INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **31**: 44–56 (2011)

(wileyonlinelibrary.com) DOI: 10.1002/joc.2055

Trend detection of annual and seasonal rainfall in Calabria (Southern Italy)

Tommaso Caloiero,[a] Roberto Coscarelli,[b] Ennio Ferrari[c]* and Marco Mancini[a]
[a] *Dipartimento di Ingegneria Idraulica, Ambientale, Infrastrutture Viarie, Rilevamento (DIIAR), Politecnico di Milano, Milan, Italy*
[b] *Consiglio Nazionale delle Ricerche – Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI), Cosenza, Italy*
[c] *Dipartimento di Difesa del Suolo, Università della Calabria, Cosenza, Italy*

ABSTRACT: In order to investigate the behaviour of climatic and hydrological variables, several statistical and stochastic techniques are currently applied to time series. In the present study a statistical analysis of annual and seasonal precipitation has been performed over 109 cumulated rainfall series with more than 50 years of data observed in a region of Southern Italy (Calabria). Trend analyses have been made by using both nonparametric (Mann–Kendall test) and parametric (linear regression analysis) procedures. The long historical series of monthly rainfall data employed in this work have been previously processed through a pre-whitening (PW) technique in order to reduce the autocorrelation of rainfall series and its effects on outcomes of trend detection. The application of the above mentioned procedures has shown a decreasing trend for annual and winter–autumn rainfall and an increasing trend for summer precipitation. Moreover the Mann–Whitney test has been used to evidence the possible change points in the data. The higher percentages of rainfall series show possible year changes during decade 1960–1970 for almost all of the temporal aggregation rainfall. Copyright © 2009 Royal Meteorological Society

KEY WORDS climatic trend analysis; nonparametric tests; seasonal rainfall; Calabria

Received 23 December 2008; Revised 23 October 2009; Accepted 24 October 2009

1. Introduction

In recent years, with growing concerns about the impacts of climatic changes (IPCC, 2007), researchers have employed various statistical and stochastic techniques to identify trends and shifts in hydrological series at different temporal scales of aggregation. With respect to rainfall, nonparametric statistical tests have often been applied to confirm what is already noticed by means of more usual techniques, such as moving averages and regression analysis (Matyasovszky *et al*., 1993a, 1993b; Bradley, 1998; Kundzewicz and Robson, 2000; Burn and Hag Elnur, 2002).

Trend detection on large spatial scales has evidenced a significant increment in precipitation in Northern and Central Asia, eastern parts of North and South America, Northern Europe. In the Himalayan region, Sharma *et al.* (2000) showed an increase in the annual precipitation for the period 1943–1993. Similar results have been observed in North Carolina (Boyles and Raman, 2003) and Canada (Hamilton *et al*., 2001). In Argentina, a rise of the yearly number of rainy days and no significant trend for the daily rainfall amount have also been detected (Lucero and Rozas, 2002). On the contrary, growing drying conditions have been observed in Sahel, Mediterranean area, Southern Africa and Southern Asia. The Central Sahel progressively recorded wetter years since the end of the 1990s (Lebel and Ali, 2009). Liu *et al.* (2008) showed a negative trend in most of the precipitation stations of the Yellow River Basin. In Nigeria annual rainfall, number of rainy days and mean daily rainfall revealed a decreasing behaviour for the period 1961–1990 (Hess *et al*., 1995). Analysis of rainfall change for the winter period during 1950–1994 on the West Coast of USA showed a reduction affecting the entire boreal hemisphere (Chen *et al*., 1996).

As regards analyses developed for European countries, studies on series collected in Ireland from 1940s to 1990s (Kiely *et al*., 1998; Hoppe and Kiely, 1999; Kiely, 1999) confirmed the increase in the total annual precipitation in Northern Europe. Moreover Kiely (1999) showed how intensity of rainfall is growing and the return period of extreme events is reducing: 30-year return period events are becoming 10-year events. In Germany a positive linear tendency in heavy precipitation for the winter, spring and autumn seasons was found. In the summer season, however, heavy precipitation exhibits mostly negative trends (Zolina *et al*., 2008). With regards to the Mediterranean areas, annual decrease in precipitation has been detected by several authors (Giuffrida and Conte, 1989; Amanatidis *et al*., 1993; Kutiel *et al*., 1996; Esteban-Parra *et al*., 1998; Piervitali *et al*., 1998; De Luis *et al*., 2000; Feidas *et al*., 2007; López-Moreno *et al*., 2009). In Spain, Mosmann *et al.* (2004) revealed

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*Correspondence to: Ennio Ferrari, Dipartimento di Difesa del Suolo, Universitá della Calabria, Cosenza, Italy. E-mail: ferrari@dds.unical.it a rising trend in precipitation during the summer season of the period 1960–1980. Gonzalez-Hidalgo *et al.* (2008) showed that trends for winter months (December–January–February) in Spain are dominated by an East–West gradient with a latitudinal temporal shift. Positive trends are mainly located in coastal areas, while negatives ones predominate inland. A regional scale study of precipitation recorded at 15 stations in Hungary (Kertész and Mika, 1999) showed a negative trend in the annual rainfall depths of about 1 mm/year.

In Italy an increasing trend for annual maxima of long daily rainfall series in Northern and Central Italy (Montanari *et al.*, 1996; De Michele *et al.*, 1998) and a negative trend in Sicily (Aronica *et al.*, 2002; Cannarozzo *et al.*, 2006) have been shown. Brunetti *et al.* (2001a) analysed the trend of 67 series recorded in Italy for the period 1951–1996, evidencing how the annual rainfall amount and the number of rainy days per year are diminishing, with rise in rainfall intensity. A further study based on a larger database (1920–1998) of daily rainfall series from North-Eastern Italy revealed no significant trend for the total annual rainfall, negative trend for rainy days and positive trend for intensity of events (Brunetti *et al.*, 2001b).

Different studies of hydrological variables for the Calabria territory (Southern Italy) have shown negative trends for annual and monthly precipitation (Coscarelli *et al.*, 2004; Cotecchia *et al.*, 2004; Ferrari and Terranova, 2004). Particularly Capra *et al.* (2004) have noted a general decrease in the annual precipitation of about 6.5 mm/year, with specific values of about 3 mm/year at low altitudes and 11 mm/year at high altitudes.

The European precipitation trend can be explained on the basis of the atmospheric circulation over the Mediterranean area. In fact, in the warm season, dry conditions are generally associated with subtropical anticyclones, whereas wet conditions are usually connected with thunderstorms caused by advection of cool air (Mennella, 1967; Pinna, 1977). The results of Colacino and Conte (1993), who identified, especially in the last 50 years, a positive air pressure trend over Italy and a contemporary significant increase in the height of the 500 hPa surface, could suggest that precipitation patterns may be caused by an increase in the frequency of subtropical anticyclones over the western Mediterranean basin and by a reduced number of extratropical cyclones (Lionello *et al.*, 2002). In addition, more frequent anticyclones over southern part of Europe (Rodwell *et al.*, 1999) may be due to the strengthening in the NAO (Hurrell, 1995, 1996), which has also caused an increase in the westerlies, with consequent advection of warm and moist air over large areas of Central and Northern Europe (Hurrell, 1995; Jones *et al.*, 1997).

The problem of detecting shifts or change points in rainfall data has been analysed in several studies (Buishand, 1984; Salas, 1992; Kundzewicz and Robson, 2000). Kiely (1999) found significant reductions in rainfall up to 30% since 1975 in studies of eight catchments in Ireland. Ngongondo (2006) detected two rainfall change points at 1965 and 1979 in the annual pluviometric data of Malawi, after which the rainfall declined.

The majority of the studies mentioned so far have assumed that the observed data are serially independent. However, hydrological time series often display statistically significant serial correlations, which increase the probability that a nonparametric test could detect a significant trend (von Storch and Navarra, 1999; Yue *et al.*, 2002b). In order to limit the influence of serial correlation on nonparametric tests, pre-whitening (PW) method was proposed by Kulkarni and von Storch (1995) and by von Storch and Navarra (1999). Zhang *et al.* (2000) employed such method in detecting trends in Canadian temperature and precipitation records. PW has also been applied to limit the influence of serial correlation on the Mann–Kendall (MK) test in the streamflow trend detection studies (Douglas *et al.*, 2000; Burn and Hag Elnur, 2002). Other studies (Yue and Wang, 2002b) investigated the influence of serial correlation on the Mann–Whitney (MW) test to identify the significance of a shift in the mean.

In opposition to the traditional approach, which assumes that long-term trends are deterministic components of the time series, and that the processes represented by the time series are nonstationary, Koutsoyiannis (2006) proposed a stochastic modelling approach which, by hypothesizing stationarity and by simultaneously admitting a scaling behaviour, reproduces climatic trends (considering them as large-scale fluctuations). More recently, a modified MK test which takes into account data scaling has been proposed by Hamed (2008).

In this paper the nonparametric and parametric tests used are briefly described and then applied to detect trends and shifts in annual and seasonal rainfall series observed in Calabria (Southern Italy). Finally, the main results of the statistical analyses are discussed, with particular reference to the geographical distribution of the detected trends within the examined region.

2. Data and methods

Calabria is a region of Southern Italy with an area of 15 080 km^2. Because of its geographic position and mountainous environment, its climate is characterized by mild winters and hot summers with low precipitation. Particularly, the Ionian side is influenced by warm air currents coming from Africa and high temperatures, with short and heavy rainfalls, can be observed. Since the Tyrrhenian side is influenced by western air currents, it presents milder temperatures and mainly orographic precipitation. In the inland zones colder winters with snow and cooler summer with some precipitation are observed (Versace *et al.*, 1989; Caloiero *et al.*, 1990). The monthly and annual rainfall data set used in this work was selected from the original rain gauge network of the Centro Funzionale of Calabria region, which until 2000 consisted of 296 stations, with a density of 1 station per

51 km^2 (Figure 1(a)). Taking into account the missing data in the rainfall series within the period 1916–2000, ultimately 109 series longer than 50 years, and with at least 5 years in decade 1991–2000 and 3 years in period 1996–2000, have been selected, with a density of 1 station per 138 km^2 (Figure 1(b)). The geographical distribution of the 109 rain gauges is shown in Figure 2.

2.1. Analysis of trends

The trend analysis has been performed through the application of simple nonparametric and parametric tests. Nonparametric tests are distribution-free methods, more suitable for non-normally distributed, censored and missing data, which are frequently encountered in hydrological time series (Hirsch *et al*., 1992; Salas, 1992). The best known nonparametric approaches are based on the MK test (Mann, 1945; Kendall, 1962; Lettenmaier, 1988) and the Spearman's rho (SR) test (Yue *et al*., 2002a), which is as robust as the MK test though less frequently used in hydrologic trend analysis (Lettenmaier, 1976; McLeod *et al*., 1983). Moreover, the Brillinger's test could be applied to deal with the effect of serial correlation on the assessment of the significance of trend (Brillinger, 1989). The test is much more complicated than the MK test, and requires a subjective choice of the running average of order, of the degree of smoothing of the periodogram component and of the amount of tapering. More recent nonparametric methods for trend analysis include wavelets (Antoniadis *et al*., 1994; Gilbert, 1999; Craigmile *et al*., 2004) and other smoothing methods, such as locally weighted scatterplot smoothing LOWESS (Champely and Doledec, 1997).

The MK test applied in this study is a rank-based method for evaluating the presence of trends in time-series data, without specifying whether the trend is linear or nonlinear. This test was found to be an effective tool for identifying trends in hydrologic and other related variables, resistant to the effect of extreme values (Hirsch *et al*., 1982; Burn, 1994). The data are ranked according to time, and then each data point is compared to all the data points that follow in time. The MK statistic (Kendall, 1962) is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\,(x_j - x_i) \tag{1}$$

where x_i is the data value at time i, n is the length of the data set and $\operatorname{sgn}(z)$ is equal to $+1$, 0, -1, if z is greater than, equal to, or less than zero respectively. The null hypothesis is that the data are independent and identically distributed, i.e. data have no autocorrelation and trend. For the MK statistic it holds:

$$E(S) = 0 \quad \operatorname{Var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^{n} t_i\, i\, (i-1)(2i+5) \right] \Big/ 18 \tag{2}$$

where t_i denotes the number of tied values of extent i.

For $n > 10$, the test statistic,

$$Z_{\mathrm{MK}} = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{for } S < 0 \end{cases} \tag{3}$$

approximately follows a standard normal distribution (Kendall, 1962). The probability value, p, of the Z_{MK} statistic of sample data can be estimated by using the standard normal cdf $\Phi(Z_{\mathrm{MK}})$:

$$p = 1 - \Phi(Z_{\mathrm{MK}}) = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z_{\mathrm{MK}}} \mathrm{e}^{-t^2/2} \quad \mathrm{d}t \tag{4}$$

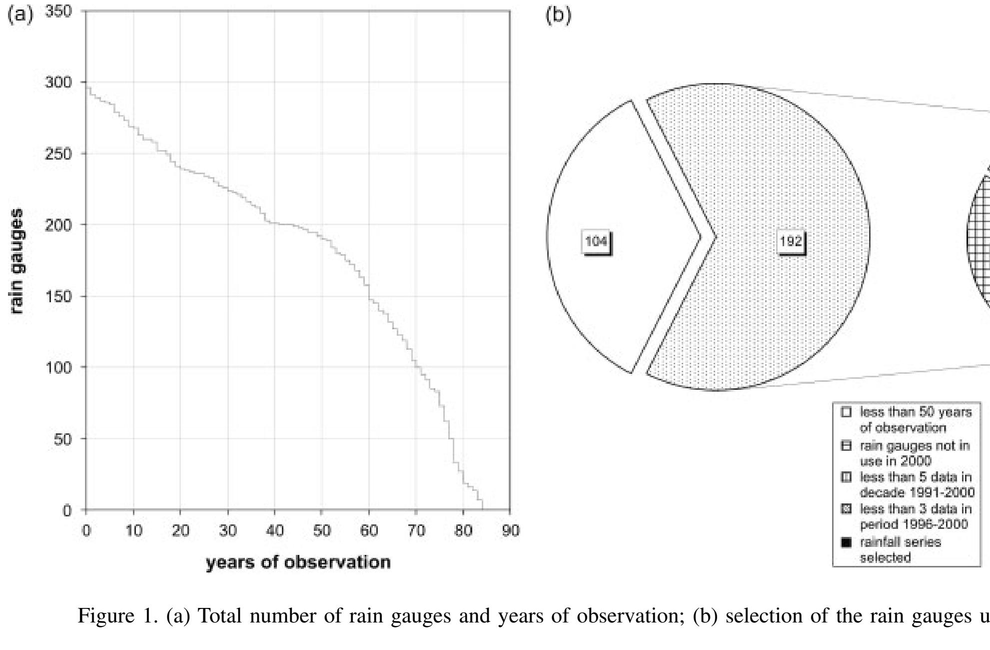

Figure 1. (a) Total number of rain gauges and years of observation; (b) selection of the rain gauges used in this work.

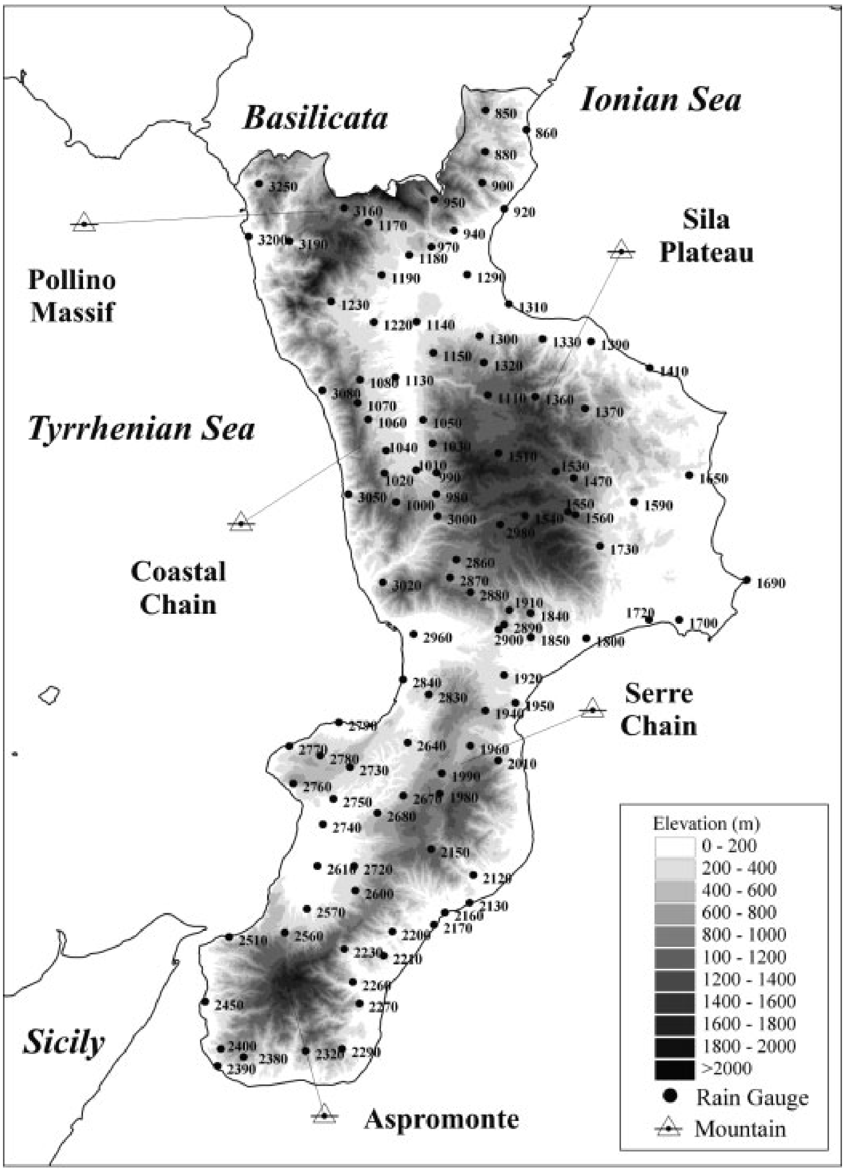

Figure 2. Location of the selected rain gauges.

At the significance level α, the existing trend is considered to be statistically significant, if $p \leq \alpha/2$ in the case of the two-tailed test.

The parametric analysis has concerned the linear regression on seasonal and annual rainfall, expressed as $Y = \beta_0 + \beta_1 X + \varepsilon$. Assuming as null hypothesis that no trend occurred in data series ($\beta_1 = 0$), for each series the confidence interval of the sample estimate of the slope parameter, b_1, has been obtained as:

$$b_1 \pm t_{n-2,1-a/2} \cdot s_{xy} \Big/ \sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2} \qquad (5)$$

where s_{xy} is the covariance and $t_{n-2,1-\alpha/2}$ is the $100(1-\alpha/2)$ percentage point of a Student's t-distribution with $(n-2)$ degrees of freedom (Draper and Smith, 1999). Then each interval has been tested whether or not it contains zero that is the population value of slope parameter β_1 when no trend occurred.

2.2. Identification of shifts

The best known parametric tests for verifying and identifying shifts in statistical properties of hydrologic time series are the Student t-test, the Lepage test and methods based on a Bayesian analysis. Nonparametric tests for shift detection based on a change point algorithm use the Wilcoxon–Mann–Whitney rank sum test and the associated Hodges–Lehmann estimator of trend magnitude (Hodges and Lehmann, 1963; Hirsch and Gilroy, 1985).

In this study a particular form of the nonparametric Mann–Whitney (MW) test, developed by Pettitt (1979), has been employed, following recent statistical analyses of annual and seasonal rainfall time series (Kiely *et al.*, 1998; Kiely, 1999). The MW statistic for a specific year t $(1 \leq t \leq n)$ is given by:

$$U_t = \sum_{i=1}^{t}\sum_{j=1}^{n} \operatorname{sgn}\left(x_i - x_j\right) \qquad (6)$$

A time series with no change point would result in a continually increasing value of $|U_t|$. In the case of existing change points, the MW statistic would exhibit local maximum values. The most significant change point can be identified by the maximum value of $|U_t|$, $K_n = \max\limits_{1\le t\le n} |U_t|$. The probability of a change point being at the year, where the value of $|U_t|$ is a maximum, is approximated (Pettitt, 1979) by:

$$p = 1 - \mathrm{e}^{-\frac{6K^2{}_n}{n^3+n^2}} \tag{7}$$

Introducing the series $\hat{U}(t) = |U_t|$, for each year t the series of significance probabilities of change point can be defined as:

$$p(t) = 1 - \mathrm{e}^{-\frac{6\hat{U}(t)^2}{n^3+n^2}} \tag{8}$$

The Pettitt form of the MW test is extremely useful for detecting shifts in the mean of a sample series, when the change point is unknown, since it provides in any case the most probable change point year of the time series, which correspond to the greatest value of the series $p(t)$. Actually, results obtained from this test have to be examined carefully since they are often characterized by high uncertainty.

2.3. Effects of serial correlation on trend detection

The presence of a serial correlation in the hydrological time series changes the rate of rejecting the null hypothesis of no trend (Yue and Wang, 2004). It particularly alters the variance of the MK statistic, whereas it does not alter its mean and its distribution type (Yue *et al.*, 2002a), thus leading to a disproportionate rejection of the null hypothesis of no trend when it is true. As regards the MW test, simulation experiments have shown that when there is no shift, or a moderate shift, in the mean, a positive serial correlation will increase the possibility to reject the null hypothesis of no shift in thecase it is true, while negative serial correlation will reduce the possibility to detect a shift (Yue and Wang, 2002b).

Several studies (Yevjevich, 1965; O'Connell, 1971; Salas *et al.*, 1979) concluded that simple models such as AR and ARMA models are, for most cases of hydrological series, capable of reproducing the range statistic. In particular, lower-order AR and ARMA models have been widely used for modelling annual, seasonal and daily hydrologic time series (Salas, 1992). The statistical characteristics of the samples of hydrologic series are important for deciding the type of model. Series that present both the autocorrelation function and the partial autocorrelation function decaying to zero as the number lags increases (long memory) generally require ARMA models. Otherwise, if the autocorrelation function gradually decays and the partial autocorrelation function drops to zero after just a few lags (most commonly, after one or two lags), than AR models are more adequate (Salas *et al.*, 1980; Bras and Rodriguez-Iturbe, 1985; Wang and Jain, 2003).

In order to take into account the effects of serial correlation on the outcomes of trend identification tests, various approaches have been suggested in literature. Those predominantly used are the PW, trend-free pre-whitening (TFPW), variance correction (VC) and block resampling techniques, a special version of which is the block bootstrap (BBS) (Khaliq *et al.*, 2009).

The PW and TFPW approaches are based on the assumption that the time series of hydrological variables could be adequately described by an autoregressive process of order one, AR(1), although other formulations of time-series models could be better fitted to hydrological time series (Salas *et al.*, 1980). Moreover, they involve modification of the original data and work with reduced samples. PW techniques allow to 'correct' the time series before conducting the trend identification test, mainly by using the sampling lag-1 serial correlation coefficient r_1 (Kulkarni and von Storch, 1995; von Storch and Navarra, 1999). If r_1 is non-significant at the chosen significance level α, then the trend identification test is applied to the original time series, otherwise it is applied to the pre-whitened time series.

Since the removal of the AR(1) process can modify the existing trend (Fleming and Clarke, 2002), a TFPW approach has been introduced by Yue *et al.* (2002b). For a given time series of interest, the slope of the trend is estimated by using the Sen's robust slope estimator method. Then the time series is detrended by assuming a linear trend and the lag-1 serial correlation coefficient r_1 is evaluated. If r_1 is non-significant at the chosen α significance level, then the trend identification test is applied to the original time series. Otherwise the trend identification test is applied to the detrended pre-whitened series recombined with the previously estimated slope of trend.

The VC approach is based on the fact that N serially correlated observations contain as much information as N^* ($<N$) uncorrelated observations. Yue *et al.* (2002b) demonstrated through extensive Monte Carlo simulations that the presence of serial correlation in a time series does not alter the asymptotic normality of the MK test statistic S, nor does it alter the mean of S. However, it does change the variance of S, which can be corrected by using an effective sample size (Bayley and Hammersley, 1946; Hamed and Rao, 1998; Yue and Wang, 2004).

In the BBS approach, the original series is resampled in predetermined blocks for a large number of times to estimate the significance of the observed test statistic (Kundzewicz and Robson, 2000). This approach avoids the modification of original data and also incorporates the effects of serial correlation higher than just the PW approach in a manner similar to the VC approach. The method reproduces blocks of the observed series to form synthetic series, trying to preserve the original dependence within the blocks, though it is destroyed at boundaries between blocks. Each observed record is first divided into blocks of consecutive observations.

The synthetic replicates of the original data series have been obtained by randomly resampling the blocks of observations with replacement and concatenating them to provide simulated series of length equal to that of the observed record.

From the analysis of the autocorrelation functions and of the partial autocorrelation functions of the rainfall series used in this paper, the AR(1) model has been considered as the most adapt to reproduce the statistical features of the rainfall series. Usually to reduce the influence of an AR(1) component on the application of both the MK and MW tests (Kulkarni and von Storch, 1995; Douglas *et al.*, 2000; Zhang *et al.*, 2000; Burn and Hag Elnur, 2002), it is applied the pre-whitening procedure as suggested by von Storch and Navarra (1999):

$$Y_t = X_t - r_1 \cdot X_{t-1} \tag{9}$$

where r_1 is the lag-1 serial correlation coefficient of the sample data, that can be expressed as:

$$r_1 = \frac{\dfrac{1}{n-1}\displaystyle\sum_{t=1}^{n-1}[X_t - E(X_t)][X_{t+1} - E(X_t)]}{\dfrac{1}{n}\displaystyle\sum_{t=1}^{n}[X_t - E(X_t)]^2} \tag{10}$$

where $E(X_t)$ is the mean of the sample data. von Storch and Navarra (1999) demonstrated that pre-whitening operation is not necessary for $r_1 \leq 0.1$.

3. Results and discussion

Most rainfall series recorded in rain gauges of Calabria region and analysed in this work present serial correlations in data, especially the annual and winter ones (Table I). For this reason, the nonparametric procedures described above for the exploratory analysis of trend and shift (MK and MW tests) have been applied to annual and seasonal precipitation series after pre-whitening of the data through von Storch's procedure (von Storch and Navarra, 1999). Alternatively, the block-bootstrap procedure has been applied (simulations: 1000; block dimension: 2) to perform a comparison with the pre-whitening approach to assess significance of trend. All tests have been performed at 5% confidence level. As previously noted, the influence of serial correlation on the results obtained from nonparametric tests (Yue and Wang, 2002a, 2002b; Yue *et al.*, 2002b) can be evidenced by comparing the total number of stations showing significant trends of the different data sets for each aggregation time (Figure 3).

Moreover, a test based on the statistical significance of linear regression slope of rainfall data with time has been applied for the same goal. The most important result concerns the negative trend found for annual and autumn–winter rainfalls, and the positive one revealed for summer rainfalls, confirming the regression analysis of the seasonal rainfall time series. In particular, the difference between the winter and summer rainfalls is becoming smaller than in the past for 72% of the rain gauges set (Figure 4). Moreover, 16% of the rain gauges show concomitant negative trends for winter and summer rainfalls and only 12% show positive ones.

Table I. Number of autocorrelated series.

Period	*No.* of autocorrelated series ($r_1 > 0.1$)
Annual	70
Winter	78
Spring	67
Summer	17
Autumn	34
Aut–Win	53
Spr–Sum	37

The identification of abrupt changes and shifts for all the long aggregation rainfalls observed in Calabria has been performed through the MW test. The uncertain results obtained from this test can be due to the short dimension of the series and to various factors, such as station relocations, changes in observing procedures (including instrumentation) and in methods of calculating monthly mean, factors that are difficult to identify in Calabria, since there is a lack of metadata provided by the Centro Funzionale. Generally, the magnitude of the variations caused by these inhomogeneities is as large as, or even larger than, the signal that is being studied, causing distortions in subsequent analyses (Slonosky *et al.*, 1999).

With reference to the results obtained from the pre-whitening procedure, more details on trend and shift detection for the various temporal aggregations are shown in the following paragraphs.

3.1. Annual rainfall

The annual rainfall data show negative trends for the most part of the series, which is a typical feature of all the long aggregation rainfalls observed in Calabria. In fact the MK nonparametric test reveals a statistically significant trend for 52 series, which is negative for 50 series and positive for 2 series (Figure 5(a)). Similar results have been obtained through regression analysis of annual precipitation values with time: they show significant trend for 49 series out of 109, negative for 47 series and positive for 2 series (Figure 5(b)). Significant negative trends are distributed all over the region, with higher values observed in the main elevated areas (Coastal Chain, southern part of region and Serre Chain). The identification of the most probable change point years in annual precipitation observed in Calabria suggests the years 1967 (17% of the rain gauges), 1961 (12%) and 1982 (11%) (Figure 5(c)).

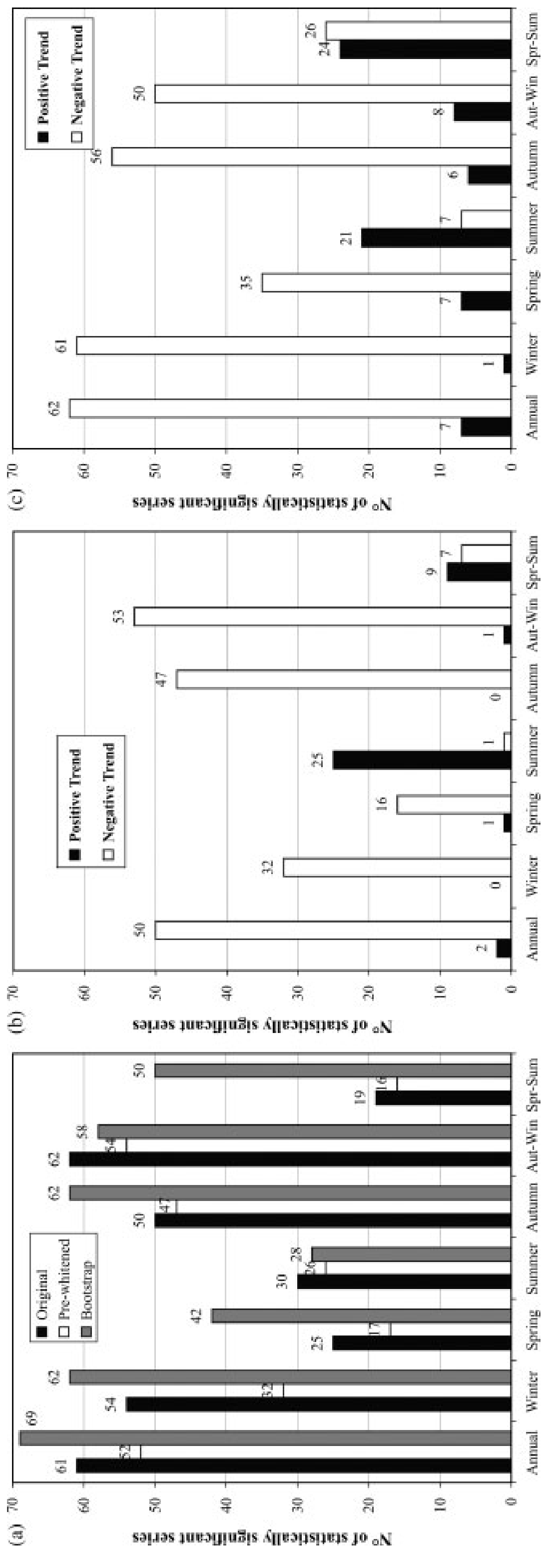

Figure 3. (a) Comparison of trends for different time aggregations of original data set, pre-whitened data set and block-bootstrap procedure (MK test); (b) negative and positive trends for pre-whitened data set (MK test) and (c) negative and positive trends for block-bootstrap procedure (MK test).

3.2. Seasonal rainfall

Further analyses were separately made on rainfall data aggregated for winter, spring, summer, autumn, autumn –winter and spring–summer seasons. As for annual precipitation, the six pre-whitened data series thus obtained were analysed in order to evaluate both the presence of trends (nonparametric MK test, statistical significance of linear regression slope of rainfall data with time) and the presence of shifts (MW test).

3.2.1. *Winter*

The MK nonparametric test shows 32 series with a negative trend (Figure 6(a)). A statistically significant trend of linear regression slope with time has been recognized for 34 rain gauges (31%), all characterized by negative values (Figure 6(b)). Significant negative trends are mainly present over the main mountains (Coastal and Serre Chains). The most probable change point year for winter precipitation is 1974, as revealed by 35% of the rain gauges (Figure 6(c)).

3.2.2. *Spring*

The MK test shows 17 series with a significant trend: a negative one for 16 series and a positive one for 1 (Figure 7(a)). A statistically significant trend with time for 20 series out of 109 (18%) has been detected through linear regression analysis. More specifically, results show a negative trend for 18 series and a positive trend for 2 series (Figure 7(b)). The significant negative trends are mainly positioned in central mountainous part of the region (Coastal Chain and Sila Plateau). The most probable change point years for winter precipitation are 1942 (15% of the rain gauges), 1981 (12%) and 1961 (11%) (Figure 7(c)).

3.2.3. *Summer*

Elaborations on summer precipitation show an opposite trend to the previous ones, especially to winter and annual precipitation. The MK nonparametric test, only for the series with statistically significant results (5% confidence level), shows 25 series with a positive trend and only 1 (Polistena rain gauge, code 2720) with a negative trend. The rain gauge stations with a positive trend seem to have a uniform distribution over the whole Calabrian territory (Figure 8(a)). The obtained quantitative evaluation of these trends, showed by the interpolating curves with the same value of the linear regression slope (Figure 8(b)), does not seem to be particularly high. Figure 8(c) summarizes the results of the MW test for an estimate of the change year: 22 series have a probable change year coincident with 1963.

3.2.4. *Autumn*

The results obtained by elaborating the autumn rainfall data are similar to those relative to the winter precipitation. In this case, 47 out of 109 series (about 43%) present a significant negative trend, evaluated through the

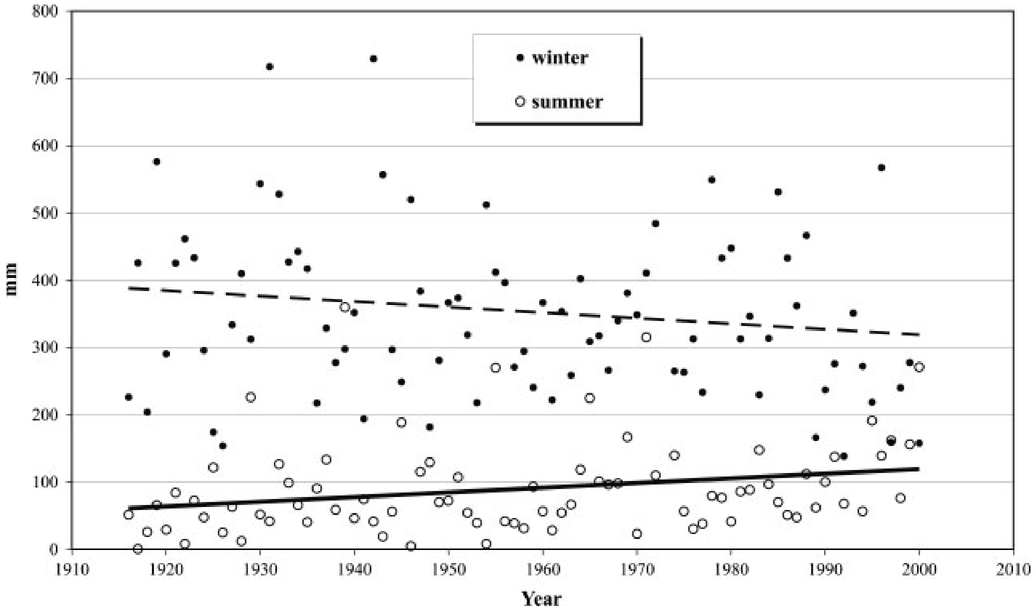

Figure 4. Example of comparison between trends of winter and summer precipitation (Catanzaro rain gauge, 1850 code).

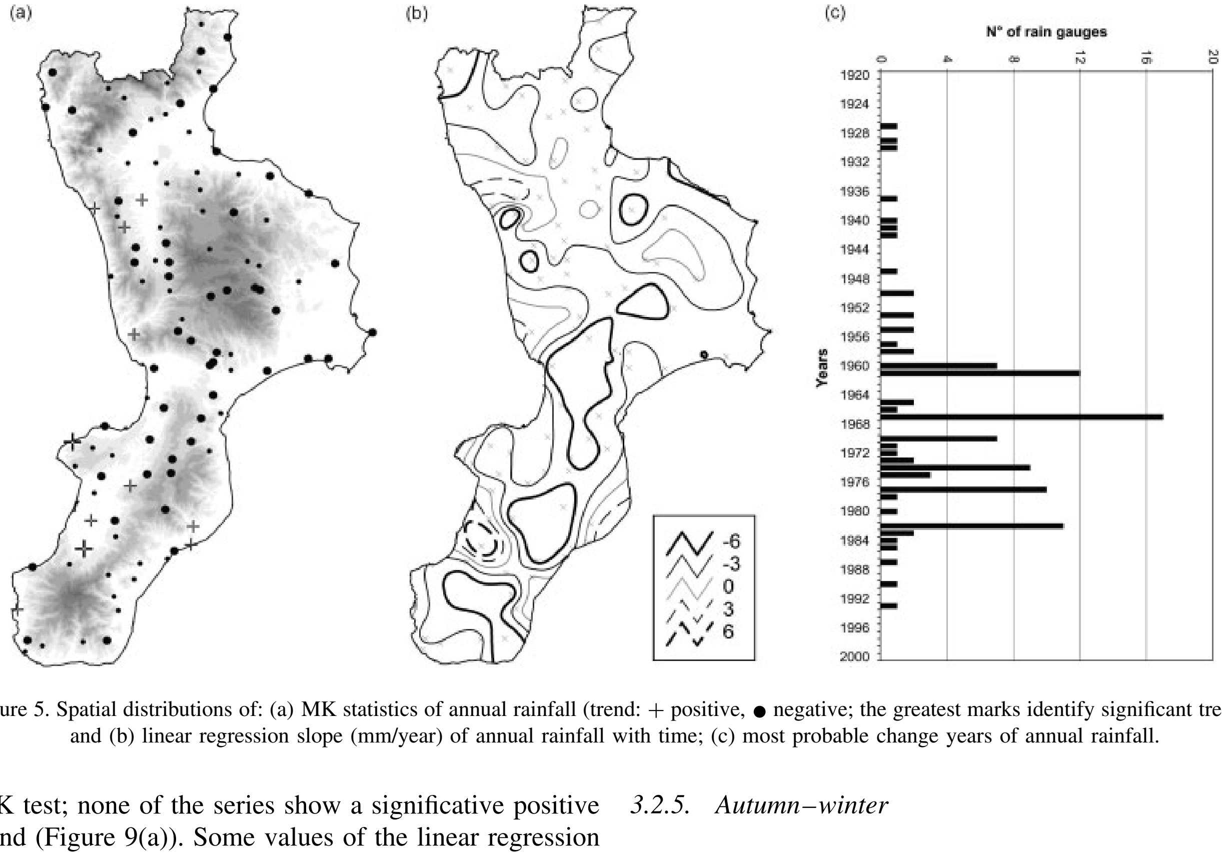

Figure 5. Spatial distributions of: (a) MK statistics of annual rainfall (trend: + positive, ● negative; the greatest marks identify significant trends) and (b) linear regression slope (mm/year) of annual rainfall with time; (c) most probable change years of annual rainfall.

MK test; none of the series show a significative positive trend (Figure 9(a)). Some values of the linear regression slope calculated for the various series are lower than −4 mm/year and localized along the Southern Ionian side of Calabrian territory and in a few areas near the Northern Tyrrhenian coast (Figure 9(b)). The regression analysis carried out on the precipitation series registered at Laghitello CC rain gauge (code 1070) showed the lowest value of the slope (about 8 mm/year). As to what concerns the most probable change years, 1960, 1967 and 1977 reveal the highest frequencies, equal respectively to 24, 19 and 17 rain gauges out of 109 (Figure 9(c)).

3.2.5. Autumn–winter

Linear regression analysis shows statistically significant results for 54 series of autumn–winter rainfalls out of 109 (53 data series with a negative trend and 1 with a positive one) (Figure 10(b)). The same percentages of negative and positive trends emerge from the nonparametric tests (Figure 10(a)). The distribution of the negative trends of autumn–winter rainfalls is very similar to the one showed for annual rainfalls (Figure 5(a) and (b)), with higher values observed in the main mountains of the southern part of Calabria (Serre Chain). The most probable change

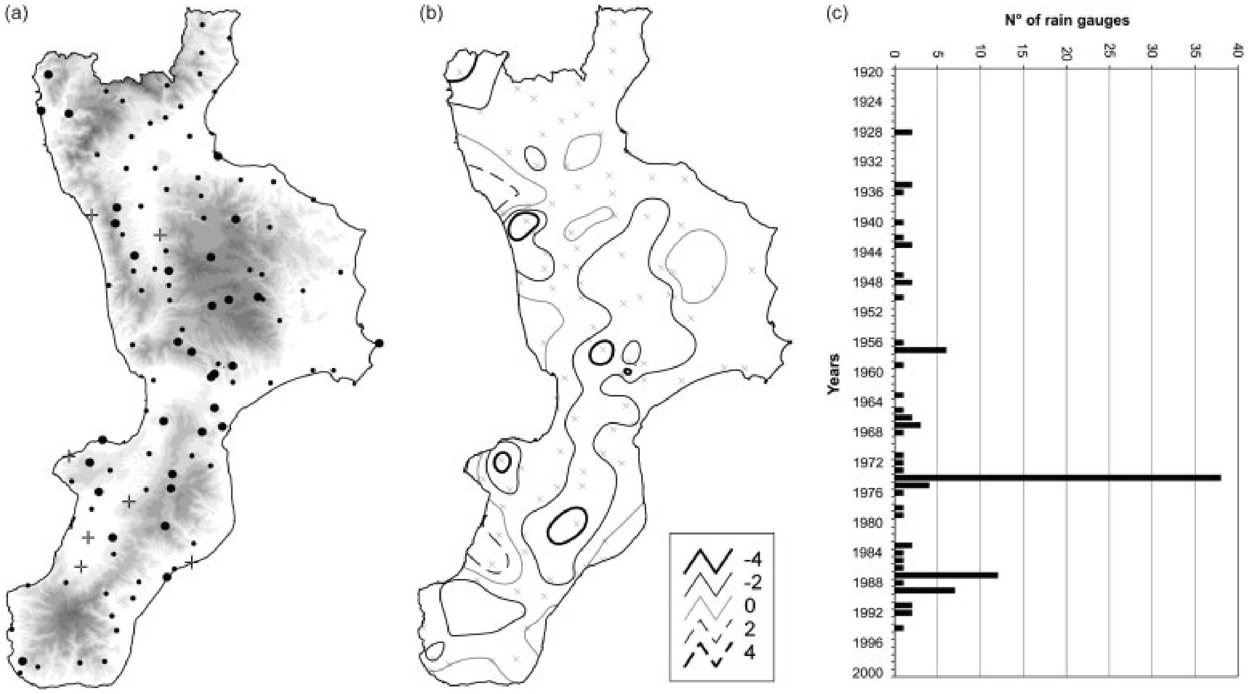

Figure 6. Spatial distributions of: (a) MK statistics of winter rainfall (trend: + positive, ● negative; the greatest marks identify significant trends) and (b) linear regression slope (mm/year) of winter rainfall with time; (c) most probable change years of winter rainfall.

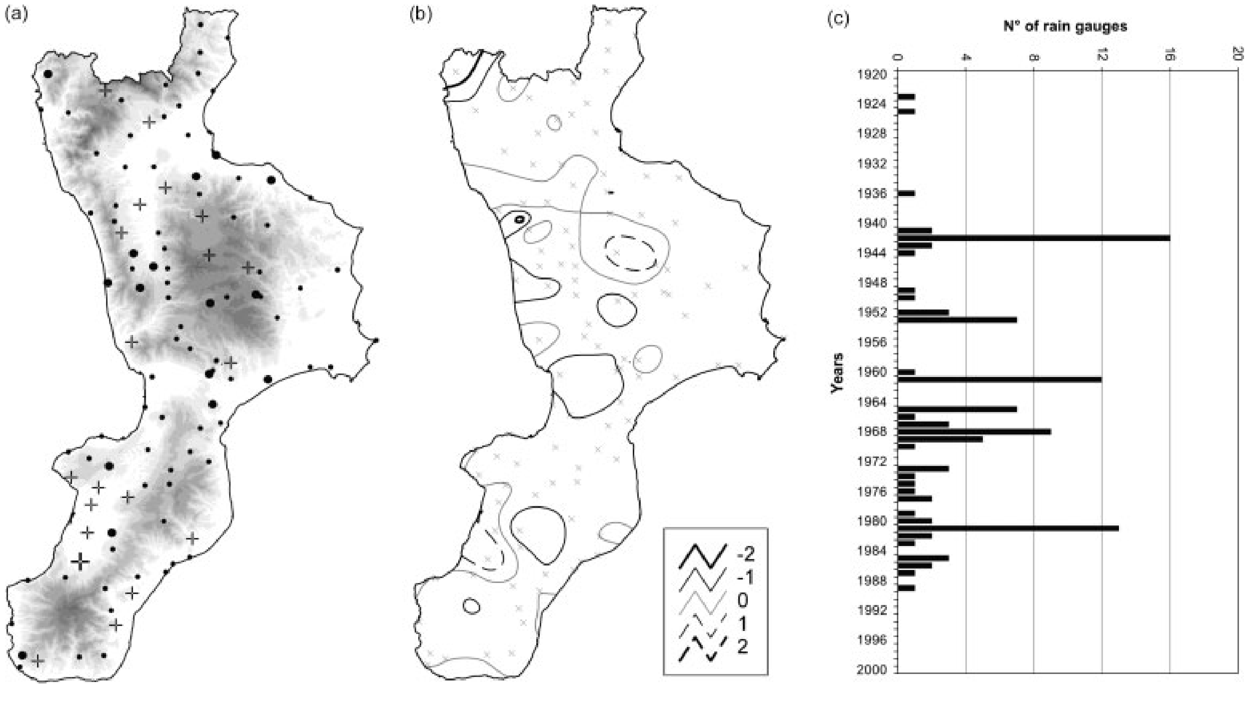

Figure 7. Spatial distributions of: (a) MK statistics of spring rainfall (trend: + positive, ● negative; the greatest marks identify significant trends) and (b) linear regression slope (mm/year) of spring rainfall with time; (c) most probable change years of spring rainfall.

point years for winter precipitation are 1961 (19% of the rain gauges) and 1974 (14%) (Figure 10(c)).

3.2.6. *Spring–summer*

With regards to the aggregated precipitation in spring and summer season, the results of MK test show that only 16 series (about 15% of the total) have significative trends: 9 series out of 16 show a negative trend (Figure 11(a)). The spatial distribution of the linear regression slope is not uniform, and often high and low values of slope are observed in nearby rain gauges (Figure 11(b)). The highest value is about 4 mm/year (Castellace rain gauge, code 2570), the lowest one is about −3.6 mm/year (Laghitello CC rain gauge, code 1070). In addition, the application of the Mann–Whitney test does not show clear results (Figure 11(c)).

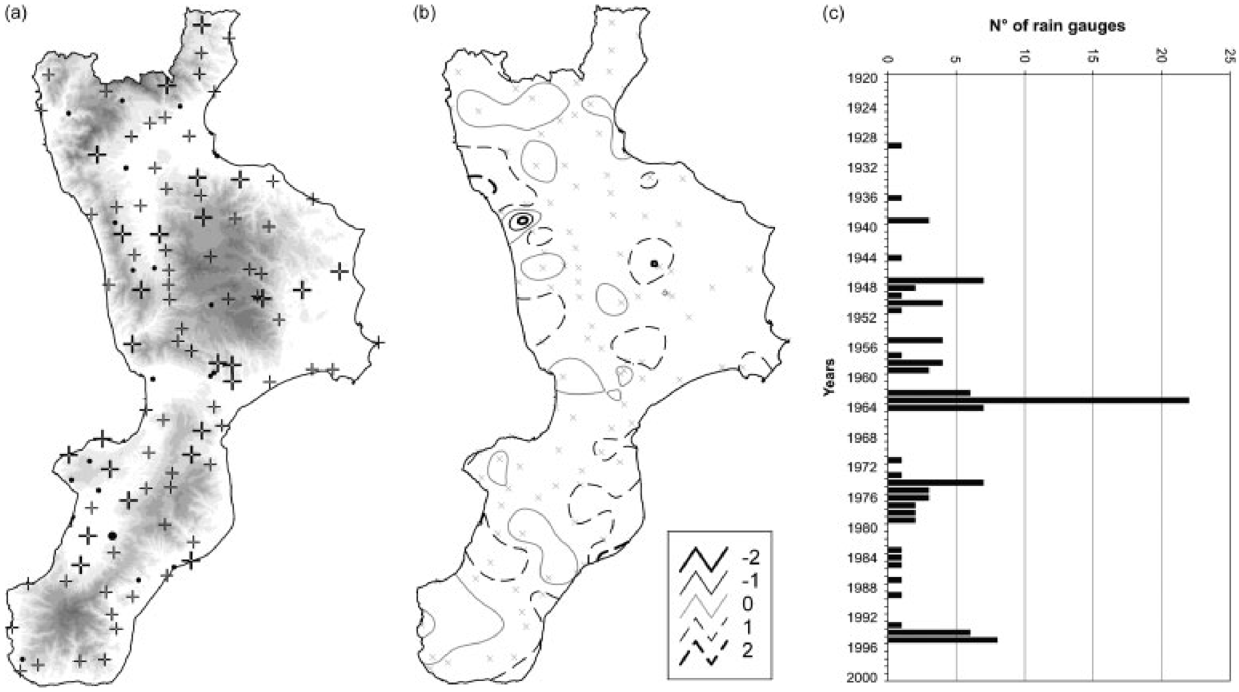

Figure 8. Spatial distributions of: (a) MK statistics of summer rainfall (trend: + positive, ● negative; the greatest marks identify significant trends) and (b) linear regression slope (mm/year) of summer rainfall with time; (c) most probable change years of summer rainfall.

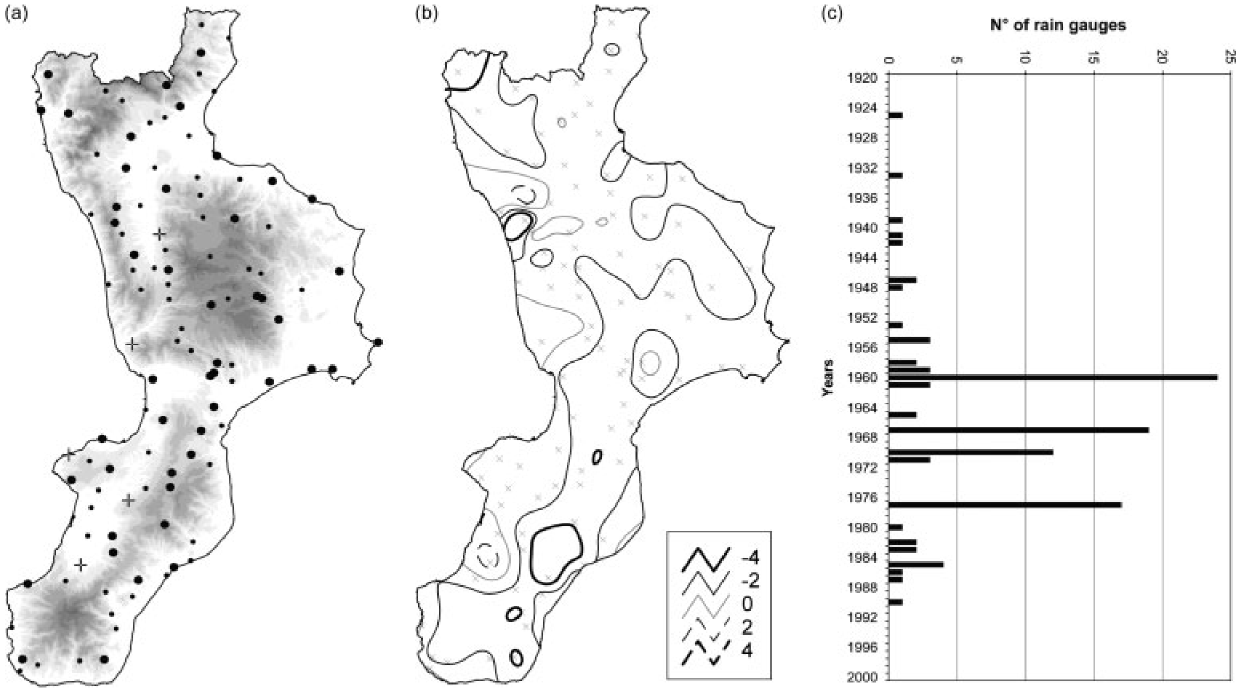

Figure 9. Spatial distributions of: (a) MK statistics of autumn rainfall (trend: + positive, ● negative; the greatest marks identify significant trends) and (b) linear regression slope (mm/year) of autumn rainfall with time; (c) most probable change years of autumn rainfall.

4. Conclusions

The paper analyses the behaviour of annual and seasonal precipitation in the Calabria region (Southern Italy) looking for trends in long historical data series. A pre-whitening technique has been used to pre-process the historical data, in order to reduce the serial correlation in long time series, as well as its effects on trends.

Two methods have been applied to detect significant trends of 109 rainfall series with more than 50 years of observation: the nonparametric MK test and the linear regression analysis which present similar results for annual and seasonal rainfalls.

For the annual rainfalls, results reveal a feature typical of almost all the long cumulated precipitation observed in Calabria, with negative trend detected in the main

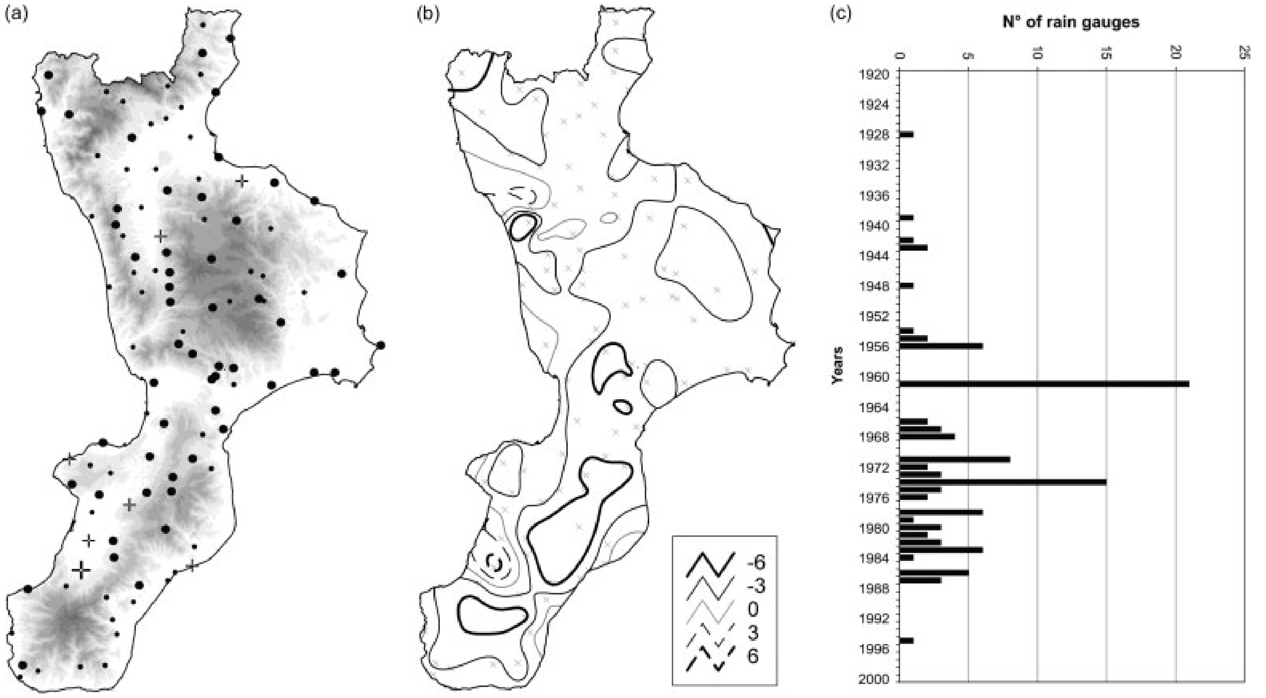

Figure 10. Spatial distributions of: (a) MK statistics of autumn–winter rainfall (trend: + positive, ● negative; the greatest marks identify significant trends) and (b) linear regression slope (mm/year) of autumn-winter rainfall with time; (c) most probable change years of autumn-winter rainfall.

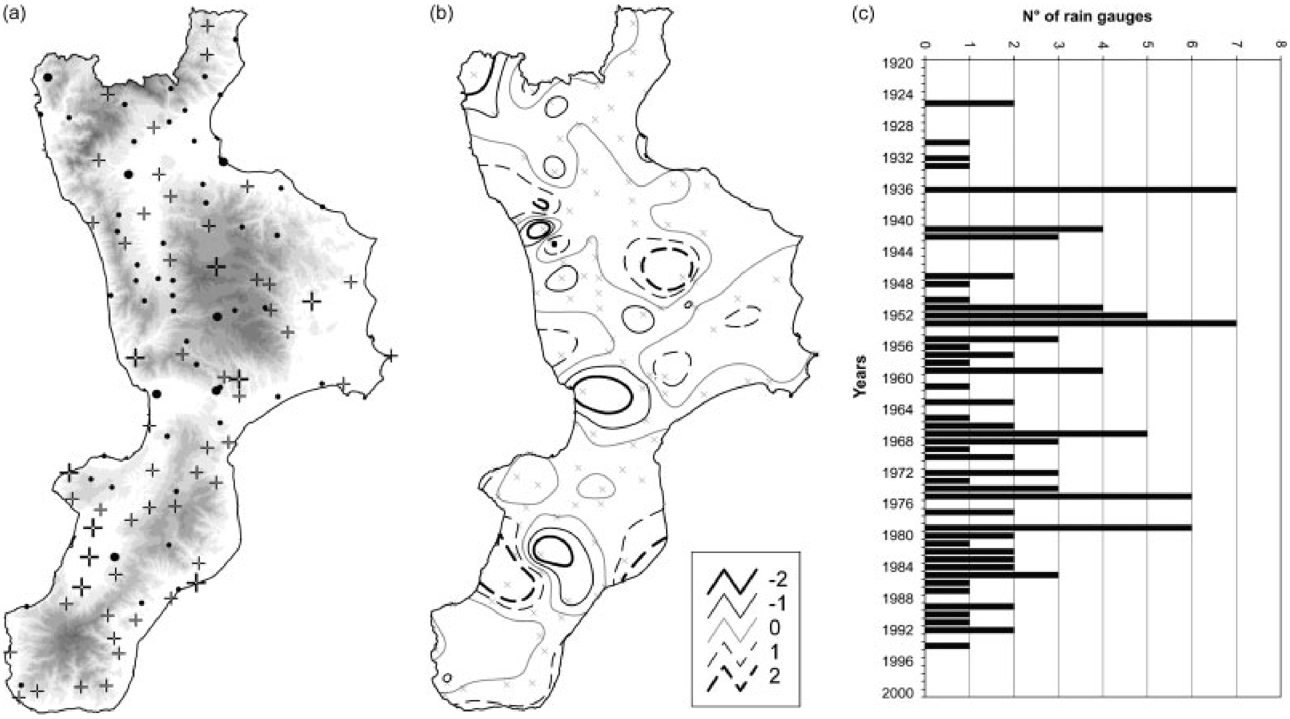

Figure 11. Spatial distributions of: (a) MK statistics of spring–summer rainfall (trend: + positive, ● negative; the greatest marks identify significant trends) and (b) linear regression slope (mm/year) of spring-summer rainfall with time; (c) most probable change years of spring-summer rainfall.

elevated areas of the region. On a seasonal temporal scale, negative trends are mainly present over the higher mountains of the south-western part of the region for the winter rainfalls and on the mountains located in the central part of the region for the spring rainfalls. The results obtained for the autumn rainfall data are similar to the ones identified for the winter precipitation in the Northern Tyrrhenian coast. On the contrary, for the summer precipitation, the results show a general positive trend uniformly distributed over the whole Calabria region. As regards the six-month aggregation rainfalls, the distribution of the negative trends of autumn–winter rainfalls is very similar to the one shown for annual rainfalls, while the most uncertain results obtained for the spring–summer precipitation reflect the different behaviours of trend evidenced in the single seasonal precipitation.

The statistical significance of trend in precipitation, provided by the application of MK test on the pre-whitened data, has been confirmed through a comparison with a block-bootstrap procedure.

The shift analysis based on the Mann–Whitney test, performed in order to highlight the possible change points in the data, shows more probable change years in the decade 1960–1970 for annual, summer, autumn and autumn–winter aggregation rainfalls.

If confirmed in the next years, the results of trend analysis of annual and seasonal rainfalls could affect the water resources management in Southern Italy. In fact, as reported in the IPCC's Fourth Assessment Report (2007), changes in precipitation may lead to changes in runoff and water availability, and drought-affected areas could suffer from a decrease in water resources, with possible adverse impacts on agriculture, water supply and energy production.

Acknowledgements

The authors are grateful to the anonymous reviewers for the precious remarks and comments which led to improve the initial version of this paper.

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