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Breakpoints in annual rainfall trends in Córdoba, Argentina

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ABSTRACT

Long-term rainfall variability in the Province of Córdoba, Argentina is studied. The methodology used was developed by Tomé and Miranda (2004), and the most notable breakpoints in the time series were determined in order to identify sudden transitions from one period to another with a different linear trend sign. All the rain gauges operated by the "Servicio Meteorológico Nacional" (SMN) of Argentina in Córdoba Province, in the period 1930–2006, were analyzed. One of the stations studied, Córdoba Observatorio, has reliable rainfall data since 1873. In this case, the 1925–2006 period and the 1873–2006 period were studied to analyze the influence of series length in terms of the piecewise linear trends produced.

Analyzing only one breakpoint in all the series, a trend change is observed from negative to positive in the 1950s in the north area of the region, while in the other areas the opposite change occurs in the 1970s.

The residual sum of squares obtained with the partial trend method is compared to that produced by the traditional method. This comparison shows how the multiple trend method enables regional changes to be determined for a given climatological variable.

1. Introduction

Throughout the 20th century, great temporal and spatial changes in rainfall trends have been reported all over the world. While some studies show increasing rainfall, in other regions the evaluations show the opposite results (http://epa.gov/climatechange/science/recentpsc.html). For instance, in Europe, the rain series in Ireland show an increase in annual precipitation between 1940 and 1990, particularly on the West Coast (Hoppe and Kiely, 1999; Kiely, 1999; Kiely et al., 1998). The climate of Italy, in turn, seems to be warmer and drier at the moment with a decrease in rainfall attributed to a reduction in the number of days of rain, as rainfall intensity shows a positive trend (Moonen et al., 2002; Brunetti et al., 2004; Bonaccorso et al. 2005; Cislaghi et al., 2005).

In Argentina, Penalba and Robledo (2006) have analyzed precipitation persistence and frequency trends in the Rio de la Plata basin between 1908 and 2004. Their study showed that the annual trend of rainfall frequency and persistence has increased in almost the entire region and in all seasons with the exception of the winter (JJA). Haylock et al. (2006) showed that, in the 1960–2000 period, there is an increase in rainfall in central Argentina, highly correlated with changes in surface temperature of the sea. Liebmann et al. (2004) analyzed precipitation trends between 1976 and 1999 in the region situated between 10°N–40°S and 75°W–35°W, showing that the total amount of precipitation in summer (DJF) has increased in the entire region with the exception of an ~10° area along the Amazon River and an ~5° area in central-north Argentina, from Tucumán Province to the south of Uruguay.

Doyle and Barros (2006) performed an analysis of annual precipitation over a period from 1960 to 1999, focused on the Río de la Plata basin, i.e. Central-North region of Argentina, South of Brazil, Paraguay and Uruguay. Their data showed positive trends to the south of latitude 22°. Minetti et al.

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(2003) assessed interannual precipitation variability over Argentina and Chile with nonlinear trends. They showed changes of annual precipitation for the period 1931–1999, and regionalized Argentina according to similar nonlinear trends. In regions located in central Chile and in higher altitudes of the Cuyo Cordillera and Comahue in Argentina, these authors observed decreasing trends over the whole period. In central regions of Argentina on the NW–SE diagonal they found a constant increasing trend in the period 1930–1988 and then a decreasing trend, and in the NE region they found in general a quasi-permanent increasing trend. Lucero and Rozas (2002) detected a strong positive trend in annual and seasonal precipitation, mainly in summer (JFM) and fall (AMJ) in different areas of Córdoba, Argentina, between 1950 and 1990. They also observed high frequency oscillations of about 10 and 20 years in rainfall time series.

In general, long-term precipitation variability has usually been studied by using methods that analyze rainfall behavior from a gradual perspective, either with linear or nonlinear trends. An alternative analysis, however, is to identify the breakpoints in the time series of a climate parameter which show a sudden transition from one period to another with a quasi-linear trend (Tomé and Miranda, 2004). This method is useful since it is widely recognized that global temperatures and other variables have not experienced monotonic linear changes (Seidel and Lanzante, 2004).

The purposes of this paper are to analyze the rainfall series corresponding to different sites located in the Province of Cordoba, Argentina and to assess their changing trends over time. The methodology used was developed by Tomé and Miranda (2004), and the most remarkable breakpoints in the time series were determined in order to identify temporal and regional behavior. The effect produced by the increase in the number of breakpoints over the residual sum of squares is also analyzed so as to establish the scope of the method.

2. Data and methods

The rainfall data used correspond to all the rain gauges operated by the "Servicio Meteorológico Nacional" (SMN) of Argentina in Córdoba Province, i.e. Córdoba Observatorio (CO), Pilar Observatorio (PI), Villa María de Río Seco (VMRS), Villa Dolores Aero (VD), Marcos Juárez Aero (MJ), Laboulaye Aero (LB) and Río Cuarto Aero (RC). Fig. 1 shows the region of analysis and Table 1 presents the location of the meteorological stations and the period analyzed. Trend analysis was performed of annual rainfall values, i.e. the total amount of rainfall between January 1st and December 31st of each year. In general, the data analyzed are in the period 1925–2006, with the exception of CO which starts in 1873.

Rainfall measurement from the CO station is particularly important, since it is one of the first weather stations in Argentina and South America, and has been constantly working at the same place since its inauguration on October 24th, 1871. So these data can be considered as among the earliest global weather measurement data, which dates from around 1850. In the case of the CO station, we evaluated the periods 1873–2006 and 1925–2006 to analyze the influence of series length with respect to the piecewise linear trends produced.

The annual rainfall series were analyzed with the Tomé and Miranda (2004) method. This procedure obtains the square difference between the observed values of the time series and the values evaluated from a set of partial trends. These partial trends are obtained subject to the condition that the interval between breakpoints must exceed a certain value, called MINIX, and also imposing restrictions on the difference between two successive trends. Then the algorithm determines the best combination of continuous segments, i.e. those that minimize the sum-of-square error, SS. In the present work the MINIX values adopted were equal to or greater than 10, as shorter periods of time could hardly be regarded as climate change. Also, the algorithm was used considering that two consecutive trends must be of different signs in order to analyze the time series by a cyclical behavior. Using different values of MINIX the algorithm could give the same number of breakpoints. In these cases, we chose only the breakpoints corresponding to the set of linear slopes with the lowest SS value.

To assess the level of significance of the results obtained by the algorithm, the Mann–Kendall test (Sneyers, 1990) was used. The Mann–Kendall statistic S is calculated using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=1}^{n} sign(x_j - x_k)$$

where x_j and x_k are the annual precipitation values in years j and k, $j > k$, respectively, and $sign(x_j - x_k)$ is equal to $+1$, 0, or -1 according the sign of $(x_j - x_k)$.

The values of S and variance of S ($VAR(S)$) are used to compute the test statistic Z as follows:

$$Z = S - sign(S) \, / \, VAR(S)$$

Since Z has a normal distribution, the presence of a statistically significant trend is evaluated using the Z value. To test for either an upward or downward monotone trend a two-tailed test at α level of significance ($\alpha = 0.001$ (***), 0.01 (**), 0.05 (*) and 0.1 (+)) was used.

3. Results

3.1. Córdoba Observatory — annual rainfall behavior

Fig. 2 shows annual rainfall behavior at the CO station in the period 1873–2006, and the results from the trend analysis considering one and several breakpoints, i.e. using different MINIX values. Table 2 shows the years in which the breakpoint occurs and the value of the trend obtained with different MINIX values. This table also shows the Z values and the level of significance LS obtained with the Mann–Kendall test for the periods between the years where the breakpoints occur. It should be noted that the results given by the Mann–Kendall test are not strictly comparable with those obtained with the Tomé–Miranda method. Indeed, the latter method finds the set of line segments that best fit the full set of data, whereas the Mann–Kendall test gives only the level of significance for the trend sign in the period analyzed.

Fig. 2 and Table 2 reveal that, before 1948, annual precipitation is approximately constant or slightly decreasing