The impact of inland ship emissions on air quality

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Abstract

With the rapid economic growth, China's ports and shipping industry has achieved unprecedented development, while aggravating air pollution. Taking the Yangtze River in the region of Nanjing as research area, a ship emission inventory was compiled based on real-time information received from Automatic Identification System (AIS) signals, ship-related basic data provided by China Classification Society (CCS) database and relevant data from field research. The total estimated ship emissions have been calculated in the observation area from September 2018 to August 2019 for NO_x, SO_2, PM_{10} and $PM_{2.5}$.

Introduction

The main emissions discharged by ships include NO_x, SO_2, PM, volatile organic compounds (VOCs) and black carbon (Moldanová et al., 2009). Due to the large number of domestic inland river vessels, limited legislation for emission control and no monitoring infrastructure, information on inland river vessel emissions is very limited.

Objective

In this study, we aim to compile a ship emission inventory for the Jiangsu section of the Yangtze River using a bottom-up approach based on AIS data. We calculated the emissions of each vessel. Emission characteristics such as ship type, monthly variation and spatial distribution will be discussed.

The objectives of this study are:

- To explore the impact of emissions from inland waterway vessels on the surrounding air quality.
- To study the spatial and temporal characteristics of pollutants emitted from inland waterway vessels.

Methods

To estimate shipping emissions from the Yangtze river, we adopt the AIS method to obtain high-resolution ship information and emission factors. Equation (1) given below will be used for calculating the emissions from a single ship based on its main power (Fan et al., 2016).

$$E = P \cdot L \cdot f_{LLAM} \cdot f_{EF} \cdot f_F \cdot T \quad , \qquad (1)$$

where

E is the mission from the main engine;

P is the main engine power of the ship;

L is the main engine load factor;

f_{LLAM} is the low load adjustment multiplier of the main engine;

f_{EF} is the emission factor;

f_F is the fuel correction factor;

T is the sailing time.

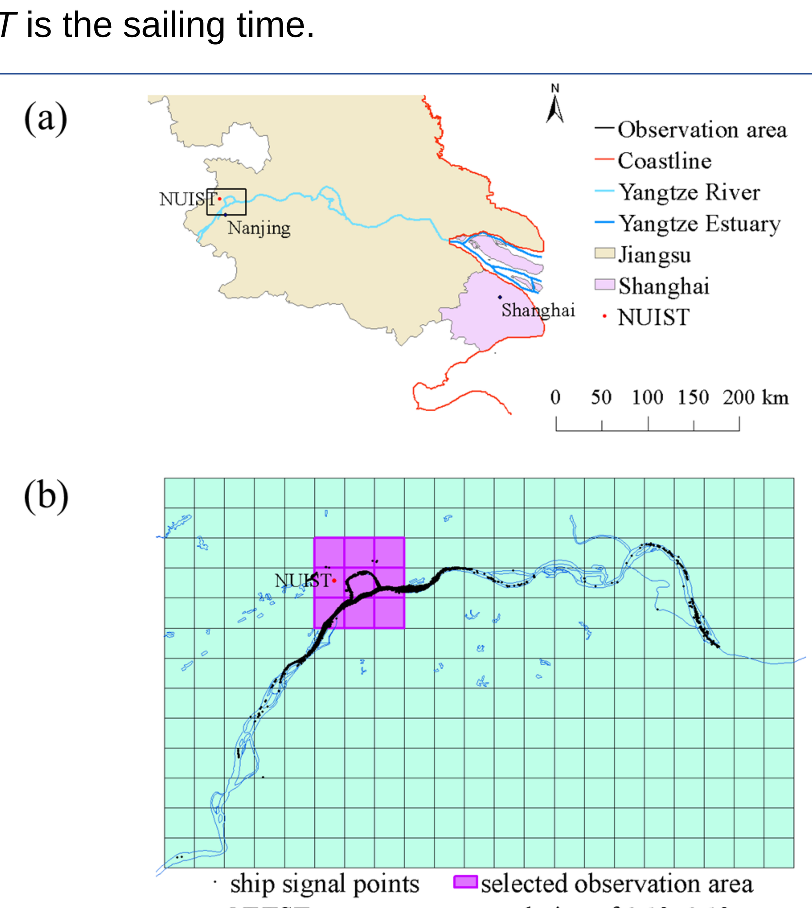

Figure 1. The map of the study area. (a) Schematic map of the Jiangsu section of the Yangtze River. (b) Schematic diagram of the ship signals that can be received by AIS with a resolution of 0.1°×0.1°. The black dots are the ship locations received by AIS, which show the range of the AIS receiver. The purple box is the selected observation area within the longitude of 118.65 °E to 118.95° E and the latitude of 32.05°N to 32.25° N.

Since the Engine power is missing in the AIS data, we develop a method to relate the engine power to the ship type, length and speed.

The supplied power of a ship engine is proportional to the surface area times the cubic of the speed: $P_{ship} \sim A_s v^3$. The actual speed of ship is obtained by correcting the speed with the actual river flow. Figure 2 shows that the actual ship speed after correcting for water speed tends to be rather constant throughout the year.

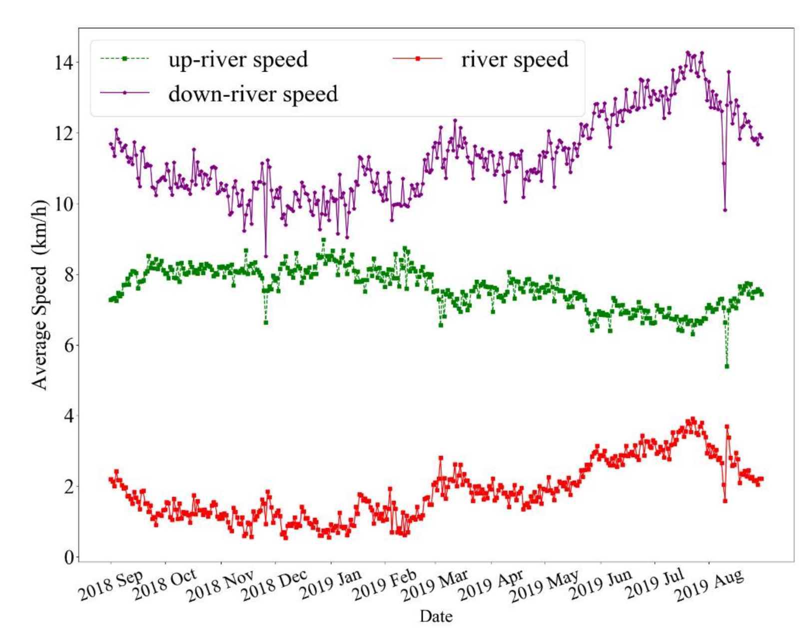

Figure 2. Average daily river speed (red line) and ship speed over a year. Up-river speed and down-river speed of the ships are coming directly from AIS data. The river speed is based on the average difference between downstream speed and upstream speed.

Results & Discussion

Emissions from cargo ships are higher than other types of ships, followed by tankers and tugs (Figure 3). The cargo ships contribute more than 58% of emissions of all species in the Nanjing section of the Yangtze River. This is because cargo ships are the dominant vessel type in this region and the number of can account for 81% of the total.

Ship emissions peaked in summer due to the high river speed and therefore more engine power (proportional to v^3) needed for upstream ships. From November to February, the emissions have been lower (Figure 4), possibly because the water flow of the Yangtze River is lower at this period and ship activities during Spring Festival are reduced. In February and March, we see that pollutant emissions increased due to the increase in the number of ships. This is closely related to the resumption of factory work and human activities after the holiday.

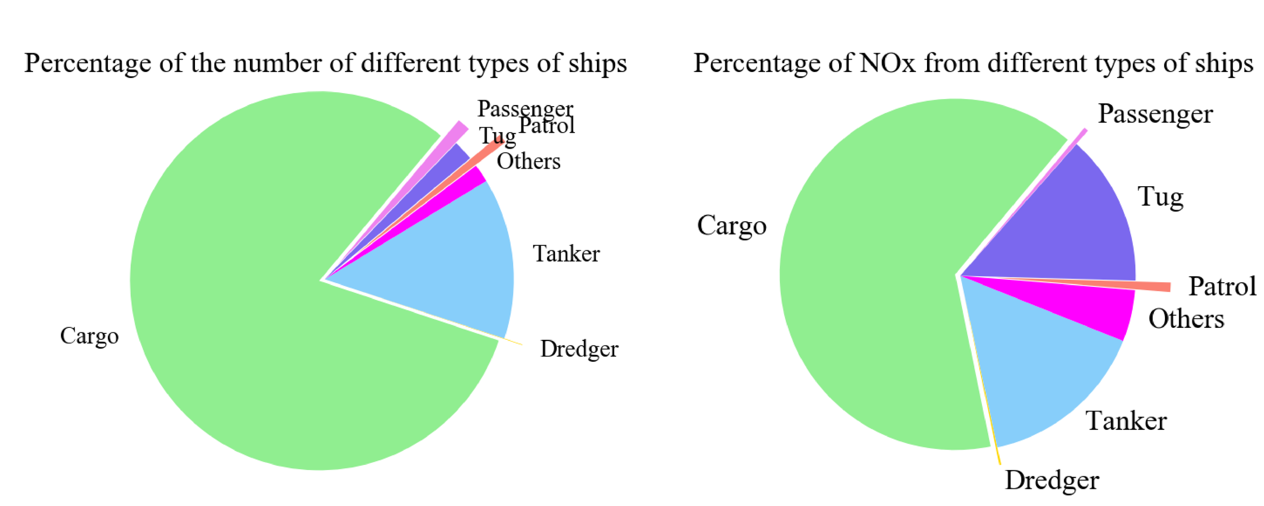

Figure 3. Emissions from different ship categories

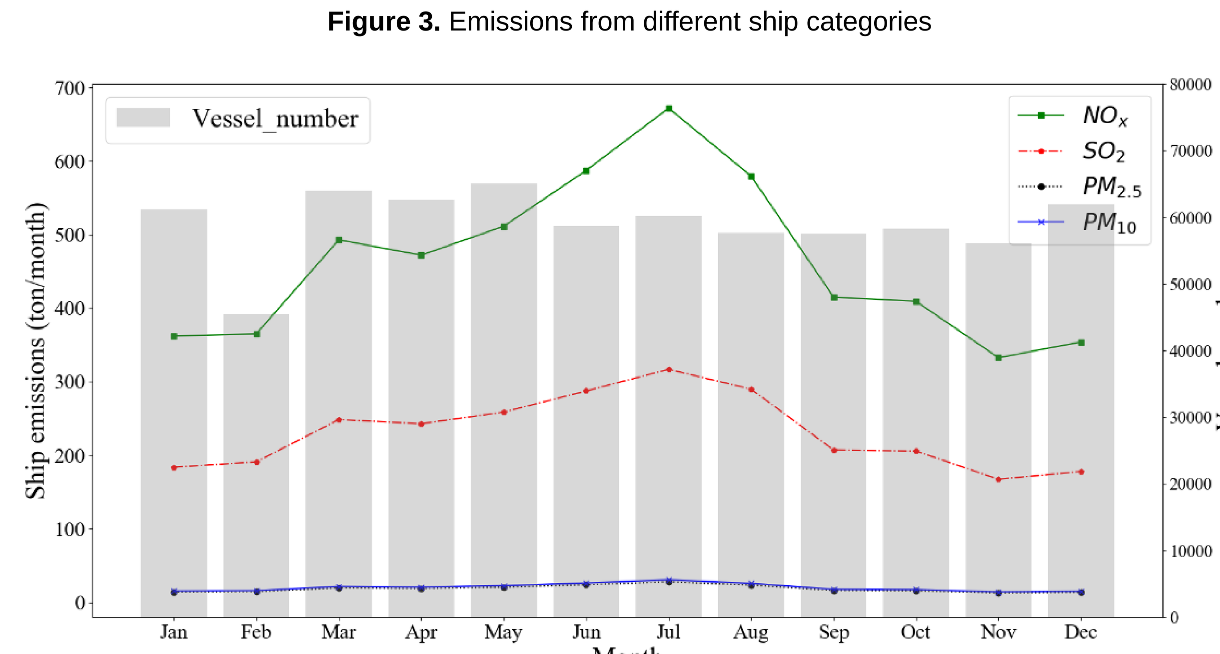

Figure 4. Monthly changes in the emissions from inland river ships. The grey bar chart is a graph of the number of ships.

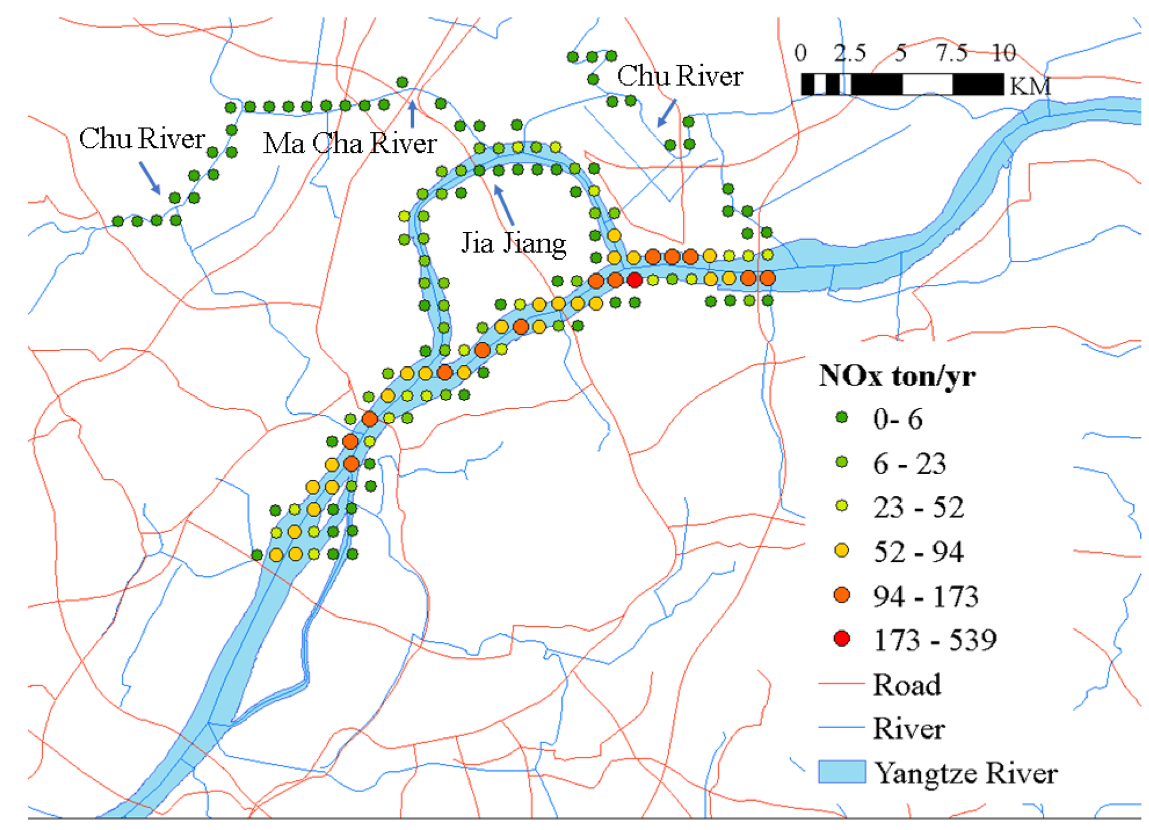

Figure 5. Spatial distribution of ship emission based on AIS data in the observation area with a resolution of 0.01°×0.01°. The observation area also has a slightly wider branch of the Yangtze River, known as the Jia Jiang. On these rivers, ship emissions are much smaller than the emissions from ships on the main Yangtze River.

The emissions of NO_x, SO_2, PM_{10} and $PM_{2.5}$ from ships on the observation area were **6679, 3341, 292 and 265 ton per year**, respectively (Figure 5). Ship emissions in the observation area are mainly concentrated in the main channel of the Yangtze River. Due to the limitations of the observation range, we propose a new river length-based method to estimate ship pollution. In Figure 6 we extrapolated our emissions per km to the river outside our study area assuming that the ship density and speed is rather constant in this region.

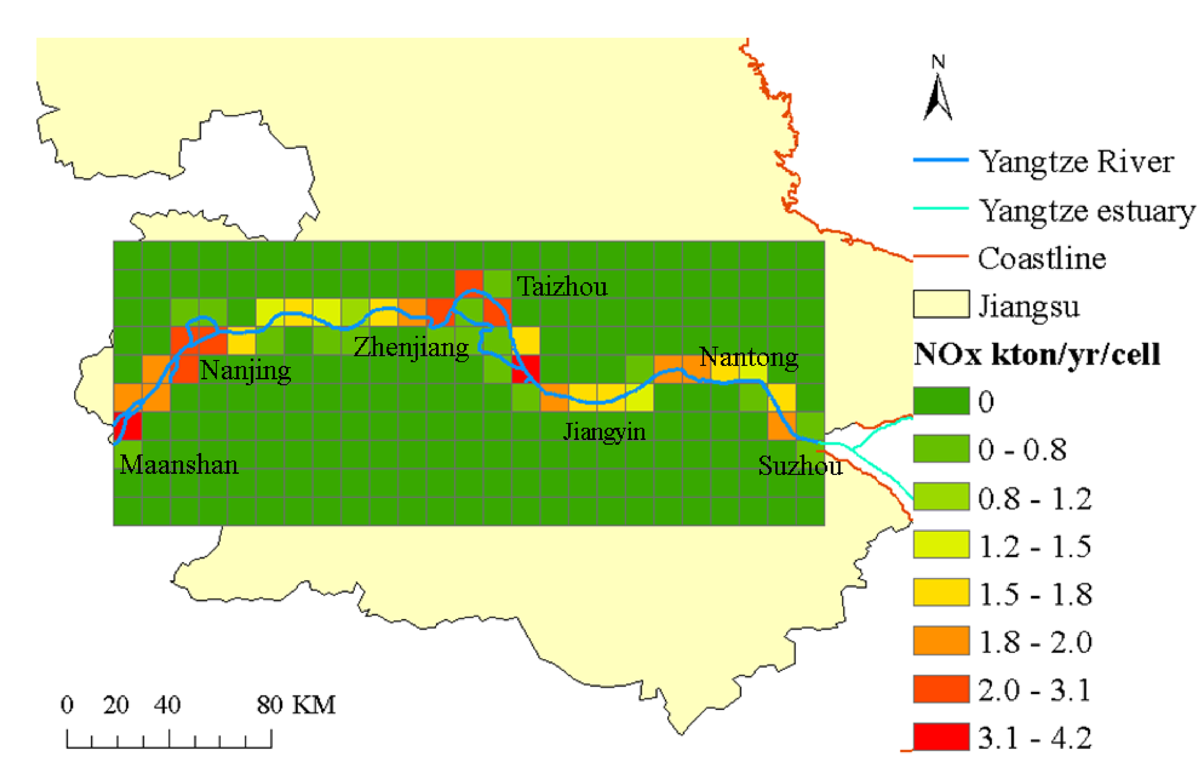

Figure 6. Spatial distribution of NO_x emissions in the Jiangsu section of the Yangtze River

Conclusions

- The ship number sharing rate of various types of ships is uneven, with **cargo ships** accounting for 81%, while patrol ships and dredger ships accounting for only about 1%.
- The monthly changes in air pollutants from ships tend to be consistent, peaking **in summer.**
- Emissions from vessels on the Yangtze River **cannot be neglected** and the inland ship emissions inventory can provide a theoretical basis for legislation on controlling vessel emissions in the inland navigation zone.
- The same method of deriving ship emissions will be used for the port of Rotterdam, to derive the impact of ship emission in this region.

Major References

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