清華大學
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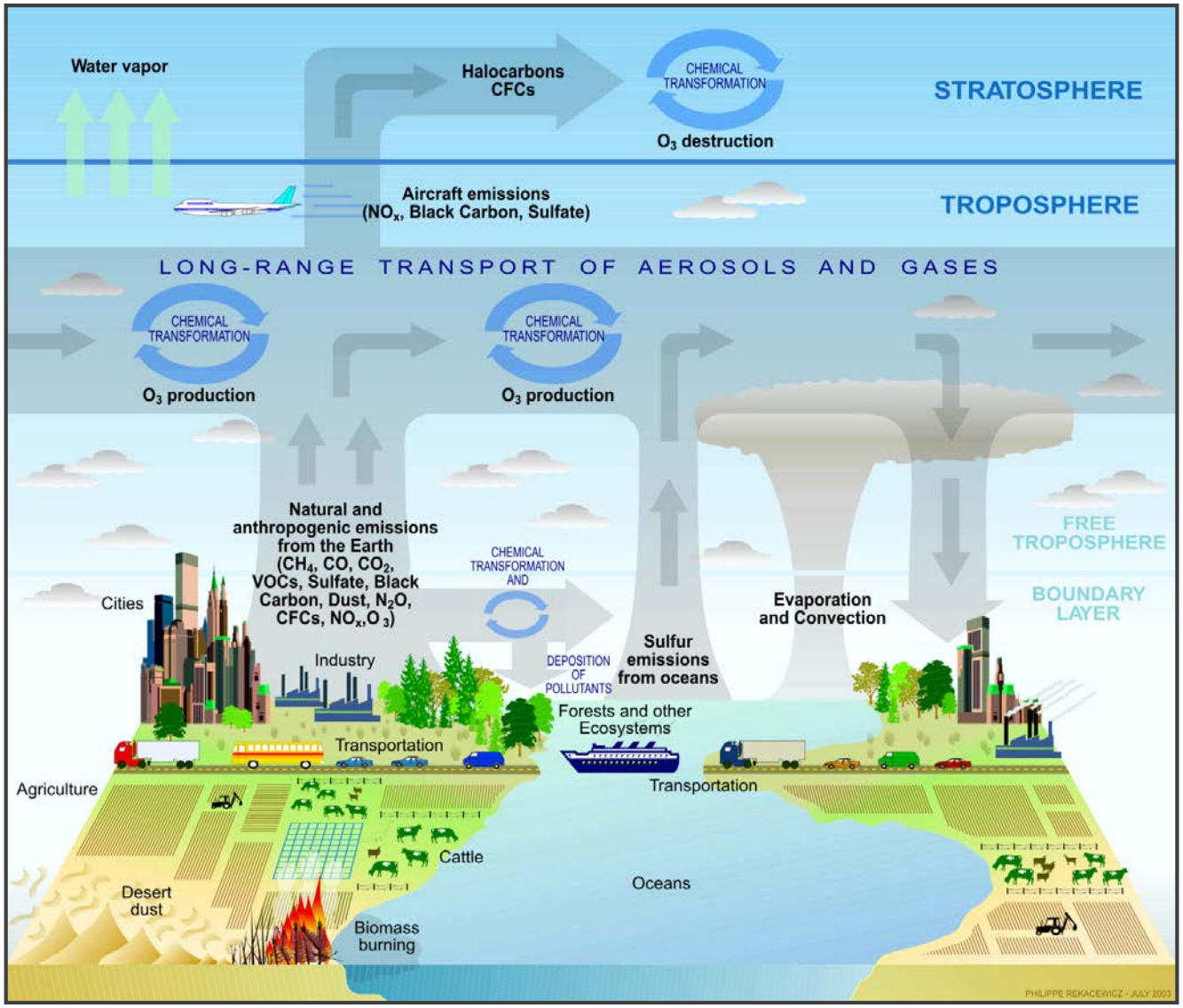
Development and application of Multi-resolution Emission Inventory for China (MEIC) model

Kebin He Qiang Zhang

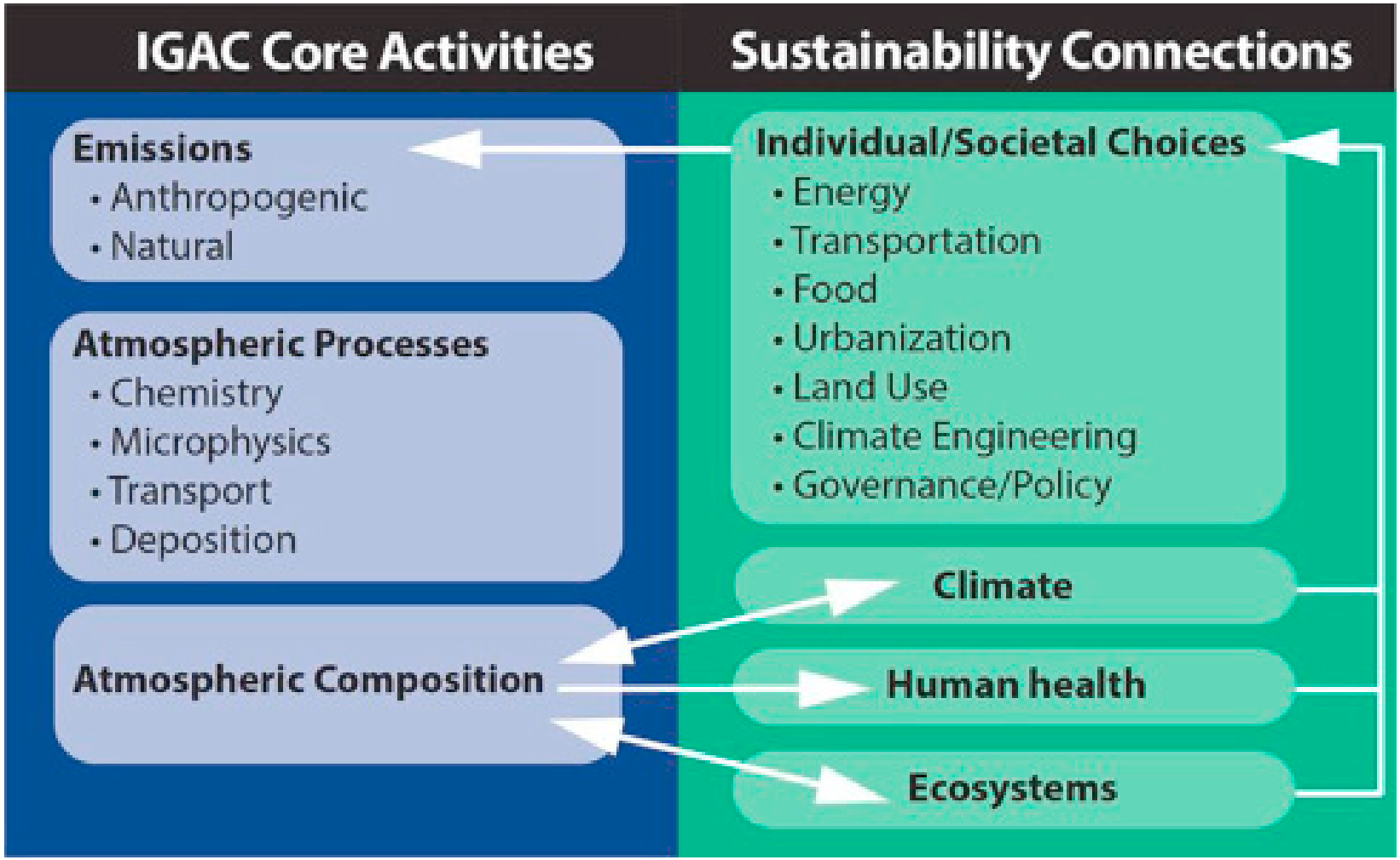
Tsinghua University

Emission inventory plays a key role in atmospheric chemistry research



Source: The International Global Atmospheric Chemistry (IGAC) Program

Emission inventory plays a key role in atmospheric chemistry research



Multi-resolution Emission Inventory for China (MEIC)

MEIC Home Introduction Dataset Users Publications Team http://meicmodel.org/

MIX Asian emission inventory was developed by the MEIC team

MEIC team recently released an Asian emission inventory, MIX, in years of 2008 and 2010. MIX was developed to provide up-to-date model-ready emissions for multiple chemical transport models and climate models. Integrating latest MEIC, REAS2, PKU-NH_3, and CAPSS emission inventories, MIX covers ten air pollutants and greenhouse gaseous (SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$, BC, OC and CO_2) with a resolution of 0.25 degree at Asia scale. MIX recently has been used to support MICS-Asia (Model Inter-Comparison Study for Asia) and TF HTAP (Task Force Hemispheric Transport of Air Pollution) projects as the base emission inventories for modeling. Gridded emissions of MIX can be accessed here.

The MEIC model contributes to the national emission inventory guidelines

The development of a complete emission inventory is an essential step in an air quality management process. To guild

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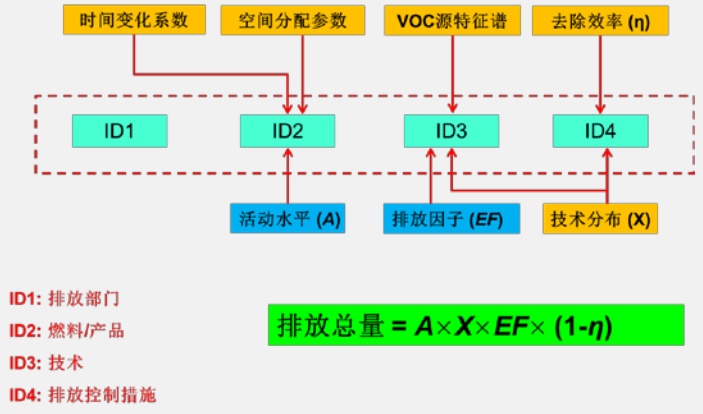
Methodological framework of the MEIC model

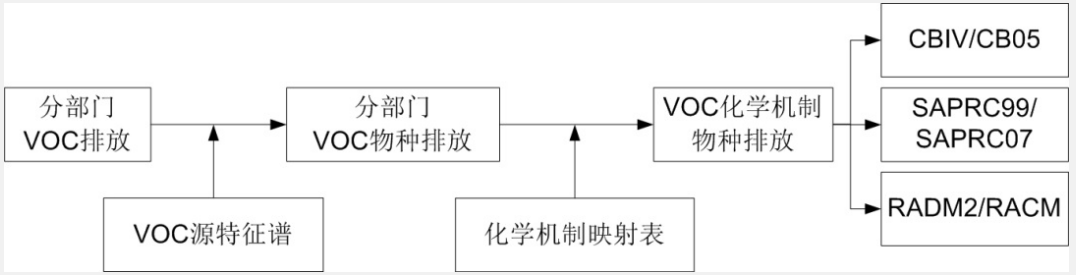
Module 1: emission estimates



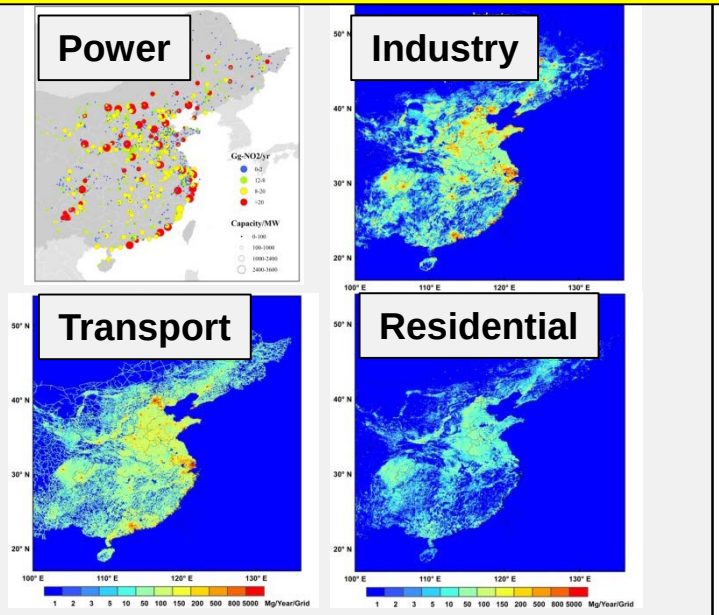
ID1: 排放部门
ID2: 燃料/产品
ID3: 技术
ID4: 排放控制措施

排放总量 = $A \times X \times EF \times (1-\eta)$

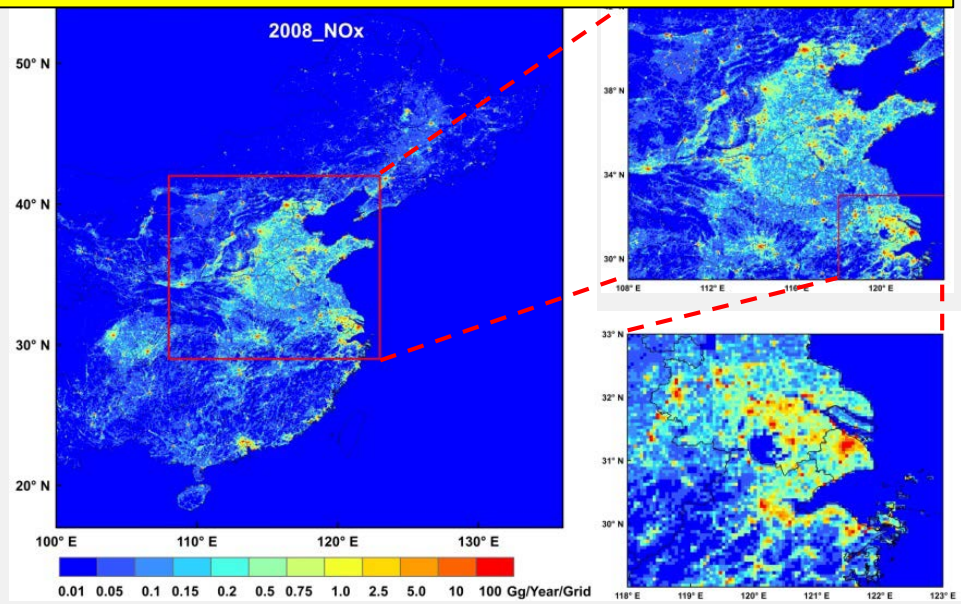
Module 3: speciation mapping of NMVOC



Module 2: spatial-temporal allocation

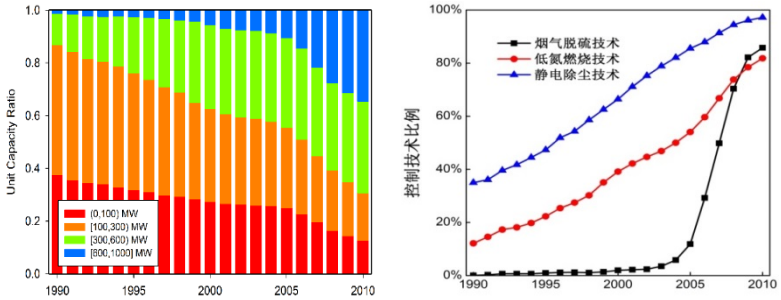


Model output: model ready emissions input

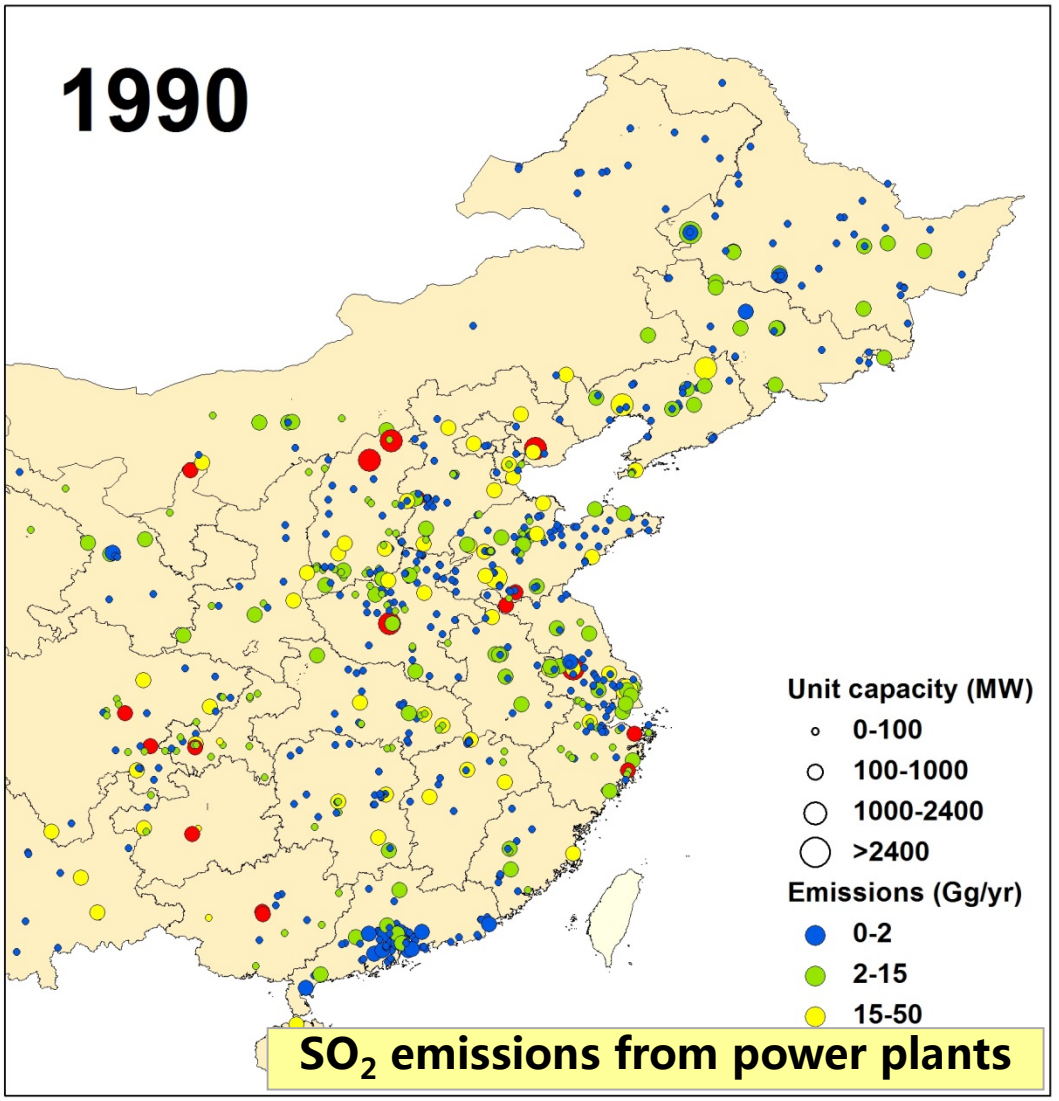


China Power Emissions Database (CPED)

- Location
- Time of startup
- Time of retirement
- Combustion technology
- End-of-pipe abatement
- Removal efficiency



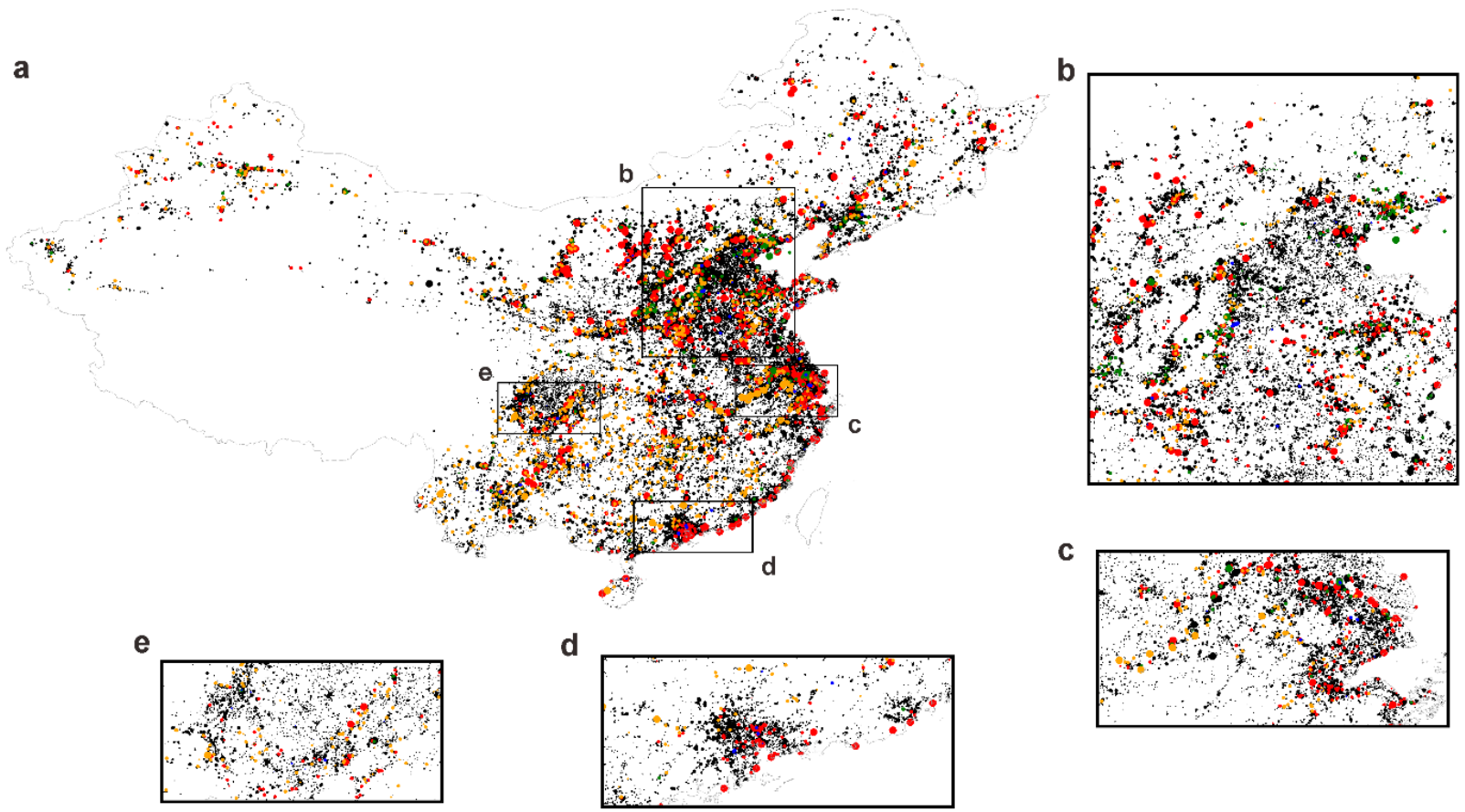
Technology distribution



SO_2 emissions from power plants

Liu et al., ACP, 2015

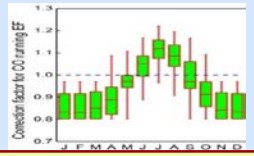
Point source emissions from the industry sector



Zheng et al., EST, 2018

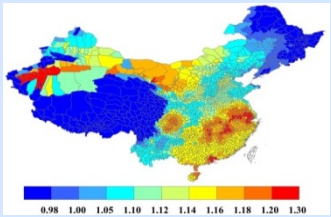
High resolution mapping of road transport emissions

Emission factor

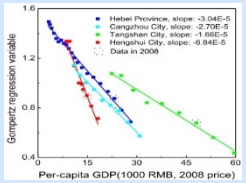


Corrected by meteorology factors

County level EF

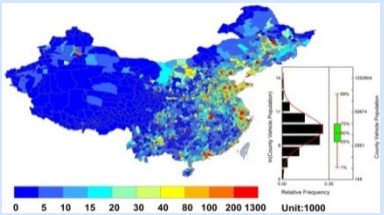


Vehicle ownership

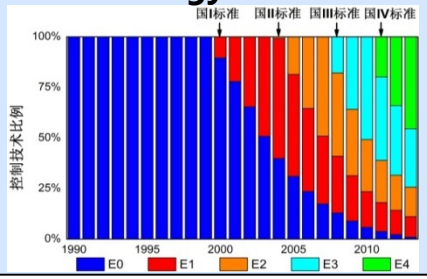


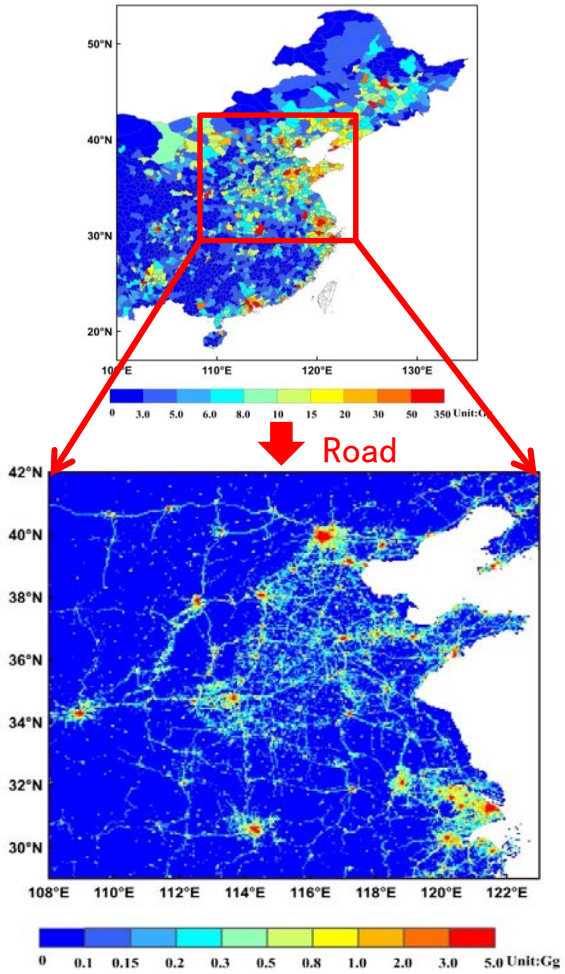
Vehicle ownership model

County level activity



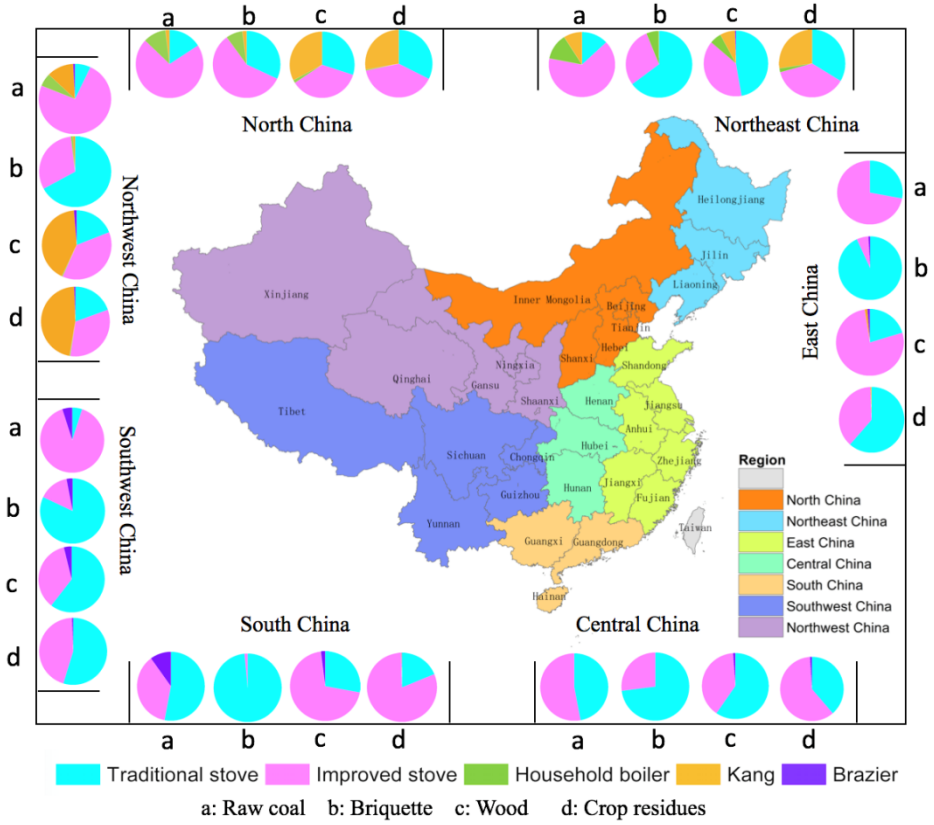
Technology distribution

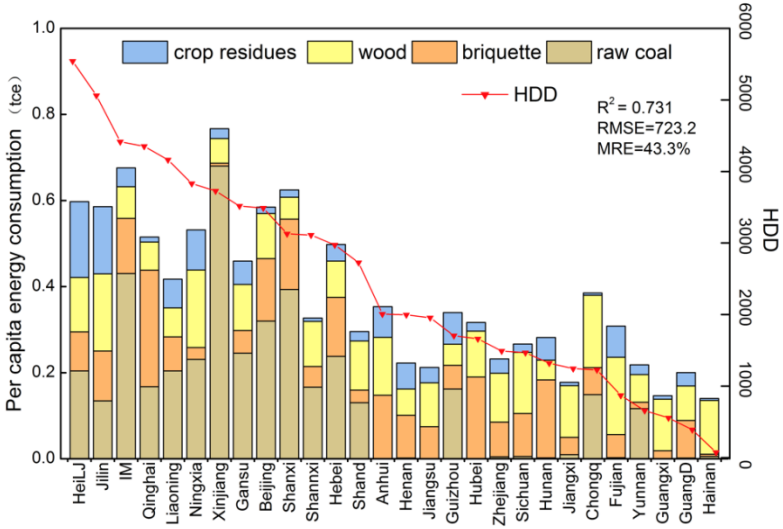


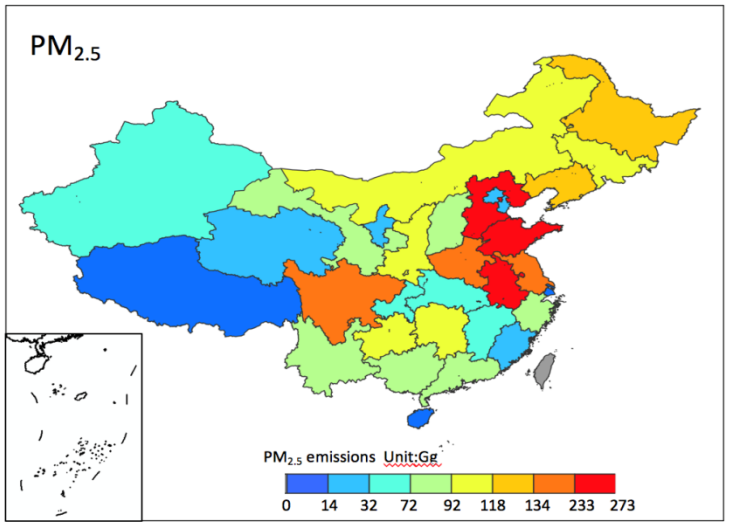


Zheng et al., ACP, 2014

Residential emission estimates based on national survey







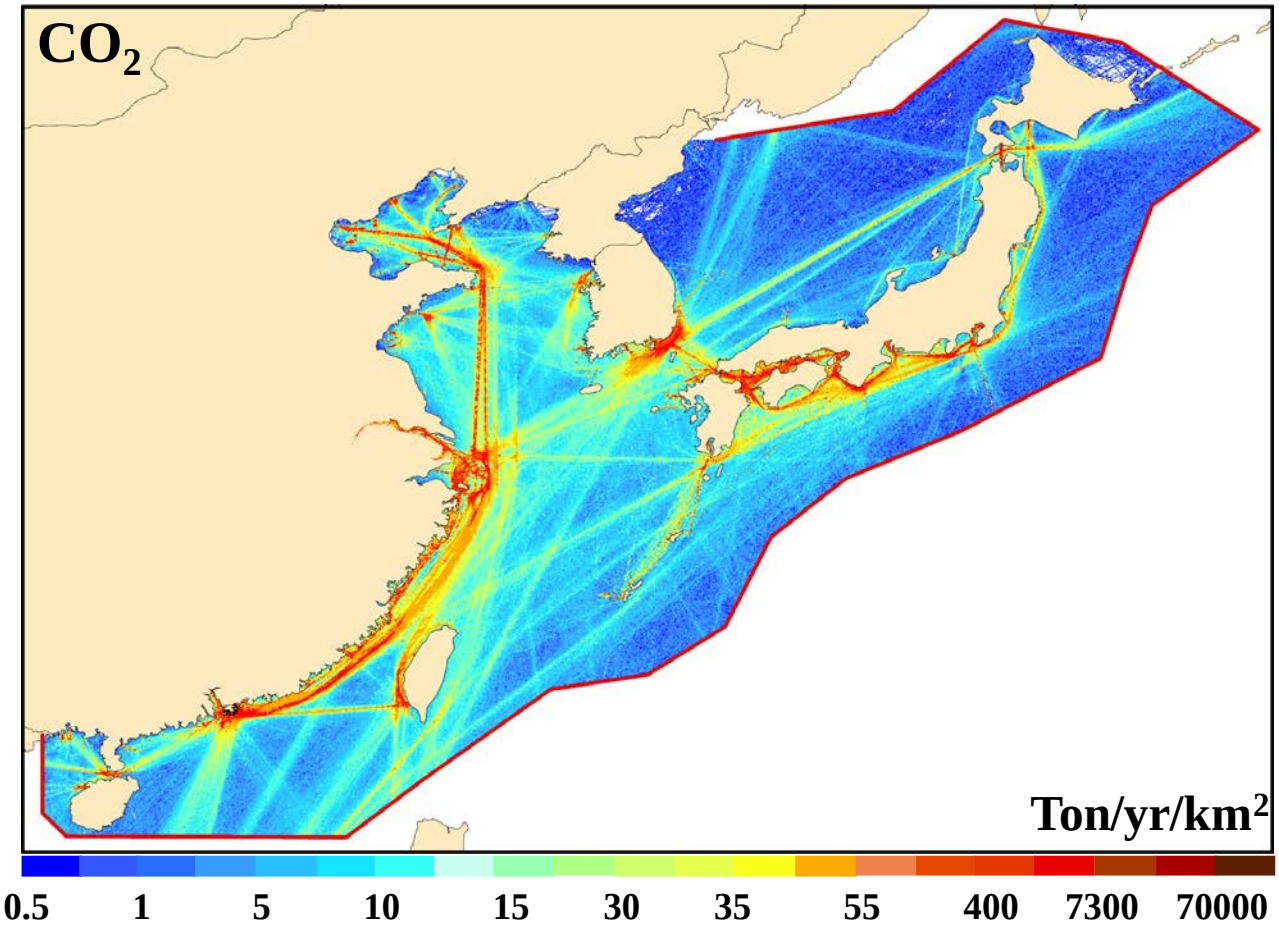
Peng et al., in prep.

Emission estimates of ocean-going vessels in East Asia

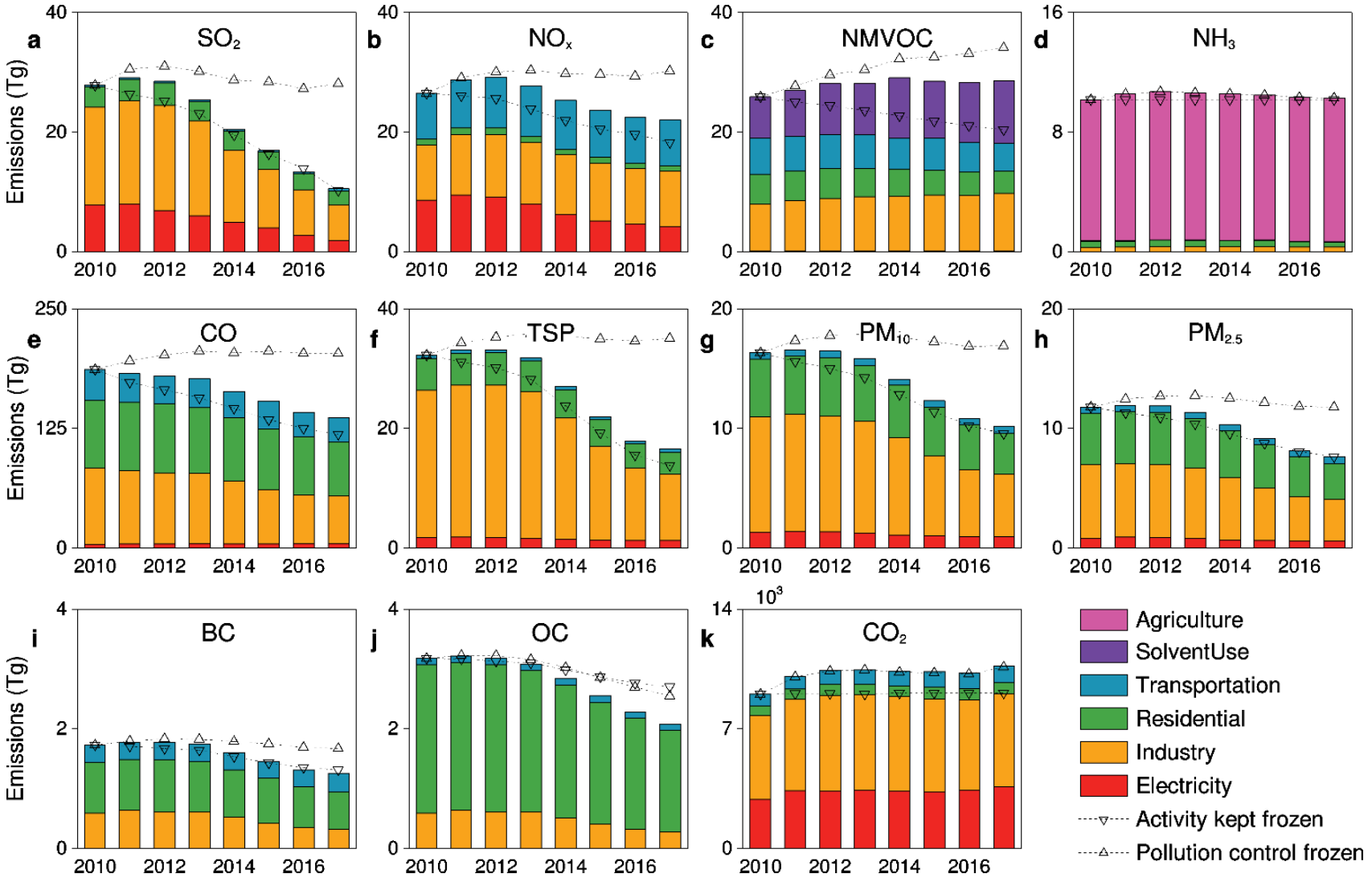
nature climate change

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.

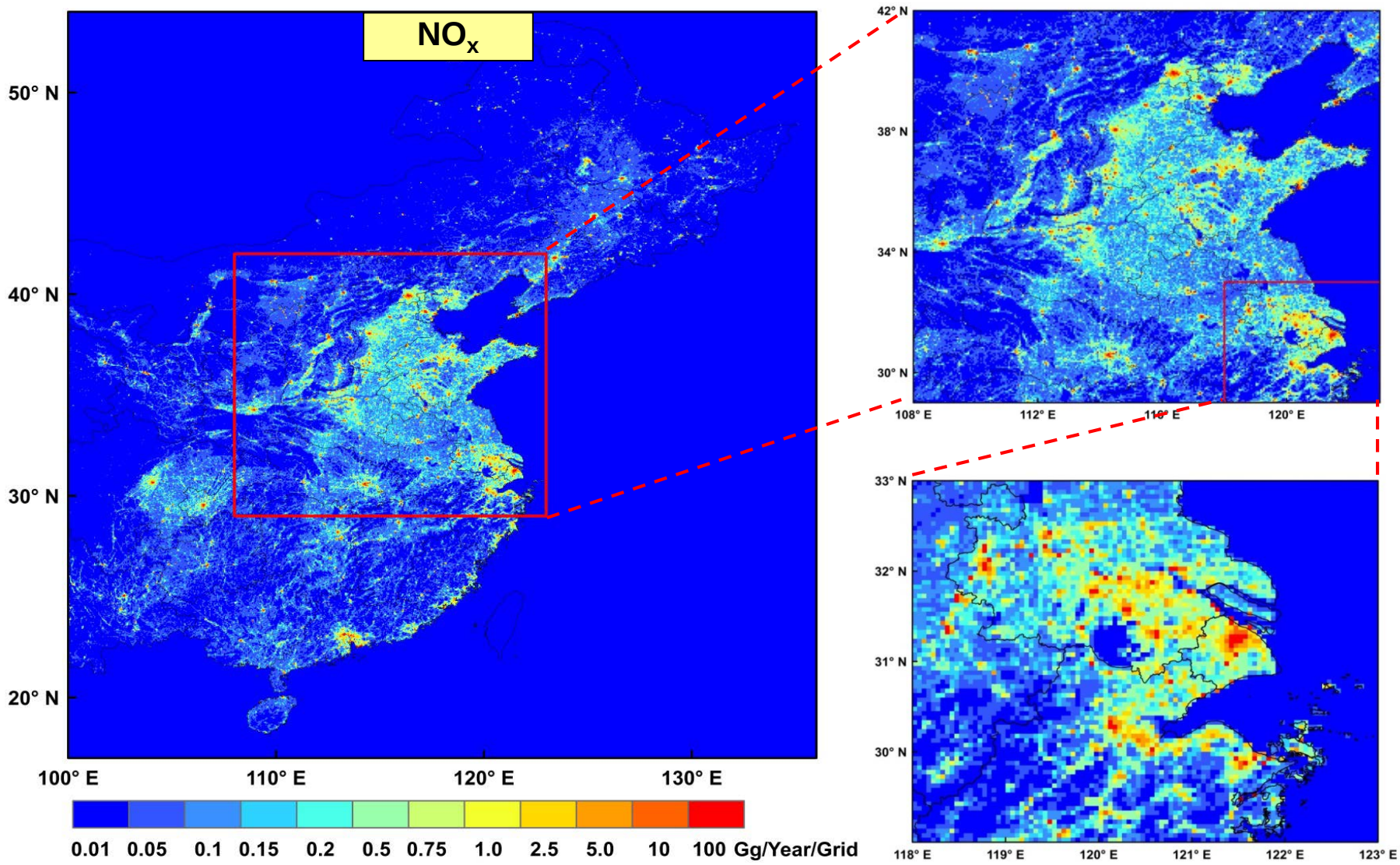


China's anthropogenic emissions from 2010-2017



Zheng et al., ACPD, in review.

Multi-resolution emissions input for models



High resolution emission inventories for Jing-Jin-Ji

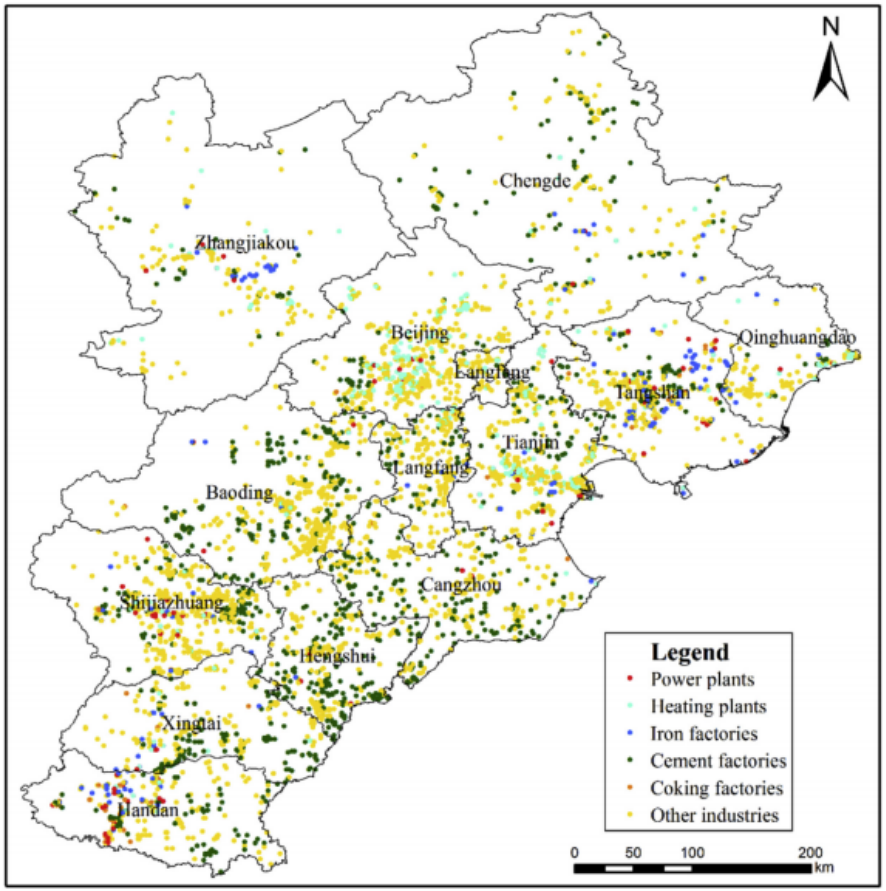


Fig. 1. Study domain and location of point sources in the BTH region.

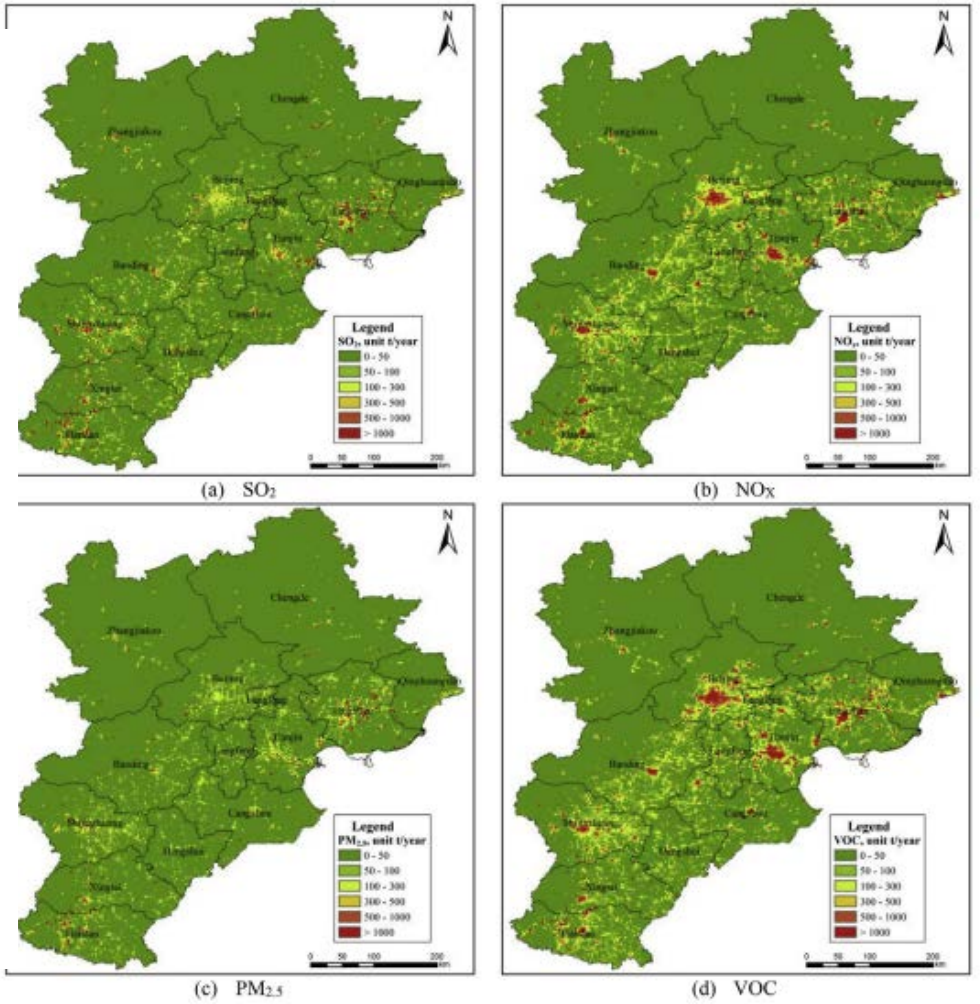
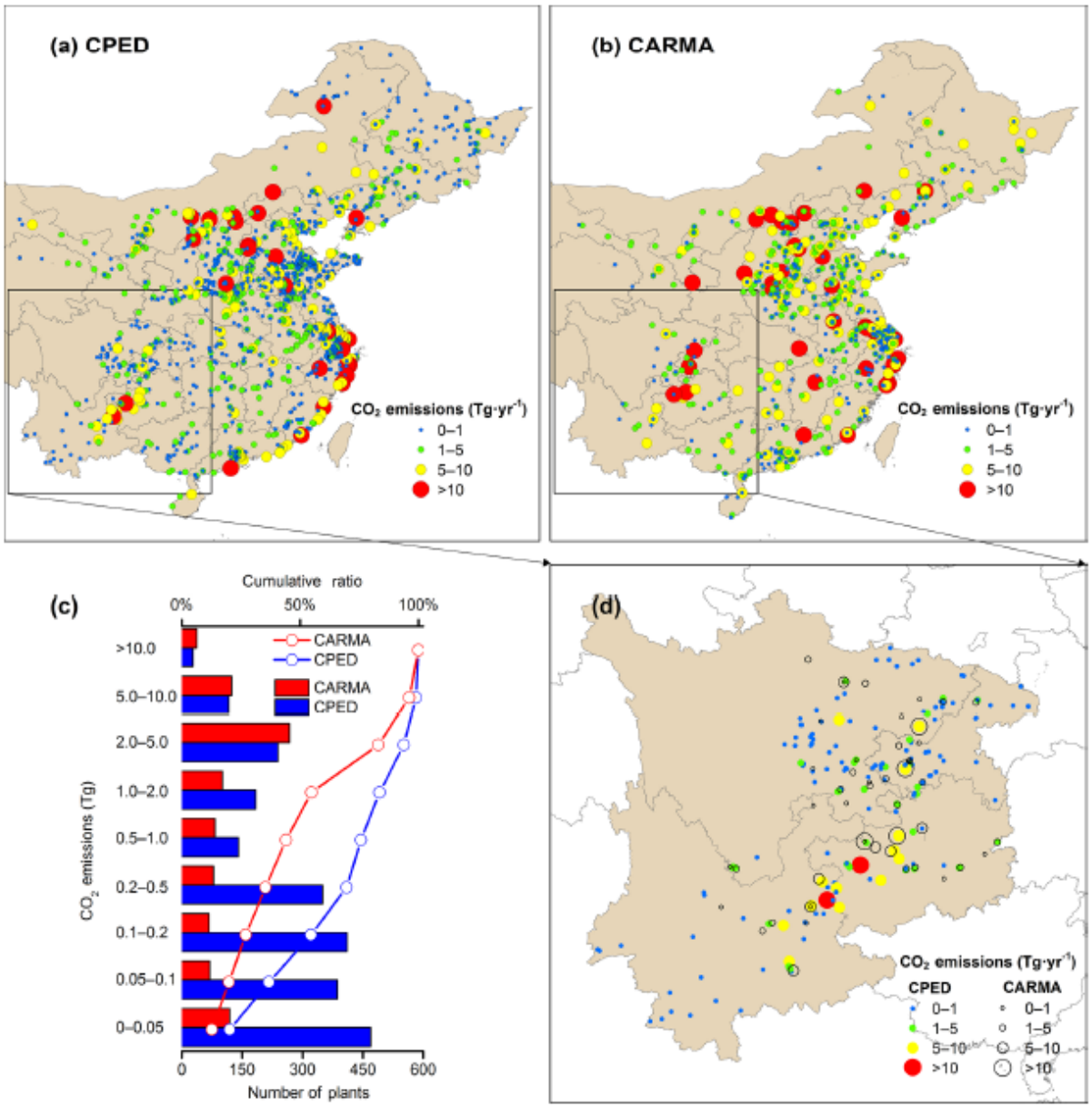


Fig. 4. Spatial distribution of air pollutant in the BTH region for the year 2013.

Qi et al., AE, 2017

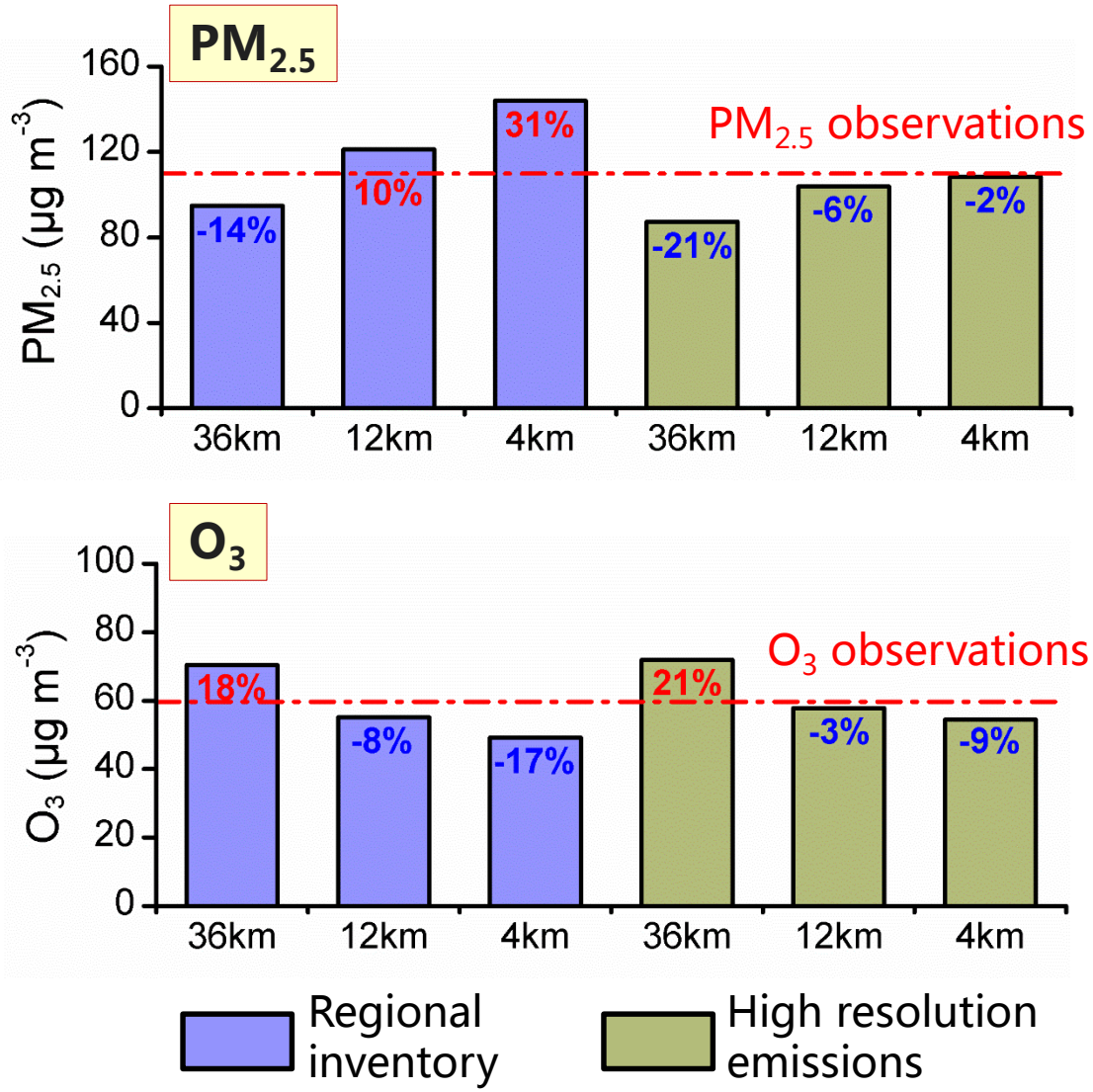
Comparison with global emissions product



Liu et al., ACP, 2015

High resolution emissions data can reduce modeling bias

- 36km -> 4km: Modeling biases increase for regional inventory, while decrease for high resolution emissions data.
- High resolution emissions data at 4km scales reduce modeling bias of $PM_{2.5}$ from 31% to -2%, and of O_3 from -17% to -9%.

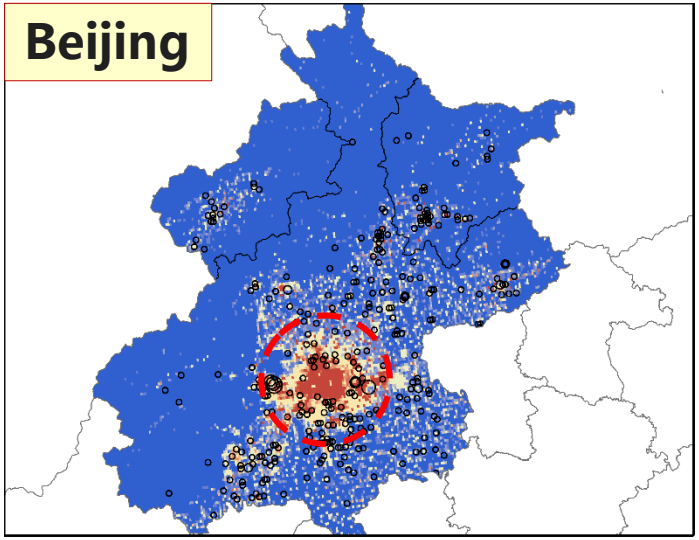


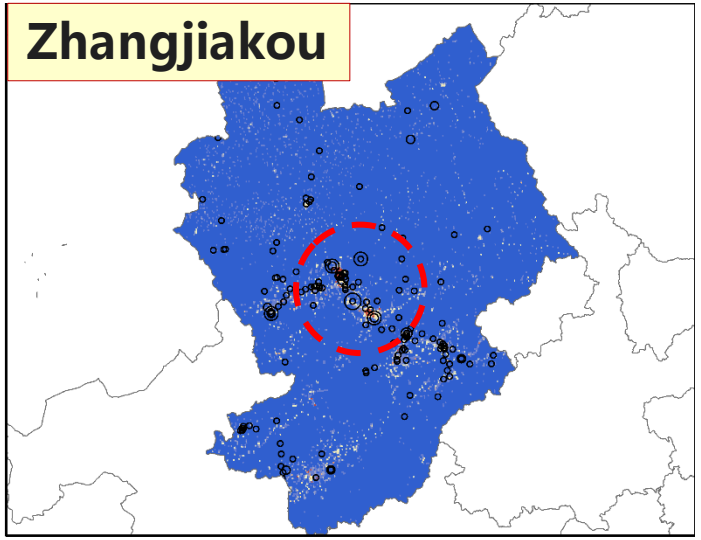
Zheng et al., ACP, 2017

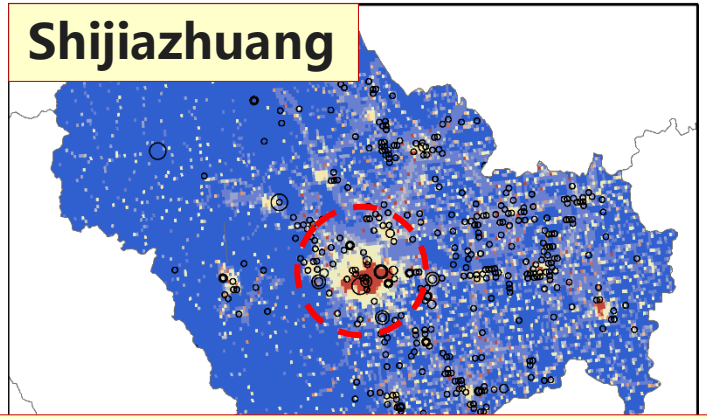
High resolution emissions data can reduce modeling bias

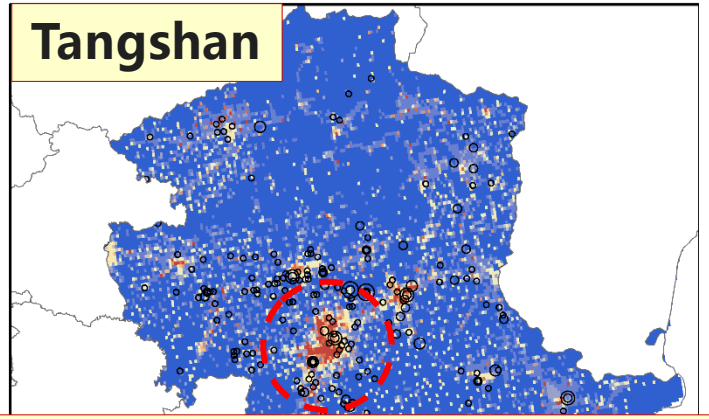
Dot : industry plants

Map : population







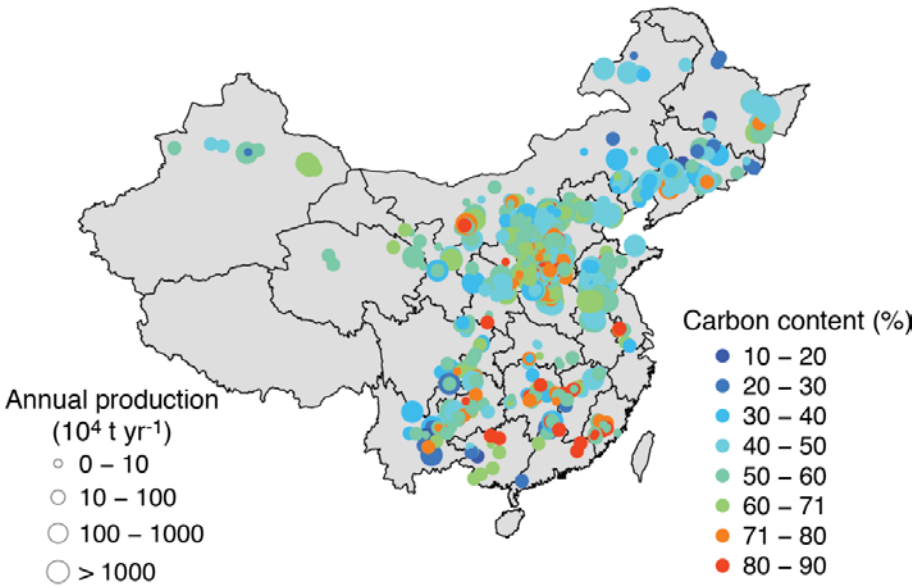


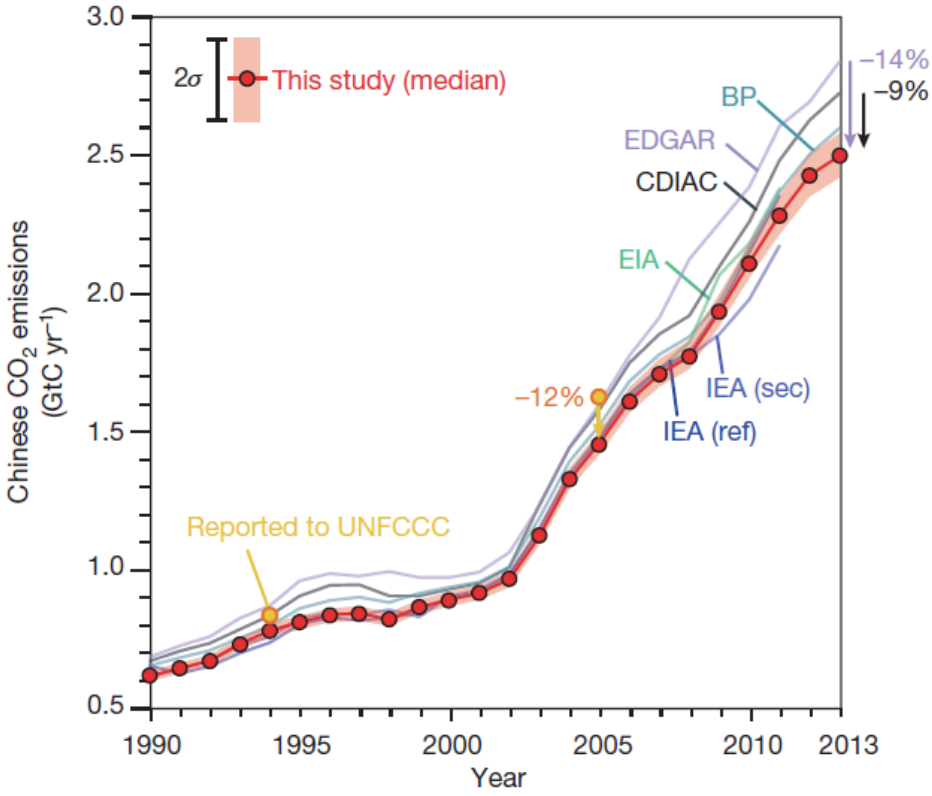
The weak correlation between point source emissions and population indicates that the spatial allocation of emissions based on population used by regional inventories can introduce large biases. **Zheng et al., ACP, 2017**

Application of the MEIC model

- **Emission characteristics and mitigation potential**
- **Evaluation of emissions data based on CTM and observations**
- **Socioeconomic drivers of emissions**
- **Effects of trade on emissions and environment**

Revisit China's anthropogenic CO_2 emissions





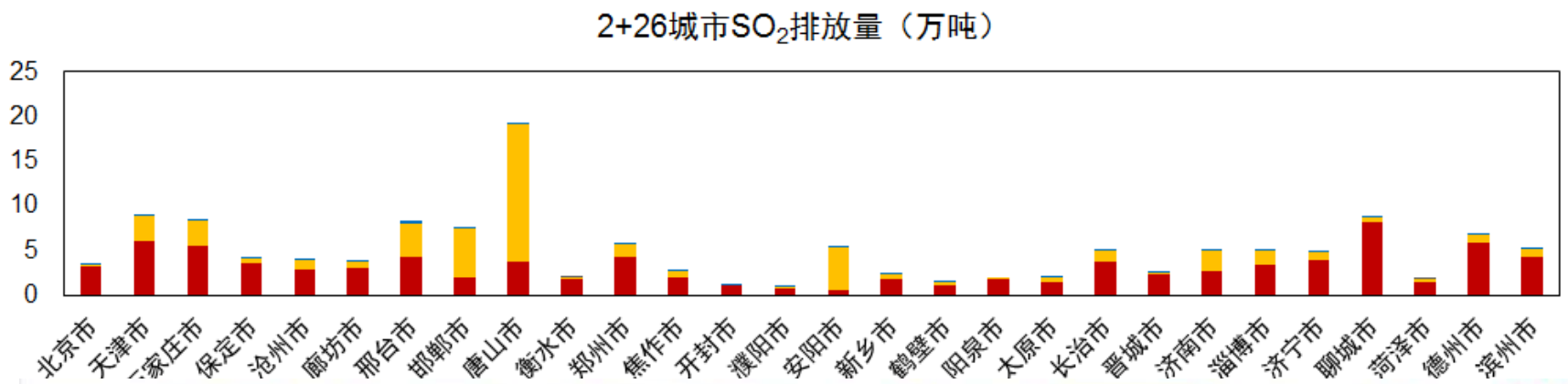
Measured carbon content in coal

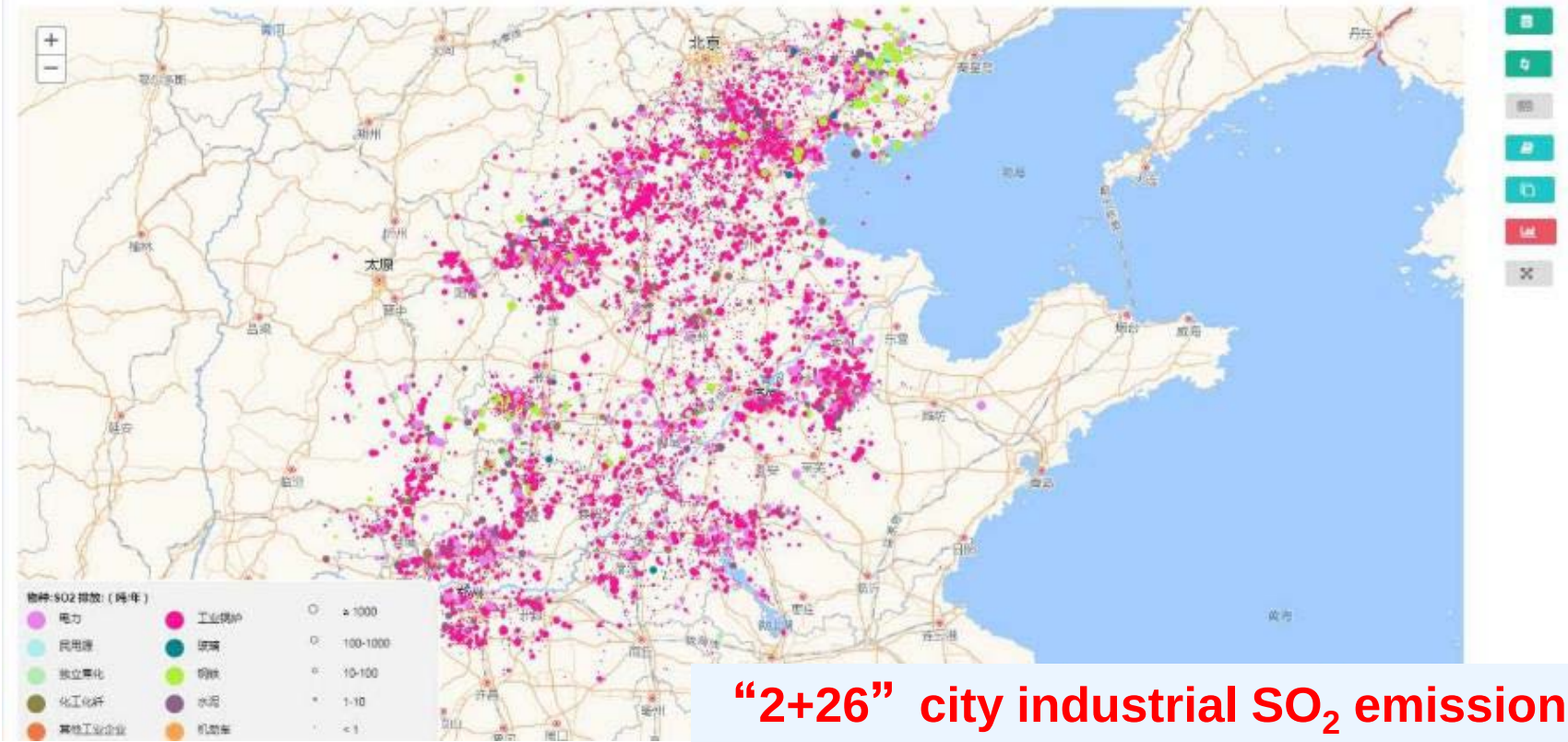
Revisited CO_2 emissions in China

The emissions estimates for China CO_2 emissions based on the MEIC model combined with measured emission factors are 9-14% lower than global emission inventories.

Liu et al., Nature, 2015

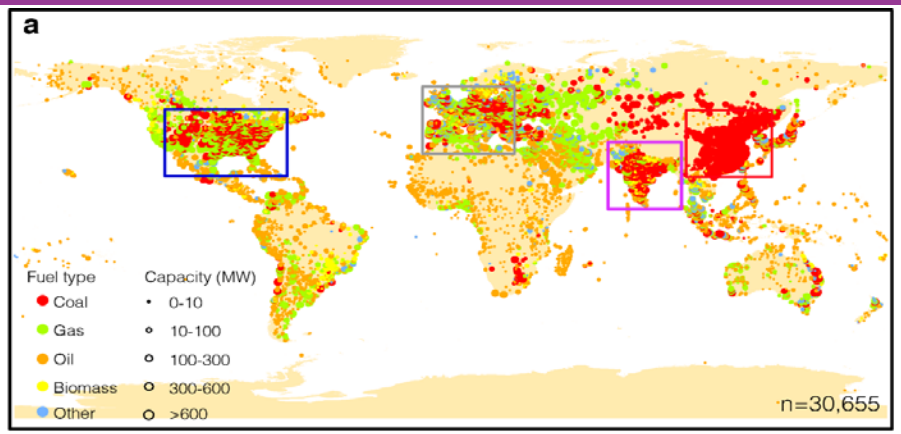
Operational emission inventories for the “2+26” cities

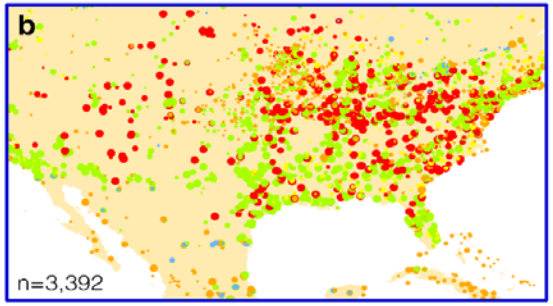


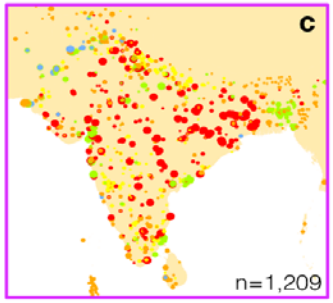


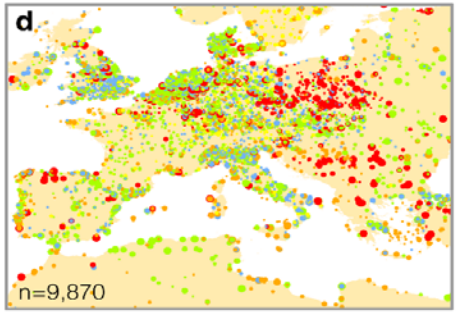
“2+26” city industrial SO_2 emissions

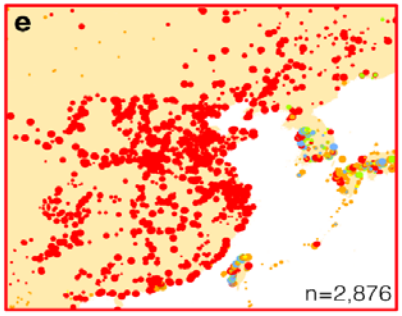
Global Power Emissions Database (GPED)

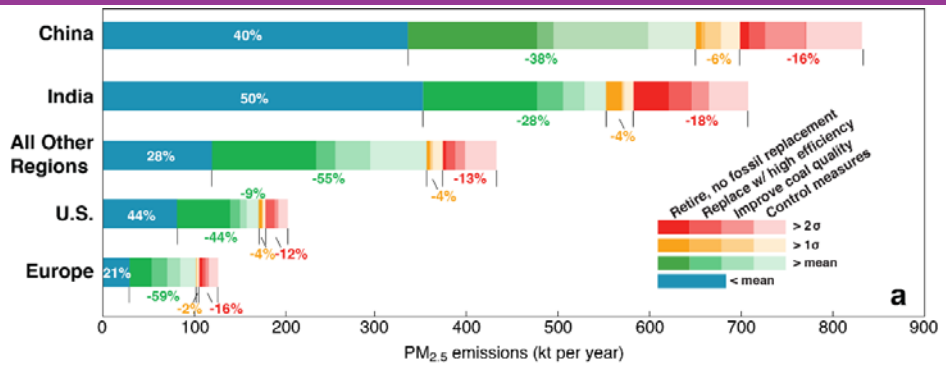


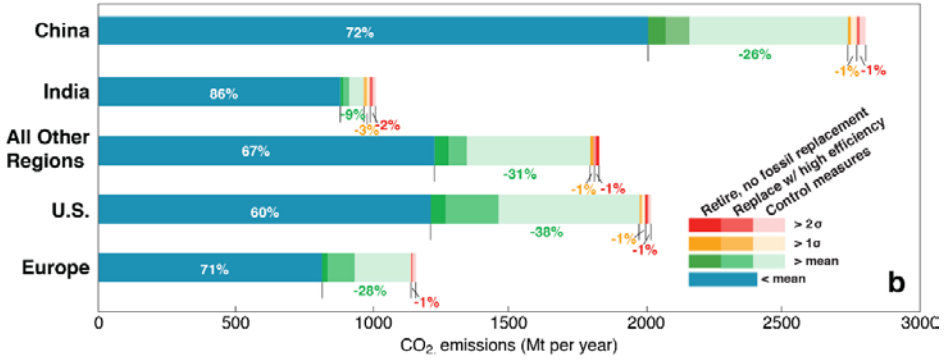


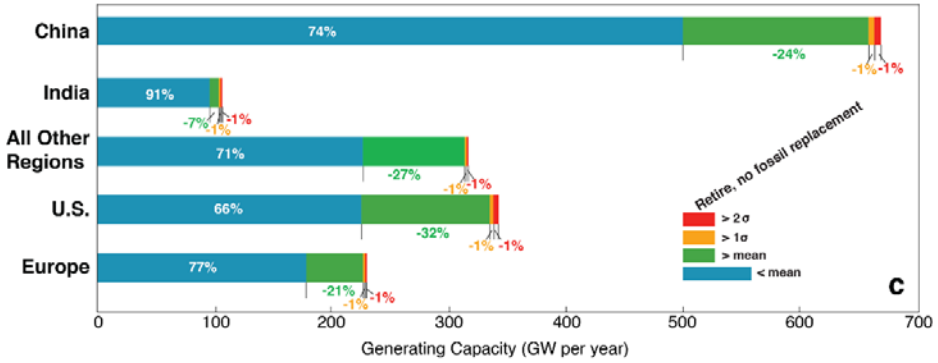












Tong et al., Nat. Sustain., 2018.

Application of the MEIC model

- **Emission characteristics and mitigation potential**
- **Evaluation of emissions data based on CTM and observations**
- **Effects of trade on emissions and environment**

Driver analysis of the declining NO_x emissions

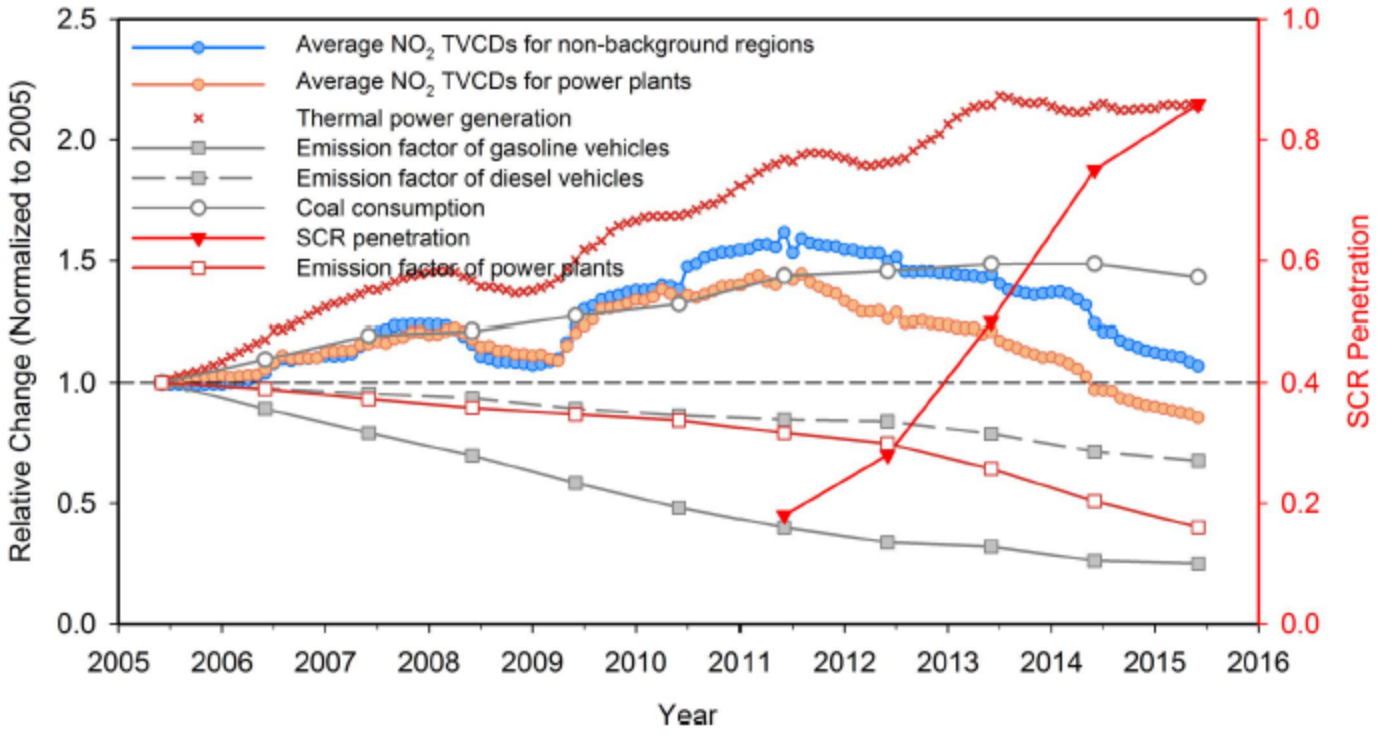
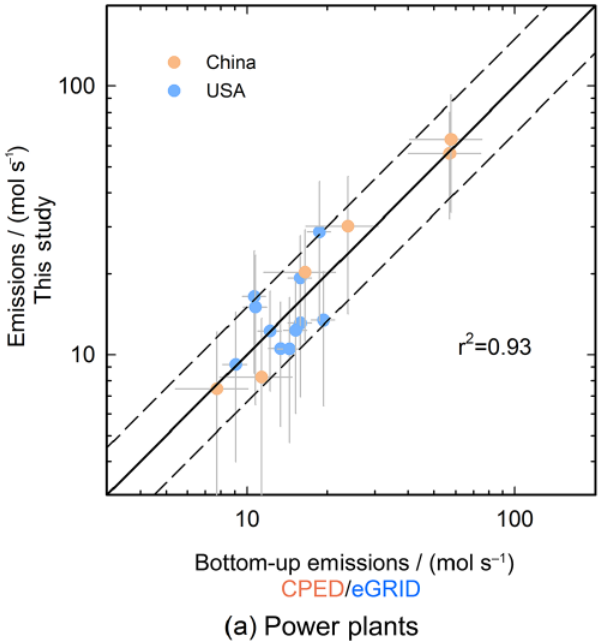


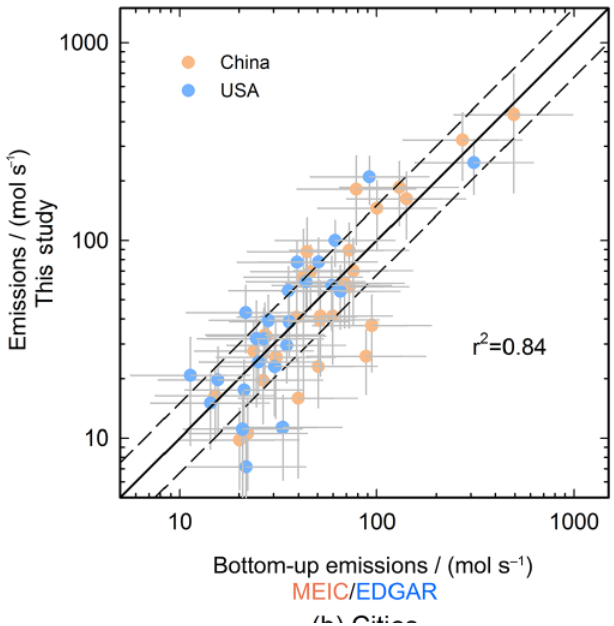
Figure 3. Monthly variations in average NO_2 TVCDs for non-background regions in China and selected power powers, and thermal power generations after a 12-month moving average. Note that the first point of the 12-month moving average represents the data for the period from January to December of 2005. Annual coal consumption (grey circles), average emission factor of gasoline vehicles (grey squares with solid lines), diesel vehicles (grey squares with dash lines) and coal-fired power plants (red squares), and SCR penetrations (red triangles) for China are also shown.

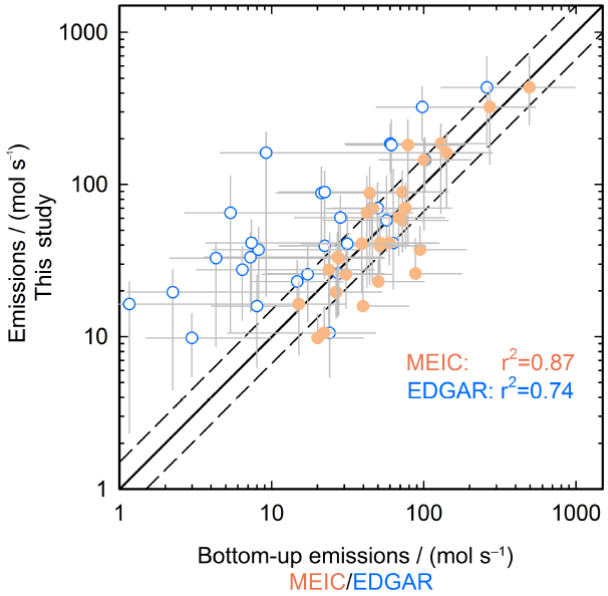
Liu et al., ERL, 2016

Evaluation of NO_x emissions at city scale



(a) Power plants





NO_x emissions from China cities are underestimated by global emission inventories.

Liu et al., ACP, 2016

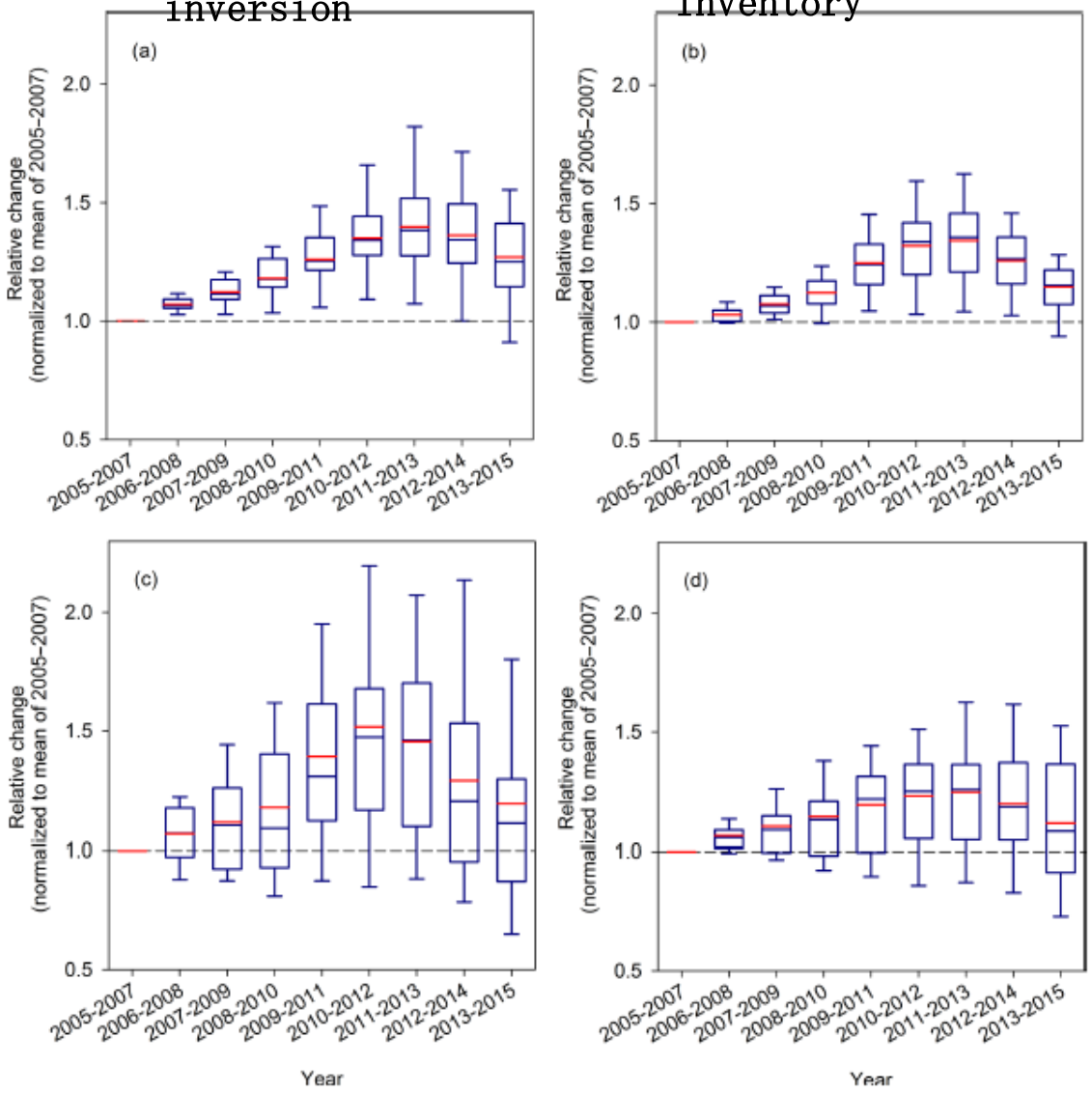
Evaluation of NO_x emissions at city scale

Satellite inversion

Emission inventory

Province

City



Liu et al., ACP, 2017

Application of the MEIC model

- Emission characteristics and mitigation potential
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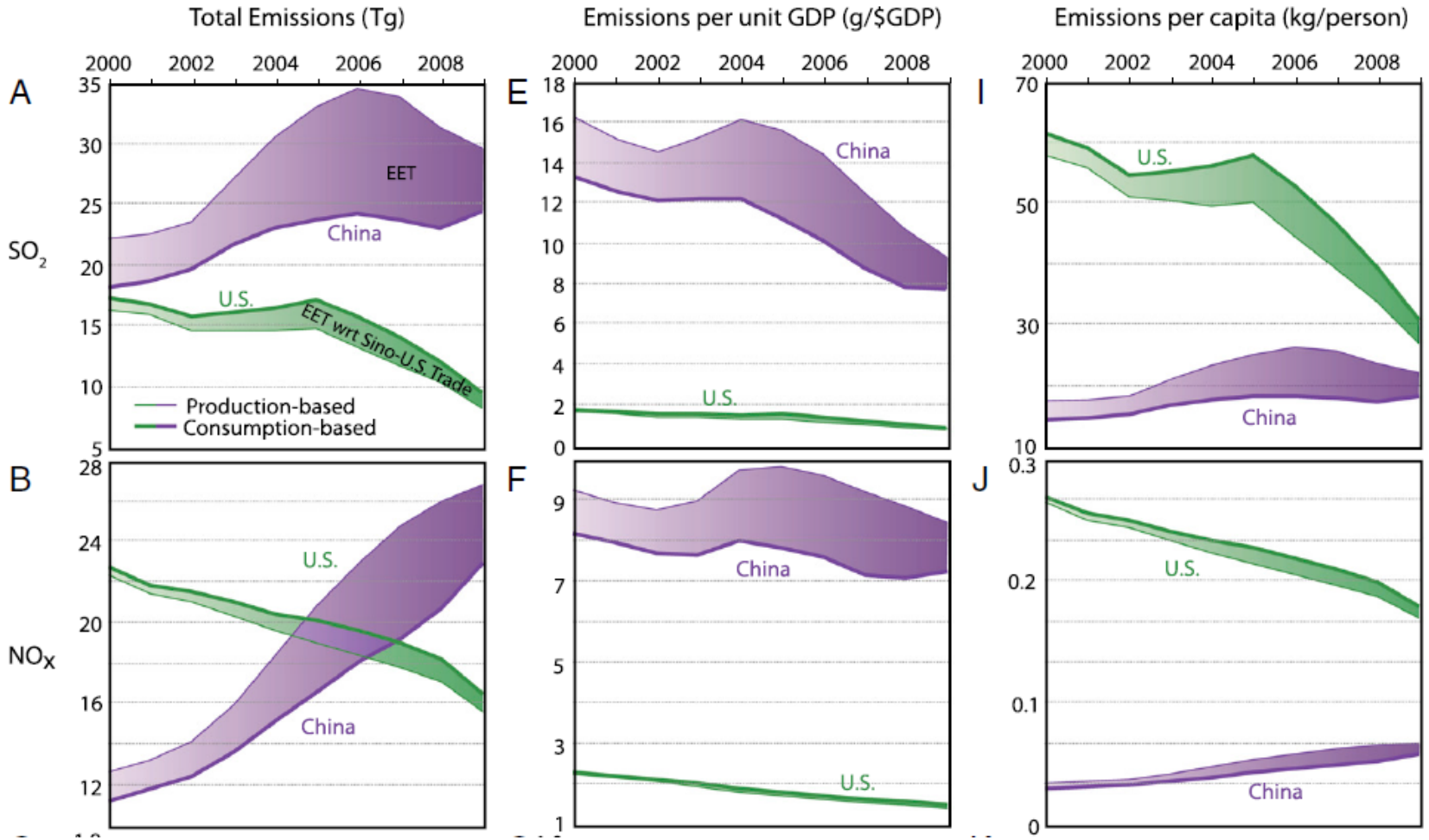
- Socioeconomic drivers of emissions
- Effects of trade on emissions and environment

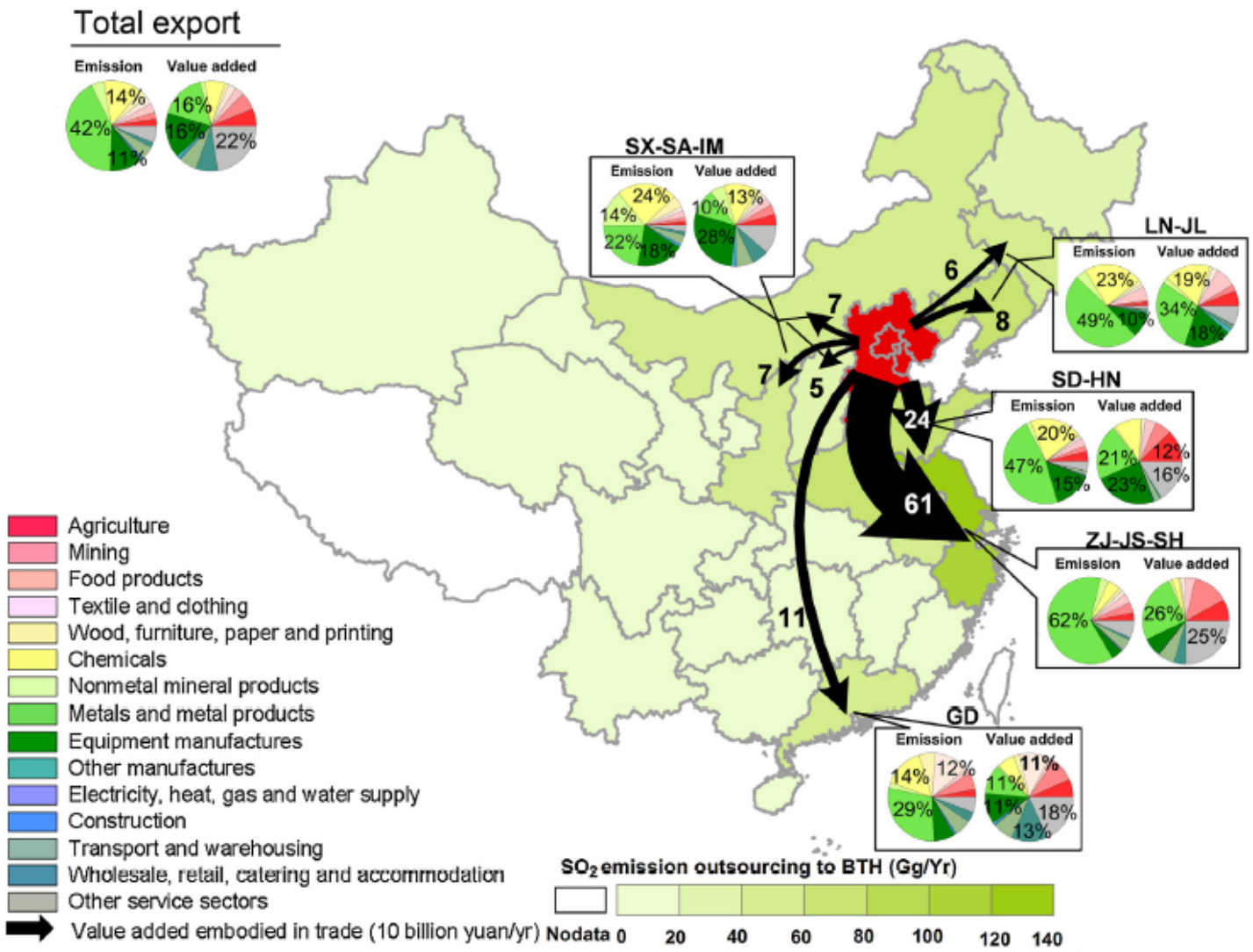
International trade plays a key role in China's air pollutant emissions



Export accounts for 20%-30% of China's air pollutant emissions.

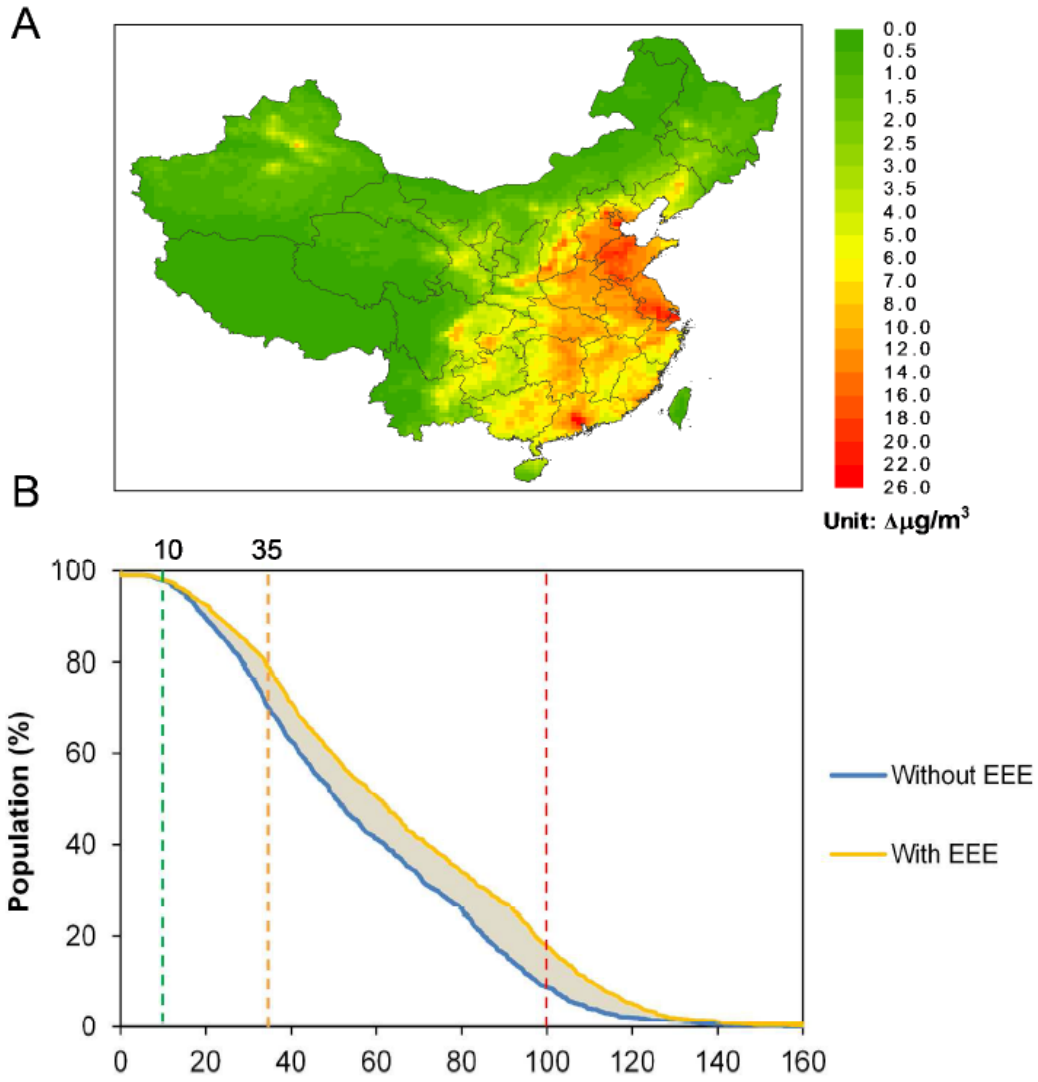
Lin et al. (2014), China's international trade and air pollution in the United States, *P. Natl. Acad. Sci. USA*, 111, 1736–1741

China's air pollution transport embodied in trade are dominated by heavy industry



Zhao et al. (2016), Environment-economy tradeoff for Beijing-Tianjin-Hebei's product exports, *Appl. Energ.*, 184, 926-935.

International trade contributes 15% to $PM_{2.5}$ exposure in China

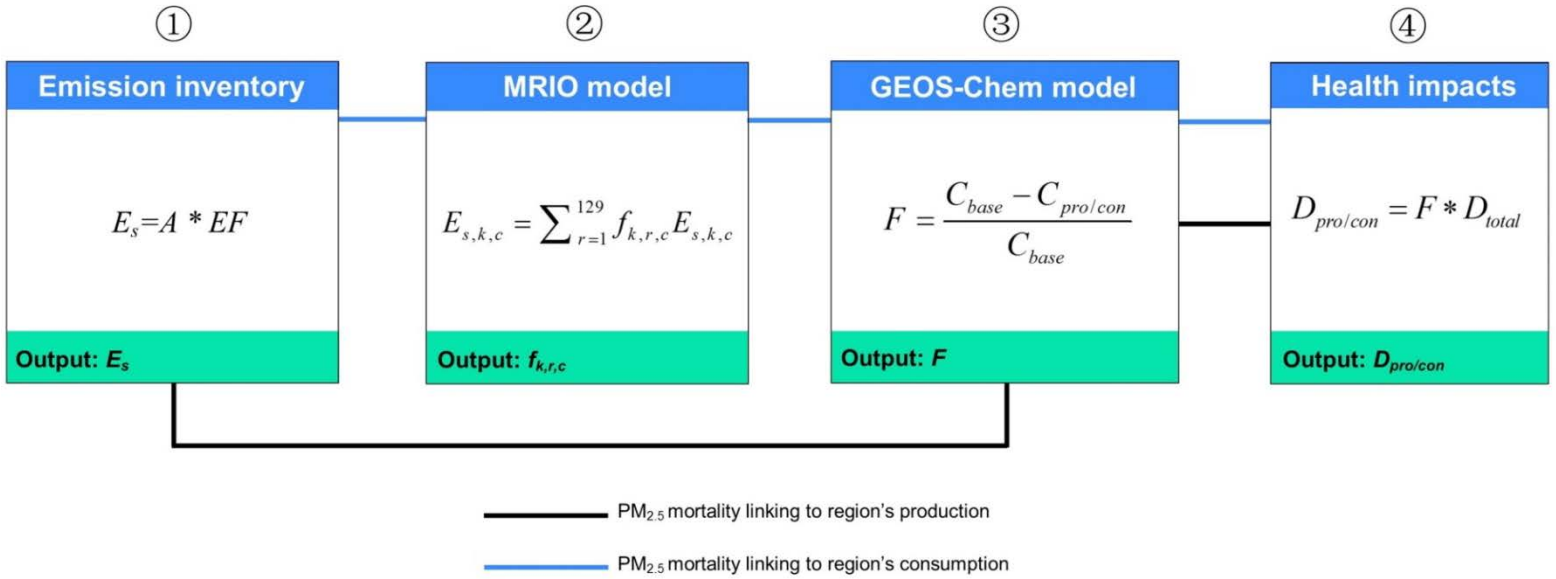


Air pollutant emissions embodied in Chinese exports increase $PM_{2.5}$ exposure by 8 ug/m^3 (15%) in China.

In Eastern China, the $PM_{2.5}$ exposure is increased by 15-20 ug/m^3.

Jiang et al. (2015), Revealing the hidden health costs embodied in Chinese exports, *Environ. Sci. Tech.*, 49, 4381-4388.

Methodology framework to access $PM_{2.5}$ mortality from international trade



E_s: anthropogenic emissions of species *s* (NO_x, SO_2, CO, BC, OC and NH_3) from 228 countries and regions.

A: activity rates, such as fuel consumption or material production.

EF: emission factor of per unit fuel consumed or production produced.

$E_{s,k,c}$: total production-based emissions from sector *k* in region *c*.

$f_{k,r,c}$: the production (or output) fraction of sector *k* in region *c* induced by consumption activities in region *r*.

C_{base}: the modeled $PM_{2.5}$ concentration from the base case.

$C_{pro/con}$: the modeled $PM_{2.5}$ concentration from production and consumption scenario.

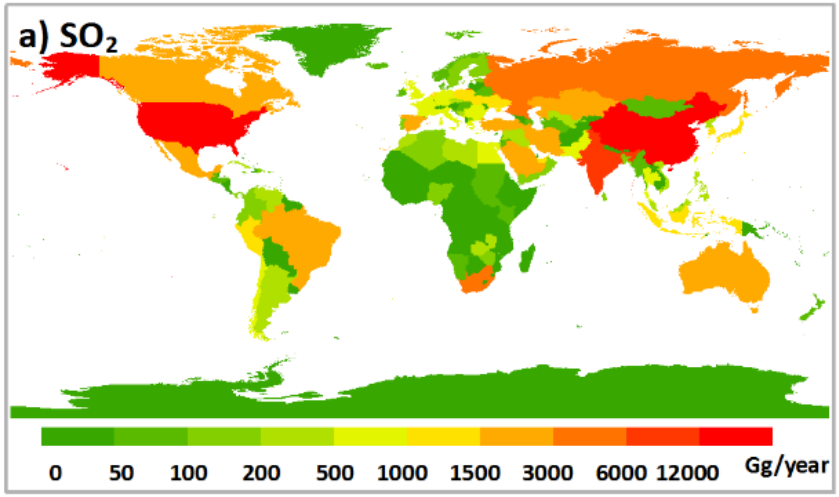
F: the GEOS-Chem modeled fractional contributions of $PM_{2.5}$ due to production or consumption in a given region.

D_{total}: the grid-based global $PM_{2.5}$-related premature deaths calculated using the IER model and high-resolution $PM_{2.5}$ concentrations from the GBD study.

$D_{pro/con}$: the grid-based premature deaths from a given region's production or consumption.

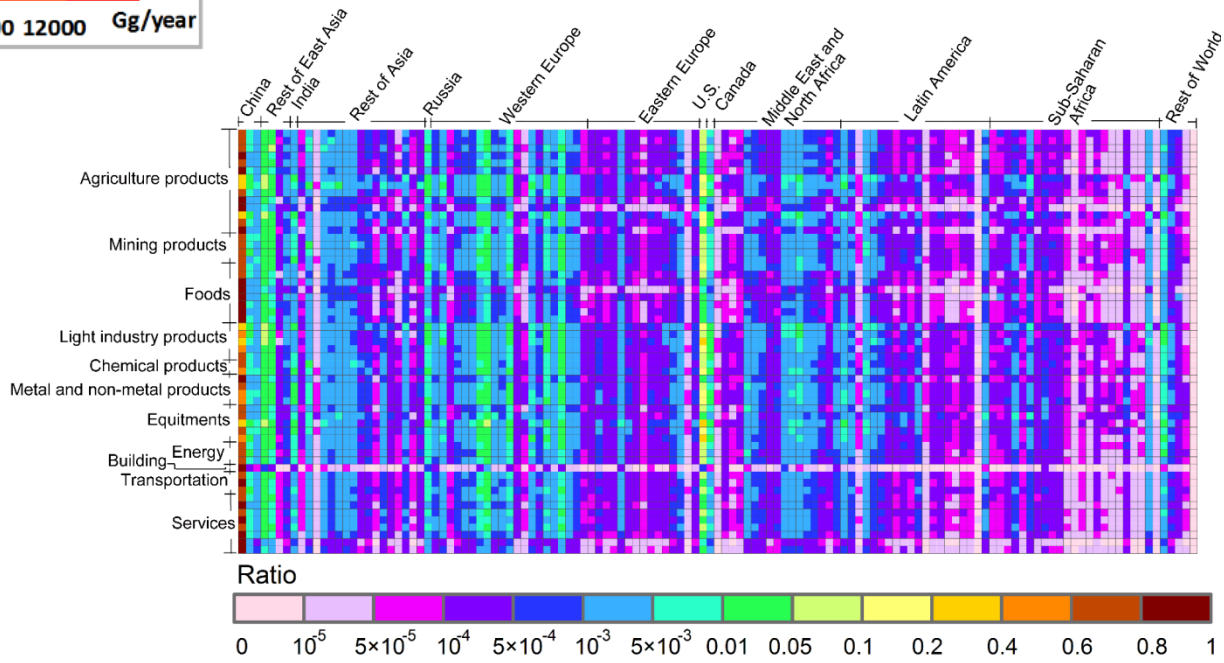
Zhang et al. (2017), Transboundary health impacts of transported global air pollution and international trade, *Nature*, 543, 705-709.

Consumption-based accounting of air pollution



Global SO_2 emission inventory

Tracing emissions to final consumption destinations



*Zhang, Q.,……, **K. B. He**, and D. B. Guan (2017), Transboundary health impacts of transported global air pollution and international trade, **Nature**, 543, 705-709, doi:10.1038/nature21712.*

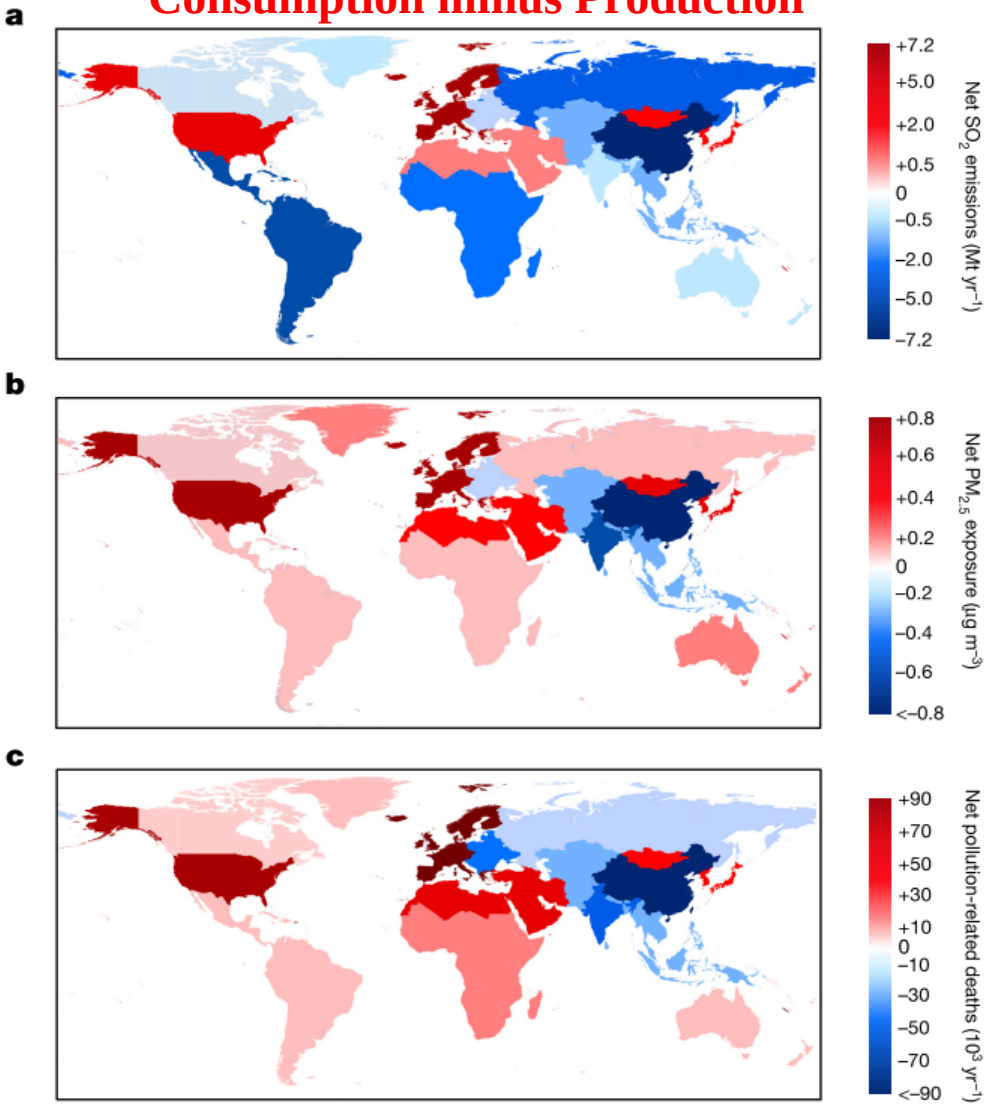
Consumption-based accounting of air pollution

Consumption minus Production

Net SO_2 emissions

Worldwide population-weighted mean $PM_{2.5}$ concentration

Worldwide premature mortality due to $PM_{2.5}$ exposure



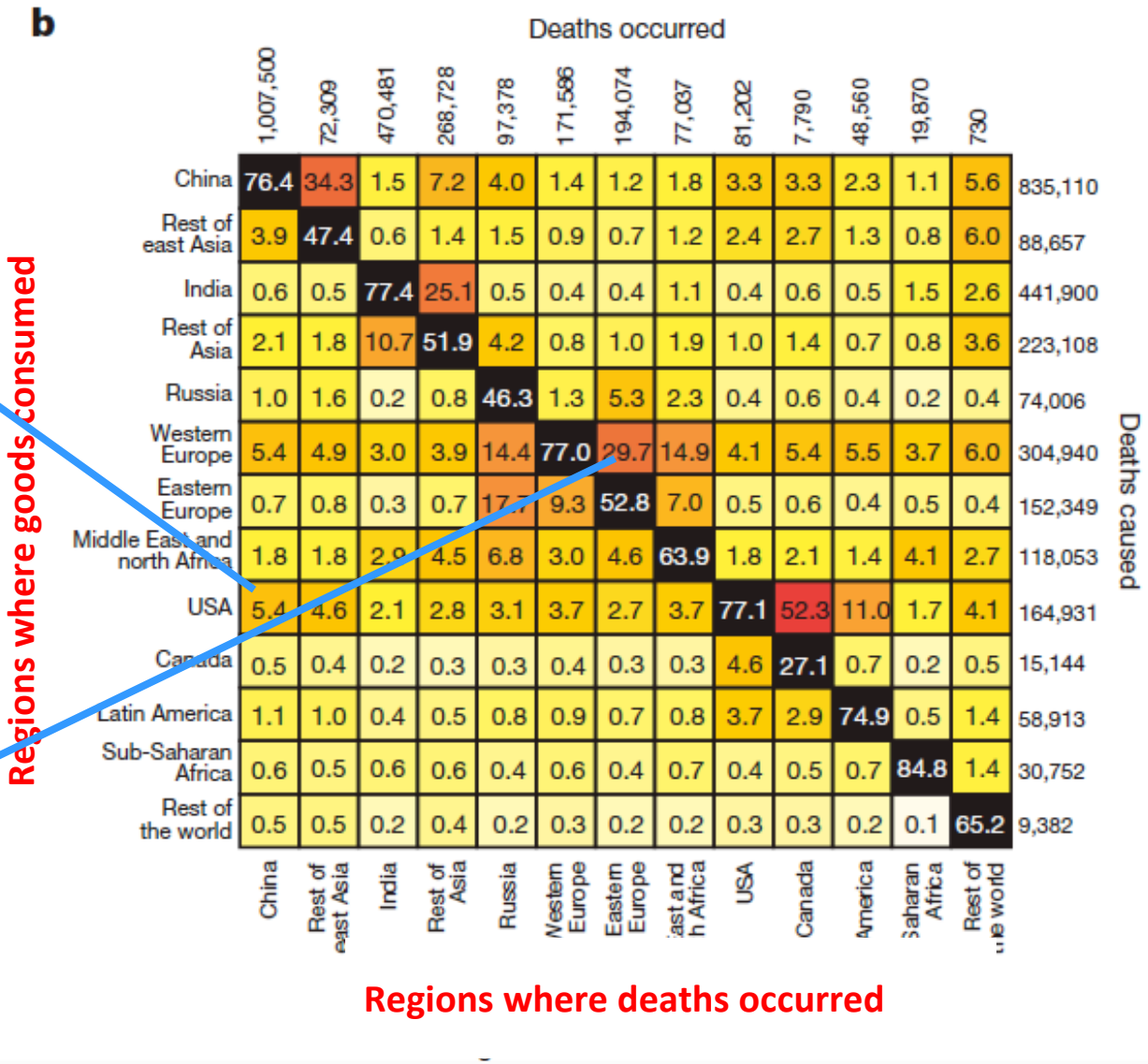
Net importers are shown in shades of red and net exporters in shades of blue

*Zhang, Q.,……, **K. B. He**, and D. B. Guan (2017), Transboundary health impacts of transported global air pollution and international trade, **Nature**, 543, 705-709, doi:10.1038/nature21712.*

Proportion of $PM_{2.5}$-related deaths in a given region that are linked to goods and services consumed in that and other regions

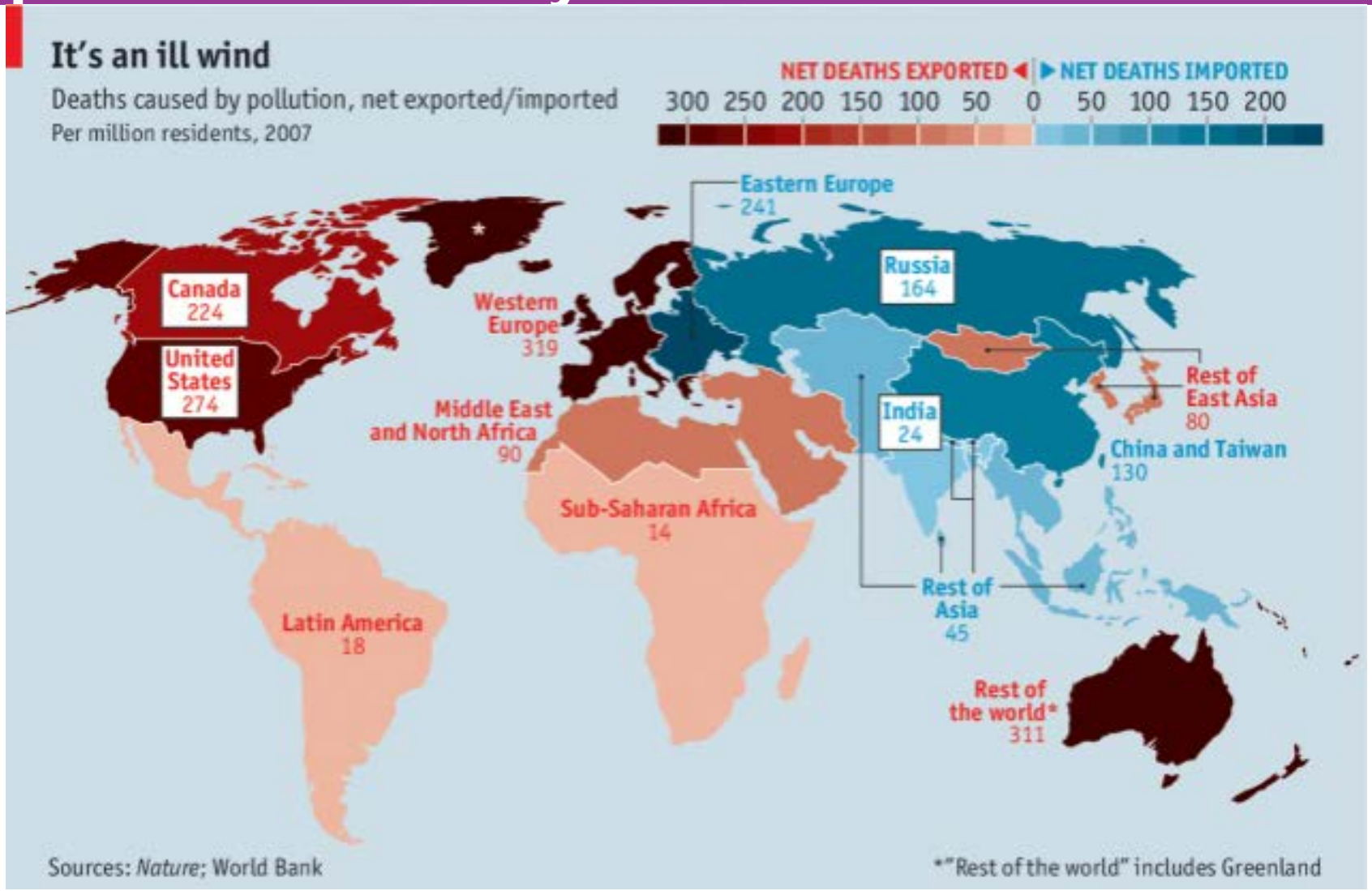
5.4% (54,400) deaths in China due to consumption in USA

29.7% (57,600) deaths in Western Europe due to emissions in Eastern Europe



Zhang et al. (2017), Transboundary health impacts of transported global air pollution and international trade, *Nature*, 543, 705-709.

The effects of international trade on air pollution mortality



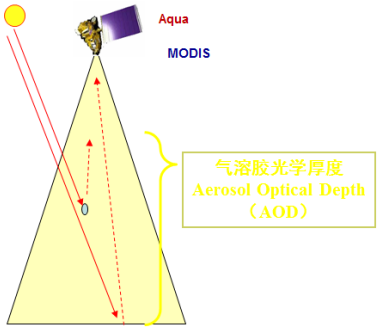
Zhang et al. (2017), Transboundary health impacts of transported global air pollution and international trade, *Nature*, 543, 705-709.

Thank you!

Perspectives

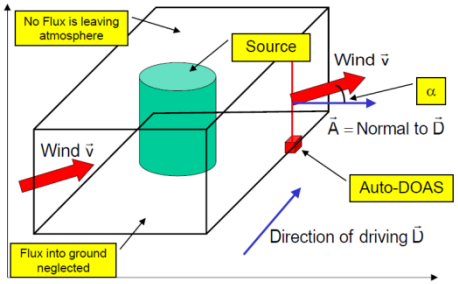
Multi-dimensional verification

Satellite observations



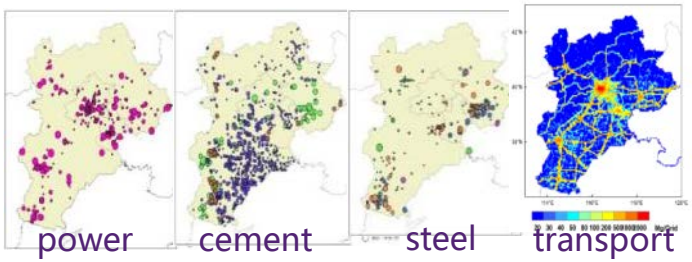
Ground observations

Aircraft measurements

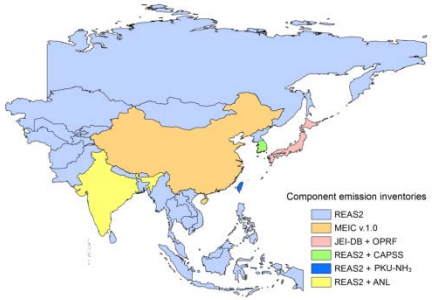


Development of High-resolution emission inventory

Emission allocation improvement



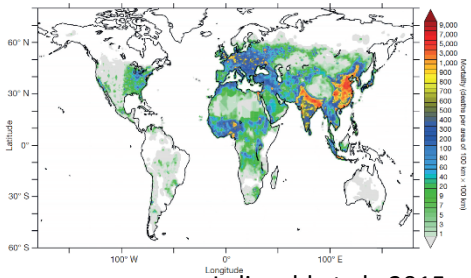
Regional data assimilation



Li et al., 2017

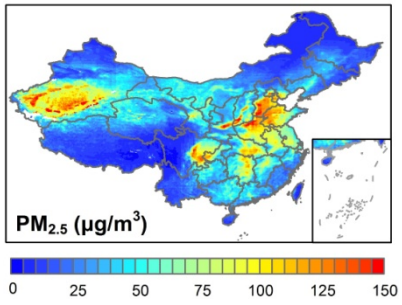
Evaluation of environmental impacts at finer scales

Human health

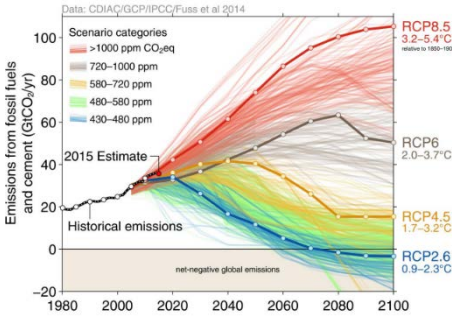


Lelieveld et al., 2015

Air quality



Climate



CICERO