- **Introduction**
  - Motivation - Why do we want to model ammonia deposition?
  - Theory - How can we model ammonia deposition?
  - Theory - Concentration dependence of ammonia deposition
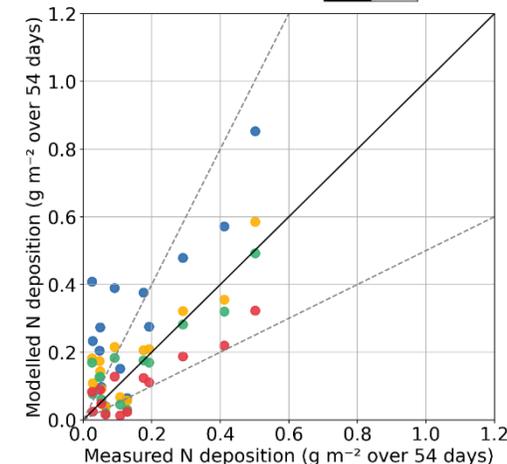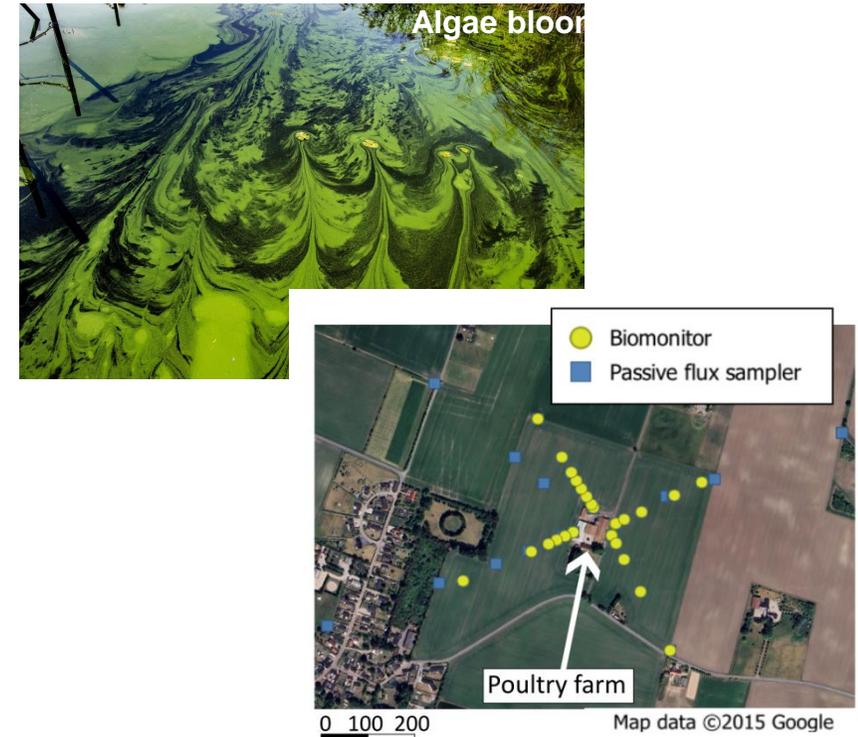 - Background – guidance, and validation of guidance
- **Methods**
  - Experimental dataset used and modelling set up
  - 4 methods of modelling ammonia deposition
- **Results**
  - Intercomparison of ammonia deposition using the 4 methods
  - Sensitivity test of impact of deposition rate and plume depletion
- **Conclusions**
- **Summary**

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Introduction: Motivation

What's wrong with too much Nitrogen (N) deposition?

- Regulating nitrogen deposition, particularly ammonia (NH_3), is important for **preserving sensitive habitats and species** e.g. N deposition causes direct damage to sensitive species and acidification of soils and freshwaters.

Regulations related to Nitrogen deposition

- EU member states must maintain such sites (Natura 2000) and make NH_3 reduction commitments where necessary

- Natura 2000 has led to **national regulations** such as the UK's Habitats Regulations (2017)

Modelling the impact from sources of NH_3

- Farming is the largest source of NH_3, and can be located close to, or some distance from, sensitive habitats

- **Air dispersion models** often used to ensure farming activities don't exceed **regulatory deposition limits**
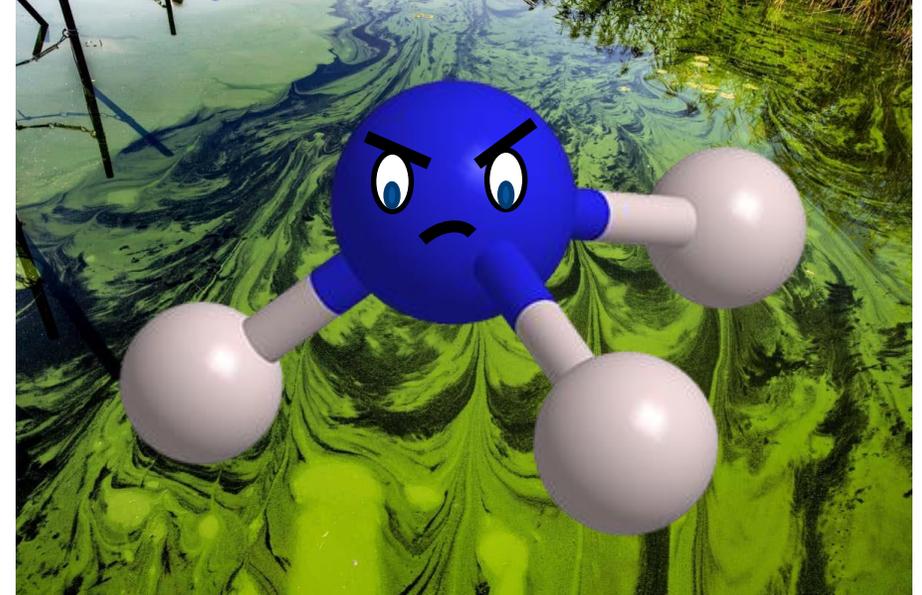
Algae bloom in the boat harbor on lake Glindow, Werder, Germany.
Hans-Joachim Aubert/Alamy
https://www.newscientist.com/question/humans-affect-nitrogen-cycle/

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Introduction: Modelling Nitrogen Deposition

- Gaseous pollutant **dry deposition rates** can be defined by dependence on resistance terms: e.g. in ADMS[1] it is the sum of:

  - **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)

- Other models, e.g. DEPAC[2] ('DEPosition of ACidifying Compounds'), also include a **compensation point term** (C_{cp}) allowing for bi-directional transfer of the gas

- Reciprocal of resistances defines deposition velocity ($\boldsymbol{v_d}$):

$$v_d = \frac{1}{R_{tot}}$$

- Dry deposition rate per unit area (F_{dry}) is assumed to be proportional to the near surface concentration (C):

$$F_{dry} = v_d\, C \quad \text{or} \quad F_{dry} = v_d\, (C - C_{cp})$$

R$_{tot}$=

R$_{aerodynamic}$

+

R$_{sub\text{-}layer}$

+

R$_{surface\text{-}layer}$

+

C$_{cp}$
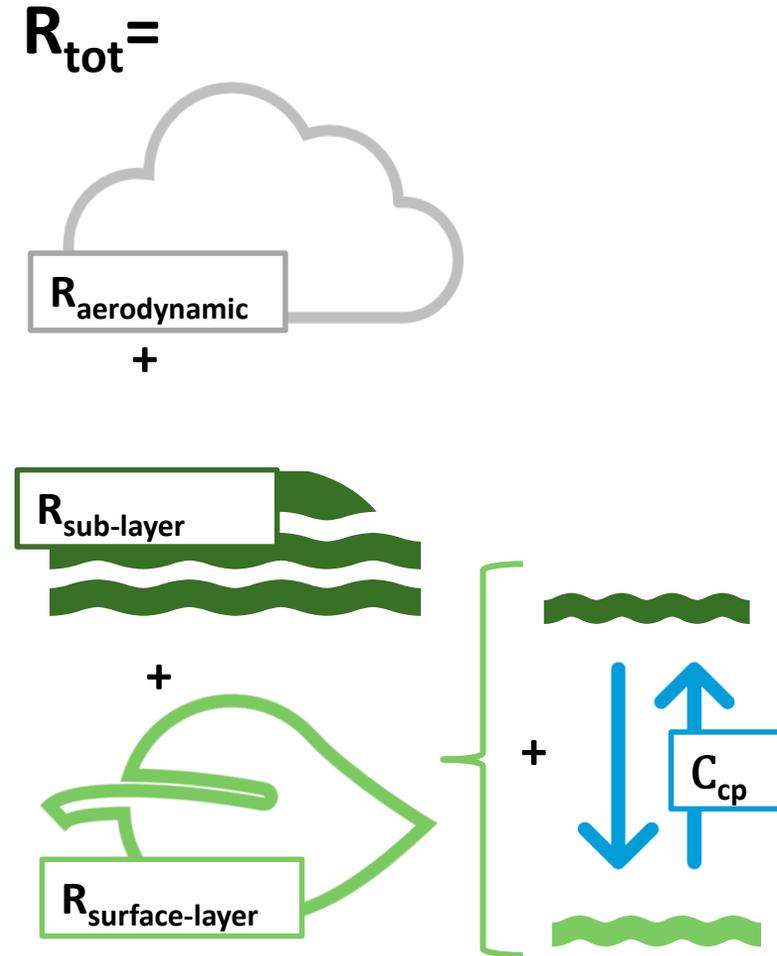
[1] Carruthers, D.J., et al., 1994. DOI:199410.1016/0167-6105(94)90044-2
[2] van Zanten, M., et al., 2010. RIVM, Report number: 68018001/2010

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Introduction – Concentration Dependent Deposition

$$F_{dry} = v_d\, C$$

- **At high near-ground concentrations, NH₃ deposition is inhibited** e.g. Figure 1

- Tens to hundreds of metres from a farm (where deposition may occur) there is therefore a risk associated with neglecting this inhibition in modelling:

  - reduces plume depletion in the near field leading to…

  - …relatively higher concentrations (and hence higher deposition) at large distances

- We refer to this dependence of v_d on concentrations as **Concentration Dependent Deposition Velocity (CDDV)**
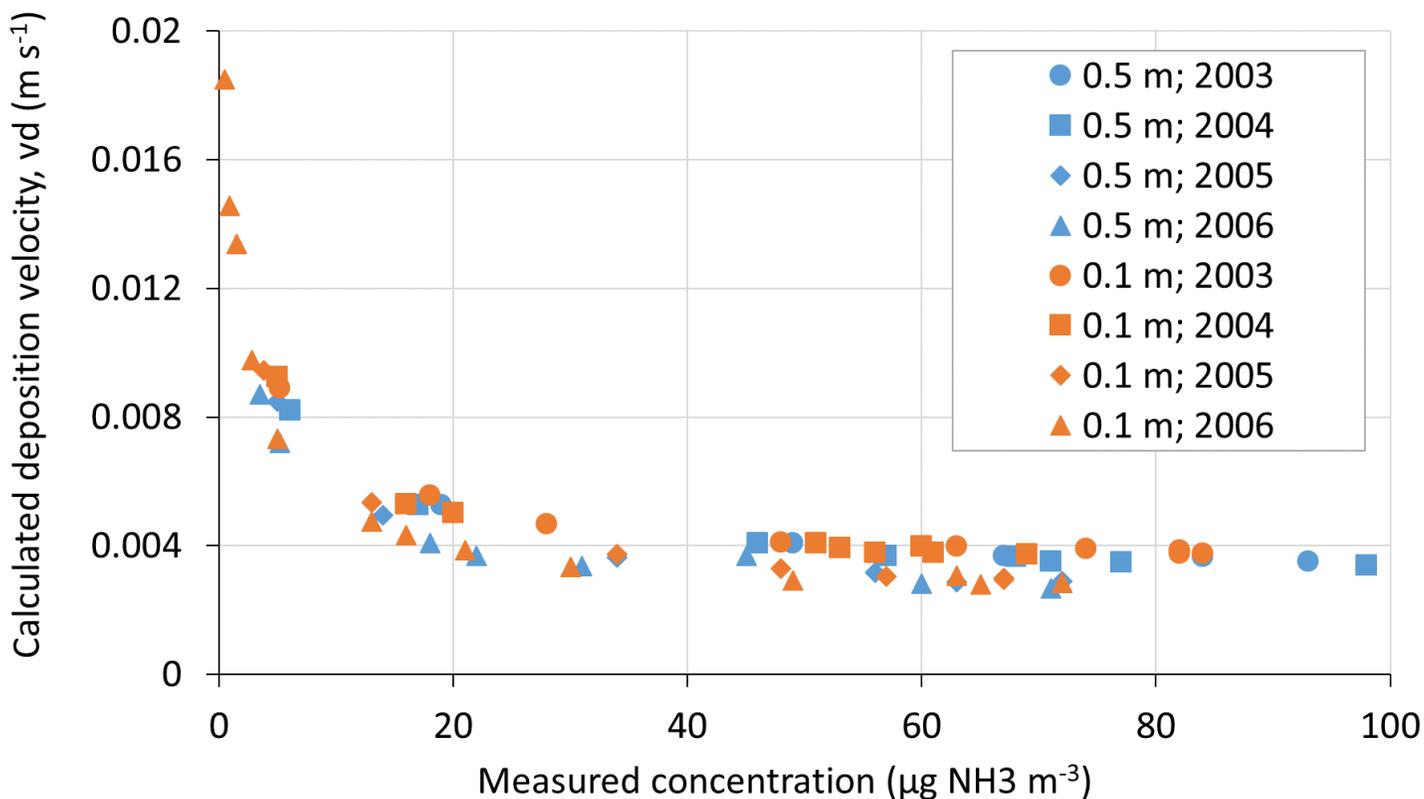

Figure 1. Multi-year, annual average NH₃ v_d estimates against ambient concentrations at two heights (0.1 m and 0.5 m)[3]

[3] Cape, J.N., et al., 2008.
DOI:10.1016/j.atmosenv.2008.04.027

Introduction – Guidance and validation of guidance

- In 2010: UK government released NH_3 modelling guidance for intensive farming, recommending using **CDDV derived from annual average concentrations.**

Total annual average NH_3 concentration (process contribution + background, µg/m³)		< 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

- Modelling methods such as this should be validated through comparison with measurements whenever possible e.g. the recent **Dutch National Institute for Public Health & the Environment (RIVM') 'Knowledge Programme Nitrogen' (KPN):**

  - Comprehensive NH_3 concentration and deposition model inter-comparison

  - Validation included use of the Ringsted poultry farm case study (Denmark)[4], in addition to other concentration only datasets

- We use Ringsted to compare UK guidance modelling approach with other methods that use CDDV, using CERC's ADMS 6 dispersion model

[4] Sommer, S.G., et al., 2009.
DOI:10.1016/j.atmosenv.2008.10.045

Related talks/posters:
A validation study for eight operational models regarding concentration and deposition of ammonia and nitrogen oxides at local scale – Roy Wiching Kruit, RIVM (Poster)

Estimating concentration and deposition of ammonia and nitrogen oxides at the local scale: an intercomparison of eight operational models - Gudrún Thorkelsdottir, RIVM (Talk)

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- Ringsted poultry farm NH_3 measurement campaign

- Ringsted Farm site (Figure 2):

  - Two barns housing hundreds of chickens

  - Each with a row of 4 exhausts

- NH_3 measurements:

  - radially from 20-600 m

  - **passive flux samplers** measuring **concentrations:**
    - *three periods of two/three weeks*

  - **pot biomonitors** measuring **surface deposition flux:**
    - *54-day exposure*

- Baseline ADMS model configuration for this case study was configured during RIVM's KPN project
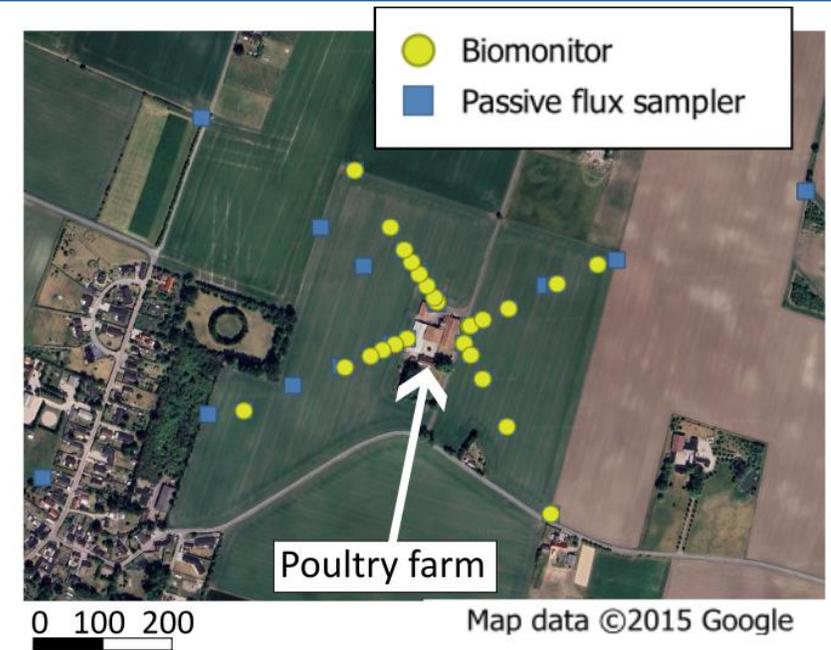

Figure 2. Ringsted poultry farm site, with NH_3 passive flux samplers (blue) & deposition biomonitors (yellow)

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Methods – 4 modelling methods

#	Approach	Temporal variation of v_d	Static or Variable v_d	Concentration modelled with:
1	UK Guidance	Period	Static	ADMS
2	Hourly implementation of UK Guidance	Hourly	Static	ADMS
3	"Big-leaf"	Hourly	Variable	ADMS
4	DEPAC	Hourly	Variable	OPS-ST

- **General method:** initial model concentration $\longrightarrow$ obtain v_d from concentration (CDDV) $\longrightarrow$ use CDDV as input for modelling ammonia concentration & deposition

- **Methods 1 & 2:** static v_d values obtained from UK guidance table

- **Method 3 & 4:** variable v_d, calculation includes dependence on surface characteristics & met. conditions

- **Method 3:** v_d calculation method implemented from [5, 6, 7] with guidance from UKCEH (who implement big-leaf methodology in CBED within APIS)

- **Method 4:** v_d values provided by RIVM (KPN project), values interpolated to cover domain

[5] Smith, R. I., et al., 2000. DOI:10.1016/S1352-2310(99)00517-8
[6] Air Quality Consultants, 2018. www.wealden.gov.uk/UploadedFiles/Ashdown-Forest-Air-Quality-Monitoring-and-Modelling-August-2018-Volume-1.pdf
[7] Wehr, R., et al., 2017. DOI:10.5194/bg-14-389-2017

Concentration

Legend:
- y = x
- y = 2x
- y = 0.5x
- Method 1 (UK guidance, annual)
- Method 2 (Pseudo-UK guidance, hourly)
- Method 3 (Big-leaf)
- Method 4 (DEPAC)

Concentration plot: Observed, period mean, NH₃ (µg m⁻³) vs Modelled, period mean, NH₃ (µg m⁻³)

Deposition

Deposition plot: Measured N deposition (g m⁻² over 54 days) vs Modelled N deposition (g m⁻² over 54 days)
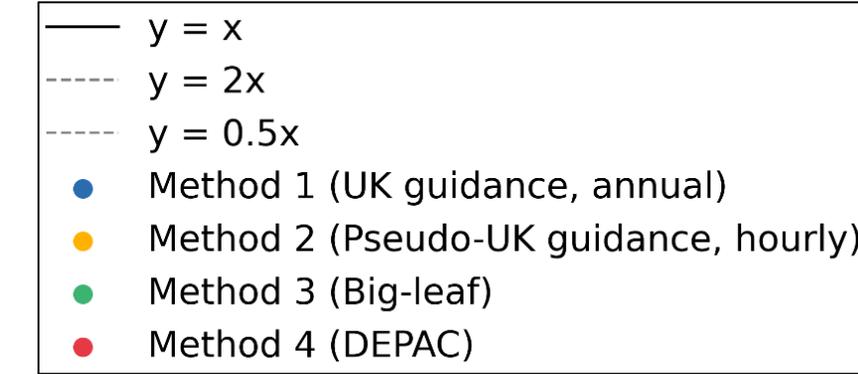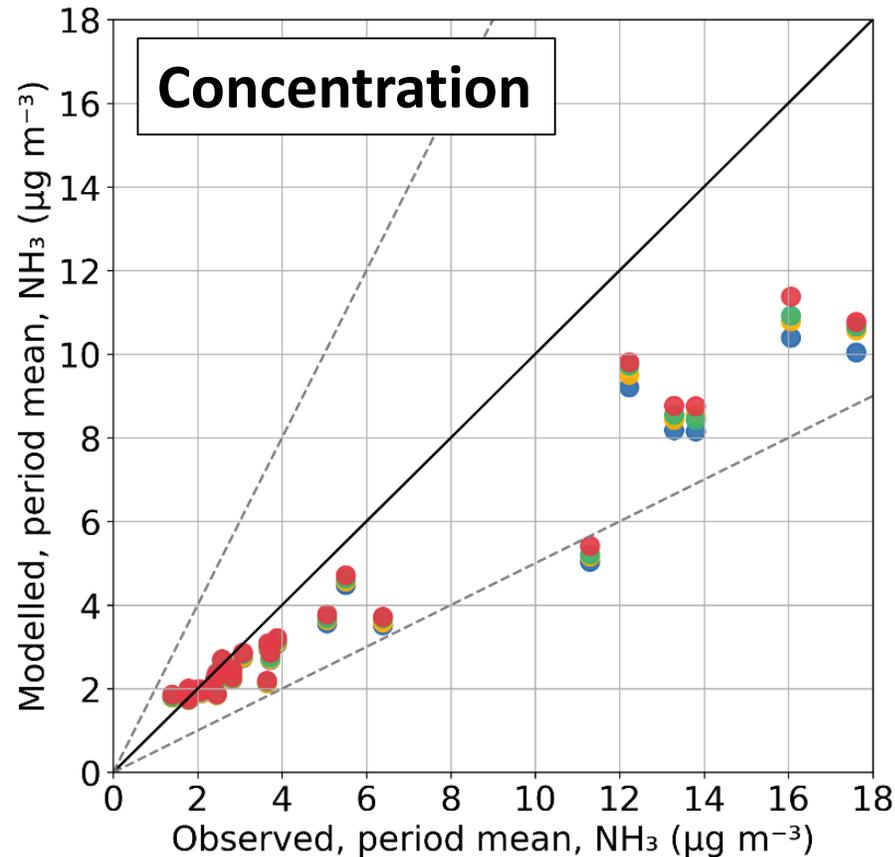
Figure 3. Modelled (a) concentrations and (b) deposition for the Ringsted study. Note: plume depletion is not modelled for the hourly deposition function.

- Modelled **concentrations are under-predicted** for all methods. So, for a consistent deposition module, **deposition** fluxes would also generally be **under-predicted** (i.e. not 1:1)

- 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 appears to over-predict deposition and the more complex hourly methods (big-leaf and DEPAC) predict much lower values

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Sensitivity test:

- Testing effect of plume depletion due to deposition rate on far-field concentration & deposition

- v_d = 0.3, 0.03 and 0.003 m/s

- Model configured for Ringsted with buildings removed (buildings increase plume dispersion)

Results:

- Concentration: reducing rapidly for the largest v_d due to high plume depletion (Figure 4, left)

- Deposition:

  - Near-field: deposition proportional to v_d

  - Far-field: the high v_d case results in lower deposition compared to to the lower v_d case

$$F_{dry} = v_d\, C$$

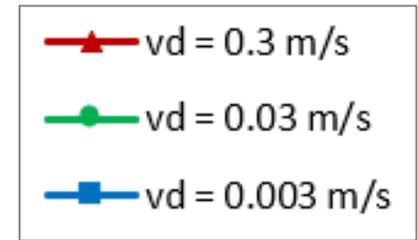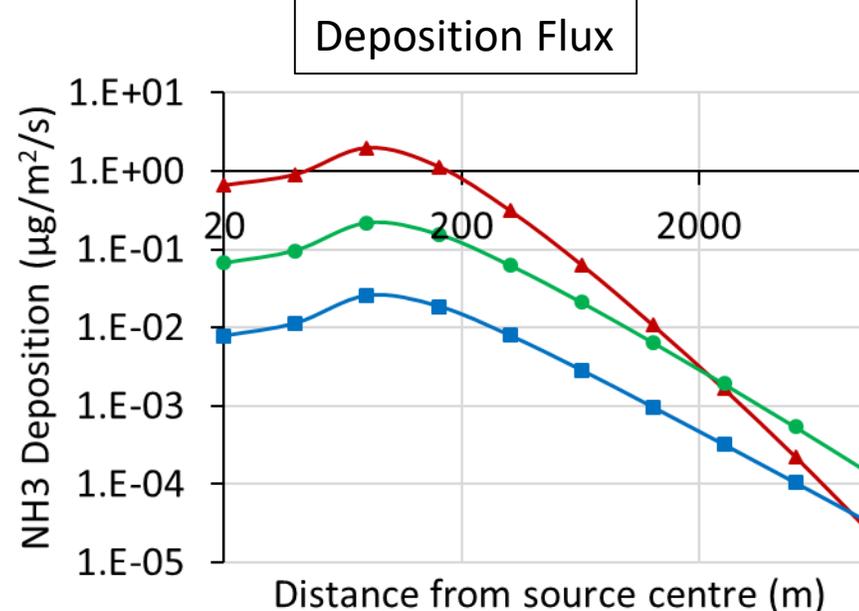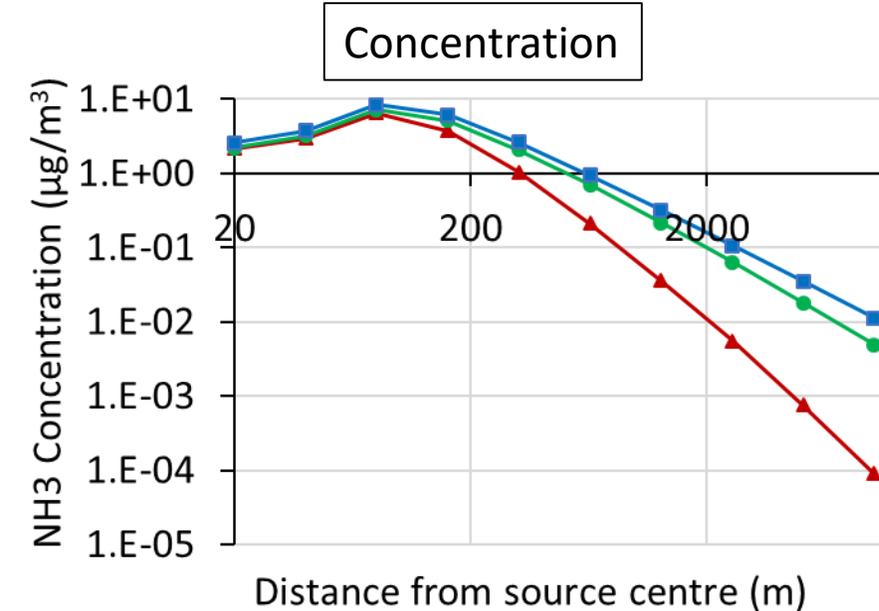*Figure 4. Sensitivity testing of the influence of deposition velocity (v_d) magnitude on near and far-field (a) concentration and (b) deposition of NH₃; axes use a log scale.*

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Conclusions

Intercomparison of NH$_3$ CDDV modelling methods

- **Choice of deposition method strongly influences modelled NH$_3$ deposition**, both at low and high concentrations.

- This was shown using the Ringsted case study, which has a number of deposition measurements in the near field (20–600 m from the source); showed a wide range of modelled deposition values; may be over-predicted using the current UK guidance approach.

- Improvements: consider inaccuracy in the biomonitor measurements; additional case studies are needed to reach firm conclusions.

Concentration Dependent Sensitivity Test

- For v_d in the range appropriate to NH$_3$ (i.e. 0.003-0.03 m/s) **more conservative values correspond to conservative (higher) 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 will be higher** and non-linear effects could lead to the high v_d result i.e. **more conservative values of v_d correspond to lower far-field NH$_3$ deposition**.

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Summary & Acknowledgements

- Ammonia deposition (in particular coming from intensive farms) can cause harm to sensitive habits

- It is important to accurately model ammonia deposition to ensure regulatory limits are not exceeded, in particular, should use concentration dependent deposition velocity (CDDV)

- Intercomparison of four CDDV methods:

  - UK guidance annual: simple, based on annual average concentrations

  - UK guidance hourly implementation: simple, based on hourly average concentrations

  - Big-leaf: detailed calculation method, hourly

  - DEPAC: detailed calculation method, hourly

- Find that the current UK method may overpredict deposition

- Sensitivity test: highlights the possibility that a "conservative" high deposition velocity may result in too much depletion of the plume in the near-field, leading to underestimated deposition in the far-field at sensitive sites.

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Thank you for listening!

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