Science of the Total Environment 573 (2016) 1–10

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

An AIS-based high-resolution ship emission inventory and its uncertainty in Pearl River Delta region, China

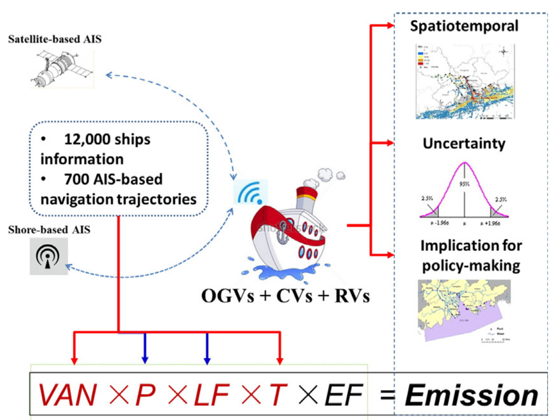
Cheng Li [a], Zibing Yuan [a], Jiamin Ou [a], Xiaoli Fan [a], Siqi Ye [b], Teng Xiao [a], Yuqi Shi [a], Zhijiong Huang [a], Simon K.W. Ng [c], Zhuangmin Zhong [a], Junyu Zheng [a,*]

[a] School of Environment and Energy, South China University of Technology, Guangzhou 510006, China
[b] Guangdong Environmental Monitoring Center, Modiesha Street, Haizhu District, Guangzhou, 510308, China
[c] Civic Exchange, 23/F, Chun Wo Commercial Centre, 23-29 Wing Wo Street, Central, Hong Kong

HIGHLIGHTS

- A comprehensive database with >12,000 ships information was established.
- A yearlong AIS dataset was used to develop time-in-mode and spatiotemporal surrogates.
- A bottom-up approach was used to estimate emissions from major ship source sectors.
- The ECA region covered over 80% of the total ship emissions in the PRD region.
- Application of AIS data reduced uncertainty in ship emission estimates.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 June 2016
Received in revised form 30 July 2016
Accepted 30 July 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Ship emission inventory
Automatic identification system
Spatiotemporal characteristics
Pearl River Delta
Emission control area

ABSTRACT

Ship emissions contribute significantly to air pollution and impose health risks to residents along the coastal area. By using the refined data from the Automatic Identification System (AIS), this study developed a highly resolved ship emission inventory for the Pearl River Delta (PRD) region, China, home to three of ten busiest ports in the world. The region-wide SO_2, NO_X, CO, PM_{10}, $PM_{2.5}$, and VOC emissions in 2013 were estimated to be 61,484, 103,717, 10,599, 7155, 6605, and 4195 t, respectively. Ocean going vessels were the largest contributors of the total emissions, followed by coastal vessels and river vessels. In terms of ship type, container ship was the leading contributor, followed by conventional cargo ship, dry bulk carrier, fishing ship, and oil tanker. These five ship types accounted for >90% of total emissions. The spatial distributions of emissions revealed that the key emission hot spots all concentrated within the newly proposed emission control area (ECA) and ship emissions within ECA covered >80% of total ship emissions in the PRD, highlighting the importance of ECA in emissions reduction in the PRD. The uncertainties of emission estimates of pollutants were quantified, with lower bounds of −24.5% to −21.2% and upper bounds of 28.6% to 33.3% at 95% confidence intervals. The lower uncertainties in this study highlighted the powerfulness of AIS data in improving ship emission estimates. The AIS-based bottom-up methodology can be used for developing and upgrading ship emission inventory and formulating effective control measures on ship emissions in other port regions wherever possible.

* Corresponding author.
E-mail address: zheng.junyu@gmail.com (J. Zheng).

http://dx.doi.org/10.1016/j.scitotenv.2016.07.219
0048-9697/

1. Introduction

Rapid economic growth has fueled significant progress of shipping industry in China, resulting in great energy demand and significant emissions of air pollutants (Endresen et al., 2003, 2007; Corbett et al., 2007; Dalsøren et al., 2007). Since 1980s, control measures have been focused on land-based emission sources and their emissions have been greatly reduced (Zhong et al., 2013; Zhao et al., 2013). Ship emissions, a significant contributor to ambient pollutants in coastal areas (Ye, 2014), were however largely ignored (Lu et al., 2010; Zhao et al., 2013). In order to understand the impact of ship emissions on air quality and to formulate effective control measures for ship emissions, a detailed understanding on the emission characteristics and the development of a high-resolution emission inventory for ship sources are needed.

As an international manufacturing hub with a dense waterway network, the Pearl River Delta (PRD) region in southern China shows booming shipping industry. According to *Global Port Development Report* (Shanghai International Shipping Institute, 2015), Shenzhen, Hong Kong and Guangzhou were among the top ten ports worldwide in terms of container throughput in 2015. The PRD as a port cluster was bound to contribute the largest throughput in the world. In 2015, the PRD was designated as a vessel emission control area (ECA) by the Ministry of Transport of China (2015). A series of stringent control measures have been or will be implemented according to a prescribed schedule. To better describe emission characteristics, efforts have been paid to develop ship emission inventories around some ports in this region, e.g. Hong Kong (Yau et al., 2012; Ng et al., 2013) and Shenzhen (Ye et al., 2014; Yang et al., 2015). However, this kind of port-level emission inventory cannot support regional air quality modeling to quantify their impacts because of limited coverage and low spatial and temporal resolutions. Development of a high-resolution region-wide emission inventory is therefore needed in the PRD.

In recent years, considerable efforts have been paid and technological advancements have been achieved to improve the accuracy of ship emission estimates, such as on-board survey of fuel consumption and action (Cooper, 2003; Hulskotte and Denier, 2010; Song, 2014) and field-testing and reviewing of ship emission factors (Todd and Andrew, 2007; Zhang et al., 2015; Song, 2015). The Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM) was also developed which combined ship characteristics and activity-based emission factors to establish ship emission inventory in North America (Wang et al., 2007; ICF international, 2009; Corbett, 2010; Bandemehr et al., 2015). Automatic Identification System (AIS) data was increasingly applied to improve activity-based estimation such as load factor (Winther et al., 2014) and to develop more accurate spatiotemporal surrogates to replace empirical waterway network (Wang et al., 2008; MARIN, 2010, 2011; Yang et al., 2015). Despite improved techniques in information collection, current studies on ship emissions are still subject to a number of limitations. First, most studies targeted on ocean-going vessels (OGVs), while local ship emissions from rivers and coastal areas were ignored (Agrawal et al., 2008; Yau et al., 2012; Merk, 2014; Tan et al., 2014). Secondly, although the representativeness of spatiotemporal surrogates had been improved by AIS density distribution data (Jalkanen et al., 2009, 2011; Gutierrez et al., 2012), the influence from traffic routes of ship types and activity modes on ship emissions were lack of consideration. Furthermore, the uncertainties in ship emission estimates were generally analyzed in qualitative ways (Fu et al., 2012; Ng et al., 2013) and only the uncertainties from emission factors (Todd and Andrew, 2007; Entec UK Limited, 2010) were considered. It calls for a quantitative assessment of the uncertainties in ship emissions arising from both emission factor and activity level data.

In this study, we aimed to establish a high-resolution ship emission inventory for the PRD region by using a bottom-up approach for the base year of 2013. Main engine power, load factor, time-in-mode, fuel consumption and other ship activities data were collected from the refined data from AIS, field survey and local statistics. The estimated emissions covered all kinds of OGVs, coastal vessels (CVs) and river vessels (RVs) within PRD waters, except the transit ships which sailed through without hotelling in ports of the region (excluding Hong Kong). Emissions distribution maps and temporal surrogates with ship types and activity modes were developed. The uncertainties of ship emission inventory were quantitatively estimated, and implications for control policies were discussed.

2. Data and methods

2.1. Study domain and ship categorization

The study domain was set within the latitude of 21.54 to 24.53°N and the longitude of 111.55 to 115.61°E, covering all ports with >2100 berths, major fairway network and the proposed ECA in the PRD region, as shown in Fig. 1. Nine port groups in this study domain are administrated by local Maritime Departments (MDs), namely Guangzhou, Shenzhen, Huizhou, Zhuhai, Dongguan, Foshan, Zhongshan, Zhaoqing and Jiangmen.

This study estimated ship emissions from OGVs as well as CVs and RVs in PRD waters. According to the characteristics of the ship administration system in China, we developed a new approach in identifying the ship type. OGVs are certified by both International Maritime Organization (IMO) and Maritime Mobile Service Identify (MMSI), therefore IMO number and MMSI code were used to define OGVs, while CVs only have MMSI codes for identification. As all kinds of local ships are also registered in MD, we used MD registration number to identify RVs. Under these three categories, vessel calls were further divided into 84 sub-categories by ship type and dead weight tonnage (DWT). Details for source classification are listed in Table 1. It was noted that the ship types in port statistics in MD were not classified based on DWT. To deal with that, an adaptive sampling period statistic approach based on real-time AIS data was adopted by considering port sizes and wharf structure to remove errors in individual sampling period.

To investigate and evaluate the impact of cruising speed on emissions, ships were alternatively categorized according to their operational modes, i.e. fairway cruise, slow cruise, maneuvering and hotelling (Entec UK Limited, 2010; Ng et al., 2013), as shown in Table SI-1.

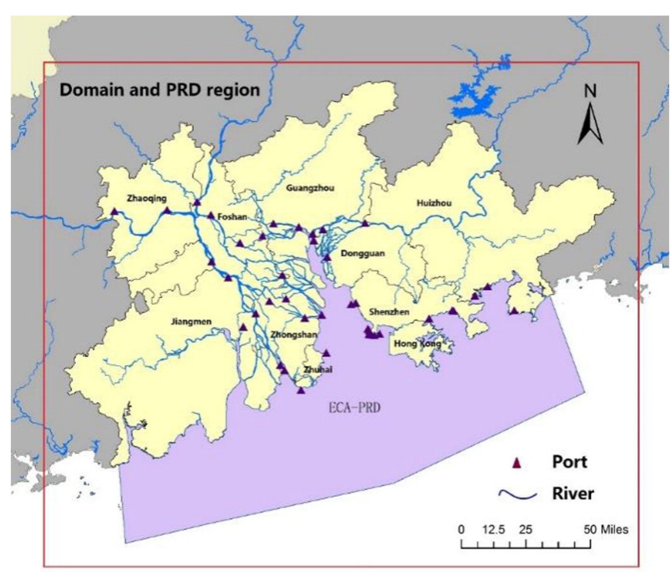


Fig. 1. Waterway and port distribution map of the research domain in the PRD region.