Atmospheric
Chemistry
and Physics

Supplement of

Impacts of shipping emissions on PM$_{2.5}$ pollution in China

Zhaofeng Lv et al.

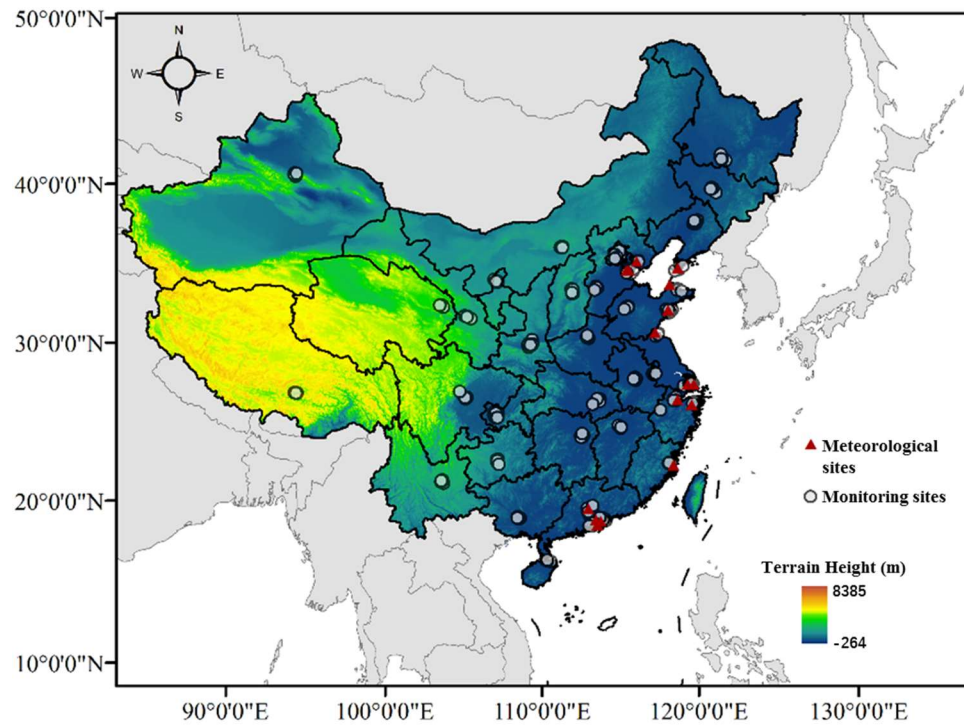*Correspondence to:* Huan Liu (liu_env@tsinghua.edu.cn)

Figure S1. Terrain height and locations of the selected monitoring sites and metrological sites in China
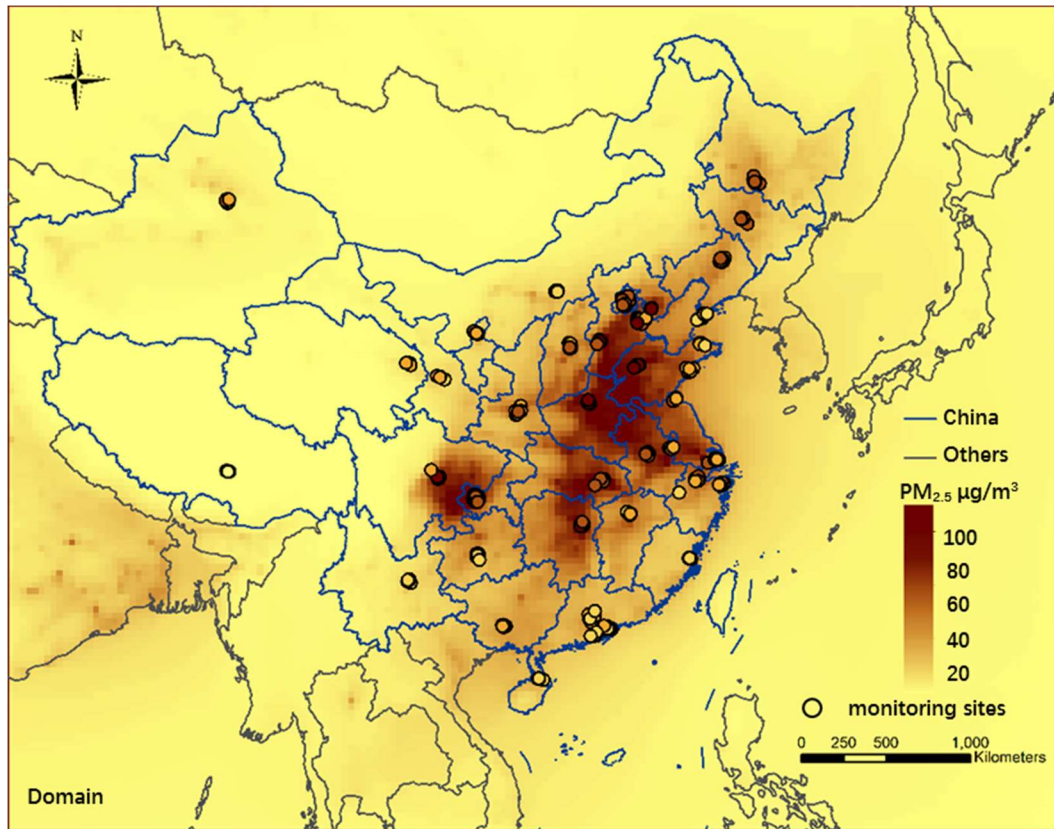
Figure S2. Spatial validation of the predicted PM$_{2.5}$ annual mean concentrations. The gridded background color represented the predicted concentrations. The color of points showed the observed concentrations.
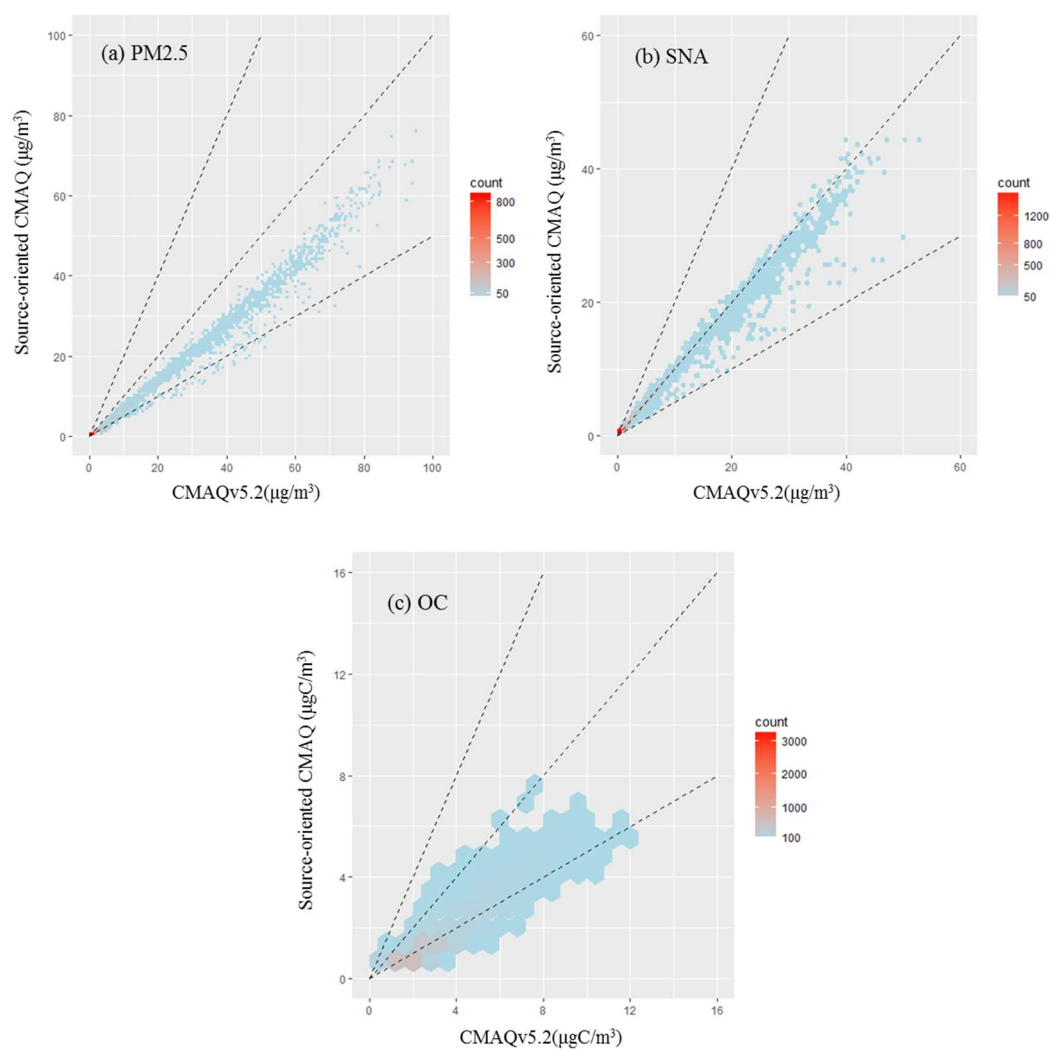
Figure S3. Comparison of the monthly mean concentrations in summer predicted by CMAQ version 5.2 and the source-oriented CMAQ at all grids within China, including: (a) PM$_{2.5}$ (b) SNA (c) OC.

Figure S4. Spatial distributions of SO$_2$ emissions from cargo ships at a resolution of 3 km×3 km (unit, ton/grid) in (a) winter; (b) spring; (c) summer; and (d) fall.

Figure S5. Spatial distributions of SO₂ emissions from containers at a resolution of 3 km×3 km (unit, ton/grid) in (a) winter; (b) spring; (c) summer; and (d) fall.
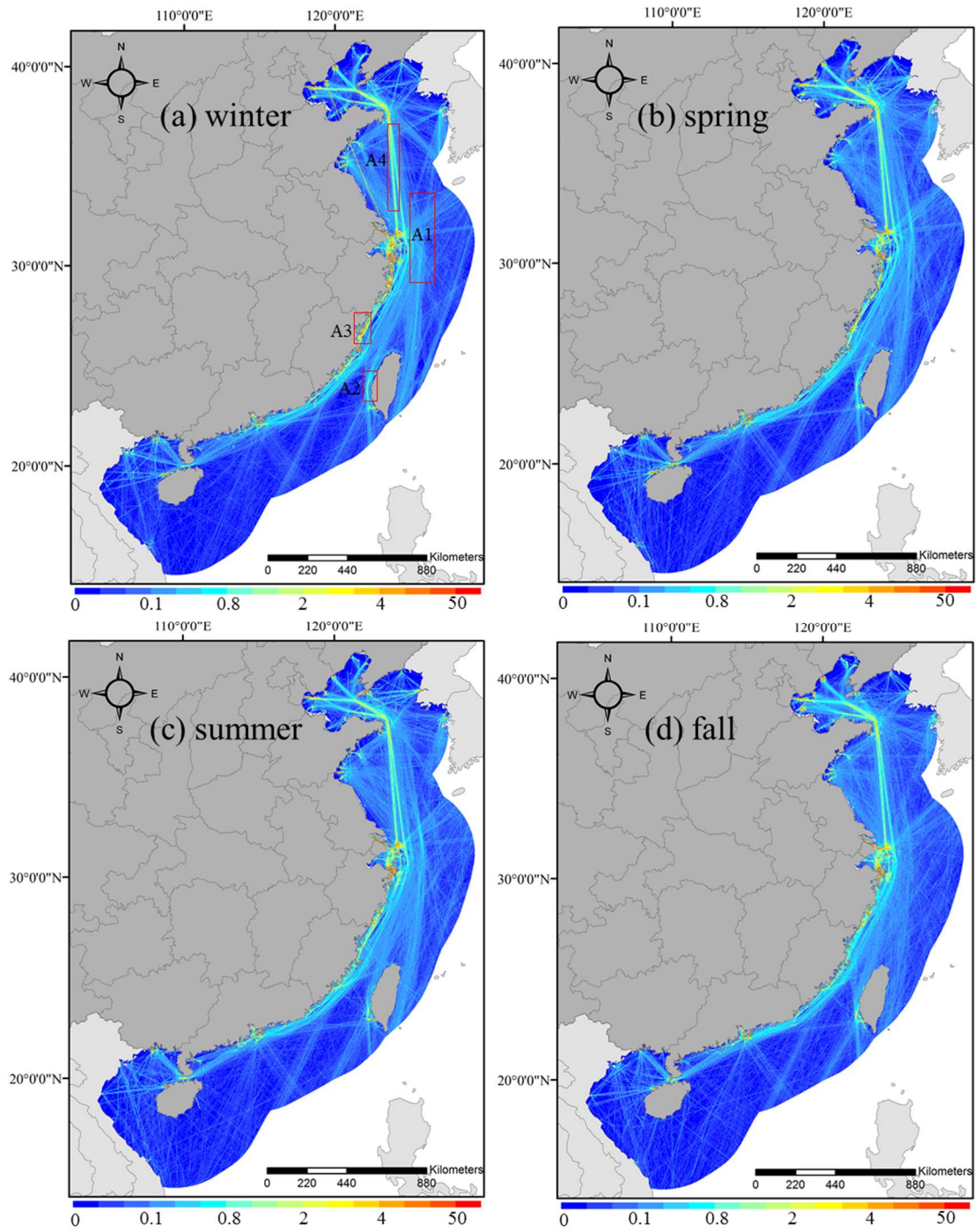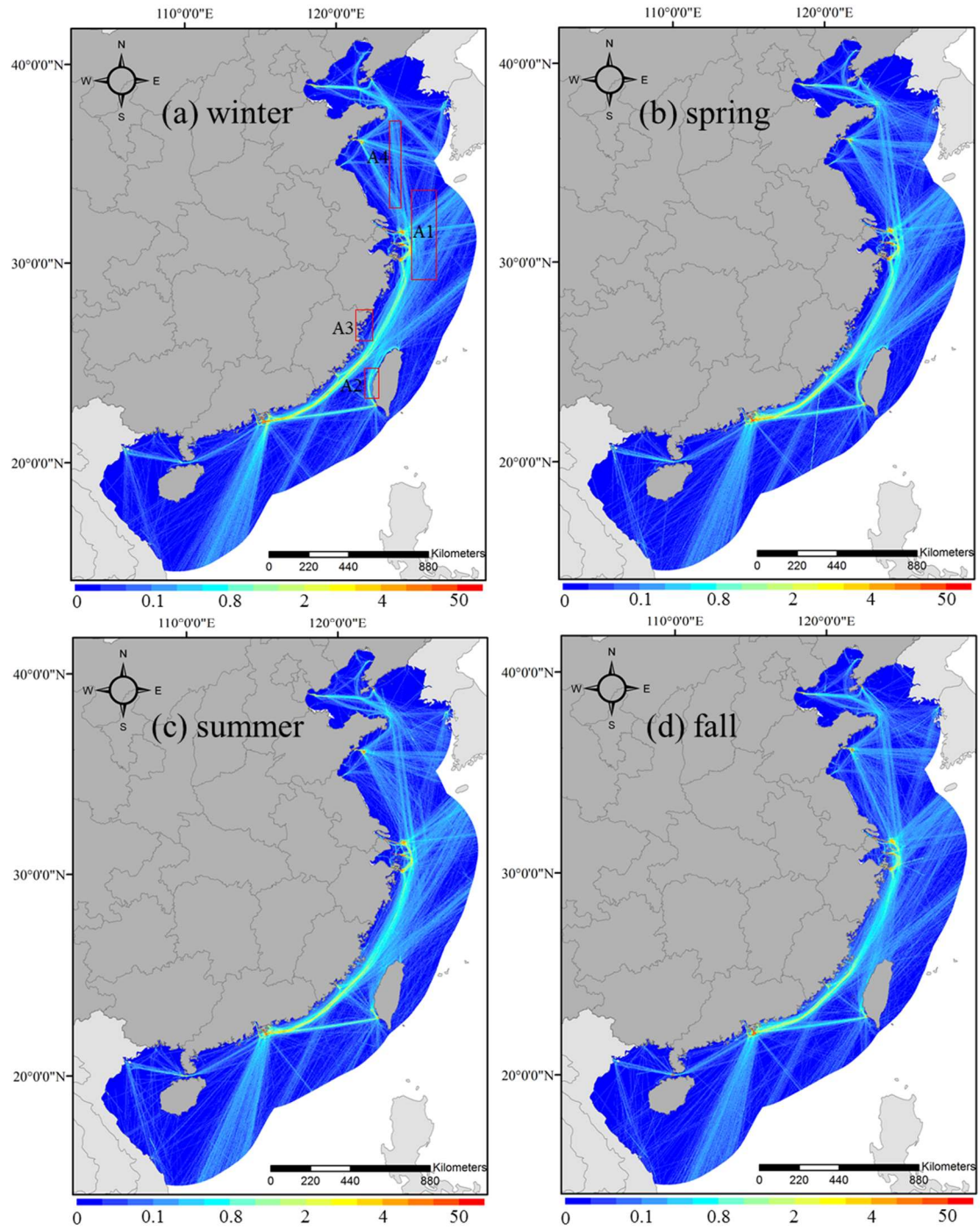
Figure S6. Spatial distributions of SO$_2$ emissions from tankers at a resolution of 3 km×3 km (unit, ton/grid) in (a) winter; (b) spring; (c) summer; and (d) fall.
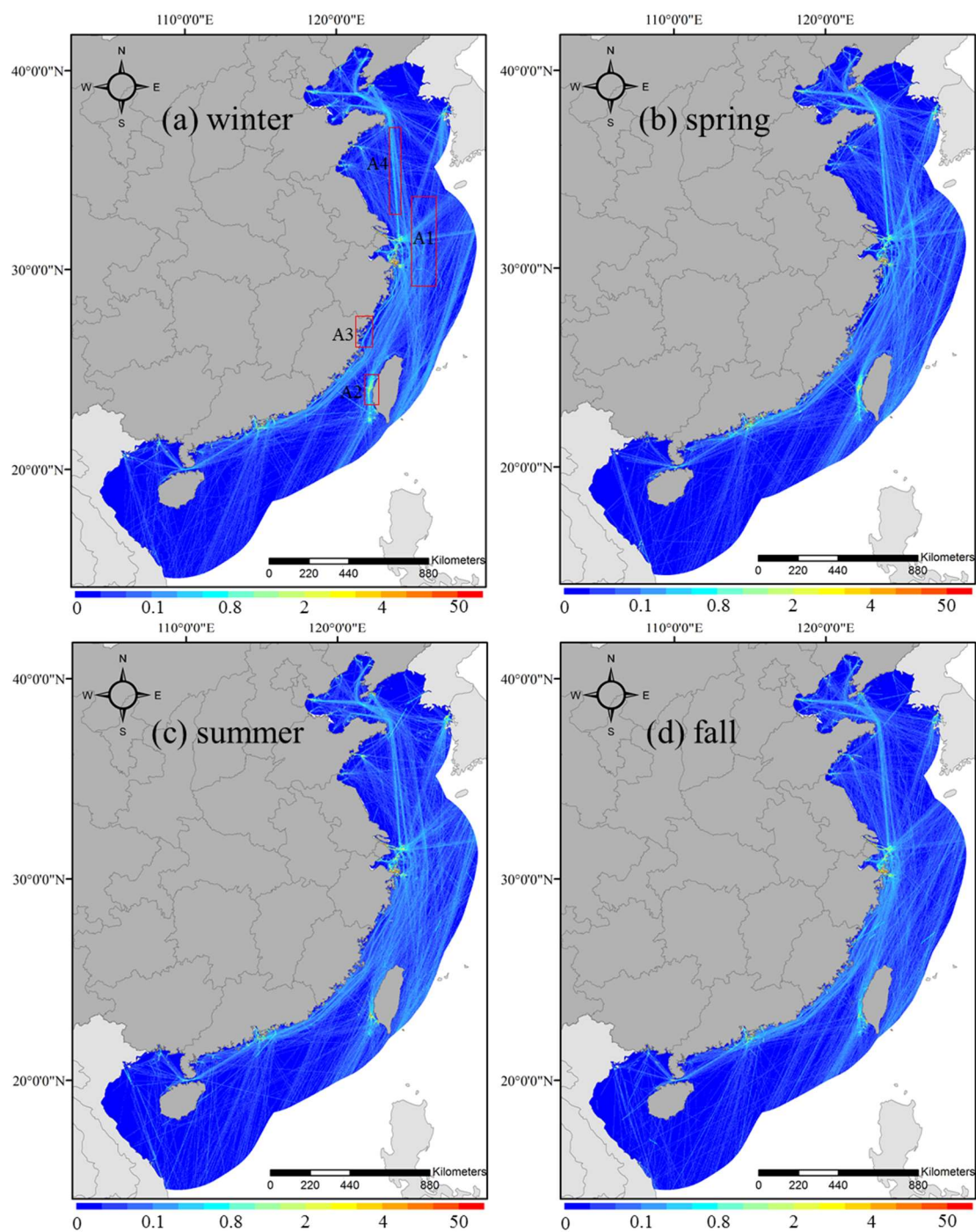
Table S1. Ship types

Ship type		Description (Liu et al., 2016)
Cargo ship	Auto Carrier	Self-propelled dry-cargo vessels that carry containerized automobiles.
	Bulk Carrier	Self-propelled dry-cargo ship that carries loose cargo.
	General Cargo	Self-propelled cargo vessel that carries a variety of dry cargo.
	Reefer	Self-propelled dry-cargo vessels that often carry perishable items.
Container	Container Ship	Self-propelled dry-cargo vessel that carries containerized cargo.
Tanker	Tanker	Self-propelled liquid-cargo vessels including chemical tankers, oil tankers, liquefied gas tanker, etc.
Others	Cruise Ship	Self-propelled cruise ships.
	Miscellaneous	Category for those vessels that do not fit into one of the other categories or are unidentified, including harbor service vessels, fishing boats.
	Oceangoing Tugs/Tows	Self-propelled tugboats and towboats that tow/push cargo or barges in the open ocean.
	RORO	Self-propelled vessel that handles cargo that is rolled on and off the ship, including ferries.

Table S2. Convert factors from total HC (THC) emissions of shipping to lumped species in

CB05 mechanism

Lumped Species	Convert factor (moles/kg THC)
PAR	43.92
OLE	0.70
TOL	0.65
XYL	0.79
FORM	0.01
ALD2	0.00
ETH	0.01
ISOP	0.00
MEOH	0.00
ETOH	0.01
ETHA	0.00
IOLE	0.26
ALDX	0.11
TERP	0.00
UNR	4.66

Table S3. Convert factors from total HC (THC) emissions of shipping to lumped species in SAPRC-07 mechanism

Lumped Species	Convert factor (moles/kg THC)
ACET	1.02
ALK1	0.80
ALK2	0.08
ALK3	0.31
ALK4	1.25
ALK5	3.49
ARO1	0.69
ARO2	0.79
BACL	0.00
BALD	0.00
CCHO	0.00
CRES	0.00
ETHE	0.00
GLY	0.00
HCHO	0.00
IPRD	0.00
ISOP	0.00
MACR	0.11
MEK	0.00
MEOH	0.00
MGLY	0.00
MVK	0.00
OLE1	0.63
OLE2	0.28
PHEN	0.00
PRD2	0.08
RCHO	0.00
TERP	0.00

Table S4. Statistics for meteorological predictions

Statistics	Jan	Apr	Jul	Oct	Annual
T2 (°C)					
MB	-1.0	-0.7	-0.3	-0.9	-0.7
NMB (%)	-15	-4	-1	-4	-6
NME (%)	16	12	6	8	10
R	0.9	0.9	0.9	0.9	0.9
WS10 (m/s)					
MB	-0.4	-0.9	-1.1	-0.8	-0.8
NMB (%)	-9	-21	-28	-23	-20
NME (%)	32	35	38	38	36
R	0.7	0.6	0.7	0.7	0.7
WD10(degree)					
MB	4.5	2.8	0.4	4.0	3.0
NMB (%)	2	1	0	2	1
NME (%)	18	16	18	21	18
R	0.4	0.5	0.5	0.5	0.5
RH (%)					
MB	2.6	4.8	0.9	3.0	2.8
NMB (%)	4	8	1	4	4
NME (%)	17	19	11	14	15
R	0.8	0.8	0.8	0.8	0.8

MB, mean biases; NMB, normalized mean biases; NME, normalized mean errors; R, correlation coefficients.

Table S5. Statistics for PM$_{2.5}$ concentration

Statistics	Jan	Apr	Jul	Oct	Annual
Hourly PM$_{2.5}$ (μg/m^3)					
Mean OBS	90.4	50.7	38.1	53.0	58.3
Mean SIM	118.8	60.3	52.4	72.3	76.2
MB	29.5	10.0	14.1	19.4	18.3
NMB (%)	30	20	42	37	32
NME (%)	67	69	87	77	75
MFB (%)	14	-1	14	17	11
MFE (%)	52	57	61	60	57
R	0.5	0.4	0.3	0.5	0.4

Mean OBS, monthly average of observations; Mean SIM, monthly average of simulations; MB, mean biases; NMB, normalized mean biases; NME, normalized mean errors; MFB, mean fractional bias; MFE, mean fractional error; R, correlation coefficients.

Reference:

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, Nature Climate Change, 6, 1037-1041, 10.1038/nclimate3083, 2016.