UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF LIGHTNING-GENERATED ELECTRIC FIELDS AND DEVELOPMENT OF AUTOMATED MEASURING SYSTEM FOR CLOUD-TO-GROUND LIGHTNING IN MALAYSIA

SYAHRUN NIZAM BIN MD ARSHAD @ HASHIM

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By

SYAHRUN NIZAM BIN MD ARSHAD @ HASHIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Philosophy

May 2017

Dedicated to my beloved mother, Siyah binti Bujang, my father, the Late Md Arshad @ Hashim bin Don, my truly loved wife Wan Syamimah binti Abd Sari and my family, for your Patience, Love, Encouragement, and Sacrifices.....

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Philosophy

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May 2017

Chair : Mohd Zainal Abidin bin Ab. Kadir, PhD

Faculty : Engineering

Lightning flash produces electric discharges naturally into atmosphere which somehow result in negative consequences especially to power, electronic and communication systems. Hence, the knowledge of such characteristic is crucial to be obtained to fulfil the task of mitigating lightning problems that may occur. Furthermore, most studies regarding this were done in the temperate and sub-tropical regions manually which time consuming for analysing a timeframe purposes. This is due to the reason that an automated system is not available in the present market. Thus, this study is aimed to produce an automated measuring system for cloud-to-ground in Malaysia in order to reduce the analysed time. Measurements of the generated electric fields were done using parallel plate antenna system from May to October 2013 at Universiti Putra Malaysia, Serdang, Selangor, Malaysia, where the measurement site has a geographical coordinate of 2°59'19.9"N latitude and 101°43'29.8"E longitude. It is known that Malaysia is generally a tropical climate country with maximum monsoon rain occurring from October to December due to southwest monsoon and inter monsoon period.

This thesis presents the characteristics of cloud-to-ground lightning generated vertical electric field waveforms recorded in Malaysia using Automated Characterisation of Lightning Electric Fields–Center of Electromagnetic and Lightning Protection (ACLEF-CELP). A total of 142 return strokes of negative lightning and 34 return strokes of positive lightning were found during the measurement period, and with preliminary breakdown pulses. The main purpose of this study includes characterisations of 12 and 4 types criteria to be considered for return stroke and preliminary breakdown pulses, respectively.

Analysis of the measured cloud-to-ground lightning data is done using Matlab software which is used to analyse the data and serves as a database. It is found that, the initial peaks of electric field and its derivative for first return strokes are larger than those for the subsequent return strokes for both positive and negative return strokes. Data were analysed using ACLEF-CELP system and compared to another set of data with a similar climate condition. Both manual and automated data were compared and it is found that they are compatible with each other. Also, comparison of overall results

with published data such as from Sri Lanka, Sweden, Germany, Japan and United States of America shows that several electric field and its derivative parameters are affected by geographical region. The ACLEF-CELP system could reduce analysis time where cloud-to-ground lightning data could be easily characterized with increment of efficiency. This is important specially when dealing with numerous data such as from a cloud-to-ground lightning.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN MEDAN ELEKTRIK KILAT YANG DIHASILKAN DAN PEMBANGUNAN SISTEM MENGUKUR AUTOMATIK UNTUK KILAT AWAN-KE-BUMI DI MALAYSIA

Oleh

SYAHRUN NIZAM BIN MD ARSHAD @ HASHIM

Mei 2017

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Fakulti : Kejuruteraan

Kilat menghasilkan pelepasan elektrik secara semulajadi ke atmosfera yang mengakibatkan kesan negatif terutamanya kepada kuasa, sistem elektronik dan komunikasi. Oleh itu, pengetahuan bahawa ciri-ciri mesti diperolehi untuk memenuhi tugas meringankan masalah kilat yang mungkin berlaku. Selain itu, kebanyakan kajian mengenai topik ini dilakukan di kawasan sederhana dan sub-tropika dengan menggunakan sistem manual yang memakan masa terlalu lama untuk menganalisisnya. Ini dilakukan dengan alasan sistem automatik tidak tersedia di pasaran. Oleh itu, kajian ini bertujuan untuk mengurangkan masa untuk dianalisis data flash kilat awan ke tanah yang diperhatikan di Malaysia di kawasan tropika. Pengukuran medan elektrik yang dihasilkan telah dilakukan menggunakan sistem antena plat selari dari Mei hingga Oktober 2013 di Universiti Putra Malaysia, Serdang, Selangor, Malaysia, di mana tapak pengukuran mempunyai koordinat geografi 2°59'19.9 "N latitud dan 101°43 '29 .8 "E longitud. Adalah diketahui bahawa pada umumnya Malaysia mempunyai iklim tropika dengan maksimum hujan monsun yang berlaku dari Oktober hingga Disember akibat musim monsun barat daya dan tempoh monsun musim panas.

Tesis ini membentangkan ciri-ciri kilat Awan ke Tanah yang menghasilkan bentuk gelombang elektrik menegak yang direkodkan di Malaysia menggunakan Pencirian Automatik Medan Elektrik Kilat-Pusat Elektromagnet dan Perlindungan Kilat (ACLEF-CELP). Sebanyak 142 nyahcas sambaran kembali negatif dan 34 nyahcas sambaran kembali positif yang didapati dengan denyutan permulaan pecah tebat (PBP) hadir dan dianalisis. Tujuan utama kajian ini termasuk 12 dan 4 ciri-ciri kriteria untuk dipertimbangkan untuk nyahcas sambaran kembali dan PBP.

Kajian ini dilakukan menggunakan perisian Matlab yang digunakan untuk menganalisis data dan berfungsi sebagai pangkalan data. Puncak awal medan elektrik dan derivatifnya untuk nyahcas sambaran kembali pertama adalah lebih besar daripada mereka untuk nyahcas sambaran kembali berikutnya untuk kedua-dua nyahcas sambaran kembali positif dan negatif. Data dianalisis dengan menggunakan sistem ACLEF-CELP dan dibandingkan dengan set data yang lain di mana keadaan iklim yang sama. Kaedah manual dan data automatik dibanding dan didapati ianya serasi antara satu sama lain. Selain itu, perbandingan hasil keseluruhan dengan data terbitan

seperti di Sri Lanka, Sweden, Jerman, Jepun dan Amerika Syarikat menunjukkan bahawa beberapa medan elektrik dan parameter derivatifnya dipengaruhi oleh kawasan geografi. Sistem ACLEF-CELP dapat mengurangkan masa analisis di mana data kilat awan ke tanah dapat mudah dicirikan dengan peningkatan kecekapan. Ini penting terutamanya apabila berurusan dengan banyak data seperti dari petir awan ke tanah.

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I sincerely hope that this thesis will build the talents and self-confidence of the readers so that they will get some new ideas to build a new product better than this.

I certify that an Examination Committee has met on date of 5 May 2017 to conduct the final examination of Syahrun Nizam Md Arshad @ Hashim on his thesis entitled "Characterization of Lightning-Generated Electric Fields and Development Automated Measuring System for Cloud-to-Ground Lightning in Malaysia" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

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This is to confirm that:

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LIST OF ABBREVIATIONS AND NOTATIONS

ACLEF-CELP	Automated Characterisation of Lightning Electric Fields–Centre for Electromagnetic and Lighting Protection Research
AM	Arithmetic Mean
BIL	Breakdown, Intermediate and Leader
BL	Breakdown and Leader
CA	Cloud-to-Air
CG	Cloud-to-Ground
CELP	Centre for Electromagnetic and Lighting Protection Research
FRS	First Return Stroke
FT	Fourier Transform
GM	Geometric Mean
GUI	Graphic User Interface
IC	Cloud-to-Cloud
ICC	Initial Continuous Current
LEF	Lightning Electric Fields
LH0033	Buffer Amplifier
MRSM	Maktab Rendah Sains Mara
Max	Maximum
Med	Median
Min	Minimum
NLDN	Vaisala's U.S. National Lightning Detection Network
NO	Nitric Oxide
NO_x	Nitrogen Oxides
NO_2	Nitrogen Dioxide
PBP	Preliminary Breakdown Pulses
PCP	Positive Charge Pocket
RS	Return Stroke
SD	Standard Deviation
SNR	Signal Noise Ratio
SRS	Subsequence Return Stroke
STFT	Short-time Fourier Transform
TNBR	Tenaga Nasional Berhad Research
UPM	Universiti Putra Malaysia
URS	Undefined Return Stroke
VHF	Very High Frequency
WT	Wavelet Transform

LIST OF SYMBOLS

C_c	Capacitance between Cloud and Plate
C_g	Capacitance between Ground and Plate
dE/dt	Electric Field First Derivative
$E_{dE/dt}$	Peak Amplitude First Derivative
E_n	Vertical Electric Field
E_p	Peak Amplitude
E_{pbp}	Peak of Preliminary Breakdown Pulses
E_{sf}	Slow Front Amplitude
h	Plate Height Respect to Ground.
M_{AVG}	Average Multiplicity
N_g	Ground flash density
$T_{pbp\text{-}rs}$	Duration before Return Stroke of Preliminary Breakdown Pulses
T_{pbp}	Duration of Preliminary Breakdown Pulses
$T_{peakpbp}$	Peak Time of Preliminary Breakdown Pulses
$T_{FWHM\_dE/dt}$	Full Width Half Maximum First Derivative
$T_{peak\_dE/dt}$	Time to peak first derivative
T_{FWHM}	Full Width Half Maximum
T_{sf}	Slow Front Time
$T_{10\text{-}90}$	10 to 90 % Time
T_p	Peak Time
T_{zc}	Zero Crossing Time
V_c	Cloud Voltage Respect to Ground
V_g	Plate Voltage Respect to Ground

LIST OF SI UNITS

Quantity	Unit	Symbol
Thermodynamic temperature	Kelvin	K
Electric current	Ampere	A
Time	Second	s
Electrical potential	Volt	V
Electric charge	Coulomb	C

CHAPTER 1

INTRODUCTION

1.1 Background

Lightning is a transient and high current electrical discharge that travels between the atmosphere and the earth or between different parts of the atmosphere. The main sources of lightning are thunderclouds called cumulonimbus [1]. Lightning phenomena has existed long before human life in the earth came to be and it may even have played very important role in the progression of life in our world [2]. Lightning strikes involve the formation of channels carrying tens of kilo-amperes (kA) of electric current with channel peak temperatures in the order of 30,000 K.

It is therefore understandable that over the year, a large number of studies have been conducted to measure and model various features and effects of lightning discharges aimed at improving the understanding of the physics of the lightning phenomena and processes, and the role of lightning in the global circuit. Thus, lightning can generally be said to be a huge air electrical breakdown that can be categorized into Cloud-to-Ground (CG), Cloud-to-Cloud or Inter-Cloud (CC), Intra-Cloud (IC), and Cloud-to-Air (CA). Note that only CG will be considered in this study.

Thus, lightning strikes have far reaching and frequently disastrous consequences affecting important services such as aviation, power transmission and distribution equipment, communication lines and equipment, as well as the day-to-day human life. It has been recently established that the rate of lightning occurrence and the universal electric circuit in general can be significantly influenced by changes in the earth's environment. Furthermore, lightning activities may have consequences to life due to changes in the global balance of nitrogen oxides, mainly nitric oxide, and nitrogen dioxide which largely controls the amount of ozone in the atmosphere [3]. Lightning and other effects of thunderstorms have been a major concern for the aviation industry as it has been reported that a typical commercial plane is struck by lightning once a year on average e.g. plane struck by lightning after London, Gatwick airport take-off as reported by Rachel [3,4]. On 3 April 2014, Maktab Rendah Sains Mara (MRSM) student in Alor Gajah, Melaka, Malaysia died due to lightning strike. Over the years, a large number of studies have been conducted to measure and model various features and effects of lightning discharges, which served to improve our understanding of the physics of the lightning processes and the role of lightning in the global circuit.

Each year some 320,000 CG lightning discharges occur in the Malaysia alone. CG lightning can be further subdivided into four categories, based on the direction of the initial step leader and the polarity of cloud charge lowered to ground. There are downward negative, upward positive, downward positive and upward negative, which yields opposite-polarity labels for upward negative and upward positive [1]. A leader can be defined as a self-propagating discharge creating a channel with electrical conductivity. All CG lightning discharges involve a step leader initiated from either the cloud or the ground or a ground-based object, and this leader can carry either positive or negative charges. The propagation of the leader is due to the ionization known as

dielectric breakdown of the air that results from the high electric field at the tip of the leader. The electric field required for electrical breakdown of dry air between two parallel plate electrodes at sea level is about 3MV m−1 and decreases with decreasing pressure for example in higher altitudes and with the presence of hydrometeors [3]. Note that the downward negative and upward negative are refer as negative return stroke, also the downward positive and upward positive are refer as positive return stroke.

1.2 Problem Statement

Malaysia is well known as the "lightning crown of the world" especially in the Klang Valley as it receives the third highest number of lightning strike in the world [5]. A year's lightning month with an average of 86,000 strikes was recorded and has killed 224 people and injured 2,000 more in the last eight years in Peninsular Malaysia alone [5]. Most electrical outages as reported by TNB are due to lightning strike either in the transmission system or distribution network [5]. The lack of knowledge of the physical characteristics of such lightning phenomena, occurrence have accounted for millions of dollars loss of property as well as aggressively affecting people lives.
Based on these outages, a database of lightning faults must be made available where it can be used for several applications. However, this is only useful and fully utilized if a full wave shape of the return stroke is acquired. Previously, researches are done to characterize both negative and positive lightning return strokes manually, hence this work is meant to introduce an automated CG lightning characterization process using Automated Characterisation of Lightning Electric Fields–Center of Electromagnetic and Lightning Protection (ACLEF-CELP) system. Both manual and automated data are compared and it is found that the analysis could be found in chapter 4. The lightning characteristics are manually divided into several criteria which are width half maximum first derivative of return stroke $T_{FWHM\_dE/dt}$, peak amplitude first derivative of return stroke $E_{dE/dt,}$ time to peak first derivative of return stroke *Tpeak_dE/dt*, full width half maximum of return stroke T_{FWHM}, slow front amplitude of return stroke E_{sf}, slow front time of return stroke T_{sf}, 10 to 90 % time of return stroke $T_{10\text{-}90}$, peak amplitude of return stroke E_p, peak time of return stroke T_p, zero crossing time T_{zc} of return stroke. It also contains the PBP to RS time $T_{pbp\text{-}rs}$ and ratio of PBP to RS peak $R_{pbp\text{-}rs}$. By means this automated lightning characterisation process will speed up the process of characterization and reduce the data analysis time while increase the accuracy.

In Malaysia, normally lightning strokes considered are 2/50 μs and 8/20 μs for voltage and current standard, respectively as in IEC60071 standard. This standard is used to design lightning protection system such as for relay or surge arrestor for distribution network and transmission system. Nowadays, the lightning electrical field are determined conventional by analysing every frame of data acquired. This technique is prone to the lack of number of data and can contribute imperfection of data analysis due to human error. Problem occur when dealing with lightning characteristics manually has been faced by [6,8], such problems are the sample size below than 100 sample. From this problem, the proposed system which is developed based on comprehensive criteria that are manually implemented using GUI. It creates one-time development algorithm and can process thousands of data for characterization. This

work is aimed at characterization analysis of lightning phenomena using the electric field method.

Hence, the main purpose of this dissertation is to characterize lightning generated electric fields of different CG lightning RS with the aim of improving the understanding of the physical processes involved, infer various parameters of these processes, and develop, design and construct new automated model analysis system that can be used to describe their salient properties.

1.3 Aim an Objectives

The aim of this work is to characterize the lightning generated electric fields produced by negative and positive lightning return strokes. These are done using a proposed automated measuring system for CG lightning, named ACLEF-CELP. In order to achieve this particular aims the following objectives are considered;

1. To determine a set of criteria for each lightning electric field characteristic based on detected waveform (PBP, FRS, and SRS) for both negative and positive lightning.

2. To develop a suitable algorithm to differentiate negative and positive types of lightning return stroke.

3. To develop, design and construct a prototype of an automated lightning characterisation and monitoring system for single detection system.

1.4 Assumptions and Limitation of the Study

In the course of this research work, some assumptions were made and limitations encountered and set. The assumptions are made and the limitations set are in accordance to previous literatures and standard, which are;

1. Only vertical electric field component was taken into account as it is assumed to be sufficient to elaborate the lightning discharge behaviour.

2. The timeframe set for this study is limited to 200 ms due to the reason that this is can note that maximum range that can be obtained by the available oscilloscope. This is appropriate for analysing the data proposes.

3. The lightning discharge characterisations are based on 218 measured timeframes using one station located in Universiti Putra Malaysia, Selangor, Malaysia where the measurements are made within the period between May and October 2013. The measured data is considered sufficient to represent the discharge behaviour in tropical region and consist of lightning measurement campaign which are deal with numerous data space.

1.5 Contributions of Research

In a modest effort, this study has tried to contribute the following to research;
Comparative understanding of lightning discharge processes in difference meteorology conditions, such as tropics, subtropics and climates. This understanding will assist in characterising CG lightning electric field as it would contain both negative and positive return strokes. The automated characterisation system prototype named ACLEF-CELP was proposed for an automated characterization process of negative and positive lightning return strokes because it will overcome the manual characteristic which is reduce the time consumption for doing characterize data and increase the efficiency when it deal with huge number of data.

This thesis also characterizes Preliminary Breakdown Pulses (PBP), Return Stroke (RS) and Subsequence Return Stroke (SRS). It contains duration before return stroke, duration, peak and peak time of PBP. It also contains full width half maximum first derivative of return stroke $T_{FWHM\_dE/dt}$, peak amplitude first derivative of return stroke $E_{dE/dt}$, time to peak first derivative of return stroke $T_{peak\_dE/dt}$, full width half maximum of return stroke T_{FWHM}, slow front amplitude of return stroke E_{sf}, slow front time of return stroke T_{sf}, 10 to 90 % time of return stroke $T_{10\text{-}90}$, peak amplitude of return stroke E_p, peak time of return stroke T_p, zero crossing time T_{zc} of return stroke. It also contains the PBP to RS time $T_{pbp\text{-}rs}$ and ratio of PBP to RS peak $R_{pbp\text{-}rs}$. This represent a new method that identifies the specific slow front value and time that can be used to compare with the previous research findings.

This ACLEF-CELP system has an advantage of selecting CG lightning activity amongst many types of lightning activities. Its ability to obtain any captured data as Undefined Return Stroke (URS) in dataset file and not include it in the analysis is also an added advantage. It will define it as zero data parameter for the filtering signal to make sure it is purely a CG flashes.

1.6 Thesis Organization

This thesis consists of 5 chapters, where Chapter 1 describes the background of this project, problem statement, objectives and scope of work. Chapter 2 review of previous published works in the literatures. This involves works on lightning signal on RS, SRS and PBP. Also de-noising method for eliminates the noise in the signal are analysed and discussed.

Chapter 3 describes the development of the method used in this research, where the relationship between the developed method and findings from literature reviews is presented. Chapter 4 presents the results of the appropriately designed model these

findings were compared and validated accordingly with previous findings. Finally, Chapter 5 presents the conclusion of this study and suggestions for future works.

REFERENCES

[1] Uman, M. A., "The Lightning Discharge," Academic Press, 1987.

[2] A. Nag and V. Rakov, "Parameters of Electric Field Waveforms Produced by Positive Lightning Return Strokes," IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 4, pp. 932-939, 2014.

[3] Rakov, V. A., and M. A. Uman, "Lightning: Physics and Effects," Cambridge Univ. Press, New York, 2003.

[4] Rachel O'Donoghue "Virgin Atlantic flight struck by LIGHTNING after Gatwick take-off" United Kingdom Daily Star Online, 22nd March 2017, 2017

[5] The Star Online "Klang Valley buildings prone to lightning, say experts" National The Star Online, 1 November 2016, 2016.

[6] Weidman, C. D., and E. P. Krider, "The fine structure of lightning return stroke wave forms," J. Geophys. Res., 83(C12), pp.6239–6247, 1978.

[7] Le Vine, D. M., J. C.Willett, and J. C. Bailey, "Comparison of fast electric field changes from subsequent return strokes of natural and triggered lightning," J. Geophys. Res., 94, 13, pp.259–13,265, 1989.

[8] Cooray, V., and S. Lundquist, "On the characteristics of some radiation fields from lightning and their possible origin in possible origin in ground flashes," J. Geophys. Res., 87(C13), 11, pp.203–11,214, 1982.

[9] Bils, J.R., Thompson, E.M., Uman, M.A., and Mackeras, D.: "Electric field pulses in close lightning cloud flashes," J. Geophys. Res., 93, pp.15933–15940, 1988.

[10] Villanueva, Y., Rakov, V.A., Uman, M.A., and Brook, M.: "Microsecond-scale electric field pulses in cloud lightning discharges," J. Geophys. Res., 99, pp.14353–14360, 1994.

[11] Krehbiel, P. R., "The Earth's Electrical Environment, chap. The electrical structure of thunderstorms," pp. 90–113, National Academy Press, 1986.

[12] Simpson, G., and F. J. Scrase, "The distribution of electricity in thunderclouds," Proc. Roy. Soc. London A, 161, pp.309–52, 1937.

[13] Vonnegut, B., "Possible mechanism for the formation of thunderstorm electricity," Bull. Am. Meteor. Soc., 34, pp.378–81, 1953.

[14] Vonnegut, B., "The atmospheric electricity paradigm," Bull. Am. Meteor. Soc., 75, pp. 53–61, 1994.

[15] Wilson, C. T. R., "A theory of thundercloud electricity," Proc. Roy. Soc. A, 236, pp. 297–317, 1956.

[16] Moore, C. B., and B. Vonnegut, "The thundercloud, In Lightning," Vol. 1, Physics of Lightning, ed. R. H. Golde, pp.51–98, New York, Academic Press, 1977.

[17] Reynolds, S. E., M. Brook, and M. F. Gourley, "Thunderstorm charge separation," J. Meteor., 14, pp.426–36, 1957.

[18] Takahashi, T., "Riming electrification as a charge generation mechanism in thunderstorms," J. Atmos. Sci., 35, pp.1536–48, 1978.

[19] Jayaratne, E. R., C. P. R. Saunders, and J. Hallett, "Laboratory studies of the charging of soft-hail during ice crystal interactions," Q. J. R. Meteor. Soc., 109, pp.609–630, 1983.

[20] Schoene, J. D., "Direct and nearby lightning interaction with test power distribution lines," PhD dissertation, University of Florida, Gainesville, 2007.

[21] Goto, Y., and K. Narita, "Electrical characteristics of winter lightning," J. Atmos. Terr. Phys., 57, pp.449–59, 1995.

[22] Boccippio, D.J., E.R. Williams, S.J. Heckman, W.A. Lyons, I.T. Baker, and R. Boldi, Sprites, "ELF transients, and positive ground strokes," Science, 269, pp.1088–91, 1995.

[23] Berger, K., "Blitzstrom-parameters von aufwärtsblitzen," Bull. Schweiz. Elektrotech. Ver., 69, pp.353–360, 1978.

[24] Rakov, V. A., "Lightning flashes transporting both negative and positive charges to ground, in Recent Progress in Lightning Physics," edited by C. Pontikis, pp. 9-21, Research Signpost, Kerala, India, 2005.

[25] Jerauld, J. E., M. A. Uman, V. A. Rakov, K. J. Rambo, D. M. Jordan, and G. H. Schnetzer, "Measured electric and magnetic fields from an unusual Cloud-to-Ground lightning flash containing two positive strokes followed by four negative strokes," J. Geophys. Res., 114, D19115, doi:10.1029/2008JD011660, 2009.

[26] Ting Wu, Yuji Takayanagi, Tsuyoshi Funaki, Satoru Yoshida, Tomoo Ushio, Zen-Ichiro Kawasaki, Takeshi Morimoto, Masahito Shimizu. "Preliminary breakdown pulses of Cloud-to-Ground lightning in winter thunderstorms in Japan," Journal of Atmospheric and Solar-Terrestrial Physics 102, pp.91-98, 2013.

[27] Beasly, W.H., Uman, M.A., and Rustan, P.L. "Electric fields preceding cloud to ground lightning flashes," J. Geophys. Res., 87, pp.4883–4902, 1982.

[28] Clarence, N.D. and Malan, D.J., "Preliminary discharge processes in lightning flashes to ground," Q. J. R. Meteorol. Soc., 83, pp.161–172, 1957.

[29] Schonland, B.F.J., "The lightning discharge," Handbuch der Physik, 22, pp.576–62, 1956.

[30] Thomson, E.M., "Characteristics of Port Moresby ground flashes," J. Geophys. Res., 85, pp.1027–1036, 1980.

[31] Gomes, C., Cooray, V., and Jayaratne, C., "Comparison of preliminary breakdown pulses observed in Sweden and in Sri Lanka," J. Atmos. Terr. Phys., 60, pp.975–979, 1998.

[32] Weidman, C. D., and E.P. Krider, "The radiation field waveforms produced by intracloud lightning discharge processes," J. Geophys. Res., 84(C6), pp.3159–3164, 1979.

[33] Rakov, V.A., "Lightning electric and magnetic fields," Proc. 13th Int. Zurich Symp. On Electromagn. Compat., Zurich, Switzerland, pp.561–566, 1999.

[34] Rakov, V. A, M.A. Uman, G.R. Hoffman, M.W. Masters, and M. Brook, "Bursts of pulses in lightning electromagnetic radiation: observations and implications for lightning test standards," IEEE Trans. on EMC, 38, No. 2, pp.156–164, 1996.

[35] Krehbiel, P. R., M. Brook, and R. McCrory, "An analysis of the charge structure of lightning discharges to the ground," J. Geophys. Res., 84, pp.2432–2456, 1979.

[36] Proctor, D. E., R. Uytenbogaardt, and B. M. Meredith, "VHF radio pictures of lightning flashes to ground," J. Geophys. Res., 93, 12, pp.683–12,727, 1988.

[37] Rhodes, C., and P. R. Krehbiel, "Interferometric observations of a single stroke cloud-to-ground flash," Geophys. Res. Lett., 16, pp.1169–1172, 1989.

[38] Kitagawa, N., and M. Brook, "A comparison of intracloud and cloud-to-ground lightning discharges," J. Geophys. Res., 65, pp.1189–1201, 1960.

[39] Isikawa, H., "Nature of lightning discharges as origins of atmospherics," in Proc. Res. Int. Atmos. (Nagoya Univ.), vol. 8A, pp. 1–273, 1961.

[40] Gurevich, A.V., K.P. Zybin, and R.A. Roussel-Dupre, "Lightning initiation by simultaneous effect of runaway breakdown and cosmic ray showers," Phys. Lett. A, 254, pp. 79–87, 1999.

[41] Gurevich,Kitagawa, N., "On the electric field change due to the leader processes and some of their discharge mechanism," Pap. Meteor. Geophys. (Tokyo), 7, pp. 414–7,424, 1957.

[42] Proctor, D. E., R. Uytenbogaardt, and B. M. Meredith, "VHF radio pictures of lightning flashes to ground," J. Geophys. Res., 93, 12, pp.683–12,727, 1988.

[43] Ogawa, T., "Initiation of Lightning in clouds," J. Amos. Electr., 13, pp.121–132, 1993.

[44] Master, M. J., M. A. Uman, W. H. Beasley, and M. Darveniza, "Lightning induced voltages on power lines: Experiment," IEEE Trans. PAS, PAS-103, pp. 2519–2529, 1984.

[45] Willett, J. C., J. C. Bailey, V. P. Idone, A. Eybert-Berard, and L. Barret, "Submicrosecond intercomparison of radiation fields and currents in triggered lightning return strokes based on the transmission-line model," J. Geophys. Res., 94, 13, pp.275–13,286, 1989a.

[46] Thottappillil, R., and M. A. Uman, "Comparison of return stroke models," J. Geophys. Res., 98(D12), 22, pp.903–22,914, 1993.

[47] Cooray, V., R. Montano, and V. Rakov, "A model to represent negative and positive lightning first strokes with connecting leaders," J. Electrostatics, 60, pp. 97–109, 2004.

[48] Jerauld, J., M. A. Uman, V. A. Rakov, K. J. Rambo, and G. H. Schnetzer, "Insights into the ground attachment process of natural lightning gained from an unusual triggered-lightning stroke," J. Geophys. Res., 112, D13113, doi:10.1029/2006JD007682, 2007.

[49] Brook, M., M. Nakano, P. Krehbiel, and T. Takeuti, "The electrical structure of the Hokuriki winter thunderstorms," J. Geophys. Res., 87, pp.1207–1215, 1982.

[50] Orville, R. E., and A. C. Silver, "Lightning ground flash density in the contiguous United States: 1992-1995," Mon. Wea. Rev., 125, pp.631–638, 1997.

[51] Orville, R. E., and G. R. Huffines, "Lightning ground flash measurements over the contiguous United States: 1995-1997," Mon. Wea. Rev., 127, pp.2693–2703, 1999.

[52] Fuquay, D. M., "Positive cloud-to-ground lightning in summer thunderstorms," J. Geophys. Res., 87, pp.7131–7140, 1982.

[53] Wang, C., M. Yan, X. Liu, Y. Zhang,W. Dong, and C. Zhang, "Bidirectional propagation of lightning leader," Chinese Sci. Bull., 44(2), pp.163–166, 1999.

[54] Idone, V. P., R. E. Orville, D. M. Mach, andW. D. Rust, "The propagation speed of a positive lightning return stroke," Geophys. Res. Lett., 14, pp.1150–1153, 1987.

[55] Jerauld, J., M. A. Uman, V. A. Rakov, K. J. Rambo, and D. M. Jordan, "A triggered lightning flash containing both negative and positive strokes," Geophys. Res. Lett., 31, L08,104, doi:10.1029/2004GL019457, 2004.

[56] Lyons,W., M. Uliasz, and T. Nelson, "Large peak current cloud-to-ground lightning flashes during the summer months in the contiguous United States," Mon. Weather Rev., 126, pp.2217–2233, 1998.

[57] Rakov, V. A., and G. R. Huffines, "Return stroke multiplicity of negative cloud-to-ground lightning flashes," J. Appl. Meteor., 42(10), pp.1455–1462, 2003.

[58] Ishii, M., K. Shimizu, J. Hojo, and K. Shinjo, "Termination of multiple-stroke flashes observed by electromagnetic field," in Proc. 24th Int. Conf. on Lightning Protection, pp. 11–16, Birmingham, United Kingdom, 1998.

[59] Rust,W. D., D. R. MacGorman, and R. T. Arnold, "Positive cloud to ground lightning flashes in severe storms," Geophys. Res. Lett., 8, pp.791–794, 1981.

[60] Fuquay, D. M., "Positive cloud-to-ground lightning in summer thunderstorms," J. Geophys. Res., 87, pp.7131–7140, 1982.

[61] Lin, Y. T., M. A. Uman, J. A. Tiller, R. D. Brantley,W. H. Beasley, E. P. Krider, and C. D. Weidman, "Characterization of lightning return stroke electric and magnetic fields from simultaneous two-station measurements," J. Geophys. Res., 84, pp.6307–6314, 1979.

[62] Golde, R. H., "Occurrence of upward streamers in lightning discharges," Nature, 160, pp.395–396, 1947.

[63] Wagner, C. F., "Lightning and transmission lines," J. Franklin Inst., 283, pp.558–594, 1967.

[64] Idone, V. P., and R. E. Orville, "Lightning return stroke velocities in the Thunderstorm Research International Program (TRIP) ," J. Geophys. Res., 87, pp.4903–4915, 1982.

[65] Idone, V. P., "Length bounds for connecting discharges in triggered lightning," J. Geophys. Res., 95, 20, pp.409–20,416, 1990.

[66] Wang, D., V. A. Rakov, M. A. Uman, N. Takagi, T.Watanabe, D. E. Crawford, K. J. Rambo, G. H. Schnetzer, R. J. Fisher, and Z. I. Kawasaki, "Attachment process in rocket-triggered lightning strokes," J. Geophys. Res., 104, pp.2143–2150, 1999a.

[67] Lin, Y. T., M. A. Uman, and R. B. Standler, Lightning return stroke models," J. Geophys. Res., 85, pp.1571–1583, 1980.

[68] Mallat, S., "A wavelet Tour of Signal Processing," Academi Press, New York, 1999.

[69] Strang, G., "Wavelets and Dilation Equations: A brief introduction," SIAM Review, 31: pp.614-627, 1989.

[70] Wells, R.O., "Parametrizing Smooth Compactly Supported Wavelets," Transform American Mathematical Society, 338(2): pp.919-931, 1993.

[71] Meyer, Y., "Wavelets: their past and their future, Progress in Wavelet Analysis and its Applications," Gif-sur-Yvette, pp. 9-18, 1993.

[72] Morlet, J., Arens, G., Fourgeau, E. and Giard, D., "Wave propagation and sampling theory, Part1: Complex signal land scattering in multilayer media," Journal of Geophysics, 47: pp.203-221, 1982.

[73] Cooray. V, "The lightning flash," IET Press, 2003.

[74] N. Azlinda Ahmad, "Broad band and HF radiation from cloud flashes and Narrow Bipolar Pulses," Phd Thesis, Uppsala University, Sweden, 2011.

[75] S. R. Sharma, M. Fernando and C. Gomes, "Signatures of electric field pulses generated by cloud flashes," Journal of Atmospheric and Solar-Terrestrial Physics, vol. 67, no. 4, pp. 413-422, 2005.

[76] C. Gomes, V. Cooray and C. Jayaratne, "Comparison of preliminary breakdown pulses observed in Sweden and in Sri Lanka," Journal of Atmospheric and Solar-Terrestrial Physics, vol. 60, no. 10, pp. 975-979, 1998.

[77] A. Galvan and M. Fernando, "Operative characteristic of a parallel-plate antenna to measure vertical electric fields from lightning flashes," Uppsala, 2000.

[78] W. I. Ibrahim, M. R. Ghazali, S. A. Ghani and Z. A. Malek, Z. A., "Measurement of vertical Electric fields from lightning flashes using parallel plate antenna," in International Conference On Electrical, Control And Computer Engineering 2011 (INECCE). Pahang, Malaysia, pp. 466-471, 2011.

[79] O. Zheng Jie, "Characterization of Lightning Generated Electric Field," Undergraduate, Universiti Putra Malaysia, 2011.

[80] Lin, Y. T., M. A. Uman, J. A. Tiller, R. D. Brantley,W. H. Beasley, E. P. Krider, and C. D. Weidman, "Characterization of lightning return stroke electric and magnetic fields from simultaneous two-station measurements," J. Geophys. Res., 84, pp.6307–6314, 1979.

[81] Vaisala. "Fault Analysis and Lightning Location System™ FALLS® Client and FALLS® Server - User-friendly software to analyize the impact of lightnings - Vaisala. [Online]. Available: http://www.vaisala.com/en/products/thunderstormandlightningdetectionsystems/Pages/FALLS.aspx. [Accessed: 09- Dec- 2014].

[82] Haddad, M.A., Rakov, V.A., "Cummer, S.A., New measurements of lightning electric fields in Florida: waveform characteristics, interaction with the ionosphere, and peak current estimates," J. Geophys. Res. Atmos. 117 (D10), 2012.

[83] Fisher, R.J., Uman, M.A., "Measured electric field Rise-times for first and sub-sequent lightning return strokes," J. Geophys. Res.77 (3), pp.399–406, 1972.

[84] Chin-Leong Wooi, Zulkurnain Abdul-Malek, Noor-Azlinda Ahmad, AliI. El Gayar, "Statistical analysis of electric field parameters for negative lightning in Malaysia," Journal of Atmospheric and Solar-Terrestrial Physics 146, pp.69–80, 2016.

[85] Hojo, J., M. Ishii, T. Kawamura, F. Suzuki, and R. Funayama, "The fine structure in the field change produced by positive ground strokes," J. Geophys. Res., 90, pp.6139–6143, 1985.

[86] Willett, J.C., Krider, E.P., "Rise times of impulsive high-current processes in cloud-to-ground lightning," IEEE Trans. Antennas Propag. 48(9), pp.1442–1451, 2000.

[87] Cooray, V., Lundquist, S., "Characteristics of the radiation fields from lightning in Sri Lanka in the tropics," J. Geophys. Res.: Atmos. 90 (D4), pp.6099–6109, 1985.

[88] Ishii, M., and J. Hojo, "Statistics on fine structure of cloud-to-ground lightning field waveforms," J. Geophys. Res., 94, 13, pp.267–13,274, 1989.

[89] Weidman, C. D., and E. P. Krider, "Submicrosecond risetimes in lightning return-stroke fields," Geophys. Res. Lett., 7, pp.955–958, 1980a.

[90] Pavlick, A., D. E. Crawford, and V. A. Rakov, "Characteristics of distant lightning electric fields," paper presented at 7th International Conference on Probabilistic Methods Applied to Power Systems, Assoc. per gli Studi sulla Qualita dell 'Energia Elet., Naples, Italy, 2002.

[91] F. Santamaría, C. Gomes and F. Román, "Comparison Between the Signatures of Lightning Electric Field Measured in Colombia and that in Sri Lanka," in 28th International Conference on Lightning Protection, 2006.

[92] Lin, Y. T., M. A. Uman, J. A. Tiller, R. D. Brantley,W. H. Beasley, E. P. Krider, and C. D. Weidman, "Characterization of lightning return stroke electric and magnetic fields from simultaneous two-station measurements," J. Geophys. Res., 84, pp.6307–6314, 1979.

[93] Krider, E. P., C. Leteinturier, and J. C.Willett, "Submicrosecond fields radiated during the onset of first return strokes in cloud-to-ocean lightning," J. Geophys. Res., 101, pp.1589–1597, 1996.

[94] Willett, J. C., E. P. Krider, and C. Leteinturier, "Submicrosecond field variations during the onset of first return strokes in cloud-to-ground lightning," J. Geophys. Res., 103, pp.9027–9034, 1998.

[95] Heidler, F., and C. Hopf, "Measurement results of the electric fields in cloud-to-ground lightning in nearby Munich, Germany," IEEE Trans. Electromagn. Compat., 40(4), pp.436–443, 1998.

[96] A. Nag and V. Rakov, "Parameters of Electric Field Waveforms Produced by Positive Lightning Return Strokes," IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 4, pp. 932-939, 2014.

[97] Beasley,W. H., M. A. Uman, D. M. Jordan, and C. Ganesh, "Simultaneous pulses in light and electric field from stepped leaders near ground level," J. Geophys. Res., 88, pp.8617–8619, 1983.

[98] Cooray, V., "A novel method to identify the radiation fields produced by positive return strokes and their submicrosecond structure," J. Geophys. Res., 91, pp.7907–7911, 1986a.

[99] Cooray, V., "Correction to: A novel method to identify the radiation fields produced by positive return strokes and their submicrosecond structure," J. Geophys. Res., 91, 13,318, 1986b.

[100] A. Nag, V. Rakov, D. Tsalikis and J. Cramer, "On phenomenology of compact intracloud lightning discharges," J. Geophys. Res., vol. 115, no. D14115, 2010.

[101] Hojo, J., M. Ishii, T. Kawamura, F. Suzuki, and R. Funayama, "The fine structure in the field change produced by positive ground strokes," J. Geophys. Res., 90, pp.6139–6143, 1985.

[102] Cooray, V., M. Fernando, C. Gomes, T. Sorensen, V. Scuka, and A. Pedersen, "The fine structure of positive return stroke radiation fields: a collaborative study between researchers from Sweden and Denmark," Proc. 24th Int. Conf. on Lightning Protection, pp. 78-82, Staffordshire University, Birmingham, United Kingdom, 1998.

[103] Rakov, V. A., M.A. Uman, and R. Thottappillil, "Review of lightning properties from electric field and TV observations," J. Geophys. Res., 99, 10, pp.745–10,750, 1994.

[104] C. Schumann, M. M. F. Saba, W. Schulz and R. B. G. da Silva, "Electric field waveforms of positive return strokes. XIV International Conference on Atmospheric Electricity," Rio de Janeiro, Brazil, 2011.

[105] Heidler, F., F. Drumm, and C. Hopf, "Electric fields of positive earth flashes in near thunderstorms," Proc.24th Int. Conf. on Lightning Protection, Birmingham, United Kingdom, Staffordshire University, pp. 42–47, 1998.

[106] Fleenor, S.A., C. J. Biagi, K.L. Cummins, E. P. Krider and X. M. Shao, "Characteristics of cloud-to-ground lightning in warm-season thunderstorms in the Central Great Plains," Atmos. Res., 91, doi: 10.1016/j.atmosres.2008.08.011, 333–352, 2009.

[107] M. M. F. Saba, W. Schulz, T. A. Warner, L. Z. S. Campos, C. Schumann, E. P. Krider, K. L. Cummins and R. E. Orville, "High-speed video observations of positive lightning flashes to ground," J. Geophys. Res., vol. 115, no. 24201, 2010.

[108] X. Qie, Z. Wang, D. Wang and M. Liu, "Characteristics of positive cloud-to-ground lightning in Da Hinggan Ling forest region at relatively high latitude, northeastern China," Journal of Geophysical Research: Atmospheres, vol. 118, no. 24, pp. 13,393-13,404, 2013.

[109] A. Nag, and V. A. Rakov "Positive lightning: An overview, new observations, and inferences," J. Geophys. Res., vol. 117, no. D08109, 2012.

[110] J. S. Mäkelä, N. Porjo, A. Mäkelä, T. Tuomi and V. Cooray, "Properties of preliminary breakdown processes in Scandinavian lightning," Journal of Atmospheric and Solar-Terrestrial Physics, vol. 70, no. 16, pp. 2041-2052, 2008.

[111] A. Nag and V. Rakov, "Electric Field Pulse Trains Occurring Prior to the First Stroke in Negative Cloud-to-Ground Lightning," IEEE Transactions on Electromagnetic Compatibility, vol. 51, no. 1, pp. 147-150, 2009.

[112] Z. A. Baharudin, M. Fernando, N. Ahmad, J. S. Mäkelä, M. Rahman and V. Cooray, "Electric field changes generated by the preliminary breakdown for the negative cloud-to-ground lightning flashes in Malaysia and Sweden,"

Journal of Atmospheric and Solar-Terrestrial Physics, vol. 84-85, pp. 15-24, 2012.

[113] Y. Zhu, V. A. Rakov, S. Mallick, M. D. Tran, J. Pilkey and M. A. Uman, "Preliminary Breakdown Pulse Trains in Electric Field Records of Negative Cloud-to-Ground Lightning," in XV International Conference on Atmospheric Electricity, Norman, Oklahoma, U.S.A., 2014.

[114] I. Kolmašová, O. Santolík, T. Farges, W. Rison, R. Lán and L. Uhlíř, "Properties of the unusually short pulse sequences occurring prior to the first strokes of negative cloud-to-ground lightning flashes," Geophys. Res. Lett., vol. 41, no. 14, pp. 5316-5324, 2014.

[115] T. Ushio, Z. Kawasaki, K. Matsu-ura and D. Wang, "Electric fields of initial breakdown in positive ground flash," J. Geophys. Res., vol. 103, no. 12, pp. 14135-14139, 1998.

[116] Y. Zhang, Y. Zhang, W. Lu, D .Zheng and Q. Meng, "An analysis of the initial breakdown pulse for positive cloud-to-ground flashes," in 7th Asia-Pacific International Conference On Lightning (APL), Chengdu, China, 2011, pp. 165-160.

[117] Y. Zhang, Y. Zhang, W. Lu and D. Zheng, "Analysis and comparison of initial breakdown pulses for positive cloud-to-ground flashes observed in Beijing and Guangzhou," Atmospheric Research, vol. 129-130, pp. 34-41, 2013.

[118] C. Gomes and V. Cooray, "Radiation field pulses associated with the initiation of positive cloud to ground lightning flashes," Journal of Atmospheric and Solar-Terrestrial Physics, vol. 66, no. 12, pp. 1047-1055, 2004.

[119] Malay Mail Online "Lightning kills jogging couple" http://www.themalaymailonline.com/malaysia/article/lightning-kills-jogging-couple, 13 March 2017, 2017

[120] Harold S. Haller and Wojbor A. Woyczynski, "Interception efficiency of CVM-based lightning protection systems for buildings and the fractional Poisson model," Geophysics (physics.geo-ph); Instrumentation and Methods for Astrophysics (astro-ph.IM), February 4, 2016

[121] Lamine M. Mili, Timothy Pratt, A. A. (Louis) Beex, "Application of Wavelets to Filtering and Analysis of Self-Similar Signals," Master Thesis, Virginia Polytechnic Institute and State University, USA 2014.

[122] Shabnam Wahed; Masud Rana; S. M. Kamrul Hasan; Mohiuddin Ahmad, "Toward letter recognition system: Determination of best wavelet and best rhythm using EEG" 2016 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), pp. 1 - 4, DOI: 10.1109/CEEICT.2016.7873099, 2016.

[123] M. A. Haddad, V. A. Rakov and S. A. Cummer, "New measurements of lightning electric fields in Florida: Waveform characteristics, interaction with the ionosphere, and peak current estimates," J. Geophys. Res., vol. 117, no. D10101, 2012.

[124] N. A. Ahmad, M. Fernando, Z. A. Baharudin, V. Cooray, H. Ahmad and Z. Abdul Malek, "Characteristics of narrow bipolar pulses observed in Malaysia," Journal of Atmospheric and Solar-Terrestrial Physics, vol. 72, no. 5-6, pp. 534-540, 2010.

[125] V. A. Rakov, M. A. Uman, G. R. Hoffman, M. W. Masters and M. Brook, "Burst of pulses in lightning electromagnetic radiation: observations and implications for lightning test standards," IEEE Transactions on Electromagnetic Compatibility, vol. 38, no. 2, pp. 156-164, 1996.

[126] 'LCMSysSet'. Mapping Clusters of Lightning [Online]. Available: http://www.meteo.psu.edu/~hns/LCMSysset.htm. [Accessed: 09- Dec- 2014].

[127] M. Ferro, M. Saba and O. Pinto, "Time-intervals between negative lightning strokes and the creation of new ground terminations," Atmospheric Research, vol. 116, pp. 130-133, 2012.

[128] O. Pinto Jr., I. R. C. A. Pinto, M. M. F. Saba, N. N. Solorzano and D. Guedes, "Return stroke peak current observations of negative natural and triggered lightning in Brazil. Atmospheric Research," vol. 76, no. 1-4, pp. 493-502, 2005.

[129] M. Brook, R. W. Henderson and R. Pyle, "Positive lightning strokes to ground," J. Geophys. Res., vol. 94, no. D11, pp. 13295-13303, 1989

[130] V. A. Rakov, "A Review of Positive and Bipolar Lightning Discharges," Bull. Amer. Meteor. Soc., vol. 84, no. 6, pp. 767-776, 2003.

[131] Murphy, M.J. and Krider E.P.: 'Lightning charge analyses in small convection and precipitation electrification (CaPE) experiment storms', J. Geophys. Res., 1996, 101, (D23), pp.29615–29626

[132] Weidman,C. and Krider, E.P.: 'Variations á l'échelle submicroseconde des champs électro-magnétiques rayonnés par la foudre', Ann. Telecommun., 1984, 39, pp.165–174

[133] Cooray, V., Fernando, M., Gomes, C., and Sorenssen, T.: 'The fine structure of positive lightning return stroke radiation fields' accepted to be published in IEEE Trans. (EMC). 2003