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LIGHTNING STATISTICS IN SWITZERLAND

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Abstract - In this paper we present the results of a recent study on lightning statistics in Switzerland during an eight-year period from 1999 till 2006, using data from the EUCLID (European Cooperation of Lightning Detection) LLS (Lightning Location System). After a brief presentation of the history of lightning detection in Switzerland, statistics of some salient lightning parameters in Switzerland are presented. It is shown that there is a relatively high lightning activity in Switzerland especially in the Canton of Tessin, located south of the Alps. Additionally, it is found that the lightning flash density in some regions of Switzerland (Tessin) is higher than the maximum lightning flash density in Austria and Germany while the flash median peak current and the number of strokes per flash (flash multiplicity) are similar in the three countries. We observed a significant improvement of network performance from 1999 to 2006.

1 INTRODUCTION

The knowledge of lightning parameters is of paramount importance in the design of protection systems for various types of structures, including power and telecommunication systems. As discussed in [1], there are different methods to obtain statistical data on lightning. Lightning Location Systems (LLS), which are widely used today, can be a useful tool for the establishment of regional lightning statistics. These systems provide, besides the lightning coordinates and discharge type, other lightning parameters such as estimations of the lightning peak current and the number of strokes per flash.

LLS networks appeared commercially in the late 70's and one such network was installed for the first time in Switzerland in 1989 as described in the following section. All statistics presented in the present paper were obtained from the lightning database of the EUCLID (European Cooperation of Lightning Detection) network. When lightning parameters are extracted from LLS, it is important to take into account the performance and limitations of the LLS network (e.g. [1]). Indeed, LLS network is based on remote detection of lightning activity and it comprises a number of measuring stations spread over a wide geographic region (e.g. Europe). Therefore, LLS-extracted data have some limitations compared to data obtained by direct measurements. Especially we note that various limitations of the system have different effects on different lightning parameters. Some factors which might influence the data obtained by LLS are:

1) Misclassification of a certain number of Cloud-to-Cloud (CC) discharges as positive Cloud-to-Ground (CG) strokes. This misclassification affects the statistical distribution of the number of CC and positive CG flashes, as well as the median peak current of positive flashes. This is due to the limitations of the algorithms currently used to distinguish between CC and CG strokes. Normally, a set of discrimination criteria based on the shape and amplitude of the waveform are used for this classification.

2) The peak current is estimated from the distant electromagnetic field measurements. Since the electric field is attenuated as it propagates, the measured field peak at a given sensor depends on the ground conductivity along the propagation path and on the distance between the stroke and the sensor. Those factors should be taken into account for an ideal peak current determination. Further, many of the networks in use today contain a mix of sensor technologies, some of which are based on electric field sensors (type LPATS) and some on magnetic field sensors (type IMPACT). It is therefore important that the LPATS sensors be correctly calibrated relative to the IMPACT sensors.

3) Changes in the network configuration such as integration or upgrade of sensors, as well as changes in

the sensors' threshold and calibration or changes in different computing algorithms, could also affect the data. Thus, the milestones of network changes should be always considered in the interpretation of the data.

4) Flash parameters, such as polarity, peak current and location are actually associated with the first stroke only. As a result, any error in locating the first stroke, its misclassification or false grouping, will lead to errors in flash statistics.

5) Strokes with very small peak current could be missed by LLS. Conversely, some strokes with very large peak current could also be affected by location errors due to the usage of information from distant sensors.

6) Some networks measure signal strength using also electric field sensors (LPATS sensors) that are not calibrated in absolute field strength [V/m]. Typically, those sensors are calibrated relative to IMPACT sensors in the same network (this is essential).

7) Whenever networks have different sensor baselines, sensor gains, sensor waveform parameters, sensor thresholds, or central processing algorithms, it is likely that they will report different subsets of the lightning discharges [2].

In addition to the limitations mentioned above, as with any other statistical analysis, one should always consider the number of events (the sample size) involved in each particular dataset in order to estimate the reliability of the statistical results before performing further analysis and interpretations.

2 HISTORICAL EVOLUTION OF LIGHTNING LOCATION SYSTEMS PERFORMANCE IN SWITZERLAND

Prior to the installation of a modern LLS, lightning statistics in Switzerland were determined by counting thunderstorm days or using CIGRE counters. In 1989, Switzerland was one of the first countries that installed a LLS formed by six LPATS sensors. The data obtained from this LLS included the stroke location, peak current and type of stroke, cloud-to-cloud (CC) or cloud-to-ground (CG). The location error was estimated at that time from direct measurements for strikes to two towers: the St. Chrischona Tower, Basel-Switzerland, for which the error was up to 1.3 km, and the Peissenberg tower, Germany, for which the error was as high as 4.2 km [3]. The Swiss LLS was run by the lightning research department of the Swiss PTT. Research activity with the system stopped in 1995 and the data acquisition was also stopped in 1998.

The Swiss LLS network started again operating in 1999. The same year, the network was joined with the German and the Austrian LLS and with some sensors from the northern part of Italy. This joint network formed the basis of the EUCLID network. In Switzerland only two LPATS sensors located in Bern and Renens were used. Nowadays the EUCLID LLS includes local lightning detection networks of 17 countries in Europe including Switzerland. This provides an excellent means of obtaining the real-time lightning activity in Europe. Data are centrally acquired and processed using two servers (LP2000) located in Vienna-Austria and Karlsruhe-Germany.

In general, the evolution of the lightning location system in Switzerland could be divided into two main periods:

• From the beginning of 1999 till the end of 2001, when the network was in its initial forming stages; sensors from Austria, Germany, northern Italy and only three LPATS sensors in France were available.

• From the beginning of 2002 until the end of 2006, when the data from all the IMPACT sensors in France were included and the sensor in Renens was upgraded to LPATS IV. There were also some minor software upgrades of the central processor (LP2000) during 2005.

The improvement of the network performance in Switzerland during this eight-year period could also be seen from the Averaged Number of Sensors Reporting (ANSR). The ANSR and the Average Number of Sensors Locating (ANSL) are network parameters that are directly related to the overall stroke detection efficiency of the LLS [4]. Comparing ANSR with ANSL did not reveal any significant differences between these two parameters, thus only the ANSR will be presented. The ANSR in Switzerland for the year 1999 is shown in Fig. 1. During that year, the ANSR ranged between 3 and 12 with an average value of 8.3. The lightning activity in the main parts of southern and western Switzerland in 1999 were covered by ANSR values ranging from 6 to 9, while the northern parts were covered by ANSR values of 9 to 12.

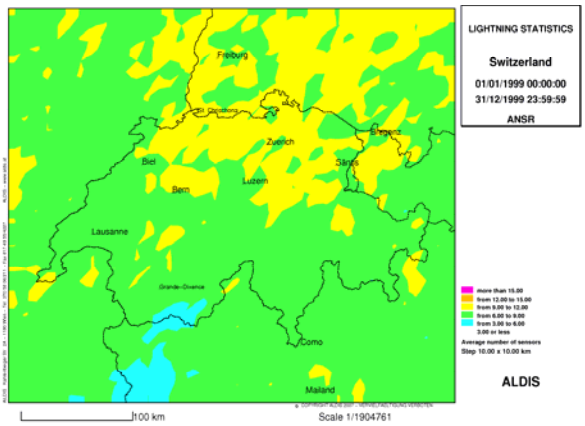

Fig. 1 - ANSR in Switzerland during 1999.
(ANSR value: Yellow: 9-12, Green: 6-9, Blue: 3-6)

Fig. 2 shows the ANSR in Switzerland for the year 2006. The ANSR ranged between 6 and 18 in 2006 with an average value of 11.7. The lightning activity in the main parts of southern Switzerland in 2006 were covered by ANSR values ranging from 9 to 12 while the main parts of central and northern Switzerland were covered by ANSR values of 12 to 15.

A comparison between Fig.1 and Fig.2 reveals a significant improvement in ANSR from 1999 to 2006, which is mainly the result of integration of additional sensors and network upgrades.

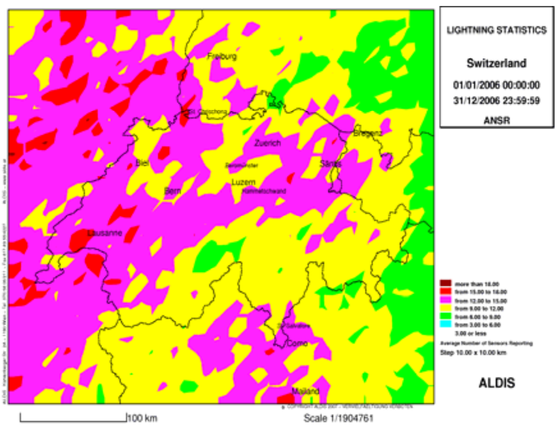

Fig. 2 - ANSR in Switzerland during 2006.
(ANSR: Red: 15-16, Magenta: 12-15, Yellow: 9-12, Green: 6-9)

3 STATISTICAL ANALYSIS OF LIGHTNING ACTIVITY IN SWITZERLAND

In this chapter, some statistics of lightning activity in Switzerland are presented. The statistics have been calculated over a rectangular area around Switzerland. The lower left corner of this rectangular area corresponds to 5.9E, 45.8N while its upper right corner corresponds to 10.8E, 48.0N.

3.1 Temporal statistics of number of flashes/strokes

Fig. 3 shows the annual number of CG flashes, CG strokes, and CC discharges in Switzerland reported by the LLS from 1999 till 2006. One can observe that the highest lightning activity was observed in 2000, followed by 2001, 2006 and 2003, with the rest of the years in the considered period exhibiting a significantly lower activity. The maximum number of flashes and strokes detected in Switzerland during the year 2000 was about 200’000 flashes and 335’000 strokes.

It should be noted that the number of detected flashes and strokes is quite sensitive to the detection efficiency of the network as well as to the algorithm used in grouping strokes into flashes. Further, one could see that the number of CC discharges increased significantly in 2006. The reason is probably related to the upgrade of the Austrian network to a new sensor technology (LS7000 sensors). This type of sensor could also increase the overall detection efficiency in some parts of Switzerland because it detects more strokes with smaller peak current. On the other hand, the increased sensitivity might have caused an increased number of misclassified CC discharges as positive CG discharges.

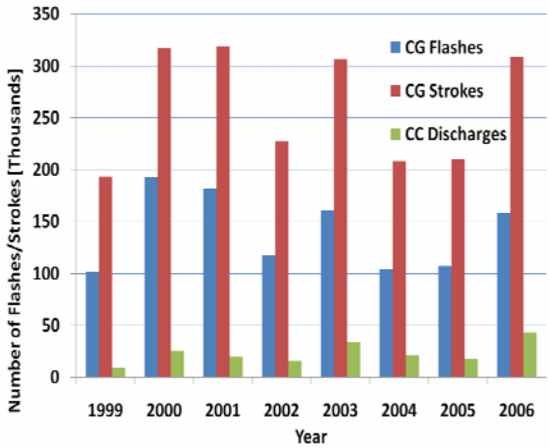

Fig. 3 - Annual number of CG flashes/strokes and CC discharges in Switzerland.
(CG Flashes: Blue, CG Strokes: Red, CC Discharges: Green)

The monthly distribution of the total number of CG flashes during the eight-year period from 1999 to 2006 is presented in Fig. 4. Monthly distributions are not sensitive to the performance and the configuration of the network. As expected, the highest lightning activity occurs during summer (June, July and August) with a maximum in July. It is worth noting that the highest lightning activity in Austria occurs in August (data from 1992-2001). Further, in Switzerland, the lightning activity in June appears to be higher than August while this is the opposite in Austria [2].

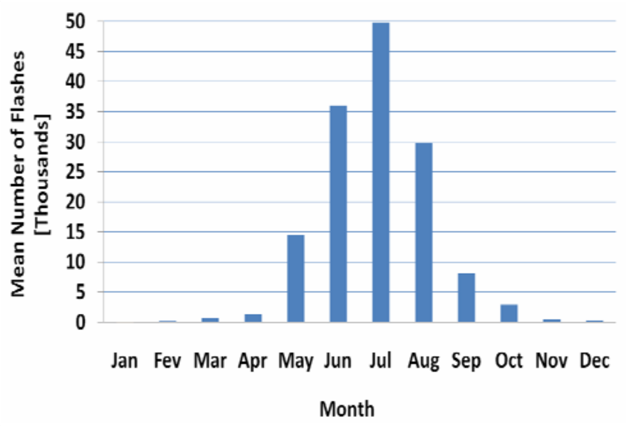

Fig. 4 - Monthly mean number of CG flashes during 1999-2006.

The diurnal distribution of the total number of CG flashes in Switzerland from 1999 to 2006 is shown in Fig. 5. One can see that most of the flashes occurred during the afternoon, mostly between 2 and 6 PM, with a maximum at 4 PM. This is similar to Austria for data obtained during the 1992-2001 period. The diurnal distribution of the number of flashes is also relatively insensitive to the DE of the network because it depends more on the detection of the storms than on the DE of individual flashes/strokes.

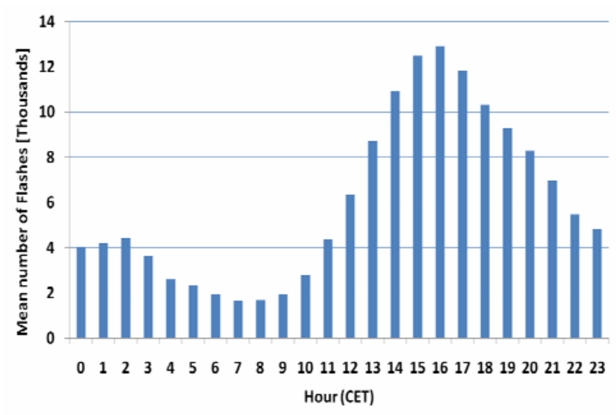

Fig. 5 - Diurnal number of CG flashes during 1999-2006.

3.2 Flash peak current

Fig. 6 shows the annual median peak current of positive and negative flashes during the period from 1999 to 2006. The median peak current varies between 14 kA and 20 kA for positive flashes and between 11 kA and 15 kA for negative flashes. One can see high values of median flash peak currents in 1999. This is because LPATS sensors had not yet been calibrated at that time. These sensors are sensitive to the local electric field enhancement and therefore it is necessary to calibrate them relative to other IMPACT sensors around Switzerland. Additionally, in 1999 the Swiss network was operated for the first year within the EUCLID network and had undergone many changes and upgrades.

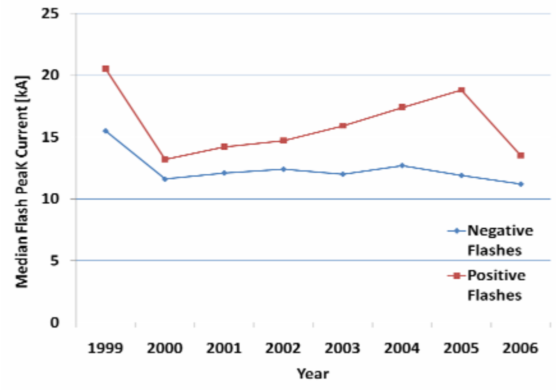

Fig. 6 - Annual median peak current of negative and positive CG flashes in Switzerland.

Further we can observe a significant decrease of the positive peak currents in 2006. This decrease in 2006 is probably related, at least in part, to misclassification of CC discharges due to a higher rate of detection of CC strokes. On the other hand, one can observe a more stable behavior of the median peak current of negative flashes. The median peak current for negative flashes stays around 12 kA from the year 2000 on. This evolution of the network and its relative stability during the second period of its operation can also be seen in the annual statistics of multiplicity, as shown in Fig. 7.

A comparison with similar data obtained from the LLS network in Germany from 1999 to 2002 [5], shows a quite similar median peak current for negative flashes. Further, we note a similar decrease of median peak current of negative flashes, in both Swiss and German data from 1999 to 2000. This is presumably because both networks were integrated and calibrated at the same time. In Germany the median peak current of positive and negative flashes are almost identical while, in Switzerland, the median peak current of positive flashes is slightly higher than the median peak current of negative flashes. This similarity between median peak current of positive and negative flashes is unexpected because positive flashes are usually characterized by significantly higher peak currents compared to negative flashes. This odd result could be due to misclassifications of CC discharges as positive CG strokes. As CC discharges have small amplitudes, they can bias the median flash peak current of positive flashes toward smaller values.

3.3 Number of strokes per flash (multiplicity)

Fig. 7 shows the average number of strokes per flash (multiplicity) for positive and negative flashes during the 8-year period from 1999 to 2006. Multiplicity of negative flashes ranges between 1.75 and 2.2, with a sudden increase in 2002. After this increase in 2002, the multiplicity of negative flashes remains stable. The average multiplicity for the last 5 years of the network's best performance (2002-2006) is 2.13 while it is 2.0 for the whole 8-year period. The stable average multiplicity after 2001 for negative flashes could be related the following reasons:

At the end of 2001, the French IMPACT sensors were included and, therefore, the coverage of Switzerland was more evenly distributed from the geographic and technological points of view. In fact, integration of more sensors in France resulted in better geographic coverage of western parts of Switzerland. Further, as all sensors in France were of type LPATS (based on TOA only technology) before this integration, the additional IMPACT sensors (based on combined TOA and MDF technologies), resulted in more balanced distribution of detection technology around Switzerland. Also, the upgrade of the sensor located in Renens to LPATS IV technology in early 2002 had a significant effect on improving the detection efficiency by detecting more strokes resulting in a higher multiplicity for negative flashes. Although, the increase in the maximum number of allowed strokes per flash in 2002 could also have a minor effect on increase of average multiplicity, the multiplicities more than 15 are very rare in practice.

The average multiplicity of positive flashes for the whole 8-year period (1999-2006) in Switzerland is 1.22 while this value for the last 5 years (2002-2006) is 1.24. Also, this parameter was more stable for the last 5 years. This shows also the fact that most of the positive flashes are actually single-stroke flashes as the average multiplicity is always around one. The average multiplicity of negative flashes in Austria has been reported to be 2.1 for negative flashes and about 1.16 for positive flashes in 2001 [2], which are very similar to the values found in Switzerland. The data obtained from accurate-stroke-count studies using high-speed cameras in Brazil, [6, 7], shows an average negative flash multiplicity of 3.8 for 233 studied negative CG flashes. A similar analysis in Florida and New Mexico, [8] shows an average flash multiplicity of 4.6 for 76 analyzed flashes; while the flash multiplicity reported by LLS in these regions are 2.4 and 2.1, respectively. We note that flash multiplicities reported by NLDN are also similar to values found in Switzerland while the flash multiplicities reported by accurate-stroke-counts in Brazil and the United States are quite higher. The reason for this discrepancy could be the limited DE of the LLS.

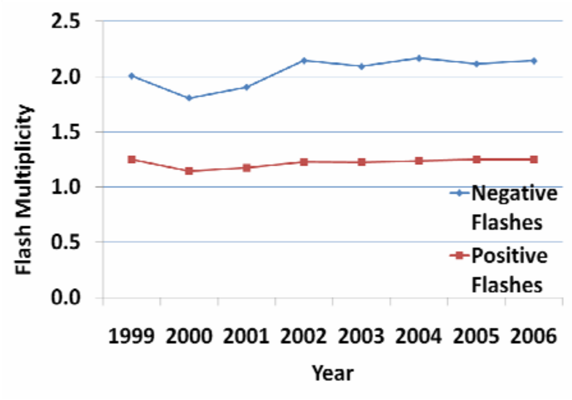

Fig. 7 - Average multiplicity of negative/positive CG flashes

3.4 Flash polarity

It is known that the negative flashes are more frequent than positive ones and that the relative number of positive flashes increases during the winter. For example about 90% of total flashes in Austria during the summer (1992-2001) were negative flashes while this percentage decreased to about 80% during the winter [2]. This seems not to be exactly the case in lightning statistics of Switzerland during 1999-2006. In Switzerland, the percentage of negative flashes appears to be about 80% during the summer (June, July, and August) and it decreases down to about 70% in January, March and April. The unusual point in these data is that the percentage of negative flashes in February and December slightly exceeds 80% which is even higher than in the summer as can be seen in Fig. 8.

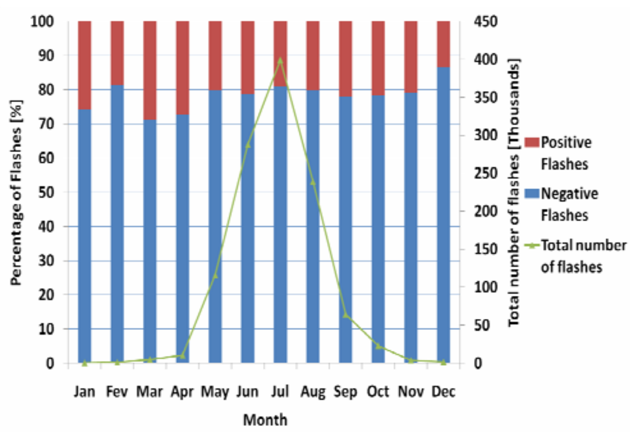

Fig. 8 - Monthly percentage of positive and negative flashes (Positive Flashes: Red, Negative Flashes: Blue, Total Flashes: Green)

Analysis of the same data for individual years in Switzerland (not represented), shows that the percentage of negative flashes in February has been always as high as in the summer, except for in 2001. On the other hand, the percentage of negative flashes in December had extremely high values in 1999 and 2004 while exhibiting extremely low values in 2001 and 2002. In addition, the percentage of negative flashes in December 2000 and 2003 is similar to that in the summer. It is only during 2005 and 2006 that the percentage of flashes in December becomes lower than in the summer, similar to the statistics in the other countries. We believe that these abnormal variations are mostly due to the frequent misclassification of positive flashes. Nevertheless, the small number of flashes (superimposed on the graph) in Jan-Mar and Nov-Dec, makes its statistics less reliable.

3.5 Interstroke interval

Fig. 9 shows the annual distribution of the arithmetic and geometric mean of interstroke interval for negative and positive CG flashes. The geometric mean of the interstroke interval for negative CG flashes is always about 50% higher than that for positive CG flashes. The variations of interstroke interval are less pronounced for negative flashes than for positive flashes. Additionally the geometric mean of the interstroke interval for negative flashes is rather constant (around 60ms) during all of the time period considered except for a decrease in 2006.

Comparing these results with the results obtained in Austria [2], we can see that the arithmetic mean of the inter-stroke intervals for the negative flashes in Switzerland is quite similar to the value in Austria, which ranges between 80 ms and 90 ms. We observe in general slightly smaller values for the arithmetic mean of interstroke interval for positive flashes in Switzerland, which is in the range 70 ms to 95 ms, while this value has been reported to be between 70 ms and 110 ms in Austria, [2]. Additionally, the geometric mean of the interstroke interval for negative flashes in Brazil obtained from accurate stroke count studies is 61 ms [6, 7]. This is the same value obtained in Switzerland.

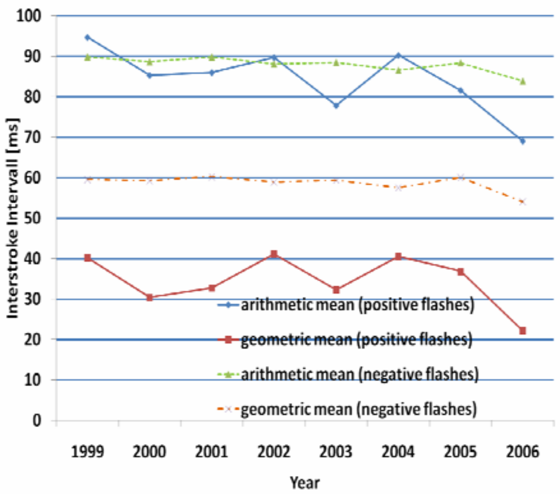

Fig. 9 - Annual arithmetic and geometric mean of interstroke interval for negative and positive CG flashes during 1999-2006.

3.6 Spatial map of Lightning Flash density

Fig. 10 shows the ground flash density (GFD) in Switzerland during the 8-year period from 1999 to 2006. The GFD in Figure 10 varies between 1 and 3 flashes km^{-2} yr^{-1} across most of the Swiss geographical regions. This value is quite similar to the GFD reported for Austria by Schulz et al. [2005]. Nevertheless, we note much higher GFDs in Switzerland, exceeding 6 flashes km^{-2} yr^{-1}, in the region south of the Alps. One can see that the minimum of GFD is usually situated over the top of high mountains in the Alps, and the highest GFD is south of the Alps, in the Canton of Tessin in southern Switzerland. The reason for this is basically thunderstorm cells moving from the south and being blocked by the Alps. This region is also considered to have one of the highest lightning activities in Europe. Among various hotspots in Switzerland, it is worth mentioning the Säntis Tower and the Die Rigi Tower as well as the other hotspots in the region of Tessin (e.g. Monte St. Salvatore, Monte Ceneri), Zurich, Bern, Basel (St. Chrischona Tower) and Biel (Le Chasseral Tower).

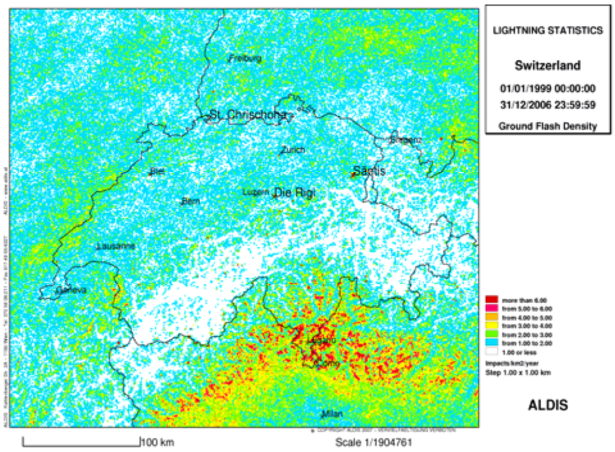

Fig. 10: Ground Flash density (Impacts.km^{-2}.$year^{-1}$), 1999-2006. (White: Less than 1, Blue: 1-2, Green: 2-3, Yellow: 3-4, Orange: 4-5, Red: 5-6)

4 SUMMARY AND DISCUSSION

In this paper, we presented an analysis of the lightning activity in Switzerland during the eight-year period from 1999 to 2006. Statistical maps and graphs have been generated for different lightning parameters in Switzerland during this period using EUCLID's lightning database and software provided by ALDIS. The results are mainly composed of the most important statistics for various lightning parameters, including flash density, flash multiplicity and flash peak current. In this paper, only the most important results are included and more detailed results can be found in [9]. In general, the most important points that we could see in these results are the following:

- Considering the flash density map, Fig. 10, the flash density in Switzerland is highest in the region of Tessin and south of the Alps. This is because of the blocking effect of the Alps on thunderstorm cells that come to Switzerland from the northern part of Italy.

- There is a large number of hotspots in the lightning flash density map that are located in various parts of Switzerland including the region around the Säntis tower as well as around some transmission towers near Luzern, Biel, Basel, Zurich and Bern. Our detailed study around the Säntis tower shows that the highest lightning activity in Switzerland occurs in this region. The telecommunications tower on the top of this mountain exhibits a particularly high lightning activity as the tower initiates a large number of upward discharges. We have observed flash densities exceeding 100 flashes per year on the Säntis Tower.

- One could see the improvement of the lightning location network in Switzerland during this eight-year period from 1999 till 2006. This improvement could be seen by means of various parameters and analyses including ANSR and the length of the semi major axis of the accuracy ellipse. After the first three years of operation, the network performance has become stable, resulting in stable inferred lightning parameters.

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