Comparison of radar precipitation fields with lightning observations

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1 Introduction

Lightning activity and convective precipitation are two related characteristics of thunderstorms, and their relationship can be used as a quantitative indicator of the rainfall regime. Besides, a better knowledge of local thunderstorm phenomenology is useful to assess weather surveillance tasks.

The objective of this paper is to analyze the relationship between precipitation and lightning in the North Western Mediterranean coast, in order to improve the knowledge of thunderstorms.

2 Background

Two approaches can be distinguished in the study of the relationship between convective precipitation and lightning. While some authors have calculated rain yields for long temporal and spatial domains (Petersen and Rutledge 1998; Rivas Soriano et al., 2001), others have focused on thunderstorm case studies (Sheridan et al. 1997, Tapia et al. 1998, Carey and Rutledge 1998, Soula and Chauzy, 2001; Seity et al., 2001), calculating a rainfall-lightning ratio, with the aim to report a correlation between convective precipitation and lightning. The present study is a case-by-case study, using daily rainfall accumulations and total lightning information (intra-cloud and cloud-to-ground flashes).

The Rainfall-Lightning ratio (RLR) is the usual parameter for the estimation of the convective rainfall volume per cloud-to-ground (CG) lightning flash. Intense storms tend to produce lower RLR values than moderate storms, even if the RLR depends on the thunderstorm type and local climatology (Williams et al., 1989; Tapia et al., 1998; Seity et al., 2001). According to a summary table for thunderstorms in various regions in Kempf and Krider (2003), the RLR in isolated thunderstorms take precipitation values between 38 and 72 $10^3 m^3$ per CG flash. Moreover, the RLR could be used to estimate precipitation and to aid in the short-term prediction of flash-floods in areas with poor radar coverage (Tapia et al. 1998).

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3 Data sources

The studied data are composed of lightning observations, and radar products from the Servei Meteorològic de Catalunya (SMC). The region of interest covers approximately an area of 53000 km^2 in Catalonia (NE Spain) and the Mediterranean Sea (Fig.1).

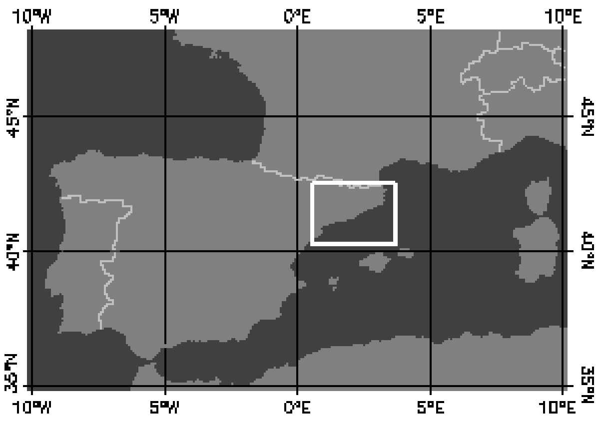

Fig. 1. Region of interest in the NE Spain.

3.1 Lightning data

Lightning information was collected by the Meteocat SAFIR lightning detection network (hereafter XDDE). The network is composed by three sensors, covering the region of Catalonia, and its contiguous sea. The SAFIR system (Richard and Lojou, 1996) uses interferometric technique to detect intra-cloud (IC) discharges in the VHF range (108-116 MHz). The system is completed with a LF antenna which detects all return strokes of CG flashes. The thunderstorm activity can therefore be observed by counting both types of flashes, and by considering the rate of individual sources. The XDDE spatial accuracy is around 2-3 kilometres, and its efficiency around the 90% (Montanya et al., 2006).

In the studied region thunderstorms may take place the whole year, but the thunderstorm season starts at the end of May and lasts until the end of October, and even to middle November. According to a preliminary analysis of the whole 2005 lightning data (Pineda, 2006), the thunderstorm distribution had its maximum in August (31% of the CG of the year), followed by September (27%) and June (18%). The spatial distribution of the thunderstorms pattern change as the season goes on. In June a 97% of the CG flashes were inland. In August, still the 80% of CGs were inland, while in September thunderstorms begin to move to coastal regions. In October, thunderstorms where mainly offshore, with only 20% of CG flashes inland. November was particularly active in 2005, with the 6% of the annual CG flashes (73% of them offshore).

For this study, the 40 days with more lightning during 2005 over the study region were selected. After a detailed analysis, 6 days were rejected due to problems in the quality of the data, being the final sample composed of 34 days. These 34 days contains more of the 75% of the CG flashes registered in 2005 over the study region. The final sample included days of May (3 days), June (8), July (4), August (11), September (5) and October (3).

3.2 Radar data

The weather radar network of the SMC is made up of three C-band Doppler radar systems (Table 1) operating in a highly complex topography environment. Technical details of the network can be found in Bech *et al.*, (2004).

Table 1. Current SMC weather radars

Radar	**Longitude (ºE)**	**Latitude (ºN)**	**Altitude (m)**
Puig Bernat (PBE)	1.88	41.37	610
Puig d'Arques (PDA)	2.99	41.89	535
Creu del Vent (CDV)	1.40	41.60	825

The radar quantitative precipitation estimates (QPE) used in this study were originated from a volumetric short range mode scan (130 km for PBE and PDA radars and 150 km for CDV) updated every six minutes. A composite product was built by selecting the most intense reflectivity (Z) value available for each pixel.

4 Radar and Lightning data processing

Total lightning data is composed of IC and CG flashes. The lightning network configuration considers a IC flash sample duration of 100 µs with an associated radius of 7 km. For the CG flashes, the multiplicity delay is 0.5 seconds, while the multiplicity radius is also 7 km.

Hourly precipitation estimations are obtained through previous conversion of rainfall rate (R) from Z using the standard power-law Marshall and Palmer (1948) Z-R relationship. Daily amounts of precipitation are obtained from the hourly QPE.

The computation of the daily amount of precipitation and lightning activity has been done as follows. Firstly, the region of interest has been divided in cells using a regular mesh of 0.1 degrees, which in the present latitude correspond to approximately 91 km^2 (Fig.2). Then the average of precipitation and the number of IC, total CG and positive CG flashes has been calculated for each cell.

(a)

(b)

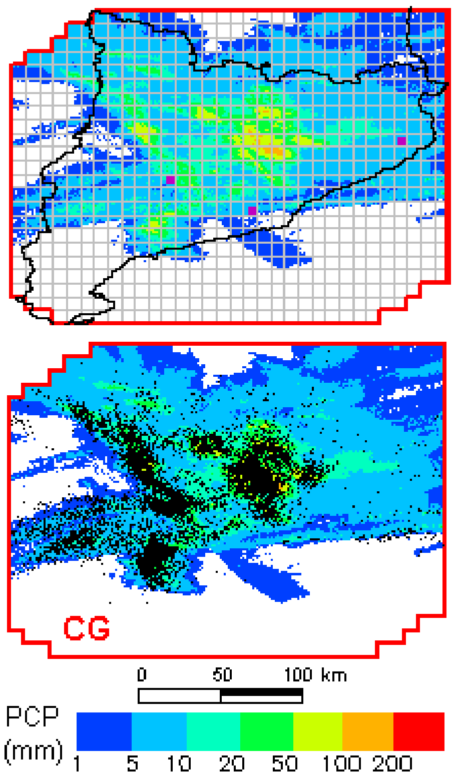

Fig. 2. (a) Region of interest with the 0.1 degrees mesh. Cumulative rainfall (August 18th) with Catalonia contours in black and radar locations in purple; (b) Cumulative rainfall (August 18th) and total CG flashes (black dots).

Afterwards, different thresholds have been used to consider only the convective cells for each day. A lightning threshold was fixed to a minimum of one CG per cell, while four thresholds of precipitation were used: 1, 2, 5 and 10 mm (hereafter T1,T2,T5 and T10). Once the cells were labeled, the daily amounts of precipitation and lightning were computed for the convective area of the region of interest.

Regarding lightning data, a correction has been done to data, taking into account a XDDE efficiency of the 90% (Montanya et al., 2006). Such correction is necessary to facilitate the lightning-precipitation results comparison with prior literature (i.e. Kempf and Krider, 2003). Finally, the Rainfall Lightning Ratio was computed on a daily basis.

5 Results and discussion

The results found applying the 4 different thresholds for the selection of the convective cells are shown in Table 2. It can be observed that the elimination in the computation of the cells with a daily rainfall average of less than 2 mm reduces the convective cells in a 17%, while the reduction of CG flashes is only of the 6%, and the rainfall volume is only reduced in a 4%. When applying a threshold of 5 mm, convective cells were reduced in more than a half from original ones. However, these cells contains the 70% of the total registered CG flashes. The reduction in rainfall volume is less important compared to lightning, and this difference has the effect of raising the mean daily rainfall volume per CG flash (RLR). This difference in the percents can also indicate that the lightning activity area is not restricted to the highest rainfall areas, but spreads to zones with lower rainfall accumulations. When considering as convective only the cells with a daily rainfall average of more than 10 mm, the total convective area is reduced to only an 18% of the original area. This threshold seems too restrictive in order to account the convective rainfall area.

Table 2. Lightning and precipitation parameters (34 days totals) for the 4 thresholds proposed to identify convective rainfall. Percent under values indicate the convective cells selected (compared to T1) after applying the different thresholds.

Thresh.	Convective Cells	CG flashes	Total Rainfall Volume (10^9 m^3)	Mean Daily RLR (10^3m^3 CG^{-1})
T1	7010	85451	4095.43	56.2
T2	5849 (83%)	80169 (94%)	3938.43 (96%)	58.9
T5	3294 (47%)	59879 (70%)	3154.55 (77%)	67.0
T10	1250 (18%)	33470 (40%)	1832.25 (45%)	61.8

The Rainfall Lightning Ratio found in the studied region, (processing 34 days with T2), has a mean value of 58.9 10^3m^3 per flash. The daily range of variation is quite wide, as it goes from 18.2 to 168.8 10^3m^3 per flash (Fig.3). Monthly RLR mean values are the following: 139.7 10^3m^3 per flash for May, 50.0 for June, 38.2 for July, 41.4 for August, 55.5 for September and 99.0 for October.

These results agree in magnitude with other case studies (see summary in Kempf and Krider, 2003). The mean value for the whole studied period is close to the ones found by Soula and Chauzy (2001) and Seity et al., (2001) in France. Meanwhile, if we consider the months of July or August, mean values are more similar to the 43 10^3m^3 found in Florida (Tapia et al., 1998) or the 38 10^3m^3 for the Southeastern United States (Buechler et al, 1990).

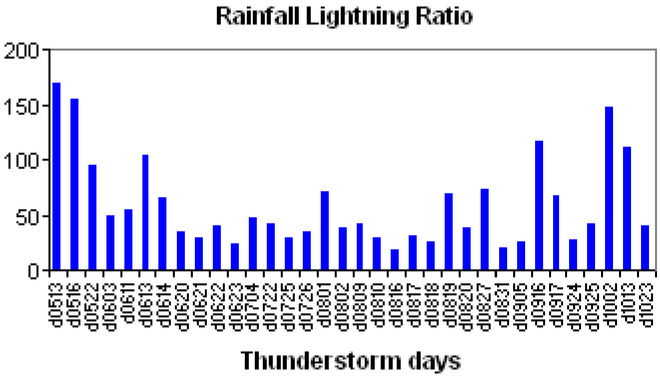

Fig. 3. Rainfall Lightning Ratio (10^3m^3 CG^{-1}) for the studied days.

The daily rainfall volume has been compared with different types of lightning available. Table 3 summarizes the correlations for a linear fitting between rainfall volume (with different thresholds) and types of lightning. Figure 4 shows, as an example, the daily rain volume versus the daily counts of CG flashes, after processing with T2.

Table 3. Coefficients of correlation (R^2) for a linear fitting between rainfall volume (with different thresholds) and lightning (intra-cloud, cloud-to-ground, positive CG and total flashes).

Thresh	IC	CG	CG+	IC+CG
T1	0.666	0.672	0.466	0.673
T2	0.626	0.677	0.466	0.684
T5	0.675	0.699	0.464	0.728
T10	0.781	0.750	0.539	0.779

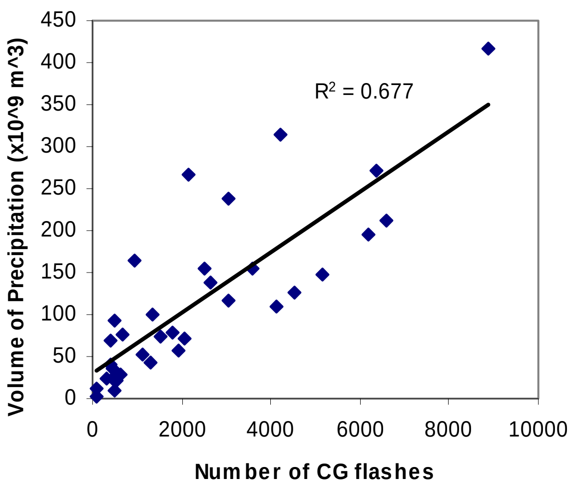

Fig. 4. Daily rain volume (T2) vs. daily counts of CG flashes.

From the overall correlation coefficients presented in Table 3, in most of the cases the R^2 is higher as more restrictive is the threshold to select the convective area. Looking to the different types of lightning, the best fitting were obtained with total lightning (IC+CG), followed by the IC flashes.

6 Summary and future work

This study analyzes the relationship between lightning and precipitation in 34 thunderstorms days of the 2005 season in Catalonia (NE Spain) and its coastal area, in the NW Mediterranean Sea. Data examined includes C-band volumetric radar observations and total lightning, including both cloud-to-ground and intra-cloud flashes. In the selected days, a total of more than 85000 CG flashes were observed (70% of the total registered CG flashes in 2005 in the study region).

The Rainfall Lightning Ratio found in the studied region has a mean value of 58.9 $10^3 m^3$ per flash. These results agree in magnitude with other case studies in other regions. The daily rainfall volume has been compared with different types of lightning available, being the best fitting with total lightning (IC+CG), followed by IC flashes, CG flashes and positive CG flashes.

Soula and. Chauzy (2001) and Seity et al. (2001) have found good correlations between the rainfall volume and the percent of positive CG flashes. In this study this correlations are not the best ones. As indicated by many authors, positive CG with low peak currents (under 10 kA) detected by DF sensors (as in the XDDE) can be misidentified as intra-cloud lightning flashes (Cummins et al., 1998; Orville and Huffines, 2001; Carey et al., 2003). In order to obtain better correlations, a filter of this kind can be test on the XDDE.

From this analysis, it is clear that lightning data can be useful for estimating the locations and amounts of convective rainfall, when only lightning data is available. Meanwhile, rainwater volume per CG flash can vary much more from one day to another, and the RLR depends on factors like the season of the year, or the convective regime or the storm intensity. A good identification of the convective area of the storm will help to reduce such variability. In this sense, rainfall intensities could be calculated in the hourly rainfall estimations, and use such information afterwards to delimitate the convective areas in the daily accumulations, more than using a daily volume threshold, which is mixing convective and stratiform rainfall.

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