

INFLUENCE OF SERIAL CORRELATION ON CLIMATIC VARIABLES TRENDS ANALYSIS IN SICILY

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ABSTRACT

The intense climatic anomalies occurred in the last decades, led the scientific community to officially admit the existence of a climate change, mainly due to human activities. Researchers have studied trends and variations in temperatures and rainfall in several areas of the world. The analysis of precipitation and temperature trends has become a topic of particular interest because the knowledge of rainfall and temperatures evolution represents a support tool in forecasting future climatic scenarios and, consequently, for water resources management.

In several studies aimed at identifying trends in climatic data, the nonparametric test of Mann-Kendall is frequently used with the assumption that the observed data are characterized by serial independence. However, many hydrological series, such as minimum and average annual runoff, often show a statistically significant serial correlation.

This study is based on previous analysis of time series of precipitation and temperature recorded in Sicily in the past century, which have confirmed the existence of trend in precipitation and temperature time series, using the Mann-Kendall test. The aim of this work is to deepen the analysis of trends in rainfall and air temperature using techniques able to remove the serial correlation in order to obtain results not influenced by it.

Whit this purpose, two different procedures have been used, namely the pre-whitening and the trend-free pre-whitening.

With reference to the monthly precipitation data, which are self-correlated, the pre-whitening process identifies a number of decreasing trends less than those identified in the previous studies while the trend-free pre-whitening procedure doubles the number. When data are aggregated at seasonal and annual scale, the trend-free pre-whitening procedure individuates the same number of decreasing trends observed in the previous studies, while the alternative pre-whitening procedure, slightly reduces this number.

The temperature series are highly auto-correlated and for this reason, the pre-whitening procedure completely eliminates the trend presence. The trend-free pre-whitening procedure individuates more stations with positive trends than the previous studies ones. If the temperature data are aggregated to seasonal and annual time scale, the trend-free pre-whitening procedure results are consistent with previous studies. In fact positive trends are observed at all levels of confidence and time aggregation.

1 INTRODUCTION

The climatic anomalies occurred during the last decade, led the scientific community to admit officially the existence of climate modification due to human activities (IPCC, 2007); this change, nowadays commonly known as global warming, has received great attention from researchers all around the world. Trend and variations in global temperatures in the stratosphere have been studied, as they represent the most evident effect of the changes taking place in the global climate system. In particular the increase in global temperatures causes a more intense evaporation of water from oceans, soils and vegetation. The increased load of humidity in the atmosphere involves the intensification of the hydrological cycle, a phenomenon that can lead to a higher frequency and a stronger magnitude of extreme events such as floods and droughts, and thus leading to changes in water availability (Huntington, 2006). In fact the precipitation is the main forcing regulating hydrological systems and hence variations in its quantity, intensity and duration could have effects on surface runoff and groundwater recharge. In addition, changes in rainfall patterns could have results in significant consequences on the mechanisms that regulate ecosystems, on the availability of water resources and consequently in agriculture.

In this context, the research for trends in precipitation and temperature time series has become a topic of particular interest, because their presence could be a signal of climatic change, and because the knowledge of the evolution of runoff and temperatures over time can become a valuable tool in forecasting possible future scenarios for planning and managing water resources in an area.

In several studies aimed to identifying trends in series of climatic data the nonparametric test of Mann-Kendall (1945) is frequently used. The non-parametric tests have the advantage of being usable even if the data are not normally distributed, as most of the hydro-meteorological variables. Most of the studies in the scientific literature assumes that the observed data are characterized by serial independence. However, many hydrological series, such as minimum and average annual runoff, often show a statistically significant serial correlation. The existence of this correlation leads to an increased probability that the Mann-Kendall test can identify a trend when it does not exist, or in other words the increase of the probability of rejection of the null hypothesis.

Von Storch (1995) showed that the existence of serial correlation in a series leads to an increase of type I error or the erroneous acceptance of the hypothesis on which the test is conducted. In order to overcome this problem, he suggested the use of a procedure named *pre-whitening* (PW). This procedure is not always reliable, since, the removal of serial correlation may remove part of any trend. The PW may therefore reduce the power of Mann-Kendall test, increasing the type II error or the erroneous rejection of the hypothesis under which the test is carried out. Furthermore, the trend magnitude, evaluated over a pre-whitened series, is lower than the one assessed on the original series. Since the PW is not always a reliable procedure in the removal of serial

correlation from a hydrological series, Yue et al. (2002) proposed an alternative methodology, indicated as *trend-free pre-whitening* (TFPW). This procedure is based on the assumption that a hydrological series can be represented as a linear trend component with an AR(1) component. The ability of TFPW is limited to series for which the trend can be approximated as linear.

This study builds on previous analysis of time series of precipitation and temperature recorded in Sicily in the past century. Cannarozzo et al. (2006) and Liuzzo et al. (2008) have verified the existence of trend in time series of precipitation and temperature recorded in Sicily, using the Mann-Kendall test. In this work the analysis of trends in rainfall and air temperature is deepened using techniques for removing the serial correlation. The precipitation and temperature series recorded in Sicily between 1920 and 2000 have been processed with the PW and TFPW procedures and then the classical and the seasonal Mann-Kendall tests have been performed.

2 DATASET AND CASE STUDY

The trend analysis has been carried out using monthly precipitation data recorded in 247 stations distributed over Sicily in the period 1921-2000 (Figure 1), and monthly temperatures data measured at 83 weather stations distributed over the whole Sicilian territory for the period 1924-2006 (Figure 2).

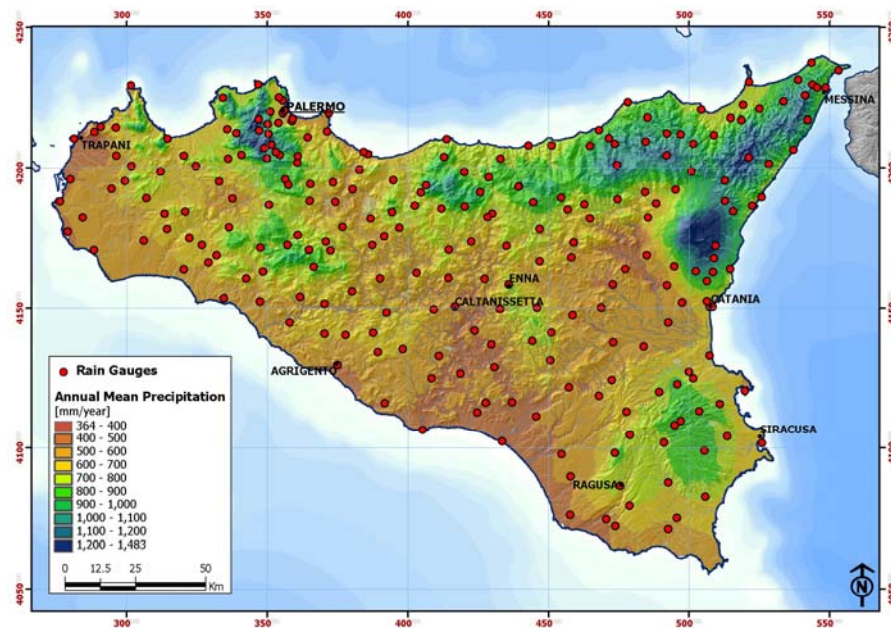


Figure 1. Locations of rain gauges and annual mean rainfall map over the period 1921-2000

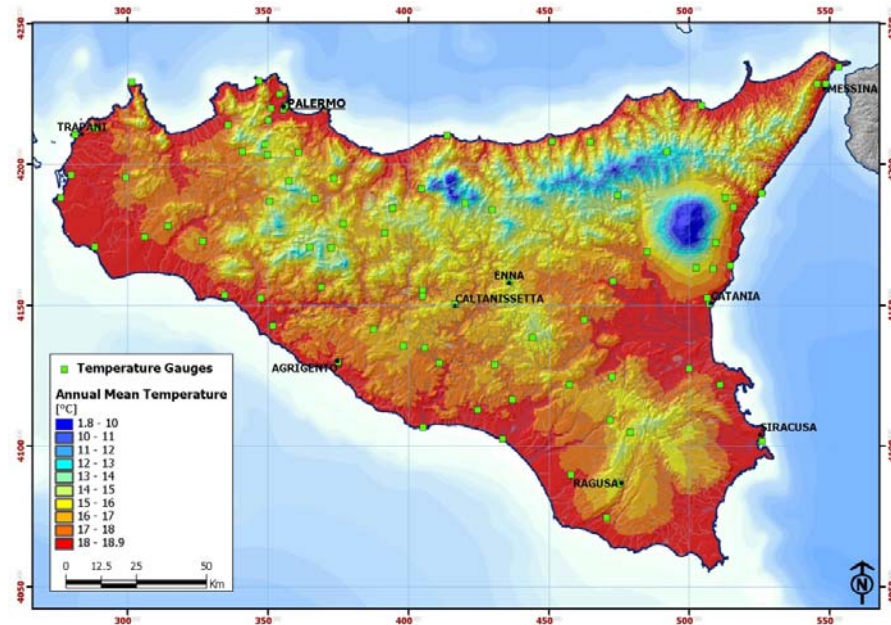


Figure 2. Location of thermometric stations and annual mean temperature map over the period 1921-2000.

The study of trends requires the use of complete and homogeneous series for the examined period. To do this, it was necessary a preliminary process of interpolation that filled the gaps in the considered series, producing a complete and homogeneous dataset. The precipitation dataset was completed with the procedures described by Di Piazza et al. (2010, 2011). The temperature time series were reconstructed using a elevation-temperature relationship and a geostatistical spatial interpolation, the Residual Ordinary Kriging (Di Piazza et al., 2010).

3 TREND ANALYSIS AND PREVIOUS STUDIES

The first aspect to be considered in the study of climate trends is the homogeneity of the series. A time series is considered homogeneous if the variations are due solely to weather and climate changes. In the case of precipitation and air temperature series the main causes of non-homogeneity can be: i) the relocation of the station at a different site, ii) the change of the instrument used to perform measurements and iii) the change in measurement practices. In order to give more validity to the trends analysis, the homogeneity of the dataset has been checked to exclude any station that, due to human factors, showed non-homogeneity. For this purpose different statistical tests can be performed and, among them, the Kruskal-Wallis (1952) is one of the most used. The test is used to test the hypothesis H_0 , that is if k independent groups come from the same population and/or from populations that have the same median. All the observations of k groups must be treated as a single dataset and converted into ranks.

The parameter g can be calculated from the sums, with a simplified formula, which

also offers the advantage of avoiding the inaccuracies due to the averages:

$$g = \left(\frac{12}{N(N-1)} \sum_{i=1}^k \frac{R_i^2}{n_i} \right) - 3(N+1) \quad (1)$$

where n_i is the number of sample data or the i -th group, N is the total number of observations of the k samples, k is the number of compared groups, R_i is the sum of the ranks of the sample or the i -th group, and the sum is extended to all the k groups.

The parameter g is distributed as the χ^2 with $k-1$ degrees of freedom, where k is the number of groups being compared, when the sample sizes meet the minimum conditions required for the validity of χ^2 . The approximation to the χ^2 distribution improves as the number of k groups increase and within each group the number of observations is high (in this case greater than 5).

The results of the statistical test of Kruskal-Wallis test indicate that, in the case of precipitation, only two time series are not homogeneous implying the removal of these stations. The Kruskal-Wallis test applied to the temperature series indicates that all the considered series are homogeneous.

The presence of trend in the considered series has been verified in former studies by Cannarozzo et al. (2006) and Liuzzo et al. (2008), which applied the non-parametric test of Mann-Kendall. Originally used by Mann (1945) and subsequently modified by Kendall (1962), this test allows to investigate the presence of a long-term trend in climate data without the need to make assumptions about the data distribution. In addition, nonparametric tests are generally less affected by the presence of outliers in the series. The null hypothesis of the Mann-Kendall states the absence of trend in the population from which the dataset under investigation has been extracted. The alternative hypothesis affirms instead the presence of a trend, positive or negative, in the analyzed series. The Mann-Kendall test statistic, denoted by S , is calculated with the expression:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(y_j - y_i) \quad (2)$$

where y is the precipitation or the temperature at time i and j , n is the length of the series, whereas the sign function is defined as follows:

$$\text{sign}(\mathcal{G}) = \begin{cases} 1 & \text{if } \mathcal{G} > 0 \\ 0 & \text{if } \mathcal{G} = 0 \\ -1 & \text{if } \mathcal{G} < 0 \end{cases} \quad (3)$$

Under the null hypothesis that y_i are independent and identically distributed for $n \geq 8$, the test statistic S is well interpreted by a normal distribution with zero mean and variance equal to:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad (4)$$

therefore, once defined the standardized test statistic

$$Z = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \quad (5)$$

it is compared with a standard normal distribution at fixed confidence level.

The main results of the studies of Cannarozzo et al. (2006) and Liuzzo et al. (2008) are shown in Figures 3 and 4, which show the trends of annual rainfall and temperature in Sicily. In these maps, for a fixed confidence level, equal to 95%, the spatial distribution of the slope β of the line interpolating the data has been reported. The slope has been calculated using the expression suggested by Hirsch et al. (1982):

$$\beta = \text{Median} \left[\frac{(y_j - y_i)}{(j - i)} \right] \quad (6)$$

where y is the precipitation (or temperature) measured at time i and the time j . There is a statistically significant negative trend in annual rainfall over the whole Sicily, mostly concentrated along the south coast. Cannarozzo et al. (2006) also showed that there is a negative trend in the winter rainfall. In summer there are not statistically significant trends. As regards the temperature, Liuzzo et al. (2008) observed a positive trend on the annual average as shown in Figure 4 and a statistically significant positive trend on data aggregated at seasonal time scale.

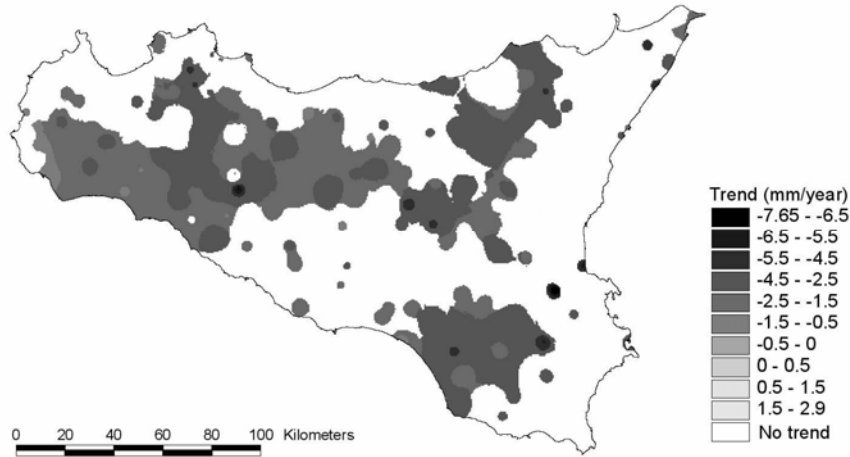


Figure 3. Trends of annual precipitation at 95% confidence level.

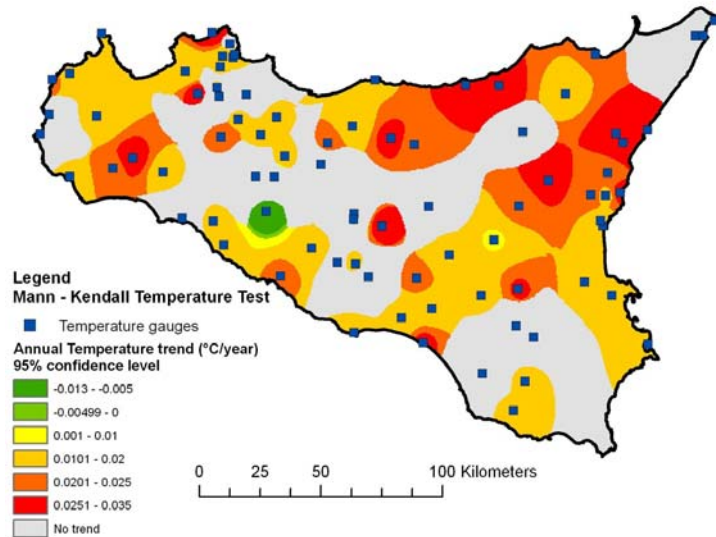


Figure 4. Trend of annual temperatures at 95% confidence level.

4 INFLUENCE OF SEASONALITY AND SERIAL CORRELATION IN THE ANALYSIS OF TRENDS

Precipitation and temperature have a marked seasonal behaviour. In Sicily, winters are characterized by mild temperatures and precipitation are concentrated in this season. In summer, temperatures rise and rain events become rare. In order to take into account this characteristic of time series in the analysis of trend, the seasonal Mann-Kendall test has been performed as suggested by Hirsch et al. (1982). The results obtained in this analysis are consistent with the findings of Cannarozzo et al. (2006) and Liuzzo et al. (2008), confirming the existence of a general trend towards lower rainfall and higher temperatures. In particular the results related to rainfall, reported in Table 1, shows the existence of a large number of negative trends when the test is applied to the four seasons, or when the seasonal statistic is calculated considering 12 months. For temperatures, as summarized in Table 2, the seasonal Mann-Kendall test identifies positive trends, in both cases (4 seasons and 12 months).

In order to assess the extent of serial correlation in the series of precipitation and temperatures, the lag-1 serial correlation coefficients have been calculated. Subsequently the empirical cumulative distribution functions have been assessed (*ecdf*). The precipitation *ecdf* (Figure 5) shows that 50% of the 245 series has a serial correlation coefficient ranging between 0.3 and 0.5, while temperatures data show higher correlation coefficient, greater than 0.8.

The presence of serial correlation coefficients different from zero for both precipitation and temperature requires the use of techniques for removing the serial correlation in these series. The presence of a strong serial correlation in the series of monthly temperature portends a more significant reduction in the number of trends

identified in these series than the series of precipitation, characterized, as mentioned, by low values of the correlation coefficient.

Table 1. Results obtained by the seasonal MK test for rainfall. Number of stations showing trend for fixed level of confidence α .

RAINFALL		α		
		0.1	0.05	0.01
SEASONS	Negative Trend	152	126	81
	Positive Trend	3	2	1
	No trend	90	117	163
MONTHS	Negative Trend	129	115	75
	Positive Trend	4	2	1
	No trend	112	128	169

Table 2. Results obtained by the seasonal MK test for temperatures. Number of stations showing trend for fixed level of confidence α .

TEMPERATURE		α		
		0.1	0.05	0.01
SEASONS	Negative Trend	3	3	3
	Positive Trend	70	67	65
	No trend	11	14	16
MONTHS	Negative Trend	4	4	3
	Positive Trend	72	68	66
	No trend	8	12	15

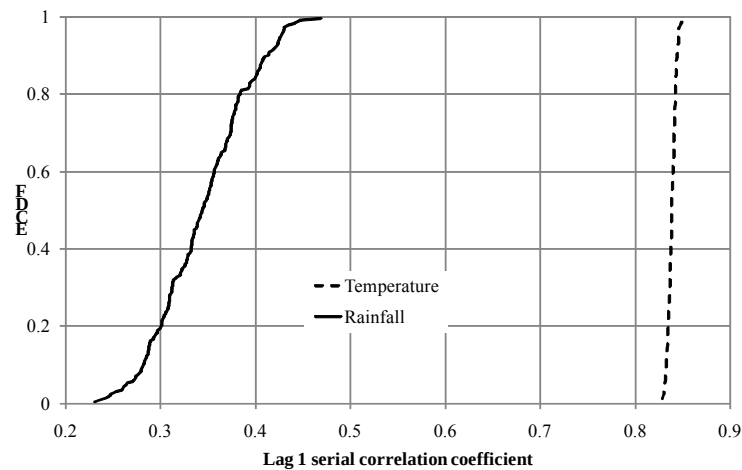


Figure 5. Empirical CDF of lag-1 serial correlation coefficient for monthly temperatures and precipitation.

Two different procedures for removing the serial correlation from precipitation and temperature data have been performed: prewhitening (PW) proposed by von Storch (1995) and subsequently used by Kulkarni and von Storch (1995), by Douglas et al. (2000), by Zhang et al. (2000, 2001) and Burn and Hag Elnur (2001), and trend-free pre-whitening (TFPW) proposed by Yue et al. (2002).

The PW procedure transforms the initial dataset as follows:

$$Y_t = X_t - \rho_1 X_{t-1} \quad (7)$$

where Y_t is the data value pre-whitened at time t , X_t is the data value at the time t and ρ_1 is the lag-1 correlation coefficient.

The TFPW procedure is based on the assumption that a hydrological series can be represented as a linear trend component with a AR(1) component. The ability of TFPW is limited to series for which the trend can be approximated as linear. The method requires the estimation of the trend magnitude using the equation (6). If β is close to zero it is not necessary to apply the procedure since there is not a trend in the series. If β is not 0, the trend is removed from the series using the following expression:

$$X'_t = X_t - T_t = X_t - \beta t \quad (8)$$

where T_t is the trend component estimated at time t . Then the lag-1 serial correlation coefficient is calculated from the series in which the trend has been removed. The pre-whitened series is obtained as follows:

$$Y'_t = X'_t - \rho_1 X'_{t-1} \quad (9)$$

The residuals obtained should be an independent series. Finally, the trend is identified and the residuals are added:

$$Y_t = Y'_t + T_t \quad (10)$$

The obtained series preserves the trend, but at the same time they are no longer affected by serial correlation.

The need to use two different techniques for removing the serial correlation arises from the fact that the pre-whitening is not always reliable, since, in the removal of serial correlation, as mentioned earlier, it also leads to the removal of part of any trend. The pre-whitening therefore may reduce the power of the Mann-Kendall test, increasing the II type error. Furthermore, the magnitude of a trend evaluated in a series pre-whitened is lower than the one assessed on the original series.

Once the serial correlation has been removed, the Mann-Kendall test was applied to the series of monthly precipitation (from January 1921 to December 2000) and the series of the monthly temperatures (from January 1924 to December 2006). The results of this analysis are summarized in Tables 3 and 4. The application of the Mann-Kendall test to the TFPW series of precipitation determines a higher number of negative trends than those reported by Cannarozzo et al. (2006), while the PW procedure reduces the number of negative trends. This confirms what was stated from a theoretical point of view, *i.e.* the PW process, reducing the power of the Mann-Kendall test, wrongly rejects the hypothesis of the presence of trend.

Table 3. Results obtained for the continuous series of monthly precipitation (January 1921 in December 2000). Number of stations showing trend for fixed level of confidence α .

RAINFALL	Series			α
	Cannarozzo et al. (2006)	PW	TFPW	
Negative Trend	89	23	153	0.1
Positive Trend	1	1	4	
No trend	155	221	88	
Negative Trend	63	10	127	0.05
Positive Trend	1	1	4	
No trend	181	234	114	
Negative Trend	28	0	88	0.01
Positive Trend	1	1	3	
No trend	216	244	154	

Table 4. Results obtained for the continuous series of monthly average temperatures (from January 1924 in December 2006). Number of stations showing trend for fixed level of confidence α .

TEMPERATURE	Series			α
	Liuzzo et al. (2008)	PW	TFPW	
Negative Trend	2	0	3	0.1
Positive Trend	56	0	65	
No trend	26	84	26	
Negative Trend	2	0	2	0.05
Positive Trend	48	0	61	
No trend	34	84	21	
Negative Trend	0	0	2	0.01
Positive Trend	35	0	54	
No trend	49	84	28	

The application of PW procedure to the temperature series totally eliminates the presence of trends, due to the high coefficient of correlation that characterizes those series. The TFPW procedure identifies a number of positive trends slightly higher than those found by Liuzzo et al. (2008).

In order to deepen the analysis of the influence of serial correlation on the results of Mann-Kendall test, it was considered appropriate to apply the two techniques of serial correlation removing to aggregated data. In particular, annual, seasonal and monthly time scale have been considered (monthly aggregation is the creation of series made by precipitation or temperature recorded in a particular month). As suggested by Partial and

Kahya (2006), firstly data have been aggregated to the annual, seasonal and monthly time scale, and then the serial correlation removal has been carried out. The results obtained in the case of annual rainfall and temperature are shown in Tables 5 and 6.

At the annual scale of aggregation, the TFPW procedure follows the results obtained by Cannarozzo et al. (2006) with regard to rainfall and by Liuzzo et al. (2008) for temperatures. Again, the PW procedure slightly reduces the number of negative trends found in precipitation series and positive trends in temperature series. This is due to the fact that the annual aggregated data have a low coefficient of correlation, and consequently the transformation through the PW procedure does not substantially change the series on which the Mann-Kendall test is then performed.

The results of the analysis on monthly and seasonal aggregated series are similar to those obtained for the annual series. The TFPW procedure identifies negative rainfall trends concentrated in winter and in December, January and February, exactly as they were exposed by Cannarozzo et al. (2006). For the same variable, the PW procedure reduces the number of trends identified in the winter of around 5% and the number of monthly trend of 20-30%. Again, the low correlations between the precipitation observed in a season or in a month and those observed in the same season or month of the following year implicate that the results are insensitive to procedure of trend assessment.

Using the TFPW procedure, seasonal aggregated temperature series show positive trends in agreement with the observations of Liuzzo et al. (2008). The PW procedure reduces by 20-30% the number of positive trends observed in the study of Liuzzo et al. (2008). For monthly data the TFPW procedure follows almost identically the results of Liuzzo et al. (2008), namely the presence of statistically significant positive trend with $\alpha = 0.05$ in more than 50 on 84 stations in January, February, May, October and December. The alternative PW procedure reduces the number of positive trends while in two months, January and May, more than 50 stations show statistically significant positive trend at the same level of confidence.

Table 5. Results for annual precipitation after the serial correlation removal. Number of stations showing trend for fixed level of confidence α .

RAINFALL	Series			α
	Cannarozzo et al. (2006)	PW	TFPW	
Negative Trend	177	152	173	0.1
Positive Trend	1	1	1	
No trend	67	92	71	
Negative Trend	153	126	151	0.05
Positive Trend	1	1	1	
No trend	91	118	93	
Negative Trend	104	61	97	0.01
Positive Trend	1	0	1	
No trend	140	184	147	

Table 6. Results obtained for the annual temperatures after the serial correlation removal. Number of stations showing trend for fixed level of confidence α .

TEMPERATURE	Series			α
	Liuzzo et al. (2008)	PW	TFPW	
Negative Trend	3	3	3	0.1
Positive Trend	66	49	68	
No trend	15	32	13	
Negative Trend	3	2	3	0.05
Positive Trend	63	36	65	
No trend	18	46	16	
Negative Trend	1	1	2	0.01
Positive Trend	57	10	63	
No trend	26	73	19	

5 CONCLUSIONS

This study has been focused on Sicilian precipitation and temperature trends and on the influence of serial correlation in trends analysis.

Previous studies, using the Mann-Kendall test, showed the presence of a negative trend for precipitation, and an increasing trend for temperature. In the present study the influence of serial correlation on the outcome of non-parametric test of Mann-Kendall in identifying trends in climate variables has been analyzed. In order to remove serial correlation, two different procedures have been applied to the precipitation and temperature data measured in Sicily: the pre-whitening and the trend-free pre-whitening.

With reference to the monthly precipitation series (January 1921-December 2000), which are fairly self-related, the PW procedures identifies a number of decreasing trends lower than those identified by Cannarozzo et al. (2006), while the TFPW procedure doubles this number. If data are aggregated at monthly, seasonal and annual scale the TFPW procedure confirms the same number of decreasing trends observed by Cannarozzo et al. (2006), while the alternative PW procedure reduces, albeit insignificant, this number.

The series of monthly temperature (January 1924-December 2006) are highly autocorrelated, and for this reason the PW procedure completely eliminates the presence of trends. The TFPW procedure raises by 20% the number of stations with positive trends ($\alpha = 0.05$) compared with that found from Liuzzo et al. (2008). If the temperature data are aggregated to a monthly, seasonal and annual scale and the TFPW procedure is used, the results are consistent with those of Liuzzo et al. (2008): positive trend have been observed at all levels of confidence and aggregation. The PW procedure slightly reduces the number of stations with positive trends.

This study confirms and strengthens the existence of a climatic change in Sicily. The fact that precipitation is going to decrease has been demonstrated at annual, seasonal

and monthly time scale, at all level of confidence and this result is not affected by serial correlation. Temperatures are increasing at annual, seasonal and monthly time scale. The high serial correlation characterizing these data, if correctly managed, does not hide the trends existence, which is confirmed using the TFPW procedure.

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