ROTATIONAL RAMAN TEMPERATURE LIDAR AND DATA CALIBRATION

Kiyotaka UCHIDA[(1)], Toshikazu HASEGAWA[(1)], Dengxin HUA[(1), (2)], and Takao KOBAYASHI[(3)]
[(1)] *EKO Instruments Co., Ltd.,*
1-21-8, Hatagaya, Shibuya-ku, Tokyo 151-0072, Japan, uchida@eko.co.jp
[(2)] *Xi'an University of Technology,*
No. 5 South Jinhua Road, Xi'an 710048, hua@net-eko.com
[(3)] *University of Fukui,*
3-9-1, Bunkyo, Fukui city, Fukui 910-8507, Japan, kobayasi@fuee.fukui-u.ac.jp

ABSTRACT

Radiosonde is widely used in monitoring of heat island phenomenon, environmental assessment, and so on. However, it has several problems, i.e. influence of wind, measurement time, aviation and radio wave control, and others. Compared with radiosonde, the lidar gives real time and effective measurement with easy operations.

We have developed the lidar system, which can measure temperature profile in the lower troposphere with low cost. In this report, a temperature lidar system, which is based on rotational Raman scattering method, was calibrated with radiosonde. As a result, the lidar could measure temperature profile up to 1,000m in both daytime and nighttime, and RMS error of six data set average between radiosonde and lidar was 1.0K.

1. INTRODUCTION

We have developed the lidar system for the measurement of temperature, humidity and aerosol of upper air up to 5km since 2001 in order to monitor global warming, heat island phenomenon, and environmental assessment etc. We have already completed the production of two prototype models. With respect to measuring temperature, Rayleigh scattering method is applied in this lidar, which calculated output is a relative temperature based on the specified altitude temperature. In order to measure absolute temperature, the system needs to equip a temperature calibrator at the specified altitude.

On the other hand, a temperature lidar using rotational Raman scattering method can measure absolute temperature directly, and its measurement range is up to 1km in the case the system uses the same laser in the lidar system using Rayleigh scattering method. Therefore, Raman temperature lidar can be used as a temperature calibrator of Rayleigh temperature lidar. In addition, Raman lidar itself can be provided in the market at lower cost than existed model.

In this report, stability and practical availability of Raman lidar system were validated by comparing with radiosonde measurements.

2. LIDAR SYSTEM

Applied lidar system consists of the spectrometer for rotational Raman scattering, which is developed by University of Fukui, and other modules including transmitting and receiving system, which are described in [1] to [4] in detail. The goal of this system is to achieve <1K of temperature accuracy and stable operation in long term.

(1) HARDWARE

Spectral distribution of the cross section by rotational Raman scattering of nitrogen and oxygen molecules, and those temperature coefficient for ultraviolet laser whose center wavelength is 354.7nm are shown in Fig. 1.

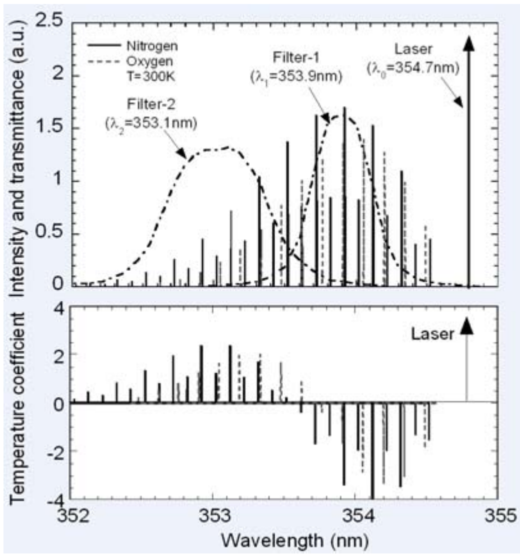

Fig. 1 Spectral distribution of the rotational Raman scattering for the UV laser.

System diagram is shown in Fig. 2. UV laser using Nd:YAG/THG is emitted to the upper air from the top of telescope sub mirror. Laser power is maximum 300mJ of pulse at 355nm with 20Hz repetition. Back scattering from the air is collected at the telescope that diameter is 250 mm, and its signals are extracted by the spectrometer and saved in the digitizer. Saved data can be processed in PC.

Optical design is shown in Fig. 3. Back scattering light collected by telescope is guided to spectrometer unit through optical fiber. The incident light reflected on grating and edge mirror is transmitted to two interference filters; IF-1 and IF-2, and finally detected by two photo multiplier tubes; PMT-1 and PMT-2. These two signals are used for determining temperature by rotational Raman scattering method. Spectral transmittance curves of two filters are plotted in Fig. 1. Wavelength positions of two filters are set where showing opposite sign of temperature coefficient in order to get higher temperature response. In addition, back scattering light, which mainly consists of Mie and Rayleigh scattering, is detected by detector; PMT-3.

Lidar specifications are shown in Table 1 in detail.

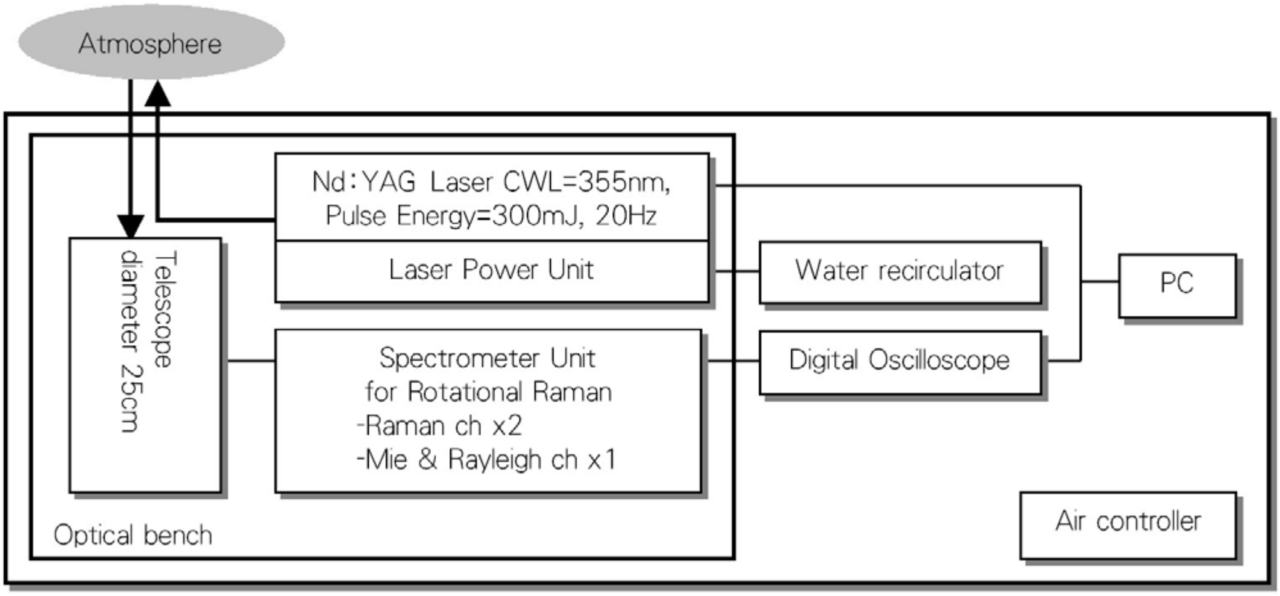

Fig. 2 Block diagram of the lidar system.

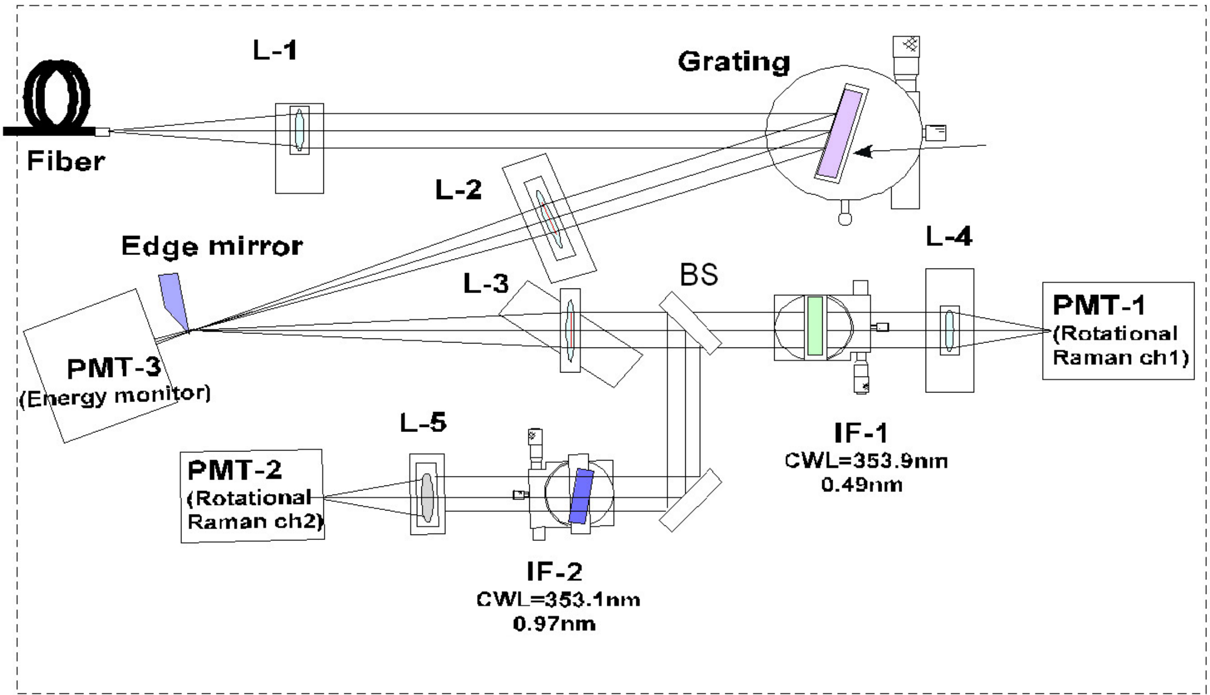

Fig. 3 Optical design of rotational Raman lidar for temperature measurement.

Table. 1 Lidar Specifications

Item		Specifications
Laser system		Nd: YAG, THG, center wavelength: 355nm, frequency: 20Hz, pulse energy: maximum 300mJ
Telescope		Diameter 250mm with UV coating, FOV: 0.1mrad
Filters	Raman ch1	CWL: 353.9nm, FWHM: 0.49nm
	Raman ch2	CWL: 353.1nm, FWHM: 0.97nm
A/D and data interval		100 MSample/s by Lecroy LT584, data interval: 1.5m
Averaging time		200 seconds (4000 shot)
Range resolution		30 m
Measurement property		Temperature [K]
Measurement principle		Temperature dependence of rotational Raman scattering intensity by atmospheric molecules
Measured range		up to 1.0 km

(2) DATA ANALYSIS PROCEDURE

In the data analysis procedure of rotational Raman scattering method, time series smoothing, detector function correction, and background noise rejection etc. are carried out. After that, temperature response function S(z), in which z means altitude in meter, is calculated as a ratio of two rotational Raman scattering channels. Temperature response function S(z) is approximated as second order function of temperature T(z) and written as equation (1). Using this formula, temperature T(z) can be determined by using calibration constants A, B and C.

$$\ln(S(z)) = A \cdot T(z)^{-2} + B \cdot T(z)^{-1} + C \qquad (1)$$

Temperature profile of each altitude can be calculated using two rotational Raman scattering signals and three calibration constants A, B, and C. Those calibration constants are determined by at least one dataset of lidar and radiosonde. In this report, calibration constants A, B, and C were derived for all dataset, and only one calibration constant is determined after quality check.

In order to investigate the error between radiosonde and lidar, RMS; root mean square, error for each time was calculated by sampling the temperature data at thirty altitude points. In this data sampling, altitude ranges of sampling were derived with considering overlap function and signal to noise ratio of lidar data, and then thirty data were sampled at even intervals.

3. EXPERIMENTAL RESULTS

Comparison measurement of lidar and radiosonde was performed from 2005/02/21 15:00 to 2005/02/22 18:00. Comparison measurements were performed at EKO Instruments at Hatagaya, Shibuya-ku, Tokyo. Six radiosondes were released from the roof of the building, and lidar was installed at the north side of the building.

Applied radiosonde, model RS-01G, was manufactured by Meisei Electric. Its specifications are as follows; resolution is 0.1 degree C, accuracy is +/-0.5 degree C. It took about four minutes to measure temperature up to 1km altitude. In this duration, the balloons were moved a few km horizontally by wind.

The result shows that RMS error between radiosonde and lidar were in the range from 0.2K to 2.1K, and the average was 1.0K. In all data, lidar could measure accurate temperature up to 1km in both daytime and nighttime.

Scatter diagram of radiosonde and lidar temperature is shown in Fig. 4, and compared representative temperature profiles are shown in Fig. 5. Temperature linearity in the scatter diagram, lapse rate and the temperature changing behavior according to the altitude show good agreements between radiosonde and lidar.

However, one dataset shows about +2K of offset in Fig. 4. It might be caused by the lack of rejection rate of Mie scattering in the Raman scattering detection. This point should be discussed in future studies.

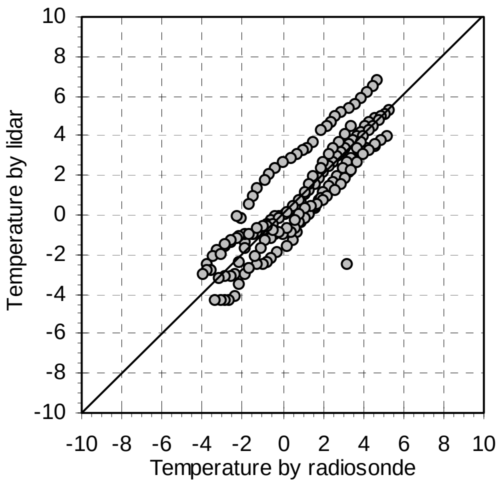

Fig. 4 Scatter diagram of radiosonde and lidar temperature data.

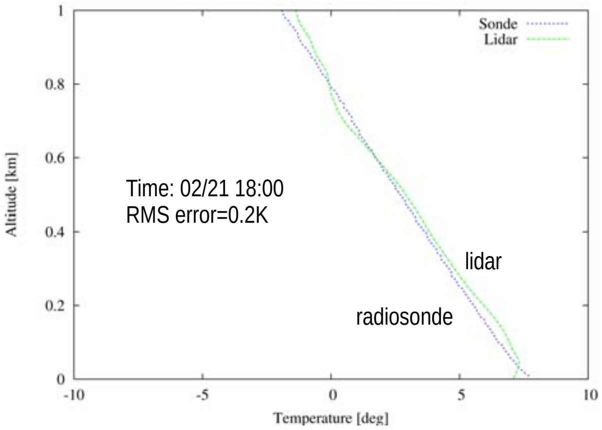

Fig. 5 Compared temperature profile between radiosonde and lidar at 18:00 2005/02/21.

4. CONCLUSIONS

In conclusion;

1) Measurement range of rotational Raman scattering method was up to 1km in both daytime and nighttime.
2) Calibration constants A, B, and C were optimized by using six times data, and the derived constants were applied for all data.
3) RMS error was in the range from 0.2K to 2.1K, and the average was 1.2K.

A further direction of this study will be as follows;

1) It is important to realize higher efficiency and rejection ratio of Mie scattering for rotational Raman scattering channels. Investigation to improve optical design has been already started. Single grating and double interference filter-method are applied in new design. It makes the efficiency 29%, and the rejection ratio 10^{-7} level.
2) Additionally, more precise mechanical design, faster time response amplifier, better signal to noise ratio system will be applied.
3) It is the final goal to apply Raman lidar into multi purpose lidar system, and to measure absolute temperature up to 5km with <1K accuracy.

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