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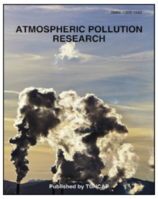

Observations of aerosol color ratio and depolarization ratio over Wuhan

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ABSTRACT

The aerosol color ratio, depolarization ratio and aerosol optical depth (AOD) were measured by a two-wavelength-depolarization lidar at Wuhan, China during the period from May 2015–July 2016. The annual average AOD at Wuhan was about 0.33 during the period 2015–2016. The seasonal average AOD is small (0.26 ± 0.25) during the winter (December–February) season and large (0.4 ± 0.1) during the summer (June–August) season. The monthly average color ratio is small (0.23 ± 0.09) in January and large (0.76 ± 0.21) in August with an annual average value 0.54. The maximum monthly mean depolarization ratio (0.2 ± 0.07) occurred in the month of October, while the minimum (0.06 ± 0.02) occurred in the month of September, and the annual mean depolarization ratio was about 0.17. An analysis of temporal variations of color ratio and depolarization ratio suggests the presence of coarse and non-spherical particles during the autumn. The aerosol color ratio between 0.3 and 2.0 km was large (0.65), suggesting a large number of coarse particles in this range. The vertical distribution of the depolarization ratio is uniform. Finally, the spatial aerosol distribution under different weather conditions and its relationship with the color ratio is investigated in detail. The color ratio value of 0.74 could be used as a threshold for distinguishing polluted weather from clean weather. The aerosol optical and physical properties are investigated to provide a comprehensive understanding of aerosol radiative forcing and environmental problems in this region.

1. Introduction

Aerosols play an important role in the assessment of Earth's radiation, climate, the formation of precipitation and clouds and environmental problems (Twomey et al., 1984; Albrecht, 1989; Kaufman et al., 2002). The Intergovernmental Panel on Climate Change has reported that both the direct and indirect effects of tropospheric aerosol is essential for reducing the uncertainty in environment and climate change due to aerosols (IPCC, 2007). And the optical and physical properties of aerosols have a significant effect on the formation and transport of air pollutants. Thus, an investigation of the spatial-temporal distribution of tropospheric aerosols is very essential for eliminating the uncertainty in aerosol environment and climate change.

The optical and physical properties of aerosols are important parameters, which affects radiative processes. Many lidar research groups have focused on studying Asian dust and tropospheric aerosols all over the world. For example, Sugimoto studied the optical properties of dust and anthropogenic aerosol plumes by a two-wavelength polarization lidar over Northwest Pacific (Sugimoto et al., 2002). Freudenthaler analysed depolarization ratios of the pure Saharan dust at several laser wavelengths (Freudenthaler et al., 2009). Haarig measured the linear depolarization ratio of aged dust at three wavelengths over Barbados (Haarig et al., 2016). Iwasaka found that the depolarization ratio (DR) of free tropospheric aerosols was large over the Taklimakan desert (Iwasaka et al., 2003). Sakai investigated the backscatter, depolarization ratio and relative humidity of free tropospheric aerosol by the Raman lidar over Nagoya in 1994–1997 (Sakai et al., 2000). There are also many studies about aerosol characteristics in China. For example, Huang studied the vertical structure of dust

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aerosol by using three Micro Pulse Lidars (MPLs) during 2008 over the Loess Plateau (Huang et al., 2010). Zhou analysed the relationship of dust plume depolarization–attenuated backscatter over Lanzhou (Zhou et al., 2013). Chiang measured the numerical distribution of depolarization ratio and aerosol optical depth (AOD) over Chungli (Chiang et al., 2008). Wu investigated the tropospheric aerosol over Hefei (Wu et al., 2011). Wang analysed the relationship between water vapour and aerosols using Raman lidar (Wang et al., 2012). Some studies indicate particle shape and size as the important parameters of aerosol that affect radiative processes (Koepke and Hess, 1988; Lacis and Mischenko, 1995), although there are some studies (Zhang et al., 2014; Wang et al., 2015a,b,c) that focus on the analysis of aerosol optical properties over Wuhan, Central China. On the other hand, observations of aerosol particle shape and size in Central China are still very limited due to a lack of ground-based observations. Therefore, it is very essential and urgent to research the atmospheric aerosol physical properties in Central China to improve knowledge of regional environmental problems due to aerosols. Meanwhile, in recent years, haze is more and more frequent, and environmental problems is more and more serious over Wuhan. It is also urgent to research its environmental problems caused by aerosol particles. To meet the requirements for the observation of aerosol particle shape and size, lidar dual-wavelength-depolarization techniques are utilized. The information of aerosol color ratio and depolarization can be roughly measured by employing a two-wavelength-depolarization lidar.

In this paper, we discussed the temporal and spatial variations of the optical and physical properties of tropospheric aerosols by using a two-wavelength-depolarization lidar during the period of May 2015–July 2016. First, monthly and seasonal variations of AOD, color ratio and depolarization ratio were analysed. Then, spatial height variations of aerosol color ratio and depolarization ratio were investigated. Finally, spatial distribution of aerosols color ratio depolarization ratio under different weather conditions were investigated in detail. In addition, the National Oceanic and Atmospheric Administration (NOAA) Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model was employed to understand the aerosol sources in the lower atmosphere. A comprehensive understanding of aerosol radiative forcing and environmental problems in this region is provided through the further statistical analysis.

2. Study site and instrumentation used

2.1. Study site location

The lidar system is located on the roof of information department of Wuhan university (114°21′E, 30°32′N). Its location belongs to the business centre of Wuhan. Wuhan is a large-scale comprehensive city, located in the Yangtze River Basin. External pollution is easy to deposit, and one of China's largest steelmaking plant (Wuhan Iron and Steel plant) is located in Wuhan. Environmental pollution seriously impacts the city's air quality and human health. It is urgent to research its environmental problems due to Wuhan is a city of large-scale crowds in the center of China (Zhang et al., 2014, 2016; Wang et al., 2015a,b,c). A two wavelength polarization lidar system was used to monitor the environment in Wuhan. The experimental data were collected for 145 days during the period from May 2015 to July 2016. According to threshold method and meteorological data, the data with clouds was removed and 128 days of data are available. The daily observations time are about 11 h (from 19:00 LT to 6:00 LT), and the details of monthly observations are shown in Table 1.

2.2. Lidar system description

This lidar system included three parts: emitting system, signal receiving system and data acquisition system. There is a Nd:YAG (Quantel CFR) laser, beam expander and two mirrors in the laser emitting system (Fig. 1). The laser emits a mixed beam of 355 nm and 532 nm wavelengths. The pulse energy of the 355-nm and the 532-nm wavelengths are 36.4 mJ and 76.2 mJ, respectively. The pulse repetition frequency of the 355-nm and the 532-nm band are both 20 Hz. The laser passes through the beam expander by a high reflection mirror reflecting. Finally, it fired into the sky. The beam expander was used to reduce the divergence angle of output laser. The signal receiving system consisted of telescope and segregator system. A Schmidt-Cassegrain telescope (8-inch) was used to collect the atmosphere backscatter signal. There are collimating lens, beam splitters and narrowband interference filters in the segregator system. The lidar signal was collimated by a collimating lens. Then, the 355 nm and 532 nm signals are separated by beam splitters. The 532-nm signal is separated by polarizer beam splitters into a parallel (P) and perpendicular (S) beam. The sky background light was suppressed by a narrowband filter.

The signal acquisition system consists of three channels: a 355-nm channel, a 532-nm perpendicular channel, and a 532-nm parallel channel. Data acquisition is done via photomultiplier tube (PMT). The collected signals for all channels were detected by PMT. The PMT receives optical signal and converts it into an amplified electrical signal. The electrical signal was recorded by Licel at a 20-MHz sampling rate. Due to the coaxial design, it was essential to take into account the problem of near-field gain saturation. The photon counting mode would cause the near-field gain saturation, leading to the distortion of near field signal. So licel data acquisition system is set to analog counting mode. Licel is a stable data acquisition system developed by a German company. Finally, the atmosphere backscattered signals were stored in control center. The vertical and temporal resolutions of the data was 7.5 m and 60 s, respectively. This lidar system has been compared with a Mie-lidar system (Gong et al., 2011a,b) at this site and the signal of 532 nm is consistent. The lidar signal on the range of 0–6 km is reliable. In addition, the channel gain constant is measured before starting the signal acquisition every day. We cover the receive telescope and make the system in normal working condition. When the system is in a stable working state after five minutes, the data collected by licel was the channel gain constant. Then, the acquired signal subtracts the gain constant to correct the acquired signal. If the subsequent optical units and the configuration of the two channels is fixed, the gain constant should also be the same during the entire observation period. More details about the system are listed in Table 2.

3. Methods

First of all, the Fernald method (Fernald et al., 1972; Fernald 1984; Klett, 1981) is used to obtained the aerosol backscatter coefficient, and extinction coefficient was used to calculate the AOD. Then, the aerosol backscatter coefficient was used to calculate the color ratio and depolarization ratio. Finally, the data were analysed statistically.

3.1. Fernald method

On the basis of the Fernald method, the received lidar signal from distance r, P(r), can be expressed as a function of atmospheric absorption characteristics $\alpha(r)$ and atmospheric scattering $\beta(r)$ characteristics (Fernald et al., 1972):

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