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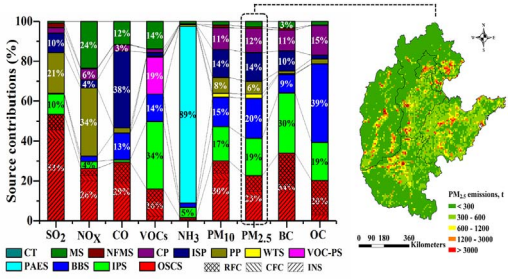
A regional high-resolution emission inventory of primary air pollutants in 2012 for Beijing and the surrounding five provinces of North China

Huanjia Liu[a,b], Bobo Wu[a,b], Shuhan Liu[a,b], Panyang Shao[a,b], Xiangyang Liu[a,b], Chuanyong Zhu[b,c], Yong Wang[a,b], Yiming Wu[a,b], Yifeng Xue[a,d], Jiajia Gao[b,e], Yan Hao[a,b], Hezhong Tian[a,b,*]

[a] State Key Joint Laboratory of Environmental Simulation & Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China
[b] Center for Atmospheric Environmental Studies, Beijing Normal University, Beijing 100875, China
[c] School of Environmental Science and Engineering, Qilu University of Technology, Jinan 250353, China
[d] National Engineering Research Center of Urban Environmental Pollution Control, Beijing Municipal Research Institute of Environmental Protection, Beijing 100037, China
[e] Department of Air Pollution Control, Beijing Municipal Institute of Labour Protection, Beijing 100054, China

GRAPHICAL ABSTRACT



(CT = crematoria, MS = mobile sources, NFMS = nonferrous metal smelting plants, CP = cement plants, ISP = iron and steel plants, PP = power plants, WTS = waste treatment sources, VOC-PS = VOCs product-related sources, BBS = biomass burning sources, IPS = industrial processes sources, PAES = primary ammonia emission sources, OSCS = other stationary combustion sources (including residential fuel consumption, commercial fuel consumption, industrial non-point sources), RFC = emissions from residential fuel consumption, CFC = emissions from commercial fuel consumption, INP = emissions from industrial non-point sources).

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A high resolution regional emission inventory of typical primary air pollutants (PAPs) for the year 2012 in Beijing and the surrounding five provinces (BSFP) of North China is developed. It is compiled with the combination of bottom-up and top-down methods, based on city-level collected activity data and the latest updated specific emission factors for different sources. The considered sources are classified into 12 major categories and totally 36 subcategories with respect to their multi-dimensional characteristics, such as economic sector, combustion facility or industrial process, installed air pollution control devices, etc. Power plant sector is the dominant contributor of NO_x emissions with an average contribution of 34.1%, while VOCs emissions are largely emitted from industrial process sources (33.9%). Whereas, other stationary combustion sources represent major sources of primary $PM_{2.5}$, PM_{10} and BC emissions, accounting for 22.7%, 30.0% and 33.9% of the total emissions, respectively. Hebei province contributes over 34% of the regional total CO emissions because of huge volume of iron and steel production. By comparison, Shandong province ranks as the biggest contributor for NO_x, PM_{10}, $PM_{2.5}$, SO_2, VOCs and OC. Further, the BSFP regional total emissions are spatially distributed into grid cells with a high resolution of 9 km × 9 km using GIS tools and surrogate indexes, such regional population, gross domestic product (GDP) and the types of arable soils. The highest emission intensities are mainly located in Beijing-Tianjin-Tangshan area, Jinan-Laiwu-Zibo area and several other cities such as Shijiazhuang, Handan, and

* Corresponding author. State Key Joint Laboratory of Environmental Simulation & Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China.
E-mail address: hztian@bnu.edu.cn (H. Tian).

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Zhengzhou. Furthermore, in order to establish a simple method to estimate and forecast PAPs emissions with macroscopic provincial-level statistical parameters in China, multi-parameter regression equations are firstly developed to estimate emissions outside the BSFP region with routine statistics (e.g. population, total final coal consumption, area of cultivated land and possession of civil vehicles) using the software 1stOpt. We find the estimated PAPs emissions of 31 provinces show close correlation with the well-recognized MEIC inventory. This high resolution multi-pollutants inventory provides necessary input data for regional air quality models that could help to identify and appoint the major influence sources, better understand the complex regional air pollution formation mechanism, and benefit for developing the corresponding joint prevention and control policies of regional complex air pollution in North China.

Abstract

1. Introduction

In recent years, extreme air pollution events have occurred frequently in China, especially in Beijing and the surrounding five provinces of North China (BSFP, including Beijing, Tianjin, Hebei, Shanxi, Shandong and Henan province). The BSFP region is a part of mid-eastern China located between 31° N and 43° N latitude dwelled with a huge population of over 334 million, an entire GDP (gross domestic product) of around RMB 14.91 trillion (equivalent about USD 2.4 trillion) in 2012 (NBSC, 2013). Previous studies demonstrated that the BSFP region center with the capital city of Beijing is one of the regions experiencing the most severe air pollution problems (Gao et al., 2014, 2015; Lee et al., 2015; Lelieveld et al., 2015; Li et al., 2015; Sun et al., 2016; Tao et al., 2016; Yang et al., 2016). Large volume of various primary air pollutants (PAPs) emissions due to intensive industrial manufacturing activities and huge fossil fuel consumption for industrial and domestic uses in this region have already caused a series of environmental problems, such as high-occurrences of heavy haze episodes, ground-level photochemical smog, acid deposition and climate change (Sun et al., 2015; Yang et al., 2016: Cao et al., 2016). In addition to environmental impacts, the air pollution associated with human activities has posed seriously negative impacts on human health (Betha et al., 2014). A cooperative study used a global atmospheric chemistry model to analyze the relationship between premature mortality and outdoor air pollution, and it indicated that outdoor air pollution led to about 3.3 million premature deaths per year worldwide, predominantly in Asia, especially in the BSFP region of China (Lelieveld et al., 2015). Indeed, the frequent occurrence of severe atmospheric pollution episodes in the BSFP region have captured worldwide great attention (Lin et al., 2016). Therefore, it is of great importance to ascertain the quantities, concentration, sources and spatial distribution characteristics of PAPs in BSFP region. The integrated high-resolution and source-specific emission inventory of BSFP region can not only help the scientific community to better understand the emission characteristics, but also guide the policymakers to formulate and implement accurate and effective atmospheric control management policies.

A high-resolution emission inventory of multiple air pollutants can provide a reliable pollutants emission database which can be used to probe the contribution of regional and sectoral emission sources and to drive regional meteorology-chemistry coupled air quality models (such as WRF/CMAQ, WRF/Chem, WRF/CAMx, etc.) (Tan et al., 2016; Liu et al., 2017). Some developed countries have begun to establish their national emission inventories, such as the UK National Atmospheric Emission Inventory (NAEI), the US National Emission Inventory (NEI), and the Australian National Pollutant Inventory (NPI). Further, the global emission inventories of PAPs have been developed in previous studies (Bouwman et al., 1997; Junker and Liousse, 2008; Pacyna et al., 2006; Winijkul et al., 2015). In order to control urban ambient SO_2 and NO_X concentration as well as regional acidic pollutants, researchers have firstly paid much attention to emission of SO_2 and NO_X in the late 1990's (Hao et al., 2002; Li et al., 1999; Tian et al., 2007). In recent years, emission inventories of several air pollutants for China have been developed, such as CO (Wang et al., 2005), NH_3 (Huang et al., 2012), VOCs (Bo et al., 2008; Wei, 2009), SO_2 (Li et al., 1999; Tian et al., 2013b), NO_X (Hao et al., 2002; Shi et al., 2014; Tian et al., 2011), hazardous trace elements (Hg, As, Pb, Ni, Sb, etc.) (Cheng et al., 2014; Tian et al., 2014, 2015; Wang et al., 2009, 2010; Zhang et al., 2015; Zhou et al., 2015a). In addition, other emission inventories were dedicated specifically to single source category, like power plants (Tian et al., 2013a, 2014), vehicles (Cai and Xie, 2013; Guo et al., 2007), crematories (Xue et al., 2016), cement plants (Lei et al., 2011; Hua et al., 2016a), iron and steel industry (Wang et al., 2016), biomass burning (Cao et al., 2010; Zhang et al., 2013), industrial boilers (Xue et al., 2016), municipal solid waste (MSW) incineration (Tian et al., 2012). Regional emission inventories in China such as Yangtze River Delta, the Pearl River Delta and Beijing-Tianjin-Hebei were established for regional air pollution controlling and policymaking (Fu et al., 2013; Zhang and Tang, 2009; Zhou et al., 2015b). Besides, large-scale national (MEIC) and even continental (TRAC-P, INTEX-B, REAS) inventories were also developed (Zhang et al., 2009; Streets et al., 2003; Ohara et al., 2007).

In the past decade, in order to successfully hold the several major international events, including 2008 Beijing Olympic Games, 2014 Asia-Pacific Economic Cooperation (APEC) Summit in Beijing, and 2015 Beijing IAAF World Athletics Championships and the massive parade commemorating the 70th anniversary of World War II, multiple short-term campaigns on air quality control measures/pollution mitigation measures have been carried out. These short-term practices demonstrated that long distance transportation of air pollutants emissions from the surrounding provinces have ascertain impacts on Beijing's local air quality (Hua et al., 2016b; Wang et al., 2017; Yang et al., 2016). However, a comprehensive and high-resolution inventory of PAPs which is specially developed for the large BSFP region in recent years has not been reported.

In the context of reinforced mitigation measures against severe air pollution, this study presents an integrated high-resolution and source-specific emission inventory of anthropogenic activities. It is dedicatedly developed for BSFP region of China for the year 2012, and includes sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), non-methane volatile organic compounds (VOCs), ammonia (NH_3), particulate matter of diameter smaller than or equal to 10 μm (PM_{10}), particulate matter of diameter smaller than or equal to 2.5 μm ($PM_{2.5}$), black carbon (BC) and organic carbon (OC) emissions. The emission inventory is further spatially disaggregated into grid cells with a high resolution of 9 km × 9 km and the underlined uncertainties involved in the emission estimates are quantitatively analyzed with Monte Carlo simulation. Moreover, in order to establish a simple method to estimate and forecast PAPs emissions with macroscopic provincial-level statistical parameters (e.g. population, total final coal consumption, area of cultivated land and possession of civil vehicles) in China, multi-parameter regression equations are firstly developed to estimate emissions outside the BSFP region with routine statistics by using the software 1stOpt.