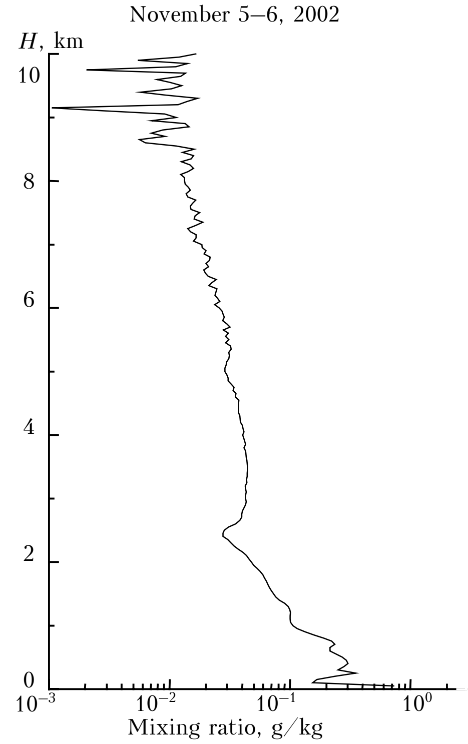

Fig. 2. The night mean profile of vertical water vapor distribution.

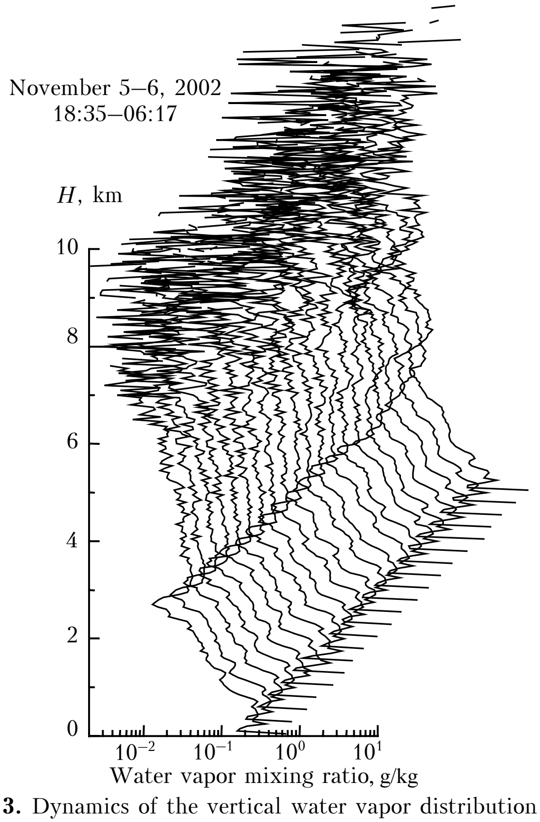

Fig. 3. Dynamics of the vertical water vapor distribution in the troposphere.

The first results of the remote laser monitoring of water vapor obtained with the use of technical potential of SLS have made it possible to draw the following conclusions:

1. The use of acetone filter provides a complete suppression of the Rayleigh line wing of exciting radiation at the wavelength of 308 nm while providing an effective transmission of RS signals at the wavelengths of 332 nm and 347 nm.
2. Temporal and vertical resolution of the obtained water vapor profiles already at the present time enable us to study in detail the water vapor dynamics everywhere in the troposphere at nighttime.

Future trends of the development of UV-channels at the Siberian Lidar Station for remote laser monitoring of water vapor are connected with the use of a large receiving mirror of 2.2-m diameter and the change of recording mode to the regime of analog detection that would allow the transition to 24-hour monitoring of water vapor at least in the atmospheric boundary layer and a considerable increase in the effectiveness of obtaining lidar data to be achieved.

Acknowledgments

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