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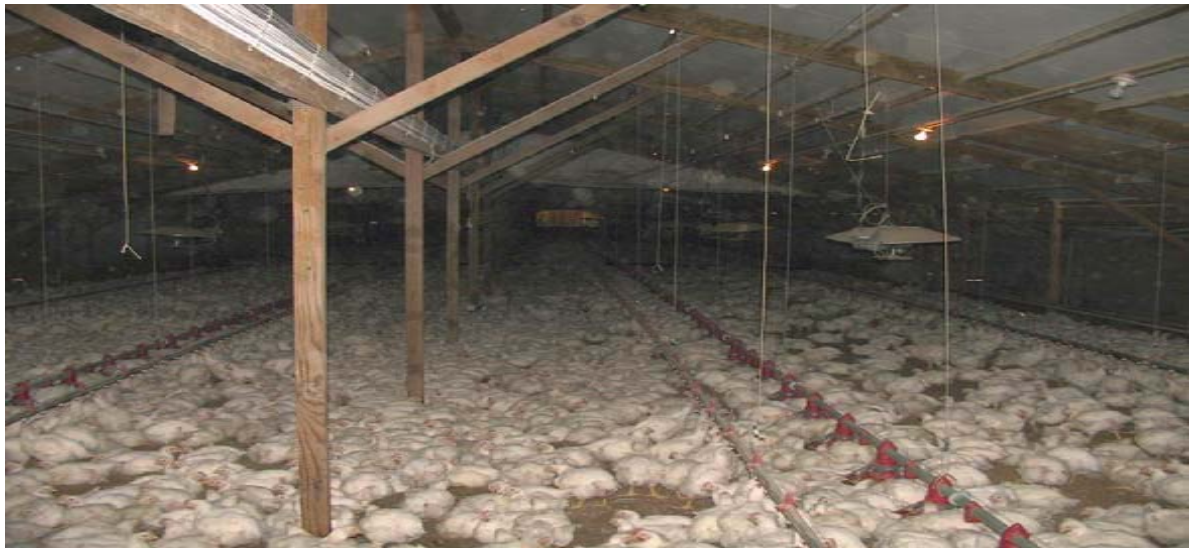
Overview of Statistical Methodology Used to Develop EEMs for Broiler Operations



3/14/2012

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Outline of Presentation

- Background of National Air Emissions Monitoring Study (NAEMS)
- Consent Agreement Requirements
- Broiler Emissions-Estimating Methodologies (EEMs) Development
- Charge questions to the Science Advisory Board

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Background of the NAEMS

- Voluntary Consent Agreement
  - Coordinated with several stakeholders

- Agreement's goals are to:
  - Ensure compliance with applicable Federal regulations
  - Monitor and evaluate AFO emissions
  - Promote a national consensus on methodologies for estimating AFO emissions

Monitoring Protocol

- Developed through a collaborative effort involving numerous stakeholders
- Represents the opinions of the scientists, government experts, and stakeholders involved in the development process
- Designed to provide a framework for developing a comprehensive field sampling plan for collecting quality-assured air emissions data
- Sites were monitored in accordance with the
  - Quality Assurance Project Plan
  - Site Monitoring Plan

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Monitored Site Selection Process

- Candidate farms were identified from those operations participating in the Consent Agreement
- Science Advisor selected farms based on a set of pertinent factors
- Final sites selected for the study were approved by EPA
- Broilers
  - West Coast site (California)
  - Southeast site (Kentucky)

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NAEMS Organization Structure

- Agricultural Air Research Council
  - Selected the Science Advisor and Independent Monitoring Contractor
- Independent Monitoring Contractor – Purdue University
  - Provided technical & administrative oversight
- Science Advisor – Dr. Al Heber
  - Identified potential farms to be monitored and drafted the study's quality assurance project plan
  - Provided oversight of the Principal Investigators
- Principal Investigators
  - Monitored selected sites
- US EPA
  - Interpreted data and developed emissions-estimating methodologies

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Consent Agreement Requirements

- The emission estimating methodologies will be used to determine and certify compliance with:
  - Clean Air Act permitting requirements
  - CERCLA and EPCRA reporting requirements
- All EEMS (for all animal sectors) will be finalized collectively
- The EPA is required to develop daily and annual emissions-estimating methodologies

Broiler Industry

- A vertically integrated industry
- Production cycle
  - Broiler houses are operated on an “all in-all out” basis and are cleaned between flocks
  - Two phases
    - Grow-out: birds are raised to market weight
    - Clean-out: houses are cleaned before restocking
  - Clean-out types
    - Decaking: upper layer of litter is removed and may be “top-dressed” with fresh bedding
    - Full litter cleanout: all litter is removed and new bedding added
  - Most common type of house is an enclosed, single floor, mechanically ventilated structure with a compact soil floor covered with dry bedding

Broiler EEMs Submitted to SAB for Review

- Six pollutants: NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP, VOC
- Two sets of EEMs:
  - Grow-out periods
  - Litter clean-out periods
- Grow-out, three types of EEMs:
  - Inventory (I)
    Data are routinely recorded by growers
  - Inventory and ambient (IA)
    Data easily obtained from local meteorological stations
  - Inventory, ambient, and confinement (IAC)
    Data that would require installation of an on-site monitoring system for confinement house parameters
- Clean-out, EEMs for two types of activities:
  - Decaking
  - Full litter clean-out

EEM DEVELOPMENT

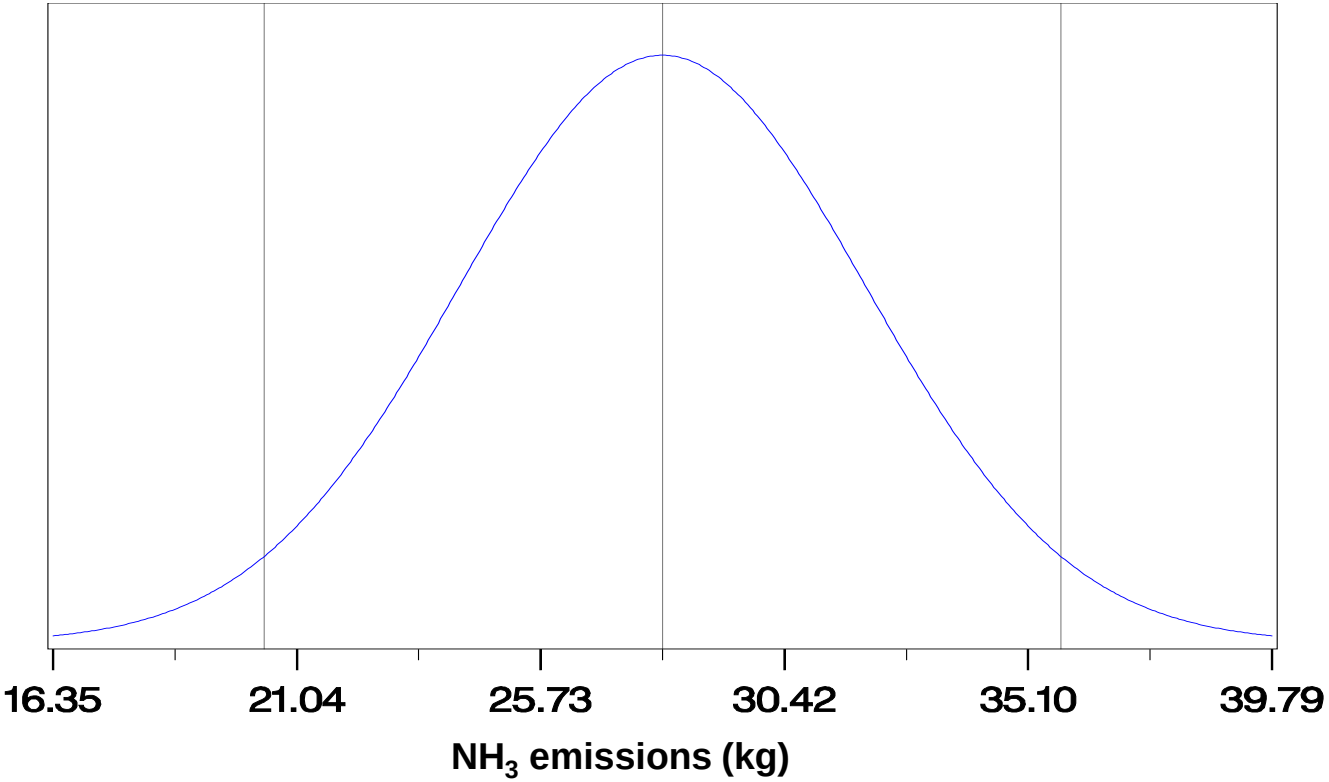
Grow-out Period EEM Input

Daily predictor variables for example

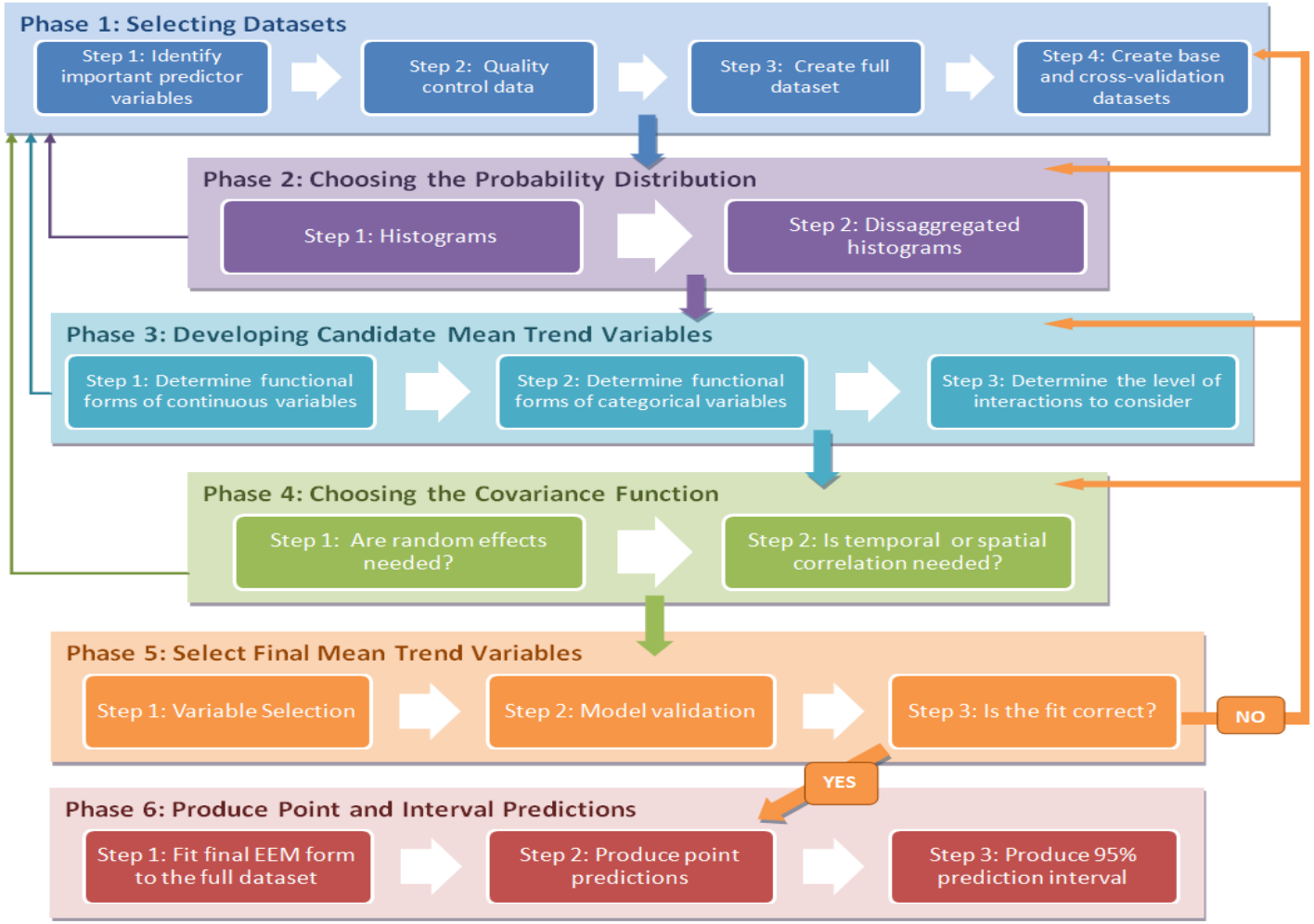
- Number of birds = 25,000
- Flocks since full cleanout = 3
- Mass per bird = 2.3 kg
- Temperature = 25 °C
- Relative humidity = 39 %
- Pressure = 101 kPa

Grow-out Period EEM Output

- Daily emissions point prediction (kg)
- 95% prediction interval (lower and upper bounds, kg)



Overview of EEM Development Approach



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NAEMS Daily and Continuous Broiler Data

Category	NAEMS Data
Animal Inventory	No. of birds
	Avg. weight (kg)
	Bird age (days)
	Stocking density (kg/m^2)
Ambient meteorology	Temperature (^{o}C)
	Relative humidity (%)
	Atmospheric pressure (kPa)
	Wind speed (m/s)
	Wind direction (^{o})
	Solar radiation (W/m^2)
Animal confinement	Temperature (^{o}C)
	Relative humidity (%)
	Fan operational status (on/off)
	Differential static pressure (Pa)
	House ventilation flow rate (dscm)

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NAEMS Periodic Broiler Data

Category	Description	
Mass balance	Incoming bedding	Addition rate
		Solids content (wet weight %)
		Total Kjeldahl Nitrogen (TKN) content (wet weight %)
	Litter in house	Solids content (wet weight %)
		TKN content (wet weight %)
		Sulfur content (wet weight %)
	Litter removed at full clean-out	TKN content (wet weight %)
		Solids content (wet weight %)
	Decaked litter	TKN content (wet weight %)
		Solids content (wet weight %)
		Ash content (wet weight %)
	Volume of litter produced (ft^3)	

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Selection of Broiler Predictor Variables for NH_3

NAEMS Data Submitted to EPA:
- 1,279 Daily NH_3 emissions observations
- 15 candidate predictor variables

Completeness and Useability Assessment

Full Dataset:
- 1,211 Daily NH_3 emissions observations
- 8 candidate predictor variables

Base Dataset:
- 994 Daily NH_3 emissions observations (~80%)
- 8 candidate predictor variables

Cross-validation Dataset:
- 217 Daily NH_3 emissions observations (~20%)
- 8 candidate predictor variables

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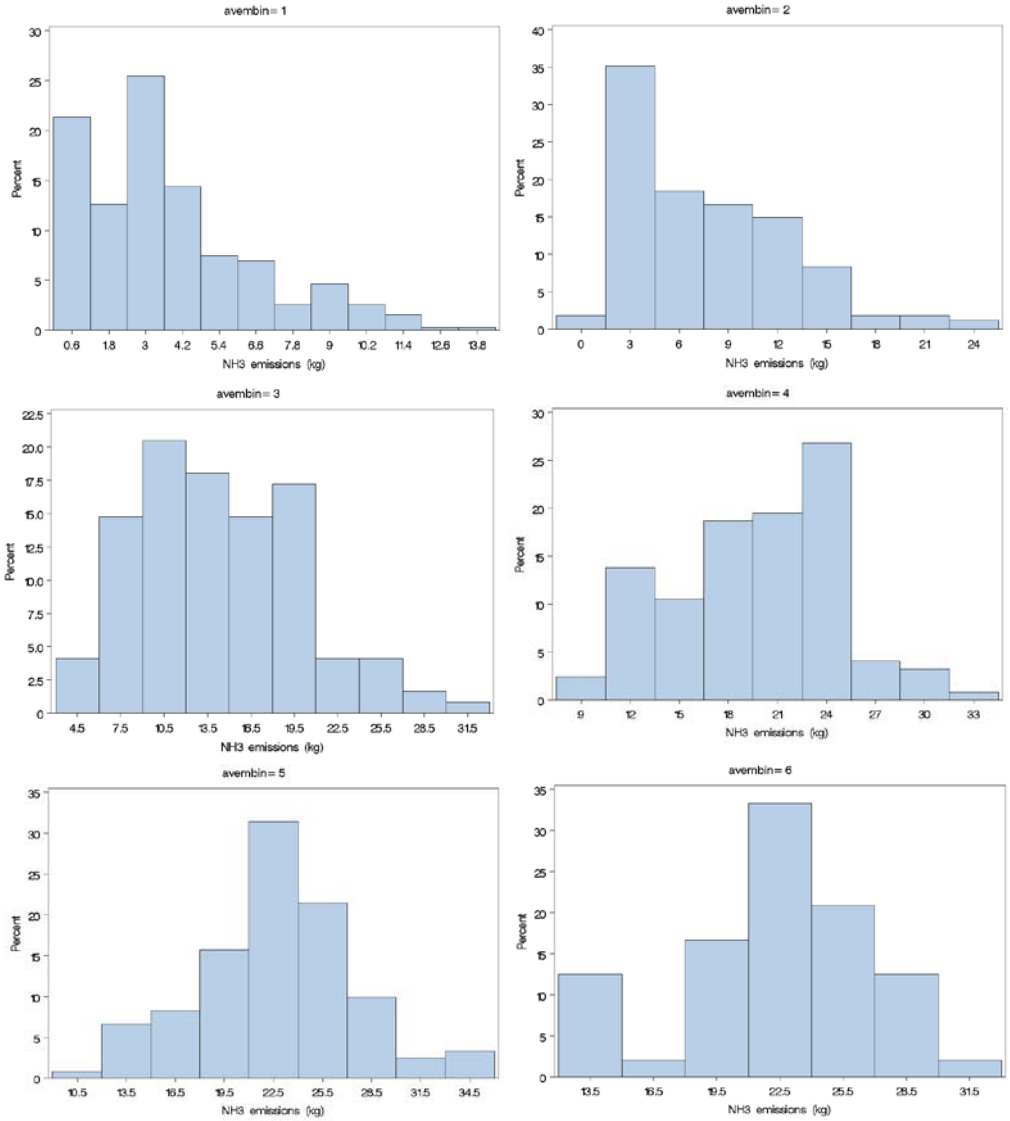
Selected Broiler Predictor Variables

Category	Description	Abbreviated Variable Name
House Inventory (I)	No. of birds	*birds*
	Avg. bird weight (kg)	*avem*
	Litter build-up	*buildup*
Ambient Meteorology (A)	Temperature (^oC)	*ta*
	Relative humidity (%)	*ha*
	Atmospheric pressure (Pa)	*pa*
Confinement (C)	Temperature (^oC)	*tc*
	Relative humidity (%)	*hc*

Normal Distribution Used for Emissions

- For base data, the distribution was skew right
- For different conditions subset distributions more symmetric



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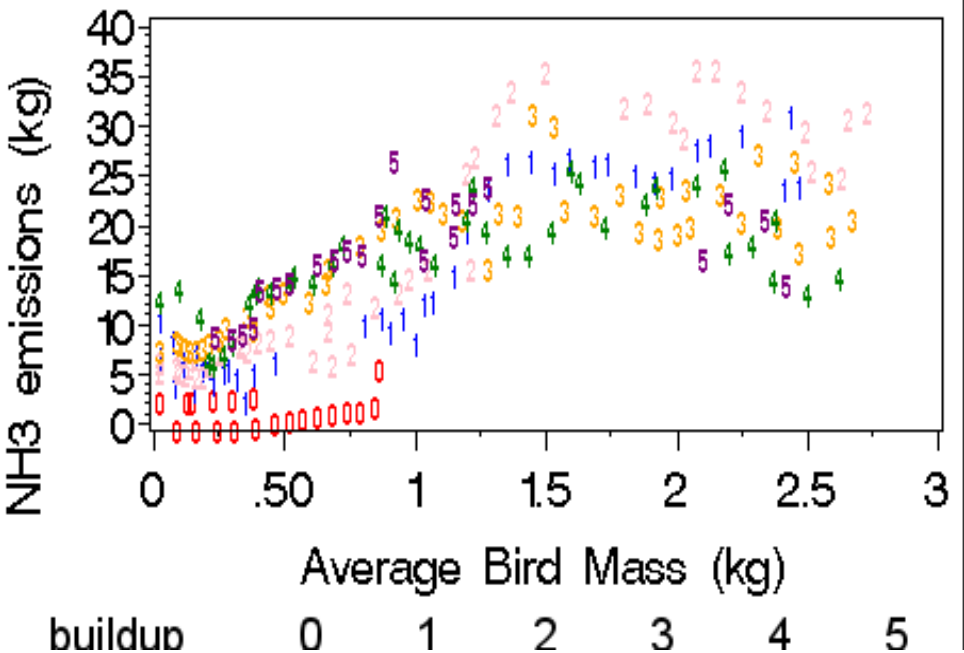
Functional Forms

- Highly variable emissions at lower bird mass
- Emissions decrease at high bird mass
- Cubic function of average bird mass best fit for the data



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Main Effect Mean Trend Variables

Original Predictor	Functional Form	Name
Litter build-up	Indicator variable	*build*
No. of birds	Linear	*birds*
Avg. bird mass (kg)	Cubic polynomial	*avem*, $avem^2$, $avem^3$
Ambient temperature (^oC)	Linear	*ta*
Ambient relative humidity (%)	Linear	*ha*
Atmospheric pressure (Pa)	Linear	*pa*
Confinement temperature (^oC)	Linear	*tc*
Confinement relative humidity (%)	Linear	*hc*

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Features Considered

- Serial correlation
  - Included Auto-regressive order 1 (AR(1)) covariance function
- Random effects of *house* and *site*
  - Not statistically significant
- Different variance under different conditions
  - No evidence supporting an increase in the variance with increasing mean emissions
  - Variance difference for three sites could not be used in application of EEM

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Variable Selection

- Backward elimination based on p-values
  - Base data
- Corroborated by other fit statistics
  - Cross-validation data

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Final NH_3 EEM Fit Statistics

Fit Statistic	I	IA	IAC
-2LL	3,811	3,676	3,522
BIC	3,815	3,684	3,531
% in PI	94	97	97
Width (kg)	14	13	13
RMSE (kg)	3.8	3.3	3.5
R^2	0.81	0.85	0.84
γ_0 (kg)	-0.14✓	-0.23✓	-0.04✓
γ_1	0.99✓	0.99✓	0.97✓

Grow-out Period EEM Input

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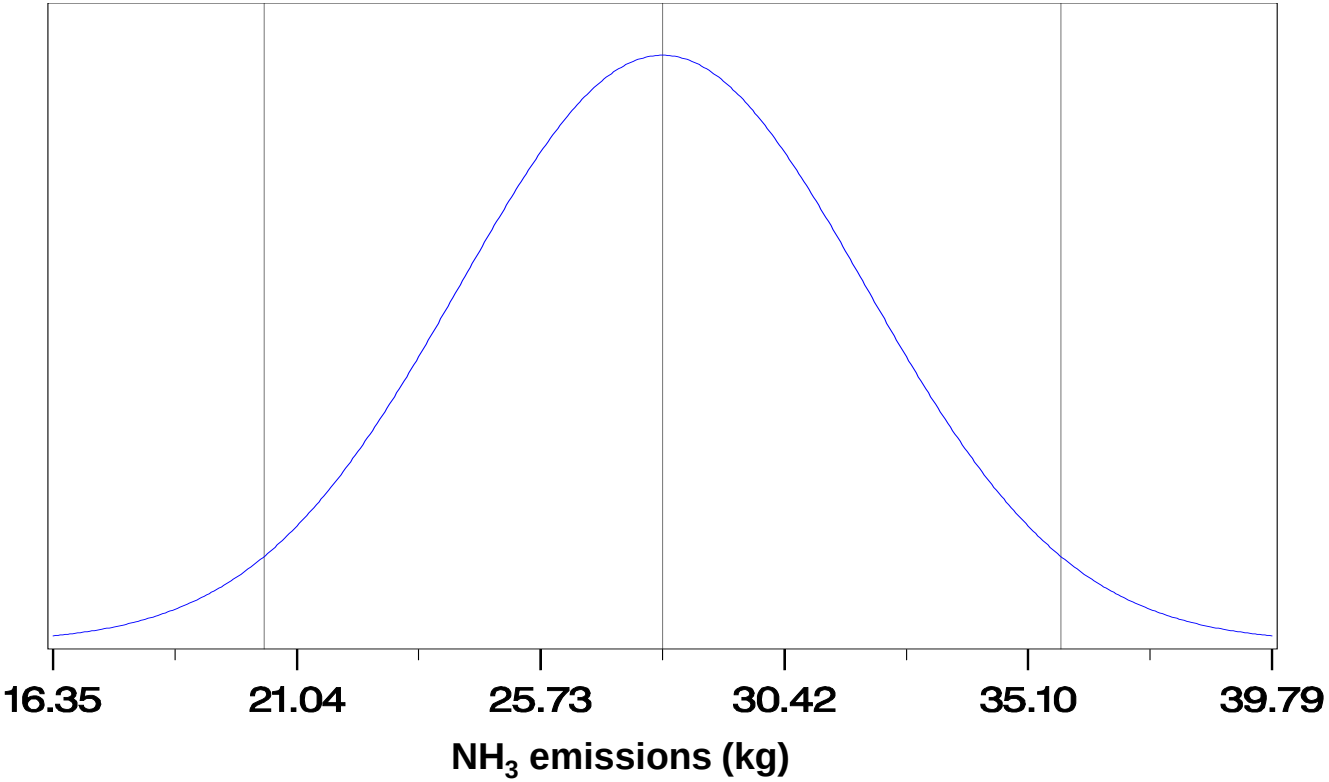

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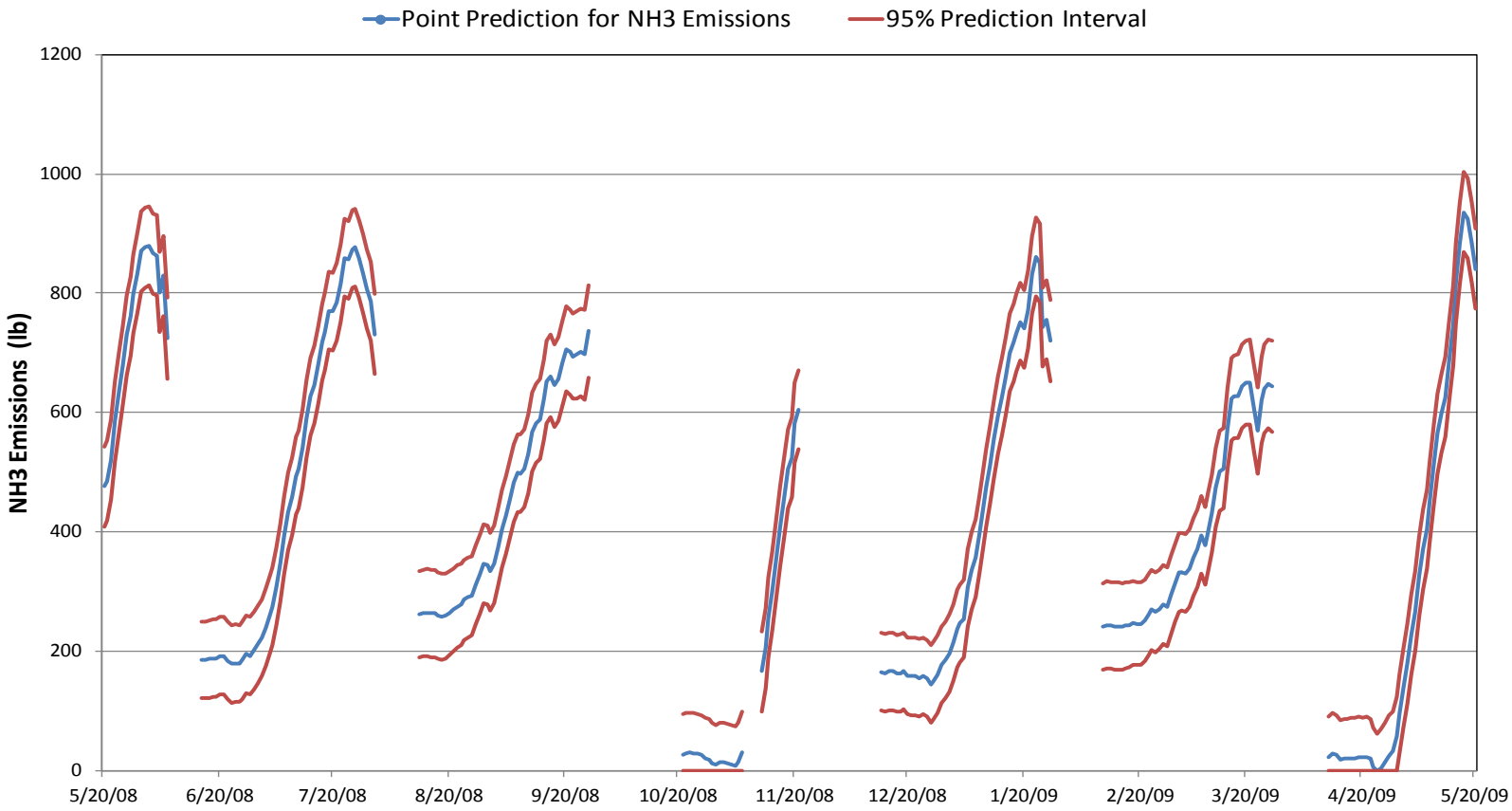
Daily NH_3 Emissions for Grow-out Period



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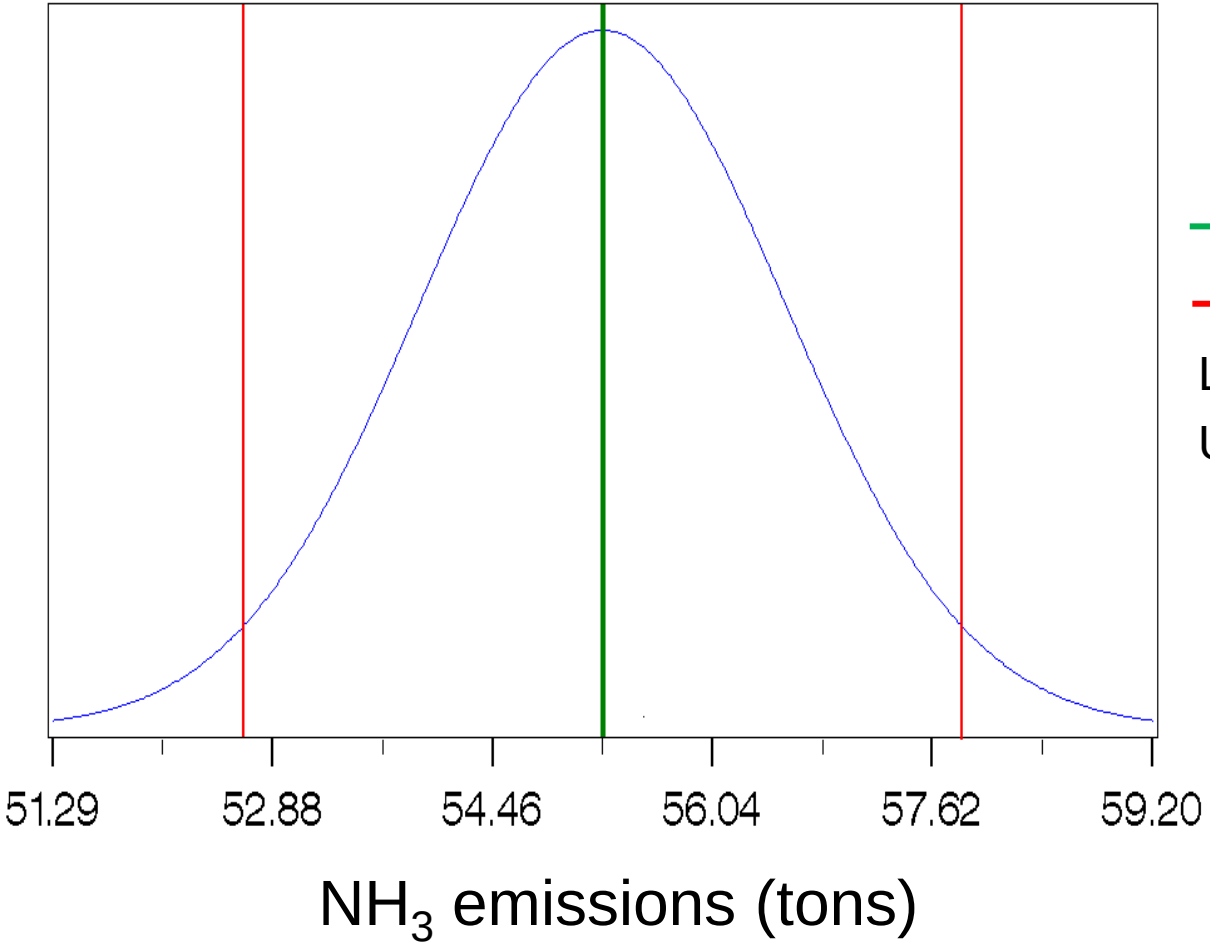
Annual NH_3 Emissions for Grow-out Period



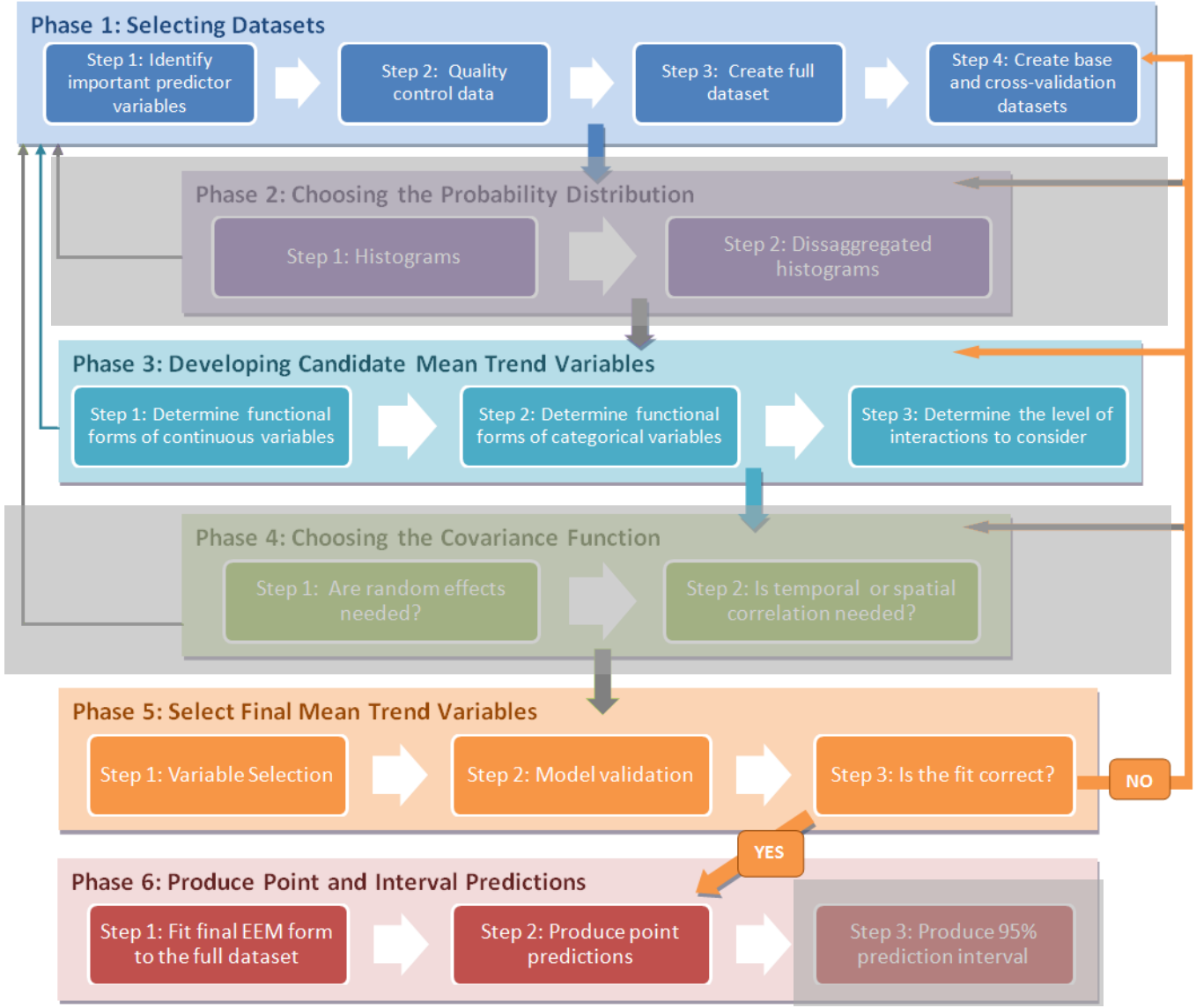
Point Estimate (55.3 tons)

95% Prediction Interval

Lower Bound: 52.7 tons

Upper Bound: 57.8 tons

Overview of Clean-out Period Approach

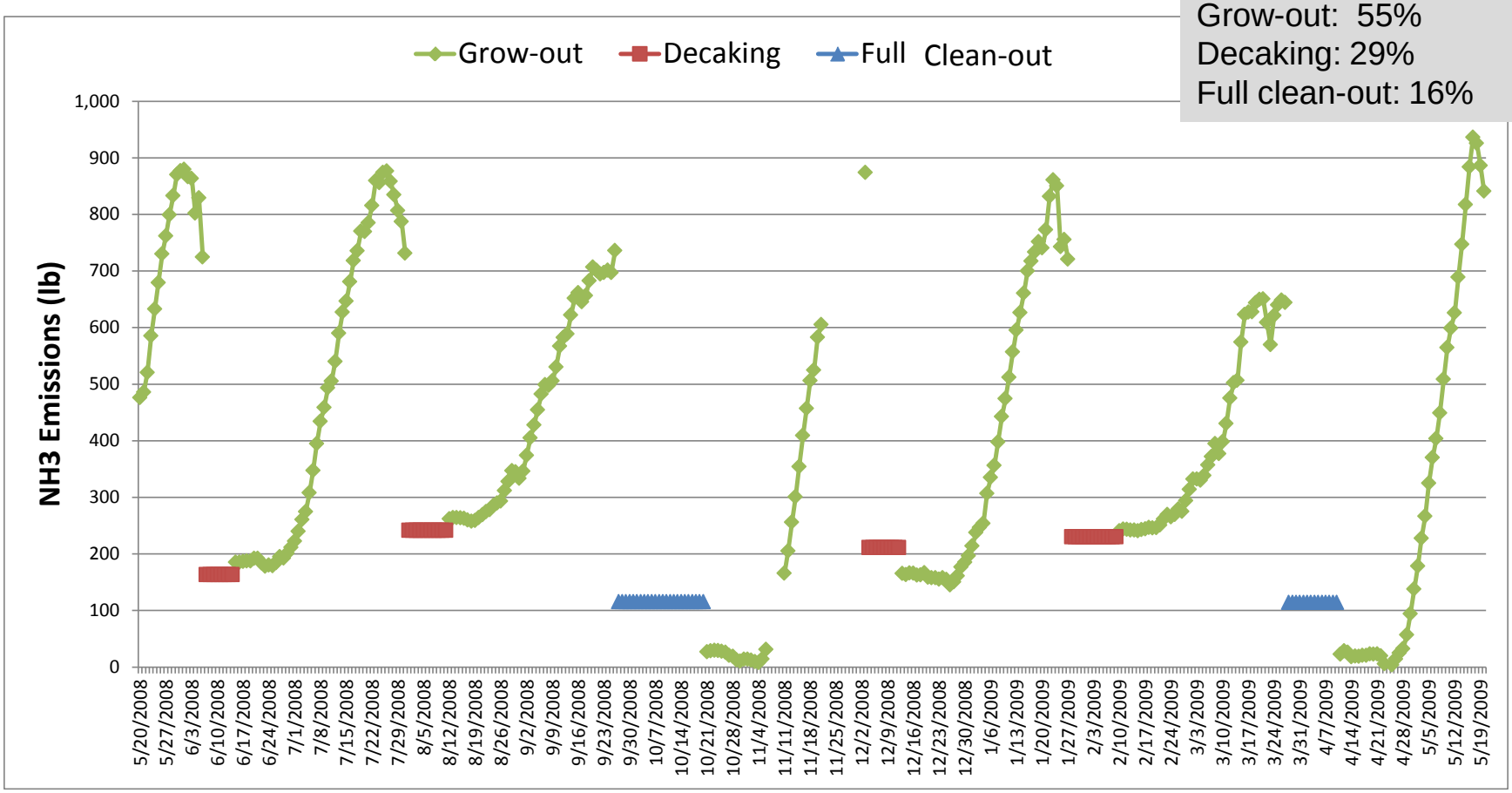


EEMs for Broiler Clean-out Periods

- Inputs:
  - Cumulative Weight (CW) =
    Sum [(daily bird inventory) * (Avg. daily mass (kg))]
  - Litter decaking versus full litter clean-out
- Output:
  - Daily point estimate in grams NH_3/kg bird

Daily NH_3 Emissions for Grow-out and Clean-out Periods

Yearly Emissions:
Grow-out: 55%
Decaking: 29%
Full clean-out: 16%



Same Process Used for Other Pollutants

- H_2S and PM_{10} data contained negative emissions values
  - Percent of total values that were negative = 1.1% for H_2S and 0.3% for PM_{10}
  - Negative numbers were not used in EEM development
- Different functional forms for average mass (i.e., exponential, quadratic) for some pollutants
- Only VOC data from Kentucky sites were used to develop the VOC EEM

SAB CHARGE QUESTIONS

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Statistical Methodology

- Statistical Methodology used to develop draft EEMs:
  - The EPA considers this statistical methodology to be the best approach for analyzing the data and intends to use this same approach to develop draft EEMs for the egg-layers, swine and dairy confinement houses.

- Question 1: Please comment on the statistical approach used by the EPA for developing the draft EEMs for broiler confinement houses. In addition, please comment on using this approach for remaining animal types.

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Negative and Zero Data

- EPA used the following general approach regarding inclusion of negative and zero emissions values in our data set
  - The EPA evaluated whether the negative or zero values represent the variability in emissions measurements due to the means of obtaining the measurements
  - The EPA included zero values because these values potentially represent instances where the emissions from the source are zero
  - The EPA reviewed the data to determine if data quality measures were properly performed according to the Quality Assurance Project Plan. If the data did not follow data quality measures, the EPA contacted the Science Advisor to determine if the corrected data could be submitted.

- Question 5: Please comment on the EPA's approach for handling negative or zero emission measurements.

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Volatile Organic Compounds (VOC) Data

- The two broiler sites used different VOC measurement techniques. Based on our analysis of the measurement and analytical techniques used for the VOC data, the EPA decided to use only the VOC data from the Kentucky sites when developing the draft VOC emissions estimating methodology

- Question 7: Please comment on the approach EPA used to develop the draft broiler VOC emissions estimating methodology