High-resolution and real-world emission model and inventory for urban vehicle fleets in China

International Workshop on “Mobile source emission modeling and emission reduction strategies”

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Outline

- Background and Research Motivation
- Methodology framework and data source
- Emission measurement and model development
  - PEMS measurement
  - Chasing measurement
  - Multiscale emission model development
- Traffic dynamics and high-resolution emission inventory
  - Urban traffic flow
  - Inter-city traffic flow
  - High-resolution emission inventory: case studies of Macao, Nanjing and Beijing
- Mesoscale air quality modeling
Vehicle emissions are one of the most important local PM$_{2.5}$ sources for many megacities in China.

### Sectoral allocation of local sources

- **Beijing (81 μg/m$^3$)**
  - Vehicle/Mobile sources: 31%
  - Coal combustion: 29%
  - Dust: 28%
  - Industrial: 22%
  - Residential, agricultural and others: 52%

- **Shanghai (53 μg/m$^3$)**
  - Vehicle/Mobile sources: 29%
  - Coal combustion: 28%
  - Dust: 28%
  - Industrial: 22%
  - Residential, agricultural and others: 52%

- **Hangzhou (55 μg/m$^3$)**
  - Vehicle/Mobile sources: 29%
  - Coal combustion: 28%
  - Dust: 28%
  - Industrial: 22%
  - Residential, agricultural and others: 52%

- **Guangzhou (39 μg/m$^3$)**
  - Vehicle/Mobile sources: 29%
  - Coal combustion: 28%
  - Dust: 28%
  - Industrial: 22%
  - Residential, agricultural and others: 52%

- **Shenzhen (30 μg/m$^3$)**
  - Vehicle/Mobile sources: 29%
  - Coal combustion: 28%
  - Dust: 28%
  - Industrial: 22%
  - Residential, agricultural and others: 52%

Data source: Ministry of Environmental Protection.
Note: For Shanghai and Shenzhen, their mobile source sectors include off-road sources and ships.
Background

- Beijing is the leader in vehicle emission controls within China.
- “Vehicle-Fuel-Road” integrated control system.

Now, traffic measures are increasingly important now in the system, including the notable restrictive policies on registration and usage (e.g., license control, regular traffic restriction, odd-eve restriction).
Research Motivation

- Significant climate forcing and health impacts due to key components (e.g., Black carbon, BC; Polycyclic aromatic hydrocarbon, PAHs)
- Uncertainty from in-use high emitters and high off-cycle emissions

Polycyclic hydrocarbons

Sulphate

Ash

Black carbon (soot)

Emissions distribution for truck fleets in Beijing and Chongqing (tested by chasing)

Wang et al., 2012
Research Motivation

- High-resolution emission inventory is an irreplaceable tool compared with conventional inventory technology (registration data based).
  - High-resolution: hourly, link-level, vehicle techno. group (category, fuel, standard, model year)

- Impacts from urban traffic congestion and inter-city freight transportation are of great concerns.

Location: Jing-Zang Expressway

Location: Guomao Bridge

Beijing
Total area: ~16,000 km²
Urban area: ~1,000 km²
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Methodology framework and data source

- **Annual Average Hourly Traffic Volume**
  - Traffic loop detector, RFID, Camera, Simulation

- **High-resolution vehicle speed profiles**
  - Floating car, RFID, GPS survey,

- **Real-world fleet composition database**
  - RFID, Remote sensing, Camera Non-local vehicle survey

- **Inter-city highway traffic monitoring data**
  - From Ministry of Transport

- **Type-approval emissions**
  - Dynamometer

- **Real-world micro emission rates**
  - PEMS

- **High emitters**
  - Chasing, Remote sensing

- **Deterioration**
  - Remote sensing, Dynamometer, IM

- **Emission factor models for Chinese cities (e.g., EMBEV)**

- **High-resolution vehicle emission inventory**

- **Life-cycle climate impact**

- **Air quality and health impacts**

- **Regional:** CMAQ
  - Traffic model and data

- **Mesoscale:** AERMOD
  - Emission test and model

- **Near-road:** AERMOD/R-line
  - High-resolution inventory

- **Impact assessment**

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2016/4/14
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Portable Emission Measurement System

- We are dedicated to developing PEMS methods for high-resolution and real-world measurements of PM, BC, VOCs and unregulated species (e.g., PAHs).
PM measurement of HDDVs: real-world BC emissions

- Improvements from less congested traffic and more strict emission standard
- Significantly higher BC emissions from mechanical pump injection engine equipped HDDVs
PM measurement of HDDVs: real-world PAHs emissions

Average particle-borne total PAHs emissions

Comparison of specified PAHs emissions by engine type

- We are expanding functions and applicability of the PEMS method to more unregulated pollutants.
PEMS can play an essential role in understanding the real-world emission complexity from powertrain (e.g., hybrid vs. ICEV), engine (e.g., lean burn vs stoichiometric), after-treatment (e.g., SCR) and traffic conditions (e.g., congestion).
Plum chasing measurement: Improved understanding of high-emitters based on large-sized vehicle samples

- Significantly higher BC emissions discerned by chasing for non-local trucks in Beijing.
Multiple-Scale emission models for Urban vehicle fleets

- **E.g., the Emission factor Model for BEijing Vehicle fleet (Version 2.0)**
  - Beijing’s official model (Beijing Environmental Protection Bureau, since 2010)
  - Other city-level emission factor models: Macao, Guangzhou, Nanjing, etc.

- **Data fundamental and key method**
  - Dynamometer tests for thousands of light-duty vehicles and PEMS tests for hundreds of both light-duty and heavy-duty vehicles
  - Speed correction functions: dynamo. tests over various cycles; operating binning method; micro-trip method

- Average emission factors for urban transit buses
  - (g/km, an average speed of 18 km/h)

- Speed-correction function for China IV urban bus
  - $y = 10.219x - 0.797$
  - $R^2 = 0.58$

Multiple-Scale emission models for urban vehicle fleets

- The National Emission Inventory Guidebook (MEP, 2015)
  - Its archetype is the EMBEV model with full considerations in regional distinctions
  - Applied by many cities for source apportionment

See detailed information via Wu et al., ACP, 2012; Zhang et al., Atmos. Environ., 2014; Zhang et al., Appl. Energy, 2014; Yue et al., 2015; Zheng et al., 2015; Wu et al., Environ. Pollu., 2016, under review.
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High-resolution vehicle emissions in Beijing based on real-world urban and inter-city traffic data

Urban Traffic Flow: High-resolution traffic volume and fleet composition by radio-frequency identification (RFID) technology

- In Nanjing, nearly 600 RFID detection stations have been built, covering +90% of local vehicles.
- Detailed vehicle specifications (e.g., manufacturer, vehicle model, emission standard, fuel type, vehicle size).
Urban Traffic Flow: Resolving congestion maps into dynamic hourly speed profiles

- The congestion map is technically supported by the floating car system using more than 60,000 taxis as probe vehicles (GPS based).

Real-time congestion map in Beijing based on the floating car system
Urban Traffic Flow: Individual vehicle usage data

- Nearly 500 private passenger cars in Beijing have been investigated for one to six months.

- Comparable habitual travel distance and lower random travel distance in Beijing than German cities.
- Lower fraction of random travel in Beijing
- Fundamental to evaluate mileage threshold for BEVs and electrified mileage for PHEVs
- Improve emission inventory regarding traffic conditions, cold start and evaporative emissions.
Case 1: High-resolution emission inventory in Macao (Generation 1)

Traffic volume
Manual camera record & TransCAD modeling

Vehicle speed
GPS field investigation

Fleet composition
Remote sensing database

2010 Typical weekday

HC emission density (g/h)

- ≤ 170
- 171~410
- 411~720
- 721~1020
- 1021~1420
- 1421~1770
- 1771~2710
- ≥ 2711
Case 2: High-resolution emission inventory in Nanjing
*(Generation 2A)*

- Features: higher temporal (real-time) and fleet (vehicle specifications) resolutions based on RFID data

**Traffic volume**
- RFID data validated by traffic loop detectors and camera record

**Vehicle speed**
- Floating car plus RFID

**Fleet composition**
- RFID

![Map of Nanjing showing traffic data](image)
Case 3: High-resolution emission inventory in Beijing (Generation 2B)

- **Features:** Integrated urban and inter-city traffic data

  **Traffic volume**
  - Urban: Annual average hourly traffic volume, real-world traffic count, traffic density model
  - Inter-city: highway traffic monitoring

  **Vehicle speed**
  - Urban: Real-time congestion map, GPS survey
  - Inter-city: highway traffic monitoring

  **Fleet composition**
  - Urban: Vehicle remote sensing and registration data; traffic count
  - Inter-city: highway traffic monitoring
  - **Real-world recognition of non-local trucks**

PM$_{2.5}$, 2013 weekday

00:00
Traffic demand by vehicle category and region in Beijing

- 67% of light-duty passenger vehicles, 73% of public buses and 78% of taxis within the 5th Ring Rd.
- Preliminary results show 78% of local heavy-duty trucks and 90% of non-local duty trucks outside the 5th Ring Rd. (40%~50% concentrated within the 5th and 6th Ring Rds.)
- Good agreement (i.e., within ±6% for most category) with mileage travelled data from vehicle inspection database (weekends combined); Annual average mileage of LDVs was 14,500 km per year.
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Mesoscale Simulation of primary air pollutants

- **Mesoscale air quality modeling with AERMOD**
  - **Pollutants:** CO, BC, NOₓ/NO₂ (oxidized by ozone)
  - **Emissions domain:** within 6th Ring Rd in 4728 grids
  - **Receptors domain:** within 5th Ring Rd in 3779 fine grids
  - **Input data:** gridded emissions, ground and high-altitude meteorological data (wind speed, direction, sunshine, cloud, etc.), geographic information (e.g., land use)
  - **Mechanisms:** dispersion plus NO/NO₂ chemical

![Map of Beijing cities](image)

- **Within 5th Ring Rd:** 3779 fine grid (0.5 km*0.5 km)
- **In between 5th and 6th Ring Rds:** 949 coarse grid (1.5 km*1.5 km)

![Graphs showing wind speed and ozone concentration](image)
Results: NO₂ simulation results

- Simulated daily NO₂ concentrations were 26 to 42 ug/m³, responsible for 56% of urban ambient NO₂ concentration.
- Two peaks associated with traffic rush hours and low concentration in afternoon due to high O₃ level.
Results: BC simulation results (preliminary)

Simulated contribution by vehicles

Daily average BC contribution was 3.5 ug/m³ in the urban area for 2013 weekday.

Significantly higher BC contribution in the nighttime, consistent with other measured data

- High BC emissions from HDTs and bad dispersion conditions
Relevant publications

- **Vehicle emission measurement**

- **Emission model development and control strategies**

- **Traffic dynamics and high-resolution emission inventory**
Thanks for your attention!

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