Disclaimer

Recent CMU Ammonia Modeling and Emissions Inventory

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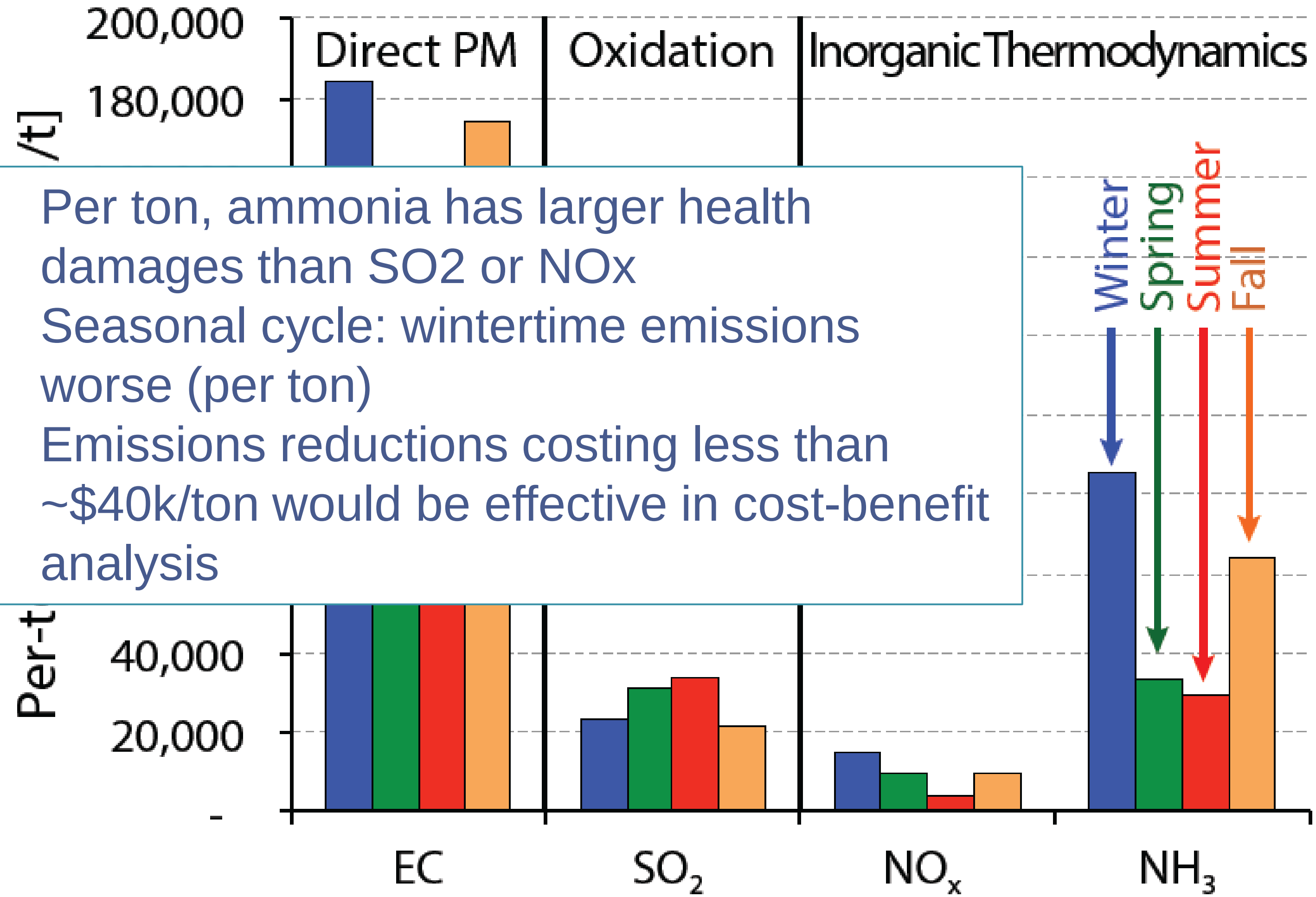
Ammonia, PM2.5, and Health

Heo et al. (2016), Environ. Sci. Technol. 2016, 50, 6061−6070.



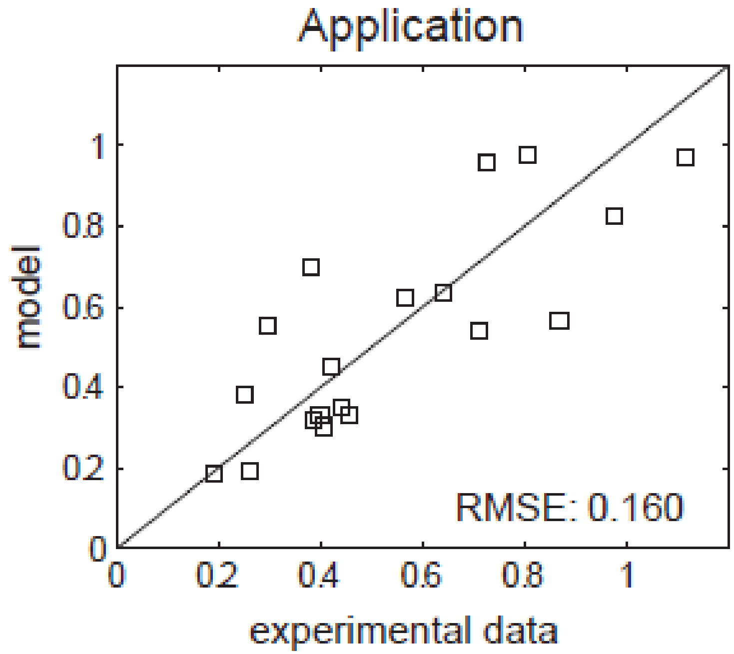
- Per ton, ammonia has larger health damages than SO2 or NOx
- Seasonal cycle: wintertime emissions worse (per ton)
- Emissions reductions costing less than ~$40k/ton would be effective in cost-benefit analysis

Social cost = Monetized cost of premature mortality due to PM2.5 exposure from incremental ton of emissions

Ammonia Emissions: Variability

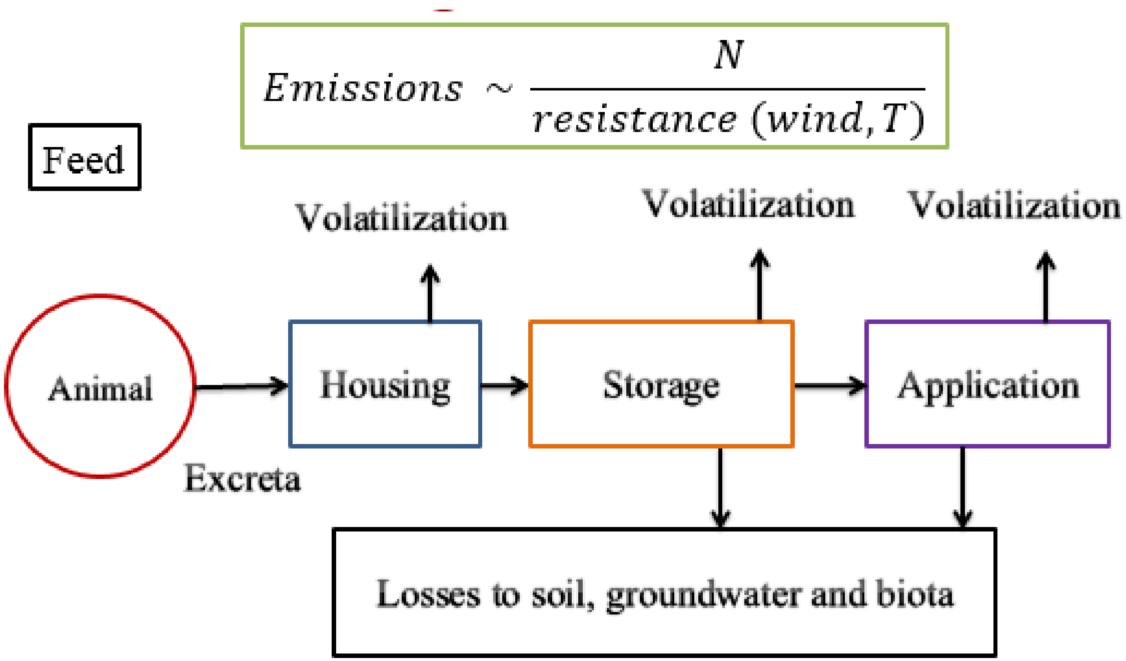
- Emissions depend on a variety of factors including:
  - meteorology
  - management practices
  - manure characteristics
- Lots of variability – how to build inventory?
- Our approach: emissions model rather than direct emissions factors

Fraction of N volatilized during manure application



Scatter-plot of fraction of input nitrogen volatilized as ammonia, comparing application sub-model predictions and experimental data showing range of measured data (Pinder, et al., 2004)

Process-based Models



- Track nitrogen through manure management
- Includes:
  - mass balances
  - mass transfer laws
- Goal is that such a model can capture variability seen in measurements

Philosophy and Goals

- We are air quality modelers looking to build national emissions inventories
- Therefore, we focus on:
  - emission factors unbiased compared to literature
  - seasonal cycle (daily variability would be nice…)
  - regional-scale variability in emission factors
  - computational efficiency
  - scalability: do we have national data on inputs?
- …leads to following compromises
  - tune model to measurements rather than “first principles”
  - omit “details” (e.g. ventilation rates) when we don’t have national data (or no systematic regional variation)
  - predicting EFs for “average” farm rather than specific farm

Versus Other Approaches

More Empirical

More Process-Oriented

Constant Emission Factors

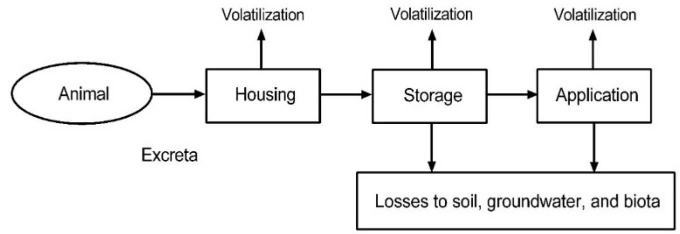
Emissions = g/animal/day x # animals

Empirical Emission Factors

Emissions= f(T, wind, etc.)

Semi-Empirical Process Model

First Principles Process Model



Emissions Measurements

Historical Measurement Campaigns

- Short-term monitoring deployments
- Many researchers, many farms
- Limited monitoring reporting of farm and measurement conditions

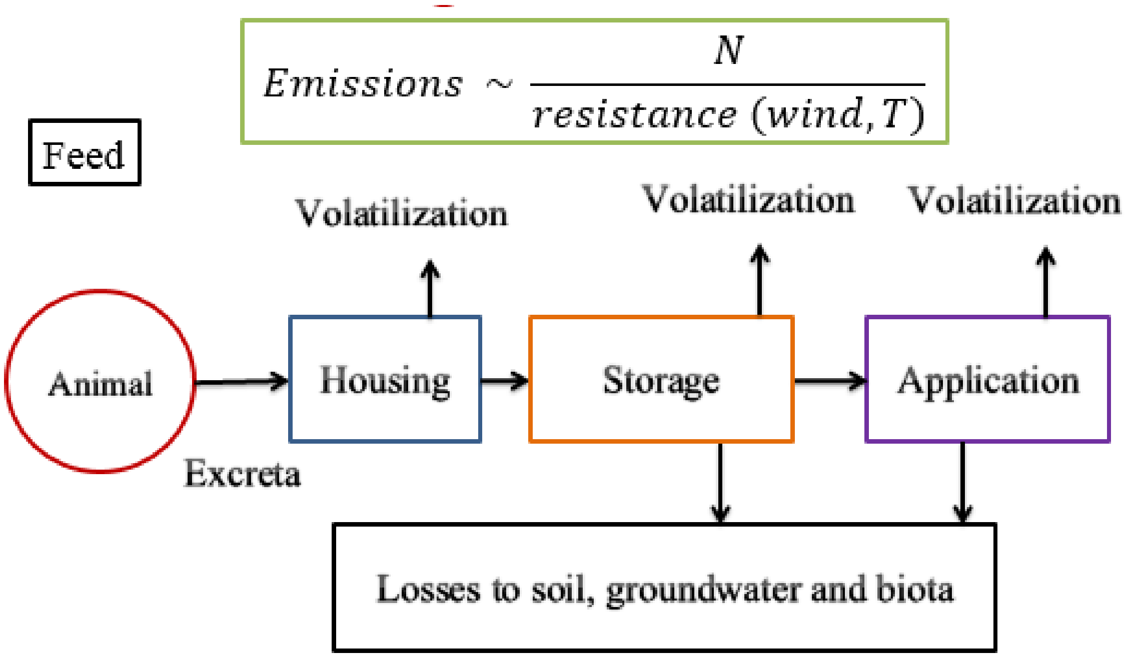
National Air Emissions Monitoring Study

- 1-3 years of data collection (long-term measurements of seasonal cycles)
- Consistent measurement techniques
- Extensive monitoring of meteorological and farm management conditions

Objectives

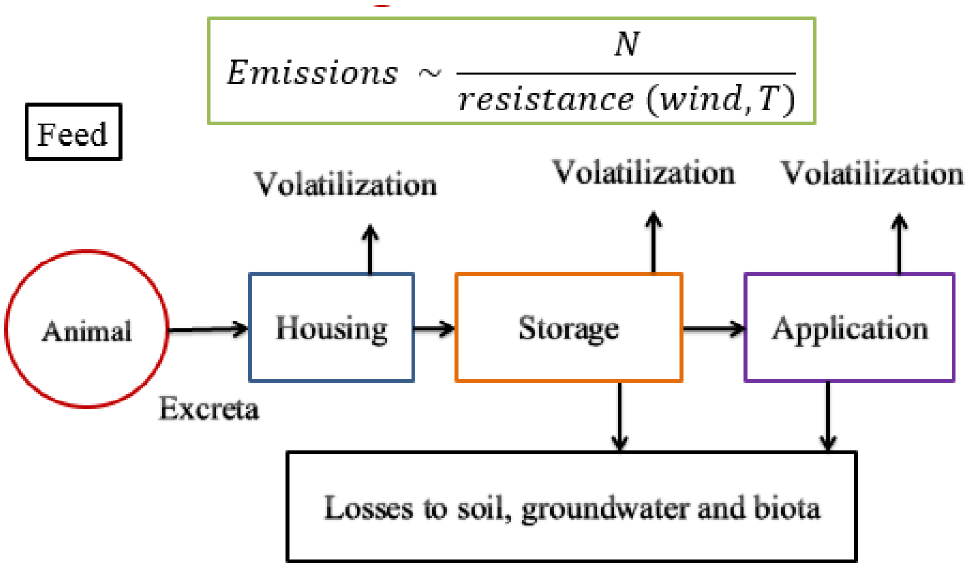
- Build process-based farm emissions models (FEMs) for all livestock types
- Evaluate … especially for seasonal (and daily) variability (e.g. NAEMS data)
- Build national inventory
- Provide some feedback on needs from air quality modeler standpoint

Methods: Details



- Each farm has a manure management train with mass balances on: 1) ammoniacal N; 2) urea; 3) manure volume
- Each component (e.g. housing, storage) has NH3 volatilization … emissions

Methods: Details



Emissions computed:

$$EF = \frac{A[TAN]H^*}{r}$$

key output ← EF: emission factor

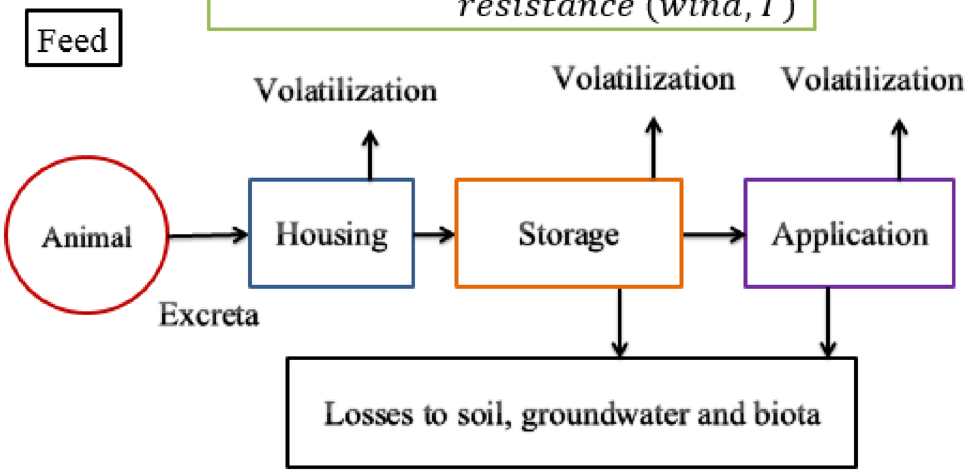
model parameter ← A: surface area fouled by manure; H*: effective Henry's Law constant

mass balance ← [TAN]: total ammoniacal nitrogen conc.

tuned to obs ← r: mass transfer resistance parameter

Methods: Details

$$Emissions \sim \frac{N}{resistance\,(wind, T)}$$



Emissions computed:

$$EF = \frac{A[TAN]H^*}{r}$$

$$r = r_a + r_b + r_s$$

Aerodynamic and quasi-laminar resistances: standard atmospheric theory

<u>Surface resistance</u>:
<u>tuned</u> to match measured EFs (!!)
r_s = f(practices, meteorology)

e.g. for beef feedlots…

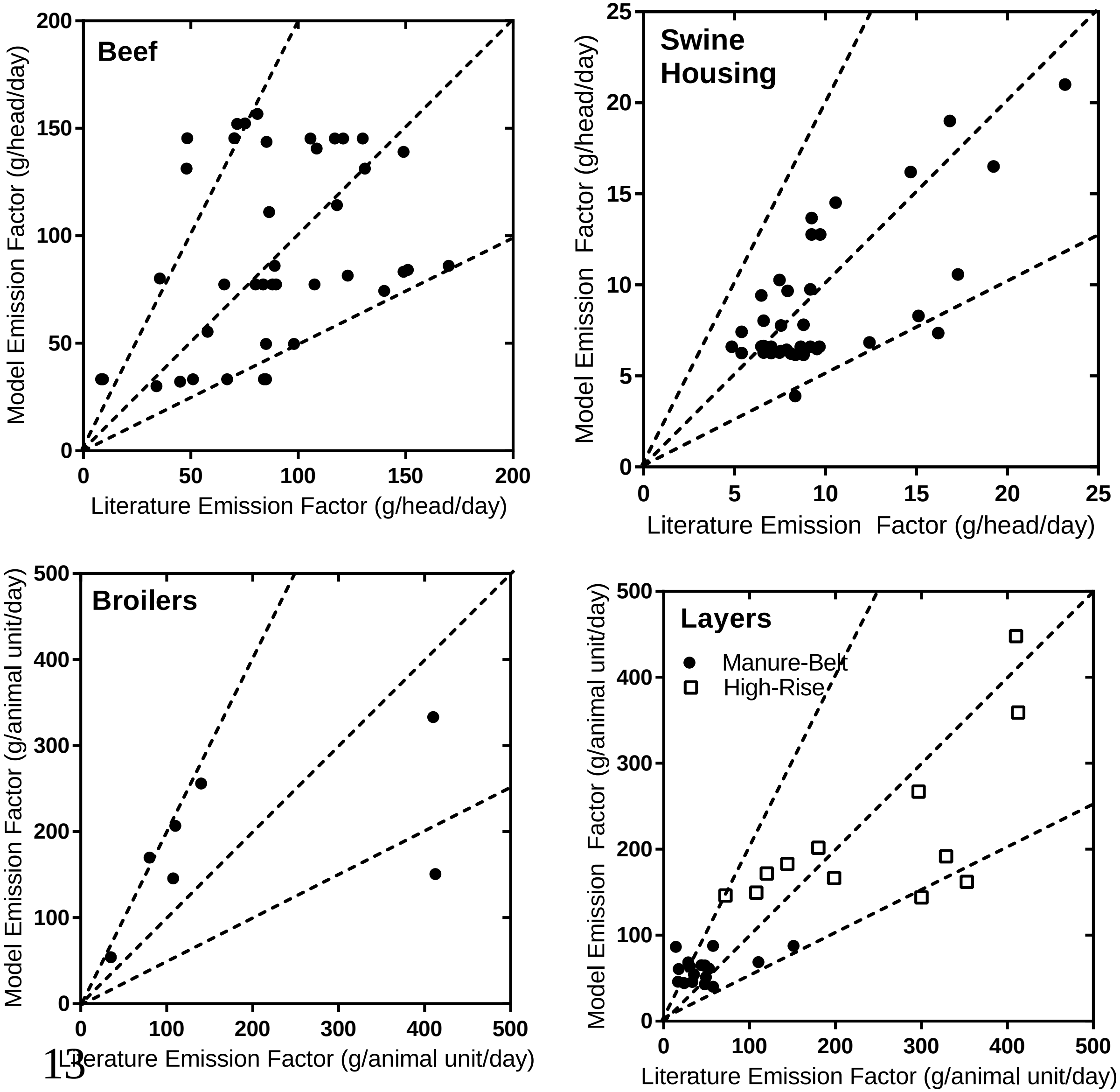
$$r_s = H_1 T + H_2 u + c$$

where H_1 and H_2 are constants tuned to capture variability due to temperature and wind speed

Methods: Summary

- How we get seasonal (daily) variability
  - resistance depends on meteorological variables
- How we get variability due to practices
  - separate resistance sub-model for each
    - livestock type
    - manure management stage: housing, storage, application
    - major practice: e.g. deep pit and shallow pit swine housing
  - Other differences (e.g. frequency of housing clean out)
- Regional variation is combination of meteorology and practices

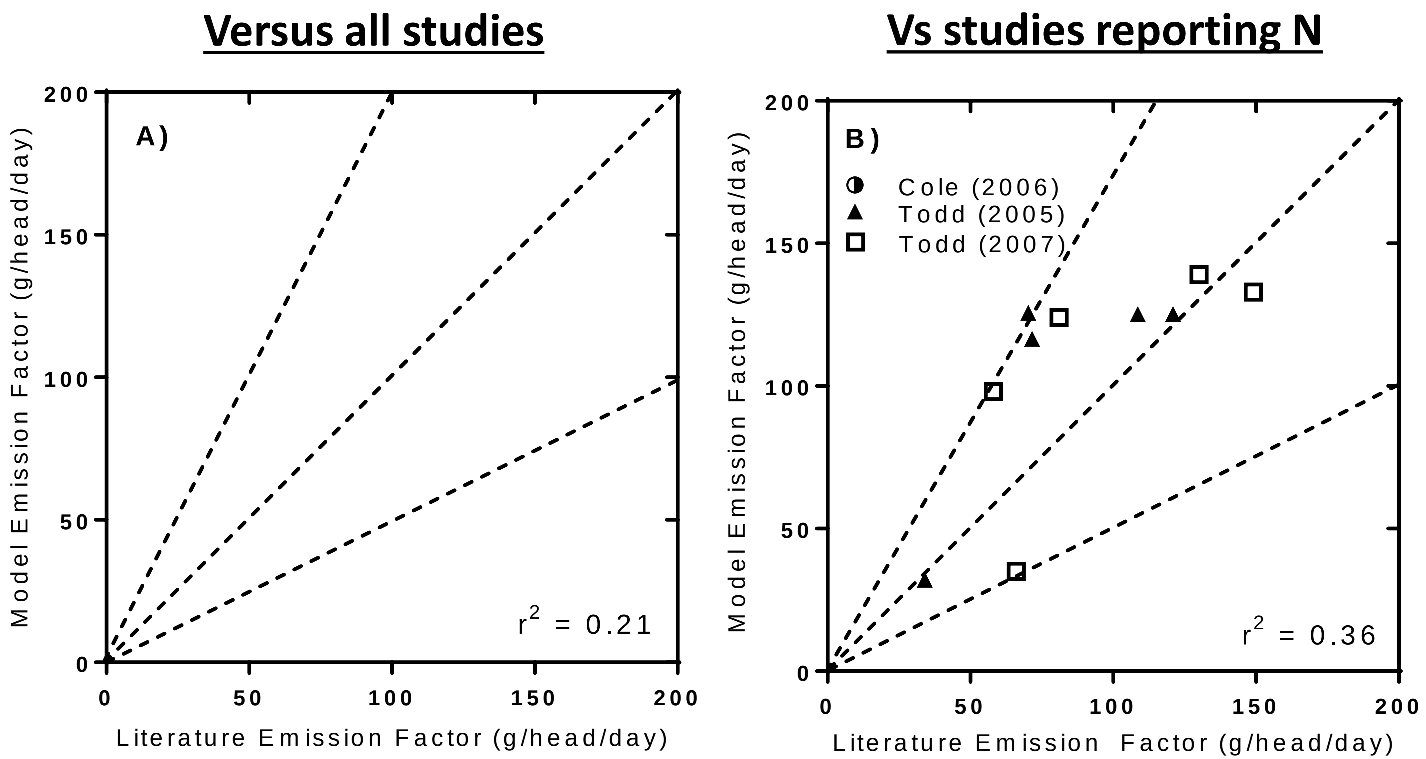
FEM: Tuning and Evaluation



- Unbiased (because tuned)
- R^2 values range from 0.21 for beef to 0.7 for layers
- Model EF is within a factor of two of measured … at farm scale

- Not an independent evaluation … assesses how well simple model captures more complex reality

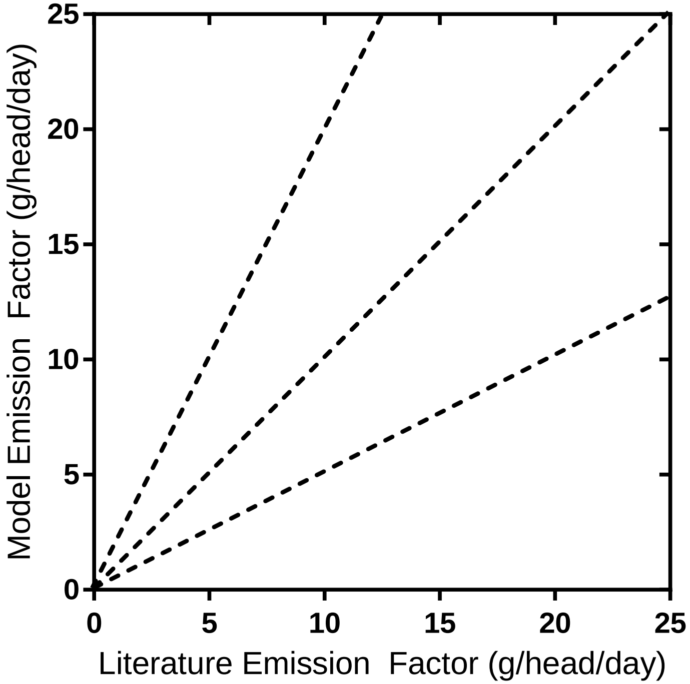
Role of “Contextual Information”



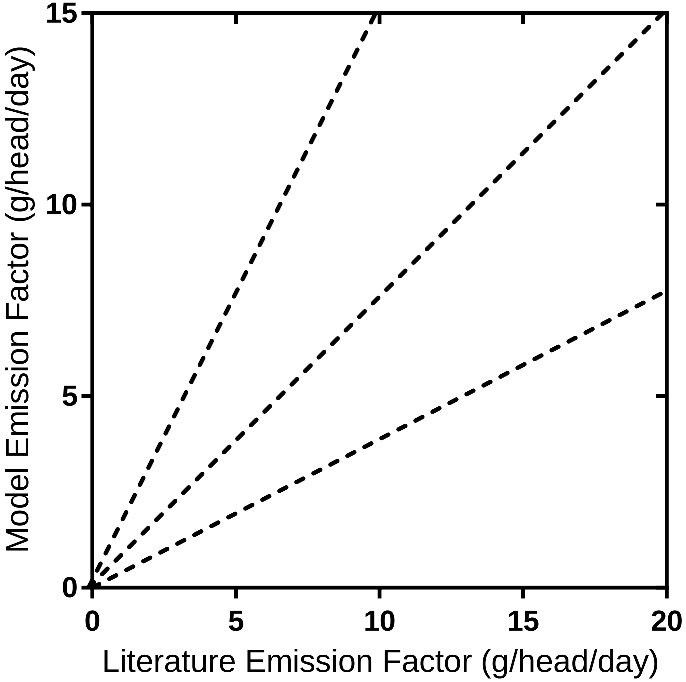
- Not all studies report all required input parameters (e.g. feed or manure nitrogen)
- Measurements need to report feed N, other practices, and meteorological conditions to put results in context and be useful to process-based models and inventories

Open vs Enclosed Sources

Swine Housing: Enclosed

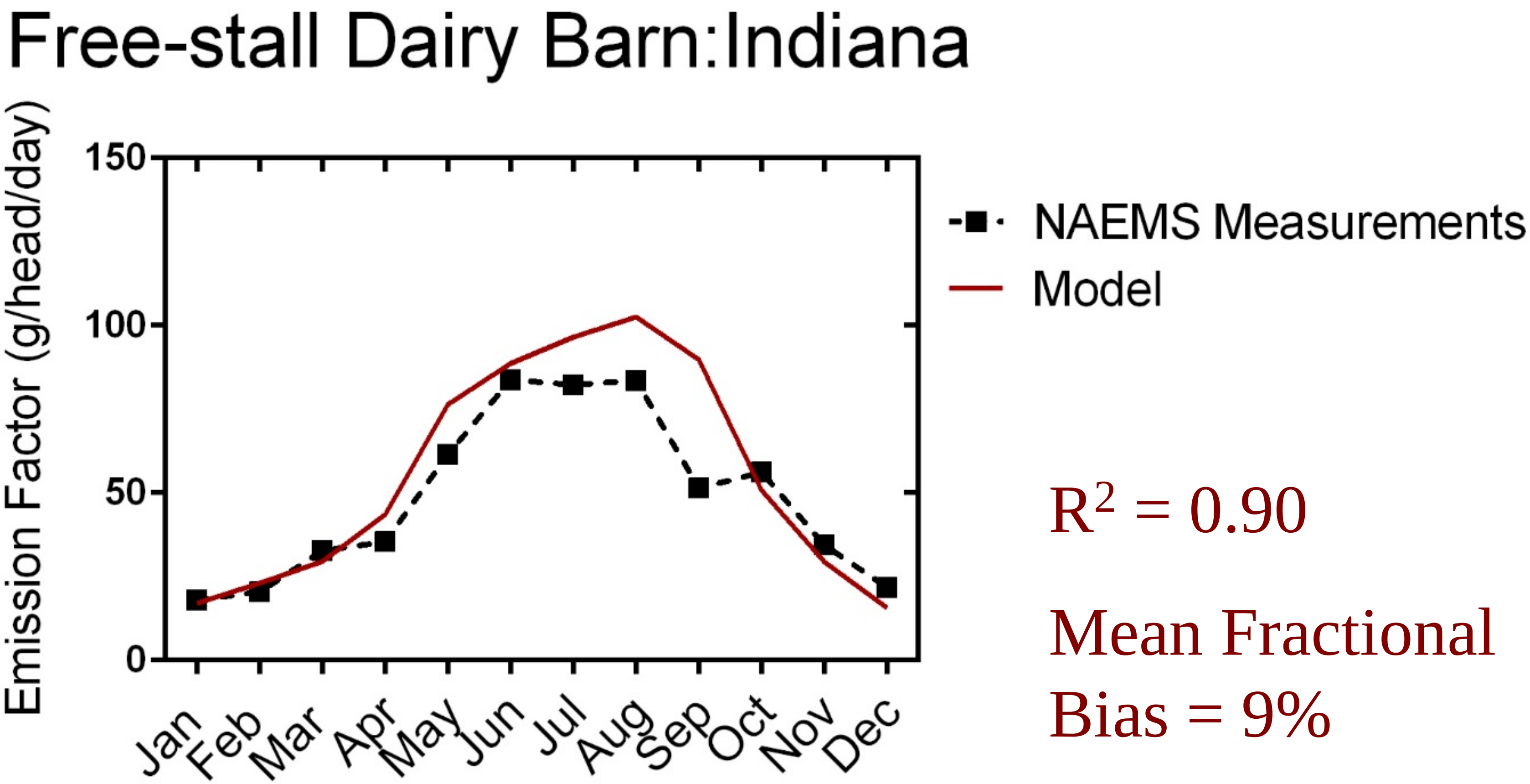


Swine Storage: Open



- Open (outdoor) sources are more difficult to measure … need to infer emissions rate from downwind concentrations

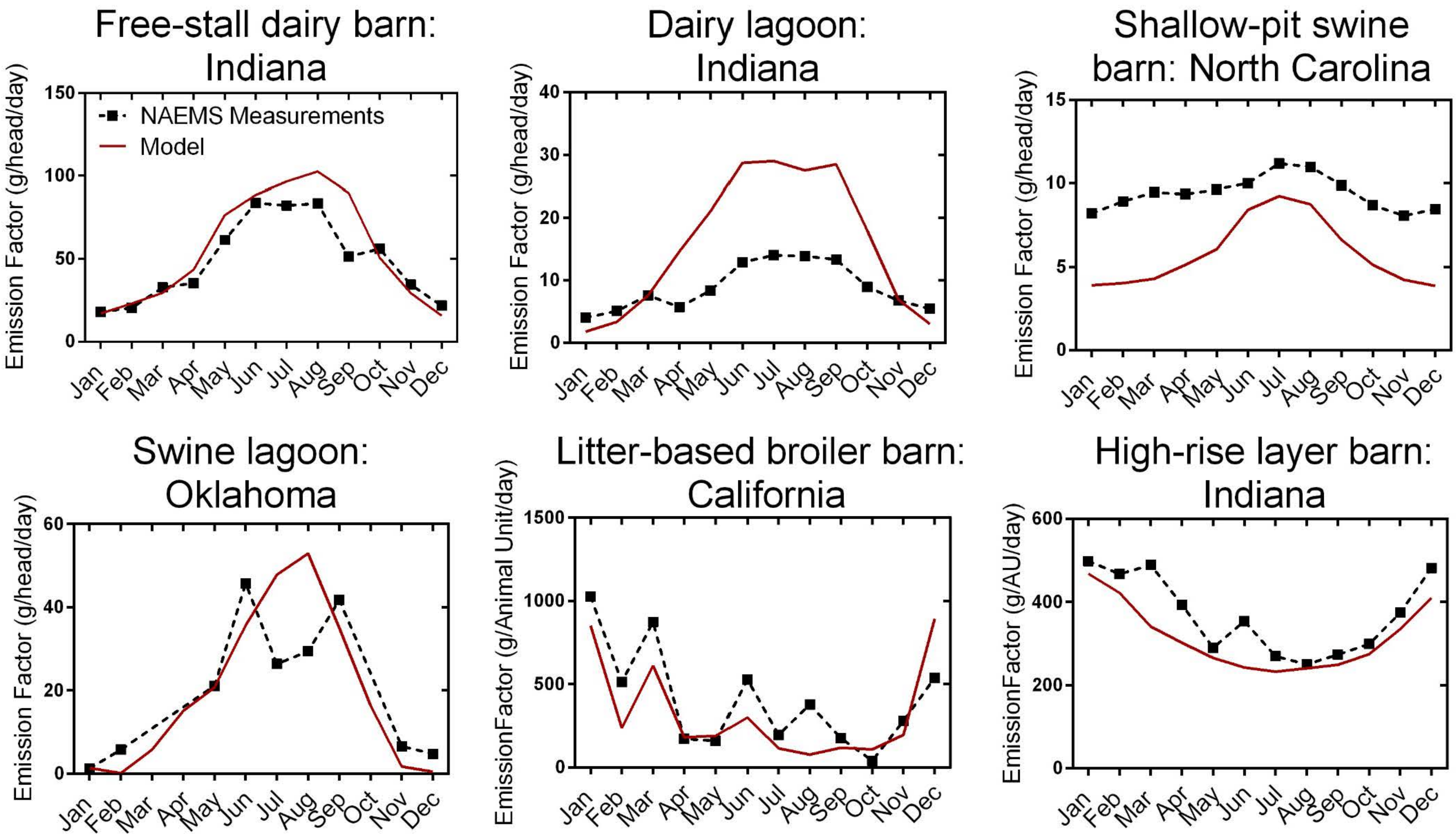
Evaluation: Seasonal Cycle



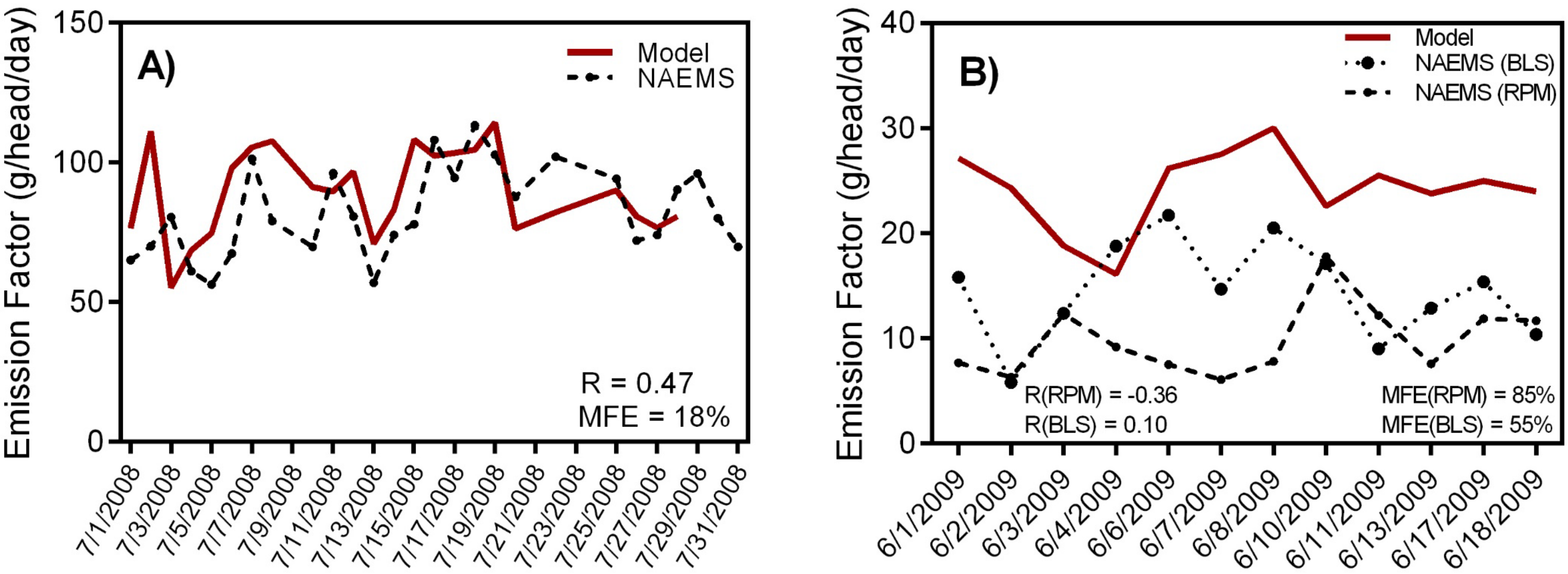
$R^2 = 0.90$

Mean Fractional Bias = 9%

Evaluation: Seasonal Cycle



Evaluation: Daily Variability



- Daily variability in housing emissions tends to be better characterized by the model than storage emissions
- Multiple open-source measurement techniques from NAEMS do not always agree

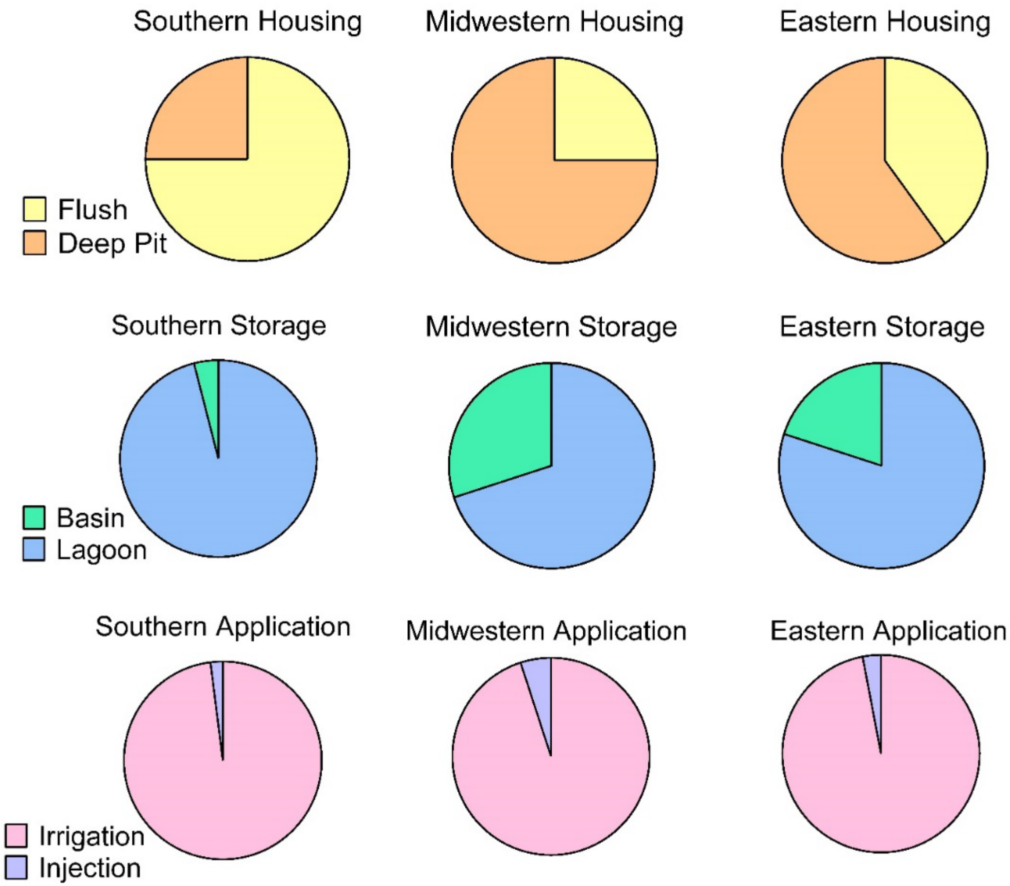
National Emissions Inventory

Meteorology → **National Climate Data Center:**
- Temperature, Precipitation, Wind Speed
- Daily time resolution, Climate Division spatial resolution

Management Practices → **National Animal Health Monitoring Survey:**
- Housing type, Storage type, Application methods
- Multi-state regional spatial resolution

Animal Population → **USDA Agricultural Census:**
- County-level animal numbers from 2012

Regional Farming Practices



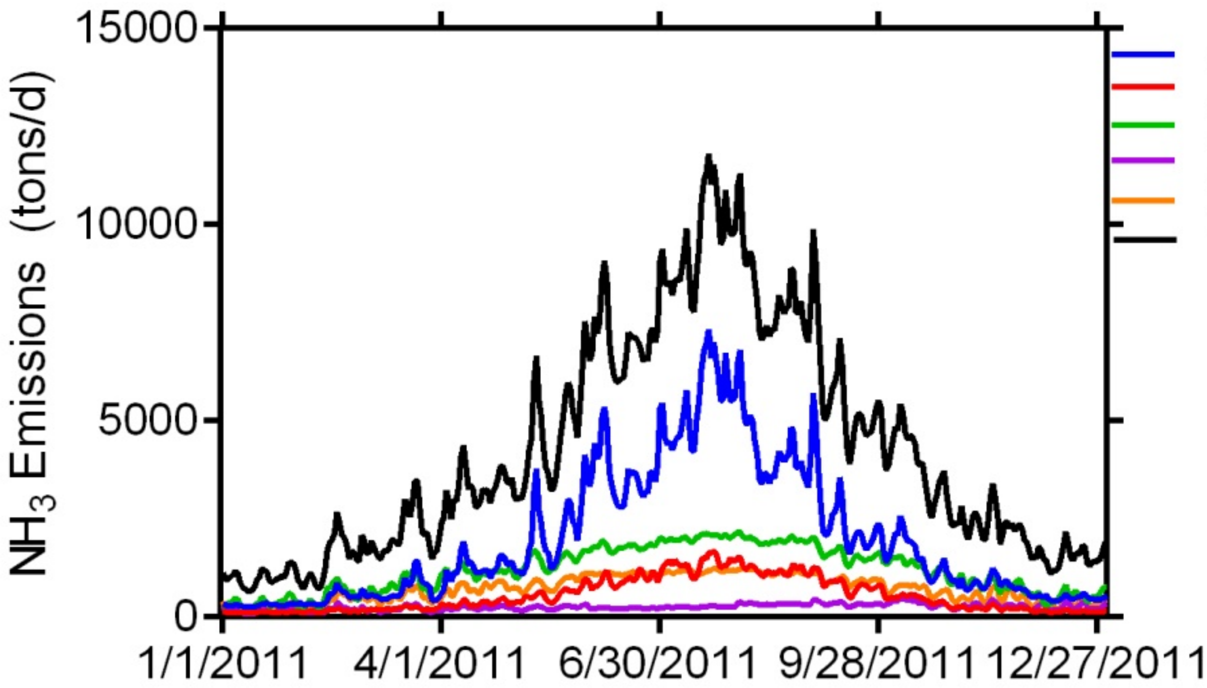
- Regional variation in housing, storage, and application practices
- Swine shown as example

- Previously, we obtained animal health survey data from USDA
- Now, we only get very high-level summaries

Inventory Calculations

1. Run FEM model for county-specific meteorology to produce daily emission factors.
   - ➢ Repeat for all farm practices
2. Compute a county composite EF as weighted average across all manure management practices in that county.
   - ➢ Repeat for all animal types.
3. Emissions = (emission factor) x (animal population)
4. Result is ammonia emissions with
   - Daily temporal resolution
   - County spatial resolution
   - …by livestock type, management stage, practice

2011 Results: National Totals



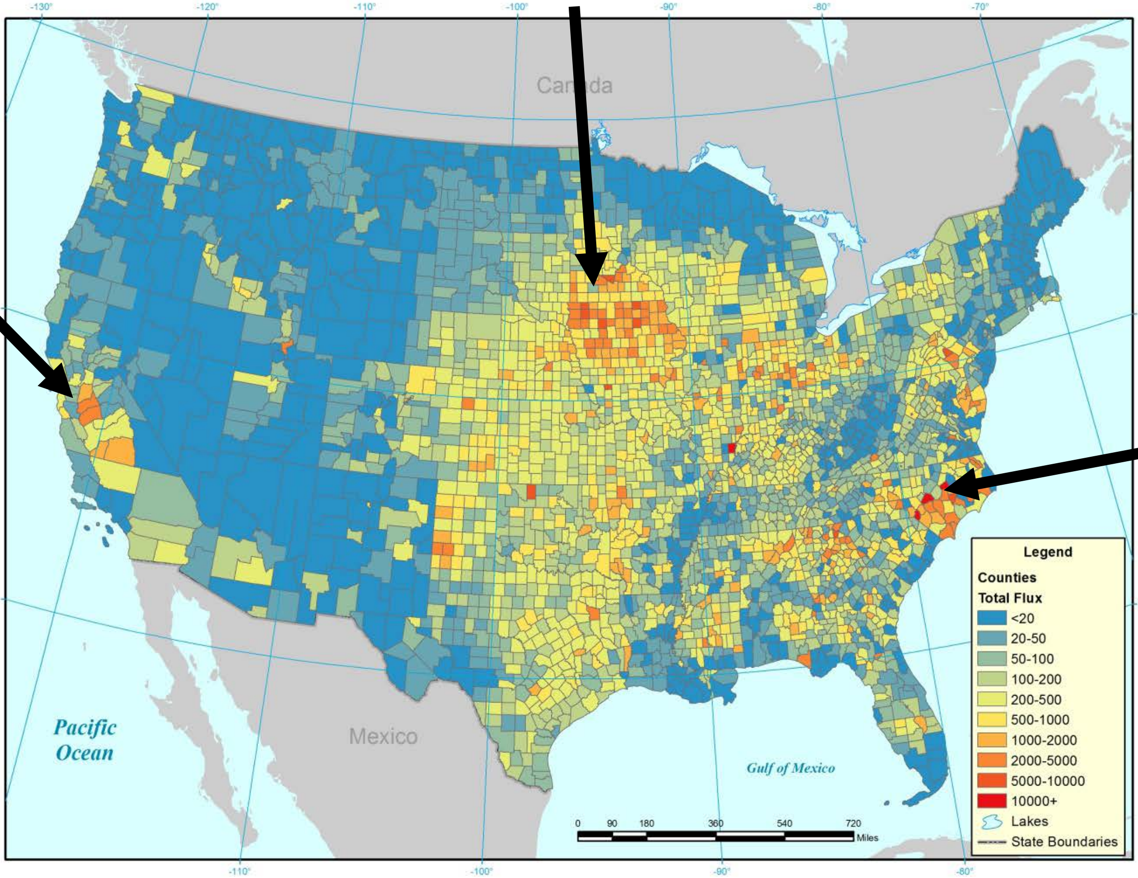
- Seasonal and daily variability apparent
- Summer emissions dominated by swine production
- Beef and broilers are more important during wintertime (relative to swine)
- Layer emissions have reverse seasonal emission pattern

Spatial Distribution

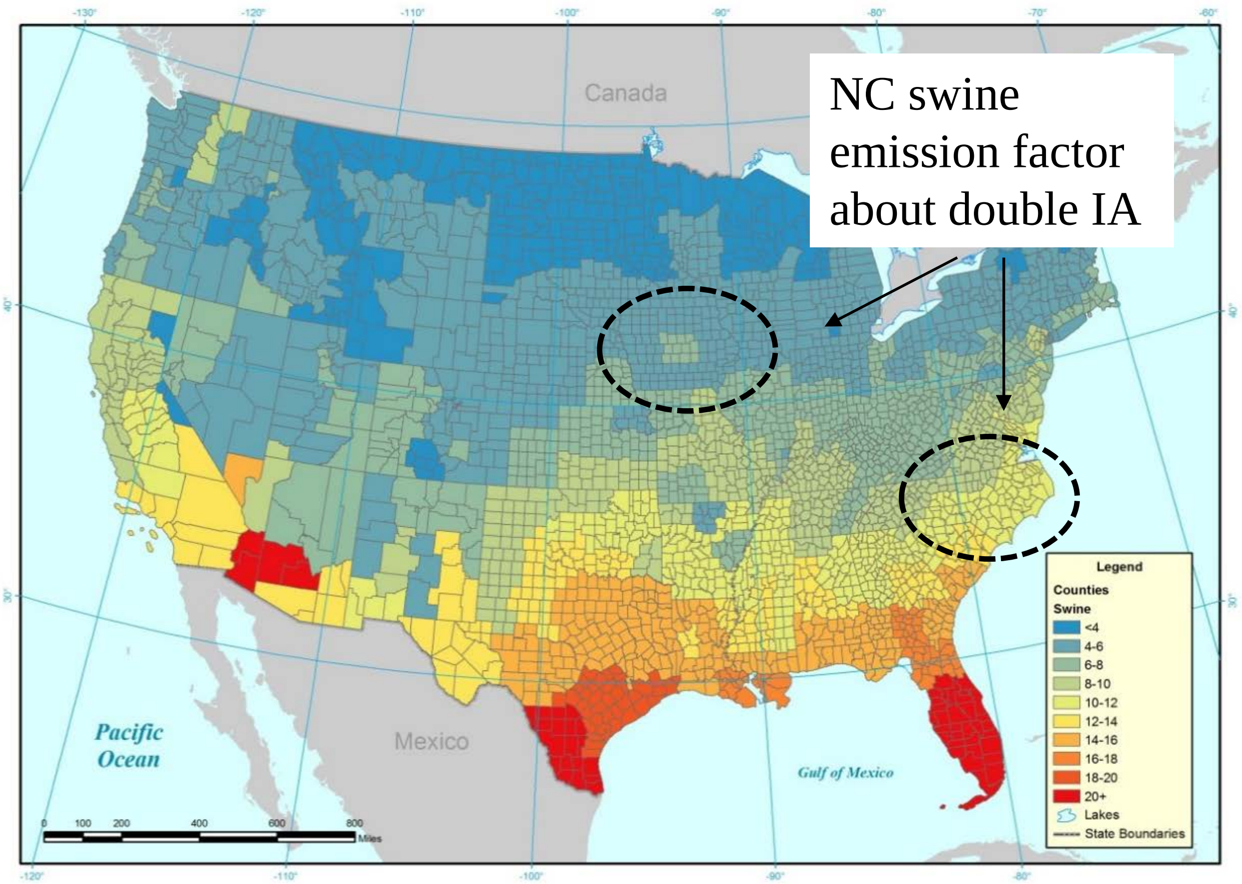
San Joaquin Valley: Cattle and Poultry Production

Iowa: Beef and Swine Production

NC Coastal Plain: Broiler and Swine Production

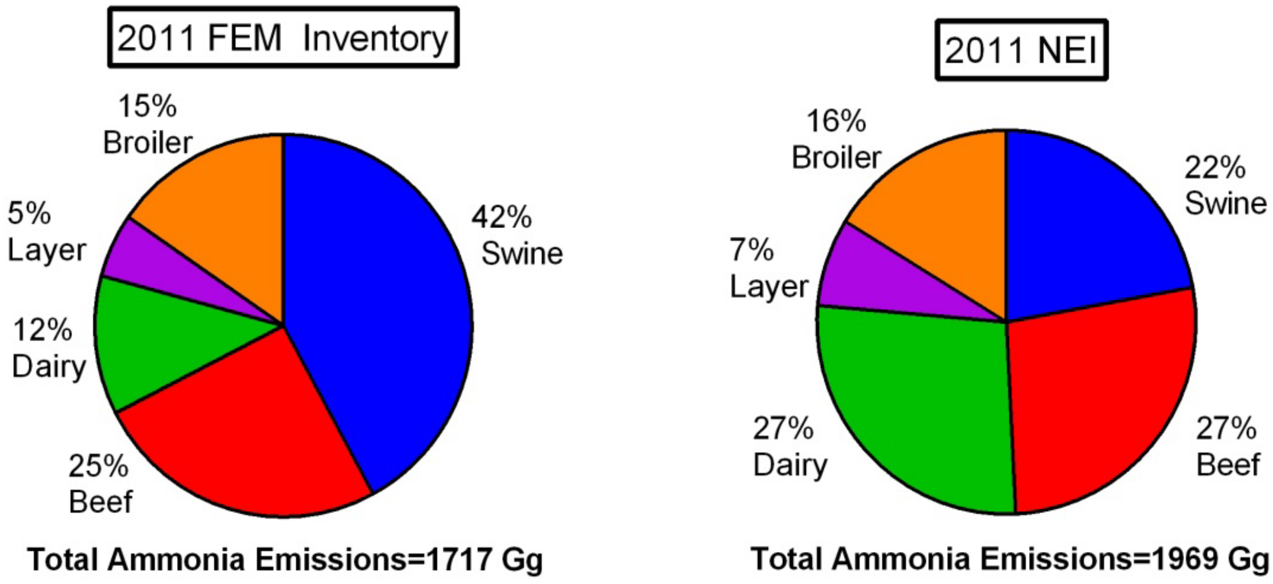


Regional Emission Factors



- Higher emission factors in warmer places
- Differences in practice less significant than T differences

Animal Contributions vs 2011 NEI



- Similar magnitude of emissions in 2011 FEM inventory and 2011 NEI
- Much greater swine emissions in our inventory (swine storage emissions higher in NAEMS compared to prior literature)
- Much smaller contribution from dairy

Conclusions 1

- Framework: process-based model tuned to observed emissions factors
  - captures regional and seasonal variability
  - unbiased overall compared to EFs used in tuning
- FEM captures seasonal cycle and practice differences; limited on daily variability
- First national inventory based on process-based modeling
  - similar total emissions as NEI 2011
  - swine ↑ but dairy ↓
  - stronger seasonal cycle

Conclusions 2

- EF measurements should report “context”
  - meteorology, pH, manure N, etc.
- EF measurements from open sources problematic due to dispersion assumptions
- Manure management / farm practice data is as much of a limiting factor as EF measurements
- Beef on pasture seems under-measured