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PRECIPITATION SEASONALITY IN EASTERN AND SOUTHERN COASTAL SPAIN

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ABSTRACT

The nature of the seasonality of precipitation in eastern and southern coastal Spain (including both the Mediterranean and the far southwestern Atlantic provinces) is examined using monthly precipitation values available for 410 sites for the period 1964–1993. Important contrasts are illustrated between eastern (Mediterranean) and southern (Atlantic) areas. In the east, seasonality is more subdued due to incursions of fronts from the north at all times of the year. In the far south, the months of July and August are almost completely dry, but the period October–February is wet due to incursions of active Atlantic frontal systems. In central areas (Almería, Murcia, Alacant, València and the Illes Balears) the significance of extensive severe thunderstorm development during September and October produces an autumn peak in precipitation amount. The spatial variation of precipitation seasonality is further examined using the seasonality index derived by Walsh and Lawler (Walsh PD, Lawler DM. 1981. Rainfall seasonality: description, spatial patterns and change through time. *Weather* **36**: 201–208). Trends of this index through the 30-year period are identified for some areas using linear regression on 5-year running means of the index, and indicate that seasonality is increasing in the south (Andalucía), around the uplands of Catalunya (near Lleida) in the east, and in a few smaller areas in between. In the south, the increase in seasonality is due to a greater concentration of precipitation during the cooler part of the year, so that the period January–March is becoming drier, but October–December, wetter. The overall cool season precipitation remains much as for the present, though some evidence for drying is indicated for Málaga, Jaén and Granada. Precipitation in the normally dry month of July is also increasing. In upland Catalunya, there are indications of a greater concentration of cool season precipitation, with, notably, higher amounts in October and some evidence of warm season drying, notably in June. Copyright © 2001 Royal Meteorological Society.

KEY WORDS: climate change; Mediterranean; precipitation seasonality; seasonality index; Spain

1. INTRODUCTION: CLIMATIC AND PHYSIOGRAPHIC BACKGROUND

The coast of peninsular Spain, between Portugal in the west and the French border in the east, lies mostly within the western Mediterranean basin and comprises the geographical extent of the study region used in this paper. It extends from about 36°N near the Gulf of Cádiz to 44°N near the French border at the eastern extremity of the Pyrenees (Figure 1), along about 1500 km of coastline, and includes the Balearic Islands (the Illes Balears: Eivissa; Formentera; Mallorca; Menorca). The western-most part of the region, the Gulf of Cádiz, has an Atlantic coastline.

The coastline is generally rugged with, in the Mediterranean part, significant areas of higher ground abutting directly onto the sea, but with some notable lowland embayments around Málaga, Almería, Murcia, València, Tarragona and Barcelona, and the Guadalquivir Valley opening into the Atlantic in the southwest (Figure 1). The Ebro delta also provides a significant area of coastal lowland between Tarragona and Castelló. The highest elevations exceed 3000 m above sea level in the Pyrenees and in the Sistema Penibético. The region incorporates 17 administrative provinces. Combinations of these provinces

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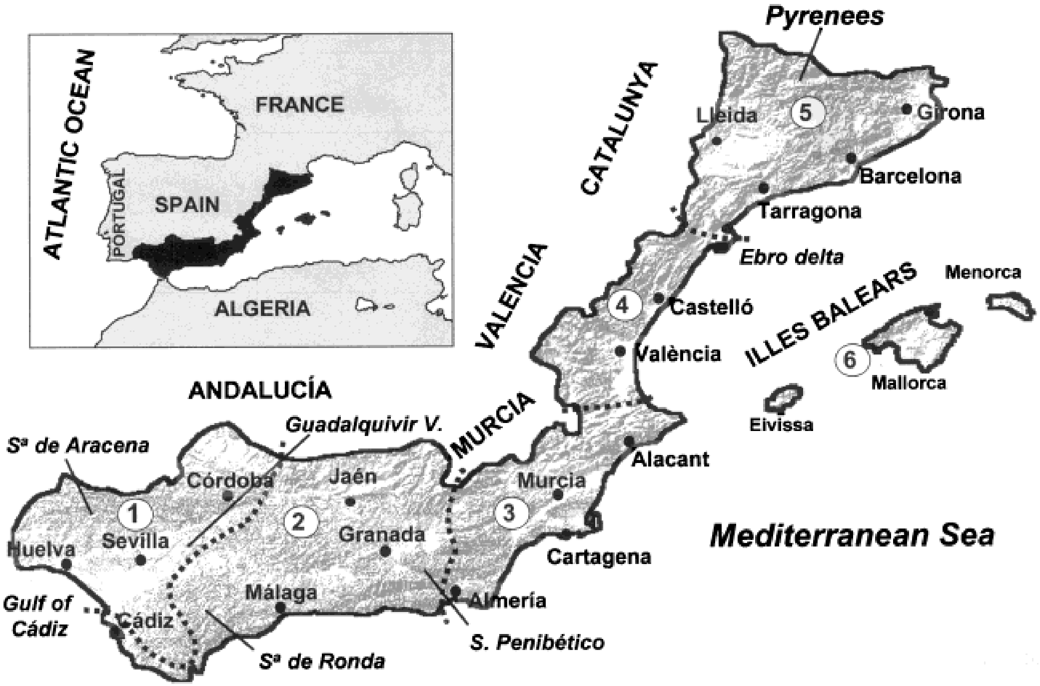

Figure 1. The study area showing generalized topography, the sites for which daily precipitation data are available for the study period, locations mentioned in the text and the six precipitation affinity areas (Romero *et al*., 1999a)

closely match the six daily rainfall affinity areas derived in an earlier study (Table I; Romero *et al*., 1999a, Figure 8), and reference to these provinces and the affinity areas is made throughout this paper. The location of affinity area boundaries and provincial capital cities is shown in Figure 1.

Climatologically, the study area provides a contrast between strong Atlantic influences during the cooler part of the year in the southwest and the characteristically Mediterranean climate of provinces further east. For quite a significant proportion of the year, most Mediterranean parts of the region are sheltered from all but the most intense and active of Atlantic disturbances by the central Spanish plateau and the Pyrenees, and also by higher land flanking the Mediterranean coast. During the warmer part of the year, generally from May to September, the region is under the influence of relatively high pressure. This area of higher pressure is generally stronger and longer lasting in the south than it is in the north, and is thus more likely to inhibit precipitation in the former areas.

During the cooler months between October and April, surface pressure is generally reduced, allowing more frequent incursions of precipitation-producing weather systems. These bring winter precipitation of a relatively low intensity, but of a spatially extensive nature to the Mediterranean Basin. The Atlantic coast in the area of Cádiz (Figure 1) is particularly subject to strong Atlantic influences during this time

Table I. Provinces referred to and their correspondence to the six daily affinity areas (Romero *et al*., 1999a)

Affinity area	Composition by provinces	Name referred to in paper
1	Huelva, Sevilla, Córdoba	Guadalquivir Valley
2	Jaén, Cádiz, Granada, Málaga	Central Andalucía
3	Almería, Murcia, Alacant	Almería-Alacant
4	València, Castelló	València
5	Tarragona, Barcelona, Girona, Lleida	Catalunya
6	Illes Balears	Illes Balears

of year. In the north, Catalunya is prone to more frequent incursions of Atlantic systems at almost any time of the year because of its higher latitude. Precipitation-bearing fronts which precede invasions of cold air from the north are able to filter around the eastern end of the Pyrenees, making Catalunya and the easternmost parts of the Balearic Islands (notably Menorca) more prone to frontal precipitation than areas only a little further southwest along the mainland coast. The Balearic Islands, though, with this exception, generally possess a precipitation climatology which is similar to that of the nearer parts of peninsular Spain to their west (València and Alacant).

In most parts of the region, warm season precipitation is much more scattered in both time and space than it is in the cool season. Precipitation often results from severe local storms which are generated by local convection, particularly at higher elevations or where convergence occurs between meso-scale circulations and the synoptic-scale gradient. The most significant meso-scale systems are those which generate strong sea-breezes along the coastline during hot summer and early autumn days. The degree of convergence between local and larger-scale circulations frequently determines where and when severe storms may develop and is particularly notable over the Balearic Islands, where convergence between opposing seabreeze systems may occur (Ramis *et al*., 1990). Such warmer season storms are best generated and are at their most severe during the transition between summer and autumn, from late August to late October when the northern hemisphere westerlies begin to strengthen and expand southwards and upper level cold pools (cut-off lows) tend to form over Spain and the western Mediterranean basin (for example, see Ramis *et al*., 1997). In addition, low-pressure areas may be generated by the interaction between topography and the synoptic-scale circulation. Quite frequently, surface lee depressions develop to the south of the Alps ('Genoa cyclogenesis'; Reiter, 1975), and also to the north of the Atlas Mountains in Algeria (Ramis *et al*., 1998). The former disturbances can cause strong northerly winds which may bring rain to parts of Catalunya, Menorca and eastern Mallorca, and the latter may produce strong easterly winds affecting the Catalunya and València regions.

The combined effect of these two dominant sets of precipitation-generating processes is to produce a general 'rainy season' from September through to April, although the actual months of peak precipitation activity vary from location to location. In most parts, July and early August are generally dry, or almost so. The north of Catalunya (Lleida and Girona) does, however, experience a higher frequency of warm season precipitation than parts further south, and particularly so in areas of higher altitude and relief, for example, the highest parts of Lleida (Font, 1983).

1.1. The data base

This paper uses the 30-year daily precipitation data base for Mediterranean Spain first described by Romero *et al*. (1998a). The selected period was restricted to 30 years by the paucity of data prior to the commencement year of 1964. The data set comprises daily precipitation values for a total of 410 sites, from which actual and mean monthly and yearly precipitation have been derived. The data set comprises sites with a better than 90% availability, with missing values interpolated (see Romero *et al*., 1998a). The distribution of sites through the study area is comparatively even, with an exceptional coverage for Mallorca, and slight deficiencies present only within the lowest parts of the Guadalquivir Valley and in the mountainous areas of Andalucía, the northern part of València province and in some parts of Catalunya (Romero *et al*., 1998a). Since the data set has been used on a number of earlier occasions to study the spatial organization of precipitation in the area (Romero *et al*., 1998b, 1999a,b,c), and in order to restrict the total number of figures in this paper, the exact location of gauges is not shown here, but may be found in Romero *et al*. (1998a; Figure 2).

1.2. The aims of the study

Earlier studies using the data set concentrated specifically on daily precipitation and produced local and regional detail of the spatial organization of daily precipitation across the region. The current study addresses the broader canvas of seasonality using monthly and annual precipitation. The often quite

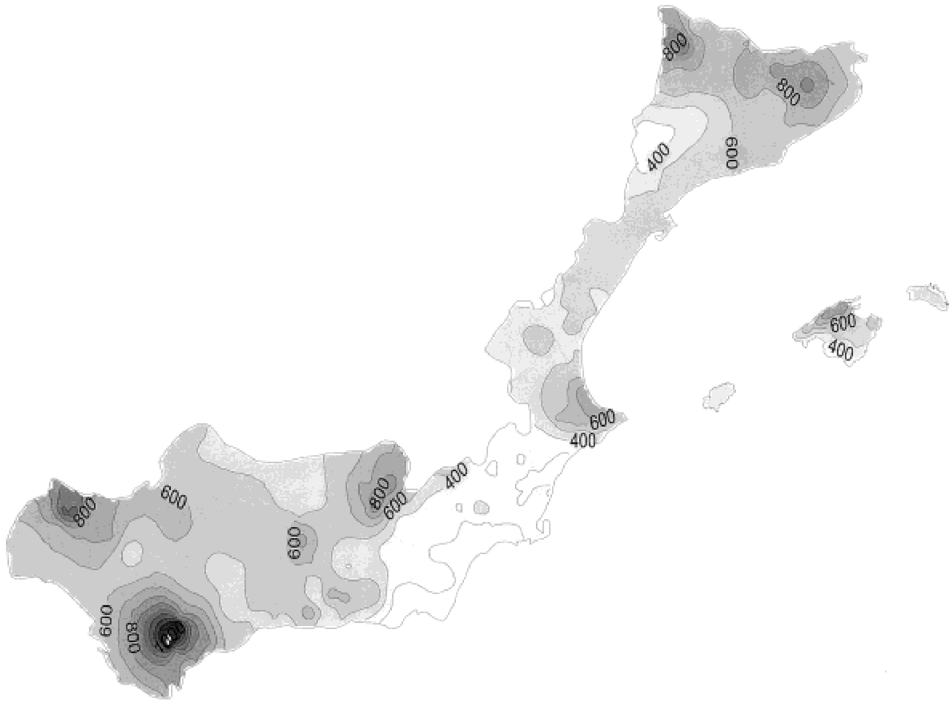

Figure 2. Average annual precipitation (mm), 1964–1993, for the study region

pronounced seasonality in precipitation distribution was demonstrated by Romero *et al.* (1998a,b). This seasonality tends to produce a cool season precipitation maximum, although severe local storms extend this maximum into the autumn in many areas, and frontal rainfall is sustained into the summer in the far north, causing a somewhat reduced seasonality here. Additionally, the seasonal delivery of precipitation may vary quite considerably between years. This variation may be of particular importance in a 'Mediterranean' climate, which is characterized anyway by hot and mostly dry summers.

The second element of this study has been to determine if there have been any changes in seasonality through the period. Thirty years is a relatively short period over which to study climatological trends, but the south of Spain is subject to a large number of environmental pressures linked to a recent significant increase in tourism and urban and industrial development, and local 'received' knowledge from farmers and municipal and regional governments supports climate change projections (Esteban-Parra *et al.*, 1998; Met. Office, 1999) that precipitation amounts and the seasonal distribution of precipitation may have changed over the past few decades. If these trends continue into the 21st century, then the serious problems they could produce will need to be anticipated and planned for. It, therefore, seemed appropriate to attempt to project currently identifiable precipitation trends into the future using the only available detailed pre-existing data set to investigate in more spatial detail than has previously been possible, whether there currently exists any empirical evidence to support projected regional changes in the spatial and temporal distribution of precipitation from global climate models (GCMs). Even though the data set duration is short, any statistically significant and clear signals from a large number of sites (in this case, 410) over a comparatively small geographical area may be taken as a very strong signal of what may occur over the next few decades. Precipitation data are notoriously noisy, but to a certain extent this noise may be offset by consistency in results between a large number of sites.

2. ESTABLISHED TRENDS IN SPANISH PRECIPITATION

Much attention is currently being directed at the possible impacts of global warming and induced regional climate change. Projections of future climates in the Mediterranean basin using different scenarios suggest increasing aridity throughout the year for many areas in future decades (Met. Office, 1999). This concern, in particular, is one of the main reasons for the research presented in this paper, which searches for evidence of changes in precipitation seasonality: changes in monthly precipitation distributions during the ‘average’ year. Esteban-Parra *et al.* (1998) investigated annual and seasonal rainfalls for a longer period, 1880–1992, using 40 sites throughout the whole of Spain, and found evidence for significant decreases in overall rainfall in southern Spain from the 1980s onwards, though they were careful not to link this trend closely with greenhouse-gas global warming, but pointed out that Spain is ‘in a critical area for GCM-based observations’. Maheras (1988) also noted a significant decrease in western Mediterranean precipitation from about 1980, principally affecting the months between June and February, that is, excluding the spring. By contrast, and working on Portuguese monthly and annual rainfall, Corte-Real *et al.* (1998) were unable to identify any long-term trend in rainfall in an essentially Atlantic precipitation régime, using daily data for two stations, and monthly data for 75 stations for the period from 1951 to 1990. Further, Lana and Burgueño (1998) found that the length and frequency of drought episodes in Catalunya showed no recent increase or decrease over time for periods between 25 and 53 years for 31 sites in the province. Overall, though, there appears to have been a general decrease in the intensity of the atmospheric circulation over the western Mediterranean Basin since the mid-1970s (Redaway and Bigg, 1996). Results from this latter study also suggested at the time that there may exist a long-term periodicity of precipitation in the area as a whole of around 20 years. Apart from the predictions from GCMs the empirical picture appears a little variable and confused, but strongly suggests that the time is ripe for a detailed sub-regional study, as there may well be numerous, perhaps conflicting, local trends in the seasonal distribution of precipitation.

3. ANNUAL PRECIPITATION

Figure 2 shows the average annual precipitation for the study area for 1964–1993. There is a clear bimodal distribution of maximum amounts at the northern and southern extremes, together with smaller pockets of higher totals in between. Average annual values for the study period vary from below 300 mm along parts of the Almerian and Murcian coasts to more than 900 mm in the Catalunyan Pyrenees, and in the Sierra de Aracena, and reach more than 1300 mm along the western flanks of the Sierra de Ronda (Figure 1). The higher precipitation levels in the south are mainly, though not entirely, a function of the exposure of comparatively extensive areas of high ground to cooler season invasions of Atlantic weather systems. The far southwest, near Huelva and the Guadalquivir Valley, is particularly prone to cool season precipitation emanating from active wintertime Atlantic depressions and fronts (Font, 1983). In the north, there is more reliable and general warm season precipitation associated with the incursion through southern France of rain-bearing fronts even in the hotter summer months of July and August (Romero *et al.*, 1999b). In all areas, though, the occurrence of late summer and autumn thunderstorms makes a significant contribution to annual precipitation totals. These are often particularly severe in the area around València, and over the Balearic Islands, where local topography and/or convergence between sea-breeze systems are highly conducive to their development under the appropriate atmospheric conditions (generally the presence of an upper cold pool).

4. SEASONAL PRECIPITATION

All parts of the region are subject to a considerable degree of precipitation seasonality. Initially this study utilized the political provinces of the region as a basis by which the monthly rainfalls could be regionalized. However, this gave too fragmented a picture across such a wide area and it was difficult to portray the results graphically, and so a means of further rationalization was sought. After much consideration, the original regionalization based on daily rainfalls derived by Romero *et al.* (1999a; Figure 3) was utilized. This regionalization made geographical sense in that the six areas are discrete units, generally well-defined in terms of topography and local climatology, so that they made for ease of association between this and earlier studies. The conclusions reached were similar in all respects irrespective of whether provincial or affinity areas were utilized and, with a very few exceptions, monthly rainfall amounts and their seasonal distribution between the constituent provinces show very little variation within the six affinity areas.

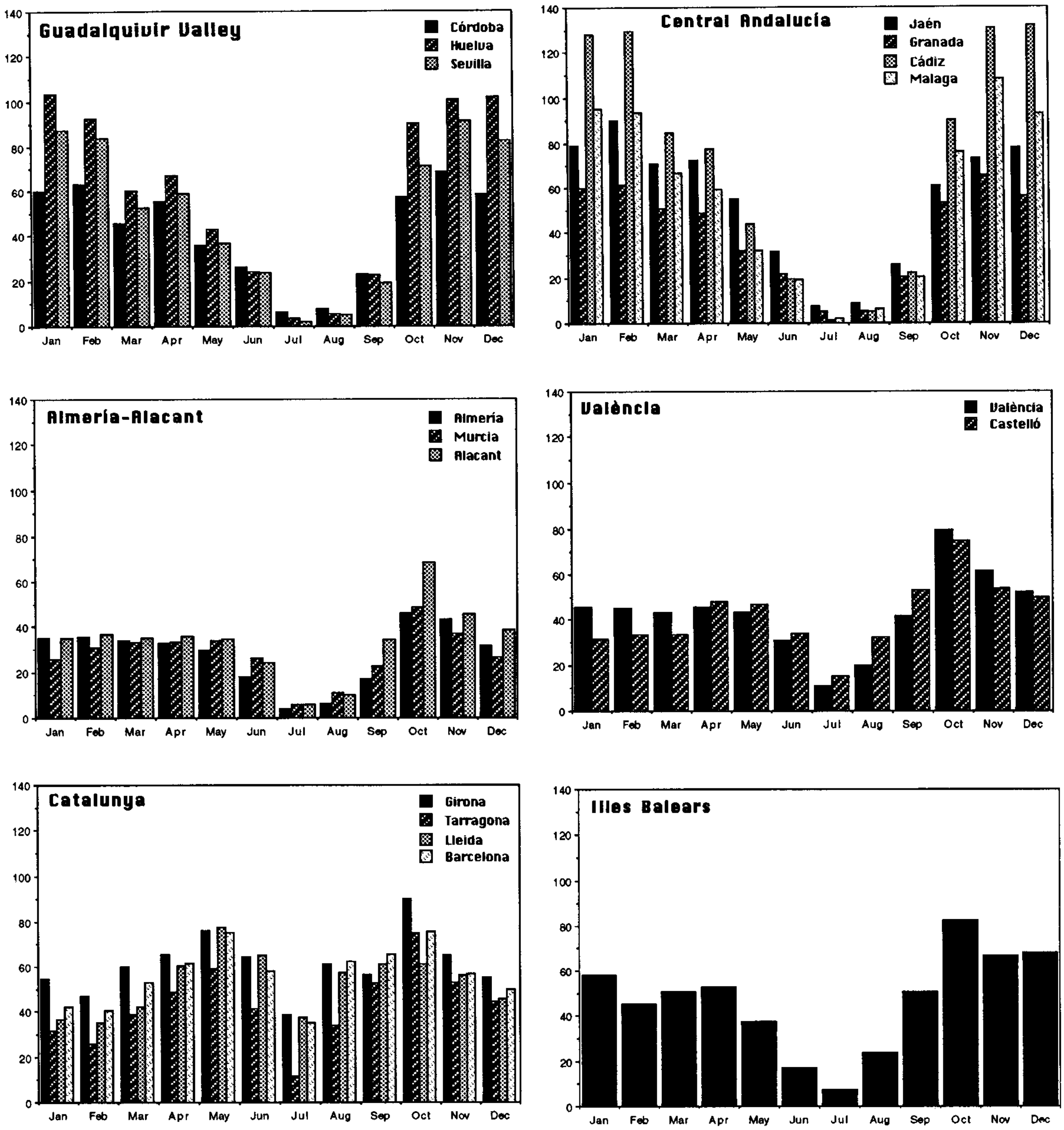

Figure 3. Mean precipitation by affinity area (Romero *et al.*, 1999a), 1964–1993, subdivided by province

The general variation in seasonal precipitation distribution across the study region is shown in Figure 3, where simple arithmetic average monthly rainfalls for the constituent provinces of each affinity area are displayed. The affinity area mean monthly rainfalls appear in Table IV. Note that the provincial means shown in Figure 3 are weighted according to the number of gauges in each province, that is, the affinity area mean is not the simple unweighted mean across each constituent province. In most areas, average amounts are inflated by the inclusion of higher altitude sites, where precipitation is both more frequent and more intense. The considerable within-area homogeneity is clear from the graphs in Figure 3, though there are some exceptions. Within Catalunya, Tarragona province is drier than the other three through much of the year, within Central Andalucía (four provinces), Granada is slightly drier for the wetter part of the year and Cadiz is wetter; and in Guadalquivir Valley (three provinces), Cordoba is drier in the wetter part of the year.

For Catalunya, warm season precipitation is increased by the higher incidence of summertime incursions of maritime air and frontal disturbances around the northern flank of the Mediterranean summer anticyclone, so that there is quite reliable rainfall in July and August, yielding monthly averages of more than 50 mm at some higher altitude locations. A bimodal distribution occurs through the year, with peaks in precipitation-generating activity in the late spring and mid-autumn (May and October, respectively, Figure 3). More central areas (Almería-Alacant, Illes Balears and València) possess the lowest annual average precipitation (Figure 2) and have, on average, a single distinct autumn precipitation maximum, again centring on October, lower mean values in July and August, and generally uniform monthly amounts between December and May (Figure 3). Precipitation is at its most seasonal in southern areas (Guadalquivir Valley and Central Andalucía), strongly influenced by the exposure of western provinces (Huelva, Sevilla and Córdoba) to winds and systems from the Atlantic during the time of dominance of westerly winds between October and April. Precipitation is considerably enhanced also by the presence of higher ground and by the generation of severe thunderstorms in the early autumn. For these areas there is a single, pronounced annual peak in precipitation-generating activity between October and February inclusive, with hardly any precipitation occurring during July and August (Figure 3).

5. THE SEASONALITY INDEX

A seasonality index (SI_i) permits a quantification of the variability of precipitation through the year using a single figure. Such an index does not by itself provide a month-by-month detailed look at seasonal variation, which may confuse by the presentation of too much information, but rather it should be complemented by a detailed analysis of monthly precipitation across an area, as in the current study. A commonly used SI_i is that derived by Walsh and Lawler (1981):

$$SI_i = \frac{1}{R_i} \sum_{n=1}^{n=12} \left| X_{in} - \frac{R_i}{12} \right| \tag{1}$$

where R_i is the total annual precipitation for the particular year under study and X_{in} is the actual monthly precipitation for month n. Though the index only provides a relatively crude arithmetic description of precipitation seasonality, its ease of computation makes it an ideal tool for the study of spatial and temporal variation in seasonality, provided that complementary information on precipitation amount is also considered. The index does not provide information on when and how much precipitation occurs, and relies simply on the summation of modulus monthly differences from a notional 'equal misery' monthly mean representing an even distribution of precipitation amongst all 12 months, equivalent to 8.33% of the annual total per month. Higher index values indicate a greater overall departure from an equal distribution of precipitation through the year, with near zero values indicating that there is little or no seasonal variation in precipitation (Table II).

A long-term mean $\overline{SI_i}$ for each site may subsequently be calculated directly from the accumulated SI_is over a longer period, j, 30 years in the current study:

Table II. Seasonal precipitation régimes indicated by the SI_i (after Walsh and Lawler, 1981)

SI_i	Precipitation régime
<0.19	Precipitation spread throughout the year
0.20–0.39	Precipitation spread throughout the year, but with a definite wetter season
0.40–0.59	Rather seasonal with a short drier season
0.60–0.79	Seasonal
0.80–0.99	Markedly seasonal with a long dry season
1.00–1.19	Most precipitation in <3 months
>1.20	Extreme seasonality, with almost all precipitation in 1–2 months

$$\overline{SI_i} = \frac{1}{30} \sum_{j=1}^{j=30} SI_{ij} \tag{2}$$

An alternative index using a similar formula may also be calculated using long-term average monthly precipitation data directly ($\overline{SI}$), but the resulting index will possess a lower magnitude, since the process of averaging smoothes year-to-year 'noise' in the monthly precipitation values. This distinction is important. SI_i was computed for all 410 sites within the study region for each of the 30 years of the data base. A map of the spatial distribution of the mean index ($\overline{SI_i}$) for each site over the period appears in Figure 4. Comparison between the distribution and magnitude of long-term mean indices (Figure 4) and the graphs of provincial mean monthly precipitation (Figure 3) should be made with caution: the latter reflect $\overline{SI}$ whilst the former reflects $\overline{SI_i}$. The provincial monthly precipitation (Figure 3) is further 'smoothed' by aggregation into affinity areas (Table IV).

One of the important restrictions of the index is that it does not indicate when or how wetter periods are distributed through the year. Walsh and Lawler (1981) used the ratio $\overline{SI}/\overline{SI_i}$ as a 'replicability index' (Bello, 1998) to indicate whether or not the wettest period occurs over a small range of months, or whether it may occur in any month during the year. Higher values of the replicability index indicate that the wettest month of the year generally occurs in only the same few months every year. Lower values indicate that the wettest month of the year tends to be more evenly spread amongst a larger number of different months. For example, areas with very pronounced wet and dry seasons will tend to have the

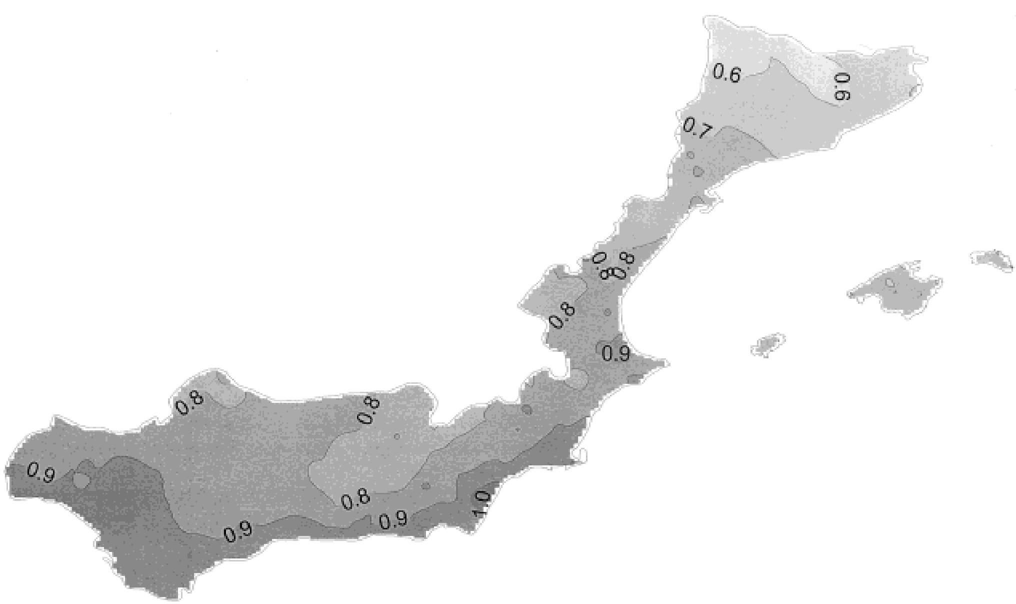

Figure 4. Mean values of the $\overline{SI_i}$ (after Walsh and Lawler, 1981) for the study region for 1964–1993

wettest months in individual years concentrated during the period of the wet season: a high replicability index.

The values of the mean $\overline{SI_i}$ for the full 30-year period (Figure 4) illustrate well the increased seasonality of southern and central areas when compared to the north (see also Figure 3), with indices of more than 0.9 along much of the coast west from Murcia, and exceeding 1.0 just to the east of Almería. Elsewhere in southern and central areas, the index is generally around 0.8. Only in the north, north and east of Tarragona, do $\overline{SI_i}$ values fall generally below 0.7, with precipitation being the least seasonal in the uplands of the Pyrenees. Mean values, of course, may mask considerable annual variability in the $\overline{SI_i}$. In individual years, indices exceeding 1.3 or 1.4 have occurred within the study period along the coast from Málaga to Murcia, together with parts of the southern flanks of the Guadalquivir Valley. Further north values only exceed 1.2 patchily around València and Tarragona, and rarely exceed 0.9 in the Catalunyan Pyrenees. Lowest SI_i values recorded for individual years are generally around 0.6 or 0.7 in the far south, about 0.5 between València and Tarragona, but dip below 0.4 in the uplands of northern Catalunya.

Table III summarizes the affinity area means and extremes of the index. The most extreme seasonality occurred in 1983 across most central and southern parts of the study region, but other years were more seasonal in some northern provinces and in the Illes Balears. Over southern areas much of the extreme variation in 1983 was brought about by a very wet November and notably dry January and September. Further north, in València, a wet February contributed to the high index. Both this area and the Tarragona part of Catalunya also experienced a wet August. In most provinces other months were also particularly dry. The lowest indices occurred over many parts of the study region during either 1977 or 1969. Particularly consistent monthly precipitation occurred in 1977 in València and in the Illes Balears, with February and March contributing significantly as they were particularly dry compared with normal expectations. Only in January and May was the provincial mean precipitation consistently above 50 mm. The year 1977 was a dry year with little marked month variation in precipitation. On the other hand, 1969 was a wet year even for the southern areas with a notably low SI_i in that year. Much higher than usual cool season precipitation was matched by sustained higher falls in most warm season months, which are usually dry. This contrast further illustrates that the index should be used with care and with reference to actual precipitation amounts.

Values of the replicability index, $\overline{SI}/\overline{SI_i}$, vary between 0.27 in Catalunya and 0.66 in central Andalucía and the Guadalquivir Valley. This range reflects a tendency for the month with the highest rainfall in individual years to be more consistently restricted to a few months in the far southwest (high index value) than in the northeast (low index value), when any of a large number of months may yield the highest yearly total. In the south, the probability that March and the months between May and September inclusive will contribute the highest monthly total to the calendar year is extremely small and even in April the probability is on average only about 10%. The tendency for the wettest month to occur between October and March decreases northeastwards as the amount of warm season precipitation increases, so that for northeastern provinces it is comparatively rare for January, February or March to be the wettest month of the year, though the frequency of January being the wettest month is still 11.0% in the Illes Balears. September progressively emerges as a more important contributor to annual precipitation towards the northeast.

Table III. $\overline{SI_i}$ mean values and years with extreme SI_i values for each affinity area

Affinity area	Mean	Highest	Year	Lowest	Year
1. Guadalquivir Valley	0.89	1.13	1983	0.73	1986
2. Central Andalucía	0.85	1.16	1983	0.61	1969
3. Almería-Alacant	0.89	1.13	1983	0.73	1989
4. València	0.83	1.07	1983	0.64	1977
5. Catalunya	0.65	0.84	1988	0.49	1972
6. Illes Balears	0.74	0.99	1974	0.56	1977

The mean contribution of each month to the overall index (the mean weight on the $\overline{SI_i}$) may be represented by taking the expression $1/R$ into the modulus part of the expression for SI_i and plotting the monthly value of

$$\frac{\left|\frac{X_{in}}{R_i} - \frac{1}{2}\right|}{SI_i} \tag{3}$$

for each site (mapped in Figure 5), or graphed for the six affinity areas (Figure 6). A month which contributes significantly more or less than 8.33% to the annual precipitation is one which makes a significant contribution to the SI_i: be it a notably wet month, or a notably dry month. This critical level is marked in Figure 6. Months making a significant contribution towards seasonal variation in precipitation make a contribution well above this level. Note that because of the operation of the modulus effect in the overall expression, months which are both significantly wetter *and* drier than the threshold

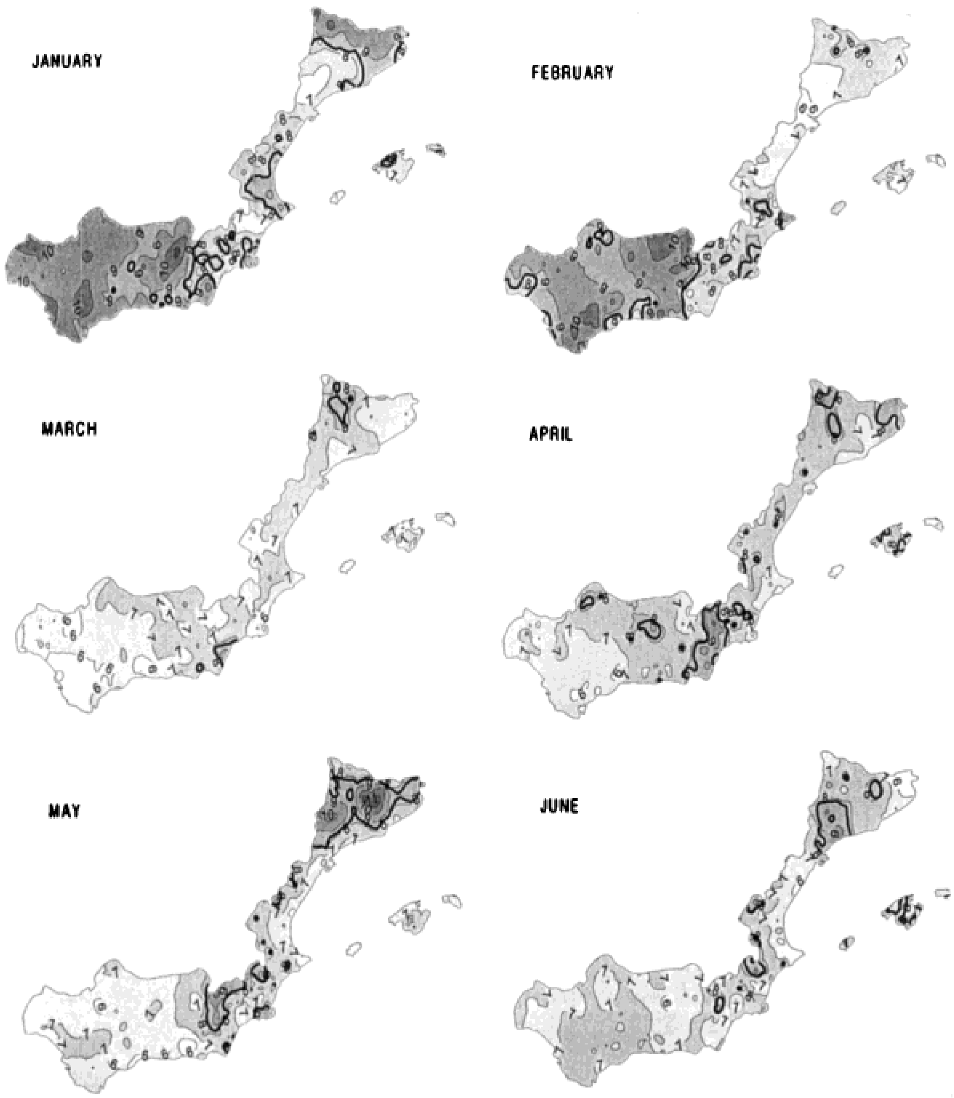

Figure 5. The importance of each month to the SI_i for the study region. Maps show the spatial variation in the expression X_n/R, the mean percentage monthly weight on the SI_i. The critical level of 1/12 (8.333%) is marked by a thicker isoline

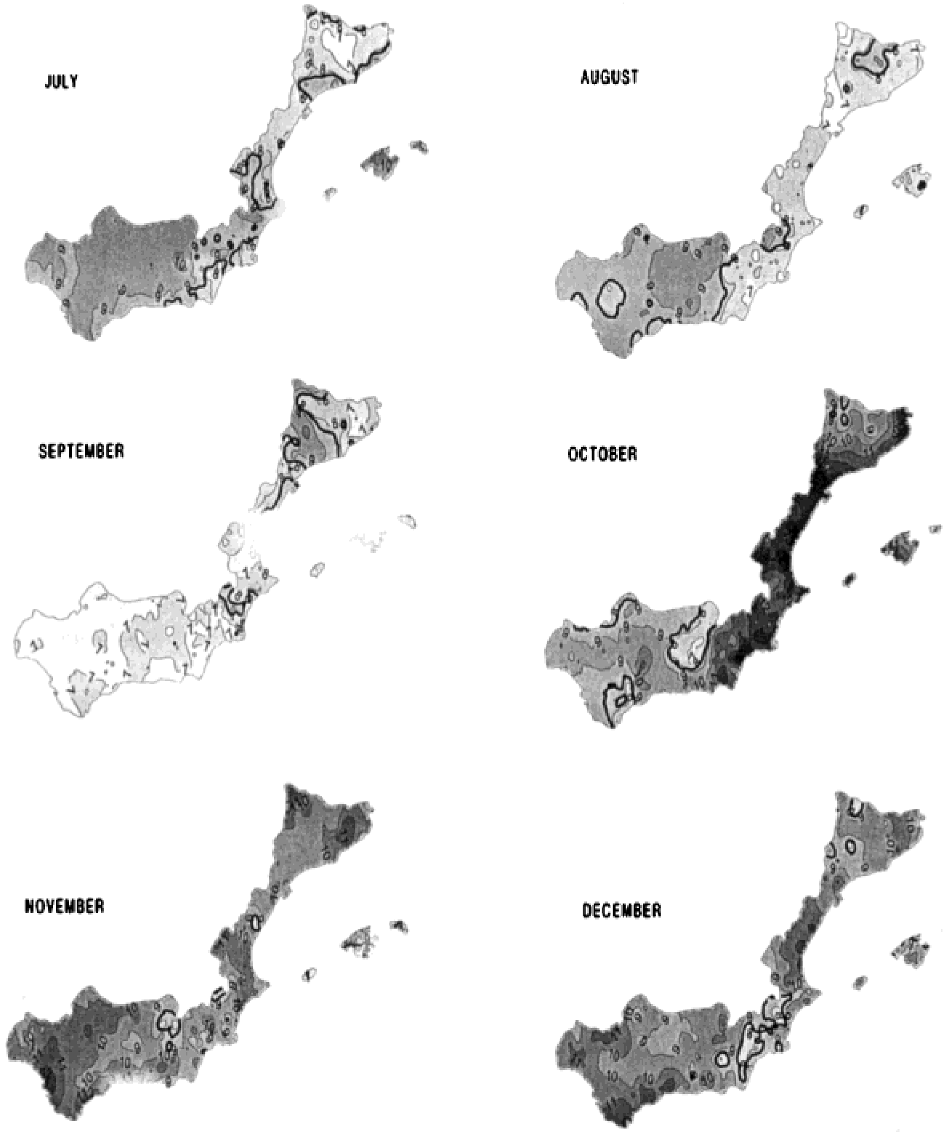

Figure 5 (*Continued*)

8.33% appear above the critical level. The powerful contribution made by the month of October emerges for all parts of the region, but is particularly pronounced for Almería-Alacant and València, illustrating the importance here of autumnal thunderstorms to overall annual precipitation, as both water providers and natural hazards. October's impact decreases both to the north and to the south because of the increasing role played by summer precipitation towards the Pyrenees (Catalunya), and by winter precipitation from the Atlantic in the far southwest (Guadalquivir Valley). The importance of the extended period of cool season precipitation in the Guadalquivir Valley and Central Andalucía is also well-illustrated in Figures 5 and 6, with all months between October and February inclusive above the 8.33% critical level. The relative importance of dry months in the summer also emerges for southern areas and for the Illes Balears: for both July and August in the Guadalquivir Valley and Central Andalucía, and for July in the Illes Balears.

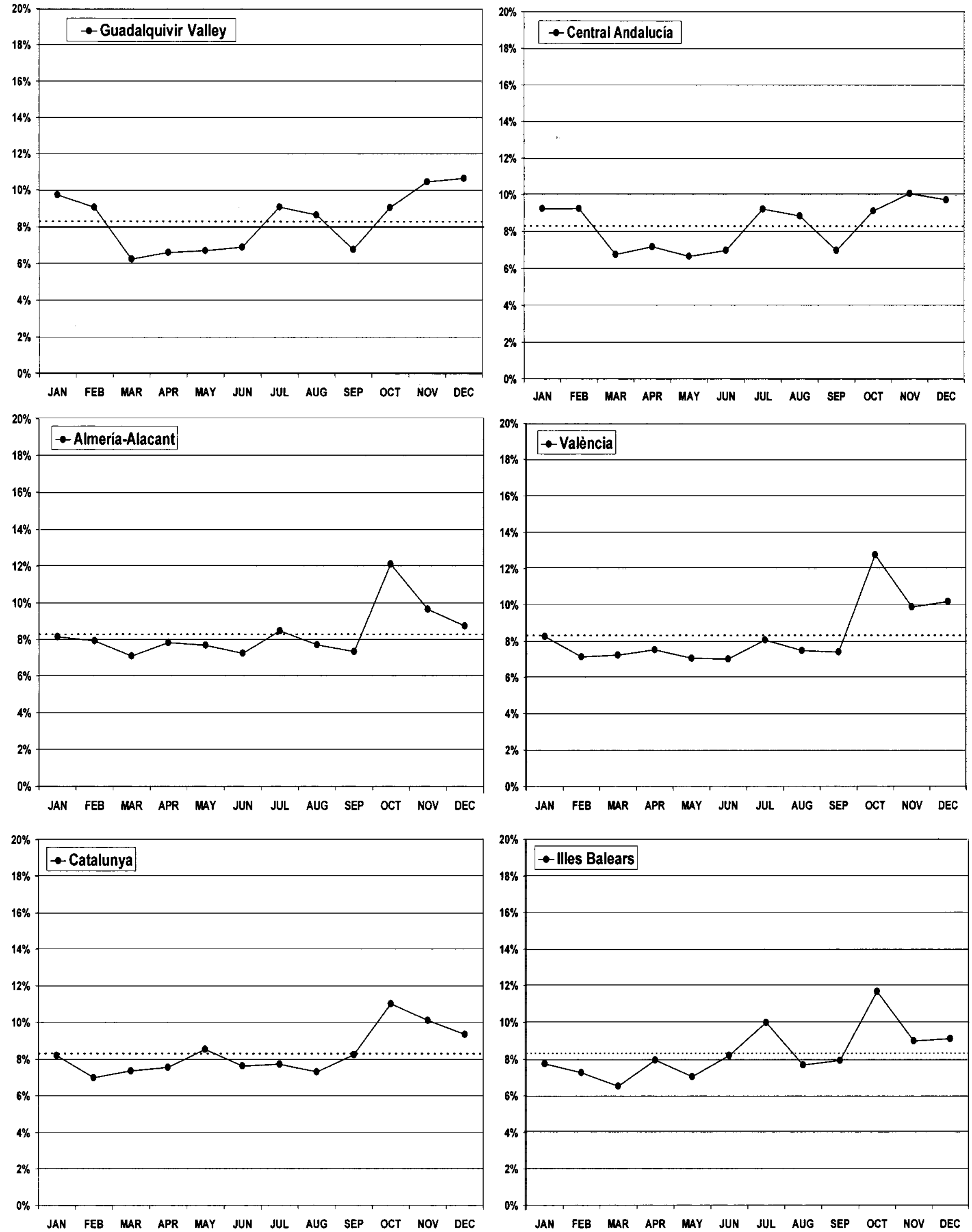

Figure 6. Monthly mean percentage weight on the SI_i for the six affinity areas (Romero *et al.*, 1999a)

5.1. Mean monthly precipitation

The operation of the SI_i demands that, for comparative purposes, mean monthly precipitation must be standardized with respect to the yearly total for each site or area. The general absolute level of monthly precipitation amount was indicated in Figure 3. Figure 7 shows the progression of mean monthly precipitation through a 'typical' year with each month's precipitation expressed as a percentage of the mean annual precipitation at each site ('monthly percentage contribution' = MPC). There is a clear advance of precipitation north to south across the region during the late summer to winter period, and a retreat during the spring and early summer. The relatively high incidence of precipitation, maintained throughout the summer in the far north, spreads southwards down the coast in August and September as the incidence of late summer and early autumn thunderstorm activity increases. By October, all areas experience quite substantial falls of precipitation, generally of a showery nature, with a high frequency of high intensity falls and electrical activity. As the season advances, more extensive rainfall also occurs,

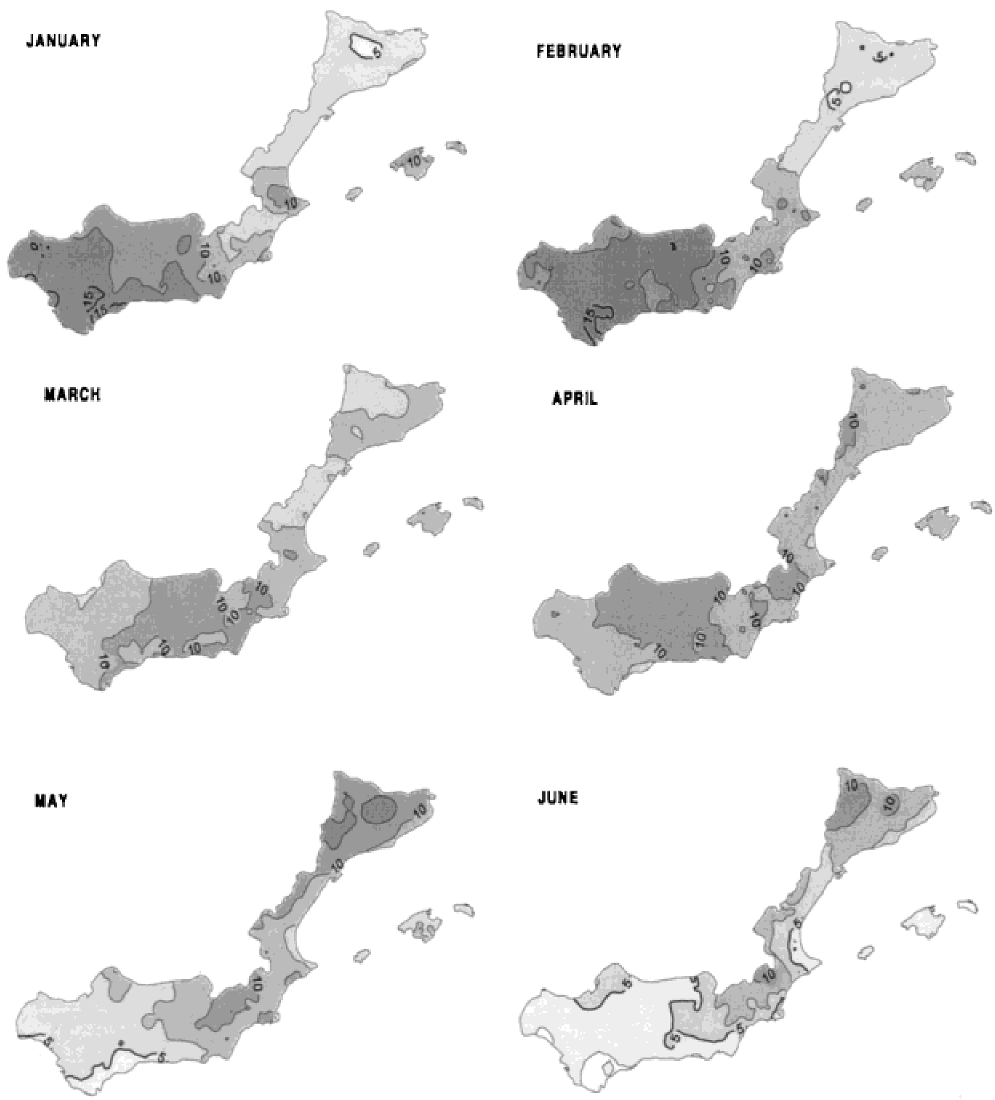

Figure 7. Mean monthly precipitation for the study region expressed as a percentage of mean annual precipitation

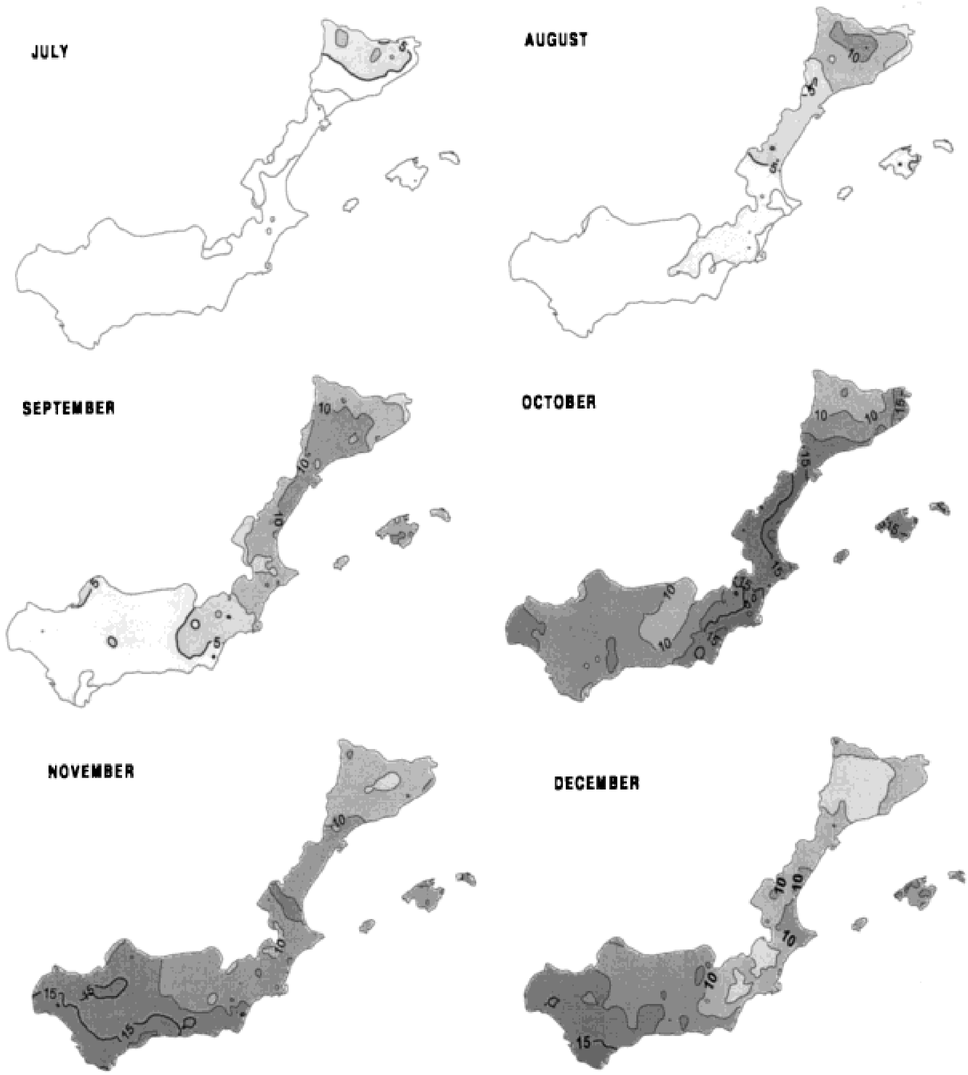

Figure 7 (*Continued*)

associated with the gradual extension of Atlantic westerly winds into the western Mediterranean Basin. From November onwards convectional activity decreases markedly and westerly activity dominates in all areas. This activity includes both the incursion of mobile systems from the Atlantic, through the Gulf of Cádiz and around the Pyrenees, and locally-generated low-pressure areas, typically located east of the Illes Balears. The most active systems enter the basin through the Gulf of Cádiz and these continue to be a strong influence on precipitation delivery into January and February, particularly in provinces closest to the Atlantic Ocean itself, so that the contributions of January and February to the yearly total remains significantly high in, for example, Huelva and Cádiz. Once higher pressure begins to develop in the Mediterranean from March onwards, and the zone of strongest westerlies moves north, these southern provinces begin to dry out significantly, though precipitation amounts resulting from low pressure areas migrating around the Pyrenees and developing in the western Mediterranean Basin may remain significant further north. May and June may still produce significant proportions of annual totals in central areas due to a combination of synoptically-produced precipitation and local convection associated with strong insolation.

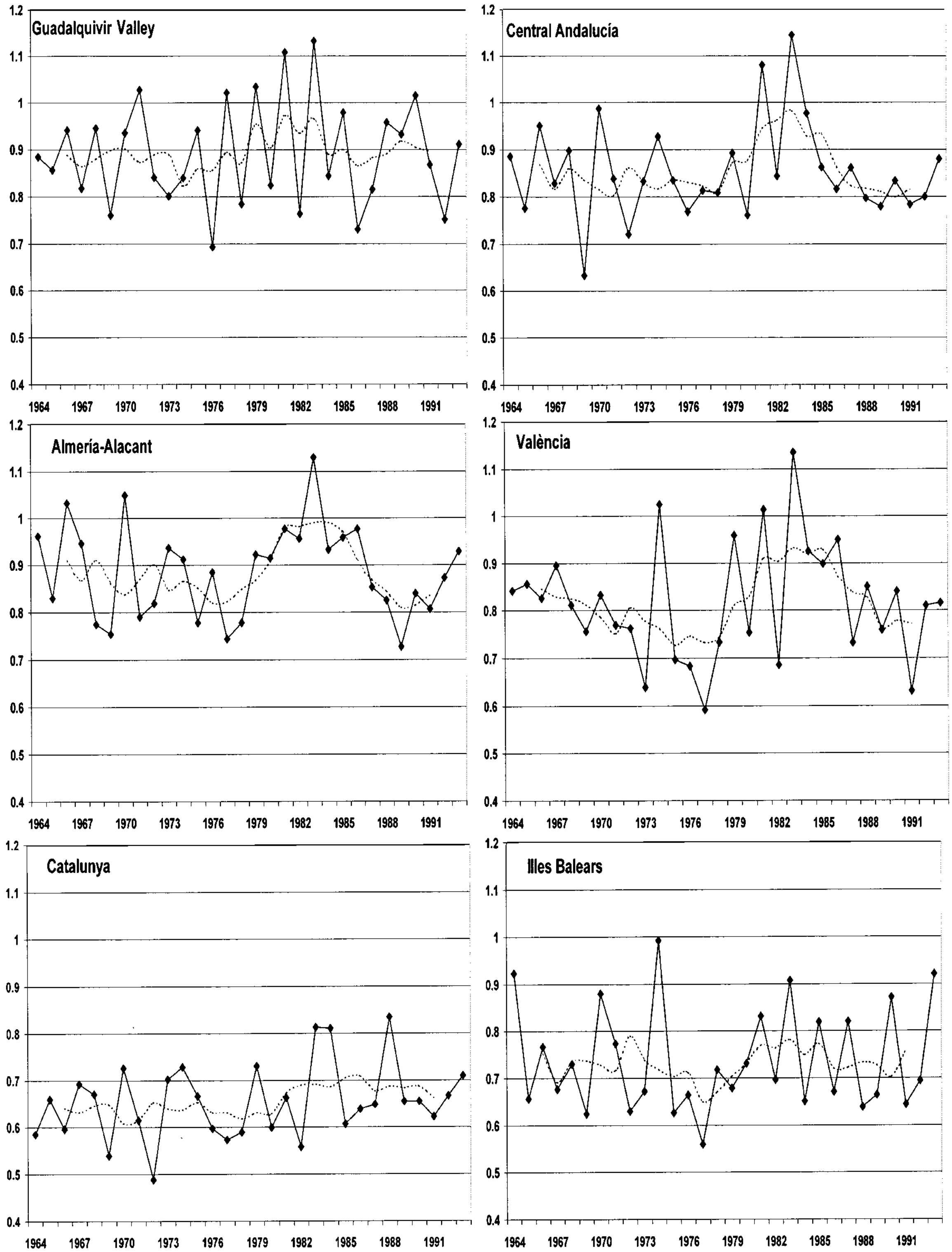

Figure 8. Changes in the SI_i between 1964 and 1993. Values are shown for the six affinity areas after Romero *et al.* (1999a)

6. TRENDS IN THE SI_i, 1964–1993

The SI_i shows considerable annual and spatial variability. Its variation through the study period is summarized in Figure 8, averaged for each area, with the 5-year running mean shown to remove extreme fluctuations. The graph shows a notable year-to-year oscillation for many areas, and this is particularly apparent in the south and in the Illes Balears. The series shows a slightly more complex oscillation in the north, so that the combined series appear to be quite irregular. The nature of these oscillations, and any teleconnections they may have with, for example, the North Atlantic Oscillation (NAO) lies beyond the remit of the current study, but Esteban-Parra *et al*. (1998) clearly demonstrated a negative correlation between Andalucian winter rainfall and the NAO, and Corte-Real *et al*. (1998) also found that Portuguese rainfall was strongly linked to a number of quasi-periodic oscillations. Rodriguez-Puebla *et al*. (1998) have also linked annual precipitation over western Spain with the NAO and the Eastern Atlantic Oscillation for various important (that is, rainy) months, and for eastern parts, the Southern Oscillation Index. A sustained period of higher indices affected southern and central parts of the study region (that is, apart from Catalunya and Illes Balears) in the early and mid-1980s. From these generalized figures, though, a clear *trend* through the period is apparent only for Catalunya. Graphical displays of the index for individual sites through the period exhibit a considerable amount of year-to-year 'noise', so that no clear trend is generally apparent for *entire* affinity areas, shown in Figure 8. The calculation of 5-year running means, however, successfully reduces the scatter of points around the trend line and also filters out many of the oscillations.

Aggregation into areas here has apparently smoothed the series to the extent that only general oscillations emerge, and has masked often contrasting within-area trends in the magnitude of the index. Maps showing the trend in the index across the study region show that there are large areas where significant positive and negative trends have occurred (Figure 9). Most locations exhibit a positive trend: towards increasing seasonality, though the patterns are quite complex. Notably, for Catalunya, the index is increasing at a rate greater than 0.003/year (Table V). A tendency towards increasing seasonality is also indicated for much of Catalunya (as far south as Tarragona, but excluding much of Girona province). In

Figure 9. Trend in the SI_i between 1964 and 1993 using 5-year running mean values

both Andalucía and Catalunya the majority of individual sites exhibit trends associated with correlation coefficients which are significant at appreciably better than the 95% confidence level ($r > 0.34$ or $r < -0.34$ for $n = 26$). Significant negative trends occur only around Granada, in Girona province, and in parts of Almería province.

Some quite important changes in the distribution of precipitation through the year may be inferred from the information presented so far. A 30-year period is, of course, a very short sample duration from which to project into the future, but nevertheless if these trends are continued they could have far-reaching implications for the economies of the affected areas. Figure 10 summarizes the trends in monthly contribution to the index: the percentage change per year in the weight on the index contributed by each month, the averages for which were shown in Figure 6. Note though that, again, these trends do not directly imply changes in 'wetness' or 'dryness'. An increasing trend may indicate increasing aridity for an already dry month, but increasing wetness for an already wet month, illustrating the ambiguity of the index. Clearly, in such circumstances, the result must be viewed alongside trends in monthly precipitation *per se*. Of particular note are the changes in the 'importance' of cool season precipitation to the index in València and Alacant-Almería, with a monthly oscillation suggesting a reduction for October and December, both generally quite wet months, but an increase for November, and again in January and February. For Catalunya and the Illes Balears the period October–December, particularly December, is becoming less important, and December has generally been viewed as an important contributor to the yearly total. In the south (Guadalquivir Valley and Central Andalucía) the entire period from October to March is generally quite wet, but the contribution of October–December precipitation to the index in increasing, whilst that of January and February is decreasing. Few significant changes are indicated for other times of the year.

The significance of the cool season shifts is that precipitation during the winter 'wet season' of October–April inclusive in the south is apparently becoming more concentrated in the late autumn and early winter: October, November and December. In central and northern provinces, with the exception of Lleida, the late autumn-early winter rains are also becoming more concentrated into the month of November, with the traditionally reliably wet month of October becoming significantly drier, along with December. For València and Almería-Alacant, this trend is compensated for by an increase in the contributions made by January and February precipitation. In Lleida there is some evidence of summertime drying (notably, June) and a concentration of cool season precipitation into the month of October.

6.1. Trends in monthly precipitation

The main changes in seasonality translated into equivalent precipitation across the study region are illustrated in Figure 11. The maps have been constructed using 5-year running means of the MPC. The maps show the fitted annual trend (the slope of the regression line) through the 30-year period and indicate the extent to which each month's precipitation increased or decreased with respect to the annual total precipitation. Positive trends imply increasing importance of a month's precipitation ('wetting' trend); negative, decreasing ('drying' trend). Clearly, since the trends are derived simply using linear regression on empirical data, it is essential only to consider those which are statistically significant: that is, those which possess a correlation coefficient which is above a critical absolute level. Within a 30-year period, there are 26 5-year running mean values, so that the critical correlation level for statistically significant results at better than the 5% confidence level is $r < -0.34$ or $r > 0.34$. Only those trends which are significantly better than this confidence level are referred to in the subsequent discussion. The trends shown may be considered as indicators of possible, rather than confirmation of, climate change. However, the presence of large areas over which statistically significant trends occur, comprising many rain gauge sites for each of which the trend is in itself significant, lends further weight to the probability that the trends identified may have some credence attached to them for the 30-year period under consideration.

The MPC for January and February decreased consistently west of Almería, but increased from Almería to Alacant. In January, an increase also occurred in many parts of Girona and Barcelona

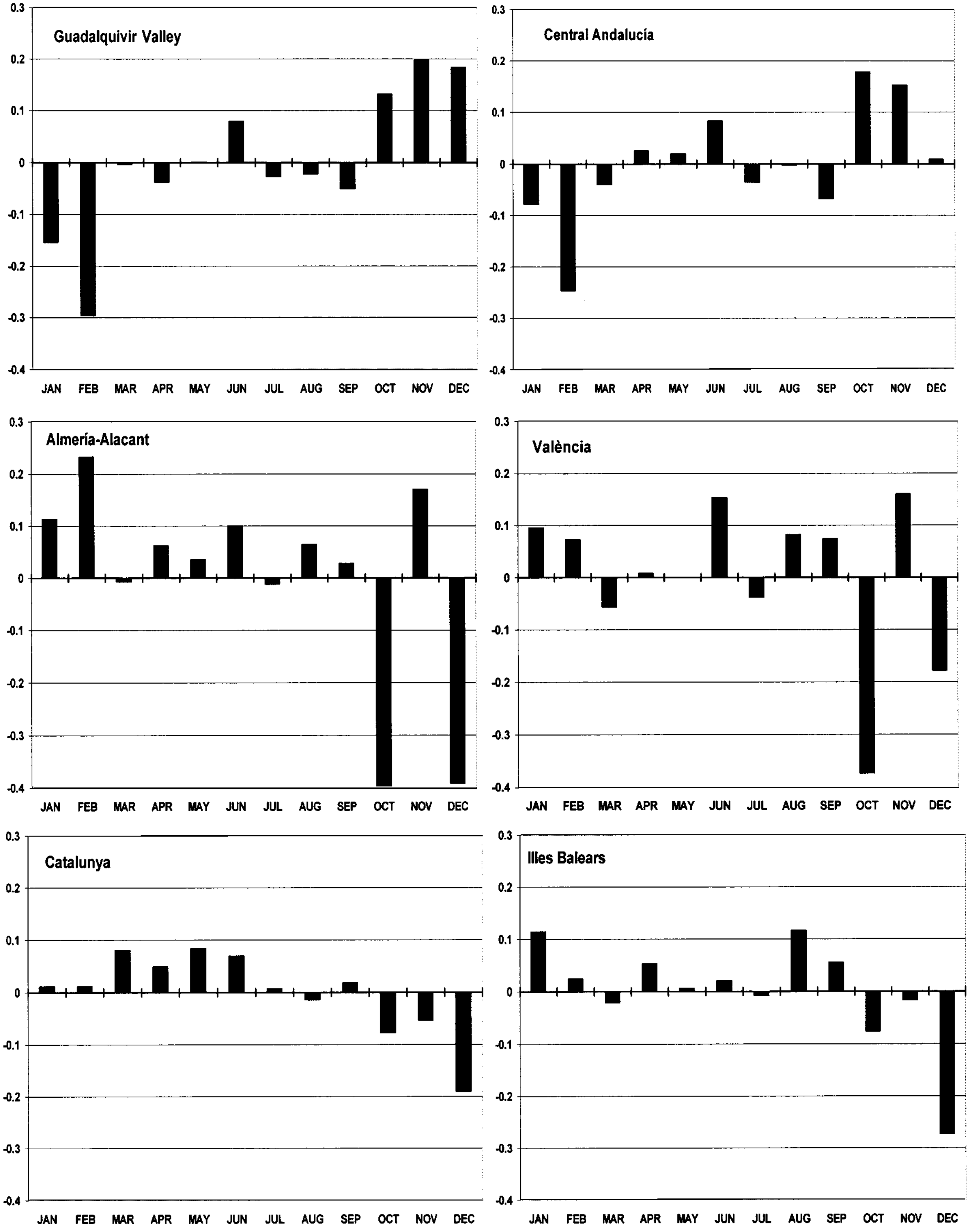

Figure 10. Trends in the monthly contribution (percent) to the SI_i (see Figure 7)

provinces, and in February a slight decrease is indicated for the higher parts of Lleida. For March, there was either a distinct negative trend or no trend at all across the study region. Statistically significant and marked negative trends applied across areas to the west of Cartagena, and again between Alacant and Tarragona, with significant but weak trends in parts of Girona and Lleida provinces and in eastern Mallorca. April MPC increased across the higher parts of Catalunya, and also in southern provinces west of Almería, centered on Jaén, Huelva and Córdoba, though no trend emerged for the lowlands of the Guadalquivir Valley. In contrast, the April MPC decreased for Almería and Barcelona provinces. Towards the end of the spring period, in May, the spatial patterns of trend in the MPC become much more variable and 'spotty', with only some central areas, notably in Alacant province and around Cartagena, showing a marked positive trend. The June MPC decreased over most parts of the study region: an already dry month became a little drier. The changes were particularly marked over the provinces of València, Alacant and Murcia, in central areas; in Sevilla, Córdoba and parts of Almería in southern areas; and for Barcelona province and parts of the Illes Balears in the north. No significant trends emerged for July, but the August MPC decreased significantly in some central and northern areas: centring on Castelló. Small parts of Girona province and the Illes Balears also exhibited a drying trend.

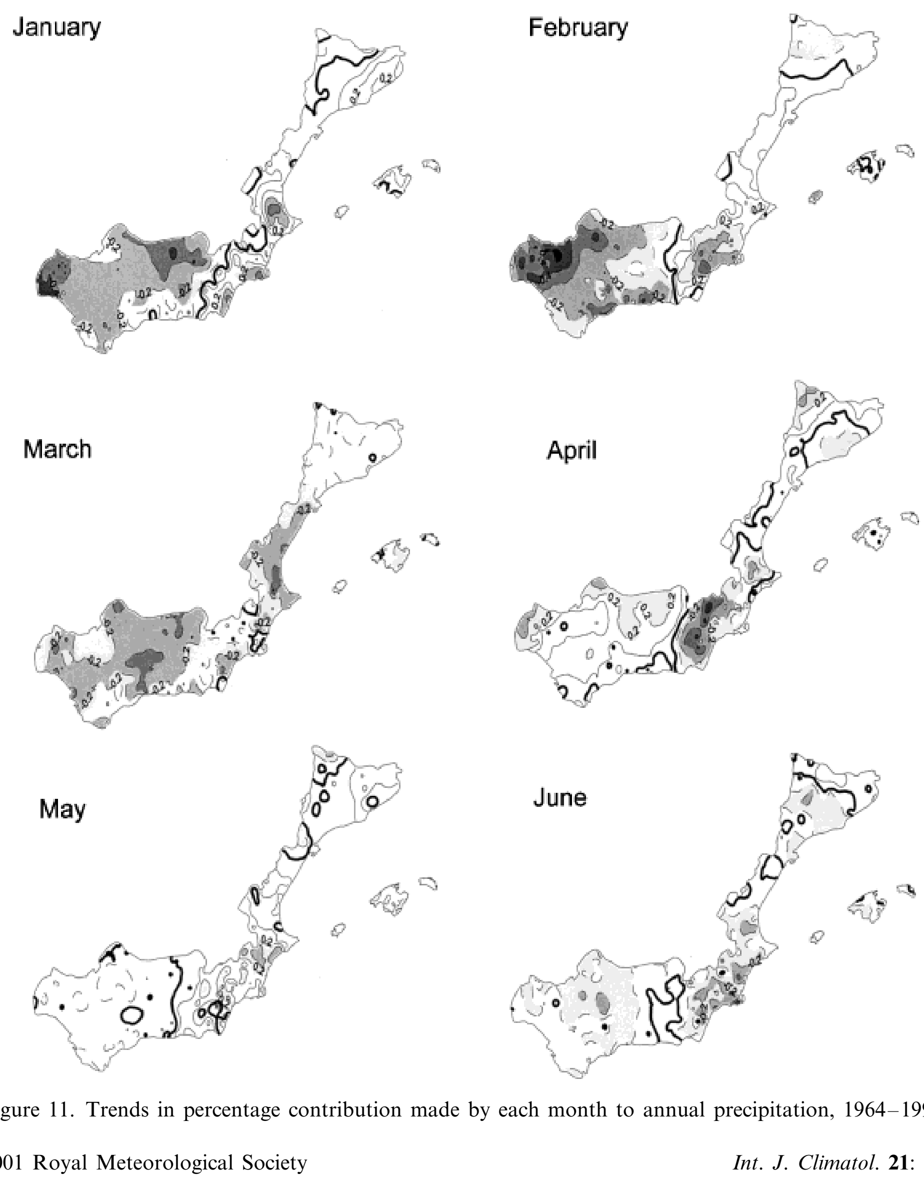

Figure 11. Trends in percentage contribution made by each month to annual precipitation, 1964–1993

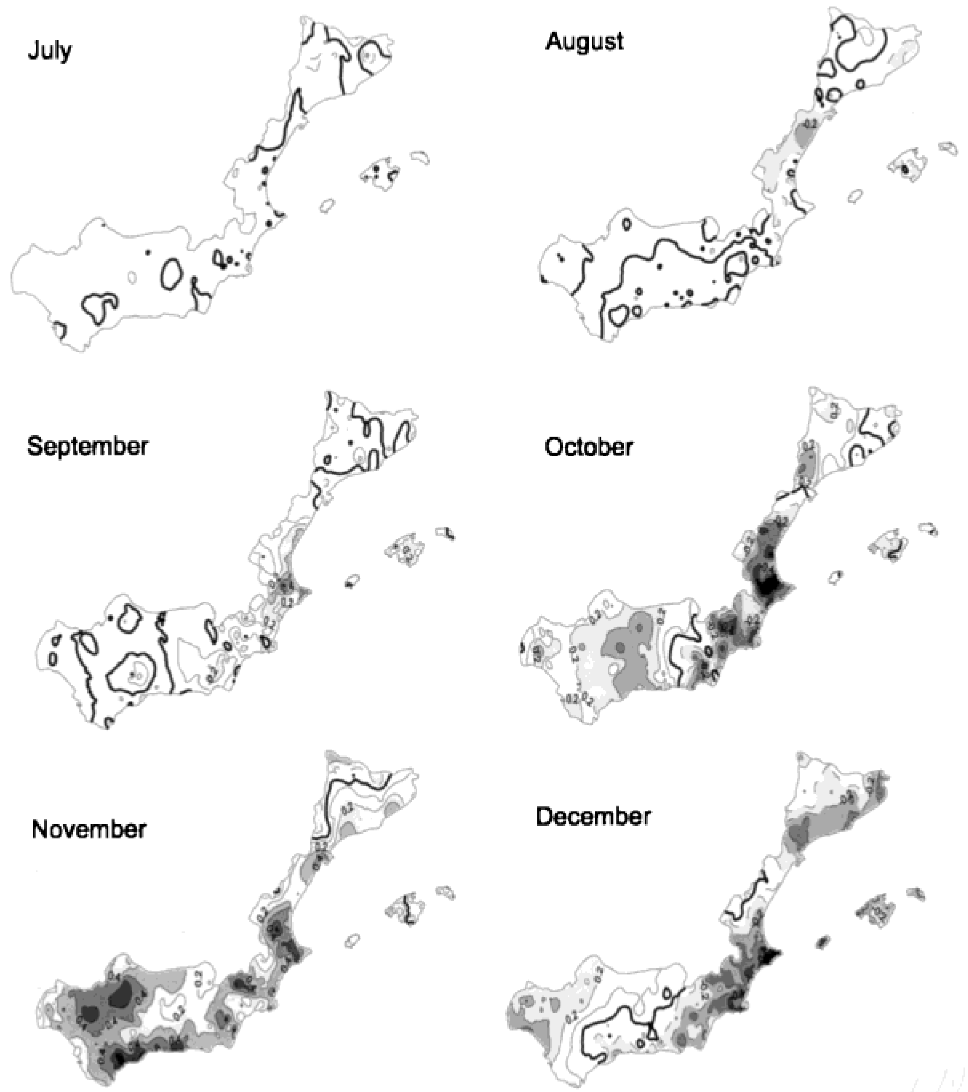

Figure 11 (*Continued*)

Autumn precipitation is of particular importance to many parts of the study region, partly because of the damage potential of severe convectional storms in September and October, but also because they provide some respite following the long, dry summer. The increase in September MPC focused on Almería, València and the island of Mallorca. However, in October, the whole swathe of the coast from Almería in the south to the Ebro delta, between Castelló and Tarragona in the north, has experienced a decrease in precipitation activity. This decrease was marked around València, and also over the lowlands around the cities of Almería and Murcia. In contrast, there were marked increases in the MPC for October in the rest of the south, notably for Málaga, Jaén and Córdoba, and for parts of Catalunya in the north, particularly the uplands behind Tarragona and the higher parts of the Pyrenees in Lleida. Very marked increases in the November MPC occurred through the study period. Only the upper parts of Tarragona, Lleida and Girona provinces did not share in this trend. Particularly marked increases occurred in València, Almería, Málaga, Córdoba, Sevilla and Granada provinces, but the increases were less notable for many higher elevation parts in central areas. In contrast, once again, the December MPC increased only in the far southwest, centred on Huelva, Sevilla and Córdoba provinces. For central and northern areas, and including southern areas east from Málaga, plus the Illes Balears, December's MPC decreased through the study period.

7. PRECIPITATION AMOUNTS AND SEASONALITY: A SCENARIO FOR THE NEAR FUTURE

Many parts of southern Spain are undergoing an economic renaissance. However, development for tourism, coupled with dramatic industrial and associated urban expansion, are placing extreme and increasing pressures on an extremely fragile environment. A major characteristic of the environment of southern Spain is its seasonal aridity. Water resource provision has always been a high priority and a major problem, and the provision of an appropriate and viable water resource management strategy is a pressing need for the near future. This need is exacerbated when there seems the possibility that the basis to water input to the region, that is, precipitation, may also be changing. If precipitation is decreasing then there is clearly a major problem. If precipitation amounts remain much the same over the long term, however, but subtle changes occur in when it occurs through the year, these changes may be much harder to detect, and yet may have very serious consequences for local areas.

GCMs are currently used to attempt to predict future changes in monthly and annual precipitation due to increased global greenhouse gas concentrations in the atmosphere. Such models much always be compared with reality if they are to be confirmed and/or fine-tuned. Indeed, no GCM currently provides us with an adequate spatial resolution to provide information to enable sub-national governments to take necessary remedial action in response to changed precipitation amount or seasonality. A 30-year period of climatological data, such as used in this study, is perhaps insufficient in itself to provide a reliable prediction into the near future, though spatial consistency in trends over quite considerable areas, as demonstrated here, does permit the placing of greater confidence in results. Nevertheless the results should be compared with whatever other sources of prediction are available in order to search for consistency. Coarse spatial resolution monthly precipitation predictions based on greenhouse gas concentrations are, however, available, against which empirical results from this study may be judged. Such a comparison appears in the conclusion to this study.

7.1. Projected changes in area monthly precipitation

In an attempt both to summarize the findings of the paper and to provide some insight into a possible future seasonal precipitation climatology of the study region, projections of possible future increases or decreases in provincial precipitation have been made using the mean trends (the slopes of the regression lines) for 5-year running mean MPCs, from the 1964–1993 mean baseline. The absolute values of the 'present' and 'future' (+30 year) means for each affinity area are presented in Table IV and the changes in MPC are portrayed graphically in Figure 12. Whilst the indicated absolute individual monthly precipitation are sometimes extreme, the overall message contained within Table IV is that overall annual precipitation for each area changes by between −20% (Catalunya) and +26% (València). Precipitation in Almería-Alacant increases by 10%, but decreases by 4% in Illes Balears, by 5% in Guadalquivir Valley and by 12% in Central Andalucía. Projected significant reductions in annual means for Catalunya and Central Andalucía must cause concern, but for most parts of the study region some important changes in seasonality are also indicated (Table IV and Figure 12). These indicate a likely increased concentration of precipitation into fewer months during the cool season, plus some important trends towards drier or wetter months at other times of the year.

For Catalunya there is little consistent change in seasonality over the 30 years. Exceptions occur in October and December, and for the Lleida area, where October precipitation is increasing, as reflected by increases in the seasonality index (Table V). However, this is a part of Spain which currently experiences comparatively reliable and evenly distributed precipitation, with copious provision of rain and snow in higher altitude areas, but where the overall amount of precipitation is apparently decreasing (Table IV).

Table IV. Mean monthly precipitation for the six affinity areas for the baseline 1964–1993 period and for a period 30 years into the future, nominally 1994–2023

Area	J	F	M	A	M	J	J	A	S	O	N	D	Year
Guadalquivir Valley	105.2	97.8	63.5	67.6	41.9	23.1	2.8	5.5	22.1	87.1	104.6	104.2	725.4
	25.4	14.2	16.0	92.9	16.0	0.0	8.7	10.3	21.0	101.3	188.4	194.9	689.1
Central	74.1	77.1	58.4	58.4	37.9	24.1	5.0	6.9	22.1	62.3	80.0	71.8	578.1
Andalucía	23.1	27.0	23.3	58.0	21.8	0.0	11.8	6.1	25.2	77.1	144.9	90.5	508.8
Almería-Alacant	30.2	33.3	33.8	33.8	33.2	23.8	5.5	9.7	24.6	51.4	40.6	30.8	350.7
	72.0	39.0	36.4	17.9	41.8	0.0	10.3	6.7	55.1	23.5	65.1	18.6	386.4
València	40.7	41.9	40.5	46.2	44.3	31.8	12.2	23.1	44.9	78.0	59.4	51.9	514.9
	107.7	53.9	22.2	52.1	58.3	13.8	21.2	9.3	103.9	40.6	114.7	53.2	650.9
Catalunya	38.2	35.9	46.1	58.5	72.7	57.6	32.0	53.0	60.1	69.4	56.5	47.0	627.0
	37.4	21.9	31.8	49.6	58.3	29.6	21.3	42.2	45.5	86.3	56.9	20.9	501.7
Illes Balears	58.2	45.3	50.7	52.5	37.6	17.3	7.6	23.8	50.6	82.7	66.8	68.2	561.0
	92.0	62.0	36.2	50.3	5.3	0.2	11.1	12.3	64.0	62.8	72.3	17.4	538.9

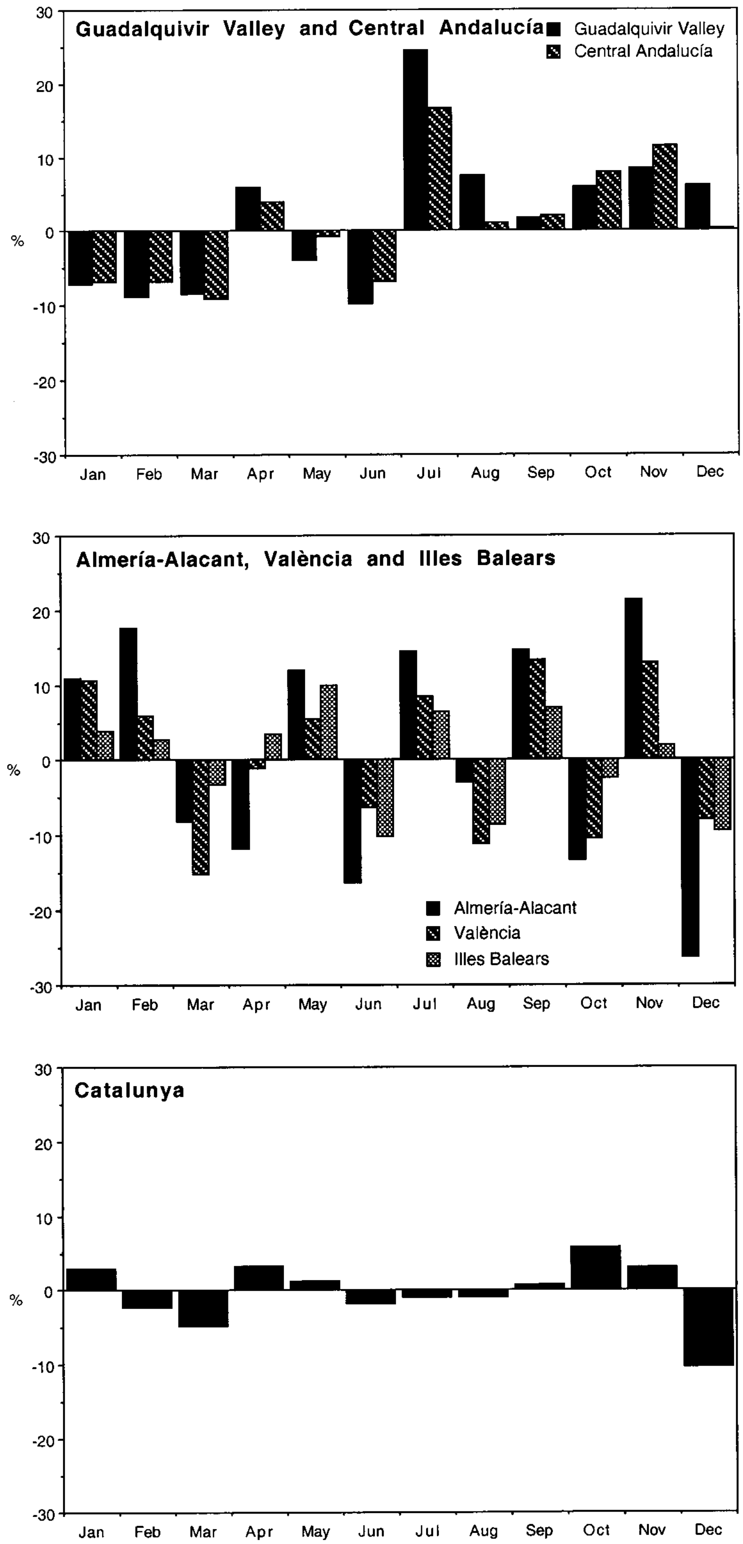

Figure 12. Projected 30-year change in MPC (see text), 1964–1993, derived from overall trend using 5-year running mean values

Table V. Mean values of $\overline{SI}$ derived from trends indicated by the regression line fitted to 5-year running means, 1964–1993, for: 1964 (year = −2); 1993 (year = 28); 2023 (year = 58)

Affinity area/Province	1964	1993	2023
Guadalquivir Valley	**0.83**	**0.90**	**0.98**
Córdoba	0.75	0.86	0.97
Huelva	0.88	0.89	0.89
Sevilla	0.85	0.96	1.07
Central Andalucía	**0.85**	**0.90**	**0.95**
Jaén	0.77	0.79	0.80
Granada	0.86	0.85	0.84
Cádiz	0.87	0.98	1.09
Málaga	0.88	0.98	1.07
Almería-Alacant	**0.88**	**0.89**	**0.90**
Almería	0.94	0.93	0.92
Murcia	0.87	0.87	0.88
Alacant	0.85	0.89	0.93
València	**0.81**	**0.85**	**0.89**
València	0.82	0.85	0.88
Castelló	0.79	0.84	0.90
Catalunya	**0.61**	**0.70**	**0.78**
Tarragona	0.78	0.80	0.81
Barcelona	0.59	0.67	0.75
Girona	0.66	0.64	0.62
Lleida	0.54	0.68	0.81
Illes Balears	**0.72**	**0.74**	**0.76**

However, the monthly changes in MPC indicated for central provinces (Almería-Alacant, València and Illes Balears; Figure 12) imply some interesting changes in the way precipitation is distributed through the year. Notably, these changes are not consistent between consecutive months and often alternate between negative and positive in consecutive months. Both January and February have become wetter relative to the annual mean. By contrast, March and April have become drier, particularly so for Almería-Alacant and València in March, and Almería-Alacant in April. For the rest of the year, the contributions made by May, July, September and November to the annual total have increased, but, conversely, June, August, October and December have decreased. These latter autumn and early winter reductions may become serious if sustained; notably so, as the cooler part of the year is when groundwater and reservoir reserves are traditionally recharged, and increases in September rainfall (from thunderstorms) raise the spectre of an increase in the urban flood hazard. Changes in the summer months (June–August) are less significant as these are months when rainfall amounts have been, and will continue to be, small.

Whilst the seasonal changes in MPC on an affinity area basis show little consistency for central areas and no strong pattern for the north, some very notable, significant and consistent changes are indicated for the Guadalquivir Valley and Central Andalucía. Most notable are positive changes in October, November and December, with opposite trends in January, February and March. Some important changes are also indicated during the summer dry season, with increased dryness in June, but contrasting increased wetness in the normally very dry month of July. June is still a relatively wet month, so that equivalent changes in absolute amount are perhaps more notable. April, too, appears to becoming wetter. Across most of the southern provinces a pronounced shift of precipitation is occurring with a reduction in MPC for January–March inclusive, and an increase for the three late autumn and early winter months, October–December inclusive. This shift may have important implications for the agricultural economies, as well as water resource provision of these provinces.

7.2. Projected changes in the SI_i

Using the regression line fitted to 5-year running means for the seasonality index, it is possible, in a way similar to that used to infer changes in monthly precipitation (above) to produce a future scenario for the index across the region. Trends in the index were discussed earlier (Figure 10). Such inferred predictions must be considered with great care, since the computed trends, if large, cannot be maintained over very long periods of time without exceeding the known limits of the index. It would be, for example, extremely unlikely in the western Mediterranean region for the *mean* index to increase beyond about 1.5, a magnitude reached in only in 1 or 2 years at a few locations in the study region. As an experiment, however, models of the distribution of the index across the region have been constructed for 1964 ('year zero') at the beginning of the study period, 1993, at its end, and for 2023, after a lapse of a further 30 years. Because of the uncertainty of predictions based on only 30 years of data, and particularly because of the 'noise' associated with typical precipitation data, small changes from one year to the next may be magnified considerably after 60 years (the final 'prediction'), such that the patterns shown in Figure 13(c), for 2023, are spatially highly variable, and are shown only for the purposes of comparison. They should not be taken as firm predictions, but as qualitative rather than quantitative assessments. In a similar way, and with similar caution, the graphs of 'initial' (1964), 'present' (1993) and 'future' values for the expression X_{in}/R_i used to indicate the 'importance' of each month to the index have been computed using the trends shown in Figure 10 (Figure 14). Projected provincial and affinity area mean values for the index are shown in Table V.

The predicted hypothetical evolution of the index over the study region after the first 30 years (1964–1993) may be taken as a model for possible changes to the index (Figure 13(a and b)). The spatial progression across the regions was discussed earlier (see Figure 4), and indicates a clear increase from north to south, as the summer rains of the northern provinces give way to a near total drought in southern provinces and the cool season rains dominate in the south. Increases in the index are indicated across much of the study region, so that after 30 years the magnitude of the index in coastal fringes of the south, between Cádiz and the Sierra Nevada exceeds 1.0 (see Table II). However, a decrease in the index is indicated for a small area inland to the north of Málaga, and for upland parts of Girona province. Increases from 0.8 to more than 0.9 are indicated for quite a considerable part of Andalucía. Taken to their extreme after a lapse of a further 30 years (Figure 13(c)), the magnitude of the index exceeds 1.1 over coastal parts of the extreme south and in the Guadalquivir Valley, but are reduced below 0.6 to the north of Málaga and below 0.5 in a small area of upland Girona.

8. DISCUSSION AND CONCLUSIONS

The IPCC HADCM2 model using the HCGGa4 scenario (http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html) has predicted future monthly precipitation up to 2100 based on observed (to 1990) and predicted (from 1991) levels of atmospheric CO_2, the latter assuming a 1% per annum increase in CO_2 levels. However, its spatial resolution is broad (2.5° latitude, 3.75° longitude). As a check on the results obtained in the present study, the SI_i was calculated for each year using model-predicted monthly precipitation data for the period 1960–2029 for the seven model grid points over and near eastern Spain. The 5-year running mean trend in SI_i over the period, averaged for the seven grid points was 0.0008/year which is two-thirds of the trend found in the current study. The overall trend derived for the present study for the present study for the eastern parts of the study area (Catalunya, Illes Balears, Almería-Alacant and València) is 0.0012/year. The equivalent figure for the whole study region is 0.0014. Mean values for the six affinity areas are: Guadalquivir Valley, 0.0025/year; Central Andalucía, 0.0017/year; Almería-Alacant, 0.0004/year; València, 0.0013/year; Catalunya, 0.0027/year; Illes Balears, 0.0006/year. The margin of difference between the model and the current study for eastern areas may be explained by the low spatial resolution of the model, and the consequent averaging in of large areas outside the geographical areas embraced by this study. Both theoretical and empirical studies, however, indicate a general trend towards

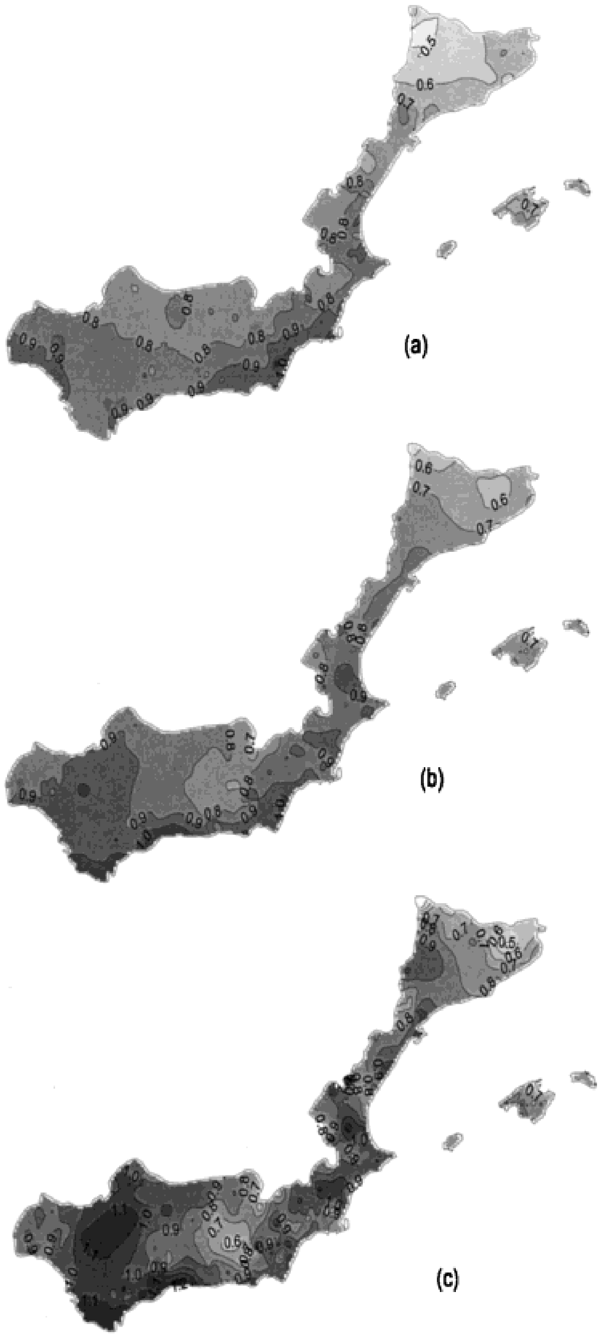

Figure 13. The spatial variation in the mean $\overline{SI_i}$ across the study region for (a) 1964, 'initial'; (b) 1993, 'present'; and (c) 2023, 'future'; determined from the fitted regression line using 5-year running means of the index for the 30 years 1964–1993

increasing seasonality. What this study has permitted is the superimposition of far greater sub-regional detail, and there is considerable small-area variation in the extent to which seasonality is changing, tending to corroborate the reasons given about for the differences between the IPCC model and the current study. Indeed in some parts, albeit small, there are indications that seasonality may in fact be decreasing slightly (Figure 13).

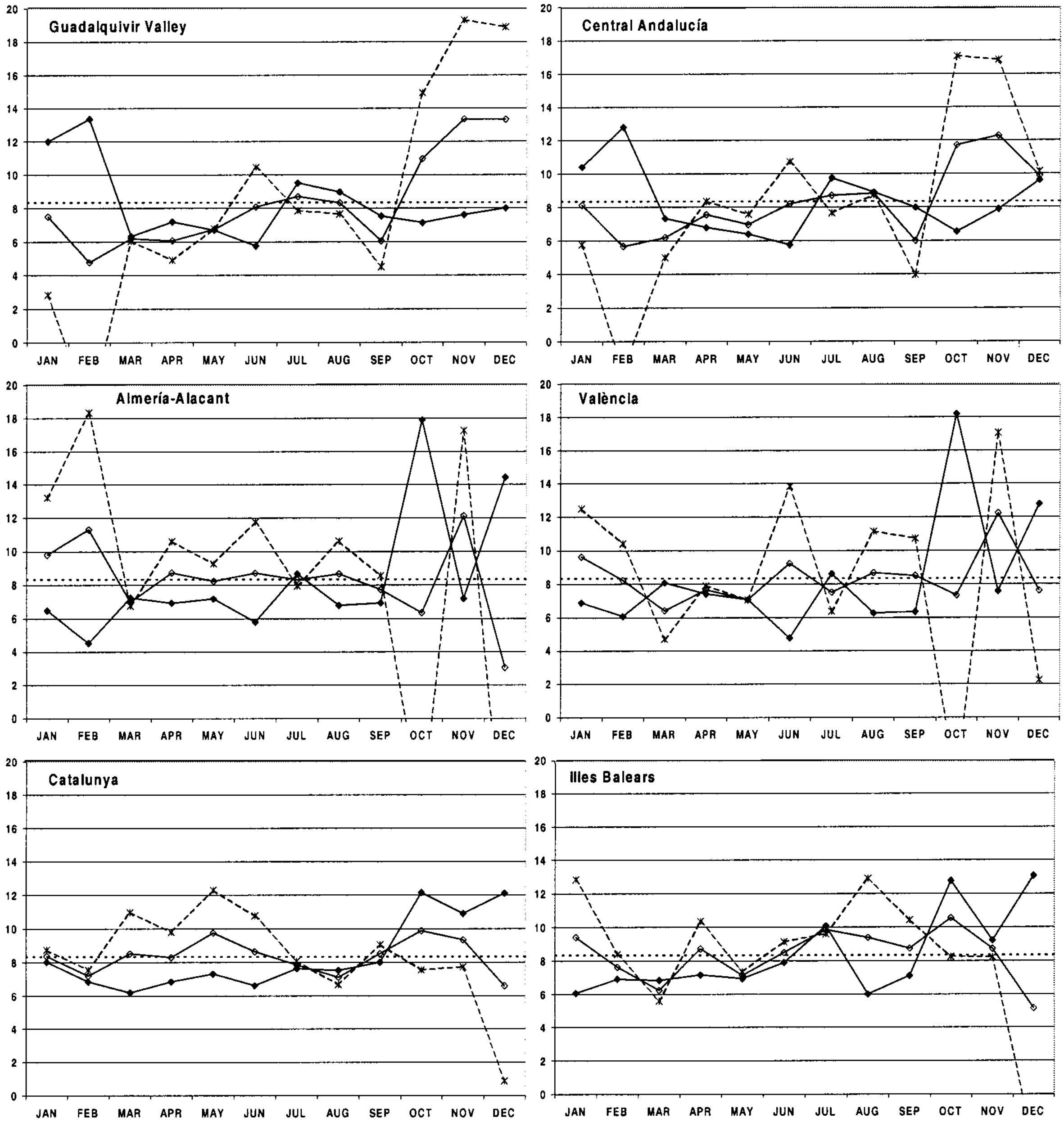

Figure 14. 'Initial' (1964), 'present' (1993) and 'future' (2023) monthly weights on the SI_i for the three areas across the study region (see Figure 6 for the 30-year mean). The graphs are based on the trends indicated in Figure 10. 'Initial' values are shown with a solid line and solid symbols, 'present' values by a solid line and open symbols, and the 'future' by a dashed line

Such projected changes in the seasonality index reflect quite important shifts in the mean precipitation of certain months, as indicated earlier in the paper when looking at trends in monthly precipitation. The graphs in Figure 14 showing the weight of individual months to the index (see the section introducing the SI_i, above) for 'initial', 'present' and 'future' years help to indicate what could happen in the near future, though, again, the results must be treated with extreme caution. The importance of precipitation in January and February and in the July and August dry period to southern provinces decreases between the initial and present states, and is compensated for by the increasing importance of precipitation between

October and December inclusive. By contrast, the importance of high precipitation values in October and December for central provinces is decreased noticeably between the initial and present situations, with the November weighting on the index increasing in part compensation. January and February have also assumed a significant weight on the index by the 'present' situation. For northern provinces the dominance of precipitation in October, November and December has diminished in magnitude and extent through time, so that only October and November weigh significantly at the 'present' time. If these trends continue, then very considerable increases in the amount of precipitation falling in October, November and December may be expected across southern provinces, with an associated marked decrease in precipitation between January and March inclusive. For central provinces, autumn and early winter precipitation is set to become more concentrated into the month of November, and the late winter, early spring rains are set to increase in importance, with greater aridity during the summer months. For northern provinces a more spatially complex picture emerges so that the overall mean trend masks out smaller-scale changes.

Though considerable caution must be placed on the results from this study, they strongly suggest that, irrespective of whether overall precipitation amounts are increasing or decreasing, the distribution of precipitation through the year may be changing quite markedly for many parts of eastern and southern coastal Spain. These are the parts where environmental stress through aridity already contrast with very brief periods of sometimes devastating storm precipitation. They are also the parts of Spain where pressures due to tourism and urban and industrial expansion are continuing apace. Two of the main tourist areas in Mediterranean Spain (encompassed by the Almería-Alacant and Illes Balears affinity areas) are apparently, in general terms not undergoing a significant increase in seasonality of precipitation. Their seasonality index trends are respectively 0.0004/year and 0.0006/year. These are, however, both areas which experience very modest amounts of annual precipitation, and very little summer rainfall. By contrast, increased concentration of precipitation into fewer cool season months further south and west in Guadalquivir Valley (trend, 0.0025/year) and Central Andalucía (0.0017/year) is producing a trend towards even greater seasonality, in areas where the cool/warm season contrast is already considerable. However, the greatest trend is to be found in the far northeast in Catalunya (0.0027/year), a reflection of increasing dryness, notably in March and December, and also slightly during the summer, and increased rainfall in October and November. This area is one of the recognized EU 'motors' of rapid growth and changes to its precipitation régime, and a reduction in the annual precipitation amount, could have marked implications for continued development. If precipitation is becoming more concentrated into fewer 'wet' months during the year, as the cool season is apparently contracting in Andalucía, and if the autumn storms in, say Alacant, Catalunya or the Balearics are becoming more concentrated into 1 or 2 months, then this may dictate that significant changes be made to urban drainage networks or the capacity for long-term water storage to cope. There are inevitably further questions raised by the results obtained in this study.

ACKNOWLEDGEMENTS

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