Livestock-environment-interaction in naturally ventilated housing on the example of ammonia

Huyen Vu, Moustapha Doumbia, Qianying Yi, Thomas Amon, David Janke, Sabrina Hempel

Goal: We use fluid dynamics and reaction-kinetics modelling to better understand the complex interaction between outdoor climate, indoor microclimate and the emission source strength and gas dilution of naturally ventilated livestock housing. This basic understanding will be further used to improve the prediction of emission values, to optimize monitoring systems and to identify and evaluate emission mitigation potentials.

Relevance

More than 90 % of emitted ammonia is associated with agriculture, about half of it is related to livestock husbandry (particularly cattle and pig housing). Without adapting the husbandry several thousand tons of ammonia are expected to be additionally released from livestock husbandry as a consequence of climate change at the end of the century.

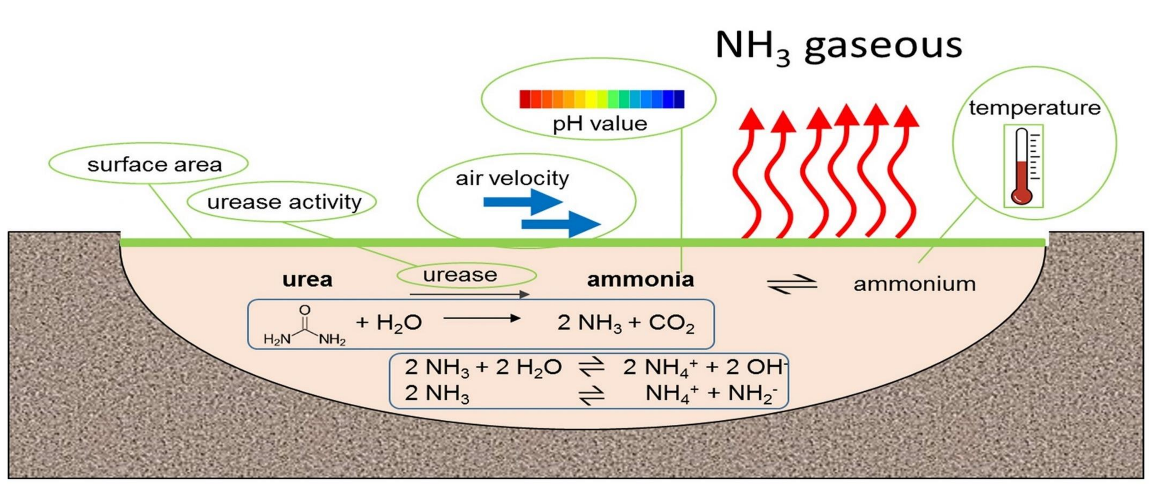
Ammonia emission causes large nitrogen entries into soils, water and vegetation leading to eutrophication and acidification.

The potential chemical reaction products of the short living ammonia affect the climate system and are a threat to the health of animals and humans. For example, ammonia is a significant source of indirect emissions of nitrous oxide and a source of the secondary inorganic aerosols (SIA) ammonium sulfate and ammonium nitrate (i.e., particulate matter).

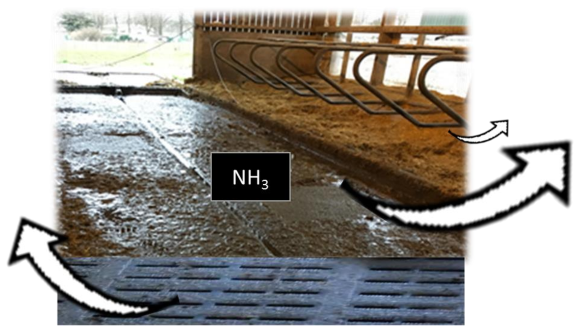
Uncertainty

There are large differences in the emission rate between individual farms, which are not well understood so far. One of the reasons is the complex interaction between outdoor climate, indoor microclimate and the emission source strength and gas dilution.

Reaction-kinetics modeling



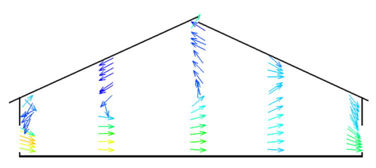
$$E = \frac{k * A * [C] * f}{H}$$

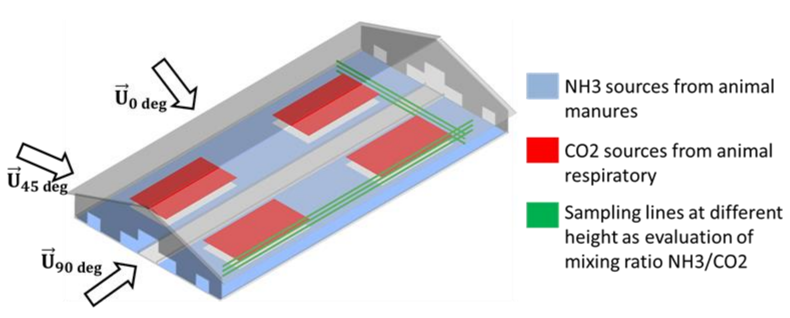


The strength of the emission from a urine puddle depends on the TAN concentration ([C]), the surface area (A) and three parameters (k,f and H) which depend on the temperature and pH of the liquid and the wind speed at the surface. The change in the TAN concentration over time, closely related to the change in the urea concentration, can be described mathematically by two coupled differential equations.

Fluid dynamics modeling (CFD & wind tunnel)

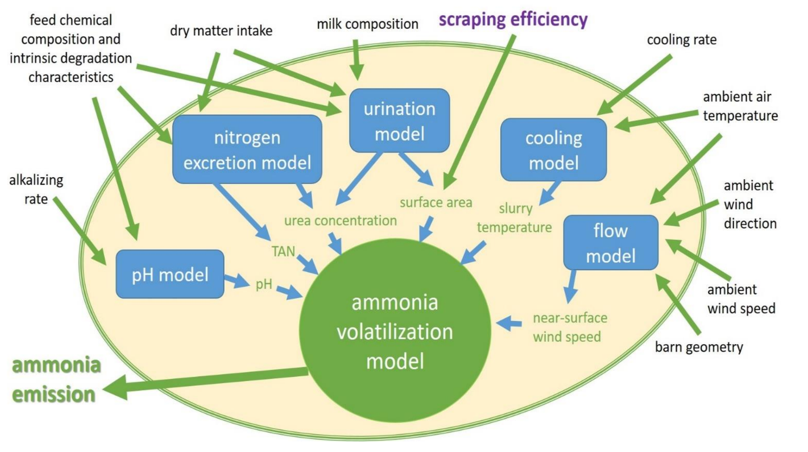
Raynolds-averaged Navier-Stokes (RANS) simulations for various boundary conditions have been conducted.

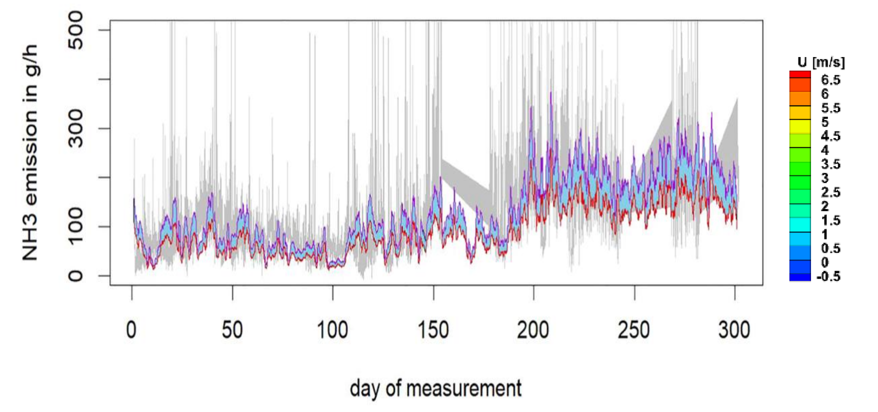




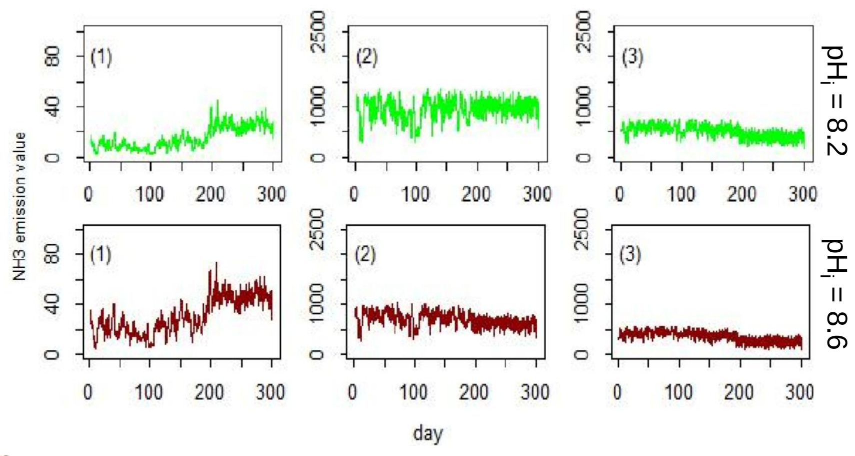
Compartment specific downscaling of wind speed using computational fluid dynamics improved the correlation between model and measurements from 0.5 to 0.6 for ten month of hourly values.

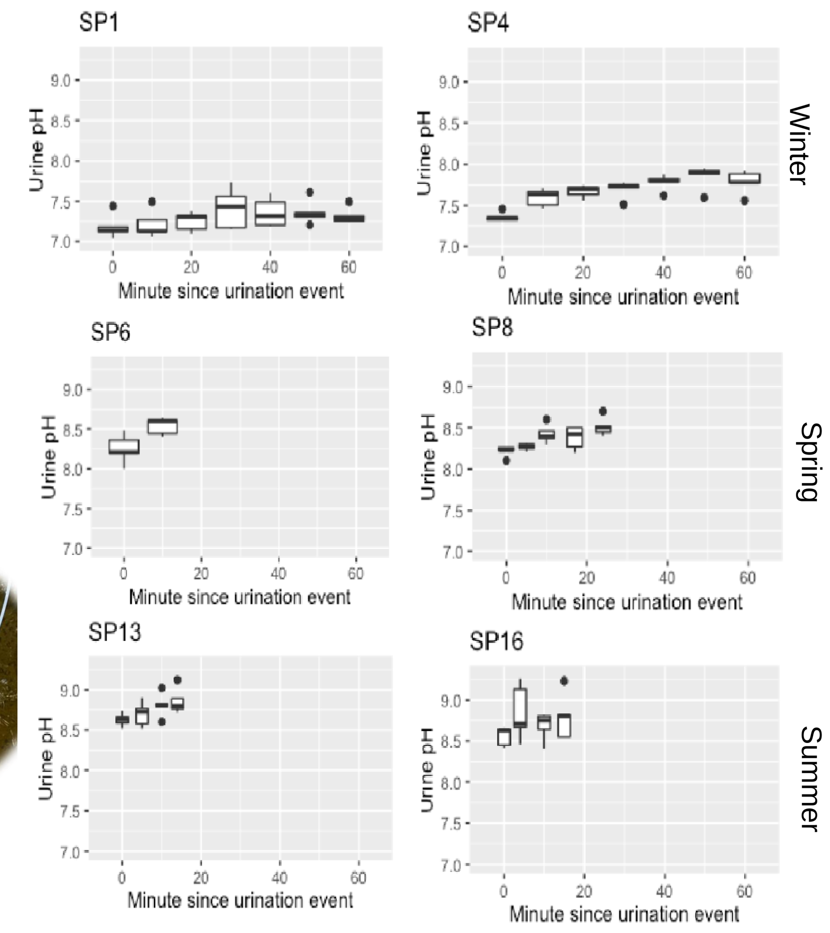
The influence of pH dynamics



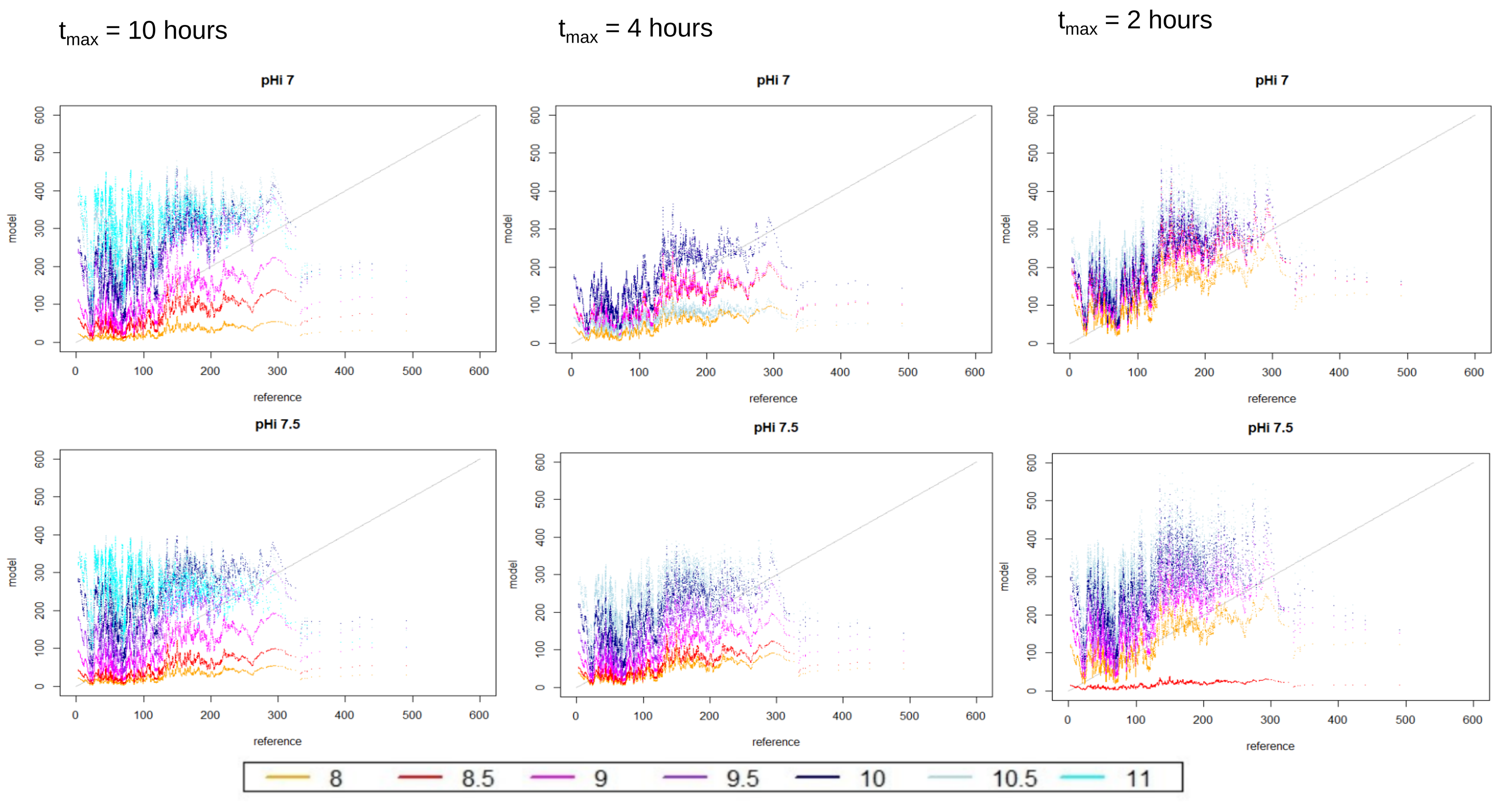


The pH dynamics interacting with ambient temperature have a crucial, non-linear impact on the overall ammonia emission rates by using different initial pH values and increasing functions.





We investigated different pH behaviors over time and simulated their influence on the ammonia emission values within a year. To refine the pH model, we measured the pH dynamics of fresh urine puddles within the first hour in a dairy barn. The asymptotic pH values were approximately 0.5 higher than the measured initial pH values within a urine puddle.



A high correlation of the modeled ammonia emissions with the measurements was observed for $pH_f = 9$ (i.e. the asymptotic pH value) with the pair $pH_i = 7$ or 7.5 (i.e. the initial pH value).

When simulating different late exponential decays (t_{max}), pH values showed the best match if reaching saturation after 4 hours with $R^2 = 0.77$ compared to 10 and 2 hours at $R^2 = 0.19$ and 0.16, respectively.

Conclusion: There is great potential for coupling different (semi-)mechanistic modeling approaches to project ammonia emission dynamics from livestock housing using easily accessible input data. The deviations between our modeled and the measured long-term average emission value were of the same order of magnitude as the deviation between the emission values determined by the different approaches of gas concentration balancing. The pH dynamics of urine puddles showed the best agreement with a double-exponential increasing function and a later exponential decay when the pH began to decrease after 4 hours. Further model refinement, more dynamic coupling between the modules and adding specific modules are expected to further improve the overall model performance.

Leibniz Institute for Agricultural Engineering and Bioeconomy
Max-Eyth-Allee 100 | 14469 Potsdam | Germany | atb@atb-potsdam.de | www.atb-potsdam.de

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