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Number size distribution of aerosols at Mt. Huang and Nanjing in the Yangtze River Delta, China: Effects of air masses and characteristics of new particle formation

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ABSTRACT

Aerosol number spectra in the range of 10 nm–10 μm were observed at Mt. Huang (Aug. 15–Sep. 15) and Nanjing (Oct. 13–Nov. 15) by a wide-range particle spectrometer (WPS) in 2011. Based on the backward trajectories obtained using the HYSPLIT model, the transport pathways of observed air masses during the study periods were classified into the following four groups: maritime air mass, continental air mass, marine–continental mixed air mass and local air mass. The variations in the aerosol number spectrum and the new particle formation (NPF) events for various types of air masses were discussed, along with meteorological data. The results showed that the average number concentration was 12,540 cm^{-3} at Nanjing and only 2791 cm^{-3} at Mt. Huang. The aerosol number concentration in Nanjing was 3–7 times higher than that in Mt. Huang; the large discrepancy was in the range of 10–100 nm. Different types of air masses had different effects on number concentration distribution. The number concentration of aerosols was higher in marine air masses, continental air masses and continental–marine mixed air masses at 10–50 nm, 100–500 nm and 50–200 nm, respectively. Under the four types of air masses, the aerosol size spectra had bimodal distributions in Nanjing and unimodal distributions in Mt. Huang (except under continental air masses: HT1). The effects of the diverse air masses on aerosol size segments of the concentration peak in Mt. Huang were stronger than those in Nanjing. The local air masses were dominant at these two sites and accounted for 44% of the total air masses. However, the aerosol number concentration was the lowest in Mt. Huang and the highest in Nanjing when local air masses were present. The number concentrations for foreign air masses increased at Mt. Huang and decreased at Nanjing. Different types of air masses had greater effects on the aerosol spectrum distribution at Mt. Huang than at Nanjing. During the NPF events, the particle growth rates at Mt. Huang (6.5–9.0 nm h^{-1}) were faster than those at Nanjing (4.8–5.6 nm h^{-1}). The relative humidity at Mt. Huang (36–65%) was higher than that at Nanjing (30–47%), but the wind speed trend was the opposite. The air masses during the NPF events were clean, i.e., they were mainly from over the ocean or districts with low ultrafine particle concentrations.

1. Introduction

Aerosol particles can directly affect the global climate by absorbing and scattering solar radiation and can affect cloud microphysical properties by acting as cloud condensation nuclei, which indirectly change the Earth's radiation balance (McCormick and Ludwig, 1967; Lohmann and Feichter, 2005;

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Friedman et al., 2009; Fan et al., 2012). Aerosol particles also play an important role in atmospheric chemistry processes that lead to the increasing number of hazy days and decreased visibility; haze greatly endangers human health by providing a reaction medium for viruses and bacteria (Pöschl, 2005; Russell et al., 1999; Han et al., 2012).

Aerosol number size distributions are continuous and typically multimodal. Hussein (2005), Hussein et al. (2005) modified the three-modal theory proposed by Whitby (1978) based on observational results of the aerosol number spectrum distribution and divided the sizes into four modes: nucleation mode ($D < 20$ nm), Aitken mode (20 nm $< D <$ 100 nm), accumulation mode (100 nm $< D <$ 1000 nm) and coarse mode ($D > 1$ μm). Nucleation mode particles, also called new particles, mainly form by the gas-particle transformation process of low-volatile substances in the atmosphere (Kulmala, 2003; Kulmala et al., 2004). Nucleation mode particles have significant environmental impacts in the atmosphere despite their short residence time and minimal mass. Observations show that NPF events can occur in the range of hundreds of kilometers, which has been observed in remote boreal forest, suburban, urban, desert and coastal environments, and such events occur on 5%–50% of the days of a year (Kulmala et al., 2004; Stanier et al., 2004; Shen et al., 2011; Dal Maso et al., 2005; Yue et al., 2010a; Nilsson et al., 2001; Dowd, 2001). With the development of observation methods, aerosol particles can be measured as they form in real time (Kulmala et al., 2007, 2012, 2013). The typical growth rate of new particles is 1–20 nm/h in the troposphere (Kulmala et al., 2001, 2004), and newly formed aerosol particles can grow to Aitken mode particles, or even to CCN, by coagulation and condensation. Dowd (2001) calculated that the aerosol scattering ability and CCN concentration increased 3-fold due to an NPF event based on observations along the coast. Aitken mode particles mainly originate from the direct emissions of combustion processes, such as diesel, gasoline, and natural gas engine exhaust particulate matter (Harris and Maricq, 2001; Ristovski et al., 2000; Kittelson, 1998). Accumulation mode particles mainly originate from the coagulation and condensation of Aitken mode particles. Coarse mode particles are generated by mechanical process and contribute little to the number concentration, except during dust storms (Whitby, 1978; Saliba et al., 2007).

Many measurements of aerosol size distributions have been conducted in various regions of the world including urban, rural, forested, coastal and remote mainland areas in developed and developing countries (Kulmala et al., 2004; Shen et al., 2011; Kiendler-Scharr et al., 2009; Manninen et al., 2010; Yue et al., 2010b; Birmili and Wiedensohler, 2000). These observations indicated that the aerosol number concentration had a significant seasonal variation: the concentration in winter was higher than that in the summer due to the low temperatures and heating process (Hussein et al., 2004; Wehner and Wiedensohler, 2003). Most observations showed that the 24 h average number concentration in the range of 10–500 nm was 5000–25,000 cm^{-3} in urban areas (Woo et al., 2001; Kim et al., 2002). Changes in meteorological elements and the boundary layer have large impacts on number size distribution (Väkevä et al., 2000; Kang et al., 2009, 2013; Li et al., 2000); for example, the increase in the boundary layer depth and wind speed, the change of wind direction, and rain/snow processes can reduce the number concentration. In addition, the long-range transport of air masses, especially the source and nature of the air mass, has a large impact on the number concentration. Birmili et al. (2001) studied the impacts of air masses on the number size distributions in central Europe (51.32°N, 12.56°E) and found that the number concentration was high for Aitken mode particles and low for accumulation mode particles when the air masses were from the Atlantic Ocean; however, the number concentration of accumulation mode particles was higher when air masses originating from Russia simultaneously moved over. Nilsson et al. (2001) found that NPF was closely related to the source and nature of the air mass. Sogacheva et al. (2005) and Nishita et al. (2007) also conducted similar studies. However, comparisons of the effects of different air masses on the aerosol number concentration distributions in urban and mountain areas are still very rare.

As one of the fastest growing economic regions in East Asia, aerosol pollution in the Yangtze River Delta has become one of the most harmful pollutants. The aerosol number size distribution in different air mass types has not been thoroughly studied in this region. Based on observational results at the SORPES station, Ding et al. (2013a,b) investigated the variations in pollution gases and $PM_{2.5}$ and how the distributions of the intense atmospheric pollution modify weather. Herrmann et al. (2014) systematically researched the major distributions of aerosols and new particle formation in the YRD region. It is important to understand the evolution of the number size distributions in different air mass types to determine the aerosol formation mechanisms and sources and help control regional air pollution. We observed aerosol number concentrations in the size range of 10 nm–10 μm and meteorological elements at Mt. Huang and Nanjing and then divided the air masses into four types (i.e., maritime, continental, marine–continental mixed and local air masses) using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. This paper comparatively analyzed the characteristics of aerosol number size distributions under different air mass types and the conditions of the NPF events at two observation sites.

2. Instruments and experiments

2.1. Instruments

Particle number concentrations in the size range of 10 nm–10 μm were measured by a wide-range particle spectrometer (WPS) produced by USA MSP. The instrument combines the principles of differential mobility analysis (DMA), condensation particle counting (CPC) and laser light scattering (LPS). DMA and CPC are used for measuring particles in the size range of 10–500 nm, and LPS is used for measuring particles in the range of 0.35–10 μm. The introduction of the instrument and related principles are based on Gao et al. (2009). We chose the sample mode with 48 channels for DMA and 24 channels for LPS. Thus, it takes approximately 5 min for one complete scan of the entire size range with a 3 s scanning period for each channel. The WPS sample flow was set to 1 L/min, the DMA sample flow was set to 0.3 L/min, the LPS sample flow was set to 0.7 L/min, and the laboratory temperature was approximately 25 °C. We used a drying tube in the air inlet section when the RH was large (foggy and rainy days).