Using mobile measurements to update on-road transportation emissions inventories

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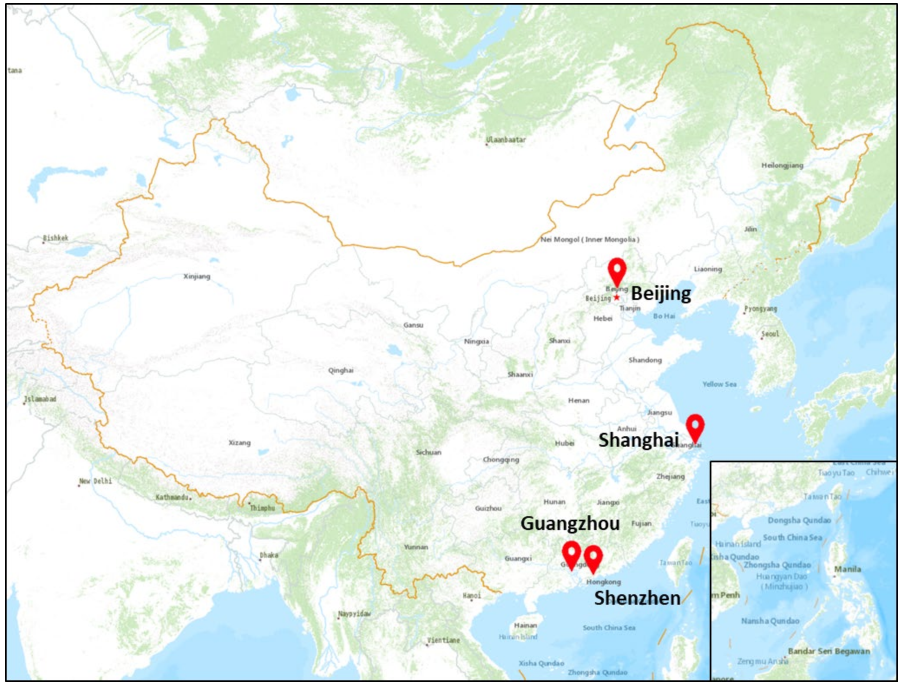
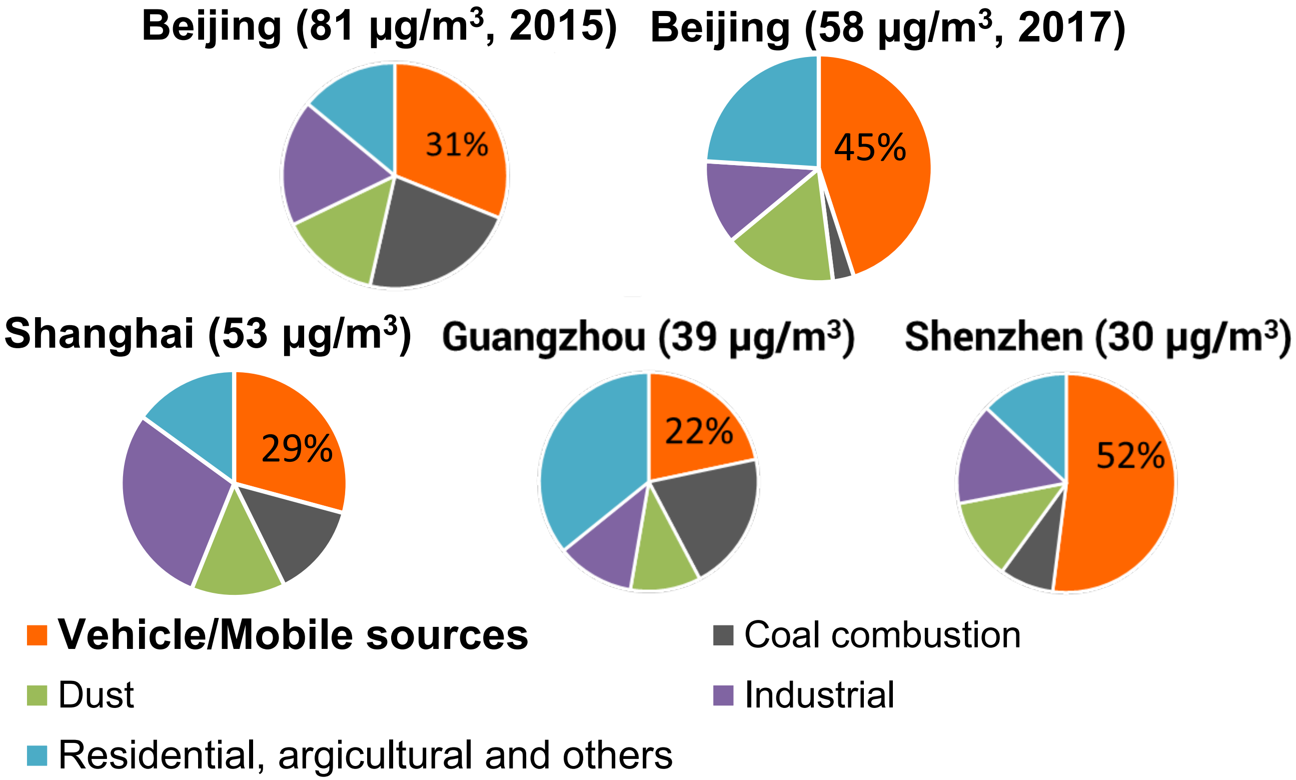
Outline

- Background
- Methods
- Results and discussion
- Summary

Vehicle emissions and air pollution problems in China

- **Official source apportionment of ambient $PM_{2.5}$ pollution**





Data source: Ministry of Ecological Environment of China; Note: Cross-boundary transport not included

- Other relevant concerns : high fraction of nitrate aerosol (e.g., over 30% in Beijing), summertime O_3 pollution, and exceedance of NO_2 concentrations in urban areas

HDDV emissions control in China

- Controlling air pollutant emissions from HDDVs are one of the prioritized tasks in the new “Clean Air Action Plan (2018-2010)”
- Generally, the European regulatory systems have been used in China
- China III and earlier stages: typically no modern aftertreatments
- China IV and China V (implemented nationwide since 2015):
  - SCR as mainstream aftertreatment for NO_X control (2.0 g/kWh for China V)
  - Almost no DPF adoption
- China VI: recently implemented since Jul 2019 in a few cities/regions
  - PEMS regulations: conformity factors of 1.5 for NO_X and 2.0 for PN (China VIb)
  - OBD requirements: capability of remote on-board sensor-based monitoring

Technology innovation to enhance in-use surveillance

Regulated methods

PEMS
1~2 vehs per day

Dynamometer
1~2 vehs per day

Real-world efficient methods

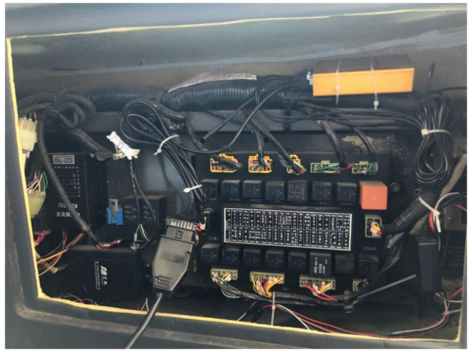
Non-intrusive

Plume chasing
50~80 vehs per day
2~5 mins per veh

Remote sensing
1000+ vehs per day
Short snap per veh

Remote OBD monitoring

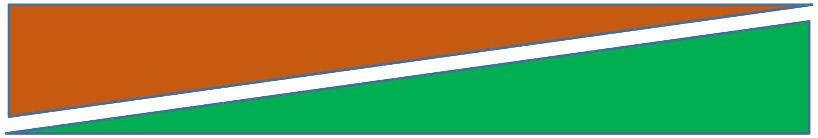
Applicable to key fleets
NOx sensor required



OBM data logger
Data collection and transmission (to cloud)

Accuracy

High accuracy
Small sample size



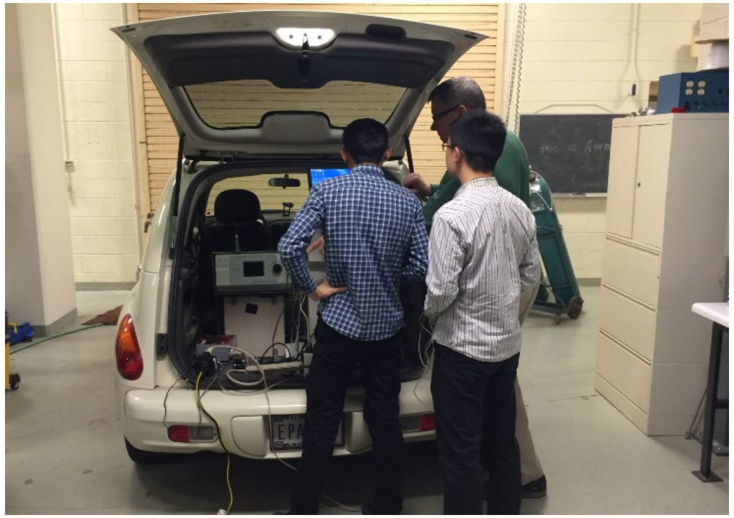
Low accuracy
Large sample size

Fleet coverage

Tsinghua-NRMRL collaborative project

- Sponsored by Ministry of Science and Technology of China (MOST)-USEPA collaborative agreement on technology innovation for environmental protection
- A focus on developing cost-effective road emission measurement methods
- Collaborative project on motor vehicle plume chasing and joint research workshops

Technical communication at EPA ORD NRMRL in RTP, NC



Joint workshop at Tsinghua University, Beijing

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Research framework

1. Method evaluation
- Concurrent PEMS-chasing tests
- Optimize EF calculation methods

2. Plume chasing
- Large-scale field tests
- EF database based on plume chasing

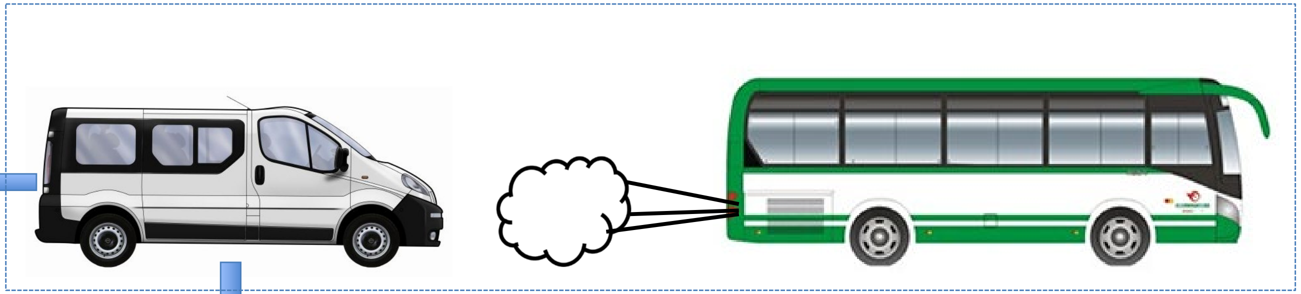
3. Emission inventory update
- Updating key EFs for HDVs
- Updating fleet-level emission inventories

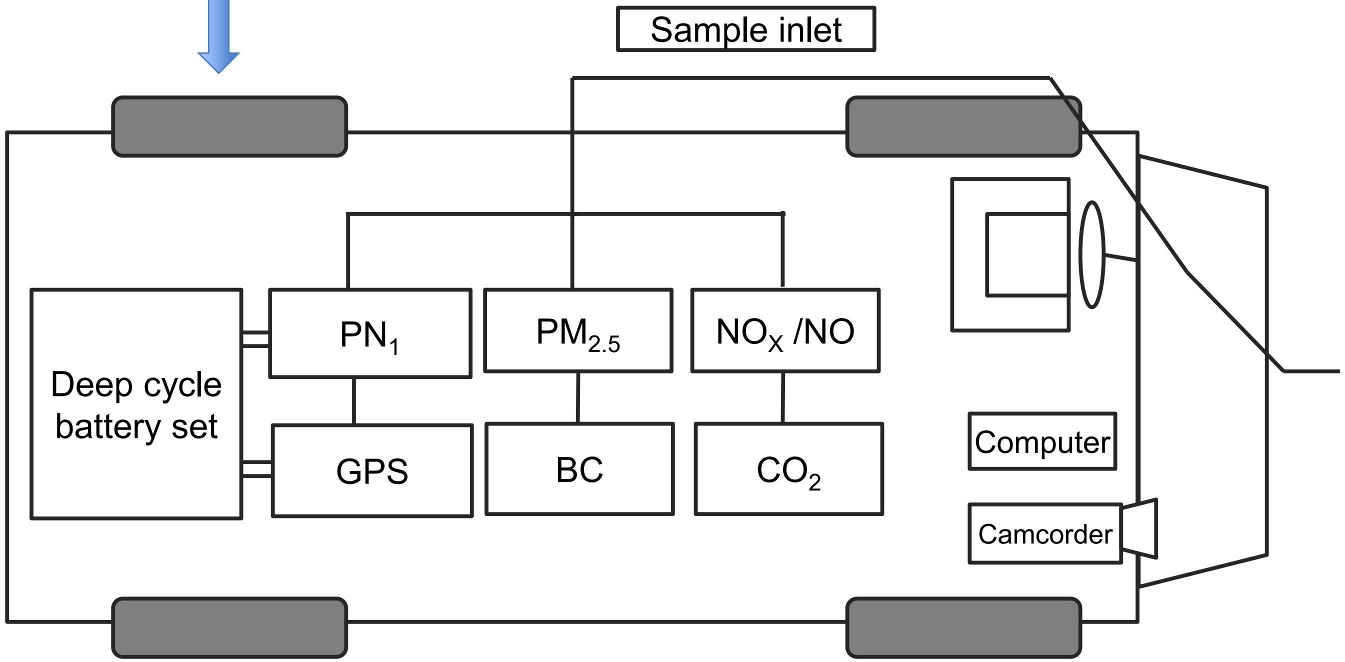
4. Air quality simulations
- Gridded emission input
- WRF/2D-VBS CMAQ
- Impact from updated EFs on ambient NO_2, O_3 and $PM_{2.5}$

Mobile chasing platform

Pollutant analyzers (Resolution: 1Hz)

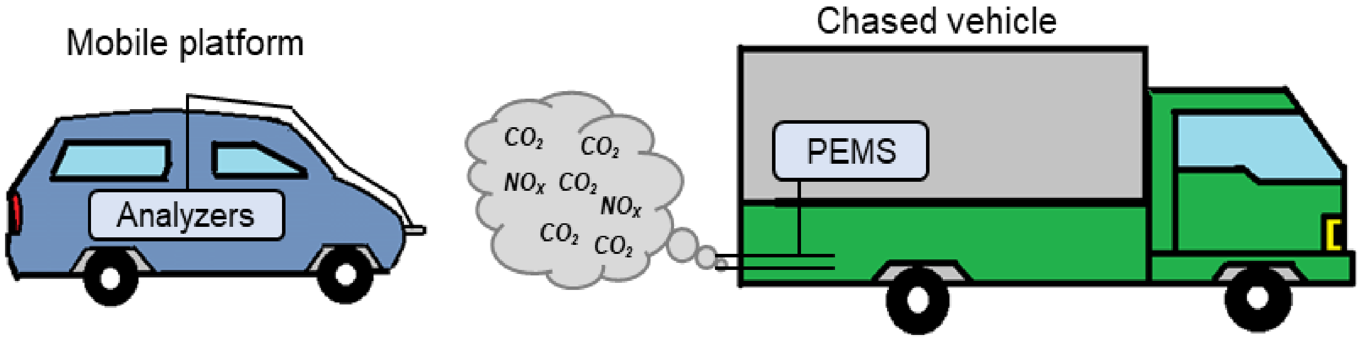
- Licor 820
- Eco physics nCLD66
- Magee AE33 (880 nm)
- TSI DustTrak 8530
- TSI CPC3007





Concurrent PEMS-chasing tests

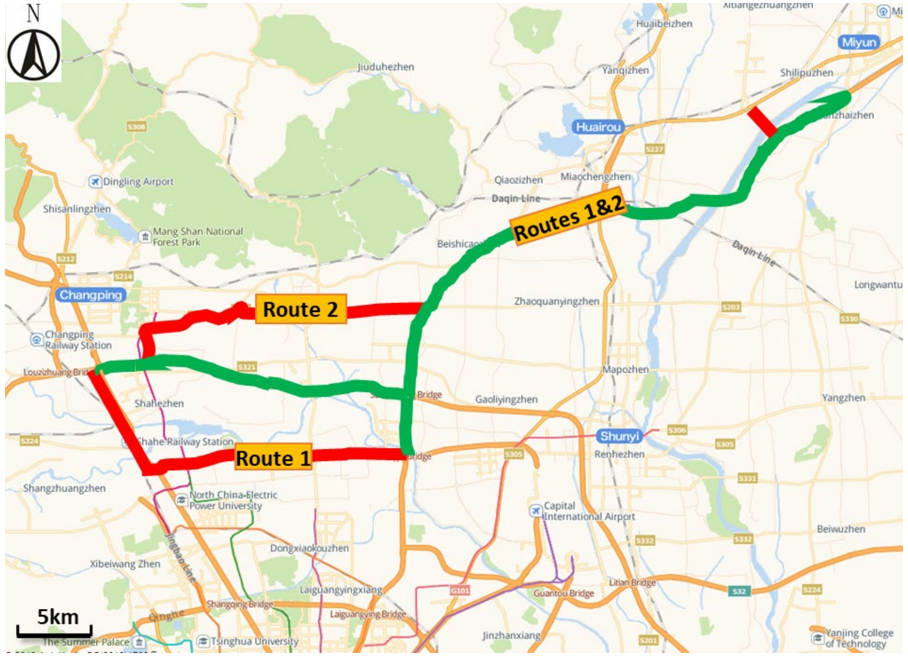
- 12 heavy-duty diesel trucks recruited for concurrent PEMS-chasing tests to evaluate plume chasing for NO_X emission factors.



PEMS: SEMTECH-EcoStar

Test fleet: 4 China III (no SCR), 4 China IV (SCR) and 4 China V (SCR)

Experimental routes in Beijing.

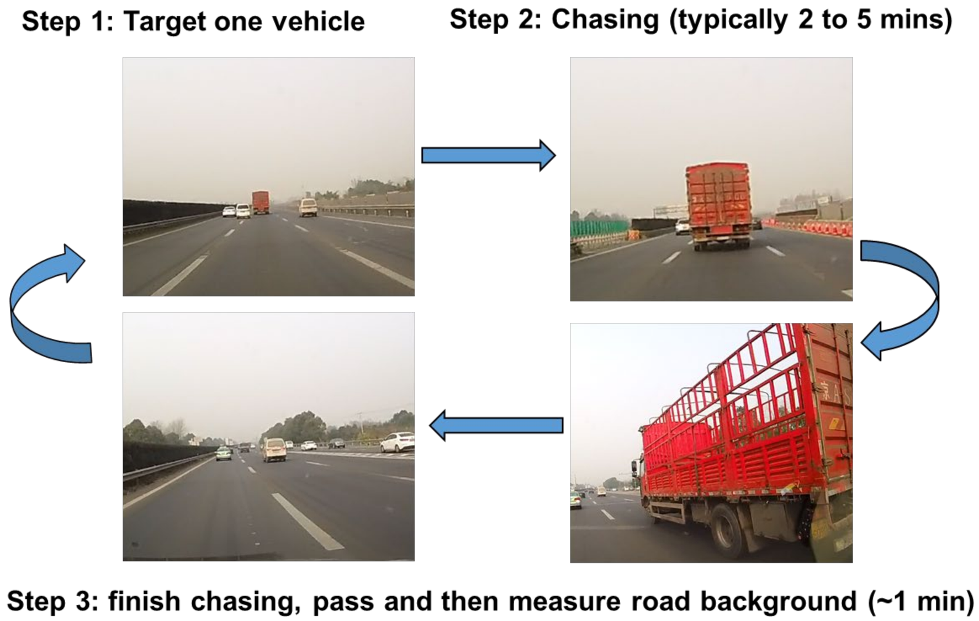


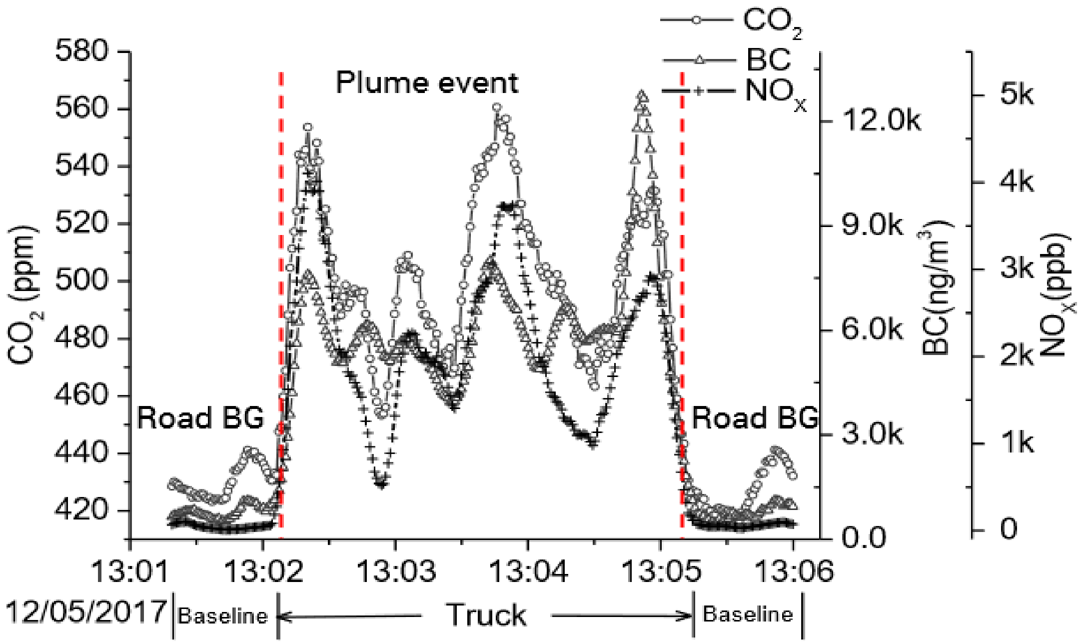
Local roads (20~40 kph)

Express roads (50~80 kph)

Testing procedure and EF calculations

- Measure **road background** and exhaust plumes intended for targeted vehicles

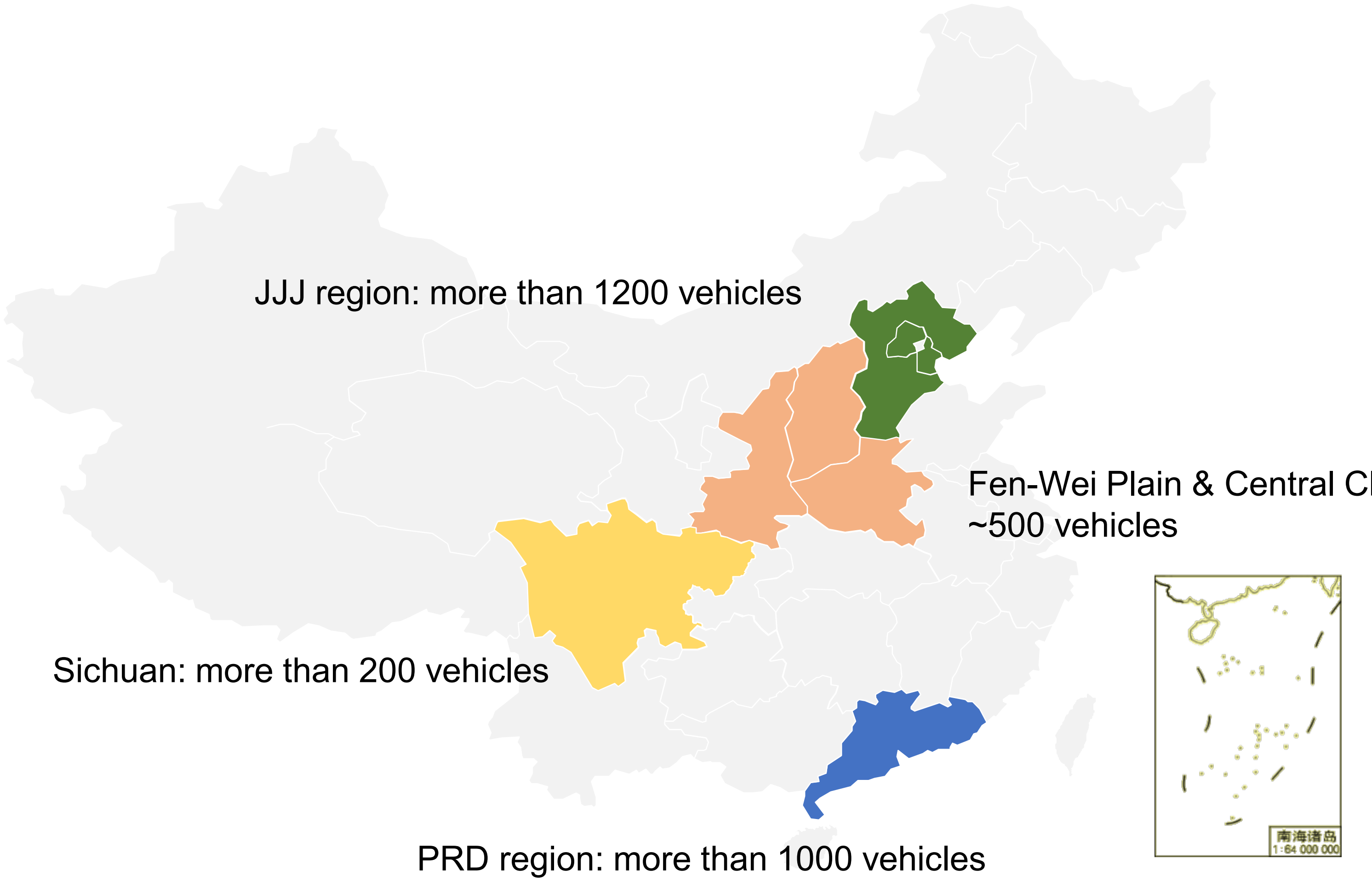




- **NO_X EF (g NOx per kg fuel) calculations**
  - Approach A: linear regression without BG subtraction (slope indicates fuel based NOx emissions)
  - Approach B: moving average ratio with BG subtraction

Mobile chasing for HDV emissions

- Nearly 3000 vehicles measured by using mobile chasing since 2017



Vehicle emission models in China

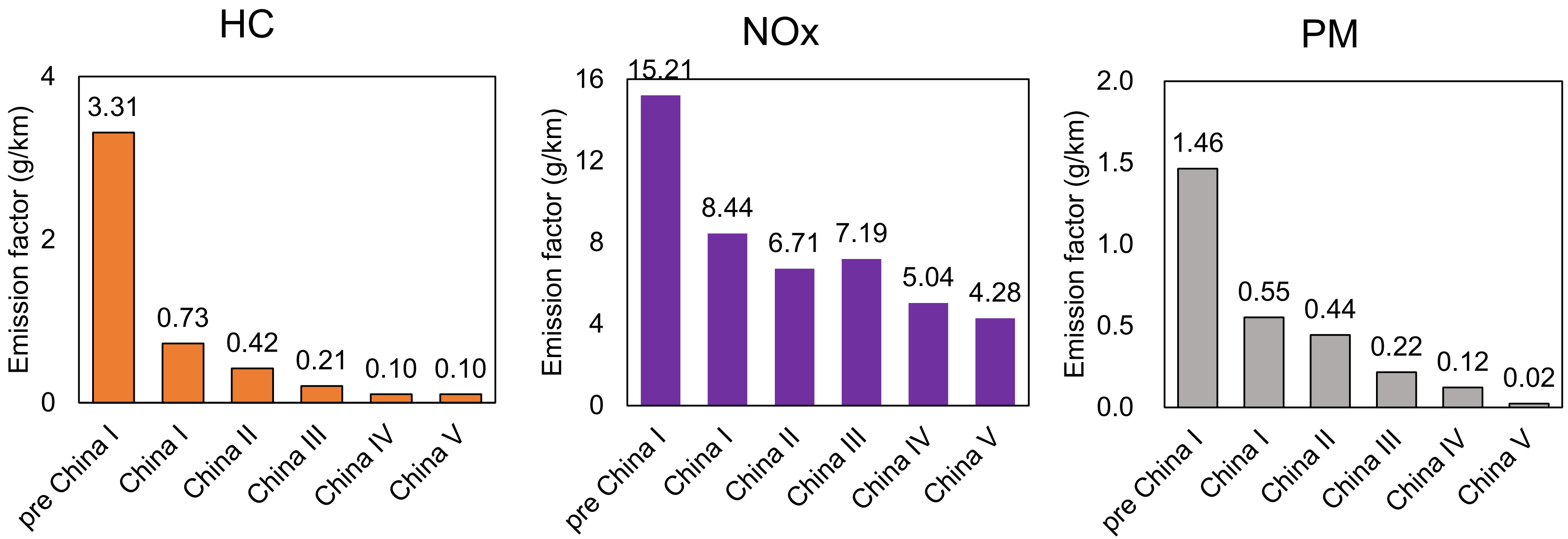
- International models (e.g., MOBILE/MOVES; COPERT) have been used to estimate vehicle emissions in China since 1990s.
- Local emission measurements are fundamental to develop emission models and reduce uncertainty in policy decisions.
  - ***EMBEV*** (Tsinghua): initially sponsored by the Beijing EPB, and based on thousands of LDV dynamometer tests and hundreds of **LDV/HDV PEMS tests**
  - China's National Emission Inventory Guidebook (Tsinghua and VECC): developed for the MEP in 2015, largely based on the EMBEV
  - EMBEV-Link: city-scale link-level emission inventory models based on real-world traffic datasets
- The *Guidebook* for road sector will be updated soon, as supported by China MOST

EMBEV: Zhang et al., Atmos. Environ., 2014; EMBEV-China: Wu et al., Sci. Total Environ., 2017; EMBEV-Link: Yang et al., Atmos. Chem. Phys., 2019

EMBEV emission factors: heavy-duty diesel vehicles

- Major data sources: PEMS tests for pre-China IV HDVs (and China IV urban buses)
- Mode-specific emission rates available (i.e., similar to MOVES)
- Few tests for China IV and China V trucks, and their emission factors are largely estimated based on the reduction trends in European fleets (i.e., 30% ↓ from China III to China IV)

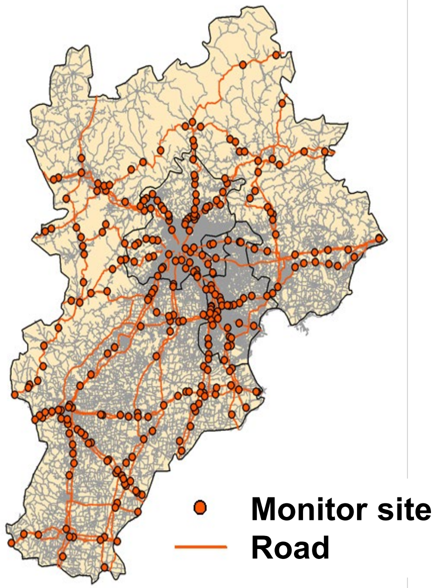
Estimated emission factors (GVW>12 t) under a typical driving cycle (40 km h^{-1})

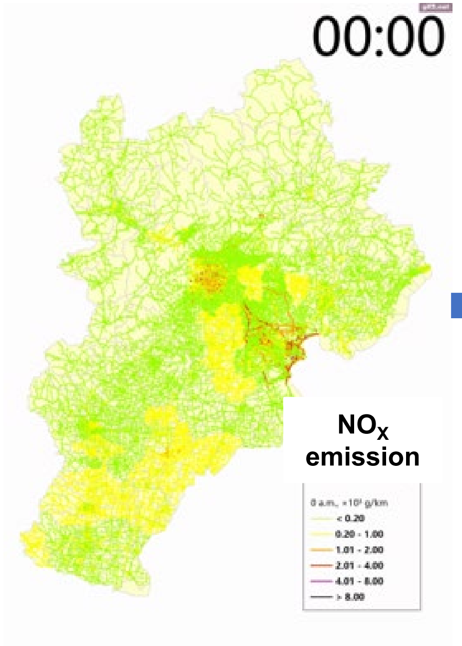


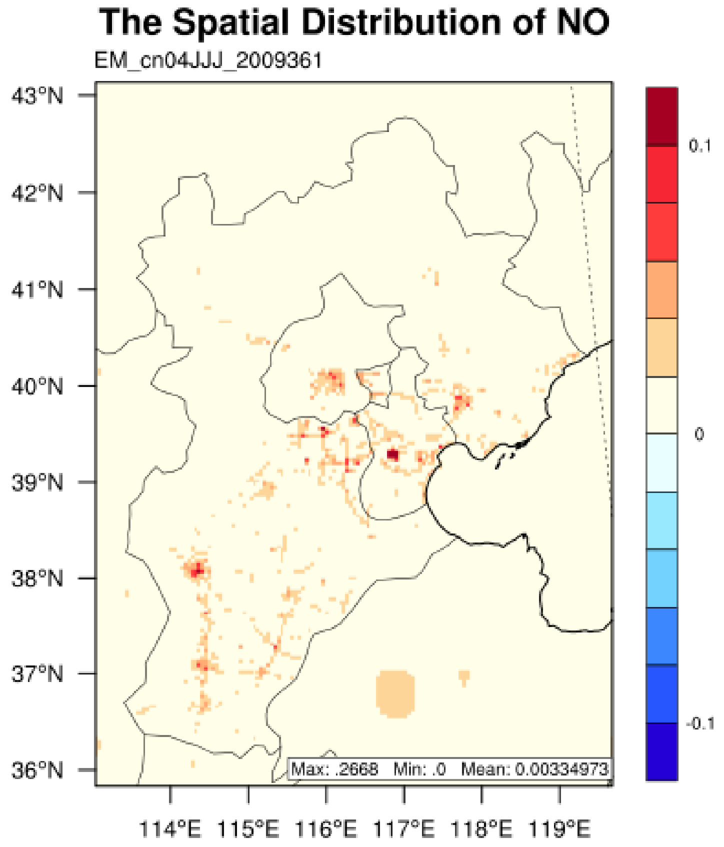
Wu et al., 2017, STOTEN

Gridded emission input

~900 traffic sites (mostly express roads)



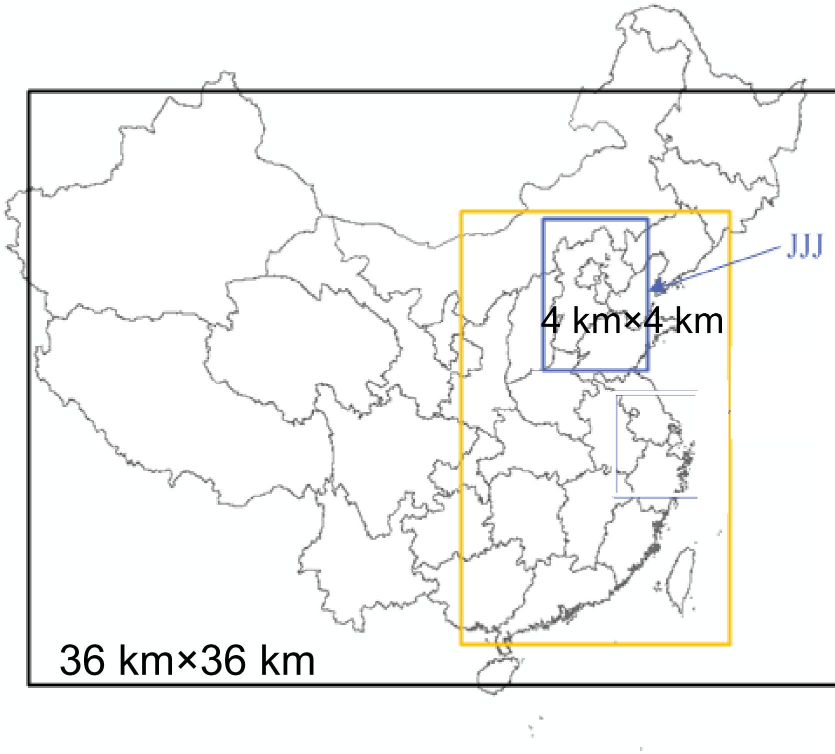




- **Real-world traffic datasets aided allocation**
  - Total fleet emissions by vehicle category
  - Temporal and spatial allocations, based on specific road lengths (considered the effects from vehicle volumes, urban/rural, city, speed)

Air quality simulation systems

- WRFv3.3 configuration
  - Planetary boundary layer: Mellor-Yamada-Janjic TKE
  - Land surface layer: Noah
  - Microphysics: WSM3
  - Cumulus scheme: G-D
  - Long/short wave radiation: RRTM
- CMAQv5.0.1 enhanced by **2D-volatility basis set (VBS)** module
  - Improve the simulation performance of SOA
  - Gas-phase chemistry scheme: SAPRC99
  - Aerosol module: AERO6
- WRF-CMAQ model system
  - Three-layer nested simulation (36km-12km-4km)
  - Focus region: Beijing-Tianjin-Hebei (JJJ)
  - Duration: January, May, August and November in 2020



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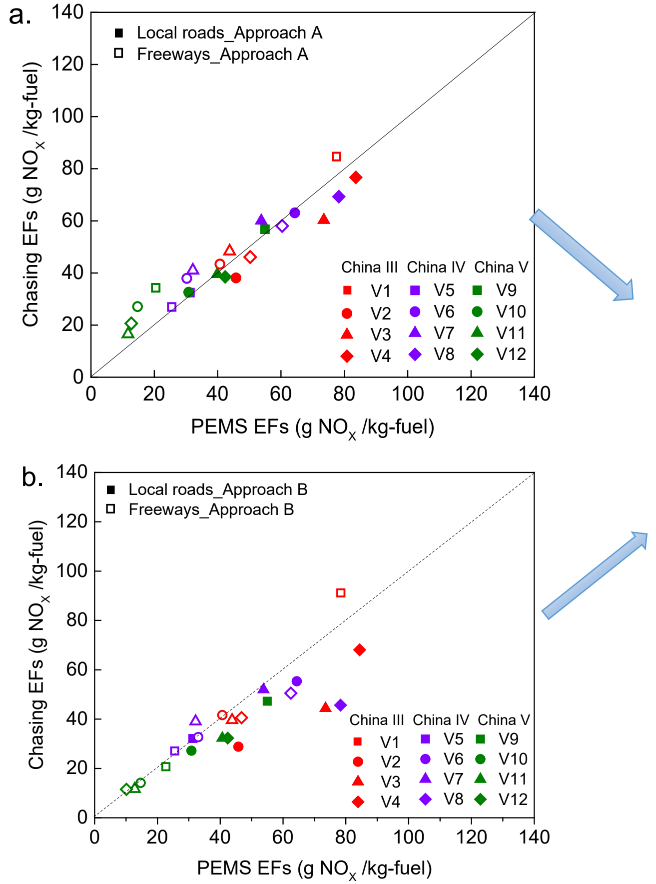
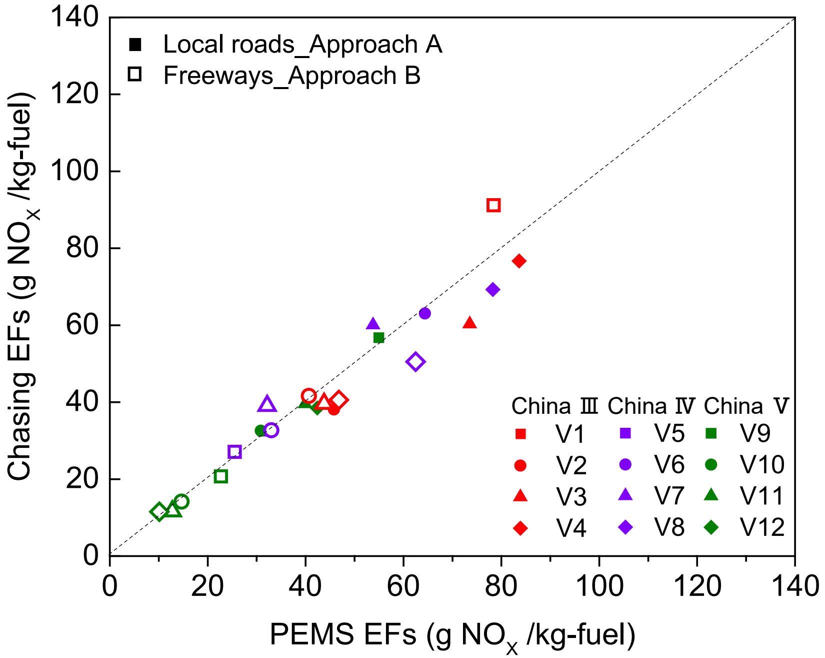
Comparison of NO_X emission factors between mobile chasing and PEMS

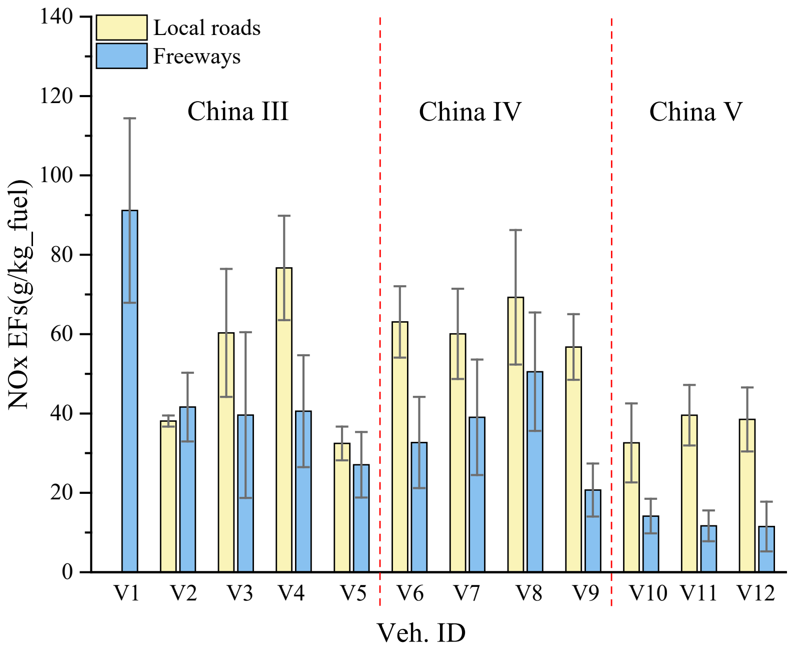
- Vehicle-specific relative errors within ±20%
- Fleet-average errors: -3.8% (local roads by approach A) and -0.3% (freeways by approach B)



Concurrent PEMS-Chasing comparison
(12 HDVs, 245 chasing tests)



NOX emission factors on local roads and freeways for PEMS results

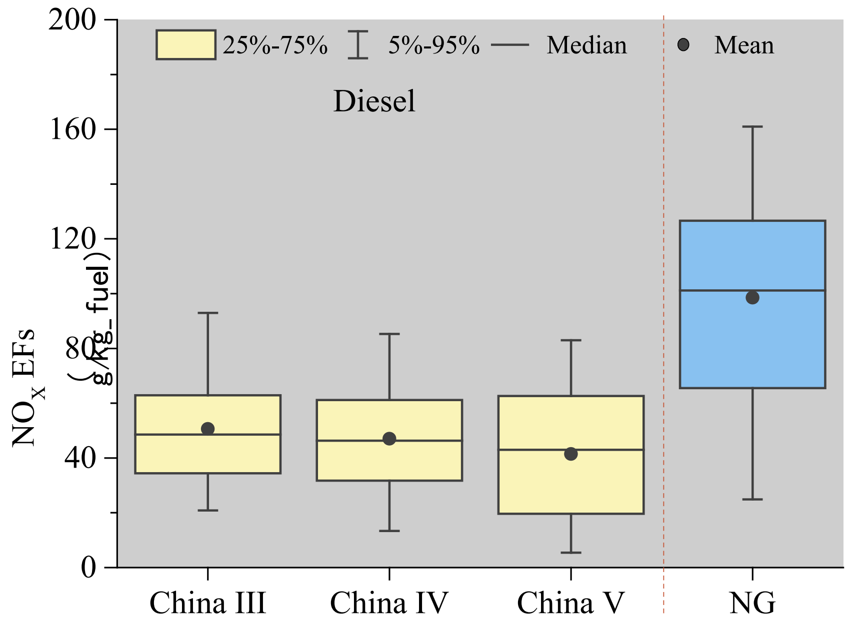


Note: The solid markers indicate measurements on local roads, while the hollow markers indicate measurements on freeways.

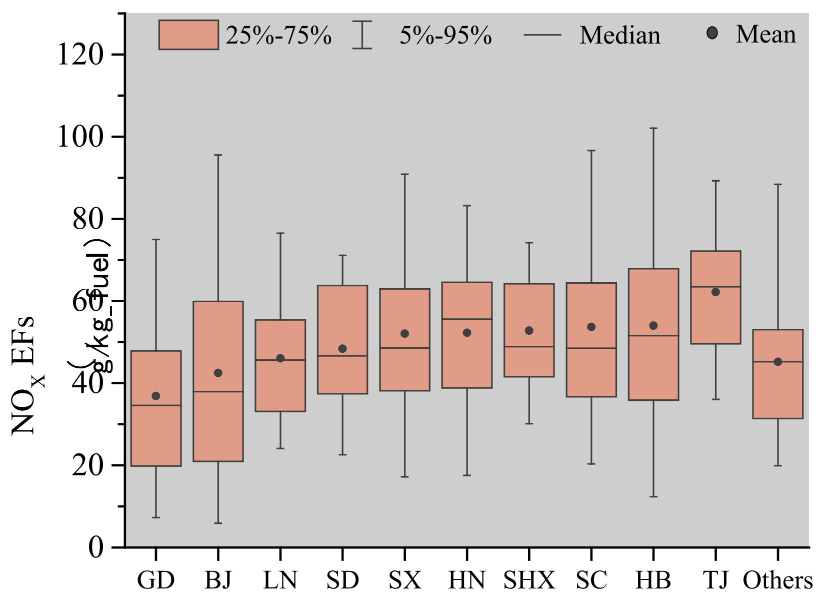
Mobile chasing for HDV emissions——NO_X

- **NO_X emissions**: No significant improvement in China IV diesel trucks (claimed to have adopted SCR) compared with China III trucks; limited improvements for China V diesel trucks.
  - Failure to refill urea tanks and tampering with the SCR device are suspected
- **NG HDVs**: Significantly higher NO_X emissions (lean-burn engines, no NO_x aftertreatment)
- **HDDVs registered in various provinces:** Beijing not significantly improved compared to other provinces

Impact of emission standard and fuel



Impact of registration place——HDDV

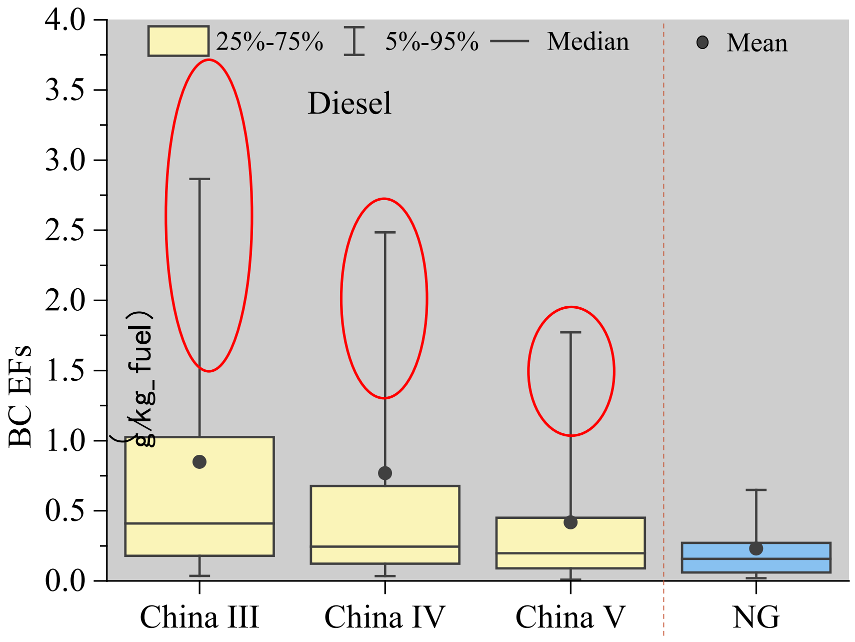


Note: GD:Guangdong; BJ:Beijing; LN:Liaoning; SD:Shandong; SX:Shanxi; HN:Henan; ; SHX:Shaanxi; SC:Sichaun; HB:Hebei；TJ: Tianjin

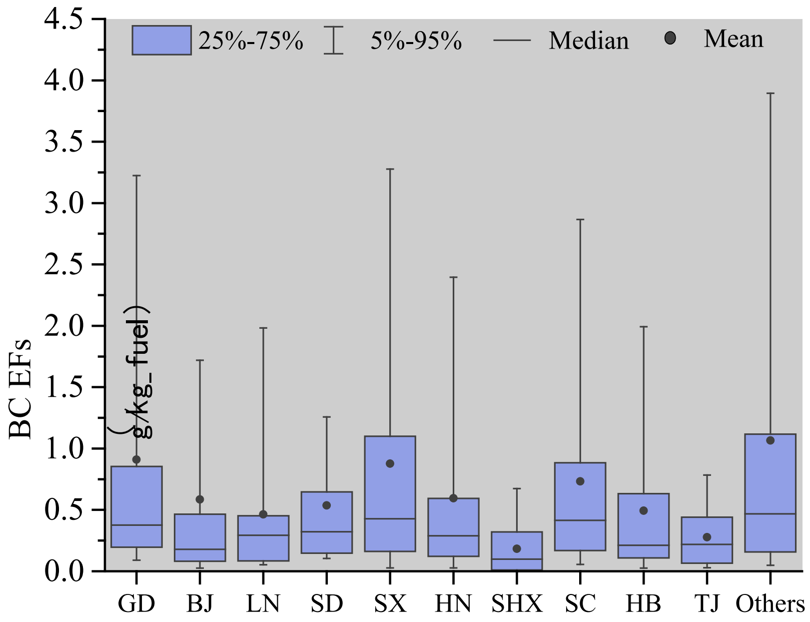
Mobile chasing for HDV emissions——black carbon (BC)

- **BC emissions**: decrease with emission standards; high emitters exist for China III to China V
- **HDDV in various provinces**: related to different vehicle emission control policies

Impact of emission standard and fuel



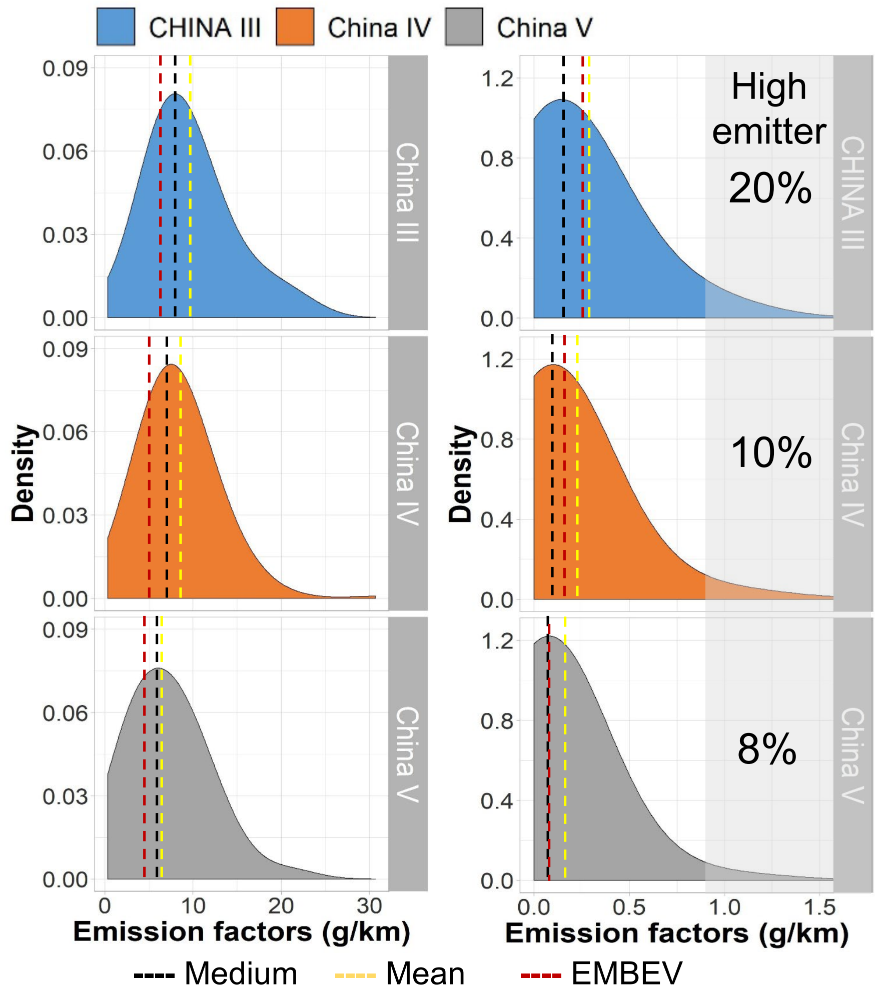
Impact of registration place——HDDV



Note: GD:Guangdong; BJ:Beijing; LN:Liaoning; SD:Shandong; SX:Shanxi; HN:Henan; ; SHX:Shaanxi; SC:Sichaun; HB:Hebei； TJ: Tianjin

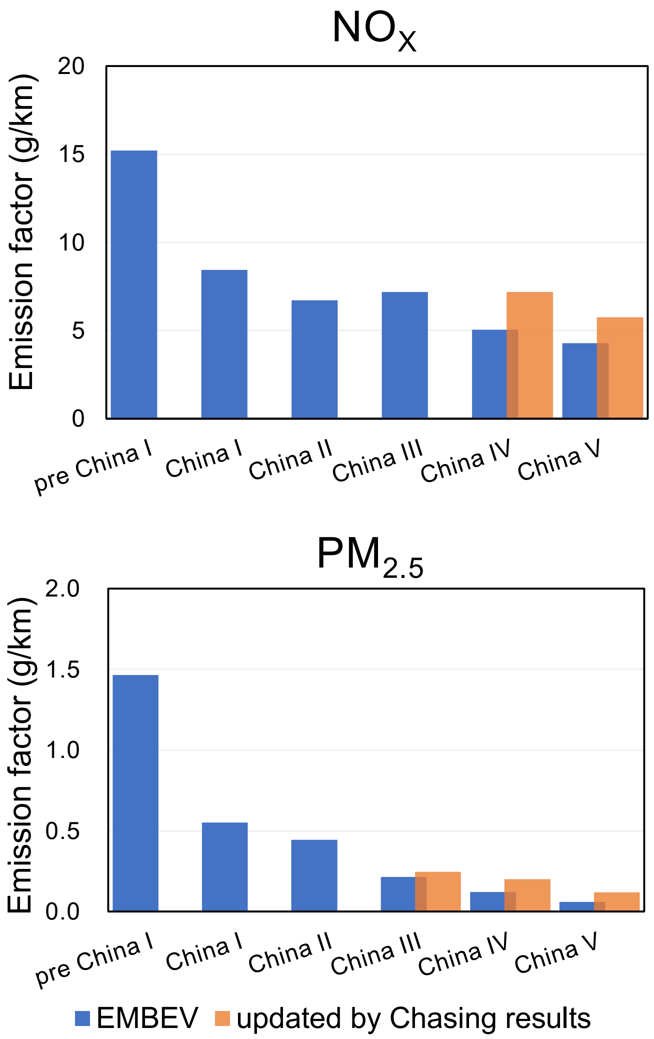
A revisit of NO_x and $PM_{2.5}$ emissions for HDVs

NO_X and $PM_{2.5}$

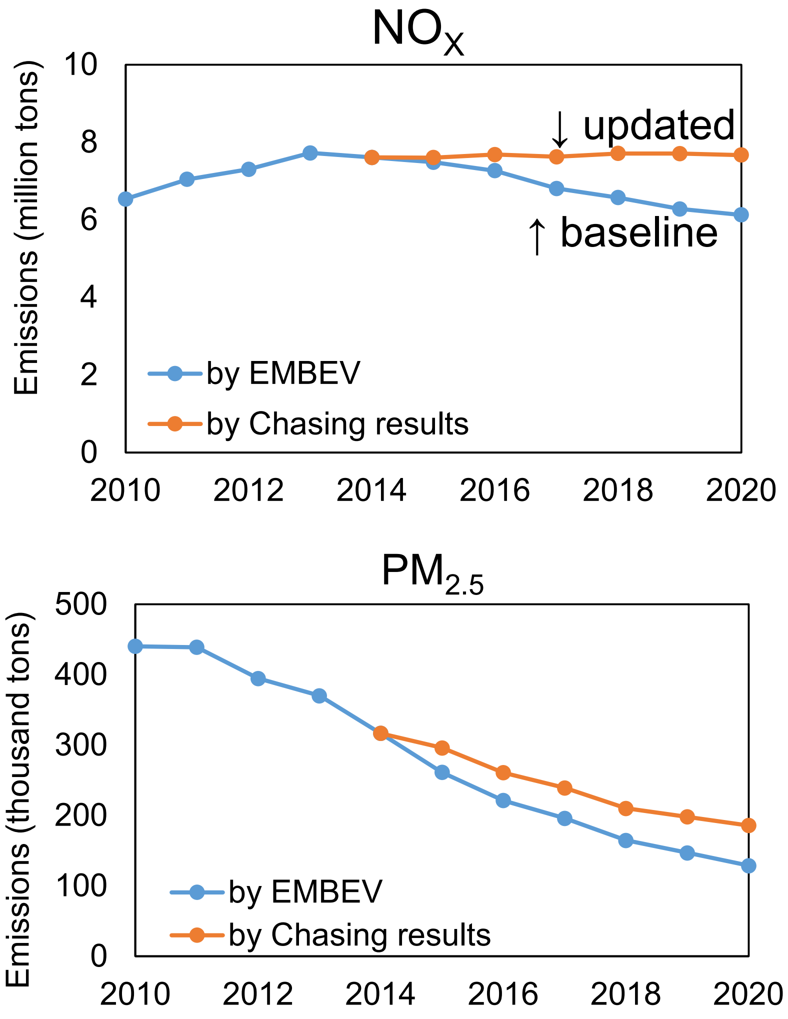


* Average GVW: 20 t, Driving speed: 40 km/h, BC/$PM_{2.5}$=0.7

Emission factor



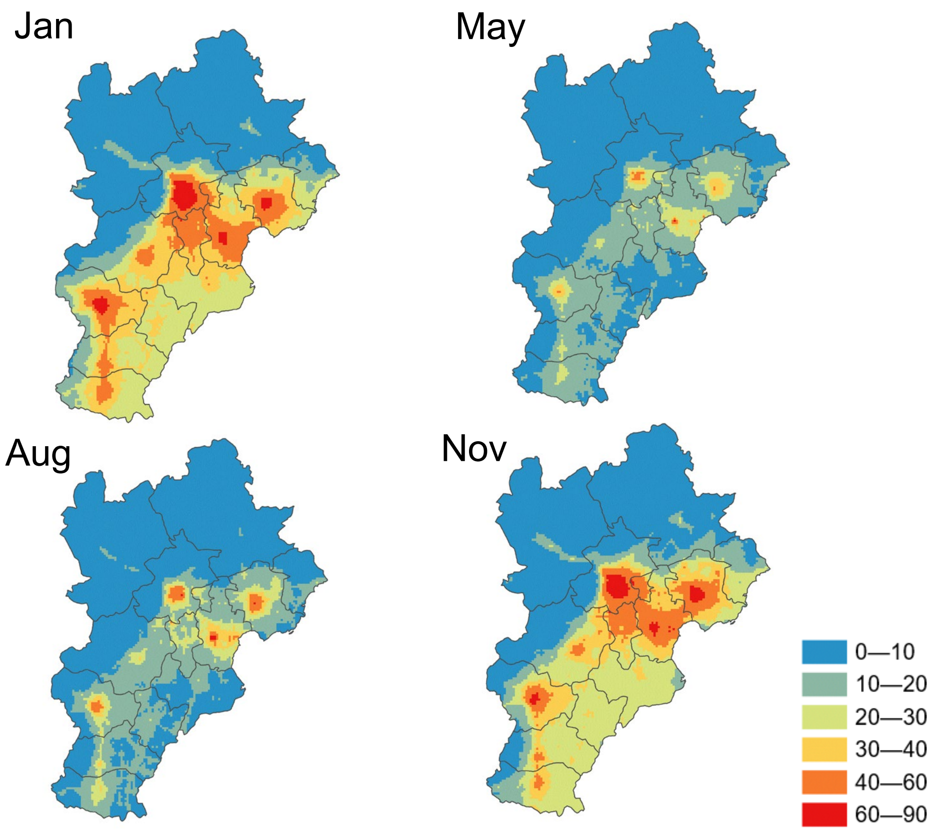
Total emission trends



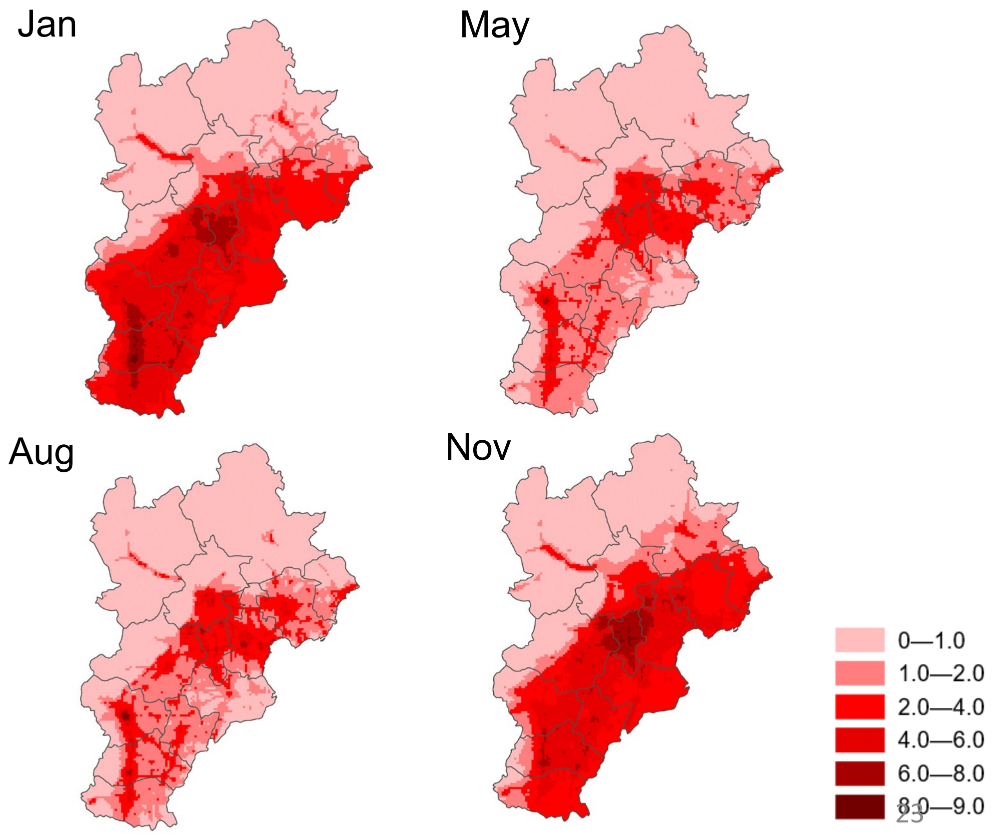
Air quality impacts: nitrogen dioxide

- Monthly average NO_2 concentrations are estimated to increase 2-4 μg m^{-3} (12%-15%) in Beijing-Tianjin-Hebei region when the simulations apply the chasing NO_X emission factors.

2020 baseline NO_2 concentration



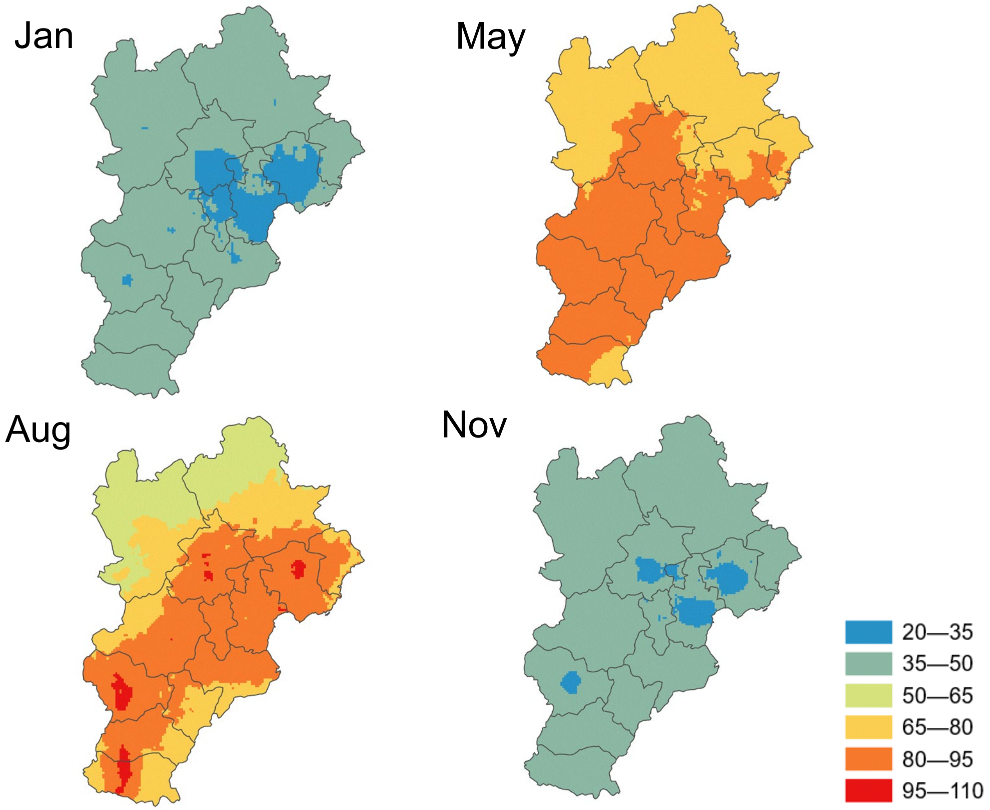
NO_2 concentration change



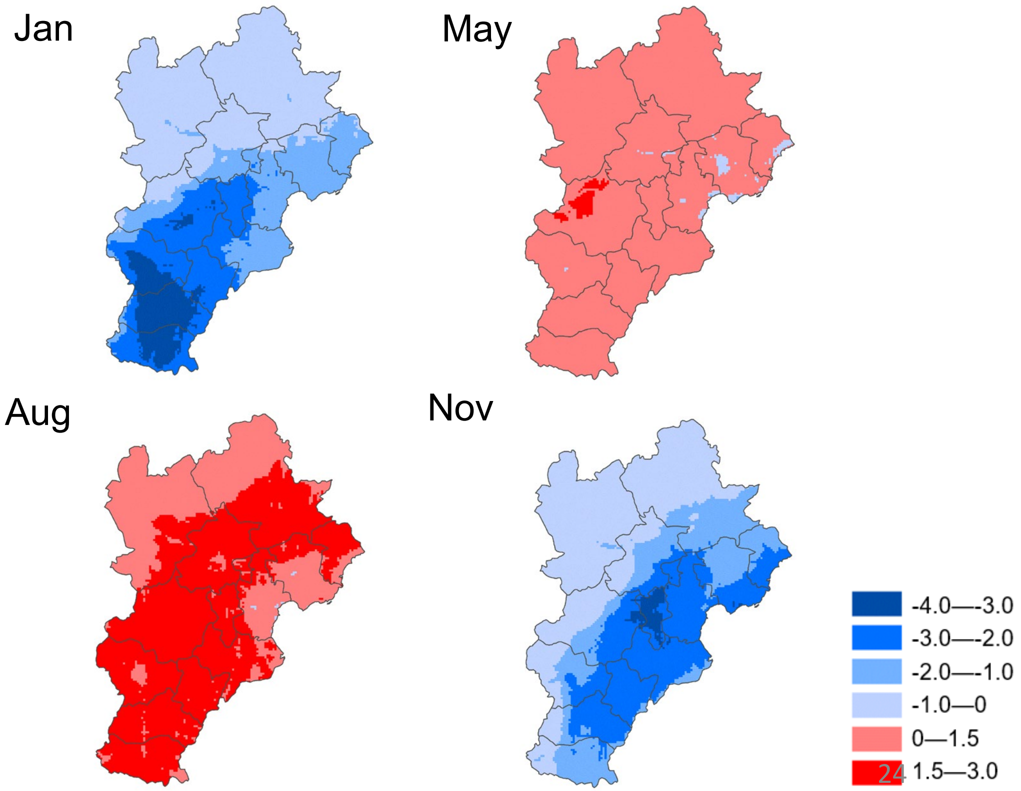
Air quality impacts: ozone

- Summer: O_3 concentrations increased due to increased NO_X emissions
- Winter: O_3 concentrations decreased by ~2 ppbv due to strong VOC-limited conditions.

2020 baseline 8-h maximum O_3 concentration



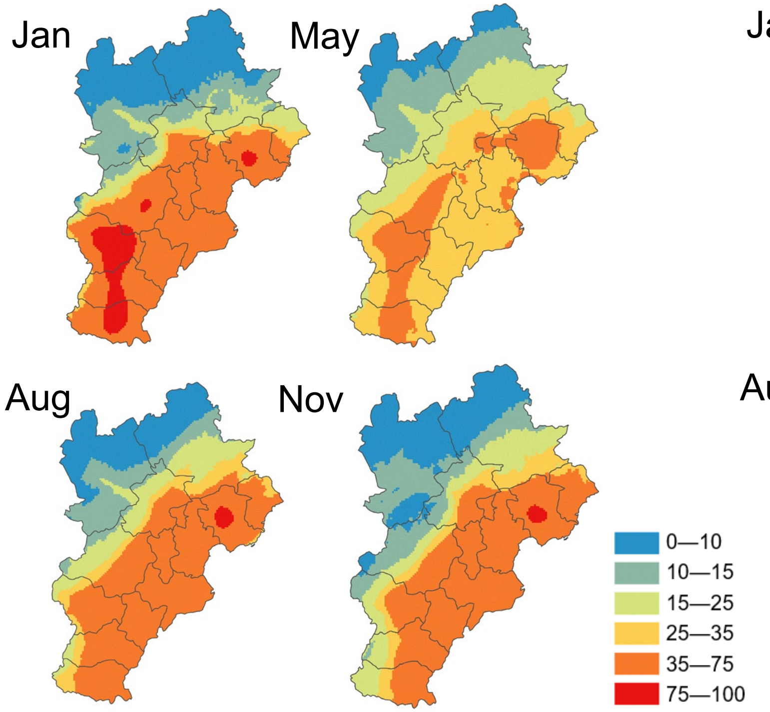
O_3 concentration change



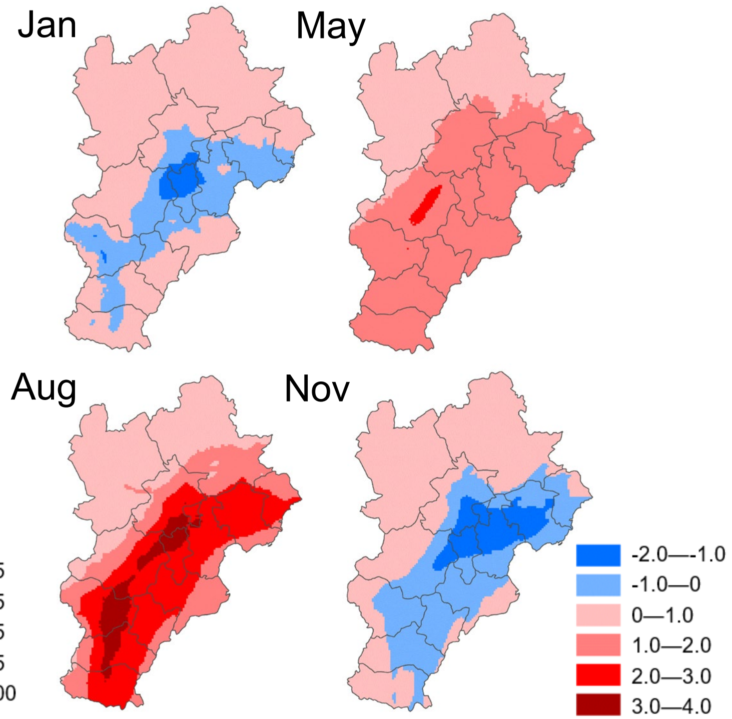
Air quality impacts: $PM_{2.5}$ and key components

- Summer: $PM_{2.5}$ is predicted to increase 1.2-2.3 μg m^{-3} (4%-5%) due to increased nitrate.
- Winter: decreased atmospheric oxidability (i.e., O_3) leads to $PM_{2.5}$ reduction from baseline

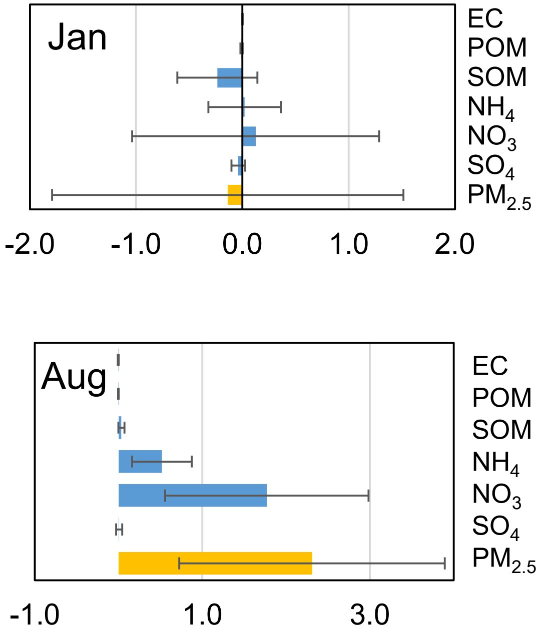
2020 baseline $PM_{2.5}$ concentration



$PM_{2.5}$ concentration change



Changes by aerosol component



Summary

- On-road evaluations were conducted for plume chasing tests by comparing with PEMS measurements.
- Chasing tests indicate that NO_x emissions have not been significantly improved with the emission standard for HDVs in China.
- BC emissions for HDVs have been reduced with the emission standard; however, high emitters were still found among the fleet.
- With updated NO_x emission factors, which will not decline before 2020, we estimated increased ambient concentrations for annual NO_2 and $PM_{2.5}$, and summer O_3 in the Jing-Jin-Ji region.

Thank you for your attention !

Contact. E. zhsjun@Tsinghua.edu.cn

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