Response to Referee's Comments #2

Dear Editor and Referees,

We are pleased to submit our responses to all the comments and revision for manuscript acp-2018-1163. We appreciate all the comments and suggestions that are especially helpful. All the referees' comments have been addressed carefully.

Best regards with respect,

Yan Zhang, representing all co-authors

Reviewers' comments are in blue.

Authors' responses are in black.

Revisions in manuscript are in *italic*, underlined.

1. General comments: This study presented the importance of geographical locations of ship emissions to the environmental and human health effects. The manuscript has been well written and organized. Take the YRD region– one of the busiest port cluster in the world as the example, this study result is helpful to understand the meaningful points of future ECA policy. The authors should explicit the key implication through the paper, including the abstract, result and conclusion part.

Response:

Thank you for the comments and the suggestions. We have expanded on the key implications of these research results for potential ECA regulations throughout the manuscript.

Revisions in the manuscript:

1. Page 2, line 6-8: "in particular, in the YRD region, expanding the boundary of 12 NM in China's current DECA policy to around 100 NM would include most of the shipping emissions affecting air pollutant exposures, and stricter fuel standards could be considered for the ships on inland rivers and other waterways close to residential regions."

2. Page 5, lines 6-15: "In China, a few studies reported the contribution to air pollution from shipping in different offshore coastal areas or individual ship-related sources. For example, Mao et al. (2017) estimated primary emissions from OGVs at different boundaries in the PRD region, and concluded that further expansion of emission control area to 100 NM would provide even greater benefits. However, the impacts of shipping emissions at varying distances from shore on air quality and potential human exposure, which are important when considering ECA policy, have not been rigorously studied. Mao and Rutherford (2018) studied NO_x *emissions from three categories of merchant vessels—OGVs, coastal vessels (CVs) and river vessels (RVs) in China's coastal region. But less attention was paid to the impacts of inland waterway traffic and port-related sources like container-cargo trucks and terminal port equipment on air quality and potential human exposure."*

3. Page 5, line 30; page 6, line 1-3: "The results of this study could be informative to the consideration of the distance of regulated emissions in the design of future emissions control areas for shipping in YRD, or regulations on the sulfur content of fuels for individual ship-related sources in Shanghai."

4. Page 16, line 7-10: "The results of these YRD analyses suggest that although ambient ship-related SO_2 *concentrations were mainly affected by shipping inland or within 12 NM, expanding China's current DECA to around 100 NM or more would reduce the majority of the impacts of shipping on regional* $PM_{2.5}$ *pollution."*

5. Page 19, line 10-12: "The results of the analyses of individual shipping-related sources indicated that ship-related sources close to densely-populated areas contribute substantially to population exposures to air pollution."

6. Page 20, line 26-29; page 21, line 1-2: "For example, policymakers could consider whether to expand China's current DECA boundary of 12 NM to around 100 NM or more to reduce the majority of shipping impacts on air pollution and exposure or to develop more stringent regulations on the sulfur content of fuels for ships entering inland rivers or other waterways close to residential regions due to their significant influence on local air quality and human exposures in densely populated areas."

The details should be improved:

2. Page 6-7, 2.2.2 Non-shipping emission inventories part. For the national scale domain and regional scale domain, several sets emission data has been used. The authors should make clearer how they merge the emission together. How did they use 2015 national emission database to make a regional 27 km × 27 km resolution that included 5 pollutants? Did they use spatial interpolation method? Which year are the IIASA data for CO and NH3?

Response:

Thank you for the question. The 2015 national emission database (including PM_{10}, $PM_{2.5}$, SO_2, NO_x and VOCs) at a 27 km × 27 km resolution (Zhao et al., 2018) and 2015 IIASA database at a 0.5 °× 0.5 °resolution (CO and NH_3) (Stohl et al., 2015) was allocated to domain 1 (81 km × 81 km) and domain 2 (27 km × 27 km) by spatial interpolation in Arcgis 10.2. We have clarified the method and the year of IIASA data in the revised manuscript.

Revisions in the manuscript:

1. Page 8, line 17-18: "supplemental emission data on these pollutants in 2015 were obtained from the International Institute for Applied Systems Analysis (IIASA) database (at a 0.5 °× 0.5 °resolution) (Stohl et al., 2015)."

2. Page 8, line 28-29: "National and local emission data were allocated to simulation grids by spatial interpolation in ArcGIS 10.2 (ESRI, 2013)."

3. Page7, line 15-16: "The initial and boundary conditions for meteorology were generated from the Chinese National Centers for Environmental Prediction (NCEP) Final Analysis (FNL)", here the authors should confirm the NCEP FNL data source.

Response:

Thank you for pointing out this. We are sorry for the written mistake. The data source should be "National Centers for Environmental Prediction (NCEP) Final Analysis (FNL)" and it has been corrected in the revised manuscript.

Revisions in the manuscript:

1. Page 9, line 7-8: "The initial and boundary conditions for meteorology were *generated from the National Centers for Environmental Prediction (NCEP) Final Analysis (FNL) (NCEP, 2000)"*

4. Page 9, line 12-17: The authors compared the result of YRD shipping emission with Fan et al.'s and Chen et al.'s studies. The authors quoted Liu et al. (2018) to compare the proportion of YRD shipping emissions in whole China. However, Liu et al. (2018) also reported YRD shipping emissions. Why not compare the result with the values in Liu et al. (2018) as well?

Response:

Thank you for the suggestion. We've added the comparison with the 2013 YRD shipping emission estimates in Fu et al. (2017). This paper is from the same research group as Liu et al. (2018), but reports more pollutants than in Liu et al. (2018). In addition, the comparison with the results in Fan et al. (2016) has been removed because the values were for the year 2010, much earlier than the baseline year 2015 in this study.

Revisions in the manuscript:

1. Page 11, line 22-25: "The emission estimates of SO_2, NOx and $PM_{2.5}$ were slightly lower than Chen et al.'s estimates for 2014 year due to the different temporal or spatial statistical scope (Chen et al., 2019; Fu et al., 2017)."

2. References: "Fu, M., Liu, H., Jin, X., and He, K.: National- to port-level inventories of shipping emissions in China, Environ. Res. Lett., 12, 114024, 10.1088/1748-9326/aa897a, 2017."

5. Page 10, line 12-16: The authors quoted Fu et al. (2012), which used 2010 vessel call data to estimate shipping emissions. I suggest authors reviewed recent studies using AIS data to make comparisons in Shanghai port.

Response:

Thank you for the suggestion. We've reviewed the results in Fu et al. (2017) which reported 2013 shipping emissions in Shanghai Port using AIS data. We've added some discussion on the comparison between the values in this study and in Fu et al.'s study.

Revisions in the manuscript:

1. Page 13, line 1-6: "Emissions estimates from this study fall within the range of estimates from other studies (Fu et al., 2012; Fu et al., 2017). On the basis of shipping visa data, Fu et al. (2012) determined that the total amounts of SO_2, NO_X, and $PM_{2.5}$ in the vicinity of Shanghai port in 2010 were 3.5 × 10^4 ton/yr, 4.7 × 10^4 ton/yr, and 3.7 × 10^3 ton/yr, respectively, substantially lower than estimates in this study. Using AIS data, Fu et al. (2017) reported 5 × 10^4 tons of SO_2 and 7× 10^4 tons of NOx from shipping in Shanghai port in 2013, close or a bit lower than the results in this study."

6. Page 12, line 6-15: The contribution to SO2 from ships in different coastal areas was not discussed in this paragraph. But in the following paragraph, the authors discussed cumulative contributions from ships at different distance to both SO2 and PM2.5. It shows no consistency when authors discussed SO2 results throughout the section 3.2.2.

Response:

Thank you for this comment. We've supplemented the data of average and peak contribution to SO_2 from ships in different coastal areas in Table S4. Also, we've added some discussion in the revised manuscript.

Revisions in the manuscript:

1. Page 14, line 24-25: "The average and peak contributions from the shipping emissions in specific offshore coastal areas to the ambient SO_2 and $PM_{2.5}$ concentrations on shore for the two months are listed in Table S4. Shipping emissions beyond 12 NM had a much smaller impact on ambient SO_2, which average contributions were below 0.01 μg/m^3 and peak contributions were below 0.06 μg/m^3 (Table S4)."

2. Table S4 Average and peak contributions from ship emissions in different offshore coastal areas to the ambient SO_2 and $PM_{2.5}$ concentrations in January and June

Offshore distance	*Average contribution (μg/m³)*				*Maximum contribution (μg/m³)*			
	SO_2		*$PM_{2.5}$*		*SO_2*		*$PM_{2.5}$*	
	January	*June*	*January*	*June*	*January*	*June*	*January*	*June*
Inland and within 12 NM	*0.52*	*0.70*	*0.24*	*0.56*	*6.00*	*8.79*	*1.62*	*4.02*
12-24 NM	*0.005*	*0.007*	*0.01*	*0.04*	*0.03*	*0.05*	*0.05*	*0.20*
24-48 NM	*0.01*	*0.009*	*0.04*	*0.07*	*0.06*	*0.05*	*0.11*	*0.34*
48-96 NM	*0.02*	*0.008*	*0.07*	*0.07*	*0.05*	*0.03*	*0.14*	*0.30*
96-200 NM	*0.00*	*0.001*	*0.003*	*0.01*	*0.004*	*0.003*	*0.02*	*0.05*

7. Page 14, line 1-6: The authors discussed the population-weighted PM2.5 from both shipping source and all pollution sources. Then, what's the proportion of population-weighted PM2.5 from the shipping source among all pollution sources? I suggest some discussion here.

Response:

Thank you for the suggestion. We have added the proportion of population-weighted $PM_{2.5}$ among all pollution sources along with some discussion.

Revisions in the manuscript:

1. Page 17, line 11-15: "Thus, population-weighted $PM_{2.5}$ concentrations from shipping sources accounted for 0.9% to 15.5% of the population-weighted $PM_{2.5}$ concentrations from all pollution sources in June, larger than the contributions of 0.2% to 1.6% in January, which was attribute to higher shipping-related population-weighted $PM_{2.5}$ concentrations in June and higher population-weighted $PM_{2.5}$ concentrations from all pollution sources in January."

8. Page 15, line 25: The uncertainty analysis is lacked in the section of result and discussion. The uncertainties of shipping emission inventories should be discussed here.

Response:

Thank you for pointing out this. We've added section 3.4 Limitations where we discuss the uncertainties associated with our shipping emission inventories.

Revisions in the manuscript:

1. Page 19, line 14-29; page 20, line 1-10:

*"**3.4 Limitations***

Limitations in the study were mainly related to some missing information, assumptions and model inputs during estimation of shipping emissions. When estimating shipping emission inventory, underestimations of actual emissions may be introduced by missing information. For example, AIS data has a high coverage of coastal vessels, but many inland vessels are not equipped with AIS. Therefore, emissions from those inland vessels without AIS devices were supplemented by using 2015 vessel call data provided by Shanghai MSA and Shanghai Municipal MSA. However, emissions from fishing boats were probably underestimated because AIS devices on some fishing boats may not be in use. Similarly, limited information exists on auxiliary boilers in the Lloyd's register and CCS databases so we calculated the main engine and auxiliary engine emissions but did not consider auxiliary boiler emissions in this study, which may cause underestimation of shipping emissions.

We did not consider the external effects of water flow, wind, and waves when calculating engine power for ships going over the region. These factors may increase fuel consumption of individual vessels by as much as 10% to 20%, while the effects of waves on emissions estimations over extensive geographical regions are negligible (Jalkanen et al., 2009; Jalkanen et al., 2012). The downstream of the Yangtze River is located in the geographically plateau region, and the river flow is below 0.5 m/s (Song and Tian, 1997; Xue et al., 2004). For Shanghai, located at the end of mouth of the Yangtze River to the East China Sea with a flat terrain, the river flow is very slow. Given that ships traveling the Yangtze River near Shanghai have speeds over ground (SOG) of about 5-10 knots (3-5 m/s), the relative ratios of water flow to the SOG is within 20%. This would introduce some uncertainties. In our future work, we will fill the gap in the basic ship data and consider the external effects when building the shipping emission inventory.

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Reference:

Fu, M., Liu, H., Jin, X., and He, K.: National- to port-level inventories of shipping emissions in China, Environ. Res. Lett., 12, 114024, 10.1088/1748-9326/aa897a, 2017.

Liu, H., Meng, Z. H., Shang, Y., Lv, Z. F., Jin, X. X., Fu, M. L., and He, K. B.: Shipping emission forecasts and cost-benefit analysis of China ports and key regions' control, Environ. Pollut., 236, 49-59, 10.1016/j.envpol.2018.01.018, 2018b.

Stohl, A., Aamaas, B., Amann, M., Baker, L. H., Bellouin, N., Berntsen, T. K., Boucher, O., Cherian, R., Collins, W., Daskalakis, N., Dusinska, M., Eckhardt, S., Fuglestvedt, J. S., Harju, M., Heyes, C., Hodnebrog, Ø., Hao, J., Im, U., Kanakidou, M., Klimont, Z., Kupiainen, K., Law, K. S., Lund, M. T., Maas, R., MacIntosh, C. R., Myhre, G., Myriokefalitakis, S., Olivié, D., Quaas, J., Quennehen, B., Raut, J.-C., Rumbold, S. T., Samset, B. H., Schulz, M., Seland, Ø., Shine, K. P., Skeie, R. B., Wang, S., Yttri, K. E., and Zhu, T: Evaluating the climate and air quality impacts of short-lived pollutants, Atmos. Chem. Phys. 15, 10529–10566, https://doi.org/10.5194/acp-15-10529-2015, 2015.

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