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Identification of Lightning Frequency Strength and Risk Levels of Lightning in Sweden

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***Abstract*—The lightning activity pattern in Sweden was evaluated using the available lightning striking data recorded by the Swedish Lightning Location System. The analysis was done for entire country and three selected zones of the country and found that annually, the highest lightning activity is taking place along the southern part (zone A) of country while the lowest activity at the northern part. Results suggests that the variation of lightning activity is cyclic with 3 -4 years period each 3 zones and the entire Sweden. Further, it was revealed that the risk of lightning strike is increasing during the last 15 years.**

***Index Terms*— Lightning, Risk Matrix, Pattern**

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.

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.

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 1,000 deaths and injuries each year, with damages exceeding $1 billion. In Sweden, the annual number of deaths due to lightning is about only 1 (Eriksson &Örnehult, 1988).

Lightning occurs approximately 100 times per second worldwide, resulting in nearly 1.4 billion flashes per year (Oliver, 2005). Lightning occurs when a cloud reaches cumulonimbus cloud type 3 to 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. However, thickness of the charged cloud may vary and normally it will be 10-12 km. The down draft can be felt as a cold wind before the rain starts.
Many factors affect the frequency, distribution, strength and physical properties of a "typical" lightning flash in a 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). To a certain degree, the ratio between IC, CC and CG lightning may also vary by season in middle latitudes. Figure 1 shows the type of lightning strokes.

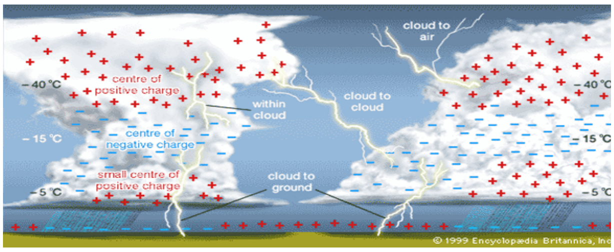

Figure 1: Type of lightning strokes – (*1999 encyclopedia Britannica, Inc.*)

A typical cloud to ground lightning flash culminates in the formation of an electrically conducting plasma channel through the air in excess of 5 km (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).
It is very useful if system can develop to identify the pattern of the lightning strikes worldwide. In addition, position of lightning can hit on ground as well as most risk areas (levels) of lightning can be hit worldwide, to be avoid loss of thousands (1,000) of human lives and billions of property damages. The technique is useful to derive and identify the patterns and relationships. Risk matrix is used to assess the lightning frequencies, regions and its magnitude.

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A. *Lightning 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. However, all these studies had a common limitation in digitizing hardware, arising due to the capture of a very small sample of events in a given thunderstorm for detailed analysis on the individual lightning waveforms. Thus, the exact location of the lightning stroke is not known in most of these studies and the method used to measure the distance is based on estimating time for travel of thunder.

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). They have stressed that these systems are strong in detecting and processing data from many different thunderstorms but weak in extracting the details of individual waveforms, thereby limited to produce average lightning parameters in extensive research on lightning. Even to produce average lightning parameters, these systems require special attention to be paid on frequent changes in network configurations while operating over many years.
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). By using these millions of data identify and explain lightning risk areas in Sweden and how it varies from north pole to equator.

II. METHODOLOGY

A. *Risk Calculation*

Hazard, Vulnerability, Capacity and Risk are the key words in the sphere of disaster management. Identification of hazard, vulnerability and risk are key considerations for creating safer human settlements, through a process of disaster risk reduction. Risk is associated with hazard, vulnerability and capacity.

The approach for the risk map is developed through the general equation of risk which is given below.

Risk=(Hazard ×Vulnerability)/Capacity

It is always useful to go by the basic approaches especially in a multi-varying analysis of number of elements. In this approach the basis of risk reduction is elementarily indicated. Risk is a combination of hazard and vulnerability where;

Hazard – Any phenomenon, substance or situation, which has the potential to cause disruption or damage to infrastructure and services, people, their property and their environment.

Vulnerability – A concept which describes factors or constraints of an economic, social, or geographic nature, which reduces the ability of a community to prepare for and cope with the impact of hazards.

Capacity – The resources and skills people possess, can develop, mobilize and assess, which allow them to have more control over shaping their own future and coping with disaster risks.

Risk – The probability that negative consequences may arise when hazards interact with vulnerable areas, people, property and environment.

III. RESULTS AND DISCUSSION

A. *Risk Matrix*

There are various ways to calculate risk matrix, however, the most common form of risk matrix is the one demonstrating the relationship between the likelihood of the risk and impacts of the event. Risk likelihood can also be described as frequency. For hazard risks, magnitude is often referred to as severity of the risk should it materialize. An example of a Risk matrix is presented in the Figure 2. By using plotted areas on the graph, we can label risk areas from 1 to 4. According to the graph below the mean value of magnitude and below the mean value of frequency is label Risk area 1. Above the mean value of magnitude and below the mean value of frequency is label Risk area 2. Above the mean value of frequency and below the mean value of magnitude is label to Risk area 3. Finally, above the mean value of both magnitude and frequency is label as Risk area 4. This area is most dangerous lightning strike area in any ware in the world.

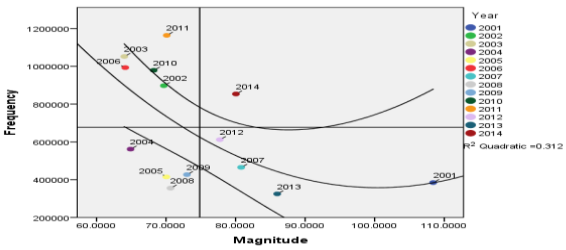

Figure 2 Risk matrix

Table 1 Assigning values for lightning severity

Frequency	Magnitude	Risk reduction category	Risk Value
Above mean	Above mean	Risk should be terminated	4
Below mean	Above mean	Risk should be transferred	3
Above mean	Below mean	Risk should be treated	2
Below mean	Below mean	Risk should be tolerated	1

According to Table 1, the risk should be mitigated or minimized. However, this paper is not focusing on risk reduction measures of the lightning strikes. The fitting curve was generated through quadratic fit value and 95% confidential values were generated to define the judgment line and critical line of the lightning risk. The new values, 1 to 3, are assigned respectively. The new value 1 represent the lowest risk values implying that this risk can be easily tolerated through existing capacity or can be ignored due to low damage. New risk value 2 represents the modest level of risk (heat) at which attempts should be made to mitigate impacts from lightning. Proper action planning, mitigation measures should be proposed to these heat categories.

B. Lightning Strikes Risk during the Period of 2011-2014

According to the data set of lightning during the period of 2001 – 2014the risk matrix can represent as below Figure 3. The matrix was divided into four main categories based on the mean values of frequency and magnitude which represent the status above or below the average of lightning strike during past 15-yearperiod of time. The lightning values are plotted over the matrix and generate the well-fitted line and range of confidence area. The location of the lines represents the risk level of lightning risk over the area.

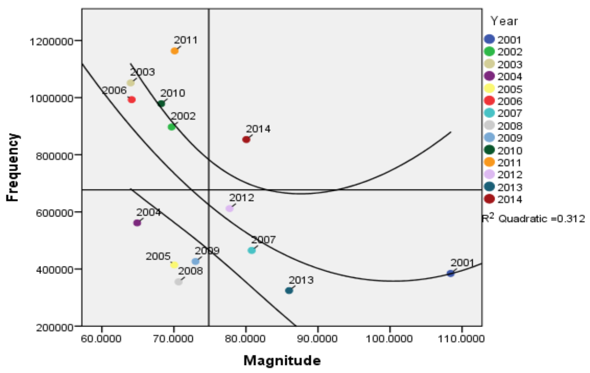

Figure 3 Frequency and Magnitude of lightning strikes during the 2001 - 2014

According to the chart in Figure 3, Year 2014 has highest risk situation compared to other years. However, risk can be classified into following categories and the risk categories are assigned with ISO 31000 standard:

Considering the risk reduction off the lightning can be allocated sufficient financial support for risk reduction measures. New value 3 represents extreme events, which are hard to mitigate. The lightning heat variation map was calculated in entire region (see for example Figure 4). As per the analysis, the lightning strike heat variation map (risk) increases rapidly since 2008, and 2014 had the highest lightning risk since 2001.

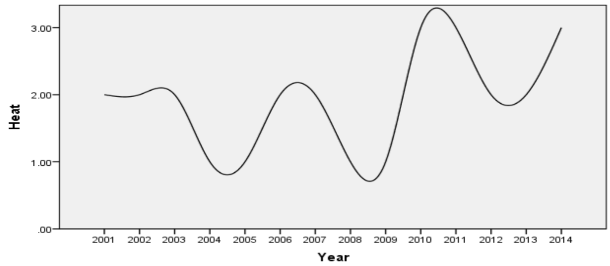

Figure 4(Lightning severity variation by Year 2001 - 2014)

According to the analysis, the peaks had occurred every 4 years. Same variations had been calculated for different zones and results are shown below:

The area of the Sweden is divided into main three parts(regions) shows in below Figure 5, 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 risk pattern variation with latitude values.

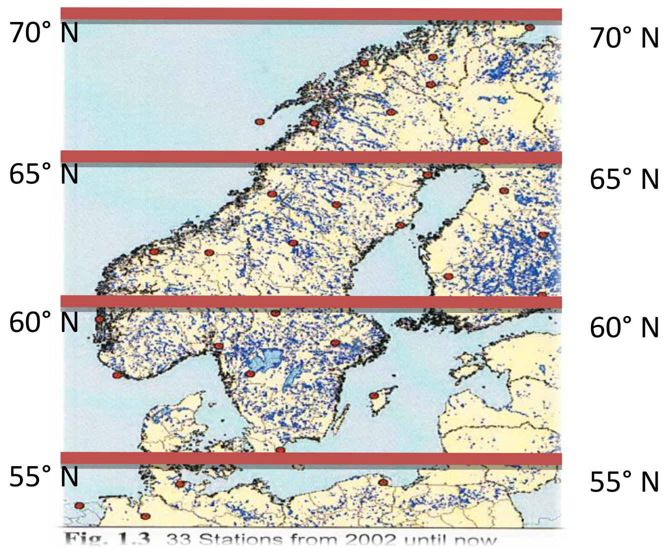

Figure 5 (Division of three zones with latitude)

C. Zone A:

In Zone A, which is below latitude 60, mean values of frequency and magnitude are 441,141 and 75.48, respectively. The fitting curve (Figure 6) was generated through quadric fit and 95% confidential values were generated to define the judgment line and critical line of the lightning risk.

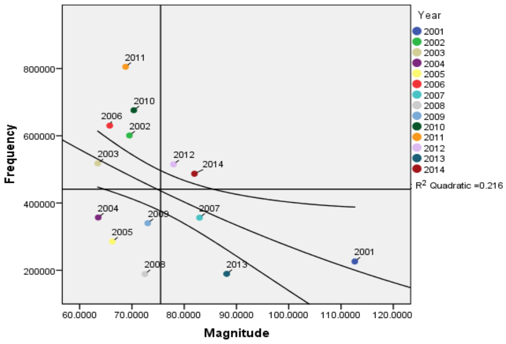

Figure 6 (Zone A Heat Matrix)

The values are categorized into three groups; below the confidence range, between the confidence value range and above the confidence value range. The new values, 1 to 3, are assigned respectively. Figure 7shows the variation of the risk in Zone A.

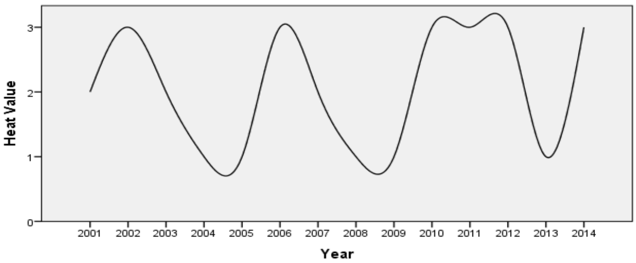

Figure 7(Heat value variation of Zone A)

According to the Figure 7 in a Zone A, there is a 4-year lighting strike pattern (cycle) and the pattern had changed in 2011 and 2012, probably due to impacts from some other factors. If the original pattern is continued lightning risk will be reduced in 2015-2016.

D. Zone B:

Zone B heat map was generated (Figure 8) by considering the frequency and magnitude of the lightning that occurred between latitudes of 60 to 65. The mean values of frequency and magnitude (RNSS) are 190,986 and 74.36.

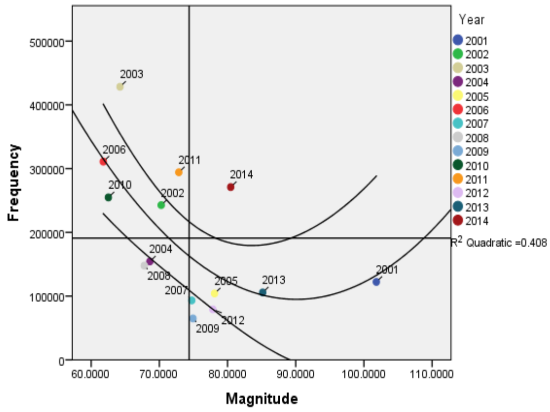

Figure 8(Heat value variation of Zone B)

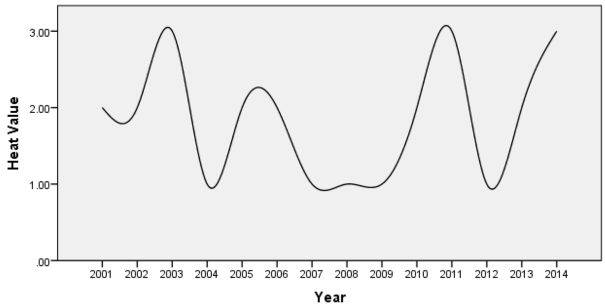

Figure 9(Heat value variation of Zone B)

The heat value variation of the zone (Figure 9) is complex but peaks had occurred in 2003, 2006, 2011 and 2014. It can be considered that, peaks had occurred at 3-year intervals and the variation had been changed between 2008 and 2010.

E. Zone C:

Zone C heat map was generated (Figure 10) by considering the frequency and magnitude of the lightning that occurred between latitudes of 65 to 70. The mean values of frequency and magnitude (RNSS) are 45051 and 72.06.

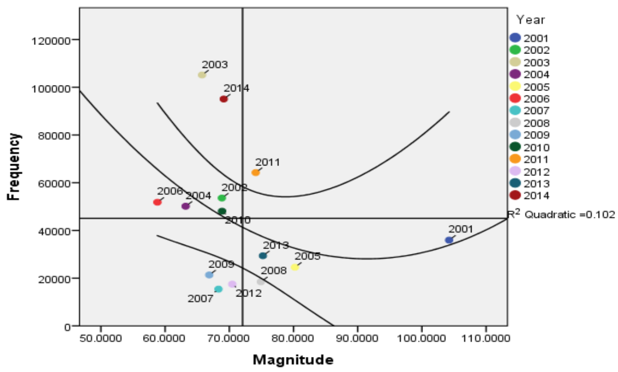

Figure 10(Zone C Heat Matrix)

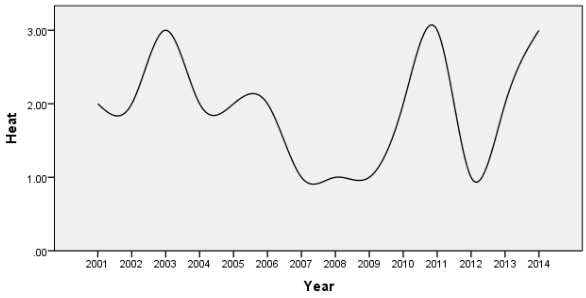

Figure 11(Heat value variation of Zone C)

The heat map value variation is complex in Zone C also (Figure 11). Similar to Zone B, the peak value variation occurs in periods of 3 years except between 2008 and 2010.

IV. CONCLUSION

In this paper, lightning activities in three selected zones in Sweden was analyzed to understand the level of risk and variation of lightning activity. Results show that there is a general trend of increasing lightning activity in all three zones during last 15 years. Each year, the highest count of lightning strike was observed in zone A, which is closest to the equator and the lowest at the zone C, which is located close to the North pole. It is interesting to note that the frequency of lightning shows an oscillating pattern with a maximum at each 4th year in zone A, while zone B and C shows a peak activity at each 3rd year. However, some variation of this cyclic pattern is observed between 2008 – 2010time periods. This could be due to some effects cause by unknown climatic changes or data recording errors of the lightning location systems. Data strongly suggests that there is a tendency of increasing risk of lightning strike in Sweden during the last 15 years.

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