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Study on aerosol optical properties and radiative effect in cloudy weather in the Guangzhou region

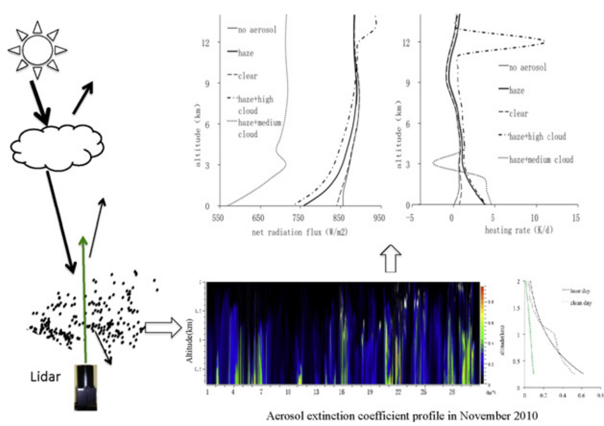
Tao Deng [a,*], XueJiao Deng [a], Fei Li [a], ShiQiang Wang [b], Gang Wang [c]

[a] Institute of Tropical and Marine Meteorology/Guangdong Provincial Key Laboratory of Regional Numerical Weather Prediction, China Meteorological Administration, Guangzhou 510080, China
[b] Zhuhai Meteorological Administration, Zhuhai 519000, China
[c] Haizhu Meteorological Administration, Guangzhou, 510000, China

HIGHLIGHTS

- Large amount of aerosols dramatically attenuated solar radiation in Guangzhou region.
- Investigated the aerosol extinction coefficient profile distribution and inverted the height of boundary layer using the lidar
- Evaluated the impact of different types of clouds on aerosol radiation effects

GRAPHICAL ABSTRACT



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ABSTRACT

Currently, Guangzhou region was facing the problem of severe air pollution. Large amount of aerosols in the polluted air dramatically attenuated solar radiation. This study investigated the vertical optical properties of aerosols and inverted the height of boundary layer in the Guangzhou region using the lidar. Simultaneously, evaluated the impact of different types of clouds on aerosol radiation effects using the SBDART. The results showed that the height of the boundary layer and the surface visibility changed consistently, the average height of the boundary layer on the hazy days was only 61% of that on clear days. At the height of 2 km or lower, the aerosol extinction coefficient profile distribution decreased linearly along with height on clear days, but the haze days saw an exponential decrease. When there was haze, the changing of heating rate of atmosphere caused by the aerosol decreased from 3.72 K/d to 0.9 K/d below the height of 2 km, and the attenuation of net radiation flux at the ground surface was 97.7 W/m^2, and the attenuation amplitude was 11.4%; when there were high clouds, the attenuation was 125.2 W/m^2 and the attenuation amplitude was 14.6%; where there were medium cloud, the attenuation was 286.4 W/m^2 and the attenuation amplitude was 33.4%. Aerosol affected mainly shortwave radiation, and affected long wave radiation very slightly.

* Corresponding author.
E-mail address: tdeng@grmc.gov.cn (T. Deng).

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1. Introduction

With economic development, aerosol pollutants in the Pearl River Delta (PRD) region have become significant, and their influence on regional air quality and climate cannot be ignored (Wu et al., 2005; Chan and Yao, 2008; Deng et al., 2008; Zhang et al., 2008). In one aspect, aerosol can influence climate directly by absorbing and scattering the solar radiation. In another aspect, aerosol can increase cloud droplet concentration, changing cloud droplet size and the lifetime of clouds, and affect the climate indirectly (Bréon et al., 2002; Ackerman et al., 2004; Penner et al., 2004). Cloud covers 2/3 of the area of the earth and plays an important role in adjusting the radiation budget of the earth-atmosphere system, especially in the low-latitude areas (Ramanathan et al., 1989; Dowling and Radke, 1990). The existence of clouds can cause an important influence on the aerosol radiation effect (Satheesh 2002). The simulation result of the aerosol climate effect model is closely related to the radiation parameters (e.g. The scattering efficiency, the single scattering albedo and the asymmetry factor) (Quaas et al., 2004; Myhre, 2009); however it is not enough to know that the radiation flux of the ground surface and top atmosphere layer may improve the simulation capability of the model, it is crucial to know about the vertical distribution of aerosol and radiation parameters, especially the radiation parameters of aerosol when cloud is available. NASA established the MPLNET (micropulse lidar observation net), used for monitoring the vertical distribution of long-term aerosol and cloud. Welton et al. (2002) used lidar to detect the vertical distribution and optical properties of aerosol in the Indian Ocean Experiment (INDOEX). In the process of observing the floating dust in the aerosol characteristic experiment (ACE-2) (Welton et al., 2000), the observation results of lidar were more consistent with other instruments. The satellite-borne lidar CALIPSO (Cloud-Aerosol Lidar with Orhthogonal Polarization), ground-based micropulse lidar and other detection methods was used to detect the long-distance transfer and vertical distribution structure of aerosol (Huang et al., 2008; Mamouri et al., 2009; Redemann et al., 2012; Cao et al., 2013; Wu et al., 2014). The relationship between AOD and ground PM_{10} was improved by using lidar data (Zeeshan and Oanh, 2014). In Beijing area, the impact of boundary layer structure on the vertical distribution of aerosol was detected by using lidar (Guinot et al., 2006). Liu et al. (2012) used lidar date to study the aerosol direct radiative forcing in the Yangtze River Delta region. In the Pearl River Delta region, Wu et al. (2009) and Cheng et al. (2008) made further study on the chemical and physical properties of surface aerosol, and thence obtained the optical properties of surface aerosol of the local area, and further discussed the surface radiation effect. However, research on the vertical distribution of optical properties of aerosol in cloudy weather and their radiation effects in the Pearl River Delta is very scarce.

In November 2010, this study utilized the lidar located the Guangzhou Wushan Satellite Ground Meteorotogical Station (23.483N°, 113.483E°, elevation of 70.7 m.) to make a month observation and carry out inversion for the aerosol extinction coefficient profile and the boundary layer height in different weather conditions. Then, from the radiation perspective, study the impacts of the different types of clouds on the aerosol radiation effects. The study results in this paper provided important radiation parameters for the research on climate change and the urban boundary layer.

2. Data and methods

In this paper, the micropulse lidar system used was manufactured by the Sigma Space Corporation of the United States. In such a polarization micropulse lidar system, the lidar emits a green laser beam with the wavelength of 527 nm; its minimum vertical resolution and maximum detection height were 15 m and 60 km, respectively. The visibility meter (Model 600 forescatter visibility meter produced by the Belfort Corporation of the United States) was used for verification.

The SBDART (Santa Barbara DISORT Atmospheric Radiative Transfer) model was jointly developed by Ricchiazzi et al. (1998) of the University of California, USA. It is integrated with the discrete-ordinate transmission model (DISORT), low-resolution atmospheric transmission model (LOWTRAN) and medium-resolution atmospheric transmission model (MODTRAN), simultaneously, introduced the latest standard atmosphere profile database, atmospheric absorption gas database, standard aerosol database and surface albedo database, while improving the cloud physics module based on spherical water drop and ice crystal computed with a Mie scattering model and considered the impacts of continuous absorption, molecules, aerosol, scattering and absorption of cloud and rain, earth curvature and refraction on the path and calculation for the content of total absorbing substances. The SBDART model enables calculation of various forms of radiation with wavelengths from 250 nm to 100 μm in the atmosphere.

2.1. Inversion of extinction coefficient by lidar

The lidar equation can be expressed as:

$$[P(r)D[n(r)]-n_b(r)-n_{ap}(r)]r^2/CEO_{olp}(r)=(\beta_1(r)+\beta_2(r))T^2 \quad (1)$$

Where $P(r)$ is the energy of the atmospheric backscatter echo signal received by the lidar at the height of r; E is the emitted energy of the lidar; C is the lidar constant; $O_{olp}(r)$, $n_b(r)$, $n_{ap}(r)$ and $D[n(r)]$ are respectively the overlap fill correction, background noise correction, afterpulse correction and deadtime correction; $T=\exp[-\int_0^r(\sigma_1(r')+\sigma_2(r'))dr']$ is the atmospheric transmissivity; $\beta_1(r)$·$\beta_2(r)$ and $\sigma_1(r)$·$\sigma_2(r)$ are respectively the backscatter coefficient and extinction coefficient of aerosol (cloud) and air molecules.

The lidar equation has two unknown numbers, namely $\beta_1(r)$ and $\sigma_1(r)$. For the study in this paper, the lidar equation was solved by using the Fernald method (Fernald, 1983) and the extinction backscatter ratio was S; the extinction backscatter ratio herein was the ratio of the extinction coefficient and backscatter coefficient. As for details of the backward integral used for solving lidar equation, see Deng et al. (2010).

$$\sigma_1(r)=-\frac{S_1}{S_2}\cdot\sigma_2(r)+\frac{X(r)\cdot\exp[2\left(\frac{S_1}{S_2}-1\right)\int_r^{r_c}\sigma_2(r')dr']}{\frac{X(r_c)}{\sigma_1(r_c)+\frac{S_1}{S_2}\sigma_2(r_c)}+2\int_r^{r_c}X(r')\exp[2\left(\frac{S_1}{S_2}-1\right)\int_r^{r_c}\sigma_2(r'')dr'']dr'} \quad (2)$$

Where: $X(r)=[P(r)D[n(r)]-n_b(r)-n_{ap}(r)]r^2/CEO_{olp}(r)$ is the corrected normalized backscatter signal.

2.2. Inversion of cloudy optical thickness

The transmissivity of the cloud was calculated by using the received lidar signal below and above the cloud respectively (Chen et al., 2002):

$$T_c=\sqrt{X(r_t)/X(r_b)} \quad (3)$$

The subscript b is the cloud base; the subscript t is the cloud top.

The optical thickness of the cloud can be expressed as:

$$\tau=\frac{1}{2}\ln X(r_b)-\frac{1}{2}\ln X(r_t) \quad (4)$$

2.3. Inversion of boundary layer height

Generally the concentration of aerosol within the boundary layer was much higher than in the upper atmosphere, and even had stronger