Shipping Emissions and Air Quality Impacts in East Asia

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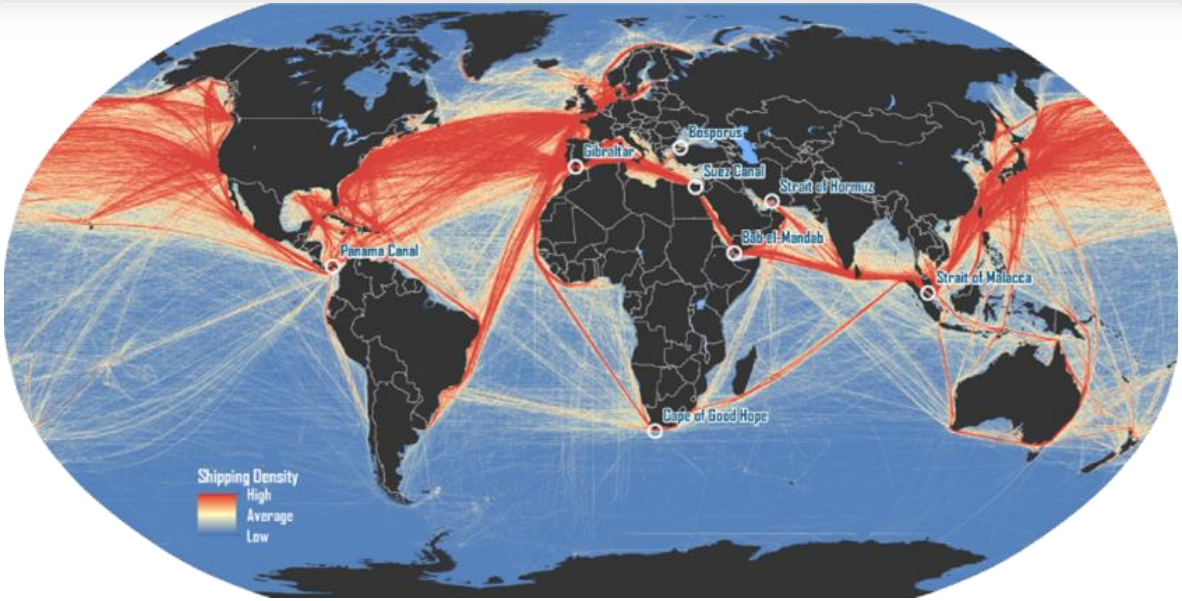
Acknowledgement：Drew Shindell, Kebin He, Mingliang Fu, Xinxin Jin, Greg Faluvegi, Cary Shindell

East Asia Is a Significant Source in Seaborne Trade



CIMSEC.org

- Asia's share of world seaborne trade reached 38.7% and 49.4% for goods loaded and unloaded in 2013

Review of Maritime Transport 2014

- 8 of the Top 10 global container ports are located in East Asia in 2014

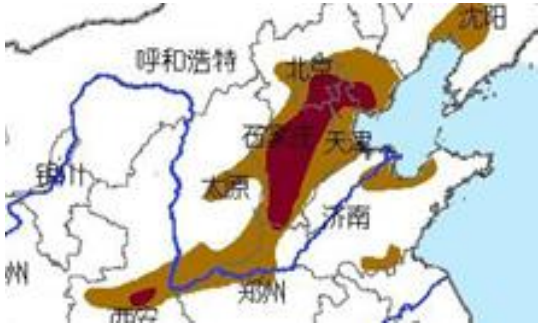
World Shipping Council

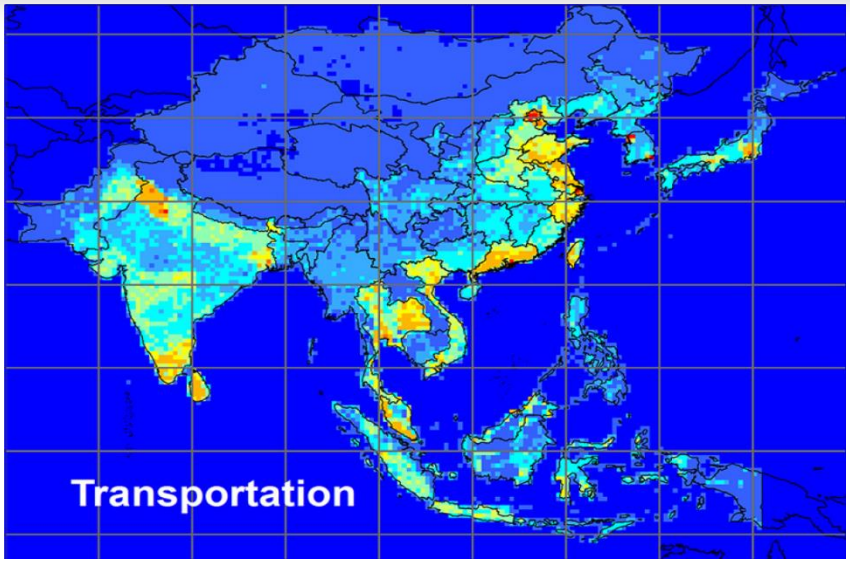
Based on the Demand of the Atmospheric Pollution Control in China

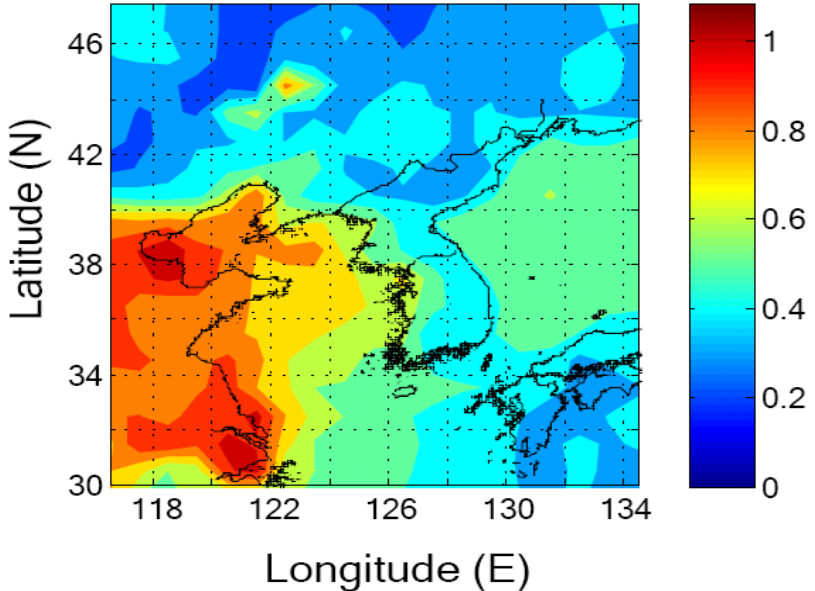
Beijing-Tianjin-Hebei Heavy Pollution Forecast issued by the China Meteorological Administration and the Ministry of Environmental Protection for the first time on Feb 21, 2014

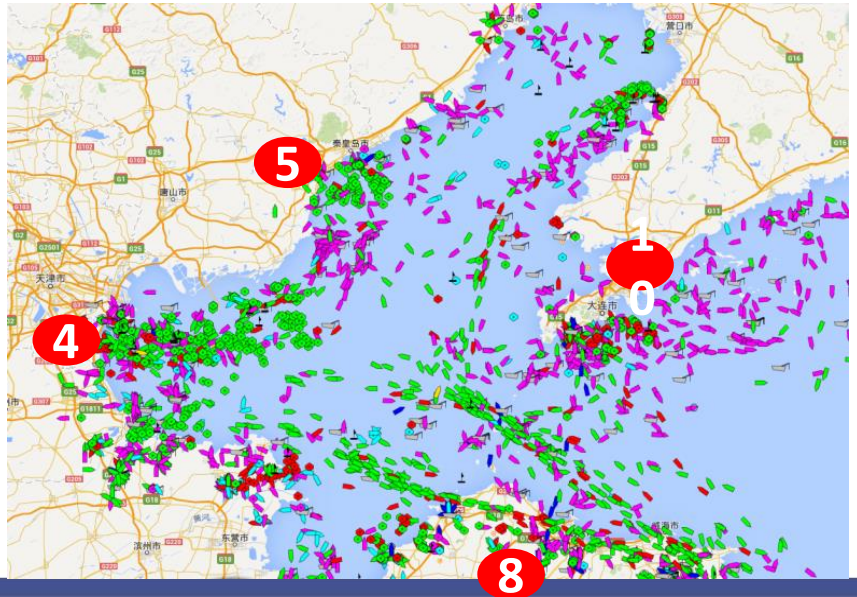
Legend

- Moderate
- Heavy
- Severe









Disaggregate Dynamic Method Based On AIS Data

$$E_{total} = E_{propulsion} + E_{auxiliary} + E_{boiler}$$

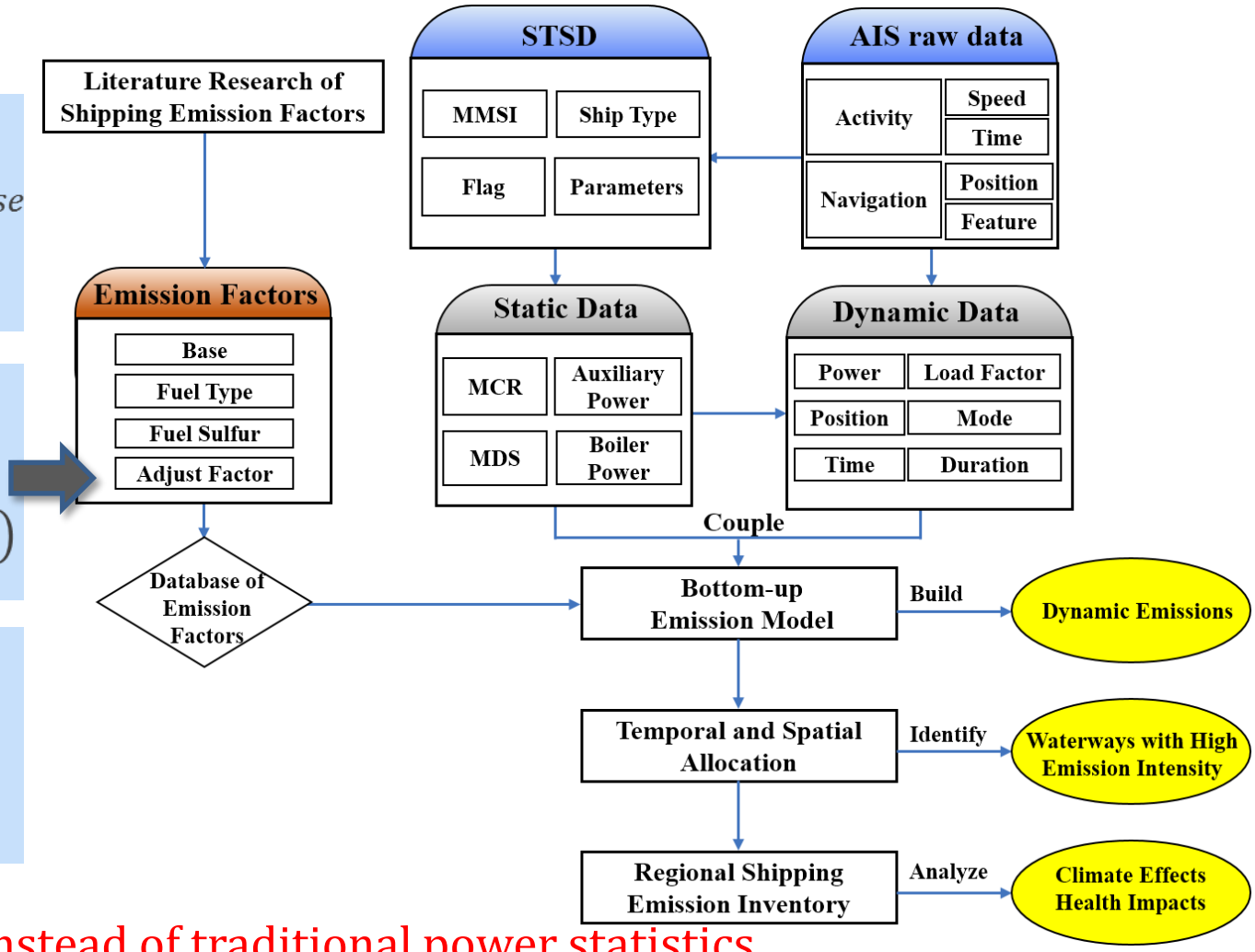
$$E_{propulsion} = MCR \cdot EF_{propulsion\_base} \cdot \sum_T LF_t \cdot A_{LF,t} \cdot \Delta T_t$$

$$+$$

$$E_{auxiliary} =\cdot EF_{auxiliary} \cdot \sum_T \left(P_{auxiliary,i,j} \cdot \Delta T_t\right)$$

$$+$$

$$E_{boiler} = EF_{boiler} \cdot \sum_T \left(P_{boiler,i,j} \cdot \Delta T_t\right)$$



✓ Real-time power instead of traditional power statistics

Static Ship Data

In this study, 65903 vessels by Gradient Boosting Regression Tree

- Lloyd's Register
- China Classification Society
- Other sources

✓ Static ship data includes vessel type, rated engine speed, rated engine power, length, width, height, design max speed, dead weight tonnage (dwt), maximum draught, build year, etc.

Auto Carrier

Bulk Carrier

Container Ship

Cruise Ship

General Cargo

Miscellaneous

Oceangoing Tugs/Tows

RORO

Refrigerator ship

Tanker

In this study, all vessels are divided into **10 OGV types**

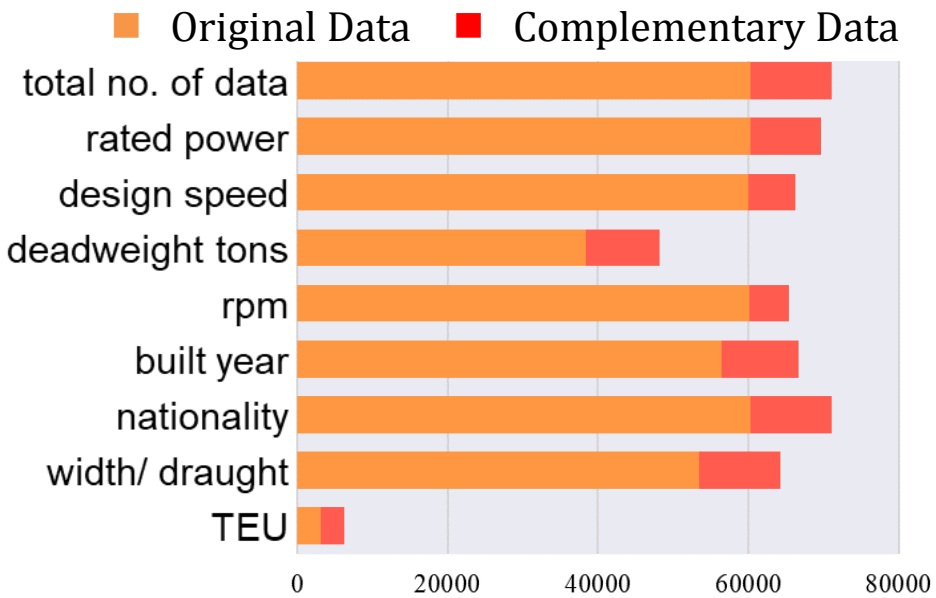
Static Ship Data

- ✓ Lloyd's Register
- ✓ China Classification Society
- ✓ Other sources

Data filtering and integration

- Lloyd's data is more suitable for Europe and the United States
- Many of our ships are registered in other countries

Increase Data Value

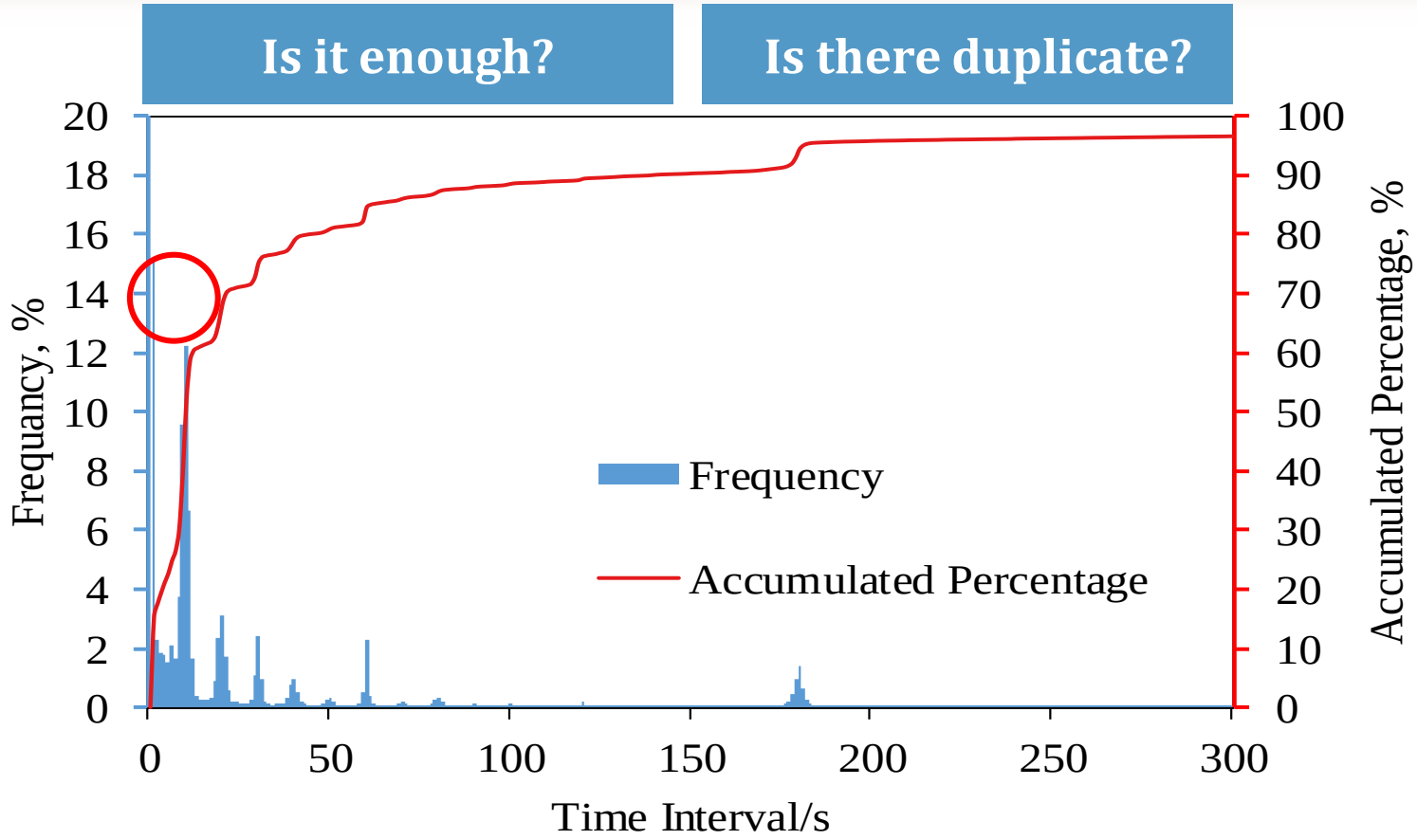


Number of complementary ship data

Optimize Representation

- 4761 container ships, accounting for **95.0%** of a world total of 5014
- **New ship types** such as salvage boats, sludge cleaners and special vessels

Ship Movements Data (the AIS data)



- ✓ **98%** of the intervals: less than **6 minutes** ---- short enough.
- ✓ Duplicate messages ----- Time Sequences Method.

Ship Movements Data (the AIS data)

AIS statistics in East Asia and in the other studies

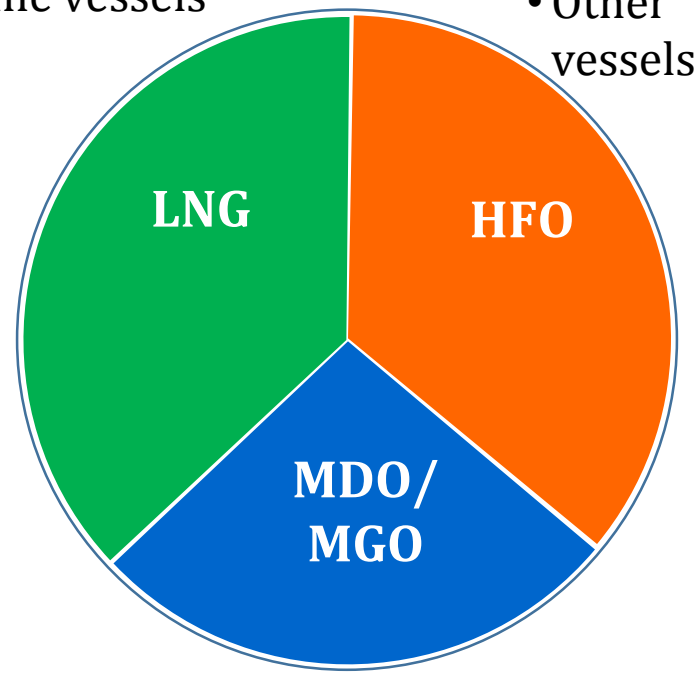
Ship category	Ship number[a]	Ratio of in service[b]	Ships in service	ships observed on AIS	% of in-service ships observed on AIS
Auto Carrier	70	0.93	65	60	92%
Bulk Carrier	1,511	0.93	1,405	1,208	86%
Container Ship	524	0.93	487	391	80%
Cruise Vessel	2	0.93	2	/	/
General Cargo	1,172	0.93	1,090	764	70%
Miscellaneous	1,543	0.96[c]	1,481	649	44%
Tugboat	367	0.96[c]	352	252	72%
RORO	440	0.93	409	344	84%
Reefer	126	0.93	117	35	30%
Tanker	1,387	0.93	1,290	1,007	78%
Sum: Transport ships	5,232	0.93	4,866	3,809	78%
Sum: Non-Transport ships	1,910	0.96	1,833	901	49%

[a] Number of ships registered in East Asia countries; [b] Data is for 2012 transport ships, referenced from the Third IMO GHG study for 2012[7]; [c] Data is for 2012 non-transport ships, referenced from the Third IMO GHG study for 2012[7].

Fuel types and sulfur contents

Fuel types

- LNG Otto-cycle engine vessels
- Other vessels



- Harbor service vessels, such as work vessels, tugs, crew boats, etc.

Fuel sulfur contents in this study

- ✓ No specific Sulfur control regulation was assigned in this area as mandatory in 2013.
- ✓ Sulfur content for HFO: 2.43%, MDO/MGO: 0.13%

IMO, MEPC 67/20, 2014

Emission factors for different engines

Emission factors for main engine, g/kW· h

Engine type	Fuel type	Tier	Model Year	PM	NOx	SO_2	CO	NMVOC	CO_2	N_2O	CH_4
SSD [a]	HFO (2.43% Sulfur content)	Tier 0 [d]	≤ 1999	1.335	18.1	9.261	0.54	0.6	607	0.031	0.012
MSD [b]			≤ 1999	1.330	14	10.215	0.54	0.5	670	0.034	0.01
SSD [a]		Tier 1	2000-2010	1.335	17	9.261	0.54	0.6	607	0.031	0.012
MSD [b]			2000-2010	1.330	13	10.215	0.54	0.5	670	0.034	0.01
SSD [a]		Tier 2	2011–2015	1.335	15.3	9.261	0.54	0.6	607	0.031	0.012
MSD [b]			2011–2015	1.330	11.2	10.215	0.54	0.5	670	0.034	0.01
SSD [a]	MDO/ MGO (0.13% Sulfur content)	Tier 0 [d]	≤ 1999	0.199	17.0	0.515	0.54	0.6	607	0.031	0.012
MSD [b]			≤ 1999	0.200	13.2	0.568	0.54	0.5	670	0.034	0.01
SSD [a]		Tier 1	2000-2010	0.199	16.0	0.515	0.54	0.6	607	0.031	0.012
MSD [b]			2000-2010	0.200	12.2	0.568	0.54	0.5	670	0.034	0.01
SSD [a]		Tier 2	2011–2015	0.199	14.4	0.515	0.54	0.6	607	0.031	0.012
MSD [b]			2011–2015	0.200	10.5	0.568	0.54	0.5	670	0.034	0.01
Otto [c]	LNG	na	all	0.03	1.3	0.003	1.3	0.5	457	0.018	8.5

a b c mean Slow speed diesel engine, Medium speed diesel engine and Otto-cycle LNG-fueled engine, respectively.
d IMO Tier 0 refers to all ships constructed prior to 1st,Jan, 2000 which did not have an IMO Tier requirement at the time of construction

✓ **Emission factors for different engines are from:**

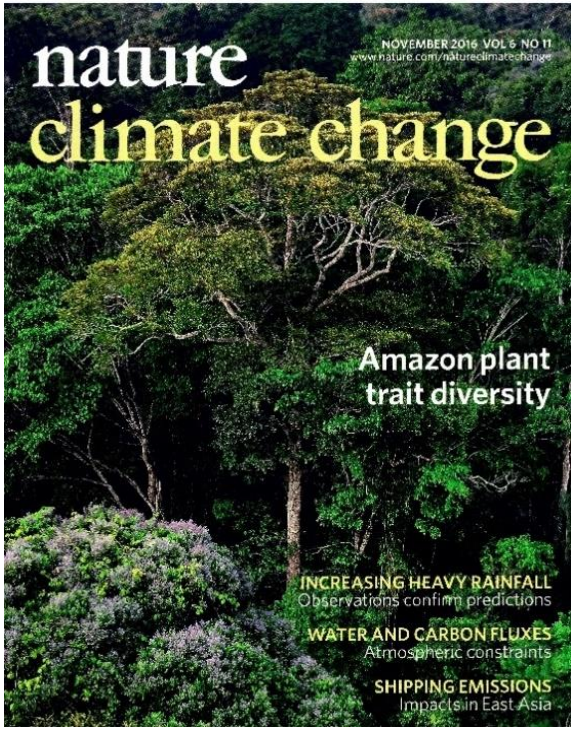
1. **ME**
   - Third IMO Greenhouse Gas study
   - IMO study
   - Lack et al
2. **AB**
   - Third IMO Greenhouse Gas study 2014
3. **AE**
   - Third IMO Greenhouse Gas study 2014
4. **Adjus-tment factors**
   - EEA
   - EPA

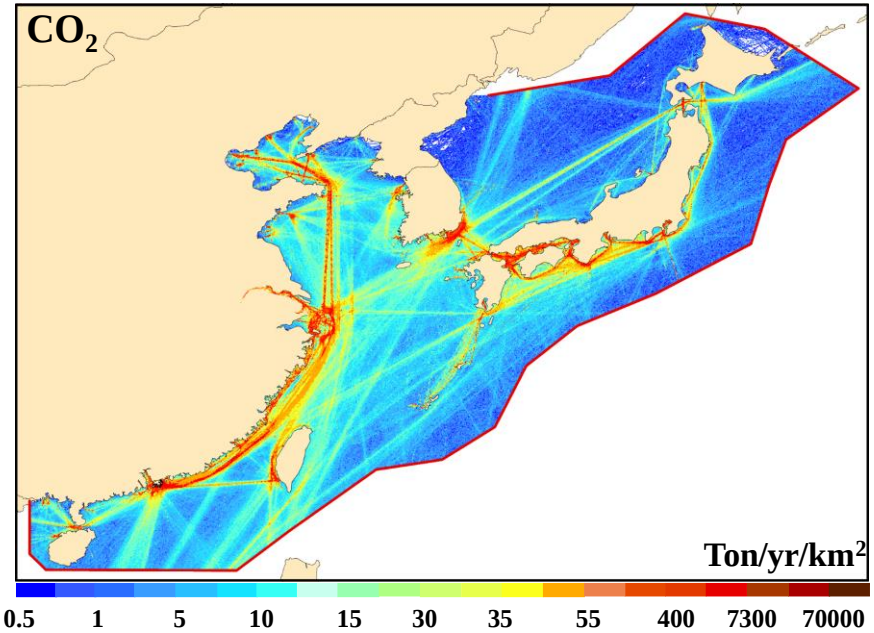
Temporal and spatial distribution and atmospheric environmental effects of marine vessels' emissions

nature climate change

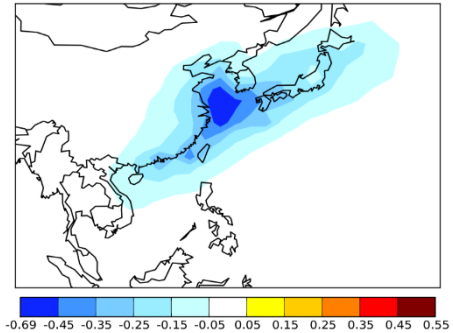
Health and climate impacts of ocean-going vessels in East Asia

Huan Liu, Mingliang Fu, Xinxin Jin, Yi Shang, Drew Shindell, Greg Faluvegi, Cary Shindell and Kebin He. Vol 6 (NO 11), 2016, 6, 1037-1041.

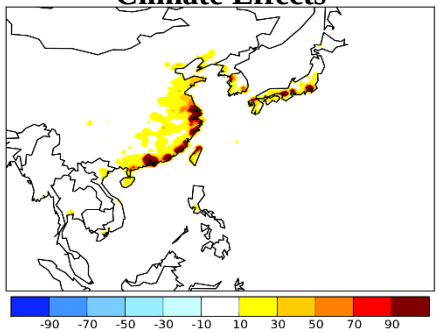




Temporal and Spatial Distribution and Regulatory Effects of Emissions

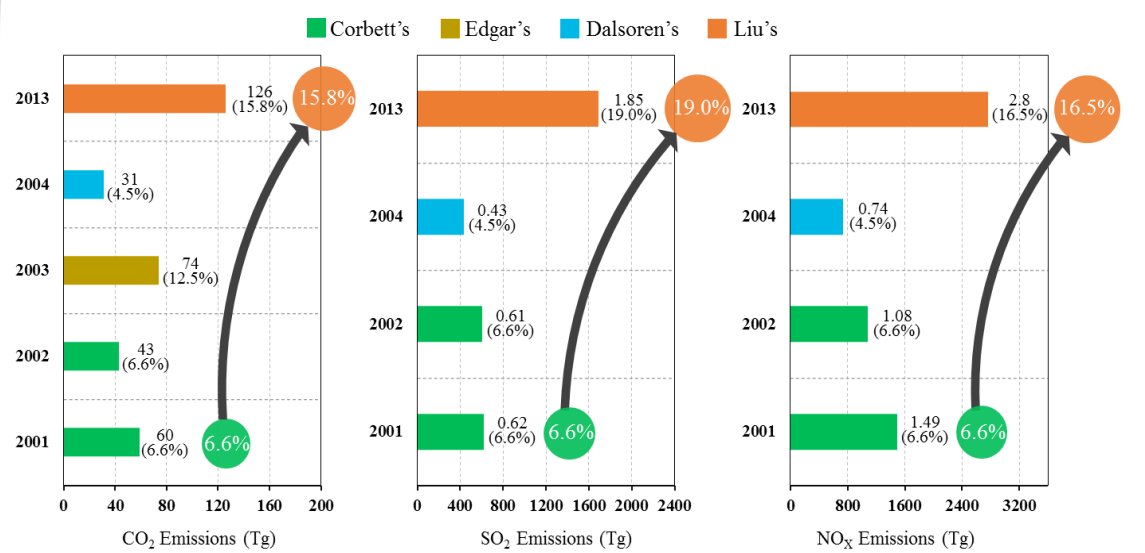


Medium-scale Long-term Climate Effects



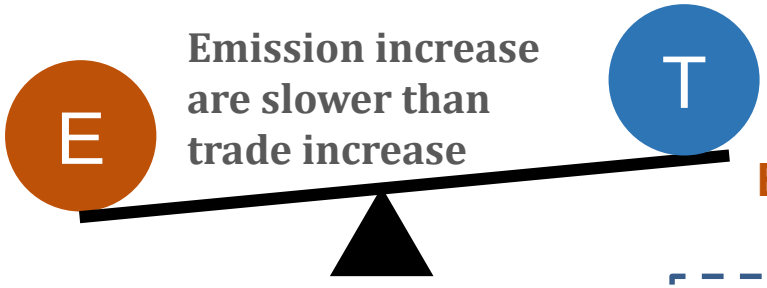
Number of Premature Deaths affected by Ship Emissions

Results: Growth of Shipping Emissions in East Asia



4-7% of global shipping emissions in the early 2000s

→ update the contribution of East Asia to **14%-19%**.



Emission increase are slower than trade increase

Trade | **Seaborne trade: 2.62 times from 2003 to 2013 (90,003,566 to 236,285,057 TEU) in East Asia.**

Emission | **Emissions: 1.7 times for 2003 to 2020**

1. Improvements in engine efficiency.

2. Missing some small ships.

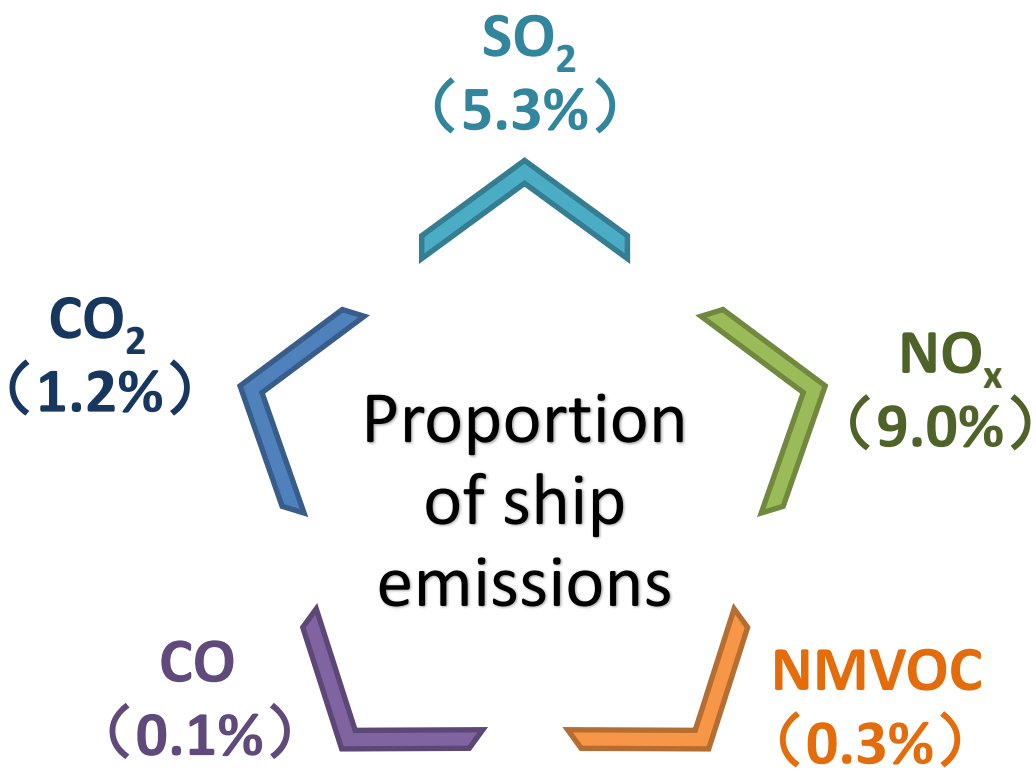
Emission increases are not consistent for different pollutants (1.85 times for NOx, 2.7 times for SO_2, 1.7 for CO_2).

Our bottom-up method accounts for differences in regional distribution proxy, while previous word used the same spatial distribution proxy as CO_2.

Results: Comparison with Land-based Emissions

- ✓ **Ship emissions of East Asia in 2013 are about 0.1%~5.3% of total emissions from all sources in 2008(depending on pollutants).**

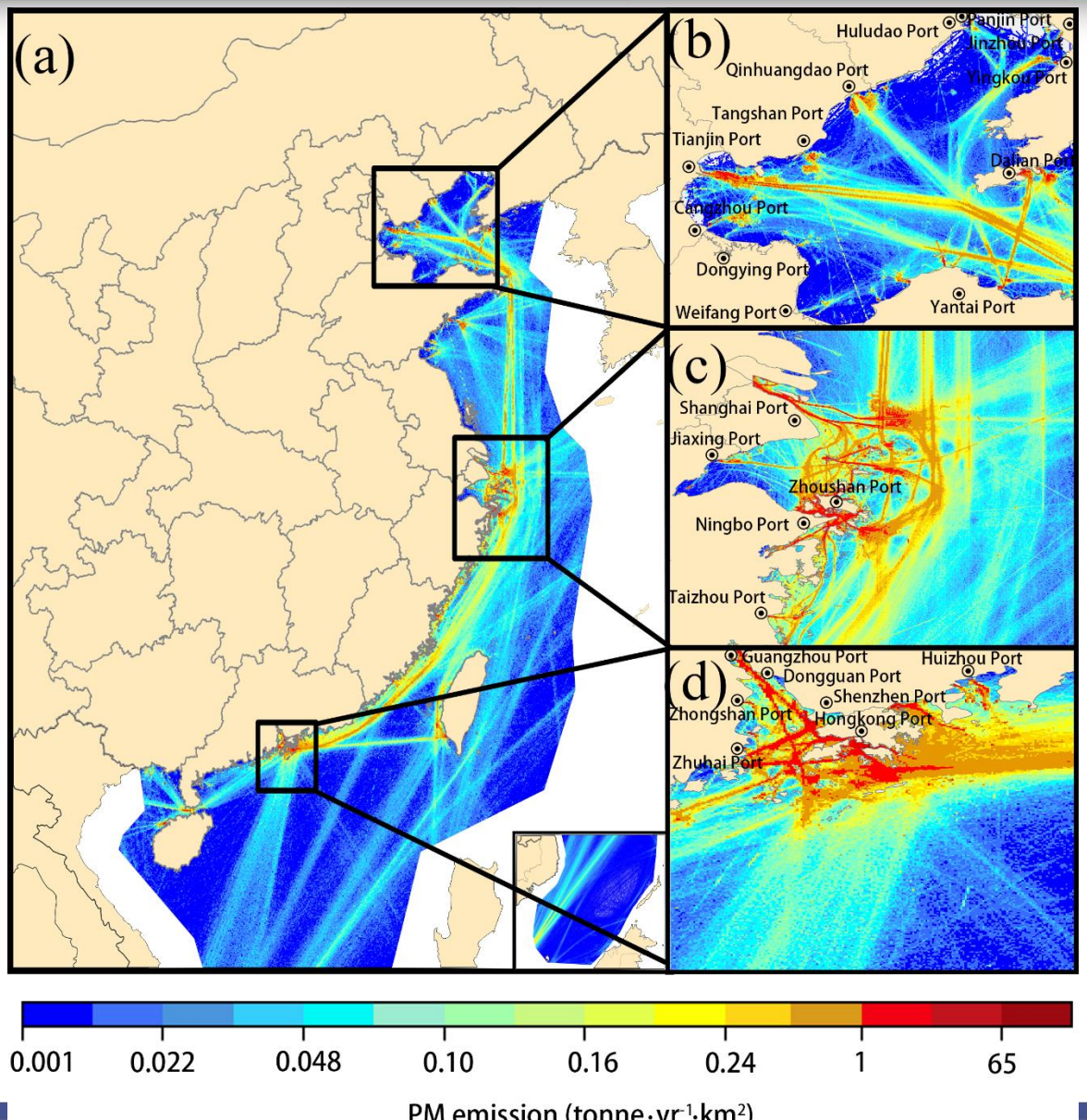
- ✓ Land-based emission inventory: the latest update in REAS 2.1.



Results： Ship emissions in China and regions

- ✓ China 2013 (Tg yr^{-1}):
  NO_x 1.91±0.01,
  PM 0.164±0.001
  SO_2 1.30±0.01
  CO_2 86.3±0.3

- ✓ 9%, 11%, 11%, 12%, 13% and 11% global shipping emissions of CO, NMVOC, NO_x, PM, SO_2 and CO_2 (IMO report 2015)



8% Area

37% Emissions

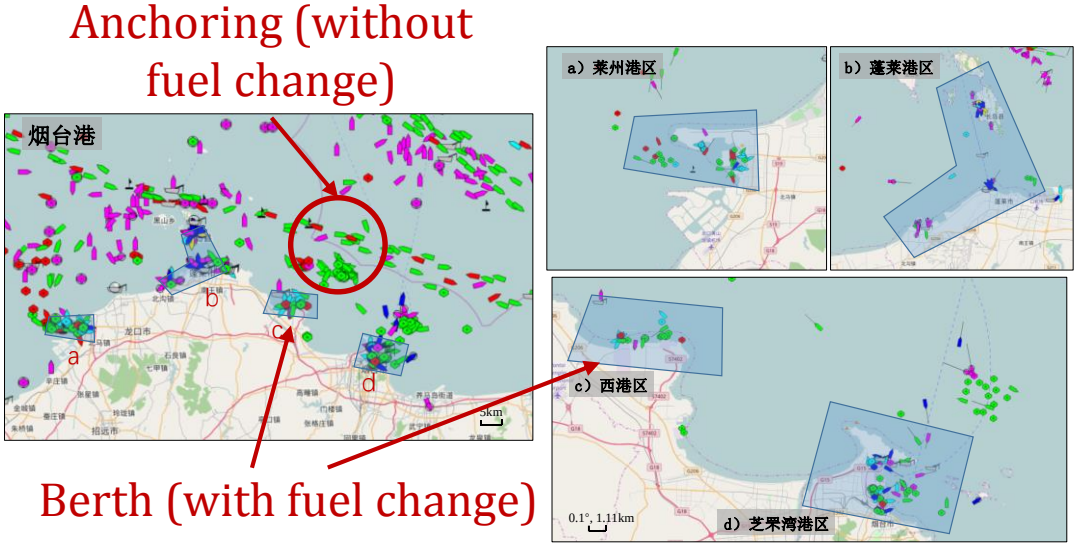
Fu, M., Liu, H.*, Jin, X., & He, K. (2017). National-to port-level inventories of shipping emissions in China. *Environmental Research Letters*.

Division method of port range

- ✓ Artificially divide berths (districts) in each port
  - Based on port maps and dynamic positioning of ships
  - 25 ports, 71 districts
- ✓ High-resolution AIS data to match the driving state of ships in port
  - Increase the AIS data resolution to get a high-resolution inventory
  - Port division and resolution of inventory: 0.01° ×0.01
- ✓ Match the emissions of auxiliary engine and boiler in port

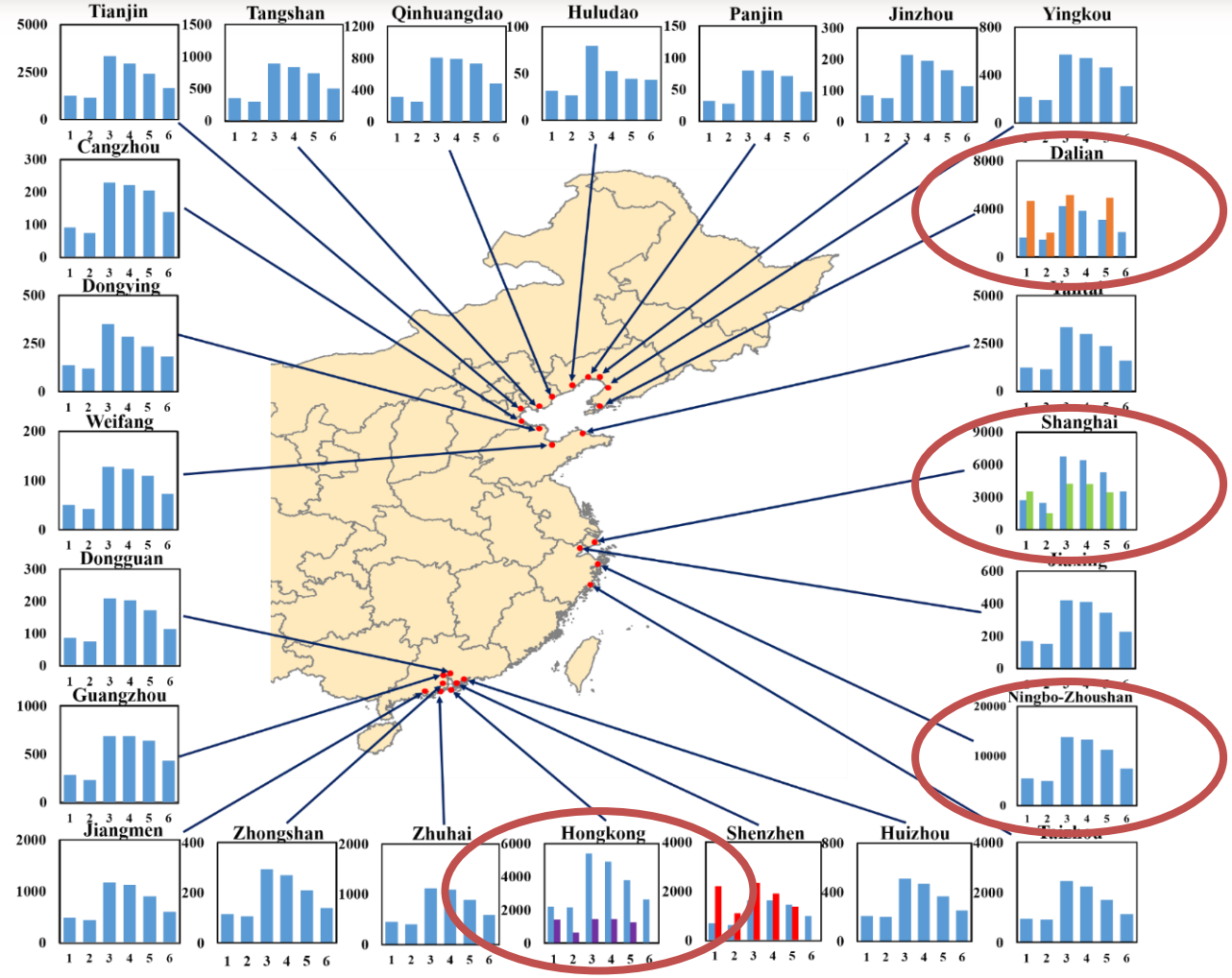
Number of berths in each area

Area	No. of Berths
Core ports in BRA	10
Non-core ports in BRA	15
Core ports in YRD	23
Non-core ports in YRD	3
Core ports in PRD	13
Non-core ports in PRD	7
Total	**71**



Berth division and dynamic positioning of ships in Yantai Port

Results：Ship emissions in ports



1, 2, 3, 4, 5, 6 on *X-axis* represent CO, NMVOC, NOx·10^{-1}, PM, SO_2·10^{-1}, CO_2·10^{-6} respectively; *Y-axis* is the shipping emission in terms of tonne.

This study Fu *et al* 2012 Ng *et al* 2013 Yang *et al* 2015 Tan *et al* 2014

23-147 times higher than from the Port of Los Angeles

Fu, M., Liu, H.*, Jin, X., & He, K. (2017). National-to port-level inventories of shipping emissions in China. *Environmental Research Letters*.

Prediction method of ship emissions

■ Idea: extrapolate 2020 inventory from 2013 inventory

Three Core Factors in Ship Emission Prediction

Ship emis-sions

$$= \sum \left(\sum_T LF_t \cdot A_{LF,t} \cdot \Delta T_t \right)$$

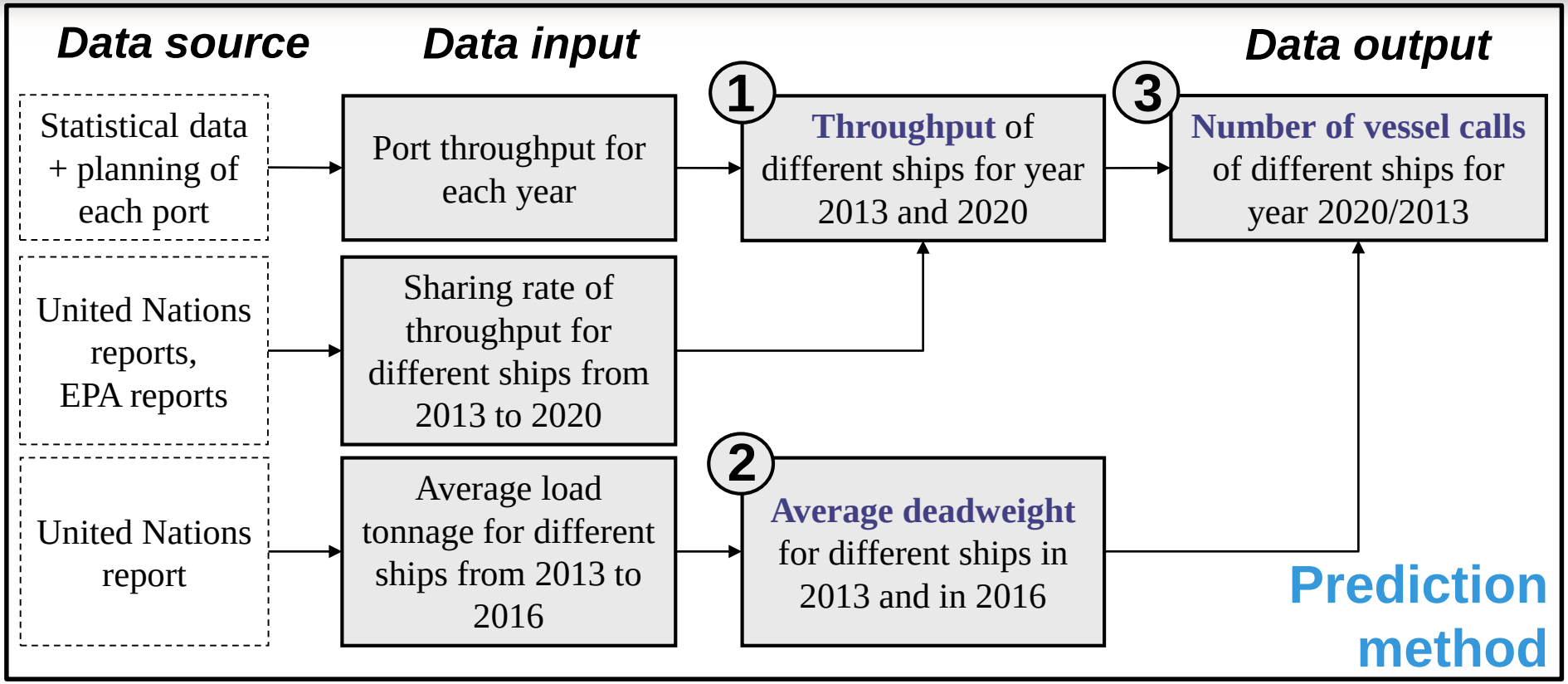
$$E_{propulsion} = MCR \cdot EF_{propulsion\_base} \qquad E_{auxiliary} = \cdot EF_{auxiliary} \qquad E_{boiler} = EF_{boiler}$$

$$+ \cdot \sum_T \left(P_{auxiliary,i,j} \cdot \Delta T_t \right) + \cdot \sum_T \left(P_{boiler,i,j} \cdot \Delta T_t \right)$$

- ✓ 1.Rated power→MCR
  - Ship emissions are proportional to the rated power MCR
- ✓ 2.Vessel calls
- ✓ 3.Fuel consumption of the fleet (requirements of fuel consumption of new ship by IMO)
  - Changes of fuel consumption reflects engine technology improvement
  - The data for the emission factor under this scenario is missing
  - We use the improvement of fuel consumption to represent the impact of technological progress, and we think **emissions are proportional to fuel consumption**

Next: respective analysis of the impact of **3 core factors** on ship emissions

Prediction of vessel calls growth



$$\text{Number of Voyages}_i = \frac{\textit{Total tonnes of cargo moved}_i}{\textit{average DWT}_i \cdot \textit{utilization rate}}$$

Assume that the no-load rate is constant

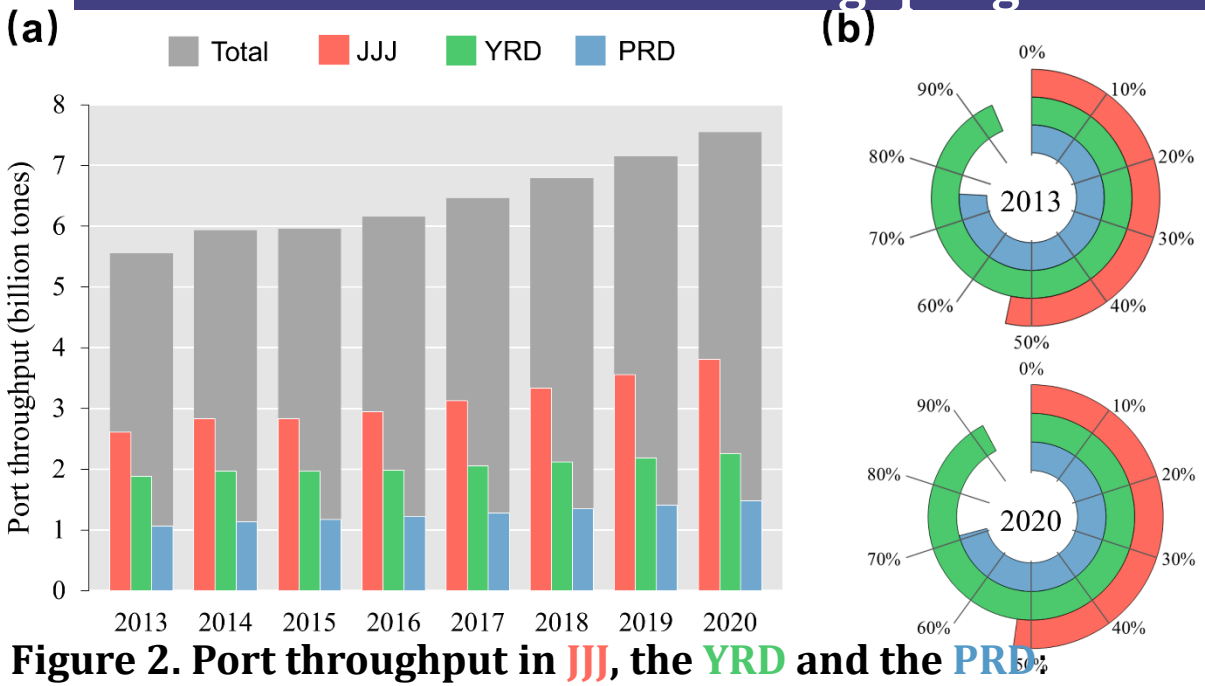
- ✓ Assuming that the no-load rate of each ship is constant, the number of vessel calls is determined by the **throughput** and the **average deadweight**

EPA, 2009; UNCTAD, 2012-2016; Regional development planning

Prediction of vessel calls growth

- ✓ Prediction of throughput for different ships in each port
  - Historical throughput: 25 ports from 2013~2015; 11 ports in 2016
  - Planning throughput (2020): 19 ports have target values with an annual growth rate; Other ports have an annual growth rate of 4% (*from research of Ministry of Transportation*)
  - The sharing rate of throughput for different ships in 2013 and 2020: United Nations reports and EPA reports

Prediction of throughput growth in each port



- ✓ From 2013 to 2020, the throughput in JJJ, the YRD and the PRD increased by **46%**, **20%** and **40%**, respectively.
- ✓ Some non-core ports are growing faster

Figure 2. Port throughput in JJJ, the YRD and the PRD:
(**a**) Port throughput projections from 2013 to 2020; (**b**) the proportion of core ports in 2013 and 2020.

EPA, 2009; UNCTAD, 2012-2016

Thank You!

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