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Lightning jump as a nowcast predictor: Application to severe weather events in Catalonia

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ABSTRACT

Several studies reported sudden increases in the total lightning flash rate (intra-cloud+cloud-to-ground) preceding the occurrence of severe weather (large hail, wind gusts associated to thunderstorms and/or tornadoes). Named "Lightning Jump", this pattern has demonstrated to be of operational applicability in the forecasting of severe weather phenomena. The present study introduces the application of a lightning jump algorithm, with an identification of cells based solely on total lightning data, revealing that there is no need of radar data to trigger severe weather warnings. The algorithm was validated by means of a dataset severe weather events occurred in Catalonia in the period 2009–2014. Results obtained revealed very promising.

1. Introduction

Lightning jumps (LJ), defined as sudden increases in the total lightning flash rate (Williams et al., 1999) , tend to precede severe weather occurrences on the ground (e.g. Darden et al., 2010; Fehr et al., 2005; Kane, 1991; Lang et al., 2000; Pineda et al., 2011; Tessendorf et al., 2007; Williams et al., 1999) The sudden increase in lightning activity is believed to be a response to the rapid intensification of the updraft that leads to an increasing number of ice particle collisions and thus greater charge separation and lightning (Carey and Rutledge, 1996; Deierling et al., 2008; Goodman et al., 2005; Steiger et al., 2007; Wiens et al., 2005; Williams, 2001) . The trends in the total lightning (intra-cloud + cloud-to-ground; IC + CG) flash rate have shown a better performance (as compared to CG flash rates) as a tool for severe weather warning decision support (Schultz et al., 2011) .

Gatlin and Goodman (2010) and Schultz et al. (2011) demonstrated the operational applicability of the total lightning jump algorithm developed by Schultz et al. (2009). Schultz et al. (2011) has tested this algorithm to a set of 711 thunderstorms, in order to analyze the quality of the prediction of severe weather phenomena. The results obtained in that analysis revealed very promising, obtaining good values of the probability of detection (~79%) and false alarm (~22%) indices. Chronis et al. (2015) had modified the preliminary algorithm of Schultz et al. (2009), expanding the LJ to a longer time period of the life cycle of a thunderstorm. Chronis et al. (2015) examined over 2200 storms using automated tracking and real-time data feeds, with the main goal of comparing objective metrics of intensity, in order to determine if storms with lightning jumps lasted longer and contained larger radar derived intensity metrics like Maximum Expected Size of Hail (MESH). These works also pointed out that the total lightning jump is much more effective for severe weather nowcasting, compared to other predictors used for the same purpose like the IC:CG ratio (Pineda et al., 2011) or changes in the dominant CG polarity (Carey and Rutledge, 1998; Lang et al., 2004; Pineda et al., 2016; Soula et al., 2004; Wiens et al., 2005) patterns also linked to severe weather but highly variable and thus not effective

Severe weather is understood hereafter as the presence of at least on of these phenomena in a thunderstorm: hail of diameter equal or over 2 cm, wind gusts with speeds equal or larger than 25 m/s, and tornadoes. Regarding the hail size, 2 cm is the most common threshold used in many studies made around the World (Cao, 2008; Schuster et al., 2005; Tuovinen et al., 2009) . However, Allen and Tippett (2015) have explained the set of a larger threshold for the US (1 in., 2.5 cm) motivated by operational purposes, arguing that observers use inches instead of cm. Nonetheless, some American authors (e.g. Cintineo et al., 2012) still use the 0.75 in. (1.9 cm) threshold.

The lightning jump algorithm is intended to warn about severe weather, identifying rapid increases in total lightning flash rate preceding severe weather manifestations. The lead time between occurrence of lightning jump and severe weather phenomenon varies

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depending of the different studies, but most of them agree that lightning jumps occur several minutes in advance of severe weather. Williams et al. (1999) registered differences between 5 and 20 min. Dimitrova et al. (2011) observed lightning jumps in three types of thunderstorms: multi-cellular, super-cellular, and multi-cell system evolving to super-cell thunderstorm. In each case a lightning jump was detected, but showing different lead times on respect the severe weather occurrence. In particular, these differences were 12, 20 and 24 min on respect the three cases presented before. Steiger et al. (2007) presented an analysis exclusively for super-cells, with lead times between lightning jumps and severe weather between 5 and 30 min. In the same way, Goodman et al. (2005) found an average lead time of 12 min, while Williams et al. (1999) established a value of 7 min, for hail events. Finally, Metzger and Nuss (2013) studied 34 cases of severe weather, but only in 18 of them that lightning jumps preceding the phenomena were found. In those cases with occurrence of both, observation and lightning jump, the time difference was of 14 min in average.

The main aim of this study is the evaluation of the utility of using trends in total lightning activity for diagnosing the potentiality of severe weather in a thunderstorm. An adaptation of the Schultz et al. (2009) algorithm was applied and tested in Catalonia. A key feature of the present work is that the algorithm attempts to predict severe weather without the use of any radar observable. This not means that weather radar is not useful for the identification of severe weather phenomena (in fact, it has been used here for the validation of events), but the present paper intends to show how the use of the algorithm may forecast a large number of cases using only electrical data. The manuscript is divided as follows: first is the presentation of the area of study. Then, the severe weather database used in this work and the remote sensing networks, joined with the methodology are introduced. This section includes the characteristics of the algorithm, the relationship between lightning jumps and the database, and the contingency tables and the verification indexes. Next, results are presented, and, finally, the conclusions and a brief discussion are developed.

2. The study area

Catalonia is a region of 32.000 km^2 placed at the Northeastern of the Iberian Peninsula (Fig. 1), surrounded by the Ebro Valley (west), the Pyrenees (north), and the Mediterranean Sea (east and south). The region has a wide diversity of geographic features, with four main orographic systems: the Pyrenees range, west-east oriented, delimits the northern extension of the region, and with heights moving near 3000 m ASL; the PrePyrenees, moving parallel more or less 40 km at the south of the first one and peaks between 1500 and 2000 m ASL; and the Coastal and Pre-Littoral ranges, running both parallel to the coast, from South-west to North-east, and with heights around 500 m and 1000 m, respectively. Furthermore, several flat landscapes are placed on between some of these ranges. This terrain variability, combined with the high sea surface temperature of the Mediterranean Sea, is one the factors that favours the relatively high occurrence of severe weather phenomena in the region.

Severe weather affects Catalonia in different ways. Hail mainly hit flat areas in western and the central Catalonia (Fig. 2), and are more important specially in Summer (Aran et al., 2007; Farnell and Llasat Botija, 2013; Rigo and Llasat, 2016; Rigo and Pineda, 2016) . Because of the severity of this phenomenon, the hailstorms produce important economical losses, mainly in the areas where agriculture plays an important role in the economy. During the period 2000–2009 the average economical loses were of 15 M € per year only in crops (Aran and Pena, 2009) . Tornadic and straight winds associated to thunderstorms events have a different geographical distribution. In the first case, tornadoes mostly occur in the coastal areas, and in some cases are waterspouts (Gayà et al., 2011) . Furthermore, some other case was registered in flat areas. Anyhow, tornadoes in Catalonia do not produce damages as important as hail, with the exception of those few cases that hit populated areas (Bech et al., 2007, 2011). Finally, strong wind gusts associated with thunderstorms are relatively common in the region, mainly in areas similar to the affected by hailstorms (Gayà et al., 2011; López, 2007; Ramis et al., 1997) , but the number of documented cases is relatively low, mainly because the damages produced are lower than the caused by hail and, moreover, the phenomenon is not as visually spectacular as tornadoes. A review of episodes with wind gusts exceeding 25 m/s as recorded by the Automatic Weather Stations network of the Meteorological Service of Catalonia resulted in a list of 65 events for the period 2007–2015. It is important to remark that observations had to be more or less coincident in time and space with lightning activity. This value is between the number of hail cases (maximum) and tornadoes (minimum), but the relevance in the press is clearly lower than the other two phenomena.

3. Data and methodology

3.1. Data

3.1.1. Database

Case study episodes was selected from the Severe Weather Database (hereafter SWDB) of the Meteorological Service of Catalonia (hereafter, SMC), which includes hail events, wind gusts associated to thunderstorms, and tornadoes in Catalonia from 2004 to 2015 (Rigo et al., 2015) . The wind speed threshold associated with gusts was reduced in relation to the original definition (25 m/s to 20 m/s, see the Introduction section). The cause is the observation of many reported events with strong damages in which the measured speed have not reached the original threshold in any automatic weather station. Although older severe weather reports exist, the SWDB was restricted to these twelve years because this period encompasses the same uniform and reliable remote sensing data quality. The process to identify, analyze, validate and finally include a severe weather event was the following. The information sources, similar to the used by other climatology works (e.g. Schuster et al., 2005; Tuovinen et al., 2009) , include technical reports, local or regional newspapers, local spotters, social networks and other internet sources, or information collected by the technical staff of the SMC. The description of each event considers the following information: date, time, coordinates type of phenomenon, and magnitude if it is possible.

In all the events, the same procedure was applied. The initial step was the identification of the characteristics associated with the phenomenon (date, time, coordinates, type of phenomenon, and its magnitude), if it is possible. Products used for validation, detailed later on, included: reflectivity radar animations, maps of lightning strokes, and wind, hail and rainfall measurements from automatic weather stations or hail-pads, if they are available. All the data comes from the SMC networks. All those cases that could not be validated, were discarded. The validated events finally included in the database were divided into two types: those with information for all the fields, and those lacking of some information, mainly the magnitude of the phenomena. In some of the cases, the validation was made using photographs or registers provided by official spotters of the SMC.

To conclude this point, it is important to notice that the current database considers each event as it is, allowing different observations very close in time and distance of the same (or other) phenomenon. The preliminary objective is to have a set or registers as wide as possible and, if it is necessary, to reduce the set picking up only the more representative values (mainly, the maximum daily or hourly values, or those associated with damaged structures).