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Lightning activity in Belgium during 2001-2011

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***Abstract*— In this study we present cloud-to-ground (CG) and cloud-to-cloud (CC) lightning activity over the period 2001-2011 in Belgium. Particular attention is given to the geographical incidence of both CG strokes and flashes; of interest for lightning protection purposes. Depending on the adopted settings to validate and locate CG discharges, a mean stroke and flash density over this 11-year period (/km^2/yr) in Belgium is found ranging from 0.74-1.8 and 0.48-0.99, respectively. The CC/CG flash ratio experiences a yearly variation with an average value of 1.94. Most of the lightning activity takes place during the summer months with a peak in the afternoon. In addition, for the year 2011, CG detections are correlated with outage reports of high-voltage transmission lines provided by the Belgian transmission system operator ELIA. Looking at outage reports having an allocated lightning cause, we detect in 74% of the cases lightning activity that could be the reason of the outage.**

Lightning detection, total lightning, lightning climatology

I. INTRODUCTION

Knowledge about certain lightning parameters, e.g., lightning incidence, number of strokes per flash (multiplicity), peak current, time span of continuing current, etc. are a necessity to build a properly working protection against (in)direct lightning strikes. A first step is to collect information concerning the amount of cloud-to-ground (CG) flashes in the area of interest. In the past, ground flash densities N_g were extracted based on the amount of observed thunderstorm days T_d. Various relationships have been published ever since [1] correlating N_g and T_d depending on, e.g., geographical regions, and are mostly of the following form:

$$N_g = a\, T_d^{\,b}\ (\mathrm{km}^{-2}\ \mathrm{yr}^{-1}), \quad (1)$$

with *a* and *b* variables. Nevertheless, not two thunderstorms are the same. Hence, the above N_g-T_d relation only provides an initial guess about the true amount of occurred CG flashes. Moreover, not only is the knowledge of flash densities of importance for lightning protection, but so are stroke densities as well. Hence, direct observations of lightning discharges are needed.

Lightning location systems (LLSs) have greatly advanced our knowledge on lightning with respect to the spatial and temporal occurrence of lightning all over the world. However, even though LLSs offer a big improvement compared to the N_g-T_d relation, one cannot blindly trust the observations. The performance of a network obviously depends on the position and type of sensors, sensor outages, the method to determine the ground strike locations, topographic effects, etc. Hence, a homogeneous detection efficiency over a large region is almost never reached. This should be kept in mind when using this info for lightning protection purposes.

In these research notes, we update the work of [2] in which the lightning severity over the period 2001-2005 in Belgium was discussed for the first time. We include data until 2011 and apply a more reliable method to calculate flash densities over Belgium than was presented in [2]. In addition, cloud-to-cloud (CC) activity is taken into account as well, resulting in a more complete picture of the total lightning activity over Belgium.

II. BELGIAN LIGHTNING DETECTION NETWORK

The Royal Meteorological Institute of Belgium (RMI) has been operating a SAFIR (Système d'Alèrte Foudre par Interférométrie Radioélectrique) lightning detection system since 1992. In the beginning, solely three antennas were connected to the central processor to observe electrical activity in thunderstorms. This was expanded with a fourth sensor in 1996. In 2000, the sensors were upgraded to the current SAFIR-3000 type. Thus, at present, the current operational SAFIR network consists out of four sensors placed in Dourbes, Oelegem, La Gileppe and Mourcourt, see Fig. 1. Within the current operational processor (OP) the localisation of lightning discharges is operated in the VHF band and uses solely the latter four sensors. An interferometric lightning location retrieval method for VHF signals is used to retrieve after triangulation the location of the sources. In addition, the sensors are equipped with an E-field antenna detecting the LF return stroke, allowing the discrimination between CC and CG electrical signals. Once a LF signal is detected, the CG stroke is assigned a location using the position of a time-correlated VHF signal.

Besides OP, RMI is running in parallel Vaisala's Total Lightning Processor (TLP) as a test processor (TP) since the beginning of 2010. TP in its turn uses a combination of time-of-arrival (TOA) with magnetic direction finding (MDF) to locate CG discharges. Note that not only does the method differ for locating CGs between OP and TP, but also the amount of sensors that can contribute to a valid solution. Besides the former four SAFIR sensors used by OP, TP receives data from an extra fifth SAFIR sensor positioned in Ukkel. In addition, TP shares data with Vaisala's demo-

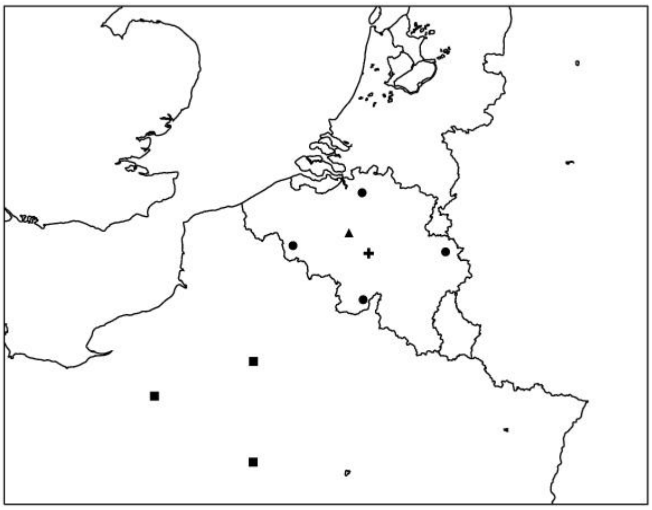

Figure 1. In addition to the four SAFIR sensors operated by OP (dots), TP uses data from an extra fifth SAFIR sensor (triangle), an LS7001 (cross) and three LS8000 sensors (squares).

network around Paris in cooperation with Météorage from 2011 onwards. This non-operational network provides TP with lightning data from three LS8000 [1] sensors in Evreux, Compiègne and Renardières. An extra LS7001[2] is placed in Ernage (Belgium) for study purposes, and was only operational from August 26th 2011 onwards, bringing the total available sensors to nine for TP. The sensor positions for TP are depicted in Fig. 1 as well.

III. DATA AND METHODOLOGY

Data over the period 2001-2011 are used for the analysis. During this time period no network changes for OP occurred. No comparison will be made here between OP and TP for 2010-2011 for following reason. Investigation of the performance of TP has shown that on a regular basis and throughout the day CGs are detected, even in fair-weather circumstances. To remove these, we make use of the angle and time information from the LS8000 and require that at least one angle information is needed to make a valid solution out of the raw data. These sensors are located around Paris, leading to a drop in the detection efficiency in the Northern part of Belgium. This is solved with the additional LS7001 in the center of Belgium, but was only operational at the end of August 2011. Thus, no valuable comparison can be made at the moment, but is planned for the future.

To have a valid CG detection, OP requires that a minimum of two sensors pick up electromagnetic radiation from the same discharge. However, with two sensors it is highly possible that a false detection is made out of surrounding noise. Hence, to exclude these we perform in addition calculations for which at least three sensors participate in a valid detection. In this way potential false detections are removed from the dataset. However, the downside is that an unknown proportion of the true CG discharges can be removed as well.

Following the methodology in [3] and [4], single point signals can be grouped according to their separation in time and space. It is found that flashes with multiple CG discharges have a temporal separation d*t* less than 1s and a spatial separation d*r* smaller than ~10km. Hence, signals with $dt > 1$s and/or $dr > 10$km originate from a different flash. Thus, an individual signal belongs to a certain flash if $dt < 1$s and $dr < 10$km. In addition, an interstroke criterion $dt_{interstroke} < 0.5$s is used as well. If at least one signal in a flash is of type CG, the entire flash is classified as a CG flash, else it is a CC flash. The location of the first CG stroke in a CG flash is used as the position of the flash.

IV. LIGHTNING ACTIVITY OVER BELGIUM

A. Cloud-to-ground detections

Fig. 2 depicts for each year the amount of detected CG strokes and flashes in case a valid detection is made out of a minimum of two sensors. A total of 603336 strokes were detected over the 11 year period that fall within the Belgian territory. The flash algorithm creates 331861 flashes leading to a mean multiplicity of 1.82. The CG stroke and flash densities for each year using a minimum of two or three sensors are presented in Table 1. We find a mean stroke and flash density ranging from 0.74-1.8 and 0.48-0.99/km^2/year, respectively.

A map depicting the mean flash density during 2001-2011 is plotted in Fig. 3 with a resolution of 4x4 km^2. Note that the values are divided by 16 to represent the mean values per km^2 per year. It is clearly seen that the CG flashes are inhomogeneous distributed over Belgium. One can wonder whether this reflects the true spatial occurrence of CG flashes over this period or is caused by an inhomogeneous detection efficiency of the network. It is seen that the largest densities are found within the domain of which the four SAFIR sensors are the vertices of an imaginary square. In addition, the area within

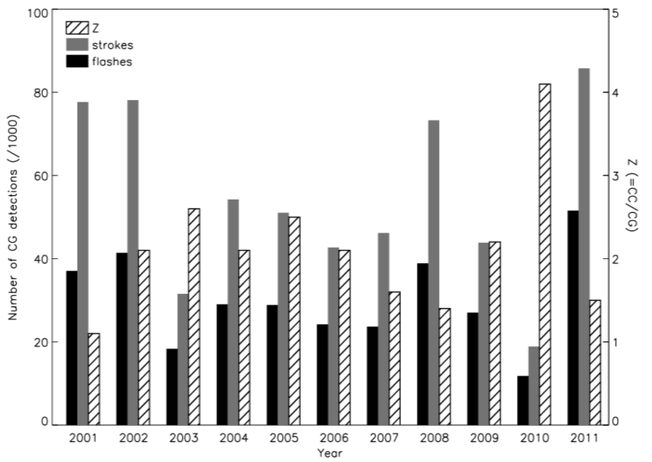

Figure 2. The amount of CG strokes (*grey*) and flashes (*black*) as detected by OP using a minimum of 2 sensors for a valid detection are plotted for each year. The ratio between CC flashes and CG flashes, *Z*, is plotted as well (//).

[1] Combines LF and VHF technology for the detection of total lightning.
[2] Employs LF combined MDF and TOA technology to detect CG discharges.

TABLE I. CLOUD-TO-GROUND DENSITY (/km^2)

	Flashes		Strokes	
Year	**2 sensors**[a]	**3 sensors**[b]	**2 sensors**	**3 sensors**
2001	1.27	0.72	2.54	1.23
2002	1.36	0.74	2.56	1.20
2003	0.60	0.29	1.03	0.43
2004	0.95	0.34	1.77	0.50
2005	0.94	0.45	1.67	0.68
2006	0.79	0.43	1.40	0.64
2007	0.77	0.43	1.51	0.69
2008	1.27	0.50	2.40	0.76
2009	0.88	0.36	1.44	0.50
2010	0.39	0.16	0.62	0.24
2011	1.69	0.84	2.81	1.24
2001-2011	0.99	0.48	1.80	0.74

[a]A minimum of 2 sensors participate in a valid detection.
[b]A minimum of 3 sensors participate in a valid detection.

a few tens of kilometers around the sensors clearly experiences a minimum in flash detections. A similar behavior is found as well when a minimum of 3 sensors is employed (not shown here) and suggests that some regions are favored to detect lightning compared to others. A possible explanation of this spatial variability is given in Section IV-B.

A ground-truth campaign was performed over Belgium during August 2011. For this, a GPS synchronized field measurement (FM) system was used consisting out of a flat plate electric field antenna, an integrator, a fiber optic link and a high-speed camera. In this way, the change of the electric field during lightning activity up to a few tens of kilometers away is recorded continuously. The camera takes 200 frames per second, enough to separate the individual strokes that exist in a multi-stroke flash. From this ground-truth campaign the detection efficiency (DE) has been determined based on the observation of 57 flashes and a total of 210 strokes. A stroke and flash DE for OP was found of 70% and 93%, respectively. In the assumption that we can apply these values over the entire 11-year period, a mean stroke and flash density that ranges from 1.1-2.5 and 0.52-1.06 (/km^2/year) is found, respectively. For more details on the operational and technical aspects of the FM system, we refer the interested reader to [5, 6]. An in-depth analysis of the ground-truth campaign is found in [7].

B. Cloud-to-cloud detections

In Fig. 4 we plot the average amount of CC signals per km^2 per year. In here, we opt not to present a CC flash density map as the horizontal extent of a CC flash can easily exceed a few tens of kilometers. It is clearly seen that some regions, and in particular around the sensors and along four of the base lines, experience a minimum in the amount of CC detections. A fixed parameter in OP excludes a sensor from participating in a solution when the detected signal is within 15 km. In addition,

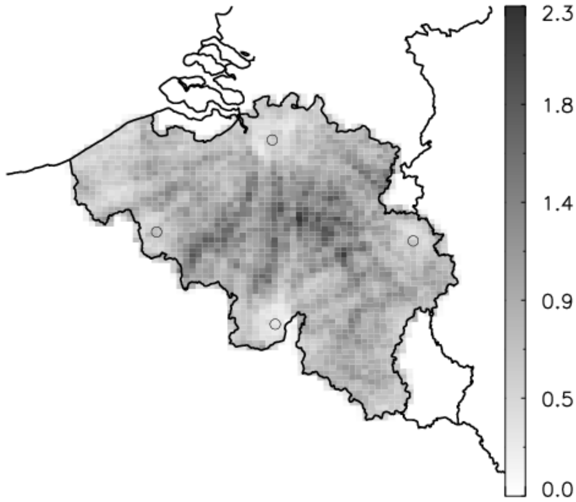

Figure 3. CG flash density (/km^2/yr) averaged over 2001-2011. The open circles depict the positions of the 4 SAFIR sensors operated by OP.

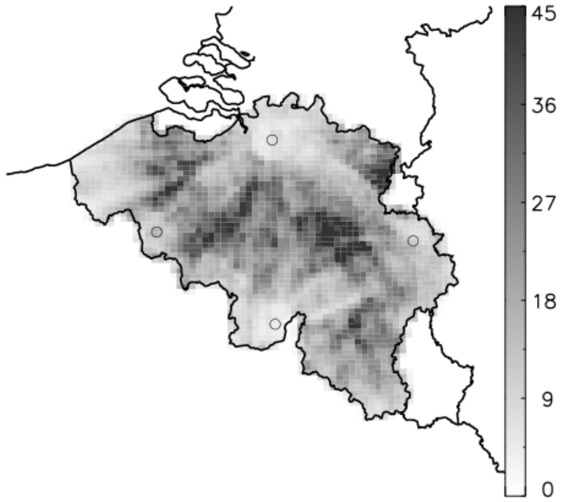

Figure 4. CC signal density (/km^2/yr) averaged over 2001-2011. The open circles depict the positions of the 4 SAFIR sensors operated by OP.

a pair of sensors participate in a solution only when the angle between their base line and the position of the discharge is larger then 15°. However, one could wonder why the remainder of the sensors do not contribute more in the latter areas to augment the CC signal density. A more in-depth analysis could shed light on this issue, but is probably due to a fast decreasing detection efficiency with distance at VHF frequencies. A similar behavior is found in Fig. 3 as mentioned in previous section. This is not surprising since a CG is assigned the position of a time-correlated CC signal.

A total of 644175 CC flashes have been detected during 2001-2011, leading to an average CC/CG flash ratio, *Z*, of 1.94 over Belgium. The distribution of Z as a function of year is depicted in Fig. 2, experiencing a minimum in 2001 (*Z*=1.1) and a maximum in 2010 (*Z*=4.1). The change of *Z* seems to be somewhat connected to the CG activity, with a higher *Z* related

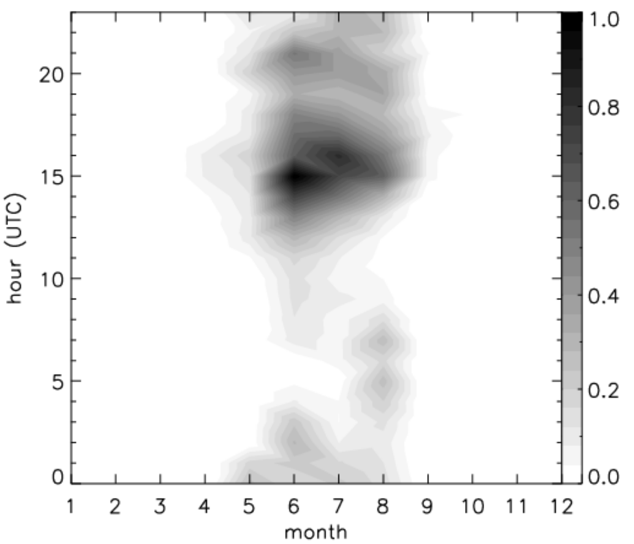

Figure 5. Intensity distribution of CG flashes as a function of month and time (UTC) averaged over 2001-2011.

to lower CG activity and vice versa lower *Z* values are related to higher CG activity. In addition, we obtain with the grouping algorithm that on average a CC flash consists out of 7 CC signals, whereas for every CG stroke 5 CC signals are detected within a given CG flash.

C. Annual variation

Fig. 2 shows an annual variability in amount of CG detections. This behavior is found as well when looking at the total lightning data (not shown here). 2010 clearly is the year with the least lightning activity, followed in 2011 with the largest amount of lightning detections. Annual variations are found as well in other parts of the globe. Hence, one could wonder what causes a sudden increase/decrease between subsequent years. The onset of thunderstorms has been studied by many authors in the past and various elements are found to impact the development of convective systems. One such factor is the convective available potential energy (CAPE); an indicator of atmospheric instability. Large values of CAPE imply that sufficient updraft velocities are available for the development of a thunderstorm. This in its turn leads to the necessary charge separation and subsequent occurrence of lightning discharges. An increase in lightning activity with CAPE has been demonstrated for instance by [8] and [9]. CAPE in its turn is controlled by the wet bulb temperature. A relation between lightning activity and surface wet bulb temperature was quantified for the first time in [10]. Some further investigation is needed to clarify whether during 2010 average CAPE values were rather low compared to 2011 to account for the observed discrepancies.

D. Seasonal and daily variation

The CG lightning activity as a function of month and time (UTC) is plotted in Fig. 5, averaged over 2001-2011. It clearly shows a seasonal dependence with lightning dominating during the summer months. On average 95% of annual lightning registrations are recorded between May and September with a lightning peak in June. Furthermore, above 70% of the activity takes place in the afternoon with a maximum between 15:00-16:00 UTC.

V. TRANSMISSION LINES

High-voltage transmission lines between 30kV and 380kV in Belgium are mainly operated by ELIA. These lines have lengths of up to a few tens of kilometers, making them vulnerable to direct lightning hits or flashover events. Outage reports were provided by ELIA for 2011. In addition to line number and voltage level, the time of electrical failure with a timing accuracy of about 1-2s and the cause of the disruption is provided for each outage. The latter one is either classified as coming from an unknown source or is meteorological related, i.e., caused by lightning. A total number of 204 outages were reported in 2011, of which 117 are lightning related.

We apply this to the CG detections of OP and TP. An outage report is correlated to a CG detection if the time difference between the time stamp of the outage and the CG detection is within 5s, and the distance between the position of the CG and a tower belonging to the line is within 5km. From this, we find that out of the 117 lightning related outages OP and TP find in 56 and 86 of the cases, respectively, a CG detection that meets the above criteria. Both OP and TP find two additional correlations between a CG detection and an outage report with unknown cause. The lower amount of matches found by OP can be explained by the lower location accuracy (LA) of the system compared to TP. From the ground-truth campaign in August 2011 [7] the location accuracy has been derived for OP and TP using those CG flashes in the camera's field of view whose strokes follow the same channel. As the lower part of the channel is unresolved, the derived LA values are upper limits. A LA of 6km and 1km is found for OP and TP, respectively, owing to the different methodology in locating LF sources.

VI. CONCLUSIONS

We have presented total lightning characteristics over Belgium. The data is based on the Belgian lightning detection network over an 11-year period spanning 2001 through 2011. The amount of detections varies over the years and no clear trend is noticeable. The spatial lightning distribution over Belgium is somewhat inhomogeneous. However, this inhomogeneity could be at least partly attributed to the positions of the various sensors favoring detections in the center of Belgium. The latter needs further investigation. A mean CG stroke and flash density is found ranging from 0.74-1.8/km^2/yr and 0.48-0.99/km^2/yr, respectively. The CC/CG flash ratio experiences a yearly variation with an average value of 1.94. Most of the lightning activity takes place during the summer months with a peak in the afternoon. In addition, CG detections of 2011 have been correlated to outage reports of high-voltage transmission lines as well. A lower amount of CG detections observed by OP overlap with an outage report than when TP detections are used. This is attributed to the known lower location accuracy of OP. Using TP, we find in 74% of the lightning related outage reports a CG that could be the cause of the electrical failure.

Acknowledgment

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References

[1] S. A. Prentice, "Frequency of lightning discharges," in Lightning, vol. I, Golde R. H., Academic Press, N. Y., 1977, pp. 465-496.

[2] C. Bouquegneau, P. Lecomte, and L. Remmerie, "First mapping of the lightning severity in Belgium," Proceedings of the 13th ICAE, Beijing, P.R. China, August 2007, vol. II, pages 702-705.

[3] C. Drüe, T. Hauf, U. Finke, S. Keyn, and O. Kreyer (2007), "Comparison of a SAFIR lightning detection network in northern Germany to the operational BLIDS network," J. Geophys. Res., 112, D18114, doi:10.1029/2006JD007680.

[4] C. Finke (1999), "Space-time correlations of lightning distributions," Mon. Weather Rev., 127, 1850-1861.

[5] W. Schulz, B. Lackenbauer, G. Diendorfer, and H. Pichler, "LLS data and correlated continuous field measurements," SIPDA, São Paulo, Brazil, 2005.

[6] W. Schulz, and M. Saba, "First results of correlated lightning video images and electric field measurements in Austria," SIPDA, Curitiba, Brazil, 2009.

[7] D. R. Poelman, W. Schulz, and C. Vergeiner, "Performance characteristics of three distinct lightning detection networks covering Belgium", ILDC conference, Boulder, USA, 2012.

[8] E. R. Williams, and N. Renno, "Conditional instability, tropical lightning, ionospheric potential and global change," 19th Conference on Hurricanes and Tropical Meteorology, Am. Meteorol. Soc., Miami, Fla, 1991.

[9] E. R. Williams, "Meteorological aspects of thunderstorms," in Handbook of Atmospheric Electrodynamics, edited by H. Volland, pp. 27-60, 1995.

[10] E. R. Jayaratne, and Y. Kuleshov (2006), "The relationship between lightning activity and surface wet bulb temperature," Meteorol. Atmos. Phys., 91, 17-24, doi:10.1007/s00703-004-0100-0.