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Recent trends and temporal behavior of thermal variables in the region of Castilla-León (Spain)

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RESUMEN

El estudio del comportamiento de las temperaturas en Castilla y León se plantea a partir del análisis de las tendencias de las anomalías térmicas regionales de la zona de estudio. El trabajo se desarrolla en dos fases. Una primera en la que se depuran, completan y homogeneizan las series de datos de trabajo. Las variables que conciernen a estas series son las temperaturas máximas, mínimas y medias, corresponden a un total de 38 estaciones representativas de todo el ámbito regional y abarcan el periodo 1931-1996. La homogeneización se realiza mediante la aplicación de la metodología establecida por Alexandersson y Moberg (1997). Una vez construidas las series homogéneas, en una segunda fase se procede a desarrollar el análisis de su comportamiento temporal a partir de series de anomalías regionales. Para ello se calculan los valores de las anomalías, en cada uno de los observatorios seleccionados, para el período de 1945-1996, a partir de los valores medios mensuales, estacionales y anuales del intervalo 1961-1990. A continuación, y de acuerdo con la metodología descrita por Jones *et al*. (1982) y Jones y Hulme (1996), se determinan los valores representativos de toda la región. Los resultados obtenidos para todo el periodo analizado (1945-1996), indican que tan sólo existen tendencias crecientes, a un nivel de confianza del 95%, en las máximas y medias de invierno. Fuera de este umbral, la tendencia es del mismo signo en verano, mientras que son decrecientes en todas las variables en sus estaciones equinocciales. Frente a ello, destaca el comportamiento de las temperaturas en el subperiodo 1972-1996, en el que las temperaturas máximas, mínimas y medias anuales presentan una tendencia creciente a ese nivel de confianza. Esta circunstancia se confirma en los valores estacionales, sobre todo de primavera y verano, y secundariamente de invierno y otoño. Así pues, se puede señalar cómo en los últimos veinticinco años analizados se observa una tendencia creciente en los valores de las anomalías de las temperaturas máximas, mínimas y medias, tanto anuales como estacionales, que se puede promediar en torno a 0.05 °C/año.

ABSTRACT

The behavior of temperatures in the region of Castilla-León in Spain was explored in a study of trend analyzes of the regional thermal anomalies in the zone. The work was developed in two steps: in the first, the working data series were refined, completed and homogenized. The variables addressed in these series were the maximum, minimum and mean temperatures corresponding to 38 weather observatories representative of the whole regional area and their length spanned the 1931-1996 period. Homogenization was carried out by applying the methodology established by Alexandersson and Moberg (1997). Once the homogeneous series had been constructed, in a second phase we analyzed their temporal behavior from regional anomaly series. To do so, the values of the anomalies were calculated at each of the selected stations –for the 1945-1996 period– from the mean monthly, seasonal and annual values of the 1961-1990 period. Then, following the methodology described by Jones *et al.* (1982) and Jones and Hulme (1996), the representative values for the whole region were determined. The results obtained for the whole period analyzed (1945-1996) indicated that, for a confidence interval of 95%, increasing trends are only seen for the maximum and mean winter values. Outside this threshold, the trend found was of the same sign in summer, whereas trends were decreasing for all the variables for their equinoctial seasons. By contrast, the behavior of temperatures in the 1972-1996 sub-period was striking; the annual maximum, minimum and mean temperatures displayed a certain increasing trend for that confidence interval. This was confirmed with the seasonal values, above all for spring and summer, and also (secondarily) those of winter and autumn. Thus, over the past 25 years analyzed there has been an increasing trend of about 0.05ºC/year in the values of the maximum, minimum and mean temperature anomalies, both annual and seasonal.

Key words: Homogeneous database, SNHT, thermal anomalies, regionalization, trends, climatic change, Castilla and León.

1. Introduction

The possibility of a climate change ocurring is currently spurring interest in studies on climatic variables, as shown by the considerable body of evidence concerning such issues (De Gaetano, 1996; Kadioglu, 1997; Labajo and Piorno, 1998; Jones, *et al.*, 1999; Labajo and Piorno, 1999). However, determination of the trends of such variables, which have often been quoted as having really low values, means that such values must be studied with maximum guarantees of accuracy and reliability.

Achieving this aim is often hindered by a problem common to a large part of the weather observatories involved; i.e., the low quality of the available information, due both to the presence of missing areas and the heterogeneity of some of the temporal series available. This problem is further exacerbated by the fact that, in order to obtain a suitable and objective assessment of the climate at any spatial scale, it is necessary to start out with large and sufficiently homogeneous databases, which must be subjected to optimum quality controls. This issue has been addressed by many authors (Alexandersson, 1986; Karl and Williams, 1987; Rhoades and Salinger, 1993; Alexandersson and Moberg, 1997, among others).

Additionally, these long temporal series are no longer available or fail to cover the territory analyzed with sufficient density and uniformity to be able to establish an analysis at large scale. Nevertheless, there are many works that have used long time intervals, greater than centuries and covering hemispheric regions, if not the whole of the planet (Jones *et al.*, 1982; 1986; Jones, 1988; Vinnikov *et al.*, 1990; Karl *et al.*, 1994; Schönwise *et al.*, 1994, among others).

In any case, it is still necessary to perform other studies at smaller scale, both temporal and spatial because these would complement the existing information. Such small-scale studies are very useful when attempting to account for other specific types of behavior that might otherwise be overlooked, and to ‘‘confirm the stability of the results obtained’’ at larger scales (Labajo and Piorno, 2001). This partly explains the appearance of so many works addressing such matters (Hanssen-Bauer *et al.*, 1995, 1997; Oñate and Pou, 1996; Türkes, 1996; Kadioglu, 1997; Esteban-Parra *et al.*, 1995; and many more).

The present work was developed in keeping with this wish. The aim focuses on analyzing the behavior of the thermal variables (maximum, minimum and mean temperatures) at monthly, seasonal and yearly scale in the region of Castilla-León (Spain) for the period between 1945 and 1996. To accomplish this, and in the light of the foregoing, it was first necessary to create an homogeneous database that would be representative of the space studied. This database served as a starting out point for constructing the regional series of thermal anomalies and, from these, discerning their possible trends as a function of their temporal behavior. Thus, this work was carried out to offer a possible model for the analysis of thermal variables that would include current methodology –covering aspects ranging from data treatment and the homogenization of the working series to their regionalization– with a view to determining their possible trends. In our case, we applied the information thus derived to the Regional Community of Castilla and León.

2. Database

Variations and changes, sometimes sharp, in the information provided by weather recordings, changes in the location of weather observatories or in environmental and urban conditions where they are located, negligence in collecting the information, or changes in observational practices, etc., are the usual drawbacks affecting data quality. Such possible changes mean that it is necessary to construct an homogeneous database that will eliminate or at least minimize these circumstances so that bias will not lead to misinterpretations.

There are a good number of assays for performing homogenization tests on a temporal series, some of them parametric and others non-parametric (Mitchell *et al.*, 1966; Sneyers, 1975). Among the former (parametric tests), used to detect and quantify inhomogeneities in climate series (Peterson and Easterling, 1994; Easterling and Peterson, 1995; Alexandersson and Moberg, 1997; Moberg and Bergstrom, 1997), one of the most useful is the Standard Normal Homogeneity Test (SNHT) for shift detection, developed by Alexandersson and Moberg (1997). Here we decided to use this test to analyze the quality of temperature data in Castilla-León. In this process, we performed a preliminary quality control of the data handled and then applied the test in question (SNHT). This allowed us to construct a regional series of the variables of interest and of the environment addressed in our study.

2.1. Criteria used to choose the observatories and quality control of the information

The network of meteorological stations in Castilla-León features a series of problems deriving from the spatial distribution of the stations, their level of coverage, and the age and continuity of the recordings.

Choice of the weather stations was made on the basis of spatial criteria, on one hand, and the nature of their recordings, on the other. We first chose those that would be representative of the geographic environment of the region. Then, a study was made of the *metadata* of the stations selected to assess the quality of the data recorded, eliminating the stations showing the greatest number of irregularities in their recordings, non-standardized recordings, inappropriate locations, excessively short series, etc. This led us to limit the total number of weather stations to be included in the database that was to be homogenized to 64, which were then subjected to new selection and control criteria.

Owing to the scarcity of weather stations with observations pre-dating 1930 and the doubtful reliability of many of them as regards data between 1936 and 1940, we considered that the period between 1945 and 1997 was a priori the most reliable and suitable owing to the coincidence of this period in most of them. We also started out from the premise that in all the stations there would be at least one common period of observation of 20 years, located in the 1961-1980 interval. It was accepted that these would lack a maximum of 5% of data from that period and hence the series with too many gaps were discarded (more than 20% of the whole series). Thus, all series had a minimum of 50 years of observation.

Most of the weather stations chosen here belongs to the flat area of Castilla-León, perhaps including the foothills of its mountainous areas. Thus, we attempted to ensure a maximum representation of different spaces and of homogeneous areas as regards their altitudinal intervals with a view to achieving maximum characterization of such a broad regional content (94,147 km^2).

On the other hand, considering the future regionalization of temperatures to be carried out in the study zone, we attempted to ensure that the stations would cover it uniformly in order to obtain an average series for the whole region. To this end, the territory was divided into a grid of 15 cells of 1º × 1º latitude and longitude, between 40º- 43ºN and 2º-7º W, where –when possible– there was a minimum of two and a maximum of five stations present in each of the resulting cells.

We thus selected a total of 38 observatories from the network of the National Institute of Meteorology (NIM) of Spain for the working network (Fig 1.). The data series on monthly mean maximum and minimum temperatures, obtained from the data measured at each station, were supplied by the NIM. The network contains eight of the nine complete observatories of the zone that are located in provincial capitals in the region. This allowed a contrast of the behavior of the variables studied at those points and the behavior they showed in the rest of the network, with a

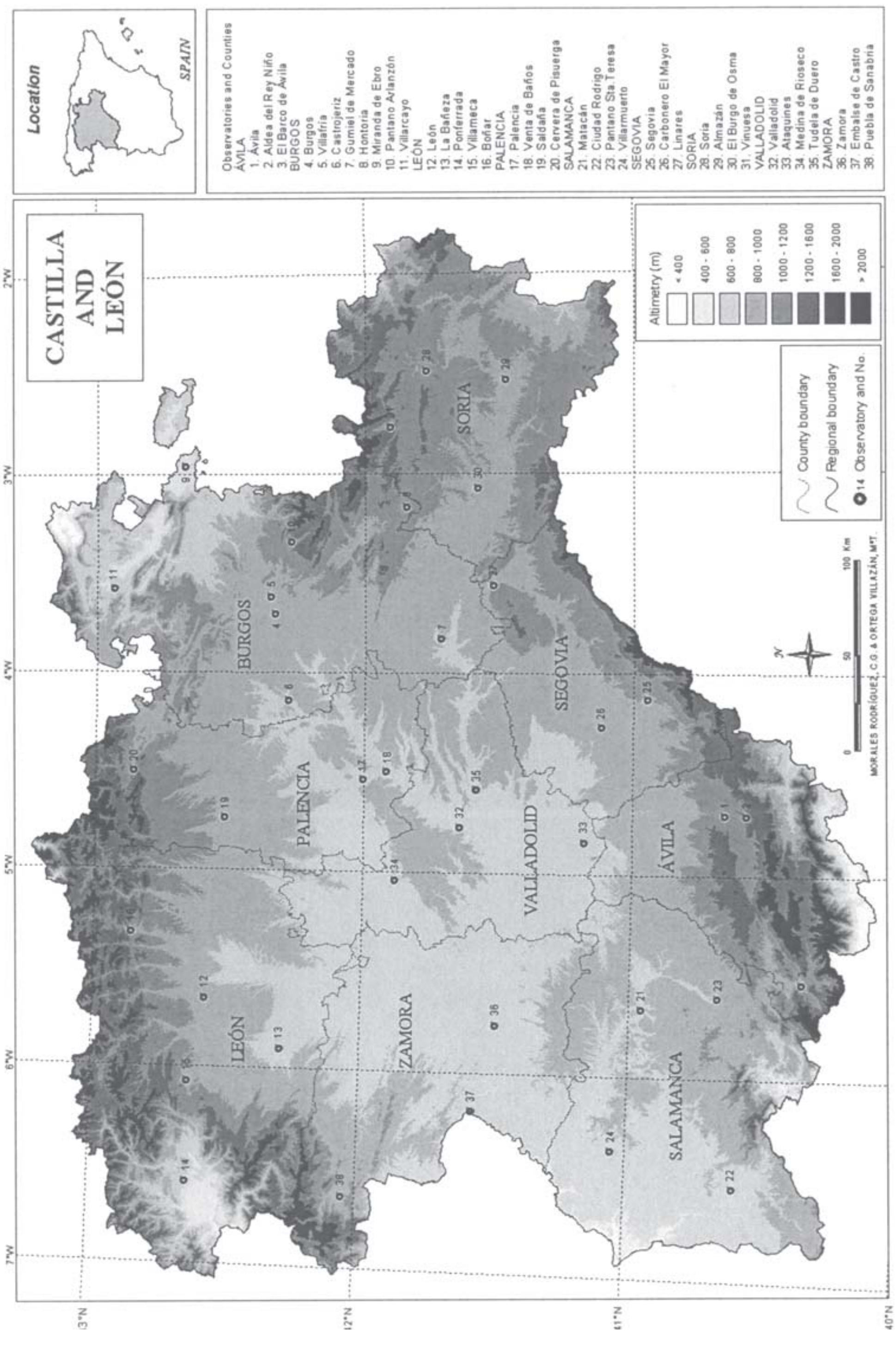

Fig. 1. Map of location of observatories on an altimetric model of Castilla-León

view to determining whether urban characteristics imply significant changes in the temperature recordings and their climatic trends.

Additionally, all the information of this broad network was subjected to quality control carried out in different successive steps and this was applied to maximum, minimum, and mean temperatures.

• First, the different gaps existing in the series of monthly values of each station were detected.

• Certain logic filters of general nature were applied to detect the anomalous data.

• The next step consisted in filling in the original gaps. To this end, it was necessary to calculate –month by month– the correlations of the data series of each station with those of the others. The missing data were assigned the values estimated from the regression equations obtained, as long as the corresponding correlation coefficients were equal to or higher than 0.5. In practice, the correlation levels must have been very high since none of them was found in that threshold and were nearly always above 0.9, 20% of them lying between 0.7 and 0.9.

• The filling-in was always performed from the best-correlated weather stations, first selecting the four best ones.

The result was the construction of an unadjusted database of monthly, seasonal and yearly maximum, minimum and mean temperatures. This formed the basis of the next step in homogenization.

2.2 Homogenization of the temperature series

The creation of a homogeneous database of maximum, minimum and mean temperatures was carried out by applying the above SNHT of Alexandersson and Moberg (1997) to the monthly, seasonal and yearly information. This was done using specific software that includes some modifications introduced by our Group of Research on Climate Change, as reported in Aguilar *et al.* (1999). Thus, it was developed in two successive stages, of which the first or preliminary one generated the reference database to be used in a later and final stage, in which the original series were reappraised to correct the anomalous data and obtain the definitive homogenization.

When trends lasted less than six years the inhomogeneities were not corrected. The process was applied as many times as necessary to the monthly, seasonal and yearly series from each station until the final stage was completed, this allowing us to check that the series was in fact homogeneous. From this information, we corrected the series to create a homogenized database for the stations selected. As example, figures 2a and 2b show the differences between homogenized and non-homogenized series in Zamora. We thus obtained a representative series of the thermal values for Castilla-León.

To verify whether the homogenization process introduces significant variations that might alter the behavior of the trends in the original data, we contrasted both series –original and homogenized– from each weather station by analyzing their corresponding variances. The Levene test of homogeneity of variances was applied to each pair of montly series of maximum, minimum and mean temperatures.

The results were almost always much higher the significance level employed ($\alpha = 0.05$). Only one exception was found, corresponding to the series of maximum temperatures at Ponferrada, for

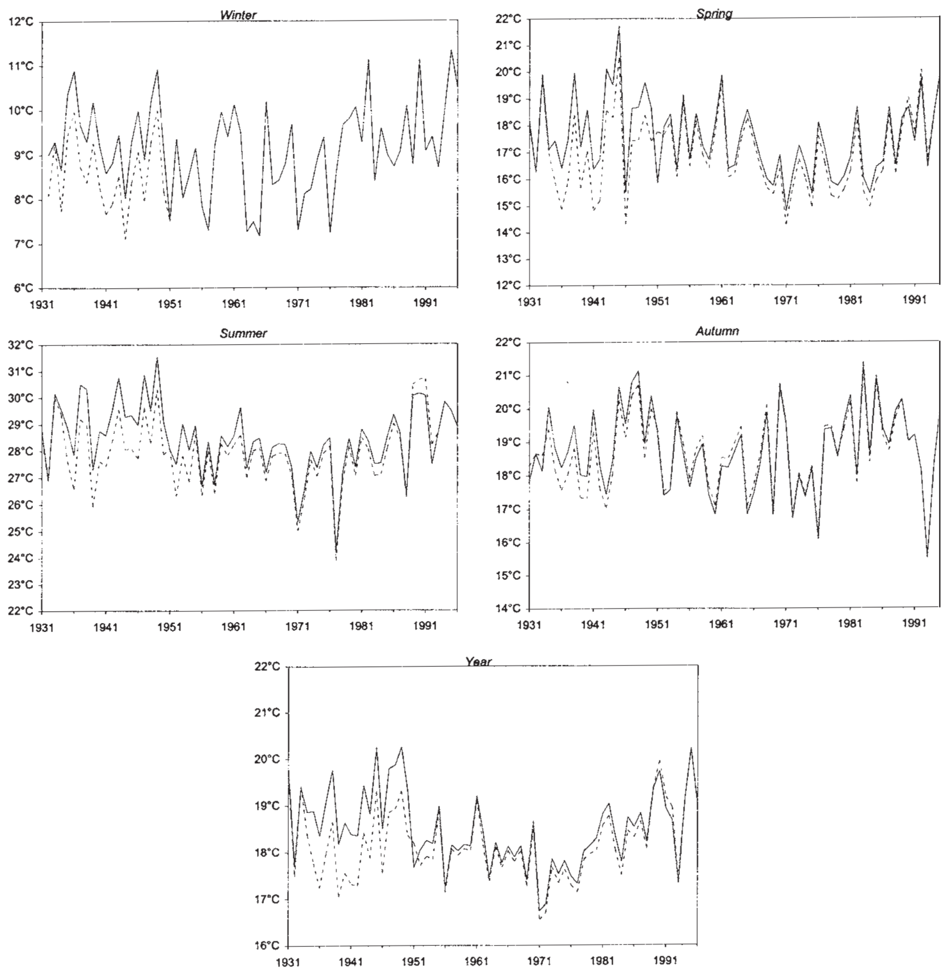

Fig. 2a. Differences between homogenized (continous line) and non-homogenized series (dashed line) of seasonal and annual maximum temperatures in Zamora (Spain).

which the Levene statistic took a value of 0.0416, slightly lower than 0.05. It is therefore possible to accept the homocedasticity between the original and homogenized series, which allows the latter to be accepted as a basis for this work.

Application of the method of Alexandersson and Moberg (1997) to the refined and filled-in data series of the stations allowed us to create a homogeneous database of monthly, seasonal and yearly values for the maximum, minimum and mean temperatures. This database now served as the starting point to continue our studies on the evolution of the climate in the Regional Community of Castilla-León.

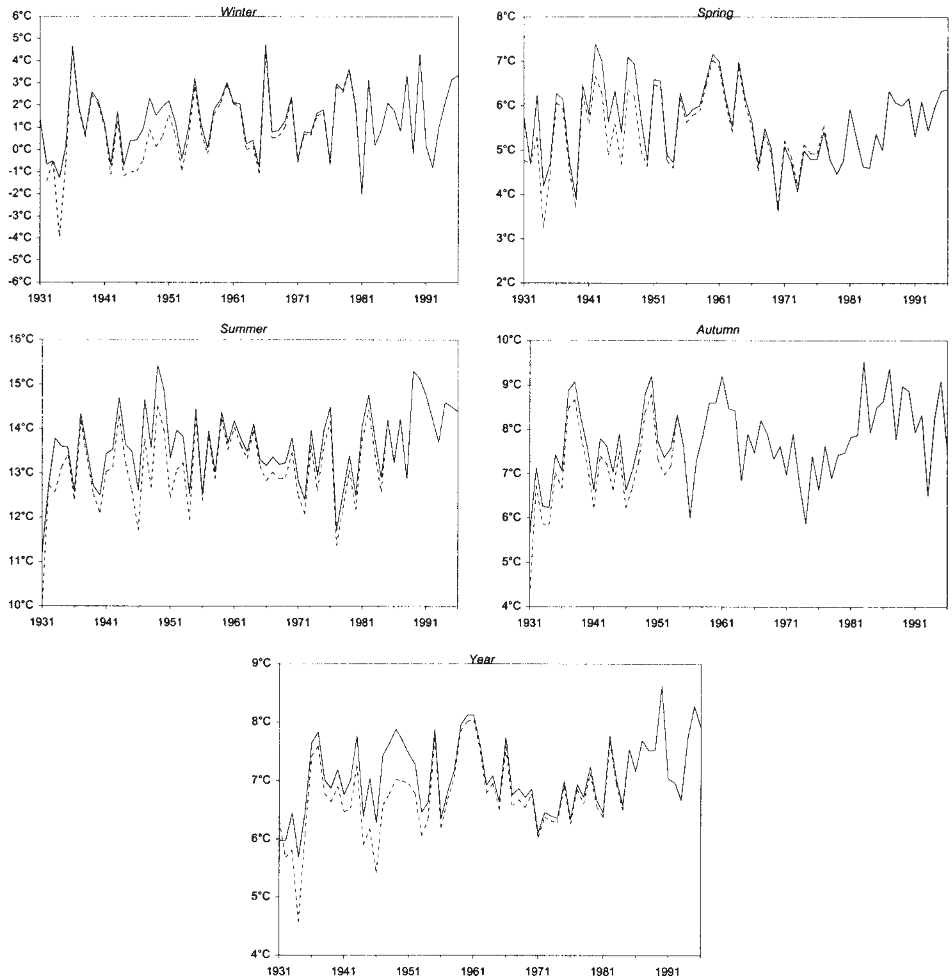

Fig. 2b. Differences between homogenized (continous line) and non-homogenized series (dashed line) of seasonal and annual minimum temperatures in Zamora (Spain)

3. Regionalization of temperatures

Having constructed the homogeneous database, we used this to confect the series of the regional maximum, minimum and mean temperature values in order to establish their trends. These regional values were established monthly, seasonally and yearly from the series of absolute or standardized anomalies with respect to a common reference period (Jones and Hulme, 1996; Vinnikov *et al.*, 1990). The reason for this was to eliminate, or if this was not possible, to minimize local influences that might bias the data.

3.1 Method for the construction of regional series of thermal anomalies

We have already mentioned the need to establish regional temperature series. Despite the paucity of works addressing this as regards Spanish territory, there are some that do allow application of specific methodologies to construct series that are representative of particular spatial environments. To find a procedure that would best model the regional behavior of the thermal anomalies, we tested several methods for the interpolation of spatial values, such as the kriging method, polynomial regression, the Shepard method and triangulation with linear interpolation. Of all such methods, the reciprocal of the distance method was the one that was most appropriate: on one hand, for the grid constructed and, on the other, for the analysis of the thermal variables. The methodology used here was that employed by Brunet *et al.* (1999), which in turn includes the proposals of Jones *et al.* (1982) and of Jones and Hulme (1996). This is a simple weighted interpolation method on a spatial grid of regular square cells that affords results with a high degree of goodness, as shown in the works such as that of Karl *et al.* (1994).

There were several reasons for selecting this method. Some of the methods were ruled out because they introduced either specific trends or specific weighting factors and in our case we considered all the stations and their values with the same weight within the grid. On other occasions, such methods demanded a grid of greater density than that confected, or even failed to conserve the original values because they are methods of interpolation through approximation, which are more appropriate when there is no certainty about the quality of the data and of the measurements. This latter is a circumstance that we consider no longer exists thanks to the homogenization process.

The problems involved in using the method of the reciprocal of the distance would arise if we attempted to observe the spatial distribution of the anomalies, with the appearance of wide spaces without data, behaving as large “gaps”. The reason for this is because this method is unable to generate values beyond the limits proposed for the original data. To solve this problem, the values generated were verified and contrasted with those of the weather stations that had been discarded and not used in the homogenized network. Accordingly, this could be solved by increasing the density of the network of stations to be used. If we had been attempting to establish the spatial distribution, this would only have involved assessment and correction since the adjustment required to generate a contour map would lead to the appearance of such gaps, completely in disagreement with the real values. Moreover, in this case it would be necessary to use different methods and to design a specific algorithm. However, the aim of the present work was not to determine the spatial distribution of regional anomalies but, instead, their temporal behavior from average regional values. It was thus preferable to assume these acceptable limitations and not those derived from the use of other methods that generated undesirable trends in the data series.

The series of absolute anomalies, T_i, were obtained from the original series from the homogenized database, using the mean values of each series in the 1961-1990 period; the last “normal climatic” period established by the World Meteorological Organisation (WMO) as a reference values. With the data obtained, we established the average series of the region, T_r, first constructing those of each of the cells of the 1º long × 1º lat grid and then using the series of absolute anomalies of the stations included in each of them (Fig. 1).

As a function of the above, the average series of anomalies for each cell were calculated from the stations included in each of them, weighting them as a function of the reciprocal of their distance to its centre, using the following expression:

$$\Delta T_r = \frac{\sum_1^n d_i \Delta T_i}{\sum_1^n d_i}$$

where ΔT_r is the maximum, minimum or mean temperature anomaly, interpolated in the centre of each cell; ΔT_i is the maximum, minimum or mean temperature anomaly, established at each observatory included in the study; d_i is the reciprocal of the distance of the i^{th} observatory to the centre of its cell and n is the number of observatories included in the cell.

Following this, from the average data obtained from each cell the series of average values for the whole region were obtained, repeating this process both for the maximum, minimum, and mean temperatures in monthly, seasonal and annual periods.

4. Trend analysis

Having obtained the regional series of maximum, minimum and mean temperature anomalies, both annual and monthly, and seasonal, we next attempted to determine the temporal behavior of each of the variables and, with this, the trends possibly shown by them. Thus, we first made a graphic interpretation of the anomalies calculated, whose evolution is shown in Fig. 3. Owing to space constraints, this does not include the monthly series. These graphics also show the mobile means for five years so that, if they do exist, possible partial trends can be seen.

From analysis of these plots, in most cases one can deduce the possible existence of a change in trend towards the beginning of the seventies. According to the data of Labajo *et al.* (1998), 1972 can be taken as the year in which the possible change in the trend of the behavior of the climatic variables in Castilla-León started. In view of this, the trend analysis was performed both for the complete series (1945-1996) and for the partial series (1945-1971 and 1972-1996).

In both periods, which are very similar in length, at first glance the working series show different types of behavior (Fig. 4). Thus, whereas in the first subseries a certain decreasing trend is seen in the thermal anomalies, in the second one this trend seems to be increasing. This difference in behavior is seen to a greater or lesser extent in all cases.

To check whether the trends observed graphically for the whole period (1945-1996) and for the partial periods (1945-1971 and 1972-1996) were significant at a sufficiently high confidence interval (95%), the Spearman test (Sneyers, 1975) was applied to the complete series and to the two subseries. In the cases in which the trend indices were sufficiently high, even though not reaching the established confidence interval, they were checked using the Mann-Kendall test. The results are shown in Table 1.

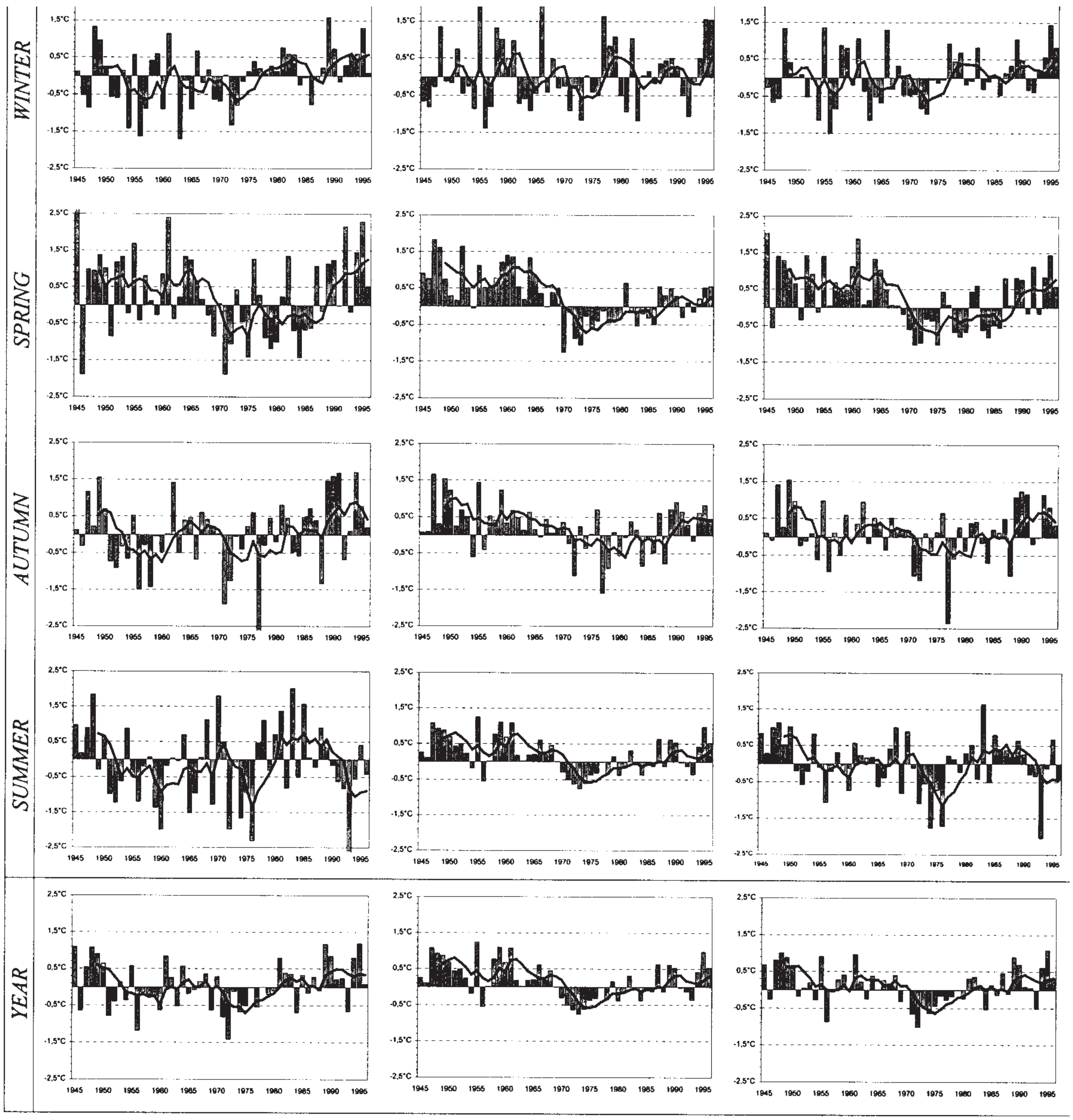

Fig. 3. Seasonal and annual evolution of the regional temperature anomalies for the period 1945-1996 (bars: temperature anomalies; lines: mobile mean at five years).

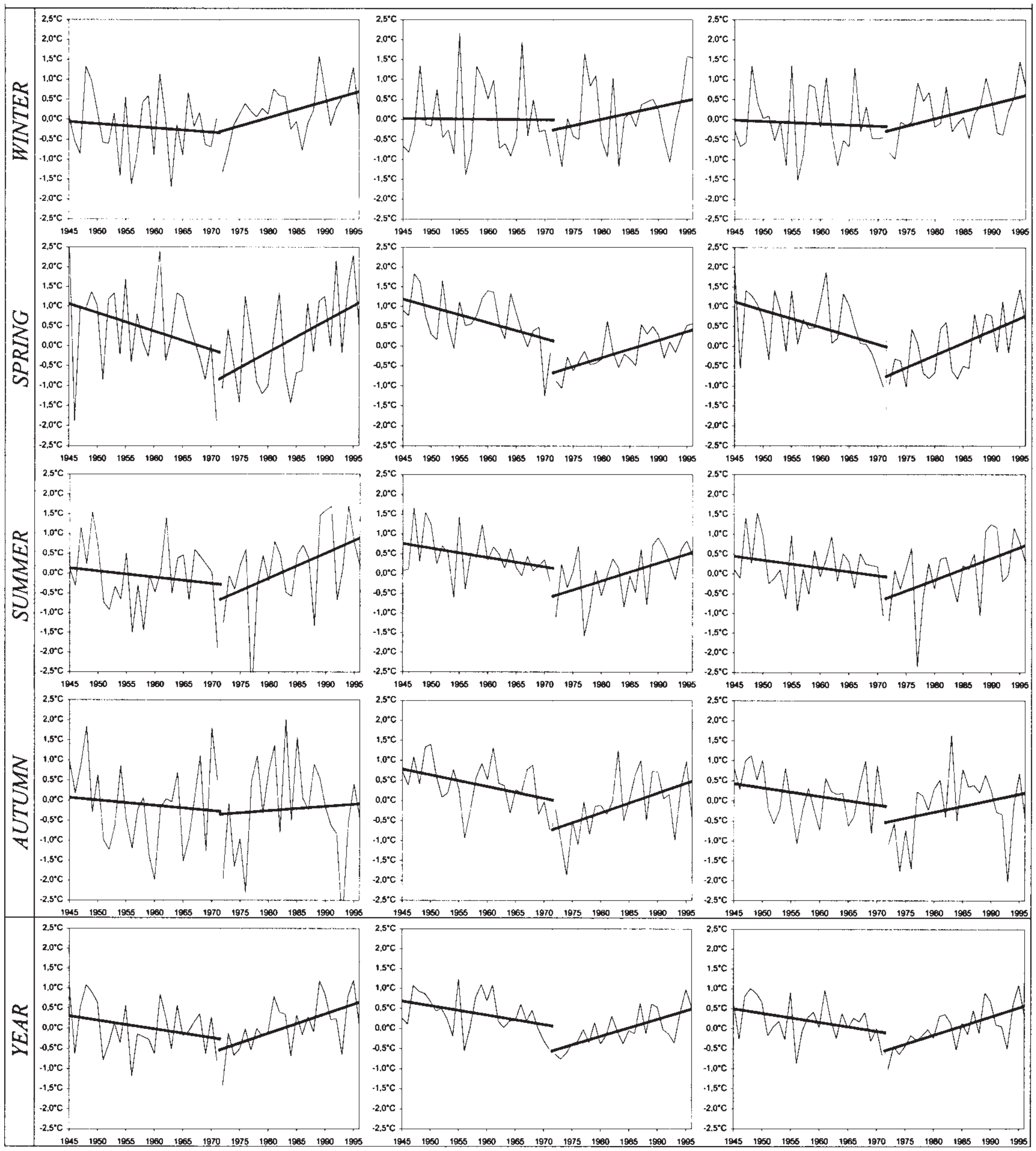

Fig. 4. Seasonal and annual trends of the regional temperature anomalies for the subperiods 1945-1971 and 1972-1996 (thin lines: temperature anomalies; thick lines: trend over mobile mean at five years).

Table 1. Results of tend analysis, applying the Spearman test, of the regional series of mean seasonal and annual temperature anomalies for the 1945-1996 period.

		Winter	Spring	Summer	Autumn	Year
	r_s	0.2704	-0.0741	0.2149	-0.0410	0.0898
T maximum	α_s	0.053	0.602	0.126	0.773	0.527
	trend	NT	NT	NT	NT	NT
	r_s	0.1453	-0.5102	-0.1898	-0.3067	-0.3163
T minimum	α_s	0.304	0.000	0.178	0.017	0.022
	trend	NT	D	NT	D	D
	r_s	0.2574	-0.2619	0.0530	-0.1708	-0.0882
T mean	α_s	0.065	0.061	0.709	0.226	0.534
	trend	NT	NT	NT	NT	NT

r_s, Spearman coefficient; level of confidence: 95%; $\alpha_0 = 0.05$; α_s, level of probability of the null hypothesis (no trend). Trend: I = increasing trend; D = decreasing trend: NT = no trend.

Table 1-B. Results of tend analysis, applying the Mann-Kendall test, for the regional series of seasonal and annual mean temperature anomalies for the 1945-1996 period.

		Winter	Spring	Summer	Autumn	Year
	r_τ	0.1916	-0.0558	0.1508	-0.0317	0.0679
T maximum	α_τ	0.045	0.559	0.115	0.740	0.479
	trend	I	NT	NT	NT	NT
	r_τ	0.0935	-0.3213	-0.1463	-0.2036	-0.2142
T minimum	α_τ	0.328	0.001	0.126	0.033	0.025
	trend	NT	D	NT	D	D
	r_τ	0.1885	-0.1795	0.0271	-0.1176	-0.0513
T mean	α_τ	0.049	0.060	0.776	0.218	0.592
	trend	I	NT	NT	NT	NT

r_τ, Mann-Kendall coefficient; level of confidence: 95%; $\alpha_0 = 0.05$; α_τ, level of probability of the null hypothesis (no trend). Trend: I = increasing trend; D = decreasing trend; NT = no trend.

Considering the whole period analyzed, and in view of the results obtained, no significant trend can be seen in any of the three variables. Only the annual minima point to a decreasing trend in an evident way, although the values attained by the r_s coefficient are not very high. These values are governed by the behavior, also with a decreasing trend, seen in the equinoctial seasons. The maximum and mean winter anomalies seem to show the opposite kind of behavior. In this case, no trend values are seen at the level of confidence established (α_s = 0.053 and α_s = 0.065, respectively). However, one could speak in terms of a trend when the Mann-Kendall correlation was used, since, as shown in Table 1-B, the values of α_τ were indeed now significant.

In any case, what seems clear is that on evaluating the sign of the coefficient, an increasing trend is seen in the winter and summer anomalies for the three variables analyzed, always with positive values (except in the case of the minimum of summer). By contrast, the equinoctial seasons reflect a decreasing trend. This kind of disparate behavior shows that the annual thermal anomalies do not display a homogeneous trend.

A different situation is seen on scrutinizing the results obtained from application of this test to the above two subseries, as may be seen in Tables 2 and 3: From the results obtained, it may be seen that between 1945 and 1971 there is no trend at the level of confidence considered, except for the equinoctial seasons in the case of the minima, and the spring in the case of the means, where a decreasing trend is seen in the anomaly values. This seems to be consistent with what was observed for the whole subperiod since in all cases the sign of the coefficient was negative. Regarding the annual values, only the minima reach the level of significance considered, although if this were established for a confidence level of 90% the means would show a similar behavior because the r_s

Table 2. As in Table 1, but for the 1945-1971period.

		Winter	Spring	Summer	Autumn	Year
T maximum	r_s	- 0.1355	- 0.3083	- 0.0757	- 0.1227	- 0.2436
	α_s	0.500	0.118	0.707	0.542	0.221
	trend	NT	NT	NT	NT	NT
T minimum	r_s	- 0.0726	- 0.4377	- 0.2753	- 0.3858	- 0.3864
	α_s	0.719	0.022	0.165	0.047	0.046
	trend	NT	D	NT	D	D
T mean	r_s	- 0.0568	- 0.4206	- 0.1203	- 0.2753	- 0.3388
	α_s	0.778	0.029	0.550	0.165	0.084
	trend	NT	D	NT	NT	NT

r_s , Spearman coefficient; level of confidence: 95%; $\alpha_0 = 0.05$; α_s , level of probability of the null hypothesis (no trend). Trend: I = increasing trend; D = decreasing trend; NT = no trend.

Table 3. As in Table 1, but for the period 1972-1996.

		Winter	Spring	Summer	Autumn	Year
T maximum	r_s	0.4169	0.5038	0.4015	- 0.0554	0.5462
	α_s	0.038	0.010	0.047	0.793	0.005
	trend	I	I	I	NT	I
T minimum	r_s	- 0.2738	0.6638	- 0.4977	- 0.5162	- 0.6585
	α_s	0.185	0.000	0.011	0.008	0.000
	trend	NT	I	I	I	I
T mean	r_s	0.3862	- 0.6377	- 0.4800	- 0.3092	- 0.6562
	α_s	0.057	0.001	0.015	0.133	0.000
	trend	NT	I	I	NT	I

r_s , Spearman coefficient; level of conficence: 95%; $\alpha_0 = 0.05$; α_s , level of probability of the null hypothesis (no trend). Trend: I = increasing trend; D = decreasing trend; NT = no trend.

values is 0.084. These values were confirmed by application of the Mann-Kendall test, since although the values obtained were different, the relationship between both values as expressed by Siegel and Castellan (1988), is: $-1 \leq (3 \cdot \text{Kendall } \tau - 2 \cdot \text{Spearman R}) \leq 1$); the signs of the trend were established in the same terms as those recorded with the Spearman test. Table 2-B shows the results of the Mann-Kendall test for the 1945-1971 period.

Regarding the second period (1972-1996), the value of the Spearman coefficients (r_s) was always positive, such that regardless of the existence of a trend at the level of confidence considered ($\alpha_s = 0.05$) all the variables studied indicated at least three seasons per year with an increasing trend and two of these were always spring and summer. Whereas for the minimum temperatures the third seasonal period was autumn, for the maximum temperature it was winter, although if in the latter the value of α_s was 0.058, α_t would be 0.045 for a value of $\tau = 0.2876$, as may be seen in Table 3-B.

Table 2-B. As in Table 1-B, but for the 1945-1971 period.

		Winter	Spring	Summer	Autumn	Year
	r_τ	0.1054	-0.2251	-0.0484	-0.0712	-0.1624
T maximum	α_τ	0.441	0.100	0.723	0.602	0.235
	trend	NT	NT	NT	NT	NT
	r_τ	-0.0427	-0.3048	-0.2194	-0.2764	-0.2877
T minimum	α_τ	0.755	0.026	0.108	0.043	0.035
	trend	NT	D	NT	D	D
	r_τ	-0.0427	-0.3333	-0.1111	-0.1909	-0.2308
T mean	α_τ	0.755	0.015	0.416	0.162	0.091
	trend	NT	D	NT	NT	NT

r_τ, Mann-Kendall coefficient; level of confidence: 95%; $\alpha_0 = 0.05$; α_τ, level of probability of the null hypothesis (no trend). Trend: I = increasing trend; D = decreasing trend; NT = no trend.

Table 3-B. As in Table 1-B, but for the 1972-1996 period.

		Winter	Spring	Summer	Autumn	Year
	r_τ	0.3067	0.3733	0.3000	0.0333	0.3800
T maximum	α_τ	0.032	0.009	0.036	0.815	0.008
	trend	I	I	I	NT	I
	r_τ	0.1867	0.4800	0.3400	0.3800	0.4867
T minimum	α_τ	0.191	0.001	0.017	0.008	0.001
	trend	NT	I	I	I	I
	r_τ	0.2867	0.4667	0.3400	0.2000	0.5133
T mean	α_τ	0.045	0.001	0.017	0.161	0.000
	trend	I	I	I	NT	I

r_t, Mann-Kendall coefficient; level of confidence: 95%; $\alpha_0 = 0.05$; α_τ, level of probability of the null hypothesis (no trend). Trend: I = increasing trend; D = decreasing trend; NT = no trend.

Thus, it may be seen that all the thermal variables show increasing trends in the anomalies for at least three quarters of the year in the period between 1972 and 1996. Moreover, the maximum, minimum, and mean temperatures show significant increasing trends, with coefficients always above 0.5 and with high levels of confidence.

This positive behavior in trend observed in the later period is reflected in an elevated annual increase. Quantification of this increase reveals a high trend coefficient value: on average around 0.05ºC/year. Of these trends, the spring and winter maximum temperatures are those that have undergone the greatest increase, namely, 0.07 ºC/year, whereas the winter minima have shown the lowest increase: 0.02 ºC. These results are shown in Table 4.

Table 4. Values of annual trend coefficients (in ºC/year) for the 1972-1995 period.

	Winter	Spring	Summer	Autumn	Year
T maximum	0.053	0.070	0.069	0.037	0.057
T minimum	0.018	0.045	0.045	0.052	0.040
T mean	0.036	0.058	0.057	0.044	0.049

These values are similar to the results obtained by Galan *et al*. (2001) for the Southern Plateau of Spain and are consistent with those reported by Brunet *et al.* (1999) for similar periods in the last quarter of the last century in Cataluña, although in this case the trend coefficients are higher: around 0.03 ºC/year. It is true that the differences are appreciable, but they are also logical since that area is a warmer climatic domain than the one studied here.

5. Conclusions

Calculation of the trends of atmospheric variables, among them temperatures, demands high precision in the data and, in view of the many factors that may introduce bias, it is necessary to construct a homogeneous database for the series recorded at weather stations. Moreover, so that the interpretation will be fully valid from the point of view of their spatial referencing such data must cover the whole area analyzed in a uniform way and with sufficient density. The area must be completely represented as regards all its topoecological features. To construct the database, here we applied the SNHT method of Alexandersson and Moberg (1997), whose quality was ratified by the results obtained.

Furthermore, analysis of the regional behavior of the trends must be addressed from the absolute anomalies, which must be weighted so that they will have full spatial representativeness. To do so, use of interpolation and weighting methods such as the reciprocal of the distance, despite its simplicity, are very effective when attempting to construct the average regional series of temperatures. To establish a clear distribution of the trends of the variables along the year, as well as in their annual mean values, they must be studied comparatively in seasonal temporal periods since both circumstances will permit a better interpretation of the behavior of the trend of the variables along time. In this sense, application of the method proposed by Jones (1982, 1986) proved to be extremely effective.

After we had constructed a homogeneous database, we constructed the regional series of annual and seasonal maximum, minimum and mean temperatures as the first and second contributions to this work. From these, and using a simple correlation method such as that of Spearman, whose results were contrasted and verified using the Mann-Kendall method, it was possible to determine that for the period analyzed in Castilla-León (1945-1996) it is not possible to speak in terms of trends in the behavior of the annual temperatures, although a certain tendency for the maxima to increase and for the minima and mean temperatures to decrease is seen. Despite this, once the series had been analyzed in seasonal periods, it can be said that there is a trend towards an increase in the winter and summer, both in the anomalies in the maxima and in the minima, and in means, together with a trend towards a decrease in the latter in the equinoctial seasons.

On interpreting the behavior of the series in both partial intervals (1945-1971 and 1972-1996), two clearly contrasting situations are seen. Whereas in the first period there is no clear trend, with the exception in a decrease in minima, a possible decreasing trend is seen in almost all cases. Nevertheless, in the second period almost the opposite occurs. The annual series show a clear tendency to increase as regards anomalies, with coefficients that are always positive. This is also reflected in the persistently increasing type of behavior first in the summer and spring series and, second, in the winter and autumn series.

These circumstances prompted us to propose as a conclusion, based on the methodology used, that although in the first period a certain decreasing trend in the temperature anomalies would be possible, these have changed sign over the past 25 years, in which a clear increasing trend in thermal anomalies is seen and hence in the annual and seasonal mean temperatures, the central months of the year (spring and summer) being those that most show this type of behavior. In annual terms, this increase was established from coefficients of variation in the trend as being close to 0.05 ºC/year.

Despite the urban and expansionist characteristics of such cities, the data obtained from the stations located in the provincial capitals of the region, did not reveal significant alterations in the temperature recordings and their climatic trends, and showed that they were fairly comparable to those obtained at other stations located in rural areas. A different matter would be to quantify the magnitude of this trend in comparison with the values reported for rural areas, the difference between which would point to the existence of "heat islands" that, regardless of whether they occur or not, evolve following the same trend as surrounding areas. This validates the quality of the method applied.

The above conclusions afford a starting point from which to determine the causes of this kind of behavior, not only from the statistical point of view but also as regards their relationship with changes in atmospheric dynamics within a space in the mid-latitudes of the northern hemisphere. In this sense, it would be interesting to relate the seasonal distribution of trends, which are mainly increasing in nature, with the North Atlantic Oscillation (NAO) index. However, this would lie outside the scope of the present work, which was to determine the existence or not of trends in the temporal behavior of temperatures and, if detected, their sign and amount.

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