S4-3

Development of UV Aerosol and Molecular Scattering Lidar for Wind and Temperature Measurements

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1. Introduction

Development of active remote sensors of major atmospheric parameters such as temperature, humidity and wind speed has long been a high priority need in basic scientific and practical applications. Furthermore, simultaneous measurements of several major atmospheric parameters are also needed for precise diagnosis of the atmospheric environment.

In this report, we will describe the principle of a new lidar technique for measuring simultaneously wind velocity and temperature of the atmosphere. The efficient single frequency ultraviolet lasers and high spectral resolution spectroscopic techniques are essential to realize this high-sensitive multi-parameter measurement lidar. Although ground based systems for the measurement of the troposphere to the stratosphere is discussed, extension to the spaceborne system is possible. Theoretical analysis and preliminary experimental results are reported.

2. Principle of wind and temperature measurement

Atmospheric wind measurements with direct detection technique have been realized by detecting the Doppler shift of molecule and aerosol backscattering using etalon filters by Chanin[1] and Korb[2] and various lidar systems have been developed[3-7].

The spectral relation of the backscattered signal ν_S, the laser ν_L and the narrow band filters (ν_1 and ν_2) is shown in Fig.1. Using the filter transmission function $h(\nu)$ and the backscattering signal intensity $I_M(\nu)$, the filter output intensity is given by the convolution function:

$$I_i(\nu_s) = \int h(\nu - \nu_i) I_M(\nu - \nu_s) d\nu \qquad (1)$$

where the subscript M denotes the Mie backscattering, i is the i-th filter channel. The Doppler shift $\nu_d = \nu_S - \nu_L$ of the Mie backscattering can be determined by the ratio $r(\nu_s)$ of two channel signals $I_1(\nu_s)$ and $I_2(\nu_s)$, i.e. $r(\nu_s) = I_1(\nu_s)/I_2(\nu_s)$. The velocity sensitivity θ_V is

$$\theta_V = \frac{2}{\lambda \cdot r(\nu_s)} \frac{dr(\nu_s)}{d\nu_s} \qquad (2)$$

The velocity sensitivity depends on the filter width and the signal frequency. It is interesting to note that the velocity sensitivity for the Mie backscattering can be made very high.

The similar velocity measurement can be applied for the molecular detection using the Rayleigh-Brillouin (R-B) backscattering. The R-B scatter is caused by the density fluctuations in the gas. The general distribution of a R-B line has been modeled[8-10]. To use the R-B scatter for the wind measurement, wide bandwidth filters can be used and located at both side of the backscattering spectrum ν_3 and ν_4, as shown in Fig.1. To eliminate the effect of Mie component, filter frequencies are selected at the point where the velocity sensitivity for the Mie and the R-B scattering is same[6].

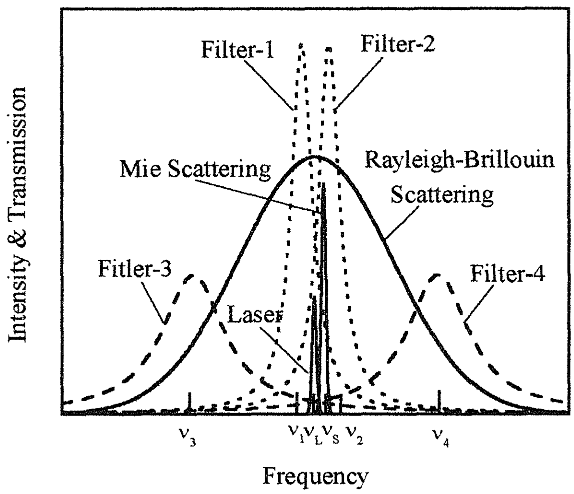

Fig.1. Frequency spectra of filters, laser and Mie and Rayleigh-Brillouin backscatter signals.

Since the wind velocity causes the R-B spectrum shift and the temperature changes the spectral width, the velocity and temperature can be determined independently. If two filters are used, summation of the two channel signals

$$s(T,\nu_s) = I_3(T,\nu_s) + I_4(T,\nu_s) \qquad (3)$$

is temperature dependent, where I_3 and I_4 are the normalized intensity. The Doppler frequency ν_d is determined by Eq.(2), and the temperature can be derived from Eq.(3), simultaneously.

3. High resolution Rayleigh/Mie lidar system

The aerosol-molecular lidar system has been developed using a laser transmitter, a 25cm telescope receiver, and a computer for data processing, as shown in Fig.2. The transmitter uses the 3rd harmonic (355nm) of Nd:YAG laser, the beam is transmitted through a collimeter and pointed into the atmosphere by a scanning mirror. The backscattered light is collected by the telescope and coupled to the optical fiber with 50μm core diameter. The fiber beam splitter separates the light into the Mie and Rayleigh channel filters. Two etalon filters are utilized to discriminate the Doppler shift of Mie backscattering and Rayleigh backscatter. Normalized R-B backscattering signals are also used for temperature measurement. Four detectors and counter boards are used for receiving and sampling the signals, and the data is processed by a Pentium II PC. The lidar system parameters are listed in Table 1.

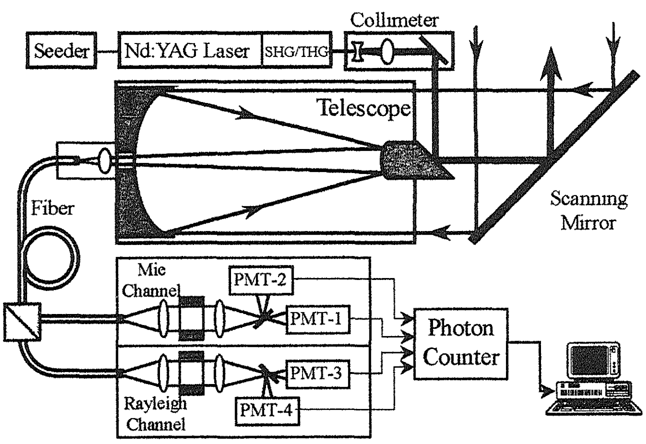

Fig. 2 Diagram of the aerosol-molecular lidar for wind and temperature measurements.

The Mie scattering signal from the troposphere was experimentally obtained and the result is shown in Fig.3. From the velocity sensitivity $\theta_V \approx 7\%/(m/s)$, the wind velocity accuracy corresponds to about 1 m/s at the range of 4km.

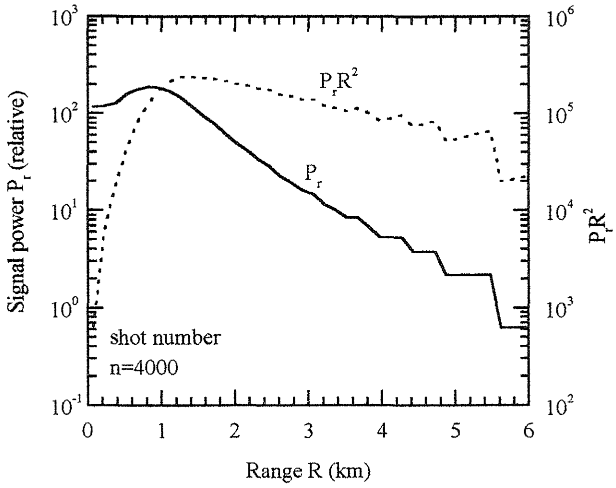

Fig.3 Received Mie signal power vs. range in the clear atmosphere.

Table 1. Parameters of the Rayleigh/Mie lidar

	Present system	Improved system
Laser:	Nd:YAG(3rd harmonic)	
Wavelength (λ)	355nm	
Energy (E)	30mJ	1mJ
PRF	20Hz	10kHz
Average Power (W)	0.6W	10W
Spectral width	180MHz	30MHz
Telescope diameter	25cm	
Optical efficient (η_s)	0.1 (total)	
Detector:	PMT(Photon Counting)	
Q.E. (η)	30%	
Rayleigh filter:		
Transmission	0.7	
Full width($\Delta\nu_f$)	1.6GHz	
Separation	5.4GHz	
Mie filter:		
Transmission	0.6	
Full width($\Delta\nu_f$)	180MHz	
Separation	200MHz	

4. Analysis of detection sensitivity

(a) Velocity sensitivity

Aerosol Mie backscattering can be used for high sensitive and accurate wind measurement of the troposphere by the ground based lidar. The velocity sensitivity increases with the narrow band-width of the etalon filter and the narrow spectral width of the laser, as shown in Fig.4. With the parameters of Table 1, the velocity sensitivity for aerosol detection is about 9.5%/m/s

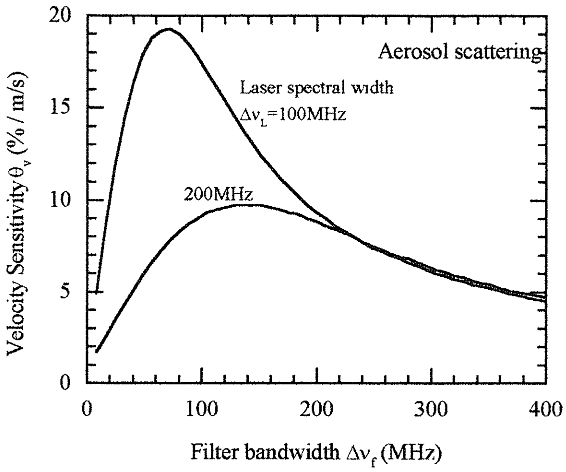

Fig.4 Velocity sensitivity vs. filter width $\Delta\nu_f$ for the Mie backscattering.

The velocity sensitivity based on the R-B scattering is shown in Fig.5. The velocity sensitivity is high for narrow band filter width at about 3.1GHz filter position. The R-B method has lower sensitivity than the Mie scattering because of wide scattering spectrum. On the other hand, the R-B measurement provides a very large velocity measurement range.

(b) Temperature sensitivity

The temperature sensitivity with the R-B scattering centered at ν_S is defined as

$$\theta_T = \frac{1}{s(T,\nu_s)} \cdot \frac{ds(T,\nu_s)}{dT}, \tag{4}$$

and it is shown in Fig.5 for various filter width. One can find the optimum filter parameters for temperature sensitivity. By comparison with the velocity sensitivity of the R-B scattering detection, the filter position for the maximum temperature sensitivity is located at 3.3GHz. The temperature sensitivity for 1K change is

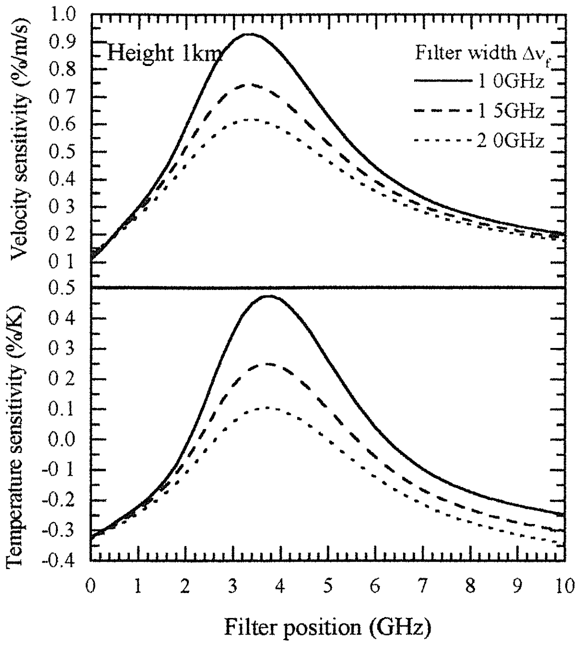

Fig.5 Velocity and temperature sensitivity vs. filter position for various filter width for the R-B scattering at 1km height.

one third of the velocity sensitivity for 1m/s.

5. Measurement accuracy

The velocity measurement accuracy is simulated using the system parameters in Table 1 and the result is shown in Fig.6. With the designed system, the velocity measurement with the Mie scattering method can have high accuracy compared with Rayleigh scattering

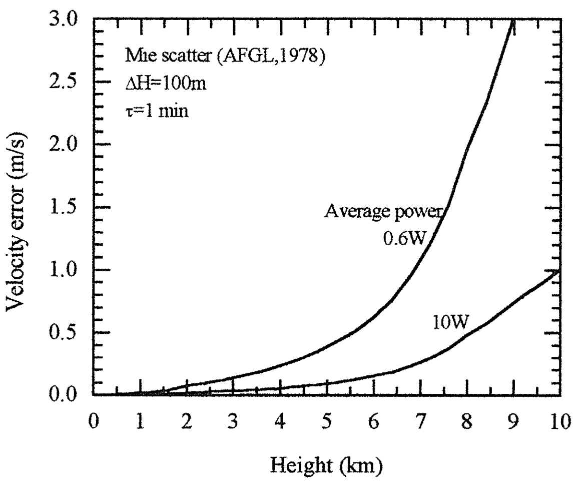

Fig.6 Velocity accuracy vs. height with the Mie backscattering.

method. In the troposphere measurement accuracy with the Mie method is about 1m/s up to 10km height for the 10W laser power. The R-B method will be used for the high altitude where aerosols are quite less, and the accuracy is about 1m/s up to 20km with the laser power of 10W, as shown in Fig.7.

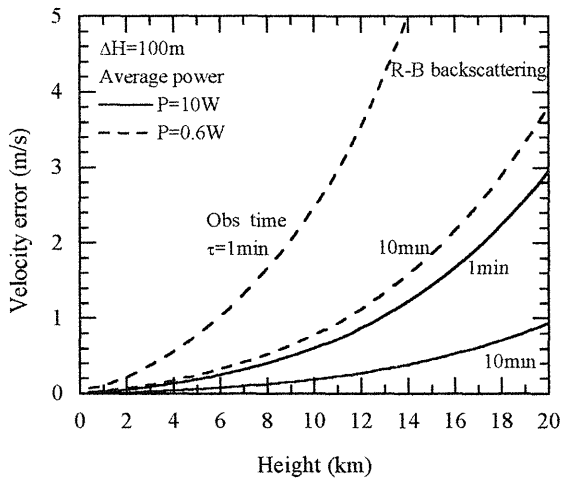

Fig.7 Velocity accuracy vs. height with the R-B backscattering.

The temperature accuracy with the R-B backscattering is shown in Fig.8. Since the temperature sensitivity is low, the measurement takes longer time compared with the velocity measurement. However the accuracy can be about 3K up to 20km with 10min observation time.

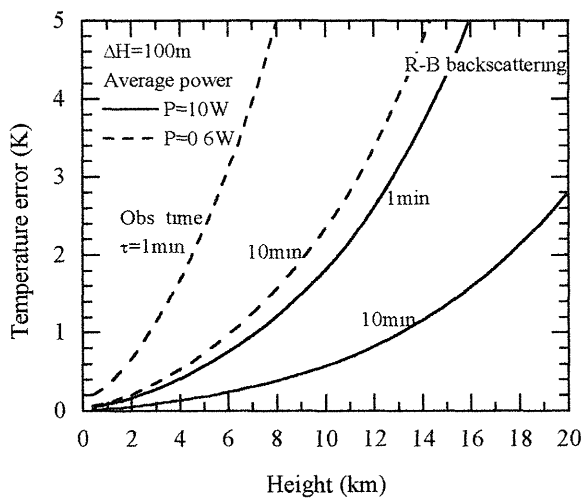

Fig.8 Temperature accuracy vs. height with the R-B backscattering.

6. Conclusion

We have analyzed a new lidar method of temperature measurement based on the R-B backscattering. The temperature profile can be obtained together with the wind velocity measurement. A high-spectral resolution lidar system detecting the Mie and Rayleigh scattering has been developed using the UV laser for the velocity and the temperature measurements in the troposphere.

This system can be used as a basic sensor for accurate observation and forecasting severe weather such as temperature inversion layer, heat island, wind shear, and turbulence.

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