Assessment of seasonal and annual rainfall trend in Calabria (southern Italy) with the ITA method

T. Caloiero, R. Coscarelli and E. Ferrari

ABSTRACT

In this paper, an investigation on the temporal variability of seasonal and annual rainfall in the Calabria region (southern Italy) was carried out using a homogeneous and gap-filled monthly rainfall dataset of 129 rain gauges in the period 1951–2006. In particular, possible trends have been assessed by means of the Innovative Trend Analysis (ITA) technique, which allows the identification of a trend in the low, medium and high values of a series. Moreover, the results obtained with the ITA have been compared with the ones obtained with the Mann–Kendall test. These analyses have been performed in five rainfall zones (RZs) of the study area, characterized by different climatic conditions. As a result, both the methods evidenced a negative trend of the annual rainfall in the entire study area. On a seasonal scale, this negative tendency has been confirmed in autumn and winter although with some differences among the several RZs.

Key words | graphical techniques, Mann–Kendall test, monthly rainfall, trend analysis

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INTRODUCTION

Climate change impacts are studied using both information derived by global models, which is one of the primary tools in understanding this phenomenon at a global scale (Hamlet & Lettenmaier 2000; Wei & Watkins 2011; Raghavan *et al.* 2013), and station information, which is better suited for local scale analysis. In particular, in the last few decades rainfall changes have received much attention, particularly in some areas such as western China (Zhang *et al.* 2014; Chang *et al.* 2016) and the Mediterranean basin (Caloiero *et al.* 2019a) which are considered a major hotspot of climate change, subject to strong warming and drying. As regards the Mediterranean basin, it is climatically affected by the interaction between mid-latitude and tropical processes, being located in a transition zone between the arid climate of North Africa and the temperate and rainy climate of central Europe (IPCC 2013). Therefore, within the context of climate change, numerous studies related to rainfall trends have been performed in this area. The majority of these studies are based on non-parametric and/or parametric methods, such as for example the linear regression analysis, the Mann–Kendall test, the Spearman's rho test, and the Sen's slope methods (Gedefaw *et al.* 2018). Specifically in the Mediterranean basin, del Rio *et al.* (2011) detected a broad decrease in annual rainfall, albeit other authors (e.g. Piervitali *et al.* 1997; Zhang *et al.* 2005; Caloiero *et al.* 2018a) put in evidence of some differences occurring between the east and west of the region. In fact, over the last 50 years the west-central Mediterranean area has been characterized by a rainfall decrease (Longobardi & Villani 2010), although with irregular trends and high variability across the decades. Conversely, the eastern Mediterranean showed different results, with some authors detecting positive trends (Maheras *et al.* 2004; Altin & Barak 2014), and others obtaining negative tendencies especially for Israel (Shohami *et al.* 2011; Ziv *et al.* 2014). As regards Italy, many regional studies analysed annual rainfall, evidencing a decrease in its amounts, especially in the southern regions of the country. Specifically, a different seasonal trend

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behaviour, with decreasing rainfall amounts in the winter-autumn period and a rainfall increase in the summer months, has been evidenced in thorough analyses at regional scale performed in Campania (Diodato 2007; Longobardi & Villani 2010), Basilicata (Piccarreta *et al.* 2004), Sicily (Liuzzo *et al.* 2016), Calabria (Caloiero *et al.* 2011), and Sardinia (Montaldo & Sarigu 2017; Caloiero *et al.* 2019a). As regards the Calabria region, it is one of the centre-most regions within the Mediterranean basin, where the climate changes dynamics are directly caused by the influence of the central Europe and the North Africa climates, and it is one of the Italian regions most affected by drought and prone to desertification phenomena (Coscarelli *et al.* 2016). Several studies evidenced changes in rainfall, but these studies are mainly based on non-parametric tests and did not specify if low or high rainfall contributed to the detected trends. In order to overcome such a problem, Şen (2012) proposed the Innovative Trend Analysis (ITA) technique which allows a graphical trend evaluation of the low, medium, and high values in the data. This method has been widely applied in trend analyses of several hydrological variables. For example, the ITA method has been applied for the analysis of annual rainfall series in India (Malik *et al.* 2019), Ethiopia (Gedefaw *et al.* 2018), Italy (Caloiero *et al.* 2018b) and in Turkey (Haktanir & Citakoglu 2014). Also in Turkey, Şen (2014) and Ay & Kisi (2015), applied the ITA to temperature data and Kisi & Ay (2014) studied some water quality parameters registered at five stations. Yilmaz (2019) and Caloiero (2018) applied the ITA method for the analysis of drought trends in Turkey and New Zealand, respectively. The ITA technique was also used to analyze the trends of heat waves (Martínez-Austria *et al.* 2015), of sea wave height and energy periods (Caloiero *et al.* 2019b), of monthly pan evaporations (Kisi 2015) and of streamflow data (Tabari & Willems 2015).

In this study, the annual and seasonal high quality rainfall series recorded in a region of southern Italy (Calabria) were analysed, and the temporal changes of the different series were detected using the ITA technique and the non-parametric Mann–Kendall test. In particular, the investigation was carried out considering five rainfall zones (RZs) of the study area, characterized by different climatic conditions. The application of the ITA technique allowed to detect the trend of the low, medium and high precipitation monthly data. This work is an enhancement of the analysis made by Caloiero *et al.* (2018c).

METHODOLOGY

The ITA procedure can be performed using the following three steps:

1. divide the time series into two equal parts (ideally more than 30 years of observation);
2. sort separately each part in ascending order;
3. locate in a Cartesian diagram the first and the second half of the time series on the x-axis and on the y-axis, respectively.

In Figure 1, a graphical representation of the method on a Cartesian coordinate system is shown.

Results of the trend analysis depend on the position of the data in the Cartesian diagram with respect to the 1:1 ideal line (45° line). If the data fall close to the ideal line, there is no trend in the time series. If data are located above the 1:1 line, there is an increasing trend in the time series. If data fall below the ideal line, there is a decreasing trend in the time series (Şen 2012, 2014). In order to

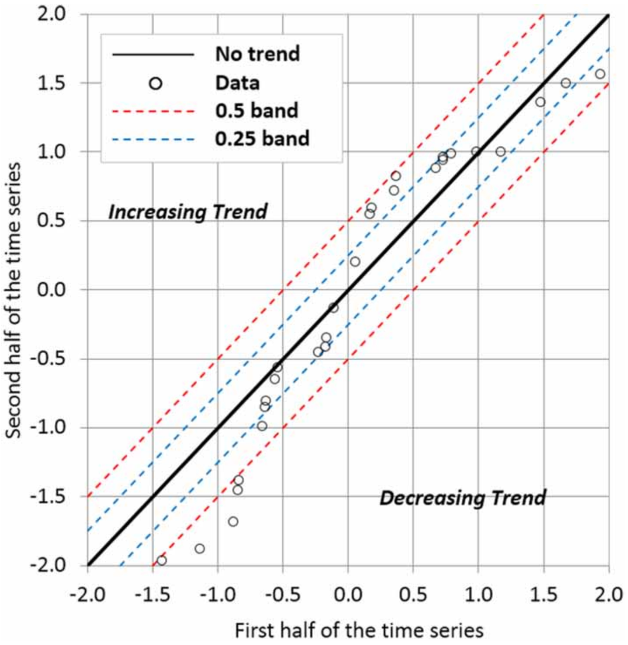

Figure 1 | Example of the Innovative Trend Analysis (ITA) proposed by Şen (2012).

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). In particular, in this paper we considered normalized rainfall and thus two confidence bounds (0.25 and 0.5) have been added as the distance from the line 1:1 (Figure 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. The application of the ITA method allows clear identification of trends of low, medium and high values of any hydro-meteorological or hydro-climatic time series, even though it does not allow evaluation of the significance of the trends.

Differently from other parametric or non-parametric methods, the main advantage of the ITA method (Şen 2012) is that it does not require any initial assumptions (e.g. serial correlation, non-normality, sample number, etc.). In this study, with the aim of evaluating the possible existence of temporal tendencies, the rainfall series were also analysed for trends with a parametric and a non-parametric method. The slopes of the trends were calculated by the Theil–Sen estimator (Sen 1968) and the statistical significance was assessed with the Mann–Kendall non-parametric test (Mann 1945; Kendall 1962). The Theil–Sen estimator was selected with the aim of avoiding the influence of the outliers in the trend slope evaluation. In fact, when a time series contains very low or very high values at the beginning or at the end of the considered period, linear regression methods are prone to their influence, resulting in overestimated or underestimated slopes while the Theil–Sen estimator is not susceptible to the influence of extreme values.

STUDY AREA AND DATA

Located between 37° 54′ and 40° 09′ N and between 15° 37′ and 17° 13′ E, Calabria belongs to the southernmost part of the Italian peninsula. It covers an area of 15,080 km^2, with a significant coastline length of about 700 km. Although it does not present many high peaks (the tallest mountain is 2,266 m a.s.l.), it is the most mountainous area in the country with about 42% of the regional area over 500 m a.s.l. (Figure 2). Calabria is a region characterized by a typically Mediterranean climate, presenting sharp contrasts due to its position within the Mediterranean Sea and its orography. Specifically, warm air currents coming from Africa and high temperatures affect the Ionian side, leading to short and heavy precipitations. The Tyrrhenian side, instead, is affected by western air currents, which cause milder temperatures and more intense precipitations when compared to the Ionian side. Cold and snowy winters and fresh summers with some precipitation are typical of the inner areas of the region (Caloiero et al. 2014).

The database used in this study was the one presented in Brunetti et al. (2012a). The original precipitation series registered in the Calabria region from 1916, and stored by the Multi-Risk Functional Centre of the Regional Agency for Environment Protection, were checked to eliminate inhomogeneities from the data series and lack of data. Moreover, the Calabria region was subdivided into distinct homogeneous areas (RZs), characterized by different climatic conditions (Brunetti et al. 2012b). This was performed through the Principal Component Analysis that is a multivariate technique which allows the analysis of a data table and to represent it as a set of new orthogonal variables called principal components. Moreover, by means of this technique the pattern of similarity of the observations and of the variables can be displayed as points on a map (Abdi & Williams 2010). In order to obtain the five RZs, Varimax rotation of the principal components was applied to the correlation matrix of daily records. Varimax rotation (also called Kaiser–Varimax rotation) maximizes the sum of the variance of the squared loadings, that is, ‘loadings’ correlations between variables and factors. As a result, high factor loadings are present for a few variables and low factor loadings for the remaining variables. In this way, by means of this methodology each original variable tends to be associated with one of the (or a few) components, each component characterizes only a few variables (Kaiser 1958) and the interpretation of the results is largely simplified. Specifically, the first five Empirical Orthogonal Functions, which explained 90% of the total variance, on the Tyrrhenian side led to the identification of the North-Western Zone (T1) and the South Zone (T2) with 31 and 21 rain gauges, respectively. On the Ionian side, the North Zone (I1), the Central Zone (I2) and the South Zone (I3) with 21, 31 and 25 rain gauges, respectively,

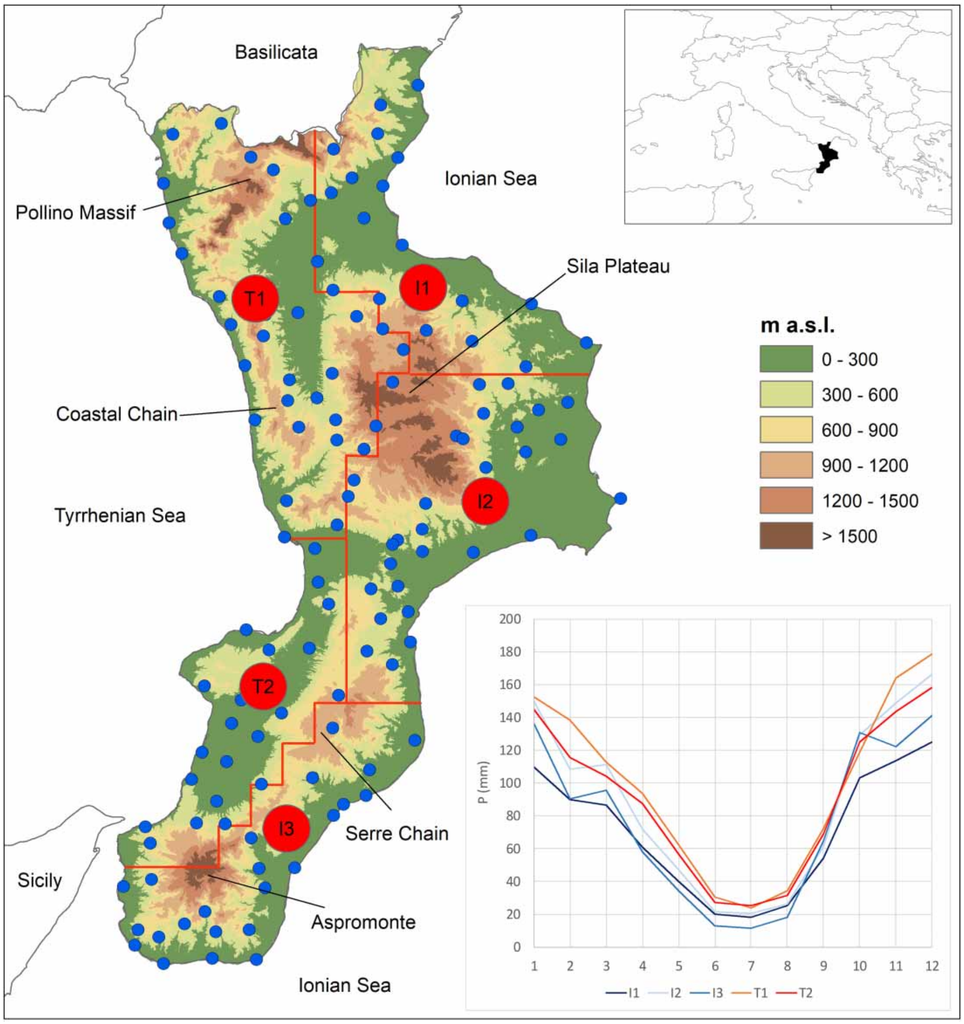

Figure 2 | Localization of the selected 129 rain gauge stations and of the five rainfall zones on a DEM of the Calabria Region and mean monthly rainfall values for each rainfall zone.

were identified (Figure 2). For each RZ the rainfall values of the rain gauges were normalized, and then an average rainfall anomaly series was obtained considering the rain gauges falling in each RZ. Specifically, rainfall data was normalized by calculating the mean and standard deviation on a monthly basis. Then, for each observed monthly value of the variable, the mean was subtracted and the difference was divided by the standard deviation.

RESULTS AND DISCUSSION

For every RZ of the Calabria region, the ITA method was applied to analyse the behaviour of the two equal parts in which each time series has been divided. Specifically, each sample was split into two sub-periods (1951–1978 and 1979–2006). In the following, results are discussed considering low, medium and high values which were identified as lower than −1.5, between −1.5 and 1.5 and higher than 1.5, respectively. The results of the ITA method applied to the average annual rainfall of the five RZs are shown in Figure 3.

With the exception of some extreme values, a negative trend was detected, mainly for the highest values of each sub-period. This tendency is particularly clear for the RZs I2, I3 and T2, and, less marked, also for the RZ I1. As an example, for the RZs I2 and I3 the second highest anomalies in the sub-period 1951–1978 are 2.0 and 2.2, respectively, and about 0.7 in the sub-period 1979–2006 for both the

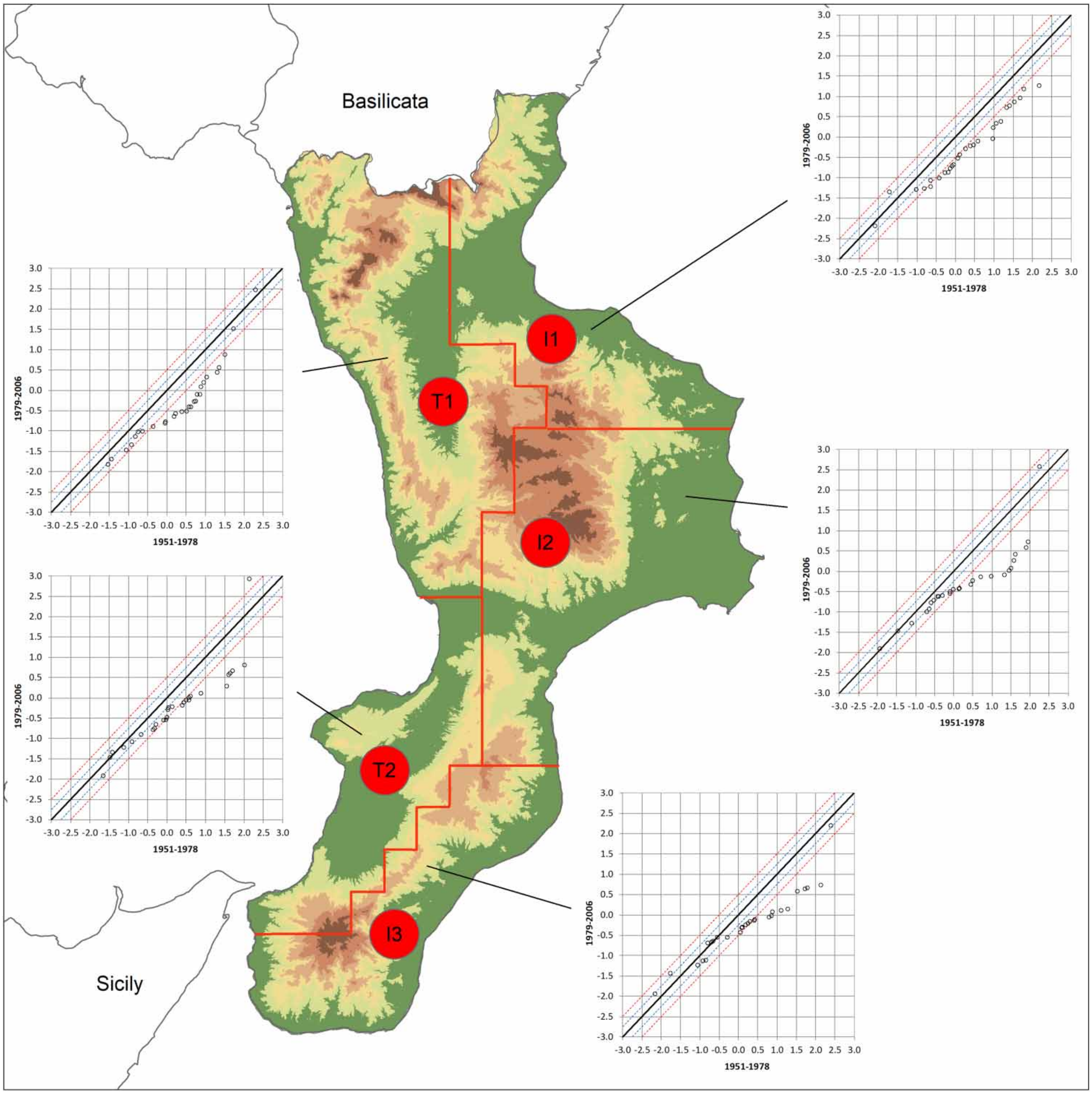

Figure 3 | Results of the ITA method for the average annual rainfall of each RZ.

RZs. On the contrary, the RZ T1 shows a negative tendency for the medium values of the average annual rainfall.

As regards the winter season, the results of the ITA procedure for the five RZs are represented in Figure 4. In this case, a double tendency can be detected: negative for the lowest values and positive for the highest ones. This trend is particularly evident for the RZs I1, I2 and T2. Particularly, the highest anomalies value of the RZ I2 is 1.0 for the first sub-period and 2.0 for the second one. On the other hand, the lowest anomalies are −1.0 and −1.6 for the first and the second period, respectively.

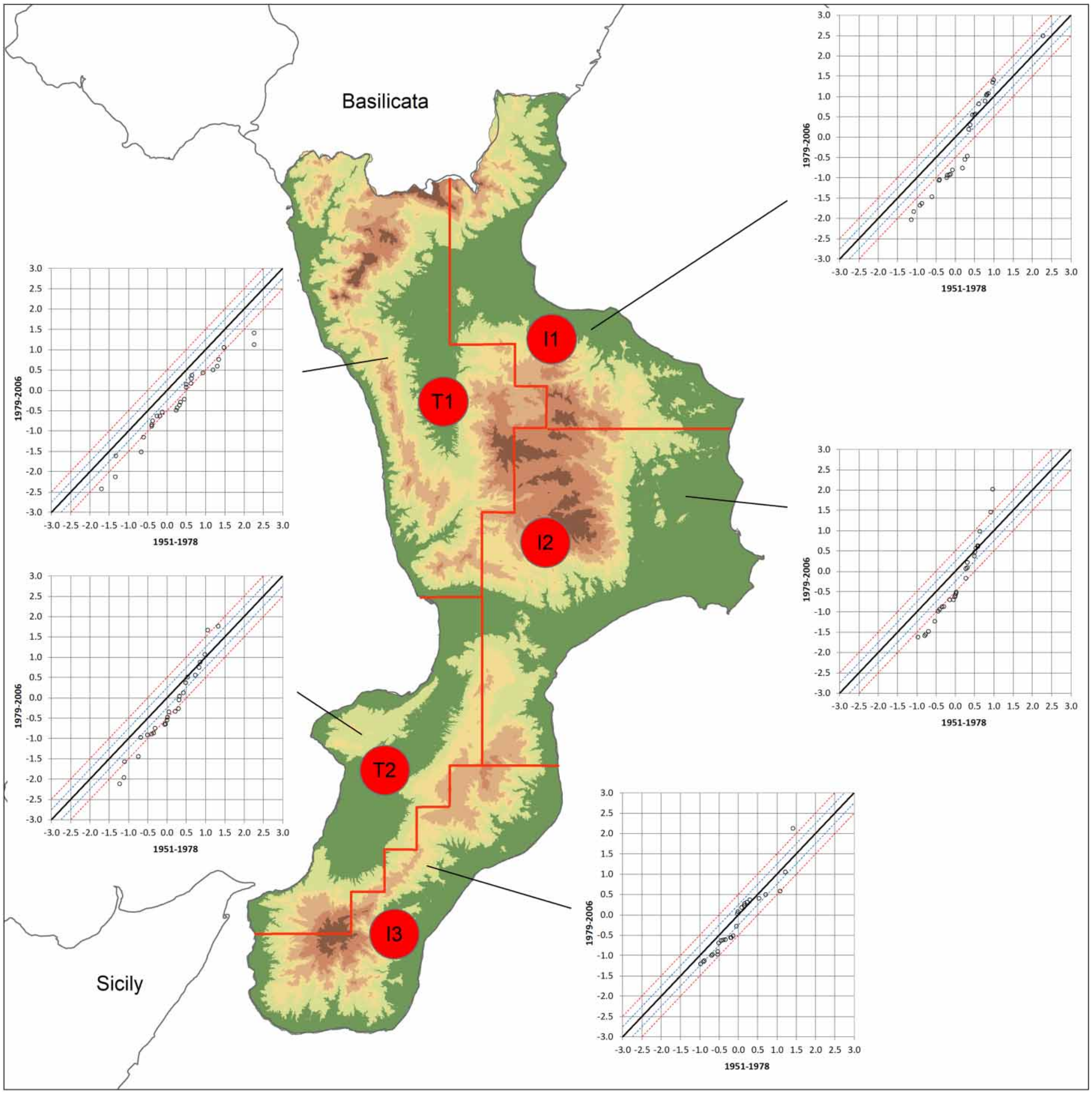

Figure 4 | Results of the ITA method for the average winter rainfall of each RZ.

The RZ T1 shows a negative tendency for all the data, especially for both the lowest and highest values. In particular, the highest anomalies for this RZ are about 2.3 for the sub-period 1951–1978 and 1.4 for the sub-period 1979–2006; as regards the lowest values, these are about −1.7 for the first sub-period and −2.4 for the second one. No clear trend is evident for the RZ I3.

As concerns the spring season (Figure 5), no clear trend is evident for all the RZs. Besides, the highest values detected in the RZs I2, I3, T2 and T3 show a negative tendency; on the contrary, the highest value for RZ I1 presents a positive trend. In particular, the highest values for RZ I3 were about 2.9 for 1951–1978 and 1.6 for 1979–2006.

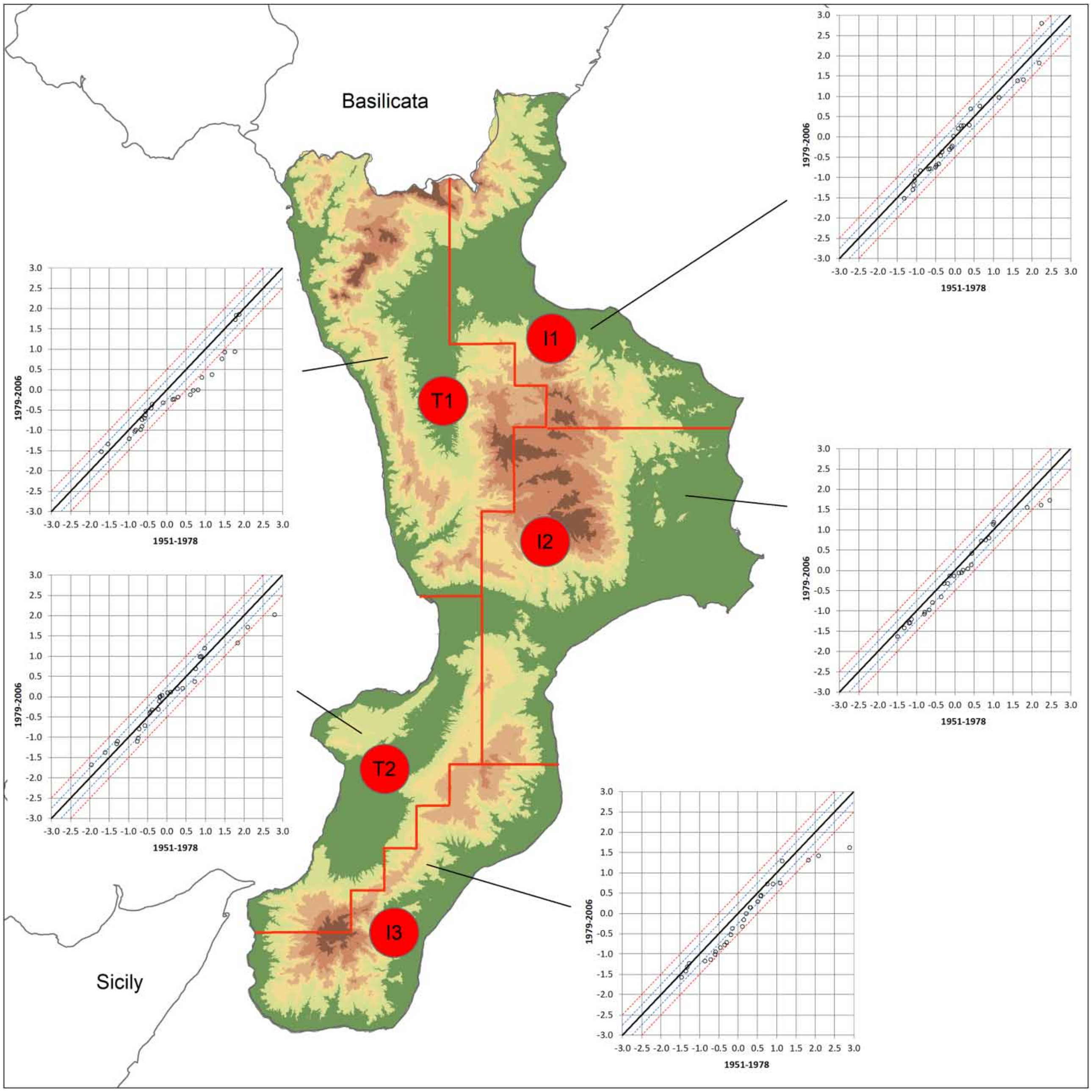

Figure 5 | Results of the ITA method for the average spring rainfall of each RZ.

For the summer season, the only significant result can be ascribed to the RZ I1, which shows a clear positive tendency for the highest values (Figure 6). In this case, the five highest anomalies range between 1.0 and 1.7 for the first period and between 1.8 and 2.7 for the second one. The other RZs, with the exception of some points, do not show particular features.

The last analysis, concerning the autumn values, exhibits negative trends of the highest values of the average anomalies for almost all the RZs (Figure 7). This tendency is particularly clear for the rainfall anomalies of the Ionian side. For example, the six highest values in the RZ I2 range between 1.8 and 2.7 for the period 1951–1978 and between 0.2 and 1.2 for the period 1979–2006. As regards

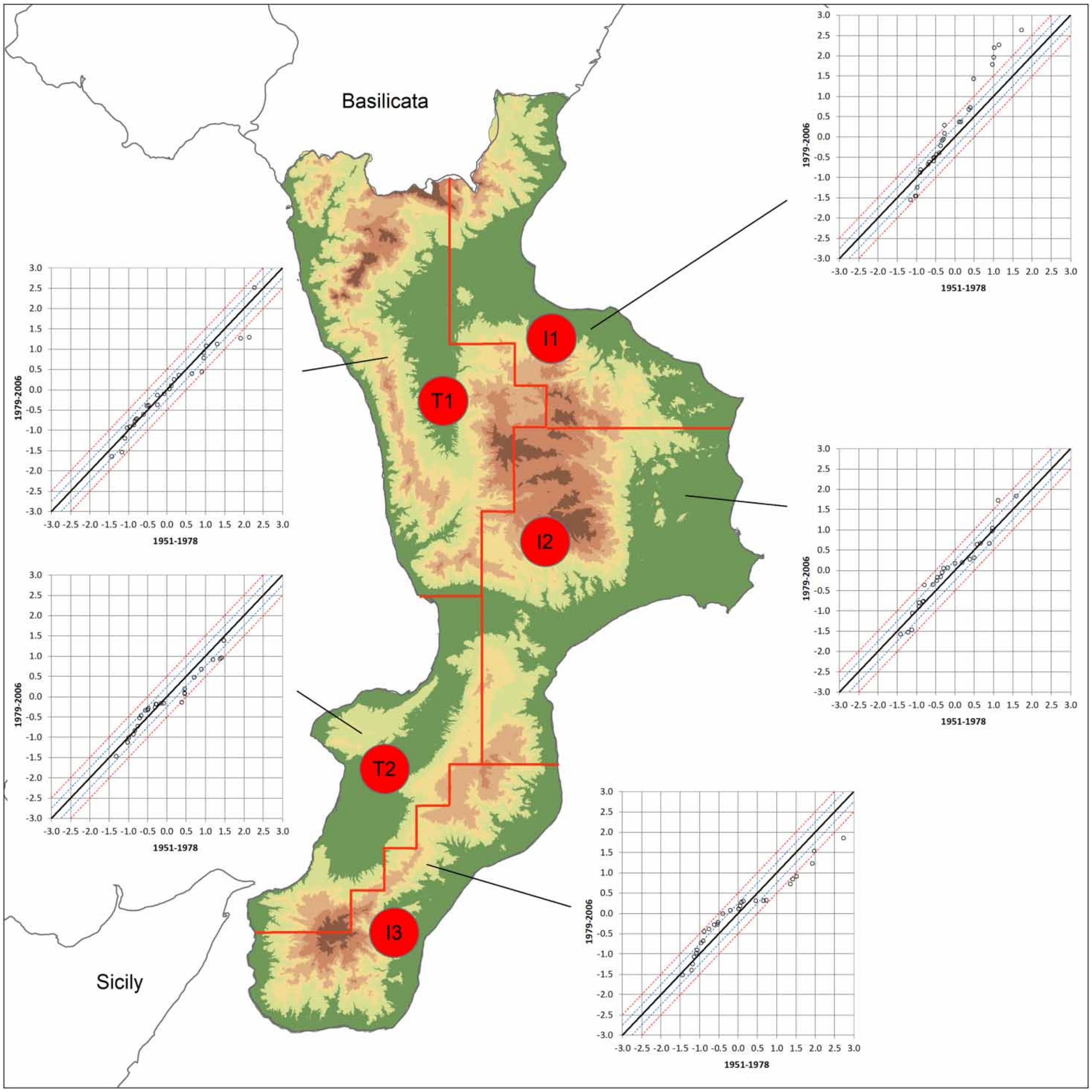

Figure 6 | Results of the ITA method for the average summer rainfall of each RZ.

the RZ I3, the highest anomalies are 3.0 for the first period and 1.0 for the second one. On the Tyrrhenian side, the same trend is less evident especially for the RZ T1.

The results of the trend analysis obtained by means of the ITA method have been verified through the Mann–Kendall test applied to the mean series of rainfall evaluated in each RZ. Table 1 shows the trends of annual and seasonal precipitation obtained for each RZ through a two-tailed MK test with different significance values.

In particular, the highest trend rates of annual rainfall observed in Calabria were –53.2 mm/decade (RZ I2) and –45.8 mm/decade (RZ T1). Moreover, the same trend is evident for autumn: –34.3 mm/decade for the RZ I2, –28.9 mm/decade for the RZ I3 and –25.0 mm/decade for

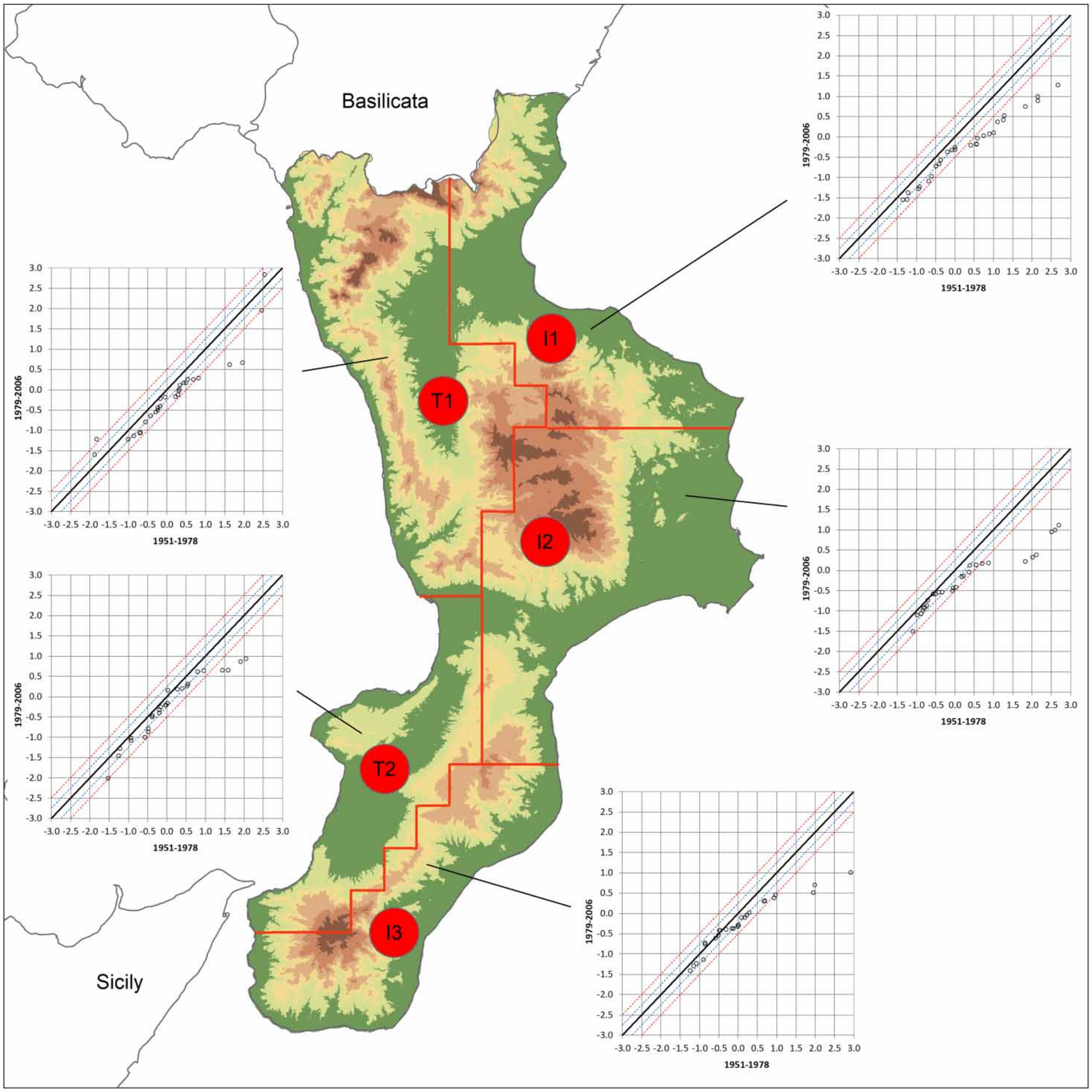

Figure 7 | Results of the ITA method for the average autumn rainfall of each RZ.

the RZ I1. Also, the winter season shows high trend values: −14.2 mm/decade was observed for the RZ I2, −31.4 mm/decade for the RZ T1 and −13.1 mm/decade for the RZ T2. For the remaining seasons, only spring shows two significant trend values for the RZs I2 and T3.

The rainfall reduction in the winter period confirmed the results obtained in other Italian regions (Diodato 2007; Longobardi & Villani 2010; Brunetti *et al.* 2012a; Caloiero *et al.* 2019a). As evidenced by Maheras *et al.* (2004), this rainfall behaviour could be related with the time variability of the circulation types. In particular, by analysing the daily circulation types at 500 hPa for the period 1958–2000, they found a general positive trend of anticyclonic circulation, normally associated with a lower-than-average probability

Table 1 | Results of the Mann–Kendall test for monthly, seasonal and yearly total precipitation

	I1 mm/ decade	I2 mm/ decade	I3 mm/ decade	T1 mm/ decade	T2 mm/ decade
Year	–37.6***	–55.5***	–39.2**	–48.5***	–34.4**
Winter	–10.6	–20.4**	–4.4	–29.9***	–14.3*
Spring	–5.3	–9.7*	–11.0**	–8.8	–3.1
Summer	3.0	3.0	2.7	1.2	2.0
Autumn	–25.6***	–23.2**	–16.2*	–8.1	–11.4

Asterisks indicate the significant results obtained through a two-tailed test: 10% (*), 5% (**) and 1% (***).

of rainfall, and a negative trend of cyclonic types. Similar results have been obtained by Guijarro *et al.* (2006) who, by analyzing the temporal variability of cyclonic geostrophic circulation in the Mediterranean basin for the period 1957–2002, detected a negative trend in the cyclone frequencies in the Western Mediterranean, mainly in winter.

CONCLUSIONS

In this work, the ITA method was applied at annual and seasonal rainfall anomalies evaluated in five sub-regions of the Calabria region (southern Italy). On an annual scale, the results of the ITA method showed a negative trend of the highest values, this was particularly clear for the RZs I2, I3 and T2. On a seasonal scale, the results of the ITA technique evidenced a negative trend for the lowest values and a positive one for the highest values of the winter anomalies, especially in the RZs I1, I2 and T2. No clear tendencies were detected in spring for all the RZs, although the highest values of the RZs I2, I3, T2 and T3 showed a negative trend while the highest values for RZ I1 evidenced an increase. In summer, a clear positive tendency was detected for the RZ I1 and for the highest values. Finally, in autumn a negative trend of the highest values was evidenced in all the RZs.

Subsequently, the results obtained with the ITA have been compared with the ones obtained with the MK test, evidencing that the ITA method has some advantages when compared to the MK trend test. In fact, the ITA method provides details about the trends of annual and seasonal total precipitation data in terms of evaluation of different values (low, medium and high values). As a result of the MK analysis, a negative trend of the annual rainfall has been evidenced, mainly due to the negative tendencies of the winter and autumn rainfall which, in the Mediterranean area, constitute the seasons with the highest rainfall.

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