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Aerosol composition and sources during high and low pollution periods in Ningbo, China

Jing-Sha Xu [a], Hong-Hui Xu [b], Hang Xiao [c,d], Lei Tong [c,d], Colin E. Snape [e], Cheng-Jun Wang [f], Jun He [a,*]

[a] International Doctoral Innovation Centre, Department of Chemical and Environmental Engineering, University of Nottingham Ningbo China, Ningbo, Zhejiang, China
[b] Zhejiang Meteorological Science Institute, Hangzhou, China
[c] Hazardous Air Pollutants Lab, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen, China
[d] Ningbo Urban Environment Observation and Research Station-NUEORS, Chinese Academy of Sciences, Ningbo, China
[e] Faculty of Engineering, University of Nottingham, Energy Technologies Building, Triumph Road, Nottingham NG7 2TU, UK
[f] College of Chemistry and Materials Engineering, Wenzhou University, Wenzhou, China

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ABSTRACT

Due to the rapid industrialization of the Yangtze River Delta (YRD) region in China, heavy air pollution episodes have occurred frequently over the past five years which are of great concern due to their environmental and health impacts. To investigate the chemical characteristics of the highly polluted aerosols in this region, a sampling campaign had been conducted in Ningbo from 3 December 2012 to 27 June 2013, during which a month long high pollution episode had been captured. Daily average $PM_{2.5}$ concentrations during high and low pollution periods were 111 μg m^{-3} and 53 μg m^{-3}, respectively. The most polluted day was 8 January 2013 with a $PM_{2.5}$ concentration up to 175 μg m^{-3}. To understand the origin of the highly polluted aerosols, meteorological conditions, air mass backward trajectories, distribution of fire spots in surrounding areas and various categories of aerosol pollutants were analyzed, including trace metals, inorganic species, PAHs and anhydrosugars. Total metal concentrations were 3.8 and 1.6 μg m^{-3} for the high and low pollution episodes, respectively, accounting for 3.4% and 3.1% of the total $PM_{2.5}$ mass. Total concentrations of ionic species accounted for more than 50.0% of the $PM_{2.5}$ by mass, with dominant ions (nitrate, sulfate, ammonium) accounting for over 42.0% of the $PM_{2.5}$ mass concentrations in both periods. During the high pollution episode, enhanced Cd–Pb and biomarker (levoglucosan, mannosan) levels indicated the contributions from coal combustion, traffic and biomass burning to fine aerosol $PM_{2.5}$. The average diagnostic ratio of Fla/(Fla + Pyr) was 0.54 in high pollution episode, which was intermediate between that for wood (>0.50) and coal combustion (0.58). BaP/Bpe was 0.49 and 0.30 for the highly and lightly polluted aerosols respectively, associated with the significant non-traffic emissions (<0.60). In addition, stagnant weather conditions during the high pollution period and long-range transport of air masses from heavy industries and biomass burning from northern China to Ningbo could be considered as the main factors for the formation of the aerosols during high pollution period.

1. Introduction

Atmospheric aerosols can greatly affect the Earth's radiation budget and climate change along with greenhouse gases (Gkikas et al., 2016; Xin et al., 2016), and they have been verified to have significant impacts not only on visibility/haze, but also on air quality and public health, particularly those fine particles with aerodynamic diameters less than or equal to 2.5 μm ($PM_{2.5}$) (Wang et al., 2014). Highly polluted aerosols can potentially lead to lung cancer, respiratory diseases and cardiopulmonary mortality for long term exposure (Pope Iii et al., 2002; Tie et al., 2009). Generally, atmospheric aerosols can be divided into primary ones directly emitted from various sources and secondary ones formed through gas-to-particle transformation processes. In recent decades, many regions have encountered heavy aerosol pollution, including Indonesia (Field et al., 2004; Forsyth, 2014; Langmann, 2007), United States (Odman et al., 2009; Park et al., 2006; Schichtel et al., 2001), Northern Europe (Toledano et al., 2012), and China (Tao et al., 2014; Wang et al., 2015c; Zhang et al., 2015a).

In China, a number of cities have experienced severe aerosol pollution with an Air Pollution Index (API) higher than 500 that is categorized as the unhealthiest level by China's Ministry of Environmental Protection (MEP). Less than 1% of the top 500 cities in China can meet the World Health Organization air quality standards (Li and Zhang, 2014). Power plants, heavy industry and vehicles were reported to be mainly responsible for the occurrence of severe aerosol pollution episode especially in winter when domestic coal consumption increased significantly (Li and Zhang, 2014). From satellite observations, northern

* Corresponding author.
E-mail address: jun.he@nottingham.edu.cn (J. He).

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and eastern China were reported to be affected by hazardous dense aerosol pollution the most frequently (Tie et al., 2006). The Yangtze River Delta (YRD), located at the eastern coast of China bordering the East China Sea, has experienced many aerosol pollution events due to its remarkable economic growth and accelerated urbanization over the past 30 years (Liao et al., 2014), especially the rapid development of heavy industries, such as iron and steel, automobile manufacturing, oil and gas (Cheng et al., 2014). Additionally, another significant contributor of severe aerosol pollution in this area could be the open burning of biomass including agricultural waste which tends to be a common practice for land clearance by local farmers (Cheng et al., 2014). Previous studies have revealed high levels of aerosol pollution and extremely low visibilities in the YRD (Fu et al., 2008; Gao et al., 2011). Meteorological stations observed the average visibility of this region has shown a trend of 2.4 km decrease per decade from 25 to <20 km in the period of 1981–2005 (Gao et al., 2011). A few studies have been conducted to investigate the aerosol pollution episodes occurring in megacities of the YRD including Nanjing, Shanghai and Hangzhou (Cheng et al., 2013b; Wang et al., 2014), but none of these studies have reported detailed information on particulate compositions.

Located at the south of YRD region, Ningbo is adjacent to Hangzhou and Shaoxing, about 15 km to the west coast of the East China Sea. As the second largest city of Zhejiang Province, it has a population of approximately 8 million and covers an area of around 10,000 km^2. Before 2000, the number of days affected by severe aerosol pollution in Ningbo was reported to be less than 15 per year. The visibility of Ningbo ranged from 8.6 to 14.9 km in 1980. However, the number of heavy aerosol pollution days was rapidly increased to 50 per year after 2001 and the visibility observed in 2003 ranged from 3.8 to 11.7 km, which was an obvious decrease compared to that of 1980 (Cheng et al., 2013b). In January 2013, a long lasting aerosol pollution episode occurred in central and eastern China and it was considered as the most severe aerosol pollution since 2000. However, only a few studies have reported this particular event (Andersson et al., 2015; Cheng et al., 2013b; Ji et al., 2014; Wang et al., 2014). The previous studies mostly focused on the study of aerosol number concentrations, visibility, OC and EC in YRD. Only one report discussed the source apportionment of combustion-derived black carbon aerosols by using carbon isotopes (Andersson et al., 2015). Their results preliminarily show that biomass combustion contributed around 30% to the severe aerosol pollution in North China Plain (NCP, Beijing) and Yangtze River Delta (YRD, Shanghai). For black carbon, it was found that the petroleum usage and coal combustion could account for 46% and 66% of BC in YRD and NCP, respectively. In this study, the chemical characteristics including trace metals, ionic species, polycyclic aromatic hydrocarbons (PAHs) and biomarkers for high and low aerosol pollution periods in Ningbo have been investigated, and also diagnostic ratios, organic tracers and air mass backward trajectories have been adopted for a qualitative source analysis for this particular aerosol pollution event.

2. Experimental

2.1. Sampling site and aerosol collection

The sampling site (29.80N, 121.56E) is located at the southern city of YRD—Ningbo, shown in Fig. 1(a) and (b). It is less than 10 km away from the central business district (CBD). A 24-h sampling was conducted at the air monitoring station on the rooftop of Science and Engineering Building (SEB) in the University of Nottingham Ningbo China (UNNC) from December 3rd 2012 to June 27th 2013, using a high volume sampler (Model: TH-1000H, Tianhong Instrument Co., Ltd. Wuhan, China) with the flow rate of 1.05 $m^3\ min^{-1}$. 20 cm × 25 cm glass fiber filter (Huitong Instrument Co., Tianjin, China) was loaded to capture $PM_{2.5}$. In total, 32 $PM_{2.5}$ samples were collected and blank filters were obtained every two weeks from the sampler without their pump on.

2.2. Air mass backward trajectory and fire-spot analysis

To investigate the effects of medium and long-range transport of aerosols on local air quality, air mass transport pathways were studied through backward trajectory analysis which was carried out using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) 4.9 model (Draxler and Rolph, 2013; Rolph, 2013). A 4-day (96 h) backward trajectory was started at the sampling site every 6 h during each sampling day at 500 m above ground level (agl) and then these computed trajectories were clustered by applying TrajStat 1.2.1.0 (http://www.arl.noaa.gov/HYSPLIT.php) (Wang et al., 2009). TrajStat is a geographic information system (GIS) based software which can identify aerosol potential sources from long-term measurement data by using various trajectory statistical analysis methods. In this software, there are two clustering models—Euclidean distance and angle distance (Turpin and Huntzicker, 1995). The Euclidean distance model has been applied in this study because it concerns both the directions and distances of the trajectories while the angle distance only concerns the directions of the trajectories. In addition, Moderate Resolution Imaging Spectroradiometer (MODIS) fire-spots in this study were obtained from Fire Information for Resource Management System (FIRMS) Web Fire Mapper. Each fire-spot that was detected by satellites represents the center of an approximately 1 km pixel marked as containing one or more fires, or other thermal activities.

2.3. Chemical analysis of aerosol samples

2.3.1. Quality assurance and control

Before sampling, fresh blank filters were prebaked for 4 h at 550 °C in a muffle furnace in order to remove any absorbed carbonaceous compounds. Equilibration of filters was carried out at constant temperature of 22 °C ± 1 °C and relative humidity (RH) at 30% ± 5% for 24 h before

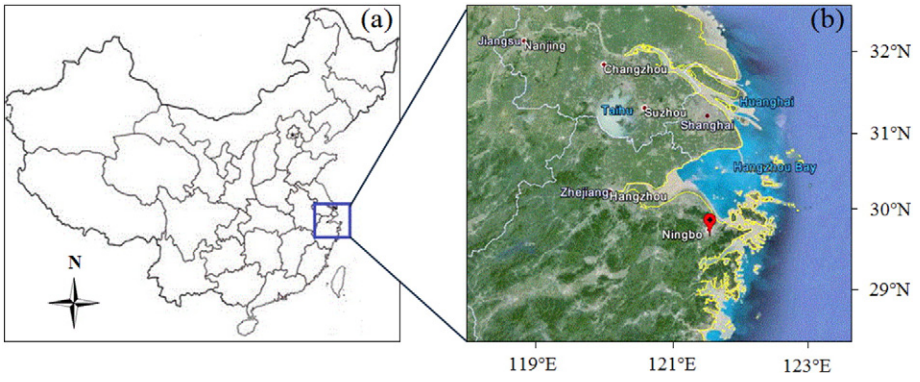

Fig. 1. (a) Location of YRD region in China and (b) Location of Ningbo in YRD.