1. THE CLIMATE OF SPAIN: PAST, PRESENT AND SCENARIOS FOR THE 21ST CENTURY

Manuel de Castro, Javier Martín-Vide and Sergio Alonso

Contributing Authors

J. Abaurrea , J. Asín, M. Barriendos, M. Brunet, J. Creus, E. Galán, M.A. Gaertner, C. Gallardo, J.C. González-Hidalgo, J. A. Guijarro, Y. Luna, A.D. Pozo-Vázquez, J. Quereda, F.S. Rodrigo, C. Rodríguez-Puebla, R. Romero, A. Rosell-Melé

Reviewers

C. Almarza, E. Zurita

ABSTRACT

Due to its complex orography and geographic situation, Spain has great climatic variability. The spatial differences of annual mean temperature values surpass 18ºC on the Peninsula and the average annual accumulated precipitation ranges from barely 150 mm to over 2500 mm.

To this we must add the high interannual climatic variability and the noteworthy range of extreme daily values. Thus, for example, rainfall variability reaches rates of over 20% in Mediterranean regions and the Canary Isles, and the sequences of consecutive rainless days can exceed 4 months in the South. Interannual variability is fundamentally conditioned by different patterns of general atmospheric circulation in the northern Hemisphere, among which we can highlight the North Atlantic (NAO index). Furthermore, extreme daily temperature values cover an interval of between –40ºC and +50ºC and daily precipitation maximums can exceed 500 mm.

Analysis of recent temperature tendencies enable us to confirm that there has been quite a general rise in annual mean temperature since half-way through the 70s of the XX century, by an amount slightly higher than what has been observed at global scale, warming being more evident in winter. Furthermore, the complex spatial distribution of precipitation and the high temporal variability of this do not enable us to define any general tendency. However, abundant results indicate a downward tendency in the South of the Iberian Peninsula and in the Canary Isles in the second half of the XX century, which appears to tally with the positive tendency of the NAO index observed in the last few decades. There are no conclusive results, either, of the evolution of the number of days with heavy rainfall.

The tendency of future climate resulting from the application of global climate models is affected by different sources of uncertainty. Among these, we can highlight the evolution of global anthopogenic emissions of greenhouse gasses (GHGs) and of sulphate aerosols. For this reason, the IPCC has established a set of emission scenarios (SRES), according to different suppositions regarding population growth, the evolution of socio-economic activities and of technological progress throughout the XXI century. This report only considered the scenarios known as A2 and B2. The former corresponds to an evolution of GHGs that is increasing more rapidly than the latter. Thus, in A2, the global CO_2 concentration would reach 850 ppm in the year 2100, 120% higher than at present, and in B2 around 760 ppm, approximately double the present value.

Taking into consideration the average results of the set of six global climate models, temperature increases are projected on the Iberian Peninsula which are essentially uniform throughout the XXI century, with an average tendency of 1.2ºC every 30 years in winter and of 2ºC every 30 years in summer for scenario A2, and of 1.1ºC and 1.8ºC respectively, for scenario B2. With regard to precipitation, the change tendencies throughout the century are generally not uniform, with notable discrepancies among the global models, which makes the result less reliable. All of them, however, coincide in a significant reduction of total annual precipitation, somewhat greater in scenario A2 than in B2. These reductions are maximum in spring and somewhat lower in summer.

The low spatial resolution of the global climate models do not allow for spatial discrimination of the projection of climate change in Spain, because of its relatively small geographic area. For this reason, we considered the results provided by a regional climate model, with a resolution of 50x50 km2, nested in one of the previous global models. It should be pointed out, however, that the projections with the regional model presented here only refer to the last third of a century (2070-2100) and correspond to the regionalisation of the climate change simulated by one

single global model. For this reason, although they present greater spatial detail and the results essentially coincide with that of eight other European regional models nested in the same global model, the reliability of the results should theoretically be considered lower than those of the average of the ensemble of the six global models.

The most relevant changes projected by the regional model for the last third of the century in relation to present climate can be summarised in the following points:

a) On the inland Peninsula, the temperature increases in relation to the present climate in scenario A2 reach values of between 5ºC and 7ºC in summer and between 3ºC and 4ºC in winter. In scenario B2, the distribution of warming is similar to that of scenario A2, but generally 1ºC less intense. On the coast of the Peninsula and of the Balearic Isles, the warming projected is around 2ºC less than that on the inland Peninsula in all the seasons of the year, and in the Canary Isles, around 3ºC less in summer and 2ºC less in winter.

b) The changes projected for accumulated precipitation are spatially more heterogeneous. In winter there are slight increases in the Northwest and slight decreases in the Southwest in both emission scenarios. In spring there are greater generalised decreases, although somewhat higher in scenario A2 than in B2. In summer, the increase in precipitation is maximum throughout the whole territory, except in the Canary isles. In autumn, a slight increase in the Northeast is projected for scenario A2, and a decrease in the Southwest, both of these less intense than in scenario B2.

c) An increase is projected in the range and frequency of monthly temperature anomalies in future climate in relation to the present climate. Although this increase is not noted in a regular manner throughout the whole territory, in all the seasons of the year and in the two emission scenarios the increases in range remain at around 20%. Furthermore, no significant alterations have been observed in the frequency of monthly precipitation anomalies, although this conclusion is especially questionable.

d) The frequency of days with extreme maximum temperatures on the Iberian peninsula tends to increase significantly in spring and, to a lesser degree, also in autumn, whereas in the Balearic and Canary Isles, no appreciable changes have been noted, the same as what occurs in the other two seasons of the year throughout the whole territory. The frequency of days with extreme minimum temperatures on the Peninsula presents a downward tendency.

Considering the set of results of climate change projected throughout the XXI century for Spain by the different climate models considered in this report, we can arrange their degree of reliability, in a descending order, in the following manner: 1º Progressive tendency towards and increase in average temperatures throughout the century. 2º More accelerated tendency towards warming in the more accelerated emission scenarios (A2). 3º Increases in average temperature are significantly greater in summer months than in winter ones, with intermediate values in the remaining months. 4º Warming in summer is greater in inland areas than close to the coast or on the islands. 5º Generalised tendency towards less annual accumulated rainfall in both emission scenarios throughout the century. 6º Greater range and frequency of monthly temperature anomalies in relation to the present climate. 7º Greater frequency of days with extreme maximum temperatures on the Peninsula, particularly in summer. 8º The greater reduction of precipitation on the Peninsula is projected in the months of spring in both emissions scenarios for the last third of the century. 9º Increase in precipitation in the West of the Peninsula in winter and in the Northwest in autumn. 10º Changes in precipitation are in general greater in the more accelerated emission scenario (A2).

1.1. CLIMATE EVOLUTION IN THE PAST

At scales of thousands of years, tens of thousands and even greater, Spain's climate has followed the general patterns laid out by natural fluctuations and global climate changes. The glacial periods – the best known changes of the geological past – have left numerous visible marks of the landscape and varied palaeoclimatic records. Climatic changes have, however, been expressed locally, as a result of modulation of global change by the geographic factors and physiographic variables of the different regions of Spain. Numerous palynological records in lakes pay witness to changes in vegetation like, for example, those obtained in Padul (Granada) (Pons and Reille 1988), Banyoles (Gerona) (Pérez-Obiol and Julià 1994) and Sanabria (Zamora) (Sobrino *et al.* 2004). These analyses have shown that the climate in Spain has repeatedly changed as a result of natural processes, as has occurred all over the planet, and in certain periods in the past, there have been climatic conditions radically different from the present ones. Thus, as an example, polar waters and probably icebergs entered the Mediterranean through the Straits of Gibraltar on many occasions during the last glacial period (Cacho *et al.* 1999).

The glacial periods, which must have been characterised by temperatures several degrees below the current ones, were much longer than the interglacial ones, and while they lasted, there were abrupt climatic oscillations at geological scale, such as the *Dansgaard-Oeschger* warm cycles during the last glaciation (between 110,000 and 10,000 years BP). These rapid oscillations were caused by changes in oceanic currents, which had a great impact on the Iberian environment, as can be seen in the profound changes in the vegetation (Burjachs and Julià 1994). The relevance of these episodes demonstrates the existence of sudden changes in climate, which, in spite of their distant origin, are capable of spreading globally. Indeed, the environmental conditions of the Iberian Peninsula and of the Mediterranean basin have been very sensitive to the climatic variability of the North Atlantic region. The climatic variability of the Peninsula has been closely related to changes in marine circulation, although different areas have shown responses that have been attenuated to a greater or lesser degree, depending on their location (Sánchez-Goñi *et al.* 2002).

The transitions from glacial periods to interglacial ones were rapid on a geological scale, with occasional abrupt recessions to quasiglacial conditions, as occurred during the *Younger Dryas* episode (between 13,000 and 11,600 years BP) in most of Europe, although this oscillation may not have affected the whole Iberian Peninsula (Pérez-Obiol and Julià 1994; Allen *et al.* 1996; Carrión 2002). The interglacial periods, like the one we have been in for the last 10,000 years (the Holocene) are warmer, in comparison to the glacial periods, and climatically more regular, although there have been some brief fluctuations (Leira and Santos 2002).

Climatic conditions during the Holocene have not remained totally constant, either, and different studies have shown that, in general terms, Iberian climates have become more arid and temperatures have been rising gradually (Araus, *et al.* 1997; Jalut *et al.* 1997; Jalut *et al.* 2000; Davis *et al.* 2003; Rimbu *et al.* 2003). Some of these authors suggest that this tendency is probably the opposite to what has occurred in other parts of Europe and the North Atlantic.

The climatic scenario for just over the last thousand years on the Iberian Peninsula has been characterised, in general terms, by a warm episode during the Middle Ages, between IX and XIII-XIV centuries, accompanied by relatively abundant and regular precipitations. The medieval warming period was followed by an episode of relative cooling and increased pluviometric irregularity between the XIV and XIX centuries. Dendroclimatic studies carried out on the Iberian Peninsula have permitted the reconstruction, in a sporadic manner since the XII century, and more continued since the XV century, of values of mean annual temperature and rainfall in several points of the territory. Temporal analysis of the variability of these series, including varying degrees of extreme values, has demonstrated the alternation of periods with very differentiated climatic characteristics (Creus *et al.* 1997; Saz and Creus 1999; Saz 2003)

(Figure 1.1). Thus, the climate in the initial centuries was characterised by high rainfall and temperature values, with a very regular regime that lasted well into the XIV century, when both variables started to show a notable downward trend and an increase in the frequency of extreme values. This behaviour was the prelude to the start of a very variable and particularly cold climate phase, which reached its peak in the XVII century and lasted until the end of the XVIII and the first decades of the XIX. It corresponds to the phase known as the Little Ice Age (LIA), during which climatic variability was very high, while, at the same time, there were pulses of differing intensity that aggravated its characteristics. The LIA has also been identified on the Iberian Peninsula with the use of coastal marine records (Luque and Julià 2002), and lacustrian (Desprat *et al.* 2003) and documentary ones, using in this case, rogation “pro pluviam” records and ones related to claims for flood damage (Martín-Vide and Barriendos 1995; Barriendos and Martín-Vide 1998). One of the most notable pulses during the LIA, with increased droughts and torrential rainfall in the eastern Mediterranean, took place at the end of the XVIII century (Barriendos and Llasat 2003).

With regard to climatic risks, in certain periods of the LIA these were more frequent and of greater magnitude than during the XX century, with a noteworthy impact on the societies of the time. The recent period, from the middle of the XIX century to the present has involved, from the secular point of view and with reference to the LIA, a return to conditions of greater climatic regularity.

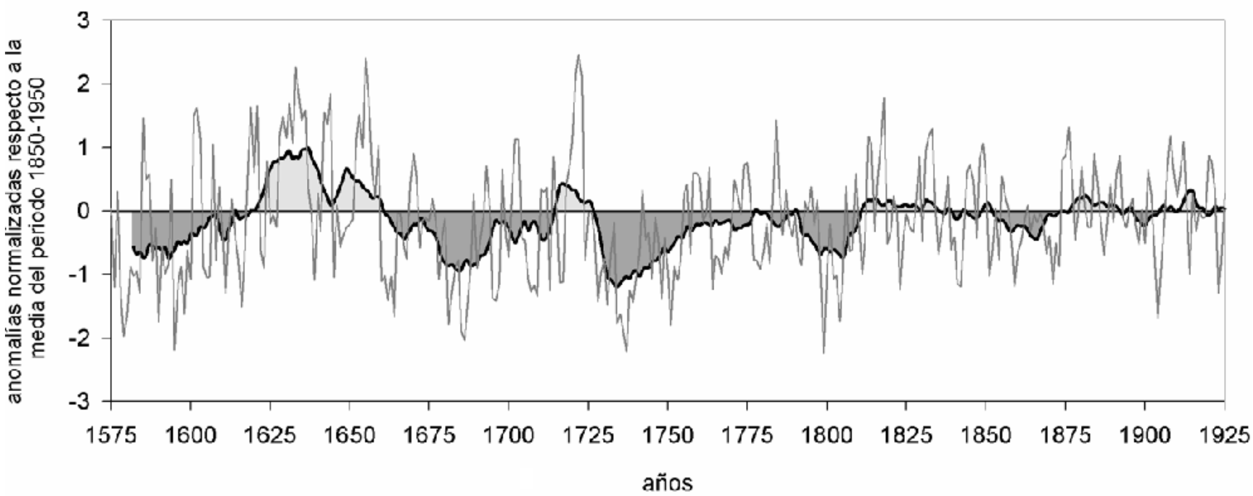

Fig. 1.1. *Annual precipitation anomalies in NW Spain (1575-1925) –smooth curve using 15-year moving averages (By J.Creus).*

1.2. THE PRESENT CLIMATE

1.2.1. Temperature

a) Mean annual temperature

Although the distribution of the mean annual isotherms provides quite a good reproduction of the hypsometric map, the latitudinal differences between northern and southern Spain, even excluding the Canary Isles, along with the different characteristics of the Atlantic ocean and the Mediterranean sea, give rise to certain differences. The main spatial values and models of mean annual temperature for the Iberian Peninsula and the Balearic Isles are the following: the value for sea level ranges from just below 14ºC on points of the coast of Cantabria to over 18ºC in the southern Mediterranean and the South Atlantic; 2) along the eastern Mediterranean coast, mean annual temperature ranges from 15ºC in some sectors of the Catalonian coast to 18ºC on the coast of Almeria, whereas on the Balearic Isles, the values next to the sea are between 16 and 18ºC; 3) the mean annual temperature can be negative above an altitude of 2,800 m in the northern half of the Peninsula (Pyrenees) and in shaded areas above 3,100 m in the south (sierra Nevada); 4) the northern plateau presents values of between 10 and 12.5ºC and the southern plateau, between 12.5 and 15ºC, in general; 5) the lowlands of the Ebro basin have mean annual temperatures a little above 14ºC, those of the Guadalquivir valley are between 17 and 18ºC and those of Extremadura are slightly over 16ºC; 6) the values decrease in the coast-inland direction; 7) the values increase from North to South, at equal altitude; 8) inland, values decrease from West to East (Figure 1.2).

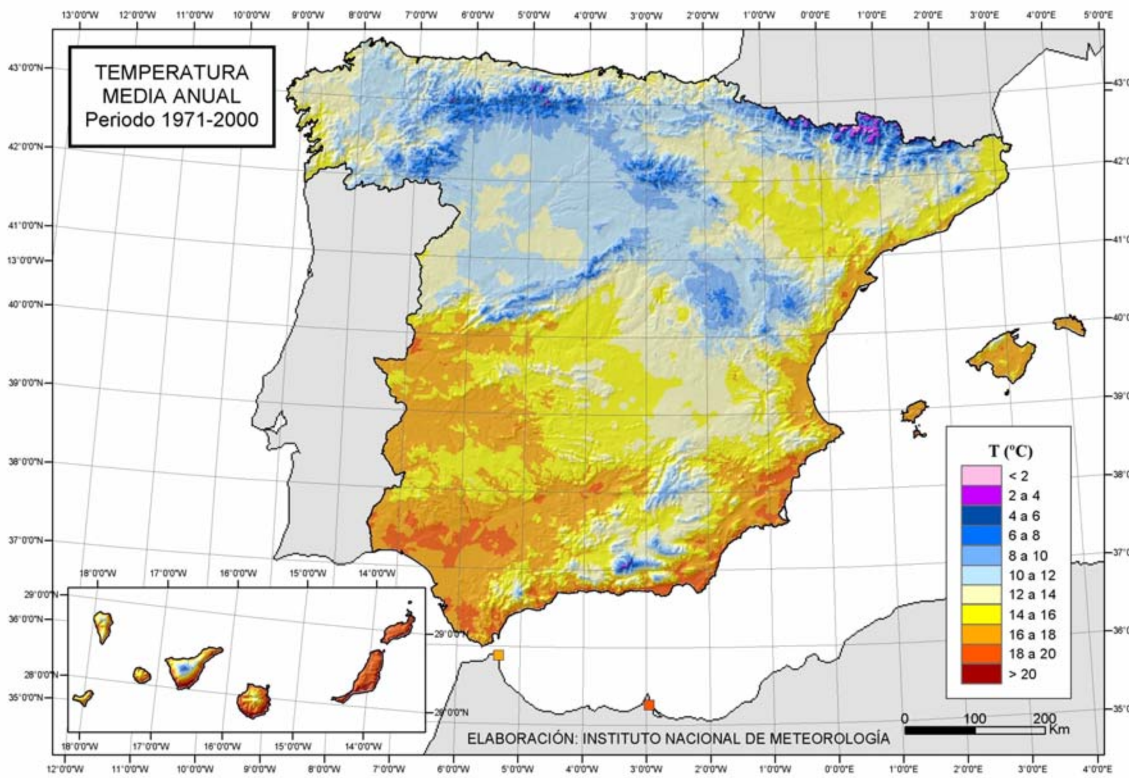

Fig. 1.2. *Annual mean temperature (ºC)(1971-2000) (Source: Spanish Meteorological Institute).*

The temperature difference of slightly over 4ºC between the mean annual temperatures of the northern and southern coasts of the Iberian Peninsula constitute a latitudinal gradient of just over 1ºC/200 km. On the coast of North Africa, Ceuta and Melilla present values comparable to those of the south coast of the Peninsula. On the Canary Isles, temperatures are appreciably higher than in the rest of Spain at equal altitude, surpassing 20ºC, and even reaching 21ºC on the coasts. In short, the mean annual temperatures tally with global averages, but they show considerable contrasts between the higher, northern lands and the lower, southern ones.

b) Mean temperatures in January and July

January presents the lowest mean monthly temperature, with the exception of certain parts of the Canary Isles and some capes in Galicia, whereas February can be one tenth of a degree lower than January. On the other hand, the highest monthly averages are not exclusive to July, but rather, in many of the coastal observatories like the Balearic Isles, Canary Isles, Ceuta and Melilla, these are registered in August and are due to the thermal inertia of the sea water, although these show little difference from the preceding month. The main characteristics of the isotherm map for the month of January can be summarised as follows: 1) the 6ºC isotherm encompasses the whole northern half of the Peninsula, with the exception of the coastal and pre-coastal fringe below 500 m altitude; 2) in the southern half of the Peninsula, the same isotherm encompasses Madrid, much of Castilla-La Mancha, the Sierra Morena mountains, some inland regions of the Valencia Regional Autonomy, the main Sierra Bética and Penibética mountains, as well as the higher parts of Extremadura, Majorca and Tenerife; 3) the 12ºC isotherm appears on the southern Mediterranean and South Atlantic coasts, Ceuta, Melilla and below around 700 m on the Canary Isles.

The main characteristics of the isotherm map for the month of July can be summarised as follows: 1) the 24ºC isotherm covers a large area in the southern half of Spain, with the exception of an eastern strip comprising Castilla-La Mancha, along with the Cordillera Ibérica mountains, some parts of inland Valencia, the main Sierra Béticas mountains and some parts of the Montes de Toledo and Sierra Morena mountains; 2) temperatures of over 24ºC are also reached, in the northern half, in the lower lands of the Ebro basin; 3) the 16ºC isotherm only appears in the Cordillera Cantábrica mountains and at the higher levels of the Galaico Massif and the Montes de León mountains, of the Pyrenees and of the Ibérica and Central mountain ranges of Sierra Nevada and of the Teide; 4) the Cantabria coast in the north does not reach 20ºC. Summertime is only cool in the higher mountain ranges and on the coast of Cantabria, whereas much of the southern half of the Peninsula can be considered to be very hot. In the Mediterranean course of the Guadalquivir river, between Jaén and Seville, a monthly average of 27ºC is surpassed.

c) Extreme temperatures

It is well known that the 40ºC threshold is surpassed every summer in some capital cities of Andalucia, such as Córdoba and Seville, as well as in other parts of the southern half of Spain. Even this value has been greatly surpassed on occasions. Thus, Écija (Seville) has recorded on different occasions the temperature of 47ºC (July 7th 1959, several days in July 1967, etc.). Likewise, in Seville 47ºC has been reached (August 6th 1946). During the heat wave in July 1995, Seville and Córdoba reached 46.6ºC. The record of 51ºC registered on July 30th, 1876 in Seville is doubtful, as well as other values of over 50ºC in smaller observatories. We must consider, however, in view of the existing records, that on certain occasions, a temperature of 50ºC has been reached in some parts of the Guadalquivir basin.

Temperatures of 40ºC are not exclusive to Andalucia, and, although less frequently, they have been reached and surpassed in Castilla-La Mancha, Extremadura and Murcia, and, on rarer occasions, in the lowlands and mid-altitude lands of Navarre, La Rioja, Aragón, Valencia, Alicante, Mallorca, inland Catalonia, lowlands of Orense and certain point of the Rías Bajas, towns of Madrid, Tenerife and eastern islands of the Canary Isles. The maximum absolute temperature even of Bilbao has exceeded 40ºC, under the influence of southern conditions. The 45ºC isotherm can be considered as being exclusive to the Guadalquivir valley. Although the clearest and most general atmospheric heat wave situation with temperatures of over 40ºC is due to advection of air from the Sahara in the lower layers of the troposphere, in some parts of Spain this threshold has been reached in other situations (*föhn* – type westerly wind on the Valencia coast, southerly wind, also of the *föhn* on the Basque coast, etc.).

With regard to minimum absolute temperatures, on the coasts of the Mediterranean, the Peninsula and Balearic Isles, the coasts of the South Atlantic and the lowlands of the Canaries, frost is infrequent or even non-existent. But the continentality and the altitudes of the inland Peninsula and of the mountain ranges on occasions permit very low minimums. The observatories of Castilla- La Mancha and Castilla y León have recorded minimum temperatures of below –10ºC and, in some places, less than –20ºC, over a thirty year period. Temperatures of below –10ºC can also be registered in the Ebro basin, the Intrabetic *hoyas* (topographic depression), such as Granada, inland Galicia and Cataluña, as far as the coast of Guipuzcoa.

Likewise, at the higher levels of the main mountain ranges, temperatures have dropped below the aforementioned thresholds. During the last international period, the aerodromes of Los Llanos (Albacete), at only 704 m altitude, recorded –24,0ºC, Villafría (Burgos), -22,0ºC, Vitoria, little over 500 m, -21,0ºC, and Matacán (Salamanca), -20,0ºC. The official record for minimum temperature in Spain is held by Estany Gento, in the Pyrenees of Lérida, at an altitude of 2120 m, with –32ºC, on February 2nd 1956, during one of the harshest cold spells of the XX century. Temperatures of –40ºC have probably been reached, at some stage, on the highest summits of the Aragón Pyrenees. Set in an area of the Cordillera Ibérica mountains between Zaragoza, Teruel and Guadalajara are some of the coldest parts of Spain in winter, if we take into account their relatively modest altitude, between 850 and 1,100 m. The Calamocha and Molina de Aragón observatories have recorded values of between –28ºC and –30ºC.

d) Mean annual temperature range and continentality

The annual mean range (difference between the mean temperatures of the hottest and coldest month) which is a good index of continentality, is notably high on the Plateau, especially the southern part, and the in the Ebro basin. In some parts of the southern Plateau, an annual mean range of 20ºC can be surpassed. Values of 18ºC and even higher are common in the lowlands of the Ebro valley and its tributaries, and of between 16 and 17ºC on the northern plateau. To the contrary, the coastal areas of the Canary Isles have minimum annual mean ranges, due to their insularity and low latitude. Thus, on the coasts of the Canaries, the hottest month is differentiated from the coldest one by between only 5ºC and 7ºC. On the Peninsula the lower level of continentality, or the greater oceanic influence can be found on the coasts of La Coruña, and is around 9ºC. To the contrary, the eastern Mediterranean coast and that of the Balearic Isles present a relatively high range, around 14ºC due to the influence of a sea that is practically closed-off and surrounded by highlands.

1.2.2. Rainfall

a) Mean annual rainfall

Rainfall is the most important climatic element in Spain, both from the point of view of climate and as a resource, given the modest amount that falls in much of the territory and its high temporal and spatial variability. The mean annual total has traditionally been used to distinguish three large zones: rainy Spain, dry Spain and semiarid Spain. The dividing line between the rainy and dry parts of Spain is usually established by the 800 mm isoyet and, in some cases, the 600 mm or intermediate one. The dividing line between dry Spain and semiarid Spain is established by the thresholds of 300 or 350 mm. The representation of three categories is not perfectly separated in space, but is interspersed in numerous sectors. Thus, the map of mean annual rainfall in Spain is a very complex one, with many enclaves with high or low pluviometry inserted into regions presenting the opposite sign (Figure 1.3).

Rainy Spain fundamentally comprises, in a continuous manner, almost all of the North and Northwest of the country. In most cases, mean values are above 1,000 mm, and in the sectors most exposed to wet maritime airflow, 2,000 mm can be surpassed. There are also numerous sectors of the peninsula and even of the islands, that surpass the threshold of 800 mm, almost always in mountain ranges. The largest area, dry Spain, occupies a huge area in the centre of the Iberian Peninsula, taking in the flatlands of the two Plateaus, the lowlands of the Ebro basin, the Guadalquivir Basin, and much of the eastern coast, except for the Southeast and the southern Mediterranean and South Atlantic coasts. Also belonging to dry Spain are the Balearic Isles, excepting the Tramuntana mountains in Majorca, some of the highlands and other mid-level ones on the Canaries, Ceuta and Melilla. Values of around 500 mm are quite frequent in dry Spain. Semiarid Spain is represented mainly by the Southeast of the Peninsula, that is, much of the province of Almeria and sectors of Murcia, Granada and Alicante. There are also some small enclaves in the Ebro and Duero basins, as well as in Lanzarote, Fuerteventura and the lowlands of the remaining Canary Isles, except La Palma.

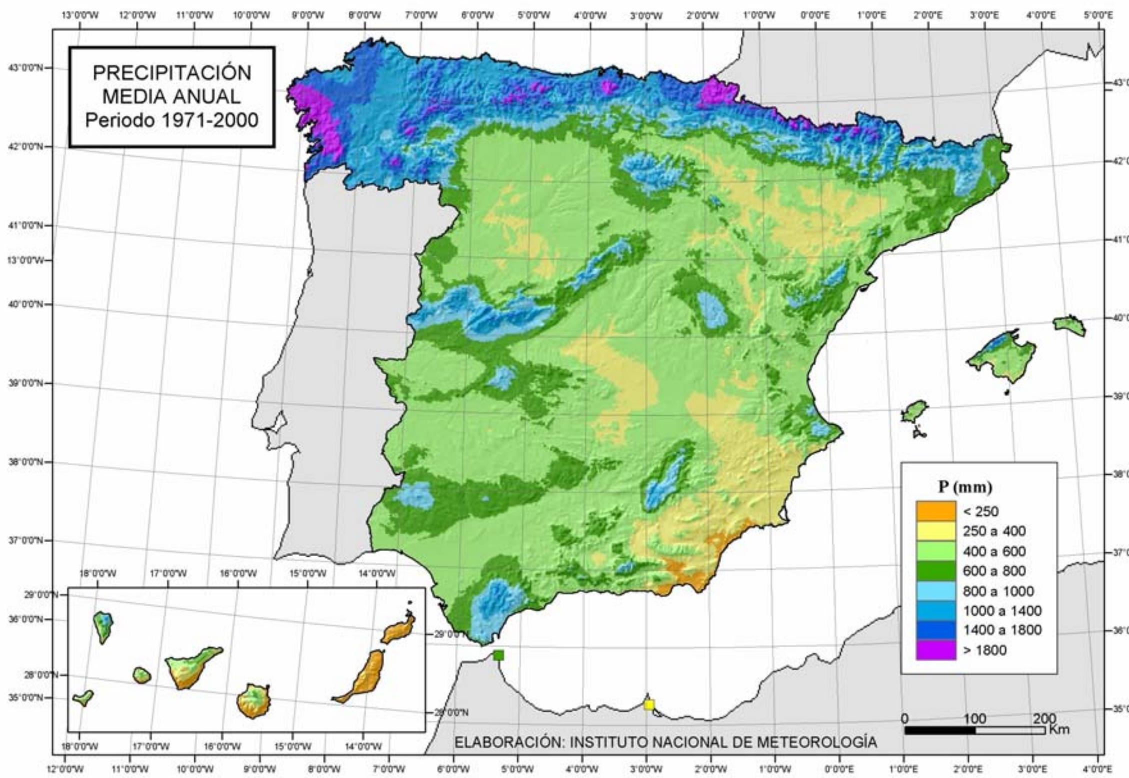

Fig. 1.3. *Annual mean precipitation (mm) (1971-2000) (Source: Spanish Meteorological Institute).*

At joint scale, annual rainfall on the Iberian Peninsula decreases from North to South and from West to East, so that on an imaginary diagonal line running from Galicia to Almeria, we can see the extreme contrast with regard to rainfall. In the Canary Isles, rainfall also diminishes from North to South on each island, and from West to East in the archipelago. In the Balearic Isles, rainfall generally increases from Southwest to Northeast.

In peninsular Spain the mean annual volume of rainfall during the 1961-1990 period was estimated at 327.286 x10^6 m^3, which is an average height of 665 mm. The lowest value for peninsular Spain corresponds to Cabo de Gata (Almería), between 125 and 150 mm, depending on the period analysed, whereas in certain well-exposed parts of rainy Spain, values can exceed 2,500 mm. This means that the latter values are over 20 times greater the former. On the Balearic Isles, the extreme values are around 1,400 mm, in the Tramuntana mountains, and little over 300 mm in some parts of Formentera. On the Canaries, the range of values is approximately between 1,100 and 1,300 mm, in the Northeast of La Palma, and less than 100 mm in sectors of Lanzarote, Fuerteventura and on the south of the other islands, except for La Palma.

b) Interannual rainfall variability

In accordance with Mediterranean climates, rainfall in much of Spain is characterised by its high interannual variability. The 20% threshold for the annual variation coefficient enables us to establish the dividing line between Mediterranean climates and mid-latitude marine west coast ones on the Iberian Peninsula. In the Mar Menor sea, and in certain other parts of the east coast, the annual variation coefficient reaches 40%, which is a very high interannual variability. On the Canary Isles it also exceeds this value (Figure 1.4).

c) Seasonal rainfall regime

One of the most surprising climatic facts in mainland Spain is the extraordinary variation in seasonal rainfall regimes. Thus, there is no general rainy season, and not even a dry one, although, in this case, a high percentage of the territory is subjected to dry or very dry summers. On the two archipelagos, apart from summer minimums without exception, the maximum is well defined, in autumn on the Balearic Isles and in winter in the Canaries.

The seasonal rainfall regimes enable us to draw up a complex and varied spatial mosaic. In Spain, there are no less than 13 seasonal rainfall regimes of the 24 theoretically possible ones, resulting from the decreasing arrangement of the mean quantities of the four seasons (Table 1.1).

Table 1.1. *Global conclusions in relation to seasonal rainfall regimes in Spain (Martín Vide and Olcina 2001)*

Conclusions	*Regimes represented*	*Main distribution areas*
Winter max. ⇒ summer min.	WSASU WASSU	Atlantic, Cantabria and Southern Mediterranean sides and Canaries
Summer max. ⇒ winter min.	SUASW, SUSAW	Catalonia Pyrenees and one sector of the Cordillera Ibérica mountains (Jiloca-Guadalaviar)
Autumn max.⇒spring min.	ASWSU, ASSUW, AWSSU, ASUSW	Eastern Mediterranean side and Balearic Isles
Spring max⇒autumn min.	SAWSU, SASUW, SWASU, SSUAW, SSUWA (exception)	Inland peninsula
	Balanced	Valle de Arán

W: winter (DJF); S: spring (MAM); SU: summer (JJA); A: autumn (SON)

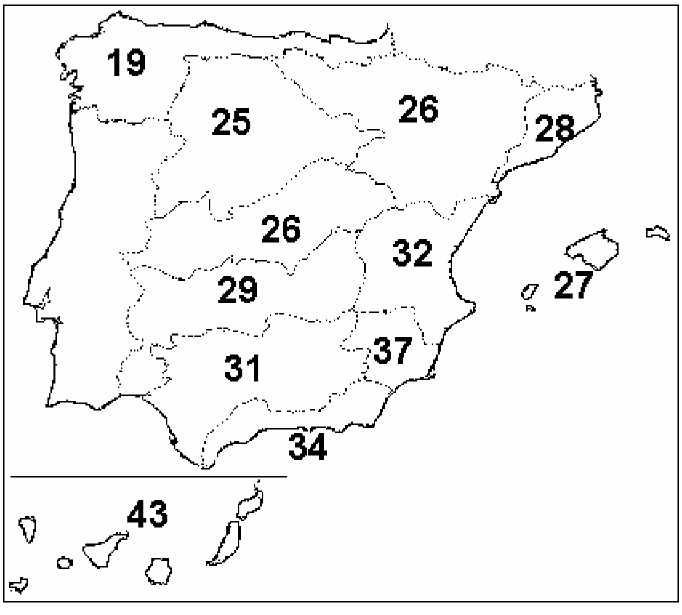

Fig. 1.4. *Mean coefficient of variation (%) of annual rainfall according to watersheds, based on data from 274 stations (basic period 1940-1989). (Martín-Vide 1996)*

In the Arán valley rainfall is distributed so evenly over the four seasons, that we can speak of a balanced regime. The regimes of the first and second groups are opposed, assuming that the ones presenting the summer maximum are constituted by the total inversion of the typical Mediterranean regime and the of the west coast marine ones. The lack of wintertime rainfall in parts of the eastern peninsula constitutes a unique range of seasonal regimes in Spain. Summer is extremely dry in southern Spain, including the Canary Isles. The percentage of summer, compared with the annual total, is less than 3% in the Straits of Gibraltar and throughout almost all the Canary Isles.

d) Frequency of rainfall and dry spells

For Peninsular Spain we can establish the following spatial values and patterns in relation to the mean annual number of days with appreciable rainfall: 1) it shows a clear decrease from North to South; 2) there is generally a certain decrease from West to East; 3) it presents relative maximums over the main mountain ranges; 4) it exceeds 100 days, almost without exception, further north than 40ºN, in Galicia, the Montes de León, the northern coast and the Cordillera Cantábrica, the highest parts of the Pyrenees and pre-Pyrenees and of the Central and Ibérica mountains, La Rioja and much of the northern Plateau; 5) it does not reach 50 days in the most arid sector to the Southeast of the Peninsula; 6) it barely reached 20 days in parts of southern Fuerteventura, Gran Canaria and Tenerife; and 7) the maximum is found in the eastern extreme of the Cantabrian fringe (San Sebastián, 188.0 days, in the 1951-1990 period).

In general, much of Spain, with the exception of the rainy northern fringe and the semiarid areas, presents an annual percentage of days of rainfall of between 15 and 35 %. If we use the threshold of 1 mm to consider one day of rainfall, part of the Southeast will total less than 30 days a year, whereas in the north, a total of 140 days can be surpassed. Consequently, the frequency of rainfall in much of Spain, with the exception of Galicia, the Cantabrian fringe, the western Pyrenees and nearby sectors, can be considered to be relatively low or very low.

The seasonal distribution of rainy days shows greater regularity and generality than the amounts. Winter and spring together are the seasons with the highest frequency of rainfall and summer has the least amount of rainy days. The lower the latitude, the lower the frequency of rainfall in summer.

The sequences of consecutive dry days can be very long in southern Spain, not only in the hotter half of the year, and this fact reflects the seriousness of droughts (Figure 1.5). In the 1951-1990 period, with the 0.1mm threshold, dry periods of over 4 months have been recorded in observatories in Andalucia, Extremadura and Castilla la Mancha, some of these lasting for over 5 months in Málaga, Almería and Huelva.

In much of Spain, snow is an infrequent phenomenon; the number of days with snow is only relevant in the big mountain ranges of the peninsula. Together, the spatial patterns and values most indicated in relation to the annual average number of days are: 1) altitude is the most decisive factor, so that, while snow is a rare phenomenon at sea level, with less than 5 days' occurrence, above around one thousand metres on the Iberian Peninsula and the Balearic Isles, and above around 2,000 on the Canary Isles, several days are always registered on the solid hydrometeor, reaching an average of ten or more; 2) the whole Spanish coastline, except for Cantabria, part of the Catalonia coast and the coast of Menorca, have snow for less than one day a year; 3) snow is practically unheard of on the lower, southernmost lands of Cadiz, in Ceuta or Melilla, and below around 1,200 m in the Canaries; 4) snow is more frequent in the northern half of the Peninsula than in the southern half; above around 1,800 m in the former and above 2,300 in the latter, there is a higher number of days with snow than rainy days; 5) In the Balearic Isles, the snow only makes an appearance on the summits of sierra Tramuntana, in

Majorca and 6) in the Canary Isles, snow only appears at the highest elevations of Tenerife, La Palma and Gran Canaria.

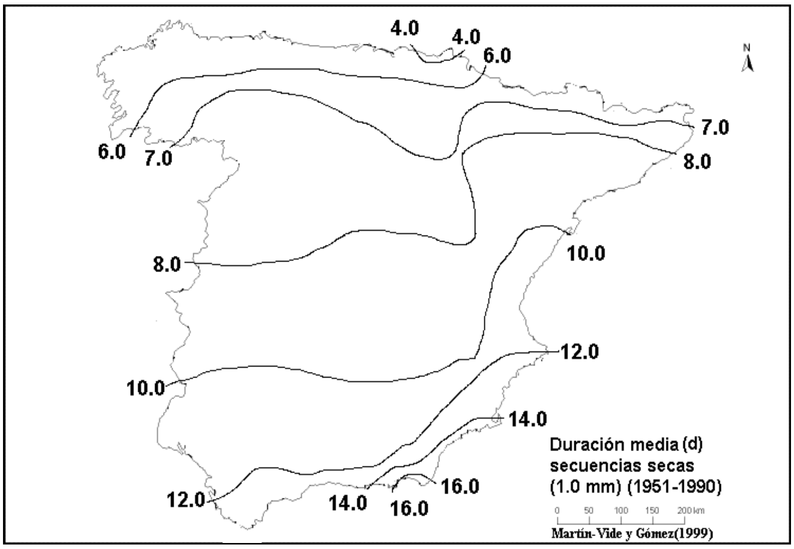

Fig. 1.5. *Average duration of sequences of dry days, with a threshold of 1.0 mm, in the 1951-1990 period (Martín-Vide and Gómez 1999).*

The number of days on which the snow settles presents very low values, except in the higher mountain ranges, where the snow layer can persist for quite a few days. The Pyrenees are, by far, the area with the biggest amount and longest duration of snow, which, above 3,000 m, does not melt in summer, allowing for the existence of small glaciers. Winter is the season with most snow. In the northern half of the Peninsula, above about one thousand metres, only the three summer months escape precipitation in the form of snow. On the summits of the Pyrenees, snow can fall in mid-summer.

Hail is an infrequent phenomenon, with an average occurrence of less than 5 days a year in most of Spain, but not without serious economic consequences for the agricultural sector. Even averages of less than one day are common in Andalucia and in the Canaries, the least affected regions. Northern Spain is, on the other hand, the region most affected by hail, with the highest number of days, 10 or more in La Coruña, Asturias and Cantabria, although some inland regions of the Valencia Regional Autonomy and of the Ebro valley, with fruit and vegetable crops very sensitive to hail suffer greater damage and economic losses. The hail calendar in Spain is dual: in much of the country, the hotter months of the year, from spring to autumn, the one with the greatest number of days with hail, caused by storms, whereas in the northernmost fringe the cold months present a greater frequency, associated with cold fronts.

e) Rainfall intensity

Daily rainfall intensity is high in many parts of the country, and the maximum daily amounts estimated for a return period of 10 years are above 100 mm in a high percentage of the Mediterranean coastal and pre-coastal areas of Peninsula, in parts of the Balearic Isles, in others at mid- and high elevations in the Canaries, in many sectors of Galicia and Cantabrian regions, in massifs of the Pyrenees, on the Southwest sides of the Cordillera Central mountains and in sectors of western Andalucia. The central areas of the two Plateaus, however, present more modest intensities, which can be below fifty millimetres for the return period considered. In any case, there is a clear dependence of monthly and yearly precipitation on a very low number of rainy days in much of Spain.

The time of year with the highest risk of torrential rainfall is at the end of summer and in autumn along a coastal and pre-coastal fringe on the eastern, Mediterranean side of the Iberian Peninsula, from Catalonia to eastern Andalucia, covering, inland, the Ebro basin as far as Zaragoza and, to the North, areas of the Pyrenees, spreading eastwards towards the Balearic Isles. In an area covering the eastern Plateau, La Rioja and part of Navarre, it is not uncommon for the maximum daily values to occur in a summer month, whereas in the western area, these occur above all in winter.

The records of daily rainfall in Spain confirm the existence of registers of over 500 mm, almost always in autumn. This amount in one day, even if it is distributed throughout the 24 hours, implies considerable hourly intensities. On one occasion, it may have exceeded 800 mm, November 3rd 1987 in Oliva (Valencia), with 817 mm., although some doubt is cast upon this datum at present, as it may have been the total accumulation of this day and the preceding one. The area of greatest daily rainfall intensity in Spain is the one comprising the regions of Safor, in southern Valencia, and the neighbouring Marina Alta, in northern Alicante. For a return period of 10 years, in certain parts of this region, 250 mm could be expected to be reached or surpassed. Likewise, in some mountain ranges (Grazalema, Cádiz; de Gata, Cáceres) the estimated values are very high.

The percentage contribution of the rainiest days to the annual totals is considerable on the eastern coast of the Iberian Peninsula: 25% of the days with the biggest amounts constitute over 70% of the annual total (Figure 1.6).

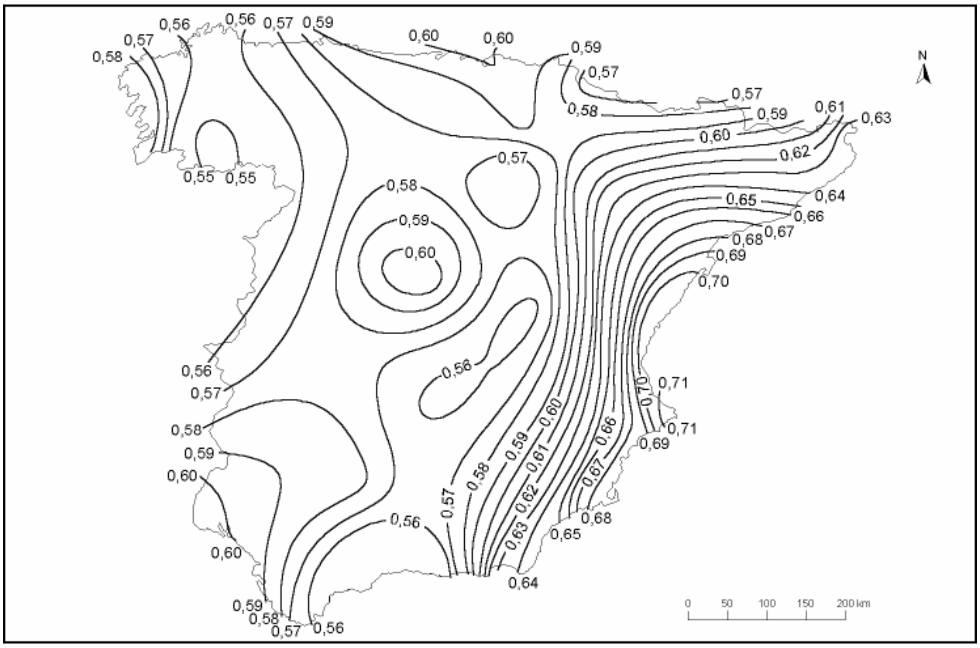

Fig. 1.6. *Index of daily rainfall concentration – the value 0.61 corresponds, approximately, to 70% of the annual total by 25% of the rainiest days- (Martín-Vide 2004).*

In a large part of the fringe closest to the Mediterranean sea, as well as in parts of the mountains, the rainfall intensities over short periods of time (hours or minutes) can reach very high values, typical of certain humid tropical climates, but without reaching their records. The maximum amounts expected in one hour for a return period of 10 years exceeds 50 mm in large parts of the eastern Mediterranean coastal and pre-coastal areas of the Iberian peninsula and in some of the other aforementioned sectors. Many showers in Catalonia, the Valencia Regional Autonomy, Murcia, the Balearic Isles and regions of Andalucia sometimes exceed intensities of 1 mm/min. These downpours, although they do not tend to last long, often cause flooding or drainage problems. In exceptional cases in some parts of Spain, in the previously mentioned regions, instant intensity peaks of over 5 mm/min. One of the records is held by the Valencia town, Manuel, which registered 119 mm in one hour, on July 1st 1993, and did not fall below an intensity of 4 mm/min during 20 minutes).

1.2.3. Other climatic elements

a) Solar radiation

Spain is subjected to an appreciable amount of solar radiation, with values lower than those recorded in tropical latitudes, in conditions of high pressure, but similar to those observed on the equator. The available series for solar radiation, which is measured in very few places (in 1998, 29 observatories comprised the national radiometry network), enable us to conclude: 1) mean daily global solar radiation is lower than 15 MJ/m^2 on the Cantabrian fringe and in much of Galicia, the Pyrenees and the Ebro valley, and it does not reach 12 MJ/m^2 in the more shaded sectors to the north of the Cordillera Cantábrica mountains and on the Basque coast; 2) the southern half of the Peninsula, Ibiza and a large area of the Canary Isles surpass 16 MJ/m^2; 3) in the sectors of the Andalucia coast, as well as in parts of the Canaries, over 18 MJ/m^2 is recorded. The monthly maximums of daily global solar radiation are reached in June and July, with over 20 MJ/m^2, except on the Cantabrian fringe, and up to more than 25 MJ/m^2 in the southern half of the Peninsula, Ibiza and sectors of the Canary Isles. The minimums are concentrated in December, followed by January, with values of less than 10 MJ/m^2, except in parts of the Andalucia coast and in the Canaries, with values of below 5 MJ/m^2 in Galicia, the Cantabrian regions, the Pyrenees and part of the Duero and Ebro basins.

b) Insolation

With the use of insolation records from 88 observatories for the 1961-1990 international period, it has been established that the extreme values occur in Izaña, with 3,448 hours of sunlight per year, in the clear atmosphere, above the layer of clouds, and in Bilbao airport, with 1,525 hours. In Peninsular Spain mean annual insolation also presents great variation, as the values are practically doubled from Bilbao to Cadiz, an observatory that exceeds 3,000 hours of sunlight a year. As a whole, the area with less sunlight in Spain is the Cantabrian fringe, which does not reach 1,750 hours, whereas the a higher amount of sunlight hours occurs on the Costa de la Luz coast, between Cadiz and Huelva, which reaches or slightly surpasses the 3,000-hour threshold.

The 2,000-hour sunshine duration isopleth, a threshold above which solar energy uses can reasonably cover many domestic needs, is practically restricted to Asturias, Cantabria, the Basque country, a non-Atlantic coast stretch of Galicia and some sectors of the Pyrenees. The rest of the country has abundant insolation. The whole southern half of Peninsular Spain, the Balearic Isles, much of the Canary Isles and even large areas in the northern half of the Peninsula, such as the west of the Duero basin, Aragón and southern Catalonia, have over 2,500 hours of sunlight a year. In the Canary Isles, locally and in the northern mid-heights, between around 700 and 1,200 m, relatively low insolation values can be found.

c) Cloudiness

Based on the data on insolation and on the number of days when the sky was clear, or with cloud cover, from 88 Spanish observatories for the 1961-1990 period, the mean annual number of clear days is between only 25.8 in the Vitoria aerodrome and 176.2 in Izaña. In Peninsular Spain there is also much contrast, an example of which is the aforementioned maximum and the 155.8 days in Cádiz, which is six times greater than the first value. The area with the lowest number of clear days, less than 40, is made up of Asturias, Cantabria, the Basque Country and inland Galicia. To the contrary, the area with the highest number of clear days consists of the Guadalquivir valley and the coast of Huelva and the Atlantic coast of Cadiz, as well as places like the Canary Isles, with over 120 days.

The mean annual number of days with cloud cover is between only 13.4 in El Hierro airport and 170.1 and 169.9, in San Sebastián and in Vitoria aerodrome, respectively. In Peninsular Spain there are also sharply contrasting figures. In Cadiz only 53.3 days are registered, less than one third of those in the aforementioned Basque capitals. In the Balearic isles, the airports of Palma de Mallorca and of Ibiza do not reach fifty days. The map showing the number of cloudy days indicates less than 60 days for the Mediterranean coast, from Valencia to Malaga, the south of Majorca, Ibiza, certain parts of the Northeast of Catalonia, the Atlantic coast of Cadiz, Lanzarote, Fuerteventura and the south of the remaining Canary Islands, and high levels for this archipelago. On the other hand, there are over 120 cloudy days in Galicia, except for the Rías Bajas, Asturias, Cantabria, the Basque Country, the Upper Ebro as far as Logroño, northern Castilla y León, part of the Ibérica, Central and Pyrenees mountain ranges and humid parts of the Canary Isles.

d) Air humidity

The values of mean annual relative humidity for the 1961-1990 period for 90 main observatories range from 88 % at Monte Hacho in Ceuta, exposed to the humid air circulating around the Straits of Gibraltar, to 49 % in Izaña, at 2,367 m, immersed in the very dry air covering the trade winds thermal inversion. On the same island of Tenerife and on other mountainous ones of the Canaries, at altitudes lower than that of the aforementioned observatory, the characteristic and persistent sea of clouds gives rise to very high values. Besides the places mentioned, the mean annual values of relative humidity exceed 70% in Galicia, Asturias, Cantabria, the Basque Country, the Pyrenees, the northern third of Castilla y León, the Balearic Isles, the Northeast of Catalonia, the Mar Menor sea, the coast of Cadiz, Ceuta, Melilla and mid-heights and coastal points of the Canaries. In Galicia and the regions of Cantabria, they approach 80%. In short, it is northern Spain and the coasts the areas that present the highest relative humidity; to the contrary, the places furthest away from the sea, Madrid and the surrounding areas, with the lowest annual average.

With regard to the annual relative humidity regime, the following patterns can be established: 1) mean monthly values present variation inland of the Iberian Peninsula, with a winter maximum (75-80%) and a summer minimum (40-50%); 2) annual variation is, to the contrary, low or very low on the coasts and islands (less than 15%); 3) in some coastal observatories in northern Spain, the maximums occur in summer and the minimums in winter. Indeed, in inland Spain, the maximum values in December, January or another winter month, exceed 75 % and in many places, 80 %, whereas in July and August, it is not unusual for them to register below 50 and even 40%. The three-month summer period is the one with the highest relative humidity on the northern coasts of Galicia, Asturias and Cantabria, although it differs little from the other stations.

e) Atmospheric pressure

In much of Spain, atmospheric pressure presents its maximum in winter, almost always in January, and the lowest values in spring, above all in April and in summer, apparently the opposite pattern of what is to be expected. In any case, there are observatories in the northern Plateau, which, with small differences in relation to the winter months, present the maximum value in a summer month. The general seasonal behaviour is due to the predominance of low relative pressures in the inland areas of the Peninsula in summer, resulting from the intense heating of the air, with the consequent drop in atmospheric pressure (1,015-1,017 hPa), whereas on the Cantabrian fringe, there is a belt of high pressure (1,020 hPa) associated with the Azores anticyclone, prolonged in ridge-form towards northern Spain; and to the predominance in winter of high thermal pressures inland (1,020-1,022 hPa) and to a cyclonic area in Galicia, with frequent frontal depressions and cold fronts.

f) Winds

The peninsular nature of much of Spain, the complex orography and the insularity of the rest of the territory favour regional and local winds that become climatically significant elements in the areas they affect. Among the regional winds, we can highlight the Northwest wind, North wind, East wind, West wind and Southwest wind. The Trade Winds are typical of the Canary Isles. Apart from these, the regime of sea breezes characterises the atmosphere of the coasts during the hot half of the year and on other stable days.

The lowest values of total wind speed were recorded in some observatories in the southern Plateau, as well as in certain regions protected from the wind (Bierzo, valleys in Orense, plains of Álava, inland Catalonia), whereas the highest one, for the 1961-1990 period, is in Tarifa, followed by two mountain observatories, Izaña and Turó de l'Home (Montseny, Barcelona). Mountain tops are windier than depressions; certain capes and coastal sectors present high total wind speeds.

With regard to maximum gusts, in the aforementioned period the maximum recorded was in Izaña 200 km/h, and the vast majority of Spain's observatories have, on occasions, surpassed speeds of 100 km/h. Whereas total wind speed does not show any general pattern in its temporal distribution throughout the year, maximum gusts generally occur from October to March. On combining high total wind speed with maximum gusts, the windiest areas of the country are located in the vicinity of the Gibraltar Straits, some capes of La Coruña, the coast of Guipuzcoa, northern Navarre, some buttes in the Ebro valley, the north and south coasts of Catalonia, the trade wind windwards in the Canary Isles and the summits and mountain passes of the main mountain ranges.

1.2.4. Climatic regionalisation

The wide range of values of the climatic elements and their complex spatial distribution hinder the establishment of a clear climatic regionalisation in Spain, which will always have numerous subtypes (Linés 1970; Font Tullot, 2000; Capel Molina 2000; Martín Vide and Olcina 2001) (Table 1.2).

1.2.5. Recent climate tendencies

It is very difficult to make a global and comparative synthesis of the results obtained from the different analyses and studies of the recent tendencies of climatic variables in Spain. The reason fundamentally lies in the use of different observation periods, the variety of the methods used in the statistical treatment of the data, the different spatial cover and the complexity of the territory itself. Even so, there is no doubt about the generalised temperature rise in Spain during the last quarter of a century, whereas rainfall has shown no clearly defined tendencies.

Table 1.2. *Climatic regionalisation of Spain (Martín Vide and Olcina 2001)*

Type	*Subtypes*	*Variety*	*P (mm)*	*Seas. Rainfall Reg.*	*T (ºC)*	*ΔT (ºC)*	*Other charact.*
OCEÁNIC	ATLANTIC	Galicia	1000-2500	Winter max and summ. Min.	11-15	8,5-12	Abundant Cloudiness and High Environmental Humidity
		Asturias and Cantabria	900-1500		12-14	10-11	
		Basque coast	1100-2000		12-14	10-12	
	MOUNTAIN	-	1000-2500	-	<12	-	
MEDITERRANEANO	SUB-MEDI-TERRANEAN	-	700-900		11-14	14,5-16	-
	CONTINENTAL	Northern Plateau	350-550	Wint. Or spring and summ. Min.	10-12,5	16-18	Frosts freq.in wint.
		Southern Plateau	350-550		12-15	18-20,5	High summ. Max. Temp
		Ebro Valley	300-550	Equinoctial maximums	13-15	18-20	Dry NW wind
	EAST FRINGE	Catalonia	550-750	Autumn max. And summer min.	14-17	14-17	Torrential rainfall in autumn
		Valencia	400-850		15,5-17,5	13,5-16,5	
		Baleric Isles	400-800		16-18	13,5-15,5	
	SOUTHERN	Coastal	400-750	Winter max. And summ. Min.	17-18,5	10-13,5	Frost exception
		Guadalquivir Valley	550-650		17-18,5	15-18,5	Very high summ. Max. Temp.
		Extremadura	450-600		16-16,5	16,5-18	High summ. Max. Temp
	ÁRID OR FROM SOUTHEAST	-	150-350	Summ. Min.	14,5-18,5	13,5-17,5	Extrema aridez
	MOUNTAIN	-	600-2000	-	<14	-	-
SUBTROP. / TROPICAL (Canaries)	COASTAL	-	75-350	Winter ma. And summ. Min	18-21	5-7,5	Trade winds in N and extreme aridity in S
	SEA OF CLOUDS	-	500-1000		13-16	6-8	High environmental humidity
	IN HEIGHT	-	450-700		<12	12-14	Very dry air

P, mean annual rainfall (mm); Seas. Rainfall Reg., seasonal rainfall regime; T, mean annual temperature (ºC); ΔT, annual mean temperature range (ºC).

a) Temperature increase

The increase in the mean annual temperature of the earth's surface during the last century, and more specifically, following the end of the 70's of the XX century, it was confirmed by the analyses based on regional series obtained through the interpolation of the observations covering different regions of Spain and of the longest individual series existing in the country (Raso 1997). Although a long-term understanding of air temperature in Spain is still far from being complete at a detailed spatial scale, some recent studies deal with the country as a whole or with certain parts of the Peninsula. Thus, in a preliminary analysis for the 1864-1999 period of homogenised regional series of monthly averages of maximum and minimum and mean temperatures from 98 observatories covering the whole of Spain, a statistically significant increase has been established in the three variables, both annually and seasonally, more obvious in winter than in summer (Brunet *et al.* 2001a). With an explicit correction of the urban effect, a research project dealing with 45 Spanish observatories, 27 of these with series starting in 1869, has reached the following conclusion: 1) maximum temperatures have risen significantly since the 70's of the XX century, except in Galicia, by 0.6ºC/decade, as a mean value, although with appreciable regional variations; 2) minimum temperatures have undergone a similar increase; and 3) warming has been detected mainly in winter (Staudt 2004). As a whole, it is the North and Northwest of the Peninsula the area with the lowest variations (Oñate and Pou 1996). Although on the Peninsula, the year in which the recent global warming started can be established somewhat before the one often used at global scale – 1976- the tendencies of the series of mean annual temperature in Spain analysed in the *European Climate Assessment (ECA)* from this year (Badajoz-Talavera, Salamanca, San Sebastián, Roquetes-Tortosa and Valencia) show, like the rest of the European ones, an increase of at least 0,3ºC/decade, in the 1976-1999 period (Klein Tank *et al.* 2002). This contrasts with negative tendencies in the previous thirty-year period 1946-1975. In Badajoz, Tortosa and Valencia there is a significant tendency throughout the 1946-1999 period, both in the number of hot days and summer days (positive) and in the number of cold days (negative).

Different studies of Spanish regions coincide in one essential fact: After the decade of the 70s, warming has become visible and significant. Thus, several studies with data from 9 stations in the northern Plateau have revealed a growing significant tendency of mean annual minimum temperatures of 0.051ºC/year, in the 1972-1994 period, which did not exist in the longer temporal interval 1945-1994 (Labajo *et al.* 1998; Labajo and Piorno 2001), and of mean annual maximums (Labajo and Piorno 1998). The rise in minimum and mean temperatures, but not in maximums, had already been established in 5 cities of the same regions (including Madrid), with series which in two cases started in 1869 and finished in 1992 (Esteban-Parra *et al.* 1995).

Analysis of the variations and tendencies of the maximum and minimum mean annual temperatures in the Southern Plateau in the 1909-1996 period, following the homogenisation with the use of the SNHT test of the series from 21 stations, and the subsequent design of a regional series, showed, as the most relevant results: 1) Maximum annual temperatures have shown a significant increase, calculated at 0.71ºC during the aforementioned period, whereas the tendency of the minimums, also positive, lacks any statistical significance; and 2) The temporal evolution shows phases parallel to the planetary ones, and that of the final interval 1972/73-1996, is characterised by a significant increase, both in maximum and minimum temperatures, of 1.62ºC and 1.49ºC, respectively (Galán *et al.* 2001). Similar results were obtained from 7 main observatories in the region (Cañada *et al.* 2001).

For Aragón, Navarre and La Rioja, analysis of the homogenised series of mean seasonal values of maximum and minimum daily temperatures in 15 observatories during the 1921-1997 and 1938-1997 periods, respectively, provided the following results: 1) Since the beginning of the seventies, generalised warming has been recorded, which is not seasonally homogeneous, given that it is not detected in autumn, but which is particularly clear in relation to maximum springtime temperatures, 0.143ºC/year (1975-1997), and summer ones, 0.096ºC/year (1973-1996); 2) in spring, the increase in daily temperature range is significant; and 3) with the exception of autumn, there has been a general decrease in variability since half way through the 70s, so that the anomalies observed do not exceed those previously observed (Abaurrea *et al*. 2001).

Analysis of the 23 stations in the Segura basin for the 1940-1997 period, coincide with regard to the significance of their growing tendency since the 70s. Likewise, spring is the season that presents most warming, 0.123ºC/year for the maximums (1970-1997). The greatest increases in maximums occur in the mountain areas, whereas it is the lowlands that have shown the biggest increase in minimums (Horcas *et al.*,2001).

Other regional series of maximum, minimum and mean temperatures at seasonal and annual resolution for Catalonia, based on data from 23 stations, preferably located in non-urban sectors, and with the verifications of homogeneity by the SNHT test, have allowed for the establishment of temporal patterns in the region for a period greater than one century (1869-1998). Three phases have been distinguished: a thermal increase between 1869 and 1949, of 0.01ºC/year; a brief cold spell, although also significant, of -0.03ºC/year, from half way through the century to the middle of the 70s; and the notable temperature rise since then until the end of the period, by 0.07ºC/year (Brunet *et al.* 2001b) (Figure 1.7). For the whole period, the increase is of 0.89ºC, winter, with 1.78ºC, being the season subjected to the highest level of warming, and summer, to the smallest increase, 0.59ºC. The series of annual and seasonal mean maximum and minimum temperatures confirm similar patterns, with a slightly bigger increase in the former ones (0.96ºC) than in the latter ones (0.82ºC) (Brunet *et al.* 2001c). For the Fabra observatory (Barcelona), respective analyses of daily maximum and minimum daily temperatures have confirmed their different behaviour patterns and the general upward tendency (Serra *et al.* 2001).

In a study based on data from 23 observatories in the Valencia Regional Autonomy and in Murcia, for the common period 1940-1996, a notable difference was noted in the evolution of the daily temperature range of the urban and rural observatories, which led to the conclusion that much of the warming observed in the thermal series of the former was due to urban influence (Quereda and Montón 1999), and very recently, an attempt has been made to evaluate this effect with the use of teledetection (Quereda *et al.* 2004). Furthermore, a change can be seen in the day-to-day variability of the series of daily temperatures in Cádiz-San Fernando over a period lasting from the first quarter of the XIX century to the last decade of the XX century (Moberg *et al.* 2000).

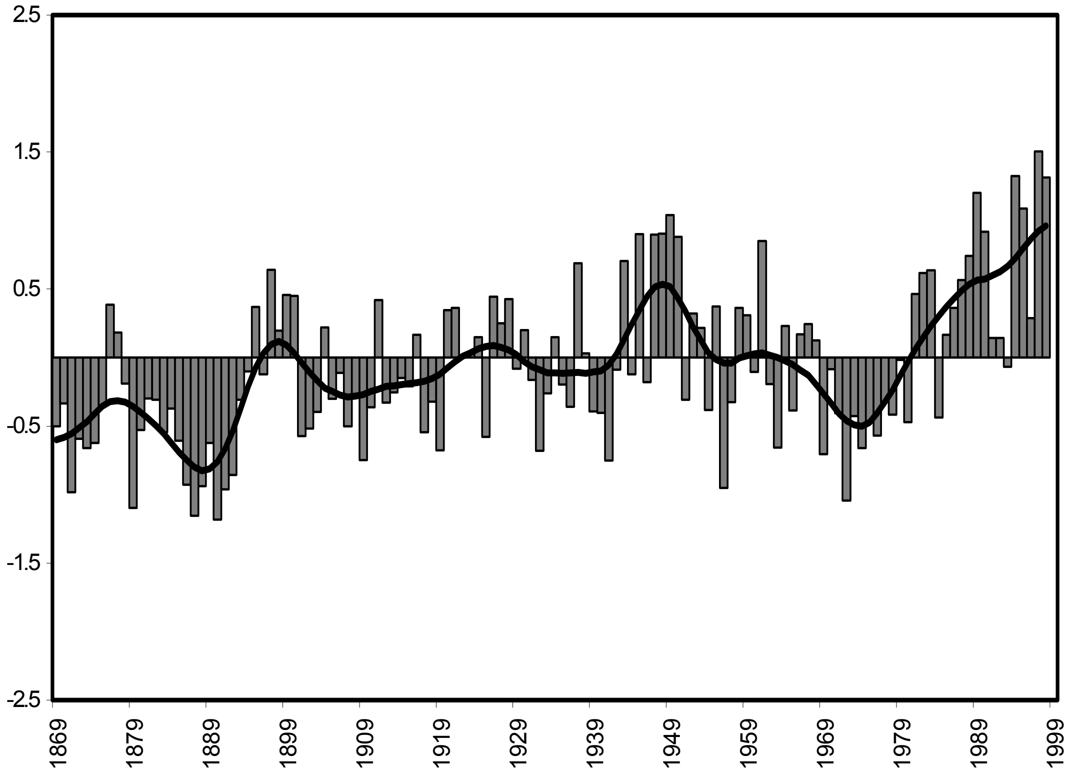

Fig. 1.7. *Annual mean temperature anomalies, relative to the average for 1961-1990, in NE Spain (ºC)(1869-1998) –smooth curve using a 13-point Gaussian filter (Modified from Brunet et al.* 2001b*).*

b) Rainfall undefined trends

The tendency to decrease of the rainfall totals in subtropical latitudes mentioned in the third IPCC report (IPCC 2001) cannot be easily verified in the case of Spain, given the complexity of the spatial distribution of rainfall, not only with regard to amount, but also to its seasonal distribution and temporal concentration, which requires the use of a considerable number of climatic series, rarely available with the necessary longitude. There is no exhaustive study allowing the whole country to be covered at detailed spatial resolution. Furthermore, the high temporal variability in much of Spain, inherent to its Mediterranean condition, requires long series, preferably centennial ones. The 10 Spanish mean annual rainfall series analysed in the *ECA* (Badajoz-Talavera, Madrid, Málaga-airport, Navacerrada, Salamanca, San Sebastián, Torrevieja, Roquetes-Tortosa, Valencia and Zaragoza-airport) for the 1946-1999 period, unlike a certain number of European series, do not show any increase in the totals, in accordance with a foreseeable general increase in global rainfall. In the case of the same Spanish observatories, no significant tendency was observed, either, in the annual number of rainy days (≥1mm). With regard to the evolution of the amounts of rainfall above determined thresholds, and the percentage contribution of the rainiest days to the annual total, which could reflect variations in rainfall intensity, only Madrid shows a negative tendency in the first case, and together with Tortosa, in the second one (Klein Tank *et al.* 2002).

In the secular context, the longest annual rainfall series for the Iberian Peninsula, starting in the XIX century (Gibraltar, at the end of the XVIII, 1791), show no significant tendencies, with the exception of some southern ones (Gibraltar, San Fernando) with a statistically significant downward trend (Wheeler and Martín-Vide 1992; Quereda and Montón 1997). Research into the 53 longest annual rainfall series available up to 1990, including some from the Balearic Isles and the Canary Isles, produced a map with a broad central area, from Extremadura to Valencia Regional Autonomy and Catalonia, as well as the Balearic Isles and the Canary Isles, with no defined tendency; the North and Northwest of the Peninsula, with a certain upward trend; and the South and Southeast of the Peninsula, with a tendency to decrease (Milián 1996). In another analysis of data from 40 observatories on the Peninsula and the Balearic Isles, during the 1880-1992 period, differentiated behaviour was detected between the northern Iberian fringe, with an upward tendency, and the inland and Mediterranean side, showing a downward trend (Esteban-Parra *et al.* 1998). In other studies with time duration series somewhat lower than one century (Serrano *et al.* 1999; García *et al.* 2002; Muñoz-Díaz and Rodrigo 2004) or with grid data from the 1900-1996 period (Rocha 1999) no clear annual tendencies were detected, although there does appear to be a consistent decrease in springtime rainfall.

Regionally, a series of annual areal rainfall for the watersheds in the Southeast and East, covering the 1864-2000 period, showed no significant tendency (Chazarra and Almarza 2002). Almost thirty annual series for the Ebro basin, in the 1920-2000 period, which allowed for regionalisaiton according to temporal evolution, showed no monotonous tendencies in any of the areas considered (Abaurrea *et al.* 2002). Nor were they detected in the southern Plateau in 6 observatories (Galán *et al.* 1999). In Catalonia, with data from 121 stations, no significant tendency was detected in the annual rainfall during the last century and a half, although it was in spring, with a decrease of over 25% (Saladíe 2004). Other analysis also dealing with time duration series close to or over one century detect certain rainfall anomalies and some rainy periods, and among other general facts, we can identify the initial period of the series, up to the end of the XIX century or the beginning of the XX century, as rainy, like the 60s and 70s of this last century, whereas, in comparison, at the end of the 70s, a dry period started (Rodríguez *et al.* 1999; Rodrigo *et al.* 2000; Ramos 2001, etc.). In the secular context of the last half millennium, the amount of rainfall, reconstructed with the use of *proxy data*, shows a reduction in the last few decades of the XX century both in the South of the Peninsula (Rodrigo *et al.* 1999), (Figure 1.8) and in the North (Saz 2003).

When the analysis refers to the last third of the XX century, a significant decrease can be seen in the amount of rainfall in certain regions covering Peninsular Spain and the Balearic Isles. This occurs in the 1963-1985 period in the eastern and Pyrenees sectors of the Ebro basin (Abaurrea *et al.* 2002). In some studies, this decrease is particularly due to the reduced winter rainfall and -as we have pointed out previously- spring rainfall also, which is associated with the increase in atmospheric pressure in the western Mediterranean since the 70s of the XX century, in turn partly caused by the reinforcement of the positive mode of the Mediterranean Oscillation (Dünkeloh and Jacobeit 2003) and also by the occurrence of a positive phase of the NAO. In the regions of Spain on the Mediterranean façade, from Andalucia to Catalonia, including the Balearic Isles, the reduction of rainfall in the 1964-1993 period, on comparing its two 15-year sub-periods, occurred in much of Andalucia and Catalonia, in Menorca and the Northwest of Mallorca, whereas the variation is positive in much of the Valencia Regional Autonomy and Murcia, as can be seen from the analyses from 410 weather stations (Romero *et al.* 1998; Guijarro 2002). The downward tendency during the last international period (1961-1990) has been confirmed for southern Spain in other studies (Rodrigo *et al.* 1999). In the Valencia Regional Autonomy almost one hundred rainfall stations confirm the reduction of annual rainfall and an increase in interannual variability during the last international period (1961-1990), although with very notable spatial differences (De Luis *et al.* 2000).

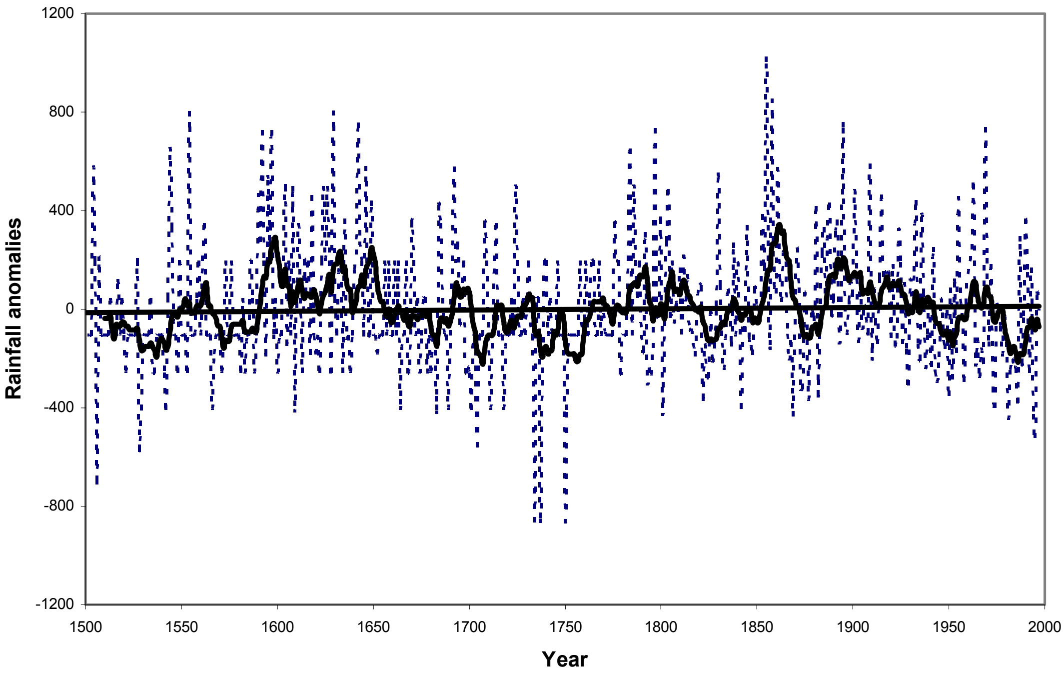

Fig. 1.8. *Annual precipitation anomalies in Andalucia (mm) (1500-2000) –smooth curve using 10-year moving averages (Rodrigo et al. 1999, 2000).*

With regard to interannual rainfall variability, which presents great complexity in Peninsular Spain (Rodríguez-Puebla *et al.* 1998), the hypothesis of an increase has not been clearly confirmed in a secular context. Thus, the anomalies in rainfall during the XX century show similar behaviour to those of the previous four centuries in Andalucia (Rodrigo *et al.* 2000), although there is high variability in the second half of the XX century (Pita *et al.* 1999). In the last few decades, interannual variability has also increased in other regions, and even in the southern Plateau the growing tendency appears to cover the XX century (Galán *et al.* 1999).

The possible changes in the seasonal distribution of rainfall, with ecological and socioeconomic implications, indicate heterogeneous spatial behaviour patterns. An unpublished analysis of data from 55 Iberian meteorological stations for the 1949-2003 period has shown a decrease in winter rainfall in the Cantabirain corniche (Bilbao, 2,22 mm/year) and in spring rainfall in more southern regions (Seville, 1,4 mm/year) (Rodríguez-Puebla, pers. com.), with no tendencies in summer and autumn. A seasonal index applied to over 400 rainfall stations in eastern and southern Spain has shown an increase throughout the 1964-1993 period in Andalucia and inland Catalonia, coinciding with an increase in rainfall in October (Sumner *et al.* 2001). In the Valencia Regional Autonomy there has been a decrease in winter rainfall, and even in autumn, accompanied by greater interannual variability in the last international period (González-Hidalgo *et al.* 2001). An index of intrannual rainfall concentration has shown a growing tendency in San Fernando and Madrid during periods starting half way through the XIX century and ending at the end of the XX century (López 1999).

Temporal rainfall patterns at daily resolution are of great interest in the context of Spanish climates, given the high temporal concentration of rainfall, with the consequent problems related to drainage and erosion. There are very few studies in this respect, however. The analyses published do not allow us to infer an increase in the daily intensity of rainfall, that is to say, a greater influence of the days with big amounts over the total number of days of rainfall. Thus, for the 1958-1997 period, and based on data from 18 observatories on the Iberian Peninsula, in much of the country, except for the Southeast, there has been a tendency towards a lower number of days with big amounts of rainfall (Goodess and Jones 2002). The tendencies of the 10 rainiest days in the Valencia Regional Autonomy are not clear, either, nor of their percentage contribution to annual totals, the former presenting downward trends and the latter upward ones (González-Hidalgo *et al.* 2003). In any case, chronological analysis of the daily rainfall series shows quite different behaviour patterns from one observatory to another (López 2001). In Barcelona an analysis covering the period from 1917 to the end of the XX century detected an increase in the amount accumulated by the days reaching or surpassing the 95% percentil (29.5 mm), in a context of less rainy days (Burgueño *et al.* 2004). In the Canary Isles, a clear decrease in rainfall was detected during the second half of the XX century, fundamentally due to a decrease in the most abundant daily amounts (García-Herrera *et al*. 2003).

1.2.6. Low-frequency variability patterns

The dipole constituted by the Azores anticyclone and the Icelandic low, that composes the North Atlantic Oscillation, has a noteworthy influence on winter rainfall in centre and Southwest of mainland Spain. The correlation between the NAO index and monthly rainfall in the cold months is significant and negative in the area in question, with abundant rainfall, often associated with depressions in the vicinity of the Gulf of Cadiz. To the contrary, in its positive phase, it receives amounts of rainfall that are clearly below normal, given the proximity of the Azores high.

Certain change patterns can be deduced from the growing number of studies relating low-frequency variability patterns with the behaviour of the climatic variables in Spain. Thus, the clear positive tendency of the NAO index since the middle of the 60s (Gámiz-Fortis *et al.* 2002), which has been associated with the aforementioned decrease in rainfall, also seems to involve a growing tendency in relation to atmospheric pressure. An analysis of the evolution of synoptic circulation on the Iberian Peninsula in the XX century has started to show that the subtropical pattern is becoming increasingly frequent, at the expense of the westerlies (Fernández and Rasilla 2001). In any case, the North Atlantic pattern is modulated by other ones, such as the EU2 for drought on the Iberian Peninsula (Vázquez López 1999). The influence of the NAO, and of other teleconnections, such as the SCAN or the EA, showing changes in phase in 1976, affects rainfall variability in Galicia (Taboada *et al.* 2002). However, the decadal oscillations of the NAO, and the tendencies of this, are not clearly seen in the Iberian temperature records, which are much more sensitive to the location of the southern centre of the dipole than to the barometric gradient in the North (Castro-Díez *et al.* 2002). It is precisely the position of the Iberian Peninsula that prevents certain low-frequency variability patterns from clearly becoming manifest, and during winter, temperatures in periods of over 15 years therefore only show hemispheric variability, fundamentally radiative (Pozo-Vázquez 2000).

The duration of insolation is positively correlated with the NAO index in southern Europe, and a positive phase of the aforementioned pattern therefore involves anomalies of the same sign (Pozo-Vázquez *et al*, 2004). A percentage of 50% of the variability in rainfall in the three-month period of spring is accounted for by the NAO and EA patterns (Martín *et al.* 2004), which can explain their downward tendency in some regions of Spain. The dry and rainy periods in the same season are influenced by the AO, the EA/WR and the Southern Oscillation Index, and the springtime reduction during the El Niño episodes can be estimated at 10% (Rodó *et al.* 1997; Rodríguez-Puebla *et al.* 2001; Mariotti *et al.* 2002). The decrease in the number of cyclonic days and in the number of days with a negative anomaly of pressure in the March-April period in the western Mediterranean basin (Laita and Grimalt 1997), as well as the variability observed in temperature (Pozo-Vázquez *et al.* 2001), following ENSO episodes could be related to the greater frequency, intensity and persistence of El Niño for just over the last 20 years. To the contrary, there is no relationship between El Niño and storms over the sea on the coast of Catalonia (Camuffo *et al.* 2000). The clear increase in the number of days with red rain in Elche, in the last few years of the 1949-1994 period, might be the reflection of an increase in meridional circulation (Quereda *et al.* 1996). Baroclinic activity and winter rainfall are clearly interrelated in eastern Cantabrian region (Sáenz *et al.* 2001)

The daily data on different variables from the Roquetes-Tortosa observatory for the 1910-1994 period enable us to conclude that the climate therein has tended to be warmer and drier (Piñol *et al.* 1998). Thus, the increase in mean annual temperature by 0.10ºC/decade has led to an increase in estimated potential annual evapotranspiration of 13mm/decade. As there has been no significant change in rainfall, there has been a growing tendency towards hydric deficit. Furthermore, from June to September in the 1941-1994 period, daily minimum relative humidity fell by 0.8%/decade. All of this has led to a rise in the forest fire risk indices.

1.3. FUTURE CLIMATE

1.3.1. Global climate models

In order to make projections of climate change related to the growing accumulation in the atmosphere of greenhouse gasses (hereinafter GHGs) and of aerosols, resulting from human activity, global climate models are currently used. A climate model consists of a mathematical representation of the processes taking place in the "climate system", the state of which defines the climate. The climate system is considered to be made up of five components: atmosphere, hydrosphere, cryosphere, lithosphere and biosphere (Peixoto and Oort 1992). Between them, there are huge exchanges of matter, heat and momentum and incessant interactions through a multitude of physical, chemical and biological processes, all of which makes the earth's climate system tremendously complex. Global climate models are currently the best tool available for the study of the processes constituting the state of the climate. This is why they are indispensable for establishing the response of the climate to disturbances caused by human activity. Consequently, the capacity of the models to project the future evolution of the climate basically depends on an understanding of the processes governing the climate system.

At present, most global climate models include a certain level of representation of the five components of the climate system, of the processes taking place in each one of them, and of those determining the mutual exchanges. Current climate models explicitly include both the atmosphere and ocean processes along with their major interactions. This is because the ocean plays a crucial role in the Earth's climate and its variability. Although until less than a decade ago, its function was underestimated, it is now believed to be as important as the atmosphere. Thus, understanding climate and predicting its evolution involves considering the ocean too.

The models in which the atmosphere and the ocean jointly interact are generally known by the AOGCM (Atmosphere-Ocean General Circulation Model), which will be used hereinafter to refer to them.

The AOGCM are based on the resolution of a set of mathematical equations that express the laws of Physics governing the dynamics of the atmosphere and the ocean. It is a complex, non-linear set of differential equations that have no analytical solution. Thus, they must be solved in an approximate manner, by applying numerical techniques, which require a division of the space occupied by the atmosphere and by the ocean into three-dimensional cells. In each one of these, values of the variables are assigned that characterise the state of the atmosphere and of the ocean, such as temperature, motion, density, etc. This allocation is based on direct or indirect observations of these variables at global scale in a determined initial instant. In order to derive the temporal evolutions of the variables in each cell of the model grids, the initial values are used to solve the equations. These evolutions are obtained in discrete temporal intervals (time steps), the duration of which must be in accordance with the size of the cells. The smaller this size, the smaller the time step. The spatial resolution of the atmospheric part of the current AOGCM ranges from 2º to 10º latitude and longitude horizontally, and vertically, from 10 to 30 layers are considered between the surface and the upper limit of the atmosphere, each one with variable thicknesses, whereas the horizontal and vertical resolutions of the oceanic part are usually similar or somewhat higher than the atmospheric ones.

Furthermore, the discretisation needed in the numerical techniques in order to solve the differential equations set implies that they cannot be used to solve those atmospheric or oceanic processes with spatial or time scales lower than the resolution of the model, for example, individual clouds in the atmospheric models or intermediate scale eddies in the ocean models. This is why the effect should be calculated using a parametric representation according to values of the basic variables solved by the model. This procedure is called parametrisation.

The AOGCM models are combined with empirical or semi-empirical mathematical representations of other components of the climatic system, such as the cryosphere, soil surface or plant cover. The current, more complete models also include representations of the carbon cycle, such as exchanges between the atmosphere, the biosphere and the oceans, and of processes affecting the aerosols in the atmosphere, such as chemical reactions, aggregations, deposition and effects on the formation of clouds (see chapters 3 to 6 of the IPCC report 2001).

We previously pointed out that the set of differential equations of an AOGCM is solved in discrete temporal intervals or “steps”. This means that in each one of them, the model must solve all the equations in order to calculate the updated vales of the variables in all the cells of the three-dimensional grid encompassing the planet. This involves having to do millions of mathematical operations in each time step (from 30 to 60 minutes, depending on the models), until the whole integration period has been completed, which is usually extended to hundreds of years. This obviously requires the use of the most powerful computers available.

There are currently only a couple of dozen AOGCM models, developed in climate centres and universities thanks to a huge effort invested in scientific research. A clear example of this is that in the first report by the Intergovernmental Panel on Climate Change (IPCC), drawn up in the year 1990, results were presented from only two AOGCM, whereas in the latest one (IPCC 2001) almost a score of these more perfected models were mentioned.

The AOGCM models used to quantify the future response of the climate to disturbances caused by human activity must previously be evaluated. The reliability test for an AOGCM, with regard to reproducing the main processes of the climate system, is based on a systematic comparison between results of simulations with current climate conditions and the climatological data observed. Simulations of the present climate with AOGCMs take into account the evolution of values observed of atmospheric concentrations of GHGs. The models can also be evaluated considering palaeoclimatic conditions, for example, the last glacial period. Once its quality has been satisfactorily evaluated, the model is used to make simulations of the temporal evolution of climate change.

In this type of evaluations, it has been seen that most of the current AOGCMs have been greatly improved in the last ten years. This is attributed to several causes, among which we can highlight a better knowledge of the characteristics of the oceans and of the processes of exchange with the atmosphere, consideration of the processes affecting the sulphate aerosols in the atmosphere, and of the increased spatial resolution of the models (smaller cell size) permited by the tremendous increase in computing power. Indeed, the simulations generally provide a very acceptable reproduction of the evolution of global temperature over the last 150 years. So much so, that the tests carried out with different evolutions of GHGs have allowed for a discrimination of the contribution of human activity to climate change, with an acceptable degree of reliability (Stott *et al*. 2001).

The AOGCM models, however, still provide some uncertain results, to a great extent associated with deficiencies in the parametrisations of some physical processes that are determinant for the climate, such as those related to the formation of clouds and precipitation, the thermohaline circulation of the oceans, the dynamics of sea ice or biogeochemical exchanges in the climate system, among others (for more details, see chapter 14 of the report - IPCC 2001). Apart from these deficiencies, there is the problem that the spatial resolution of the AOGCMs is still too low to reproduce orographic and coastal details, which in many parts of the planet, are decisive with regard to determining climate at regional scale. An illustrative example of this is the case of the Iberian Peninsula, which will be subsequently dealt with.

1.3.2. Climate simulations with global models

In order to simulate the future evolution of the Earth's climate, the AOGCM models must be transitorily forced with evolutions of the levels of GHGs and aerosols accumulated in the atmosphere according to how emissions caused by human activity are expected to change. That is to say, to design what are known as "emission scenarios". This is done considering different suppositions regarding future demographic and socioeconomic development in the world. The emission scenarios currently used to make projections with climate models throughout the XXI century are known as SRES (Special Report on Emission Scenarios). They constitute a set of emission scenarios created by a group of world experts from the IPCC (Nakicenovic *et al*. 2000), taking into account coherent hypotheses of the future evolution of world population growth, energy demand, efficient use of this or global economic growth, among other considerations.

For each of these scenarios, we made a quantification of future anthropogenic emission of GHGs and sulphur compounds (IPCC 2001). By way of an illustration, Figure 1.9 shows the evolutions of CO_2 and SO_2 emissions corresponding to the six scenarios that have been used up to now to make climate projections with the AOGCM models. In the same figure are included the evolutions of global CO_2 concentration for each of the emission scenarios considered, according to the result of the application of the carbon balance models (for example, Cramer and Field 1999). From these six scenarios, the so-called A2 and B2 are the two most used by the AOGCM models. From a purely technical point of view, however, they should all be considered as equally probable. In this sense, it should be pointed out that none of them correspond exactly to the emission objectives established by the Kyoto protocol.

Of the AOGCM mentioned in the third IPCC report (2001), six have been used to make detailed simulations considering different evolutions of levels of GHGs and sulphate aerosols throughout the XX and XXI centuries (table 1.31). The IPCC's Data Distribution Centre (DDC) avails of the set of results derived from different simulations made with these six AOGCM. These simulations generally cover a period of 240 years, from 1860 to 2100. In the first 130 years (1860-2000) the concentrations of GHGs observed in the atmosphere are considered, together with estimates of sulphate aerosols, and after this year, different emission scenarios are taken into account. Table 1.3 provides details of the SRES emission scenarios considered in the simulations made by each AOGCM, the results of which can be obtained from the DDC-IPCC. Most of these data correspond to the monthly values of the variables most used in studies of the impact of surface climate change (temperature, precipitation, pressure, etc.), corresponding to each one of the cells of the mesh of the model covering the whole of the Earth's atmosphere.

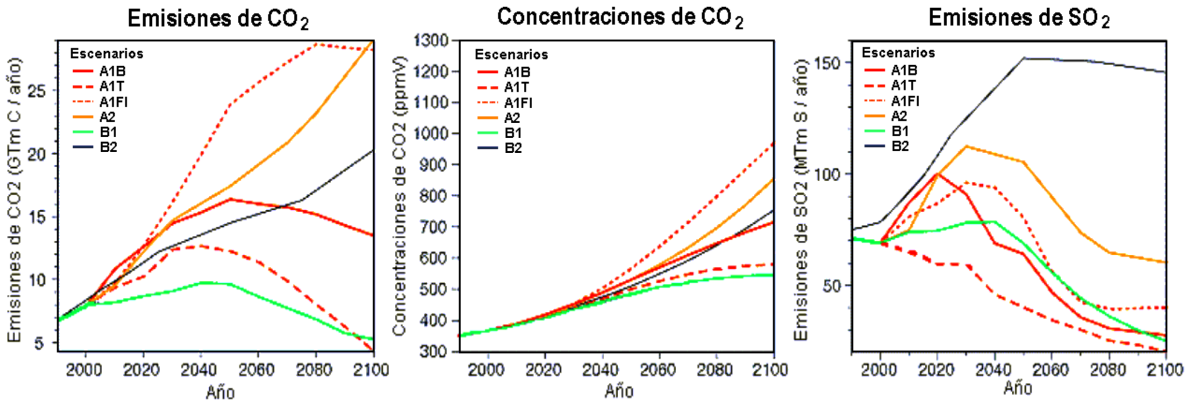

Fig. 1.9. *Evolutions of global CO_2 and SO_2 emissions into the atmosphere resulting from human activities, and of global CO_2 concentrations that would result from these emissions, according to different SRES scenarios. Taken from IPCC (2001)*

Table 1.3. *Characteristics of the AOGCM, ans SRES emission scenarios simulated by these, the results of which can be obtained from the DDC-IPCC: http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html. The horizontal size of the atmospheric and oceanic cells is expressed in degrees of latitude-longitude, and the number of levels on the vertical appears in brackets).*

NAME OF THE MODEL	CENTRE (COUNTRY)	ATMOSPHERIC RESOLUTION	OCEANIC RESOLUTION	SIMULATED SRES SCENARIOS
CCSR/NIES 2	CCSR/NIES (Japan)	5.6 × 5.6 (20)	2.8 × 2.8 (17)	A1,A1FI,A1T,A2,B1,B2
CGCM 1,2	CCC (Canada)	3.7 × 3.7 (10)	1.8 × 1.8 (29)	A2,B2
CSIRO-Mk2	CSIRO (Australia)	5.6 × 3.2 (9)	5.6 × 3.2 (21)	A1,A2,B1,B2
ECHAM4/OPYC3	MPIM (Germany)	2.8 × 2.8 (18)	2.8 × 2.8 (11)	A2,B2
GFDL R30 c	GFDL (USA)	2.25 × 3.75 (14)	1.875 × 2.25 (18)	A2,B2
HadCM3	UKMO (United Kingdom)	2.5 × 3.75 (19)	1.25 × 1.25 (20)	A1,A1FI,A2,B1,B2

The evaluation of the results obtained at global scale in the set of simulations corresponding to the XX century (IPCC 2001), shows that the quality of none of them is clearly higher than any of the others. Indeed, Lambert and Boer (2001) showed, for example, that the distributions of temperature, pressure and rainfall resulting from a mean value of an ensemble of several AOGCM, are generally more similar to the ones observed than those obtained from any of them individually. In spite of the differences between the results obtained by each of the models, comparison with observations enables us to feel reasonably sure that the AOGCMs are suitable for simulating future climate changes, notably reducing the uncertainties involved in climatic projections (IPCC 2001).

Although it has been pointed out before that none of the SRES scenarios can be presumed to be more probable than any of the others, the climate projections that are now presented correspond to groups A2 and B2, due to being the two considered by the highest number of AOGCMs. This enables us to perceive the future response of the future climate according to the evolutions of anthropogenic emissions. Furthermore, only the results of the models included in DDC-IPCC are presented. In spite of the fact that these AOGCM have been evaluated with current climatic data, and that it was ensured that all of them reasonably reproduced the main features of global climate, each simulation presents differences in relation to the others. Thus, for example, Figure 1.10 shows projections of mean annual changes in global air surface temperature, obtained with different AOGCMs, for the two emission scenarios considered. Therein it can be seen that, in some cases, the differences between models exceed the individual interval of the projected climatic changes. But, it must be said that, as the IPCC points out, these differences do not invalidate the results, but rather provide valuable information, because they facilitate an objective evaluation of the reliability involved in each individual projection. Indeed, analysis of the set of results obtained with different models enable us to identify the features of the projected global climate change common to all the simulations, which can be considered to be most reliable. Thus, for instance, as all the models coincide in that the temperature increase is greater in scenario A2 than in B2, we can be quite sure that future global warming will be determined, to a great extent, by the rhythm of the increase in anthropogenetic emissions of GHGs and aerosols.

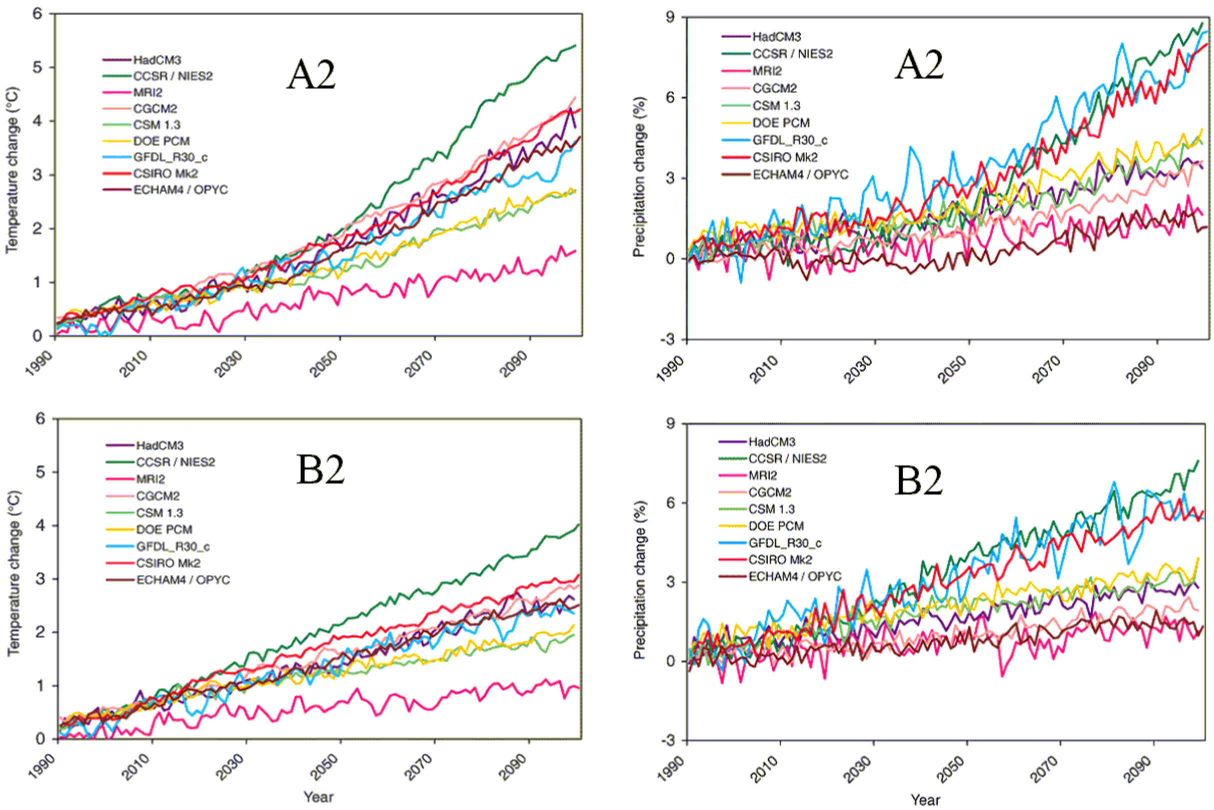

Fig. 1.10. *Evolutions of mean global changes in temperature (above) and in precipitation (below) in relation to 1990 values, simulated by different AOGCMs considering SRES-A2 (left) and SRES-B2 (right) emission scenarios. Figure taken from IPCC (2001)*

1.3.3. Future climate projections in Spain made with global models

Because of the differences between models, it was considered most convenient first to show the results of the spatial distribution on the Iberian Peninsula of projected changes in surface temperature and rainfall throughout this century obtained with a determined AOGCM. The results of simulations with several AOGCM in an inland area of the Peninsula are afterward presented, in order to make a simple comparison and to compose rests of the set.

The AOGCM chosen for the first analysis is the HadCM3, developed in the Hadley Centre for Climate Prediction and Research (United Kingdom). As has already been mentioned, this choice must not be seen as indicative of the superiority of this AOGCM over any other one, although it is true that the results of the simulations with the HadCM3 model in relation to climate change (1960-90) on the Iberian Peninsula generally present an acceptable fit with the observations. But the main reason for this choice was that a regionalisation method was applied to this model output in order to obtain greater detail of the changes projected for the last third of the century on the Iberian Peninsula, as is presented in the following section.

The HadCM3 model is an improved version of the previous HadCM2, in which, apart from increasing resolution, it is not necessary to make an artificial adjustment in the heat flux and freshwater flow in order to establish a correspondence with the behaviour observed. In Gordon *et al*. (2000) and Pope *et al*. (2000) a complete description of the model can be found. A brief explanation, however, of the main characteristics of this AOGCM is included.

The atmospheric sub-model has a horizontal resolution of 2.5º latitude and 3.75º longitude covering the whole planet. This means that the cells have horizontal dimensions of approximately 300 x 300 km in average latitudes. Vertically, the atmosphere is divided into 19 levels, with variable spacing between them. The model includes sophisticated parametrisations of solar and terrestrial radiation exchanges, explicitly including the effects of GHGs and aerosols, of the atmosphere-surface-vegetation exchanges and of cloud and precipitation formations. In this sub-model, the emission, transport and deposition of sulphur compounds is also interactively simulated.

The ocean sub-model has a horizontal resolution of 1.25º latitude and longitude and considers 20 levels vertically. A series of improvements has been included in this sub-model, among which we can highlight the one that permits the mixture of water from the Mediterranean with the Atlantic through the Straits of Gibraltar, in spite of the fact that the large size of the cells prevents this from being explicitly resolved by the model, as well as a better parametrisation of processes of sea ice and snow accumulation.

In the experiments with the HadCM3 model, the atmosphere and ice cover are initiated with available values and the ocean is considered to be at rest. With these initial values, the model is applied over a period of 1,000 years, with levels of GHGs and aerosols corresponding to pre-industrial times. Such a long period is needed in order for a suitable adjustment between atmosphere and oceans to be made. At the end of this period, the state of the simulated climate represents the conditions previous to the year 1860. From that year to the present, the model was forced with growing levels of GHGs and aerosols, deduced from the available observations. In the future years, the evolutions of GHGs and aerosols correspond to the diverse SRES emission scenarios. The results obtained with the model in the 1960-1990 period are used to appraise their degree of correspondence with present climatology. Lastly, the projections of climate change with the model are obtained from the differences between the climate simulated for the 1960-1990 interval and the one resulting from any 30-year period throughout this century. In the experiments with the other AOGCMs a similar sequence is followed. We now present climate change scenarios for three periods: 2010-2040 2040-2070 and 2070-2100.

Figure 1.11. shows the results of the spatial distributions on the Iberian Peninsula of the change in mean seasonal surface air temperature (at a height of 2 metres) in relation to the mean values simulated for the 1960-1990 period, considering the three thirds of the 21st century mentioned. The spatial distribution of the changes is presented in a discretised manner, in accordance with the cell sizes of the HadCM3 model. The projections presented correspond to two SRES emission scenarios: A2 and B2.

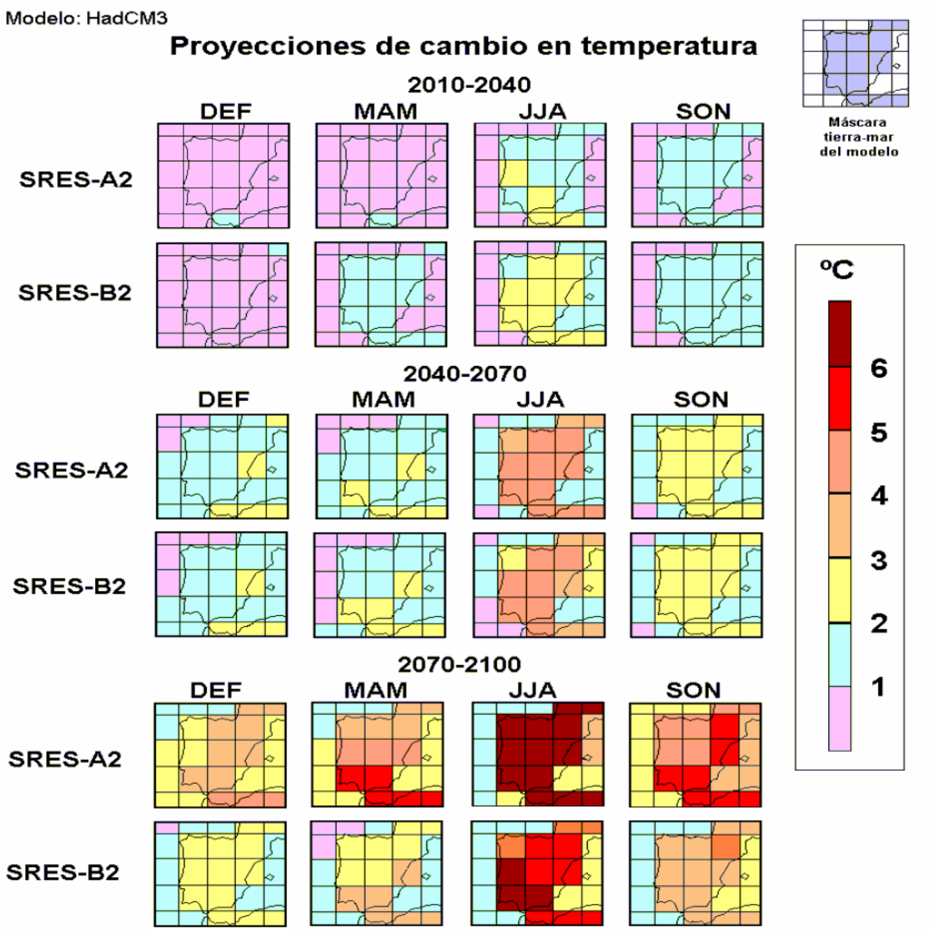

Fig. 1.11. *Projections of changes in air temperature next to the ground (at 2 m), averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn), corresponding to three periods of the 21st century: 2010-2040 2040-2070 and 2070-2100, and to two SRES emission scenarios (A2 and B2). The simulations were made with the HadCM3 model and the results were taken from the IPCC-DDC. In the upper right-hand corner appears the mesh of the model over the Iberian Peninsula, in which the shaded grids correspond in the model to continental area and the white ones to the ocean.*

What is seen more clearly in the figure is a progressive warming throughout the century in the whole region, although the intensity and cadence of this is different, depending on zones and SRES scenarios. This warming is generally more intense and rapid in the summer months (JJA) than in the winter ones (DEF), in scenario A2 than in B2 and in the inland areas than in the coastal ones. The progressiveness of the warming is almost linear in all the zones, although it is a little more accelerated at the end of the 21st century than at the beginning. In most of the Peninsula, the rhythm of the increase in mean temperatures is between 2 and 3ºC every 30 years in the summer months and between 1 and 2ºC in the winter ones, the highest values corresponding to the A2 SRES scenario. The maximum increases in mean seasonal temperature in the last third of the century exceed 6ºC in summer in the whole Peninsula in scenario A2, and in the Southwest in scenario B2. The average warming in the winter months for this period, however, remains below 4ºC in the SRES-A2 and below 3ºC in the SRES-B2.

Finally, it can clearly be seen that differences in warming between the two emission scenarios increase throughout the century.

Changes in precipitation generally present greater spatial variability when they are expressed in percentages. This is due, to a great extent, that current climate precipitation in some areas is so scarce, that a small future climate change is seen in an artificially high percentage. This is why it is preferable to analyse changes in rainfall using differences between values for future climate and for the present one. Obviously, this type of analysis has a disadvantage, in that one same change in absolute values would have greater relative importance in a dry area than in a rainy one. But, on the other hand, the values of absolute change facilitate a more direct quantification of alterations of water availability in any of the areas. Thus, figure 1.12 presents the absolute changes projected in seasonal precipitation throughout the century in relation to the period 1960-1990, expressed in mm/day. In order to deduce the changes in precipitation accumulated in each season, the values in mm/day would have to be multiplied by the number of days of this period, which is 90, because in the simulations with climate models, the years are considered with a uniform duration of 360 days.

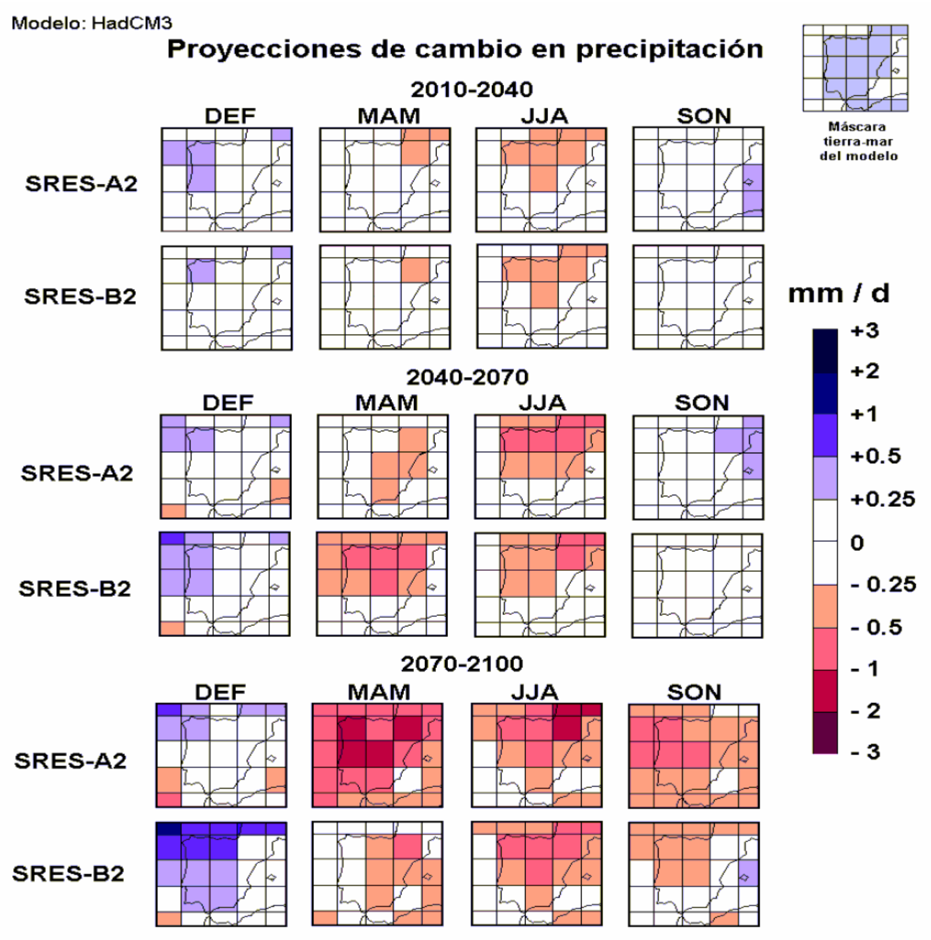

Fig. 1.12. *Projections of changes in mean precipitation (in mm / day), averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn), corresponding to three periods of the 21st century: 2010-2040 2040-2070 and 2070-2100, and to two SRES emission scenarios (A2 and B2). The simulations were made with the HadCM3 model and the results were taken from the IPCC-DDC. In the upper right-hand corner appears the mesh of the model over the Iberian Peninsula, in which the shaded grids correspond in the model to continental area and the white ones to the ocean.*

In contrast with the changes simulated for temperature, which always have a positive sign (warming), those for precipitation do not have the same sign in the different zones and times of year. Thus, changes in the amount of precipitation in the winter months (DEF in the figure) generally have a positive sign in all the zones of the Iberian peninsula, and this occurs for the two emission scenarios considered. In the other seasons, however, above all in spring and summer, there is a predominance of changes with a negative sign, that is, a decrease in the amount of rainfall in the climate projected, compared with the present one. Another characteristic of the evolutions of changes in seasonal rainfall throughout the century is that they generally do not present as much linearity in the tendency as in the case of temperatures. Thus, for example, in scenario B2, the decrease in rainfall in spring is somewhat greater in the middle third of the century than in the final third. Other non-linear behaviour patterns in the temporal evolution of changes in seasonal rainfall can be seen in determined cells of the AOGCM situated over the Iberian Peninsula. Noteworthy among these is the case of the East and Northeast of the Peninsula in scenario A2, in which the model projects rainfall increases in autumn in the first two thirds of the century and decreases in the final third.

Comparing the changes in seasonal rainfall projected for the two emission scenarios, the winter increases can generally be seen to be smaller and the decreases in spring and summer bigger in A2 than in B2. However, an exception to this general behaviour can clearly be observed in the changes projected for the middle third of the century during spring, when the opposite occurs.

It is precisely the spatial and temporal irregularities appreciated in the projected changes in rainfall that indicate the greater uncertainty that they present, if we compare them with those obtained in the case of temperatures. This is essentially due to the fact that the occurrence of rainfall in any place and at any time is associated with physical processes that are more difficult to simulate correctly with the models, whereas the processes determining air temperature close to the ground are more conditioned by the seasonality of solar radiation reaching the planet throughout the year, the calculation of which is made with a high degree of certainty. The most reasonable procedure for reducing the uncertainty of projected changes in rainfall lies in considering the results provided by an ensemble of AOGCMs.

In accordance to this, we considered the results from six AOGCMs included in the DDC-IPCC database (http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html). Specifically, these are the models called CCGM, CSIRO, HadCM3, NIES2, ECHAM4 and GFDL, the characteristics of which were shown in Table 1.3. In order to make this analysis in a simple way, we only considered the results of the changes in seasonal temperature and rainfall obtained in the cell of the mesh of each model that includes the centre of the Iberian Peninsula. It must be kept in mind that the grid of the six models considered have different horizontal resolutions (see Table 1.3). Figure 1.13 illustrates the comparative size and location of the cell considered for each de AOGCM.

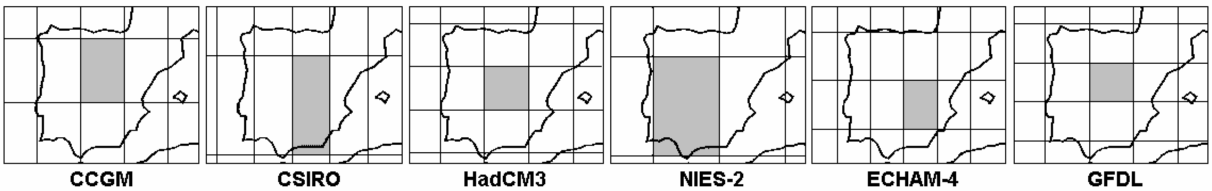

Fig. 1.13. *Illustration of the meshes of the six AOGCMs considered. In order to make the comparison we took the simulated results for each model in the grids which include the centre of the Peninsula.*

The changes in the mean seasonal temperatures projected for the centre of the Iberian Peninsula in each third of the 21st century, the model and emission scenario are shown in figure

1.14. Comparing the results of the six models, differences in the changes simulated for each one are observed, but so are similarities. The differences lie in the specific values of temperature change for each period, season and emission scenario. The NIES2 model is the one that generally simulates the biggest warming, whereas the differences between the others are somewhat smaller. However, it must be taken into account that this lack of coincidence in the values of temperature change could partly be related to the different spatial resolution over the Iberian Peninsula of the different AOGCMs. All the models coincide in the progressive warming throughout the century in relation to the 1960-1990 period. In all of these, then, maximum warming is projected for the summer months and the minimum for winter, and it can also be seen that in emission scenario A2, the temperature increases are greater than in B2. The qualitative coincidence in this set of results is indicative of their high degree of certainty.

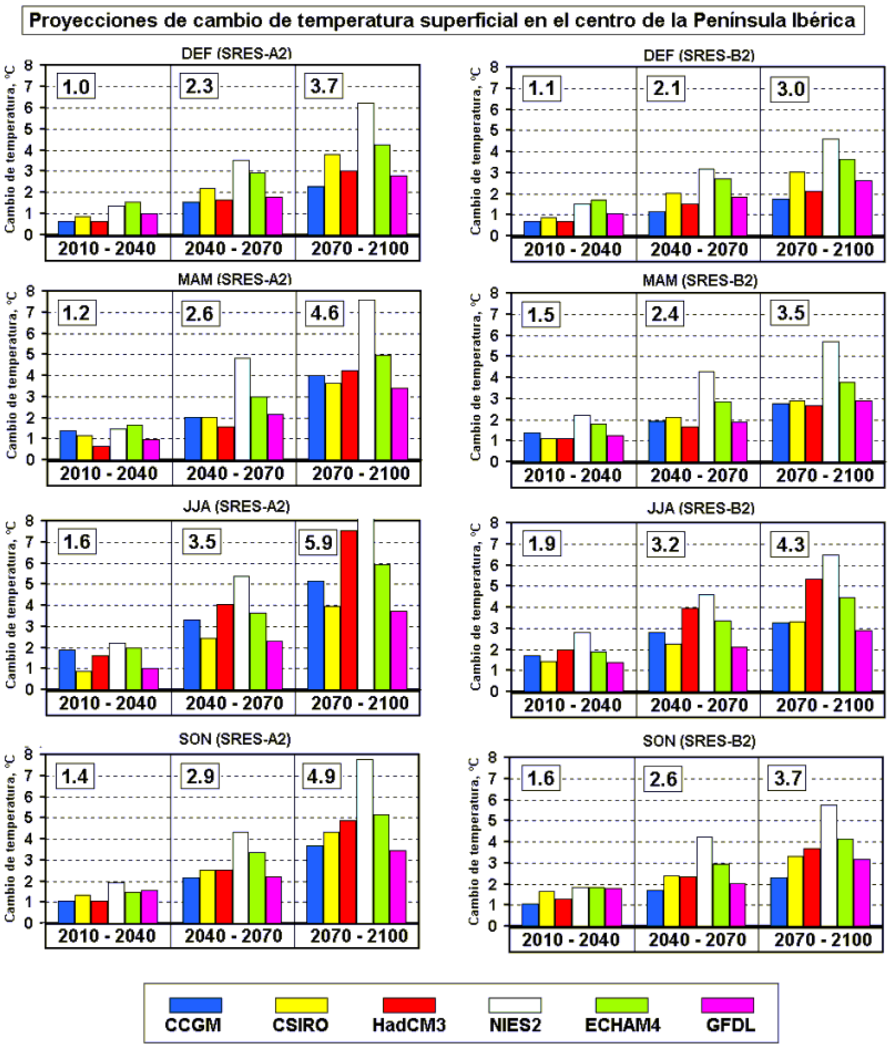

Fig. 1.14. *Changes projected by six AOGCMs in surface mean air temperature (ºC) in the grid of each one, which includes the centre of the Peninsula (see figure 1.13). The results are seasonal averages (DJF winter, MAM spring, JJA summer and SON autumn) and correspond to two emission scenarios (A2 in the left-hand column and B2 in the right.-hand one). Each figure shows the changes in each third of the 21^{st} century in relation to the present climate. The average values of the set of six models considered are shown in the box.*

Considering the values of the mean temperature increases of the set of models framed in figure 1.14, it can be seen that the highest rhythm of seasonal warming corresponds to the summer of scenario A2 and the lowest one to the winter months of scenario B2. It can also be seen that in scenario A2 the warming rhythm accelerates in all seasons as the century elapses, whereas in scenario B2, the evolutions of warming generally present a more linear tendency.

Figure 1.15 shows the comparison between the changes projected by the six AOGCMs for rainfall in the centre of the Peninsula. Therein, more discrepancies can be seen between the models, which indicates the lower degree of reliability of the projections of changes in rainfall in relation to those of temperature. This, however, could be partly due to the greater spatial variability of the changes in rainfall simulated by all the models, which makes the different sizes of the cells over the Peninsula more determinant than in the case of changes in temperature. Some similarities can, however, be observed in the results of the AOGCMs analysed. Thus, for example, almost all of them coincide in projecting decreases in rainfall in the future climate in relation to the 1960-1990 period, although some models simulate certain seasonal positive changes. Likewise, a majority of models project a progressive decrease in seasonal rainfall in scenario A2 throughout the century, although this behaviour is not evident in scenario B2.

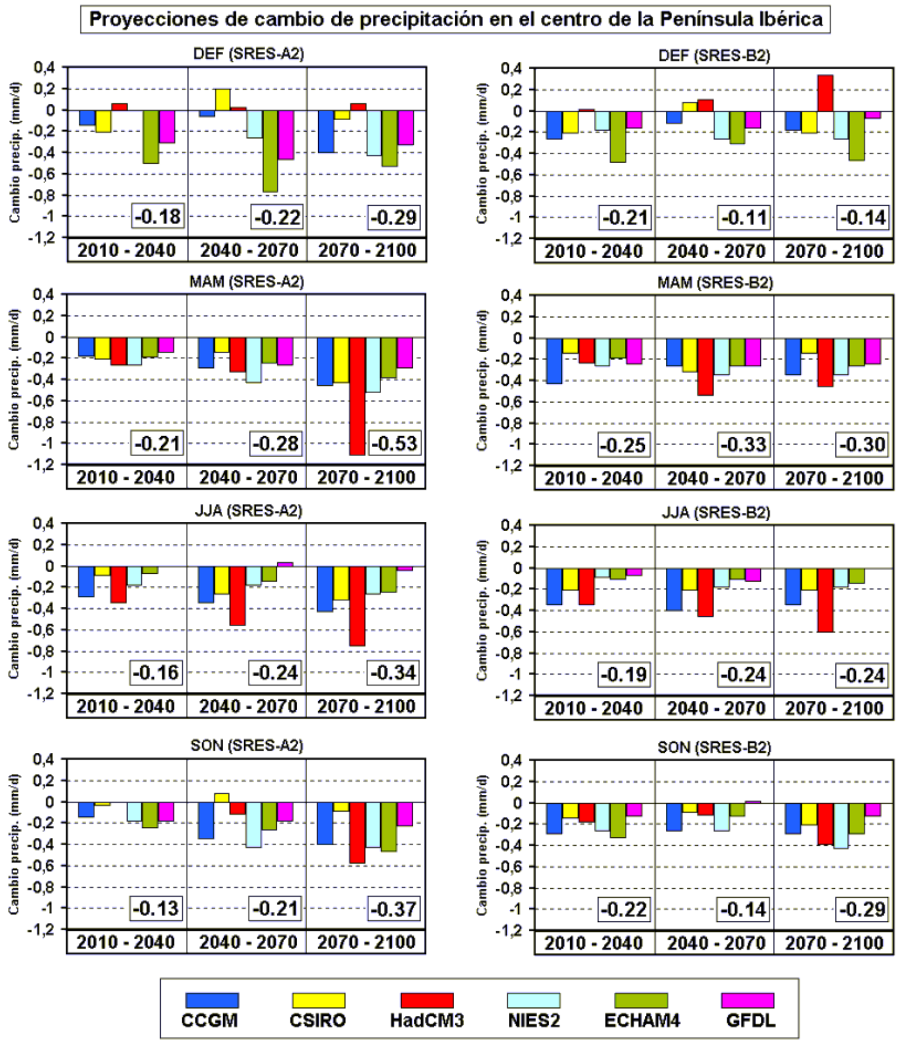

Fig. 1.15. *Changes projected by six AOGCMs in mean precipitation (mm / day) in the grid of each one, which includes the centre of the Peninsula (see figure 1.13). The results are seasonal averages (DJF winter, MAM spring, JJA summer and SON autumn) and correspond to two emission scenarios (A2 in the left-hand column and B2 in the right.-hand one). Each figure shows the changes in each third of the 21st century in relation to the present climate. The average values of the set of six models considered are shown in the box.*

In the centre of the Iberian Peninsula, the HadCM3 model simulates the greatest decreases in rainfall in spring, summer and autumn, whereas it projects increases in rainfall in winter months. The progressiveness of these changes throughout the century is more in this model than in the others. The model showing the lowest projections of changes in annual rainfall is the CSIRO, but the progressiveness of these changes is quite irregular. Emphasis has been placed on this characteristic because the values of the changes included in the figure correspond to differences between seasonal rainfall simulated for each third of the 21st century and those simulated for the 1960-1990 interval. Thus, if the value of a change were greater in a previous third than in a subsequent one, this would signify a relative increase in rainfall between the first one and the second one.

Considering the joint averages of the six AOGCMs, the values of which are framed in figure 1.15, it can be seen that in scenario A2, the progressiveness of the changes is regular in all the seasons of the year. Which means to say, the absolute value increases throughout the century. Calculating the units of change used in the figure, the results of average distribution of annual rainfall changes in the three periods of the century are: 61.2, 85.5 and 137.7 mm/year. However, what can be seen in scenario B2 are absolute values of annual change which are lower in the middle third of the century (78.3, 73,8 and 87,3 mm/year). This means that the middle third would be less dry than the other two. Furthermore, this different progressiveness of the change in annual rainfall throughout the century in both scenarios (A2 and B2) can be seen in the results of most of the AOGCMs considered, which endows this result with a degree of certainty.

1.3.4. Regional climate models

Although the results of climate projections obtained with different AOGCMs present reasonable similarities at global scale, when regional scales are considered, distributions of temperature and, above all, rainfall present clear discrepancies, as was pointed out in the previous section. This reduced reliability at regional scale can be attributed, to a great extent, to the insufficient spatial resolution of the AOGCMs and to the use of physical parametrisations not well adapted to mesoscale processes. Low spatial resolution can distort the lines of the coast and smooth the orographic features. Besides, it has already been pointed out that the models cannot realistically reproduce atmospheric processes with a similar or smaller size than that of the cells in which the domain is discretised. Furthermore, it must be kept in mind that certain physical parametrisations of the AOGCMs have been developed and validated for the broad spatial resolution that they use. This is why they are not usually suitable for reproducing smaller-scale atmospheric processes, some of which could be the ones that most contribute to the characteristics of local climate. In particular, the climates of the Iberian Peninsula are the result of the action of global atmospheric circulation, of the interactions between this macroscale flow and orography, of sea-land contrasts and of other more local effects (Castro *et al*. 1995). But the present AOGCMs are incapable of reproducing these climate features on the Peninsula. An illustrative example is shown in figure 1.16, where the distributions of seasonal temperature and rainfall simulated by the HadCM3 model for the 1961-1990 period are compared with the climatologies for this period. It is obvious that the climate features at regional scale of the Peninsula have not been reproduced because the low spatial resolution of the AOGCM does not permit this. But increasing the resolution of the AOGCMs would involve an increase in computing time and also the adaptation of the physical parametrisations to this higher resolution at all the latitudes of the planet. The solution to the first problem depends on the availability of sufficiently fast and powerful computers, although no results of global climate models at resolutions greater than 100 km yet exist. But to solve the second problem, perhaps we will have to wait a bit longer. Consequently, in order to obtain more suitable approximations to climates at regional or sub-regional scale, other techniques are currently applied, based on the simulations with the AOGCMs.

These techniques can be arranged into two categories: statistical downscaling methods and regional models. The former translate the information provided by the AOGCMs into high-resolution descriptions of the climatic variables, by means of multivariable statistical regressions between series of mean values of temperature and precipitation variables observed in stations included in one cell of the global model and the mean values of other atmopspheric variables (predictors) simulated therein. These regression equations are used to infer the corresponding climatic information in each area, with the use of values simulated by the AOGCM for disturbed climate (Sailor and Li 1999 or von Storch and Zwiers 1999, among others). The results obtained with statistical methods should be analysed with caution, because they are based on the implicit supposition that spatial correlation between local variables and predictors within one cell of the model, obtained under present climate conditions, is not altered after an appreciable global climatic change, and furthermore, the results critically depend on the predictors chosen (Huth 2004).

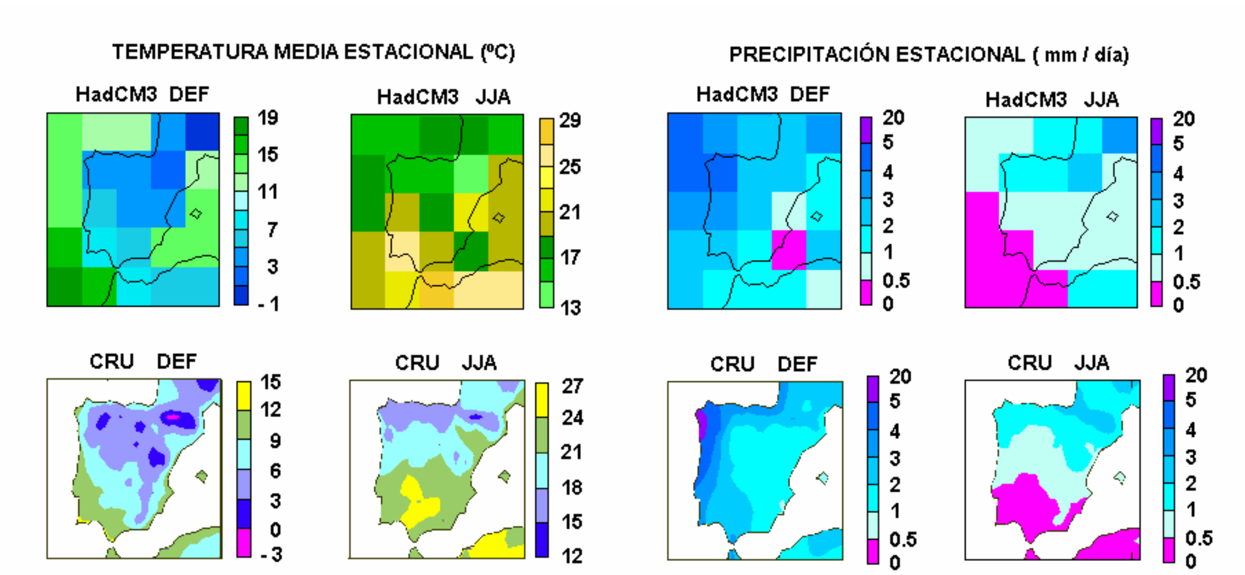

Fig. 1.16. *Comparison between mean temperatures (in ºC) and precipitation (in mm /day) averages in winter (DJF) and summer (JJA) simulated by the AOGCM HadCM3 (upper row) and the climatology designed by the Climate Research Unit (CRU) of East Anglia University (lower row). In both cases, the period is 1961-1990. Note that the colours and values in temperature scales are different on each map, but those for precipitation are the same.*

Regional climate models (hereinafter RCM) are considered as the most promising technique for making reasonable projections of climate change at regional scale (IPCC 2001). The RCM are essentially similar to the atmospheric sub-model of any AOGCM, but they are applied to a limited area of the planet, with more resolution, that is, with the use of smaller cells. They are nested in the mesh of the global model (figure 1.17). This means that in the RCM, the initial values of the variables simulated and their temporal evolution in the domain boundaries are derived from results obtained by an AOGCM. In short, the RCM are feeded through the boundaries with values simulated by the AOGCMs. The procedure currently followed therefore consists of using the AOGCM output data to simulate the response of global circulation to macroscale forcings and the RCM in order to take into account smaller-scale forcings than the size of the cell in the AOGCM, in accordance with the principles of physics, and to highlight the simulation of atmospheric circulation patterns and climatic variables at finer spatial scales (IPCC 2001).

The RCM technique, initiated at the beginning of the last decade of the 20th century (Dickinson *et al*. 1989), is currently used for a whole range of applications, from palaeoclimatic studies to projections of anthropogenic climate change. They provide results with high spatial resolution (between 50 and 20 km) by means of time-slice simulations of several decades and are capable of describing climatic feedback mechanisms at regional scale. The current RCM are generally adapted versions of limited area models used operatively for high-resolution weather forecasting. There are, however, RCMs that link atmospheric processes and other components of the climate system (ocean, hydrology, vegetation, etc.).

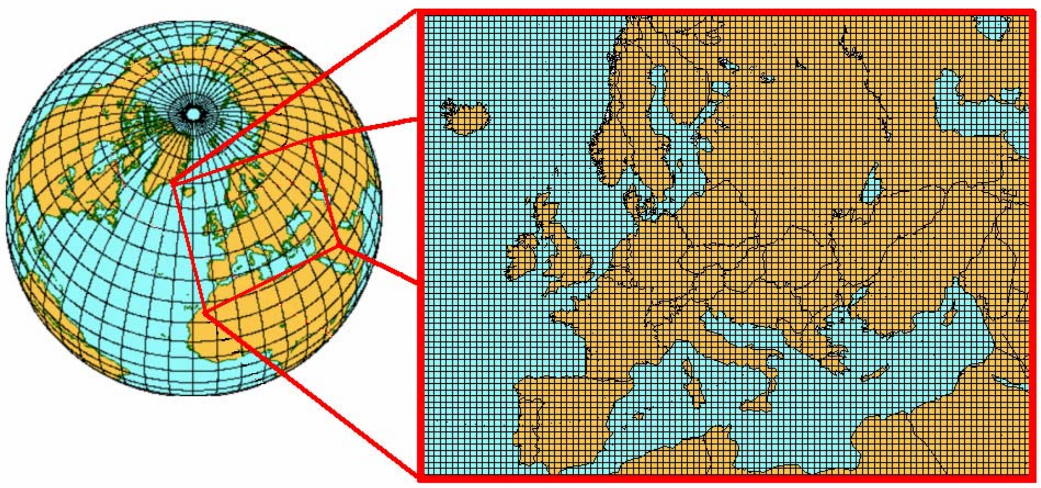

Fig. 1.17. *Example of the application domain of an RCM over Europe with a grid of 50 km. The nesting technique consists of providing the RCM with information on the evolution of the atmospheric variables in the lateral boundaries. This information is obtained previous to the simulation with an AOGCM which uses a grid with lower resolution (bigger-sized grids)*

It must be remembered, however, that an RCM cannot correct errors generated by the AOGCM in which it is nested. For this reason, an AOGCM should be chosen that has been well validated and that realistically represents the features of global circulation affecting the region in question, or the nesting should be considered within a set of different AOGCMs. It is also important that the RCM include suitable physical parametrisations in order to simulate moist convection processes, energy exchanges between the air and the ground or radiative effects of the clouds, of GHGs or of aerosols. Finally, the choice of the size of the cells of the RCM mesh should be taken as a compromise between the scale of those atmospheric processes most influencing the climate of the region in question, and the available computing power. In spite of the fact that RCMs can be applied to a limited area of the planet, the computing time is much greater than what is needed by an AOGCM in order to simulate the same period. This is why the current RCMs do not usually simulate periods of more than a few tens of years (usually 30 years), although the increase in computing power will enable these periods to be lengthened before long.

1.3.5. Future climate projections in Spain using an RCM

This section presents the results obtained from a series of simulations with the regional climate model known as PROMES (Gallardo *et al*. 2001). This is a model that numerically resolves the primitive equations of atmospheric dynamics and includes suitable parametrisations of the physical processes of radiative exchange, of cloud formations and precipitation and of turbulent exchange of mass, momentum and energy between the atmosphere and the surface. They are integrated considering a Lambert conformal horizontal projection in an area of 6,000 x 4,500 km covering almost all of Europe and North Africa, including the Canary Isles archipelago. The horizontal resolution of the simulations, the results of which are presented here, is 50 km. In the vertical direction the RCM PROMES considers 35 layers of varying thickness, much less in the lower layers of the atmosphere.

The simulations were carried out within the framework of the PRUDENCE research project, funded by the V Framework Programme of the EU. In this project, the results were compared of eight RCMs developed in different European centres or universities (Christensen *et al*. 2002). Specifically, the Spanish modelling group participating in this project (MOMAC Group from Castilla La Mancha University in Toledo) is the one that created the PROMES model. All of these European RCMs were implemented and nested in the HadAM3H global atmospheric model, developed in the Hadley Centre for Climate Prediction and Research in the United Kingdom (Pope *et al*. 2000), which uses a horizontal resolution of approximately 140 km at the latitudes of the Iberian Peninsula. This global atmospheric model uses the ocean surface temperatures provided by the aforementioned AOGCM HadCM3. Although the simulation with the HadAM3H global atmospheric model covers the 1950 – 2100 period, the experiments with the RCMs nested therein were done covering two time-slice 30-year periods, due to the aforementioned greater computing effort required by these models. One corresponding to present climate conditions (1960-1990), in which the current levels of atmospheric GHGs and aerosols were considered, and another relating to the last third of this century (2070-2100), taking into account the SRES-A2 and SRES-B2 emission scenarios. Consequently, each RCM did a total of three experiments of 30 years each. For the choice of the mentioned global atmospheric model in which the RCMs were nested, the generally acceptable quality of the results they present was taken into account.

Using the set of numerous output variables of the RCM PROMES, to illustrate the impact on Spain's climate of the projected climate change, this section presents results corresponding to mean daily temperatures of surface air (2 metres above ground) and accumulated daily precipitation for each season of the year. In the first place, the results of the simulation using PROMES corresponding to the 1960-1990 period was commented upon (herein after called control simulation) and these results were compared with climatological values derived from observations during this period. This gives us an idea of the degree of fit with reality of the simulations with this RCM. Subsequently the results of the two climatic projections (A2 and B2) were shown as the difference between the values obtained for each scenario and those simulated for the 1960-1990 period. Likewise, we present the results of seasonal changes in evapotranspiration and wind speed for each scenario, in relation to the present climate. Lastly, an analysis is included of projections of changes in climatic extremes associated with temperatures and rainfall.

a) Comparison between control simulation and climatology

Before commenting upon the results of this comparison, the following two statements should be taken into account:

- The climatology with which the results of a RCM control run are compared should be discretised in cells of a similar size to those of the model, in order for the topography of the domain to be similar. This is why we considered the climatology developed by the Climate Research Unit of East Anglia University (United kingdom) based on values observed daily from 1960 to 1990 in a set of weather stations in Spain and Portugal (New *et al*. 1999). This database can be found in Internet at the address *http://ipcc-ddc.cru.uea.ac.uk*. With these specific observations, the mean values corresponding to cells of 0.5º x 0.5º in latitude-longitude were assigned. Consequently, these are spatial distributions of climatological values resulting from a spatial interpolation method following certain objective criteria, not the actual ones.

- The values of the control simulation with the PROMES model are the result of the nesting of this RCM in the experiment made with a global climate model, considering that the atmospheric component of the climate system contains concentrations of GHGs and of aerosols corresponding to the concentrations observed in the 1960-1990 period. Which means to say that we cannot expect the daily sequence of the global circulation fields of the atmosphere and the ocean to correspond with what actually occurred, as we are dealing with a reproduction of mean climatological values.

Consequently, the comparison should be made by analysing the similarity between the spatial distributions of 30-year averages of the variables considered, instead of between values corresponding to a determined point, month or year. Furthermore, as climatology only includes values in continental areas, where there are observatories, it will be seen that a resolution 0.5º x 0.5º does not permit good correspondence between the situation of the Balearic Isles or the Canary Isles and that of the cells in which the climatological values are assigned.

Figure 1.18 allows for a graphic comparison between the distributions of seasonal average values of mean daily temperature on the Iberian Peninsula and on the Balearic Isles. A good level of similarity is generally observed between the simulated values and climatology. The model, however, tends to highlight more the effect of orography in the temperatures, so that in the higher areas the model simulates lower temperatures than the climatological values. This bias is perceived in all the seasons of the year, although it is more obvious in summer and autumn, resulting in a bias of 2 to 4 degrees at elevations of over 600 m. However, in the rest of the zones and stations, the simulated values are more similar to the climatological ones. On the islands, the differences remain below 2 degrees. However, it must be remembered that the resolutions of the model and of the climatology do not allow the smaller islands to be suitably resolved. This general behaviour has also been observed in the control simulations (1960-1990 period) made by the other RCMs used in the aforementioned PRUDENCE European project.

The distributions of the mean seasonal precipitation simulated and the climatological ones are shown in figure 1.19. Although the model presents more spatial variability than climatology, it can be seen that they acceptably reproduce the North-South gradients in summer and the West-East ones in the other seasons of the year. The greater variability observed in the results of the model appear to be due to the fact that this tends to increase orographic effects. The simulated values of seasonal precipitation on the Atlantic coast generally correspond very well with those of climatology. However, the ones simulated in the south-western half are generally lower than the climatological ones. The simulated distribution of precipitation for the summer season is the one that shows the greatest similarity with climatology, whereas the greatest differences are noted in winter, especially in the Centre and East of the Peninsula. However, analysing the simulated annual evolutions of precipitation for different sub-regions of the Peninsula, it has been seen that they acceptably reproduce climatological values, discriminating well between the most and least rainy seasons of the year for each of the zones of the Peninsula.

To summarise, it could be said that the model tends to highlight topographic effects more than climatology developed by the CRU , in spite of the fact that the spatial discretisation of the terrain is very similar in both cases: 50 km in the PROMES model and 0,5º latitude-longitude in the climatology of the CRU. It must also be remembered that the CRU climatological values are the result of a spatial interpolation treatment among those registered on specific observatories, which are generally not located in the higher areas of the territory. For this reason these should also be considered to present a certain degree of smoothing in mountain areas. However, the most notable aspect of this comparison between the values simulated by the RCM PROMES and the CRU climatology for the 1960-1990 period is that the model acceptably reproduces the different climate regimes of the Iberian Peninsula. Consequently, we can assume that the results of the simulations with future climate scenarios made with the aforementioned RCM, which is now shown, present a reasonable degree of reliability with regard to their capacity to regionalise climatic changes simulated at global scale by the AOGCM HadCM3.

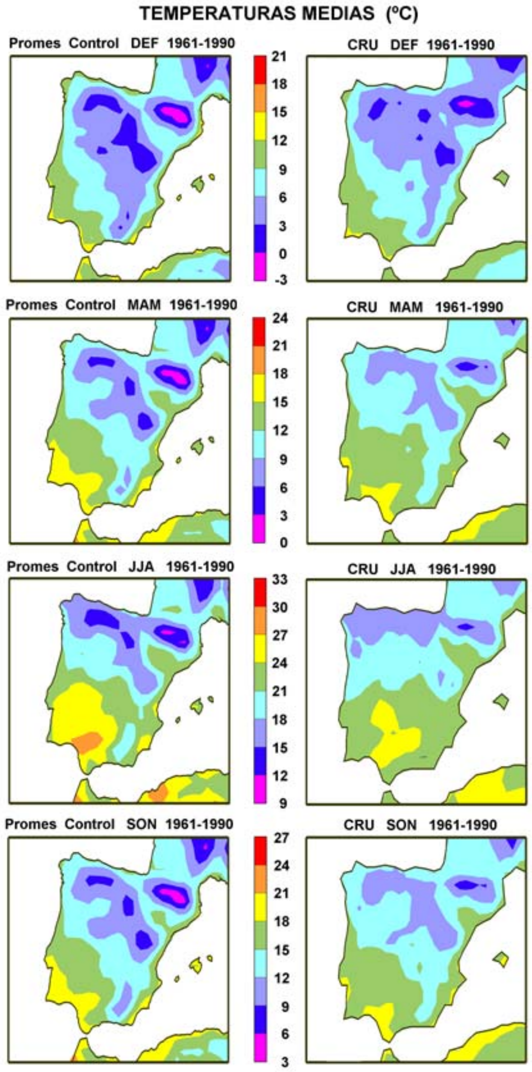

Fig. 1.18. *Comparison of daily mean temperatures (in ºC) simulated by the RCM-PROMES (left-hand column) and designed by the CRU (right-hand column) based on climatological data for the period 1961-1990. Each figure corresponds to averages for one season of the year: (DJF winter, MAM spring, JJA summer and SON autumn). The colour scales include different temperature values for each season.*

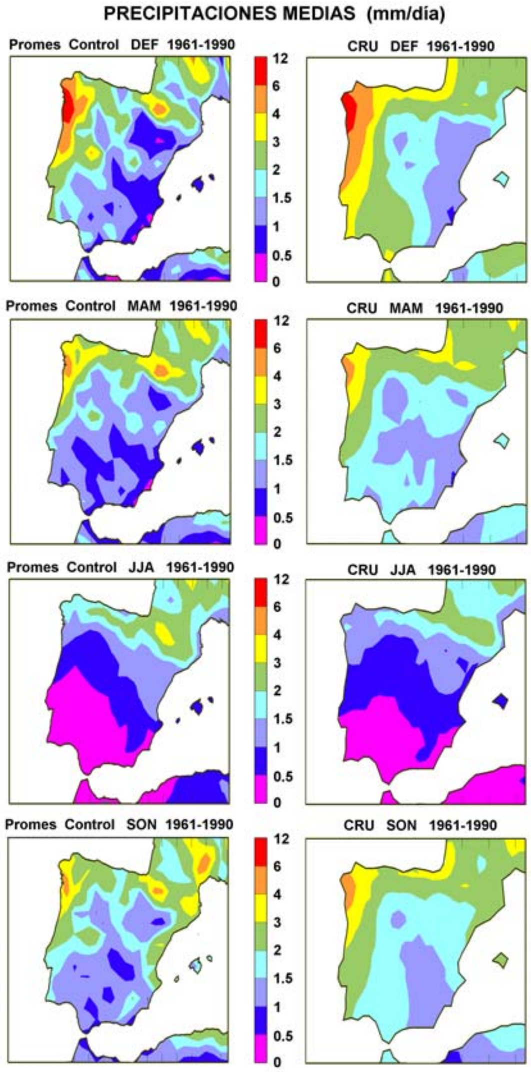

Fig. 1.19. *Comparison of mean seasonal precipitation (en mm/day) simulated by the RCM-PROMES (left-hand column) and designed by the CRU (right-hand column) based on data for the period 1961-1990. Each figure corresponds to one season of the year: (DJF winter, MAM spring, JJA summer and SON autumn).*

b) Changes in mean temperatures projected in the future climate scenarios

This sub-section includes the changes projected for the seasonal averages of mean daily temperatures in the two emission scenarios considered (SRES-A2 and SRES-B2), corresponding to the last third of the XXI century (2071-2100 period), with respect to the modelled values in the control simulation (1961-1990 period). Although it cannot be assumed that the evolution of these changes throughout the century shows a perfectly linear growing behaviour pattern, it seems reasonable to presume that in periods previous to this one, these changes would register lower values, as can be deduced from the results obtained with the AOGCMs.

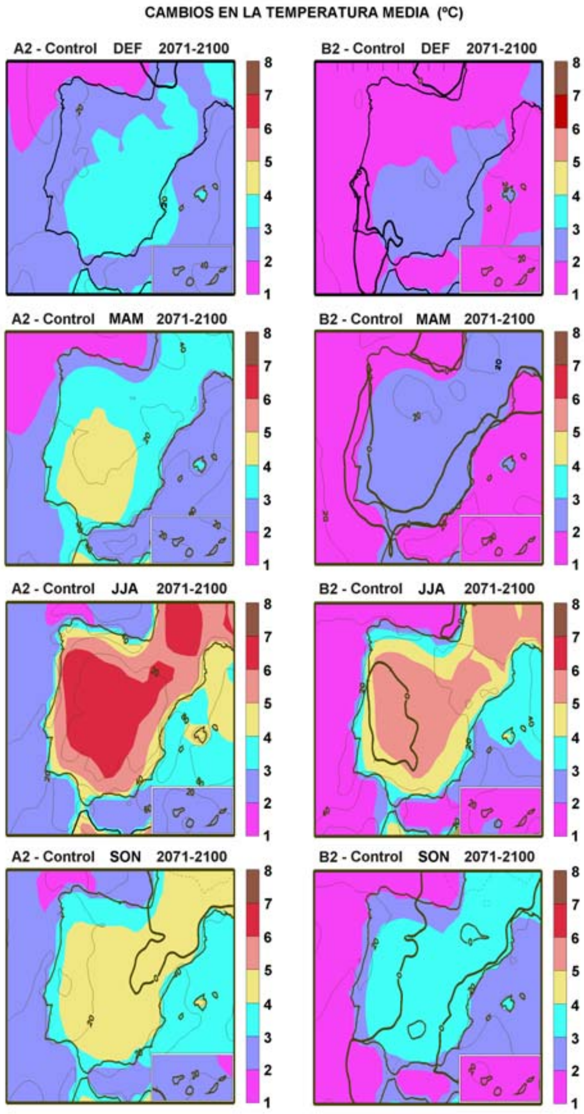

Fig. 1.20. *Projections of change in daily mean surface air temperature (ºC), averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn) in the Iberian Peninsula, Balearic Isles and Canary Isles (lower right-hand corner on each map), corresponding to two SRES scenarios: A2 in the left-hand column and B2 in the right-hand column. The values correspond to differences between the simulation of the period 2071-2100 and the control one (1961-1990). The isolines in the figures show the percentages of changes in interannual variability (positive in continuous line, negative in broken line and zero in continuous thick line).*

The projections of seasonal change in mean daily temperatures are shown in figure 1.20. The general behaviour pattern shows that the most intense temperature increases correspond to the scenario SRES-A2, which is the one with the highest emissions of GHGs. The differences between scenarios A2 and B2 remain at around 1ºC. The winter months are those that present smaller increases in daily temperature, with values of between 2 and 4 ºC for scenario A2 and between 1 and 3ºC for scenario B2. The spatial distribution of these changes in winter is similar in both scenarios, the smallest increases corresponding to the Northeast of the Peninsula and the Canary Isles, and the biggest ones to the south-eastern half of the Peninsula. The season in which temperature increases are greatest is summer, values exceeding 6ºC in scenario A2, and over 5ºC in B2. Such big changes occur in the inland zone of the Peninsula. A clear gradient between the periphery and the inland zone can be perceived, which could be related to the regulating effect of the sea breezes. This can also be said of the two archipelagos, although the small size of these does not allow us to perceive this gradient. In spring and autumn, the projected increases reach intermediate values between the winter and summer ones. Increases in autumn, however, are greater than those of the spring, particularly in scenario B2. Although they are not shown graphically, the projected changes for the seasonal averages of maximum and minimum daily temperatures present a spatial distribution similar to those of mean temperatures. However, the values of the changes are around 1ºC higher for the maximums than for the minimums, those of the latter being similar to those of mean temperatures. This means that the range of daily thermal oscillation increases compared to the present climate. This behaviour can be seen in all the seasons and in most of the areas of the territory, except on the islands or very close to the coast. In their essential aspects, the previous results are similar to those obtained by Räisänen *et al*. (2004) who used another regional climate model within the framework of the aforementioned European project PRUDENCE.

c) Changes in mean precipitation values projected in future climate scenarios

We will now analyse the changes projected for mean seasonal rainfall for the two emission scenarios considered (A2 and B2) corresponding to the period 2071-2100, taking as a reference the values modelled in the control simulation (1961-1990). Before presenting the results, it should be pointed out that it would not be correct to use a simple temporal interpolation to deduce changes in rainfall in periods previous to 2071-2100. This can be seen in the results obtained with the AOGCMs represented in figure 1.15, where it can be observed that no AOGCM simulates a uniform tendency of change in seasonal rainfall on the Iberian Peninsula throughout the 21st century.

Figure 1.21 shows the values of the seasonal changes expressed in mm/day. Multiplying these values by the number of days in each season, which is 90, because in the climate simulations with models the years are considered with a uniform duration of 360 days, the changes can be deduced in the total amounts of seasonal rainfall. What can be appreciated more clearly in the figure is that the changes have a greater absolute magnitude in scenario A2, regardless of their sign. Thus, in winter there are increases in the Northwest of the Peninsula that exceed the value of 1 mm/day in scenario A2, whereas in B2 these remain below 0.5 mm/day in this region. Something similar occurs in autumn, but in the Northeast of the Peninsula. This result tallies with that obtained by Sumner *et al*. (2003), who used the simulations made with another global model (ECHAM4 of the Max-Planck Institut für Meteorologie in Hamburg). Apart from these two exceptions, the changes in precipitation in Spain have a negative sign. This means that decreases in seasonal precipitation in relation to the present climate are projected for the last third of the 21st century, which are generally of greater magnitude in scenario A2 than in B2, except for the vicinity of the Pyrenees for the summer months, in which the magnitude of the changes are similar in both scenarios. In the Canary Isles, no appreciable change in total precipitation can be appreciated in any season of the year.

d) Projected changes in evapotranspiration and wind module

We now present the differences obtained between the seasonal averages of daily surface evapotranspiration projected for the last third of the 21st century, and the ones simulated in the control experiment (present climate). It must be mentioned that the amounts of water that evaporate from the surface were simulated with a parametrisation scheme implemented in the PROMES regional climate model. The scheme therefore provides a good link between atmospheric and edaphic processes. This scheme, developed by Decoudre *et al*. (1993), does not only calculate the amount of water that evaporates from the ground, but also the water that tanspires from the different types of plant cover included in each cell of the model (Arribas *et al*.

2003). It should also be pointed out that in all the simulations (control and scenarios) the same type of land uses have been maintained.

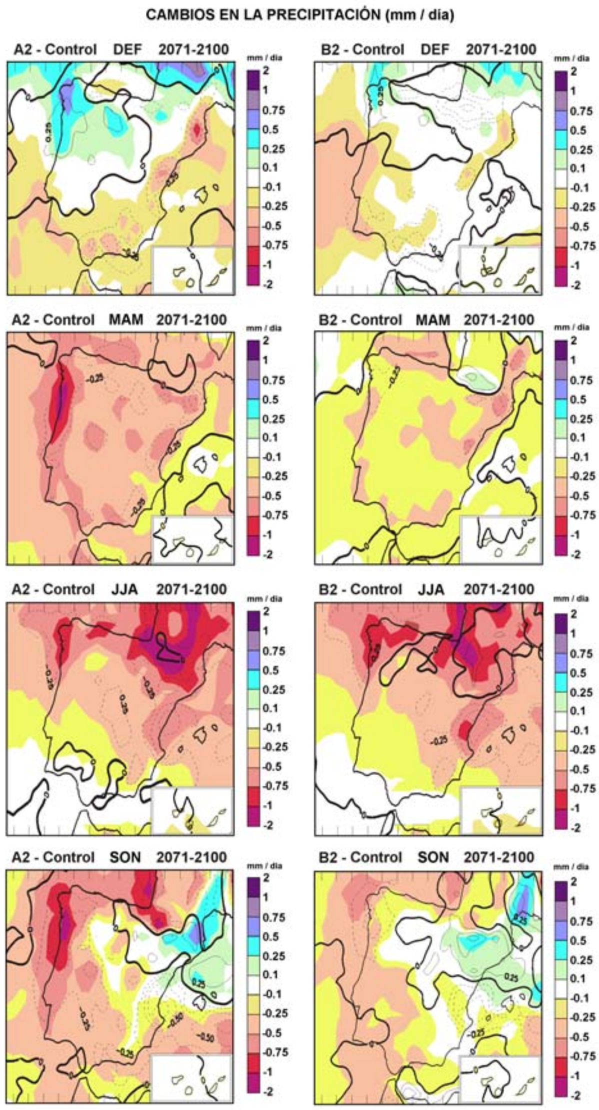

Fig. 1.21. *Projections of changes in precipitation (in mm/day) averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn) in the Iberian Peninsula, Balearic Isles and Canary Isles (lower right-hand corner on each map), corresponding to two SRES scenarios: A2 in the left-hand column and B2 in the right-hand column. The values correspond to differences between the simulation of the period 2071-2100 and the control one (1961-1990). The isolines in the figures show the percentages of changes in interannual variability (positive in continuous line, negative in broken line and zero in continuous thick line).*

The results obtained from the two emission scenarios considered (A2 and B2) present a notable percentage decrease in the average amounts of water evapotranspired in summer and autumn in most of the Peninsula compared with the values obtained in the simulation of the present climate. The maximum reductions are observed in the southern half of the Peninsula during the summer months, and in some areas these reach values of around 60% in scenario A2 (figure 1.22), whereas in autumn they remain below 40%. In emission scenario B2, the decreases in evaporation are more moderate, and in general these do not exceed 40% in summer and 20% in autumn. In both seasons, a slight increase in evapotranspiration in the northern third of the

Peninsula can be observed, which does not surpass 20% in the two scenarios simulated. In the winter months, however, increases in surface evapotranspiration are projected for practically the whole Peninsula, and in some areas the increases exceed 40%, although in most of the territory, they remain below 20% (figure 1.22). No significant differences are appreciated between the results obtained for the two emission scenarios considered. Lastly, in the spring months, slight decreases in evapotranspiration are obtained in the southern half of the Peninsula (less than 20%) and increases in the northern half, exceeding a value of 40% in the Northeast. With regard to the Canary Isles and Balearic Isles, none of the simulations show significant changes in the seasonal averages of water evaporated from the surface, compared with the values simulated in the control experiment (present climate).

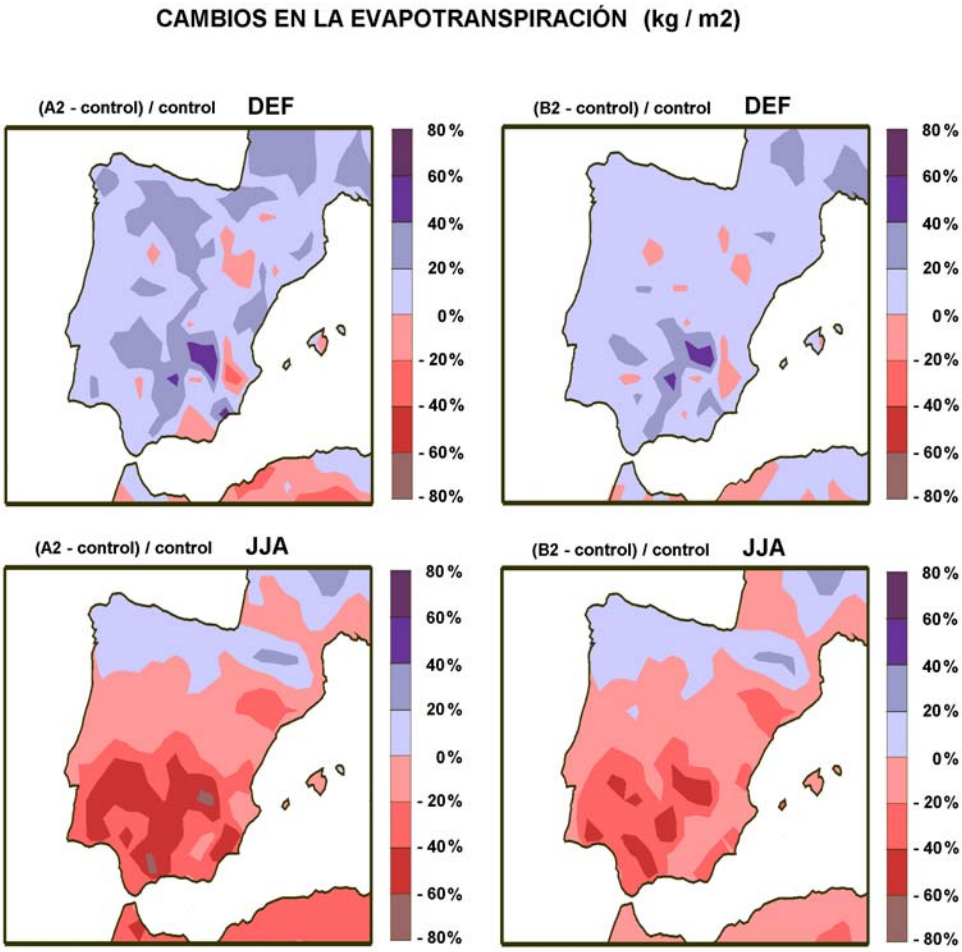

Fig. 1.22. *Projections of percentage change in evapotranspiration in winter (DJF) and summer (JJA) months, corresponding to two SRES emission scenarios: A2 in the left-hand column and B2 in the right-hand column. The values correspond to change percentages between the simulation of the scenario and the control one in relation to the control one.*

In relation to the surface wind module (10m above ground), the percentage changes projected in the two scenarios in relation to the present climate present different signs depending on the time of year, and also different ones on the Peninsula and the Balearic Isles in relation to the Canary Isles. Thus, in summer, a significant increase is observed in the average wind intensity in most of the Peninsula, reaching increases of above 10%, except in the Northwest, where slight decreases are obtained (figure 1.23). But in the other seasons of the year, there is a predominance of negative changes in average wind intensity over the Peninsula and the Balearic Isles, the biggest of these in autumn, with decreases exceeding 10% in the Northeast and 5% in most of the Peninsula. However, in the vicinity of the Gibraltar Straits, increases are projected in the wind module in all the seasons of the year, except in winter. However, the seasonal distribution of the change in wind intensity projected for the Canary isles area is practically opposed to that of the Peninsula. Summer is the time of year in which the projected changes show a negative sign, which means that there is a projected decrease in average wind in the future climate compared with the present one, whereas in the other seasons of the year, increases in average wind intensity are simulated, the biggest one being in spring and winter (figure 1.23). In all cases, the positive and negative differences in the wind module projected in Spain for the end of the century (2071-2100) in comparison with the values of the 1961-1990 period (present climate) are somewhat more accentuated in the simulation of scenario A2 than in B2.

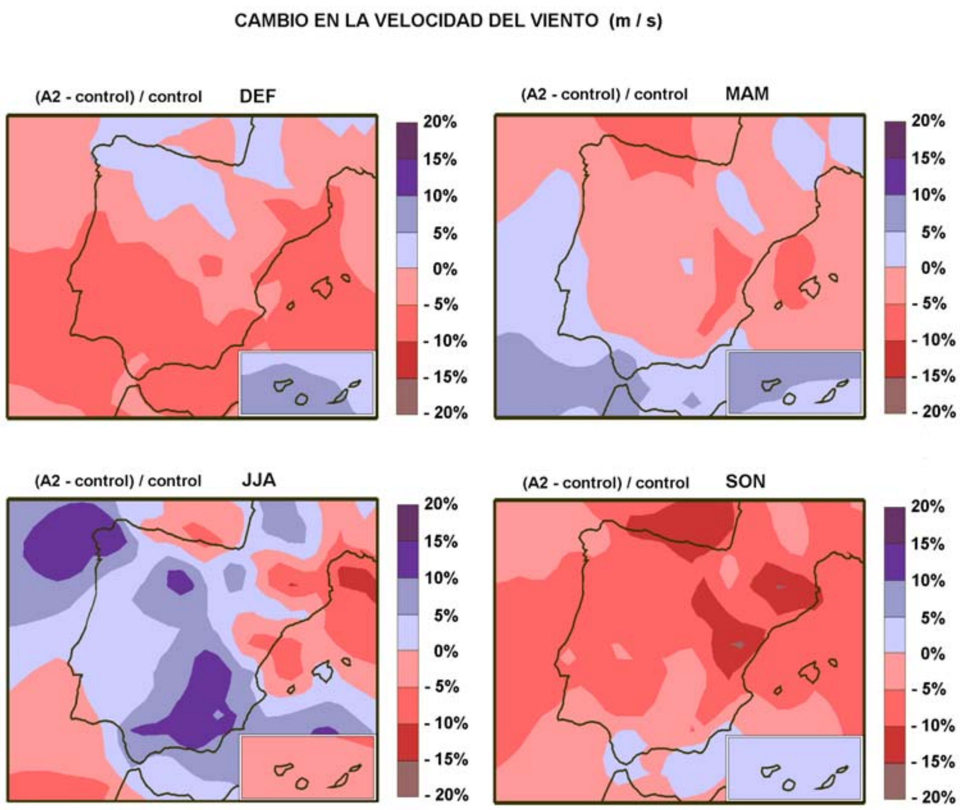

Fig. 1.23. *Projections of percentage change in the surface wind speed module for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn), corresponding to SRES-A2 emission scenarios. The values correspond to change percentages between the simulation of the scenario and the control one in relation to the control one.*

e) Changes in the variability and extremes of temperatures and rainfall projected in the scenarios of future climate

An aspect of the projections of future climate which is as important as changes in mean temperature values or in any other climatic variable, is a possible change in variability in relation to the present climate. Variability is understood as the standard deviation from the temporal statistical average. Different time scales of variability can be considered: inter-seasonal, interannual, or interdecadal. We now present the results obtained from the application of a simple analysis of interannual variability, which consists of considering the value of the following percent ratio:

$$\frac{\sigma_f - \sigma_a}{\sigma_a} \cdot 100$$

where σ_f is the standard deviation from the distributions of monthly temperature averages in the future period (2071-2100) and σ_a of the simulated period of the present climate (1961-1990). Thus, a positive value (or negative one) of this ratio would indicate the percentage of the increase (or decrease) in the variability of monthly temperatures or rainfall in the projected climate, compared with that of the simulations in the control experiment (present climate). This calculation is made for each season of the year. The results obtained from this simple analysis are shown in figures 1.20 and 1.21 by means of isolines superimposed over the spatial distributions of the increases in mean seasonal temperatures and rainfall.

This figure shows that the monthly variability in projected mean temperatures for the last third of the century is generally greater than that of the present simulated climate, with positive percentages of around 20% or below. Some differences can be appreciated, however, between the two emission scenarios considered. Thus, in B2 the percentages of change in temperature variability are lower than in A2. With regard to distribution according to seasons, the biggest changes are observed in summer and the smallest in autumn. However, the spatial and seasonal distribution of the percentages of changes in temperature variability is not regular over the Peninsula. Scenario A2 presents increases of over 20% in the periphery of the Peninsula in summer, whereas in the Northeast there is hardly any alteration in autumn. In scenario B2, however, few changes are observed in variability in autumn, and those in summer are much smaller than in scenario A2, more similar to those observed in winter and spring. Furthermore, in the Canary Isles, the percentages of change in variability are similar in the four seasons and the two scenarios, with values of around 20%, except in scenario A2 in winter, when values of 40% are reached. These increases in temperature variability would mean that the monthly thermal anomalies in the climate projected for the end of the century will tend to be more intense than in the present climate. Figure 1.24 provides an outline of the qualitative change that the distribution of frequencies of mean temperatures in the future climate would undergo in comparison with the present, according to the simulated climate change results. From this figure, we can deduce that in the extremely hot months, the rise in temperatures in the future climate will be somewhat greater than the values of the increase projected for the mean temperatures of the present climate. The magnitudes of this percentage would be the values indicated.

With regard to the change in the interannual variability of rainfall, applying the same simple procedure as the one used for temperatures, no appreciable changes were observed in any season of the year (figure 1.21). Increases of around 20% only appear in the Northeast of the Iberian Peninsula during winter. These results appear to indicate that the frequency of anomalies in the monthly or seasonal rainfall of the projected climate for the last third of the 21st century would be similar to that of the present climate. However, the application of the simple statistical method used is questionable in the case of rainfall because its frequency distribution does not adjust to a Gaussian type curve, as it mostly occurs with temperatures. For a more correct analysis of the possible alteration in rainfall variability, we would have to consider the frequency of daily extreme events, including rainfall intensity (IPCC 2001). An analysis in this respect will subsequently be presented.

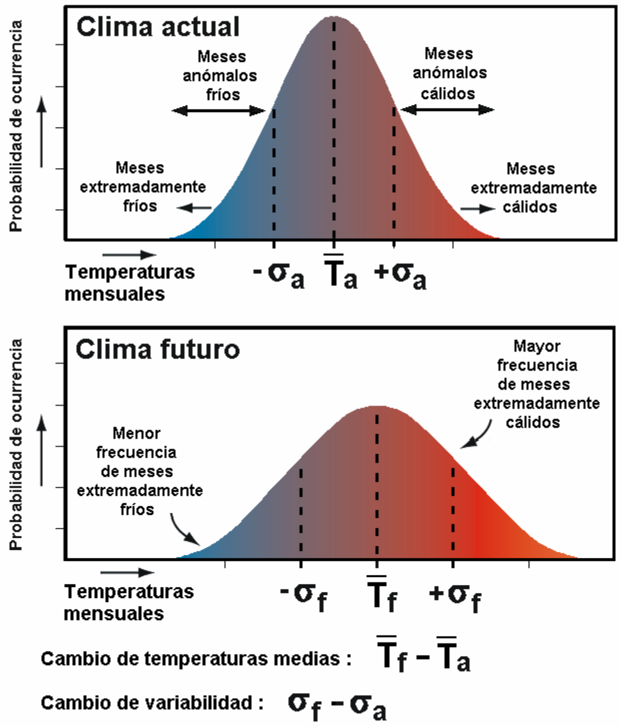

Fig. 1.24. *Illustration of the distributions of frequency of monthly temperatures in the present climate and in the projected climate.*

It must be mentioned, however, that the interannual variability that an AOGCM can simulate depends to a great extent on the way in which it models atmosphere-ocean interactions. Thus, although most AOGCMs seem to be able to project increases in interannual variability in scenarios of disturbed climates, others present contradictory results (page 362 of the IPCC report 2001). Which means to say that there is still great uncertainty regarding the possible alteration of low-frequency variability in future climate scenarios. Consequently, as the interannual variability simulated by any regional climate model is closely linked to the information provided by the AOGCM in which it is nested, the previous results should be considered with due caution.

A study complementing the one on alteration of low-frequency climate variability is the one relating to the possible changes in the so-called climate extremes. Values of atmospheric variable that are very distant from the climatological averages, occurring in exceptional meteorological conditions, are understood as climatic extremes. The interest aroused by this other type of study lies in the fact that it is believed that the impacts of future climate changes due to changes in climate extremes will probably be more severe than those related to average climate changes. Although these events are relatively infrequent, they can have a great impact on the environment or on human health. There are many possible criteria or indices for characterising extreme climatic events. The most used ones are chosen because of the availability of the variables required for calculating them, the ease with which they are interpreted and their applicability to impact studies, and also because they allow for an objective and complete description of the frequency and intensity of climatic extremes.

Of the wide range of indices of climatic extremes applicable to temperatures, we could consider those based on percentiles. Thus, as Jones *et al*. (1999) showed, in order to characterise the intensity of extremely hot or cold temperature conditions, we would have to use, respectively, 90 percentile of the distribution of maximum daily temperatures (hereinafter $T_{max}90$) and 10 percentile of the distribution of minimum daily temperatures (hereinafter $T_{min}10$). Using the simulations with the RCM PROMES these intensity indexes of daily thermal extremes were calculated for each one of the two 30-year periods (1961-1990 and 2071-2100) and each season of the year. The differences between the values corresponding to emission scenario A2 and the control experiment (present climate) are now presented. These differences between percentiles are expressed in ºC.

The biggest changes in T_{max}90 are observed in summer and spring in the inland area of the Peninsula, reaching values of 7ºC. In winter the differences are smaller, not reaching 5ºC. The spatial distributions of the changes in T_{max}90 are very similar to those of the average changes in maximum daily temperatures (hereinafter T_{max}), but the same is not so for the values. The changes projected for T_{max}90 are generally greater than for T_{max}, except inland on the Peninsula in summer, where the latter ones surpass the former ones by a few tenths of a degree. What is most noteworthy, however, are the changes T_{max}90 obtained in spring, above all, and in autumn, as they are clearly bigger than the changes in T_{max} (figure 1.25). Thus, it can be seen that in spring, the changes in T_{max}90 reach 7ºC whereas the changes in T_{max} are around 2ºC lower in most of the Peninsula. In autumn, however, these differences remain at around 1ºC lower, although in the North and Northeast of the Peninsula, they reach 2ºC.

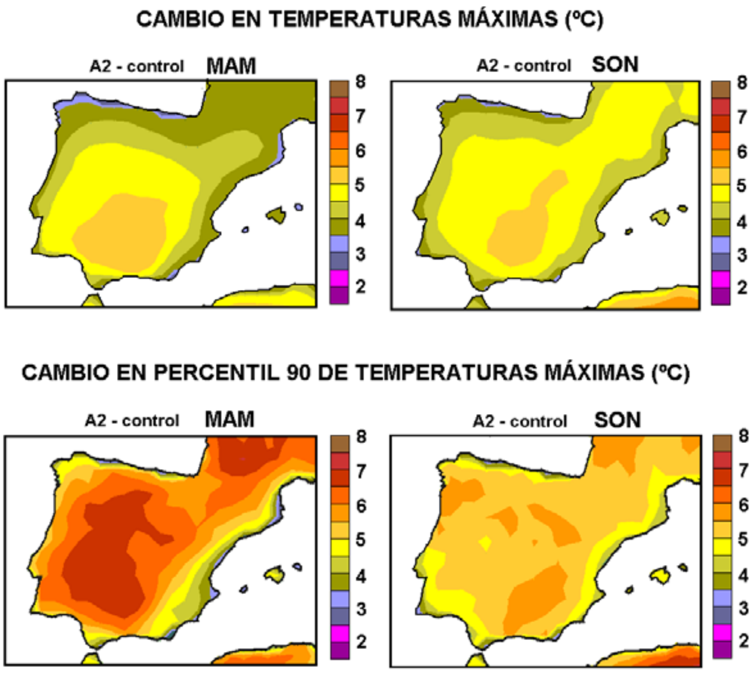

Fig. 1.25. *Differences in seasonal averages of daily maximum temperatures (above) and in 90th percentiles (below) between the simulation with A2(2071-2100) emission scenarios and the control one (1961-1990) corresponding to spring (MAM) and autumn (SON).*

For a correct interpretation of this different seasonal behaviour in the changes projected for T_{max} and T_{max}90, perhaps a more detailed statistical analysis of these changes would be needed. This result, however, could be an indication that in the climate projected for 2071-2100 there is a greater frequency of extremely hot days at the end of spring and the beginning of autumn, compared to the present climate. We must keep in mind that both T_{max} and T_{max}90 were calculated for each season considering the days included in three-month: December – February for winter, March – May for spring, June – August for summer and September – November for autumn. The bigger increase of T_{max}90 in relation to that of T_{max} in spring could therefore be in accordance with the fact that the warming projected for the month of May is greater than what corresponds to April and is more similar to that of the summer months. A similar explanation could be applied to the projections for autumn, because the increase in T_{max} in September is also bigger than in the other months of autumn. In the results of projections of climate extremes at the end of this century for emission scenario SRES-A2 obtained by Sánchez *et al*. (2004) an increase in the frequency of heat waves in spring and autumn can be appreciated, and this seems to be in consonance with what was previously established. Shär *et al*. (2004) and Beniston (2004) coincide in an increase in summer heat waves in Europe in future climate scenarios.

With regard to the changes projected in $T_{min}10$, a very similar behaviour to that obtained for T_{min} is observed. But once again it can be seen that the increases in $T_{min}10$ are somewhat smaller than those in T_{min} in spring and autumn on most of the Iberian Peninsula. The same thing occurs in the summer months in the North of the Peninsula, but not in the rest of the territory. However, the differences between the increases in $T_{min}10$ and in T_{min} do not generally exceed a value of 1 degree. Which means to say, that they are smaller than those mentioned in the case of $T_{max}90$ and T_{max}. Using the previous reasoning, it could be speculated that the fact that the changes projected for $T_{min}10$ are smaller than for T_{min} might be an indication that in the climate in the last third of the century, there would be less frequency of extremely cold days. However, the results of Sánchez *et al*. (2004) indicate a higher frequency of cold spells, but this might possibly be due to criteria considered by these authors to define the occurrence of these extreme events.

We now include a brief analysis of the changes projected for daily rainfall extremes in the emission scenario SRES-A2, in comparison with the simulation of the present climate. In order to characterise the intensity and frequency of these extreme events, different criteria can be considered (Jones *et al*. 1999). In this case, one of these was selected: Number of days with accumulated rainfall, of over 1 mm for each season of the year, averaged over a period of 30 years. Hereinafter, this index will be know as NPr1.

For each one of the two 30-year periods considered (1961-1990 control and 2071-2100 scenario) we calculated the seasonal averages of NPr1 and the differences between the values corresponding to scenario SRES-A2 and to the control experiment (present climate). The differences were calculated as a percentage in relation to the values simulated in the control experiment (present climate). On expressing the differences in percentage, the numerical results thus obtained should coincide with those that would be obtained considering any percentage of the distributions of daily rainfall. Thus, for example, as the number of days with rainfall corresponding to the 90^{th} percentile (indicated by NPr90) is by definition the total number of days with rainfall (NPr1), then the percentage change of NPr90 between the two experiments of scenario and control would be equal to the percentage change of NPr1:

$$\frac{N\,Pr\,90\,(A2) - N\,Pr\,90\,(control)}{N\,Pr\,90\,(control)} = \frac{0.1 \cdot N\,Pr\,1\,(A2) - 0.1 \cdot N\,Pr\,1\,(control)}{0.1 \cdot N\,Pr\,1\,(control)} = \frac{N\,Pr\,1\,(A2) - N\,Pr\,1\,(control)}{N\,Pr\,1\,(control)}$$

Figure 1.26 shows the distributions of the changes in NPr1 projected for the Iberian Peninsula for each season of the year. Therein, it can be seen that in spring and summer, the changes in NPr1 have a negative sign, that is, a lower number of rainy days, throughout the whole Peninsula. In summer, values of percentage differences for Npr1 are not seen in the southernmost part of the Peninsula, because in the control experiment (1961-1990) NPr1 is very small (< 10 days),which gives rise to unrealistic change percentages.

The negative changes in NPr1 might be related to the greater persistence and duration of the periods of rainless days in the scenario of disturbed climate, than in the present one. However, in winter, an increase of over 10% in the NPr1 can be observed in the Northeast of the

Peninsula, and the same can be observed in autumn in the Northeast and the Levant. The regions and time of year in which these positive changes in NPr1 are simulated essentially coincide with those of increases in accumulated rainfall shown in figure 1.21. Sánchez *et al*. (2004) present results of changes in rainfall extremes simulated for the disturbed climate scenario, considering an intensity index of extreme rainfall (percentile 90) encompassing the whole Mediterranean region. These authors show that changes in the torrentiality of rainfall on the Peninsula present a high spatial variability in all the seasons of the year. This could be related to the fact that simulated extreme rainfall shows a high degree of uncertainty. Likewise, Christensen and Christensen (2003) present results of regional climate simulations for the end of the 21st century, in which an increase can be seen in torrential rains during the summer months in Europe, although this result presents a high degree of uncertainty for the Iberian Peninsula. A possible procedure for reducing these levels of uncertainty could be by analysing the complete set of simulations made by the regional climate models used in the European project PRUDENCE.

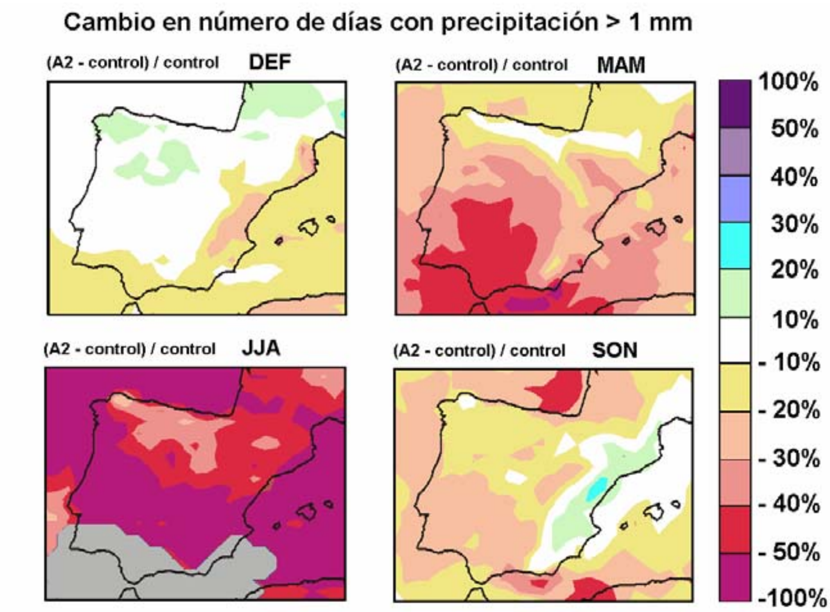

Fig. 1.26. *Changes in the number of days with precipitation over 1 mm between the simulation of A2 (2071-2100) emission scenarios and the control one (1961-1990), expressed in percentages in relation to the present simulated climate, corresponding to each season of the year (DJF winter, MAM spring, JJA summer and SON autumn). The grey colour in the summer figure indicates that in those regions there is too little precipitation in the control experiment.*

1.3.6. Conclusions

In order to analyse disturbance of Spain's climate possibly deriving from global climate change due to the accumulation of GHGs throughout the 21st century, the results were used of a set of climate simulation models. In this analysis, six global models (AOGCM) were considered, along with a regional model. The results obtained with them are not climatic predictions, but rather projections of how future climate could be altered, taking current climate characteristics (1961-1990 period) as a reference. Also taken into account were two possible scenarios of global emissions of GHGs and aerosols, designed by the Inter-governmental panel of experts for the study of Climate Change (IPCC), based on demographic, social and economic criteria. These scenarios, known by the abbreviations SRES-A2 and SRES-B2, are the two that have been most used to date to make projections of climate change.

In the results of the climate scenarios made by the six AOGCMs considered, there are discrepancies regarding the magnitude of the changes projected in relation to temperatures and to the total amounts of rainfall in Spain in the 21st century, although notable qualitative coincidences can also be seen. The most significant results obtained can be summarised as following:

a) The models coincide in that the growing tendency of mean temperatures present a regular behaviour pattern throughout the century, although this warming is more accentuated in emission scenario SRES-A2 than in SRES-B2.
b) The models coincide in that the temperature increase projected throughout the century is more intense in summer than in winter, and reaches intermediate values in the other two seasons of the year.
c) Taking the average of the set of six AOGCMs, in emission scenario SRES-A2 the average tendency of temperature over the century varies by approximately 1.2ºC every 30 years in winter and by 2ºC every 30 years on the Iberian Peninsula.
d) In emission scenario SRES-B2 these mean temperature increases reach an approximate value of 1.1ºC every 30 years in winter and 1.8ºC in summer.
e) The six AOGCM coincide in projecting a significant decrease in total annual rainfall over the Iberian Peninsula, which is somewhat more intense in scenario A2 than in B2.
f) This decrease tends to be bigger in spring and smaller in winter.
g) The tendencies of change in seasonal rainfall are not generally uniform throughout the century, although there are notable discrepancies between models. Some models project more accentuated decreases in rainfall in some seasons of the year up to the middle third of the 21st century, and other simulate more uniformly progressive decreases throughout the century.

The discrepancies observed in the climate changes projected for the Iberian Peninsula by the different AOGCMs are fundamentally considered to be related to the different spatial resolutions used by each one (cell sizes between 600 and 250 km) and to the different degree of complexity of the parametrisation schemes of atmospheric and oceanic processes that they use. For this reason, an analysis has been made of the changes projected for future climate on the Iberian Peninsula, considering the results obtained by one of the six AOGCMs, that uses a relatively high resolution (more spatial detail) and which uses a more complete and updated set of physical parametrisations. This is the case of the model HadCM3 developed in the Hadley Centre for Climate Research in the United Kingdom.

Th results of the projected changes in mean temperature and rainfall obtained with the global model HadCM3 allow for a certain spatial discrimination over the Iberian Peninsula. As an outline, the most relevant conclusions of the projected climate changes in Spain obtained using the aforementioned global model are:

a) The smallest temperature increases are obtained in the Northeast of the Peninsula and the biggest ones in the South.
b) The greater upward tendency of temperatures throughout the century corresponds to the summer months and the smaller one to winter, both of these more accentuated in emission scenario A2 than in B2.
c) In the projections of change in rainfall, generalised decreases are obtained in annual values, which are higher in scenario A2 than in B2, but the spatial and seasonal distributions of these are not uniform in Spain.
d) For the last third of the 21st century, an increase in winter rainfall is projected in most of the territory, and in autumn a slight increase in the Northeast of the Peninsula, whereas it is in spring and summer when the biggest generalised decreases are obtained.
e) The absolute values of change in seasonal rainfall reach lower values in the intermediate periods than in the last third of the century, although generally maintaining the sign of the changes projected for the end of the century.
f) The downward tendencies in rainfall are more accentuated in emission scenario A2, whereas the upward ones are somewhat greater in scenario B2.

In order for the results of climate change projections to have greater spatial resolution, the regional climate model PROMES was used, nested in the global model HadAM3. The cell size of the regional model is 50 km, which allows for a more suitable reproduction of the orographic features of the Peninsula and also to allow the bigger islands of the Balearic and Canary Isles to be considered. Indeed, it has been seen that the PROMES model provides a more satisfactory reproduction than the global model of the climatological distributions of temperature and rainfall over Spain. This would seem to indicate that the projections of future climate obtained with the PROMES model are more appropriate for analysing impacts at regional scale than those derived directly from the global model.

The projections of climate change made with the regional model only correspond to the last third of the 21st century (2071-2100), and they were deduced taking as a reference the climate simulated by this model in the 1961-1990 period (control experiment). Likewise, the two GHG emission scenarios were considered (A2 and B2). The results presented correspond to mean temperature (in ºC), rainfall (in mm), amount of water evapotranspired (in $kg \cdot m^{-2}$) and wind speed (in $m \cdot s^{-1}$). A summarised outline is now presented of the most relevant projections for each variable, each season of the year and each emission scenario, with a discrimination of the different regions of Spain to the extent permitted by the resolution of the model.

a) Changes in mean temperatures:

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	**A2**	Increases of between 2 and 3ºC in the west and north of the Peninsula and the Canary Isles, and of between 3 and 4ºC in the rest of the territory
	B2	Distribution of warming similar to that of scenario A2, but 1ºC less intense
Spring	**A2**	Increases of between 4 and 5ºC in the south-west of the Peninsula, of between 2 and 3ºC on the Cantabrian fringe, northern Galicia and Canaries, and of between 3 and 4ºC in the rest of the territory
	B2	Increases of between 1 and 2ºC in the Canary Isles, Cantabrian fringe and northern Galicia, and of between 2 and 3ºC in the rest of the territory
Summer	**A2**	Increases of between 5 and 7ºC inland on the Peninsula, of between 4 and 5ºC close to coastal zones on the Peninsula and the Balearic Isles and of between 2 and 3ºC in the Canary Isles.
	B2	Distribution of warming similar to that of scenario A2, but generally 1ºC less intense
Autumn	**A2**	Increases of between 2 and 3ºC in the Canary Isles, of between 3 and 4ºC in the northern third of the Peninsula and of between 4 and 5ºC in the rest of the territory
	B2	Distribution of warming similar to that of scenario A2, but generally 1ºC less intense

b) Changes in accumulated precipitation:

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	**A2**	Increases by over 10 mm in the north-eastern quadrant of the Peninsula, decreases by over 10 mm in the southern third and the peninsula Mediterranean regions, without any appreciable changes (±10 mm) in the rest of the territory
	B2	Increases by over 10 mm in northern Galicia and without any appreciable changes (±10 mm) in the rest of the territory
Spring	**A2**	Decreases by over 20 mm in practically all of the Peninsula, without any appreciable changes (±10 mm) in the Balearic and Canary Isles
	B2	Decreases by over 10 mm in practically all of the Peninsula, without any appreciable changes (±10 mm) in the Balearic and Canary Isles
Summer	**A2**	Decreases by over 40 mm in northern Galicia, Cantabrian fringe, Pyrenees and Northeast of the Peninsula, decreases by between 10 and 40 mm in the rest of the territory, except in the Canary Isles, without any appreciable changes (±10 mm)
	B2	Distribution of the changes in seasonal rainfall similar to that of scenario A2
Autumn	**A2**	Increases by over 10 mm in the Northeast of the Peninsula, decreases by over 20 mm in the south-western half, without any appreciable changes (±10 mm) in the rest of the territory
	B2	Distribution of changes similar to that of scenario A2, although somewhat less intense in the south-western half of the Peninsula

c) Changes in evapotranspiration (en %)

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	A2	Increases by less than 20% in practically the whole territory
	B2	Increases by less than 20% in practically the whole territory
Spring	A2	Increases by over 20% in most of the north-eastern quadrant of the peninsula and the Pyrenees, increases by less than 20% in the rest of the northern half, and decreases by less than 20% in the rest of the territory
	B2	Increases by over 20% in Galicia, and less than 20% in practically the rest of the territory
Summer	A2	Decreases by over 20% in the southern third of the Peninsula, by less than 20% in the centre and the Balearic Isles, and increases by less than 20% in the northern third of the Peninsula
	B2	Distribution of the changes similar to that of scenario A2, but less intense in the southern third of the Peninsula
Autumn	A2	Increases by less than 20% in the northern third of the Peninsula and the north of the Levant/Mediterranean coast, decreases by over 20% in the southern third of the Peninsula and decreases by less than 20% in the rest of the territory
	B2	Distribution of changes in evapotranspiration similar to that of scenario A2

d) Changes in wind intensity (in %)

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	A2	Decreases by over 5% in the southern half of the Peninsula and the Balearic Isles, increases by over 5% in the Canary Isles, without any appreciable changes (± 5%) in the rest of the territory
	B2	Increases by over 5% in the Canary Isles, without any appreciable changes (± 5%) in most of the rest of the territory en la mayor
Spring	A2	Increases by over 5% in the Canary Isles and in the Gibraltar Straits, decreases by over 5% in the Cantabrian fringe, inland Levant and the Balearic Isles, without appreciable changes (± 5%) in the rest of the territory
	B2	Without appreciable changes (± 5%) in the whole territory
Summer	A2	Increases by over 5% in the centre and Southeast of the Peninsula, without appreciable changes (± 5%) in most of the rest of the territory
	B2	Decreases by over 5% in most of the Peninsula and the Balearic Isles, without appreciable changes (± 5%) in the southern third of the peninsula and the Canary isles
Autumn	A2	Decreases by over 10% in the Cantabrian fringe Northeast and the Eastern Peninsula, decreases by between 5 and 10% in the rest of the territory, except in the southern third of the Peninsula and the Canary Isles, where there are no appreciable changes (± 5%)
	B2	Decreases by over 5% in the north-eastern quadrant of the Peninsula, Cantabrian fringe and the Balearic Isles, without any appreciable changes (± 5%) in the rest of the territory

As a compliment to the analysis of the changes projected for the mean values of climatic variables, we have also included an initial approach to a possible alteration of the interannual variability of monthly values in the last third of the century (2071-2100) in relation to that of the 1961-1990 period. The most relevant results of this analysis can be summarised in the following points:

a) An increase is projected in the range and frequency of monthly thermal anomalies in the future climate in comparison to the present one.
b) Although this increase cannot be seen in a regular manner throughout the whole territory, the increases in range remain at around 20% in all the seasons of the year and in both emission scenarios. This means that in the anomalous hottest months in the future climate, the temperature increases will be around 20% higher than the projected values for average warming.

c) The percentages of change in the variability of monthly temperatures are somewhat lower in the B2 scenario than in A2, the same as what occurs with the magnitudes of average warming.
d) No significant alterations can be found in the frequency of anomalies in monthly rainfall in the future climate scenarios considered, although this conclusion is questionable, because the statistical method used is not the most suitable one for this type of analysis.

Finally, an analysis has been included of possible alterations of the occurrence of extreme climatic events in the future climate scenarios, in comparison with the present climate. To this end, we considered the values of extreme percentiles of the daily distributions of maximum and minimum temperature, as well as the frequency of days with rainfall higher than 1 mm. In this case, only the results of emission scenario A2 were considered. The most relevant conclusions can be summarised as:

a) The frequency of days with extreme maximum temperatures on the Iberian Peninsula tends to increase very significantly in spring and to a lesser degree in autumn, whereas in the Balearic and Canary Isles, no appreciable changes have been observed, as occurs in the other two seasons of the year throughout the whole territory.
b) The frequency of days with extreme minimum temperatures on the Peninsula tends to decrease.
c) The persistence and duration of periods of rainless days generally tend to decrease in the same zones and seasons for which negative changes are projected in seasonal rainfall, an to increase in the cases in which increases in rainfall are simulated in the future climate, compared to the present one. Although this analysis appears to indicate that would be no significant change in the degree of torrentiality of rainfall in the projected climate, this result presents a high degree of uncertainty.

By way of a conclusion, the following table provides an outline of the most relevant projections of climate change in Spain, arranged according to the degree of certainty provided by the results of the simulations by the set of models considered. To this end, we considered the degree of consensus among the different climate models available, so that the highest degree of certainty is assigned to those changes in which all the models coincide, the degree of certainty decreasing along with a decrease in the number of coinciding models. The lowest degree of certainty corresponds to the situation in which only a minority group of models provides similar results.

Table 1.4. *Level of uncertainty of the most relevant climate changes projected for Spain*

Certainty	Most relevant climate changes projected for Spain
*****	Progressive upward trend of mean temperatures throughout the century
*****	The warming tendency is more evident in the scenario of more accelerated emissions (SRES-A2)
*****	The increases in mean temperature are significantly greater in the summer months than in winter, with intermediate values in the others.
****	Warming in summer is greater in the inland areas than close to the coast or on the islands
****	Generalised tendency towards less accumulated annual rainfall in both emission scenarios throughout the century
***	Greater range and frequency of monthly thermal anomalies related to the present climate
***	More frequency of days with extreme temperatures on the Peninsula, especially in summer
***	The biggest decrease in rainfall on the Peninsula is projected in the spring months in both emission scenarios
**	Increased rainfall in the West of the Peninsula in winter and in the Northeast in autumn.
**	Changes in rainfall tend to be more significant in the scenario of more accelerated emissions (SRES-A2)

(***** very high certainty, **** high certainty, *** medium certainty, ** low certainty)

1.4. REFERENCES

Abaurrea J., Asin J. and Centelles A. 2002. Caracterización espacio-temporal de la evolución de la precipitación anual en la cuenca del Ebro. In: Guijarro Grimalt Laita and Alonso (Eds.). El Agua y el Clima Asociación Española de Climatología Serie A nº 3. pgs. 113-124

Abaurrea J., Asín J., Erdozain O. and Fernández E. 2001. Climate Variability Analysis of Temperature Series in The Medium Ebro River Basin. In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change. Berlín Springer. Pgs. 109-118.

Allen J.R., Huntley M. B. and Watts W.A. 1996. The vegetation and climate of northwest Iberia over the last 14000 yr. Journal of Quaternary Science 112 125-147.

Araus J.L., Febrero A., Buxo R., Camalich M.D., Martin D., Molina F., Rodriguez-Ariza M.O. and Romagosa I. 1997. Changes in carbon isotope discrimination in grain cereals from different regions of the western Mediterranean Basin during the past seven millennia. Palaeoenvironmental evidence of a differential change in aridity during the late Holocene. Global Change Biology 32: 107-118.

Arribas A., Gallardo C., Gaertner M.A. and Castro M. 2003. Sensitivity of Iberian Peninsula climate to land degradation. Climate Dynamics 20(5): 477-489.

Barriendos M. and Llasat M. 2003. The case of the “Maldá” anomaly in the western mediterranean basin AD 1760-1800. Climatic Change 61: 191-216.

Barriendos M. and J. Martín-Vide 1998. Secular Climatic Oscillations as Indicated by Catastrophic Floods in the Spanish Mediterranean Coastal Area 14th-19th Centuries. Cliamtic Change 38: 473-491.

Beniston M. 2004. The 2003 Heat Wave in Europe. A shape of things to come? Geophysical Reserach Letters 31: L02022

Brunet M., Aguilar E., Saladíe O., Sigró J. and López D. 2001a. The Spanish Temperature Series. Time variations and trends over the last 150 years. Geophysical Research Abstracts 3: GRA3 5333 76.

Brunet M., Aguilar E., Saladíe O., Sigró J. and López D. 2001b. the Variations and Trends of the Surface Air Temperature in the Northeastern of Spain from Middle Nineteenth Century Onwards. In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change Springer. Berlín, DE. Pgs. 81-93

Brunet M., Aguilar E., Saladíe O., Sigró J. and López D. 2001c. A Differential Response of Northeastern Spain to Asymmetric Trends in Diurnal Warming Detected on a Global Scale. In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change Springer. Berlín, DE. Pgs. 95-107.

Burgueño A. C. Serra and X. Lana 2004. Monthly and annual statistical distributions of daily rainfall at the Fabra Observatory Barcelona NE Spain for the years 1917-1999. Theoretical and Applied Climatology 77 57-75.

Burjachs F. and Julià R. 1994. Abrupt Climatic Changes During the Last Glaciation Based on Pollen Analysis of the Abric-Romani Catalonia Spain. Quaternary Research 423: 308-315.

Cacho I., Grimalt J.O., Pelejero C., Canals M., Sierro F.J., Flores J.A. and Shackleton N. 1999. Dansgaard-Oeschger and Heinrich event imprints in Alboran Sea paleotemperatures. Paleoceanography 14: 698-705

Camuffo D., Secco C., Brinblecombe P. and Martín-Vide J. 2000. Sea Storms in the Adriatic Sea and the Western Mediterranean during the Last Millennium. Climatic Change 46: 209-223.

Cañada R., Galán E., Fernández F. and Cervera B. 2001. Análisis de las tendencias de las temperaturas máximas y mínimas medias anuales en la Meseta sur española durante el siglo XX. In: Pérez-Cueva, López Baeza and Tamayo (eds.). El Tiempo del Clima. Buñol Garmas Asociación Española de Climatología Serie A nº 2. Pgs. 53-63.

Capel Molina J.J. 2000. El clima de la península Ibérica Barcelona Ariel 281 pgs.

Carrión J.S. 2002. Patterns and processes of Late Quaternary environmental change in a montane region of southwestern Europe. Quaternary Science Reviews 21(18-19): 2047-2066.

Castro M., Fernández C., Gaertner M.A. and Gallardo C. 1995. Relevance of regional models for analyzing future climate change in the Iberian Peninsula. In: Moreno J.M. and Oechel W.C. (eds.) Global Change and Mediterranean-type Ecosystems. Ecological Studies 117. Springer. Pgs. 1-34.

Castro-Díez Y., Pozo-Vázquez D., Esteban-Parra M.J. and Rodrigo F.S. 2002. NAO and the winter temperature variability in southern Europe. Geophysical Research Letters 29: 1-4.

Chazarra A. and Almarza C. 2002. Reconstrucción desde 1864 de la serie de precipitación útil de las cuencas del Sureste y Levante. In: Guijarro, Grimalt, Laita and Alonso (eds.). El Agua y el Clima. Asociación Española de Climatología Serie A nº 3. Pgs. 159-168.

Christensen J.H., Carter T. and Giorgi F. 2002. PRUDENCE Employs New Methods to Assess European Climate Change EOS Vol. 82 p. 147.

Christensen J.H. and Christensen O.B. 2003. Severe Summer Flooding in Europe Nature 421: 805-806.

Cramer W. and Field C.B. 1999. Comparing global models of terrestrial net primary productivity NPP. introduction. Global Change Biology 5: III-IV.

Creus J., Fernández A. and Manrique E. 1997. Dendrocronología y clima del último milenio en España. Aspectos metodológicos y avance de resultados. In: Ibáñez, Valero Garcés and Machado (eds.) El paisaje mediterráneo a través del espacio y del tiempo. Implicaciones en la desertificación. Geoforma. Logroño. Pgs. 311-331.

Davis B.A.S., Brewer S., Stevenson A.C. and Guiot J. 2003. The temperature of Europe during the Holocene reconstructed from pollen data. Quaternary Science Reviews 22(15-17): 1701-1716.

Decoudre N.I. K. Laval and A. Perrier 1993. SECHIBA a new set of parameterizations of the hydrologic exchanges at the land-atmosphere interface within the LMD atmospheric general circulation model. Journal of Climate 6: 248-273.

De Luis M., Raventós J., González-Hidalgo J.C., Sánchez J.R. and Cortina J. 2002. Spatial analysis of rainfall trends in the region of Valencia east Spain. International Journal of Climatology 20: 1451-1469.

Desprat S., Goni M.F.S. and Loutre M.F. 2003. Revealing climatic variability of the last three millennia in northwestern Iberia using pollen influx data. Earth and Planetary Science Letters 2131-2 63-78.

Dickinson R.E., Errico R.M., Giorgi F. and Bates B.T. 1989 A regional climate model for western United States. Climatic Change 15: 383–422.

Dünkeloh A. and Jacobeit J. 2003. Circulation dynamics of Mediterranean precipitation variability 1948-98. International Journal of Climatology 23: 1843-1866.

Esteban-Parra M.J., Rodrigo F.S. and Castro-Díez Y. 1995. Temperature Trends and Change Points in the Northern Spanish Plateau During the Last 100 Years. International Journal of Climatology 15: 1031-1042.

Esteban-Parra M.J., Rodrigo F.S. and Castro-Díez Y. 1998. Spatial and temporal patterns of precipitation in Spain for the period 1880-1992. International Journal of Climatology 18: 1557-1574.

Fernández F. and Rasilla D. 2001. Secular Variations of the Synoptic Circulation over the Iberian Peninsula. In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change Springer. Berlín, DE. Pgs. 229-238.

Font Tullot I. 2000. Climatología de España y Portugal Salamanca Universidad de Salamanca.

Galán E., Cañada R., Fernández F. and Cervera B. 2001. Annual Temperature Evolution in the Southern Plateau of Spain from the Construction of Regional Climatic Time Series. In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change Springer. Berlín, DE. Pgs. 119-131.

Galán E., Cañada R., Rasilla D., Fernández F. and Cervera B. 1999. Evolución de las precipitaciones anuales en la Meseta meridional durante el siglo XX. In: Raso and Martín-

Vide (eds.). La Climatología española en los albores del siglo XXI. Vilassar Oikos-tau Asociación Española de Climatología Serie A nº 1. Pgs. 169-180.

Gallardo C., Arribas A., Prego J.A., Gaertner M.A. and Castro M. 2001. Multi-year simulations with a high resolution regional climate model over the Iberian Peninsula. Current climate and 2xCO_2 scenario. Quarterly Journal of the Royal Meteorological Society 127: 1659-1682.

Gámiz-Fortis S.R., Pozo-Vázquez D., Esteban-Parra M.J. and Castro-Díez Y. 2002. Spectral characteristics and predictability of the NAO assessed through Singular Spectral Analysis. Journal of Geophysical Research 107: 1-15.

García-Herrera R., Gallego D., Hernández E., Gimeno L., Ribera P. and Calvo N. 2003. Precipitation trends in the Canary Islands. International Journal of Climatology 23: 235-241.

García, J.A., Serrano, A. and De la Cruz Gallego, M. 2002. A spectral analysis of Iberian Peninsula monthly rainfall. Theoretical and Applied Climatology 71: 77-95.

González-Hidalgo J.C., De Luis M., Raventós J. and Sánchez J.R. 2001. Spatial distribution of seasonal rainfall trends in a western Mediterranean area. International Journal of Climatology 21: 843-860.

González-Hidalgo J.C., De Luis M., Raventós J. and Sánchez J.R. 2003. Daily rainfall trend in the Valencia Region of Spain. Theoretical and Applied Climatology 75(1-2): 117-130.

Goodess C.M. and Jones P.D. 2002. Links between circulation and changes in the characteristics of Iberian rainfall. International Journal of Climatology 22: 1593-1615.

Gordon C., Cooper C., Senior C.A., Banks H.T., Gregory J.M., Johns T.C., Mitchell J.F.B. and Wood R.A. 2000 The simulation of SST sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dynamics 16: 147-168.

Guijarro J.A. 2002. Tendencias de la precipitación en el litoral mediterráneo español. In: Guijarro, Grimalt, Laita and Alonso (eds.). El Agua y el Clima. Asociación Española de Climatología Serie A nº 3. Pgs. 237-246.

Horcas R., Rasilla D and Fernández-García F. 2001. Temperature Variations and Trends in the Segura River Basin. An Exploratory Analysis. In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change Springer. Berlín, DE. Pgs. 133-142.

Huth, R. 2004. Sensitivity of Local Daily Temperature Change Estimates to the Selection of Downscaling Models and Predictors. J. Climate 17: 640-652.

IPCC 2001. Climate Change 2001. The Scientific Basis. [Edited by J. T. Houghton Y. Ding D.J. Griggs M. Noguer P. J. van der Linden and D. Xiaosu]. Cambridge University Press 994 pgs.

Jalut G., Esteban A., Bonnet L., Gauquelin T. and Fontugne M. 2000. Holocene climatic changes in the Western Mediterranean from south-east France to south-east Spain. Palaeogeography Palaeoclimatology Palaeoecology 1603(4): 255-290.

Jalut G., Esteban A., Riera S., Fontugne M., Mook R., Bonnet L. and Gauquelin T. 1997. Holocene climatic changes in the western Mediterranean. installation of the Mediterranean climate. Comptes Rendus de l´Academie des Sciences Serie II Fascicule A- Sciences de la Terre et des Planetes 325(5): 327-334.

Jones P.D., Horton E.B., Folland C.K., Hulme M., Parker D.E. and Basnett T.A. 1999. The use of indices to identify changes in climatic extremes. Climatic Change 42: 131-149

Klein Tank A., Wijngaard J. and Van Engelen A. 2002. Climate of Europe. Assessment of observed daily temperature and precipitation extremes De Bilt ECA y KNMI 36 pgs.

Labajo J.L. and Piorno A. 1998. Análisis del comportamiento temporal de la temperatura en Castilla y León. primeros resultados. In: Fernández Galán and Cañada (coords.). Clima y ambiente urbano en ciudades ibéricas e iberoamericanas. Parteluz, Madrid. Pgs. 577-591.

Labajo J.L. and Piorno A. 2001. Regionalization of precipitation in Castilla and Leon Spain. Analysis of its temporal behaviour In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change Springer. Berlín, DE. Pgs. 163-173.

Labajo J.L., Piorno A. e Izquierdo M.J. 1998. Temporal Behaviour of the Annual Mean pressure on the Northern Spanish Plateau between 1945 and 1994. International Journal of Climatology 18: 637-648.

Laita M. and Grimalt M. 1997. Vorticity and pressure anomalies in the Western Mediterranean during El Niño/Southern oscillation extremes. International Journal of Climatology 17: 475-482.

Lambert S.J. and Boer G.J. 2001 CMIP1 evaluation and intercomparison of coupled climate models. Climate Dynamics 17(2/3): 83-106.

Leira M. and Santos L. 2002. An early Holocene short climatic event in the northwest Iberian Peninsula inferred from pollen and diatoms. Quaternary International 93(4): 3-12.

Linés A. 1970. The Climate of the Iberian Peninsula. In: Landsberg H.E. (ed.). World Survey of Climatology Amsterdam Elsevier.

López J.A. 1999. Estudio de la distribución de precipitación en el año hidrológico a partir de un índice de concentración y el desfase. In: Raso and Martín-Vide (eds.). La Climatología española en los albores del siglo XXI. Vilassar Oikos-tau Asociación Española de Climatología Serie A nº 1. Pgs. 281-287.

López J.A. 2001. Trends in Daily Precipitation Regimes and their Extremes at Three Observatories in the Iberian Peninsula In: Brunet and López (eds.). Detecting and Modelling Regional Climate Change Springer. Berlín, DE. Pgs. 203-213.

Luque J.A. and Julià R. 2002. Lake sediment response to land-use and climate change during the last 1000 years in the oligotrophic Lake Sanabria Northwest of Iberian Peninsula. Sedimentary Geology 1481(2): 343-355.

Mariotti A., Zeng N. and Lau K. 2002. Euro-Mediterranean rainfall and ENSO. a seasonally varying relationship. Geophysical Research Letters 29(12): 1621.

Martín M.L., Luna M.Y., Morata A. and Valero F. 2004. North Atlantic teleconnection patterns of low-frequency variability and their links with springtime precipitation in the western Mediterranean. International Journal of Climatology 24: 213-230.

Martín-Vide J. 1996. Decálogo de la pluviometría española. In: Marzol, Dorta and Valladares (Eds.). Universidad de la Laguna, A.G.E. Clima y agua. La gestión de un recurso climático: 15-24

Martín-Vide J. 2004. Spatial distribution of a daily precipitation concentration index in Peninsular Spain. International Journal of Climatology 24: 959-971.

Martín-Vide J. and Barriendos M. 1995. The use of rogation caremony records in climatic reconstruction. a case study from Catalonia Spain. Climatic Change 30: 201-221.

Martín-Vide, J. and Gómez, L. 1999. Regionalization of Peninsular Spain based on the length of dry spells. International Journal of Climatology 19: 537-555.

Martín-Vide J. and Olcina J. 2001. Climas y tiempos de España Madrid Alianza Editorial 258 pgs.

Milián T. 1996. Variaciones seculares de las precipitaciones en España Universidad de Barcelona 407 pgs. Tesis doctoral inédita.

Moberg A., Jones P.D., Barriendos M., Bergström H., Camuffo D., Cocheo C., Davies T.D., Demarée G., Martín-Vide J., Maugeri M., Rodríguez R and Verhoeve T. 2000. Day-to-day temperature variability trends in 160-to 275-year long European instrumental records. Journal of Geophysical Research 105(D18): 22849-22868.

Muñoz-Díaz D. and Rodrigo F.S. 2004. Spatio-temporal patterns of seasonal rainfall in Spain 1912-2000 using cluster and principal component analysis comparison. Annales Geophysicae 22: 1435-1448.

Nakicenovic N., Alcamo J., Davis G., de Vries B., J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E.L. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Raihi, A. Roehrl, H.-H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor and Z. Dadi 2000 IPCC Special Report on Emissions Scenarios Cambridge University Press 599 pgs.

New M., Hulme M. and Jones P. (1999): Representing twentieth-century space-time climate variability. Part I: Development of a 1961-90 mean monthly terrestrial climatology. *J.* Climate 12: 829-856.

Oñate J.J. and Pou A. 1996. Temperature Variations in Spain Since 1901. a Preliminary Analysis. International Journal of Climatology 16 805-816.

Peixoto J.P. and Oort A.H. 1992. Physics of Climate. American Institute of Physics. New York.

Pérez-Obiol R. and Julià R. 1994. Climatic-Change on the Iberian Peninsula Recorded in a 30000-Yr Pollen Record from Lake Banyoles. Quaternary Research 411 91-98.

Piñol J., Terradas J. and Lloret F. 1998. Climate warming wildfire hazard and wildfire occurrence in coastal Eastern Spain. Climatic Change 38 345-357.

Pita Mª.F., Camarillo J.M. and Aguilar M. 1999. La evolución de la variabilidad pluviométrica en Andalucía y sus relaciones con el índice de la NAO en Raso and Martín-Vide Eds. La Climatología española en los albores del siglo XXI. Vilassar Oikos-tau Asociación Española de Climatología Serie A nº 1. Pgs. 399-408.

Pons A. and Reille M. 1988. The Holocene-Pleistocene and Upper-Pleistocene Pollen Record from Padul Granada Spain - a New Study. Palaeogeography Palaeoclimatology Palaeoecology 663-4 243-263.

Pope V.D., Gallani M., Rowntree P.R. and Stratton R.A. 2000. The impact of new physical parametrisations in the Hadley Centre climate model - HadAM3. Climate Dynamics 16: 123-146.

Pozo-Vázquez D. 2000. Causas físicas de la variabilidad espacio-temporal del clima de la Península Ibérica en escalas interanual a decadal. NAO y ENSO Universidad de Granada 334 pgs. Tesis doctoral inédita.

Pozo-Vázquez D., Esteban-Parra M.J., Rodrigo F.S. and Castro-Díez Y. 2001. The association between ENSO and winter atmospheric circulation and temperature in the North Atlantic region. Journal of Climate 16: 3408-3420.

Pozo-Vázquez D., Tovar-Pescador J., Gámiz-Fortis S.R., Esteban-Parra M.J. and Castro-Díez Y. 2004. NAO and solar radiation variability in the European North Atlantic region. Geophysical Research Letters 31 L05201.

Quereda J. and Montón E. 1997. ¿Hacia un Cambio Climático? La Evolución del Clima Mediterráneo desde el Siglo XIX Castellón Fundación Dávalos- Fletcher. 520 pgs.

Quereda J. and Montón E. 1999. La hipótesis de la "estabilidad" climática en el Mediterráneo español. In: Raso and Martín-Vide (eds.). La Climatología española en los albores del siglo XXI. Vilassar Oikos-tau Asociación Española de Climatología Serie A nº 1. Pgs. 427-438.

Quereda J., Montón E., Escrig J., Ruescas A. and Mollà B. 2004. Detection of the urban effect over temperature trend by means of NOAA-AVHRR imagery MeCEO First Mediterranean Conference on earth observation Remote Sensing. Belgrado. Pgs. 33-40.

Quereda J., Olcina J. and Montón E. 1996. Red dust rain within the Spanish Mediterranean area. Climatic Change 32 215-228.

Räisänen J., Hansson U., Ullerstig A., Döscher R., Graham L.P., Jones C., Meier M., Samuelsson P. and Willén U. 2004. European climate in the late 21st century. regional simulations with two driving global models and two forcing scenarios. Climate Dynamics 22(1): 13-31.

Ramos M.C. 2001. Rainfall distribution patterns and their change over time in a Mediterranean area. Theoretical and Applied Climatology 69 163-170.

Raso J.M. 1997. The recent evolution of mean annual temperatures in Spain en Martín-Vide Ed. Advances in Historical Climatology in Spain 201-223 Vilassar de Mar Oikos-tau.

Rimbu N., Lohmann G., Kim J.-H., Arz H.W. and Schneider R. 2003. Arctic/North Atlantic Oscillation signature in Holocene sea surface temperature trends as obtained from alkenone data. Geophysical Research Letters 301280 13 1-4.

Rocha A. 1999. Low-frequency variability of seasonal rainfall over the Iberian Peninsula and ENSO. International Journal of Climatology 19 889-901.

Rodó X., Baert E. and Comín F. 1997. Variations in seasonal rainfall in Southern Europe during the present century. relationships with the North Atlantic oscillation and the El Niño-Southern oscillation. Climate Dynamics 13 275-284.

Rodrigo F.S, Esteban-Parra M.J, Pozo-Vázquez D. and Castro-Díez Y. 1999. A 500-year precipitation record in southern Spain. International Journal of Climatology 19 1233-1253.

Rodrigo F.S., Esteban-Parra M.J., Pozo-Vázquez D. and Castro-Díez Y. 2000. Rainfall variability in southern Spain on decadal to centennial times scales. International Journal of Climatology 20 721-732.
Rodríguez R.; Llasat M.C. and Wheeler D. 1999. Analysis of the Barcelona precipitation series 1850-1991. International Journal of Climatology 19 787-801.
Rodríguez-Puebla C., Encinas A.H., Nieto S. and Garmendia J. 1998. Spatial and temporal patterns of annual precipitation variability over the Iberian Peninsula. International Journal of Climatology 18 299-316.
Rodríguez-Puebla C., Frías M.D. and Encinas A.H. 2001. Relationships between Dry and Wet Periods in Spring Precipitation over the Iberian Peninsula and Atmospheric Circulation en Brunet and López Eds. Detecting and Modelling Regional Climate Change 397-404 Berlín Springer.
Romero R., Guijarro J.A., Ramis C. and Alonso S. 1998. A 30 year 1964-93 daily rainfall database for the Spanish Mediterranean regions. first exploratory study. International Journal of Climatology 18: 541-560.
Sáenz J., Zubillaga J. and Rodríguez-Puebla C. 2001. Baroclinic Activity and Interannual Variability of Winter Precipitation in the Northern Iberian Peninsula. In: Brunet and López (Eds.) Detecting and Modelling Regional Climate Change. Springer, Berlín, DE. Pgs. 405-416.
Sailor D.J. and Li X. 1999. A semiempirical downscaling approach for predicting regional temperature impacts associated with climatic change. Journal of Climate 12: 103–114.
Saladíe O. 2004. Variaciones y tendencia secular de la precipitación en el sector nororiental de la Península Ibérica 1850-2000. Universidad de Barcelona. 496 pp. Tesis doctoral inédita.
Sánchez-Goñi M.F.S., Cacho I., Turon J.-L., Guiot J., Sierro F.J., Peypouquet J.-P., Grimalt J.O. and Shackleton N.J. 2002. Synchroneity between marine and terrestrial responses to millennial scale climatic variability during the last glacial period in the Mediterranean region. Climate Dynamics 19: 95–105.
Sánchez E., Gallardo C., Gaertner M.A., Arribas A. and Castro M. 2004. Future climate extreme events in the Mediterranean simulated by a regional climate model. first approach. Global and Planetary Change (in press).
Saz M. 2003. Temperaturas y precipitaciones en la mitad norte de España desde el siglo XV. C.P.N.A Diputación General de Aragón, Zaragoza. 293 pp.
Saz M. and Creus J. 1999. La variabilidad del clima español en el pasado. frecuencia de valores extremos de temperatura y precipitación reconstruidas desde el s. XV. In: Raso and Martín-Vide (Eds.) La Climatología española en los albores del siglo XXI. Vilassar Oikos-tau Asociación Española de Climatología Serie A nº 1. pgs 501-510.
Schar C., Vidale P.L., Lüthi D., Frei C., Häberli C., Liniger M. and Appenzeller C. 2004. The role of increasing temperature variability in European summer heatwaves. Nature 427: 332-336.
Serra C., Burgueño A. and Lana X. 2001. Analysis of maximum and minimum daily temperatures recorded at Fabra Observatory Barcelona NE Spain in the period 1917-1998. International Journal of Climatology 21: 617-636.
Serrano A., Mateos V.I. and García J.A. 1999. Trend analysis of monthly precipitation over the Iberian Peninsula for the period 1921-1995. Physics and Chemistry of the Earth B 24: 85-90.
Sobrino C.M., Ramil-Rego P. and Gómez-Orellana L. 2004. Vegetation of the Lago de Sanabria area NW Iberia since the end of the Pleistocene. a palaeoecological reconstruction on the basis of two new pollen sequences. Vegetation History and Archaeobotany 131: 1-22.
Staudt M. 2004. Detección de cambios térmicos en la Península Ibérica con datos homogéneos regionales. Universidad de Granada. 559 pp. Tesis doctoral inédita.
Stott P.A., Tett S.F.B., Jones G.S., Allen M.R., Ingram W.J. and Mitchell J.F.B. 2001. Attribution of twentieth century temperature change to natural and anthropogenic causes. Climate Dynamics 17: 1-22.
Sumner G., Homar V. and Ramis C. 2001. Precipitation seasonality in eastern and southern coastal Spain. International Journal of Climatology 21: 219-247.

Sumner G.N., Romero R., Homar V., Ramis C., Alonso S. and Zorita E. 2003. An estimate of the effects of climate change on the rainfall of Mediterranean Spain by the late twenty first century. Climate Dynamics 20: 789-805

Taboada J.J., Naranjo L., Lage A. and Pérez-Muñuzuri V. 2002. Estudio de la variabilidad de la precipitación en Galicia y su relación con patrones de teleconexión. In: Guijarro Grimalt Laita and Alonso (Eds.) El Agua y el Clima. Asociación Española de Climatología Serie A nº 3. pgs. 93-100

Vázquez López L.A. 1999. La Circulación Atmosférica Euroatlántica y el clima de pequeños territorios. La Península Ibérica y Cataluña Universidad de Barcelona Tesis doctoral inédita.

von Storch H. and Zwiers F.W. 1999. Statistical Analysis in Climate Research. University Press. Cambridge, UK. 494 pgs.

Wheeler D. and Martín-Vide J. 1992. Rainfall Characteristics of Mainland Europes most Southerly Stations. International Journal of Climatology 12: 69-76.