Lightning Analysis And Forecasting[1]

Jean Souviron
Cogitech, Jean Souviron
Montreal, Quebec, Canada

Denis Jacob, Viateur Turcotte, Ronald Frenette, Michel Nadeau
Montreal Weather Centre
Environment Canada
St-Laurent, Quebec, Canada and
Stéphane Lachapelle[2], James Caveen[3]
Montreal Weather Centre
Environment Canada
St-Laurent, Quebec, Canada

1. INTRODUCTION

In the mid 1990's we were receiving lightning data from the Hydro Quebec Network and the data was displayed on a PC using a proprietary display program. The numerous limitations of that system made us develop a UNIX display interface that could work on any of our UNIX workstations. At the same time we developed a client-server approach to feed lightning data to our interface which made it independent of the lightning database. The latter could be located on any machine anywhere on the network. Another plus was to allow for freedom with the format of the database, only the server had to know it. This was a blessing when in the late 1990's came the Canadian Lightning Detection Network (CLDN). The only modification needed to the whole system was to build the portion feeding the database and some modifications to the server to take into account some changes in the format. This gave us time to add two new tools to the interface: an analysis and a forecast tool.

2. THE CLDN IN BRIEF

The CLDN is made of 81 detectors across Canada mostly south of 60N. The sensors used are 26 IMPACT ES and 55 LPATS IV from Global Atmospherics, Inc. (GAI), Tucson. They allow for the detection of 90% of cloud-to-ground strokes (positive and negative) and about 10% of cloud-to-cloud or intra-cloud strokes. The accuracy is expected to be 500 metres for the cloud-to-ground strokes. The CLDN and the National Lightning Detection Network (NLDN) being interconnected through GAI, they both help each other in improving detection, coverage and accuracy, and form the North American Lightning Detection Network (NALDN) (Cummins et al., 1999).

3. THE TASK AT HAND

The NADLN sensors cover nearly 20 million square kilometres and detect lightning over a greater extent. Of most interest to Environment Canada meteorologists is the portion going from 35 degrees N to 65 degrees N and from 50 degrees W to 140 degrees W. This is about 3000 kilometres by 6000 kilometres or 18 million square kilometres. From that area many thousands of flashes an hour will reach the interface. It worked fine if the only thing done was to display them on our workstations (then HP 9000/755 with 192 Mb of memory) in real time.

On the other hand doing a forecast meant building two analysis fields over that area and for each analysis at least three real numbers were necessary to describe the field at each grid point: latitude, longitude and the density of flashes. On our machine this means 24 bytes for each grid point. At a 10 kilometre resolution about 180 000 grid points would be necessary which mean 7.2 Mb of memory to get a forecast. Still OK but at a 1 kilometre resolution this becomes 720 Mb and if we dare thinking in terms of 500 metres resolution a mere 2.88 Gb would be required! To get the resolution down we had to think differently.

4. THE ANALYSIS ALGORITHM

An analysis is done using all the flashes received within a certain time interval. This interval must be long enough to get a decent number of flashes

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[2] Stéphane Lachapelle worked at the database in the client-server aspect of this project.
[3] James Caveen worked at the server in the client-server aspect of this project.

and not too long to stay within the lifetime of a thunderstorm. We usually used 10 minute intervals in our calculations.

The main task is to get rid of the grid points that would get a zero density of flashes while minimizing calculations about them. For that we use a horizontal histogram at the bottom of the area with bins the size of the wanted resolution. Each bin receives the flashes above them. Then the bins not separated by an empty bin are grouped. For each group if the external bins contain only one flash it is kept only if the flash it contains is within the resolution to the closest flash in the group. Next we build a vertical histogram along the western edge and using a similar method we can further split the previous groups. Lastly, for each group of bins obtained we further split them along the horizontal, but this time only if they show two distinct maximum. To keep a group of bins it must contain at least three flashes. Also the groups of bins are ordered in terms of their total number of flashes (Fig. 1.).

As we will see the size of the bin (the resolution) will be critical to the quality of the analysis. A big bin will gather all the flashes together, while a small one will tend to discard too many flashes.

The next step is to find the periphery of each group. This is done by sorting the flashes by increasing angle (counter-clockwise) using the south-easternmost flash as a reference. Starting from the reference we keep and go to the next outside flash which is the one forming the smallest angle (counter-clockwise), this gives us the convex hull of the group (Sedgewick, 1990).

Quite often the convex hull is not the most appropriate shape. For example, a banana shape group would have a concave section. We added a parameter to allow for concavity. To build concave portions we scan the flashes again starting from the reference and try to add inside flash but only if they form an angle greater than 60 degrees between two consecutive hull flashes. The least convexity allowed at 60 degrees was derived by trial and error having in mind the goal of getting something aesthetic, not too saw-toothed. At the other end the most convexity is 180 degrees, meaning we follow the convex hull as it is. This being subjective, the interface allows the user to choose a percentage of convexity within that range.

The last step is to build a grid inside each hull with the wanted resolution and calculate the density of flashes at each grid point. This way we end up doing calculations only for the non zero density grid points, which rarely covers more than a few percent of all possible grid points (Fig. 2.).

5. THE FORECAST ALGORITHM

To be able to make a forecast we need at least two analysis. To stay within the lifetime of a thunderstorm we usually use a 30 minute forecast based on two analysis 10 minutes apart. The interface allows for changing these intervals.

Each analysis is now formed of groups of flashes. The main problem is to properly associate the groups of the two analysis one to one. To do that we use one parameter to measure their associativeness. This parameter is calculated by multiplying the distance between their density centres and the difference between the area they cover. By minimizing this parameter we can find the groups that are closest to each other while having the most similar size. Of course we don’t associate groups that would give speed beyond the value of 150 km/h.

When groups in the first analysis cannot be associated with any of the second analysis, they are considered as being dissipated or merged and no speed and direction are calculated. When groups in the second analysis cannot be associated with any of the first one, they are given the average speed and direction of the groups that are already associated within 50 km. Also the size of the groups are forecast to increase or shrink by an amount equal to the logarithm of the absolute value of the difference in area multiplied by the number of time steps involved to reach the forecast time. The maximum factor of expansion allowed is set to 2. If the resultant area is smaller or equal to zero the group is considered dissipated (Fig. 3.).

6. RESULTS

We studied the case of the derecho of the night of July 5th 1999 over south-western Quebec (Serge Mainville, 1999, 2000). The time step used was 10 minutes and there was no overlapping between the two analysis, the forecast period was 30 minutes. The analysis were done at 0540Z and 0550Z and the forecast was valid at 0620Z. We made an analysis at

0620Z for comparison. We varied the resolution between 10 and 1 kilometre and the convexity between 50% and 100%. For this particular case the best results were obtained at 5 km resolution with 50% convexity (Fig. 4.).

On the two analysis the derecho was detected as well as a small cell to the southwest. The speed and direction of the derecho was about 320 degrees at 100 km/h while for the small cell it found 290 degrees at 95 km/h. The analysis at the forecast time show the derecho, the small cell to the southwest and a new cell to the northeast which is almost touching the derecho. If we do a 10 km resolution analysis the latter gets merged with the derecho, therefore our algorithm not being able to split a big cell in two smaller ones we will consider this northeast cell as part of the derecho for comparison to the forecast.

As a whole the derecho has been forecast with the appropriate speed but the direction is off by about 30 degrees too south. The forecast area for the derecho is too large. For the small cell to the southwest the direction is perfect and the speed is good, the forecast cell being only a couple of kilometres away from the analysis. The forecast size of the small cell is good as well.

Other time periods and geographic areas were analysed but with less scrutiny so we wont show the results here except that they showed us some of the strengths and weaknesses with the technique.

7. STRENGTHS AND WEAKNESSES

Strengths:

- Good technique to analyse points or discrete values distributed at random, find groups of them and contour them.
- Techniques that use little memory at all scales and coverage (about 15 Mb maximum).
- Techniques that work on our workstations in real time.
- The cells can grow or decay.
- The centre of density is used, it will follow the active portion (negative) of the cells.
- The look can be fairly realistic.
- Mathematics are simple.
- Works well at 5-10 km resolution, 10 minutes time steps and 10 to 30 minutes forecast, 50% convexity.

Weaknesses:

- The time steps don't overlap, more difficult to associate cells.
- Only two time steps used for the area tendency.
- Short living thunderstorms not well forecast with 10 minutes time steps.
- The border of the groups are flashes.
- Three flashes are necessary to build a group.
- No forecast densities.
- Problems at the edges of the map.
- 0% convexity adds a fair amount of computation.

9. SUMMARY AND CONCLUSIONS

Many parameters have an effect on the quality of the forecast:

- The resolution.
- The convexity of the hull.
- The forecast length.
- The time steps used in the analysis.
- The type of thunderstorms (super-cells, area of cells).

There are still improvements to be done to these algorithms: like adding a buffer zone around the map, accelerating the convexity calculations, using more than two analysis to build a forecast or calculating the maximum speed used for the association of groups. But these algorithms look promising.

REFERENCES

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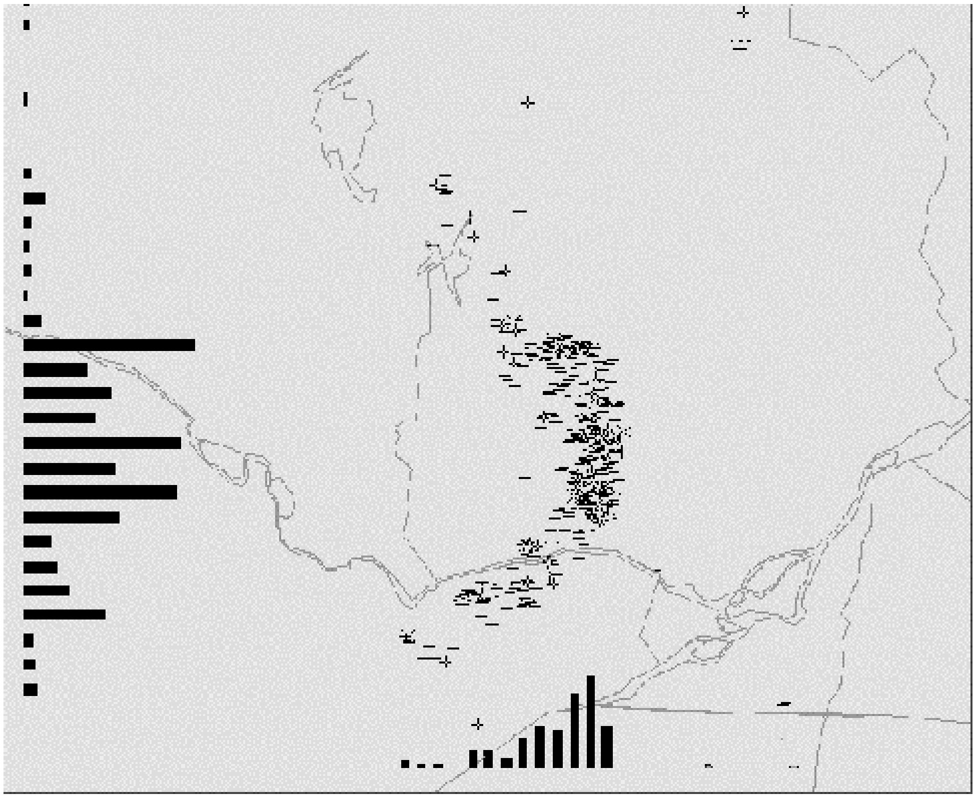

Fig. 1. Horizontal and vertical histograms at 10 kilometre resolution. At this resolution it is difficult to split the derecho area from the small cell to the southwest.

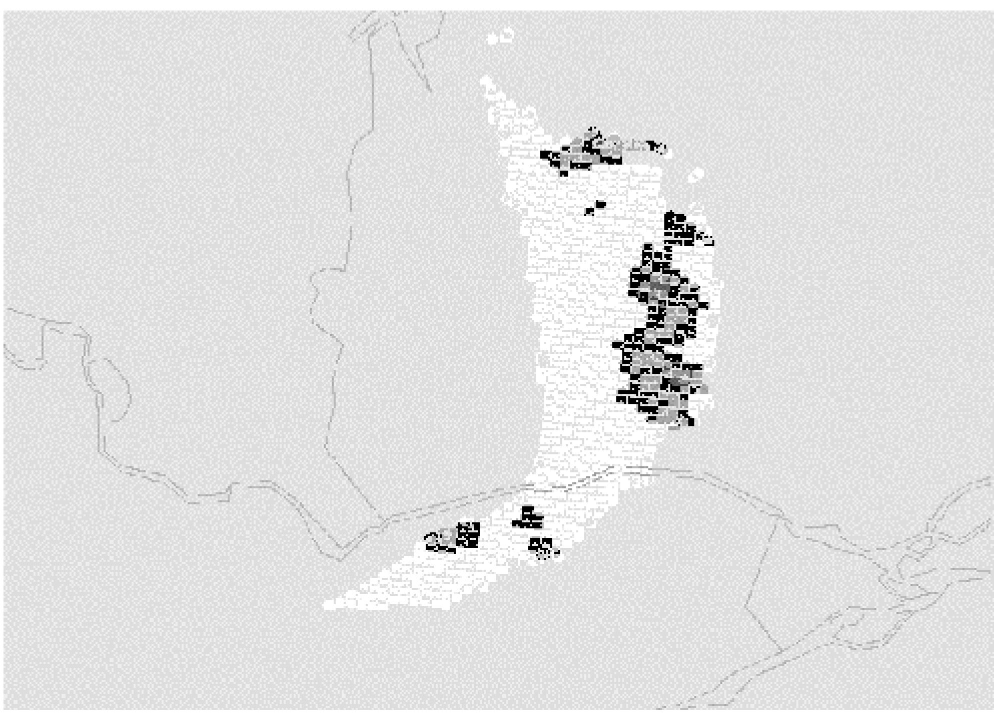

Fig. 2. Analysis of flash densities at 10 kilometre resolution.

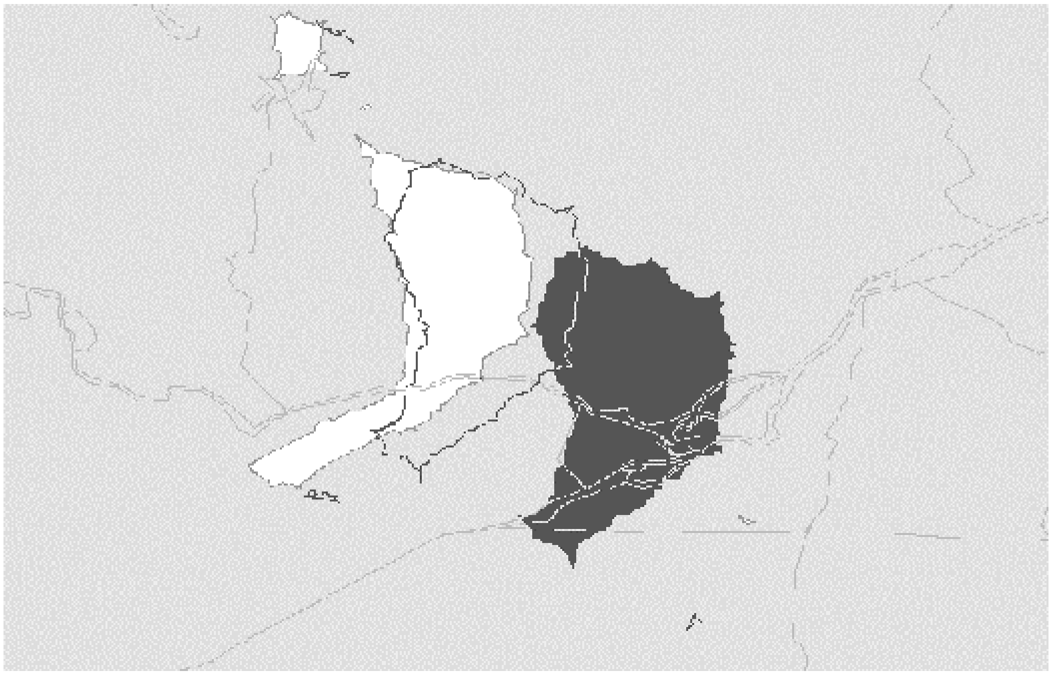

Fig. 3. Analysis at 0540Z (white left), analysis at 0550Z (middle) and forecast at 0620Z (black filled) all at 10 kilometre resolution 50% convexity.

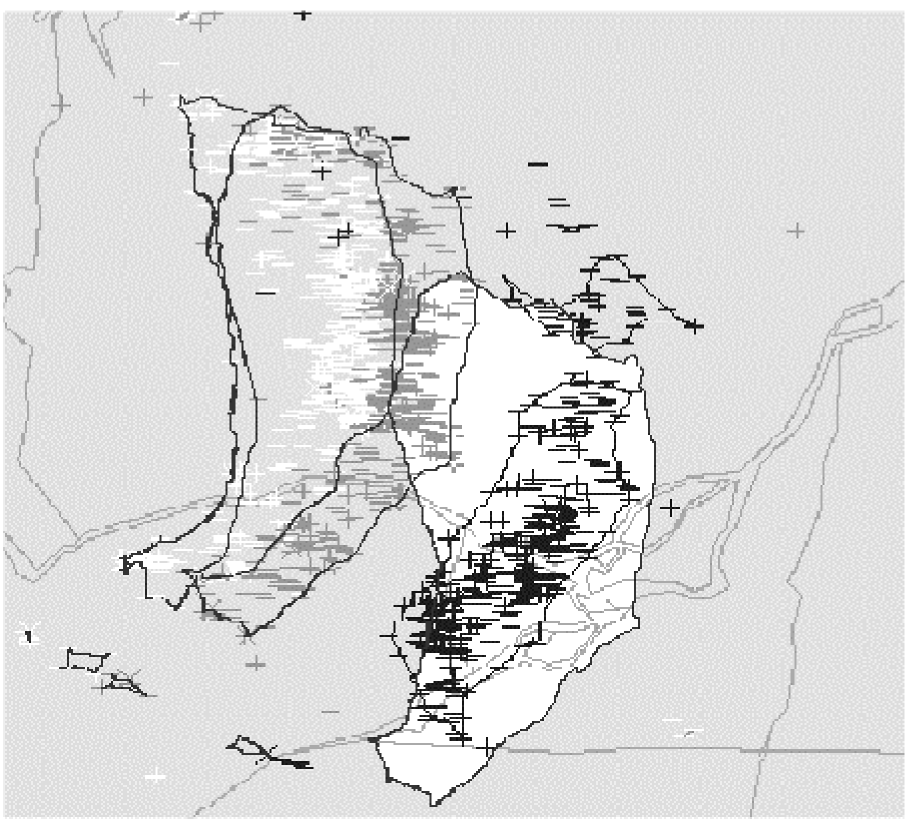

Fig. 4. Analysis and flashes at 0540, 0550 and 0620Z (left,middle,right) and 30 minute forecast at 0620Z (white filled). All done at 5 kilometre resolution and 50% convexity.