Successes and Challenges in Reducing Emissions and Ambient NO_2 in High-Traffic Areas

The Near-Road Environment in London

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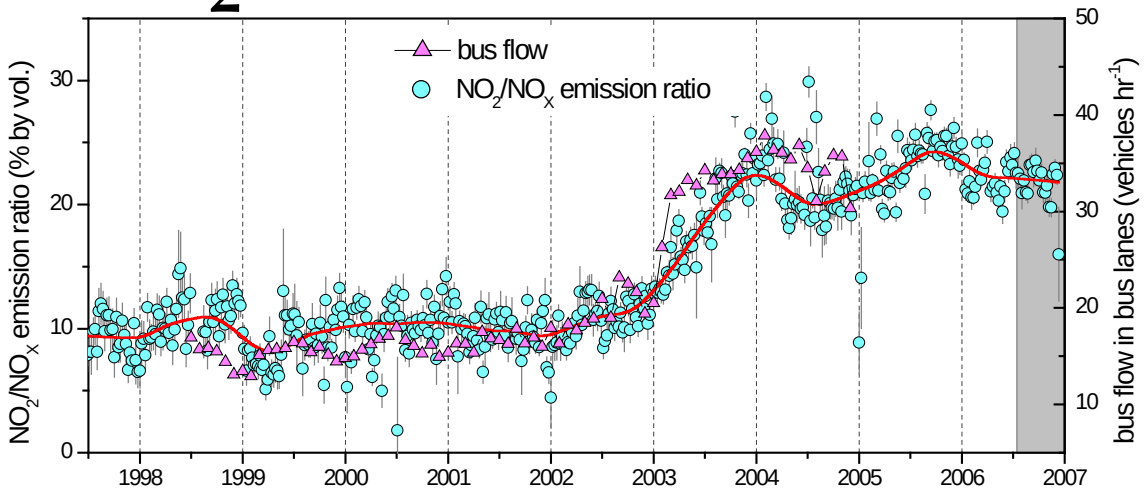
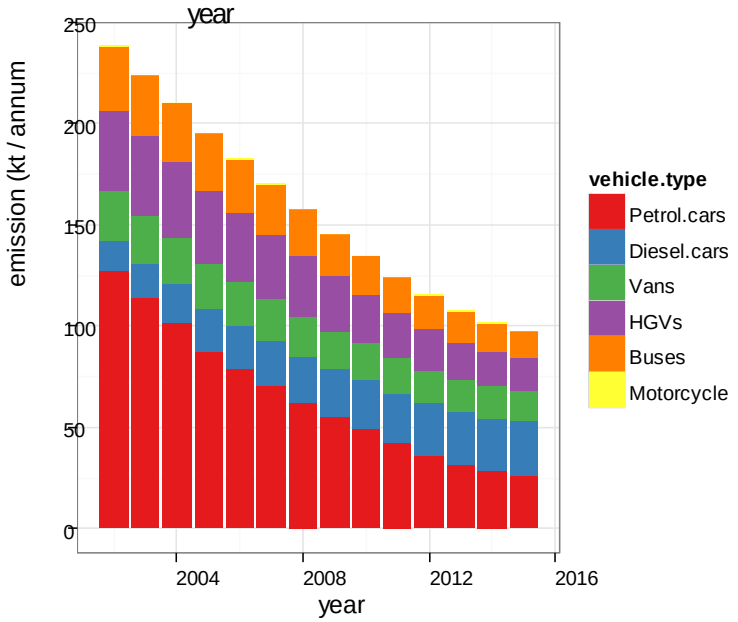
Background

- Emissions of NO_x are important at all scales in atmospheric science
- At the local scale concentrations of NO_2 are of interest from a health perspective
- Much of the interest in NO_2 in Europe is motivated by European ambient air quality Directives
  - **Annual mean** limit of 40 μg m^{-3} (~ 21 ppb)
  - **Hourly limit** of 200 μg m^{-3} (~ 105 ppb) not to be exceeded more than 18 times in a calendar year
  - Should have been met by 2010…
- Today, many locations in Europe (mostly close to roads) do not meet the Directive limits

Directly emitted NO_2 and emissions of NO_x

- NO_2 hourly exceedances **2 in 2002; 463 in 2003** at Marylebone Road in London
- Importance of *directly* emitted NO_2 first detected observed – CRT particle filters + ?*
- …but expected urban road transport NO_x emissions to decrease by over a factor of two by 2015 – so a non-issue?

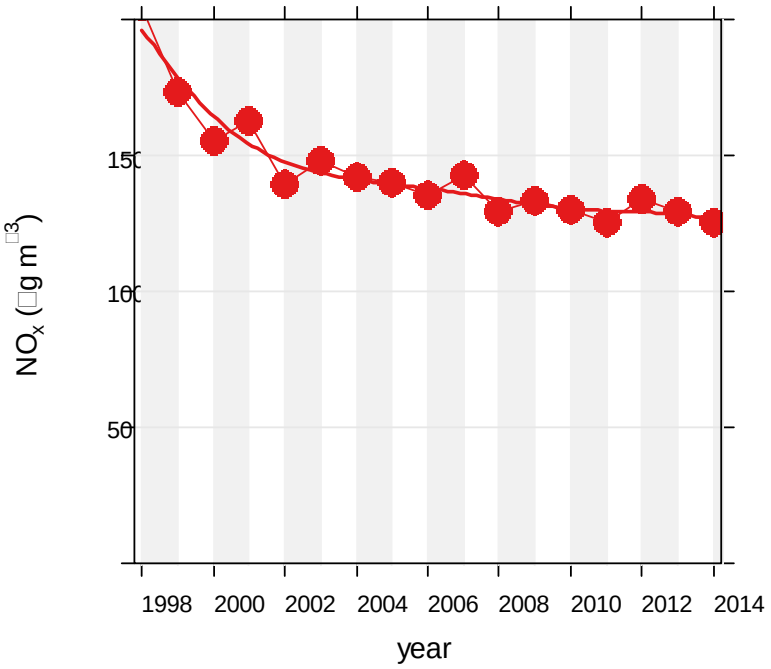


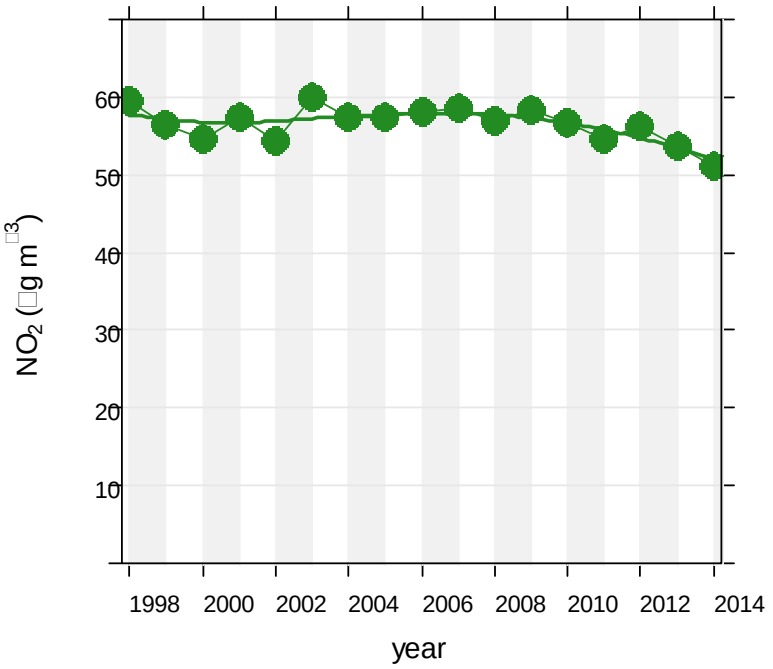


*Carslaw, D.C. (2005). Evidence of an increasing NO_2/NO_x emissions ratio from road traffic emissions. *Atmospheric Environment*, 39(26) 4793-4802.

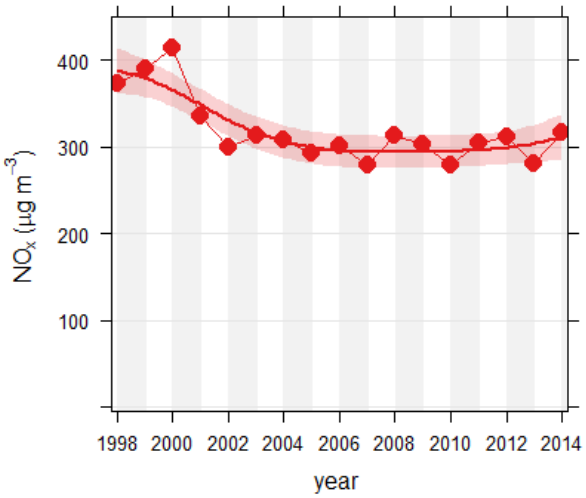
Trends in ambient NO_x and NO_2 in London at *roadside* sites

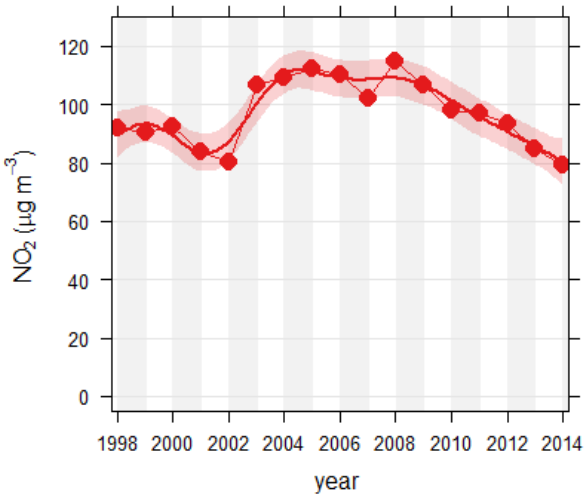
- Simple aggregated mean across 32 sites in London with at least 10 years of data
- More evidence of downward trends elsewhere in the UK and across Europe

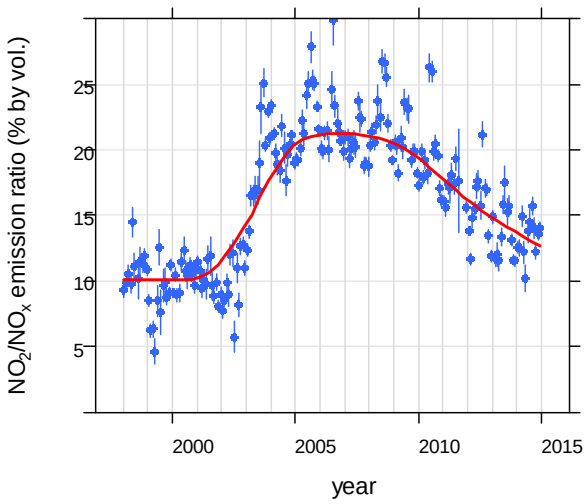




Primary NO_2 emissions can be very important



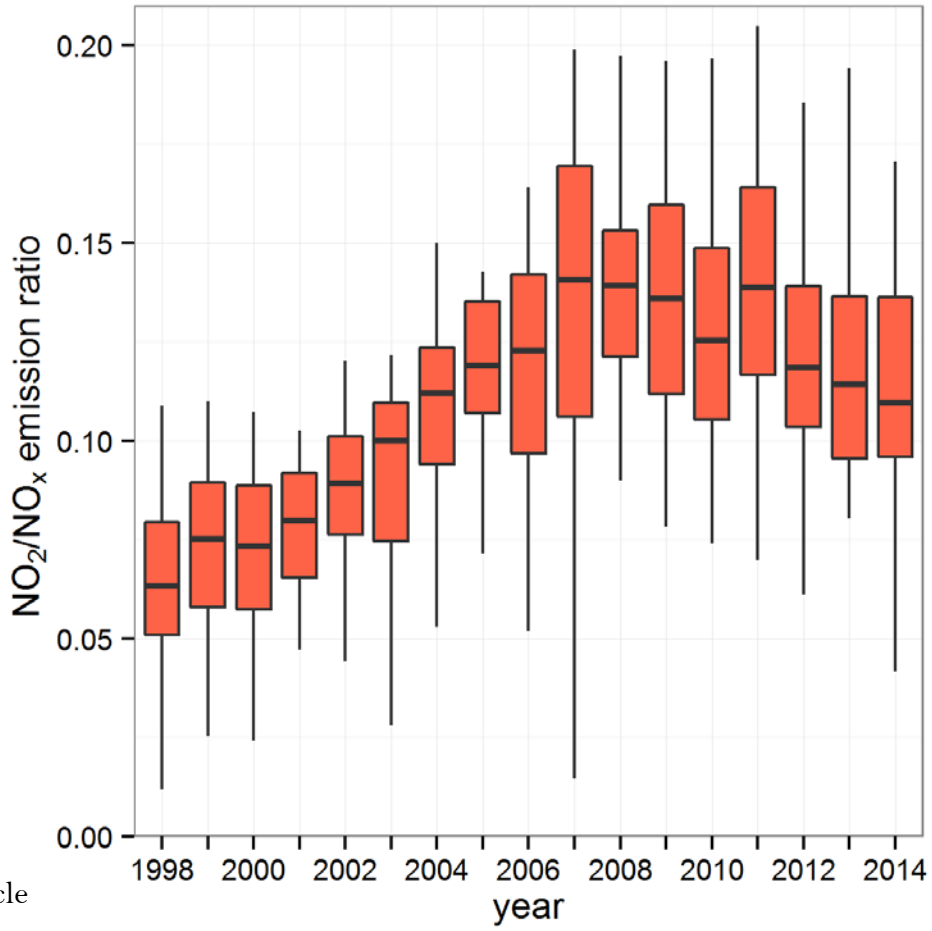




- In 2008: NO_x = 312 µg m^{-3} , NO_2 = 115 µg m^{-3}
  hours > 200 µg m^{-3} = 812
- In 2014: NO_x = 316 µg m^{-3} , NO_2 = 79 µg m^{-3}
  hours > 200 µg m^{-3} = 17
- Very different NO_2 response is due to primary NO_2 emissions

Road vehicle primary NO_2 across the UK

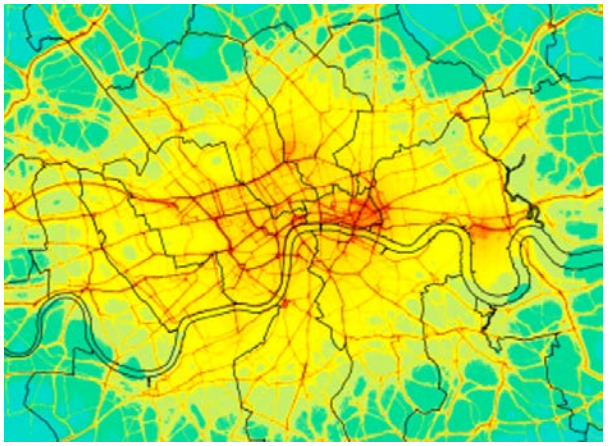
- Analysis of 49 UK roadside ambient sites*
- Substantial increases since the late 1990s
- Evidence of decreases over past few years



*Carslaw, D.C. and Beevers, S.D. (2005). Estimations of road vehicle primary NO_2 exhaust emission fractions using monitoring data in London. *Atmospheric Environment*, 39(1): 167-177.

Some London roads have very high concentrations of NO_2

- Oxford Street so far in 2015 …
  - Mean **156 µg m^{-3}**
    761 hours > 200 µg m^{-3}
    maximum = **620 µg m^{-3}**
  - For EU limits, highest of any concentrations in the world (…to my knowledge!)
- It is important we understand the sources of NO_x and NO_2 if we are to tackle this issue effectively



Source: Sean Beevers, KCL

Vehicle emission remote sensing

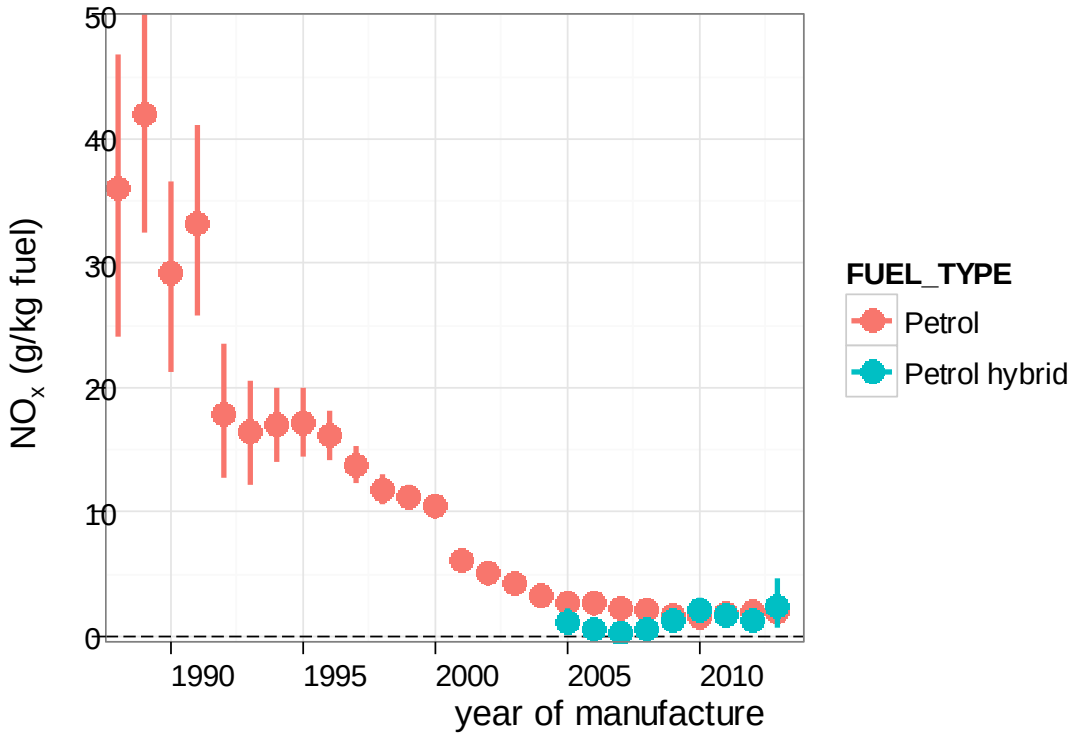
- Used the University of Denver instrument for 2 x 6 weeks in 2012 and 2013 – measures **NO_2 and NH_3**
- > 100,000 vehicle measurements mostly in London
  - On-road experiments *and* controlled conditions

- Focus on quantifying the NO_2 component in exhaust
- Emissions information on buses and taxis – important in central London
- Improved quantification of emissions from different emission technologies
- Measurements of an *urban-optimized* SCR retrofit system on buses
- First on-road Euro 6 remote sensing measurements?

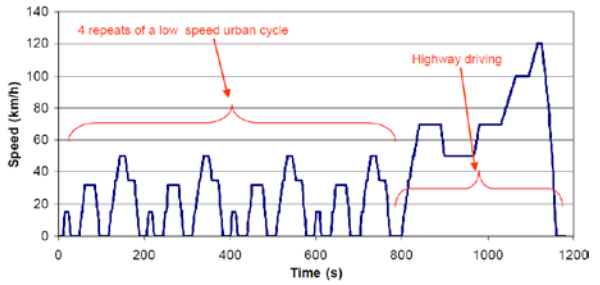
Gasoline passenger car NO_x

Based on > 30,000 measurements

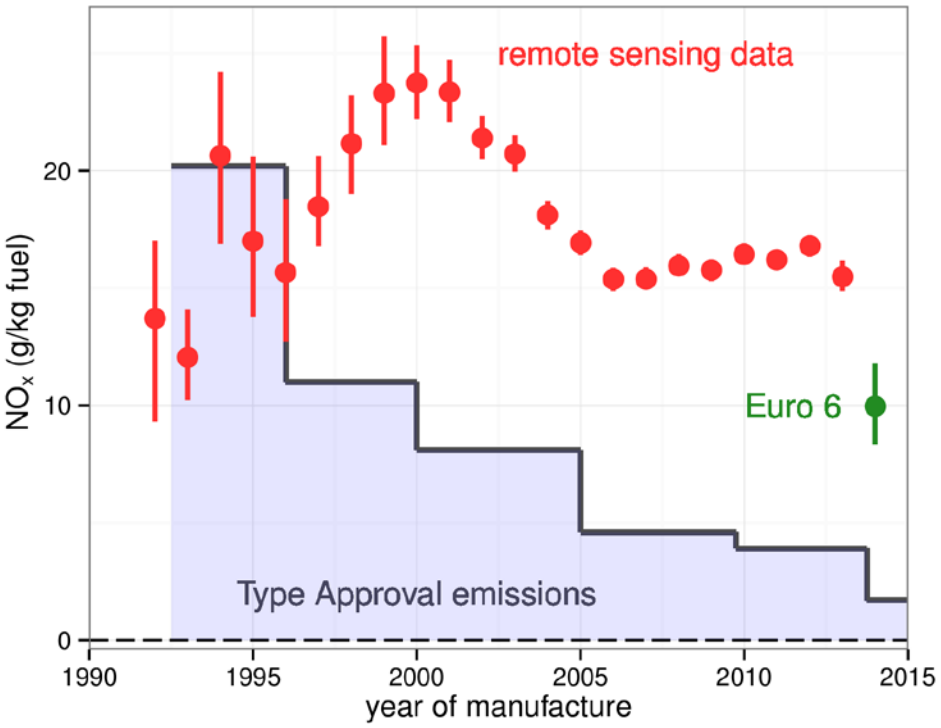
- Modern gasoline vehicles are very low emitters of NO_x and NO_2
- Still useful to accelerate the removal of older non-catalyst and catalyst vehicles though…



Diesel car NO_x – comparison with Type Approval emissions

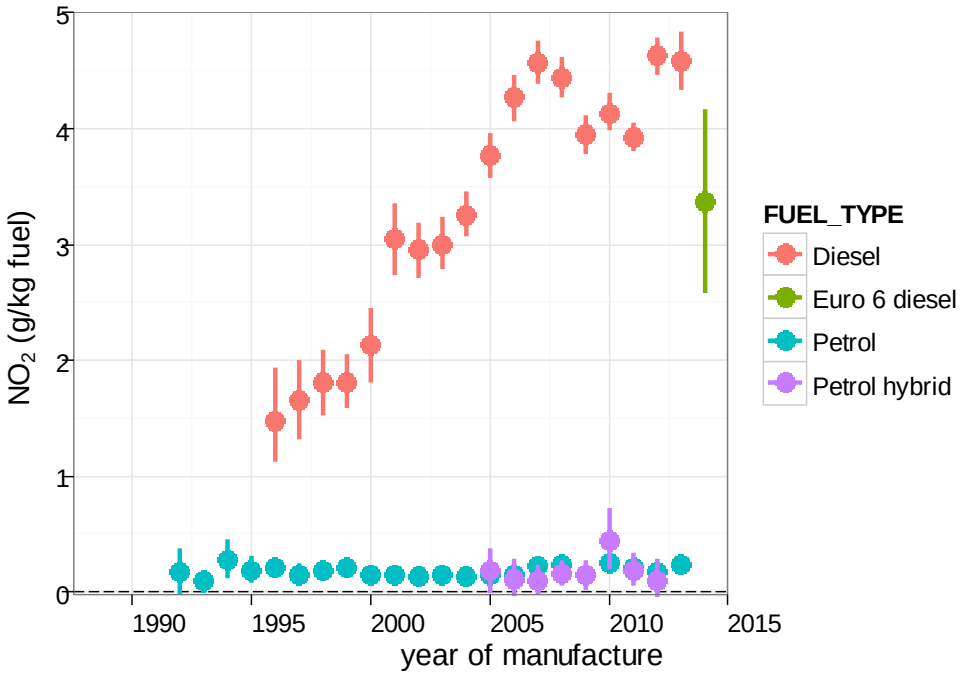


- Type Approval emissions
  - 1000s of new car models tested each year, including CO_2 and NO_x
  - NO_x is legislated **NO_2 is not**
  - Tested over New European Test Cycle (NEDC)
- Compare with remote sensing data
  - Use *same* measurement unit – g NO_x per kg fuel burnt
  - Sample is >25,000 vehicles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



Primary NO_2 from passenger cars – trends over time

- Gasoline 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?

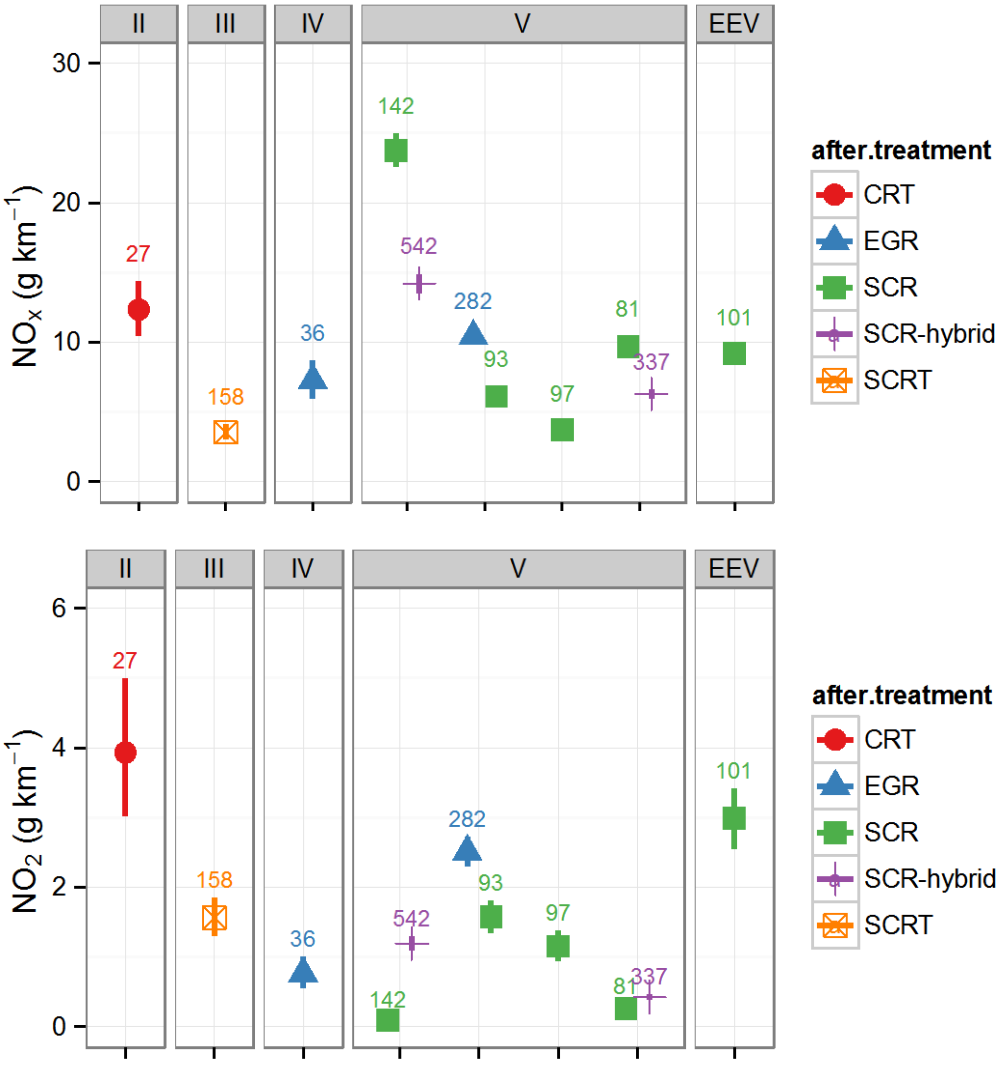


Urban bus emissions – example from Oxford

- 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

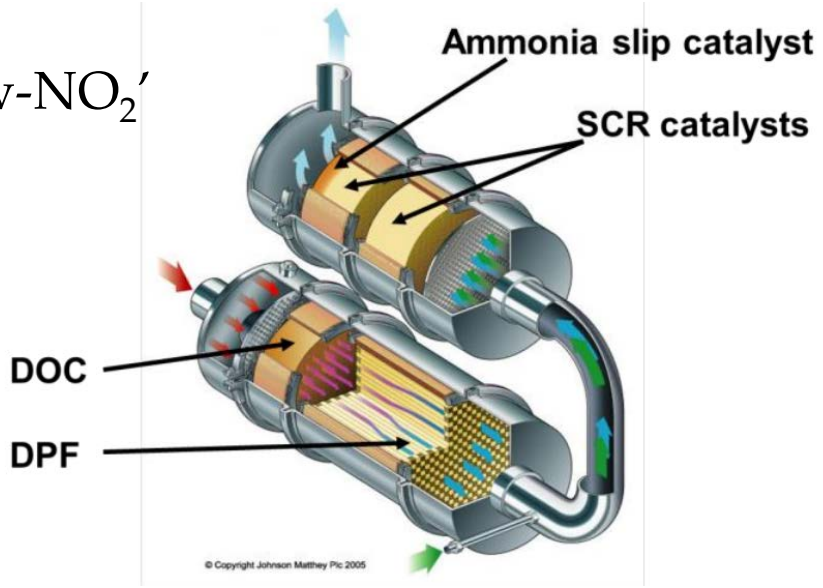
Urban bus emissions

- 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



Transport for London (TfL) retrofit bus emissions

- > 1000 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?**

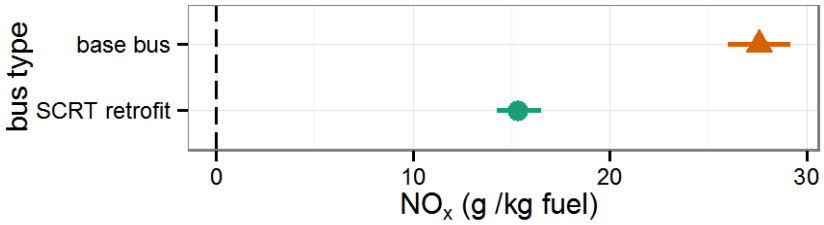


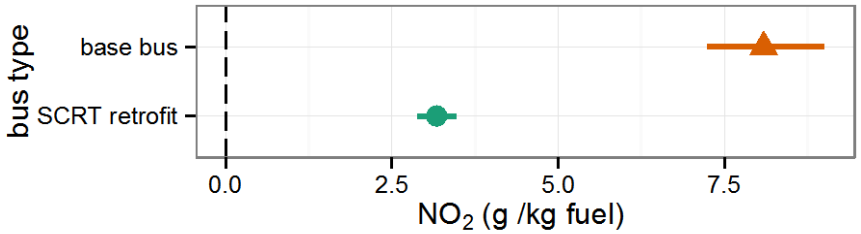
*Carslaw, D.C. and Rhys-Tyler, G. (2013). New insights from comprehensive on-road measurements of NO_x, NO_2 and NH_3 from vehicle emission remote sensing in London, UK. *Atmospheric Environment*, Vol. 81 339-347.

Measurements

- Two weeks in west London (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]

On-road measurements in London

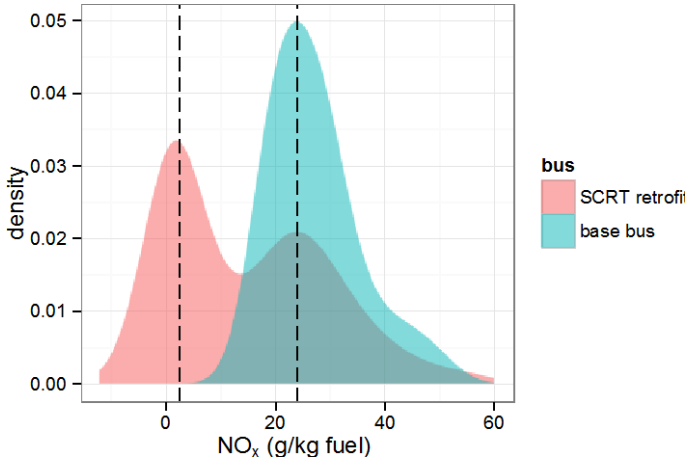


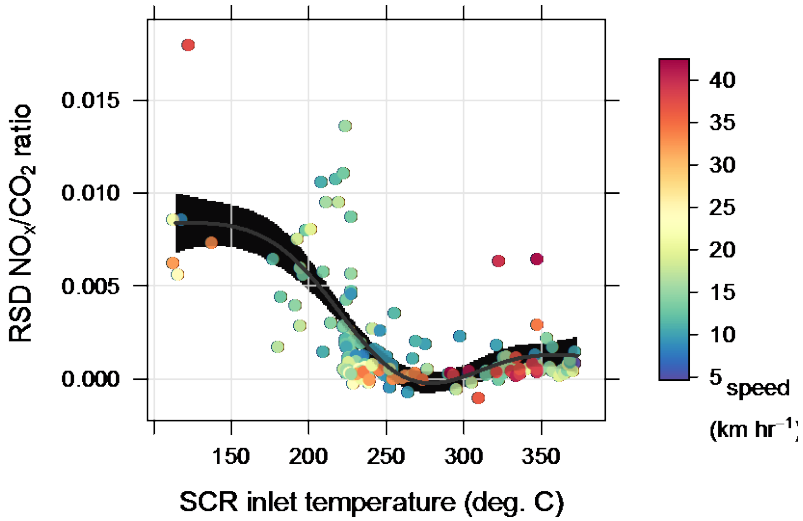


- On average we see a **45%** reduction in emissions of NO_x
- The corresponding reduction in NO_2 is **61%**
- These reductions are *relatively* substantial compared with the average performance of the bus fleet in London including OEM SCR systems

A closer look at the emissions

- 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





Concluding remarks

- Two main things have occurred over past 10 years or so
  - Directly emitted NO_2 emissions from diesel vehicles increased, and
  - Diesel total NO_x emissions (light and heavy duty) have not decreased as expected
- Emissions of NO_x and NO_2 from modern gasoline passenger cars are consistently low
- Euro 6 diesel passenger 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

Concluding remarks

- The wider bus / truck 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
- Challenging for emissions inventories…
- NO_2 as an issue in Europe will remain important for many years to come

Acknowledgements

- King's College London
- Defra for funding the emissions measurements
- Don Stedman & Gary Bishop, University of Denver, for use of the FEAT instrument