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A high-resolution air pollutants emission inventory in 2013 for the Beijing-Tianjin-Hebei region, China

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HIGHLIGHTS

- An updated high-resolution emission inventory of 2013 for the BTH region is established.
- Facility-based emissions are calculated for power and key industries sources.
- The spatial distribution of emission is investigated.
- The emission inventory is evaluated by uncertainty analysis.

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ABSTRACT

We developed a high-resolution Beijing-Tianjin-Hebei (BTH) regional air pollutants emission inventory for the year 2013. The inventory was established using a bottom-up approach based on facility-level activity data obtained from multiple data sources. The estimates from the BTH 2013 emission inventory show that the total emissions of SO_2, NO_X, $PM_{2.5}$, PM_{10}, CO, NMVOC, NH_3, BC, and OC were 2,305, 2,686, 1,090, 1,494, 20,567, 2,207, 623, 160, and 254 Gg, respectively. The industry sector is the largest emissions source for SO_2, NO_X, $PM_{2.5}$, PM_{10}, CO, and NMVOC in the BTH region, contributing 72.6%, 43.7%, 59.6%, 64.7%, 60.3%, and 70.4% of the total emissions, respectively. Power plants contributed 11.8% and 23.3% of the total SO_2 and NO_X emissions, respectively. The transportation sector contributed 28.9% of the total NO_X emissions. Emissions from the residential sector accounted for 31.3%, 21.5%, 46.6% and 71.7% of the total $PM_{2.5}$, NMVOC, BC and OC emissions, respectively. In addition, more than 90% of the total NH_3 emissions originate from the agriculture sector, with 44.2% from fertilizer use and 47.7% from livestock. The spatial distribution results illustrate that air pollutant emissions are mainly distributed over the eastern and southern BTH regions. Beijing, Tianjin, Shijiazhuang, Tangshan and Handan are the major contributors of air pollutants. The major NMVOC species in the BTH region are ethylene, acetylene, ethane and toluene. Ethylene is the biggest contributor in Tianjin and Hebei. The largest contributor in Beijing is toluene. There is relatively low uncertainty in SO_2 and NO_X emission estimates, medium uncertainty in $PM_{2.5}$, PM_{10} and CO emission estimates, and high uncertainties in VOC, NH_3, BC and OC emission estimates. The proposed policy recommendations, based on the BTH 2013 emission inventory, would be helpful to develop strategies for air pollution control.

1. Introduction

Rapid economic growth in China has led to severe air pollution, which causes air pollution-related problems, such as smog and haze. The Beijing-Tianjin-Hebei (BTH) region is one of China's most developed regions as well as one of the regions experiencing the most severe air pollution problems. Air quality monitoring data released by the Ministry of Environmental Protection show that the average $PM_{2.5}$ concentration for the BTH region in 2013 was 106 μg/m^3, which is 47% higher than the national average, and the number of heavy air pollution days was over 70 (China Environmental State

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Communique, 2013). In September 2013, the China State Council released the Action Plan for Air Pollution Prevention and Control (APAPPC). The goal of the APAPPC is to improve the air quality of the entire country, particularly in key regions, including the BTH region, Yangtze River Delta (YRD) region and Pearl River Delta (PRD) region. For the BTH region, there are specific targets set in the plan, such as reducing $PM_{2.5}$ level by 25% based on 2012 level and controlling the annual average $PM_{2.5}$ concentration in Beijing under 60 $\mu g/m^3$ (APAPPC). Policy makers and researchers are facing formidable challenges in forming effective strategies for air quality management to achieve these goals.

Air pollutants emission inventories are essential for understanding air pollution emission sources and facilitate the development of effective strategies for air pollution prevention. Researchers and policy makers have focused on emission inventories in the past decades. Several emission inventories have been developed for China. Inventories have been developed on the national scale (Streets et al., 2003; Zhang, 2005; Ohara et al., 2007; Zhang et al., 2009), for an individual source (Zhao et al., 2008; Lei et al., 2011a; Lu et al., 2011b), and for a specific pollutant (Zhang et al., 2007; Wei et al., 2008; Fu et al., 2008; Su et al., 2011b; Zhao et al., 2013). In recent years, major developed regions have been affected by air pollution. Regional joint prevention and control of air pollution has become an important air pollution control strategy for China. Many regional emission inventories have been developed. Fu et al. (2013) established an emission inventory in 2010 for 25 cities in the YRD region, and Huang et al. (2011) estimated the emissions of 16 major cities in 2007 for the YRD region. Zheng et al. (2009) developed a high-resolution emission inventory in 2006 for the PRD region. However, for the BTH region, the majority of previous studies have only focused on an individual pollutant or developed on the province scale. Zhou et al. (2015) established an ammonia emission inventory for the BTH region in 2010. Su et al. (2011a) established an emission inventory for non-methane volatile organic compounds in 2008. Wang et al. (2003) established an emission inventory for biogenic volatile organic compounds for Beijing in 2003. Zhao et al. (2012b) established an emission inventory on province level for 8 provinces in Huabei region, which contains BTH region. No previous studies have provided a comprehensive and detailed emission inventory for the BTH region. Furthermore, because factory- and facility-level activity data are difficult to access in China, the majority of the previous studies have used the emission estimation methods depended on province-level statistical data. As a result, it is difficult to allocate emissions to specific sources, making it difficult to meet the requirements of air quality simulation or to develop pollution control measures. Along with the implementation of the APAPPC, the BTH region would develop several specific air pollution emission control measures and have stricter air pollution emission standards. Therefore, an updated and high-resolution air pollutants emission inventory with knowledge of NMVOC speciation of the BTH region is critical as the basis for policy development and evaluation.

In this study, a comprehensive emission inventory for the BTH region in 2013 was developed based on facility-level activity data obtained from multiple sources. The pollutants analyzed were SO_2, NO_X, $PM_{2.5}$, PM_{10}, CO, NMVOC, NH_3, BC, and OC. The emissions were distributed into 3 km $\times$ 3 km resolved grids to describe the spatial characteristics of air pollutant emissions in the BTH region. Section 2 describes the methodology and data sources. The results for sectoral emissions, spatial distributions, NMVOC speciation, and uncertainties assessment are presented in Section 3. The implications and future improvements are also discussed.

2. Data and methodology

2.1. General methodology

The BTH region is located in northern China and includes Beijing, Tianjin and 11 cities in Hebei, for a total of 13 cities (see Fig. 1). The BTH region is one of the most economically developed regions in China. In 2013, it represented 2.3% of the national territory and 8.0% of the population, generated 10.9% of the total national GDP, and owned 13.0% of the nation's vehicle fleet (China National Statistics Yearbook, 2014). Moreover, it is also the region with the worst air pollution in China. In 2013, the annual average $PM_{2.5}$ concentration in the BTH region was 106 $\mu g/m^3$. In this study, the BTH region was set between latitudes 36.05N-42.62N and longitudes 113.46E-119.85E.

A bottom-up approach was adopted in this study to develop a high-resolution emission inventory for the BTH region in 2013. This method has been developed and validated by our previous study (Zheng et al., 2017). We used the same method to compile a complete emission inventory over the BTH region. The emission sources in our inventory were divided into five major sectors: power, industry, residential, transportation and agriculture. These five sectors were further subdivided by fuel type, product type and technology. These sectors were treated as point, nonpoint and mobile sources with corresponding methods for emission estimation.

Power and industry sectors were treated as point sources. The number of point sources considered in this study was 12,461, which include most of the boilers and major emission facilities used in power plants, heating plants, iron and steel factories, cement factories, coking factories and other industries. The point source emissions were estimated based on detailed facility-level investigation data using Equation (1):

$$E_{i,s} = \prod_{n} A_i F_{i,s} \left(1 - \eta_{i,n,s}\right), \tag{1}$$

where A is the activity data, F is the uncontrolled emission factor, η is the removal efficiency, and the subscripts i, s, and n represent the facility, air pollutant type (i.e., SO_2, NOx, $PM_{2.5}$, PM_{10}, CO, NMVOC, NH_3, BC and OC) and type of air pollution control device, respectively.

The residential, non-road transportation and agriculture sectors, which are diffuse sources without identifiable stacks, were treated as nonpoint sources and estimated at the province level using Equation (2):

$$E_{j,k,m,s} = A_{j,k} X_{j,k,m} F_{j,k,m,s} \sum_{n} \left(Y_{j,k,m,n} \times \left(1 - \eta_{n,s}\right)\right), \tag{2}$$

Where X is the fraction of activity rates contributed by a specific technology, Y is the penetration of a specific pollution control technology, and the subscripts j, k and m represent sector, fuel or product and technology, respectively. The remaining parameters are the same as in Equation (1).

On-road transportation sector was considered as mobile sources. The method established by Zheng et al. (2014) was adopted. In this study, and the on-road transportation emissions for each city were estimated using the 2013 data (e.g., vehicle numbers, fuel use and emission factors). The emissions from motorcycles were also included in this work, where provincial emissions were estimated and then allocated to city based on vehicle ownership.