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Impacts of shipping emissions on ozone pollution in China

Zhenyu Luo et al.

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

Figures

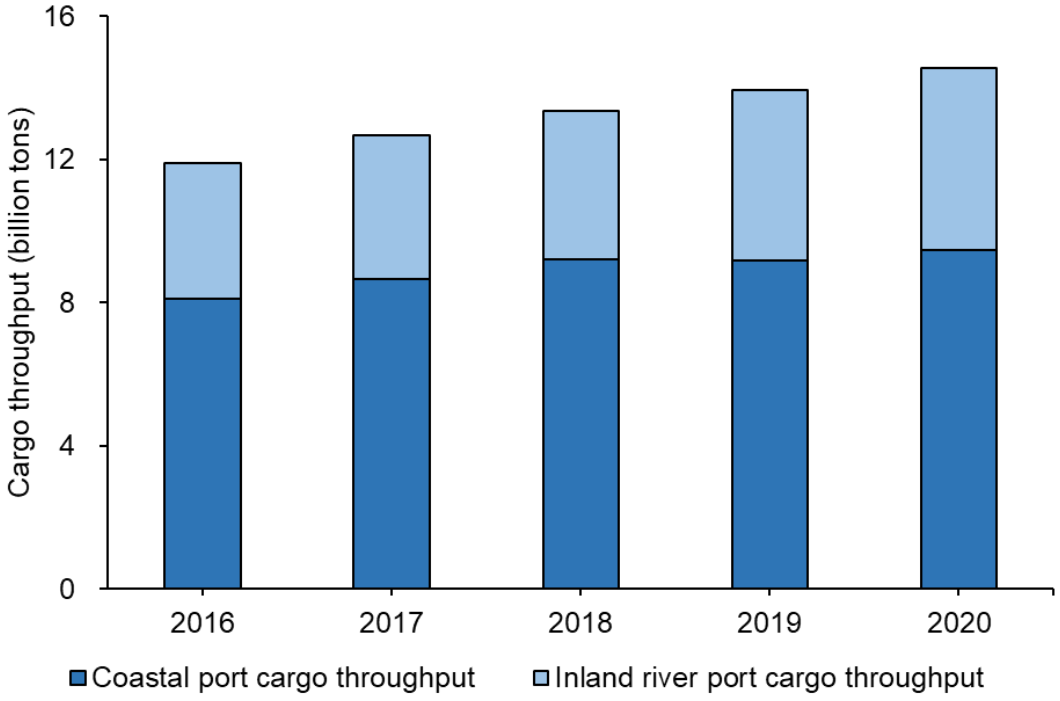

Figure S1. Cargo throughput from 2016 to 2020.

Figure S2. Study domain. Maps created with MeteoInfoMap (http://www.meteothink.org).

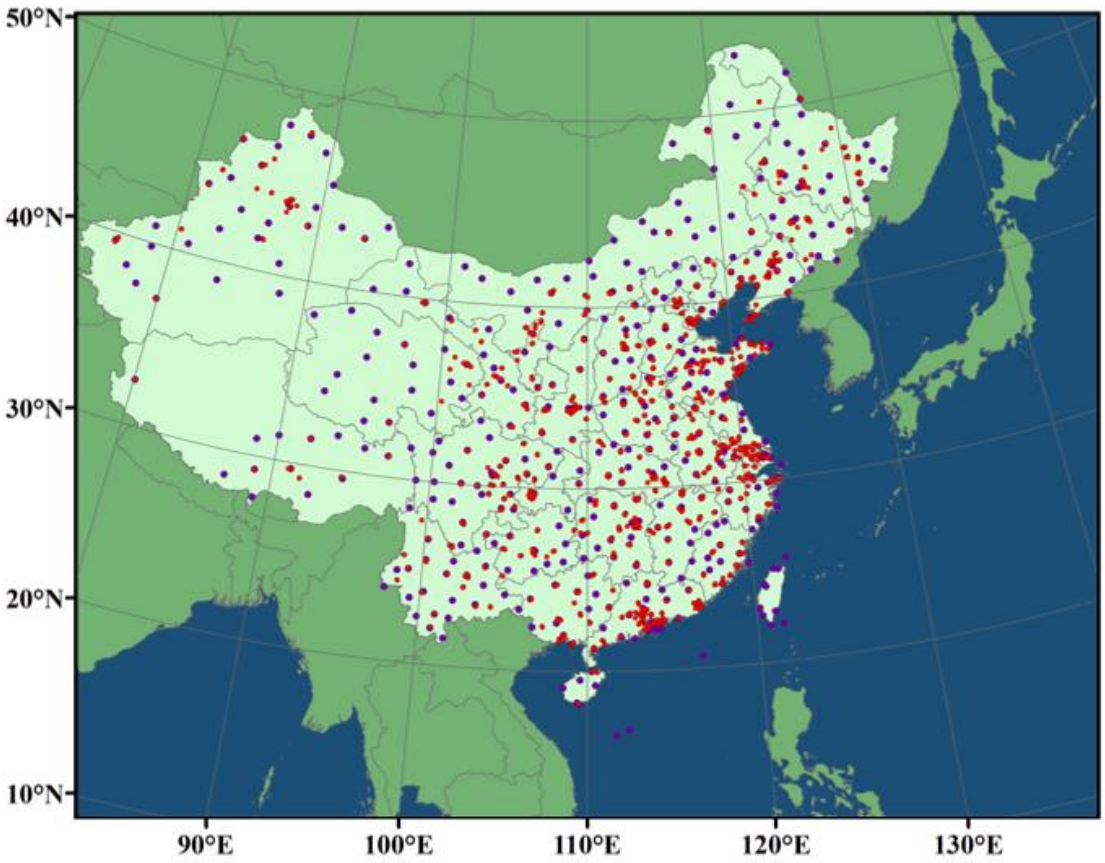

Figure S3. Distribution of 401 meteorological (purple dots) and 1455 air pollutant (red dots) observation stations.

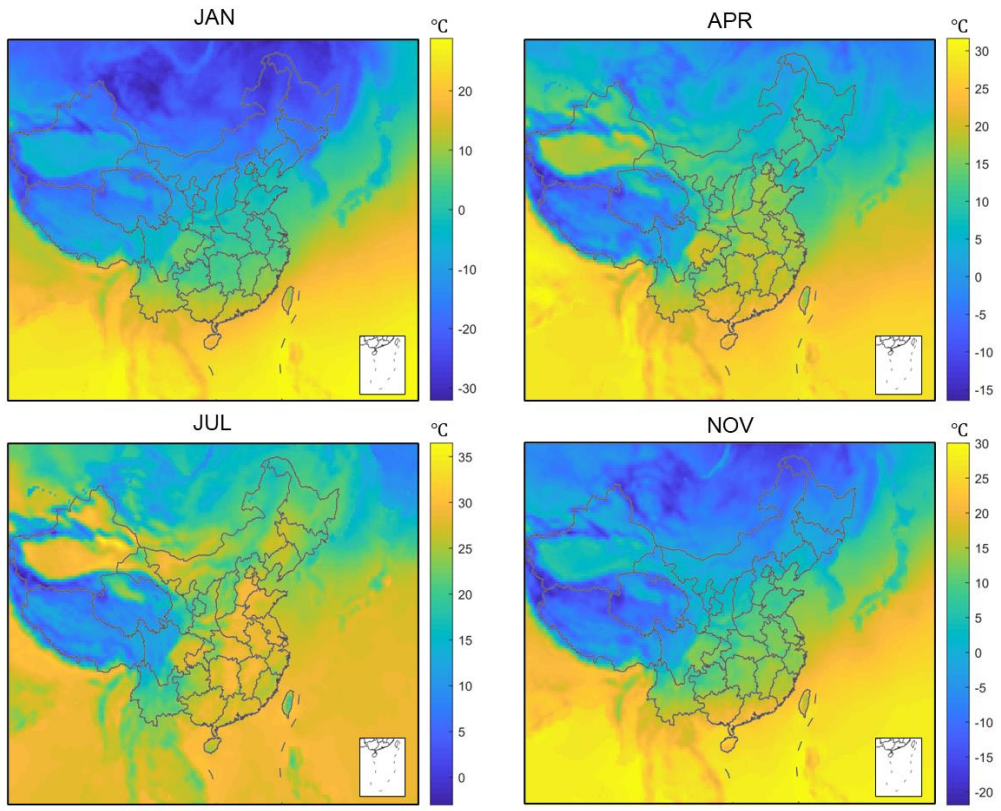

Figure S4. Seasonal temperature. Maps created with MeteoInfoMap (http://www.meteothink.org).

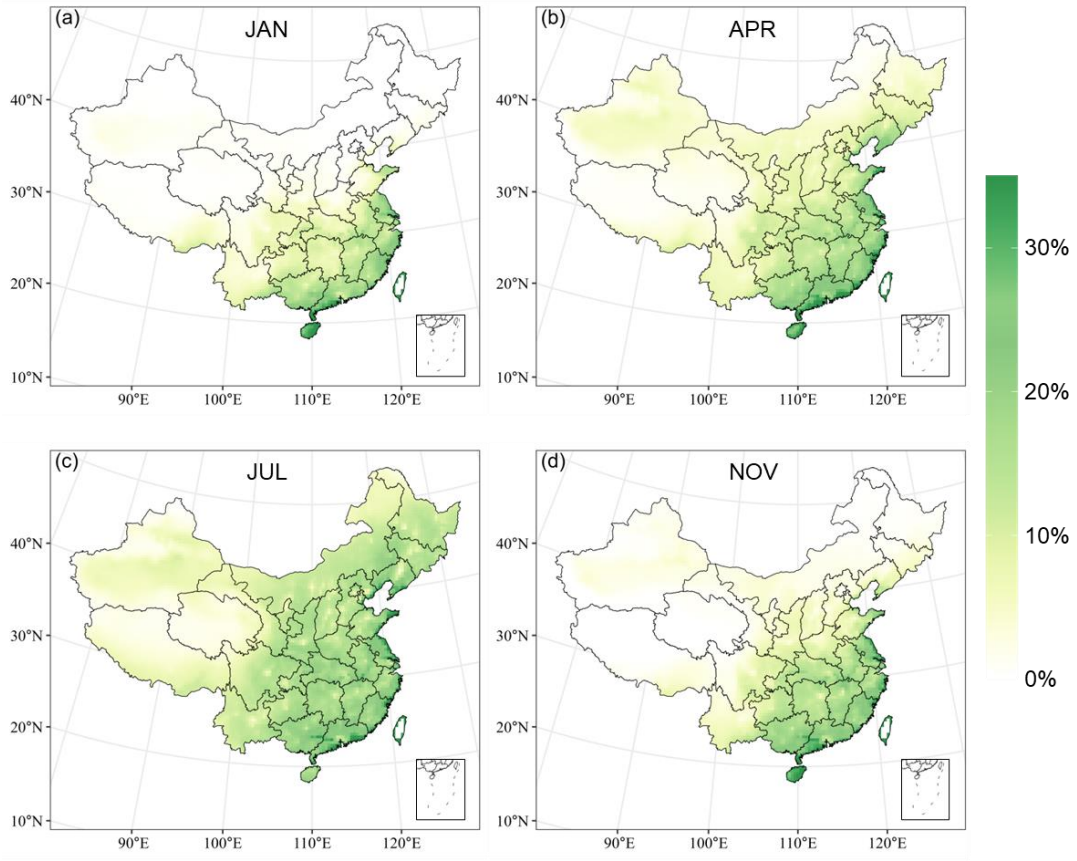

Figure S5. Seasonal relative contribution of shipping emissions to O_3. Maps created with MeteoInfoMap (http://www.meteothink.org).

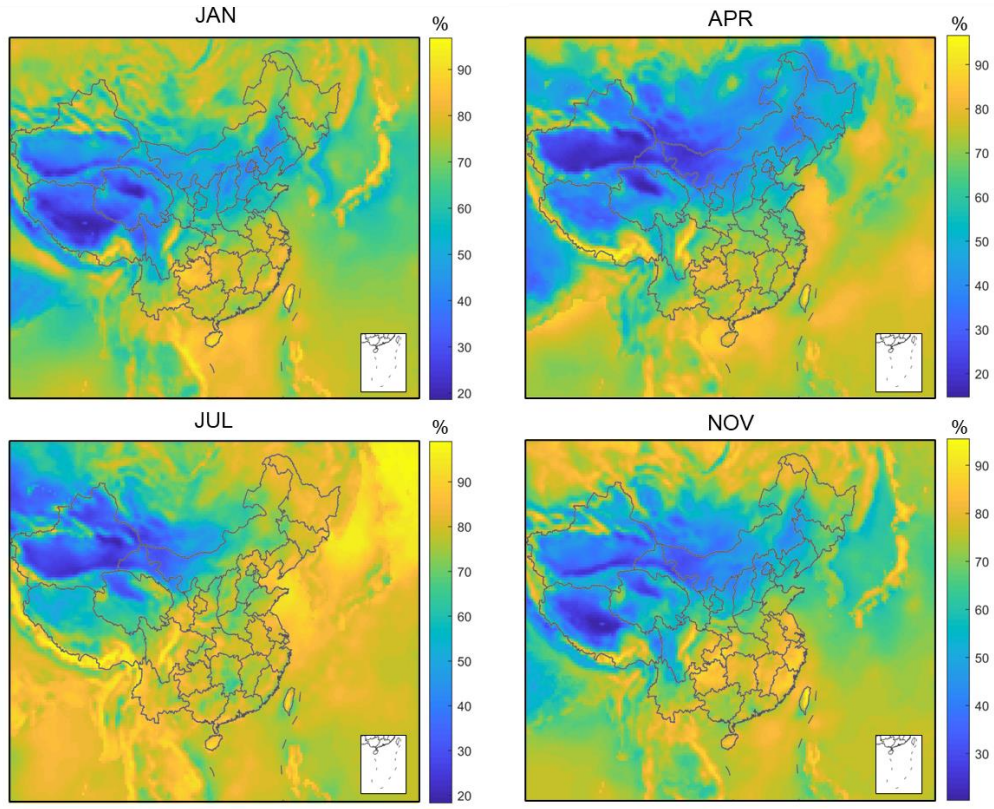

Figure S6. Seasonal relative humidity. Maps created with MeteoInfoMap (http://www.meteothink.org).

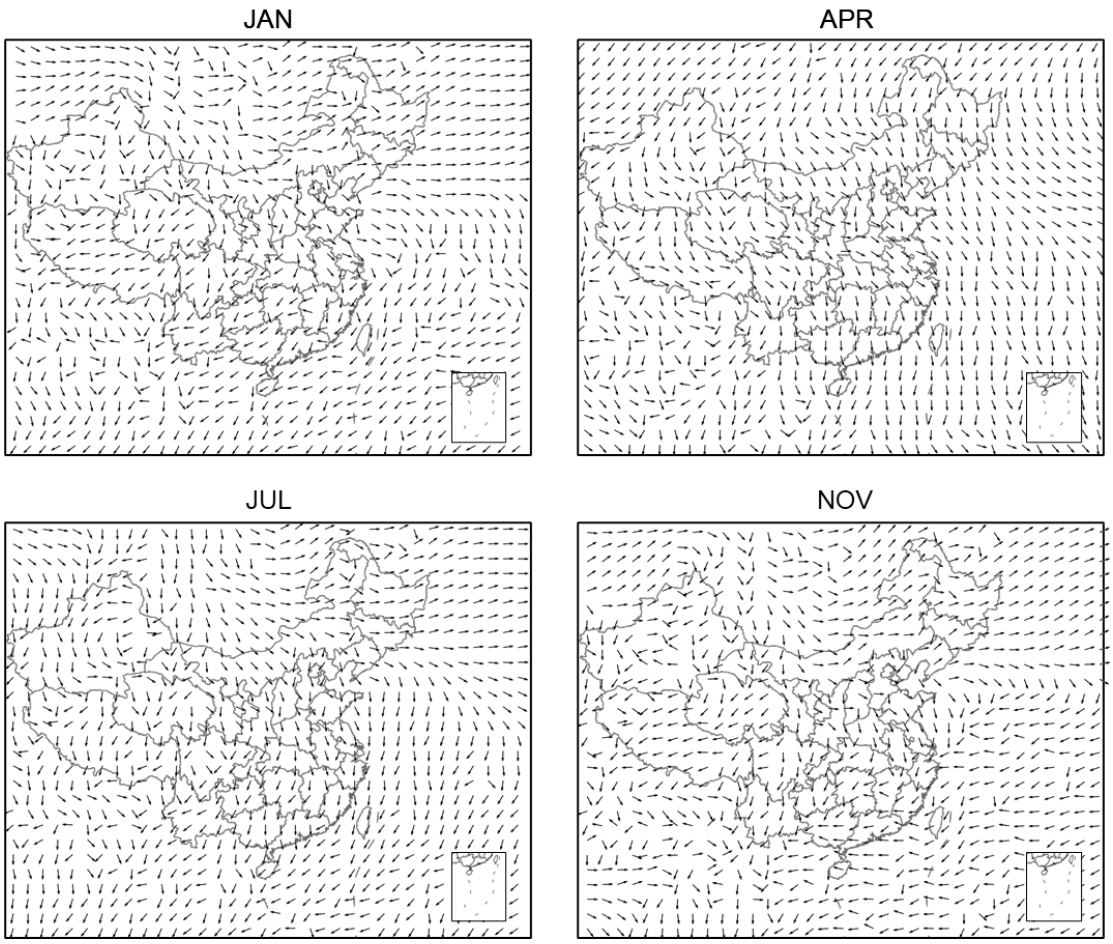

Figure S7. Seasonal wind direction. Maps created with MeteoInfoMap (http://www.meteothink.org).

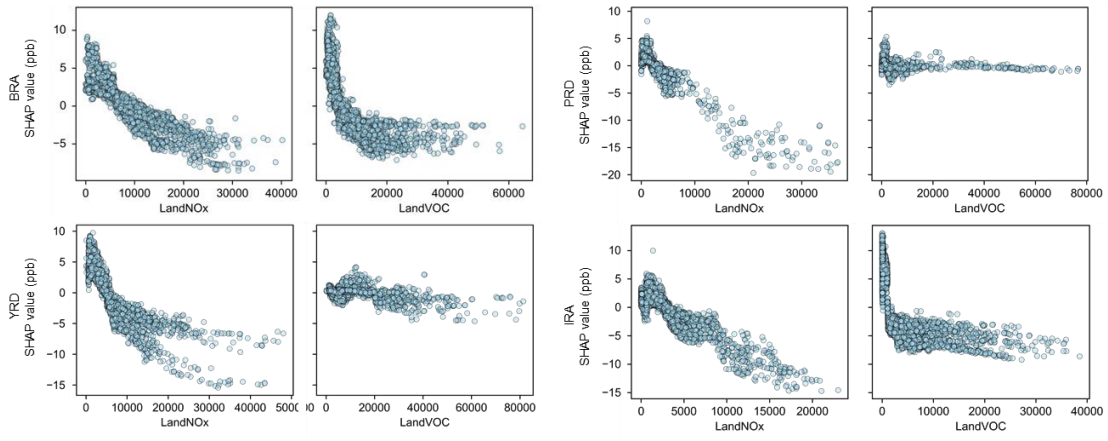

Figure S8. SHAP dependence plot for (a) BRA, (b) YRD, (c) PRD, and (d) IRA.

Tables

Table S1. WRF performance.

Statistics	Month	Mean OBS	Mean SIM	MB	NMB	NMGE	MFB	MFE	R
WS10 (m/s)	Winter	2.69	3.01	0.32	0.25	0.57	0.20	0.55	0.60
	Spring	3.08	3.24	0.17	0.13	0.45	0.11	0.48	0.65
	Summer	2.60	2.56	-0.04	0.04	0.45	0.03	0.49	0.54
	Autumn	2.38	2.53	0.14	0.14	0.50	0.11	0.52	0.58
WD10 (°)	Winter	195.48	176.16	-1.79	-0.01	0.25	-0.08	0.57	0.33
	Spring	186.14	176.72	0.33	0.01	0.26	-0.01	0.49	0.37
	Summer	170.30	159.04	-3.12	-0.01	0.29	0.01	0.49	0.33
	Autumn	183.37	172.62	1.01	0.01	0.29	-0.01	0.60	0.31
T2 (°C)	Winter	-1.55	-1.85	-0.30	-0.13	-0.35	-0.12	0.16	0.92
	Spring	14.73	13.88	-0.84	-0.12	0.27	-0.08	0.16	0.93
	Summer	24.96	24.24	-0.72	-0.03	0.09	-0.04	0.10	0.88
	Autumn	7.45	7.08	-0.36	-0.07	-0.16	0.14	0.14	0.92
RH (%)	Winter	62.80	64.00	1.20	0.05	0.19	0.03	0.19	0.81
	Spring	56.40	57.76	1.36	0.04	0.20	0.03	0.21	0.84
	Summer	72.48	72.30	-0.19	0.00	0.13	-0.01	0.14	0.78
	Autumn	67.65	66.13	-1.52	-0.01	0.16	-0.02	0.17	0.81

* $MB = \frac{\sum_{i=1}^{N} S_i - O_i}{N}$, $NMB = \frac{\sum_{i=1}^{N} S_i - O_i}{\sum_{i=1}^{N} O_i}$, $NMGE = \frac{\sum_{i=1}^{N} |S_i - O_i|}{\sum_{i=1}^{N} O_i}$, $MFB = \frac{2 \times \sum_{i=1}^{N} \frac{S_i - O_i}{S_i + O_i}}{N}$, $MFE = \frac{2 \times \sum_{i=1}^{N} \frac{|S_i - O_i|}{S_i + O_i}}{N}$, $R = \frac{\sum_{i=1}^{N} [(S_i - \bar{S}) \times (O_i - \bar{O})]}{\sqrt{\sum_{i=1}^{N} (S_i - S)^2 \times \sum_{i=1}^{N} (O_i - \bar{O})^2}}$,

* N is the total number of samples in the dataset, S_i is the simulated value of the *i*-th sample, O_i is the observed (measured) value of the *i*-th sample, $\bar{S}$ is the mean of the simulated values, $\bar{O}$is the mean of the observed values.

Table S2. Emissions used in the CMAQ model.

Emissions	Year	Reference
Shipping Emissions	2016-2020 2016-2019: Monthly-averaged from annual totals 2020: Monthly	This study
Land-based anthropogenic emissions in China (mobiles, industry, power, domestic, and agriculture)	2016-2020 Monthly	MEIC (http://www.meicmodel.org/, last access: November 2023)
Anthropogenic emission from other countries within the modeling domain	2010	MIX emission inventory (Li et al., 2017)
Open burning	2015	Cai et al (Cai et al., 2017)
Biogenic emissions	Real	Model of Emissions of Gases and Aerosols from Nature (MEGANv3, https://sites.google.com/uci.edu/bai, last access: July 2023)
Emissions from windblown dust	Real	In-line calculated in CMAQ (https://www.epa.gov/c

		maq, last access: July 2023)
Emissions from sea salt	Real	In-line calculated in CMAQ (https://www.epa.gov/cmaq, last access: July 2023)

Table S3. CMAQ performance (Number of stations:1455).

Pollutants	Month	Mean OBS	Mean SIM	MB	NMB	NMGE	MFB	MFE	R
Maximum daily 8-hour average O_3	Winter	40.53	37.57	-2.69	-0.05	0.60	-0.39	0.82	0.58
	Spring	77.92	77.26	0.06	0.04	0.43	-0.11	0.55	0.69
	Summer	69.24	79.15	9.67	0.19	0.51	-0.01	0.57	0.69
	Autumn	37.60	43.08	5.50	0.19	0.74	-0.18	0.83	0.58

* $MB = \frac{\sum_{i=1}^{N} S_i - O_i}{N}$, $NMB = \frac{\sum_{i=1}^{N} S_i - O_i}{\sum_{i=1}^{N} O_i}$, $NMGE = \frac{\sum_{i=1}^{N} |S_i - O_i|}{\sum_{i=1}^{N} O_i}$, $MFB = \frac{2 \times \sum_{i=1}^{N} \frac{S_i - O_i}{S_i + O_i}}{N}$, $MFE = \frac{2 \times \sum_{i=1}^{N} \frac{|S_i - O_i|}{S_i + O_i}}{N}$, $R = \frac{\sum_{i=1}^{N} [(S_i - \bar{S}) \times (O_i - \bar{O})]}{\sqrt{\sum_{i=1}^{N} (S_i - S)^2 \times \sum_{i=1}^{N} (O_i - \bar{O})^2}}$,

* N is the total number of samples in the dataset, S_i is the simulated value of the *i*-th sample, O_i is the observed (measured) value of the *i*-th sample, $\bar{S}$ is the mean of the simulated values, $\bar{O}$is the mean of the observed values.

Table S4. Five-year average of total O_3 and shipping-related O_3 across China. (ppb)

	Total	All ships	RVs	CVs	OGVs
China	40.77	3.49 (8.6%)	1.07 (2.6%)	1.08 (2.6%)	1.34 (3.3%)
BRA	31.02	4.48 (14.4%)	0.80 (2.6%)	1.60 (5.2%)	2.08 (6.7%)
YRD	25.64	5.55 (21.6%)	1.70 (6.6%)	1.76 (6.9%)	2.09 (8.2%)
PRD	28.77	8.92 (31.0%)	2.32 (8.1%)	2.40 (8.3%)	4.20 (14.6%)
IRA	41.23	3.95 (9.6%)	1.55 (9.6%)	1.14 (9.6%)	1.26 (9.6%)

* The numbers in parentheses indicate the relative contribution.8.32

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