S1-3 **Rotational Raman Lidar using a New Blocking Filter System for Atmospheric Temperature Measurement**

Masahiro Funada, Chikao Nagasawa, Yasukuni Shibata and Makoto Abo

Graduate School of Electrical Engineering, Tokyo Metropolitan University
1-1, Minami-Osawa, Hachioji-shi, Tokyo 192-0397, Japan
Phone: +81-426-77-1111 Fax: +81-426-77-2756
E-mail: funada@ecomp.metro-u.ac.jp

1. Introduction

There is a lidar method using the anti-Stokes rotational lines of N_2 and O_2 Raman spectra to determine the temperature of the atmosphere up to 30km[1)]. The method makes use of the variation with the temperature of the envelope of the intensities of the backscattered rotational Raman spectrum[2)]. For each temperature of the gas, the ratio of the fluxes through two narrow and close-by filters takes a definite value directly related to the temperature. The major difficulty of this method is due to the very small spectral shift between the Raman lines and the Rayleigh and Mie lines. The filters chosen for such measurement must have a sufficiently high rejection at the laser wavelength to eliminate most of the contribution of the Rayleigh and the Mie backscattered signals. However, it is difficult to get the filter having such a high rejection. In this method, therefore, the filter is nearer at the laser line (near filter) must be chosen at the position having enough distance from the Rayleigh and Mie lines. Consequently, the position is not the best sensitive one to measure the variations of temperature.

In this paper, we estimate the influence by the Rayleigh and the Mie scattering, and propose a new blocking filter using both the atomic filter and the interference filters in order to suppress the influence.

2. The Rotational Raman Spectrum

The cross section of Raman scattering is about three orders of magnitude smaller than the corresponding Rayleigh cross section, and the scattered signal consists of radiation that has suffered a frequency shift that is characteristic of the stationary energy states of the irradiated molecule. The selection rules of frequency shift of the rotational Raman scattering allow rotational transitions for which the change in the molecular rotational quantum number J can be only 0 or ± 2. The spectrum distribution of the rotational Raman scattering by atmosphere molecules(N_2 and O_2) is shown in Fig. 1.

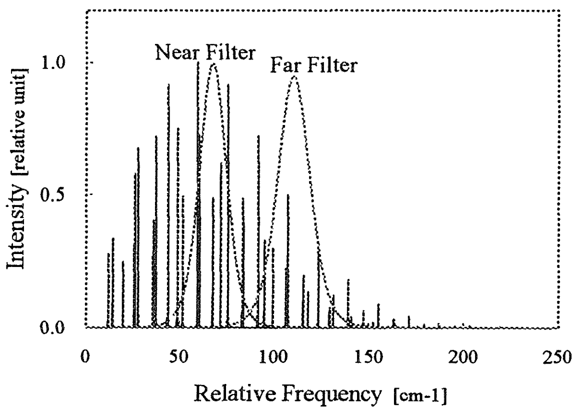

Fig.1 Calculated distribution of the intensity of the rotational Raman line backscattered by atmospheric molecules (at 255[K], 5[km]), and position of the filters. (The center frequencies of the near and far filters are 68 and 107 cm^{-1} from the laser frequency, respectively. The bandwidths of the near and far filters are 19 and 22 cm^{-1}, respectively. The laser frequency is 25716cm^{-1}.)

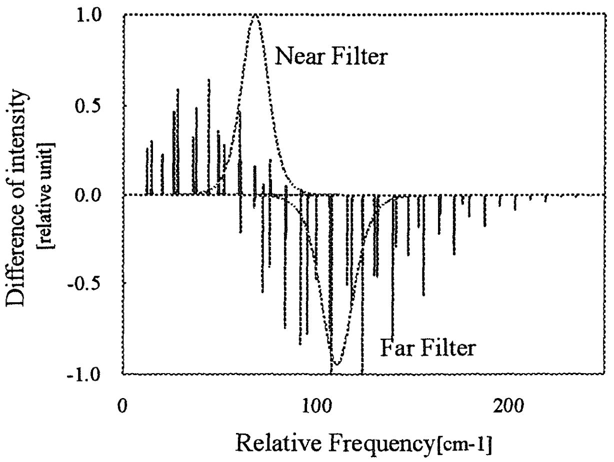

Fig.2 Difference of the intensity of the rotational Raman scattering by atmospheric molecules at temperature between 275 and 255 K in 5 km altitude.

The intensity of the rotational Raman scattering depends on the temperature as shown in Fig. 2 (The filter parameters and laser frequency are same that of Fig.1.). To measure atmospheric temperature, therefore, detection of fluxes transmitted by two bandpass filters at each altitude is carried out, and then the temperature at the each altitude is deduced by comparing the ratio of the actual transmitted fluxes with that (Eq. (2)) of intensity transmitted by two filters (Eq. (1)) which is given by calculation under the modeled atmospheric parameters beforehand. Position of each filter should be chosen by first the sensitivity of the measurements to the variations of temperature and second the available flux intensity through the filter. But, influence by the Mie and Rayleigh scattering must be also considered at choice of the near filter position.

$$I_x(t,z)=\int_{-\infty}^{+\infty} Ft_x(\omega) I_{scat}(t,z,\omega)d\omega \quad \cdots(1)$$

$$R(t,z)=\frac{I_{near}(t,z)-I_{far}(t,z)}{I_{near}(t,z)+I_{far}(t,z)} \quad \cdots\cdots\cdots(2)$$

where x = near or far according to the filters, t is temperature [K], z is altitude [km], ω is frequency [cm^{-1}], Ft_x (ω) is transfer function of x filter, $I_{scat}(t, z, \omega)$ is total intensity of the rotational Raman, the Rayleigh and the Mie backscattering.

3. Influence by the Mie and Rayleigh scattering

As a good compromise, center frequencies of the near and the far filter are chosen at being distant of around 68 and 107 cm^{-1}, respectively to the laser line. We estimated the transmitted intensity of the rotational Raman, Rayleigh and Mie backscattering up to 30km under the condition of the U.S. Standard atmospheric model[5] and the backscattering coefficient model of the aerosol by a composite of a ground visibility of 23km of Ismail et al.[6] and EOS Report[7] (ref. Fig.3). The ratio of the intensities of the Rayleigh and the Mie scattering to the rotational Raman backscattering transmitted by the near filter are shown in Fig. 4.

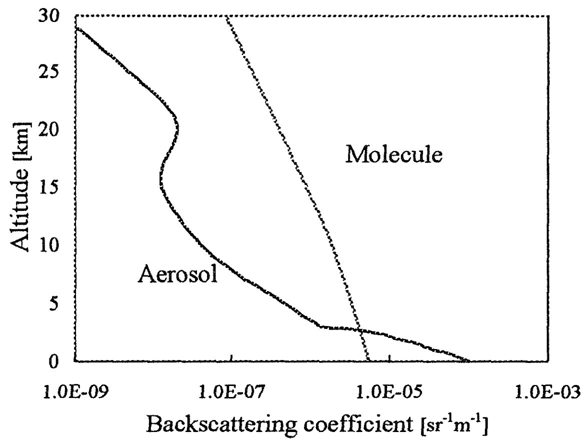

Fig.3 The assumed profiles of the backscattering coefficients of the atmospheric molecule and aerosol.

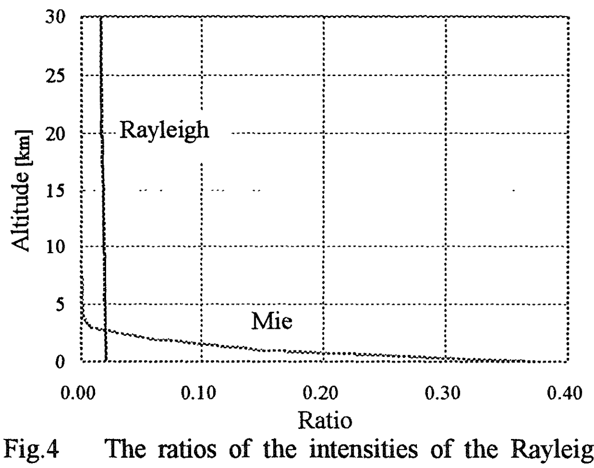

Fig.4 The ratios of the intensities of the Rayleigh and Mie scattering, respectively to Raman scattering intensity transmitted through the near filter up to 30km under the condition of the U.S.Standard atmospheric model. (The filter and laser parameters are the same as that of Fig.1.)

Provided the near filter position changes close to being distant of around 44cm^{-1} to the laser line, the sensitivity to the variances of the intensity of the rotational Raman scattering becomes better obviously (ref. Fig.2), however, the influence by the Mie scattering in lower altitude becomes too large to detect the variation of the intensity of the rotational Raman scattering.

4. A new blocking filter system

We propose a new blocking filter system consisting of an atomic filter and the near and far interference filters in order to suppress influence of both the Rayleigh and Mie scattering. In this method, the near filter can be located at the best sensitive position.

In this paper we describe the result analyzed with a Cs atomic filter[3),4)]. The resonance frequency of the Cs atom is 25715.865 cm^{-1} (388.865 nm), and, when the Cs atomic parameters are given in Table 1, the transmittance around the resonance frequency of the Cs filter is shown in Fig.5. Scheme of the rotational Raman lidar with the Cs filter is described in Fig.6. Table 2 gives the lidar characteristics of this scheme.

We present that most of the influence of the Rayleigh and Mie scattering is suppressed and affection to the Raman scattering is neglected, because the transmittance of the Cs filer is small enough to suppress that; the bandwidths of the Rayleigh and the Mie line are about 0.067 cm^{-1} (1GHz) and a tenth of that, respectively.

We estimated the error in the new temperature measurement method by using the Cs filter (Fig. 7). The lidar characteristics are given by Table 2. The atmospheric condition is the same as that used in Fig.4. It is suggested that the accuracy is improved significantly comparing to the conventional method.

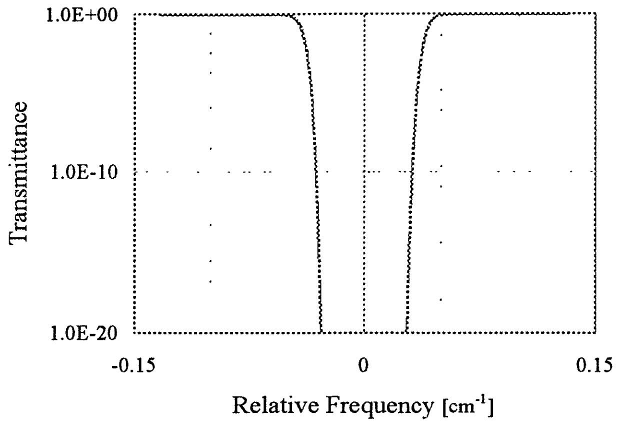

Fig.5 Transmittance around the resonance frequency of Cs filter. Cs atomic parameters are given by Table1.

Table 1 Cs atomic parameters

Resonance wavelength	25715.865 (cm^{-1})
Oscillator strength	0.028
Vapor temperature	320 (K)
Atomic weight	132.9 (amu)
Atomic density	6.069×10^{14} (cm^{-3})
Cell length	5 (cm)

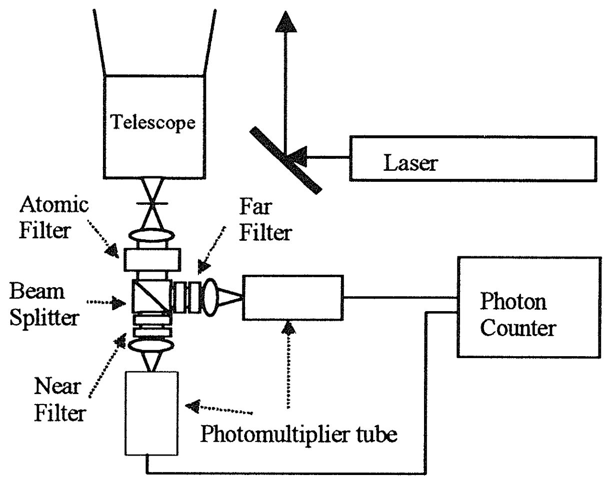

Fig. 6 Scheme of the rotational Raman lidar using the atomic filter and the interference filters.

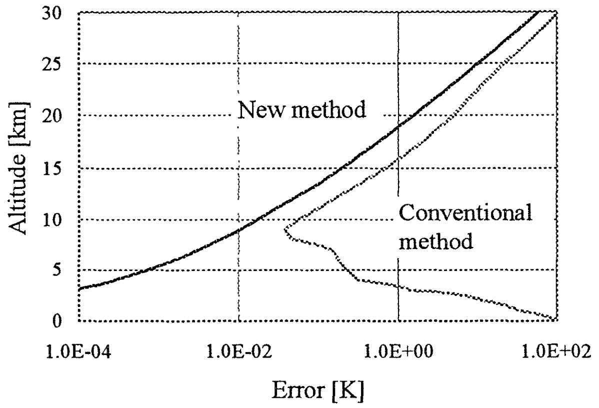

Fig. 7 Accuracy profiles of the two methods up to 30km.

Table 2 Lidar characteristics

Laser	
Wavelength	388.865 (nm)
Energy	300 (mJ)
Repetition rate	10 (Hz)
Filters	Near / Far
Wavelength	388.2 / 387.2(nm)
Bandwidth	0.29 / 0.35(nm)
Telescope diameter	0.80(cm)
Integration time	60 (min)

5.Conclusion

The new blocking filter system consisting of an atomic filter and two interference filters is proposed for atmospheric temperature measurement by the rotational Raman lidar.

By means of the simulated calculation, it is concluded that the precision of measurement, especially in troposphere, is improved significantly comparing to the conventional method by suppression of influence of the Rayleigh and Mie scattering and optimization of the near filter location.

We are currently developing a lidar system with an expected performance that is simulated in this paper.

References

1) D. Nedeljkovic, A. Hauchecorne, and M. L. Chanin, "Rotational Raman Lidar to Measure the Atmospheric Temperature from the Ground to 30km", IEEE transaction on geoscience and remote sensing, 31, 90-101(1993).
2) C. M. Penney, R. L. St. Peters, and M. Lapp, "Absolute rotational Raman cross sections for N2, O2, and CO2", J. Soc. Am., 64, 712-716, (1974).
3) K. Noguchi, H. Shimizu, and C. Y. She, "Optimization of the High Spectral Resolution Lidar for Measuring Atmospheric Temperature", The Japan Society Applied Physics, 54, 972-978 (1985). (in Japanese)
4) E. D. Hinkley, ed., Topics in Appl. Phys., 14, 3 (1976)
5) U. S. Standard Atmospheric, U. S. Government Print-ing Office (1976).
6) S. Ismail and E. V. Browell, "Airborne and spaceborne lidar measurements of water vapor profiles: a sensitivity analysis", Appl. Opt., 28, 3603-3614 (1989).
7) NASA, "Lidar Atmospheric Sounder and Altimeter. Earth Observing system", vol. 11d, Instrumental Panel Report (1987).