ADMS-AIRPORT: MODEL INTER-COMPARISIONS AND MODEL VALIDATION

David Carruthers, Christine McHugh, Stephanie Church, Mark Jackson,
Matt Williams, Catheryn Price and Chetan Lad

CERC, 3 King's Parade, Cambridge CB2 1SJ, UK

Abstract: The functionality of ADMS-Airport and details of its use in the Model Inter-comparison Study of the Project for the Sustainable Development of Heathrow Airport (PSDH) have previously been presented, Carruthers et al (2007). A distinguishing feature is the treatment of jet engine emissions as moving jet sources rather than averaging these emissions into volume sources as is the case in some other models. In this presentation two further studies are presented which each contribute to the overall evaluation of the model.
In the Heathrow study on adding capacity (third runway) further comparisons have been made between the measured NO_x, NO_2 and PM_{10} concentrations from the large number of automatic monitoring sites located in the neighbourhood of Heathrow Airport and the ADMS-Airport predictions. A range of tools is employed with which to present the comparisons including the BOOT validation toolkit and concentration wind roses.
In the CAEPport study a fictional but realistic airport was 'constructed' for a model inter-comparison study the purposes of which were (i) to determine that air quality airport models put forward for CAEP (ICAO's Committee on Environmental Aviation Protection) analysis are 'sufficiently robust, rigorous and transparent' for forthcoming CAEP analyses and (ii) to explain differences in the models. The study included consideration of both emissions and air pollution concentrations however the focus here will be on the modelled concentrations. Results for ADMS-Airport from this study will be presented along with those of the other participating models – EDMS, LASPORT and ALAQS.

Key words: *ADMS-Airport, CAEP, airport air quality, airport emissions.*

1. INTRODUCTION

The functionality of ADMS-Airport and model evaluation was presented in Carruthers et al (2007) and the PSDH Modelling Inter-comparison study report, CERC (2007). In this paper we present further evaluation of the model comprising model validation at Heathrow Airport in which model predictions are compared with data from continuous automatic monitoring sites in the vicinity of the Airport, and further evaluation of the model by assessment of its ability to be used for the requirements of modelling for CAEP local air quality assessments including comparisons with other candidate models. The Heathrow and CAEP studies are presented in the following two sections of this paper followed by some general conclusions.

2. HEATHROW AIRPORT STUDY

As part of an assessment of possible development of Heathrow Airport to allow for runway operation with 'mixed mode' or the operation of a third runway, the impacts on air quality of the proposals have been assessed using ADMS-Airport. The study consisted of a 2002 Base Case study and nine future scenarios. In this paper we will present some examples of validation of the model from the base case study. The full details of the emission inventory and model set-up for the study can be found in CERC (2007) however, to summarize: the emission data for the airport sources were supplied by AEA and traffic data were supplied by Hyder Consulting for the major roads; other inventory data were taken from the London Atmospheric Emissions Inventory (LAEI) for London, Greater London Authority (2005), and the National Atmospheric Emissions Inventory (NAEI) for the area to the west of Heathrow; meteorological data input to the model (standard hourly sequential data) were from the measuring site at the Airport whilst background concentration data for NOx, NO_2, PM_{10} and O_3 were obtained from the relevant upstream rural monitoring sites for the meteorological conditions prevailing.

Analysis of model predictions and comparison with monitoring data at Heathrow Airport

Table 1 compares monitored and modelled annual average NO_2 calculated from the hourly time series of concentrations, excluding those hours for which either modelled (162 hours) or monitored concentrations (up to 1195 hours) are missing. It is, therefore, a like-for-like comparison. The Table also shows the BOOT statistics[3]: standard deviation, correlation, fraction of modelled values within a factor of two of monitored values and the fractional bias of the hourly averages. If, for each hour, the model predicted concentrations that were identical to those monitored, the correlation and fraction of values within a factor of 2 would take their maximum values of 1, whilst the fractional bias would be 0.

Across the sites the mean correlation for hourly NO_2 is 0.68 and the fraction of values within a factor of 2 is 0.84; the mean fractional bias for NO_2 is +0.018. For NO_X, the mean correlation is 0.61, there is an average of 0.77 of modelled values within a factor of 2 of monitored values and the average fractional bias is +0.013 corresponding to a very small mean over-estimate by the model. Similar comparisons for PM_{10} showed similar model performance with annual average PM_{10} around Heathrow typically being about 25 $\mu g/m^3$.

Figure 1. shows the comparison of monitored and modelled annual averages of NO_X and NO_2 (calculated from hourly time series output) as scatter plots. The dotted lines show where the annual average is a factor of 2 of the monitored

value. Figure 2 shows “box and whisker” plots for each receptor for NO_X and NO_2. In the “box and whisker” plots percentiles of the ratio (modelled/monitored) are plotted. Table 1 and Figures 1 and 2 show that there is no significant trend to over or under-prediction by ADMS-Airport and that most hourly predictions are within a factor of 2 of the monitored (0.77 for NO_X and 0.84 for NO_2).

Table 1. Comparison of mean (μgm^{-3}), standard deviation (μgm^{-3}), correlation, fraction within a factor of 2 (FA2) and fractional bias for monitored and modelled NO_2 at automatic monitoring sites. Values are calculated from hourly time series output, excluding those hours for which either monitored and modelled values are not present. (*Excluding LHR10 that was acknowledged in the study to be an outlier.)

	Annual average		Standard deviation		Correlation (Monitored = 1)	FA2 (Monitored = 1)	Fractional bias (Monitored = 0)
	Monitored	Calculated	Monitored	Calculated			
LHR2	52.09	48.04	23.39	26.21	0.62	0.86	0.08
LHR5	43.41	36.31	20.99	23.34	0.63	0.80	0.18
LHR6	25.47	28.40	18.42	22.91	0.64	0.78	-0.11
LHR8	32.07	31.67	21.88	24.59	0.72	0.82	0.01
LHR10	39.28	58.65	24.04	40.56	0.57	0.71	-0.40
LHR11	35.93	35.16	21.05	25.75	0.71	0.85	0.02
LHR14	36.30	34.57	24.44	24.4	0.75	0.85	0.05
LHR15	32.43	34.15	18.58	23.63	0.66	0.85	-0.05
LHR16	45.26	47.18	22.47	29.44	0.67	0.87	-0.04
Average*	38.03	39.35	21.70	26.76	0.66	0.82	-0.029
Average	37.87	36.94	21.40	25.03	0.68	0.84	0.018

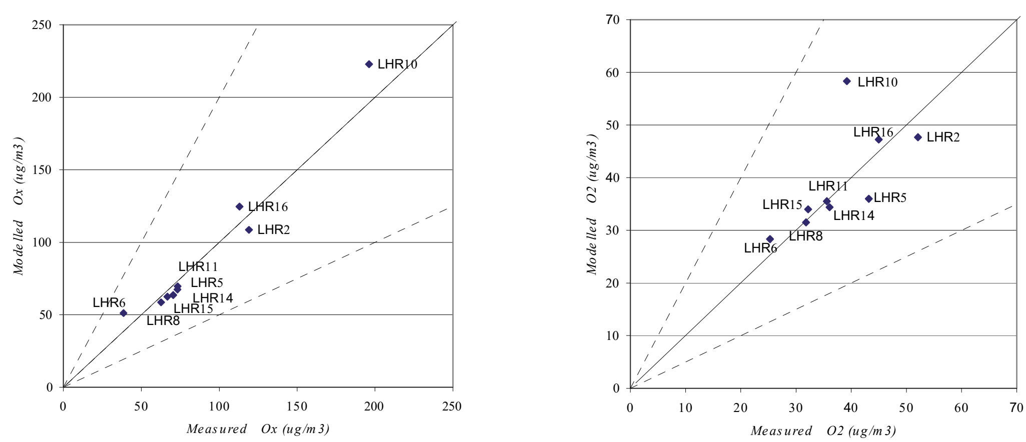

Figure 1. Comparison of monitored and modelled annual average NO_X (left) and NO_2 (right) concentration (μgm^{-3}) at the automatic monitoring sites. Dotted lines show where modelled values are a factor of 2 of monitored values.

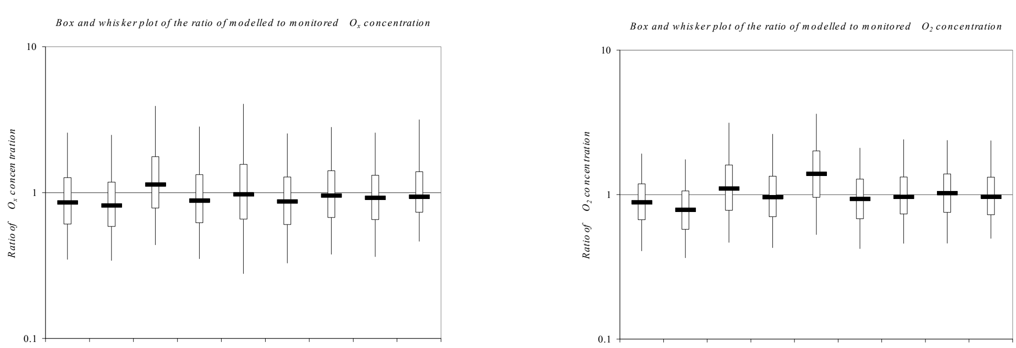

Figure 2. “Box and whisker” plots for the ratio of (modelled/monitored) hourly concentrations of NO_X (left) and NO_2 (right). The plots indicate the 95[th] percentile ratio (top), 75[th], 50[th] (middle bold), 25[th] and 5[th] (bottom).

At Heathrow airport there is a northern and a southern runway both of which have close to an east-west alignment. Allowing for take-offs to the east or the west there are four modes of runway operation referred to as 27R, 27L, 09R and 09L that describe,

- 27R take-off to the west from the northern runway.
- 27L take-off to the west from the southern runway.
- 09R take-off to the east from the southern runway.
- 09L take-off to the east from the northern runway.

The LHR2 monitoring site is just north of the eastern end of the northern runway, close to the starting position of aircraft taking off on 27R. LHR2 monitoring site records a strong signature from aircraft take-off when runway 27R is operational. When 27R is operational the wind is mostly, but not exclusively, from the south-west, west or north-west

Figure 3 shows the comparison of measured and modelled concentrations for hours when there are departures (D) on 27R and hours when there are arrivals (A) on 27R as a function of hour of the day. The diurnal variation as well as the difference between departures and arrivals on 27R is well-captured by ADMS-Airport.

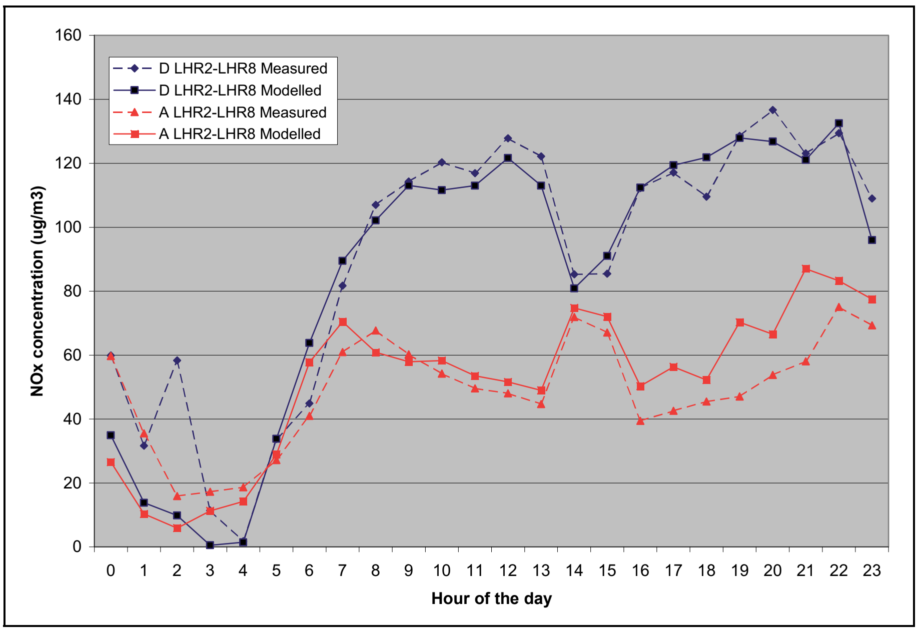

Figure 3. Comparison of modelled and monitored average NO_X concentration (μgm^{-3}), as a function of hour of the day, for LHR2 (minus the background concentration measured at site LHR8) for those hours when there are departures on 27R (blue) or arrivals on 27R (red). Monitored concentrations are shown by dashed lines and modelled concentrations by solid lines.

Polar plots

Polar plots, or, concentration wind roses, in which average concentrations are plotted as a function of wind speed and wind direction, have been used to gain insight into the behaviour of sources by indicating the location and nature of the important sources. They have proved particularly useful at LHR2 since monitored concentrations for airport sources (from the south west) tend to show large concentrations for large wind speeds, indicating that the aircraft sources are buoyant, in contrast to other ground level sources such as road traffic emissions that are less buoyant and show the highest concentrations for the lower wind speeds. Figure 4 shows polar plots for monitored and modelled NO_X concentrations at LHR2. The monitored and modelled plots compare well, the modelled plots capturing the main features. At LHR2 the maximum NO_X concentrations are due to north-easterly, low wind speed conditions that would indicate the influence of non-airport sources including the airport Perimeter Road.

3. CAEP CAPABILITES AND INTERCOMPARISION STUDY

The purpose of this study was to provide CAEP with a side-by-side comparison of the four local air quality currently being proposed for use for CAEP model assessment for assessing emissions and pollutant concentrations in the vicinity of airports. It should be noted that as CAEP requires overall assessment of impacts of many airports both emissions and concentrations need, as far as is possible, to be calculated from a generic approach applicable to all airports, thus, the use of the models may be quite different from that for a detailed local study such as that described above for Heathrow Airport. The approach adopted was to use a mock airport to exercise the candidate models regarding basic functionality of (i) emission source characterization and (ii) pollutant dispersion modelling according to a common set of input parameters, a shared set of meteorological data, and a uniform array of downwind receptors. The individual model results were compared against each other to understand the range of potential answers provided to CAEP during the CAEP/8 Work Programme. Emission sources considered were as follows:

1. Aircraft main engines (LTO cycle and start-up)
2. Auxiliary power units (APU)
3. Ground Support Equipment (GSE)
4. Landside surface transportation and parking facilities
5. Stationary sources
6. Fuel storage and handling activities
7. Training fires

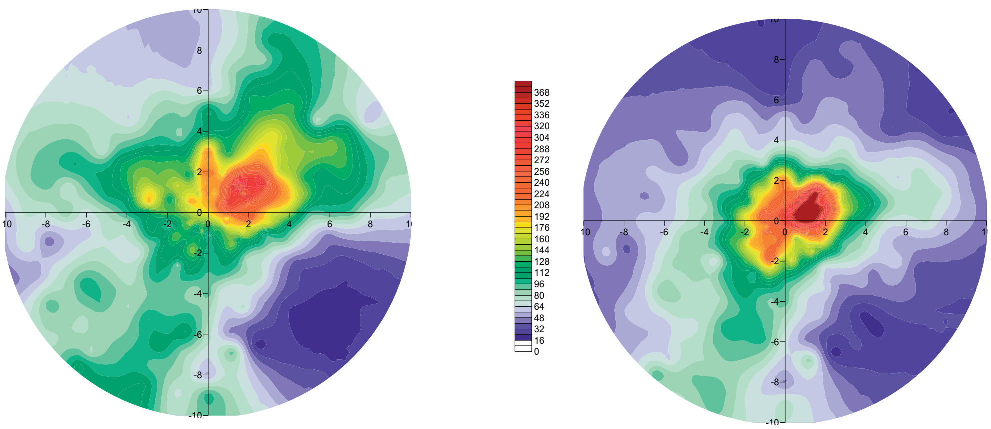

Figure 4. Monitored (left) and modelled (right) NO_X concentrations at LHR2 (μgm^{-3}), averaged per wind direction-wind speed category. Categories with fewer than 4 hourly concentrations are excluded.

For a full discussion the reader is referred to CAEP (2008). In this paper we shall present one set of concentration modelling results as illustration of the approach adopted and the differences. The figure shows NOx concentrations for all sources in the neighbourhood of the airport for each of ADMS-Airport, AEDT/EDMS, ALAQS and LASPORT. We have not marked which model produced which set of contours, as CAEP's purpose was to illustrate differences/similarities in model performance, rather than use this study to determine absolute accuracy, quite a different requirement than that of the validation regarding Heathrow Airport.

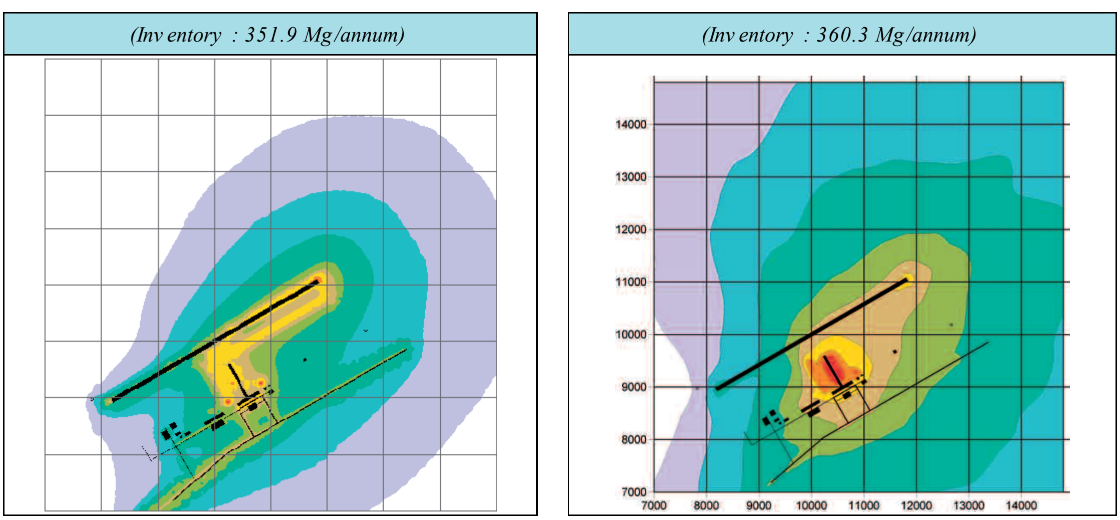

Figure 5: Annual mean NOx concentration contours (μgm^{-3}) from all sources, calculated by four different models.

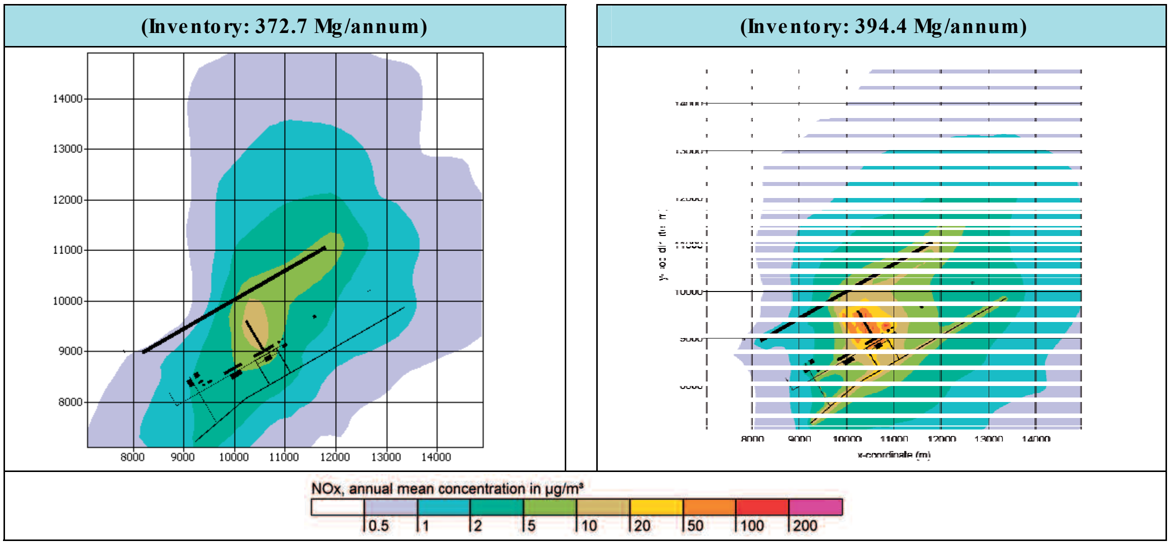

Figure 5 (cont): Annual mean NOx concentration contours (µgm^{-3}) from all sources, calculated by four different models.

Note although emissions input to each model were different, as the models used different emissions calculators, total emissions are marked on the figures so, taking these into account, the extent to which the dispersion model affects the concentration values and their spatial distribution can broadly be determined and significant differences between the models are apparent.

4. CONCLUSIONS

Modelling air quality around airports is currently a matter of great interest both to those assessing local developments and to international bodies such as CAEP who require tools for source apportionment and assessment of relative impacts. This requires models to be "fit for purpose" as judged against different criteria. ADMS-Airport has recently been involved in model inter-comparisons and assessments for both purposes.

In assessing a model for use studying local impacts against EU air quality standards it is the comparison with monitored data that is important and this was carried out using statistical measures and the BOOT validation toolkit. Polar plots or concentration wind roses were used to gain insight into the relative importance of different sources and different physical processes such as plume rise and hence assess whether the model is getting the right answers for the right reason.

The CAEPport exercise was not concerned about comparison with monitored values or air quality standards. It used a fictional but realistic airport to assess model performance in terms of ability to use input data in the given format, ability to calculate emissions and ability to output air quality concentrations in a given format. The emissions and concentrations output were then compared between models and for different source groups. The exercise was thus able to provide insight as to the fitness for purpose of models put forward for use in the CAEP/8 Work Programme.

REFERENCES

CAEP, 2008: LAQ Candidate models capabilities and inter-comparison study Annexe. MODFT (Modelling & Databases Task Force) CAEP/8 4th meeting, California, Feb 2008.

Carruthers, D. J., C. McHugh, M. Jackson and K. Johnson, 2007: Developments in ADMS-Airport to take account of near-field dispersion and applications to Heathrow Airport. *Proceedings of the 11th Harmonisation Conference.* http://www.harmo.org/Conferences/Proceedings/_Cambridge/publishedSections/Op346-351.pdf

CERC, 2007: Air Quality Studies for Heathrow: Base Case, Segregated Mode, Mixed Mode and Third Runway Scenarios modelled using ADMS-Airport. DfT Publications 78APD02904CERC and http://www.dft.gov.uk/consultations/closed/heathrowconsultation/technicalreports/airquality.pdf

Greater London Authority, (2005): London Atmospheric Emissions Inventory 2002 (LAEI 2002), julius.mattai@london.gov.uk