Analysis of Lightning Strike Variations in Sweden from 2000 – 2014

Hewage Nihal, Perera S.S., Boralugoda S.K., Fernando I.M.K., Cooray V.

***Abstract*—Lightning is a natural phenomenon; in which massive electric discharge occurs between the electrically charged regions within clouds, clouds to clouds or between a cloud and the Earth's surface. Lightning flash is referred as the temporal equalization of charge regions within the atmosphere. Lightning occurs approximately 40–50 times a second worldwide, resulting in nearly 1.4 billion flashes per year. Present Lightning Location and Protection(LLP) systems used in many countries are capable of studying long-term characteristics of CG lightning flashes with a typical range of 600 km with many sensors interconnected to form lightning detection networks that span thousands of kilometres that can capture lightning in vast land masses.**

The ultimate purpose of this study is to assess the possibility of occurrence and variation of cloud-to-ground lightning strikes over the geographical boundary covered by the LLP system of Sweden. Thus, the study measures the cloud density and lightning strike frequencies within the period of the last fourteen years (2000-2014) recorded by Lightning Detection Centers of the LLP system which were holistically dispersed all over Sweden.

Wavelet theories, time frequency analysis and Range Normalization of Signal Strength (RNSS) were used to analysis the results. Wavelet theories have been used to analysis the pattern over the period. Time frequency analysis and RNSS values were used to determine risk status.

According to the analysis, two types of lightning strike patterns were identified in Sweden. One is "Annual Lightning Strike Pattern" which occurred between 0.7-1.4 year and the anther is "Extreme Lightning Strike Pattern" which occurred every 3-5 year period and its frequency increased equator to polar sides of Sweden. Lightning risk was calculated over the period by using RNSS values as magnitude and lightning frequency. The results show that the lightning risk also varied in similar patterns and its return pattern varies from 4 – 3 years from Southern to Northern part of Sweden respectively..

***Index Terms*—Lighting, Lightning Location and Protection system (LLP)**

I. Introduction

Lightning is a natural phenomenon; in which massive electric discharge occur between the electrically charged regions within clouds, from clouds to clouds or between a cloud and the Earth's surface. Lightning flash is referred as temporal equalization of charged regions within the atmosphere. And it is referred as a strike if it hits an object on the ground. Emphasis is made on mathematical and statistical modeling of observational data available from Sweden,

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Lightning occurs when a cloud reaches cumulonimbus cloud type 3 or 9, with type 9 being the most dangerous. At the beginning a small cloud is formed and it will expand with time. Two processes will be continuously happening in the cloud as down draft and up draft, which will initial result in the cloud becoming plus or minus charged. The small cloud forms at a height of 480-520 m from mean sea level (MSL) and its normal height from MSL will be 600m when it is charged.

There are three primary types of lightning: from a cloud to itself (intra-cloud or IC); from one cloud to another cloud (CC) and between a cloud and the ground (CG). Although lightning is always accompanied by the sound of thunder, distant lightning may be seen but it could be too far away for the thunder to be heard at the same instant or not at all.

Lightning occurs approximately 100 times a second worldwide, resulting in nearly 1.4 billion flashes per year (Oliver, 2005).

Many factors affect the frequency, distribution, strength and physical properties of a "typical" lightning flash in a particular region of the world (Oliver, 2005). These factors include ground elevation, latitude, prevailing wind currents, relative humidity, proximity to warm and cold bodies of water, etc (Oliver, 2005).

A typical cloud to ground lightning flash culminates in the formation of an electrically conducting plasma channel through the air in excess of 5 kilometers (3.1 miles) in height, from within the cloud to the ground surface. The actual discharge is the final stage of a very complex process (Uman, 2001). A typical thunderstorm has three or more strikes to the Earth per minute at its peak (Uman, 2001).

As human beings are terrestrial and most of their possessions are on the surface of the Earth where lightning can damage or destroy them, CG lightning is the most studied and best understood of these three types, even though IC and CC are more common types of lightning. Relative unpredictability of lightning limits a complete explanation of how or why it occurs, even after hundreds of years of scientific investigation. The threat from lightning in convective storms is a significant source of concern for public safety and a wide range of weather sensitive operations (McCaul et al., 2008). According to Curran et al.(2000), in the United States alone, lightning is responsible for nearly 1000 deaths and injuries each year, with damages exceeding $1 billion. In Sweden, the annual number of deaths due to lightning is about 1 (Eriksson & Örnehult, 1988)

II. Lightening detection in Sweden

In Sweden, characteristics of cloud-to-ground (CG) flashes which occurred during thunderstorms have been focal to many enthusiastic researchers (Norinder, 1956, Norinder and Knudsen, 1961, Cooray and Lundquist, 1982, Cooray and Lundquist, 1983, Cooray and Pérez, 1994, Gomes et al., 1998). Most of these studies had been carried out remotely either by using lightning flash counters or by using a sensor system such as flat plate antenna to sense the electric field generated by distant lightning strikes and then digitizing the detected signals using transient recorders (Sonnadara et al., 2006). According to (Soonadara et al., 2006), the insights provided by these studies have created an ever developing platform in understanding the physics of the lightning process as well as in understanding the many engineering problems caused by electromagnetic fields generated by lightning.

Present lightning locating systems used in many countries are capable of studying long-term characteristics of CG lightning flashes with a typical range of 600 km with many sensors interconnected to form lightning detection networks that span thousands of kilometers and therefore can capture lightning in vast land masses (Diendorfer et al., 1998), (Orville et al., 2002).

In recent years, there have been several attempts to study the long term characteristics of Swedish thunderstorms using the data provided by the Swedish lightning locating system (Fernando et al., 1998, Sonnadara et al., 2006).

In late 1979 a lightning location system was installed in Sweden by the Institute of High Voltage Research, which is currently under the Division for Electricity and Lightning Research of Uppsala University. The system was a magnetic direction finding system manufactured by the Lightning Location and Protection (LLP), which later became part of Global Atmospherics (GA).

III. Phenomenon of lightning

The lightning events are classified into two main types:

1. Cloud-to-Ground lightning (CG).
2. Cloud to Cloud lightning (CC).

Each of these types of lightning events generates electromagnetic wave to accompany the activity. The waveforms always clarify the propagation and impulsive characteristics of lightning activities. The impulsive contribution in line with the electromagnetic lightning propagation indicates a peak amplitude which occurs within 0-300µs for CG and 0-12µs for IC. The changes in time scale of cloud-to-ground and intra-cloud lightning electric field waveform are discussed below.

IV. Cloud-to-Ground Lightning Discharge (CG)

The cloud to ground (CG) electromagnetic lightning is twofold in their type polarization): negative and positive, in which the altitude of negative charge belts in the cloud are typically lower than the positive charge belts (Umahi 2013). The stroke channel lengths for (-) CGs are typically 5-8km.

V. In-cloud Lightning Discharge

A newly discovered type of an intra-cloud (IC) lightning, Narrow Bipolar Event (NBE), transfers electric charge between cloud charge layers, but it is usually too strong (peak currents ~30-40kA) and significantly very fast (~25µs) when compared to common IC events (LeVine 1980; Willett 1989; Smith et al., 1999; Lay 2008).

VI. Some basic lightning concepts

Several concepts based on theory and laboratory experiments have formed the basis of recent lightning parameterizations for mathematical/numerical cloud models. Though there is disagreement about the molecular and microphysical processes responsible for initiating a lightning flash, there is broad agreement that a flash is initiated when the ambient electric forces on atmospheric ions and electrons in some region become strong enough to force air to create a conducting channel through which large electric currents flow (e.g., Uman 1969, Chapter 7; MacGorman and Rust 1998, Chapter 5). (Kasemir 1960, 1984) suggested that, once a flash is initiated, the spark propagates bidirectional (initially parallel and antiparallel to the electric field) from the point of initiation. Bidirectional propagation appears to be supported by a study of sparks from ungrounded objects (Kasemir 1984) and by studies of lightning strikes to instrumented aircraft (e.g., Mazur 1989a, b). Data from three-dimensional lightning mapping systems indicate that a lightning flash typically develops both upward and downward from its initiation point (e.g., Shao and Krehbiel 1996). However, knowledge of many details of this development, including the average velocity in each direction, remains uncertain (e.g., Rakov et al., 1998; Cooray 1998), and these details may affect the structure and charge distribution of flashes.

VII. Time Series Analysis

Time series analyses is analyzing of the observations collected within a given time period. Objective of time series analysis are; data compression, explanatory, signal processing and prediction. Time series analysis can summarize the series of observation and generate simple pattern to understand the relationship of different parameters. Most of the research studies related to seasonal analysis such as climate variations and temperature variation with other variables can be analyzed through time series analysis. The time series results will help to forecast the events which may occur in future.

Time series analysis has different components and those can be explained by the following equation (see equation 1)

$$X_t = m_t + s_t + Y_t \quad --------(1)$$

In here, mt represents the trend component which changes slowly and s_t represents the sessional components describing on yearly, monthly and hourly basis. Random noise components are Y_t, which contain random irregular cyclic components of unknown frequencies that can be fitted on an autoregressive process, moving average process or combination of above two process.

VIII. Identified Pattern by Location

The area is divided into main three parts, Zone A: Area between latitude 55°-60°, Zone B: Area between latitude 60°-65° and Zone C: Area between latitude 65°-70°, in order to identify the strike pattern variation with latitude values.

The strike patterns of Zone A, Zone B and Zone C were plotted over the time scale bar shown in Figure 1 (Lightning strike variation by zone). Every year, highest strikes counted in Zone A and it gradually reduced to Zone B and Zone C. The total lightning counts were plotted over the time scale bar which shown in Figure 2(Lighting strike variation by year).

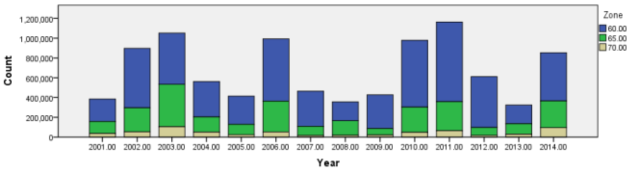

Figure 1-Lightning strikes variation by zone

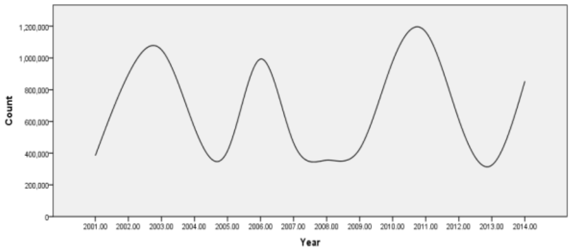

Figure 2-Lightning Strike Variation by Year

According to the Figure 1and Figure 2, the following observations can be made:
Every year, the highest lightning strike count is in Zone A, which is towards the Equator, the lowest lightning strike count is in Zone C, which is towards the Pole.

IX. Time Series Analysis- Analysis by Frequency

The total time period considered (2003 to 2014) was divided into three separate time periods as 2003–2006, 2007–2010 and 2011–2014. Frequency of strike was plotted in each of the three time periods and analysis was conducted for the three zones, Zone A, Zone B and Zone C.

The Continuous Wavelet Transformation Plot (CWT) was developed for entire data base to observe the pattern and relationship of the lightning strike over the period. The plot colour is varied from red to blue, describes the lighting strike signal relationship strong to weak respectively.The CWT was calculated for same periods such as 2003 – 2006, 2007 – 2010 and 2011 – 2014 for identify the relationship between different zones, A, B and C. Then observe the relationships in each category, see Figure 1.

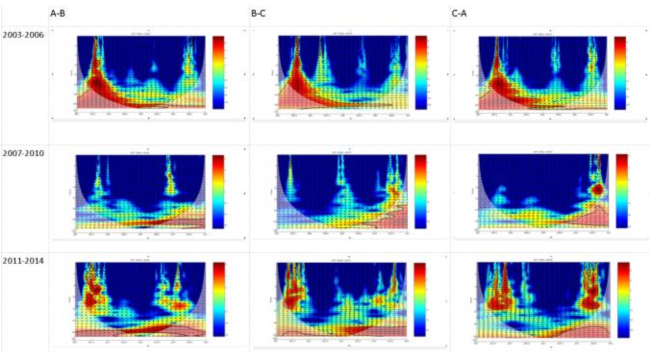

Figure 1: Wavelet Analysis for Different Zones

According to above figure, A& B zones had relationships in 2003, 2006, 2007,2010,2011,2013 and 2014. In A &C zones had relationship in 2003, 2005, 2006, 2010, 2011, 2012 and 2014. In B&C zones had relationship in 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011 and 2014. In 2003, 2006, 2010, 2011 and 2014 had relationship between all three zones. In addition, there could be easily identified two main observations in given period;

- Every year there was a lightning strike period (very strong relationship). This event return period is varied from 0.7-1.4 year.
- 60-80 day period pattern was observed in the figure; means, every 4.5 – 6 year period lighting strikes had strong relationship.

Some trends and cyclic patterns in the lightning strikes throughout the year could be observed. The highest frequency of lightning strike per month observed in every zone was felt in the period of May to September. Same pattern can be observed throughout the analyzed period which was 2003 to 2014. Figure 4 illustrates the frequency analysis of the zones by month.

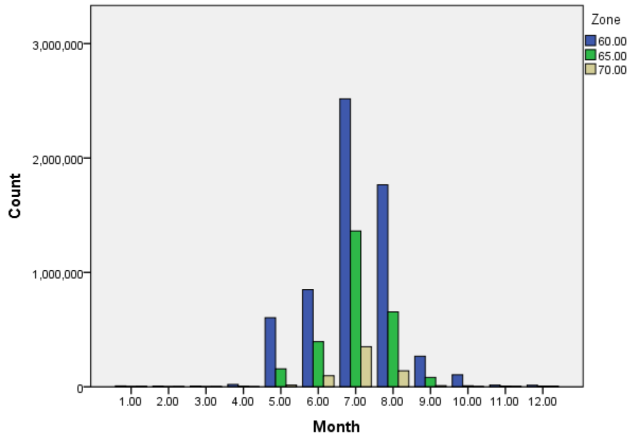

Figure 2-Lightning Frequency varied over month

X. Conclusion & Recommendations

Lightning strike can be categorized as two types; Cloud to cloud and cloud to ground. The most hazardous strike as far as people are concerned is cloud to ground strikes. These strike locations had been monitored for a period of time and lightning strike data recorded, which include; location, magnitude, after shots, etc. High-end computers were required to filter the data in required formats for analysis and further calculations. The lightning strike data were collected from Sweden due to unavailability of lightning strike data in Sri Lanka. The data were collected for the period of 2001 to 2014 and a total of nearly 10.7 million raw data were analyzed under this work.

The highest frequency of lightning strike per month could be observed in every zone was felt in the period of May to September. Every year, the highest lightning strike count is in Zone A, which is towards equator, the lowest lightning strike count is in Zone C, which is towards polar. Lightning strike density is increasing to Zone C to Zone A by more than 50% density increase. Zone C to Zone B increase by 50% and Zone B to Zone A increase by 66.67%.

Total RNSS mean values were increasing since last 10 years. Every year there was a lightning strike period (very strong relationship). This event return period is varied from 0.7-1.4 year. 60-80-day period pattern was observed in the analysis; means, every 4.5 – 6 year period lighting strikes had strong relationship. However, the lightning pattern relationship between zones is varied. The relationship between B&C was stronger than other two. The relationship changes as;

B&C > A&C>A&B

The study has following recommendations which needed to be considered for future developments;

• to conduct lightning resilient/ fighting capacity assessment over Sweden to estimate the precise lightning risk.

• Lightning strike prediction is important to prevent damages. For this purpose, cloud volume is needed to be calculated. As a recommendation, it is necessary to have a system for measure the cloud volume to predict the lightning stroke.

• to have such systems in Sri Lanka, to prevent the annual lightning damage around the country

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