[Cambridge Statistics Discussion Group (CSDG)]

Quantifying personal exposure to air pollution with sensor technologies and digital science

Dr Lia Chatzidiakou
ec571@cam.ac.uk
the Rod Jones' group

Yusuf Hamied Department of Chemistry
University of Cambridge

22nd November 2023

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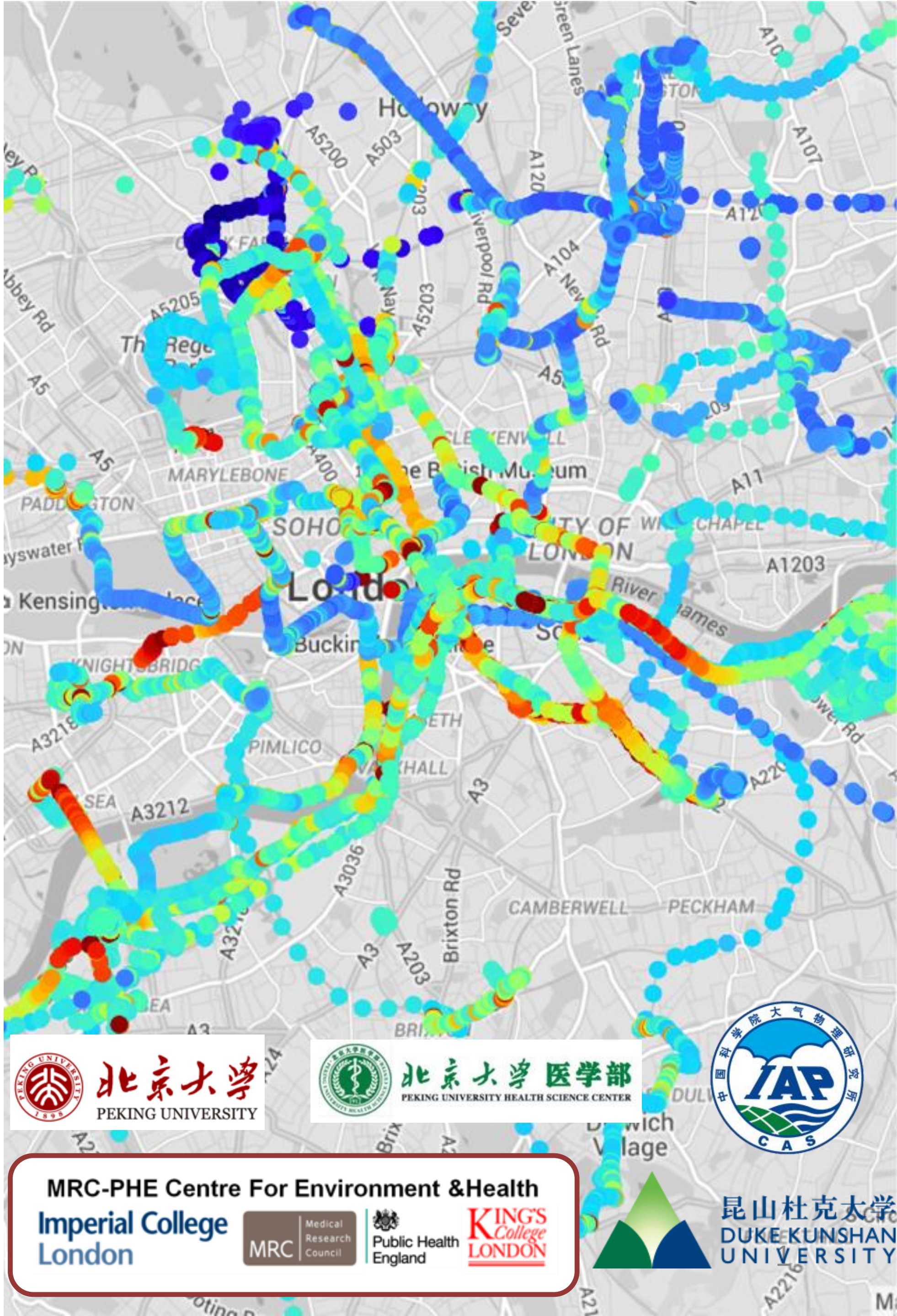

北京大学 PEKING UNIVERSITY

北京大学医学部 PEKING UNIVERSITY HEALTH SCIENCE CENTER

MRC-PHE Centre For Environment &Health
Imperial College London · MRC Medical Research Council · Public Health England · King's College London

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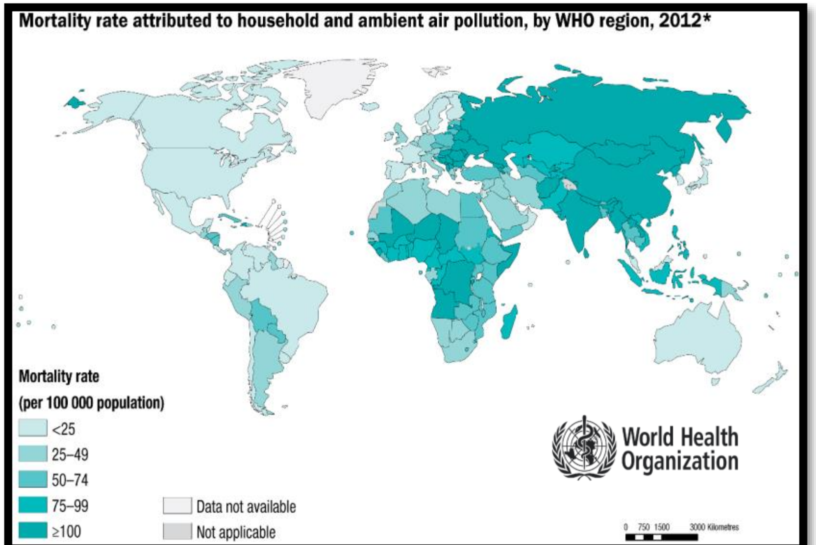
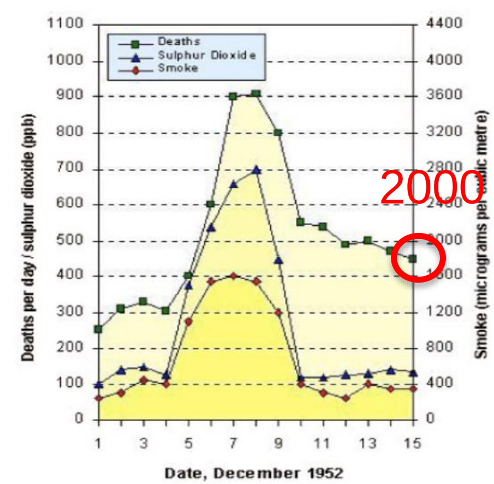
Air pollution and human health:
a national problem but a global crisis

Estimated 8M premature deaths annually globally



The 1952 London smog



Low-income countries are worst affected

(92% of pollution-related deaths)

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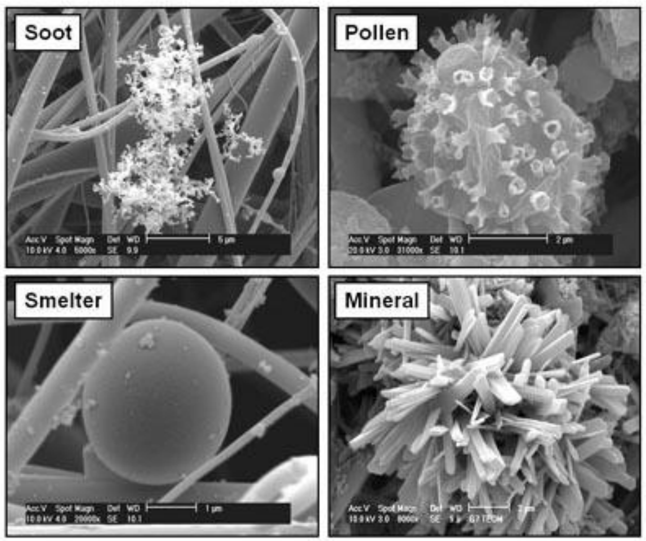
Common air pollutants (reminder)

NO and NO_2 levels in Cambridge on one afternoon



PM collected on filters and examined with a microscope. PM can be made up of different chemicals.

NOx (NO + NO_2)

- Primarily emitted by cars and trucks
- Associated with asthma attacks, respiratory illness and cardiovascular effects

Particulate Matter (PM)

- Emitted directly or formed in the atmosphere
- Particles less than 2.5 micrometers in diameter, (fine particles or $PM_{2.5}$), pose the greatest risk to health.

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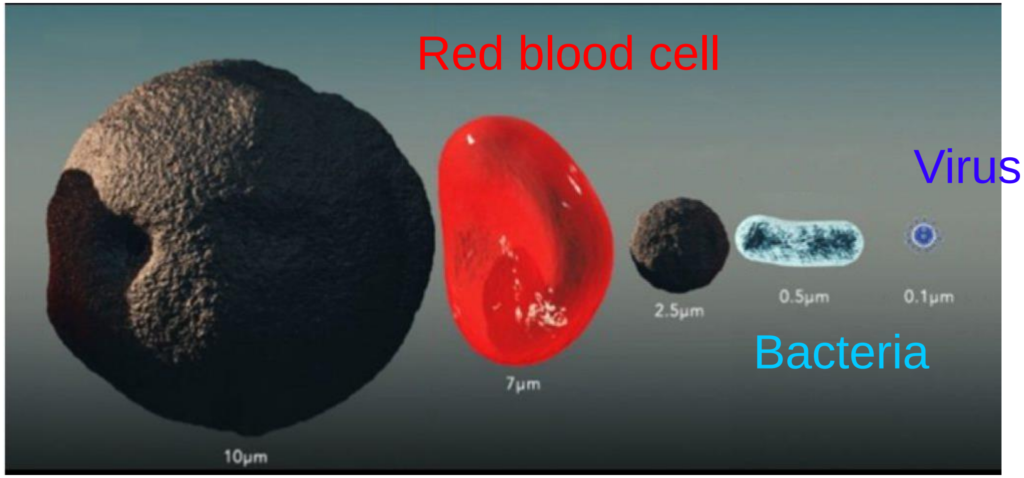
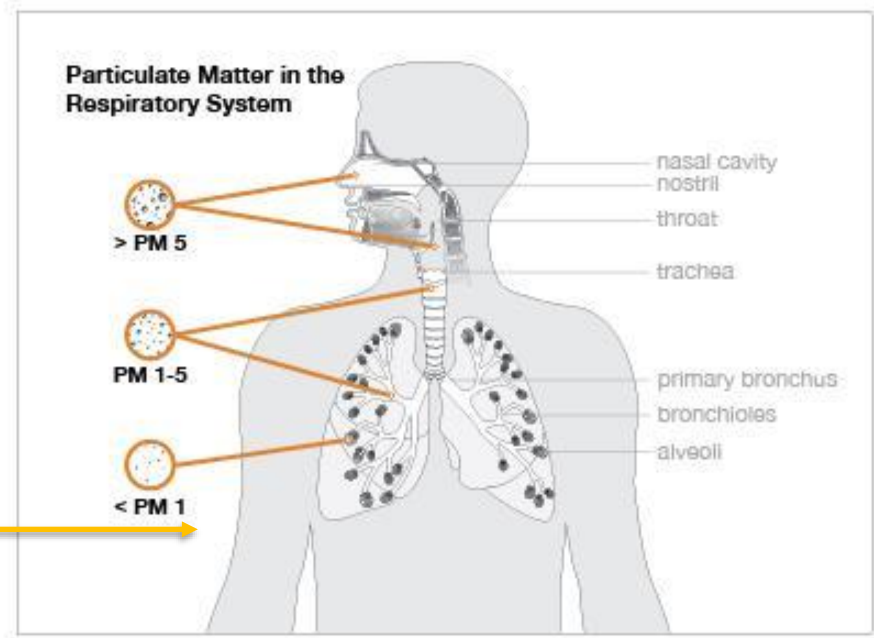
Particulate Matter (PM)



Particle size is important:

- **Affects transport**
- **Time suspended in the air**
- **Related to chemical composition**
- **Deposition in the lungs**



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Measurement techniques for air quality

Reference-grade instrumentation

- **Expensive** to set up and maintain
- Require roadside **infrastructure** to house them
- Well-quantified **accuracy**

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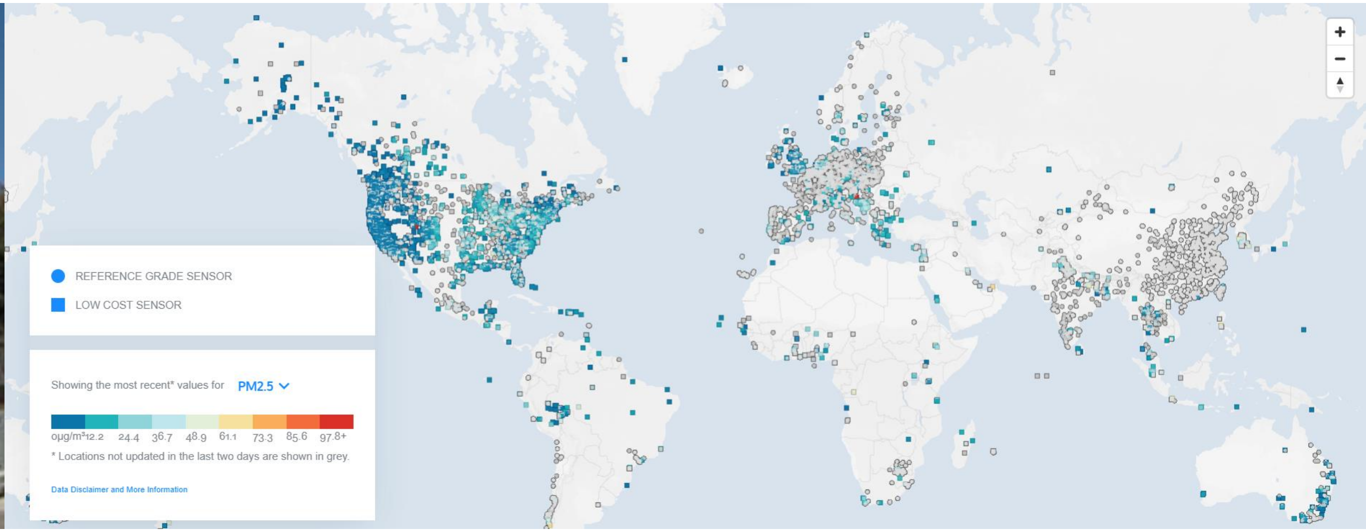
Measurement techniques for air quality

Reference-grade instrumentation

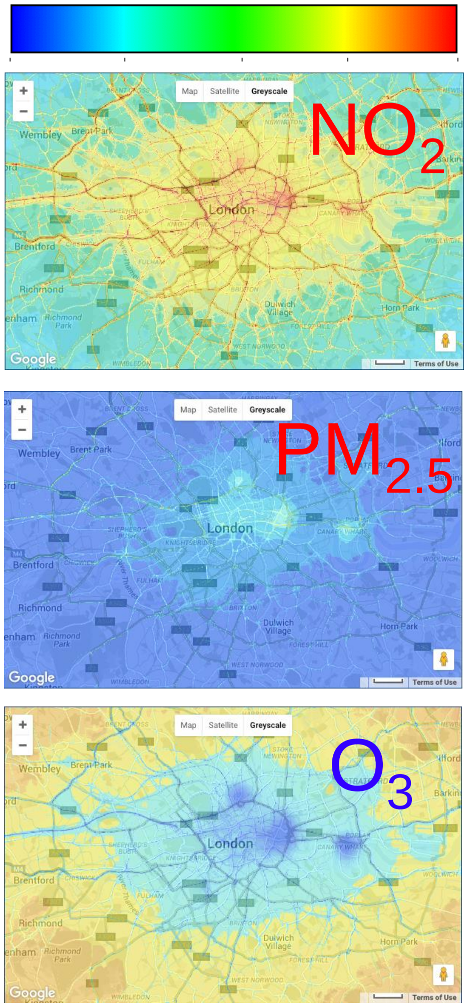
openaq



- **Expensive** to set up and maintain
- Require roadside **infrastructure** to house them
- Well-quantified **accuracy**

⇒ **Less resources where most needed**

Air pollution and human health: what do we know?



Modelled *annual averages*

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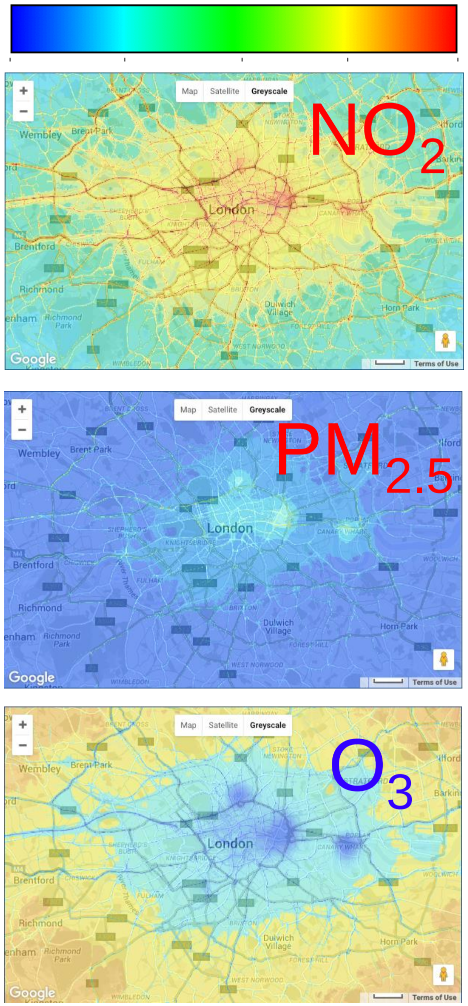
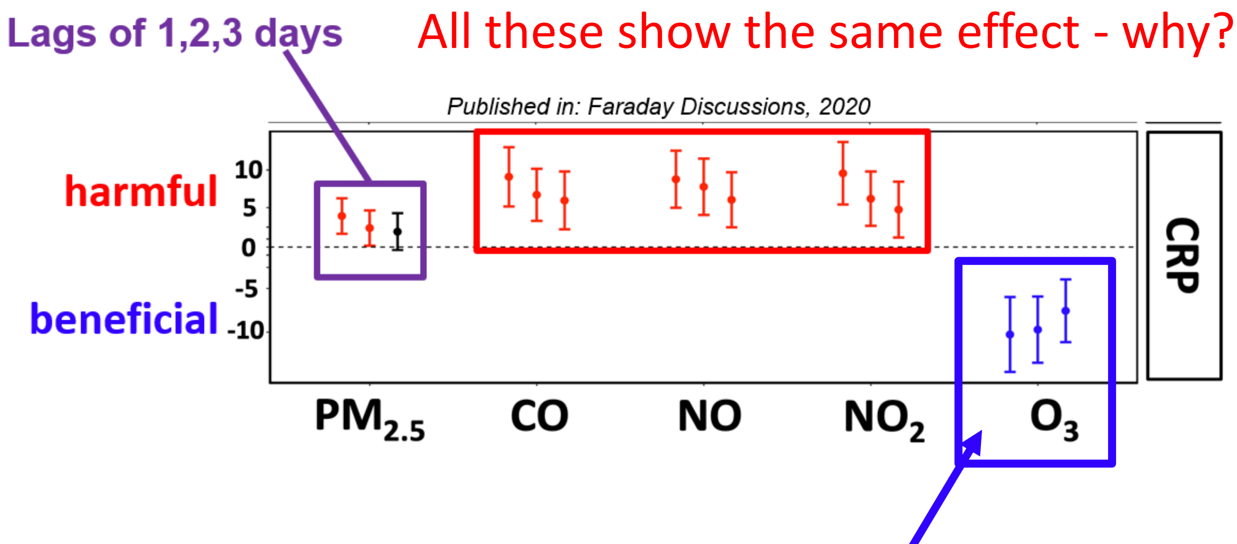
Air pollution and human health: what do we know?



Modelled *annual averages*

- Single and dual pollutant models for NO_2 and $PM_{2.5}$ all only explain the *same fraction* of health outcomes….. (UK COMEAP)



- Some studies suggest surface O_3 can have a *protective* effect? ...O_3 often ***anti-correlated*** with other pollutants

⇒ *Cannot reliably distinguish causal links*

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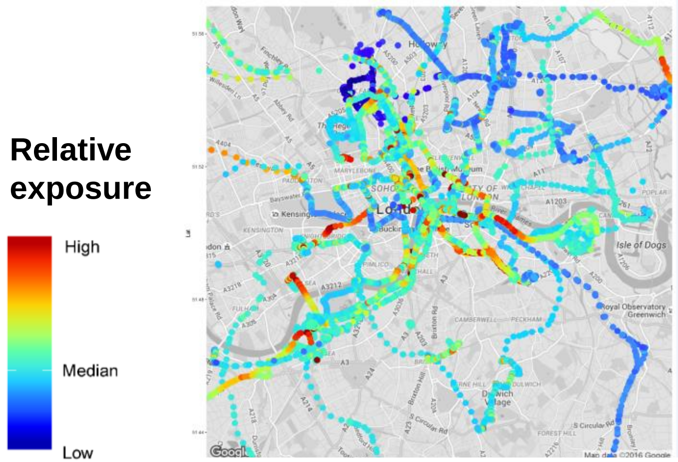
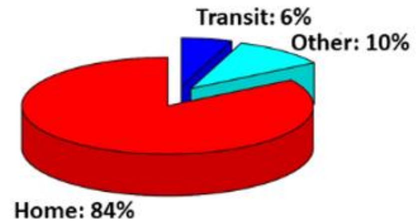
Critical knowledge gaps: personal and indoor exposure

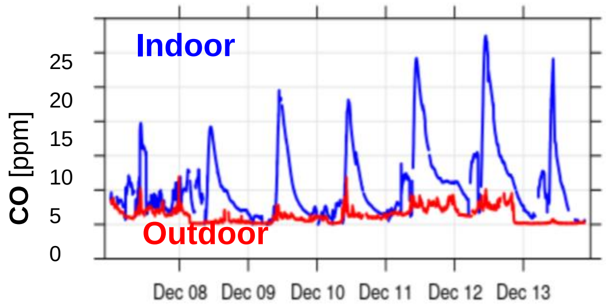


Map of personal exposure to NOx during commuting (London)

- **Activity patterns**

- **Time budget**





- **Indoor air quality (indoor sources, vs outdoor air) very different from ambient pollution**

⇒ Linking activity to exposure and to health

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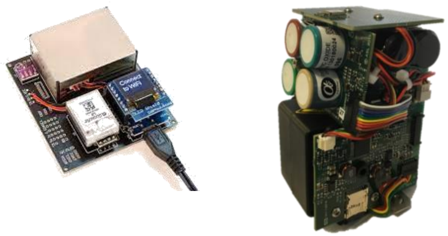
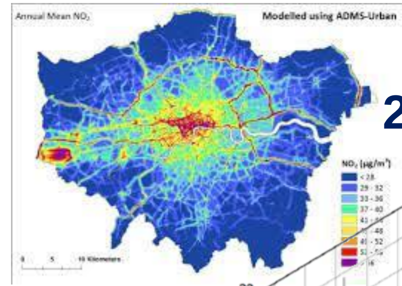
State-of-the-art health models: the next step

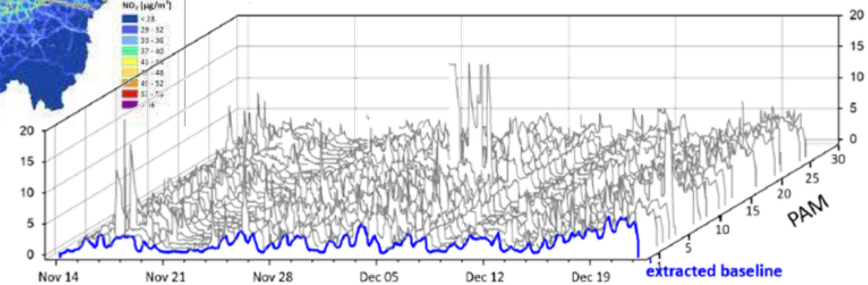
1. Sensor networks



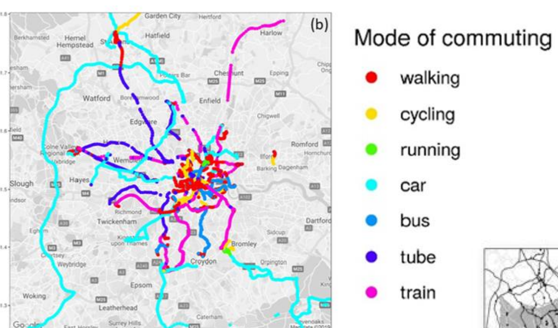
Published in:
Chatzidiakou et al., Atmos. Meas. Tech., 2019



2. Data assimilation methods

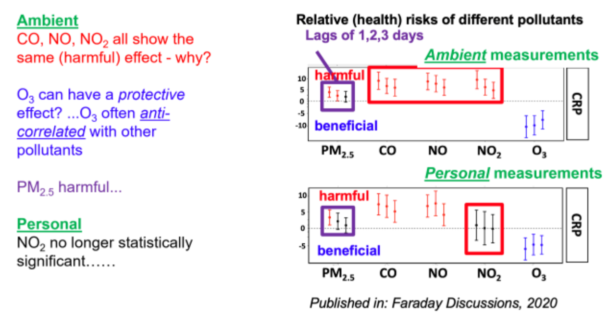


3. Automated time - activity patterns



Published in:
Chatzidiakou et al., BMC Env. Health, 2022

4. Novel health and exposure metrics



- *"Everyone's disease is the product of the individual history of exposures, superimposed on their underlying genetic susceptibilities"*
- *Beyond hard and rare outcomes…*

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Sensor networks

Observational technologies

Exposure

- O_3, NO_2, NO, CO
- Size-speciated PM
- Noise
- T, RH

Activity

- GPS
- Accelerometer
- Noise

Published in:
Chatzidiakou et al., AMT, 2019

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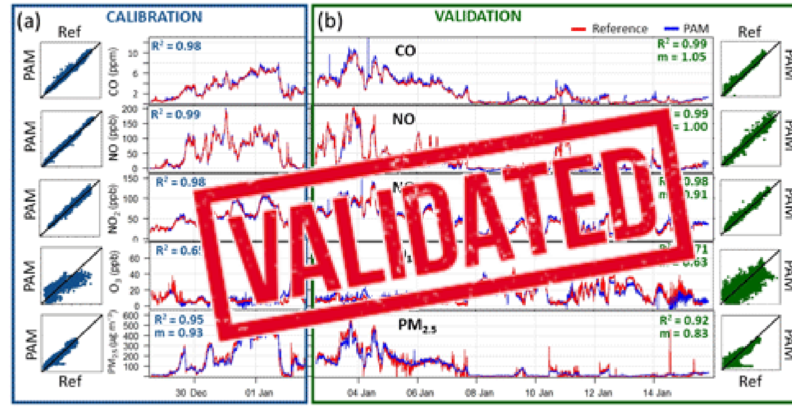
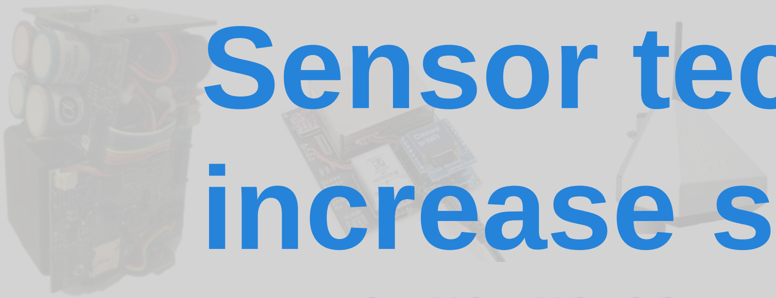


⇒ Integration of new and historic data from multiple sources, over a variety of scales, resolutions and frequencies

Sensor networks + GIS information

Observational technologies



Sensor technologies increase spatial and temporal resolution in a way not possible before

Exposure

- O_3, NO_2, NO, CO
- Size-speciated PM
- Noise
- T, RH

Activity

- GPS
- Accelerometer
- Noise

Published in:
Chatzidiakou et al., AMT, 2019

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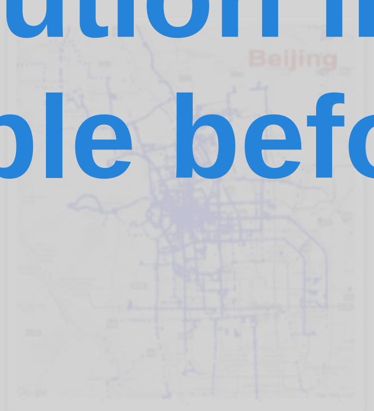


⇒ Integration of new and historic data from multiple sources, over a variety of scales, resolutions and frequencies

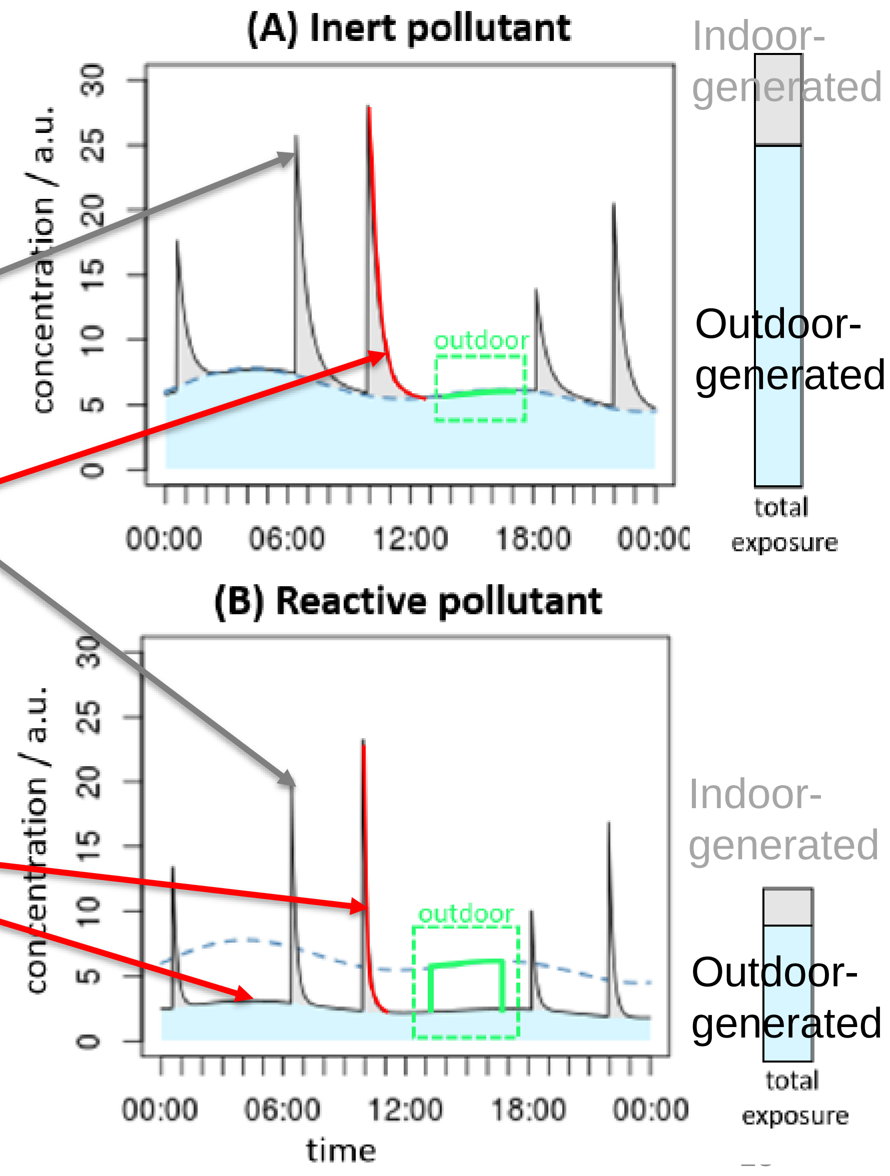
Data assimilation methods (indoor air)

A simple model to estimate indoor air pollution levels

Indoor sources (cooking, cleaning, smoking etc)

Ventilation to outdoors

Ventilation and other processes (indoor sinks)



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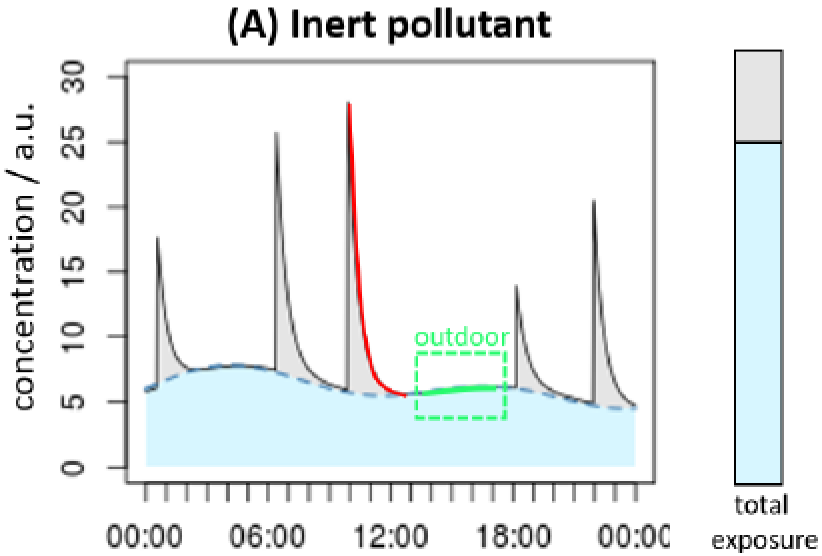
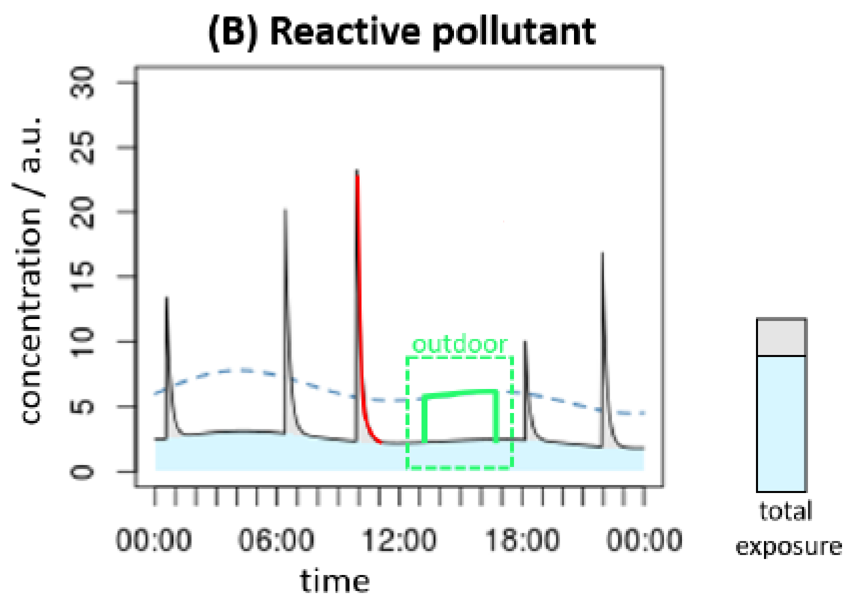
Data assimilation methods (indoor air)

Location, building characteristics, materials, operation and maintenance ⇒ *Large variation between and within microenvironments*



Examples of a "Victorian" and contemporary school with notable differences in indoor air pollution (London)



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Data assimilation methods (indoor air)

Location, building characteristics, materials, operation and maintenance ⇒ *Large variation between and within microenvironments*

Examples of a "Victorian" and contemporary school with notable differences in indoor air pollution (London)

The Guardian
Newspaper of the year

Air pollution worse inside London classrooms than outside, study finds

Exclusive: study of schools in capital finds dangerous levels of fine particulate pollution within classrooms, putting children at risk

The mayor of London, Sadiq Khan, has announced a £1m fund to help tackle air pollution in schools. Photograph: Stefan Rousseau/PA Images

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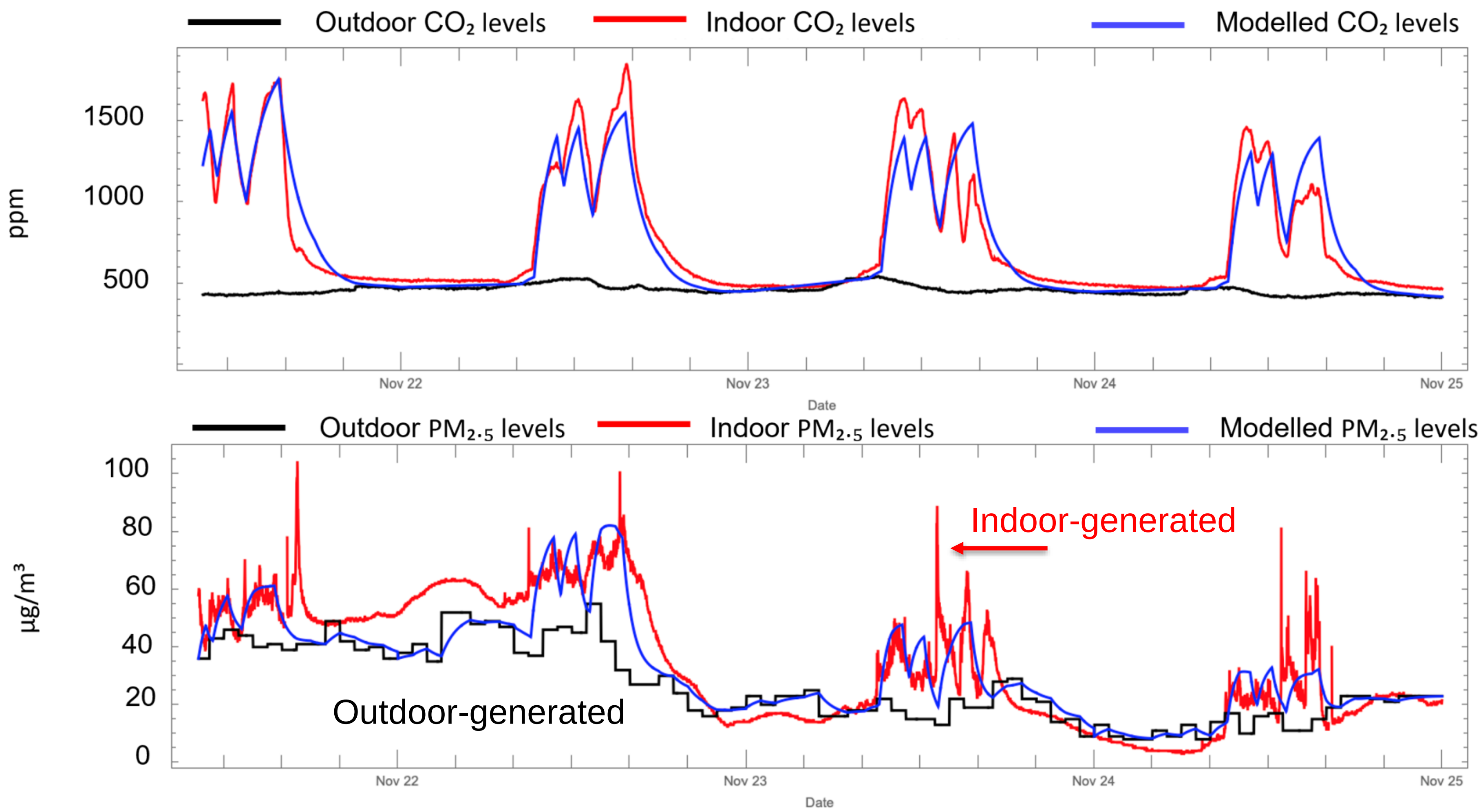
Outdoor measurements vs personal exposure (school)



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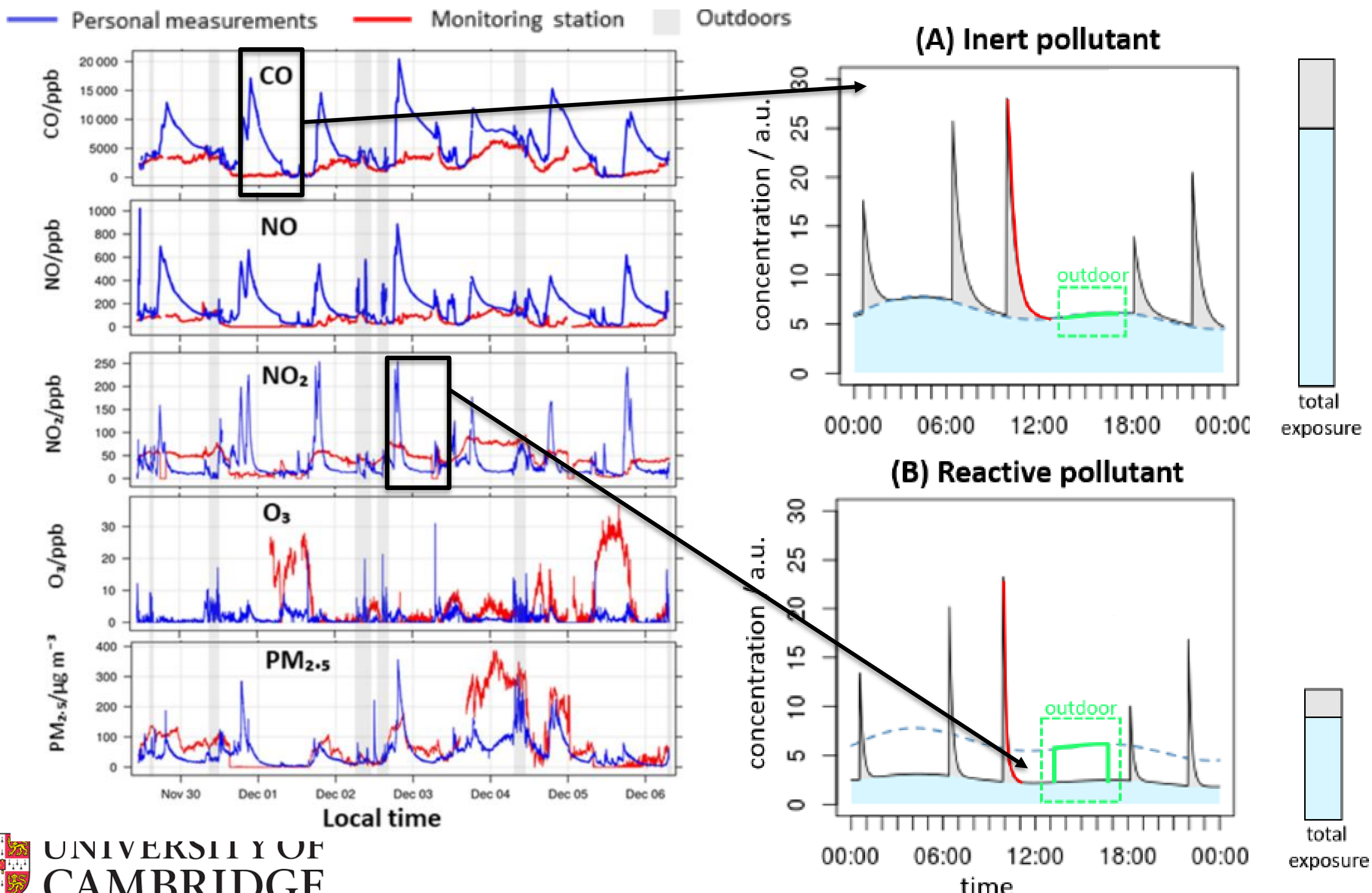
Outdoor measurements vs personal exposure (home)



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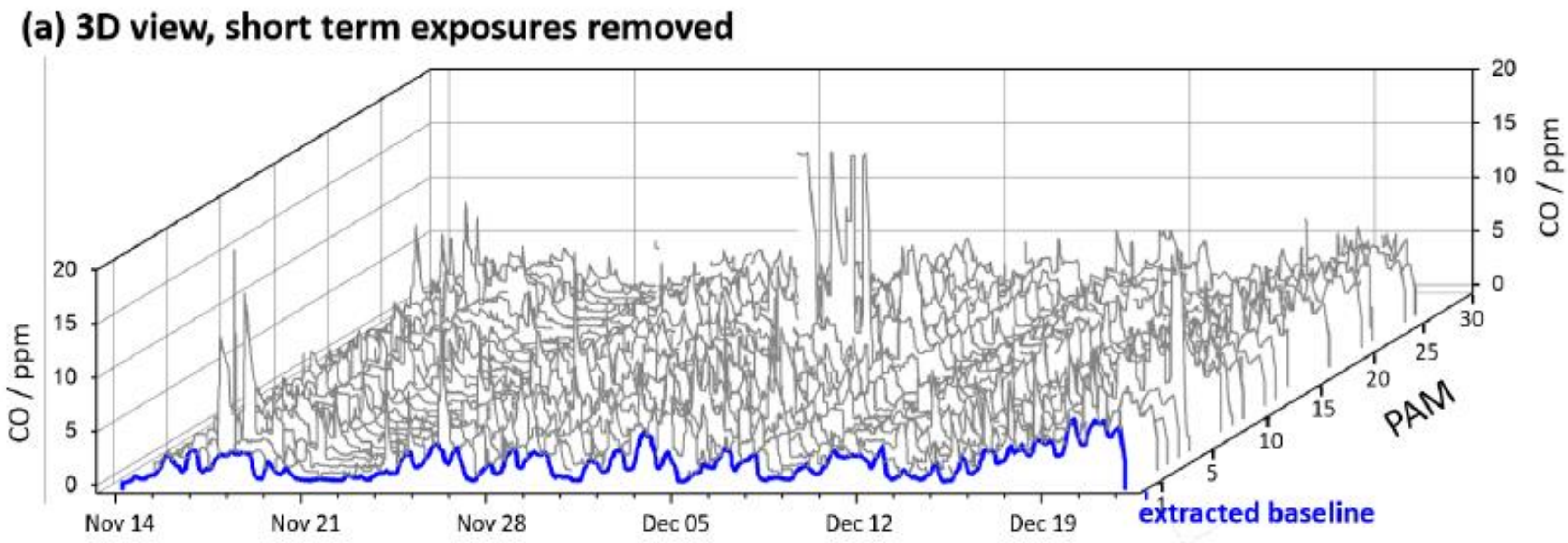
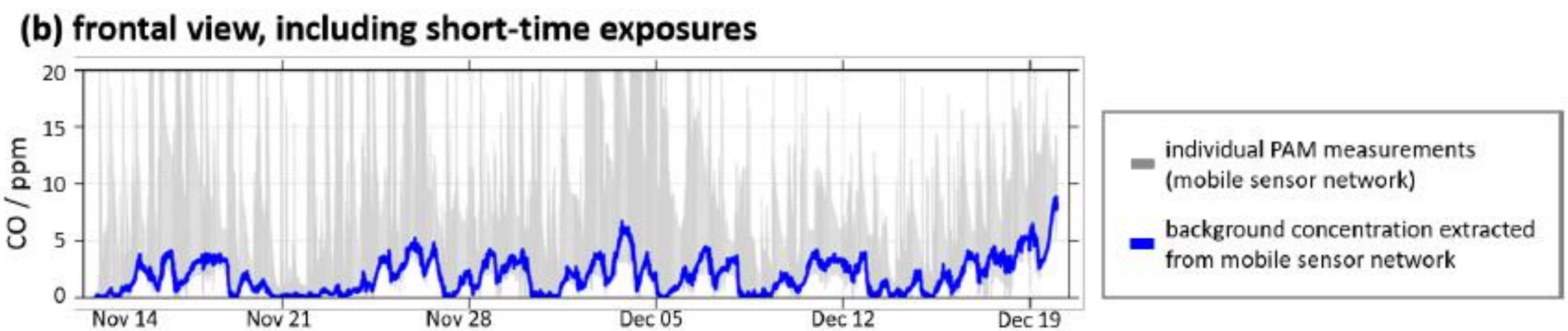
Outdoor measurements vs personal exposure (sensor network)





⇒ Separate the indoor- from the outdoor-generated component of exposure !

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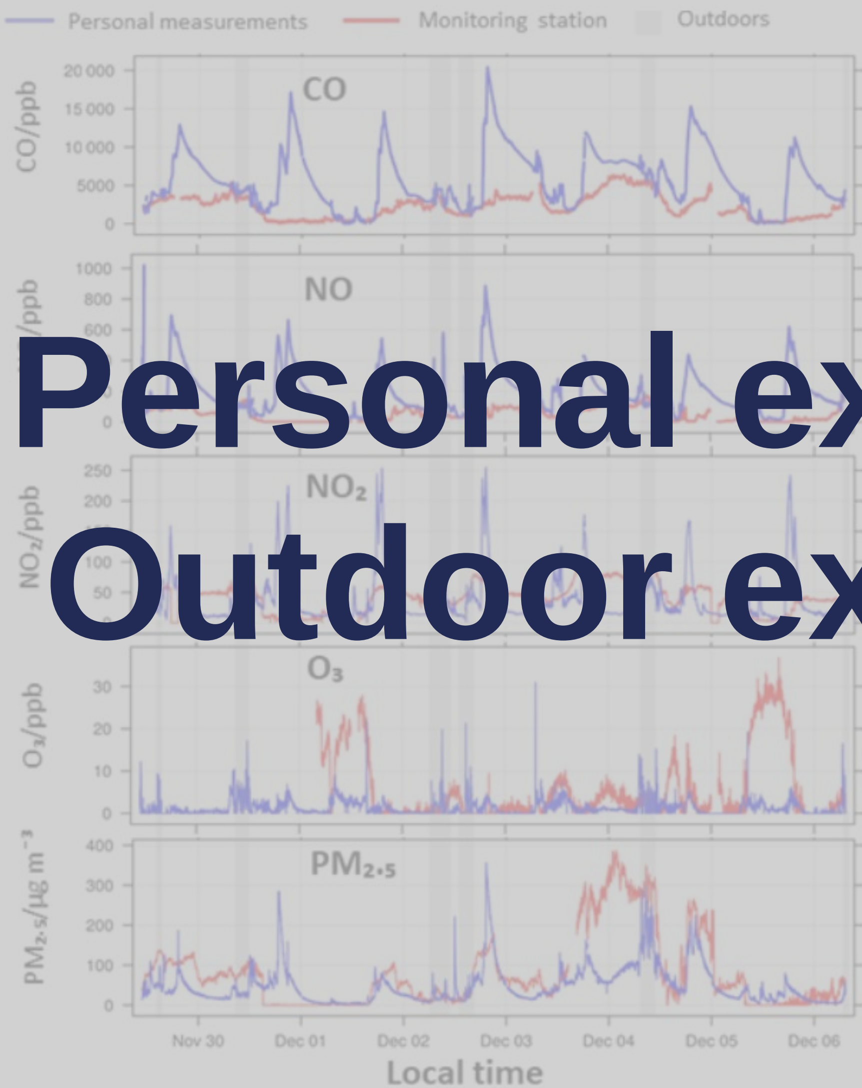
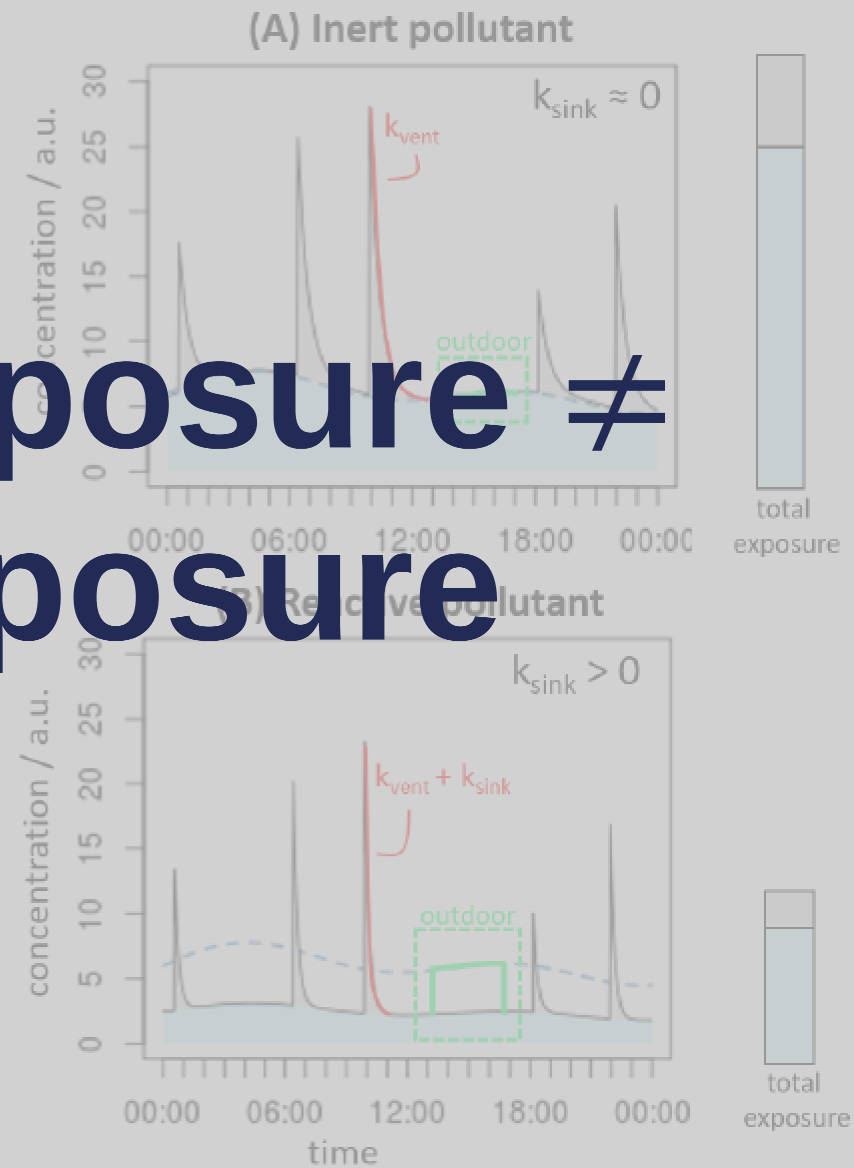
Are outdoor measurements good proxies of personal exposure?





Personal exposure ≠ Outdoor exposure

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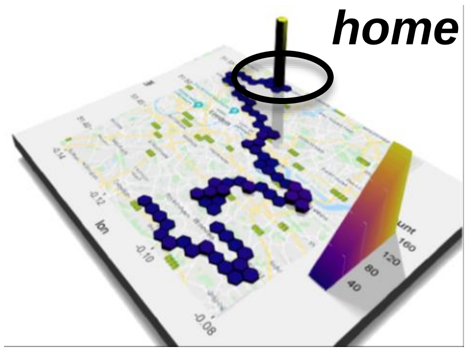
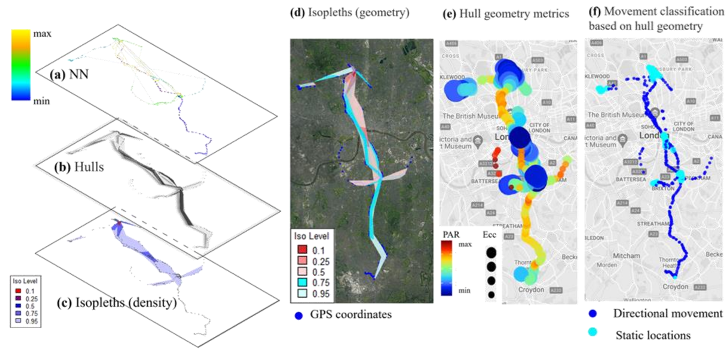
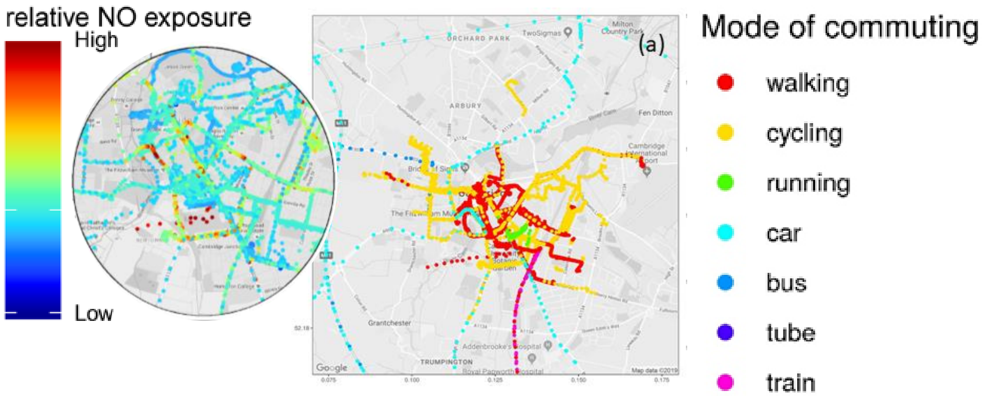
Automated time-activity patterns



Geo-spatial and temporal clustering



Mode of transport classification (AI algorithm)



⇒ Automated interpretation with advanced spatial analysis, AI and innovative methods

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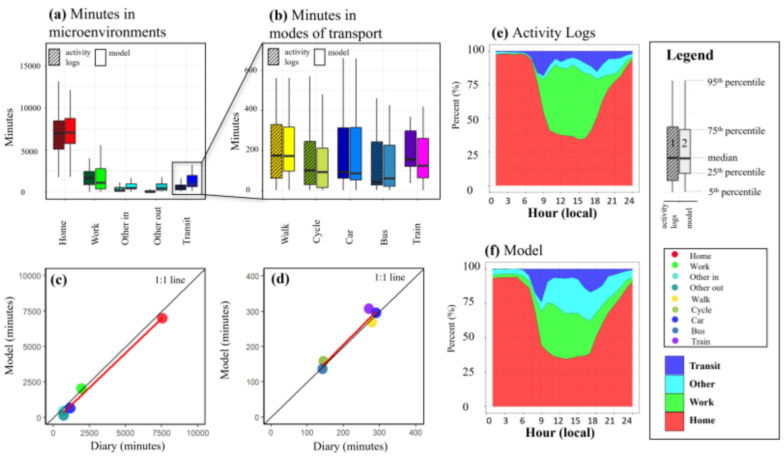
Chatzidiakou et al., BMC Environmental Health., 2022

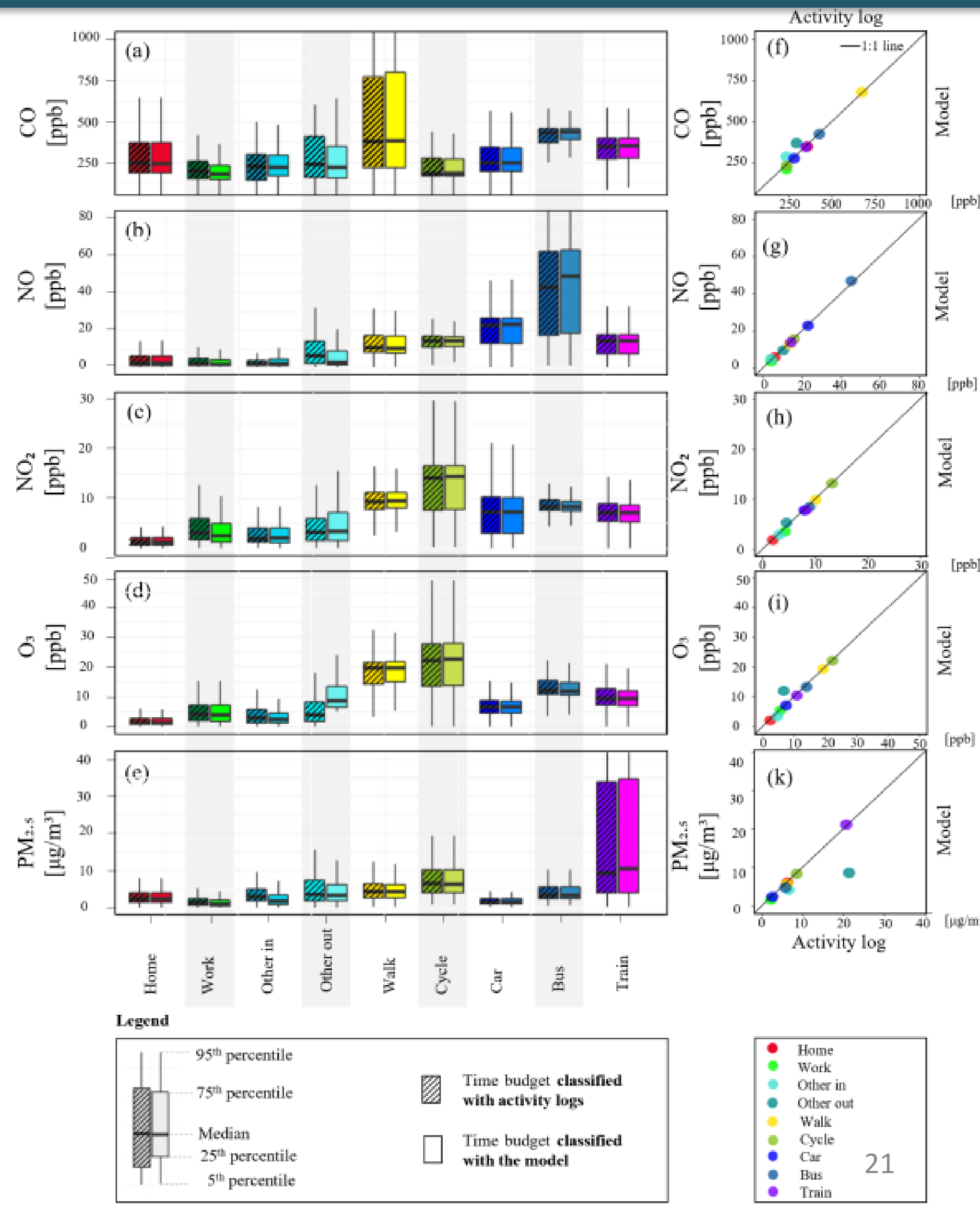
Automated time-activity patterns



⇒ **Commuting small fraction of time-budget**

⇒ **Maximum exposure to PM in the London Underground**

⇒ **Maximum exposure to NOx and ozone during street-level commuting**



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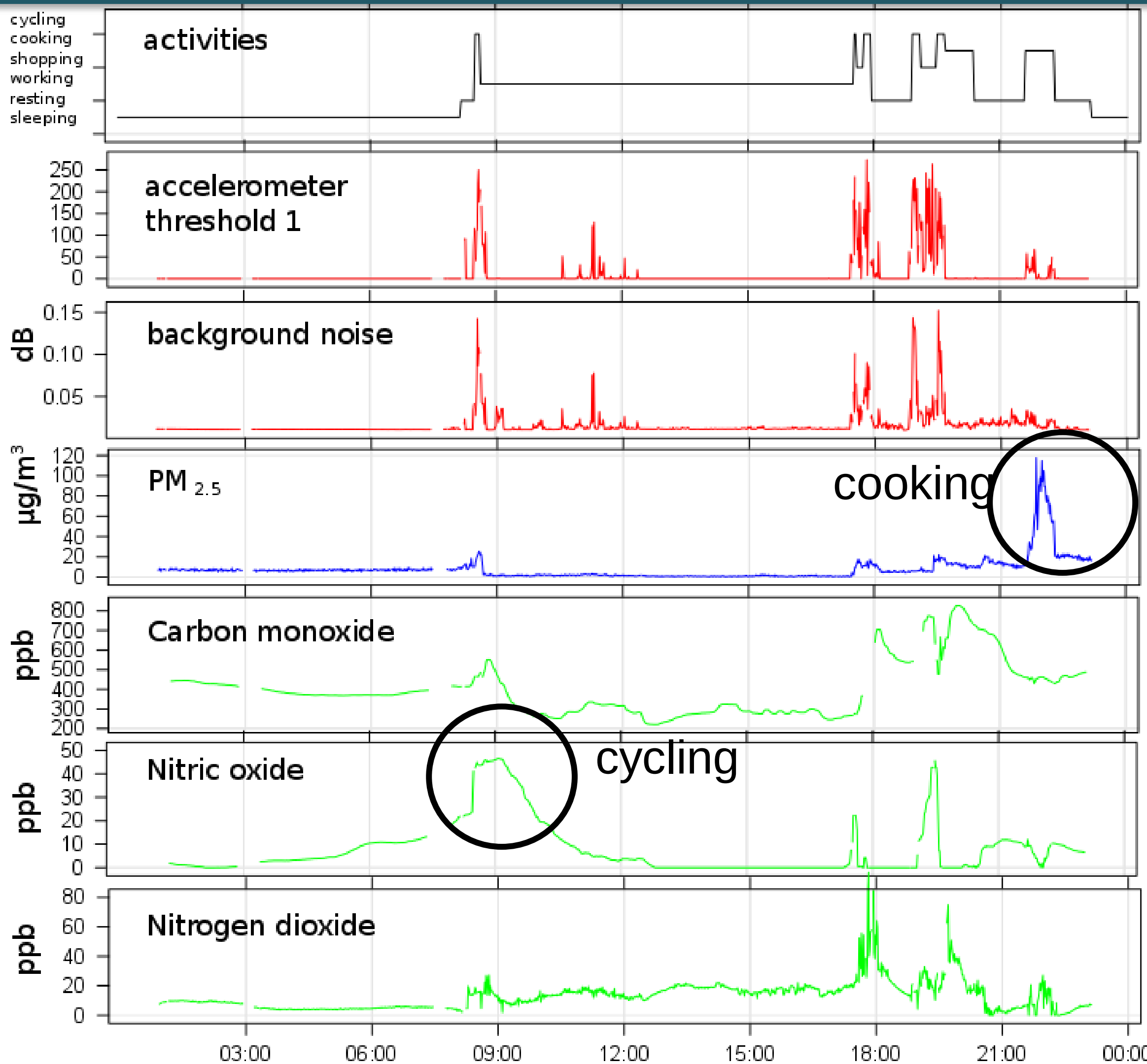
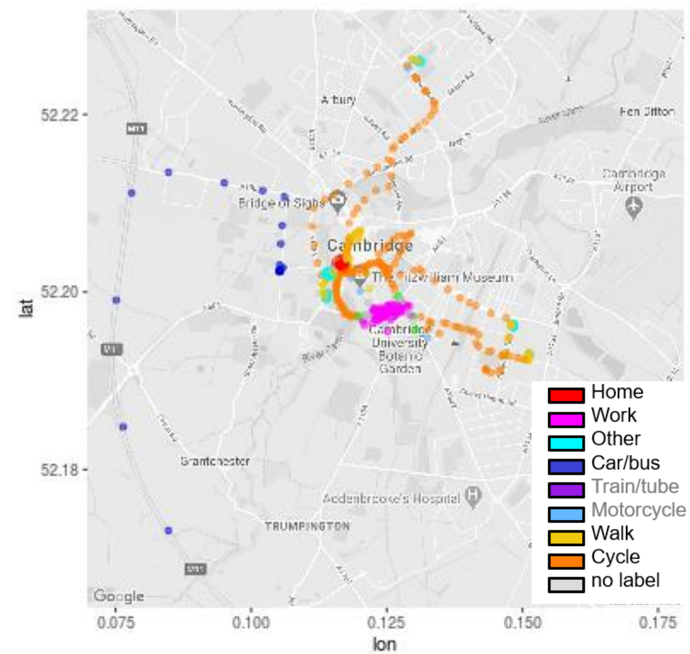
Deployment of a PAM: illustrative example



Time series of PAM parameters during a typical day

Peak exposure events due to local outdoor (traffic) and indoor (cooking) sources cannot be captured with outdoor networks



Visited locations and commuting mode during one typical week

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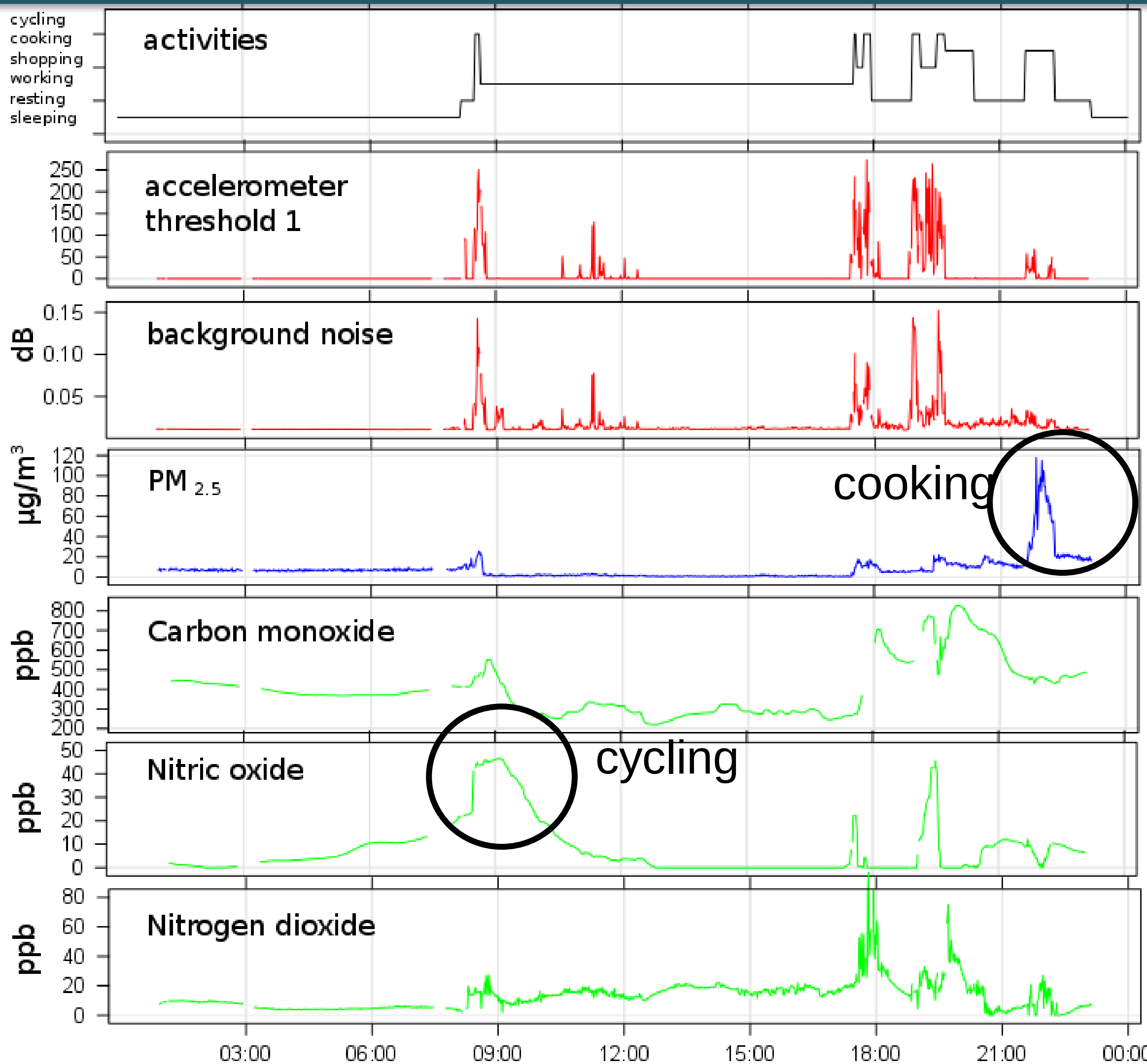
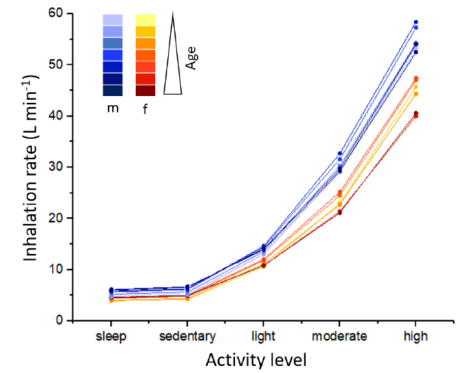
Why physical activity important?

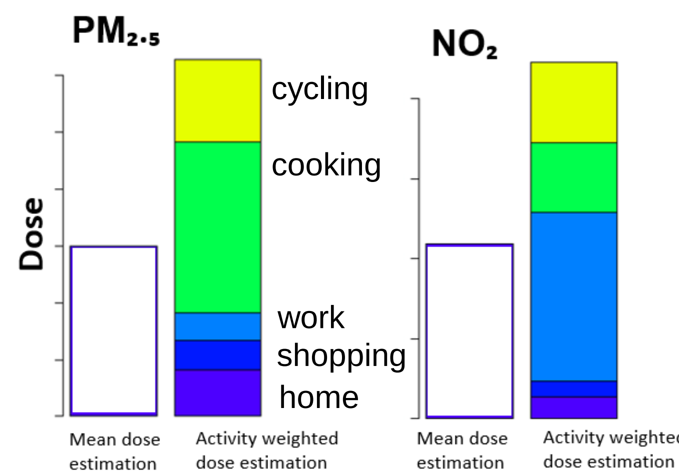


Time series of PAM parameters during a typical day



Physical activity important for dose!!!

Total exposure * inhalation rates



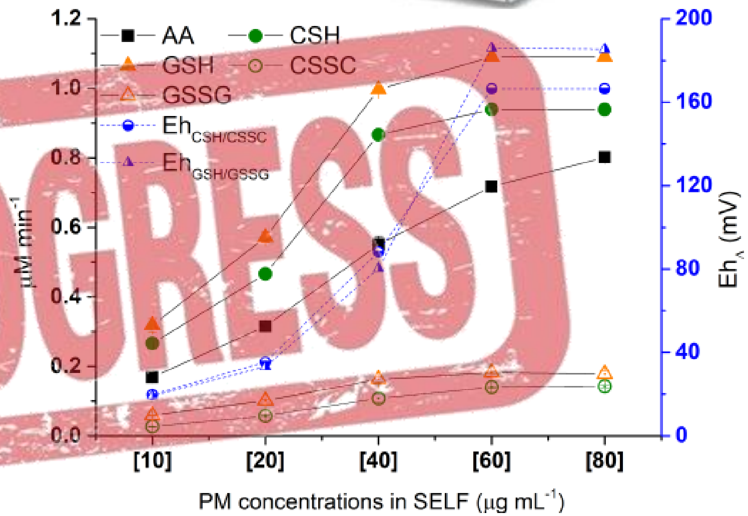
Why physical activity important?

⇒ **Different sources operate in different microenvironments**
⇒ **Affect chemical composition**
⇒ **Particle toxicity is very different !!!**

LTQ-Orbitrap Mass Spectrometer @UCAM.

The *oxidative potential* of inhalable airborne particles is a measure of their ability to directly cause oxidative stress in the lung by depleting the antioxidants naturally present in the lung fluids.

- Extraction of inhalable and respirable PM samples in a surrogate lung fluid containing glutathione and ascorbic acid (natural antioxidant).
- HPLC-MS analysis of the extracts.
- Measurements of the kinetics of the depletion of the natural antioxidants.



Example of depletion kinetics from Shahpoury et al. 2019, Atmos. Meas. Tech., 12, 6529–6539, 2019.

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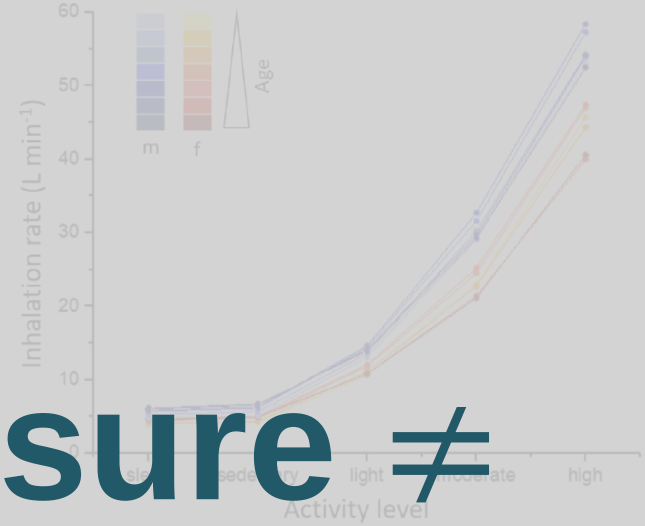
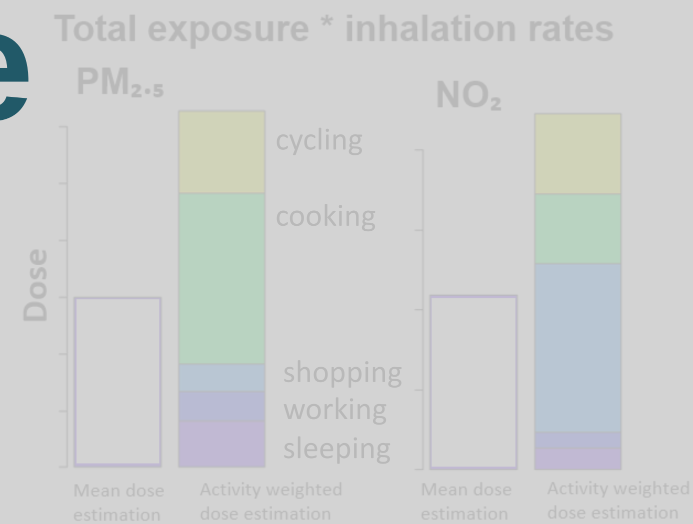
Deployment of a PAM: illustrative example

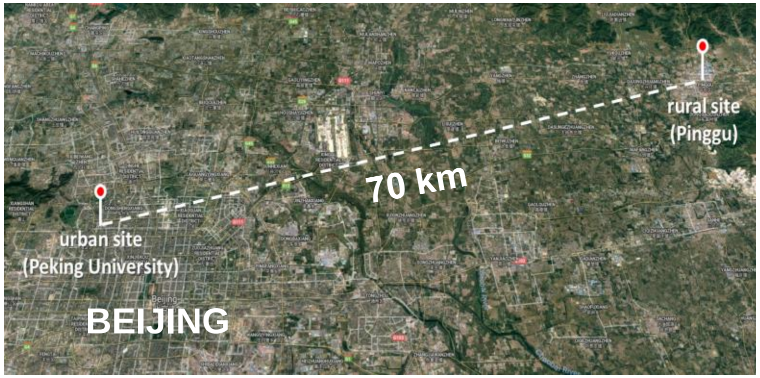
Time series of PAM parameters during a typical day





Personal exposure ≠ Personal dose

The AIRLESS project



~ 250 participants

- 2 weeks summer/winter
- Parallel medical monitoring


Journal of Exposure Science & Environmental Epidemiology (2020) 30:981–989
https://doi.org/10.1038/s41370-020-0259-6

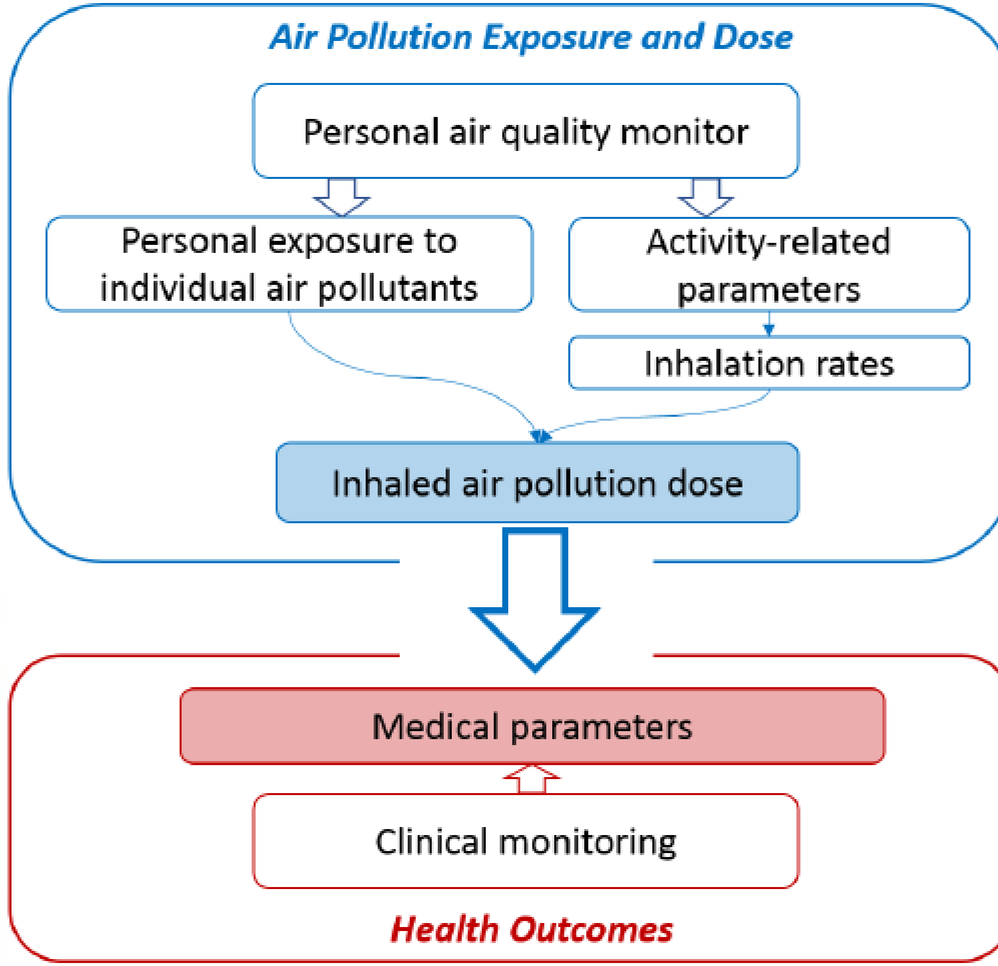
ARTICLE

Using low-cost sensor technologies and advanced computational methods to improve dose estimations in health panel studies: results of the AIRLESS project

Lia Chatzidiakou[1] · Anika Krause[1] · Yiqun Han[2,3,4] · Wu Chen[3] · Li Yan[2,4] · Olalekan A. M. Popoo
Mike Kellaway[5] · Yangfeng Wu[6] · Jing Liu[7] · Min Hu[3,8] · AIRLESS team · Ben Barratt[2,4,9] · Frank J. I
Tong Zhu[3,8] · Roderic L. Jones[1]

Received: 14 January 2020 / Accepted: 29 July 2020 / Published online: 12 August 2020

Chatzidiakou et al., 2020



To establish more reliable links between air pollution exposure and health (in China)

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Urban Beijing

High-rise residential blocks

Centralised heating

Peri-urban Beijing (Pinngu)

Agriculture activities

Biomass burning for domestic energy (cooking, heating)

Frequent “haze” episodes

Atmos. Chem. Phys., 19, 7519–7546, 2019
https://doi.org/10.5194/acp-19-7519-2019

Atmospheric Chemistry and Physics
EGU

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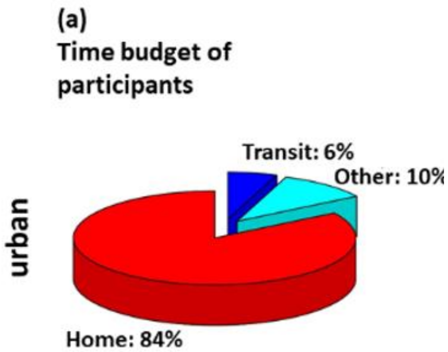
Introduction to the special issue “In-depth study of air pollution sources and processes within Beijing and its surrounding region (APHH-Beijing)”

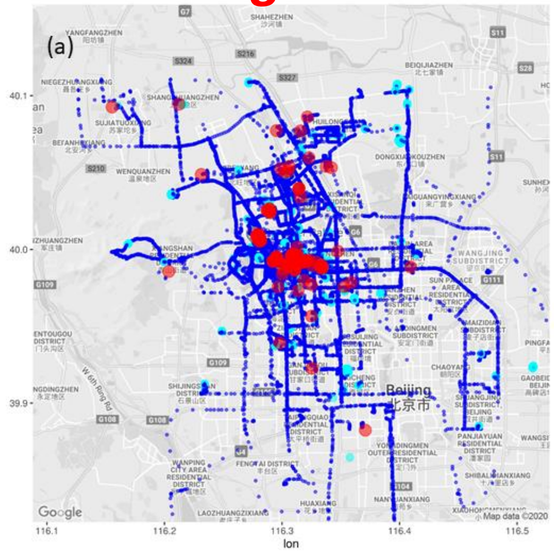
Personal activity vs ambient monitors…

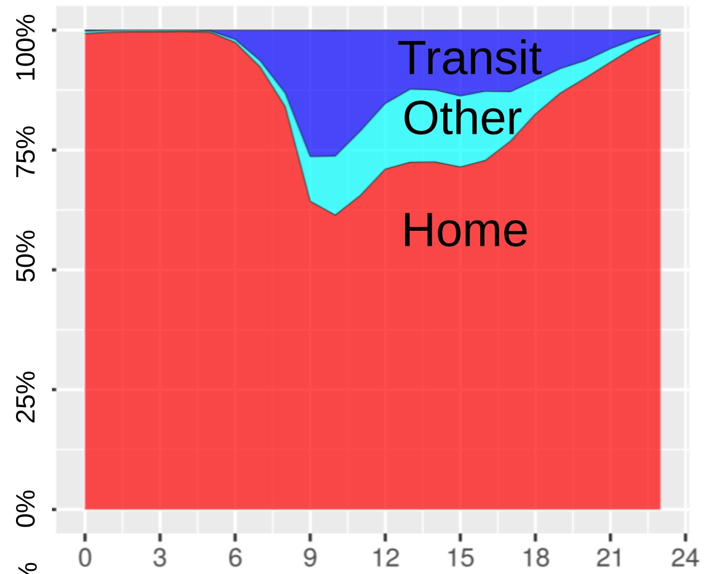
1) **Over 80% of time spent indoors**

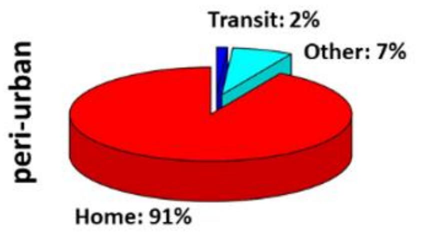
2) **Large spatial coverage**

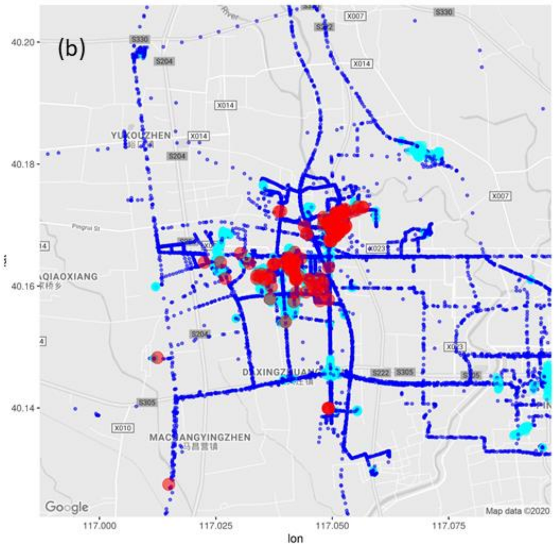
3) **Diurnal patterns**

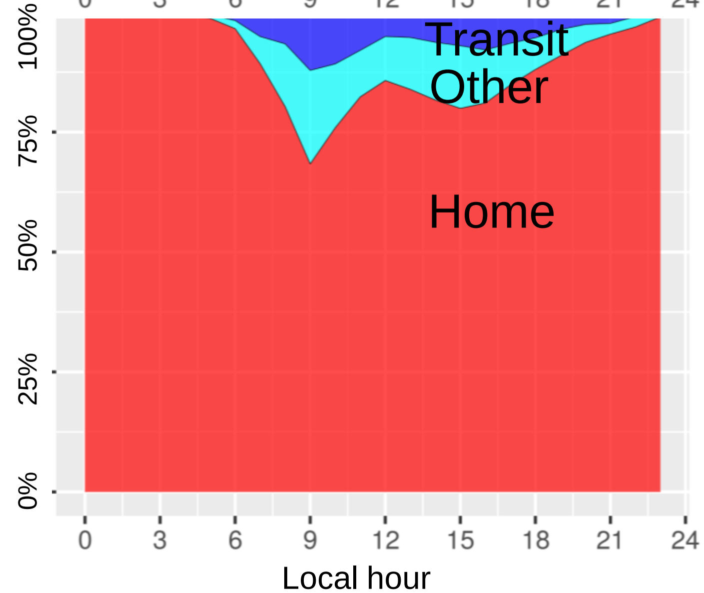












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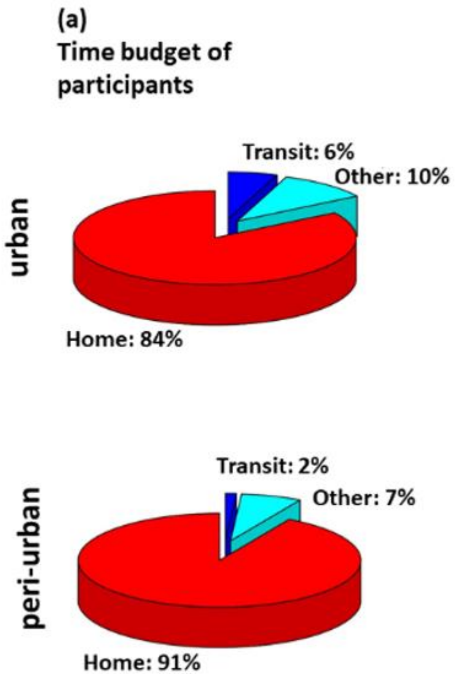
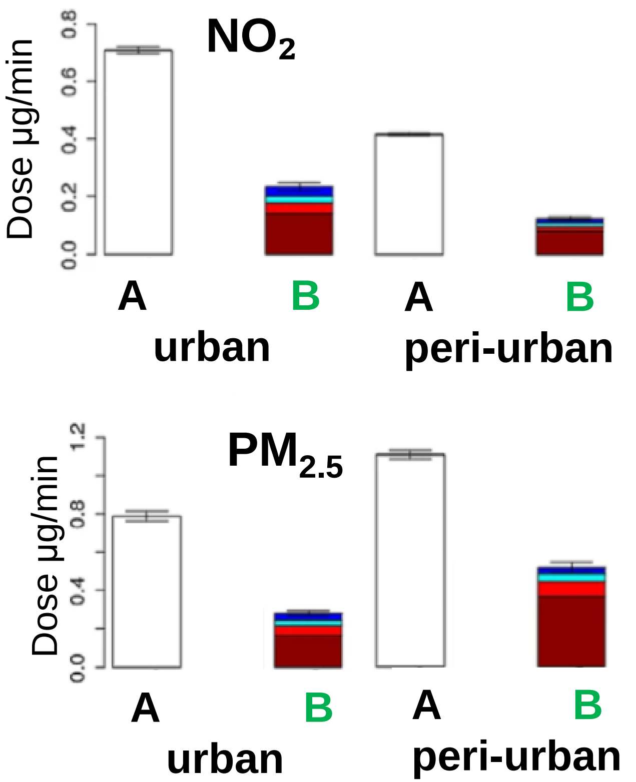
Personal activity vs ambient monitors…

1) Over 80% of time spent indoors





A: ambient measurements + generic inhalation

B: personal monitoring + activity

2) Exposure not well represented (overestimated) by outdoor air quality…..

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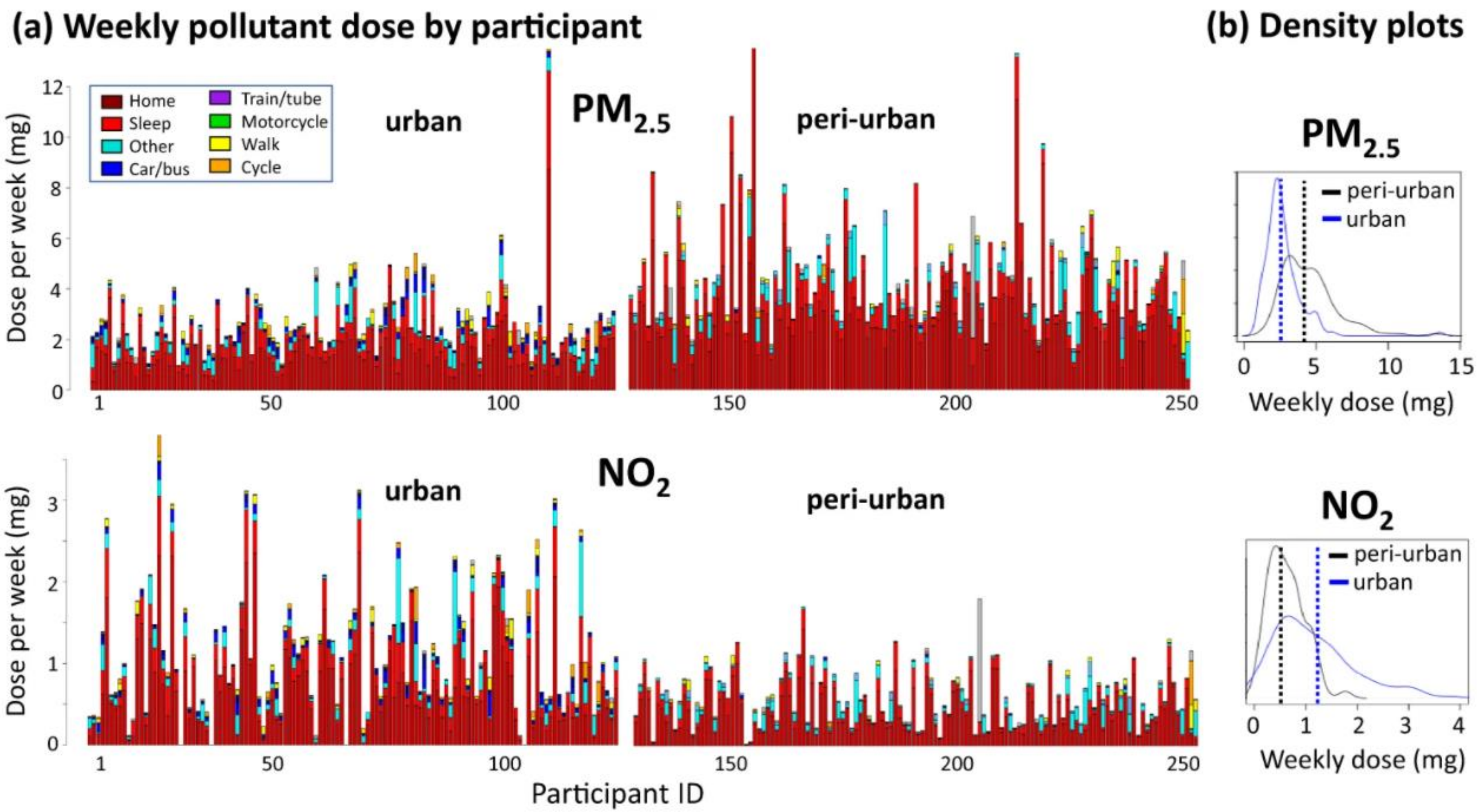
The AIRLESS project: personal dose



The home microenvironment was the most important modifier of personal dose

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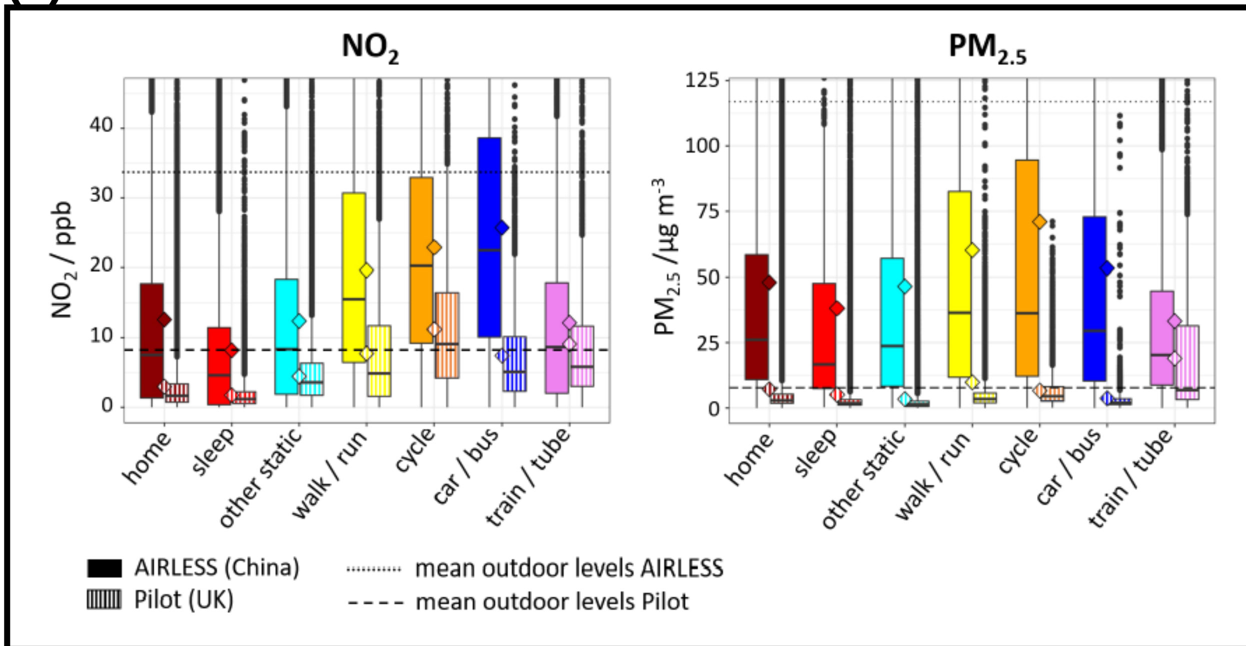
How does this compare to the UK?

(a) Absolute concentrations



Pollutants monitored with PAMs in 250 AIRLESS participants and 35 London participants during a week.

1) ***Outdoor affects personal*** *exposure*
2) ***CHINA: home*** *exposure* ***high***
3) ***UK: PM in underground*** *high*

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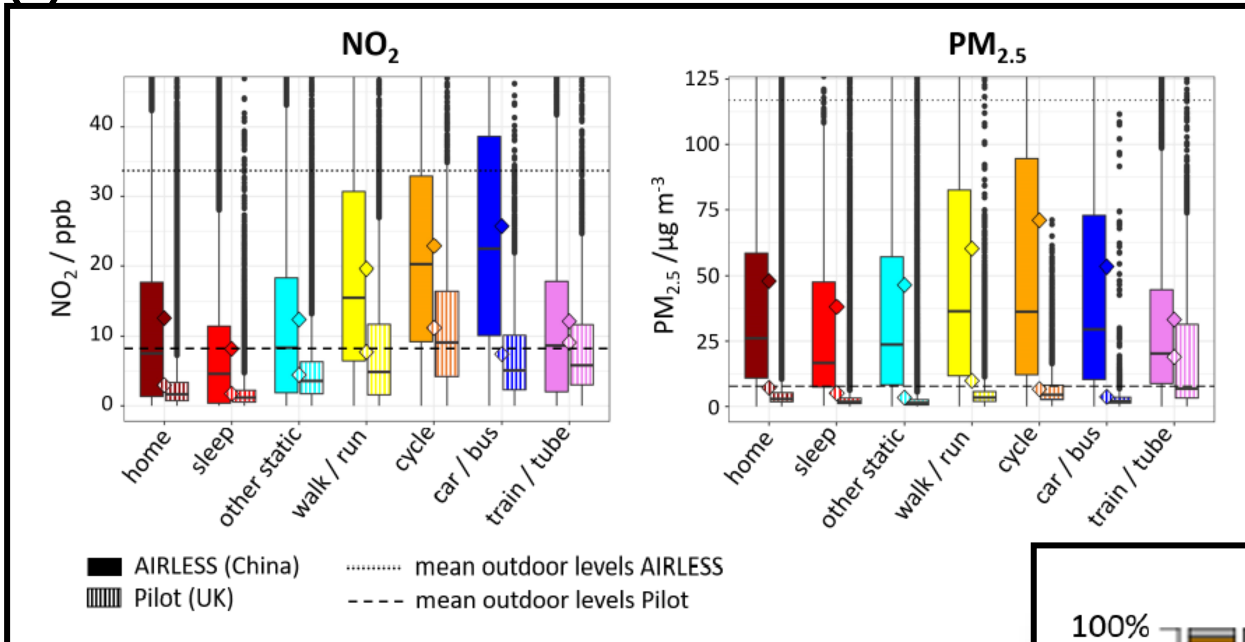
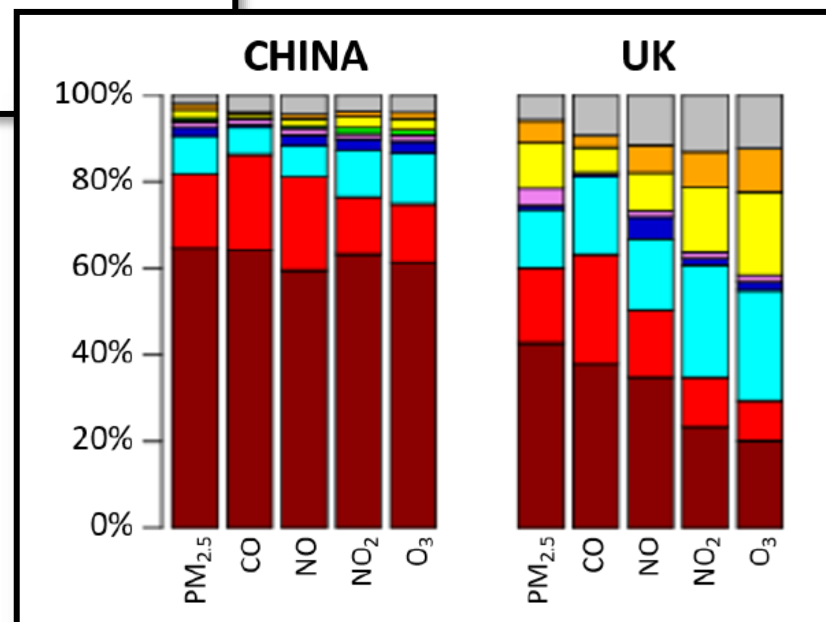
How does this compare to the UK?

(a) Absolute concentrations



Pollutants monitored with PAMs in 250 AIRLESS participants and 35 London participants during a week.

(b) Normalised dose



1) ***Outdoor affects personal*** *exposure*

2) ***CHINA: home*** *dominates exposure*

3) ***UK: PM in underground*** *very high*

4) ***UK: commuting*** *significant faction*

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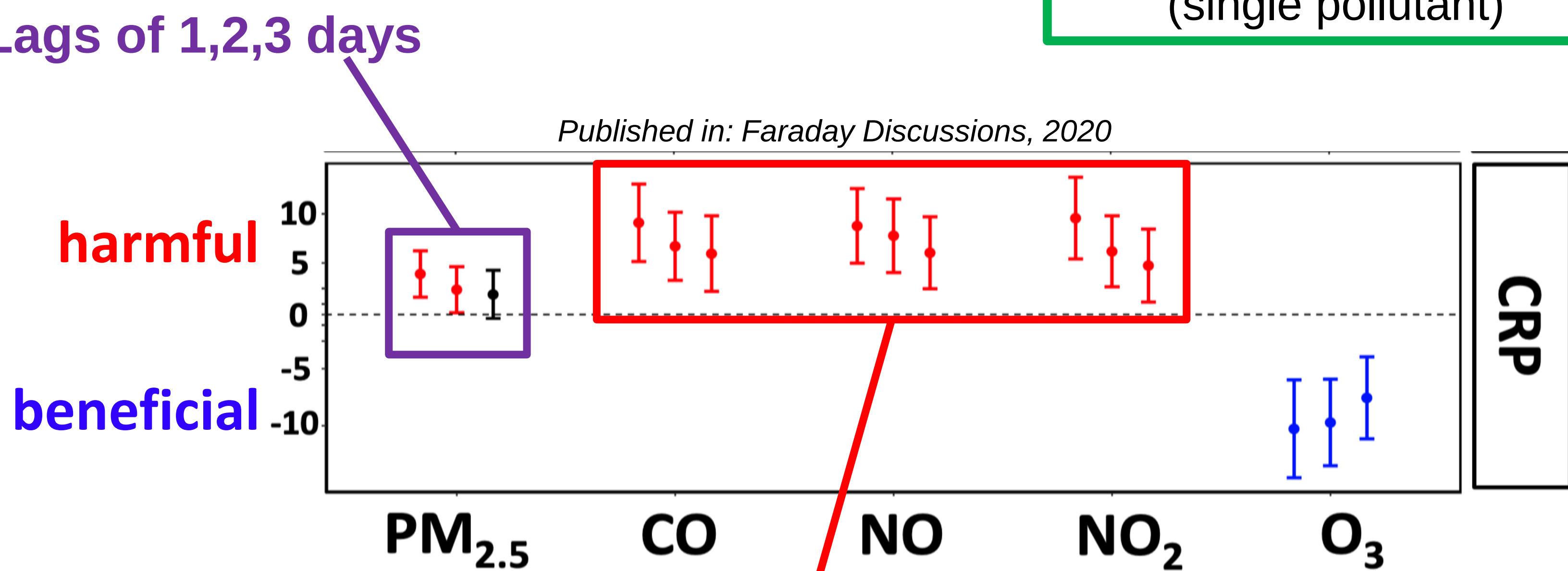
Relative (health) risks of different pollutants

(using ambient air measurements)

Mixed effect linear models
(single pollutant)



C-reactive protein (CRP) is released into the blood within a few hours after tissue injury, the start of an infection or other inflammation.

- ***$PM_{2.5}$, CO, NO and NO_2 all show significant harmful associations (proxies?)***
- ***O_3 shows significant beneficial outcome (?)***

Analysis and graph by Yiqun Han

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Relative (health) risks of different pollutants

(using ***personal*** measurements)

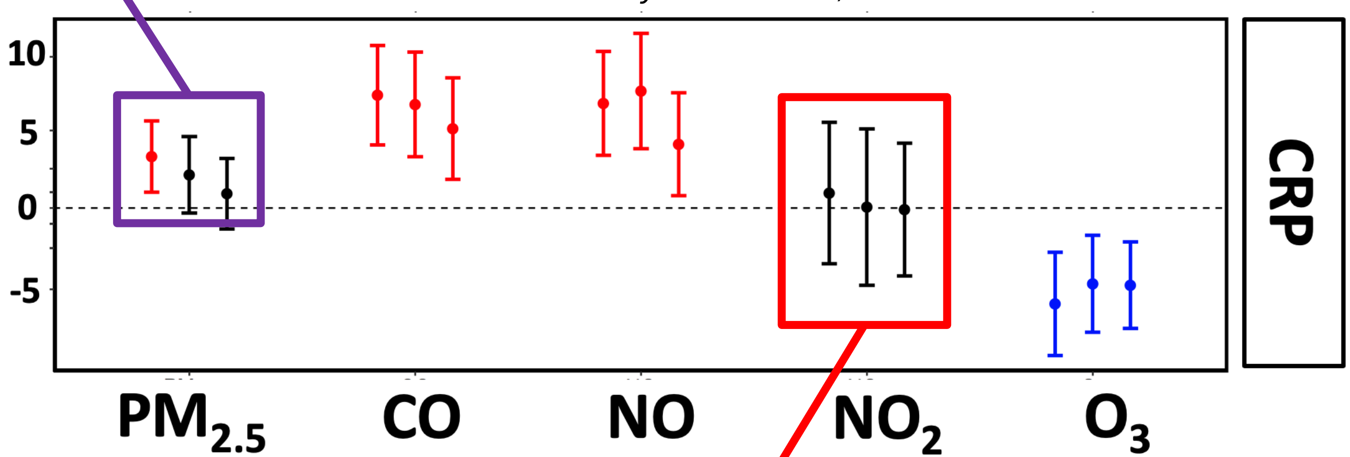
Mixed effect linear models (single pollutant)

Lags of 1,2,3 days

Published in: Faraday Discussions, 2020

harmful

beneficial



C-reactive protein (CRP) is released into the blood within a few hours after tissue injury, the start of an infection or other inflammation.

Key difference: NO_2 risk no longer statistically significant……

Exposure 'error'…..

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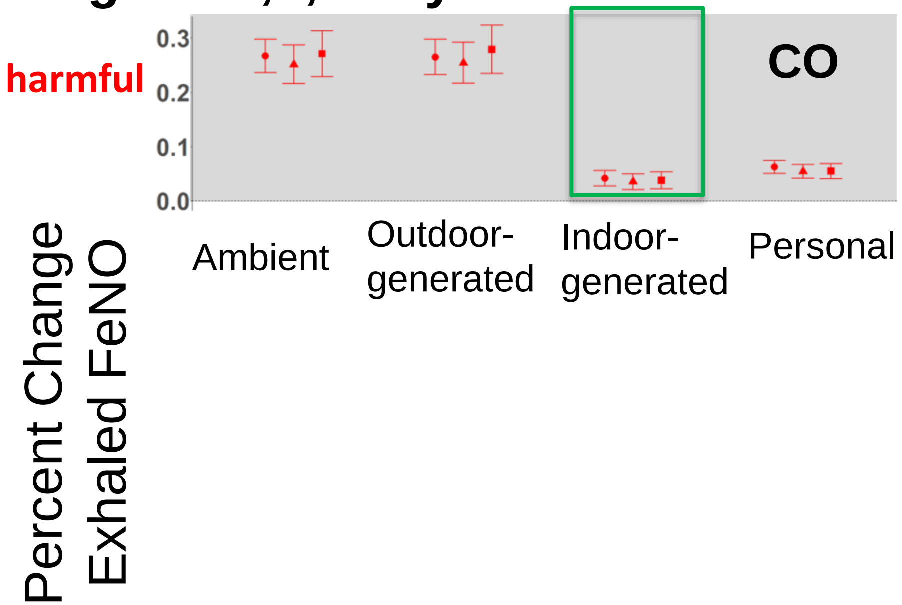
Analysis and graph by Yiqun Han

Relative (health) risks of different pollutants

Lags of 1,2,3 days



Mixed effect linear models (single pollutant)

⇒ ***Indoor-generated CO a proxy for indoor combustion sources?***

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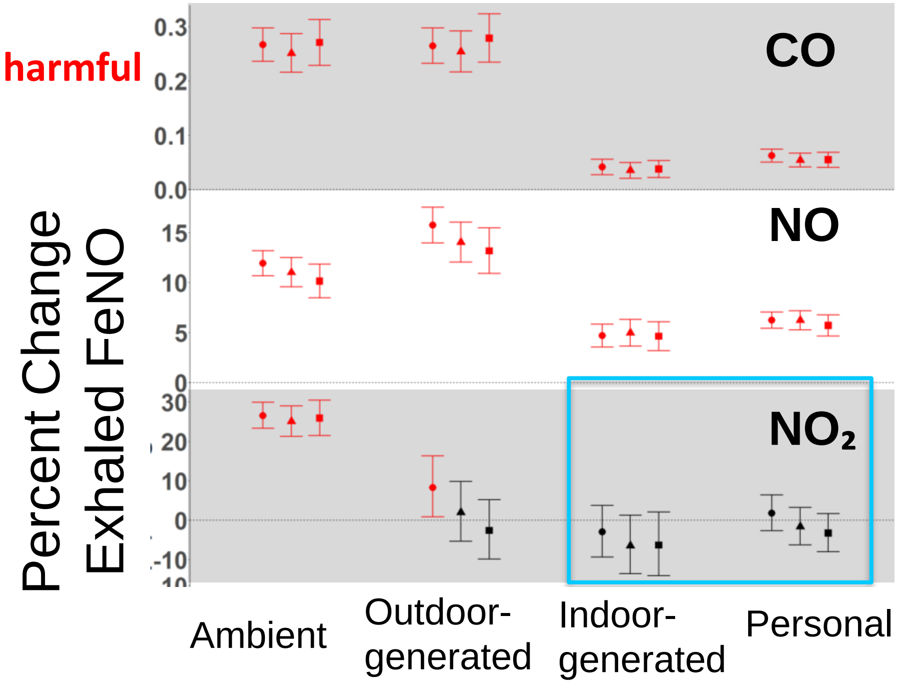
Relative (health) risks of different pollutants

Lags of 1,2,3 days



Mixed effect linear models (single pollutant)

⇒ ***Indoor-generated CO a proxy for indoor combustion sources?***

⇒ ***Outdoor-generated NO_2 a proxy for traffic intensity***

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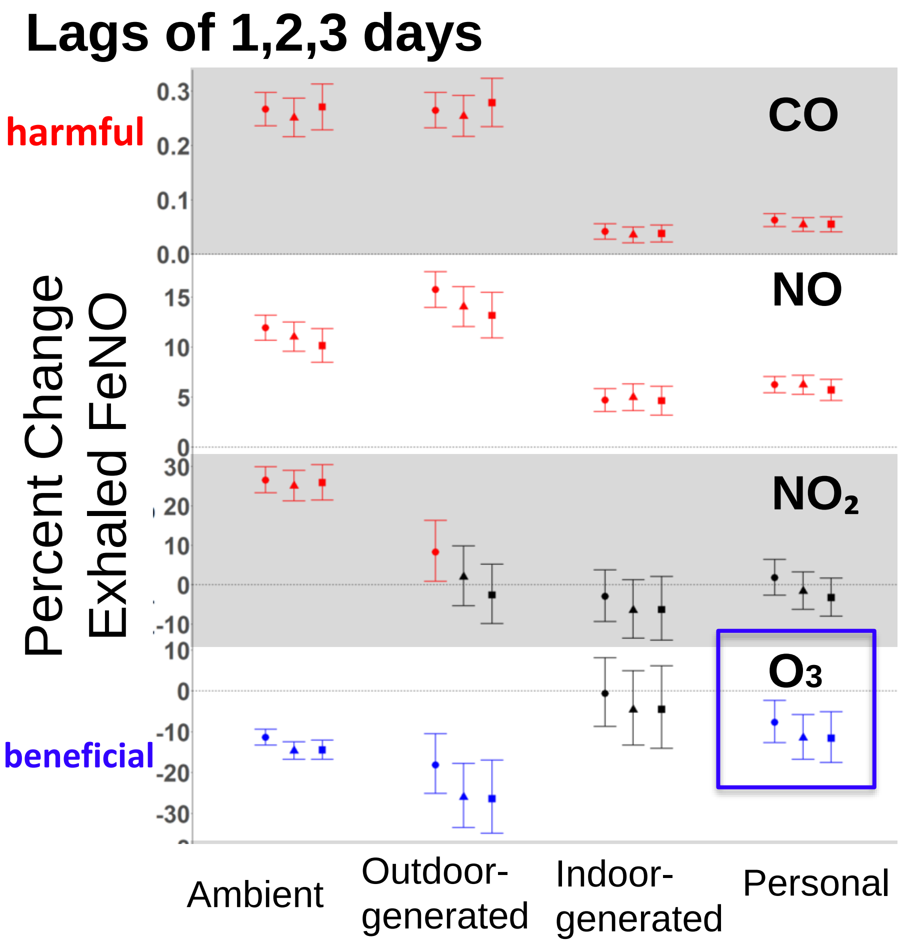
Relative (health) risks of different pollutants



Mixed effect linear models (single pollutant)

⇒ ***Indoor-generated CO a proxy for indoor combustion sources?***

⇒ ***Outdoor-generated NO_2 a proxy for traffic intensity***

⇒ ***Single-pollutant models cannot control for correlation (or anti-correlation) between pollutants***

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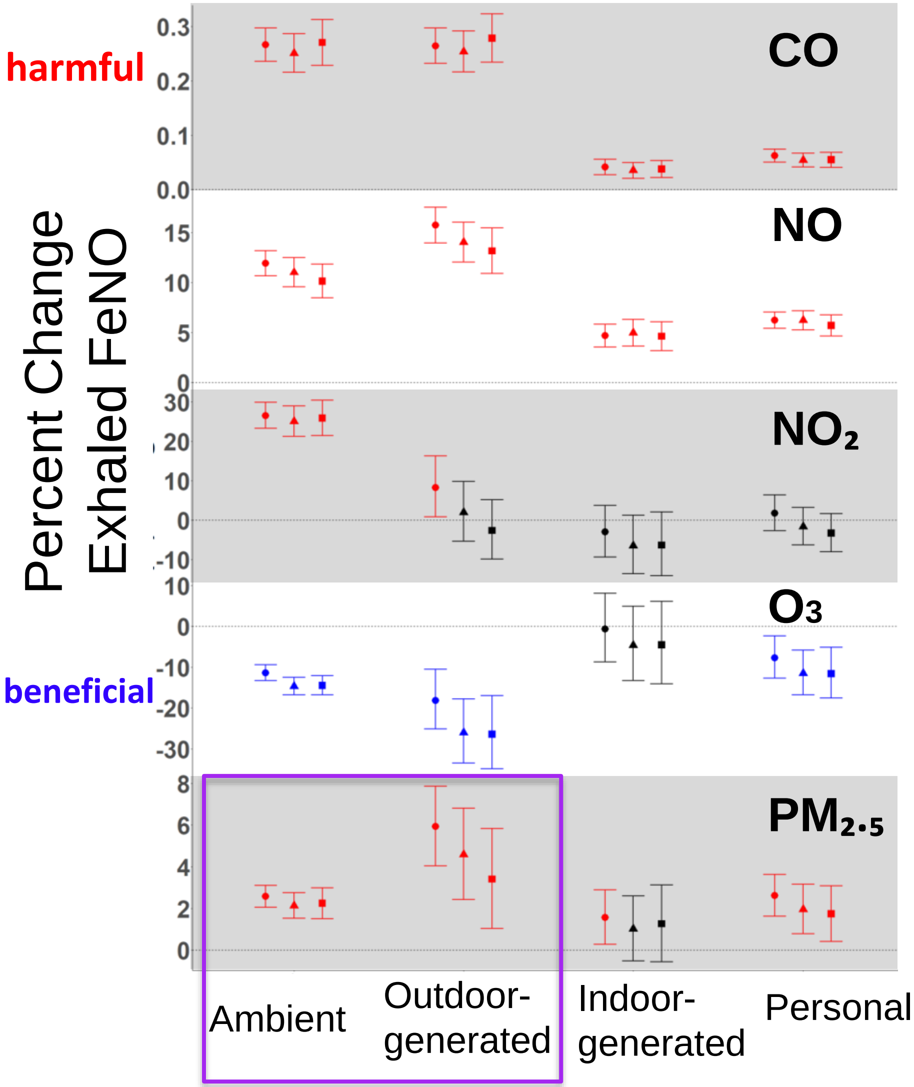
Relative (health) risks of different pollutants

Lags of 1,2,3 days



Mixed effect linear models (single pollutant)

- ⇒ ***Indoor-generated CO a proxy for indoor combustion sources?***
- ⇒ ***Outdoor-generated NO_2 a proxy for traffic intensity***
- ⇒ ***Single-pollutant models cannot control for correlation (or anti-correlation) between pollutants***
- ⇒ ***Outdoor-generated PM more toxic than previously thought***

Personal monitoring vs ambient measurements

⇒ ***Health risk assessment bias from exposure ‘error’***

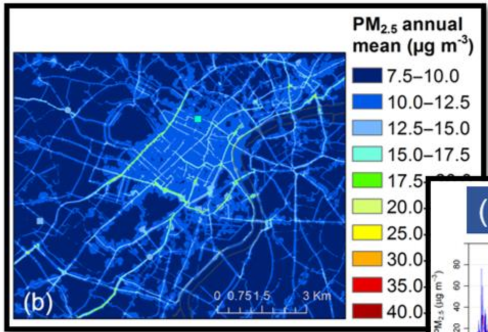
⇒ ***Effects of source-related exposure on health?***

⇒ ***Improved statistical methods!***

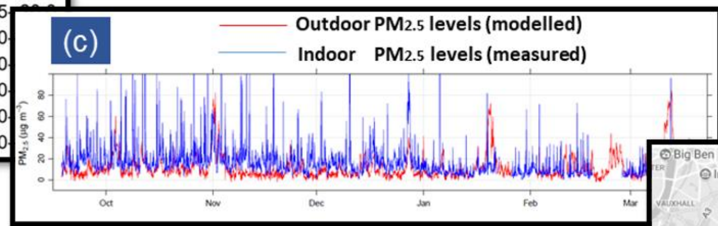
⇒ understanding and policy implications….

Measurements and models: the next steps

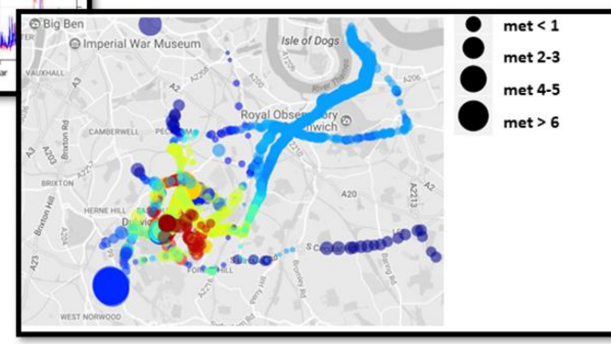
(a) Outdoor dispersion modelling



(b) Indoor air pollution modelling



(c) Activity modelling



⇒ Extrapolate personal exposure in large-scale health studies to create more reliable health-response functions

⇒ Advanced scientific knowledge for efficient policy and decision-making

⇒ Empower individuals/communities to reduce environmental health risks

⇒ Societal gains

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Dr Lia Chatzidiakou

ec571@cam.ac.uk

+ teams!!

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