ROAD SOURCE MODEL INTERCOMPARISON STUDY USING NEW AND EXISTING DATASETS

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Abstract: Near-road exposures to traffic-generated air pollutants are a public health concern. Air dispersion models are useful tools for quantifying exposure levels, but they must undergo extensive validation prior to use in order for there to be confidence in the model results. There are many challenges associated with near-road air dispersion modelling studies. It is often difficult to quantify emissions from road traffic and the pollutants are subject to chemical transformations over very short temporal and spatial scales; other complications arise from meteorological measurement uncertainty. By setting up field experiments that simplify some of these factors, for instance using an inert gas, it is possible to reduce uncertainty and focus on the fundamental dispersion processes.

The recent Idaho Falls tracer study (Finn *et al.*, 2010) involved the release of the tracer gas sulphur hexafluoride from a ground level line source. Fifty-six receptors were placed downwind of the source at a height of 1.5 m and an additional two receptors were located upwind. These receptors sampled at fifteen minute intervals. The experimental data from this study cover a wide range of atmospheric stabilities, with measurements of wind speed, direction and lateral meandering recorded at three heights above ground level. An older dataset, from the Caltrans Highway 99 study, includes measurements of the same pollutant from vehicles travelling alongside other traffic on Highway 99 in California (Benson, 1989). For this study, receptors were placed on either side of the road at distances of 50, 100 and 200 m, and at four locations within the road, spaced approximately 800 m apart. The receptors sampled at thirty minute intervals. Meteorological measurements were recorded at two heights above ground level.

This paper presents results of a model intercomparison exercise using these experimental datasets. Comparisons are made between the UK model ADMS-Roads, the US-EPA regulatory model AERMOD, California's CALINE and the US-EPA research model RLINE. The model results are compared using the new MyAir Model Evaluation Toolkit (Stidworthy *et al.*, 2013) which has been developed as part of the EU FP7 PASODOBLE project.

Key words: *Air quality, road, dispersion, MyAir, ADMS, AERMOD, CALINE, RLINE*

INTRODUCTION

Millions of people worldwide are exposed to high levels of atmospheric pollutants due to emissions from traffic. Whilst static monitors can be used to measure pollution levels in specific locations, air dispersion models are able to assess the number of people exposed, as they can calculate contour maps of pollution levels. Such models must undergo extensive validation prior to use to ensure that they are fit for purpose. Field experiments where emission rates are known, and detailed measurements of meteorological parameters and resultant concentrations have been taken, allow models to be assessed; by removing uncertainty relating to model inputs, the dispersion modules can be scrutinised in detail. The two datasets used in this model intercomparison exercise are the recent Idaho Falls tracer study (Finn *et al.*, 2010) and the Caltrans Highway 99 experiment (Benson, 1989).

The model evaluation exercise undertaken in this work is calculated by the MyAir Model Evaluation Toolkit (Stidworthy *et al.*, 2013). The approaches used by this new tool draw on previous methodologies for performing statistical evaluation of air dispersion models as discussed, for instance, by Chang and Hanna, 2004. A full description of the results presented in this extended abstract is given in the forthcoming work by Heist *et al.* (2013).

The experimental data used for the model intercomparison are discussed in the first section below. Brief descriptions of the dispersion models included in the exercise are then given, followed by an overview of the MyAir Toolkit. The results of the model intercomparison exercise are then presented, and discussed, with references being given at the end of the paper.

EXPERIMENTAL DATA

Two experimental datasets have been selected for use in this near-road dispersion model intercomparison exercise. The most recent dataset has been derived from the Idaho Falls tracer study. In this experiment, a 54 m long, near-ground level line source was used to represent the road. A grid of receptors located downwind of the road measured concentrations of the tracer gas sulphur hexafluoride, as shown in Figure 1 a). The measurements were taken at fifteen minute intervals. Experimental data were collected on four separate days, in which a range of meteorological conditions were observed. The measurements taken during this study are all accurate to within ±20% of US NIST-certified standards, and mostly to within ±10%. Meteorological data were recorded using several sonic anemometers, a 30 m meteorological tower and a radar wind profiler. The data presented in this paper are only a subset of the experimental data recorded during the Idaho Falls field study. Concentrations due to dispersion over a barrier were also recorded, but have not yet been modelled.

The second dataset used in this study is derived from an experiment undertaken in the early 1980s on Highway 99 in Sacramento, California. In this study, the same tracer gas was released from the exhaust pipes of eight modified vehicles, which were driven with other vehicles along a straight segment of this four-lane, heavily trafficked highway; the vehicles were evenly distributed on all lanes of the highway. Monitors were located both in the central reservation, as well as perpendicular to the road, as shown in Figure 1 b). The measurements were taken at thirty minute intervals; measurement uncertainty values are not available for this study. Meteorological data were recorded on a 12 m meteorological tower. Concentrations recorded at receptors downwind of the road source only are included in the analysis presented in the following sections.

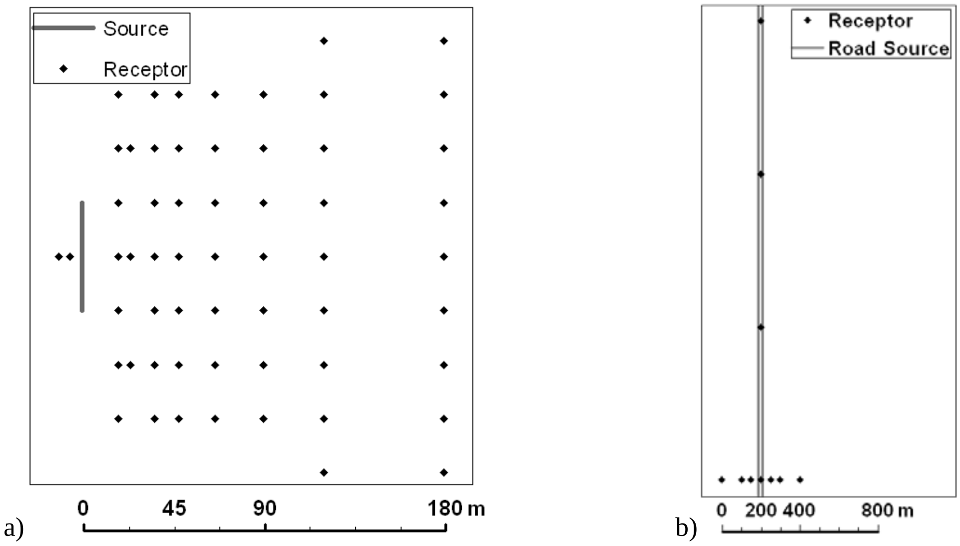

Figure 1. Experimental model setups a) Idaho Falls tracer study & b) Caltrans Highway 99 study

These two datasets are able to test different features of a near-road source dispersion model. The Idaho Falls experiment was undertaken in a relatively controlled environment, where the release was from a line source rather than a road source. The absence of vehicle-induced turbulence in this experiment reduces the uncertainty relating to the definition of the source term and the high resolution grid of receptors allows detailed analysis of the spatial variation of concentrations, in particular lateral dispersion. Further, this experiment was undertaken using the most up-to-date meteorological equipment, which results in the associated meteorological measurements being highly resolved, and reliable. In the Caltrans 99 experiment, the many non-experimental vehicles on the road produce turbulence. This turbulence is difficult to quantify, leading to uncertainty regarding the source term; however, this experiment mimics the real-world scenarios that the dispersion models need to be able to represent. The meteorological measurements associated with the Caltrans 99 study are not as highly resolved as the for the Idaho Falls study, and they are generally less reliable due to the 30 year gap between experiment and current analysis.

DISPERSION MODELS

Results from four near-road dispersion models are presented in this paper: ADMS-Roads, AERMOD, CALINE and RLINE; relevant model features are summarised in Table 1. All models considered in the study are steady state Gaussian plume models. Three out of the four models considered are new generation models; that is they use the Monin-Obukhov length to categorise the meteorological conditions (refer to the second column in Table 1). The models use different methods for representing the road sources, as indicated in the third column in Table 1. For the Idaho Falls study, ADMS-Roads, CALINE and RLINE represent the release as a line source. AERMOD, which does not model line sources explicitly, represents the release as both an area and volume source. For the Caltrans study, RLINE, AERMOD and CALINE account for the traffic-induced turbulence by an initial vertical mixing height that represents the spread of the emissions within the road; for the two former models, this is user defined, whereas for CALINE, the value is calculated allowing for the residence time in the road. For this study, ADMS-Roads models the source as a 'road' source, which is a line source with an initial mixing height; traffic induced turbulence is also accounted for during dispersion. The fifth column of Table 1 summarises model status: release versions of ADMS-Roads[1], AERMOD[2] and CALINE[3] are currently available as operational models; RLINE is, at present, a research tool.

Table 1. Summary of near-road dispersion models used in the intercomparison study

Model	Meteorological classification	Road source representation	Reference	Status
ADMS-Roads	Monin-Obukhov	Line or road	McHugh *et al.*, 1997	UK model for dispersion from road sources
AERMOD	Monin-Obukhov	Area & volume	Cimorelli *et al.*, 2005	US EPA regulatory model for short range dispersion
CALINE4	Pasquill Gifford	Line	Benson, 1989	California's model for detailed project-level CO analyses
RLINE	Monin-Obukhov	Line	Snyder *et al.*, 2013	US EPA research tool

ANALYSIS USING THE MYAIR TOOLKIT

The MyAir Model Evaluation Toolkit has been developed under the local forecast model evaluation support work package of the EU's 7th Framework project, PASODOBLE. The Toolkit draws on existing best practice such as the EU Joint Research Council's (JRC) FAIRMODE initiative on model evaluation (Thunis *et al.*, 2010) and the 'openair' project tools (Carslaw and Ropkins, 2011). The evaluation of model performance across receptors produces scatter plots and analyses, with categorisation by receptor type. The data plotted are also exported to auxiliary files in order to provide an audit trail and to make the data available for further analysis and visualisation.

The toolkit outputs of specific interest for this study are the summary statistics of the concentrations calculated by the model: mean, standard deviation (Sigma), mean bias, normalised mean square error (NMSE), correlation coefficient (R), fraction of modelled values within a factor of two of the observed (Fac2), fractional bias (Fb) and fractional standard deviation (Fs). Note that the sign of the bias and fractional bias calculated by the Myair Toolkit is consistent with openair and the DELTA tool, but not with the BOOT package (Chang and Hanna, 2004). The frequency scatter plots generated by the toolkit are useful for looking at how the spread of values varies between the models.

RESULTS

The comparisons presented are between modelled and observed data paired in time and space. Table 2 shows the statistical results calculated by the MyAir Toolkit for the Idaho Falls dataset, for the four models in the comparison exercise, with two entries for AERMOD (area and volume source representations). For this study, the correlation between observed and modelled data is good for all models, but all models exhibit some underprediction; over 50% of modelled data are within a factor of two of the observations for all models. The statistics associated with the RLINE model are better than for the other models, with the exception of correlation, for which ADMS-Roads achieves the result closest to unity. However, given the measurement uncertainty, the difference between all models' results may not be statistically significant. The performance of RLINE for this study is likely to be positively influenced by the use of the Idaho Falls dataset in the formulation of the vertical dispersion curves which are used in RLINE. Figure 2 shows the frequency scatter plots for all model results, as generated by the MyAir Toolkit. The colour of each hexagonal cell on the plot represents the number of data points within the cell, as indicated by the key to the right of the plot. The plots are shown on logarithmic scales, and all points within the dashed lines are within a factor of two of the observed data.

Table 2. Idaho Falls summary statistics calculated using the MyAir Toolkit

Data	Mean	Sigma	Bias	NMSE	R	Fac2	Fb	Fs
Observed	5.62	9.01	0.00	0.00	1.00	1.00	0.00	0.00
ADMS-Roads	3.89	6.04	-1.74	1.16	0.88	0.69	-0.37	-0.40
AERMOD (area)	4.04	7.20	-1.58	1.26	0.82	0.58	-0.33	-0.22
AERMOD (volume)	3.88	7.24	-1.75	1.26	0.84	0.58	-0.37	-0.22
CALINE	3.66	5.30	-1.96	1.97	0.76	0.58	-0.42	-0.52
RLINE	4.53	7.46	-1.09	0.96	0.84	0.72	-0.22	-0.19

[1] ADMS-Roads version 3.1 was used in this study
[2] AERMOD version 12060 was used in this study
[3] CALINE4 was used in this study

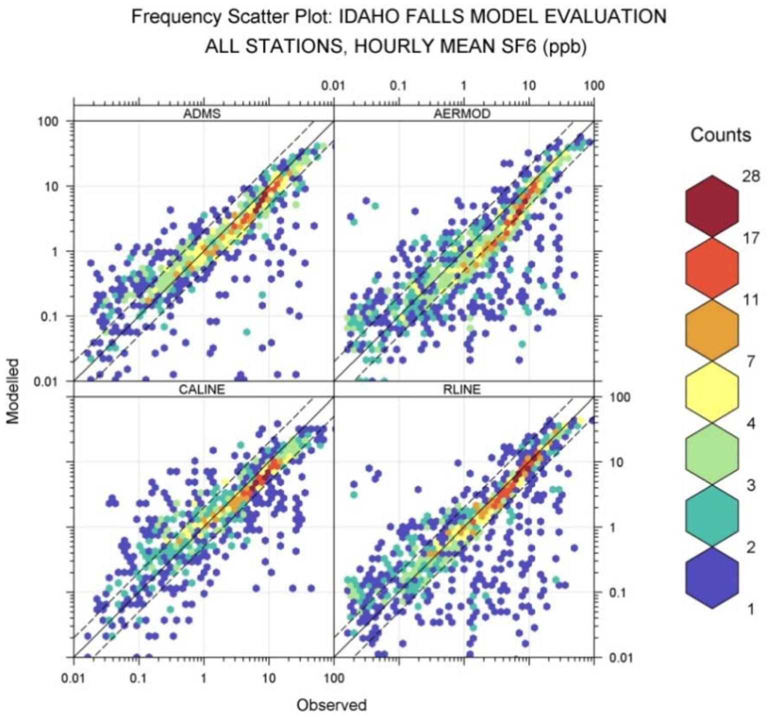

Figure 2. Frequency scatter plots of modelled against observed SF_6 concentrations for all Idaho Falls data, showing ADMS-Roads, AERMOD (volume source), CALINE 4 and RLINE.

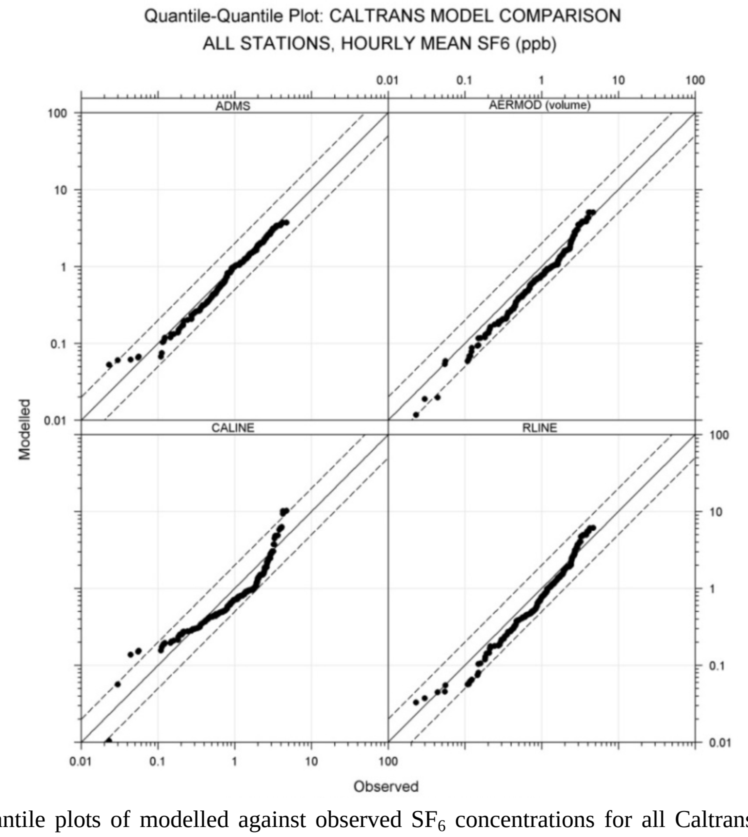

Figure 3. Quantile-quantile plots of modelled against observed SF_6 concentrations for all Caltrans data, showing ADMS-Roads, AERMOD (volume source), CALINE 4 and RLINE.

Table 3 gives the results of statistical analysis of the Caltrans study. The models also perform well for this study, and it may be that once again, the difference between the models' performances is not statistically significant compared to the measurement uncertainty. The possible exception to this is CALINE, which has a noticeably higher NMSE and lower correlation compared to the other models. ADMS-Roads achieves the best NMSE, correlation and model predictions within a factor of two of the observations; AERMOD, with the emission represented as a volume source, has the best standard deviation and fractional standard deviation; and RLINE demonstrates closest agreement to the mean concentration, bias and fractional bias. Figure 3 shows the quantile-quantile plots for all model results, as generated by the MyAir Toolkit. As for the frequency scatter plots, the results are shown on logarithmic scales, and all points within the dashed lines are within a factor of two of the observed data. When the data are presented in this way, where the observations are no longer paired in space and time, with the exception of CALINE, each of the models shows good agreement with observations.

Table 3. Caltrans summary statistics calculated using the MyAir Toolkit

Data	Mean	Sigma	Bias	NMSE	R	Fac2	Fb	Fs
Observed	1.47	0.96	0.00	0.00	1.00	1.00	0.00	0.00
ADMS-Roads	1.34	0.88	-0.13	0.20	0.78	0.85	-0.09	-0.08
AERMOD (area)	1.29	1.05	-0.18	0.31	0.72	0.76	-0.13	0.09
AERMOD (volume)	1.26	1.03	-0.21	0.28	0.77	0.78	-0.15	0.08
CALINE	1.22	1.32	-0.26	0.86	0.47	0.68	-0.19	0.31
RLINE	1.40	1.26	-0.07	0.34	0.75	0.78	-0.05	0.27

DISCUSSION

This paper summarises the results from a road source model intercomparison study undertaken with four models and two observational datasets. Comparisons between modelled and observed concentrations made for data paired in both space and time are encouraging for all models. When this restriction is removed, as shown in the quantile-quantile plot Figure 3, comparisons are excellent, particularly for the ADMS-Roads, AERMOD (volume source) and RLINE models.

The Idaho Falls dataset has a grid of receptors downwind of the source, which allows evaluation of the models' ability to represent lateral dispersion; the detailed source and meteorological data available for this recent study are likely to contribute to the good performance of the dispersion models. Good comparison between model data and observations for the Caltrans experiment is also encouraging, as there is more uncertainty for this real-world experiment, for instance in relation to vehicle induced turbulence. The receptor network for Caltrans is such that there is less emphasis on lateral dispersion, and this, together with the increased averaging time, explains why the statistics for most models are better for Caltrans than Idaho Falls. Further details of the study, including analysis of results categorised according to wind speed and meteorological conditions are given in Heist *et al.* (2013).

DISCLAIMER

This paper has been reviewed in accordance with the United States Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

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