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NEI 2020: Livestock Waste Emissions inventory Development with Semi-Empirical Process-based Farm Emissions Model (FEM)

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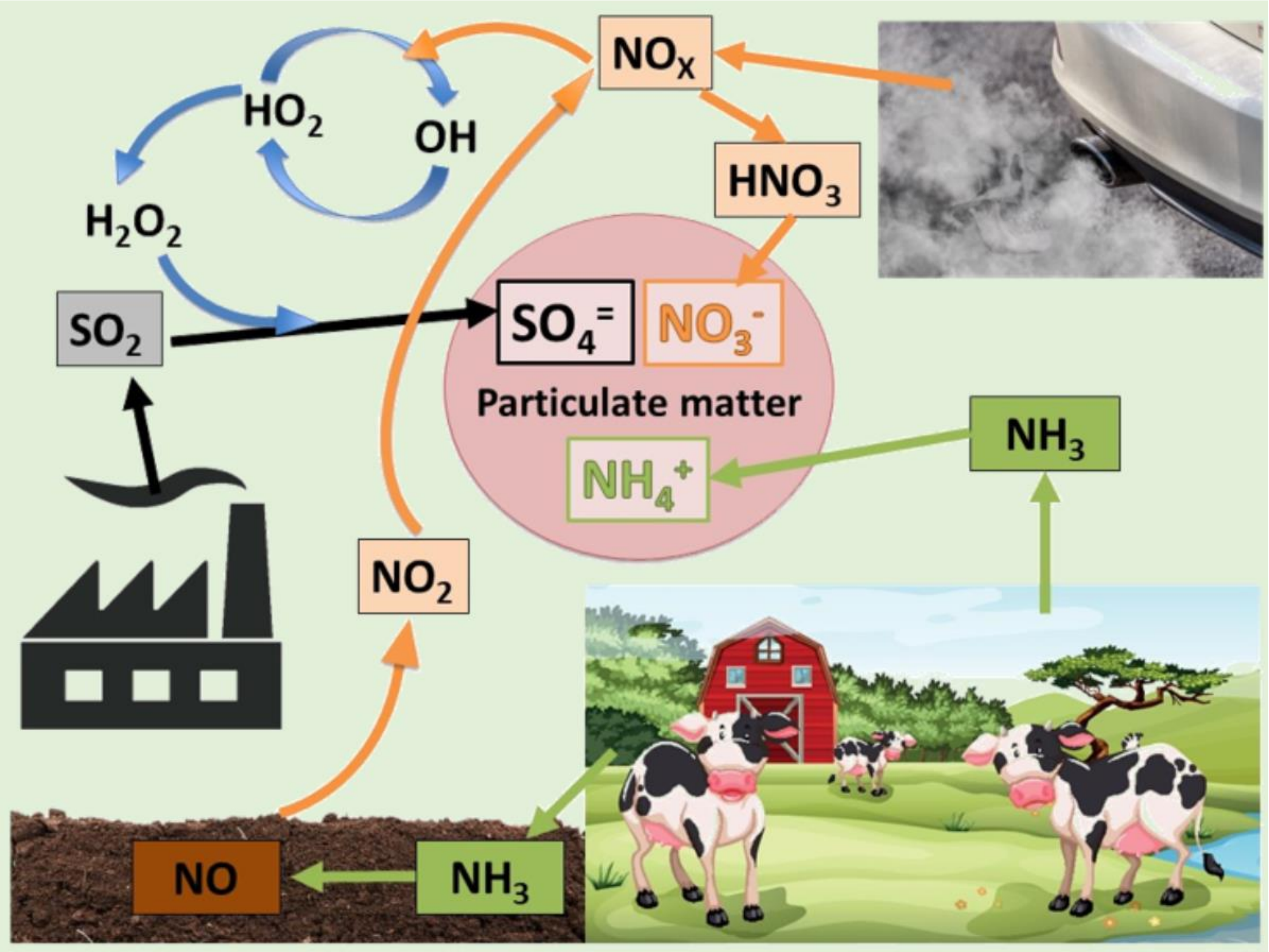
Gas-to-Particle Conversion between NH_3, and Acid Gases



(Stiles, Farming Connect, 2020)

Acid Gases: H_2SO_4, HNO_3 and HCl

- Acidification of soils and acid rains
- Mostly from anthropogenic emissions

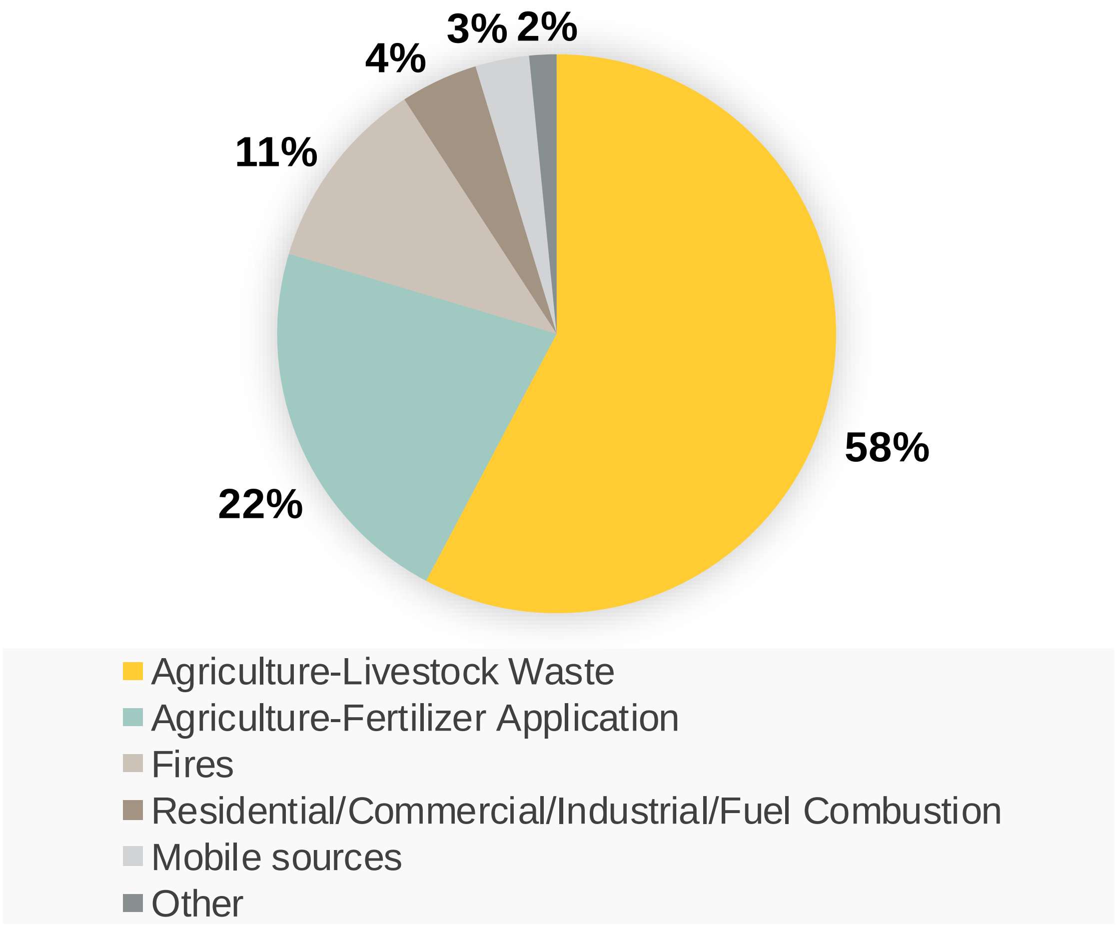
Ammonia: NH_3

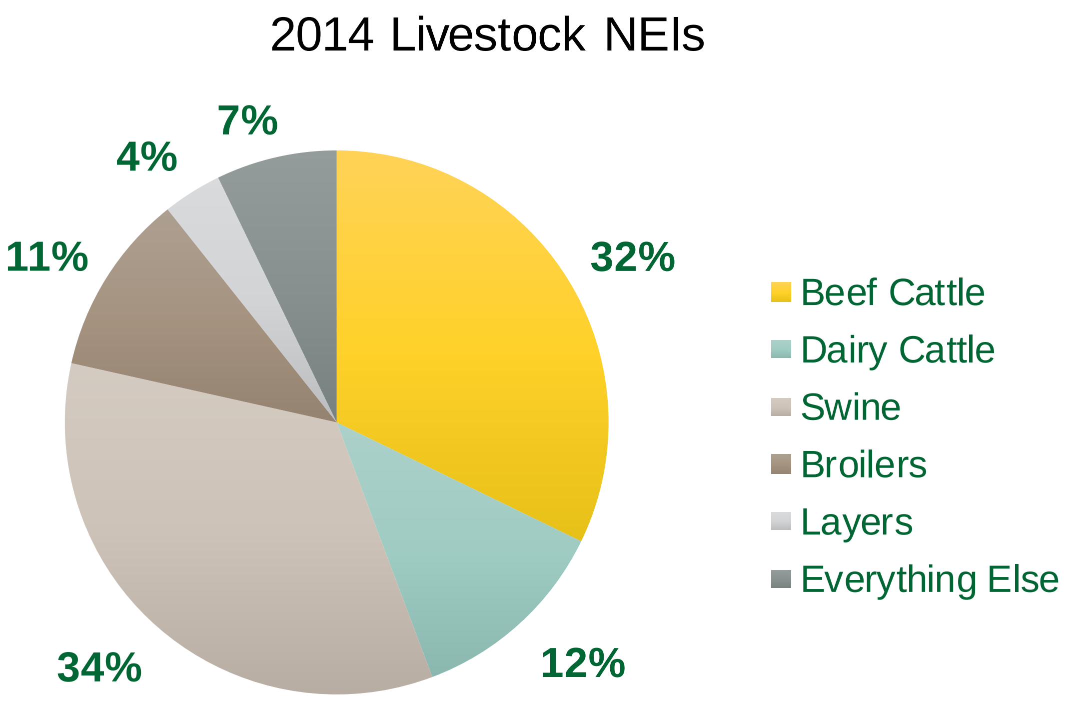
- Roles of determining acidification and eutrophication
- Most alkaline pollutants in the atmosphere to neutralize the acid gases
- Forming the secondary fine particles in the atmosphere for long-range transportation

Fine Particles: $PM_{2.5}$

- Formed from reactions with Ammonia and Acid Gases
- Degradation of visibility

Contributors of NH_3 Emissions





Farm Emission Model (FEM)

1. **Manure types** : Dairy, Cattle, Poultry and Swine
    - Nitrogen Inputs (manure and urine), Dryness of excretion, Surface for housing /storage, Runoff area based on precipitation, and so on.

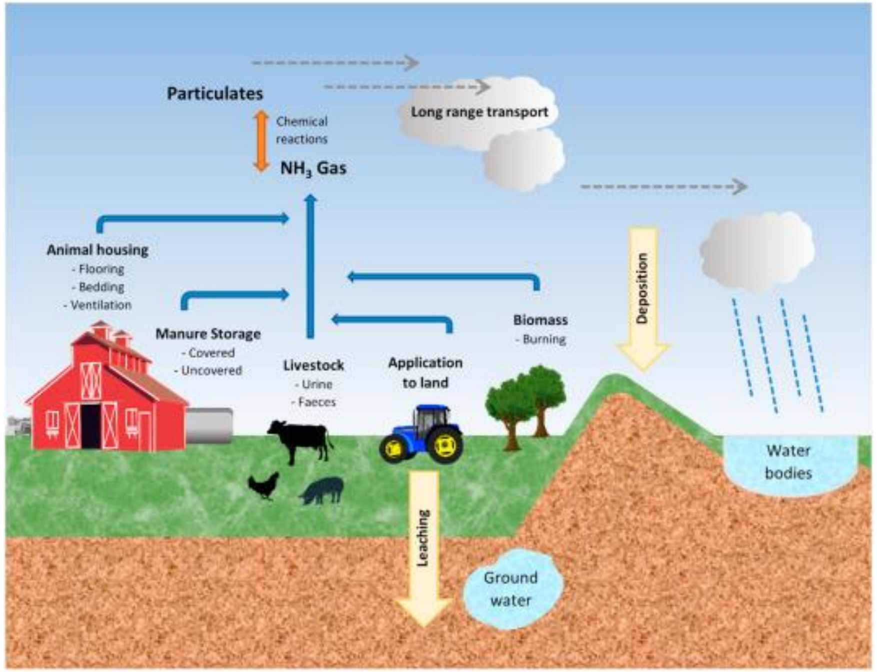
2. **Management Practice**
    - <u>Housing</u>: tiestall, freestall, deep-pit, shallow-pit, manure-belt, high-rise, no-housing
    - <u>Storage</u>: lagoon, earthbasion, and slurry tank
    - <u>Application</u>: irrigation, injection, traininnghose, and broadcast
    - <u>Grazing</u>: seasonal, monthly, weekly, daily.
    - <u>pH</u> also plays a critical role in NH_3 emissions from housing and storage

3. **Meteorology**

    Ambient temperature $\uparrow$ → NH_3 emissions $\uparrow$
    - Higher temperature increases volatility of ammoniacal nitrogen

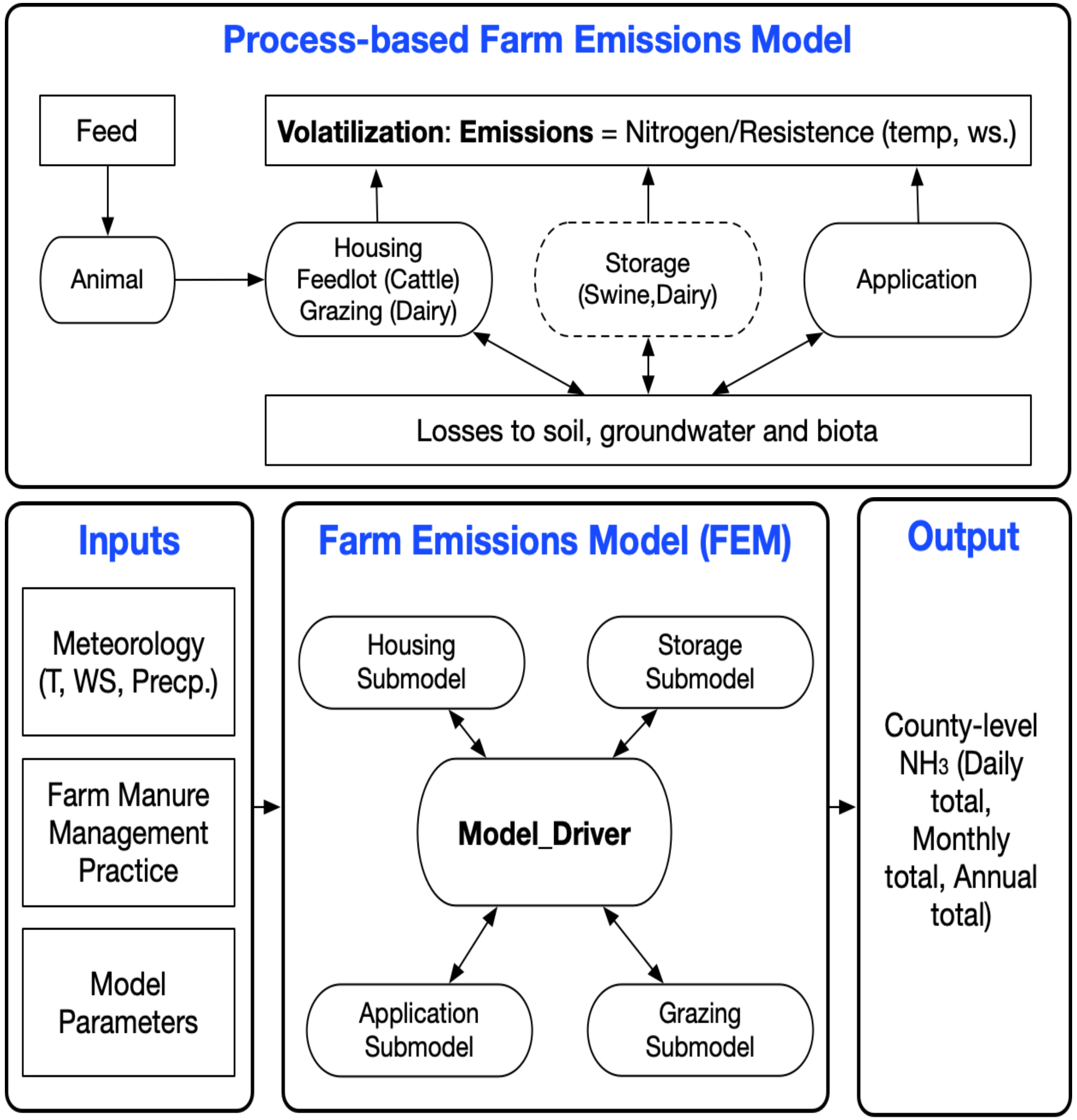
    Wind speed $\uparrow$ → NH_3 emissions $\uparrow$
    - Higher wind speed decrease surface resistance

    Precipitation $\uparrow$ → NH_3 emissions $\downarrow$
    - Precipitation allows for greater ground infiltration



(Wyer et al., Env. Manag., 2022)

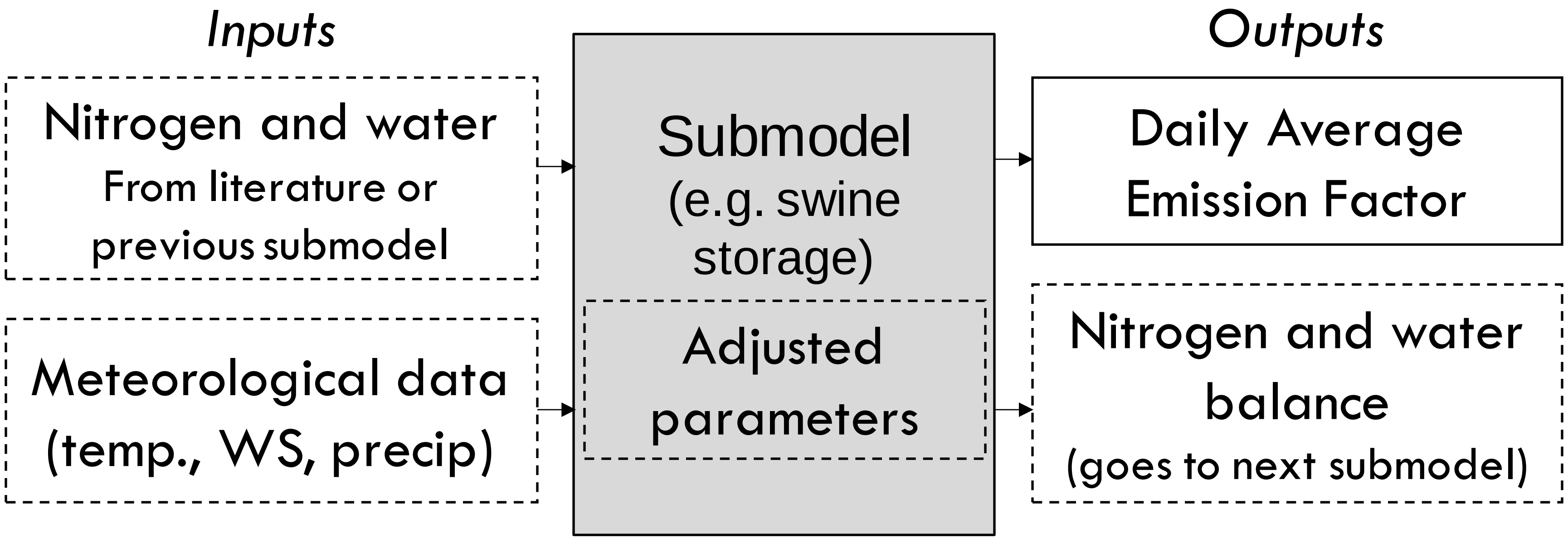
Farm Emission Model (FEM) Data Flow Diagram



- The FEM is based on a nitrogen mass balance whose inputs are meteorological parameters, regionalized manure management practices, and other model parameters that define the inputs needed to build the emissions equation.
- The EF from each stage of the process is constrained via the use of tuned parameters to ensure agreement with reported NH_3 EFs (e.g., NAEMS and CFPR?)
- The key inputs to FEM simulations

1. Daily Meteorology (temp, wind speed, and precipitations)
2. Manure management practices by livestock type
   - Manure management stage (housing, application, storage, grazing)
   - Major practice by stage (e.g. deep-pit, shallow-pit housing,,,,,)
3. Model Parameters
   - Manure characteristics (e.g., manure volume, urine conc., pH,,,,)
   - Surface mass transfer resistance from manure to atmosphere

FEM Submodel Data Flow Diagram



$$EF = \{A*[TAN]*H\} / r$$
$$r = r_a + r_b + r_s$$

r_a =Aerodynamic resistances
r_b =Quasi-laminar resistance
r_s = Surface resistance: Tuned to match measured EFs from observations

Hutchings et al (1996) A model of ammonia volatilization from a grazing livestock farm

For other animal housing:
$r_s = H_1 + H_2T$

For Beef feedlots housing:
$r_s = H_1T + H_2u + C$

: H1 and H2 are constants and tuned to capture variability due to temperature and wind speed

FEM: Animal-specific Model Parameters

Number	Parameters	Default	Decriptions
1	Hp1	1.10	turned parameters for housing (s/m-C)
2	Hp2	0.00	turned parameters for housing (s/m)
3	Sp1	20.00	storage tuned resistance for no cover (s/m)
4	Sp2	400.00	storage tuned resistance for crust (s/m-C)
5	Ap1	150.00	tuned resistance for application (s/m)
6	Ap2	-50.00	tuned dry matter content function
7	Ap3	300.00	tuned dry matter content function
8	Gp1	11.97	tuned grazing resistance pature (s/m)
9	Gp2	5.45	tuned grazing resistance drylot (s/m-C)
10	crt	0.50	pcrust: fraction storage with crust
11	sld	1.00	solid factor: emission factor for solid manure
12	hlf	4.00	Urea halflife: half life of urea
13	hph	7.70	pH of manure in housing
14	sph	7.40	pH of manure in storage
15	aph	7.40	pH of manure application
16	gph	8.20	pH of manure grazing
….	….	….	….

Critical Input to FEM

- Submodel-specific parameters
- Nitrogen inputs (manure and urine)
- Dryness of animal excretion
- Surface area for housing and storage submodels
- Dry matter contents during application submodel
- Grazing hours
- Runoff area calculation based on precipitation

FEM: Farm Configuration Input

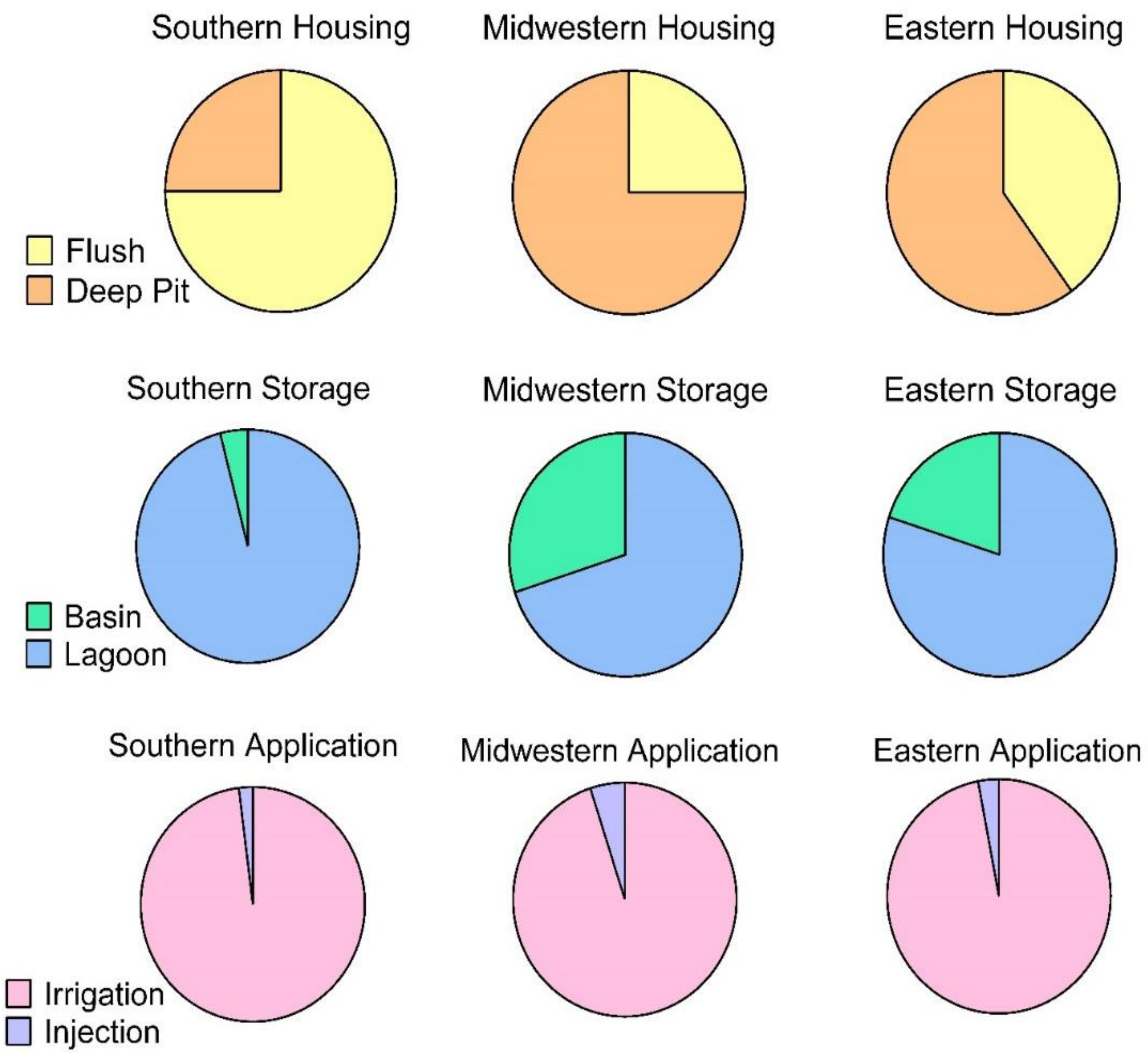
Submodel	Configuration	Value	Description
Grazing	confined_summer	1 or 0	Summer grazing
	confined_winter	1 or 0	Winter grazing
	pasture	1 or 0	Pasture resistance
	drylot	1 or 0	Drylot resistance
Housing	tiestall	1 or 0	Tiestall (=Deep-Pit)
	freestall	1 or 0	Freestall (=Shallow-Pit)
	nohousing	1 or 0	No housing=1
	liquid	1 or 0	Liquid phase animal waste
	solid	1 or 0	Dry phase animal waste
Storage	lagoon	1 or 0	Lagoon storage
	earthbasin	1 or 0	Earth basin storage
	slurrytank	1 or 0	Slurry tank storage
Application	irrigation	1 or 0	Irrigation application
	injection	1 or 0	Injection application
	trailinghose	1 or 0	Trailing hose application
	broadcast	1 or 0	Broadcast application
	summer_application	1 to 4	Summer application : 1=daily, 2=weekly, 3=monthly, 4=seasonally
	winter_application	1 to 4	Winter application : 1=daily, 2=weekly, 3=monthly, 4=seasonally

Critical Input to FEM

Submodel-specific Farm Practice Inputs

- Type of Housing:
  - Tiestall (Deep-pit for Swine)
  - Freestall (Shallow-pit for Swine)
- Type of animal waste
  - Liquid and dry phase
- Type of Storage
  - Lagoon, Slurry Tank, or Basin Tank
- Type of Application
  - Irrigation, injection, broadcast,
- Application Practice
  - Summer or Winter
- Type of Grazing
  - Pasture or drylot
- Grazing Practice
  - Confined summer or winter

Swine: Farm Managements by Regions over U.S.



Required:

- Updating Configuration input
- Updating Parameter input

Resources:

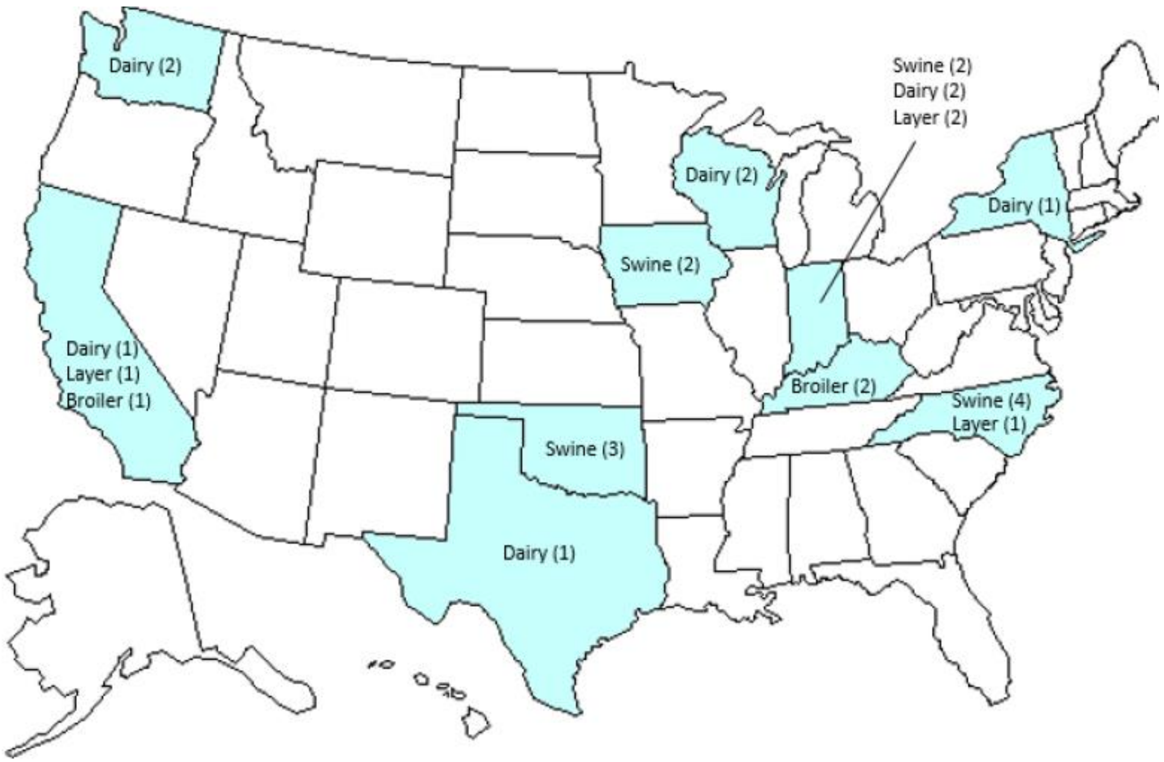
- National Animal Health Monitoring System (NAHMS)

- Midwest: Idaho, Iowa, Minnesota, Montana, North Dakota, Nebraska, South Dakota, Wisconsin, and Wyoming.

- Eastern: Connecticut, Delaware, Illinois, Indiana, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, and Vermont.

- Southern: The rest of the states

Livestock Waste NEI Development with the FEM



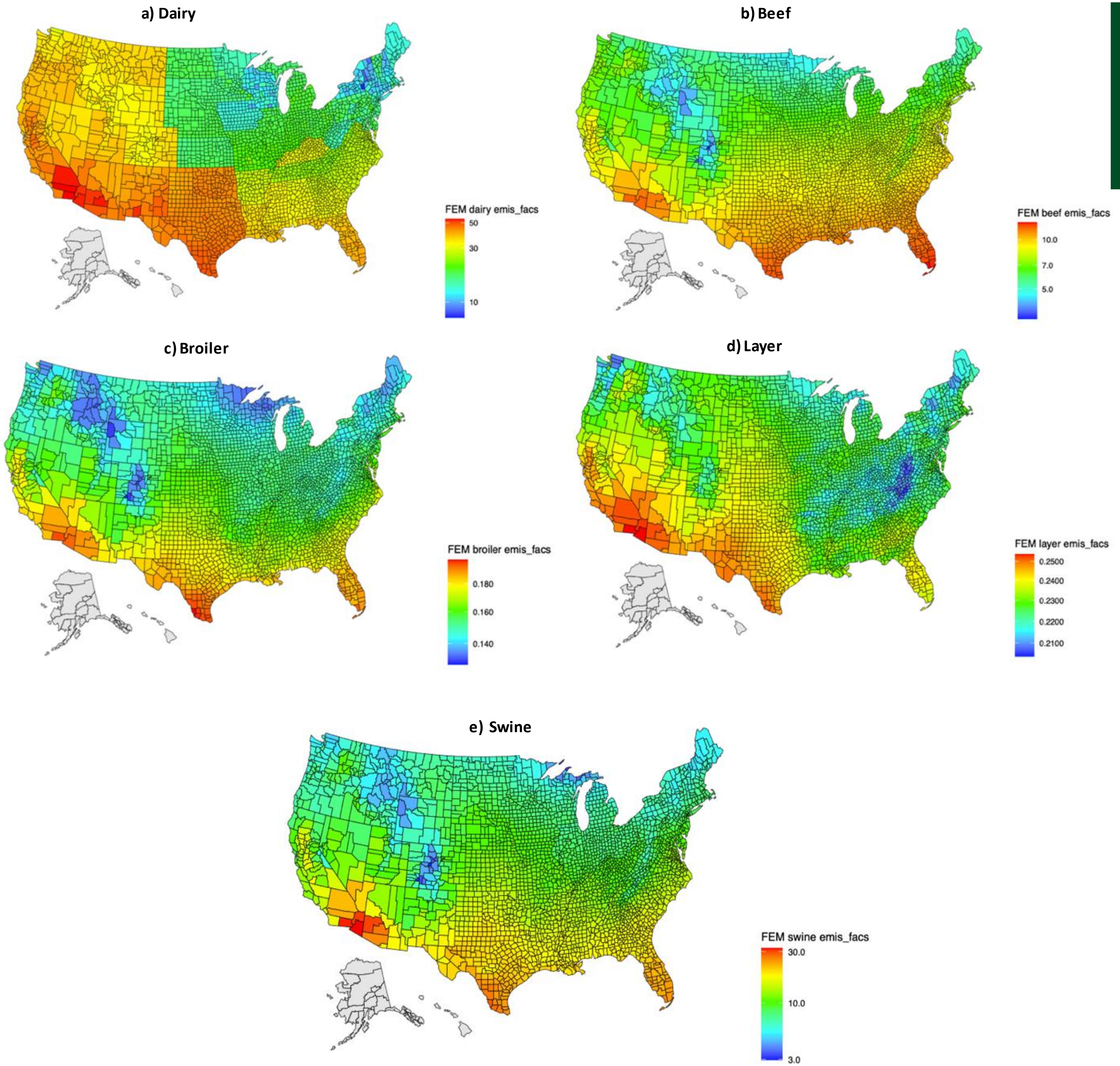
National Air Emissions Monitoring Study (NAEMS)

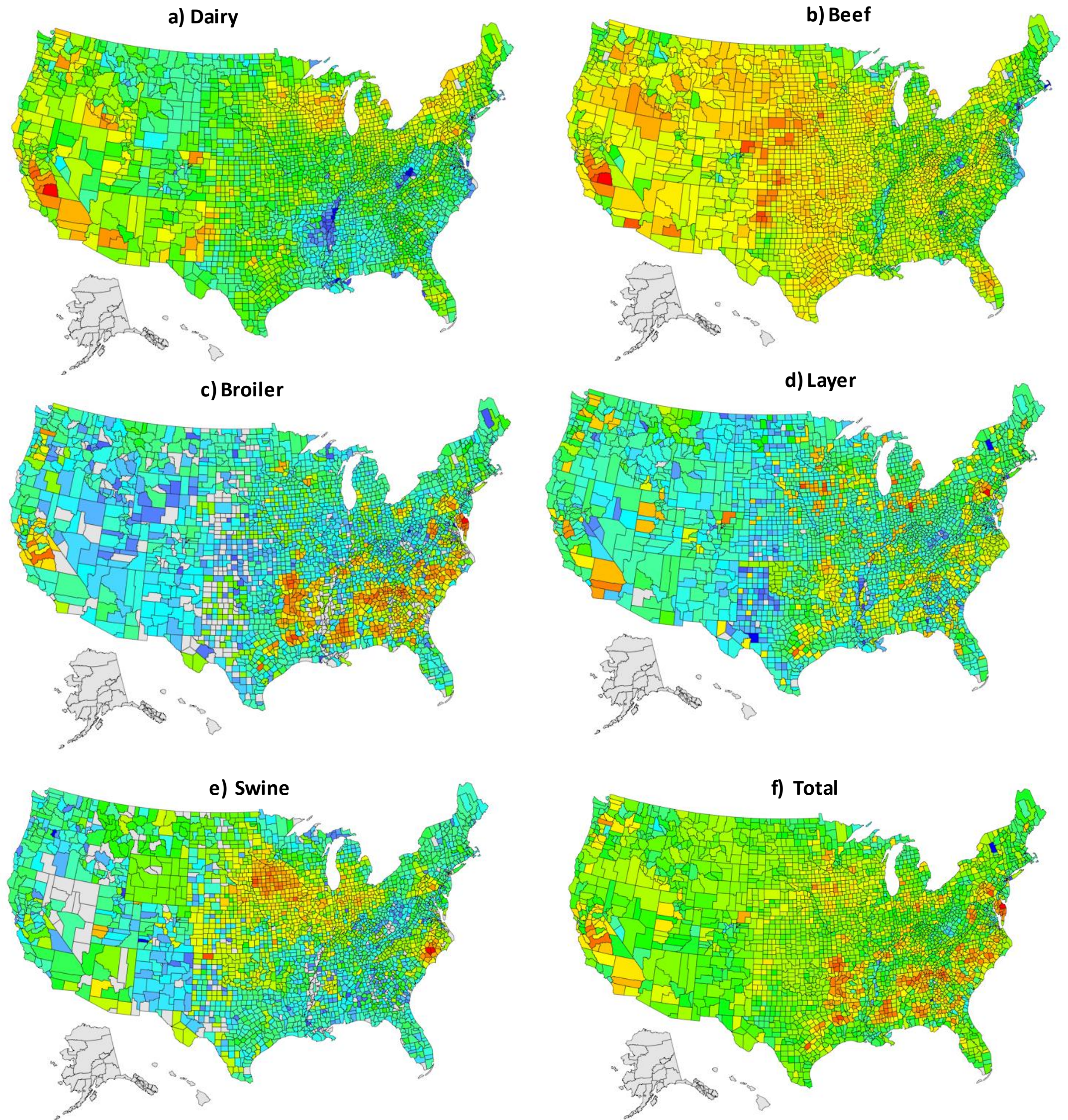
- ~ 2 years of consecutive data collection (long-term measurements of seasonal cycles)
- Consistent measurement techniques
- Extensive monitoring of meteorological and farm management conditions
  - Dairy : 9 sites
  - Swine: 11 sites
  - Layer: 4 sites
  - Broiler: 3 sites

NEI Livestock Waste Development

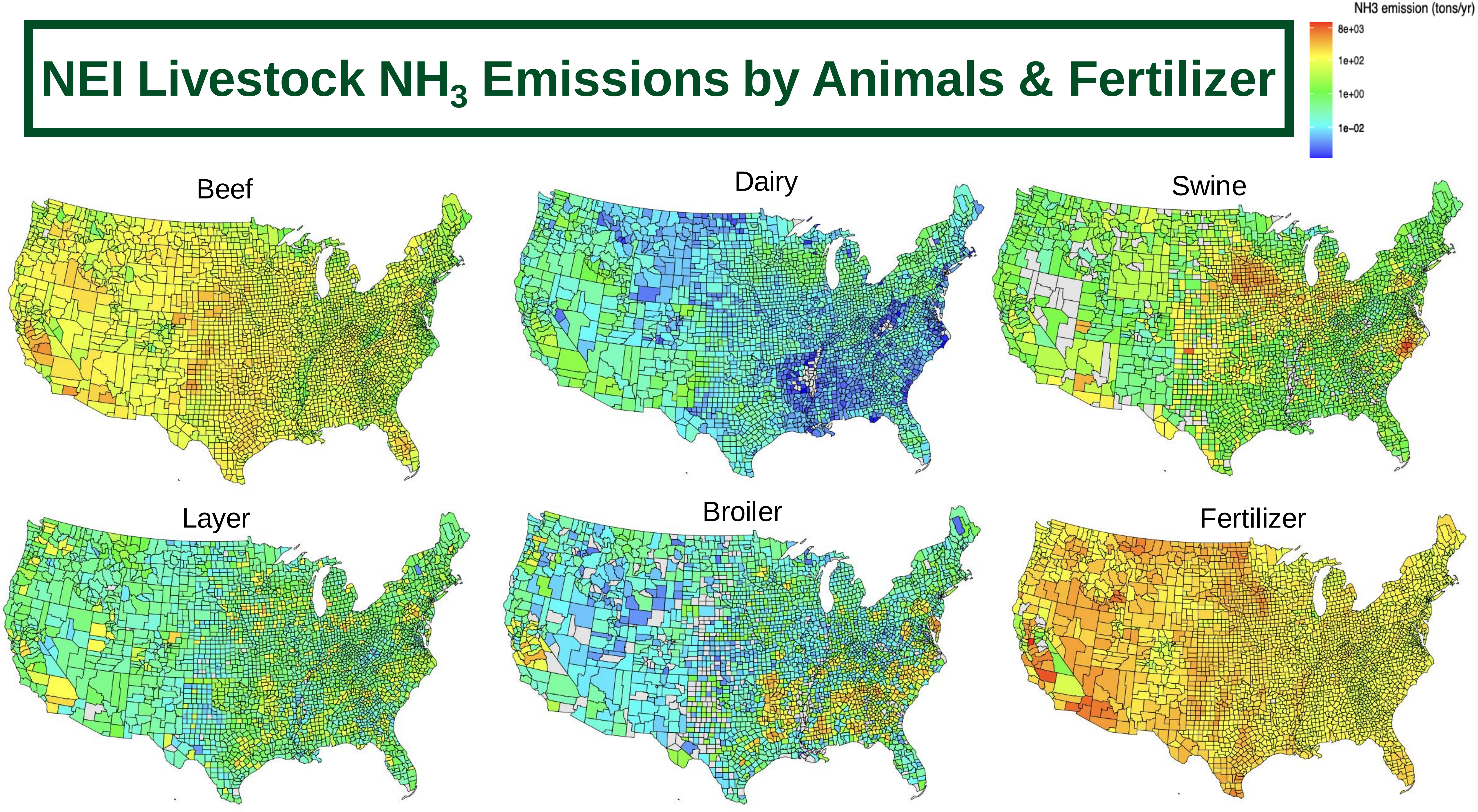
- **FEM Enhancements**
  - **Meteorology (Temperature, WS, and precipitation)**
    - County-level daily meteorology inputs for a spatiotemporal representation
  - **Farm Configuration: Monte-Carlo probabilistic distribution approach**
    - Develop a farm configurator tool that can generate the farm configuration probability tables
  - **Daily total emissions by process (Housing, Storage, Application, Grazing)**
  - **FEM Gitub (Public):** https://github.com/bokhaeng/FEM
- **Development of 2020 NEI**
  - Applied the updated FEM to develop the 2020 NEIs livestock waste emissions
    - Turning parameters and farm configuration by NAMES and NEI2014
  - 2020 NEI Livestock Wastes are published with the 2020 NEI EMP package
  - “Non-FEM” animal types (e.g., Turkey, Goats,,,,) are treated same as NEI 2017
- **Development of 2021 NEI**
  - Daily total NH_3 and VOC emissions by animal type
  - Enhancing the meteorology-dependency of NH_3/VOC to CTM modeling

FEM NH_3 Emission Factors & Animal Population

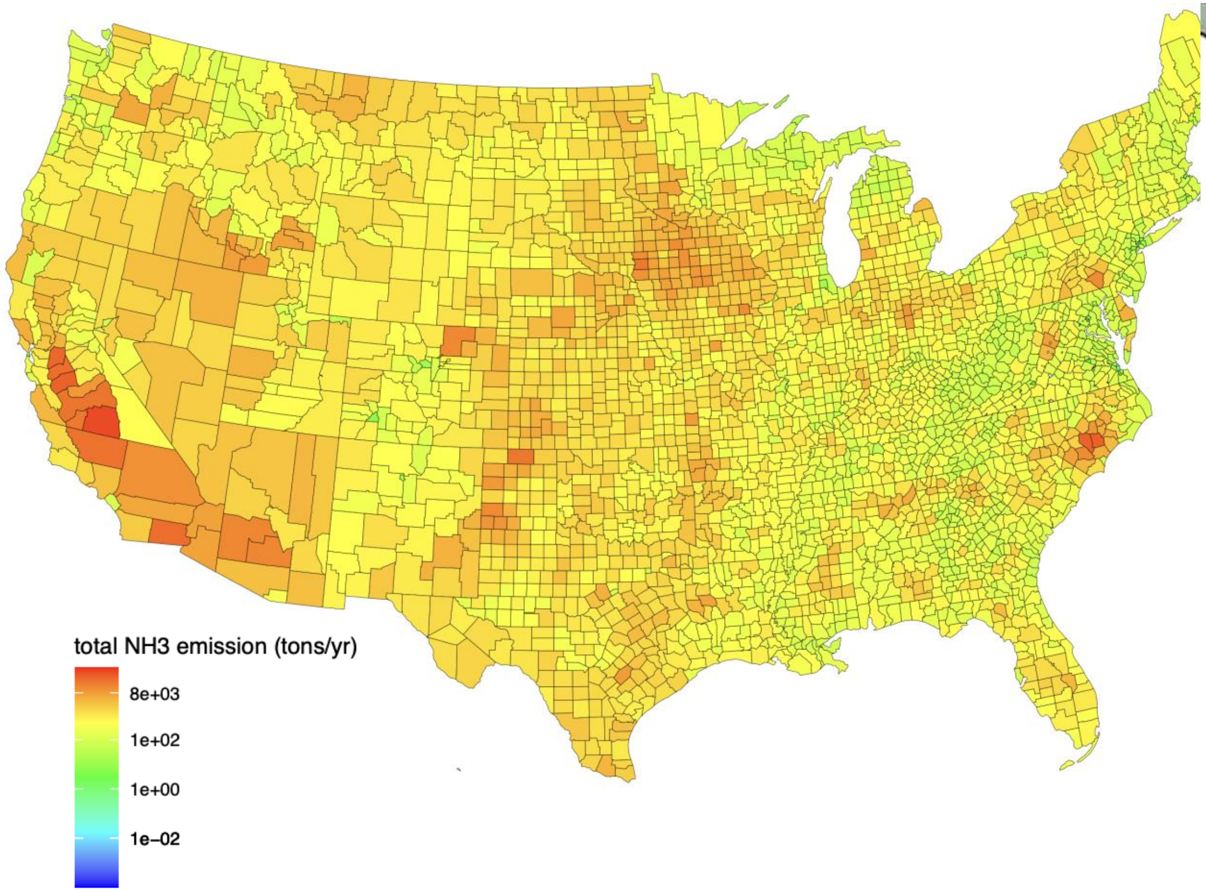


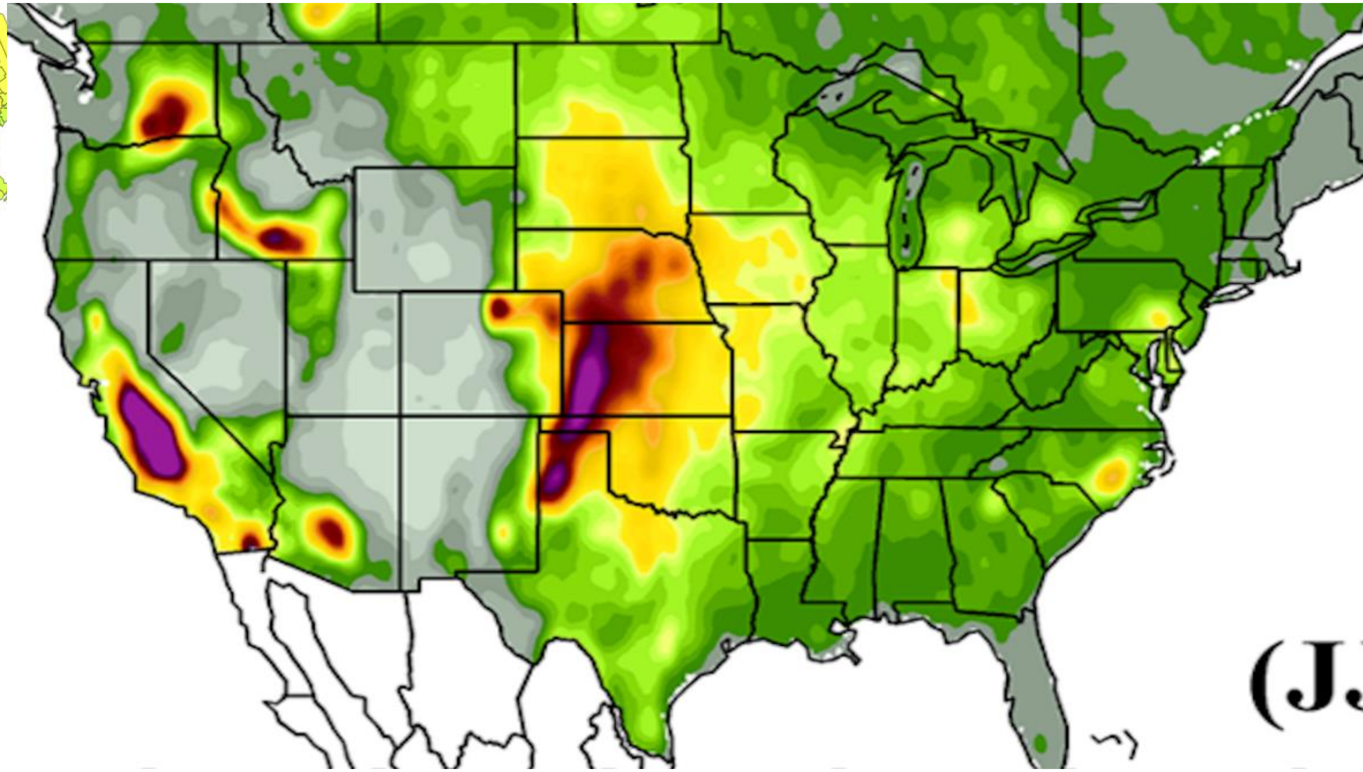


NEI Livestock NH_3 Emissions by Animals & Fertilizer

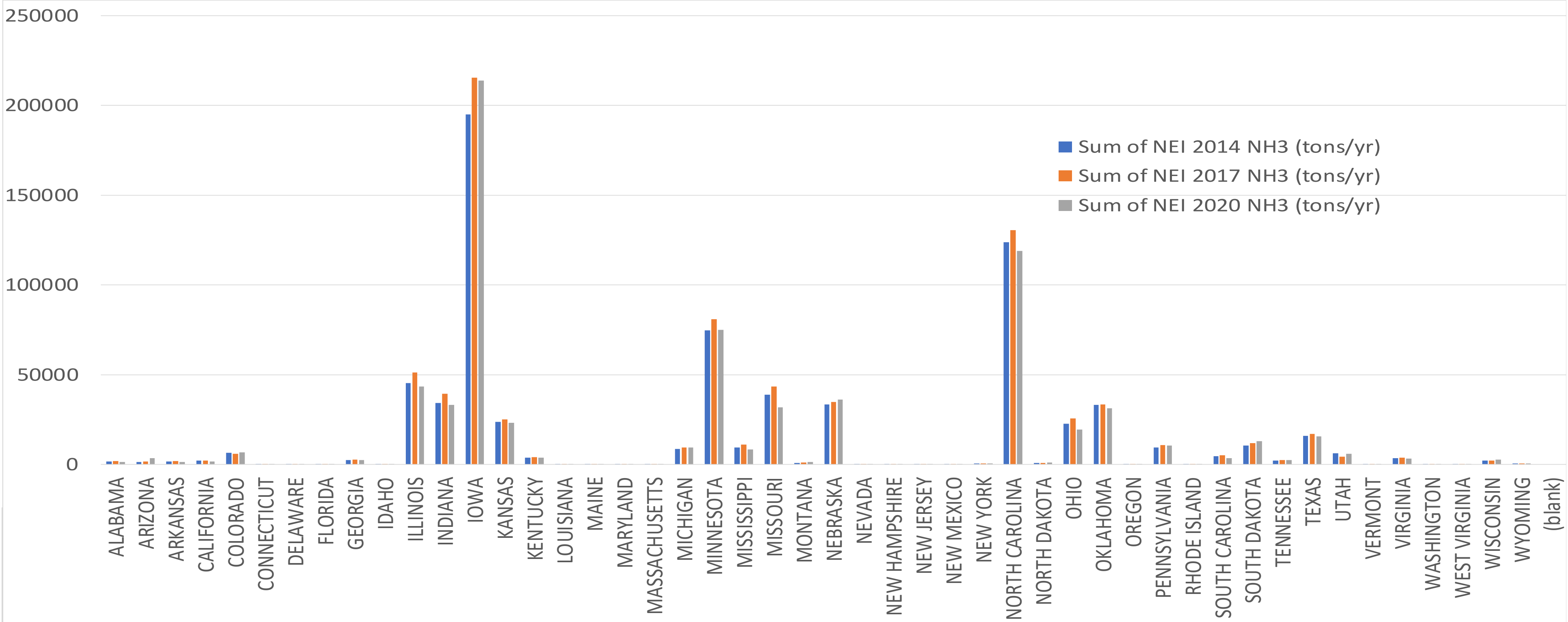


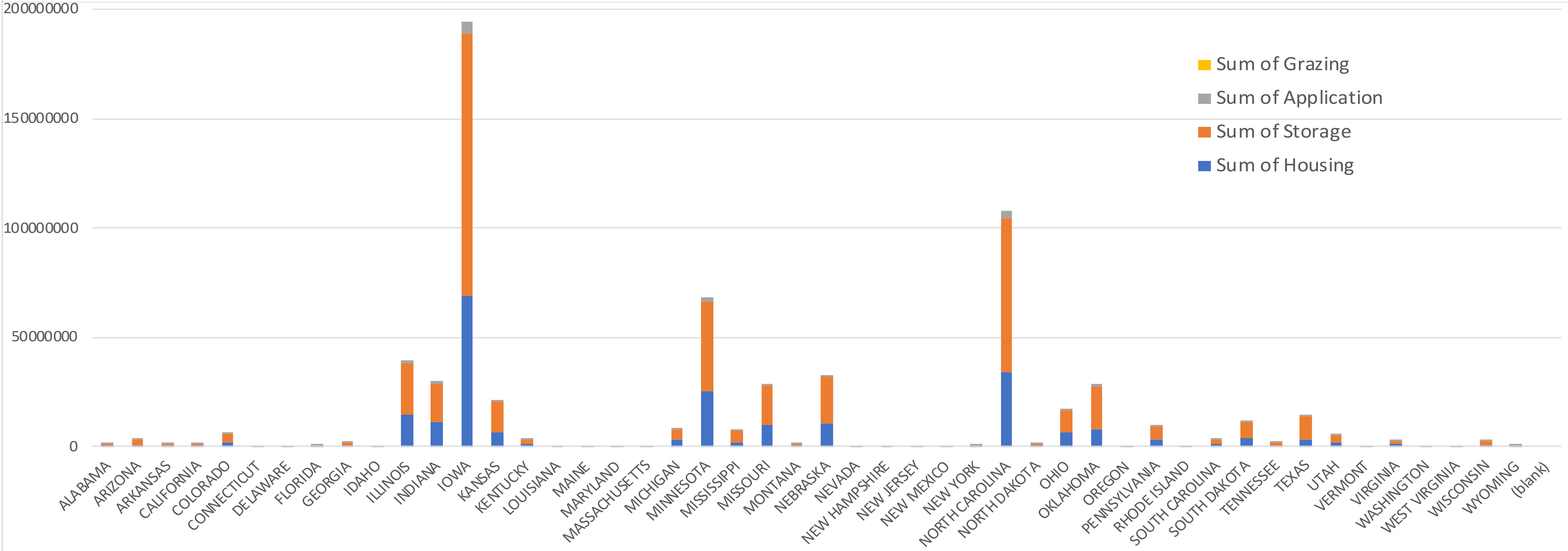
Inconsistent Spatial Distribution of NH_3 between NEI and Satellite





Agricultural Sector: Fertilizer + Animals (Beef, Dairy, Swine, Broiler, Layers, Sheep, Horses, and Goats)





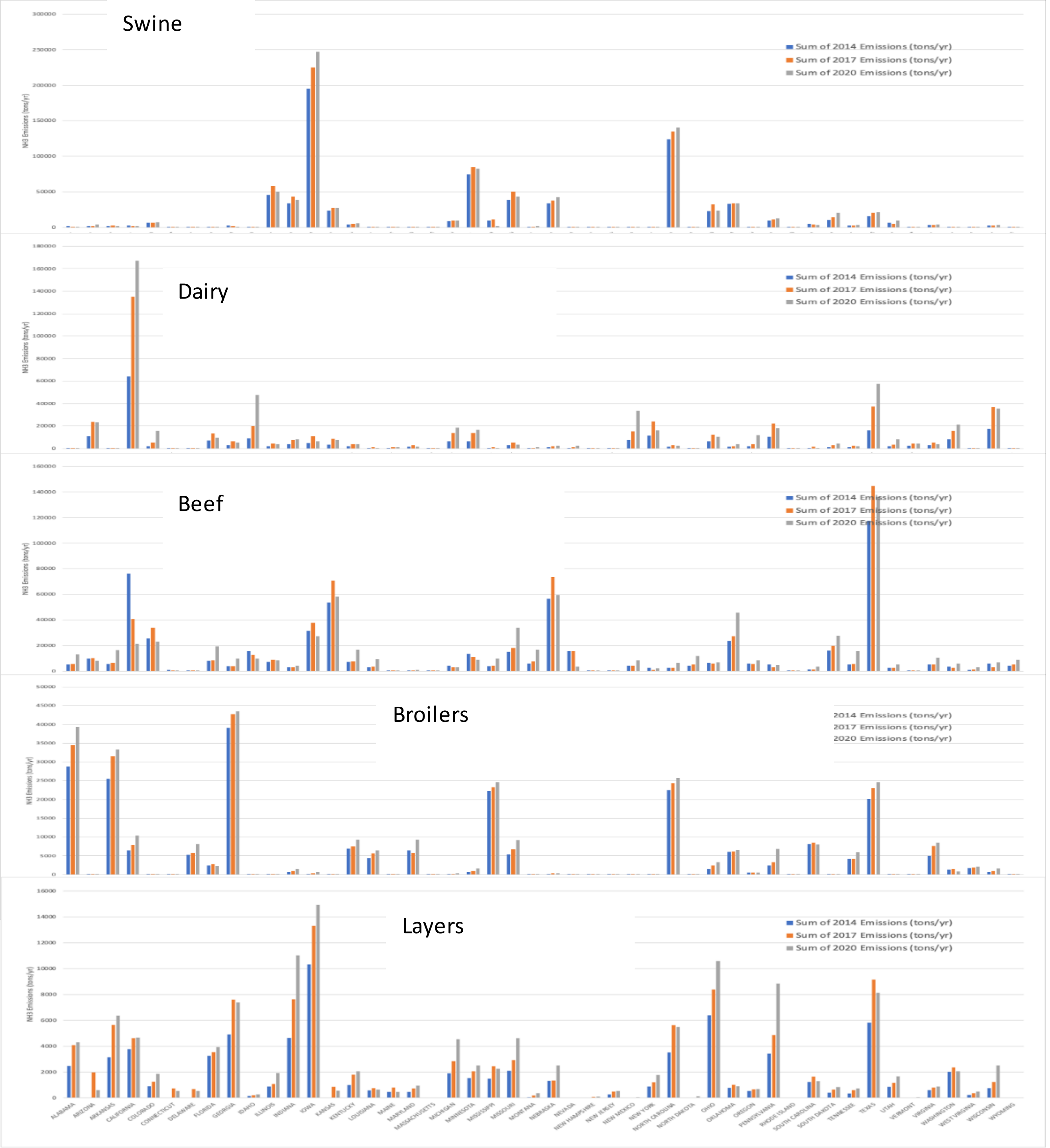
NEI Swine NH_3 Comparison

[Condition]

1. 2014 animal counts
2. Different meteorology
3. Different model parameters and farm configuration inputs

[Findings]

- 2020 EFs (tons/year-head) are tending higher than 2014 and 2017 EFs
- Storage is the most sensitive to meteorology
- Housing is less sensitive to meteorology due to indoor temperature control system like ventilation system



State-level Comparison of Livestock NH_3 Emissions between 2014, 2017 and 2020

Animal	Animal Population (Number of animals*1000)			Total Emissions (tons/year)		
	NEI2014	NEI2017	NEI2020	NEI2014	NEI2017	NEI2020
Beef	79,367	81,414	80,658	590,424	634,695	698,170
Dairy	9,035	18,888	18,802	225,919	475,573	580,858
Swine	67,766	72,145	77,255	722,622	834,314	845,306
Layer	362,319	497,254	509,914	73,492	109,404	127,548
Broiler	1,506,271	1,621,047	1,676,730	228,723	260,764	299,691

- Between the years, the results are comparable
- Local meteorology plays a critical role in county-level NH_3 emissions from livestock wastes
- Further tuning and developments are needed to develop the ***spatiotemporal*** NH_3 and VOC emissions from livestock wastes sector