DEVELOPMENT OF ULTRAVIOLET MULTI-SPECTRUM LIDAR FOR METEOROLOGICAL APPLICATIONS

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ABSTRACT

We have designed a practical meteorological lidar system for simultaneous measurements of key meteorological parameters such as temperature, wind velocity, humidity and several optical parameters of aerosol and clouds particles of the troposphere. Single or double parameter measuring systems have already been developed using ultraviolet lidar systems and further extension to measure the key meteorological parameters is promoted in this work. The ultraviolet multi-spectrum detection technique is used and the analysis of filter efficiency, accuracy and range capability of the system are made. Some basic results are reported on the characteristics and requirements for realization of this new lidar scheme.

1. INTRODUCTION

The present technology for meteorological measurement is based on the balloon borne radiosonde sensor technology. Dynamical approach for measuring accurate, real-time and wide area is needed for operational and mobile use in a variety of recent meteorological applications.

We have been developing the lidar systems for measuring one or two meteorological important parameters of temperature, wind velocity, humidity and aerosols, using the ultraviolet wavelength of 355 nm [1] - [5] and useful data have been obtained.

In this paper, we will report the design of the ultraviolet multi-spectrum (MS) lidar system for simultaneous measurements of major meteorological parameters including temperature, wind velocity, humidity and dust parameters. The ultraviolet multi-spectrum filtering technique is used in the system. System analysis of filter efficiency, accuracy and range capability of the system is examined and some basic results are reported on the characteristics and requirements for realization of this new lidar scheme.

2. DEVELOPMENT OF ULTRAVIOLET LIDAR SYSTEMS

We have developed several lidar systems using the ultraviolet wavelength of 355 nm for measuring one or two meteorological parameters [1] - [5]. The use of the ultraviolet wavelength rather than the visible wavelength comes from several salient advantages. First, the Rayleigh scattering power increases inversely with the fourth power of the laser wavelength and the solar background noise is relatively low. Second, eye-safety condition can be realized ~10^3 times easily by the increase in the maximum permissible exposure (MPE) in the ultraviolet than the visible wavelength.

Development of our previous lidar systems and performances are reviewed briefly.

2.1 TEMPERATURE LIDAR [1] – [3]

Figure 1 shows the temperature lidar system using the ultraviolet laser. The system employs the injection seeded single-frequency Nd:YAG pulsed laser at the third harmonic wavelength of 355 nm. The pulse energy of the laser beam is 150 mJ with a pulse width of 10 ns and a pulse repetition frequency of 20 Hz. The 250 mm diameter telescope collects backscattered light from the atmosphere and coupled into the optical fiber and the output beam is collimated and transmitted through the Fabry-Perot interference filters and detected by the photomultiplier tubes (PMTs).

The Rayleigh scattering for the air molecules are transmitted through the Fabry-Perot filters and two channel filters are used for measuring positive and negative temperature coefficient part of the Rayleigh spectrum and Doppler-broadened spectral width provides the information of temperature of the atmosphere.

As an example, the result of the lidar measurement of height profile of the temperature and some comparison with the balloon data are shown in Fig. 2. The lidar measurement time was 12 min. It is shown that the radiosonde data and the lidar data are in good agreement. The inversion layer was observed at the altitude of 2.1 - 2.6 km.

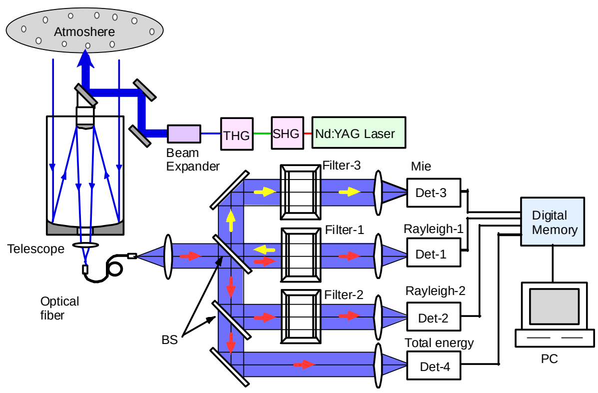

Fig.1 Schematic of the Rayleigh temperature lidar system.

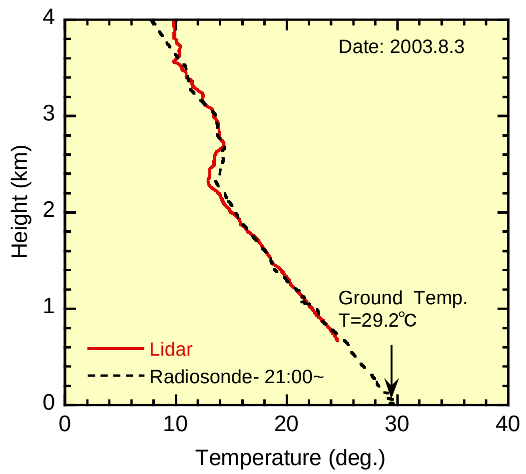

Fig. 2 Temperature profiles comparing the lidar and radiosonde data.

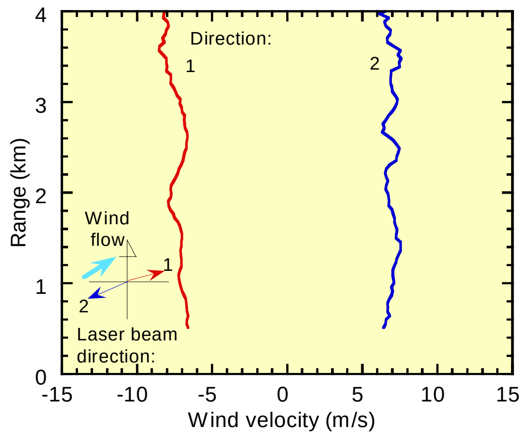

Fig. 3 Horizontal wind velocity for two opposite beam directions with an elevation angle of 3.2 °, range resolution of 50 m, and 10^2 shots average.

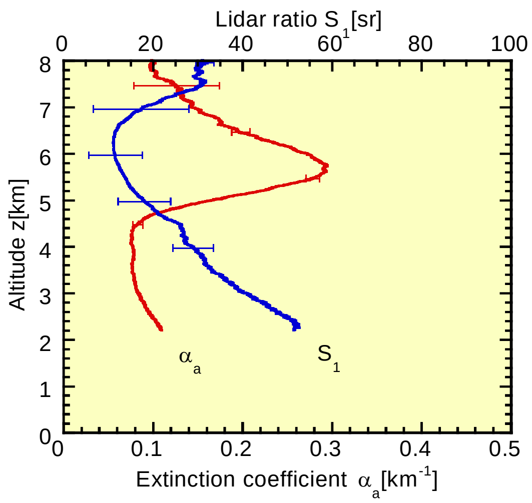

Fig. 4 Height distribution of the extinction coefficient and lidar ratio for clouds. Data with 10^4 shots average, range resolution of 300m, observed from 15:00 JST on 18 February 2004.

2.2 WIND DOPPLER LIDAR [4]

Using the UV Doppler lidar system, the Mie scattering from aerosol particles is detected by direct detection scheme and the Doppler shifted frequency is derived from the change in the transmittance of the narrow-band filter.

Horizontal wind velocity along the laser beam was measured and the result is shown in Fig. 3. The laser beam was transmitted to the atmosphere in two opposite horizontal directions. Each measurement data was averaged over 10^2 shots with 50 m range resolution. From this result the measurement accuracy of the wind velocity is estimated to be 0.42 m/s at 3.5 km range.

2.3 AEROSOL AND CLOUD LIDAR [4], [5]

The high-spectral resolution scheme lidar system was developed using the single Mie scattering filter channel and the total energy monitor channel.

Figure 4 shows an example of the height distribution of the corrected Mie and Rayleigh backscatter, extinction coefficient and lidar ratio. The measurement accuracy of the extinction coefficient and lidar ratio is $1.3x10^{-2}$ km^{-1} and 3 sr at 3 km altitude, respectively.

3. DESIGN OF MULTI - SPECTRUM LIDAR SYSTEM

Figure 5 shows the block diagram of the multi-spectrum lidar system for meteorological multi-function and multi-parameter measurements of the troposphere. The system is capable of simultaneous measurements of temperature, wind, humidity and aerosol and cloud optical parameters such as extinction and lidar ratio.

The injection seeded single frequency pulsed Nd:YAG laser is used at ultraviolet wavelength of 355 nm. The backscattered light is corrected by telescope, transmitted through a high - spectral - resolution Fabry - Perot interference filters and detected by seven PMT detectors.

The backscatter spectrum and filter spectrum is shown in Fig. 6. The filter system is designed to measure the Mie scattering frequency shift of the aerosols and the spectral width of the Rayleigh scattering of the atmospheric moleculrs. The output signal of the PMT-2, 4 and 5 are used for the measurement of wind velocity, the output of the PMT-2, 3, 5 and 6 for the temperature measurement, and the output of the PMT-2 and 5 for the measurement of extinction coefficient and lidar ratio.

For the humidity measurement, the vibrational Raman spectrum of water vapor is used with the band-path filter and PMT-7 as widely used.

System design parameters of the multi-spectrum lidar is listed in Table 1. Same parameters are used in the previous UV lidar systems.

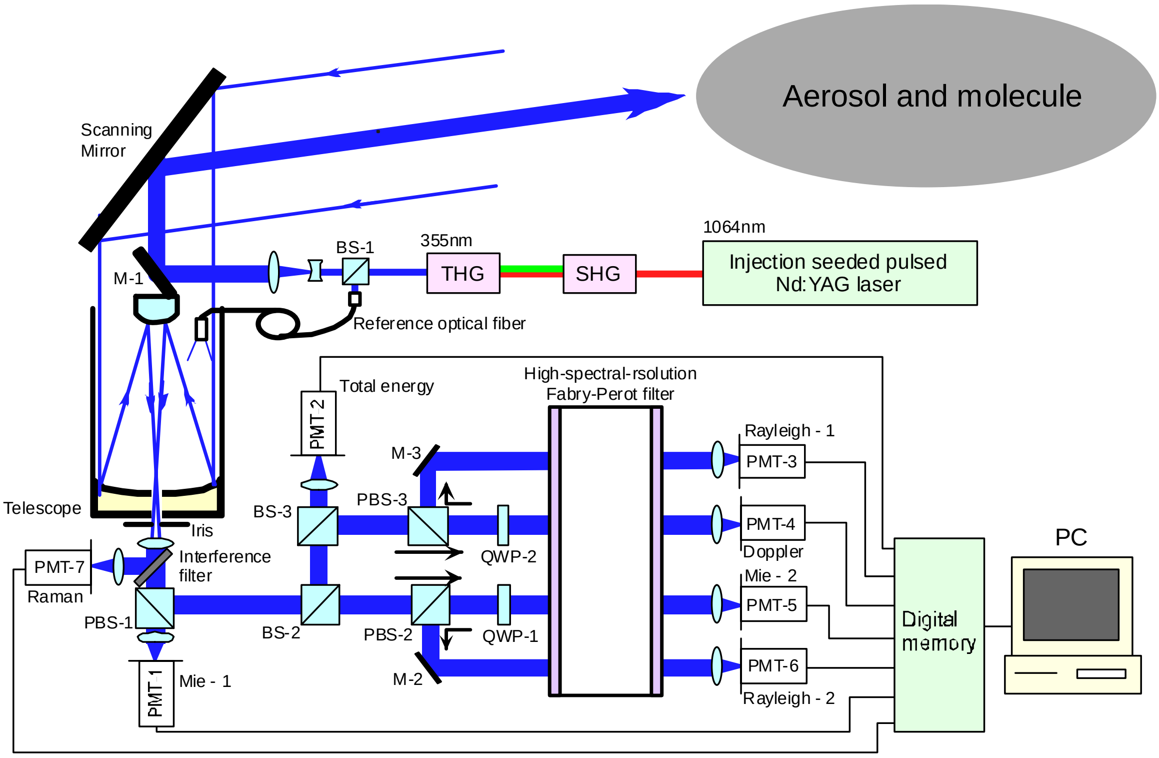

Fig. 5 Schematic of the multi-spectrum meteorological lidar system.

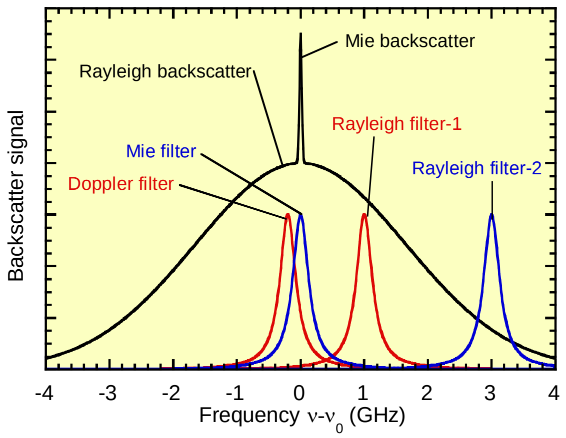

Fig. 6 Backscatter spectrum and filter functions.

Table 1 System parameters.

Laser: Nd:YAG third harmonics	
Wavelength	355nm
Energy per pulse	200mJ/pulse
Pulse repetition frequency	20Hz
Spectral width	150MHz
Optics:	
Telescope diameter	250mm
Fiber core diameter	100μm
Spectral width of Fabry-Perot filter	150MHz
Detector: PMT	
Quantum efficiency (@ 355nm)	23%

4. SYSTEM ANALYSIS

The measurement accuracy of the system depends on the Doppler sensitivity, the temperature sensitivity, the signal-to-noise ratio SNR and the rejection ratio of Mie and Rayleigh backscatter κ [5]. Using the reflection beam geometry of the Fabry-Perot filter, the rejection of the Mie backscatter can be improved from our previous temperature lidar system.

Figure 7 shows the calculated measurement accuracy of the multi-spectrum lidar system. For the estimation of the system performance, the standard atmospheric model of clear air with clouds at higher altitude is used [6] and is shown in Fig. 7 (a).

Figure 7 (b) shows the height profile of the relative error of extinction coefficient measurement and Fig. 7 (c) and (d) show the profiles of temperature and wind velocity measurement error, respectively.

It is shown that high accuracy can be obtained in this multi-spectrum system, similarly with previous ultraviolet lidar systems [1] - [5]. By changing the observation time and range resolution, the accuracy can be changed to meet the requirements of practical applications.

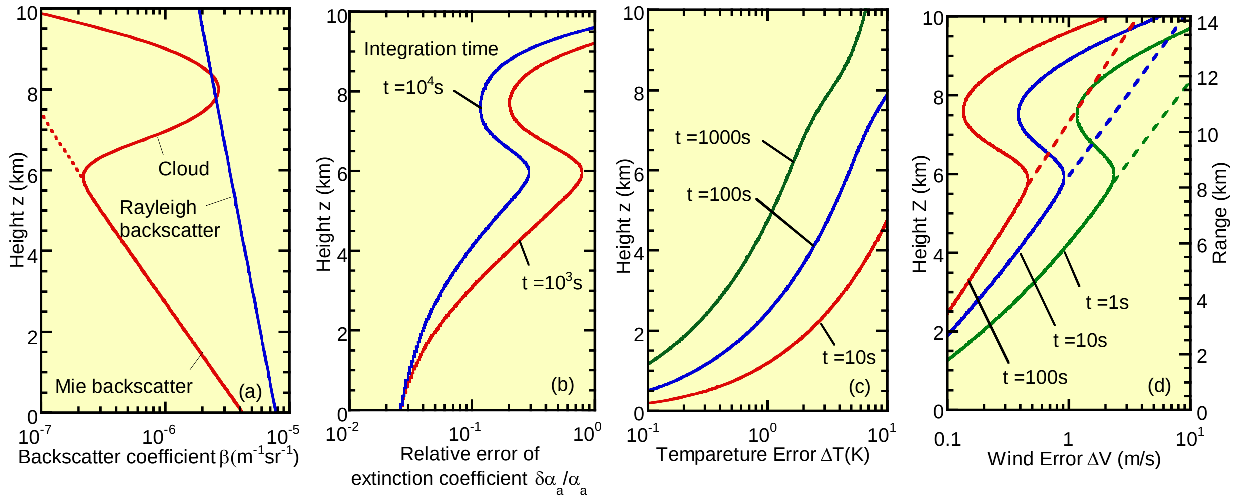

Fig. 7 Height distribution of the measurement accuracy. (a) is the backscatter coefficient model, (b) is the relative error or extinction coefficient $\Delta\alpha_a/\alpha_a$ with 600 m range resolution, (c) is the temperature error ΔT with 50 m range resolution, and (d) is the wind velocity error ΔV with 50 m range resolution for vertical and 45^o elevation angle range.

5. CONCLUSIONS

We have proposed the design of the ultraviolet multi-spectrum lidar system for measuring key meteorological parameters, i.e., temperature, wind velocity, humidity, and aerosol extinction coefficient with lidar ratio. Efficient system can be realized by using the Fabry-Perot interference filter and the multi-filter and detection system. Further improvement in the laser and filter-detection system is necessary for realizing a compact and mobile system.

This system will be useful for operational meteorological observation as an alternative technique to the present radiosonde system. New application fields are expected in the 3-dimentional, real-time and multi-parameter sensing experiments necessary for studying dynamical phenomena like heat island and environmental pollution.

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