PREDICTING CONVECTIVE RAINFALL AMOUNTS FROM LIGHTNING FLASH DENSITY

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1. INTRODUCTION

Lightning is a major cause of fire in Canada's boreal forest, accounting for most of the area burned each year. On average, lightning causes over 4 000 of the 11 000 forest fires in Canada and accounts for 82% of the 2.5 million ha burned each year (Higgins and Ramsey 1992).

Being able to predict the numbers and locations of lightning-caused forest fires would be helpful to forest protection agencies. Models have been built to do such predictions but often fall short because of the lack of necessary data (Fuquay *et al.* 1979, Kourtz and Todd 1992, Anderson 1998).

One such data shortage is convective precipitation. Lightning is a result of the convection within thunderstorms and therefore naturally associated with convective precipitation. These two factors tend to cancel each other out: increased lightning activity may cause more ignitions but these are often extinguished by the greater amount of rainfall associated with the storm.

Convective rainfall is routinely measured in the US and southern Canada by weather radar and reported at synoptic weather stations. Unfortunately, these measurements do not extend into Canada's boreal forest. To provide fire prediction capabilities, an alternate method to estimate the amount of convective rainfall is needed.

One such alternative is to estimate convective rainfall from lightning activity observed by a lightning detection system. Intuitively, lightning activity is indicative of the strength of convection; hence, the temporal and spatial density of lightning flashes (flashes per hour per unit area) would be a predictor of convective rainfall.

In this paper, lightning activity and other hourly data is correlated with hourly rainfall in central Saskatchewan. This location is ideally suited for this study as it is at the southern portion of the boreal forest, has hourly weather observations from several automatic stations, and is well covered by the province's lightning-detection network.

2. METHODOLOGY

2.1 *Lightning Activity*

Saskatchewan's Department of Environment and Resource Management (SERM) has been running a wide-band magnetic gate lightning detection network since the mid-1980s (Krider *et al.* 1976). This network consists of nine advanced lighting direction finders (ALDF) positioned around central Saskatchewan. Theoretical detection efficiency within the central region of the province is in the order of 90% to 100% with location accuracies of 10 kilometres or less (Janischewskyj and Chisholm 1992).

Lightning data detected by the system has been collected and stored in databases. These data include individual flash records containing the date, time, latitude, longitude, signal strength, and multiplicity. This study used the lightning data for the years 1996 to 1999.

2.2 *Hourly Observations*

Saskatchewan's Department of Environment and Resource Management also manages a network of weather stations used to observe fire weather conditions throughout the province. Three hourly weather stations were selected from the study, as shown in Table 1, and data were collected from May 1 to September 30 for each of the years from 1996 to 1999.

Table 1. Weather stations used in study.

Station	Latitude	Longitude
Candle Lake	53.7653 ° N	105.1200 ° W
Meadow Lake	54.4061 ° N	108.6428 ° W
Waskesiu	53.8817 ° N	106.1275 ° W

The data were collected by automatic Forest Technology Systems (FTS) station model WR-62 data loggers. The stations were equipped with temperature and humidity sensors stored in a non-ventilated Stevenson screen, a tipping bucket rain gauge, and an anemometer mounted on a 10-metre mast. Hourly measurements were made of dry-bulb temperature, relative humidity, wind speed, and direction and precipitation. One minute averages of each were made in estimating the hourly value with the exception of precipitation. The station sites followed World Meteorological Organization (WMO) standards and were situated in openings typically 100 m wide.

2.3 *Lifting Condensation Level*

A factor that must be considered is the evaporation of precipitation as it falls to the ground. The extent of evaporation depends on the dryness of the atmosphere below the cloud and the distance rain must fall from the cloud to the surface. Given only surface observations, both terms can be accounted for by the lifting condensation level (*LCL*): the level at which a parcel reaches saturation following adiabatic ascent from the surface. In other words, the LCL is the cloud-base height

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Proc. 20th Conf. on Severe Local Storms, Sept. 11-15, 2000, Orlando, Florida, USA. Amer. Meteorol. Soc.

on a typical, convective day.

The lifting condensation level can be approximated from the dew-point depression at the surface as

$$LCL = 0.12\ (T - T_d) \qquad (1)$$

where T and T_d are the dry bulb and dewpoint temperatures in °C, resulting in an LCL in kilometres (Irabarne and Godson, 1973)

The dew-point depression can be approximated from the relative humidity, U_w, as

$$T - T_d = 35(-\log U_w) \qquad (2)$$

Combining equations 1 and 2 yield

$$LCL = 0.12(35(-\log U_w)) \qquad (3)$$

2.4 *Regression Analysis*

A multiple linear regression was conducted of the logarithm of the rainfall (*rain*) amounts against the logarithm of the lightning density (*ltg*) and the logarithm of the *LCL*.

$$\ln(rain) = a_1 \ln(ltg) + a_2 \ln(LCL) + b \qquad (4)$$

Rainfall was the amount of measured precipitation (in millimetres) over the course of an hour.

Lightning density was calculated as the number of flashes, both negative and positive, that occurred within a certain radius of the weather station over the same hour. Densities were calculated for 100, 50, 25, 10 and 5 km radii and regressed separately to see how the size of the analysis area affects the regression.

The LCL was calculated from the observed relative humidity at the beginning of the hour.

The regression analysis was conducted for each of the three weather stations and each of the four years. This gives a means to see how results vary spatially and temporally.

3. RESULTS AND DISCUSSION

3.1 Results

Tables 2 and 3 show the results of the regression analysis of the logarithm of the rainfall against the logarithm of the lightning density and the logarithm of the *LCL*; Table 1 shows the correlation coefficients and Table 3 shows the degrees of freedom. The tables show each station's results by year and by analysis radius.

3.2 Discussion

The analysis shows a set of mixed results. Some results show correlations on some years and no correlation on other years. For example, the r^2 values for Candle Lake at the 10 kilometre radius were 0.3235, 0.4093 and 0.4511 for 1996, 1998 and 1999, respectively. On the other hand, in 1997, the correlation coefficient was 0.0093.

Spatially, there is little agreement between the stations for the same year and radius of study. For example, the 1996 data produced good fits ($r^2 > 0.25$) for most radii at both Candle Lake and Waskesiu but poor results at Meadow Lake.

There is a general increase in correlation values with decreasing analysis radius, yet there is a corresponding decrease in the degrees of freedom. Indeed, most of the regressions at 5 km radii are conducted with ten or less points. Also, this radius is well within the location error range of the lightning detection network. It would be a mistake to draw any conclusions from the 5 km data.

A survey of the regression coefficients (not included in this paper) shows that rainfall is positively correlated with lightning density and negatively correlated with LCL. This occurred in all cases where the r^2 value was greater than 0.1 and degrees of freedom were of ten or more. This agrees with the conceptual model.

While these results may not be encouraging, they may be reflecting the extreme nature of convective showers; where a narrow rainband can release tens of millimetres of rain while the surrounding area a few hundred metres away is untouched. The high correlations may be the areas receiving the rainfall, while the poor correlations represent the near misses.

5. CONCLUSIONS

This study set out to establish a relationship between lightning activity and convective rainfall. This relationship exists but is not as clear cut as one may expect. The regression analysis shows that in some cases, clear correlations exist with r^2 values of 0.40 and greater while in other cases, there is no correlation at all. This is likely due to the characteristics of convective showers, namely the narrow band of high precipitation.

The study showed little agreement spatially, namely that a good correlation at one station for one year did not correspond to a good relationship at another station for the same year. This reinforces the rainband argument.

The study did show increased correlation with the smaller analysis radius; yet, as the radius was reduced, correlations were based on fewer points. It would appear that a 10 to 25 kilometre radius may be the best for this type of analysis.

A possible future direction may be to split the prediction into two stages. The first would be probabilistic, namely to predict the probability that a convective rainband would cover a station or area. The second stage wound predict the rainfall amounts assuming the station or area is within the rainband.

6. REFERENCES

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Table 2. Correlation coefficients of regression analysis of log (lightning) and log (LCL) against log (rain).

Correlation coefficients (r^2)

Candle Lake

Year	100 km	50 km	25 km	10 km	5 km
1996	0.1775	0.2701	0.4467	0.3235	0.4695
1997	0.0134	0.0280	0.0919	0.0093	0.4586
1998	0.0441	0.0091	0.0302	0.4093	0.0269
1999	0.1279	0.1047	0.0052	0.4511	0.4511
1996-99	0.0744	0.0655	0.1048	0.0678	0.2014

Meadow Lake

Year	100 km	50 km	25 km	10 km	5 km
1996	0.0343	0.0404	0.0567	0.0437	0.2383
1997	0.0352	0.0340	0.0083	0.2307	0.0759
1998	0.1929	0.1152	0.1079	0.0513	0.0908
1999	0.1112	0.0945	0.1793	0.2901	0.9090
1996-99	0.0732	0.0659	0.0815	0.0842	0.0604

Waskesiu

Year	100 km	50 km	25 km	10 km	5 km
1996	0.0604	0.135	0.1233	0.2507	0.5804
1997	0.0019	0.0091	0.0210	0.1475	0.0635
1998	0.2184	0.2297	0.2283	0.3547	0.2334
1999	0.0479	0.0516	0.0418	0.3367	0.0247
1996-99	0.0640	0.0952	0.1012	0.1499	0.2663

Table 3. Degrees of freedom for regression analysis of log (lightning) and log (LCL) against log (rain).

Degrees of freedom

Candle Lake

Year	100 km	50 km	25 km	10 km	5 km
1996	49	41	32	14	9
1997	94	74	46	19	5
1998	39	31	26	13	3
1999	72	36	27	10	10
1996-99	263	191	140	65	25

Meadow Lake

Year	100 km	50 km	25 km	10 km	5 km
1996	59	47	29	15	9
1997	119	71	34	19	6
1998	56	42	32	17	7
1999	31	21	13	5	1
1996-99	274	190	117	65	32

Waskesiu

Year	100 km	50 km	25 km	10 km	5 km
1996	76	54	45	17	6
1997	57	42	28	15	5
1998	57	46	37	24	14
1999	57	40	35	12	3
1996-99	256	191	154	77	37