The advantages of using intra-cloud data for severe weather warnings

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Abstract
After a period of testing, the Meteorological Service of Catalonia (***SMC***) put in pre-operational mode on 2016 an algorithm for nowcasting severe weather (here defined as hail of size over 2 cm., strong winds associated with convection, downbursts, and/or tornadoes), based on sudden rise of total lightning (***TL***) rate in thunderstorms. The algorithm, called lightning jump (***LJ***), was adapted and modified from different works made in the USA (Schultz et al, 2009; Williams et al., 1999; Darden et al., 2010; Gatlin and Goodman, 2008). The main differences are centred in the use exclusively of lightning data, instead of the combination with other remote sensing data (radar or satellite imagery). Farnell et al. (2017) shown that in the case of severe weather, lightning activity is quite intense for being detected during a large period (more than 20 minutes). In fact, this is one of the principles of the algorithm: the maintenance of a large lightning rate per minute for more than 14 minutes. The second key parameter is a sudden increase of this activity, which, in fact, is the LJ itself. The exclusive use of the electrical activity registers allows to refresh the algorithm warning more frequently (each minute, instead of the 6 minutes for radar imagery, or 15 minutes for the satellite data), and in near real-time: the warning is triggered only one minute after the occurrence of the LJ. This fact results fundamental at the time of generate alerts to population.
The Meteorological Service of Catalonia manages one of the few lightning location systems (***LLS***) in Europe that detects cloud-to-ground (***CG***), but also intra-cloud (***IC***) flashes in practically all the totality. This fact results providential at the time of running the algorithm, because of the influence of the IC in the total lightning activity. The present work shows the differences in the results of the algorithm, in the different LLS configurations: identifying only CG; detecting some IC; and with a whole detection of total flashes. The analysis has been made for several events of severe weather in Catalonia (NE of the Iberian Peninsula) for the period 2006-2013.

PRELIMINARIES

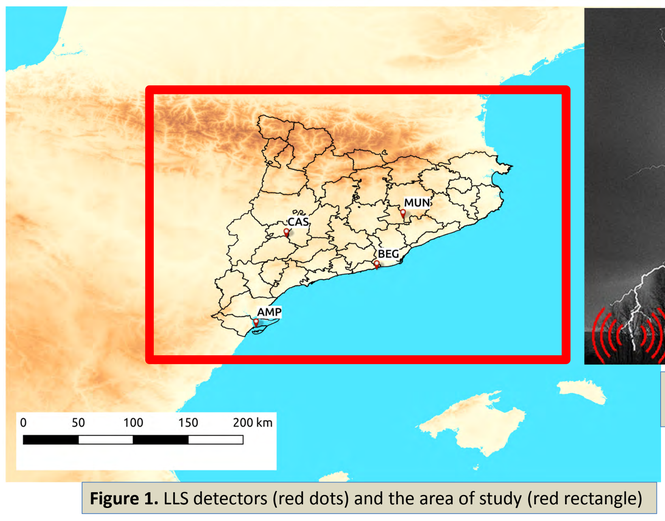


Figure 1. LLS detectors (red dots) and the area of study (red rectangle)

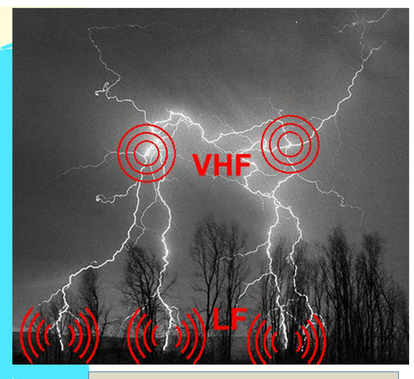


Figure 2. VHF helps IC detection. CG detection is made by means of LF.

Lightning detection and allocation

The LLS of the SMC detects and allocates the **IC and CG flashes** (fig. 1), using **different frequencies and techniques** (fig. 2, Farnell et al., 2017).

The path of the IC flashes is not well detected as using a LMA (Lightning Map Array, van der Velde et al, 2012), but it allows to track partially their trajectories (fig. 3).

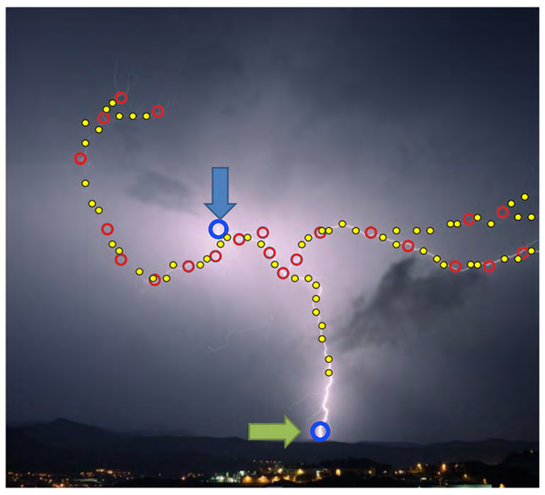


Figure 3. The path of IC tracked by a system like the LLS of the SMC (red dots). The yellow dots show the path identified by a LMA. Blue dots indicate the unique identification of IC (blue arrow) in most of LLS systems and CG allocation (green arrow)

The Lightning Jump phenomenon

LJ is a sudden increase of the total lightning (IC plus CG flashes) activity.
It is **associated with strong updrafts**, this is, «powerful» charge separation (Williams 2001).
Its detection (fig. 4) is **used as a predictor of severe weather** (Hail > 2 cm, downbursts, strong wind gusts, and tornadoes/waterspouts)
The tool used in the SMC is an adaptation of the Schultz et al. (2011), but using exclusively flashes (instead of radar and lightning data), and takes profit of the capabilities of the LLS.

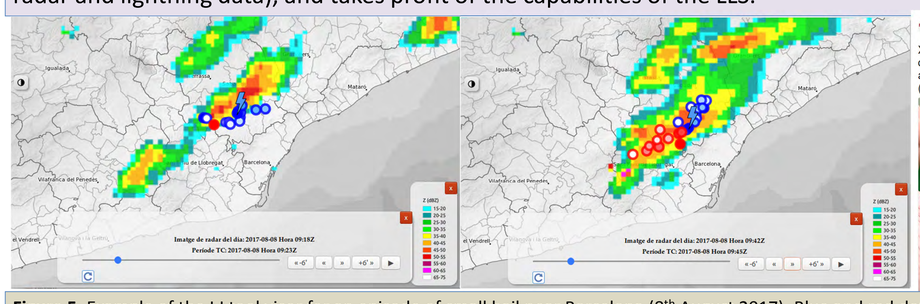
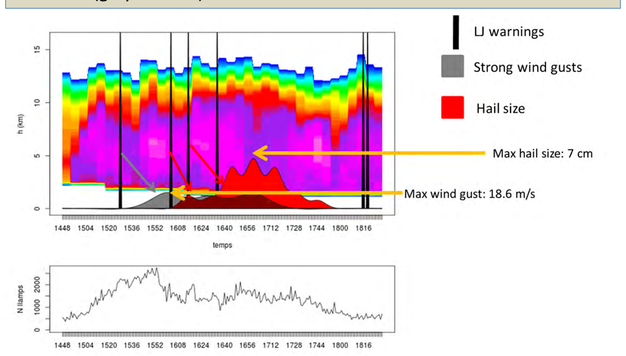


Figure 5. Example of the LJ tool visor for an episode of small hail near Barcelona (8th August 2017). Blue and red dots are associated with the centroids of the cell (only using lightning) detected minutely. Red points are associated with "no multiplicity" and blue ones show "multiplicity" centroids. Blue flashes indicate the LJ warning. Radar chart is placed under the lightning activity, in order of provide further information to forecaster. Right picture shows the verification of the warnings.

Figure 4. Example of a severe thunderstorm observed on 5th July 2012. Vertical cross section of the cell from the point of view of radar (top) and total lightning flash rate evolution (bottom). Vertical black lines indicate the time of the LJ warnings. The arrows indicate the time of the maximum hail and wind gust (yellow) and the relationship between the phenomena and the alerts (grey and red)



The Lightning Jump tool at the SMC

The LJ at the SMC detects cells minutely considering multiplicity (this is all the red points of a IC flash in fig. 3), or level 1 alert, and non-multiplicity (only the blue dot with the blue arrow in fig. 3), associated with a level 2. These two behaviours are observed in fig. 5: the larger number of blue dots than red ones is because multiplicity allows a better detection of the cell. Then the number of TL varies depending on the version of the algorithm.
The analysis of the alerts has allowed to know that:

- **Level 1 are associated with small hail and large rain rates** (moderate updrafts can provide the increase of the TL)
- **Level 2 produces severe weather** (largest updrafts produce enough IC flashes for the increment of the TL with non-multiplicity)

In any case, the IC have revealed as fundamental for the triggering of the alerts.
We wonder if: **is it possible to use the tool only with CG flashes?**

ARE CG ENOUGH?

The Experiment

The LJ tool has run off-line over 871 days with lightning activity over the region of study (fig. 1), with severe weather records in the same day (D), or the contiguous (D-1, D+1). Period of analysis: 2006-2015. Different configurations of TL flashes:

- Only CG, without any IC (LJW0)
- CG plus IC, with multiplicity (LJW1)
- CG plus IC, without multiplicity (LJW2)

The Goals

1. Identify the number of warnings for each configuration
2. Detect in which cases CG flashes are enough
3. Consider the evolution of TL for different configurations for specific cases with warnings
4. Evaluate spatially the area of interest
5. Characterize seasonally the region of study

1. Number of warnings for each configuration

The number of alerts considering only CG was of 6. On the contrary, using ICs the number has been 3874 (LW1) and 1388 (LJW2).

2. Cases where CG flashes only are enough

We have focused in characterize briefly events with LW0 (fig. 6): in all cases the warnings occurred near or after the event, with a very short Lead Time, in comparison with LJW1 (50' in advance, in average) and LJW2 (30'). Moreover, no LJW0 were triggered in most of the severe hail events (>3 cm) occurred in Catalonia for the period of analysis.

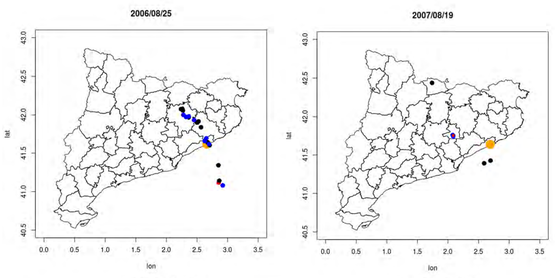


Figure 6. Two cases where the tool triggered LJW0 (considering only CG flashes). Yellow big dot marks the place where very heavy rain occurred. Small red dots indicate LJW0, black ones are for LJW1 and blue ones for LJW2.

3. TL evolution in LJW

The evolution of TL before the warning is very variable, depending on the type of data used (fig. 7). The number of CG flashes is near a third of the TL in LJW2 and ~5% for LJW1, even lower in many cases. Taking into account that a LJW needs continuity in time and space of LJW (Farnell et al., 2017), it is complicated the triggering of alerts in many events, when CGs are null in a large part of time.

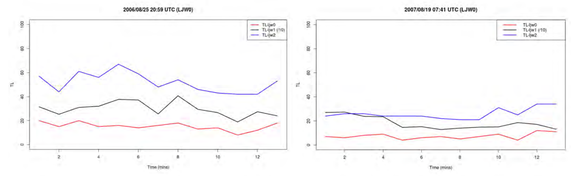


Figure 7. Time evolution of TL for the LJ tool in cases of only CGs (red line), for CG+IC without multiplicity (blue line), and with multiplicity (black line). The selected times are related with the two LJW0 shown in fig. 6.

4. Areas more prone to be affected

Fig. 8 shows the spatial distribution of the three types of LJW. Maps of LJW1 and LJW2 show a similar pattern, with a maximum in the Central part (black ellipse). On the opposite, the few LJW0 have occurred over the Sea and the Coastal areas, being probable a sea influence in these cases.

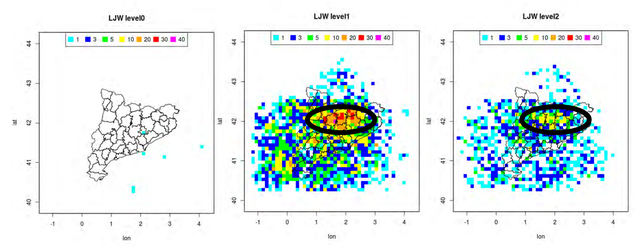


Figure 8. Spatial distribution of LJW for the three categories: LJW0 (left), LJW1 (centre), and LJW2 (right), for the period 2006-2013

5. Season distribution of LJW

Fig. 9 presents a Gaussian monthly distribution of LJW1 and LJW2, with the maximum centered between July and August. LJW0 have occurred only during August to October (the period when the Sea surface temperature reaches maxima values).

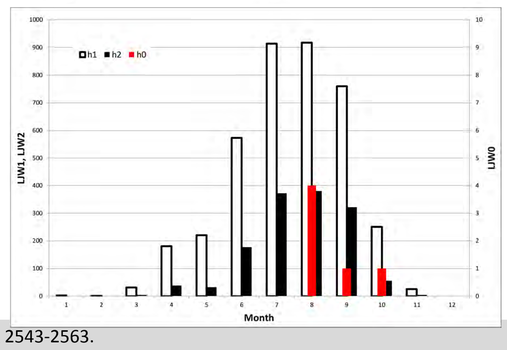


Figure 9. Monthly distribution of LJW for the three categories: LJW0 (red), LJW1 (white), and LJW2 (black), for the period 2006-2013

CONCLUSIONS

We have shown that severe weather cannot be forecasted using only CG flashes, because:

- The rates are low, without a continuity of the 14 minutes of flashes activity (necessary for the triggering of alerts)
- The low rates cannot help to a rising of the flashes activity exceeding the double of the standard deviation for the previous twelve minutes (main condition of the LJ, see Farnell et al, 2017)
- The influence of sea is observed in those cases with LJW0 (however, most of severe weather events occur in areas far to the coast, except waterspouts)

We strongly suggest the separate identification of IC and CG, considering both types of flashes for the application of the LJ algorithm.

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