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EXTENDED ABSTRACT

An inter-comparison of methods for modelling deposition of ammonia from intensive farms

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Introduction

Regulating nitrogen deposition, particularly ammonia (NH_3), is important for preserving sensitive habitats and species. For instance, ammonia causes direct damage to sensitive species and acidification of soils and freshwaters. Under EU directives, EU member states must maintain such sites (classified as Natura 2000) and make NH_3 reduction commitments where necessary. These have led to national regulations such as the UK's Habitats Regulations (2017). Farming is the largest source of NH_3, and farms can be located close to, or some distance from, sensitive habitats. Although measurements can assess the relative impact of an operational farm, air dispersion models are often used to ensure that farming activities do not exceed regulatory nitrogen deposition limits.

Gaseous pollutant dry deposition rates are defined by their dependence on various resistance terms: for example, in ADMS [1], they relate to the sum of the aerodynamic (affected by e.g. meteorological conditions, surface roughness), sub-layer (affected by e.g. molecular diffusivity), and surface-layer (affected by e.g. stomatal opening, chemical reactivity) resistances. Other models, such as RIVM's DEPAC ('DEPosition of ACidifying Compounds') module, further break down the surface-layer resistance term and include a compensation point term which allows for bi-directional transfer of the gas. The reciprocal of resistances is used to define a deposition velocity (v_d) parameter, and the dry deposition rate per unit area (F_{dry}) is assumed to be proportional to the near surface concentration (C): $F_{dry} = v_d C$. As NH_3 is a highly reactive substance, NH_3 deposition fluxes are relatively large, e.g. compared to NO_X, but at high near-ground concentrations, NH_3 deposition is inhibited. For example, Figure 1 shows measurements from a fumigation experiment [2], where annual average NH_3 concentrations were measured at two heights above the vegetation and combined with measured resistances (field and flux chamber) to estimate annual average deposition velocities. Within tens to hundreds of metres of a farm, where deposition may occur, there is therefore a risk associated with neglecting this inhibition in modelling. Specifically, the dependence of NH_3 deposition on ambient concentrations reduces plume depletion in the near field, leading to relatively higher concentrations (and hence higher deposition) at large distances, potentially at sensitive habitats.

In 2010, the UK government introduced air quality intensive farming guidance for NH_3 that recommended modelling concentration-dependent deposition (CDD) velocities derived from annual average concentrations. Modelling methods such as this should be validated through comparison with measurements whenever possible, for instance, the recent Dutch National Institute for Public Health & the Environment (RIVM') 'Knowledge Programme Nitrogen' (KPN) involved an NH_3 concentration and deposition model inter-comparison, using data from the Ringsted poultry farm in Denmark [3][1].

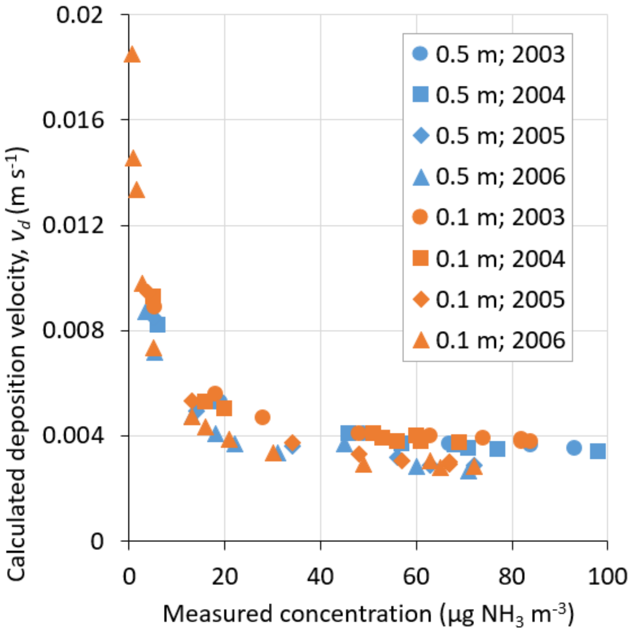

Figure 1 – Multi-year, annual average NH_3 v_d estimates against ambient concentrations at two heights (0.1 m and 0.5 m) [2].

Here, we utilise this dataset to compare the current UK guidance modelling approach with other methods that account for CDD including: hourly CDD velocity method; implementation of the 'big-leaf' approach used in UK CEH's CBED ('Concentration Based Estimated Deposition') model; and DEPAC. Methods are tested using CERC's ADMS 6 dispersion model [1].

Methods

Full details of the Ringsted poultry farm NH_3 measurement campaign are given in [3]. The baseline ADMS model configuration for this case study was configured recently during RIVM's KPN project. Figure 2 shows the Ringsted Farm site, comprising two barns housing hundreds of chickens, each with a row of 4 exhausts. NH_3 measurement equipment was placed radially from the farm up to distances of 600 m, measuring concentrations using passive flux samplers (three periods of two/three weeks) and surface deposition flux pot biomonitors (54-day exposure).

Method 1 – UK guidance modelling approach

UK government air quality intensive farming guidance states that CDD velocities should be used when deriving NH_3 dry deposition from annual average concentrations. The

[1] CERC's involvement in this project was part-funded by RIVM, with financial contributions from the Northern Ireland Department of Agriculture, Environment and Rural Affairs (DAERA) and the Atmospheric Dispersion Modelling Liaison Committee (ADMLC).

concentration thresholds (Table 1) lie within the range of the measurements (Figure 1). A dispersion model such as ADMS is executed twice: once to calculate average ground-level concentrations (without accounting for plume depletion); and secondly to calculate deposition fluxes using spatially varying deposition velocities (Table 1).

Figure 2 – Ringsted poultry farm site, with NH_3 passive flux samplers (blue squares) & deposition biomonitors (yellow circles). Two barns viewed from the southeast (inset).

Table 1 - Current UK guidance NH_3 concentration dependent deposition velocities.

Total annual average NH_3 concentration (process contribution + background, µg/m^3)		< 10	10 – 20	20 – 30	30 – 80	> 80
Deposition velocity (m/s)	Short vegetation	0.02	0.015	0.01	0.005	0.0035
	Tall vegetation	0.03	0.015	0.01	0.005	0.0035

Method 2 - Hourly implementation of UK regulatory modelling approaches

Resistance terms underlying NH_3 deposition processes depend on parameters including ambient concentrations and meteorological conditions that vary on short timescales (e.g. hourly). Thus, methods that account for hourly dependence may provide more accurate estimates of NH_3 deposition than the annual average *Method 1*. As a first step to quantifying the impact of hourly dependence, *Method 2* applies spatially-varying CDD velocities from Table 1 on an hourly basis, even though they are derived from annual data; resulting hourly deposition fluxes are then averaged to calculate an annual value. *Method 2* neglects the direct influence of hourly meteorology on NH_3 deposition velocity.

Method 3 – 'Big-leaf' approach used in UK CEH's CBED model

UK CEH operate the Air Pollution Information System (APIS) which provides data for the UK relating to pollutants that are harmful to habitats and species. APIS incorporates a 'big-leaf' methodology within its CBED model to derive deposition fluxes from hourly concentrations, accounting for the dependency of NH_3 deposition on surface characteristics, ambient concentrations and meteorology. The name 'big-leaf' refers to the description of the various types of vegetation present as a single leaf representing the entire area; method details are given in Smith *et al.* [4]. Our implementation of the 'big-leaf' method uses hourly concentration and meteorological data from *Method 2*. Hourly calculations of v_d using the equations given in [4] provide deposition fluxes; we interpolate values for gross primary production (GPP) and the rate of carbyonyl sulphide (OCS) uptake (ROCS) in plants, which vary over the growing season, from Table 5.26 of reference [5] which uses measurements from [6].

Method 4 - RIVM's DEPAC module

RIVM develop and support OPS-ST, a dispersion model that incorporates complex modelling of NH_3 deposition via DEPAC. DEPAC accounts for surface characteristics, ambient concentrations and meteorology, and outputs hourly predictions of v_d. OPS-ST was set up for Ringsted by RIVM during the aforementioned KPN project and the group subsequently shared their output for inclusion in the current study. DEPAC v_d values were interpolated to generate a spatially varying deposition file covering the full domain prior to being used as hourly input to ADMS. Note that these v_d values correspond to OPS-ST, rather than ADMS, concentrations.

Results

Intercomparison of ammonia deposition models

The 'big-leaf' and DEPAC methods are similar with regard to the use of a compensation point approach to allow bi-directional exchange of ammonia, but differ in terms of how the compensation point concentration, and associated resistance terms, are calculated. Negative v_d values, representing ammonia exchange from stomata to the atmosphere, are necessarily set to zero (i.e. no deposition) in ADMS for both these methods. Figure 3(a) and (b) compare modelled and measured concentrations and deposition flux values, respectively. As modelled concentrations are under-predicted for all methods, for a consistent deposition module, deposition fluxes would also generally be under-predicted i.e. the 'best' outcome for deposition is not 1:1 agreement between modelled and measured values. Modelled deposition ranges by up to a factor of 10 for the lowest and a factor of 3 for the highest values. The UK guidance (annual) method appearing to over-predict deposition and the more complex hourly methods (big-leaf and DEPAC) predict much lower values.

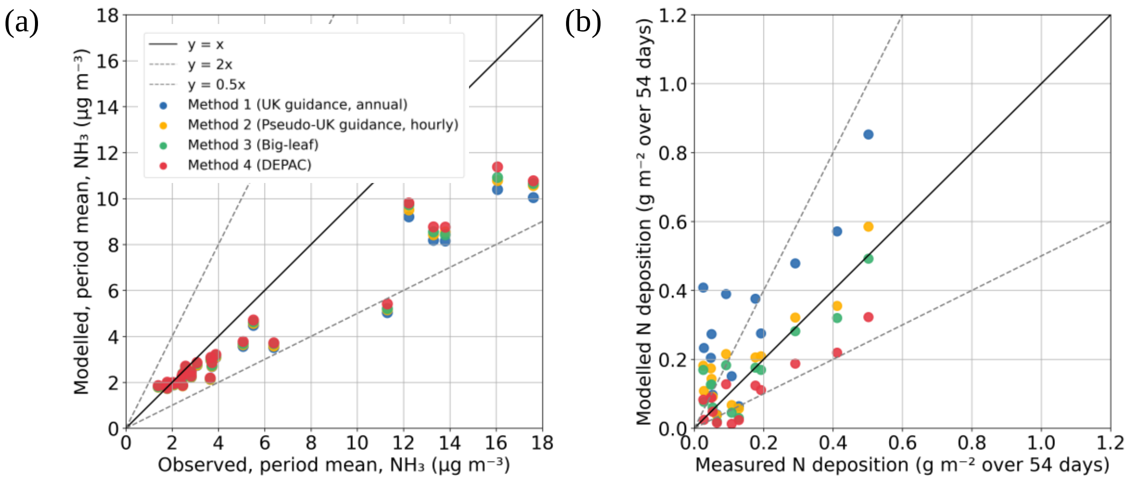

Figure 3 – Modelled (a) concentrations and (b) deposition flux for the Ringsted study. Note: plume depletion is not modelled for the hourly deposition function.

Sensitivity Testing

One consequence of the non-linear relationship between concentrations and deposition is that use of 'conservative' v_d estimates (i.e. high v_d values) can result in relatively lower predictions of deposition at moderate to large distances from a pollution source. Figure 4 presents outcomes of sensitivity testing exploring the effect of the use of a range of v_d values (0.3 – 0.003 m/s) on concentrations and deposition. The model was configured as for Ringsted but with the two buildings removed, to inhibit plume dispersion. Figure 4(a) shows concentrations reducing rapidly for the largest v_d due to high plume depletion. Figure 4(b) shows that, although near-field deposition is proportional to v_d, in the far-field, the high v_d case results in reduced deposition relative to the lower v_d cases.

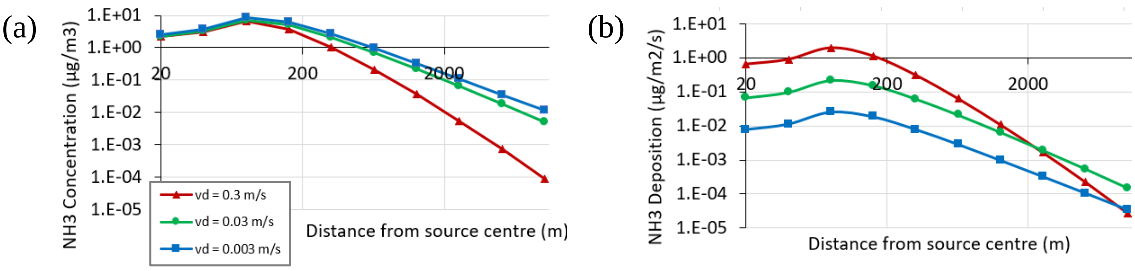

Figure 4 – Sensitivity testing of the influence of deposition velocity (v_d) magnitude on near and far-field concentration and deposition of NH_3; axes use a log scale.

Discussion

The choice of deposition method strongly influences modelled NH_3 deposition, both at low and high concentrations. The Ringsted study, which has a number of deposition measurements in the near field (20 – 600 m from the source), indicates that there is a wide range of modelled deposition flux and deposition may be over-predicted using the current UK guidance approach. Not considered here is the inaccuracy in the biomonitor measurements. Additional case studies are needed to reach firm conclusions.

The sensitivity testing results indicate that, for deposition velocities in the range appropriate to NH_3 i.e. 0.003-0.03 m/s (Figure 1), more conservative v_d values correspond to conservative predictions of deposition within distances relevant to local scale dispersion modelling. However, for other source types where the plume disperses closer to the ground (e.g. fertiliser applications), plume depletion is higher and non-linear effects could lead to the same outcome as demonstrated with the higher deposition velocity i.e. more conservative values of v_d correspond to lower far-field NH_3 deposition.

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