Process-based modelling of NH_3 exchange over a grazed field

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Abstract
In this study a process-based ammonia (NH_3) exchange model for a grazed field has been described and evaluated. The presented model is based on a patch-scale NH_3 exchange model, GAG (Generation of Ammonia from Grazing), which has been here extended to the field scale. GAG accounts for the total ammoniacal nitrogen and water content of the soil as well as the soil pH under a single urine patch. The new, field scale model combined multiple runs of the patch-scale model including both urine-affected and unaffected areas. The field-scale model was tested over two modelling periods, using NH_3 flux measurements taken at an intensively managed grassland, Easter Bush, UK. The model represented well the observed fluxes. It was found that the temporal evolution of the NH_3 exchange flux was dominated by the NH_3 emission from the urine patches. The results also showed that the evolution of NH_3 emission from urine patches deposited in different time steps could be substantially different: in some cases the first high NH_3 emission peak occurred a day or two days after the deposition of the given urine patch. Furthermore, according to our findings, NH_3 fluxes over the field in a given day could be considerably affected by the NH_3 emission from urine patches deposited several days earlier. The approach is designed to provide a balance between simplicity and process representation to allow it to be ultimately applied in regional scale atmospheric emission, transport and deposition modelling.

Keywords
Ammonia exchange, grazing, process-based modelling

Introduction
The environmental effects of strong emission of reactive nitrogen compounds (N_r), dominated by ammonia emission (NH_3) is widely discussed in the literature (Galloway et al., 2008, Fowler et al., 2013). Sutton et al. (2011) identified five key environmental threats: soil, air and water quality, greenhouse balance and ecosystems. Volatilization of NH_3 is influenced by meteorology, especially temperature. This meteorological dependence raises the question: how will NH_3 emission alter in a changing climate? A way to address this question and simulate the subsequent environmental consequences is to construct meteorology-driven models of NH_3 emission from every agricultural source (Sutton et al., 2013). In this study an NH_3 emission model for grazed fields was constructed and evaluated based on measurements.

Model application
Over a grazed field, the great majority of NH_3 is emitted from the urine patches (Laubach et al., 2013). The GAG model (Móring et al. 2016) is capable of simulating NH_3 volatilization from a unit of NH_3 source on the field: a single urine patch. To derive the NH_3 emission flux over a urine patch, GAG calculates the soil pH as well as the TAN (total ammoniacal nitrogen) and the water budget of the soil under the patch. However, in order to apply the GAG model to a grazed field, further circumstances have to be considered. Firstly, multiple urine patches are deposited in every time-step that may overlap (Dennis et al., 2013). Secondly, in addition to the NH_3 emission from the urine patches, the total NH_3 flux over a grazed field is affected by the NH_3 exchange with the areas that were not affected by urine (Sutton et al., 2001).

The chance of the overlap of two urine patches, apart from the frequency of the urination events, depends on the animal density on the field and the length of the grazing. Since in the present model application the animal density was relatively low and the modelling period was short, the effect of overlap was neglected.

With the above assumption, over a grazed field two types of area can be distinguished: (a) area covered by urine, and (b) area that is not affected by urine, referred to as "non-urine area" hereafter (as shown in Fig. 1).

It was assumed that the total NH_3 flux over the field is the sum of the emission from the urine affected area and the exchange with the non-urine area. Whilst NH_3 emission flux over every urine patch was calculated by GAG, for the non-urine area a slightly different approach was used. Under the urine patches there is a strong variation in the TAN budget and soil pH (Laubach et al., 2012), whereas under the non-urine area, in the absence of any considerable nitrogen input, the soil chemistry is practically undisturbed. Thus, for the non-urine area a modified version of GAG was applied in which constant soil chemistry was assumed.

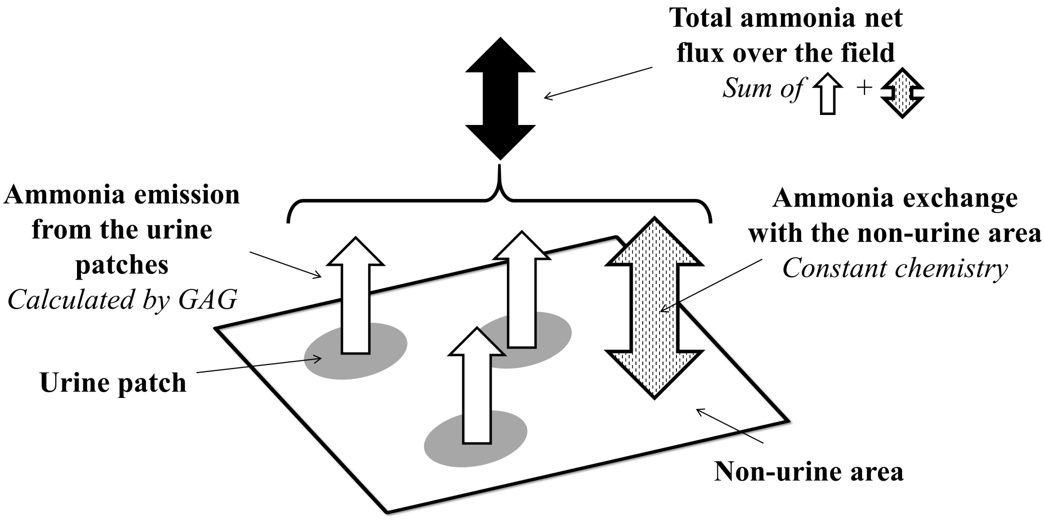

Figure 1. The schematic of the field scale model, depicting the components of the total net ammonia flux over the field.

Validation data

The field scale application of the GAG model was tested using measurements taken over a grassland at Easter Bush, UK (55.87° N, 3.03° E, 190 m a. s. l.) by CEH (Centre for Ecology and Hydrology). At the site NH_3 fluxes were derived using the gradient method. This technique calculates the fluxes based on measurements of the vertical gradient of NH_3 air concentration and micrometeorological variables. Ammonia concentration measurements were conducted by using a high-resolution NH_3 analyzer, AMANDA (Ammonia Measurement by ANnular Denuder sampling with online Analysis, Wyers et al., 1993). The concentration gradients were obtained from concentration measurements at three heights: 0.44, 0.96 and 2.06 m above ground.

Along with the NH_3 concentrations and micrometeorological variables, all the input meteorological variables required by the GAG model were measured at the site (for the instrumentation, see Milford et al., 2001). From the measurement database two time periods were chosen for model validation: 26/08/2002 00:00 - 04/09/2002 09:00 (denoted by P2002) and 20/06/2003 00:00 - 25/06/2003 05:00 (denoted by P2003).

Results

The model results for both modelling periods, P2002 and P2003, are illustrated in Fig. 2. In the case of P2002 (Fig. 2.a) the model was in a good accordance with the observations. It captured the characteristic daily variation of NH_3 exchange detected over 31/08-02/09, and the magnitudes of the modelled and measured values were quite close to each other. The largest difference occurred on 02/09 when the model clearly underestimated the observations. The simulated fluxes from the patches represent well these observations, which suggests that the model might have derived stronger deposition fluxes over the non-urine area than occurred in reality. The large discrepancies between the simulated and measured values in the beginning of P2002, according to the metadata, were coupled with large uncertainty in the observations.

In P2003 (Fig. 2.b) the simulation agreed with the observations reasonably well. The match with the observed fluxes was especially good in the second half of 23/06. The largest difference emerged on 24/06, in the morning, when an emission peak was detected during the measurements at 04:00-08:00 AM. Although there was a midday peak also in the simulation, it occurred 6 hours later than the maximum in the observation. The increase in measured fluxes was linked to the period of maximum wind speed (with largest values of windspeed between 04:00-08:00 AM, not shown here). Although windspeed is included in the model, the larger effect on measured fluxes could imply a proportionately larger effect of turbulence on the fluxes (through atmospheric and within canopy resistances – see the parametrization in Móring et al., 2016) than estimated by the model. In addition, it should be noted that between 20/06 11:00 AM and 3:00 PM the NH_3 concentration denuder in the middle height was not functioning properly, and afterwards it was not operating until 23/06 01:00 PM, suggesting uncertainty in the measured dataset.

Examining the contribution of the urine patches and the non-urine area to the NH_3 exchange flux over the whole field in the two modelling periods (Fig. 2. a-b), it can be seen that in both cases the temporal evolution of the fluxes was dominated by the urine patches. Without the urine patches in both experiments net NH_3 deposition would have occurred, confirming the considerable effect of the presence of grazing animals on NH_3 exchange over grasslands.

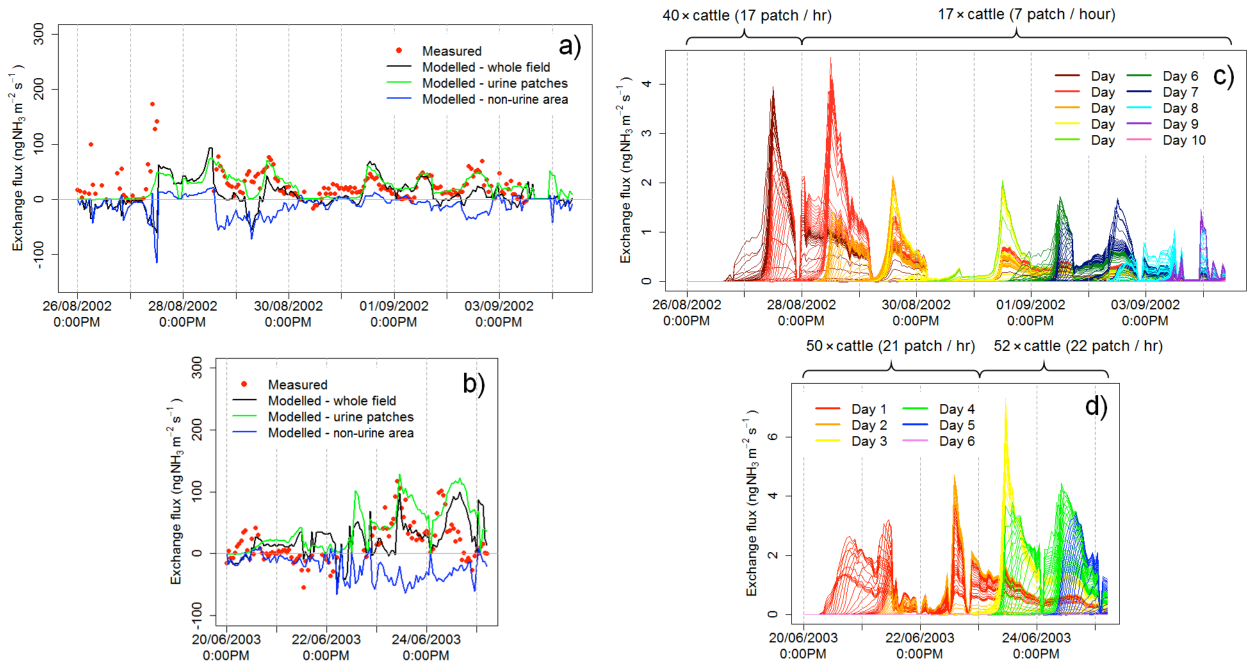

Figure 2. Left panel: The simulated and the measured NH_3 fluxes (red dots) in the modelling periods P2002 (a) and P2003 (b). The contribution of the patches (green line), and non-urine area (blue line) to the modelled NH_3 fluxes over the whole field (black line) is also illustrated. Right panel: Contribution of the urine patches to the simulated NH_3 fluxes over the whole field in the modelling periods P2002 (c) and P2003 (d). Each line indicates NH_3 fluxes expressed for the whole field from urine patches deposited in a given time step, while the different colours indicate the days of the urination events. The numbers above the plots show the number of cattle grazing over the simulation period and in brackets how many urine patches were deposited hourly.

The contribution to the exchange flux was also investigated for the groups of patches deposited in the different time steps (Fig. 2. c-d). In this figures each line represents the NH_3 emission flux from urine patches deposited in a given time step. The ensemble of the fluxes from the different patches showed a clear daily variation with NH_3 emission peaks at midday in both modelling periods. In P2002, these peaks became lower from the fourth day because after the second day instead of the initial 40 animals only 17 cattle were grazing on the field, depositing less urine patches.

In the original, patch scale model experiment (Móring et al., 2016) the first and highest peak in NH_3 emission occurred about 12 hours after urine application. By contrast, in the current results (Fig. 2. c-d) it can be observed that in some cases the highest peak over an individually deposited urine patch emerges only a day or two days after the urination event. For example, in P2002 (Fig. 2. c) from the urine patches deposited on the third day (orange lines) the highest emission occurred on the fourth day, or from the patches deposited on the sixth day (dark green lines) the maximal flux was observed two days later. Further examples from P2003 (Fig. 2. d) are the urination events on the second day (orange lines) from which the highest flux can be observed a day after. These differences emphasize the importance of the initial conditions after urine deposition on the subsequent and total NH_3 emission.

It has to be also noted that NH_3 fluxes over the whole field in a given day can be substantially affected by urine patches deposited several days earlier. In Fig. 2. c, for instance, on 02/09 the fluxes originating from the urination events 6 day before (red lines) are comparable with those from urine patches deposited two days before (dark green lines).

Conclusions

In this study an NH_3 emission model developed for a single urine patch (Móring et al., 2016) was applied for field scale. The new, field scale model was tested over two modelling periods, using measurements taken at Easter Bush, UK. According to the results, the model represented well the observed fluxes. It was found that the temporal evolution of NH_3 exchange flux over a grazed field was dominated by the NH_3 emission from the urine patches, which was substantially reduced by simultaneous NH_3 deposition to the non-urine parts of the same field. The results also showed that the evolution of NH_3 emission from urine patches deposited in different time steps could be substantially different. Moreover, NH_3 fluxes over the whole field in a given day could be considerably affected by the emission from urine patches deposited several days earlier.

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