MEASUREMENTS OF THE VERTICAL TEMPERATURE PROFILE BY MEANS OF THE SPONTANEOUS RAMAN SCATTERING CHANNEL OF THE ATMOSPHERIC LASER SOUNDING STATION

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The vertical profile of the atmospheric temperature up to 14.5 km *has been measured based on the ratio of the intensities for two sections of the rotational line spectrum of spontaneous Raman scattering (SRS) by the nitrogen molecules. The estimate of the error in determining the temperature profile is given as a function of altitude. The experimental results presented in the paper confirm the possibility of measuring the temperature up to the altitudes of the tropopause by the SRS technique predicted at the design stage of the laser sounding station.*

As is well known,[1] the air temperature can be measured based on the ratio of the intensities for two sections of rotational line spectrum of the spontaneous Raman scattering (SRS) by nitrogen molecules. In this case the temperature dependence of the line intensity on the quantum number is used

$$I(T) \sim \exp\left[\frac{-BJ(J+1)}{KT}\right], \tag{1}$$

where $B = 1.9895$ and J is the rotational quantum number.

The lidar return in the photon counting mode for the selected section of the spectrum of the rotational SRS can be represented in the following way:

$$N(\lambda, H) = C\,\Phi(H)\,\beta^R_{J\pi}(H)\,T(\lambda_0, H)\,T(\lambda, H)H^{-2} + N_n, \tag{2}$$

where C is the instrumental constant including the number of emitted photons, $\Phi(H)$ is the geometric factor, $\beta^R_{J\pi}(H)$ is the volume backscattering coefficient for the rotational SRS with the quantum rotational number J, $T(\lambda, H)$ is the volume transmission coefficient, H is the altitude, and N_n is the background.

A comparison of the intensities for two sections of the spectrum of the rotational SRS makes it possible to eliminate the effect of the source instability which distorts the effect of the geometric factor as well as of the atmospheric transmission. Then on account of Eqs. (1) and (2) we obtain

$$R = \frac{N_1 - N_{n1}}{N_2 - N_{n2}} = \exp\left[\frac{\alpha}{T} + \beta\right], \tag{3}$$

where R is the ratio of two signals, α and β are the instrumental constants depending on the choice of the sections of the rotational SRS, and T is the temperature. From this formula we can obtain the relation for the temperature

$$T = \frac{\alpha}{\ln R - \beta}. \tag{4}$$

Thus, the vertical profile of the temperature can be determined based on the optimal choice of the sections of the rotational SRS with different rotational quantum numbers. In addition, as calculations of Ref. 2 show, the sensitivity of the ratio R with respect to the temperature can reach 1.5–2 % by one degree.

From Eq. (3) we can obtain the estimate of the error in determining the temperature

$$\delta T = \frac{T^2}{\alpha}\frac{\delta R}{R}, \tag{5}$$

where

$$\delta R = \sqrt{\left(\frac{\partial R}{\partial N_{s1}}\right)^2 \delta^2 N_{s1} + \left(\frac{\partial R}{\partial N_{s2}}\right)^2 \delta^2 N_{s2} + \left(\frac{\partial R}{\partial N_{n1}}\right)^2 \delta^2 N_{n} + \left(\frac{\partial R}{\partial N_{n2}}\right)^2 \delta^2 N_{n2}} \tag{6}$$

and $N_s = N - N_n$ is the number of signal counts.

Assuming that the photocounts obey the Poisson statistics, i.e., $\delta^2 N_s = N_s$ and $\delta^2 N_n = N_n$, from Eq. (6) we can obtain

$$\delta R = \frac{\sqrt{N_1 + R^2 N_2}}{N_2 - N_{n2}}. \tag{7}$$

Denoting the contribution of the noise to the signal as

$$\theta = \frac{N_n}{N_s}, \tag{8}$$

we can reduce Eq. (5) to a more convenient form

$$\delta T = \frac{T^2}{\alpha}\sqrt{\frac{1}{(1-\theta_1)^2 N_1} + \frac{1}{(1-\theta_2)^2 N_2}}. \tag{9}$$

The SRS channel of the laser sounding station has the coaxial configuration.[3] The laser radiation is directed along

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the optical axis of the receiving antenna with the parabolic mirror 2.2 m in diameter. That allows us to reduce the length of the shadow zone down to 500 m. At the same time, due to the long focal length of the receiving mirror (10 m), the effect of the geometric factor is such that the dynamic range of the signal is shortened by a factor of approximately 50 within the 1–10 km altitude range. This factor is favourable since it eliminates the danger of illumination of the photon counters when signals are recorded from the low–altitude atmospheric layers.

The beam width of the receiving antenna is $3 \cdot 10^{-4}$ rad which provides for the high degree of spatial selection of the background. The double monochromator selects out two spectral sections whose centers correspond to the rotational quantum numbers $J = 6$ and $J = 14$. In addition, the suppression of the background at the carrier frequency is equal to 10^8.

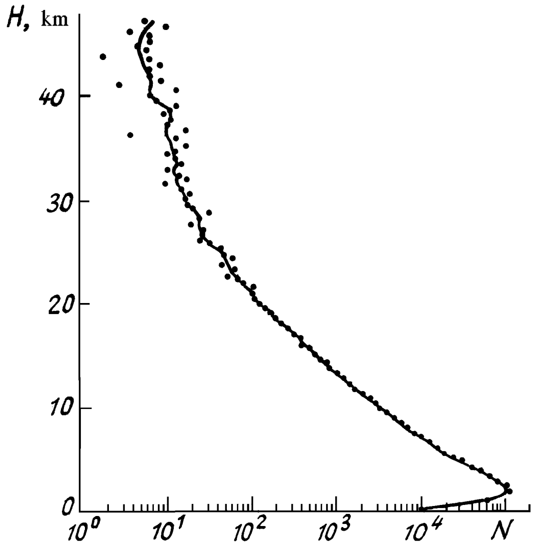

FIG. 1. The profile of lidar return for $J = 6$.

An LTI–411 laser ($\lambda = 532$ nm, $E = 50$ mJ, and $f = 14$ Hz) was used as a transmitter.

The profile of the SRS lidar return for the channel with $J = 6$ obtained on December 26, 1991 is shown in Fig. 1. The signal was recorded up to an altitude of about 35 km. The measurement time was equal to 15 min and the spatial resolution was 480 m.

The temperature profile obtained according to relation (4) is shown in Fig. 2, in addition, the parameters α and β were refined with the help of the model profile according to the All–Union State Standard (AUSS) 24631–81. The refined values were equal to $\alpha = 1042.3$ and $\beta = -2.436$. A comparison shows the good agreement of the measured profile with the model one. Figure 3 shows the dependence of the statistical estimate of the error in determining the temperature profile vs altitude. It is shown that the measurement was made with the meteorological accuracy of 0.5 deg up to an altitude of 5 km.

Thus, the possibility of measuring the temperature by the SRS technique up to the altitudes of the tropopause predicted at the design stage of the laser sounding station is experimentally confirmed. The speed of response, the spatial resolution, and the measurement accuracy up to the altitudes of 15 km can be considerably improved when the average emitted laser power is increased by an order of magnitude, which is technically possible. Moreover, the temperature up to the altitudes of 20–25 km can be estimated.

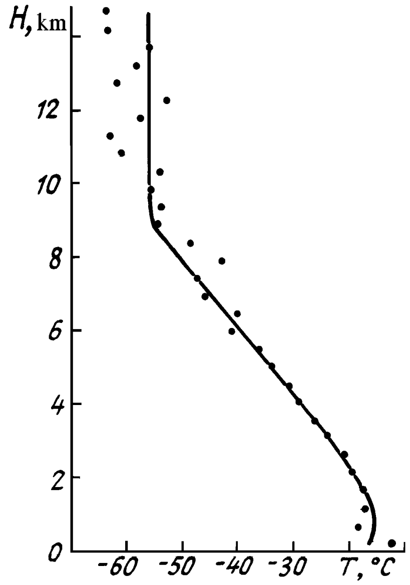

FIG. 2. The temperature profile. The model profile according to the AUSS 24631–81 *is shown by the solid line.*

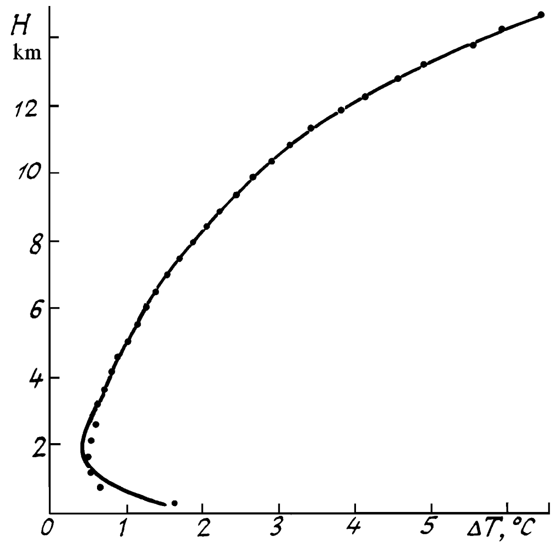

FIG. 3. The vertical profile of the estimate of the statistical error in determining the temperature.

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