A Geographically and Seasonally Resolved Ammonia Emission Inventory for Dairy Farms

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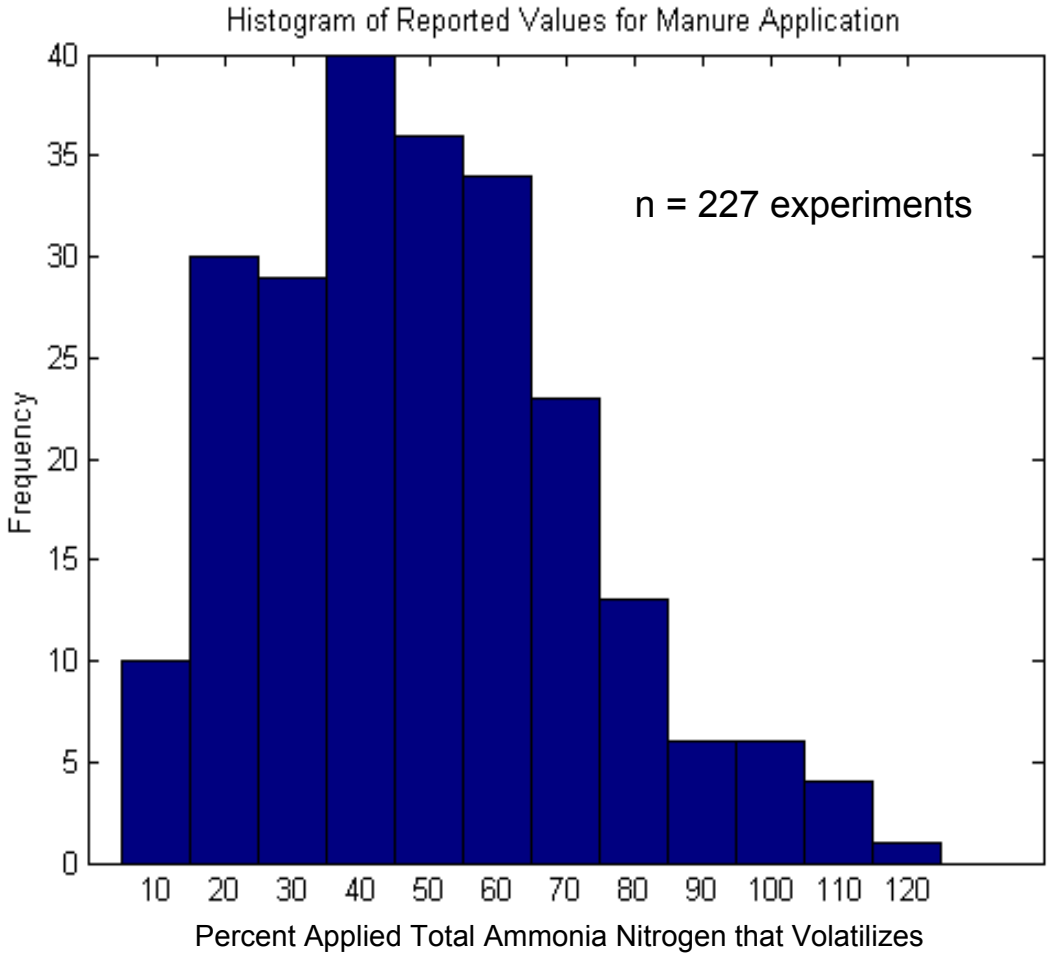
Ammonia

- Contributes to formation of inorganic particulate matter
- Deposition of Nitrogen
  - Forest ecosystems
  - Surface and coastal waters
- Not a criteria pollutant under Clean Air Act
- Sources:
  - 55-85% volatilization from livestock manure
  - Dairy farms are substantial fraction: 20-60%

Seasonal and Geographic Variation

- Ammonium nitrate aerosol is a significant fraction of $PM_{2.5}$
- Sensitivity of [PM] to $[NH_3]$
  - Dependent on
    - Temperature
    - Relative Humidity
    - $[HNO_3^-]$
  - Ranges from 0 to 4.7

Uncertainty and Variability in Emissions

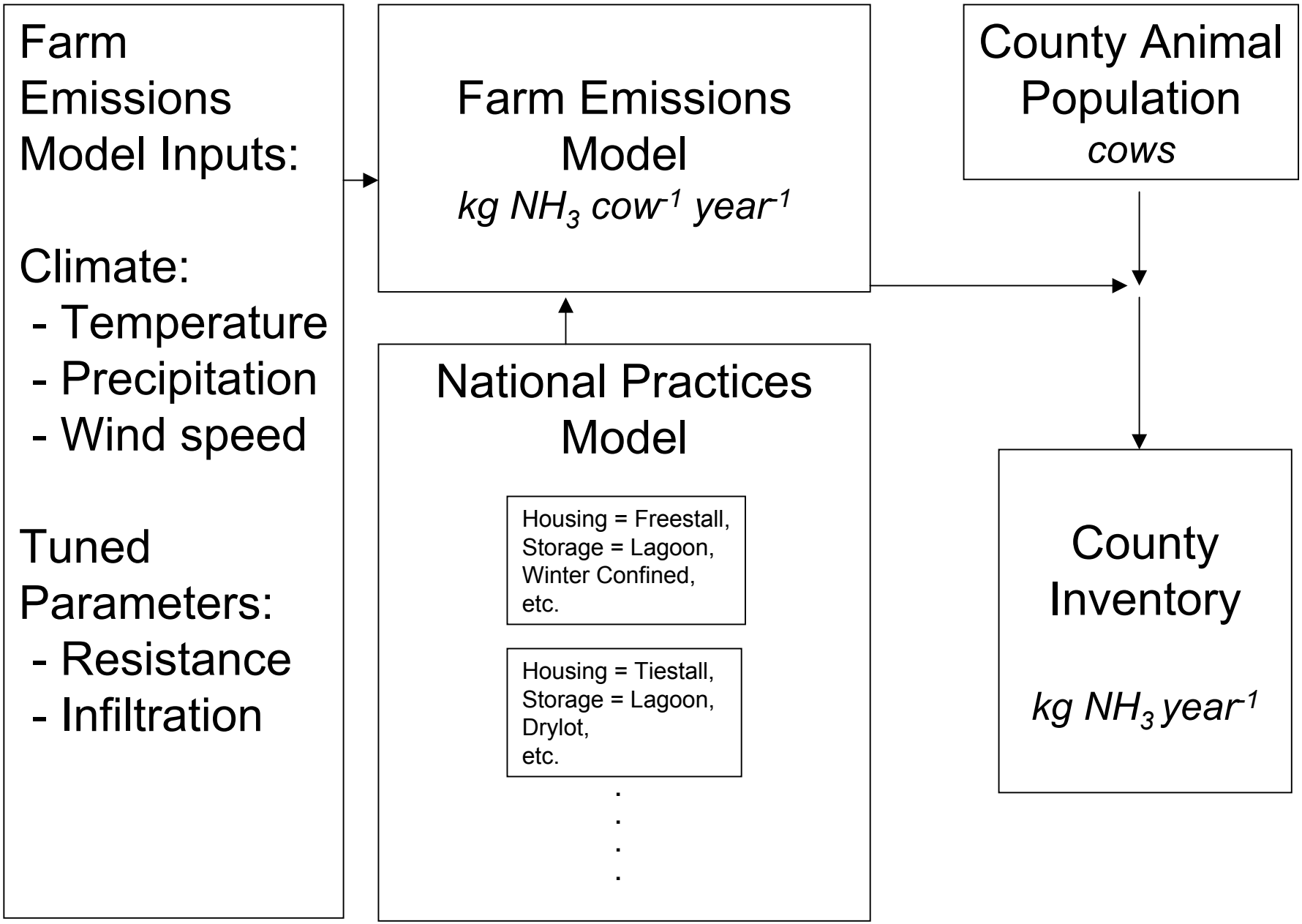


- Variability
  - Farming practices
  - Climate
- Uncertainty
  - Incomplete understanding
  - Measurement error

Source: Plochl, Matthias. Neural network approach for modelling ammonia emission after manure application on the field, *Atmospheric Environment*. 35 (2001) 5833-5841

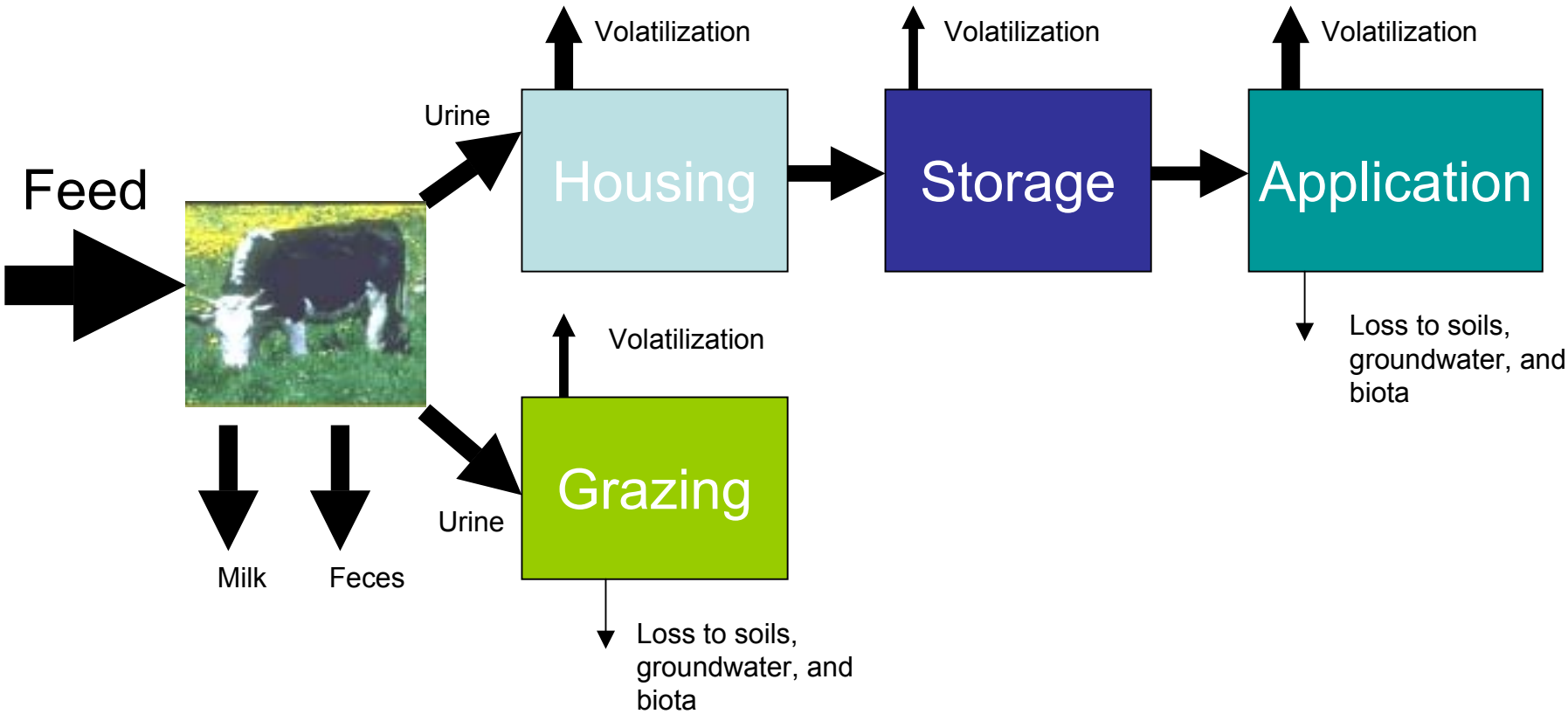
Approach

- Partially mechanistic model of ammonia emissions from a single dairy farm
  - Combines experimental results and physical principles to explain variation in emission factors
  - Focus on temporal and geographic variation
- Combine farm model with farming practices to generate national inventory
- Tool for evaluating change in emissions from regulation


Farm Emissions Model Inputs:
Climate:
- Temperature
- Precipitation
- Wind speed
Tuned Parameters:
- Resistance
- Infiltration
Farm Emissions Model
kg NH3 cow-1 year-1
National Practices Model
Housing = Freestall, Storage = Lagoon, Winter Confined, etc.
Housing = Tiestall, Storage = Lagoon, Drylot, etc.
County Animal Population
cows
County Inventory
kg NH3 year-1

Farm Emissions Model

Nitrogen Flows



Inputs:

From Housing:
Volume
TAN mass
Urea mass

Climate:
Temperature
Wind Speed
Precipitation
pH
Mass transfer resistance

Storage Sub-Model

Variables:

- Volume

$$dV/dt = \text{precipitation} - \text{evaporation}$$

- Mass of urea nitrogen

$$dU/dt = -\text{urea hydrolysis rate law}$$

- Mass of Total Ammonia Nitrogen (TAN)

$$dM/dt = \text{urea loading} - \text{emissions}$$

$$\text{Emissions} = \text{Area}[TAN]H^{*}r^{-1}$$

H^{*}: Effective Henry's Law Constant

r : mass transfer resistance

Outputs: NH_3 Volatilized
To Application: Volume
Mass TAN

Reported Inputs:
Values as reported

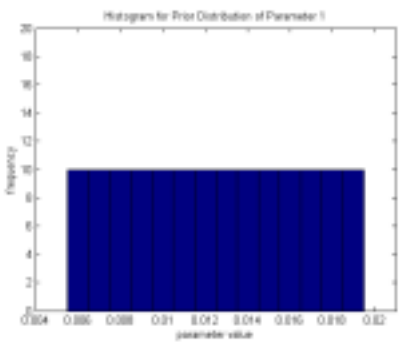
T: 8 | 12 | 15

U_{10}: 1.3 m/sec

Unreported Inputs:
Ranges based on similar research

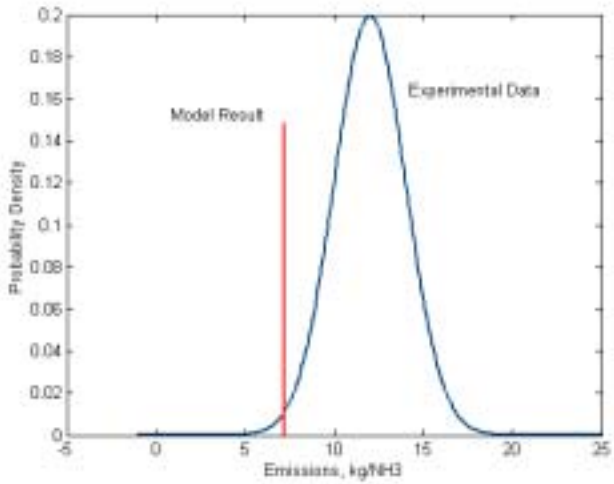
pH: 7.9 | 8.3 | 8.5

Prior Distribution for Parameter:



Farm Emissions Model:

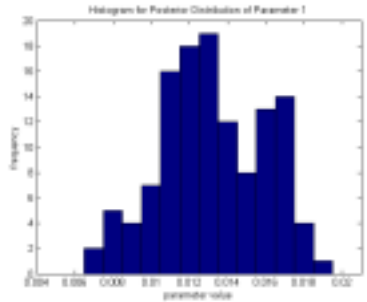
Calculate likelihood for each iteration



Likelihood = Pr(model | data)

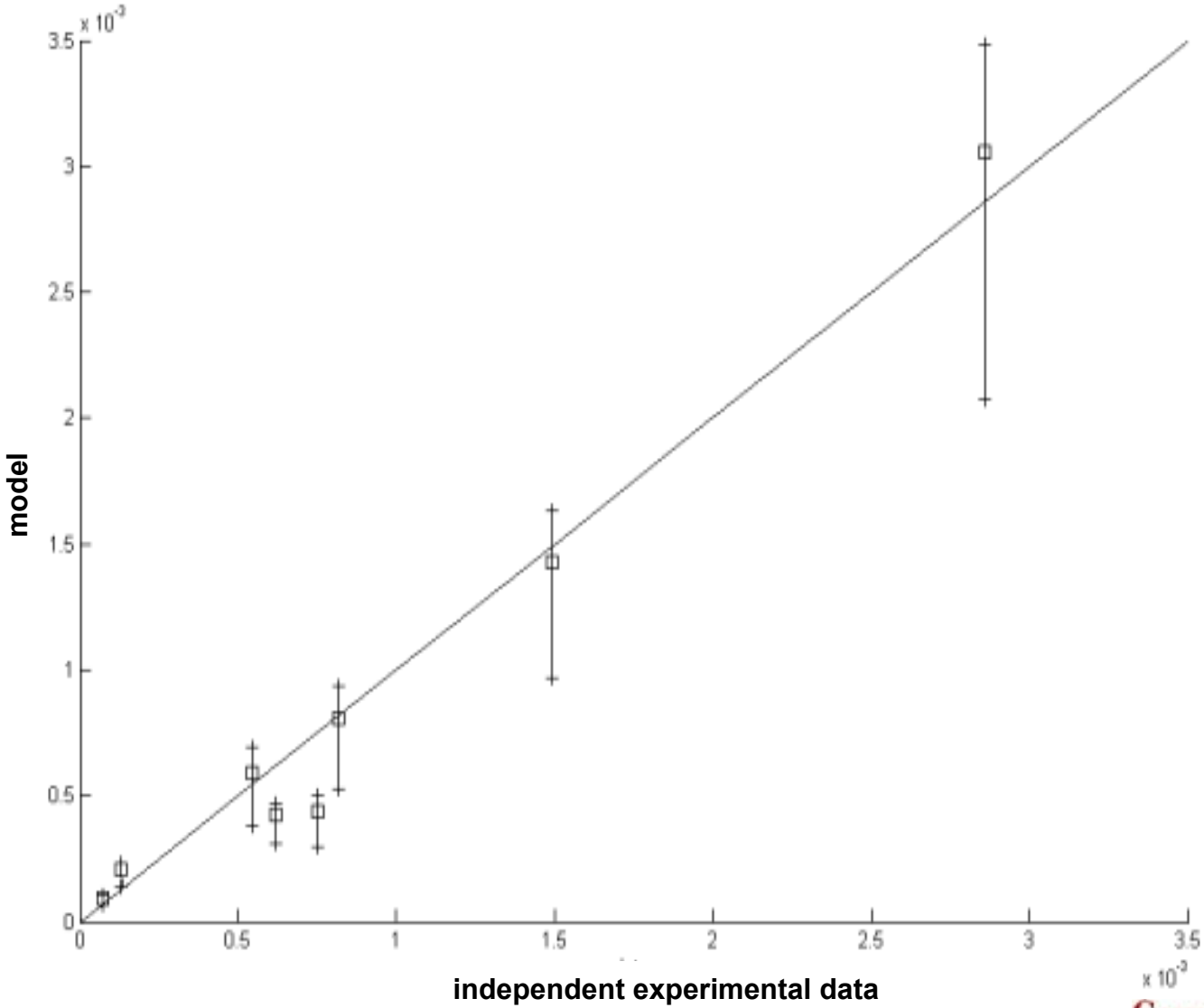
Update Posterior Distribution

Posterior Distribution for Parameter:



Verification of Tuned Parameters

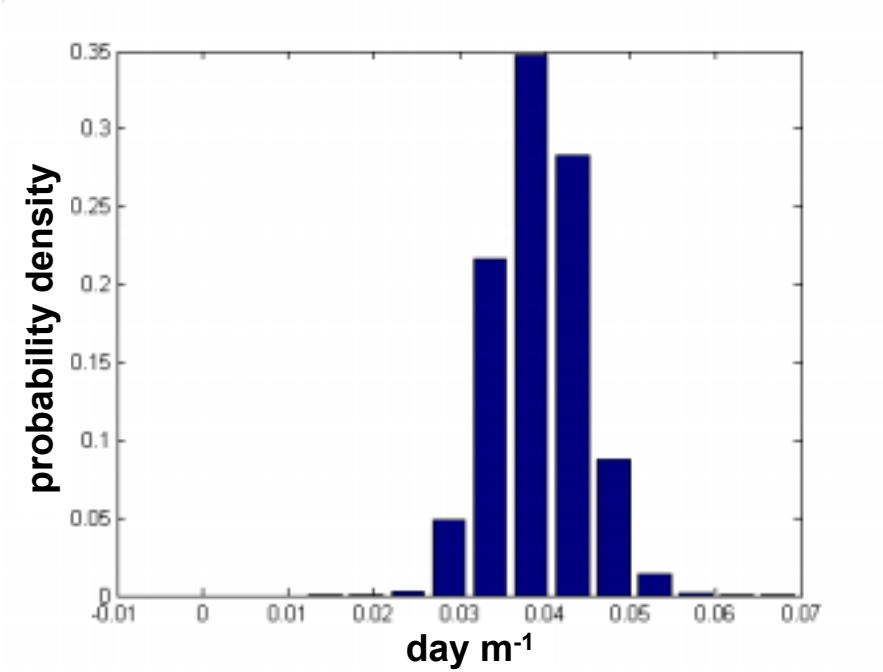
Storage Surface Resistance



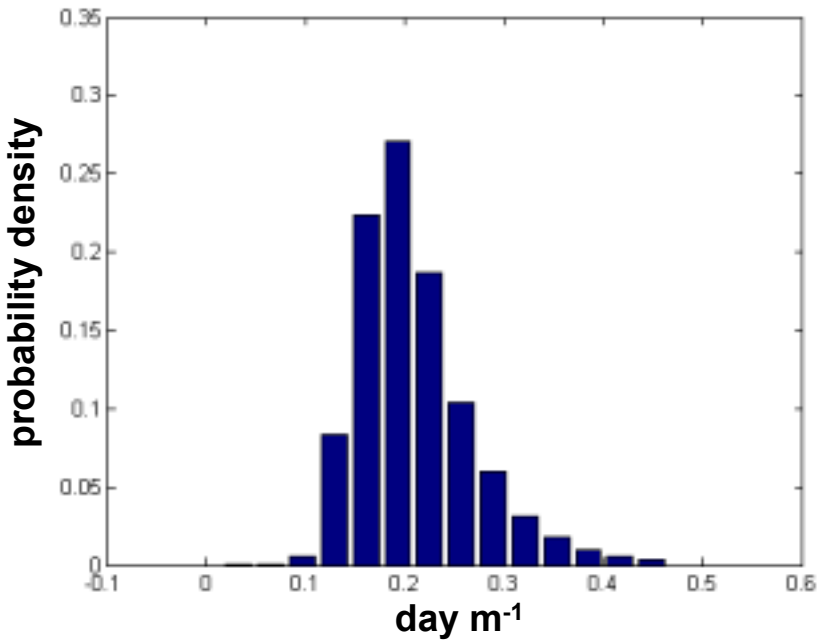
Tuned Resistance Parameters

Storage Surface Resistance

No crust



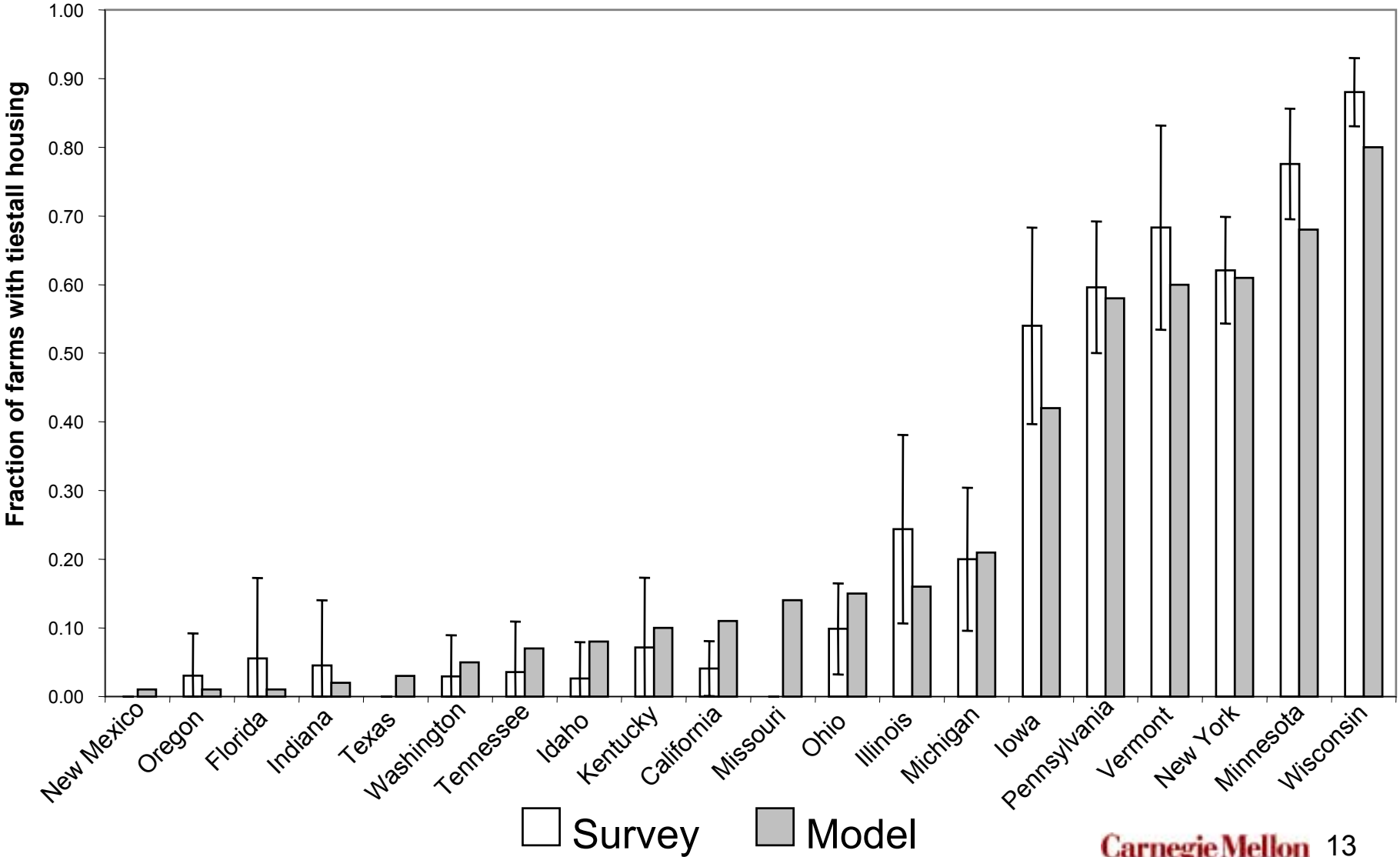
Wheat Straw Cover



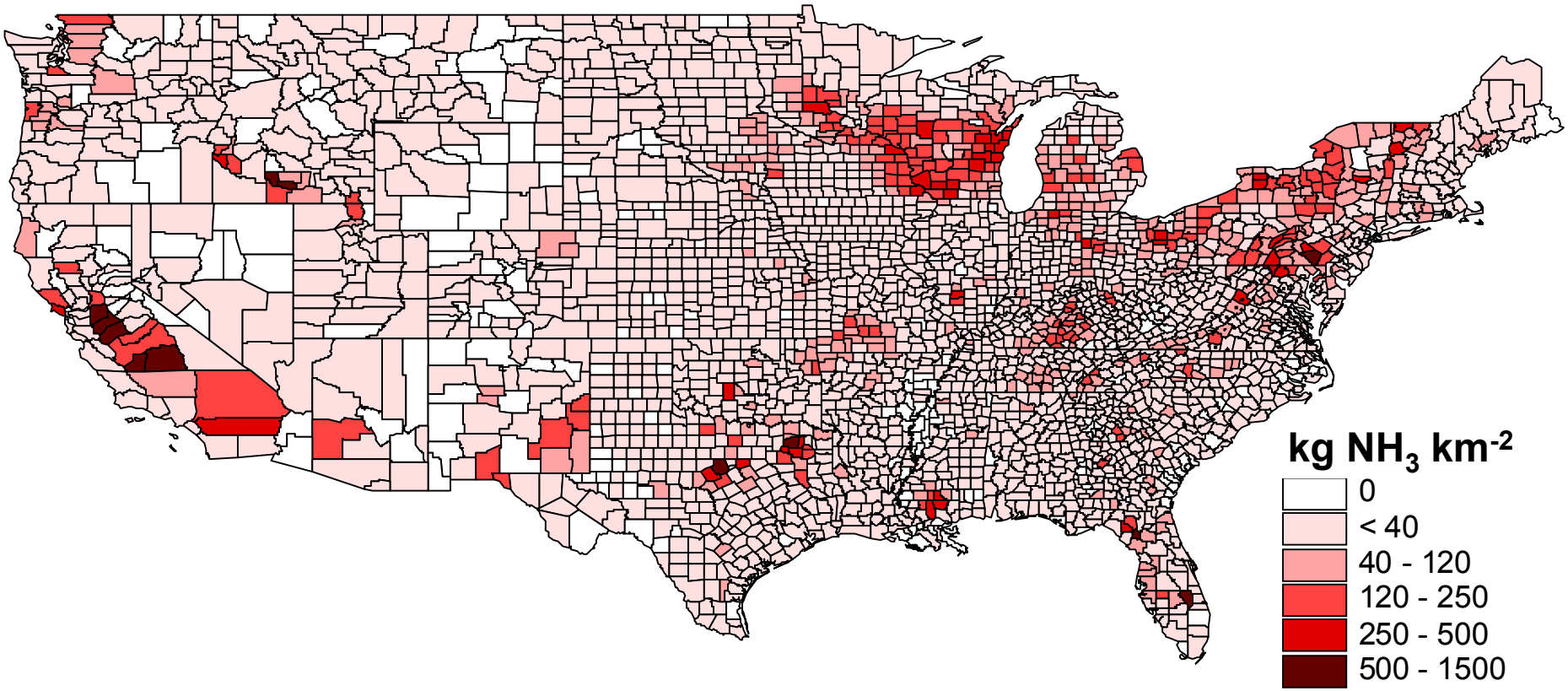
National Practices Model

- Survey data from USDA
- Data are sparse
- Stepwise logistic regression to predict 13 different farming practices
- Predictors:
  - Temperature, Rainfall
  - Historical cow populations
  - Milk yield
  - Other practices on the farm

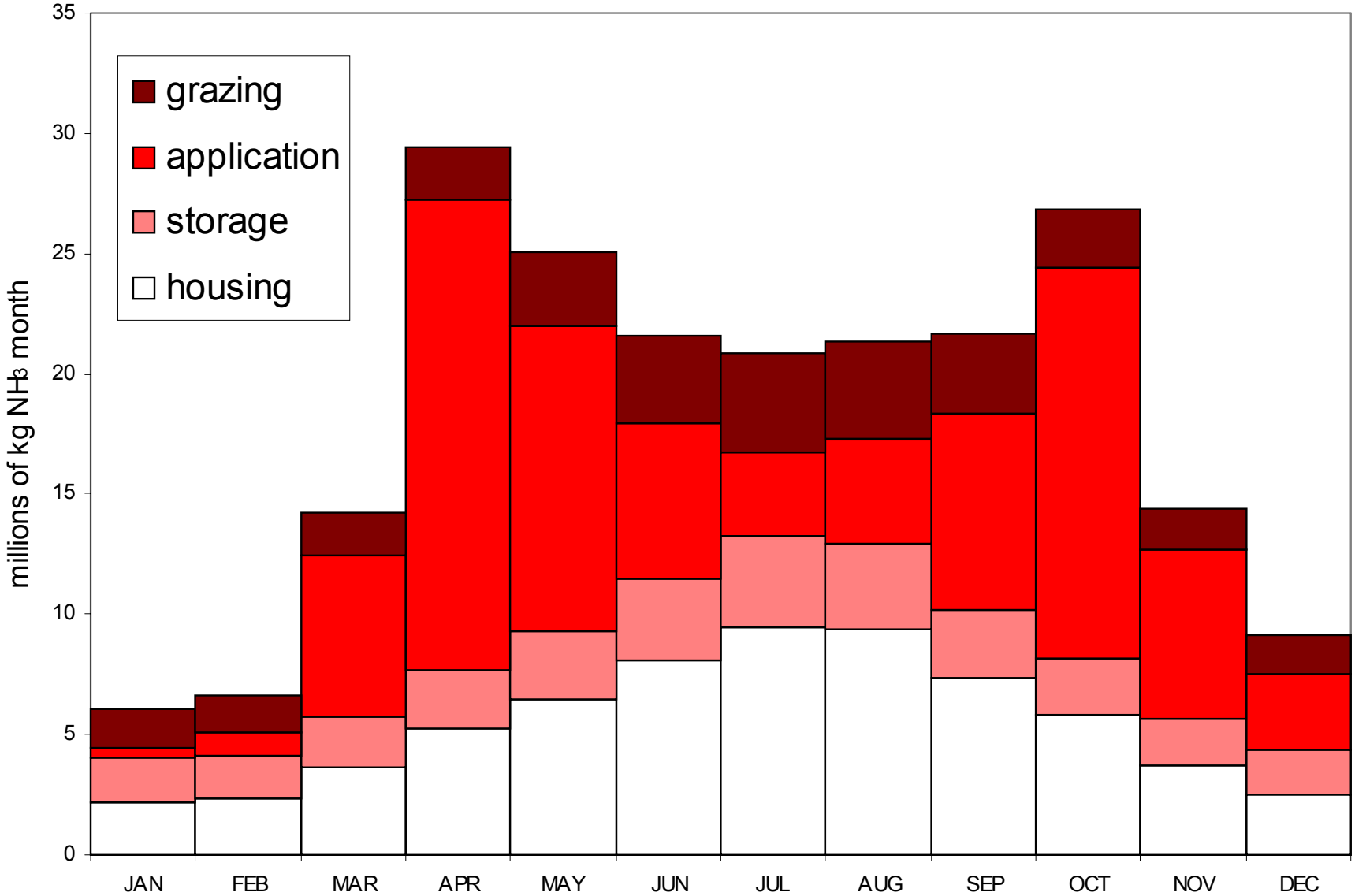
Verification of Farming Practices

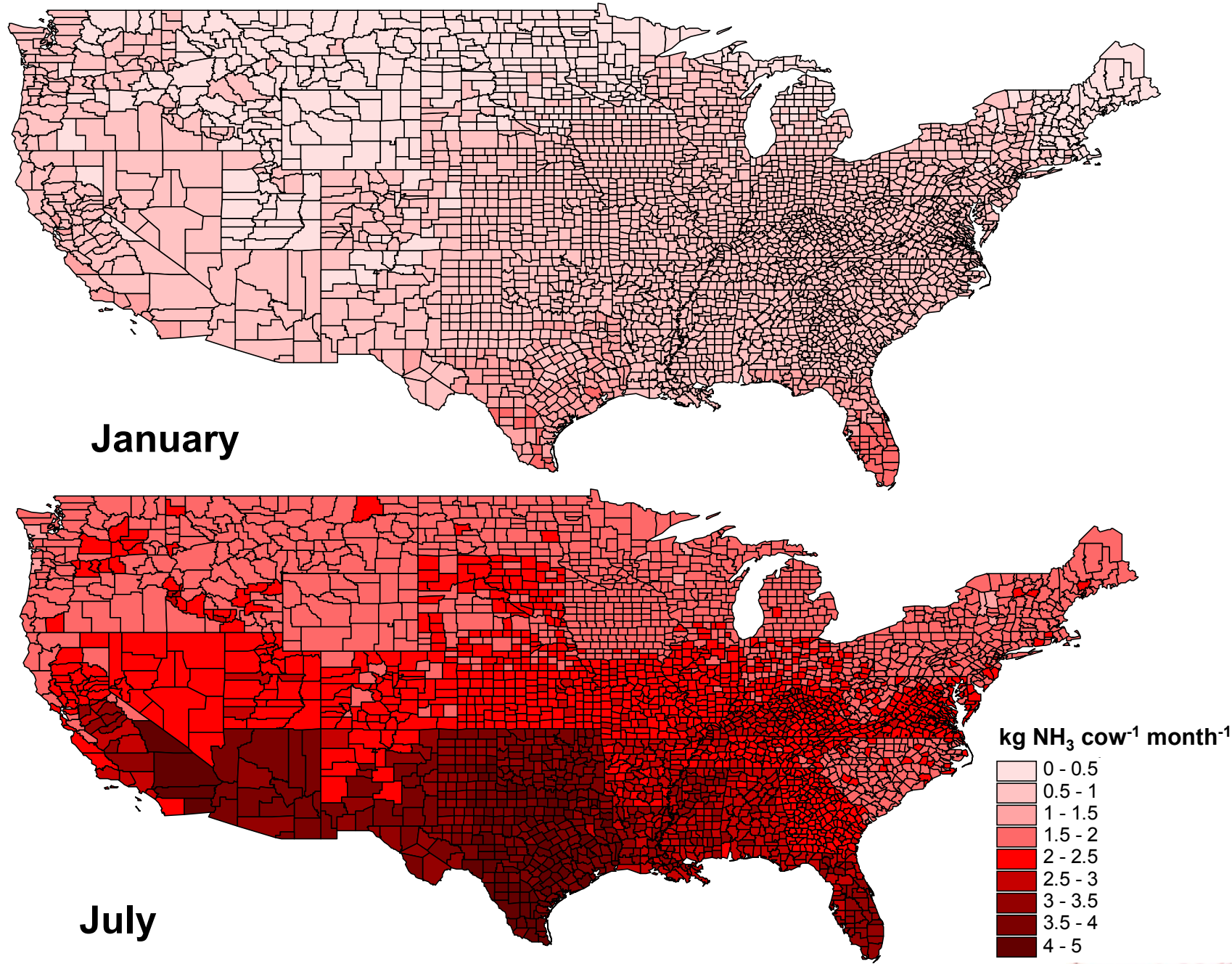


National Inventory

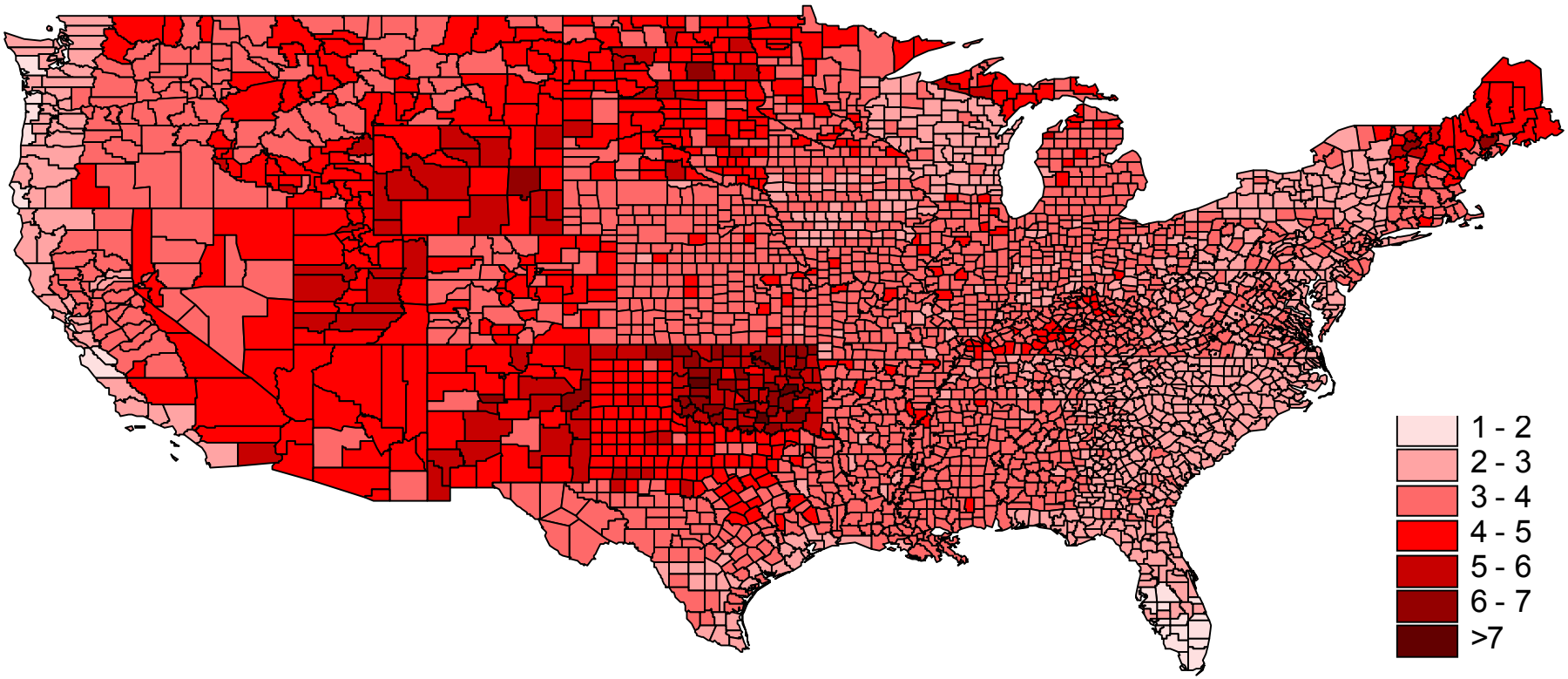


Seasonal Variability in National Emissions




January
July
kg NH_3 cow^{-1} $month^{-1}$
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 5

Ratio of July to January Emission Factors



Evaluate Regulatory Options

- Substitute traditional farming practices with control strategies
- Apply proportionally with National Practices Model

Control Strategy	Percent Reduced	Range
Wheat Straw Cover Only	4.5%	3.3-4.6%
Injection Only	27%	25%-31%
Both Straw & Injection	41%	37%-43%

Conclusions

- Seasonally and geographically varied emission inventory
  - Factor of 4 seasonal change
  - As high as factor of 7 geographical change
- Reducing emissions
  - In the winter, reduce housing emissions
  - In the spring and fall, reduce application emissions
  - Need to address entire farm
- Use air quality model to validate

Questions and Comments