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Real-world emissions of inland ships on the Grand Canal, China

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HIGHLIGHTS

- Distance-based and fuel-based emission factors of gaseous and PM from 7 inland ships were measured using PEMS.
- Average distance-based emission factors of CO, HC and PM for manoeuvring mode are higher than those for cruise mode.
- NO_x in this study is nearly twice of estimated Tier 1 standard limit (in unit of g kg^{-1} fuel).
- Distance-based emission factors of four pollutants are higher with the increase of engine loads.

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ABSTRACT

Ship emissions are widely recognized as a relevant source of the total air pollution and have a remarkable impact on air quality of the sea, territorial waters and coastal areas. To assess this impact, various emission models have been developed to calculate the emission inventory of ship based on ship activity data. However, few studies in China have collected the emission factors of local ship which are decisive factors in accurate assessment of ship emission inventory. This study intends to obtain emission data of inland ships on the Grand Canal of China by conducting on-board emission tests. We measured CO, HC NO_x and PM emission from 7 inland ships of different engine powers, and derive distance-based and fuel-based emission factors on the basis of the cruise and manoeuvring (including port departure and port arrival) operating modes. The results show that average distance-based emission factors of CO, HC and PM for manoeuvring mode are higher than those for cruise mode. For NO_x, average distance-based emission factors for cruise mode are higher than those for port arrival mode but lower than those for port departure mode. Particular number (PN) distribution analysis indicates that larger amounts of small size PM ($D_p < 0.01$ μm) appeared on manoeuvring mode, which can affect regional air quality and human health. The average fuel-based emission factor of NO_x in this study is 1.4–4.3 times higher than those in on-board studies. When compared with estimated Tier 1 standard limit (in unit of g kg^{-1} fuel), NO_x in this study is nearly twice of Tier 1. The higher NO_x emission indicates that stricter emission strategies and policies should be implemented to control ship emission in China. It is noticeable that distance-based emission factors of four pollutants are higher with the increase of engine loads.

1. Introduction

With the rapid growth of water-borne commerce, marine activities, particularly those in Asia, have risen dramatically over the past decade (Yau et al., 2012; Streets et al., 2000). However, various research studies which attempt the estimation of global emissions from shipping indicate that ship emission is one important source of the total air pollution worldwide (Poplawski et al., 2011; Marmer and Langmann, 2005; Tzannatos, 2010a; Hulskotte and Denier van der Gon, 2010; Butt, 2007; Corbett, 2003; Howitt et al., 2010). IIASA's research (Cofala et al., 2007) on exhaust pollutants from global shipping estimated that the levels of NO_x and PM emissions are 24.3 and 1.9 million tons, respectively. Moreover, part of shipping emissions occur in coastal areas, thus dispersing directly onto the mainland and causing environmental problems that affect both human health and ecosystems (Lonati et al., 2010; Miola and Ciuffo, 2011). Due to close proximity to the container port, approximately 3.8 million people risk direct exposure to shipping and port-related emissions in Hong Kong (Galbraith et al., 2008).

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Numerous studies on the evaluation of the impact of atmospheric shipping emissions on air quality at the local scale and on climate at the regional scale have been reported in literature over the last decade. Some studies have focused on emission measurements for ships and the estimation of the magnitude of shipping emissions to the atmosphere. Van der Zee et al. (2012) by measured Nitrogen oxides (NO and NO_2) and ultrafine particles (particle number (PN) concentration) at five measuring sites in Amsterdam, illustrate that ship exhausts have an impact on air quality near houses along waterways. Other works have addressed the characterization of emissions from ships and their impact of ports on adjacent urban areas by means of dispersion modeling. Studies in Sweden (Isakson et al., 2001), Los Angeles (Minguillón et al., 2008), Turkey (Kesgin and Vardar, 2001), Alaska (Mölders et al., 2010), Greece (Tzannatos, 2010b), Vancouver (Lu et al., 2006) and Scotland (Marr et al., 2007) assessed the contribution of ports to measured concentrations of air pollution in cities.

In China, some papers focus on the impacts of ships emission characteristics on air quality. Zhao et al. (2013) indicates that ship traffic has a non-negligible contribution on ambient levels of fine particles on Shanghai port. Meanwhile, other studies focus on emission inventory of ships in China. Yang et al. (2007) develops an air pollutant emission inventory for marine ships in the Shanghai Port in 2003 based on the marine activity statistical data from 1998 and other experts' previous studies. Zhang et al. (2010) develops the Pearl River Delta regional ship emission inventory by categories with the use of appropriate estimation and the collection of activities data. Yau et al. (2012) develops a detailed maritime emission inventory for ocean-going vessels (OGVs) in Hong Kong by a network model based on a bottom-up activity-based network model. Unfortunately, emission factors used in the three papers are taken directly from previous European and US ship emission database, which might not reflect the local conditions and performance of technologies. Therefore, it is of great importance to improve the understanding of the emission characteristics of ships in China for accurate estimation of ships emissions inventory.

The objective of this study is to improve the understanding of inland ships emission levels in China by acquiring their real-world emission factors on the Grand Canal. The Grand Canal, the longest artificial waterway in the world, is more than 3500 km long. Excavated over 1400 years ago, it links Hangzhou and Beijing, and has strongly been benefiting regional development since its accomplishment (Fig. 1(a)). In modern era, the Grand Canal still plays an important role in supplying water for irrigation, transporting cargoes, and recreational activities. The Grand Canal offered ample facility to transport food and goods from south to north in the early times. Meanwhile, it also greatly improved the administration and defense of China as a whole, strengthening the economic and cultural intercourse between north and south, and contributing to the prosperity of the area along the route (Yang et al., 2012; Wang, 2012).

In this work, we measured tailpipe of CO, HC, NO_x, and PM emissions of ships using a portable emission measurement system (PEMS), then analyzed emission levels of inland ships on the basis of the measurement results, and generated distance-based and fuel-based emission factors for ships. We also compared fuel-based emission factors with those presented in previous studies, and compare these emission factors under different engine loads.

2. Experimental section

2.1. Study area

Sunan Canal, a part of the Grand Canal, is one of the busiest transporting cargo waterways in China. This section of the canal crosses the south of Jiangsu Province from Zhenjiang to Suzhou, with its length 211 km and over 80 m width (Fig. 1(b)). As a result of the rapid economic development of the Yangtze River Delta region and subsequently intensive use of marine transportation, more concerns have been focus on the air quality along the waterway.

In this study, typical sailing routing was selected to have on board emission test, which are about 14 km from Zhenjiang to Danyang.

2.2. Portable emission measurement system

A combined on-board emission test system was employed to measure the emissions from inland ship under real driving conditions. This system has two main parts: SEMTECH-DS and Electrical Low Pressure Impactor (ELPI). SEMTECH-DS is able to test instantaneous emissions of gaseous pollutants, such as CO_2, CO, HC, and NO_x. This equipment is used for on-road emission monitoring of diesel vehicles, and uses heated flame ionization detector (HFID) for total hydrocarbon (THC), non-dispersive ultraviolet (NDUV) analyzer for nitric oxide (NO) and nitrogen dioxide (NO_2), non-dispersive infrared (NDIR) for CO and carbon dioxide (CO_2) measurements (Liu et al., 2011). In addition, a temperature/pressure sensor and a GPS device were included to monitor environmental situation and instantaneous location and speed. A whole-exhaust, mass flow measurement device (SEMTECH EFM) built by Sensors Incorporated, was used to measure the exhaust flow rate based on pitot tube technology. To

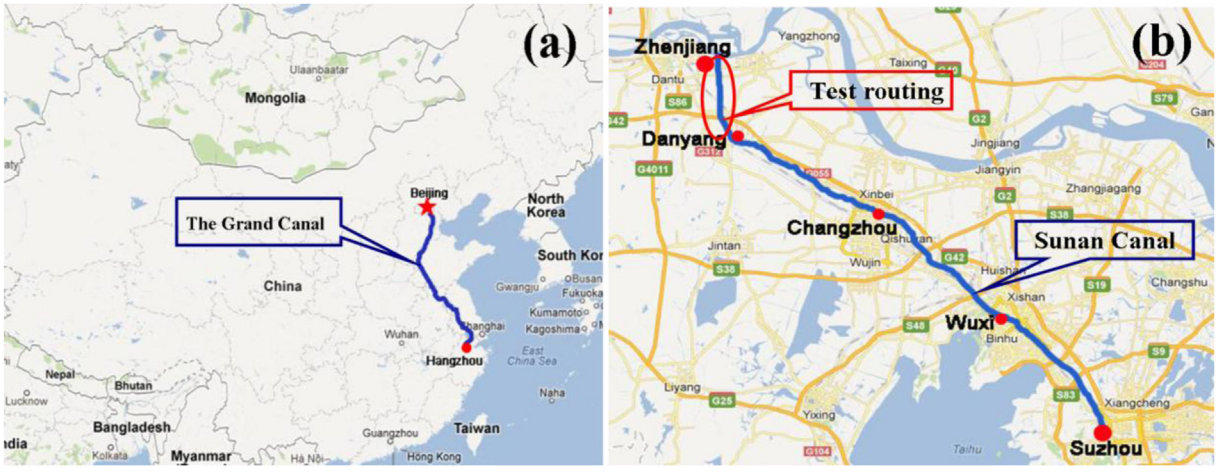

Fig. 1. (a) The territory of the Grand Canal of China, (b) The detail of test routing.