A Mobile Sensor Network to Map CO$_2$ in Urban Environments

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Overview

- We present a pilot study to show the potential for a mobile sensor network to monitor greenhouse gas concentrations and to derive emissions in cities.
Can we map greenhouse gases, specifically $\text{CO}_2$, at a spatial resolution of neighborhoods / blocks across the city with a network of mobile sensors?
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Emerging Opportunities...
• Rise of flexible (open source), compact technologies.
• Enhanced access to mobility services/platforms
But how do you go from concentrations to emissions?
Proposed Approach: Using the aerodynamic resistance (with a number of assumptions!)

Sensible heat flux & temperature are used to calculate the aerodynamic resistance for heat. Surface temperature is calculated with a radiometer at the surface. Assuming that the aerodynamic resistance of CO$_2$ and heat are the same, the flux is computed.

\[ F_{CO_2} = \frac{c_{tower} - c_{car}}{r_{aC}} \]

where

\[ r_{aC} = r_{aH} = \frac{T_{30m} - T_{surface}}{H} \]
The Mobile Sensor System
System Components

System Specifications
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- **Total delayed response time**: 13 s with 3 m sample tube at flow rate of 700 cc/min.
Built & Tested: 5 mobile systems

Image: In total 5 sensors were built – the image shows the full setup including the sample inlet tube and the temperature probes.
Study Area: 12.7 km² transect, Vancouver, BC

Image: 12 km² transect study area in Vancouver, BC. The transect is 1km x 12.7km covering the major land cover types in the city. Sunset Urban Climate tower is shown in orange.
Study Area: Tour of Vancouver

Video: A tour of Vancouver during the measurement campaign as seen through a dashboard camera. Local climate zones include Forest – A, compact midrise, compact high rise, compact lowrise, and open lowrise
Measurement period: 10:30 - 14:00
With convective and steady weather
- $T_{air} = 20^\circ - 22^\circ$ C
- Winds: 2.5 m/s
- Cloudless

* data measured at 30m Urban Climate Tower "Vancouver Sunset" (SE section of Transect)
Sampling Methods: Vehicle Installation

Image A: Shows the temperature probe covered by PVC tube and reflective tape and sample inlet tube at 2m height - ±0.5°C Accuracy from -10°C to +85°C ; Image B: Shows sensor installation in vehicle.
Sampling Methods: **Bike Installation**

Image: Shows the installation of the sensor on a bike rack – the inlet is at approximately 2m height.
Sampling Methods: Deployment Transects

Image: The image shows 5 planned transect routes for the measurement campaign. Goal: to cover (almost) all navigable roads (and some trails) along the transect in 3.5 hours.
Pilot Study - Mapping CO$_2$ Emissions: Results
Raw Data: Visualized in Google Earth
Average CO$_2$ Mixing Ratios per 100m Grid Cell
Calculated Emissions: Concentrations to Emissions

Image: Calculated emissions map generated using the aerodynamic resistance approach using CO$_2$ concentration measurements.
Mapping Emissions - Methods: Emissions Inventory
Traffic Emissions Inventory

Traffic Emissions Inventory derived from Vancouver's traffic count data and calculated per grid cell using fuel consumption and emissions factors.
Building Emissions Inventory

Image: Building emissions inventory generated by combining factors of building morphology, urban context, and population density derived from LiDAR, building topology, and census data.
CO₂ Mixing Ratios Vs. Traffic Emissions Inventory

Observed CO₂ Mixing Ratios Binned by Traffic CO₂ Inventory

Traffic CO₂ Inventory (kg CO₂ hr⁻¹ ha⁻¹) - log

Observed Near Surface CO₂ mixing ratios (ppm)
CO₂ Mixing Ratios Vs. Total Emissions Inventory
Calculated CO\textsubscript{2} emissions vs. Traffic Emissions Inventory

- **Downtown**
- **West End**
- **Fairview & Mt. Pleasant**
- **Riley Park & Kensington-Cedar Cottage**
- **Sunset & Victoria-Fairview**

**Graph Details:**
- **Y-axis:** Calculated CO\textsubscript{2} Emissions (log)
- **X-axis:** Traffic CO\textsubscript{2} Inventory (log)

The graph shows a scatter plot comparing calculated CO\textsubscript{2} emissions with traffic CO\textsubscript{2} inventory across various locations.
Calculated CO₂ emissions vs. Building Emissions Inventory

Calculated CO₂ Emissions Vs. Building CO₂e Inventory

- Downtown
- West End
- Fairview & Mt. Pleasant
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- Sunset & Victoria-Fairview

Calculated CO₂ Emissions (log)

Building CO₂e Inventory (log)
Calculated CO$_2$ emissions vs. Total Emissions Inventory

Calculated CO$_2$ Emissions Vs. Total CO$_2$ Inventory (Traffic + Buildings)
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- Currently exploring visualization & feedback opportunities for planning and open science.
- Collaboration potential with local mobility providers for long term & spatially extensive/intensive monitoring.
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- Tools: Python, R, QGIS, GDAL/OGR, Processing

References
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The slides & links can be found on github:

joeyklee.github.io/presentations/ICUC-JLEE-2015
Thanks!
Questions? Comments?

Many thanks to ICUC organizers and community.
Methods: Multipoint Calibration

Image: Multipoint Calibration of Sensor System showing observed values versus known concentrations.
Methods: Sensor Drift

Image: Testing for sensor drift of the five mobile sensors over a seven-day measurement period. Each line corresponds to one of the five mobile CO₂ sensors.
Image: The images above show typical urban features characteristic for each neighborhood in the study area and were taken with a dashboard camera during the measurement campaign.