17th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 May 2016, Budapest, Hungary

A REVIEW OF DISPERSION MODELLING OF AGRICULTURAL AND BIOAEROSOL EMISSIONS WITH NON-POINT SOURCES

Jenny Stocker[1], Andrew Ellis[1], Steve Smith[2], David Carruthers[1], Akula Venkatram[3], William Dale[1] and Mark Attree[1]

[1]Cambridge Environmental Research Consultants, Cambridge, UK
[2]A S Modelling & Data Ltd, UK
[3]University of California, CA, US

Abstract: This paper presents some key aspects of a review of limitations and uncertainties associated with modelling pollutant dispersion from non-point sources, focussed on emissions from agricultural and bioaerosol sources. The plume dispersion models ADMS and AERMOD were used to represent releases from four sheds housing intensively farmed poultry. When the emission and volume flow rates used in the modelling were derived from measurements, the models give reasonably accurate predictions for the period average near-source NH_3 concentrations. However for releases with non-negligible efflux, modelling using non-point sources allowing for the momentum and buoyancy of the release (line, point and area sources in ADMS; buoyant line source in AERMOD) has much better agreement with observations than those that do not (volume sources in ADMS; volume, area and default line source in AERMOD); in these cases, neglecting plume rise results in an overestimate of both period average and maximum concentrations.

Key words: *Dispersion, ammonia, odour, non-point sources, agriculture, poultry*

INTRODUCTION

There are many regulated sources of pollution which have complex geometries near or at ground level. These include pig and poultry farms which may have high emissions of ammonia (NH_3) and particulates from sheds of intensively farmed animals, from litter and manure storage, and land spreading, and also composting sites, where bio-waste such as that contained within windrows emits fungi and bacteria. In environmental impact assessments such sources are often represented using 'non-point source' configurations i.e. line, area, jet or volume sources. In contrast to point sources, for which extensive model validation has been conducted, the use of non-point sources to model agricultural and bioaerosol emissions is relatively poorly quantified. This is both because the sources usually have crudely defined physical characteristics and because the emissions are often highly uncertain.

A review of approaches to modelling pollutant dispersion from non-point sources was recently undertaken for the particular case of agricultural and bioaerosol sources (Stocker *et al.* 2016). Part of the review involved collating a parameter space of values used to characterise non-point source types. This was then used to formulate idealised modelling scenarios, where concentration outputs from the ADMS (Carruthers *et al.*, 1994) and AERMOD (Cimorelli *et al.*, 2005) models were compared for the different non-point source types. The review also involved using ADMS and AERMOD for three agricultural and one bioaerosol real-world case studies; model predictions were compared with observations to assess the suitability of each source type and model for each case. Overall the review has led to a number of conclusions on the best approach to modelling agricultural and bioaerosol sources. The current paper focuses on presenting results from the most robust study, that for Whitelees Farm (Hill *et al.*, 2014), where continuous monitoring of NH_3 concentrations was undertaken close (60 m) to four poultry sheds. The results from two other studies involving particulate emissions from poultry housing and one of the dispersion of bioaerosols from a small UK composting site are not discussed further in this paper.

CASE STUDY DESCRIPTION

Whitelees Farm is located in South Lanarkshire, Scotland. The site houses approximately 37,000 laying hens housed in four identical rectangular sheds, closely spaced and aligned parallel to each other. Each shed is divided into two buildings ventilated through a series of ten fan-assisted cowls pointing upwards at a 45° angle on each long side, giving a total of 80 vents. Meteorological data from an onsite automatic weather station were recorded at 30 minute intervals and then averaged to derive hourly values for modelling. Data were available for the period between 14th August 2013 and 4th November 2013. Three datasets were used for model validation: continuous NH_3 monitoring from a single station approximately 60 m to the north of the farm (co-located with the meteorological measurements); two sets of fixed-period NH_3 measurements recorded using Alpha Samplers at 9 locations surrounding the farm; and odour measurements from transects on the 19th of September ('sniffers' measured odour levels for a ten minute period within each hour at each location). Volume flow rates, NH_3 and odour concentrations were measured at a number of vents across the site during two days of the campaign; on these two days, a maximum of 4 vents operated per building. These measurement data were used to estimate average flow rates and emissions and are summarised in Table 1. Figure 1 a) shows the locations of the NH_3 monitors and meteorological station and Figure 1 b) indicates where the odour measurements were recorded.

Table 1. Calculated emissions parameters for the Whitelees farm site

Modelling period	**Volume flow rate (m^3/s)**	**NH_3 emission rate (g/s)**	**Odour emission rate (ou_E/s)**
19/09/2013	55.8	0.86	14740
Whole period	52.7	0.98	14470

a) b)

Figure 1. a) Aerial photograph of the location of the onsite meteorological station (White 1) co-located with continuous ammonia monitoring equipment; White 2 to White 9 indicate the locations of additional ammonia measurements; figure taken from Hill *et al.* (2014), reproduced here with permission from Sniffer. b) Whitelees Farm showing buildings (orange rectangles) and receptors (dark green dots); receptor numbers and arrows of locations of odour measurements on Sept 19th; background map courtesy of ©Crown copyright and database right, 2015.

MODEL CONFIGURATION

When modelling dispersion from a poultry house, it is standard practice to model a representative subset of sources on the building as, typically, release data are not available on a vent-by-vent basis. This was the approach taken for the current study. Figure 2 shows the horizontal representation for each source type (point, jet, volume, area and line) used to model the release. Single area and volume sources were used to model all four sheds and the line sources located to approximate the position of the side vents on of the sheds. Four vents were assumed per building, with two vents evenly spaced along each side. In order to model the odour emissions, average emissions and volume flow rates were used for the day when odour concentrations were measured. For modelling longer periods (i.e. to predict NH3concentrations), the average parameters measured across the campaign were used. For point, line, and area sources, the vertical component of the calculated exit velocity was used as the modelled exit velocity. Source dimensions and exit parameters are given in Table 2; note that ADMS volume and AERMOD volume, area and default line source types do not allow for plume rise in the dispersion calculations. The surface roughness length was taken as 0.2 m to represent the mainly open area around the site. Receptors were 1.5 m above ground. Versions 5.1 (ADMS) and 15181(AERMOD) were used throughout.

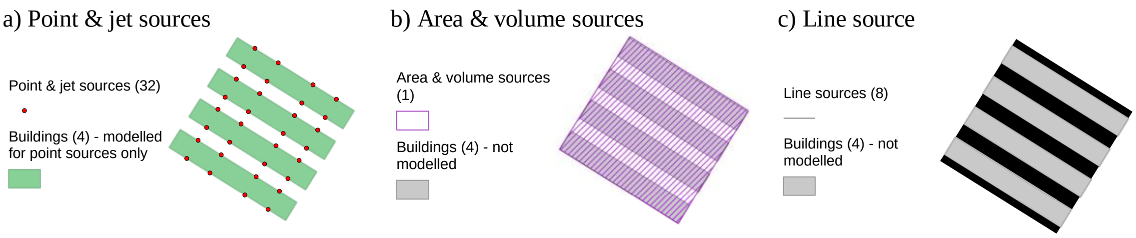

Figure 2. Source representations for Whitelees Farm; buildings explicitly modelled with point sources only

Table 2. Whitelees farm source parameter ranges; *ADMS only, AERMOD jet sources are wind aligned; +AERMOD area and default line source do not account for plume rise

Idealised source type	Source dimensions (m)			Efflux parameters	
	Height (m)	**Diameter (m) / Dimensions: Length (m) x Width (m) x Depth (m)**	**Elevation angle to horizontal***	**Temperature (°C)**	**Ammonia / odour velocity (m/s)**
Point	2	0.72	n/a	17.4	2.8 / 3.0
Jet*	2	0.72	45°	17.4	4.0 / 4.2
Volume	2	94 x 90 (x 2)	n/a	n/a	n/a
Area+	2	94 x 90	n/a	17.4	0.0062 / 0.0066
Line+	2	94 x 5	n/a	17.4	2.8 / 3.0

RESULTS

Tables 3 and 4 present the model evaluation statistics relating to the continuous monitor for both ADMS and AERMOD. These comprise: period averages (mean); normalised mean square error (NMSE); correlation (R); the number of modelled values within a factor of two of the observed (Fac2); the index of agreement (IoA), used to represent overall model performance (spans between -1 and +1, with values approaching +1 representing better performance); and maximum concentrations. Model performance is quite variable depending on model and source type, but of note is that modelled means are within a factor of two of the observed for all cases, suggesting that the simplifications regarding the emission and volume flow rates are appropriate. For ADMS, NMSE, R and IoA indicate generally good model performance for all sources except the volume source, for which concentrations are overestimated. For AERMOD, the statistics indicate that model performance is good for the point and buoyant line sources, but limited for the area, default line and volume sources. In addition these cases exhibit very large overestimates of maximum values. The conclusion is that the source types which take into account the initial plume momentum and buoyancy perform significantly better than those which are assumed to be passive. Comparing ADMS and AERMOD, we conclude that AERMOD has a tendency to predict higher concentrations than ADMS, with the notable exception of the buoyant line source which gives the lowest model predictions over all source types. The plot of NMSE against fractional bias, Figure 3, summarises the models' performance; the most accurate models have symbols that are closest to (0,0). Figure 4 presents a selection of ADMS and AERMOD contour plots of modelled concentrations for one of the fixed periods (27 days), with the measurements overlaid using the same colour scale. For ADMS, the jet source model configuration has been presented alongside the volume source results. The jet source gives a good representation of the spatial variation of the observations, both near and far from the source, whereas, as we would anticipate from the previous discussion, the volume source overpredicts ground level concentrations at all locations. The AERMOD point source slightly overpredicts the concentrations and the volume source significantly overpredicts. Figure 5 presents comparisons between the measured and modelled odour concentrations for the single day considered. Observed odour concentrations are reasonably well predicted by the ADMS jet and AERMOD point source types; the AERMOD buoyant line source follows a similar trend to the other source types, but exhibits a large underprediction.

Table 3. ADMS Model evaluation statistics for Whitelees; 'best' values are in bold

Idealised source type	**Average statistics**						**Maximum statistics**	
	Obs. Mean (μg/m³)	**Mod. mean (μg/m³)**	**NMSE**	**R**	**Fac2**	**IoA**	***Obs. maximum***	**Mod. maximum**
Area	*119*	67	0.97	**0.66**	0.41	0.61	*362*	**388**
Jet	*119*	96	**0.60**	0.63	**0.53**	**0.65**	*362*	445
Line	*119*	**104**	0.90	0.52	0.52	0.60	*362*	961
Point	*119*	87	1.07	0.47	0.41	0.57	*362*	872
Volume	*119*	163	7.54	0.18	0.48	0.26	*362*	3997

Table 4. AERMOD Model evaluation statistics for Whitelees: 'best' values are in bold

Idealised source type	**Average statistics**						**Maximum statistics**	
	Obs. Mean (μg/m³)	**Mod. mean (μg/m³)**	**NMSE**	**R**	**Fac2**	**IoA**	***Obs. maximum***	**Mod. maximum**
Area	*119*	196	13.3	0.14	**0.44**	0.04	*362*	5736
Default line	*119*	200	13.3	0.14	**0.44**	0.02	*362*	5750
Buoyant line	*119*	64	**1.2**	**0.60**	0.33	**0.58**	*362*	**198**
Point	*119*	**151**	1.9	0.48	0.43	0.46	*362*	1789
Volume	*119*	**151**	9.8	0.15	0.35	0.19	*362*	4860

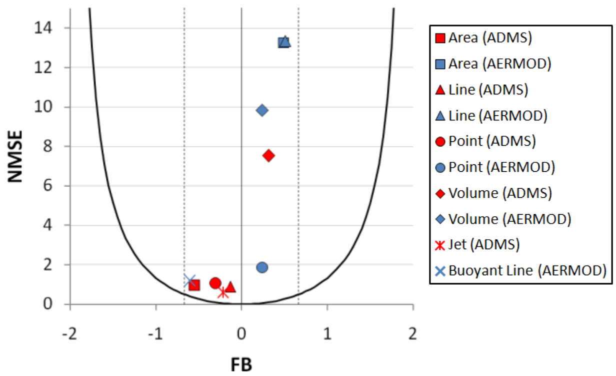

Figure 3. NMSE against fractional bias (FB) for all source types; buildings explicitly modelled with point sources only. Black line indicates minimum NMSE possible for FB.

DISCUSSION

This model evaluation study demonstrates that when accurate estimates (or measurements) of emission and volume flow rates are available, the dispersion models ADMS and AERMOD are able to predict average near-source concentrations within a factor of two of the measured values when non-point source types are used to represent the release. Using source types for which models allow for initial plume momentum and buoyancy leads to much better model performance. As the sources at Whitelees are jets at a 45° angle, it is unsurprising that this source type performs best in ADMS. For AERMOD, where the jet source type could not be used due to the source type restrictions (wind alignment), the new buoyant line source gives the best correlation with measurements, however concentrations are underpredicted. Although the non-point source types considered neglect building effects, predicted model concentrations are comparable to those from point source configurations where the effect of buildings are included. This suggests that the impact on dispersion of low-level agricultural sheds and buildings at waste sites may be unimportant. Possible explanations for this are the limited downwash resulting from the low buildings and the limited impact of building-induced turbulence because the sources are already spread out.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the UK Atmospheric Dispersion Modelling Liaison Committee who funded this study and to Sniffer who provided the Whitelees dataset.

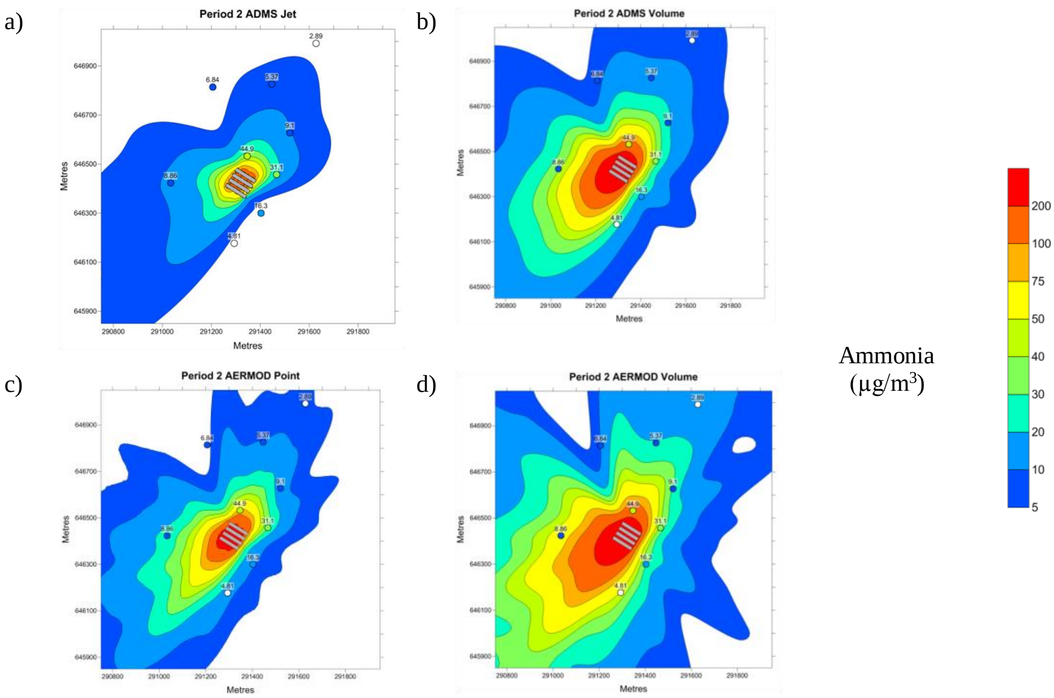

Figure 4. Period average NH_3 for Whitelees ‘Run 2’: a) ADMS jet, b) ADMS volume, c) AERMOD point and d) AERMOD volume. Observations shown by the circles, the buildings are shown in grey (modelled in c)).

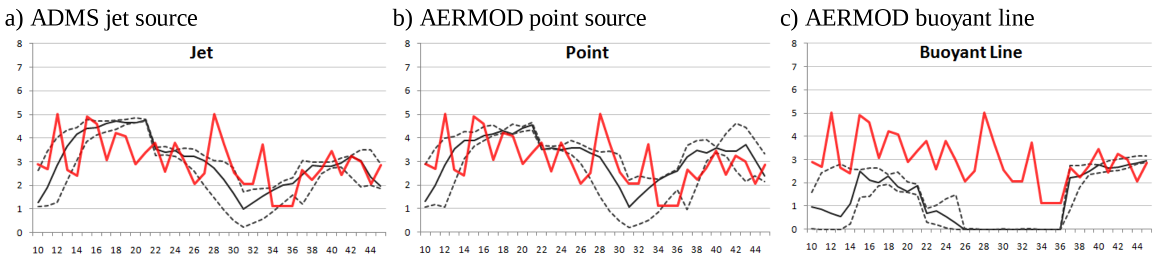

Figure 5. Short-term odour results for Whitelees a) ADMS jet, b) AERMOD point and c) AERMOD buoyant line sources; observations shown in red, minimum, median and maximum modelled values shown in black, where range of modelled values corresponds to wind direction adjustments of ±15°. Horizontal axis shows transect receptor number, as shown in Figure 1b).

REFERENCES

Carruthers, D. J, R. J. Holroyd, J. C. R. Hunt, W-S. Weng, A. G. Robins, D. D. Apsley, D. J. Thompson and F. B. Smith, 1994: UK-ADMS: A new approach to modelling dispersion in the earth's atmospheric boundary layer. *J. of Wind Engineering and Industrial Aerodynamics*, **52**, 139-153.

Cimorelli, A. J., S. G. Perry, A. Venkatram, J. C. Weil, R. J. Paine, R. B. Wilson, R. F. Lee, W. D. Peters and R. W. Brode, 2005: AERMOD: a dispersion model for industrial source applications. Part I: general model formulation and boundary layer characterization. *J. Appl. Meteorol.*, **44**, 682–693.

Hill, R., B. Bealey, C. Johnson, A. Ball, K. Simpson, A. Smith, M. Theobald, C. Braban, I. Magaz and T. Curran, 2014. SCAIL Agriculture. Sniffer ER26 Final Report. http://www.scail.ceh.ac.uk/agriculture

Stocker, J., A. Ellis, S. Smith, D. Carruthers, A. Venkatram, W. Dale and M. Attree, 2016: A review of the limitations and uncertainties of modelling pollutant dispersion from non-point sources. Report for the UK Atmospheric Dispersion Modelling Liaison Committee.