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LONG PRESSURE SERIES FOR BARCELONA (SPAIN). DAILY RECONSTRUCTION AND MONTHLY HOMOGENIZATION

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ABSTRACT

Daily meteorological records for Barcelona, Spain, start unofficially in 1780. The records are of very good quality, although the metadata are far from complete. This study gives the general characteristics of the daily instrumental records, details of the data sources together with the reconstruction of the daily and monthly pressure series. In the second part of this paper, a separate time series made up of three (deterministic, periodic and random) components is analysed, and a methodological approach based on the cumulative deviation from the mean is then used to homogenize the monthly pressure series. Copyright © 2001 Royal Meteorological Society.

KEY WORDS: Barcelona; homogenization; pressure series

1. INTRODUCTION

The search for long meteorological series is a vital component of reconstructing the climate during the 18th and 19th centuries. Surface pressure series on a daily basis for Madrid and Barcelona have recently been collected as a result of the Annual to Decadal Variability of Climate in Europe (ADVICE) Project. These will enable better synoptic patterns and other climate information to be established for both southwestern Europe and the continent as a whole during the Early Instrumental Period (EIP: 1780–1860) (Jones *et al*., 1997, 1999).

Following the collection of data and the task of unit conversion, correction and the elimination of mistakes, the homogeneity of the monthly series has to be assessed. Information on the history of the station is necessary for detecting and explaining any possible break points in the series. This may include changes in the site location, measurement procedures, types of instruments, time of measurement, etc. Such information, or metadata, is not always available and in the case of Barcelona not very much is known for some periods.

Despite the fact that there is this lack of metadata, the surface pressure series for Barcelona is excellent in terms of length, quality and there are very few gaps. The series is practically continuous from 1 January 1780 up to the present day.

This paper provides the data sources, the general characteristics of the daily instrumental records and the reconstruction of the monthly pressure series for Barcelona. A new methodological approach for evaluating the homogeneity and determining the break points is then explained and applied to the monthly pressure series for Barcelona.

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2. DATA RECONSTRUCTION

2.1. Data sources

Meteorological records in Barcelona were first made in a continuous and systematic way in 1780. The first scientist whose instrumental observations have been conserved was Francisco Salvá, a doctor who studied in France and participated actively in the development of the Barcelona Royal Academy of Medicine, as well as participating in numerous scientific activities that thrived during the period of the Age of Enlightenment.

Salvá was also very interested in the work of the 'Société Royale de Médecine' and the 'Societas Meteorologica Pallatina' (Fierro, 1991); although there is no evidence that he nor any other observer at the time in Spain were in contact with these societies. It would appear that observers in Spain knew about the work of these foreign institutions but only on an individual basis, mainly due to their relative geographical isolation. The work of these two societies was followed by different groups of observers in France, Central Europe, the UK, Scandinavia and other European countries (Kington, 1988). Salvá may have had contact with the 'Société Royale de Médecine' as a result of his professional connections and as a result of living in France for a few years. It is known from indirect references that he employed the method of observation used by Louis Cotte, the French Society's scientific secretary (ARAMM, 12-8-Molina-31).

Salvá made meteorological observations at his home uninterruptedly between 1780 and 1826. When, as an elderly professor, he could no longer work, his pupil Pedro Vieta fortunately took over the responsibility of the work and strictly followed Salvá's procedural methods. Vieta moved the observatory to the building of the *Diario de Barcelona* newspaper and worked from 1827 to 1854. Vieta ceased making any more observations 2 years before his death, although another doctor, J.R. Campaner, continued to make them and get them published in the press. He also decided to set up an entire observatory in the quarters of the Academy of Medicine. His activities were contemporary with the Spanish Meteorological Office (Instituto Nacional de Meteorología), where work began in 1861. The first records from the Spanish Meteorological Office were not published, however, until 1885. Meanwhile, the *Diario de Barcelona* used data recorded by Dr Albert Burkhart, who was an optician who made meteorological observations close to the urban area of the Academy of Medicine during the 10-year period 1876–1885.

The scientific work of the different observers in Barcelona studying meteorological phenomena would not be of any use for climatic research had the data not been conserved in some type of documentary or bibliographical form (Vinas y Riera, 1977). Salvá fortunately preserved his observations in a documentary source manuscript (ARAMB, Francisco Salvá, *Tablas Meteorológicas*, 3 vols, 1780–1824). The third volume of a total of four is missing (Barriendos *et al*., 1997).

Instrumental records preserved in original documents are very scarce. Apart from the observations in Salvá's *Tablas Meteorológicas*, there are very few other sources that exist. One case is that of the daily recordings made by Lorenzo Presas (1849–1874), which were preserved in the Archive of the Barcelona Royal Academy of Sciences and Arts.

The *Diario de Barcelona* newspaper is a valuable source of information for completing the meteorological data through to the 20th century. Fortunately, the doctors of medicine who recorded the instrumental data in the last two decades of the 18th century and during a large part of the 19th century not only did this out of personal interest but also made the information as widely available as possible. Records of the daily observations appeared uninterruptedly every day on the front cover of the *Diario de Barcelona* right from the first edition (1 October 1792). The lack of original documentation has been resolved as a result of this bibliographical source. The data from the third volume of Salvá's *Tablas* (1799–1811) have been retrieved, for example, along with those corresponding to the 3 years after the *Tablas* came to an end until the time when the observatory was moved (1824–1826). Lastly, the original documentation with the observations after 1826 has been not found but it has been covered by the data that appeared every day in the *Diario de Barcelona*. Without the data that appeared in the newspaper, the pressure series for Barcelona would contain large gaps.

There is a slight difference in the availability of the monthly data. Apart from the aforementioned sources of daily data, from 1861 onwards there was an official meteorological observatory in Barcelona run by lecturers at the University of Barcelona. The monthly data were later published by the Spanish Meteorological Office in the *Spanish Statistical Yearbook*.

2.2. The general characteristics of the daily instrumental records

The different private and institutional meteorological observers inevitably produced different sets of changes. Table I presents the different observers with some additional supplementary ones, which may be useful for further research in the future.

The observatories located in private buildings were all within the medieval town of Barcelona. The distance between them was less than 500 m (Figure 1). The biggest problem is the lack of information

Table I. Different observation periods on a daily resolution

Period	Observer	Location
1) 1 January 1780–31 December 1826	Salvá	11, Petritxol Street
2) 1 January 1827–30 January 1854	Vieta	22, Llibreteria Street
3) 31 January 1854–31 July 1876	Campaner	47, Carme Street (Royal Academy of Medicine)
4) 1 August 1876–18 April 1885	Burckhart	1–5, Zurbano Street
5) December 1866–December 1879	SMN[a]	Old University Building
6) January 1880–31 July 1936[b]	SMN[a]	New University Building
7) 1 August 1936–31 December 1943	SMN[a]	110, Travessera de Dalt
8) 1 January 1944–31 December 1989	INM[a]	Airport, El Prat

[a] Spanish Meteorological Office.
[b] Published in the *Diario de Barcelona* from 19 April 1885.

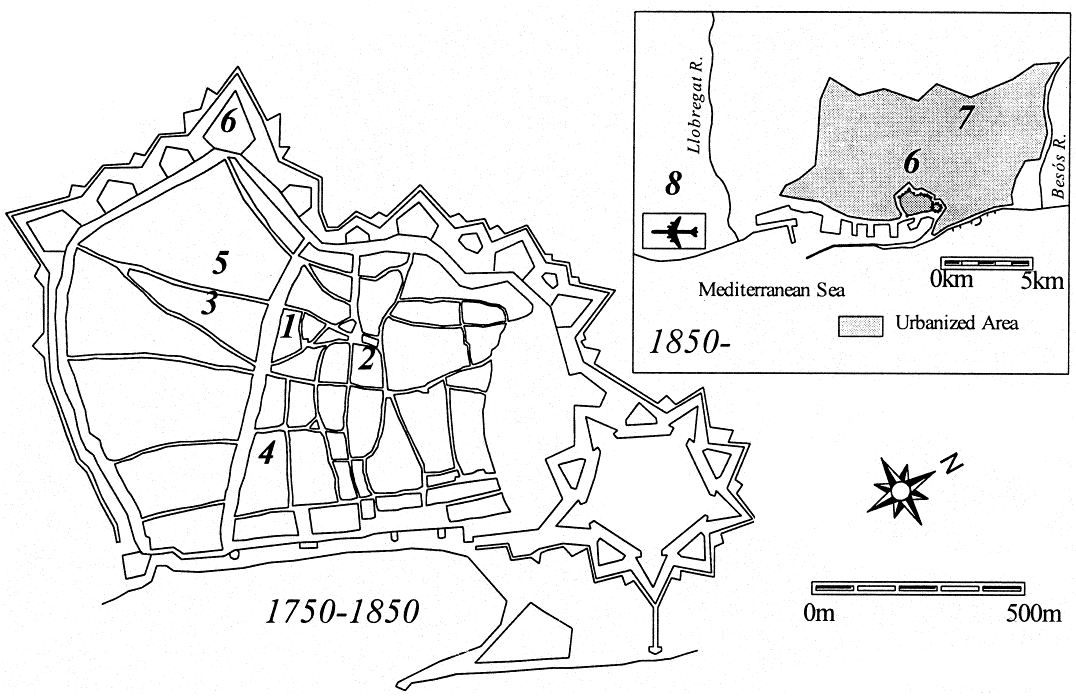

Figure 1. Location in Barcelona of old instrumental records (description of the series in Table I)

concerning the conditions of observation, the methods and the instruments used by each observer. There is only one piece of information that can be used to ascertain the degree of meticulousness that was applied: the first observer had four thermometers that were cross-calibrated to determine any possible fault or imprecision. The first change of location of the observatory is verified by the attempts of a physics professor to reproduce the same conditions in which the old observations were made at the new site (*Diario de Barcelona*, 2 February 1827, p. 257).

The different observations that enable the reconstruction of a daily series are peculiar in that they are from private sources published in the *Diario de Barcelona* from 1780 to 1885. Thereafter, the official observatory at the University provided the data appearing in the newspaper. Further research is required at the Spanish Meteorological Office to locate the unpublished manuscript sources containing the daily observations for the period 1861–1885 and those from 1885 to 1900, which were published in the *Diario de Barcelona*.

The continuity of the official observations up to the present is reliable, although many changes of location did take place. The observatory moved to the northern part of the Ensanche quarter at the start of the Civil War (1936); it was moved near to the harbour, then to the upper part of the city and in recent years it was then moved again to the new Vila Olímpica area, close to the sea. Due to the importance of altitude in atmospheric pressure measurements, the Spanish Meteorological Office has suggested that use be made of the excellent series from the Barcelona international airport at El Prat de Llobregat, 14 km from the city centre. This series covers the period from 1944 to the present day, although the data for 1989 onwards are not available at present.

In general terms, there are three daily observations for the EIP and after: morning (06:00–07:00 h), noon–afternoon (14:00 h) and evening (22:00–23:00 h). The parameters recorded are usually: outside temperature, atmospheric pressure, wind direction, state of the sky, atmospheric phenomena, and rain and evaporation on a monthly basis. Wind speed and relative humidity are also given in J.R. Campaner's data from 1854 onwards. Rainfall and evaporation were also recorded on a daily basis after 1854.

As far as atmospheric pressure is concerned, none of the observatories have information on the type of barometer that was used, the location, bulb height, nor any other aspect concerning the conditions in which the measurements were taken.

2.3. The reconstruction of monthly pressure series

The monthly series of mean pressure used in this paper has been taken from the daily diaries of Salvá, Vieta and Campaner up until 1866, the first as a manuscript document and the others as data published in the *Diario de Barcelona*. The series from 1867 to 1989 has been obtained directly from the Spanish Meteorological Office. This last series has some gaps (1868, 1869, 1874, 1895 and 1896) which are covered by data from the *Diario de Barcelona* (Table II).

Some formal aspects concerning the available observations of atmospheric pressure must be allowed for. While the most outstanding fact is the complete continuity of the series from beginning to end, every time the observatory was moved there was a change in the system of units that was being used. Great care has been taken to identify and convert each set of data due to the fact that no direct indications are given in the original sources. It has been established, however, that the barometer used by Salvá measured in French inches, the one used by Vieta measured in Burgos inches while Campaner's measured in mmHg. All data were converted to mmHg using official conversions (Table III).

The data in mmHg for the period 1780–1860 were converted to 0.1*hPa, the unit selected for calculating the complete series.

Lastly, the selection of the time records was conditioned by the fact that the official series of daily and monthly means are made up of the records taken at 08:00 h and 15:00 h. While a more-detailed time database will become obtainable in the future, the first two observations (morning and noon–afternoon) were selected for the EIP.

Table II. Different observation periods on a monthly resolution

Period	Observer	Location	Height	Co-ordinates
January 1780–January 1827	Salvá	11, Petritxol Street	ca. 30 m	41.2°N–2.01°E
February 1827–January 1854	Vieta	22, Llibreteria Street	ca. 30 m	41.2°N–2.01°E
February 1854–December 1866	Campaner	47, Carme Street (Royal Academy of Medicine)	?	41.2°N–2.01°E
January 1867–December 1879	SMN	Old University Building	15 m	41.23°N–2.09°E
January 1880–July 1936	SMN	New University Building	42 m	41.23°N–2.09°E
August 1936–December 1943	SMN	110, Travessera de Dalt	94 m	41.24°N–2.09°E
January 1944–December 1989	INM	Airport, El Prat	6 m	41.17°N–2.04°E

Table III. Unit conversions

French system (Paris inch)	Castilian system (Burgos inch)
Feet: 324.83575 mm	Feet: 278.635 mm
Inch: 27.069646 mm	Inch: 23.219583 mm
Line: 2.2558039 mm	Line: 1.9349652 mm

Source: Order in Council, 9 December 1852 (Basora, 1865).

3. HOMOGENIZATION OF THE MONTHLY SERIES

There are obvious inconsistencies in the monthly series of surface pressure for Barcelona during the period 1780–1989, especially in the EIP, which can be seen just by a quick inspection. A new methodological approach for evaluating the homogeneity and for correcting the breakpoints in the series is set out and applied below.

3.1. Homogenization methodology

Homogenization of the monthly series, $x(m, y)$ is done by means of:

(a) A control interval that is homogeneous with a time span of Y years.
(b) R homogeneous series of reference, $g(m, y)$, which correspond to a regional grid.

A monthly correction factor for each month of the non-homogeneous period or periods is thus obtained.

The operational procedure is similar to that of Jones *et al.* (1985). Firstly, the monthly mean of the series for the homogeneous period is calculated

$$\overline{X_0}(m) = \frac{\sum_{y=1}^{Y} x(m, y)}{Y}, \quad m = 1, 2, \ldots, 12, \tag{1}$$

where the subscript m is the monthly indicator.

The reference series in the case of Barcelona were Paris (1780–1989) and Gibraltar (1821–1989), these being obtained from the ADVICE dataset (Jones *et al.*, 1999).

The next step is to calculate the average for the R homogeneous series of reference for every month. If the influence of the different points is not similar, however, it would be better to calculate a weighted average:

$$\overline{G_0}(m) = \frac{\sum_{i=1}^{R} \alpha_i \overline{g_{0,i}}(m)}{\sum_{i=1}^{R} \alpha_i}. \quad (2)$$

α_i are the weightings described in Jones *et al.* (1985) and

$$\overline{g_{0,i}} = \frac{\sum_{y=1}^{Y} g_i(m, y)}{Y}, \quad m = 1, 2, \ldots, 12; \quad i = 1, 2, \ldots, R. \quad (3)$$

Lastly, the correction factor for every month (m) and for the non-homogeneous period (j) in the control period is

$$\Delta_j(m) = C_j(m) - C_0(m), \quad (4)$$

where

$$C_0(m) = \overline{X_0}(m) - \overline{G_0}(m) \quad (5)$$

and

$$C_j(m) = \overline{X_j}(m) - \overline{G_j}(m). \quad (6)$$

Accordingly, $C_0(m)$ is the difference between the monthly mean m of the problem series $X_0(m)$ and the weighted average of the means of month m of the reference series in the control period (period in which all of the series are considered to be homogeneous). In the same way, $C_j(m)$ is the difference between the means of each month of the problem series $X_j(m)$ and the weighted averages of the means of the corresponding months of the reference series, in each of the non-homogeneous j periods detected.

The correction is thus applied to each non-homogeneous j period. The correction factors are additive, i.e. they are added to the values of the series undergoing correction.

3.2. Identification of the break points

The most critical step is the identification of the j periods or $(j-1)$ breakpoints. These can be identified by:

(a) non-objective methods applied to the series or to the series of anomalies with respect to the mean of the control period;
(b) objective methods based on the monthly series considered as a time-dependent function.

An objective method has been used in this paper to identify the breakpoints. Three components (two deterministic and one random) of the series have been taken into consideration for this purpose (Rodríguez, 1995). The application of the cumulative deviation to the three-component model is known as the Roberts method (Rodríguez and Martín-Vide, 1998):

$$x = (P + T)(1 + R). \quad (7)$$

The first term (P) in the first factor is the simple periodic seasonal, annual or some other component related to periodicity caused by atmospheric circulation in connection with astronomical factors (season cycle, etc.). The second term (T) in the first factor is the transitory component, such as the mean or any change in the mean produced by systematic error, natural change or human activity (climatic change, any urban effect).

There are two terms in the second factor, the first a constant equal to 1, which reproduces the values of the deterministic component, while the second (R) stands for the dependency of the random component range with the values for the aforementioned deterministic component. This concept of meteorological signal is called the three-component model.

The cumulative deviation can thus be defined as

$$S^* = \sum (x - \mu), \tag{8}$$

where μ is the mean value.

If we consider the three aforementioned components, the cumulative deviation would be

$$S^* = \sum [(P + T)(1 + R) - \mu]. \tag{9}$$

Two main components [one deterministic (S^*_{D}) and the other random (S^*_{R})] can thus be considered, where the deterministic component is

$$S^*_{\mathrm{D}} = \sum [P + T - \mu] \tag{10}$$

and the random component is

$$S^*_{\mathrm{R}} = \sum (P + T)R. \tag{11}$$

It is easy to prove that the random component within the same limit is 0 (Rodríguez *et al.*, 1996) and that the range of ΣP is much lower than $\Sigma (T - \mu)$, also within the same limit.

If there are any transitory components in the series that are different to the mean value, the cumulative deviation can be expressed as

$$S^* \approx \sum (T - \mu). \tag{12}$$

If the transitory components are the result of systematic errors, i.e. step functions, the accumulated deviation will show a linear evolution with a non-zero slope. Any discontinuity in the linear evolution will be a breakpoint. The points of discontinuity that separate linear intervals with markedly different slopes are breakpoints. Each breakpoint is an interval boundary, where the mean values show a deviation of the complete series from the mean—a non-zero slope—or a null deviation but with a difference to the mean of the previous or following zero-interval slope (Figure 2).

This idea can be formulated as

$$\frac{\Delta S^*}{\Delta t} \approx T - \mu. \tag{13}$$

In the stationary series, $T - \mu \approx 0$. If the series has a different sub-series, the difference between each average value and the mean value for the ε series will be

$$\varepsilon = \frac{\Delta S^*}{\Delta t}. \tag{14}$$

The larger this value, the bigger the systematic error will be.

The urban effect and climatic changes do not produce any marked nor constant deviation in the mean value. The accumulated deviation will thus show a polynomial evolution without any discontinuity.

3.3. Correction

After determining the breakpoints, the series needs to be corrected using Equation (4). The corrected series should thus have no significant breaks and must maintain the general characteristics of the initial series. The non-significant breakpoints are those where displacement is less than the standard deviation. The tests for homogeneity should also give better results than the previous series.

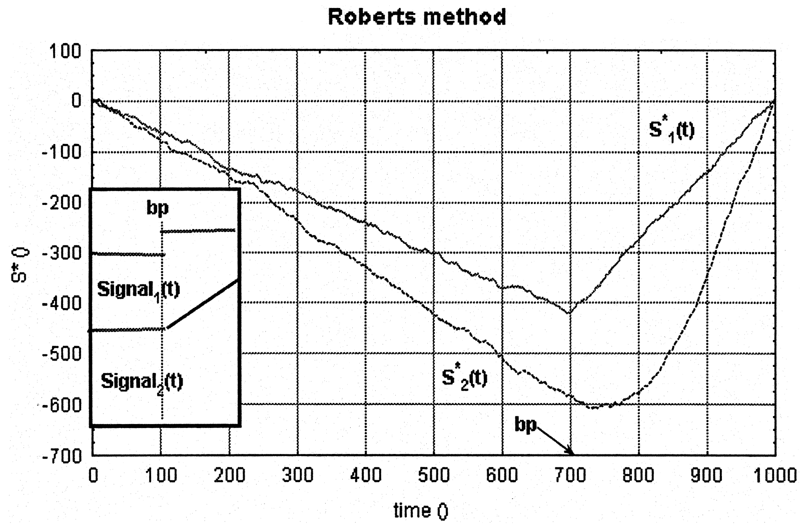

Figure 2. Evolution of the cumulative deviation for two signs with a breakpoint (bp) in $t = 700$. 1, step function; 2, linear function with a non-zero slope

If the correction applied to the whole series is good, the cumulative deviation will obviously have a lower range than the initial series and the evolution will be close to zero. The homogeneity of the corrected series is re-examined by applying the same test again, which may detect any new breakpoint, and an improved result being checked by using the von Neumann test. These will not be significant if the jump is close to one order of magnitude less than the standard deviation of the series.

The von Neumann function is used to test the homogeneity of the corrected series. This function is the evolution over time of the von Neumann ratio (WMO, 1966) and is defined as

$$N = \frac{\sum_{i=1}^{T-1} (x_i - x_{i+1})^2}{\sum_{i=1}^{T} (x_i - \mu)^2} \rightarrow N(t) = \frac{\sum_{\tau=1}^{t} (x(\tau) - x(\tau+1))^2}{\sum_{\tau=1}^{t} \left(x(\tau) - \frac{\sum_{\tau=1}^{t} x(\tau)}{t} \right)^2}. \quad (15)$$

It is not difficult to prove (Buishand, 1987) that

$$\lim_{t \to \infty} N(t) = 2 \quad (16)$$

for the stationary series.

The application of the von Neumann function to the corrected series will clearly give an evolution nearer to 2 than in the case of the original series. The general characteristics of the series do not change as a result of the application of the correction factors in the homogenization procedure. Lastly, the process will have to be repeated if the new breakpoints are important, i.e. if their displacement is of a greater order of magnitude than the standard deviation.

4. RESULTS

The control interval of the pressure series for Barcelona is the sub-period recorded at Barcelona airport by the Spanish Meteorological Office from 1944 to the end of the series. The shift in the control period is the result of correction for altitude. There is clearly an overall displacement of the control interval mean for the early sub-period, for there are breakpoints determined by the cumulative deviation method explained previously (Figure 3).

This method gives the correction factors (Table IV) and provides a new series. The new series has a cumulative deviation close to 0. There are, however, three breakpoints (Figure 3) that determine the corresponding correction factors (Table V).

The second application of the method gives a new and final corrected series (Figure 4).

The von Neumann ratio for the final series is 1.7. This is closer to 2 and better than the 1.4 value for the initial series (Figure 5).

The characteristics of the annual distribution for the final series are also similar to those of the control interval. The smallest values appear in spring, primarily in April, while in winter relatively high values are registered.

The final series for monthly pressure consists of 2520 values, the mean being 1016.3 hPa and the standard deviation 3.5 hPa. The highest average monthly pressure was 1030.5 hPa, corresponding to February 1918, while the lowest value was for May 1862, with 999.4 hPa. Fifty percent of the values in the series are between 1014.3 and 1018.2 hPa, which is a reduced interquartile range (3.9 hPa), in accordance with the sub-tropical latitude of Barcelona; 83.8% of the 2520 values are between 1010 and

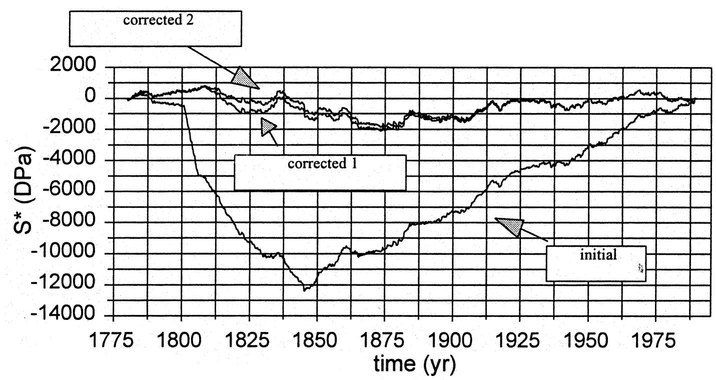

Figure 3. The cumulative deviation of the initial and corrected pressure series

Table IV. Breakpoints and correction factors for the Barcelona pressure series (1780–1989)

Range				Shift
Breakpoint		Breakpoint		(DPa)
Year	Month	Year	Month	
1780	January	1788	December	−3
1789	January	1800	December	−2
1801	January	1806	May	−64
1806	June	1833	November	−16
1833	December	1845	May	−15
1845	June	1861	May	−14
1861	June	1884	February	+5
1884	March	1915	December	+8
1916	January	1943	December	+4
1944	December	1989	December	+7

Table V. The breakpoints and correction factors for the Barcelona pressure series (1780–1989) following the second application of the method

Range				Shift
Breakpoint		Breakpoint		(DPa)
Year	Month	Year	Month	
1780	January	1808	June	+2
1808	July	1822	May	−8
1822	June	1836	April	+4
1836	May	1989	December	0

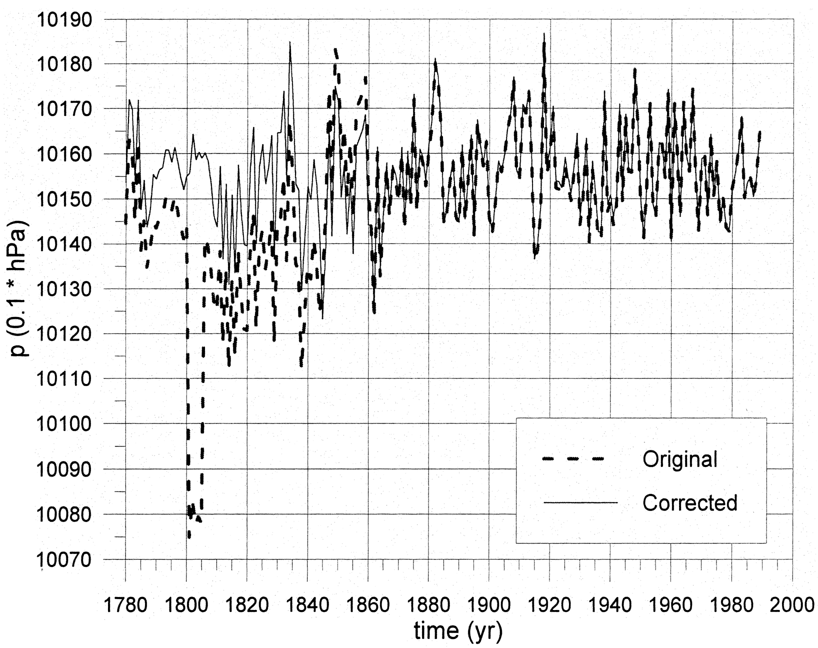

Figure 4. Initial and final series versus grid

1020 hPa. Although the median of the series coincides with the mean (1016.3 hPa) and the frequency distribution is almost symmetric, the series is not Gaussian due to a positive kurtosis (1.3). The corresponding annual series is given in Figure 6.

5. CONCLUSION

Systematic meteorological observations in Barcelona began in 1780, and were performed by Dr Francisco Salvá. The observations were continued by other doctors, and later (1861) by the Spanish Meteorological Office. The compilation of the daily pressure figures allowed for the reconstruction of monthly series of pressure of more than 200 years, ranging from 1780 to 1989. The homogenization of the series was realized by applying the Roberts method, which involves the application of the cumulative deviation to a climate sign model of three components (periodic, transitory and random). The final series of monthly pressure series can be found at the following electronic addresses: www.ysi.net/roberto/pressbar.zip and http://www.cica.es/aliens/aeclima/aec.htm (website of the Spanish Climatological Association).

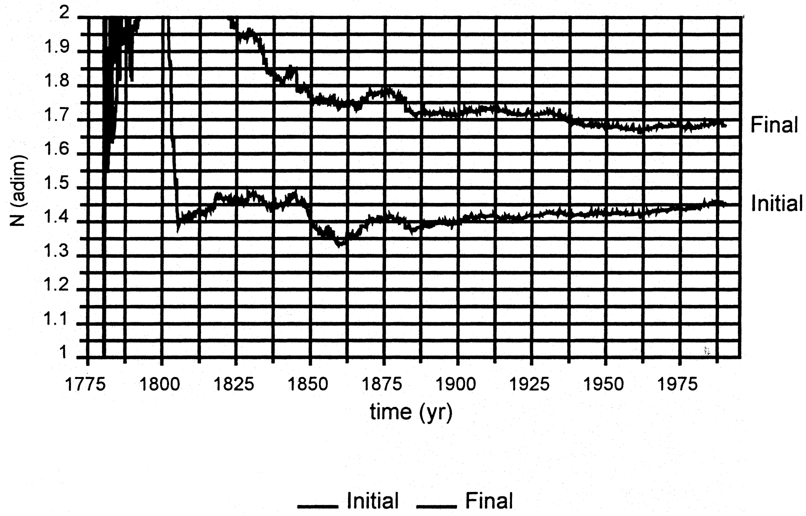

Figure 5. The Von Neumann function

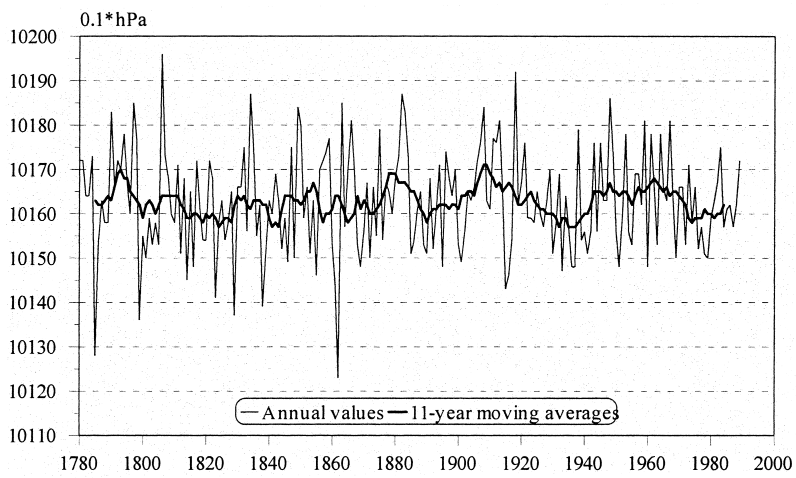

Figure 6. Annual mean pressure series

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