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mrowland2015@yahoo.com

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Assessing the potential for lightning-induced damage in commercial broiler houses in Mississippi and Alabama

By

Matthew Ryan Rowland

Approved by:

Gary D. Chesser, Jr. (Major Professor)

John E. Linhoss (Co-Major Professor)
John Wesley Lowe
Joseph L. Purswell
Jeremiah D. Davis
Jesse C. Campbell
Joel O. Paz (Graduate Coordinator)
Scott T. Willard (Dean, College of Agriculture and Life Sciences)

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in Agriculture
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Matthew Ryan Rowland

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Name: Matthew Ryan Rowland

Date of Degree: December 10, 2021

Institution: Mississippi State University

Major Field: Agriculture

Major Professor: Gary Daniel Chesser, Jr.

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Candidate for Degree of Master of Science

Modern broiler houses are expensive to build, maintain, and insure. Protecting them from extreme weather events is a major concern to producers, integrators, and insurance companies. Lightning strikes can cause catastrophic fires and electrical damage and can lead to costly bird losses. A greater understanding of the impact of lightning on the commercial broiler industries of MS and AL is needed. The objectives of this research were collection of baseline resistance data for broiler houses and equipment in both states, and mapping lightning strike densities across MS and AL, evaluating annual, monthly, seasonal, and diurnal patterns. 63.5% of surveyed broiler houses were at or below the recommended 25 Ω (ohms). Ufer grounding resulted in lower resistance ratings than grounding rods. Lightning strike density was elevated in counties near the Gulf Coast, highest during the summer months. Producers should inspect their grounding systems annually to mitigate lightning-induced damage.

DEDICATION

I would like to dedicate this work to my parents, Greg & Tammy Rowland, my brother, Alex Rowland, and my grandparents, James & Shirley Rowland and Troy & Mary Bess Gilmore. I love you all. Thank you for the never-ending support, encouragement, and love and for making me who I am today.

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CHAPTER I

INTRODUCTION

1.1 U.S. Broiler Industry

In 2020, an estimated 9.22 billion broilers were produced in the U.S., with an estimated total value of production of $21.6 billion (USDA-NASS, 2021a). As shown in Figure 1.1, broilers are produced in 30 states, with the top 5 broiler producing states located in the Southeast. Alabama (AL), ranked 2nd in broiler production, produced 1.2 billion broilers with an estimated commodity value around $2.41 billion in 2020. Mississippi (MS), ranked 5th in broiler production, produced 732 million broilers with an estimated commodity value around $1.68 billion in 2020 (USDA-NASS, 2021a). Broiler production is the largest agricultural commodity in MS and AL, providing over 65,000 jobs per state, exceeding $15 billion in overall economic impact (NCC, 2018b; NCC, 2018c).

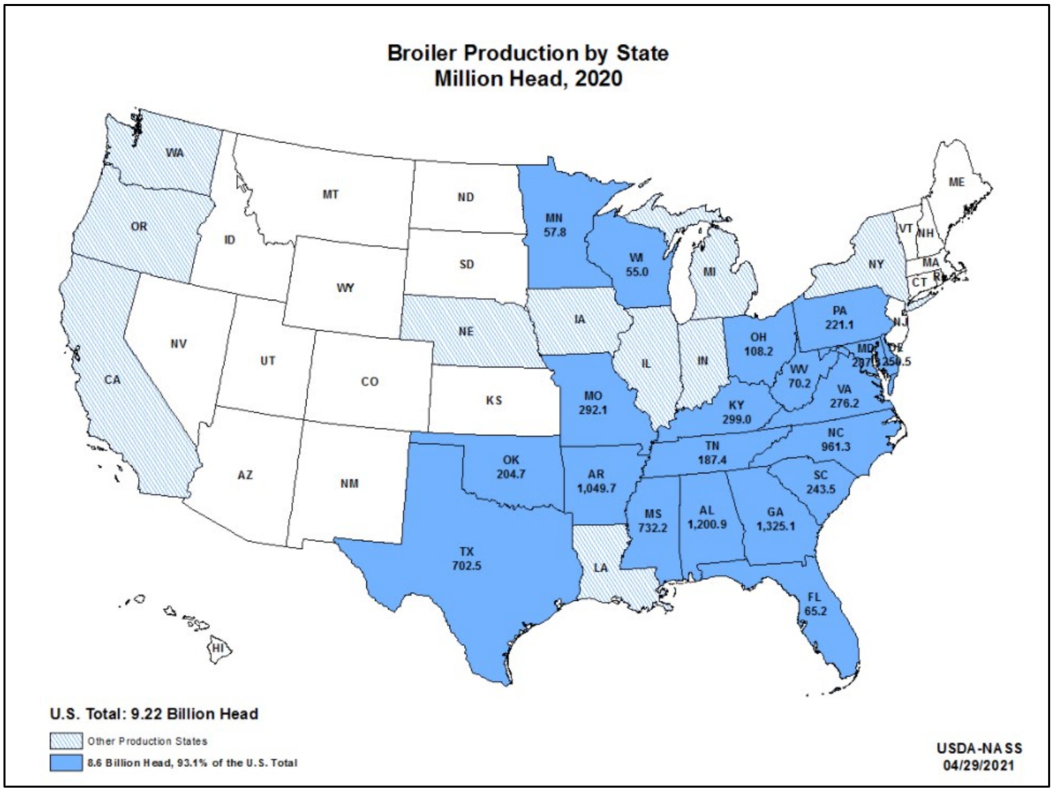

Figure 1.1 United States broiler production by state in 2020.

(USDA-NASS, 2021b)

In the United States, broiler production has expanded rapidly over the past 50 years, from producing 10 billion pounds of chicken in 1990 to 59.4 billion pounds of chicken in 2020 (Fig. 1.2) (USDA-NASS, 2021a). This is largely accredited to improved genetics, better quality nutrition, and a controlled growing environment. Overall, the poultry industry in the U.S. employs over 1.3 million people directly and indirectly, reporting nearly $347 billion in total economic activity in the United States (NCC, 2018a). Dohlman (2021) predicts that broiler production and consumption is expected to increase over the next decade.

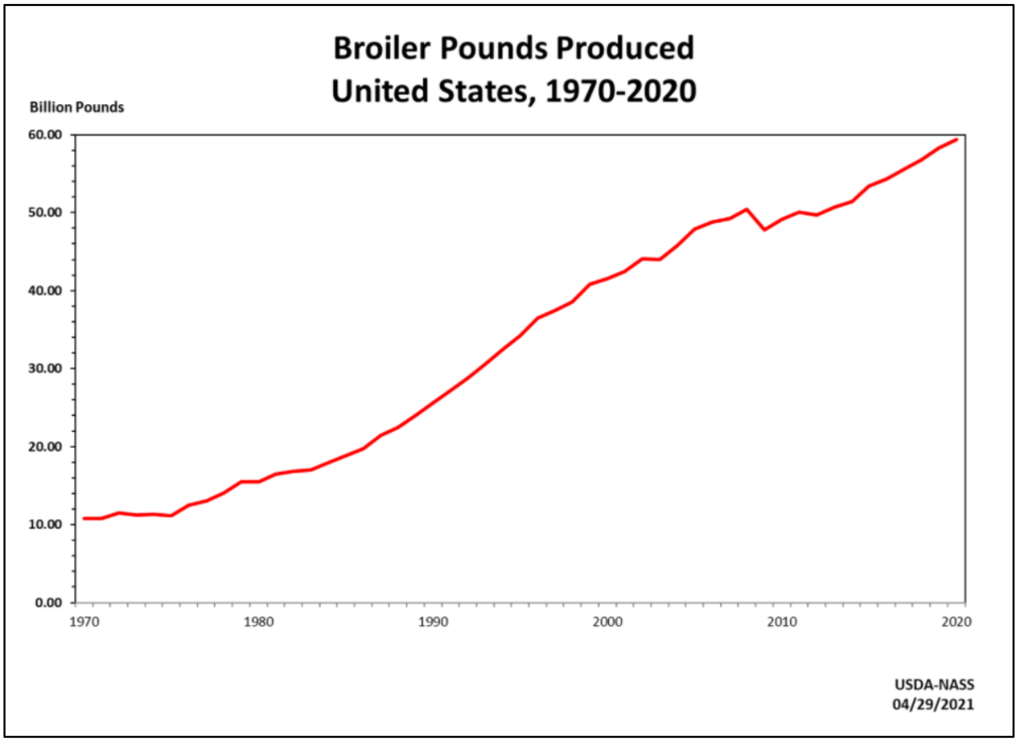

Figure 1.2 Broiler pounds produced in United States, 1970 - 2020 (USDA-NASS, 2021c)

1.2 Commercial Broiler Production

The commercial broiler industry is organized in a vertically integrated system, meaning poultry production companies, or poultry integrators, manage every step of production including breeding, hatching, processing, and quality assurance. Poultry integrators issue contracts to independent growers to grow the birds according to their practices, standards, and policies. In MS and AL alone, there are 6 – 10 integrators that contract with growers across the two states. Contract production is beneficial to broiler producers by providing a guaranteed market, reducing producer's exposure to direct market risks (USDA-ERS, 1999). To obtain a contract from an integrator, producers must prove their financial ability to provide land, capital, and insurance for broiler production facilities (Donald et al., 2004). Contracted growers are required to construct, finance, and operate the facilities necessary to raise the birds from chicks to market weight. Birds are housed for 35 – 70 days with target weights determined by contract. 95% of all broilers are produced on around 25,000 independently contracted commercial farms across the United States (Tabler & Wells, 2017; NCC, 2019). Figure 1.3 illustrates the location of broiler production throughout the United States in 2017 (USDA-NASS, 2017).

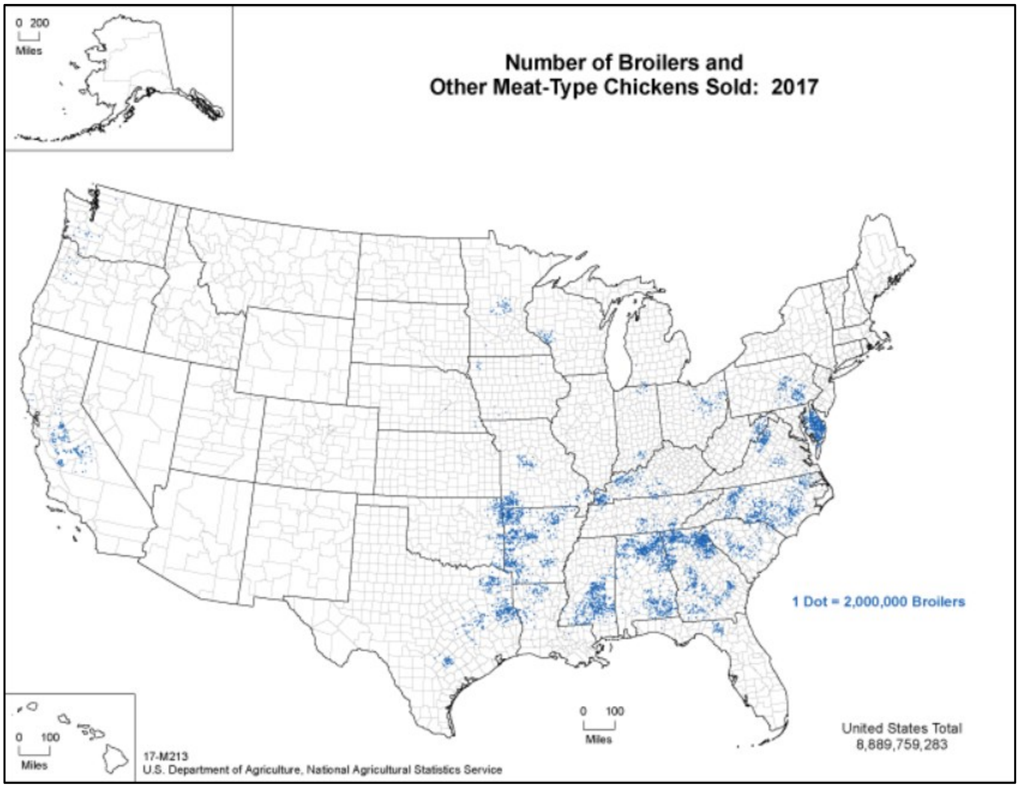

Figure 1.3 Broiler density distribution across the United States from the 2017 USDA-NASS Ag Census.

(USDA-NASS, 2017)

1.3 MS Insurance Claims and Concerns

Integrators provide the chicks, feed, and veterinary services for broiler operations. Producers provide housing, labor, energy inputs, insurance, and other operating expenses and supplies on broiler operations. Example budgets calculated by Cunningham and Fairchild (2011) illustrate the initial investment on a four-house broiler operation cost at $924,000, or $231,000 per house, with fixed costs at $102,788 per year. In addition, operational expenses for the same farm are shown in Table 1.1 (Cunningham & Fairchild, 2011; MacDonald, 2014). However, in recent years, producers have seen a substantial increase in insurance premiums for poultry houses, with 40% of growers surveyed reporting an increase of 10 percent or higher (Leggett, 2019). This is due to “hard” market conditions for insurance companies, resulting from increased payouts due to extreme weather events and overall economic uncertainty. Insurance companies charge higher premiums to compensate for increased payouts to reduce their economic risk. Increased liability for broiler operations has led some insurers to refuse to issue policies for broiler production.

Table 1.1 Cost Breakdown of Broiler Producer Farm Expenses

Expense	**Percentage (%)**
Fuel	35-37%
Electricity	20-23%
Insurance/Taxes	7-15%
Bedding	9%
Equipment replacement	7%
Repair/Miscellaneous	11-19%

(Cunningham & Fairchild, 2011; MacDonald, 2014)

Similar to concerns expressed by Louisiana broiler growers (Fekete, 2010), broiler houses are susceptible to damage from extreme weather events. Extreme weather events, such as thunderstorms and hurricanes, are common in the Southeastern United States. This is due to the proximity to the Gulf of Mexico, allowing moisture from the oceans to interact with drier air currents from the Northwestern U.S. (Williams, 1992; Williams et al., 2005). Wind and lightning from these extreme weather events account for two out of top three causes of loss in MS broiler house insurance claims. Lightning, or excess voltage from indirect lightning strikes, also has the potential to start fires, the third cause of loss, on broiler operations (Leggett, 2019). Modernization of broiler house equipment and technology in recent years has optimized environmental control systems, but these controllers are susceptible to electrical damage from lightning. Loss of the environmental control systems could result in the loss of entire flocks in a few hours. This time is shortened as external temperatures increase. Lightning can also strike other equipment and structures on a broiler farm, resulting in costly repairs or replacement of essential equipment.

Insurers, integrators, producers, and researchers are currently seeking solutions to mitigate the risk posed by lightning and other extreme weather factors. However, while implementation of improvements would be beneficial to broiler producers, the effect on insurance premiums as a result is currently unknown (Leggett, 2019). A data-driven understanding of spatial and temporal variation for lightning and improvements to broiler house electrical grounding and protection systems could serve to reduce insurance premiums or mitigate future increases in insurance premiums in MS and AL.

1.4 Lightning Production

Lightning is a high current electrical discharge resulting from the breakdown of insulating properties of air to balance two opposingly charged electrical fields, either within the cloud (cloud-to-cloud/IC flash) or between the cloud and the ground (cloud-to-ground/CG flash) (American Meteorological Society, 2015; Lang et al., 2017). Electric fields within thunderstorms, typically negatively charged, are created by the collision of rapidly supercooled water molecules within different levels of a cloud (Workman & Reynolds, 1950; Cummins &

Murphy, 2009). Increased saturation levels were found to increase electric field buildup, while cloud base height and strong updrafts correlate with increased lightning strikes (Reynolds et al., 1957; Saunders et al., 1991; Dash et al., 2001; Williams et al., 2005; Saunders et al., 2006).

Lightning strikes, or CG flashes, have the potential to cause injury or fatalities in humans and animals and property damage to buildings and structures through ignition of fires and damage to electrical wiring and components. Lightning fatalities have decreased in recent years due to improvements in construction practices for electrical systems, despite an increasing population in the United States (Holle, 2012b; Holle, 2016a). Property damage from lightning and lightning-induced fires vary annually. The Insurance Information Institute reported over $41 million in property damage from lightning events in the United States in 2019. Additionally, they reported an average of $108 million each year in damage from lightning-induced fires in nonresidential properties from 2007 – 2011(Insurance Information Institute, 2020). In MS and AL, property damage from lightning is a major concern for producers, integrators, and insurance companies. In MS, from 2015 – 2019, one insurer reported paying an estimated $12 million in claims with lightning as the primary cause of claim (Leggett, 2019). Lightning can short or destroy environmental control systems, equipment, or structures on broiler production facilities through a direct/indirect strike or lightning-induced fire, potentially leading to the loss of an entire flock and replacement of equipment.

The need to understand the required parameters, distribution, and climatology of lightning has resulted in development of Lightning Location Systems (LLS). Development of LLS to track lightning strikes spatially has been improving since the 1920's to parameterize isolated lightning strike events. LLS began using magnetic direction-finding (MDF) and time-of-arrival (TOA) geolocation system technologies around the late 1980's to develop continuous monitoring systems over larger areas (Krider et al., 1980; Shultz et al., 2005; Cummins & Murphy, 2009). LLS track electromagnetic frequencies emitted by the pulsing of low frequency IC flashes and high “burst” frequencies of CG flashes, or lightning strikes (Cummins & Murphy, 2009). LLS have been utilized in many countries, including the contiguous United States, Canada, Austria, Brazil, Japan, Spain, and France, to parametrize flashes and understand spatial and temporal distributions (Shultz et al., 2005).

The National Lightning Detection Network (NLDN) was established and expanded from 1983 to 1989 to create a LLS that covered the contiguous 48 United States using new MDF sensors (Krider et al., 1980) and a prototype interface in 1979. Commercialization of the NLDN allowed historical lightning data and lightning location systems to be accessible for research, meteorology, utilities, and many other applications across the United States. In 2004, the NLDN installed Improved Accuracy from Combined Technology (IMPACT) sensors, a combination of MDF and TOA sensor technologies, and increased the number of sensors in the network to improve the accuracy of lightning data collected. The NLDN, currently owned and operated by Vaisala, Inc., has grown significantly since expanding its network of sensors in 2009 to include Canada (NALDN) and the collection of current & historical global lightning data (GLD360) (Cummins et al., 1998; Orville, 2008; Cummins & Murphy, 2009; Vaisala, 2021a). Cummins and Murphy (2009) and Murphy and Nag (2015) evaluated the flash detection efficiency (FDE) of the NLDN to determine the accuracy of the LLS. They discovered, with the implementation and increase in newer sensors, FDE was 95% or higher with some variation due to low magnitude, positively charged IC pulses.

Vaisala, Inc. collects and processes lightning data to build visual representations of lightning patterns and distributions, reported annually in the Vaisala Lightning Report (Vaisala, 2021a). The real-time data is used to identify spatial and temporal patterns in lightning to create early warning systems for its customers to better protect from the threat of lightning. Researchers have used the NLDN to evaluate lightning strike densities throughout the United States (Zajac & Ruteledge, 2001; Holle, 2014). These strike densities have been used to make recommendations for lightning protection strategies for populations in heavy lightning locations (Holle, 2012a; Holle, 2016b). Krider et al. (1980) initially used the MDF sensor technology to pinpoint location of CG flashes to identify the ignition point of forest fires. Other topics of interest are the increased number of positively charged strikes in regional areas and the comparison of CG flashes between land-locked, coastal, and oceanic regions (Williams & Renno, 1993; Williams & Stanfill, 2002; Carey & Buffalo, 2007).

1.5 Electrical Grounding Practices for Commercial/Agricultural Structures

Structures and equipment should be properly electrically grounded to create a direct path for lightning and faulty electrical discharge to travel into the Earth to reduce the risk of lightning-induced electrocution and structural or equipment damage. The National Electrical Code (NEC) was created and revised every 3 years by the National Fire Protection Agency (NFPA) in conjunction with the Institute of Electrical and Electronic Engineers (IEEE). It illustrates minimum standards designed to outline the construction of electrical systems in residential and commercial operations (Stetson, 1998; Switzer, 1999). The NFPA developed minimum standards for electrical systems specifically for agricultural operations to protect individuals, livestock, structures, and equipment consulting with the American Society of Agricultural Engineers (ASAE) (Stetson, 1998).

Electrical and construction contractors are recommended to follow NEC guidelines for proper electrical grounding of broiler houses. However, the lack of standardization in broiler house construction practices leads to inconsistencies in construction. Standardization of these construction practices and commissioning would give producers a set of standards to meet for their operation. It would also give integrators, loan agencies, and insurance companies guidelines to ensure sound construction and operation.

Modern broiler houses use controllers and sensors to monitor and maintain internal environmental parameters, such as temperature and ventilation, and mechanical processes to ensure an optimized growing environment (Hamrita & Mitchell, 1999; Furlong et al., 2004; Upachaban et al., 2016). Optimizing the growing environment is essential to broiler operations as broiler genetics have greatly increased growth rates, requiring a particular environment to thrive (Hamrita & Mitchell, 1999). These controllers, like other electronic devices, are susceptible to excess voltage or overcurrent from lightning or other electrical systems, potentially resulting in the loss of the environmental control systems. Gates et al. (1992) developed a methodology to test the overvoltage limits of commercially available environmental controllers and sensors. It was recommended that a testing protocol and protection standard for environmental controllers and sensors should be developed (Gates et al., 1992). However, there is little research in overvoltage protection for systems for current environmental controllers. Loss of the controlled environment or mechanical systems for extended periods of time can result in increased stress on broilers within a house, leading to low final weights or the loss of an entire flock (Linhoss, 2019; Van Wicklen, 2003).

1.6 Objectives

Protection of lives and equipment on broiler production facilities is essential. Reducing lightning claims for insurance companies could potentially help stabilize or reduce insurance premiums. However, a greater understanding of lightning patterns across MS and AL is necessary. A general baseline of current grounding systems across both MS and AL would be beneficial to making further recommendations to producers on improving grounding systems. Therefore, the objectives of this research are: 1) collect baseline resistance data for broiler houses and equipment in MS and AL, 2) mapping lightning strike densities across both states, and 3) evaluate annual, monthly, seasonal, diurnal, and regional patterns throughout both states.

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CHAPTER II

FIELD SURVEY OF BROILER FARM ELECTRICAL GROUNDING SYSTEMS IN MISSISSIPPI AND ALABAMA

2.1 Introduction

Lightning strikes are a significant concern for broiler producers in the Southeast U.S., especially MS and AL where strike densities are among the highest in the nation. Being adjacent to the Gulf of Mexico, MS and AL are prone to violent thunderstorms throughout the year, ranking 8th and 14th in lightning strike totals according to the 2020 Vaisala annual lightning report (Vaisala, 2021). Strikes can ignite fires and damage or destroy housing equipment such as controllers, motors, and other electrical equipment. While prevention of direct lightning strikes is not possible, mitigation of lightning-induced damage is possible through proper earth grounding.

Proper earth grounding of house structures, electrical systems, and equipment is necessary for a safe and efficient electrical system capable of minimizing damage caused by lightning strikes (Van Wicklen, 2003; Van Wicklen, 2004; Linhoss & Purswell, 2019). Moreover, proper earth grounding is more important as adoption of automated environmental control and food and water delivery systems have increased vulnerability to catastrophic bird losses from lightning-induced electrical failures. Increases in the frequency and severity of severe weather events in the Southeast also elevate the importance of effective electrical grounding systems. Additionally, poultry house insurance companies have begun to increase insurance premiums due to these increased vulnerabilities and severe weather events, as well as the high replacement costs of digital controllers and electrical equipment and increases in construction costs.

Insurance companies are encouraging stronger damage protection/prevention strategies, including more robust electrical grounding systems to protect houses from lightning-induced damage. The burdensome increase in premiums is a significant concern for producers and a catalyst for producers, integrators, and researchers alike to develop strategies and management practices with the goal of better protecting houses from lightning-induced damage and preventing catastrophic losses.

2.1.1 Electrical Grounding

The National Electrical Code (NEC) is a set of minimum standards designed to outline the construction of electrical systems in residential and commercial structures. It was developed by the National Fire Protection Agency (NFPA) in conjunction with the Institute of Electrical and Electronic Engineers (IEEE) (Stetson, 1998; Switzer, 1999). The American Society of Agricultural and Biological Engineers (ASABE) worked with the NFPA to develop minimum standards for electrical systems specifically for agricultural sectors (Stetson, 1998). Electrical grounding is the process of connecting electrical systems to the earth to limit voltage imposed by lightning or unintentional surges to stabilize the voltage to earth during normal operation, according to NEC Section 250.4 (1) (NFPA, 2020). Non-current carrying materials, systems, or structures that could become energized should also be grounded to redirect any excess voltage to the earth (NFPA, 2020; NLSI, 2011). The NEC allows for the installation of multiple grounding electrodes if resistance measurements at the grounding electrode exceed 25-Ω (ohms) in NEC Section 250.53 (2) (NFPA, 2020). Further guidelines for electrical grounding systems are outlined in the National Electrical Code (NFPA, 2020) and the National Lightning Safety Institute (Zimmerman et al., 2002; NSLI, 2011).

Grounding rods are the most used grounding electrode in broiler production facility construction. They are usually stainless steel or copper/zinc-plated steel rods and must be 5/8-inch diameter minimum. They must be driven at least 8 feet into the earth to meet NEC code (NFPA, 2020). The grounding electrodes are then bonded to electrical system via a grounding electrode conductor, typically a copper, aluminum, or copper-clad aluminum wire, 4 to 6 AWG depending on the material (NFPA, 2020). These electrodes use an acorn nut to securely connect the grounding electrode conductor to the grounding electrode, according to manufacturer torque specifications (Figure 2.1). Due to the unpredictability of lightning strike locations, many electrical grounding systems often implement air terminals, or lightning rods, on top of structures or trees connected to grounding electrodes to give the excess voltage a direct path to the earth, avoiding nearby electrical systems or other structures (Gustafson & Morgan, 2004).

Figure 2.1 Proper electrical ground outside a broiler production facility utilizing acorn clamps.

(Brothers et al., 2011)

Another type of grounding electrode used in broiler production is concrete-encased electrodes, referred to as Ufer grounding. Originally analyzed by H.G. Ufer during WWII for explosives storage units, concrete-encased electrodes were utilized to ensure an effective ground for electrical systems in areas where traditional grounding electrodes, such as water pipes and grounding rods, were not possible due to environmental conditions (Ufer, 1964). Instead of installing a separate grounding electrode to ground the electrical system, this type of grounding electrode grounds the electrical system through the concrete-encased steel used to reinforce concrete structures.

In broiler production facilities, the steel reinforcement located in the concrete slab of the control room and chain wall construction around the perimeter of the facility is utilized (Figure 2.2) (Linhoss & Purswell, 2019). For NEC standards, bare, zinc-galvanized, or electrically conductive steel bars or rods, at least ½ inch in diameter connected continuously, must be encased by at least 2 inches of concrete horizontally that is in direct contact with the earth, connected by a grounding electrode conductor larger than 4 AWG wire (NFPA, 2020). The porous structure and bentonite composition of the concrete footpad surrounding the rebar reduce resistance ratings in areas where grounding rods are difficult to install (Lim & Gomes, 2013; Cabral et al., 2016).

Figure 2.2 Ufer grounding connection on the generator service panel of a broiler farm.

While electrical grounding systems have improved significantly over the past few decades, there are external and environmental factors that affect the efficiency of an electrical grounding system. A major factor affecting earth resistance is earth or soil resistivity, or a value that is indicative of the resistance of a soil between two points. This is often measured using a 3 or 4 dipole method when designing electrical grounding systems. This value is often collected and utilized in the construction and design of electrical grounding systems in conjunction with different environmental effects (Switzer, 1999; Alipio & Visacro, 2014; Malanda et al., 2018). Soil type, depth, and temperature, moisture content, chemical and mineral breakdown, and vegetation or surrounding structures can influence the seasonal fluctuation of earth resistance values. These values can also change due to electrode contact and corrosion (Schaefer, 1955; Choun et al., 2012; Malanda et al., 2018). Understanding how these factors affect the accuracy and efficiency of electrical grounding systems is essential to effectively protect individuals, electrical systems, and structures from over-currents, short circuits, and lightning strikes.

2.1.2 Electrical Grounding in Broiler Production

The adoption of automated environmental control systems in broiler production has increased vulnerability to system damage and catastrophic bird losses. Current broiler houses rely on sensitive electronic controllers to automate several environmental control parameters and responses. Temperature and static pressure sensors signal these controllers to start or stop radiant heaters or tunnel ventilation systems for birds to maintain a thermal homeostasis. Timing sensors are used to ensure feed and water delivery systems are providing food and water *ad libitum*. Digitalization of computer-controlled systems along with creation of localized networks for farm management requires efficient grounding systems to protect these sensitive controllers.

Broiler house electrical system construction should follow NEC guidelines to ensure an efficiently grounded electrical system (NFPA, 2020). In addition to NEC guidelines, researchers recommend all electrical systems and equipment be properly grounded at a resistance rating of 25-Ω (ohms) or less to protect sensitive electrical systems and equipment. All connections from the control systems to grounding electrodes, or grounding rod, should be checked and maintained according to NEC standards and manufacturers specifications to ensure efficient grounding and a continuous path to the earth (Van Wicklen, 2003; Van Wicklen, 2004; Donald & Campbell, 2004; Brothers et al., 2011; Linhoss & Purswell, 2019). Additionally, adoption of Ufer grounding in broiler facility construction has gained traction in recent years and should improve resistance and grounding system resiliency, although research is lacking in validation of this assumption (Linhoss & Purswell, 2019).

Development of management strategies and practices will help to better protect broiler production facilities from lightning-induced damage. The objective of this study was to survey earth ground resistances of broiler production facilities in MS and AL to gather and provide baseline data on the quality of electrical grounding systems in production facilities of varying ages and grounding system types.

2.2 Materials and Methodology

2.2.1 Survey Parameters and Data Collection

A field survey was conducted in the summer of 2021 of 51 broiler houses in MS and 45 broiler houses in AL for three different integrators across both states. Survey parameters included houses age, electrical system/controller update, grounding system type (Ufer or traditional grounding rod), geographic elevation, soil type, and earth ground resistance measurements. Electrical resistance was measured at control room service panels, generator service panels, and generator frames with an earth ground resistance meter (Fluke 1630-2/1630-2 FC, Fluke Corporation, Everett, WA) (Figure 2.3). Additionally, history of past direct strikes and any other pertinent information were also collected.

Figure 2.3 Fluke earth resistance meter used to collect grounding resistances.
(Linhoss & Purswell, 2019)

2.2.2 Statistical Analysis

PROC GLM in SAS (SAS, Version 9.4, 2020) was utilized to analyze differences in mean resistances among broiler house electrical grounding systems using Ufer grounding vs. traditional grounding rod electrodes as effects. Significance was considered at $P \leq 0.05$. Means were adjusted using house age as a covariant to account for differences in construction practices or other extraneous effects.

2.3 Results

Survey results from resistance measurements taken across 14 farms in MS and AL are presented in table 2.1. The most consistent grounding locations were at the control room service panels, generator transfer switch service panels, and generator frames. Sixty-one of the ninety-six houses surveyed, or 63.5%, were at or below the 25-Ω (ohm) recommendation. However, two houses on Farm 4 had no ground and one Ufer ground in AL was disconnected (Figure 2.4). Thirty-nine of the houses, or 40.6%, utilized an Ufer grounding system, with the oldest house surveyed utilizing this type of electrode constructed in 2007. Six of the fourteen farms had a mean resistance rating above the recommended 25-Ω (ohms). Farms 1, 3, 5, and 6 reported direct strikes to their operation, costing large sums to repair damage and replace controllers. Where available, the grounding electrode was surveyed at generator service panels and frames. Of those surveyed, only one generator service panel and two generator frames exceeded the 25-Ω (ohm) recommendation. House age ranged from 1998 to 2021.

Table 2.1 Resistance summary results at grounding locations at 14 farms (96 houses) in MS and AL.

State	Farm #	# of Houses	Ufer (Yes/No)	Control Room				Generator Service Panel[1] (Ω)	Generator Frame[1] (Ω)	Year Built[2]
				< 25 Ω (ohms)		> 25 Ω (ohms)				
				# of Houses	Range (Ω)	# of Houses	Range (Ω)			
MS	1	9	No	3	11.45 - 18.49	6	32.52 - 69.65	12.98 & 25.46	0.15	1989-2005
	2	4	No	0	-	4	76.92 - 119.9	-	118.3	2008
	2^{U}	4	Yes	4	0.657 - 12.48	0	-	184	121	2020
	3	4	No	4	7.146 - 24.1	0	-	64.52	-	1990
	4	6*	No	4	10.89 - 22.3	0	-	-	-	1999
	5	8	No	8	0.273 - 12.56	0	-	-	0.83 & 2.53	2011
	6	8	No	8	4.683 - 14.85	0	-	0.42 & 0.31	-	2010
	7	8	Yes	5	6.779 - 19.85	3	27.77 - 36.85	1.08 & 0.29	-	2011
AL	8	3	Yes	1	10.54	2	211.8 - 228.8	-	-	2013
	9	4	Yes	4	0.14 - 11.5	0	-	-	-	2014
	10	8	Yes	8	0.158 - 5.022	0	-	-	-	2013-2021
	11	4	Yes	1	24.03	3	56.36 - 108.3	-	-	2016
	12	12	No	5	1.007 - 3.095	7	37.2 - 826.4	-	-	2007-2015
	13	8	Yes	6	1.041 - 9.259	2	55.67 - 73.15	0.25 & 0.54	-	2007-2013
	14	6	No	0	-	6	31.69 - 69.1	-	-	1998

Figure 2.4 Disconnected ground on surveyed broiler farm.

Figure 2.5 illustrates the comparison of the mean resistance of broiler house grounding electrodes, comparing the use of Ufer grounding electrodes to non-Ufer grounding electrodes. House age was used as a covariant in the model to adjust for differences in construction practices and other extraneous factors. Utilization of Ufer grounding electrodes shows improvement in the reduction of mean resistance rating of grounding systems in broiler houses. However, these improvements are not significantly different at the $\alpha = 0.05$ level ($p = 0.3467$).

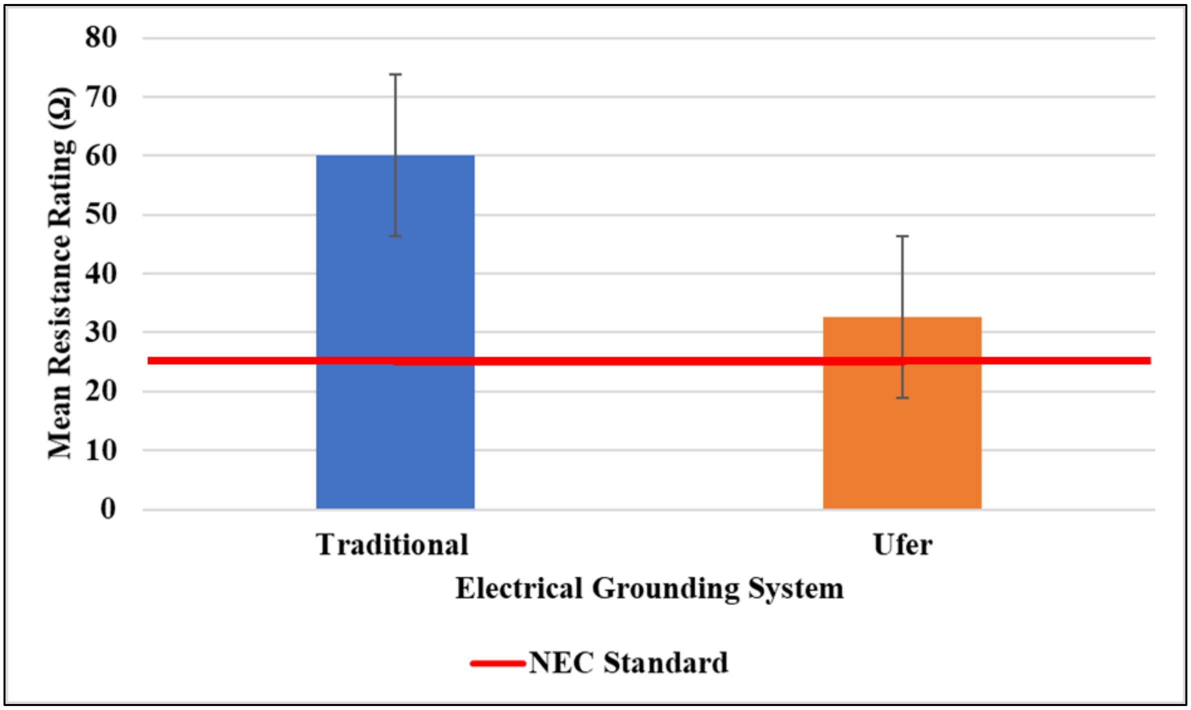

Figure 2.5 Comparison of Ufer electrical grounding system mean resistance vs. non-Ufer (traditional grounding rod) electrical grounding system mean resistance.

Figure 2.6 illustrates the number of houses above and below the NEC Standard of 25 Ω (ohms) based on the age of the houses and the type of grounding electrode. All 14 houses built between 1998 and 2005 utilized a traditional grounding electrode. There were 6 houses above 25 Ω and 8 houses below 25 Ω. For houses built between 2006 and 2013, 39 houses utilized a traditional grounding electrode, and 23 houses utilized a Ufer grounding electrode. For traditional grounding electrodes during this time, 17 houses were above 25 Ω and 22 houses were below 25 Ω. For the Ufer grounding electrodes during this time, 7 houses were above 25 Ω and 16 houses were below 25 Ω. For houses built between 2014 and 2021, 2 houses utilized a traditional grounding electrode, and 16 houses utilized an Ufer grounding electrode. All traditional grounding electrodes utilized by houses built during this time were below 25 Ω. For the Ufer grounding electrodes during this time, 3 houses were above 25 Ω and 13 houses were below 25 Ω. This data indicates that electrical grounding practices are effective in current systems, but there is room for improvement.

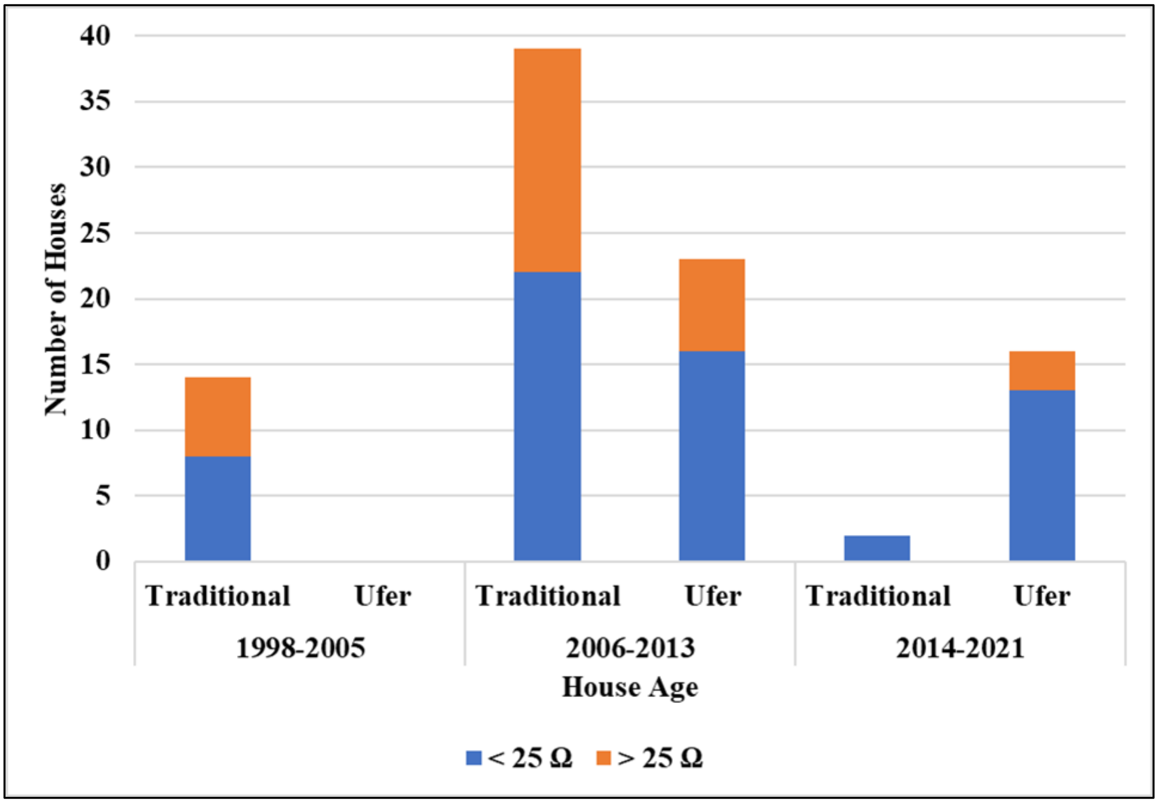

Figure 2.6 Number of houses above and below the 25 Ω based on the initial construction age of the houses and the type of grounding system.

2.4 Conclusions

Resistance measurements for ninety-six broiler houses were collected to determine a quantitative baseline of electrical grounding systems in MS and AL. Effects of house age (or electrical system age) and type of electrical grounding system were analyzed.

- 61 houses, or 63.5%, of surveyed houses were at or below the 25 Ω (ohm) recommendation.
- 39 houses, or 40%, of surveyed houses utilized a Ufer grounding system.

- Six of the fourteen farms, or 42.8%, had a mean resistance rating at or below the 25 Ω (ohm) recommendation.
- 58.5% of houses utilized a traditional grounding system, where 41.5% utilized a Ufer grounding system.
- Based on surveyed houses, new broiler house construction practices have moved towards utilizing Ufer grounding systems.
- For houses constructed between 2006 and 2013, traditional grounding systems had a higher resistance value than Ufer grounding systems.

Broiler houses that were electrically grounded were at or below the NEC recommendation in 63.5% of surveyed houses. However, three surveyed houses were not electrically grounded or had disconnected grounding rods. Six of the fourteen farms surveyed had a mean resistance rating above the NEC recommendation. Installation of electrical grounding systems on all current and non-current carrying electrical equipment and structures across a farm will help to better protect the farm from lightning-induced damage and potential fires.

40% of surveyed houses utilized a Ufer ground, majority in houses constructed between 2014 and 2021. Based on surveyed houses, broiler house construction practices have moved towards utilization of Ufer grounding systems in newer broiler houses. Ufer grounding systems displayed lower resistance ratings compared to the traditional grounding rod resistance ratings.

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CHAPTER III

MAPPING AND ANALYSIS OF LIGHTNING STRIKE DENSITY PATTERNS FOR MISSISSIPPI AND ALABAMA

3.1 Introduction

Lightning strikes are a major concern for broiler producers in the Southeast United States, especially MS and AL. Modernization of broiler house equipment and technology has optimized environmental control systems necessary to ensure broiler comfort and welfare. However, these costly systems are susceptible to electrical damage from lightning. Lightning can also ignite fires on poultry operations. Some locations in MS and AL are more prone to lightning strikes, resulting in multiple strikes and significant equipment loss. Lightning has many points of entry on the typical broiler farm to cause catastrophic damage, including electrical lines and equipment, and structural components of a house (Gustafson & Morgan, 2004; Van Wicklen, 2004). Private conversations with insurance companies in MS reported that nearly 40% of total claims form poultry house damage or loss originate from either lightning strikes or lightning-induced fires (Leggett, 2019). Lightning fatalities have decreased in recent years, but property damage from lightning and lightning-induced fires varies annually. In 2019, the Insurance Information Institute reported over $41 million in property damage from lightning events and $108 million from lightning-induced fires in non-residential properties in the United States (Insurance Information Institute, 2020). From 2015 – 2019, one insurer reported paying an estimated $12 million in claims from lightning-induced damage (Leggett, 2019). Damage to environmental controllers on broiler operations from lightning or lightning-induced fires could potentially lead to the loss of an entire flock and replacement of essential equipment.

Large insurance payouts for broiler operations from lightning and other extreme weather events have led to an increase in insurance premiums in recent years. This is a result of “hard” market conditions for insurance companies. To reduce their economic risk, insurance companies increase premiums to offset their economic risk with increasing liability. This increased liability has resulted in some insurers ceasing to issue policies to broiler operations. Producers, integrators, insurers, and researchers are seeking solutions to mitigating the risk from lightning. Implementation of improvements would be beneficial to producers, but the effect on insurance premiums as a result is currently unknown (Leggett, 2019).

The creation of LLS has improved understanding of lightning patterns around the world. Vaisala, Inc. uses the NLDN, a LLS based in the U.S., to parameterize and display lightning data to identify spatial and temporal patterns across the United States. This data is used to make recommendations for lightning protection strategies in locations with increased lightning strikes (Zajac & Ruteledge, 2001; Holle, 2012a; Holle, 2012c; Holle, 2016b; Vaisala, 2021a). According to the 2020 Vaisala Annual Lightning Report, MS and AL were among the top 15 states with the highest recorded flash density, ranking 8th and 14th respectively. From year to year, the densest areas of lightning strikes are closer to the Gulf Coast, illustrated in Figure 3.1.

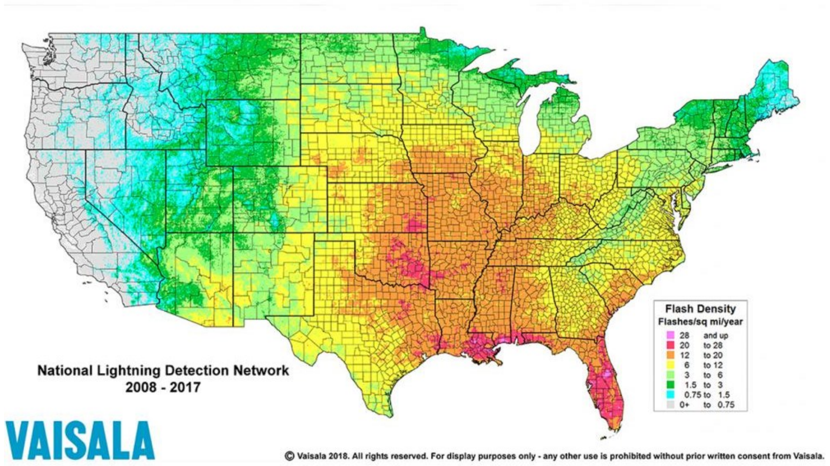

Figure 3.1 Flash density across the contiguous 48 United States from 2008 to 2017, collected by the NLDN, published by Vaisala, Inc.

(Vaisala, 2018)

Strike density maps are used to understand the distribution of lightning strikes over large areas. However, little research has focused on lightning patterns surrounding broiler operations in the Southeast U.S. Evaluation of lightning patterns around heavy broiler producing areas in MS and AL would identify areas more prone to lightning and understand spatial and temporal patterns of lightning strikes in the last decade. This could lead improvements in lightning protection systems in geographic areas prone to lightning for current and future broiler houses.

3.1.1 Objectives

The objectives of this study were to 1) map lightning strike densities across MS and AL for 10 years, 2) evaluate annual, monthly, seasonal, and diurnal patterns throughout both states, and 3) analyze strike totals in a one-mile radius of surveyed broiler operations.

3.2 Methodology

3.2.1 Data Integration and Modeling Methods

Arc-GIS geographic information software (ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, CA) was used to display point, line, and strike density data for creating maps.

State and county TIGER/Line shapefiles were obtained from the U. S. Census Bureau (2019) for MS and AL. These shapefiles served as the base layer for all maps created in this study. County land area was also retrieved from the U.S. Census Bureau. State and county shapefiles were projected using the Universal Transverse Mercator - Zone 16 (UTM – 16) projection system to ensure accurate distance measurements and transformations of other shapefiles (Setiawan & Sediyono, 2005).

The number of broiler farms w/inventory, number of broilers sold, and value of production for broiler farms in each county in MS and AL were obtained from the USDA – NASS 2017 Ag Census (USDA-NASS, 2017). Number of broiler farms w/inventory was combined with county shapefiles to create a broiler farm density map per county across MS and AL.

Lightning strike data from 2011 – 2020 was utilized to build lightning strike density maps for MS and AL. The 10-year historical data set collected by the NLDN, valued at $10,000, was procured from Vaisala, Inc. on February 24, 2020, December 15, 2020, and January 14, 2021. Detection efficiencies for the NLDN are at or above 90% (Cummins & Murphy, 2009; Murphy & Nag, 2015). Time resolution for this dataset was at the 1-millisecond level, providing time, data, latitude, longitude, and polarity of lightning strikes. Data was obtained as a text file (.txt) and formatted using Excel to create lightning strike point shapefiles to create strike density maps.

Lightning strike point shapefiles were reprojected using the Universal Transverse Mercator - Zone 16 (UTM – 16) projection system.

Lightning strike point shapefiles were displayed along with state and county boundary shapefiles. Selection by location tools were used to isolate the number of lightning strikes within the 149 counties of MS and AL, individually for all 10 years. Isolated strike data per county was tabulated again in Excel and formatted to determine number of strikes per county annually, seasonally, monthly, and for the 10-year period. This data was also formatted to determine the number of strikes per county diurnally for counties with increased broiler farm density in MS and AL. Data processing began January 15, 2021, and was completed in early May 2021.

Lightning strike point shapefiles were also transformed using the kernel density estimation function in Arc-GIS to determine strike densities annually, seasonally, and monthly across MS and AL. The kernel density equation uses Equation 3.1 to build a hotspot raster analysis of a population based on the distance between different features to create density values (Arc-GIS Pro).

$$D = \frac{1}{(R)^2} \sum_{i=1}^{n} \left[\frac{3}{\pi} \times pop_i \left(1 - \left(\frac{dist_i}{R} \right)^2 \right)^2 \right] \tag{3.1}$$

$$For\ dist_i < R$$

where:

D = calculated density value per raster cell

R = radius around individual points

i = input points within the radius distance of the (x,y) location

pop_i = population field value of point i (optional parameter)

$dist_i$ = distance between point i and the (x,y) location

Calculated density values were broken down by output cell size, set at one square kilometer, to determine an expected number of strikes per square kilometer across MS and AL. Raster output and state/county shapefiles were displayed to create annual, seasonal, and monthly maps. The kernel density function was unable to be used for an overall 10-year strike density map due to volume of the overall dataset and hardware/software constraints.

GPS locations of surveyed broiler farm locations across MS and AL were used to create a point shapefile to display in conjunction with state/county shapefiles and lightning strike point shapefiles. Elevation for each broiler farm was obtained through the Natural Resources Conservation Services (NRCS) as well. The buffer tool in Arc-GIS was used to create a one-mile buffer around each broiler farm location. Selection by location tools were used to isolate lightning strikes within each buffer radius for each broiler farm for all 10 years. The number of strikes were collected and tabulated in Excel to determine the number of strikes that occurred within a one-mile radius of each farm monthly.

3.2.2 Statistical Analysis

Statistical analysis was utilized to determine differences between strike totals, means, and calculated density values of the isolated county data across 10 years. Strike data was analyzed using a PROC GLM in SAS Version 9.4 (SAS Institute, Cary, North Carolina).

3.3 Results and Discussion

3.3.1 Broiler Farm Density

Figure 3.2 illustrates the distribution of the broiler farms in both states by county from the USDA – NASS 2017 Ag Census, broiler farms with inventory. AL broiler production is comprised of 2,246 farms, while MS broiler production is comprised of 1,386 farms.

In AL, broiler production is most heavily concentrated in the northeastern corner of the state, which hosts the densest population of broiler farms. These counties are Cullman, Dekalb, Blount, Marshall, and Lawrence, with a farm density of >100 broiler farms in each county. Morgan county broiler farm density is between 76 – 100 broiler farms. Franklin, Randolph, Jackson, and Etowah counties have a density ranging from 51 – 75 broiler farms. Another area of broiler farm concentration exists in the southeastern corner of AL as well. Crenshaw county has a density ranging between 76 – 100 broiler farms. Geneva, Coffee, and Pike counties have a density ranging from 51 – 75 broiler farms. 16 counties across AL have a density ranging between 21 – 50 broiler farms. 36 counties across AL have a density ranging between 1 – 20 broiler farms. One county in AL has no broiler farms.

In MS, the majority of broiler production is focused in the central – southern region of the state. Jones county is the only county in MS with a density of >100 broiler farms. Neshoba, Jasper, Leake, Smith, and Covington counties have a density ranging from 76 – 100 broiler farms. Wayne, Newton, Simpson, and Scott counties have a density ranging from 51 – 75 broiler farms. 9 counties in MS have a density ranging from 21 – 50 broiler farms. 44 counties in MS have a density ranging from 1 – 20 broiler farms. 19 counties in MS have no broiler farms.

Understanding the spatial distribution of broiler houses in MS and AL will specify the areas of interest in comparison with lightning strike densities.

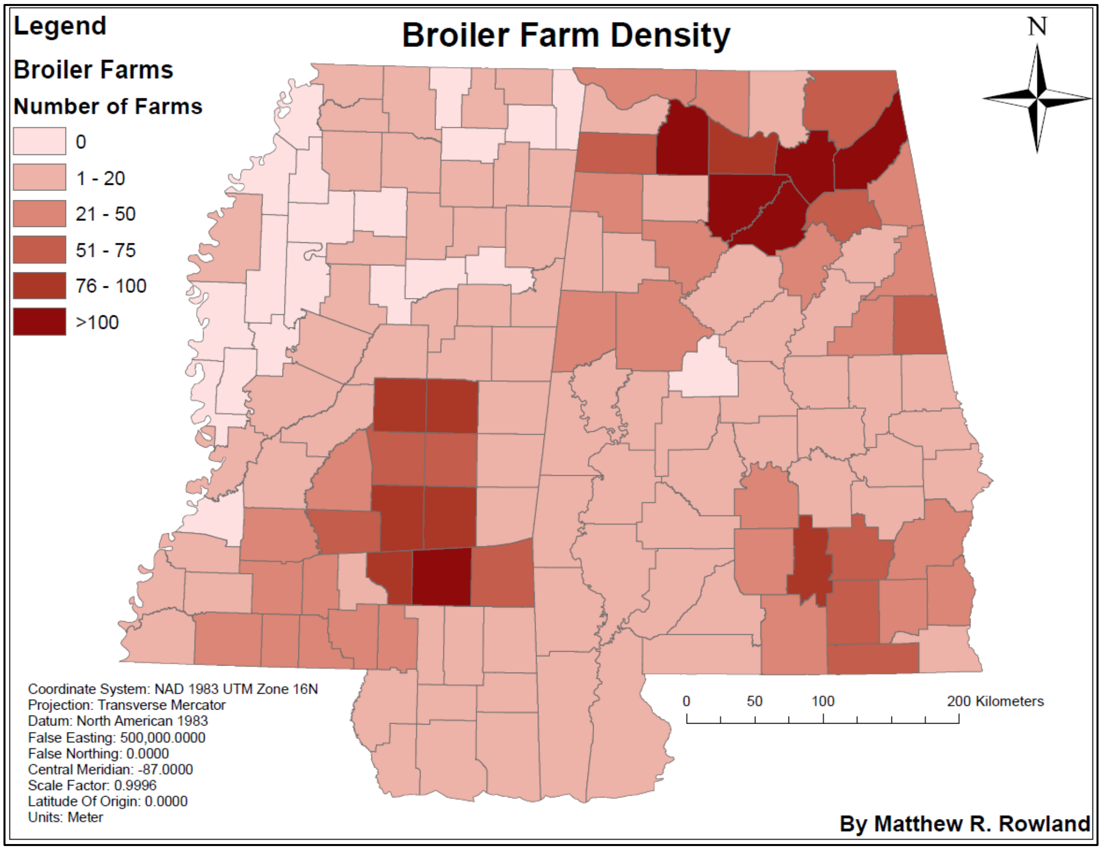

Figure 3.2 Broiler farm density in MS and AL.

(2017 USDA-NASS Ag Census)

3.3.2 10-year Mean Strike Density

Figure 3.3 illustrates overall mean lightning strike density per square kilometer per year for 82 counties in MS and 67 counties in AL from 2011 to 2020. MS experienced higher strike densities than AL. This is similar to findings reported in the Vaisala Annual Report, where MS ranks 8th in lightning strike totals to AL's rank of 14th (Vaisala, 2021a). Previous strike density distributions that use data collected from the NLDN in previous years also indicate MS and AL with slightly higher lightning distributions when compared to other areas of the contiguous United States (Zajac & Rutledge, 2001; Orville et al., 2011; Holle et al., 2016a). The highest mean lightning strike densities were experienced in the southern counties of both states located near or adjacent to the Gulf Coast. Counties immediately adjacent to the coast experienced 10-year mean strike densities exceeding 9 strikes per square kilometer per year. Counties located within 150 kilometers of the coastline experienced mean strike densities ranging from 6 – 9 strikes per square kilometer in MS and 5 – 9 strikes per square kilometer in AL. Mean strike densities decreased for counties located greater than 200 kilometers from the coastline, ranging from 5 – 6 strikes per square kilometer in MS and less than 5 strikes per square kilometer in AL. MS shows an elevated hotspot of increased mean strike densities in the northwestern counties. AL shows lower mean strike densities in the easternmost counties, where a large portion of broiler farms are located. Counties with increased broiler farm density in MS are in areas of increased strike density than counties with increased broiler farm density in AL. This is attributable to an increased overall strike density in MS, and closer proximity to the Gulf Coast.

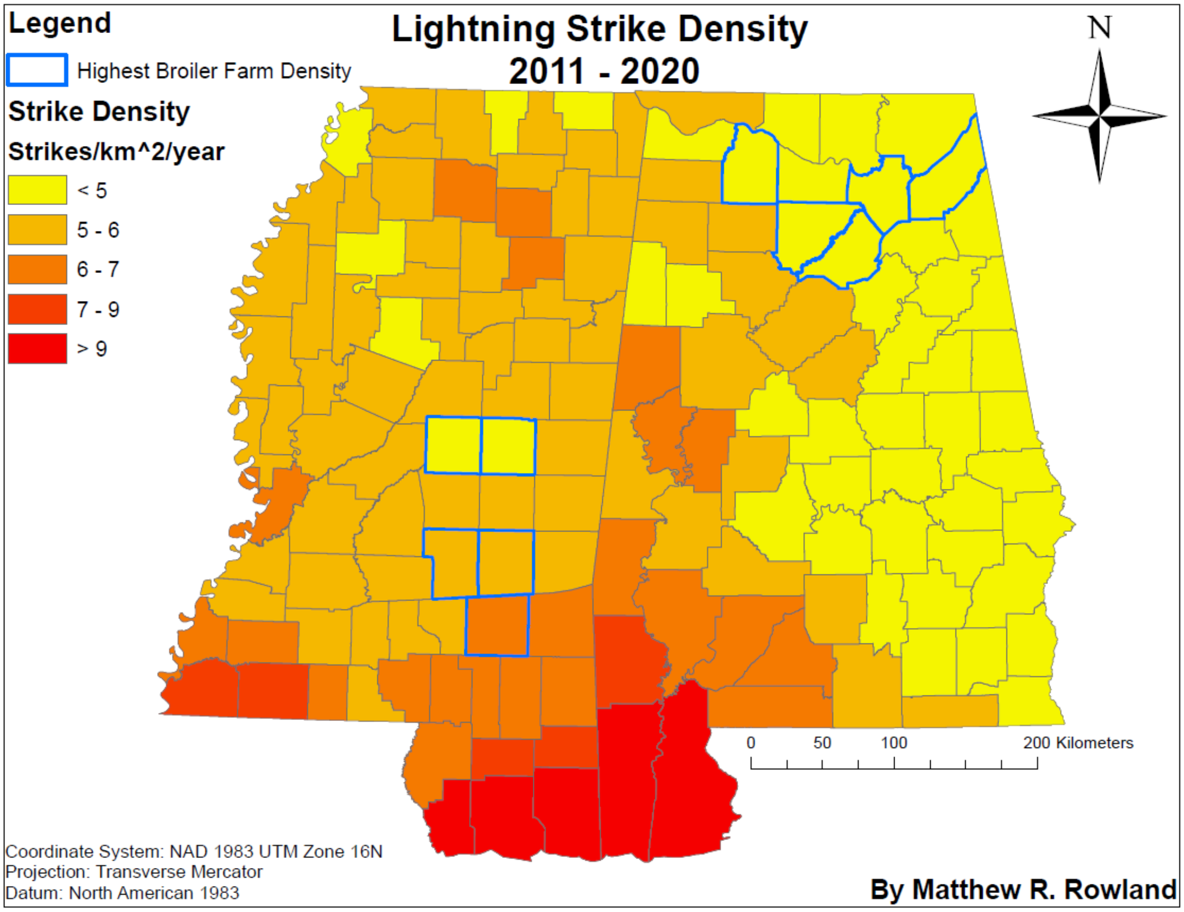

Figure 3.3 Mean lightning strike densities per square kilometer from 2011-2020 by county for MS and AL.

3.3.3 Annual Strike Density

Figure 3.4 illustrates the total annual strikes each year from 2011 to 2020 in MS and AL, respectively. Significant variation is observed from year to year, attributable to naturally occurring cyclical/variable weather patterns. MS experienced 7% more annual strikes than AL over the 10-year period. However, AL experienced a greater number of strikes than MS in 2012, 2013, and 2015. The highest occurrence of lightning strikes was in 2011 for both states, where lightning strike totals of 983,775 and 921,331 for MS and AL, respectively. The lowest occurrence of lightning strikes was in 2013, 2019, and 2020.

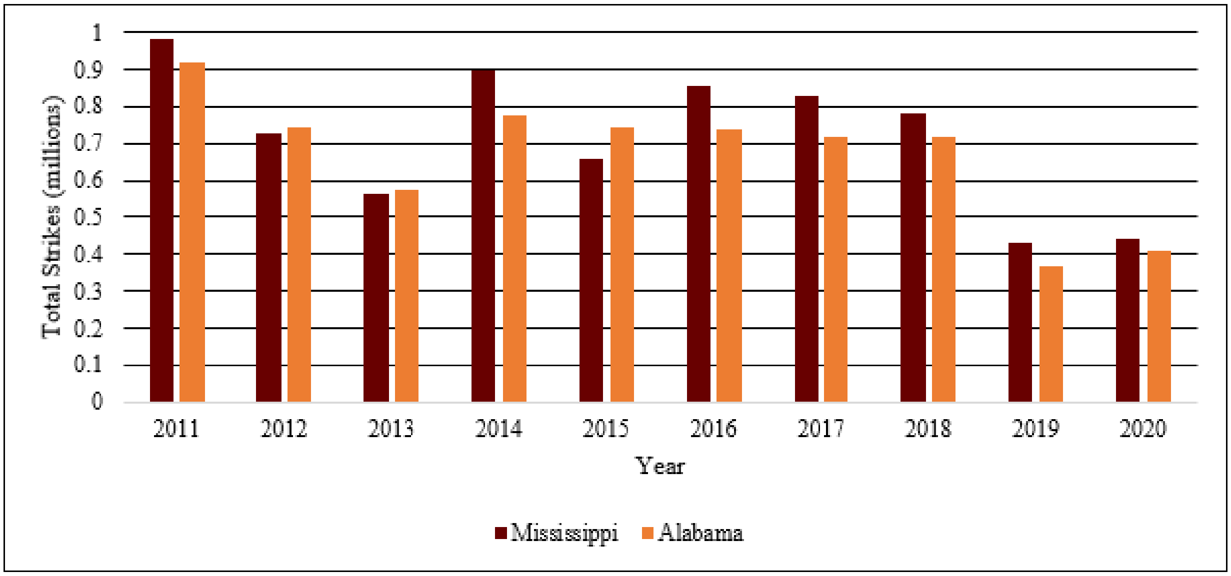

Figure 3.4 Total annual strikes (2011-2020) in MS and AL.

Figure 3.5 illustrates the high-resolution kernel density distribution of the total annual lightning strikes from 2011 to 2020 across MS and AL. Improved resolution of strike density maps through kernel density distributions isolates hotspots and variations across MS and AL. The highest densities of lightning per square kilometer occurred in counties near or adjacent to the Gulf Coast. These counties experienced strike densities from 5 to >20 strikes per square kilometer, with the highest strike densities experienced in 2012, 2014, 2015, 2016, 2017, and 2018. Increased strike densities between 10 and 20 strikes per square kilometer were experienced in 2011 for north MS and northwestern AL. Strike densities from <5 to 10 strikes per square kilometer were experienced in MS and AL for 2013, 2019, and 2020.

Counties with increased broiler farm densities in MS have experienced increased strike densities in comparison to counties with increased broiler farm densities in AL. MS counties experienced 5 – 10 strikes per square kilometer in 2011, 2016, and 2017. Additionally, MS counties experienced 10 – 15 strikes per square kilometer in 2014. Counties with increased broiler farm densities in AL have experienced 5 – 10 strikes per square kilometer in 2011. However, counties with increased broiler farm density in AL experienced <5 strikes per square kilometer from 2012 – 2020. Increased strike densities could indicate an increased potential of lightning strikes near broiler operations.

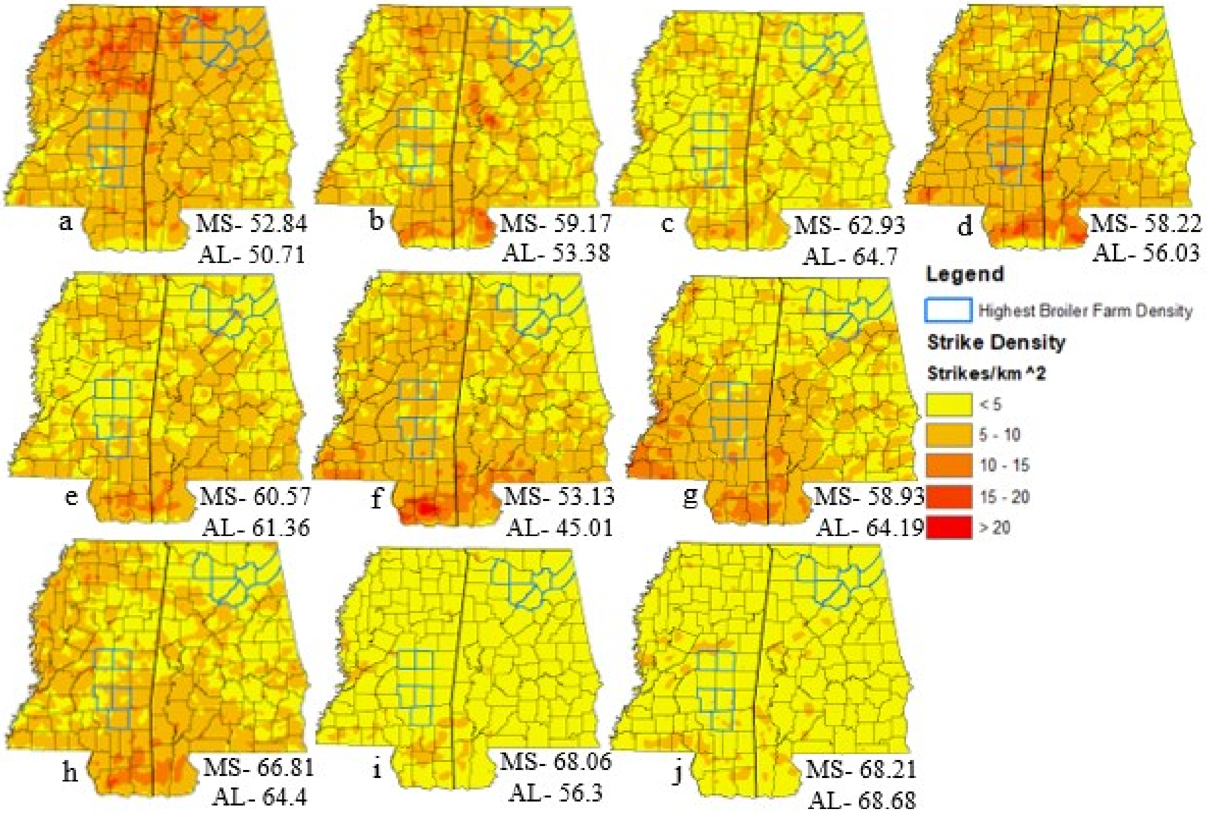

Figure 3.5 Lightning strike kernel densities of annual strikes in MS and AL for a) 2011, b) 2012, c) 2013, d) 2014, e) 2015, f) 2016, g) 2017, h) 2018, i) 2019, and j) 2020. Mean annual rainfall (inches) is illustrated below each year. Counties with the highest broiler farm density for MS and AL are outlined.

3.3.4 Seasonal Strike Density

To interpret seasonal variations in strike density, strike totals were separated by seasonal months, as illustrated in Figure 3.6. For both MS and AL, the summer months (June, July, August) experienced the highest concentration of strikes across the 10-year period, accounting for 55 and 63% of the total strikes in each state, respectively. Summer strike totals for AL were 6% higher than MS. Spring months (March, April, May) accounted for 30% of the total strikes in MS and 23% of strikes of total strikes in AL. Winter months (January, February, December) and Autumn months (September, October, November) experienced less than one million strikes per season in both MS and AL.

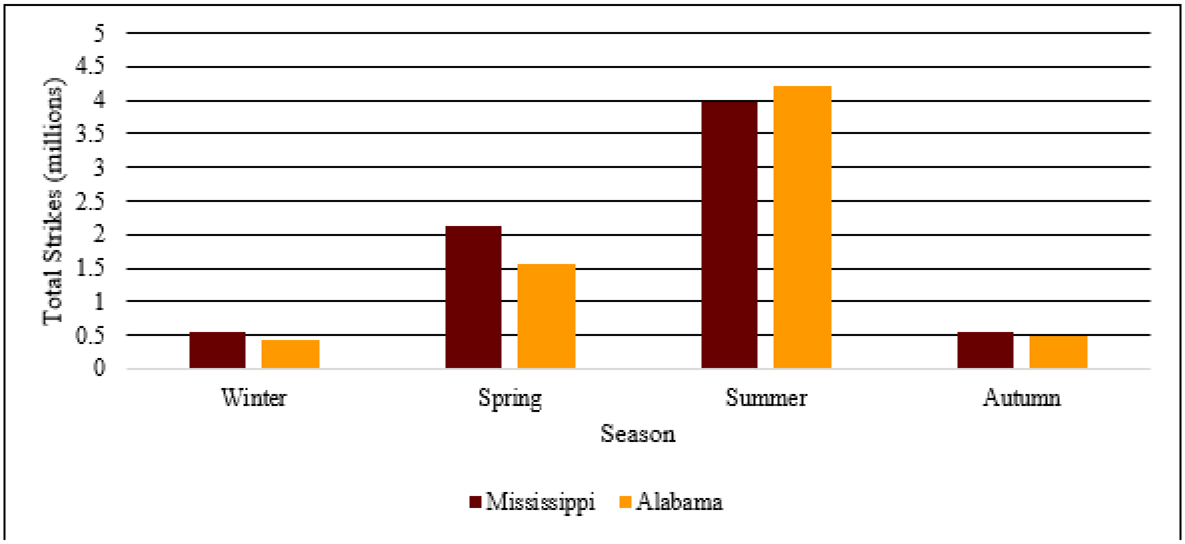

Figure 3.6 Total strikes organized by seasonal distribution for 2011 to 2020. Winter (January, February, December), Spring (March, April, May), Summer (June, July, August), and Autumn (September, October, November)

Figure 3.7 shows the kernel densities of the annual summer (June, July, August) strikes from 2011 to 2020 to show the spatial distribution of lightning across MS and AL. Similar to the annual distribution, summer strike densities were variable across both MS and AL. The highest densities of lightning per square kilometer occurred in counties near or adjacent to the Gulf Coast. These counties experienced strike densities from 2 to >8 strikes per square kilometer, with the highest strike densities experienced for summer months in 2011, 2012, 2014, 2015, 2016, 2017, and 2018. Increased strike densities between 4 and >8 strikes per square kilometer were experienced in 2011 for summer months in north MS and northwestern AL. Strike densities from <2 to 6 strikes per square kilometer were experienced in MS and AL for summer months in 2013, 2019, and 2020.

Counties with increased broiler farm densities in MS have experienced increased strike densities for summer months in comparison to counties with increased broiler farm densities in AL. MS counties experienced 2 – 8 strikes per square kilometer in 2011 and 2016. Counties with increased broiler farm densities in AL have experienced 2 – 6 strikes per square kilometer for summer months in 2011. Counties with increased broiler farm density in MS and AL experienced <2 strikes per square kilometer for summer months in 2019 and 2020. Increased strike densities could indicate an increased potential of lightning strikes near broiler operations.

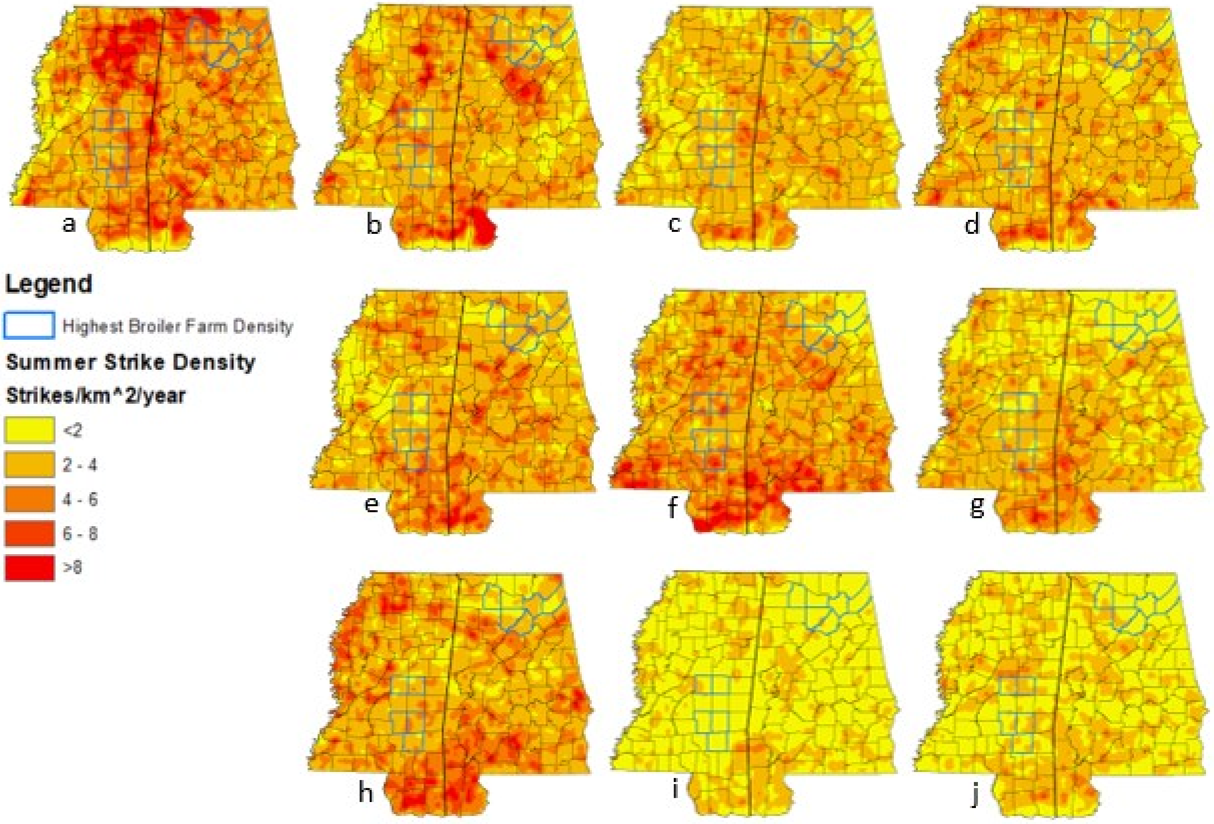

Figure 3.7 Lightning strike kernel densities of summer (June, July, August) total strikes in MS and AL for a) 2011, b) 2012, c) 2013, d) 2014, e) 2015, f) 2016, g) 2017, h) 2018, i) 2019, and j) 2020. Counties with the highest broiler farm density in MS and AL are outlined.

3.3.5 Monthly Strike Density

Figure 3.8 illustrates the total strike counts by month across the 10-year period for MS and AL. Overall, MS experienced 7% more strikes than AL, although AL strike totals were higher than MS during warmer months from June to August. Similar to the seasonal distribution in Figure 2.5, overall strike counts were higher in June, July, and August. The highest level of strike totals occurred in July, accounting for 21 and 25% of the total annual strikes for MS and AL, respectively. June strike totals accounted for 17 and 19%, and August strike totals accounted for 17 and 18% of the annual strikes for MS and AL, respectively. Strike counts in April and

May were also elevated when compared to autumn and winter months. The lowest strike totals occurred in October, accounting for 2 and 1%, and November, accounting for 1 and <1%, in MS and AL, respectively. This data supports the theory that lightning strike probability is higher during warmer months and producers are at an elevated risk of experiencing lightning-induced damage. Producers should perform annual inspections of their grounding systems and make necessary repairs prior to the summer months.

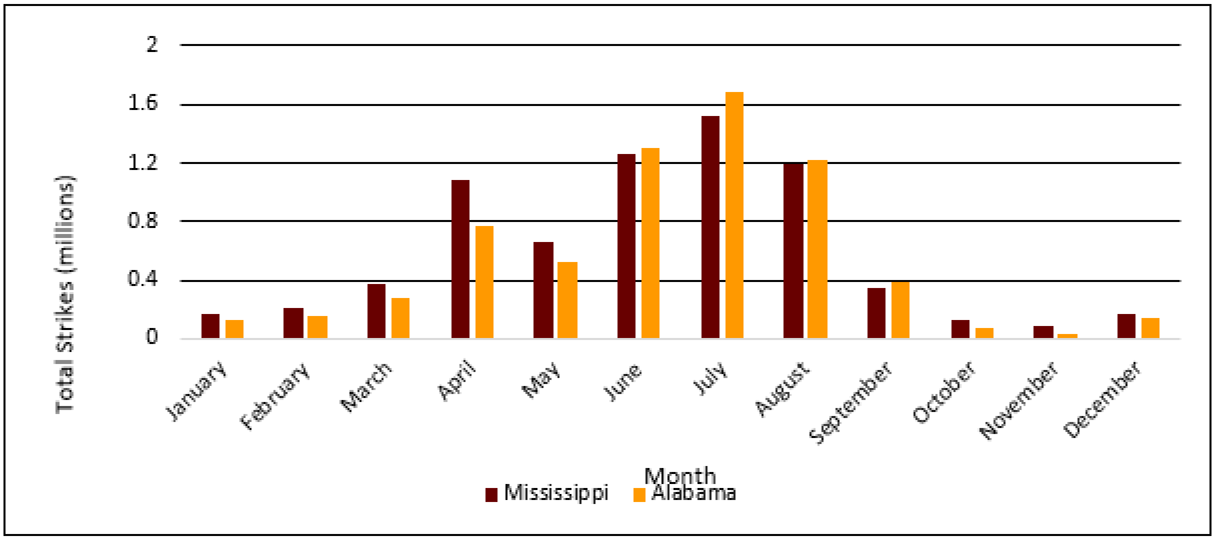

Figure 3.8 Total monthly strikes in MS and AL from 2011-2020.

3.3.6 Counties with the highest broiler farm density in MS and AL

Figure 3.9 illustrates the mean strike density for the top five counties with increased broiler farm density in MS and AL across the 10-year period. Strike densities for counties in MS counties are higher than those in AL. This is attributable to the geographic proximity of MS counties to the Gulf Coast. The top five counties with increased broiler farm density in MS experienced 48, 50, 28, 39, and 19% higher strikes than the top five AL counties, respectively. This data indicates a higher probability of lightning damage in MS counties than AL counties.

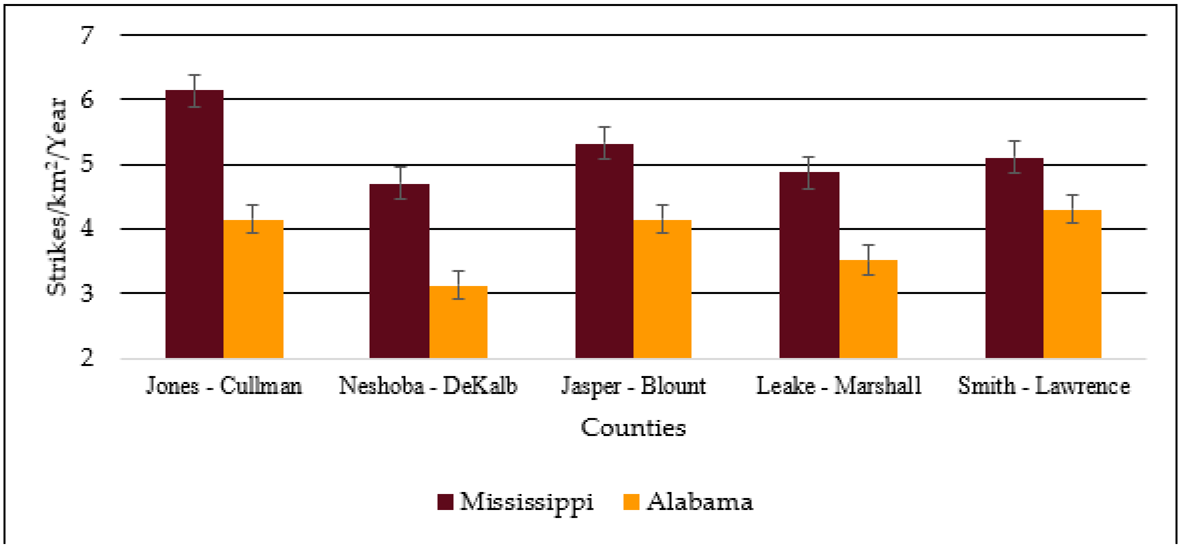

Figure 3.9 Mean strike densities and standard error for counties with increased broiler farm density in MS and AL from 2011 – 2020. Number of farms per county is also displayed.

3.3.7 Diurnal strike distribution

Figures 3.10 and 3.11 illustrate the diurnal strike distribution of mean strikes in the counties with increased broiler farm density in MS and AL, respectively. For both states, there is an elevation in the number of strikes in the 12-hour period from 4 p.m. to 4 a.m. This indicates an increased potential of lightning strikes during evening and night hours, leaving growers with limited access resources, labor, integrator service tech, power company, and first responder availability due to work schedules. Growers must ensure all alarms, sensors, and emergency power systems are operational to reduce loss.

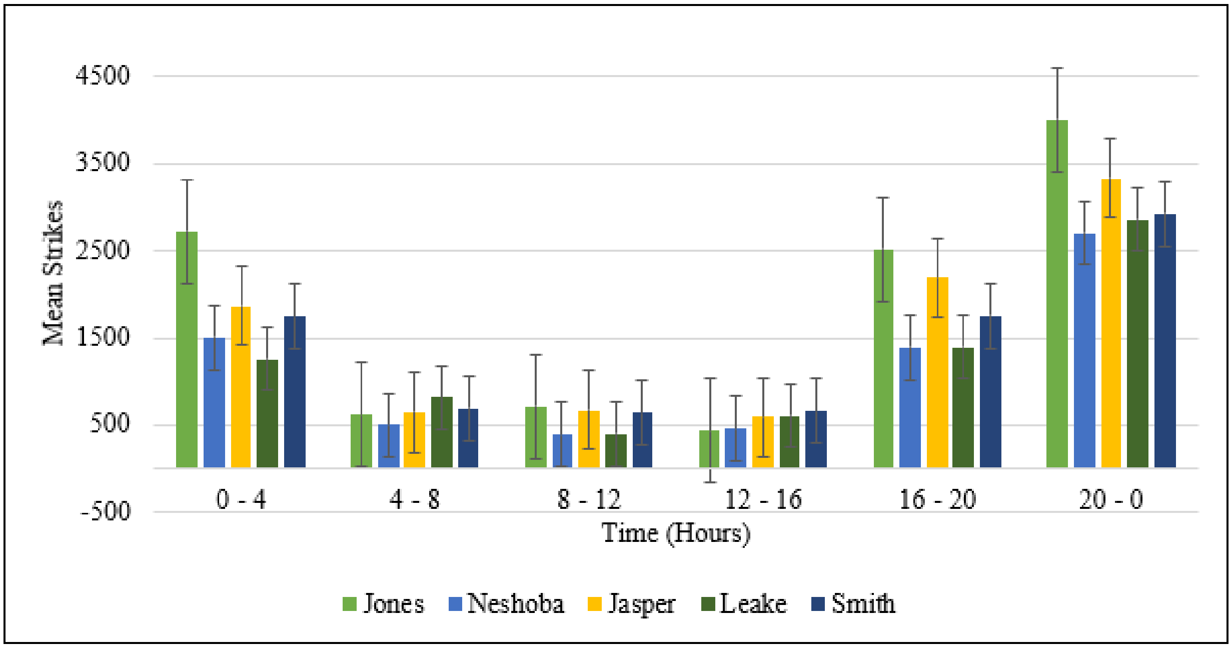

Figure 3.10 Diurnal strike distribution of mean strikes in the counties with increased broiler farm density in MS in four-hour intervals for 2011 – 2020.

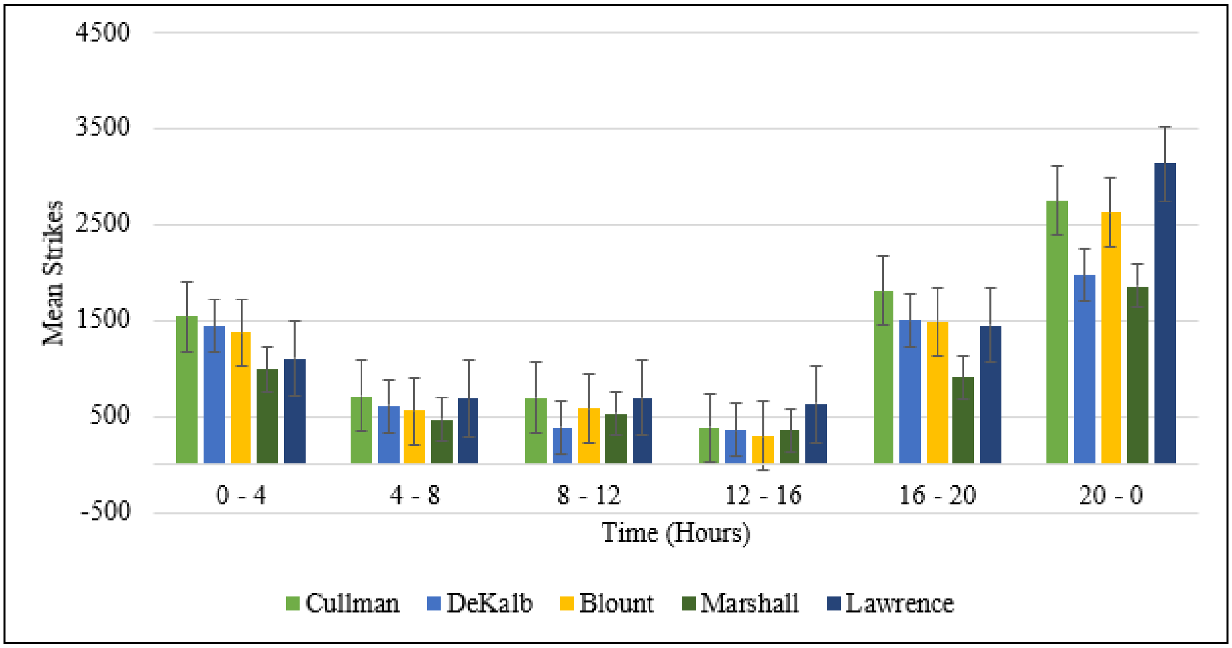

Figure 3.11 Diurnal strike distribution of mean strikes in the counties with increased broiler farm density in AL in four-hour intervals for 2011 – 2020.

3.3.8 Isolated lightning strikes around surveyed broiler farms

Table 3.1 illustrates the number of lightning strikes within a one-mile radius of surveyed broiler farm locations in July for 10 years across MS and AL. Lightning strike points were isolated within a one-mile radius to determine the total number of strikes around each broiler farm, shown in Figure 3.12. Most farms saw an increase in the number of strikes in 2011, 2012, 2015 and 2016. July strike totals for the 10-year period vary due to geographic location, but farms 3, 4, 5, and 6 in MS and farms 9, 11, and 14 in AL experienced over one hundred strikes within a one-mile radius. Some farms had elevated strike counts within the one-mile radius for just one year, such as Farm 11 experiencing 65 strikes in 2012 and Farm 6 experiencing 40 strikes in 2016. The isolated strike counts within a one-mile radius illustrates variability of lightning strikes.

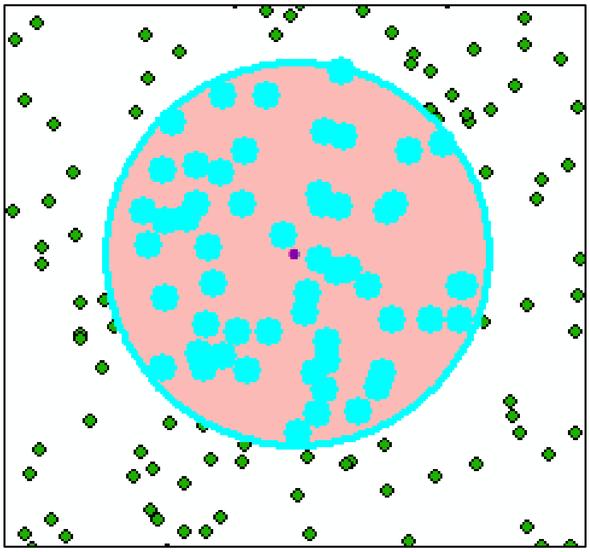

Figure 3.12 Lightning strikes isolated within a one-mile radius of a broiler farm location.

Table 3.1 Lightning strike count within a 1-mile radius of broiler house locations surveyed in MS and AL for July across 10 years.

State	Farm	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
MS	**1**	19	1	1	0	10	21	2	5	1	11	71
	2	36	8	0	0	3	26	4	9	6	0	92
	3	13	8	11	0	10	21	10	14	0	20	107
	4	20	9	11	0	10	17	7	13	1	18	106
	5	18	15	3	21	21	29	3	19	6	13	148
	6	8	4	7	1	11	40	13	7	2	29	122
	7	13	4	4	14	3	12	7	8	1	29	95
AL	**8**	14	35	8	3	7	10	4	2	0	4	87
	9	6	6	1	6	29	28	10	12	1	2	101
	10	3	5	7	1	2	18	12	17	13	4	82
	11	3	65	12	2	36	23	16	23	2	1	183
	12	11	8	11	2	18	18	5	8	3	4	88
	13	3	11	9	5	0	19	7	16	0	4	74
	14	7	13	6	9	19	28	11	11	1	6	111

3.4 Conclusions

Lightning strike densities were mapped from 2011 to 2020 across MS and AL. Broiler farm density maps were created to determine counties with an increased number of houses. Annual, seasonal, and monthly lightning strike densities were created to see spatial and temporal variation across MS and AL for the 10-year period. Isolated lightning strikes were analyzed to determine patterns annually, seasonally, monthly, diurnally, and for counties with increased broiler farm densities. Surveyed broiler farm locations were analyzed to determine the number of strikes within a one-mile radius across the 10-year period. Mapping and analysis of data supports the following conclusions.

- MS broiler farms density is elevated in the central-southern area of the state.
- AL broiler farm density is elevated in the northeastern corner of the state, with a small increase of broiler farm density in the southern part of the state.
- Historically, MS has an increased number of strikes across the 10-year period.

- Coastal regions experience increased lightning strikes, which decreases as distance from coastal areas increases.
- Eastern AL experienced fewer strikes consistently across the 10-year period.
- 2011 experienced the most lightning strikes of the years in the 10-year period for MS and AL.
- 2019 and 2020 experienced the least lightning strikes of the years in the 10-year period for MS and AL.
- More than 50% of annual lightning strikes occur during the summer (June, July, August) months for MS and AL.
- Less than 10% of annual lightning strikes occur during the autumn (September, October, November) and winter (January, February, December) months for MS and AL.
- July experiences the highest number of lightning strikes for MS and AL. November experiences the lowest number of lightning strikes for MS and AL.
- There is an increase in lightning strikes in MS and AL between the hours of 4 p.m. CST and 4 a.m. CST.
- July strike totals for surveyed broiler farm locations were elevated in 2011, 2012, 2015, and 2016.

Broiler farm density indicates MS farms in a closer proximity to coastal areas than AL farms. Subsequently, MS houses have a higher probability of experiencing lightning strikes than AL houses due to increase in lightning strike densities near coastal counties. However, AL has a substantial density of farms in close proximity to the coast as well. Producers should ensure lightning protection systems are installed and operational consistently due to an increased density of lightning strikes near coastal areas. Producers should consistently maintain and improve electrical grounding systems and equipment to protect their operations from lightning-induced damage and potential fires.

Lightning strikes vary annually. Increased lightning strikes during summer months, especially July, indicates producers should ensure electrical grounding systems and equipment are properly connected and installed prior to the summer months. Elevated temperatures during these summer months also shortens the time before the birds experience increased thermal stress. The majority of lightning strikes were observed during evening and night hours for MS and AL. Producers, employees, and broiler service technicians are not normally on site during these hours. Power companies and emergency medical services can also be difficult to reach or have increased response times to remote areas. This indicates producers need to have all alarms, backup systems, and electrical grounding systems and equipment installed and operational to maintain production and safety on their farms.

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CHAPTER IV

CONCLUSIONS

In summary, fluctuations in lightning strike patterns across MS and AL indicate the need of proper electrical grounding systems, especially for commercial broiler production facilities near the Gulf Coast. Lightning strikes are elevated during the summer months, particularly in July. Elevated temperatures during summer months, especially July when lightning is also elevated, increase the possibility of thermal stress in broilers without environmental control systems. Producers should ensure all parts of the electrical grounding system are properly connected annually before the summer months, preferably early spring. Future research into lightning polarity and weather patterns across the Southeast U.S. could help to predict lightning patterns across broiler producing areas to better protect broiler operations from lightning-induced damage.

Standardization of broiler house construction and commissioning practices would serve to streamline recommendations and best management practices for grounding systems and other structures susceptible to severe weather event damage. This could also benefit insurance companies in calculating loss claims across broiler houses to minimize risk for insurers, potentially reducing insurance premiums on broiler producers. Utilization of Ufer grounding systems has shown to reduce resistance ratings in commercial broiler production operations. Mitigation of lightning strike damage through improved grounding practices could help to reduce the risk of insuring broiler operations, potentially reducing insurance premiums for broiler producers. Further research into how environmental factors, such as soil type, moisture content, vegetation, and soil resistivity, affect resistance ratings could serve to reduce resistance ratings on broiler operations, further mitigating damage from lightning, over-currents, and excess voltage. Implementation of Ufer grounding systems in new construction and further validation of existing Ufer grounding systems could serve to better protect broiler operations from lightning-induced damage.