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Analysis of extreme rainfall in Barcelona using a microscale rain gauge network

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ABSTRACT: Extreme storms registered by the urban rain gauge network installed and supported by CLABSA (Clavegueram de Barcelona S. A.) in Barcelona in the period 1994–2001 have been investigated. Eleven rain events presenting intensities for durations between 5 min and 24 h with return periods equal to or larger than 5 years for any of the network gauges have been found. A cluster analysis has yielded four main classes of extreme rainfall events in this area, related to the meteorological scales involved: local (18%), mesoscale (37%) and synoptic storms (27%), as well as more complex rain events originated by multiscale mechanisms acting together (18%). An intensity index to classify extreme rainfall events in order to their complexity and severity, taking into account the contribution of the different scales implied in the rainfall processes, has been calculated. The frequency distribution of the intensity index values obtained for the urban network has resulted very similar to that calculated for rain data recorded by the Jardí gauge of the Observatory Fabra of Barcelona during 1927–1992 inclusive. Copyright © 2009 Royal Meteorological Society

KEY WORDS rain gauge network; extreme rainfall; storm classification

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1. Introduction

The relationship between the maximum rainfall amounts registered in time intervals of different durations for the same rainfall event is very important in certain applications, as the planning of the sewer network of a city or the design of civil engineering works (Sumner, 1978; Eicher, 1991), as well as providing information about the fine structure and the spatial and temporal organization of the rainfall, and, therefore, its origin. Some studies (Lorente and Redaño, 1991; Krajewski *et al.*, 2003; Villarini *et al.*, 2008) have been dedicated to this issue, due to the importance of this information in the investigation of the origin and evolution of the meteorological rainfall situation. Casas *et al.* (2004) investigated the relationship between the maximum rainfall rate values for time intervals from 5 min to 24 h in order to classify the extremely intense events recorded in Barcelona between 1927 and 1992.

In the work of Casas *et al.* (2004) 44 extreme rain events were selected from series of true maximum rainfall amounts in different time intervals registered by a Jardí gauge (Burgueño *et al.*, 1987, 1994) located in the Observatori Fabra of Barcelona during the period 1927–1992. These events, showing rainfall amounts with return periods equal to or longer than 5 years in any of the considered durations between 5 min and 24 h, were characterized and classified into four clearly differentiated groups reflecting the contribution of local, mid and synoptic scale processes respectively in the origin of the rainfall. In addition, the use of an intensity index, IP, (Casas *et al.*, 2004) taking into account the maximum rainfall rate registered for every storm in four characteristic durations (5 min, 1, 2 and 24 h) was suggested.

In order to compare the results obtained from rain data registered only by rain gauge with those calculated using data from a network, in the present work the study of Casas *et al.* (2004) has been extended to the intense storms registered between 1994 and 2001 by the urban rain gauge network installed and supported by CLABSA (Clavegueram de Barcelona S. A.), a company that controls the sewer systems of Barcelona (Lorente and Redaño, 1990; Enjamio *et al.*, 2005). The method of classification using the clusters analysis has been applied and the IP has also been calculated. The values obtained for this index are distributed in a very similar way to those obtained by Casas *et al.* (2004).

2. Analysis of the extreme rainfall registered by the microscale rain gauge network of Barcelona

The urban area of Barcelona (100 km^2 approximately) has a dense network of 23 high resolution tipping bucket

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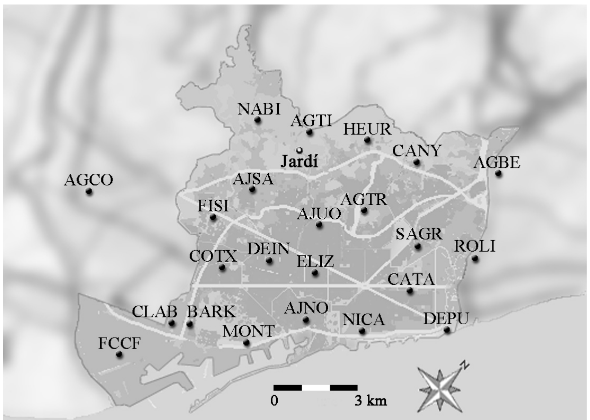

Figure 1. Microscale rain gauge network supported by CLABSA in Barcelona. The position of the Fabra observatory is marked as Jardí.

Table I. Microscale rain gauge network supported by CLABSA in Barcelona.

Rain gauge		Location (UTM) (m)	
AGBE	AGBAR-Besòs	432 572	4 590 189
AGCO	AGBAR-Cornellà	422 530	4 579 549
AGTI	AGBAR-Tibidabo	426 690	4 586 494
AGTR	AGBAR-Turó de la Rovira	430 034	4 585 878
AJNO	Ajuntament, edifici novíssim	431 351	4 581 678
AJSA	Ajuntament, Sarrià-Sant Gervasi	426 648	4 583 627
AJUO	Ajuntament, Plaça Lesseps	429 270	4 584 410
BARK	Escola Barkeno	428 485	4 578 698
CANY	Centre Pau Casals (Canyelles)	430 181	4 588 414
CATA	Escola Catalònia	433 279	4 585 023
CLAB	CLABSA	427 987	4 578 247
COTX	Cotxeres de Sants	427 879	4 580 946
DEIN	Dipòsit Escola Industrial (Remota)	428 911	4 582 279
DEPU	Depuradora Besòs	435 184	4 584 975
ELIZ	Casa Elizalde	430 373	4 583 077
FCCF	FCC-Zona Franca	427 443	4 576 149
FISI	Facultat de Físiques	426 341	4 582 030
HEUR	Palau de les Heures (F. Bosch i Gimpera)	428 357	4 587 775
MONT	Castell de Montjuic	430 431	4 579 649
NABI	Escola Nabi (Vallvidrera)	425 042	4 585 529
NICA	Poliesportiu Nova-Icària	433 035	4 582 822
ROLI	Ronda Litoral Tram 9, Sant Andreu	434 117	4 587 439
SAGR	Centre Cívic Sagrera	432 334	4 586 332

rain gauges (Figure 1, Table I). The rain gauges (Geónica S. A) have a collector funnel of area 400 cm^2 and a resolution of 0.1 mm. The integration time is 1 min and no correction has been applied to the data supplied by the equipment, since the curve of calibration of the instruments has not been provided by the manufacturer. Therefore, the maximum intensities calculated for durations shorter than 1 h could have been affected by an error of 10% (Lanza *et al*., 2006; Sevruk *et al*., 2009), whereas for durations longer than 2 h the error determining the intensity is generally smaller than 5%.

The complete records of 17 rain gauges from 1994 and 22 from 1996 onwards are available. From the rain data recorded, the true maximum rainfall amounts, i.e. the maximum amounts determined from time intervals unrestricted by fixed beginning or ending times (WMO, 1986), registered in Barcelona for durations between 5 min and 24 h in the period 1994–2001 have been calculated. Storms showing rainfall rates with return period equal to or longer than 5 years for any of the durations considered between 5 min and 24 h have been selected. Table II shows the 45 cases selected, corresponding to 11 actual rainfall events, most of them being registered with amounts up to the threshold considered by more than one gauge. The rainfall events selected are: 29 September and 19 October, 1994 (290 994 and 191 094); 24 August and 21 September 1995 (240 895, 210 995); 7 August and 13–14 October 1996 (070 896 and 141 096); 2 and 3 December 1998 (031 298), 3 and 13–14 September 1999 (030 999 and 140 999); 15 July and 9 October 2001 (150 701 and 091 001).

For all of the 45 rain cases selected, the IP proposed by Casas *et al*. (2004) has also been calculated. This index considers the extreme and severe behaviours of the storms, and is defined as (1):

$$IP(T) = \frac{1}{4}\left\{\frac{I_5}{I(5,T)} + \frac{I_{60}}{I(60,T)} + \frac{I_{120}}{I(120,T)} + \frac{I_{1440}}{I(1440,T)}\right\} \quad (1)$$

The IDF generalized equation used in this work for Barcelona (2) has been obtained by Casas *et al*. (2004):

$$I(t,T) = \frac{19\log T + 23}{(13+t)^{0.87}} \quad (2)$$

with $I(t,T)$ being the IDF generalized equation of the site of interest (duration t in minutes and return period T in years), and I_t the registered maximum intensity for every storm and t duration. Table III shows the index calculated for the return period of 5 years.

The IP reflects the severity of the registered rainfall taking into account the contribution of the different meteorological scales in the origin of the storm. The highest values of this index are reached usually in storms presenting high rainfall intensities for each of the time intervals corresponding to every meteorological scale, even though a singular storm could have a high IP for the extraordinary contribution of an only meteorological scale.

Due to their spatial and temporal characteristics, three of the 11 rainfall events selected show a clear synoptic behaviour, 29 September 1994 (290 994), 14 October 1996 (141 096) and 3 December 1998 (031 298), being registered intensities with return period higher than

Table II. Maximum rainfall precipitation (in mm) registered in durations from 5 to 1440 min (24 h) for every of the selected extreme rainfall cases.

Gauge	DDMMYY	5	10	15	20	25	30	35	40	45	50	55	60	120	360	720	1440
CANY	290994	3.0	4.7	6.3	8.0	10.1	12.2	13.9	15.0	16.3	17.4	18.6	19.7	35.1	**82.5**	**82.5**	85.1
DEPU	290994	4.3	6.5	8.1	10.6	13.1	15.8	17.6	19.3	20.5	22.0	23.6	24.9	41.4	**78.0**	**88.1**	91.0
COTX	191094	7.7	13.1	19.4	25.0	29.1	33.4	36.2	38.1	40.7	43.1	43.9	45.2	**63.2**	71.7	71.7	71.7
MONT	191094	8.7	11.3	15.7	17.7	19.8	22.4	25.6	28.5	29.5	32.6	34.2	36.2	60.3	**72.7**	72.7	72.7
AJNO	240895	11.7	21.3	29.1	**37.9**	**46.5**	**54.3**	**60.7**	**66.8**	**73.9**	**78.1**	**79.5**	**80.7**	**94.2**	**131.3**	**133.1**	**133.1**
AJNO	210995	11.4	19.9	26.3	34.6	**41.3**	**46.3**	**48.6**	**50.3**	**51.2**	**51.7**	52.1	52.6	54.6	55.3	55.3	56.3
AJUO	210995	**19.9**	**33.8**	**46.3**	**53.0**	**59.6**	**65.3**	**69.6**	**72.5**	**74.4**	**75.6**	**76.1**	**79.7**	**91.2**	**91.8**	**91.8**	94.2
COTX	210995	9.6	15.6	24.9	30.8	**39.5**	**45.4**	**47.0**	47.6	49.5	50.8	51.5	51.8	53.9	55.0	55.0	57.0
SAGR	210995	8.7	15.7	22.1	28.1	34.2	40.7	**47.4**	53.8	**59.7**	**66.0**	**72.2**	**77.9**	**89.3**	**89.4**	**89.4**	92.7
CLAB	070896	**19.4**	**25.6**	27.6	28.8	29.8	31.3	31.7	32.0	32.4	32.5	32.6	32.6	32.6	32.6	32.6	32.8
AGBE	141096	6.3	10.9	13.9	15.2	16.0	16.9	20.0	22.3	25.2	26.2	26.6	27.3	33.7	67.5	**85.3**	**105.3**
AJNO	141096	6.4	10.1	11.8	13.5	15.0	18.2	22.2	24.4	27.6	28.6	29.0	29.2	39.3	**74.1**	**92.8**	**103.5**
COTX	141096	3.8	6.2	7.9	9.4	10.3	10.8	11.6	12.0	12.6	14.0	15.4	16.1	28.1	64.8	80.4	**95.9**
ELIZ	141096	5.7	8.9	13.0	14.7	15.7	18.4	22.9	24.5	27.6	29.1	29.9	30.2	37.6	**75.4**	**94.5**	**108.1**
MONT	141096	7.0	10.1	13.2	14.5	15.3	17.6	22.9	25.2	28.0	30.0	30.6	30.8	39.6	**79.2**	**93.6**	**103.9**
NICA	141096	6.2	9.4	13.4	15.4	16.7	17.8	20.4	25.3	29.0	29.9	31.0	31.5	38.8	**80.8**	**96.5**	**108.2**
SAGR	141096	5.9	11.0	14.3	15.5	16.8	18.8	22.2	25.0	27.9	28.9	29.4	29.7	37.6	**76.2**	**93.8**	**110.1**
AGBE	031298	3.4	5.8	8.1	10.2	12.3	14.7	16.7	18.2	19.8	21.9	23.8	26.3	37.8	65.5	**87.8**	**110.2**
AGCO	031298	4.8	8.6	12.2	15.5	17.4	18.3	19.2	19.9	20.5	21.0	21.8	22.7	29.5	57.1	**93.9**	**135.7**
AGTI	031298	3.2	5.5	7.7	8.7	10.2	11.6	12.7	13.5	14.4	16.1	18.2	20.1	29.9	52.1	75.2	**98.7**
AGTR	031298	3.5	6.3	9.0	11.8	14.7	16.6	17.9	19.0	19.8	21.1	21.8	23.4	32.8	55.3	80.8	**103.4**
AJSA	031298	3.1	4.6	6.5	7.7	8.6	9.6	10.2	10.9	11.7	12.4	13.5	15.9	26.0	48.5	78.8	**106.5**
BARK	031298	3.3	5.6	7.1	8.4	9.7	11.0	11.8	12.6	13.3	13.9	14.6	15.1	22.0	48.6	**84.4**	**121.1**
CANY	031298	4.2	7.3	9.4	12.1	14.5	16.7	18.6	19.8	21.4	23.5	25.7	27.9	37.3	56.2	78.4	**101.5**
COTX	031298	2.6	4.0	5.0	6.1	7.1	7.7	8.1	8.7	9.3	9.9	10.4	10.8	19.2	45.0	77.8	**109.1**
DEPU	031298	7.2	10.5	13.2	15.7	17.6	19.0	19.7	20.4	21.5	22.6	23.7	25.5	34.3	54.9	80.4	**106.7**
ELIZ	031298	3.7	5.8	7.1	8.0	9.4	10.2	10.8	11.3	12.3	13.0	14.4	16.9	26.6	50.3	81.8	**111.5**
FCCF	031298	4.3	7.1	9.5	11.0	12.0	12.7	13.2	13.9	14.6	15.3	16.0	16.4	22.5	45.3	77.3	**111.1**
HEUR	031298	5.0	9.7	12.8	17.1	20.0	23.1	25.4	26.7	28.5	30.1	32.4	36.0	50.8	**79.2**	**108.0**	**134.0**
SAGR	031298	4.4	7.7	10.9	14.6	16.8	19.1	20.4	21.6	23.2	24.6	26.7	29.3	40.3	63.1	**90.3**	**114.2**
BARK	030999	13.7	23.9	**32.2**	**39.9**	**44.5**	**46.6**	**47.5**	47.9	48.0	48.2	48.3	48.5	50.7	56.0	56.1	56.1
AGCO	140999	12.6	23.1	31.0	**37.9**	**43.7**	**49.1**	**53.8**	**56.0**	**57.2**	**57.9**	**58.6**	**59.8**	60.6	60.7	64.1	65.9
AJSA	140999	**16.9**	**29.4**	**36.0**	**42.3**	**47.7**	**53.7**	**57.3**	**59.9**	**61.9**	**63.6**	**65.1**	**66.1**	**67.3**	67.3	69.8	74.3
BARK	140999	13.0	20.4	30.3	**37.9**	**42.4**	**46.3**	**48.8**	**50.4**	**51.3**	**52.0**	**54.4**	**55.4**	56.7	56.7	60.0	60.1
CATA	140999	11.6	22.5	30.0	34.7	37.9	40.2	41.7	42.6	43.3	43.5	44.3	45.5	46.4	46.4	55.8	**96.4**
CLAB	140999	12.2	20.8	31.0	**36.8**	**40.5**	**44.2**	**46.6**	47.6	48.3	49.2	50.9	51.7	52.6	52.6	55.2	55.3
COTX	140999	14.5	**25.3**	**34.1**	**40.6**	**45.5**	**49.6**	**52.2**	**54.3**	**55.4**	**56.0**	**56.6**	**57.3**	58.3	58.3	60.1	60.3
FCCF	140999	12.9	23.2	**32.5**	**38.1**	**43.2**	**46.9**	**48.9**	**49.5**	49.8	**52.1**	**53.1**	53.5	53.9	53.9	58.9	59.0
FISI	140999	8.7	16.3	24.3	31.8	37.5	**42.7**	**46.6**	**49.4**	**51.4**	**52.7**	**54.2**	**55.3**	56.2	56.2	57.3	58.0
HEUR	140999	11.4	20.3	24.0	28.8	35.2	41.8	**47.1**	**50.8**	**54.7**	**56.8**	**57.9**	**58.6**	60.0	60.2	63.5	78.2
MONT	140999	14.2	**25.7**	**33.6**	**38.2**	**40.9**	42.4	44.4	45.6	46.7	47.2	48.0	49.4	50.9	51.0	58.1	58.7
NABI	140999	7.9	13.3	20.0	25.5	33.0	37.3	41.5	45.9	**50.9**	**54.0**	**56.0**	**57.5**	60.0	60.0	62.8	63.7
ROLI	140999	9.5	16.8	22.7	26.9	34.5	40.6	43.9	46.1	48.8	**52.1**	52.4	52.5	53.5	53.5	53.5	**102.0**
AGTR	150701	**15.8**	19.3	20.7	21.2	25.8	28.7	29.8	30.3	30.3	31.4	34.4	39.2	**64.9**	68.7	69.7	69.7
AGTI	091001	**25.7**	**33.2**	**33.2**	35.0	35.0	35.0	35.0	35.0	35.0	35.1	35.1	35.1	41.9	41.9	42.8	43.1

In bold, quantities that have exceeded the return period of 5 years.

5 years (Table II) for the typical synoptic scale durations of 12 and 24 h (Orlanski, 1975). The event 7 August 1996 (070 896) is clearly a local storm showing intensities with return period higher than 5 years only for durations of 5 and 10 min, and event 9 October 2001 (091 001) shows high intensities also for durations shorter than 1 h, which can be considered to be typical of the atmospheric microscale. The rest of the events show high intensities for the typical durations of the meteorological mesoscale, i.e. between 1 and 12 h. So, the event registered on 24 August 1995 (240 895), shows a very high value of the IP, 1.29 (Table III), and high intensities registered for a large range of durations between 20 min and 24 h. Rainfall corresponding to 21 September 1995 (210 995), shows a

Table III. Intensity index calculated for each of the selected rainfall cases and return period of 5 years.

Gauge	DDMMYY	IP(5)
CANY	290 994	0.50
DEPU	290 994	0.59
COTX	191 094	0.77
MONT	191 094	0.74
AJNO	240 895	1.29
AJNO	210 995	0.79
AJUO	210 995	1.30
COTX	210 995	0.76
SAGR	210 995	1.10
CLAB	070 896	0.68
AGBE	141 096	0.64
AJNO	141 096	0.67
COTX	141 096	0.50
ELIZ	141 096	0.66
MONT	141 096	0.69
NICA	141 096	0.68
SAGR	141 096	0.67
AGBE	031 298	0.61
AGCO	031 298	0.65
AGTI	031 298	0.52
AGTR	031 298	0.57
AJSA	031 298	0.51
BARK	031 298	0.53
CANY	031 298	0.61
COTX	031 298	0.45
DEPU	031 298	0.75
ELIZ	031 298	0.54
FCCF	031 298	0.53
HEUR	031 298	0.80
SAGR	031 298	0.67
BARK	030 999	0.80
AGCO	140 999	0.90
AJSA	140 999	1.04
BARK	140 999	0.85
CLAB	140 999	0.79
CATA	140 999	0.84
COTX	140 999	0.89
FCCF	140 999	0.83
FISI	140 999	0.77
HEUR	140 999	0.90
MONT	140 999	0.82
NABI	140 999	0.80
ROLI	140 999	0.88
AGTR	150 701	0.88
AGTI	091 001	0.86

clear mesoscale behaviour for AJNO, COTX and SAGR gauges, whereas for AJUO the calculated IP has a very high value, 1.30, due to the high intensities registered for the four durations representing each scale: 19.9 mm in 5 min (return period $T \approx 25$ years), 79.7 mm in 1 h ($T \approx 50$ years) 91.2 mm in 2 h ($T \approx 40$ years) and 94.2 mm in 24 h (slightly below the $T = 5$ years). The event corresponding to 14 September, 1999 (140 999) shows mesoscale characteristics also for most of the gauges, whereas the index for AJSA results 1.04 and for three of the four representative durations the rainfall amounts are high: 16.9 mm in 5 min (return period $T \approx 10$ years), 66.1 mm in 1 h ($T \approx 15$ years) and 67.3 mm in 2 h ($T \approx 7$ years).

The objective classification of the 45 cases shown in Table II has been done using the clusters analysis technique (Anderberg, 1973). The dendrogram resulted is shown in Figure 2. The first vertical line drawn (short solid line L1) intersecting the hierarchical tree divides group IV from the rest of cases. This group is constituted, as expected, by AJNO 24 August 1995 (240 895) and AJUO 21 August 1995 (210 995), two cases presenting the highest values of the intensity index: 1.29 and 1.30 (Table III), showing high rainfall amounts for more than one scale. The event on 24 August 1995 (240 895) has presented intensities over the threshold imposed of 5 year return period for the gauge AJNO, for a wide range of durations between 20 min and 24 h, indicating an origin caused by mid and large scale meteorological processes acting together, as well as the events classified in group IV by Casas *et al*. (2004). In the rain event registered on 21 September 1995 (210 995), as commented, the storm has presented high rain intensities for all durations between 5 min and 24 h, depending on the gauge, showing its complex structure. Particularly, AJUO 21 September 1995 (210 995) exceeds the imposed threshold for an extremely wide range between 5 min and 12 h, being the 24 h amount 94.2 mm, a value very slightly below the 95.9 mm corresponding to the 5 year return period. Group IV is, therefore, constituted by the most complex storms, showing the joint action of processes corresponding to more than one of the meteorological scales.

Drawing a second vertical line (solid line L2, Figure 2), groups I, II and III have been obtained. Group I, as expected due to its clear time scale, is constituted by two storms registered on 7 August 1996 (CLAB 070 896) and 9 October 2001 (AGTI 091 001). All cases corresponding to the events 29 September 1994 (290 994), 14 October 1996 (141 096) and 3 December 1998 (031 298) (22 records) have been classified as a common group. As commented before, these events have a clear synoptic origin (group III). The 19 remaining cases constitute group II, most of them showing high intensities for mesoscale durations lower than 6 h. Attending to the subdivision of group II (dashed line L3, Figure 2), subgroup IIA identifying small mesoscale consists of AJNO and COTX 21 September 1995 (210 995) and all records corresponding to 3 September 1999 (030 999) and 14 September 1999 (140 999). Subgroup IIB, corresponding to large mesoscale, is constituted for all cases of 19 October 1994 (191 094) and 15 July 2001 (150 701). An isolated case 21 September 1995 (SAGR 210 995) remains out of this sub-classification. Despite of its situation into group II, this case could be included into group IV due to its high intensity index, 1.10 (Table III) and its temporal characteristics showing high rainfall rates in the mid and large

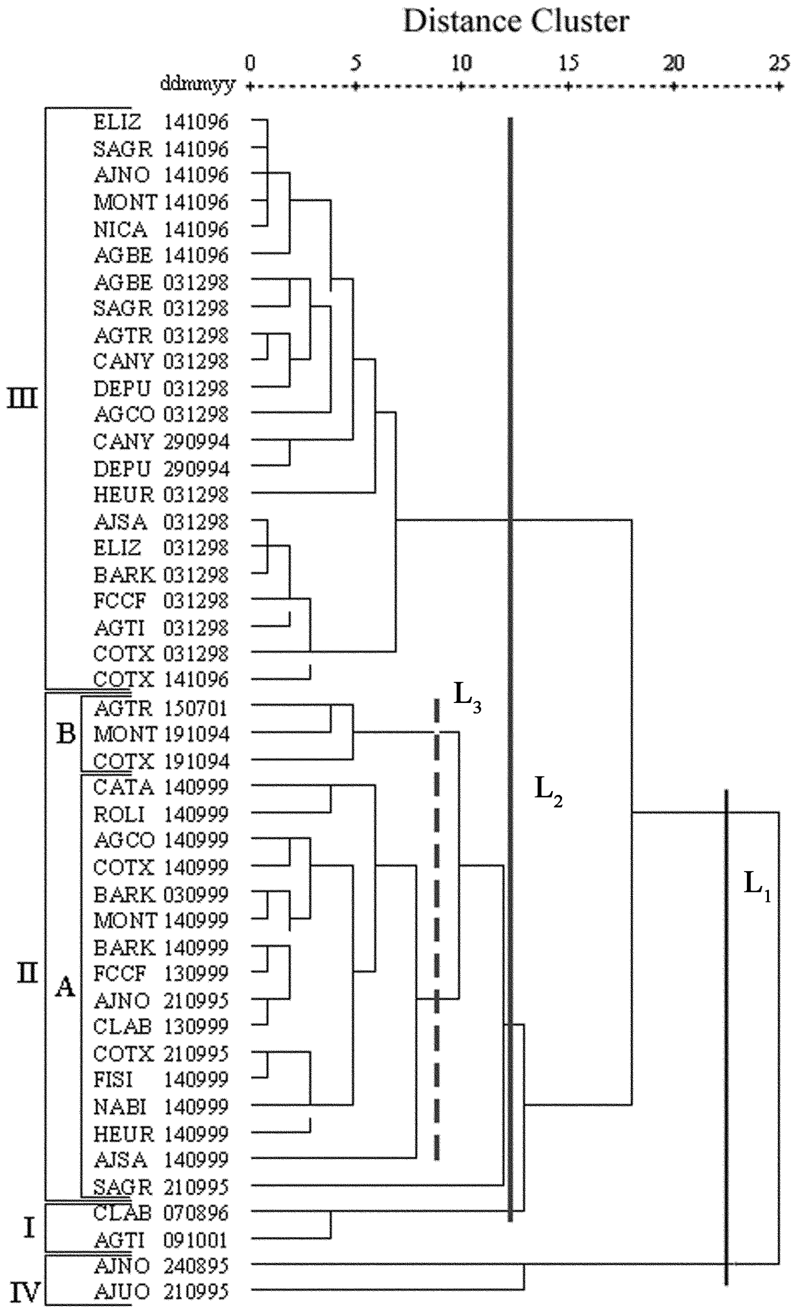

Figure 2. Dendrogram of the 45 rain cases selected.

scale (from 35 min. to 24 h). Table IV shows the classification obtained.

Whereas the two microscale storms detected 7 August 1996, 9 October 2001 (CLAB 070 896 and AGTI 091 001) have only been registered by one gauge with amounts over the imposed threshold ($T \geq 5$ years), the remaining events, specially those corresponding to synoptic scale (group III), have been registered by many gauges due to their larger spatial scale. It is noted that the synoptic rainfall which occurred on 29 September 1994 only appears to have been registered by two of the raingauges (CANY and DEPU 290 994) because the rest were still not working.

The selected rainfall events registered by the rain gauge network have not the same distribution in groups than those registered by the Jardí gauge (Casas *et al.*, 2004), due to the influence of the spatial scale of each group. For example, 8 of 44 selected events registered by the Jardí gauge (1927–1992) were local storms of group I, the same ratio of 18% than the two storms among the 11 actual events registered by the urban network, but these two events have only been registered by one gauge with amounts over the imposed threshold of 5-year return period, and therefore constitute only the 4% of the 45 cases of Table II. Similarly, synoptic events classified in group III were the 21% of the Jardí sample, a similar ratio than the 27% corresponding to the urban network (3 of the 11 actual events), but in this case, as a consequence of the repetitions recorded by several rain gauges for a same event, group III represents 49% of the

Table IV. Classification of the 45 rain cases selected.

Group I		Group II				Group III		Group IV	
		IIA		IIB					
CLAB	070896	AJNO	210995	MONT	191094	CANY	290994	AJNO	240895
AGTI	091001	COTX	210995	COTX	191094	DEPU	290994	AJUO	210995
		BARK	030999	AGTR	150701	AGBE	141096	SAGR	210995
		AGCO	140999			AJNO	141096		
		AJSA	140999			COTX	141096		
		BARK	140999			ELIZ	141096		
		CLAB	140999			MONT	141096		
		CATA	140999			NICA	141096		
		COTX	140999			SAGR	141096		
		FCCF	140999			AGBE	031298		
		FISI	140999			AGCO	031298		
		HEUR	140999			AGTI	031298		
		MONT	140999			AGTR	031298		
		NABI	140999			AJSA	031298		
		ROLI	140999			BARK	031298		
						CANY	031298		
						COTX	031298		
						DEPU	031298		
						ELIZ	031298		
						FCCF	031298		
						HEUR	031298		
						SAGR	031298		

45 cases. The effect of the repetitions is not so notable in group II and IV, where rain events corresponding to the mesoscale were 50% of the Jardí selection, whereas the cases corresponding to the four rain network events clearly classified as mesoscale storms, together with some of the records of the complex storm of 21 September 1995 (210 995), have yielded 40% of the 45 cases. The percentages corresponding to group IV were 11% for the Jardí selection and 7% for the network selection.

Despite of these different distributions in groups, both selections show a very similar IP behaviour. Figure 3 shows the IP calculated for the 45 selected cases and $T = 5$ years, with values between 0.4 and 0.6 for the synoptic scale cases, and higher than one for the three cases constituting group IV. In this figure the two samples of intensity indices calculated have been represented, the white ones corresponding to the rainfall events registered by the Jardí gauge (1927–1992), and black ones those calculated to the 45 cases registered by the urban network of CLABSA (1994–2001).

A fitting of the two samples of indices using the lognormal standard distribution function (3) has been essayed:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln x - m}{\sigma}\right)^2} \quad (3)$$

x being the statistic variable representing indexes IP, whereas m and σ are the mean and the standard deviation of the distributions ($\ln x$) obtained from the logarithm of the indices. Mean m is the scale parameter of the lognormal distribution and σ is the shape parameter. Their estimated values for the two fittings essayed are shown in Table V. Figure 3 shows these fittings also.

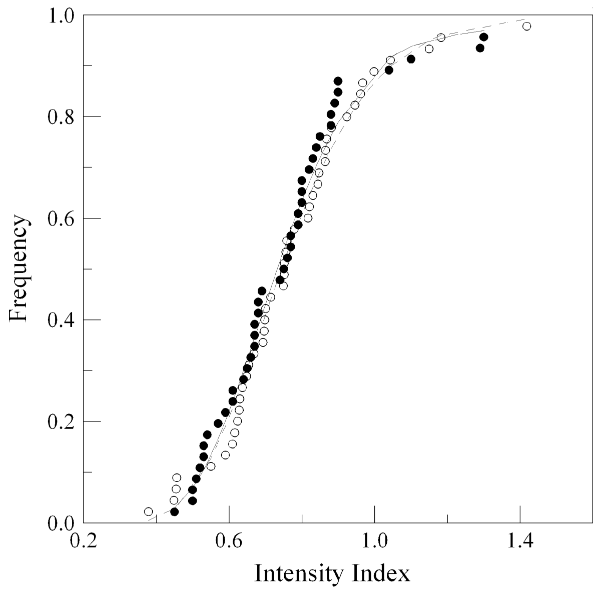

Figure 3. Intensity index values calculated for every storm selected and return period of 5 years. In white, storms registered by the Jardí gauge (1927–1992). In black, rain cases registered by CLABSA (1994–2001). The solid line is the lognormal distribution fitted to the CLABSA sample. The dashed line corresponds to the Jardí sample.

The results show the similar behaviour of the two samples of indices. With respect to the severity measure

Table V. Fitting parameters m and σ calculated for the two data sets of intensity index IP. Number of cases n.

	m	σ	n
IP (1927–1992)	0.7444	0.2651	44
IP (1994–2001)	0.7323	0.2574	45

and distribution of the extreme rain events in the zone, the sample of the 45 selected cases registered by the urban network in 8 years (1994–2001) seems to be almost equivalent to the sample of 44 events from the Jardí gauge in 66 years (1927–1992).

3. Conclusions

From the records of the rain gauge network supported by CLABSA in Barcelona in the period 1994–2001, the maximum rain precipitation for durations between 5 min and 24 h have been calculated. Extreme storms presenting a return period equal to or higher than 5 years for any of the durations considered have been selected. The selection has resulted in 45 rain cases corresponding to 11 real storms registered for several of the gauges of the rain network. These cases have been satisfactorily characterized and classified into four clearly differentiated groups using the cluster analysis technique. The first group contains highly intense storms with very short durations (equal or shorter than 15 min), representing the local rainfall events showing a clear seasonal influence and diurnal cycle. The second group corresponds to the typical mesoscale durations related to very active fronts moving slowly, where intense rainfall rate systems or mesoscale convective systems have been developed. The seasonal influence in this case is also clear. Synoptic rainfall events, with intensities exceeding the 5 year return period level only for the 12 and 24 h time interval, constitute the third group. Finally, a rainfall pattern showing high rates for large ranges of duration, associated to different scales acting together, has been found.

An Intensity Index, IP, taking into account the maximum rainfall in the 5 min, 1, 2 and 24 h time intervals has been calculated for every of the rain cases considered. This index reflects the contribution in the storm origin of local, mid and synoptic scale meteorological processes, and could be a measure of the severity and complexity of the observed rain. The calculated values of IP range from 0.4 to 0.6 for storms belonging to the synoptic scale, till values higher than one for the rain cases classified into group IV of the storms with small structures embedded in larger formations, such as mesocale organizations embedded into synoptic systems.

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