ADMS 6 Complex Terrain Validation
Hogback Ridge Tracer Experiments

Cambridge Environmental Research Consultants
April 2023

1 Introduction

During October 1982, the United States Environmental Protection Agency (US EPA) carried out a series of eleven tracer gas experiments near Farmington, New Mexico, in the United States [1]. Hogback Ridge is a small hill, with maximum elevation 104 m above the minimum elevation in the area. The terrain is semi-arid, with sparse vegetative cover of desert shrubs and grasses.

Tracer gases (SF_6 and 13B1) were released from points on the side of Hogback Ridge, and 100 samplers were arranged along the nearside of the top of the ridge to collect measurements of these tracer gases.

Among the data available from the US EPA experiments are hourly measured meteorological parameters at various heights on a tower (tower A) located at the base of the ridge, hourly measurements of SF_6 (ppt) at the 100 samplers and location data for the samplers and tracer release points.

Experiments 4, 10 and 12 have been modelled using the air pollution dispersion model ADMS, and the results compared with the measured concentrations of SF_6. These three experiments represent largely stable (experiment 4) and largely convective meteorological conditions (experiments 10 and 12).

This document compares the predictions of SF_6 concentrations by two versions of ADMS with observed values. The two versions are ADMS 5.2.0.0 (hereafter referred to as ADMS 5.2) with those of ADMS 6.0.0.1 (hereafter referred to as ADMS 6.0).

Section 2 describes the input data used for the model. The results are presented in Section 3 and discussed in Section 4.

2 Input data

2.1 Study area

The ground cover around Hogback Ridge is desert-like, with sparse vegetative cover of desert shrubs and grasses, so a roughness length of 0.02 m was used in the modelling.

Terrain data for the modelling were obtained from the United States Geological Survey's archive of 1°×1° digital elevation model (DEM) data [2]. A contoured plot of the terrain data used is shown in **Figure 1**. It extends 2.5 km in the east-west direction and 2 km in the north-south direction. The resolution of the data is approximately 80 m.

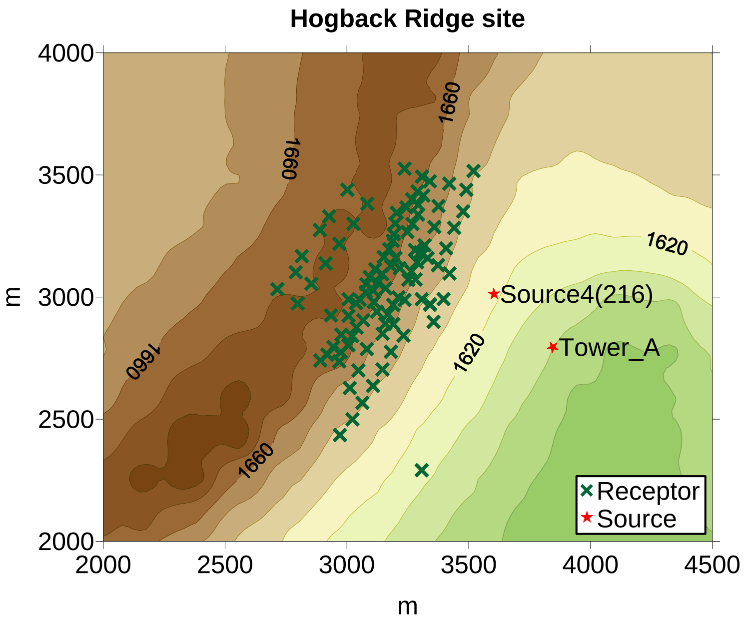

Figure 1 − Modelled area around Hogback Ridge (elevation in metres above mean sea level).

2.2 Source parameters

Table 1 below shows the different source parameters that were used for the three different experiments. All experiments were modelled as passive releases.

The location of the sources is shown in **Figure 1**.

Experiment	Source name	Pollutant	Stack height (m)	Exit V (m/s)	Exit T (°C)	Diameter (m)	Emission rate (g/s)
4	Source4(216)	SF_6	20	0	15	0.05	0.77
10	Tower A	SF_6	70	0	15	0.05	0.21
12	Tower A	SF_6	50	0	15	0.05	0.30

Table 1 − Source input parameters. T is the temperature, V the velocity.

2.3 Receptors

The monitors were arranged along the ridge (**Figure 1**), at a higher elevation than the sources.

2.4 Meteorological Data

The meteorological data used were hourly data from the instruments on Tower A, located at the base of the ridge, plus cloud cover data from the archive of International Surface Weather Observations, 1982-1997 [4]. Each experiment was approximately 9 hours long and all hours were modelled although results are only presented for hours where the wind direction was such that the receptor points were downstream of the source. The meteorological data for the complete set of experiments are presented in **Table 2**.

The values of the Priestley-Taylor parameter were chosen according to the ambient temperature at the hours being presented, the time of year (autumn) and the nature of the terrain around Hogback Ridge (desert). The local time zone at Hogback Ridge is Mountain Daylight Time

(MDT), which is 6 hours behind GMT at the time of year at which these experiments were conducted.

Time (MDT)	Wind speed (m/s)	Wind direction (°)	Ambient T (°C)	Cloud cover (oktas)	Priestley-Taylor parameter	Stability ADMS 5.2	Stability ADMS 6.0
Experiment 4, 11th October 1982 (wind measured at 40 m above the terrain)							
00:00	2.71	267.5	6.9	0	0.0	stable	stable
01:00	2.87	279.6	6.5	2	0.0	stable	stable
02:00	1.33	345.3	4.9	2	0.0	stable	stable
03:00	1.61	102.1	4.5	0	0.0	stable	stable
04:00	1.04	232.8	3.7	0	0.0	stable	stable
05:00	1.17	27.8	4.0	0	0.0	stable	stable
06:00	1.10	229.3	3.5	2	0.0	stable	stable
07:00	1.33	207.3	3.5	7	0.0	stable	stable
08:00	1.38	226.8	4.2	7	0.0	convec.	convec.
Experiment 10, 22th October 1982 (wind measured at 60 m above the terrain)							
00:00	4.92	291.9	10.0	2	0.18	stable	stable
01:00	1.26	168.8	7.1	0	0.18	stable	stable
02:00	1.34	137.9	5.6	0	0.18	stable	stable
03:00	2.08	146.5	4.5	0	0.18	stable	stable
04:00	1.15	122.5	3.0	0	0.18	stable	stable
05:00	1.01	160.0	1.9	0	0.18	stable	stable
06:00	2.50	105.7	1.5	0	0.18	stable	stable
07:00	2.58	102.9	1.4	0	0.18	stable	stable
08:00	2.08	116.4	0.9	0	0.18	**convec.**	**stable**
09:00	2.69	110.1	4.8	0	0.18	convec.	convec.
10:00	2.07	121.3	8.0	0	0.18	convec.	convec.
Experiment 12, 24th October 1982 (wind measured at 60 m above the terrain)							
00:00	2.08	85.2	12.2	7	0.16	stable	stable
01:00	1.33	187.4	10.2	7	0.16	stable	stable
02:00	2.03	169.8	7.4	2	0.16	stable	stable
03:00	1.94	149.3	7.4	2	0.16	stable	stable
04:00	2.63	119.1	6.8	2	0.16	stable	stable
05:00	2.20	67.4	6.3	2	0.16	stable	stable
06:00	2.58	77.0	6.2	2	0.16	stable	stable
07:00	3.54	90.9	6.4	2	0.16	stable	stable
08:00	3.16	112.2	5.3	2	0.16	convec.	convec.
09:00	3.02	115.3	4.9	0	0.19	convec.	convec.
10:00	3.59	128.6	7.6	0	0.17	convec.	convec.
11:00	3.93	130.6	11.5	0	0.16	convec.	convec.

Table 2 − Meteorological data. The wind direction is given in degrees from north. T is the temperature. The shaded rows indicate the hours for which data are presented.

The criteria for the stability categories presented above are as follows, where H is the boundary layer height and L_{MO} is the Monin-Obukhov length, as calculated by the model's meteorological processor:

Stable: $H/L_{MO} > 1$
Neutral: $-0.3 \leq H/L_{MO} \leq 1$
Convective: $H/L_{MO} < -0.3$

Differences between ADMS 5.2 and ADMS 6.0 are highlighted in bold.

2.5 Output Data

The model output contained short-term hourly averages of SF_6 concentration with units of $\mu g/m^3$ at receptor points positioned at the sampler locations.

The conversion from concentration in $\mu g/m^3$ to concentration in ppt was done using the Ideal Gas Equation:

$$p = \frac{10^3 \rho R^* T}{M} \rightarrow conc_{ppt} = conc_{\mu g/m^3} \times 10^6 \times \frac{R^* T}{Mp} = conc_{\mu g/m^3} \times 164.8$$

where p = 1013 mb = 101300 Pa, T = 293.15K, $M(SF_6)$ = 146 g/mol and R^* = 8.314 J K^{-1} mol^{-1}.

In the original experiments, a different subset of samplers collected measurements each hour, and this is reflected in the modelling by using a different subset of receptor points each hour.

The height above terrain of all but three of the receptor points was 0.5 m; the other three were at 8 m, 14 m and 25 m.

3 Results

Scatter plots and quantile-quantile plots of model results against observed data are presented in Section 3.1. Other statistical analysis is presented in Section 3.2. The graphs and statistical analysis have been produced by the Model Evaluation Toolkit v5.2 [5].

3.1 Scatter and quantile-quantile plots

Figure 2 shows scatter plots and quantile-quantile plots of modelled versus observed data for experiment 4, **Figure 3** shows the same plots for experiment 10 and **Figure 4** shows the same plots for experiment 12.

The scatter plots compare concentrations at a fixed location and a fixed time under particular meteorological conditions. This sort of comparison in space and time is likely to be subject to greater variation than, for instance, comparisons of arcwise maxima where the comparison is at a downstream distance, not at a downstream and crosswind location.

The scatter plots compare predicted and measured concentrations at a particular location at a particular time, i.e. an (x,t) pairing. The quantile-quantile plots compare the distribution of predicted and measured concentrations during the period having abandoned the (x,t) pairing. Predicting the distribution of concentrations accurately is relevant to calculations for permitting purposes, where the comparison with air quality limits is more important than accurately predicting a time series of concentrations at each location. The latter is a harder task.

Note that the quantile-quantile plots are linear; care should be exercised when comparing these plots with similar ones presented with logarithmic axes.

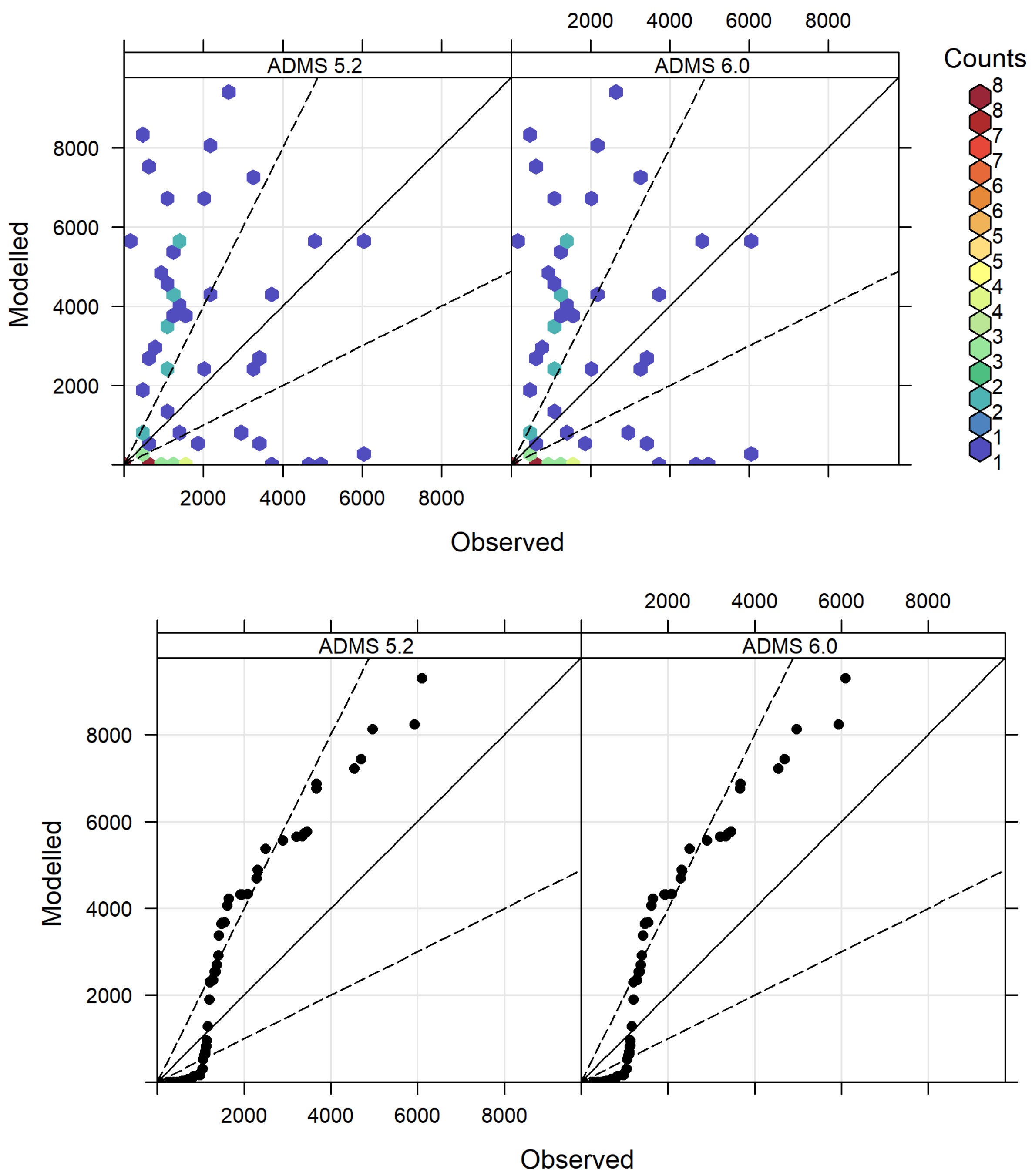

Figure 2 − Scatter plots and quantile-quantile plots of modelled SF_6 concentration against observed data for **experiment 4** (units ppt).

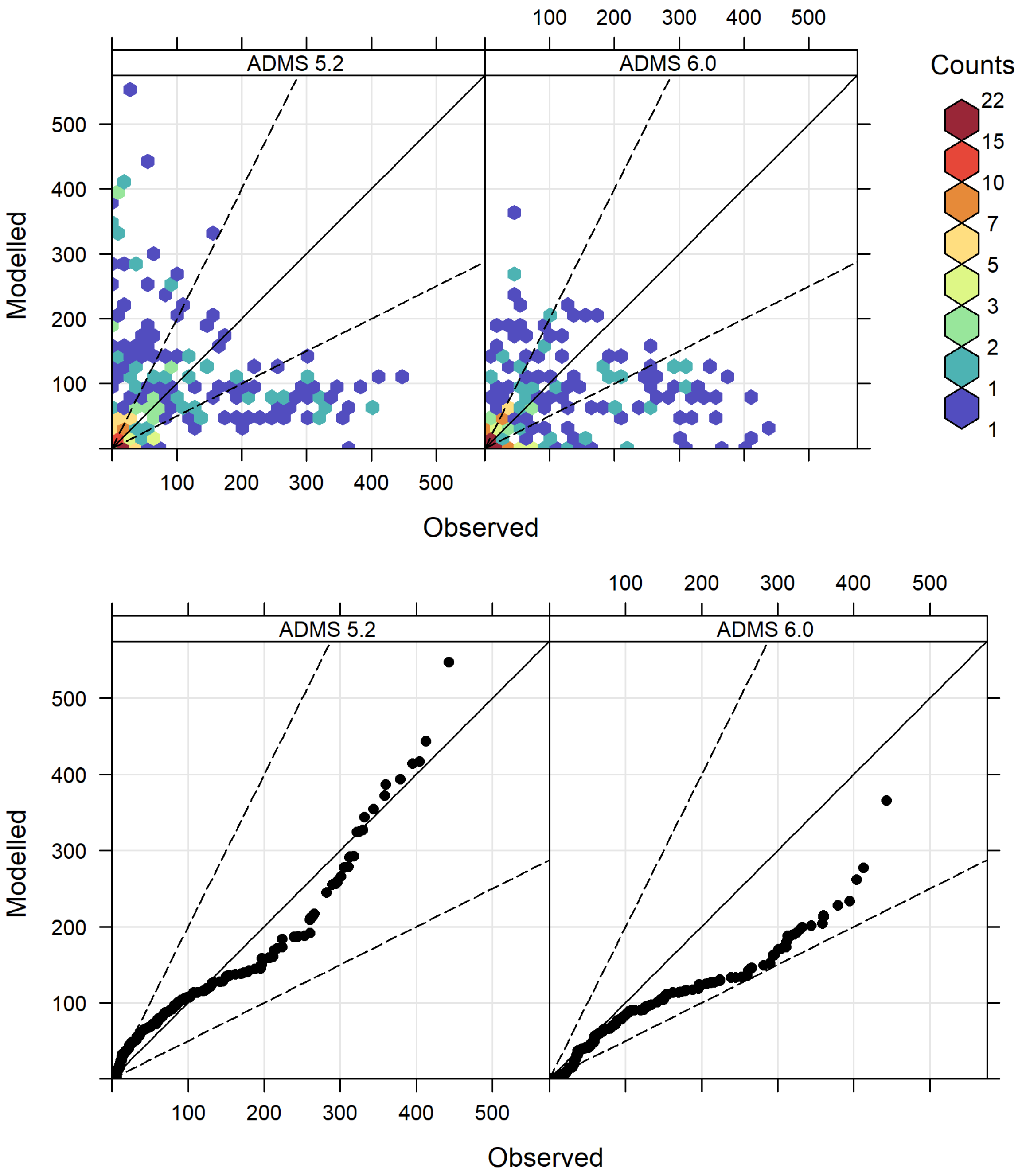

Figure 3 − Scatter plots and quantile-quantile plots of modelled SF_6 concentration against observed data for **experiment 10** (units ppt).

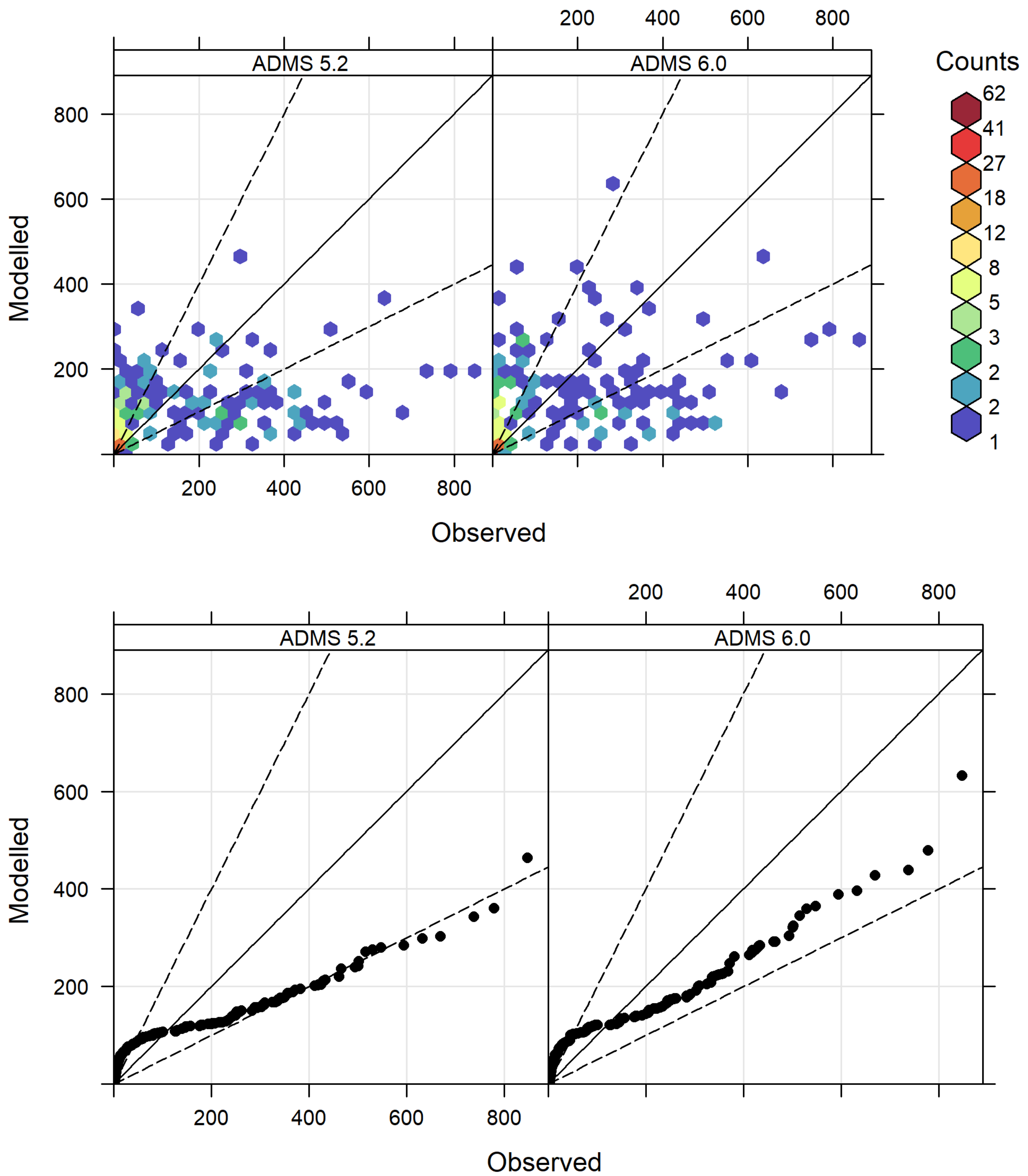

Figure 4 − Scatter plots and quantile-quantile plots of modelled SF_6 concentration against observed data for **experiment 12** (units ppt).

3.2 Statistics

The Model Evaluation Toolkit produces statistics of the data that are useful in assessing model performance. Statistics calculated include mean, standard deviation (Sigma), bias, normalised mean square error (NMSE), correlation (Cor), fraction of results where the modelled and observed concentrations agree to within a factor of 2 (Fa2), fractional bias (Fb) and fractional standard deviation (Fs). **Tables 3** to **5** summarise the statistics of the comparison of modelled against observed concentration data.

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
Observed	1478.45	1377.63	0.00	0.00	1.000	1.000	0.000	0.000
ADMS 5.2	2190.96	2620.80	712.50	2.39	0.213	0.192	0.388	0.622
ADMS 6.0	2190.96	2620.80	712.50	2.39	0.213	0.192	0.388	0.622

Table 3 – Statistics for **experiment 4** (74 pairs of data points).

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
Observed	92.64	105.40	0.00	0.00	1.000	1.000	0.000	0.000
ADMS 5.2	95.12	97.11	2.49	2.45	-0.052	0.331	0.027	-0.082
ADMS 6.0	60.00	64.90	-32.63	2.36	0.239	0.326	-0.428	-0.476

Table 4 − Statistics for **experiment 10** (239 pairs of data points).

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
Observed	119.47	171.92	0.00	0.00	1.000	1.000	0.000	0.000
ADMS 5.2	83.21	80.44	-36.26	2.48	0.457	0.257	-0.358	-0.725
ADMS 6.0	97.92	106.30	-21.55	2.08	0.466	0.278	-0.198	-0.472

Table 5 − Statistics for **experiment 12** (238 pairs of data points).

4 Discussion

The scatter and quantile-quantile plots show generally good agreement between modelled and observed concentration data. As mentioned in Section 3.1, comparisons at a fixed location and a fixed time such as those presented are likely to be subject to greater variation than, for instance, comparisons of arcwise maxima, where the comparison is at a downstream distance, not at a downstream and crosswind location. Experiment 4 is particularly challenging to model given that it is a single hour with stable flow.

The differences between ADMS 5.2 and ADMS 6.0 vary between the different experiments. There has been a change to the meteorological processor in which the solar elevation angle is calculated at the middle of the hour rather than the end of it. This only affects daytime hours, hence why we see no difference between ADMS 5.2 and ADMS 6.0 for experiment 4, which consists of only one night-time hour. Conversely, experiment 10 and experiment 12 both consist of three daytime hours. Furthermore, the three hours are around or just after dawn, when the half-an-hour shift in solar elevation angle calculation time will have a relatively large effect. As ADMS 6.0 is calculating the solar elevation angle half an hour before ADMS 5.2, it is predicting more stable conditions than ADMS 5.2; this even shifts hour 08:00 in experiment 10 from the convective to the stable category based on its H/L_{MO} value (see **Table 2**). This leads to ADMS 6.0 performing worse for experiment 10 but better for experiment 12 in terms of mean concentration, although ADMS 6.0 is better than ADMS 5.2 for both experiments in terms of correlation and Fa2. The mean concentration decreases with ADMS 6.0 for experiment 10 but increases for experiment 12. The more stable conditions predicted by ADMS 6.0 lead to thinner but more concentrated plumes; whether this gives higher or lower concentration at a given receptor depends on its position relative to the plume centreline. Note that ADMS 6.0 includes an option to use the legacy behaviour of calculating the solar elevation at the end of the hour – when this option is used, there are no difference between ADMS 5.2 and ADMS 6.0 for all three experiments.

Solar elevation calculated at the middle of the hour should be more representative of the meteorological hour as a whole for true hourly-averaged data in which the times in the meteorological data file are hour ending times in local solar time. Note however that true local solar time may differ from the times in the meteorological data file depending on the exact longitude of the dispersion site.

5 References

[1] United States Environmental Protection Agency, 1985: *Description of a Computer Data Base from Small Hill Impaction Study No.2, Hogback Ridge, New Mexico*. United States Environmental Protection Agency Complex Terrain Model Development, Atmospheric Sciences Research Laboratory, EPA/600/3-86/002.

[2] https://apps.nationalmap.gov/downloader/

[3] https://www.usna.edu/Users/oceano/pguth/website/microdem/microdem.htm

[4] United States Department of Commerce (N.O.A.A.) and United States Department of Air Force (A.F.C.C.C.), 1998: *International Surface Weather Observations, 1982-1997.*

[5] Stidworthy A, Carruthers D, Stocker J, Balis D, Katragkou E, and Kukkonen J, 2013: *MyAir Toolkit for Model Evaluation*. 15th International Conference on Harmonisation, Madrid, Spain, May 2013.

[6] Thunis P., E. Georgieva, S. Galmarini, 2010: *A procedure for air quality models benchmarking*. https://fairmode.jrc.ec.europa.eu/document/fairmode/WG1/WG2_SG4_benchmarking_V2.pdf

[7] David Carslaw and Karl Ropkins (2011). *openair: Open-source tools for the analysis of air pollution data*. R package version 0.4-7. http://www.openair-project.org/

[8] Chang, J. and Hanna, S, 2004: *Air quality model performance evaluation*. Meteorol. Atmos. Phys. **87**, 167-196.