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\textsubscript{x} are important at all scales in atmospheric science
- At the local scale concentrations of NO\textsubscript{2} are of interest from a health perspective
- Much of the interest in NO\textsubscript{2} in Europe is motivated by European ambient air quality Directives
  - **Annual mean** limit of 40 µg m\textsuperscript{-3} (~ 21 ppb)
  - **Hourly limit** of 200 µg m\textsuperscript{-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?

Trends in ambient NO\textsubscript{x} and NO\textsubscript{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

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
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…

![Graph showing NO$_x$ emissions over years of manufacture for petrol and petrol hybrid vehicles.](image)
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 NO₂ Limit Value

- >1700 measurements of buses
  - Mostly Euro V (83%)
  - Broad mix of technologies including hybrid SCRs
Urban bus emissions

- Large range in NO\textsubscript{x} performance
  - Factor of ~6 within Euro V SCR...
  - Some Euro V are higher than earlier Euro classes

- Even larger variation in NO\textsubscript{2} emissions
  - Highest NO\textsubscript{x} emitter is lowest NO\textsubscript{2} emitter
  - Very different consequences for ambient NO\textsubscript{2} concentrations
Transport for London (TfL) retrofit bus emissions

- > 1000 Euro III buses converted to a ‘low-NO\textsubscript{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\textsubscript{x}*
- Is retrofitting with SCRT effective?

*Carslaw, D.C. and Rhys-Tyler, G. (2013). New insights from comprehensive on-road measurements of NO\textsubscript{x}, NO\textsubscript{2} and NH\textsubscript{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\textsubscript{x}.
- The corresponding reduction in NO\textsubscript{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\textsubscript{x}

- Test track results
  - Importance of SCR inlet temperature
  - > 200°C gives 90% reduction in NO\textsubscript{x}

- Expect greater reduction in NO\textsubscript{x} where engine runs hotter
Concluding remarks

- Two main things have occurred over past 10 years or so
  - Directly emitted NO\textsubscript{2} emissions from diesel vehicles increased, and
  - Diesel total NO\textsubscript{x} emissions (light and heavy duty) have not decreased as expected

- Emissions of NO\textsubscript{x} and NO\textsubscript{2} from modern gasoline passenger cars are consistently low

- Euro 6 diesel passenger cars show an encouraging reduction in NO\textsubscript{x} and to a lesser extent NO\textsubscript{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
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