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Aerosol size distribution and new particle formation events in the suburb of Xi'an, northwest China

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HIGHLIGHTS

- The particle number size distribution was observed over 1 year in the suburb of Xi'an, northwest China.
- The seasonal, monthly and diurnal average particle number concentrations were investigated.
- The new particle formation (NPF) events analyzed which showed a 19% percent of the total days.
- The air masses on a NPF day mainly come from north or northwest china.
- Two types of NPF events with (type1) or without(type2)subsequentparticle growthwas observed in suburb of Xi'an.
- The wind directions which may be with different emissions play an important role in new particle growth in suburb of Xi'an.

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ABSTRACT

Particle number concentration and size distribution are important for better understanding the characteristics of aerosols. However, their measurements are scarce in western China. Based on the first measurement of particle number size distribution (10–487 nm) in the suburb of Xi'an, northwest China from November 2013 to December 2014, the seasonal, monthly and diurnal average particle number concentrations were investigated, and the characteristics of new particle formation (NPF) events and their dependencies on meteorological parameters also discussed. The results showed that the annual average particle number concentrations in the nucleation (N_{NUC}), Aitken (N_{AIT}), and Accumulation (N_{ACC}) size ranges were 960 cm^{-3}, 4457 cm^{-3}, 3548 cm^{-3}, respectively. The mean total particle number concentration (N_{TOT}) was 8965 cm^{-3} and largely dominated by particles in Aitken mode. The number concentration was dominated by particles around 67.3 nm in spring, summer and fall, while about 89.8 nm in winter. The percentage of the ultrafine size range (UFP, particles of diameter below 100 nm) to total particle number concentration was 63.2%, 69.6%, 62.2% and 58.1% in four seasons. The diurnal variation of the nucleation mode particles was mainly influenced by NPF events in summer, while by both traffic densities and NPF events in spring, fall and winter. The diurnal variation of the number concentration of Aitken mode particles correlated with the traffic emission in spring, fall and winter, while in summer it more correlated with contribution of the growth of the nucleation mode particles. The burst of nucleation mode particles typically started in the daytime (08:15–16:05, LST). The growth rates of nucleated particles ranged from 2.8 to 10.7 nm h^{-1} with an average of 5.0 ± 1.9 nm h^{-1}. Among observed 66 NPF events from 347 effective measurement days, 85 percent of their air masses came from north or northwest China, resulting in a low concentration of pre-existing particles, and only 15 percent came southerly from Qingling Mountains. Based on their growth rate, 64 and 36 percent of their subsequent particles, corresponding to types 1 and 2 NPF events, grew and seldom grew after the burst of

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nucleation mode particles. For type 1 NPF event, the nucleated particles could grow up to 40 nm or larger when surface winds shifted from westerly to easterly or southeasterly (from village areas). For type 2 NPF events, the particles kept almost unchanged when the winds stayed westerly. This implied that the surface wind direction with different emissions might play an important role in new particle growth in suburb of Xi'an.

1. Introduction

Atmospheric aerosol particles are ubiquitous and affect the radiative forcing budget of the atmosphere directly by scattering solar radiation and indirectly by affecting the properties of clouds (Seinfeld and Pandis, 2006). Aerosol particle formation increases the total number concentration of ambient submicron size particles and thereby affects climate forcing and human health (Twomey, 1997). And also Atmospheric aerosols are the primary pollutants leading to the deterioration of urban air quality (Horvath et al., 1996), which result in frequent haze events and declining visibility in urban and regional scales (Jung and Kim, 2006).

Aerosol particles are currently considered as one of the most harmful air pollutants in big cities (Qian et al., 2008; Zhang et al., 2012; Huang et al., 2014; Shen et al., 2015). Epidemiological studies have shown adverse health effects of atmospheric aerosols including respiratory irritation, changes in pulmonary function and associations between aerosol mass concentrations and mortality (Samet et al., 2000; Lippmann et al., 2000; Ayala et al., 2012; Fann and Risley, 2013). Some studies have showed relationships between fine particle concentration and respiratory and cardiovascular diseases (Pope, 2000; Samet et al., 2000). And some studies have suggested that the adverse health effects led by number concentrations of ultrafine particles (3–100 nm) would be stronger than those by the mass concentration of the fine particles (Peters et al., 1997; Penttinen et al., 2001). The size distribution of atmospheric aerosols, together with chemical composition, provides important information on the sources and processes of aerosols and for assessing their health and climatic effects.

Fine and ultrafine particles with tiny mass dominate the total particle number concentrations in the urban areas. For example, ultrafine particles account for 76% of the total particle number concentration (3–10000 nm) but only 2% of the total particle volume concentration in Beijing (Wu et al., 2008). However, current air quality standards (such as $PM_{2.5}$ and PM_{10} standards) are based on particle mass concentrations. Incorrect conclusions may therefore be drawn regarding the relationship between the particle number and observed health effects. Thus, it is important to measure the particle number size distribution to fully understand the environmental effects of atmospheric particles (Peters et al., 1997; Penttinen et al., 2001; Biswas and Wu, 2005). Many observations of the urban atmosphere have shown that the particle concentration is closely related to the density of urban traffic, and high particle concentrations are usually observed during rush hours (Tuch et al., 2003; Hussein et al., 2004; Wu et al., 2008, 2011). Moreover, aerosol size distributions exhibit obvious seasonal variations and are significantly affected by meteorological factors such as wind speed, wind direction, solar radiation, and precipitation (Wehner and Wiedensohler, 2003; Castro et al., 2010).

Ground-based in situ measurements of aerosol properties such as size distribution, chemical composition, scattering and absorption coefficient have been carried out at many sites around the world, either at long-term monitoring sites, or as part of intensive field campaigns (Solomon et al., 2007). A wide body of in situ observations of tropospheric aerosols have been made in urban and rural areas in Europe and North America, e.g. Birmingham (Harrison et al., 1999), Atlanta (Woo et al., 2001), Helsinki (Hussein et al., 2004), Leipzig (Birmili et al., 2001; Wehner and Wiedensohler, 2003), and Pittsburgh (Stanier et al., 2004), and are also conducted at some background sites, such as Mt. Waliguan, China (Kivekäs et al., 2009) and Aspvreten, Sweden (Dal Maso et al., 2007). During the recent year, efforts have been made to characterize particle number size distributions in developing countries as well, because their air pollution problems are of significant local and even regional concern, such as in Indian (Laakso et al., 2006; Kanawade et al., 2012; Siingh et al., 2013), Beijing (Wu et al., 2008; Shen et al., 2011), the Pearl River Delta (Gong et al., 2010; Liu et al., 2008; Yue et al., 2013) and the Yangtze River Delta (Xiao et al., 2015; Du et al., 2012; Herrmann et al., 2014; Wang et al., 2014; Qi et al., 2015; Huang et al., 2016; Zhu et al., 2013).

The formation of new particles in the atmosphere and its effects on the budget of the number concentration of submicron particles are a vital issue in atmospheric science (Seinfeld and Pandis, 1998). Fortunately, it is readily easy to find the new particle formation (NPF) events and growth from the measurements of particle size distributions. Typical particle growth rates range from 1 to 20 nm h^{-1} in mid-latitudes depending on the temperature and the availability of condensable vapors (Kulmala et al., 2004). It has been reported that sulfuric acid plays a dominant role in new particle formation and growth (Boy et al., 2005; Riipinen et al., 2007; Sipilä et al., 2010), and organic compounds have also been thought to have the potential role (Zhang et al., 2004; Barsanti et al., 2009). Condensation and coagulation are also important for new particle formation events.

Although studies of aerosol size distribution based on measurements have increased in China in recent years (Zhu et al., 2013; Wang et al., 2013; Wu et al., 2011, 2008; Liu et al., 2008; Yue et al., 2009; Gao et al., 2009; Guo et al., 2012; Wang et al., 2014; Xiao et al., 2015), very few studies have been conducted in western China (Gao et al., 2011). Xi'an is a large city in northwestern China, as one of the most important comprehensive industrial production base and transport hub of China, surrounding by the Loess Plateau and Qinling Mountains in its north and south. During the past decade, coal combustion, biomass burning, vehicle emissions, and fugitive dust (airborne particles that originate from unpaved roads, agricultural cropland and construction sites) are reported to be the main contributors to the high particle pollution over Xi'an (Zhang et al., 2002; Cao et al., 2009; Shen et al., 2009). It is now facing heavy air pollution problem characterized by high $PM_{2.5}$ (particles with aerodynamic diameter $\leq$ 2.5 μm) (Cao et al., 2012). The high population density and rapid industrialization have brought it an obvious increase in the primary emission of pollutants. In recent years, the regional air pollution has worsened due to the emission of pollutant and the effect of the topography, leading to an increase of haze days (Liu et al., 2016).

In order to learn the aerosol size distribution in Northwest China and the aerosol background of the heavily polluted city, we chose a suburban site of Xi'an as an example and conducted measurements