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Study of the scanning lidar on the atmospheric detection

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ABSTRACT

The scanning polarization Mie lidar (SPML) system has been developed and is described. The lidar system has two detection channels to receive the parallel and perpendicular polarization components at the laser wavelength of 532 nm, which indicates the nonsphericity of aerosol and cloud particles. It can take the horizontal, vertical and conical scans of the atmosphere with the elevation and azimuth motors. This paper discusses the current capability of the SPML lidar and its results. The observation shows that the SPML lidar can provide the multi-dimensional views of the atmosphere which is impossible to achieve with other ground-based vertically pointing lidars. It is helpful to track and monitor aerosol plumes in urban area, to determinate the planetary boundary layer height and to enhance the measurement of atmosphere in the lower height where the geometrical form factor of lidar system affects.

1. Introduction

Aerosols and clouds are fine solid particles or liquid droplets in the atmosphere, and they produce two important uncertainties in the estimation of the radiative forcing and global climate change [1]. Meanwhile, aerosol pollution and haze have become a serious problem in the urban cities of China along with the rapid economic development and high energy consumption in recent years. As the capital of Anhui province, Hefei (geographical coordinates: 32′N and 117′E) is located in the Yangtze River Delta, which is one of the largest economic regions in China. It possesses a strategically important location easily accessible from all directions of the country, and it connects the vast area of Central China. Hefei enjoys a subtropical humid monsoon climate featuring mild climate with distinct seasons and appropriate precipitation. The average temperature is 15.7 °C, the mean precipitation is about 1000 mm and sunshine-time accounts for 2100 h annually. Since the opening-up and reform, Hefei has entered a fast track for its economic and social development, but air pollution emissions are increasing steadily and the regional environment is deteriorating. The observation of the optical properties of aerosol and its temporal and spatial distributions in Hefei is helpful to understand the aerosol characteristics and its effect on the climate in the Yangtze River Delta.

Long-term monitoring of aerosols and clouds under ambient atmospheric condition is required because of spatial and temporal variability and their complicated transformation process. Lidar is one of the active remote sensing technologies and is widely used in the atmospheric

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observation because of its high resolution in both space and time. Routine monitoring of aerosol and cloud optical properties has been carried out in the framework of networks, e.g. the Aerosol Robotic Network (AERONET) [2], the European Aerosol Research Lidar Network (EARLINET) [3,4], and the Asian Dust Lidar Network (AD-NET) [5,6]. Unlike the traditional vertically pointing lidar system, the scanning lidar system can detect the return signal in any direction needed. Thus, the scanning lidar is useful to find the location of the pollution aerosol in urban area with horizontal scanning, to determinate the planetary boundary layer height and to enhance the measurement of atmosphere near surface where the geometrical overlap factor of lidar system affects with vertical scanning, and to reveal the spatial distribution of aerosols and clouds with conical scanning [7–9].

The scanning polarization Mie lidar (SPML) system was developed in 2012 for monitoring the multi-dimensional views of the pollution aerosols and clouds in urban area. The SPML lidar system and data analysis procedure are described in Section 2. Some typical results of aerosol and cloud optical properties with horizontal, vertical and conical scanning are presented in Section 3. The conclusions are given in Section 4.

2. SPML lidar system and data analysis

The schematic diagram of SPML lidar system is given in Fig. 1. The lidar employs a Nd:YAG laser as a light sources that generates the second harmonic at 532 nm. Transmitted laser energy is typically 100 mJ per pulse with the repetition rate of 20 Hz. A 22 cm diameter Schmidt–Cassegrain telescope with a field of view of 1.5 mrad is used to collect the backscatter light. The receiver has two channels to receive the parallel and perpendicular polarization components at 532 nm. The optical bandwidth of each channel is about 0.3 nm. The photomultiplier tubes (PMTs) are used as detectors and the detected signals are collected with 16 bit digitizers. The sampling rate for each channel is 20 MHz, corresponding to a range resolution of 7.5 m. The data are averaged for the given laser shots and transferred to a PC. SPML lidar can take the horizontal, vertical and conical scans of the atmosphere with the elevation and azimuth motors for the preset scanning speed and scanning range. The optical axis of lidar allows for 360° azimuth operation and elevation scans of up to 90°. The maximal scan speeds is up to 25°/s but operational scan speeds typical range from 0.1° to 5°/s depending on the target of experiment. The accuracy of orientation is about 5′. The specification of SPML lidar system is listed in Table 1.

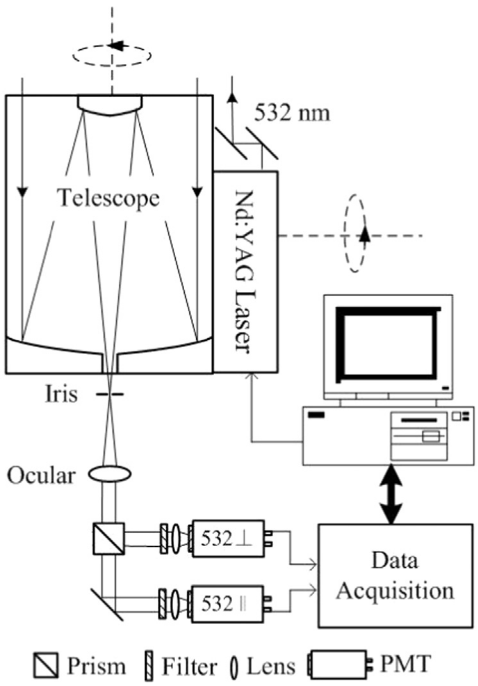

Fig. 1. The schematic diagram of SPML lidar system.

The equation of Mie scattering lidar in vertical pointed operation is described as follows:

$$P(r)r^2 = C\eta(r)\left[\beta_m(r)+\beta_p(r)\right]\exp\left\{-2\int_0^r\left[\alpha_m(r')+\alpha_p(r')\right]dr'\right\} \tag{1}$$

where $P(r)r^2$ is the range corrected signal from atmospheric molecules and particles (e.g. aerosol, dust and cloud) at a range of r. And it can be measured by the lidar system. C is the lidar system constant including the laser output energy, lidar receiver area, the optical efficiency and so on. $\eta(r)$ is the geometrical form factor of lidar system. $\beta_m(r)$ and $\beta_p(r)$ are the molecular and particle backscatter coefficients at a range of r, respectively. $\alpha_m(r)$ and $\alpha_p(r)$ are the molecular and particle extinction coefficients, respectively.

To retrieval of the particle backscatter coefficient $\beta_p(r)$ and extinction coefficient $\alpha_p(r)$, Fernald's method is used with three assumptions [10]. (1) The extinction-to-backscatter ratio (i.e. lidar ratio) for particles is assumed to be constant with altitude and equals to 50 sr at a

Table 1
Specification of SPML lidar system.

Characteristic	Value
Transmitter	
Wavelength	532 nm
Energy output	100 mJ
Pulse repetition frequency	20 Hz
Divergence	< 0.5 mrad
Receiver	
Telescope diameter	22 cm
FOV	< 1.5 mrad
Filter bandwidth	0.3 nm
Detector	PMT
Data acquisition	
Sample rate	20 MHz
Resolution	16 bit
Scanner	
Azimuth scan	360°
Elevation scan	90°
Scan speed	25°/s
Scan accuracy	5′