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

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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.
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-NH3, and CAPSS emission inventories, MIX covers ten air pollutants and greenhouse gaseous (SO2, NOx, CO, NMVOC, NH3, PM10, PM2.5, BC, OC and CO2) 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
Methodological framework of the MEIC model

Module 1: emission estimates
- ID1: emission factors
- ID2: spatial distribution
- ID3: activity levels
- ID4: emission factor (EF)

Module 2: spatial-temporal allocation

Module 3: speciation mapping of NMVOC
- CBIV/CB05
- SAPRC99/SAPRC07
- RADM2/RACM

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

1990

Unit capacity (MW)
- 0-100
- 100-1000
- 1000-2400
- >2400

Emissions (Gg/yr)
- 0-2
- 2-15
- 15-50

SO₂ emissions from power plants

Liu et al., ACP, 2015
Point source emissions from the industry sector

Zheng et al., EST, 2018

Circle size, emissions, Gg:
- [0, 1]
- (1, 10]
- (10, 100]
- (100, 5000]
- >5000

Circle colour, industry type:
- power
- cement
- iron blast furnaces
- glass
- industrial boilers
High resolution mapping of road transport emissions

Emission factor
Corrected by meteorology factors

Vehicle ownership
Vehicle ownership model

County level EF

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

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

NO$_x$
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%.
High resolution emissions data can reduce modeling bias.

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
Revisited CO₂ emissions in China

The emissions estimates for China CO₂ emissions based on the MEIC model combined with measured emission factors are 9-14% lower than global emission inventories.

Operational emission inventories for the “2+26” cities

2+26城市SO₂排放量（万吨）

“2+26” city industrial SO₂ 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

![Graph showing the relative change 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.](image)

Liu et al., ERL, 2016
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

Province

City

Liu et al., ACP, 2017
Application of the MEIC model

- Emission characteristics and mitigation potential
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- 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

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$^3$.

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


$E_s = A \times EF$

$E_{s,k,c} = \sum_{r=1}^{129} f_{k,r,c} E_{s,k,c}$

$F = \frac{C_{\text{base}} - C_{\text{pro/con}}}{C_{\text{base}}}$

$D_{\text{pro/con}} = F \times D_{\text{total}}$

$E_s$: 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 $r$.

$C_{\text{base}}$: the modeled PM$_{2.5}$ concentration from the base case.

$C_{\text{pro/con}}$: 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.

$D_{\text{total}}$: 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.

$D_{\text{pro/con}}$: the grid-based premature deaths from a given region’s production or consumption.
Consumption-based accounting of air pollution

Net SO₂ emissions

Worldwide population-weighted mean PM₂.₅ concentration

Worldwide premature mortality due to PM₂.₅ exposure

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

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
The effects of international trade on air pollution mortality

Thank you!
Perspectives

Multi-dimensional verification

Satellite observations
- MODIS
- Aqua

Ground observations

Aircraft measurements
- Source
- Wind
- Flux into ground neglected
- Auto-DOAS
- \( \vec{A} = \text{Normal to } \vec{U} \)

Emission allocation improvement

Regional data assimilation

Development of High-resolution emission inventory

Power, cement, steel, transport

Evaluation of environmental impacts at finer scales

Human health

Air quality

Climate

Lelieveld et al., 2015

Li et al., 2017

PM\(_{2.5}\) (\(\mu g/m^3\))

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