On-road emissions measured by chase techniques in China

An approach that can compliment PEMS, but not replace it!

- Dane Westerdahl, Xing Wang and K. Max Zhang (PI)
- Energy and the Environment Research Laboratory
How did we end up in China?

• The Olympic Games and the opportunity it offered
  – Aggressive controls applied to a very polluted city
• Two investigators from China
• Good food and friends
Heroic controls placed on Beijing and the region as Olympics approached

- Construction halted
- New taxis replaced old ones
- High emitting cars banned from city
- Trucks largely banned from city
- Odd/Even car use
- New buses purchased
- Industry closed
- Coal burning replaced by natural gas
- Cement plants and quarries closed
- Dirt/debris covered
- Landscape planted
- Streets cleaned
- No street bar b ques
- Unconfirmed weather modification

Most measures were implemented well before Games and had different start dates
Truck Activity refers to the period between 11:00 pm and 6:00 am. *Beijing residents are exposed to much higher diesel particulate matter levels at night.*
The significant increases of BC concentrations on NTC days demonstrate the positive impact of traffic control regulations in reducing BC emissions.
On-road Measurements in Beijing
Studying emissions in the real world
Measuring On-road Emission Factors

• The main objective of our research efforts is to obtain real-world emissions information using a mobile platform chasing method.

• Our work demonstrates that this method can become a cost-effective way to determine mobile emission factors.
## Methods to derive emission factors

<table>
<thead>
<tr>
<th>Methods</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Dynamometer                    | • Repeatable driving condition  
• Vehicle and engine conditions well characterized | • Highest cost per vehicle  
• Driving and dilution conditions are artificial*  
• Facilities are complex |
| PEMS                           | • Real-world driving conditions  
• Vehicle and engine conditions may be characterized | • Dilution conditions are artificial  
• Not time efficient for large diesel vehicles |
| On-road Chasing using mobile platform | • Lowest cost per vehicles  
• Real-world driving conditions  
• Real-world on-road vehicle population  
• Atmospheric dilution process | • Vehicles and engine conditions are less known (but may be acquired through license plates)  
• Driving conditions not controlled  
(Also a strength*) |
EERL Expertise in Mobile Platform Operation and Emission Factor Determination

- **2003-2006**: Designed platform/conducted mobile platform measurements on-road, in community air, and near airport \(^1,^2\)
- **2005**: Derived, for the first time, the size-resolved on-road particulate emission factors \(^3\)
- **2007**: Measured *fleet average* on-road emission factors for cars and trucks in Beijing using mobile platform \(^4\)
- **2008**: Measured *fleet average* and some *individual* emission factors for cars, trucks, and buses during Olympics using mobile platform \(^5\)
- **2009**: Sampled 243 *individual* trucks and 57 *individual* buses in and around Beijing (within two weeks), and derived emission factor distributions \(^6\)
- **2010**: Conducting emissions measurements in Beijing and Chongqing, focusing on NOx emissions

\(^6\) Wang et al., (2010) *Atmospheric Environment* 2010, 44
Chase study instruments

- Fast Mobility Particle Sizer (TSI 3091)
- MicroAethalometer (Magee Scientific AE 51)
- CO/temp/humidity (Q-Trak (TSI 7545)
- CO2 analyzer (Vaisala CarboCap GM70)
- NO analyzer (2b Tech Model 410)
- NOx converter (2b Tech Model 401)
- Computer datalogger
- Video camera
- Gps

Time resolution—10 seconds
Plume concentrations from a truck

Deriving Emission Factors based on Carbon Balance

\[
EF_p = \frac{\Delta[P]}{\Delta[CO_2] \times \frac{MW_c}{MW_{CO_2}} + \Delta[CO] \times \frac{MW_c}{MW_{CO}} + \Delta[BC] \times \frac{MW_c}{MW_{BC}}} \times w_c
\]

\(w_c\): mass fraction of carbon in fuel

\(MW\): molecular weight

\(\Delta\): concentration increase

\(\Delta = \text{conc}_{\text{realtime}} - \text{conc}_{\text{baseline}}\)

Method used by Stedman for EF calculation from remote sensing and Harley in tunnel studies
EF distributions: ~250 Diesel Trucks

5% heavy emitters responsible for 50% BC emissions
20% of trucks were responsible for 50% CO and PM number, 60% PM mass and 70% BC emissions

BC EF distribution: Buses by type

BC EF of Euro IV and CNG buses were 70% and 75%, respectively, lower than Euro II buses.

Particle size resolved PM concentration and emission factors for urban buses*
Objectives for December 2010 studies

Expansion of successful field studies of winter 2009 where we sampled the emissions from over 250 on-road vehicles in and around Beijing

• The main objective was to add NOx measurement and emission factors to our protocol

• A second objective was to compare our emission measurements using the on-road chasing method to Portable Emissions Measurement System (PEMS) observations

• Third objective was to expand chase studies to include a second city for chase studies
A-B: On-road truck chasing route (25.1 km)
Routes - Beijing

A-B: On-road truck chasing route (48.1 km)
C-D: PEMS comparison chasing route (19.7km Expy+11.4 Urban Road)
December 2010 activities - Chongqing

- On-road chasing study in Chongqing
  - Dec 21-Dec 27, 2010
  - Truck chased: 267

<table>
<thead>
<tr>
<th>Date</th>
<th>Route</th>
<th>Trucks Chased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 21</td>
<td>Inner Ring Rd.</td>
<td>38</td>
</tr>
<tr>
<td>Dec 22</td>
<td>Inner Ring Rd.</td>
<td>60</td>
</tr>
<tr>
<td>Dec 23</td>
<td>Inner Ring Rd.</td>
<td>61</td>
</tr>
<tr>
<td>Dec 24</td>
<td>Inner Ring Rd.</td>
<td>11</td>
</tr>
<tr>
<td>Dec 26</td>
<td>Inner Ring Rd.</td>
<td>56</td>
</tr>
<tr>
<td>Dec 27</td>
<td>Inner Ring Rd.</td>
<td>41</td>
</tr>
</tbody>
</table>
Beautiful Chongqing
Yangtze River and city skyline
December 2010 Activities - Beijing

- On-road chasing study in Beijing
  - Dec 9-Dec 14, 2010
  - Trucks sampled: 195
- PEMS vs on-road chasing comparison study in Beijing
  - Dec 15-Dec 17, 2010
  - Three trucks

<table>
<thead>
<tr>
<th>Date</th>
<th>Route</th>
<th>Trucks Chased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 9</td>
<td>6th Ring Rd.</td>
<td>26</td>
</tr>
<tr>
<td>Dec 11</td>
<td>6th Ring Rd.</td>
<td>55</td>
</tr>
<tr>
<td>Dec 12</td>
<td>6th Ring Rd.</td>
<td>NOx Test</td>
</tr>
<tr>
<td>Dec 13</td>
<td>6th Ring Rd.</td>
<td>55</td>
</tr>
<tr>
<td>Dec 14</td>
<td>6th Ring Rd.</td>
<td>47</td>
</tr>
<tr>
<td>Dec 17</td>
<td>6th Ring Rd.</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 15</td>
<td>Beijing-Chengdu Expy, 6th Ring Road</td>
</tr>
<tr>
<td>Dec 16</td>
<td>Beijing-Chengdu Expy, Urban Road</td>
</tr>
<tr>
<td>Dec 17</td>
<td>Beijing-Chengdu Expy, Urban Road</td>
</tr>
</tbody>
</table>
PEMS vs. on-road chasing comparison study
Beijing—Initial focus on NOx data
Preliminary Results

A high emitting truck in Chongqing
Preliminary Results

Correlation between on-road NOx and CO$_2$ conc.

\[ y = 10.17x - 4,344.40 \]
\[ R^2 = 0.75 \]
Very Preliminary Results

NOx emission factors
PEMS vs. Chasing method (g/kg fuel)

\[ y = 0.736x + 15.525 \]
\[ r^2 = 0.64 \]
2010 Summary

• On-road chasing methods were successfully implemented in Beijing and Chongqing.
• On-road NOx, BC, CO, CO$_2$, UFP data were collected for more than 400 diesel trucks.
• The NOx emission factors derived from the on-road chasing method with speed calibration appear to be in good correlation with those from PEMS—still under construction.
• On-going data analysis aims to add NOx emission factor distributions for on-road Chinese trucks.
Conclusions from On Road Studies

• A time- and cost- effective approach allows us to sample a large number of trucks and buses
  – Real-world on-road emissions of areal-world vehicle population

• Useful support for air pollution control measures:
  – Identify heavy emitters and implement emission reduction programs to control them
  – Need to improve fuel quality in entire region rather than specific cities*
  – Clean –burning buses work
Will Chase methods replace PEMS?

NO—but

• Allows consideration of real world PM
  – UFP size and numbers down to 5.6 nm
  – Black carbon

• Allows testing of many vehicles—40 or 50 a day
  – Produces a better representation of on road fleet

• Easy to set up and operate
  – But labor intensive to analyze

• Ideal for use in developing world
Can Chase methods compliment PEMS?

Yes

• Quick means to generate emissions hypotheses
• Screening tool for finding high emitters
  – Follow up with PEMS
• Can be applied in areas far from lab support
• New metrics/compounds can be added
• Methods could be used together to generate better PM and black carbon emissions data
Acknowledgements

• Dr. Zhenghua Li and Prof. Wu Ye at Tsinghua University
• Prof. Xiaochuan Pan at Peking University School of Public Health
• Dr. Jingnan Hu at Chinese Research Academy of Environmental Sciences
• Mr. Jianjun Zheng at Chongqing Research Academy of Environmental Sciences
• Although the research described has been funded wholly or in part by the USEPA contract EP-C-06-003 to SRA International, it has not been subject to the Agency’s review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.
A better future for Beijing?
Maybe, but traffic and traffic growth will remain a serious challenge for rest of China
Ambient Black Carbon
A tale of 2 cities
Daytime truck traffic strongly reflected in Chongqing ambient air