
# Mobile plume chasing development for heavy-duty vehicles emissions in China

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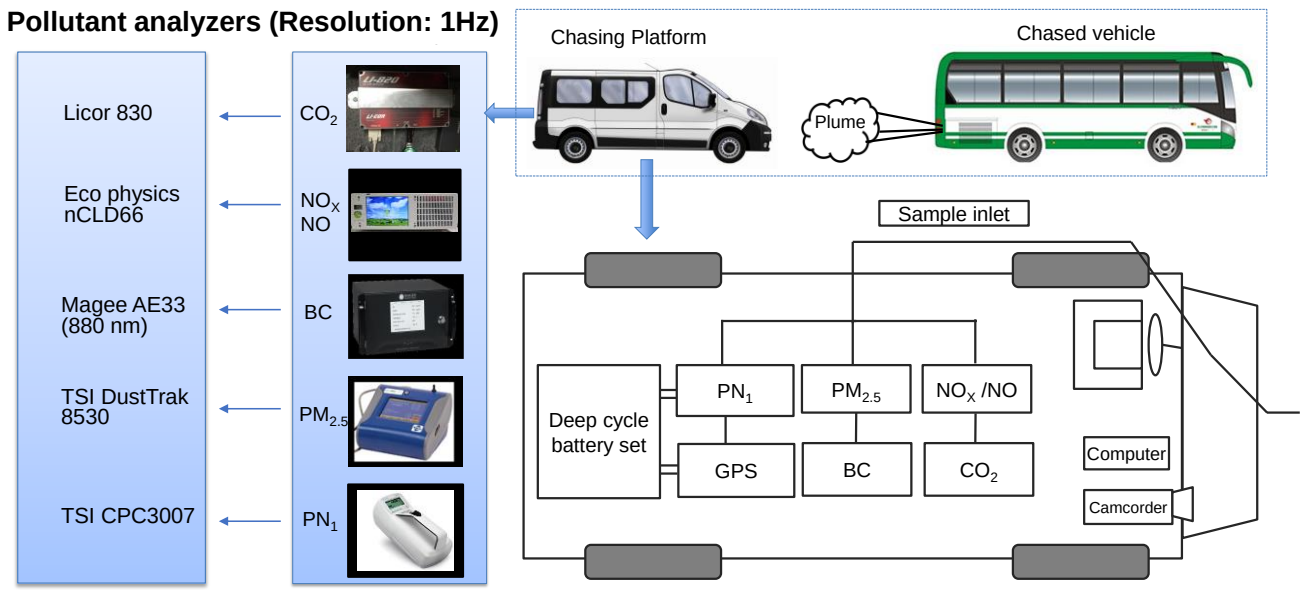
# Contents

- **System development and reliability verification**
- Real-world emissions by a large-scale test
- Applications based on plume chasing results
- Summary and future perspectives

# Mobile Plume chasing platform development (1Hz)

- Using a mobile platform equipped with a rapid response instrument system to chase the target vehicle
  - ✓ Real-world $NO_X$ and BC emission factors (g/kg-fuel)
  - ✓ Identify high-emitters

## Chasing platform and instruments




# Real-time concentration display and database

- Real-time display the concentration of $CO_2$, $NO_X$, BC and other pollutants
- Dataset construction: raw data, vehicle info, driving condition and emission factor


➢ **Raw test data**
- *Concentration*
- *Speed, Location*
- *Tem, RH, WS,WD*
- *Plate number*
- *Load*
- *Record video*
- …

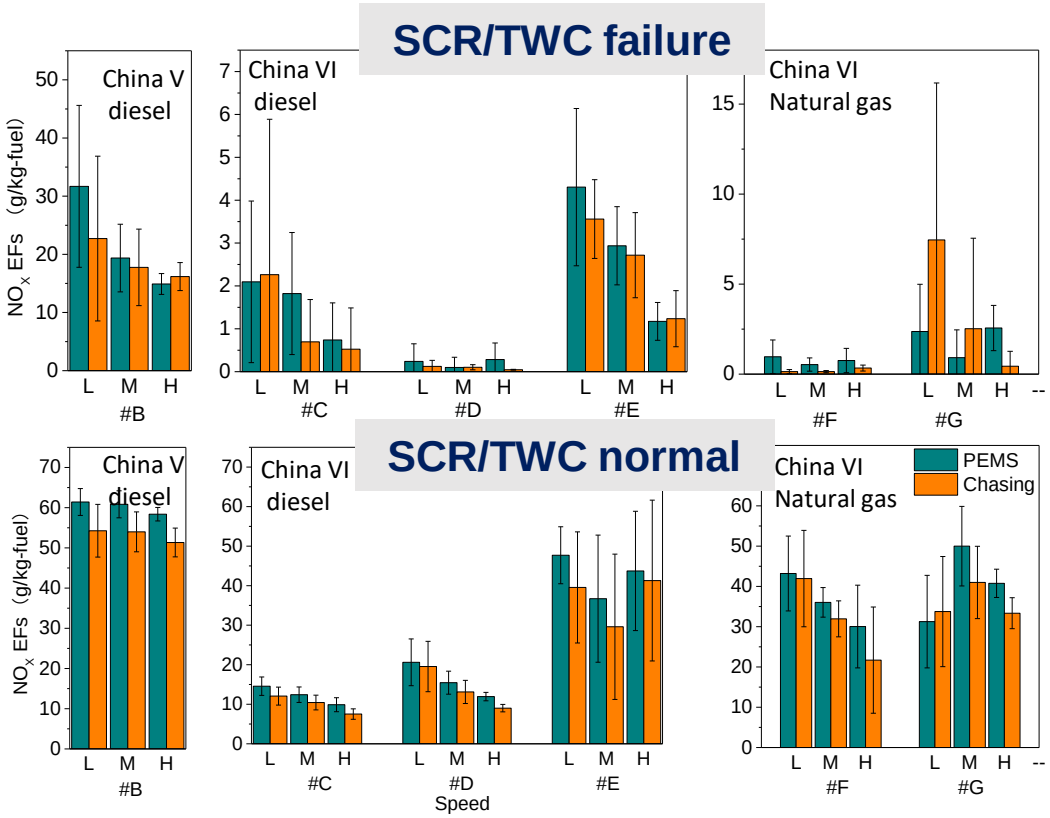
➢ **Vehicle info**
(~71% queried in VECC database)
- *Fuel*
- *Type*
- *GVW*
- *Brand*
- *Emission standard*
- *Registration date*

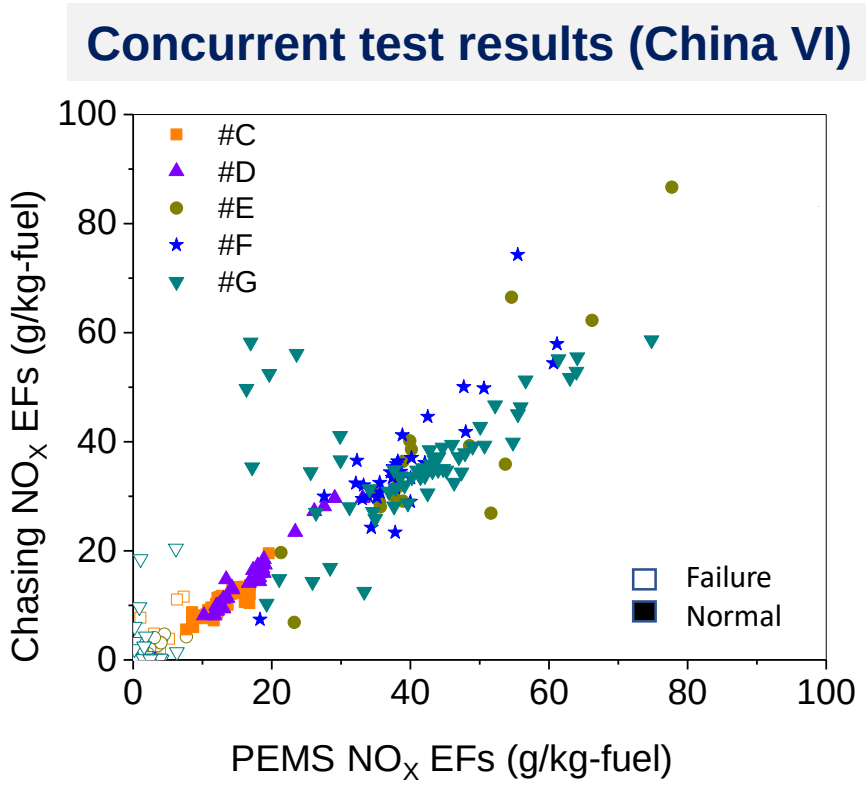
➢ **Driving condition**
- *Individual EF*
- *Speed, Location*
- *Tem., RH*
- *Background conc.*

➢ **Emission factors**
- *$NO_X$、BC*
- *g/kg_fuel*
- *g/km*
- *g/kWh*
- …

# PEMS Validation of plume chasing: track testing

- The low-emitting China VI vehicles can be effectively captured by plume chasing
- Significant differences were identified by plume chasing between after-treatment normal vs. failure vehicles



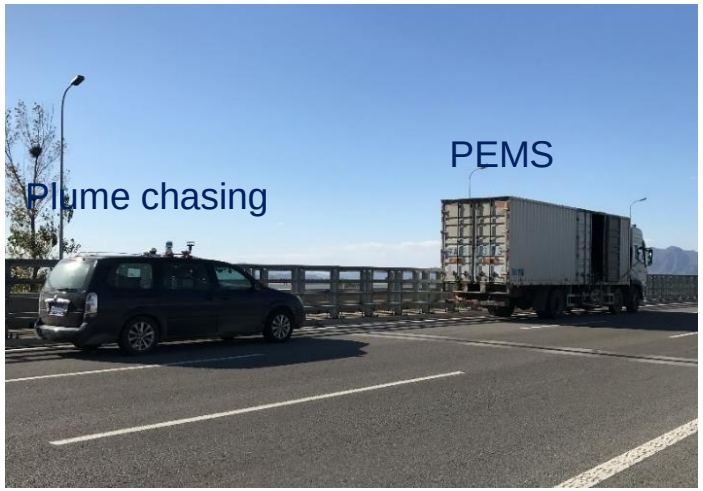
# Good agreement of $NO_X$ and BC emission factors between plume chasing and PEMS

- **Real-world concurrent chasing-PEMS test:** 12 China III-China V HDTs, 245 plume chasing tests

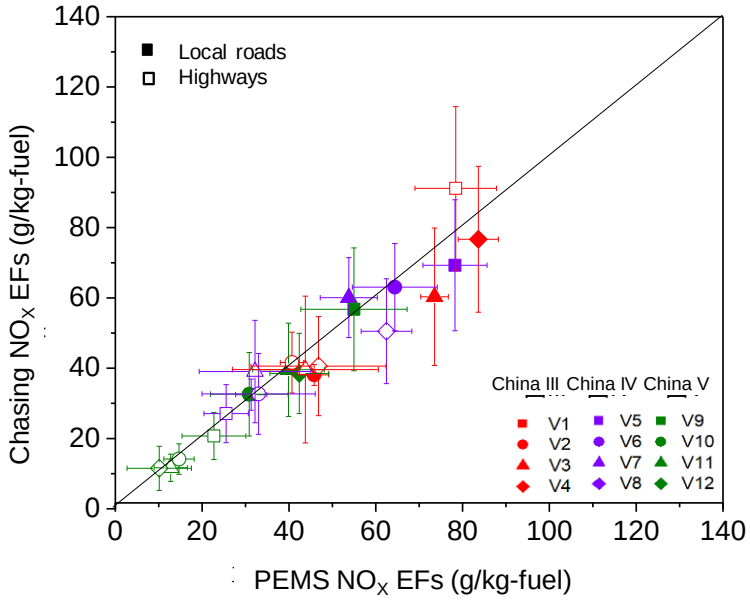
  $NO_X$ vehicle-specific EFs: approximately ± 20% between chasing and PEMS results

  BC vehicle-specific EFs: +10% relative error at local roads and +27% at highways

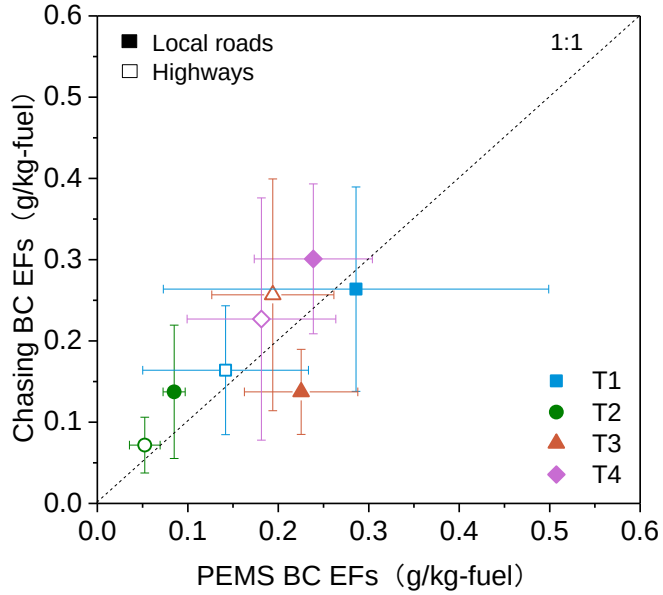
## Concurrent test on real road




## $NO_X$ EFs




## BC EFs



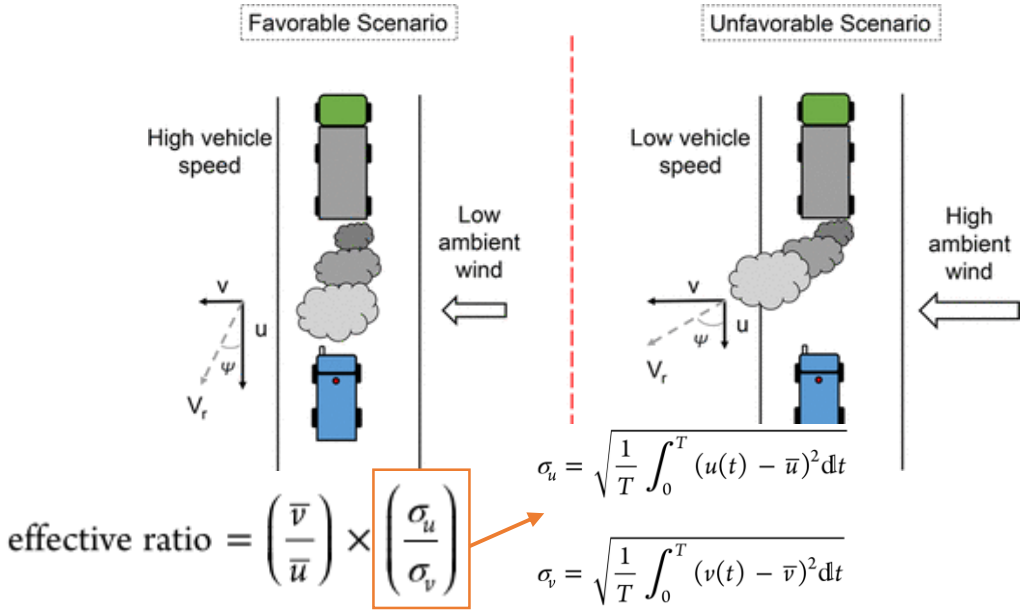



*Wang et al., Evaluating mobile monitoring of on-road emission factors by comparing concurrent PEMS measurements, Science of the Total Environment.*

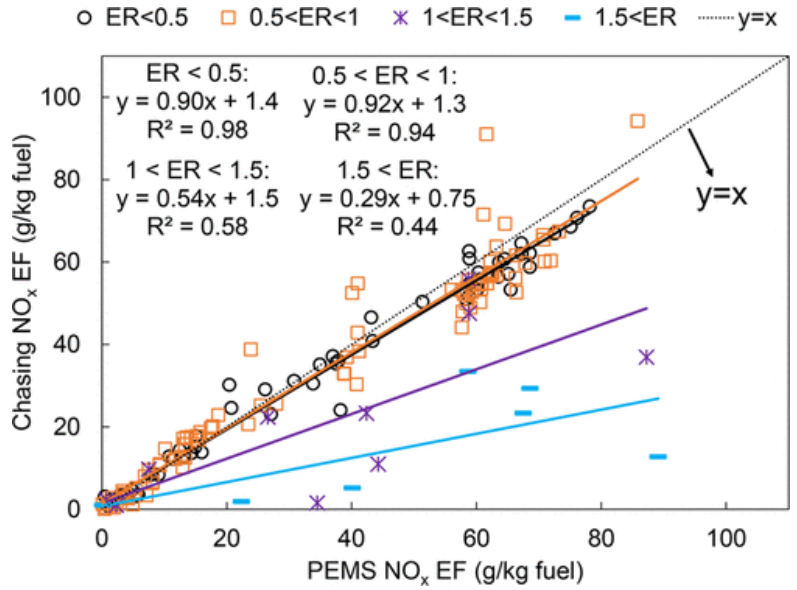
# Sensitivity analysis of plume chasing results to environmental conditions

- **Effective ratios (ER)**: reflected wind speed and wind direction
- **Significant correlation between ER and Chasing $NO_X$ EFs**: ER can be used to filter valid data and improve the reliability of the chasing test, indicating the impact from cross wind

## Two methodological scenarios for chasing test




## Comparison of chasing-PEMS EFs for different effective ratios




*Xiang et al., Evaluation of the Relationship between Meteorological Variables and NOx Emission Factors Based on Plume-Chasing Measurements, ACS ES&T Engineering.*

# Contents

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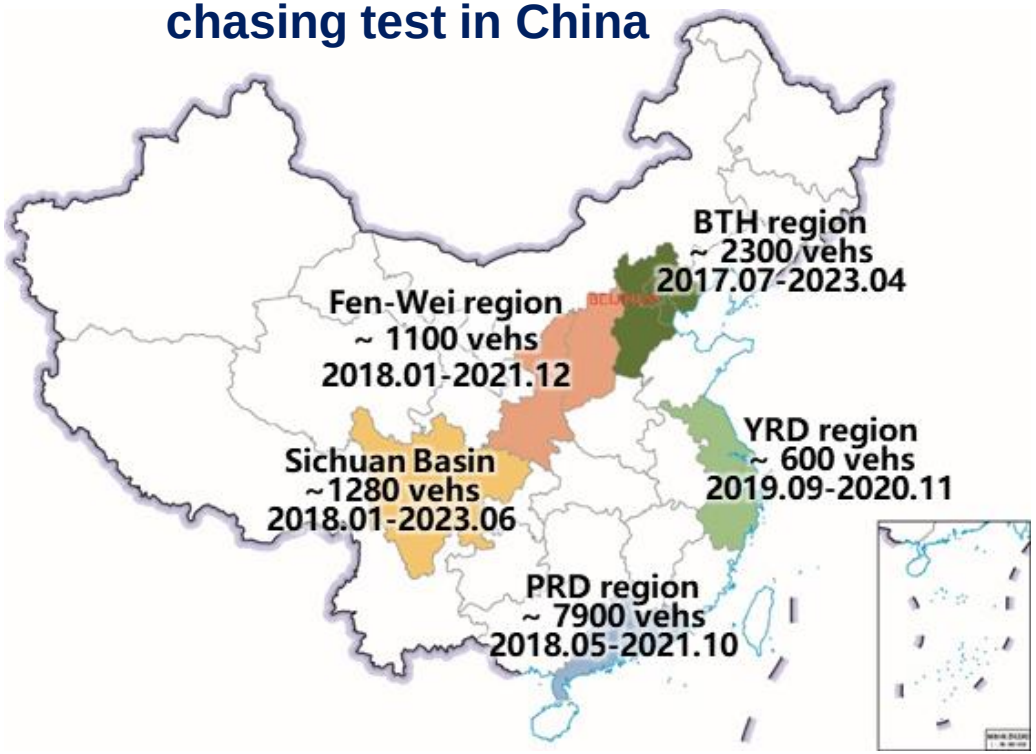
# Overall progress in China's plume chasing measurements

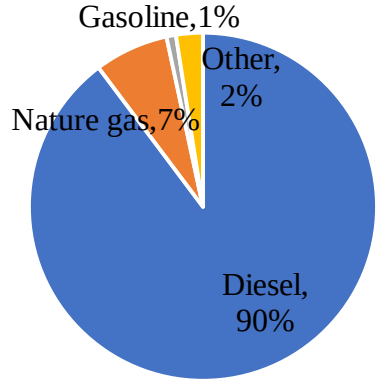
- Large-scale real-world chasing tests have been conducted in multiple regions of China
- A total of nearly 13,000 samples were collected, ~ 70% matched with detailed vehicle information

## Sample distribution of plume chasing test in China

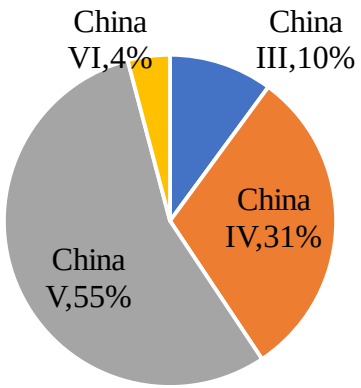



## Fleet composition of chased vehicles

### Fuel type

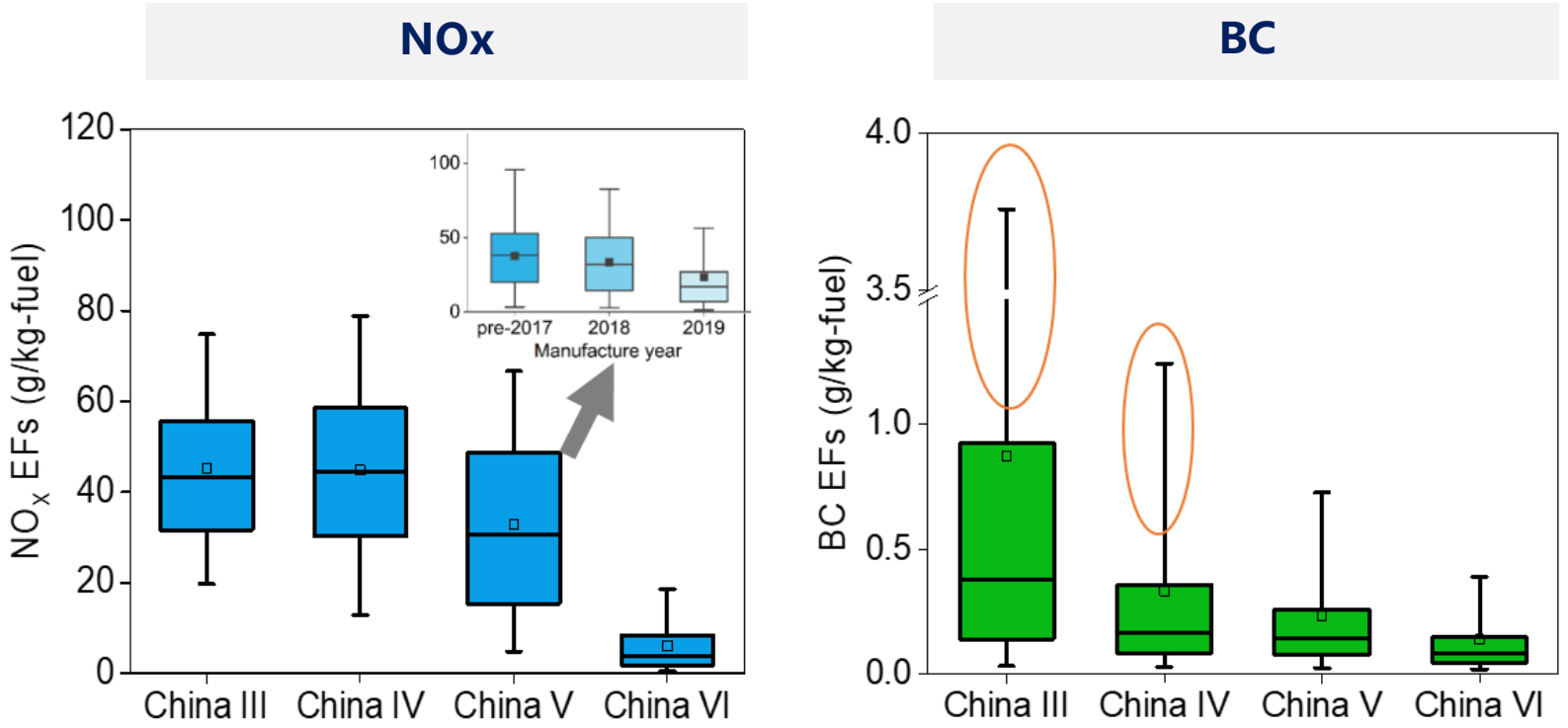



### Emission standard



# Plume chasing confirmed China's recent progress in reducing $NO_X$ emissions from diesel trucks

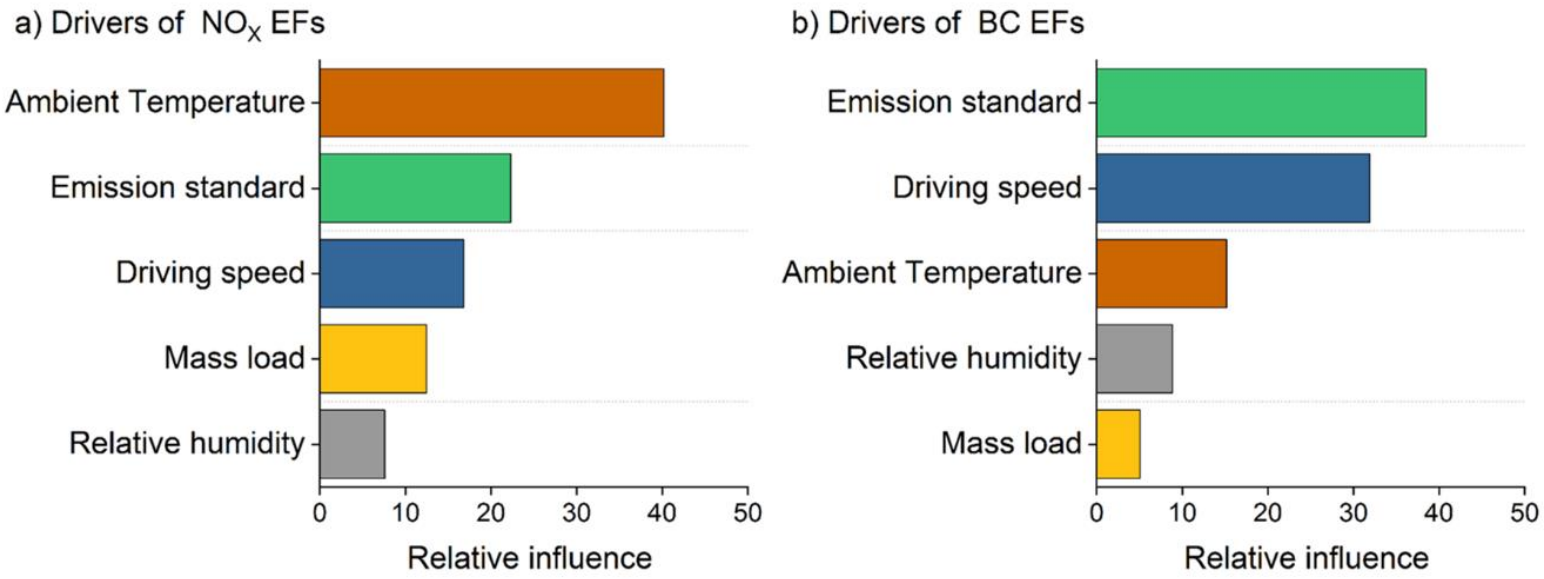
- **NOx:** Limited reduction from China III to China V. Significant $NO_X$ control benifits have been confirmed for post-2018 China V and China VI HDTs.
- **BC:** Significant reductions from China III to China VI, but high-emitters still exist. Fleet-average BC EFs are 1.6-2.3 times than the fleet-median value



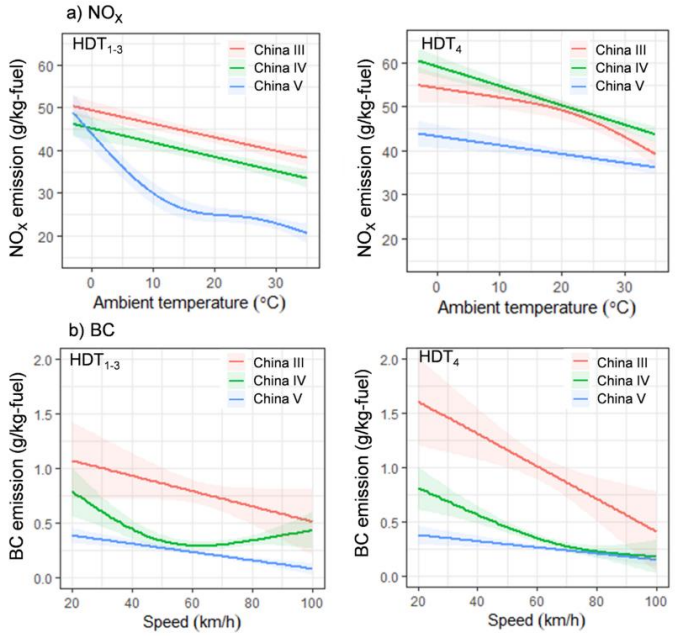
# Key drivers of $NO_X$ and BC emissions were investigated by plume chasing

- Gradient Boosting Machine (GMB) model to identify the key drivers: **ambient temperature** for $NO_X$, **emission standard and speed** for BC
- **Low temperature penalty:** 137% $NO_X$ emissions increase when ambient temperature from -3℃ to +35℃ (4.5-31 tons China V HDTs)

**Relative influence of drivers**




**Sensitivity to ambient temperature**






*Wang et al., Emission measurements on a large sample of heavy-duty diesel trucks in China by using mobile plume chasing. Environmental Science & Technology.*

# Contents

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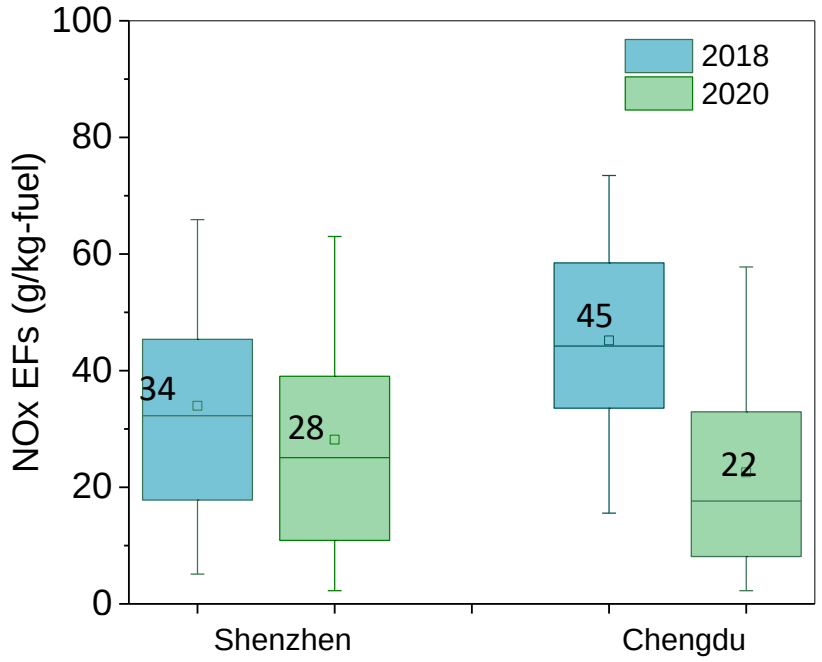
# Continuous tracking and evaluation of fleet-average emissions based on plume chasing test method

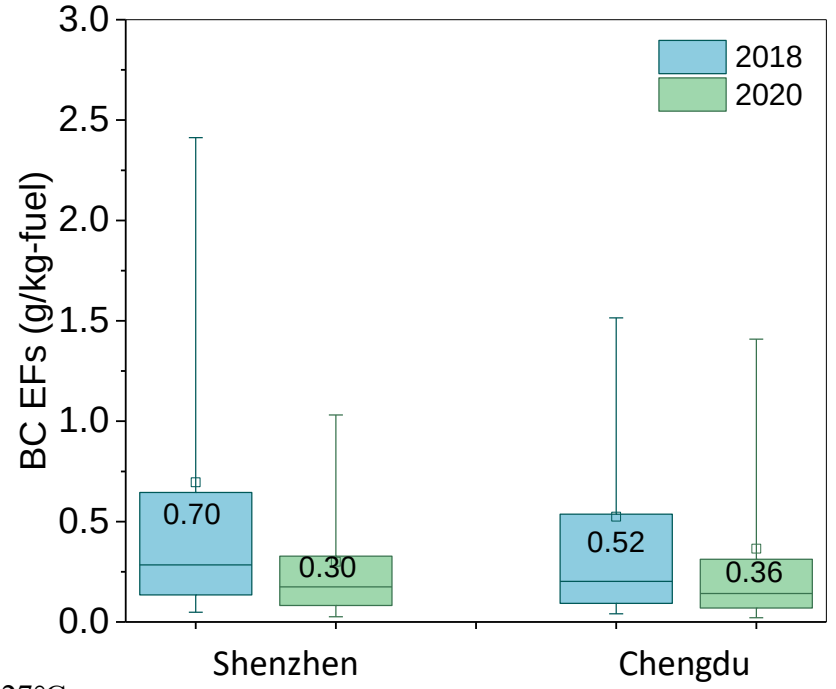
Significant decrease in fleet average emissions has been observed from 2018 to 2020:

- Shenzhen showed a reduction of 17% in $NO_X$ and 57% in BC emissions
- Chengdu showed a decrease of 50% in $NO_X$ and 31% in BC emissions

**NOx**




**BC**

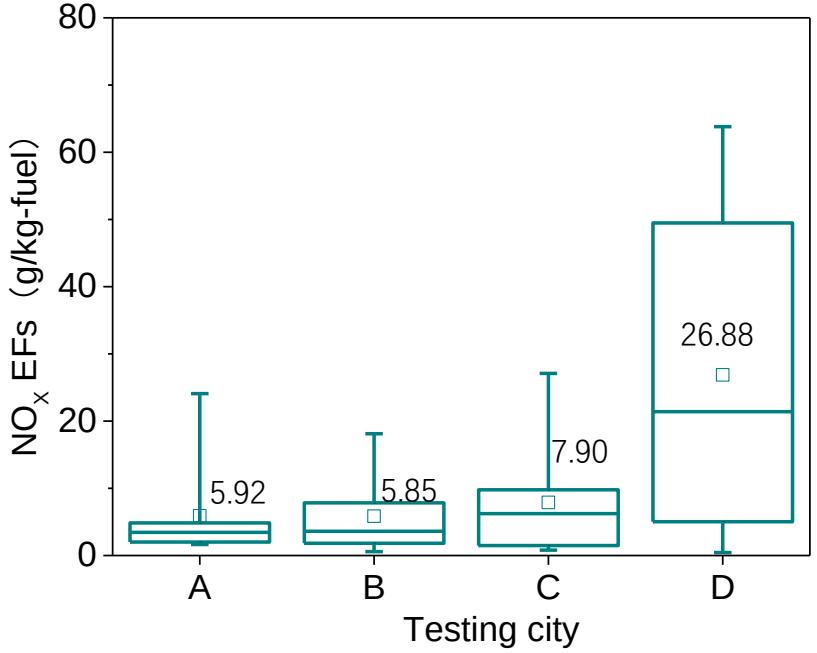



Note: Tem. during Chengdu' test: 2018, 13℃; 2020, 22 ℃; Tem. during Shenzhen' test: 2018, 28℃; 2020, 27℃

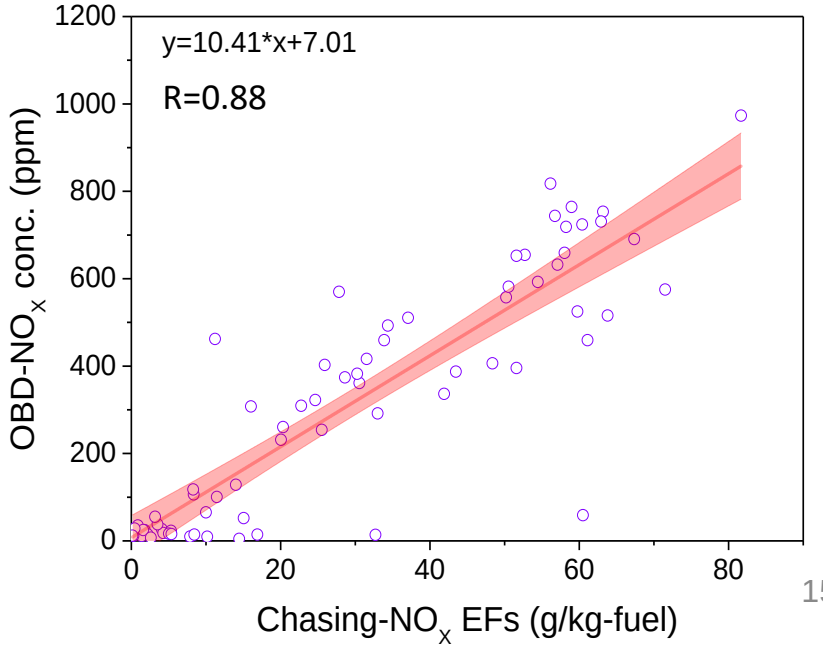
# Plume chasing revealed $NO_X$ emission discrepancy for China VI vehicles measured in different cities

- The fleet average $NO_X$ EFs in City D is **3.4-4.6** times that of other cities
- In City D, for 104 China VI HDDTs, the consistency between plume chasing and OBD data is well verified, **Pearson R=0.88**

## $NO_X$ emissions of China VI HDTs




## Good agreement of Chasing-OBD results (in city D )



# Plume chasing shows a good agreement with the annual inspection results(Lug down tests,more than 20 provinces)

- **Manufacture Year:** both show $NO_X$ reduction with model year, Pearson R=0.9
- **Vehicle manufacturer:** three of the five OEMs with the worst lug-down emission results were also the worst in plume chasing, Pearson R=0.6
- Suggest that our plume chasing samples are good representatives of Chinas in-use HDVs

## Manufacture year

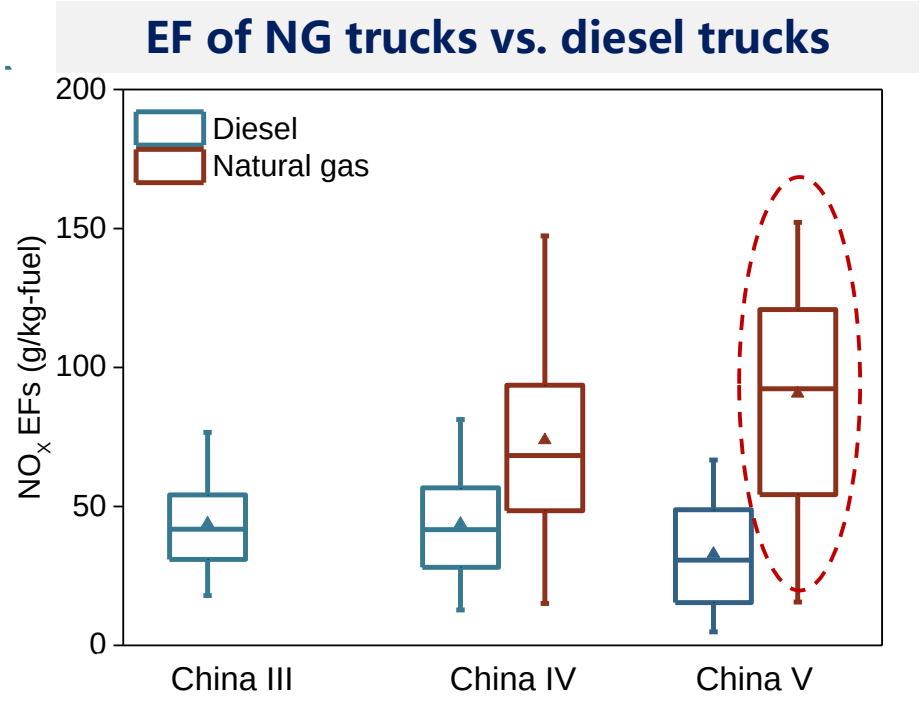
| MY | I/M program NOx (ppm) | Plume chasing NOx (g/kg-fuel) |
|---|---|---|
| 2016 | 641.3 | 35.6 |
| 2017 | 578.9 | 36.7 |
| 2018 | 543.2 | 30.9 |
| 2019 | 523.7 | 29.1 |
| 2020 | 494.3 | 23.4 |

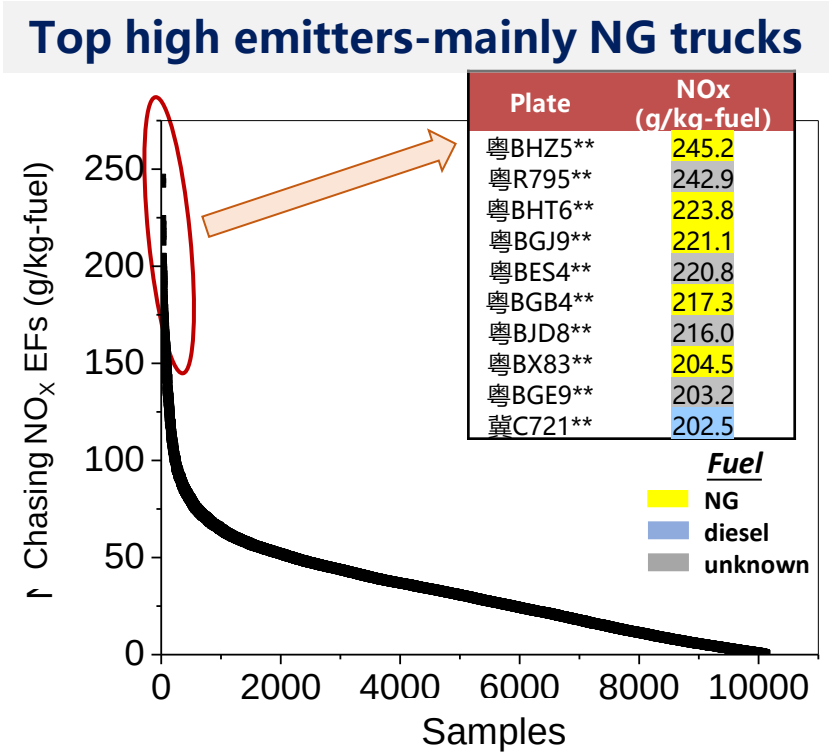
## Vehicle manufacturer

| OEMs | I/M program NOx (ppm) | Plume chasing NOx (g/kg-fuel) |
|---|---|---|
| A | 424.4 | 21.1 |
| **B** | 730.1 | 40.7 |
| C | 372.4 | 18.2 |
| D | 600.7 | 29.6 |
| E | 491.2 | 18.5 |
| **F** | 609.3 | 32.2 |
| G | 355.5 | 26.8 |
| H | 299.5 | 10.3 |
| I | 303.7 | 12.5 |
| J | 665.2 | 11.0 |
| **K** | 656.9 | 35.2 |
| L | 574.1 | 28.0 |
| M | 544.6 | 35.9 |
| N | 537.2 | 30.4 |
| O | 506.4 | 36.6 |

# Real-world high $NO_X$ emissions from NG trucks drive the early implementation of China VI for NG

- Plume chasing has revealed much higher $NO_X$ emissions of natural gas China IV/V trucks using lean-burn engines
- The finding directly prompted the early implementation of China VI NG HDV emission standard (a switch to stoichiometric engine plus TWC)



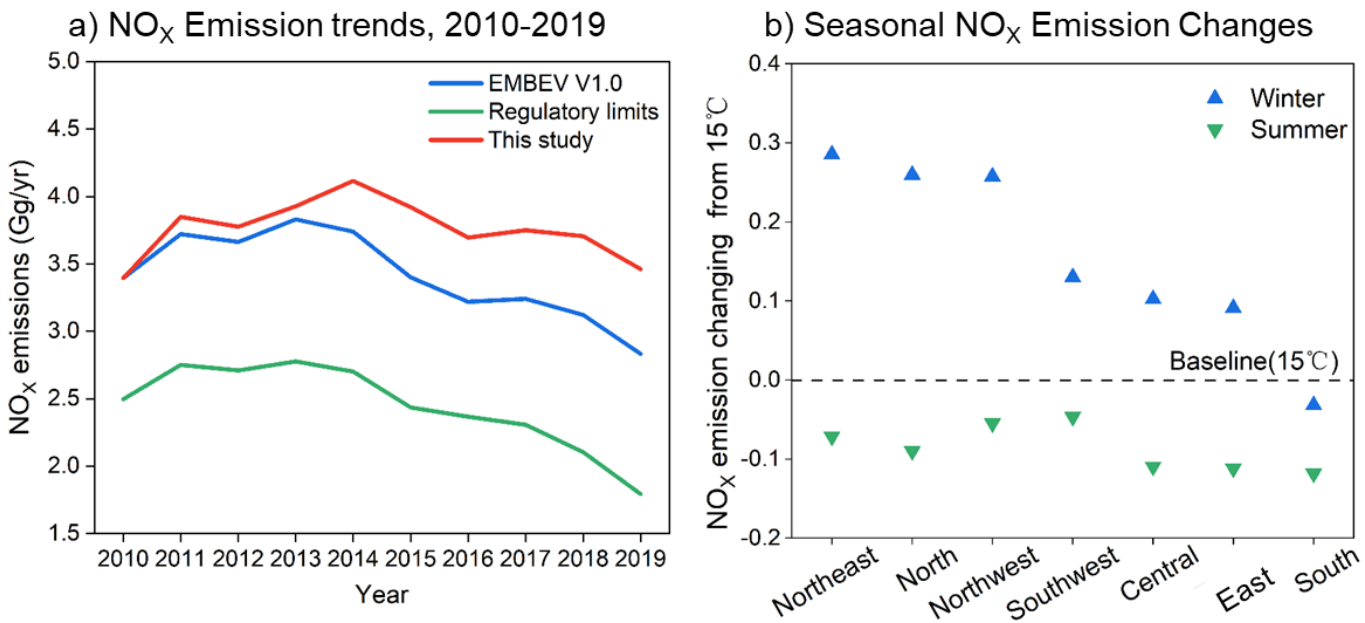
# Updating localized emission models and inventories based on plume chasing test results

- **Revisit historical emission trends:** previous studies **underestimate 18%** compared to the updated emission inventory in China in 2019
- **low-temperature penalty:** caused a 9−29% increase in $NO_X$ emissions in winter in major regions of China

## Improvement of emission factor model

- **Basic emission factors for HDTs**
- **Corrections for emission factors**
  - ✓ Temperature correction factor ($C_{temp}$)
  - ✓ Speed correction factor ($C_{speed}$)
  - ✓ High-emitter correction ($C_{high\text{-}emitter}$,BC)

## Annually variations in $NO_X$ emissions



# Contents

- System development and reliability verification
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# Summary and Recommendation

Summary

- Plume chasing is validated to applicably measure real-world emissions from heavy-duty vehicles, including low-emission China VI vehicles, and is also sensitive to identify after-treatment failures
- A large-scale plume chasing test involving 13,000 vehicles revealed limited NOx emission reductions in China IV and V diesel vehicles, and high emissions from lean-burn natural gas vehicles
- Plume chasing results have been used to update key modules of the national emission inventory, such as ambient temperature, speed, and the high emitters module

Recommendation

- We recommend to develop testing standard on mobile plume chasing in China as well as in other regions to promote the application
- Accumulate plume chasing in various regions and years to improve emission accounting
- Important to synchronize plume chasing with other testing methods, in particular on-board monitoring (OBM), to enhance the capability of high-emitting detection and in-use compliance enforcement

# Thanks for your time！


## Contact information

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