CAMBUSTION

High spatio-temporal RDE NOx emissions from in-service buses

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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)

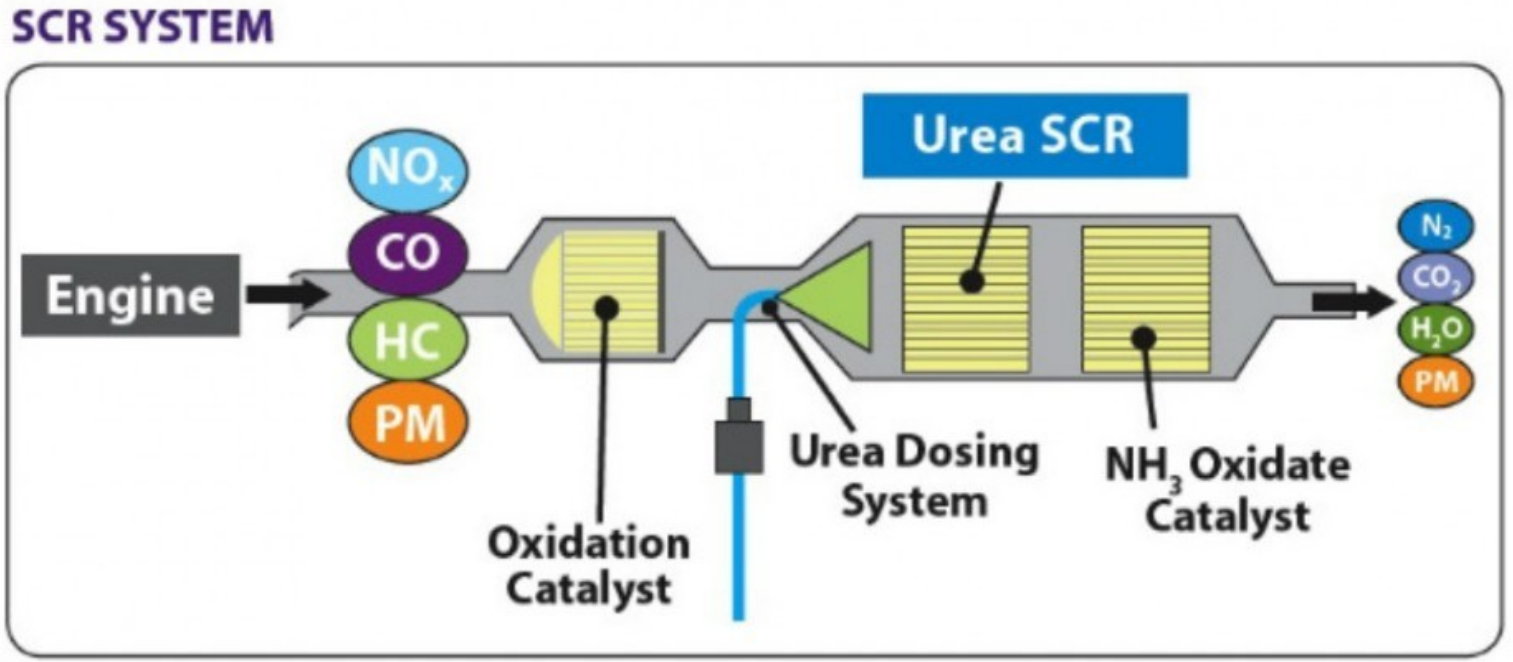
Euro 5 passenger car 7-seater diesel no SCR
(80,000 miles)

Sampling arrangements

- Fast NOx measured immediately post aftertreatment in both buses

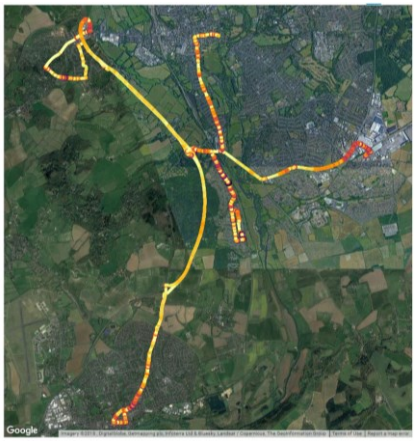
- Euro VI bus with additional exhaust temperature measurement
- GPS, dashcam and emissions logged from within in-service bus

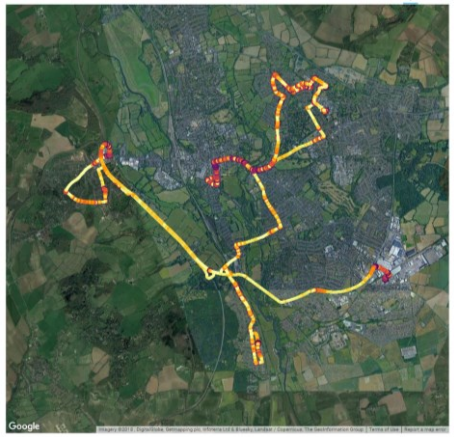
SCR NOx aftertreatment system fundamentals



Routes

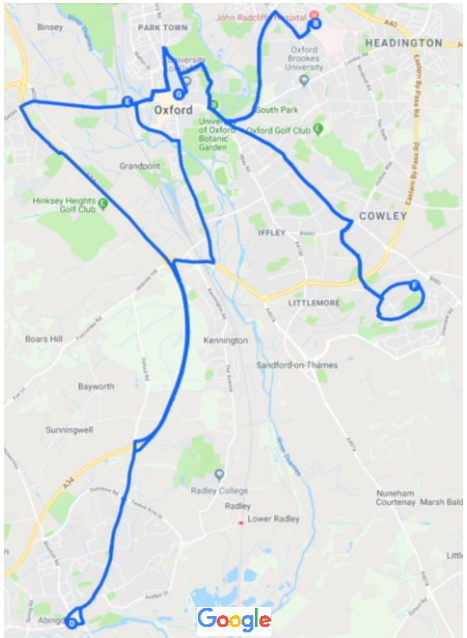
Euro V hybrid - 35A / X3 / 13
(Kennington – Matthew Arnold School – Abingdon – City Centre – JR Hospital)





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:

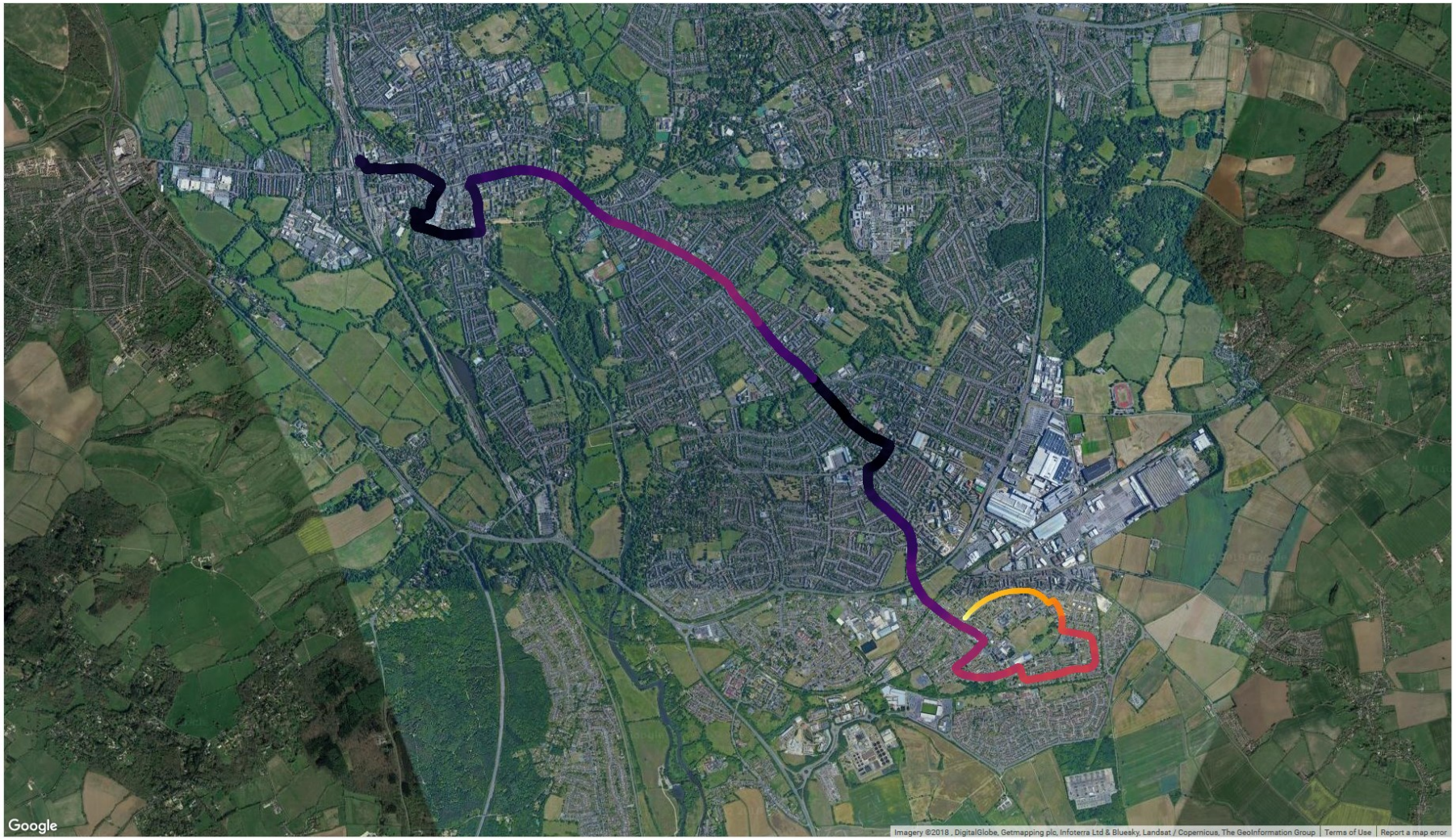
	EU V bus	EU VI bus	EU 5 car
Passenger capacity	73	101	7
Engine capacity	4.76 l	5.1 l	2 l
NOx ppm	350	100	110 / 190*
NOx g/h	66	20	8 / 15*
NOx g/h/passenger	0.90	0.20	1.14 / 2.14*

*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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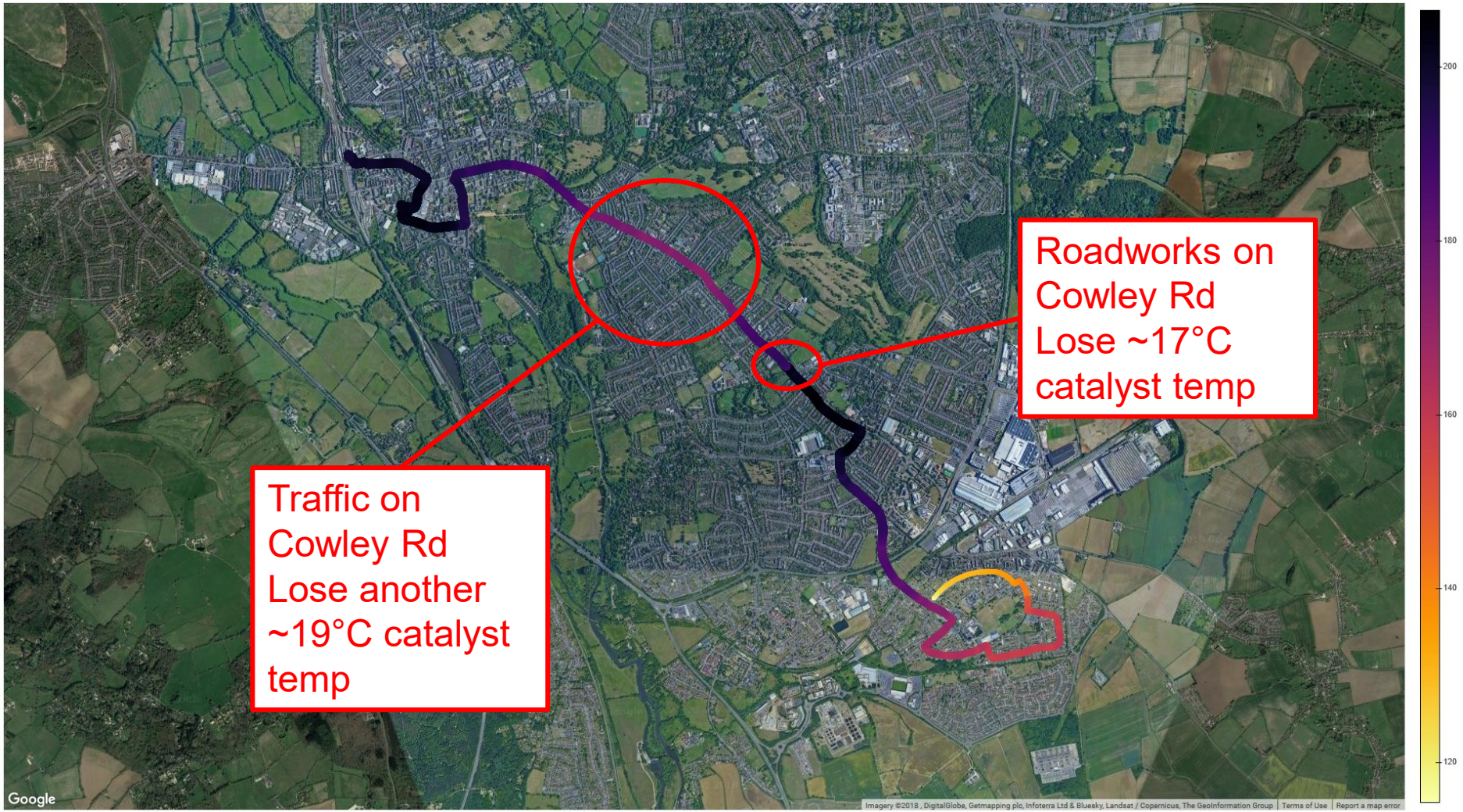

Transients are also important (NOx emissions)

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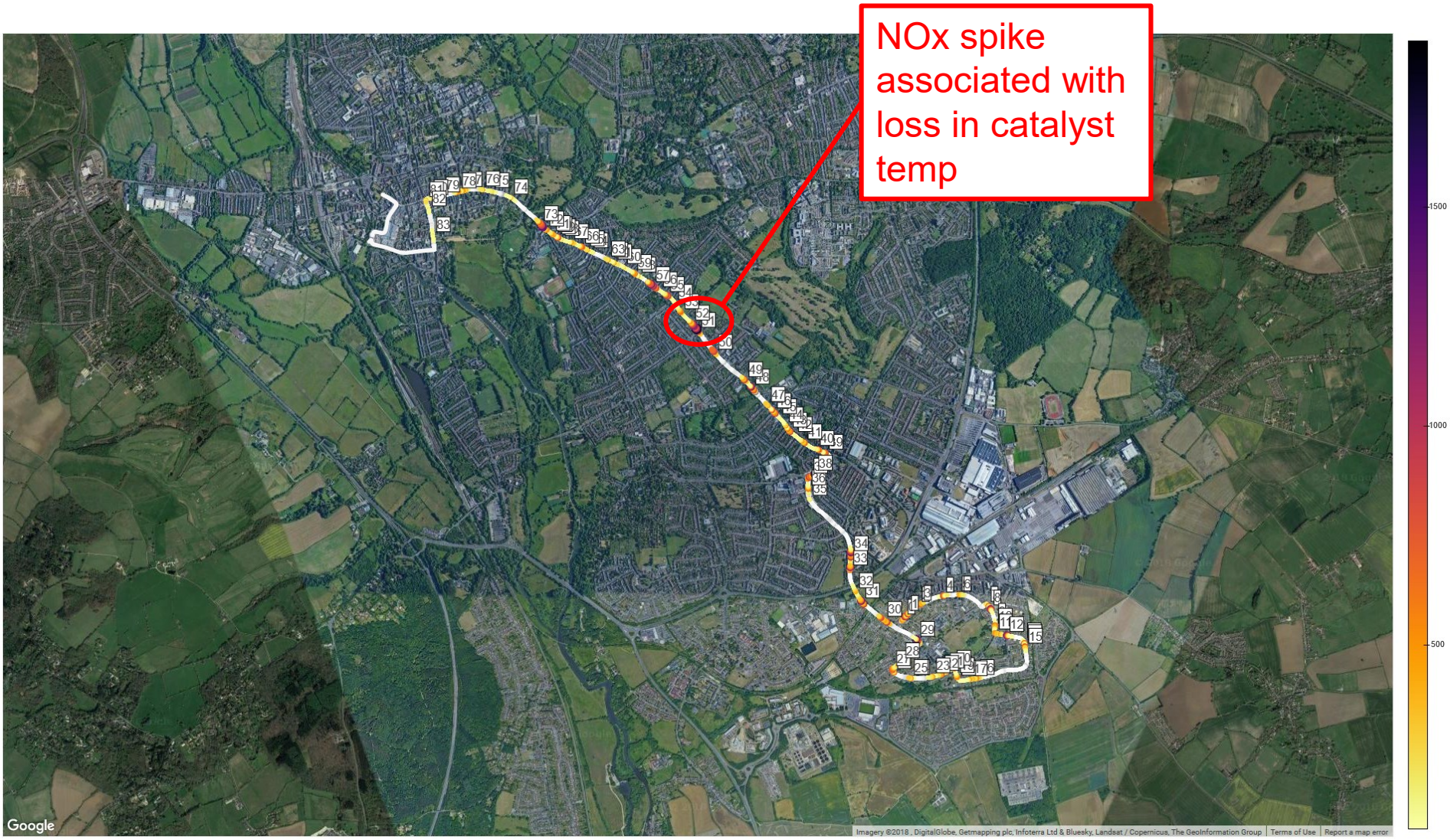
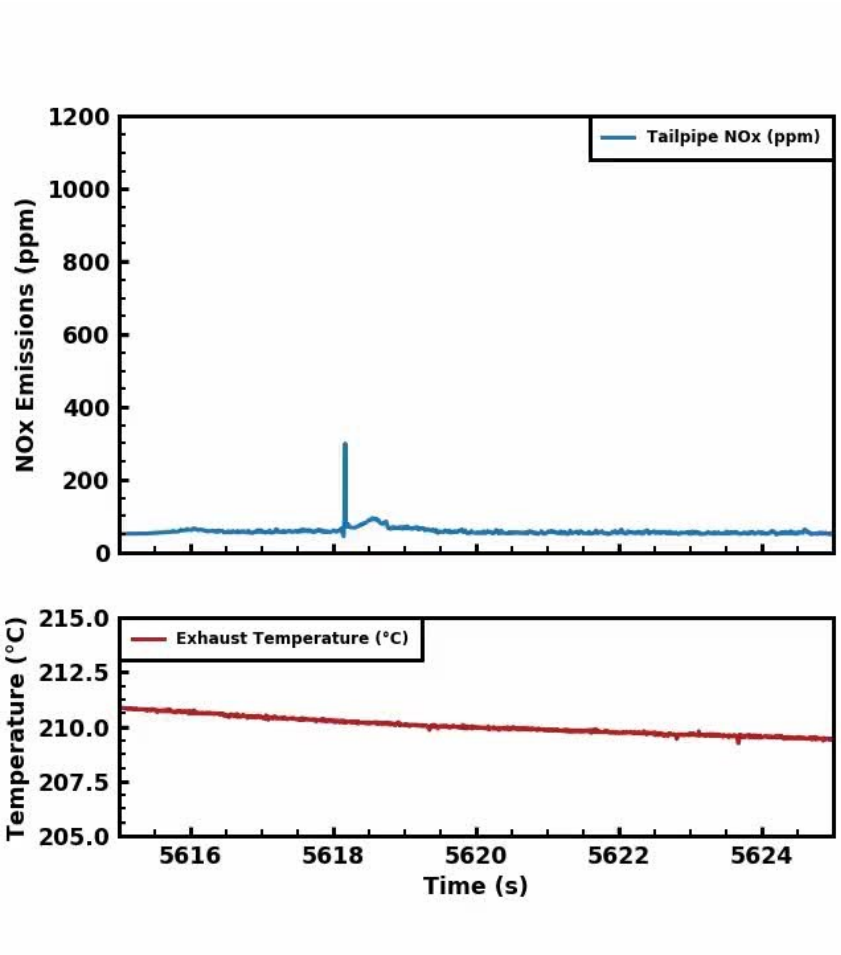
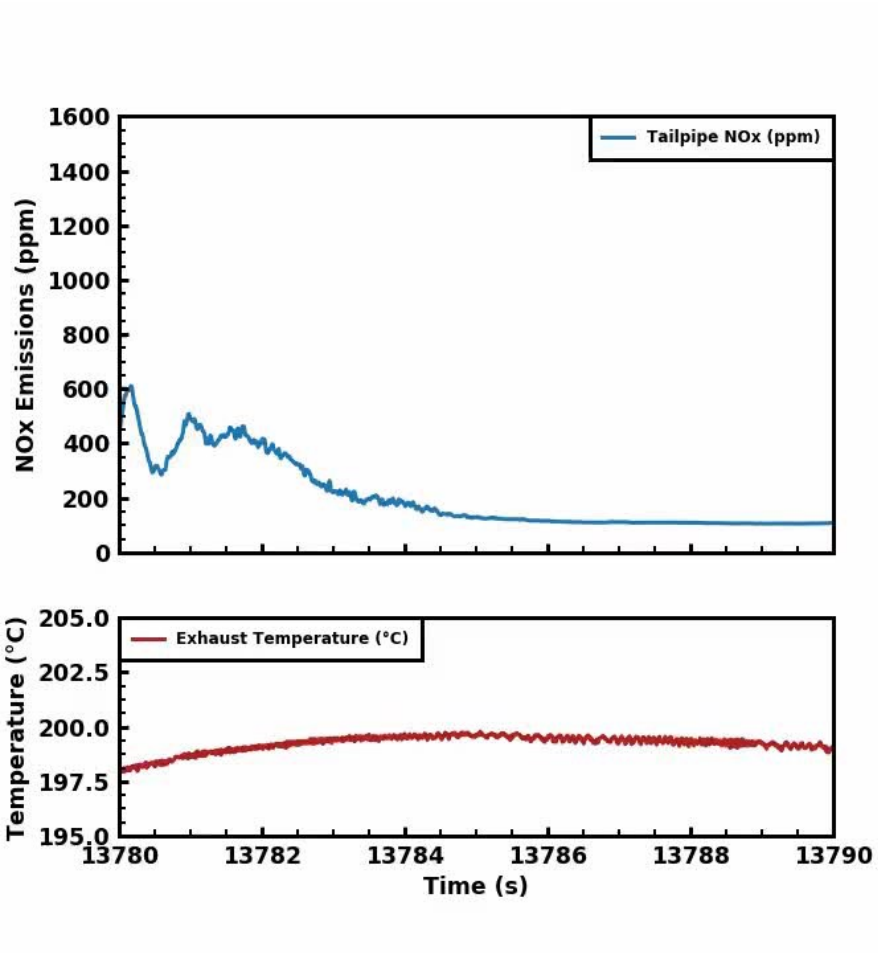


Eu VI bus stop manoeuvre

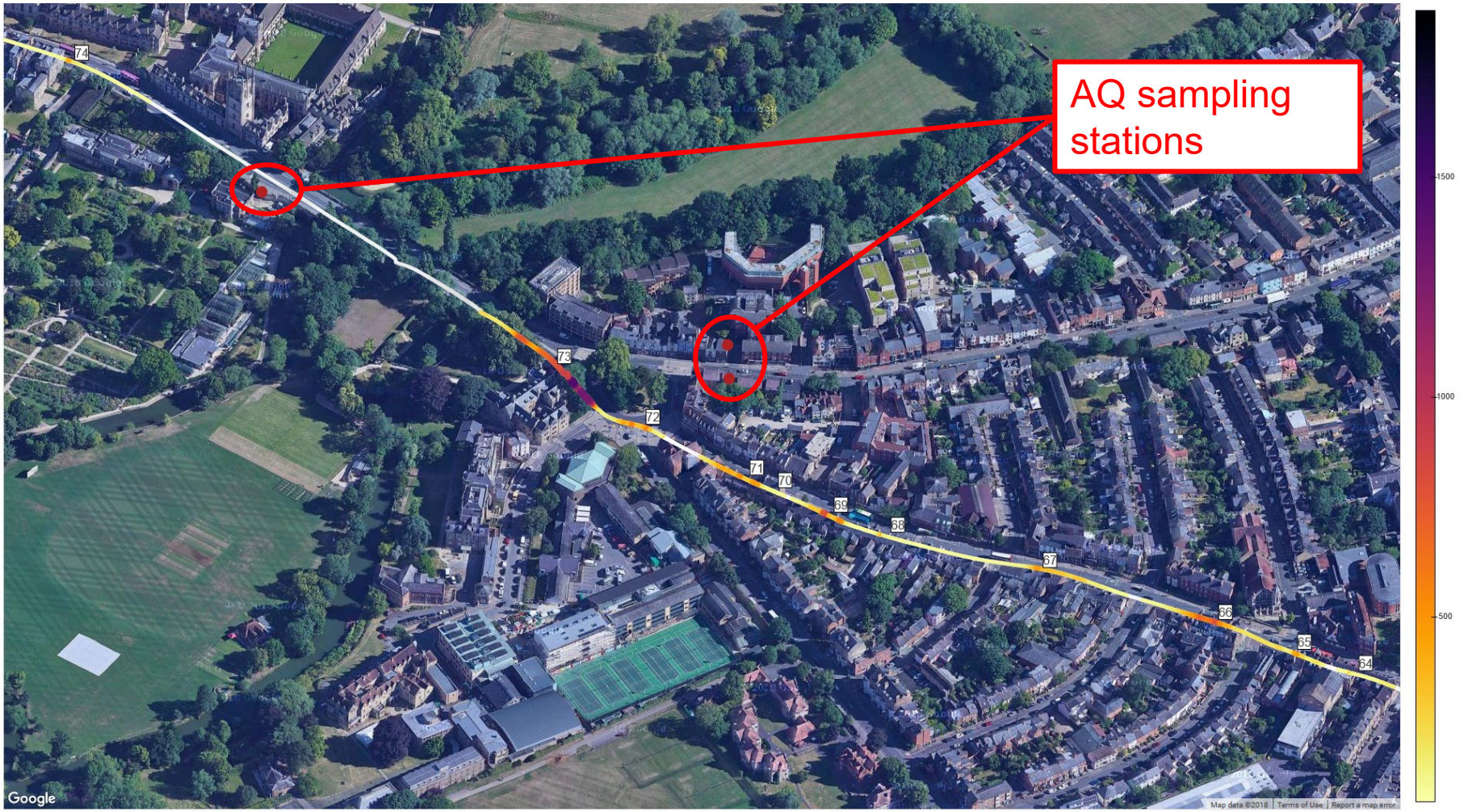


#73. Run 3 North Eu VI: *The Plain roundabout*



Typical emissions manoeuvres …

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



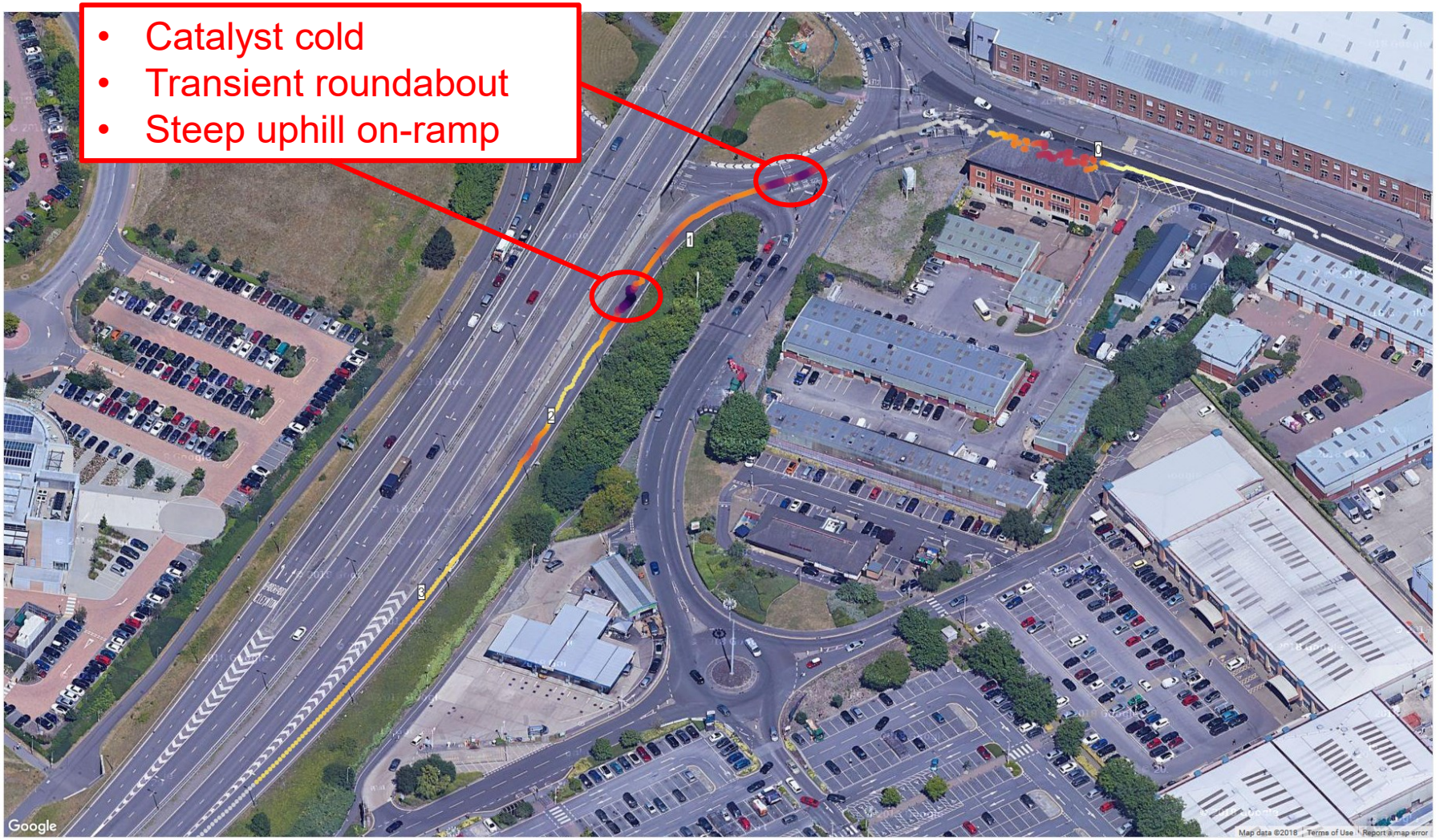
Eu V & VI start of route

- 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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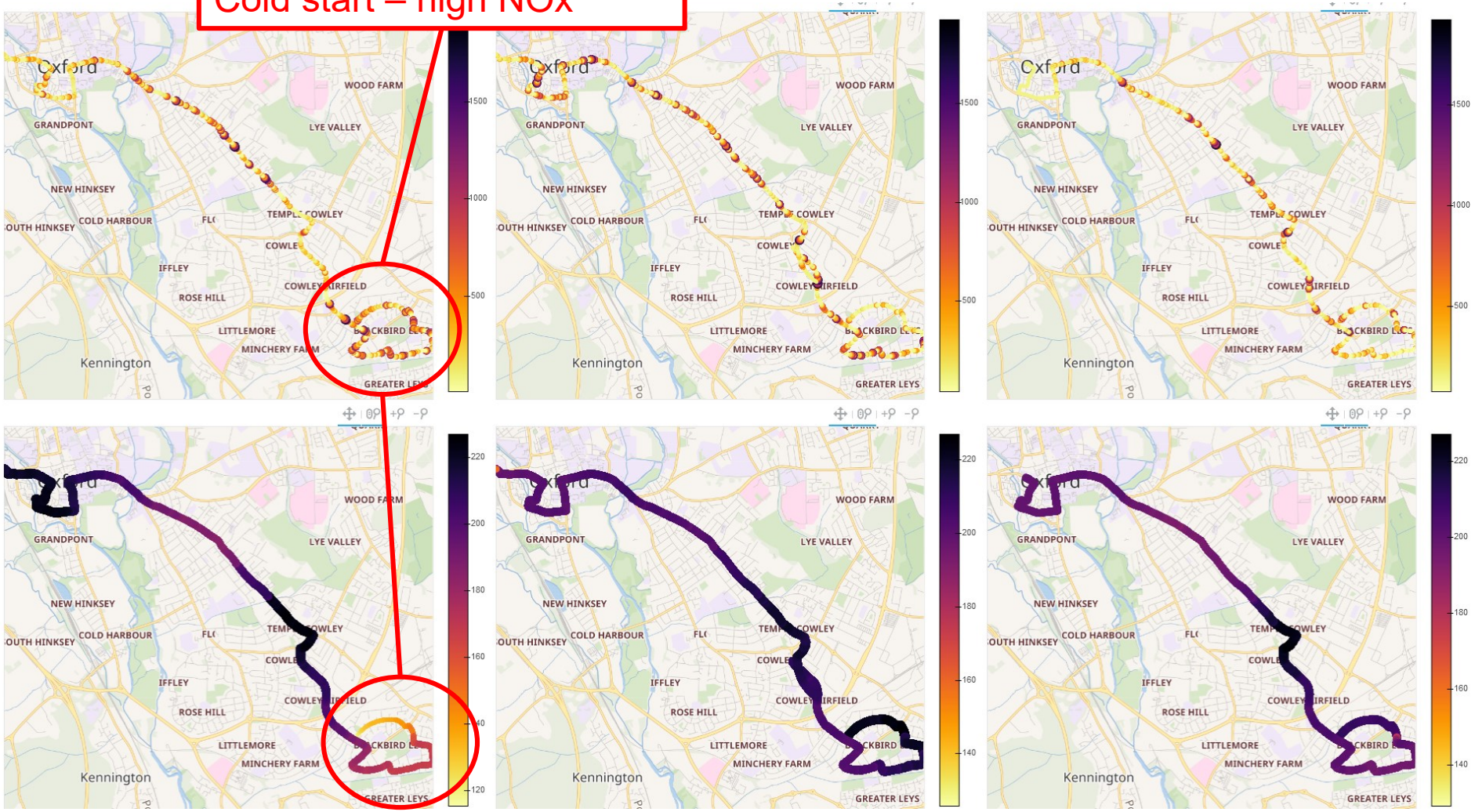
Comparison of 3 x Eu VI north runs

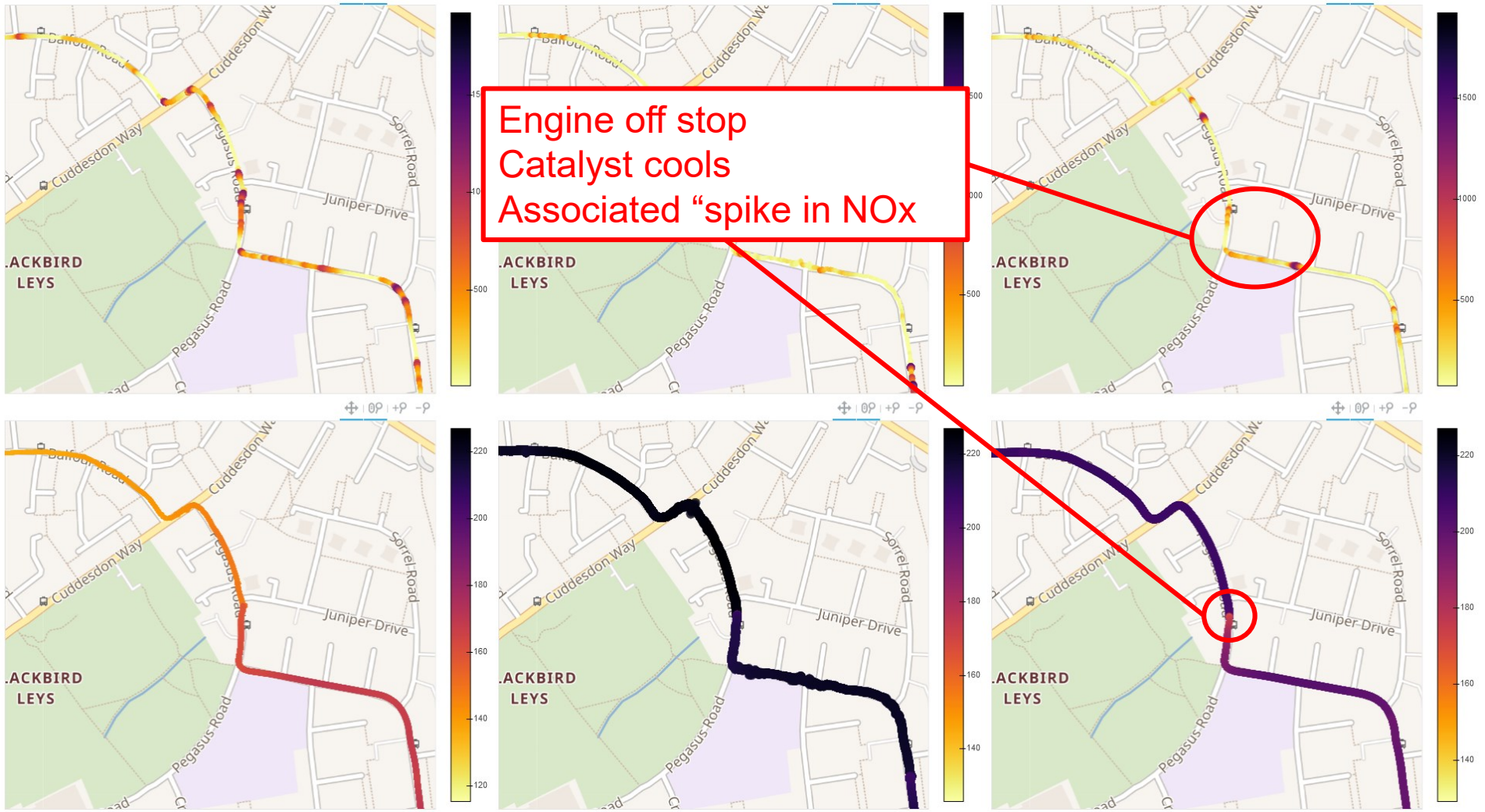
Cold start – high NOx



Comparison of 3 x Eu VI Blackbird Leys

Bus stop location correlates with emissions:

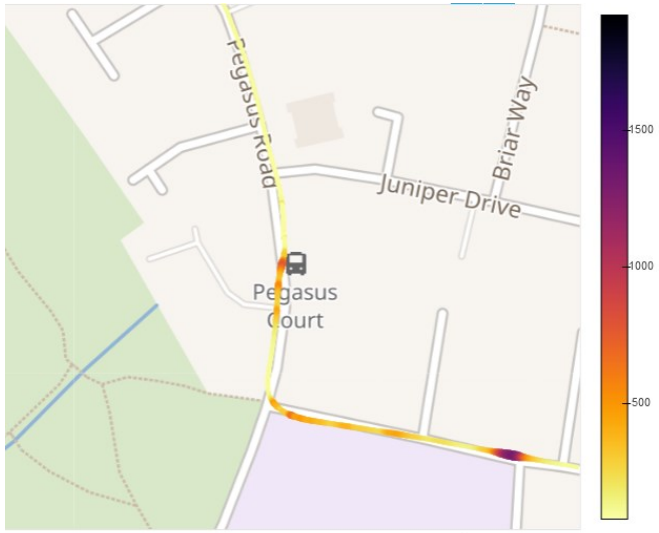
Comparison of 3 x Eu VI Blackbird Leys



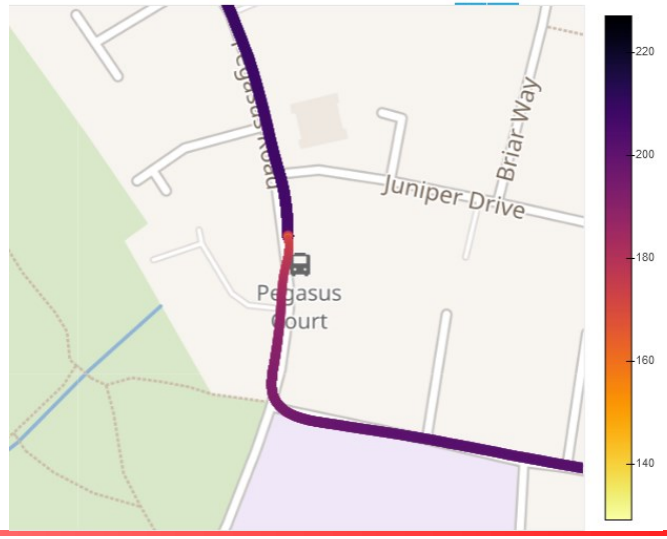
Bus stop location correlates with emissions:

Effects of 4-min engine switch-off Eu VI

NOx



Ex temp



Wikimedia maps
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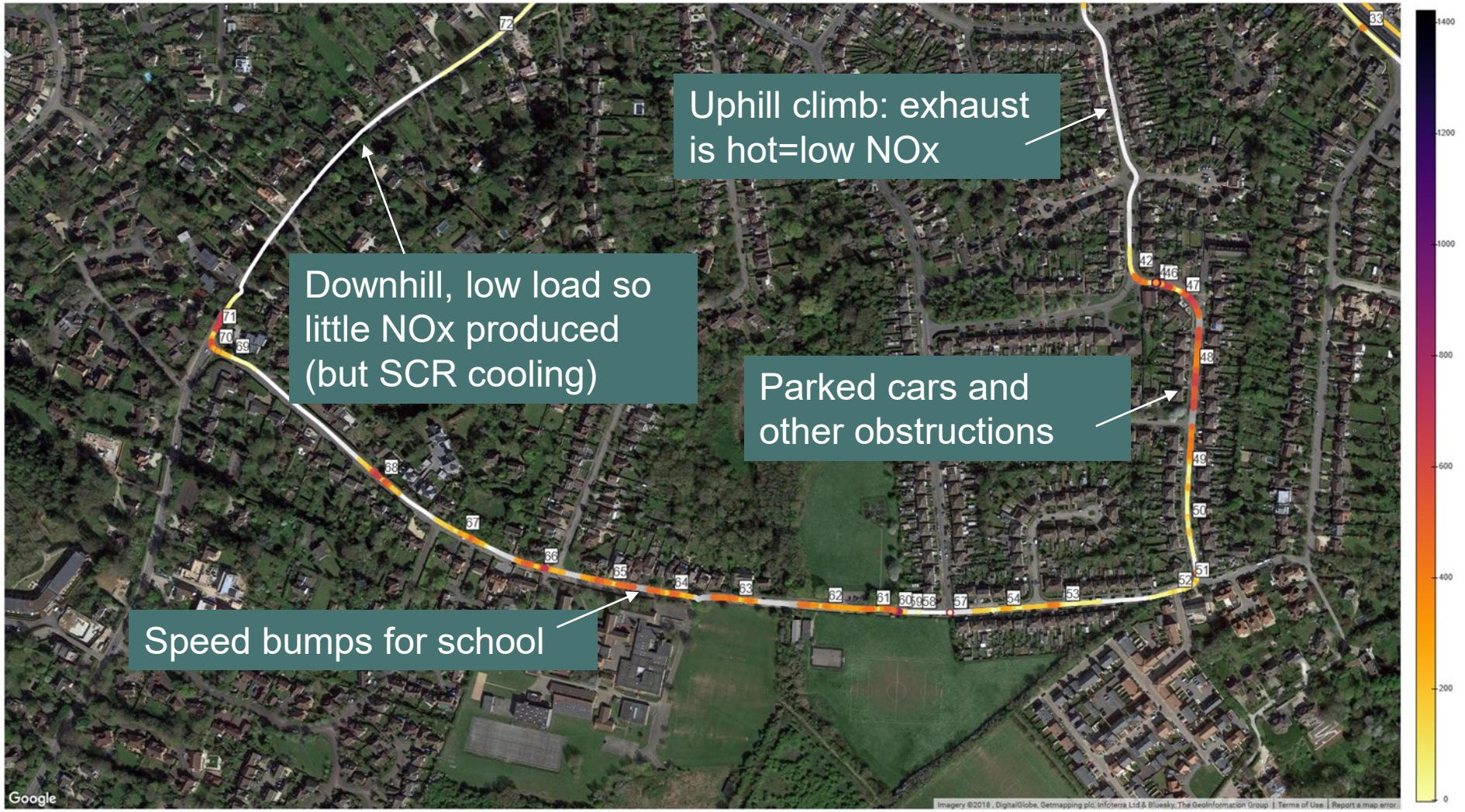
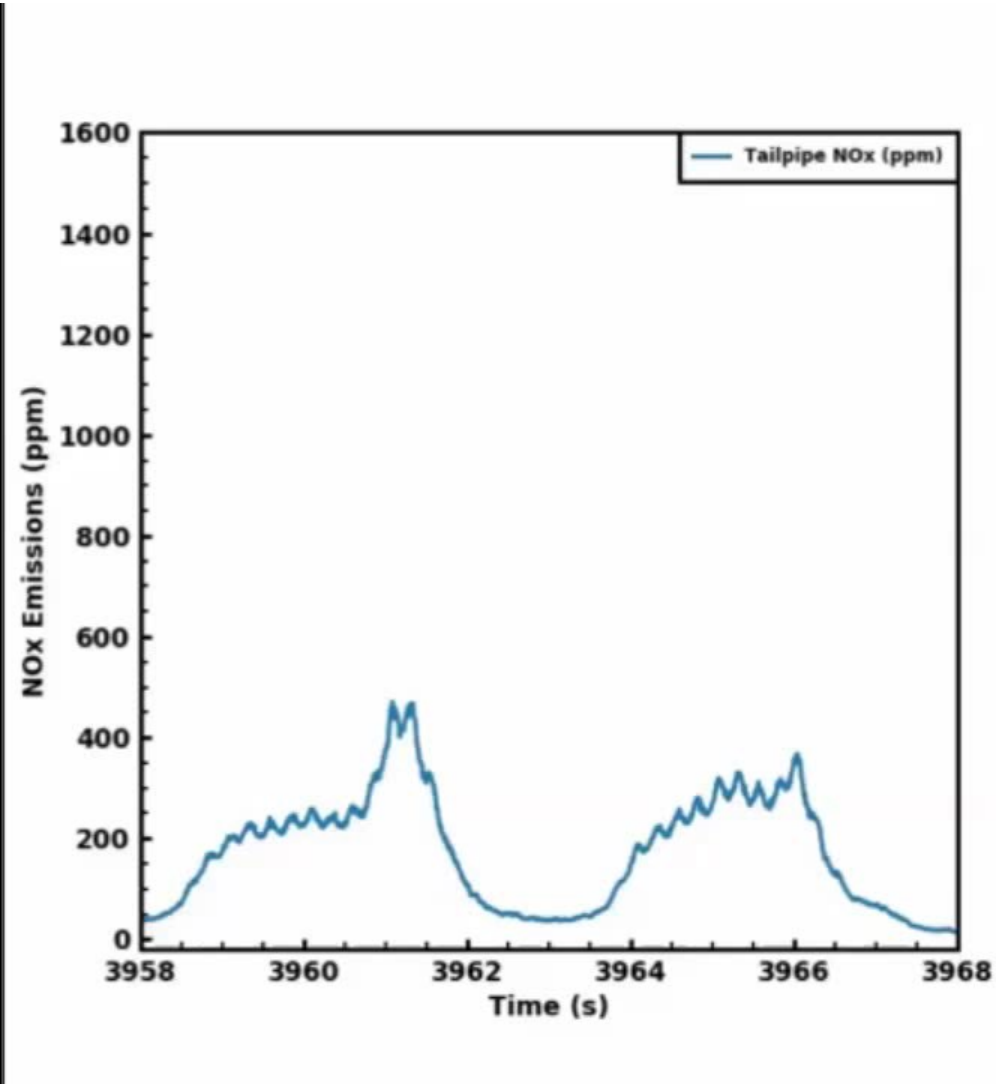
Eu V negotiating speedbumps – MA school

NOx around school, SCR temperature dependency

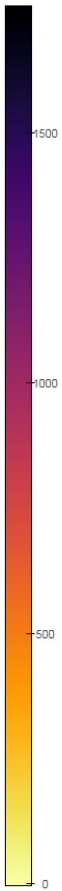


Eu V negotiating speedbumps – MA school



Eu V bus & Eu 5 car uphill

Bus



Car

Comparison with Millbrook cycles

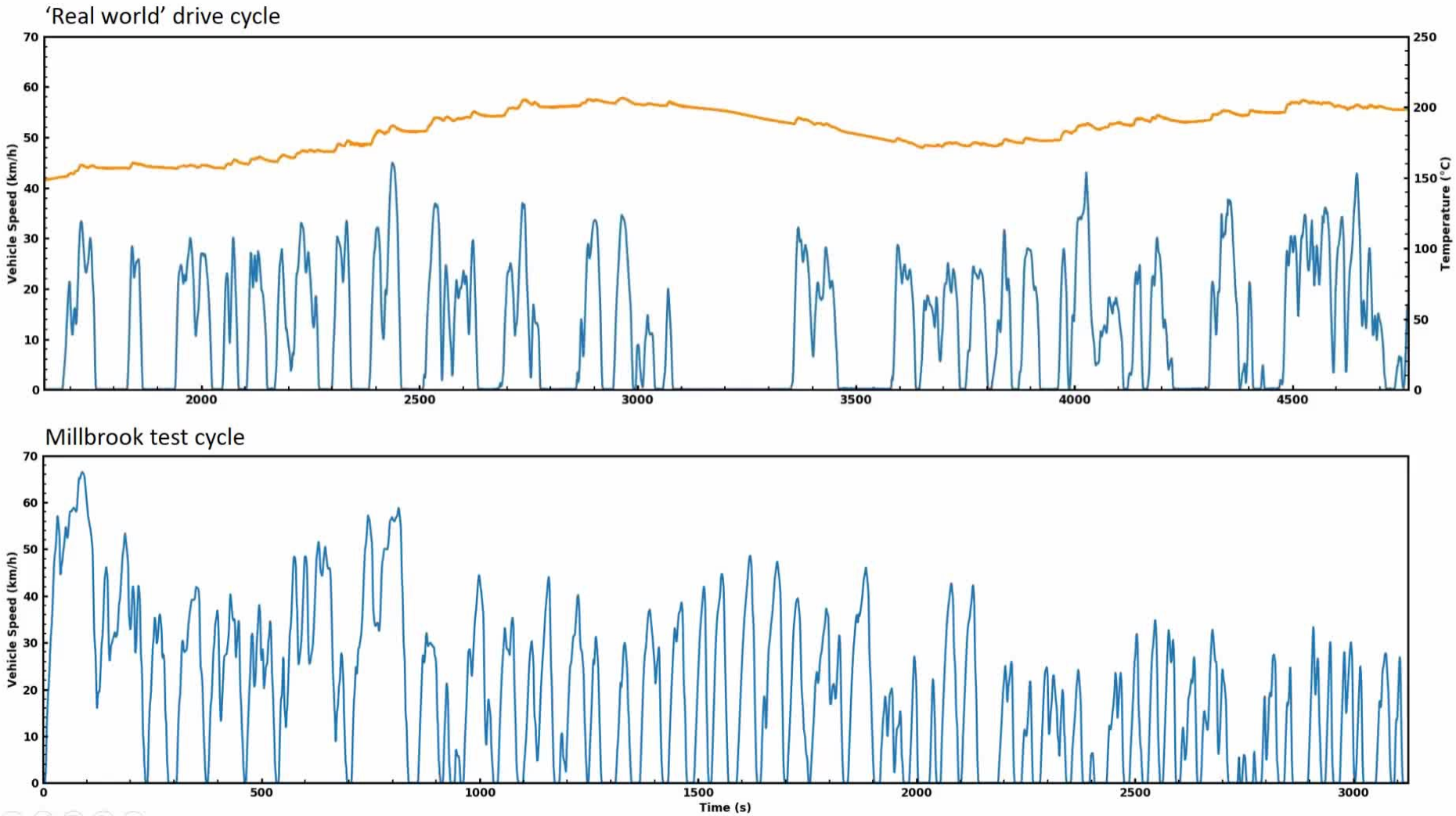
Comparison between our RDE route and Millbrook bus test cycle and new UKBC.

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

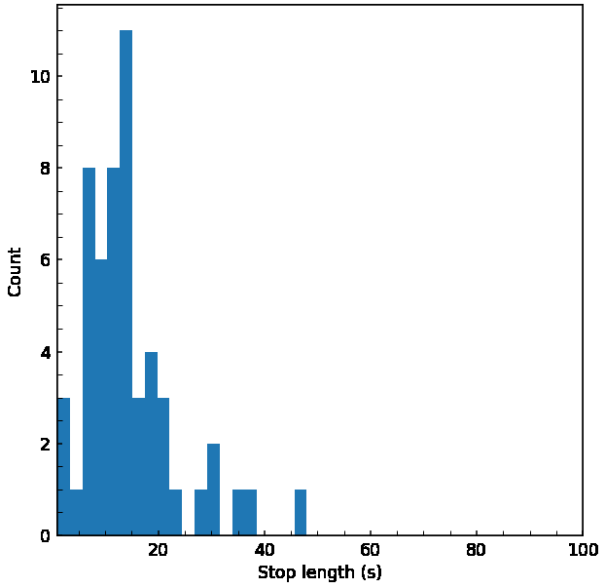
Comparison with Millbrook cycles



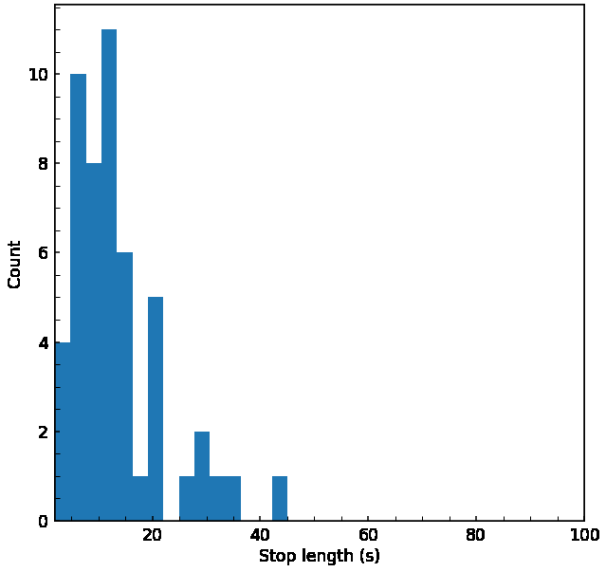
Comparison with Millbrook cycles

Stop length distribution (cut at 100s)

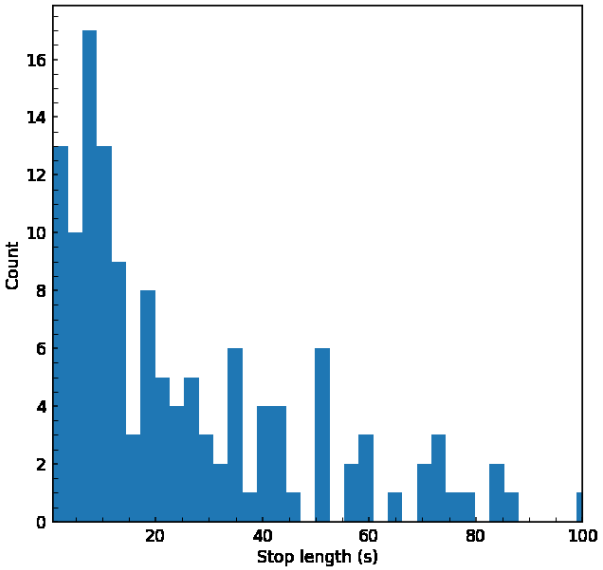
UKBC test cycle



Millbrook test cycle



'Real world' drive cycle

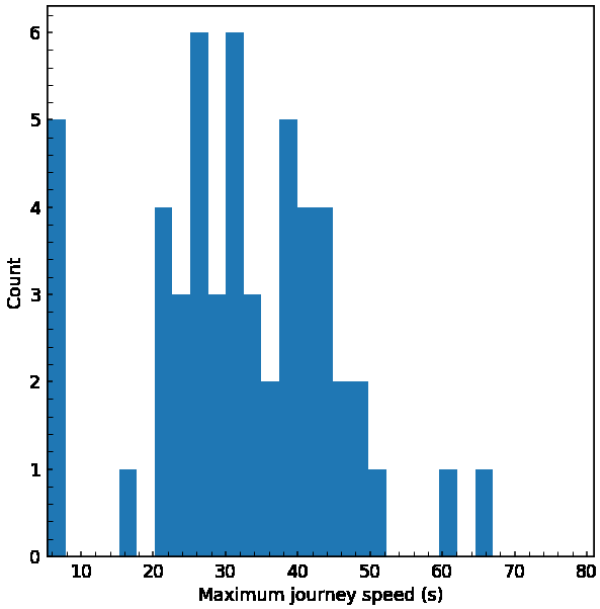


RDE has longer stops – more catalyst cooling time

Comparison with Millbrook cycles

EUVI Maximum speed distribution

UKBC test cycle



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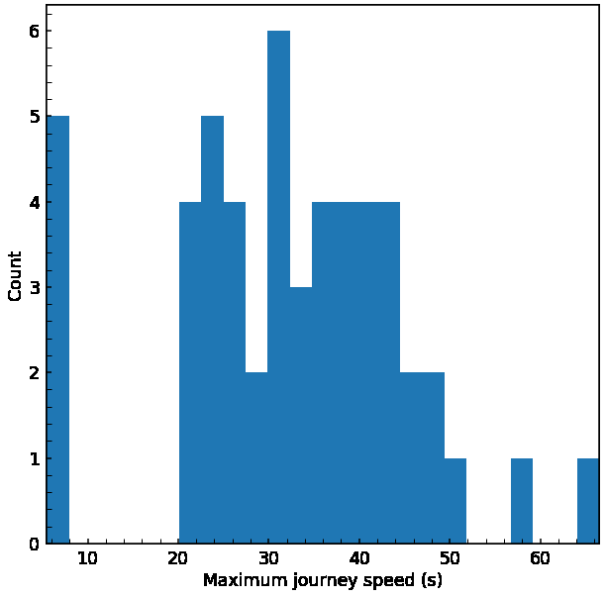

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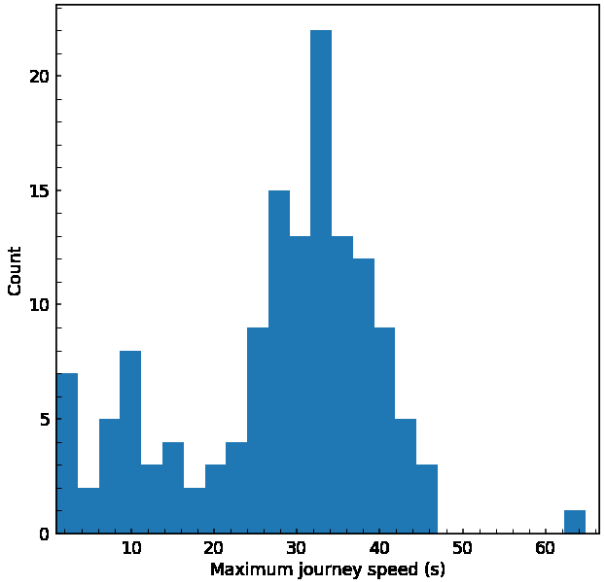
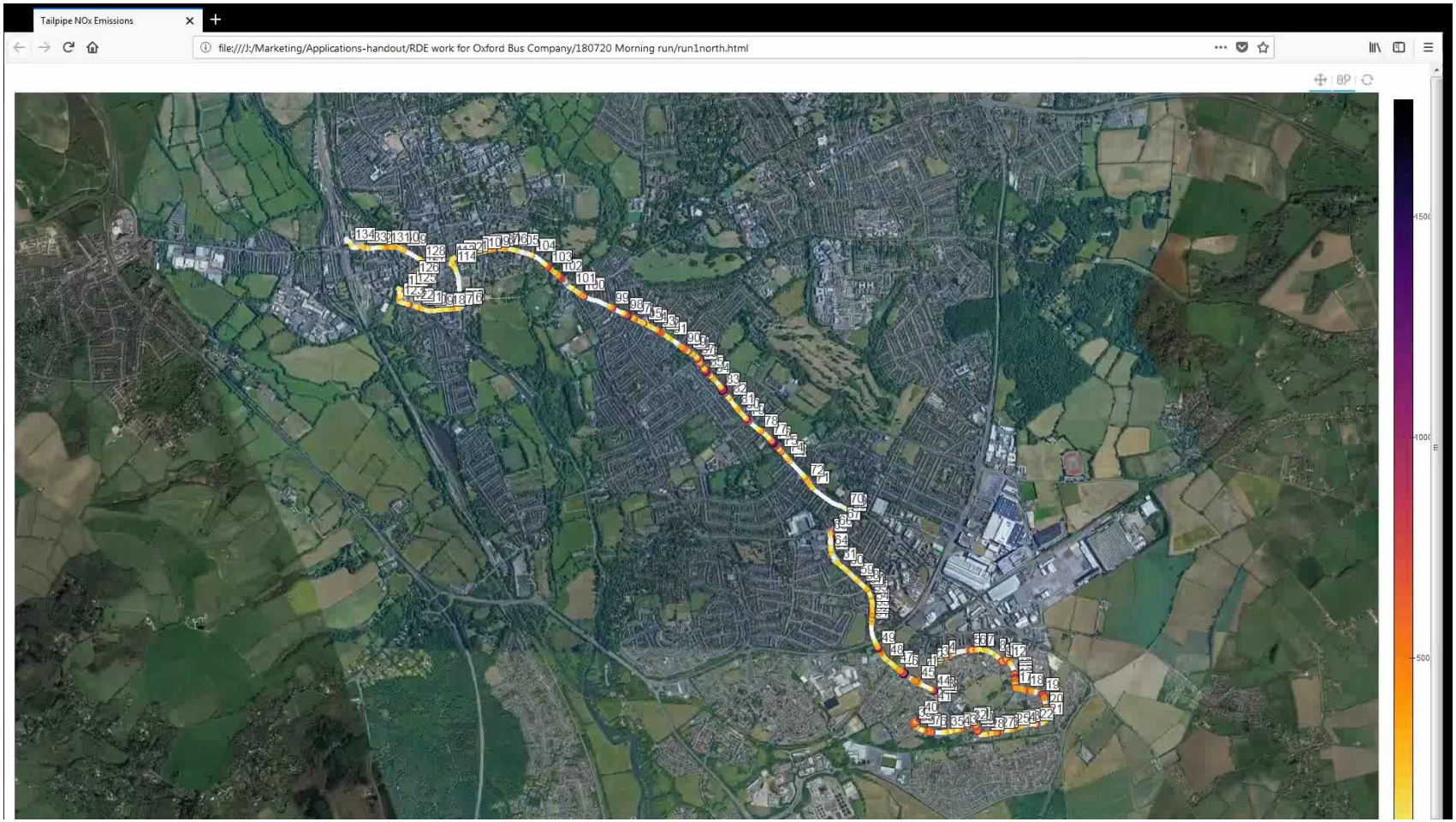


RDE has lower speeds – less catalyst heating opportunity?

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 ➔ 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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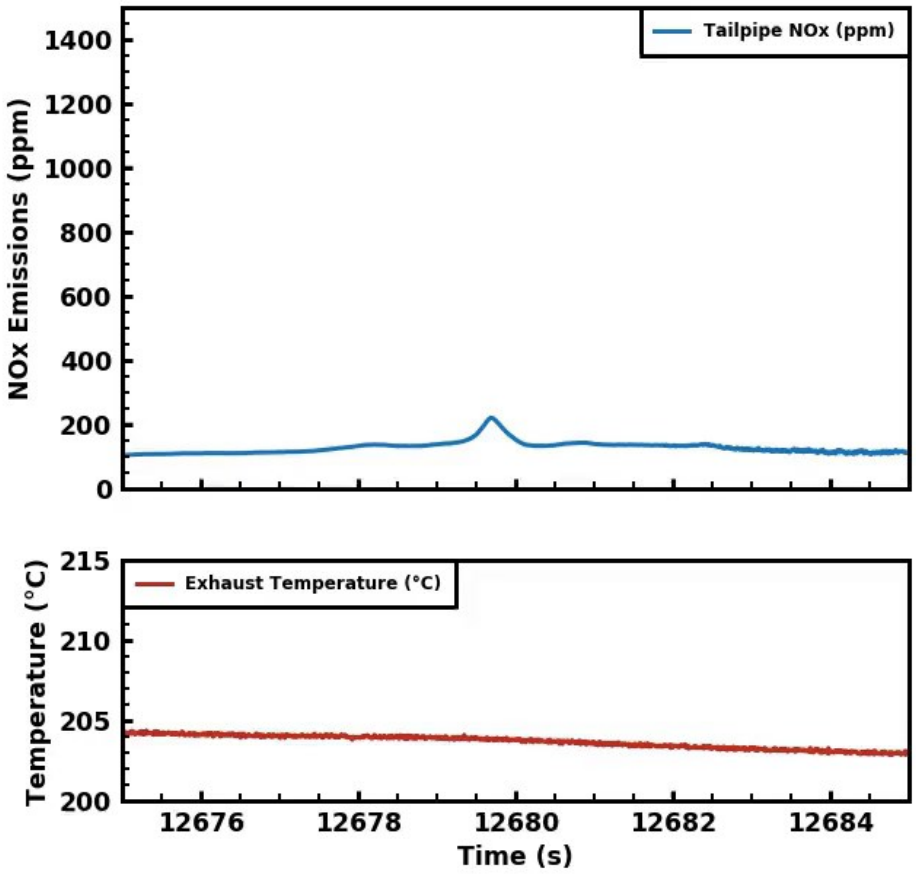
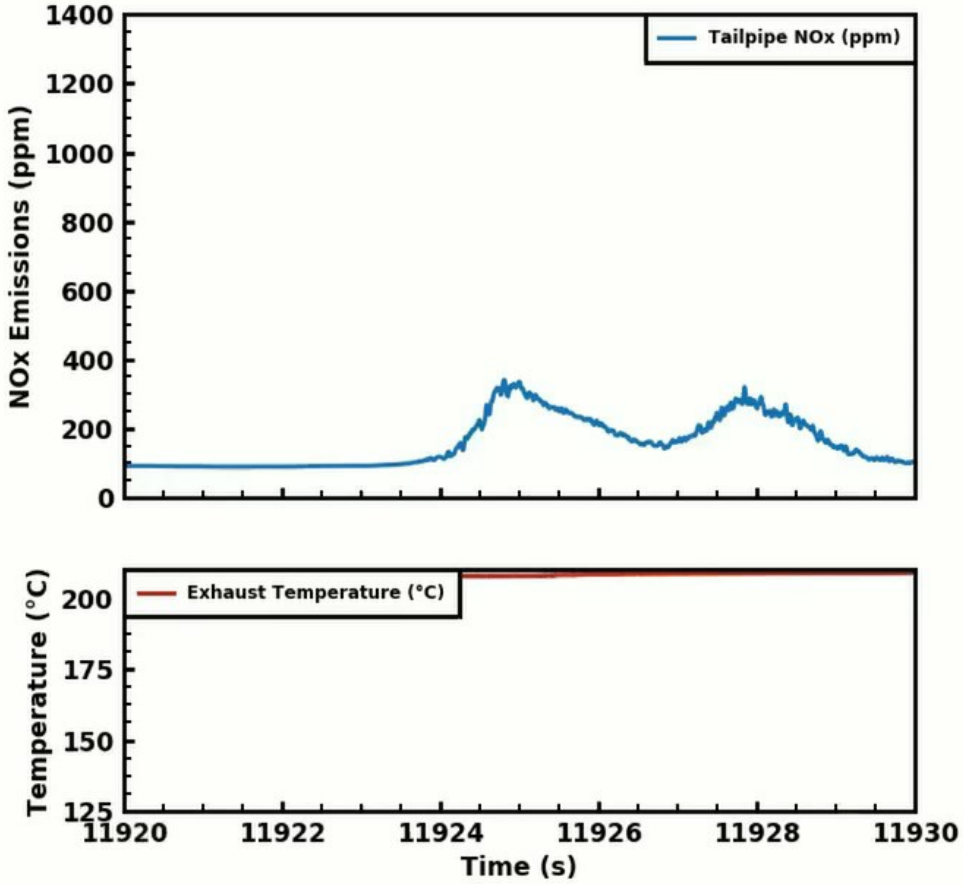
Sampling arrangements near rear seats

Eu VI negotiating parked vehicles and accel gearshifts

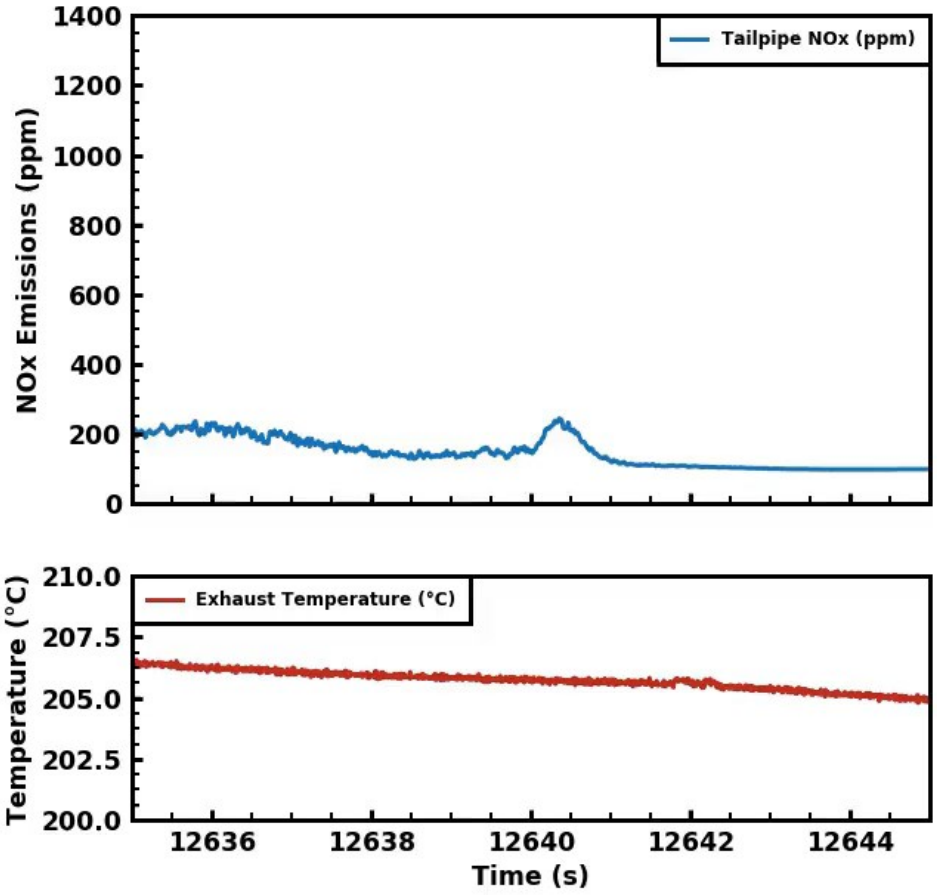
Eu VI negotiating parked vehicles and accel gearshifts



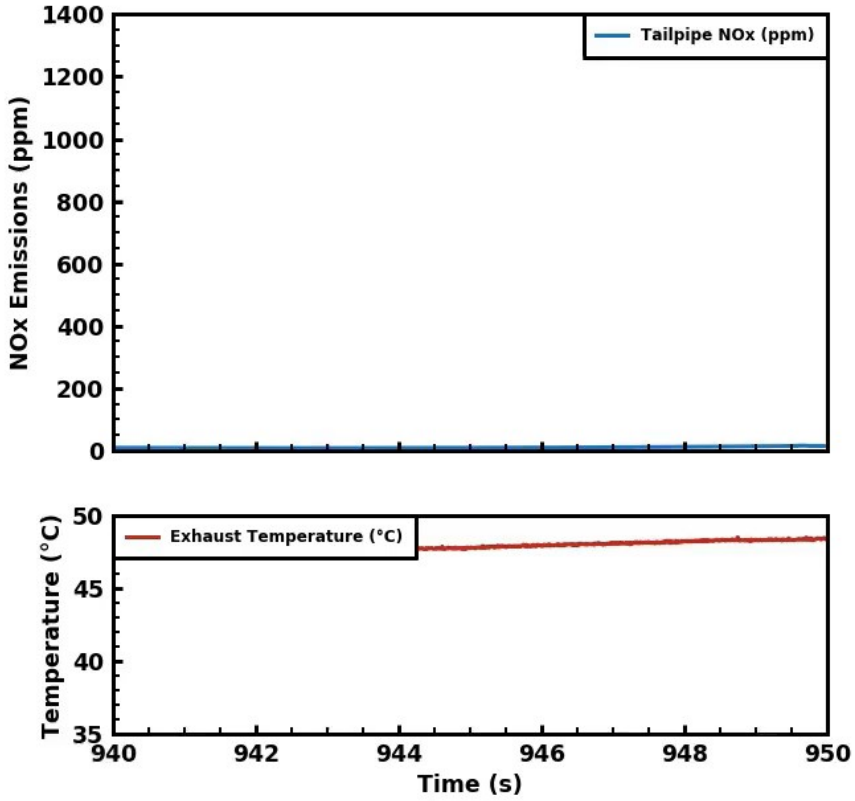
Effects of 4-min engine switch-off Eu VI



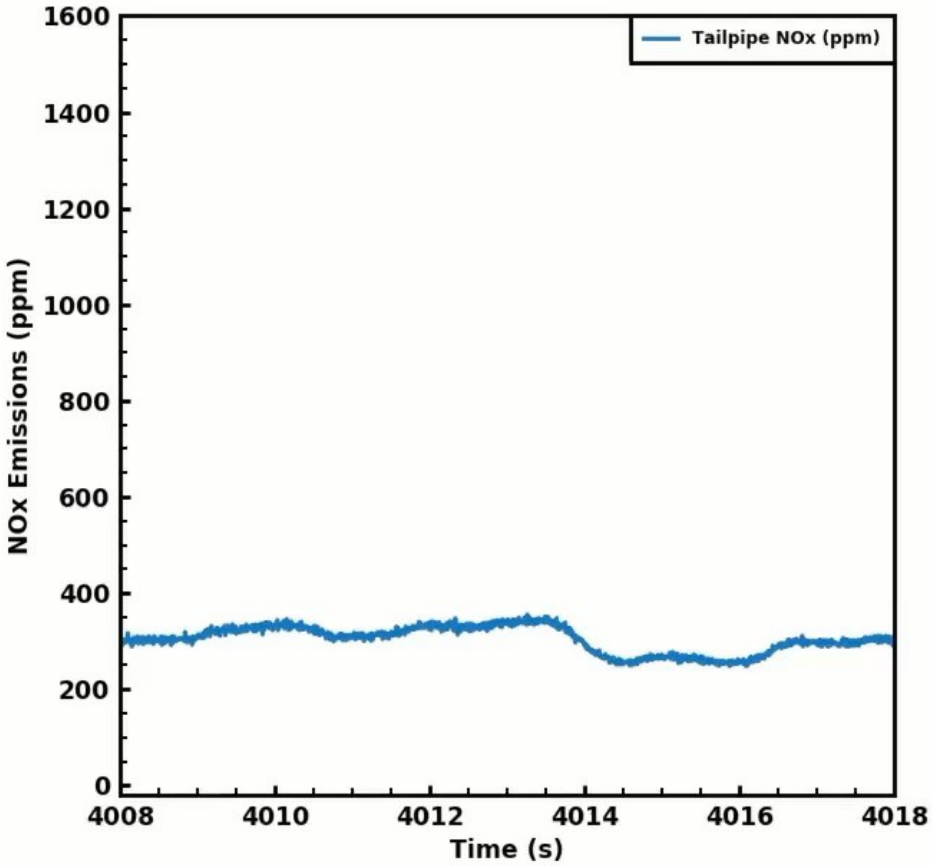
Eu VI uphill gearshifts



Eu VI worst emissions before start of route



Eu V bus stop manoeuvre – Outside School



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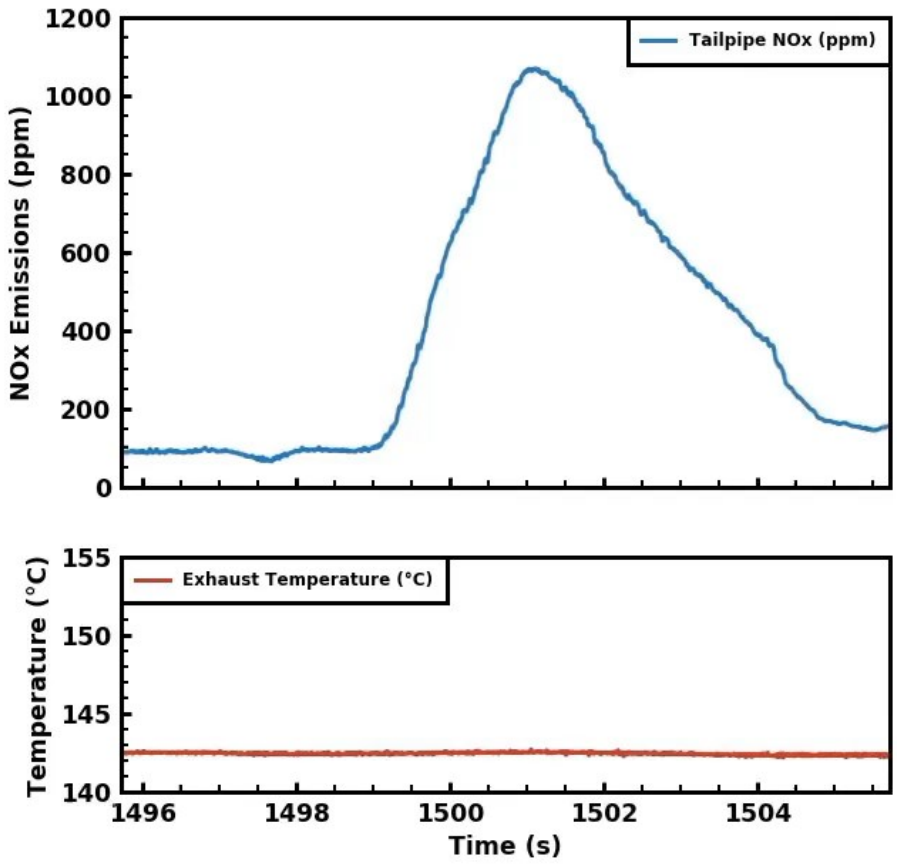
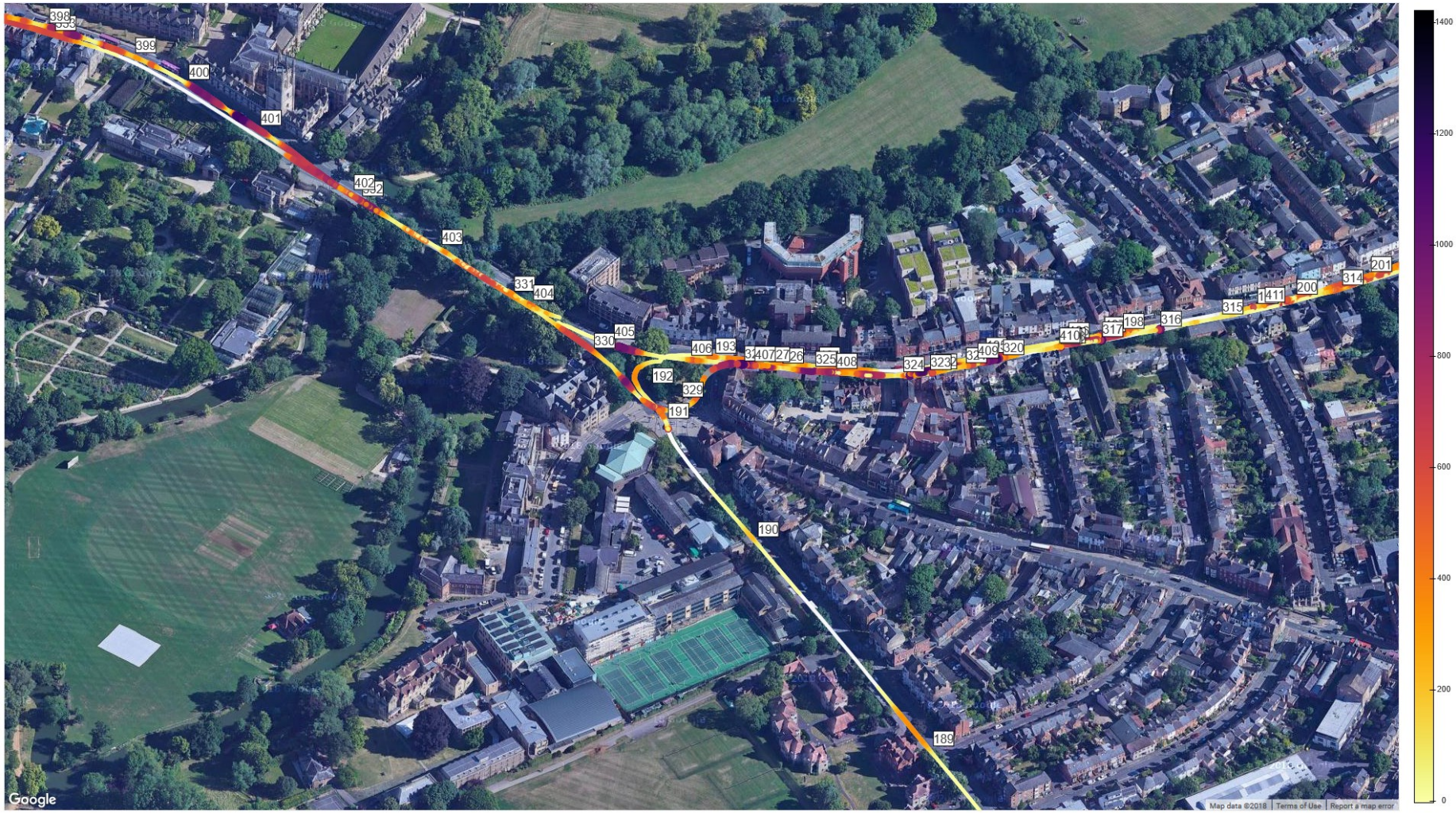
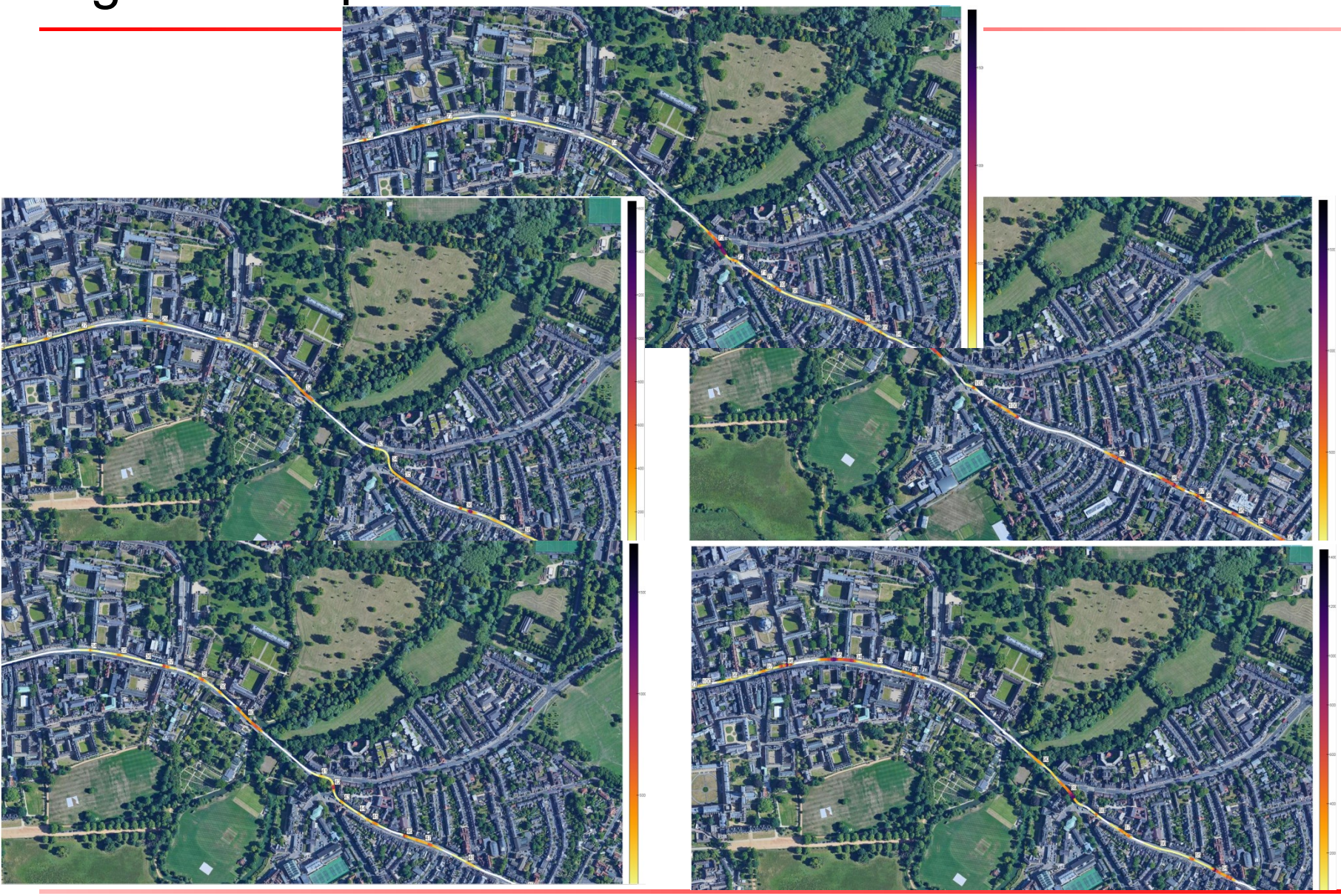


High St comparison

- EU V overlay



High St comparison – EU VI



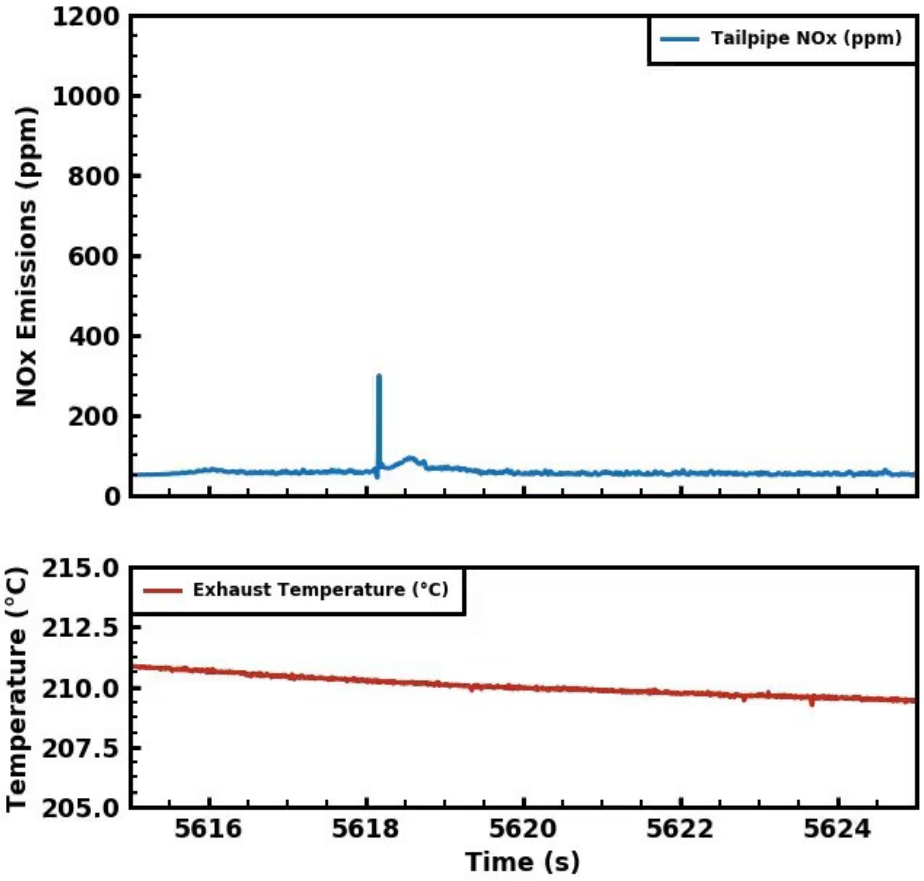
High St comparison – EU 5

Eu VI bus stop pull-away uphill

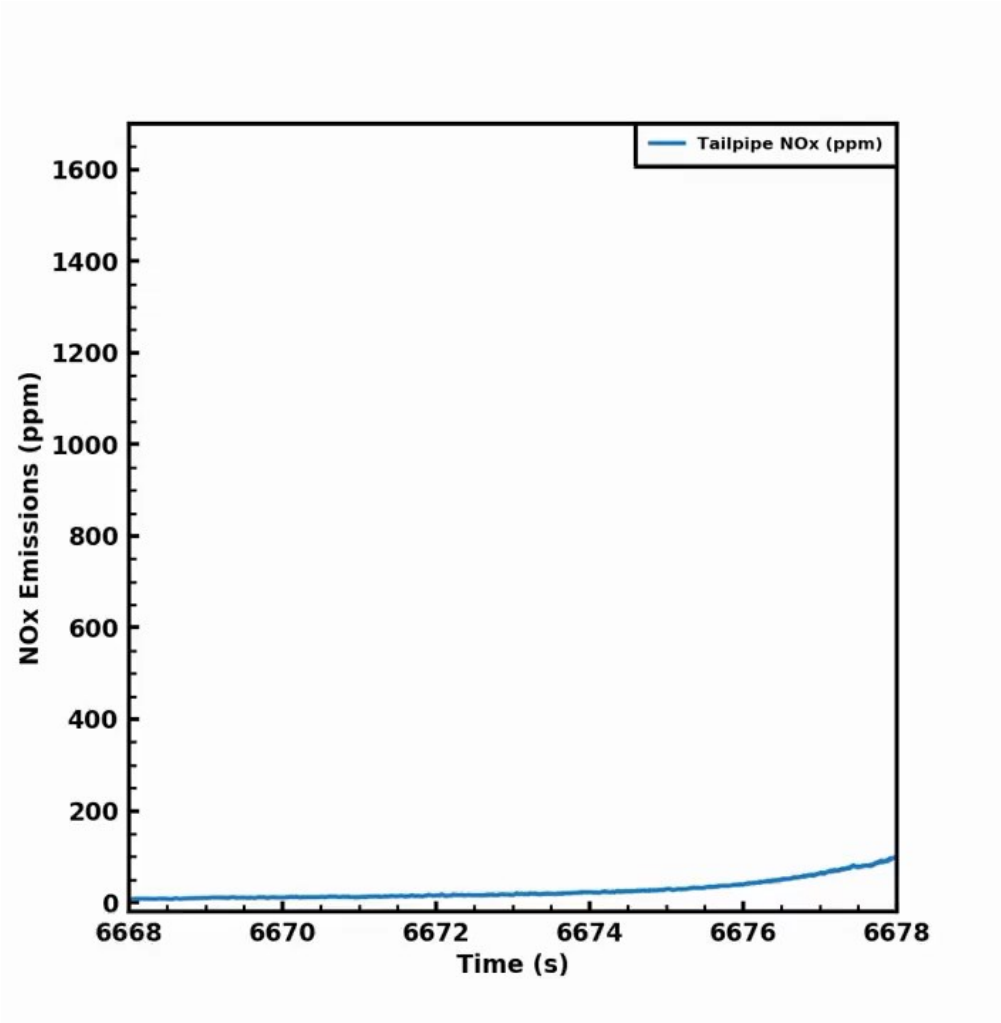
#36. Run 1 South Eu 6

Eu VI bus stop pull-away uphill

#36. Run 1 South Eu VI



Eu V bus stop manoeuvre



Eu V bus stop manoeuvre – Town centre