Process-based model to estimate agricultural livestock ammonia emissions

Midwest and Central States
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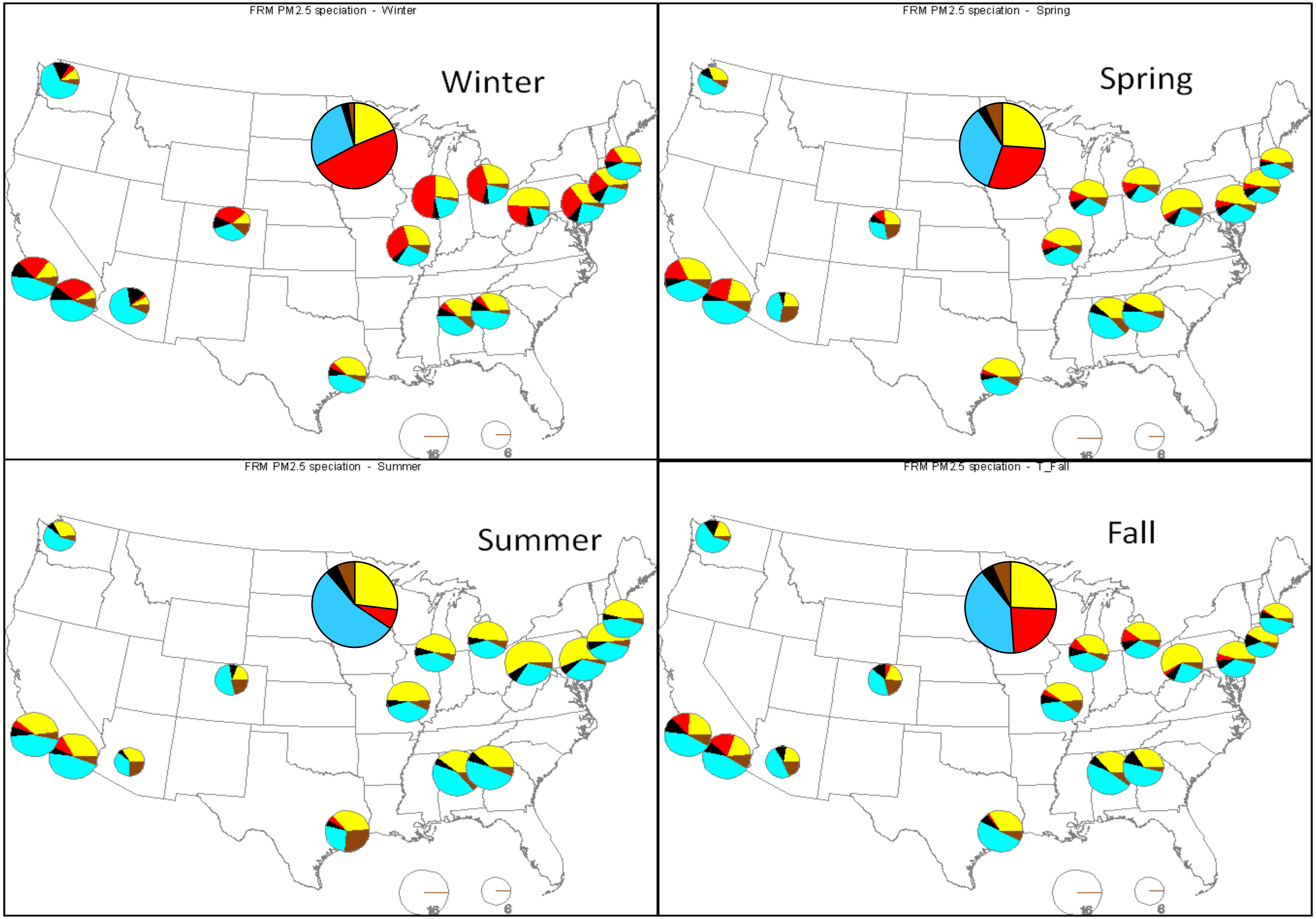
Discussion topics

- Agricultural livestock role in fine particulate ($PM_{2.5}$) concentrations

- Manure management at farms

- LADCO process-based farm emissions model
  - Background
  - Summary of what the model does
  - Validation of model NAEMS dairy and swine
  - Current state of the model

Ammonium nitrate is significant in the upper Midwest



Seasonal $PM_{2.5}$ composition for select urban areas 2008-2010

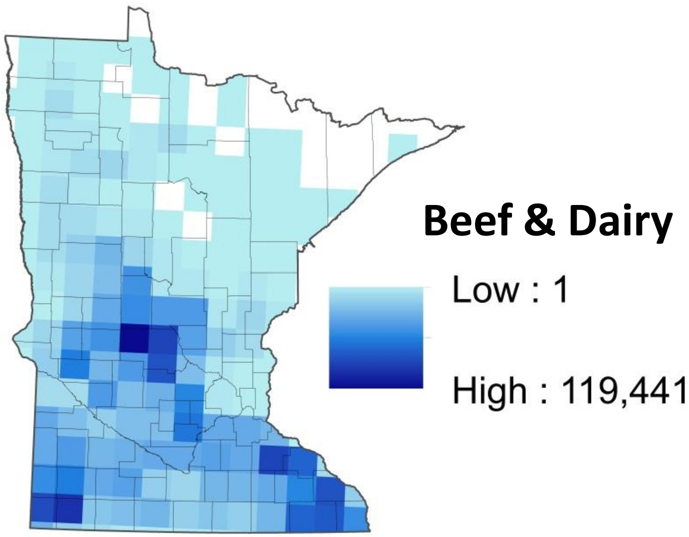
Source: U.S. EPA

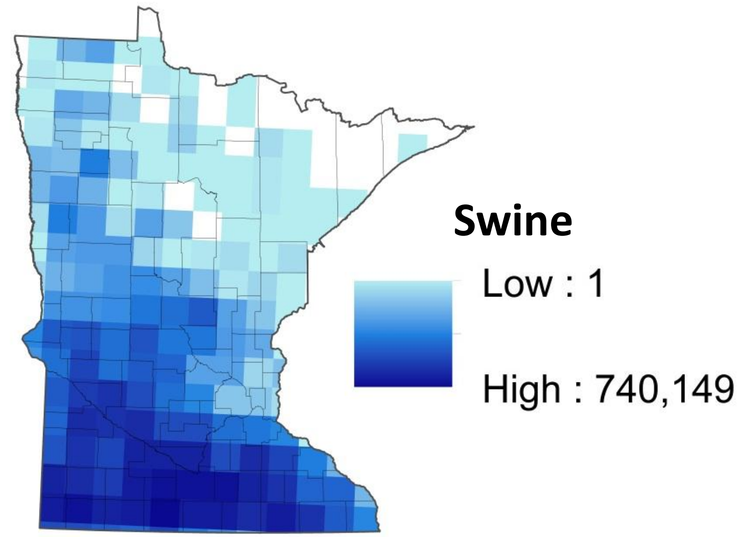
Agricultural livestock

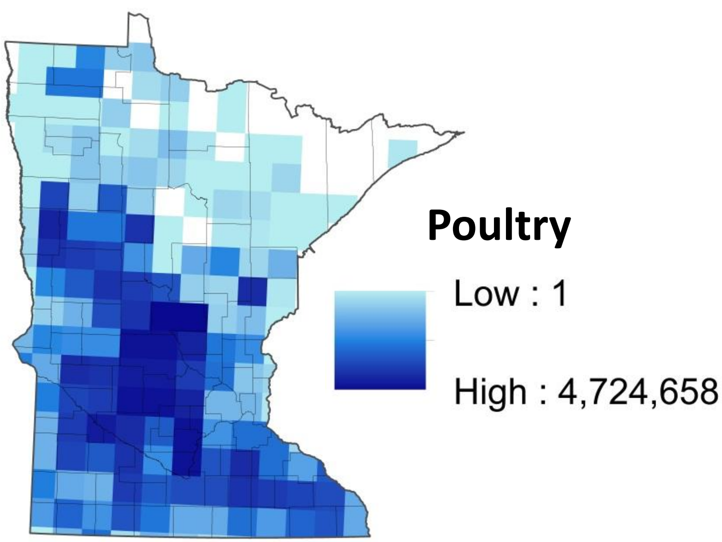
…make up 63% of national ammonia emissions

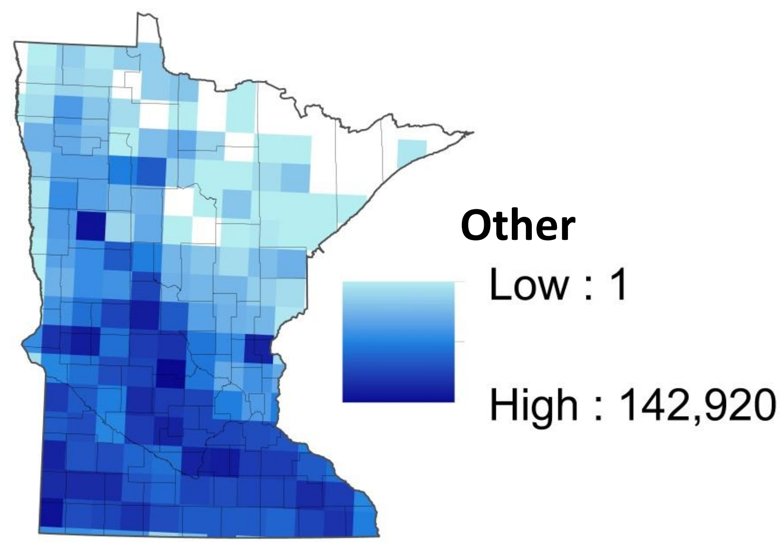
… emit a total of 33,200 tons ammonia/year

In Minnesota alone… there is a lot of livestock

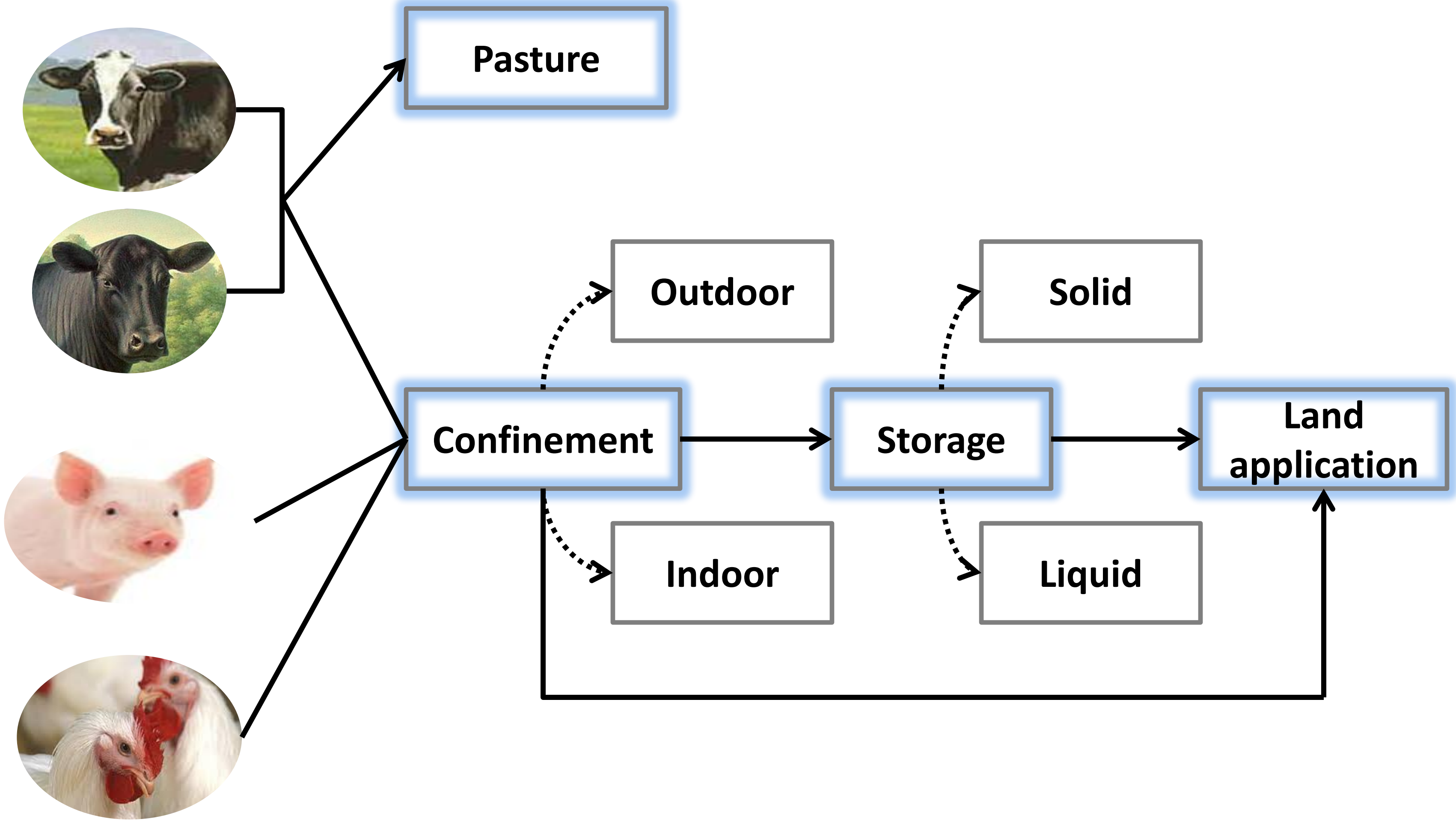






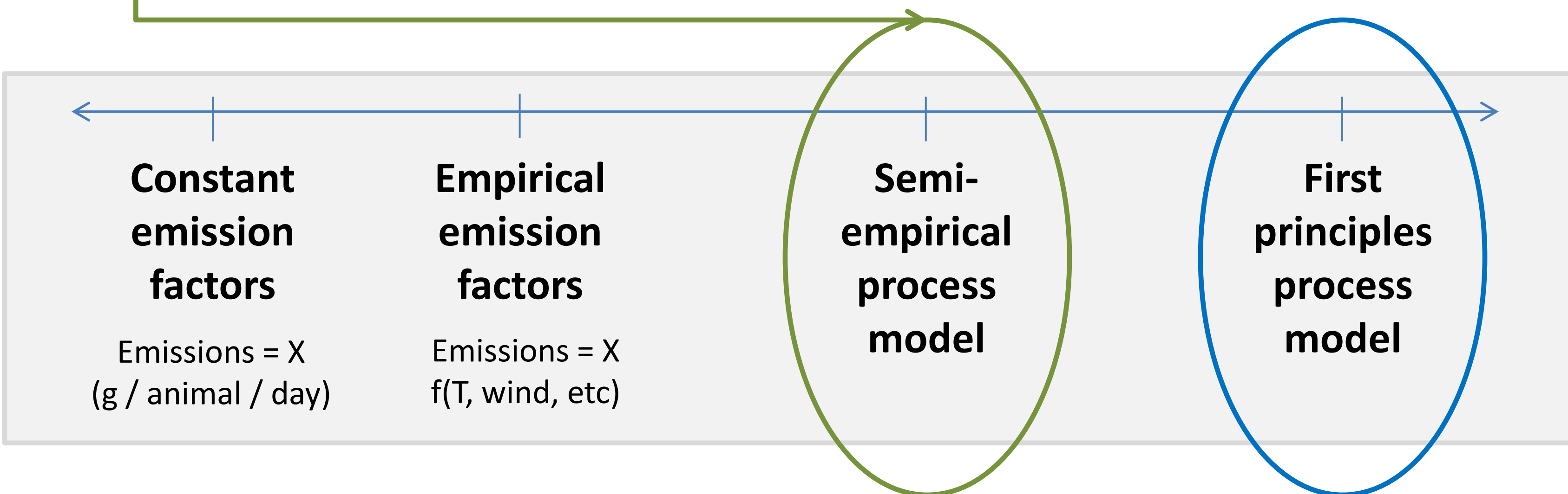


Manure management at farms



Emission calculation methodology

- ❖ USEPA and Carnegie Mellon University statistical model based on measurement data (NAEMS study)
  - ❖ Science Advisory Board* recommends first-principles process-based model. EPA announced on April 15 NACAA Agriculture committee call they are not pursuing at this time.



- ❖ LADCO farm emissions model

*http://yosemite.epa.gov/sab/sabproduct.nsf/0/ae6639dd6b79360e852579a4004e5529!OpenDocument&TableRow=2.3#2

LADCO ammonia model history

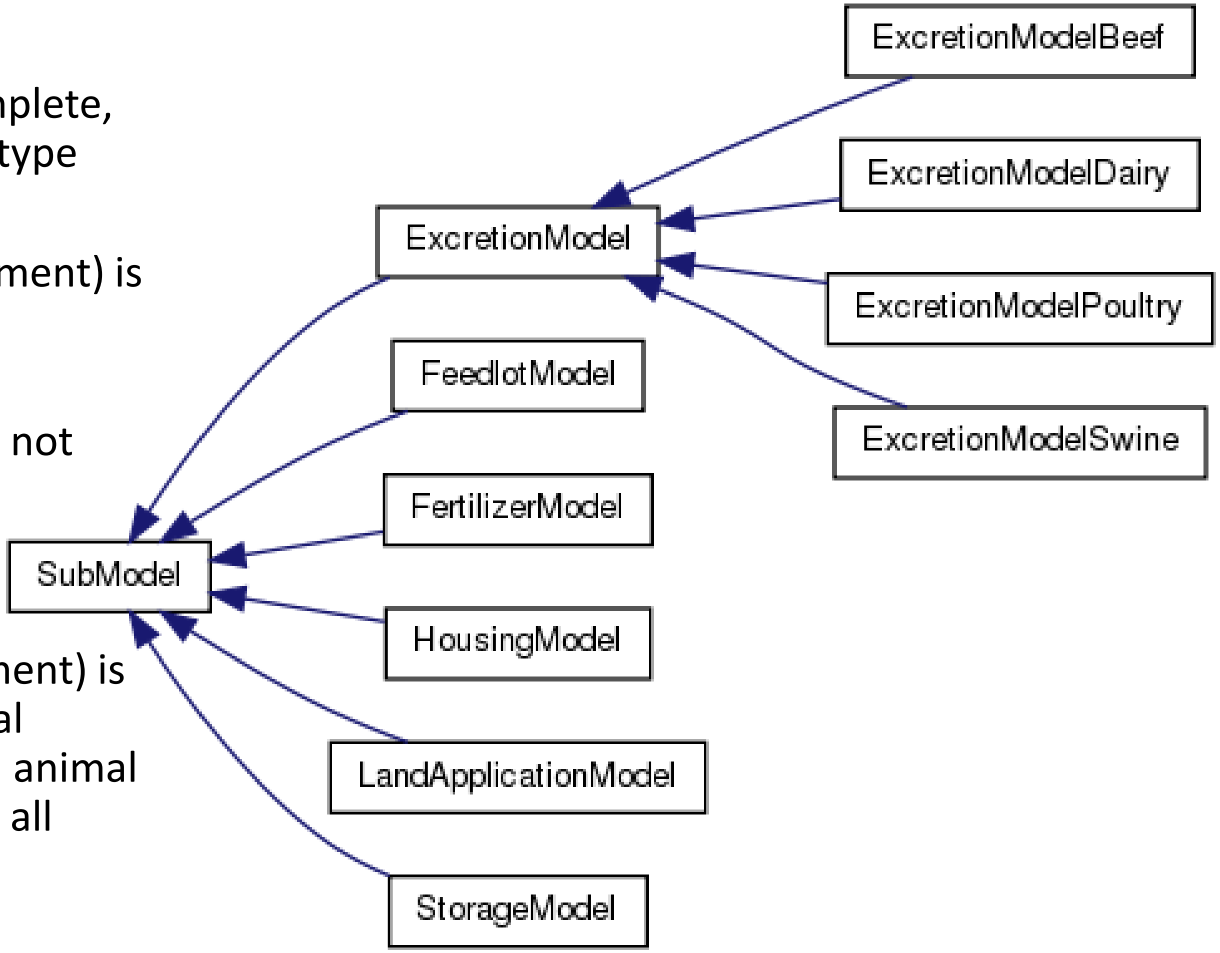
- ❖ **2003 – 2004** Lake Michigan Air Directors Consortium (LADCO) contracts with UC-Davis and UC-Riverside to integrate UC-Davis processed-based emissions model into CONCEPT (Beta version 0.1)

- ❖ **2008** LADCO contracts with UC-Riverside to re-write model in C/C++ to substantially decrease model computational time (Beta version 0.1)

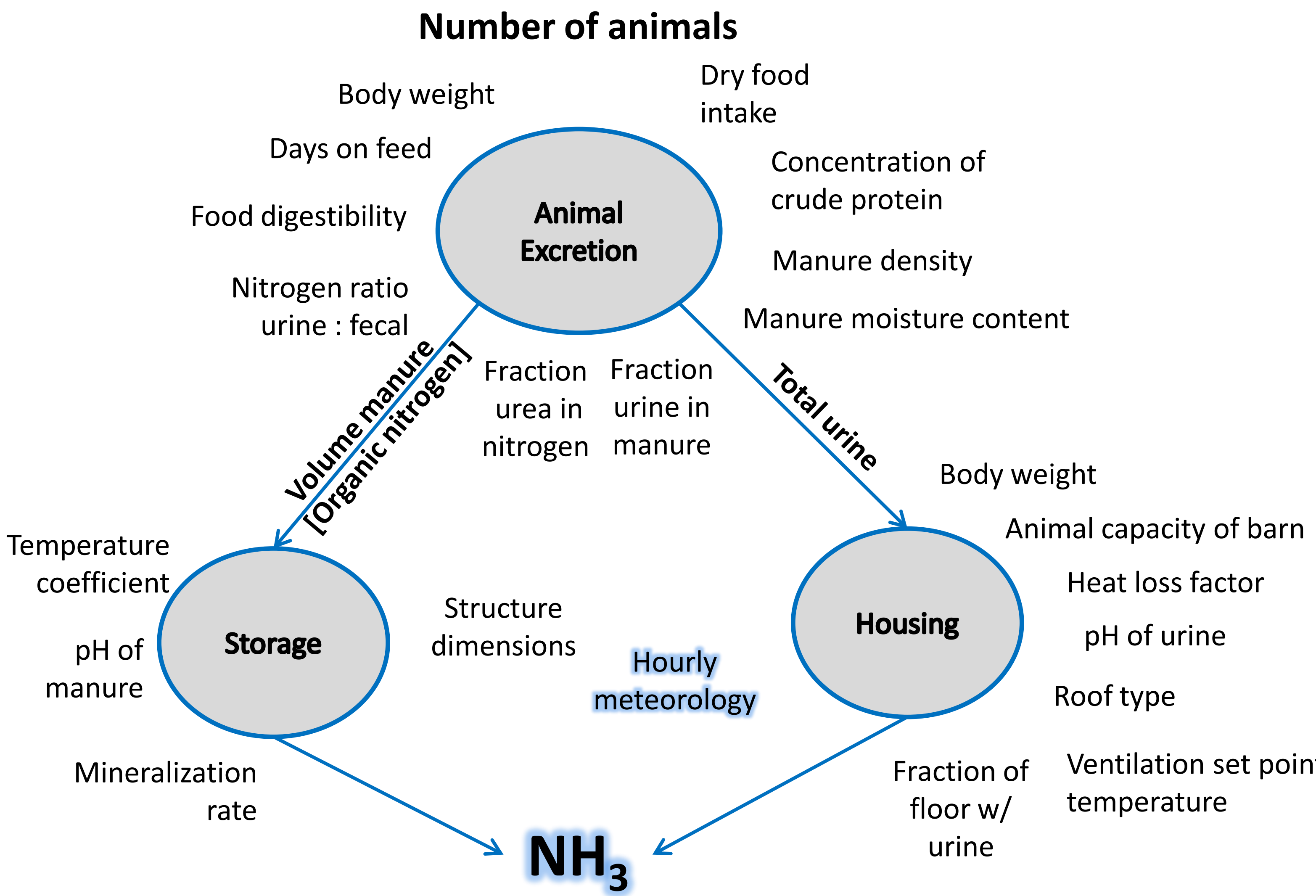
- ❖ **2013-2014** Minnesota tests, refactors, does minor repairs, validates model performance and provides documentation

Current model structure and status

- **Excretion** is the most complete, separate for each animal type
- **Feedlot** (outdoor confinement) is in initial stages
- **Fertilizer** is a placeholder, not from livestock emissions.
- **Housing** (indoor confinement) is substantive for mechanical venting, one model for all animal types, animals indoors at all times
- **Land application** is incomplete
- **Storage** one model for all animal types, basin not lagoon



Model input variables



$$[\mathrm{N}_{CO(NH_2)_2}] = \frac{\mathrm{N}_{CO(NH_2)_2}}{\mathrm{Vol}_{\mathrm{Manure}_T}}$$

$$[\mathrm{N}_T] = \frac{\mathrm{NE}_T}{\mathrm{DOF}/\mathrm{Vol}_{\mathrm{Manure}_T}}$$

$$[\mathrm{N}_{organic}] = [\mathrm{N}_T] - [\mathrm{N}_{CO(NH_2)_2}]$$

$$\mathrm{Urine}_T = \mathrm{Manure}_T \times \text{urine fraction}$$

Animal Excretion

$$\mathrm{Manure}_T = \frac{\left[\frac{\mathrm{DME}_T}{(1-\text{manure moisture})}\right]}{\mathrm{DOF}}$$

$$\mathrm{Vol}_{\mathrm{Manure}_T} = \frac{\mathrm{Manure}_T}{\text{manure density}}$$

where

$\mathrm{N}_{CO(NH_2)_2}$ = urea nitrogen concentration (kg/m^3)

N_T = total nitrogen concentration (kg/m^3)

$\mathrm{N}_{organic}$ = organic nitrogen concentration (kg/m^3)

NE_T = total nitrogen excretion per animal (kg)

DME_T = total dry matter excretion per animal (kg)

DOF = days on feed

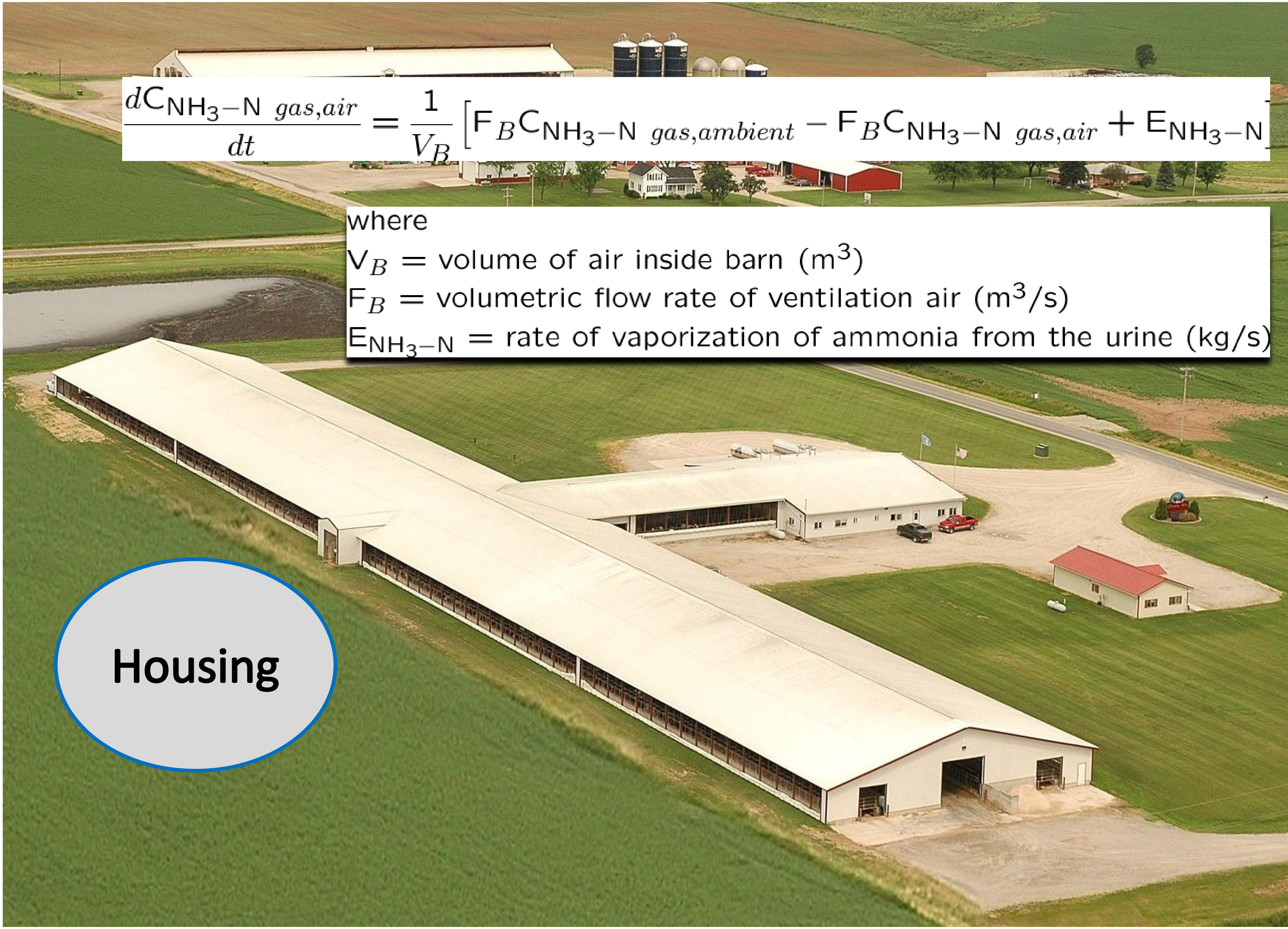
$$\frac{dC_{NH_3-N\ gas,air}}{dt} = \frac{1}{V_B}\left[F_B C_{NH_3-N\ gas,ambient} - F_B C_{NH_3-N\ gas,air} + E_{NH_3-N}\right]$$

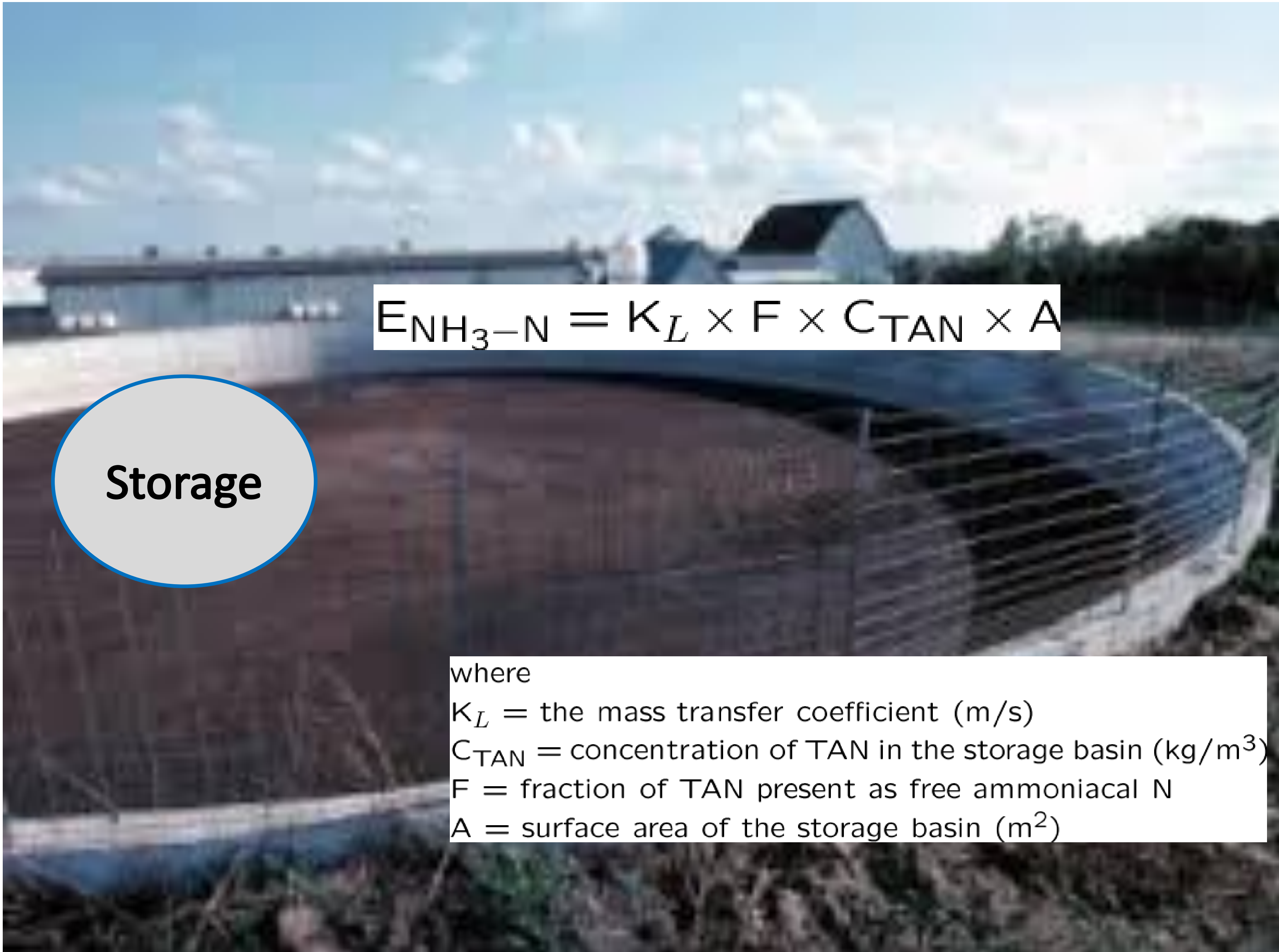
where

V_B = volume of air inside barn (m^3)

F_B = volumetric flow rate of ventilation air (m^3/s)

E_{NH_3-N} = rate of vaporization of ammonia from the urine (kg/s)





$$E_{NH_3-N} = K_L \times F \times C_{TAN} \times A$$

where

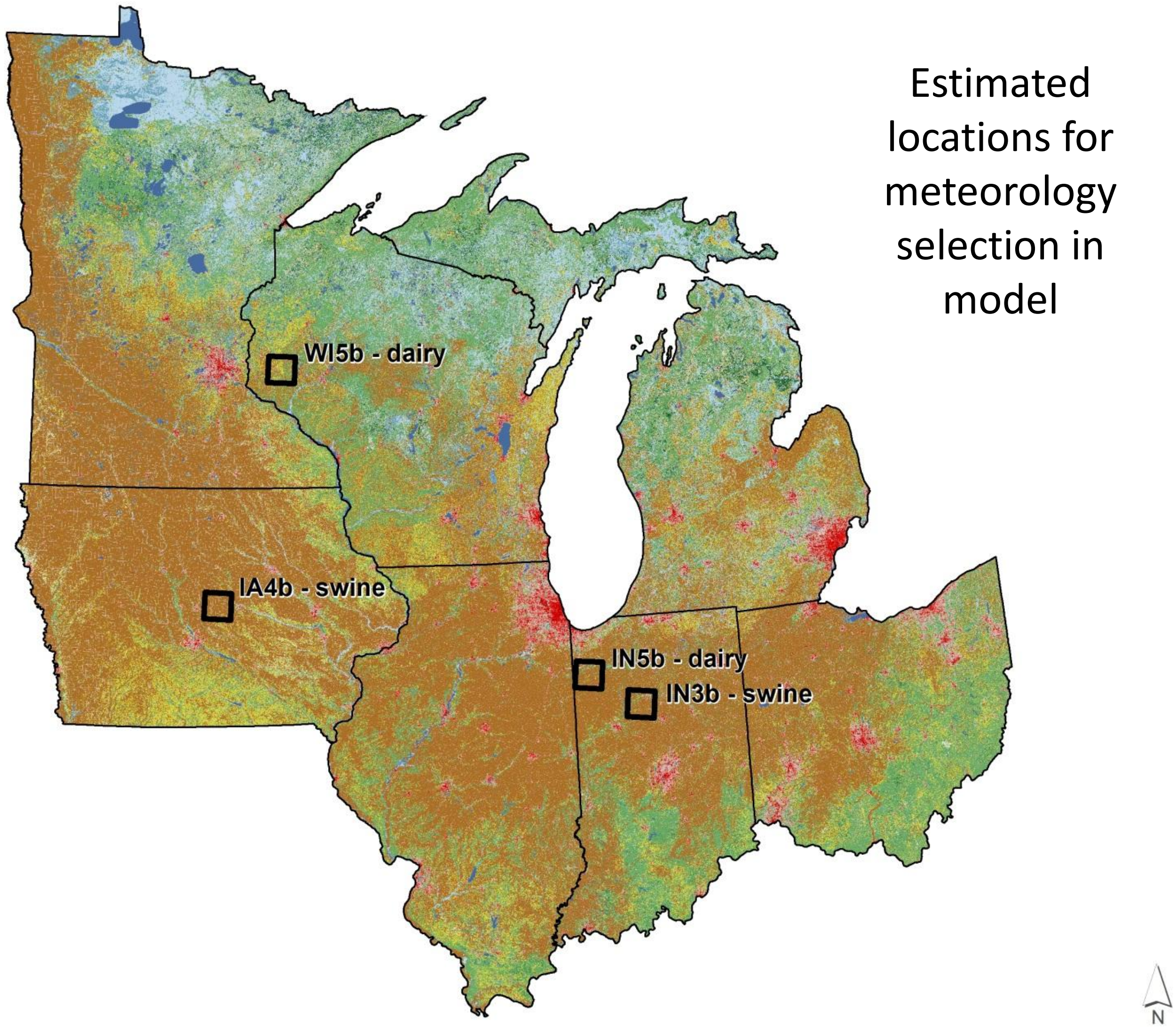
K_L = the mass transfer coefficient (m/s)

C_{TAN} = concentration of TAN in the storage basin (kg/m^3)

F = fraction of TAN present as free ammoniacal N

A = surface area of the storage basin (m^2)

Validation with national air emissions monitoring study (NAEMS) housing data

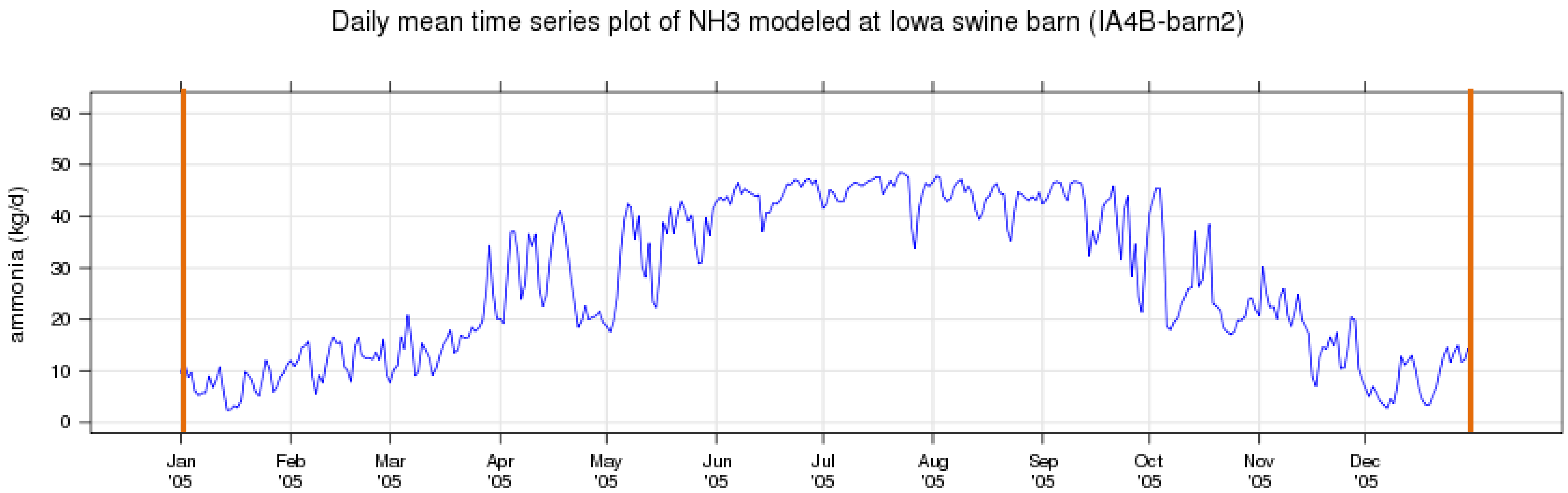


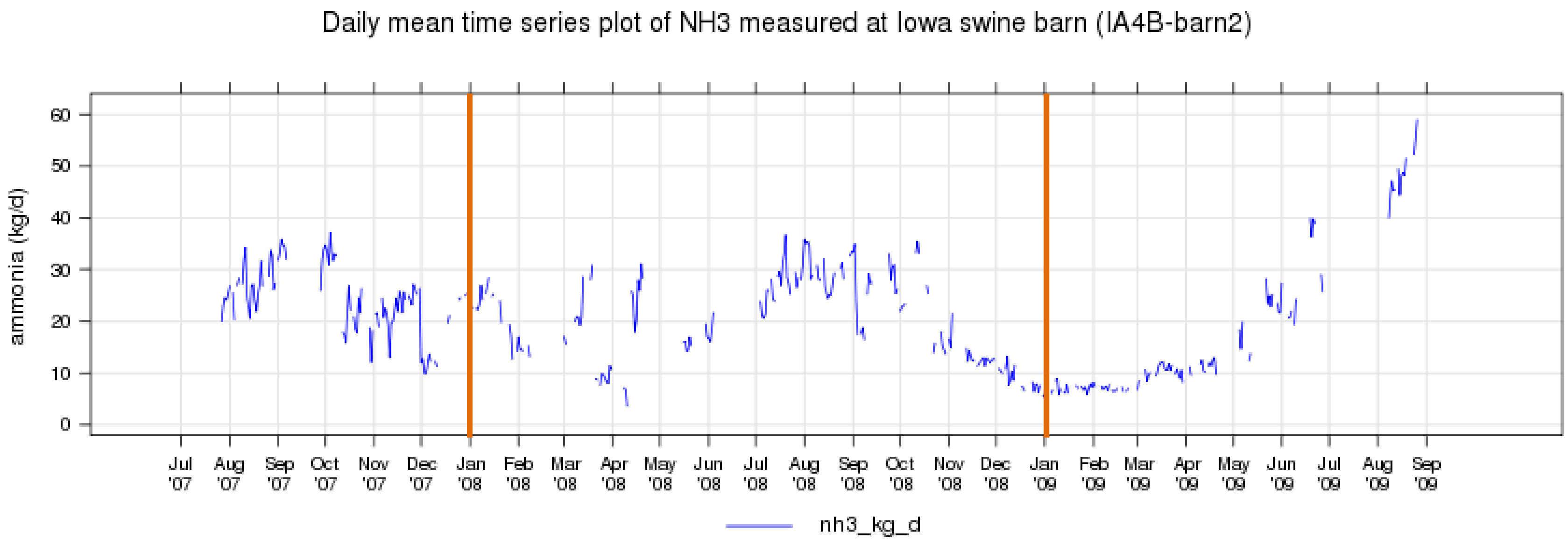
Estimated locations for meteorology selection in model

Housing sub-model input data summary

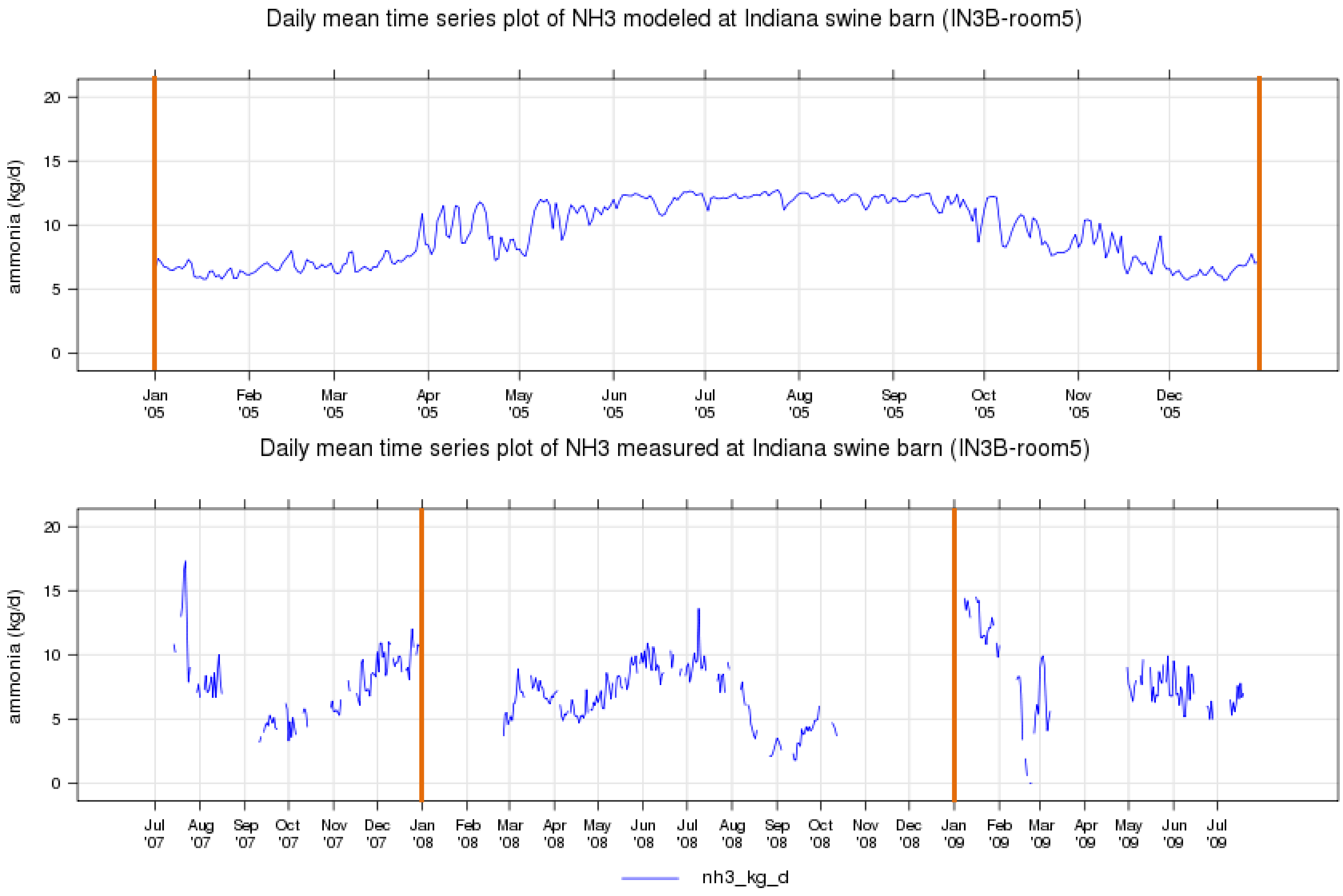
Parameters	Farms			
	Marshall County IA	**Carroll County IN**	**St Croix County WI**	**Jasper County IN**
Animal Type	Swine (gestation)	Swine (finishers)	Dairy	Dairy
Number of Animals	1020	1064	211	850
Animal Weight (kg)	249	64	703	700
Barn Length (m)	86	86	93	472
Barn Width (m)	25	61	28	29
Eve Height (m)	3.3	12	4	4.3
Roof Slope	4:12		4:12	4:12
Ventilation	mechanical	mechanical	mechanical	mechanical

Swine barn – Marshall County, Iowa

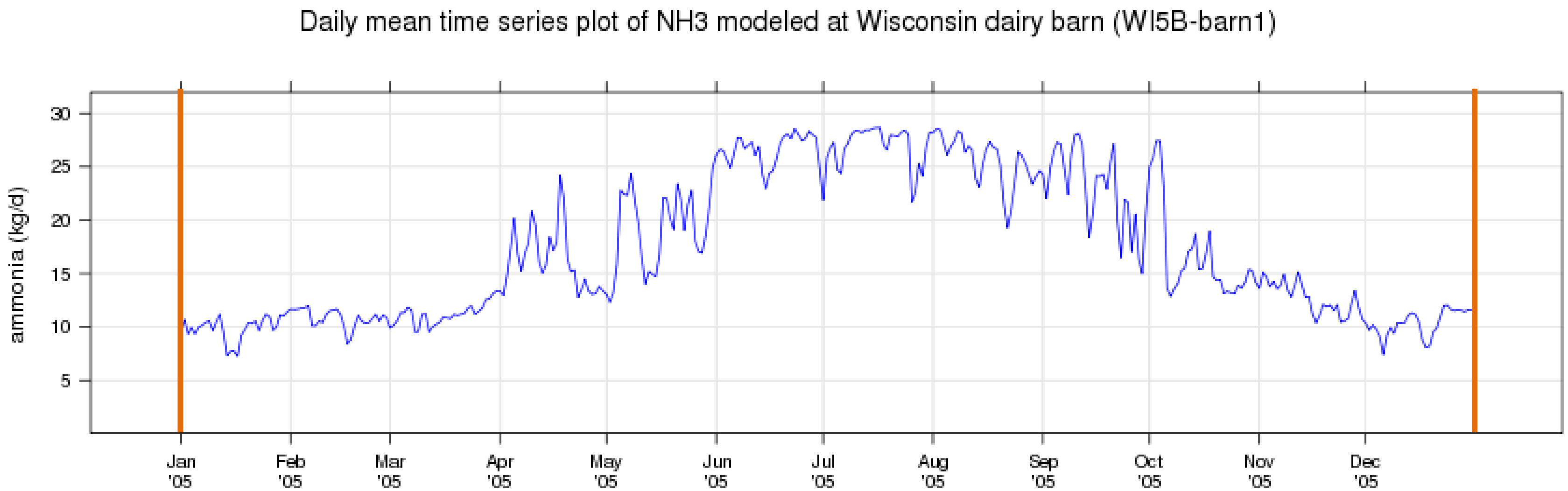


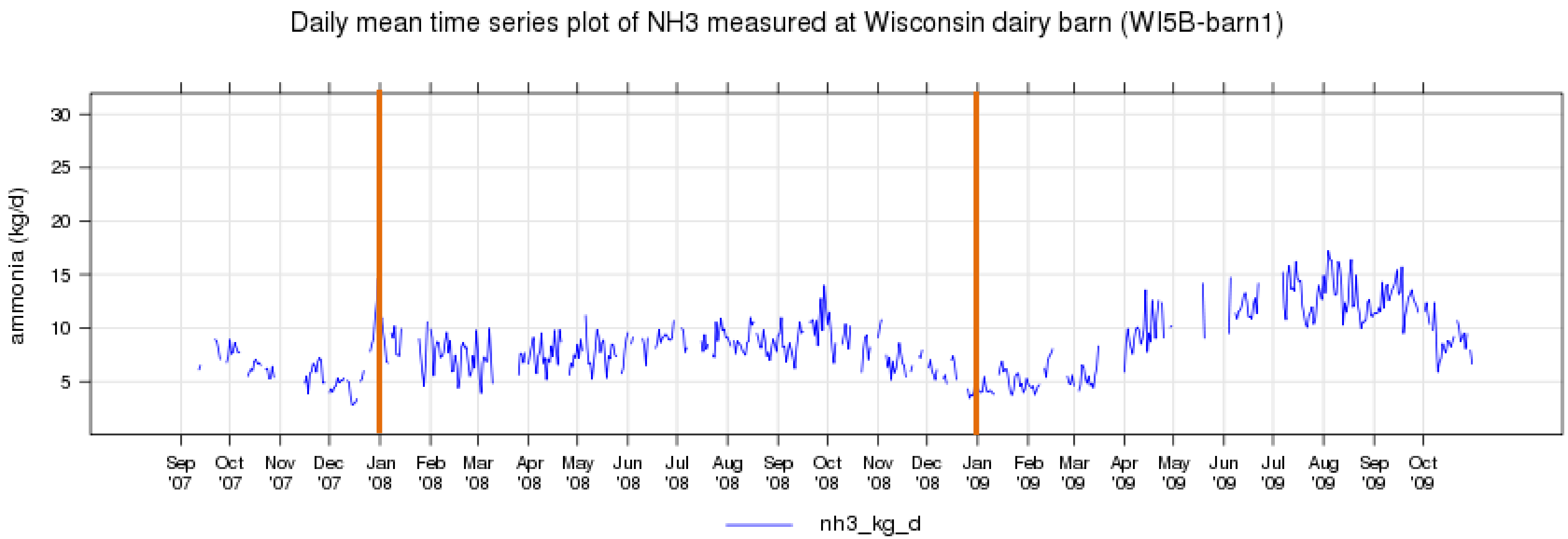


Swine barn – Carroll County, Indiana

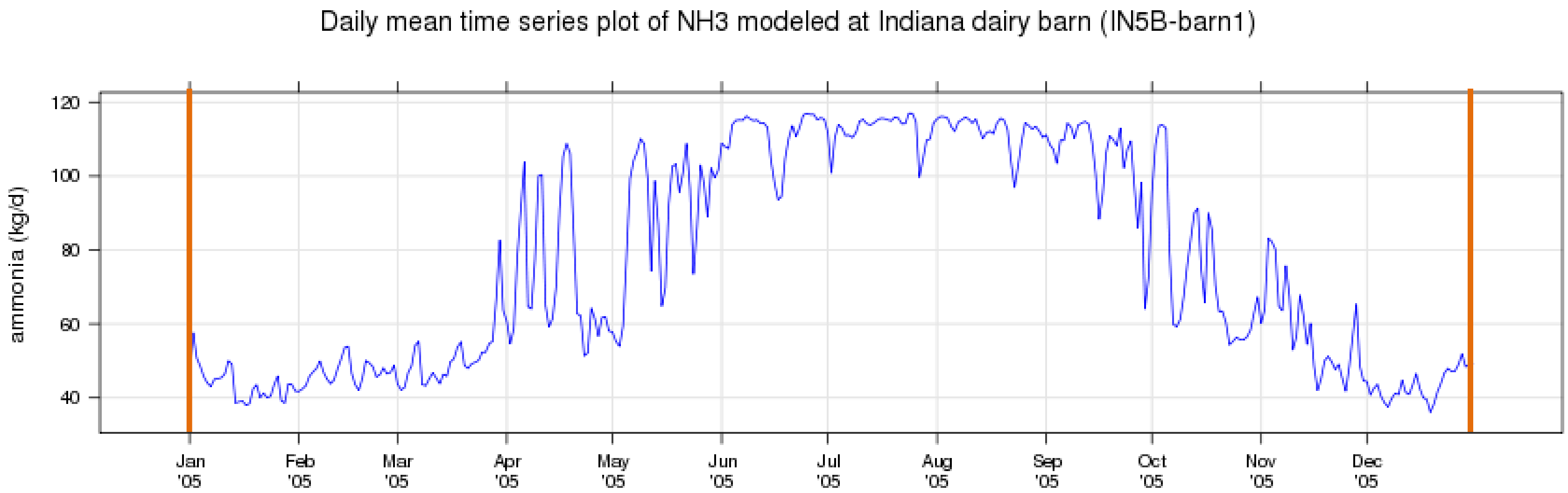


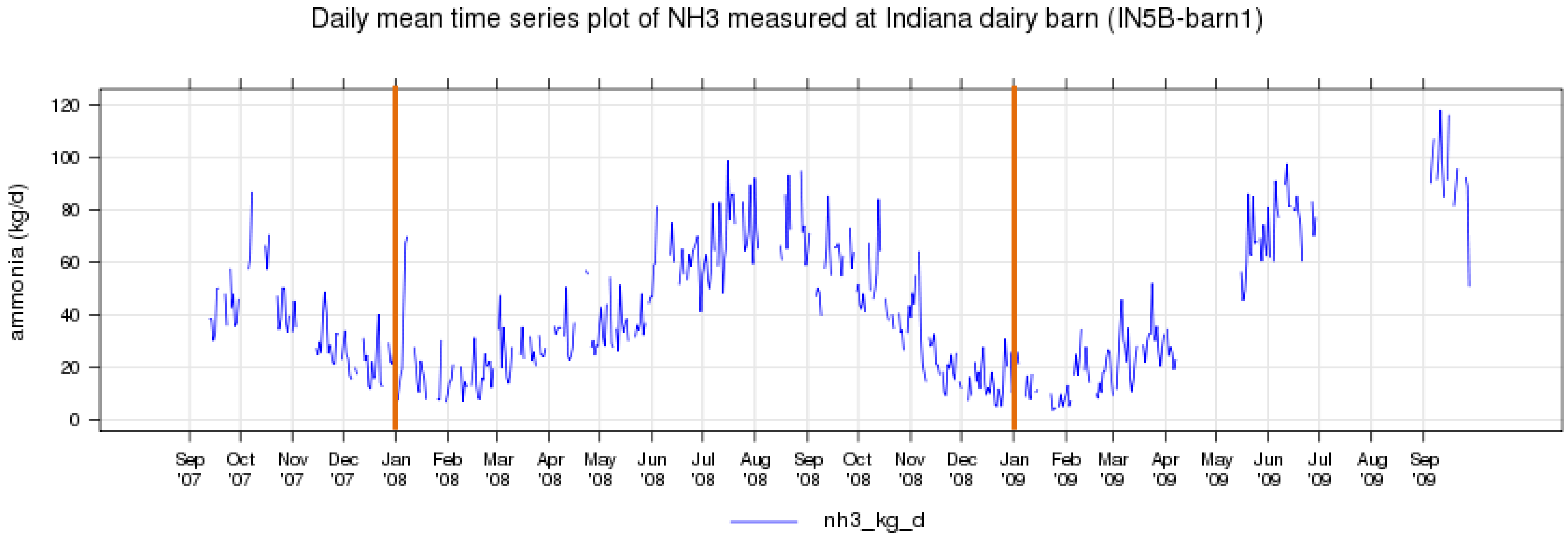
Dairy barn – St. Croix, Wisconsin



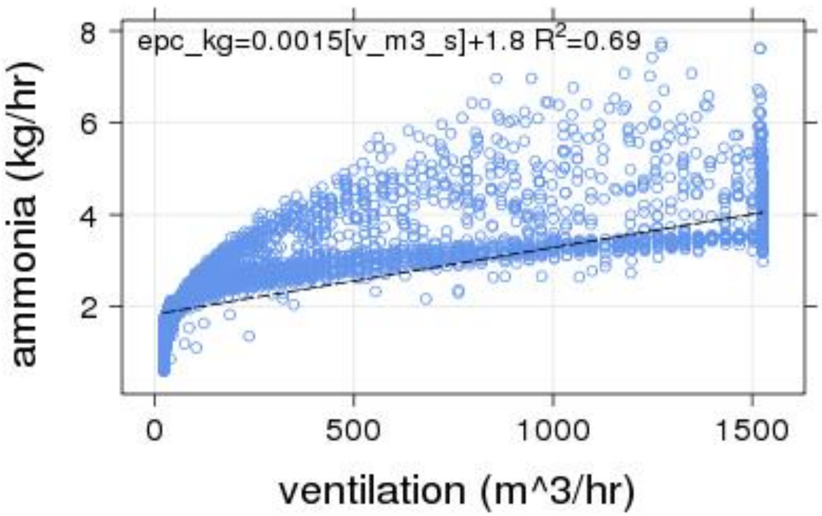


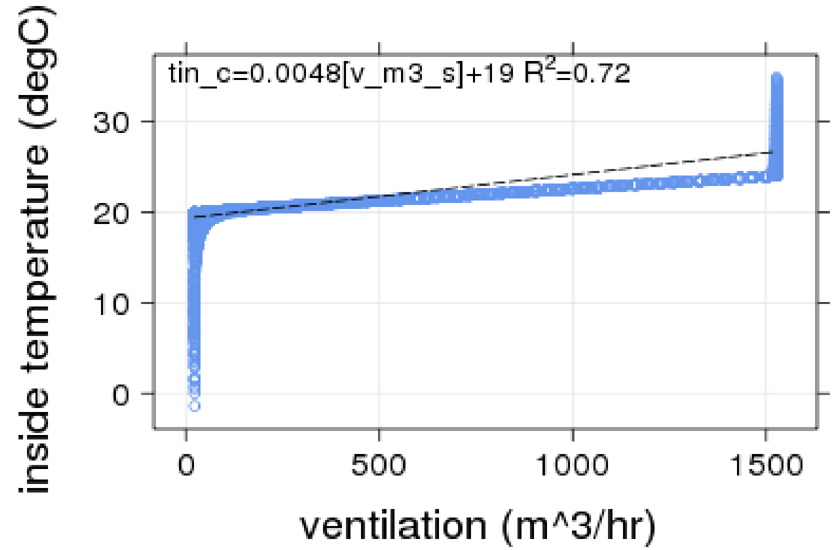
Dairy barn – Jasper county, Indiana





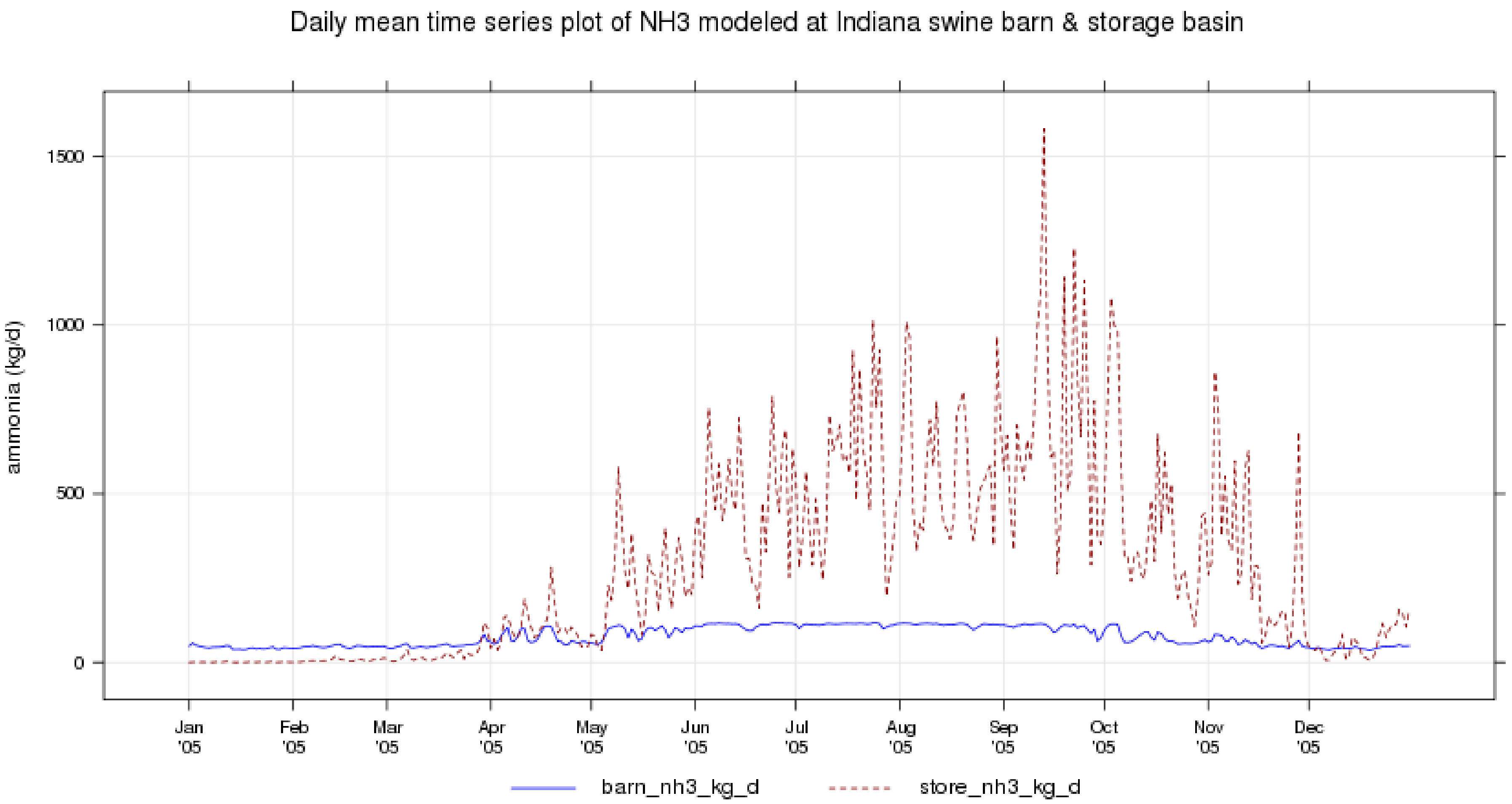
Housing ammonia/ventilation relationship





- Ammonia emissions from housing have a strong relationship with building ventilation
- Ventilation rates to maintain constant temperature inside the barn
- Temperature inside the barn varies with outside temperature, animal heat production, and heat flow through walls & roof

Dairy barn – Jasper county, Indiana



Model package – MPCA deliverables to LADCO

- Model code—refactored, most recent version– C++
- Default input data files (or examples)
- Run scripts
- Documentation (web browser application)
  - Code
  - Code function – what the model does
  - Requirements – what the science document says model should do
  - Enhancements list
  - Flow diagrams
    - Manure management practices
    - Data
  - References (Science document, published articles, other)
  - Sensitivity analysis
  - Validation of housing model for dairy and swine
    - upper MidWest NAEMS data
  - User's manual

Acknowledgements

- Minnesota Pollution Control Agency
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