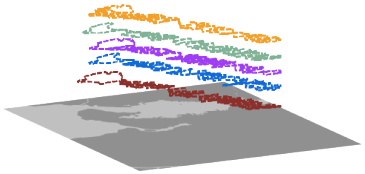
A Mobile Sensor Network to Map CO_2 in Urban Environments

Joey Lee[1], Andreas Christen[1], Zoran Nesic[2], & Rick Ketler[1]
Department of Geography[1]
Department of Land and Food Systems[2]
The University of British Columbia

9th International Conference on Urban Climate
Toulouse, France
July 24, 2015

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.



sensor development

design → testing →

mapping emissions: methods

measurement campaign → calculated emissions

traffic counts & building energy data → generate emissions inventories

→

mapping emissions: results

observed mixing ratios & emissions inventory data per 100m grid cell →

calculated emissions vs. emissions inventory

observed mixing ratios vs. emissions inventory

RESEARCH QUESTION

PRELIMINARY RESULTS

Research Question

Can we map greenhouse gases, specifically CO_2, at a spatial resolution of neighborhoods / blocks across the city with a network of mobile sensors?

Motivations: Why Mobile Sensing?

Motivations: Why Mobile Sensing?

- Cities are a major source of GHGs into the atmosphere (Estimated 70%, Rosenzweig 2010).

Motivations: Why Mobile Sensing?

- Cities are a major source of GHGs into the atmosphere (Estimated 70%, Rosenzweig 2010).
  - Currently there are a lack of tools to monitor CO_2 emissions in cities; existing tools are limited by funding, time, expertise, spatial & temporal resolution.

Motivations: Why Mobile Sensing?

- Cities are a major source of GHGs into the atmosphere (Estimated 70%, Rosenzweig 2010).
  - Currently there are a lack of tools to monitor CO_2 emissions in cities; existing tools are limited by funding, time, expertise, spatial & temporal resolution.
  - There's a need to validate fine scale emissions inventories.

Motivations: Why Mobile Sensing?

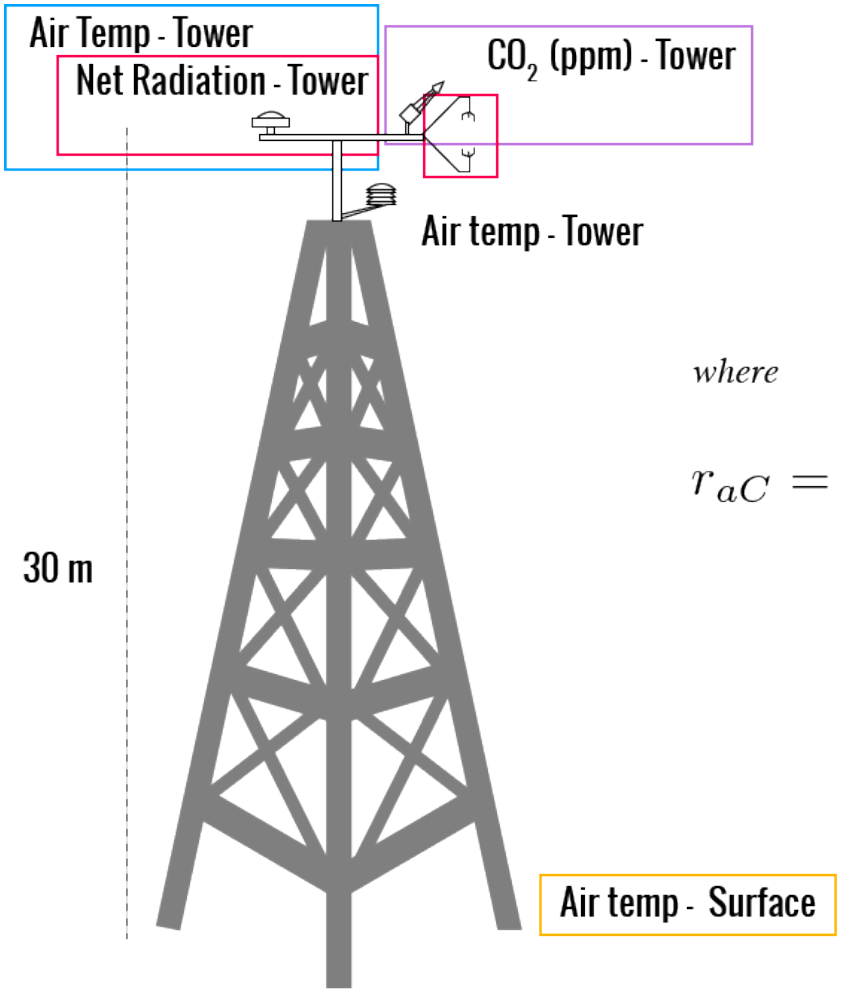
- Cities are a major source of GHGs into the atmosphere (Estimated 70%, Rosenzweig 2010).
  - Currently there are a lack of tools to monitor CO_2 emissions in cities; existing tools are limited by funding, time, expertise, spatial & temporal resolution.
  - There's a need to validate fine scale emissions inventories.

Emerging Opportunities…

- Rise of flexible (open source), compact technologies.
- Enhanced access to mobility services/platforms

But how do you go from concentrations to emissions?

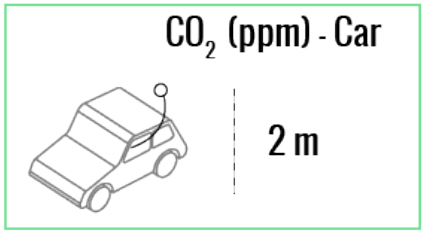
Proposed Approach: Using the aerodynamic resistance (with a number of assumptions!)



$$F_{CO_2} = \frac{c_{\text{tower}} - c_{\text{car}}}{r_{aC}}$$

where

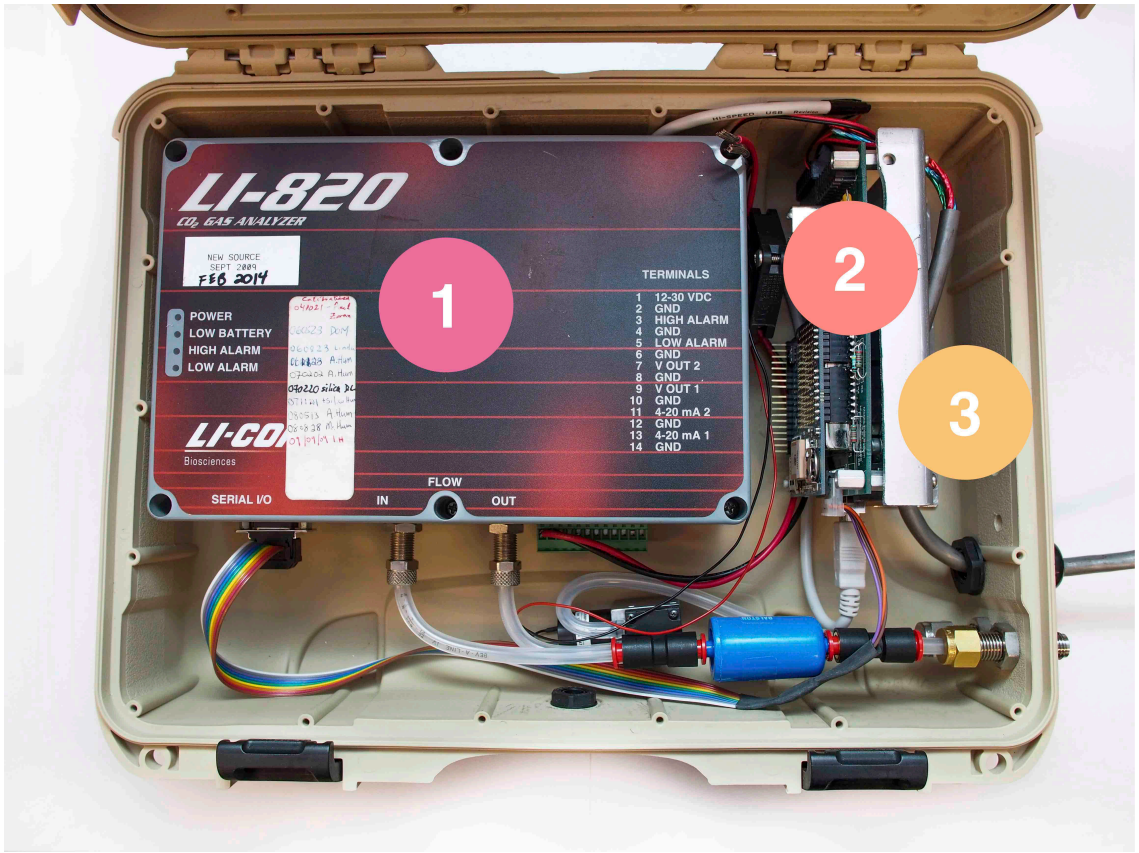
$$r_{aC} = r_{aH} = \rho c_p \frac{T_{30m} - T_{surface}}{H}$$



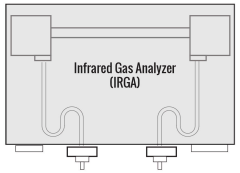
Sensible heat flux & temperature are used to calculate the aerodynamic resistance for heat. Surface temperature is calculated with a radiometer at the surface. Assuming that that the aerodynamic resistance of CO_2 and heat are the same, the flux is computed.

The Mobile Sensor System

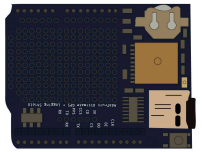
System Components



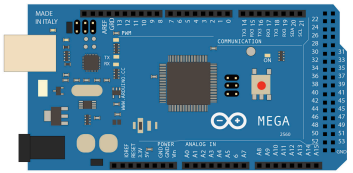
1 IRGA



2 Adafruit GPS



3 Arduino Mega



1. IRGA – Licor LI-820 (Licor Inc, Lincoln, NB, USA), 2. Adafruit GPS (Adafruit Industries, Manhattan, NY, USA), 3. Arduino Mega (Arduino CC, Ivrea, Italy) . *Not Shown: OneWire Digital Temperature Thermometer (Maxim Integrated One Wire Digital Temperature Sensor - DS18B20, San Jose, CA, USA)

System Specifications

System Specifications

- Runs on 12 V Power supply

System Specifications

- Runs on 12 V Power supply
- Measures CO_2 mixing ratios (ppm), geoposition and speed, and air temperature at 1-second intervals.

System Specifications

- Runs on 12 V Power supply
- Measures CO_2 mixing ratios (ppm), geoposition and speed, and air temperature at 1-second intervals.

- Size: 35.8 cm x 27.8 cm x 11.8 cm, weight: 2.6 kg.

System Specifications

- Runs on 12 V Power supply
- Measures CO_2 mixing ratios (ppm), geoposition and speed, and air temperature at 1-second intervals.

- Size: 35.8 cm x 27.8 cm x 11.8 cm, weight: 2.6 kg.
- Precision: +/- 1.1 ppm

System Specifications

- Runs on 12 V Power supply
- Measures CO_2 mixing ratios (ppm), geoposition and speed, and air temperature at 1-second intervals.

- Size: 35.8 cm x 27.8 cm x 11.8 cm, weight: 2.6 kg.
- Precision: +/- 1.1 ppm
- Accuracy: +/- 3 ppm, with maximum drift of +/- 4 ppm over seven days.

System Specifications

- Runs on 12 V Power supply
- Measures CO_2 mixing ratios (ppm), geoposition and speed, and air temperature at 1-second intervals.

- Size: 35.8 cm x 27.8 cm x 11.8 cm, weight: 2.6 kg.
- Precision: +/- 1.1 ppm
- Accuracy: +/- 3 ppm, with maximum drift of +/- 4 ppm over seven days.
- Total delayed response time: 13 s with 3 m sample tube at flow rate of 700 cc/min.

Built & Tested: 5 mobile systems

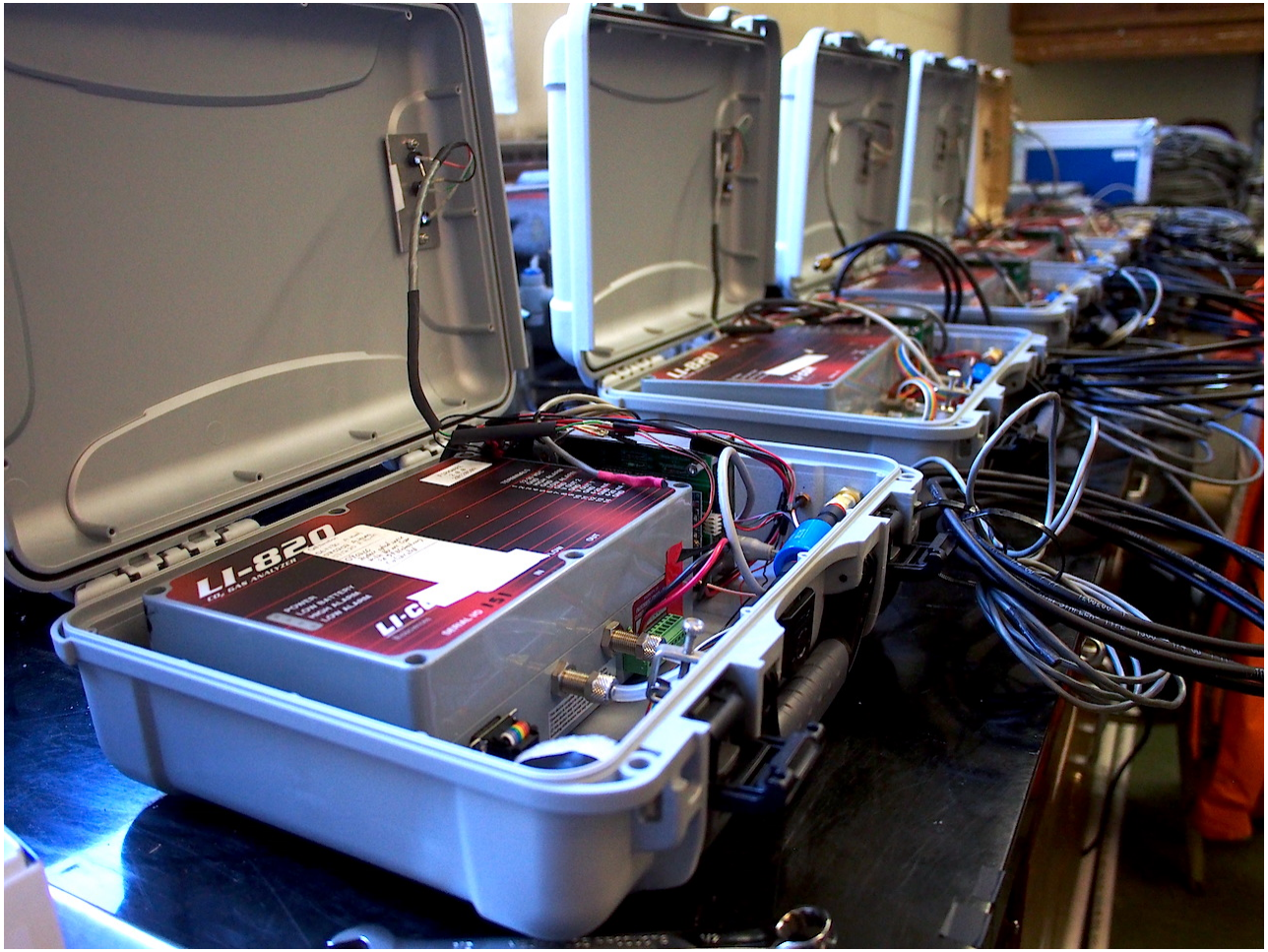


Image: In total 5 sensors were built – the image shows the full setup including the sample inlet tube and the temperature probes.

Mapping Emissions - Methods: Measurement Campaign

May 25th, 2015

Study Area: 12.7 km^2 transect, Vancouver, BC

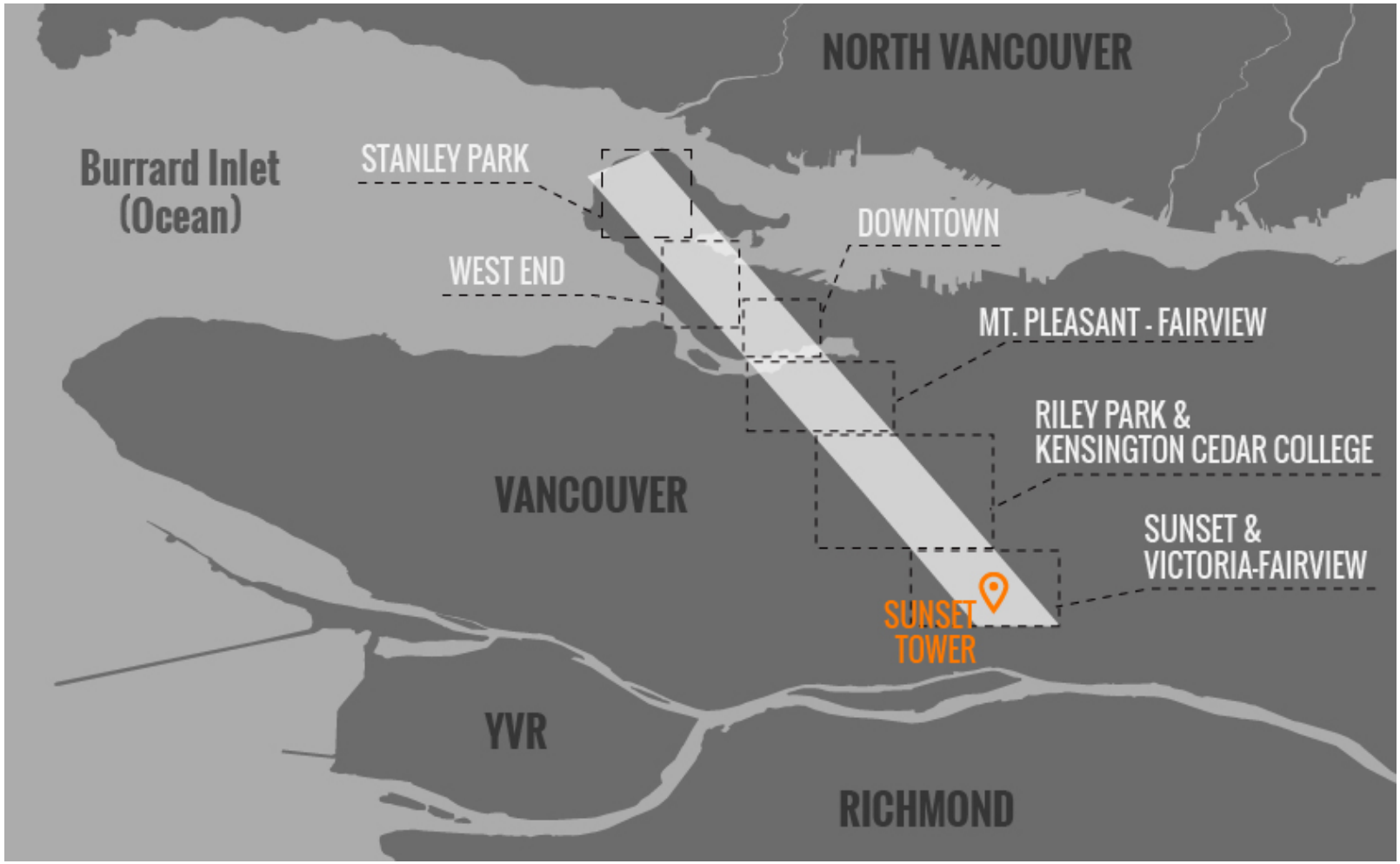


Image: 12 km^2 transect study area in Vancouver, BC. The transect is 1km x 12.7km covering the major land cover types in the city. Sunset Urban Climate tower is shown in orange.

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

Study Area: Meteorology - May 25th, 2015

Measurement period: 10:30 - 14:00
With convective and steady weather

- T_{air} = 20° - 22° 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

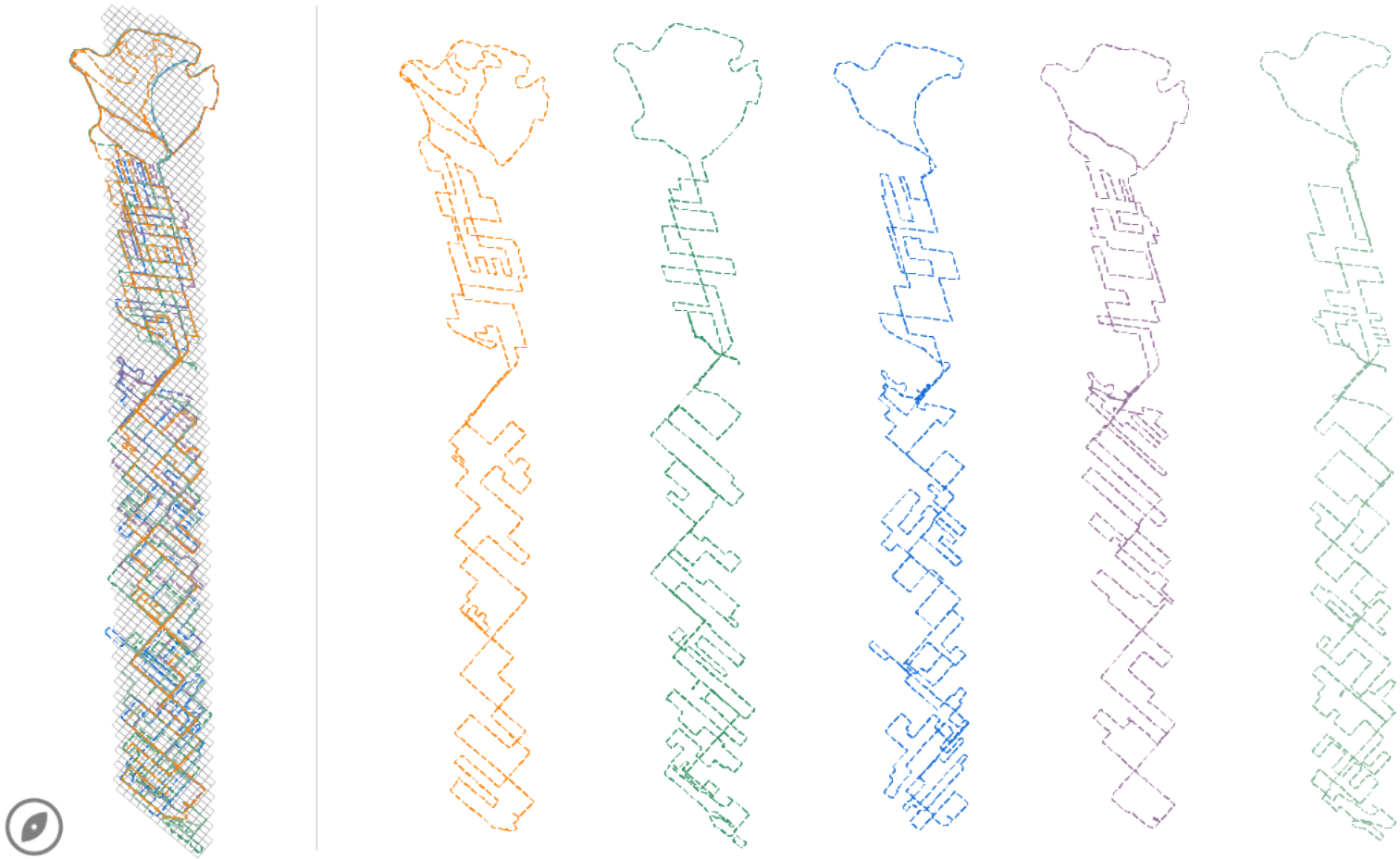
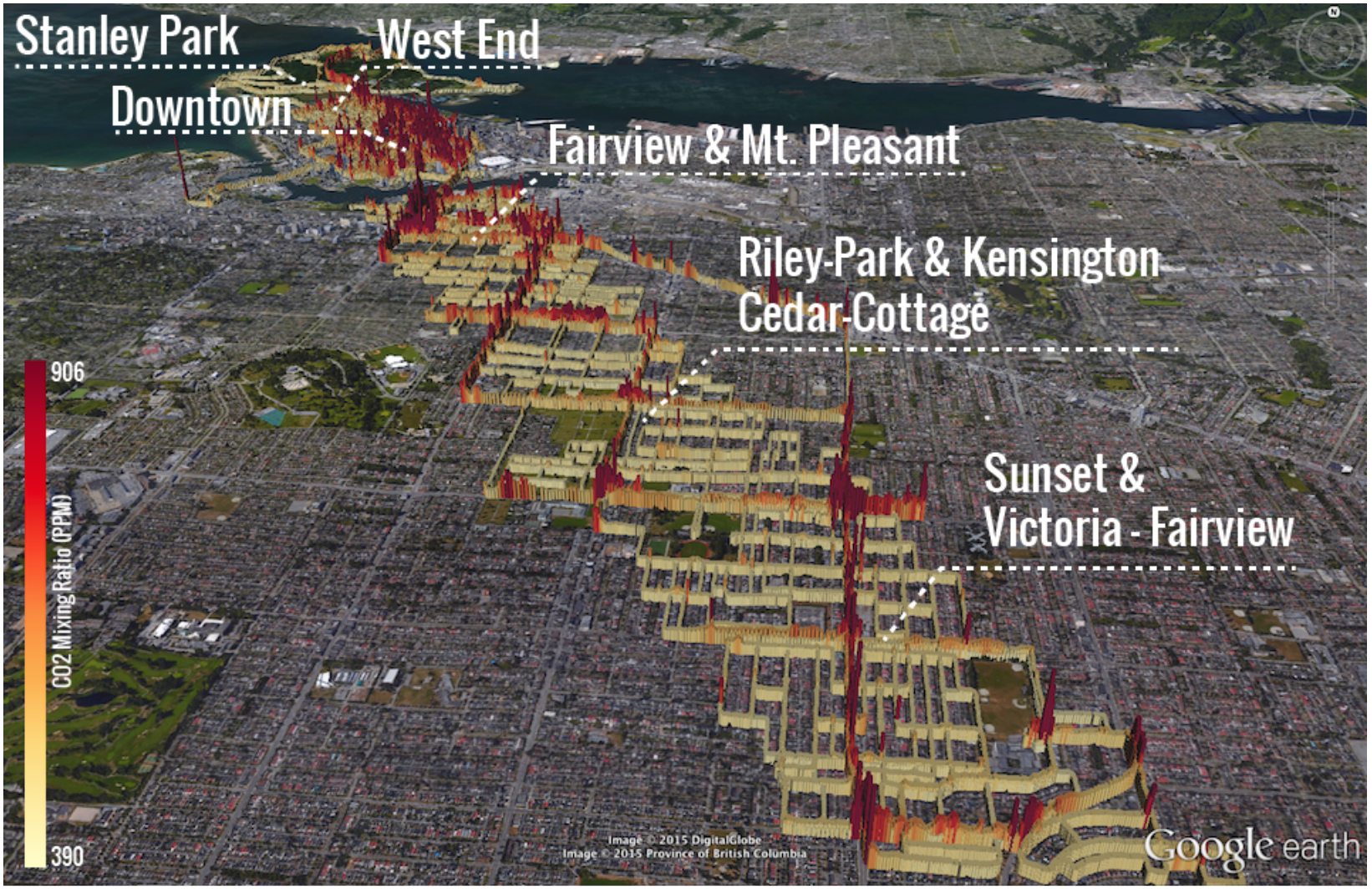


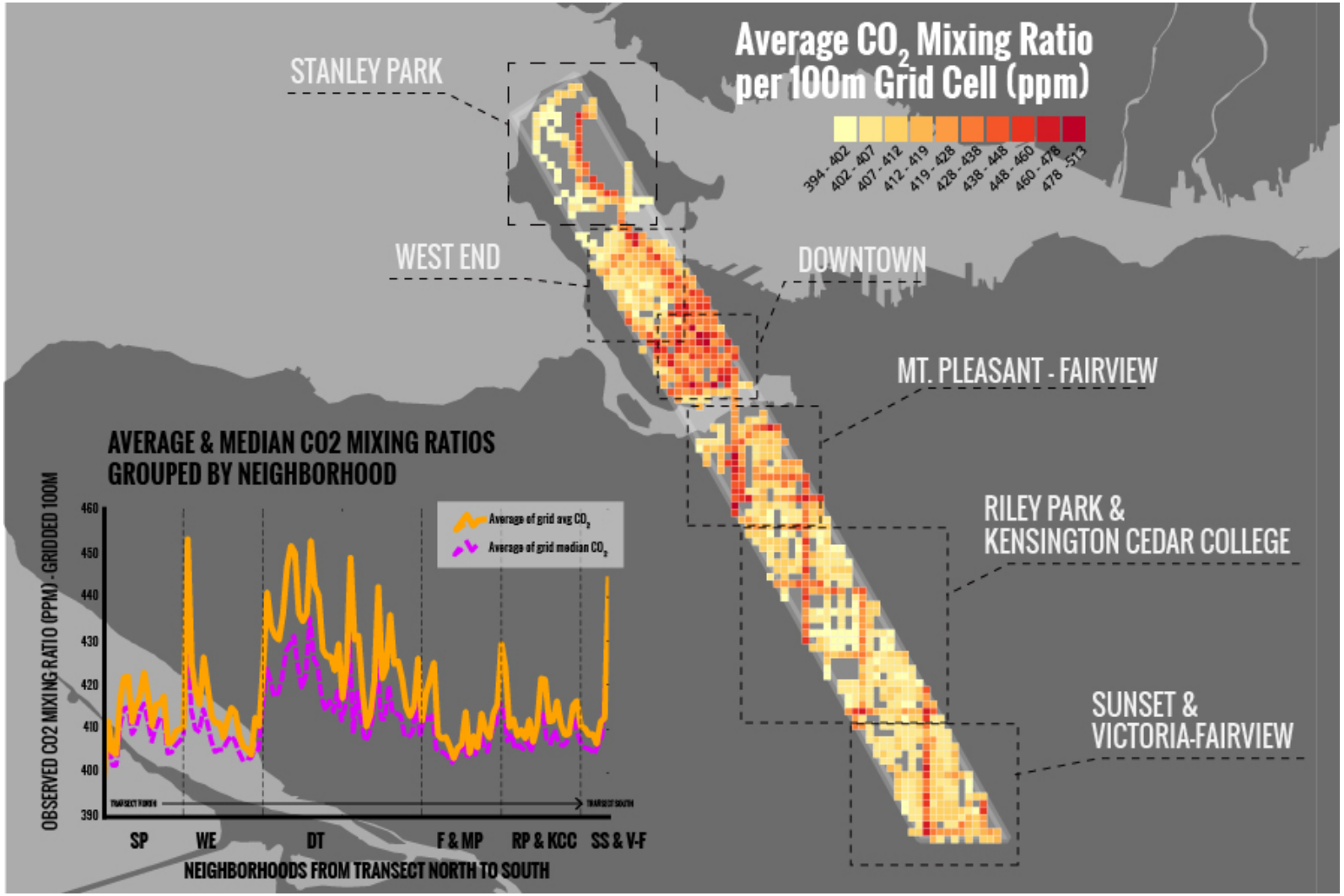
Image: The image shows 5 planned transect routes for the measurement campaign. Goal: to cover (almost) all navigable roads (and some trails) along the transect in 3.5 hours.

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

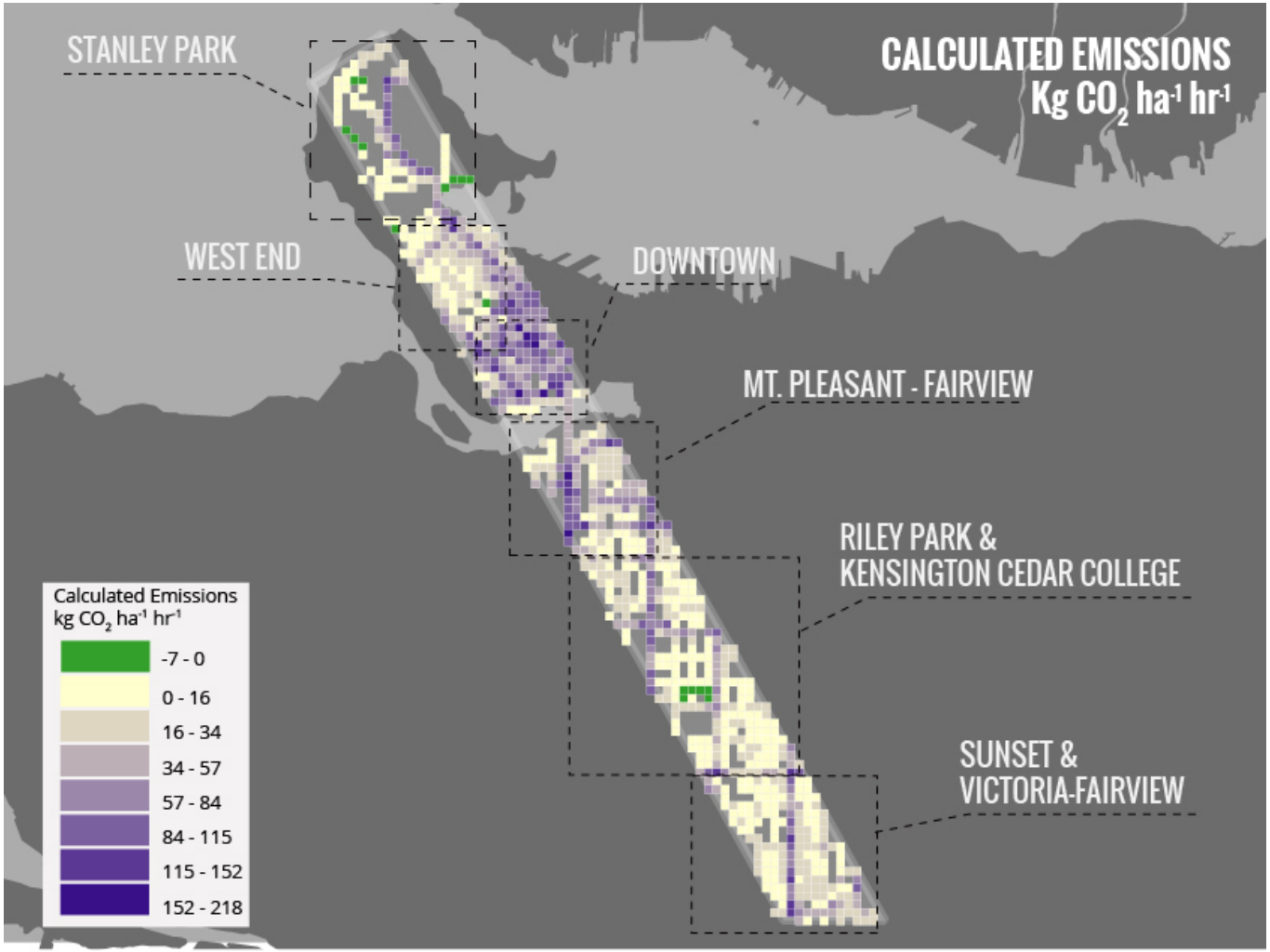


Image: Calculated emissions map generated using the aerodynamic resistance approach using CO_2 concentration measurements.

Mapping Emissions - Methods: Emissions Inventory

Traffic Emissions Inventory

process: traffic emissions inventory

OpenStreetMap

Traffic Counts CSV

street name pattern matching

↓

"interpolating" missing street traffic counts

↓

calculate distance travelled and fuel burned per grid cell

↓

multiply fuel burned by emissions factor per grid cell

↓

result: traffic emissions inventory

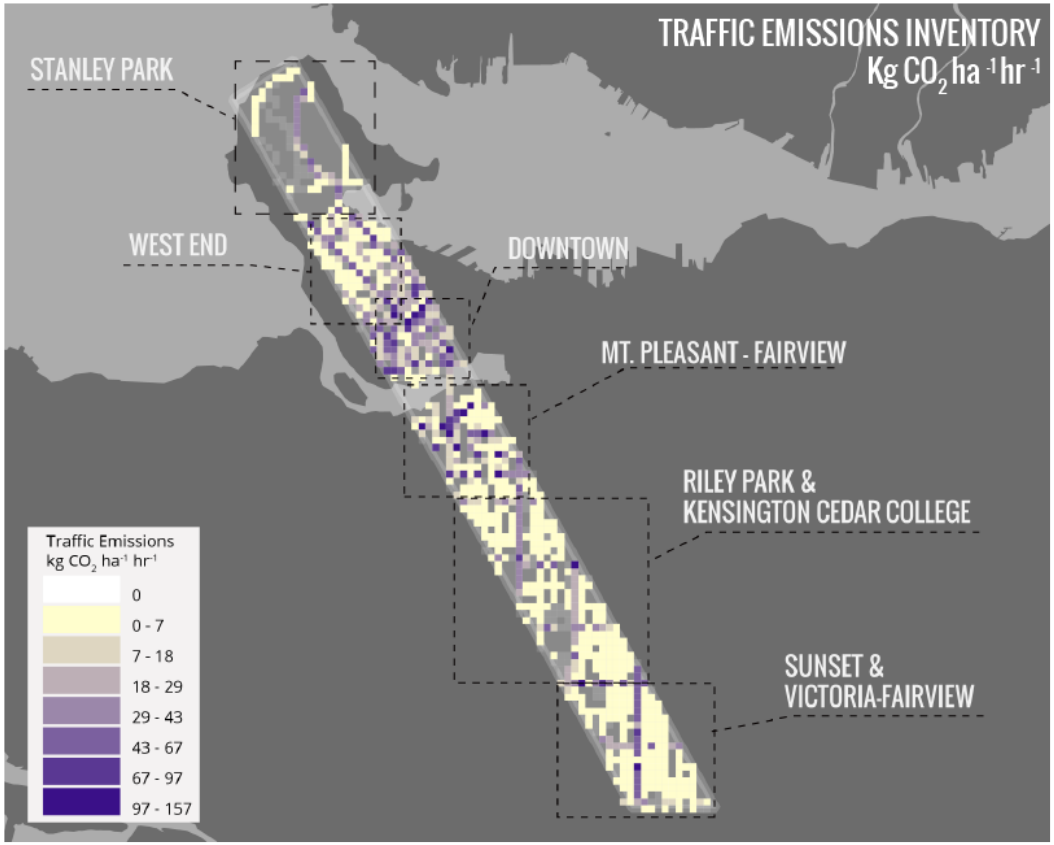
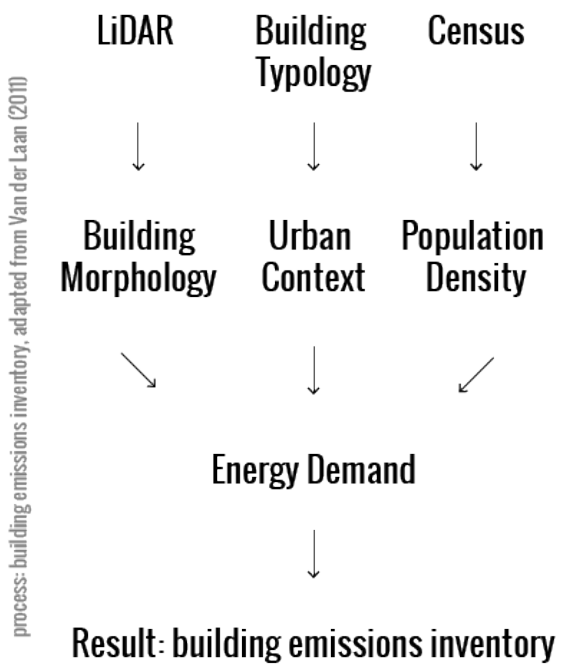


Image: The traffic emissions inventory derived from Vancouver's traffic count data and calculated per grid cell using fuel consumption and emissions factors.

Building Emissions Inventory



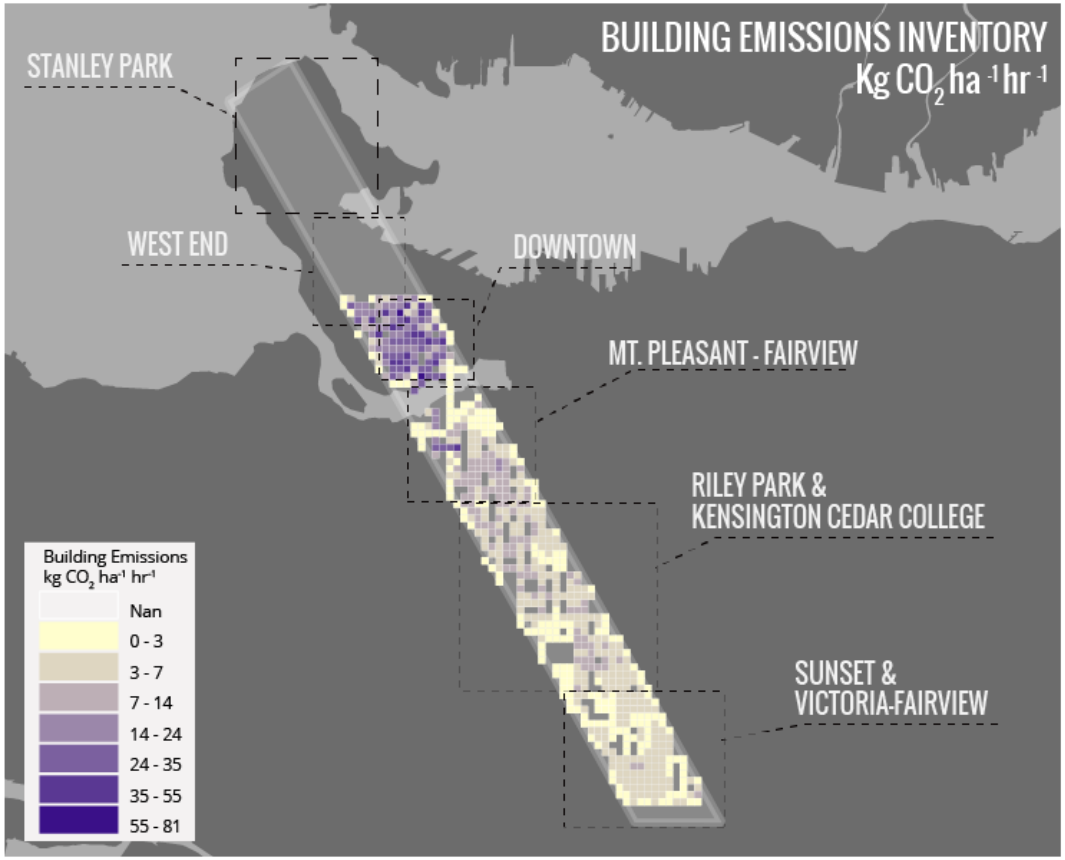
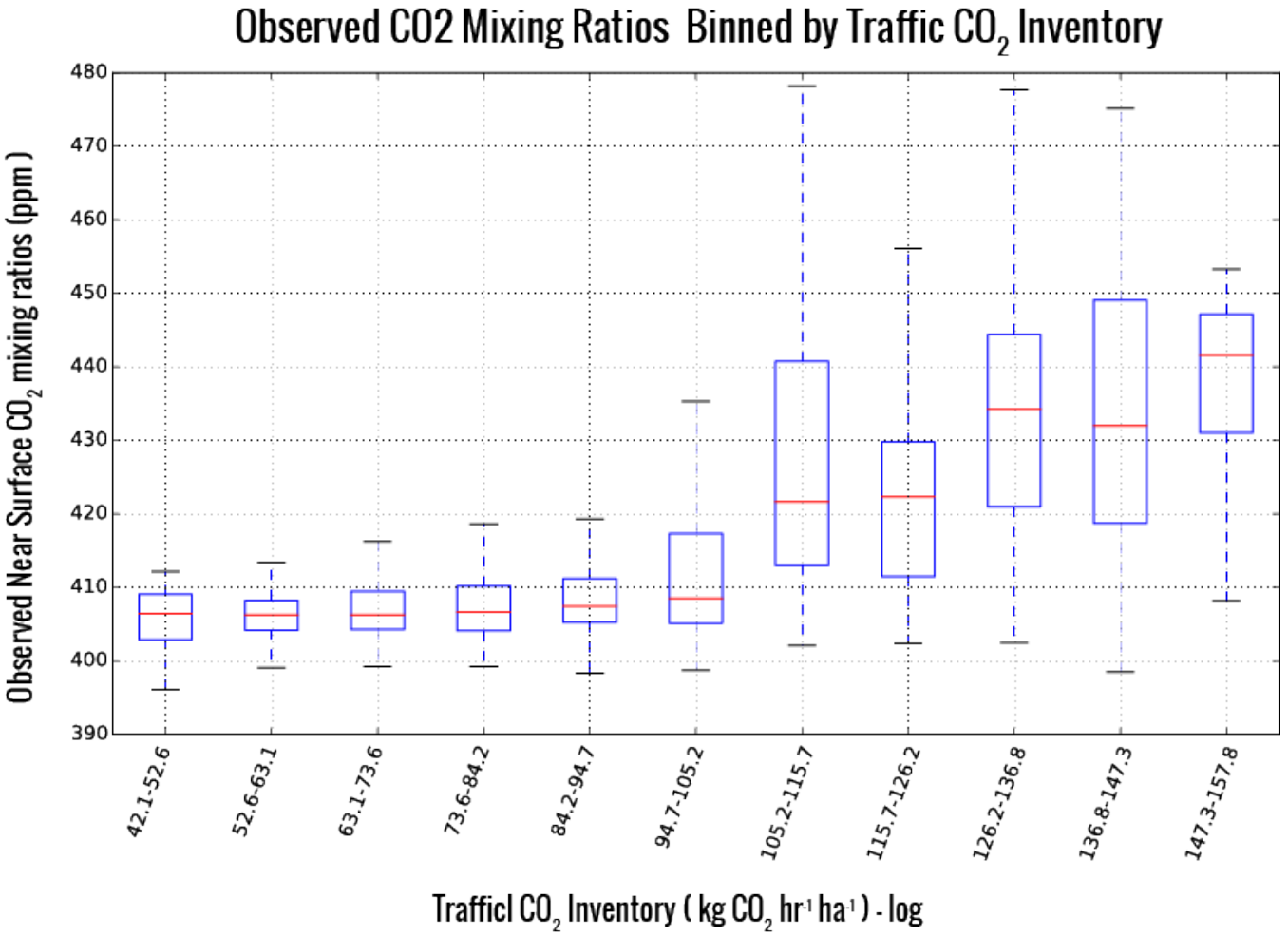
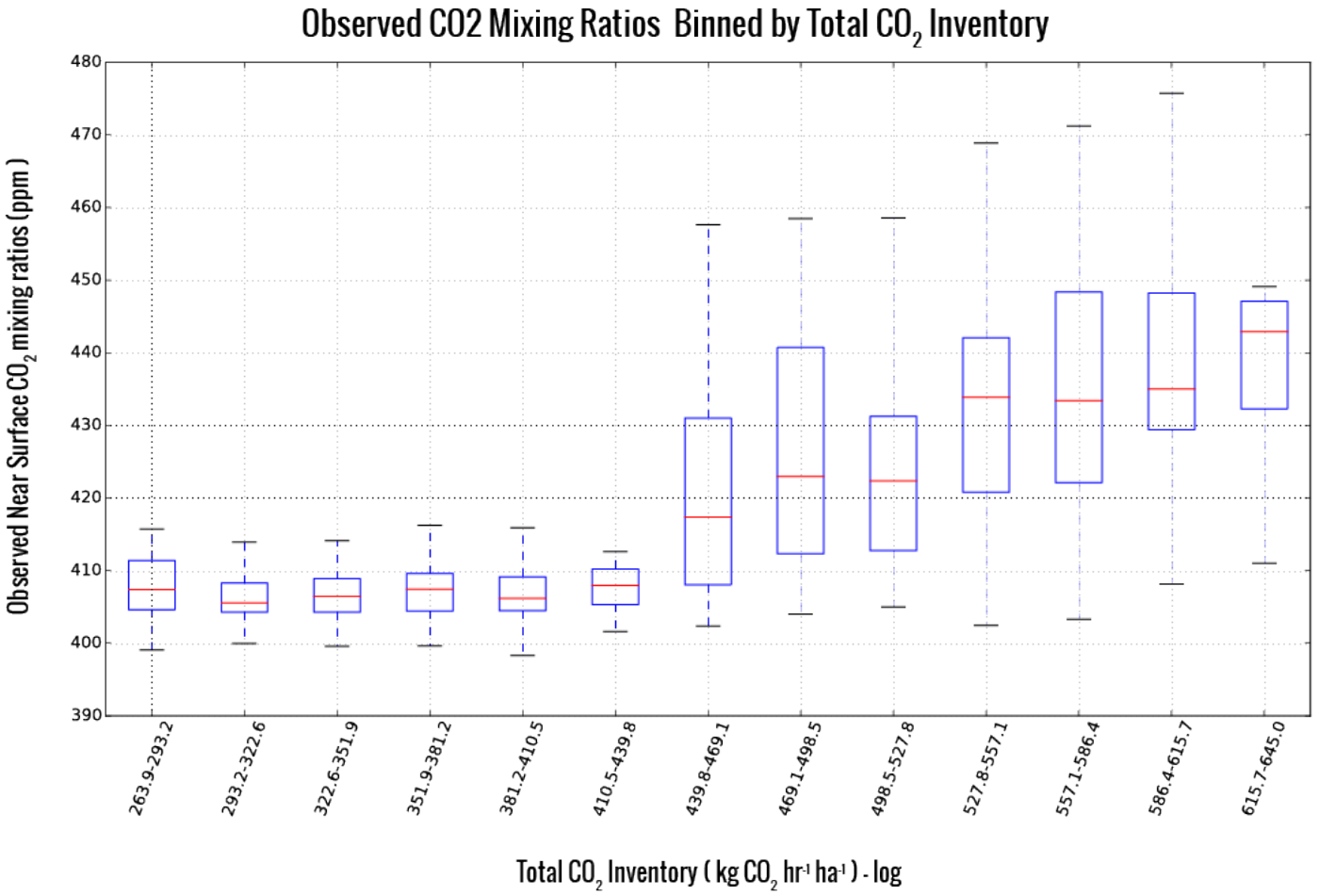


Image: Building emissions inventory generated by combining factors of building morphology, urban context, and population density derived from LiDAR, building topology, and census data.

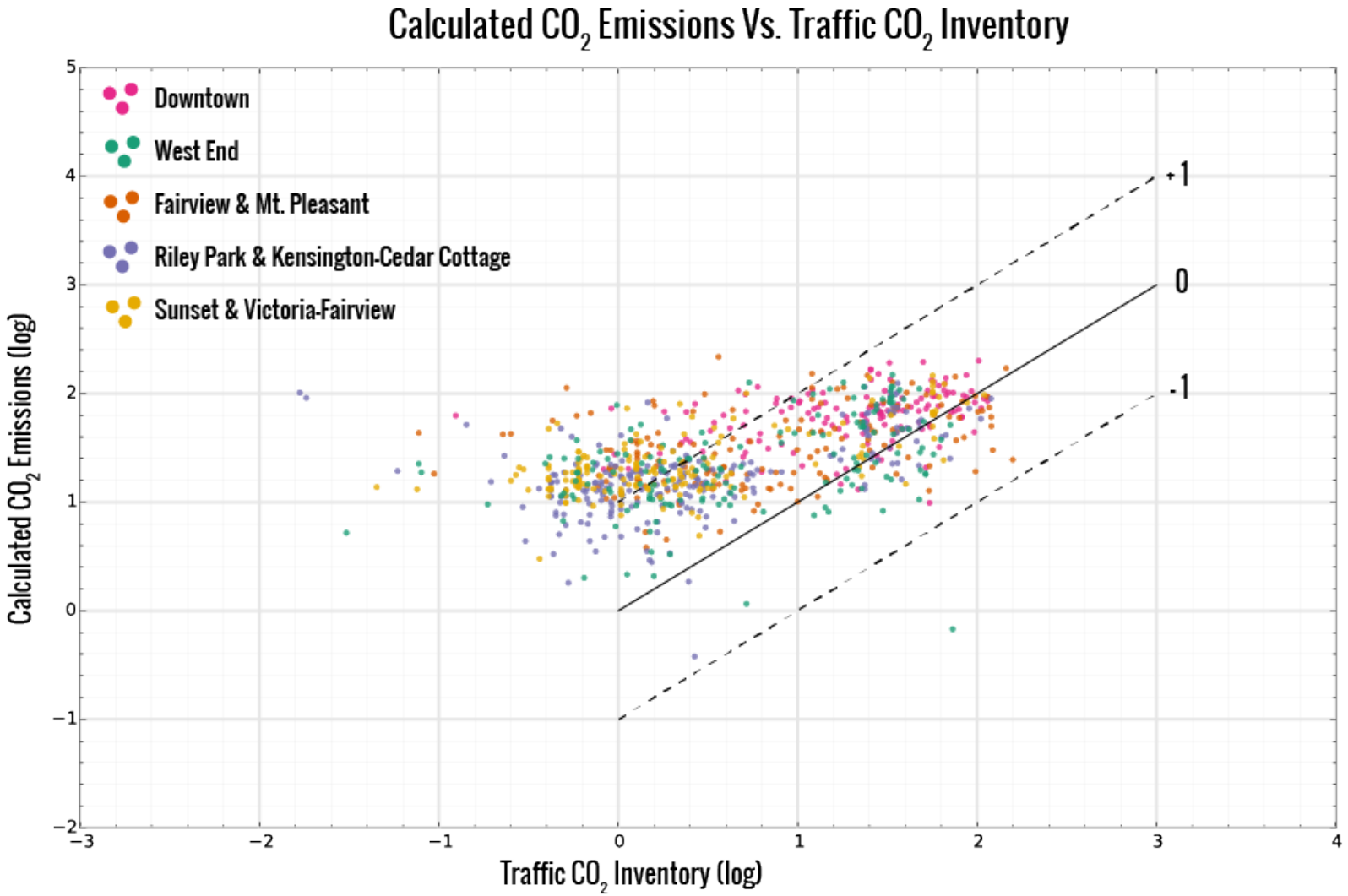
CO_2 Mixing Ratios Vs. Traffic Emissions Inventory



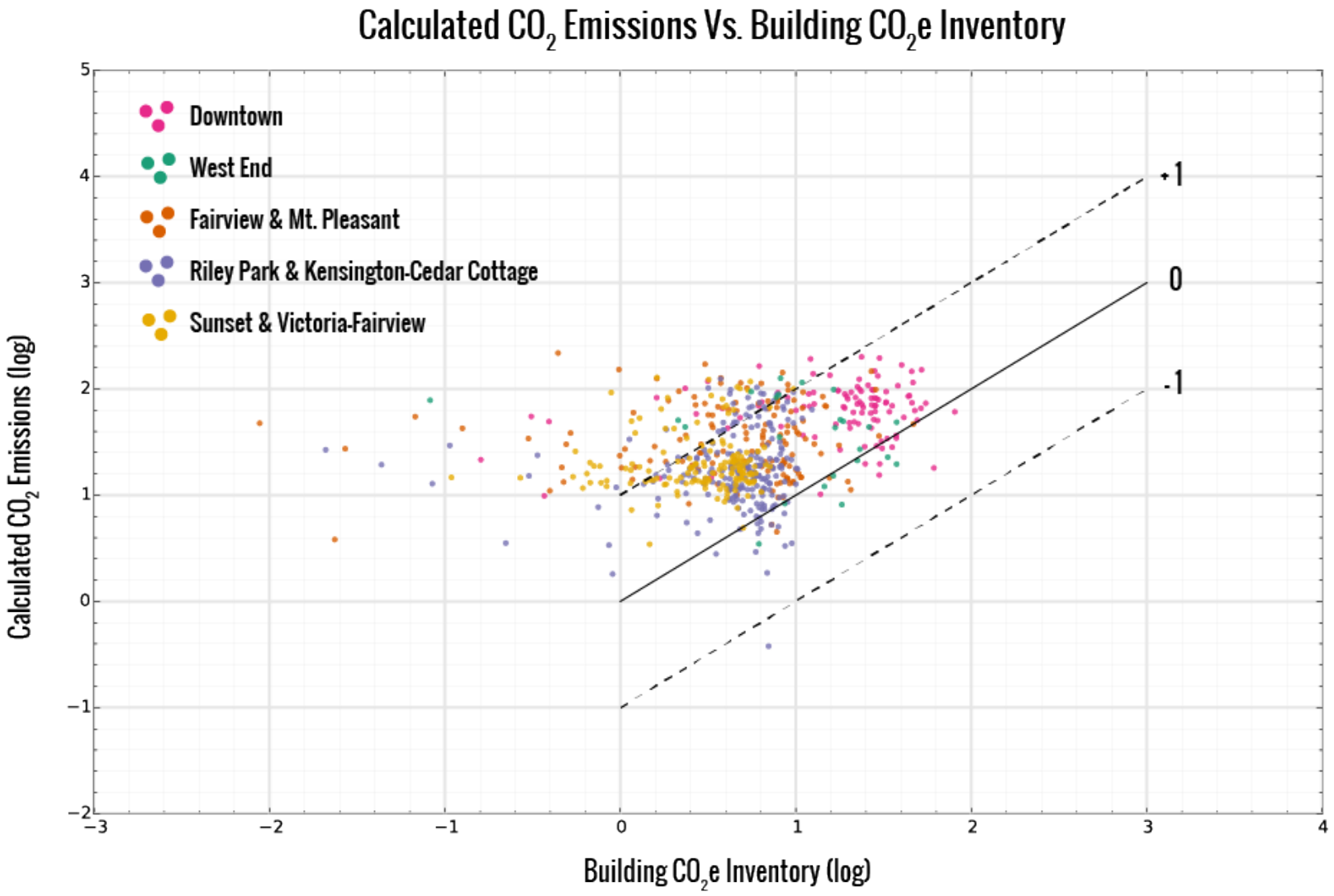
CO_2 Mixing Ratios Vs. Total Emissions Inventory



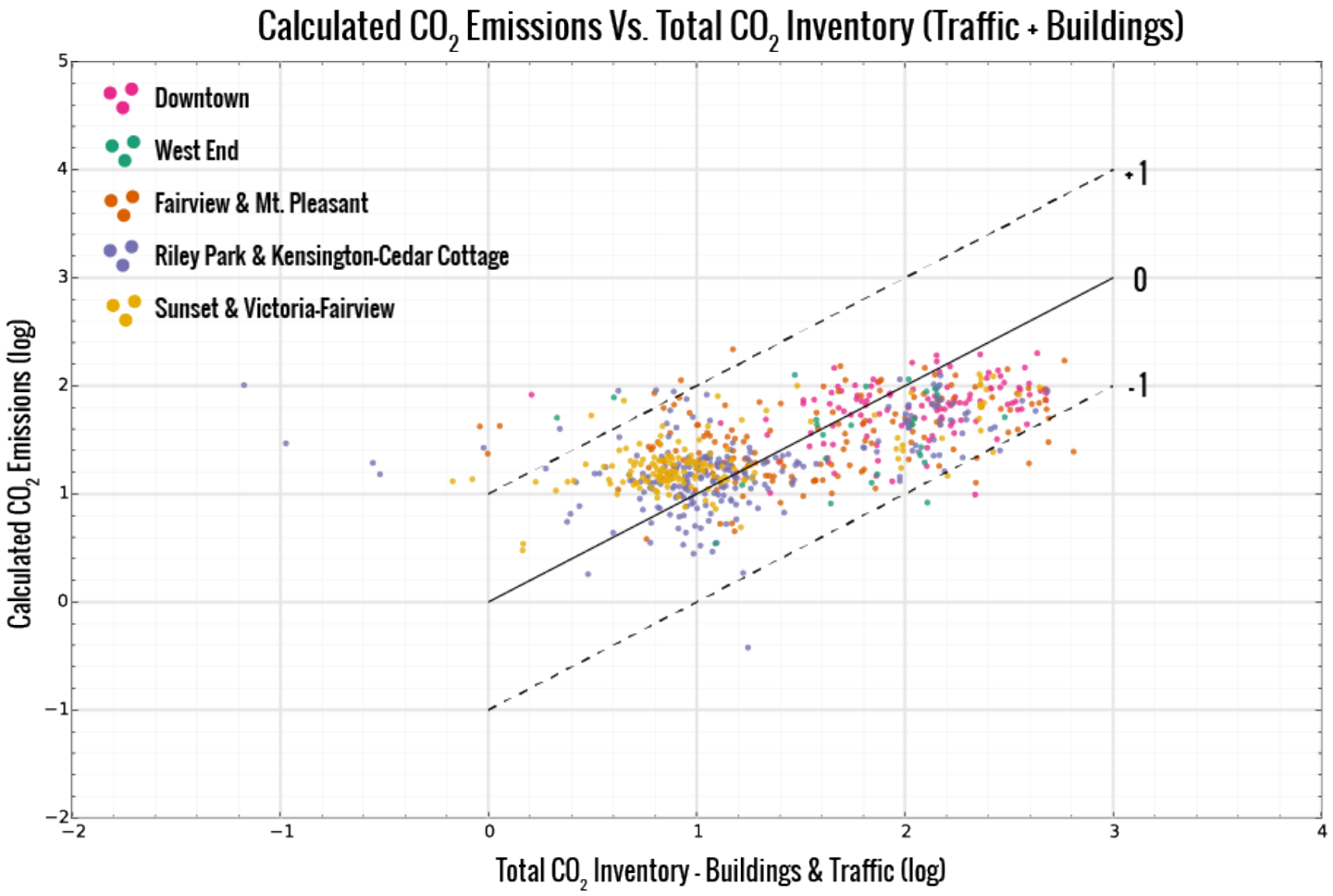
Calculated CO_2 emissions vs. Traffic Emissions Inventory



Calculated CO_2 emissions vs. Building Emissions Inventory



Calculated CO_2 emissions vs. Total Emissions Inventory



Conclusions & Future Directions

Conclusions & Future Directions

- A mobile CO_2 sensing system was developed using open source components.

Conclusions & Future Directions

- A mobile CO_2 sensing system was developed using open source components.
- The system was tested in Vancouver and evaluated against traffic and building emissions inventories.

Conclusions & Future Directions

- A mobile CO_2 sensing system was developed using open source components.
- The system was tested in Vancouver and evaluated against traffic and building emissions inventories.
- The study shows the potential for pervasive mobile sensing in GHG and pollutant monitoring in cities.

Conclusions & Future Directions

- A mobile CO_2 sensing system was developed using open source components.
- The system was tested in Vancouver and evaluated against traffic and building emissions inventories.
- The study shows the potential for pervasive mobile sensing in GHG and pollutant monitoring in cities, but relies on specific conditions and assumptions.

Conclusions & Future Directions

- A mobile CO_2 sensing system was developed using open source components.
- The system was tested in Vancouver and evaluated against traffic and building emissions inventories.
- The study shows the potential for pervasive mobile sensing in GHG and pollutant monitoring in cities, but relies on specific conditions and assumptions.
- Currently exploring visualization & feedback opportunities for planning and open science.

Conclusions & Future Directions

- A mobile CO_2 sensing system was developed using open source components.
- The system was tested in Vancouver and evaluated against traffic and building emissions inventories.
- The study shows the potential for pervasive mobile sensing in GHG and pollutant monitoring in cities, but relies on specific conditions and assumptions.
- Currently exploring visualization & feedback opportunities for planning and open science.
- Collaboration potential with local mobility providers for long term & spatially extensive/ intensive monitoring

Acknowledgements & Funding

- NSERC Discovery Grant
- NSERC CREATE - Terrestrial Ecosystems Research and World Wide Education & Broadcast Program (TerreWEB).
- UBC Geography Department, Ron Kellett, & Les Lavkulich
- Benedikt Groß, 47Nord GmBH, & Moovel Labs
- Measurement Campaign Drivers: Alex McMahon, Andreas Christen, Mark Richardson, & Thea Rodgers.
- ICUC & IAUC
- Data: OpenStreetMap.org, Vancouver Open Data, EPiCC Project, UBC Micrometeorology
- Tools: Python, R, QGIS, GDAL/OGR, Processing

References

- Van der Laan, "Scaling Urban Energy Use and Greenhouse Gas Emissions through LiDAR", MSc Thesis, 2011.
- Rosenzweig, C., Solecki, W., and Hammer, S. A. (2010). Cities lead the way inclimate-change action. Nature, pages 1–3.

Special thanks to
Andreas, Zoran, and Rick.

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

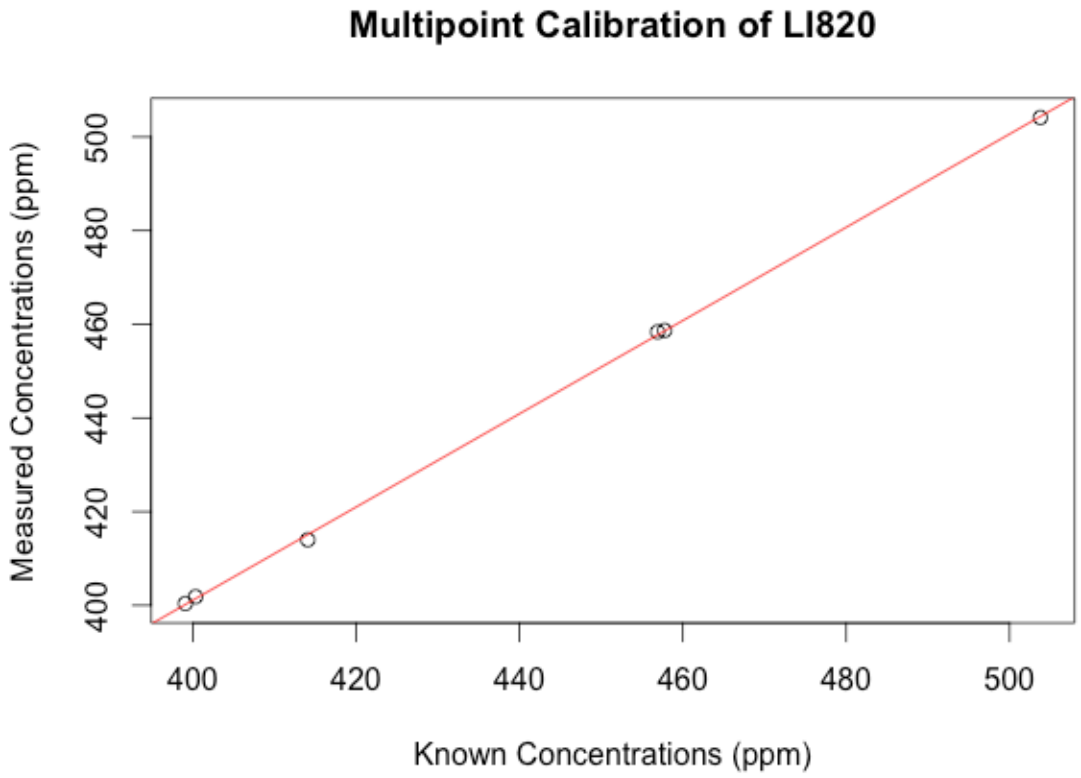


Image: Multipoint Calibration of Sensor System showing observed values versus known concentrations.

Methods: Sensor Drift

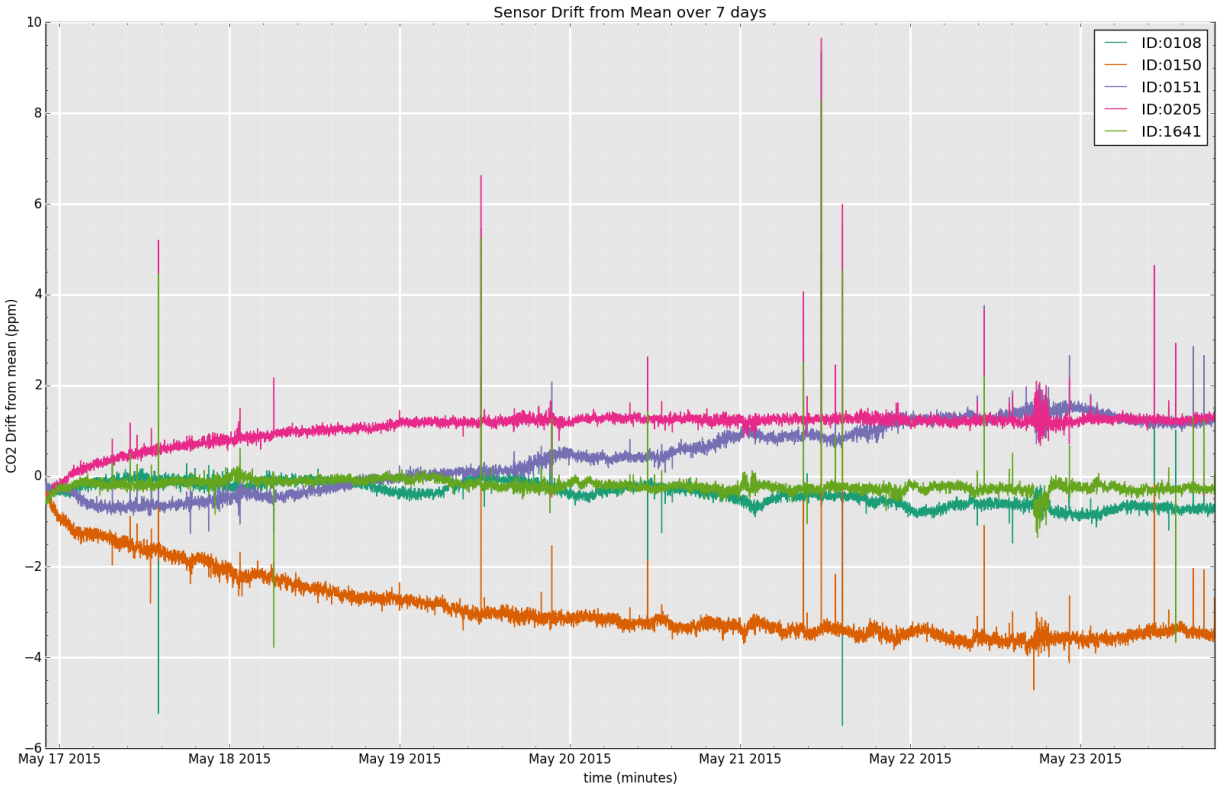


Image: Testing for sensor drift of the five mobile sensors over a seven-day measurement period. Each line corresponds to one of the five mobile CO_2 sensors.

Study Area: Local Climate Zones

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.