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Strengthening the Links Between Air Quality Emissions Inventories and Ambient Measurements:
Report of the Air Quality Expert Group

Tim Murrells

RSC Conference

Monitoring Ambient Air 2013

11th December 2013

UK Emission Trends and Ambient Concentration Trends at Marylebone Rd

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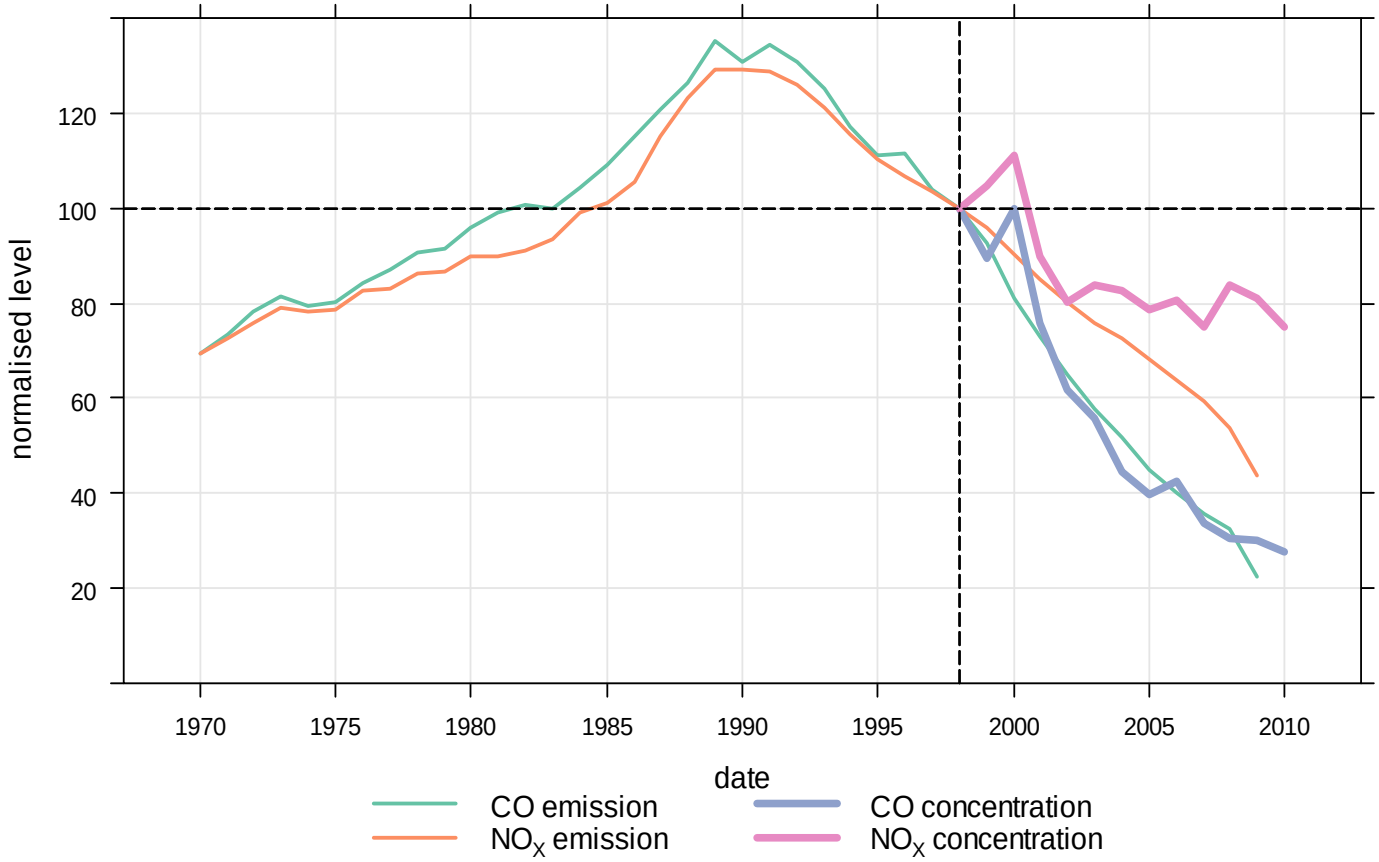

Trends in NO_x concentrations deviated from trends in emissions implied by the NAEI from the mid-2000s

AQEG Report: Linking Emission Inventories and Ambient Measurements

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- **AQEG recognised that**:
  - Emission inventories are a cornerstone of air quality management
  - There are no simple relationships between emissions and ambient concentrations
    - Contribution from multiple emission sources
    - Impact of meteorology and dispersion characteristics
    - Atmospheric transformations
  - No single accepted method for verifying inventories

- **<u>Aims of report:</u>**
  - Highlight the issues concerning comparison between emissions and ambient trends
  - Critically review commonly used inventory verification techniques
  - To provide recommendations to Defra on these issues and applicability of methods for pragmatic and routine use

AQEG Report: Linking Emission Inventories and Ambient Measurements

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- Background to emission inventories
  - Their many purposes and stakeholder interests

- Emission inventories in detail
  - Principles for compliance reporting
  - Spatial variability
  - Temporal variability
  - Chemical speciation
  - Strengths and weaknesses

AQEG Report: Linking Emission Inventories and Ambient Measurements

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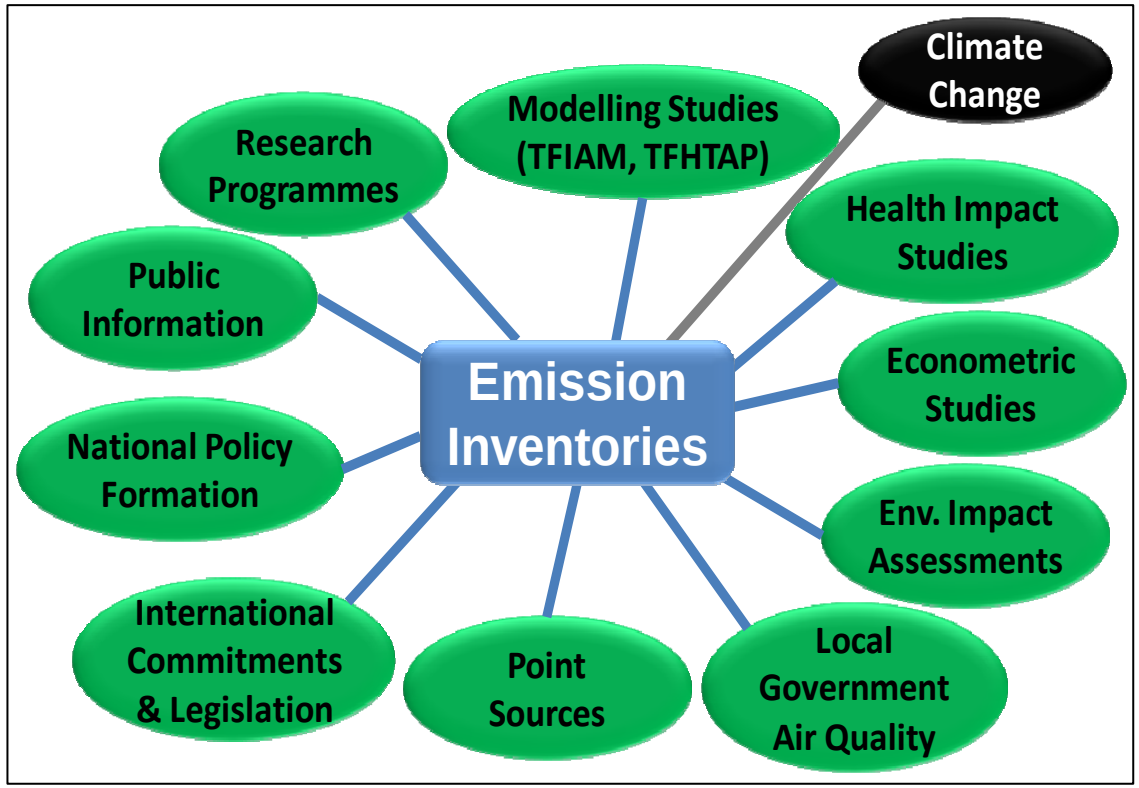
- Techniques for verifying inventories
  - Simple trends in emissions vs concentrations
  - Meteorological normalisation
  - Vehicle emission remote sensing
  - Flux and satellite-based measurements
  - NMVOC and PM speciation
  - Inverse modelling

- Their strengths and weaknesses and linkages with emission inventories

Emission Inventory Stakeholder Groups



- Major effort goes into statutory reporting of inventories to fulfil the UK's international commitments
  - Kyoto (GHG)
  - UNECE Gothenburg Protocol under CLRTAP (AQ)
  - EU National Emissions Ceilings Directive (AQ)
  - Tracking progress towards UK emission reduction targets

National Atmospheric Emissions Inventory

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- A consistent time-series in UK emissions by source sector and pollutant produced each year:
  - 1970 – current year (2011) – projections to 2030
- Coverage: UK, Crown Dependencies, Overseas Territories
- 101 air pollutants and greenhouse gases
  - Individual chemical species or groups of pollutants (e.g. NMVOCs)
- 541 individual sources in following general groups:

Energy generation	Commercial & residential combustion
Industrial combustion	Industrial processes
Extr./Distrib of Fossil Fuels	Transport
Agriculture	Waste

National Atmospheric Emissions Inventory

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- Spatial distribution of emissions at 1x1km resolution
- Temporal profiles in emissions for most sectors (month, day-of-week, hour)
- Limited chemical speciation
  - NMVOCs: profiles for 662 individual VOCs from 295 sources
  - NO_x = NO + NO_2
  - PM size
- Statistical uncertainty analysis of national inventory using Monte Carlo approach

NAEI Outputs: NO_x Emissions

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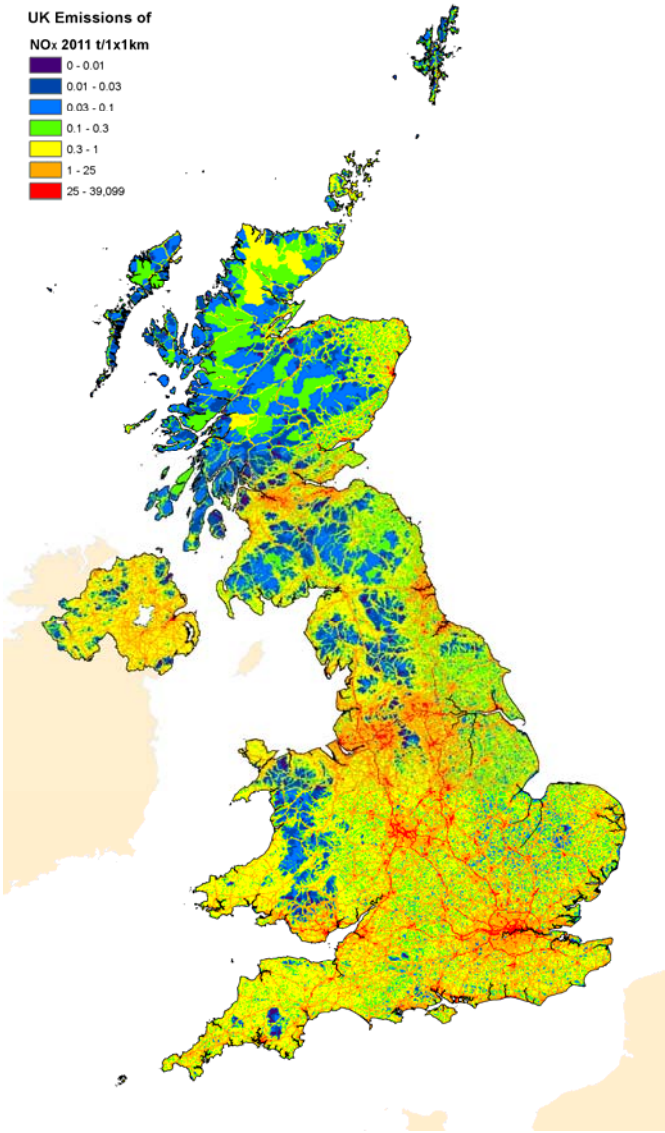

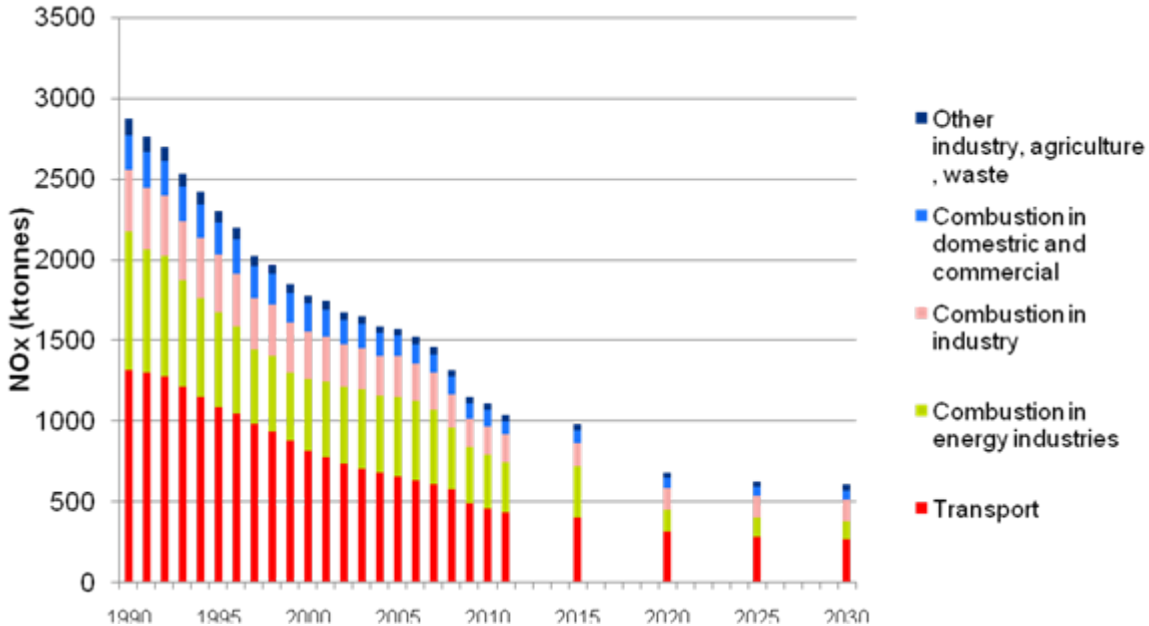

Limitations in the Current UK Inventory

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- Completeness - International reporting requirements dictate:
  - what sources are covered (e.g. biogenic VOCs and PM resuspension are not covered in national inventories
  - how emission sources are grouped
- Uncertainty in emission factors and activity data is high for some sources, especially diffuse and fugitive sources
- Spatially-resolved emissions
  - NAEI uses a large amount of 'top-down' treatment of local emissions; inventory methods not always robust at local level
  - Maps of emissions of previous years not usually updated
- Temporal profiles are updated only periodically
- Chemical speciation:
  - NMVOC speciation is updated only periodically
  - PM emissions are not chemically speciated
- Some inertia within inventory development process to introduce findings from research.

Simple Trends in Emissions and Concentrations

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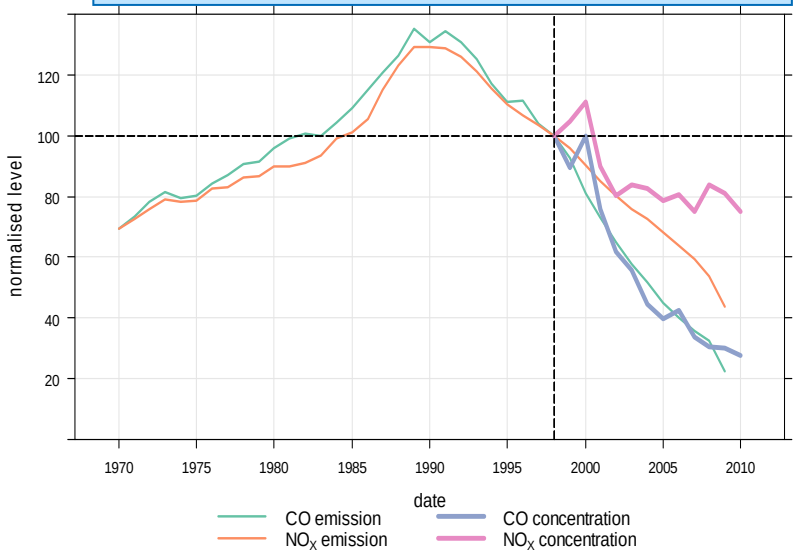
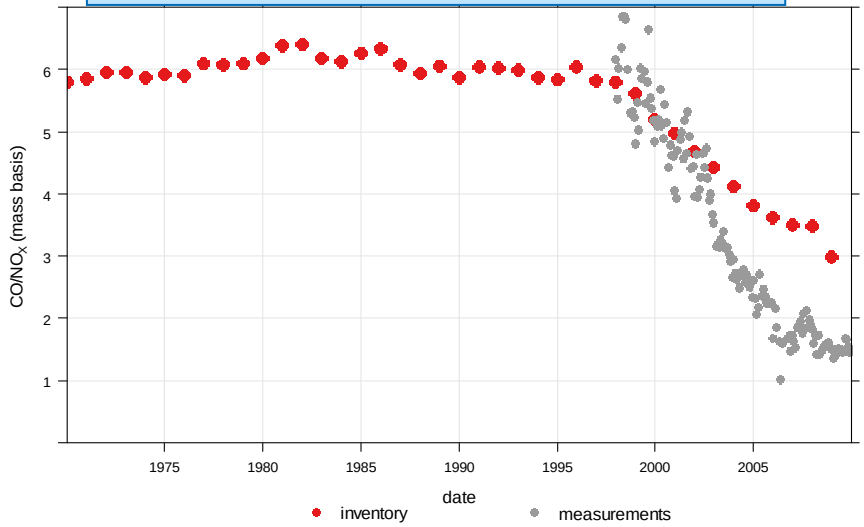
- Valuable for comparing long-term trends in emissions and concentrations
- Ratios of pollutants:
  - Ideal for comparing with inventories when emissions are from a common source
  - Reduced meteorological variability

Long-term trends in CO and NO_x concentrations at Marylebone Rd and UK emissions



Long-term trends in CO/NO_x concentrations at Marylebone Rd and UK emissions



Simple Trends in Emissions and Concentrations

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Technique	Advantages	Disadvantages	Inventory linkage
Comparing time series trends of emissions and concentrations	Straightforward, with most data readily available. Can provide a quick indication of gross mismatches. Better for time series over many years where meteorological effects are diminished.	Too simplistic for many situations. Difficult to isolate specific sources sufficiently well to allow for effective comparisons.	Can provide aggregate source-specific comparisons, e.g. urban road transport emissions. Best for longer-term trend comparisons over many years.
Comparing ambient pollutant ratios with emission inventory ratios	Simple to calculate. Removes much of the variation due to meteorology to produce clearer trends. Most useful for local sources.	Does not directly provide information on which pollutant is "wrong".	Similar to above.

- Relatively straightforward, should be carried out more often
- Helps show obvious inconsistencies between emissions and concentrations
- Can be too simplistic and does not usually indicate source of discrepancy

Meteorological Normalisation

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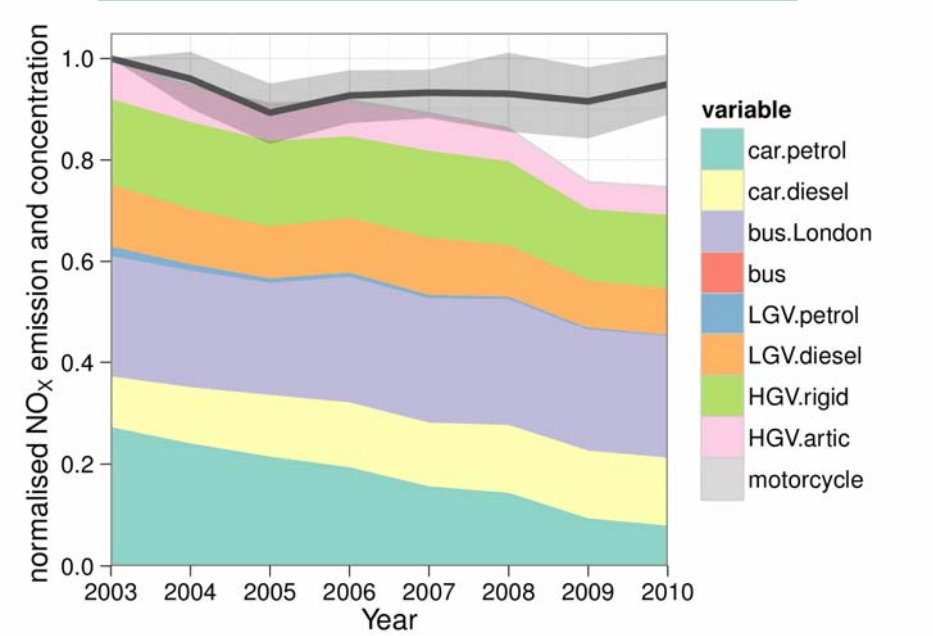
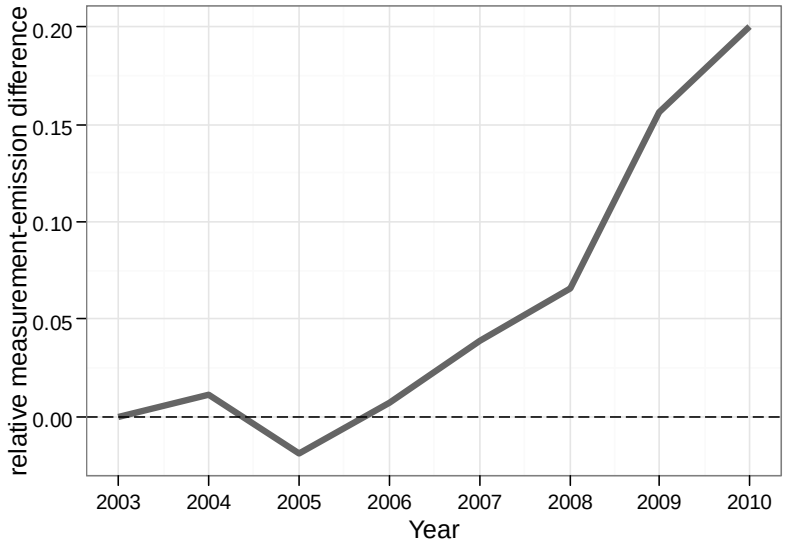
- Statistical model used to establish long-term trends in concentrations for fixed set of meteorological conditions: closer match to trends in source emissions

Mean change in UK vehicle emissions and normalised roadside increment NO_x concentrations at 13 roadside sites in London



Deviation in NO_x concentrations from emissions normalised to 2003



Meteorological Normalisation

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Technique	Advantages	Disadvantages	Inventory linkage
Meteorological normalisation ***Statistical analysis of ambient measurement data to remove the effect of meteorological variation***	Removes much of the influence of meteorology affecting ambient trends, leaving a trend that better reflects changes in source strength.	Can require sophisticated statistical models and care in developing robust models. Not carried out on a routine basis – but could be for key sites that are well characterised.	Best for comparing long-term trends in emissions for aggregate source types, e.g. road transport or total urban emissions. Has already been used for inventory comparisons.

- Helps pinpoint discrepancies between trends in emissions and concentrations more directly and more clearly than simply looking at trends in measured concentrations
- Requires sophisticated statistical models
- Still does not usually indicate precise source of discrepancy

Vehicle Emission Remote Sensing

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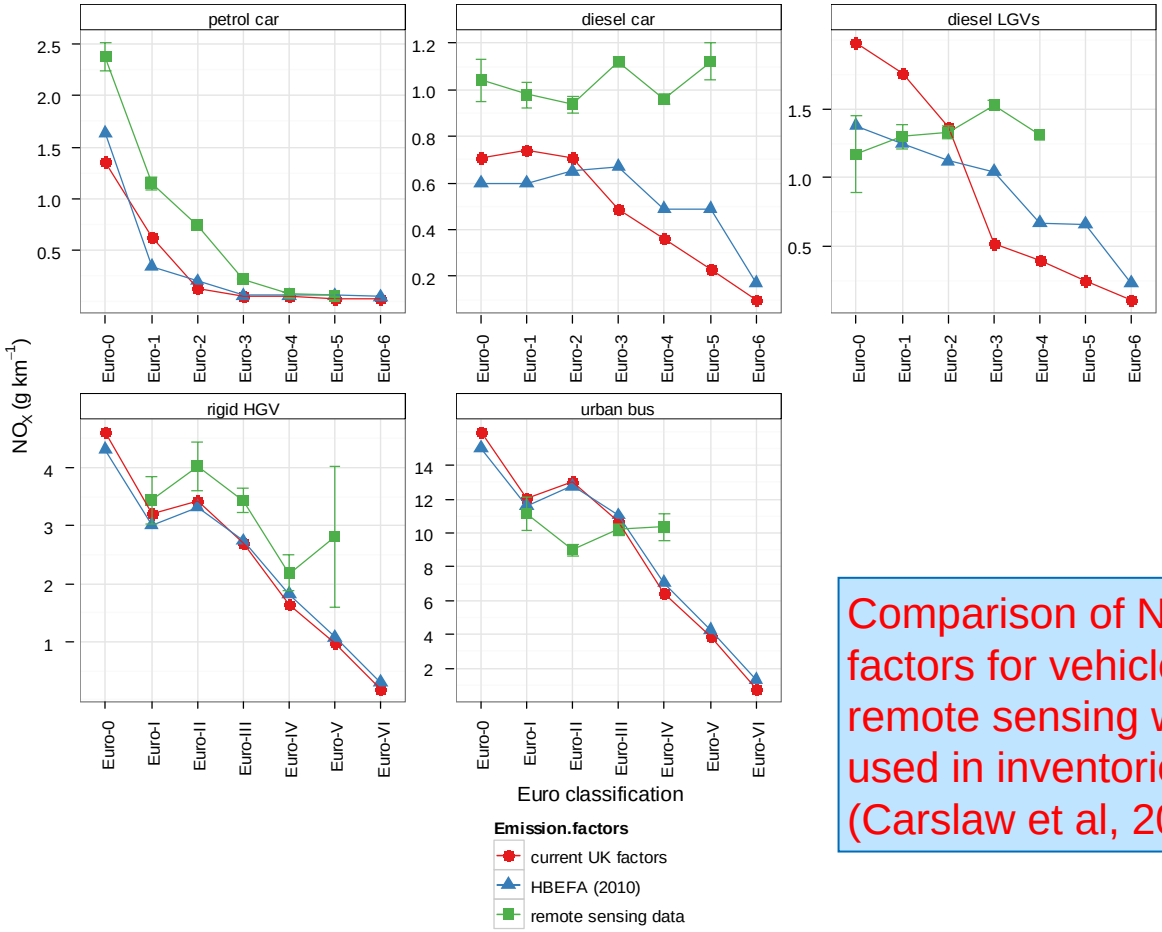
- Optical techniques to directly measure emissions in tailpipe plume of thousands of individual vehicles sampled in real-world conditions
- Direct link to emission factors of individual vehicle classes in inventory



Comparison of NO_x emission factors for vehicles derived from remote sensing with factors used in inventories (Carslaw et al, 2011)

Vehicle Emission Remote Sensing

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Technique	Advantages	Disadvantages	Inventory linkage
Vehicle emission remote sensing	Provides highly disaggregated emissions by vehicle class. Large sample sizes. Highly aligned with inventories.	Emissions are fuel-based (CO_2) ratios, not absolute estimates. Provides information on a subset of driving conditions (typically urban). Commercial systems limited by lack of NO_2. Long-term UK measurements not available.	Strong and direct linkage with emission inventories, e.g. can exactly match existing NAEI vehicle class categories, providing data for new emission factor estimates or verification of existing emission factors. Information on specific technologies, e.g. selective catalytic reduction, is potentially very useful. Has already been used for inventory comparisons.

- Large sample size - helps pinpoint emission factor inconsistencies with particular vehicle classes
- Provides closest match between “ambient” measurements and inventories
- Only one set of driving conditions

Flux and Satellite-Based Measurements

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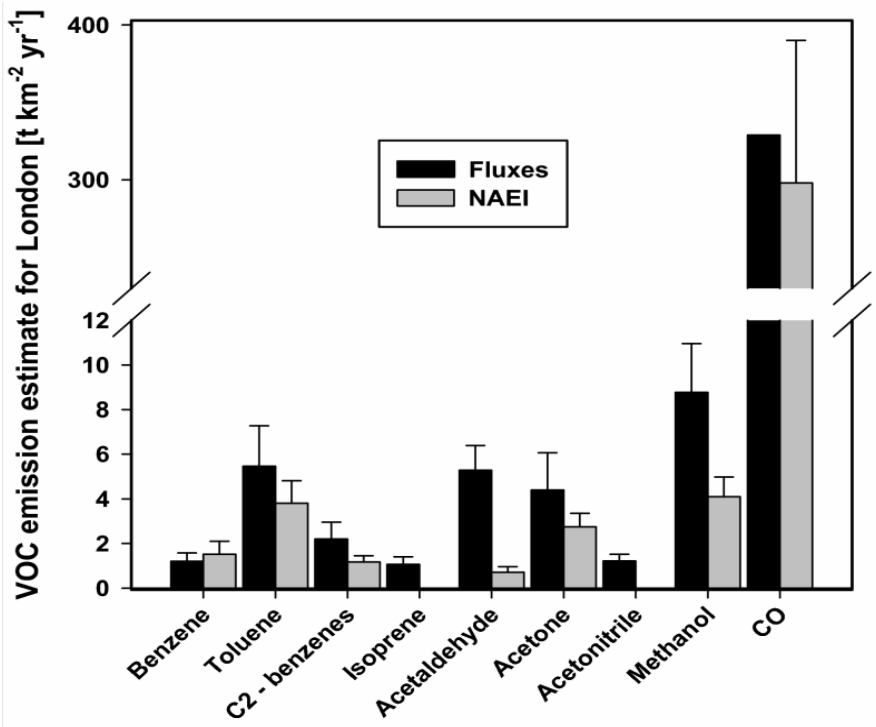
- Tower- and aircraft-based flux measurements
  - Integrated emission flux over hundreds metres to city-wide footprint
  - Gases and particles
  - Diurnal trends



Comparison between NAEI estimates of emissions and those derived from flux measurements over London (Langford et al, 2010)

Flux and Satellite-Based Measurements

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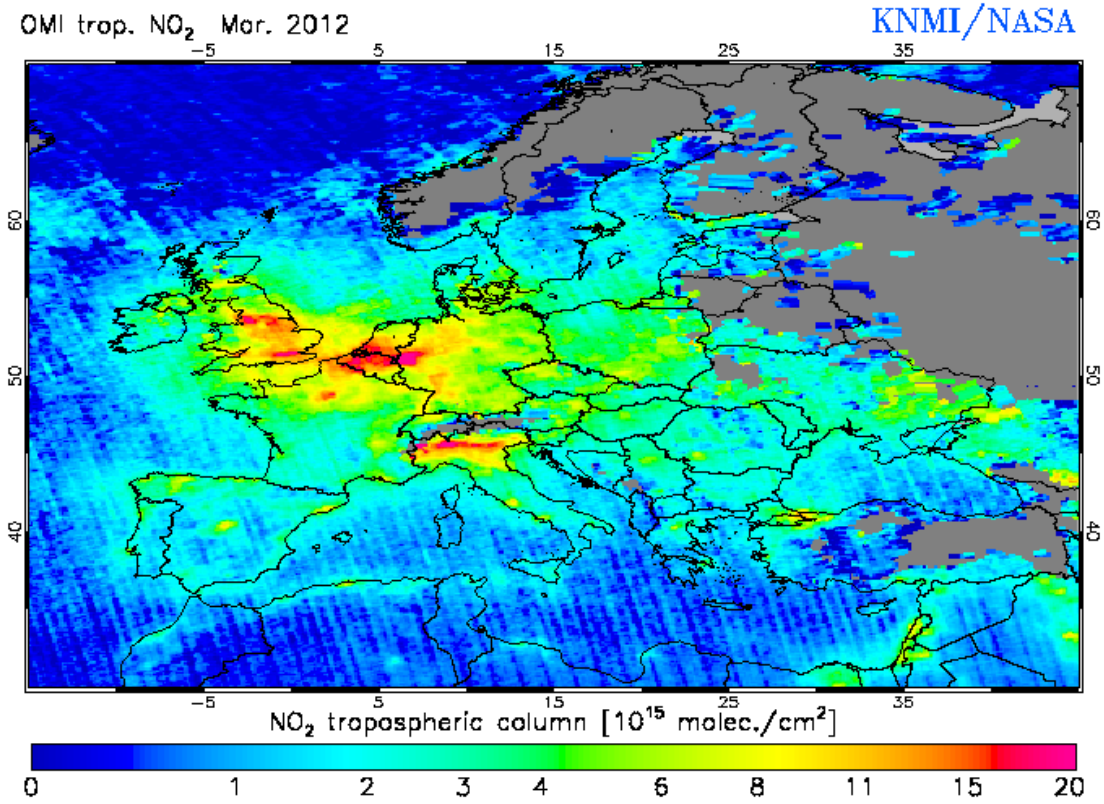
- Satellite-based methods – information on city, region, country-wide emissions



Monthly mean tropospheric NO_2 column from OMI satellite (Monks and Bierle, 2011)

Flux and Satellite-Based Measurements

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Technique	Advantages	Disadvantages	Inventory linkage
Flux measurements ***Use of fast response instruments to measure vertical fluxes of pollutants and meteorological variables in the atmosphere***	Provides a direct estimate of source strength over an area. Consistent with current inventories, i.e. aggregate emission estimate over an area. Useful for an increasing number of species, e.g. NO_x, CO, some speciated VOCs and particle metrics.	Measurements, their analysis and interpretation can be complex. Lack of longer-term measurements, although this is being addressed for some species.	Emission estimates can be compared against inventory totals over varying spatial areas. Has already been used for inventory comparisons.
Space-based remote sensing	Useful for large scale emission estimates, e.g. at a country level. An increasing number of species can be considered at increasingly higher resolutions.	Currently a limited range of species that can be measured and linked to inventories. Analysis and interpretation is complex.	Can provide country (or regional) scale emission estimates that can be compared with national emission totals. Has already been used for inventory comparisons.

- Useful for pinpointing accuracy in spatial and temporal representation of emission inventories at various resolution and spatial scales – city to national scale – and chemical speciation
- Emissions from natural sources not covered in inventories
- Measurements, analysis and interpretation can be complex

Inverse Modelling Techniques

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- Range of scales: street canyon to regional

- Examples:
  - Traffic emissions: fleet-averaged emission factors and diurnal trends
  - Traffic-induced resuspension
  - Ammonia emissions from agricultural sources – seasonal variation
  - Fugitive PM_{10} emissions from industrial site
  - Greenhouse gas emissions

- Uncertainties associated with inverse modelling

Inverse Modelling Techniques

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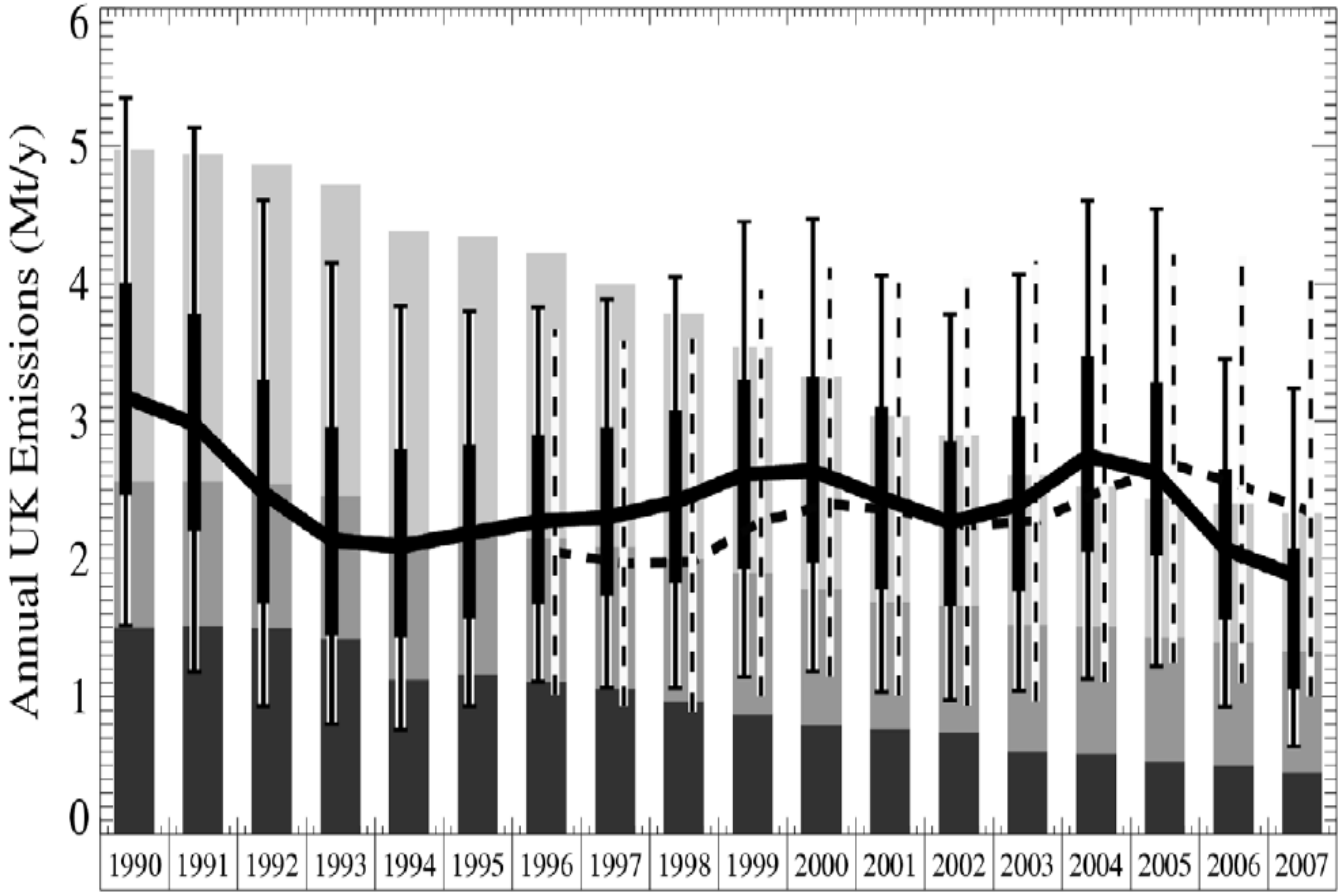

UK emission estimates for CH_4 based on NAME inversion (line) and UK GHG inventory. Cumulative columns from bottom: energy, industry (very small), agriculture, waste (Manning *et al.*, 2011).

Inverse Modelling Techniques

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Technique	Advantages	Disadvantages	Inventory linkage
Inverse modelling ***Where an air quality model is used to back calculate emission estimates using ambient measurements***	Can provide a direct, absolute estimate of emission source strength. Is applicable at small (street) to large (regional) scale. Can account for chemical reactions. Models and model methods are becoming increasingly sophisticated.	Can require sophisticated models. Care needed to rule out other causes of error, e.g. inadequate treatment of dispersion. Detection limit of measurements, e.g. CO on AURN. Some methods limited by number of measurement sites available.	Has already been used for inventory comparisons.

- Useful for point source emission applications
- Informing spatial, diurnal and seasonal variability
- Sources difficult for the inventory, where emission factors are poorly quantified
- Verifying long-term trends (GHGs)
- Important to be aware of model uncertainties
- Methods can be complex and computationally costly for routine use

Conclusions and Recommendations of Report

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- There is no universal approach for verifying emissions inventories, but a variety of techniques are available of varying complexity
- There is a large body of measurements data available, but these have been applied to inventory verification in a fairly *ad-hoc* manner
- Need to maximise use of outcomes from UK research programmes (e.g. NERC)
- Needs to be more flexibility in NAEI as a ‘test bed’ for new information from research, recognising its core function and need to meet a range of requirements
- Need for closer engagement between those involved in inventory development and measurement communities
- Needs to be a mechanism for feeding new information from verification activities into the inventory, co-ordinated by Defra and research councils
- Linkages between inventories and measurements should be considered by Defra when planning and commissioning new work

Thank you!

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