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Modeling the NH_3 emission of a naturally ventilated dairy barn - A first analysis of different approaches

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Why we want to model ammonia emissions?

- Well validated & calibrated model can be an alternative approach in estimating ammonia emissions in the the barn instead of using complex and expensive measurement setup (f.e., FTIR);
- Validated & calibrated model allows decisions makers/stackholders to develop realistic emissions reduction strategies by tuning different barn characteristics included in the model (f.e., manure quality, emitted surface, age of the manure in the barn etc.) and observing the straightforward consequences of changing of ammonia emissions in the barn resulting of such tuning.

ATB

Aims:

- To provide a comparison between different ammonia emission models from literature sources (f.e., Bjerk et.al., 2013);
- To identify the influence of ambient parameters on the modeling results;
- To identify the best model estimating ammonia emissions and possibility to its upscaling to the scale of dairy barn;
- Next development of the chosen model in order to fit model to the barn scale (if possible);
- Validate the model with measured ammonia emissions (f.e., by FTIR devices; extracted in lab from the sample points).

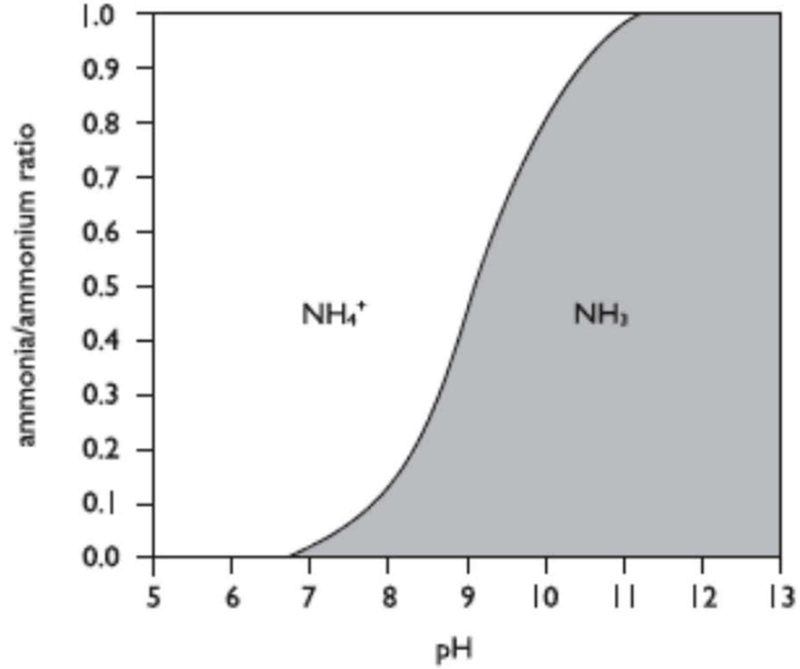


Figure 4. The dependence of the ammonia/ammonium (NH_3/NH_4^+) ratio as a function of pH.

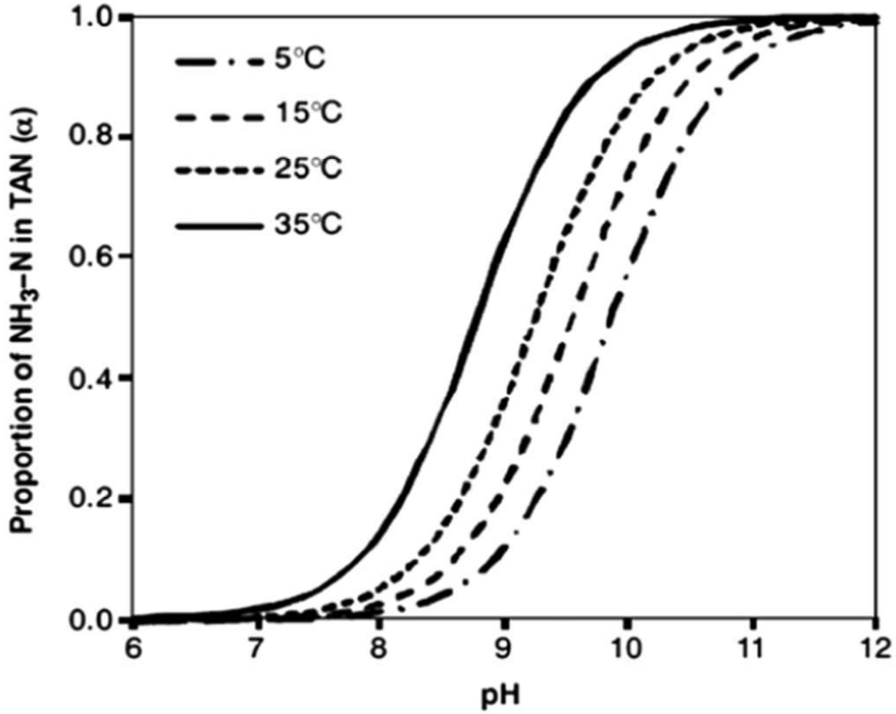


Fig. 2. Function of NH_3/NH_4^+-equilibrium with temperature and pH in aqueous solutions (Vaddella et al., 2011).

Models description

Model number and authors	Species	Emission surfaces				Factors influencing the mass transfer coefficient		Factors influencing ammonia concentration on surfaces		
		Solid floor		Slats	Pit	Influence of air velocity, (υ, m s^{-1})	Influence of air temperature (T, K)	pH at manure surface	Influence of manure temperature (T, K) on Henrys constant	Fraction of un-ionised ammonia
		Without bedding	With bedding							
1. Muck and Steenhuis (1981)	Cattle	X				$\upsilon^{0.8}$	$T^{-1.4}$	≈8.6	1.053^{-T}	Eq. (4)
2. Elzing and Monteny (1997)	Cattle			X		$\upsilon^{0.8}$	$T^{-1.4}$	8.6	1.053^{-T}	Eq. (5)
3. Monteny et al. (1998)	Cattle			X	X	$\upsilon^{0.8}$	$T^{-1.4}$	8.6	1.053^{-T}	Eq. (5)
4. Wang et al. (2006)	Cattle			X	X	$\upsilon^{0.8}$	$T^{-1.4}$	7.8–8.6	1.053^{-T}	Eq. (6)
5. Zhang et al. (1994)	Pigs				X	Eq. (7)	Eq. (7)	NA[a]	$\approx 1.05^{-T}$	Eq. (3)
6. Aarnink and Elzing (1998)	Pigs	X		X	X	$\upsilon^{0.8}$	$T^{-1.4}$	8.1–8.8	1.053^{-T}	Eq. (3)
7. Ni et al. (2000)	Pigs				X	$\upsilon^{0.7}$	T^{0}	8.0–8.9	$\approx 1.04^{-T}$	NA[a]
8. Groenestein et al. (2007)	Pigs	X	X	X		NA[a]	NA[a]	NA[a]	NA[a]	NA[a]
9. Cortus et al. (2008)	Pigs	X				$\upsilon^{0.5}$	Eq. (9)	8.2–9.2	1.053^{-T}	Eq. (3) [b]
10. Cortus et al. (2009)	Pigs				X	$\upsilon^{0.5}$	Eq. (9)	8–9	1.053^{-T}	Eq. (10)
11. Cortus et al. (2010a, 2010b)	Pigs	X		X	X	$\upsilon^{0.5}$	Eq. (9)	≈8	1.053^{-T}	Eq. (3)
12. Liu et al. (2009)	Poultry		X			NA[a]	NA[a]	6.3–9.0	$\approx 1.04^{-T}$	Eq. (6) [c]

Modelling computation on the example of Model Elzing, Monteny, 1997

A = emitting surface area (m^2)
k = mass transfer coefficient ($m \cdot s^{-1}$)
f = ammonia fraction
H = Henry's constant, describing the ratio of the concentrations of ammonia in the liquid phase and in the gas phase in equilibrium with each other

$$\frac{d[U]}{dt} = \frac{-S_m * [U]}{K_m + [U]}$$

$$\frac{d[C]}{dt} = \frac{-k * A * [C] * f}{H + V} + \frac{2 * S_m * [U]}{K_m + [U]}$$

[C] = sum of the ammonia and the ammonium concentration in the liquid ($Mol \cdot m^{-3}$)
E = ammonia emission ($Mol \cdot s^{-1}$)
V = volume of manure layer (m^3)

v = air velocity ($m \cdot s^{-1}$)
T = air temperature (°K)

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

Measuring experience:
Dummerstorf barn, Germany

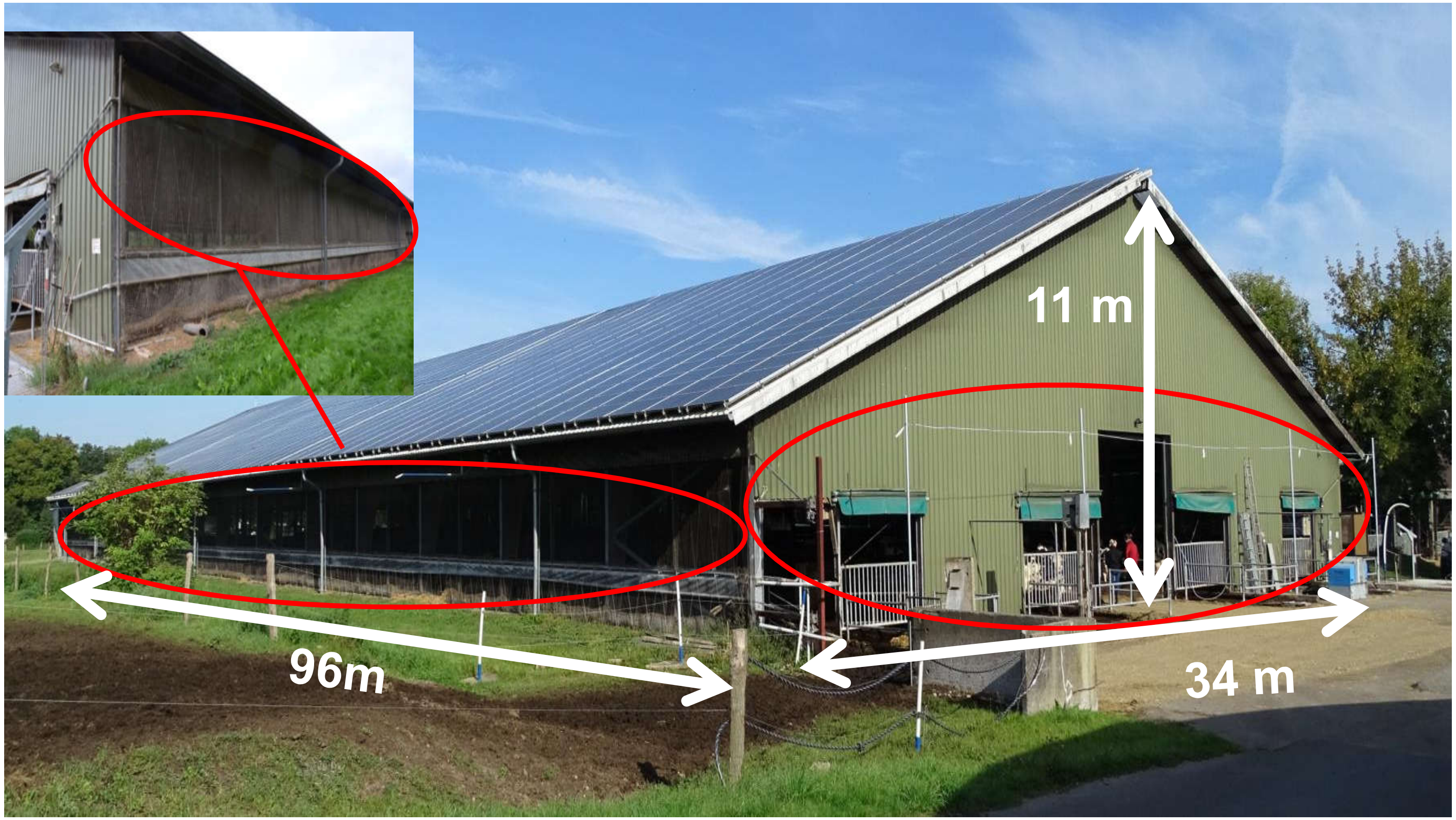
Which ambient parameters we need to input into Model?

- Temperature (two values: air temperature and manure temperature)
- Air velocity
- Surface area/Volume
- pH
- Urea concentration

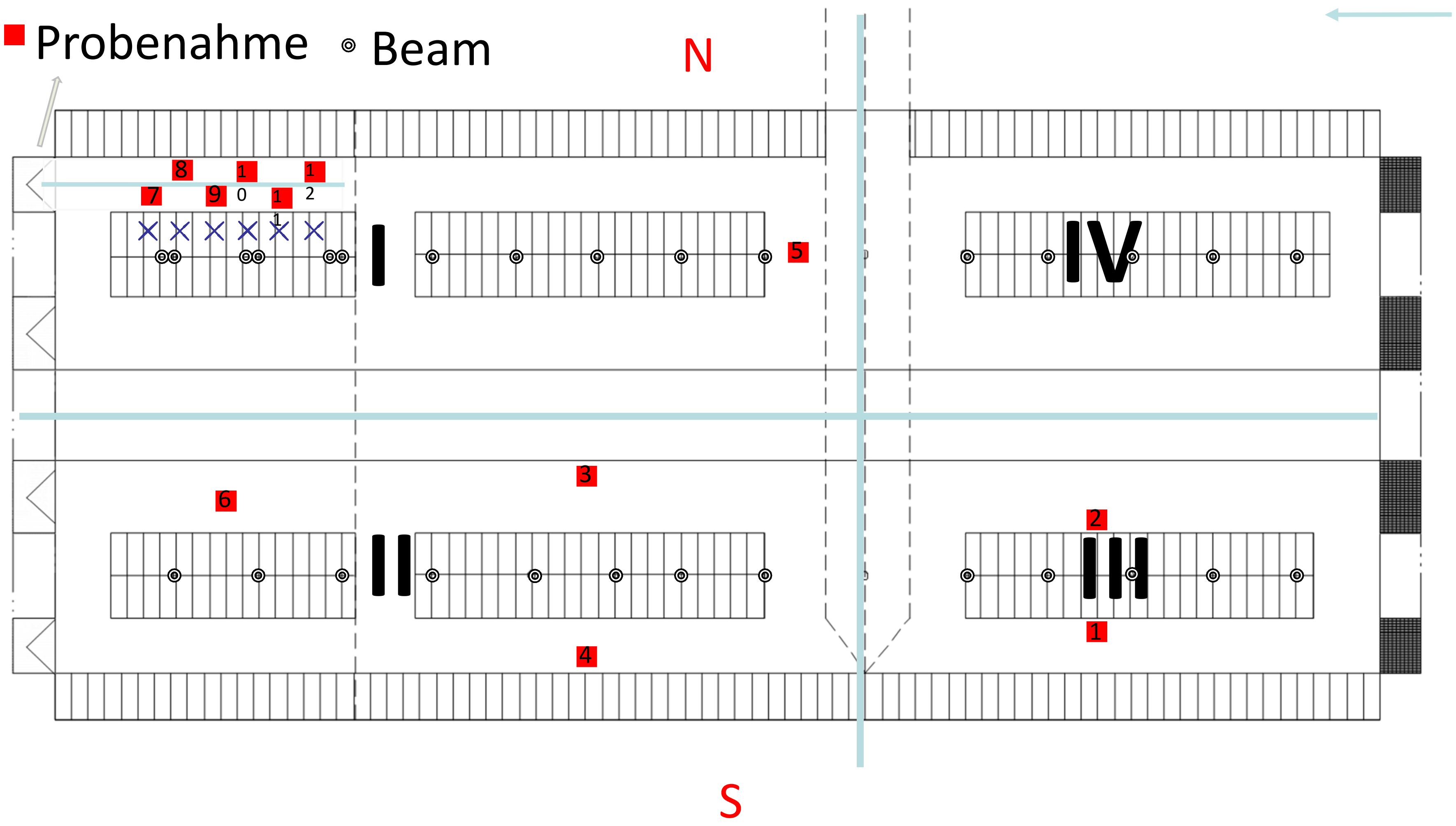
measured

Lab

Motivation



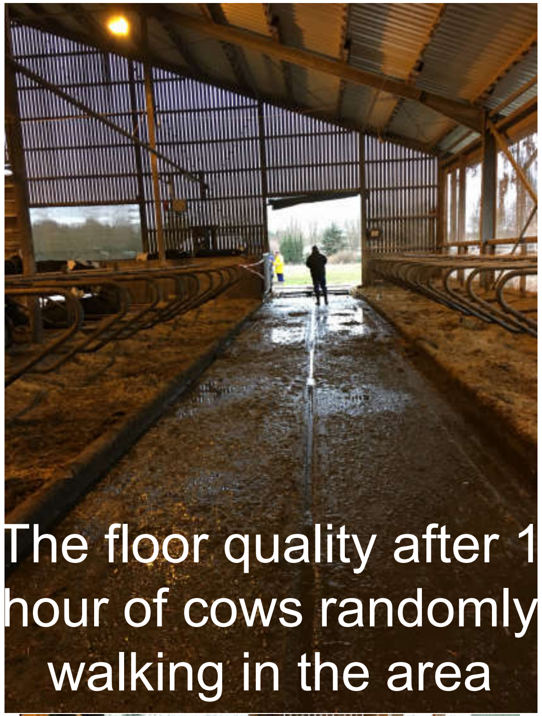
Dummerstorf: sampling measurements plan



Collecting samples and measuring ambient param. for **SP 1-6**

Collecting samples and measuring ambient param. for **SP 7-12**

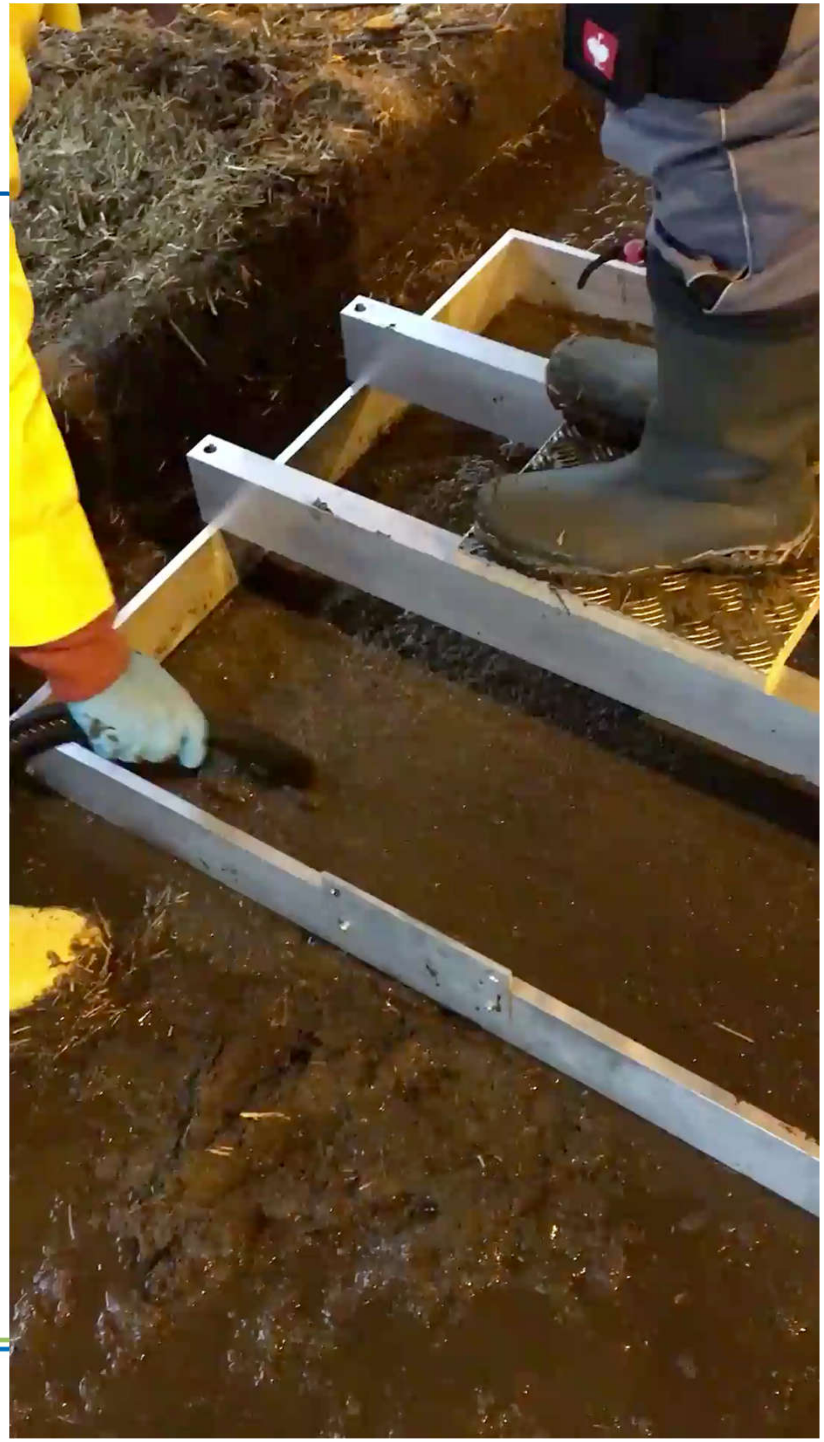
The quality of cleaned floor done by scrapper before experiment



The floor quality after 1 hour of cows randomly walking in the area

The frame measurements

After the vacuuming



Ambient parameters: spatial distribution

Dummerstorf barn, Germany

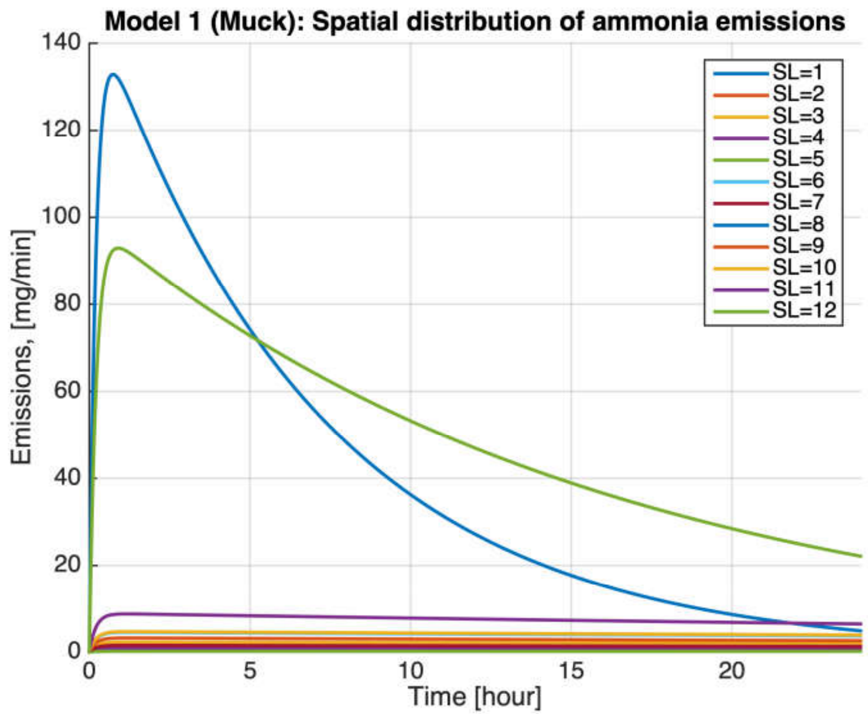
Measurement experience:

Dummerstorf measurments 11.12.2018					
SP	T_slurry	T_air	Vel	pH	UC
1	7,3	6,8	0,56	7,1	37,3
2	9,8	7,8	0,54	7,6	13,3
3	11	8,7	0,11	7,9	49,8
4	9,5	7,4	0,14	7,4	61,9
5	4,8	3,8	0,48	6,8	25,4
6	8,2	6,5	0,20	7,9	90,7
7	12,2	10,7	0,85	7,1	35,4
8	9	7,3	0,92	8,5	181,3
9	7	5,2	0,72	7,5	60,8
10	5,8	4,5	0,34	7,8	103,9
11	6,2	4	0,34	8,0	116,1
12	8,6	6,3	0,25	8,6	276,4

Modelling experience of ammonia emissions

Modelling: Comparison between emissions from different models

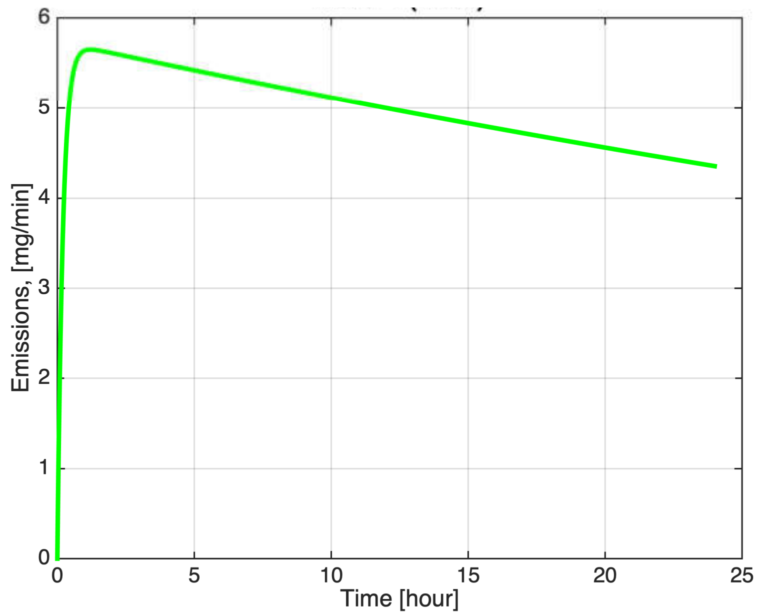
- Model 1 (Muck, 1981)



$$f = \frac{1}{1 + \frac{H^+}{3.9 \cdot 10^{-10} \cdot 1.07^{(t-293)}}}$$

T- temperature of manure/slurry (K)

Ammonia Emissions based on averaged ambient parametres

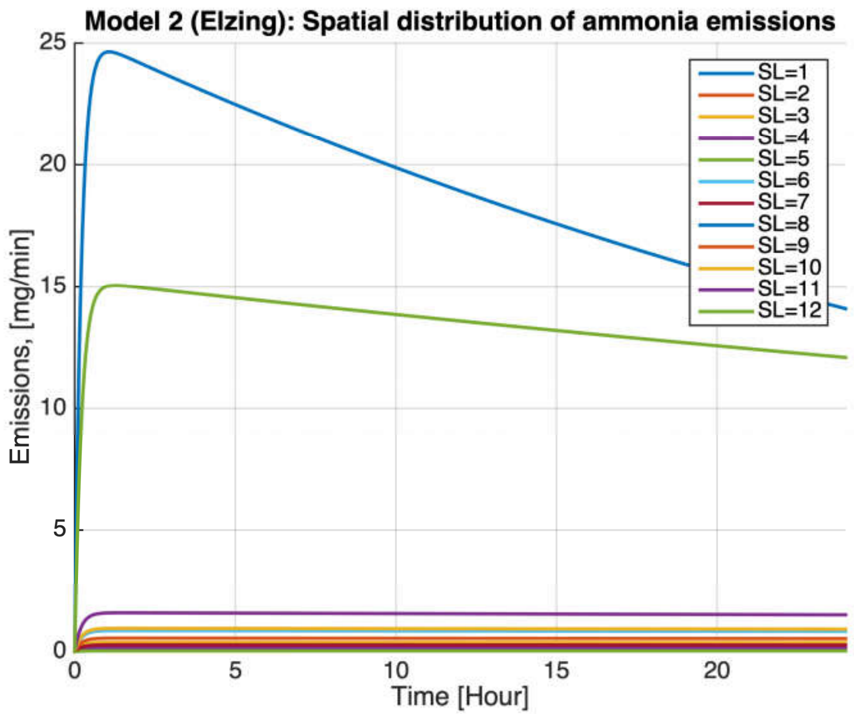


Modelling: Comparison between emissions from different models

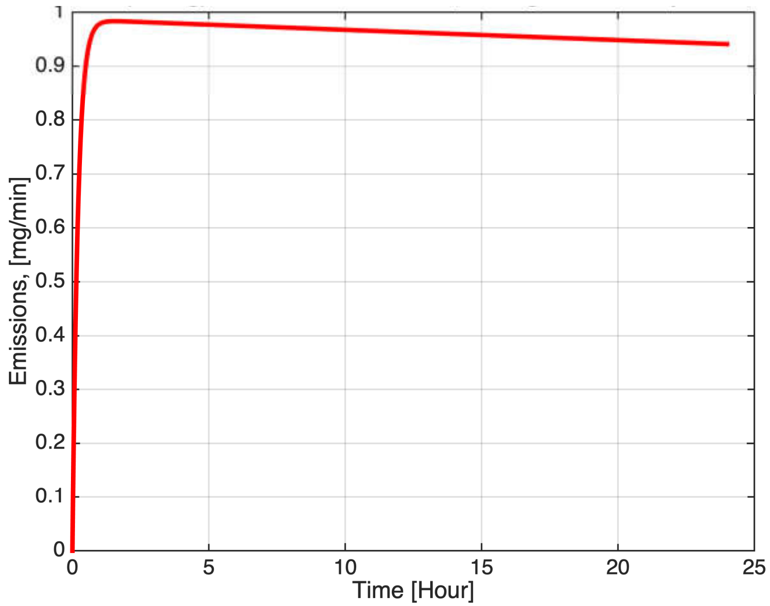
- Model 2 (Elzing, Monteny, 1997)

$$f = \frac{1}{1 + \frac{10^{-pH}}{0.81 \cdot 10^{-10} \cdot 1.07^{(t-293)}}}$$

T- air temperature (K)

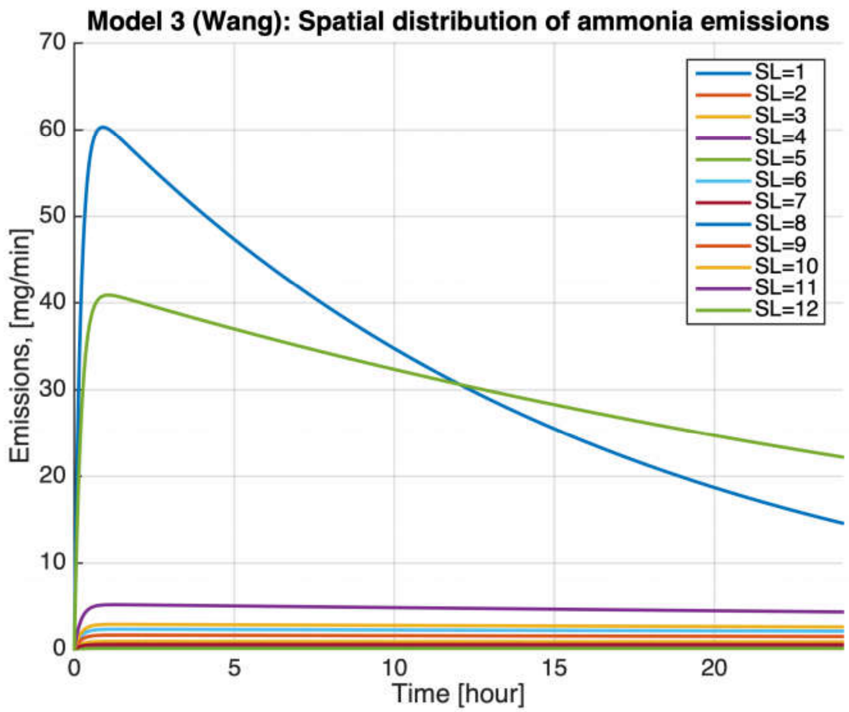


Ammonia Emissions based on averaged ambient parametres



Modelling: Comparison between emissions from different models

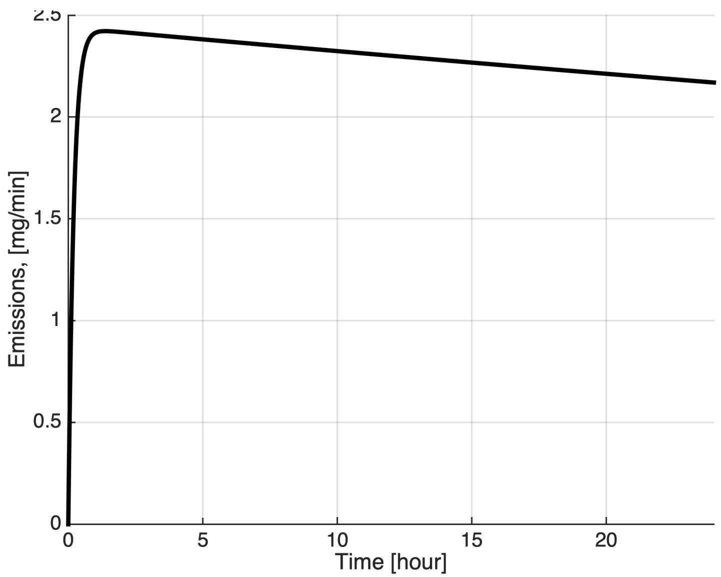
- Model 3 (Wang, Li, Zhang, 2006)



$$f = \frac{1}{1 + \frac{10^{-pH}}{0.81 \cdot 10^{-10}}}$$

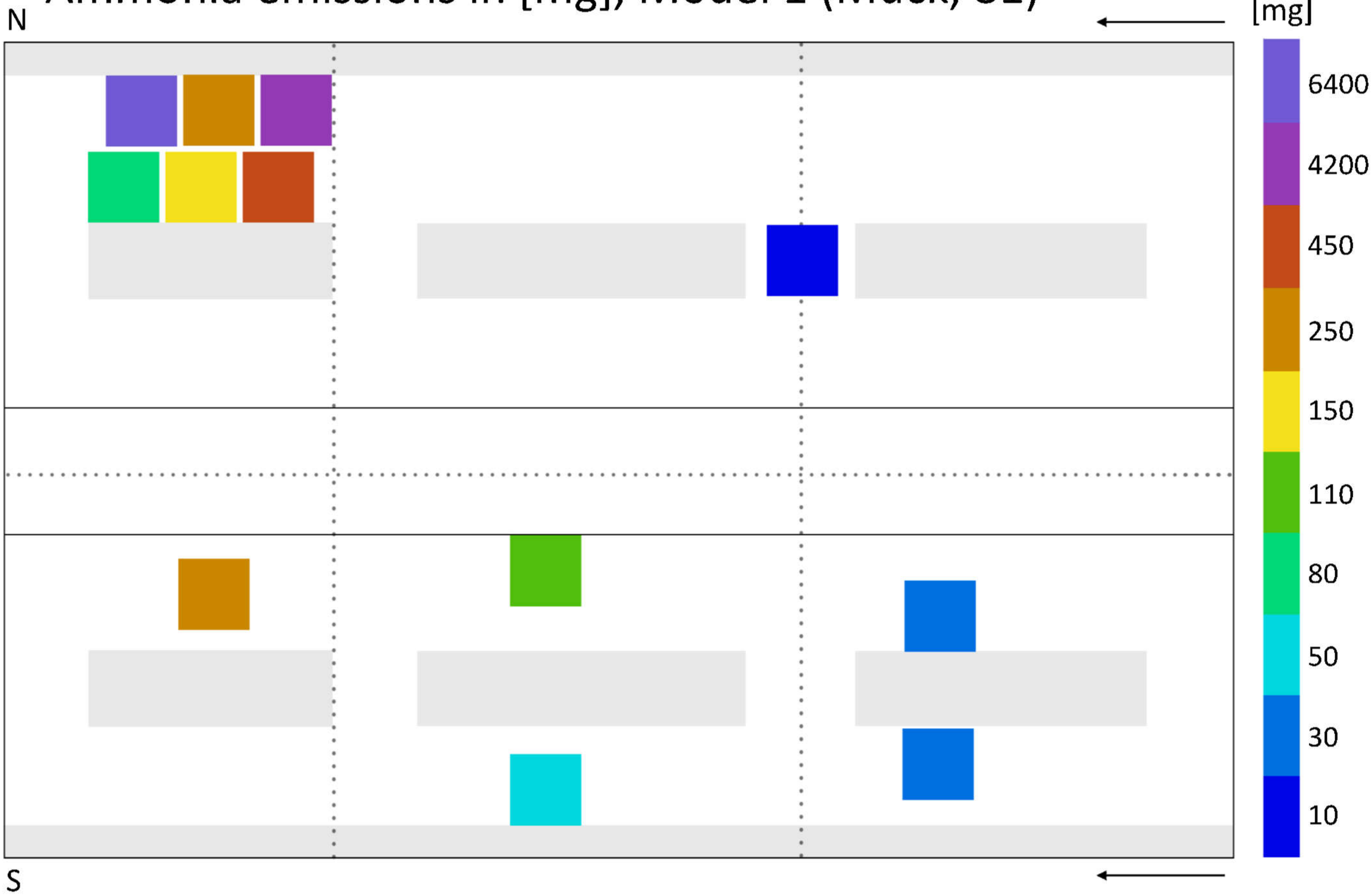
No temperature

Ammonia Emissions based on averaged ambient parametres

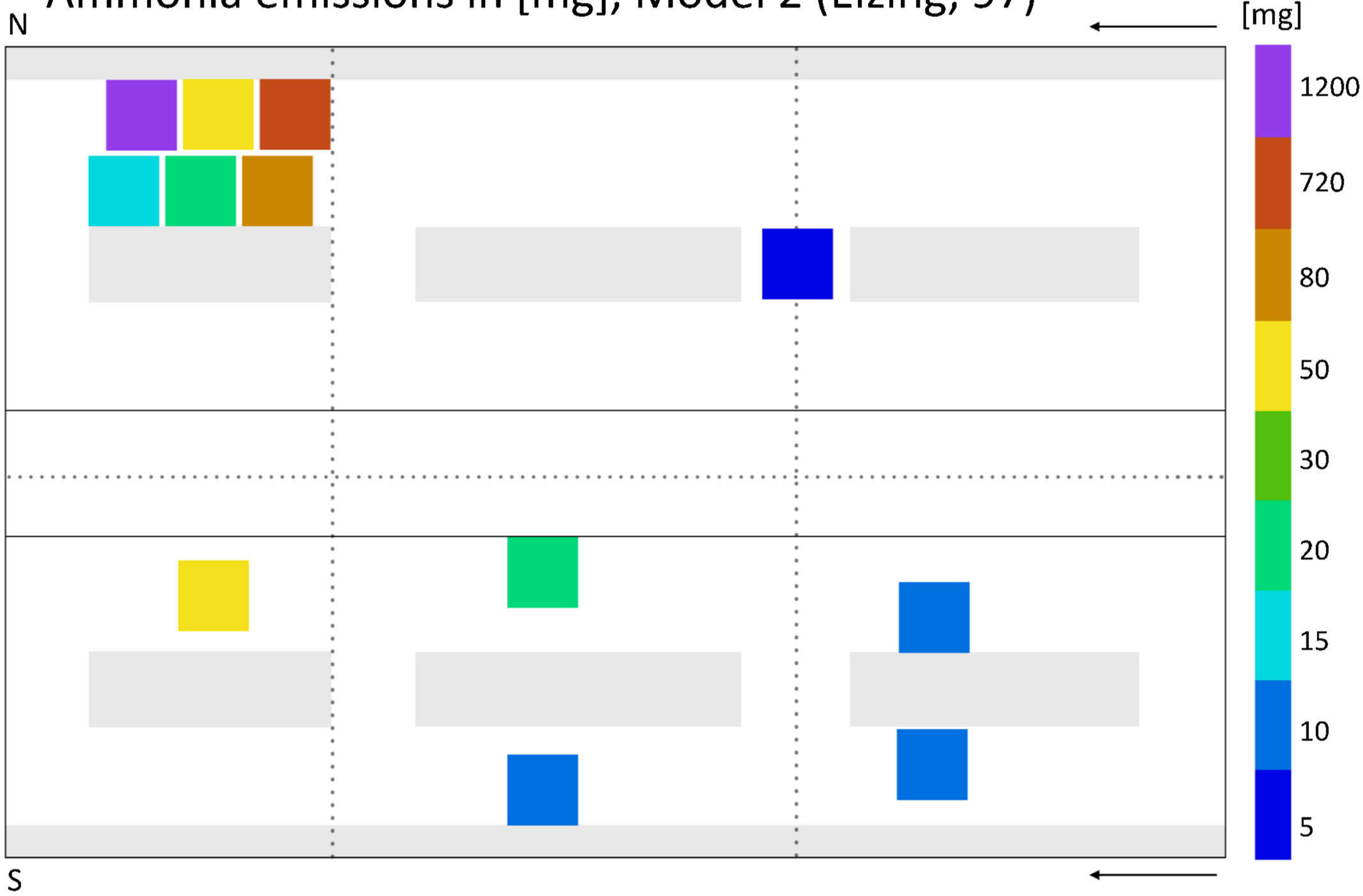


Modelling experience:
1 hour integration

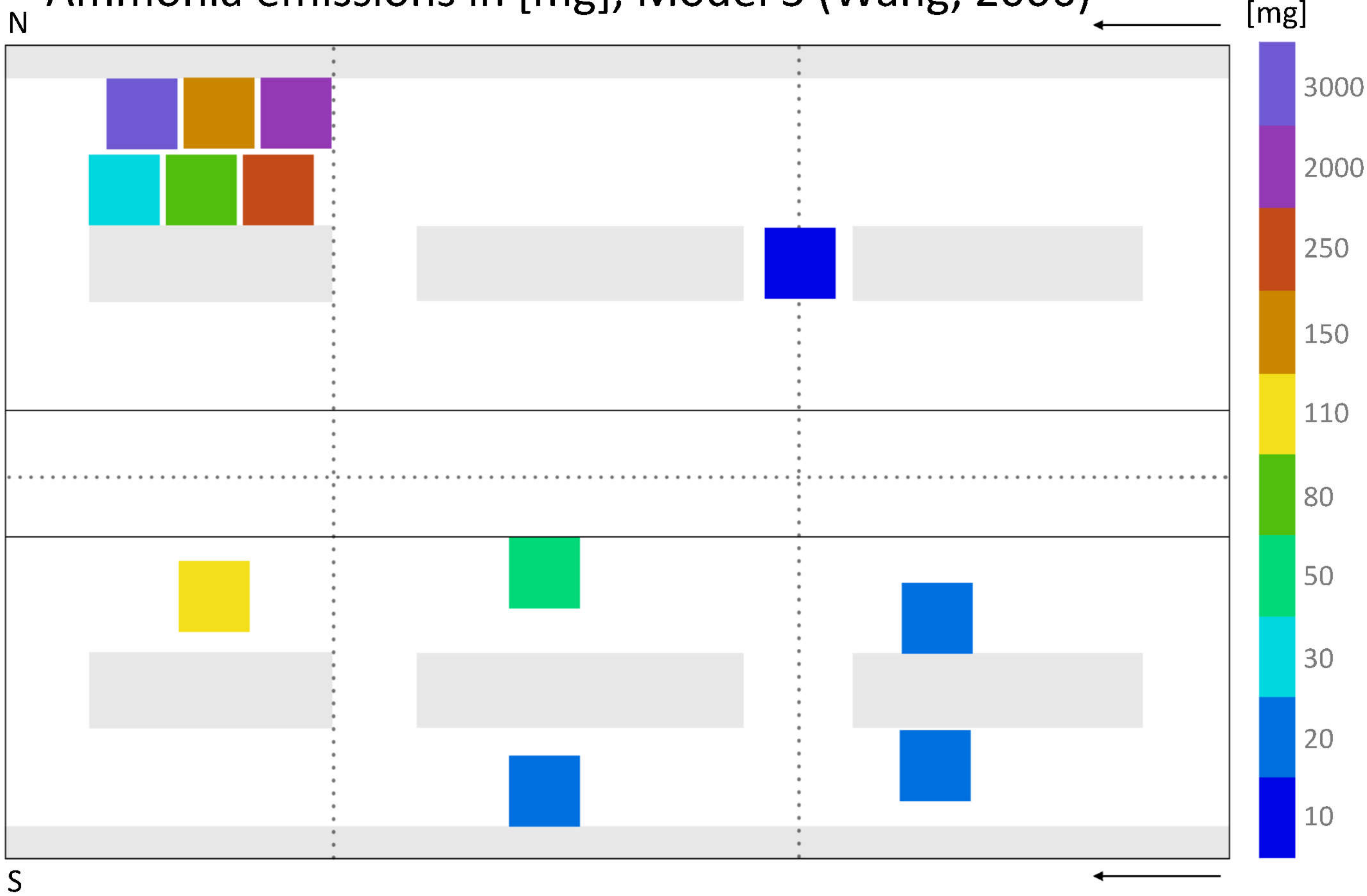
Ammonia emissions in [mg], Model 1 (Muck, 81)



Ammonia emissions in [mg], Model 2 (Elzing, 97)



Ammonia emissions in [mg], Model 3 (Wang, 2006)



Modelling: Comparison between emissions from different models for 1 hour integration

SP	Model 1	Model 2	Model 3
	Ammonia emissions [mg]		
1	32,54	6,40	15,99
2	46,93	7,84	19,58
3	111,73	18,14	43,20
4	45,53	7,47	19,31
5	7,41	1,37	4,30
6	238,43	41,38	111,09
7	75,27	13,24	26,61
8	6369,50	1195,48	2965,34
9	156,32	26,63	78,59
10	253,28	45,83	138,32
11	465,14	76,47	248,24
12	4180,15	720,62	1974,59
Modelling based on averaged amb.param	273,75	47,33	116,90
	kg/year*animal		
Emissions	7,59	1,31	3,24

Conclusion:

- All three models show similar **adequate distribution** behavior of ammonia emissions between SP;
- The emission values obtained from the **model 1** are the **highest**, the values from the **model 2** are the **smallest**;
- The values from the **model 2** are ~ **5 times smaller** than for the **model 1** and ~ **3 times smaller** than for the **model 3**;
- The **model 1** shows the most **realistic** values for dairy barns (according to literature sources, f.e., Hassouna et.al., 2016...).

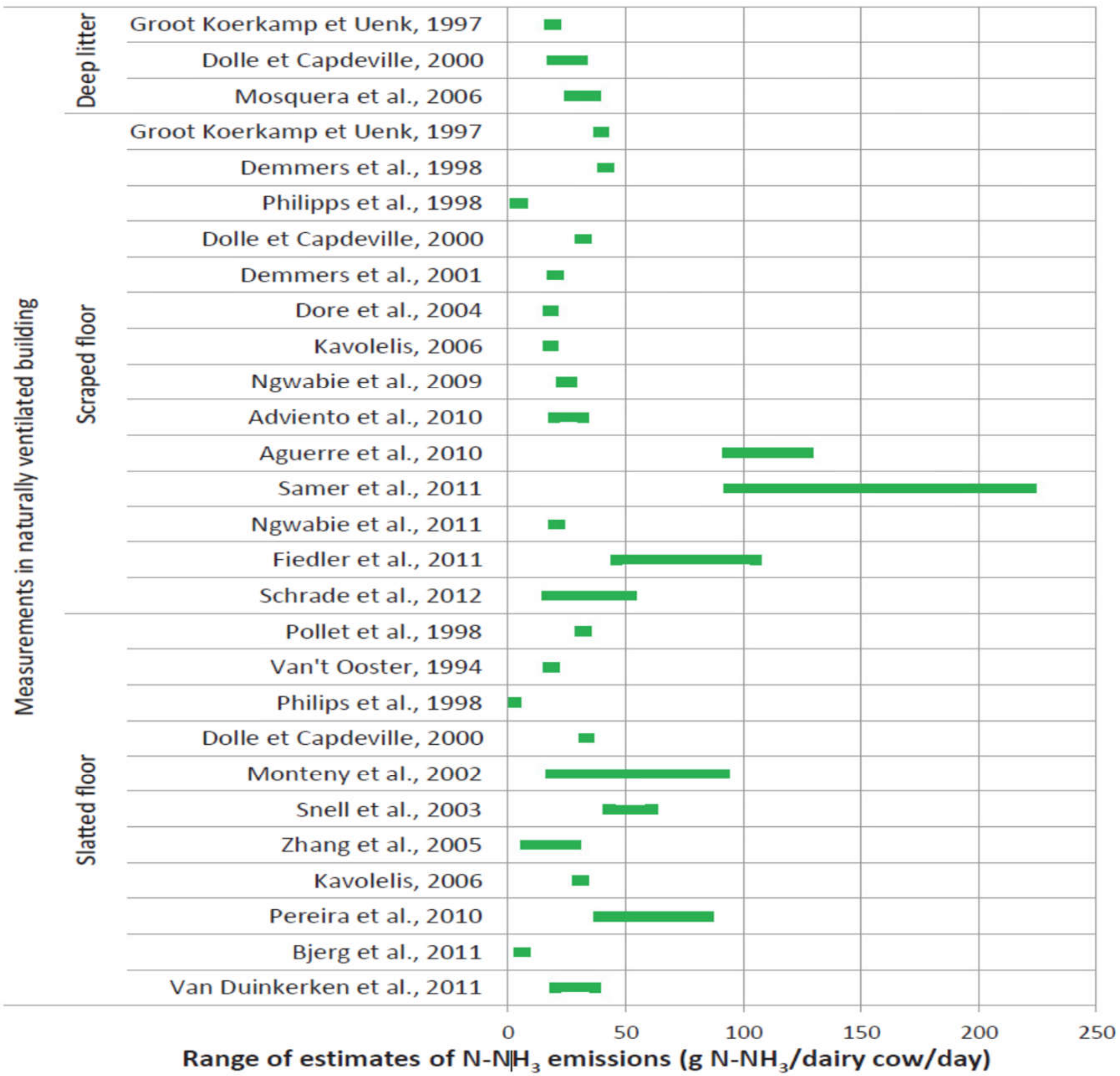


Figure IV. Variability of NH_3 emissions in a dairy cow building in the international literature (Charpiot *et al.*, 2012)

To do list:

- Find the way to **extend** the model **to the barn scale** and try to **add** the **components of housing system**, playing a crucial role on ammonia emissions (floor type, scrapping periodicity and etc.);
- Develop the procedure of **validation**, in order to **identify the most appropriate model** which suits our research interests.
- Find the way of the most reasonable **coupling** method of the final **emission model** together with the **feed intake model.**

Opened questions for discussion:

- Since models presented in Bjerg et.al, 2013 are laboratorial defined models, **are they applicable** to the real conditions in the dairy barn **and could they be upscaled to the barn size**?
- How to **transfer** the emission model (f.e., Elzing, Monteny, 1997) estimating the values of the certain area (f.e., $1m^{2)}$ **to the barn scale**?
- **Where** we should **measure ambient parameters** that they are representative for the whole barn?
- **How to handle the model**, with the starting point at **0 time** without an opportunity to introduce a new data with the certain step (every hour, two, four.. and etc.)?

Opened questions for discussion:

- What is the source of estimation of **urea concentration**: **urine** (while urinating) or **manure** (from the floor)? And how different is urea concentration extracted from urine from urea concentration extracted from manure?
- When the **conversion speed of urea concentration** stops influencing dramatically on ammonia emissions?

Thanks for your attention