

FORECASTING LIGHTNING OCCURRENCE AND FREQUENCY¹

by Kerry Anderson²

ABSTRACT

Lightning is one of the most common severe weather events, yet, is perhaps the hardest to forecast accurately. This paper reviews the physics of lightning, factors that lead to intense lightning activity, and models that have been developed to forecast lightning occurrence and frequency.

FILE COPY / RETURN TO:

PUBLICATIONS
NORTHERN FORESTRY CENTRE
5320 - 122 STREET
EDMONTON, ALBERTA

INTRODUCTION

Lightning is one of the most spectacular meteorological phenomenon and the most common severe weather to affect mankind directly. But despite decades of research and advances in instrumentation, the exact origin of lightning and the mechanisms behind the charge buildup within a thundercloud are still not understood (Dye 1990; Williams 1988; Krider and Alejandro 1983).

The problem confronting lightning research is the range of scales the phenomena encompass. Processes at the molecular level must be combined with those scaling the depth of the troposphere and greater. Though progress has been made to understand specific processes, putting these together into the big picture has eluded the research community.

Without a firmly established understanding of the principles behind cloud electrification, weather forecasters have only a superficial knowledge of lightning. They know that lightning is generally associated with convective activity and it has been assumed that methods of predicting other convective phenomena, such as rain showers and hail, should work well for predicting lightning. As a result, only a few predictive techniques have been devised to forecast lightning specifically (Sly 1965; Fuquay 1980; Andersson 1989; Anderson and Charlton 1990; Anderson 1991).

In the last decade, lightning detection systems have given meteorologists a new source of data. These systems provide real time data of lightning occurrence and its location. But, like a Pandora's box, lightning detection systems have created more questions than answers, as observers begin to look at lightning with a new degree of resolution.

¹A paper presented at the Eighth Central Region Fire Weather Committee Scientific and Technical Seminar, April 3, 1992, Winnipeg, Manitoba.

²Fire Research Officer, Forestry Canada, Northern Forestry Centre, 5320 - 122 Street, Edmonton, Alberta, T6H 3S5.

Is the intensity of lightning activity directly correlated with the intensity of convection? Observations do not seem to support this. The experience in Alberta is that although indicators of convective instability point to thunderstorm activity, there is no way of determining whether a storm will yield 1,000 or 10,000 lightning flashes (Nimchuk 1985).

The forest sector has a definite need for lightning forecasts as lightning is a major cause of forest fires. Starting 34%³ (3,101) of the near 10,000 fire occurrences annually in Canada, lightning-caused fires account for 87% (1,840,822 ha) of total area burned nationwide. The discrepancy in the percentages is due to the general inaccessibility of lightning-caused fires. As a result, a large number of them escape the initial containment attempts. For this reason, forest protection agencies are one of the main users of lightning detection systems.

This paper reviews the physics of lightning. It discusses the thundercloud, charge generation, and the lightning flash, and lightning detection. This paper also reviews models that have been developed to forecast lightning occurrence and frequency.

THE PHYSICS OF LIGHTNING

This section provides a brief overview of the basic theories and observations of thundercloud electrification and the lightning discharge. For a comprehensive background, the reader is referred to textbooks by Chalmer (1967), Uman (1969; 1987), and Golde (1977), and review papers by Latham (1981), Uman and Krider (1982; 1989), and Williams (1985).

Thunderstorm Structure

Lightning is associated with convective activity. Thunder (and thus lightning) is used by the professional weather observer to classify the severity of convective activity. Cumulonimbus clouds are the largest form of convective cloud and typically produce lightning. Cumulonimbus clouds with lightning activity are generally referred to as thunderclouds.

The classical thundercloud model was developed in the 1920s by Wilson (1920; 1926) from ground-based electric field measurements. It consists of a positive electric dipole (a positively charged region above a negatively charged region). Further research using balloon measurement identified an additional weak region of positive charge at the cloud base (Simpson and Scrase 1937; Simpson and Robinson 1941). This double-dipole structure, as shown in figure 1, has been confirmed with electric field measurements both inside and outside the cloud. Because of the weak strength of the lower charge region, both the positive dipole and the double-dipole can be used to describe the general structure of a thundercloud.

³Figures based upon a ten year annual average for 1973 to 1982 for the ten provinces and two territories (Ramsey and Higgins 1986).

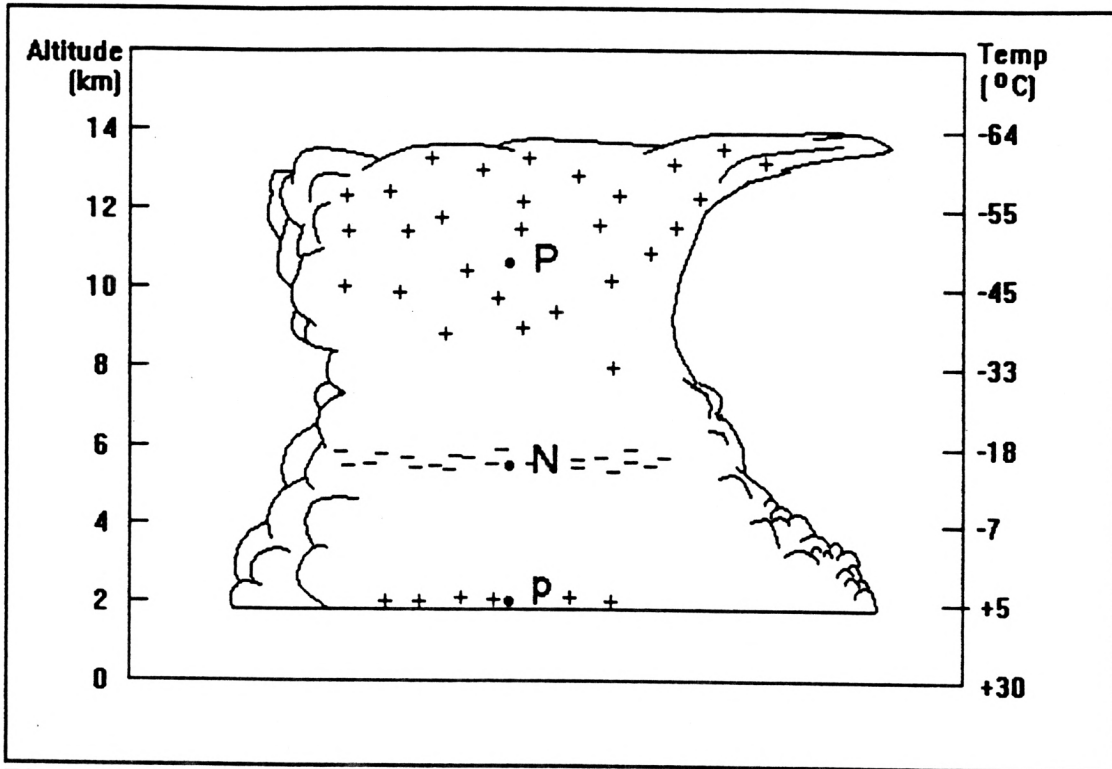


Figure 1. Typical charge distribution within a thundercloud.

The three centres of accumulated charge are commonly labelled p, N, and P. The upper positive centre, P, occupies the top half of the cloud. The negative charge region, N, is located in the middle of the cloud. The lowest centre, p, is a weak, positively charged centre at the cloud base. The N and the P regions have approximately the same charge, creating the positive dipole. Malan (1963) documented charges and altitudes above ground level for the p, N and P regions of a typical South African thundercloud (1.8 km ASL) as +10 C (coulombs) at 2 km, -40 C at 5 km, and +40 C at 10 km. These are representative of values that can vary considerably with geography and from cloud to cloud.

Research by Krehbiel *et al.* (1983; 1984), and MacGorman (1981) on the charge structure of lightning discharges has gone further to identify the nature of the negative charge region. Krehbiel's study centered on two thunderstorms that developed over Florida. In the study, Krehbiel used LDAR (lightning detection and ranging) and acoustic location to locate the sources of lightning discharges within the cloud. Doppler radar was used to define the wind-fields and areas of precipitation. General findings indicate that the negative charge region within a thundercloud is located within a subfreezing region of relatively small vertical dimension (less than a kilometre) somewhere between -10 and -25 °C (Krehbiel *et al.* 1983). Krehbiel further notes that the altitude of the negative charge centre remained constant throughout the storm growth and was not affected by the strength of the vertical wind.

There is a general association between radar reflectivity and negatively charged lightning flashes. Lightning discharge sources are located near, but not necessarily within, the area of highest

reflectivity (MacGorman *et al.* 1983). This is supported by Mazur (1983) and Mazur and Rust (1985). In two studies of thunderstorms developing off Wallops Island, Virginia, Mazur found that the region of maximum flash density was close to the leading edge of the precipitation core, defined by 50 dBZ weather radar reflectivity. Though Mazur did not state the polarity of these flashes, it is inferred that they come from the negative charge centre. Lopez, Otto, Ortiz, and Holle (1990) also observed that, in a Colorado thunderstorm, the peak lightning activity occurred in the gradient areas of high reflectivity.

The positive charge region higher up in the cloud tends to follow a different set of characteristics. Krehbiel's study (1983, 1984) noted that the positive charge region did rise steadily with time at a speed of approximately 8 m/s, suggesting that positively charged particles are carried by the updrafts within the cloud. MacGorman *et al.* (1984) noted that positive flashes occurred most frequently in the mature to late stages of growth in individual convective cells. He also noted that these flashes tended to occur in the forward swept anvil of the cloud and the stratiform layer following the cell. These observations have been supported by a number of other studies (Holle 1985; Stolzenburg 1990; Lopez, Ortiz, Augustine, Otto, and Holle 1990; Holle *et al.* 1990; Hunter *et al.* 1990). This would suggest that the positively charged particles are carried by the convective currents in the cloud and positive flashes are more likely to occur when the charge region is horizontally displaced from the negatively charged region.

Theories of Charge Generation in Thunderclouds

Several theories have been developed to explain the charge generation within a thundercloud. To be valid, these theories must be consistent with thunderstorm observations. Mason (1953; 1971) outlined such a list of conditions and parameters. These are:

1. The average duration of precipitation and electrical activity from a single thunderstorm cell is about 30 minutes.
2. The average electric moment destroyed in a lightning flash is about 100 C km, corresponding to charge of 20-30 C.
3. In a large, extensive cumulonimbus, this charge is generated and separated in a volume bounded by the -5°C and the -40°C levels and having an average radius of perhaps 2 km.
4. The negative charge is centred near the -5°C isotherm, while the main positive charge is situated some kilometres higher up; a secondary positive charge also may exist near the cloud base, being centred at or below the 0°C level.
5. The charge generation and separation processes are closely associated with the development of precipitation, probably in the form of soft hail.
6. Sufficient charge must be generated and separated to supply the first lightning flash within 12-20 minutes of the appearance of precipitation particles of radar-detectable size.

There are two general theories to explain the charge buildup required to electrify a thundercloud. They are the convective theory and the gravitational theory.

The convective theory proposes that free ions in the atmosphere are captured by cloud droplets and then are moved by the convective currents in the cloud to produce the charged regions. Vonnegut (*in* Golde 1977) proposed a positive feedback mechanism where positive ions released into the lower atmosphere by corona discharge are caught in the updrafts of a developing cumulus cloud. When raised to the upper region of the cloud, the net positive charge attracts negative ions in the upper atmosphere along the cloud's exterior. In turn, these negative ions are lowered by environmental downdrafts surrounding the cloud to produce the lower negative charge centre.

There are problems with Vonnegut's theory. The travel time required for the positive ions to reach the upper cloud regions is twenty minutes or more - too long for the charge build-up needed to create the breakdown fields for lightning initiation (Latham 1981). A second, and more serious problem with the convective theory is the incompatibility with the stratified, motionless characteristic of the negative charge region found by Krehbiel *et al.* (1983, 1984). If vertical air motions are expected to produce the charge regions, they should have a pronounced vertical dimension corresponding to the regions of strongest updraft and downdraft. Krehbiel found that the positive charge did rise with time. This does show the importance of convective currents in the cloud, though it does not necessarily support Vonnegut's model.

The gravitational theory assumes that negatively charged particles are heavier and are separated from lighter positively charged particles by gravitational settling. For the gravitational theory to work, there must be some charge exchange process between particles of different sizes. Charge can be exchanged between particles by inductive and non-inductive processes. Dye (1990) and Illingworth (1983) provide comprehensive reviews of these processes.

The inductive process assumes that charge is exchanged between colliding particles polarized in an electric field (see Figure 2). Particles are polarized by the fair weather electric field. When a cloud particle collides but does not coalesce with the underside of a falling precipitation particle, negative charge is transferred from the precipitation particle to the cloud particle. This results in a positive charge on the light cloud particle and a negative charge on the heavier precipitation particle.

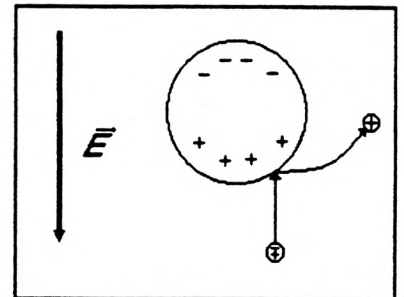


Figure 2. The inductive process.

The appeal of the inductive process is that it sets up a positive feedback system originating from the fair weather electric field. As the regions of charged particle separate, the thunderstorm's electric field is intensified. In turn, this increases the degree of polarization in the remaining particles and the efficiency of charge exchange process.

For inductive processes to be feasible, several problems must be addressed. Particles must collide so that coalescence does not occur. The collision must be in alignment with the dipole moment to exchange charge efficiently (which falls off as the cosine of the angle of deviation

from the dipole moment). They must remain in contact long enough for significant amount of charge to be exchanged. Collisions involving water particles tend to coalesce and when they do not, either the angle of contact is not in alignment with the dipole moment or the contact time is not long enough to exchange a significant charge. Collisions involving ice particles are more efficient as coalescence is less likely but whether enough charge can be exchanged by this process is debatable.

The non-inductive process assumes that charge can be exchanged independent of external electric fields. The most promising is the non-inductive exchange between ice crystals and hailstones, referred to as the ice-ice process, first proposed by Reynolds *et al.* (1957).

The effectiveness of the ice-ice process lies in the thermo-electric properties of ice (see Figure 3). The mobility of the $(OH_3)^+$ defect in ice is greater than the $(OH)^-$ defect and the number of defects increase with temperature. When warm and cold ice particle come in contact, the positive defect flows faster from the warmer to the colder particle than the converse giving the colder particle a net positive charge. Therefore in the typical scenario, a warm hailstone or snow pellet will acquire a net negative charge as it falls through a region of cold ice crystals.

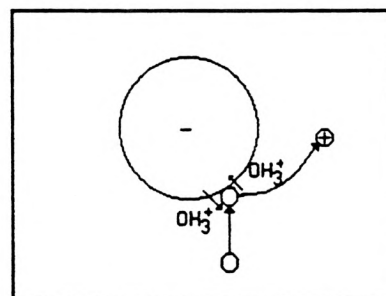


Figure 3. The non-inductive ice-ice process.

Williams (1988) further notes there exists a charge-reversal level where at warmer temperatures, the hailstone becomes positively charged and ice crystals negatively charged. Speculation about the exact temperature of the charge-reversal level is still in dispute, though observations would suggest it is near -15°C .

The problem with collision processes, and all thundercloud charge generation models in general, is the time and the precipitation rate required to generate the necessary electric fields. The first lightning flash usually occurs within 20 minutes of the formation of precipitation within the cloud. The inductive and non-inductive processes described above do approach the required electric field strengths to initiate lightning but generally fall short by about a magnitude of ten (Williams 1985). Mathpal and Varshneya (1983) calculated the electric field strengths produced by these processes at various precipitation rates. They concluded that alone, neither of these processes could account for the necessary charge build-ups. They went further to calculate combined processes and concluded that a combined induction and convection was most favourable.

Theories of thundercloud charge generation is still very speculative. The favourability of one process over another has fluctuated over time due to the inadequate number of laboratory experiments and scarcity of useful field observations (Latham 1981; Williams 1985). *One clear conclusion is that there is no unique mechanism to generate the required charge under all conditions.* For example, the ice-ice process, presently the most favoured (Dye 1990) does not explain warm cloud lightning, albeit a not too frequent event. As research develops, the most likely explanation will lie in a combination.

The Lightning Flash

The charge buildups in thunderclouds are unstable. When electric fields generated by the charge buildups becomes too strong - typically $3\text{--}4\text{ kV cm}^{-1}$ at the altitude of the negative charge region of the cloud (Latham 1981) - electrical breakdown of the air occurs and charge is exchanged within the cloud or to the ground. Charge is exchanged by a lightning flash.

Lightning can occur in four ways. Lightning can travel between points within a cloud, from a cloud to clear air, from a cloud to an adjacent cloud, and from a cloud to ground. These flashes are referred to as intracloud, cloud-to-air, cloud-to-cloud, and cloud-to-ground, respectively.

Intracloud (IC) flashes, redistributing the charge within the cloud, account for over half the lightning flashes in northern latitudes (Uman and Krider 1989). Cloud-to-cloud and cloud-to-air flashes are less common. Besides aviation, these three types of flashes have little impact on man.

Cloud-to-ground (CG) flashes are very common and have been well documented. They exchange charge between the cloud and ground. These flashes affect man greatly, causing injury and death, disrupting power and communications, and igniting forest fires. Because of these impacts, the cloud-to-ground flash has been the topic of much research.

The cloud-to-ground lightning flash can lower positive (+CG) or negative (-CG) charge, depending on the source of the flash. This can be determined by the polarity of the stroke's current. Characteristics of negative and positive cloud-to-ground flash are summarized in table 1 (Uman 1987).

Table 1. Characteristics of positive and negative cloud-to-ground flashes.

Characteristic	Negative	Positive
% occurrence	90	10
Average peak current (kA)	30	35
Average current half life (μsec)	30	230
Average number of strokes	3-4	1
% containing long continuing current	20	80

The negative cloud-to-ground lightning flash can be broken down into three stages. The stepped leader, the return stroke, and the dart leader.

The stepped leader is a small packet of negative charge that descends from the cloud to the ground along the path of least resistance (see Figure 4). In its path, the leader leaves a trail of ionized gas. It moves in steps, each typically tens of metres in length and microseconds in duration. After a step, the leader pauses for about 50 microseconds, then takes its next step. The

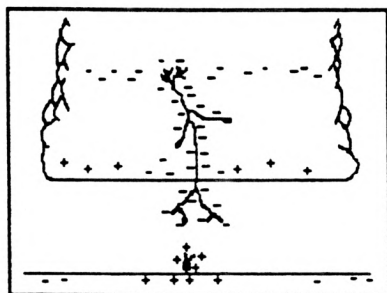


Figure 4. The stepped leader.

leader charge packet sometimes breaks up to follow different paths, giving lightning its forked appearance.

As the stepped leader approaches the ground, electrons on the surface retreat from the leader creating a region of positive charge. Corona discharges (dielectric breakdowns in the air, also known as *St. Elmo's Fire*) are

released from tall objects on the surface and reach out to the approaching leader. When the downward moving leader connects with a surface corona discharge, a continuous path between the cloud and the ground is established and a powerful return stroke is triggered (see Figure 5). The return stroke rapidly moves as a wave upwards into the cloud following the ionized trail of the stepped leader, stripping the electrons from its path.

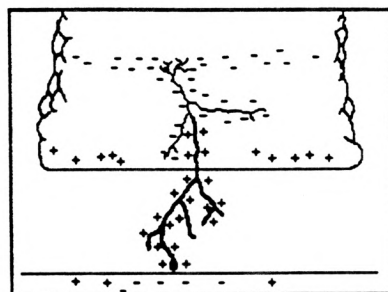


Figure 5. The return stroke.

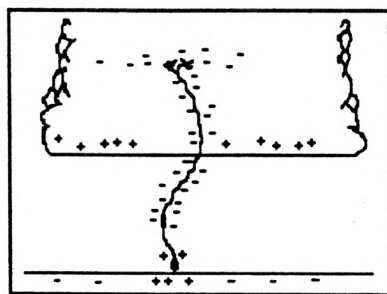


Figure 6. The dart leader.

After the return stroke, the lightning flash may end or, if enough charge in the cloud is collected, a dart leader may come down from the cloud following a direct path to the surface (Figure 6). In turn, the dart leader triggers a second return stroke (Figure 7).

A single lightning flash can be comprised of several return strokes. The average number of return strokes in a lightning flash is 3 or 4, each stroke typically separated by 40 to 80 milliseconds.

The positive cloud-to-ground flash is less common than the negative. Coming from higher altitudes in the cloud, positive flashes make up about 10% of all lightning flashes (Uman and Krider 1989). They are usually composed of a single stroke, and have longer, continuing currents (see Table 1). From the forestry perspective, positive flashes are of more concern as the longer currents are more likely to start fires (Fuquay 1972).

Several studies have concentrated on the characteristics of the positive flash but results are inconclusive due to the number of observations. The percentage of positive flash appears to increase with latitude (Takeuto *et al.* 1983) and with the height of local terrain (Uman and Krider 1989). Also, positive flashes are more common in winter storms (Takeuto *et al.* 1983; Williams 1985). The apparent cause for this is that the lower freezing level places the positive charge centre closer to the ground thus increasing the likelihood of a flash.

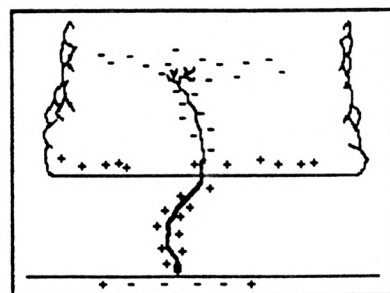


Figure 7. The second return stroke.

Positive flashes are more common in stratiform clouds while negative flashes tend to occur in areas of strong convection (Holle *et al.* 1988). Also, thunderstorms that predominantly consist

of negative flashes in their early stages, often end with positive discharges as the storm matures and the anvil spreads out (MacGorman *et al.* 1984).

A popular theory is that horizontal wind shears force a tilting of the dipole axis providing a route for the positive flash (Takeuto *et al.* 1983; Rust and MacGorman 1985; Takagi *et al.* 1986) but this has yet to be shown conclusively.

Lightning Detection

Most forest and weather services now use the wide band magnetic gate design lightning detector (Krider *et al.* 1980; 1976) manufactured by Lightning Location and Protection Inc. (LLP) of Tucson, Az. The LLP lightning detection system determines the time and location of a lightning flash by triangulating information from 12 direction finder stations situated in and around the province (see Figure 8). These data are stored on magnetic tape. Maps can be processed to show the location and polarity of lightning flashes that occur over a period of time (see Figure 9).

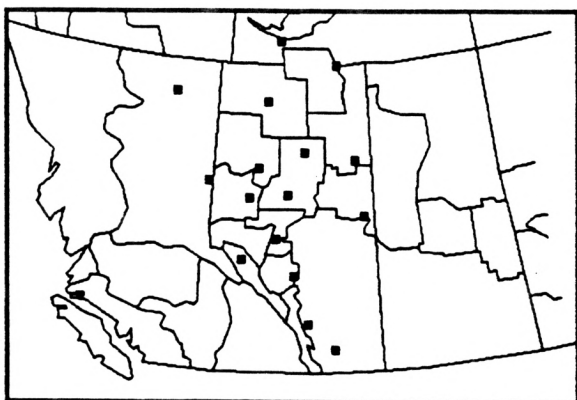


Figure 8. The Alberta Forest Service's LLP direction finder network.

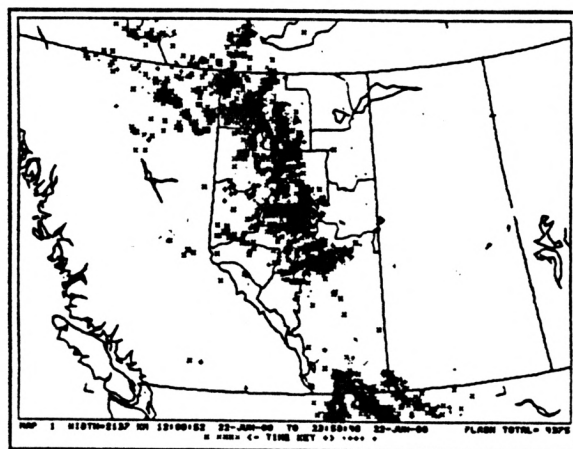


Figure 9. Lightning detection map for June 22, 1988.

The LLP lightning detection system has three components: the direction finder, the position analyzer and the remote display processor.

The direction finder (DF) senses the electromagnetic field radiated by a lightning flash using two erect, orthogonal wire loop antennas and a horizontal flat plate antenna. The antenna's bandwidths are from 1 kHz to 1 MHz. The radiated field of a lightning flash induces a current in the loops. The voltage signal measured in the loops is related to the flash's generated magnetic field strength by the cosine of the angle between the loop antenna and the direction to the flash. By comparing the voltage signals from the two loops, a direction to the flash can be determined. The flat plate antenna is used to resolve the 180 degree ambiguity associated with the calculations.

The direction finder can discriminate cloud-to-ground flash from other forms of lightning or noise by the electromagnetic signature. When the stepped leader reaches the ground, the return stroke is triggered producing a sharp voltage rise. This telling factor distinguishes a cloud-to-ground flash from other electromagnetic noise.

The direction finder sends the data of each registered lightning flash to the position analyzer (PA). The position analyzer triangulates data from direction finders to locate the position of a lightning flash. If the flash is in line with or directly between two direction finders (called the baseline), the position analyzer uses the ratio of the signal strengths as well.

From the position analyzer, users can view a map of the lightning data on a remote display processor (RDP). The display can focus on desired time and location windows covered by the detection network, and can show up to 30,000 flashes.

CURRENT MODELS TO PREDICT LIGHTNING

Several attempts have been made to make models to predict both lightning occurrence and frequency. These are summarized in this section. The reader should note that of the four models presented, only one is based upon lightning detection technology. The other models were based primarily on indirect, less reliable, techniques (such as a weather observer hearing thunder or seeing lightning) and should be regarded with caution.

Sly - 1965

In the sixties, Sly developed a set of convective indices useful in forecasting various convective processes over Alberta (Sly 1966). A modification of the Jefferson index of instability, Sly's indices took the form

$$C = C_1 = 1.6\theta_{w12m} - T_{500_{00}} - 11$$

$$C = C_2 = 1.6\theta_{w21m} - T_{500_{00}} - 11$$

$$C = C_1 = C_2 = m_{00}$$

where θ_{w12m} is the wet-bulb potential temperature ($^{\circ}\text{C}$) calculated using the 1200 UTC dew point temperature and the maximum for the day, θ_{w21m} is the wet-bulb temperature ($^{\circ}\text{C}$) calculated using the 2100 UTC dew point temperature and the maximum for the day, $T_{500_{00}}$ is the 500 millibar

temperature (°C) at 00 UTC the following day, and m_{00} is a correction due to mid-level at 0000 UTC the following day.

Of the three indices, Sly found a good relationship between the second index, C_2 , and lightning incidence over the Grande Prairie forest in Northwestern Alberta (Sly 1965). The values of the C_2 index for days when lightning was reported by a look-out tower were compared with values for days with no lightning. Sly found that a C_2 value of 31.0 was a good discriminator. Of the 106 days with a C_2 below 31.0, only 9 had lightning. For C_2 values above 31.0, the probability of lighting jumped to 80%, while for values above 34.0, the probability was 93%.

Although Sly's indices have merits, they are longer in use. Because of its age, Sly's research is based upon surface observation. It lacks the technological support (radar, lightning detection systems) that is so essential to severe weather forecasting today.

Fuquay - 1980

As part of the National Fire-Danger Rating System (NFDRS) for the United States, Fuquay developed a scheme to describe and forecast Lightning Activity Levels (LAL), a predictor of lightning-caused forest fires.

In his model, there are 6 LALs ranging from no thunderstorms (LAL 1) to numerous thunderstorms and heavy precipitation (LAL 5). Lightning Activity Level 6 is reserved for high level thunderstorms. These are of particular interest to the forester because they are often accompanied by little to no rain.

The Lightning Activity Level is primarily a descriptive scheme that can be used by observers and forecasters. It is based on maximum cloud development, maximum height of radar echoes, radar echoes (intensity and area coverage), precipitation (amount and area coverage), and cloud to ground lightning flash rates and density. If the forecaster can predict one of these factors, he or she can then determine the LAL for the day.

Andersson *et al.* - 1989

Andersson *et al.* compared the performance of three thermodynamic indices - the energy index (EI), the George's K and a modified K index (KO) - against thunder observations at weather stations in Sweden. Skill scores showed that, to a degree, all three indices were good predictors with detection rates approaching 100%. These results were hindered by high false alarm rates, as much as 40%.

The study then went on to predict lightning frequency. A regression equation to predict thunderstorm activity was built using a stepwise regression on the three indices. The regression was able to explain 37% of the variance.

The weakness of this approach was that the researchers used the thunderstorm index, *TH* ($100 \times$ number of thunderstorm observations/number of observations), which is not a good measure of the lightning activity. While useful in determining the probability of lightning occurrence, the estimate of lightning frequency is categorical (low, medium, high) at best.

Anderson - 1991

In 1991, Anderson built a scheme to forecast lightning over Alberta. This was accomplished through the development of lightning occurrence and lightning frequency prediction models. These models were built using statistical modelling and map analysis.

Anderson studied LLP lightning detection data and compared the lightning occurrence and lightning frequency in the vicinity of Stony Plain with upper air soundings from that station. The data was analyzed using a variety of statistical tests. These included *t*-tests and logistic regression to examine the probability of lightning occurrence, and linear and multiple linear regression to study lightning frequency.

The first approach was to predict days with lightning. To do this, *t* tests and stepwise logistic regressions were conducted. The *t* tests showed convective parameters, such as convective indices, temperatures, and moisture as the most significant in distinguishing between days with lightning and days without lightning. The results of the logistic regression models show that the potential for the predictability of lightning occurrence (the detection rate) is above 80%, though high false alarm rates, 30% on average, reduce the value of these predictions.

Parameter	Symbol	Contribution
Surface		
Fronts		LII
Moisture axis		Instability
Dry line		Instability
Thermal ridge		LII
Convergence		LII
Instability line		Instability
850 mb		
Axis of stronger wind		LII
Low level jet		LII
Moisture axis		Instability
Dry line		Instability
Thermal ridge		Instability
Convergence		LII
700 mb		
Axis of stronger wind		LII
Dry prod		Instability
No change line		Instability
Diluent zones		LII
500 mb		
Axis of stronger wind		LII
Wind maximum		LII
Thermal trough		Instability
PVA		LII
Diluent zones		LII
250 mb		
Axis of stronger wind		LII
Wind maximum		LII
Diluent zones		LII
850-500 mb thickness ridge		LII

Figure 10. Severe Weather Symbols.

To predict lightning flash frequency, linear regression techniques were used. Regressions using individual variables showed a large degree of scatter (*r*) but the significance of the correlation coefficient (*P*) indicate that most are not due to chance. Three multiple linear regression models were built to predict lightning frequency using stepwise linear regressions. These models show that convective indices are the most important parameters to use, but with the best *r* squared values between 0.16 to 0.49, they do not sufficiently explain the variation.

It was then shown that, from the regression equations derived through the statistical study, spatial predictions of lightning occurrence and frequency could be produced.

To account for spatial features that cannot be drawn from upper air soundings, severe weather composite maps were studied (Figure 10). These maps show parameters from various levels in the atmosphere likely to cause severe weather. This study reinforces the importance of convective parameters shown as low level moisture, surface warming,

and instability. Surface fronts, low level convergence, and positive vorticity advection (PVA) were recognized as fields that could not be accounted for by upper air soundings.

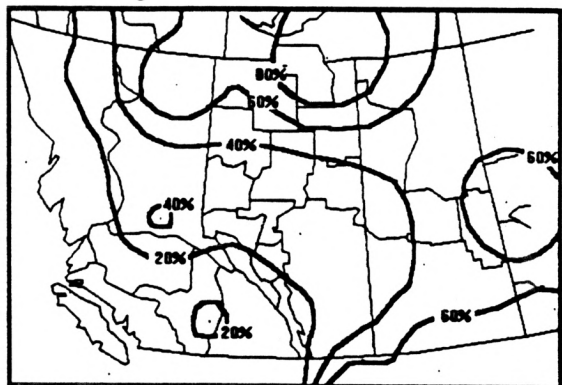


Figure 11. 0000 UTC June 24, 1988 negative lightning occurrence prediction map.

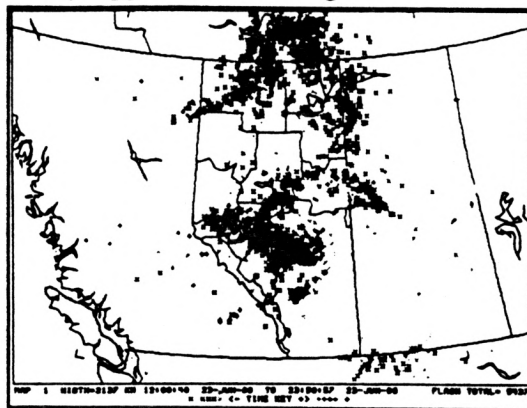


Figure 12. Lightning detection map for June 23, 1988.

Finally, a case study was presented comparing maps of forecasted negative lightning flash occurrences (Figure 11) with the actual detected lightning activity (Figure 13). The forecast maps produced acceptable results but had some short-comings because they could not assess the synoptic situation. This is clearly shown in the figures. Although the lightning activity over northern Alberta was accurately forecasted by the model, the storm over central Alberta was missed (30% probability). This storm was caused primarily by spatial features (Figure 12), namely the presence of surface fronts and convergence and the influx of positive vorticity advection (PVA). If the important spatial features from the composite map study are considered, the forecaster can adjust these maps and produce a very reliable lightning occurrence forecast.

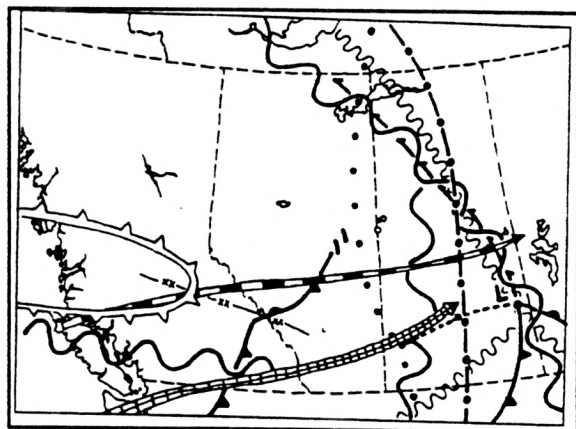


Figure 13. Composite map for 0000 UTC June 24, 1988.

The conclusions Anderson state is that the intensity of convection is the most important process in lightning occurrence and frequency, and that lightning occurrence can be forecasted with reliability. A more significant message, though, is that the techniques generated were not sufficient to predict lightning frequencies reliably. Lightning frequency is a variable that had evaded most research on the subject and it comes as no surprise in his thesis that it continues to be evasive.

BIBLIOGRAPHY

- Anderson, K.R.; Charlton, R.B. 1990. Predicting lightning occurrence and frequency from upper air soundings over Stony Plain, Alberta. Pages J40-J45 in 16th Conf. on Severe Local Storms/Conf. on Atmospheric Electricity. Oct. 22-24, 1990. Kananaskis Prov. Park, Alberta. AMS, Boston.
- Anderson, K.R. 1991. Models to predict lightning occurrence and frequency over Alberta. M.Sc. thesis. University of Alberta. 91 pp.
- Andersson, T; Andersson, A.; Jacobsson, C.; Nilsson, S. 1989. Thermodynamic indices for forecasting thunderstorms in southern Sweden. *Meteo. Mag.* 118:141-146.
- Chalmer, J.A. 1967. Atmospheric electricity. Pergamon press, New York, NY. 515 pp.
- Dye, J.F. 1990. Cloud physics and cloud electrification: what are the connections? Pages 687-691 in 16th Conf. on Severe Local Storms/Conf. on Atmospheric Electricity. Oct. 22-24, 1990. Kananaskis Prov. Park, Alberta. AMS, Boston.
- Fuquay, D.M. 1972. Lightning discharges that caused forest fires. *J. of Geophys. Res.* 77(12):2156-2158.
- Fuquay, D.M. 1980. Forecasting lightning intensity and associated weather. USDA For. Serv. Res. Pap. Int-244. Intermountain For. and Range Exp. Stn., Ogden, UT. 30 pp.
- Golde, R.H. 1977. Lightning: volume 1, physics of lightning. Academic Press, London. 496 pp.
- Holle, R.L.; Watson, A.I.; Dougherty, J.R.; Lopez, R.E. 1985. Lightning related to echo type in four MCC's on June 3-5, 1985 in the pre-storm area. Pages 358-362 in 14th Conf. Severe Local Storms. AMS, Boston.
- Holle, R.L.; Watson, A.I.; Lopez, R.E.; MacGorman. 1988. Cloud-to-ground lightning in the mesoscale convective system on May 20-21, 1979 during SESAME. Pages 501-504 in 15th Conf. Severe Local Storms. AMS, Boston.
- Holle, R.L.; Watson, A.I.; Ortiz, R.; Lopez, R.E. 1990. Spatial patterns of lightning, radar echoes, and severe weather in mesoscale convective systems. Pages 721-726 in 16th Conf. on Severe Local Storms/Conf. on Atmospheric Electricity. Oct. 22-24, 1990. Kananaskis Prov. Park, Alberta. AMS, Boston.
- Hunter, S.M.; Schuur, T.J.; Marshall, T.G.; Rust, W.D. 1990. Electrical and kinematic structure of an Oklahoma mesoscale convective system. Pages J52-J57 in 16th Conf. on Severe Local Storms/Conf. on Atmospheric Electricity. Oct. 22-24, 1990. Kananaskis Prov. Park, Alberta. AMS, Boston.

- Illingworth, A.J. 1983. Review of thunderstorm electrification processes. Pages 149-152 in 6th Conf. Atmospheric Electricity. Manchester, England. July 28-August 1, 1980. A. Deepak Pub., Hampton, VA.
- Krehbiel, P.R.; Brook, M.; Lhermitte, R.L.; Lennon, C.L. 1983. Lightning charge structure in thunderstorms. Pages 408-410 in 6th Conf. Atmospheric Electricity. Manchester, England. July 28-August 1, 1980. A. Deepak Pub., Hampton, VA.
- Krehbiel, P.R.; Tennis, R.; Brook, M.; Holmes, E.W.; Comes, R. 1984. A comparative study of the initial sequence of lightning in a small Florida thunderstorm. Pages 279-285 in 7th Intl. Conf. on Atmospheric Electricity. June 3-8, 1984. Albany, N.Y. AMS, Boston.
- Krider, E.P.; Noggle, R.C.; Uman, M.A. 1976. A gated, wideband magnetic direction finder for lightning return strokes. *J. Appl. Meteo.* 15:301-306.
- Krider, E.P.; Noggle, R.C.; Pifer, A.E.; Vance, D.L. 1980. Lightning direction-finding systems for forest fire detection. *Bull. Amer. Meteo. Soc.* 61:980-986.
- Krider, E.P.; Alejandro, S.B. 1983. Lightning: an unusual case study. *Weatherwise*, April 1983:71-75.
- Latham, J. 1981. The electrification of thunderstorms. *Q.J. of the Royal Met. Soc.* 107(452):277-298.
- Lopez, R.E.; Ortiz, R.; Augustine, J.A.; Otto, W.D.; Holle, R.L. 1990. The progressive development of cloud-to-ground lightning in the early formative stages of a mesoscale convective complex. Pages 658-662 in 16th Conf. on Severe Local Storms/Conf. on Atmospheric Electricity. Oct. 22-24, 1990. Kananaskis Prov. Park, Alberta. AMS, Boston.
- Lopez, R.E.; Otto, D.O.; Ortiz, R.; Holle, R.L. 1990. The lightning characteristics of convective cloud systems in northeastern Colorado. Pages 727-731 in 16th Conf. on Severe Local Storms/Conf. on Atmospheric Electricity. Oct. 22-24, 1990. Kananaskis Prov. Park, Alberta. AMS, Boston.
- MacGorman, D.R.; Taylor, W.L.; Few, A.A. 1983. Lightning location from acoustic and VHF techniques relative to storm structure from 10-cm radar. Pages 377-380 in 6th Conf. Atmospheric Electricity. Manchester, England. July 28-August 1, 1980. A. Deepak Pub., Hampton, VA.
- MacGorman, D.R.; Taylor, W.L.; Rust, W.D. 1984. Some characteristics of lightning in severe storms on the Great Plains of the United States. Pages 299-304 in 7th Intl. Conf. on Atmospheric Electricity. June 3-8, 1984. Albany, N.Y. AMS, Boston.

- Mach, D.M.; MacGorman, D.R.; Rust, W.D. 1986. Site errors and detection efficiency in a magnetic direction-finder network for locating lightning strikes to ground. *J. Atm. and Oceanic Tech.* 3:67-74.
- Malan, D.J. 1963. *Physics of lightning*. The English Universities Press Ltd., London. 176 pp.
- Mason, B.J. 1953. A critical examination of theories of charge generation within thunderclouds. *Tellus* 5:446-498.
- Mason, B.J. 1971. *The physics of clouds*. Clarendon Press, Oxford. 671 pp.
- Mathpal, K.C.; Varshneya, N.C. 1983. Modeling of thundercloud electrification. Pages 261-264 in 6th Conf. Atmospheric Electricity. Manchester, England. July 28-August 1, 1980. A. Deepak Pub., Hampton, VA.
- Mazur, V. 1983. Lightning flash density and storm structure. Pages 207-210 in 13th Conf. Severe Local Storms. AMS, Boston.
- Mazur, V.; Rust, W.D. 1985. Evolution of lightning flash density and reflectivity structure in a multicell thunderstorm. Pages 363-367 in 14th Conf. Severe Local Storms. AMS, Boston.
- Miller, R.C. 1969. Notes on analysis and severe-storm forecasting procedures of the military weather warning centre. Air Weather Service Technical Report 200. USAF. 158 pp.
- Nimchuk, N. 1985. The Lightning Location and Protection (LLP) system: Alberta's operational experience. Pages 11-17 in Proc. 2nd Central Region Fire Weather Committee Scientific and Technical Seminar. Canadian Forestry Service, Edmonton.
- Ramsey, G.S.; Higgins, D.G. 1986. Canadian forest fire statistics/ Statistiques sur les incendies de foret au Canada 1981, 1982, 1983. information report PI-X-49 E/F. Petawawa Natl. For. inst., Can. For. Ser., Chalk River, Ont.
- Reynolds, S.E.; Brook, M.; Gourley, M.F. 1957. Thunderstorm charge separation. *J. Met.* 14:426-436.
- Reap, R.M. 1990. Thunderstorms over Alaska as revealed by lightning location data. Pages J46-J51 in 16th Conf. on Severe Local Storms/Conf. on Atmospheric Electricity. Oct. 22-24, 1990. Kananaskis Prov. Park, Alberta. AMS, Boston.
- Rust, W.D.; MacGorman, D.R. 1985. Unusual positive cloud-to-ground lightning in Oklahoma storms on 13 May 1983. Pages 372-375 in 14th Conf. Severe Local Storms. AMS, Boston.
- Simpson, G.C.; Scrase, F.J. 1937. The distribution of electricity in thunderclouds. *Proc. R. Soc. London* A161:309-352.

- Simpson, G.C.; Robinson, G.D. 1941. The distribution of electricity in thunderclouds, II. Proc. R. Soc. London A177:281-328.
- Sly, W.K. 1965. A convective index in relation to lightning strikes in Northern Alberta. CIR 4220 TEC 566. Dept. of Transport, Canada. 11 pp.
- Sly, W.K. 1966. A convective index as an indicator of cumulonimbus development. J. Appl. Meteo. 5:839-846.
- Stolzenburg, M. 1990. Characteristics of the bipolar pattern of lightning locations observed in 1988 thunderstorms. Bull. Amer. Meteo. Soc. 71:1331-1338.
- Takagi, N.; Takeuti, T.; Nakai, T. 1986. On the occurrence of positive ground flashes. J. of Geophys. Res. 91(D9):9905-9909.
- Takeuto, T.; Isrealsson, S.; Nakano, M.; Ishkawa, H.; Lundquist, L.; Astrom, E. 1983. On thunderstorms producing positive ground flashes. Pages 374-376 in 6th Conf. Atmospheric Electricity. Manchester, England. July 28-August 1, 1980. A. Deepak Pub., Hampton, VA.
- Uman, M.A. 1969. Lightning. McGraw Hill, New York, NY. 264 pp.
- Uman, M.A.; Krider, E.P. 1982. A review of natural lightning: experimental data and modeling. IEEE Transactions on Electromagnetic Compatability, EMC-24(2):79-112.
- Uman, M.A. 1987. The Lightning Discharge. Academic Press, Orlando, FL. 377 pp.
- Uman, M.A.; Krider, E.P. 1989. Natural and artificially initiated lightning. Science 246:457-464.
- Williams, E.R. 1985. Large-scale charge separation in thunderclouds. J. of Geophys. Res. 90(D4):6013-6025.
- Williams, E.R. 1988. The electrification of thunderstorms. Scientific American, November 1988:88-99.
- Wilson, C.T.R. 1920. Investigations on lightning discharges and on the electric fields of thunderstorms. Trans. R. Soc. 221A:73-115
- Wilson, C.T.R. 1926. Discussions of the electrical state of the atmosphere. Proc. R. Soc. London 3:1-13.

Proceedings of the Eighth Central Region Fire Weather Committee Scientific and Technical Seminar

April 3, 1992
Winnipeg Manitoba

Kerry R. Anderson¹, compiler

FORESTRY CANADA
NORTHWEST REGION
NORTHERN FORESTRY CENTRE
1993

The papers presented here are published as they were submitted with only technical editing and standardization of style. The opinions of the authors do not necessarily reflect the views of Forestry Canada.

¹Research Officer, Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta.