MODELLING London's Air

MRC-PHE
Centre for Environment & Health

Public Health England | MRC Medical Research Council | Imperial College London | King's College London

David Dajnak

Environmental Research Group
King's College London

Air Quality Modelling at King's

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- LAEI 2016
- Post LAEI 2016
- London policies and Climate change
- Modelling for health research
- Human exposure modelling
- Future developments

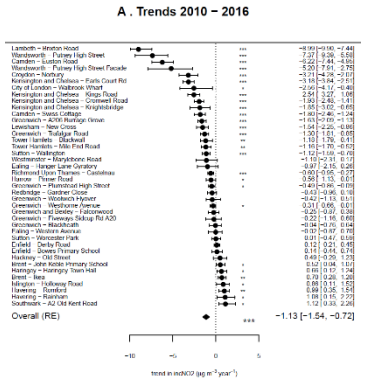
Overview

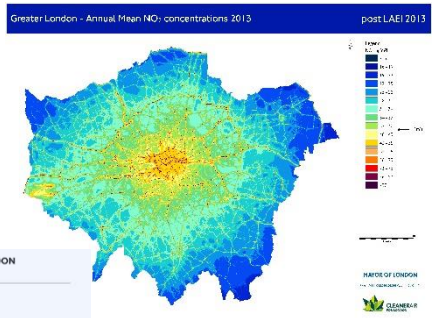
5 year funding total: £11,299,892

NIHR, NERC, MRC, ESA, HEI, NCAS, DEFRA, GLA, TfL, LA's, HPA, *IOSH and NGO's.*

Post Docs/Academics: 11 - PhDs: 14 – Papers: 150

Exposure/Policy



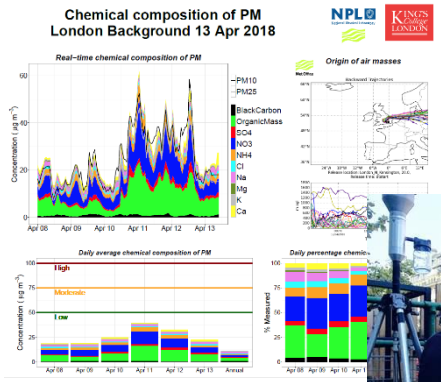


Air quality and health

Community engagement

www.breatheLondon.org

PM composition



Policy

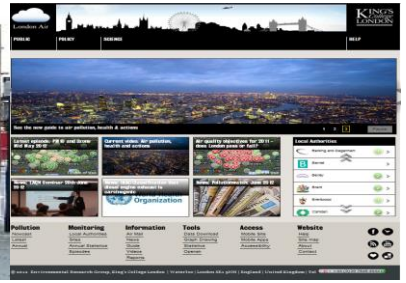
Model development

London Laboratory

Health research

Measurement

http://www.londonair.org.uk/LondonAir/Default.aspx



LAEI 2016

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New LAEI 2016

All sources have been updated

Main highlights (2013 versus 2016):

- Industrial/commercial oil: NOx doubled 1,500 to 2,900 tonnes
- Domestic Gas: NOx halved 6,600 to 2,900 tonnes
- Construction/demolition dust: PM_{10} large increase 65 to 2,376 tonnes

Main King's contribution

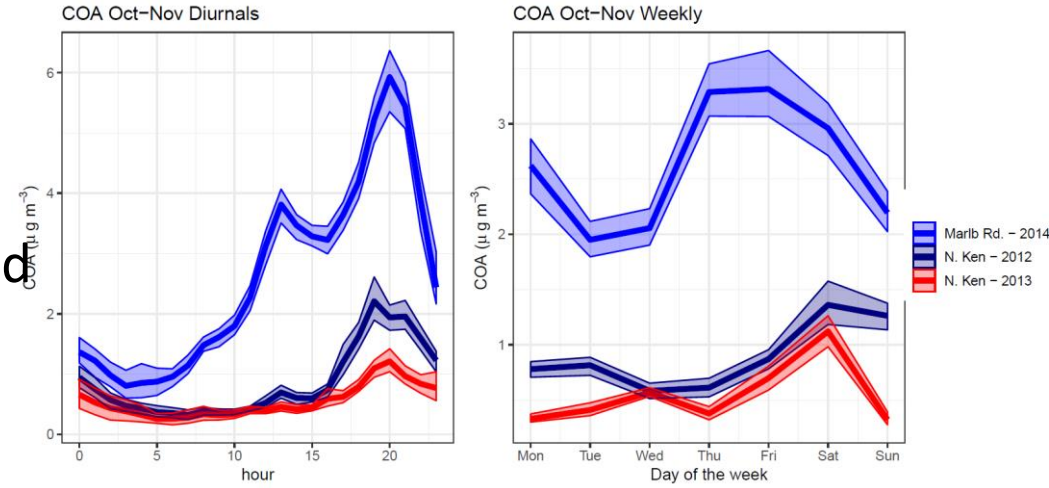
- Updated road transport and aviation sources
- NEW source: commercial catering (cooking) emissions
- NEW source: domestic wood burning (biomass) emissions
- NEW AQ background concentration approach (corrected for biomass)
- NEW AQ road dispersion approach
- NEW AQ shipping dispersion approach

Commercial catering (cooking) emissions sources

PM measurement at

- Marylebone Rd (1.2-2.4 μg m^{-3})
- North Ken (0.3-0.8 μg m^{-3})

Cooking emissions sources estimated to produce **548 tonnes of PM**

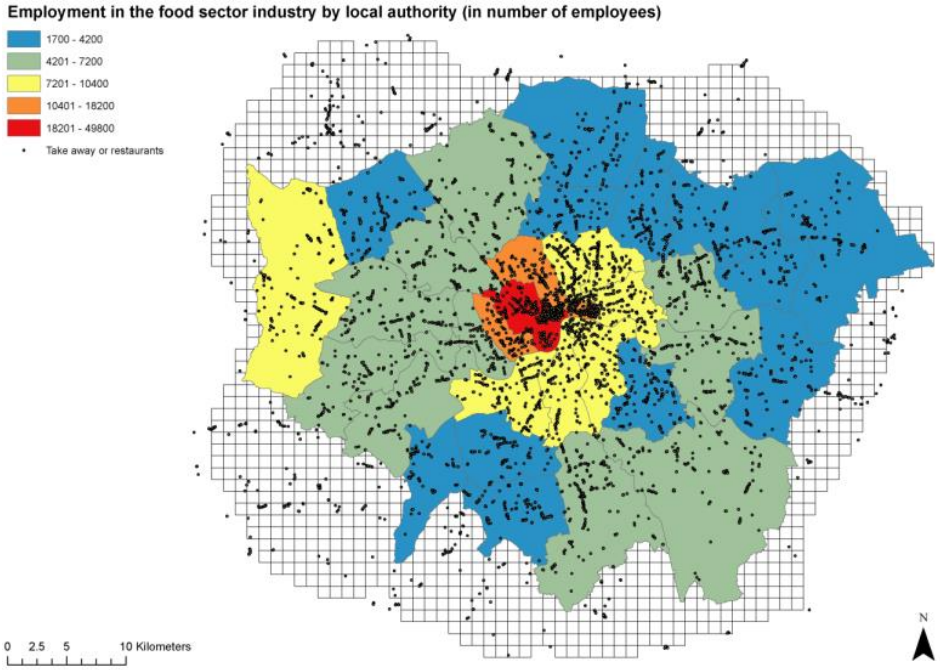


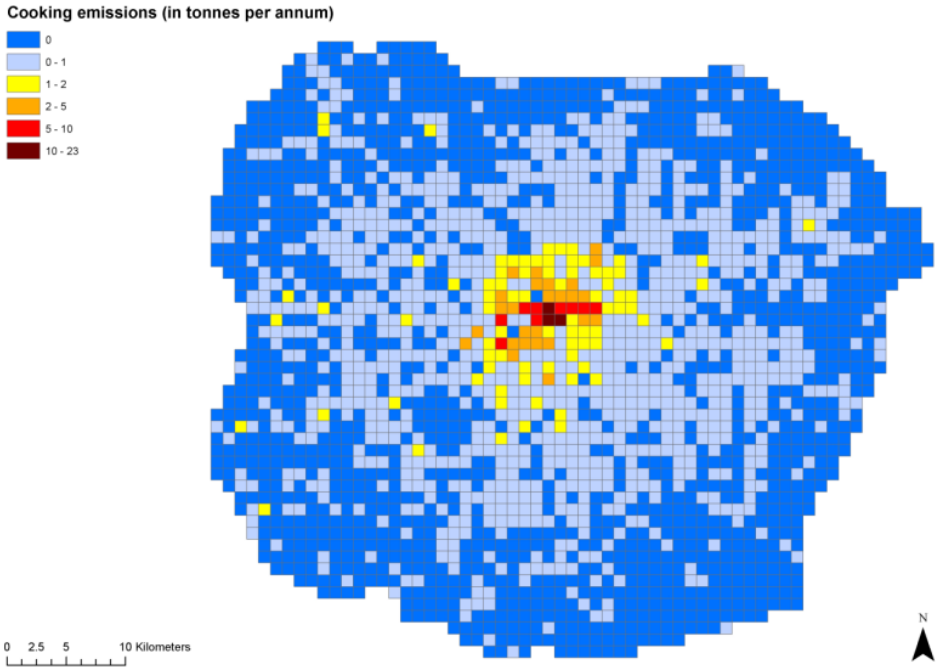
Spatial representation:

Commercial premises filtered for restaurant and Take Away combined with Employment for food industry

Predicted concentration:

1.45 MY1 and 0.66 μg m^{-3} KC1





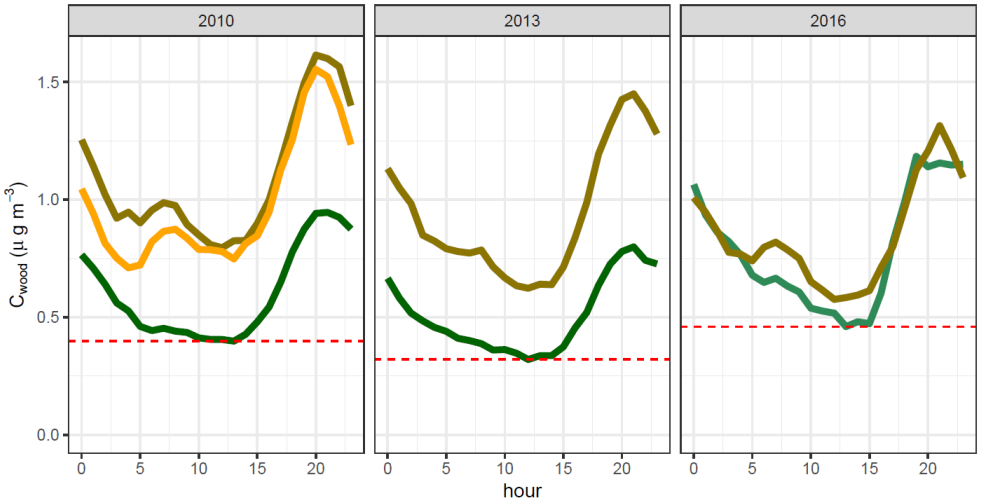
Domestic wood burning (biomass) emissions sources

- PM meas at rural and urban sites
- **Rural** concentration 0.39 μg m^{-3}
- **Urban** contribution at KC1

0.70/0.54/0.45 μg m^{-3} (2010/13/16)

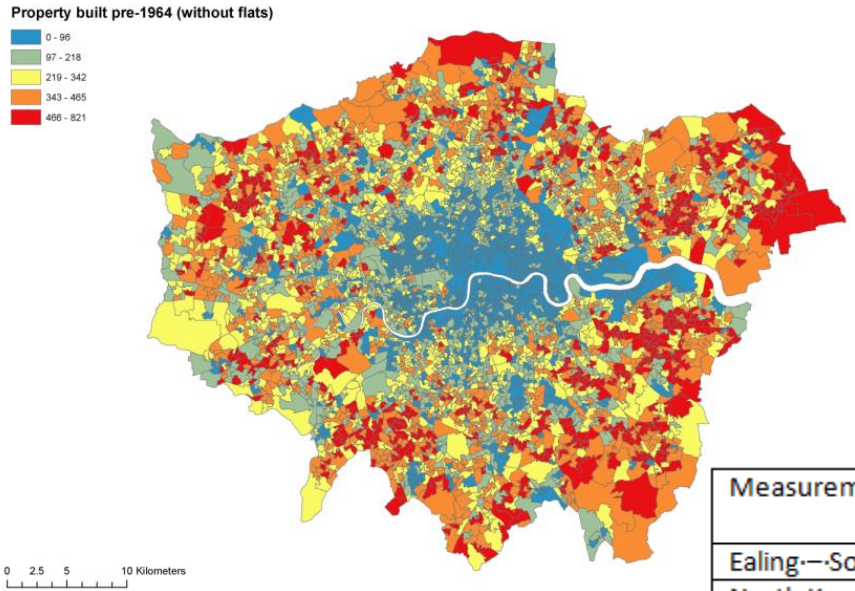
- Biomass **emissions** estimated

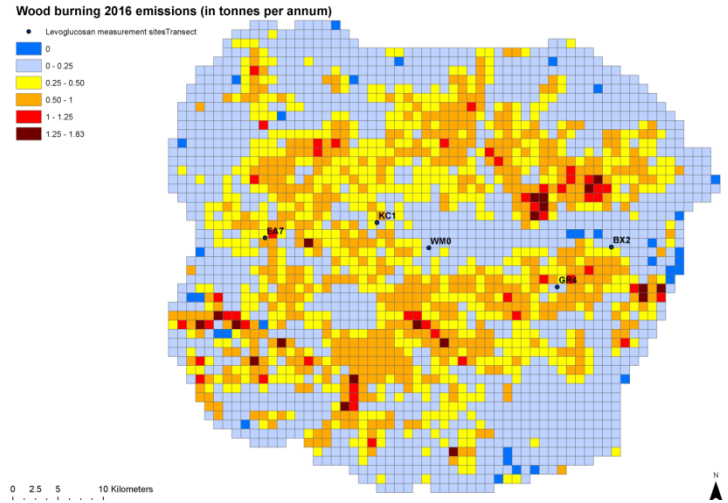
1216/938/781 t of PM (2010/13/16)



Spatial representation:

Property data filtered by age (pre 1964)



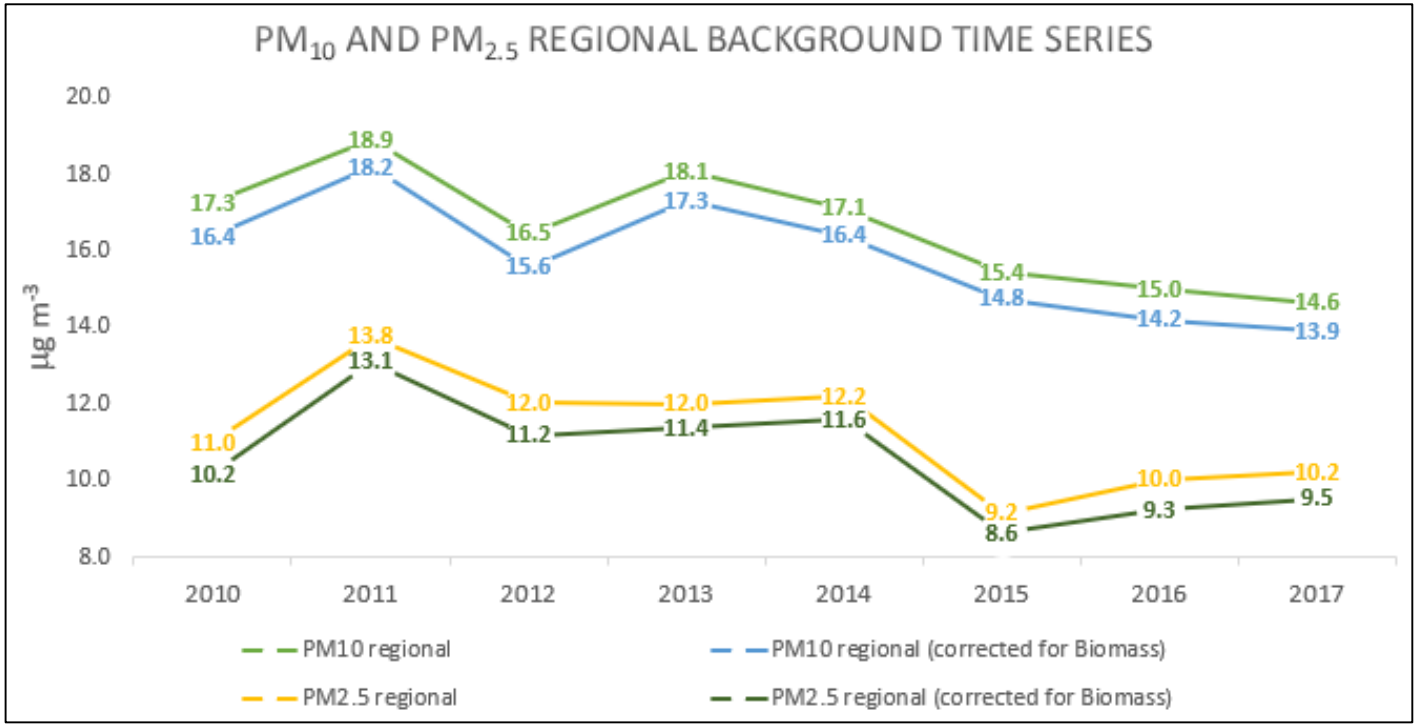


Levoglucosan transect (proportional to biomass PM)

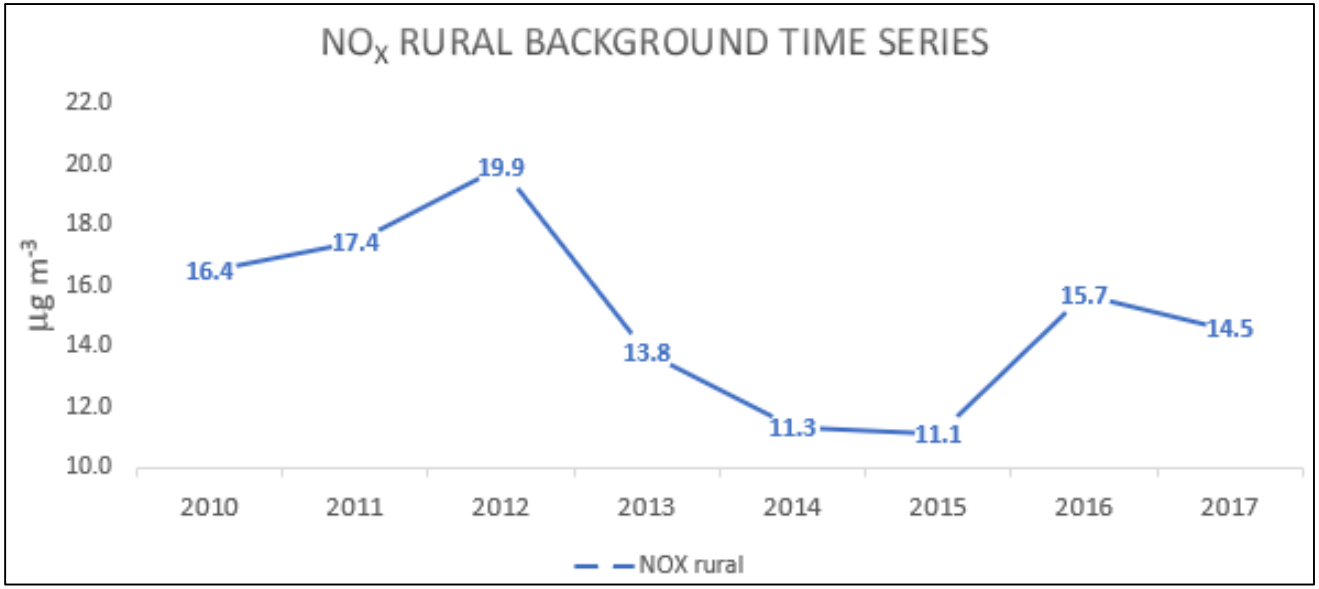
Measurement sites¤	Levoglucosan Mean¤	Estimated 2013 PM concentration (from wood burning increment)¤
Ealing—Southall (EA7)¤	190 ± 21¤	0.49¤
North Kensington KC1)¤	180 ± 20¤	0.55¤
Westminster—Horse Ferry Rd (WM0)¤	162 ±18¤	0.49¤
Greenwich—Eltham (GR4)¤	180 ± 20¤	0.53¤
Bexley—Belvedere (BX2)¤	190 ± 21¤	0.42¤

Regional and Rural Background Concentrations

Regional background $PM_{10}/PM_{2.5}$:
NEW: Correction for wood burning

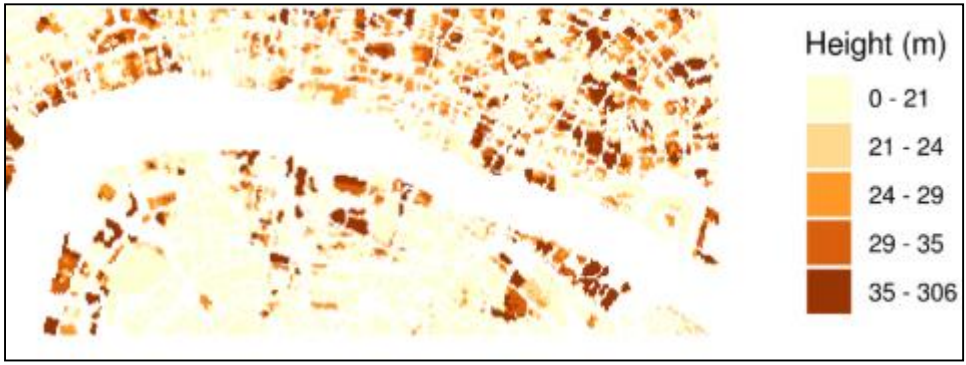


Rural NO_X:

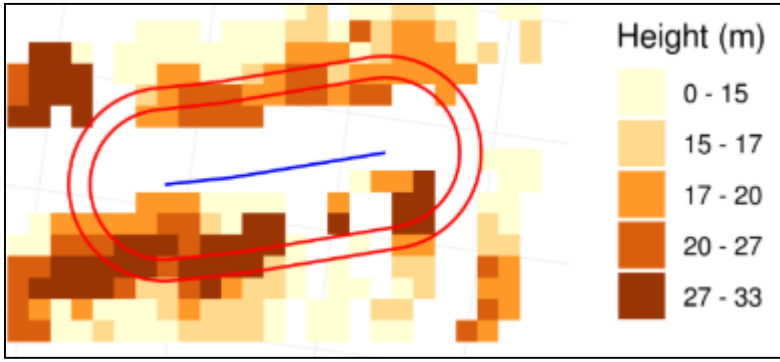


Road dispersion

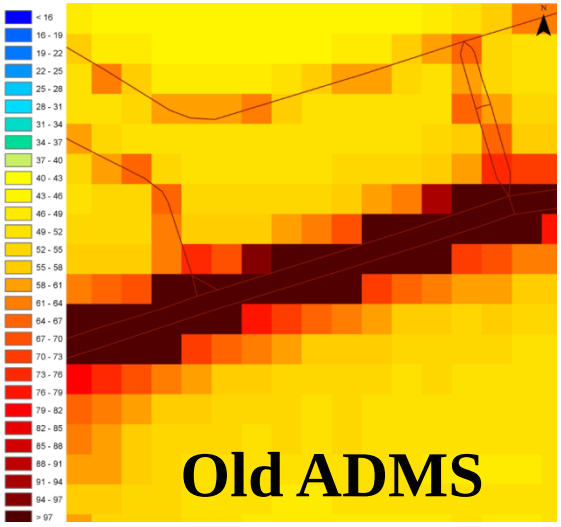
London building heights from the EU Copernicus project (10x10m)



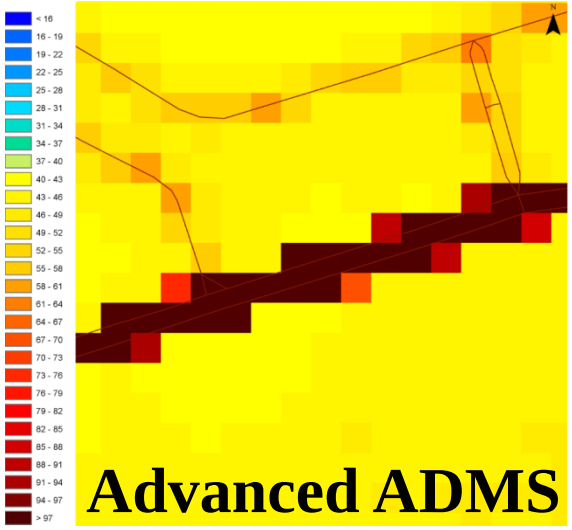
Extracting heights using road buffers and **widths** using lanes, pavements, hard shoulder and central reservations



All road links were **classified** into 200+ road types by heights, width, orientation

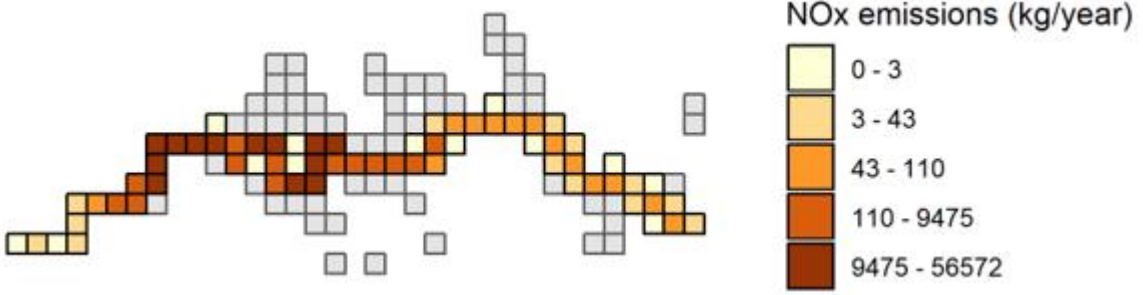


Dispersion Kernels using

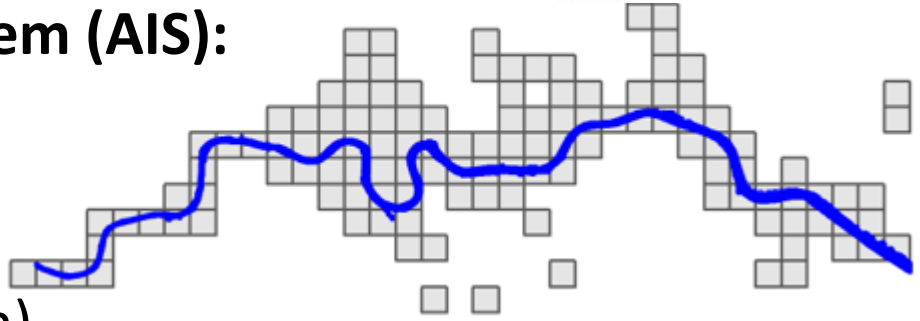


Shipping dispersion

- Using **PLAEI 2016**



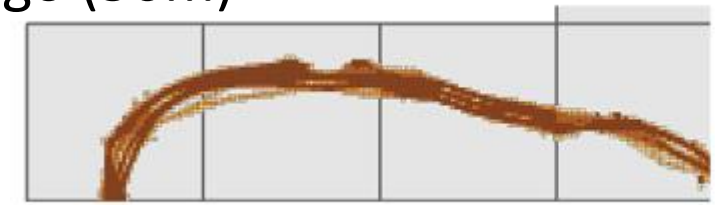
- **2016 Automatic Identification System (AIS):** position and unique ID

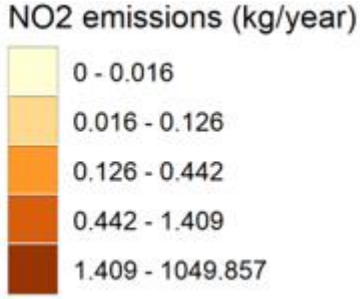


- **Four groups (release height):**

Passenger ferry (5m), Dredger (17.5m)
General cargo (30m), RoRo cargo (50m)

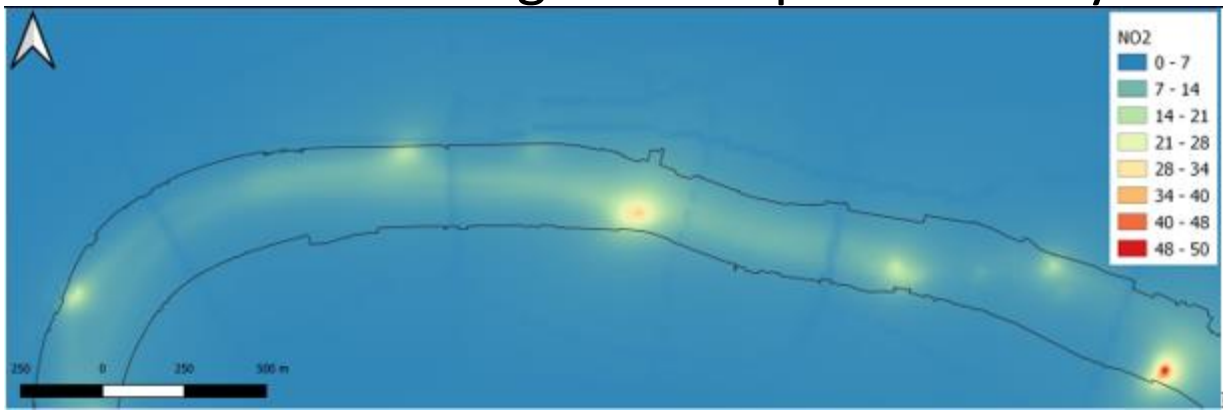
- **Categorise each GPS point:**





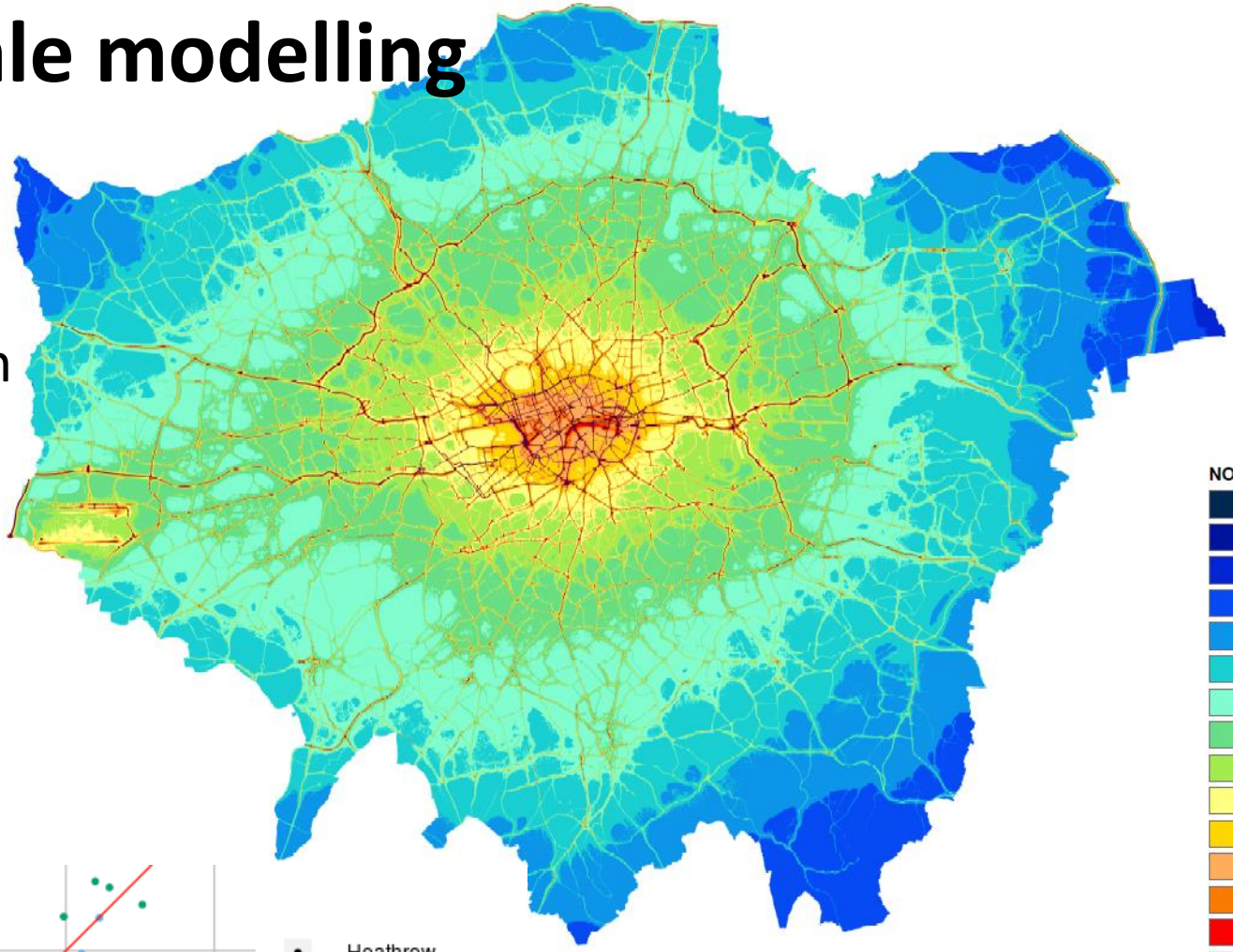
- **Distribute sailing/berth emissions:** 20x20m grids GPS point density

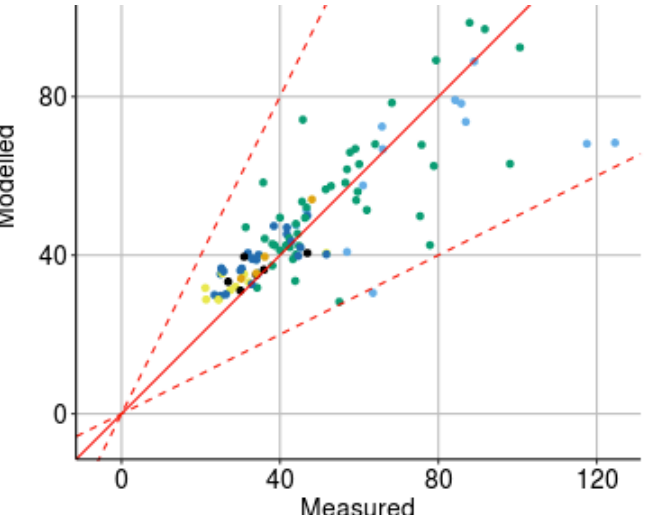
- **Dispersion of shipping emissions:** points every 20m by source category



Local scale modelling

Annual mean NO_2 concentration 2016 (LAEI2016)





- Heathrow
- Industrial
- Kerbside
- Roadside
- Suburban backgrou
- Urban background

Model 1 Stats

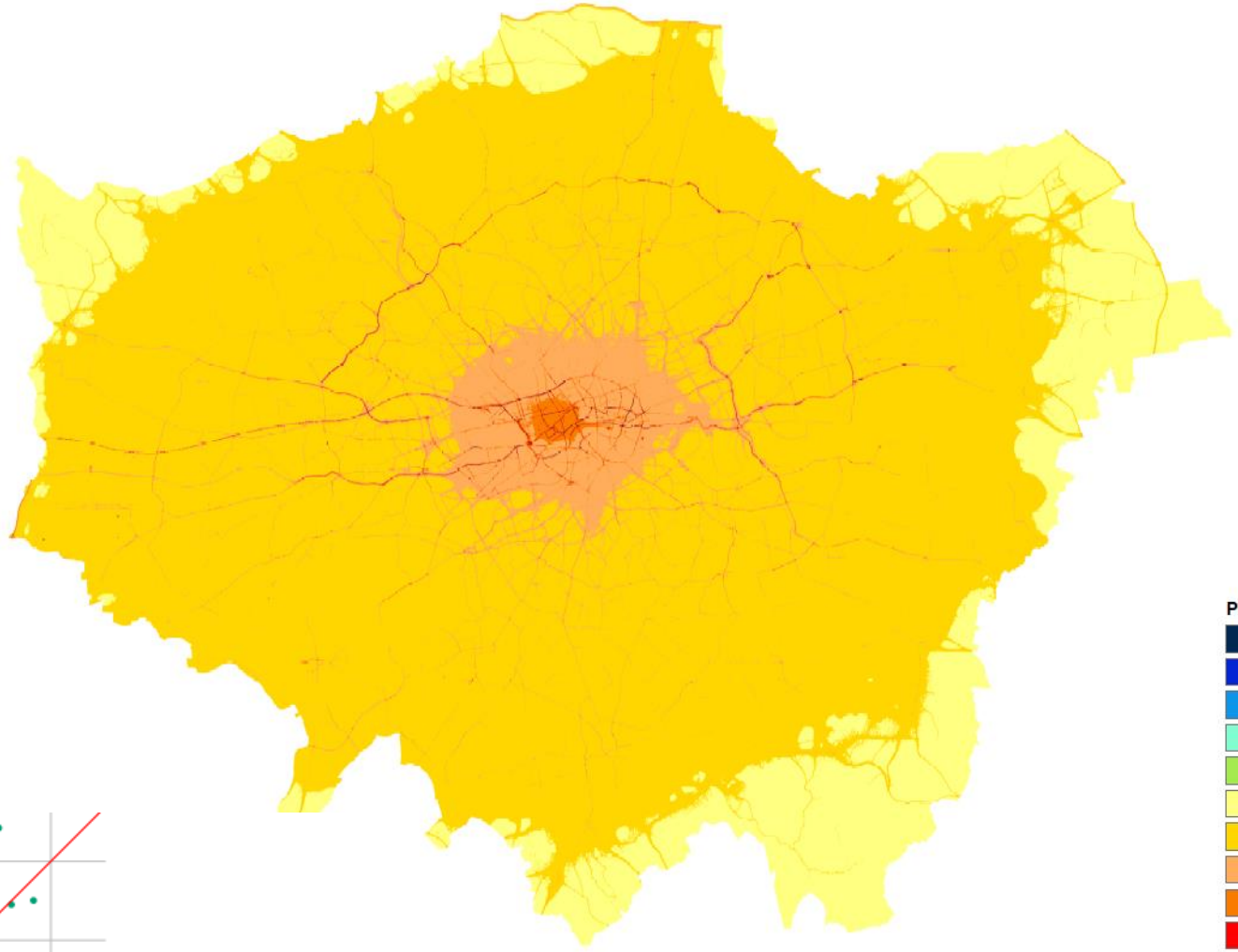
n	FAC2	MB	MGE	NMB	NMGE	RMSE	r
100	0.99	-0.18	8.23	-0.00	0.17	12.64	0.81

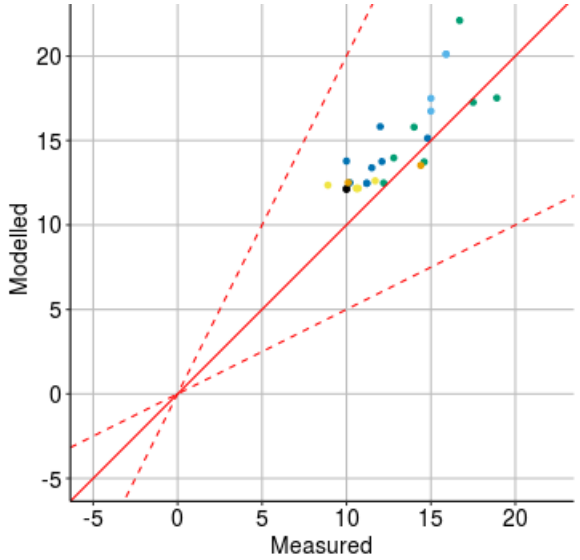
NO_2 (µg/m³)

- < 16
- 16 - 19
- 19 - 22
- 22 - 25
- 25 - 28
- 28 - 31
- 31 - 34
- 34 - 37
- 37 - 40 ← Limit
- 40 - 43
- 43 - 46
- 46 - 49
- 49 - 52
- 52 - 55
- 55 - 58
- > 58

Local scale

Annual mean $PM_{2.5}$ concentration 2016 (LAEI2016)





Heathrow
Industrial
Kerbside
Roadside
Suburban backgrou
Urban background

Model 2 Stats

n	FAC2	MB	MGE	NMB	NMGE	RMSE	r
28	1.00	1.78	2.02	0.14	0.16	2.40	0.83

$PM_{2.5}$ (µg/m³)

- 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- > 22

Post LAEI 2016

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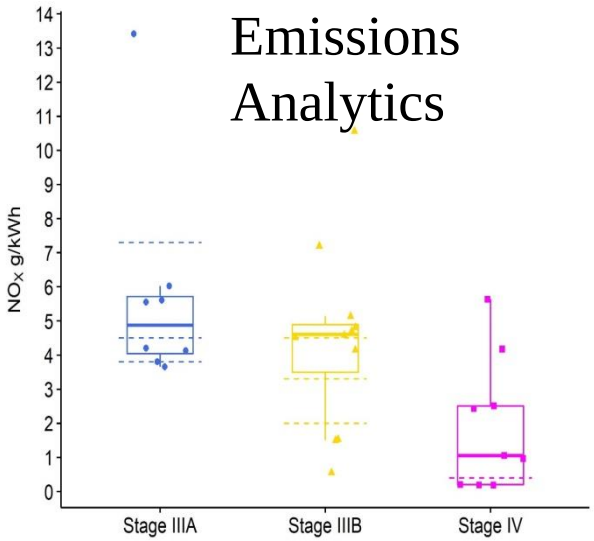
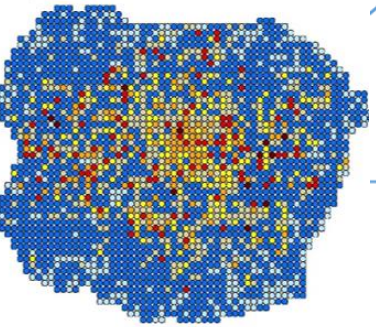
NRMM emissions (work in progress)



Excavator

Dumper



Real world emission factors

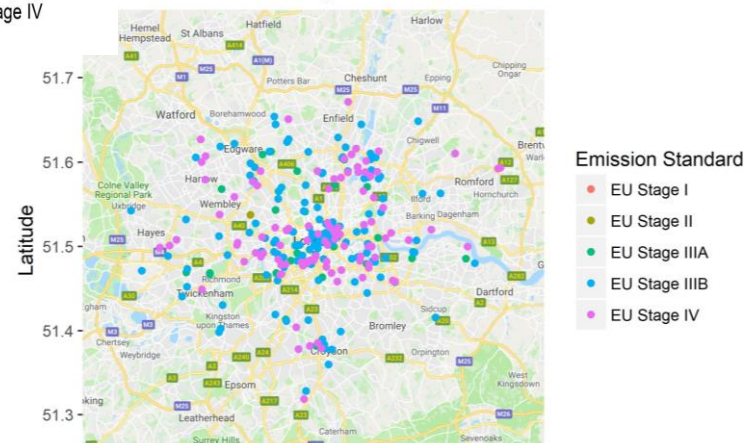
Fleet composition and location

Activity data

Construction register (types of NRMM used at sites)

'LOW EMISSION ZONE' FOR NON-ROAD MOBILE MACHINERY

NRMM active during 2017 in London



Date	Working Status	Working Hour	Actual Working Hours	ATT Working	Fuel	Water Temp.
11/30/2015	00:00 06:00 12:00 18:00 24	7.0 H	6.0 H	4.4 H		
11/29/2015	00:00 06:00 12:00 18:00 24	0.0 H	0.0 H	-		
11/28/2015	00:00 06:00 12:00 18:00 24	3.1 H	2.1 H	1.4 H		
11/27/2015	00:00 06:00 12:00 18:00 24	7.5 H	4.9 H	3.1 H		
11/26/2015	00:00 06:00 12:00 18:00 24	4.0 H	3.4 H	1.5 H		
11/25/2015	00:00 06:00 12:00 18:00 24	5.4 H	4.4 H	1.8 H		
11/24/2015	00:00 06:00 12:00 18:00 24	4.6 H	2.3 H	0.8 H		
11/23/2015	00:00 06:00 12:00 18:00 24	4.6 H	1.9 H	0.8 H		
11/22/2015	00:00 06:00 12:00 18:00 24	0.0 H	0.0 H	-		
11/21/2015	00:00 06:00 12:00 18:00 24	3.2 H	2.6 H	1.2 H		

Operators Data: e.g. some machines are idling, generators are operated 24*7, other machines are operated only 8 hours a day, etc.

Non-exhaust emissions (work in progress)

Transport for London

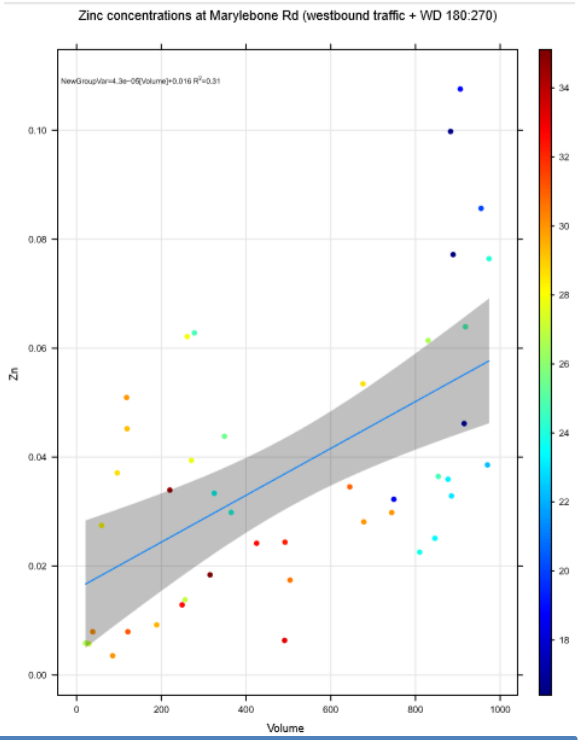
Hourly traffic data (speed, volume, class) ANPR data

Sources of vehicle PM emissions in LAEI 2016: Based on Harrison (2012) at one road side increment (month long campaigns). **They are uncertain!!**

	LDV	HDV	% total
PM10 Brake	79	21	41
PM10 Exhaust	83	17	12
PM10 Resuspension	20	80	36
PM10 Tyre	84	16	10
PM25 Brake	79	21	45
PM25 Exhaust	83	17	31
PM25 Resuspension	22	78	4
PM25 Tyre	84	16	20

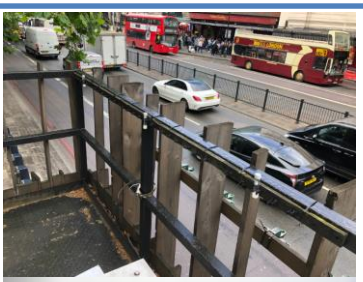
BOSCH

Brake wear chemical composition

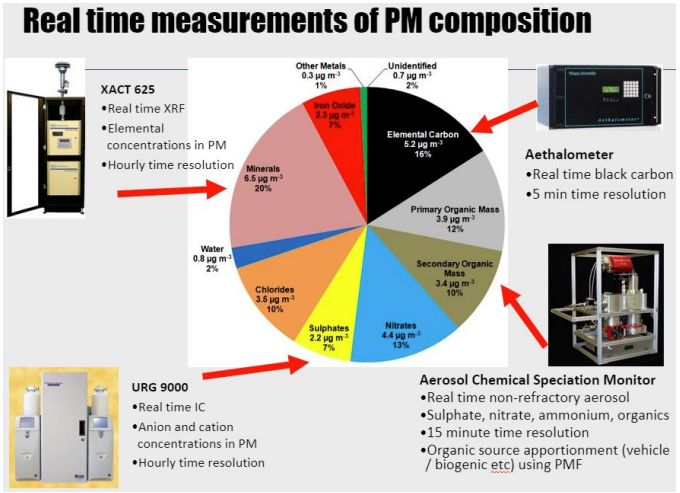


Tyre wear (**Zn**), break wear (Fe, **Cu**, Pb, Ba), and resuspension of road dust (SiO_2, Al_2O_3, Fe_2O_3, Ca)

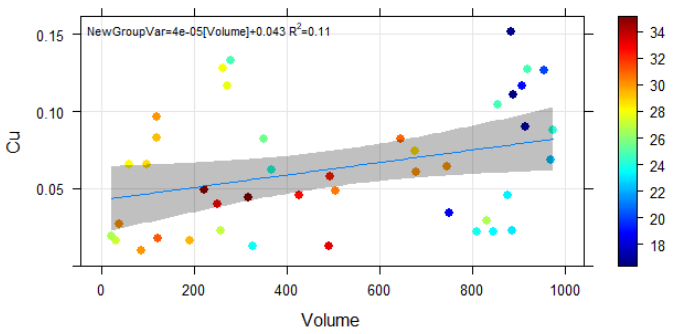
Roadside increment: Marylebone Rd vs Honor Oak Park



PM hourly data (size range, number and Chemical composition



Copper concentrations at Marylebone Rd (westbound traffic + WD 180:270



London policies and Climate change

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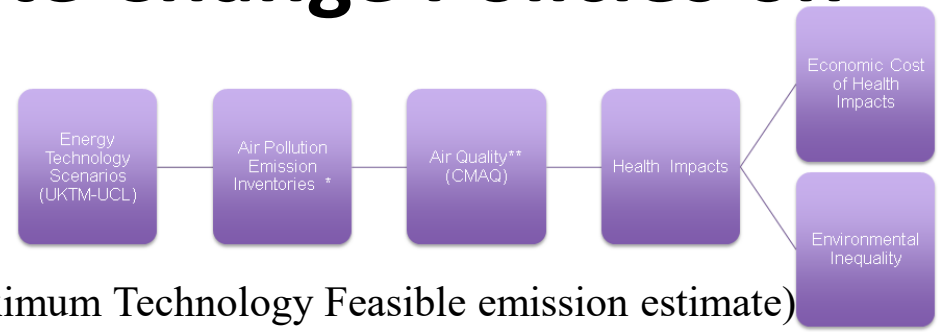
AQ modelling for London policy

- ❑Congestion charging Zone (CCZ)
- ❑Western Extension Zone (WEZ)
- ❑Remove WEZ
- ❑Low Emissions Zones (LEZ)
- ❑Mayor's Air Quality Strategy (MAQS)
- ❑Ultra Low Emissions Zones (ULEZ): 2019 > 2020 > 2021
- ❑London Environment Strategy (LES): 2025 > 2030
- ❑LES +: 2040 > 2050

The Co-Impacts of Climate Change Policies on Air Pollution and Health



DEFRA STAGE 1

- Europe (latest agreed international target)
- UK (following DEFRA's Central Plus scenario: Maximum Technology Feasible emission estimate)
- New 2030 $PM_{2.5}$ UK levels

DEFRA STAGE 2

Modelling for Health research

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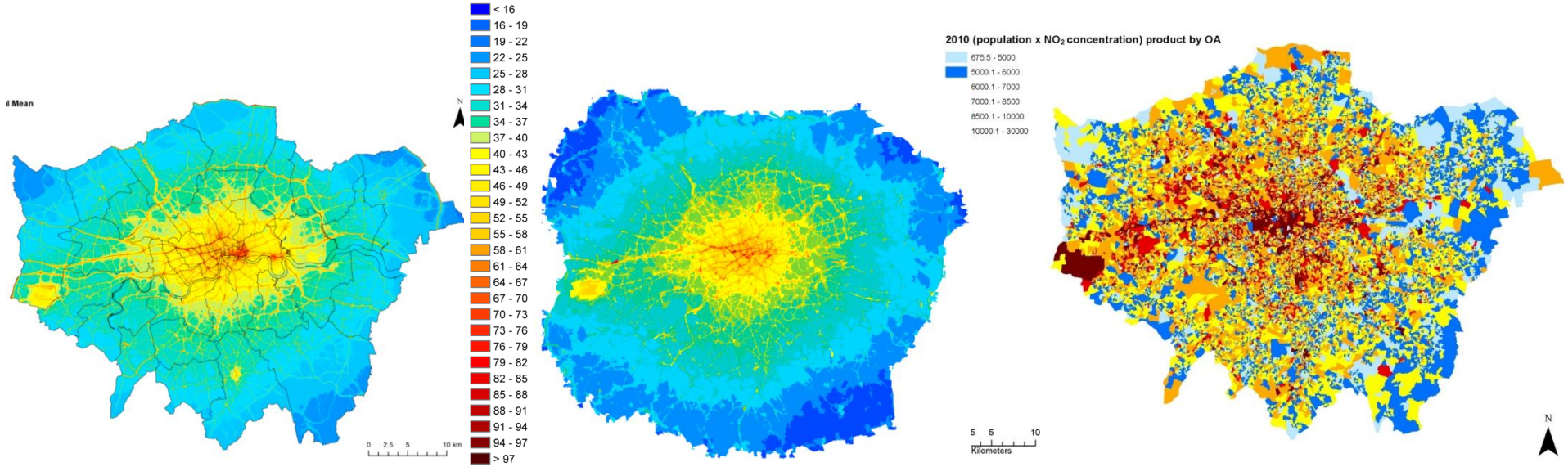
Previous model applications

Health impacts of Traffic emissions in London – TRAFFIC (NERC/MRC)

Link AQ model to epidemiology research found that air pollution adversely

- Reduce Lung function in children and young adults
- Increases the incidence of stroke and influences survival after stroke
- Association with respiratory and cardiovascular mortality
- Adverse effects on foetal growth during pregnancy
- Mental Health (incidence of dementia)



Health impacts assessments in London – air pollution

Famously quoted 9,500 premature death and £3.7 billion economic cost

Current/future model applications

- **APEX -** Create person-centric Exposure model reflecting the Air that people breath

Using New sensor, merging advanced models, augmented policy (choice /behaviour)

- **DREAM -** Identify DNA modification in children/adult genes exposed to pollution

Using high resolution models, range of chemicals, accelerated biological aging

- **CLUE II -** Investigate link between impaired cognitive development and noise/AQ

Using in/outdoor exposure monitoring 6,000 children, biomarkers, Hybrid/noise model

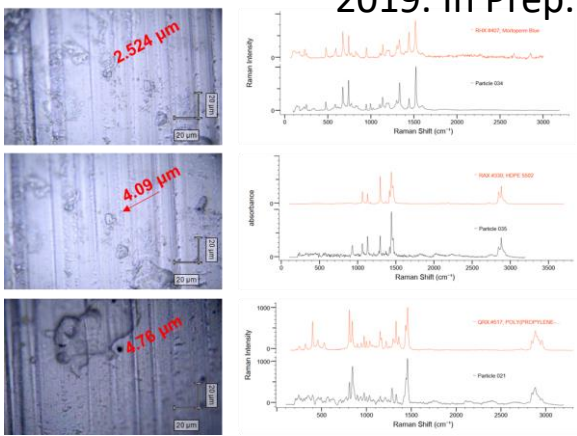
- **CHILL –** Study ULEZ impact on children lung growth, 2ry outcome, health equity

Using bioresource of primary children (IN/OUT ULEZ), monitor/model AQ

- **Micro-plastics in atmosphere**

New environmental challenge
Indoor and outdoor air sampling
Potential for human exposure in the airway if ≤PM_{10}
Potential toxicity of microplastics in pulmonary systems

Dr Stephanie Wright | Mr Joseph Levermore
2019. In Prep.



Human exposure modelling

Old ‘static’ exposure

Versus

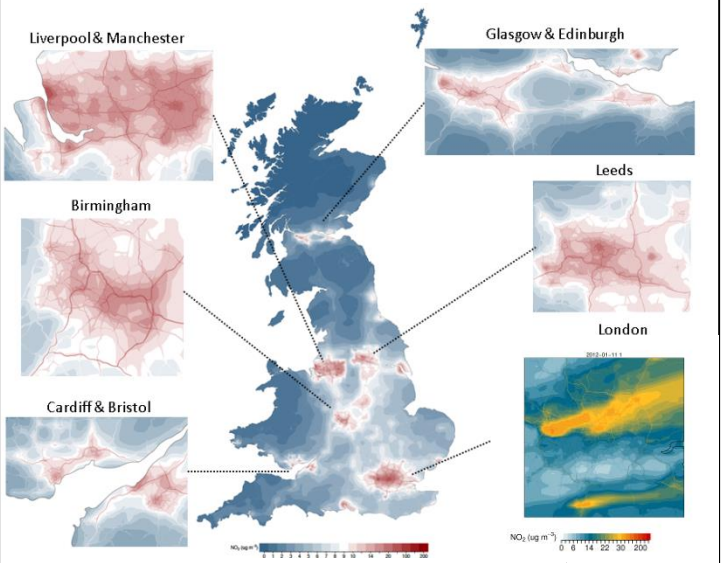
Dynamic exposure model

Hybrid exposure model

http://www.londonair.org.uk/research/Modelling-Air/custom/index.html

Outdoor air quality

CMAQ-urban air quality model (outdoor concentrations)



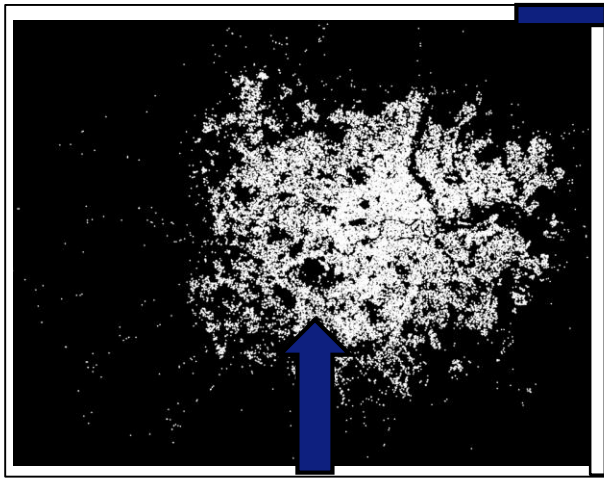
In-vehicle air quality

Micro-environmental modelling: in-vehicle (bus, car, train, tube), cycle, walk, indoors (I/O exchange - J Taylor (UCL))

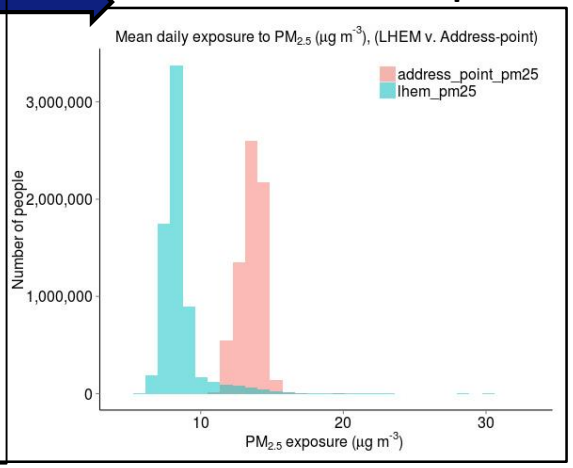
$$\frac{dC_{in}}{dt} = \lambda_{win}(C_{out} - C_{in}) - n\lambda_{HVAC}C_{in} - V_g\left(\frac{A}{V}\right)C_{in} + \frac{Q}{V}$$

Travelling

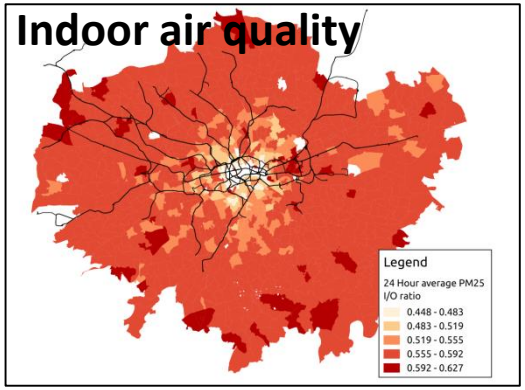
London Travel Demand Survey: Trips by transport mode: Age, gender and socio-economic status



Personal exposure



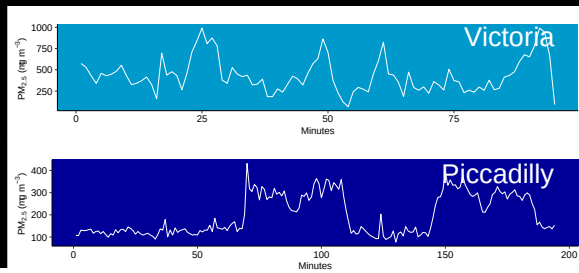
Indoor air quality



The average LHEM exposure is estimated to be 37% lower for $PM_{2.5}$, than at the residential address

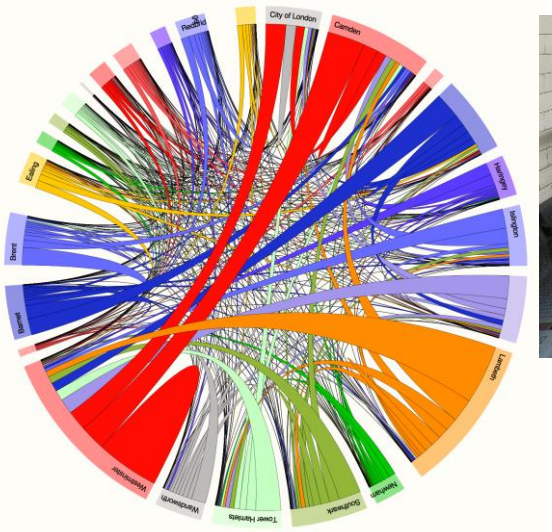
Reference: Smith et al., 2016. The London Hybrid Exposure Model (LHEM): Improving human exposure estimates to NO_2 and $PM_{2.5}$ in an urban setting. ES&T DOI: 10.1021/acs.est.6b01817

London journey's

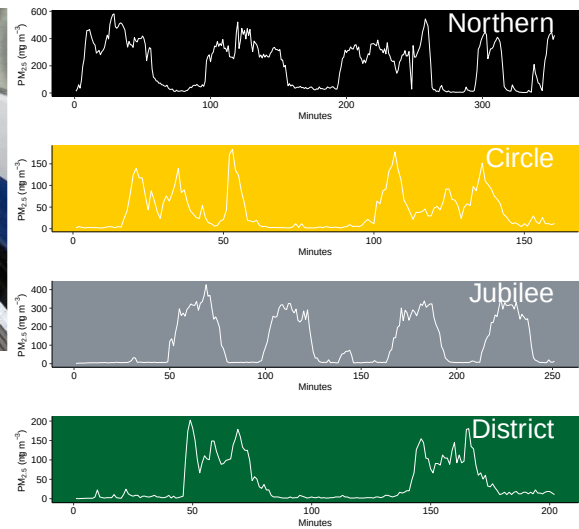


Hybrid model using people's movement data:

Surveys
Oyster cards
Banking card
Mobile phone



$PM_{2.5}$ mass on the London Underground



Future developments

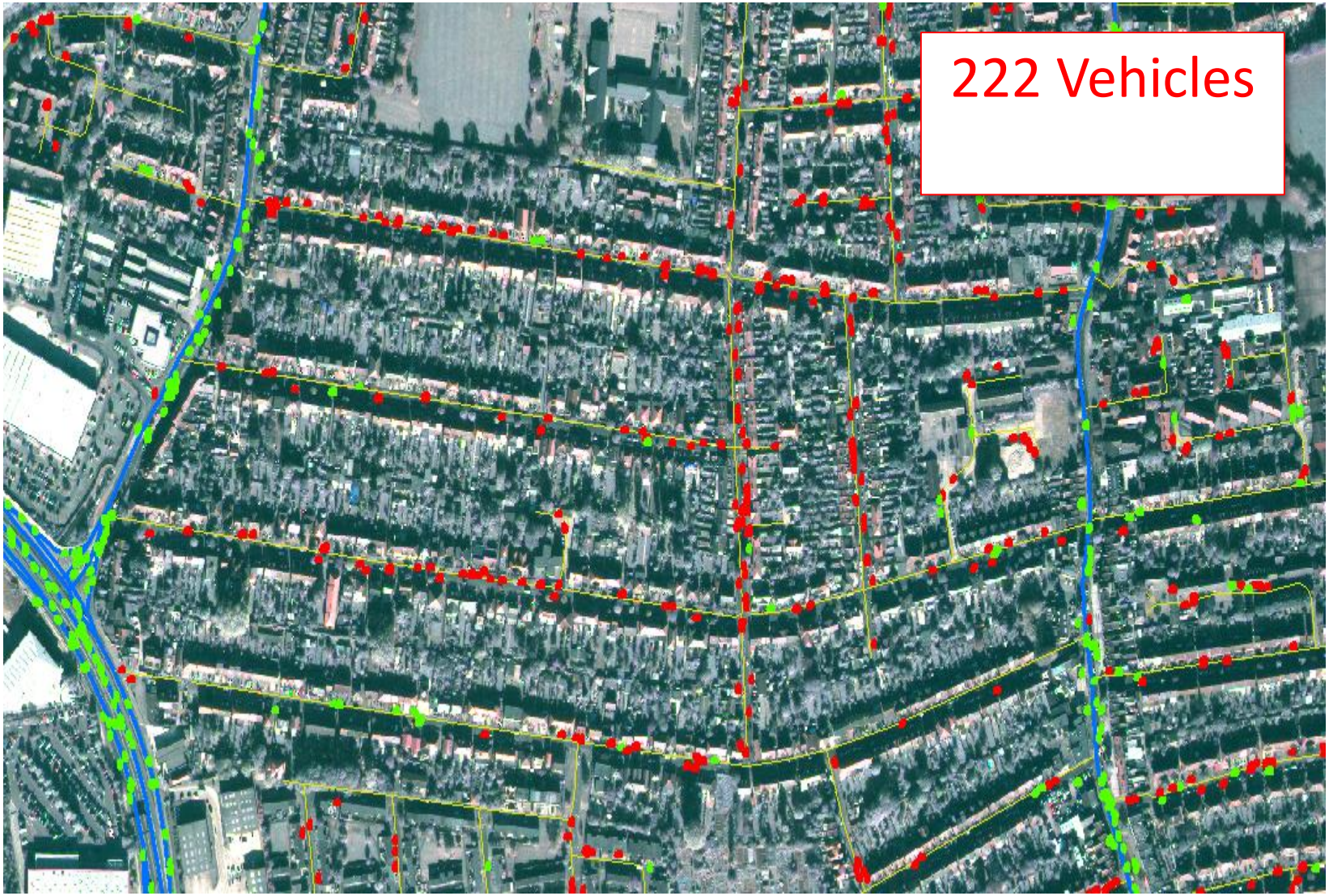
Satellite air quality modelling – Feasibility study (ESA)

Combining satellite images to process traffic data to develop inventory in UK (London)

MRC-PHE
Centre for Environment & Health

Public Health England | MRC Medical Research Council | Imperial College London | King's College London

Counting vehicles from space



Thanks for your attention…

Thanks to colleagues at ERG

Thanks to Transport for London and the Greater London Authority

Dr David Dajnak - Tel: +44 207 848 4012 - Email: david.dajnak@kcl.ac.uk

King's College London

MRC-PHE
Centre for Environment & Health

Public Health England | MRC Medical Research Council | Imperial College London | King's College London

World Health Organisation Guidelines

Guidelines based upon the best scientific evidence of health impacts and used by other agencies internationally to set their standards

(http://www.who.int/mediacentre/factsheets/fs313/en/)

Pollutant	Averaging period	Limit value	Health impact	Group 1 review?
SO_2	10 minute	500 μg m^{-3}	Respiratory system inflammation, irritation of the eyes, exacerbates asthma, hospital admissions for cardiac disease and mortality on days with high SO_2	yes
	daily	20 μg m^{-3}		
NO_2	hourly	200 μg m^{-3}	Symptoms of bronchitis in asthmatic children increase in association with long-term exposure to NO_2. Reduced lung function growth.	yes
	Annually	40 μg m^{-3}		
PM_{10}	Daily	50 μg m^{-3}	Increased mortality and morbidity, daily and over time. No threshold has been established and the WHO recommends achieving the lowest concentrations of PM possible.	yes
	Annually	20 μg m^{-3}		
$PM_{2.5}$	Daily	25 μg m^{-3}		
	Annually	10 μg m^{-3}		
O_3	8 Hourly	100 μg m^{-3}	Breathing problems, can trigger asthma, reduce lung function and cause lung diseases.	yes

Reviews of evidence: Review of evidence on health aspects of air pollution (REVIHAAP)
http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report

Health risks of air pollution in Europe (HRAPIE): http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project.-new-emerging-risks-to-health-from-air-pollution-results-from-the-survey-of-experts

Expert consultation: WHO Guideline updates
http://www.euro.who.int/__data/assets/pdf_file/0013/301720/Evidence-future-update-AQGs-mtg-report-Bonn-sept-oct-15.pdf

Legislative background – EU limit values (health)

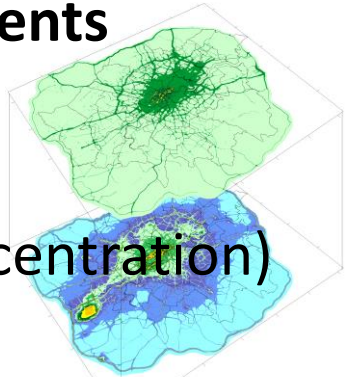
Pollutant	Averaging period	Limit value	Date of compliance
NO_2	hourly	200 μg m^{-3}, not to be exceeded more than 18 times a calendar year	1st Jan 2010
	Annually	40 μg m^{-3}	1st Jan 2010
PM_{10}	Daily	50 μg m^{-3}, not to be exceeded more than 35 times a calendar year	1st Jan 2005
	Annually	40 μg m^{-3}	1st Jan 2005
$PM_{2.5}$	Annually (stg1/2)	25 μg m^{-3}/20 μg m^{-3}	1st Jan 2015/20
	Annually (exp reduction target)	Initial conct 13-18 μg m^{-3} ~ 15% reduction	Between 2010 and 2020
O_3 Target value	Maximum daily 8 hour mean	120 μg m^{-3}, not to be exceeded on more than 25 days per calendar year, averaged over 3 years	1st Jan 2010
O_3 Long term objective	Maximum daily 8 hour mean	120 μg m^{-3}	Not defined

What is King's recipe for mapping London's Air pollution?

- Emission sources in London (we use LAEI)

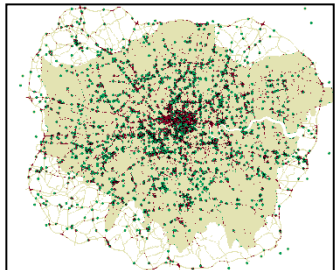


- Dispersion Model using **hourly meteorological measurements**

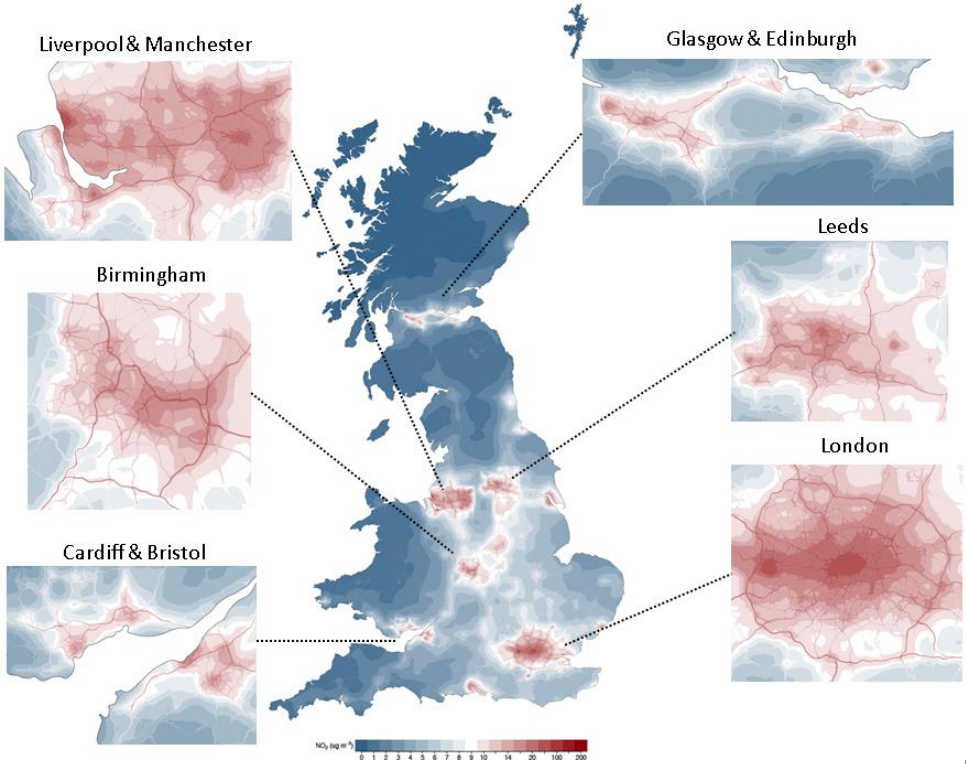


The model sums together three source categories:

- **First**, sources outside the model domain (background concentration)
  For NO_X, we use rural measurements
  For PM, we use rural and regional sources (secondary PM and natural)
- **Second**, within the model domain, but greater than 500m from a receptor location (London background)
  All London sources represented as volumes sources
- **Third**, for those sources within 500m of a receptor location
  Detailed treatment of local road/gas/rail/aircraft sources



CMAQ-urban outputs

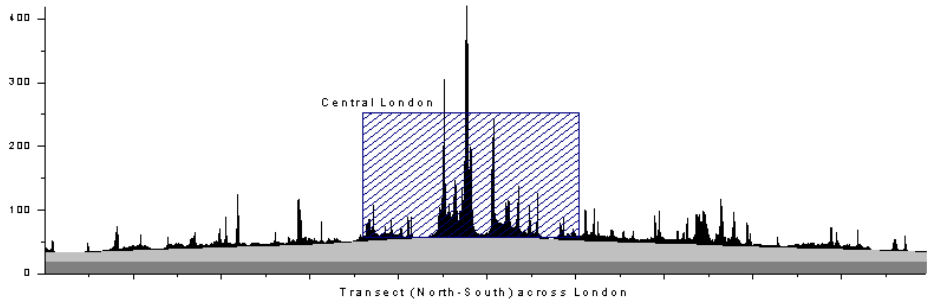


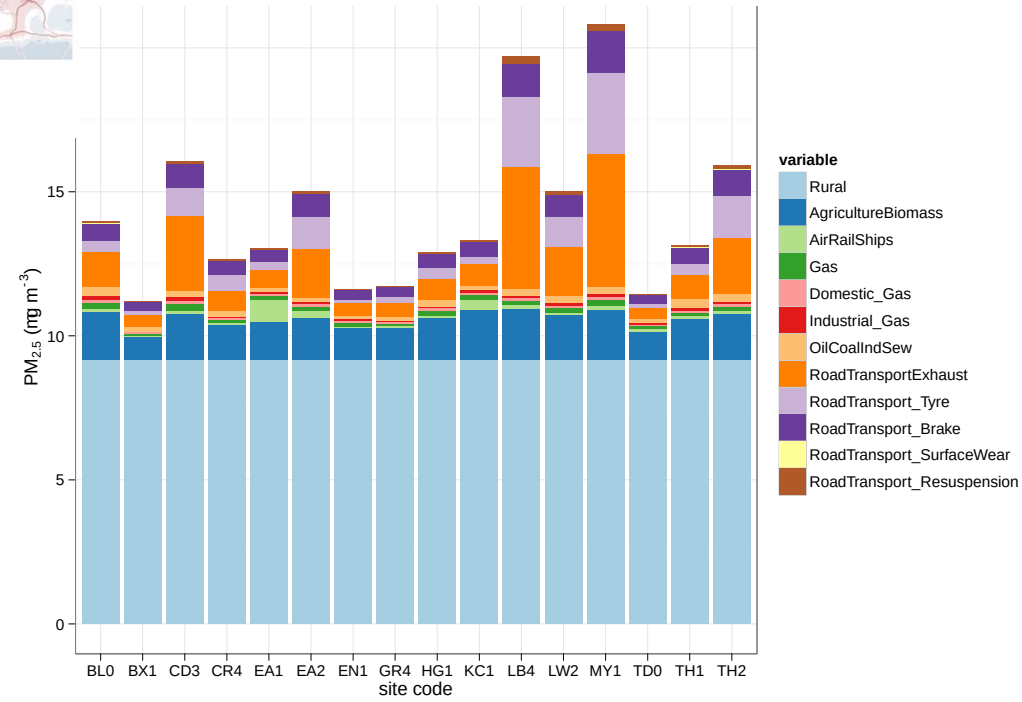
- US regulatory community model
- Applicable anywhere in the world
- Multi-scale with nesting capability – City to Continental scale
- Fine temporal/spatial grid resolution (20m hourly)
- Predict future AQ – used for policy development
- Tackle long range issue – study foot print of large source
- Multi-pollutant model
- Suitable for source apportionment
- Allows more policy issues to be tackled

CMAQ-urban performance

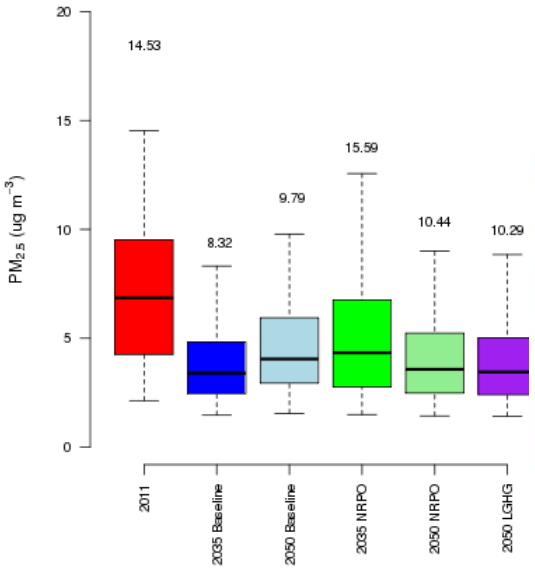
- ❑ CMAQ-UK project for DEFRA
https://uk-air.defra.gov.uk/research/air-quality-modelling?view=cmaq-uk
- ❑ DEFRA Model Intercomparing exercise
https://uk-air.defra.gov.uk/research/air-quality-modelling?view=intercomparison
- ❑ Air Quality Modelling Evalution International Initiative (AQMEII) Phase 3
http://aqmeii.jrc.ec.europa.eu

Solazzo et al. 2017. Evaluation and error apportionment of an ensemble of atmospheric chemistry transport modeling systems: multivariable temporal and spatial breakdown, Atmos. Chem. Phys., doi:10.5194/acp-17-3001-2017

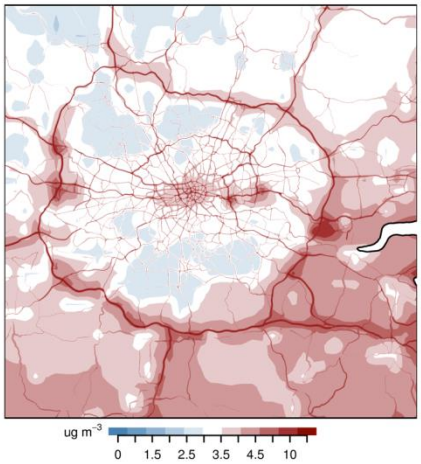


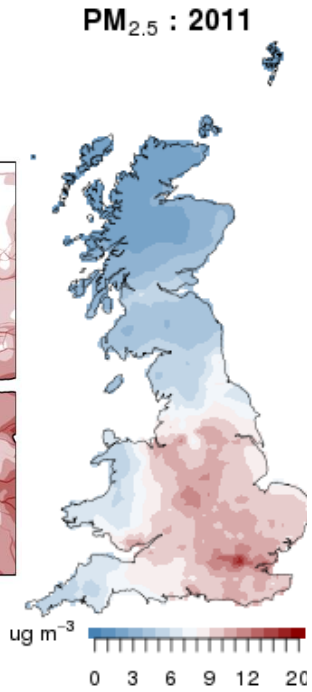


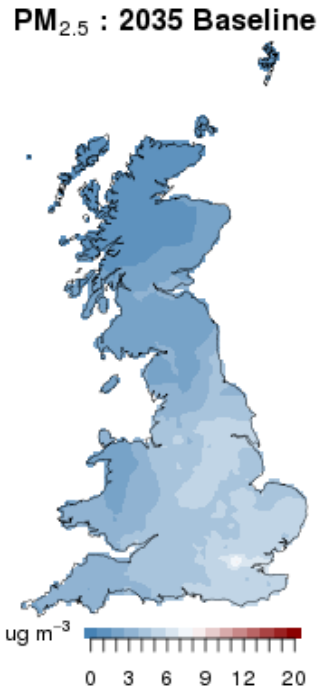
AQ climate scenarios

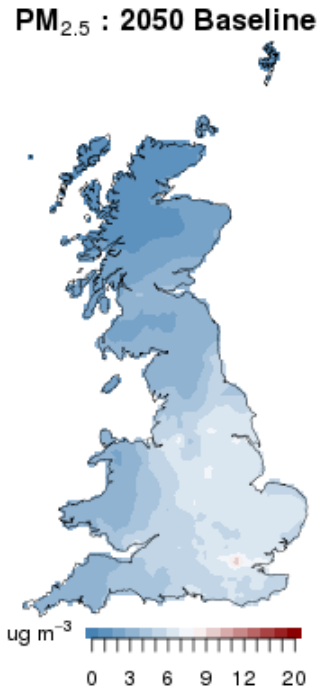


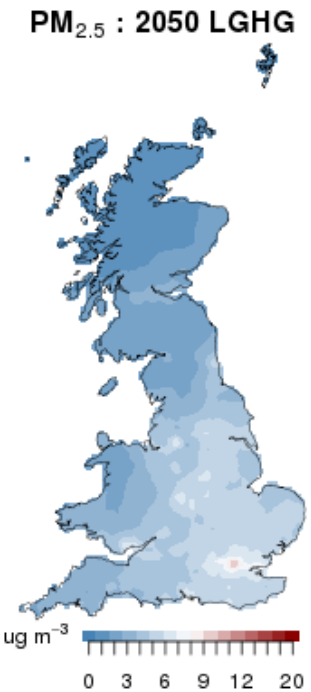
Non-exhaust vehicle emissions in 2050

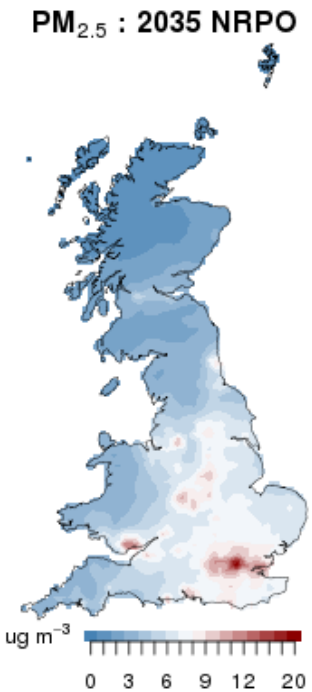


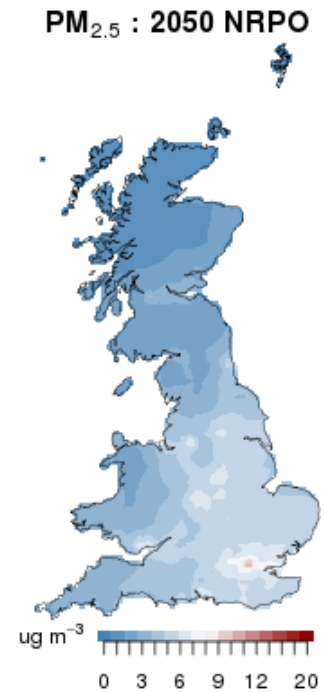












NIHR PM results

- PM declined significantly due to cleaner vehicle fleet and NRMM
- Reductions in PM are tempered
- by a 2035 peak in biomass (wood burning)
- by increase in demand for transport leading to increases in non-exhaust PM emissions