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The variability of biomass burning and its influence on regional aerosol properties during the wheat harvest season in North China

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ABSTRACT

The spatial–temporal variation of biomass burning in June during the wheat harvest season in the North China (32–41°N, 111–120°E) and its influence on the regional aerosol optical depth (AOD) and the chemical compositions of size-segregated aerosols in the urban environment were investigated to evaluate the effectiveness of the burn ban policy and the influence on regional pollution. Fire events that occurred in early and middle June accounted for approximately 89% of the events during the month, and fire points located in mid-eastern China (32.5–35.5°N, 114–120°E) comprised 71%. The occurrences exhibit oscillatory changes with a minimum in 2008 (during the Beijing Olympics) and a peak and explosive growth in 2012. Under high relative humidity and south winds, fire emissions from straw burning combined with high urban/industrial emissions to produce intensive regional haze pollution in the North Plain. The formation of secondary inorganic particles was intensified due to the interactions of smoke plumes and urban/industrial pollutants in an urban environment. Higher concentrations and percentages (79%) of sulfate, nitrate, ammonium, and organic carbon in the fine particles under high relative humidity conditions contributed to a deteriorated urban visibility. Therefore, stronger management and a comprehensive ban on wheat straw burning in June are urgently needed, especially during years when the south wind is dominant.

1. Introduction

Biomass burning has a significant impact on regional air quality, global climate change, and public health due to the release of many gaseous and aerosol particles (Penner et al., 1992; Koppmann et al., 2005; Reid et al., 2005a, 2005b; Regalado et al., 2006; Wang et al., 2007; Pereira et al., 2011; Feng and Christopher, 2013). Continental "brown clouds" are well-known globally as an effect of biomass burning, which contributes to huge environmental and climatic problems (Ramanathan et al., 2005, 2007). Recently in China, due to the elevated living standards of the rural poor, crop residues, such as wheat straws and corn stover, have been burned to clear land. This burning emits a high number of pollutants, such as CO_2, CO, CH_4, NOx, NH_3, NMOCs, black carbon, and organic carbon (BC and OC), and particulate matter (PM) (Li et al., 2007; Yang et al., 2008), which causes severe air pollution (Tang et al., 2013; Tao et al., 2013). Winter wheat is mainly planted in North China; thus, open burning mostly occurs in this region (32–41°N, 111–120°E) (Fig. 1) in June when the wheat is harvested (Huang et al., 2012). In addition, North China is a densely populated area with a huge amount of anthropogenic emissions from industrial production and vehicle exhaust (Zhang et al., 2009; Zhao et al., 2012). Thus, the combination of pollutants from biomass burning and the background emissions in North China results in regional or urban heavy haze pollution episodes with high particle

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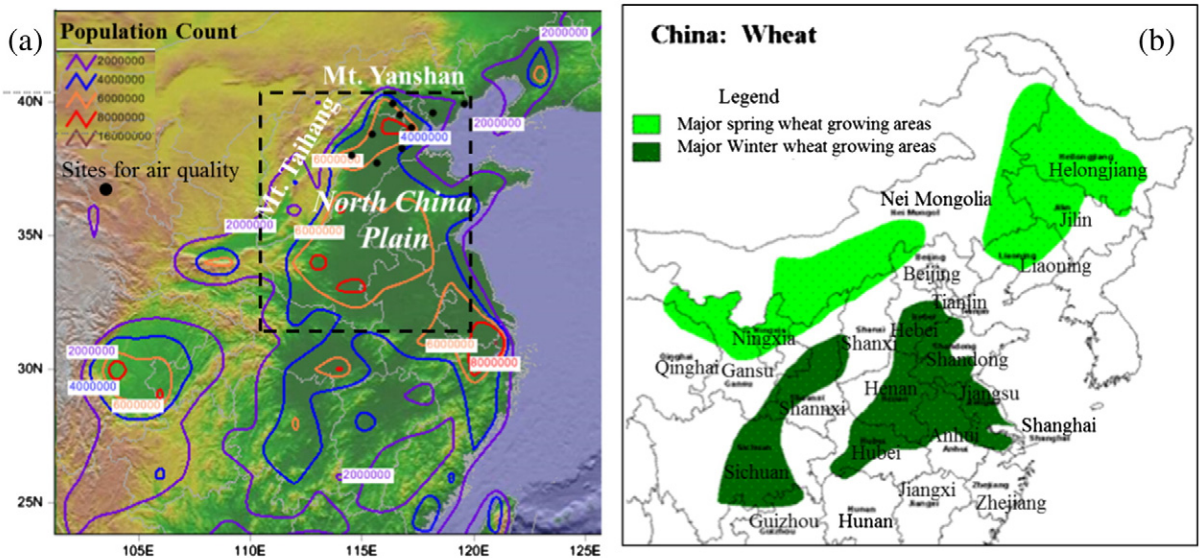

Fig. 1. (a) Topography, population count, and main cities for air quality monitoring over the North China Plain. The population count is for the year 2000 as provided by the NASA Socioeconomic Data and Applications Center (SEDAC) (http://sedac.ciesin.columbia.edu/data/set/gpw-v3-national-identifier-grid). (b) Major winter wheat growing areas (http://www.pecad.fas.usda.gov/highlights/2006/10/ch_30oct2006/).

concentrations and low visibility when the weather conditions are unfavorable for dispersion (Huang et al., 2012). The region in the piedmont plain has particularly poor air quality under prevailing southerly winds because it is blocked by mountains to the north and west (Duan et al., 2004; Li et al., 2008, 2010).

Agricultural burning has been prohibited by the Chinese government in recent years (http://www.gov.cn/zwgk/2007-06/14/content_648934.htm, http://www.gov.cn/zwgk/2013-05/27/content_2411933.htm). Specifically, stricter management was implemented in 2008 for Beijing and its surrounding provinces due to the Olympic Games. However, the effects of the recent burning ban are still unknown over North China, and the relationship between agricultural burning and aerosol loading over North China also needs to be investigated. An increased number of aerosols in the fine or accumulation mode was found during wildfires (Li et al., 2008), and chemical species had unimodal size distributions during burning (Park et al., 2013). High-level $PM_{2.5}$, OC, EC, K^+, and Cl^- were observed in the local wheat burning period (Duan et al., 2004; Li et al., 2014). However, few studies have considered the detailed chemical compositions of size-segregated aerosols in urban areas where aerosols are influenced by mixed burning emissions and high urban/industrial emissions. This lack of information may cause more deviations to the regional climate and chemical models for June.

Thus, this paper investigates the spatial–temporal variations of biomass burning in the croplands in June during the wheat harvest season in the North China using MODIS fire retrieval products to evaluate the effect of the burning ban policy. Furthermore, this research identifies the relationship between open burning and regional aerosol loading using MODIS aerosol optical depth (AOD) products and explores the characteristics of the chemical compositions of size-segregated aerosols influenced by wheat straw burning in an urban region with high haze pollution.

2. Data and method

2.1. Satellite data, PM10 data, and meteorological data

Satellite remote sensing technology provides an effective means for the large-scale and real-time monitoring of biomass burning (Ichoku et al., 2012; Feng and Christopher, 2013; Hyer et al., 2013). The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra (crosses the local equator at 0:30 AM) and Aqua (crosses the local equator at 1:30 PM) satellites with 36 spectral bands (0.41–4 m) at three different spatial resolutions (250 m, 500 m and 1 km) and a scanning width of 2330 km provides twice daily coverage of North China. Active fire information was retrieved using MODIS data (Giglio et al., 2003). In this paper, fire point data obtained from the MODIS Fire Information for Resource Management System (FIRMS), which is operated by the NASA/GSFC Earth Science Data and Information System (ESDIS) and has been applied widely for analyzing the influence of biomass burning (Wang et al., 2013). Wildfire variations under cloud-free conditions are analyzed over space and time in June during the wheat harvest season in North China from 2005 to 2012. The intensity, scale, and burning time of the fires may influence the fire retrieval results, which produces variable confidences for fire points. Thus, as introduced by MODIS Collection 5 Active Fire Product User's Guide (Giglio, 2013), this confidence estimate, which ranges between 0% and 100%, is used to assign one of the three fire classes (low-confidence fire (0–30%), nominal-confidence fire (30–80%), or high-confidence fire (80–100%)) to all fire pixels within the fire mask. The fire counts with complete confidence and confidence $\geq$80 have similar variations in June (2005–2012), as shown in Fig. 6. Thus, all fire points are used in our paper. To better elaborate the variations of agricultural burning, the land cover information based on MODIS MCD12Q1 Collection 5.1 product from 2005 to 2012 with a resolution of 500 m was used to remove wildfires which were