

We thank the reviewers for their helpful comments. We have modified the manuscript as suggested. Below shows our responses to all the comments. The reviewer's comments will be shown in blue while our responses are in black, and changes made to the paper are shown in black block quotes. Unless otherwise indicated, page and line numbers correspond to the original manuscript.

The study of Zhang et al. built a ship emission inventory based on AIS signals and basic ship-related data for YRD region. The results were compared with several other emission inventories to verify reliability of the proposed approach and demonstrate the impact inland ship emissions on densely populated regions along the river.

The topic is interesting, but the publication has major deficiencies, is difficult to follow. In my view it cannot be published in the present form but will need substantial improvements.

Major issues:

1. The title is completely inappropriate. It's named 'The impact of inland ship emissions on air quality'. The title exaggerates the actual research scope seriously. The manuscript is almost entirely about emissions (Introduction, Methods and Discussion) rather than air quality. And the only description of air quality in Line 424-425 seems not correct, because the air pollution such as PM2.5 induced by ship emission also affected by other emission sources and meteorological condition. Therefore, the title should be modified at least. Otherwise, more quantitative study on air quality should be carried out. This study only investigated the Yangzi river- Jiangsu section, which is a short section, also can NOT represent YRD region as well. The title needs to honestly reflect the scope of the work done. The title is too big at present.

Thank you for noticing this issue. Yes, we agree that the title is not appropriate since we focus on the contribution of ship emissions to total emissions.

In lines 424-425 we link the ship NO_x emissions to air pollution as NO₂ is one of the prime components of air pollution (for example reported by the WHO).

It has been specified in both the abstract and the text that the main study area is the Jiangsu section of the Yangtze River and does not represent the YRD region.

Based on the above considerations, we ultimately revised the title to "**Significant contribution of inland ships to the total NO_x emissions along the Yangtze River**".

2. There are many mistakes in the review of the research status and the current situation of ship emission control. The authors need to re-write the literature review to include the most advanced and high quality research.

We thank the reviewer for the remark, but unfortunately the reviewer did not specify his/her concern with the introduction. We have checked the literature review again and added recent literature. The text has been modified.

In lines 35-41:

"... surrounding areas and increased traffic in the connected rivers. **Ship emissions in the YRD are much higher than those in the Bohai Bay and Pearl River Delta (PRD), reaching about 50% of the total emissions in these three regions (Chen et al., 2017; Wan et al., 2020).**

Shipping emissions affecting air quality in the YRD region are mainly within 12 nautical miles of the coastline (Li et al., 2018). They can contribute between 30 % and 90 %, for example, over 75 % of ship-related SO₂ concentrations and 50 % of ship-related PM_{2.5} concentrations (Lv et al., 2018; Feng et al., 2019). The data from the Ministry of Transport of China shows that by the end of 2021, the number of inland river transport vessels is 11.36 million vessels, which is higher than the sum of coastal transport and ocean transport in China (MOT, 2022). As one of the most economically developed regions in the east of China, the Yangtze River Delta (YRD) region is the busiest inland river ship transportation corridor in China. Therefore, we focus on inland river ships..."

In line 54:

"...Georgoulias et al. (2020) firstly combined observations from the TROPOspheric Monitoring Instrument onboard the Sentinel 5 Precursor satellite (TROPOMI/S5P) with AIS data to measure NO₂ plumes that could be detected and attributed to individual ships. In recent years, studies based on the method of combining satellite data with AIS data have been carried out mostly over seas (Kurchaba et al., 2022; Riess et al., 2022) but seldom over rivers."

In line 63:

"...Li et al. (2018) and Wang et al. (2021) showed that the latest control policies have been effective in reducing ship emissions. However, ...

3. The control policy of inland ships is different from that of oceangoing ships. Even for oceangoing ships, China's current control policy is not only in the three major control areas, but for the coastal waters of 12 nautical miles. The author has not quoted the latest research on inland river-related ship emissions.

We added the policies for 2016 to 2019 to the manuscript.

In lines 60-63:

"... because the Ministry of Transport in China started the emission control of ship emissions in 2016(MOT, 2015). Domestic Emission Control Areas (DECAs) were set-up in the waters of Bohai Bay, YRD and PRD to control, for example the sulfur content of the fuel. In addition, equipment with AIS is becoming a mandatory requirement for ships of 100 gross ton and above. By the end of 2018, DECAs were expanded from the major ports to 12 nautical miles outside the coastline. The range of the Yangtze River covered by the DECAs was also raised from the original offshore cities to stretch from Shuifu in Yunnan to Liuhekou in Jiangsu (MOT, 2018). Li et al. (2018) and Wang et al. (2021) showed that the latest control policies have been effective in reducing ship emissions. However, ..."

4. This study assumed that the average sulfur content of marine distillates (MD) of 1.5 % in the study area according to Xu et al. (2019), which was based on the data of 2014. However, this study was implemented from 2018 to 2019. The sulfur content for inland ships was totally different, which makes the results wrong.

Thanks for the advice. We have checked several studies and found the latest information.

Since 2016, authorities have been gradually limiting the sulfur content of marine fuels. Ordinary inland vessels typically use general diesel oil (GDO), while larger inland ships and direct river and sea vessels use Marine fuel oil (MFO). MFO includes residual oil (RO) and marine distillates (MD). The sulfur content requirements for different fuels are shown in Table S2.

For MFO sulfur content not higher than 0.001 % was scheduled to be implemented in January 2019, but actually in October 2018, DECAAs started to response to this policy. Our study was carried in September 2018 to August 2019, the average fuel sulfur content should be well below 1.5 %. The emission factor of NO_x is closely related to the age and rotation speed of the ship's engine, the emission factor of SO₂ directly depends on the sulfur content of the ship's fuel, and the emission factor of PM is more influenced by the sulfur content of the ship's fuel. We revised the fuel correction factor (Table 2). With the modification of fuel correction factor, the NO_x, SO₂, PM_{2.5}, PM₁₀ emitted from ships in Jiangsu section of Yangtze River from September 2018 to August 2019 were 83.5, 0.04, 0.006 and 0.005 kton, respectively. The corresponding text, figures, and tables have been revised in the manuscript.

Using the former average fuel sulfur content of 1.5 % can be assumed to be the emissions of SO₂ and PM from ships in the absence of policy regulations.

We added in lines 152-157:

“... Ordinary inland vessels typically use general diesel oil (GDO), while larger inland ships and direct river and sea vessels use Marine fuel oil (MFO). MFO includes residual oil (RO) and marine distillates (MD). The sulfur content requirements for different fuels are shown in Table S2. The emission factors mentioned above are obtained based on the assumption that marine fuel is heavy oil with a sulfur content of 2.7 % (EPA, 2009). In October 2018, the DECAAs began responding to a new policy that the sulfur content of inland marine fuel cannot be higher than 0.001 % in 2019 (Wang et al. 2021). In our study, the actual inland ship emissions are calculated based on the sulfur content of 0.001 %, for which a fuel correction factor is needed. In addition, we will calculate ship emissions for an average fuel sulfur content of 1.5 % (Xu et al.,2019) for a scenario where the new policy would be absent. The fuel correction factor for each ...”

Table S2. Evolvement of fuel sulfur content requirements in inland rivers.

Fuel type	Year				
	2016	2017	2018	2019	2020
general diesel oil (GDO)	≤0.035 %	≤0.035 %	≤0.005 %	≤0.001 %	
Marine fuel oil (MFO)	residual oil (RO)		0.1-3.5 %		
	marine distillates (MD)		0.1-1.5 %		≤0.001 %

Table 2. Fuel correction factor (f_F) used in this study.

Fuel type	Sulfur content (%)	NO _x	SO ₂	PM _{2.5}	PM ₁₀
Unregulated Marine fuel	1.5 %	0.9	0.56	0.47	0.47
Regulated Marine fuel	0.001 %	0.9	0.0005	0.0007	0.0007

5. The author mentioned "We set up an AIS receiver in Nanjing University of Information Science and Technology (NUIST) to collect ship information including ship position, speed and heading, ship name, ship length and ship type". What's the power threshold for this receiver can receive from ships? What is the percentage of missing signals? With the distance getting farther, there are more missing signals. How to evaluate the emissions of lost ships? More details of the AIS receiver should be presented

Thanks for the detailed questions.

- What's the power threshold for this receiver can receive from ships?

The frequency range of the ship's AIS signal is 161.975 MHz - 162.025 MHz and we use an antenna with a frequency range between 144 MHz and 163 MHz. The receiver is passive and the reception depend mainly on the distance of the ships and meteorological circumstances.

- What is the percentage of missing signals? With the distance getting farther, there are more missing signals. How to evaluate the emissions of lost ships?

Indeed, as the distance gets farther and farther away, more and more signals are lost. However, as stated in the manuscript, the antenna is capable of receiving ship signals within at least a 50 km radius, but we only selected ship signals within a radius of less than 25 km. This is the area where even ships with weak AIS transmitters can be tracked under all conditions. In lines 97-100 we mentioned:

"The black dots in Fig. 1c are an example of the locations of ships according to the AIS signals received in a time interval of 4 hours. It shows that the antenna can receive signals within at least a 50 km radius. A region with a longitude of less than 118.95° E and a latitude of more than 32.05° N was selected as the area where all ships, including those with weak AIS transmitter can be tracked under all conditions."

6. Ship emission is not only related to the length of the river. For example, in some major ports, the emission is large while the length may not high. The author should present more proofs to prove the proposed method that estimates the emission to larger regions based on the length of the river per grid cell. Such as plotting the relationship of emission and the length for the observational area or listing some references.

The extrapolation of our results to the wider region of Jiangsu is based on a few assumptions as mentioned in the manuscript. In our study, the ports were not taken into account, so the

emissions from ships moored in the ports were not considered in this study but were taken into account in the uncertainty analysis.

When moored ships are not considered, ship emissions can be closely related to river length. The spatial distribution of ship pollution in the Jiangsu section of the Yangtze River obtained according to this method is consistent with previous studies (Xu et al., 2019; Zhu et al., 2019).

7. It was not clear that how the 3-4% underestimation in Line 327 be calculated, and except for the emission from the auxiliary engine, the emission from the boiler was also not considered. How much did the boiler emission account for?

As stated in the manuscript, 17 % of the ships in the observation area are in dock every day, and the emissions from this part of the ships are not taken into account. Moreover, the ratio between auxiliary and main engines of ships is about 20-25. 17 % multiplied by the ratio gives an underestimation of emissions.

However, during the navigation of a ship, the main engine and auxiliary engine of the ship are working at the same time. For a moored ship, the main engine stops working. We have neglected the auxiliary engines because of the conflicting numbers in the literature. Based on the study of Weng et al. (2020) in the Yangtze estuary, we estimate the underestimated emissions to be about 12 % due to neglection of the auxiliary engine and boil emissions at berth and underway.

For inland vessels, boiler emissions are much lower and generally not considered.

According to the above discussion, we have revised lines 325 to 327 in the manuscript:

“However, during the navigation of a ship, the main engine and auxiliary engine of the ship are working at the same time. For a moored ship, the main engine stops working. On average, 17 % of the ships in the observational area are in dock every day, and this part of the ship emissions have not taken into account, but the auxiliary engines are still working. Based on the study of Weng et al. (2020) in the Yangtze estuary, we estimate that our emissions show an underestimation of about 12 % because of ignoring the auxiliary engine and boiler emissions at berth and underway.”

8. Almost any sources of emission will account for a large share ratio in the grid where they emit. To illustrate the importance of emissions for inland vessels, the author should compare emissions in specific cities or regions (coastal cities, YRD ...) rather than the selected river grid cells.

Thanks for the suggestion. Comparing to the selected river grid is important because these grid cells miss shipping emissions in the bottom-up inventories.

In addition, we have added the comparison for the Jiangsu province. Since the scope of our study was the Yangtze River section in Jiangsu Province, the total pollutant emissions from ships were compared with the total non-vessel anthropogenic emissions in Jiangsu Province in 2017. SO₂, NO_x, PM₁₀ and PM_{2.5} from ships account for 0.01 %, 5 %, 0.001 % and 0.001 % of the total non-vessel anthropogenic SO₂, NO_x, PM₁₀ and PM_{2.5} in Jiangsu Province, respectively, given by the Multi-resolution Emission Inventory of China (MEIC,

[http://www.meicmodel.org/\).](http://www.meicmodel.org/)

Table S4. Non-ship emissions given by MEIC and estimated ship emissions in the Jiangsu section of the Yangtze River (kton yr⁻¹)

Sectors	SO ₂	NO _x	PM ₁₀	PM _{2.5}
Power	46.6	318.6	65.6	39.7
Industry	235.3	649.4	268.2	174.6
Residential	8.8	24.4	115.7	111.2
Transportation	24.6	545.9	42.4	41.3
Total non-ship emissions	315.3	1538.3	491.9	366.8
Ship emissions	0.04	83.5	0.006	0.005

We added in line 382:

“... in NO_x emission inventories. **When comparing the total ship emissions with the total non-vessel anthropogenic emissions in Jiangsu Province in 2017, NO_x emissions from ships still account for 5 % of the total non-vessel anthropogenic NO_x in Jiangsu Province given by the MEIC inventory (Table S4).**”

9. The author should explain why there was a big difference between JESI and SEIM, especially for SO₂ and PM_{2.5} in Section 4.1. Additionally, in the latest version of SEIM (Wang et al., 2021. Ship emissions around China under gradually promoted control policies from 2016 to 2019), the emissions over inland rivers are all included.

In the manuscript, we added an explanation of the reasons for the big differences between JSEI and SEIM. For the latest version of SEIM, the database is not yet publicly available. Here, we use SEIM v1.0.

In lines 358-359:

“... SEIM has higher values than JSEI for SO₂ and PM_{2.5} because SEIM calculated the emissions for 2017, when only major ports needed to strictly control the sulfur content of marine fuel. The sulfur content of marine fuel was 0.001 % in our study. In comparison, the sulfur content of ocean-going marine fuel in 2017 was about 2.7 %, much higher than that of inland river ship fuel. Ship pollutants that are greatly affected by the sulfur content of marine fuel, such as SO₂ and PM, will be reduced with the reduction of sulfur content. This shows that from 2017 to 2019, the policy was of a great significance for the ship emissions, effectively reducing the emissions of SO₂ and PM. For NO_x emissions both inventories compare remarkably well.”

In line 244:

“... a total of seven species (Liu et al., 2016, 2019). However, emissions over inland rivers, except for the delta region, are not included. **Emissions from ocean-going vessels, coastal vessels and river vessels have been calculated in the latest version of SEIM (SEIM v2.0) (Wang et al., 2021). Here, we use SEIM v1.0, since only this version is publicly available.**”

Smaller issues:

1. Line 183, it should be Figure S1 rather than S2.

We have fixed the text.

“Figure **S1** shows fitted linear relationship between main engine power...”

2. In Figure 9 and Figure 11, why the sharing ratio of JESI is low in some grid of which most part is river?

There are many large factories along the river, such as the Nanjing Iron and Steel Group (https://en.wikipedia.org/wiki/Nanjing_Iron_and_Steel_Group), China Petrochemical Corporation (<http://www.sinopecgroup.com/group/en/gywm/about.shtml>) and Changzhou Xinbei Industrial Park. The pollution emitted by these factories is much larger than that emitted by ships. Therefore, the sharing ratio of JSEI will be small at these grids. For easier understanding, the locations of these plants are posted on the MEIC spatial distribution map.

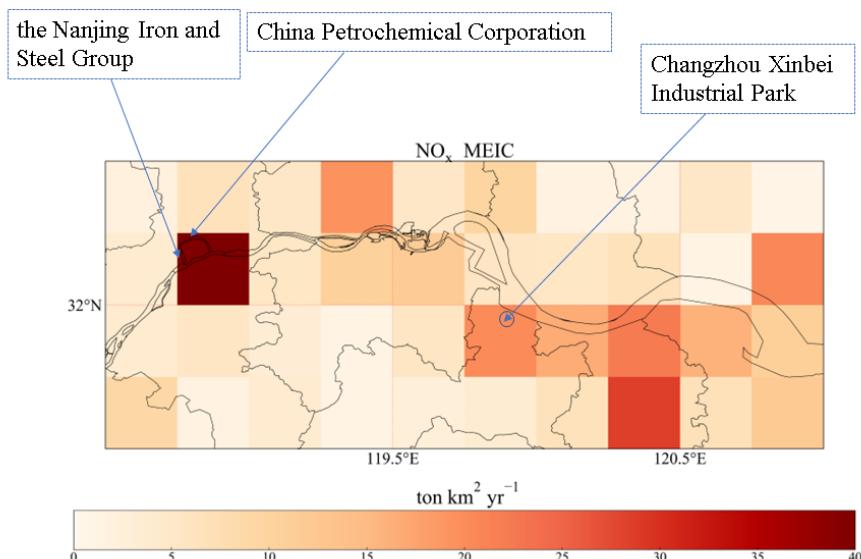


Figure R1. Spatial distribution of NO_x emissions for MEIC. The arrows point to the important industrial locations, the boxes show the name of the industrial complex, and the circle represents the area covered by the factories.

3. Line 379, why the author said “The MEIC grid cells cover a larger area than for DECSO and include more emissions than DECSO”.

As stated in lines 377-379 of the text, the grid of MEIC is within the area of 10-25 km around the river and DECSO is within the area of 5-10 km from the river. Hence the grid cells of MEIC have higher total emissions than those of DECSO. To make it easier to understand, we describe it in a more direct way:

“The MEIC grid cells are larger than the DECSO grid cells and therefore include more

emissions than for DECSO, so the share of ship emissions for MEIC is nearly half of that for DECSO.”

4. In Line 402, the author said “ship emissions accounted for more than 40 % of the total emissions in February, which shows that the pollution caused by ship activities during Spring Festival is quite significant in a time period of lower emissions in general”. However, according to MEIC, the changes in NOx emission caused by the Spring Festival is not significant. Thus, which share is more reasonable, JSEI/(JSEI+SEMI) or JSEI/DECSO. The author should give more proofs to support this sentence.

Our conclusion is based on the following.

- As stated in issue 3, a MEIC grid cell has a larger area and with same ship emissions, the effect on the ratio would be much smaller than for JSEI/DECSO. In this case, the JSEI/DECSO ratio can give us more information on the share of ship emissions in total emissions.
- In terms of monthly variability of the MEIC and DECSO inventories in the river region only, MEIC was relatively constant throughout the year, with no particularly high or low values. This is also mentioned in line 399-400 of the text:

“The JSEI/(MEIC+JSEI) ratio tends to coincide with the monthly variation in ship emissions, as there is no significant monthly variation in emissions of the MEIC inventory.”

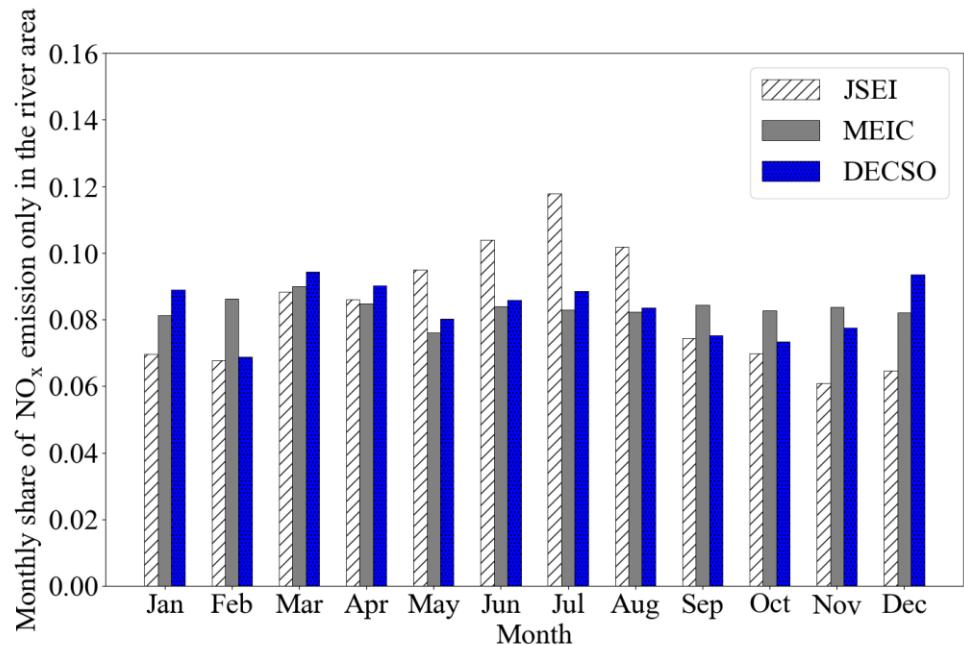


Figure R2. Seasonal cycle of NO_x emissions in the river area only for JSEI, MEIC and DECSO.

- The temporal resolution of the officially released version of SEIM is annual, and therefore, it is impossible to analyze its monthly changes.

5. The format of references should be unified. (Such as in Line 237)

Thanks for pointing this out. In line 237, the format of references is unified.

“... ship NO_x emissions (Zheng et al., 2014). Zheng et al. (2018) and Li et al. (2017) presented more details of...”

References

Chen, D., Wang, X., Nelson, P., Li, Y., Zhao, N., Zhao, Y., Lang, J., Zhou, Y., and Guo, X.: Ship emission inventory and its impact on the PM_{2.5} air pollution in Qingdao Port, North China, *Atmos. Environ.*, 166, 351–361, <https://doi.org/10.1016/j.atmosenv.2017.07.021>, 2017.

Environmental Protection Agency (EPA): ICF International: Current methodologies in preparing mobile source port-related 480 emission inventories, Final Report, April 2009, United States, 2009.

Feng, J., Zhang, Y., Li, S., Mao, J., Patton, A. P., Zhou, Y., Ma, W., Liu, C., Kan, H., Huang, C., An, J., Li, L., Shen, Y., Fu, Q., Wang, X., Liu, J., Wang, S., Ding, D., Cheng, J., Ge, W., Zhu, H., and Walker, K.: The influence of spatiality on shipping emissions, air quality and potential human exposure in the Yangtze River Delta/Shanghai, China, *Atmos. Chem. Phys.*, 19, 6167–6183, <https://doi.org/10.5194/acp-19-6167-2019>, 2019.

Georgoulias, A. K., Boersma, K. F., van Vliet, J., Zhang, X., van der A, R., Zanis, P., and de Laat, J.: Detection of NO₂ pollution plumes from individual ships with the TROPOMI/S5P satellite sensor, *Environ. Res. Lett.*, 15, 124037, <https://doi.org/10.1088/1748-9326/abc445>, 2020.

Kurchaba, S., van Vliet, J., Verbeek, F. J., Meulman, J. J., and Veenman, C. J.: Supervised Segmentation of NO₂ Plumes from Individual Ships Using TROPOMI Satellite Data, *Remote Sens.*, 14, 5809, <https://doi.org/10.3390/rs14225809>, 2022.

Li, C., Borken-Kleefeld, J., Zheng, J., Yuan, Z., Ou, J., Li, Y., Wang, Y., and Xu, Y.: Decadal evolution of ship emissions in China from 2004 to 2013 by using an integrated AIS-based approach and projection to 2040, *Atmos. Chem. Phys.*, 18, 6075–6093, <https://doi.org/10.5194/acp-18-6075-2018>, 2018.

Li, M., Liu, H., Geng, G., Hong, C., Liu, F., Song, Y., Tong, D., Zheng, B., Cui, H., Man, H., Zhang, Q., and He, K.: Anthropogenic emission inventories in China: a review, *Natl. Sci. Rev.*, 4, 834–866, <https://doi.org/10.1093/nsr/nwx150>, 2017.

Liu, H., Fu, M., Jin, X., Shang, Y., Shindell, D., Faluvegi, G., Shindell, C., and He, K.: Health and climate impacts of ocean-going vessels in East Asia, *Nat. Clim. Change*, 6, 1037–1041, <https://doi.org/10.1038/nclimate3083>, 2016.

Liu, H., Meng, Z.-H., Lv, Z.-F., Wang, X.-T., Deng, F.-Y., Liu, Y., Zhang, Y.-N., Shi, M.-S., Zhang, Q., and He, K.-B.: Emissions and health impacts from global shipping embodied in US–China bilateral trade, *Nat. Sustain.*, 2, 1027–1033, <https://doi.org/10.1038/s41893-019-0414-z>, 2019.

Lv, Z., Liu, H., Ying, Q., Fu, M., Meng, Z., Wang, Y., Wei, W., Gong, H., and He, K.: Impacts of shipping emissions on PM_{2.5} pollution in China, *Atmos. Chem. Phys.*, 18, 15811–15824, <https://doi.org/10.5194/acp-18-15811-2018>, 2018.

Ministry of Transport (MOT): Notice of the Ministry of Transport on printing and distributing the implementation plan of ship emission control zone in the waters of Pearl River Delta, Yangtze River Delta and Bohai Rim (Beijing Tianjin Hebei), available at: https://xxgk.mot.gov.cn/2020/jigou/haishi/202006/t20200630_3319179.html (last access: 27 February 2023), 2015.

Ministry of Transport (MOT): Notice of the Ministry of Transport on printing and distributing the implementation plan for the control area of air pollutant emission from ships, available at: http://www.gov.cn/zhengce/zhengceku/2018-12/31/content_5444672.html (last access: 27 February 2023), 2018.

Ministry of Transport (MOT): Statistical bulletin on the development of the transport sector in 2021,

available at: https://xxgk.mot.gov.cn/2020/jigou/zghs/202205/t20220524_3656659.html (last access: 27 February 2023), 2022.

Riess, T. C. V. W., Boersma, K. F., van Vliet, J., Peters, W., Sneep, M., Eskes, H., and van Geffen, J.: Improved monitoring of shipping NO₂ with TROPOMI: decreasing NO_x emissions in European seas during the COVID-19 pandemic, *Atmos. Meas. Tech.*, 15, 1415–1438, <https://doi.org/10.5194/amt-15-1415-2022>, 2022.

Wan, Z., Ji, S., Liu, Y., Zhang, Q., Chen, J., and Wang, Q.: Shipping emission inventories in China's Bohai Bay, Yangtze River Delta, and Pearl River Delta in 2018, *Mar. Pollut. Bull.*, 151, 110882, <https://doi.org/10.1016/j.marpolbul.2019.110882>, 2020.

Wang, X., Yi, W., Lv, Z., Deng, F., Zheng, S., Xu, H., Zhao, J., Liu, H., and He, K.: Ship emissions around China under gradually promoted control policies from 2016 to 2019, *Atmos. Chem. Phys.*, 21, 13835–13853, <https://doi.org/10.5194/acp-21-13835-2021>, 2021.

Weng, J., Shi, K., Gan, X., Li, G., and Huang, Z.: Ship emission estimation with high spatial-temporal resolution in the Yangtze River estuary using AIS data, *J. Clean. Prod.*, 248, 2020.

Xu, W., Yin, C., Xu, X., Zhang, W.: Emission Inventory and Characteristics of Air Pollutants from Inland Waterway Vessels in Jiangsu Province (in Chinese), *Environ. Sci.*, 40, 2595–2606, <https://doi.org/10.13227/j.hjkx.201810207>, 2019.

Zheng, B., Huo, H., Zhang, Q., Yao, Z. L., Wang, X. T., Yang, X. F., Liu, H., and He, K. B.: High-resolution mapping of vehicle emissions in China in 2008, *Atmos. Chem. Phys.*, 14, 9787–9805, <https://doi.org/10.5194/acp-14-9787-2014>, 2014.

Zheng, B., Tong, D., Li, M., Liu, F., Hong, C., Geng, G., Li, H., Li, X., Peng, L., Qi, J., Yan, L., Zhang, Y., Zhao, H., Zheng, Y., He, K., and Zhang, Q.: Trends in China's anthropogenic emissions since 2010 as the consequence of clean air actions, *Atmos. Chem. Phys.*, 18, 14095–14111, <https://doi.org/10.5194/acp-18-14095-2018>, 2018.

Zhu, Y., Lei, Z., Feng, X., Yuan, S., Liang, W.: A Study on the Emission Inventory of Air Pollutants from Ships in Jiangsu Section of Yangtze River Based on AIS Big Data (in Chinese), *Environ. Sci. and Tech.*, 32, 41–46, 2019.