

# ADMS 4 Flat Terrain Validation Kincaid, Indianapolis and Prairie Grass

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## 1 Introduction

This document presents a summary of ADMS model results compared against three well known field data sets: Prairie Grass, Kincaid and Indianapolis. Results are also presented for two U.S. models: ISCST and AERMOD.

ISCST is the United States Environmental Protection Agency model. It is a so-called ‘old generation’ model, similar to the UK R-91 model, based on the 1970’s description of boundary layer physics. Such models use several discrete categories to describe the stability of the atmospheric boundary layer. Gaussian distributions are assumed for the concentration in the crosswind vertical and horizontal directions in all stabilities.

ADMS has been developed in the UK and is widely used internationally by industry, consultants and regulatory bodies. AERMOD is the U.S. regulatory model. ADMS and AERMOD are both described as ‘new generation’ models. These models describe the state of the atmospheric boundary using two parameters: boundary layer depth and Monin-Obukhov length. The vertical concentration distribution is Gaussian in neutral and stable atmospheres but is a skewed in Gaussian in convective conditions. As with the ‘old generation’ models a Gaussian distribution is assumed in the crosswind horizontal direction for all stabilities.

ADMS has been extensively validated during its development against field data sets and wind tunnel data sets. Studies have covered a range of meteorological conditions (Carruthers *et al.*, 1994 [3]; Carruthers *et al.*, 1996 [4]; Carruthers *et al.*, 1998 [6]), including a comparison against LIDAR data undertaken for the UK Environment Agency with the emphasis on convective conditions. Advanced model features have also been tested, particularly the buildings module (Carruthers, McKeown *et al.*, 1999 [2]).

The three data sets used here are drawn from those that are openly available and have been generally accepted as containing enough measurements and of sufficient quality for meaningful validation. A series of workshops have been held over the last few years on ‘Harmonisation of Atmospheric Dispersion Modelling for Regulatory Purposes’. At these ‘harmonisation workshops’ a Model Validation Kit (MVK) has been developed to evaluate models. It includes the Kincaid and Indianapolis data sets and the BOOT statistical package (Olesen, 1994 [11]; Olesen, 1998 [13]; Hanna *et al.*, 1997 [8]). The BOOT statistical package is described further in Section 2.1. The Prairie Grass data set is derived from the files that have been used for the ASTM model evaluation (D6589) [1], with additional input data from United States Environmental Protection Agency Website [16].

ADMS model runs have been carried out by CERC. This document presents the results of

ADMS 4.1.0.0 (hereafter referred to as ADMS 4.1) and ADMS 4.2.2.0 (hereafter referred to as ADMS 4.2). US model runs (AERMOD, ISCST3) have been provided by the US EPA (Peters, 1998 [15]). The model referred to as AERMOD in this document is AERMOD 98022 (note that this is not the latest AERMOD version). The meteorological preprocessor is AERMET 98022.

Section 2 presents the method of analysis. Section 3 presents and discussed the results for each of the field experiments: Kincaid (3.2), Indianapolis (3.3) and Prairie Grass (3.4). Section 4 summarises the analysis.

## 2 Method of analysis

### 2.1 BOOT statistical analysis – Arcwise maximum concentration

The BOOT statistical package is distributed with the MVK (Olesen, 1994 [11] and 1997 [12]). Model predictions of ground level centreline concentrations are compared against the maximum observed concentrations for each arc, which will be referred to as centreline concentrations throughout this document. The BOOT package calculates the average and standard deviation, along with several statistical parameters: bias, normalised mean square error, correlation, proportion of values within a factor 2, fractional bias and its standard deviation.

All analyses using the BOOT statistical package are based solely on the maximum observed concentrations for each arc. Concentrations measured at other locations along each arc that are less than the maximum value, are discarded once the maximum has been located.

The maximum observed value is subject to significant inherent uncertainty due to turbulence. This means that if an experiment were repeated under identical conditions, the maximum concentration measured would be different each time. The ensemble mean predicted by the models, which represents the average over a large number of repetitions, is the value compared here with measurements. Therefore, even a ‘perfect’ ensemble average model would not match prediction with the individual observations.

## 3 Validation data sets

### 3.1 Quality indicators

The measured data have been collected on arcs downwind of a source. A quality indicator has been assigned to each hour’s measurements according to how well the maximum concentration is defined, as shown in **Table 1**. It has been recommended that data with a quality indicator of 2 or 3 should be used when analysing model behaviour. This has been followed for the Kincaid and Indianapolis data sets. There were too few quality 2 and 3 data points to do this for Prairie Grass, so all points have been included.

If a model is compared with the quality 2 and quality 3 data separately, the results, if displayed on a quantile–quantile plot, should show the quality 2 line lying above the quality 3 line as a lower maximum concentration will be observed. Note that the quantile–quantile plots

presented in this document are linear; care should be exercised when comparing these plots with similar ones presented with logarithmic axes.

Quality	Meaning
0	This value should clearly be disregarded.
1	This value is most probably not the maximum value.
2	A maximum is identified but the true value may be different e.g. the concentration pattern is irregular, there are only 2 or 3 monitors impacted, the plume is near the edge of the arc. Note: arcs where the observed maximum is essentially zero but with evidence that a plume is present aloft are included in this group.
3	A relatively well-defined maximum is observed, which is continuous in space, is away from the edge of the monitoring arc, and is not irregular or isolated.

**Table 1** – Quality indicators.

### 3.2 Kincaid

#### Experiment

The Kincaid data set contains 171 hours of tracer experiments, which were performed at the Kincaid power plant in Illinois, U.S.A. during 1980-81 (**Figure 1**<sup>1</sup>). The power plant is surrounded by flat farmland with some lakes. The roughness length is approximately 10 cm. During the experiments, SF<sub>6</sub> was released from a stack 187-m tall with a 9-m diameter.

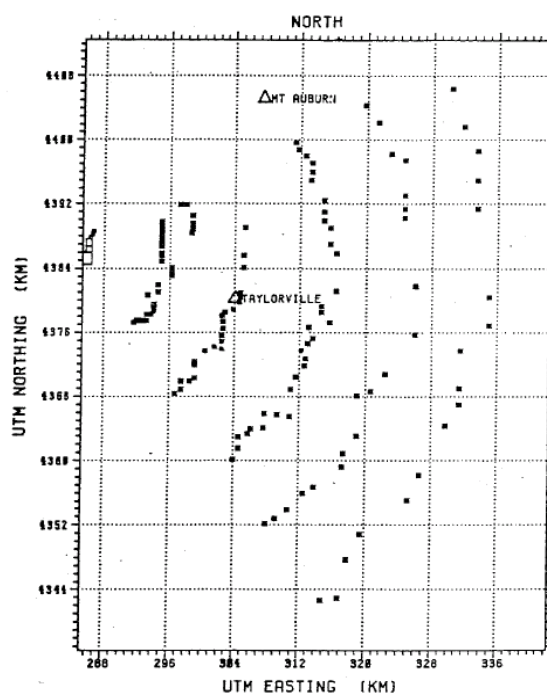
Meteorological data were composed of nearby National Weather Service data, and of temperature, wind speed and wind direction from an instrumented tower (2, 10, 50 and 100 m levels). The meteorological conditions ranged from neutral to convective.

In the ADMS and AERMOD model runs shown here, the boundary layer height was calculated using the model's own meteorological pre-processor.

The emission rate was set to 1 g/s, indicating that the observed concentrations supplied have been normalised by the emission rate.

#### Statistical analysis

Results are summarised in **Table 2** and **Figures 2** to **4** for hours when the observed data were of qualities 2 and 3. **Table 3**, **Figures 5** and **6** correspond to results for data of quality 3 only.



**Figure 1** – Example of Kincaid SF<sub>6</sub> tracer sampling array for neutral conditions.

<sup>1</sup> Figure and caption have been taken directly from the document [14].

From the BOOT statistics, ADMS is shown to give significantly better performance than other models in terms of mean, standard deviation, fraction within a factor of 2 and correlation.

AERMOD shows significant underestimates with the predicted mean (50 % of the observed) and standard deviation (61 % of the observed). ISCST3 also shows significant under-predictions.

Considering the quality 3 data only (**Table 3**), ADMS again is near to the observed mean and standard deviation, the number within a factor of 2 is approximately 70 %. AERMOD under-predicts the mean and standard deviation by even more than with the quality 2 and 3 data together.

A model would be expected to perform better compared with quality 3 data than quality 2 and quality 3 data as the maximum concentration reported is more likely to be near to the true maximum value. ISCST3 performs poorly for both data sets.

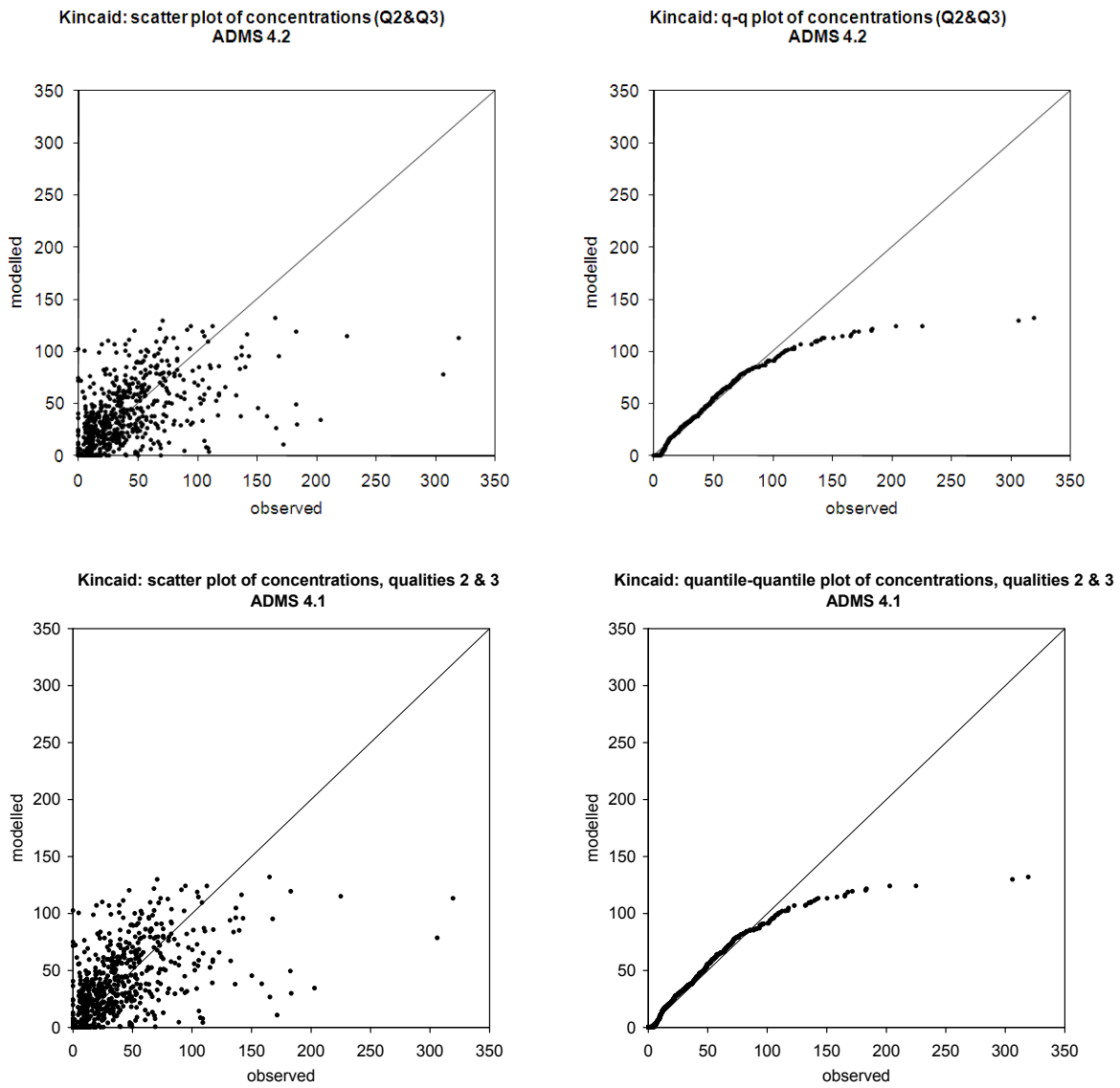
There is negligible difference in concentrations predicted by ADMS 4.2 and ADMS 4.1.

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
observed	41.0	39.3	0.0	0.0	1.00	1.00	0.00	0.00
ADMS 4.2	40.4	31.1	0.6	0.8	0.50	0.59	0.01	0.23
ADMS 4.1	40.4	31.1	0.6	0.8	0.50	0.59	0.01	0.23
AERMOD	20.3	24.1	20.7	2.3	0.35	0.33	0.68	0.48
ISCST3	23.1	53.3	17.9	3.8	0.26	0.26	0.56	-0.30

**Table 2** – BOOT statistics: Kincaid, qualities 2&3. Units for mean, sigma and bias: ns/m<sup>3</sup>.

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
observed	54.3	40.3	0.0	0.0	1.00	1.00	0.00	0.00
ADMS 4.2	48.5	31.5	5.9	0.6	0.45	0.68	0.11	0.24
ADMS 4.1	48.5	31.5	5.9	0.6	0.45	0.68	0.11	0.24
AERMOD	21.8	21.8	32.6	2.1	0.40	0.29	0.86	0.59
ISCST3	30.0	60.0	24.3	2.8	0.26	0.28	0.58	-0.39

**Table 3** – BOOT statistics: Kincaid, quality 3 only. Units for mean, sigma and bias: ns/m<sup>3</sup>.



**Figure 2** – Kincaid experiment, ADMS, quality 2 & 3 data (units are ns/m<sup>3</sup>).

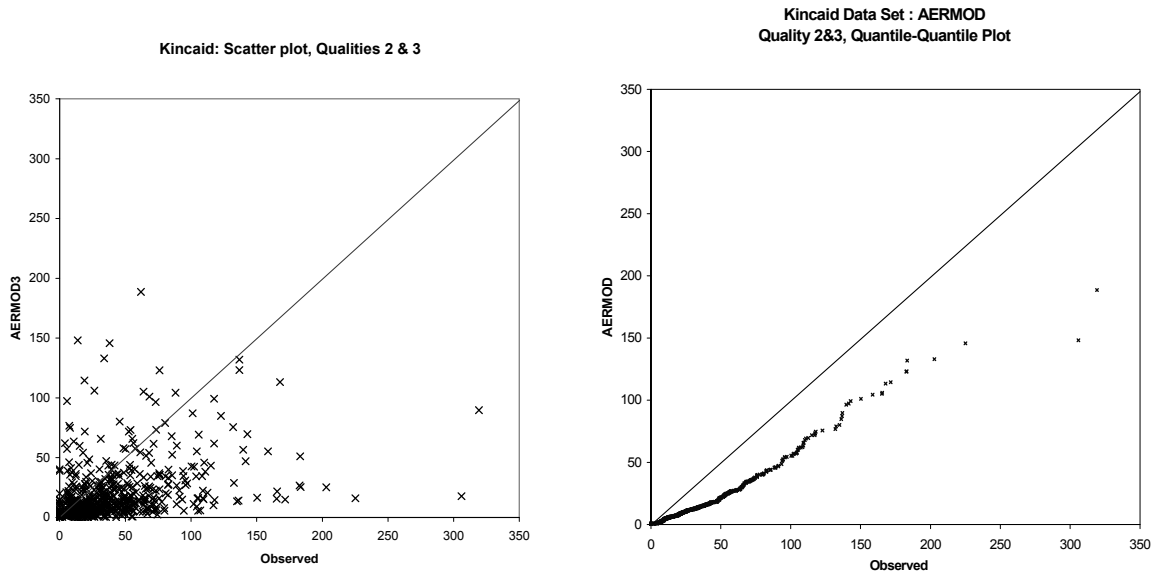


Figure 3 – Kincaid experiment, AERMOD, quality 2 & 3 data (units are  $\text{ns}/\text{m}^3$ ).

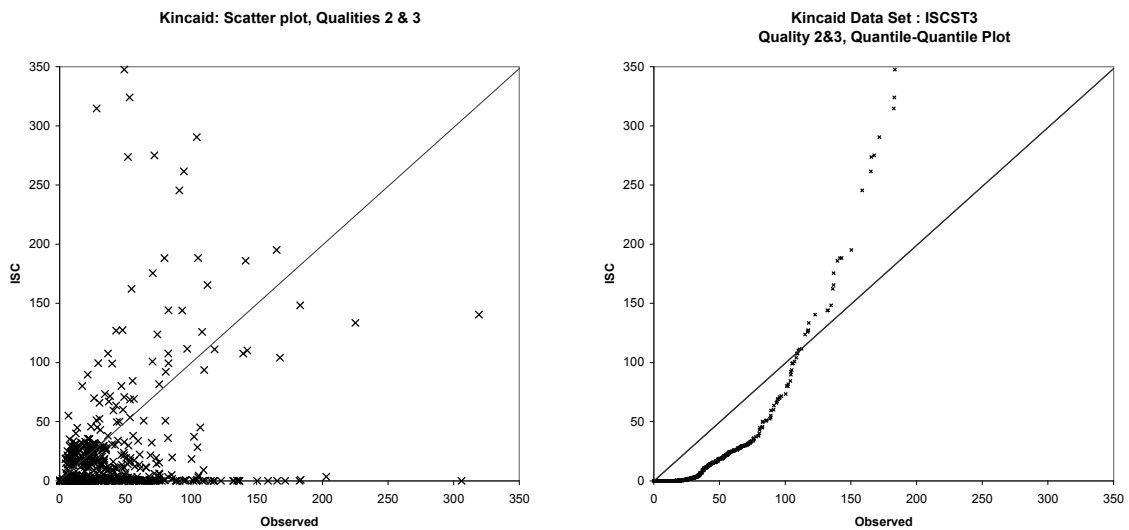
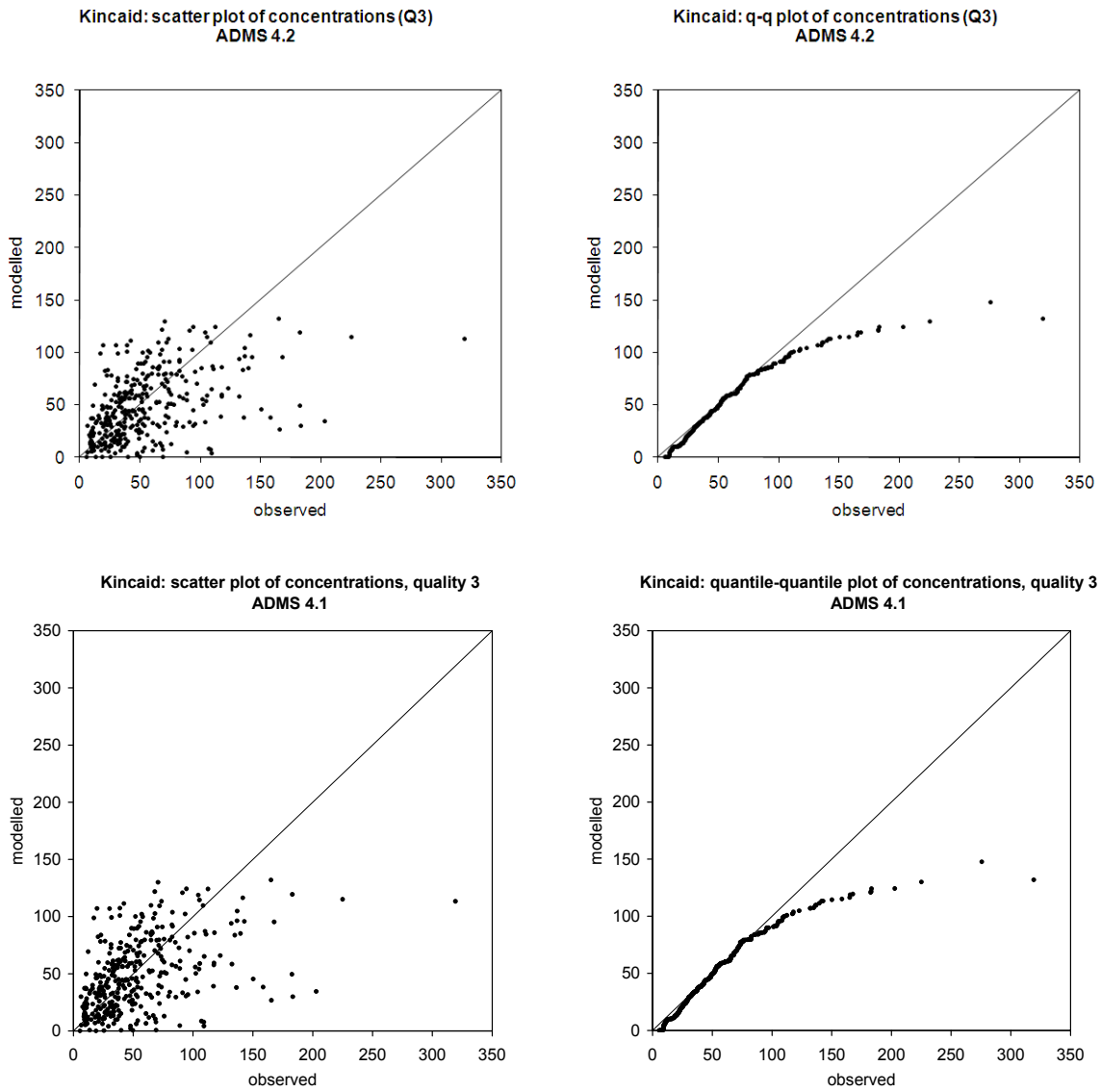
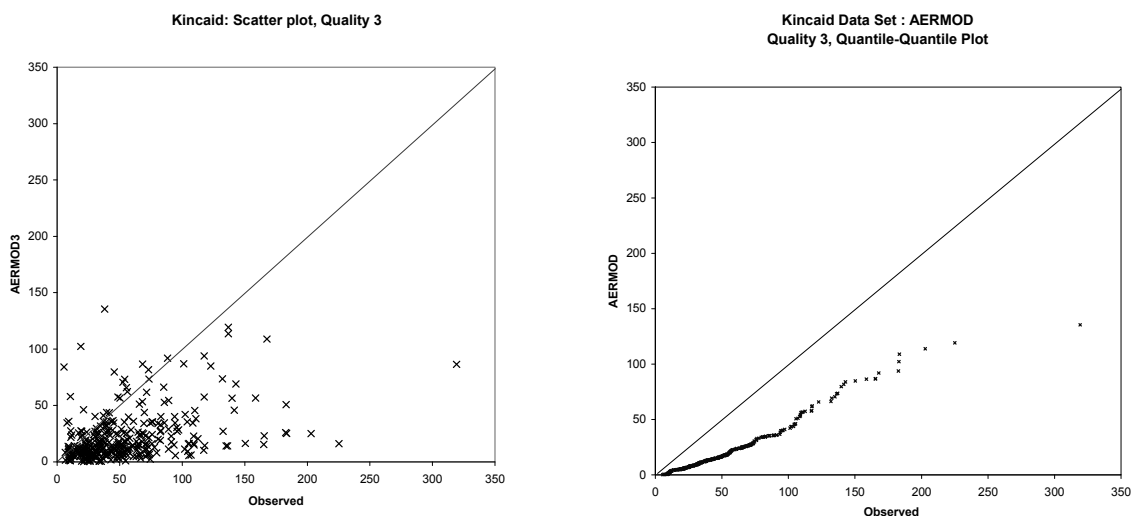


Figure 4 – Kincaid experiment, ISCST3, quality 2 & 3 data (units are  $\text{ns}/\text{m}^3$ ).



**Figure 5 – Kincaid experiment, ADMS, quality 3 data (units are ns/m<sup>3</sup>).**



**Figure 6 – Kincaid experiment, AERMOD, quality 3 data (units are ns/m<sup>3</sup>).**

### 3.3 Indianapolis

#### Experiment

The Indianapolis dataset contains the results of 170 hours of SF<sub>6</sub> tracer experiments carried out for EPRI (Electric Power Research Institute) in 1985 at the Perry-K power plant on the outskirts of Indianapolis (**Figure 7**<sup>2</sup>).

The stack of the Perry-K power plant is 83.8-m tall with a diameter of 4.72 m. The site is situated on the south-west edge of Indianapolis, in a mixed industrial/commercial/urban area with many buildings within one or two kilometres. The individual buildings were shown not to influence the plume, which tended to rise 100 m or more above the stack top most of the time, so building effects are not included explicitly in the modelling runs.

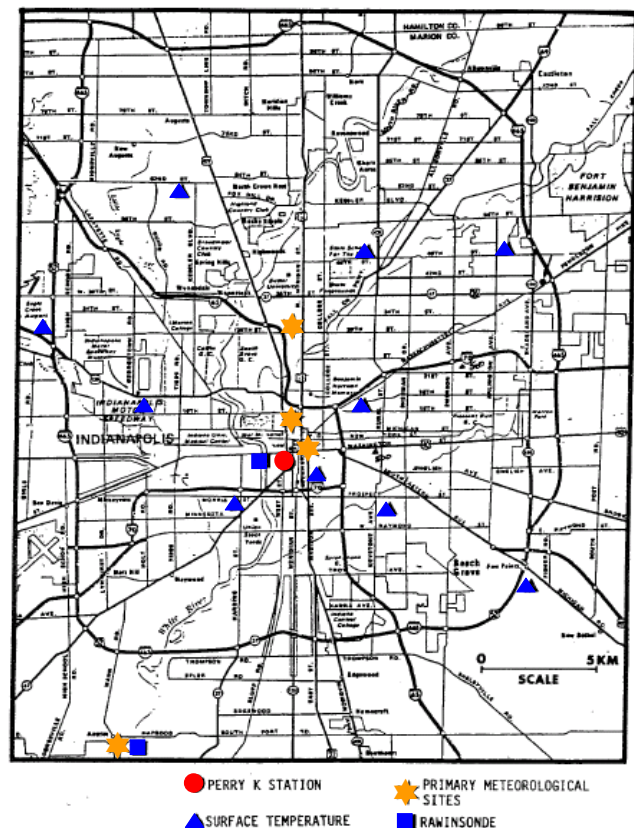
Tracer concentrations were recorded hourly from arrays of up to 160 receptors on arcs at distances ranging from 0.25 to 12 km from the stack, which were moved according to the prevailing wind direction.

Meteorological data were composed of data collected by different instrumented towers: 94-m tower (located on a bank building) providing sigma-theta, wind speed and wind direction, other 10-m towers (located in rural and suburban areas) providing wind speed, temperature difference between 2 and 10 m high, and other surface data. Meteorological conditions covered a range of stability classes and wind speeds throughout the experimental period, which covered daytime and night-time.

Results are presented here from ADMS model runs compared with observed data of qualities 2&3 and quality 3 only, as the night-time observations were unexpectedly very high given the height of the stack and the stable meteorological conditions reported. The concentrations have been normalised by the emission rate.

The following assumptions have been used in the ADMS modelling:

- (i) The region surrounding the site is an urban area, which may be considered to have a surface roughness of 3 m.
- (ii) In stable conditions, the minimum Monin-Obukhov length ( $L_{MO}$ ) was set to 100 m, to account for the 'urban heat island' effect.



**Figure 7** – Location of meteorological sensors deployed in Indianapolis for the SF<sub>6</sub> tracer study.

<sup>2</sup> Figure and caption directly taken from document [14].

### Statistical analysis

Results are summarised in **Table 4** and **Figure 8** for hours when the observed data were of quality 2 and 3. **Table 5** and **Figure 9** correspond to results for data of quality 3 only. There is negligible difference in the results from ADMS version 4.2 and ADMS version 4.1.

The BOOT analysis on the quality 2 and 3 data, **Table 4**, shows that ADMS predicts a mean value and standard deviation very close to the observed, the correlation is 30 % and the fraction within a factor of 2 is equal to 0.43. AERMOD underestimates the mean and standard deviation, has a correlation of 0.17 and a fraction of 0.41 within a factor of 2 of observations. ISCST3 over-estimates the mean by 57 % and over-estimates the standard deviation by 45 %. However, the correlation for ISCST3 of 0.16 is close to the AERMOD correlation and the 0.45 within a factor of 2 is slightly higher than the ADMS result. The fraction of hours within a factor 2 is similar for all models (40-45 %).

In **Table 5** the results are shown for the quality 3 results only. The mean is again well predicted by ADMS but AERMOD under-predicts the mean by more than for the quality 2 and quality 3 data. For all the models the fraction within a factor of 2 improves as does the normalised mean square error.

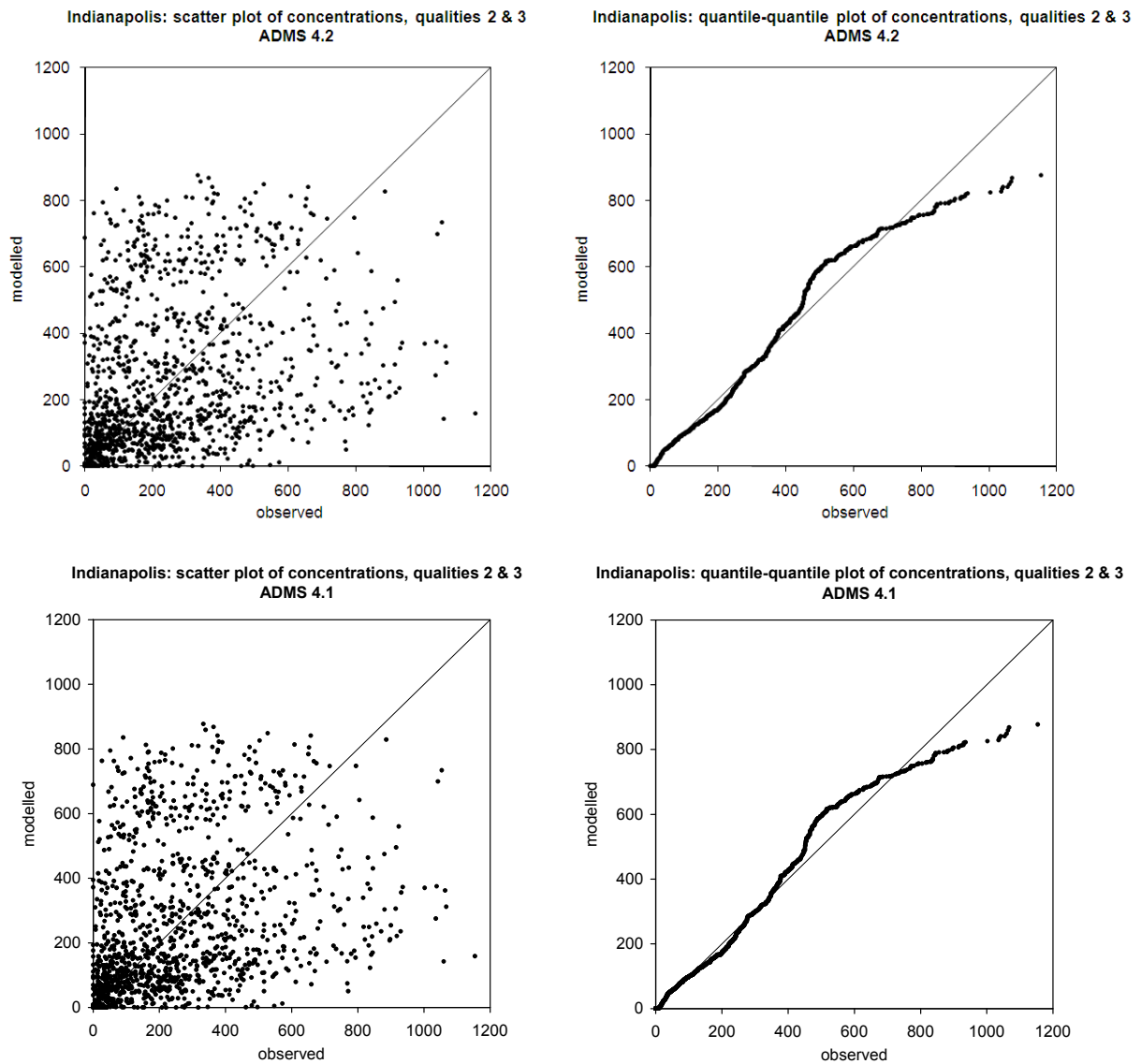
Inspection of the statistical results from ADMS shows that there is very little difference in model performance for qualities 2 and 3 (**Table 4**), compared to quality 3 only (**Table 5**).

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
observed	257.8	221.6	0.0	0.0	1.00	1.00	0.00	0.00
ADMS 4.2	260.8	226.8	-3.0	1.0	0.30	0.43	-0.01	-0.02
ADMS 4.1	260.8	226.8	-3.0	1.0	0.30	0.43	-0.01	-0.02
AERMOD	224.6	195.5	33.2	1.3	0.17	0.41	0.14	0.13
ISCST3	404.2	321.0	-146.4	1.4	0.16	0.45	-0.44	-0.37

**Table 4** – BOOT statistics: Indianapolis, qualities 2&3. Units for mean, sigma and bias: are  $\text{ns/m}^3$ .

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
observed	351.5	221.4	0.0	0.0	1.00	1.00	0.00	0.00
ADMS 4.2	348.1	237.4	3.5	0.6	0.26	0.55	0.01	-0.07
ADMS 4.1	348.1	237.4	3.5	0.6	0.26	0.55	0.01	-0.07
AERMOD	268.6	199.0	83.0	0.8	0.20	0.53	0.27	0.11
ISCST3	417.8	239.0	-66.2	0.6	0.17	0.61	-0.17	-0.08

**Table 5** – BOOT statistics: Indianapolis, quality 3 only. Units for mean, sigma and bias are  $\text{ns/m}^3$ .



**Figure 8** – Indianapolis experiment, ADMS, quality 2 & 3 data (units are ns/m<sup>3</sup>).

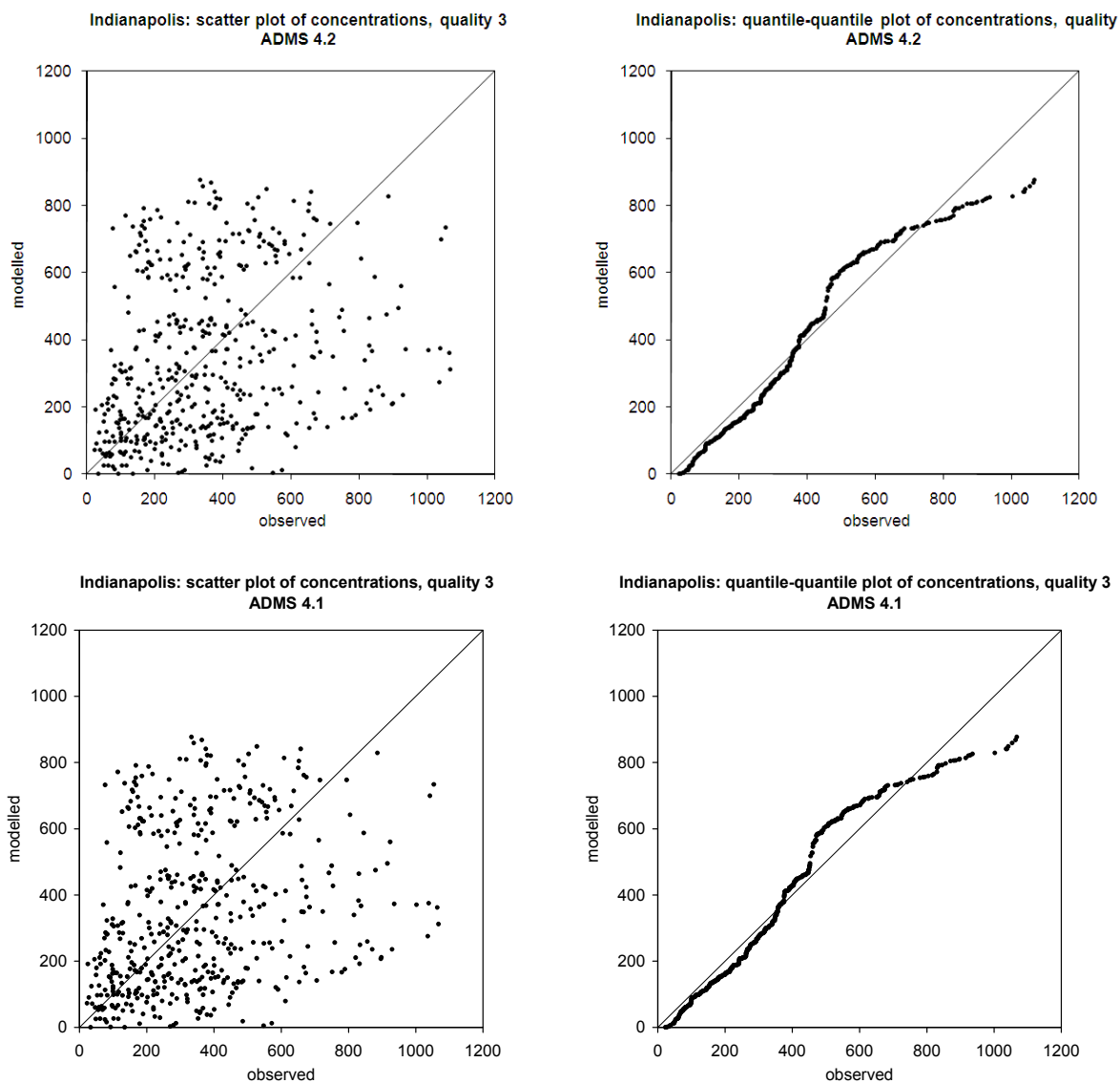


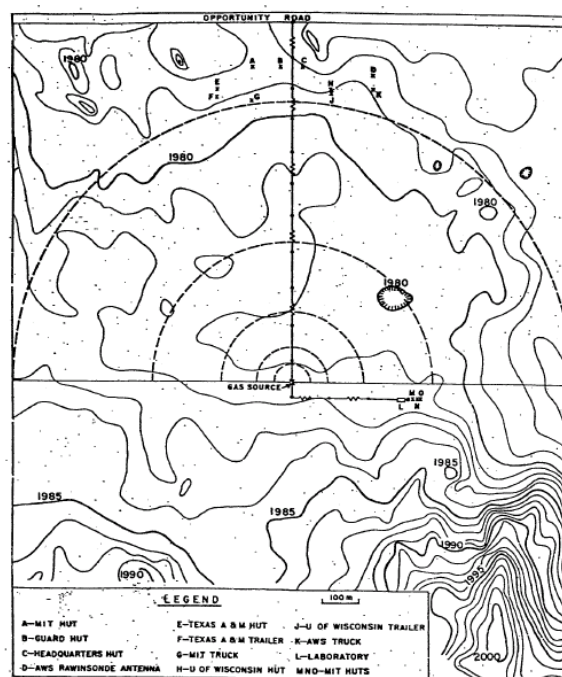
Figure 9 – Indianapolis experiment, ADMS, quality 3 data (units are ns/m<sup>3</sup>).

### 3.4 Prairie Grass

#### *Experiment*

Project Prairie Grass, designed by Air Force Cambridge Research Center personnel, was carried out in north central Nebraska in the summer of 1956 (**Figure 10**). The site was located on virtually flat land covered with natural prairie grasses. The roughness length was 6 mm. Small amounts of SO<sub>2</sub> tracer were released over 10-minute periods from near ground level (approximately 0.5 m above ground). In ADMS the release was modelled as a point source with zero exit velocity. Concentration measurements were made at a height of 1.5 m along arcs at five downwind distances: 50, 100, 200, 400 and 800 m. The emission rate was set to 1 g/s, indicating that the observed concentrations have been normalised by the emission rate.

About half of the 68 trials were conducted during unstable (convective) daytime conditions and the rest were held at night with temperature inversions present (stable conditions). Extensive meteorological measurements, including wind speed and turbulence data at more than one height, were taken on-site during the trials.



**Figure 10** – Layout of the Prairie Grass SO<sub>2</sub> tracer experiment.

#### *Statistical analysis*

The results of the Prairie Grass modelling by ADMS, AERMOD and ISCST3 data are presented in **Table 6** and **Figures 11** and **12**. Data of all qualities were included in the analysis, as there were so few data of qualities 2 and 3. The differences in concentrations predicted by ADMS 4.2 and ADMS 4.1 are negligible.

The statistical analysis suggests ADMS significantly under-estimates the mean concentration, predicting approximately 70 % of the observed mean. The correlation of all models is

reasonable, and 65 % of the ADMS 1-h averages are within a factor of 2 of the observations. The mean concentration predicted by AERMOD is almost identical to the observed mean and the bias is very close to zero. This is because the Prairie Grass results have been used directly

<b>Data</b>	<b>Mean</b>	<b>Sigma</b>	<b>Bias</b>	<b>NMSE</b>	<b>Cor</b>	<b>Fa2</b>	<b>Fb</b>	<b>Fs</b>
observed	2.23	3.90	0.00	0.00	1.00	1.00	0.00	0.00
ADMS 4.2	1.56	3.33	0.67	3.00	0.63	0.65	0.35	0.16
ADMS 4.1	1.56	3.33	0.67	3.00	0.63	0.65	0.35	0.16
AERMOD	2.14	4.35	0.09	1.83	0.75	0.73	0.04	-0.11
ISCST3	2.01	3.50	0.23	1.78	0.72	0.61	0.11	0.11

**Table 6** – BOOT statistics: Prairie Grass, all qualities. Units for mean, sigma and bias are  $\text{ms}/\text{m}^3$ .

in the AERMOD model formulation, with the original formulation being modified to take these into account for surface sources (Cimorelli *et al.*, 1996 [7]). As would be expected, the fraction of observations within a factor 2 and the correlation for AERMOD are both high (0.73 and 0.75, respectively). For ISCST3 both the mean and standard deviation are within 10 % of the observed values, 61 % of values are within a factor 2 and the correlation is 0.72. As with AERMOD, the results from Prairie Grass were used in the formulation of the ISCST3 model.

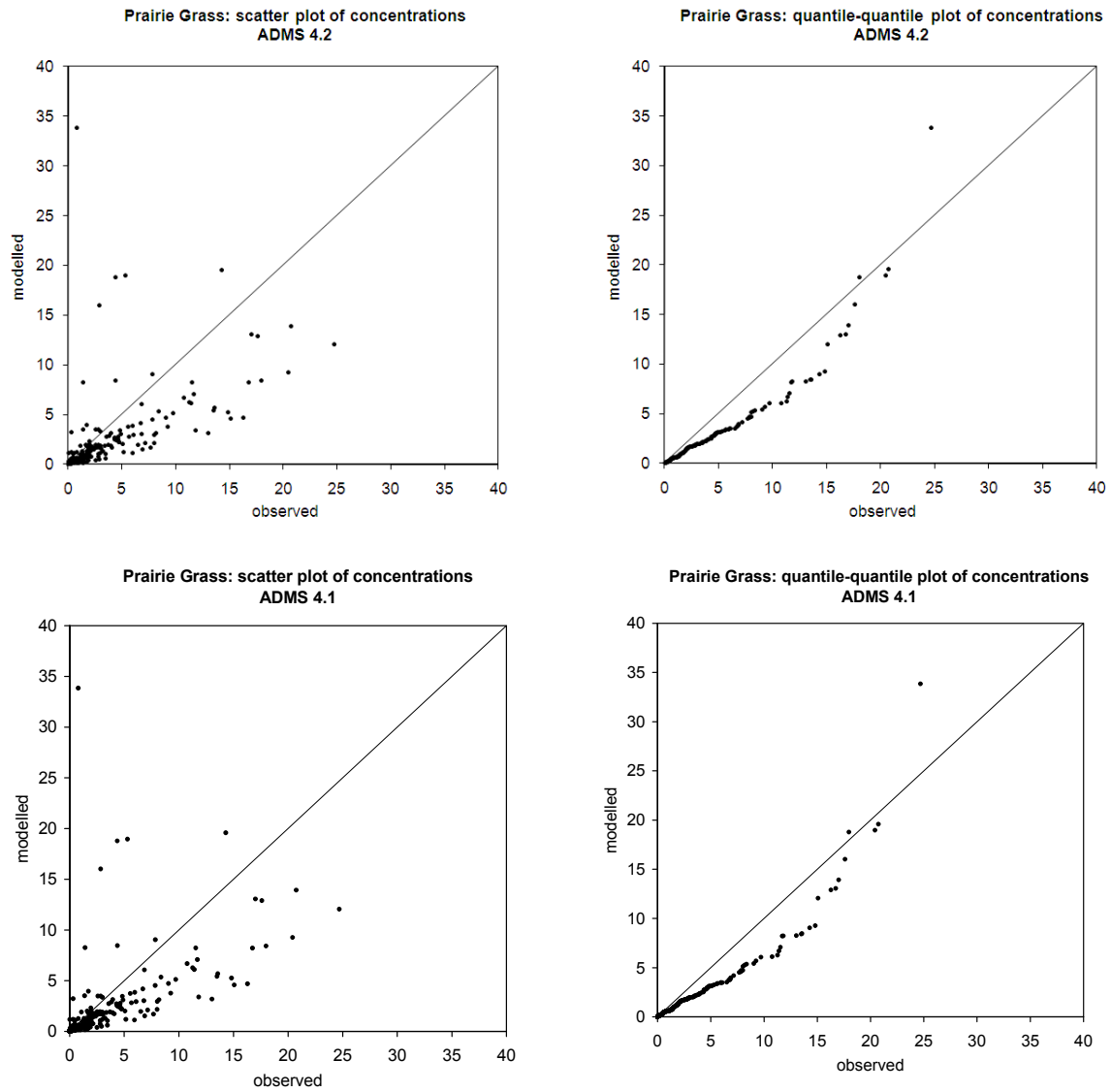


Figure 11 – Prairie Grass experiment, ADMS, all data (units are  $\text{ms/m}^3$ ).

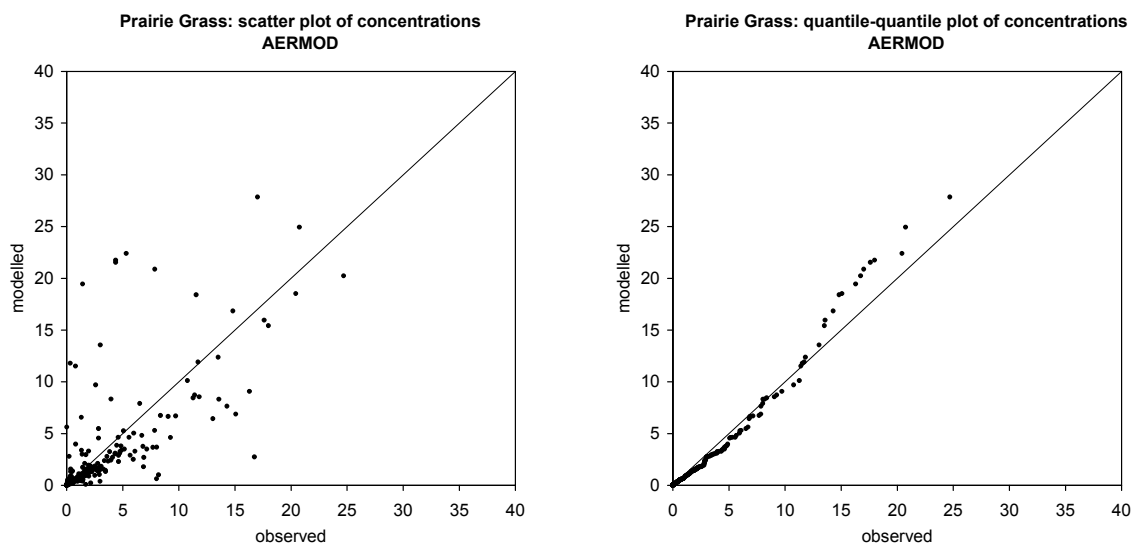


Figure 12 – Prairie Grass experiment, AERMOD, all data (units are  $\text{ms/m}^3$ ).

## 4 Summary

The three data sets used in this validation study cover a range of source elevation and meteorological conditions. The model results have been compared with observations and analysed using the methodology the arcwise maximum method (BOOT statistical package). No single statistical measure gives a complete picture of model performance, but the range of statistical measures and the plots give a fair impression of performance.

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