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Typical atmospheric haze during crop harvest season in northeastern China: A case in the Changchun region

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ABSTRACT

This study presents the mass concentrations of $PM_{2.5}$, O_3, SO_2 and NO_x at one urban, one suburban and two rural locations in the Changchun region from September 25 to October 27 2013. Major chemical components of $PM_{2.5}$ at the four sites were daily sampled and analyzed. Most of daily concentrations of SO_2 (7–82 μg/m^3), O_3 (27–171 μg/m^3) and NO_x (14–213 μg/m^3) were below the limits of the National Ambient Air Quality Standard (NAAQS) in China. However, $PM_{2.5}$ concentrations (143–168 μg/m^3) were 2-fold higher than NAAQS. Higher $PM_{2.5}$ concentrations (~150 μg/m^3) were measured during the pre-harvest and harvest at the urban site, while $PM_{2.5}$ concentrations significantly increased from 250 to 400 μg m^{-3} at suburban and rural sites with widespread biomass burning. At all sites, $PM_{2.5}$ components were dominated by organic carbon (OC) and followed by soluble component sulfate (SO_4^{2-}), ammonium (NH_4^+) and nitrate (NO_3^-). Compared with rural sites, urban site had a higher mineral contribution and lower potassium (K^+ and K) contribution to $PM_{2.5}$. Severe atmospheric haze events that occurred from October 21 to 23 were attributed to strong source emissions (*e.g.*, biomass burning) and unfavorable air diffusion conditions. Furthermore, coal burning originating from winter heating supply beginning on October 18 increased the atmospheric pollutant emissions. For entire crop harvest period, the Positive Matrix Factorization (PMF) analysis indicated five important emission contributors in the Changchun region, as follows: secondary aerosol (39%), biomass burning (20%), supply heating (18%), soil/road dust (14%) and traffic (9%).

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Introduction

Fine particulate matter ($PM_{2.5}$), ozone (O_3), sulfur dioxide (SO_2) and nitrogen oxide (NO_x) have been generally recognized as important atmospheric pollutants that most significantly affect human health and visibility (Heal et al., 2012). In China, increasing public concern about air quality and haze events requires accurate emission source quantifications, detailed chemical components and an in-depth understanding of the transport and photochemical reaction processes of

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atmospheric pollutants to develop suitable and sustainable mitigation strategies (Chan and Yao, 2008; Cheng et al., 2013; Pui et al., 2014). However, the complexity of chemical components in atmospheric $PM_{2.5}$, spatio-temporal distributions as well as heterogeneous reactions with gases remains unclear in different regions (R. Zhang et al., 2012). Therefore, long-term and systemic studies are required to elucidate the air pollution levels, possible emission sources and transport processes at specified regions.

The frequency of regional atmospheric haze events increased rapidly along with the fast-paced urbanization and increasing energy consumption over the past years (Kan et al., 2012). Previous studies have shown that haze primarily occurs in four regions: the Bejing-Tianjin-Hebei zone, the Yangtze Delta, the Pearl River Delta and the Sichuan Province (*e.g.*, Cao et al., 2012a, 2012b; X.Y. Zhang et al., 2012; Wang et al., 2013a, 2013b; Li et al., 2014; Ji et al., 2012); thus, a considerable number of studies has been ongoing in these regions. In addition, atmospheric haze problems have increased in northeastern China under the national five-year development plan in the region; thus, this area may become the fifth severe haze region. An extreme haze event from October 20 to October 23 2013, affected the public over an expansive area (>1 million km^2), nearly covering the entire region and showing an ultra-high $PM_{2.5}$ concentration in some locations (>1000 $\mu g/m^3$) (Xinhua News Agency, 2013). However, air quality studies in this region have been limited to a few cities and to basic chemical component analysis (*e.g.*, Han et al., 2010; Huang et al., 2011). More information about emission patterns and the chemical composition of the atmospheric pollutants is necessary in this region due to the importance of identifying emission sources and verifying an air quality model (Heal et al., 2012). Furthermore, studies on the issues involving emission inventory, the mechanism of haze events and a system of forecasting and warning by numerical simulation in northeastern China have been lacking.

Agricultural emission is crucial to regional air quality in northeastern China due to intense activity and the vast farmlands, which occupy approximately 30% of the total land area in northeastern China (China Agricultural Yearbook, 2012). Particulate matter and gaseous pollutants emitted from agricultural operations may initially change the air quality in a rural area and then affect adjacent towns/cities by diffusion. The air quality in agricultural regions is closely linked to the local weather, soil properties, crop types and field operations as well as the living habits in village (Hinz and Tamoschat-Depolt, 2007). The primary particles mainly originate from operations, such as soil tillage, fertilization, application of chemical substances, crop cutting and processing, straw burning and animal feed, while ammonia, biogenic VOC, and other chemical substances from these operations could generate secondary fine particles by homogeneous or heterogeneous reactions (Aneja et al., 2009). In many agricultural regions in China, spring plowing, fall harvesting and, especially biomass burning are responsible for regional haze events (Zhang et al., 2010; Qin and Xie, 2011; Liu et al., 2014). Similarly, most straw residues are open burned to be incorporated into the soil for farming season and to reduce the cost of recycling in northeastern China. Mechanical harvest and land preparation after burning also contribute to particulate matter production (Holmén et al., 2008). Additionally, coal burning for the heating supply in cities and biomass burning in most villages increase the amount of atmospheric pollutants during the wintertime in northeastern China (Cao et al., 2012a, 2012b). Thus, the possibility of haze events may greatly increase with the combination of crop harvesting and winter heating.

This study presents the atmospheric concentrations of fine particulate matter ($PM_{2.5}$) and gaseous pollutants (*i.e.*, O_3, SO_2 and NO_x) from September 25 to October 27, 2013, in the Changchun region, Jilin Province, northeastern China. Using portable real-time $PM_{2.5}$ analyzers, we measured the hourly $PM_{2.5}$ concentration at one urban, one suburban and two rural locations in the region. Gaseous pollutant concentrations were determined by real-time gas analyzers established at the suburban site. Daily sampling of $PM_{2.5}$, except for rain days, and the major chemical component analysis of $PM_{2.5}$ at the four sites were also conducted. Our primary objectives were to gain insight into the atmospheric pollutants during the harvest season and to determine the cause of the severe haze events in northeastern China.

1. Materials and methods

1.1. Study region

This study was conducted in the Changchun region (43°05′N–43°05′N, 124°18′E–127°05′E, 250–350 m a.s.l), which is the capital of Jilin Province and the natural geographical center in northeastern China (Bureau of Statistics of Jilin, 2007). The local climate is characterized as temperate continental monsoon climate. The mean annual temperature is 4.8°C, with a mean January temperature of −15.1°C and a July mean of 23.1°C. The annual precipitation is 522–615 mm, with more than 60% falling in the summer from June to August.

Changchun city is an industrial city, having the largest automobile manufacture enterprise in China, whereas there are also vast farmlands around the city in the rural areas. Maize is the dominant crop, accounting for 58% of total crop areas in Jilin province. Generally, maize is planted in early May and harvested in October. During the crop harvest, three stages are divided by different operations. The first stage is pre-harvest (*i.e.*, farm machinery preparation), the second stage is the reaping of maize with small straw burning (*i.e.*, harvest) and the third stage is characterized by strong straw burning and small land preparation after harvest (*i.e.*, post-harvest). Straw burning is primarily implemented in the second half of October. In urban areas, wintertime heating normally begins October 15, and the heat is formally supplied around October 25 in the Changchun region.

1.2. Experimental design

To elucidate the local air pollution characteristics, the possible emission sources and the role of agriculture in the Changchun region, four sampling sites (*i.e.*, one urban, one suburban and two rural) and four major atmospheric pollutants (*i.e.*, $PM_{2.5}$, O_3, NO_x and SO_2) were monitored. As shown in Fig. 1, the urban site is located in the Liaoyang residential

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