MAGIC

Envisaging a world with greener cities

Linking Traffic to Emissions to Ambient Air Quality

The Challenge:

Can we develop cities with **no air pollution** and no heat-island effect by 2050?

Adam Boies

20 Sept, 2018

UNIVERSITY OF CAMBRIDGE

Imperial College London

UNIVERSITY OF SURREY

About

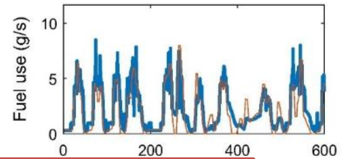
MAGIC

Envisaging a world with greener cities

We need to think differently…

- Natural ventilation in buildings
- Diluted air pollution levels
- Increased albedo
- Integrated green and blue spaces
- Public education and policy change

Linking Emissions to Impacts



Number Plate Recognition

Agent Based Modelling

Traffic flow and patterns

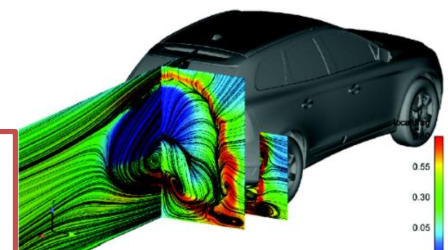
Emissions Modelling

Vehicle & Engine Data

Agent Based Modelling

Temporally Resolved Emissions

Fluidity Dispersion Modelling



Sensors

Particle Morphology

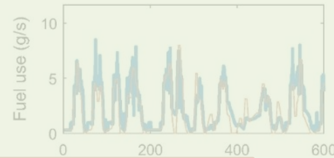
Roadside Measurement

Indoor Air Measurement

Verification

Link to Buildings (Indoor Air Quality)

Linking Emissions to Impacts



Number Plate Recognition

Agent Based Modelling

Traffic flow and patterns

Emissions Modelling

Vehicle & Engine Data

Agent Based Modelling

Temporally Resolved Emissions

Sensors

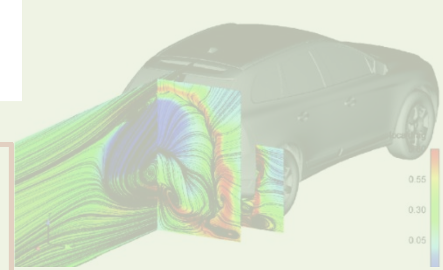
Particle Morphology

Roadside Measurement

Indoor Air Measurement

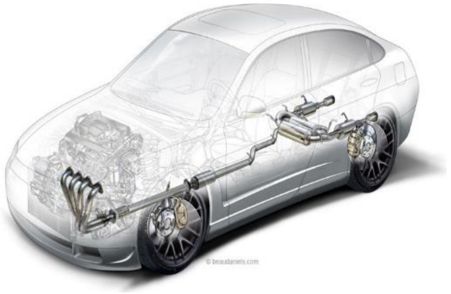
Verification

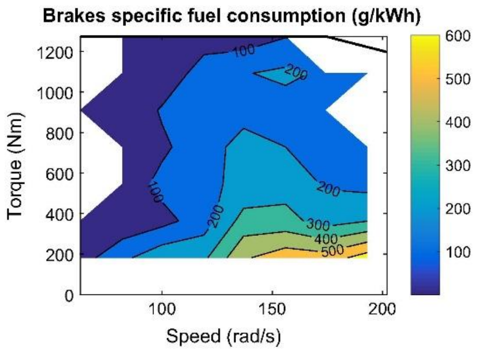
Fluidity Dispersion Modelling

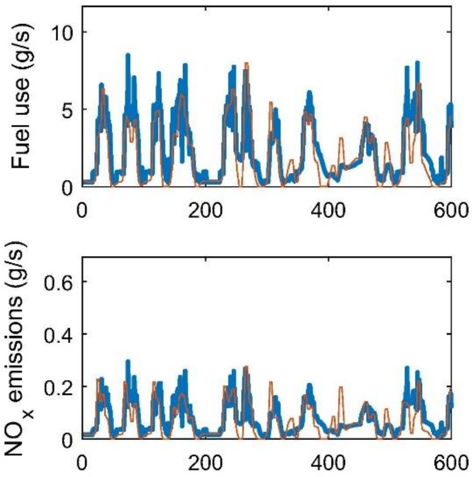


Link to Buildings (Indoor Air Quality)

Emissions Toolkit

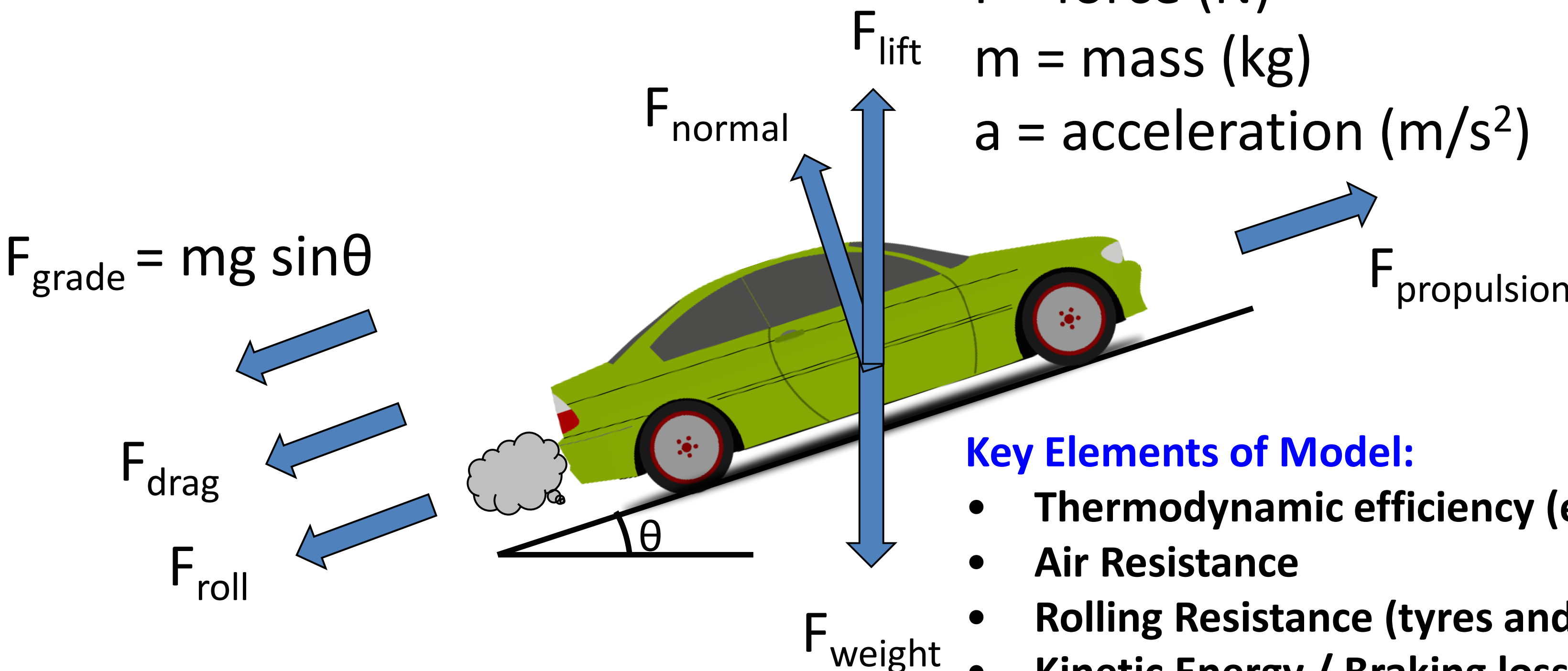






Fuel and Emissions Model

F = force (N)
m = mass (kg)
a = acceleration (m/s^2)



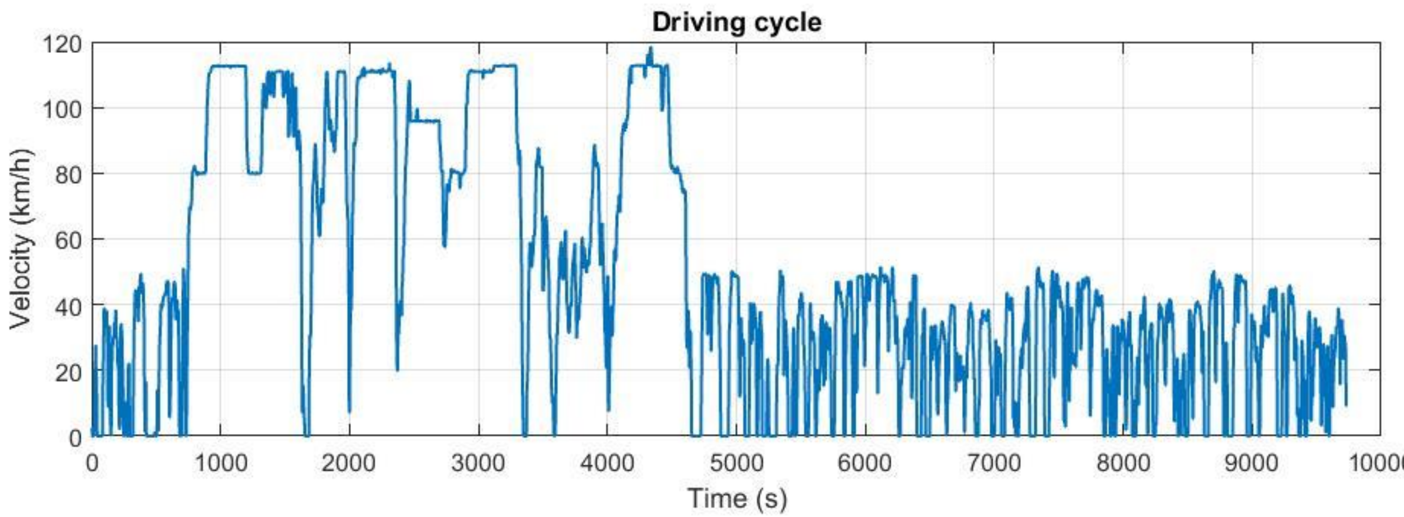
$$F_{propulsion} = F_{drag} + F_{roll} + F_{grade} + ma$$

Key Elements of Model:

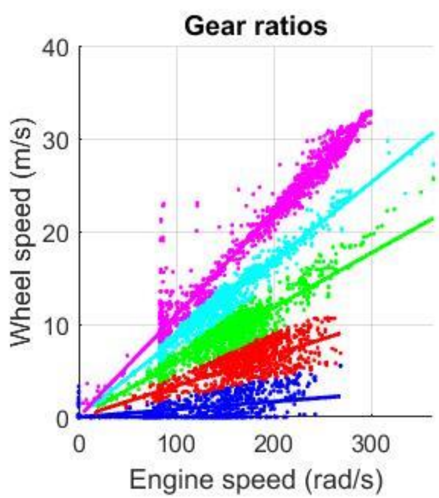
- **Thermodynamic efficiency (engine map)**
- **Air Resistance**
- **Rolling Resistance (tyres and drive train)**
- **Kinetic Energy / Braking losses**
- **(Extensive programme of parameter measurement with instrumented vehicle for validation)**

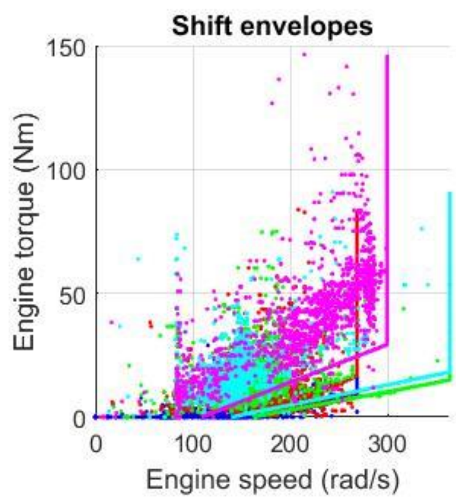
Engine maps

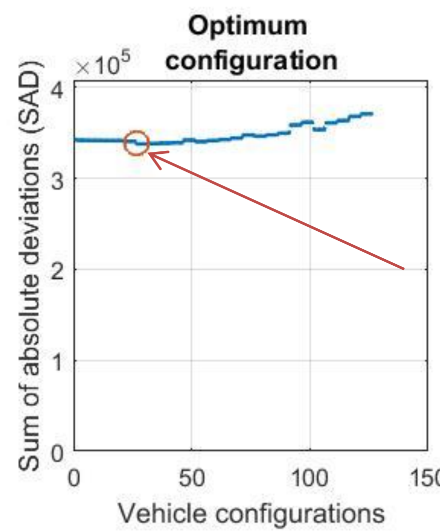
Euro 5 Petrol



Gear
5
4
3
2
1



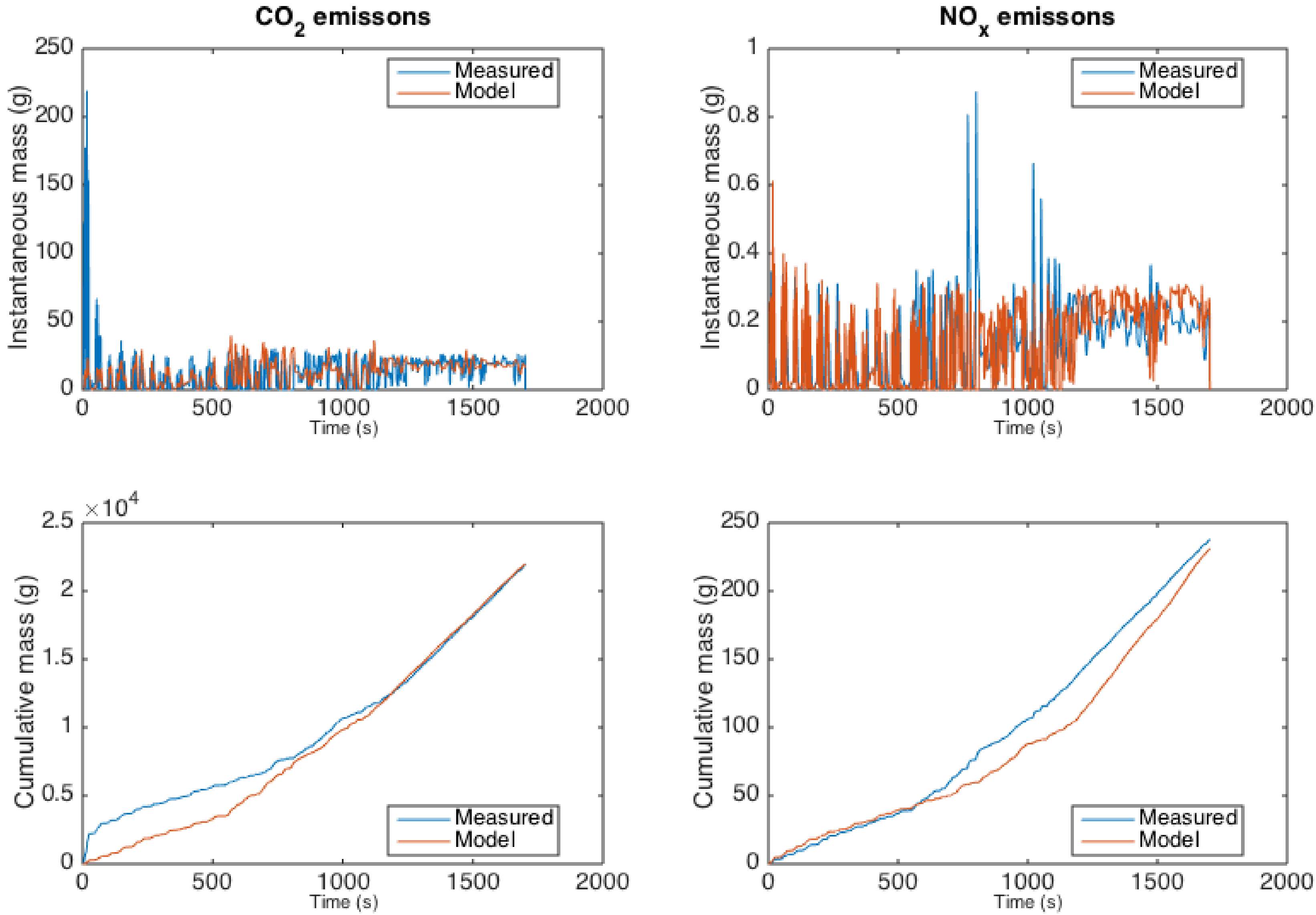




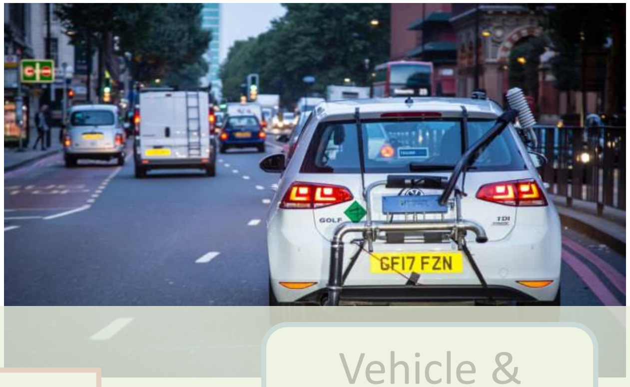
$C_dA = 0.62$
$C_{rr} = 0.007$
$m = 1035$ kg

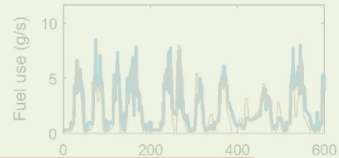
$$Shift_i = f(\omega_i, load_i)$$

Temporal Emissions



Linking Emissions to Impacts





Number Plate Recognition

Agent Based Modelling

Traffic flow and patterns

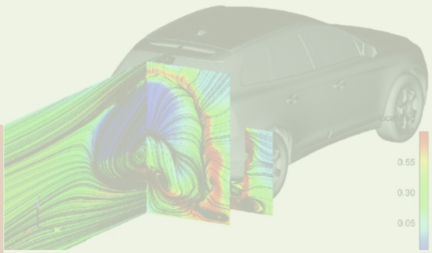
Emissions Modelling

Vehicle & Engine Data

Agent Based Modelling

Temporally Resolved Emissions

Fluidity Dispersion Modelling



Sensors

Particle Morphology

Roadside Measurement

Indoor Air Measurement

Verification

Link to Buildings (Indoor Air Quality)

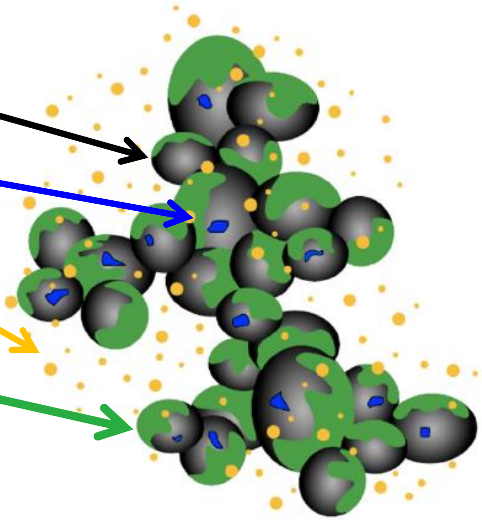
UNIVERSITY OF CAMBRIDGE

Imperial College London

UNIVERSITY OF SURREY

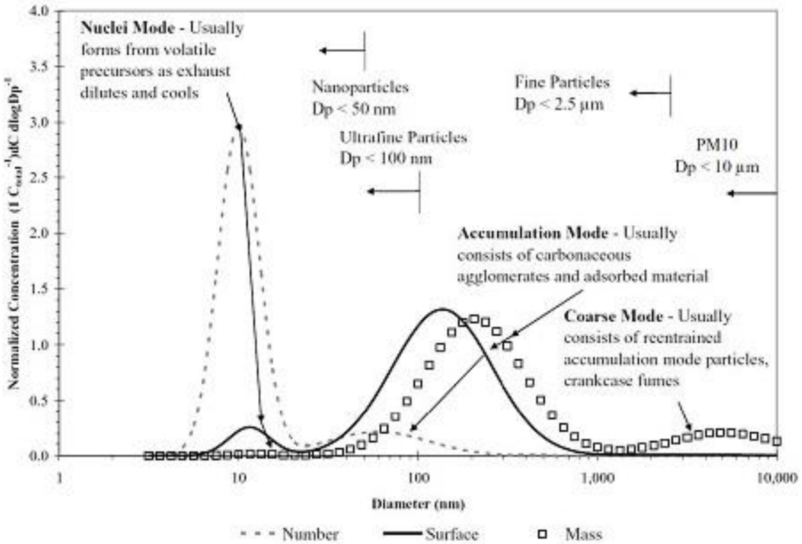
Particle Pollution

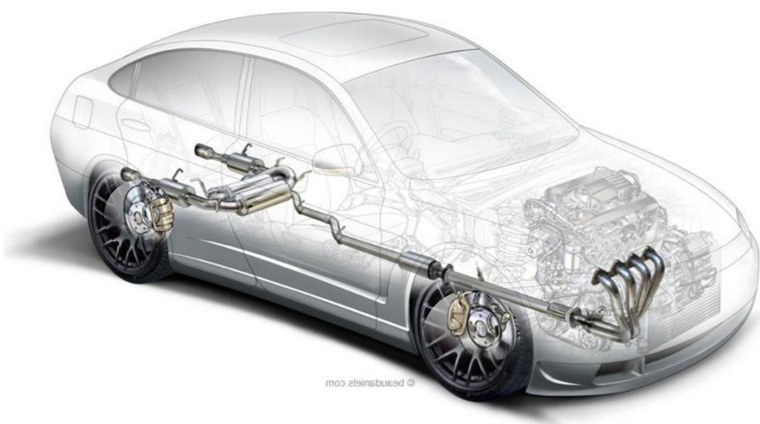
- Solid carbonaceous
- Solid ash particles
- Semi-volatile sulfuric acid + hydrocarbon particles
- Adsorbed and condensed sulfuric acid and hydrocarbon vapors



Maricq, M., J Aerosol Sci. **2007**, 38, 1079 – 1118

A Good Tracer for Emissions



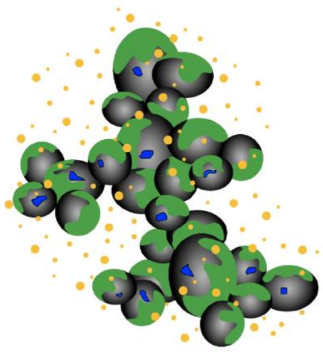


UNIVERSITY OF CAMBRIDGE

Imperial College London

UNIVERSITY OF SURREY

Soot metrics of importance

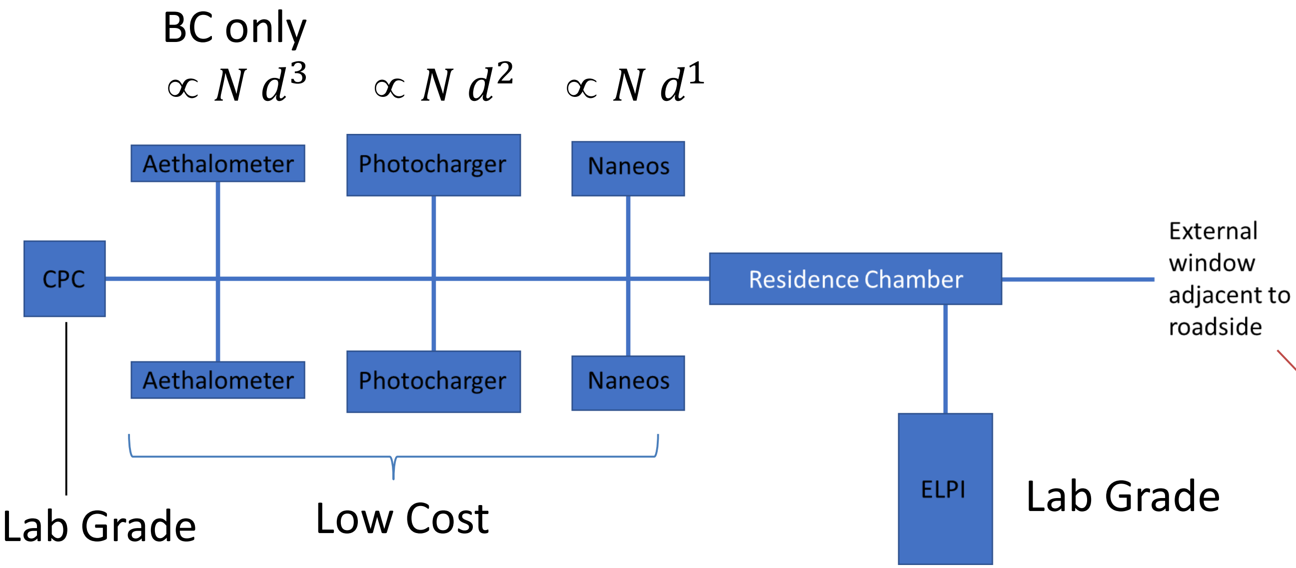


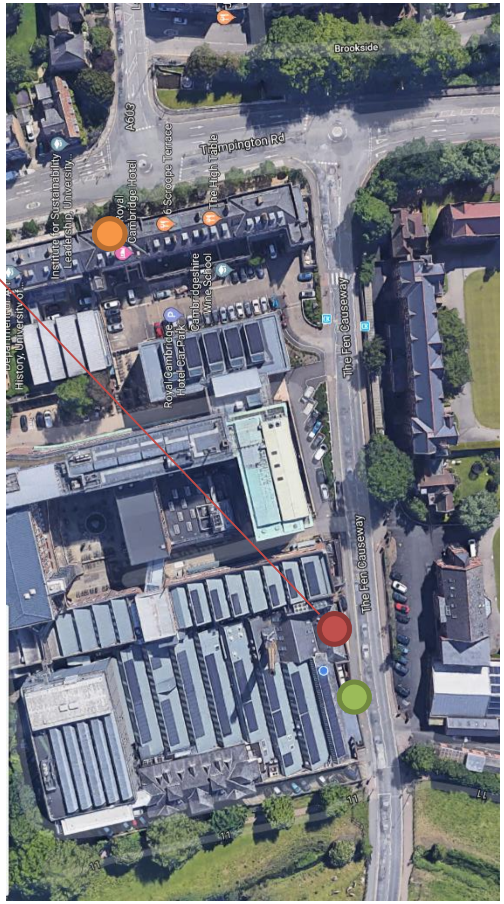
Soot consists of highly non-spherical agglomerates of non-uniform primary particles – Emissions from Vehicles

Radiative forcing	$\propto$	**Mass** concentration of BC $\propto N\, d^3$
Emissions Regulation	$\propto$	**Number** concentration of BC $\propto N\, d^0$
Chemical reactions	$\propto$	**Surface area** concentration of BC $\propto N\, d^2$
Health impacts	$\propto$	**Mass, number and surface** area concentration of BC

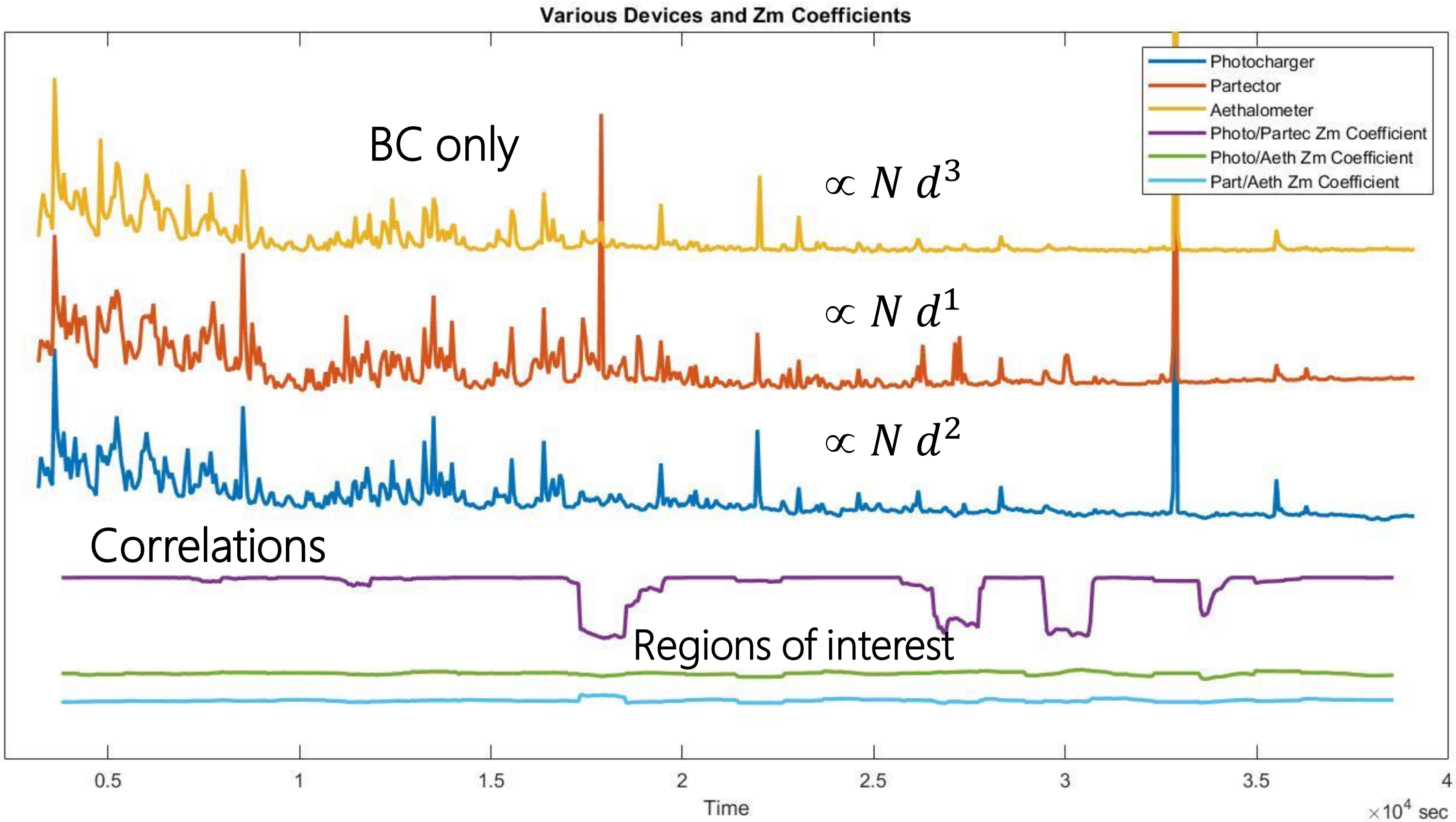
Can we measure these with low cost sensors?
Goal: Link transport to air quality

Parallel Study: Air Quality

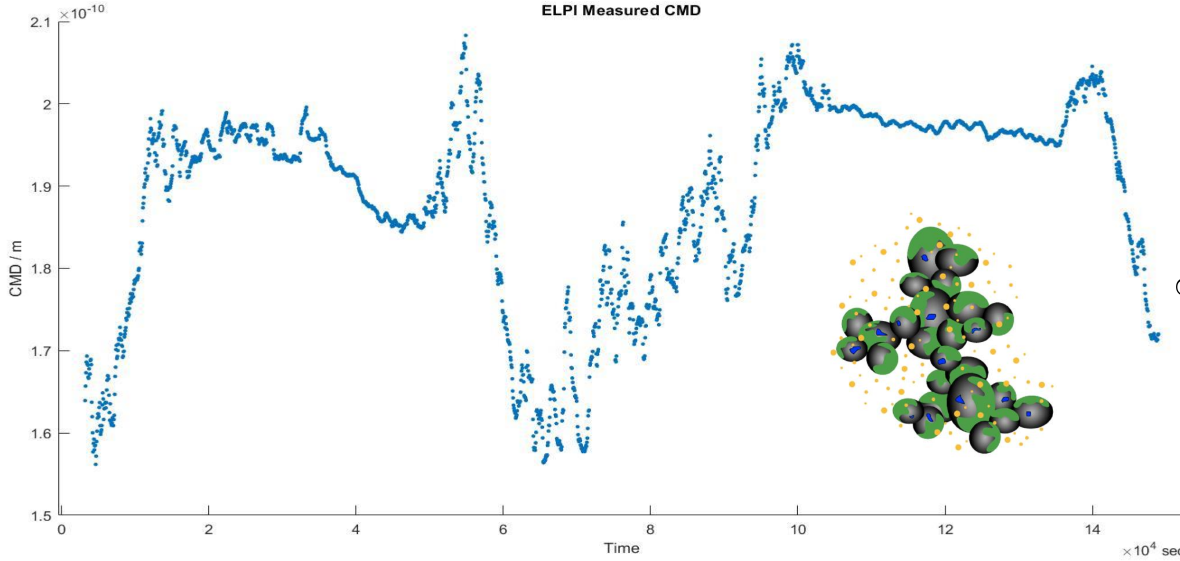




Can particles provide the link between emissions, outdoor air and indoor air pollution?

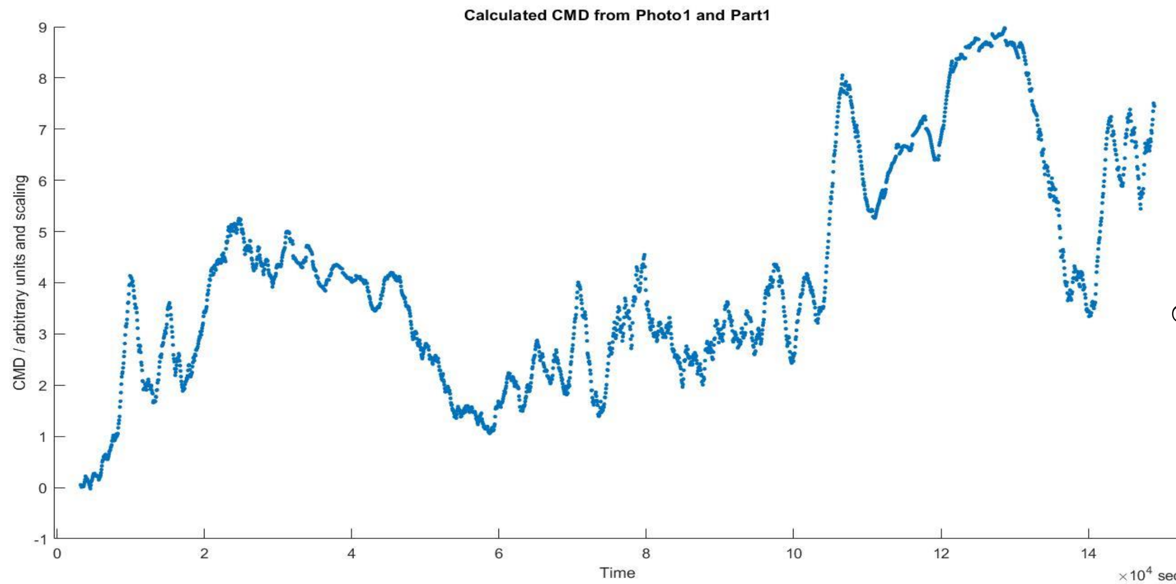


Various Devices and Zm Coefficients
Photocharger
Partector
Aethalometer
Photo/Partec Zm Coefficient
Photo/Aeth Zm Coefficient
Part/Aeth Zm Coefficient
BC only
$\propto N\, d^3$
$\propto N\, d^1$
$\propto N\, d^2$
Correlations
Regions of interest
0.5
1
1.5
2
2.5
3
3.5
4
Time
$\times 10^4$ sec



$\propto \overline{d^1}$

Morning Afternoon Night Morning Afternoon Night



Similar structure!

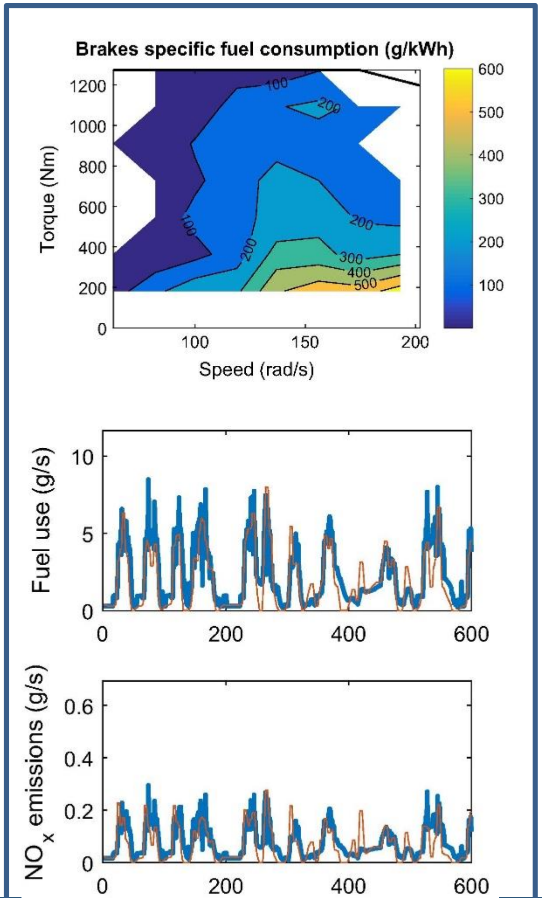
$\propto \overline{d^2}^{1/2}$

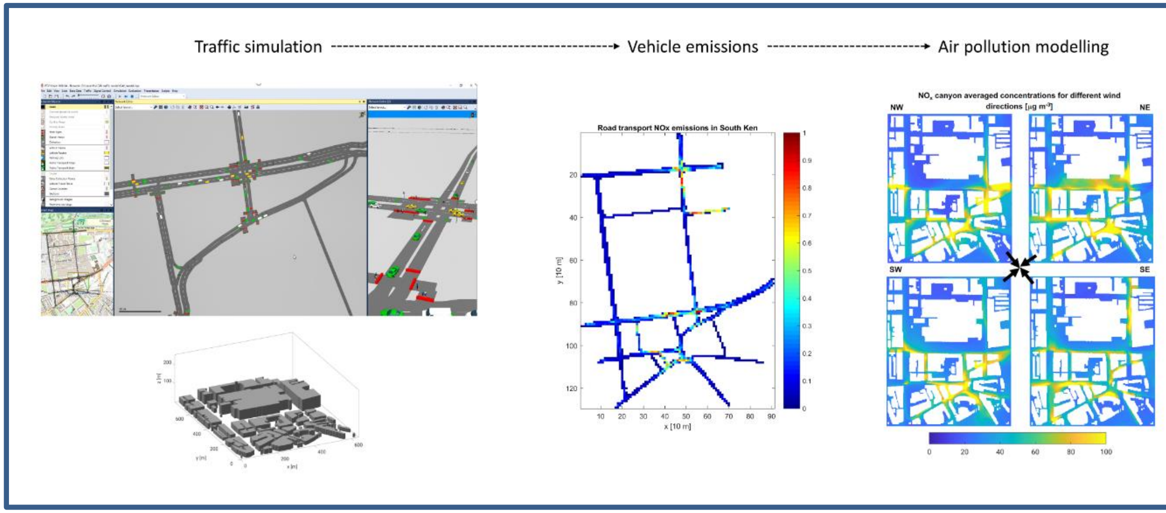
Link Emissions to Impacts in Buildings
- Large scale deployment of particle sensors

Emerging opportunity for low-cost particle measurement is available. Opportunity for co-locating with MAGIC project.

Input to MAGIC

UNIVERSITY OF CAMBRIDGE
Department of Engineering

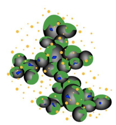


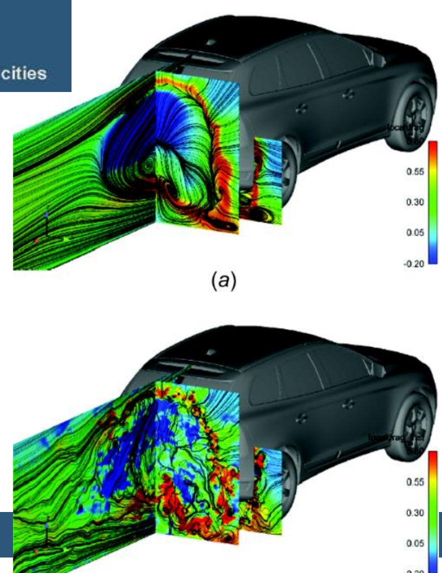


MAGIC

Envisaging a world with greener cities

Imperial College London





(a)

(b)

Every vehicle type in London

- Taxi
- Light duty
- Bus
- Heavy duty

Sterken et al. *J. Fluids Eng.* 2016;138(9):091105-091105-14. doi:10.1115/1.4033296.

MAGIC

Envisaging a world with greener cities

Transport Emissions and Air Quality

Clémence M. A. Le Cornec, Marc E. J. Stettler

Imperial College London

20th of September 2018

UNIVERSITY OF CAMBRIDGE

Imperial College London

UNIVERSITY OF SURREY

MAGIC

Envisaging a world with greener cities

Quantifying the Skill of an Operational Air Quality Model using LES

Tom Grylls, Clémence M. A. Le Cornec, Pietro Salizzoni, Lionel Soulhac, Marc E. J. Stettler, Maarten van Reeuwijk

[2018, Atmospheric Environment, in prep]

20th of September 2018

UNIVERSITY OF CAMBRIDGE

Imperial College London

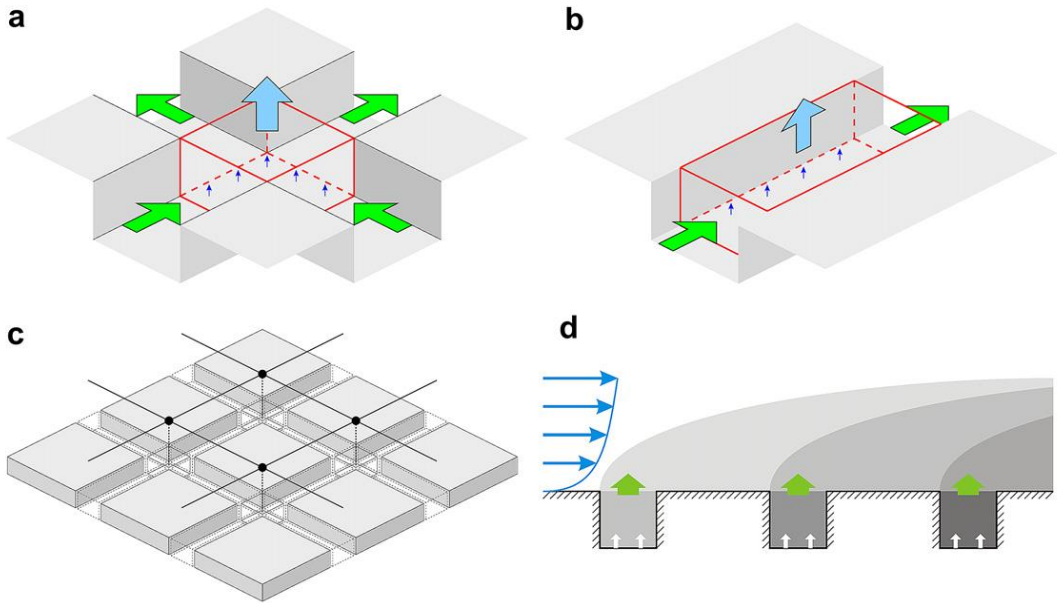
UNIVERSITY OF SURREY

Introduction

- Air quality is the greatest environmental health risk (WHO, 2016).
- Importance of urban pollution dispersion studies.
- Range of scales and heterogeneity result in a complex modelling problem.
- Turbulent and unsteady urban flow field is computationally demanding.
- Models take a range of levels of abstraction:
  - Operational
  - Large-eddy simulation (LES)

SIRANE

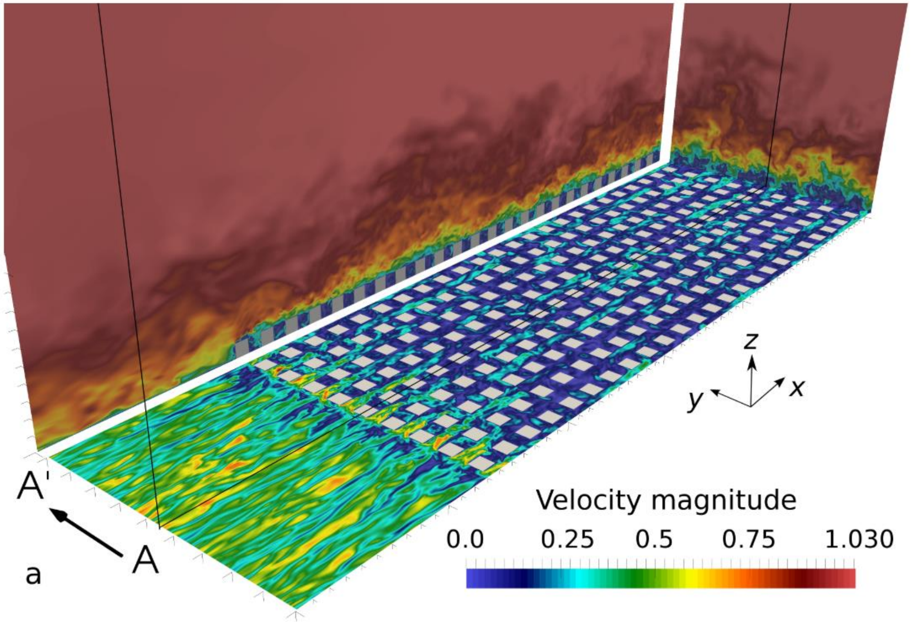
- Operational model
- Street-network (box) model.
  - Uniform concentration in each 'box'.
  - Parametrisations of the flow field.
- Quasi-steady hourly time steps.
- Photostationarity assumption.
- Validated against experimental and field data (Soulhac, 2012; Soulhac, 2017).



From Soulhac et al, 2011

DALES-Urban

- Large Eddy Simulation
- Adapted from the Dutch Atmospheric Large-Eddy Simulation model (Heus, 2010; Tomas, 2015).
- Immersed boundary method.
- Resolutions of ~1m, time steps of ~0.2s.
- Adapted to resolve the reactions of the null cycle following Zhong et al., 2015.
- Contrary to Fluidity, not an adaptive mesh.



From Tomas et al, 2016

Objectives

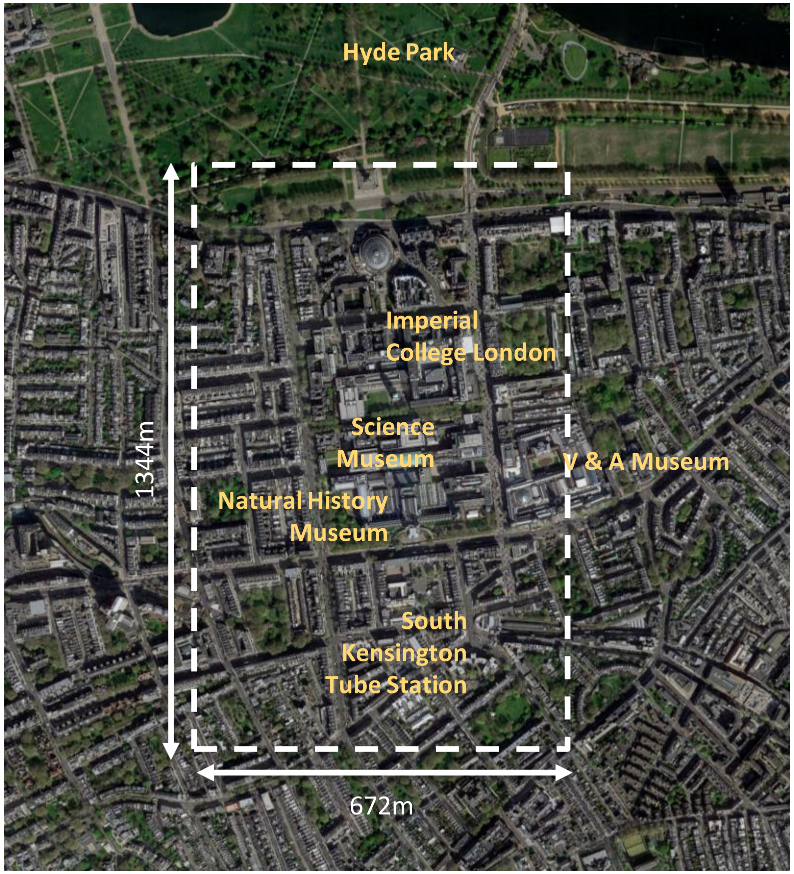
1. Assess the predictive skills of SIRANE over its quasi hourly timesteps.

2. Isolate and analyse the dispersive performances of the models from their chemical scheme.

3. Analyse how an operational model can be used to evaluate accurately pedestrian exposure.

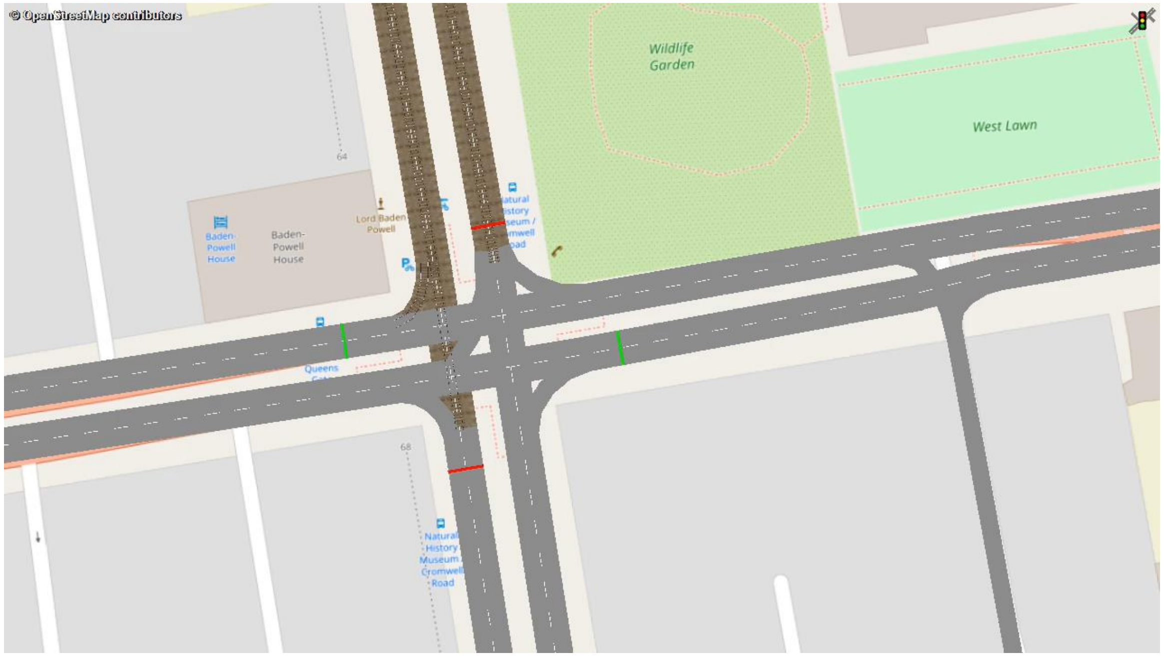
Case study

- South Kensington, London.
- Range of topological features
- Range of road types.
- Availability of high quality emissions data.
- Requirements to consider:
  - Emissions
  - Topology
  - Chemistry
  - Meteorology



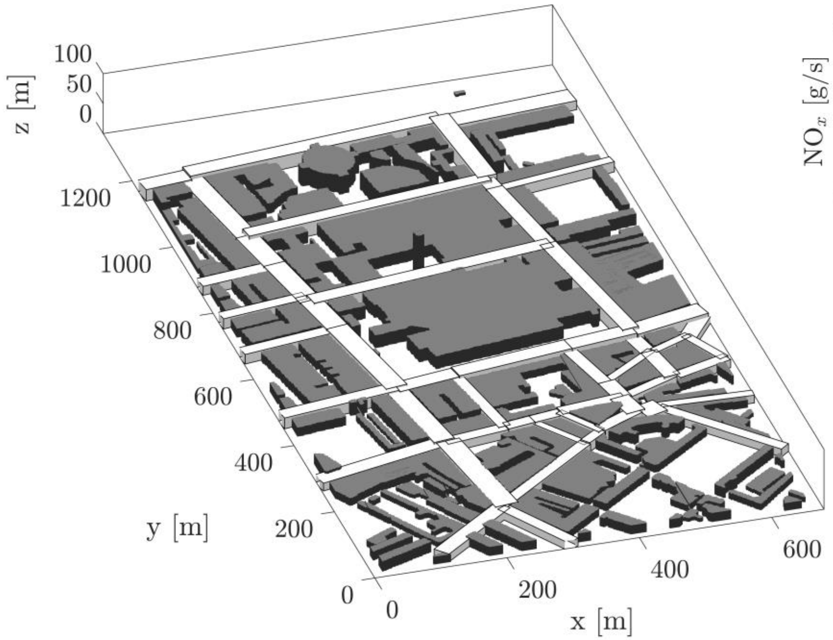
Traffic and Emissions

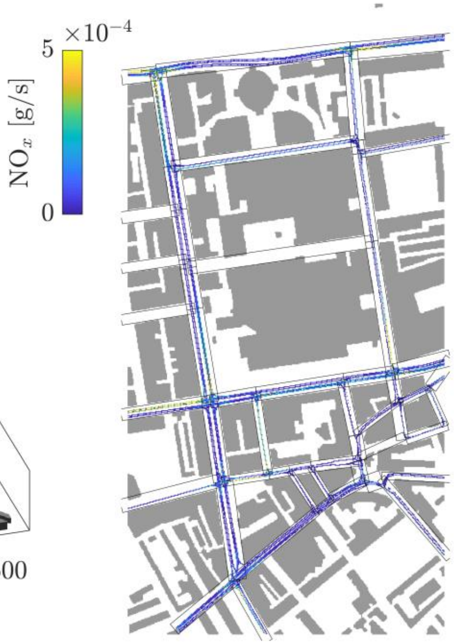
- Emissions due to road transport.
- VISSIM, traffic microsimulation model amalgamated with local traffic counts.
- Instantaneous emissions model based on speed and acceleration of each vehicle.
- DALES-Urban
  - Time-averaged and rasterised to grid.
- SIRANE
  - Spatially-averaged over street-network.



Topology

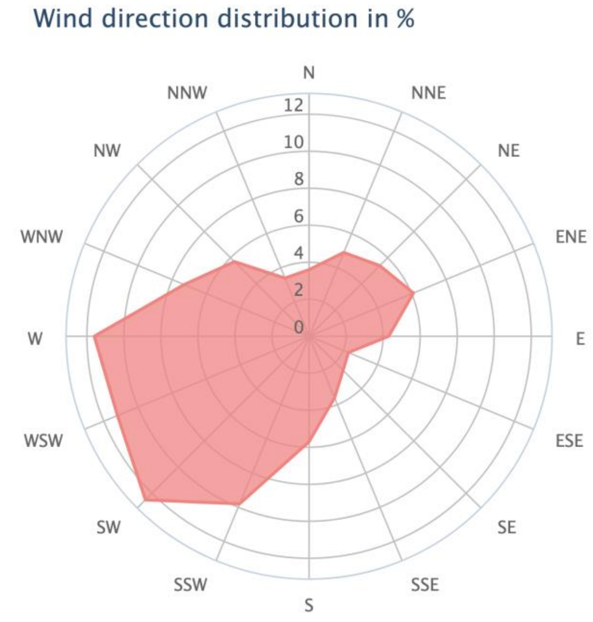
- 1-m LIDAR data.
- DALES-Urban
  - Building mask and optimized for use with the IBM.
  - Rasterised to defined grid.
- SIRANE
  - Canyon widths and heights following methodology of Soulhac et al., 2011.





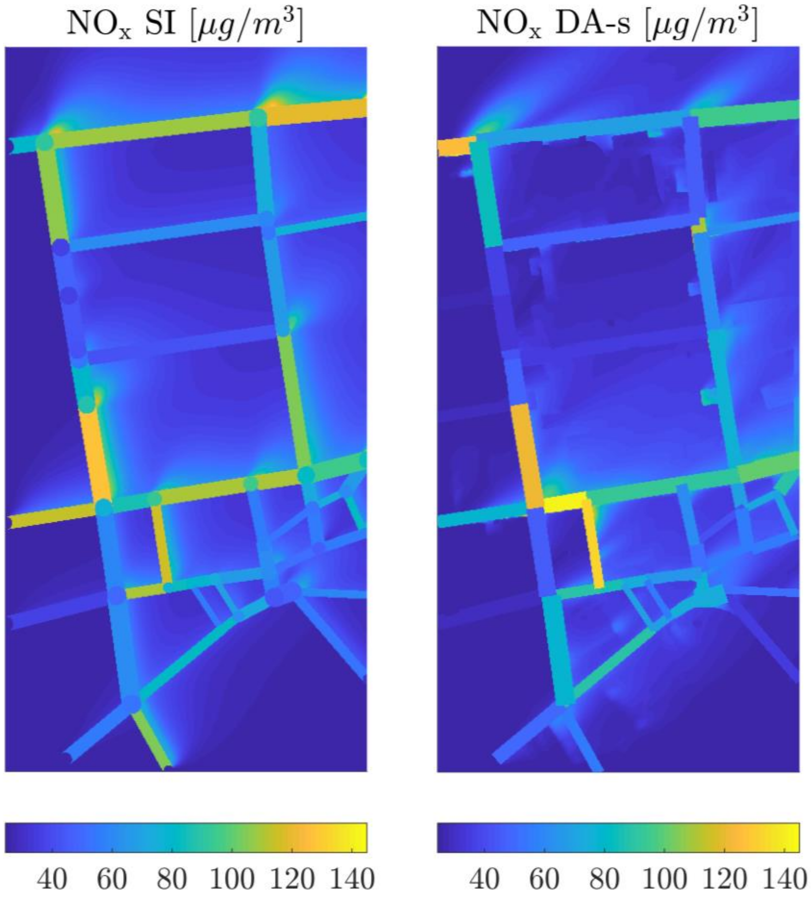
Meteorology

- SIRANE utilises field data.
- Typical conditions:
  - SW wind.
  - 3m/s wind at 30m.
  - Neutral stability.
  - Background concentrations from London Air Quality Network.
- Matched in DALES-Urban.
  - $u_* = 0.33\text{m/s}, z_{bl} = 413\text{m}.$
  - Boundary conditions.



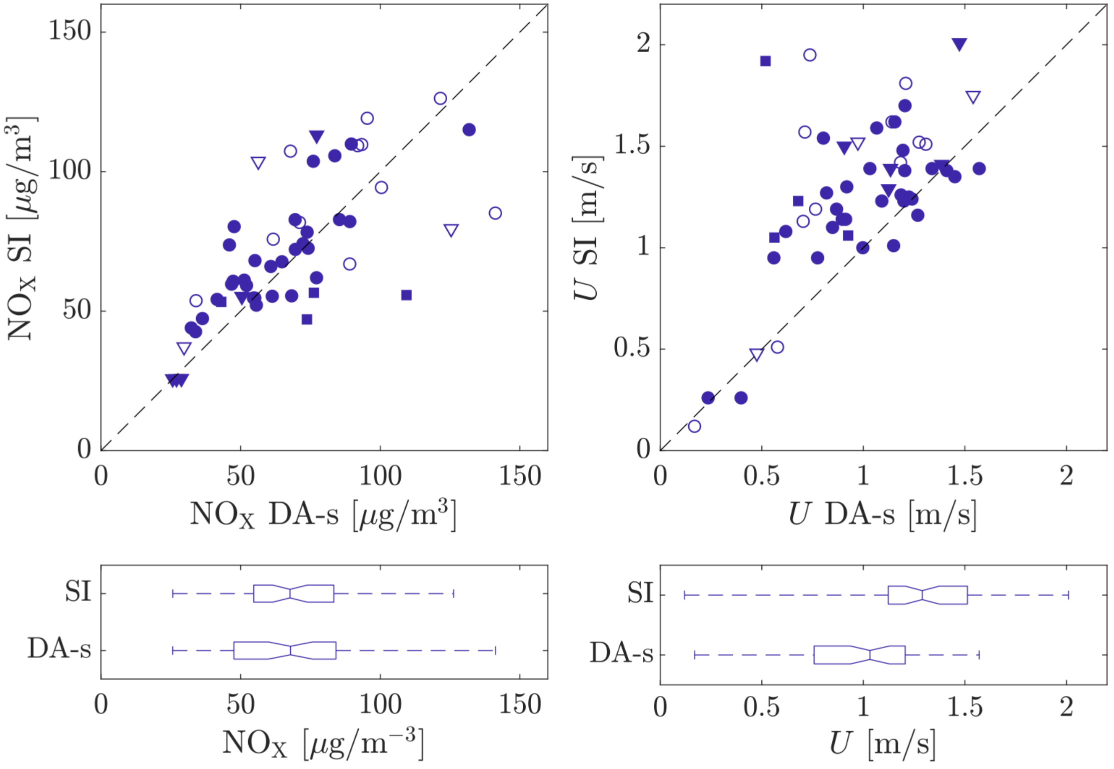
Results - Inert

- Qualitative comparison.
- Vertical exchange at intersections and downwind advection captured well.
- Statistical indices fall within ‘good’ criteria (Chang and Hanna, 2004).
- Non-ideal, infinite street canyons most erroneous.
- Tendency to overestimate the along-canyon velocity.



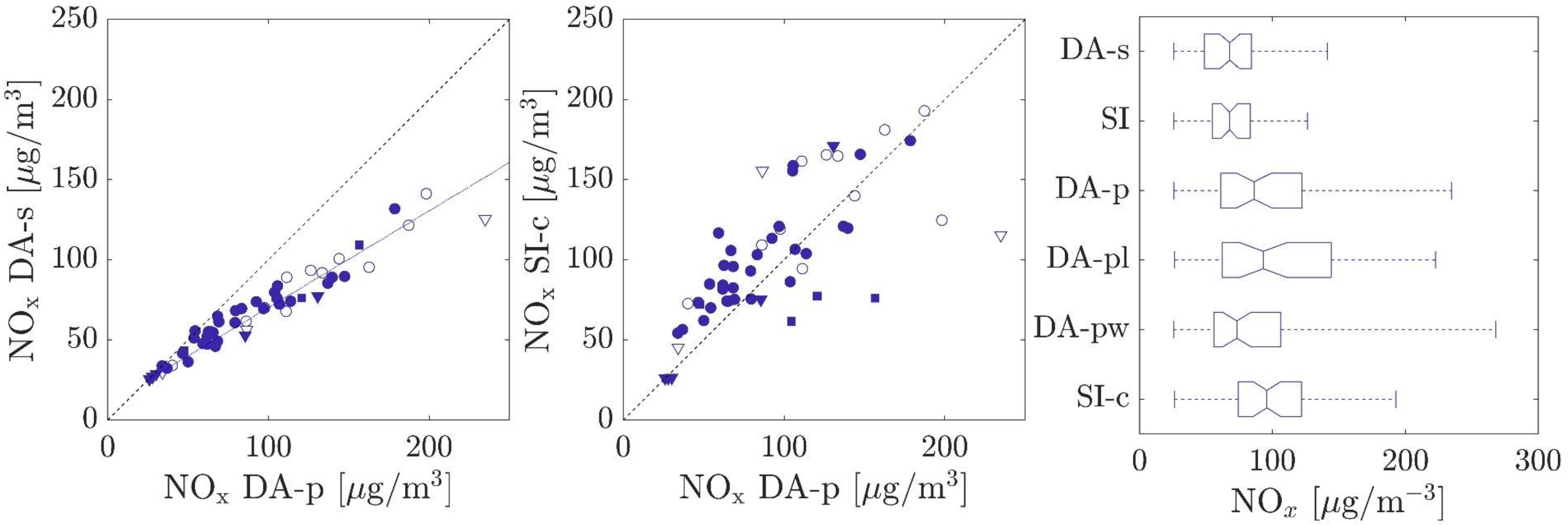
Results - Inert

- Qualitative comparison.
- Vertical exchange at intersections and downwind advection captured well.
- Statistical indices fall within 'good' criteria (Chang and Hanna, 2004).
- Non-ideal, infinite street canyons most erroneous.
- Tendency to overestimate the along-canyon velocity.



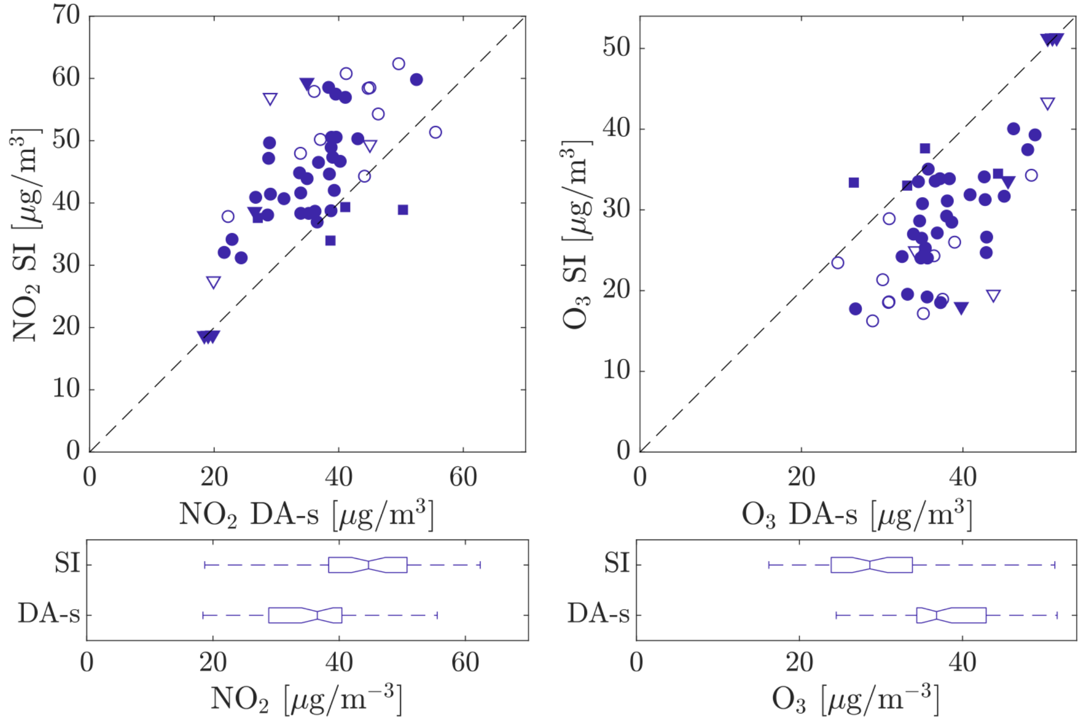
Results - Inert

- Capability to analyse in-canyon variability.
- Pedestrian level concentrations ~1.4 times higher than canyon-averaged.
- Asymmetry apparent from integral statistics.
- Prevalence of intersections and other heterogeneity limits this effect.



Results - Active

- PSS assumption leads to tendency to over- and under-estimate NO_2 and O_3 respectively.
- NO rich emissions lead to deviation from PSS.
- Analysis of the PSS defect indicates as high as 150% on busy roads.
- Agreement with field data.



Conclusion

- SIRANE was shown to perform well in predicting the canyon-averaged velocities over South Kensington, London.
- Correction to be applied to evaluate pedestrian exposure
- Identified shortcomings matched those identified in SIRANE's literature.
- Systematic bias in predicting NO_2 and O_3 concentrations due to PSS assumption.
- LES presents a key tool to conduct high-resolution urban pollution dispersion studies.

DALES-Urban

MAGIC

Envisaging a world with greener cities

Modelling NOx emissions in real-time using Artificial Neural Networks

Clémence M. A. Le Cornec, Marc E. J. Stettler

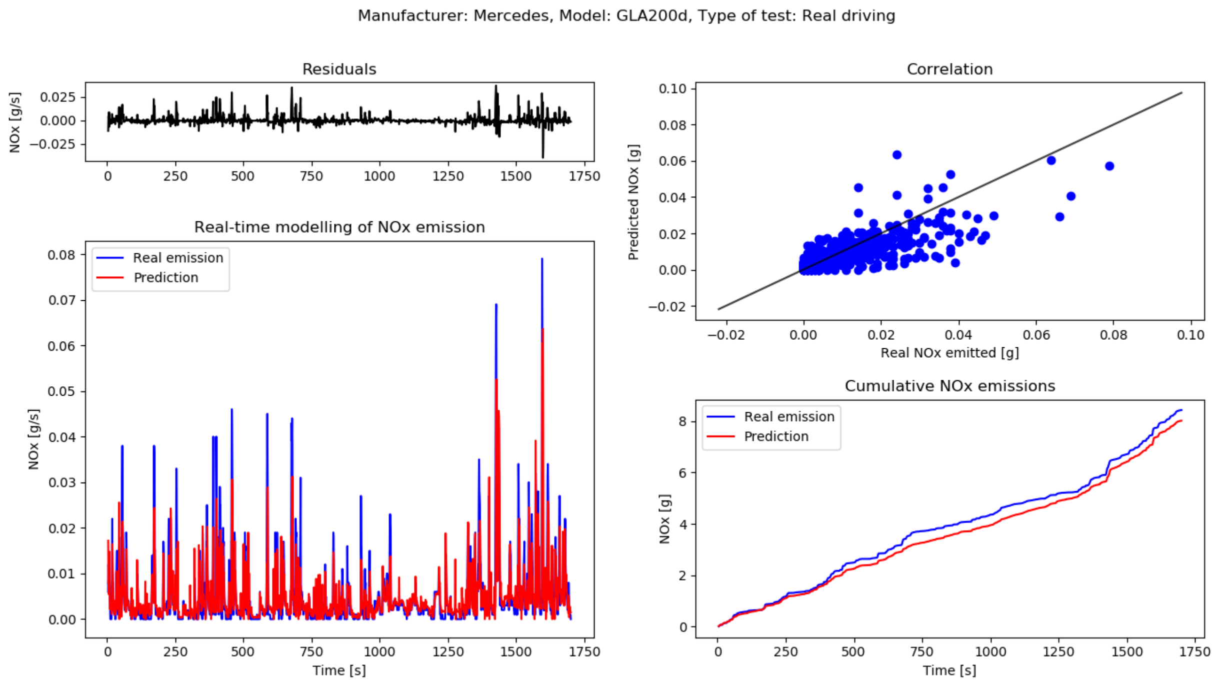
20th of September 2018

Introduction

- Importance of emissions modelling
- Highly-variable and non-linear problem
- Wide range of existing models, requiring more or less complex inputs
- Increase in computational power and data availability
- Long-short term memory network (LSTM)
- Data from the On-Board Diagnostic (OBD-II) used as inputs to predict NOx emissions
- Real-world driving conditions

Results

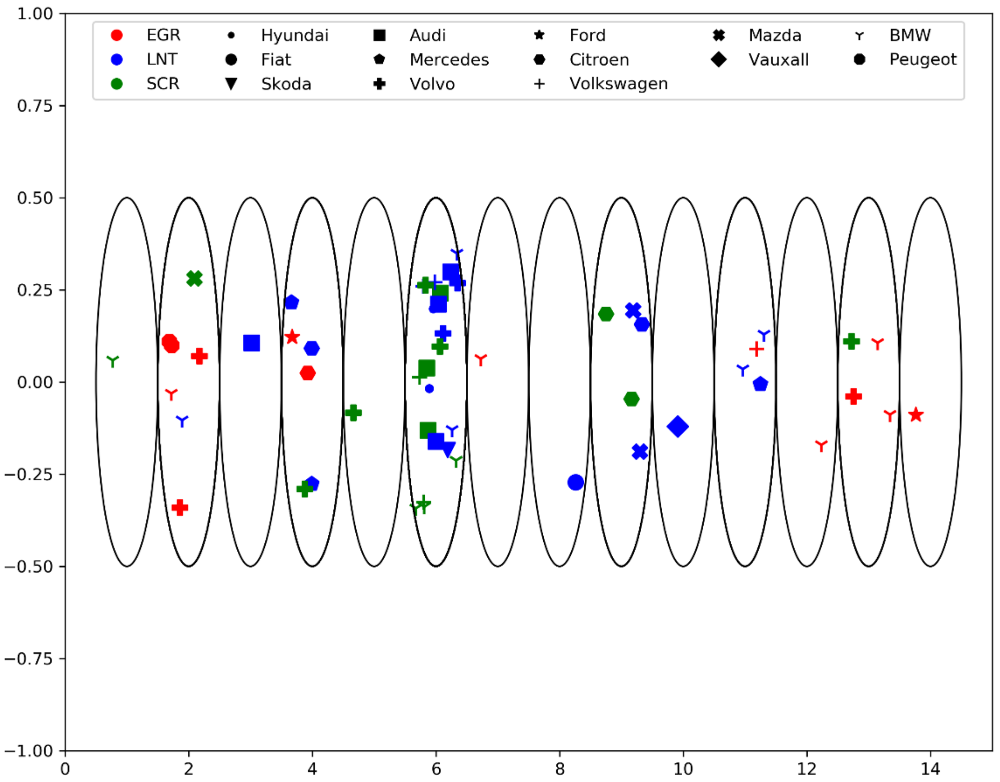
- General models are not able to produce accurate results
- Differences between the vehicles overpower the variations due to operating conditions
- Specific models present a relative error between 0.3% and 26.5% and an absolute error smaller than 0.02 g/km



SUCCESS but not implementable at a large scale

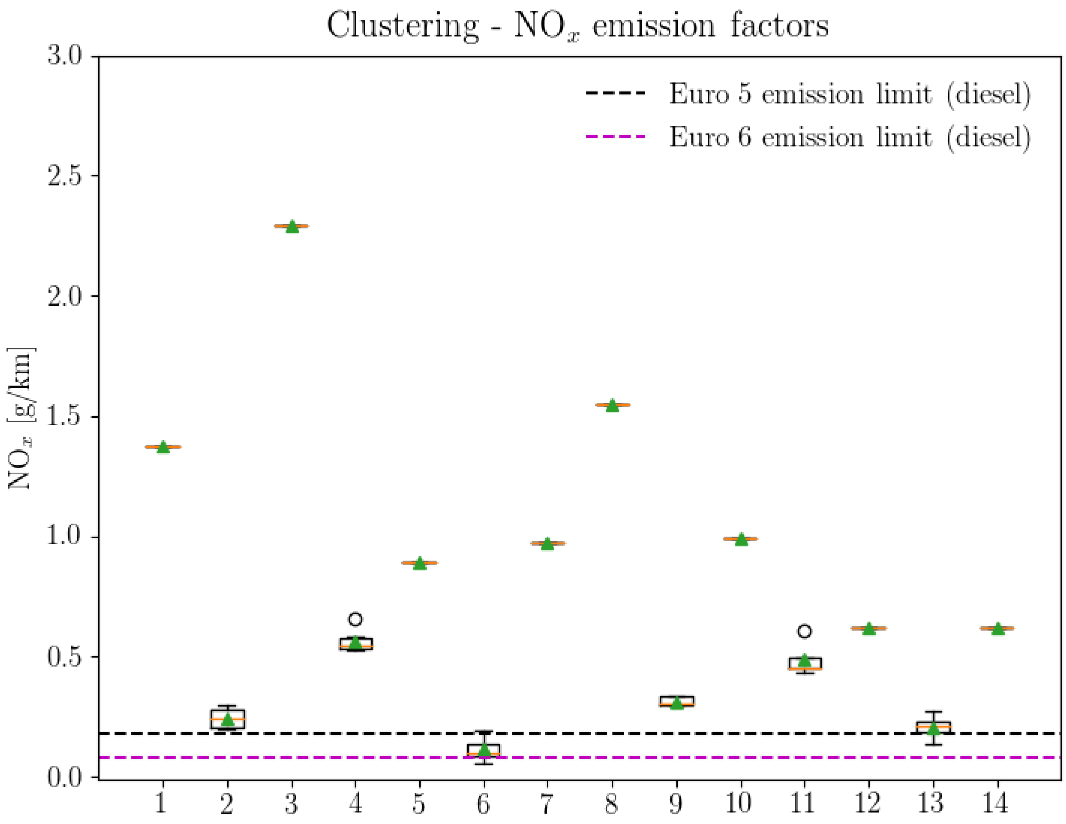
Clustering

- Reduction of the number of model needed
- Emission Analytics test in Greater London
- 58 segments of 10 km
- Unsupervised clustering (kmeans)
- Evaluation of the optimal number of clusters using the Davies-Bouldin and the Calinsky-Harabazt indices
- 14 clusters with distinct emission factors
- Hard to find a simple rule to classify a new vehicle!



Clustering

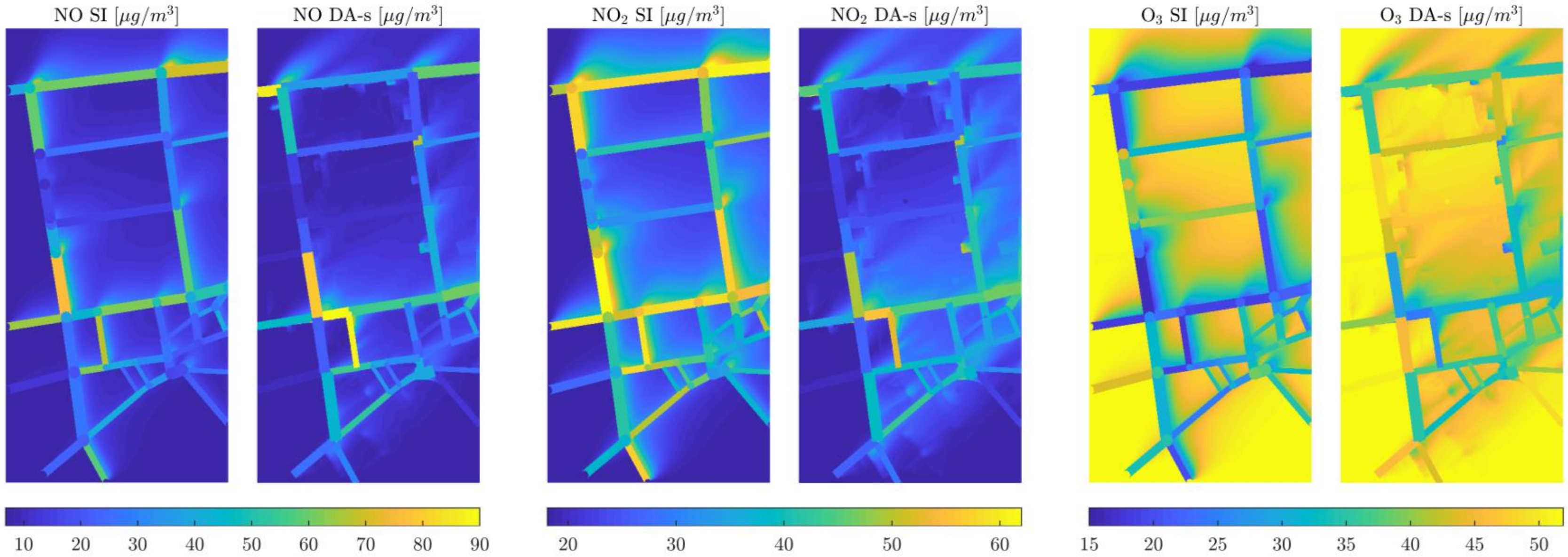
- Reduction of the number of model needed
- Emission Analytics test in Greater London
- 58 segments of 10 km
- Unsupervised clustering (kmeans)
- Evaluation of the optimal number of clusters using the Davies-Bouldin and the Calinsky-Harabasz indices
- 14 clusters with distinct emission factors
- Hard to find a simple rule to classify a new vehicle



Conclusion

- ANN models are able to produce accurate results to predict NOx emissions in real-time
- Specific models are not implementable at a large scale
- Clustering techniques and analysis are used to try to reduce the number of models needed
- Work in progress!

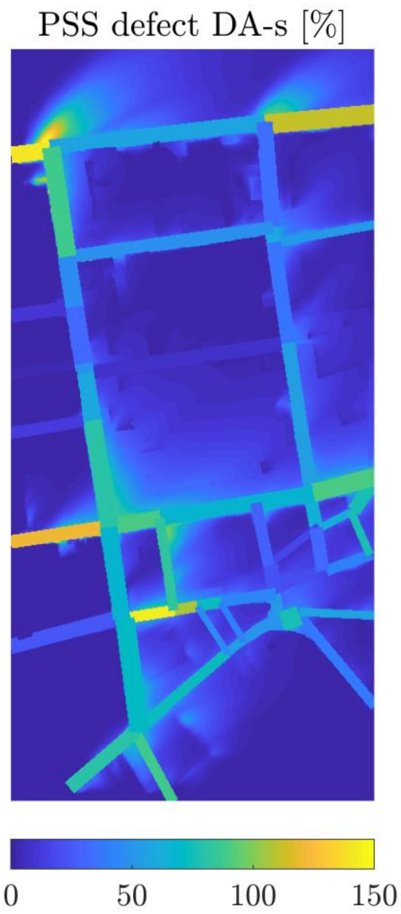
Backup slide - Results - Active



Backup slide - PSS

- PSS assumption leads to tendency to over- and under-estimate NO_2 and O_3 respectively.
- NO rich emissions lead to deviation from PSS.
- Analysis of the PSS defect indicates as high as 150% on busy roads.
- Agreement with field data.

$$d_{ps} = \left(\frac{k_3[\mathrm{O_3}][\mathrm{NO}]}{k_1[\mathrm{NO_2}]} - 1 \right) \mathrm{x}100$$



Backup slide - Sensitivity

- Case study repeated with westerly wind.
- Statistical indices indicate that same relationships hold.
- Future work: sensitivity to other parameters (e.g. stability).

Index	'Good' criteria [23]	Wind direction	Wind speed	Inert	Reactive		
				NO_x	NO	NO_2	O_3
FB[1]	$abs \leq 0.3$	SW	-0.29	-0.06	0.06	-0.23	0.27
		W	-0.04	-0.13	-0.06	-0.26	0.30
NMSE[2]	≤ 4	SW	0.20	0.08	0.16	0.09	0.10
		W	0.36	0.11	0.16	0.12	0.15
FAC2[3]	≥ 0.5	SW	0.92	1.0	0.92	1.0	0.92
		W	0.60	0.96	0.91	0.94	0.81

[1] Fractional bias
[2] Normalized mean squared error
[3] Fraction in a factor of 2 A.2

MAGIC

Envisaging a world with greener cities

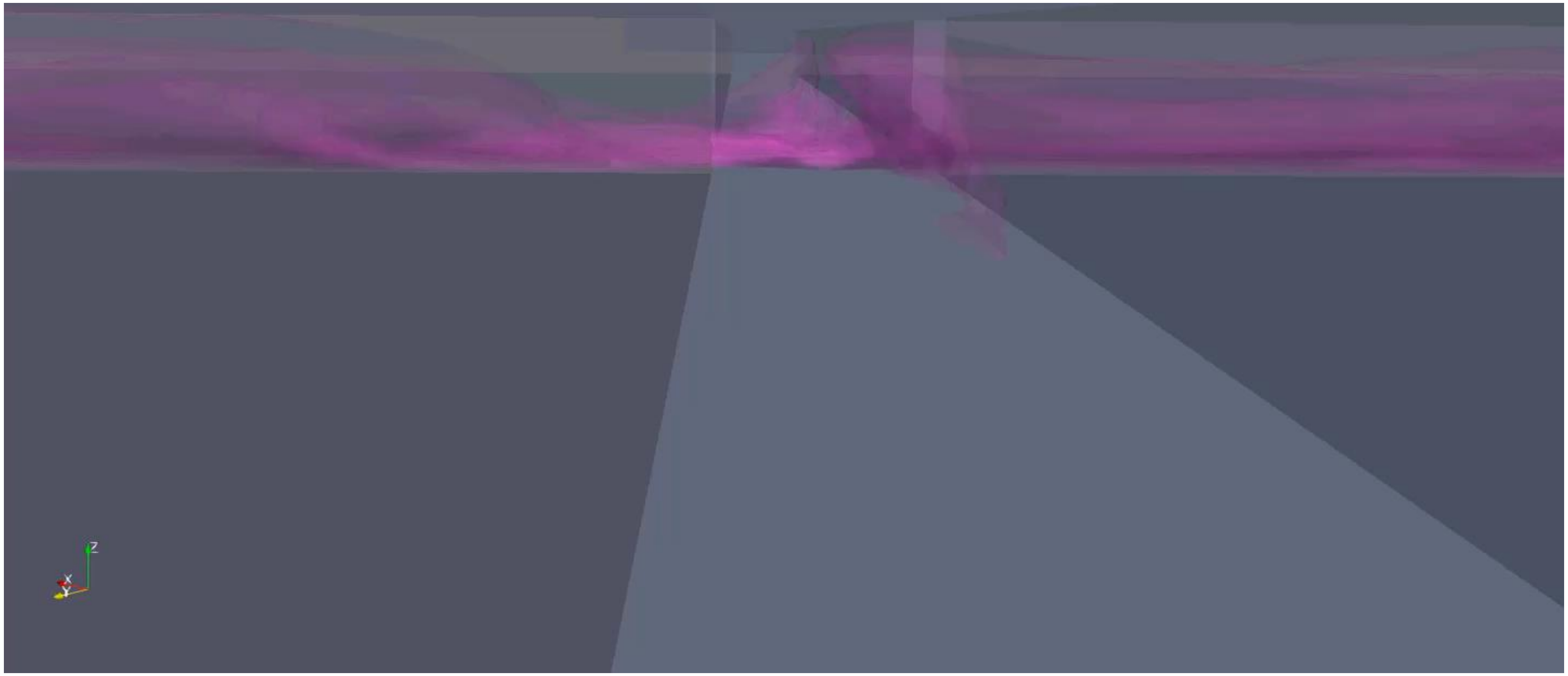
Update on Fluidity traffic model

Huw Woodward

20/09/2018

May 2017

Fluidity's traffic model



Traffic modelling

Driving behavior

Vehicle counts

Traffic lights signal control

Traffic flow model
PTV Vissim

```
579224
1 200 10.21 1.4 83.31344228 -86.1418694 14.6 0.5
1 200 10.21 1.5 83.0235285 -85.85195562 14.92 0.9
1 200 10.21 1.6 82.72583654 -85.55426367 15.36 1.22
1 200 10.21 1.7 82.4189522 -85.24737933 15.89 1.48
1 200 10.21 1.8 82.10146126 -84.92988838 16.5 1.68
1 200 10.21 1.9 81.77053528 -84.59896241 17.17 1.88
1 200 10.21 2 81.42546717 -84.2538943 17.92 2.08
1 200 10.21 2.1 81.06554982 -83.89397695 18.74 2.28
```

Vehicle dynamics

Fluidity traffic model

Instantaneous emissions model
Cars - PEMS data
Buses – onboard sensors

Emission rate$= f_1 + f_2 v + f_3 v^2 + f_4 a + f_5 a^2 + f_6 va$

Single vehicle simulation

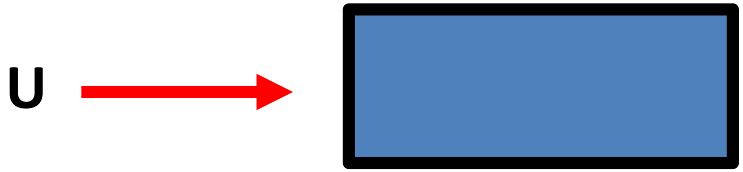
- Comparison of traffic model with low resolution to high resolution simulations

Traffic model, low resolution

$$l_{min} = 0.5m$$

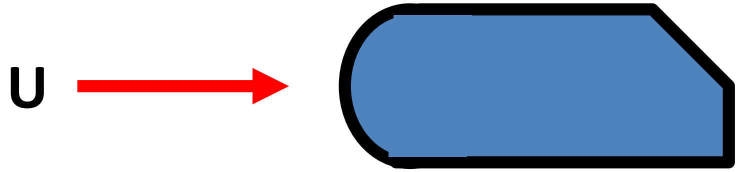
Solid boundary, rectangular block

$$l_{min} = 0.075m$$

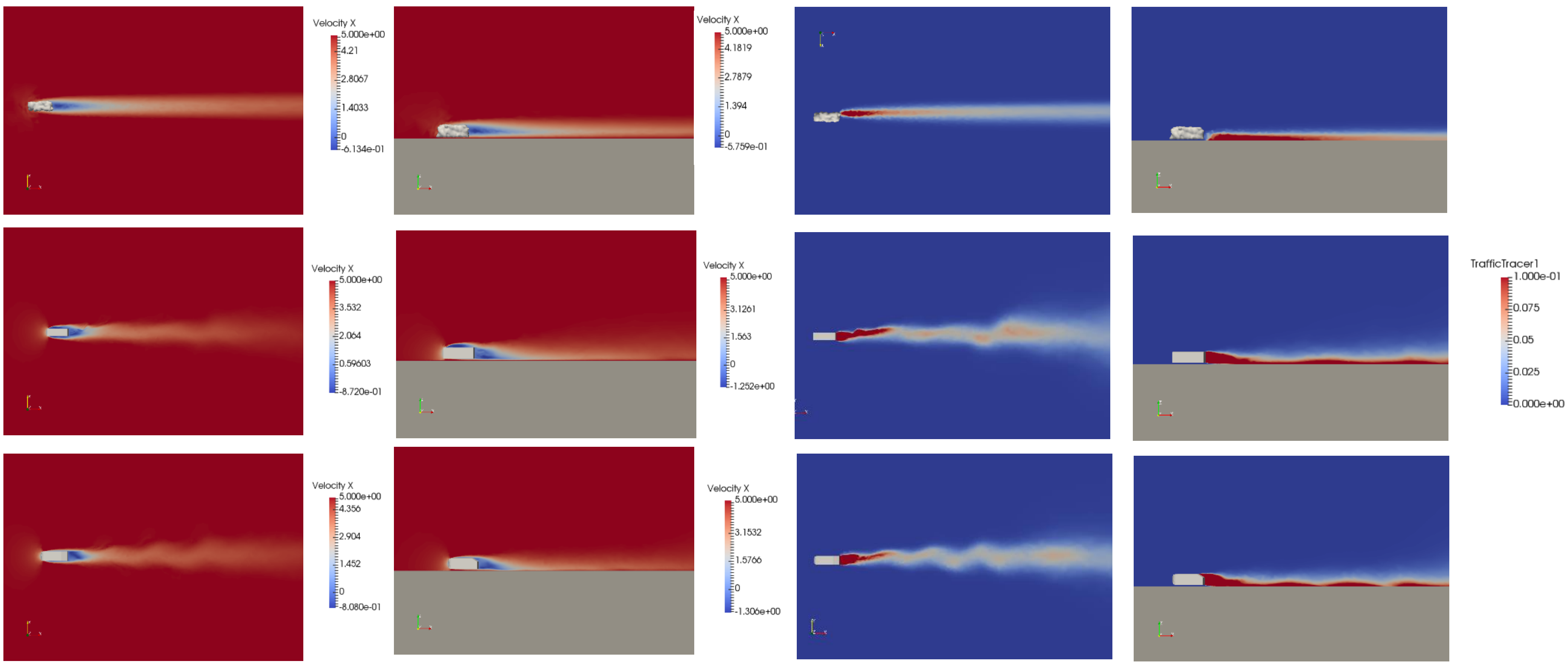


Solid boundary, ahmed body

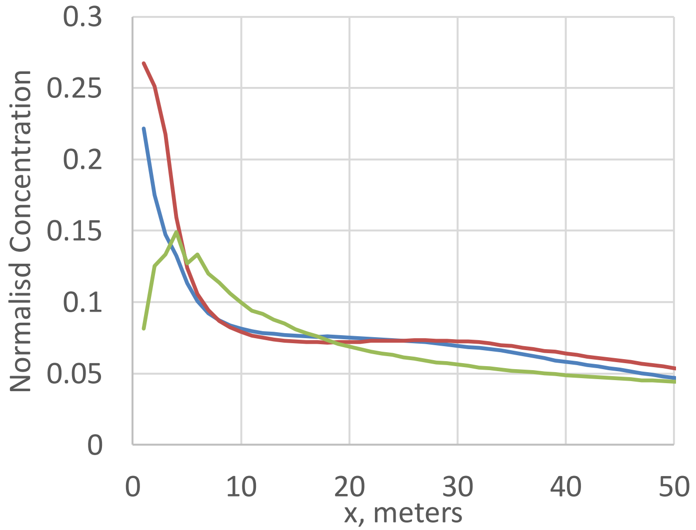
$$l_{min} = 0.075m$$

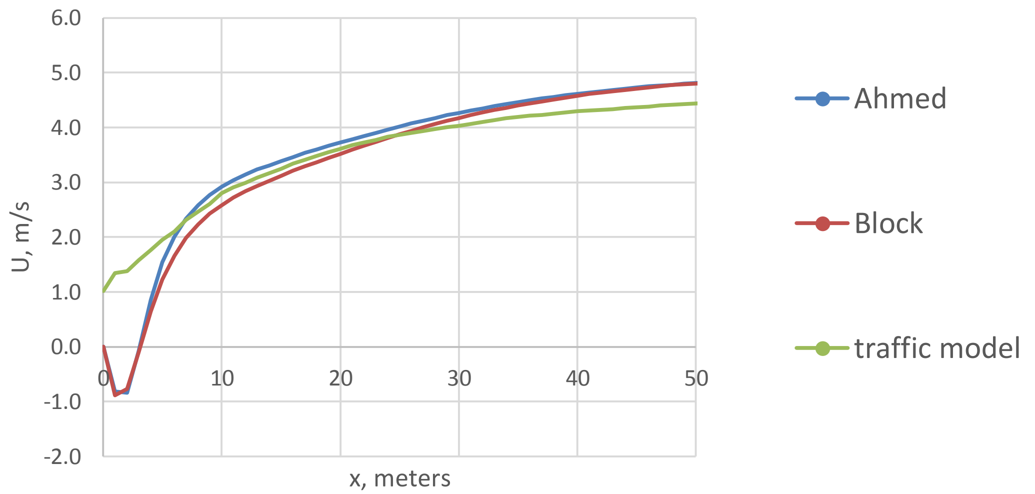


Single vehicle simulation

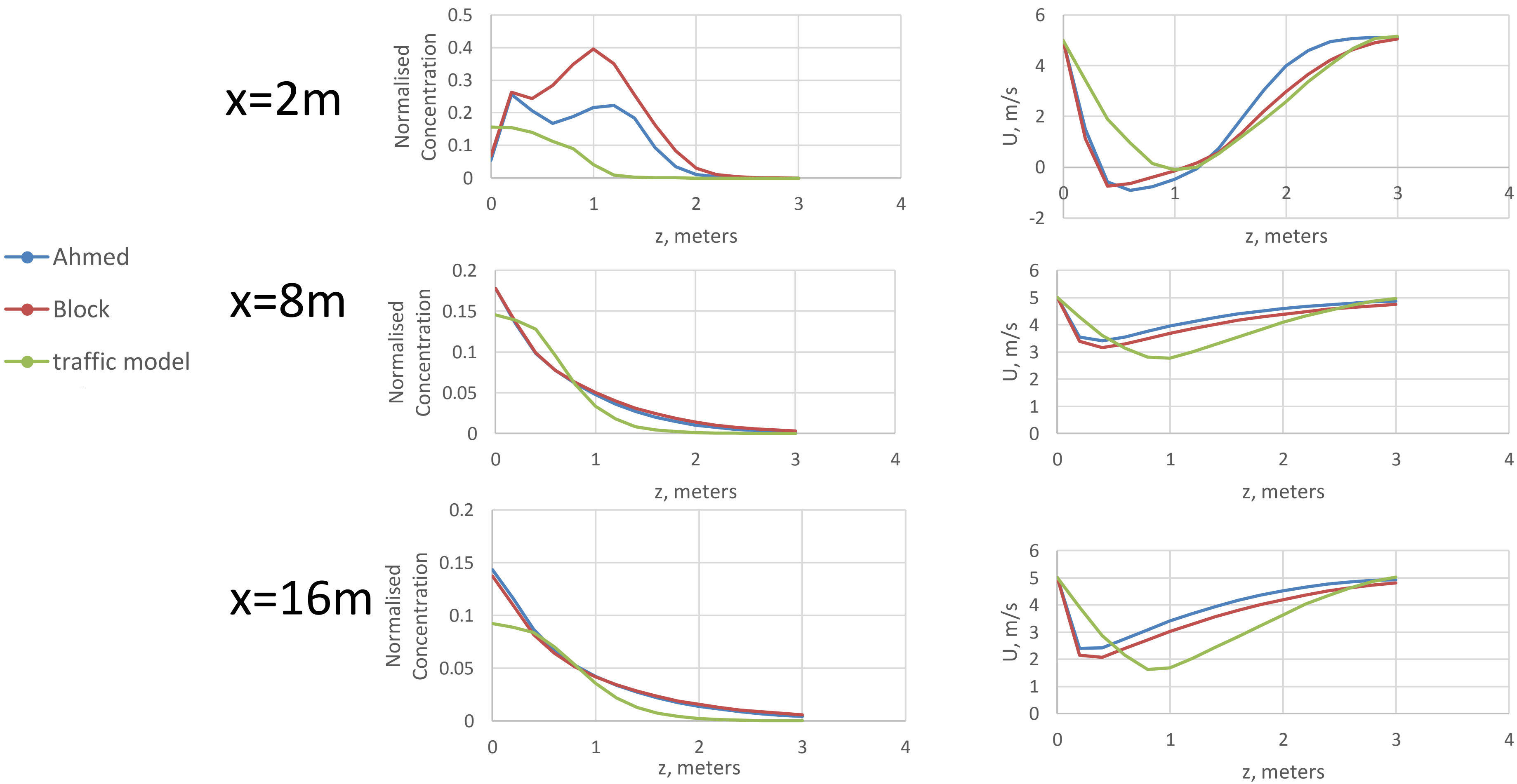


Plots along x direction from 0m to 50m at y=0m, z=0.5m





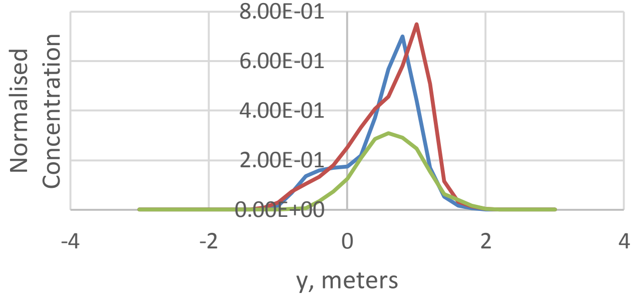
Plots along z direction from 0m to 3m, y=0m

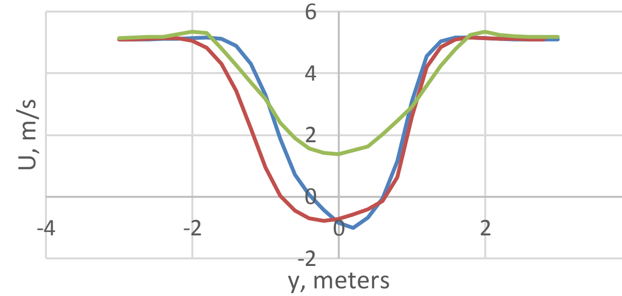


Plots along y direction from -3m to 3m, z=0.5m

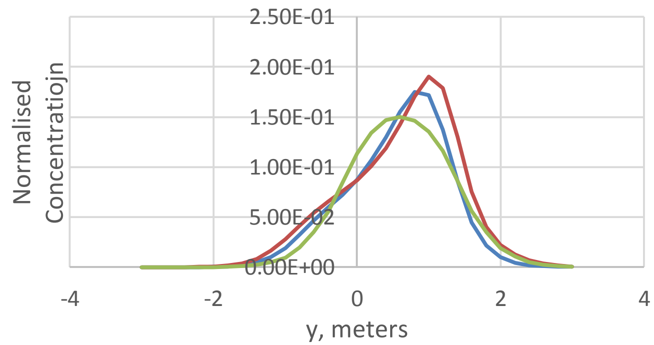
Ahmed
Block
traffic model

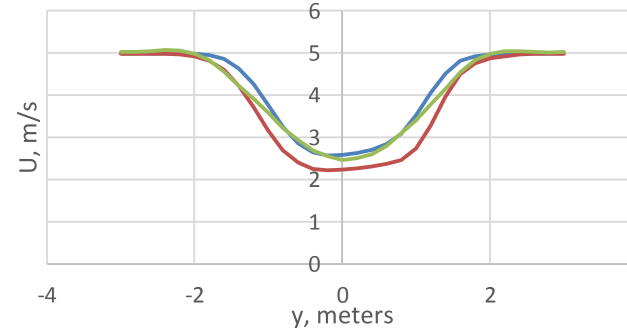
x=2m



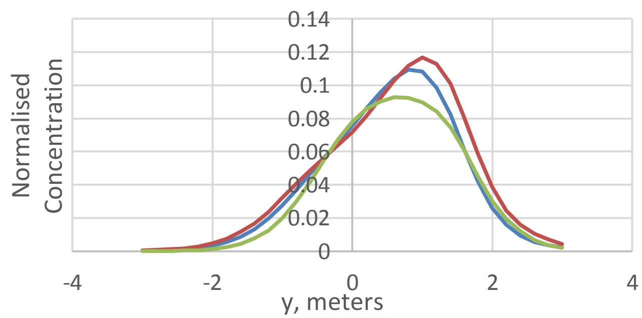


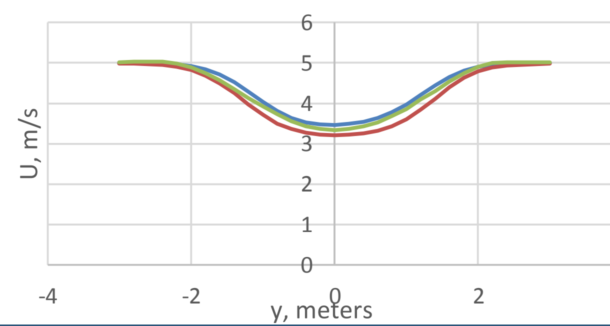
x=8m





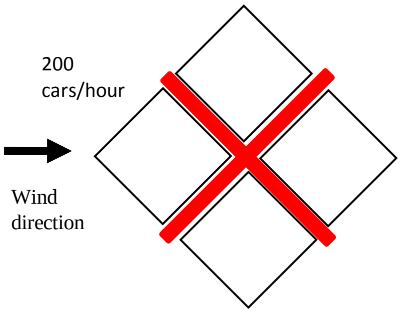
x=16m

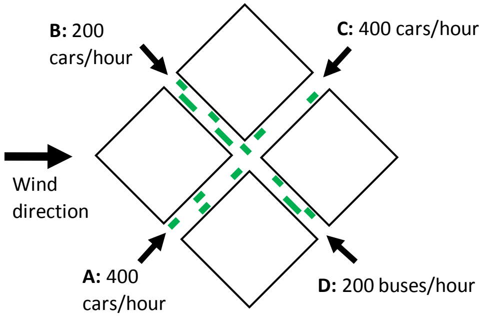


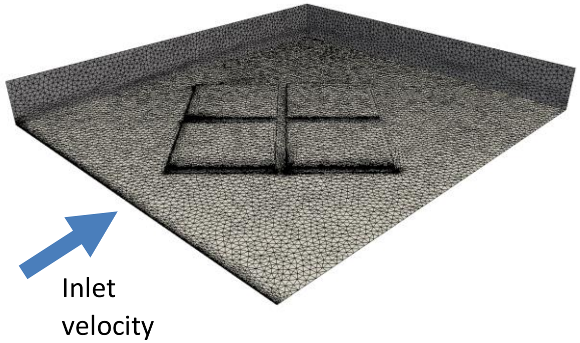


Crossroad simulation

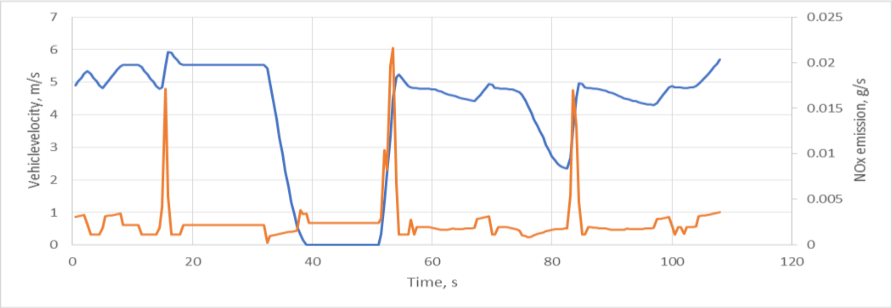
- Crossroads formed by the intersection of two canyons
- Comparison between line source model and traffic model with instantaneous emissions



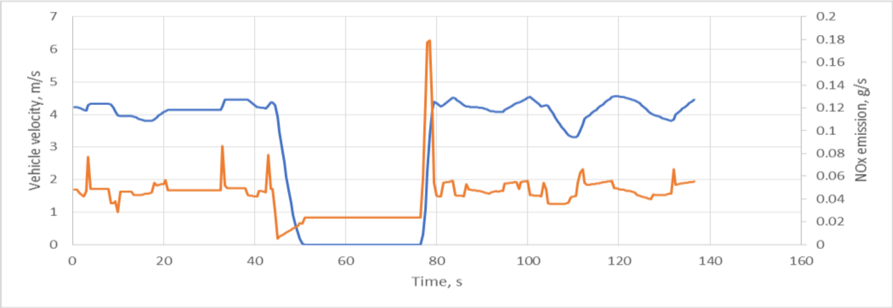




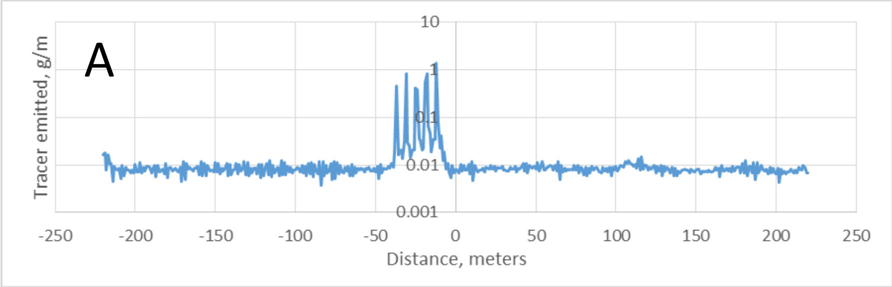
Single car emissions

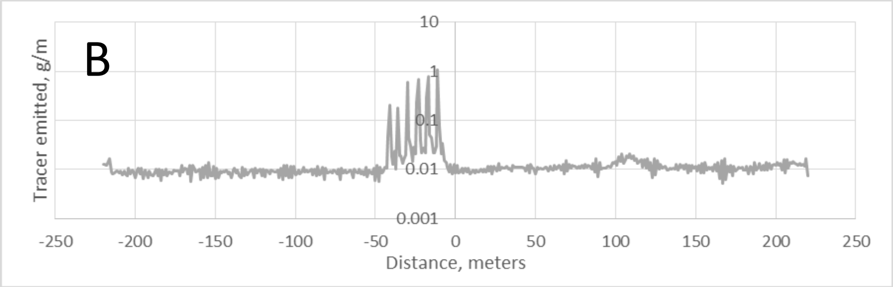


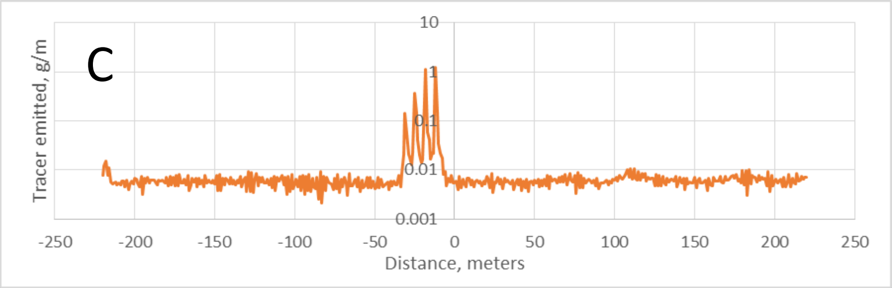
Single bus emissions

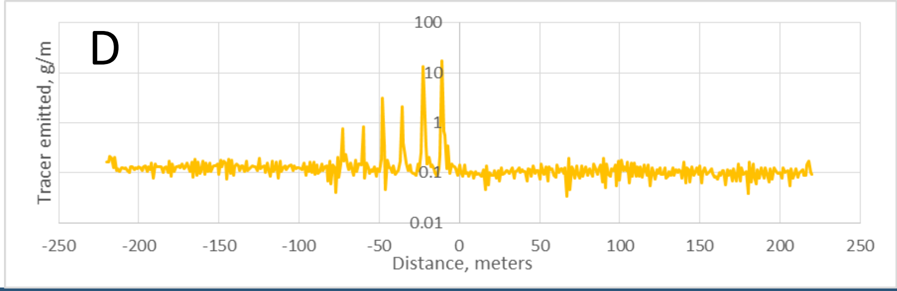


Accumulative emissions (g/m)





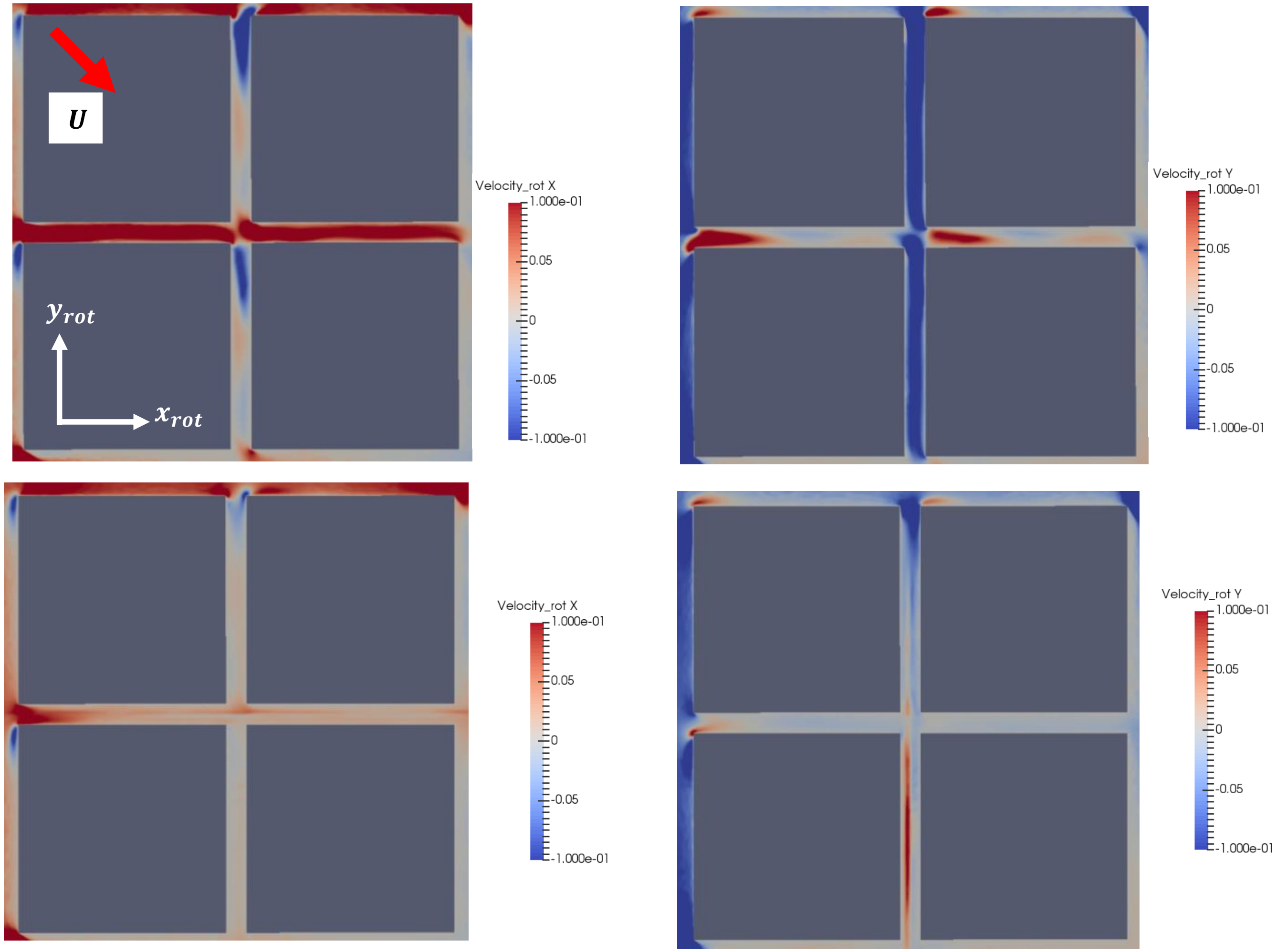




Velocity fields

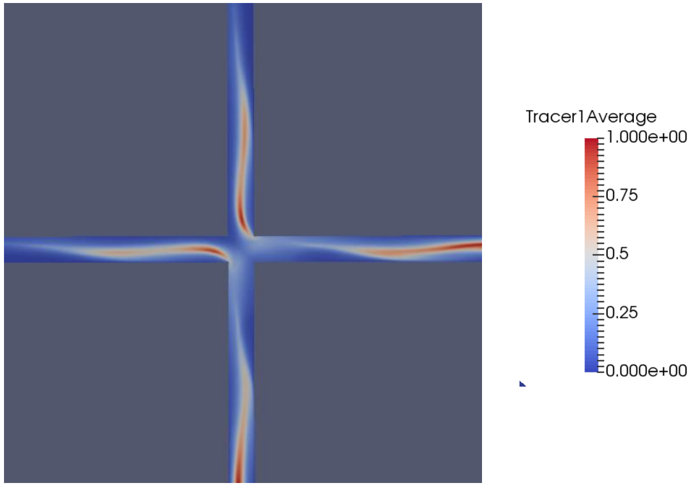
Line source

Traffic model

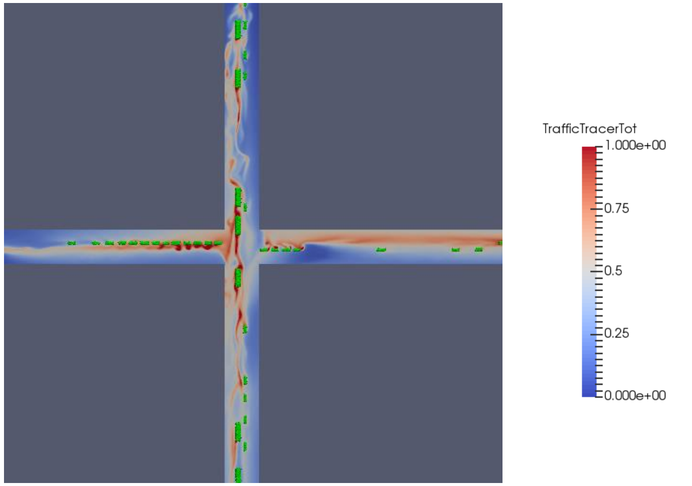


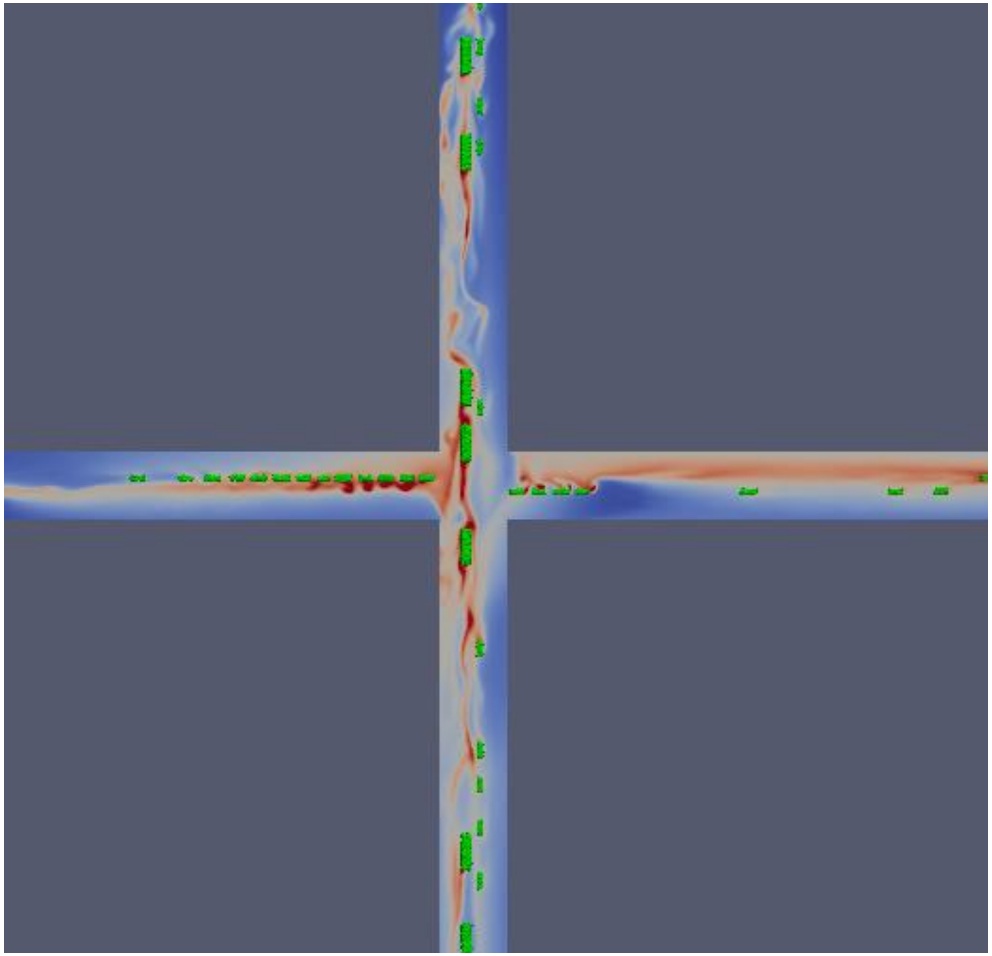
Tracer dispersion

Line source



Traffic model





Individual lane emissions