8th 2013 Asia-Pacific International Conference on Lightning, Jun. 26-28, 2013, Seoul, Korea

Lightning Flash and Strike-point Density in Belgium

C. Bouquegneau[#*1], P. Lecomte[#2], F. Coquelet[#3], D. Poelman[*2], M. Crabbé[*3]

[#]*Faculty of Engineering, University of Mons*
Rue de Houdain 9, B-7000 Mons, Belgium
[1]*christian.bouquegneau@umons.ac.be*
[2]*pierre.lecomte@umons.ac.be*
[3]*frederic.coquelet@umons.ac.be*
[*]*Royal Meteorological Institute*
Avenue Circulaire 3, B-1180 Brussels, Belgium
[2]*dieter.poelman@meteo.be*
[3]*michel.crabbe@meteo.be*

Abstract— This paper presents a map of lightning flash density N_g and lightning strike-point density N_{sg} in Belgium, taking into account the measured values recorded by the Royal Meteorological Institute of Belgium, spanning 11 years (2001-2011). Due to the actual efficiency of lightning location systems (LLS) and the average number of strike-points per flash, it is assumed that N_{sg} equals twice N_g.

I. INTRODUCTION

The lightning flash density N_g ($km^{-2}.yr^{-1}$) is generally viewed as the primary descriptor of lightning incidence, at least in lightning protection studies and standards, such as the IEC 62305-2 international standard (Lightning Protection - Risk assessment, [5]).

The ground flash density has first been estimated from records of lightning flash counters (LFC) in several countries and, more recently, from records of lightning location systems (LLS) in many countries. It can also potentially be estimated from records of satellite-based optical or radio-frequency radiation detectors, but it is worth noting that satellite detectors cannot distinguish between cloud discharges (CC: intra-cloud and inter-cloud) and cloud-to-ground discharges (CG). Hence, in order to obtain N_g maps from satellite observations, a spatial distribution of the fraction of discharges to ground relative to the total number of discharges is needed.

The evaluation of the ground flash density N_g is not straightforward, though it is a crucial parameter related to the risk calculations [1, 5]. This is due to several reasons: detection efficiency, location accuracy, misclassified events, flash/stroke misclassification, peak values of some subsequent strokes greater than peak values of first strokes, and last but not least number of channels per flash (number of ground strike-points, contacts or terminations).

For standardization purposes and safety reasons, it is a necessity to accurately evaluate the number of lightning strike-points for a geographical point at interest where a structure has to be protected against lightning.

This paper proposes a new map of lightning ground flash density N_g and lightning ground strike-points density N_{sg} in Belgium.

II. KERAUNIC LEVEL AND LIGHTNING GROUND FLASH DENSITY

The number of thunderstorm days per year (T_d, in yr^{-1}), or keraunic level, is the average number of days per year when thunder can be heard [1]. However, this is not a valuable parameter. Indeed, in temperate regions, a frontal thunderstorm can go away after some minutes or can stay during several hours in full activity. Sometimes thunder can be heard at unusual large distances, say, 40 km or even more, giving a strongly exaggerated impression of the lightning activity [2].

There are many factors influencing lightning incidence. The following parameters are important to consider: topographical factors (soil humidity, thunderstorm corridors favoured by airstreams in valleys, lightning strikes on hillsides instead of mountaintops, etc.), geological and orohydrographical factors (faults, crevices, cracks, water layers, etc.). These and other factors can be responsible for the observed inhomogeneity of the spatial distribution of lightning ground flash density [3].

If no direct measurements of the ground flash density N_g for the area in question are available, T_d is used. Apparently the most reliable expression relating N_g and T_d is the one proposed by Anderson et al. [4]:

$$N_g = 0.04\ (T_d)^{1.25} \tag{1}$$

This expression is based on the regression equation relating the logarithm of the five-year-average value of N_g measured with CIGRE 10 kHz lightning flash counters at 62 locations in South Africa and the logarithm of the value of T_d as reported by the corresponding weather stations.

The observed variation in ground flash density from one region to another in many countries is more than two orders of magnitude. Many flashes strike ground at more than one point. However, most measurements of lightning flash density do not account for multiple channel terminations on ground. When only one location per flash is recorded, while some or all strike-points in a flash are separated by distances of some hundreds of meters or more, measured values of ground flash density should, in general, be increased [3].

III. GROUND FLASH DENSITY AND GROUND SRIKE-POINT DENSITY FOR LIGHTNING PROTECTION STANDARDS

In the risk calculation, Lightning Protection Standards require the assessment of the annual number N of dangerous events [2]. This number depends on the thunderstorm activity in the region where the structure to be protected is located and on the physical characteristics of the structure.

To calculate N, one should multiply the lightning ground flash density N_g by an equivalent collection area of the structure, taking into account correction factors for the physical characteristics of the structure.

In countries where no LLS are installed, no map of N_g is available. In this case, lightning protection national standards generally propose an empirical formula relating the lightning flash density N_g to the keraunic level T_d; in temperate regions N_g can be estimated by

$$N_g = 0.1\ T_d \tag{2}$$

The value of the ground flash density N_g ($km^{-2}.yr^{-1}$) should be available from LLS observations. However, ground-based networks are not yet accurate enough, notwithstanding the proclaimed detection efficiency (DE) as high as 98% by the commercial providers. Taking into account various factors such as the location accuracy (LA) and misclassification of events, the actual DE is at best between 70% and 80%. Moreover discharges with low peak currents (less than 5 kA) are hardly recorded and we mentioned that most measurements of lightning flash density do not account for multiple channel terminations on ground. Indeed, almost one-half of all lightning discharges to ground, both in single- and multiple stroke flashes, are observed to strike ground at more than one point with a spatial separation between the multiple terminations of individual cloud-to-ground flashes or strokes ranging from some tens of meters to 8 km [3]. The number of channels per flash (number of ground contacts or ground terminations related to multiple channel terminations on ground) is not taken into account, though the average number of ground contacts is between 1.5 and 1.7 [6]. Before obtaining more accurate results, it is practical to estimate the ground strike-point density N_{sg} by multiplying the ground flash density by a correction factor of 1.5 to 1.7 [7].

We should include such distinctions in the concept of "risk estimation" (better than "risk calculation"). In Germany and in the Belgian standards [1], it was decided to include these physical events by multiplying N_g values (obtained from LLS measurements) by a factor of 2 for usual situations (flat grounds where the "effective height" could be considered as equal to the "geometrical height"; structures lower than 60 m).

The accuracy of N_g mapping is better if the number of events per grid cell increases. It is recommended that this number be at least 80 [8] or 400 [9]. A grid cell size should then be defined (example: 2 km x 2 km) to contain a sufficient number of events. The accuracy of N_g mapping then depends on the grid cell size selected and the period of observations [8].

In a lightning protection standard, what is important is not the ground flash density itself, but the ground strike-point density that we call N_{sg}.

The choice of a specific value of N_{sg} related to the risk estimation of a given building or structure, applicable to the international and national lightning protection standards, is defined through the following rule [1]: **choose the estimated maximum value of N_g on the ground flash density map of the region at interest (on the condition that these values were confirmed during a period covering at least the last 10 years) in a circular area of 10 km radius around the building or structure and, when estimating the lightning risk assessment, multiply this number by a factor of 2:**

$$N_{sg} = 2\ N_g. \tag{3}$$

IV. THE BELGIAN LIGHTNING DETECTION NETWORK AND NG VALUES OVER THE PERIOD 2001-2011

Lightning location systems have greatly advanced our knowledge on lightning with respect to the spatial and temporal occurrence of lightning all over the world.

However, even though LLS offer a big improvement compared to the N_g-T_d, see equations (1) and (2), one cannot blindly trust the observations [10, 11]. The performance of a network depends on the position and type of sensors, the applied method to determine the ground strike-points density.

Hence, a homogeneous detection efficiency over a large region is almost never reached. This should be kept in mind when using this information for lightning protection purposes. As a first approach [12], we estimated the lightning severity in Belgium over the period 2001-2005. We then applied a more reliable method over the period 2001-2011 [10].

The Royal Meteorological Institute of Belgium (RMI) has been operating a SAFIR (Système d'Alerte Foudre par Interférométrie Radioélectrique) lightning detection system since 1992. In the beginning, solely three antennas were connected to a 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 SAFIR network consists out of four sensors placed in Dourbes, Oelegem, La Gileppe and Mourcourt, see Fig. 1 [10].

Within the SAFIR network, 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 high-current LF return stroke, allowing the discrimination between CC (cloud-to-cloud) and CG (cloud to ground) electrical discharges. Once an LF signal is detected, the CG stroke is assigned a location using the position of a time-correlated VHF signal.

Fig. 1 Positions of the SAFIR sensors (dots) in Belgium.

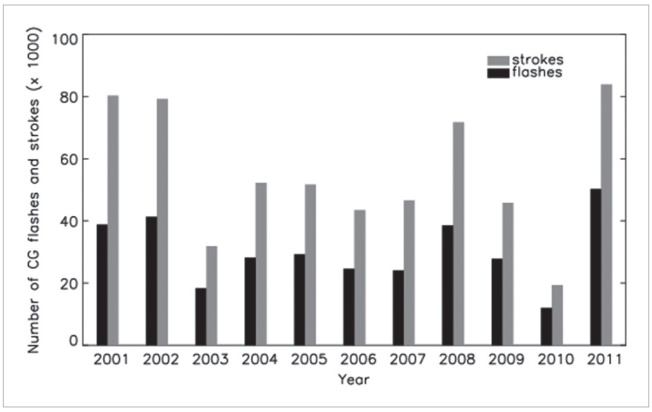

Fig. 2 The amount of strokes (*grey*) and flashes (*black*) as detected by the SAFIR network using a minimum of 2 sensors for a valid detection.

Fig. 2 [10] 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 606134 strokes were detected over the 11-year period that fall within the Belgian territory. The flash algorithm creates 333047 flashes, leading to a mean multiplicity of 1.82.

A map depicting the mean flash density during 2001-2011 is plotted in Fig. 3 [10] with a resolution of 4 km x 4 km. It is clearly seen that the distribution of CG flashes is inhomogeneous. One can wonder whether this reflects the true spatial occurrence of CG flashes during this period, or whether it is caused by an inhomogeneous detection efficiency of the network.

A more in-depth analysis is necessary to answer this question. Nevertheless, it is seen that the largest densities are found over the domain of which the four sensors are the vertices of the square. In addition, the area within a few tens of kilometers around the sensors clearly experience a minimum amount of flash detections. A similar behavior is found as well when a minimum of 3 sensors is used, and suggests that some regions are favored to detect lightning compared to others.

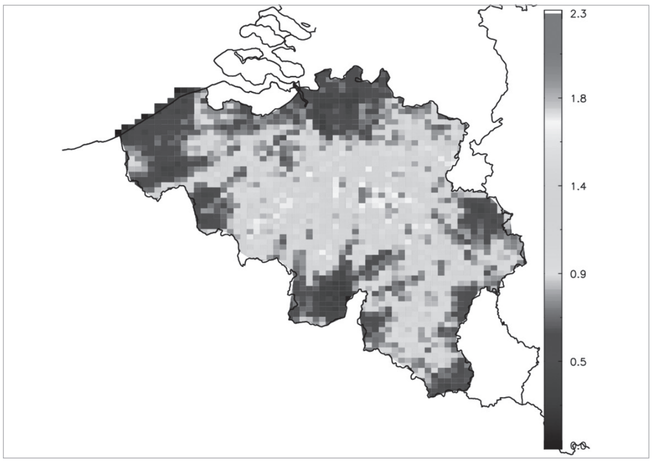

Fig. 3 CG flash density averaged over the period 2001-2011.

The CG distribution over Belgium is inhomogeneous. However, this inhomogeneity could be attributed to the sensor positions, favoring detections in the center of Belgium. This needs further investigation.

A mean stroke/flash density is found ranging from 0.74-1.8 km^{-2}.yr^{-1} and 0.48-0.99 km^{-2}.yr^{-1} respectively, depending on the minimum required sensors used. 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.

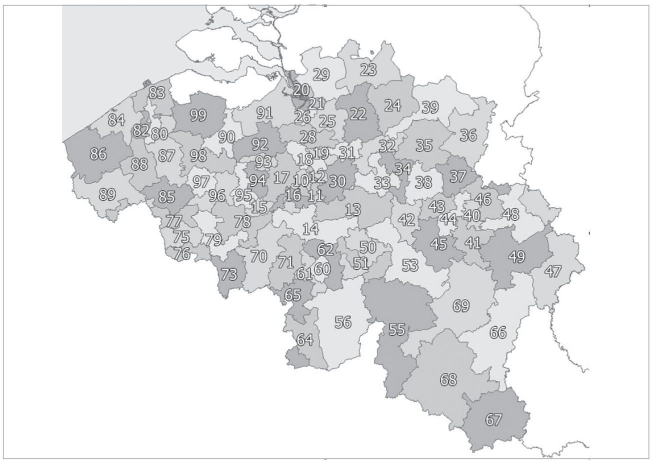

Fig. 4 Map of the first 2-digit postal codes in Belgium (Copyright: GfK Geomarketing).

V. THE BELGIAN LIGHTNING GROUND FLASH DENSITY AND LIGHTNING GROUND STRIKE-POINT DENSITY

Taking into account the important rule mentioned at the end of section III, and leading to formula (3), how can we help the "risk assessment" designer to introduce the correct value of N_{sg}, instead of N_g, at a point on the Belgian map where a building or any other structure is to be protected against lightning?

The map of Belgium (see Fig. 4) can be divided in 2761 *communes* (cities or country villages) referred to a specific postal code. Superimposing maps of figures 3 and 4, it is then possible to attach a specific value of the ground flash density N_g (km^{-2}.yr^{-1}) to each *commune*. Thanks to an

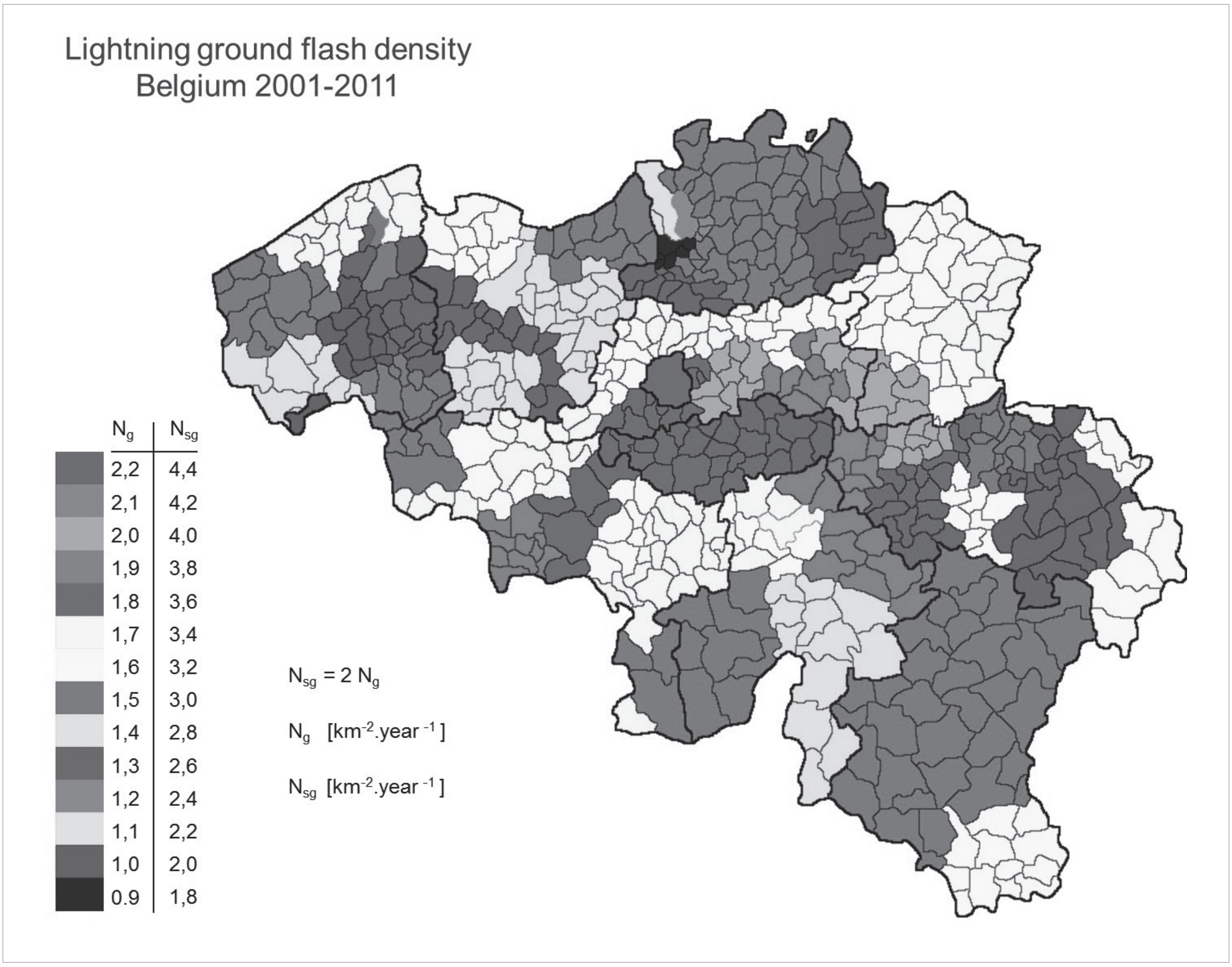

Fig. 5 Lightning ground flash density N_g and lightning ground strike-point density N_{sg} to be considered in Belgium.

appropriate software, the maximum value of N_g is computed in a circular area of 10 km radius centered at the centre of each *commune*. It is easy to classify these results in groups of tenths of flashes per km^2 per year (example: from 1.6 to 1.7 for N_g) and attribute a specific colour to each group. The corresponding intervals for N_{sg} are two tenths of flashes per km^2 per year and the same colour is attributed to this value (from 3.2 to 3.4 for N_{sg} in our example).

The complete resulting useful map for Belgium is shown in Fig. 5.

VI. CONCLUSION

The evaluation of the lightning ground flash density (N_g) and the lightning ground strike-point density N_{sg} is of crucial importance to the risk calculations especially in the Lightning Protection Standards [5]. Data from LLS are not yet accurate enough; moreover there is sometimes some confusion between stroke density, flash density and ground strike-point density.

Awaiting better detection efficiencies and better location accuracies of LLS, taking into account unknown or non-precise lightning parameters, and wishing to stay at the safe side, we multiply the recorded ground flash density (obtained from LLS) by a factor of 2 in the lightning protection standards. Focusing on the lightning risk assessment, N_g is replaced by N_{sg}.

In this paper, we have presented such a map (N_g, and N_{sg}) to be used in Belgium.

ACKNOWLEDGMENTS

The authors want to express their deep gratefulness to the RMI (Royal Meteorological Institute of Belgium).

REFERENCES

[1] C. Bouquegneau, A. Kern, A. Rousseau, *Flash density applied to lightning protection standards*, Proc. Ground'2012 & 5th LPE, Bonito, Brazil, November 2012, paper P19, pp. 91-95.

[2] C. Bouquegneau, V. Rakov, *How dangerous is lightning?*, Dover Publications, N.Y., 2010.

[3] V. Rakov et al., Lightning Parameters for Engineering Applications, Report of CIGRE C4.407, to be published in Electra, 2013.

[4] R. Anderson et al., Lightning and Thunderstorm Parameters, in Lightning and Power Systems, London, IEE Conf. Publ. n° 236, 1984.

[5] *Lightning Protection – Risk Assessment*, IEC Std 62305-2, ed.2:2010.

[6] Rakov V. and Uman M., Lightning – Physics and effects, Cambridge University Press, 2003.

[7] Diendorfer G. et al., Cloud-to-Ground *Lightning Parameters Derived from Lightning Location Systems – The Effect of System Performance*, CIGRE Report 376 (WG C4.404), April 2009, 119 pages; a summary of the report was presented at CIGRE SC C4, Kushiro Colloquium, 2009.

[8] Diendorfer G., *Some Comments on the achievable Accuracy of Local Ground Flash Density Values*, Proc. of the 29th ICLP, Uppsala, Sweden, paper 2-8, 2008.

[9] IEEE *Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines*, IEEE, 21 January 2011.

[10] D. Poelman, L. Delobbe, M. Crabbé, C. Bouquegneau, *Lightning Activity over Belgium during 2001-2011*, Proc. 31st ICLP, Vienna, Austria, 2-7 September 2012, paper 30, 5 pages.

[11] D. Poelman, W. Schulz, C. Vergeiner, *Performance Characteristics of three distinct Lightning Detection Networks covering Belgium*, ILDC Conference, 2012, Boulder (Colorado), USA.

[12] C. Bouquegneau, P. Lecomte, L. Remmerie, *First Mapping of the Lightning Severity in Belgium*, Proc. of the 13th ICAE, Beijing, P.R. China, August 2007, vol. II, pp. 702-705.