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An integrated process rate analysis of a regional fine particulate matter episode over Yangtze River Delta in 2010

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HIGHLIGHTS

- A high $PM_{2.5}$ episode over the YRD was simulated using the CMAQ modeling system.
- Integrated process rate was applied to study the formation mechanism of $PM_{2.5}$.
- Contributions of different atmospheric processes to $PM_{2.5}$ were analyzed.

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ABSTRACT

A high $PM_{2.5}$ pollution episode was detected in Shanghai in November 2010. The integrated process rate method, an advanced diagnostic tool, was applied to account for the contribution of different atmospheric processes during the high pollution episode in the Yangtze River Delta region (YRD). The $PM_{2.5}$ process analysis indicates that the emission of fine particles is the dominant source of high surface $PM_{2.5}$ concentrations in the major cities of the YRD like Shanghai, Nanjing, and Hangzhou, following horizontal transportation and aerosols. The $PM_{2.5}$ concentration could be reduced due to vertical advection and diffusion from lower levels to the upper air. The aerosols process such as homogeneous nucleation and condensation producing $PM_{2.5}$ occurs throughout the PBL layer in urban areas, causing vertical transport from upper levels down to the surface layer. The aerosols process is much more significant in a downwind rural and coastal site like Zhoushan than in the urban areas. The $PM_{2.5}$ change initiated by both horizontal transport and vertical transport is much stronger at 40–2000 m height than in the surface layer, while the $PM_{2.5}$ change caused by horizontal diffusion is very small. Dry deposition can significantly reduce concentration of the particulates in the surface level of the atmosphere, and wet deposition can remove the particles in the planetary boundary layer (PBL). The cloud processes can either increase $PM_{2.5}$ due to the aqueous-phase oxidation of SO_2 and NO_2 or remove $PM_{2.5}$ due to cloud scavenging. Solar radiation and humidity are more important to secondary pollution, and they are the significant external factors affecting the chemical reactions among sulfur dioxide, nitrogen oxides, ammonia, volatile compounds and fine particles.

1. Introduction

Pollution caused by fine particulate matter with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) has attracted much interest and more attention in recent years in the Yangtze River Delta, one of the most important city-clusters of China (Chang et al., 2009; Gao et al., 2011; Wang and Hao, 2012; Xiao et al., 2011) due to its great impact on regional haze, human health and global climate change (Ge et al., 2011; IPCC, 2007; Yang et al., 2007). To reduce the $PM_{2.5}$ concentrations and improve the air quality, China published its new National Ambient Air Quality Standards (NAAQS) in February 29, 2012 (http://kjs.mep.gov.cn/hjbhbz/bzwb/dqhjbh/dqhjzlbz/201203/t20120302_224165.htm)

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to protect public health. Within China's new NAAQS, the $PM_{2.5}$ standard was firstly established, with the annual average concentration standard of 35 μg m^{-3} and the daily average of 75 μg m^{-3}. However, most of the cities in the YRD region exceed the $PM_{2.5}$ standards (Van et al., 2010; Wang et al., 2013), especially the $PM_{2.5}$ concentration are usually very high in the winter season (Chan and Yao, 2008; Gao et al., 2011), thus the regional haze occurs frequently (Fu et al., 2008). A lot of researches have been recently conducted to examine the $PM_{2.5}$ pollution characteristics over the YRD with both measurement and modeling methods. Some studies are focused on the chemical compositions and secondary formation of $PM_{2.5}$ (Feng et al., 2009; Huang et al., 2013), some on the extinction effect of $PM_{2.5}$ (Cheng et al., 2013), and others are related to the sources of the components in $PM_{2.5}$ (Feng et al., 2013; Zhang et al., 2012). These studies provided insightful information about the chemical species, size distribution, the light extinction effect, and source apportionment of fine particles. However, very limited information is available regarding to the formation process of high concentrations of $PM_{2.5}$ in winter in the Yangtze River Delta (YRD). In this study, we investigate what are the governing chemical and physical processes contributing to the change of $PM_{2.5}$ in a high pollution episode occurred in winter over the YRD during November 19–21, 2010, with the application of the integrated process rate analysis method coupled within the CMAQ modeling system.

2. Overview of the high $PM_{2.5}$ pollution episode

2.1. Weather conditions

During the period of November 19–21, 2010, a subtropical high pressure system started to move toward the sea over the YRD area. Shanghai was at the northwest edge of the subtropical high pressure system. Both the pressure field and the southwest wind were very weak. From the afternoon of Nov. 19, the air became stable, and heavy fog formed in Shanghai and the surrounding area (http://traditionalchinese.wunderground.com). A ground-level inversion occurred during the night of Nov. 19 and in the morning of Nov. 20 (http://weather.uwyo.edu/upperair/sounding.html). During this period, surface meteorological data show that the average surface temperature was around 14.1 °C, the average relative humidity was 69.4%, and the average wind speed was only 1.3 m/s. The maximum relative humidity reached 91.8% (on Nov. 21) and the lowest wind speed was only 0.4 m/s. These conditions were very favorable for the accumulation of air pollutants. Fig. 1 shows the surface weather patterns over eastern Asia at 8:00 a.m., Nov. 19 and 20, 2010, respectively.

2.2. Air pollution observation

Under these weather conditions, the concentration of PM increased greatly, and a large-scale regional haze occurred, which is confirmed by MODIS satellite images as shown in Fig. 2. Observational data show that the highest daily concentration of PM_{10} reached 210 μg m^{-3} in Shanghai, 146 μg m^{-3} in Nanjing, 170 μg m^{-3} in Suzhou, 164 μg m^{-3} in Hangzhou, and 170 μg m^{-3} in Ningbo (MEP, 2010). The maximum hourly concentrations of PM_{10} and $PM_{2.5}$ observed at the Shanghai Academy of Environmental Sciences (SAES) site reached 317 and 193 μg m^{-3}, respectively.

(http://rapidfire.sci.gsfc.nasa.gov/subsets/?subset=FAS_China4.20101120.aqua.1km.jpg&vectors=fires+coast+borders http://rapidfire.sci.gsfc.nasa.gov/subsets/?subset=FAS_China4.20101120.terra.1km.jpg&vectors=fires+coast+borders).

The measurements are collected simultaneously at the surface site of SAES. The continuous PM_{10} and $PM_{2.5}$ concentrations were measured by Thermo Fisher commercial instruments β-ray particulate monitor. The water soluble ions were measured by a model ADI 2080 online analyzer for monitoring of aerosols, and the organic carbon and elemental carbon were measured by the carbon analyzer provided by Sunset laboratory Inc.

The daily average concentration of PM_{10} increased from 97 μg m^{-3} on Nov. 18 to 243 μg m^{-3} on Nov. 20, while $PM_{2.5}$ increased from 57 μg m^{-3} to 158 μg m^{-3}. The $PM_{2.5}/PM_{10}$ ratio increased from 58.8% to 65.0%. During Nov. 19–21, the average concentrations of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ were 192 ± 67 μg m^{-3}, 123 ± 48 μg m^{-3} and 75 ± 31 μg m^{-3}, and the maximum hourly concentrations of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ reached 317, 193 and 157 μg m^{-3} respectively. The average $PM_{1.0}/PM_{2.5}$, $PM_{1.0}/PM_{10}$ and $PM_{2.5}/PM_{10}$ ratios were 61.0%, 39.1% and 64.1%, respectively. The total period with visibility less than 5.0 km lasted for 44 h, as shown in Figs. 3 and 4.

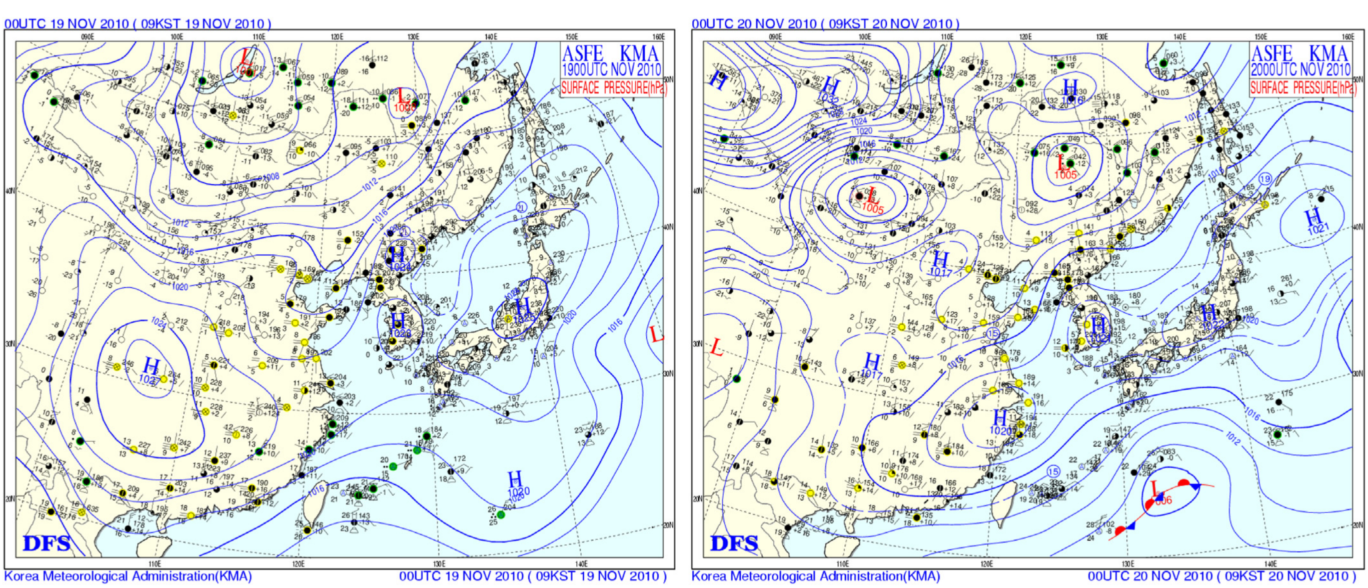

Fig. 1. Surface weather patterns over the eastern Asia at 8:00 a.m. on November 19 (left) and 20 (right), 2010 (from Korea Meteorological Administration).