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Effect of weather data source on predicted ammonia loss from field-applied slurry in Denmark

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Summary

The ALFAM2 model can be used to estimate ammonia (NH_3) volatilization from field-applied slurry, but as with all models, there is uncertainty in the accuracy of resulting estimates. The effect of error in weather inputs were assessed in this work, where gridded hourly air temperature, wind speed, and rainfall data from the Danish Meteorological Institute (DMI) were compared to on-site measurements for 53 agricultural fields in Denmark. Results showed gridded wind speeds were higher than on-site values, even after correction for measurement height, but air temperature was similar. The difference in predicted ammonia emission was generally small (median value of 1.4% of applied TAN or 5.4% of reference predictions with latest peer-reviewed parameter set, 3% and 13% with new parameter set under development), and probably not a major source of error compared to other sources. Fixed adjustment of DMI wind speed and air temperature based on median responses from the 53 locations reduced this error.

Introduction

The ALFAM2 model a semi-mechanistic model for predicting ammonia loss from field-applied manure (Hafner et al., 2019). It has been used for research (Pedersen et al., 2022; Andersson et al., 2023) and emission inventory calculations (Hafner et al., 2021). In the model, emission rate and cumulative emission depend on weather conditions, along with other variables (Fig. 1). Therefore, one potential source of error in model predictions is error in these weather inputs. This work estimates this source of error when using gridded weather data from a national meteorological source.

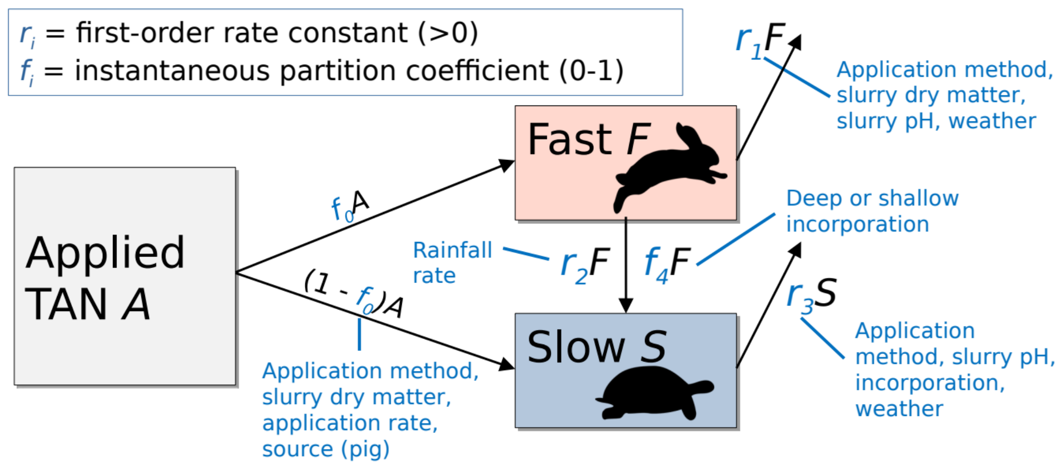

Figure 1. Structure of the ALFAM2 model, showing connections between predictor variables and primary parameters.

Methods

ALFAM2 model

Version 3.21 of the ALFAM2 R package was used (available from https://github.com/sashahafner/ALFAM2). Two parameter sets were used. Set 2 was described in Hafner et al. (2024). Set 3-alpha is a development version that may be revised, but represents the latest state of the model. It is based on some new measurements and a slightly different model structure. Both sets are available in the R package (as data objects alfam2pars02 and alfam2pars03_alpha).

Weather data

On-site weather data for April 2019, 2020, or 2021 measured using FieldSense weather stations from 53 agricultural field locations in Denmark were shared by Morten Birk. Based on latitude and longitude, these field locations were aligned with 10 km x 10 km weather grids used by the Danish Meteorological Institute (DMI) (Fig. 2). Gridded DMI weather data were then downloaded and merged with on-site measurements using DMI grid cell coordinates. All weather data had an hourly resolution. Gridded wind speed was reported at a height of 10 m, while on-site measurements were for 2 m. The gridded data were adjusted downward to 2 m values assuming a logarithmic profile and a roughness parameter of 0.01 m, following Hafner et al. (2019).

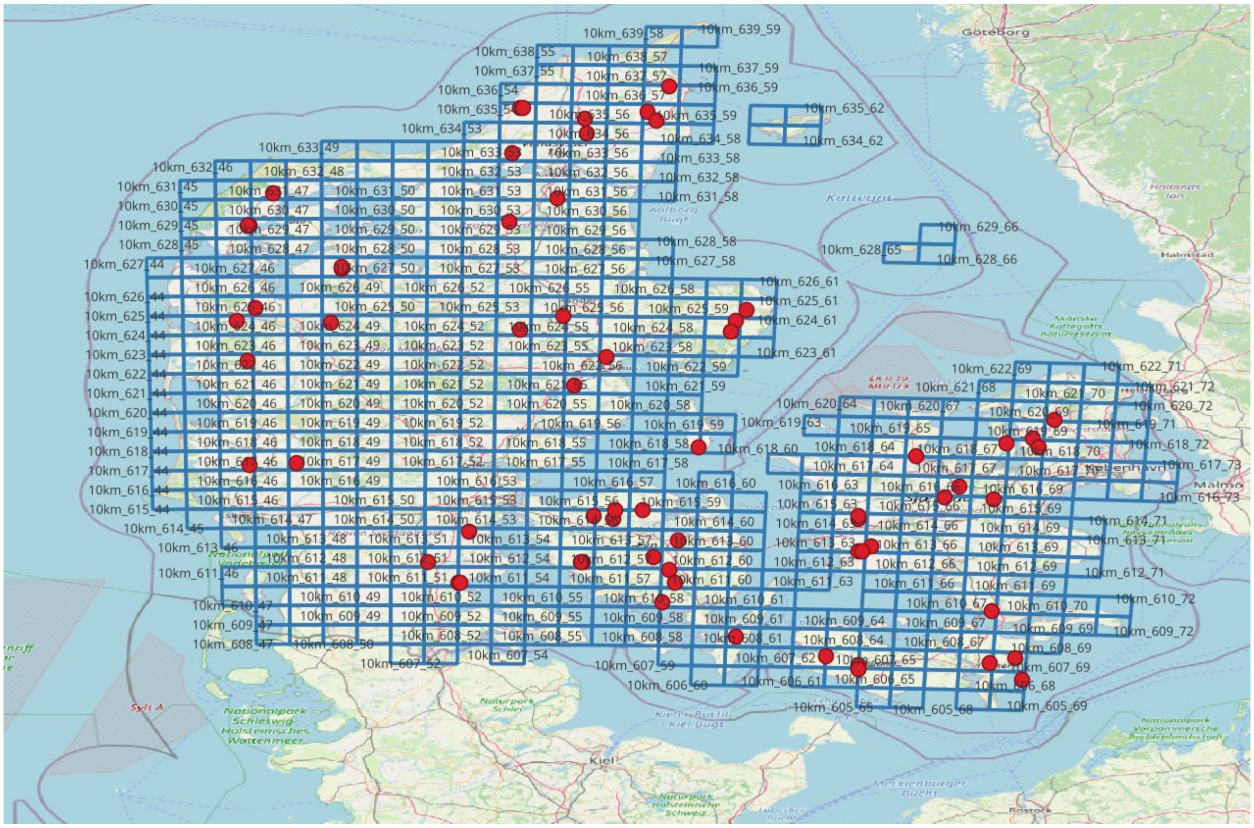

Figure 2. Alignment of on-site field-based weather stations (red circles) with DMI grid cells.

Model application

April weather data for the 53 field locations (with some dates missing for some locations) assuming a fixed application time of 9.00 provided a total of 1295 possible slurry application events in the input dataset. The ALFAM2 model was applied to predict ammonia loss from cattle slurry applied on each of the available April days, with application occurring at 9:00 and final emission determined after 7 days (168 hours). Slurry dry matter was set to 6.5%, pH 7.0, and trailing hose application at a rate of 30 t ha^{-1}, as in the latest inventory calculations for Denmark (Hafner et al., 2021). Different sets of weather input data were used for each application event. First, gridded data were compared to on-site data. To isolate the contribution of particular variables, gridded wind, temperature, and rainfall data were individually combined with on-site values for the other variables.

The difference between predicted emission based on gridded and on-site weather inputs was calculated for each application event (location × application date). These differences were summarized using quantiles, estimated with the quantile() function in R (v4.2.1) using type = 7 (default).

Results

Weather

Air temperature measurements were generally similar between the datasets. Median values were differed only by 0.2°C, while differences were larger for extremes (Table 1). In contrast, on-site wind measurements were lower than gridded values. The median gridded value was about 25% higher than the FieldSense value (Table 1). On an hourly basis, rain was rare. For hours with rain in at least one datasets (i.e., excluding hours with no rain), median values differed by about 25%. Extremes were more similar.

Analysis of differences in weather measurements on an hourly basis provides more insights, particularly of differences away from the median. The median value of air temperature differences was 0.2°C, and differences beyond 2°C were rare (Table 2). Wind was consistently different, however, with a median difference of 0.9 m s^{-1} and an 80th percentile of 1.5 m s^{-1}. This tendency for gridded data to overestimate on-site wind speed may be related to vegetation or buildings that serve as wind breaks around fields, or inaccuracy in the logarithmic profile or roughness parameter used for adjusting gridded data. Rain, when present, differed by 0.1 mm h^{-1} (Table 2), not a small difference compared to typical values (Table 1).

Table 1. Quantiles for hourly gridded (DMI) and onsite (FieldSense) weather data for March, April, and May for 53 locations in Denmark.

	Min.	10%	20%	30%	40%	50%	60%	70%	80%	90%	Max.
Temperature, on-site (°C)	-7.0	1.8	3.7	5.1	6.2	7.2	8.2	9.4	11.0	13.4	22.9
Temperature, gridded (°C)	-5.1	2.5	4.3	5.5	6.5	7.4	8.4	9.5	10.9	13.1	21.0
Wind, on-site (m s^{-1})	0.1	0.32	0.94	1.47	1.95	2.45	2.97	3.56	4.28	5.39	13.21
Wind, gridded (m s^{-1})	0.08	1.23	1.76	2.22	2.61	3.07	3.6	4.3	5.06	6.21	13.27
Rain, on-site (mm h^{-1})	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
Rain, gridded (mm h^{-1})	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
Rain, > 0 on-site (mm h^{-1})	0.0	0.0	0.1	0.1	0.2	0.20	0.3	0.5	0.8	1.3	10
Rain, > 0 gridded (mm h^{-1})	0.0	0.0	0.0	0.0	0.0	0.25	0.3	0.5	0.8	1.5	15

Table 2. Quantiles for differences between hourly DMI and FieldSense weather data for April and 1-7 May for 53 locations in Denmark.

	Min.	10%	20%	30%	40%	50%	60%	70%	80%	90%	Max.
Temperature (°C)	-9.33	-1.63	-0.97	-0.52	-0.15	0.17	0.5	0.87	1.35	2.19	7.83
Temperature, absolute (°C)	0.00	0.16	0.33	0.50	0.70	0.91	1.16	1.47	1.91	2.67	9.33
Wind (m s^{-1})	-3.88	-0.63	-0.18	0.13	0.38	0.63	0.88	1.16	1.51	2.11	7.22
Wind, absolute (m s^{-1})	0.00	0.15	0.31	0.46	0.63	0.81	1.02	1.26	1.58	2.13	7.22
Wind, relative (-)	-0.94	-0.19	-0.06	0.04	0.15	0.27	0.43	0.69	1.23	3.43	68.8
Rain (mm h^{-1})	-13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5
Rain, > 0 (mm h^{-1})	-13.9	-0.8	-0.3	-0.2	0.0	0.1	0.1	0.2	0.3	0.6	-13.9

Emission predictions

The use of gridded weather inputs resulted in higher predicted emission, primarily due to differences in wind speed (Fig. 3). This difference in emission varied substantially among observations. Quantiles from calculated emission differed quite consistently by 2% of applied TAN (Table 3). This value is identical to the difference between only two predictions based on median weather inputs (Table 1). But the difference between results with the two sets of inputs varied with location and date, and the median difference was a smaller fraction of applied TAN: 1.4% (Table 3). Expressed as a fraction of “reference” emission calculated using on-site weather, the median difference was about 5%. With parameter set 3-alpha, which shows a higher sensitivity to weather, these median differences reached 3% of applied TAN, and 13% of reference emission. Even extreme differences were a relatively small fraction of applied TAN for parameter set 2: 80% of all differences were between -0.6% to 5% of applied TAN based on 10% and 90% quantiles (Table 3). With corrections to gridded weather data to align median air temperature and wind speed (lower left panel in Fig. 3), the median difference in emission dropped to 1% of reference on-site emission, and 80% of observations were within -13% to 8% of reference on-site emission.

Other sources of error in ALFAM2 predictions may be larger than these that result from weather uncertainty. For comparison, estimates of average ALFAM2 model error based on a cross-validation comparison of measured and calculated values is around 7.5% of applied TAN for trailing hose application. Undoubtedly some of this—potentially a large faction—comes from measurement errors, but partitioning is not possible.

Table 3. Quantiles for ALFAM2 predictions of 168 h cumulative ammonia emission based on hourly gridded (DMI) and on-site (FieldSense) weather data for April for 53 locations in Denmark.

	Min.	10%	20%	30%	40%	50%	60%	70%	80%	90%	Max.
Gridded	0.077	0.22	0.23	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.37
On-site	0.078	0.20	0.21	0.23	0.24	0.25	0.26	0.27	0.28	0.30	0.36

Table 4. Quantiles for differences between ALFAM2 predictions of 168 h cumulative ammonia emission based on hourly gridded (DMI) and on-site (FieldSense) weather data for April for 53 locations in Denmark. Reference emission was taken as the values predicted with FieldSense measurements.

	Min.	10%	20%	30%	40%	50%	60%	70%	80%	90%	Max.
Frac. applied TAN	-0.07	-0.006	0.000	0.005	0.009	0.014	0.019	0.025	0.034	0.050	0.13
% ref. emission	-37	-2.3	0.0	1.7	3.6	5.4	7.7	10	15	23	110

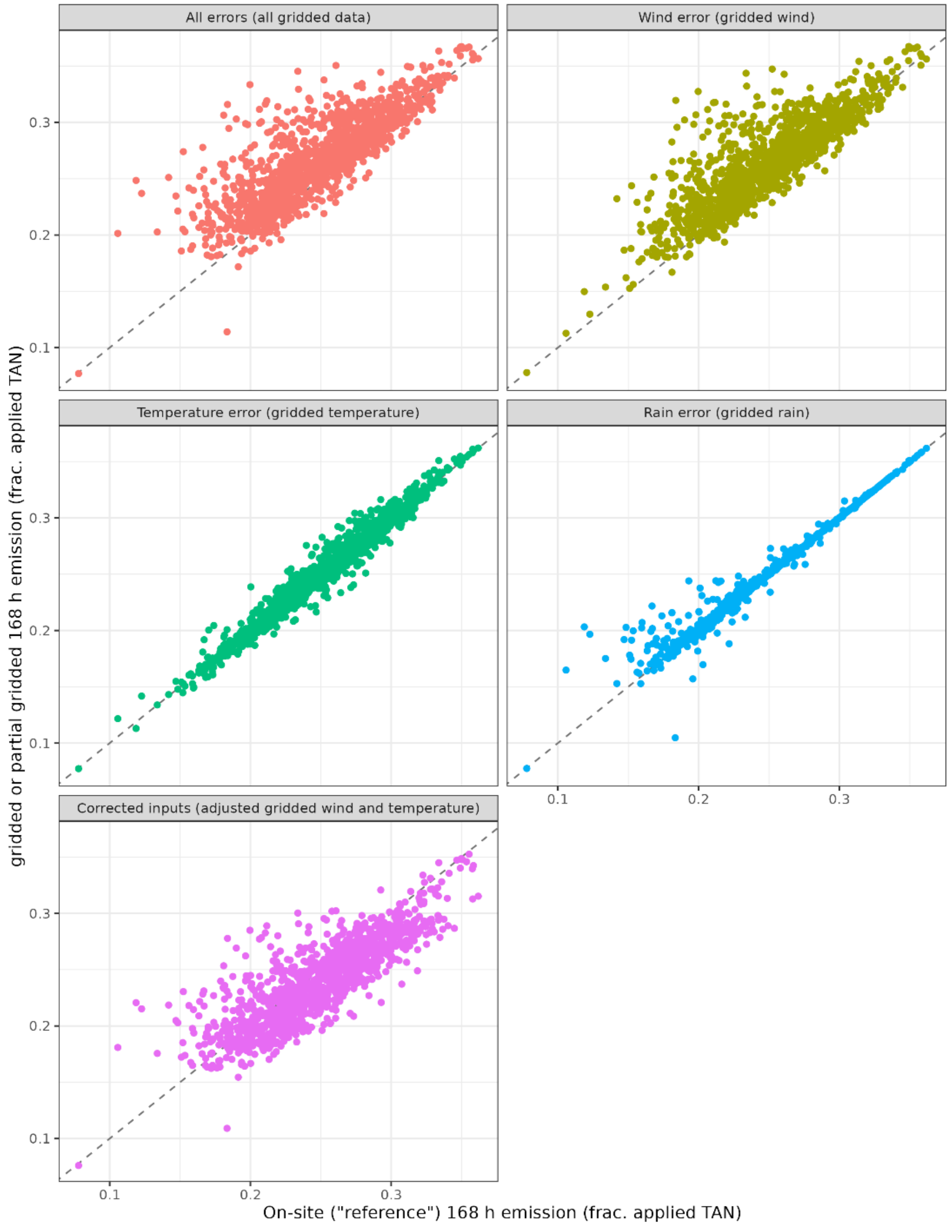

Figure 3. Comparison between ammonia loss from field-applied slurry calculated with the ALFAM2 model using parameter set 2 with different weather data. The top left plot compares gridded (DMI) and on-site (FieldSense) inputs.

Conclusions

The effect of weather data source on predicted emission is not trivial, but is small compared to other likely estimates of sources of uncertainty. Error is larger for some locations, but rarely exceeds 20% of reference predictions. Simple corrections to wind speed and air temperature reduce median error to a trivial level and avoid large differences for most observations.

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