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Analysis of convective structures that produce heavy rainfall events in Catalonia (NE of Spain), using meteorological radar

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Abstract. This paper shows a methodology for obtaining a climatology of convective systems using the meteorological radar and a network of automatic raingauges. The methodology has been applied to forty heavy rainfall events recorded in the Northeast of Spain between 1996 and 2000. First, a classification of those events has been done on the basis of the convective rainfall features at the surface. Next, an attempt was made to associate the different rainfall in surface patterns at the surface with the convective structures identified by the meteorological radar. Two algorithms have been applied to analyze convective structures. The first one (Johnson et al., 1998) identifies convective cells as a region of maximum reflectivity in 3D, and the second one (Steiner et al., 1995) identifies convective structures at the lowest level (2D). These algorithms classify pixels as rainfall/non rainfall and, then, they choose those that satisfy certain requirements to consider them as "convective". On the other hand, the other pixels of "rainfall" are classified as "stratiform". Once the identification has been done, some features of 2D (size, shape...) and 3D (centroid, reflectivity, shape e, size, VIL...) structures have been calculated to do the climatology of the events. Finally, both kinds of structures (2D and 3D) have been linked in order to classify every element as an isolated storm, supercell, multicell or MCS. This methodology has been applied to improve the tracking and nowcasting of convective structures.

1 Introduction

During the period of 1996–2000 more than 40 heavy rainfall events were recorded in the Internal Basins of Catalonia. This region is placed in the NE of the Iberian Peninsula and has a total area of near 16 000 km^2. The present paper shows the analysis of those events using a network of 126 automatic rain gauges and the meteorological radar of the Spanish Meteorological Service (I.N.M.) placed near of Barcelona. The aim of this paper is to describe some features of the convective structures observed in those events, using different algorithms which identify the convection in two and three dimensions. Besides this, a comparison with the convective features of the rainfall events obtained by using the raingauge network has been done.

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2 Selection and classification of the heavy rainfall events using raingauge data

The rainfall network is composed of 126 tipping-bucket automatic raingauges with a rainfall overturning of 0.1 mm. The precipitation is cumulated and recorded every 5 minutes. The data analyzed comprises the complete series for the period of 1996-2000. The rainfall thresholds considered in order to select a heavy rainfall event have been:

- $R > 100$ mm/24 h in at least one gauge
- $R > 60$ mm/24 h in 5 or more gauges
- $R > 35$ mm/1 h in one or more rain gauges
- $R > 200$ mm in all the event, in at least one gauge.

The β parameter (Llasat, 2001) takes account of the ratio between the rainfall which exceeds a defined threshold and total rainfall in an episode. This parameter has been used to identify the degree of convection of every rainfall event on the basis of the distribution of rainfall rate in each raingauge. On the other hand, this parameter allows compare the features of the rainfall at the surface with reflectivity data using specific thresholds. The rain rate threshold for convective events has been 35 mm/h, meanwhile the reflectivity threshold to do a first identification of convective rainfall has been 43 dBz. Daily charts of this parameter allow to classify the events in three types (Fig. 1): isolated regions with moderate-high values of "convectivity" (pattern A); wide areas with low values of beta with convective areas embedded into those regions (pattern B); and wide regions with moderate-high values of β (pattern C).

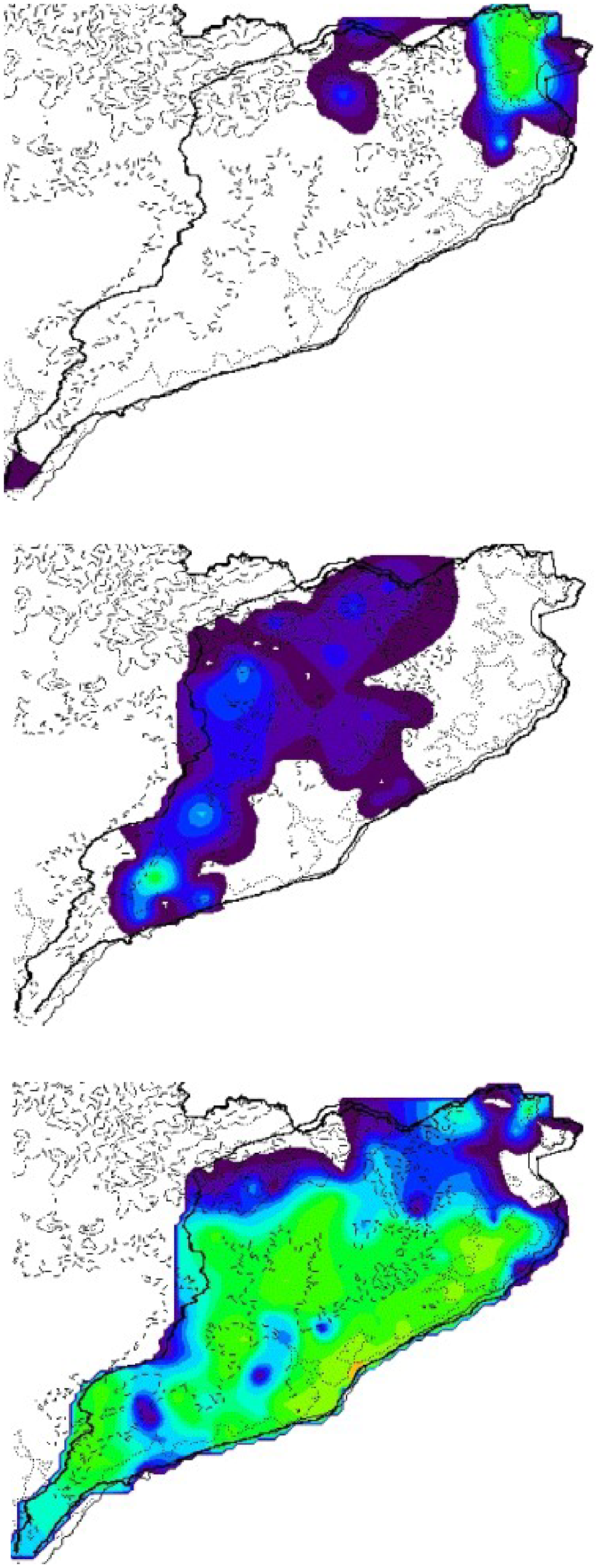

Fig. 1. Rainfall patterns associated with heavy rain events. Green and orange colors are associated with high values of β parameter. Above: pattern A; middle: pattern B; below: pattern C.

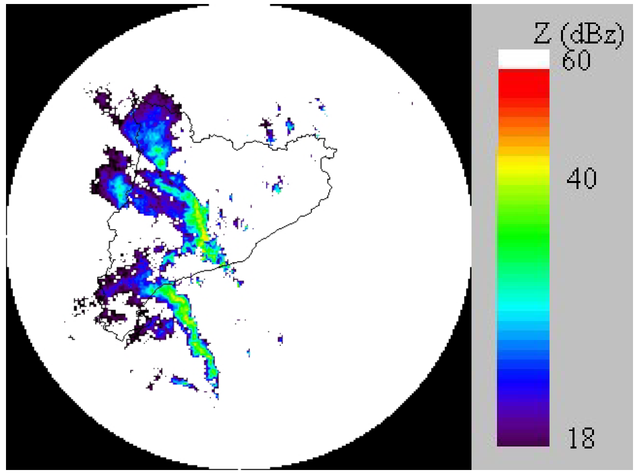

Fig. 2. Radar image of the lowest PPI. 10 June 2000 (00:00 UTC).

3 Identification of convective cells and systems from the meteorological radar

Two different operative algorithms have been used to identify the convection. Both algorithms have been applied to every radar image (Fig. 2). The first algorithm separates and identifies the convective pixels in front of the stratiform echoes (Steiner et al., 1995; Martin et al., 2001). This procedure only considers the lowest level (PPI or CAPPI) over which a 2D algorithm is applied, known as SYH (Steiner-Yuter-Houze). The algorithm labels a pixel as "convective" if it verifies a set of reflectivity requirements (Table 1) on itself and/or its neighbouring pixels. Finally, the adjacent "convective" pixels are joined to identify significant convective structures at low levels (Fig. 3a).

Another algorithm, developed by Johnson et al. (1998), has been used to detect 3D convective cells (fig. 3b). This method is known as SCIT (Storm Cell Identification and Tracking Algorithm), and it was adapted to the Spanish area by Carretero et al. (2001). Once a convective cell has been identified using this method, the tracking and nowcasting of its movement has been done. The results obtained for 2D and 3D methods have been integrated, allowing creating a database of all the convective structures Ttables 2 and 3), which have been nowcasted successfully in that cases where the method have been used. That database will be used as a climatology of convective structures detected using meteorological radar, improving the knowledge of the heavy rainfall events that affect the area. The last part of the procedure consists in linking convective cells (obtained with the 3D algorithm) to 2D structures (or convective rainfall structures). Then, it is possible to obtain information (position, size and form) about the life cycles of the multicell storms or Mesoscale Convective Systems.

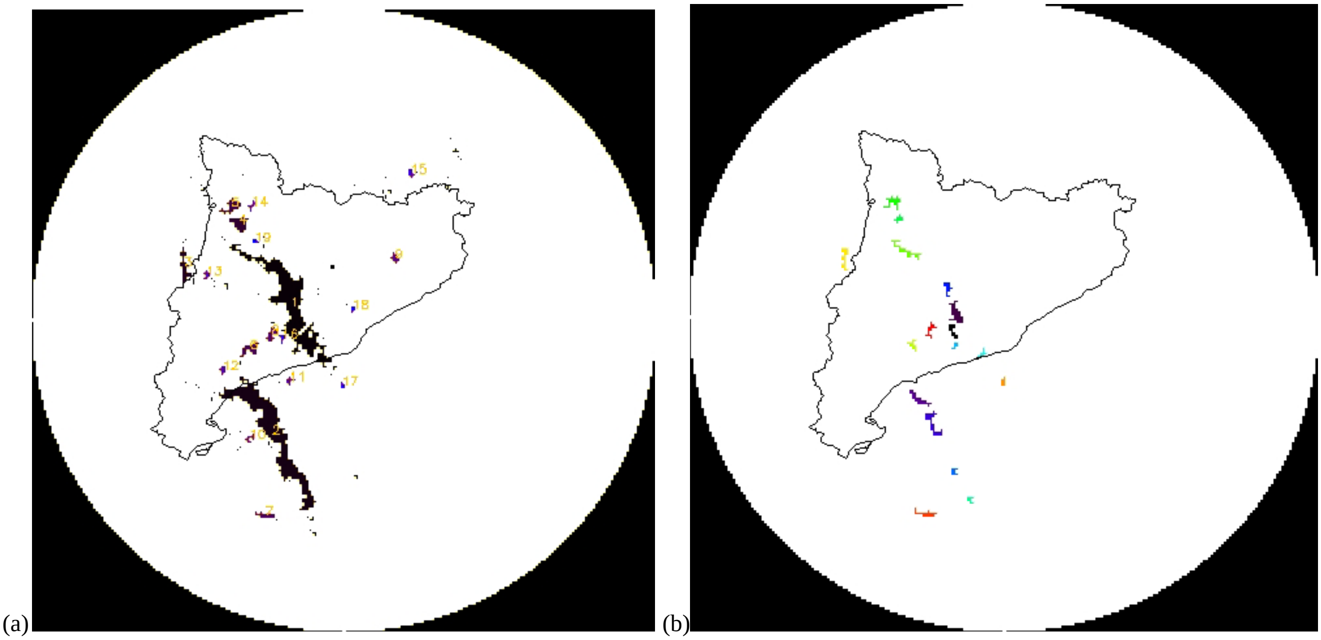

Fig. 3. 2D **(a)** and 3D **(b)** algorithms outputs for the previous image.

Table 1. Requirements used for identifying convective pixels in the 2D algorithm

Procedure name	Requirements for "convective" pixels
Reflectivity threshold	Z>43 dBz
Background reflectivity (Z_{bg})	$Z-Z_{bg} > (1/a)^{*} \cos(\pi Z_{bg}/2^{*}b)$
Position	The neighbours of a convective pixel are considered as convective.

Table 2. Features of 2D convective structures for 10 June 2000 (00:00 UTC). Index: number of the convective system; Xcen, Ycen: horizontal coordinates from the meteorological radar (km), axe Y pointing to the North; Area in km^2; Zmax and Zmed: maximum and medium reflectivity in dBz

Index	Xcen	Ycen	Area	Zmax	Zmed
1	99.5	125.3	1504	52.0	39.0
2	92.4	76.0	1440	52.0	39.6
3	58.5	140.7	136	41.0	34.6
4	79.8	157.2	128	46.0	37.2
5	76.7	163.8	116	42.0	36.0
6	83.8	108.8	104	40.0	35.6

4 Association of convective structure with rainfall patterns

The meteorological radar of the INM in Barcelona is a C-band radar. The imagery are obtained every 10 minutes in two different modes: Normal (resolution of 2×2 km^2 and range of 240 km) and Doppler (resolution of 1×1 km^2 and range of 120 km). A total of 2654 radar images have been used for analyzing the selected events.

Every image has been analyzed using both procedures. Then, the most important convective structures have been identified: every one (2D or 3D) has to verify conditions related with the area (>24 km^2), volume (3D structures must have at least 2 levels), or reflectivity (>30 dBz). Once the image has been analyzed, a file has been saved with the information explained in Tables 1 and 2. Usually the pattern A has been associated to small multicell storms (Fig. 4), meanwhile rainfall systems with wide stratiform regions and few convective cells have been linked to pattern B. Finally, Mesoscale Convective Systems have been related to rainfall situations where pattern C is the most common. The last type of structures has the greater developments (vertical and horizontal) and, also, are well-organized.

5 Conclusions

The comparison of the daily β parameter for rain gauges and radar charts allows to:

- illustrate the usefulness of this parameter for detecting convective rainfall
- identify the areas most prone to convective precipitation, for different seasons.

Two different operative algorithms have been used to identify convective cells and greater convective structures. Those structures have been associated to a different kind of rainfall patterns. The results have been applied in the improvement

Table 3. Features of 3D convective cells for 10 June 2000 (00:00 UTC). Index: number of the convective cell; Xcen, Ycen: horizontal coordinates from the meteorological radar (km), axe Y pointing to the North; Area in km^2; Htop: height of the cell top (km); Zmax and Zmed: maximum and medium reflectivity in dBz; Vil and Dvil: Vertical Integrated Liquid (kg/m^2) and VIL Density (g/m^3); Hcen: height of the cell centroid (km); Orie: direction (radians); Incl: slope (radians); Vol: volume (number of cells); Ejmax: maximum horizontal axis at lowest level (km)

Index	Xcen	Ycen	Htop	Zmax	Zmed	Vil	Dvil	Hcen	Orie	Incl	Vol	Ejmax
2	100.0	121.8	5.8	54.0	44.6	14.2	2.5	2.6	−1.4	0.7	49.0	2.5
4	99.8	121.8	7.8	52.0	42.9	13.4	1.7	2.9	−0.4	0.6	108.0	3.3
6	85.5	121.8	6.8	52.0	40.0	10.9	1.6	3.3	0.4	0.6	120.0	4.8
5	92.5	121.8	4.8	52.0	43.7	7.8	1.6	2.1	−1.3	0.9	69.0	3.3
1	101.1	121.8	4.8	54.0	43.1	12.7	2.7	2.7	1.5	0.8	43.0	2.8

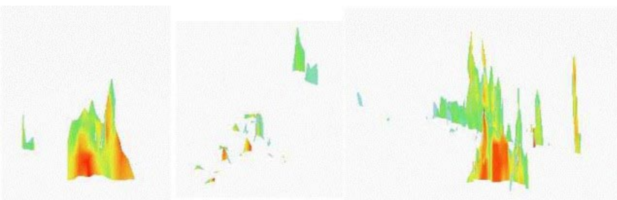

Fig. 4. Different types of convective structures (showed in 3D perspective). Small multicell storm (left), convective cells embedded into a stratiform structure (center), and Mesoscale Convective System (right).

of the tools for nowcasting the movement of convective structures. The future work includes the seasonal and spatial (by regions) analysis of convection.

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