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Observation of aerosol optical properties and particulate pollution at background station in the Pearl River Delta region

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ABSTRACT

Measurements of fine particles (PM2.5), coarse particles (PM10) and aerosol optical properties were carried out at a background station-Dinghushan in the Pearl River Delta (PRD) region from 2009 to 2012. It showed that the long-term mean concentrations of PM2.5 and PM10 were as high as (51 ± 31) μg/m^3 and (76 ± 43) μg/m^3, respectively. Particulate pollution in the PRD region was mitigated over the last four years, and the annual mean concentrations of PM2.5 was decreased to (39 ± 25) μg/m^3 in 2012 from (65 ± 33) μg/m^3 in 2009. The concentrations of PM2.5 and PM10 were low in summer and high in the other three seasons. The correlation between the daily concentrations of PM2.5 and PM10 was generally high ($R > 0.90$). The long-term mean PM2.5/PM10 ratio reached up to 0.67, the ratio was high in autumn (0.71) and low in summer (0.57). Atmospheric visibility was poor, the long-term mean of aerosol optical depth (AOD) at 500 nm was 0.91 ± 0.40, and Ångström exponent was 0.97 ± 0.36. The values of AOD were low in winter and summer, and high in spring and autumn. The correlation between particulate matter (PM) concentrations and AOD was high. The correlation coefficient in dry season (October–next March) was better than that was in wet season (April–September). In addition, the correlation also demonstrated great differences for different air masses.

1. Introduction

The atmospheric aerosols are a complex and dynamic mixture of solid and liquid particles from natural and anthropogenic sources, with diameters of about 10–10^{-3} μm. Aerosols influence the radiation balance of the earth–atmosphere system by direct and indirect radiation effect, which is one of the most important factors in weather and climate change (Kim et al., 2004; Wang et al., 2011). Aerosols are also one of the main pollutants that affect air quality situation in cities, and have a great effect on both the local and regional environments (Hu et al., 2010; King et al., 1999). Aerosols are directly involved in the formation of clouds and the wet deposition processes. When sunlight passes through the atmosphere, aerosol particles can scatter and absorb sunlight, reducing atmospheric visibility and solar radiation, thereby changing the temperature of the environment and also affecting the growth rate of plants (Wang et al., 2009). In addition, many of atmospheric aerosol particles, which are the end-result of gaseous pollutants, can enter human body and the different-sized particles can deposit in various parts of the respiratory system. Poisonous particles also can be absorbed by the blood and could endanger human health (Fujii et al., 2001; Kocifaj et al., 2006). The smaller the particles, the greater the specific surface area, the more are particles easily absorbed toxic substances and these toxic substances are more

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likely to be inhaled into bronchi and lungs. Some research showed that even a slight increase in particulate matter could cause respiratory and cardiovascular system diseases and mortality (Dockery and Pope, 1994; Espinosa et al., 2002; Marcazzan et al., 2003).

The aerosol optical depth (AOD) was used to describe the aerosol extinction effect of a vertical column in the cloudless atmosphere. This was related to aerosol extinction coefficient, mass concentration and hygroscopic growth (Xin et al., 2007). In recent years, the development of international satellite remote sensing technology serves as a support to obtain aerosol properties with high spatial and temporal resolution. There have been many studies related to the inversion of aerosol concentration that has high spatial and temporal resolution by using the correlation between PM2.5, PM10 and AOD (Gupta and Christopher, 2008; Gupta et al., 2006; Hutchison, 2003; Liu et al., 2007; Wang and Christopher, 2003). Due to the spatially and temporally inhomogeneous nature of aerosol chemical components and the optical properties, the correlation between PM2.5, PM10 and AOD usually exhibits significant differences in the various regions and is limited to local applicability (Al-Saadi et al., 2005; Pelletier et al., 2007; Schäfer et al., 2008; Schaap et al., 2009). These relationships were scarce and undefined in most regions of China, resulting in very large errors in estimating the PM2.5 or PM10 concentration based on satellite remote sensing. It is necessary to investigate the correlation by using satellite remote sensing, especially in the high aerosol emitting region in China.

The Pearl River Delta (PRD) region in Southern China is the most developed region of China and has been highly polluted. Due to the increased economic activities and the number of vehicles within the region, high PM levels and poor visibility have become a serious problem. In recent years, some research have been carried out to study the air pollution in the PRD region (Koelemeijer et al., 2006; Wu et al., 2008). These studies have deepened the understanding of the mechanism of air pollution formation in this region. The regional air pollution was mainly caused by photochemical pollution (such as automobile exhaust) superimposed by industrial emissions of aerosols and sulfate particles, which resulted in increased concentrations of particulate matter and decreased visibility (Wu et al., 2012). Studies of atmospheric pollution in the PRD region were mostly focused on urban areas, while studies of atmospheric pollution background areas are few (Liu et al., 2010; Xu et al., 2009). The primary focus of this paper was to analyze particulate pollution, extinction characteristics and the correlation between PM and AOD at a background station-Dinghushan in the PRD region.

2. Methods

2.1. Sampling site and experimental setup

Dinghushan Forest Ecosystem Research Station (DFERS), Chinese Academy of Sciences, also referred to as Dinghushan Biosphere Reserve (112°33′39″–112°33′41″E, 23°09′21″–23°11′30″N), is located in the mid-section of Guangdong Province in south China in a northeastern suburb of Zhaoqing, 84 km away from Guangzhou (Fig. 1). It is surrounded mostly by hills and valleys, the altitude of the reserve ranges from 100 to 700 m above sea level. Typical climatic characteristics of this site are subtropical humid monsoon climate, with alternating winter and summer climate. The annual average temperature is 20.9° and annual precipitation is 1564 mm. There are no obvious atmospheric pollution sources around this station, and it is a suitable observation station to research background atmospheric pollutants in the PRD region.

Particulate matter mass concentration was measured by TEMO PM2.5, which provides a continuous direct mass measurement of particulates utilizing the tapered element oscillating microbalance (TEMO) (Patashnick and Rupprecht, 1991; Tian and Chen, 2010). This method measures the accumulation of mass on a filter that is attached to the tip of a hollow, tapered, and oscillating glass rod. Mass accumulation on the filter is obtained based on the change in the oscillating frequency overtime. It should be noted that this method measures the dry mass of the aerosols under investigation and may undervalue the aerosol concentration due to aerosol evaporation. The instrument has a detection limit of 0.1 $\mu m/m^3$ and a precision of ± 1.5 $\mu m/m^3$ for 1-h averaged, ± 0.5 $\mu m/m^3$ for 24-h averaged. The filters were exchanged every week, the inlet was cleaned every month, and the flow rates were monitored and calibrated every month. Leak check and K0 test were also performed every month (Xin et al., 2012).

Microtops II solar photometers were used to take measurement. Columnar AOD was estimated base on the Beer–Lambert–Bouguer law (Ichoku et al., 2002; Morys et al., 2001). The measurements could be performed each day between 10 A.M. and 2 P.M. (local time), depending on the required sky conditions for performing measurements. The observers record and judge the real-time cloud condition with free cloud or less than a half (in order to assure no cloud within a field of sun/view angle of 30°) during the observation. This method can efficiently reduce the cloud impact (Xin et al., 2011, 2007). According to the Beer–Lambert–Bouguer law, the AOD of the total atmosphere can be obtained as

$$\tau(\lambda) = -\frac{1}{m(\mu)} \ln\left[\frac{V(\lambda)}{\theta V_0(\lambda)}\right] \tag{1}$$

where $V_0(\lambda)$ is the calibration coefficient, $V(\lambda)$ is the measurement of the photometer, θ is the sun –earth distance factor, $m(\mu)$ is the atmospheric mass, and μ is the zenith angle of the sun.

The optical depth calculated by (1) includes the aerosol optical depth $\tau_{aer}(\lambda)$, the Rayleigh scattering optical depth of the air molecules $\tau_m(\lambda)$, and absorption optical depth by gases like O_2, H_2O, O_3, etc, $\tau_{ab}(\lambda)$

$$\tau(\lambda) = \tau_{aer}(\lambda) + \tau_m(\lambda) + \tau_{ab}(\lambda) \tag{2}$$

The method of calculating $\tau_m(\lambda)$ and $\tau_{ab}(\lambda)$ in each band considering bandwidth and error correction is discussed in detail by Zhang et al. (2000).

Then the aerosol optical depth is given by

$$\tau_{aer}(\lambda) = \tau(\lambda) - \tau_m(\lambda) - \tau_{ab}(\lambda) \tag{3}$$

Ångström exponent is defined by the wavelength dependence of optical thickness (Ångström, 1929)

$$\tau_{aer}(\lambda) = \beta\lambda^{-\alpha} \tag{4}$$

β is the turbidity coefficient, which represents the content of the aerosol in the atmosphere; α is the Ångström exponent,