# Real Time Bus Emissions in Oxford

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IAPSC – 4 Dec 2019

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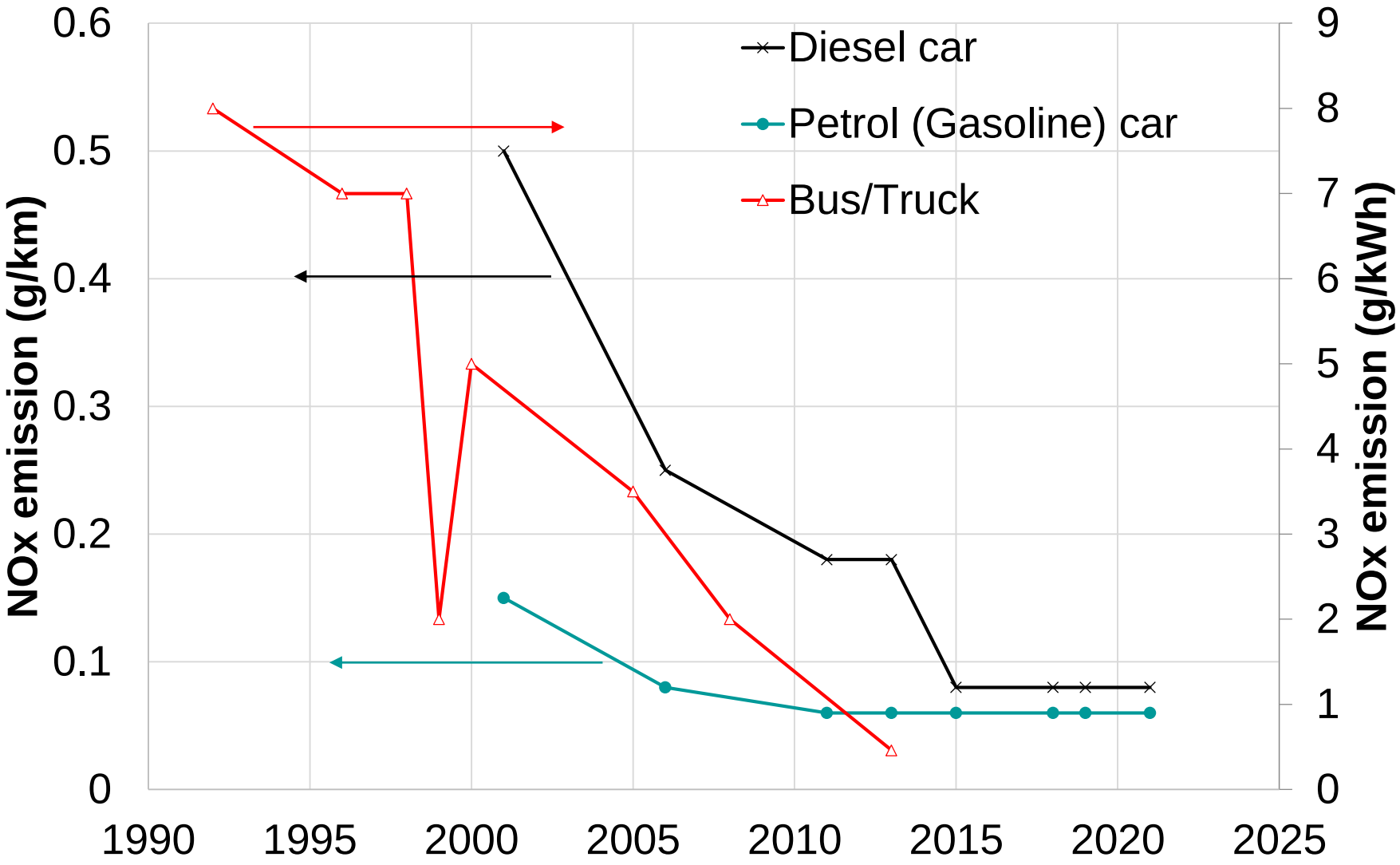
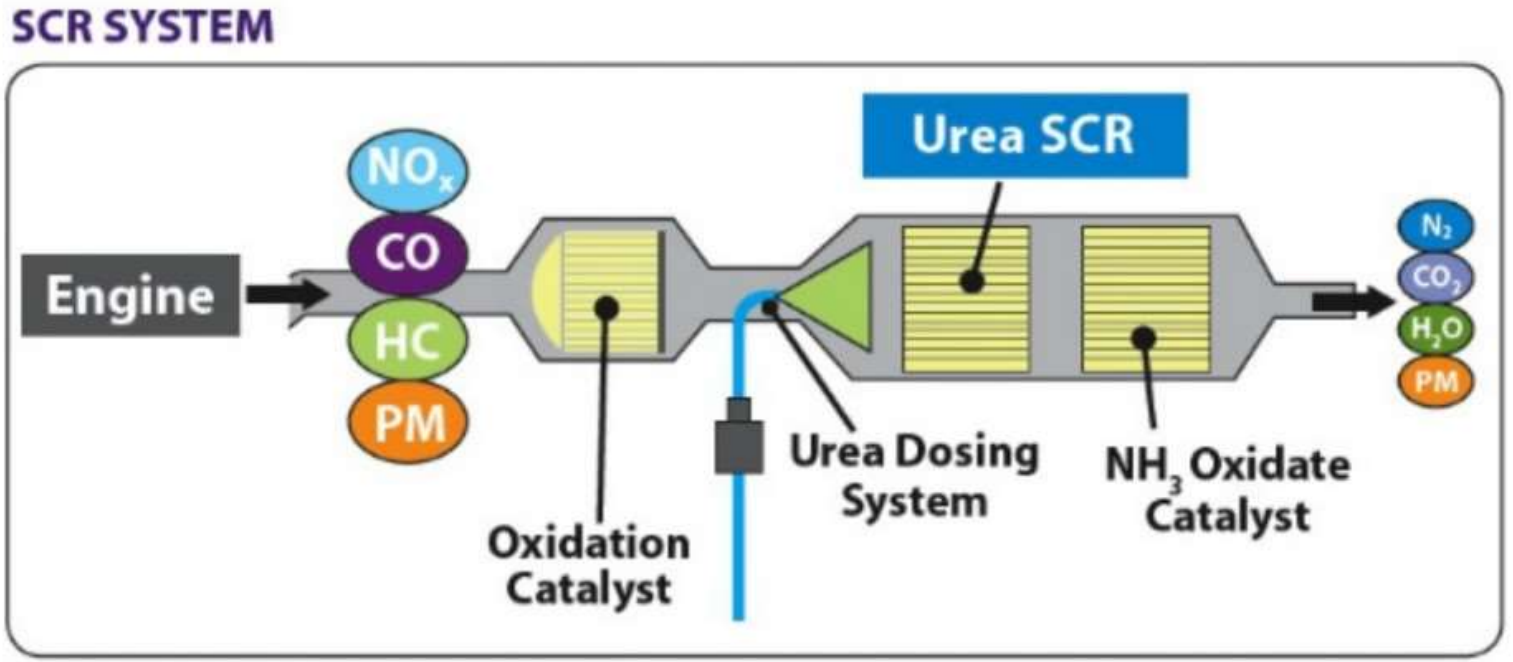
- Control of NOx emissions from vehicles
- Fast RDE
- Bus routes
- Results
- Comparison with legislative tests

# EU NOx emissions legislation



# SCR NOx aftertreatment system fundamentals



# Fast RDE $NO_x$ and NO


- Based on CLD with $T_{10\text{-}90\%}$ response time of ~2 milliseconds
- Two channels
- Capable of simultaneously logging vehicle ECU data
- Integrated GPS data
- Dashcam
- 12V (car) battery powered

# Vehicles tested

Euro V hybrid with SCR
(251,000 miles)

Euro VI with SCR
(119,000 miles)

Euro 5 passenger car 7-seater diesel no SCR
(80,000 miles)

# Sampling arrangements

- Fast NOx measured immediately post aftertreatment in both buses

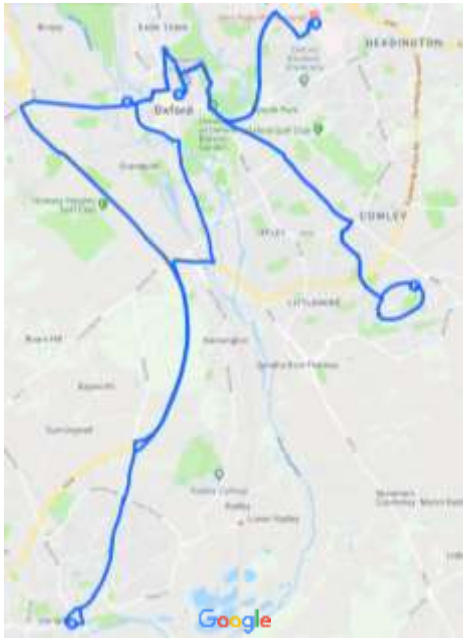

- Euro VI bus with additional exhaust temperature measurement
- GPS, dashcam and emissions logged from within in-service bus

# Routes

Euro V hybrid - 35A / X3 / 13
(Kennington – Matthew Arnold School – Abingdon – City Centre – JR Hospital)

Euro VI – City 5
Blackbird Leys – City Centre


Euro 5 car
Equivalent routes as "taxi"
(where road constraints permitted)




All tested on “hot” summer days (17, 26, 29°C)

# Accuracy of GPS

- Differential GPS measurements accurate to 0.1 cm
- Gives accuracy on emissions ~30 cm

# NOx measurements

- NOx measured in ppm
- Without exhaust mass flow data, or high speed rpm cannot obtain mass
- All data is therefore comparative – not legislatively compliant tests

- Estimates can be made at idle:

| | EU V bus | EU VI bus | EU 5 car |
|---|---|---|---|
| Passenger capacity | 73 | 101 | 7 |
| Engine capacity | 4.76 l | 5.1 l | 2 l |
| NOx ppm | 350 | 100 | 110 / 190* |
| NOx g/h | 66 | 20 | 8 / 15* |
| NOx g/h/passenger | 0.90 | 0.20 | 1.14 / 2.14* |

*Air con off / on

# Process of identifying reasons for “emissions events”

- Record emissions, GPS, dashcam and thermocouple data
- Identify and number all significant tailpipe emissions events
- Zoom in to precise location of event (affects local air quality?)
- Plot emissions data alongside dashcam and exhaust temperature

# Exhaust temperature is important!

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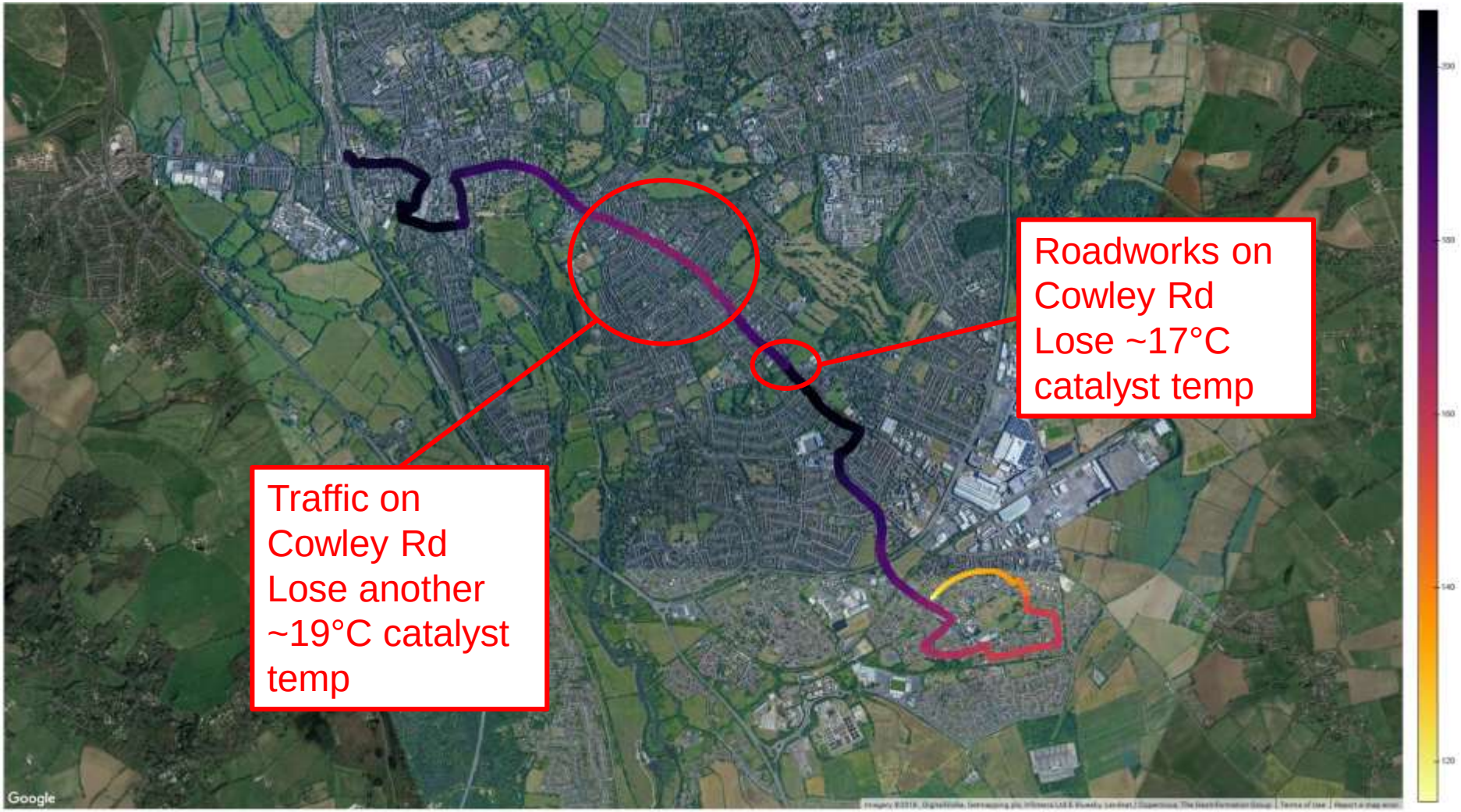

# Transients are also important (NOx emissions)

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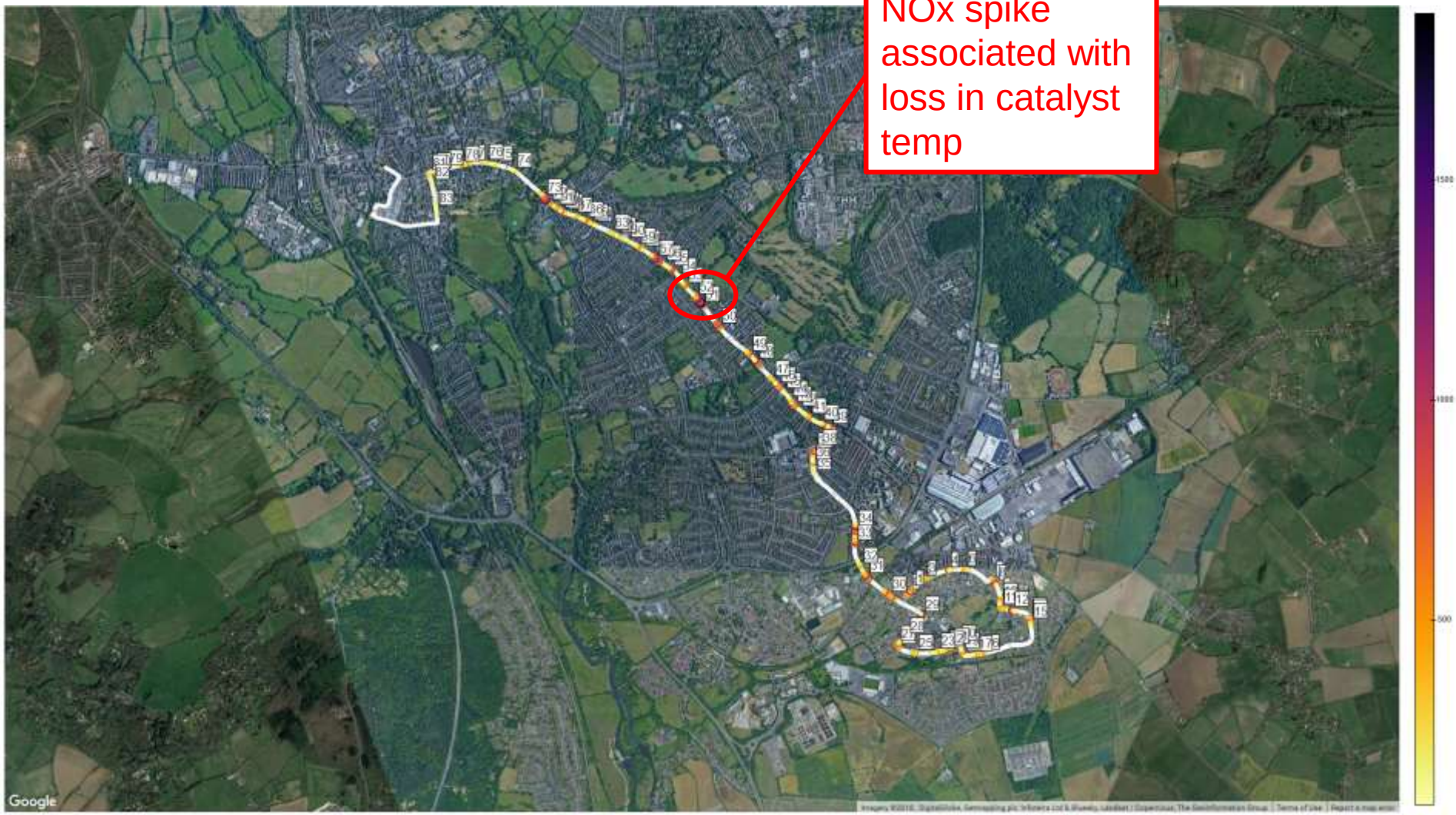
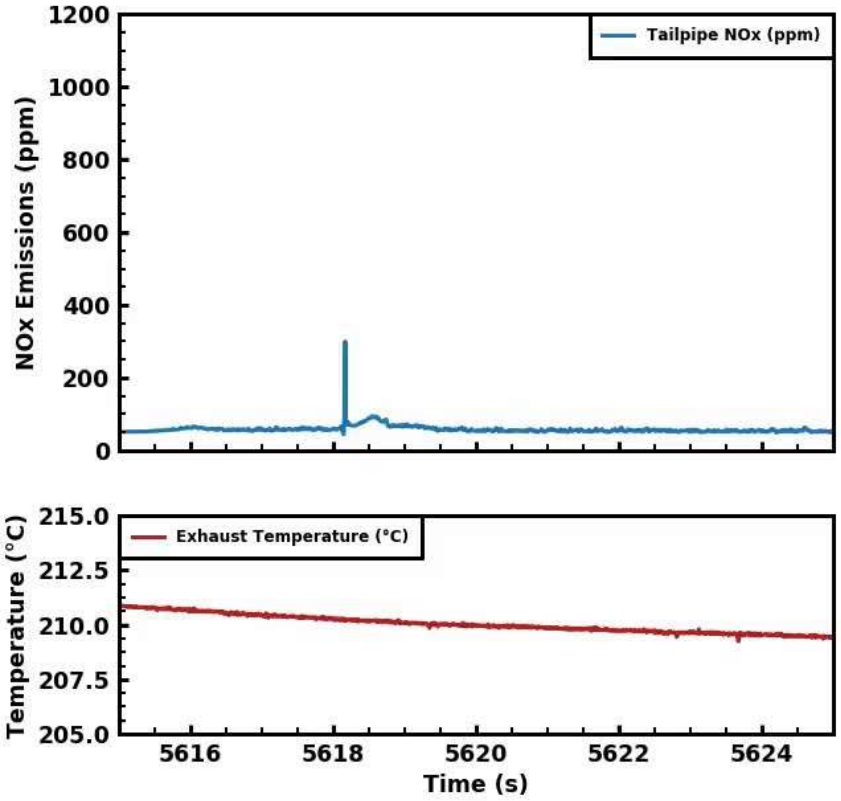
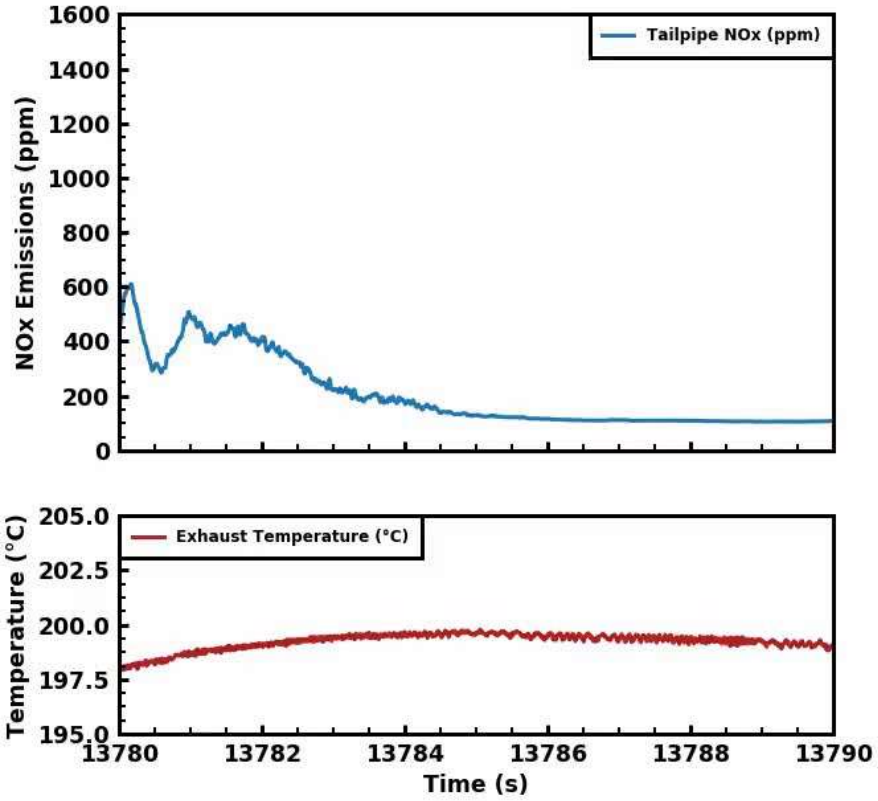


# Eu VI bus stop manoeuvre

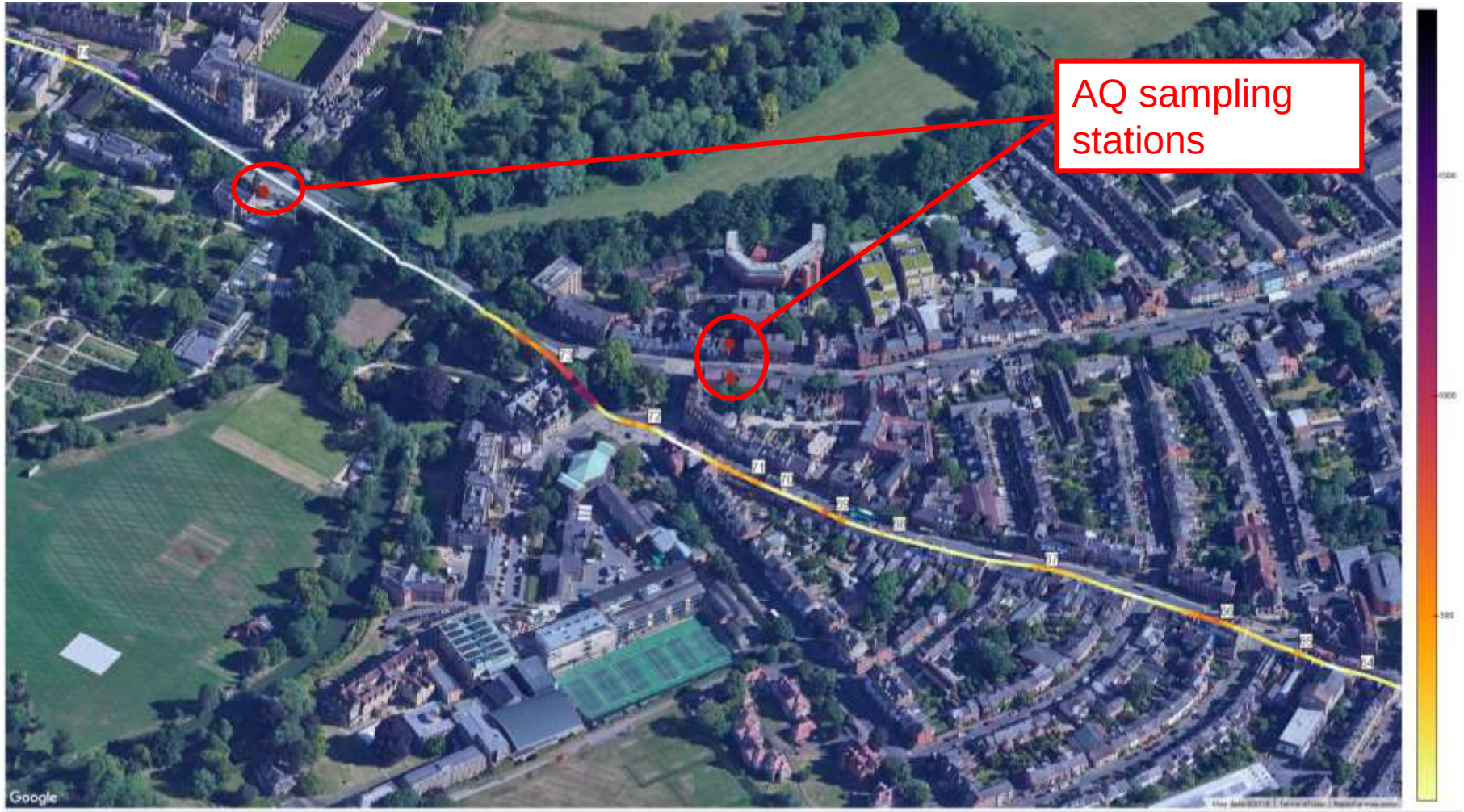



# #73. Run 3 North Eu VI: *The Plain roundabout*




# Typical emissions manoeuvres …

#73. Run 3 North Eu VI: *The Plain roundabout*



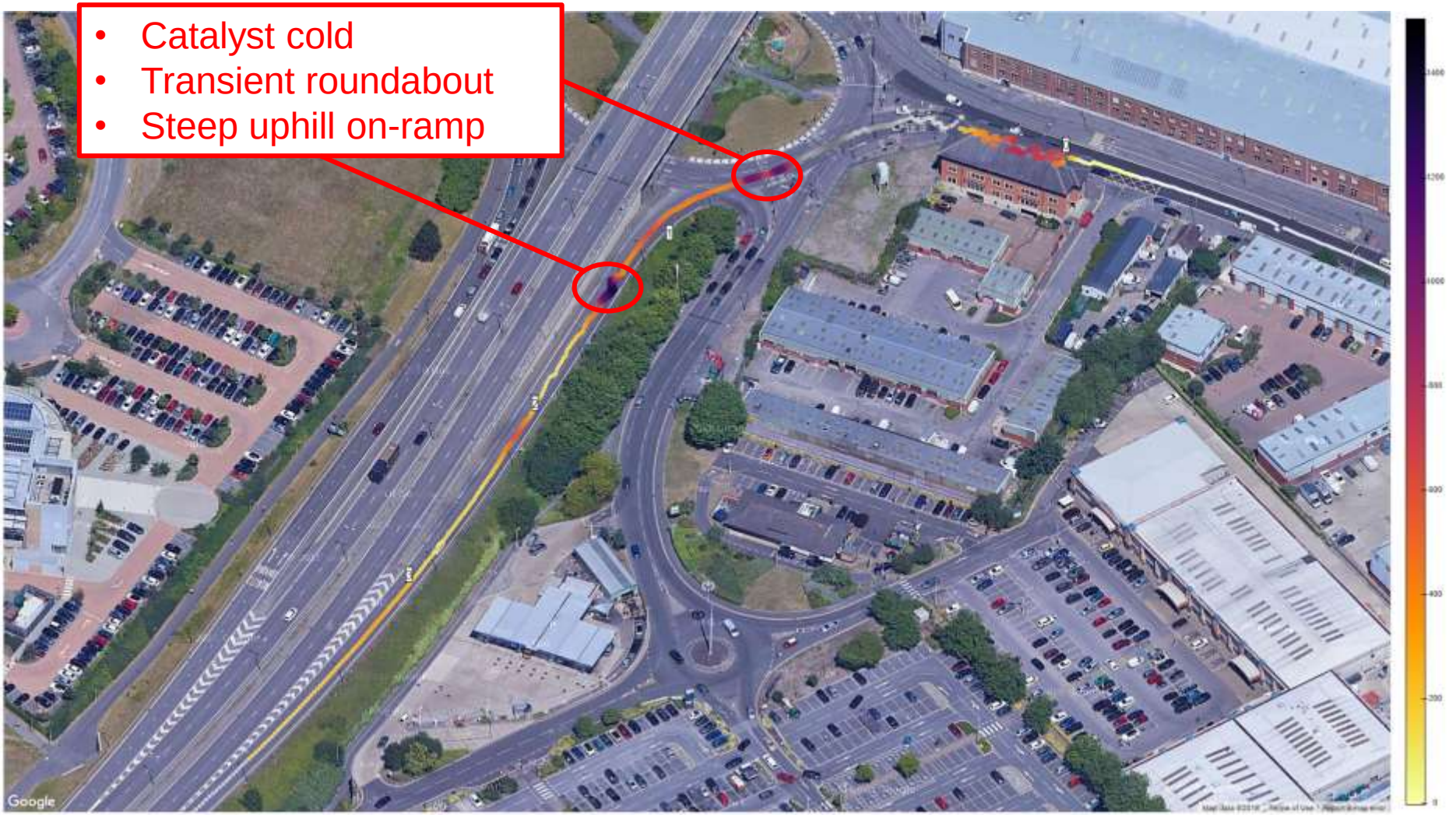
# Eu V & VI start of route

- Cold start ➔ high NOx emissions
- EU V – constant high levels, EU VI – more transient

EU V


EU VI

# Eu VI worst emissions before start of route



# Comparison of 3 x Eu VI north runs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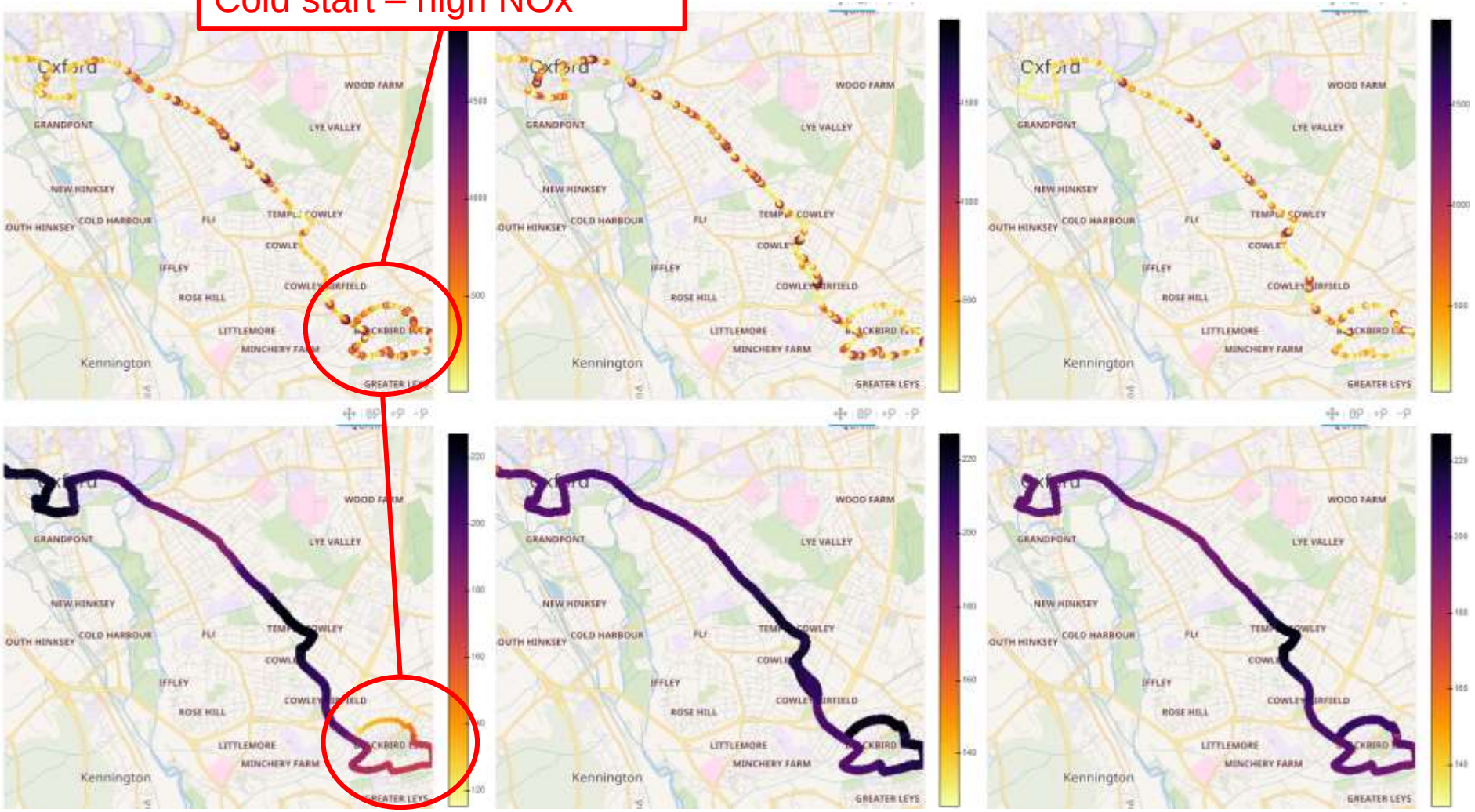
# Comparison of 3 x Eu VI north runs

Cold start – high NOx

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# Comparison of 3 x Eu VI Blackbird Leys

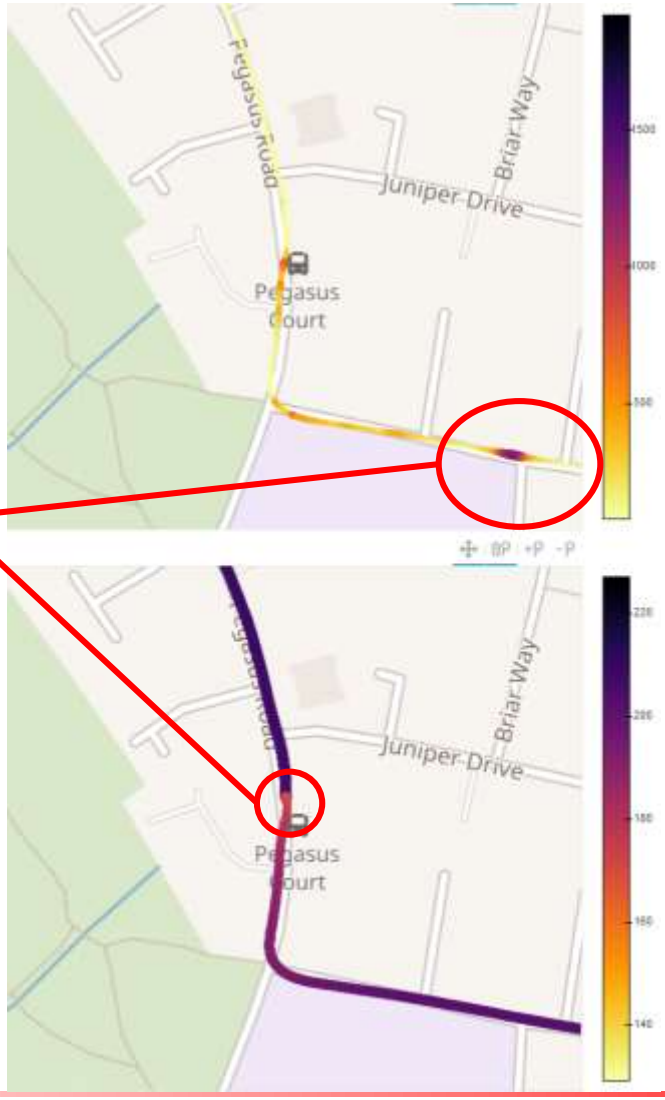

*Bus stop location correlates with emissions:*

# Effects of 4-min engine switch-off Eu VI

NOx

Engine off stop
Catalyst cools
Associated “spike in NOx

Ex temp

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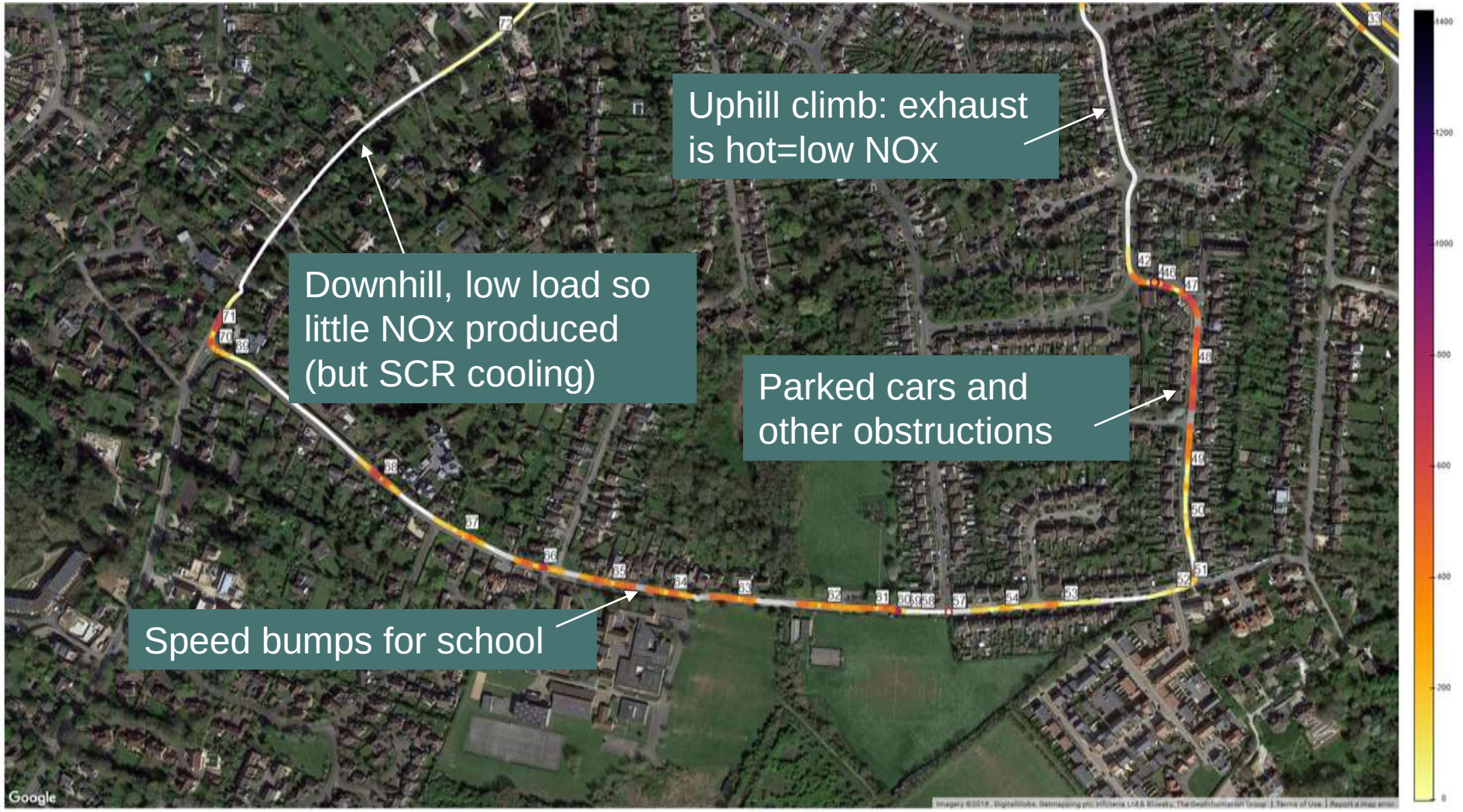
# Eu V negotiating speedbumps – MA school

# NOx around school, SCR temperature dependency



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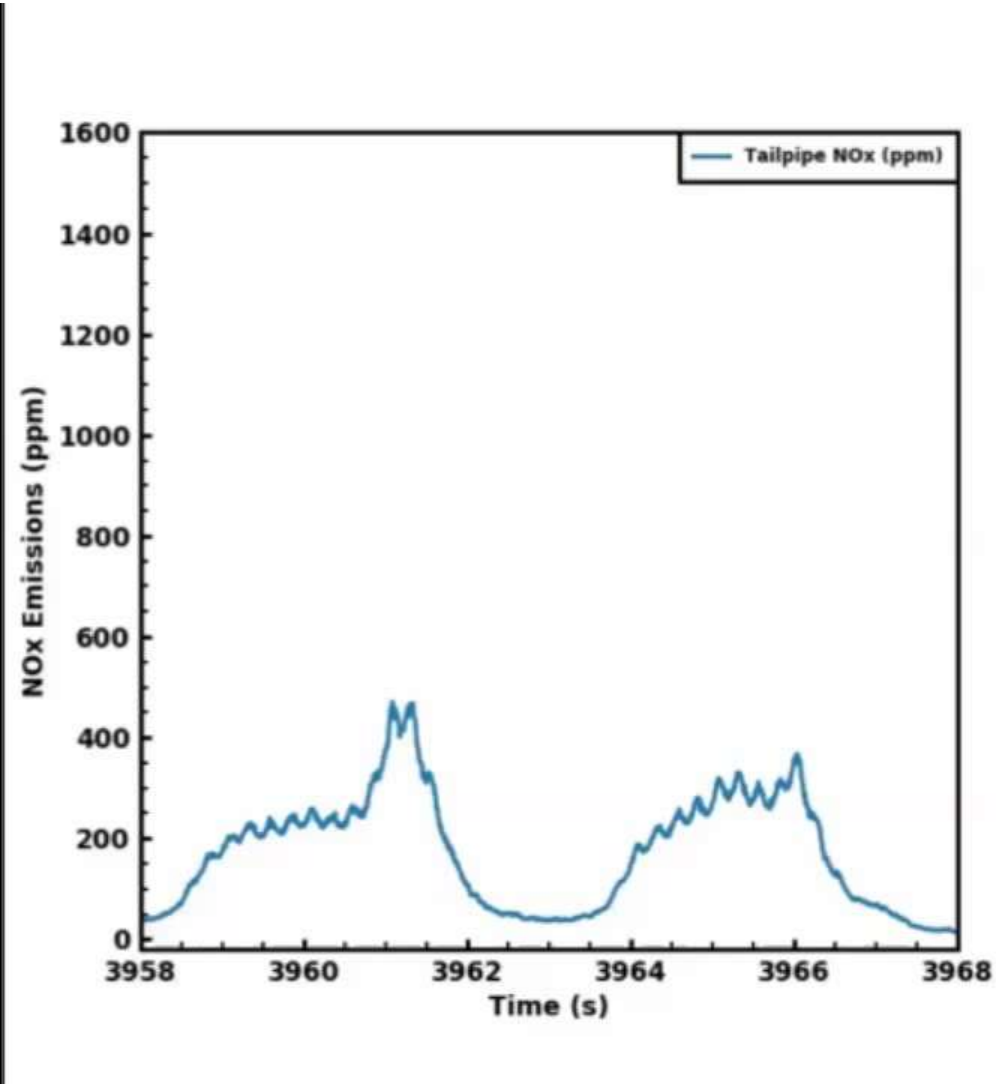



# Eu V bus & Eu 5 car uphill

Bus


Car

# Comparison with Millbrook cycles

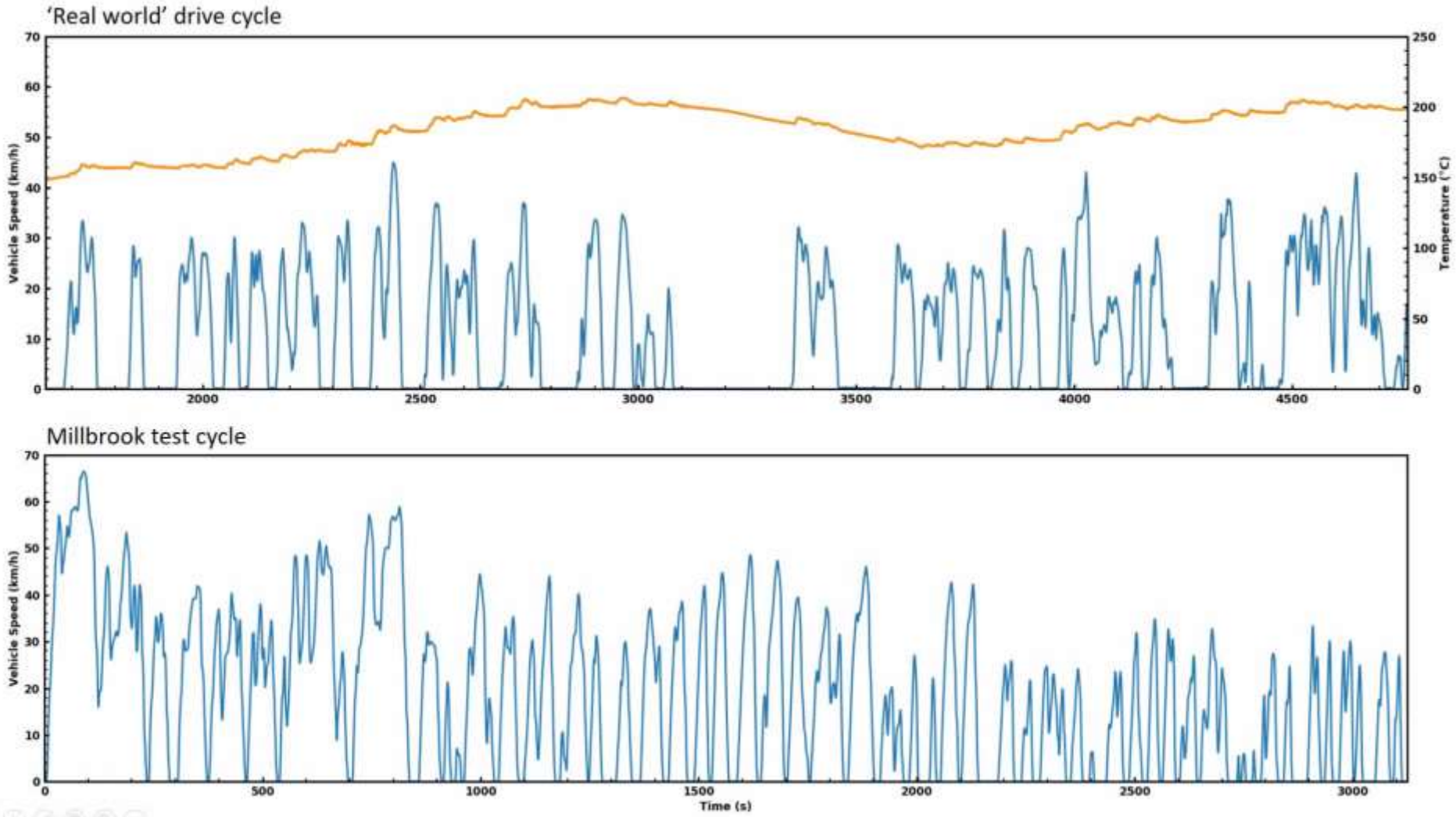
Comparison between our RDE route and Millbrook bus test cycle and new UKBC.

RDE was a mainly urban route, with only a short section of motorway travelling to the first bus stop. Key observations:

- The accelerations are much more spread out, longer stops, cooling everything down between sharp accelerations…
- The accelerations are to marginally lower speeds (20-30 km/h, occasionally hitting 45).
- There is only one ‘high speed’ event, at the very start, which matches the cycle, however here there are a couple of long stops before the route starts.

- Average stopped time EUVI: 1019s,
- stopped time UKBC: 780s,
- stopped time Millbrook: 708s

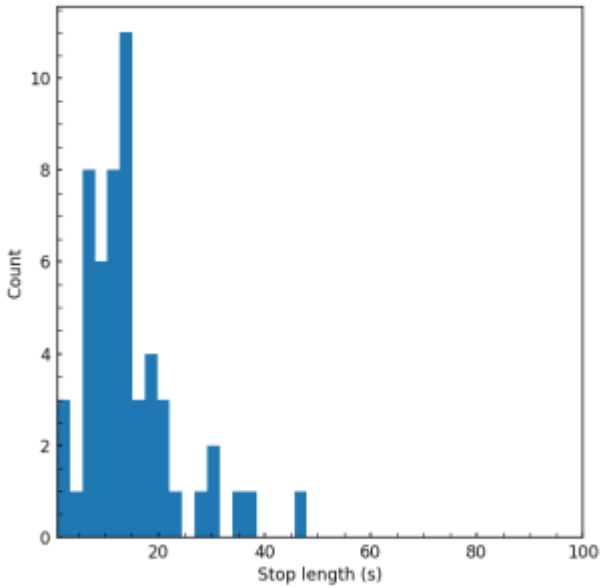
# Comparison with Millbrook cycles



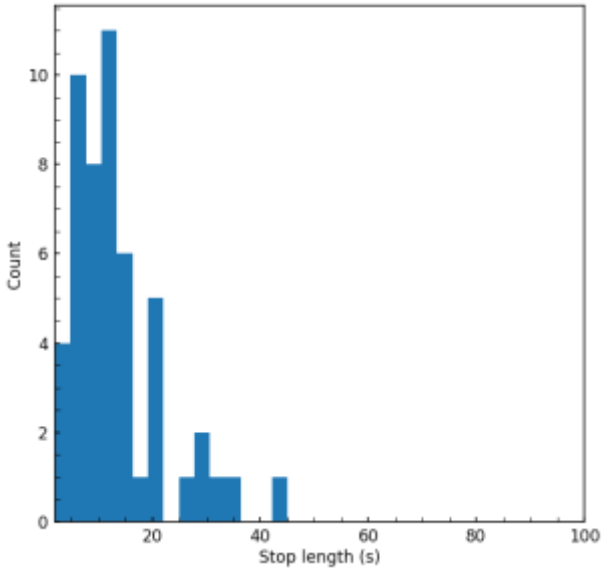
# Comparison with Millbrook cycles

## Stop length distribution (cut at 100s)

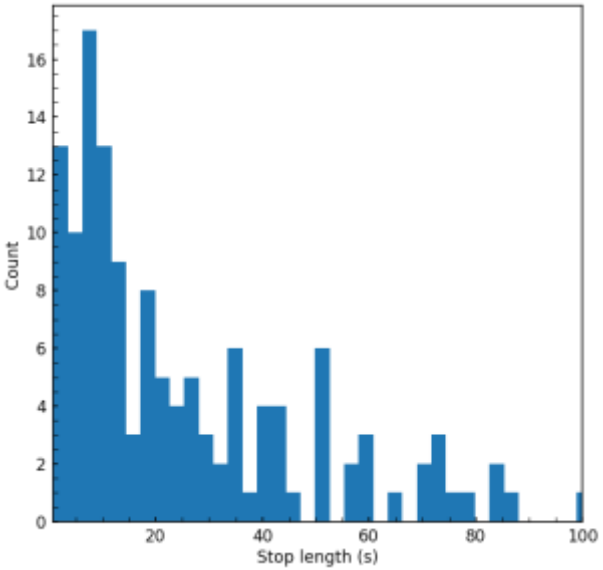
UKBC test cycle




Millbrook test cycle




'Real world' drive cycle

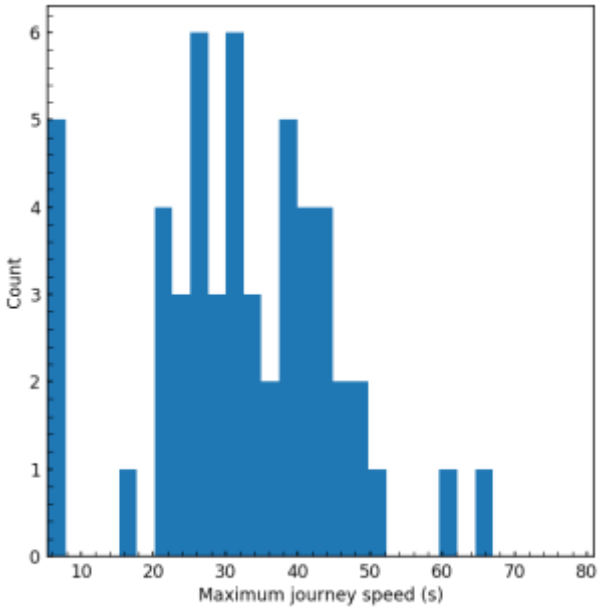



RDE has longer stops – more catalyst cooling time

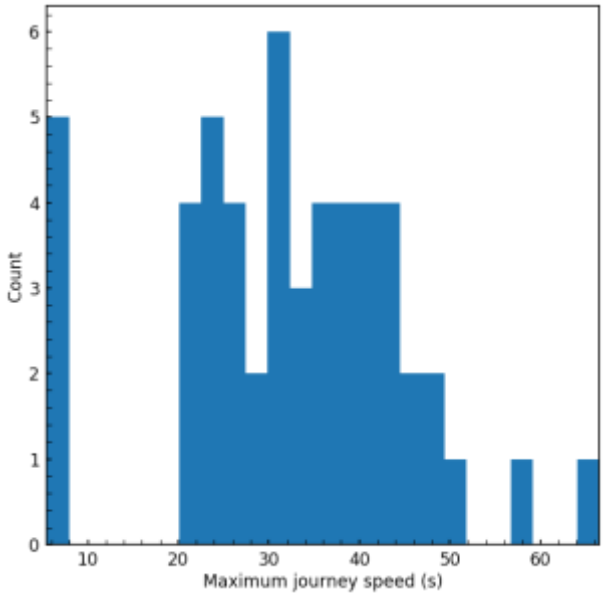
# Comparison with Millbrook cycles

## EUVI Maximum speed distribution

UKBC test cycle




Millbrook test cycle

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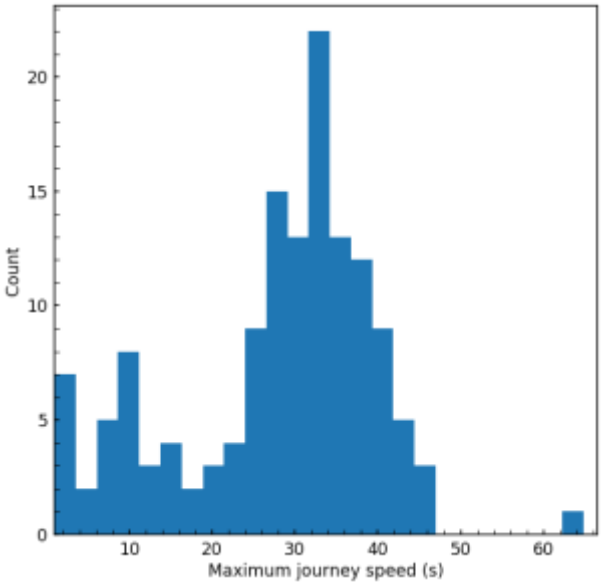
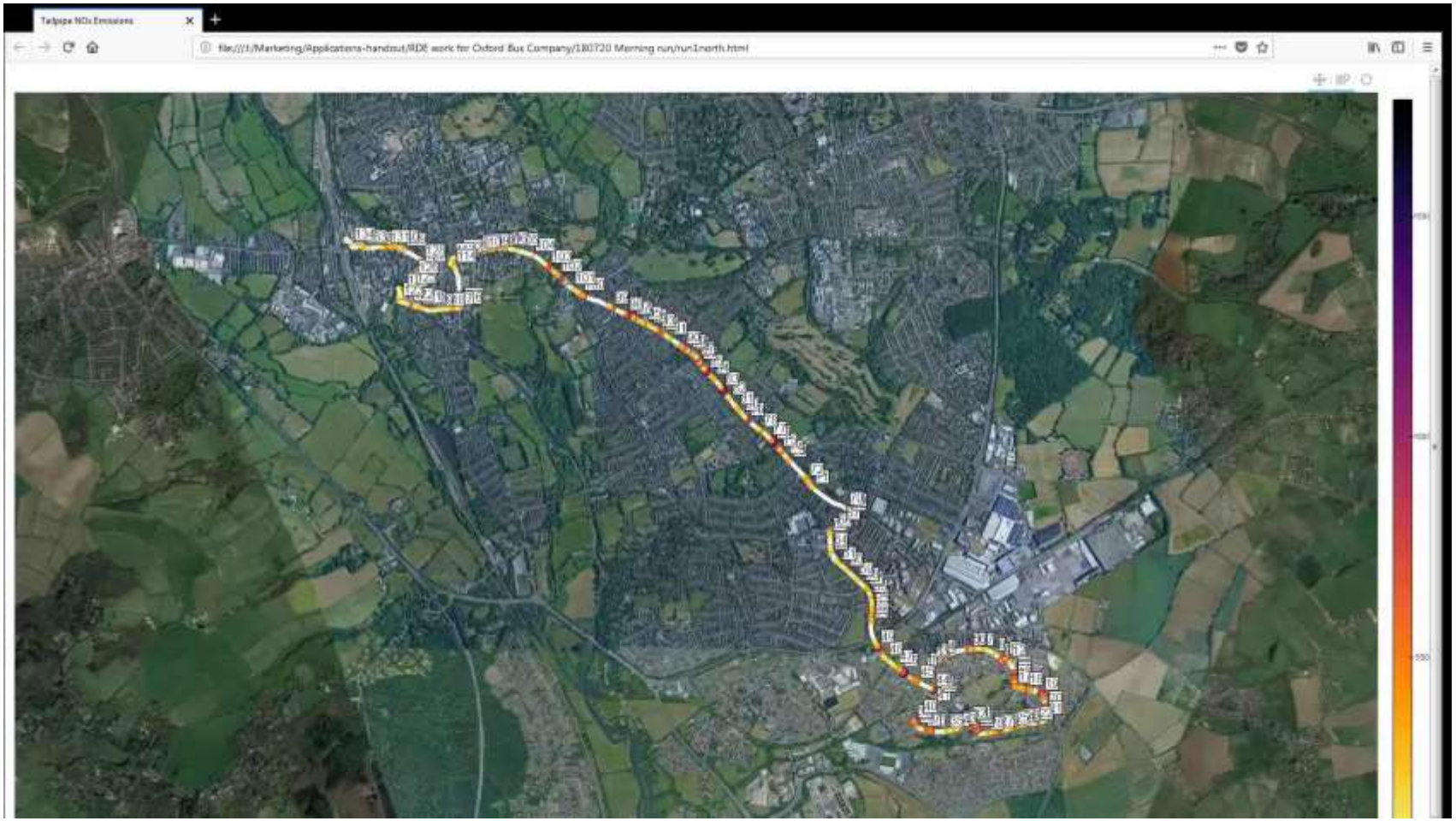



RDE has lower speeds – less catalyst heating opportunity?

# Emissions maps



http://oem.eng.ox.ac.uk/

# Possible data gathering improvements

- Get some engine (ECU) data - logged as fast as possible to align with emissions data
- Produce repeatable transients for direct comparisons (e.g. exhaust temperature, speed bump, bus stop)

# General conclusions

- “Repeatability” depends on road conditions, but general conclusions can be drawn
- Eu VI generally lower emissions than Eu V
- Eu 5 car generally highest emissions
- Eu VI bus has particularly noticeable NOx emissions gear change 3 & 4
- It’s all about temperature:
  - Engine off stops – SCR cools, NOx “puff”
  - Engine loaded (uphill, high pax load, A34) ➔ hot SCR ➔ v v low NOx
- Eu VI – wait 30s after restart before moving off?

# Thank you!

- Oxford Bus Company


- Oxford City Council

# High spatio-temporal NOx RDE emissions

http://oem.eng.ox.ac.uk/

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