Singapore Maritime Research Conference (SMRC) 2025

Unlocking Insights with Big Data for Clean and Decarbonized Shipping

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Newton Advanced Fellowship by the Royal Society

National Science Foundation for Distinguished Young Scholars

Tsinghua University, China

Global shipping emission growth

Phase 1 (before 2008)

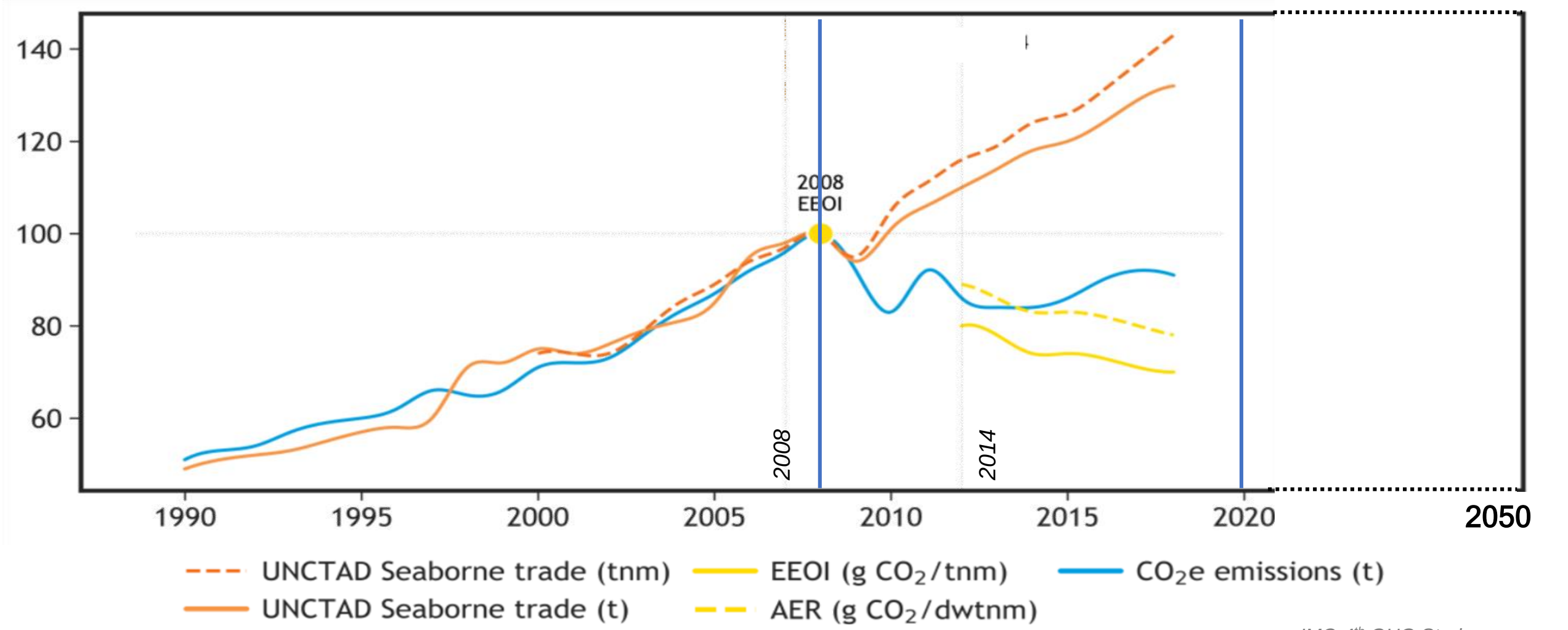
Phase 2 (2008-2020)

Phase 3 (2020 to now)

Emission growth

Emission control

Deep transition



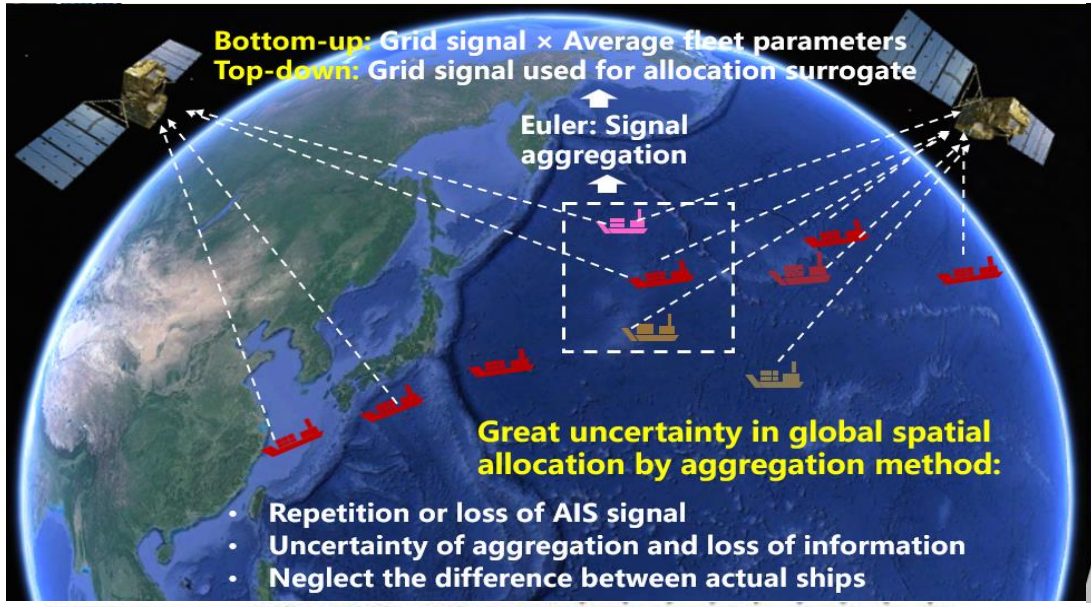
IMO 4th GHG Study

Difficulties in accurately quantifying shipping emissions

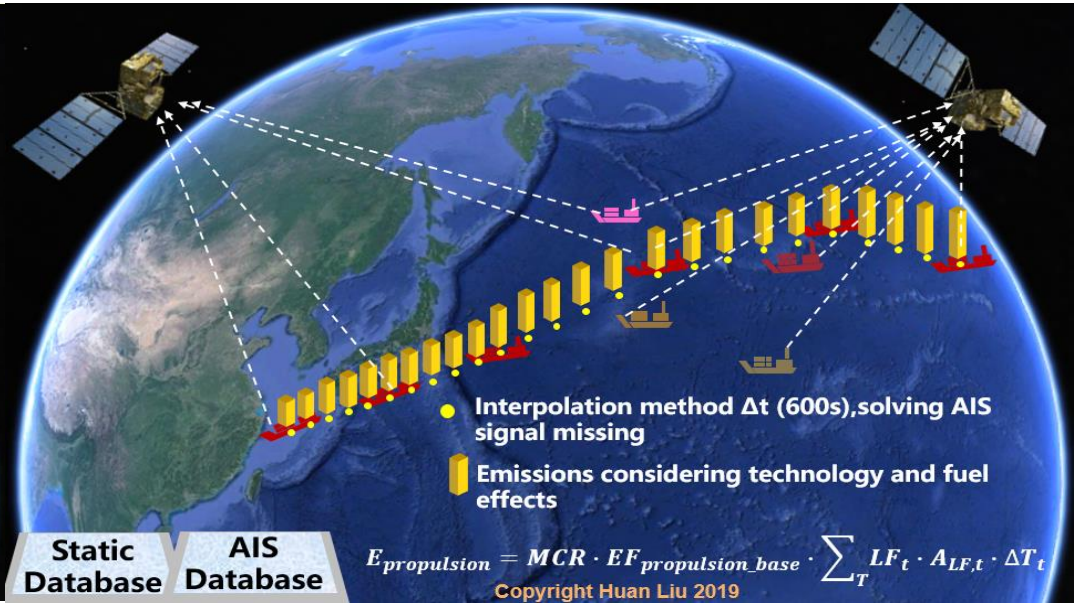
- Changing navigational state: position, speed, heading, etc.
- Complex technical parameters: main engine power, design speed, etc.
- Various marine fuel type: HFO, MGO, LNG, etc.
- Emissions reduction policies: ECA, energy efficiency, emission limits, etc.

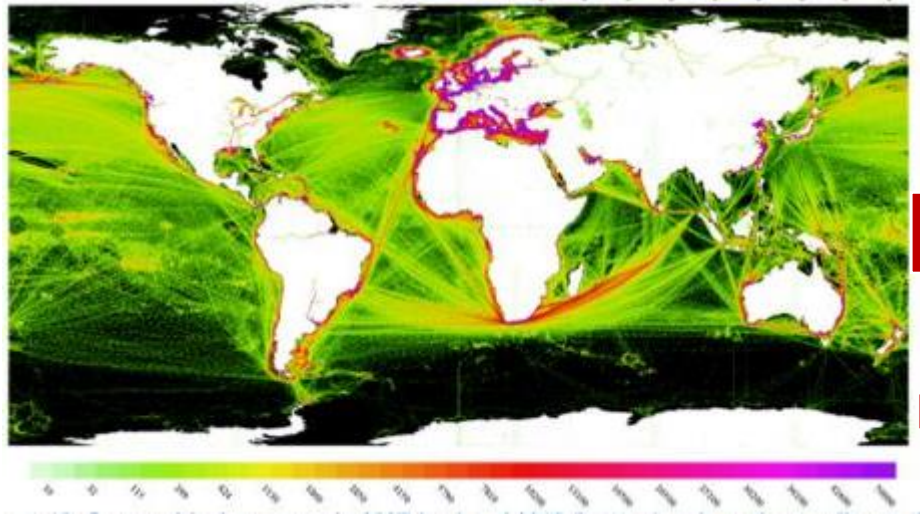
Establishment of SEIM (Shipping Emission Inventory Model)

Second generation: Euler Model

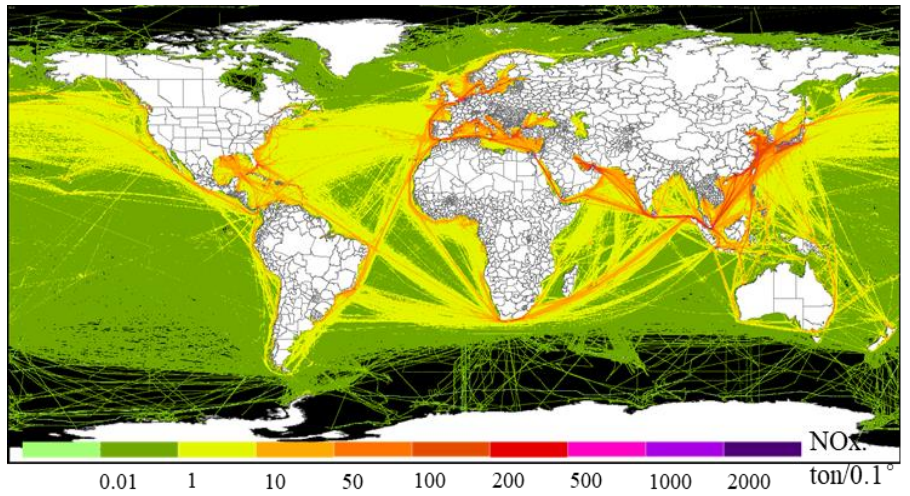


Third generation: Disaggregate dynamic method





IMO, 2012



SEIM, 2013

Liu et al., Nature Climate Change, 2016

Development of SEIM

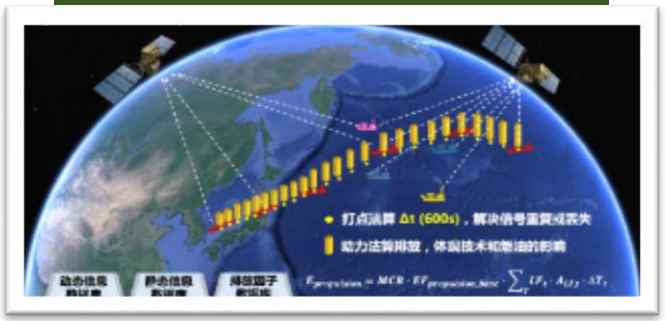
Shipping Emission Inventory Model (SEIM)

Nature Climate Change, 2016 (SEIMv1.0); Atmospheric Chemistry & Physics, 2021 (SEIMv2.0); Earth System Science Data, 2024 (SEIMv2.2);

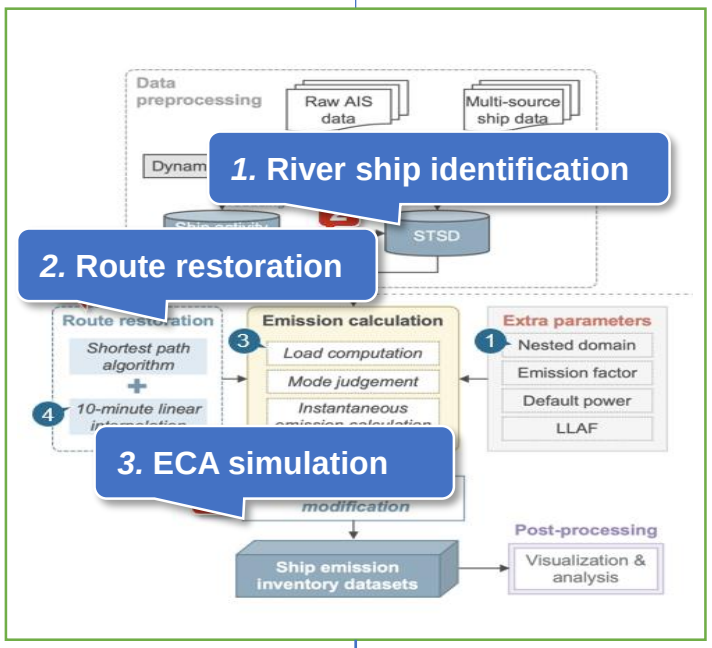
SEIMv1.0

Emission factor database + Global ship AIS database + Ship technical specifications database

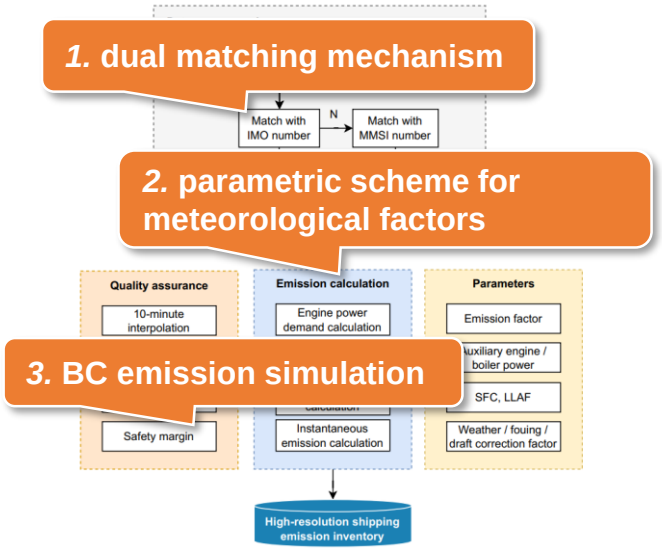
disaggregated dynamic method



SEIMv2.0

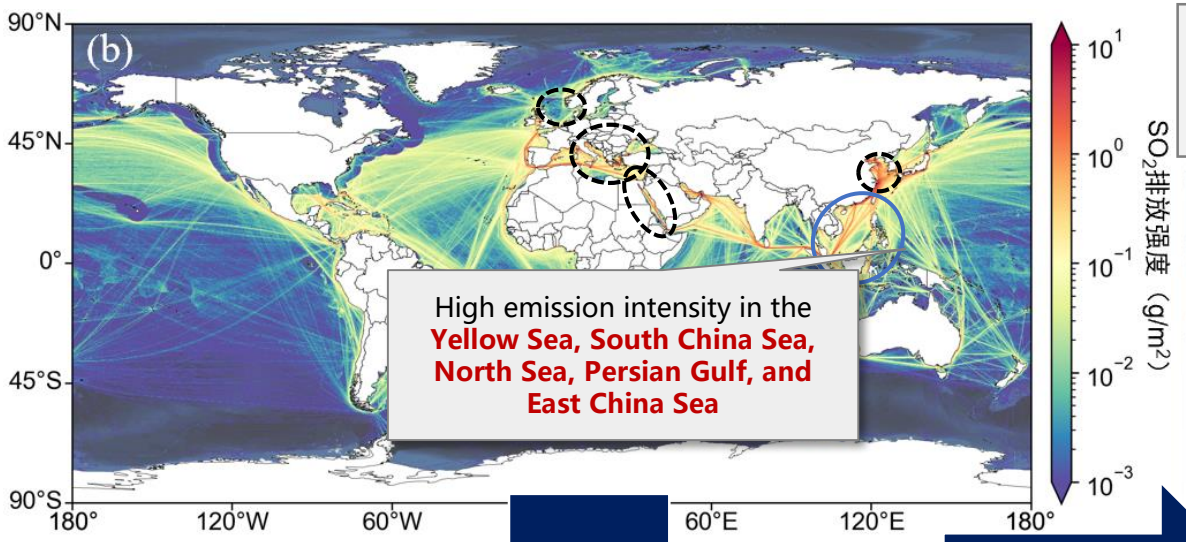


SEIMv2.2

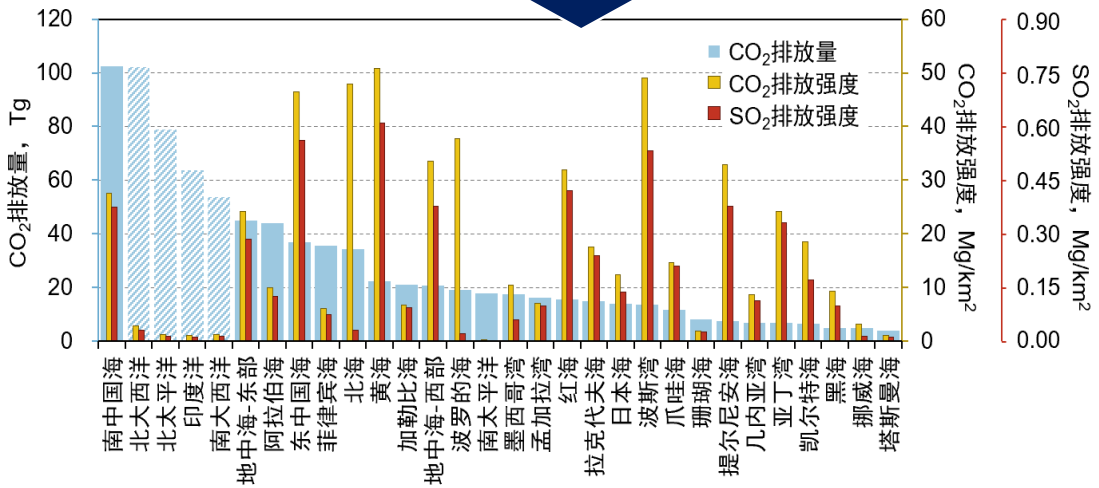


High-resolution ship emission inventories supporting multi-level demands

SEIM：Characteristics of global shipping emission



By area

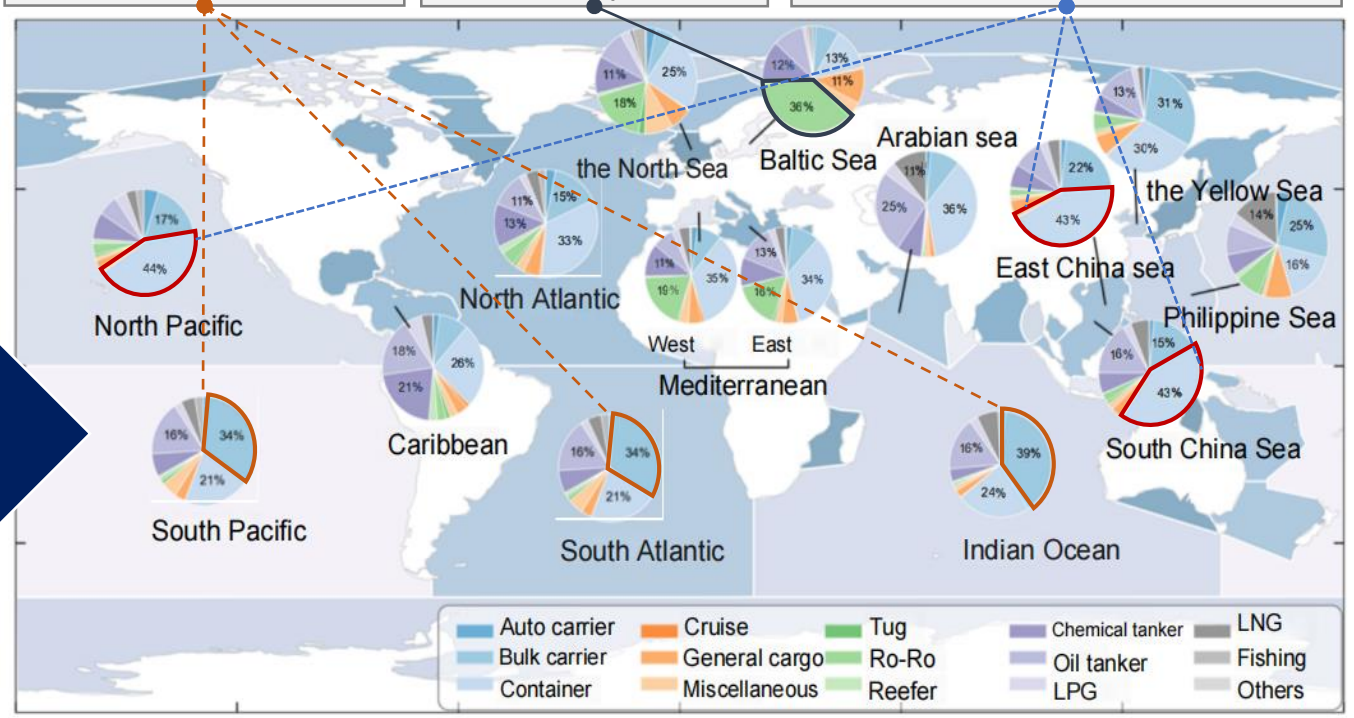


By ship category

Bulk carriers are major emiters in the Southern Hemisphere

Roll-on/roll-off ships (Ro-Ros) are major emiters near Europe

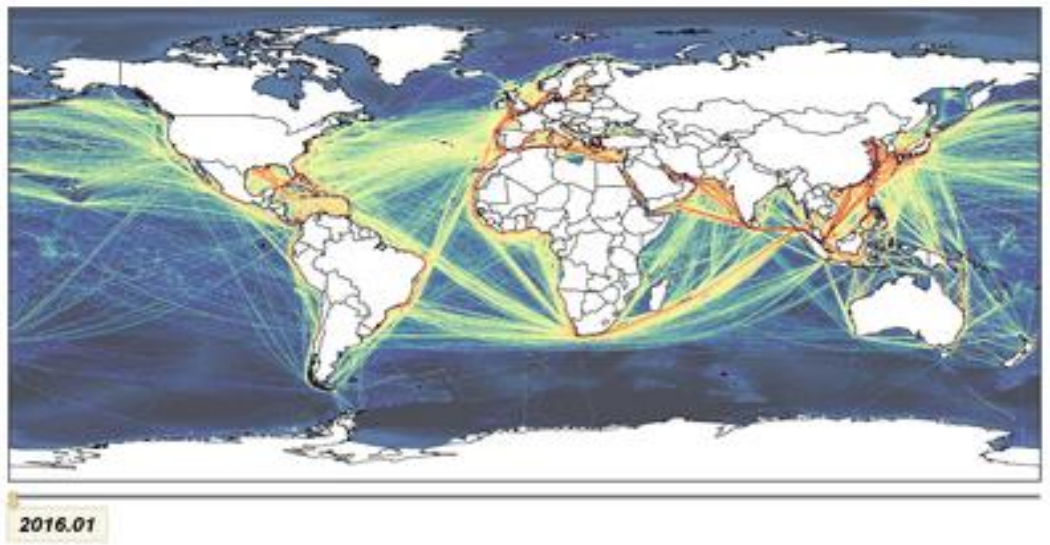
The emission contribution of **container ships** is>40%, higher than the global average (31%)

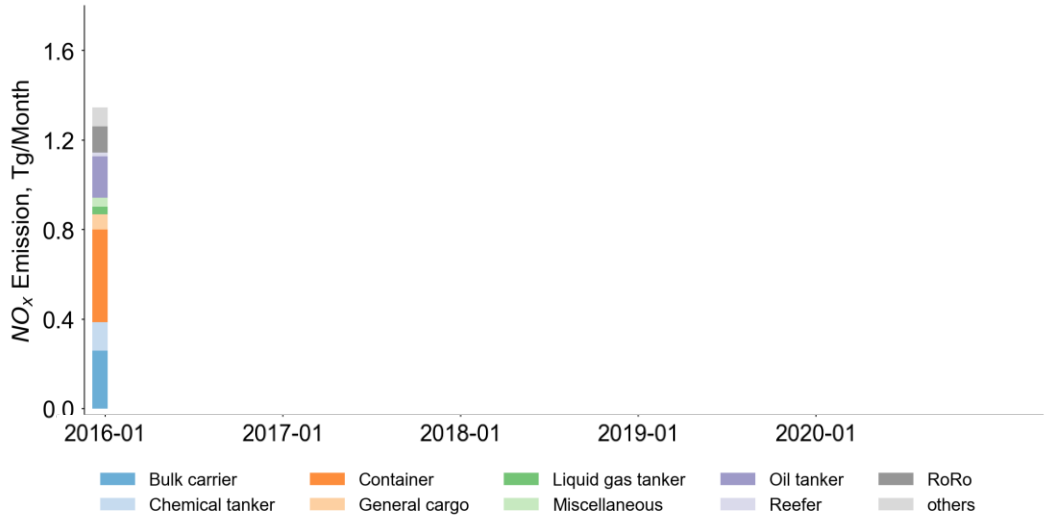


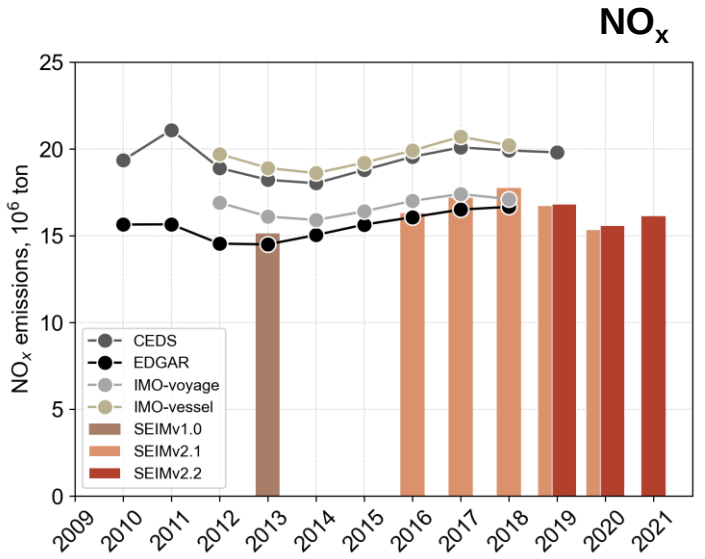
Regional cooperation for emission reduction & **tailored emission reduction measures** based on local conditions are both important.

Yi & Wang, et al., Earth System Science Data, 2024

SEIM：Global shipping emission real-time variation







Model version

SEIMv1.0

SEIMv2.0

SEIMv2.2

Similar study

CEDS

EDGAR

IMO-voyage

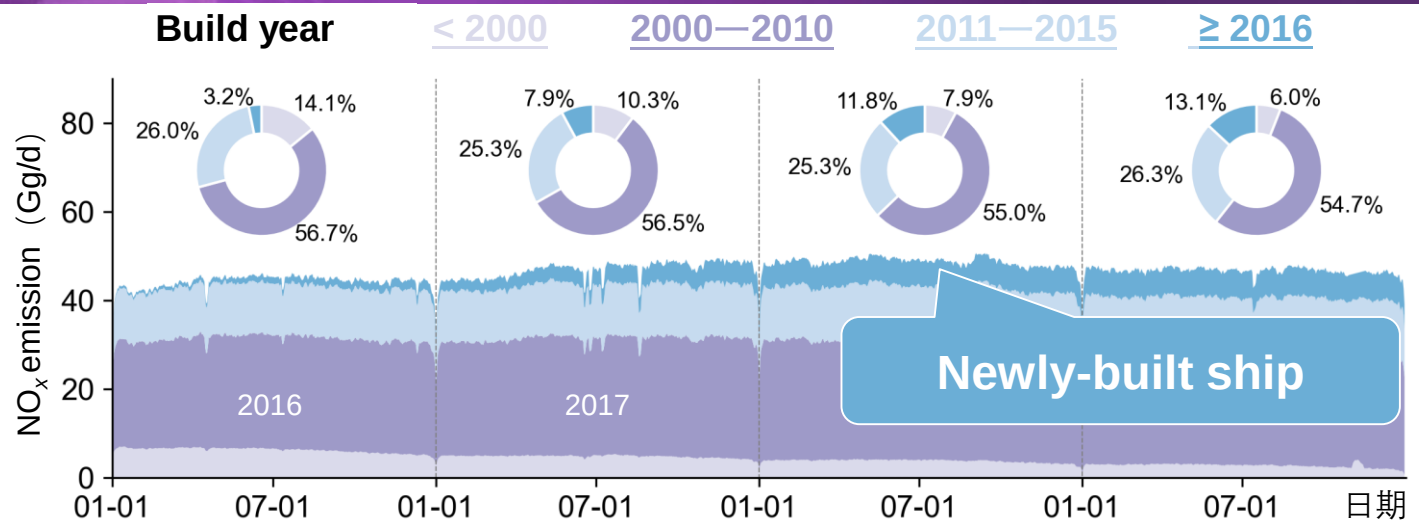
IMO-vessel

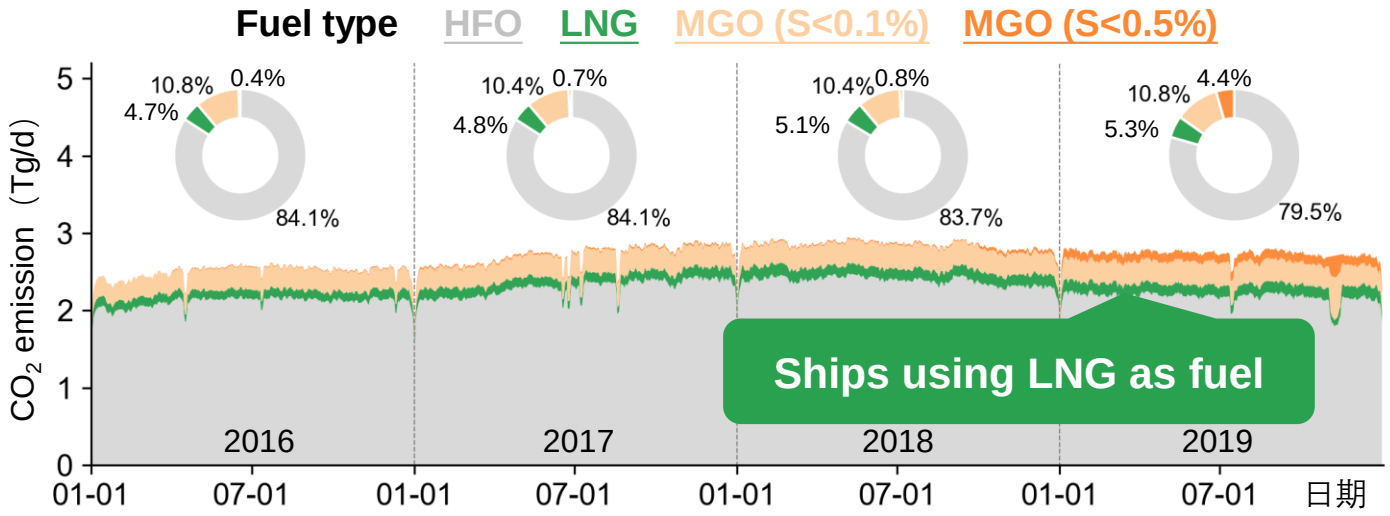
- **A high spatio-temporal resolution global inventory of ship emissions has been established (0.1°)**
- **The total amount of emissions and their interannual variation trend are consistent with IMO and other research institutions**

Yi & Wang, et al., Earth System Science Data, 2024

Insignificant effects of fleet iteration

- The contribution of **newly built ships (built after 2016)** to NOx emissions increased from 3.5% to 14.2%;
- **Ships built during 2000 to 2010** always contribute>50% of emissions



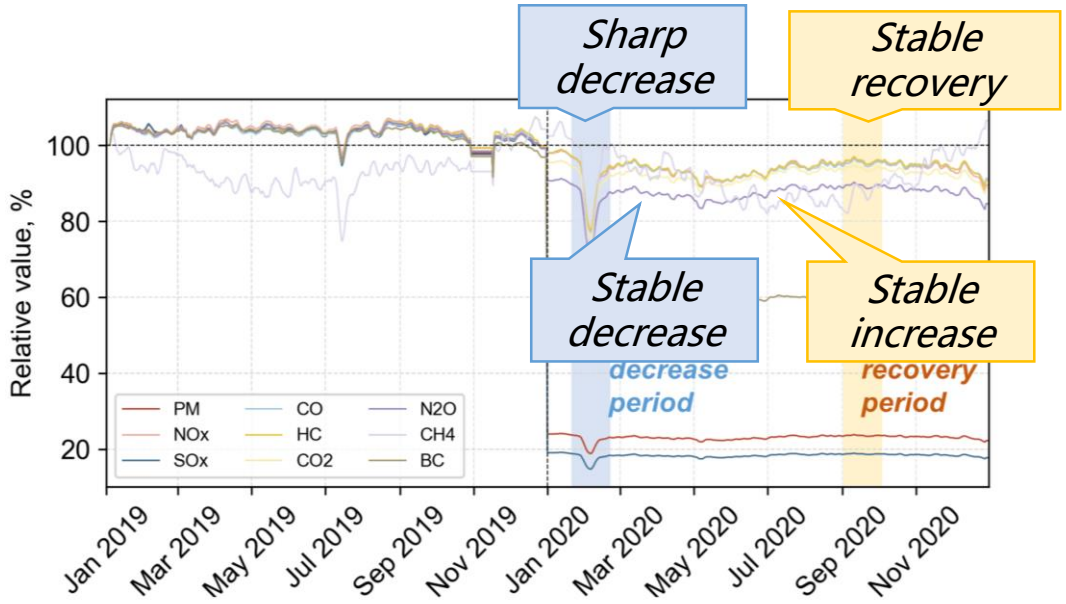


- The contribution of **LNG** ships to total CO_2 increased from 4.7% to 5.3%;
- The contribution of **HFO** (heavy fuel oil) decreased from 84.1% to 79.5%

Yi & Wang, et al., Earth System Science Data, 2024

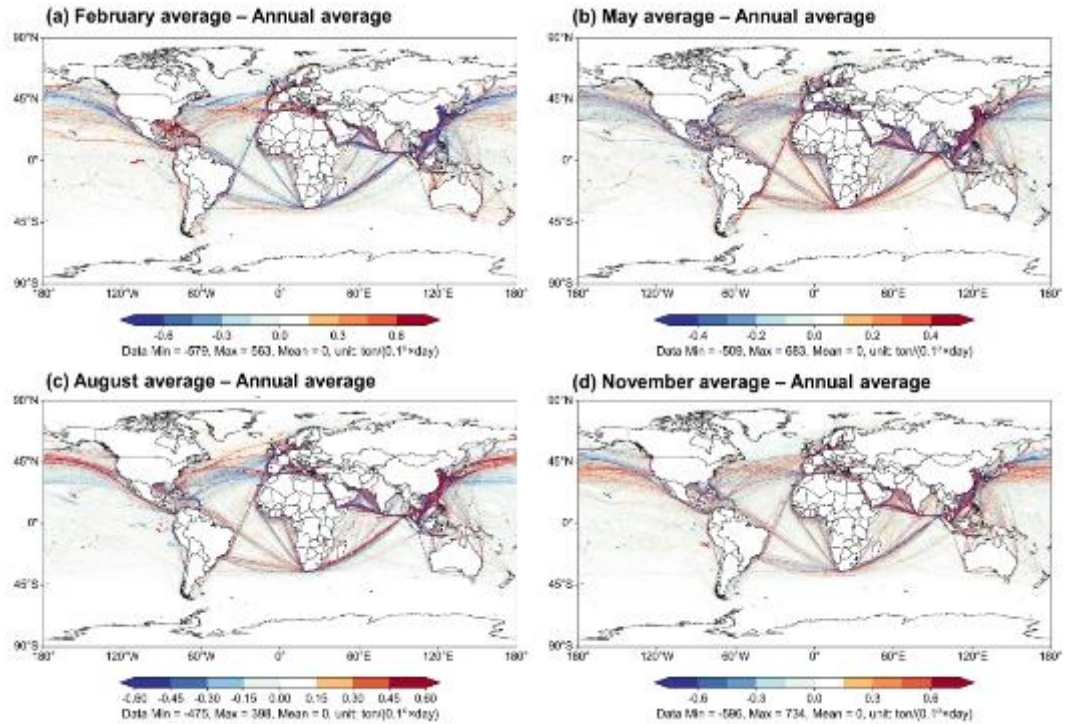
Capturing short-term fluctuations in global ship emissions during the pandemic

Daily emissions



- Global ship emissions experienced **several phases** of impact from the pandemic
- The decline phases were related to **reduced cruising speeds and decreased trade volumes** during the pandemic, while the recovery phase saw the opposite trend.

Spatial difference in various periods



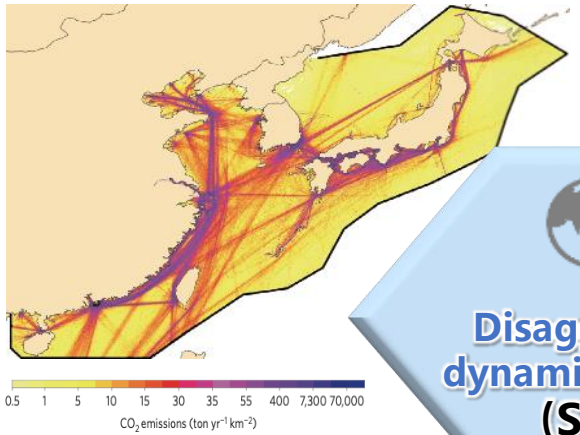
- Asian routes - North American and European routes - Recovery
- Unveiling **the asynchronous impacts of the pandemic.**

Yi & He et al., Science of the Total Environment, 2024

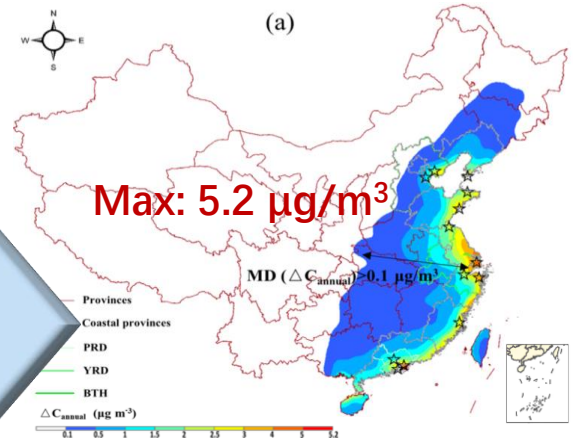
Policy Upgrade Domestic Ship Emission Control Areas (DECAs) supported by SEIM

identification of control objectives and ranges

High-resolution emission inventories

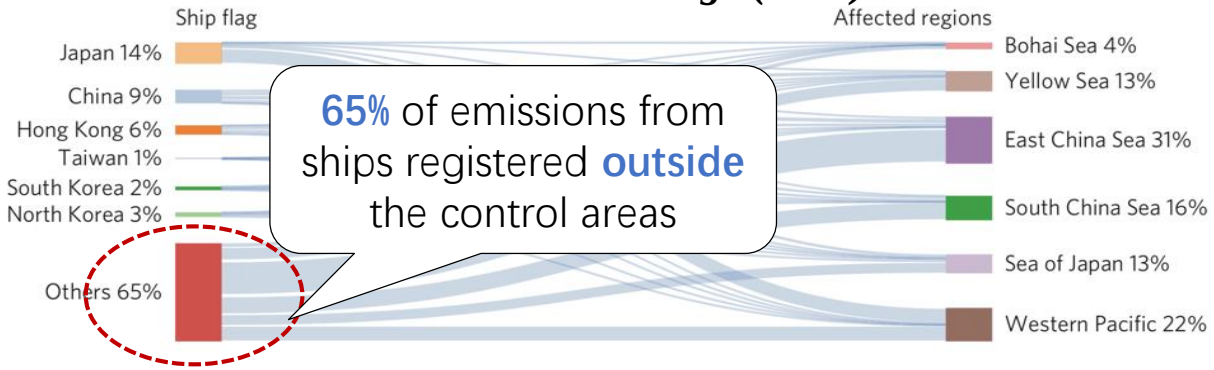


Atmospheric impacts



Disaggregated dynamic methods (SEIM)

Nature Climate Change (2016)



New regulation framework


国家自然科学基金委员会

内 参

第 5 期（总 95 期） 2016 年 11 月 7 日

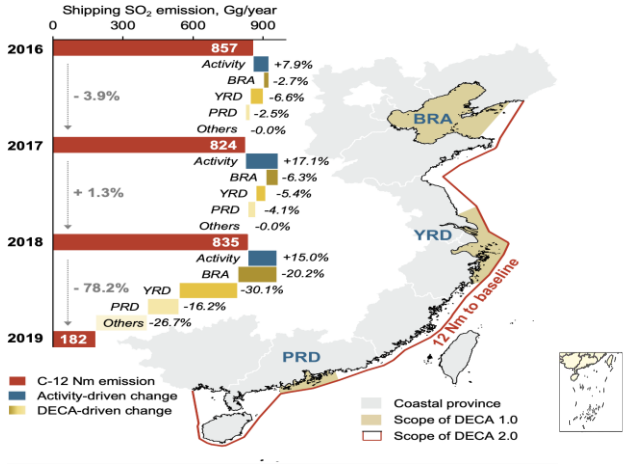
科学基金成果显示

我国急需按国际标准建立海运排放区
加强对远洋船舶排放监管

——东亚地区海运排放量的 65%来自区域外的远洋船舶

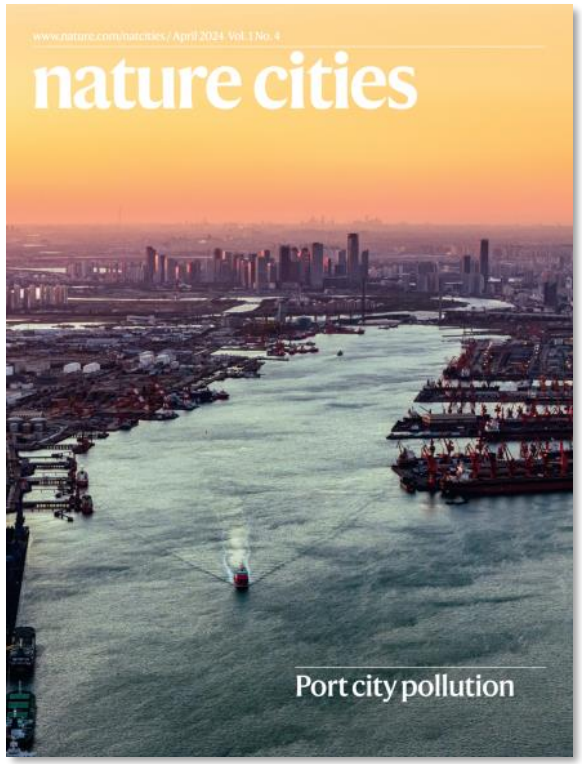
本文提要：海运是全球运输业的基石和大宗商品首选的运输方式，但同时也产生大量温室气体和多种大气污染物。东亚作为全球海运最繁忙和发展增速最快的区域，却一直缺失精准的海运排放清单。在国家自然科学基金重大研究计划

2017 DECA v1 → 2019 DECA v2



Liu et al., Nature Climate Change, 2016; Wang & Yi et al., Atmospheric Chemistry and Physics, 2021

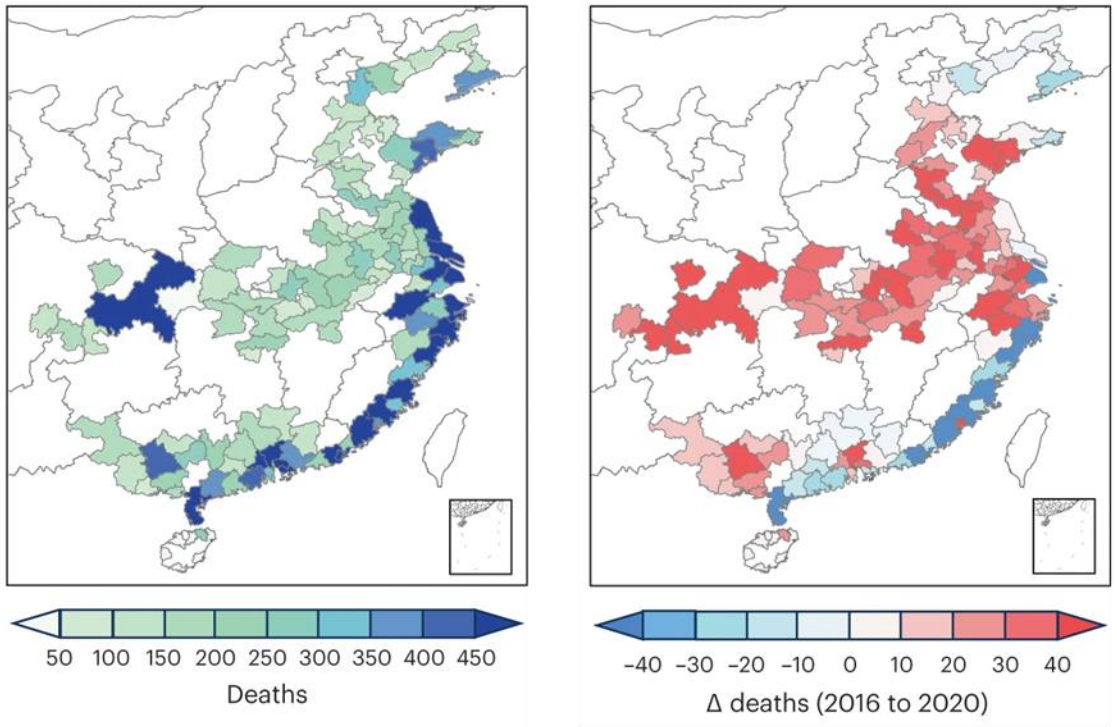
Identification of shipping-related health burden



Cover story - Port city pollution

We investigate the ships impacts in Chinese port cities from 2016 to 2020 in context of profound multifaceted transformations on emissions control and demographic characteristics.

Shipping-related health burden



- Population increased in most coastal port cities and megacities along the Yangtze River.
- The shipping-related mortality increased for almost all cities along inland rivers and some coastal megacities.

Luo & Lv et al., Nature cities, 2024

Global shipping emission growth

Phase 1 (before 2008)

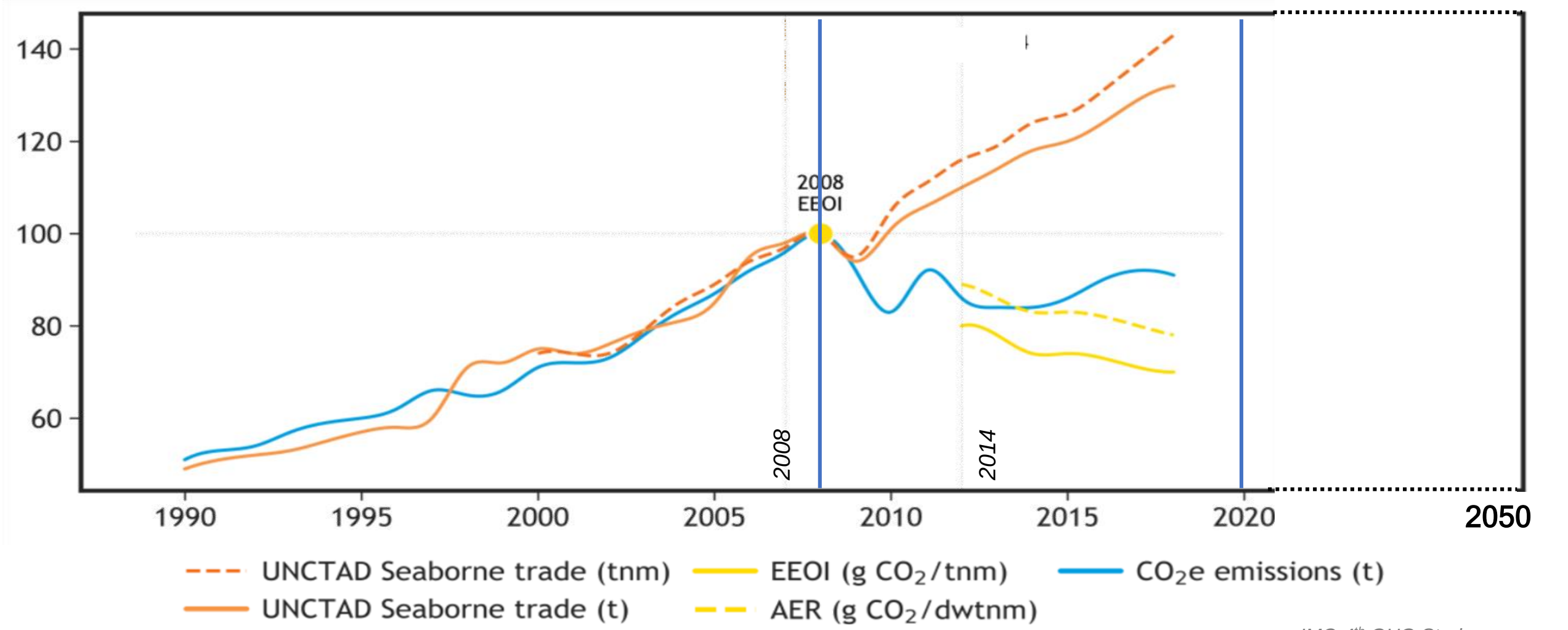
Emission growth

Phase 2 (2008-2020)

Emission control

Phase 3 (2020 to now)

Deep transition



IMO 4th GHG Study

Decarbonization: Coupling technology and trade

Fleet iteration

Alternative fuels

Technical measures

Operation

Voyage management

Trade partner

Government

Trade optimization

Cargo carrier

Net zero

Trade-driven method for reconstructing global historical shipping emission inventory

- A **trade-driven method** was developed **to reconstruct global historical shipping emission inventory** for CO_2 and five key atmospheric pollutants from 1970 to 2021.

Data collection

CEPII RESEARCH AND EXPERTISE ON THE WORLD ECONOMY

UN Comtrade Database

IMO INTERNATIONAL MARITIME ORGANIZATION

Lloyd's Register

AIS Automatic Information System

CCS

IEA International Energy Agency

UNITED NATIONS UNCTAD

Data integration

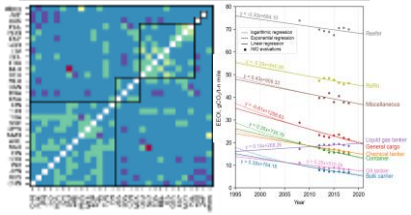
- ✓ Marine fuels
- ✓ **9** types of vessels
- ✓ **300,000** vessel registration records
- ✓ **800,000** international voyages
- ✓ **30 billion** AIS signals
- ✓ **Top 50** maritime countries
- ✓ **>1,000** commodities
- ✓ **1.2 million** bilateral trade flows (annually)

Technical framework

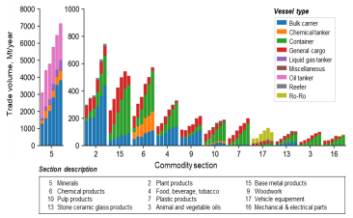
$$E'_{y,o,d,p} = \begin{cases} \sum_c \sum_v W_{y,o,d,c} \times \mathrm{SP}_{o,d,c} \times \mathrm{VD}_{y,c,v} \times \mathrm{EI}_{y,v,o,d,p} \times D_{o,d} \times 10^{-6}, & if\ y \geq 1995 \\ E_{\mathrm{avg},o,d,p} \times \frac{\mathrm{FC}_y}{\mathrm{FC}_{\mathrm{avg}}}, & if\ y < 1995 \end{cases}$$

$$E_{y,g,p} = \sum_o \sum_d E'_{y,o,d,p} \times \mathrm{GAF}_{o,d,p} \times \mathrm{PAF}_{y,g,p}$$

Emission intensities

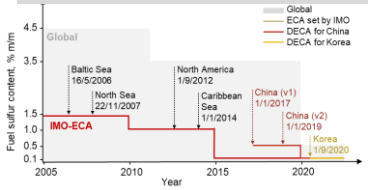


Commodity-to-vessel

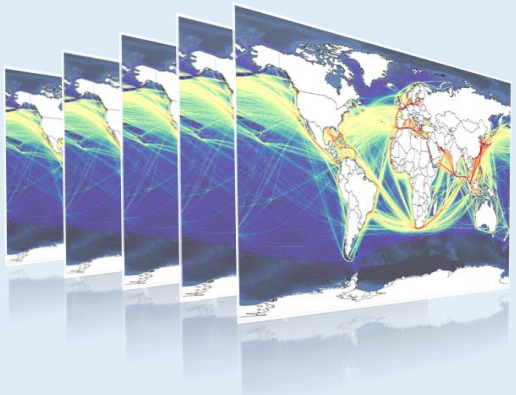


Route-to-grid

Policy adjust factor



Emission inventoris

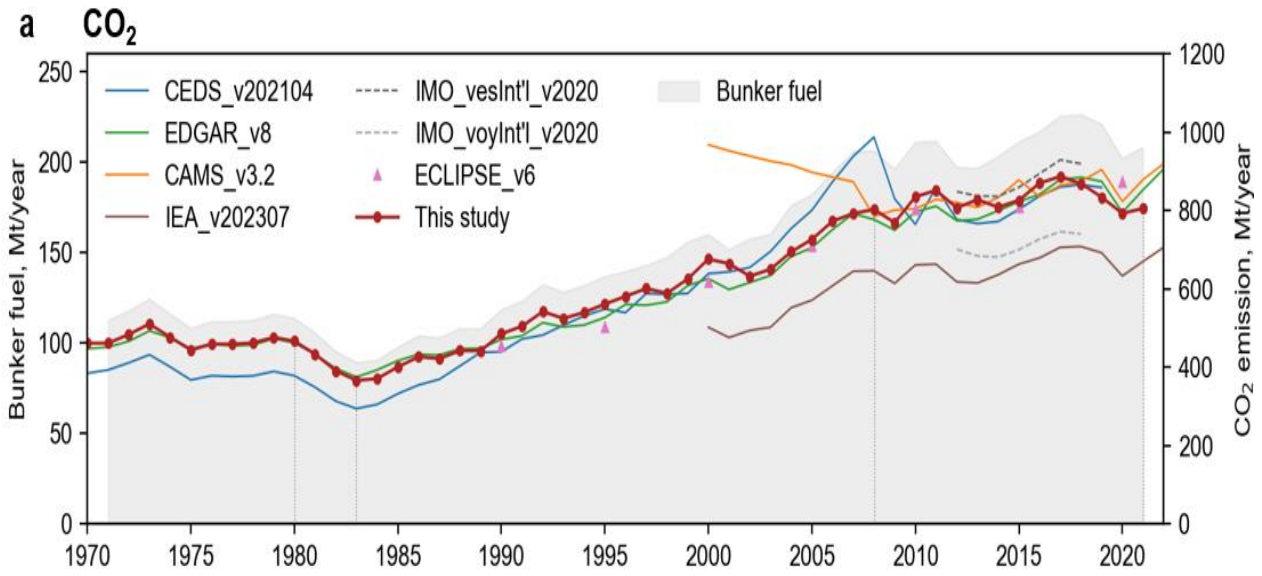


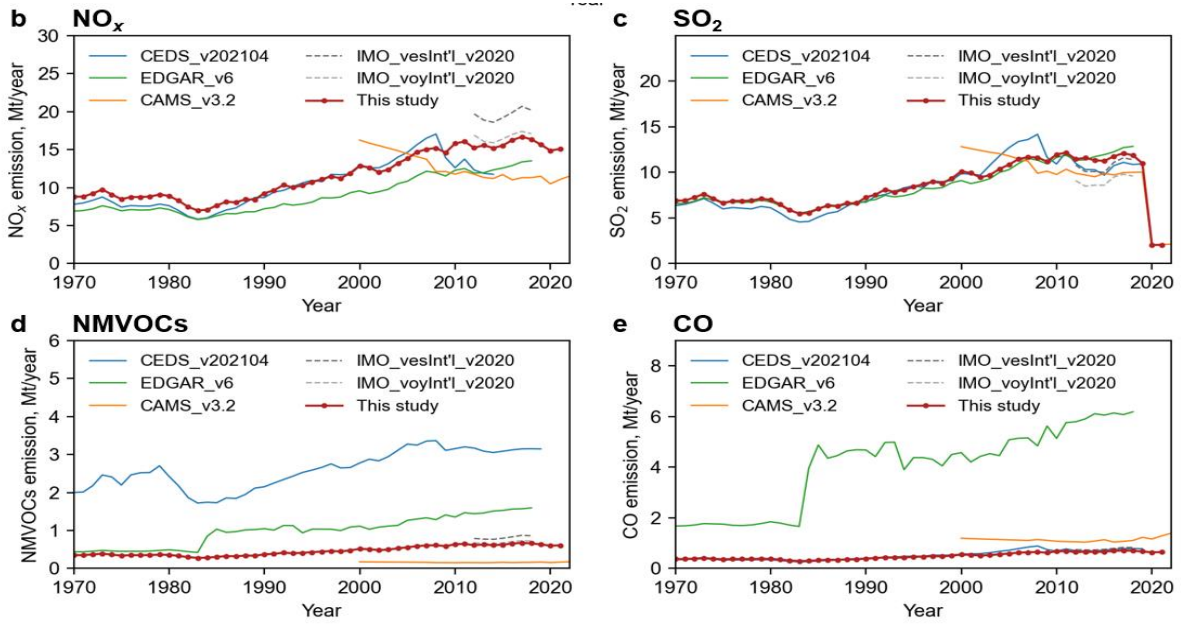
- 1970-2021, annualy
- 0.1°×0.1° spatial grids
- CO_2 & 4 air pollutants
- Structured by economy /commodity/vessel type

Wang & Liu et al., One Earth, 2025*

Inter-annual variations of global shipping emission from 1970 to 2021

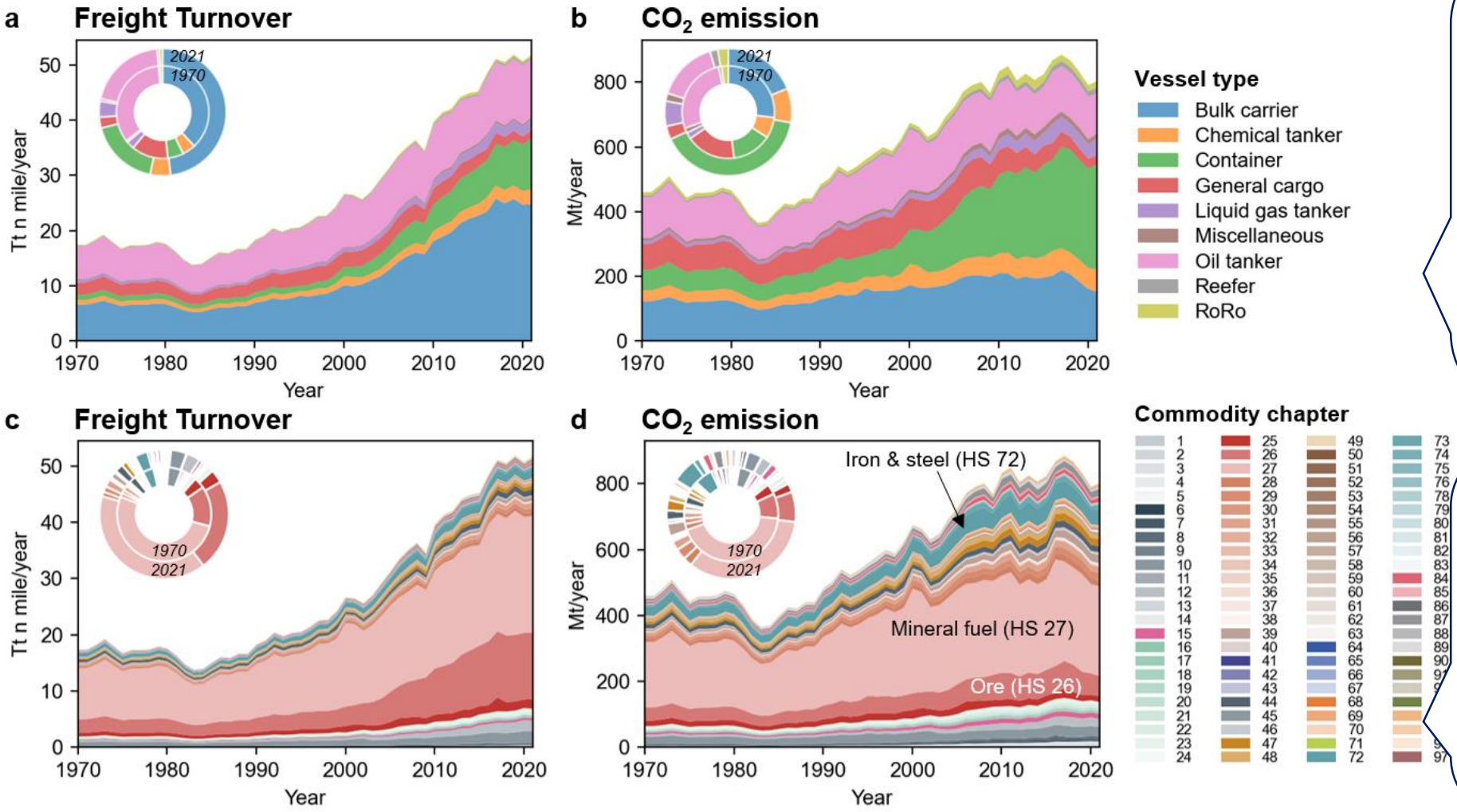
- Global shipping NOx, SO2, NMVOCs, CO, and CO2 emissions are traced back to 1970.
- Global shipping CO_2 emissions increased by 1.7 times during 1970-2021.
- The highest estimates of NMVOCs and CO emissions can be up to 16.1 times and 8.2 times higher, respectively, than the lowest estimates, while our estimates fall within a median range.





Wang & Liu et al., One Earth, 2025*

Structural changes of global shipping emission from 1970 to 2021



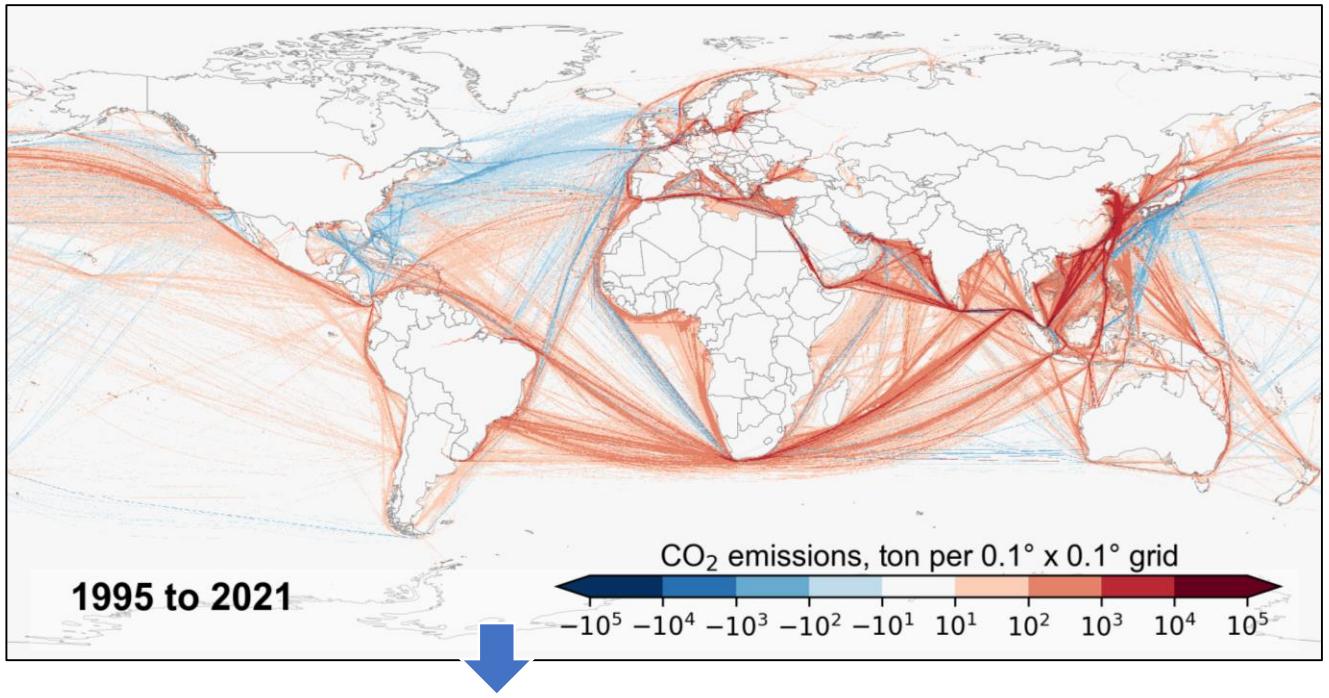
- **Containers**' contribution to freight turnover increase from **5.5% to 17.8%,** the corresponding share of emissions share has increased from **13.8% to 40.4%**
- **Bulk carriers**' contribution remains stable due to their relatively **low emission intensity**

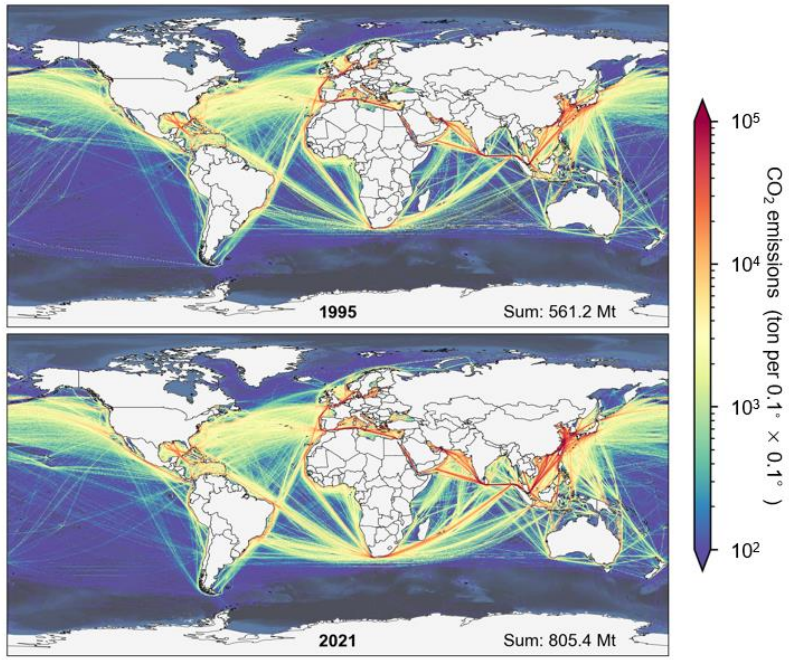
- **Mineral fuels**' contribution to emissions increases from **33.3%** in 1970 to **46.9%** in 2021
- the substantial growth in the transport work of **ores** has been **offset** by the low energy efficiency of bulk carriers.

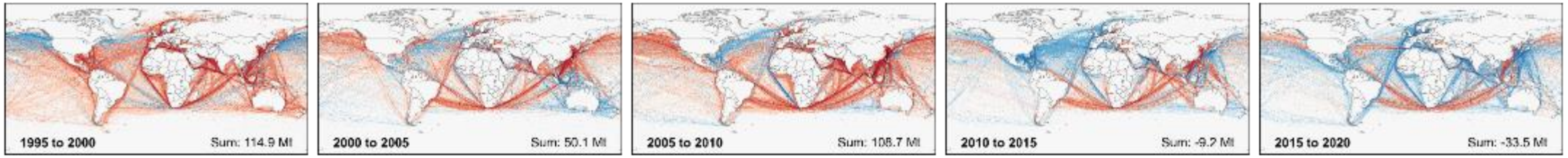
Wang & Liu et al., One Earth, 2025*

Spatial distribution changes of global shipping emissions

- Spatial distribution changes vary among different sea areas, reflecting the **economic development of the East Asian countries** and the rise of **South-South trade**



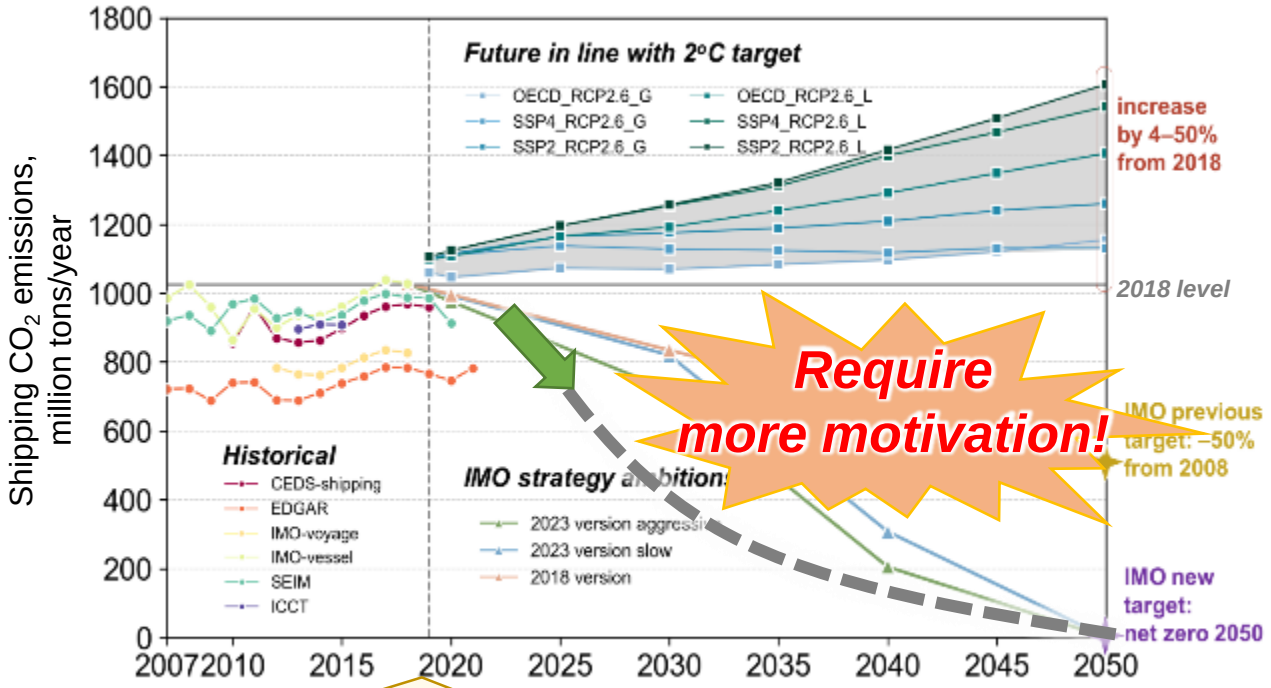




Wang & Liu et al., One Earth, 2025*

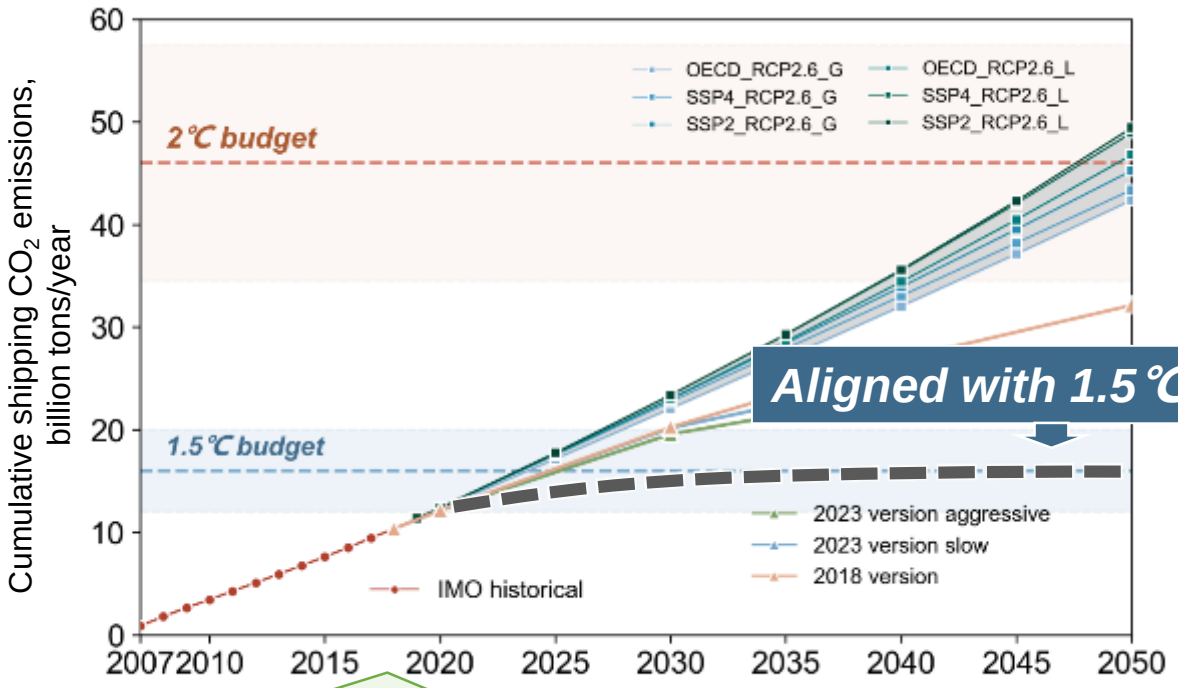
Gap identification for IMO 2023 new strategy

Annual shipping emissions



- Shipping CO_2 emissions will continue to **grow 4%-50%** from 2018 to 2050 according to IMO
- IMO pathways aim **at net-zero around 2050**

Cumulative shipping emissions



- IMO new strategy will be aligned with Paris Agreement (**under 2°C**) but not enough for **1.5 °C target**

Liu & Yi et al., Fundamental Research, 2024

New insight: High heterogeneity

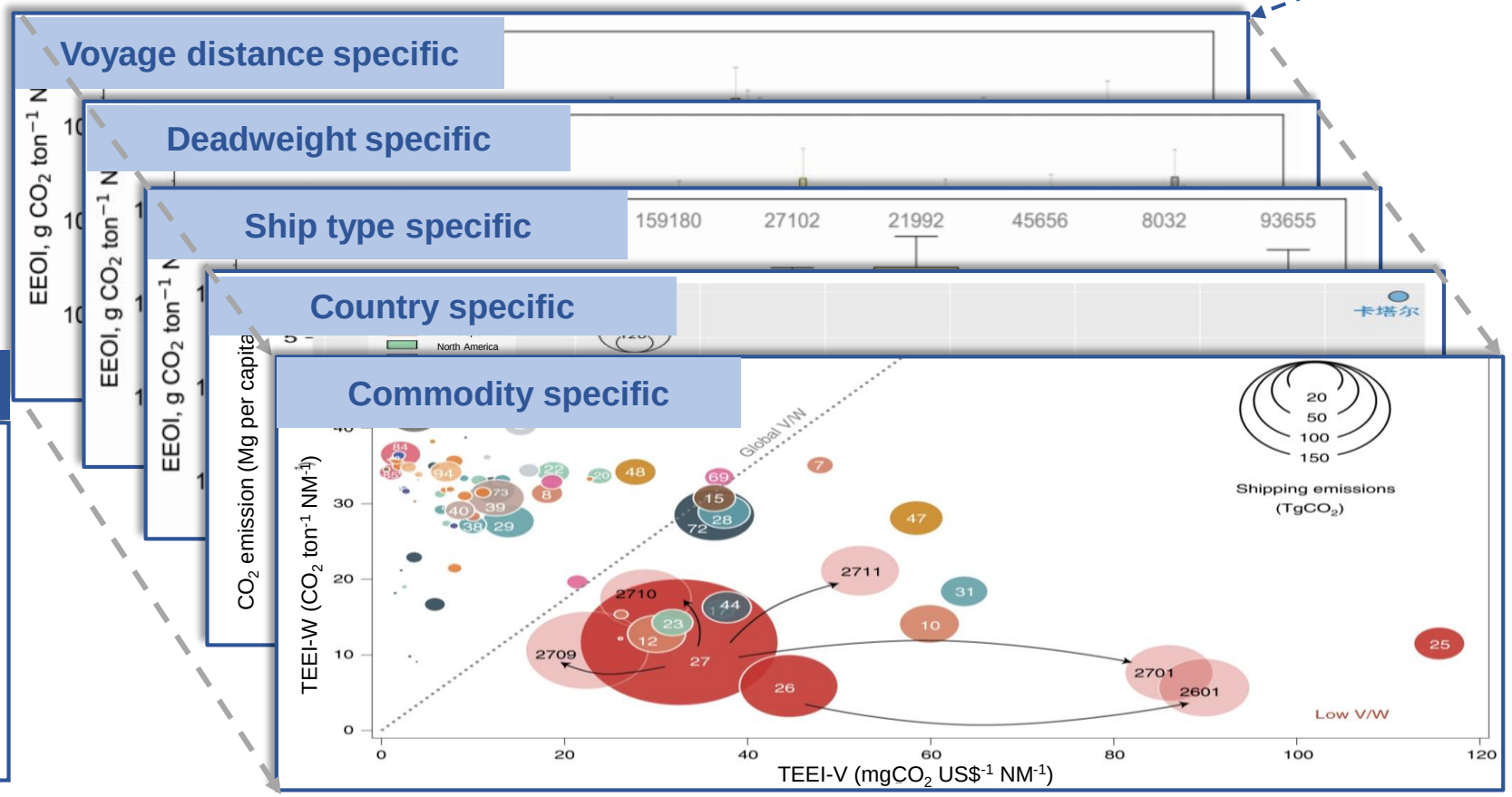
High heterogeneity: Drastic change in emission intensity

800 times | 1000 times | 500 times

1.2 million voyages

Emission intensity of Commodity *x* transported by ship *a* from place A to B

- Voyage distance specific
- Deadweight specific
- Ship type specific
- Country specific
- Commodity specific



Driver Analysis

- carbon emission ≈ 7% cargo weight
- 1$ cargo drives 81 g CO_2 emission
- 1$ GDP drives 34 g CO_2 emission

……

Liu et al., Nature Sustainability, 2019; Wang & Liu* et al., Nature Climate Change, 2021*

New Insight: Trade optimization

Driver-based emission optimization unveils 38% emission reduction potential in global shipping

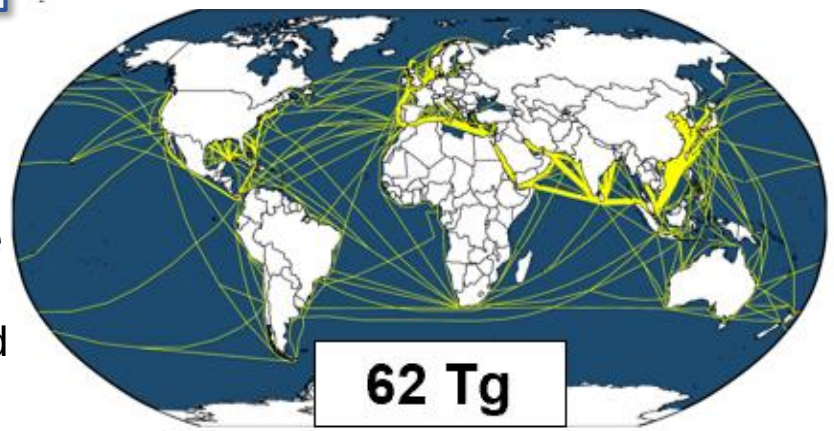
Current situation

Proximity principle

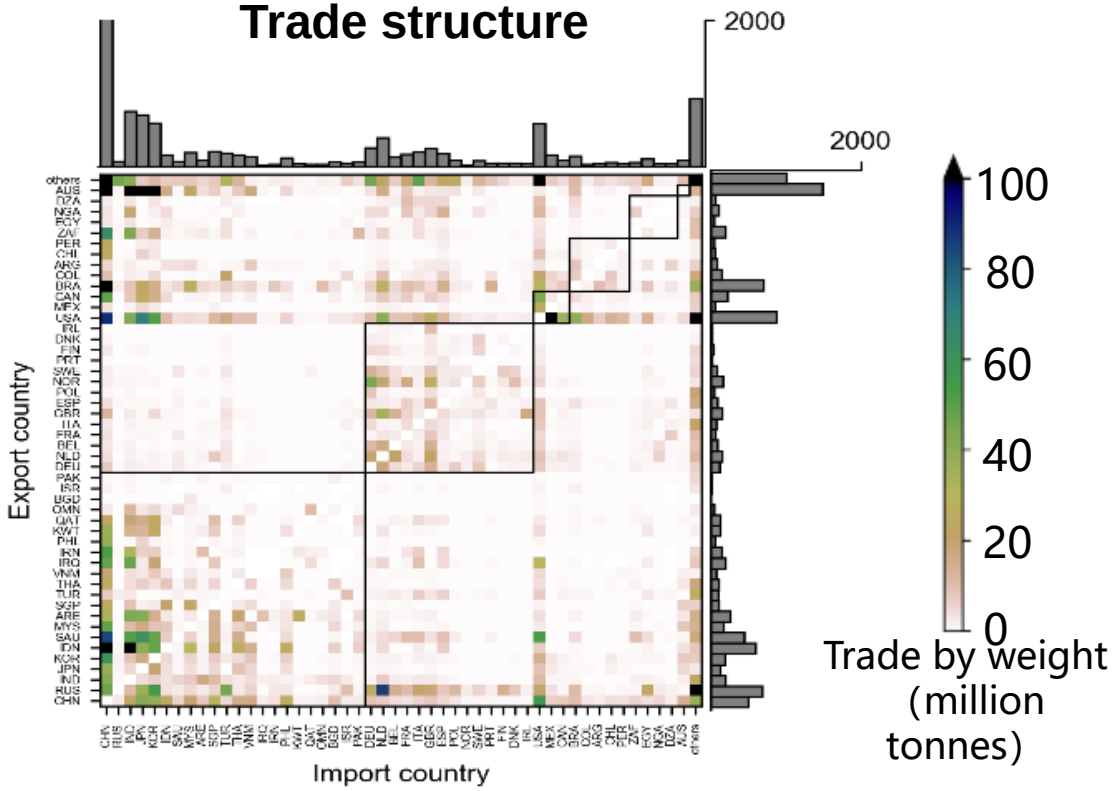
Total trade volume unchanged

Optimization outcome

Emission of crude oil



Trade structure



Liu et al., Nature Sustainability, 2019; Wang & Liu* et al., Nature Climate Change, 2021*

Thank you!

- Global shipping emissions from 1970 - 2021: Structural and spatial change driven by trade dynamics. ***One Earth***. 2025
- The high-resolution global shipping emission inventory by the Shipping Emission Inventory Model (SEIM). ***Earth System Science Data***. 2024
- Shipping-related pollution decreased but mortality increased in Chinese port cities. ***Nature Cities.*** 2024. ***封面文章***
- Advancing shipping NOx pollution estimation through a satellite-based approach. ***PNAS Nexus.*** 2024.
- Atmospheric impacts and regulation framework of shipping emissions. ***Fundamental Research.*** 2024.
- Trade-linked shipping CO_2 emissions. ***Nature Climate Change.*** 2021. ***提案引用.***
- A net-zero future for freight. ***One Earth.*** 2021.
- A big data approach to improving the vehicle emission inventory in China. ***Nature Communications***, 2020.
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