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The contribution of different aerosol sources to the Aerosol Optical Depth in Hong Kong

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HIGHLIGHTS

- Sulphur has the largest influence (68%) on AOD in Hong Kong.
- South China's emissions play a greater role for sulphur aerosol in summer.
- The emissions in Rest China have greater contributions in other seasons.
- Gobi dust plays a greater role than other dusts in winter (more than 40%).
- Sahara dust contribution is greater than others in spring, which exceeds 35%.

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ABSTRACT

The contribution of major aerosol components emitted from local and remote regions to Hong Kong's Aerosol Optical Depth (AOD) in 2007 is quantitatively determined using the chemical transport model GOCART (Global Ozone Chemistry Aerosol Radiation and Transport). Of the major aerosol components, sulphur has the largest influence (68%) on Hong Kong, followed by organic carbon (OC, 13%) and dust (11%), and the influences of black carbon (BC, 5%) and sea salt (3%) are the lowest. The highest AOD is seen in September 2007 and is composed mainly of sulphur aerosols (85%). The high AOD values in March and April 2007 are caused by sulphur and OC. OC has a relative contribution of 39% in March and 30% in April.

The anthropogenic sulphur, BC, and OC emitted from every continent, as well as from China and South China, are considered respectively. In summer, South China's contribution of sulphur aerosols from anthropogenic SO_2 emissions to the total sulphur AOD in Hong Kong is more than 20%. In other seasons, sulphur aerosols from anthropogenic SO_2 emissions in Rest China (all of China except South China) accounts for more than 25%. Anthropogenic BC from South China accounts for more than 20% of total BC AOD in Hong Kong in summer. The contribution of anthropogenic BC from Rest China exceeds 40% in autumn and winter. Anthropogenic BC from Rest Asia (all of Asia except China) accounts for more than 30% in summer and autumn. The contribution of anthropogenic OC from Rest China is more than 35% in autumn and winter. The contribution of anthropogenic OC from Rest Asia exceeds 20% in summer.

Gobi dust accounts for more than 40% of the total dust AOD in winter, and its impact appears mainly in the Atmospheric Boundary Layer (ABL), where it is responsible for 50% of the dust concentration. The contribution of Sahara dust to the dust AOD in spring exceeds 35%, and its contribution to the dust concentration in the free atmosphere (40%) is larger than that in the ABL (10%). More than 35% of the dust AOD in summer and autumn comes from Taklamakan dust, which exists mainly in the free atmosphere, where it accounts for 40% of the dust concentration.

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1. Introduction

Aerosol Optical Depth (AOD), defined as the integrated extinction coefficient over a vertical column of unit cross section, is the

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degree to which aerosols prevent the transmission of light by absorbing or scattering it. AOD is related to aerosol climate forcing because aerosols affect weather and climate by scattering and absorbing solar radiation (McCormick and Ludwig, 1967). Because more and more anthropogenic aerosols are being released into the atmosphere, aerosol pollution in Hong Kong has recently become more serious. Therefore, many researchers have been studying atmospheric aerosols in Hong Kong (Qin et al., 1997; Ho et al., 2002, 2003, 2006; Yu et al., 2004; Chow et al., 2005; Louie et al., 2005; Huang et al., 2006; So et al., 2007). As such studies have developed, it has been realized that urban aerosols come not only from local sources but also from remote sources (Fang et al., 1999; Man and Shih, 2001; Cheung et al., 2005; Wai and Tanne, 2005). Continental outflows import sulphur and OC into Hong Kong, where seasonal variations are controlled by the East Asian monsoon (Zhou et al., 2005, 2009; Gu et al., 2009; Wang et al., 2009; Chen et al., 2012). The intercontinental transport of aerosols can also have potentially large impacts on regional aerosol AOD: 10%–30% of the AOD reduction in South Asia is caused by a 20% emission reduction from North America, Europe, and East Asia combined (HTAP, 2010; Yu et al., 2013). To address urban aerosols, it is necessary to understand the contribution of aerosol emissions from different regions, especially remote regions. Most previous studies have concentrated only on qualitatively determining whether emission sources in remote regions have an effect on city aerosols.

The goal of this study is to quantitatively determine the contribution of aerosol emissions from different regions to Hong Kong's aerosol AOD. Dust, BC, OC, and sulphur (caused by SO_2) aerosols are considered in this paper. Dust emissions are classified according to their deserts of origin in dust simulations. Anthropogenic emissions of sulphur (caused by SO_2), BC, and OC are classified according to their origin in different continents and the regions of China and South China. We will briefly describe the model (Section 2), compare the model's simulated AOD with measurements in Hong Kong (Section 3), provide assessments of the contribution of different aerosol sources to the AOD in Hong Kong (Sections 4 and 5), and will end with conclusions (Section 6).

2. Model description

The Global Ozone Chemistry Aerosol Radiation and Transport (GOCART) model is used to simulate the major aerosol components in the atmosphere. This model can simulate sulphates, dust, BC, OC, and sea-salt aerosols separately for a specified period of time, and be applied additionally for conducting global assessments because of its global scale. The GOCART model is driven by the meteorological fields from the Goddard Earth Observing System Data Assimilation System (GEOS DAS), which are actually global assimilated databases constrained by meteorological observations. In this study, we use the GOCART model with a horizontal resolution of 2° latitude by 2.5° longitude, and 30 vertical layers. The model has a spin-up of 3 months (from October to December 2006) prior to the simulations (from January to December 2007) because it is initialized with near-zero mass. Basic model information is listed below; detailed information can be found elsewhere (Allen et al., 1996; Chin et al., 2000, 2002; Ginoux et al., 2001).

2.1. Emissions

2.1.1. Sulphur

Anthropogenic emissions of SO_2 come from a variety of sources, including fossil fuel and biofuel combustion and transportation. In the GOCART model, these anthropogenic emissions use the Emission Data Base for Global Atmospheric Research (EDGAR) as a default (Olivier et al., 1996). Emission of SO_2 from biomass burning is calculated using a scale derived from the seasonal variations in burned biomass data. The volcanic emission of SO_2 is taken from the database for continuously erupting volcanoes (Andres and Kasgnoc, 1998) and sporadically erupting volcanoes (when data are available). The emission of dimethylsulphide (DMS) is calculated from the surface seawater concentration of DMS and sea-to-air transfer velocity by using an empirical formula (Liss and Merlivat, 1986).

2.1.2. Dust

The dust particles in the GOCART model are divided into 8 groups (0.1–0.18, 0.18–0.3, 0.3–0.6, 0.6–1, 1–1.8, 1.8–3, 3–6, and 6–10 μm) based on the size of their radius. The emission flux F_p for a size group p is expressed as:

$$F_p = S \cdot s_p u^2 (u - u_t) \quad \text{if } u > u_t \tag{1}$$

where S is the probability source function, which is actually the probability of sediments collecting in the topographic concavity regions with bald surfaces; s_p means the fraction of size group p within the soil; u means the surface wind speed; and u_t means the threshold velocity of wind when it can erode the soil, and is determined by surface wetness and particle size (Ginoux et al., 2001).

2.1.3. Organic carbon (OC) and black carbon (BC)

The anthropogenic emissions of OC and BC are taken from a global data set (Cooke et al., 1999). OC is produced not only from direct emissions but also from terrestrial sources; it is obtained from the emission of volatile organic compounds (Guenther et al., 1995). The biomass burning emissions of OC and BC in the GOCART model use the database of seasonal and interannual variations in burned biomass (Duncan et al., 2003), which is developed from long-term satellite observations including fire counts, the aerosol index, and an annual mean burned biomass inventory.

2.1.4. Sea salt

Sea salt comes mainly from the ocean, so its emission in the GOCART model is dependent on the sea surface wind speed and is calculated as follows:

$$dF/dr = 1.37 u^{3.41} r^{-3} \left(1 + 0.057 r^{1.05}\right) 10^{1.19 \exp(-B2)} \tag{2}$$

where F is the emission flux, r represents the particle radius, u represents the 10-m wind speed, and $B = (0.380 - \log r)/0.65$. Four size bins are considered in the GOCART model, with radius ranges of 0.1–0.5, 0.5–1.5, 1.5–5, and 5–10 μm, respectively.

2.2. Optical thickness

The AOD τ in the GOCART model can be calculated for a given aerosol type, mass, and wavelength, as follows:

$$\tau = B \cdot M_d \tag{3}$$

$$B = \frac{3QM}{4\rho r_e M_d} \tag{4}$$

where M_d is the aerosol dry mass and B is the specific or mass extinction coefficient ($m^2\ g^{-1}$), r_e is the particle effective radius, ρ is the particle density, and Q represents the extinction coefficient. Chin et al. (2002) further discussed the dependence of B on relative humidity (RH) and wavelength. Following the Mie theory, the value of B is estimated based on the optical property database in the

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