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Development of a multiple-field-of-view multiple-scattering polarization lidar system at 355nm for cloud measurements

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ABSTRACT

We developed a multiple-filed-of view multiple-scattering polarization lidar (MFMSPL) at 355nm to study microphysics of optically thick clouds and understand multiple scattering effects on space lidar measurements (e.g., EarthCARE). This system is based on depolarization Mie lidar technique; it uses a compact receiver module including a small telescope, polarizer, and detectors to measure co-polar and cross-polar backscatter signals, separately. The MFMSPL system has all the 10 measurement channels. The MFMSPL uses the five receiver modules with FOV of 10mrad tilted with different zenith angles (θ); it measures on-beam signals (θ=0mrad) as well as four off-beam signals (θ=10,20,30,40mrad). This MFMSPL system was based on previously developed 532nm MFMSPL system, however, we made the system more stable, robust, and compact by integrating co-polar and cross-polar channels in the receiver module than the previous system. In addition, we improved the dynamic range of the measurement in nighttime by synergy use of analog and photon counting measurements. In the conference, we present the MFMSPL system, data analysis method including calibration method, and observation results.

1. INTRODUCTION

Generally, lidar cannot penetrate optically thick clouds (or aerosols) due to strong attenuation; it generally detects only the bottom of the layer [1]. This limitation is different for space-borne lidar observations. The two-wavelength depolarization Mie lidar CALIOP [2] has a much larger footprint size (~90m) compared to that of conventional ground-based lidar (~1m at 1km altitude). This larger foot print enables the CALIOP to collect more multiple scattered signals and detect the inner part of the cloud layer. Ground-based lidars to measure multiple scattering signals have been developed. For example, Polonsky [3] developed a wide-angle imaging lidar by means of off-beam lidar returns. Cahalan [4] developed a multiple FOV lidar system using a fiber bandle. Though several "multiple scattering lidars" have been developed, there has been few multiple scattering lidar to measure depolarization ratio.

To obtain more information in the inner part of cloud layer and overcome the limitations of conventional ground-based lidars, we developed a multiple-filed-of view multiple-scattering polarization lidar (MFMSPL) at 532nm that can detect backscatter coefficients and depolarization ratios as similar as those observed by CALIOP [5]. This system was constructed by combining four channels with different zenith angles, such that each receiver channel has a 10mrad FOV and a polarization function. Thus, the total FOV of this system is 70mrad, comparable to the footprint size of the CALIOP at 1km altitude.

EarthCARE is a joint Japanese (JAXA)-European (ESA) satellite observation mission to understand the interaction between cloud, aerosol, and radiation processes in the earth climate [6]. In the EarthCARE mission, cloud and aerosol observation will be conducted by 355nm high-spectral resolution lidar ATLID.

In this study, we developed a MFMSPL system at 355nm by improving the previously developed MFMSPL, to develop and improve algorithms to retrieve optical and microphysical properties of clouds and aerosols from ATLID measurements and validate the ATLID measurements. The total FOV of the developed system is 90mrad, covering the footprint of the ATLID (~30m). This paper describes the developed MFMSPL system (Section2), calibration method (Section3), observation results (Section 4), and summary (section 5).

2. MFMSPL SYSTEM

The configuration and specifications of the MFMSPL developed in this study are depicted in Fig. 1 and Table 1.

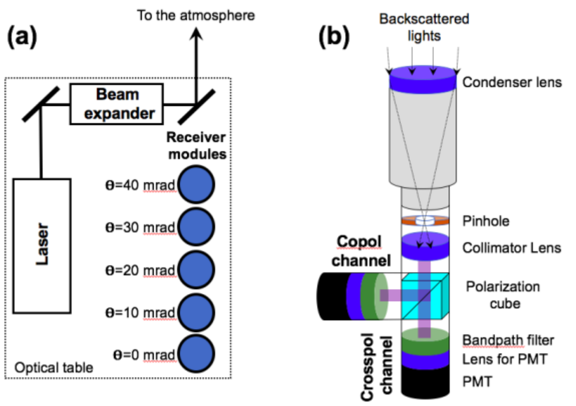

Fig.1 The MFMSPL system developed in this study. (a) Configuration of the entire system. (b) Configuration of the receiver module.

Table 1. Specifications of the MFMSPL specifications.

Transmitter	
Laser type	Nd:YAG, Q-switched, linearly polarized
Wavelength	355nm
Pulse energy	80mJ
Repetition rate	10Hz
Divergence	0.1mrad (using a 5x expander)
Receiver module (5 modules used in this system)	
Condenser lens	Φ=50mm, F~380mm
FOV	10mrad
Detector	PMT
Band-path filter	1nm (FWHM)
Data acquisition	
Transient recorder for analog measurement (40MHz, 16bit) and photon counting measurement (800MHz counting rate)	

The MFMSPL employs a commercial Nd:YAG laser with second- and third-harmonics generators (Surelite I, Continuum) and transmit the laser beam at 355nm to the atmosphere upward in the vertical direction. Backscattered lights are received by five receiver modules.

Each receiver module corrects the backscattered light with a 50mm-diameter lens and measures signal intensities of the co-polar and cross-polar components with two PMTs; the FOV of the receiver module is 10mrad. The five receiver modules are mounted and tilted from the vertical direction with different zenith angles θ; thus, they measure on-beam signals (θ=0mrad) and four off-beam signals (θ=10, 20, 30, and 40mrad). This MFMSPL system is based on previously developed 532nm MFMSPL system [5], however, we made the system more stable, robust, and compact by integrating co-polar and cross-polar channels in the receiver module. In addition, we improved dynamic range of the measurement in nighttime by synergy use of analog and photon counting measurements (TR40-16bit, Licel).

3. CALIBRATION

The receiver modules are tilted with different zenith angles in usual observation to measure on-beam signals and off-beam signals (Fig. 1), however, to calibrate the 10 channels of the MFMSPL relatively, we make all the five receiver modules upward in the vertical direction (i.e., θ=0mrad) and set a polarization sheet on each receiver module rotating in angle of 45° to the direction of the linear polarization of the laser as conducted in calibration of depolarization Mie lidars [7]. Using the measured signals, we obtain relative calibration constants CR. CR is obtained as the ratio of the measured signal at a channel P_{ch} to the signal for the co-polar component channel at θ=0mrad in the usual observation (P_1) (i.e., $CR_{ch} = P_1/P_{ch}$). This relative calibration measurement is periodically conducted.

To obtain attenuated backscatter coefficients for each channel (β_{atn}), we periodically calibrate the on-beam co-polar channel (i.e., co-polar channel at θ=0mrad) using the data measured in usual observation and Fernald method [8] as conducted in calibration of depolarization Mie lidar measurements [7]. In this calibration, we use data measured in clear-sky condition without cloud layers. Using the obtained calibration constant for the on-beam co-polar channel C_1 and relative calibration constant CR_{ch}, β_{atn} for each channel are obtained (i.e., $\beta_{atn,ch}= Z^2C_1CR_{ch}P_{ch}$, here Z is an altitude).

4. OBSERVATION AND ANALYSIS

The MFMSPL system is constructed at National Institute of Information and

Communication Technology (NICT) in Koganei, Tokyo, Japan. The signals are measured with 10s temporal resolution and with 3.75m range resolution. The measured data are averaged every 5min and 30m range; we used the averaged data in the calibration and data analysis.

Fig. 1 depicts an example of the observed and analyzed data. The data with less than 10 in signal-to-noise ratio are removed. We started usual observation from 10UTC after we conducted the relative calibration measurements. The on-beam channels indicate that cloud layers appeared from 4km to 8km on the day and it rained from 19UTC to 20UTC. The off-beam channels, which measure only multiple scattering signals and do not include single scattering signals, succeed in grasping cloud layers and rain drops appropriately. The figure also shows that the on-beam signals are fully attenuated in the lower layer of the cloud due to strong cloud attenuation (e.g., cloud layers appeared at 4km from 18UTC to 21UTC), however, the off-beam channels could detect the signals scattering from the higher layers of the cloud by multiple-scattering effect.

5. SUMMARY AND PLAN

More stable, robust, and compact the MFMSPL system was developed. We constructed the 355nm MFMSPL system in Japan and started continuous measurement in 2018. The measured data were calibrated periodically. A 355nm HSRL system is being constructed at NICT; this HSRL data will be used for the absolute calibration of the 355 MFMSPL in the near future. An improved 532nm MFMSPL system based on the system developed in this study are being constructed at National Institute for Environmental Studies in Tsukuba, Japan. The 355nm MFMSPL as well as the 532nm MFMSPL and the 355 HSRL are used for developments of the algorithms to retrieve optical and microphysical properties of clouds and aerosols and validations for EarthCARE and ADM-Aeolus [9].

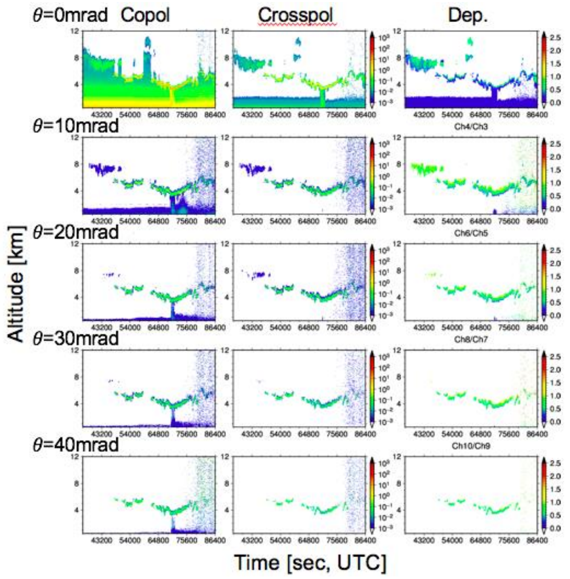

Fig. 2 Time-height cross sections of copol and crosspol components of the attenuated backscatter coefficients [/m/sr] and depolarization ratio for on-beam (θ=0mrad) and off-beam (θ=10, 20, 30, and 40 mrad) signals observed at Koganei, Tokyo, Japan on June 27, 2018.

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