Theor Appl Climatol (2011) 103:159–165
DOI 10.1007/s00704-010-0290-y

ORIGINAL PAPER

Abrupt changes in rainfall in the Eastern area of La Pampa Province, Argentina

S. Pérez · E. Sierra · E. López · G. Nizzero · F. Momo · M. Massobrio

Received: 1 July 2009 / Accepted: 22 April 2010 / Published online: 18 May 2010

Abstract The eastern area of La Pampa Province, Argentina, lies in a transition zone between the humid temperate climate stretching east and the steppe climate stretching west. The area is thus very sensitive to abrupt changes in rainfall. In order to determine the long-term occurrence of such phenomena, long-term annual precipitation series (1921–2004) from 17 stations in the study area were analyzed using the Buishand and Pettitt tests. Results showed a sharp increase in annual rainfall at the southern stations in the 1960s and at the northern and central stations in the 1970s. Increased rainfall can be considered one of the reasons for the subsequent expansion in land planted to crops in the region. While a rapid increase in rainfall can be seen as positive, some researchers believe that if an abrupt decrease in rainfall occurred in future and continued for long, the carrying capacity of the environment could be exceeded, leading to decreased production and environmental degradation.

1 Introduction

Detecting changes in the water regime of agricultural areas is essential for choosing appropriate patterns of land use so that agricultural production does not cause environmental degradation by exceeding the carrying capacity of the environment (Kessler 1994).

The western border of Argentina's agricultural area is located in a transition zone between the humid temperate climate, which extends eastward, and the steppe climate, which extends westward. These climates fall into Groups C and BS, respectively, in Köppen's scheme as modified by Trewartha (Köppen 1948; Trewartha 1968).

For this reason, the area's agricultural economy is vulnerable to changes in water regime. In particular, abrupt changes in water regime can have strong positive or negative effects on agricultural production (Viglizzo et al. 1995, 1997, 2001; Viglizzo and Frank 2006).

The existence of abrupt changes in historical series of precipitation has been detected both on the South American continent and in other geographical areas.

Minetti and Vargas (1997) and Minetti et al. (2003) examined long-term changes in annual precipitation series from locations in South America south of latitude 15° S (including Argentina, Bolivia, Brazil, Chile, and Paraguay). They found that precipitation east of the Andes increased during the 1950s and 1960s, while precipitation west of the Andes decreased during the same period.

Compagnucci et al. (2002) studied the main characteristics of summer precipitation (October to March) in west central Argentina. Using Yamamoto's statistical index, they detected a positive climate jump that occurred between 1973 and 1977.

Forte Lay et al. (2008) analyzed two periods of 30 years each (1947–1976 and 1977–2006) in the Argentine Pampa Plain. They found a greater amount of annual rainfall in the latter period.

De la Casa and Nasello (2010) found significant trends, both negative and positive, in annual rainfall in the province of Cordoba (Argentina) during the 1950s and 1970s.

S. Pérez (✉) · E. Sierra · E. López · G. Nizzero · M. Massobrio
Faculty of Agronomy, University of Buenos Aires,
Avenida San Martín 4453 Buenos Aires, Argentina
e-mail: perez@agro.uba.ar

F. Momo
Institute of Sciences, National University of General Sarmiento,
Juan M. Gutiérrez 1150,
Los Polvorines, Buenos Aires, Argentina

Narisma et al. (2007) identified some 30 areas of the world with sharp decreases in precipitation during the twentieth century. They noted that these areas are mainly located in arid and semiarid regions.

Paturel et al. (1996, 1998, 2004), Servat et al. (1999), L´Hôte et al. (2002), and Meddi and Meddi (2007) found sharp increases in the early 1920s and late 1940s as well as sharp declines in the late 1930s and late 1960s in annual rainfall series for Africa.

Vivès and Jones (2005) detected three abrupt changes in annual rainfall in Australia during the period 1890–1989. The most significant change was the increase in annual precipitation in Eastern Australia in the late 1940s. The other two changes consisted of two consecutive decreases in annual rainfall in Western Australia, the first in the mid-1890s, and the second in the late 1960s.

Against this background, we searched for the occurrence of abrupt changes in annual rainfall in the eastern area of the province of La Pampa as representative of conditions on the western edge of the Argentine Pampas.

2 Materials and methods

2.1 Data

We used monthly precipitation data from 17 localities in the northern, central, and southern subareas of the eastern area of the Province of La Pampa, Argentina (Table 1, Fig. 1) for the period 1921–2004. These data came from the official records of the National Weather Service at the National Institute of Agricultural Technology and the Directorate General of Statistics and Censuses of the Province of La Pampa.

2.2 Quality control

Data from 15 locations was selected for this study. Each location had 84 years of continuous data with less than 5% gaps in the records. A further two locations, Cereales and La Gloria, were eliminated because they did not meet these criteria.

The data from the 15 selected locations was subjected to a process of quality control in order to control for possible errors.

All data above the third quartile plus three times the interquartile range and located more than five standard deviations from the mean were treated as outliers. These outliers were then contrasted climatographically with readings from nearby stations. If the same reading was labeled as out of range for more than two seasons, the value was considered to be correct.

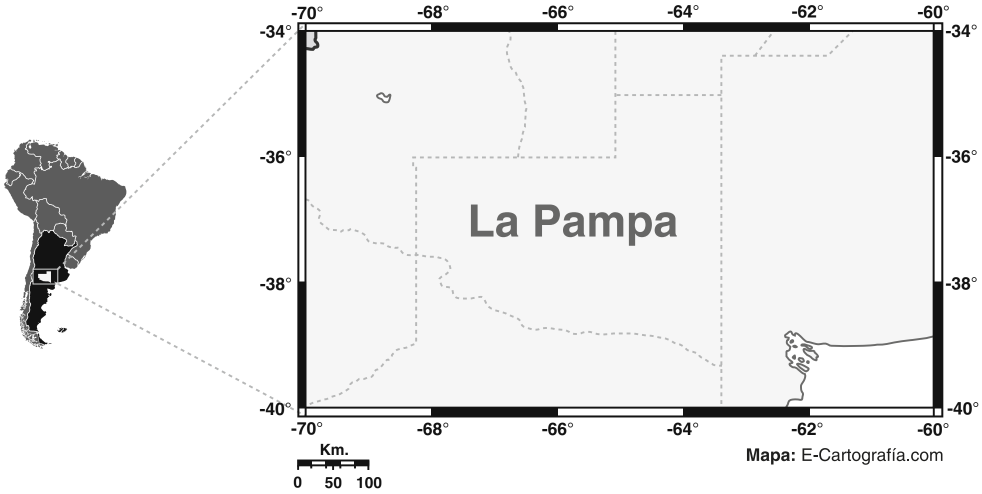
Months classed as outliers and those without data were treated as gaps. Both types of gaps were filled, but no missing data were completed if there were more than three gaps in 1 year. The missing data were estimated from the records of the nearest stations taking into account the correlation coefficient between the various observation posts on a monthly basis.

Table 1 Position of the localities

Locality	Latitude (S)	Longitude (W)	Altitude (msl)	Sub-zone	Origin of the data
Bernardo Larroudé	35°01′	63°34′	120	North	DGEyC
Realicó	35°01′	64°15′	146	North	DGEyC
Intendente Alvear	35°12′	63°32′	123	North	DGEyC
General Pico	35°40′	63°43′	143	North	DGEyC
Trenel	35°42′	64°07′	164	North	DGEyC
Eduardo Castex	35°53′	64°17′	171	North	DGEyC
Rucanelo	36°02′	64°49′	244	North	DGEyC
Lonquimay	36°28′	63°37′	136	Center	DGEyC
La Gloria	36°30′	63°45′	141	Center	DGEyC
Anguil	36°31′	64°01′	152	Center	INTA
Santa Rosa	36°37′	64°16′	175	Center	SMN
Cereales	36°49′	63°51′	124	Center	DGEyC
Macachín	37°08′	63°38′	130	Center	DGEyC
Alpachiri	37°22′	63°46′	145	South	DGEyC
Perú	37°37′	64°09′	200	South	DGEyC
Guatraché	37°40′	63°32′	169	South	DGEyC
Bernasconi	37°54′	63°43′	162	South	DGEyC

SMN National Weather Service, *INTA* National Institute of Agricultural Technology, *DGEyC* Directorate General of Statistics and Censuses

Fig. 1 Location map of La Pampa Province, Argentina



2.3 Homogeneity test

A series of climate data is homogeneous if "... variations have only been caused by variations in weather and climate" (Conrad and Pollack 1950). A climatic series may no longer be homogenous if the measuring station has changed its location, instruments, or weather observation procedures (Wijngaard et al. 2003).

The precipitation series was tested for homogeneity using the Standard Normal Homogeneity Test (SNHT) of Alexandersson and Moberg (1997) on AnClim software (Štěpánek 2006). The test was applied to series of annual values obtained by adding together the monthly values for each year.

We used the series from the National Weather Service's Santa Rosa station as a reference series because Santa Rosa is part of the network of stations that report daily to the World Meteorological Organization (WMO ID No. 87623).

The SNHT was also applied to each of the remaining series. A series of ratios $|q_i|_{i=1}^{N}$ were estimated between the observed value of the series to which the test was applied and the value of the reference station. We estimated the standardized series of ratios $|z_i|_{i=1}^{N}$ for which

$$z_i = (q_i - \overline{q_i})\big/S_q \tag{1}$$

Where q and s_q are the mean and sample standard deviation of the series q_i.

Let $1 \le \nu < N$ and $\mu_1 \neq \mu_2$ where N is the number of years of data availability. The purpose is to test the null hypothesis: $H_0 : z_i \sim N(0,1)\ \forall i$. With respect to the alternative hypothesis:

$$H_1 : \begin{matrix} z_i \sim N(\mu_1, 1)\ i \le \nu \\ z_i \sim N(\mu_2, 1)\ i > \nu \end{matrix}$$

The null hypothesis implies that the mean of standardized series z_i does not change over time, whereas the alternative hypothesis suggests that for some time ν, there is a change in the mean of the series.

The test statistic to determine whether a change has occurred in the mean of the series z_i is

$$T_0 = \max_{1 \le \nu < N}\{T_\nu\} \tag{2}$$

Where

$$T_\nu = \nu\,\overline{z}_1^2 + (N-\nu)\overline{z}_2^2 \tag{3}$$

$\overline{z}_1$ and $\overline{z}_2$ are the sample means of the first ν and last $(N-\nu)$ values of the series z_i. If T_0 is greater than some critical level for a given significance level of the test, we can reject the null hypothesis which states that the series is homogenous. According to Alexandersson (1986), the critical values for the test at significance level α=0.10 and α=0.05 for a series length N=80 are 7.70 and 8.95, respectively.

2.4 Test of randomness

The Von Neumann ratio test for randomness (Von Neumann 1941) was applied to the complete series (1921–2004) of annual precipitation and to the sub-periods defined by changes detected by the Pettitt (1979) and the Buishand test (1982; 1984).

The Von Neumann ratio N is defined as the ratio of the mean square successive (year to year) difference to the variance (Von Neumann 1941):

$$N = \sum_{i=1}^{n-1} \left(Y_i - Y_{i+1}\right)^2 \Big/ \sum_{i=1}^{n} \left(Y_i - \overline{Y}\right)^2 \tag{4}$$

If the sample contains a break, then the value of N tends to be lower than 2 (Buishand 1981). If the sample has rapid variations in the mean, then values of N may rise above 2 (Bingham and Nelson 1981).

2.5 Detection of abrupt changes

Two statistical methods were used to detect abrupt changes in annual precipitation series: the Pettitt (1979) and the Buishand U statistic (1982; 1984).

The Pettitt test is a nonparametric test derived from the Mann–Whitney test (Dagnélie 1970). The null hypothesis is the absence of a turning point in the sequence (x_i) of size N. The variable $U_{t,N}$ is defined as follows:

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} \operatorname{sgn}\left(x_i - x_j\right) \tag{5}$$

$$\text{where}\quad \begin{aligned} \operatorname{sgn}\left(x_i - x_j\right) &= 1 \quad \text{if } \left(x_i - x_j\right) > 0 \\ \operatorname{sgn}\left(x_i - x_j\right) &= 0 \quad \text{if } \left(x_i - x_j\right) = 0 \\ \operatorname{sgn}\left(x_i - x_j\right) &= -1 \quad \text{if } \left(x_i - x_j\right) < 0 \end{aligned}$$

The null hypothesis was tested using the K_N statistic defined by the maximum absolute value of $U_{t,N}$ for t ranging from 1 to $N-1$.

Using rank theory, Pettitt shows that if k represents the K_N value of the study series under the null hypothesis, the probability of exceeding the k value is approximately:

$$\operatorname{Prob}(K_N > k) \approx 2\exp\left[-6k^2 / \left(N^3 - N^2\right)\right] \tag{6}$$

For a significance level α, the null hypothesis is rejected if the estimated probability is less than α. In this case, the series presents a break at time τ where K_N is observed.

The Buishand statistic is derived from an original formulation by Gardner (1969). Gardner's statistic, a two-sided test for change in the mean at an unknown moment, is written as follows:

$$G = \sum_{k=1}^{N-1} P_K \left|S_k / \sigma_x\right|^2 \tag{7}$$

with

$$S_k = \sum_{i=1}^{k} (x_i - \overline{x}) \tag{8}$$

P_k denotes the a priori probability that the rupture occurs after the kth observation.

This formulation implies that the variance σ_x^2 is known. If it is unknown, it can be replaced by the variance of the sample D_x^2, and if P_k is uniform, we finally obtain the statistic U, as defined by

$$U = \frac{\sum_{k=1}^{N-1} \left(S_k / D_x\right)^2}{N(N+1)} \tag{9}$$

with

$$D_x^2 = \sum_{i=1}^{k} (x_i - \overline{x})^2 \Big/ N \tag{10}$$

U statistic critical values were prepared by Buishand (1982) from a Monte Carlo procedure. Since then, better estimates have been published (Buishand 1984).

Table 2 Test results of the Standard Normal Homogeneity Test applied to annual precipitation series from towns in the Province of La Pampa

Locality	Change year	*T* value
Bernardo Larroudé	1985	3.904
Realicó	1941	1.531
Intendente Alvear	1969	4.244
General Pico	1985	9.919[a]
Trenel	2003	3.954
Eduardo Castex	1970	2.646
Rucanelo	1943	3.307
Lonquimay	1988	9.257[a]
Anguil	1991	3.373
Macachín	1990	4.962
Alpachiri	1985	10.196[a]
Perú	1985	3.620
Guatraché	1930	4.133
Bernasconi	1985	2.373

[a] T value exceeds 95%

3 Results and discussion

3.1 Homogeneity test

Eleven of the annual precipitation series available (Table 2) had T values smaller than the critical value and so could be

Table 3 Von Neumann ratio test for randomness

Locality	N
Bernardo Larroudé	1.52
Realicó	1.49
Intendente Alvear	1.03
Trenel	1.15
Eduardo Castex	1.43
Rucanelo	0.44
Anguil	1.28
Santa Rosa	1.43
Macachín	1.49
Perú	1.63
Guatraché	1.61
Bernasconi	1.50

For series with n=84 and a significance level of 5%, the critical value is 1.66

Table 4 Abrupt changes in annual precipitation series detected by the Pettitt (1979) and Buishand (1982, 1984) tests

Locality	Year of change Pettitt	Year of change Buishand	Average before change (mm)	Average after change (mm)	Change (mm)
Bernardo Larroudé	1971	1971	701.8	897.6	195.8
Realicó	1971	1971	629.3	861.6	232.3
Intendente Alvear	1971	1971	661.3	975.9	314.6
Trenel	1971	1971	599.6	850.8	251.2
Eduardo Castex	1971	1971	575.9	824.2	248.3
Rucanelo	1971	1971	559.0	757.2	198.2
Average North	1971	1971	621.2	861.1	240.0
Anguil	1975	1975	581.7	797.3	215.6
Santa Rosa	1974	1974	575.3	751.5	176.2
Macachín	1975	1975	600.0	829.2	229.2
Average Center	1975	1975	586.0	794.1	208.1
Perú	1962	1962	509.1	651.1	142.0
Guatraché	1962	1962	548.5	759.1	210.6
Bernasconi	1966	1966	514.8	695.5	180.7
Average South	1962	1962	524.3	696.0	171.7

Significant change points at 5% level

considered homogeneous at the level of significance $\alpha = 0.05$ (Alexandersson 1986). The other three series had T values greater than the critical value and were, therefore, considered non-homogeneous. These were eliminated from the analysis.

3.2 Randomness test

When tested using the Von Neumann ratio test for randomness (Von Neumann 1941), the annual precipitation series for the period 1921–2004 were found not to be random at a significance level of 5%, (Table 3), showing the existence of processes in the observed values.

3.3 Detection of abrupt changes

The tests for abrupt changes (Pettitt 1979 and Buishand 1982, 1984) applied to the annual precipitation series for the period 1921–2004, indicated the occurrence of significant abrupt positive changes in all the series studied (Table 4) although patterns of change were different between and within different subareas.

Table 5 Von Neumann ratio test for randomness for the periods before and after the occurrence of abrupt change

Locality	Sub-period before year of change		Year of change	Sub-period after year of change	
	N	Critical value 5%		*N*	Critical value 5%
Bernardo Larroudé	1.82	1.58	1971	2.21	1.49
Realicó	1.67	1.58	1971	2.40	1.49
Intendente Alvear	1.82	1.58	1971	1.73	1.49
Trenel	1.71	1.58	1971	1.57	1.49
Eduardo Castex	2.20	1.58	1971	1.90	1.49
Rucanelo	1.68	1.58	1971	1.92	1.49
Anguil	1.67	1.59	1975	1.84	1.46
Santa Rosa	1.85	1.59	1974	1.60	1.47
Macachín	2.00	1.59	1975	1.93	1.46
Perú	1.64	1.54	1962	2.01	1.54
Guatraché	2.40	1.54	1962	1.94	1.54
Bernasconi	2.24	1.56	1966	1.70	1.52

The northern subarea proved to be very homogeneous, with a sharp rise in annual rainfall from 621.2 to 861.1 mm per year from 1971 onwards. This average increase of 240.0 mm in 1971 represented a percentage increase of 38.6%.

Localities in the central subarea were less homogeneous in their behavior, with abrupt increases in precipitation from 1974 or 1975 onwards, depending on the locality. The average annual precipitation in the central subarea rose from 586.0 mm for the period 1921–1975 to 794.1 mm for the period 1976–2004. This increase of 208.1 mm was equal to a percentage increase of 35.5%.

In the towns of southern subarea, a sharp increase occurred in two localities in 1962 and in one locality in 1966. The average rainfall in this subarea increased by 171.7 mm in 1962, from 524.3 mm for the period 1921–1962 to 696.0 mm for the period 1963–2004, equivalent to a percentage increase of 32.7%.

3.4 Randomness of the sub-periods defined by the change

The Von Neumann ratio test for randomness (Von Neumann 1941) was applied to the sub-periods defined by the abrupt changes identified above. All the subsets thus defined were found to be random at a significance level of 5% (Table 5).

Therefore, the behaviors observed before and after the change show that two separate, homogeneous rainfall regimes have existed in the eastern area of La Pampa within the time range studied.

What makes the overall behavior of the series nonrandom is the climate jump detected. The subsets before and after the climate jump behave randomly.

4 Conclusion

The results indicate a sharp increase in annual precipitation in the southern localities of the study area in the 1960s, with the same occurring in the northern and central localities in the 1970s. The precipitation behavior before and after the change is homogenous and corresponds to two distinct water environments.

Increased rainfall partly explains the expansion of the area planted to crops in the years after the change (Sierra et al 1995; Viglizzo et al. 1995).

However, the increased agricultural area makes the region highly vulnerable to possible reductions in rainfall. In fact, the drought affecting Argentina's agricultural area from mid-2008 until mid-2009 has had a strong impact on production (Earth Observatory 2009; WMO 2009), showing that the production system is not able to undergo this kind of event without incurring serious damage.

Villalba and Boninsegna (1985) found that the climate in the subtropical area of South America passes through alternating wet and dry periods, each lasting between 54 and 65 years. These periods give rise to alternating environments that are more or less suitable for agriculture.

With regard to recent changes, Minetti et al. (2003) point out that the severe droughts associated with La Niña during the periods 1988–1989 and 1995–1996 have reversed the increasing trend in rainfall observed over a wide area of Argentina until the late twentieth century. Rainfall decreased at the beginning of the twenty-first century.

Regarding the outlook for the future, Vera et al (2006) point out that there is a consensus on changes in long-term precipitation patterns in South America. This consensus predicts a reduction in winter precipitation over most of the continent during the period 2070–2099 with respect to 1970–1999.

The A1B scenario (Special Report on Emissions Scenarios) of the official Intergovernmental Panel on Climate Change (IPCC 2007) projects a reduction of between 10% and 20% of winter precipitation for the period 2090–2099 with respect to the base period 1980–1999 in the southwest borders of the Pampas, where the province of La Pampa lies. However, no substantial changes are foreseen for the summer season.

All these studies and projections suggest that the possibility of an environment with less rainfall in future cannot be ruled out.

Should an abrupt reduction in rainfall occur and then continue for a long time, the carrying capacity of the environment could be exceeded, causing a fall in production and parallel environmental degradation (Kessler 1994).

References

Alexandersson H (1986) A homogeneity test applied to precipitation data. J Climatol 6:661–675

Alexandersson H, Moberg A (1997) Homogenization of Swedish temperature data. Part I: homogeneity test for linear trends. Int J Climatol 17:25–34

Bingham C, Nelson LS (1981) An approximation for the distribution of the Von Neumann ratio. Technometrics 23:285–288

Buishand TA (1981) The analysis of homogeneity of long-term rainfall records in the Netherlands. R. Neth. Meteorol. Inst. (KNMI), De Bilt, Sci. Rep. N° 81-7

Buishand TA (1982) Some methods for testing the homogeneity of rainfall records. J Hydrol 58:11–27

Buishand TA (1984) Tests for detecting a shift in the mean of hydrological time series. J Hydrol 73:51–69

Compagnucci RH, Agosta EA, Vargas WM (2002) Climatic change and quasi-oscillations in central-west Argentina summer precipitation: main features and coherent behaviour with southern African region. Clim Dyn 18:421–435

Conrad V, Pollack LW (1950) Methods in Climatology. Harvard University Press, Cambridge, p 459

Dagnélie P (1970) Théorie et Méthodes Statistiques. Les Presses Agronomiques de Gembloux 2:463

De la Casa A, Nasello O (2010) Breakpoints in annual rainfall trends in Córdoba, Argentina. Atmos Res 95(4):419–427

Earth Observatory (2009) Drought in Argentina. Naturals Hazards. Available at: http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=37105 Last access: March 2010

Forte Lay J, Scarpati O, Capriolo A (2008) Precipitation variability and soil content in Pampean Flatlands (Argentina). Geofís Int 47 (4):341–354

Gardner LA (1969) On detecting changes in the mean of normal variates. Ann Math Statist 40:116–126

IPCC (2007) Cambio Climático 2007: Informe de síntesis. Contribución de los grupos de trabajo I, II y III al Cuarto Informe de evaluación del Grupo Intergubernamental de expertos sobre el Cambio Climático. IPCC, Ginebra, p 104

Kessler JJ (1994) Usefulness of the human carrying capacity concept in assessing ecological sustainability of land-use in semi-arid regions. Agric Ecosyst Environ 48(3):273–284

Köppen W (1948) Climatología. Fondo de Cultura Económica, Mexico, p 478

L´Hôte Y, Mahé G, Somé B, Triboulet JP (2002) Analysis of a Sahelian annual rainfall index from 1896 to 2000; the drought continues. Hydrol Sci J 47(4):563–572

Meddi H, Meddi M (2007) Variabilité spatiale et temporelle des précipitations du nord-ouest de l´Algérie. Geographia Technica 2:49–55

Minetti JL, Vargas W (1997) Trends and jumps in the annual precipitation in South America, south of the 15°S. Atmósfera 11:205–221

Minetti JL, Vargas W, Poblete AG, Acuña LR, Casagrande G (2003) Non-linear trends and low frequency oscillations in annual precipitation over Argentina and Chile, 1931-1999. Atmósfera 16:119–135

Narisma GT, Foley JA, Licker R, Ramankutty N (2007) Abrupt changes in rainfall during twenthieth century. Geophys Res Lett 34:1–5

Paturel JE, Servat E, Kouamé B, Boyer JF, Lubès Niel H, Masson JM (1996) Procédures d´identification de "ruptures" dans des séries chronologiques – modification du régime pluviométrique en Afrique de l´Ouest non sahélienne. IAHS Publ 238:99–110

Paturel JE, Servat E, Delattre MO (1998) Analyse de séries pluviométriques de longue durée en Afrique de l´Ouest et Centrale non sahélienne dans un contexte de variabilité climatique. Hydrol Sci J 43(6):937–946

Paturel JE, Boubacar I, Aour A (2004) Evolution de la pluviométrie annuelle en Afrique de l´Ouest et Centrale au XX siècle. Sud Sci Technol 12:40–46

Pettitt AN (1979) A non-parametric approach to the change-point problem. Appl Stat 28(2):126–135

Servat E, Paturel JE, Lubès Niel H, Kouamé B, Masson JM, Travaglio M, Marieu B (1999) De différents aspects de la variabilité de la pluviométrie en Afrique de l´Ouest et Centrale non sahélienne. Revue des Sciences de l´eau 12(2):363–387

Sierra EM, Conde Prat M, Pérez S (1995) La migración de cultivos de granos como indicador del cambio climático 1941-93 en la Región Pampeana Argentina. Rev Fac Agr 15(2–3):171–176

Štěpánek P (2006) AnClim Software for time series analysis. Dept. of Geography. Faculty of Sciences, Masaryk University. Bmo. 1,6 MB

Trewartha GT (1968) An introduction to climate, 4th edn. McGraw-Hill, New York, p 408

Vera C, Silvestri G, Liebmann B, González P (2006) Climate change scenarios for seasonal precipitation in South America from IPCC-AR4 models. Geophys Res Lett 33:L13707

Viglizzo EF, Frank FC (2006) Ecological interactions, feedbacks, thresholds and collapses in the Argentine Pampas in response to climate and farming during the last century. Quatern Int 158:122–126

Viglizzo EF, Roberto ZE, Filippin MC, Pordomingo AJ (1995) Climate variability and agroecological change in the Central Pampas of Argentina. Agric Ecosyst Environ 55:7–16

Viglizzo EF, Roberto ZE, Lértora F, López Gay E, Bernardos J (1997) Climate and land-use change in field-crop ecosystems of Argentina. Agric Ecosyst Environ 66:61–70

Viglizzo EF, Lértora F, Pordomingo AJ, Bernardos JN, Roberto ZE, Del Valle H (2001) Ecological lessons and applications from one century of low external-input farming in the pampas of Argentina. Agric Ecosyst Environ 83:65–81

Villalba R, Boninsegna JA (1985) Desarrollo de cronologías en el Noroeste Argentino. Geoacta 13(1):131–139

Vivès B, Jones RN (2005) Detection of abrupt changes in Australian decadal rainfall (1890-1989). Atmospheric Research CSIRO Atmospheric Research Technical Paper N°73, p 58

Von Neumann J (1941) Distribution of the ratio of the mean square successive difference to the variance. Ann Math Stat 13:367–395

Wijngaard JB, Klein Tank AMG, Können GP (2003) Homogeneity of 20th century European daily temperature and precipitation series. Int J Climatol 23:679–692

WMO (2009) 2000-2009, The warmest decade. Press Release N°869. Available at: http://www.wmo.int/pages/mediacentre/press_releases/pr_869_en.html Last access: March 2010