Recent findings from comprehensive vehicle emission remote sensing measurements

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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$_2$
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
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\textsubscript{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?
• Modern petrol vehicles are very low emitters of NO\textsubscript{x} and NO\textsubscript{2}
• Still useful to accelerate the removal of older non-catalyst and catalyst vehicles though…
Diesel car NO\textsubscript{x}– comparison with Type Approval emissions

• Type Approval emissions
  • 1000s of new car models tested each year, including CO\textsubscript{2} and NO\textsubscript{x}
  • NO\textsubscript{x} is legislated NO\textsubscript{2} is not
  • Tested over New European Test Cycle (NEDC)

• Compare with remote sensing data
  • Use same measurement unit – g NO\textsubscript{x} per kg fuel burnt
  • Sample is >25,000 vehicles

• Euro 6 emit 40% less NO\textsubscript{x} than Euro 5
  – Type Approval/legislation would suggest a 56% reduction
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 – $\text{NO}_x/\text{CO}_2$ 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

*Thanks to from Dr Martin Weiss, JRC, Ispra
Diesel car NO₂ – trends over time

- Petrol car emissions are consistently very low
- Diesel car NO₂ emissions have increased considerably
- Euro 6 diesel NO₂ is lower than Euro 5
  - Note uncertainties – need more measurements
  - Reduction in NO₂ emissions as catalysts become less active over time?
TfL retrofit bus emissions

- 900 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?

Source: Görsmann et al.
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]
On-road measurements in London

- On average we see a 55% reduction in emissions of NO\textsubscript{x}
- The corresponding reduction in NO\textsubscript{2} is 61%
- These reductions are substantial compared with the average performance of the bus fleet in London including OEM SCR systems
A closer look at the emissions behaviour

- 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\textdegree}C gives 90% reduction in NO\textsubscript{x}

- Expect greater reduction in NO\textsubscript{x} where engine runs hotter
The general bus fleet – measurements from Oxford

• Measurements on Oxford High Street
  – Closed to most other vehicle types
  – Exceedances of annual and hourly NO\textsubscript{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\textsubscript{2} emissions remain important across Europe
- Emissions of NO\textsubscript{x} and NO\textsubscript{2} from modern petrol vehicles are consistently low
- Euro 6 diesel 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
- TfL retrofit Euro III buses show substantial reductions in NO\textsubscript{x} and NO\textsubscript{2}
  - Particularly effective NO\textsubscript{2} reduction
Concluding remarks

• The wider bus fleet can have highly variable NO\textsubscript{x} and NO\textsubscript{2} emissions performance
  – Even for vehicles with nominally the same technology
  – Ambient NO\textsubscript{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\textsubscript{2} concentrations
  – …but much remains to be done
  – Need to remain vigilant - remote sensing is very effective in this respect