Evaluation of the UK-ADMS Buildings Effects Module using data on the near-field dispersion of ammonia at an intensive dairy farm

R A Hill[a], R J Parkinson[b], B F Pain[c], V R Phillips[d] and I Lowles[a]

[a] Westlakes Scientific Consulting Ltd, The Princess Royal Building, Westlakes Science and Technology Park, Moor Row, Cumbria, CA24 3LN.
[b] Department of Agriculture and Food Studies, Seale-Hayne Faculty, University of Plymouth, Newton Abbot, Devon, TQ12 6NQ.
[c] Institute of Grassland and Environmental Research, North Wyke Research Station, Okehampton, Devon, EX20 2SB.
[d] Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS.

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1 Introduction

Emissions of ammonia (NH_3) into the atmosphere are dominated by the contribution of intensive agricultural sources. Estimates for 1997 suggest that UK agriculture accounted for an emission of 226 kt NH_3-N (Misselbrook *et al.*, 2000). For comparison, non-agricultural sources were estimated to account for 54 kt NH_3-N in 1996 (Sutton *et al.*, 2000).

The atmospheric deposition of NH_x (gaseous NH_3 and particulate NH_4^+) has been shown to have detrimental effects on many natural and semi-natural ecosystems, principally through soil acidification and eutrophication. Critical load exceedance maps for the UK have been calculated by Sutton *et al.* (1998). Their results showed that widespread exceedances were predicted to occur (taking into account deposition of SO_x and NO_x) with the critical load for acidity in forest soils being exceeded over 76 % of rural non-agricultural land. Deposition of NH_x alone was estimated to be responsible for 43 % of the area over which exceedances were predicted to occur.

As a result of the increases in the scientific understanding of the effects of NH_3 as a pollutant national emissions are to be regulated through international legislation from the UN-ECE and European Parliament. Furthermore, the local peaks in air concentrations and deposition that occur close to livestock buildings are to be regulated through the EC Directive on Integrated Pollution Prevention and Control (IPPC).

This paper compares NH_3-N air concentrations, measured within 10-100 m of a naturally ventilated dairy farm building, with the predictions of the UK-ADMS atmospheric dispersion model. The work was conducted as part of a multi-disciplinary project evaluating the distribution and effects of UK NH_3 emissions (ADEPT project), details of which can be found in Sutton *et al.* (1998). Further details of the study and estimates of local deposition fluxes can be found in Hill (2000).

2 Methods

2.1 Site

Field experiments were conducted between 20/03/1997 and 03/04/1997 at a commercial dairy farm in Devon (UK) which housed 120 animals. Emissions of NH_3 during this period were dominated by the contribution of the main building on the site, due to the indoor overwintering of animals. The other main source of atmospheric NH_3 on the site was a slurry lagoon, located 20 m south of the main building. A second auxiliary cowshed, housing a small number of animals, was immediately to the west of the main dairy building. The layout of the study area is shown in Figure 1. No other significant NH_3 sources were present within approximately 1 km of the site.

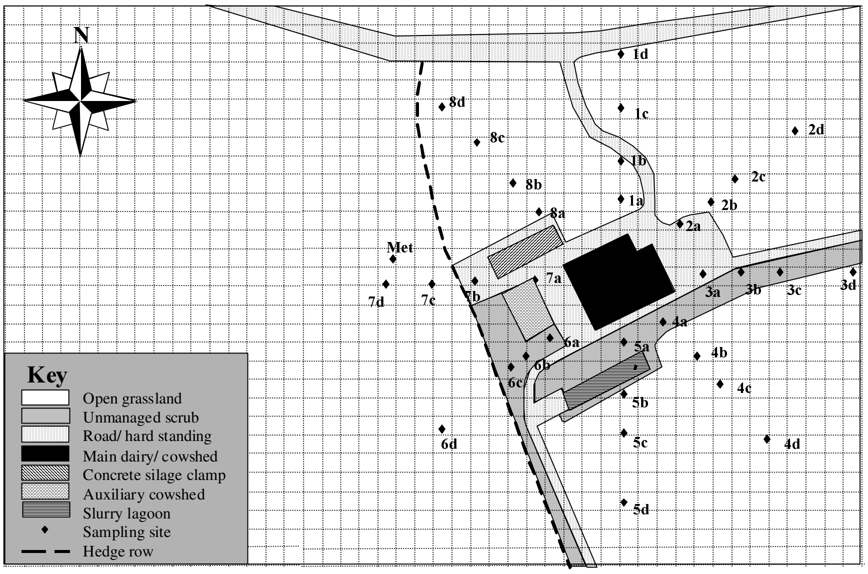


Figure 1: Map of the dairy farm in Devon (UK) showing the positions of the NH_3 sampling masts, and the layout of the buildings. The area is shown on a 10 m x 10 m grid.

2.2 Estimation of the emission flux from the building

Emissions from the main building on the site were measured using passive flux samplers following the method of Phillips *et al.* (1998). Measurements were made over two 24 hour periods, one starting on 28/03 and the second starting on the 02/04. Ammonia fluxes from the roof and walls of the buildings (in $\mu g\ NH_3\text{-}N\ s^{-1}$) were calculated from the average of the passive flux sampler measurements (in $\mu g\ NH_3\text{-}N\ m^{-2}\ s^{-1}$) and the open-face area being considered (in m^2). The total emission flux from the building was calculated as the sum of the fluxes from all the contributing ventilation points.

The passive flux samplers were positioned at 94 sites on the farm buildings. Fifty nine pairs of flux samplers were positioned on the slatted walls and other open doorways of the main building and auxiliary cowshed. The remaining samplers were positioned on the roof of the main building.

2.3 Estimation of the emission flux from the slurry lagoon

Emission fluxes (F_χ) from the slurry lagoon were calculated from air concentration measurements (corrected for background), $\chi\{x,z\}$, at the sampling mast on the downwind edge of the slurry lagoon and dispersion factors, $D_f\ \{x,z\}$, predicted using UK-ADMS, using Equation 1. Estimates of the 24 hour averaged emission flux from the lagoon were recorded for all runs with the exceptions of the run on the 28/03 where the dominant contribution of background NH_3, advected from the main building, prevented such measurements.

$$F_\chi = \frac{\chi\{x,z\}}{D_f\{x,z\}} \tag{1}$$

2.4 Measurement of NH_3 air concentrations

Air concentrations of NH_3 were measured, as 24 hour averages, using passive diffusion samplers known as "Willems badges" (Willems, 1990). Thirty two sampling masts (4.5 m in height) were positioned on a radial grid around the site. The positions of these masts are shown in Figure 1. Passive diffusion samplers were placed on the masts, in the prevailing 180^o wind sector for each run, at heights of 0.5 m, 1.5 m, 2.5m, and 4.5 m, to measure both the horizontal and vertical gradients in NH_3 concentration. A portable sampling mast was used to measure concentration gradients to 11.5 m using 13 diffusion samplers. This mast was positioned close to Site 4b in Figure 1 during the first two runs and was moved to a position close to Site 3c during the subsequent runs.

2.5 Modelling dispersion from the farm

The UK-ADMS model (version 2.2) was used to model the atmospheric dispersion of NH_3 released from the farm. A roughness length of 0.3 m was used in the model, the default for dispersion over agricultural areas (CERC, 1995). The buildings module was set up to include the main building on the site as a rectangular block (48 m x 40 m x 7 m). As the topography around the site was reasonably flat, terrain effects were not considered. Sixteen point sources were placed on the edges of the building to simulate the release of material through the naturally ventilated sides and a single point source (with a 20 m diameter) was used to simulate emissions from the roof. The hourly sequential meteorological data that were used as model input were obtained from a meteorological site adjacent to the building, shown in Figure 1.

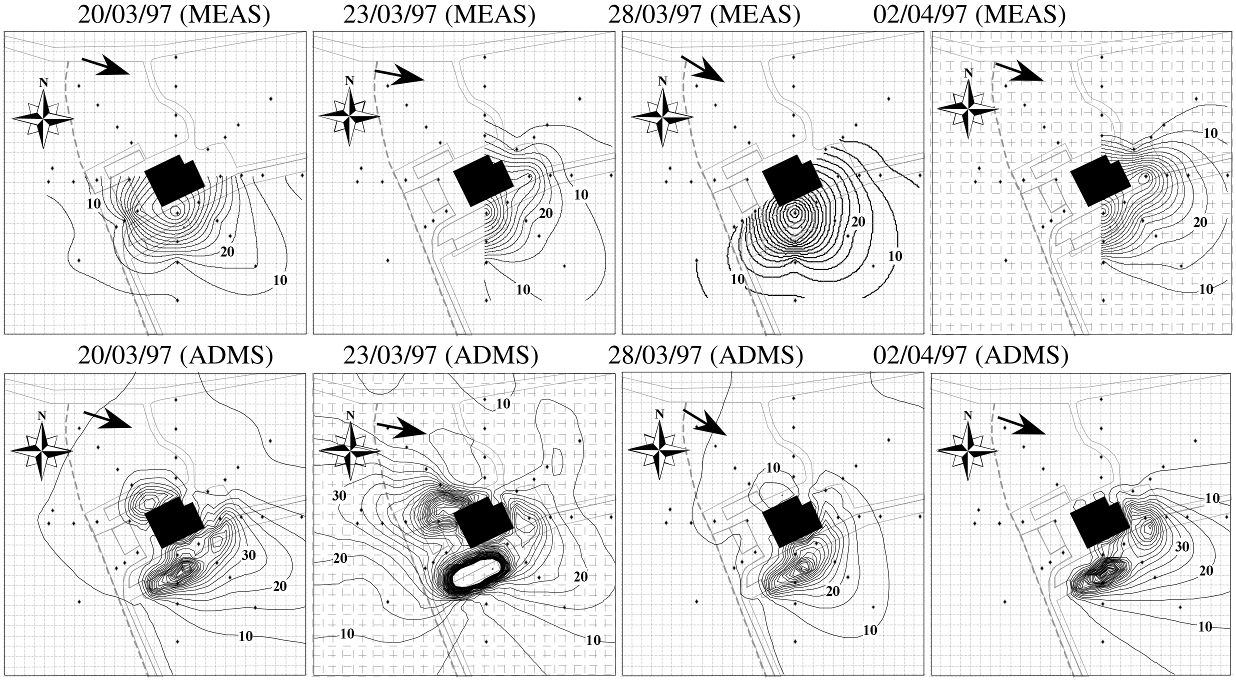
3 Results

3.1 Emissions of NH_3 from the site

The average daily atmospheric emission of NH_3-N from the site was 4.8 kg NH_3-N. This emission was distributed such that the main building walls contributed 48 %, the main building roof contributed 34 % and the slurry lagoon contributed 18 %. No emission could be detected from the auxiliary building on the site.

3.2 Horizontal distribution of ground level NH_3 concentrations

Contour plots showing the measured and modelled ground level air concentration field are presented in Figure 2. These plots were calculated using field measurements at 0.5 m and interpolating between points using Surfer 32 (Golden Software Inc.).


20/03/97 (MEAS) 23/03/97 (MEAS) 28/03/97 (MEAS) 02/04/97 (MEAS)

20/03/97 (ADMS) 23/03/97 (ADMS) 28/03/97 (ADMS) 02/04/97 (ADMS)

Figure 2: Contour plots of measured (MEAS) and modelled (ADMS) ground level air concentrations (in μg NH_3-N m^{-3}), averaged over 24 hour periods, around the dairy farm. Results are shown to scale of 1:15000. Arrows show the median wind direction. Contours are shown with a resolution of 5 μg NH_3-N m^{-3}.

The measurements demonstrated that NH_3 plumes from the building and the slurry lagoon dispersed over the fields to the south-east of the farm, as would be expected from the predominant north westerly wind directions. Maximum concentrations (up to 100 μg NH_3-N m^{-3}) were measured close to the building, decreasing to between 10 – 15 μg NH_3-N m^{-3} at 100 m from the building. Background concentrations were constant at around 4 μg NH_3-N m^{-3} for each run.

Reasonable agreements were found between plume directions, lateral spreads and magnitudes of the measured and modelled concentration distributions. However, much higher concentrations were predicted to the north east of the building during the second run (23/03) than were measured.

Modelled and measured concentrations, on sampler arrays 3, 4 and 5 (see Figure 1) were also compared directly, the results are shown in Figure 3. A single outlying datapoint was removed from the analysis (Site 5a 02/04/97). The results demonstrated a statistically significant correlation between the measured and modelled concentrations (R^2= 0.55, $p < 0.001$) with the model predicting an ensemble mean concentration of 28.3 μg NH_3-N m^{-3} which compared with an ensemble mean from the measurements of 28.9 μg NH_3-N m^{-3}. Overall, 85 % of the model predictions were within a factor of 2 of the measurements.

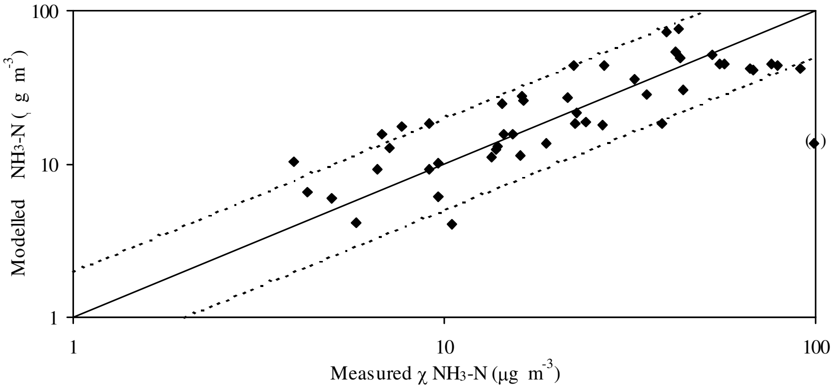


Figure 3: Comparison between measured and modelled ground level NH_3 concentrations around the dairy farm. The data point in parenthesis was excluded from the statistical analysis.

3.3 Vertical distribution of NH_3 concentrations

Measurements from the mobile 11.5 m sampling mast were compared with the predictions of the vertical NH_3 concentration profile from the UK-ADMS model (Figure 4). The measurements and model predictions were in a reasonable agreement on both the magnitude and shape of the concentration profile, though the model tending to underpredict concentrations measured on the 28/03 and 02/04.

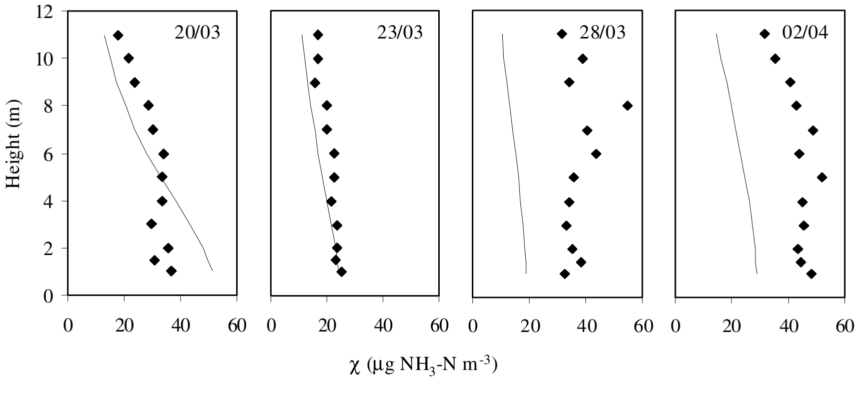


Figure 4: Vertical NH_3-N air concentration profiles measured (♦) and modelled using UK-ADMS (—).

4 Discussion and conclusions

In general, the UK-ADMS model results compared well with the measurements of NH_3 concentrations around the site, in both magnitude and distribution. Hence, for most cases, UK-ADMS was found to be a reasonably robust tool for use in the regulatory modelling of the local dispersion of agricultural emissions. However, two cases were identified where obvious differences were found between the UK-ADMS predictions and the field measurements.

Differences between the measured and modelled spatial distribution of NH_3 concentrations on the 23/03 were likely to be due to a substantial period of near-calm atmospheric conditions. During the monitoring period wind speeds at 3 m were less than 1 m s^{-1} for 46 % of the time and large standard deviations of the hourly wind direction were measured. Such conditions are well known to be difficult to treat realistically using steady-state Gaussian plume models.

Vertical concentration profiles, measured on 28/03 and 02/04, showed that the UK-ADMS model systematically underpredicted the measured concentration. This was likely to be due to the UK-ADMS Buildings effects module (Robins *et al.*, 1997) treating the building as being at an orthogonal angle to the wind for all wind directions. This may have led to the underprediction of the role of roof corner vortices for oblique wind angles, such as would have occurred during these periods. Indeed, a much improved comparison was found between the model predictions and the field measurements on 20/03 and 23/03, when the monitoring site was at an orthogonal angle to the building.

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