



**DEVELOPMENT OF SLOW ELECTRIC FIELD SENSOR IN  
LEGOLAND MALAYSIA RESORT**



**ERMAN BIN RAMLI**

**MASTER OF SCIENCE IN ELECTRONIC ENGINEERING**

**2024**



**Faculty of Electronics and Computer Technology and  
Engineering**

**DEVELOPMENT OF SLOW ELECTRIC FIELD SENSOR IN  
LEGOLAND MALAYSIA RESORT**

اونيور سيتي تیکنیکل ملیسیا ملاک  
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**Erman Bin Ramli**

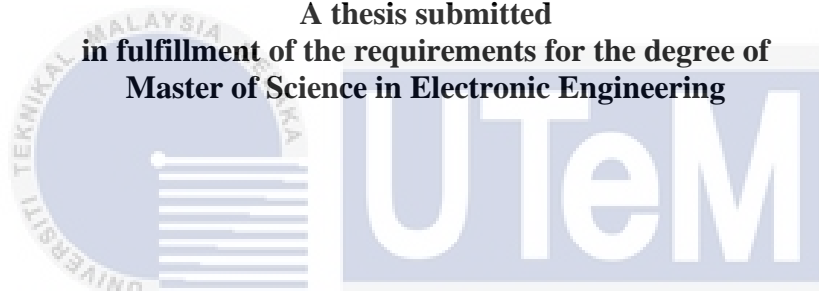
**Master of Science in Electronic Engineering**

**2024**

**DEVELOPMENT OF SLOW ELECTRIC FIELD SENSOR IN  
LEGOLAND MALAYSIA RESORT**

**ERMAN BIN RAMLI**

A thesis submitted  
in fulfillment of the requirements for the degree of  
Master of Science in Electronic Engineering



**Faculty of Electronics and Computer Technology and Engineering**

اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2024**

## DEDICATION

Dedicated to ALLAH Almighty,

My beloved wife Suria Hani Shamsuri,

My loving family members for your infinite and unfading love, sacrifice, patience,

encouragement and best wishes.

My colleagues and best friends

Mohd Riduan Ahmad,

Shamsul Ammar Shamsul Baharin,



Selventhran Ratnagandhi,

Zairi Muhamad,

Firza Fahmi,

Murni Masrom,

اونيور سیتی اونیورسیتی  
Dian Hafini Yusoff, كل ملیسیا ملاك

And to everyone.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## ABSTRACT

Considering the industry's needs in general and LEGOLAND Malaysia Resort's specific requirements, LEGOLAND Malaysia Resort only required a short-range lightning detection system with a distance and radius of 7-8 km or less. This lightning information was needed to inform and warn visitors to move from open or wet areas to safe sheltered areas such as buildings or shade. Based on these requirements and considering the characteristics of the slow electric field, indeed it was deemed sufficient and suitable as a prediction method for LEGOLAND Malaysia Resort. This research pioneered a novel approach by delving into the analysis of the slow electric field, aiming to develop a waveform analysis to estimate the distance and radius of lightning occurrences at LEGOLAND Malaysia Resort. The newly implemented and installed Lightning Detection System (LDS) at LEGOLAND Malaysia Resort leveraged a straightforward and cost-effective setup, incorporating a capacitive antenna, slow and fast electric field sensors and dedicated data analysis software. In order to achieve accurate data, proper grounding and isolation from electrical noise were essential, as signal interference from power lines, towers or machinery could potentially trigger false signals. The effectiveness and accuracy of the LDS underwent a rigorous comparison with data from a weather service provider subscribed monthly by LEGOLAND Malaysia Resort, namely the Data Transmission Network (DTN), where lightning information from the DTN was sent to LEGOLAND Malaysia Resort via email. A comprehensive data set of approximately 50,000 lightning strikes was collected between July 2020 and July 2022. The analysis was made with a focus on December 2020 as the peak of the rainy and lightning season in Malaysia, showed that the LDS demonstrated superior lightning detection capabilities compared to DTN, identifying 69% of strike compared to DTN 31%. Negative Cloud-to-Ground (-NCG) lightning dominated the data, accounting for over 75% of all strikes at Legoland Malaysia Resort, Intracloud (IC) lightning represented 13%, while Narrow Bipolar Event (NBE) and Positive Cloud-to-Ground (+PCG) lightning comprised 5% and 2%, respectively. -NCG lightning was the most common type of cloud-to-ground lightning, accounting for about 70% of all lightning worldwide. Apart from that, 45% of lightning occurred Within the Reversal Distance (WRD), while the remaining 55% happened Beyond the Reversal Distance (BRD). This research contributed detailed documentation on the analysis of slow electric field data, encompassing waveform patterns and key characteristics. The comparative evaluation between the novel system and the current subscription service at LEGOLAND Malaysia Resort shed light on the efficiency and capabilities of the newly introduced methodology and served as a valuable resource for future research and refinement of lightning detection systems.

# **PEMBANGUNAN PENDERIA MEDAN ELEKTRIK TERUBAH PERLAHAN DI LEGOLAND MALAYSIA RESORT**

## **ABSTRAK**

*Dengan mengambil kira keperluan industri secara am dan keperluan Taman Tema LEGOLAND Malaysia secara khususnya, Taman Tema LEGOLAND Malaysia hanya memerlukan sistem pengesanan kilat jarak dekat dengan jarak dan jejari 7-8 km atau kurang. Maklumat kilat ini diperlukan untuk memaklumkan dan memberi amaran kepada pengunjung agar berpindah dari kawasan lapang dan basah ke kawasan terlindung yang selamat seperti bangunan atau berbumbung. Berdasarkan keperluan ini dan mengambil kira ciri-ciri medan elektrik perlahan, ia dianggap sangat sesuai sebagai kaedah mengesan kilat untuk Taman Tema LEGOLAND Malaysia. Penyelidikan ini mempelopori pendekatan dengan mendalami analisis medan elektrik perlahan, bertujuan untuk membangunkan analisis bentuk gelombang untuk menganggarkan jarak dan jejari kilat di Taman Tema LEGOLAND Malaysia. Sistem Pengesanan Kilat (LDS) yang baru dilaksanakan dan telah dipasang di Taman Tema LEGOLAND Malaysia memanfaatkan persediaan yang mudah dan kos efektif, menggabungkan antena kapasitif, penderia medan elektrik perlahan dan pantas serta perisian analisis data khusus. Untuk mendapatkan data yang tepat, pbumian dan pengasingan yang betul daripada hingar elektrik adalah penting, ini kerana gangguan isyarat daripada talian kuasa, menara atau jentera berpotensi mencetuskan isyarat palsu. Keberkesanan dan ketepatan LDS telah melalui perbandingan yang ketat dengan data daripada penyedia perkhidmatan cuaca yang dilanggan setiap bulan oleh Taman Tema LEGOLAND Malaysia, iaitu Rangkaian Penghantaran Data (DTN), di mana maklumat kilat daripada DTN dihantar ke Taman Tema LEGOLAND Malaysia melalui e-mel. Set data komprehensif kira-kira 50,000 kejadian kilat telah dikumpul antara Julai 2020 sehingga Julai 2022. Analisis dibuat dengan tumpuan pada Disember 2020 sebagai kemuncak musim hujan dan kilat di Malaysia, LDS menunjukkan keupayaan pengesanan kilat yang unggul berbanding DTN, dengan mengesan 69% kejadian kilat berbanding DTN 31%. Kilat Negatif Awan-ke-Tanah (-NCG) mendominasi data, menyumbang lebih 75% daripada semua kejadian kilat di Taman Tema LEGOLAND Malaysia, kilat Antara-Awan (IC) mewakili 13%, manakala kilat Bipolar Sempit (NBE) dan kilat Positif Awan-ke-Tanah (+PCG) terdiri daripada 5% dan 2%, masing-masing. Kilat -NCG ialah jenis kilat awan-ke-tanah yang paling kerap berlaku, menyumbang kira-kira 70% daripada semua kilat di seluruh dunia. Selain itu, 45% kilat berlaku dalam Jarak Pembalikan (WRD), manakala 55% lagi berlaku di Luar Jarak Pembalikan (BRD). Penyelidikan ini menyumbangkan dokumentasi terperinci tentang analisis data medan elektrik perlahan, merangkumi corak bentuk gelombang dan ciri-ciri utama. Penilaian perbandingan antara sistem novel dan perkhidmatan langganan semasa di Taman Tema LEGOLAND Malaysia memberi penerangan tentang kecekapan dan keupayaan metodologi yang baru diperkenalkan dan berfungsi sebagai sumber berharga untuk penyelidikan masa depan dan penghalusan sistem pengesanan kilat.*

## ACKNOWLEDGEMENTS

Embarking on this thesis journey has been transformative, and I deeply appreciate the support that made it possible. First and foremost, I owe immense gratitude to my advisor, Dr. Mohd Riduan Ahmad, for their unwavering guidance and encouragement throughout the process. Their insightful feedback, patience, expertise, valuable suggestions and challenging questions that pushed me to refine my work were instrumental in shaping this research. Beyond academia, I owe a debt of gratitude to the participants who generously shared their time and insights with me. Their participation was the heart of this research, and I am truly humbled by their willingness to engage.

Among the most important and also the main character in this research is LEGOLAND Malaysia Resort who has allowed me to carry out this research at LEGOLAND Malaysia Resort itself, without permission and cooperation from LEGOLAND Malaysia Resort, it is inevitable that this research could not be carried out and become a reality. Thank you very much to you, Legoland Malaysia Resort, “everything is awesome” and I am indebted to you.

Finally, I want to express my deepest thanks to my family and friends for their unwavering love and support. They believed in me even when I doubted myself, and their encouragement kept me going during challenging moments. This thesis is as much theirs as it is mine.

## TABLE OF CONTENTS

	PAGE
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>vi</b>
<b>LIST OF FIGURES</b>	<b>viii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xxxiii</b>
<b>LIST OF PUBLICATIONS</b>	<b>xxxvi</b>
<b>LIST OF APPENDICES</b>	<b>xxxvii</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Introduction	1
1.2 Research Background	1
1.3 Problem Statements	2
1.4 Objectives	4
1.5 Scopes of Research	4
1.6 Research Gap and Contribution	5
1.7 Thesis Organization	6
<b>2. LITERATURE REVIEW</b>	<b>7</b>
2.1 Introduction	7
2.2 Overview of Lightning Flashes	7
2.2.1 Cloud-to-Ground (CG) Lightning	9
2.2.2 Intracloud (IC) Intercloud or Cloud-to-Cloud (CC) Lightning	12
2.2.3 Initial Breakdown Process (IBP)	16
2.2.4 Narrow Bipolar Events (NBE)	18
2.3 Overview of Lightning Localization Techniques	21
2.3.1 Magnetic Direction Finding (MDF)	22
2.3.2 Time of Arrival (TOA)	24
2.3.3 Interferometer Technique (ITF)	31
2.3.4 Direction of Arrival (DOA)	40
2.4 Atmospheric Electric Field	42
2.5 Critical Review	48
2.6 Summary	49



<b>3.</b>	<b>METHODOLOGY</b>	<b>51</b>
3.1	Introduction	51
3.2	Overview of Research Studies	51
3.3	Design, Development and Construction of Lightning Detection System	53
3.3.1	Capacitive Antenna	56
3.3.2	Buffer Amplifier Circuit	61
3.3.3	Picoscope	70
3.3.4	Installation of Lightning Detection System	73
3.3.5	Troubleshooting of Lightning Detection System	83
3.4	Data collection	89
3.5	Data Transmission Network (DTN)	92
3.6	Summary	94
<b>4.</b>	<b>RESULT AND DISCUSSION</b>	<b>96</b>
4.1	Introduction	96
4.2	Lightning Waveform Collection	96
4.3	Type of Lightning Waveform Collection	96
4.4	Localization Data Set	101
4.4.1	Case Study 1	107
4.4.2	Case Study 2	111
4.4.3	Case Study 3	120
4.4.4	Case Study 4	125
4.4.5	Case Study 5	135
4.4.6	Case Study 6	149
4.4.7	Case Study 7	154
4.4.8	Case Study 8	177
4.5	Statistical Analysis	189
4.5.1	Detection Efficiency	189
4.5.2	Type of Lightning	191
4.5.3	Lightning Localization	193
4.5.4	Fast Electric Field Intensity	195
4.5.5	Return Stroke Slow Electric Field Intensity	196
4.5.6	Static Slow Electric Field Intensity	197
4.6	Discussion	199
4.7	Summary	205
<b>5.</b>	<b>CONCLUSION AND FUTURE WORKS</b>	<b>206</b>
5.1	Conclusion	206
5.2	Future Works	208
	<b>REFERENCES</b>	<b>210</b>
	<b>APPENDICES</b>	<b>225</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	Research gap and contribution	5
2.1	Steps in a CG Lightning Discharge	10
2.2	Characteristics of each type of CG Lightning	11
2.3	Effects of CG Lightning	12
2.4	Steps in an IC Lightning Discharge	14
2.5	Steps in CC Lightning Discharge	14
2.6	Effects of IC and CC Lightning	15
2.7	The sequence of IBP	17
2.8	Characteristics of NBE	19
2.9	Applications of MDF	23
2.10	Advantages of MDF	23
2.11	Disadvantages of MDF	23
2.12	Applications of TOA	24
2.13	Advantages of TOA	25
2.14	Disadvantages of TOA	25
2.15	Comparison on studies used TOA and MDF techniques	26
2.16	Comparison on studies used TDOA	30
2.17	Applications of ITF technique	31
2.18	Advantages of ITF technique	31
2.19	Disadvantages of ITF technique	32
2.20	Previous studies using ITF technique	35

2.21	Applications of DOA lightning tracking	40
2.22	Several and common DOA estimation methods for lightning	41
2.23	DOA lightning tracking challenges and future directions	42
2.24	Comparison between Fast and Slow Electric Field	45
2.25	Key difference between Fast and Slow Electric Field	46
3.1	Software requirement	54
3.2	Hardware requirement	55
3.3	Characteristic of designing and constructing capacitive antenna	61
3.4	Capacitance and resistance value for upper frequency limit calculations	63
3.5	Slow and fast electric field sensor components list	68
3.6	Picoscope 4000 series specification	71
4.1	Lightning localization comparison	97
4.2	Types of lightning and their differences	98
4.3	Comparison on studies used Lightning Detection System (LDS) and Data Transmission Network (DTN)	102
4.4	Reasons for sensor coupling	199
4.5	Key techniques for distinguishing between lightning and noise	200
4.6	The importance of grounding	202
4.7	The importance of keeping the LDS away from other electrical sources	203
4.8	The importance of installing LDS in the area to be protected	204

## LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Types of lightning (a) Cloud-to-Air (b) Cloud-to-Ground (c) Intracloud (d) Intercloud (Zulkurnain Abdul Malek, 2017; Lightning Awareness – SHE Conference)	8
2.2	Types of CG lightning (a) Downward Positive (b) Upward Negative (c) Upward Positive (d) Downward Negative (Hwang et al., 2022)	9
2.3	(a) IC lightning (b) CC lightning (Photo created by Author)	13
2.4	The sequence of IBP (Lutgens and Tarbuck, 2000; The Atmosphere - 8th edition)	16
2.5	Variations in lightning activity and thundercloud top of the Hangzhou Bay case (Liu et al., 2021)	20
2.6	Lightning localization techniques (Ammar Al-Ammari, 2019)	21
2.7	The atmospheric electric field (Baghdasaryan et al., 2015; 5th International TEPA Symposium - Presentation transcript)	44
2.8	The atmospheric electric field variation (Srivastava et al., 2015)	45
2.9	Fast and slow electric field changes (Yuan et al., 2017)	47
3.1	Flow chart of the research studies and work	51
3.2	Overview and installation location of the lightning detection system	53

3.3	Capacitive antenna design	60
3.4	Capacitive antenna measurement	60
3.5	Circuit diagram of high-speed buffer amplifier circuit (Edirisinghe et al., 2001)	62
3.6	AC analysis for slow electric field sensor	65
3.7	AC analysis for fast electric field sensor	65
3.8	Flow chart of the designing and constructing of lightning detection system for slow and fast electric field sensor	67
3.9	Multisim circuit simulation for slow electric field sensor	69
3.10	Multisim circuit simulation for fast electric field sensor	69
3.11	Slow and fast electric field sensors, calibrated using LeCroy Wavesurfer 3054 oscilloscope	70
3.12	Picoscope 4000 series	70
3.13	Picoscope 6 software graphical user interface (GUI)	72
3.14	Capacitive antenna	73
3.15	Picoscope, power supply, cables, and tools	73
3.16	Location to place the capacitive antenna, on the rooftop of the S&A Building	75
3.17	Connection between the capacitive antenna to the sensor using a male-female BNC connector	76
3.18	The box containing the sensor must be tightly fastened	77
3.19	+12VDC and -12VDC power supply	77
3.20	Capacitive antenna to buffer amplifier circuit connection	78

3.21	Installation and connection of picoscope 4000 series with buffer amplifier circuit and desktop computer	79
3.22	Picoscope 4000 series connection	79
3.23	Picoscope 6 software sample interval setting	80
3.24	Picoscope 6 software resolution setting	80
3.25	Picoscope 6 software lightning strikes event-triggered setting	80
3.26	Picoscope 6 software display with two sources A and B	81
3.27	Picoscope 6 software lightning strikes event-triggered data capture setting	82
3.28	Signal obtained with a very high noise level received on rooftop of S&A building LEGOLAND Malaysia Resort at 4:26:07 PM on March 8 <sup>th</sup> , 2020	83
3.29	Signal obtained with no noise received on rooftop of S&A building LEGOLAND Malaysia Resort at 7:19:29 PM on March 12 <sup>th</sup> , 2020	84
3.30	Signal obtained with noise received on rooftop of S&A building LEGOLAND Malaysia Resort at 3:16:10 PM on April 11 <sup>th</sup> 2020	85
3.31	Celcom telecommunication tower and air conditioning compressor on rooftop of S&A building	86
3.32	Chemical storeroom LEGOLAND Malaysia Resort	87
3.33	Disassemble and reassemble of lightning detection system	88
3.34	Lightning detection system new location, on rooftop of chemical storeroom LEGOLAND Malaysia Resort	88

3.35	A complete cycle flow chart of how data collection has been done with the lightning detection system	89
3.36	Lightning strike captured at 3:9:26 PM on December 3 <sup>rd</sup> 2020	90
3.37	Slow electric field waveform captured at 3:9:26 PM on December 3 <sup>rd</sup> , 2020	91
3.38	Fast electric field waveform captured at 3:9:26 PM on December 3 <sup>rd</sup> , 2020	91
3.39	Data Transmission Network (DTN)	92
3.40	Email DTN to LEGOLAND Malaysia Resort which provides information such as weather and lightning	93
3.41	Email DTN to LEGOLAND Malaysia Resort which provides information about lightning and graphical user interface	94
4.1	Types of lightning waveforms captured by lightning detection system, (a) Narrow Bipolar Event (NBE) and (b) Intracloud (IC)	99
4.2	Types of lightning waveforms captured by lightning detection system, (a) Negative Cloud-to-Ground (-NCG) and (b) Positive Cloud-to-Ground (+PCG)	100
4.3	DTN data, no lightning observed within 8 km in the last 15 min captured at 3:42 PM on December 3 <sup>rd</sup> 2020	108

4.4	LDS data, slow electric field waveform captured at 3:24:21 PM on December 3 <sup>rd</sup> 2020, type of lightning is IC and it is WRD with return stroke amplitude $3.33 \times 10^{-1}$ and static amplitude $-1.76 \times 10^{-1}$	109
4.5	LDS data, fast electric field waveform captured at 3:24:21 PM on December 3 <sup>rd</sup> 2020, type of lightning is IC and it is WRD with amplitude $4.55 \times 10^{-1}$	109
4.6	LDS data, slow electric field waveform captured at 3:09:26 PM on December 3 <sup>rd</sup> 2020, type of lightning is IC and it is WRD with return stroke amplitude $2.38 \times 10^{-1}$ and static amplitude $-5.45 \times 10^{-1}$	110
4.7	LDS data, fast electric field waveform captured at 3:09:26 PM on December 3 <sup>rd</sup> 2020, type of lightning is IC and it is WRD with amplitude $3.30 \times 10^{-1}$	110
4.8	DTN data, no lightning observed within 16 km in the last 15 min captured at 4:33 PM on December 9 <sup>th</sup> 2020	111
4.9	LDS data, slow electric field waveform captured at 4:32:25 PM on December 9 <sup>th</sup> 2020, type of lightning is NBE and it is WRD with return stroke amplitude $2.68 \times 10^{-2}$ and static amplitude $-8.41 \times 10^{-1}$	112
4.10	LDS data, fast electric field waveform captured at 4:32:25 PM on December 9 <sup>th</sup> 2020, type of lightning is NBE and it is WRD with amplitude $-6.54 \times 10^{-1}$	112



4.11	DTN data, lightning has occurred within warning area about 5.8 km to the east captured at 6:06 PM on December 9 <sup>th</sup> 2020	113
4.12	LDS data, slow electric field waveform captured at 6:06:57 PM on December 9 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with return stroke amplitude $1.33 \times 10^{-2}$ and static amplitude $-4.86 \times 10^{-1}$	114
4.13	LDS data, fast electric field waveform captured at 6:06:57 PM on December 9 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with amplitude $5.88 \times 10^{-1}$	114
4.14	LDS data, slow electric field waveform captured at 6:06:05 PM on December 9 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with return stroke amplitude $3.09 \times 10^{-1}$ and static amplitude $-5.51 \times 10^{-1}$	115
4.15	LDS data, fast electric field waveform captured at 6:06:05 PM on December 9 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with amplitude $3.03 \times 10^{-1}$	115
4.16	DTN data, lightning has occurred within advisory area about 19 km to the east captured at 6:37 PM on December 9 <sup>th</sup> 2020	116
4.17	LDS data, slow electric field waveform captured at 6:36:23 PM on December 9 <sup>th</sup> 2020, type of lightning is NBE and it is BRD with return stroke amplitude $2.35 \times 10^{-1}$ and static amplitude $-4.76 \times 10^{-2}$	117

4.18	LDS data, fast electric field waveform captured at 6:36:23 PM on December 9 <sup>th</sup> 2020, type of lightning is NBE and it is BRD with amplitude $2.41 \times 10^{-1}$	117
4.19	DTN data, no lightning observed within 24 km in the last 15 min captured at 7:03 PM on December 9 <sup>th</sup> 2020	118
4.20	LDS data, slow electric field waveform captured at 6:52:15 PM on December 9 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.63 \times 10^{-1}$ and static amplitude $-3.14 \times 10^{-2}$	119
4.21	LDS data, fast electric field waveform captured at 6:52:15 PM on December 9 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $2.15 \times 10^{-1}$	119
4.22	DTN data, lightning has occurred within caution area about 15.6 km to the northwest captured at 2:31 PM on December 10 <sup>th</sup> 2020	120
4.23	LDS data, slow electric field waveform captured at 2:31:32 PM on December 10 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.04 \times 10^{-1}$ and static amplitude $-4.44 \times 10^{-1}$	121
4.24	LDS data, fast electric field waveform captured at 2:31:32 PM on December 10 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $1.65 \times 10^{-1}$	121

4.25	DTN data, lightning has occurred within your warning area about 6.0 km to the northeast captured at 3:35 PM on December 10 <sup>th</sup> 2020	122
4.26	LDS data, slow electric field waveform captured at 3:26:32 PM on December 10 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with return stroke amplitude $9.60 \times 10^{-1}$ and static amplitude $-5.60 \times 10^{-1}$	123
4.27	LDS data, fast electric field waveform captured at 3:26:32 PM on December 10 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with amplitude $8.78 \times 10^{-1}$	123
4.28	LDS data, slow electric field waveform captured at 3:15:16 PM on December 10 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with return stroke amplitude $8.61 \times 10^{-2}$ and static amplitude $-3.98 \times 10^{-1}$	124
4.29	LDS data, fast electric field waveform captured at 3:15:16 PM on December 10 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with amplitude $1.15 \times 10^{-1}$	124
4.30	DTN data, no lightning observed within 8 km in the last 15 min captured at 3:42 PM on December 15 <sup>th</sup> 2020	125
4.31	LDS data, slow electric field waveform captured at 3:37:23 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.33 \times 10^{-1}$ and static amplitude $-3.65 \times 10^{-2}$	126

4.32	LDS data, fast electric field waveform captured at 3:37:23 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $6.65 \times 10^{-1}$	126
4.33	LDS data, slow electric field waveform captured at 3:35:26 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.74 \times 10^{-1}$ and static amplitude $-6.33 \times 10^{-4}$	127
4.34	LDS data, fast electric field waveform captured at 3:35:26 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $7.72 \times 10^{-1}$	127
4.35	LDS data, slow electric field waveform captured at 3:35:06 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.93 \times 10^{-1}$ and static amplitude $-6.93 \times 10^{-4}$	128
4.36	LDS data, fast electric field waveform captured at 3:35:06 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $7.83 \times 10^{-1}$	128
4.37	LDS data, slow electric field waveform captured at 3:34:36 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.63 \times 10^{-1}$ and static amplitude $-5.43 \times 10^{-4}$	129
4.38	LDS data, fast electric field waveform captured at 3:34:36 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $7.47 \times 10^{-1}$	129

4.39	LDS data, slow electric field waveform captured at 3:33:18 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.40 \times 10^{-1}$ and static amplitude $-2.27 \times 10^{-4}$	130
4.40	LDS data, fast electric field waveform captured at 3:33:18 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $7.07 \times 10^{-1}$	130
4.41	LDS data, slow electric field waveform captured at 3:33:13 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.67 \times 10^{-1}$ and static amplitude $-1.52 \times 10^{-4}$	131
4.42	LDS data, fast electric field waveform captured at 3:33:13 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $7.48 \times 10^{-1}$	131
4.43	LDS data, slow electric field waveform captured at 3:33:05 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with return stroke amplitude $2.83 \times 10^{-1}$ and static amplitude $-4.58 \times 10^{-2}$	132
4.44	LDS data, fast electric field waveform captured at 3:33:05 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with amplitude $7.80 \times 10^{-1}$	132
4.45	DTN data, lightning has occurred within warning area about 4.6 km to the southeast captured at 3:53 PM on December 15 <sup>th</sup> 2020	133

4.46	LDS data, slow electric field waveform captured at 3:53:58 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with return stroke amplitude $8.53 \times 10^{-1}$ and static amplitude $-8.63 \times 10^{-2}$	134
4.47	LDS data, fast electric field waveform captured at 3:53:58 PM on December 15 <sup>th</sup> 2020, type of lightning is -NCG and it is WRD with amplitude $9.99 \times 10^{-1}$	134
4.48	DTN data, no lightning observed within 8 km in the last 15 min captured at 3:56 PM on December 17 <sup>th</sup> 2020	135
4.49	LDS data, slow electric field waveform captured at 3:55:40 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $3.19 \times 10^{-1}$ and static amplitude $-3.09 \times 10^{-3}$	136
4.50	LDS data, fast electric field waveform captured at 3:55:40 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $3.28 \times 10^{-1}$	136
4.51	LDS data, slow electric field waveform captured at 3:55:30 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.62 \times 10^{-1}$ and static amplitude $-4.54 \times 10^{-1}$	137
4.52	LDS data, fast electric field waveform captured at 3:55:30 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $2.60 \times 10^{-1}$	137

4.53	LDS data, slow electric field waveform captured at 3:52:08 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $4.12 \times 10^{-1}$ and static amplitude $-3.70 \times 10^{-3}$	138
4.54	LDS data, fast electric field waveform captured at 3:52:08 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $4.22 \times 10^{-1}$	138
4.55	LDS data, slow electric field waveform captured at 3:48:56 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.20 \times 10^{-1}$ and static amplitude $-1.76 \times 10^{-1}$	139
4.56	LDS data, fast electric field waveform captured at 3:48:56 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $2.20 \times 10^{-1}$	139
4.57	LDS data, slow electric field waveform captured at 3:45:36 PM on December 17 <sup>th</sup> 2020, type of lightning is +PCG and it is WRD with return stroke amplitude $2.70 \times 10^{-1}$ and static amplitude $-1.00 \times 10^0$	140
4.58	LDS data, fast electric field waveform captured at 3:45:36 PM on December 17 <sup>th</sup> 2020, type of lightning is +PCG and it is WRD with amplitude $2.68 \times 10^{-1}$	140

4.59	LDS data, slow electric field waveform captured at 3:45:01 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $2.84 \times 10^{-1}$ and static amplitude $-4.15 \times 10^{-1}$	141
4.60	LDS data, fast electric field waveform captured at 3:45:01 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $2.79 \times 10^{-1}$	141
4.61	LDS data, slow electric field waveform captured at 3:41:21 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with return stroke amplitude $1.40 \times 10^{-1}$ and static amplitude $-4.51 \times 10^{-1}$	142
4.62	LDS data, fast electric field waveform captured at 3:41:21 PM on December 17 <sup>th</sup> 2020, type of lightning is -NCG and it is BRD with amplitude $1.39 \times 10^{-1}$	142
4.63	LDS data, slow electric field waveform captured at 3:36:12 PM on December 17 <sup>th</sup> 2020, type of lightning is IC and it is BRD with return stroke amplitude $2.40 \times 10^{-1}$ and static amplitude $-2.70 \times 10^{-1}$	143
4.64	LDS data, fast electric field waveform captured at 3:36:12 PM on December 17 <sup>th</sup> 2020, type of lightning is IC and it is BRD with amplitude $2.40 \times 10^{-1}$	143
4.65	DTN data, no lightning observed within 16 km in the last 15 min captured at 4:04 PM on December 17 <sup>th</sup> 2020	144