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Fine resolution modelling of ammonia dry deposition in Great Britain

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Abstract

Work is presented on the initial development of a detailed treatment of NH_3 dry deposition in an atmospheric transport model for Great Britain. There is considerable local variability in agricultural emissions of NH_3. Because of the ground level nature of the emissions and variable deposition velocities (V_d) to different land surfaces, a model is required that incorporates the land-use dependence of NH_3 dry deposition, together with a detailed (multi-layer) treatment of atmospheric diffusion and transport. The initial results of applying a variable V_d are presented together with a budget of net NH_3 dry deposition over the country. Differences in concentration due to the use of variable V_d, compared with a spatially uniform value, are indicated.

The Model

The model described, referred to as UKTERN, has been developed from the TERN model, of which a more detailed description can be found in ApSimon *at al.* (1994). It is a Lagrangian model and follows columns of air, of defined cross section and which extends from the earth's surface to the top of the mixing layer. The model consists of 33 vertical layers of variable depth, with the resolution becoming especially detailed close to the earths surface. The grid resolution used for UKTERN is 20 km, with spatially-disaggregated NH_3 emission estimates derived from agricultural census information (Eager, 1992; Sutton *et al.*,1993), as shown in Figure 1. A straight line trajectory approach is employed, with trajectories originating from 8 wind sectors. The results are combined statistically, suitably weighted by the frequency of the winds in each sector. An assumed mean wind speed of $8ms^{-1}$ is used to move the air column.
There are two main aspects of this model, which distinguishes it from previous work (Metcalfe *et al.,* 1989; Sandnes *et al.,* 1992; Asman and van Jaarsveld, 1992). The first feature is the enhanced treatment of vertical diffusion, utilising a multi-layer approach and an assumed profile of the turbulent diffusivity. Vertical mixing is determined by the equation

$$\frac{\partial \chi}{\partial t} = \frac{\partial}{\partial z}\left(K_z \frac{\partial \chi}{\partial z}\right)$$

where χ is the concentration of the species under consideration. The vertical diffusivity (K_z) is defined as a function of height, dependent on the diurnal cycle and prevailing stability conditions. In the model, K_z has been assumed to increase in proportion to height over a layer of depth H_z to a maximum value K_{max} and remain constant over the rest of the mixing layer. The second part of this investigation is on the treatment of the land-use dependence of NH_3 dry deposition within an atmospheric transport model.

Gaseous NH_3 is removed from the atmosphere by dry deposition, wet deposition and by chemical conversion. Dry deposition is by way of deposition velocities (V_d) which remove material from the lowest layer of the air column. In the case of NH_3, a landuse database is used which contains information on the % land cover of the main types of landuse for each 20 km square. For this initial study, a separate V_d is assigned to each landuse to reflect the overall effectiveness of the surface to be a recipient for NH_3 dry deposition. These landuse categories, and the initial values of V_d assigned to them for NH_3, are listed in Table 1. In future work, it is expected that resistances will be used to more accurately describe the temporal and spatial variations of V_d. Other chemical species in the model are listed in Table 2, together with the applied V_d for each species. These values are taken to be independent of landuse. A detailed description of the chemical processes in the model can be found in ApSimon *at al.* (1994). Wet deposition is calculated using a washout coefficient dependent on a specified rainfall rate. A background concentration of 0.1 μgm^{-3} is used for NH_3 and 0.2 μgm^{-3} for NH_4^+. All other species have initially been given zero background values.

Results and Discussion

The motivation behind this work was to see whether the detailed treatment of the diffusion process and dry deposition, described in the previous section, would produce significantly different results from previous models which assumed instantaneous mixing (Metcalfe *at al.*, 1989, Sandnes *at al.*, 1992) and dry deposition rates independent of landuse type (Asman and van Jaarsveld, 1992, Metcalfe *at al.*, 1989, Sandnes *at al.*, 1992). Figure 2 shows the results from the model with the detailed treatment of diffusion included, together with the landuse dependent values of V_d for NH_3. There is a strong correlation between areas of high emission and large ground level concentrations. This is more evident in this model because of the use of multi-layer diffusion and limited rates of dry deposition to the main emission areas. Figure 3 is a comparison plot of two runs of the model. The first run uses the landuse-dependent V_d (as shown in Figure 2), whereas the in the second run a constant value of 0.01 ms^{-1} was assigned to the NH_3 V_d, independent of landuse. The difference map produced can be split into two areas of interest. In the east of England, there is a greater concentration due to smaller landuse-dependent V_d, compared with the assumed constant value of V_d. In Wales, northern England and Scotland, the reverse in true with the more detailed treatment of V_d resulting in more deposition and smaller air concentration. These differences can be attributed to the 'type' of land prevalent in these areas. In the east, the land is relatively flat and has a large amount of arable crop cover. On the rest of the map however, there are regions where more semi-natural ecosystems dominate, such as moorland and forests. Thus the eastern area will on average be assigned a value of V_d smaller than 0.01 ms^{-1}, resulting in less NH_3 being removed from the atmosphere, whereas the rest of the land will have in general a greater value than this being used. This will affect air concentrations. Figure 4 shows the NH_3 dry deposition budget for Great Britain produced by the model using the enhanced diffusion process and the inclusion of landuse-dependent deposition velocities. These results show the importance for NH_3 allowing V_d to vary with landuse. The multi-layer approach is also important since this provides a more realistic treatment of atmospheric mixing, allowing the land-use effect on deposition to be seem more clearly. Future work will focus on a more detailed resistance analysis and compensation point treatment of the dry deposition process.

LandClass	V_d/ms^{-1}
Arable	0.003
Grassland	0.01
Moorland	0.02
Forest	0.03
Urban	0.004
Sea	0.004

Table 1. Initial NH_3 values of V_d assigned to the landuse database.

Specie	V_d/ms^{-1}
SO_2	0.008
SO_4^{2-}, NO_3^-, NH_4^+ aerosol	0.001
PAN	0.002
NO	0.000
NO_2	0.001
HNO_3	0.04

Table 2. Dry deposition velocities for other chemical species used by the model.

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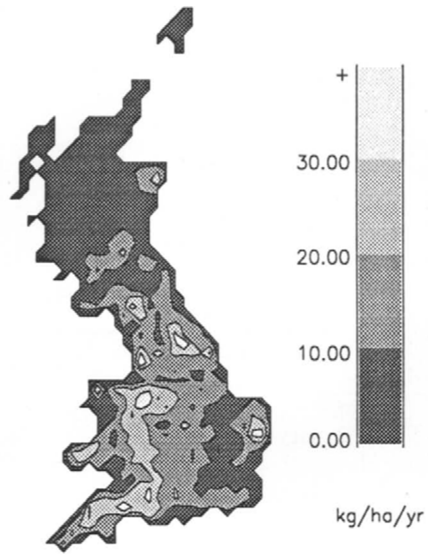

Figure 1. N–NH_3 emission map of Great Britain.

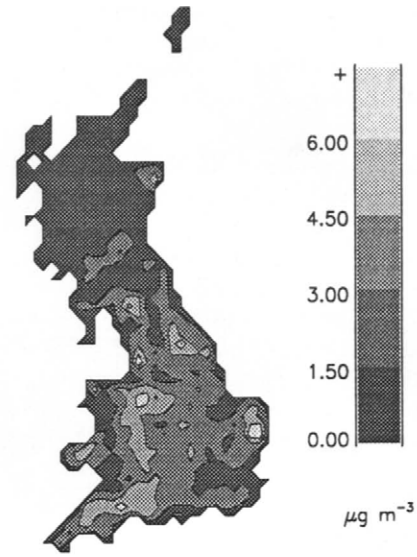

Figure 2. NH_3 concentration map of Great Britain using land–dependent V_d and detailed vertical diffusion.

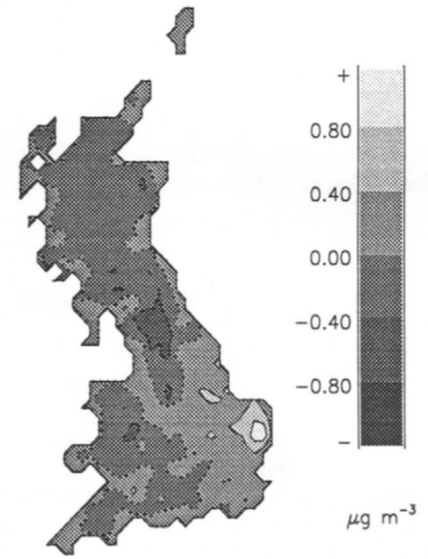

Figure 3. Difference in concentration between a run of the model with land–dependent V_d and that with constant V_d. Dotted line is zero contour.

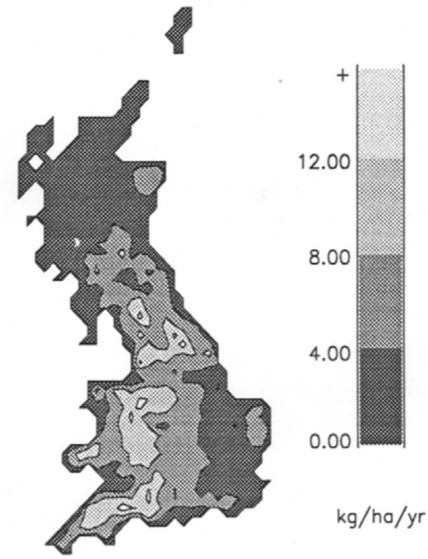

Figure 4. N–NH_3 dry deposition map of Great Britain using land–dependent V_d.