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Vertical distribution of water-soluble, sea salt, and dust aerosols in the planetary boundary layer estimated from two-wavelength backscatter and one-wavelength polarization lidar measurements in Guangzhou and Beijing, China

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ABSTRACT

Vertical and temporal distributions of water-soluble, sea salt, and dust aerosols in the planetary boundary layer (PBL) were analyzed from two-wavelength (532 and 1064 nm) backscatter and one-wavelength (532 nm) polarization lidar measurements taken at Guangzhou in July 2006 and Beijing in August 2006. We used an algorithm that estimates the extinction coefficients for each aerosol component from the three-channel lidar data. The results revealed water-soluble aerosols, most of which were anthropogenic aerosols, were dominant in both cities. Air pollution events occurred on 12 and 22–24 July in Guangzhou and on 3–11, 16–19, and 23–25 August in Beijing. Differences in temporal variation of extinction coefficient of water-soluble particles (σ_{WS}) in the lower layers during the air pollution periods were distinct: σ_{WS} was higher in the nighttime at Beijing, whereas σ_{WS} was higher in the daytime in Guangzhou. Meanwhile similar vertical structures of σ_{WS} in the planetary boundary layer were found for both cities: σ_{WS} increased as the altitude increased. We suggest that different mechanisms contributed to the temporal and vertical variations of σ_{WS} in each city: hygroscopic growth mainly enhanced σ_{WS} in the nighttime and at high altitude for Beijing, while the transport of aerosols in the local area mainly enhanced σ_{WS} in the daytime and at high altitude in Guangzhou. Distinct differences were also observed in the sea-salt components in Guangzhou and in the dust components in Beijing. The correlation of the dust concentration and aerosol depolarization ratio implies that internal mixing of water-soluble and dust particles occurred in Beijing during the air pollution periods.

1. Introduction

Air pollution in urban areas of China poses serious problems. Pollutants such as anthropogenic aerosols and gases affect human health, air quality, and climate, and reports have shown that air pollutants originating in China are transported to East Asian countries and the western Pacific Ocean (e.g., Hatakeyama et al., 2001). Hence, it is important to clarify the temporal and spatial distributions of air pollutants in China.

Intensive observation campaigns were conducted at the Pearl River Delta (PRD) in autumn 2004 and summer 2006. The PRD, located in southeastern China with the South China Sea at its southern border, is one of the most urbanized areas in China. One of the aims of the campaigns was to characterize the temporal and spatial changes of the chemical and optical

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properties of aerosols in urban areas of China. Chemical compositions and optical properties of aerosols were measured by various samplings and active and passive remote-sensing instruments (e.g., Ansmann et al., 2005; Tesche et al., 2007). There are striking differences between summer and autumn climates in the PRD. Summer has higher humidity, and the East Asian monsoon system brings southerly (from the sea) prevailing winds in summer and northerly (from the continent) winds in autumn. Generally, the southerly wind brings cleaner air masses from the sea to Guangzhou. These seasonal differences of the climate generate seasonal variations in aerosol properties in the PRD. During the summer campaign from 1 July to 6 August 2006 (this campaign is referred to as PRD2006), ground-based measurement with dual-wavelength polarization Mie-scattering lidar developed by the National Institute for Environmental Studies (NIES, Japan) was conducted at Guangzhou (23.16°N, 113.33°E) located in the northern PRD (Sugimoto et al., 2009). Ground-based measurements with the dual-wavelength polarization Mie-scattering lidar of the NIES were also conducted in Beijing (39.99°N, 116.42°E) in August 2006. Air pollution in Beijing has become a serious problem. The optical and microphysical properties of aerosols derived from Raman lidar measurements in the winter season in Beijing have been reported recently (Tesche et al., 2007; Xie et al., 2008). In this study, we investigated the aerosol properties in the summer season.

We analyzed the vertical and temporal distributions of each aerosol component in the planetary boundary layer (PBL) using the NIES lidar data obtained for Guangzhou in July 2006 and for Beijing in August 2006. We used algorithms developed by Nishizawa et al. (2007) that estimated the extinction coefficient at $\lambda = 532$ nm for two types of aerosol components: water-soluble particles (σ_{WS}) with sea salt (σ_{SS}) or water-soluble particles with dust (σ_{DS}). Water-soluble particles are defined as a mixture of sulfate, nitrate, and organic carbon particles. Sugimoto et al. (2009) analyzed the same National Institute for Environmental Studies of Japan (NIES) lidar data obtained for Guangzhou and reported the aerosol structure in the PBL when air pollution occurred. In this study, we mainly examined the difference between the vertical and temporal variations of aerosols in Guangzhou and those in Beijing when air pollution occurred.

2. Observed data used in the analysis

The NIES lidar has three channels that detect the perpendicular ($P_{\perp}$) and parallel components ($P_{||}$) to the linearly polarized transmitted laser at $\lambda = 532$ nm and the total component P ($P = P_{\perp} + P_{||}$) at $\lambda = 1064$ nm. The signals were recorded up to 24 km with 6 m resolution and were averaged every 10s corresponding to 100 shots. The details of the lidar system have been reported by Sugimoto et al. (2000). We defined the following parameters as measured ones: $P_{obs,\lambda} = P_{\lambda}Z^2$, $\beta_{obs,\lambda} = P_{\lambda}Z^2/C_{\lambda}$, and $\delta_{obs} = P_{\perp}/P_{||}$, where Z and C_{λ} are the altitude and calibration constant, respectively. Hereafter, $P_{obs,\lambda}$, $\beta_{obs,\lambda}$, and δ_{obs} are used to refer to the range-corrected receiving signal strength, attenuated backscattering coefficient, and total depolarization ratio, respectively. Before applying the algorithm, the spectral ratio of C_{λ} ($C_{SR} = C_{532}/C_{1064}$) was evaluated using the signals for the water clouds based on the method of Sugimoto et al. (2001). We averaged the data every 30 m vertically and 15 min temporally and used these averaged data in the actual analysis.

In addition, we used radiosonde data and surface meteorological data that are downloadable from the University of Wyoming website at http://weather.uwyo.edu/wyoming/.

3. Method of analysis

3.1. Data analysis procedure

We used two types of algorithms (forward and backward) developed by Nishizawa et al. (2007). Details of the two algorithms are described in Subsection 3.2. The forward algorithm retrieves the aerosol properties at each layer, starting from the lowest layer and works up to the highest layer, using the calibrated lidar signals $\beta_{obs,\lambda}$ and δ_{obs}. The backward algorithm retrieves the aerosol properties at each layer, starting from the highest layer and working down to the lowest layer, as well as the calibration constant C_{λ} using the raw signals $P_{obs,\lambda}$, δ_{obs} and C_{SR} evaluated in advance (see Section **2**). These two algorithms are designed to improve the accuracy of the retrievals and to extend the areas where the aerosol properties can be retrieved (i.e., the backward algorithm is applied to the data under clear-sky condition and determines calibration constant C_{λ} for all the records, and the forward one derives the aerosol properties below clouds).

We then estimated the temporal and vertical distributions of σ_{WS}, σ_{SS}, and σ_{DS} under clear-sky conditions and below clouds: (1) The backward algorithm was first applied to the lidar data to obtain C_{λ} for each record. (2) We extracted data obtained under clear-sky condition using the retrieved aerosol backscattering coefficient at $\lambda = 532$ nm. (3) The C_{λ} values for each time record were linearly interpolated from the retrieved C_{λ} values for the clear-sky conditions, and $\beta_{obs,\lambda}$ was evaluated. (4) We removed the data contaminated by clouds, fog, and precipitation. (5) We applied the forward and backward algorithms to the data. For the Beijing data, we did not consider sea-salt aerosols, since Beijing is more than 150 km from the sea.

We modified the cloud mask scheme proposed by Nishizawa et al. (2007) and used it in our analysis. The modified scheme detected a layer consisting of clouds or fog using β_{obs} at $\lambda = 1064$ nm and removed the data for the layer above the fog or clouds. We considered a layer to consist of clouds when one of the following two criteria was satisfied: (1) $\beta_{obs,1064} > 0.015\ km^{-1}\ sr^{-1}$, or (2) $\beta_{obs,1064} > 0.01\ km^{-1}\ sr^{-1}$ and $d\beta_{obs,1064}(Z)/dZ > 0.01\ km^{-2}\ sr^{-1}$. The data contaminated by precipitation were manually removed. The threshold values were empirically determined from the data measured during the observation period.

3.2. Description of forward and backward algorithms

The following assumptions are made in the forward and backward algorithms. (1) Two types of aerosol model, sea salt and dust, are assumed. The sea-salt model consists of two aerosol components: water-soluble and sea-salt components. The dust model also has two aerosol components, water-soluble and dust components. (2) Size distributions and refractive indices for each aerosol component are prescribed based on reports by Smirnov et al. (2002) and Hess et al.