A NOVEL METHOD TO LOCATE A FAULTY OR NOISY DIRECTIONAL SENSOR IN A LIGHTNING LOCATION NETWORK IMPROVES POWER LINE OUTAGE CORRELATION PROCESS

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Abstract: A faulty or noisy directional sensor can really deteriorate the performance of lightning location network and therefore real-time power line outage correlation process. In exposed area of LLN coverage a bigger error ellipse is seen as a by-product of direct influence of noisy or faulty sensor. Locating the sensor which is causing the abnormality in the network can sometimes be a time consuming procedure. Therefore a novel method to locate a problematic sensor in LLN was developed. A technique previously used in the high resolution flash density map calculation was modified and applied to the new method. First results were obtained from EUCLID dataset in the SCALAR region where the LLN anomaly was observed. The new method already contributed to minor adjustments in LLN especially for setting the proper gain and threshold in LS700x series of sensors. The visual interpretation is done using 3D OpenGL graphics and clearly shows the exposed area in LLN where modifications were made. Correlation accuracy between lightning and estimated power line outage location were compared before and after improvements in LL network.

1 INTRODUCTION

In 2008-2009 a second modernization interval of Slovenian lightning location system SCALAR took place. During the process the old LPATS III sensors were replaced with the new LS7000 and LS7001 models and the old sensors were moved to the neighboring country Croatia to cover their region and to contribute to the south part of SCALAR network. Figure 1 shows the latest position of SCALAR sensors as of 2010. As SCALAR network has been part of the EUCLID lightning location network, its sensor upgrade also extended the coverage of the EUCLID network.

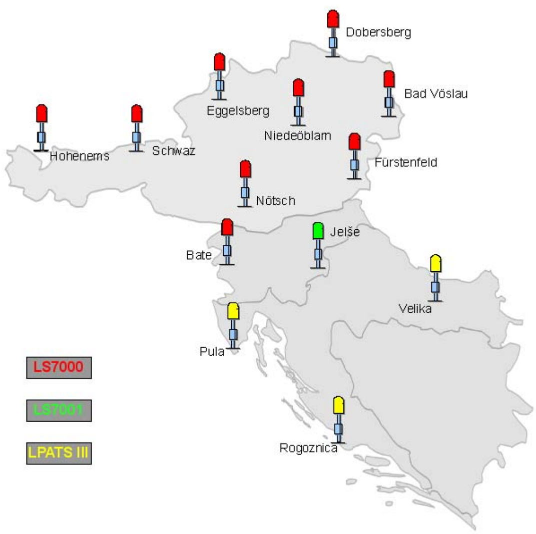

Figure : Lightning location system SCALAR in 2010.

Because sensors were placed in the area previously not covered by the EUCLID network, the expectations of the coverage improvements were quite high. First results, however, were not as promising. Figure 2 shows half a day's worth of lightnings with confidence error ellipses in the newly covered area. As can be seen, the error ellipses are considerably large and oriented in a certain direction.

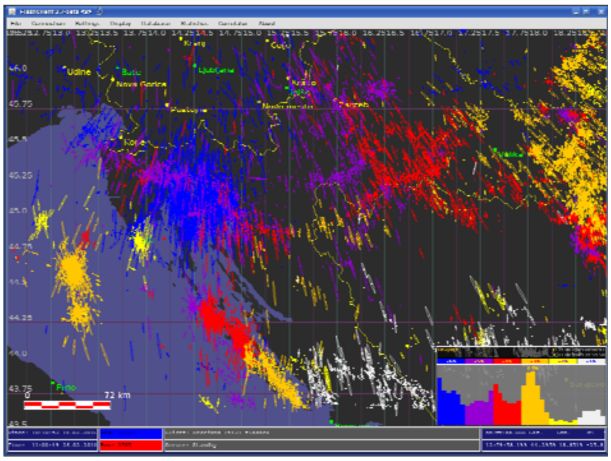

Figure 2: Lightnings' error ellipses oriented in a certain direction.

2 PROBLEM IDENTIFICATION AND DATA ANALYSIS

After several recorded thunderstorms in the newly covered area, the pattern of the lightning error ellipses' orientations became evident. It appeared that there is a common source of noise in the EUCLID LL network.

To identify the problem and to find the so called hot-spot in the network, a new analysis method was developed. The basic idea behind the method is an algorithm that calculates the density of intersections between lightning error ellipse orientation directions. Since a larger error ellipse is mainly the result of a two sensors solution, it is expected to find the higher intersection density in the middle of the baseline between two sensors. Figure 3 illustrates the new analysis method and indicates the quantity of calculation that must be performed by the algorithm to obtain the result. Each new error ellipse could theoretically (roughly) double the amount of already produced intersections. Therefore computation complexity rises with the exponential tendency and additional data preparation is needed to avoid performance issues.

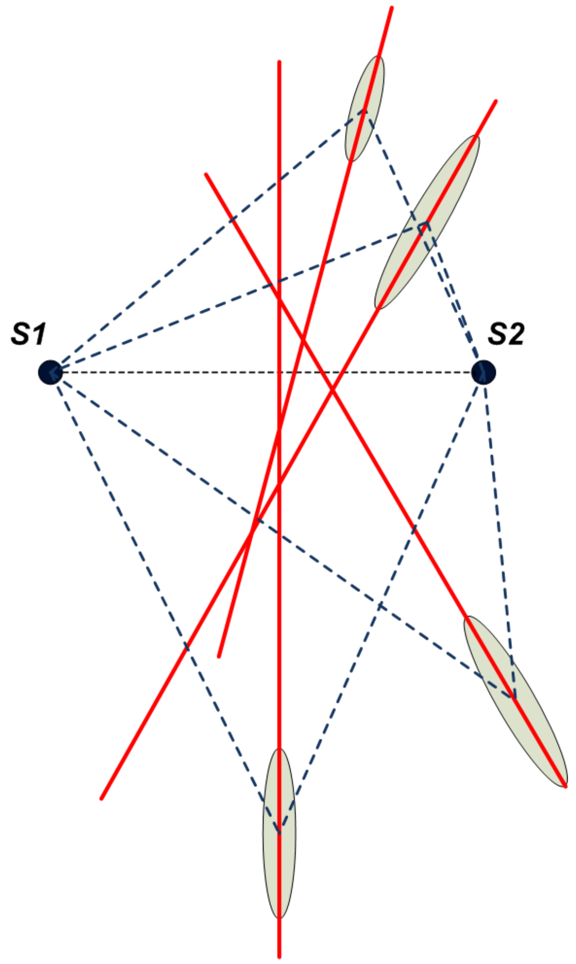

Figure 3: The new analysis method is based on density of intersections between lightning error ellipses directions.

2.1 Area of interest selection and data preparation

Normally, the analysis should be performed over the whole area of EUCLID network coverage, but on other hand, the computation time and amount of data needed to do so would likely take too much time and effort to show the benefit and capability of the method. Therefore, a smaller area of interest was selected in a way to satisfy several requirements. The first one was to cover the area where the error ellipses orientations indicate that the hot-spot could be (shown in Figure 2). The second was to cover as different as possible models of magnetic directional LL sensors in the previously selected hot-spot surrounding. The third was regarding the amount of lightning data selected with the size of area of interest. The amount of data is exponentially related to the computation time and is playing an important role.

In addition to those requirements regarding area selection, further filtering of lightning data was performed. Most importantly, only lightnings with error ellipses larger than 5 km were selected. The lightning locations calculated by the algorithm for those ellipses correspond to two or sometimes three sensors solutions only. Needless to say, at least two sensors contributions have to be in the magnetic direction manner. On Figure 4, the selected area for analysis covers various LL sensor models (LPATS, IMPACT and latest LS700x series). Unfortunately the LPATS series of sensors are only TOA type of sensors, but they can always contribute to three sensors solution lightning location.

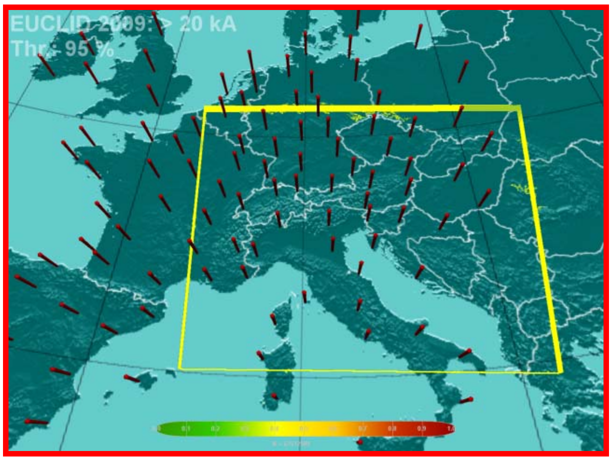

Figure 4: EUCLID sensors position and selected area of lightning data used in new analyses method computation.

Furthermore, lightning data was divided in three classes based on the amplitude. Class A corresponds to amplitudes in range between 0 and 5 kA, class B in 5 – 20 kA and class C 20 kA and above. Due to continuously changing nature of the EUCLID network, analysis of lightning data in different time frames was also performed. For example, in 2009 some tuning on LS700x series of sensors took place and the results of such modification were analyzed.

3 NEW ANALYSES METHOD DESCRIPTION

The basic idea behind the method is rather simple; for each detected lightning in the given time frame and geographical region of interest, the line on which the major semi-axis of the error ellipse lies is found. This can be done simply by extending the major semi-axis to stretch across the geographical region of interest.

Once the line is obtained, its intersections with lines corresponding to other lightning's error ellipses are calculated.

3.1 Lightning location and error ellipse angle transformation

Since lightnings' locations are given in longitude and latitude, the intersections should be found with the use of spherical geometry. In the current algorithm implementation, however, this is avoided by using transformation from Cartesian coordinates using Lambert conical projection. This projection is also used by the background image in the display program.

When performing transformation, both lightning's location and the angle of error ellipse's major semi-axis are transformed (the latter is transformed by transforming two points lying on the major semi-axis). For each lightning coefficients of semi-axis line are calculated:

$$y = k_1 \cdot x + k_0$$

The problem of finding intersection is therefore reduced to solving the system of equations formed by two of such lines.

Suppose we have three lightnings, with their corresponding longitude, latitude and angle of error ellipse semi-major axis (0° means pointing in north-south direction):

Lon [°]	Lat [°]	Angle [°]
0	40	0
10	50	90
20	60	0

Table : Simple example data set

The results obtained by described transformation are shown graphically on Figure 5.

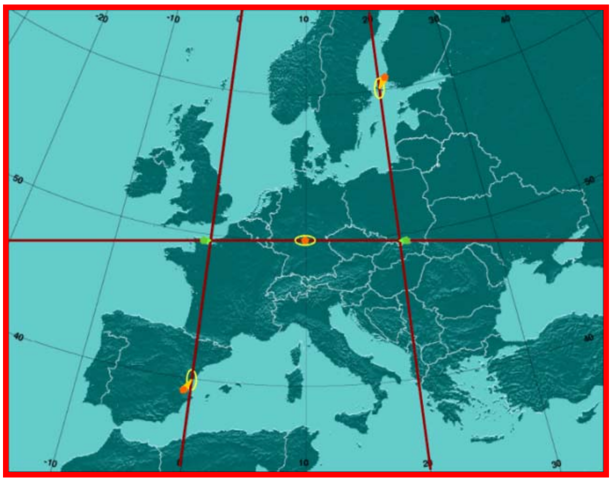

Figure 5: Example of data transformation and intersections determination

As can be seen, inaccuracies occur due to combination of straight lines and Lambert conical projection. However, given sufficiently small geographical region of interest, these inaccuracies are negligible.

3.2 Intersections and gridding

When an intersection is calculated, its coordinates (in the projection used) are obtained.

In order to obtain the mesh, the display region is discretized – divided in small pieces. Each of these has a counter of intersections that fall into it.

This way, once all intersections are calculated, a 3-D mesh is obtained where z component represents the number of intersections. The mesh is stored (along with data set information) in a binary file that can be opened by the display program.

3.3 Amount of data and speed considerations

The number of intersections increases rapidly with number of lightnings in the given data set, which results in longer processing time.

Therefore the algorithm is implemented in a way that allows for parallel execution using multiple threads.

For example, calculation of the mesh for lightnings detected by EUCLID in year 2009 in the region 4°/40°/22°/51° involved calculation of intersections between 1310176 lightnings and took 110 minutes on personal computer with quad core Intel Core i7 920 2.66 GHz processor and 6 GB of RAM.

3.4 Data display

The calculated mesh can be opened and displayed in the display program that has been developed alongside the gridding program.

The program is built using Qt framework and utilizes hardware-accelerated drawing of 3-D scene using OpenGL library.

The display consists of three main elements; the mesh, where z component represents the number of intersections (normalized to the maximum number of intersections found in the region), background image (map of the display region) and markers which show the locations of sensors.

The scene can be rotated, panned and zoomed in or out, and the threshold for mesh display can be set (i.e. only parts with value above the threshold are displayed). This allows for easy visual analysis of the obtained results.

4 RESULTS

The results of analysis based on the previously described separation of data in classes are discussed.

4.1 Class A results and comparison

In this class lightning data with absolute peak amplitude lower than 5 kA were compared. Figures 6 and 7 show the intersection density before and after fine tuning of LS700x sensors in September 2009 (especially in Austrian ALDIS LL network). In Figure 6 three larger peaks indicate the hot-spots produced by pairs of more sensitive or even noisy sensors. In general, LS700x sensor series are more sensitive and can sense lightning with very low peak amplitude. Therefore sensor signal threshold is set to lower values than in older sensor models. Lowering the threshold, on other hand, causes sensor receiver to process the lightning signals close to the RF noise floor. Because the IC signals lie in the same peak amplitude range, it is easy for a sensor to pick up noise signal or misclassify a CG signal with an IC one.

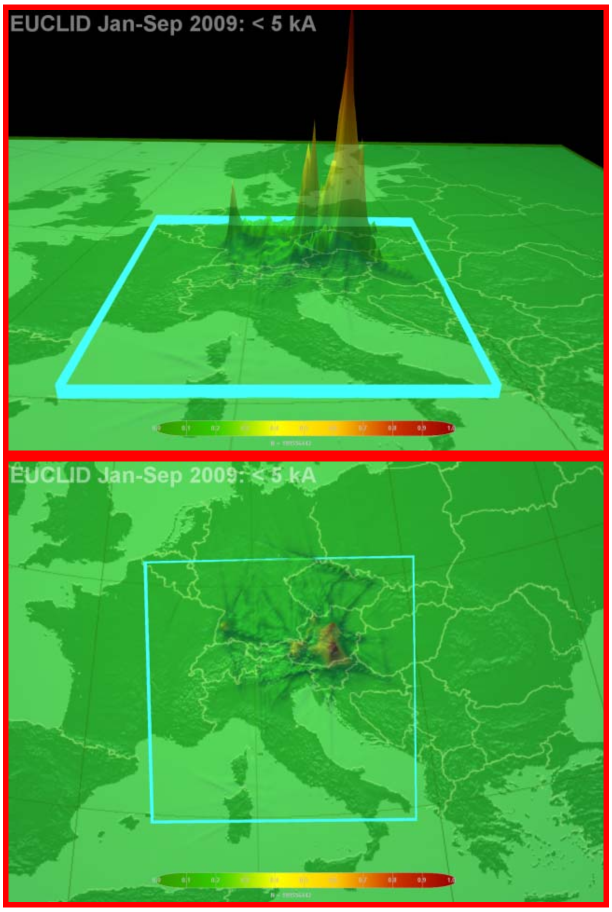

Figure 6: New method discovers hot-spot area (Class A data, first ¾ of 2009).

This results in lightning locations with larger error ellipse and is identified by the method as a hot-spot. Improvement can be noticed on Figure 7, where only one hot-spot remains.

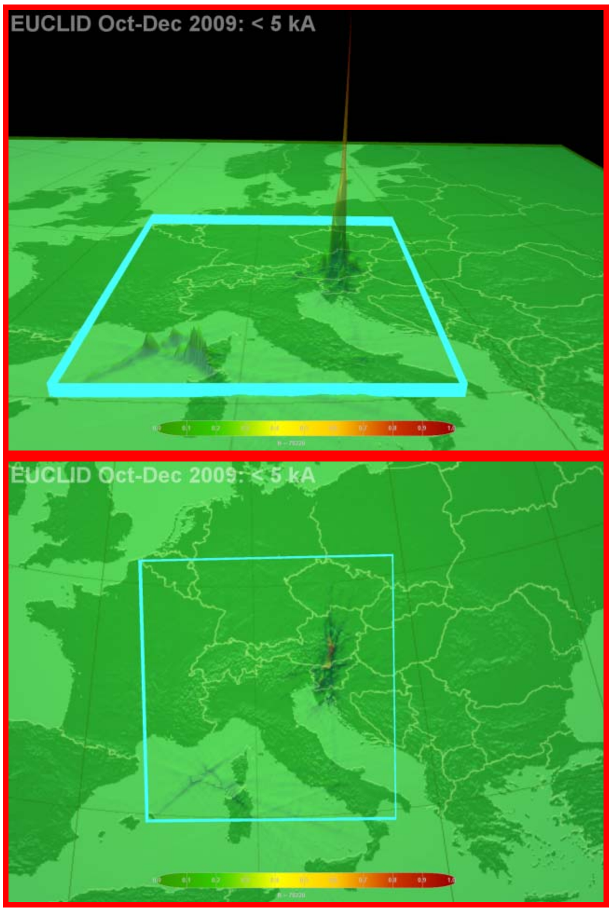

Figure 7: Improvement as identified by the method after LS700x treshold tuning (Class A, last ¼ of 2009).

It should be noted that neither of hot-spots lie on the base lines of the older IMPACT sensors (for example in Italy which is covered exclusively by IMPACT sensors).

4.2 Class C results and comparison

As class B results are very similar to the class C, only results of the latter are further discussed. In this class, lightning locations with absolute peak amplitudes greater than 20 kA were processed.

For a lightning with peak amplitude above 20 kA, it is not uncommon that 10 or more sensors in surrounding area detect its signal. Signal to noise ratio in such conditions is favored the most by the sensor, therefore there is virtually no misclassification of lightning type at sensors site. Figures 8 and 9 show intersection density for the peak amplitudes over 20 kA, processed in the same way as for the Figures 6 and 7. All figures also have the same area of interest and the same time interval division. There are no obvious hot-spots to be observed before or after the sensors tuning. The area with increased intersection density indicates only that close to this group of sensors, more thunderstorms took place compared to the area with lower density. This is in accordance with the fact that a lot of sensors detect the lightning with peak amplitude greater than 20 kA even at larger distances (even more then 500km).

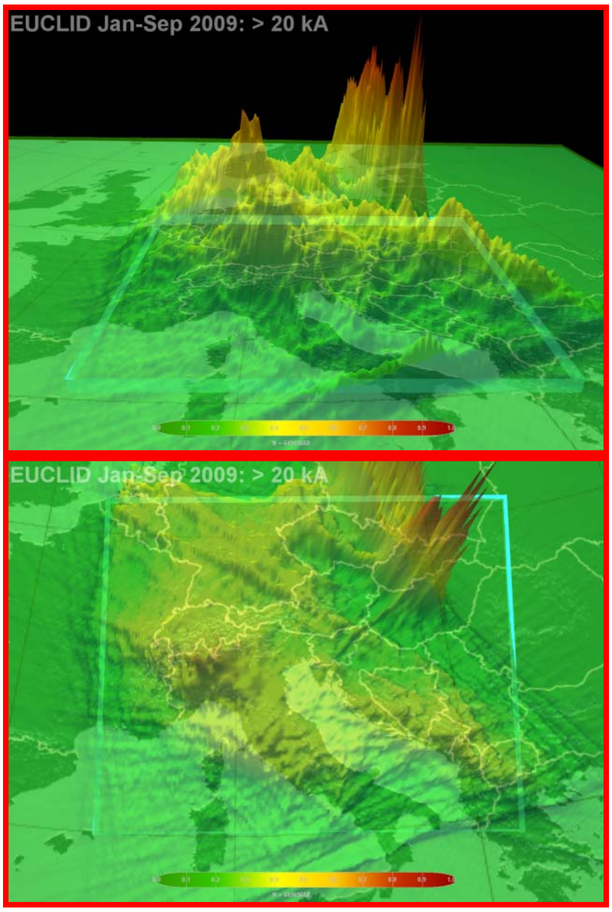

Figure 8: No obvious hot-spot is observed by the method prior to LS700x treshold tuning (Class C, first ¾ of 2009).

The area chosen for the analysis was also chosen for being the area with the highest flash density observed in Europe (west part of Slovenia, east part of Italy and south part of Austria). Hence it would be expected that the highest intersections density observed by the new method would correspond to the highest flash density area, but this is not the case. One reason for this is that a larger error ellipse is mainly produced when lightning with lower peak amplitude is detected.

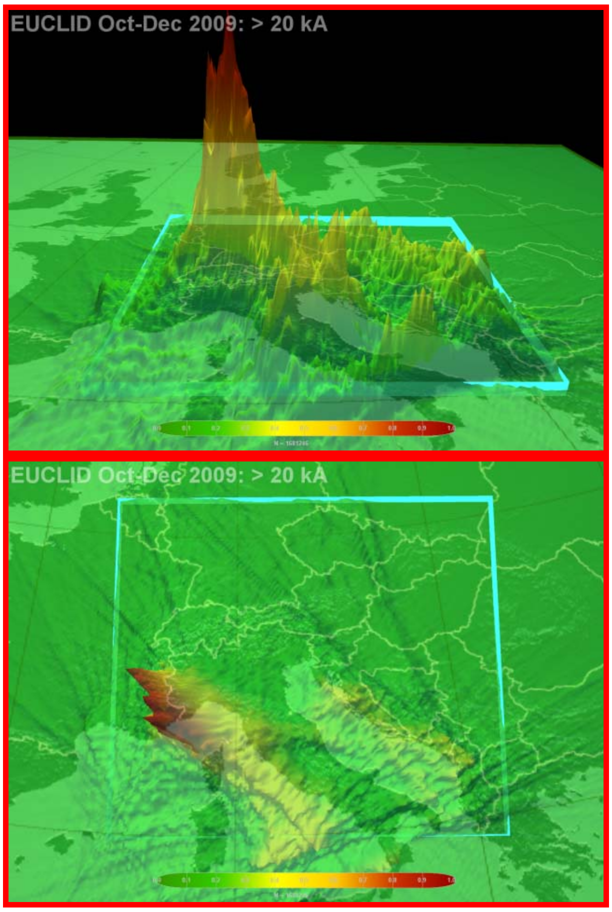

Figure 9: Large area of increased intersection density indicates only that thunderstorms are more common in the area (Class C, last ¼ of 2009).

The new analysis method is not sensitive to the flash density in the area of interest. Its results are mainly dependent on RF noise and lightning mislocation.

5 POWER LINE OUTAGE CORRELATOR IMPROVEMENTS

Regardless of the fact that the real-time power line outage correlator for transmission and distribution grids based on lightning information was introduced many years ago, work on its' improvements are still ongoing [4, 5]. Because the lightning location is directly tied to the performance of the correlation process, the comparison of the data before and after implementation of the new method of identification of the noisy sensor in LLS was performed. Figures 10 and 11 are showing successful automated power line outage correlation on the 110kV transmission level based on lightning location. The best lightning candidate which caused the power line outage is colored red. One can immediately see the difference between big confidence error ellipse on Figure 10 and small ellipse and therefore more accurate lightning location, presented in Figure 11.

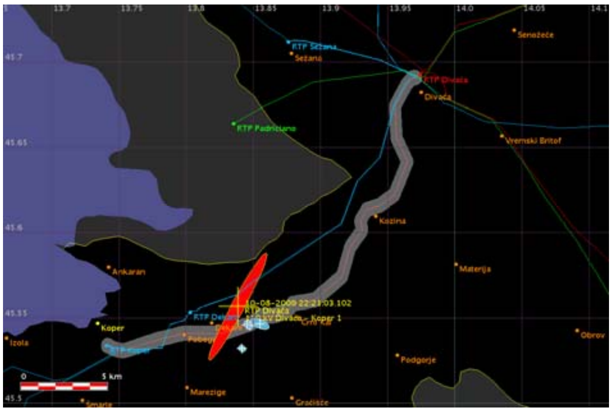

Figure 10: A large area red confidence error ellipse is the best candidate for 110 kV power line outage, but lightning's location accuracy is disturbed by one of the noisy sensor in the LL network.

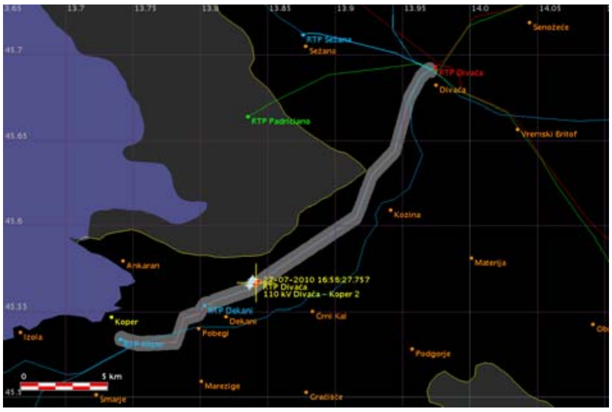

Figure 11: Improvments over previously shown power line outage correlation. Lightning strokes are very close to the power line corridor and confidence error ellipse is very small.

6 CONCLUSION

The new method for identification of the noisy hotspot in the lightning location network has been devised and presented. After the modernization and expansion of SCALAR-EUCLID LL network the problem with large confidence error ellipses has become more evident; accordingly, the problem identification and data preparation on selection area is also described. In addition, calculation algorithm is explained in detail and its speed optimization is considered.

The presented method has been successfully tested on selected area covered by various types of lightning location sensors. In the end, comparison of results over two time intervals and between two amplitude classes has been made.

With better and more precise results the real-time power outage correlator has confirmed the lightning location accuracy improvements of the LLS.

There is still room for improvements, especially in more precise intersection calculation. In future, analysis of data sets for the whole EUCLID coverage area might also be considered.

Nevertheless, the new analysis method has already been used to identify a noisy hot-spot in the EUCLID network and prompted the debate on the proper configuration of parameters for newer types of lightning location sensors.

7 REFERENCES

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