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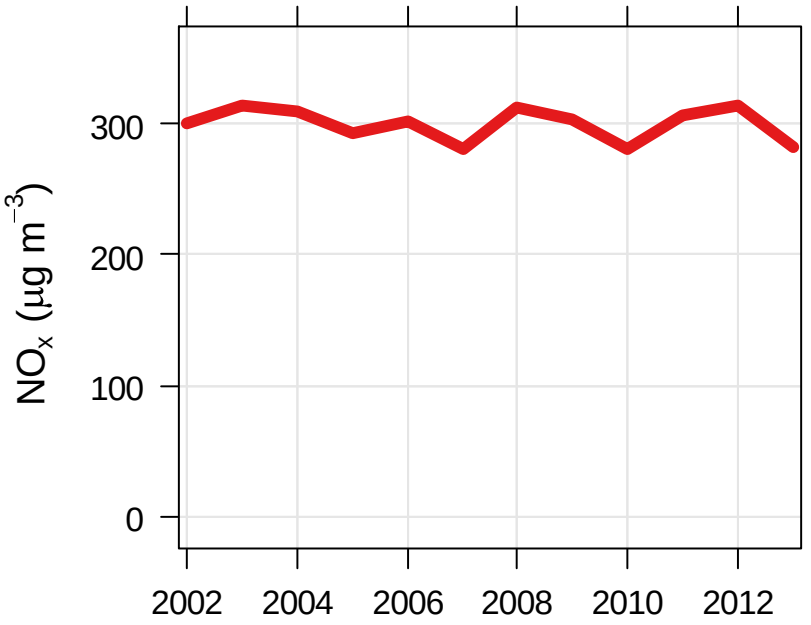
Recent findings from comprehensive vehicle emission remote sensing measurements

23-24th June 2014
Frontiers in Air Quality Science, London

David Carslaw

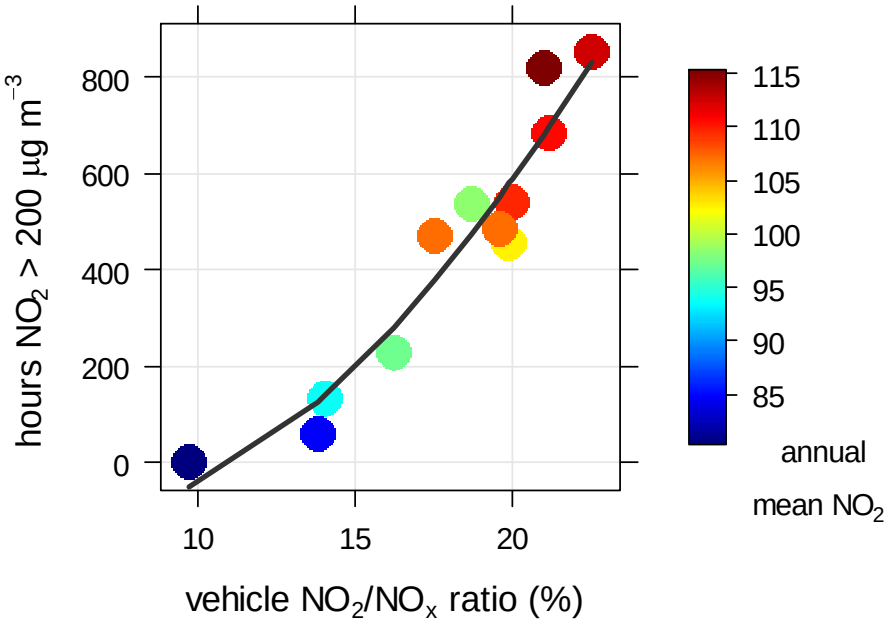
Trends at Marylebone Road over *12 years*

- Concentrations of total NO_x have effectively been constant for over a decade
  - This is very convenient for showing how primary NO_2 emissions affect things
  - What about hourly NO_2 exceedances (hours > 200 μg m^{-3})?



Trends at Marylebone Road over 12 years

- Concentrations of total NO_x have been almost constant for over a decade
  - This is convenient for showing how primary NO_2 emissions affect things
  - What about hourly NO_2 exceedances (hours > 200 μg m^{-3})?
- Hourly exceedances have varied from 2 hours (meets Limit Value) to 853
- It is **directly emitted (primary) NO_2 emissions** that control this behaviour
  - Diesel vehicle technology change – oxidation catalysts used to ***deliberately*** convert NO to NO_2



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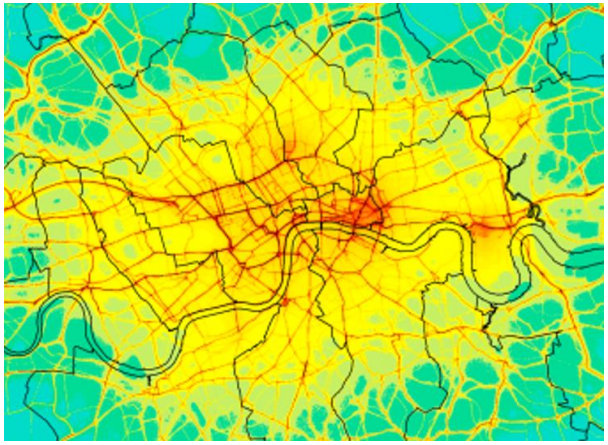
Other hot spots (or hot lines?) are worse

- Oxford Street 2013
  - Annual mean **134 µg m^{-3}**
    1568 hours > 200 µg m^{-3}
    maximum = **489 µg m^{-3}**
  - Highest annual mean concentration and most hourly NO_2 exceedances in the World?
  - Highest in the (long) history of air pollution?
- It is essential we understand the sources of NO_x and NO_2 if we are to tackle this issue effectively



Source: Sean Beevers

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What would we like to know?

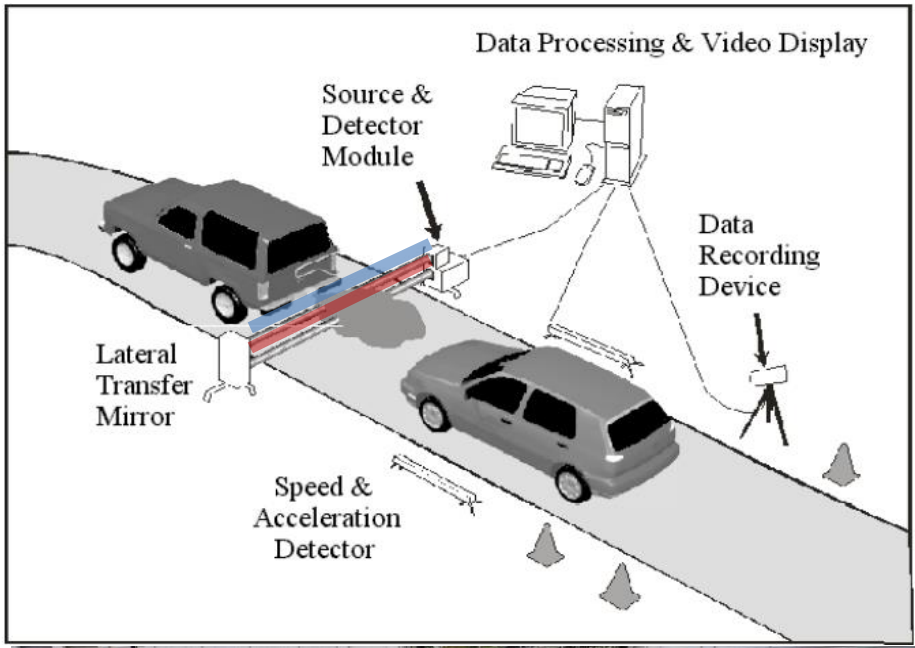
Ideally we want to know what every vehicle emits at all times!

- Failing that (as we surely will) we need reliable emission estimates that can be reconciled with atmospheric measurements
- Vehicle emission remote sensing is a very useful technique in this respect
- Two Defra-funded projects with the aim of better understanding these issues

Vehicle emission remote sensing

- Developed in the late 1980s by Don Stedman/Gary Bishop at the University of Denver
- non-intrusive technique to determine the concentration of certain pollutants in situ using IR/UV absorption spectroscopy
  - Can measure CO, HC, NO, **NO_2**, NH_3, SO_2 *as a ratio to* CO_2
- Rapid measurements (ca. 50) in 0.5 seconds of the exhaust plume
- Number plate photographed
- Speed and acceleration measured
- Several key benefits

Note – focus in USA is *IM* (inspection and maintenance) – identifying 'broken' vehicles



Measurement campaigns in 2012 and 2013

2012

- Denver instrument for 6 weeks
- 70,000 measurements at 4 locations across London
- Focus on quantifying the NO_2 component in exhaust
- Information on buses and taxis – important in central London

2013

- Denver instrument for 6 weeks
- Improved quantification of emissions from different bus technologies
- Measurements of an **urban-optimised** SCR system on buses
- On-road experiments *and* controlled conditions (test track)
- First on-road Euro 6 remote sensing measurements?

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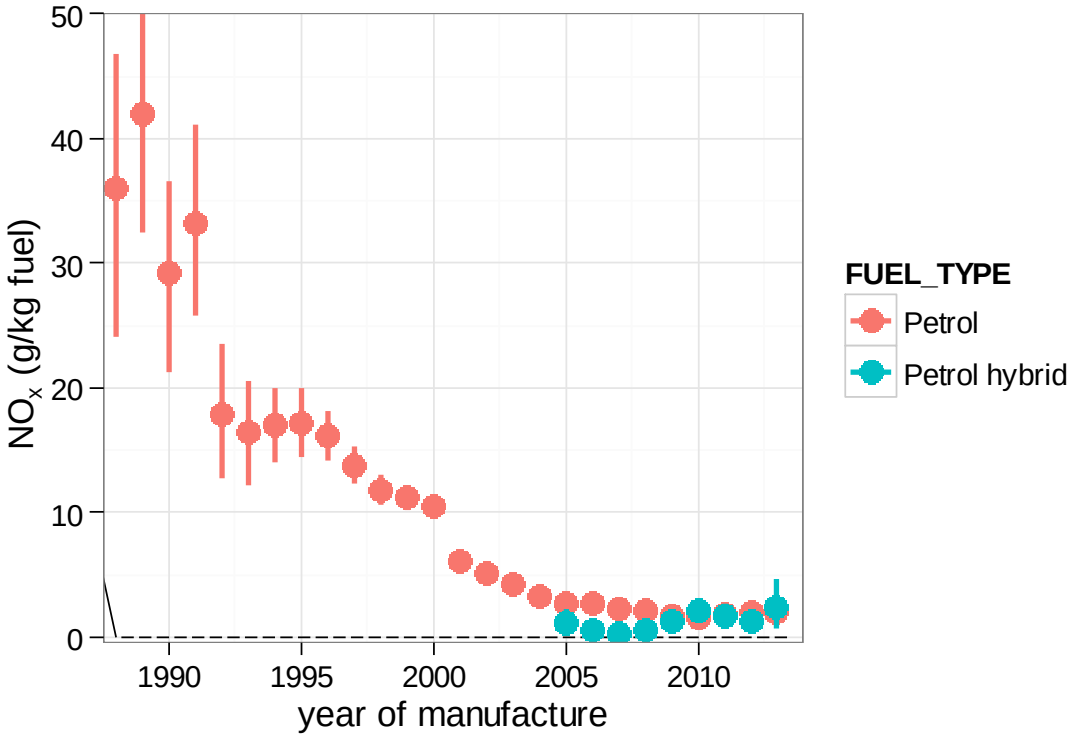
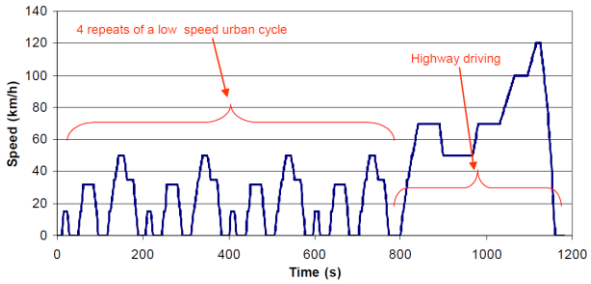
Petrol car NO_x

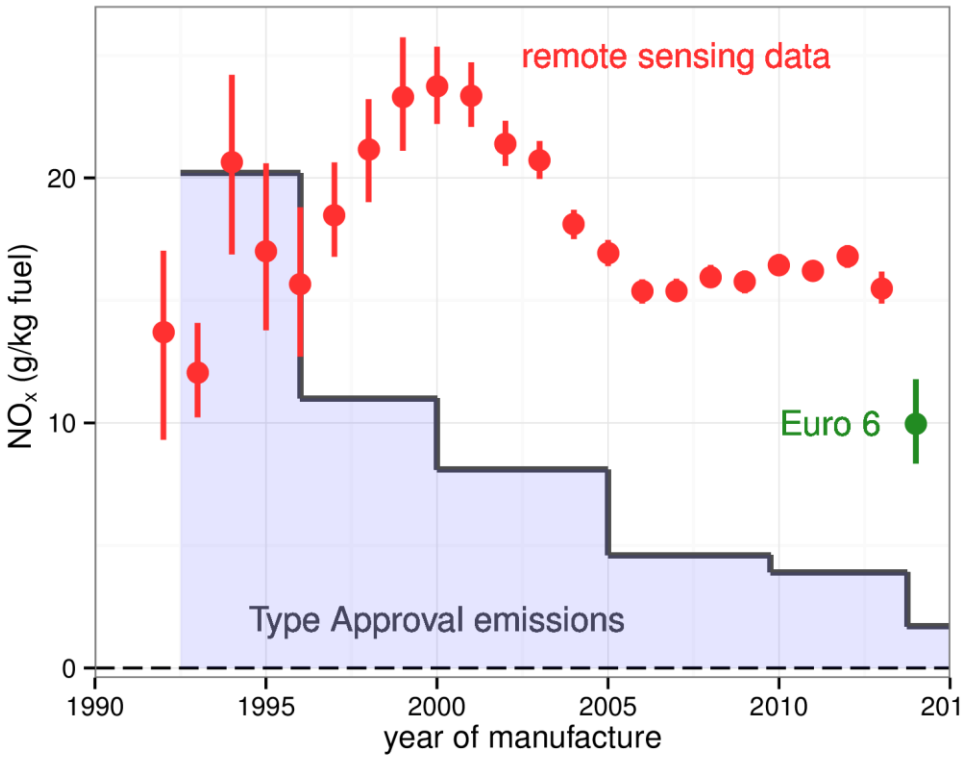


- Modern petrol vehicles are very low emitters of NO_x and NO_2
- Still useful to accelerate the removal of older non-catalyst and catalyst vehicles though…

Diesel car NO_x– comparison with Type Approval emissions

- Type Approval emissions
  - 1000s of new car models tested each year, including CO_2 and NO_x
  - NO_x is legislated NO_2 is not
  - Tested over New European Test Cycle (NEDC)
- Compare with remote sensing data
  - Use *same* measurement unit – g NO_x per kg fuel burnt
  - Sample is >25,000 vehicles
- Euro 6 emit **40% less NO_x than Euro 5**
  - Type Approval/legislation would suggest a 56% reduction





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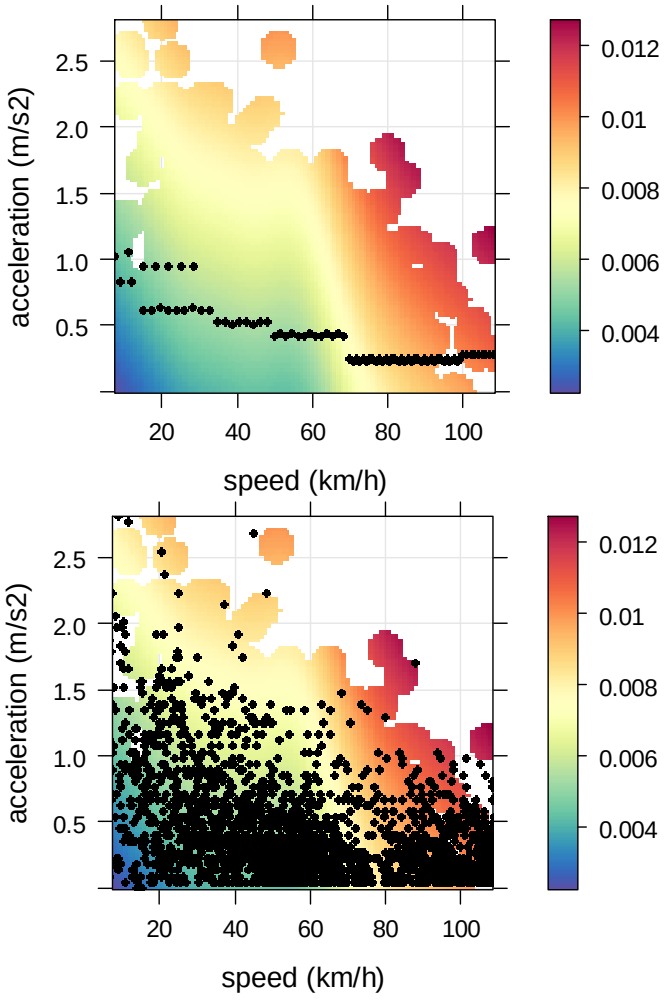
How representative are NEDC and remote sensing measurements?

- Black circles show driving conditions over the Type Approval test cycle (NEDC) **top plot**
- Coloured region is that covered by the remote sensing measurements – NO_x/CO_2 ratio
- Actual driving conditions are much more dynamic than the NEDC
- Portable Emission Measurement System (PEMS)* data **bottom plot** example of a diesel car in Milan (140 km of driving)
- The RSD data are representative of typical urban and suburban driving conditions



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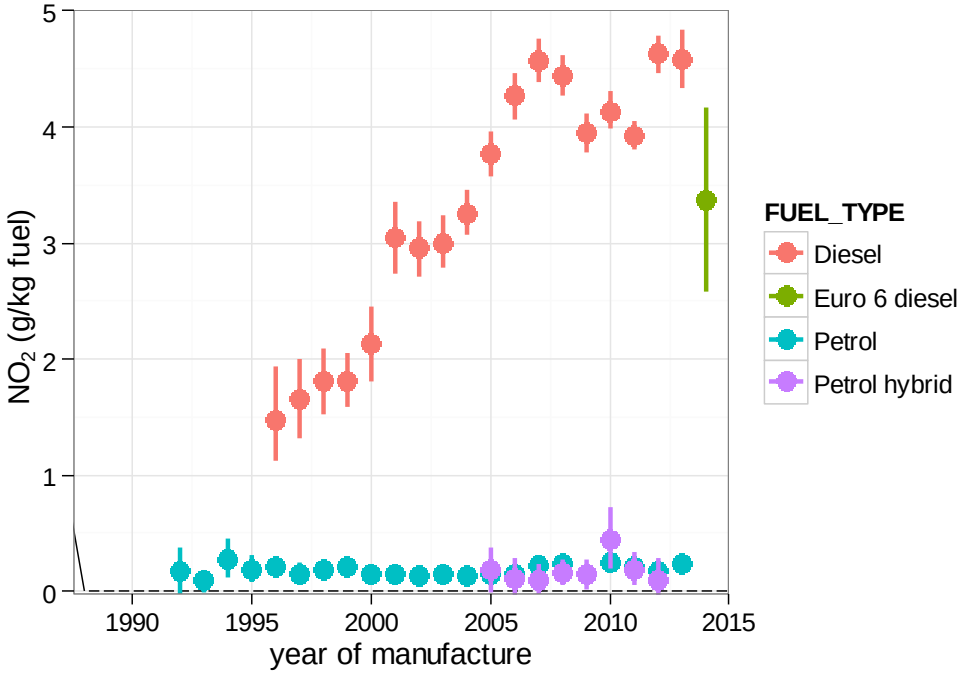
*Thanks to from Dr Martin Weiss, JRC, Ispra

Diesel car NO_2 – trends over time

- Petrol car emissions are consistently very low
- Diesel car NO_2 emissions have increased considerably
- Euro 6 diesel NO_2 is lower than Euro 5
  - Note uncertainties – need more measurements
  - Reduction in NO_2 emissions as catalysts become less active over time?



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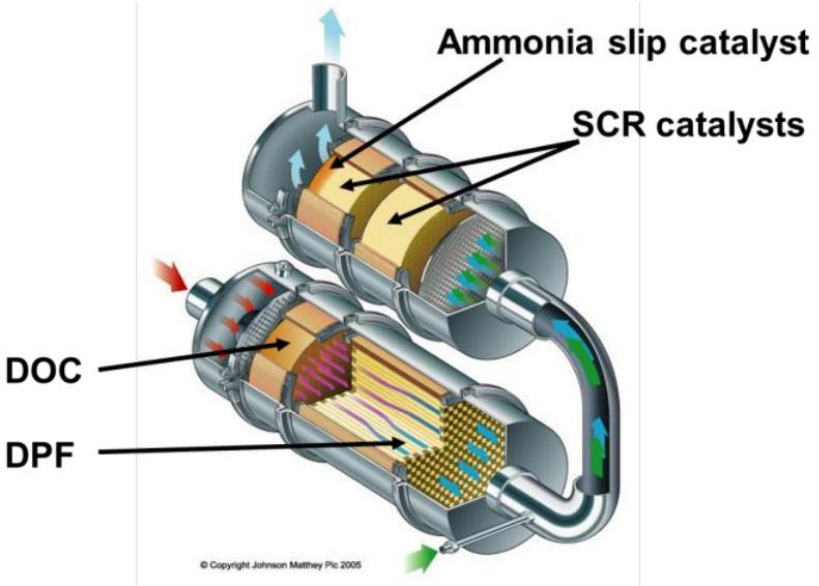
TfL retrofit bus emissions

- 900 Euro III buses converted to a 'low-NO_2' SCRT
  - CRT = Continuously Regenerating Trap
  - SCR = Selective Catalytic Reduction
  - Thermally optimised + larger catalyst
- Certain bus routes targeted
  - Remote sensing measurements over 2 weeks
  - Ambient measurements over several years
- Our 2012 measurements showed Original Equipment Manufacturer (OEM) SCR systems were largely ineffective at reducing NO_x
- **Is retrofitting with SCRT effective?**



Source: Görsmann et al.

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What did we measure?

- Two weeks on Putney Hill (on-road measurements)
  - >700 SCRT buses over a range of speeds/accelerations
  - 122 nominally identical Euro III non-SCRT buses measured
- Controlled measurements at a test track location – single bus
  - Full SCRT
  - SCR only
  - Base bus (just the silencer)
  - Engine/exhaust measurements at 1 Hz
  - [+ black carbon + commercial remote sensing instrument]

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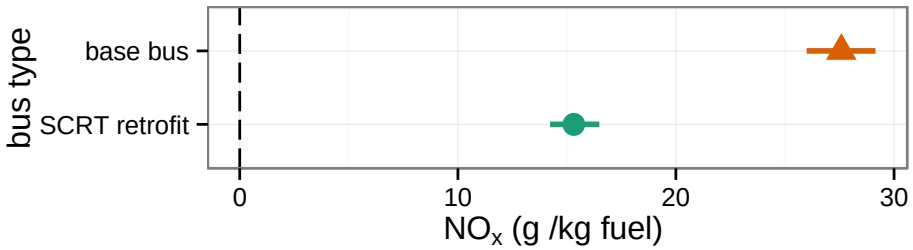
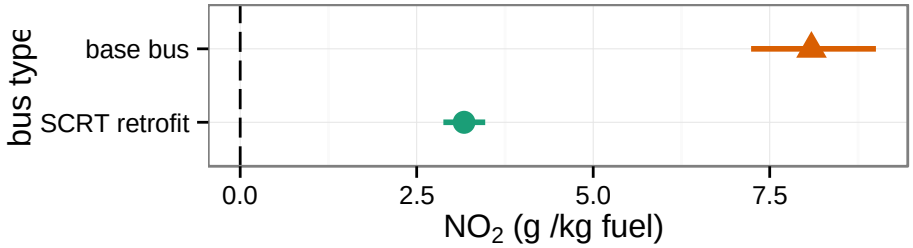
On-road measurements in London





- On average we see a **55%** reduction in emissions of NO_x
- The corresponding reduction in NO_2 is **61%**
- These reductions are substantial compared with the average performance of the bus fleet in London including OEM SCR systems

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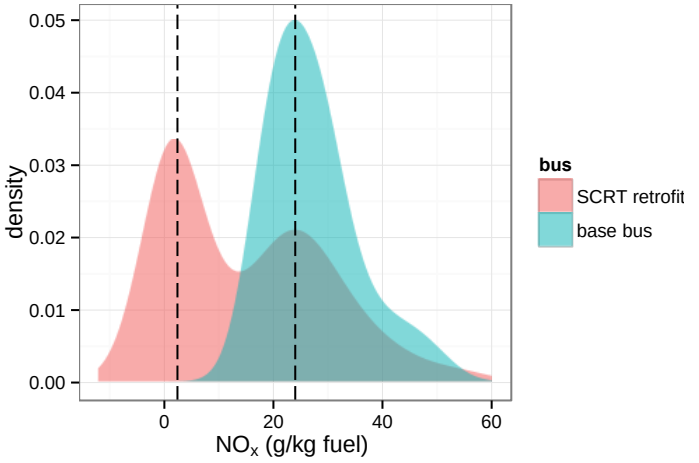
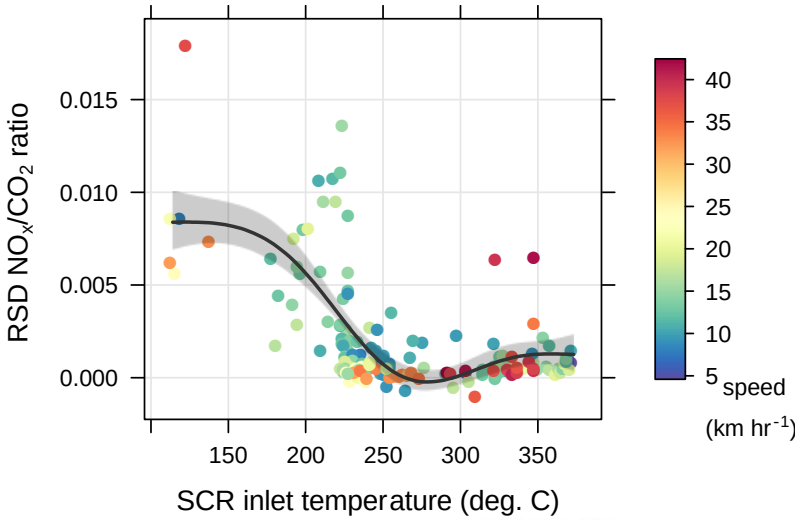
A closer look at the emissions behaviour

- Emissions distribution
  - SCRT buses sometimes behave like base buses
  - Other times there is ~90% reduction in NO_x
- Test track results
  - Importance of SCR inlet temperature
  - >200°C gives 90% reduction in NO_x
- Expect greater reduction in NO_x where engine runs hotter





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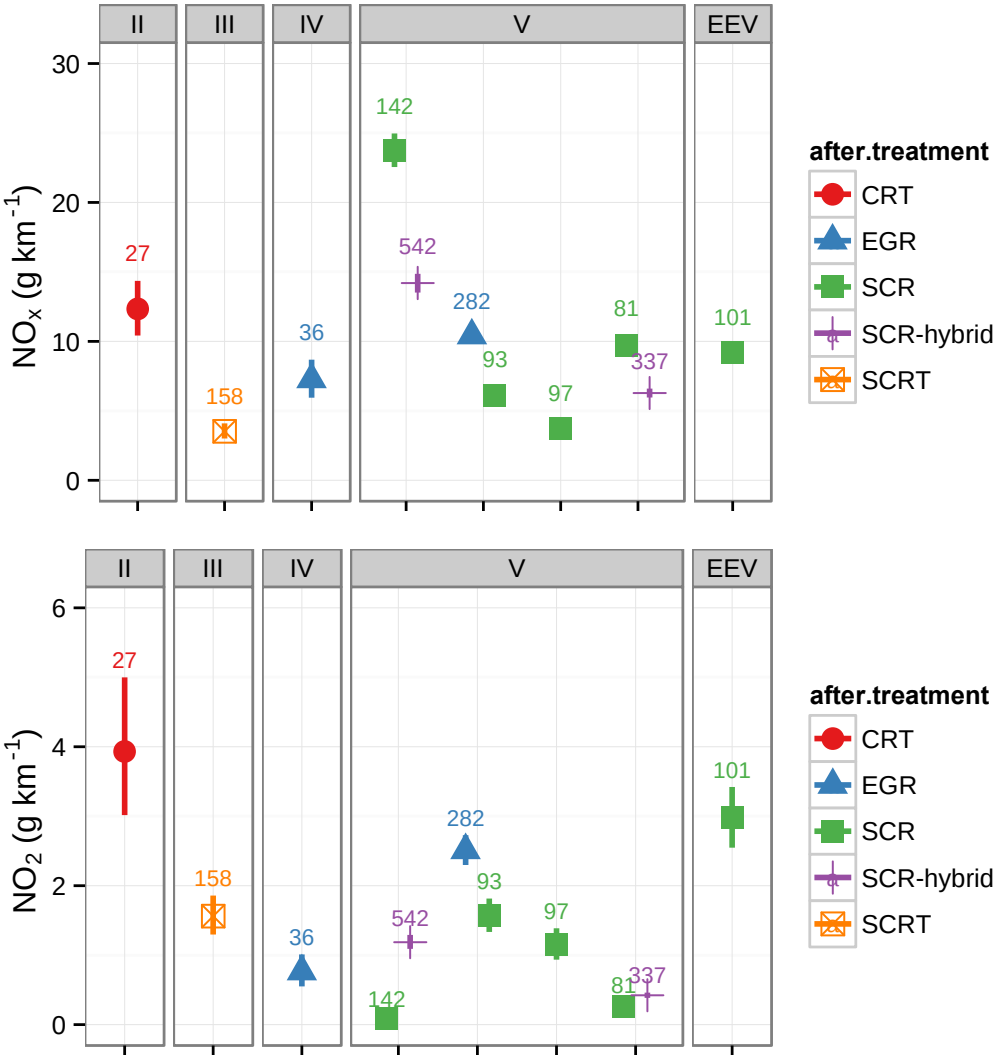
The general bus fleet – measurements from Oxford

- Measurements on Oxford High Street
  - Closed to most other vehicle types
  - Exceedances of annual and hourly NO_2 Limit Value
- >1700 measurements of buses
  - Mostly Euro V (83%)
  - Broad mix of technologies including hybrid SCRs

Results from Oxford

- Large range in NO_x performance
  - Factor of ~6 within Euro V SCR…
  - Some Euro V are higher than earlier Euro classes
- Even larger variation in NO_2 emissions
  - Highest NO_x emitter is lowest NO_2 emitter
  - Very different consequences for ambient NO_2 concentrations



Concluding remarks

- Primary NO_2 emissions remain important across Europe
- Emissions of NO_x and NO_2 from modern petrol vehicles are consistently low
- Euro 6 diesel cars show an encouraging reduction in NO_x and to a lesser extent NO_2
  - Need more data from wider range of emission reduction technologies
- TfL retrofit Euro III buses show substantial reductions in NO_x and NO_2
  - Particularly effective NO_2 reduction

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Concluding remarks

- The wider bus fleet can have highly variable NO_x and NO_2 emissions performance
  - Even for vehicles with nominally the same technology
  - Ambient NO_2 issues could be very dependent on choice of urban bus fleets in many urban areas
- Overall our recent measurements provide encouraging news for future NO_2 concentrations
  - …but much remains to be done
  - Need to remain vigilant - remote sensing is very effective in this respect