A discussion on the paper
“Estimates of CO$_2$ traffic emissions from mobile concentration measurements”

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Outline

- Introduction
- Materials and Methods
- Results and Analysis
- Discussion
Introduction

- Urban area plays a disproportionately large part (>70%) of fossil fuel CO₂ emission in the worldwide range [Duren and Miller, 2012]. Within the urban core, the dominant source of emissions often is the traffic [Erickson et al., 2013].

- There are several challenges:
  1. Concentration data requires a high spatial and temporal resolution.
  2. The influence of traffic conditions on the boundary conditions for CO₂ dilution and pollutant dispersal.

- The objective of this experiment is to derive on-road emissions and develop a model for on-road concentrations, we then use data to infer instantaneous emission rates.
Materials and Methods

Fig. 1  Map of trip route along California State Route 24.
Materials and Methods

- LICOR-840A
  - A function of time and position
    - C
    - $C_b$
    - $C-C_b$
  - $C$ and $C_b$ comparison

- GPS receiver
  - Velocity, Acceleration, Road grade
    - BB 2008
    - Ross
    - Forward Modeling
    - Parameter Estimation
      - $E_B$
      - $E_R$
      - $E_{ML}$
      - $E_{MO}$
    - Comparison:
      - $E_B$ compared to $E_R$
      - $E_{ML}$ compared to $E_{MO}$

- ML model
  - MOVES Lite
Materials and Methods

Fig. 2 Illustration of prototype node used in this experiment.
Materials and Methods

Model for Roadway CO$_2$ Concentration

\[ C - C_b \propto F E v^{-4/3} \] (Baker, 1996)

\[ F = \frac{v}{d} N_{\text{lanes}} \quad d^{-1} = \left( \frac{W_{\text{car}}/2}{\tan(\theta_{\text{car}}/2)} + l_{\text{car}} - l_{\text{cam}} \right)^{-1} \]

\[ C - C_b = \kappa \frac{E N_{\text{lanes}}}{d} v^{-1/3} \]

Total highway emissions:

\[ Q = \frac{E N_{\text{lanes}}}{d} \]

\[ C - C_b = \kappa Q v^{-1/3} \]
Materials and Methods

Model for Roadway CO$_2$ Concentration

\[ Q = \frac{EN_{\text{lanes}}}{d} \]

The per car emission rate: \[ E = P_f f_c f_{\text{oxid}} f_m \]

The vehicle fuel consumption rate:

\[ P_f = \frac{1}{\eta_t} \left( \frac{f_0 VN}{2000} + P_{\text{acc}} + \frac{1-c}{\epsilon} H \{ P_{\text{load}} \} \right) \quad (\text{Ross, 1994, 1997}) \]

The engine speed :

\[ N = \frac{f_N}{1 + (v / v_t)^{-6}} + N_{\text{idle}} \]

(Thomas and Ross, 1997)
Materials and Methods

Model for Roadway CO$_2$ Concentration

The engine load:  
$$P_{\text{load}} = P_{\text{roll}} + P_{\text{air}} + P_{\text{inertia}} + P_{\text{grade}} $$  
(Ross, 1997)

$$P_{\text{roll}} = C_R M g v$$  
$$P_{\text{air}} = 0.5 \rho C_d A v^3 / 1000$$

$$P_{\text{inertia}} = f_1 M v a$$  
$$P_{\text{grade}} = M g v \sin \theta$$

$$C - C_b = N_{\text{lanes}} v^{-1/3} d^{-1} \left( k_{\text{fr0,acc}} + k_{\text{fr0,N}} \frac{1}{1+ (v/v_t)^6} + H \left\{ k_{\text{roll}} v + k_{\text{air}} v^3 + k_{\text{inertia}} v a + k_{\text{grade}} v \sin (\tan^{-1} \theta) \right\} \right)$$

**Table 1. Model Parameter Summary**

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Definition</th>
<th>Prior Bounds</th>
<th>Result</th>
<th>Result/Expected $^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{\text{fr0,acc}}$</td>
<td>$\frac{k_{\text{f,c,oxid} f_{m}}}{\eta_t} \left( \frac{f_{0} V N_{\text{idle}}}{2000} + P_{\text{acc}} \right)$</td>
<td>12–3200</td>
<td>$98.0^{+10.4}_{-10.0}$</td>
<td>0.20</td>
</tr>
<tr>
<td>$k_{\text{fr0,N}}$</td>
<td>$\frac{k_{\text{f,c,oxid} f_{m}}}{\eta_t} \frac{f_0 V}{2000} f_N$</td>
<td>14–5400</td>
<td>$757^{+19}_{-18}$</td>
<td>1.2</td>
</tr>
<tr>
<td>$k_{\text{roll}}$</td>
<td>$\frac{k_{\text{f,c,oxid} f_{m}}}{\eta_t} \frac{1-c}{e} C_R M$</td>
<td>2.0–200</td>
<td>$64.1^{+2.6}_{-3.4}$</td>
<td>3.0</td>
</tr>
<tr>
<td>$k_{\text{air}}$</td>
<td>$\frac{k_{\text{f,c,oxid} f_{m}}}{\eta_t} \frac{1-c}{e} \frac{0.5 \rho C_d A}{1000}$</td>
<td>0.0050–0.30</td>
<td>$0.0586^{+0.0040}_{-0.0033}$</td>
<td>0.91</td>
</tr>
<tr>
<td>$k_{\text{inertia}}$</td>
<td>$\frac{k_{\text{f,c,oxid} f_{m}}}{\eta_t} \frac{1-c}{e} f_i M$</td>
<td>30–1100</td>
<td>$215^{+3}_{-3}$</td>
<td>0.87</td>
</tr>
<tr>
<td>$k_{\text{grade}}$</td>
<td>$\frac{k_{\text{f,c,oxid} f_{m}}}{\eta_t} \frac{1-c}{e} M g$</td>
<td>280–10000</td>
<td>$1800^{+13}_{-13}$</td>
<td>0.77</td>
</tr>
</tbody>
</table>

$^a$Results correspond to 16%, 50%, and 84% in the marginalized distributions.

$^b$Assumes $\kappa = 0.00137$ (see text).
Materials and Methods

Model for Roadway CO\textsubscript{2} Concentration

\[ C - C_b = \kappa N_{\text{lanes}} v^{-1/3} d^{-1} \left( E_{\text{fro,acc}} + E_{\text{fro,N}} + E_{\text{roll}} + E_{\text{air}} + E_{\text{inertia}} + E_{\text{grade}} \right) \]

**fro, acc** : accessories and idling engine friction at zero load

**fro, N** : the increase with engine speed in engine friction at zero load

**roll** : rolling resistance

**air** : air drag

**inertia** : inertia

**grade** : road grade
Results and Analysis

Fig. 3 Example data sequence for one evening trip made prior to the opening of the fourth bore.
Fig. 4  Example data sequence for the full evening data set made prior to the opening of the fourth bore.
Results and Analysis

Forward Modeling

- $Q$, the total highway surface emission rate, is relatively **insensitive to congestion**, because $Q$ is approximately independent of vehicle speed.

- The **velocity correction** for vehicle-induced turbulence does a reasonable job of predicting concentrations.

**Fig.5** Forward modeling results for all evening data.
Results and Analysis

Parameter Estimation

Fig. 6 Comparison of the Highway 24 concentration data above background to the maximum likelihood model.
Results and Analysis

Parameter Estimation

Fig. 7  The distributions and correlations for the emissions rate constants.
Results and Analysis

Three emissions models

- **Ross model**: velocity, acceleration, and road grade [Ross, 1994, 1997]

- **BB08**: its only input is speed [Barth and Boriboonsomsin, 2008]

- **MOVES Lite**: velocity, acceleration, and road grade [Frey and Liu, 2013]
Fig. 8  Instantaneous vehicle emission rates for our maximum likelihood model compared to three alternative models presented in the literature.
Fig. 9  Same as Figure 8 only for the period after the fourth bore is open.
Discussion

- Mobile concentration measurements in this paper can be a promising and useful method/dataset for testing, improving existing emission models when traffic and fleet information are readily available.

- For the application in this paper, further work will focus on improving the derivation of baseline emission rates and extending the transport modeling to predict absolute (rather than relative) emission rates.
Thank you