

Supplement of

Annual changes of ship emissions around China under gradually promoted control policies from 2016 to 2019

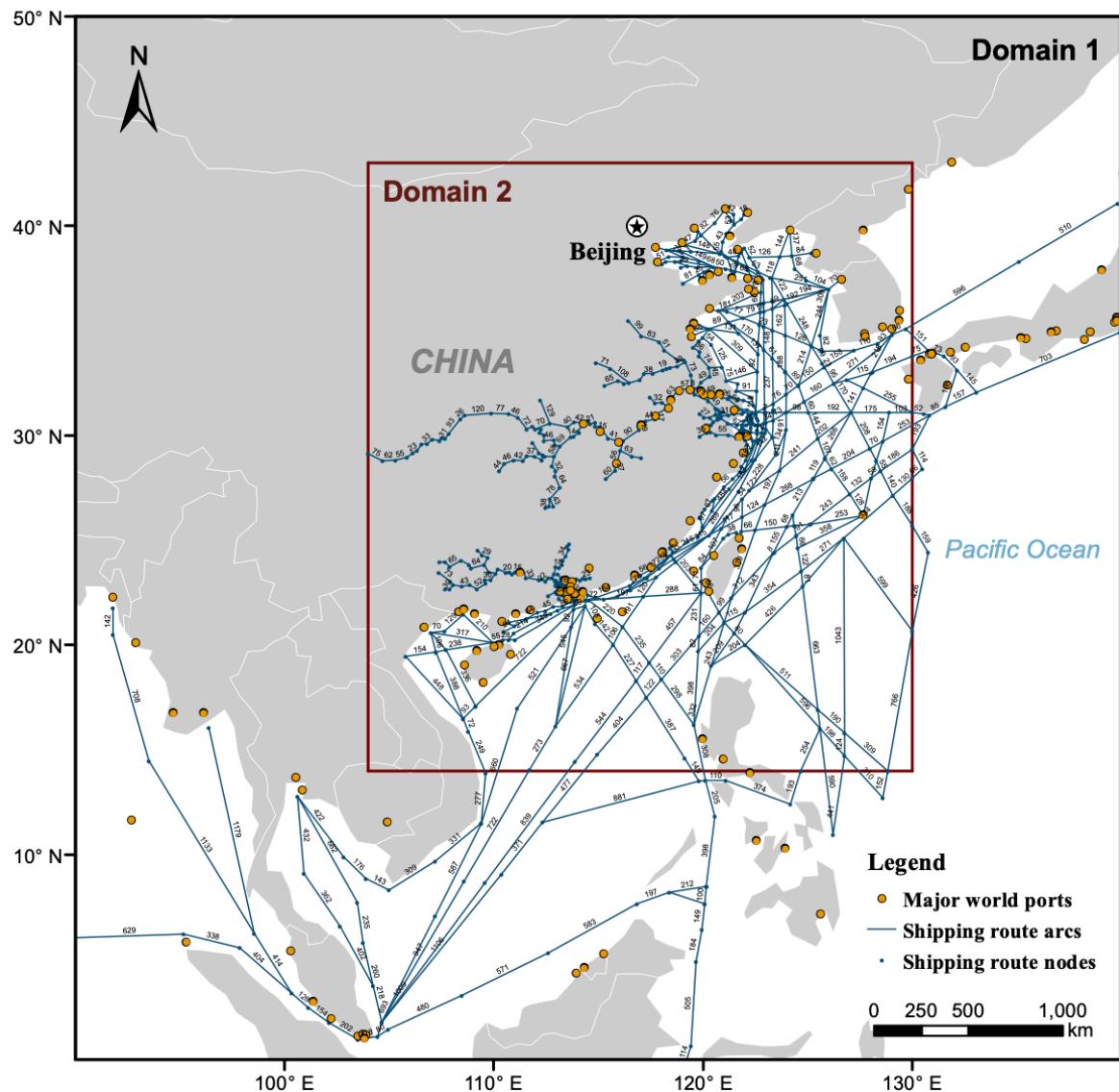
Xiaotong Wang^a, Wen Yi^a, Zhaofeng Lv, Fanyuan Deng, Songxin Zheng, Hailian Xu, Junchao Zhao, Huan Liu*, Kebin He

State Key Joint Laboratory of ESPC, School of Environment, Tsinghua University, Beijing 100084, China

Correspondence to: liu_env@tsinghua.edu.cn (H. Liu)

^aThese authors contributed equally to this work

Supplementary Figures



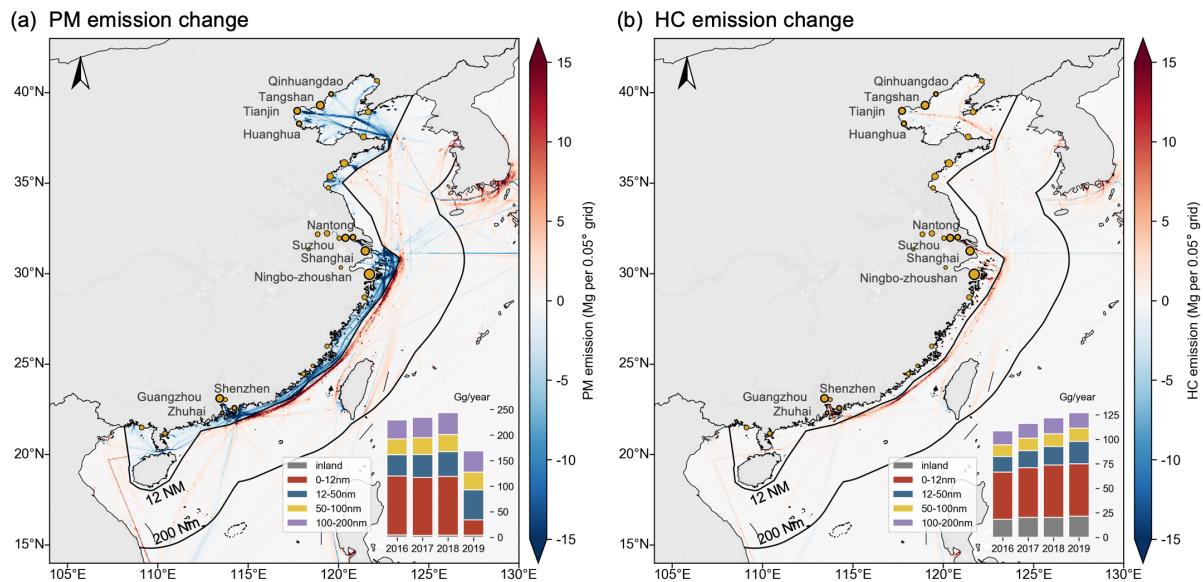


Fig. S2. Spatial distribution changes of PM and HC emissions from shipping over China in 2019 compared to 2016.

Supplementary Tables

Table S1. Actual implementation of China's step-by-step DECA policy

Region and ports		DECA 1.0		DECA 2.0	
		2016	2017	2018	2019
Coastal	BSA		(Berth, MGO-0.5%) Tianjin, Qinhuangdao, Tangshan, Huanghua	(Berth, MGO-0.5%) All region	(All modes , MGO-0.5%) 12 nautical miles
	YRD	(Apr. – Dec., Berth, MGO-0.5%) Shanghai, Ningbo-Zhoushan, Suzhou, Nantong	(Berth, MGO-0.5%) Shanghai, Ningbo-Zhoushan, Suzhou, Nantong; (Sep. – Dec., Berth, MGO-0.5%) All region	(Berth, MGO-0.5%) All region; (Oct. – Dec., all modes, MGO-0.5%) Shanghai, Ningbo-Zhoushan, Suzhou, Nantong	
	PRD	(Oct. – Dec., Berth, MGO-0.5%) Shenzhen	(Berth, MGO-0.5%) Shenzhen, Guangzhou, Zhuhai	(Berth, MGO-0.5%) All region	
Other area					
River		GDO-0.035% GDO-0.005%	(Jul. to Dec.)	GDO-0.001%	GDO-0.001%

Note: Yellow background stands for low sulfur oil; Green background stands for general diesel oil

Table S2. Total emission of air pollutants and GHGs in relevant studies and this study

Based Year	SO ₂	NO _X	PM ₁₀	PM _{2.5}	HC	CO	CO ₂	Reference
2013	1300	1910	164	-	69	74	86	(Fu et al., 2017)
2013	1010	1443	107	87	67	118	-	(Li et al., 2018)
2014	1194	2208	181	167	112	242	78	(Chen et al., 2017)
2014	999	1149	-	120	36	88	-	(Huang et al., 2019)
2016	1795 (38.1%)	2528 (32.3%)	230 (40.0%)	-	109 (57.7%)	114 (54.5%)	139 (61.3%)	This study
2017	1824 (40.3%)	2670 (39.8%)	235 (43.3%)	-	116 (68.7%)	122 (64.6%)	148 (71.9%)	This study
2018	1894 (45.7%)	2802 (46.7%)	244 (48.7%)	-	122 (76.8%)	127 (72.2%)	155 (80.5%)	This study
2019	1264 (-2.8%)	2858 (49.6%)	169 (3.0%)	-	127 (84.5%)	132 (78.8%)	161 (87.4%)	This study

Note: The percentages in brackets show the relative changes in emissions of the target year compared to 2013.

Table S3. Proportion of China ship emission in the globe

Year	SO ₂	NO _x	PM	HC	CO	CO ₂
OGV emission around China (Mg)						
2016	1510	1263	160	62	68	86961
2017	1628	1333	170	67	74	95141
Global OGV emission from 4 th IMO GHG report (Mg) (IMO, 2020)						
2016	15781	8943	1352	654	606	675300
2017	16202	9252	1399	675	625	693400
Contribution of OGV around China waters to global OGV emissions						
2016	9.6%	14.1%	11.8%	9.5%	11.2%	12.9%
2017	10.0%	14.4%	12.2%	10.0%	11.8%	13.7%
Average	9.8%	14.3%	12.0%	9.7%	11.5%	13.3%

Table S4. Emission structures of ship emission of NOx, SO₂, PM, HC of China in 2016-2019 (Unit: %)

Statistical dimension	2016				2017				2018				2019				
	NO _x	SO ₂	PM	HC	NO _x	SO ₂	PM	HC	NO _x	SO ₂	PM	HC	NO _x	SO ₂	PM	HC	
Vessel type	Auto carrier	1	1.1	1.1	0.9	1	1.1	1.1	0.9	1	1.1	1.1	0.9	1.1	1.3	1.3	0.9
	Bulk carrier	32.2	24.1	24.3	35.3	32.9	24.1	24.4	36	32.2	23.4	23.6	35.1	33	23.1	23.4	35.6
	Container	27.5	31.7	32.6	27.5	28.9	34.5	35.3	28.7	31.4	37.5	38.4	31.2	30.7	42.9	43.2	30.5
	Cruise	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
	General cargo	4.1	4.6	4.6	3.7	3.9	4.3	4.3	3.5	3.9	4.4	4.3	3.4	3.9	4.6	4.5	3.5
	Miscellaneous	2.2	2.2	2.3	2.1	2	2	2.1	1.9	1.9	1.8	1.9	1.8	2.1	1.4	1.6	2
	Ocean Tug	1.3	0.2	0.2	1.5	1.3	0.2	0.3	1.6	1.3	0.2	0.3	1.6	1.3	0.2	0.3	1.5
	Ro-Ro	3	3.3	3.2	2.6	2.8	3	2.9	2.4	2.6	2.7	2.6	2.2	3.2	2	2.1	2.9
	Reefer	0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.2
	Chemical tanker	4	4.7	4.6	3.7	4	4.7	4.6	3.6	3.7	4.5	4.4	3.4	3.8	5.4	5.2	3.5
Fuel type and sulfur content (m/m)	Oil tanker	6.3	8.5	7	5.8	6.3	8.2	6.9	5.9	6.3	8.1	6.9	5.9	6.6	9	7.8	6.2
	LPG	1	1.6	1.3	1	1.1	1.6	1.3	1	1.1	1.7	1.4	1	1.1	1.8	1.5	1
	LNG	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
	Fishing	7.9	8.7	8.9	6.7	6.4	7.1	7.2	5.3	5.9	6.4	6.5	4.9	5.4	3.8	4.1	4.6
	Others	8.9	8.7	9.1	8.8	8.9	8.6	9	8.8	8.1	7.6	7.9	8	7.3	4	4.5	7.4
	HFO	79.5	98.2	98.1	74.8	45.5	84.5	81.9	41.7	83.9	99	99	79.1	80.4	98.3	98.4	75.8
	LNG	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0.1	0.1	0.1	0.1	0.1

Table S4 Emission structures of ship emission of NO_x, SO₂, PM, HC of China in 2016-2019 (Unit: %; continued)

Statistical dimension	2016				2017				2018				2019				
	NO _x	SO ₂	PM	HC	NO _x	SO ₂	PM	HC	NO _x	SO ₂	PM	HC	NO _x	SO ₂	PM	HC	
OGV	59.7	70.4	69.6	56.9	61	73.1	72.5	57.8	64.1	77	76.4	60.9	65.8	87.6	86.5	62.4	
OGV/CV/RV	CV	27.1	29.4	30.2	24.9	24.2	26.8	27.4	22.1	21.6	23	23.6	19.8	19.3	12.4	13.5	18.1
RV		13.2	0.2	0.2	18.2	14.9	0.1	0.1	20.1	14.3	0	0	19.3	14.9	0	0	19.6
< 2000		9.4	9.7	9.5	7.7	8.3	8.4	8.2	6.7	7.8	8	7.8	6.3	8.4	8.8	8.5	6.9
Vessel build period	2000 – 2010	69.7	62.7	63.4	70.3	67.8	59.9	60.4	68.4	65.1	56.2	56.7	65.6	62.1	47.9	48.8	62.8
	2010 – 2016	18.2	24.2	23.8	19.2	17.8	23.5	23.2	18.5	17.7	23.3	23	18.4	18.9	27.3	27	19.5
	> 2016	2.6	3.4	3.4	2.8	6.2	8.2	8.2	6.4	9.4	12.6	12.5	9.7	10.6	16	15.7	10.8
DWT range (ton)	0 – 9999	45.2	35.5	35.6	47.2	42.5	31.5	31.4	44.9	39.2	27.5	27.4	41.7	38.8	18.4	19	41.4
	10000 – 19999	8	9.3	9.2	7.4	7.7	9	8.9	7	7.5	8.9	8.7	6.8	7.3	8.8	8.7	6.7
	20000 – 29999	6.3	7.2	7.3	5.8	6.6	7.8	7.8	6.1	6.9	8.2	8.2	6.4	6.9	9	9	6.4
	30000 – 39999	5.1	5.8	5.9	4.8	5	5.8	5.8	4.7	5.2	6	6.1	4.8	5.2	6.3	6.3	4.9
	40000 – 49999	4.8	5.7	5.5	4.4	4.9	5.8	5.7	4.5	4.9	5.8	5.6	4.5	5.2	6	5.8	4.8
	50000 – 59999	5	5.9	5.9	4.8	5.5	6.4	6.4	5.2	6.2	7.1	7.2	5.8	6.6	8.3	8.3	6.3
	60000 – 79999	5.7	6.7	6.6	5.4	6.3	7.3	7.3	6	7.4	8.3	8.3	6.9	7.8	9.4	9.4	7.2
	80000 – 99999	2.7	3.1	3.2	2.7	2.8	3.3	3.4	2.8	2.8	3.3	3.4	2.8	2.7	3.8	3.8	2.6
	100000 – 119999	4.9	6	6	5.1	4.6	5.7	5.7	4.7	4.4	5.4	5.5	4.5	4.3	6.7	6.5	4.5
	120000 – 159999	3.9	4.7	4.8	4.1	4.8	5.9	6	5	5	6.2	6.4	5.3	4.8	7.4	7.3	5
	160000 – 199999	4.9	5.8	5.9	4.9	5.5	6.6	6.8	5.4	6.5	8	8.2	6.5	6.3	9.5	9.5	6.3
	> 200000	3.5	4.3	4	3.2	3.9	4.8	4.6	3.7	4.1	5.3	5.1	3.9	4.1	6.6	6.3	3.9
Operating mode	Cruising	69.5	70	71.2	63.9	70	73.3	74	64.3	70.9	73.4	74.6	65.4	70.5	77.1	78	64.9
	Maneuvering	19	14.1	16.1	26.6	18.8	13.7	15.6	26.3	17.9	12.7	14.4	25.3	18.2	11.1	12.7	25.6
	Anchorage	2	2.2	2.3	2	1.7	2	2	1.7	1.4	1.7	1.7	1.5	1.4	1.3	1.3	1.5
	Berth	9.5	13.7	10.4	7.5	9.6	11.1	8.4	7.7	9.8	12.2	9.3	7.9	9.9	10.4	8	8

Supplementary References

- Chen, D., Wang, X., Li, Y., Lang, J., and Zhao, Y.: High-spatiotemporal-resolution ship emission inventory of China based on AIS data in 2014, *Science of The Total Environment*, 609, 776-787, 2017.
- Fu, M., Liu, H., Jin, X., and He, K.: National- to port-level inventories of shipping emissions in China, *Environmental Research Letters*, 12, 114024, 10.1088/1748-9326/aa897a, 2017.
- Huang, Z., Wang, H., Tang, Y., Peng, D., and Ma, D.: Emission Prediction of Marine for 2030 in China, Vehicle Emission Control Center (VECC), Beijing, 60pp, 2019.
- IMO: Fourth IMO GHG Study - Final Report, CE Delft, 2020.
- 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, 10.5194/acp-18-6075-2018, 2018.