APPENDIX AVAILABLE ON REQUEST

Research Report 155

The Impact of the Congestion Charging Scheme on Air Quality in London

Part 1. Emissions Modeling and Analysis of Air Pollution Measurements

Frank Kelly et al.

Appendix F. Model Performance for the Years 2001 to 2004

Note: Appendices Available on the Web may appear in a different order than in the original Investigators' Report, and some remnants of their original names may appear in Table and Figure numbers. HEI has not changed the content of these documents, only the letter identifier.

Appendix F was originally Appendix C.

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APPENDIX F

Model Performance for the Years 2001 to 2004

Model performance for the years 2001 to 2004

The evaluation process of the Environmental Research Group's Air Pollution Tool Kit (ERG APT) was undertaken using the comprehensive measurement network within London (see Figure F1). This was split into 2 stages, first a calibration exercise to factor the background and roadside contributions to reflect measurements at approximately 30 NO_X sites throughout London. These factors were generated using a multiple regression approach. The next stage was a further test of model performance through the addition of another 20-30 sites. All comparisons with measurements were made using fully ratified data and assuming data capture rates in excess of 75%, for the year. The instruments used include: continuous chemiluminescence oxides of nitrogen (NO_X) analysers, Tapered Element Oscillating Microbalance (TEOM) particles with an aerodynamic diameter of 10 µm or smaller (PM_{10}) monitors, PM_{10} Beta Attenuation monitors (BAM) and PM_{10} gravimetric instruments (Klein Filter and Partisol). All PM_{10} concentrations from BAM and TEOM instruments are expressed as "gravimetric equivalent" in accordance with standard UK procedures (Bureau Veritas, 2006).

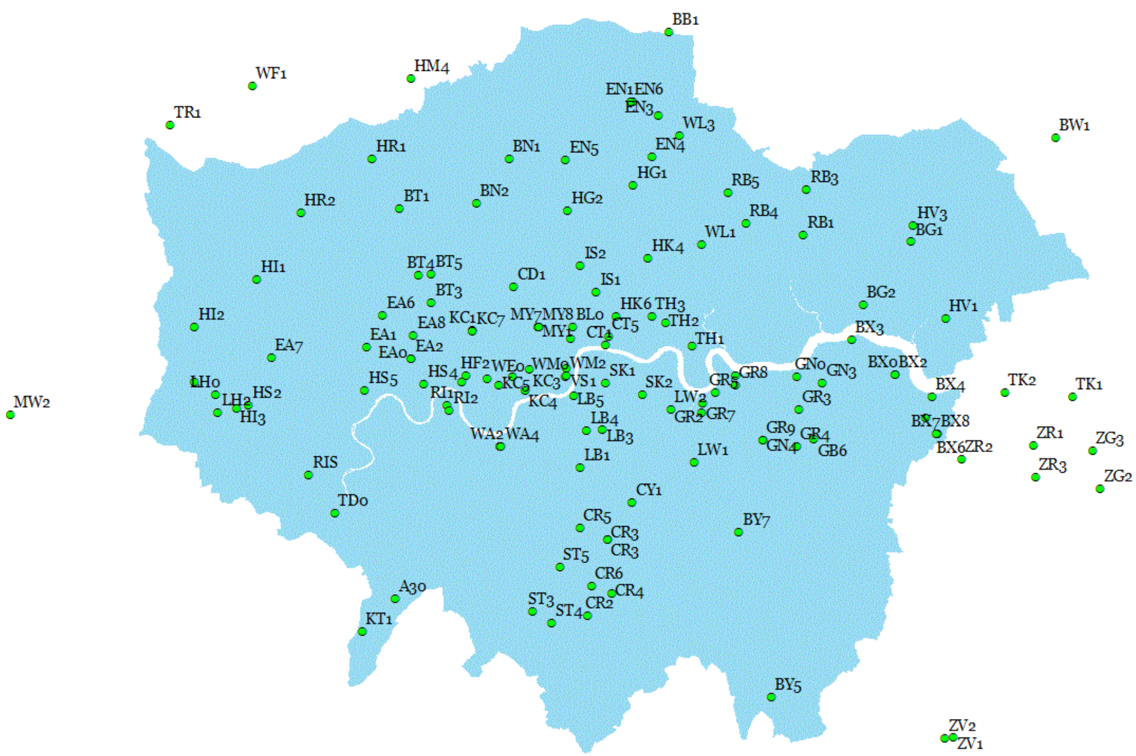


Figure F1. London Air pollution monitoring sites

From this analysis a number of model performance statistics have been used to test the ability of the APT to replicate measured data across London. These include the root mean square (RMS) error, the fractional bias (FB) and the residual frequency (predicted-measured), for each pollutant and year combination. These are summarised in Table F1. The measured vs modelled results are also shown in Figure F2 along with a 1:1 line and two lines showing ± 30% error, typically used when describing model performance (European Commission, 2005).

The measure of model performance recommended by the US EPA is the fractional bias screening test and whilst the use of RMS error is commonplace, the term fractional bias is less so. Therefore a short definition and interpretation is provided. The general expression for the FB is given by:

$$FB = 2\frac{(PR - OB)}{(PR + OB)}$$

where OB and PR refer to the averages of the observed (OB) and predicted (PR) concentrations.

The FB gives values that range between -2.0 (extreme under prediction) to +2.0 (extreme over prediction). Values of the FB that are equal to -0.67 are equivalent to under prediction by a factor of two, while values of the FB that are equal to +0.67 are equivalent to over prediction by a factor of two. Model predictions with a fractional bias of zero are relatively free from bias.

Table F1. Model and measurement results (2001 – 2004)

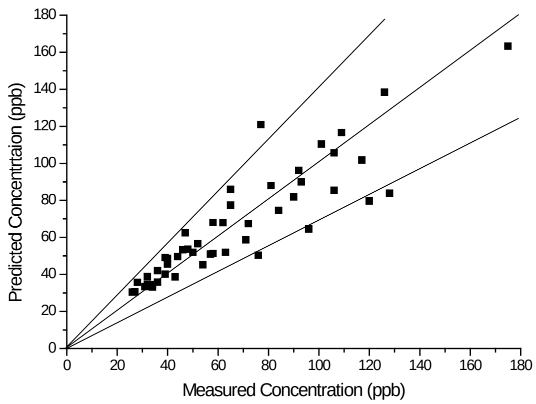
Pollutant	Year	Number of sites	Measured average & error[1]	Model average & ± RMS error	Model Fractional Bias
NO_X (ppb)	2001	50	66.7 ± 6.7	65.5 ± 15.1	0.005
NO_X (ppb)	2002	56	57.3 ± 5.7	57.2 ± 13.7	-0.002
NO_X (ppb)	2003	56	61.4 ± 6.1	58.6 ± 14.4	-0.030
NO_X (ppb)	2004	52	53.8 ± 5.4	54.4 ± 14.5	0.008
NO_2 (ppb)	2001	50	26.0 ± 2.6	28.4 ± 3.7	0.094
NO_2 (ppb)	2002	56	24.4 ± 2.4	26.2 ± 3.4	0.071
NO_2 (ppb)	2003	56	27.6 ± 2.8	27.7 ± 3.7	0.015
NO_2 (ppb)	2004	52	25.0 ± 2.5	26.3 ± 4.0	0.056
PM_{10} mean ($\mu g\ m^{-3}$)	2001	34	28.3± 1.38	28.8 ± 2.4	0.014
PM_{10} mean ($\mu g\ m^{-3}$)	2002	41	28.1 ± 1.38	28.5 ± 3.8	0.003
PM_{10} mean ($\mu g\ m^{-3}$)	2003	43	31.5 ± 1.38	30.5 ± 3.3	-0.037
PM_{10} mean ($\mu g\ m^{-3}$)	2004	49	27.2± 1.38	27.1 ± 5.3	-0.018

[1] Measurement error is assumed to be ± 10% (2 σ). These estimates are described in (ERG, 2002). PM10 measurement error (2 σ) assumed to be the same as daily estimates (Bureau Veritas, 2006)

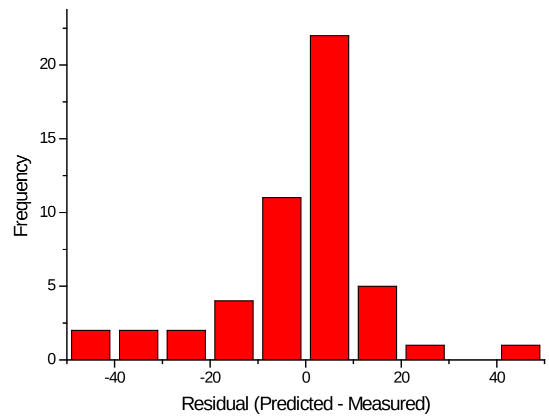
Results in Table F1, show a number of features of the model performance. The first was that across all sites and years the average modelled and measured NO_X agree to within 2.8 ppb. For NO_2 the maximum difference between model and measured averages was 2.4 ppb and for PM_{10} was within 1 $\mu g\ m^{-3}$. RMS error results also indicate good model performance and for annual mean NO_X, annual mean NO_2, and annual mean PM_{10} average values are: ± 25 %, ± 14 %, ± 13 % across all years.

The fractional bias statistics for the toolkit predictions across all years were never greater than ± 0.09 and it can therefore be concluded that the model is relatively free from bias.

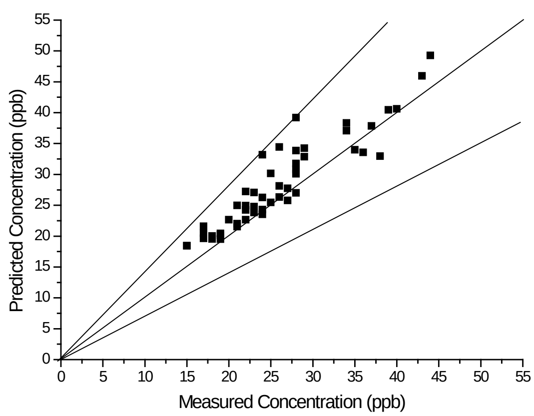
Nitrogen Oxides (NO_X) 2001 (ppb)



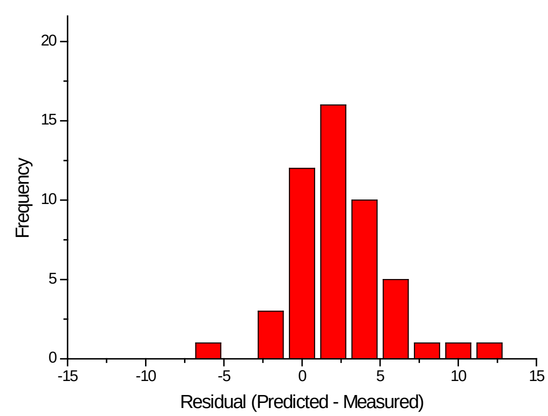
NO_X residuals (predicted-measured) (ppb)



Nitrogen Dioxide (NO_2) 2001 (ppb)

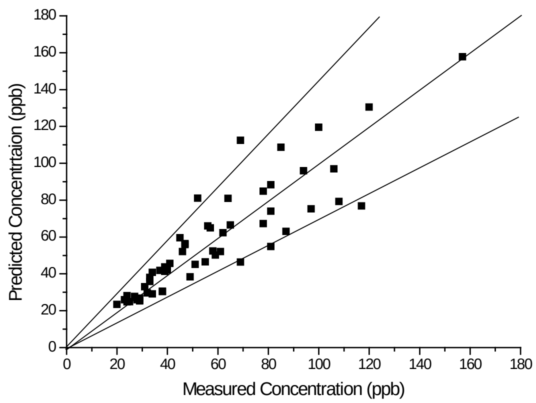


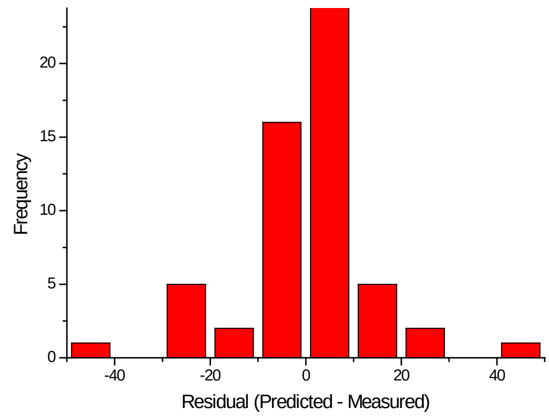
NO_2 residuals (predicted-measured) (ppb)



Nitrogen Oxides (NO_X) 2002 (ppb)

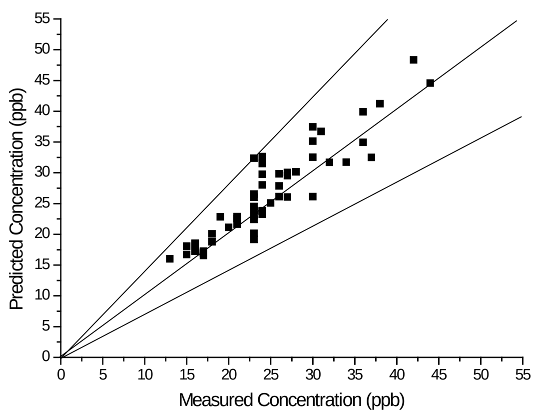
NO_X residuals (predicted-measured) (ppb)

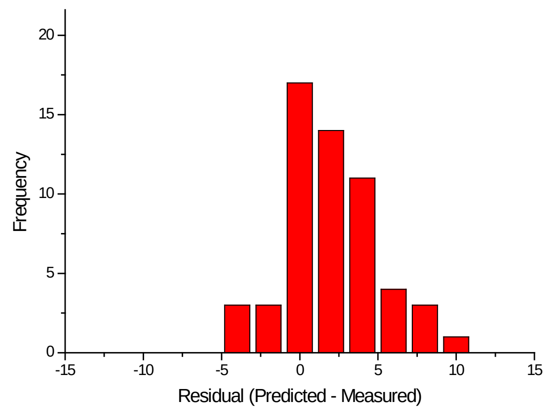




Nitrogen Dioxide (NO_2) 2002 (ppb)

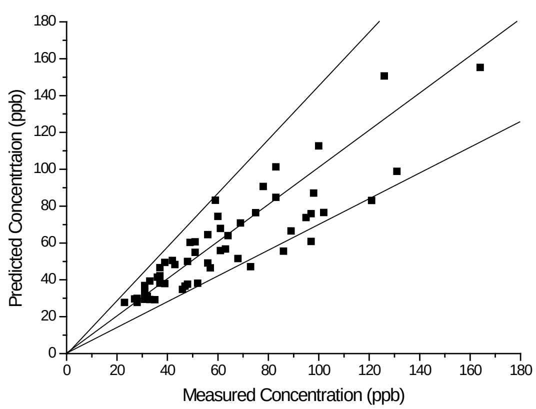
NO_2 residuals (predicted-measured) (ppb)

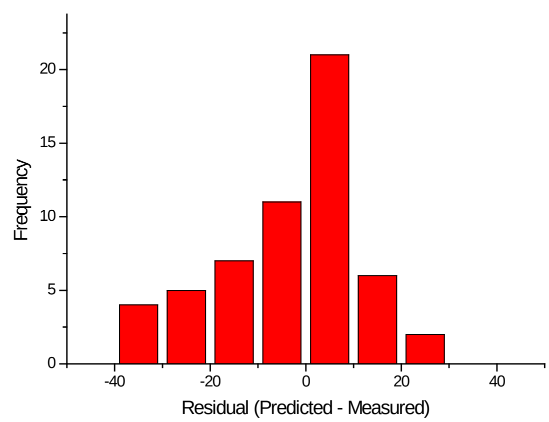




Nitrogen Oxides (NO_X) 2003 (ppb)

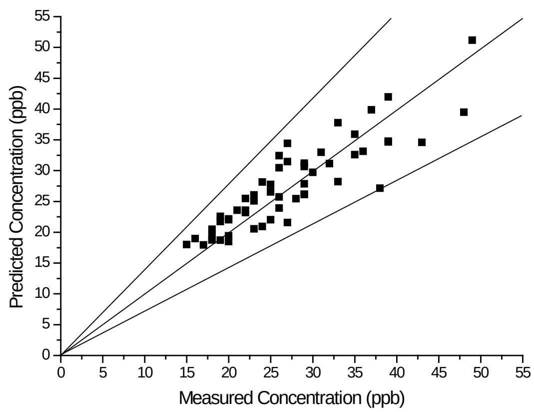
NO_X residuals (predicted-measured) (ppb)

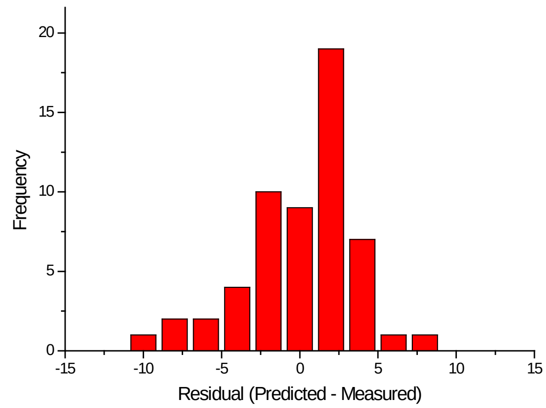




Nitrogen Dioxide (NO_2) 2003 (ppb)

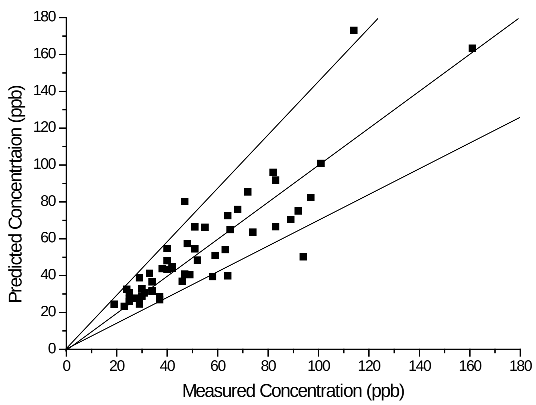
NO_2 residuals (predicted-measured) (ppb)

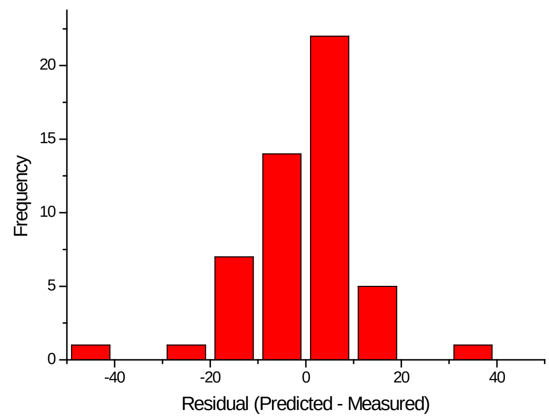




Nitrogen Oxides (NO_X) 2004 (ppb)

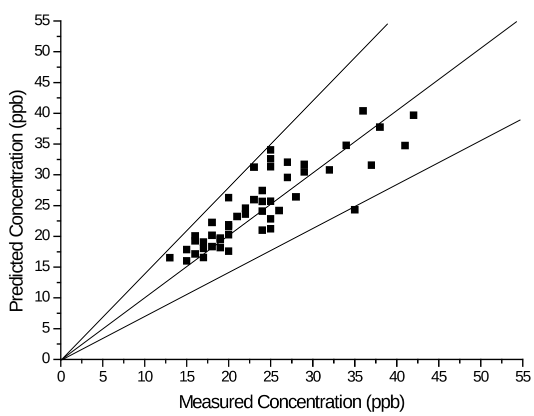
NO_X residuals (predicted-measured) (ppb)

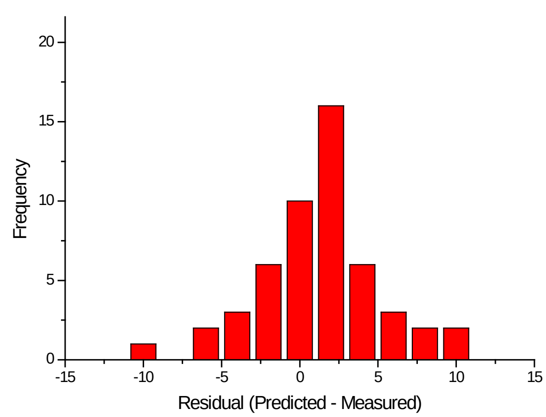




Nitrogen Dioxide (NO_2) 2004 (ppb)

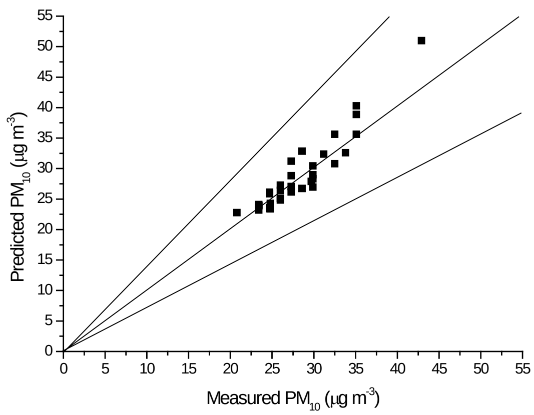
NO_2 residuals (predicted-measured) (ppb)

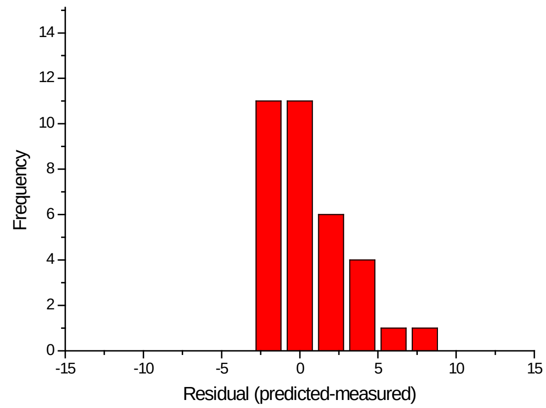




Annual Mean PM_{10} 2001 ($\mu g\ m^{-3}$)

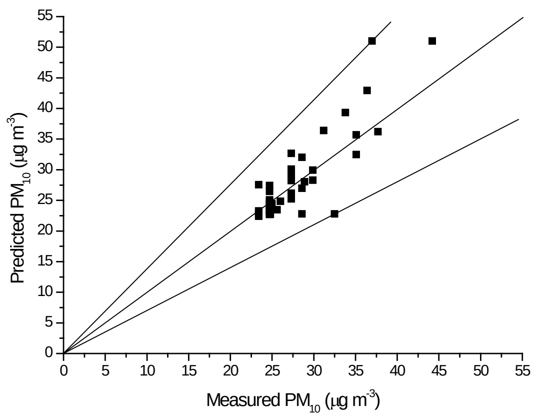
PM_{10} residuals (predicted-measured) ($\mu g\ m^{-3}$)

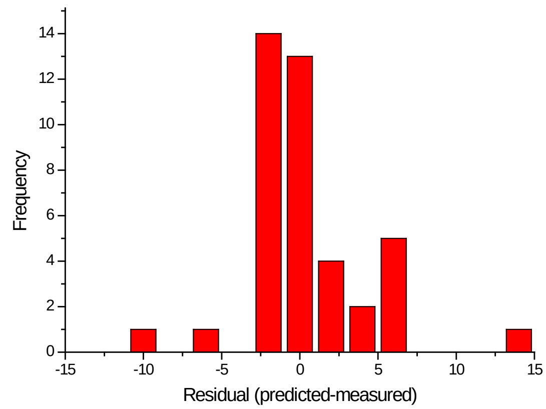




Annual Mean PM_{10} 2002 (μg m^{-3})

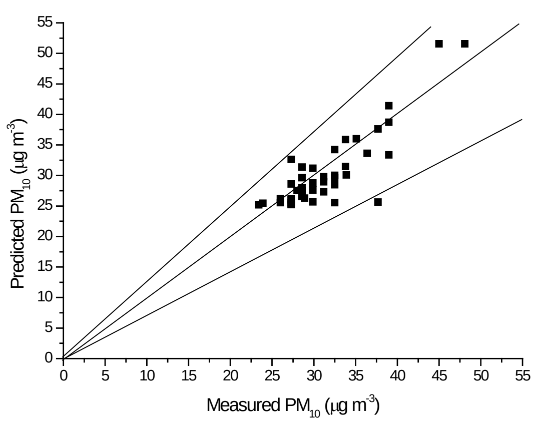
PM_{10} residuals (predicted-measured) (μg m^{-3})

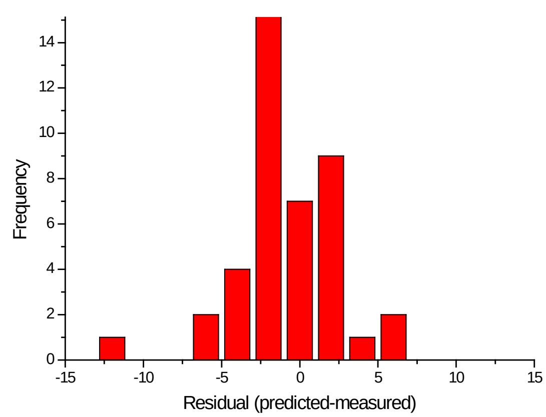




Annual Mean PM_{10} 2003 (μg m^{-3})

PM_{10} residuals (predicted-measured) (μg m^{-3})





Annual Mean PM_{10} 2004 (μg m^{-3})

PM_{10} residuals (predicted-measured) (μg m^{-3})

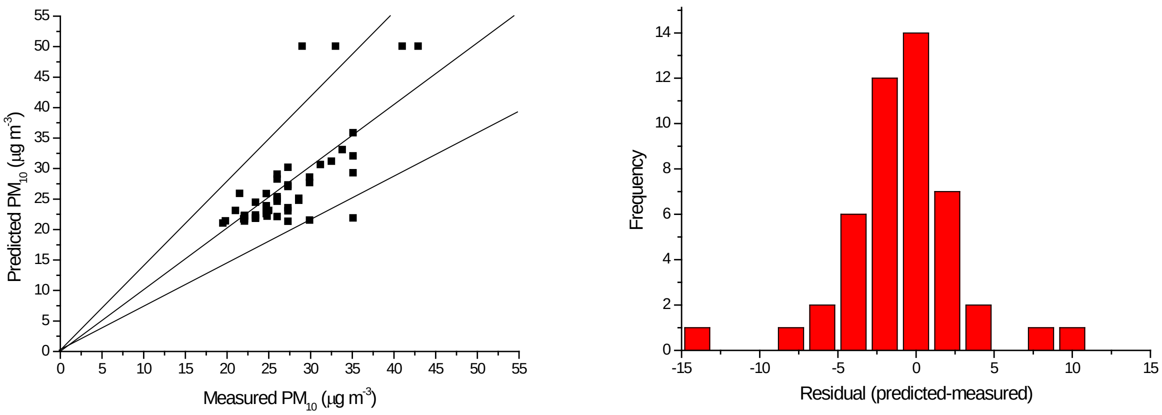


Figure F2. APT performance results for 2001-2004

Measured vs predicted scatter plots are provided in Figure F2 for each pollutant and for each year. Alongside each of the scatter plots is the associated residual plot. Whilst all model predictions show some scatter due to model uncertainty the residual (predicted – measured) frequencies should be normally distributed (or near normal). It is unlikely that with 40 – 60 points that a normal distribution is possible, however the model results do show that majority of residuals occur at or very close to zero and that the frequency of these drops away quickly. Overall therefore the toolkit model performance between the years 2001 to 2004 show good agreement with the measurements from the LAQN.

Air Pollution Model Uncertainty

A complete formal assessment of model uncertainty has not been undertaken. To provide a meaningful estimate of model uncertainty is a significant undertaking and one that is often limited to a Monte Carlo assessment using uncertainty distributions for parameters based upon expert judgement. This approach has been undertaken initially for the LAEI for road traffic and is representative of a network total emission for a base year. These results are described in appendix A. The uncertainty of other sources within the LAEI has not been undertaken.

As an alternative a number of sensitivity tests of the CCS changes could be undertaken to give the reader a feel for the uncertainty of any forecast change. However within the TfL literature only a central traffic change based upon vehicle km in 2002 and 2003 was published. Hence the model assessment described in chapter 1 has been limited to providing the reader with the contribution made by the individual vehicle and speed changes without the uncertainty of each change being accounted for.

The uncertainty of the model to estimate an annual mean surface of concentrations can be described in a more limited way using the RMS error summarised above.

References

Bureau Veritas. 2006. UK Equivalence Programme for Monitoring of Particulate Matter. Report for: Department for the Environment, Food and Rural Affairs, Welsh Assembly Government, Scottish Executive, Department of Environment for Northern Ireland. N^{o}: BV/AQ/AD202209/DH/2396.

European Commission. 2005. Proposal for a Directive of the European Parliament and the Council on ambient air quality and cleaner air for Europe. COM(2005) 183 final. Luxemburg: Commission of the European Communities.

Abbreviations

APT	Air Pollution Toolkit
BAM	Beta Attenuation monitors
ERG	Environmental Research Group
NO_x	oxides of nitrogen
PM_{10}	particles with an aerodynamic diameter of 10 µm or smaller
TEOM	Tapered Element Oscillating Microbalance
RMS	root mean square
SEM	Standard error of the mean