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Ground-based network observation using Mie–Raman lidars and multi-wavelength Raman lidars and algorithm to retrieve distributions of aerosol components

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ABSTRACT

We improved two-wavelength polarization Mie-scattering lidars at several main sites of the Asian dust and aerosol lidar observation network (AD-Net) by adding a nitrogen Raman scatter measurement channel at 607 nm and have conducted ground-based network observation with the improved Mie–Raman lidars (MRL) in East Asia since 2009. This MRL provides $1\boldsymbol{\alpha}+2\beta+1\delta$ data at nighttime: extinction coefficient (α_{532}), backscatter coefficient (β_{532}), and depolarization ratio (δ_{532}) of particles at 532 nm and an attenuated backscatter coefficient at 1064 nm ($\beta_{at,1064}$). Furthermore, we developed a Multi-wavelength Mie-Raman lidar (MMRL) providing $2\alpha+3\beta+2\delta$ data (α at 355 and 532 nm; β at 355 and 532; β_{at} at 1064 nm; and δ at 355 and 532 nm) and constructed MMRLs at several main sites of the AD-Net. We identified an aerosol-rich layer and height of the planetary boundary layer (PBL) using $\beta_{at,1064}$ data, and derived aerosol optical properties (AOPs, for example, α_a, β_a, δ_a, and lidar ratio (S_a)). We demonstrated that AOPs cloud be derived with appropriate accuracy. Seasonal means of AOPs in the PBL were evaluated for each MRL observation site using three-year data from 2010 through 2012; the AOPs changed according to each season and region. For example, $S_{a,532}$ at Fukue, Japan, were 44 ± 15 sr in winter and 49 ± 17 in summer; those at Seoul, Korea, were 56 ± 18 sr in winter and 62 ± 15 sr in summer. We developed an algorithm to estimate extinction coefficients at 532 nm for black carbon, dust, sea-salt, and air-pollution aerosols consisting of a mixture of sulfate, nitrate, and organic-carbon substances using the $1\alpha_{532}+2\beta_{532\ \mathrm{and}\ 1064}+1\delta_{532}$ data. With this method, we assume an external mixture of aerosol components and prescribe their size distributions, refractive indexes, and particle shapes. We applied the algorithm to the observed data to demonstrate the performance of the algorithm and determined the vertical structure for each aerosol component.

1. Introduction

It is essential to observe the optical and microphysical properties and chemical composition of aerosols and to understand their spatial distribution and temporal variation

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in order to assess the effects of aerosols on the atmospheric environment and the climate. Ground-based lidar networks covering a wide area have been established to observe aerosol optical properties and to monitor their temporal variation and movement. Examples include the Asian dust and aerosol lidar observation network (AD-Net) [1], the European Aerosol Research Lidar Network (EARLINET) [2], and the Micro-Pulse Lidar Network (MPLNET) [3]. Mie scattering lidar is a highly sensitive method and is used worldwide for studying aerosol optical properties. The AD-Net uses two-wavelength (532 and 1064 nm) Mie scattering lidars with a depolarization measurement function at 532 nm. The MPLNET uses one-wavelength Mie-scattering lidars. However, the EARLINET uses multi-wavelength Raman lidars. The Raman lidar is more powerful in that it can directly measure the extinction and backscatter coefficients of aerosols as well as the extinction-to-backscatter ratio (i.e., lidar ratio) [4], which is usually assumed or selected in Mie-scattering lidar data processing. It should be noted that the Raman lidar has to measure much weaker Raman backscattered signals than the particle and molecule backscattered signals that Mie-scattering lidar measures.

Various aerosol components (e.g., dust (DS), sea-salt (SS), black carbon (BC), organic-carbon, sulfate, and nitrate) mix in the atmosphere both externally and internally. The individual aerosol components have specific optical and microphysical characteristics [5,6]. It is useful to classify aerosol components in an aerosol mixture and to evaluate their concentration and microphysics in order to assess the effects of aerosols on the atmospheric environment and the climate. For example, such light-absorbing aerosols as BC reduce cloud formation by absorbing sunlight, thereby cooling the surface and heating the atmosphere [7]; they also affect the large-scale circulation and hydrologic cycle by altering regional atmospheric stability and vertical motions [8]. The information on concentration and microphysics for each aerosol component as well as measured aerosol optical properties (e.g., extinction and backscatter coefficients, and depolarization ratio for several wavelengths) are useful for evaluating the performance of numerical models and data assimilation [9,10].

The AD-Net has conducted network lidar observation covering a wide area in East Asia using compact, two-wavelength backscatter (β) and one-wavelength polarization (δ) Mie-scattering lidar (i.e., $2\beta+1\delta$ Mie-scattering lidar) since 2001 to monitor aerosols as well as clouds in East Asia. We developed some algorithms to identify several main aerosol components in the troposphere (e.g., DS, SS, and air pollution aerosol consisting of a mixture of sulfate, nitrate, organic-carbon, and BC substances) and retrieve their vertical distributions in an extinction coefficient assuming an external mixture of some aerosol components and prescribing their microphysical and optical properties [11,12]. Lidar measurements with more channels (e.g., extinction and backscatter coefficients and depolarization ratio for several wavelengths) enable classifying more components of aerosols and evaluating their optical and microphysical properties. For example, lidar ratios measured using a Raman lidar and a high-spectral-resolution lidar (HSRL) effectively classify BC aerosols with strong light absorption and aerosols with weak light absorption (e.g., SS and sulfate) and for estimating their extinction coefficients [13]. Depolarization ratios have been used for classifying non-spherical DS and spherical aerosols [11]. Most spherical aerosols are air pollution aerosols. Spectral (color) ratios of backscatter coefficients, which are sensitive to particle size, are used for classifying large aerosols (e.g., SS and DS) and small aerosols (e.g., air pollution aerosols) [12].

In this study, we improved the compact Mie-scattering lidars at several main sites of the AD-Net by adding a nitrogen Raman scatter measurement channel at 607 nm (Mie–Raman lidar) to better assess the movements and optical properties of aerosols and realize more advanced aerosol classification, and we have conducted continuous measurements since the end of 2009. The improved Mie–Raman lidar (MRL) provides $1\alpha+2\beta+1\delta$ data: extinction (α) at 532 nm, backscatter (β) at 532 and 1064 nm, and depolarization ratio (δ) at 532 nm. From a statistical point of view, we focus on the seasonal features of aerosol optical properties (AOPs) derived from the data observed for three years 2010 through 2012. Sugimoto et al. [14] used MRL data measured at Phimai, Thai (see Table 1) in 2012 and 2013 and discussed features of AOPs in the planetary boundary layer (PBL). In this study, we focus on AOPs at the other MRL sites. There is little long-term observation data for the lidar ratio and depolarization ratio of aerosols derived from Raman lidar and HSRL measurements in East Asia [15,16], although several studies involve temporal observations and campaign observations [17–19]. Using the $1\alpha+2\beta+1\delta$ data, we also developed an algorithm to estimate vertical profiles of 532 nm extinction coefficients for BC, DS, SS, and air pollution aerosols except BC substances (AP) consisting of a

Table 1
Observation sites with MRL and MMRL in AD-Net.

Site	Location	Lidar	Operation status
Japan			
Toyama	36.70°N, 137.19°E	MMRL	Currently in operation from Feb. 2015
Tsukuba	36.05°N, 140.12°E	MRL	Currently in operation from June 2009
Matsue	35.48°N, 133.01°E	MRL	Currently in operation from Oct. 2009
Fukuoka	35.52°N, 130.47°E	MMRL	Currently in operation from Sep. 2013
Fukue	32.63°N, 128.83°E	MRL	Currently in operation from Sep. 2009
Hedo	26.87°N, 128.25°E	MMRL[a]	Currently in operation from Feb. 2014
Korea			
Seoul	37.45°N, 126.95°E	MRL	Currently in operation from July 2009
Thailand			
Phimai	15.18°N, 102.57°E	MRL	Currently in operation from Feb. 2011

[a] The MRL was operated at the Hedo site from September 2009 to February 2014.