

## Analysis of the maximum daily temperature evolution on the Spanish Central Plateau

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### RESUMEN

Se ha realizado un análisis temporal del comportamiento de las frecuencias anuales y estacionales de los valores extremos de las temperaturas máximas diarias en la Meseta Central española. Con los datos diarios de temperatura máxima, medidos entre 1961 y 2003 en 14 observatorios meteorológicos, se construyeron las series de anomalías de temperaturas máximas diarias para cada uno de los observatorios, toda la zona de estudio y cada una de las dos subzonas en las que se puede dividir la Meseta Central. Para determinar los valores extremos más altos y más bajos de las anomalías de temperatura máxima diaria, se consideraron los valores de los percentiles  $P_{95}$  y  $P_{05}$  de las series de anomalías consideradas. A continuación se construyeron las series de frecuencias anuales de días con valores extremos de anomalías de temperatura máxima diaria más altos y más bajos. El análisis de tendencia de estas series revela que, a lo largo del periodo de estudio, la frecuencia anual de los casos extremos más bajos de anomalías de temperatura máxima diaria tendió a disminuir, mientras que la de los casos extremos más altos tendió a aumentar. De un análisis de las gráficas de la evolución temporal de las frecuencias anuales puede deducirse que existe una variación de la tendencia alrededor del año 1972, variación establecida previamente para otras variables (presión, temperatura media anual, etc.) en la zona de estudio. Los resultados que se obtienen considerando el intervalo de tiempo entre 1973 y 2003 indican que la tendencia es la misma que la que se obtiene para todo el periodo de tiempo estudiado pero con un nivel de confianza más alto. Por último, se puede ver que la primavera y el verano son las estaciones que más influyen en el comportamiento anual de las frecuencias de los valores extremos de temperatura máxima diaria.

### ABSTRACT

An analysis of the temporal behavior of the annual and seasonal frequencies of extreme maximum daily temperature values on the Spanish Central Plateau is performed. With the daily data on maximum tempera-

tures measured at 14 weather stations, between 1961 and 2003, we constructed a series of maximum daily temperature anomalies for each of the observatories and in the study zone, and also in the two subzones into which the Central Plateau can be divided. To determine the highest and lowest extreme values of the maximum daily temperature anomalies, the  $P_{05}$  and  $P_{95}$  percentiles of the anomaly series were considered as thresholds. Next we constructed the series of annual frequencies of days with the highest and lowest extreme values of maximum daily temperature anomalies. Trend analysis of these series revealed that during the period studied the annual frequency of the lowest extreme cases of maximum daily temperature anomalies has tended to decrease while that of the highest ones has tended to increase. From an analysis of the temporal evolution of the annual frequencies it may be deduced that a variation in the trend occurred around 1972, variation previously established for other variables (pressure, annual mean temperature, etc.) in the area of study. The results obtained upon considering the interval of time between 1973 and 2003 indicate that the trend was the same as that obtained for the whole period studied but the level of confidence is higher. Finally, it may be seen that spring and summer are the seasons that most affect the behavior of the annual frequencies of the extreme maximum daily temperature values.

**Keywords:** Maximum daily temperature, extreme values, frequency, trend.

## 1. Introduction

Of all the elements that determine the climate and its evolution, temperature is the one that best detects the existence of possible climate change. In general, investigations carried out in the last decades of the past century have involved the reconstruction of series and the temporal evolution of mean monthly or annual values. Such studies reveal an increase in the mean temperature of the air at global scale along the 20th century, which became more evident after the seventies (Peterson and Easterling, 1994; Jones and Hulme, 1996; Jones and Moberg, 2003). In the Iberian peninsula, monthly mean temperature and the maximum monthly mean and minimum monthly mean temperatures have a temporal behavior similar to that obtained on a global scale (Labajo and Piorno, 1999; Galán *et al.*, 2001; Morales *et al.*, 2004).

The last two reports on Evaluation of Climatic Change (IPCC, 2002, 2007) point to the need to study the behavior of the extreme events undergone by the different elements of the climate since, in principle, they could be responsible for the temporal evolution shown by their mean global values. This has been under scrutiny in recent years (Plummer *et al.*, 1999; Brunetti *et al.*, 2001; López, 2002; Labajo *et al.*, 2004; Shouraseni *et al.*, 2004; Labajo *et al.*, 2008; Peralta-Hernández *et al.*, 2009).

In the Iberian Peninsula, as the mean temperature presents an increasing temporal trend, one can try to confirm whether this trend can be determined by the temporal behavior of its minimum and maximum values establishing the temporal evolution of the annual frequency shown by the extreme values of both variables. In this regard, for some years studies have addressed these aspects at different spatial scales, some of which include the Iberian Peninsula (Manton *et al.*, 2001; Salinger and Griffiths, 2001; Domonkos *et al.*, 2003; Klein and Können, 2003).

The present work develops an analysis of the temporal behaviour of the frequency of extreme maximum daily temperature values (TMAD) over the central zone of the Iberian Peninsula (Spanish Central Plateau (CP)) from series of daily data obtained at the main weather observatories of the synoptic and climatological networks of the state meteorology agency of Spain (Agencia Estatal de Meteorología, AEMET).

## 2. Data and methodology

### 2.1 Study zone

The study zone is delimited by latitudes 38° 01' N and 43° 14' N, and longitudes 0° 54' W and 06° 07' W. These coordinates encompass an area of more than 180 000 km<sup>2</sup> in the central part of the Iberian Peninsula (Fig. 1). Almost the whole of the periphery of the zone is limited by mountain ranges of varying heights and extents. The zone is crossed from SW to NE by another mountain range that divides it into two parts both having almost the same surface area. These two parts are enough different in geographic-physical terms to be differentiated from each other, such that the CP can be divided into a northern zone (Northern Subplateau: NS), with coordinates of 40° 05' N and 43° 14' N, and 1° 46' W 7° 02' W, and a southern one (Southern Subplateau: SS), with coordinates of 38° 01' N and 41° 19' N and 0° 54' W and 5° 24' W. The northern part has a mean height of about 800 m, and the South of about 600 m. The climate in both subplateaus is Mediterranean continental with cold winters, warm summers, and rainfall in spring and autumn.

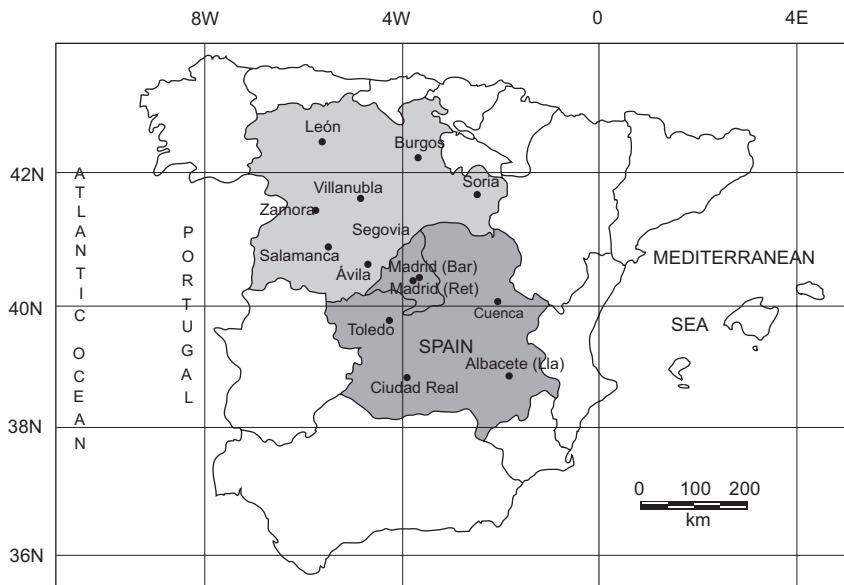


Fig. 1. Study zone.

### 2.2 Data

We used data on maximum daily temperatures (TMAD) obtained at first-level observatories distributed across the synoptic and/or climatological network of the AEMET. Although the quality of data is controlled by the AEMET, working data series have been analyzed to locate and eliminate any possible anomalous data as a result of errors of transcription. We have applied a series of logical filters, such as, limiting the TMAD values between 50 °C and -10 °C, among others.

Of all the weather stations located in the zone, we chose only those showing, for the same interval of time, less than 10 % of gaps and erroneous data (some erroneous data were corrected resorting to additional information from other sources). The interval of time considered for this study is a period of 43 years from 1961 to 2003 and 14 observatories were selected of those actually present

in the zone. Of these 14 stations, eight are located in the northern half of the zone and six in the southern part. Those located on the NS are Ávila, Burgos, León, Salamanca (Matacán), Segovia, Soria, Villanubla (Valladolid) and Zamora, and those on the SS are Barajas (Madrid), Ciudad Real, Cuenca, Los Llanos (Albacete), Madrid (Retiro) and Toledo (Fig. 1).

The number, and percentage, of gaps during quality control of the TMAD data series of the selected observatories, together with those initially present at them are shown in Table I.

Table I. Gaps (number and percentage) existing in the data series of the stations selected for the period 1961-2003.

| Observatories | Nº of gaps | % of gaps | Observatories | Nº of gaps | % of gaps |
|---------------|------------|-----------|---------------|------------|-----------|
| Ávila         | 311        | 2         | Zamora        | 58         | 0.38      |
| Burgos        | 1          | <0.01     | Los Llanos    | 0          | 0         |
| León          | 0          | 0         | Ciudad Real   | 0          | 0         |
| Salamanca     | 0          | 0         | Cuenca        | 44         | 0.29      |
| Segovia       | 691        | 4.5       | Barajas       | 8          | 0.05      |
| Soria         | 56         | 0.49      | Madrid        | 0          | 0         |
| Villanubla    | 102        | 0.7       | Toledo        | 0          | 0         |

Techniques of multiple linear regressions between the series of nearly observatories are used to fill the gaps in the series. The correlations among the series from the selected observatories were very high, with correlation coefficients above 0.90, and in some cases 0.99, thereby guaranteeing the quality of the definitive data series.

From this daily data base, the series of daily maximum temperature anomalies (ATMAD) were constructed for each observatory, understanding by anomaly the daily difference between each TMAD value on one day of the year and the mean values corresponding to that day of the year. To accomplish this, the difference between each of the data of the working series and the corresponding mean value obtained as an average –for each of the 365 days of the year– of the data of the original series (not filled) was calculated. The homogeneity of the ATMAD, previously established for monthly average values of temperature by the Alexandersson method (Alexandersson and Moberg, 1997), has been verified creating the corresponding series predicted by means of a model of multiple regression with all the real series. We verified that the series of differences between the real series and the corresponding are obtained with the model behave as a white noise. In addition, the homogeneity of the variance has been checked with the Levene (1960).

The fact that the series of daily anomaly values instead of the series of maximum daily temperature values were considered can be justified for two reasons: the first is because those values do not depend on the altitude of the observatories and can therefore be compared directly with one another without having to make any type of correction, which is not the case of the observed temperature values. The second is because on using the anomaly data instead of the daily observational data, the annual periodicity that affects the daily temperature values is filtered out.

With the series of anomalies from each observatory, the regional ATMAD series were built for the CP, and for the NS and the SS. To build these series, the inverse distance method was employed (Jones and Hulme, 1996) in cells limited for 38° and 43° N and 1° and 6° W for the whole of the CP, 40° - 43° N and 2° - 6° W for the NS and 38° - 41° N 1° - 5° W for the SS. In each case, the series from all the stations located in each zone were used because in this way the typical peculiarities

that the TMAD data showed at each one, which might affect the regional behavior, would be taken into account. The ATMAD series of the two subplateaus were included because it was considered of interest to be able to compare the results obtained at each of the stations with one another and with those obtained for the whole of the CP.

From the ATMAD series of each of the observatories and of the CP and both subplateaus, the series of annual frequencies of extreme anomalies (FATMAD) were built, in each case determining the number of days in the year on which the ATMAD values were above or below a certain threshold.

### 2.3 Methodology

From the regional series of daily anomalies we determined the thresholds that would allow us to determine the extreme anomaly values, both for the lowest and for the highest values, in the ATMAD series.

The thresholds of extreme temperature values can be established in different ways, some of them somewhat arbitrary, such as considering 0 °C as the lower threshold of the extreme values of minimum temperature in winter. These arbitrary thresholds are not always enough representative, such that many authors have adopted the criterion of percentiles to define them. Currently, this criterion is widely used to determine the thresholds of extreme values of climate variables (Manton *et al.*, 2001; Salinger and Griffiths, 2001, DeGaetano and Allen, 2002; Griffiths *et al.*, 2003; Labajo *et al.*, 2004, 2008).

The range of the percentiles used may be determined by the range of variability of the variable, fluctuating between the percentiles  $P_{01}$  and  $P_{10}$  for the case of the lowest values and between  $P_{90}$  and  $P_{99}$  for the highest ones. Here we used the  $P_{05}$  and  $P_{95}$  percentiles. The choice of the percentiles can be justified by the definition of the statistical parameter called *trimedia*. The *trimedia* is the mean obtained excluding from the original series the values which are below the value of the percentile  $P_{05}$  or exceeding that of the percentile  $P_{95}$ . This eliminates the strong influence that extreme values have on the mean and thus avoids distortion of this statistic.

To determine the values of the thresholds with a view to establishing which TMAD were extreme, the above criterion was applied to the series corresponding to the individual observatories and to the regional series. The results are shown in Table II.

Table II shows the threshold values corresponding to those of the same percentiles, obtained considering the TMAD series from each station for the same period of time. These thresholds were not included in the case of the regional series because they were not enough significant, since the observatories where the corresponding TMAD series were obtained are not all at the same height above sea level.

Using the percentile values, we calculated the number of days per year on which the ATMAD values were higher or lower than the thresholds determined with the  $P_{05}$  and  $P_{95}$  percentiles, respectively. The series thus obtained were those of the annual frequencies of extreme TMAD values (FATMAD). Also the monthly and seasonal series of FATMAD were constructed.

Finally, using the FATMAD data the temporal behavior of the annual frequencies of extreme maximum temperatures was analyzed, first establishing graphically their temporal evolution and then, with the Spearman method (Mitchell *et al.*, 1966; Sneyers, 1975), studying the possible trend of the series along the period of time considered (1961-2003).

Table II. Threshold of extreme events, lowest and highest ( $P_{05}$  and  $P_{95}$  percentiles) of the ATMAD series and of the TMAD series at each of the weather stations and in the study zone ( $^{\circ}\text{C}$ ).

| Stations                | ATMAD    |          | TMAD     |          |
|-------------------------|----------|----------|----------|----------|
|                         | $P_{05}$ | $P_{95}$ | $P_{05}$ | $P_{95}$ |
| Ávila                   | -6.99    | 6.88     | 3.8      | 30.0     |
| Burgos                  | -7.22    | 7.31     | 3.8      | 30.4     |
| León                    | -6.69    | 6.67     | 5.0      | 30.4     |
| Salamanca               | -6.48    | 6.45     | 5.8      | 32.4     |
| Segovia                 | -7.19    | 6.86     | 4.4      | 31.8     |
| Soria                   | -7.34    | 7.30     | 4.2      | 31.4     |
| Villanubla (Valladolid) | -6.48    | 6.56     | 5.4      | 31.6     |
| Zamora                  | -6.50    | 6.36     | 6.0      | 32.6     |
| Los Llanos (Albacete)   | -6.30    | 5.90     | 8.0      | 34.6     |
| Ciudad Real             | -6.60    | 6.20     | 8.6      | 36.2     |
| Cuenca                  | -6.80    | 6.70     | 6.3      | 33.0     |
| Barajas (Madrid)        | -6.40    | 6.10     | 8.2      | 35.2     |
| Madrid (Retiro station) | -6.00    | 5.70     | 7.6      | 33.0     |
| Toledo                  | -6.85    | 5.65     | 8.6      | 35.4     |
| Northern Subplateau     | -6.39    | 6.42     |          |          |
| Southern Subplateau     | -6.20    | 5.79     |          |          |
| Central Plateau         | -6.21    | 6.02     |          |          |

### 3. Results

From the data on the extreme anomaly values of daily maximum temperature (FATMAD), for the series from each of the observatories we constructed the corresponding plots of temporal evolution. These plots include the linear trend line and are shown in Figures 2-5.

It may be inferred from Figures 2-5 that at nearly all the stations the trend observed along the whole study interval is decreasing for the case of the lowest values ( $P_{05}$  threshold) and it is increasing for the case of the highest values ( $P_{95}$ ). The slope of the trend line is different for each of the plots, indicating that the level of confidence associated with the trend observed is also different in each case.

In Figures 2-5, it is also possible to observe that the variability in the series of FATMAD values is high. For the lowest extreme values ( $P_{05}$  threshold), the highest frequencies are seen in 1971 for nearly all the stations. For the highest extreme values ( $P_{95}$  threshold), at many of the observatories a frequency maximum is seen in 1997.

The trend lines shown in the plots confirm the existence of trends throughout the study period, except in the case of the observatories in Leon and Soria. To check whether these trends are significant, at least with a level of confidence of 90 %, the Spearman test (Mitchell, 1966; Sneyers, 1975) was applied to the FATMAD series obtained for each of the observatories considered. The results are shown in Table III.

The results appearing in Table III indicate that for the lowest FATMAD values ( $P_{05}$  threshold) the series from all the stations show a decreasing trend, at a level of confidence higher than 95 %, with the exception of Leon, for which the trend shows a confidence level below 90 % and hence is not very significant. Regarding the FATMAD series with the highest values ( $P_{95}$ ), the trend is

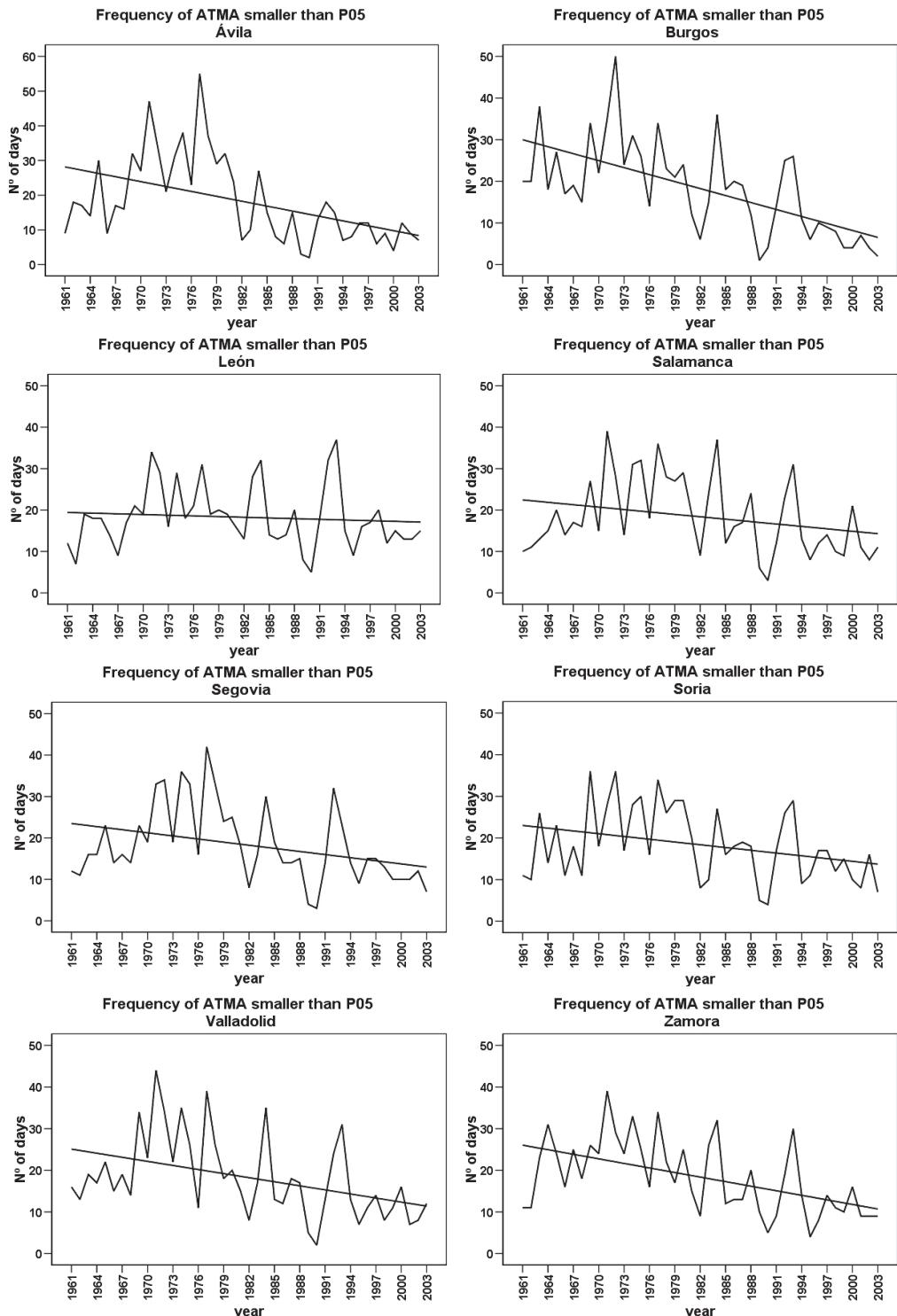


Fig. 2. Temporal evolution of annual frequency of the lowest extreme values of ATMAD (FATMAD) at each of the stations of the Northern Subplateau, between 1961 to 2003.

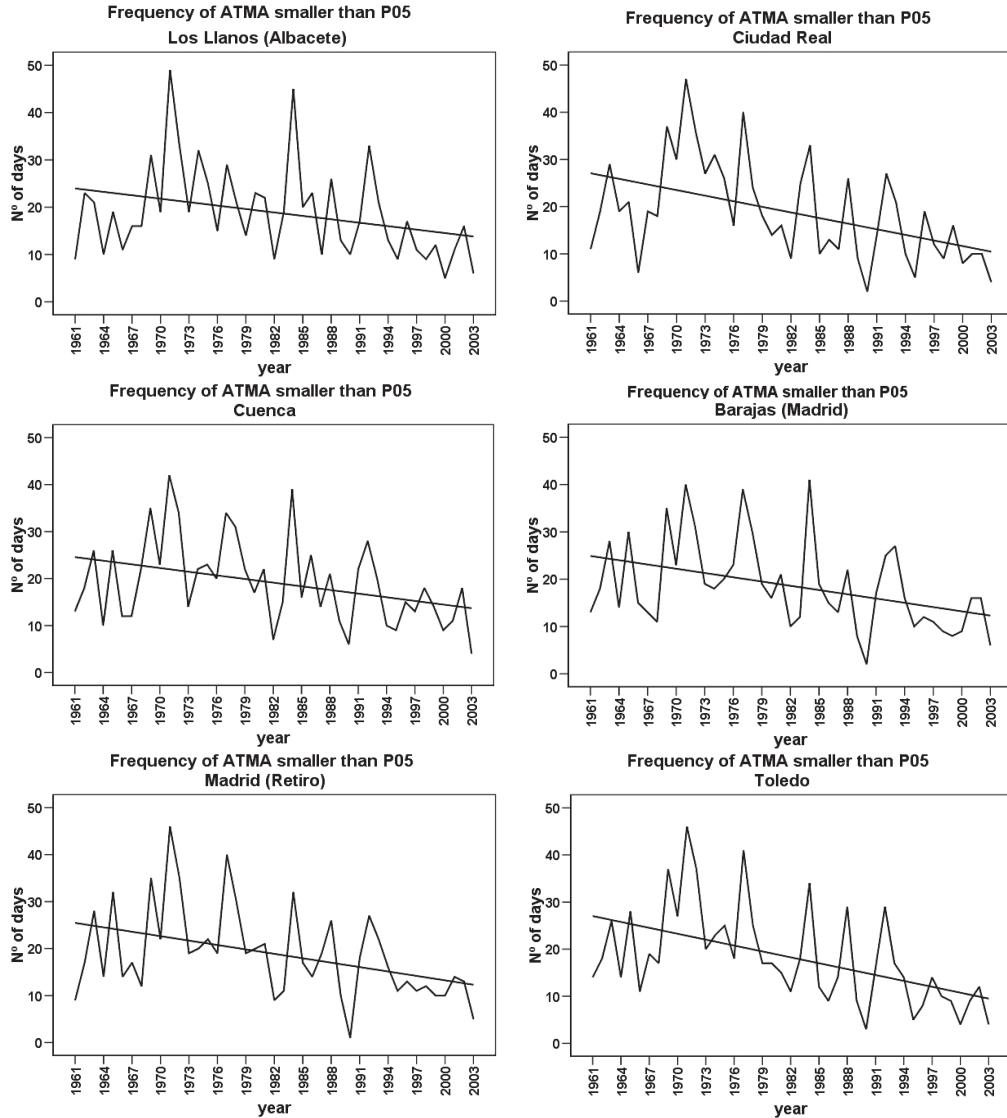


Fig. 3. The same as the Fig. 2 at each of the weather stations of the Southern Subplateau.

increasing; in most cases at a level of confidence higher than 95 %. The exceptions are León and Soria, for which the level of confidence is very small, and Cuenca, where the trend is not significant at a confidence level greater than or equal to 90 % either, although it is significant for a confidence level of 88 %.

The analysis of Figures 2-5 reveals the possible existence of a change in trend as regards the behavior of the FATMAD over 1972. The beginning of this change in trend, both as regards to the temporal behavior of the temperature (Labajo and Piorno, 1998; Galán *et al.*, 2001; Brunet *et al.*, 2001) and in that of other climate elements, such as atmospheric pressure (Labajo *et al.*, 1998), can be established around 1972 using the Mann-Kendal test. Accordingly, 1972 can be considered as the year in which a trend change in the FATMAD data occurred. In light of these considerations, we determined the trends of the two subseries into which the complete series were divided (1961-

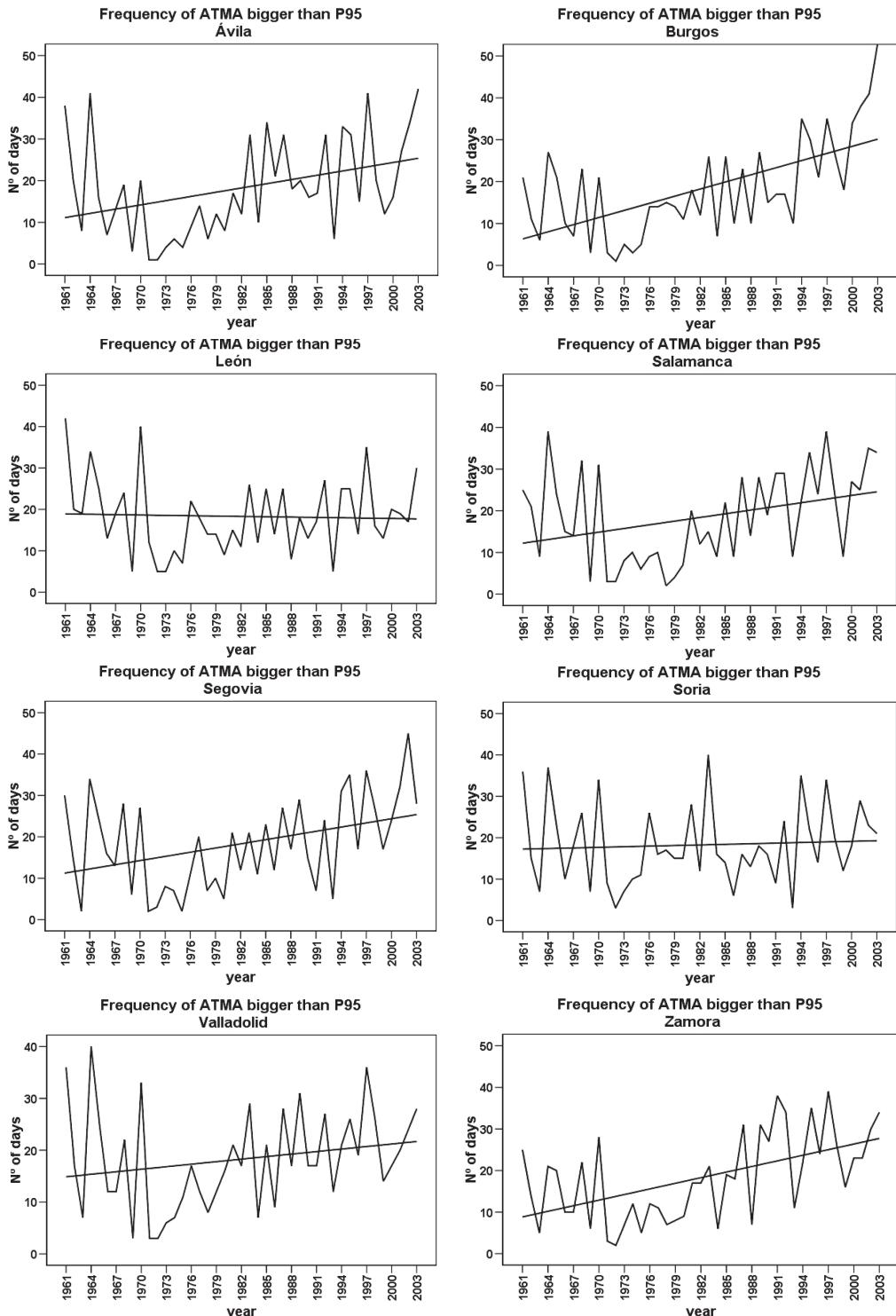


Fig. 4. Temporal evolution of annual frequency of the highest extreme events of AMAD (FATMAD) at each of the stations of the Northern Subplateau, between 1961 to 2003.

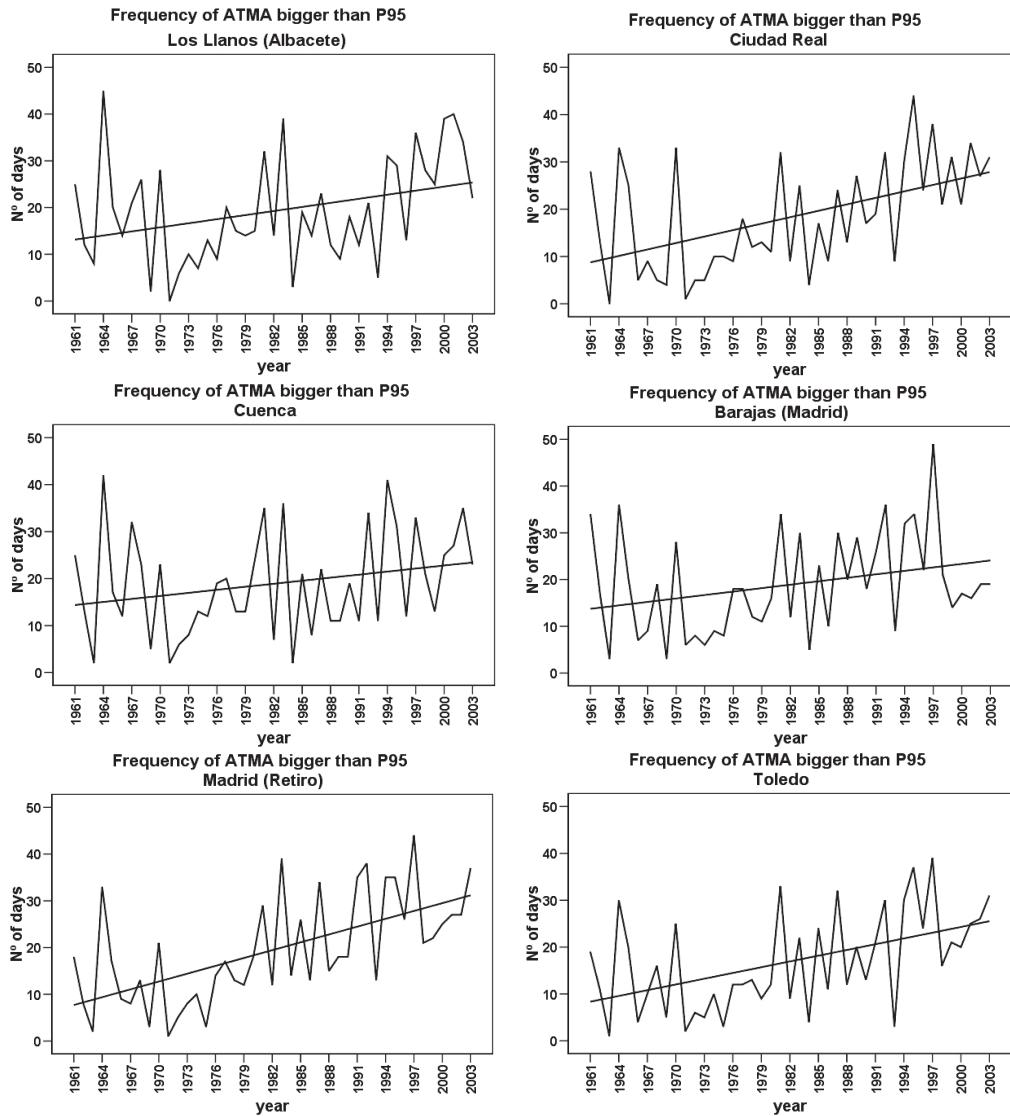


Fig. 5. The same as the Fig. 4 at each of the weather stations of the Southern Subplateau.

1972 and 1973-2003), then contrasting them with those of the complete series. The results for each of the subseries are shown in Tables IV and V.

Table IV shows that between 1961 and 1972 the subseries of the lowest FATMAD values show significant increasing trends at confidence levels above 90 % in all cases, except in the case of Burgos and Madrid (Barajas) where the level of confidence is slightly lower (90 %). In the subseries with the highest FATMAD values, the sign of the Spearman coefficient indicates that the trend is decreasing in all cases, but that it is only significant at a confidence level higher than 90 % in Ávila, León and Valladolid.

Table V reveals that between 1973 and 2003 the temporal behavior of the lowest and highest FATMAD series values was the opposite of that corresponding to the 1961-1972 period. In the case of the subseries of FATMAD values lower than the threshold value corresponding to  $P_{05}$ , all show

Table III. Trends of the FATMAD series of values lower or higher than the thresholds established with the  $P_{05}$  and  $P_{95}$  percentiles for the stations in the study zone, in the interval 1961-2003, for a level of confidence of 90% or greater (I = increasing, D = decreasing, N = no significant trend).

| Stations                | FATMAD < $P_{05}$ |                   |       | FATMAD > $P_{95}$ |                   |       |
|-------------------------|-------------------|-------------------|-------|-------------------|-------------------|-------|
|                         | $r_s$             | $\alpha_s$        | Trend | $r_s$             | $\alpha_s$        | Trend |
| Ávila                   | -0.558***         | <10 <sup>-3</sup> | D     | 0.375*            | 0.013             | I     |
| Burgos                  | -0.654***         | <10 <sup>-3</sup> | D     | 0.561***          | <10 <sup>-3</sup> | I     |
| León                    | 0.163             | 0.297             | N     | 0.038             | 0.807             | N     |
| Salamanca               | -0.321**          | 0.036             | D     | 0.340**           | 0.026             | I     |
| Segovia                 | -0.431***         | 0.004             | D     | 0.372**           | 0.014             | I     |
| Soria                   | -0.323**          | 0.034             | D     | 0.128             | 0.413             | N     |
| Villanubla (Valladolid) | -0.509***         | <10 <sup>-3</sup> | D     | 0.279*            | 0.070             | I     |
| Zamora                  | -0.547***         | <10 <sup>-3</sup> | D     | 0.539***          | <10 <sup>-3</sup> | I     |
| Los Llanos (Albacete)   | -0.345**          | 0.023             | D     | 0.335**           | 0.028             | I     |
| Ciudad Real             | -0.509***         | <10 <sup>-3</sup> | D     | 0.482***          | 0.001             | I     |
| Cuenca                  | -0.376**          | 0.013             | D     | 0.242             | 0.118             | N     |
| Barajas (Madrid)        | -0.441***         | 0.003             | D     | 0.308**           | 0.044             | I     |
| Madrid (Retiro station) | -0.426***         | 0.003             | D     | 0.644***          | <10 <sup>-3</sup> | I     |
| Toledo                  | -0.586***         | <10 <sup>-3</sup> | D     | 0.452***          | 0.002             | I     |

\*Level of confidence  $\geq 90\%$  and  $\leq 95\%$  ( $\alpha \leq 0.10$  and  $\alpha \geq 0.05$ ). \*\*Level of confidence  $\geq 95\%$  and  $\leq 99\%$  ( $\alpha \leq 0.05$  and  $\alpha \geq 0.01$ ). \*\*\*Level of confidence  $\geq 99\%$  ( $\alpha \leq 0.01$ )

Table IV. The same as the Table III, for the interval 1961-1972.

| Stations                | FATMAD < $P_{05}$ |            |       | FATMAD > $P_{95}$ |            |       |
|-------------------------|-------------------|------------|-------|-------------------|------------|-------|
|                         | $r_s$             | $\alpha_s$ | Trend | $r_s$             | $\alpha_s$ | Trend |
| Ávila                   | 0.670**           | 0.017      | I     | -0.649**          | 0.022      | D     |
| Burgos                  | 0.033             | 0.291      | N     | -0.480            | 0.114      | N     |
| León                    | 0.695**           | 0.012      | I     | -0.551*           | 0.063      | D     |
| Salamanca               | 0.834***          | 0.001      | I     | -0.430            | 0.163      | N     |
| Segovia                 | 0.763***          | 0.004      | I     | -0.392            | 0.207      | N     |
| Soria                   | 0.629**           | 0.028      | I     | -0.413            | 0.182      | N     |
| Villanubla (Valladolid) | 0.705**           | 0.010      | I     | -0.547*           | 0.066      | D     |
| Zamora                  | 0.063**           | 0.021      | I     | -0.389            | 0.212      | N     |
| Los Llanos (Albacete)   | 0.568*            | 0.054      | I     | -0.322            | 0.308      | N     |
| Ciudad Real             | 0.634**           | 0.027      | I     | -0.310            | 0.326      | N     |
| Cuenca                  | 0.565*            | 0.056      | I     | -0.323            | 0.306      | N     |
| Barajas (Madrid)        | 0.483             | 0.111      | N     | -0.336            | 0.285      | N     |
| Madrid (Retiro station) | 0.605**           | 0.037      | I     | -0.326            | 0.301      | N     |
| Toledo                  | 0.660**           | 0.020      | I     | -0.217            | 0.499      | N     |

a highly significant decreasing trend; that of León at a level of confidence higher than 95 % and all the rest at levels of confidence above 99 %. The subseries of FATMAD values higher than  $P_{95}$  in all cases show increasing trends, with a high level of significance since the level of confidence exceeds 99 % for most observatories and only Soria has a confidence level higher than 90 %.

Table V. The same as the Table III, for the interval 1973-2003.

| Stations                | FATMAD < P <sub>05</sub> |                   |       | FATMAD > P <sub>95</sub> |                   |       |
|-------------------------|--------------------------|-------------------|-------|--------------------------|-------------------|-------|
|                         | r <sub>s</sub>           | α <sub>s</sub>    | Trend | r <sub>s</sub>           | α <sub>s</sub>    | Trend |
| Ávila                   | -0.667***                | <10 <sup>-3</sup> | D     | 0.638***                 | <10 <sup>-3</sup> | I     |
| Burgos                  | -0.696***                | <10 <sup>-3</sup> | D     | 0.795***                 | <10 <sup>-3</sup> | I     |
| León                    | -0.404**                 | 0.024             | D     | 0.429**                  | 0.016             | I     |
| Salamanca               | -0.584***                | 0.001             | D     | 0.720***                 | <10 <sup>-3</sup> | I     |
| Segovia                 | -0.675***                | <10 <sup>-3</sup> | D     | 0.680***                 | <10 <sup>-3</sup> | I     |
| Soria                   | -0.551***                | 0.001             | D     | 0.339*                   | 0.062             | I     |
| Villanubla (Valladolid) | -0.557***                | 0.001             | D     | 0.566***                 | 0.001             | I     |
| Zamora                  | -0.632***                | <10 <sup>-3</sup> | D     | 0.686***                 | <10 <sup>-3</sup> | I     |
| Los Llanos (Albacete)   | -0.574***                | 0.001             | D     | 0.533***                 | 0.002             | I     |
| Ciudad Real             | -0.599***                | <10 <sup>-3</sup> | D     | 0.659***                 | <10 <sup>-3</sup> | I     |
| Cuenca                  | -0.507***                | 0.004             | D     | 0.367**                  | 0.042             | I     |
| Barajas (Madrid)        | -0.561***                | 0.001             | D     | 0.401**                  | 0.025             | I     |
| Madrid (Retiro station) | -0.570***                | 0.001             | D     | 0.639***                 | <10 <sup>-3</sup> | I     |
| Toledo                  | -0.672***                | <10 <sup>-3</sup> | D     | 0.594***                 | <10 <sup>-3</sup> | I     |

On comparing the above results with those obtained for the whole period of time studied (1961-2003), it may be seen that the trends of the FATMAD series between 1973 and 2003 are more clearly defined than those established for the complete series. In this period of time, the FATMAD series from all the stations considered show a highly significant trend, while on considering the complete period of time studied some of them do not show a significant trend (e.g., León, Soria and Cuenca).

Once the behavior of the individual series of maximum daily temperature had been addressed, we analyzed –in the same way– the behavior of the regional series. As stated in Section 3, from the thresholds obtained for the regional ATMAD series for the whole zone studied (CP) and its two differentiated parts (Table I) we obtained the FATMAD frequency series.

For the CP, the FATMAD series include the number of days in the year, for each year and averaged for the zone, on which the ATMAD values were below the P<sub>05</sub> threshold (-6.21), and other series include the number of days with ATMAD values higher than the P<sub>95</sub> threshold (6.02).

For the northern part of the CP (NS), the FATMAD series were established for the -6.39 and 6.42 thresholds, respectively, and for the southern part (SS) for the 6.20 and 5.79 thresholds.

The temporal behavior of these regional series is shown, for the CP, in Figure 6, which include the trend line. As in the case of the series of individual observations, in the regional series it may be seen that there is a trend, which is increasing for the frequency series with the highest values and decreasing for those with the lowest values in the period between 1961-2003.

To establish the degree of significance of the trend observed in Fig. 6, we applied –as in the case of the individual observatories– the Spearman test (Mitchell *et al.*, 1966; Sneyers, 1975) to the FATMAD series. The results are shown in Table VI.

As expected, these results show that –averaged for the whole study zone and each of the two subzones– the trends of the series from each of the observatories persist. These trends are increasing for the highest ATMAD values and decreasing for the lowest ones, with the same or higher level of confidence. In the regional series it is also possible to discern the change in trend observed in the individual series and the behavior of the corresponding subseries is in complete concordance with that of these latter.

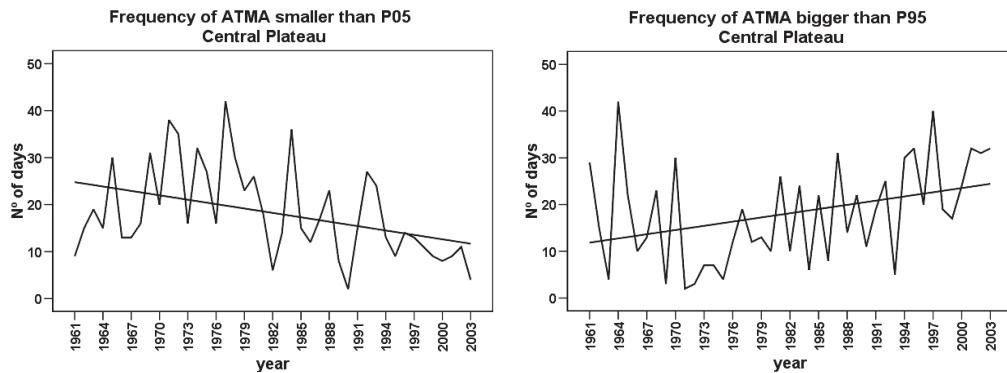


Fig. 6. Temporal evolution of the annual frequency of the lowest and highest in between 1961-2003.

Table VI. Trends of the FATMAD series lower or higher than the thresholds defined by the  $P_{05}$  and  $P_{95}$  percentiles in the study zone, in the interval 1961-2003.

| Stations            | FATMAD $< P_{05}$ |            |       | FATMAD $> P_{95}$ |            |       |
|---------------------|-------------------|------------|-------|-------------------|------------|-------|
|                     | $r_s$             | $\alpha_s$ | Trend | $r_s$             | $\alpha_s$ | Trend |
| Northern Subplateau | -0.452***         | 0.002      | D     | 0.404***          | 0.007      | I     |
| Southern Subplateau | -0.452***         | 0.002      | D     | 0.443***          | 0.003      | I     |
| Central Plateau     | -0.467***         | 0.002      | D     | 0.388***          | 0.010      | I     |

The results obtained for the FATMAD series for the two subplateaus are very similar, indicating the homogeneous behavior of the extreme values of maximum daily temperature across the CP. These results are in good agreement with those obtained in studies on monthly mean temperature performed for each of the subplateaus (Galán *et al.* 2001; Morales *et al.*, 2004) and for other zones of the Iberian Peninsula (Brunet *et al.*, 2001).

The results obtained for the FAMAD values for the 1973-2003 period are shown in Table VII, where it may be seen that the trends are the same as for the whole of the period studied in this work but the levels of confidence are higher, coinciding with the results obtained for the individual stations.

The rate of variation in FATMAD throughout the study zone was obtained from a linear model of temporal evolution. For the period of time during which the trend is best defined (1973-2003), the equations establishing the behaviour models are: For the lowest maximum temperature values ( $P_{05}$  threshold)  $\text{FATMAD} = -0.637 t + 27.284$ , and for the highest maximum temperature values ( $P_{95}$

Table VII. The same as Table VI for the interval 1973-2003.

| Stations            | FATMAD $< P_{05}$ |            |       | FATMAD $> P_{95}$ |            |       |
|---------------------|-------------------|------------|-------|-------------------|------------|-------|
|                     | $r_s$             | $\alpha_s$ | Trend | $r_s$             | $\alpha_s$ | Trend |
| Northern Subplateau | -0.652***         | $<10^{-3}$ | D     | 0.712***          | $<10^{-3}$ | I     |
| Southern Subplateau | -0.656***         | $<10^{-3}$ | D     | 0.608***          | $<10^{-3}$ | I     |
| Central Plateau     | -0.649***         | $<10^{-3}$ | D     | 0.634***          | $<10^{-3}$ | I     |

threshold) FATMAD = 0.694 t – 0.735. The correlation coefficients are significant; in both cases they are higher than 0.5 and  $R^2$ , in both cases exceeds 0.35. The t variable represents time in units of years.

The result of the linear regression model indicates that between 1973 and 2003 the highest extreme FATMAD values increased by 0.694 cases per year and the lowest ones decreased by 0.637 cases per year.

Up to this point, the annual frequencies of extreme maximum daily temperature values presented, but it seemed interesting to determine which periods of the year were those that most clearly contributed to the annual behaviour of the FATMAD. Table VIII shows the values of the Spearman coefficients and the corresponding trends of the frequencies of the ATMAD lower than the thresholds determined by  $P_{05}$  and higher than those determined by  $P_{95}$  for each of the seasons of the year between 1961 and 2003.

Table VIII. Trends of seasonal FATMAD greater than or lower than the  $P_{05}$  and  $P_{95}$  thresholds in the study zone, in the interval 1961-2003.

| Zone                | Percentiles | Variables  | Winter      | Spring    | Summer   | Autumn |
|---------------------|-------------|------------|-------------|-----------|----------|--------|
| Northern Subplateau | $< P_{05}$  | $r_s$      | -0.229      | -0.440*** | -0.119   | -0.253 |
|                     |             | $\alpha_s$ | 0.144       | 0.003     | 0.446    | 0.101  |
|                     |             | Trend      | N           | D         | N        | N      |
|                     | $> P_{95}$  | $r_s$      | 0.360**     | 0.332**   | 0.445*** | -0.127 |
|                     |             | $\alpha_s$ | 0.018       | 0.030     | 0.003    | 0.417  |
|                     |             | Trend      | I           | I         | I        | N      |
| Southern Subplateau | $< P_{05}$  | $r_s$      | -0.161      | -0.364**  | -0.348** | -0.105 |
|                     |             | $\alpha_s$ | 0.309       | 0.016     | 0.022    | 0.502  |
|                     |             | Trend      | N           | D         | D        | N      |
|                     | $> P_{95}$  | $r_s$      | 0.568***    | 0.378**   | 0.308**  | -0.026 |
|                     |             | $\alpha_s$ | $< 10^{-3}$ | 0.013     | 0.044    | 0.867  |
|                     |             | Trend      | I           | I         | I        | N      |
| Central Plateau     | $< P_{05}$  | $r_s$      | -0.141      | -0.404*** | -0.206   | -0.138 |
|                     |             | $\alpha_s$ | 0.374       | 0.007     | 0.185    | 0.376  |
|                     |             | Trend      | N           | D         | N        | N      |
|                     | $> P_{95}$  | $r_s$      | 0.386**     | 0.329**   | 0.403*** | -0.185 |
|                     |             | $\alpha_s$ | 0.011       | 0.031     | 0.007    | 0.236  |
|                     |             | Trend      | I           | I         | I        | N      |

It may be seen that only in spring the trends are well defined in all cases. In summer, the frequencies of the lowest extreme ATMAD values do not show a trend on the NS or on the CP but they do show a decreasing trend for the SS. In winter, significant trends are only seen for the frequencies of the highest ATMAD values in all cases. In autumn, the FATMAD series do not indicate a significant trend in any case.

Consequently, it may be concluded that the trend of the annual FATMAD values for both the study zone (CP) and its two subzones (NS and SS) is determined by their behavior in spring and, to a lesser extent, in summer. The behavior in winter only affects the cases of the frequencies of the highest extreme ATMAD values.

The results obtained for the 1973-2003 period are shown in Table IX. On comparing them with those obtained for the 1961-2003 period, it is clear that spring and summer are the seasons of the year that determine the behavior of the FTAMAD series throughout the year. The winter only affects the behaviour of the  $>P_{95}$  FATMAD series.

Table IX. The same as the Table VIII for the interval 1973-2003.

| Zone                | Percentiles | Variables  | Winter   | Spring     | Summer     | Autumn |
|---------------------|-------------|------------|----------|------------|------------|--------|
| Northern Subplateau | $<P_{05}$   | $r_s$      | -0.238   | -0.616***  | -0.408**   | -0.163 |
|                     |             | $\alpha_s$ | 0.197    | $<10^{-3}$ | 0.023      | 0.381  |
|                     |             | Trend      | N        | D          | D          | N      |
|                     | $>P_{95}$   | $r_s$      | 0.437**  | 0.475***   | 0.591***   | 0.039  |
|                     |             | $\alpha_s$ | 0.014    | 0.007      | $<10^{-3}$ | 0.836  |
|                     |             | Trend      | I        | I          | I          | N      |
| Southern Subplateau | $<P_{05}$   | $r_s$      | -0.144   | -0.516***  | -0.489***  | -0.107 |
|                     |             | $\alpha_s$ | 0.440    | 0.003      | 0.005      | 0.566  |
|                     |             | Trend      | N        | D          | D          | N      |
|                     | $>P_{95}$   | $r_s$      | 0.458*** | 0.587***   | 0.355**    | -0.104 |
|                     |             | $\alpha_s$ | 0.010    | 0.001      | 0.050      | 0.579  |
|                     |             | Trend      | I        | I          | I          | N      |
| Central Plateau     | $<P_{05}$   | $r_s$      | -0.160   | -0.531***  | -0.476***  | -0.098 |
|                     |             | $\alpha_s$ | 0.390    | 0.002      | 0.007      | 0.598  |
|                     |             | Trend      | N        | D          | D          | N      |
|                     | $>P_{95}$   | $r_s$      | 0.363**  | 0.452**    | 0.550***   | -0.067 |
|                     |             | $\alpha_s$ | 0.045    | 0.011      | 0.001      | 0.721  |
|                     |             | Trend      | I        | I          | I          | N      |

#### 4. Discussion

After the establishment of the maximum daily temperature anomaly series (ATMAD) at each of the observatories selected and those of the regional averages for the central zone of the Iberian Peninsula (Central Spanish Plateau) and for the two zones that can be differentiated in it (northern subplateau and southern subplateau), the thresholds of the highest and lowest extreme ATMAD values, defined in each data series with the  $P_{05}$  and  $P_{095}$  percentiles, respectively, are very similar, and they range between  $-6.20$  °C and  $-7.34$  °C for the lowest values and between  $4.55$  °C and  $7.31$  °C for the highest ones.

The FATMAD series of all the observatories studied show considerable variability; there is also some agreement in all of them. 1964 and 1997 can be considered the years of the period studied in which the frequency of days with very high maximum temperatures is the highest of the period studied at many of the observatories and also in the study zone. The lowest frequency of days with very high maximum temperatures corresponds to 1971 and 1972. The year 1971 is the one in which the frequency of days with the lowest maximum daily temperatures has its maximum value at most of the weather stations analyzed. The minimum value of the frequency of days with the lowest maximum temperatures occurred in 1990 across nearly the whole zone studied. This is in good agreement with the existence of a change in trend of the FATMAD values around 1972.

From scrutiny of the results of the trend analysis of the annual frequency of the highest extreme ATMAD values obtained at each of the observatories studied, and throughout the study zone and

its two differentiated parts, it may be inferred that in general between 1961 and 2003 there has been a trend towards an increase in the number of cases per year with temperatures much higher than normal, while in the case of the lowest extreme values the trend has been decreasing. The level of confidence of these results is high, since with the exception of a few cases (León, Soria and Barajas (Madrid)) it surpasses 90 % and in many cases it is above 95 and even 99 %.

On considering the 1973-2003 period, a clear increase can be seen in the confidence level of the results of the trend analysis, surpassing 99 % (except in the case of León, Soria, and Barajas). Regarding the regional analysis, in all cases the results reflect this increasing trend for the highest extremes and a decreasing trend for the lowest ones, at confidence levels higher than 99 %.

Overall, between 1973 and 2003 the frequency with which the highest extreme values of maximum daily temperature occur along the year has tended to increase, while the frequency with which the lowest extreme values occur has tended to decrease. Among other causes, this could be due to a possible increase along the year of the number of cloudless days or days with little cloud cover and/or a possible increase in the annual frequency with which southerly air flows over the Iberian Peninsula.

The comparative regional study suggests that on the CP and on each of its parts (NS and SS) between 1961 and 2003 the trends of the annual FATMAD frequencies have been governed by their behavior in spring and, to a lesser extent, their behavior in summer, although considering the 1973-2003 period, the influence of the behavior of the FATMAD series in summer is clearly established.

This is confirmed on analyzing the total number of cases of extreme ATMAD events occurring monthly in the study zone between 1961 and 2003. In the case of both the highest and the lowest values it may be deduced that the months in which there has been the greatest possibility of such event being reproduced are March, April, May and June (i.e., spring and the beginning of summer).

The fact that these extreme temperature events occurred in July and August with a lower frequency than those occurring from March to June could be explained, among other causes, in terms of the appearance of storm phenomena associated with a warm low pressure that settles over the Iberian Peninsula in summer.

The results obtained allow us to accept the notion that the increasing trend of mean annual temperature, previously established for the study zone (Labajo and Piorno, 1998; Galán *et al.*, 2001; Morales *et al.*, 2004), is influenced by the increase in the annual frequency of the highest extreme ATMAD cases and by the decrease in frequency of the lowest extreme cases. These findings are consistent with those obtained on studying the extreme values of maximum daily atmospheric pressure at ground level (Labajo *et al.*, 2008).

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