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Recent developments of anthropogenic air pollutant emission inventories in Guangdong province, China

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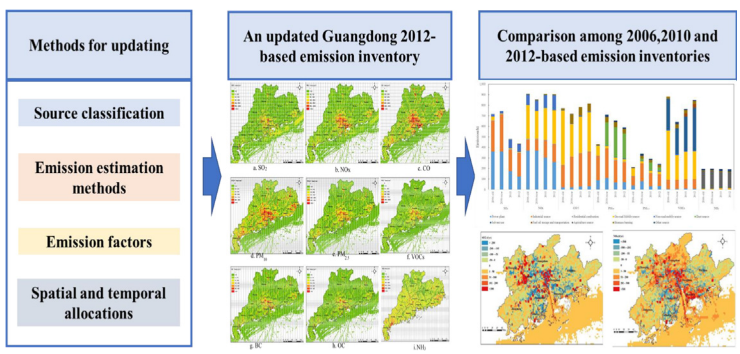
HIGHLIGHTS

- Summarized recent updates of Guangdong's regional emission inventory
- Established an updated Guangdong 2012-based high-resolution emission inventory
- Compared 2006, 2010 and 2012-based emission inventories
- Reduced uncertainties of the 2012-based emission inventory compared to previous inventories

GRAPHICAL ABSTRACT



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ABSTRACT

Emission inventory (EI) requires continuous updating to improve its quality and reduce its uncertainty. In this study, recent developments on source classification, emission methods, emission factors and spatial-temporal surrogates in the Guangdong regional anthropogenic emission inventory are presented. The developments include: ~40 additional emission sources in a re-classified source classification system, >50 improved spatial and temporal surrogates, 85% of local/domestic emission factors used, and updated estimation methods of on-road mobile, marine, and solvent use sources. The developments were updated to the recent 2012-based high resolution emission inventories, and their results were compared with previous 2006- and 2010-based emission inventories. The results indicated: (1) The total SO_2, NO_x, CO, PM_{10}, $PM_{2.5}$, BC, OC, VOCs and NH_3 emissions in 2012 were 777.0 kt, 1532.2 kt, 7305.4 kt, 1176.4 kt, 480.9 kt, 54.2 kt, 79.9 kt, 1255.1 kt and 584.1 kt, respectively, for Guangdong province, with higher emission densities observed in the central PRD region. (2) No great changes on source structures were found among three years, but their contributions varied. (3) SO_2, PM_{10} and $PM_{2.5}$ emissions showed downward trends, likely a result of strict control measures on power plant and industrial combustion sources. (4) NO_x emission exhibited relatively stable levels in 2010 and 2012, but contributions from industrial, on-road and non-road mobile sources increased. (5) VOCs emissions showed an upward trend, mainly resulting from dramatically increased light-duty passenger car population and solvent use. (6) Spatial and temporal allocations were updated with constant improvements of spatial and temporal surrogates. (7) Uncertainty ranges of emission estimates were reduced, indicating that the 2012-based PRD regional EI are more reliable. The work shown in this study can be a reference example for other regions to continuously update their emission inventories.

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1. Introduction

Accurate air pollutant emission inventories (EI) with high spatial and temporal resolution can help better understand source characteristics and improve the accuracy of air quality forecasting that can influence policy-making (Frey et al., 1999; Streets et al., 2003; Zheng et al., 2009). Characterizing and quantifying air pollutant emissions from various sources as well as reducing their uncertainties have been important research topics among academic communities as well as critical management needs for governmental agencies at both home and abroad (e.g. Streets et al., 2003; Zhang and Streets, 2008; Zheng et al., 2012; Kurokawa et al., 2013).

Air pollution EI and source apportionment studies have been a growing field of research throughout China in recent years. National and highly resolved regional and city-level emission inventories (e.g. Zhang, 2005; Zheng et al., 2009; Wang et al., 2012; Ramaswami et al., 2017) have been developed and used to support air quality modeling and policy assessments to reduce pollution levels (e.g. Zhang et al., 2008; Wang et al., 2010; Tao et al., 2015; Chen et al., 2017). The Ministry of Environmental Protection of China has issued guidebooks for compiling air pollution EIs (MEP, 2014). Currently, compiling EIs has become of high interest to local governments, particularly in areas that suffer from severe air pollutions (Pan et al., 2015; Tang et al., 2012; Qi et al., 2017).

The Pearl River Delta (PRD) region, located in Guangdong province, one of the most developed regions in China, was the first area to experience severe air pollution (Zhong et al., 2013). Since 2000, the local government has published PRD regional EIs for the base year of 1997, 2001 and 2003 using a top-down approach to support mitigation efforts. In 2009, Zheng et al. (2009) developed a 2006-based PRD regional EI with a bottom-up methodology. This inventory was the first high-resolution EI in this region that met the requirements for regional air quality modeling and has been widely used in various model applications and policy decisions (Li et al., 2013; Liu et al., 2013). Meanwhile, the methodological framework demonstrated in Zheng et al. (2009) has been widely adopted in other regional high-resolution EIs (Tang et al., 2012; Chen et al., 2014; Wang et al., 2016). Although the work done by Zheng et al. (2009) has been well recognized and has been widely applied in support of air quality modeling (>240 citations since published in 2009), there are some discrepancies which need continuous updates and improvements. For example, due to a lack of knowledge about source characteristics, some major sources were missed or misclassified. In addition, emissions of some pollutants like NH_3, BC and OC were not estimated in Zheng et al. (2009). Second, there are also high uncertainties in emission estimates and temporal and spatial surrogates for some sources and pollutants, limited by data availability and estimation method. Third, arising from a lack of local and domestic emission studies, only about 60% domestic emission factors were used to compile the 2006-based EI by Zheng et al. (2009), which may also yield high uncertainty in emission estimates.

Apart from limitations in methods and data availability, there are other factors that may bring significant changes in EIs and source characteristics for this region. For example, local and central governments have enacted a series of air pollution control polices since 2006 (Zhong et al., 2013), which would likely reduce emissions of some sources and pollutants. Some high-emitting and high consumption industries were forced to move out of the PRD regions to non-PRD areas or other provinces in the past decade (Yin et al., 2017), which may bring changes in the spatial distributions and structures of emissions that weren't accounted for in the inventory. Third, there was a 114% increase in GDP and 90% increase of vehicle population in this region during 2006–2012 (Bureau of Statistics of Guangdong, 2013). This rapid economic development and increased vehicle population would inevitably lead to emission changes. Considering these issues, there is a need for developing a timely emission inventory that uses updated emission factors, improved estimation methods, and updated activity data for the PRD region and Guangdong province.

In this paper, we (1) introduce recent developments in Guangdong or PRD regional high-resolution EI; (2) present an updated 2012-based high resolution EI for the Guangdong province (including the PRD region) with the use of these new developments; and (3) compare and analyze how emissions have evolved from 2006 to 2012. The purpose is not only to summarize recent developments in EI studies in the PRD region, but also to show how a regional EI can continuously be improved. This work can provide a reference to reduce uncertainties in emission estimates while maintaining high spatial and temporal emission estimates for other regions.

2. Data and methodology

2.1. Study domain

The study domain used in this work was extended from the PRD region used in the 2006-based inventory to the entire Guangdong province. We did this because the industry transfer policy moved high emitting industries to the non-PRD region of Guangdong province and to other provinces since 2008. Also, super-regional transport has contributed to air pollution in the PRD region, particularly to ozone and $PM_{2.5}$ (Deng et al., 2008; Zheng et al., 2010). Thus the 2010 and 2012-based EIs were developed over the whole Guangdong province, as shown in Fig. 1. There are approximately 106 million people and the total land area is 179,800 km^2, about 2% of China's total land area. The study domain includes 21 prefecture-level cities (including Guangzhou and Shenzhen which is two sub-provincial cities). Among these cities, Guangzhou, Shenzhen, Zhuhai, Dongguan, Jiangmen, Foshan, Zhongshan, and parts of Huizhou and Zhaoqing belong to the PRD region.

2.2. Developments of emission inventory in Guangdong province

In this section, we highlight the developments and updates made in the 2010 and 2012-based EI studies compared to previous EI work in this region (Zheng et al., 2009; He et al., 2011; Zheng et al., 2012; Pan et al., 2015) in terms of source classification, emission estimation methods, temporal and spatial allocation, and uncertainty analysis. The detailed updates and developments are presented in the following sections and summarized in Tables 1–3, respectively.

2.2.1. Sources classification

With a better understanding of emission source characteristics in the PRD region and Guangdong province, ten major anthropogenic source categories were identified as Level I sources, and two major developments are made in the source classification for the 2012-based EI compared to the previous work (Zheng et al., 2009; He et al., 2011; Zheng et al., 2012) (see Table S1 in the Support Information). First, some important emission sources were reclassified. For example, all fossil fuel combustion sources (including power plant, industry combustion and residential combustion source) except mobile sources were classified into the Stationed Combustion Sources sector as the Level I category. Biomass burning was upgraded to Level I due to its importance in regional air pollution (Jayarathne et al., 2014; Zhu et al., 2016). Industry was divided into the industry combustion, industry process, and industrial solvent use sources. Non-road mobile was upgraded to Level I since it was one of the most important contributors, especially in the coastal Guangdong province (Zhang et al., 2010).

Second, new sources have been added into the 2012-based source classification system. These new sources including: (1) Plastics manufacturing, synthetic rubber, food production and other process-related industries were added into the Industrial Process source; (2) Pesticide use and man-made panel production, and other industries using solvents were added into the Solvent Use source; (3) Light duty diesel vehicle, heavy duty gasoline truck, bus and taxi were added into the On-road Mobile source; (4) Fugitive dust sources including construction