Total Lightning Detection Network in Central Europe: The F.L.A.S.H. Project

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Abstract-- **Austria, Slovakia and Hungary were covered by 2 regional Total Lightning networks (SAFIR) and one Cloud-to-Ground network which is a part of the EUCLID network (www.euclid.org).**

In January 2005 the so called F.L.A.S.H. (Full Lightning Detection Austria Slovakia Hungary) project was initiated. One goal of this project was to merge all these heterogeneous networks, taking opportunity of the new Vaisala's common central processor CP8000 which is operated by ALDIS. During this project we also added a VHF sensor (LS8000) in order to extend the total lightning coverage towards the eastern part of Austria.

In this paper we will describe the configuration of the resulting network, which consists of 9 VHF sensors (8 SAFIR from different generations and 1 LS8000) and 24 LF sensors (8 IMPACT, 7 LPATS, 1 LS7000 and 8 SAFIR LF sensors). We will further show the improvements in terms of extension of coverage area, redundancy and many new features coming with the last revision of the display software LTS2005. A brief summary of the performance during last summer season will be presented, and finally, the future perspectives of the F.L.A.S.H. project, with extension to neighboring countries will conclude this preliminary study.

I. Introduction

In Western Europe most of the lightning detection networks are owned by national entities leading to a large number of neighboring, relative small, coverage areas.

Several attempts to merge those local networks have been carried out in the past. The most important, oriented in the detection of Cloud to Ground (CG) flashes, is EUCLID (**Eu**ropean **C**ooperation for **Li**ghtning **D**etection). This network gathers 18 countries in Europe (Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovenia, Slovakia, Spain, Sweden and Switzerland) and, not just building a mosaic of images obtained by each networks, it builds a true interconnected network which covers almost all the European continent on a cooperation basis.

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On the other hand, several national total lightning networks, using VHF interferometry are also operational. Some of them already shared some neighboring sensors to extent their own coverage area, as for example Belgium and Netherlands or Hungary and Slovakia.

The aim of the F.L.A.S.H. project (**F**ull **L**ightning detection **A**ustria **S**lovakia **H**ungary) is to extend these local VHF networks or CG networks to a pilot-project for a continent wide total lightning detection network.

II. Existing Networks

Total lightning detection consists in detecting and locating the Cloud-to-Ground (CG) flashes as well as the cloud flashes (IC). Since these two types of events do not radiate in the same manner, we will use two different kinds of sensors to detect them. It is well known that the CG flashes, carrying a large amount of charges in the return stroke process will radiate more intensively in low frequencies (LF) while the IC flashes, made of hundreds of very fast transient pulses will mainly radiates in Very High Frequencies(VHF).

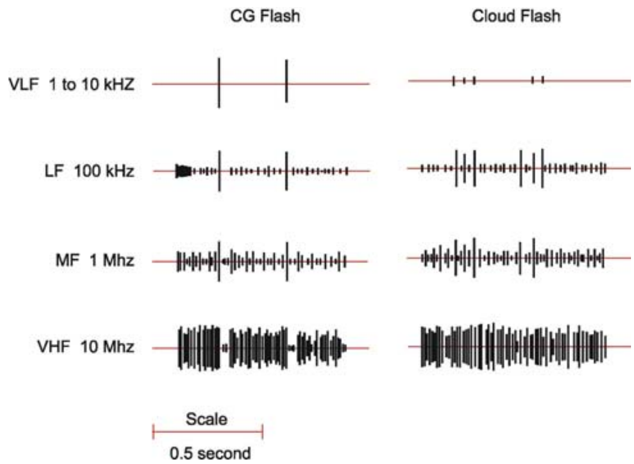

Fig. 1: Typical lightning radiations (adapted from Malan 1963).

In both LF and VHF frequency range, several location methods exist:

- In LF, there are Magnetic Direction Finders (MDF), Difference of Time-of-Arrival (DTA) systems or combination of both;
- In VHF, there are Interferometric Direction Finder (IDF) and also Difference of Time-Of-Arrival systems.

In our case, LF networks will be composed of 2 types of sensors (DTA only and MDF-DTA) but VHF networks, due to the necessity of very closely spaced sensors for VHF-DTA which do not exists in Hungary and Slovakia, will be based on IDF sensors only.

Many generations of sensors will also coexist: LPATS, IMPACT, IMPACT ESP, SAFIR-LF and LS7000 for the LF ones and SAFIR (from several generations) and LS8000 in VHF.

A. LF Networks

Prior to the initiation of the F.L.A.S.H. project, the EUCLID network (www.euclid.org), with about 120 sensors (see Fig. 2) offered the largest multinational network coverage of the European continent with LF lightning location technology.

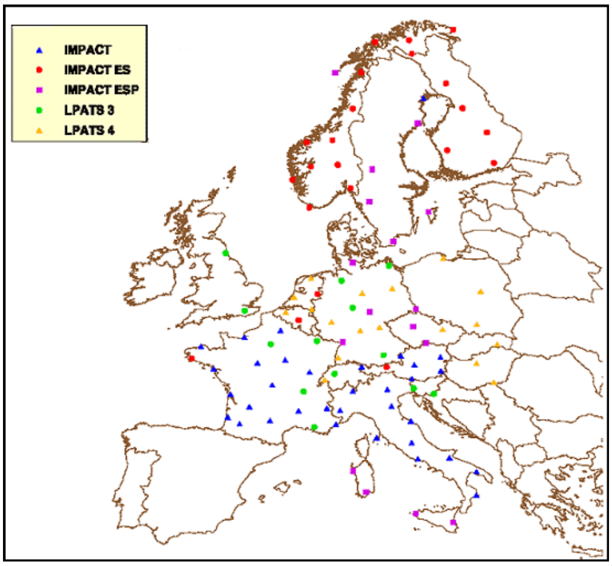

Fig. 2: EUCLID LF Network coverage (status 2004)

The origin of F.L.A.S.H. project was the idea to combine some sensors of this LF network with any overlapping VHF networks. Several regional VHF networks were available for that purpose and we decided to use the two, very closely spaced networks in Slovakia and Hungary.

In these two countries there are two SAFIR networks one consists of 5 sensors and the other one of 3 sensors. All the eight stations were equipped with an LF sensor but they were not used as DTA devices. The LF system was only a discrimination system, which flagged the location obtained in VHF when a coherent signal occurred on several LF sensors. Therefore the detection efficiency of the CG strokes was the one of the VHF network (see Fig. 3 in the VHF network presentation), because, we needed to have located at least on VHF source to be able to locate the CG stroke. Theoretically this detection efficiency should also have been reduced by the lack of detection of the LF network, but, having a quite large number of sensors in a relatively limited area should not affect so much this estimate.

B. VHF Network

The eight above-mentioned sensors, with their interferometric antennas, offered a good detection efficiency of the cloud discharges over Hungary and Slovakia (figure 3). There were however some limitations due to the very old generation of the used software. The main one, already mentioned in the previous paragraph, was the fact that time based location calculation in LF was not possible and we then used the location of the cloud portion of the CG flashes to locate those flashes. There was also a limitation on the number of events that can be processed each second.

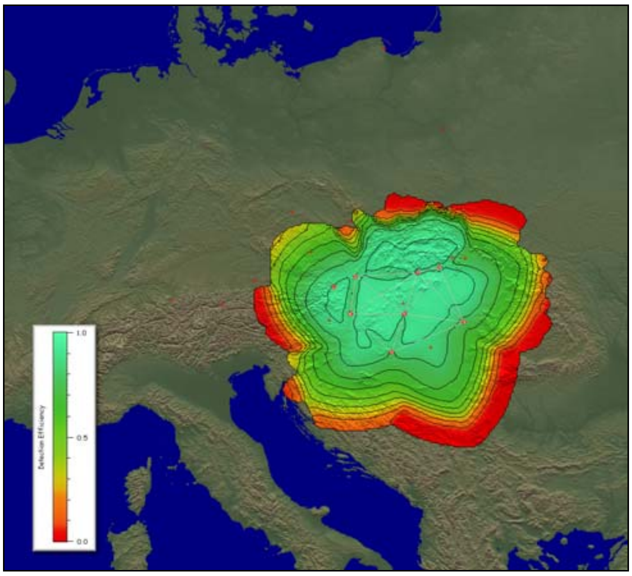

Fig. 3: Merged Slovak/Hungarian VHF Network Simulated Detection Efficiency.

III. F.L.A.S.H. NETWORK

One of the key points of the F.L.A.S.H. project was to keep all existing hardware and software and just bring some add-ons with new central processing system and new displays. The global architecture of the F.L.A.S.H. network is then based on the existing architectures augmented by new devices and features.

A. Network Architecture

Figure 4 shows the actual configuration of the F.L.A.S.H. network. 16 LF sensors from Austria, Czech Republic, Hungary, Poland and Slovakia are connected to the Vaisala's CP8000 Central Processor. This new processor is able to simultaneously process LF data, of any type (DTA, MDF or mixed) and VHF data of any type also (DTA and IDF). It is located in Vienna and operated by ALDIS. The eight SAFIR sensors from Hungary and Slovakia are also connected to this central processor. Moreover a 9th LS8000 interferometric sensor was intended to be included in this network. Unfortunately, the installation has been delayed and therefore this sensor is only up and running since March 2006. Thus, it will not be contributing to the results shown in the next chapter.

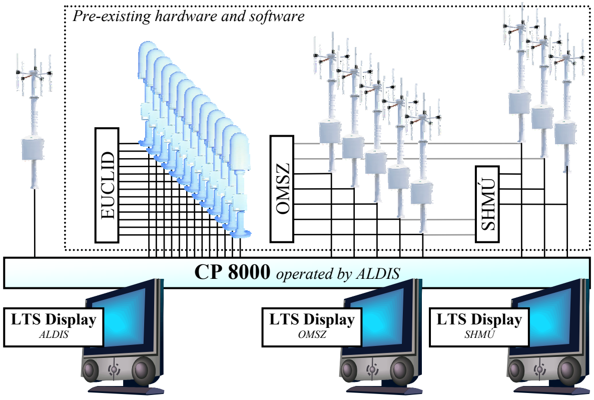

Fig. 4: F.L.A.S.H. network architecture. All equipments in the dotted area are the pre-existing ones: 16 LF sensors, 8 SAFIR sensors and all necessary central processors and displays. F.L.A.SH. project came with a new CP8000 central processor, an extra LS8000 sensor located in Austria and new LTS displays.

Thus the resulting network is a 24 LF sensors and 9 VHF sensors network fully covering Slovakia and Hungary with total lightning detection.

B. Network performances

The simulation of CG flash detection efficiency, assuming proper operation of all sensors, is shown in Fig. 5. It shows very good detection efficiency, better than 90% in the area of interest.

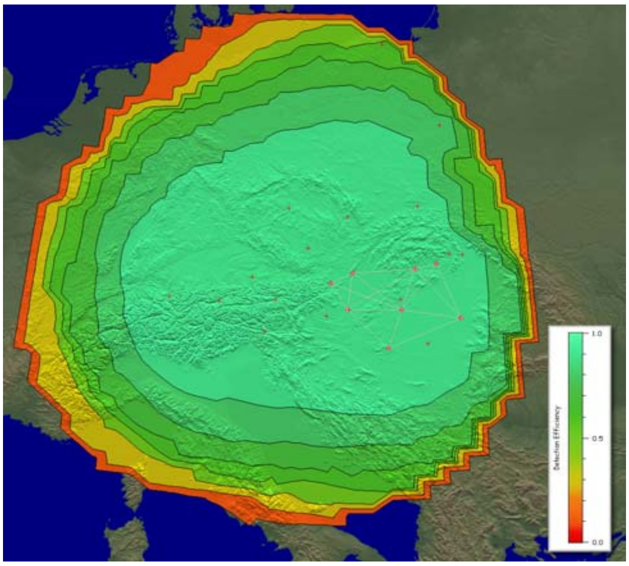

Fig. 5: CG flash detection efficiency of the F.L.A.S.H. network..

The detection efficiency of cloud discharges is shown in Fig. 6. Compared to what it was before the F.L.A.S.H. project, it has much better detection efficiency over eastern Austria, thanks to the new installed LS8000 sensor.

Once again, the global detection efficiency exceeds 90% in the area of interest.

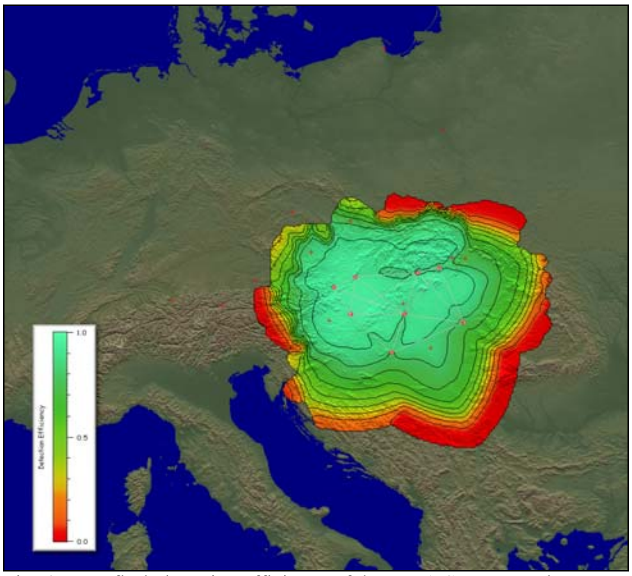

Fig. 6: VHF flash detection efficiency of the F.L.A.S.H. network

C. New Features

By centralizing the processing at the CP8000 site, the management of all sensors in the network is also centralized, providing a more efficient service to the customer. Moreover, having a redundant data archive at this site, also improves data reliability. Another big advantage of using the CP8000 as central processor is the improved location algorithm (LF and VHF).

By merging those two technologies the resulting network profits from the advantages of the individual technologies. For example, the increase in LF sensor number, in the south-eastern part of the coverage area, will improve the detection efficiency of the Cloud-to-Ground flashes. The Total lighting network will then have an independent measurement of CG locations, which will be much more accurate than the former discrimination method. Moreover, the extension of the area covered in LF will also greatly improve the range of forecast of lightning threats.

By upgrading the processing and display software, the users will get the new features that Vaisala has developed over years, e.g. the new flash branching algorithm.

Figure 7 is an illustration of this improvement. In the former SAFIR central processors (CPS and SCM), the individual events constituent the cloud discharges where connected in time ordered sequences, from the oldest one to the newest. Since cloud discharges are composed of several branches moving together this led to erratic scrawls shown on Fig. 7a.

In the new branching algorithm, a spatiotemporal constrained method is applied to associate together the events that have to be associated (Fig. 7b).

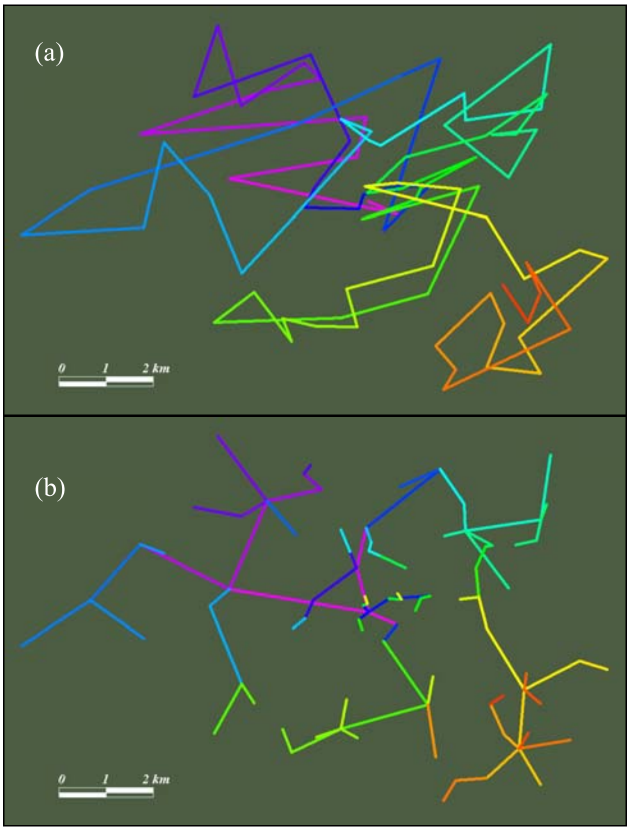

Fig. 7: One Cloud discharge sample: a) using the former "connect-the-dots" algorithm; b) using the new branching algorithm of the LTS2005. Branches are color coded according to the time of the event from purple to orange over 100 ms.

Despite the possible effect of location inaccuracy, this representation is much more realistic and provides a more convincing way to describe the cloud flash.

Many other new benefits for the management of the network will be presented in the next section.

IV. Results and Discussion

The F.LA.S.H. project was initiated on January 1st 2005. Thanks to a very efficient collaboration of all involved partners, the network was fully setup to acquire data end of May 2005.

The detailed presentation of those results was made at the 1st F.LA.S.H. Users Group Workshop, held in Vienna in September 2005 where all technical issues were also addressed. We will simply summarize here some key results, confirming the benefit of such integrated network.

Figure 8 shows the Average Number of Sensors Reporting (ANSR) for all data acquired during August 2005. The ANSR is directly related to the network detection efficiency. It clearly shows that, thanks to a very dense LF network in this area, the ANSR is above 6 all over Hungary and Slovakia. It is a bit less over Austria, but almost never lower than 4.

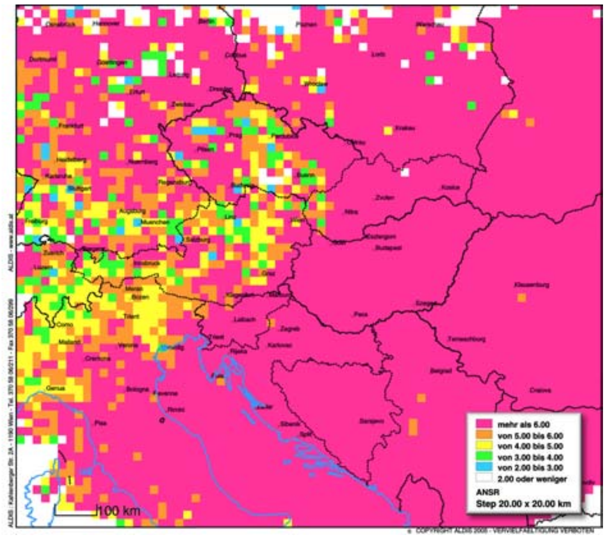

Fig. 8: Average Number of Sensors Reporting for data acquired during August 2005.

Having now an independent way to locate CG flashes, we were also able to compute an effective detection efficiency of the CG flashes, seen by the VHF network.

The DE was determined using CG strokes reported by the LF network as a ground truth. The VHF systems does not directly measure return strokes of CG strokes, but they do detect other associated discharges which occur as part of a CG stroke. Thus, the VHF network was said to have detected a CG stroke reported by the LF network if it located at least one source within 30 km of the first stroke location and within a time interval of ±300ms. A simple count of such events divided by the actual number of CG strokes within a grid box of 5x5 km provided the estimation of effective CG stroke detection efficiency of the VHF system (see Fig. 9).

The solid black line shows the result of the simulation of the detection efficiency. There is very good agreement between the observation and the simulation. For the simulated DE, we have assumed that the VHF sources were centered at a height of 4500m. This height is lower than the usual height used in such simulations (7000m) due to the fact that the VHF emissions for CGs generally occur at lower altitudes than for cloud discharges. We employed a complete propagation model including terrain blockage, 0.1° diffraction at the radio horizon, and an effective earth radius scaled up by 4/3 to take into account refraction effects. We assumed that the source power followed a Gaussian distribution centered on +36 dBm with 5 dB standard deviation.

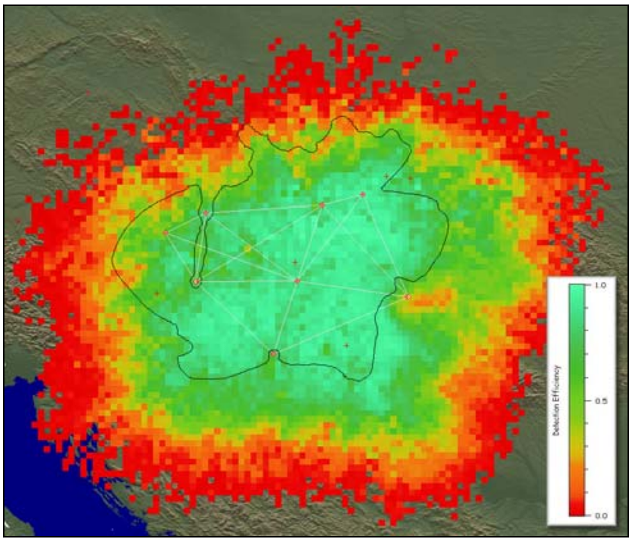

Fig. 9: Effective VHF network detection efficiency of CG. The solid black line corresponds to the 80% detection efficiency of the discharges located at an altitude of 4500m.

Another interesting feature of such total lightning networks is the ability to validate or calibrate the accuracy of one measurement with the second one. For example, we are now able, using the CG strokes as ground truth, to check the accuracy of the azimuth measurement of each VHF IDF.

In the same way as we did above we will associate to each CG stroke, the closest VHF event which occurred in a time window of ±300ms around the stroke event and in an azimuth corresponding to a possible misplacement of about 30km, in order to take into account the different nature of the two measurements. Indeed LF sensors are reporting the fast transients radiated just after the attachment process, when the return stroke start to propagate in the channel (ground impact) while VHF measurements will be mainly sensitive to stepped leader processes which occur before the return stroke or initial breakdowns within the cloud. They both can occur at different locations depending on the horizontal extent of the flash. Although the CG strokes may be misplaced, there will be no correlation of this error with the VHF measurement.

Figure 10 is an example of such a plot obtained for Bugyi sensor (20 km south from Budapest). The color picture is a two dimensional histogram of events, showing the density of samples for each pair of (VHF, LF) azimuth. The red dots line represents the zoomed average path of the difference between both (scale shown on the right side of the figure).

This example clearly shows that the tabulated coupling correction function was not properly uploaded to the sensor. SAFIR VHF antennas are made of a circular array of 5 dipoles which are very closely spaced. As a result of this disposition, there are coupling effects acting as a systematical 5 period sinusoidal azimuth error of about 5 degree magnitude. The amplitude of this azimuth error is a function of frequency and antenna geometry was calculated theoretically and is supposed to be configured at the sensor. In this particular case we have found with our data analysis, that the coupling correction function was not configured for the actual operating frequency. This has been corrected after the F.L.A.S.H. workshop.

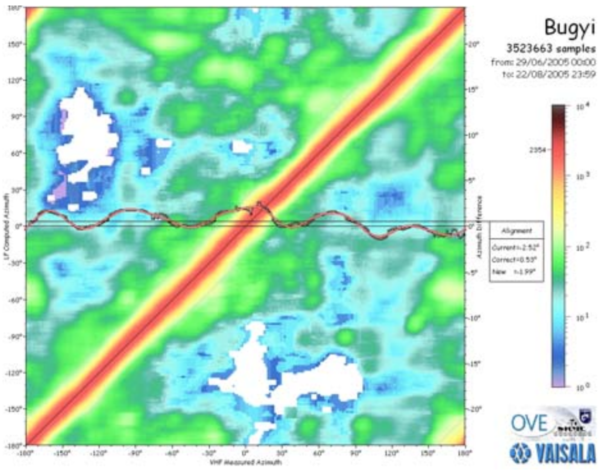

Fig. 10: Azimuth of CG strokes as seen from one particular sensor (Bugyi) as a function of the VHF azimuth measured by this sensor. CG strokes are considered as ground truth to retrieve site error corrections.

To conclude the presentation of these first results, Fig. 11 shows one of the new displays developed by Vaisala representing half an hour of the huge thunderstorm occurring August 3 (21:56 to 22:26 UTC).

This thunderstorm was made of several isolated cells that are organizing in a front line at the end of the day (shown in Fig. 11). The most recent CG strokes (i.e. occurring over the last minute) are coded as bright white dots showing the current position of the lightning cell cores. The past 30 minutes of CG flashes are coded as + or – red signs according to the polarity, while the current cloud flashes are represented with their branches in green and the past 30 minutes in the same way in blue.

The storm motion was from south-west to north east (white arrow) and we clearly see on the picture the trailing stratiform region (blue area) where many cloud activity occurs, with very few CG flashes.

One very interesting feature of such a display is the ability to maintain a lightning threat warning in an area where almost no CG occurs, thanks to the high rate of cloud flashes which could help to warn for the isolated CG that occurred about 50 km back in the stratiform region.

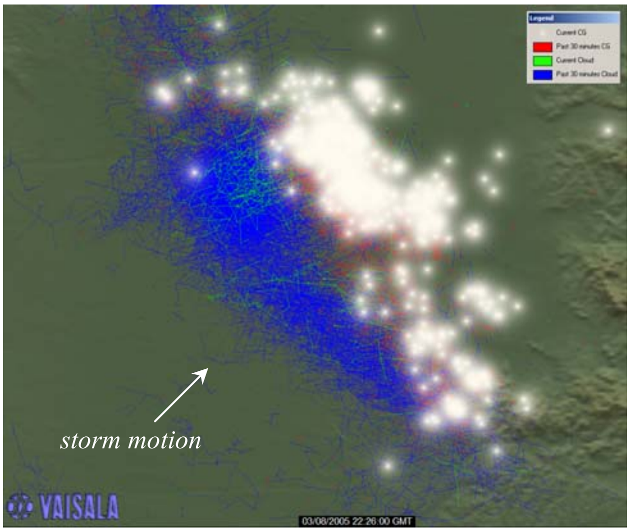

Fig. 11: 30 minutes of total lightning activity that occurred August 3, 2005, from 21:56 to 22:26 UTC.

This example well illustrates how powerful the Total Lightning detection is.

V. Future Network

Early this year, is has been decided to continue the project. Further there is interest to extend it to the two neighboring countries equipped with total lightning detection: Poland and Romania.

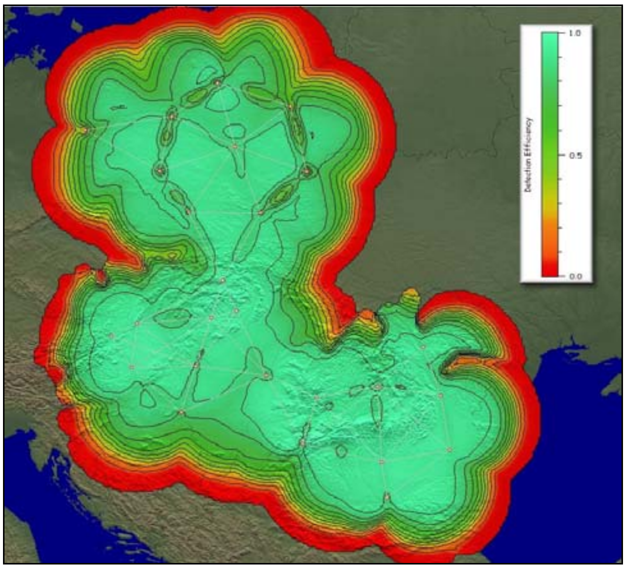

Fig. 11: Projected VHF Detection Efficiency after the integration of Polish and Romanian networks.

Figure 11 shows the resulting VHF detection efficiency of such a network providing an almost uniform coverage from Baltic Sea to Black Sea. This extended F.LA.S.H. network could be operational for next thunder storm season (summer 2006) and we hope to be able to show very exciting results at the next ILDC.

VI. Acknowledgment

We would like to acknowledge here the Hungarian Meteorological Service (OMSZ), the Slovak Hydro meteorological Institute (SHMÚ), the Austrian Meteorological Service (ZAMG) and Austro Control (ACG) for their efficient contribution to the success of this project.