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Extreme storms and rainfall erosivity factor in Évora (Portugal)

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with 7 figures and 3 tables

Summary. In Alentejo region, situated in the south of Portugal, with a Mediterranean type of climate, rainfall has a strong seasonality, high interannual and spatial variability, occurring in a small number of events, some of them with high intensities. Alentejo has traditionally an extensive agricultural land use of winter cereals and pasture and so presents each year an extensive area of bare soils potentially subject to severe precipitation erosion. The aim of research is to determinate the relationships between hydrologic characteristics, total precipitation, precipitation intensity, rainfall erosivity factor and precipitation time distribution and the meteorological conditions of extreme storms, at a synoptic scale, so as to be able to forecast the magnitude and time frequency of extreme storm erosivity in Alentejo region.

Résumé. *Évenements de fortes précipitations et le facteur "R" des pluies à Évora (Portugal).* – Située au Sud du Portugal et caractérisée par un climat de type méditerranéen, la région du Alentejo est marquée par une forte variabilité spatiale et interannuelle des pluies et encore par un régime pluviométrique irrégulier. Celui-ci comporte des événements pluvieux peu fréquents mais qui peuvent se manifester avec une forte intensitée. Traditionnellement, l'exploration agricole des sols du Alentejo est extensive et se fait avec des céréales d'hiver et des pâturages, c'est pourquoi, toutes les années, ces champs découverts sont exposés aux sévères précipitations érosives. Ainsi, l'object de cette recherche consiste à déterminer les rapports existants entre les caracteristiques hydrologiques des événements (la précipitation totale, l'intensité des pluies, le facteur d'érosivité des pluies et distribution temporelle des précipitations) et ses conditions météorologiques à l'échelle synoptique, de façon à évaluer la magnitude et la fréquence de l'érosivité provoquée par les fortes pluies.

Zusammenfassung. *Die gelegentlich starken Niederschläge und der Erosionsfaktor des Niederschlags in Évora (Portugal).* – Die im Süden Portugals gelegene und durch ein mediterranes Klima gekennzeichnete Region des Alentejo weist im Jahresverlauf räumlich erhebliche Schwankungen in Form und Menge des Niederschlags auf. Trockene und feuchte Perioden wechseln einander ab, wobei letztere zum Teil Regenfälle umfassen, die – wenn auch selten – sehr intensiv sein können. Die Böden des Alentejo werden traditionell extensiv bewirtschaftet. Dabei überwiegen Wintergetreide und Weiden, was Ursache dafür ist, daß die nur durch eine schwache bzw. geringe Gründecke geschützten Felder jedes Jahr von der erosiven Wirkung des Regens betroffen sind, vor allem bei Regenfällen stärkerer Intensität. In dieser Arbeit soll der Zusammenhang zwischen den hydrologischen Merkmalen der Episoden starken Niederschlags (gesamte Niederschlagsmenge, Intensität des Niederschlags, Erosionsfaktor und zeitliche Verteilung des Niederschlags) und den hierfür verantwortlichen meteorologischen Bedingungen untersucht werden. Dies soll es ermöglichen, die Größe und Häufigkeit der Episoden vorherzusehen, die potentiell erosive Auswirkungen auf die Böden des Alentejo haben können.

Introduction

In Alentejo region, situated in the south of Portugal, the precipitation has a large spatial and annual variability (Ventura 1994). The Alentejo region, with traditional agriculture of winter cereals and pasture, is potentiality subject to severe soil erosion due to precipitation. Many Portuguese studies have been made in order to predict the soil loss due to precipitation (hydric soil erosion)

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in agricultural areas (Ferreira et al. 1985, Roxo et al. 1993, 1994, Roxo 1994) as in forests (Rocha et al. 1986): but the results show that is difficult to find a unique rainfall index. Besides, the field determination of soil erodibility is not yet available at regional scale. Thus, it has not been easy to identify the threshold of precipitation from which the significative hydric soil erosion occurs.

The study concerns the characteristics of the erosive precipitation in Alentejo and presents the preliminary results. The overall objective of the research is to determine the relationships between hydrologic characteristics, total precipitation, precipitation intensity, rainfall erosivity factor and precipitation time distribution and the meteorological conditions of extreme storms, at a synoptic scale, in order to forecast the magnitude and time frequency of extreme storm erosivity at Évora-Cemitério raingauge, in Alentejo region, based on the meteorological conditions.

Data Acquisition

Hydrologic data

The hydrologic data acquisition was made in four steps:

1. Digitization of daily rainfall charts from 1941 to 1992 of Évora-Cemitério recording raingauge (with a total of 18994 charts).
2. Based on the digitized record, storms were listed on the basis of: date and hour of beginning, total precipitation, average precipitation intensity and total duration of storms. According to many authors the total storm duration is the time period with precipitation, possibly intermittent, preceded and followed at least by 6 h of precipitation absence. This study assumes that a 6 h interval assures the existence of independent storms.
3. Selection, from the list of storms, of the extreme storms, which are the storms with produced at least 25.4 mm (1 inch) of precipitation.
4. Using time intervals in order of magnitude of the minute extreme storms were analysed for: total precipitation, average precipitation intensity, total storm duration, hyetogram with one minute of time increment chronological graph of rainfall phenomena (expressed in percentage) and localisation of maximum cumulative precipitation between the four quarters the total duration of storm.

Meteorological data

In order to study the main synoptic conditions of the extreme storms, the synoptic charts (surface and 500 hPa charts) and meteorological data tables from the Portuguese daily weather bulletin[1] were analysed and sixteen meteorological parameters were collected. The analysis was made for 1950 to 1992 period, sufficient to permit a statistical study.

Methodology and results

The distribution of extreme storms were studied by decade, months and quarter time period of total precipitation (Table 1) and to precipitation intensity in 30 min (Table 2).

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1 Boletim Meteorológico Diário, Instituto de Meteorologia, Lisboa.

Table 1. Extreme Storms characterization. Évora-Cemitério recording raingauge.

Decade	Extreme Storms Number	
	P>= 25.4 mm	P>= 50.8 mm
1940–1949	36	9
1950–1959	45	11
1960–1969	82	12
1970–1979	44	8
1980–1989	61	12
1990–1992	8	0
Total	276	52

Month	Extreme Storms Number	
	P>= 25.4 mm	P>= 50.8 mm
October	28	5
November	46	9
December	34	10
January	42	8
February	38	7
March	33	6
April	19	2
May	12	1
June	8	1
July	4	1
August	1	0
September	11	2
Total	276	52

Quarter	Extreme Storms Number	
	P>= 25.4 mm	P>= 50.8 mm
Quarter1	85	15
Quarter2	74	14
Quarter3	68	12
Quarter4	47	12
Total	272	53

The extreme storms erosivity factors, R (Wischmeier 1978) were determinated according to Lencastre & Franco (1984) by

$$R = \frac{\sum_{i=1}^{n} E_i I_{30}}{1735} \qquad I_{30}\ \text{(mm/h)};\ R\ \text{(t.m.pé/acre)} \qquad (1)$$

and

Table 2. Extreme Storms precipitation intensity in 30 min. Évora-Cemitério recording raingauge.

	Extreme Storms Number	
Decade	I(mm/h)< T= 50 years	T= 50 years <I(mm/h)< T= 100 years
1940–1949	34	2
1950–1959	45	0
1960–1969	76	6
1970–1979	43	1
1980–1989	58	3
1990–1992	8	0
Total	264	12

	Extreme Storms Number	
Month	I(mm/h)< T= 50 years	T= 50 years <I(mm/h)< T= 100 years
October	26	2
November	45	1
December	34	0
January	42	0
February	37	1
March	32	1
April	18	1
May	12	0
June	5	3
July	2	2
August	0	1
September	11	0
Total	264	12

	Extreme Storms Number	
Quarter	I(mm/h)< T= 50 years	T= 50 years <I(mm/h)< T= 100 years
Quarter1	77	6
Quarter2	71	3
Quarter3	67	1
Quarter4	45	2
Total	260	12

I(T=50 years)=39.1 mm/h; I(T=100 years)=67.1 mm/h (Brandão, 1996)

$$E_i = (12.13 + 8.9 \, \text{Log} I_i) h_i \qquad I_i \text{ (mm/h)}; h_i \text{ (mm)}; E_i \text{ (t.m/ha)} \tag{2}$$

using four methodologies:

Method 1 – The discretization of each extreme storm into time-step increments is not considered. E_i is calculated using the total precipitation (h) and average precipitation intensity (I) of the extreme storm. R is calculated using the E of the extreme storm and the maximum precipitation intensity in 30 min (I_{30}).

Method 2 – Each extreme storm duration is sub-divided in 30 min time-steps. E_i is calculated using the precipitation (h_i) and the precipitation intensity (I_i) in 30 min time-steps. R is calculated using extreme storm E_i and the greater precipitation intensity occurred in the 30 min time-steps previously consider (I_{30}).

Method 3 – Each extreme storm duration is sub-divided in 30 min time-steps. E_i is calculated using the precipitation (h_i) and the precipitation intensity (I_i) in 30 min time-steps. R is calculated using extreme storm E_i and the maximum precipitation intensity in 30 min (I_{30}).

Method 4 – Each extreme storm duration is sub-divided in 1 min time-steps. E_i is calculated using the precipitation (h_i) and the precipitation intensity (I_i) in 1 min time-steps. R is calculated using extreme storm E_i and the maximum precipitation intensity in 30 min (I_{30}).

The application of these four methodologies allow to calculate four erosivity factors, R, for each extreme storms selected (Fig. 1).

The four group of R were organize on increase way. These incresing ordination show the methodology influence on the R magnitude (Fig. 2).

The time periods between occurrence of extreme storms with erosivity factor greater than 10 and its magnitude values were estimated by five probability distribution function: exponential, gumbel, gamma, log-normal, weibull and pearson III.

The exponential function was selected after the calculation of tree fitting tests, Qui^2, Kolmogorov-Smirnov and Cramer-Von-Mises.

The exponential function (3) with b equal 9.916 estimates the value magnitude and with b equal 8.803 estimates the time periods between the occurrence of extreme storms with erosivity factor greater than 10.

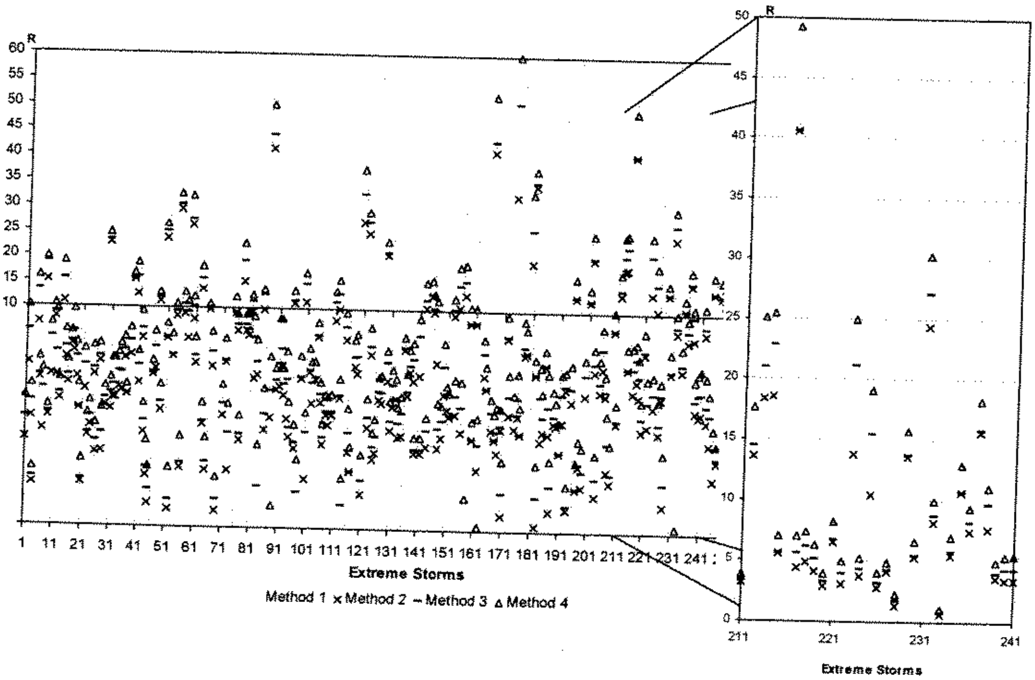

Fig. 1. Extreme storms erosivity factor in chronological order (Wischmeier 1978).

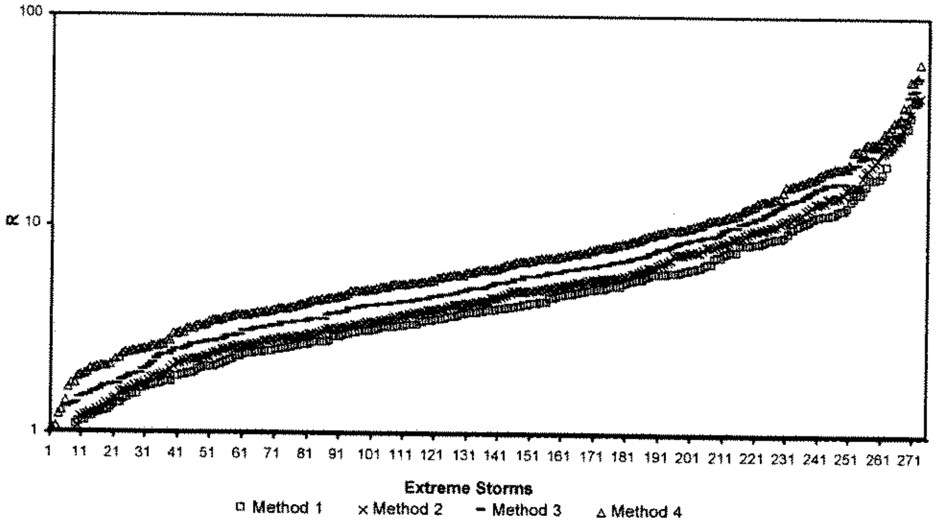

Fig. 2. Increasing ordination of extreme storms erosivity factor (WISCHMEIER 1978).

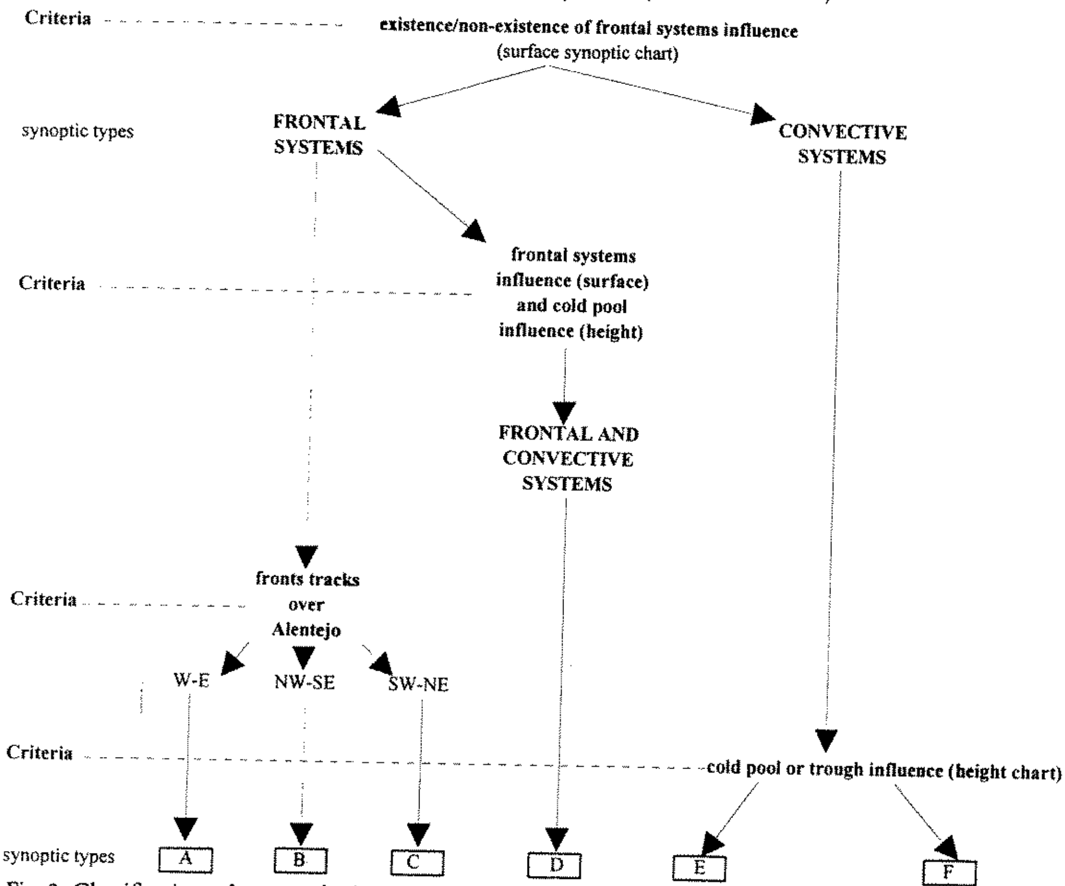

Fig. 3. Classification scheme and criteria to identify the main synoptic situations of extreme storms.

Table 3. Six synoptic situations (A to F).

SYNOPTIC SYSTEMS	Type	Fronts tracks over Alentejo	Predominant position of the low pressure center (surface)	Upper level (500 hPa) circulation
FRONTAL	A	W - E	- the low is southwest of Ireland - the low is northwest of Galice or over Galice	- Zonal - Trough (eastern part or axis)
	B	NW - SE	- the low is southwest of Ireland	- Zonal - Trough (eastern part)
	C	SW - NE	- the low is west of Iberian Peninsula or over western Iberian Peninsula	- Zonal - Trough (eastern part)
FRONTAL AND CONVECTIVE	D	W - E or SW - NE	- the low is west of Iberian Peninsula or over western Iberian Peninsula - the low is between Azores and Portugal - the low is south of Algarve (between Madeira and Cádiz Gulf)	- Cold pool is north of Galice or over Galice - Cold pool between Azores and Portugal - Cold pool between Madeira and Algarve or over Cádiz Gulf
CONVECTIVE	E	-	- the low is west of Iberian Peninsula or over western Iberian Peninsula - the low is between Azores and Portugal - the low is south of Algarve (between Madeira and Cádiz Gulf)	- Cold pool is north of Galice or over Galice - Cold pool between Azores and Portugal - Cold pool between Madeira and Algarve or over Cádiz Gulf
	F	-	- variable	- Trough (eastern part)

$$P\left[X_n \le x\right] = 1 - e^{-x/\beta} \qquad (3)$$

The study of synoptic situation allow to define a typology, based on the joint analysis of atmospheric conditions observed in altitude and surface maps. A restrict group of classification criteria was used. In Fig. 3, the adopted criteria and the resulting classification structure, with six different synoptic types, are presented. It must be pointed out that the typology definition was established taking into consideration the most representative synoptic situations of Ferreira (1985) and Ventura (1994) works. A short characterization of the different synoptic types is presented in Table 3.

Figs. 4, 5 and 6 show the summary statistics of the synoptic analysis of the extreme storms.

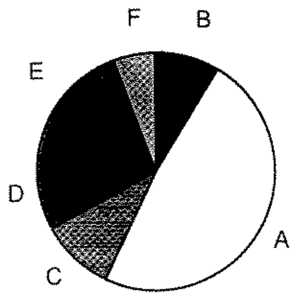

Fig. 4. Global frequency of the eight synoptic types (1950–1992).

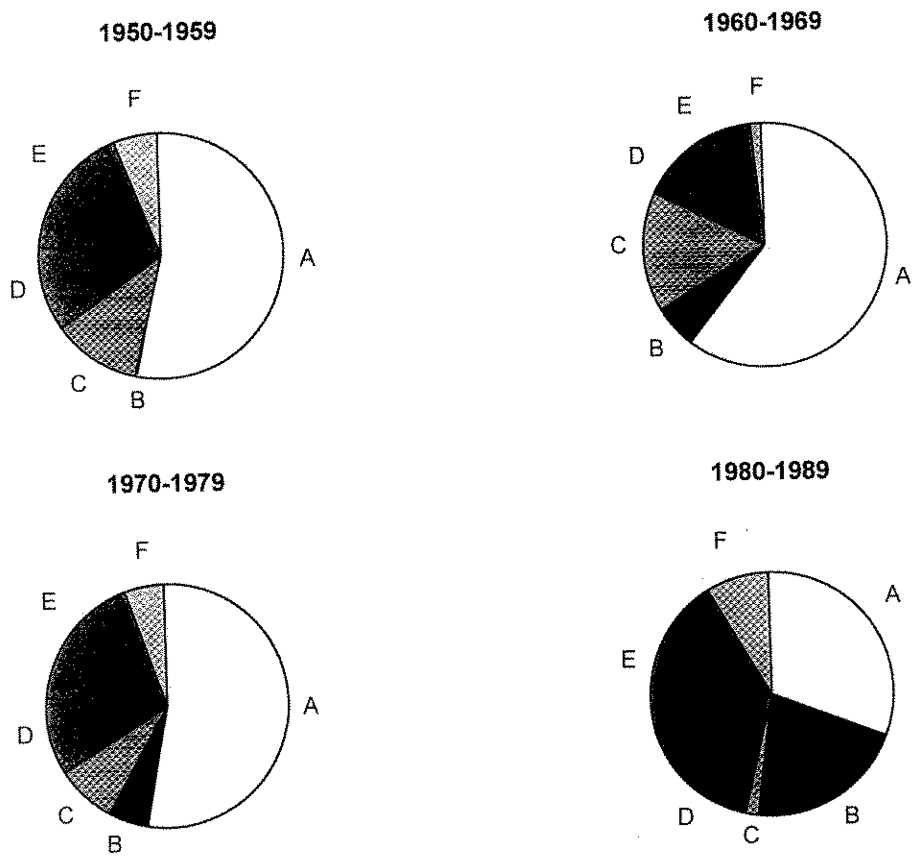

Fig. 5. Decade frequency of the eight synoptic types.

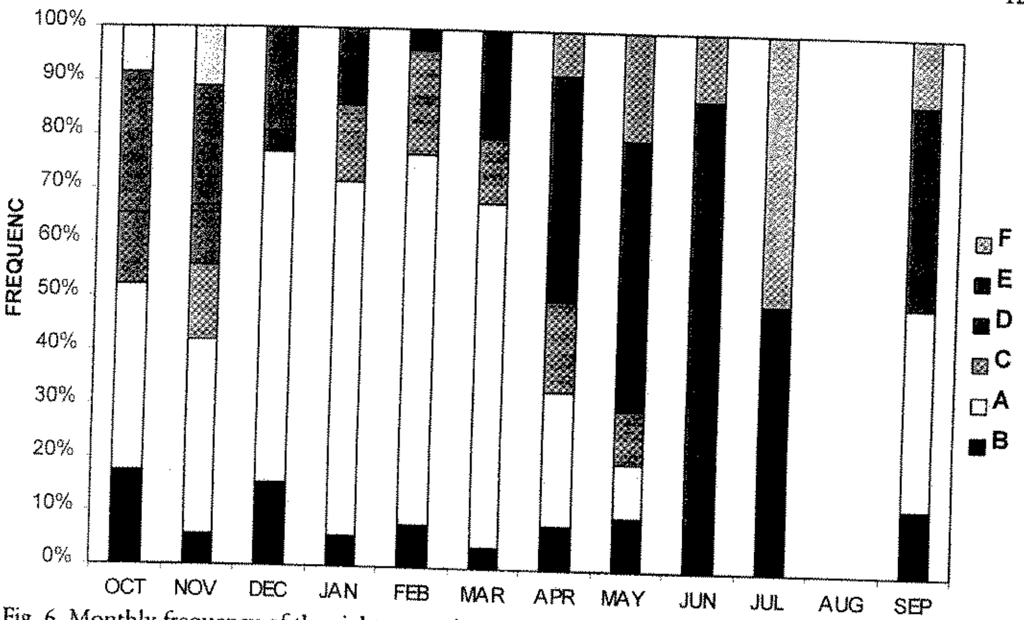

Fig. 6. Monthly frequency of the eight synoptic types (1950–1992).

Conclusions

The results of the analysis demonstrate some hydrologic characteristics and meteorological conditions of extreme storms and also the relationship between them.

The greatest number of extreme storms occurred during the sixties (29,7%).

November is the month with the greatest number of extreme storms (16,7%).

The highest values of erosivity Factor R were obtained applying method 4. They are close to those obtained by method 3.

The probability of the existence of R values greater than 10 as well as the estimation of its values, for a certain frequency, is carried out by exponential probability distribution function.

Comparing the global frenquency of the eight synoptic situations (Fig. 4): it is evident that frontal situations (A, B and C synoptic types) are predominant (67%) over convective situa- :ions (E and F synoptic types, with 24%) and mixed type (D synoptic type, with 9%). The A ›ynoptic type is predominant (48%): followed by E synoptic type (19%).

Considering the frontal situations, there is a clear predominance of frontal situations with VE trajectory over Alentejo region, which are responsible for about an half of the 211 extreme torms studied. The majority of the extreme storms observed at Évora-Cemitério raingauge are ssociated to frontal systems with W trajectory, being the heavy precipitation, generally, con- ıected to cold frontal activity.

The second most representative synoptic type is associated to the cold low (E type) which ın be characterizated by strong convective instability. Predominantly, these situations are due) the action of cold pools whose nucleus stabilizes over the Atlantic ocean between Madeira ıd Algarve, staying Alentejo region under the influence of the cold pools (nonfrontal synop- c systems) orient sectors.

The relative importance of synoptic types is similar in 50's, 60's and 70's decade (Fig. 5). However, the dominance of frontal types (A, B and C types) is more evident during the sixties. In contrast the synoptic distribution in 80's decade when there was a significant decrease on the frequency of W frontal situations (A type) which led to an increase of convective situations, namely the E synoptic type.

The synoptic types characterised by frontal situations present maximum absolute frequency between December and March while synoptic types characterised by convective situations are dominant, in relative frequency, between May and June (Fig. 6). Between September and November, frontal and convective situations present equal frequencies. In these months, there were much more extreme storms than in Spring.

The extreme storms are associated to different causes during the year and the month frequency can be linked to an annual rhythm. In Winter, frontal situation with W-E trajectory (A type) has the highest frequency. In Spring, the frontal situations have an accentuated fall and the convective situations rise.

The precipitation group 25.4–38.1 mm is predominant (60%): belonging 29% to A synoptic type. The quartil 1 group is predominant (28.6%). However, the association of quartil 2 and A synoptic type is dominant with 14.1%. The maximum precipitation intensity group in 30 min 2.8–18.6 mm/h is predominant (74.4%): in which 37.8% belongs to A synoptic type. The

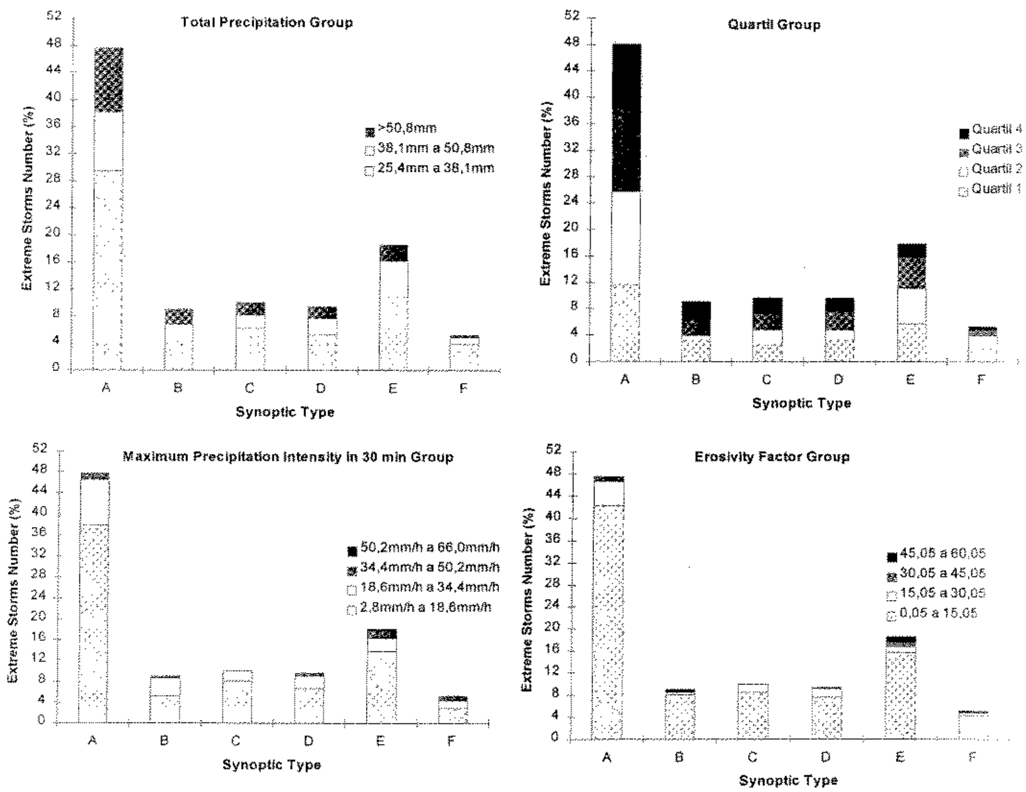

Fig. 7. Synoptic type and precipitation, quartil, maximum precipitation intensity in 30 min and erosivity factor groups.

R group 0.05–15.05 is predominant (86.7%): and 42.4% of this group belongs to A synoptic type (Fig. 7).

In the future the determination of erosivity factor (R) and the characterisation of synotic type of extreme storms will be made for the highest region of Portugal (Serra da Estrela region). This analyse will be based principally on two daily raingauges, Penhas Douradas and Covilhã. These raingauges are located at 1380 m (Penhas Douradas) and 745 m (Covilhã). Due to topographic characteristics of this region, it is expect a change on the predominant synoptic type and on the probability distribution function for the erosivity factor of extreme storms.

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