Description and evaluation of particulate deposition modelling in ADMS

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Outline

- Introduction to deposition in ADMS
- Evaluation study
  - Measurement study
  - Modelling approaches
  - Deposition analysis
  - Modelling sensitivities
- Summary

Dry Deposition in ADMS (1)

- Dry and wet deposition model options
- Dry deposition rate, F, proportional to near-surface concentration, C :

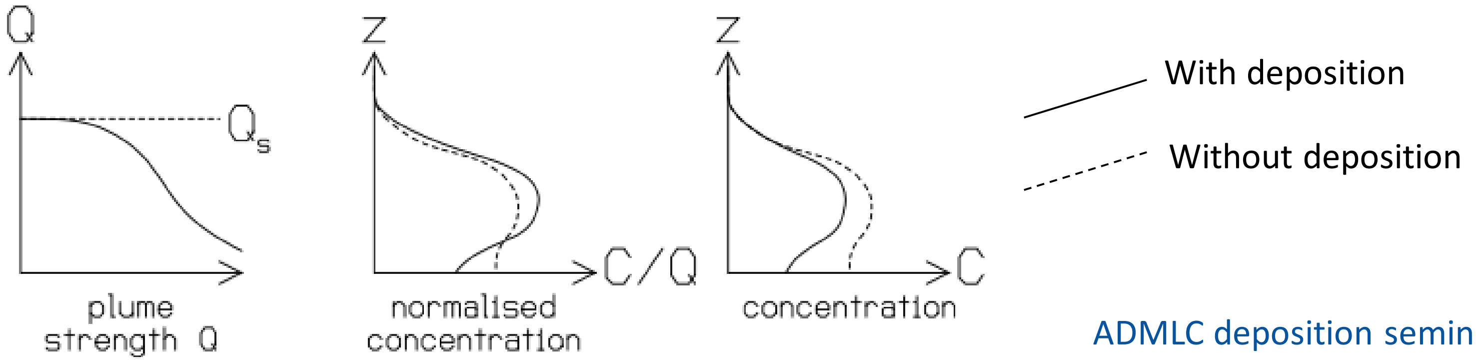
$$F = v_d C$$

- Deposition velocity, v_d, calculated as:

$$v_d = \frac{v_t}{1-\exp(-v_t/v'_d)}$$

v_t - gravitational settling velocity
v'_d - diffusive part of v_d
$v_d \to v'_d$ as $v_t \to 0$ (gases)

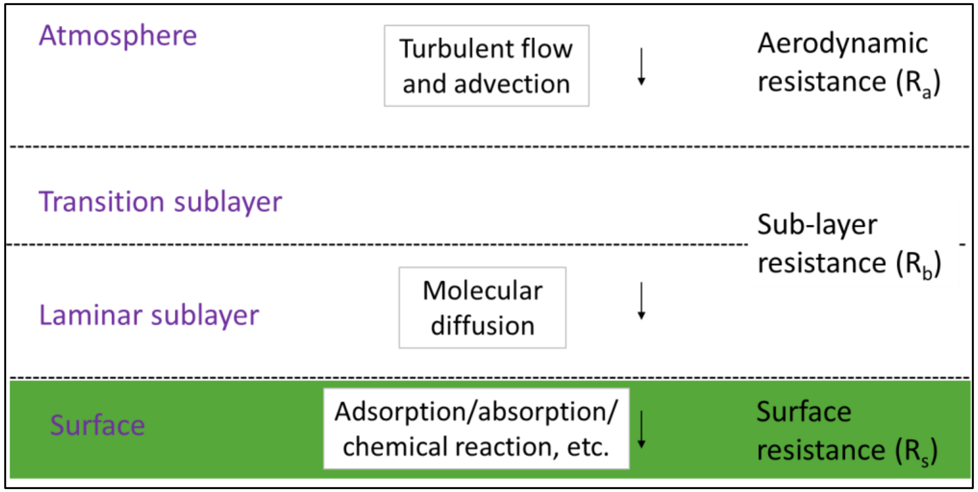
- Removal of airborne material at surface leads to:
  - Reduced effective plume strength
  - Modified vertical distribution of concentration (shape factor)



Dry Deposition in ADMS (2)

- True deposition velocity depends on:
  - Nature of pollutant
  - Atmospheric state
  - Nature of surface
- Can change with time (e.g. due to diurnal and closing of leaf stomata) and/or space (e.g. due to land use changes over region of interest)
- In ADMS:
  - Gravitational settling velocity v_t (particulates only) assumed **fixed** and is **supplied by user** (either directly or calculated from particle diameter & density)
  - Diffusive part v'_d (particulates & gases) can be supplied by user **or** calculated by model. Supplied values can be:
    - Fixed
    - Temporally varying; Hourly or seasonal (day/night for Spring/Summer/Autumn/Winter) values
    - Spatially varying (via additional input file containing list of x, y, v'_d values)
    - Spatially and temporally varying (hourly factors applied to spatially varying values)

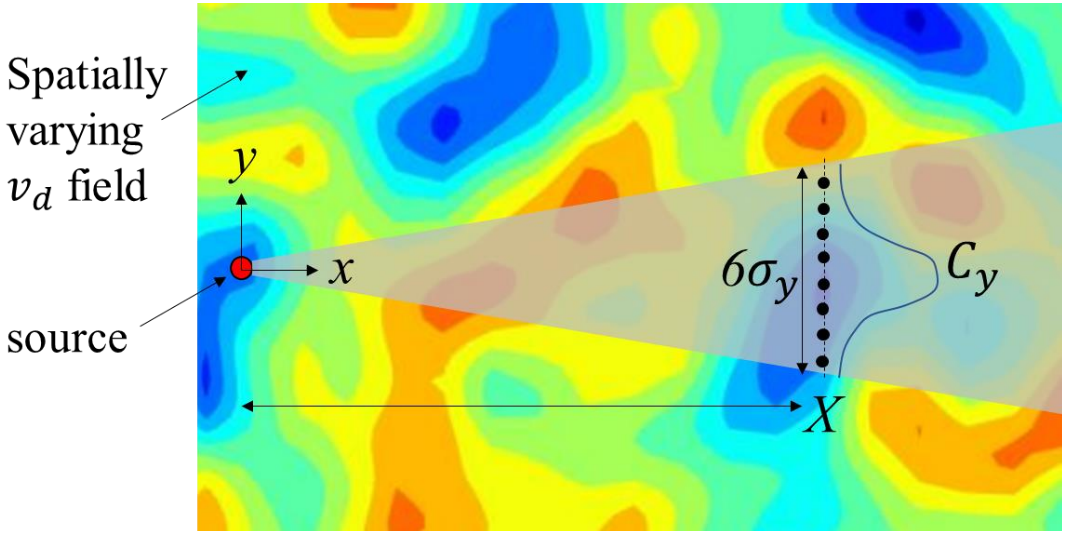
Dry Deposition in ADMS (3)



- Calculated v'_d based on resistance model
- $r = 1/v'_d$ taken as sum of three terms:
  - r_a **- Aerodynamic resistance**
    - Ability of turbulent eddies to bring material close to surface
    - Based on momentum transfer between two near-surface heights: $r_a = \frac{U(z_2) - U(z_1)}{u_*^2}$
  - r_b **- Sub-layer resistance**
    - Resistance to transfer across final zone adjacent to surface
    - For smooth surfaces, r_b represents molecular and turbulent diffusion across laminar and transition sublayers: $r_b = \frac{1}{\kappa u_*} \ln(1 + \mathrm{Sc})$. Schmidt number $\mathrm{Sc} = \nu/D$, i.e. ratio of kinematic viscosity to molecular diffusivity. $\mathrm{Sc} = 1$ assumed for gases. For e.g. $PM_{2.5}$, $\mathrm{Sc} \approx 1 \times 10^6$ so $\ln(\mathrm{Sc}) \approx 14$
  - r_s **- Surface resistance**
    - Gases: Affinity of surface (adsorption, absorption etc). Can be:
      - Estimated by model given nature of gas (reactive/non-reactive/inert) **or**
      - Supplied by user (same options as for v'_d, i.e. fixed, temporally and/or spatially varying)
    - Particulates: r_s taken as zero (particles assumed to adhere on contact)

Dry Deposition in ADMS (4)

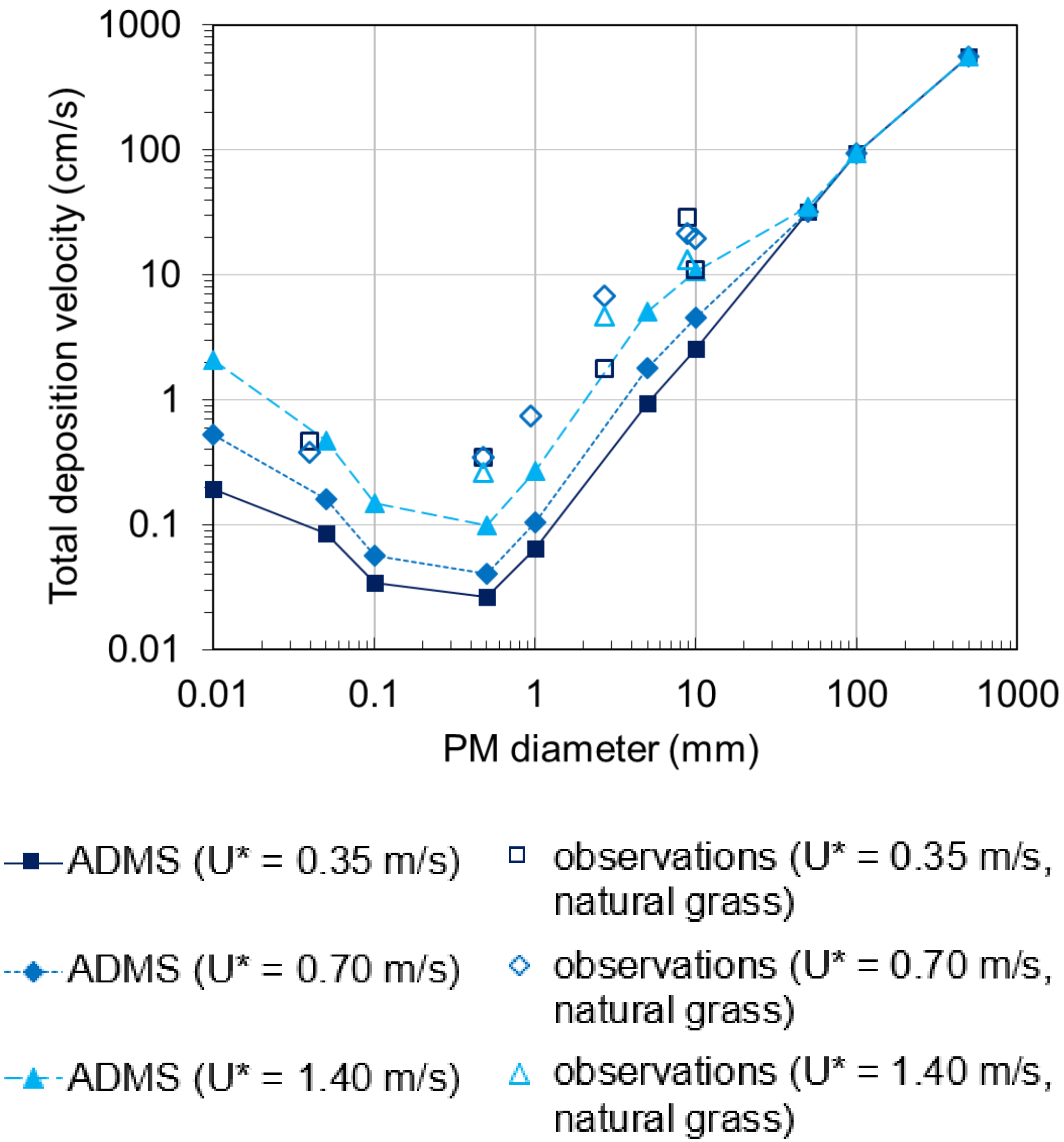
- For spatially-varying v_d:
  - During dispersion calculations: Depletion and shape factor at downwind distance X calculated using $\overline{v_d}$, a crosswind-concentration-weighted average of v_d at ~20 points across plume (between +/– $3\sigma_y$)



  - Deposition at a given output point $F(x, y) = v_d C$:
    - v_d is value extracted at x, y
    - C is near-ground concentration at x, y, calculated using $\overline{v_d}$-based depletion and shape factor

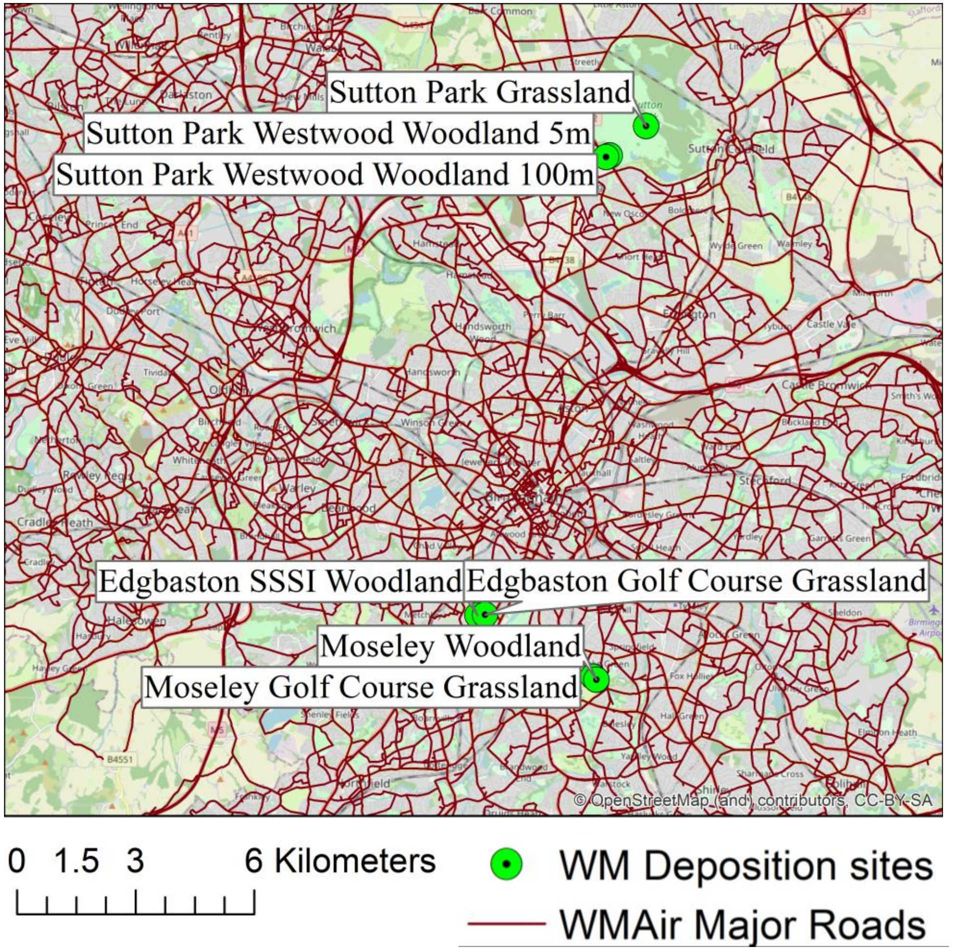
Dry deposition evaluation

- No routine measurements of dry deposition for evaluation
- Very few published studies with measurements of dry deposition fluxes available
- ADMS deposition velocity variation with wind speed and surface roughness validated against Sehmel (1980) measurements



Evaluation study: Measured data

- Fowler et al. (2004) measured heavy metal concentrations in undisturbed soils in the West Midlands, UK
- 3 sets of nearby sites with grassland/forest land use, some information about tree species and grass length
- Soil concentrations represent long-term accumulated wet and dry deposition
    - Focus on Copper concentration data from surface layer (0-5 cm below ground level), most recent deposition



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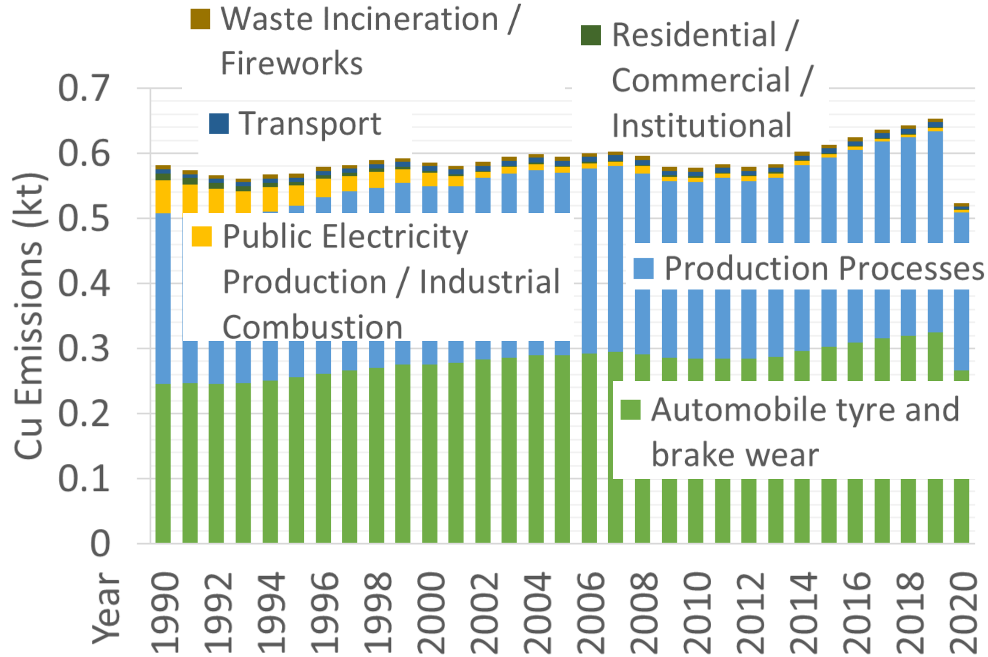
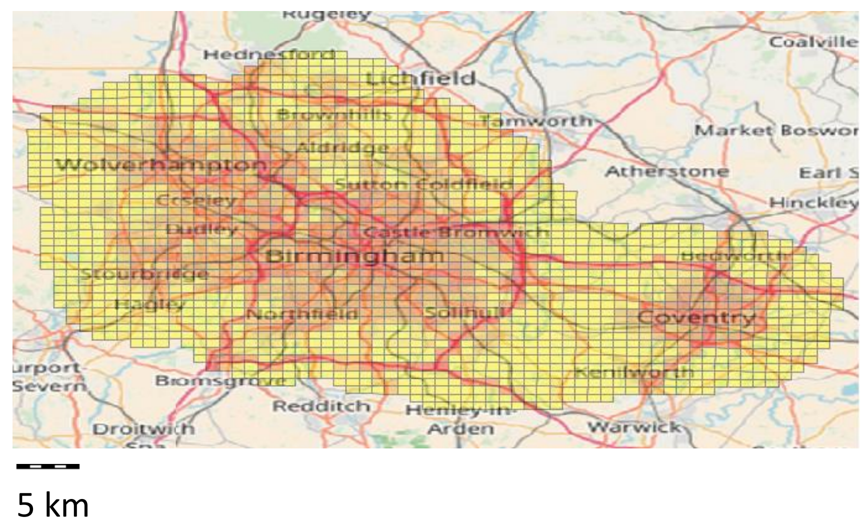
Evaluation study: Modelling approach

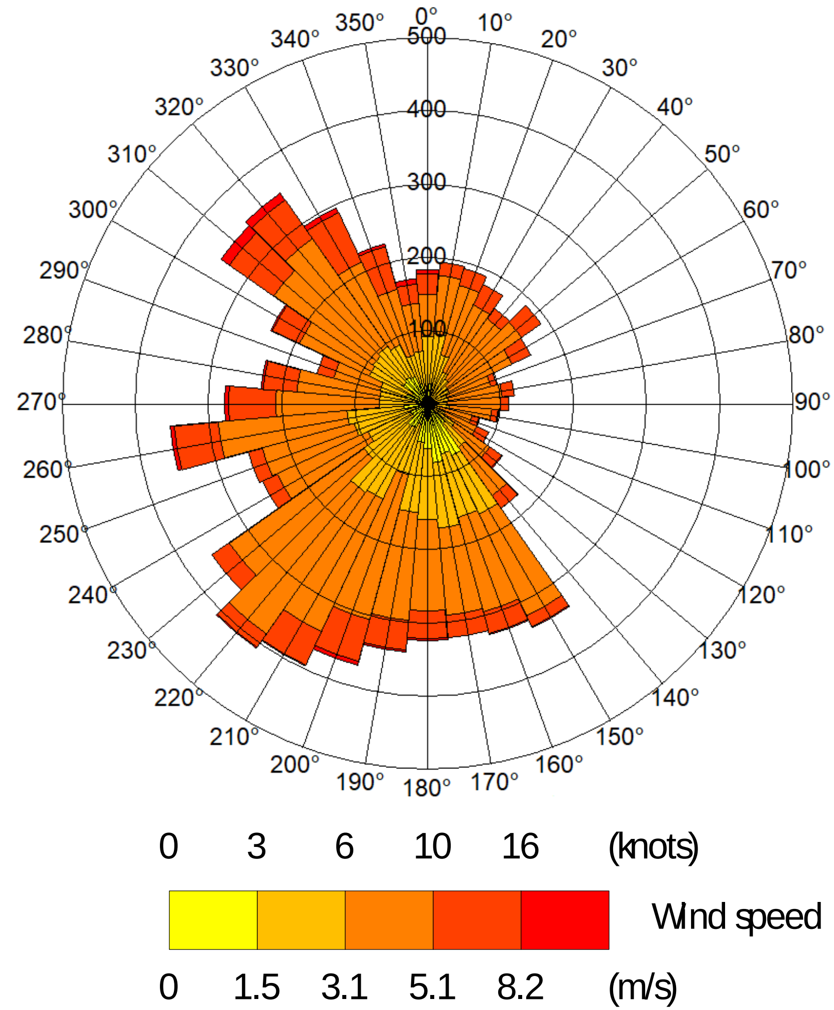
- Total Copper emissions reported in NAEI relatively unchanged from 1990 – 2019/20
- Dominant emission sectors: road traffic (non-exhaust) and production process
- NAEI gridded copper emission from 2019 used in modelling
- Industrial sector assigned 50 m depth, all other emissions 10 m depth, grid of 1 km x 1 km volume sources
- Model: ADMS-Urban version 5.0.1





Evaluation study: Modelling approach

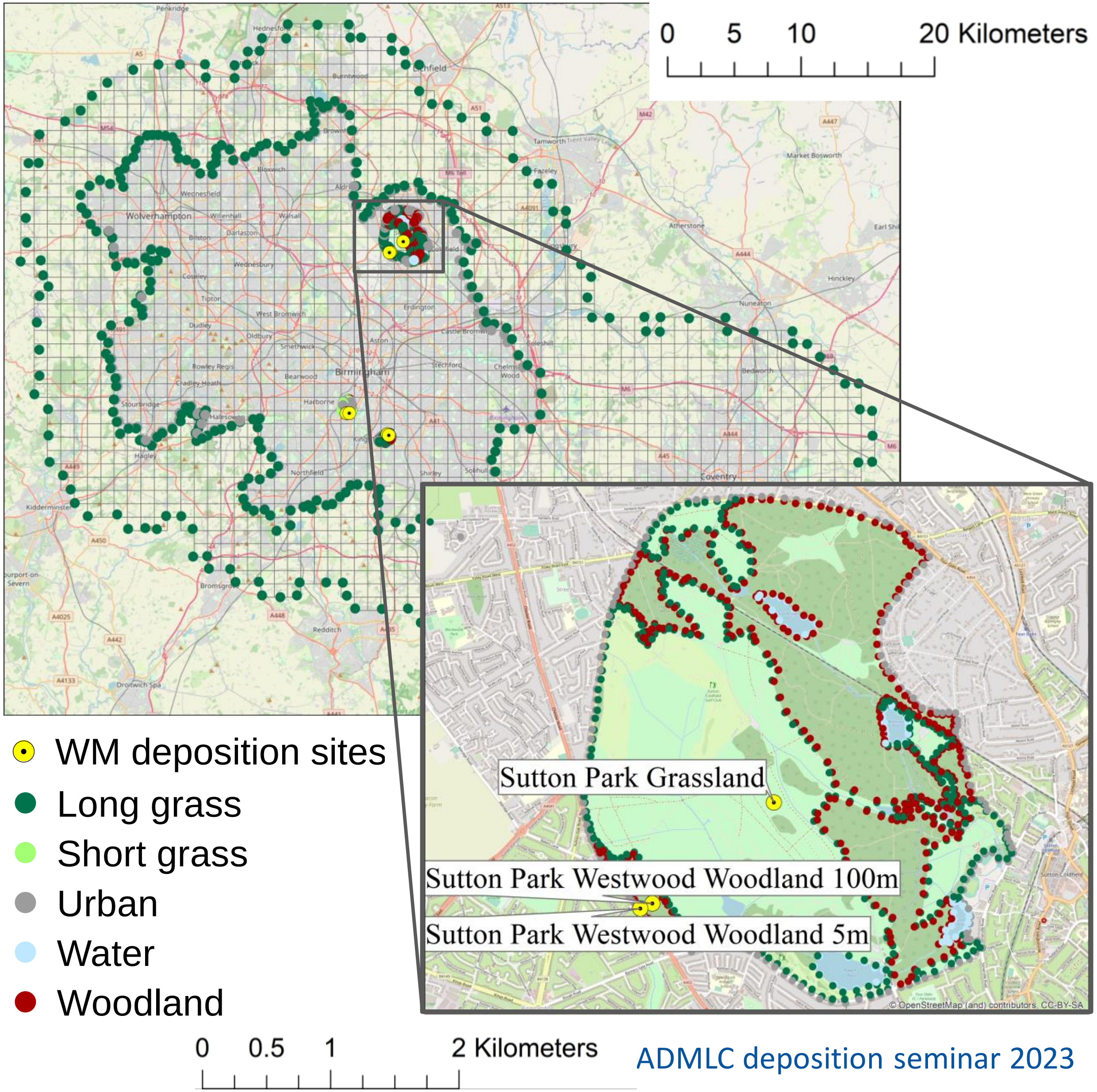
- Measured meteorological data from Birmingham Elmdon for 2016
- Met site roughness 0.5 m, dispersion site roughness 1.0 m
- Rural measurements of Copper aerosol from Automatic Urban and Rural Network (AURN) showed generally very low concentrations, no background concentrations applied
- New pollutant defined for copper particles with 2.5 μm diameter and 8940 kg/m^3 density
- Time-variation of emissions based on previous analysis of West Midlands traffic flows (Zhong et al., 2021)



Mean wind speed ~3 m/s

Evaluation study: modelling approach

- Spatially varying dry deposition velocity file defined based on land use
- Manual creation of points around borders of grassland (short and long), forest, water and urban areas
- ADMS uses deposition properties from nearest point in file
- Wet deposition run with default ADMS precipitation-dependent parameters (spatially uniform rainfall)



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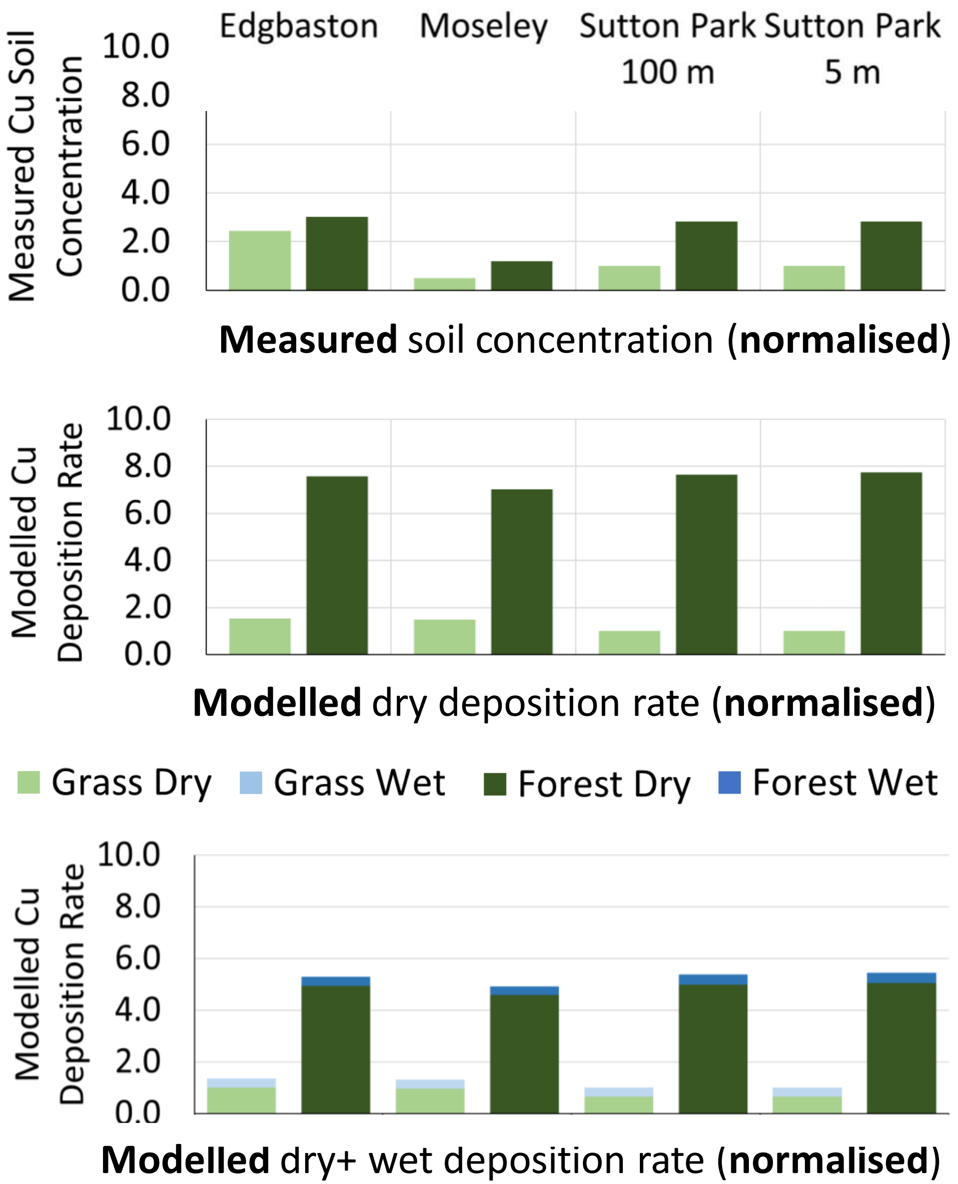
Evaluation study: Calculation of deposition velocities

- Dominant land use approach to spatial variation of deposition velocity
- Vegetation:
  - Deposition velocity per unit leaf area from Nowak et al. (2013) – as used in iTreeEco, value for 3 m/s average wind speed
  - Average Leaf area index (LAI) for forest derived from UK measurements in Iio and Ito (2014) Global database of LAI in Woody Plant Species (ORNL DAAC)
  - LAI for grassland based on grass length from Byrne et al. (2005), lower values for 'new' grassland used as WM sites are not intensively managed
- Urban (impermeable surfaces): deposition velocity value from Giardina et al. (2019) for 2.5 μm diameter particles
- Water: deposition velocity value from Emerson et al. (2020) for 2.5 μm diameter particles

Land use	Deposition velocity (m/s)
Woodland	0.008059
Long Grass	0.000563
Urban	0.0005
Short grass	0.000225
Water	0.0001

Evaluation study: deposition analysis

- Normalised measured soil concentrations and modelled deposition rates using Sutton Park grassland deposition
- Compare the relative increase in deposition in the forest relative to grassland sites
- Base run with dry deposition only: ADMS over-estimated increase in deposition for forest sites
- Including wet deposition reduces modelled forest/grassland ratio but this is still overestimated compared to measurements



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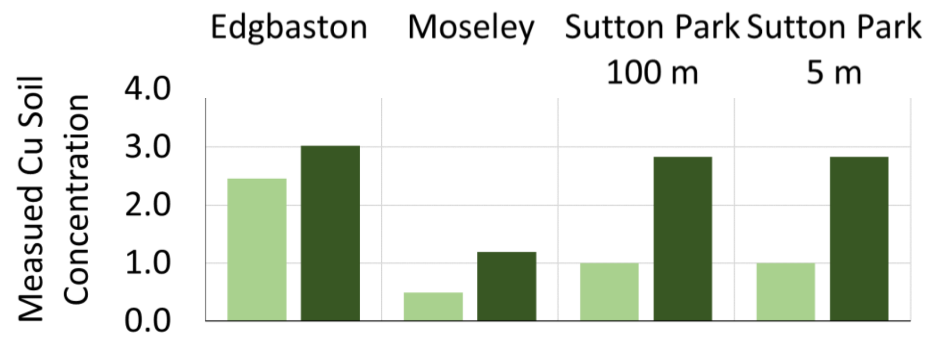
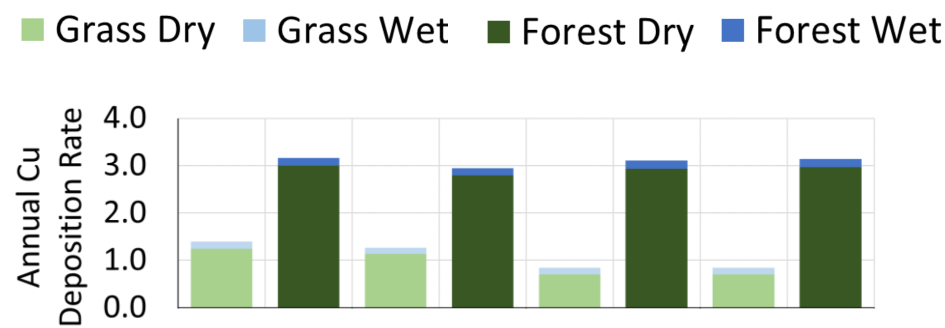
Evaluation study: deposition analysis

- ADMS temporal variation of deposition parameters is spatially uniform
- Take into account differences in summer/winter LAI for deciduous/mixed forest (van den Hurk et al., 2002)
- Created separate summer/winter .din files for leaf-on (May – November) and leaf-off periods (January-April, December)
- Deposition ratios between forest and grassland more comparable to measurements



Measured Cu soil concentration (**normalised**)



Modelled annual Cu deposition rate (**normalised**)

Land use	Deposition velocity (m/s) Winter	Summer
Woodland	0.00153	0.01002
Long Grass	0.000465	0.00261
Short grass	0.000615	0.00267

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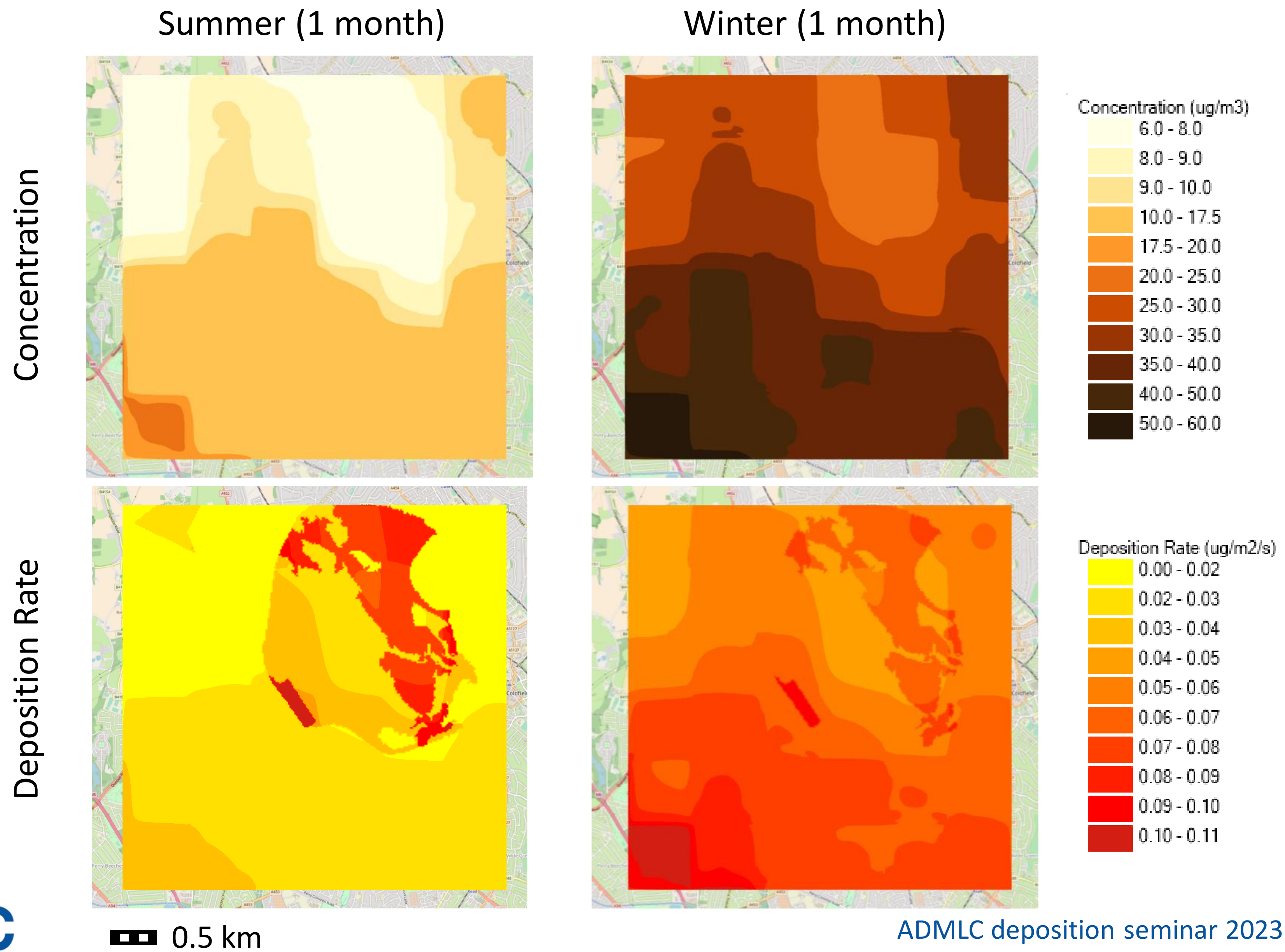
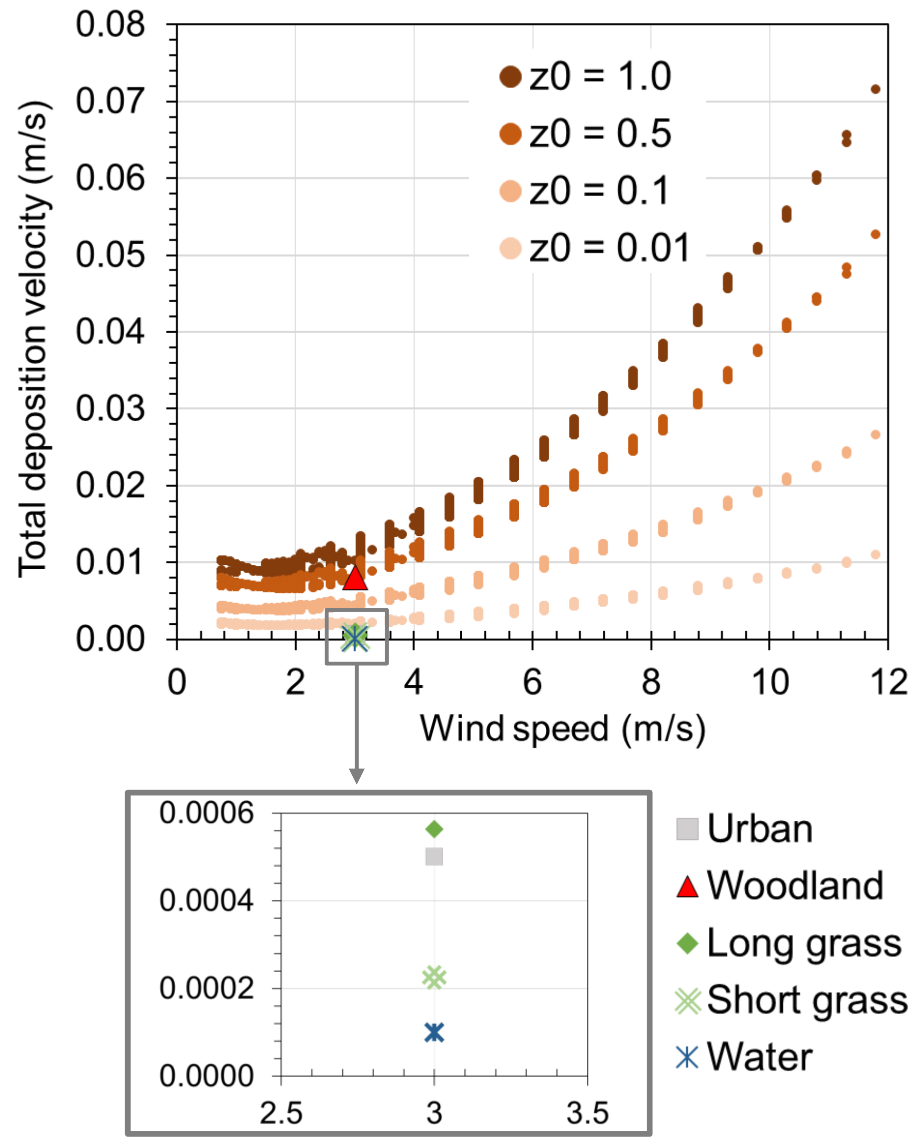
Spatial variation of concentration & deposition



Modelling sensitivities: deposition and wind speed

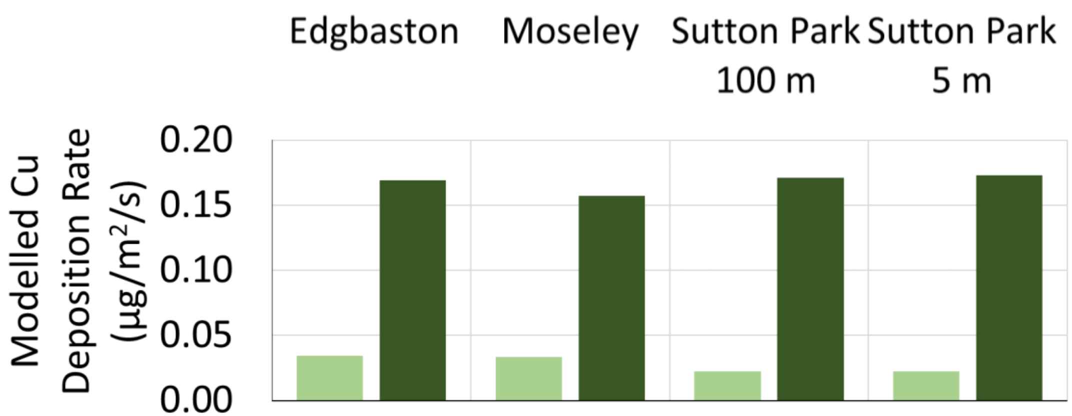
How significant is the variation of deposition velocity with wind speed?

- ADMS calculates deposition velocity dependent on local wind speed and roughness length
- Increasing roughness length increases deposition velocity
- Non-linear increase in deposition velocity with wind speed
  - Annual deposition values based on non-woodland land use are lower than values for the average wind speed and roughness length

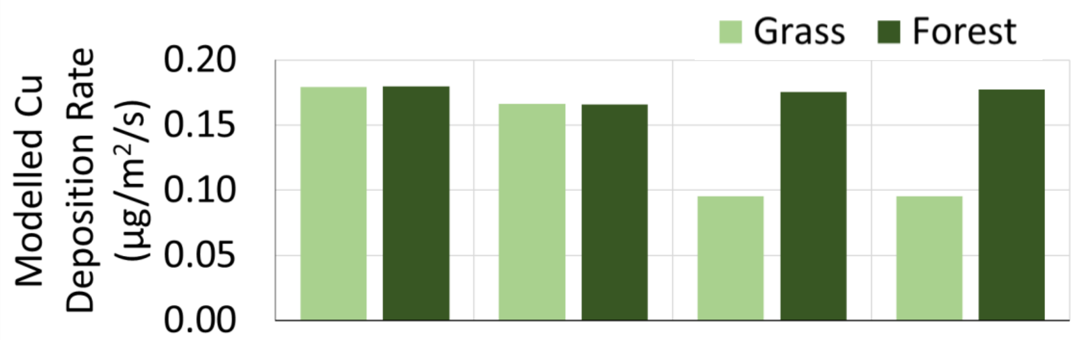


Modelling sensitivities: ADMS deposition velocity

- Is the spatial variation or temporal variation of deposition velocity more significant?
- Using ADMS deposition velocity (spatially uniform, varying with wind speed) increases dry deposition at grassland sites compared to land use based deposition velocity (spatially varying, temporally uniform)
- Woodland deposition similar for both types of deposition velocity



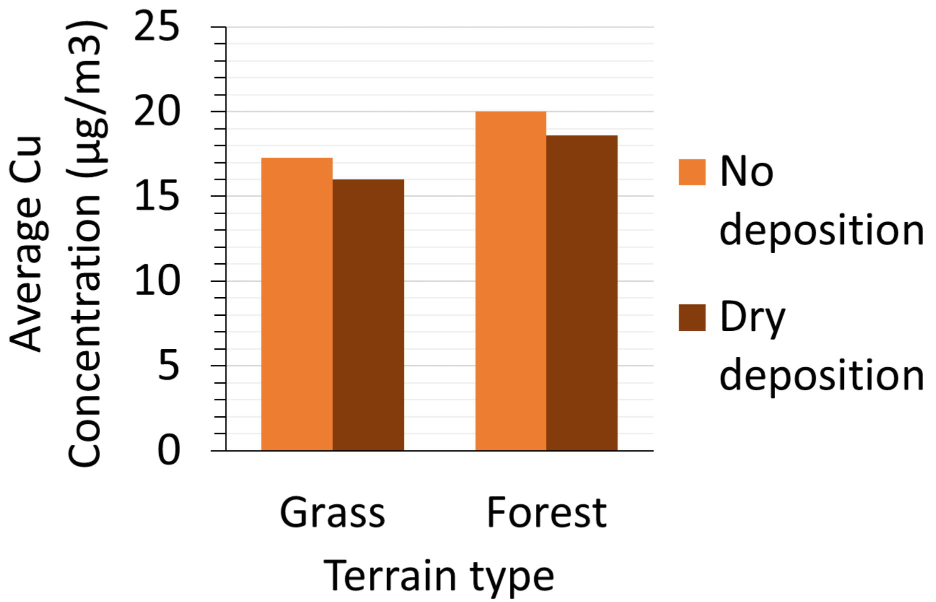
Spatially varying, land-use based dry deposition rate (**absolute**)



Spatially uniform, wind speed dependent dry deposition rate (**absolute**), roughness length 1 m

Modelling sensitivities: Concentration comparison

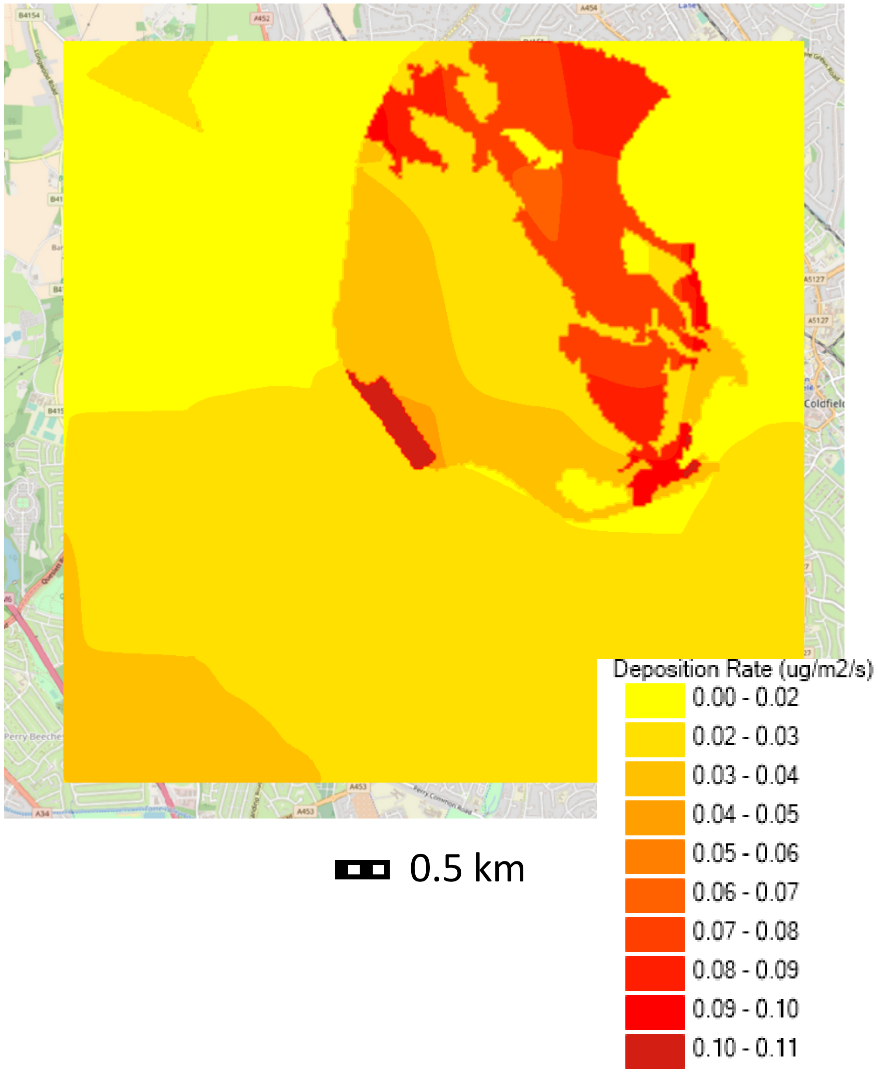
- How much are ambient annual average Copper concentrations affected by particulate deposition?
- Concentrations reduced by 7.24 – 7.54 %, little difference between grass/forest sites



Average Cu Concentration (µg/m³)			
Terrain type	No dep	Dry Dep	Percentage difference (%)
Grass	17.27	16.01	-7.54
Forest	20.02	18.62	-7.24

Summary

- Limited data availability for evaluation of deposition modelling
- Evaluation compared long term ratios of deposited particulates with annual average modelled deposition
  - Similar overall deposition for woodland from land use and wind speed dependent approaches; consistent with measured deposition
  - Spatially varying deposition allows exploration of vegetation effects; except close to sources this results in greater spatial variability in deposition than concentration gradients
  - Seasonal variation of vegetation properties can be significant for deposition



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