



# Application of the Innovative Trend Analysis Method for the Trend Analysis of Rainfall Anomalies in Southern Italy

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## Abstract

In this paper, an investigation of the temporal rainfall variability, in a large area of southern Italy, has been carried out using a homogeneous monthly rainfall dataset of 559 rain gauges with more than 50 years of observation. The area under investigation is a large portion of the Italian peninsula, ranging from the Campania and the Apulia regions in the North, to Sicily in the South, and covering an area of about 85,000 km<sup>2</sup>. Possible trends in seasonal and annual rainfall values have been detected by means of a new graphical technique, Şen's method, which allows the trend identification of the low, medium and high values of a series. Moreover, the Mann–Kendall test has been also applied. As a result, different values and tendencies of the highest and of the lowest rainfall data have emerged among the five regions considered in the analysis. In particular, at seasonal scale, a negative trend has been detected especially in winter and in autumn in the whole study area, whereas not well defined trend signals have been identified in summer and spring.

**Keywords** Rainfall · Trend · Graphical methods · Innovative trend analysis · Southern Italy

## 1 Introduction

The latest IPCC report evidenced that the highest concentration of anthropogenic greenhouse gases, since the pre-industrial era, have been detected in the last years. As a consequence, the IPCC warned that droughts will probably intensify in the current century in some seasons and, especially, in some areas such as the Mediterranean basin, due to a reduction in precipitation

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and/or an increase in evapotranspiration (IPCC 2013). In fact, significant precipitation variability characterizes this area at regional scale (e.g. Mehta and Yang 2008; Reale and Lionello 2013) resulting from synoptic dynamics of rainfall events moving and evolving along the Mediterranean basin (Lionello and Giorgi 2007). Within such a purview, in this area, several investigations have focused on the analysis of meteorological, hydrological, and climatological variables based on different methodologies (e.g. Ay and Kisi 2015). In Italy, numerous investigations carried out using long-term precipitation databases have detected a decreasing precipitation trend, even if rarely significant (e.g. Brunetti et al. 2006). The regions in which these trends were observed are principally located in southern Italy: Campania (Longobardi and Villani 2010), Basilicata (Piccarreta et al. 2013), Sicily (Liuzzo et al. 2016), Calabria (Caloiero et al. 2016) and Sardinia (Montaldo and Sarigu 2017).

These studies are based on non-parametric tests, which are better suited to deal with non-normally distributed hydrometeorology data than the parametric methods. The Mann–Kendall (MK; Mann 1945; Kendall 1962) and Spearman's rho tests are among the most widely used trend detection tests. Additionally, the trend rates are usually evaluated by the Theil (1950) and the Sen (1968) methods. In any cases, the application of these methods needs some restrictive assumptions, such as independent structure of the time series, normality of the distribution, and length of data. For example, the existence of a positive serial correlation increases the probability that the MK test erroneously detects a trend (von Storch, 1995). Moreover, the cited tests do not allow to identify the contribution of low and high values in the detected trend. Kundzewicz and Robson (2000) evidenced that a graphical technique is needed to explore data trends in order to avoid errors in detecting significant hidden (short-duration) sub-trends. With this aim, Şen (2012) proposed the Innovative Trend Analysis (ITA) technique that allows the graphical trend evaluation of the low, medium, and high values in the data. Furthermore, the ITA technique enables to overcome the cited trend detection problems (Ay and Kisi 2015). For these reasons, the ITA technique was widely applied to the trend detection of several hydrological variables. Haktanir and Citakoglu (2014) analysed the annual maximum rainfall series by means of the ITA method. Kisi and Ay (2014) studied the behaviour of some water quality parameters registered at five Turkish stations by means of the ITA and the MK methods. Şen (2014) and Ay and Kisi (2015) applied the ITA to Turkish temperature data. The ITA technique was also used to analyse the trends of the heat waves (Martínez-Austria et al. 2015), of the monthly pan evaporations (Kisi 2015) and of the streamflow data (Tabari and Willems 2015). In the majority of these studies, a comparison between the ITA and the MK methods has been performed, showing some advantages of the ITA with respect to the MK.

The aim of this study is to evaluate the trend of seasonal and annual rainfall series in five regions of southern Italy. The major novelty of the paper is the comparison between the recently proposed Sen's innovative trend test with the Mann-Kendall test. In fact, the ITA technique allows to identify the impact of low, medium, and high values in the detected trends, overcoming also some problems such as independent structure of the time series, normality of the distribution, and length of data. Moreover, as suggested by Tiwari and Pandey (2018), differently from the results obtained with the non-parametric approach, the ITA results are useful to get trend in an easy way and to describe the number of temporal clusters available in the time series. Finally, unlike the past studies focused on small areas of the same regions (e.g. Brunetti et al. 2012; Caloiero et al. 2011), this paper highlights how the analysis of a wider area can offer a better understanding of precipitation distribution patterns over space and time.

## 2 Methodology

### 2.1 Innovative Trend Analysis (ITA)

The ITA method has been first proposed by Şen (2012). Unlike the MK test or other methods, the ITA greatest advantage is the fact that it does not require any assumptions (serial correlation, non-normality, sample number and so on). First, the time series is divided into two equal parts, which are separately sorted in ascending order. Then, the first and the second half of the time series are located on the X-axis and on the Y-axis, respectively. If the data are collected on the 1:1 ideal line (45° line), there is no trend in the time series. If data are located on the upper triangular area of the ideal line, an increasing trend in the time series exists. If data are accumulated in the lower triangular area of the 1:1 line, there is a decreasing trend in the time series (Şen 2012; Şen 2014). Thus, trends of low, medium and high values of any hydro-meteorological or hydro-climatic time series can be clearly identified through this method.

In this paper, differently from past studies (e.g. Caloiero et al. 2017) which applied the ITA methods on the mean rainfall data, the rainfall series were initially converted into anomalies, normalising each monthly value over the 1961–1990 period. Then, for each region, the seasonal and yearly anomaly series have been evaluated. This choice is justified by the fact that absolute values present important spatial gradients, and anomalies avoid the different starting year of each series to bias the average result (Brunetti et al. 2012). In Fig. 1, a graphical representation of the method on a Cartesian coordinate system is shown. In order to graphically show the differences between each point and the 1:1 line, recently, some confidence limits on the ITA diagrams have been added (e.g. Kisi 2015; Tosunoglu and Kisi 2017), even though, at present, no single objective method to evaluate the limits on the ITA diagrams has been clearly identified. In particular, in this paper two confidence bounds (0.25 and 0.5) have been added as the distance from the line 1:1 (Fig. 1). The aim of these bands is only to help the reader to better appreciate the distance of the points from the no-trend line, without any statistical meaning.

### 2.2 Trend Test

As a confirmation of the results of the ITA technique, the possible existence of temporal tendencies have been verified with the well-known Mann–Kendall (MK) non-parametric test (Mann 1945; Kendall 1962).

For a series with dimension  $n$ , given the annual values  $x_j$  and  $x_i$  respectively in the years  $j$  and  $i$ , with  $j > i$ , the MK statistic is obtained as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \operatorname{sgn}(x_j - x_i); \quad \text{with } \operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \quad (1)$$

If  $x_i$  are independent and randomly ordered, for  $n > 10$  the statistic  $S$  follows a normal distribution with zero mean and variance given by:

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

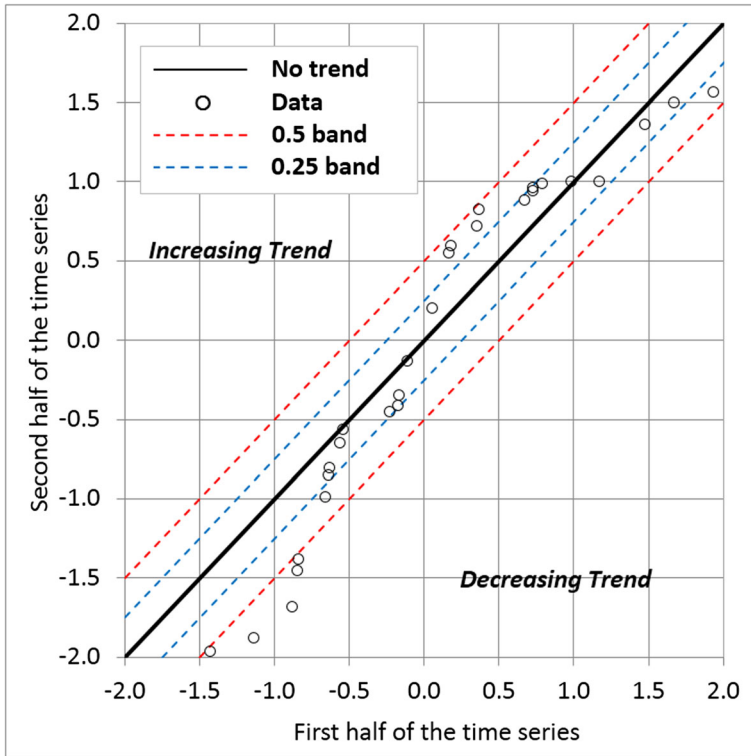


Fig. 1 Example of the Innovative Trend Analysis (ITA) proposed by Şen (2012)

where  $m$  is the number of the tied groups in the data set and  $t_i$  is the number of data points in the  $i$ -th tied group.

Finally, the standardized test statistic  $Z_{MK}$  is computed as:

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

For a specified significance level  $\alpha$ , using a two-tailed test, the null hypothesis is rejected if  $|Z_{MK}|$  is greater than  $Z_{1-\alpha/2}$  and the trend can be considered significant.

### 3 Case Study and Data Base

The region under investigation is a large portion of the Italian peninsula, extending from the Campania and the Apulia regions in the North, to Sicily in the South, and covering an area of about 85,000 km<sup>2</sup> (Fig. 2). The study area is located within the Mediterranean basin and is characterized by particular climatic conditions. The climate regime of the study area is typically Mediterranean, which dominates in particular the islands and the coastal areas. The winter season is a rather mild and rainy period, whereas the summer season is very hot and dry.

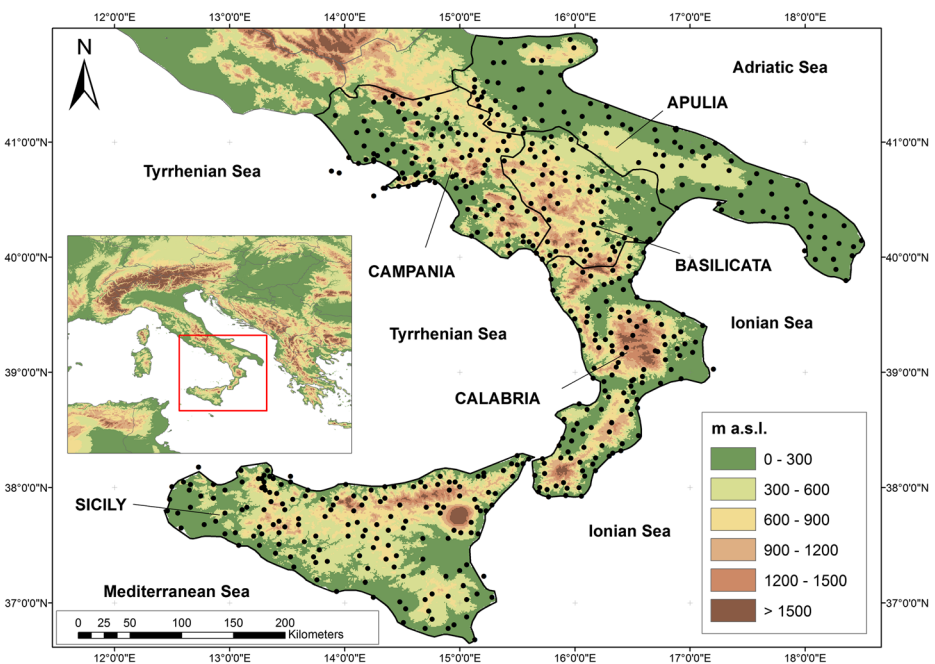
The database used in this study was the one presented in Longobardi et al. (2016) in which available precipitation time series have been tested for time series homogeneity through the combined use of direct and indirect methods. The database consists of 559 monthly precipitation series with an average density of 1 station per 138 km<sup>2</sup> (Fig. 2). Unfortunately, in the five regions of the study area different administrations managed the rainfall data during the years. For this reason, in order to study those rainfall series falling within the same time span and presenting the same length, different periods have been investigated. In particular, for Basilicata, Apulia and Calabria the 1951–2006 period has been analysed, while the 1951–2000 and 1951–2002 periods have been considered for Campania and Sicily, respectively.

## 4 Results and Discussion

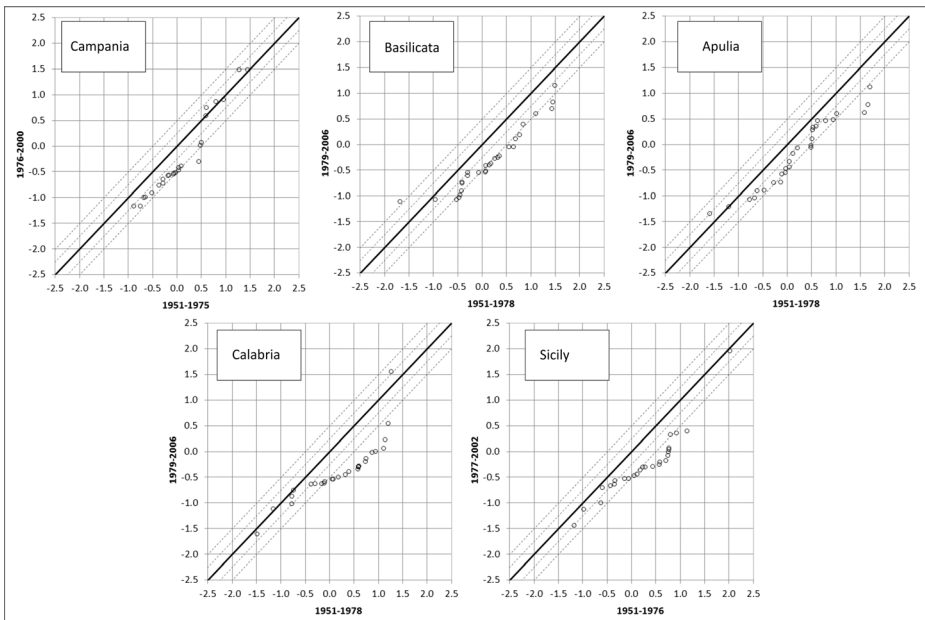
For every region of southern Italy showed in Fig. 2, an average series of rainfall anomalies has been evaluated for seasonal and annual time-scales. Then, the ITA method was performed to determine the behaviour of the two equal parts in which each time series has been divided.

With regards to the annual rainfall, a negative trend has been clearly evidenced for almost all the regions, with the exception of Campania for the high anomaly values (Fig. 3). This behaviour was mainly shown by the medium values of the subseries, which for Calabria and Sicily lie outside the 0.5 bound of the anomalies. For Basilicata and Apulia, the negative trend behaviour has been also detected for the highest values.

As to what concerns the seasonal rainfall, the results of Campania showed a clear negative tendency in winter, especially for the low and the high values (Fig. 4). A positive tendency was



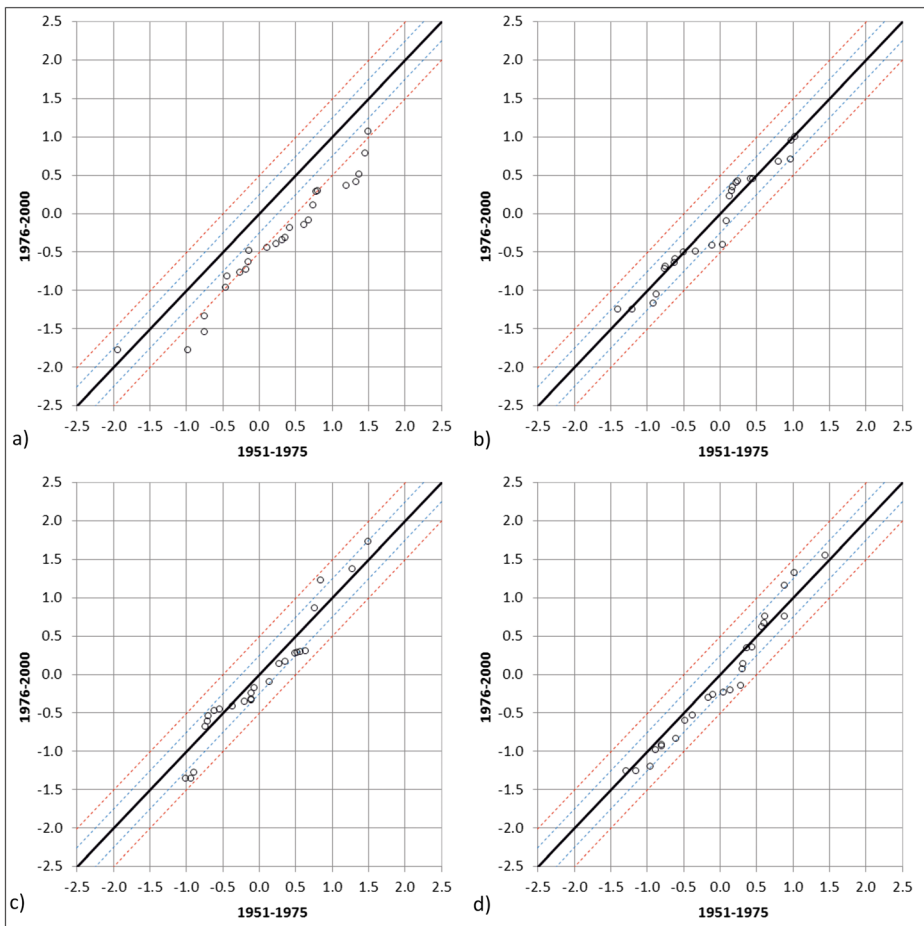
**Fig. 2** Localization of the selected 129 rain gauges and of the five regions of southern Italy on a Digital Elevation Model (DEM)



**Fig. 3** Results of the ITA method at annual scale for the five regions of southern Italy

revealed by the high anomaly values in summer and autumn, though within the 0.5 bound. The spring values did not show any clear tendency. For the Basilicata region (Fig. 5), the clearest result was the negative trend shown by the autumn rainfall anomalies, with some data outside the 0.5 bound. A particular behaviour has been detected for the winter anomalies that showed a slight positive trend for the high values and a negative one for the low and medium data. Contrasting tendencies characterize the summer values in which negative trends for the low and the high values and positive trends for almost all the medium ones have been detected. The spring season showed a negative tendency for the medium-high values, though within the 0.5 bound. Figure 6 shows the results of the ITA method for the Apulia region. The season with the clearest trend evidence was autumn, where all paired anomalies were positioned in the decreasing area, though not outside the 0.5 bound. The same situation was evidenced in spring, with the exception of the lowest values. In winter a negative trend was clear for the low and the medium values, while the highest anomalies showed a positive behaviour. In summer there was not clear evidence of trend, with almost all the points near the no-trend line. Also for the Calabria region (Fig. 7), there was a clear negative trend of the autumn rainfall, with the highest anomalies data lying largely outside the 0.5 bound. Also in winter a negative trend has been detected, more evident for the low and the medium values which reach the 0.5 bound. Though more vaguely, the negative behaviour has also been detected in spring, while in summer no trends can be clearly identified. For Sicily (Fig. 8) all the seasons evidenced a negative trend, with some exception concerning the low anomaly values for summer. Moreover, in autumn and summer there was a clear negative behaviour of the highest anomalies values.

The MK test has been applied in order to have an appraisal of the results obtained through the ITA method. Table 1 shows the results obtained by means of the MK test. In particular, significant negative results have been detected in Calabria, Sicily and Basilicata for the annual

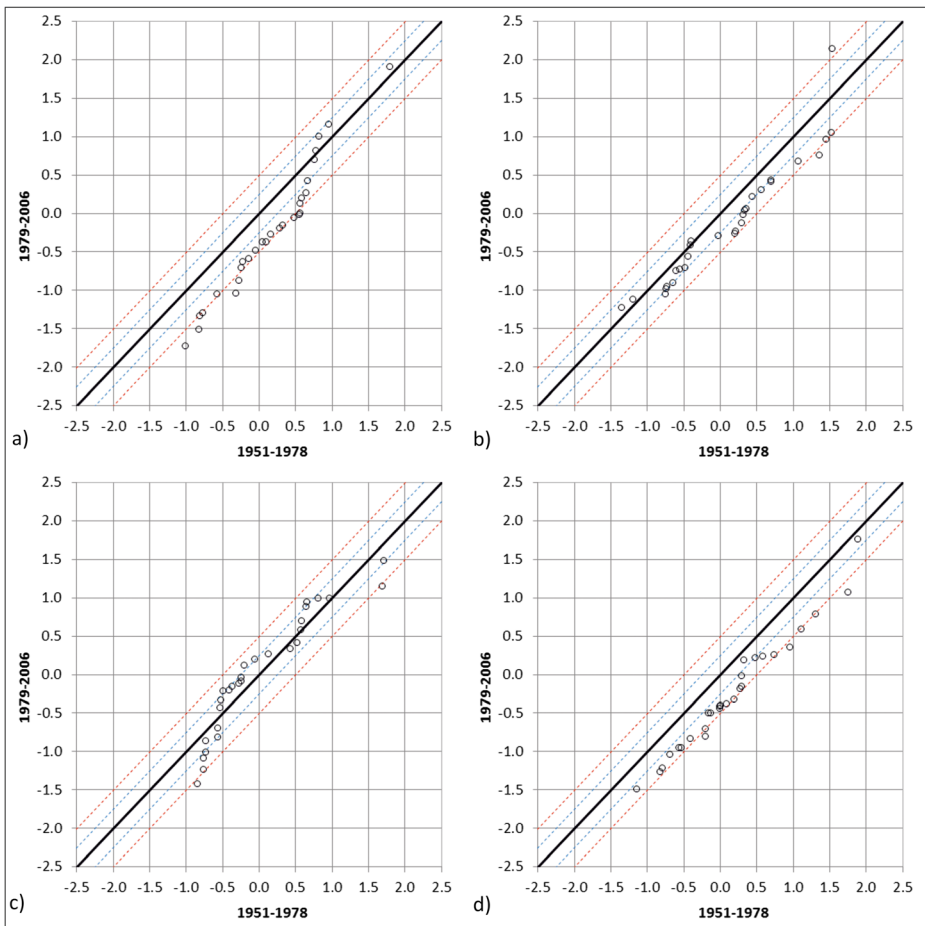


**Fig. 4** Results of the ITA method for the Campania region for winter (a), spring (b), summer (c) and autumn (d)

and the winter values, and in Calabria and Basilicata for autumn. On the other side, for all the regions no significant trend has been identified in summer, while spring shows significant trends only in Calabria.

As regards the annual rainfall anomalies, the results of the empirical trend analysis performed through the ITA method agree with the results of the trend analysis carried out by the MK test, in particular in the regions where the medium data highly deviate from the no-trend line of ITA method. As regards the seasonal anomalies, the clear negative trend showed in winter by the Campania region was significantly confirmed by the MK test. For the Basilicata region, the negative tendency detected in winter and mainly in autumn through the ITA method was confirmed by the MK test, with more statistical evidence in autumn. For the Apulia region, where the ITA method showed an undisputable negative trend in autumn, the result was confirmed by the MK test. For the Calabria region, the trend evidenced by the ITA method in winter, spring and autumn was also clear for the MK test. Finally for the Sicily, the trend evidenced by the seasonal anomalies in autumn and, at a lower degree, in winter was partially confirmed by the MK test.

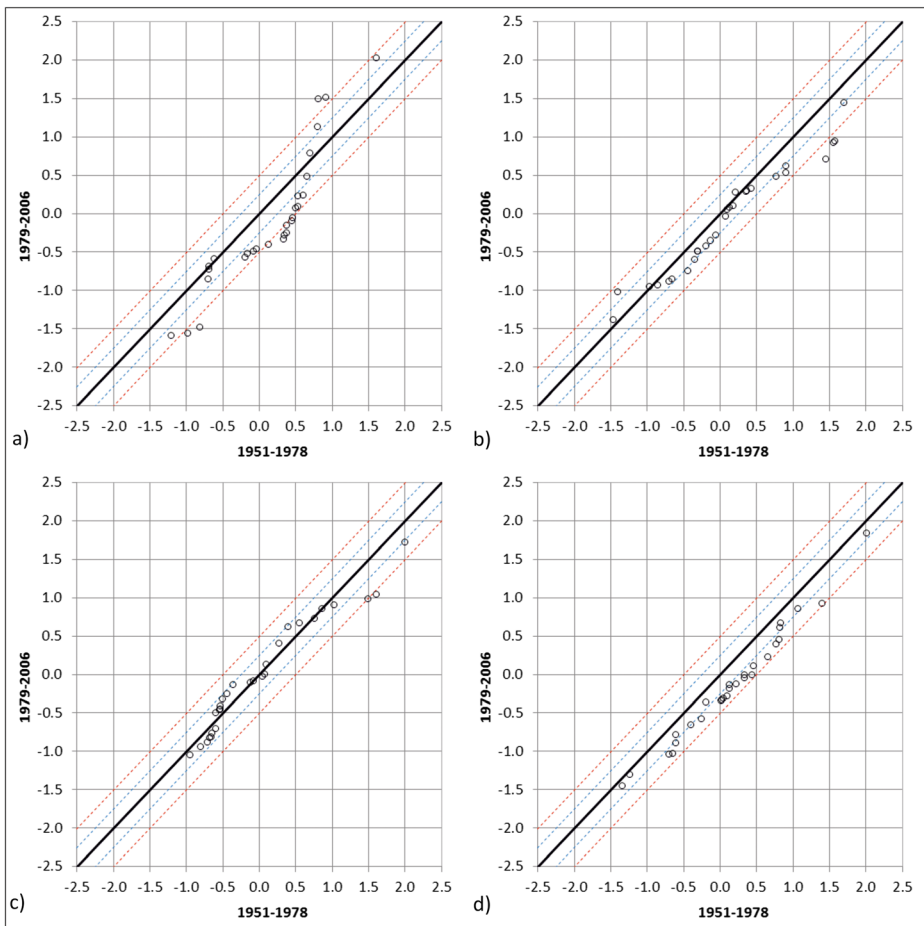




**Fig. 5** Results of the ITA method for the Basilicata region for winter (a), spring (b), summer (c) and autumn (d)

The results obtained through the application of the ITA confirmed a tendency towards a reduction in the precipitation amount during the winter months and an increase during the summer months which had been detected in various regional studies (Brunetti et al. 2012; Caloiero et al. 2011, 2016; Diodato 2007; Longobardi and Villani 2010; Piccarreta et al. 2013). In particular, similar results were obtained in Caloiero et al. (2017), but in this study, the use of rainfall anomalies allowed to add two confidence bounds in the trend detection and to avoid the influence of outlier in the trend analysis. The comparison between the ITA and the MK method performed in this work was particularly important because, as Şen (2017) showed, in recent years trend analysis applications has increased at an unprecedented rate due to the global warming. In this study, some contrasting results have emerged from the comparison between the ITA methodology and the MK test thus showing that Şen's method (2012) has some advantages when compared to these trend test. In fact, while through the MK test no trends have been detected in some analyses (e.g. in Campania for yearly data or in Apulia for spring anomalies), some trends have been obtained through the application of Şen's method (2012). Indeed, it provides details about the





**Fig. 6** Results of the ITA method for the Apulia region for winter (a), spring (b), summer (c) and autumn (d)

trends of annual and seasonal total precipitation data in terms of evaluation of low, medium and peak values. It thus presents a very different aspect from the one shown by the MK test. Indeed, as pointed out by Ay and Kisi (2015), all ranges of data can be graphically provided on the Cartesian coordinate system and, therefore, power of visual inspection and comments can be accounted for further interpretations. This is a very important issue because, as Şen (2012) argued, an efficient, effective, and optimum management of water resources requires not only the identification of monotonic trends over a given time period, but also whether the low, medium, and high values have separate trends. Despite these advantages, the ITA method has the limitation that it does not allow to determine whether the differences between each point and the 1:1 line are statistically significant. In fact, the significance of the trends has been studied by some authors which included confidence limits on the ITA diagrams but, at present, no single objective method to evaluate the limits on the ITA diagrams, has been identified among those available.

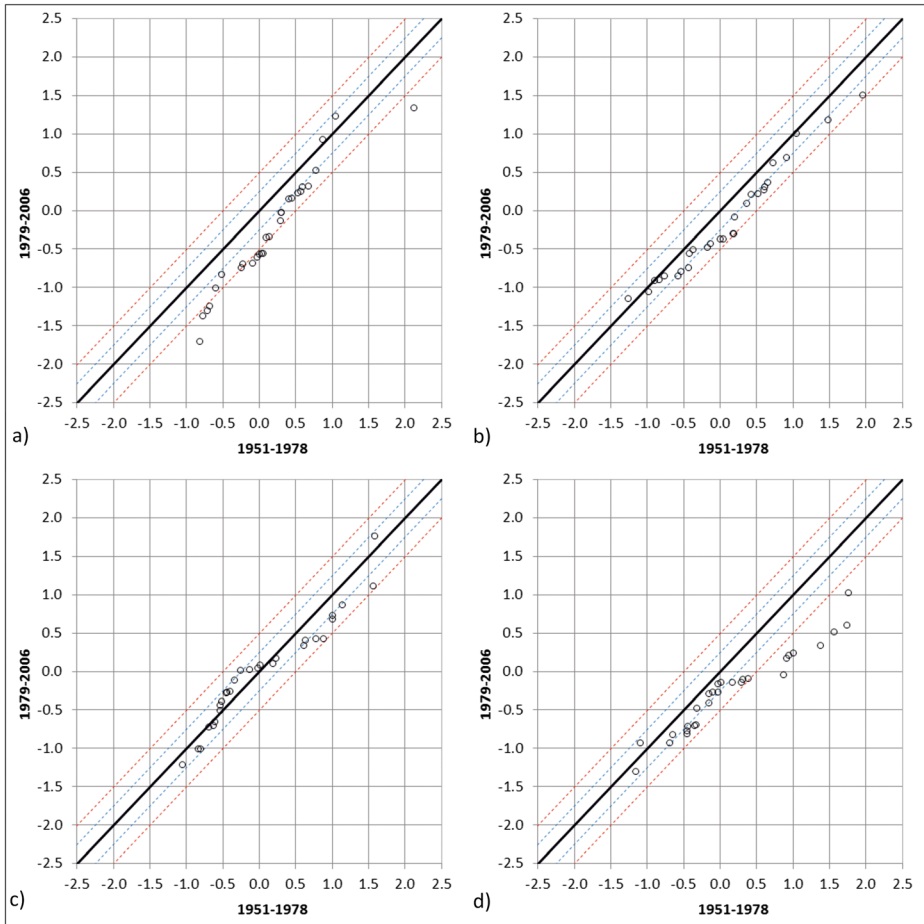
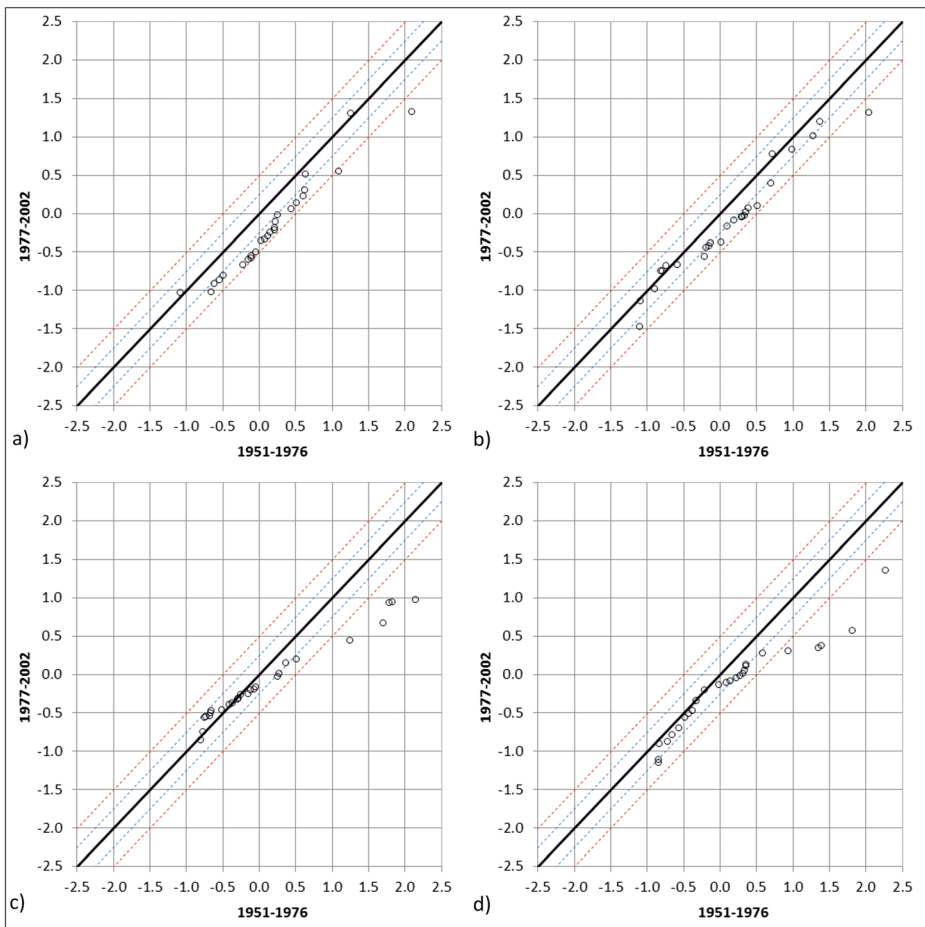


Fig. 7 Results of the ITA method for the Calabria region for winter (a), spring (b), summer (c) and autumn (d)

## 5 Conclusion

In this paper, the Innovative Trend Analysis (ITA) technique has been applied at annual and seasonal scale to the rainfall anomalies observed in 5 regions of southern Italy. Globally, at seasonal scale, the results of the ITA application evidenced that a negative trend of the winter anomalies has been detected for all the categories (low, medium and high) mainly in Campania and Sicily. The other regions, especially Apulia and Basilicata, showed a negative behaviour for the low and the medium anomalies and a positive trend for the highest ones. Instead, for spring rainfall anomalies, Campania and Sicily were the regions whose trends were not well defined. Calabria and Basilicata showed negative trends for the spring anomalies, although within the 0.5 bound. Only the Apulia region showed the most evident trends: negative for the high and the medium values, positive for the low ones. Summer was the season without clear tendencies for almost all the selected Italian regions, with the only exception of Sicily, where the highest values showed negative behaviour outside the 0.5 bound. Finally, autumn was the season where the trends of the rainfall anomalies were very clear, especially for the highest values of Calabria and Sicily, which were also very far from the no-trend line. Apulia and



**Fig. 8** Results of the ITA method for the Sicily region for winter (a), spring (b), summer (c) and autumn (d)

Basilicata showed negative trends of the autumn values, but with lower entities. Only Campania evidenced some positive trends, limited to the highest values. Subsequently, the results have been compared with the ones obtained by the MK test. The comparison between the ITA method and the MK trend test has been performed because in recent years trend analysis applications have increased, often with no attention to the possible behaviours of the low, medium and high values of a given time series. In fact, this study evidenced that the ITA

**Table 1** Results of the MK trend analysis for the seasonal and yearly total precipitation

Region	Year	Winter	Spring	Summer	Autumn
Calabria	..**	..*	..*	+	..**
Sicily	..**	..*	—	+	—
Basilicata	..**	..*	—	+	..**
Campania	—	..**	+	+	+
Apulia	..*	—	—	+	..*

Marks indicate the significant results obtained through a two-tailed test: 5% (\*) and 1% (\*\*)

method has some advantages when compared to the MK trend test, providing details about the trends of annual and seasonal total precipitation data in terms of evaluation of different categories values. Moreover, the use of a graphical technique, such the ITA method, represents a novelty since it also overcomes problems such as independent structure of the time series, normality of the distribution, and length of data, that could be present in the comparison of a large number of data series.

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## Compliance with Ethical Standards

**Conflict of Interest** None.

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