Rainfall regionalization on the basis of the precipitation convective features using a raingauge network and weather radar observations

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Accepted 13 August 2005

Abstract

The main objective of the present paper is to show a methodology for undertaking rainfall regionalization of a region taking into account the convective features of the precipitation, and useful for establishing homogeneous zones for improving the alert system. This methodology has been applied to a hydrographic region located in northeast Spain, with an area of 16000 km² and characterized by a highly contrasted topography. Information provided by meteorological radar and 5-min precipitation data for 126 automatic raingauges has been used for the period 1996–2002. The previous analysis done on the basis of the 1927–1981 rainfall rate series for the Jardí raingauge, located in Barcelona, has also been considered. To that end, the first step was to draw up a proposal for classification of the pluviometric episodes. Recourse was had for this purpose to definition of the β parameter, related with the greater or lesser convective character of the event and calculated on the basis of the rainfall intensity at the surface (Llasat, 2001) and, when data are available, on the basis of radar reflectivity. Results show that the threshold of 35 mm/h to characterize convective episodes from raingauge data can be corroborated from the radar point of view when convective precipitation is identified using 2-D algorithms with a reflectivity threshold of 43 dBZ. Once the soundness of the β parameter had been corroborated, it was applied to more than 2900 precipitation episodes recorded in the region, in order to discriminate the features of the different subregions and their time and space distribution throughout the entire series of the samples. Using this definition, 92% of the precipitation events recorded in this region, with accumulated rainfall above 35 mm, are classified as convective ones, representing 95% of the precipitation amount. Application of the β parameter combined with monthly rainfall data allows differentiation of 8 regions with different convective precipitation features.

Keywords: Rainfall; Convective precipitation; Rainfall regionalization; Weather radar; Catalonia; Spain

1. Introduction

Amongst other objectives, the advances made in hydrometeorology in recent years have included the modelling of precipitation to improve the design curves and hyetographs or to build “synthetic rainfall events”. Usually, this conceptual and mathematical modelling is based on certain climatic features of the region, and does not distinguish between the different kinds of rainfall episodes that can arise. However, their classification could help to improve this modelling by adding more information to the parameterization process. Besides this, the classification of precipitation has a wide spectrum of applications. From a meteorological point of view, the distinction between convective/stratiform
precipitation is important in determining the vertical distribution of the diabatic process and thermodynamics features, improving the rainfall retrieval accuracy from remotely sensed data, identifying and correcting effects associated with bright band and the conversion from reflectivity measurement to rainfall (Anagnostou, 2004). Considering all the alert chain involved in heavy rainfall events management, the obtaining of homogeneous areas characterized by different warning thresholds on the basis of the climatic rainfall features that include rainfall intensity and the greater or lesser possibility of having flash floods, would be very useful. Within this line, an interdisciplinary classification that endeavours to merge convective features, rainfall intensity and accumulated values, the extension of the event and possible damage, are being prepared nowadays (Llasat, in press).

However, when we try to undertake a classification of rainfall events and rainfall precipitation, we are thus faced with a problem difficult to resolve. The best solution would be to study the nature of the process that gave rise to the precipitation. In this case a distinction could be made, essentially, between precipitation of convective origin and precipitation of stratiform origin, which classification should not be identified with classification of the rainfall associated with a storm or rainfall associated with a front, as has unfortunately sometimes occurred. In a simplified form, following the definition proposed by the AMS Glossary of Meteorology (Huschke, 1959) and by Houghton (1950), it would be a matter of associating the first type with clouds of convective type, such as cumulonimbus, and the second, with clouds of stratiform type, such as nimbostratus.

Houze (1993) defines the stratiform/convective precipitation on the basis of the vertical air velocity, w. If it is less than the terminal fall velocity of ice crystals and snow, then it is called “stratiform”. Together with this feature, and using the 3-D radar imagery, the “bright band” near the melting level is a signature that helps to distinguish convective mode from stratiform mode. Although this kind of analysis would be better and could be applied to a specific event, its systematic application to a long series could be difficult if not impossible. Consequently, other approximations have been made.

Some analyses of convective systems from meteorological satellites have been performed for different regions of the world, such as Spain (Sánchez et al., 1992, 2003; Martin et al., 1998) or North America (Fritsch et al., 1986; Maddox et al., 1986; Miller and Fritsch, 1991). The problem is that within a system of eminently convective origin, it is possible to find rain of stratiform character, or, into the trailing anvil of a MCS, it is possible to find vertical motions of several meters per second, moderate intensity rainfall with a showery character and a certain vertical organization (Doswell, 1993; Doswell et al., 1996; Houze, 1997; Anagnostou, 2004).

Since the late 1980s, many methods have been developed for analyzing convection and convective precipitation from the radar imagery. Besides the fact of distinguishing the bright band, most of these methods are based on background-exceeding techniques (Steiner et al., 1995; Collier, 1989; Hand, 1996; Johnson et al., 1998; Wilson et al., 1998; Biggerstaff and Listemaa, 2000; Rigo and Llasat, 2004): they select reflectivity values, which are considered as the threshold values for identifying “convective” pixels. The main difference between those algorithms is the point of view used to analyze convection. In general, it is possible to classify them into two types. The first methodology uses only the lowest (PPI or CAPPI) radar level, and consequently works into a 2-dimensional (2D) analysis (i.e., Steiner et al., 1995). The second one uses all the volume radar and works into a 3-dimensional (3D) analysis (i.e., Johnson et al., 1998). Where possible, both methodologies are integrated in order to improve the characterization of the system and its tracking and nowcasting.

The main problem of the previous methodologies lies in the need to have information from meteorological satellites and radars, which would hinder the feasibility of the process. This problem increases when a climatological analysis for a long series is required, or when the people who would have to manage the classification are not expert in the radar or satellite analysis or require an easier tool to classify the rainfall events. Then, the third possibility would consist in studying the rainfall intensity threshold exceeded when a “heavy rain” is considered or the required threshold from which the mitigation produced by rain in the short-wave radio links occurs, both of which problems are usually related with convective rainfalls (Llasat and Puigcerver, 1985, 1997). Although the concept of high rainfall rate can vary with the climatic characteristics of the rain for each location, the literature usually considers a high intensity to be that which exceeds 0.8 mm/min (Dutton and Dougherty, 1979; Watson et al., 1982; Vilar and Burgueño, 1991). Although not all rain of convective origin exceeds that threshold, while not all rain which does exceed said threshold is convective, Llasat (2001) shows that the error made when convective rainfall is identified with 1-min intensities exceeding 50 mm/min can be misleading.

The objective of this paper lies in an attempt to overlap the ground information and weather radar
Fig. 1. Localisation of the Internal Basins of Catalonia. The localisation of the 126 automatic rain gauges from the SAIH is shown.
observations to find an objective method of classification that at the same time has a plausible physical interpretation. This objective considers the introduction of the $\beta$ parameter that allows classification of the types of pluviometric events and its application to characterize a complex Mediterranean region. To this end, the 1996–2002 series of 5-min rainfall rates provided by 126 automatic raingauges and by the meteorological radar located near Barcelona (Fig. 1) have been used. Some previous information obtained from long instantaneous rainfall intensity series (1927–1981) of a pluviograph situated near the city of Barcelona has also being considered. After this, a proposal of characterization of convective events on the basis of the instantaneous rainfall rate series of Barcelona and the 5-min rainfall series of an automatic rainfall network located in Catalonia, are undertaken. The soundness of the $\beta$ parameter and its application to characterize the physical features of convective precipitation is analyzed on the basis of radar data. Finally, a characterization of the region taking into account this parameter is presented.

2. Database and methodology

Catalonia is situated in the northeast of the Iberian Peninsula, and has an area of 35000 km$^2$. The Internal Basins of Catalonia (IBC) form a hydrographic region that comprises all the rivers that start and end in Catalonia, and covers an area of about 16000 km$^2$ (Fig. 1). The proximity to the Mediterranean Sea in combination with its specific orography have a determinant role in the development and triggering of convection. Main orographic features are a mountain range (the Littoral range) parallel to the coast with some peaks exceeding 500 m, a second range (Prelittoral) with peaks exceeding 1000 m, and the Pyrenees which exceed 3000 m. Heavy rainfalls and flash floods are not unusual in this region, giving rise to great damage and loss of human lives (Llasat, 2004).

The Jardí rate-of-rainfall gauge located in Barcelona (Fig. 1), at the Fabra Observatory (414 m a.s.l.), has been operating continuously from 1927 to 1980. The raw information consists of daily charts on which each rainfall event is recorded in the form of rainfall rate (ordinate) versus time (abscissa). Some observations, such as the presence of a thunderstorm or a gust, are also included in the charts. All this information has been digitised and used to define the $\beta$ parameter and analyze its climatic features in Barcelona, as is shown in Llasat (2001).

The SAIH (Automatic System of Hydrological Information) of the IBC is composed of an automatic raingauge network covering an area of about 16000 km$^2$ (Fig. 1). This system that has been operating since 1996 also includes a gauge network and all the information needed for the dam and water channel control. Its precipitation network is composed of 126 tipping-bucket automatic raingauges with a rainfall overturning of 0.1 mm. The precipitation is accumulated and recorded every 5 min. In this paper all the 5-min series have been submitted to a data quality control (Ceperuelo, 2004), and the $\beta$ parameter has been calculated for each raingauge.

The C-band radar of the Instituto Nacional de Meteorología (INM, Spanish Weather Service) is situated at 612 m a.s.l. near Barcelona city (Fig. 1). Table 1 shows its main characteristics. Radar volumes are obtained every 10 min and the size of the pixels is $2 \times 2$ km$^2$. Images have been slightly corrected previously by the INM and the main ground echoes have been eliminated using a ground clutter mask created previously (Sánchez-Diezma, 2001). A procedure has been applied in order to convert the polar coordinates of the primary images to Cartesian coordinates. Those pixels with reflectivity values under 12 dBZ have been removed because they could introduce a lot of noise and hinder calculus. This threshold has been selected due to the fact that the corresponding rain–rate value, using the Marshall and Palmer (1948) $Z/R$ relationship, is close to 0.1 mm/h. For this work all the imagery corresponding to heavy rainfall events over the period 1996–2002 have been analyzed using 2-D algorithms (Rigo and Llasat, 2004), and the spatial distribution of the $\beta$ parameter have been obtained for each image. Although 3-D algorithms have also been applied to identify convective cells, they are not needed for obtaining the $\beta$ parameter.

The objective of the $\beta$ parameter is to classify the pluviometric episodes on the basis of their convective features. Following the proposal made in Llasat (2001) and Llasat and Puigcerver (1997), it identifies the convective rainfall when it surpasses an intensity threshold, and it obtains the rate of convective rainfall versus total rainfall for the pluviometric episode.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Normal</th>
<th>Doppler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>240 km</td>
<td>120 km</td>
</tr>
<tr>
<td>First elevation altitude</td>
<td>0.5°</td>
<td>0.5°</td>
</tr>
<tr>
<td>Number of levels</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>PRF</td>
<td>250 Hz</td>
<td>900/1200 Hz</td>
</tr>
<tr>
<td>Frequency</td>
<td>5600–5650 MHz</td>
<td></td>
</tr>
<tr>
<td>Polarization</td>
<td>Horizontal</td>
<td></td>
</tr>
</tbody>
</table>
meteorological event or time period (month, year). It can then be used as a climatic feature or as a hydrometeorological feature of one specific event. Its interest lies in the fact that the degree of convection, or, better, of meteorological feature of one specific event. Its interest lies in the fact that the degree of convection, or, better, of convection's parameter, it suffices to use the expression

\[
\beta_{L,\Delta T} = \frac{\sum_{i=1}^{N} I(t_i, t_i + \Delta T) \theta(I - L)}{\sum_{i=1}^{N} I(t_i, t_i + \Delta T)}
\]

in which

- \( \Delta T \) is the time-interval of accumulation of the precipitation, expressed in minutes
- \( N \) is the total number of \( \Delta T \) integration steps into which the episode is subdivided
- \( I(t_i, t_i + \Delta t) \) is the precipitation measured between \( t_i \) and \( t_i + \Delta t \) divided by \( \Delta t \), that is, the mean intensity in the said interval expressed in mm/min or mm/h.

\( \theta(I-L) \) is the Heaviside function defined as:

- \( \theta(I-L) = 1 \) if \( I \geq L \)
- \( \theta(I-L) = 0 \) if \( I < L \)

Then, the rainfall events or periods can be classified as follows:

0. \( \beta=0 \) non-convective
1. \( 0 < \beta < 0.3 \) slightly convective
2. \( 0.3 < \beta < 0.8 \) moderately convective
3. \( 0.8 < \beta < 1.0 \) strongly convective.

The definition of episode is quite subjective. Where we are referring to a single raingauge, it was felt possible to distinguish between two different episodes when the time which elapses between them without rainfall exceeds 1 h, which permits an assurance that the two episodes come from different “clouds”. This lapse of time is commonly used in hydrological research. But, if we are considering a raingauge network that covers a region like the IBC, the proposed lapse time without precipitation in any raingauge of the region, to ensure that the rainfall comes from different systems, is about 3 h. This temporal resolution has also been selected considering the temporal resolution of some operative Limited Area Models that will be applied in future research to analyze the convective component of the precipitation.

3. Climatology of convective episodes in Catalonia

The previous section contains a proposal for use of the term “convective” for all episodes in which \( \beta \) is greater than zero. If we are referring not to a single raingauge but to an extended region, this term is applied when a minimum of one raingauge has a positive \( \beta \) value. Then, in order to achieve a climatology of those events, the ad hoc but long Jardí series and the short but regional SAIH series have been considered.

The application of Jardí data to the 5-min series shows that the precipitation with a mean 5-min intensity exceeding 35 mm/h is responsible for 18.2% of the total annual precipitation (Table 2). 8% of the rainfall episodes (number of slots of time with rainfall separated by at least 1 h without rainfall) are convective and provide 36.5% of the total annual precipitation (not all the precipitation of a convective episode need have an intensity above 35 mm/h). The largest number of events occurs in autumn, with mean seasonal value of 12 episodes; nevertheless the largest percentage of the total occurs in August, with just over 18%. In March, the percentage of events falls to 1.8%. 3.8% of the rainfall episodes belong to slightly convective episodes, 2.9% to moderately convective episodes and 1.3% to very convective episodes. As is shown in Table 3, it can be noted that the very convective episodes last less than 1 h, while the slightly convective ones last longer than the time threshold. Convection remains predominant when the duration of the episode is less than 70 min. The duration of the moderately convective episodes increases throughout the year from winter to autumn, when they can last some 5 h.

### Table 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage of convective episodes (( \beta&gt;0 )) versus the total number of precipitation episodes and percentage of rainfall produced by them, in Barcelona, Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Convective episodes (c.e.)</td>
</tr>
<tr>
<td>Year</td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>8%</td>
</tr>
<tr>
<td>August</td>
<td>18%</td>
</tr>
<tr>
<td>March</td>
<td>1.8%</td>
</tr>
</tbody>
</table>

\( r \) is the time which elapses between them without rainfall exceeds 1 h, which permits an assurance that the two episodes come from different “clouds”. This lapse of time is commonly used in hydrological research. But, if we are considering a raingauge network that covers a region like the IBC, the proposed lapse time without precipitation in any raingauge of the region, to ensure that the rainfall comes from different systems, is about 3 h. This temporal resolution has also been selected considering the temporal resolution of some operative Limited Area Models that will be applied in future research to analyze the convective component of the precipitation.
Regarding the maximum 5-min intensities, it is worth noting that 55% of the very convective episodes exceed the threshold of 125 mm/h, 63% of the moderately convective are between 75 mm/h and 125 mm/h and 59% of the slightly convective episodes are between 35 mm/h and 75 mm/h.

When the 126 raingauges are considered for the entire period, the distribution of convective episodes per raingauge ranges between 3% and 8% of the total rainfall episodes, which are associated with accumulated values of precipitation ranging between 15% and 40% of the total precipitation for each raingauge, where we have imposed as a condition to separate two rainfall episodes that the lapse time without precipitation should be 1 h in the raingauge in question. When the episode is considered in its entire regional domain (lapse time without precipitation in the region of 3 h), the total number of episodes recorded between 1996 and 2002 is 2964, and 498 of them are convective, being responsible for 90% of the total precipitation (Table 4). If only those events for which the accumulated rainfall is above 35 mm at a minimum of one raingauge are considered, then a total of 226 events have been identified and 208 (92%) of them had $\beta$ values greater than zero. Although this threshold can be considered low, it coincides with the less quantity than should be recorded in 1 h at one pluviograph to initiate the alert system of the Spanish National Weather Service. With this condition, the precipitation associated with those convective events was 95% of the total corresponding to the 226 events. The classification of these 208 convective events shows that 13% are of type 1, 47% are of type 2 and 40% are of type 3.

4. Comparison between ground data and radar data to estimate convective precipitation and $\beta$ parameter

The use of remote sensing was necessary for integrating both points of view: the point that considers the precipitation structure at the surface, and the point that considers the structure of the cloud system. For each radar volume, the methodology developed by Rigo and Llasat (2004) was applied. It was adapted and assimilated to the region and to the convective rainfall analysis starting from the works of Steiner et al. (1995), Biggerstaff and Listemaa (2000), and Johnson et al. (1998). The procedure is divided in two parts: the first looks at the lowest level of the volume in order to analyze the type of precipitation (2D), while the other looks at the type of rainfall structures (3D). The integration of both methodologies allows improved system characterization and its tracking and nowcasting. However, to obtain the contribution of convective precipitation to the total, it suffices to apply the 2D method. This method identifies a pixel as convective when it exceeds a given reflectivity threshold, its horizontal gradient is important, or it is situated very close to convective points (Table 5). The calculus of the value of the $\beta$ parameter for each pixel was undertaken by using different $Z/R$ ratios depending on the type of precipitation.

Some previous studies (Sánchez-Diezma, 2001; Rigo and Llasat, 2002) have determined that the reflectivity threshold to obtain pixels that could be considered as "convective" was between 40 and 45 dBZ, depending on the meteorological situation. Bearing in mind this criterion, and comparing it with the "convective" rainfall at surface obtained on

Table 3
Duration (D) of the different kinds of convective episodes recorded in Barcelona, Spain

<table>
<thead>
<tr>
<th>Season</th>
<th>1 (2 h &lt; D &lt; 6 h)</th>
<th>2 (D &lt; 2 h)</th>
<th>3 (D &lt; 0.5 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>1 (2 h &lt; D &lt; 6 h)</td>
<td>2(D &lt; 2 h)</td>
<td>3(D &lt; 0.5 h)</td>
</tr>
<tr>
<td>Spring</td>
<td>2 (0.5 h &lt; D &lt; 3 h)</td>
<td>1 (2 h &lt; D &lt; 8 h)</td>
<td>3(D &lt; 1 h)</td>
</tr>
<tr>
<td>Summer</td>
<td>3(D &lt; 2 h)</td>
<td>2(D &lt; 3 h)</td>
<td>1(2 h &lt; D &lt; 8 h)</td>
</tr>
<tr>
<td>Autumn</td>
<td>2(D &lt; 5 h)</td>
<td>3(D &lt; 4 h)</td>
<td>1(D &lt; 8 h)</td>
</tr>
</tbody>
</table>

(1) slightly convective, (2) moderately convective, (3) strongly convective.

Table 4
Number of events and convective events that have affected the Internal Basins of Catalonia between 1996 and 2002 (two events are different when the lapse time without precipitation is 3 h)

<table>
<thead>
<tr>
<th>Cumulative precipitation</th>
<th>Cumulative number of events</th>
<th>Percentage of number of convective events</th>
<th>Percentage of precipitation due to convective events (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P &gt; 0$ mm</td>
<td>2964</td>
<td>17</td>
<td>90</td>
</tr>
<tr>
<td>$P &gt; 35$ mm</td>
<td>226</td>
<td>92</td>
<td>95</td>
</tr>
</tbody>
</table>

4. Comparison between ground data and radar data to estimate convective precipitation and $\beta$ parameter

The use of remote sensing was necessary for integrating both points of view: the point that considers the precipitation structure at the surface, and the point that considers the structure of the cloud system. For each radar volume, the methodology developed by Rigo and Llasat (2004) was applied. It was adapted and assimilated to the region and to the convective rainfall analysis starting from the works of Steiner et al. (1995), Biggerstaff and Listemaa (2000), and Johnson et al. (1998). The procedure is divided in two parts: the first looks at the lowest level of the volume in order to analyze the type of precipitation (2D), while the other looks at the type of rainfall structures (3D). The integration of both methodologies allows improved system characterization and its tracking and nowcasting. However, to obtain the contribution of convective precipitation to the total, it suffices to apply the 2D method. This method identifies a pixel as convective when it exceeds a given reflectivity threshold, its horizontal gradient is important, or it is situated very close to convective points (Table 5). The calculus of the value of the $\beta$ parameter for each pixel was undertaken by using different $Z/R$ ratios depending on the type of precipitation.

Some previous studies (Sánchez-Diezma, 2001; Rigo and Llasat, 2002) have determined that the reflectivity threshold to obtain pixels that could be considered as “convective” was between 40 and 45 dBZ, depending on the methodology used and the meteorological situation. Bearing in mind this criterion, and comparing it with the “convective” rainfall at surface obtained on

Table 5
Algorithms applied to the 2D case

<table>
<thead>
<tr>
<th>Procedure name</th>
<th>Requirements for “convective” pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflectivity threshold ($Z_{bg}$)</td>
<td>$Z &gt; 43$ dBZ</td>
</tr>
<tr>
<td>Background reflectivity ($Z_{bg}$)</td>
<td>$Z - Z_{bg} &gt; \frac{1}{a} \cos \left( \frac{\pi Z_{bg}}{b^2} \right)$</td>
</tr>
</tbody>
</table>

Position

The neighbours of a convective pixel are considered as convective

In case of “Background reflectivity”, $a$ and $b$ are constants and depend on the zone.

In case of Catalonia, $a=8$ and $b^2=128$. 
Fig. 2. Total convective rainfall for the period 1996–2000: (a) percentage of total convective rainfall obtained by the meteorological radar (β chart); (b) percentage of total stratiform rainfall obtained by the meteorological radar; (c) percentage of total convective rainfall obtained by rain gauge data from SAIH (β chart). Both cases (radar and rain gauges) show the maximum convective precipitation over the Pyrenees.
Fig. 3. Charts of the three regionalizations of the Internal Basins of Catalonia using the SAIH data (1996–2002). (a) daily rainfall; (b) monthly rainfall; (c) monthly $\beta$ parameter.
the basis of the ground data, it is possible to establish here that the threshold of 43 dBZ is the most correct. On the other hand, the results obtained for the heavy rainfall events analyzed for the period 1996–2002 have helped to identify the areas where the convective precipitation presents a maximum frequency in the region. The comparison of the $\beta$ chart obtained for the entire period by means of the raingauge network and the percentage of convective rainfall calculated for the radar images shows a good agreement (Fig. 2). The main differences between the two maps are due to the application of different interpolation techniques to the precipitation values, and to the attenuation produced by the topography.

5. Application of the $\beta$ parameter to the rainfall regionalization and event characterization

Many different regionalizations had been carried out for Catalonia, on the basis of pluviometric fields like monthly rainfall or daily rainfall (Serra, 1994; Gibergans, 1994 2001). An interesting application of $\beta$ is to the improvement of these rainfall regionalizations taking account of the convective features of the precipitation (Ceperuelo and Llasat, 2004, 2005). In this work, the regionalization for the monthly and daily rainfall and monthly $\beta$ parameter has been done using the 5-min data of the SAIH network, which has the advantage of higher temporal and spatial resolution, but the disadvantage of having a shorter period (1996–2004) than the previous regionalizations obtained for a period exceeding 30 years. Fig. 3 shows the results obtained after applying Principal Component Analysis (PCA) to the monthly data, daily data and $\beta$, respectively. The selected criterion for implementing the PCA is the VARIMAX, introduced by Kaiser (1958). Table 6 shows the percentage of variance explained for the different components. The comparison with the regionalization obtained by

<table>
<thead>
<tr>
<th>Principal component</th>
<th>Cumulative percentage of variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily rainfall</td>
</tr>
<tr>
<td>1</td>
<td>54.85</td>
</tr>
<tr>
<td>2</td>
<td>62.94</td>
</tr>
<tr>
<td>3</td>
<td>68.09</td>
</tr>
<tr>
<td>4</td>
<td>72.37</td>
</tr>
<tr>
<td>5</td>
<td>74.67</td>
</tr>
<tr>
<td>6</td>
<td>76.65</td>
</tr>
</tbody>
</table>
Gibergans (2001) for all Catalonia using daily data shows a good agreement, and allows the results for the period 1996–2004 to be taken to be sufficiently representative.

Fig. 4 shows the regionalization in 8 clusters when the three previous ones are considered. Comparison with Fig. 3 also shows a good agreement and allows identification of the clusters with the greatest contribution of convective rainfall and heavy rainfalls. The IBC are divided into not very well-defined pluviometric regions when only monthly rainfall data are considered, but this figure changes to eight well-defined pluviometric regions when the influence of the $\beta$ parameter and daily rainfall are included. This fact is important not only for the design of Intensity Duration Frequency (IDF) curves for each region but also for the local rainfall forecasting (Llasat, 2001), mainly for improvement of the warning system. One observation is that the regions with the greatest contribution of convective precipitation (3 and 7) have values above 30% of the total annual rainfall, i.e., more than 150 mm/year are produced by convective events. This percentage agrees with that obtained from the Jardí series, longer than the SAIH series, that would be included in region 7. This fact constitutes a serious problem, because more than 65% of the population of Catalonia lives in regions 7 and 3. In these regions, the precipitation recorded between May and November has a convective contribution of above 50%. On the other hand, this value decreases to less than 40% in region 4.

Once this regionalization has been done, the most representative station of each region has been selected (Fig. 4). Fig. 5 shows the percentile distribution of $\beta$ values for each station. It can be noted that the percentile

![Fig. 5. Percentile distribution of $\beta$ values for the representative station of each group.](image)

Table 7

<table>
<thead>
<tr>
<th>Representative Station</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Group 6</th>
<th>Group 7</th>
<th>Group 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 &lt; \beta &lt; 0.3$</td>
<td>18.8</td>
<td>25.8</td>
<td>32.7</td>
<td>24.6</td>
<td>28.6</td>
<td>35.4</td>
<td>29.5</td>
<td>34.1</td>
</tr>
<tr>
<td>$0.3 &lt; \beta &lt; 0.8$</td>
<td>68.7</td>
<td>62.9</td>
<td>65.4</td>
<td>67.2</td>
<td>66.7</td>
<td>54.2</td>
<td>59.0</td>
<td>59.1</td>
</tr>
<tr>
<td>$\beta &gt; 0.8$</td>
<td>12.5</td>
<td>11.3</td>
<td>1.9</td>
<td>8.2</td>
<td>4.8</td>
<td>10.4</td>
<td>11.5</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Values are obtained for the most representative station of each group, included in second row and in Fig. 5. Data in brackets refer to the ratio between convective events ($\beta > 0$) and total events for each station.
distribution shows that 30% of them have values lower than 0.25, while a percentage ranging between 6% and 21% has values above 0.75. Region 1 shows the highest contribution of episodes with a high degree of convective precipitation, while in region 5 more than 75% of the convective events have a convective contribution of between 25% and 75%.

The distribution between the different types of episodes per raingauge shows that between 0.2% and 3% of the total are slightly convective (1–18% of annual precipitation), while the moderate convective ones have values between 1.5% and 6% (6–30% of annual precipitation), being concentrated in the Central Coast (region 7). Type 3 constitutes 0.5% of total episodes, but in some regions represents more than 5% of the total rainfall. The results are clearer when they relate to the representative station of each region (the one that has the nearest values to the average values of the cluster), as is shown in Table 7.

6. Conclusions

This paper has centred on obtaining an objective method of classification of rainfall episodes on the basis of raingauge data and its application to obtaining homogenous zones, taking into account their convective features. Two sources of rainfall data at surface have been considered in order to compare a long but local series (Jardi series) with a short but extensive series (SAIH series). After considering the antecedents in this field, the parameter $\beta$ has been introduced and the use of the term “convective” has been proposed for all those episodes in which $\beta$ is greater than zero, drawing up a classification of the rainfall events in the light of their greater or lesser convective character. In order to guarantee the $\beta$ parameter validity, convective events and their space distribution have been compared with weather radar information. The comparison between the $\beta$ fields obtained from the SAIH data with those obtained from the meteorological radar have determined that the reflectivity threshold to obtain pixels that could be considered as “convective” is close to 43 dBZ.

Comparison of the values obtained for the longest series with those obtained for the 126 raingauges over the period 1996–2002, corroborates the soundness of the latter. The spatial distribution shows that the percentage of convective episodes versus the total number of episodes recorded in the various zones of the Internal Basins of Catalonia ranges between 3% and 9%, and is responsible for a rainfall contribution of between 10% and 40%. The largest number of events occurs in summer and autumn. The distribution between the different types of episodes per raingauge shows that between 0.2% and 3% of the total are of slightly convective (type 1), giving rise in some cases to 18% of annual precipitation, while the moderate convective ones (type 2) have values between 1.5% and 6% and can be responsible for as much as 30% of annual precipitation, which is concentrated on the Central Coast (region 7). Type 3 (strongly convective) constitutes 0.5% of total episodes, but in some regions represents more than 5% of the total rainfall. If we consider all the moderate or heavy rainfall events (more than 35 mm are recorded at any point) that affect the region, 92% of those events are convective, with a distribution of 13% of type 1.47% of type 2 and 40% of type 3.

The application of the $\beta$ parameter to carry out a regionalization of the Internal Basins of Catalonia, in combination with daily rainfall data, allows eight sub-regions to be identified in which the features of the convective contribution to total precipitation are considerably different. The region with the highest contribution of very convective events is situated in the North, with more than 20% of the convective episodes, while region 3 records less than 6% of this kind. The $\beta$ parameter has been revealed to be a good indicator of convective activity, both from a meteorological and a climatological point of view. It can be used to substitute radar information when not available, or to complete it, in order to identify convective rainfall. The $\beta$ parameter improves the regionalization procedure on the basis of the convective rainfall features, which can help to improve the criteria used in the alert chain, which at present over the entire the region.

Acknowledgements

We would like to thank the Royal Academy of Sciences and Arts of Barcelona for providing us with the rainfall intensity data of the Jardi raingauge, the Agencia Catalana de l’Aigua de la Generalitat de Catalunya, for the SAIH data, and the Instituto Nacional de Meteorología for the radar data. This work has been sponsored by the MONEGRO (REN 2003-09617-C02-02) Spanish project, and the AMPHORE (Interreg IIIIB Medocc 2003-03-4.3-I-079) European project. Our thanks to T. Barrera for his kind collaboration and to T. Molloy for undertaking the language revision of this paper.

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