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# TEMPORAL BEHAVIOUR OF THE ANNUAL MEAN PRESSURE ON THE NORTHERN SPANISH PLATEAU BETWEEN 1945 AND 1994

J.L. LABAJO*, A. PIORNO and M.J. IZQUIERDO
*Department of General and Atmospheric Physics, University of Salamanca, Plaza de la Merced s/n, 37008 Salamanca, Spain*

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ABSTRACT

The present work analyses the behaviour of the annual mean atmospheric pressure from 1945 to 1994 as recorded at five weather stations on the Northern Spanish Plateau (Ávila, León, Palencia, Salamanca and Soria) to determine the possible existence of abrupt change and trends. The homogeneity of the variances of different parts of the data series is established. The overall trend of annual mean pressure is determined qualitatively for each station by means of statistical tests. Possible points indicating abrupt changes are explored. After the points of change had been established, the subsets that determine them at each station are studied, analysing their trend. The subsets ranging between the change point and the end of the time periods considered present an increasing trend that is quantified with a linear regression test. The results indicate that on the Northern Spanish Plateau annual mean atmospheric pressure underwent an abrupt change around 1972. From that moment on, an increase trend is observed with a value of around 0.06 mmHg year$^{-1}$. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: Spanish Plateau; pressure, annual mean; trends; abrupt change

## 1. INTRODUCTION

Until quite recently, climate was held to be something essentially invariable that could be quantified by statistical parameters of the observational time series of sufficient length (30 years or more) of the variables linked to it. However, at long time scales, a natural variability in climatic parameters has been detected and accepted. The climatic changes resulting from this long-term variability have been linked to different geological ages, particularly those corresponding to glacial periods (Lines, 1990). However, since the beginning of industrial development, and as a real consequence of it, the anthropogenic impact on the atmosphere has been strong enough to give rise to changes in the behaviour of the climate system (the climatic system has been defined in GARP (1975)).

Such changes are characterised by variations in the statistical properties of the weather elements (mean, variance, etc.) that occur at much shorter intervals of time than those accepted for natural change. The idea of climate as something very fragile and vulnerable, and the possible effects if climatic alterations on the development of human activity, have created a great interest about the climate change at scientific and social levels.

The development of research into climatic changes follows two main lines. One attempts to establish physico-mathematical models that simulate the behaviour of a climatic system under pre-set theoretical conditions. With such models, climatic variations can be related to such phenomena as the increase in the atmospheric concentration of gases responsible for the greenhouse effect (Bretherton *et al.*, 1992; Gates *et al.*, 1992; Hulme *et al.*, 1994). The other main line of inquiry aims at detecting possible climatic changes,

* Correspondence to: Department of General and Atmospheric Physics, University of Salamanca, Plaza de la Merced s/n, 37008 Salamanca, Spain. E-mail: jll45@gugu.usal.es

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primarily at the planetary scale, by comparing current climatic characteristics with those of previous times (Yonetani and McCabe, 1994). Studies have also been carried out to detect climatic changes at the regional scale, using time series of parameters that, while not directly related to climatic elements, may be affected by the variations in the climatic system (e.g. hydrological, such as river flow or lake levels) (Kite, 1989, 1993; Chiew and McMahon, 1993).

The elements usually considered in studies of climatic change are temperature and precipitation (Karl *et al.*, 1993; Storch *et al.*, 1993), although both of these are strongly affected by local scale anthropogenic modifications of the environment in which they are measured. Additionally, the variability of precipitation over time is considerably greater than that of other climatic elements. This may mask the behaviour (e.g. trend) of such elements since when the trends can be shown up they may be due to local environmental alterations. This problem can be avoided by using elements in which such influences are minimal.

It may be accepted that the elements that best indicate a time trend are those with relatively low variability, whose measurement is only affected by instrumental and observational errors. These characteristics are clearly manifested by atmospheric pressure since not even local changes in the location of the barometer would necessarily affect the homogeneity of the time series of measurements. Furthermore, modifications of the environment over time at a local scale affect pressure values much less than those of any other climatic element. Therefore, the use of atmospheric pressure as an element to study possible climatic change at regional scale could, in principle, facilitate a better understanding of global trends.

In the present work, we analyse the behaviour of the atmospheric pressure series corresponding to five weather stations located on the Northern Spanish Plateau to establish their trends and change points over the time studied. The Spanish region selected is very interesting, among other reasons, because of its specific location (between the Atlantic Ocean and the Mediterranean Basin), and the direct effect of the Azores anticyclone on the area.

## 2. DATA AND METHODOLOGY

The data series used here correspond to annual mean pressure values obtained at five weather stations located in the study zone and included in the synoptic network of the Spanish National Meteorological Institute (NMI). These values are obtained from the daily values of the pressure, measured with a mercurial barometer at 00:00, 07:00, 13:00 and 18:00 UT. The stations are located in Ávila, León, Palencia, Salamanca and Soria (Figure 1). They have been chosen due to their locations on the Northern

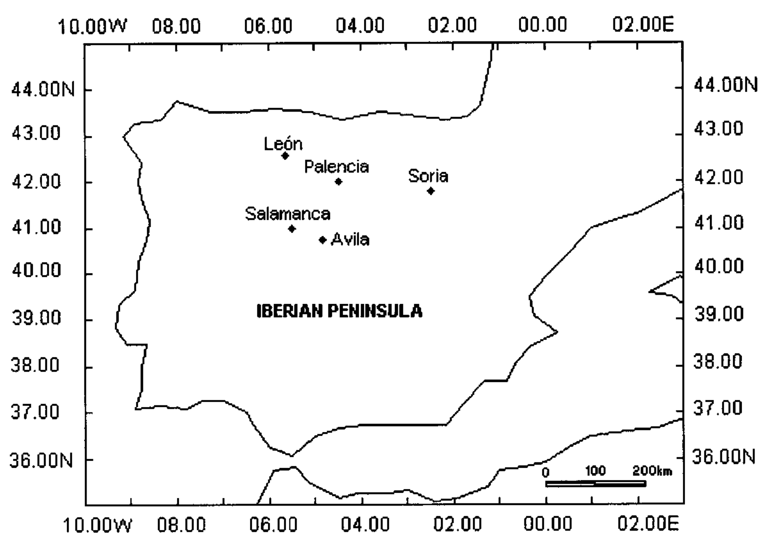

Figure 1. Geographic location of the weather stations used in this study

 

Table I. Geographic coordinates of the weather stations chosen

| Station | Longitude (°W) | Latitude (°N) | Height (m) |
|---|---|---|---|
| Ávila | 4.68 | 40.69 | 1143 |
| León | 5.63 | 42.58 | 914 |
| Palencia | 4.52 | 42.00 | 750 |
| Salamanca | 5.48 | 40.93 | 795 |
| Soria | 2.47 | 41.75 | 1083 |

Table II. Results of the short-cut Bartlett test for the working data series

| Station | $S^2_{max}/S^2_{min}$ ($k=2$, $n=25$) | Value at significant level $\alpha_0=0.05$ | $S^2_{max}/S^2_{min}$ ($k=5$, $n=10$) | Value at significant level $\alpha_0=0.05$ |
|---|---|---|---|---|
| Ávil | 1.08 | 2.30 | 2.35 | 7.11 |
| León | 1.56 | 2.30 | 3.53 | 7.11 |
| Palencia | 1.20 | 2.30 | 2.38 | 7.11 |
| Salamanca | 1.08 | 2.30 | 2.64 | 7.11 |
| Soria | 1.10 | 2.30 | 2.80 | 7.11 |

Spanish Plateau, four in the periphery and one in the centre of the zone covering the work area. Their geographic co-ordinates are shown in Table I. The time intervals have been chosen as a function of the uniformity criteria of the observations required to establish the working series.

In climatic change it is possible to consider three statistically differentiated forms: climatic trend, abrupt change and climatic fluctuations. To establish the existence of climatic fluctuations in the working series, the short-cut Bartlett test is used (Mitchell, 1966), which can be applied when the distribution of the data can be considered as Gaussian. Briefly the test is applied by dividing the working series into $k$ equal subseries, with $k \geq 2$, and $n$ values in each one. In each subseries $S^2_k$ are calculated

$$S^2_k = \frac{1}{n}\left[\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2\right]$$

where $x_i$ are the values of each subseries. If the ratio $S^2_{max}/S^2_{min}$, between the highest and lowest value of $S^2_k$, is lower than that corresponding to the proportion of the variances with a significance level $\alpha_0 = 0.05$ (see Table III-2 of Mitchell, 1966), the equality of variances, and hence their homogeneity, can be accepted for all subseries.

To determine the general trend, two non-parametric trend tests are used, one of them based on the Spearman coefficient, $r_s$, and the second on the coefficient $t$ of Kendall (Sneyers, 1975). To perform the first test, the ranges, $y_i$, of the elements $x_i$ are determined in the ranked series in increasing order. The Spearman coefficient, $r_s$, is the correlation coefficient of the linear regression between the series $i$ and $y_i$, or is obtained from the expression

$$r_s = 1 - [6\Sigma(y_i - i)^2]/[n(n^2 - 1)],$$

where $n$ is the number of data of the series and $i$ is the order of the elements in the original series. The distribution of $r_s$ tends toward a normal distribution with a mean of zero.

To examine whether the null hypothesis (no trend exists) can be rejected or not, it is necessary to calculate the probability

$$\alpha = P(|u| > |u(r_s)|), \quad \text{with} \quad u(r_s) = r_s(n-1)^{1/2}.$$

This is done using a table of reduced normal distribution. If $\alpha < \alpha_0$, the null hypothesis is rejected for a significance level of probability $\alpha_0$. In case of a trend being detected, this will be increasing or decreasing depending of whether $r_s > 0$ or $r_s < 0$.

 

To develop the second test, the value of $n_i$ is established for each element $y_i$, as the number of elements preceding it whose value is less than the value of $y_i$. The $t$ statistic of Kendall is given by $t = \Sigma n_i$, and its

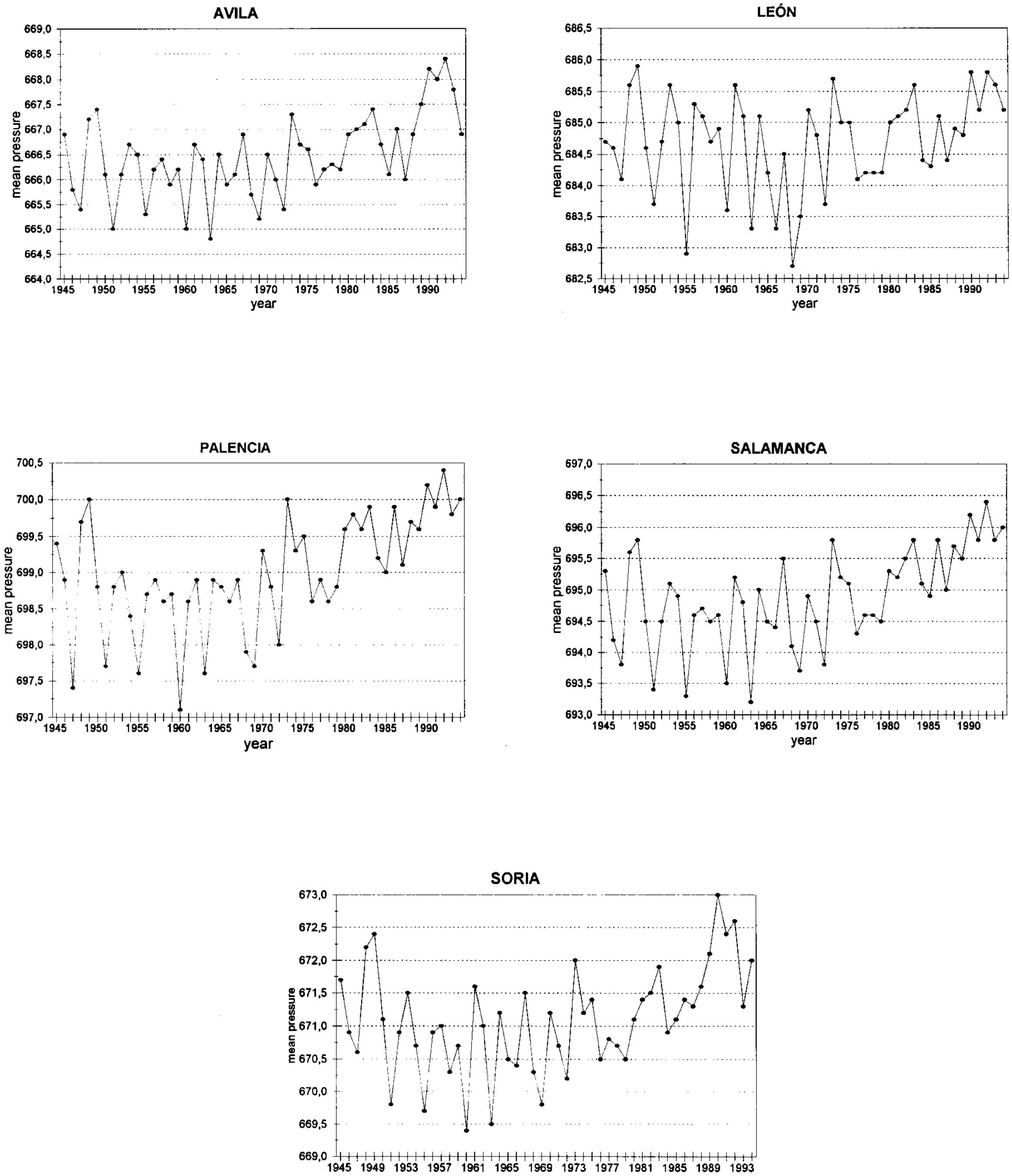


Figure 2. Time distribution of annual mean atmospheric pressure (mmHg) in Ávila, León, Palencia, Salamanca and Soria (1945–1994)

Table III. Results of the Spearman and Kendall trend tests for the original series ($r_s$ and $t$ statistics of Spearman and Kendall; $\alpha_s y \alpha_k$ probabilities corresponding to the $u(r_s)$ and $u(t)$ statistics, respectively)

| Station | $r_s$ | $u(r_s)$ | $\alpha_s$ | Trend[a] ($\alpha_0 = 0.05$) | $t$ | $u(t)$ | $\alpha_k$ | Trend[a] ($\alpha_0 = 0.05$) |
|---|---|---|---|---|---|---|---|---|
| Ávila | 0.498 | 3.49 | 0.0004 | IT | 811.0 | 3.32 | 0.0010 | IT |
| León | 0.189 | 1.32 | 0.1868 | NT | 711.0 | 1.65 | 0.0990 | NT |
| Palencia | 0.535 | 3.75 | 0.0002 | IT | 856.0 | 4.07 | 0.0000 | IT |
| Salamanca | 0.522 | 3.65 | 0.0002 | IT | 847.0 | 3.92 | 0.0000 | IT |
| Soria | 0.377 | 2.64 | 0.0082 | IT | 776.0 | 2.74 | 0.0062 | IT |

[a] IT, increasing trend; DT, decreasing trend; NT, no trend.

distribution tends towards a normal distribution whose mean is

$$E(t) = n(n-1)/4$$

and whose variance is

$$\mathrm{var}(t) = n(n-1)(2n+5)/72,$$

where $n$ is the number of cases. The null hypothesis will be rejected at a probability level $\alpha_0$ when $\alpha < \alpha_0$, with

$$\alpha = P(|u| > |u(t)|),$$

being

$$u(t) = [t - E(t)]/[\mathrm{var}(t)]^{1/2}$$

When the values of $u(t)$ are significant one concludes with an increasing or decreasing trend depending respectively, on whether $u(t) > 0$ or $u(t) < 0$.

After the verification of the existence or not of trend, we analysed the possible abrupt change in annual mean pressure at each of the weather stations using the Mann–Withney test (Sneyers, 1992). In the case of a continuous variable, the test statistic is $X_k = 2R_k - k(n-1)$, with $k = 1, 2, \ldots, n$, where $R_k = \Sigma_1^k r_i$, $r_i$ being the rank of the element $x_i$ in the data series ranked in increasing order. The change point is given by the value of $k$ for which $X_k$ is largest or smallest, depending on whether the change is a decrease or an increase.

Once the change point had been determined, we checked that the data on which the change occurred divides the original series into two statistically different subseries. For this the Lepage test is used (Lepage, 1971). This test is considered to be more powerful than those described above and other frequently used tests (Yonetani and McCabe, 1994). The Lepage statistic, HK (symbol used by Yonetani and McCabe, 1994), is given by

$$\mathrm{HK} = \frac{\left[\sum_{i=1}^{2n} iu_i - \frac{1}{2} n_i(2n+1)\right]^2}{\frac{1}{12} n_1 n_2 (2n+1)} + \frac{\left[\sum_{i=1}^{n} iu_i + \sum_{i=n+1}^{2n} (2n-i+1)u_i - \frac{1}{4} n_1(2n+2)\right]^2}{\frac{n_1 n_2 (2n-2)(2n+2)}{48(2n-1)}}$$

where $n_1$ and $n_2$ are the size of both parts, $a$ and $b$, of the series to be contrasted, $2n = n_1 + n_2$, $u_i = 1$ when, after ordering the initial series, $i$-th element belongs to subseries $a$ and $u_i = 0$ when it belong to subseries $b$. If $\mathrm{HK} > 9.210$ the two parts of the series are statistically different for a probability level of $\alpha_0 = 0.01$, and if $\mathrm{HK} > 5.991$, the parts are statistically independent for a level of $\alpha_0 = 0.05$.

If the differentiation of the two subsets into which each original series is divided by the point of abrupt change is established, we applied the two aforementioned trend tests (Sneyers and Kendall) to the second one in chronological order. If a subseries shows a trend, a linear regression, $x_i = ai + b$, is performed to

 

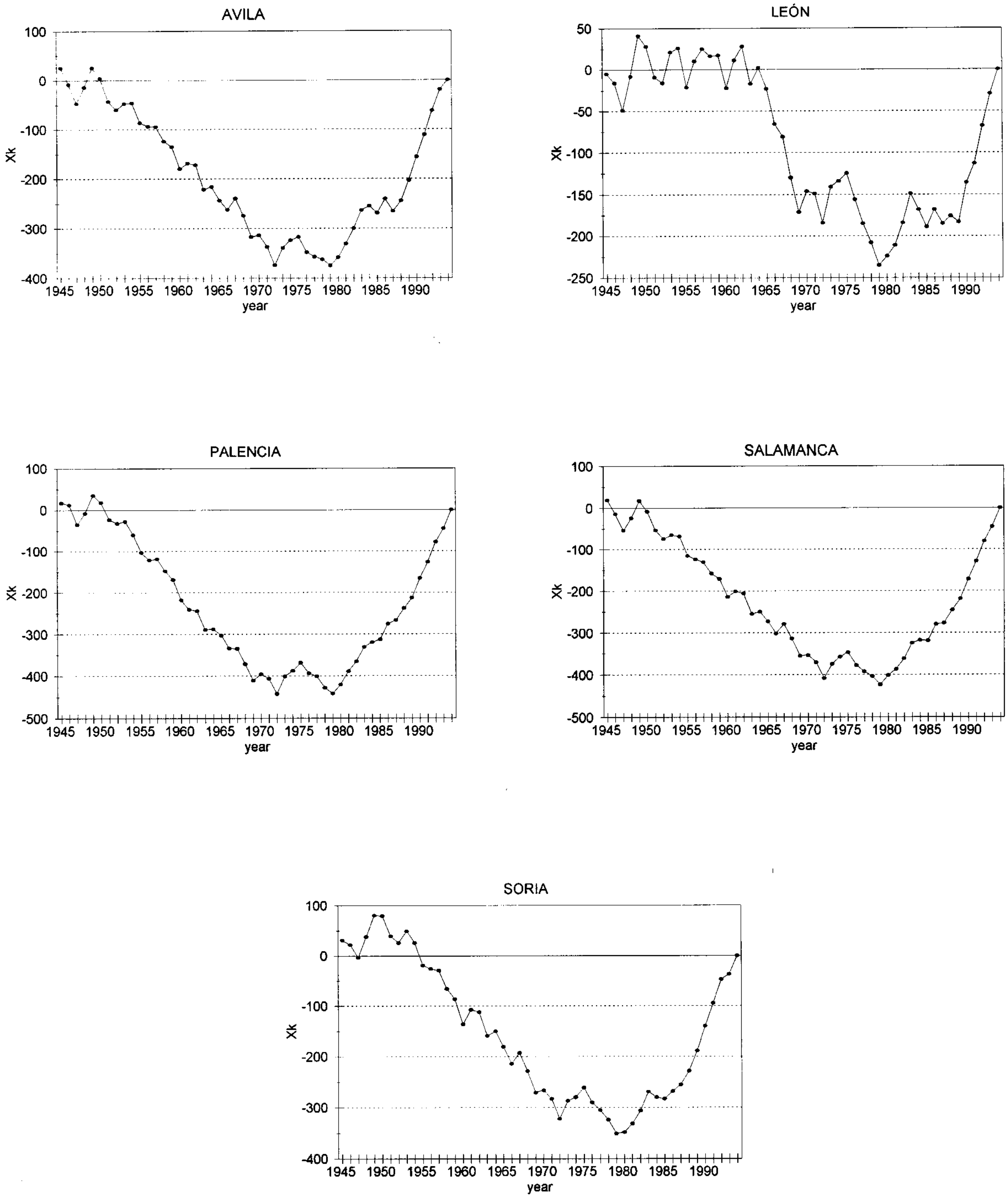


Figure 3. Plot of the $X_k$ parameter of the Mann–Withney test for Ávila, León, Palencia, Salamanca and Soria

Table IV. Values of the Lepage statistic (HK), for the two subseries determined for the change point situated in 1972 ($n_1 = 27$, $n_2 = 23$, $2n = 50$). The two subseries are statistically different to a significant level $\alpha_0 = 0.05$ or more, for HK 5.991

| Station | HK | Statistical differentiation |
|---|---|---|
| Ávila | 11.325 | Yes |
| León | 2.135 | No |
| Palencia | 16.797 | Yes |
| Salamanca | 13.294 | Yes |
| Soria | 9.084 | Yes |

quantify that trend (change per year), where $x_i$ refers to the mean pressure values during each of the years between the point of change and the end of the study period, and $i$ is the year of the date. The trend is established by checking the hypothesis that $a$ is not zero (Sneyers, 1992). This test is equivalent to checking the non-null value of the correlation coefficient between the series $x_i$ and $i$.

Table V. Results of the Spearman and Kendall trend tests for the subseries from 1945 to 1971 ($r_s$ and $t$ statistics of Spearman and Kendall; $\alpha_s y \alpha_k$ probabilities corresponding to the $u(r_s)$ and $u(t)$ statistics, respectively

| Station | $r_s$ | $u(r_s)$ | $\alpha_s$ | Trend[a] ($\alpha_0 = 0.05$) | $t$ | $u(t)$ | $\alpha_k$ | Trend[a] ($\alpha_0 = 0.05$) |
|---|---|---|---|---|---|---|---|---|
| Ávila | 0.162 | 0.84 | 0.4010 | NT | 156.0 | −0.81 | 0.4180 | NT |
| León | 0.276 | 1.44 | 0.1530 | NT | 147.0 | −1.59 | 0.1120 | NT |
| Palencia | 0.173 | 0.90 | 0.3680 | NT | 154.0 | −0.90 | 0.3680 | NT |
| Salamanca | 0.129 | 0.67 | 0.5030 | NT | 161.0 | −0.61 | 0.4160 | NT |
| Soria | 0.319 | 1.66 | 0.0970 | NT | 143.0 | −1.36 | 0.1740 | NT |

[a] IT, increasing trend; DT, decreasing trend; NT, no trend.

Table VI. Results of the Spearman and Kendall trend tests for the subseries from 1972 to 1994 ($r_s$ and $t$ statistics of Spearman and Kendall; $\alpha_s y \alpha_k$ probabilities corresponding to the $u(r_s)$ and $u(t)$ statistics, respectively

| Station | $r_s$ | $u(r_s)$ | $\alpha_s$ | Trend[a] ($\alpha_0 = 0.05$) | $t$ | $u(t)$ | $\alpha_k$ | Trend[a] ($\alpha_0 = 0.05$) |
|---|---|---|---|---|---|---|---|---|
| Ávila | 0.627 | 2.95 | 0.0030 | IT | 180.0 | 2.83 | 0.0050 | IT |
| León | 0.471 | 2.21 | 0.0260 | IT | 175.0 | 2.56 | 0.0100 | IT |
| Palencia | 0.623 | 2.93 | 0.0030 | IT | 187.0 | 3.20 | 0.0010 | IT |
| Salamanca | 0.692 | 3.25 | 0.0010 | IT | 192.0 | 3.46 | 0.0006 | IT |
| Soria | 0.625 | 2.94 | 0.0030 | IT | 185.0 | 3.09 | 0.0020 | IT |

[a] IT, increasing trend; DT, decreasing trend; NT, no trend.

Table VII. Value of the mean annual pressure trend in the interval time 1972–1994 established by the Spearman and Kendall tests. $b$, slope of the linear regression, $p = a + bi$; $r$ is the correlation coefficient

| Station | $r$ | $b$ (mmHg year$^{-1}$) |
|---|---|---|
| Ávila | 0.627 | 0.070 |
| León | 0.471 | 0.042 |
| Palencia | 0.623 | 0.055 |
| Salamanca | 0.692 | 0.065 |
| Soria | 0.625 | 0.065 |

 

## 3. RESULTS

To accomplish the analysis of the behaviour of the atmospheric pressure in the period and the zone of study, we previously verified the quality and uniformity of the data series, and we have completed the data sets when it was necessary. In order to apply the short-cut Bartlett test for checking the homogeneity of

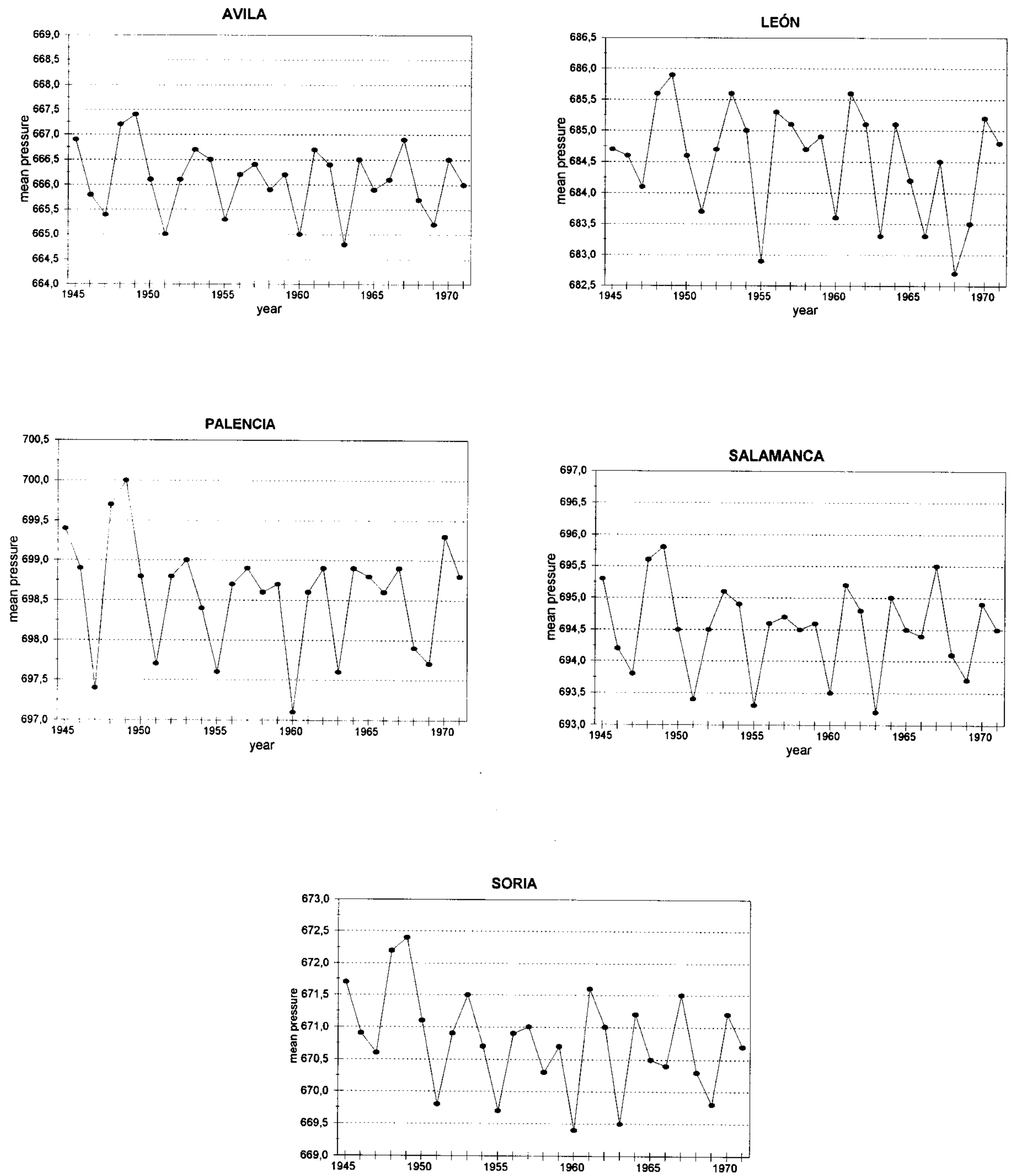


Figure 4. Time distribution of annual mean atmospheric pressure (mmHg) in Ávila, León, Palencia, Salamanca and Soria (1945–1971)

 

the working series, we have verified the normality of the data series. Once this circumstance is established, we have applied the short-cut Bartlett test to each data set, considering two ($k = 2, n = 25$) or five ($k = 5, n = 10$) equal subseries. We have considered $k = 2$ and $k = 5$ because the subseries must have the same number of elements (Mitchell, 1966). In our case the number of subseries can only be 2, 5 or 10 but the subseries with $n = 5$ are not very representative.

The results obtained on applying the Bartlett test to each working series, considering two ($k = 2, n = 25$) or five subseries ($k = 5, n = 10$), are given in Table II. This results indicated that in all cases the variances are homogeneous and the variability of annual mean pressure through the 50 years is similar. The distribution of pressure over time at each station chosen is shown in Figure 2. In this graph, the possibility of a change in the behaviour of annual mean pressure during the 1970s is shown, and a null or slightly negative trend in the first part, and a positive trend in the second part, is seen. In the event of a general trend existing, it must be positive.

Table III indicates the results obtained on applying the trend tests to the original series of the stations chosen and includes the type of trend in each case. It may be seen that, with the exception of León, annual mean atmospheric pressure seems to show an overall increasing trend at a probability level $\alpha_0 = 0.05$. In the case of Ávila, Palencia, Salamanca and Soria both tests coincided.

Figure 3 shows the behaviour of the Mann–Withney statistic, $X_k$. In all cases, a minimum is observed for 1972 and another one for 1979. In most cases, both minima have practically the same value. The difference in the values of $X_k$, in those years, on the other cases is relatively small. Then, we take the value corresponding to 1972 as the point of change of time series treated because it is the first minimum in the chronological order. This abrupt point of change divides the original series into two subseries, from 1945 to 1971 and from 1972 to 1994. The results obtained for the HK statistic applying the Lepage test with values of $n_1 = 27$, $n_2 = 23$ and $2n = 50$, are shown in Table IV. These results indicate that the two subseries into which the original series were divided considering the point of change in 1972 are statistically different at a probability level $\alpha_0 = 0.05$ or more, except in the case of León.

In this case the two subseries can be differentiated at another minor significant level. Therefore, in agreement with the results of the Mann–Withney test, we consider also for León the two subseries indicated.

Each of the two subseries are analysed applying the trend tests. Figure 4 shows the distribution of pressure over time at each meteorological station during the time interval 1945–1971. Table V gives the results obtained on applying the Spearman and Kendall trend tests to the first of the two subseries (1945–1971). To this subseries no trend is observed for any of the stations.

Figure 5 shows the distribution of pressure over time at each meteorological station during the time interval 1972–1994. Table VI gives the results obtained on applying the Spearman and Kendall trend tests to the subseries corresponding to 1972–1994 at each station.

The results obtained in the quantification of those trends, using linear regression, are shown in Table VII. In all cases the order of magnitude of the trend is the same, although the value obtained for León differed the most from the others.

The behaviour over time of the two subseries is completely different; whereas the first (1945–1971) does not point to any trend at any of the stations for a probability level $\alpha_0 = 0.05$, the second one (1972–1994) points to an increasing trend at all the stations for the same level of probability. The magnitude of the trend ranges among 0.042 mmHg year$^{-1}$ for León and 0.071 mmHg year$^{-1}$ for Ávila. The difference of behaviour of the atmospheric pressure in León, with respect to the other stations, can be related to possible instrumental and observational errors.

The present results complement those obtained in the study area, and at larger scales, for the other climatic elements such as temperature or precipitation (Storch *et al.*, 1993; Esteban-Parra *et al.*, 1995).

## 4. CONCLUSIONS

This work analyses the temporal behaviour of annual mean atmospheric pressure in the Northern Spanish Plateau. The results obtained in each weather station agree, in general, in all cases. Moreover, the previous studies of the data series confirm its quality. Therefore, the trend that presents in the data series of annual mean pressure can be due to natural climate variability or to anthropogenic influences. On the other hand, the agreements of the Mann–Withney test applications in all cases permit the consideration of a possible abrupt change in the behaviour of atmospheric pressure in 1972 or 1979. Considering the order and chronological proximity, together with the results of the Lepage test, 1972 is taken as the change point.

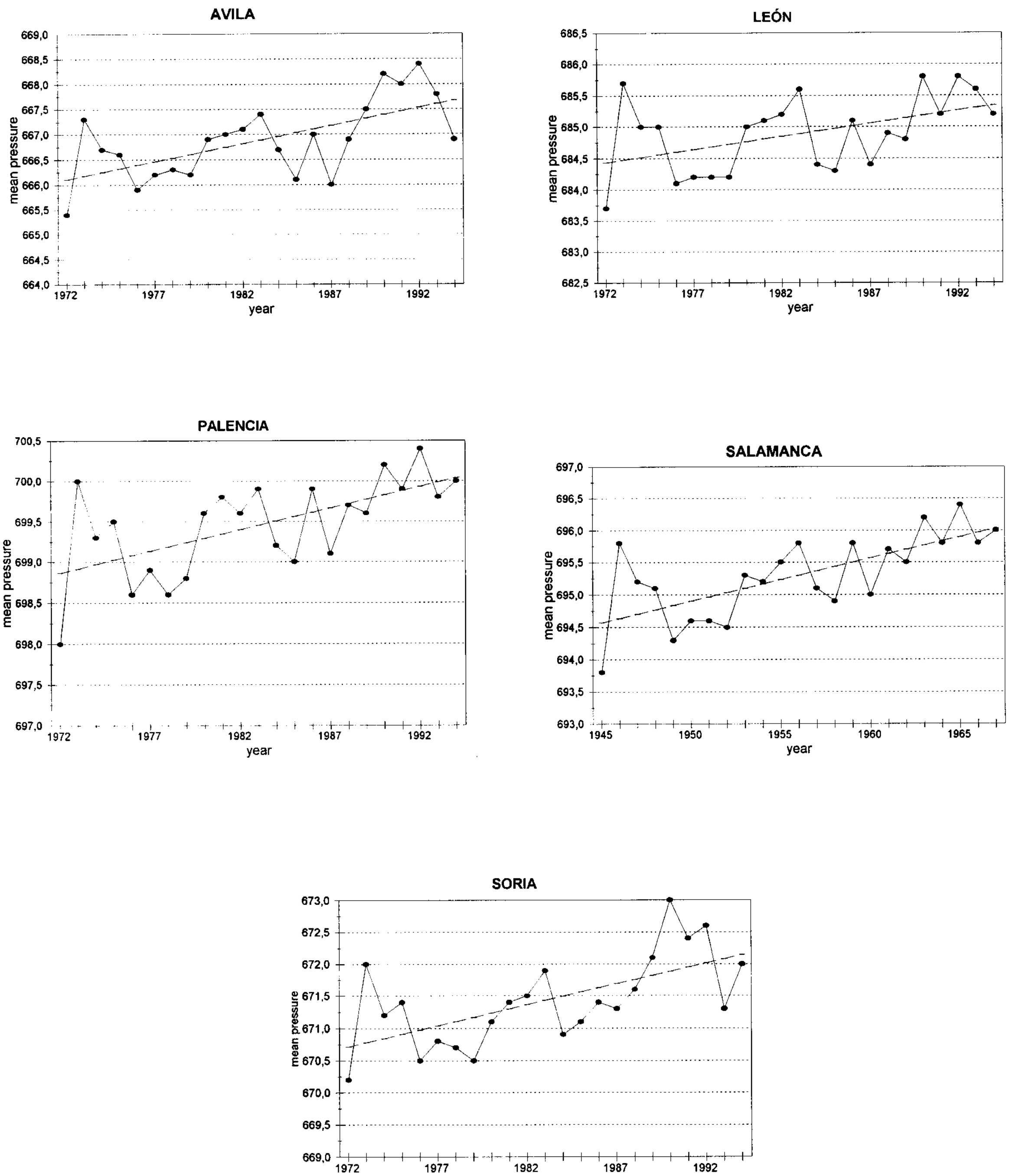


Figure 5. Time distribution of annual mean atmospheric pressure (mmHg) in Ávila, León, Palencia, Salamanca and Soria (1972–1994). The dashed lines are the straight lines of the corresponding linear regression

Therefore, the temporal analysis of annual mean pressure at the five weather stations located on the Northern Spanish Plateau allows the following principal conclusions to be drawn.

(i) The model of the behaviour obtained, corresponding to the period studied, does not point to any trend between 1945 and 1971 and an increasing trend from 1972 to 1994. The mean value of the latter is estimated to be 0.06 mmHg year$^{-1}$. This fact can also be observed in the plots in Figure 2.

(ii) The behaviour of annual mean pressure is practically the same at all the stations in the study area, corroborating the validity of the model for the whole of the Northern Spanish Plateau.

(iii) Although the value of annual variation of atmospheric pressure is small, evidently it cannot continue to increase or decrease indefinitely. Accordingly, one would expect it to tend asymptotically to a particular value or the trend to be reversed at some time in the future. The latter possibility would imply a periodic behaviour of the atmospheric pressure with a period that, if it could be determined, would permit the quantitative modelling of behaviour.

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