Introducing **PIMS**: The **P**ollution **I**n-Cabin **M**easurement **S**ystem

Douglas Booker, NAQTS

9th UCR PEMS Conference – March 15th 2019

NAQTS

Who We Are and What We Do

National Air Quality Testing Services (NAQTS) is a social business that is passionate about improving the quality of life.

We seek to **improve awareness of indoor air quality** through widespread public and commercial monitoring using our holistic, high-quality, air pollution monitoring technology.

Based in UK (Lancaster University Environment Centre and Cardiff), and in Ann Arbor, Michigan, USA

INDOOR AIR QUALITY & ENERGY EFFICIENCY

Developing models for assisting building design and modification whilst ensuring energy efficiency and good indoor air quality.

CITIZEN SCIENCE - INDOOR:OUTDOOR AIR QUALITY

Air quality toolkit for citizen science measurements. Capturing real-time pollution levels during school drop off/pick up times, as well as levels of student exposure in the classroom

OCCUPATIONAL HEALTH AND SAFETY

Evaluation of exposure to nanomaterials

AIR QUALITY MAPPING

Routine mobile monitoring for measuring time-integrated concentrations at high spatial resolution

BENCHMARKING VEHICLES "COMFORT"

Air Quality, Noise, and Vibration

Data on in-cabin comfort from 100s of vehicles per year

What do we call a measurement device for in-cabin?

PEMS

PAMS

SEMS

456,976 combinations!

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Introducing PIMS

- **PN** - CPC with 20:1 pre-dilution (IPA, d_{50} 15nm)
- **CO, NO_2, NO** – Electrochemical
- **CO, NO_2, VOCs** – Metal Oxide
- **VOCs** – Real-time and thermal desorption tubes for GC-MS Analysis
- **CO_2** – NDIR
- **T, P, RH** – BME280
- **Vibration** – 3D accelerometer and 3D Gyro
- **Noise** – dBA
- **Location** – GPS
- **OBD** – Bluetooth
- **Vibration** – 3D accelerometer and 3D Gyro
- **Web GUI** with **SQL Database**
- **GSM**

The Pollution In-cabin Measurement System (PIMS)

Integrated measurement device for a "holistic" understanding of air quality

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Introducing PIMS

- Installed into a mannequin, “Arnie”, to simulate human exposure, and for easy installation
- Outside unit can either be mounted on a suction cup, or inside with a sample line out
- Simultaneous inside and outside measurements to understand how much ambient air pollution is coming into the vehicle




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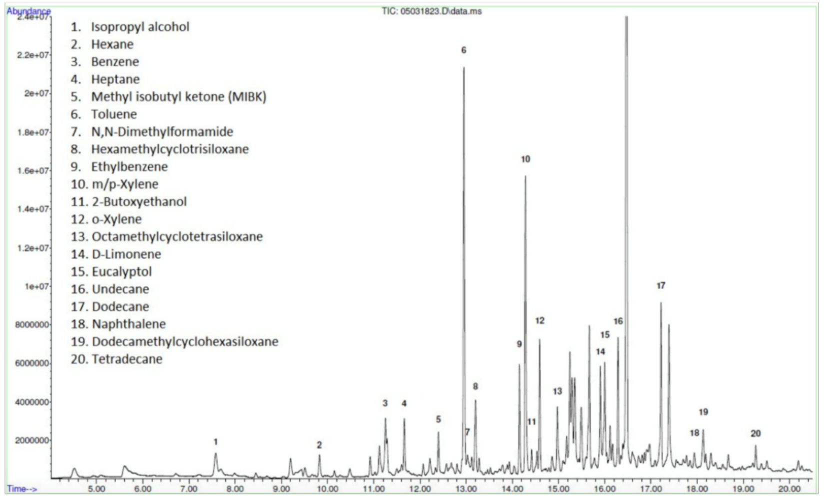
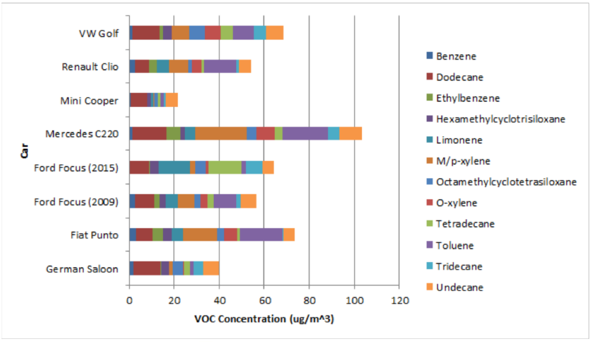
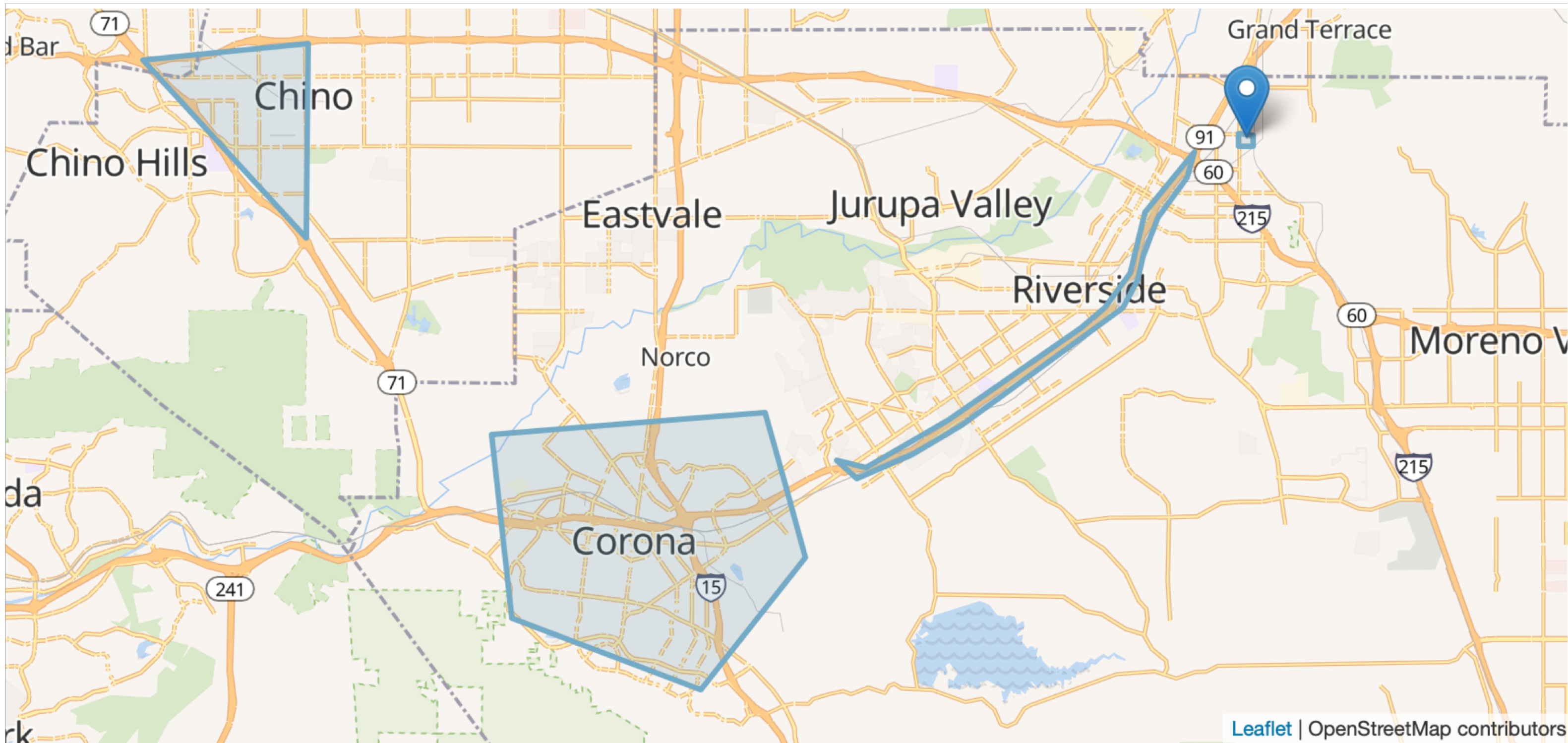
Geofencing

- Geofenced triggered thermal desorption tubes for integrated full speciation VOCs
- Automatic reporting with averaged concentrations in geofenced areas
- Understand air quality and exposure in non-attainment areas

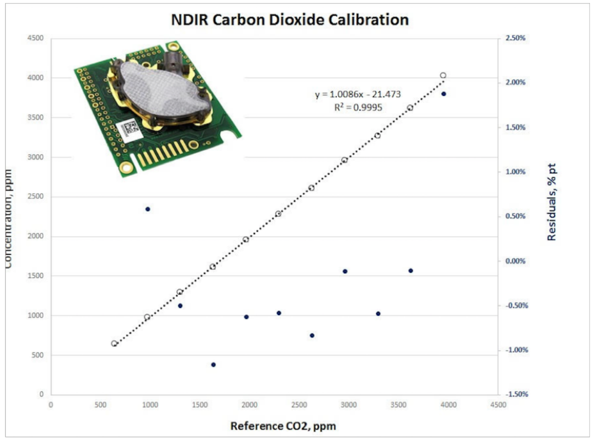


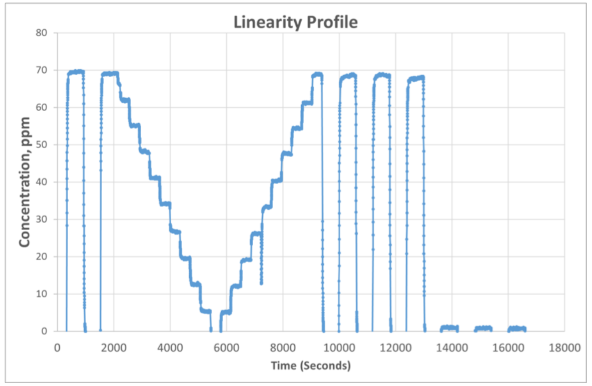


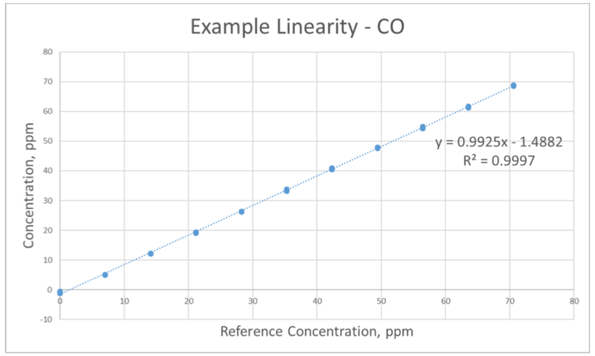


Metrology

- PN: Regulatory grade PN: ISO 27891
- CO_2: Auto Baseline algorithm used for long-term sampling
- Calibration - easy, low cost calibration using typical automotive gas bottles, e.g. 16% CO_2 Quad Blend (CO, HC, NO), and NO_2 through the integrated diluter







CERTIFICATE OF CALIBRATION

ISSUED BY Ricardo Energy & Environment
a trading name of Ricardo-AEA Ltd.
DATE OF ISSUE CERTIFICATE NUMBER DRAFT

0401

Ricardo Energy & Environment
Particle Measurement Centre
Unit 2 Ludbridge Mill
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Page 1 of 5 pages
Approved Signatory
Name Mr. Jason Southgate
Dr. Ian Marshall
Signature

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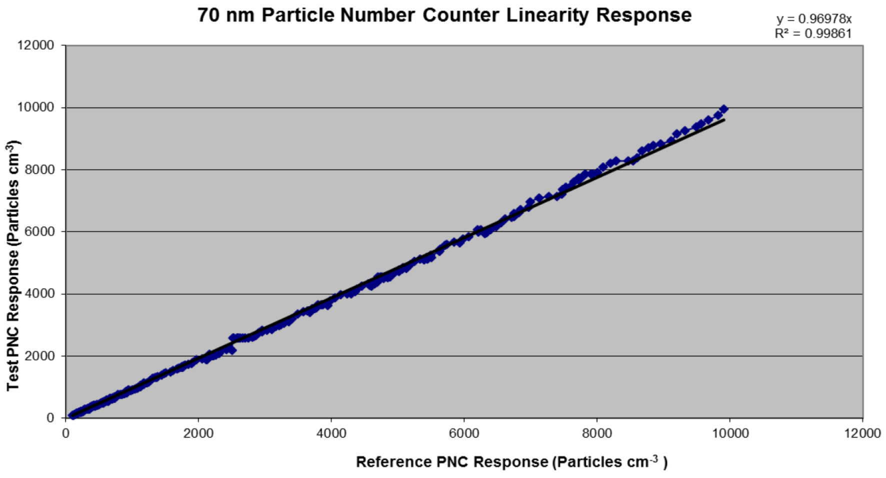
EXAMPLE ONLY

Particle counting efficiency against d_{50}=10 nm transfer standard

Diameter (nm)	Efficiency	$\|x_{min.}(a_1-1)+a_0\|$ ≤5% max	Standard Error of Estimate (SEE) ≤10% max	Correlation coefficient
200	107.0%	-	-	0.999
100	104.0%	-	-	0.999
70	97.0%	0.67%	0.90%	0.999
55	104.0%	-	-	0.997
30	98.9%	-	-	0.998
23	104.0%	-	-	0.998



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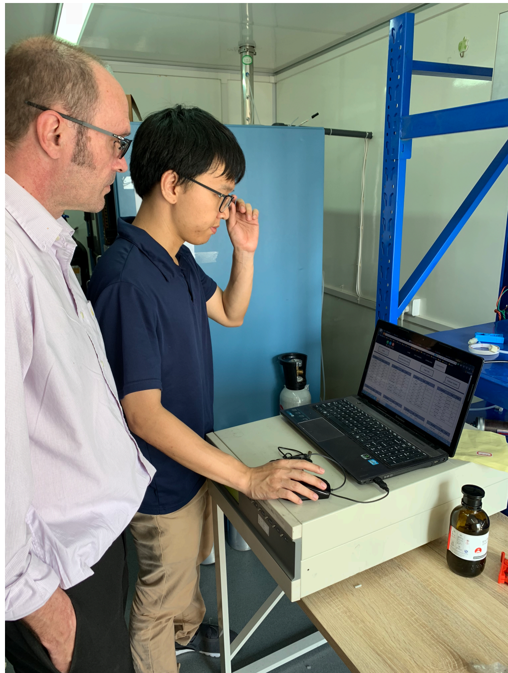
Metrology - Colocation

- Extensive colocation activities at Chinese Academy of Sciences Supersite to improve low-cost sensor accuracy
- More than 3 months colocation work



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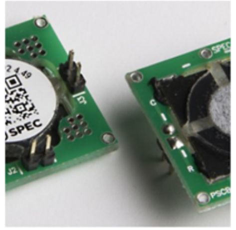
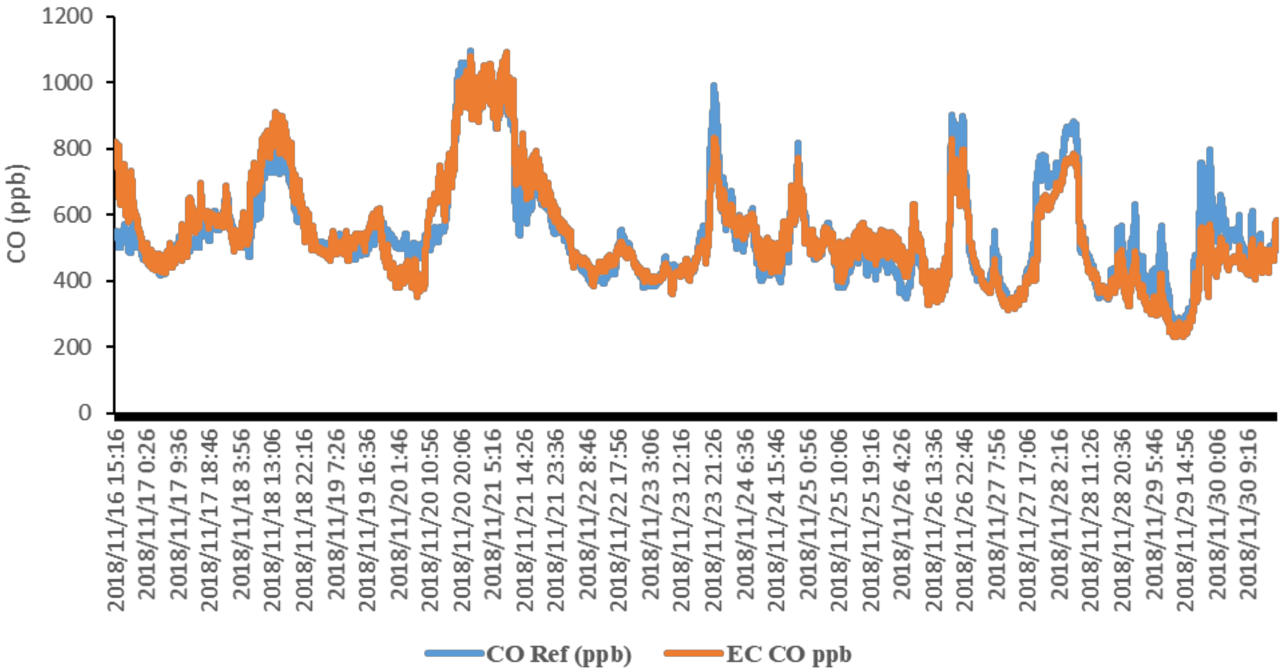
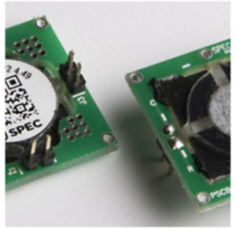
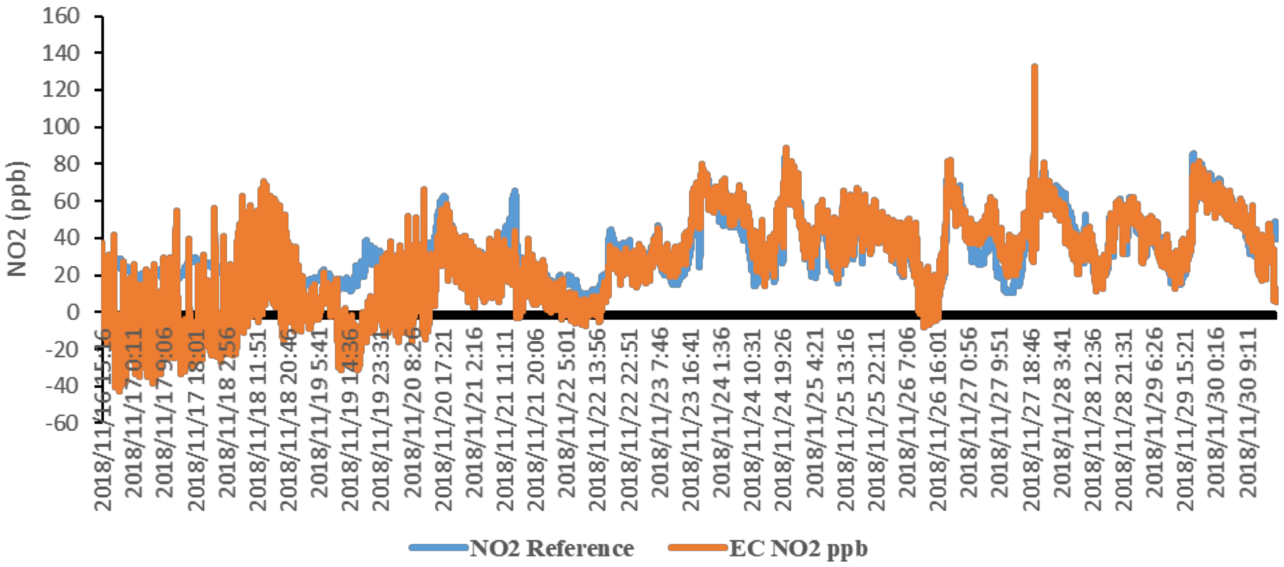
Metrology - Colocation

- CO & NO_2
- Low-cost sensors a challenge and a great opportunity
- **Low-cost sensor ≠ low cost device!**









Innovate UK
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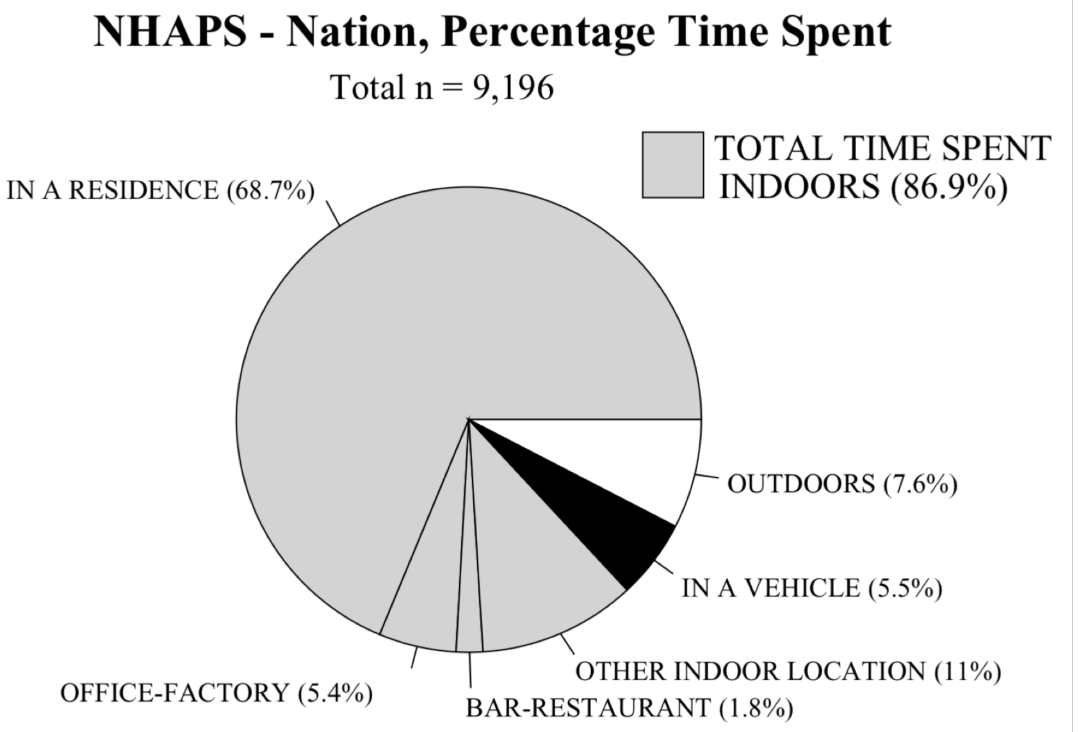
Vehicle Interior Air Quality (VIAQ)

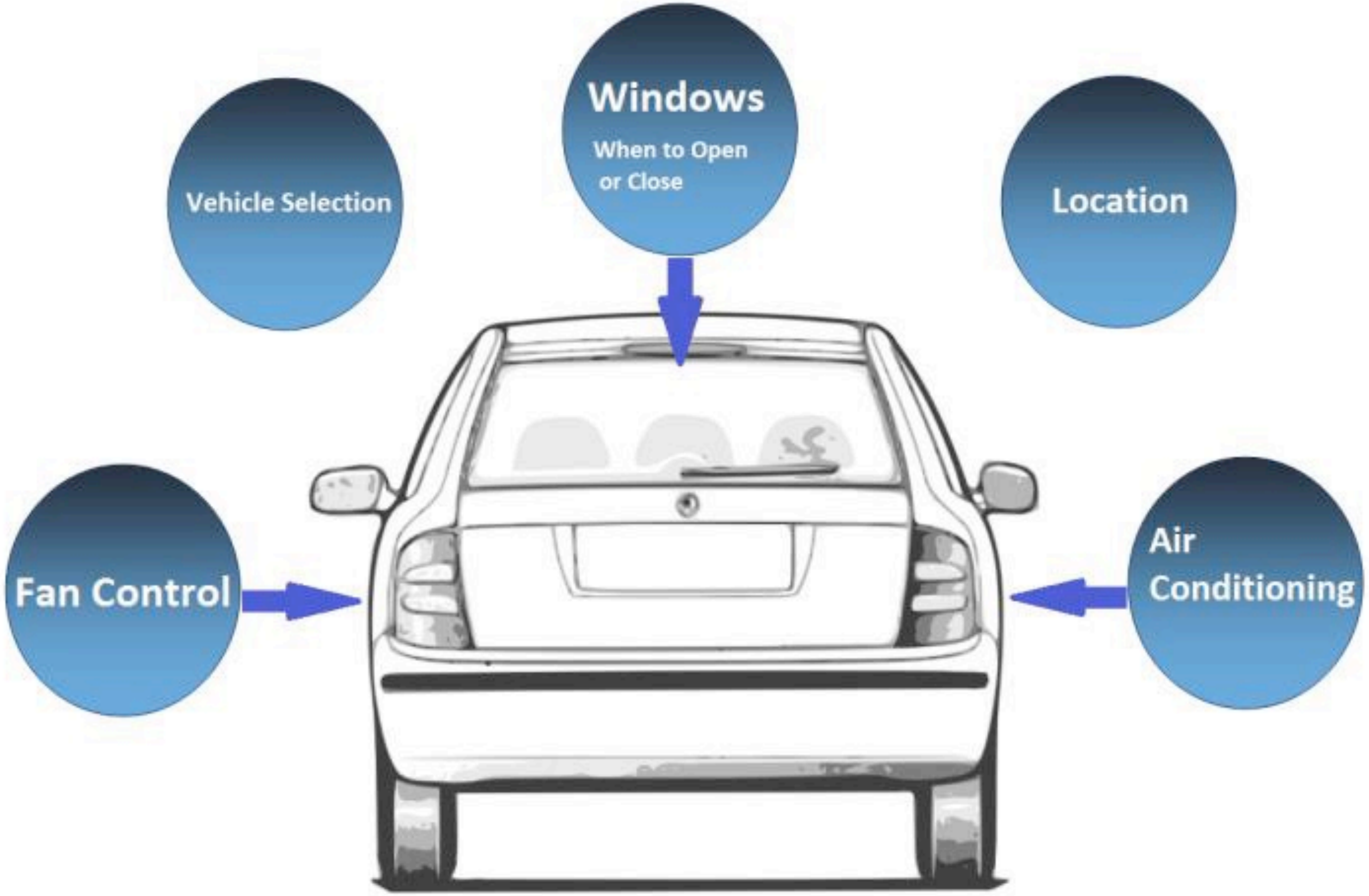
- 101 minutes per day in vehicles (Dong et al. 2004)
- Immediate proximity to significant pollutant sources (other vehicles), plus in urban areas, high outdoor concentrations



Klepeis, N. E. et al. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *J. Expo. Anal.* Environ. Epidemiol. 11, 231–252 (2001).

What causes good/bad VIAQ?

- What are the effects on VIAQ of:
  - Fan Setting
  - Vehicle selection
  - Window open/closed
  - Location
  - Air conditioning

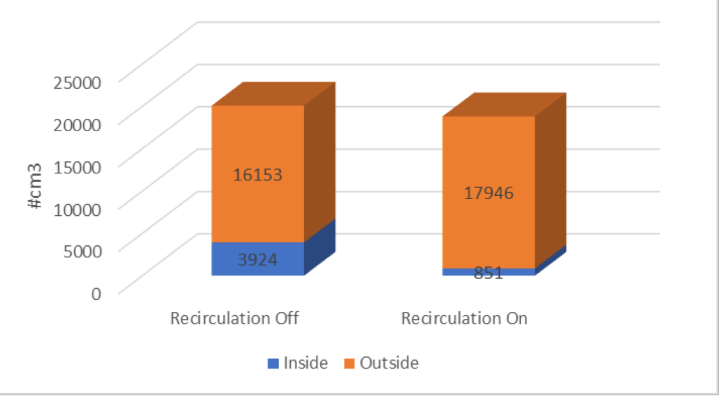


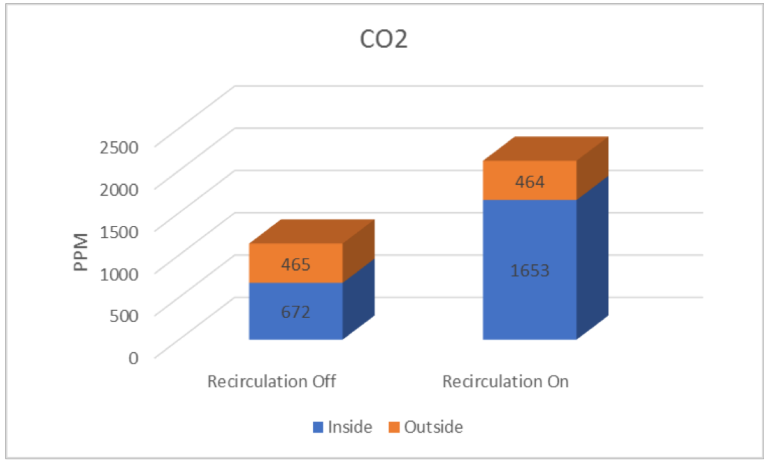
Dong, L.; Block, G.; Mandel, S. Activities contributing to total energy expenditure in the Unites States: Results from the NHAPS study. Int. J. Behavioral Nutrition Phys. Activity 1, 4 (2004)
Müller, D; Klingelhöfer, D; Uibel , s; Groneberg, D.A. Car indoor air pollution - analysis of potential sources. *Journal of Occupational Medicine and Toxicology* 6, no. 33 (2011): 1-7.

Effect of Occupant Behaviour

- **Ingress Ratio** – How much outside air pollution is getting into the cabin?
- **Stuffiness Factor** – How well is the vehicle ventilating CO_2?

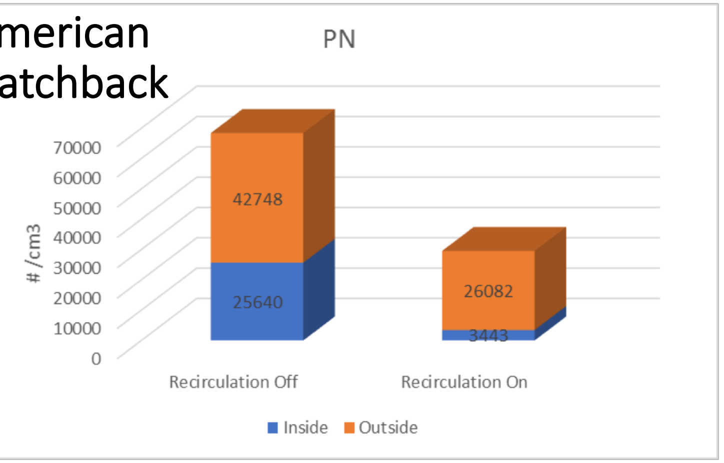
German Sedan

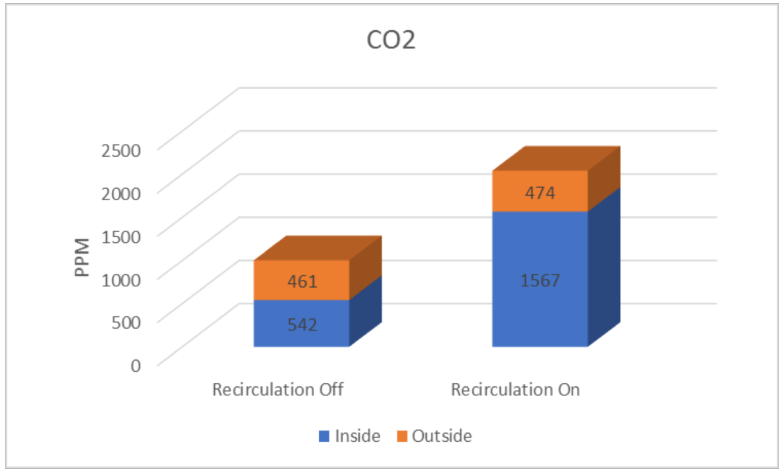




	INGRESS RATIO	STUFFINESS FACTOR
Recirculation Off	24%	1.4
Recirculation On	5%	3.6

American Hatchback



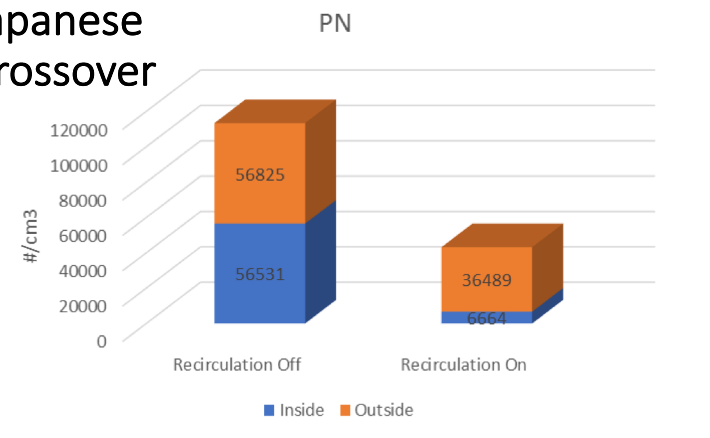


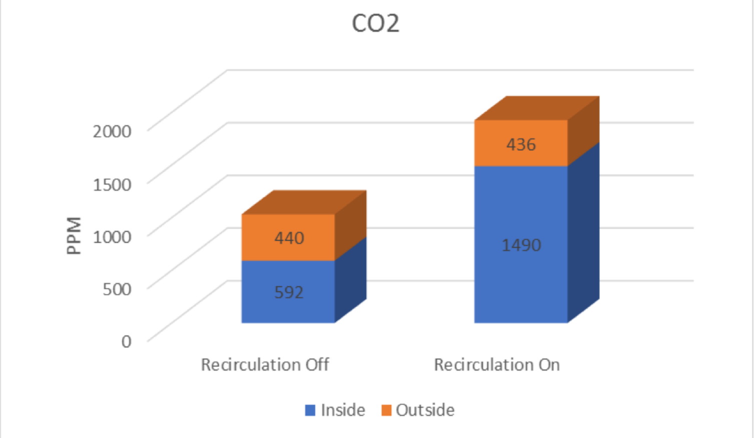
	INGRESS RATIO	STUFFINESS FACTOR
Recirculation Off	60%	1.2
Recirculation On	13%	3.3

Effect of Occupant Behaviour

- **Ingress Ratio** – How much outside air pollution is getting into the cabin?
- **Stuffiness Factor** – How well is the vehicle ventilating CO_2?

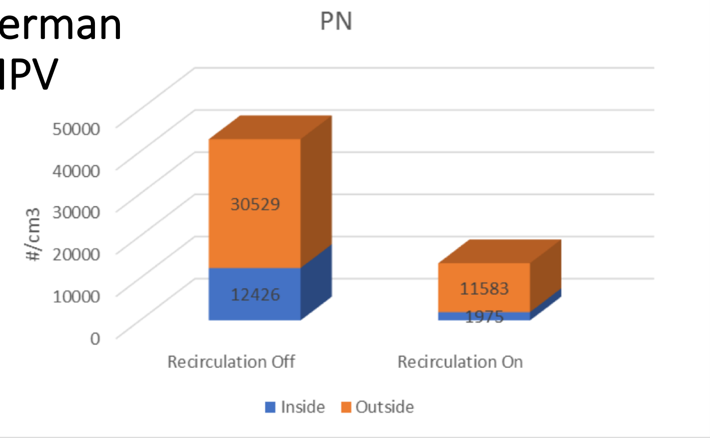
Japanese Crossover

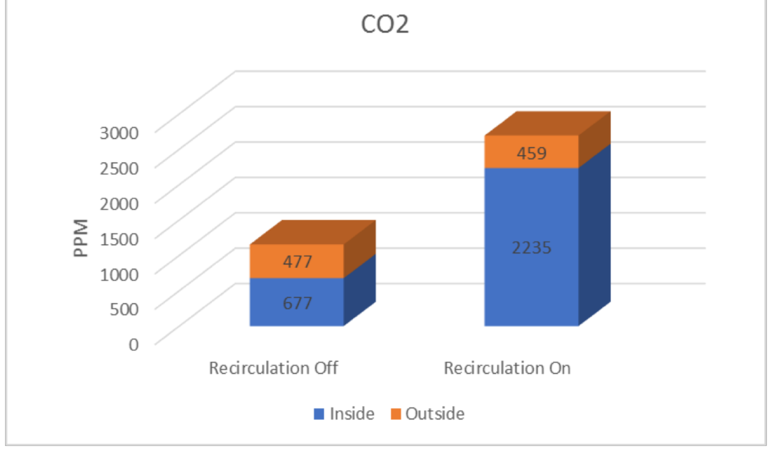




	INGRESS RATIO	STUFFINESS FACTOR
Recirculation Off	99%	1.3
Recirculation On	18%	3.4

German MPV

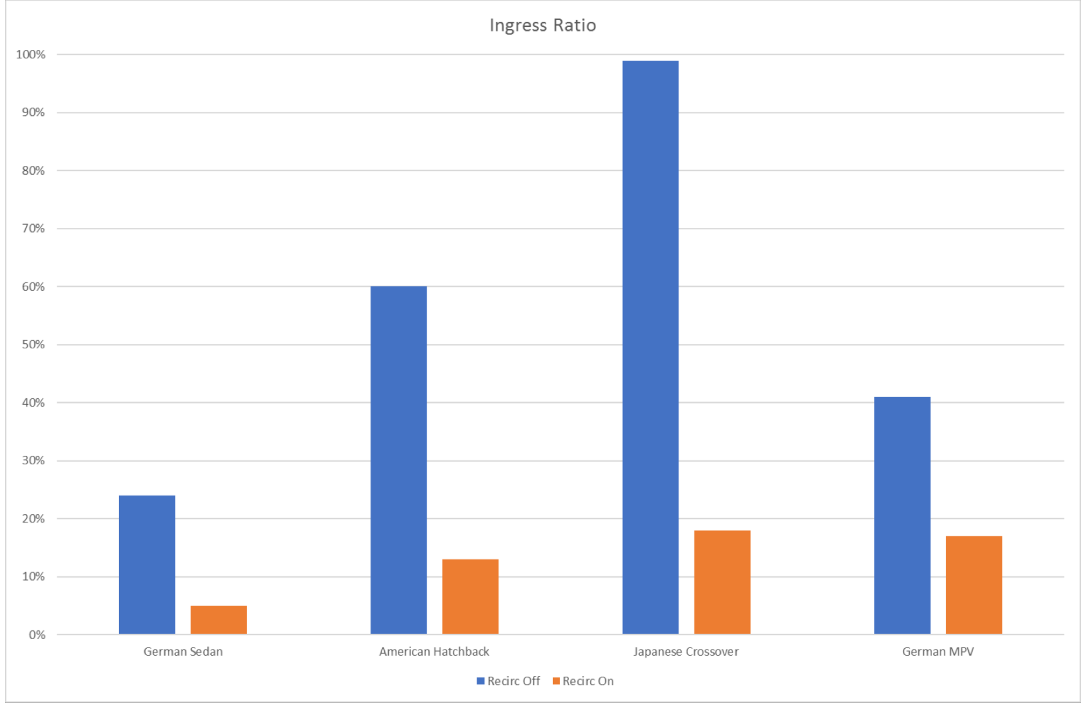


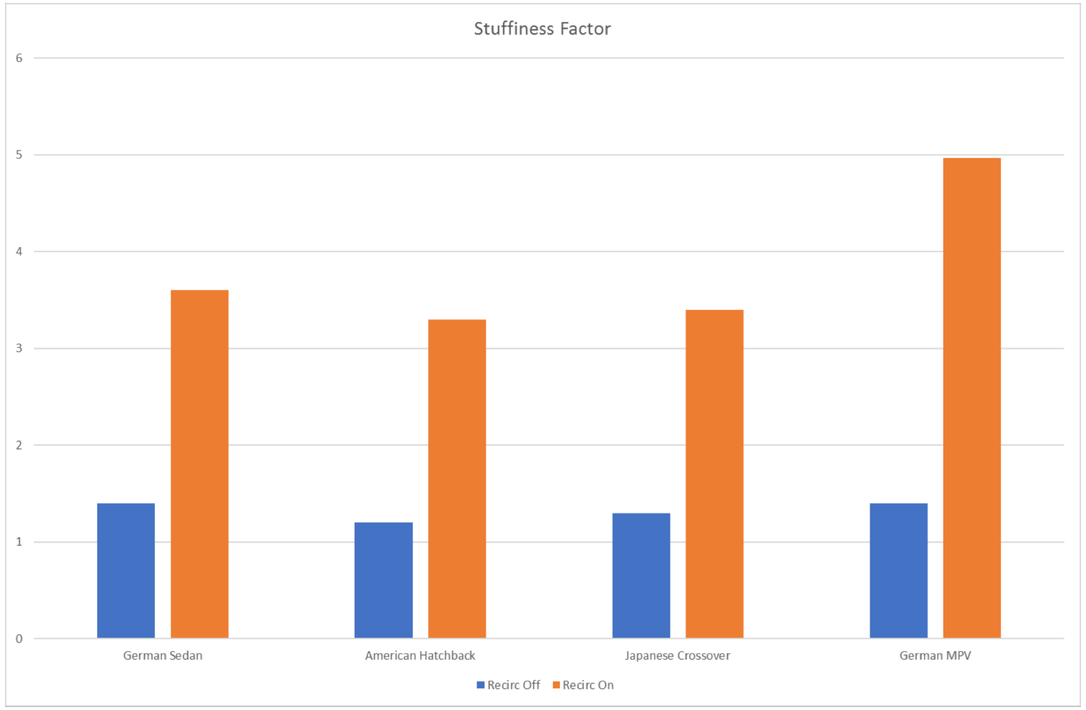


	INGRESS RATIO	STUFFINESS FACTOR
Recirculation Off	41%	1.4
Recirculation On	17%	4.97

Effect of Occupant Behaviour - Summary

- These data show the **heterogeneity of Ingress Ratios**
- 24-99% with recirculation mode off, 5-17% with recirculation mode on
- An **inherent tradeoff** between protecting passengers from ambient ingress, and adequate ventilation
- **Huge influence of passenger habit on dose**. By driver education, and automation of HVAC controls, exposure can be reduced significantly





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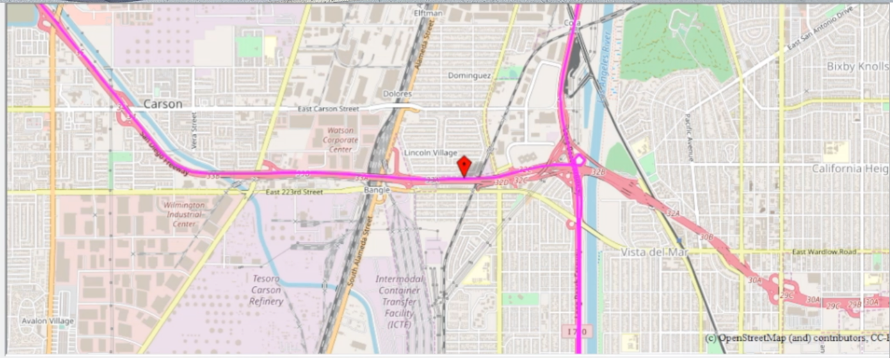
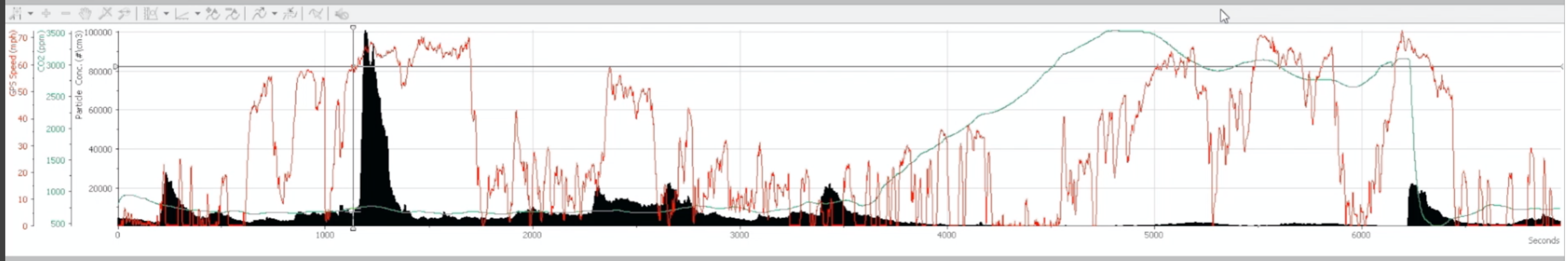
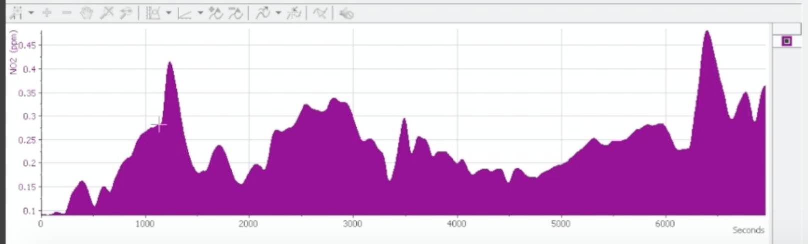
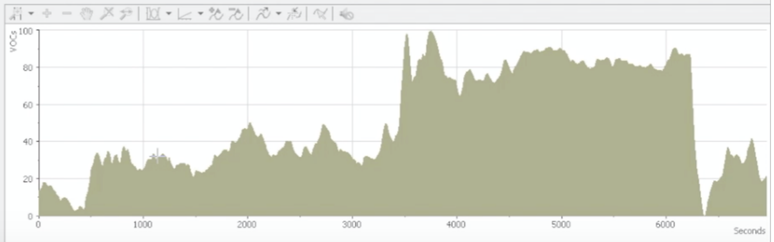
Effect of Occupant Behaviour

- Drive from Long Beach to Downtown LA
- ~ 2 hours in length
- A variety of HVAC settings
  - “Fresh Air” mode
  - Recirculation mode
- A variety of speeds
  - High
  - Low
  - Stop/start
- A variety of locations
  - Urban
  - Highway



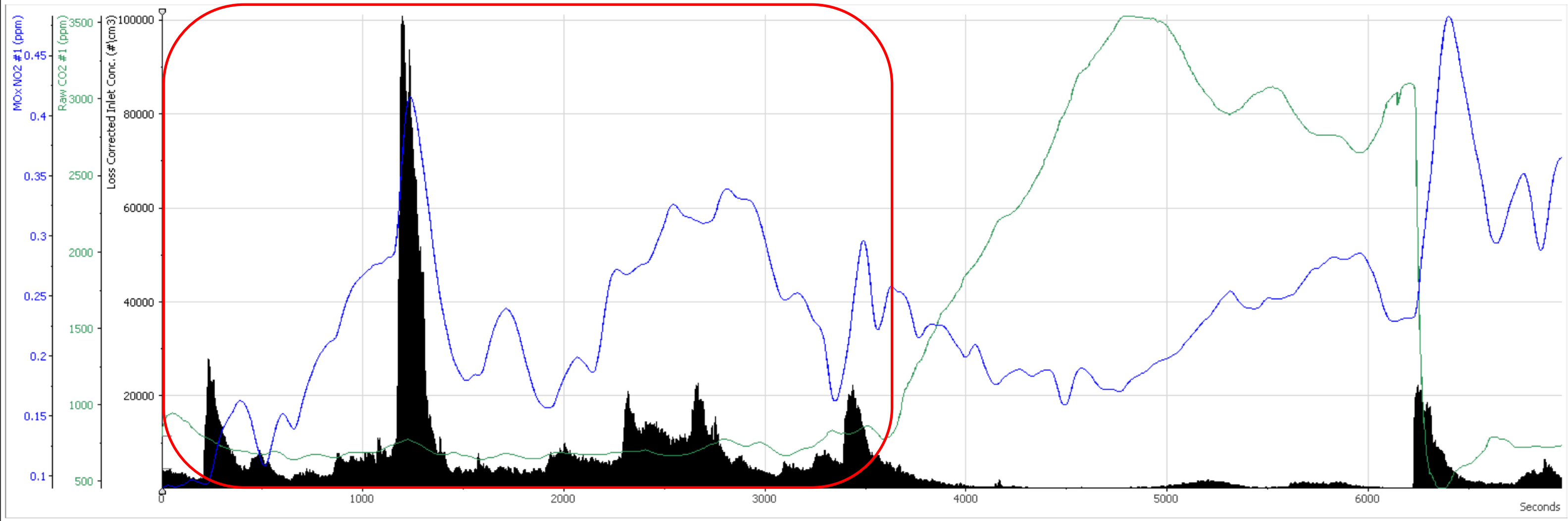


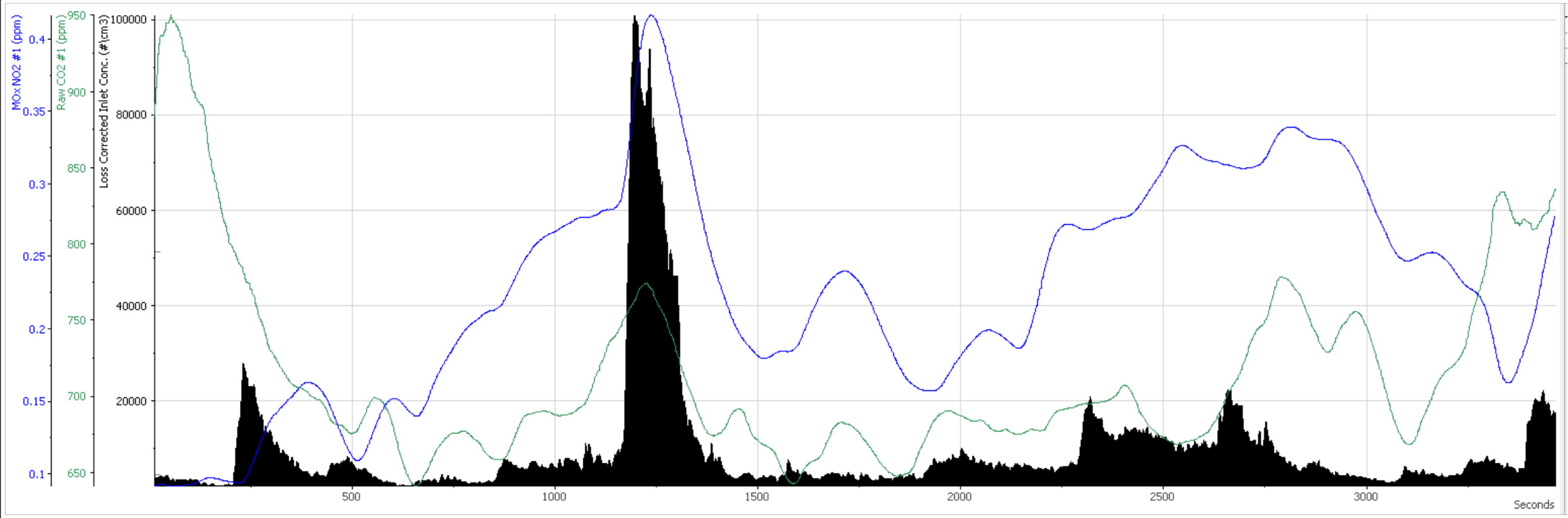




Effect of Occupant Behaviour – "Fresh Air" Mode

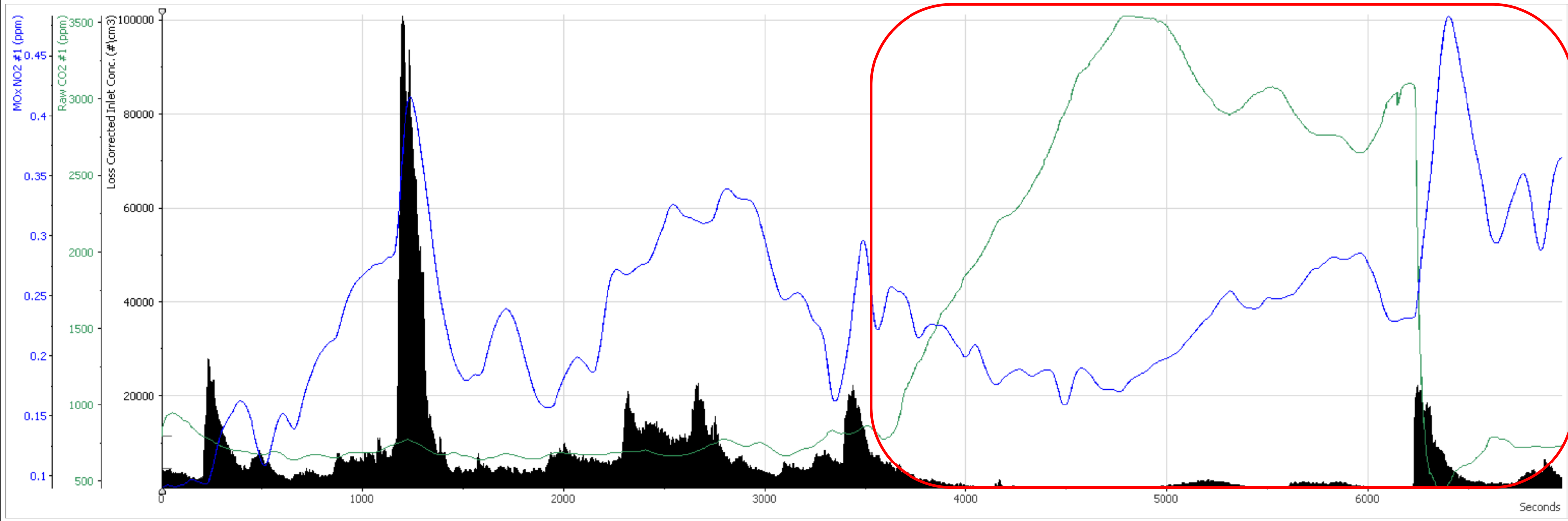
- PN peaks at 100,900 #/cm3
- NO_2 peaks associated with following dirty diesels!
- Vehicle is well ventilated, with CO_2 concentrations <1000ppm
- VIAQ is susceptible to extremely localized air quality: dirty diesels!

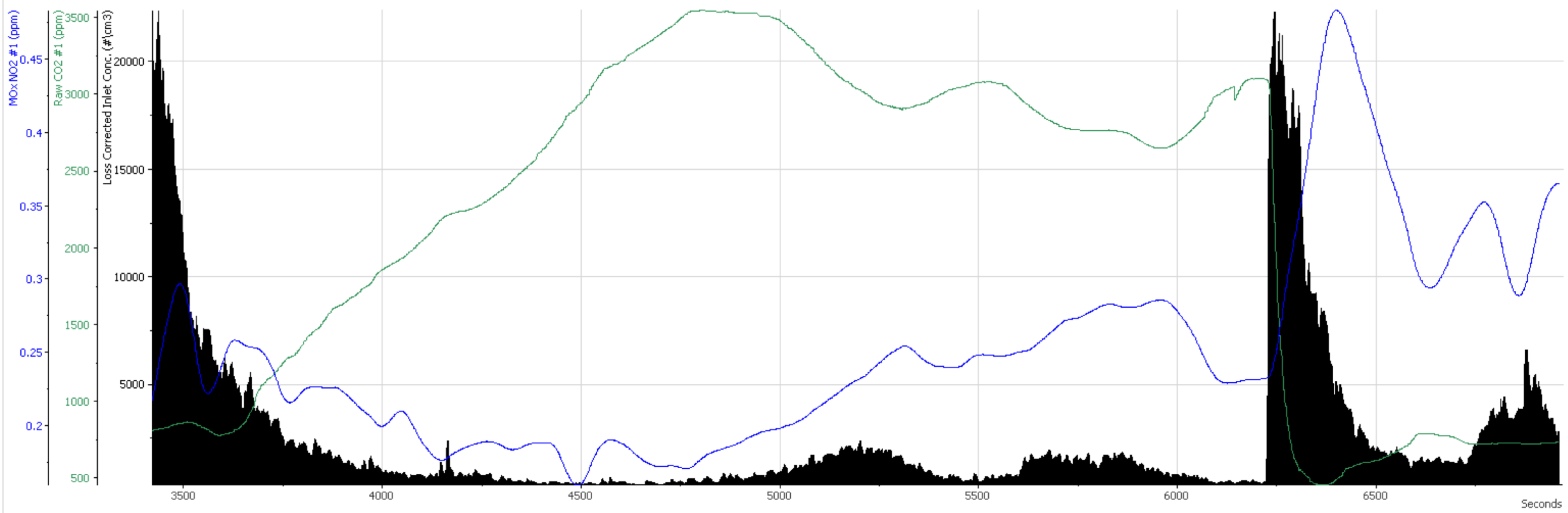




Effect of Occupant Behaviour – Recirculation Mode

- PN exponential decay to low concentrations
- CO_2 peaks at >3500ppm
- Increased leakage of HVAC associated with higher speeds, results in some CO_2 ventilation, and some PN infiltration
- Obvious dichotomy between PN & CO_2, but it is not so clear for NO_2





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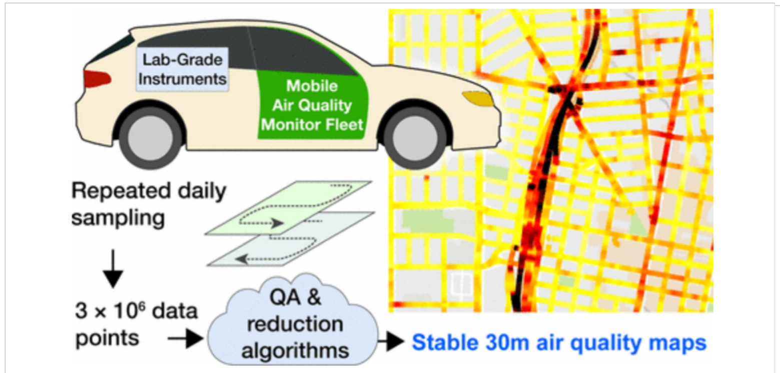
Effect of Location - Mobile Air Quality Monitoring

- Routine mobile monitoring for measuring time-integrated concentrations at high spatial resolution
- **4-5 orders of magnitude improvements** in spatial resolution than current central site monitoring stations
- Where are vehicles causing poor air quality? And in what areas are drivers exposed to higher concentrations?



Environmental Science & Technology
Article
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High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data

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Supporting Information

ABSTRACT: Air pollution affects billions of people worldwide, yet ambient pollution measurements are limited for much of the world. Urban air pollution concentrations vary sharply over short distances (≪1 km) owing to unevenly distributed emission sources, dilution, and physicochemical transformations. Accordingly, even where present, conventional fixed-site pollution monitoring methods lack the spatial resolution needed to characterize heterogeneous human exposures and localized pollution hotspots. Here, we demonstrate a measurement approach to reveal urban air pollution patterns at 4−5 orders of magnitude greater spatial precision than possible with current central-site ambient monitoring. We equipped Google Street View vehicles with a fast-response pollution measurement platform and repeatedly sampled every street in a 30-km^2 area of Oakland, CA, developing the largest urban air quality data set of its type. Resulting maps of annual daytime NO, NO_2, and black carbon at 30 m-scale reveal stable, persistent pollution patterns with surprisingly sharp small-scale variability attributable to local sources, up to 5−8× within individual city blocks. Since local variation in air quality profoundly impacts public health and environmental equity, our results have important implications for how air pollution is measured and managed. If validated elsewhere, this readily scalable measurement approach could address major air quality data gaps worldwide.

1. INTRODUCTION

Air pollution is a major global risk factor for ill-health and death.[1−4] Air pollution measurements are crucial for epidemiology and air quality management, but the extent of ground-based air pollution observations is limited.[5,6] For many developing-country regions, especially in populous parts of Asia and Africa, robust air quality monitoring is largely absent.[5] Even for high-income regions, ambient monitors are generally sparsely sited. For the 60% of the U.S. census urban areas with continuous regulatory monitoring, there are a mean of ~2−5 monitors per million people and 1000 km^2 (Supporting Information (SI) Table S1). However, primary air pollutant concentrations in cities can vary sharply over short distances (~0.01−1 km) owing to unevenly distributed emissions sources, dilution, and physicochemical transformations.[7−10] Such gradients are not well represented with routine ambient measurements, but have important implications for exposure assessment, epidemiology, air quality management, and environmental equity.[10−13]

Advances in air pollution exposure assessment techniques over the past two decades have helped address limitations of (i) data coverage and (ii) spatial resolution that are associated with central-site ambient monitoring.[10,14] These methods include satellite remote sensing (RS), chemical transport models (CTMs), land-use regression (LUR) models, and direct personal exposure measurements.[14] Each of these approaches has distinct advantages and limitations. Satellite RS instruments and CTMs

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BREATHE LONDON

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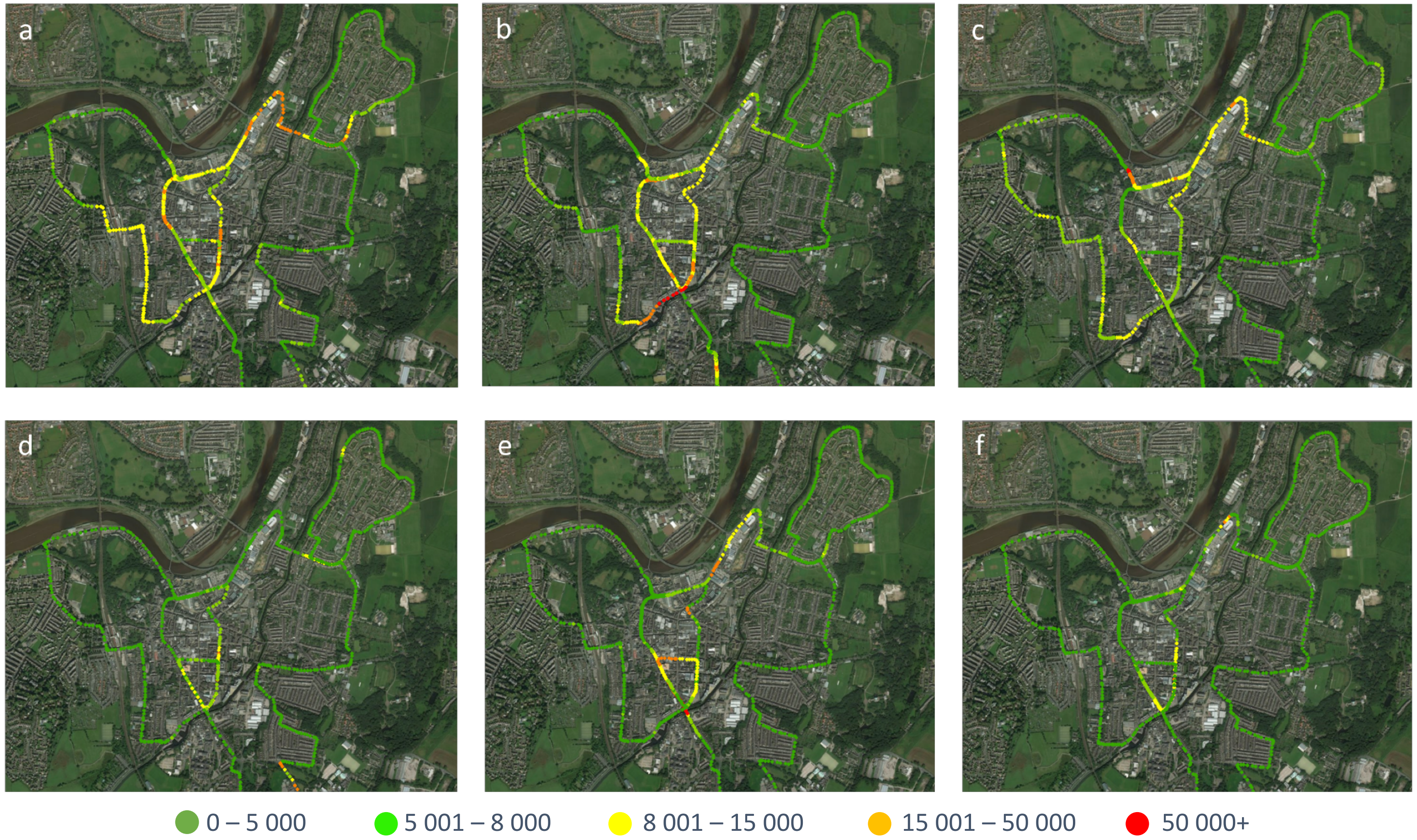
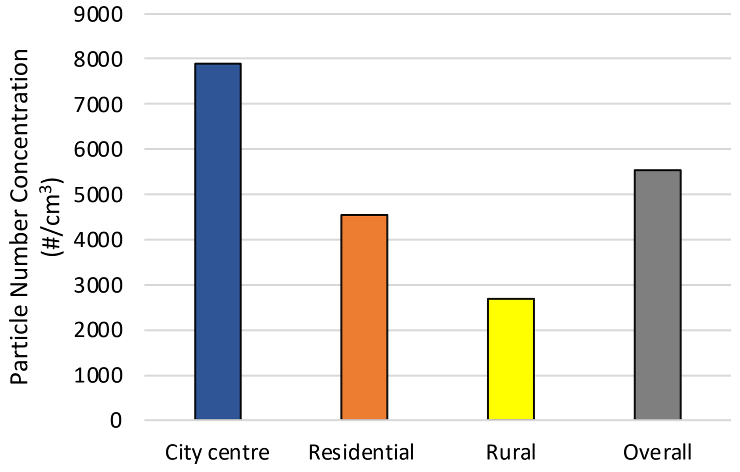
Mobile Air Quality Monitoring – Lancaster, UK

- Lancaster is a small city of 138,000 people in the North-West of England
- Over a period of 1 week, particle number concentrations were recorded every second over a 20-mile route during evening rush hour (5:30/7:00pm)





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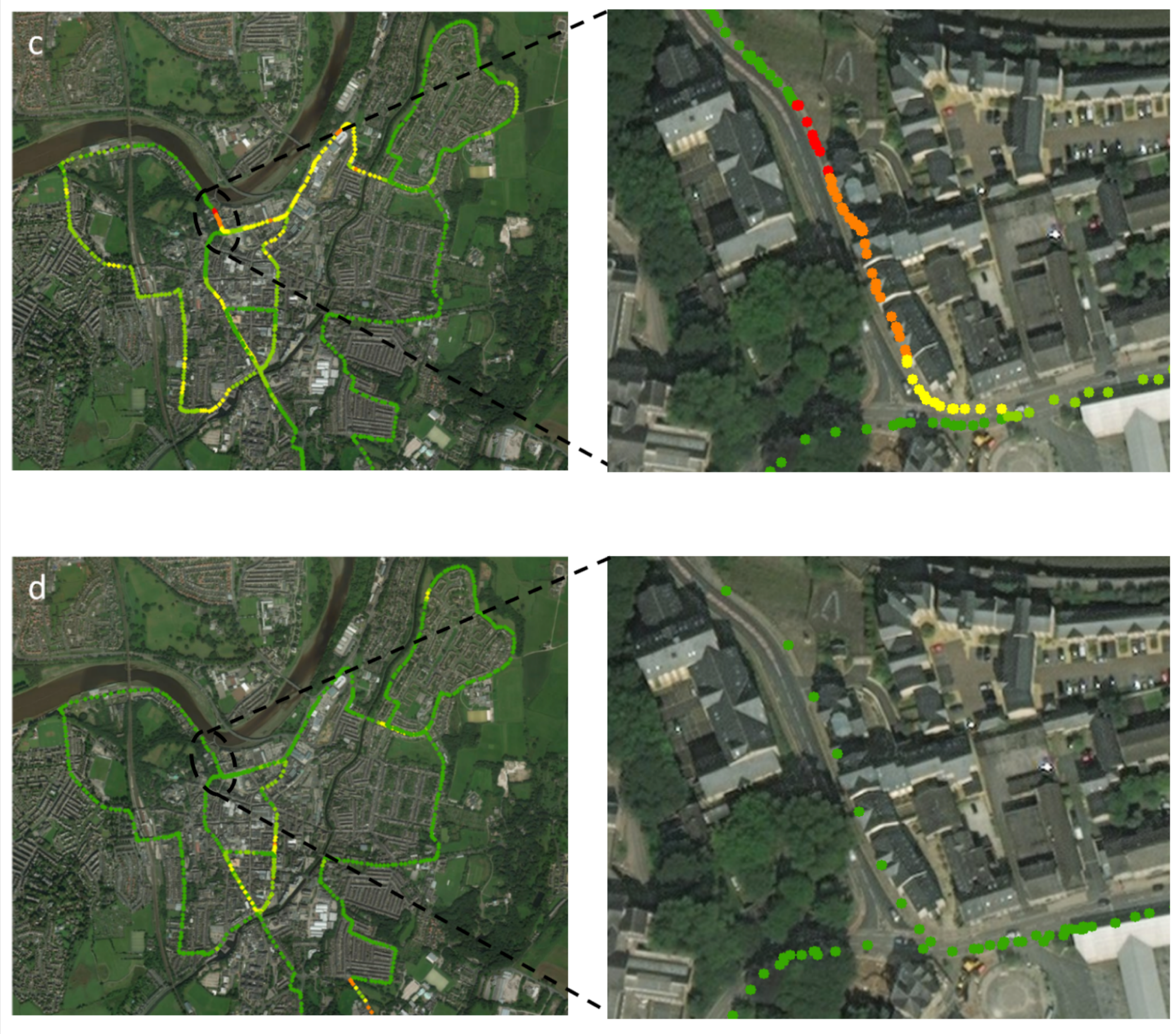
Mobile Air Quality Monitoring – Lancaster, UK

- **Air Quality ”hotspots” change in space and time!**



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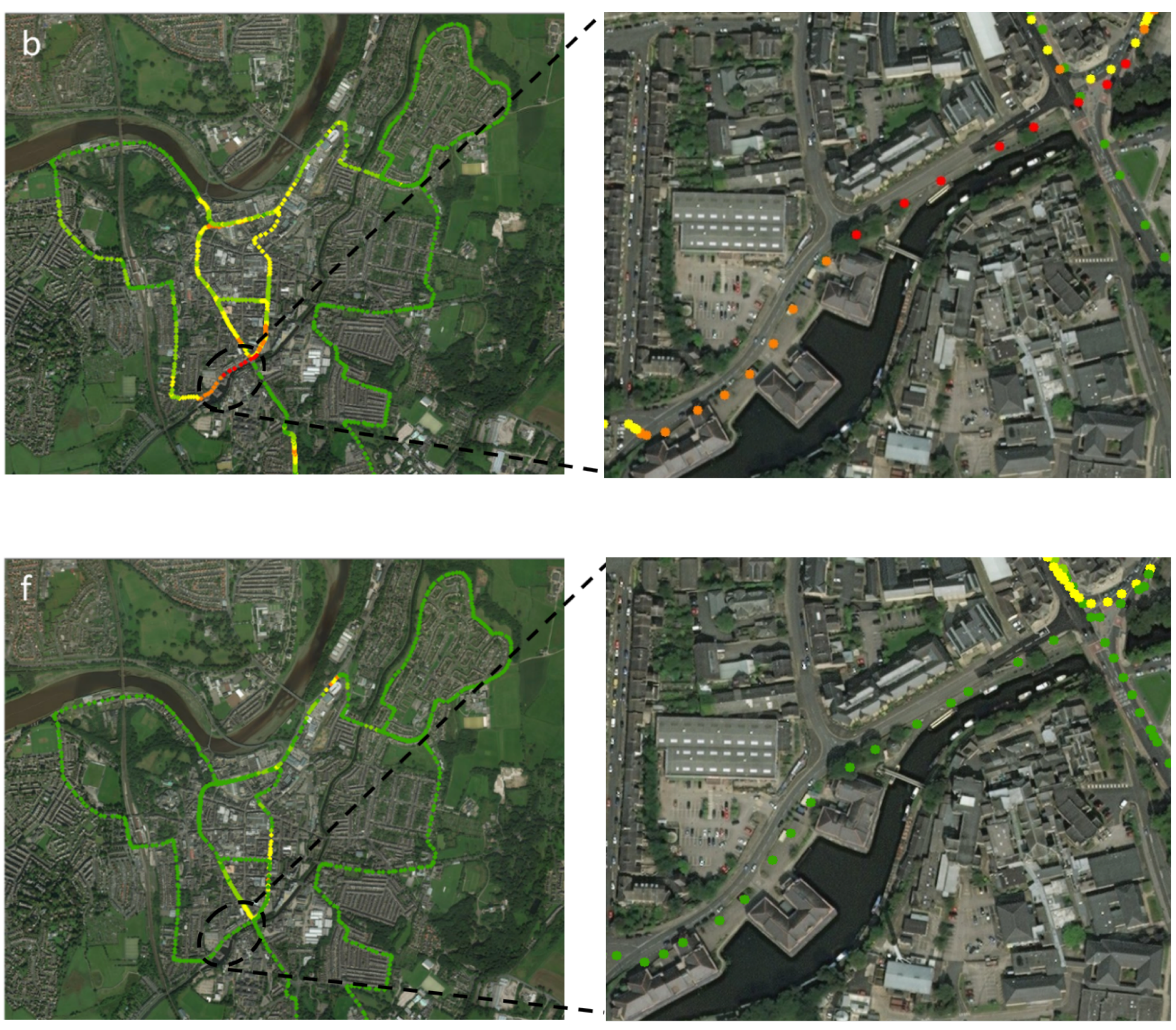
Mobile Air Quality Monitoring – Lancaster, UK

- **Air Quality "hotspots" change in space and time!**



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Air Quality Mapping

- 2 year project in Guangzhou (megacity)
- **Land-use regression model** combining: mobile air quality monitoring, fixed site stations, meteorological, land-use, traffic volume, POI data etc.
- Will map UFP and other pollutants
- Developing an **app to predict air pollution exposure**
- When combined with cellular GPS data, rich "personal exposure analytics" become possible
- Case study to demonstrate feasibility of a low-cost air quality monitoring network

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Conclusions

- Measurements to reduce population level exposure must include measurements inside AND outside vehicles
- Vehicles are already being equipped with PEMS, PIMS air quality measurements can be "piggybacked" to provide valuable air quality and exposure data
- The general public can leverage PIMS data to have informed choice when purchasing a car, and to reduce their exposure
- OEMs can use this technology to refine HVAC systems to provide "clean air cabins"
- Unregulated space? - what are the implications for occupational health and safety?

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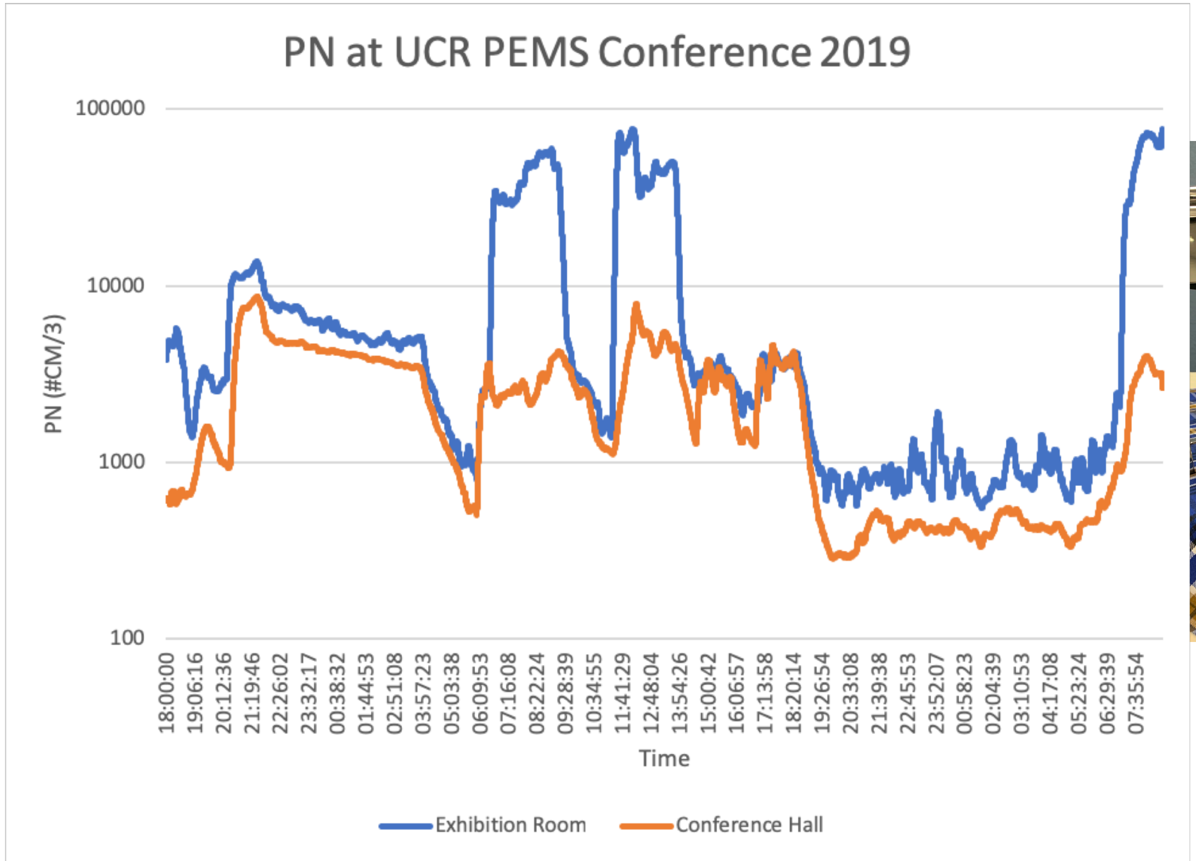
Indoor Air Quality at UCR PEMS

- Average person spends **~90% of their time indoors**.
- There is far less information / public knowledge on it!
- Particles reach 10x higher than background concentrations



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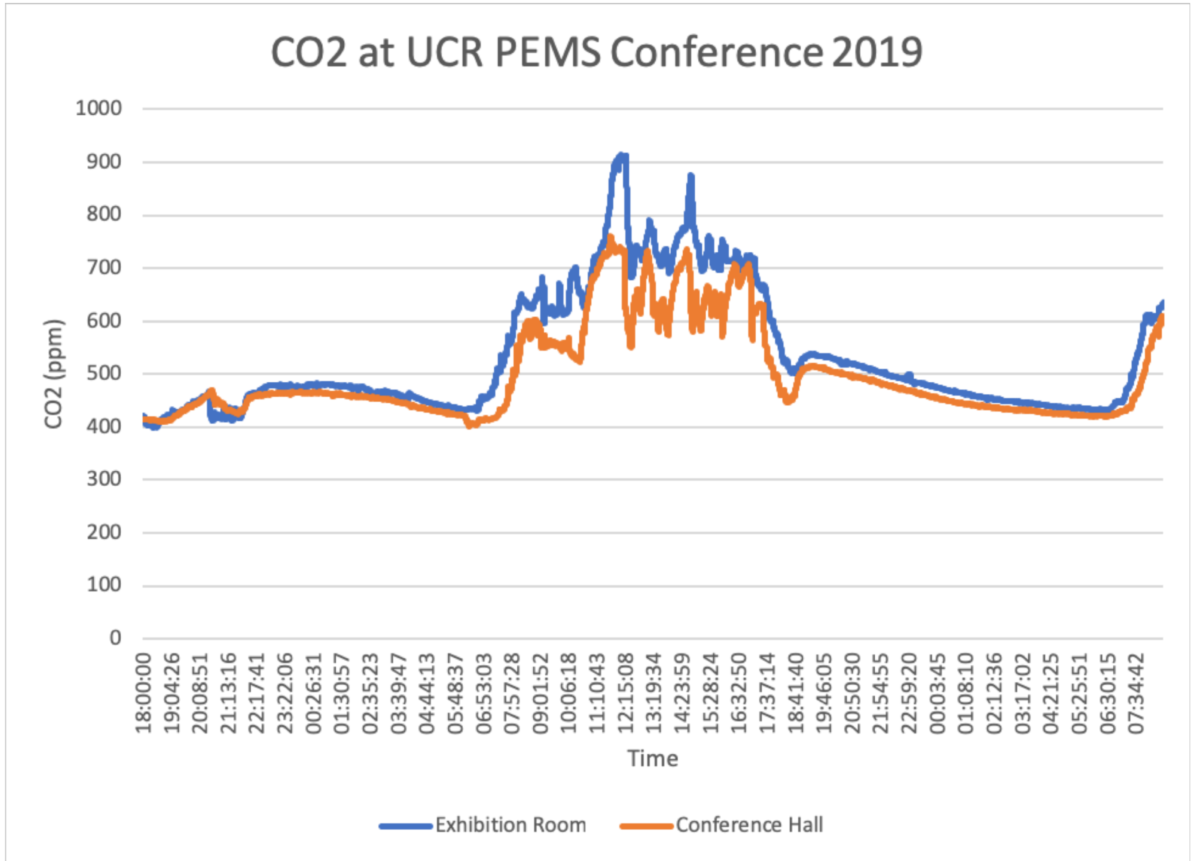
Indoor Air Quality at UCR PEMS

- Average person spends **~90% of their time indoors**.
- There is far less information / public knowledge on it!
- Very well ventilated conference, with levels not exceeding 1000ppm



Any questions?

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