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Ceilometer calibration for retrieval of aerosol optical properties

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ABSTRACT

Ceilometers are durable compact backscatter lidars widely used to detect cloud base height. They are also useful for measuring aerosols. We introduced a ceilometer (CL51) for observing dust in a source region in Mongolia. For retrieving aerosol profiles with a backscatter lidar, the molecular backscatter signal in the aerosol free heights or system constant of the lidar is required. Although the system constant of the ceilometer is calibrated by the manufacturer, it is not necessarily accurate enough for the aerosol retrieval. We determined a correction factor, which is defined as the ratio of true attenuated backscattering coefficient to the measured attenuated backscattering coefficient, for the CL51 ceilometer using a dual-wavelength Mie-scattering lidar in Tsukuba, Japan before moving the ceilometer to Dalanzadgad, Mongolia. The correction factor determined by minimizing the difference between the ceilometer and lidar backscattering coefficients was approximately 1.2 ± 0.1. Applying the correction to the CL51 signals, the aerosol optical depth (AOD) agreed well with the sky-radiometer AOD during the observation period (13–17 February 2013) in Tsukuba (9×10^{-3} of mean square error). After moving the ceilometer to Dalanzadgad, however, the AOD observed with the CL51 (calibrated by the correction factor determined in Tsukuba) was approximately 60% of the AErosol RObotic NETwork (AERONET) sun photometer AOD. The possible causes of the lower AOD results are as follows: (1) the limited height range of extinction integration (< 3 km); (2) change in the correction factor during the ceilometer transportation or with the window contamination in Mongolia. In both cases, on-site calibrations by dual-wavelength lidar are needed. As an alternative method, we showed that the backward inversion method was useful for retrieving extinction coefficients if the AOD was larger than 1.5. This retrieval method does not require the system constant and molecular backscatter signals, and can be applied to severe dust and air pollution aerosol cases in East Asia.

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1. Introduction

Aerosols play an important role in the earth's climate system through the scattering and absorption of solar radiation and by modifying cloud microphysical properties. Aerosols are closely related to human life through their potential, for instance, to damage health and disturb traffic. In East Asia, the concentrations of anthropogenic aerosols and mineral dust are extremely high (e.g., [1,2]). To predict aerosol diffusion over downwind regions, atmospheric monitoring of the source regions is required.

The diffusion range of aerosols depends on the layer altitude and the particle size. If an elevated dust layer extends to the altitude of the free troposphere, it can be transported over a long range (e.g., [3,4]). Active remote sensors such as lidar are effective tools for measuring the aerosol layer height with high temporal and spatial resolutions [5]. However, it is often difficult to set up lidar instruments in dust source regions because of limited electrical power and accessibility.

Ceilometer instruments are simple backscatter lidar systems, and can be used for monitoring boundary layer aerosols. The instruments are usually set in airports for detecting cloud bases. Since the ceilometer is a maintenance-free and eye-safe system that can withstand a wide temperature range, it has become widespread in the world. Because of the numerous installations, ceilometers have a possibility for network observation of aerosol vertical distribution.

Ceilometers do not include sophisticated systems that can measure multi-wavelength and polarization channels. Compared to lidar systems, the pulse energy of the laser is low, and the pulse repetition rate is high (several kHz). Molecular backscattering signals are barely detected by ceilometer due to the low-energy laser with a near-infrared wavelength. Accordingly, the system constant of the lidar equation cannot be determined by inversion methods and is thus derived only from system-dependent values (e.g., the receiver area). In a practical sense, this derivation procedure results in an unacceptable value of the system constant.

The quantitative estimation of aerosol optical properties is an issue for ceilometer analysis. An unknown system constant or missing molecular backscattering signals make aerosol retrieval difficult for a ceilometer alone. Ceilometer signals must be calibrated with other supplemental data for the retrieval. Wiegner and Geiß [6] calibrated ceilometer signals by using the aerosol optical depth (AOD) independently observed by the AErosol RObotic NETwork (AERONET) instrument. However, large temporal averages (1–2 h) of cloud-free profiles are needed to achieve backward integration.

There has been very little work on the retrieval of aerosol optical properties from ceilometer signals. Wiegner et al. [7] have suggested that retrieval of backscattering coefficient is feasible with a retrieval error of approximately 10% if the calibration is correctly conducted with multi-wavelength Raman lidar systems. However, the case of extremely large backscattering or extinction coefficients has not been studied. Severe dust and polluted aerosols in East Asia result in extremely large extinction coefficients. Sugimoto et al. [8] reported that the maximum extinction coefficient of dense dust was 6/km at 532 nm wavelength in Beijing on 20 March 2002. Xie et al. [9] showed that extinction coefficients reached 2.5/km at 532 nm during the heavy pollution episode over Beijing in December 2007. The applicability of ceilometers to such cases should be investigated.

Here we attempt to calibrate ceilometer signals for retrieval of aerosol optical properties by comparing them to signals observed by collocated lidar. We also investigate the applicability of the calibration correction to observation data from a dust source region in Mongolia. We discuss the extinction retrieval from strong signals in the dust case.

2. Data and analysis method

In this section, we briefly describe the specifications of the instruments (ceilometer and lidar) used in this study. We also describe the limitations of aerosol measurement with the ceilometer based on comparison with lidar signals. To retrieve accurate extinction or backscattering coefficients from ceilometers, a correction factor is needed. We present the analysis procedure used to obtain the correction factor.

2.1. Specification and performance of the ceilometer

We used a CL51 ceilometer (Vaisala, Helsinki, Finland), which can measure the vertical distribution of clouds and aerosols up to 15,400 m with 10-m resolution. The laser mounted on the ceilometer was a semiconductor laser (InGaAs diode laser) with a 910-nm wavelength, and 3.0-μJ pulse energy, and repetition rate of 6.5 kHz. The measured signals were integrated over 5 s and were stored on a computer every 6 s. Before storing, the integrated signals were calibrated by the system constant determined in the vendor software.

We conducted CL51 observations at the Meteorological Research Institute (MRI) in Tsukuba, Japan (140.13° E, 36.06°N, 25.2 m above sea level (ASL)) from 13 to 17 February 2013. Observations with Mie-scattering lidar (hereafter referred to as MRI-Lidar) were also performed in conjunction with the CL51 observations at the same station. MRI-Lidar was equipped with a dual-wavelength laser with 1064 and 532 nm wavelengths. The vertical and temporal resolutions of the MRI-Lidar signals were 7.5 m and 3 min, respectively. Detailed specifications of the MRI-Lidar are summarized by Sakai et al. [10].

We compared the CL51 and MRI-Lidar signals (Fig. 1). There was good agreement between the two signals for the height distribution of aerosols and clouds in the boundary layer. Due to noise contamination, aerosols were not detected by the CL51 above 3 km, whereas MRI-Lidar was able to detect such signals. For example, MRI-Lidar observed a thin aerosol layer at 4 km during 06–12 LST 16 February, but the layer was not recognized from the CL51 signals. It was also difficult to detect the transported aerosols above 5 km with the CL51 on 14 and 17 February.

The CL51 signals were affected by noise originating from dark current and background light. The noise occasionally