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Evaluation of a lightning location algorithm using an elevation model

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Abstract: Location accuracy is one of the important performance parameters of a lightning location system. With more and more sophisticated applications of lightning data also an increasing demand on improved location accuracy is observed.
Today lightning location systems are mainly using GPS synchronized time information to locate a lightning discharge. The location is calculated based on the time differences between sensor arrival times and estimated impact time. Assuming speed of light (c_0) for the field propagation velocity from this time differences the propagation distances to the sensors are calculated assuming the earth as an ideal ellipsoid. Distances calculated this way do not take into account any elongation of the propagation path due to mountains. This is assumed to be one of the reasons for the existence of a systematic location error in mountainous regions [Schulz, 1997].
In this paper we show how calculated lightning locations are affected by taking into account the wave travelling path elongation due to mountains by applying an elevation model for the earth. Any possible improvement of the resulting locations is evaluated by using data from lightning strikes to high towers.

Keywords: Lightning location systems; Location accuracy

1. Introduction

Since the existence of GPS for time synchronization of the sensors the information of the arrival time is mainly used to calculate lightning positions. The time information is superior to angle and signal strength information because of its small random error. This smaller time random error results in more accurate lightning positions.
It is known that the time information is not only affected by a random error but also by a systematic error. This systematic error is caused by different effects [Pifer, 1996]:

- Time errors due to elongation of the propagation path of the signals caused by obstacles (mountains) compared to the ideal propagation path over the ellipsoid.
- Time errors introduced by a propagation velocity smaller than the speed of light due to finite ground conductivity.
- Time error due to an incorrect calculation of the so called onset time.

For the systematic angle error of IMPACT sensors ("site error") a correction method called site error correction is well known. This correction method is an iterative process where the site errors of all sensors are determined by means of the time and the angle information. For this procedure strokes detected by a high number of sensors are required. In this case redundant information is available to estimate the site error (e.g. positions calculated with more than 2 angle information or positions calculated with more than 3 time information).

With this type of algorithm in principle it is also possible to determine systematic time errors. There are two fundamental choices.

- Description of the time error versus distance by an analytic function based on a physical assumption (similar to the two cycle sinusoidal function for site error correction).
- Description of the time error versus distance by an arbitrary function without any physical background.

It seems very critical to try to determine the time error without an analytic function because it may be possible that the correction algorithm converges to results with smaller time errors but wrong positions. A first approach of a partial time correction with an analytic formula which is supposed to reflect the error due to the finite ground conductivity was presented by Murphy and Pifer [1998].

In this paper we will show the improvement in location accuracy by using an elevation model. Of course the elevation model only corrects for time errors related to the signal path elongation. As elevation model we have chosen the GLOBE model which gives elevations above sea level based on WGS84 datum (http://www.ngdc.noaa.gov/seg/topo/globe.shtml). The locations reported by the LLS are also in the same datum.

The elevations given by the GLOBE model are average values of altitude over squares of a size of 30 arc seconds longitude and 30 arc seconds latitude. The 30 arc second latitude-longitude grid spacing of the data set is somewhat smaller than one kilometer spacing on ground. From this model also models of larger grid size (1 x 1 arc min, 2 x 2 arc min, 4 x 4 arc min) were derived by averaging the altitudes of neighboring grid cells.

2. Location algorithm and data

The used location algorithm minimizes angle and time deviations. By the location algorithm described in Schulz [1997] the position coordinates (latitude/longitude) and the impact time are optimized. The only change in the location algorithm when implementing an elevation model is that the original calculation of the path length of a normal section on the ellipsoid is substituted by an algorithm which calculates the length of the propagation path on the terrain model. In the alpine area of Austria we calculate elongations of the travelling path in the range of several hundred meters

In this paper locations are calculated assuming a standard deviation of 1 µs for the time information.

To test the improved algorithm we used lightning data from 1996 and 1997. During this time period the Austrian network consisted of eight IMPACT sensors [Diendorfer et al., 1998]. To avoid any influence of the angle information the positions were calculated with time information only. Only optimized positions are taken into account and therefore only strokes detected by at least four sensors are used.

3. Results

Tests of the location algorithm including an elevation model were performed on two radio towers in Austria. At the Dobratsch (2166m) a radio tower of 165m and at the Gaisberg (1287m) a radio tower of 98m height is located.

Fig. 1 shows the calculated stroke locations around the tower at the Dobratsch without using an elevation model (Fig. 1A) and when an elevation model of 2 x 2 arc minutes (Fig. 1B) is used. In both Figures several stroke clusters are visible. These stroke clusters are related to different groups of sensors detecting the strokes [see also Schulz, 1997]. The tower is represented by a circle in the center of the figure. Of course it is not proven that all the strokes in Fig. 1 actually hit the radio tower but we are assuming that the majority of the strokes closer than 1 km hit the tower. By using the 2 x 2 arc minute elevation model the stroke locations change significantly and all the stroke clusters appear more compact.

Except a more pronounced clustering of locations from Fig. 1 no obvious improvement can be seen. Therefore we tried to estimate whether there is an improvement or not by calculating the mean distance of the stroke locations to the radio tower and by evaluating the mean chisqu value.

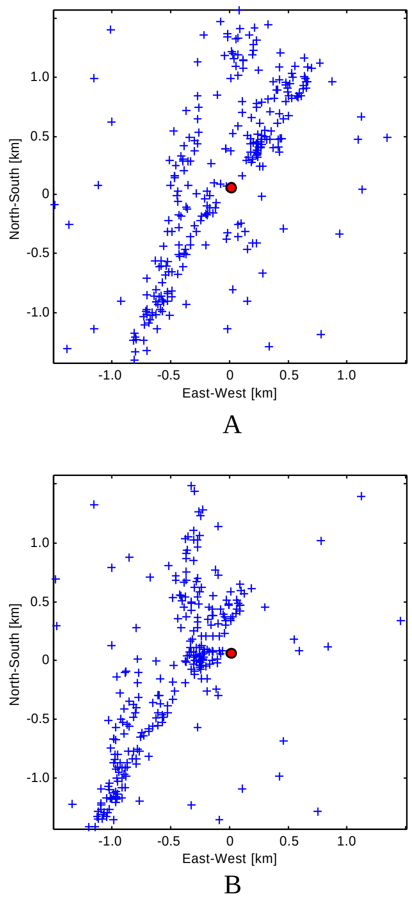

Figure 1. Flashes around Dobratsch before (A) and after (B) implementation of a 2 x 2 arc minute elevation model

Table 1 gives mean distances mean chisqu values and the number of strokes closer than 1.5 km to the radio tower at the Dobratsch for elevation models of different grid size. It is necessary to realize that the individual chisqu values of a stroke is a measure of how well the sensor measurements agree and not a measure of location accuracy.

Table 1: Mean chisqu and mean distance to the radio tower at Dobratsch

	Mean Chisqu	Mean distance to tower
Without elevation model	1.24	0.78 km (n= 261)
With elevation model (4 min grid)	1.05	0.74 km (n= 258)
With elevation model (2 min grid)	0.88	0.70 km (n= 236)
With elevation model (1 min grid)	0.45	0.98 km (n= 219)
With elevation model (30 sec grid)	2.42	1.22 km (n= 118)

The small mean chisqu for calculation with the 1 min grid is due to the reason that some strokes which had already a large chisqu when a larger grid size was used did not converge at all with the 1 min grid size. Thus the mean chisqu is reduced although the mean distance is increased.

The same evaluation was done for the tower at the Gaisberg (Table 2).

Table 2: Mean chisqu and mean distance to the radio tower at Gaisberg

	Mean Chisqu	Mean distance to tower
Without elevation model	1.70	0.42 km (n= 160)
With elevation model (4 min grid)	1.46	0.47 km (n= 162)
With elevation model (2 min grid)	0.99	0.56 km (n= 161)
With elevation model (1 min grid)	1.54	0.87 km (n= 163)
With elevation model (30 sec grid)	4.42	1.25 km (n= 70)

A decrease of the mean chisqu was expected if terrain has an effect on the systematic time error. Also an increase with smaller grid size is expected because starting from a certain grid size the elevation model is too accurate for the lightning impulse.

In Austria a grid size of 2 x 2 arc minutes corresponds to about 2.5 x 3.5 km. When testing the elevation model we see a minimum of the chisqu for the 2 x 2 arc minutes grid. It seems, that this grid size is most appropriate to represent the travelling path elongation for the frequency range dominant in lightning electromagnetic fields.

After testing the location algorithm at radio towers we reanalyzed lightning data in a large rectangle in the Alps (longitude 12° - 13°, latitude 47° - 47.5°) to see if there is also an obvious reduction of chisqu (see Table 3).

Table 3: Mean chisqu in a large rectangle

	Mean Chisqu
Without elevation model	4.46 (n= 6989)
With elevation model (4 min grid)	3.89 (n= 7046)
With elevation model (2 min grid)	3.04 (n= 7169)
With elevation model (1 min grid)	4.34 (n= 3406)

Again with the 2 min elevation model the improved location algorithm succeeds to calculate more optimized stroke locations than without an elevation model, the number of optimized strokes has a maximum and the mean chisqu has a minimum.

The distribution of the time error of the individual sensors is also an important parameter to evaluate the improvement of the calculation. Time error is the difference between the calculated time of field incidence at the sensor and the sensor reported time of field incidence. In case of a perfect correction of systematic errors the mean time error should be zero. Fig. 2 shows the distribution of the time error for the sensor in Niederöblarn before and after correction applying the 2 min elevation model.

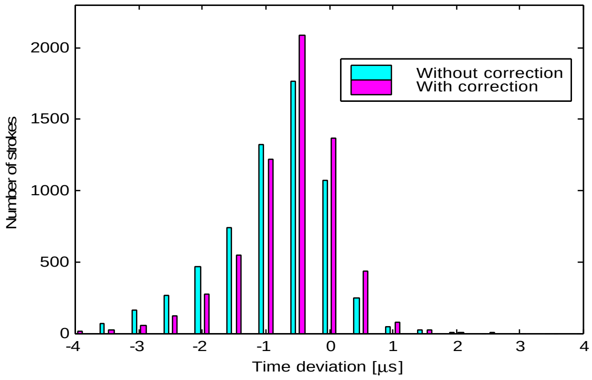

Figure 2. Time error distribution for the sensor in Niederöblarn.

It can be seen that the mean time error is reduced form -0.9µs without correction to -0.6 µs with correction. Also the standard deviation is decreased from 0.93 µs to 0.88 with correction. But there is still a relative large portion of systematic error left that could be caused by one of the other reasons for time errors mentioned above.

The same investigations were done for a different rectangle in the alps (longitude 14° - 15°, latitude 47° - 47.5°) with basically the same results.

Contrary to the results of Murphy and Pifer [1998] where not all the mean time errors of the individual sensors approached zero, in our correction all the mean time errors of the individual sensors approached zero when the elevation model of 2 arc min was applied. One reason for these different results could be that the systematic time error has different sources as stated at the beginning. Maybe it is necessary to correct first the time errors due to path elongation and in a second step apply a correction method similar to the site error correction to correct for the time errors due to finite ground conductivity.

4. Summary

Because the elongation of the propagation path is only one reason among others for the systematical error the time error can not be eliminated completely with an elevation model only.

It seems that the reduction of propagation velocity due to finite ground conductivity introduces the larger part of the error.

When an elevation model is implemented, the reduction of the chisqu value is a more significant measure for an improvement of the location accuracy than in case of site error correction. No iterative calculation is performed by correcting with an elevation model and therefore a reduction of chisqu should result directly in an improvement of accuracy because this kind of correction does not assume any hypothetical correction function but only takes into account real elevation data. Therefore it is unlikely that any reduction of the chisqu values (improved agreement of the measurements) is caused accidentally due to an erroneously converging location algorithm.

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5. References

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