DAILY RAINFALL VARIABILITY IN THE SPANISH MEDITERRANEAN AREA

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INTRODUCTION

A dense daily precipitation database, extending from 1964 to 1993, has been created for the Mediterranean regions of Spain. It is composed of complete and homogeneous series at 410 rain gauge stations (347 in the coastal fringe of peninsular Spain, and 63 in the Balearic Islands, Fig. 1). The raw data consisted of the 3366 available daily precipitation records during some period between 1951 and 1995, provided by the Instituto Nacional de Meteorología of Spain (INM). A first selection was made to consider only stations with a minimum of 1000 data values (almost three years), which yielded a set of 2842 rain gauges. The inventory of these stations showed a great variety of record lengths, with only 5 stations with no missing data. Then, a search was performed to choose the longest sub-period of 1951-95 having the highest number of stations with tolerable completion. The final decision was to keep the 410 stations with 90% of data available during 1964-93 (30 years). An iterative method was followed to check the quality of the data, as well as to fill the missing data by interpolation from the surrounding stations. A detailed description of the method can be found in Romero et al. (1998a).

The region offers an interesting scenario for meso-climatological studies on time and spatial rainfall variability: Geomorphologically, it is characterized by important coastal relief units and complex distribution of sea and land masses (Fig. 1), leading to different exposures to the rain bearing maritime winds; climatically, the western Mediterranean is subject to strong seasonal variability, since it is a transition zone between the mid-latitude low pressure belt and the subtropical highs as a result of its latitude (between 36^0 and 44^0 N). Another important climatic characteristic of the region is the torrential aspect of rainfalls, mainly during the autumn. Most of the coastal stations have registered daily rainfalls greater than 200 mm (Font 1983).

In this study we present a preliminary characterization of the rainfalls in Mediterranean Spain, followed by an objective classification of the daily rainfall patterns and a subdivision of the region in daily rainfall affinity areas.

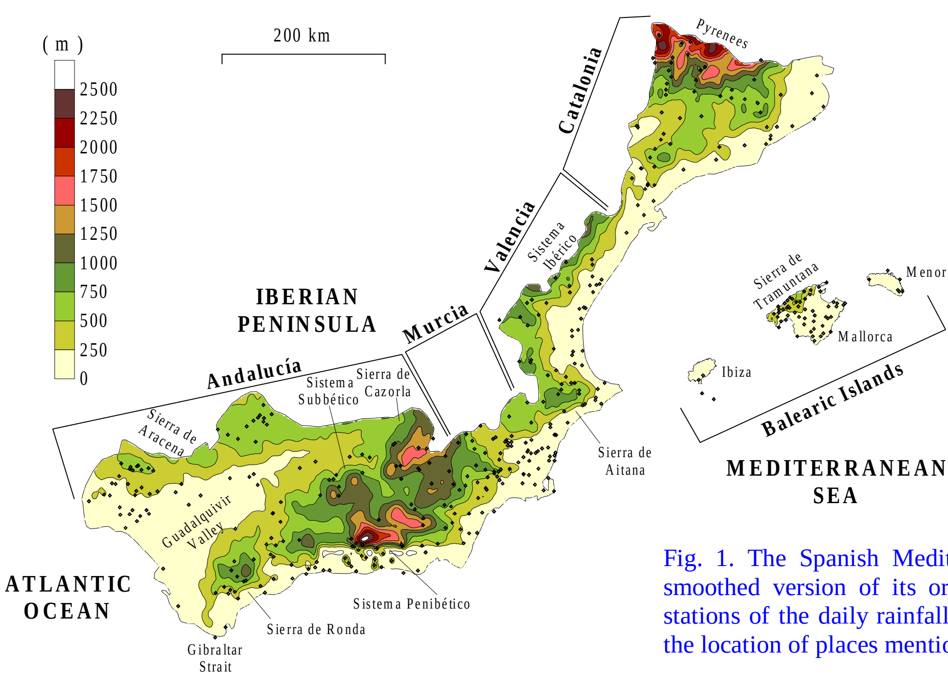

Fig. 1. The Spanish Mediterranean area. It includes a smoothed version of its orography, the position of the stations of the daily rainfall data base (410 in total), and the location of places mentioned in the text.

RAINFALL VARIABILITY

The yearly mean precipitation (Fig. 2) shows high amounts about Sierra de Ronda (in the form of an almost circular area with more than 700 mm and peak values in its centre exceeding 1500 mm), appreciable amounts also along Pyrenees, about Sierra de Aracena, Sierra de Cazorla, Sierra de Aitana and the north of Mallorca, contrasting with a general decrease toward inland areas, and very low values in a vast area of the Southeast (south of Valencia, Murcia and eastern Andalucía). In a general sense, the spatial pattern of Fig. 2 reflects a general precipitation gradient along the SE-NW direction. This feature is connected, apart from the orography, to the degree of proximity to the Atlantic waters from where the majority of storms arrive. The northwest of Catalonia and west of Andalucía (which in fact are more Atlantic than Mediterranean), are favorably exposed to the Atlantic fronts, whereas the Southeast is a depressed area sheltered by the extensive plateau of the Iberian Peninsula (Fig. 1), and where many times fronts do not arrive. This last area is the most arid zone of Spain and even possesses some limited deserts.

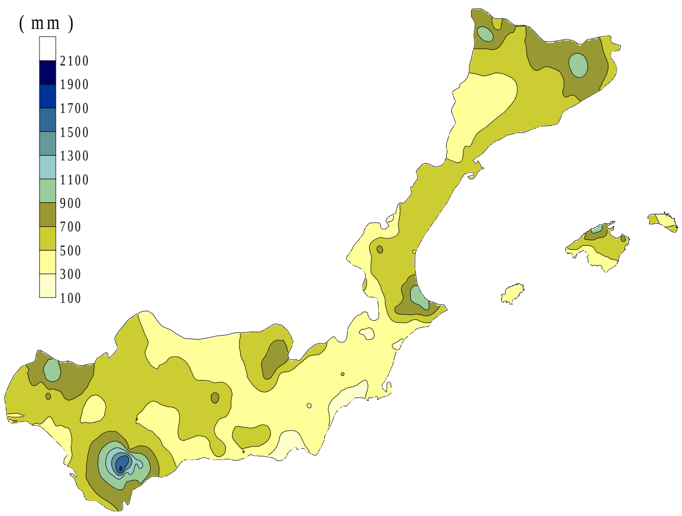

Fig 2. Yearly mean precipitation for 1984-93

The seasonal mean precipitation maps (not shown) demonstrate that both winter and autumn are quite substantial for western Andalucía, whereas most of the yearly rainfall in eastern Spain, including the Balearic Islands, occurs in autumn. During spring, mean rainfall is less important and tends to be rather uniform over the whole area. The summer is critically dry (less than 100 mm) except in the Pyrenees area. A more detailed characterization of the spatial and seasonal rainfall variability is done in Romero et al. (1998a).

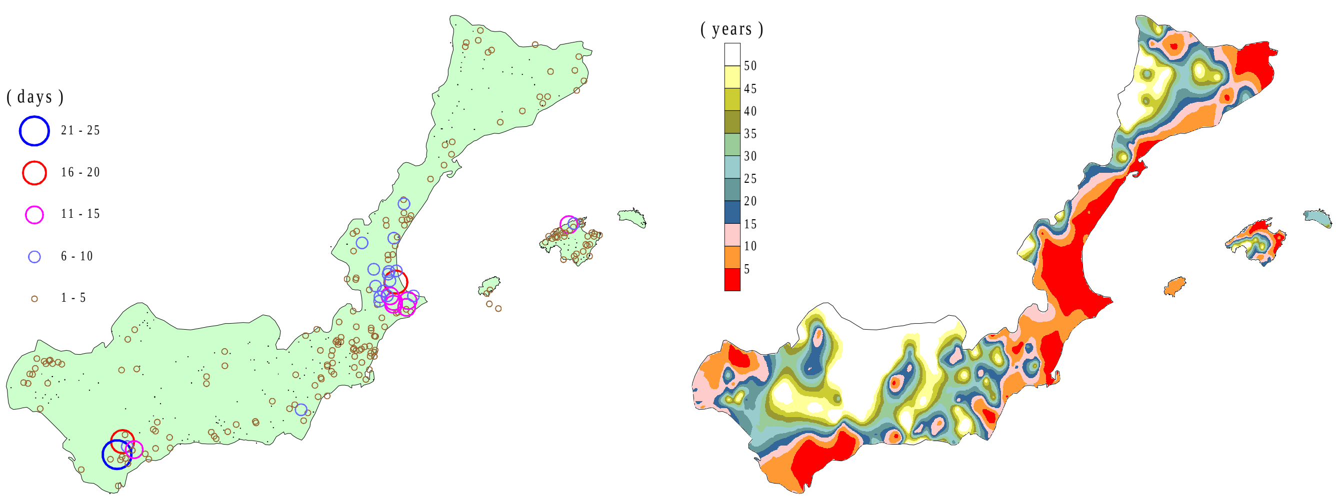

Fig 3. Days with extreme rainfalls (> 100 mm) during 1984-93 (left). Recurrence intervals of 100 mm events, for 1984-93 (right)

As noted previously, Mediterranean Spain is frequently affected by extreme daily rainfalls. Figure 3 (left) shows that extreme rainfalls tend to concentrate in coastal areas, and secondarily, in mountainous interior areas. The maximum values are found in Sierra de Ronda, where a station attains the 21-25 days category. Valencia and Murcia define an extensive area where 100 mm occurrences (in general in the 1-5 or 6-10 ranges) are given by most of the stations. It is notable the high amount of 100 mm days given by the stations located close to Sierra de Aitana. This zone has been classically considered the most torrential in Spain. Observe how the peninsular arid Southeast participates actively in this case. Extreme rainfalls are also frequent in the island of Mallorca along Sierra de Tramuntana, and in its eastern part where a minor topographic ridge exists. Ibiza also registered 100 mm rainfalls. The seasonal distribution (not shown) demonstrates that most of the 100 mm rainfalls concentrate in the autumn season. Winters occupy the second place, followed by springs. Extreme rainfalls are rare during summer. Events of 200 mm are almost exclusive of autumn, although also tend to occur during winter in Sierra de Ronda.

A direct demarcation of the torrential zones of Mediterranean Spain can be done by visualizing the recurrence intervals. For 100 mm daily rainfalls (Fig. 3 (right)), recurrence intervals lesser than 5 years are obtained about Sierra de Aracena, in a wide zone around Gibraltar Strait, in very localized zones of eastern Andalucía close to the coast or at high altitudes, in Murcia and Valencia, in the littoral of northern and southern Catalonia, zones of Pyrenees, and north and east of Mallorca. A deeper analysis of the torrential character of rainfalls is included in Romero et al. (1998a).

DAILY RAINFALL PATTERNS

Using the 30-years database, the main spatial patterns controlling significant daily rainfalls in the area have been derived. As significant days, we kept those days, in which at least 5% of the stations registered more than 5 mm, yielding a total of 3941 days. Of course, such thresholds are arbitrary. Other values were tested (15% - 5 mm, 30% - 5 mm, etc.) and quite similar rainfall patterns were obtained. However, since 3941 days represent a considerable population, we judged the 5% - 5 mm limit opportune for statistical reasons. Of the 3941 selected days, 30.0% occurred in winter, 29.6% in spring, 26.8% in autumn, and only 13.6% in summer.

The approach followed to derive the typical precipitation patterns consists in subjecting the T-mode (day-by-day) correlation matrix to principal components analysis (PCA), and carrying out cluster analysis (CA) on the most important extracted components. That is, days participating with similar loadings on the extracted components are clustered together. This approach is aimed to join days with similar precipitation distributions, irrespectively of the precipitation amounts (Sumner et al. 1995).

For deciding how many PCs to retain, we adopted the simple scree test of Cattell (1966). We retained 17 PCs, which account for 49% of the total variance. For the cluster analysis, the non-hierarchical *k-means* method (Anderberg 1973), as implemented in the *STATISTICA* utility (1994), was used. The Euclidean distance was taken as the similarity index. Hierarchical tree plots generated by Ward's method (Ward 1963) were also considered as reference for deciding how many clusters to create. A solution comprising 11 typical patterns was chosen. These pattern groups are presented in Fig. 4.

Despite the large proportion of convective rainfalls in the area, the obtained pattern groups are quite definite and clearly display the dominant role exerted by the complex topography and its connection with the main rain bearing flows. Plot of inter-seasonal variability (Fig. 5) reveals a different incidence of significant rainfall patterns through the year. The western patterns, largely stimulated by Atlantic flows, show peak frequencies in winter. The eastern patterns, which are strongly influenced by the Mediterranean dynamics, exhibit a diversity of behaviors but tend to occur in spring and autumn. Note also the high frequency of S8 and S9 during summer

An analogue classification has been done for what we call torrential rainfalls. As torrential days, we filtered days with rainfalls exceeding 50 mm in at least 2% of stations (8 stations). This criterion yielded 449 days (15 per year on the average, normally grouped in a few episodes). It is interesting to note that all the 449 torrential days were also significant days. In this case, 44.8% belong to autumn, 35.2% to winter, 14.9% to spring, and 5.1% to summer. Clearly, there is a preeminence of the fall season, as we expected. The PCA suggested the retention of 15 PCs, accounting for 68.5% of the total variance. The subsequent cluster analysis produced a solution of 8 typical torrential distributions. These distributions (not shown) display very similar spatial characteristics than the significant patterns, meaning that rainfalls are similarly highly structured regardless of its type, and strongly linked to the topography. Nevertheless, a certain tendency of enhancing the importance of coastal zones for torrential events is observed (see Romero et al. 1998b).

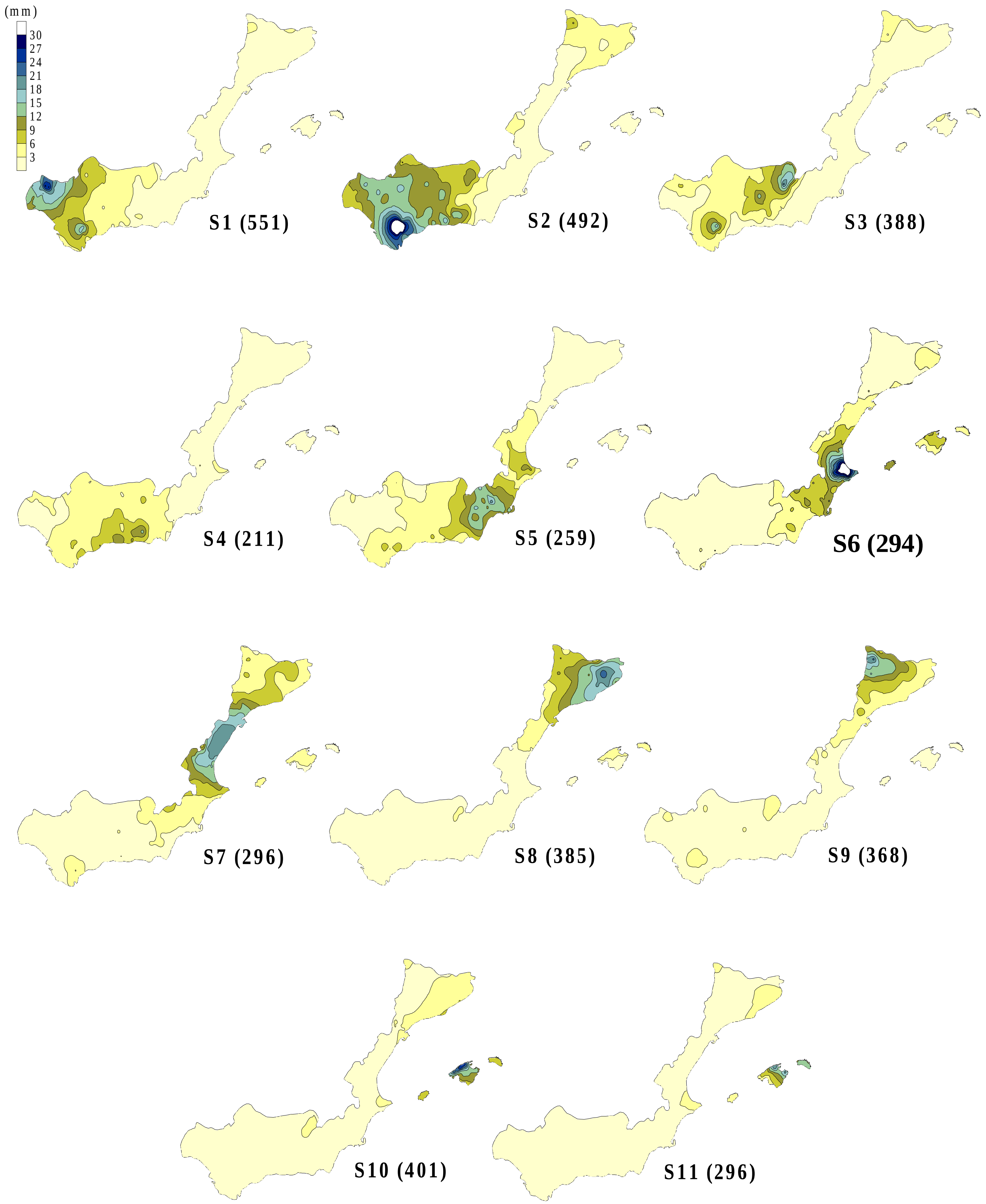

Fig 4. Daily rainfall composites for the 11 pattern groups of significant rainfall in Mediterranean Spain. The number of days for 1964-93 included in each pattern group is indicated in parentheses (total, 3941)

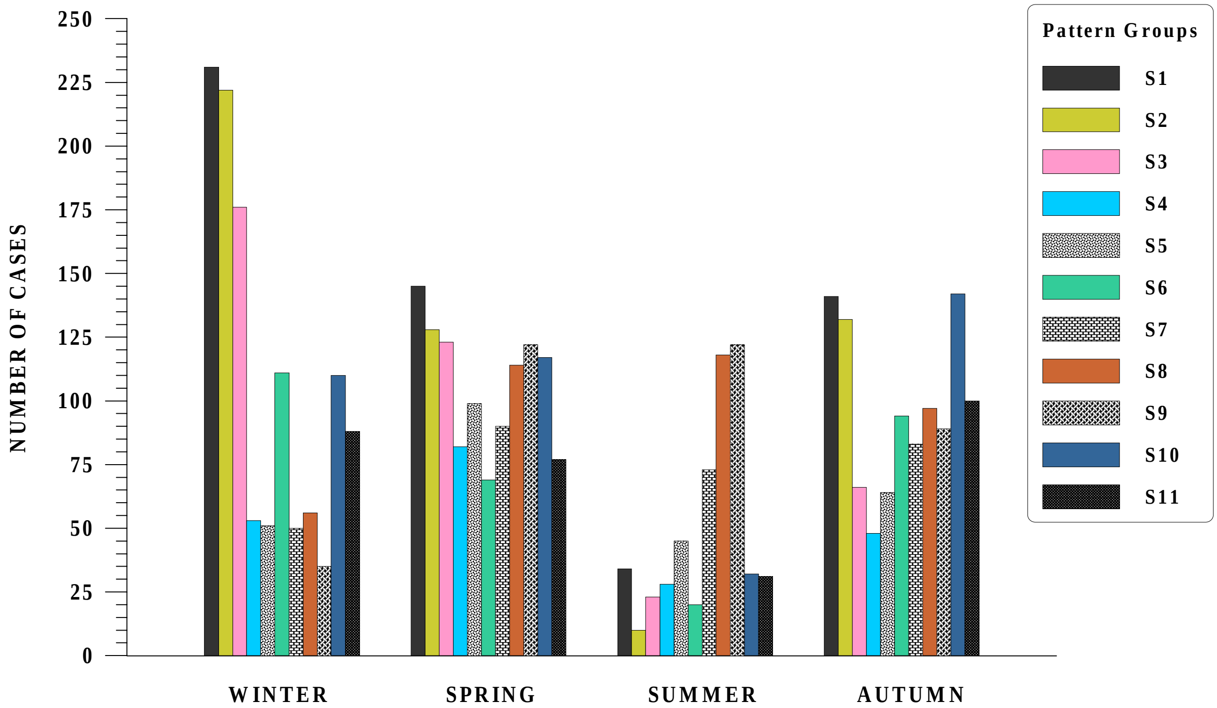

Fig 5. Seasonal distribution for the 11 pattern groups of significant daily rainfall

DAILY RAINFALL AFFINITY AREAS

A subdivision of the Spanish Mediterranean region into its daily rainfall affinity areas has been also conducted using the pluviometric database. As in previous works (e.g. White et al. 1991, Bonell and Sumner 1992, Gong and Richman 1995), the approach followed to accomplish the regionalization is first to subject the S-mode (site-by-site) correlation matrix (calculated using only the 3941 significant days) to PCA. Application of the scree test of Cattell (1966) indicated the retention of 12 PCs, which account for 58.52% of the total variance.

The traditional hard regionalization, when regions do not overlap and must be irregularly shaped, was obtained by carrying out CA (*k-means* method) of the 410 sites of the database based on the loadings attained by the 12 unrotated PCs (Bonell and Sumner 1992). This approach aims to incorporate sites into one area with similar time distributions of rainfall, irrespective of overall amount, which depend critically on altitude. A clear solution consisting of 12 “hard” affinity areas emerged from the CA. These areas are discussed in detail in Romero et al. (1998c).

A hard regionalization, although simple in concept, does not seem the choice that best preserves the underlying physics of precipitation generation and suppression. Causal mechanisms of precipitation are fuzzy and overlapping, and we would like our regionalization to reflect this fact. For that reason, we considered also a solution consisting of overlapping regions. As in Gong and Richman (1995), this is accomplished by mapping the loadings of the rotated PCs, assuming the rotation method can produce simple structures (see Richman, 1986). In fact, some authors consider the application of rotation methods as essentially an alternative to cluster analysis (Jolife 1987). In general, oblique rotation is preferred over orthogonal rotation since superior regional definition is obtained (White et al., 1991; Yarnal, 1993). VARIMAX (orthogonal) and OBLIMIN (oblique) (see Richman, 1986, for a description) methods were used in this analysis. The latter produced strong simple structures, and therefore was selected to represent the overlapping regions (depicted in Fig. 6).

As emphasized in Romero et al. (1998c), the hard regionalization and the more physically consistent overlapping regionalization are, apart from the nature of the boundaries, basically equivalent. They reflect the strong spatial organization of rainfalls in Mediterranean Spain as a result of the accentuated geographical contrasts of exposure to both Atlantic and Mediterranean rain bearing flows.

Fig 6. Daily rainfall affinity areas in Mediterranean Spain, resulting from an overlapping regionalization (threshold loading for the regions is 0.25)

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