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Analysis of daily and monthly rainfall concentration in Southern Italy (Calabria region)

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SUMMARY

High percentages of the yearly total precipitation concentration in a few very rainy days can increase the risks of floods and soil instability. In this paper, an investigation of the spatial and temporal patterns of daily and monthly precipitation concentration in Calabria (Southern Italy) has been carried out by means of a homogenous daily precipitation data set. The results show that a very dishomogeneous temporal distribution of the daily rainfall characterizes the eastern side of the region with rain gauges in which one quarter of the rainiest days represents almost three quarters of the total pluviometric amount, and a western side which presents a more homogenous temporal distribution of the rainfall. Moreover, the application of the Mann–Kendall test has shown a clear tendency toward a weaker seasonality of the rainfall distribution.

1. Introduction

One of the most important aspects of climate change that requires thorough investigation is the time distribution of rainfall and its historical changes. Rainfall is the most important climatic variable since it gives rise to opposite phenomena such as drought and floods.

Numerous studies on precipitation variability have been undertaken all over the world using various statistical procedures. A significant decrease in the number of rainy days and a significant increase in the precipitation intensity values have been identified in many places in the world, such as China (Ren et al., 2000; Gong and Ho, 2002; Zhai et al., 2005) and America (Karl et al., 1996). With regards to the Mediterranean area, several studies have been carried out to investigate trends in annual and seasonal precipitation, on a large scale (Kutiel et al., 1996; Piervitali et al., 1998; Xoplaki et al., 2006), and for entire nations or regions (Amanatidis et al., 1993; Esteban-Parra et al., 1998; De Luis et al., 2000; Feidas et al., 2007; del Rio et al., 2011). Long precipitation records have been investigated in Northern and Central Italy (Montanari et al., 1996; De Michele et al., 1998; Brunetti et al., 2006b), in Southern Italy (Palmieri et al., 1991; Brunetti et al., 2004, 2006a; Cotecchia et al., 2004) and in particular in the Calabria region (Coscarelli et al., 2004; Ferrari and Terranova, 2004; Brunetti et al., 2010; Buttafuoco et al., 2011; Caloiero et al., 2011a, 2011b).

The intensity, the amount and the pattern of the precipitation are expected to change, consequently extreme weather events, such as droughts and floods, are likely to occur more frequently.

A higher precipitation concentration, represented by greater percentages of the yearly total precipitation in a few very rainy days, has the potential to cause floods and also droughts phenomena, which are expected to impact considerably on water resources. As consequences, precipitation amounts and intensity may render the soil more vulnerable to erosion and increase slope instability. In particular, the vulnerability of soil to erosion will affect the growth conditions of plants and agricultural practices, altering land-use management strategies (Scholz et al., 2008); slope instability may increase economic and life losses. According to Klik and Truman (2003), the knowledge of temporal distribution of the heavy rainstorms is necessary for evaluating the amount of runoff and soil loss. Changes in the temporal distribution of rainfall might also modify fluvial regimes, groundwater recharge, water availability, hydroelectric production (Aguado et al., 1992; Paredes et al., 2006; Lopez-Moreno et al., 2009). For these reasons, it is important to analyze the statistical structure of precipitation rates based on daily precipitation data set.

To evaluate the varying weight of daily precipitation, a statistical index (Concentration Index – CI) can be used. In Spain,

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Martin-Vide (2004) computed the CI and then explored its spatial patterns which clearly divide peninsular Spain into two regions: an eastern façade, which presents a high concentration of precipitation with 25% of the rainiest days providing 70% or more of the annual total, and the rest of the country, which presents more regular daily amounts. Zhang et al. (2009) calculated the CI based on yearly rainfall series of the Pearl River basin, also evaluating possible trends of CI for each station. Li et al. (2010) estimated the CI values for the Kaidu River basin, individuating a region of Southern Xinjiang with the highest values of precipitation CI (the majority of the yearly precipitation amount deriving from 25% of the rainiest days).

Another important aspect, in this research area, is the concentration of the rainfall in one year: an unbalanced distribution of rainfall may cause periods of excessive rainfall and periods of drought with a negative impact on the growth of plants and crops. The statistical Precipitation Concentration Index (PCI) allows to quantify the relative distribution of rainfall patterns, and to estimate the seasonality of the precipitation. Michiels et al. (1992), analyzing the rainfall data from meteorological stations situated in a central transect of Spain, concluded that in the Southern part of the transect, the concentration of the rainfall has not a seasonal effect (not strongly confined by a typical dry or wet period) but a temporal effect (bound to the unreliable, unpredictable character of the rainfall). Always in Spain De Luis et al. (2011) made an analysis of the PCI using the monthly precipitation. The analyses of two sub-periods (1945–1975 and 1976–2005) show significant changes in the precipitation occurred in Spain from 1945 to 2005. Apaydin et al. (2006) found a moderate seasonality for rainfall in Turkey. Cannarozzo et al. (2006), applying the Mann–Kendall test to the PCI values for the Sicily territory, revealed a general steady situation in which the rainfall temporal distribution during the year has not been modified. De Luis et al. (2010) found an opposite behavior between annual precipitation and seasonal PCI in Spain.

The aim of this paper is to investigate the spatial and temporal patterns of CI and PCI in Calabria (Southern Italy) using a homogenized daily precipitation data set. The application of a trend test can also show possible tendencies towards a more homogenous rainfall distribution in the year. The results may have important effects on water management and environmental phenomena, such as soil erosion, desertification and soil instability.

2. Methodology

To determine the relative impact of different classes of daily precipitation and to evaluate the weight of the largest daily event in the total precipitation value, it is necessary to analyze the accumulated percentages of precipitation (Y) contributed by the

Table 1
Values for constants a and b of exponential curves, coefficients of determination (R^2), CI and percentage of precipitation contributed by 25% of the rainiest days.

Code	a	b	R^2	CI	Rainfall (%)	Code	a	b	R^2	CI	Rainfall (%)	Code	a	b	R^2	CI	Rainfall (%)
860	0.071	0.025	0.971	0.560	65.1	1600	0.05	0.028	0.962	0.602	68.8	2400	0.093	0.023	0.991	0.505	60.6
880	0.077	0.024	0.971	0.555	64.6	1610	0.056	0.027	0.968	0.588	67.6	2450	0.091	0.023	0.988	0.509	60.9
900	0.068	0.025	0.962	0.578	66.6	1620	0.052	0.028	0.952	0.610	69.4	2460	0.079	0.025	0.993	0.521	62.0
920	0.086	0.024	0.982	0.526	62.2	1630	0.053	0.028	0.961	0.601	68.7	2490	0.088	0.024	0.994	0.504	60.5
930	0.081	0.024	0.981	0.532	62.8	1650	0.057	0.027	0.965	0.588	67.6	2510	0.195	0.015	0.965	0.433	54.5
940	0.09	0.023	0.992	0.507	60.7	1690	0.057	0.027	0.974	0.582	67.1	2530	0.079	0.025	0.995	0.519	61.8
950	0.072	0.025	0.983	0.551	64.4	1720	0.062	0.026	0.975	0.571	66.2	2540	0.06	0.026	0.972	0.589	67.6
970	0.086	0.024	0.993	0.510	61.0	1730	0.046	0.029	0.959	0.619	70.2	2560	0.075	0.025	0.994	0.525	62.4
980	0.084	0.024	0.997	0.499	60.2	1750	0.062	0.026	0.972	0.575	66.4	2570	0.06	0.027	0.993	0.550	64.7
1000	0.066	0.027	0.995	0.536	63.4	1800	0.074	0.025	0.978	0.552	64.5	2600	0.065	0.027	0.991	0.551	64.5
1010	0.088	0.024	0.996	0.498	60.1	1830	0.064	0.026	0.981	0.569	65.9	2610	0.076	0.025	0.993	0.527	62.5
1020	0.061	0.028	0.995	0.542	64.0	1840	0.064	0.026	0.988	0.558	65.1	2620	0.083	0.024	0.995	0.511	61.1
1030	0.095	0.023	0.997	0.479	58.5	1850	0.065	0.026	0.982	0.563	65.5	2640	0.089	0.024	0.996	0.499	60.1
1040	0.078	0.025	0.995	0.516	61.6	1920	0.069	0.026	0.983	0.559	65.1	2680	0.082	0.025	0.995	0.511	61.2
1070	0.068	0.027	0.997	0.523	62.4	1930	0.062	0.027	0.988	0.559	65.2	2690	0.078	0.025	0.994	0.521	62.0
1080	0.066	0.027	0.996	0.529	62.9	1940	0.057	0.027	0.976	0.586	67.4	2740	0.083	0.024	0.995	0.511	61.2
1100	0.076	0.025	0.987	0.536	63.2	1950	0.076	0.025	0.984	0.540	63.5	2750	0.089	0.024	0.995	0.500	60.2
1110	0.079	0.025	0.993	0.522	62.1	1960	0.057	0.027	0.972	0.593	67.9	2760	0.093	0.023	0.995	0.497	59.9
1120	0.079	0.025	0.993	0.522	62.1	1970	0.064	0.026	0.968	0.578	66.6	2790	0.088	0.024	0.996	0.499	60.2
1130	0.087	0.024	0.996	0.501	60.3	1980	0.06	0.027	0.984	0.571	66.2	2800	0.085	0.024	0.996	0.508	60.9
1140	0.088	0.024	0.995	0.502	60.4	2010	0.052	0.028	0.970	0.602	68.8	2830	0.076	0.025	0.994	0.523	62.2
1150	0.092	0.024	0.995	0.493	59.7	2040	0.071	0.025	0.976	0.558	65.0	2850	0.094	0.023	0.996	0.494	59.7
1170	0.08	0.025	0.996	0.511	61.2	2090	0.061	0.027	0.983	0.569	66.0	2860	0.072	0.026	0.995	0.524	62.4
1180	0.087	0.024	0.995	0.505	60.6	2120	0.06	0.026	0.968	0.584	67.2	2870	0.075	0.025	0.995	0.523	62.3
1190	0.087	0.024	0.996	0.500	60.2	2130	0.065	0.026	0.978	0.568	65.9	2890	0.064	0.026	0.988	0.556	65.0
1260	0.08	0.025	0.996	0.501	60.5	2140	0.068	0.026	0.989	0.548	64.3	2900	0.067	0.026	0.990	0.547	64.2
1290	0.088	0.024	0.989	0.515	61.4	2160	0.067	0.026	0.979	0.563	65.4	2910	0.076	0.025	0.990	0.533	62.9
1310	0.102	0.022	0.984	0.495	59.7	2170	0.063	0.026	0.972	0.576	66.5	2935	0.079	0.025	0.996	0.511	61.2
1320	0.077	0.025	0.989	0.532	62.9	2200	0.068	0.026	0.985	0.554	64.7	2960	0.086	0.024	0.997	0.502	60.4
1330	0.056	0.027	0.962	0.595	68.1	2210	0.061	0.026	0.973	0.579	66.8	2970	0.092	0.024	0.997	0.492	59.6
1360	0.067	0.026	0.977	0.565	65.6	2220	0.06	0.027	0.977	0.575	66.5	2990	0.075	0.026	0.995	0.517	61.8
1370	0.051	0.028	0.981	0.591	67.9	2230	0.055	0.028	0.985	0.578	66.9	3000	0.08	0.025	0.997	0.508	61.0
1380	0.054	0.027	0.955	0.606	69.0	2260	0.054	0.027	0.967	0.597	68.3	3020	0.081	0.025	0.994	0.501	60.4
1410	0.059	0.027	0.974	0.578	66.7	2270	0.055	0.027	0.974	0.587	67.5	3050	0.084	0.025	0.997	0.500	60.3
1450	0.049	0.028	0.942	0.620	70.2	2290	0.079	0.024	0.983	0.538	63.3	3060	0.082	0.025	0.997	0.506	60.8
1460	0.06	0.027	0.973	0.576	66.6	2310	0.062	0.026	0.975	0.572	66.2	3080	0.079	0.025	0.996	0.504	60.7
1480	0.088	0.024	0.995	0.492	59.6	2320	0.064	0.026	0.976	0.568	65.9	3090	0.085	0.024	0.997	0.500	60.3
1510	0.079	0.025	0.996	0.510	61.2	2330	0.071	0.025	0.981	0.549	64.3	3100	0.085	0.024	0.997	0.499	60.2
1550	0.055	0.027	0.949	0.613	69.5	2340	0.064	0.026	0.971	0.579	66.7	3110	0.094	0.023	0.997	0.489	59.3
1560	0.052	0.027	0.935	0.628	70.7	2360	0.064	0.026	0.972	0.573	66.3	3150	0.066	0.027	0.995	0.538	63.6
1570	0.052	0.027	0.940	0.622	70.3	2370	0.071	0.025	0.977	0.553	64.6	3160	0.076	0.025	0.996	0.517	61.8
1580	0.05	0.027	0.932	0.624	70.4	2380	0.16	0.016	0.933	0.496	59.5	3200	0.091	0.024	0.997	0.489	59.4
1590	0.057	0.027	0.978	0.577	66.8	2390	0.079	0.024	0.979	0.536	63.2	3250	0.081	0.025	0.995	0.492	59.8

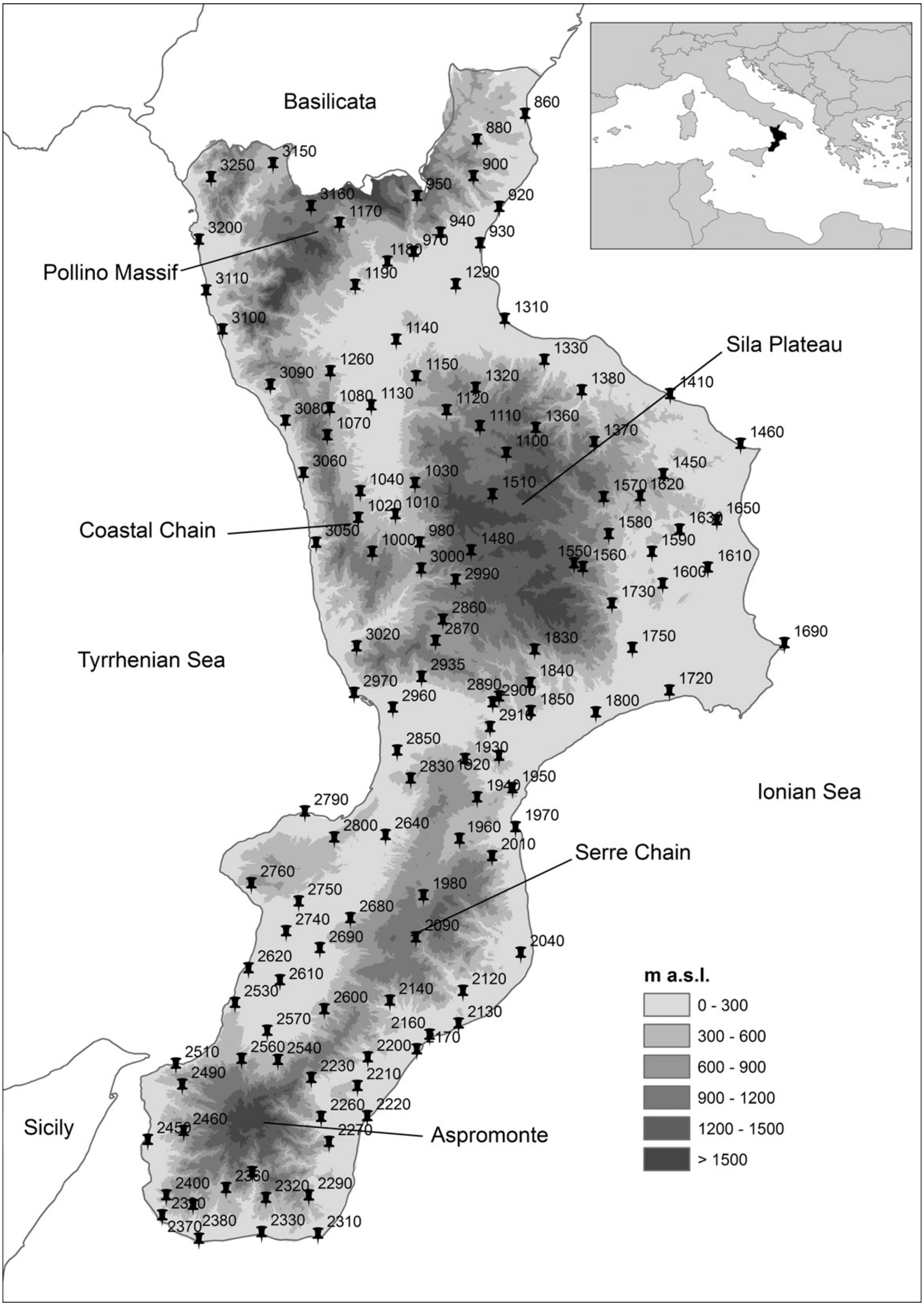

Fig. 1. Location of the selected 129 rain gauge stations on a DEM of Calabria.

accumulated percentages of days (X) during Y's occurrence (Riehl, 1949; Olascoaga, 1950; Martin-Vide, 2004; Zhang et al., 2009; Li et al., 2010). If daily events are ranked in a decreasing order and X_j is the jth highest event, Y_j is the fraction of annual precipitation provided by the highest events from the *1*st to the *j*th. If X events are expressed in terms of percentiles and Y in terms of percentage of annual precipitation, Y and X are linked by an exponential law as (Riehl, 1949; Olascoaga, 1950):

$$Y = aX\exp(bX) \quad (1)$$

where a and b are constants.

Generally this curve is called concentration curve or Lorenz curve (Shaw and Wheeler, 1994), also known as normalized rainfall curve (Jolliffe and Hope, 1996) when referring to precipitation. By defining A the area under the Lorenz curve, the area (S) enclosed

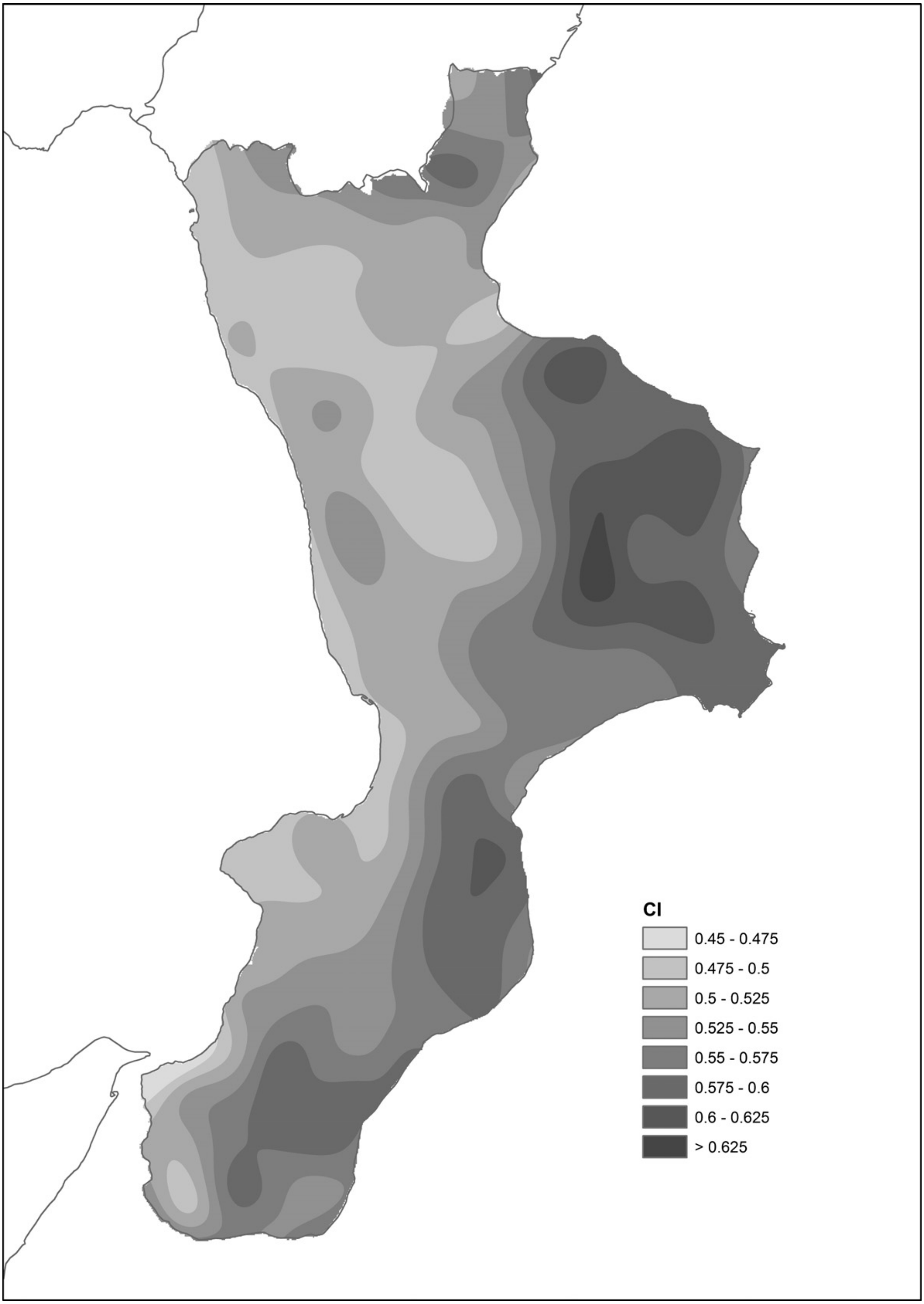

Fig. 2. Spatial distribution of the CI on the investigated area.

by the bisector of the quadrant (perfect distribution) and the Lorenz curve can be evaluated as:

$$S = 5000 - A \tag{2}$$

being 5000 the area under the equidistribution line.

Being the exponential curve expressed as in (1), the area A can be calculated as:

$$A = \left[\frac{a}{b} e^{bx} \left(x - \frac{1}{b}\right)\right]_0^{100} \tag{3}$$

The daily precipitation Concentration Index resembles the Gini coefficient and is the ratio between S and the surface area of the lower triangle delimited by the equidistribution line (Martin-Vide, 2004):

$$\mathrm{CI} = S/5000 \tag{4}$$

The procedure used in this work analyzes the daily data distribution for each rain station, using a limit of 1 mm/day as precipitation class interval and evaluating for each class: (a) the number of recorded precipitation days (absolute frequency), and (b) the pluviometric total. The cumulative frequencies, obtained by adding the absolute frequencies, in percentage are the X-values of the exponential curve; the progressive sum of the pluviometric totals (in percentage) gives the Y-values. Eq. (1) has been checked in order to verify the adequacy of such form to capture the experimental data: the coefficients of determination, R^2, range between 0.932 and 0.997 (Table 1). After the log-transformation of Eq. (1), the usual formula of the least squares method allows the estimation of a and b, and consequently the calculations of A, S and CI for each rain gauge. A high precipitation CI value indicates that the precipitation is more concentrated within few rainy days during the year, and vice versa.

In addition to examine the varying weight of daily precipitation, it is useful to analyze monthly heterogeneity of rainfall amounts, through a modified version of Oliver's (1980) precipitation concentration index (PCI) (De Luis et al., 1997). This index is described as:

$$\mathrm{PCI} = 100 \cdot \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \tag{5}$$

where p_i is the rainfall amount of the ith month, calculated for each of the rain gauges and for each year within the observation period. As described by Oliver (1980), PCI values below 10 indicate a uniform monthly rainfall distribution throughout the year, whereas values from 11 to 20 denote seasonality in rainfall distribution. Values above 20 correspond to climates with substantial monthly variability in rainfall amounts.

Two different procedures can be followed for evaluating this index: PCI can be estimated through the mean monthly rainfall data set, or calculated from the rainfall data set of each individual year and then averaged over a number of years (as done in this study).

The PCI is related to the coefficient of variance (CV) by means of the following equation:

$$\mathrm{PCI} = \frac{100}{12} \cdot \left[1 + \left(\frac{\mathrm{CV}}{100}\right)^2\right] \tag{6}$$

Comparing the standard deviation, CV and PCI for some hypothetical data sets, Michiels et al. (1992) demonstrated two features

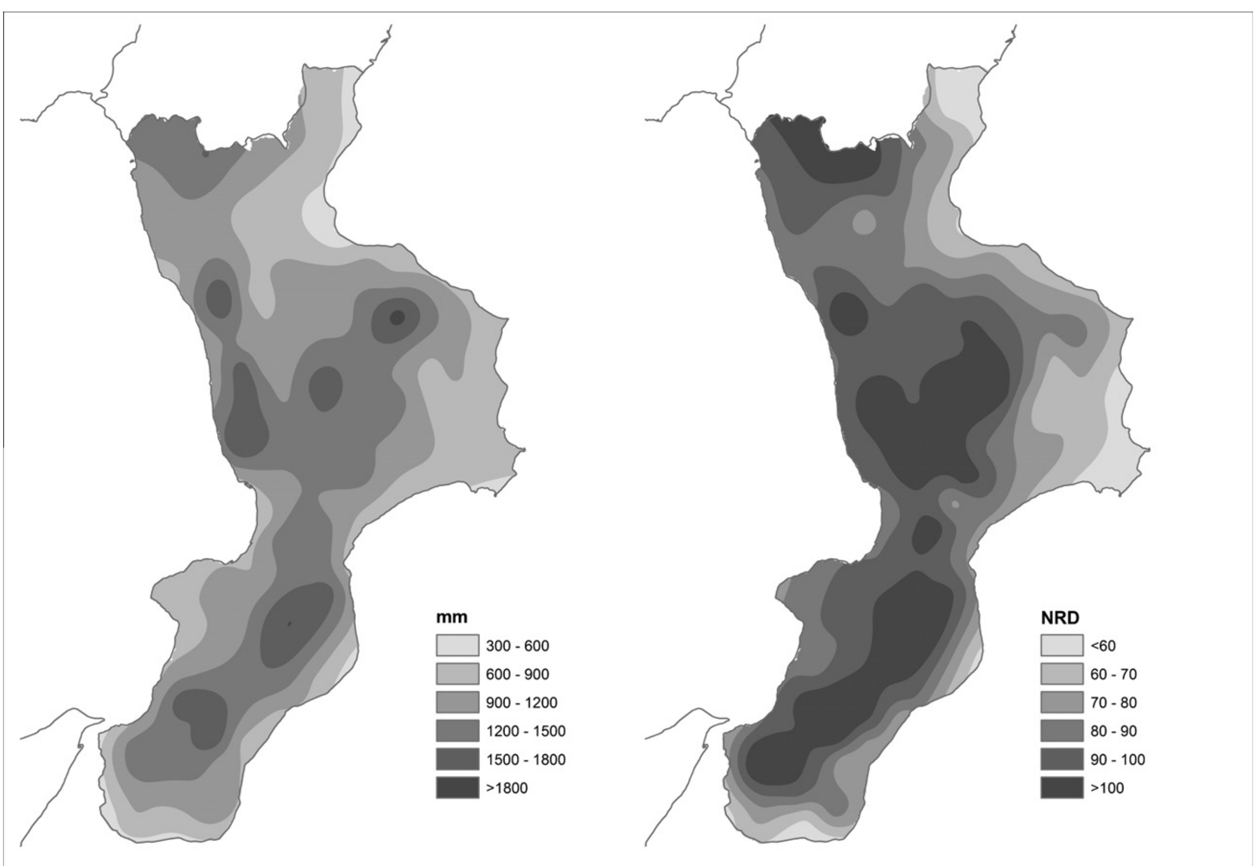

Fig. 3. Spatial distribution of the mean annual precipitation (P) and of the mean annual number of rainy days (NRD).

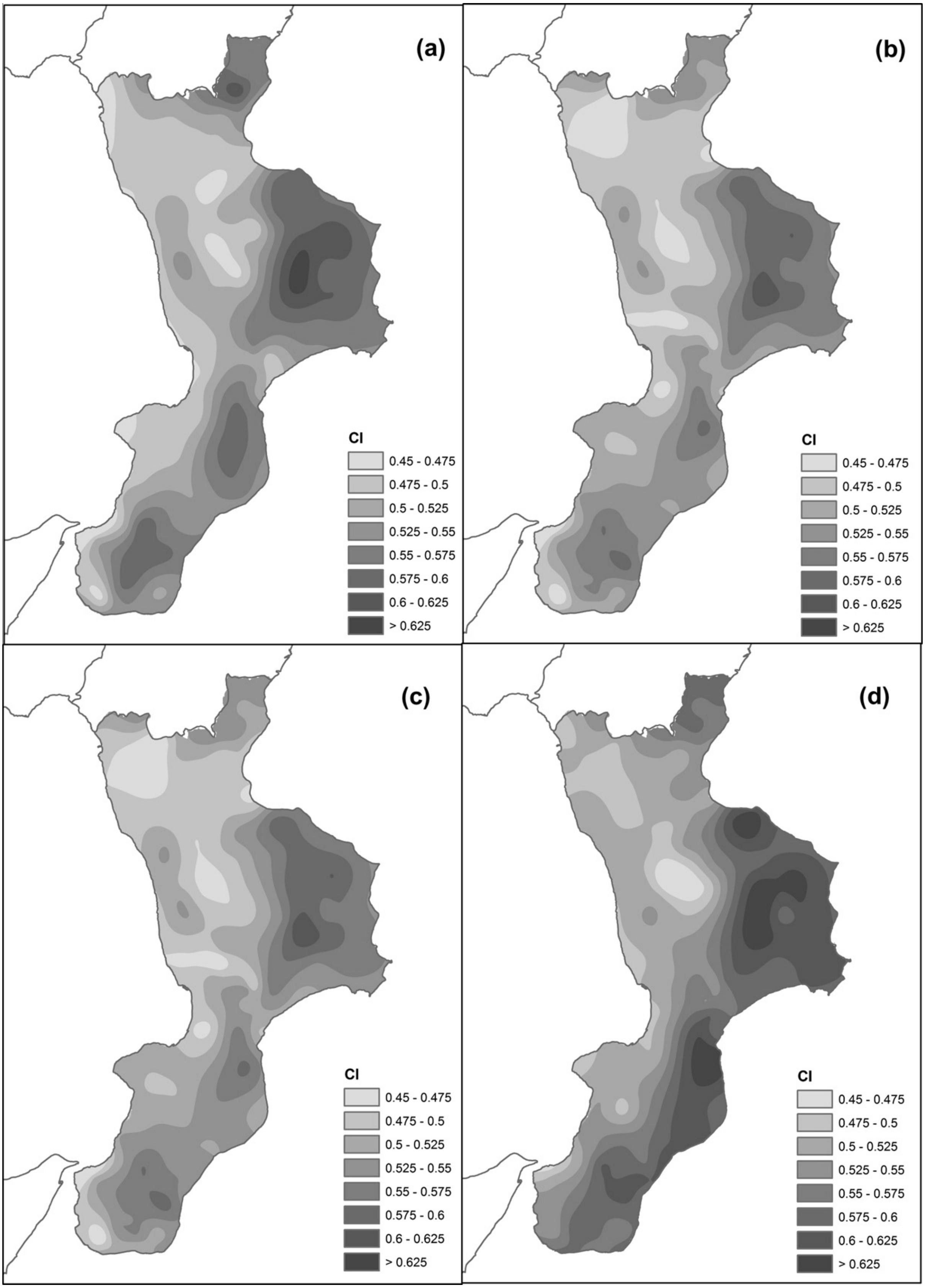

Fig. 4. Spatial distribution of the CI on the investigated area evaluated for the four seasons: (a) winter, (b) spring, (c) summer, (d) autumn.

of PCI: firstly, when the same monthly rainfall increment occurs in half of the observation period, the value of PCI doubles, whilst the pattern is not clear using CV. Secondly, the value of PCI does not change if the data sets have different amount of rainfall but the

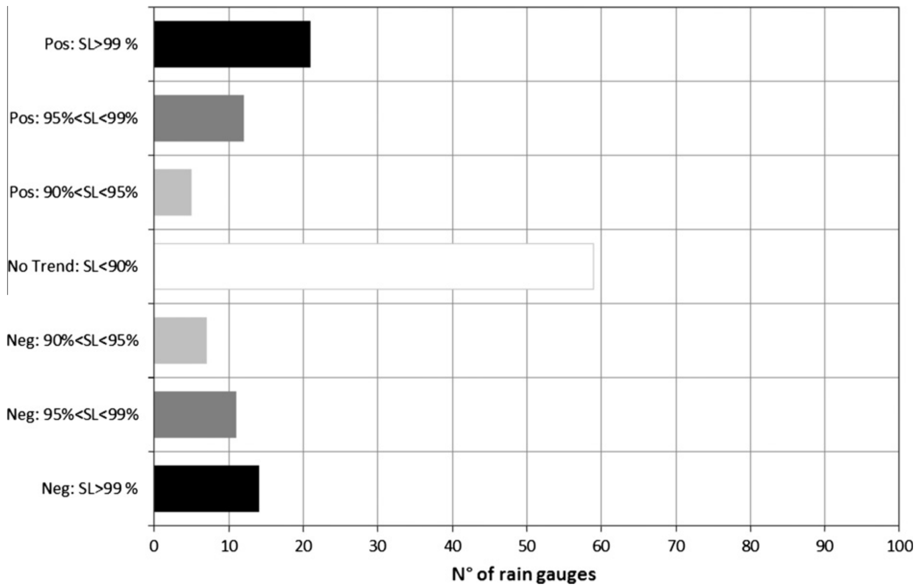

Fig. 5. Observed CI trends for different ranges of the significance level (SL).

same distribution in the different months (the standard deviation shows an opposite behavior).

Moreover, in this study, a trend analysis has been performed in order to detect the temporal behavior of the two indexes, using the well-known rank-based nonparametric Mann–Kendall test (Mann, 1945; Kendall, 1962). This test is highly recommended for general use by the World Meteorological Organization (Mitchell et al., 1966) because it can test trends in a time series without requiring normality or linearity (Wang et al., 2008).

3. Study area and data

The study area (Calabria region) is a peninsula with an oblong shape that occupies the southern part of Italy (Fig. 1) Although Calabria does not have many high summits, it is one of the most mountainous regions in Italy. Because of its geographic position and its mountainous nature, Calabria has a high climatic variability with a typically subtropical dry summer, also known as the Mediterranean climate. In summer, the influence of the Azores anticyclone favors a rather dry and temperate climate, while breeze circulations develop on the coast and inland (Federico et al., 2000). In the other seasons, Mediterranean cyclogenesis affects Calabria.

The data used in this study are a set of daily precipitation series relative to the period 1916–2006, registered in Calabria and collected by the former Italian Hydrographic Service. When the number of years of observations was too low for statistical purposes, when there were too many gaps in the series (less than 50 available years of data), or when the series ended before the year 2000, the station series were discarded from the data set. As a result, 173 rainfall series out of total of 311 were selected, with an average density of 1 station per 87 km^2.

In a large database, such as the one used in this study, it is important to pay attention to the problems arising from the data series inhomogeneities and the lack of data. Particularly the latter problem affects both the early and the most recent instrumental period, because of occasional interruptions in automatic stations, instrument malfunctions, and network reorganizations. Excluding periods with missing values from data analyses may lead to disregard valuable information, and to induce biases in many climate investigations.

In this study, the applied homogenization approach and the database used were those presented in Brunetti et al. (2010). Instead of using one single reference series (obtained as the average among the neighboring stations), each series was tested against the other series, by means of a multiple application of the Craddock test (Craddock, 1979), in sub-groups of 10 series. At the end of this procedure, 87 of the total of 173 daily precipitation series resulted homogeneous, 42 were homogenized, and 44 were discarded, with a total of 129 daily rain gauges for the 1916–2006 period (Fig. 1) available for the analysis. The estimation of the missing data was performed by exploiting a recently developed two-step procedure (Simolo et al., 2010) which preserves both the correct event time location (wet/dry days) and the statistical properties of daily precipitation series. The reconstructed period spans from the first available year of each series up to December 2006, in which period 11.5% of data was missing and required reconstructing.

4. Results and discussion

First, the CI values were estimated for all the stations. Table 1 shows the values of the coefficients *a* and *b* of the normalized rainfall curves and of CI, for each rain gauge, calculated using the above described approach. The CI values range from a minimum of 0.433 (Scilla rain gauge, code 2510) to a maximum of 0.628 (Casa Pasquale rain gauge, code 1560). By observing the spatial distribution of CI on the Calabria region (Fig. 2), the study area can be divided in two parts: the western side of the region with lowest values of CI, and the eastern side with the most daily rainfall contrast and the most critical intensity and aggressivity of rainfall. The highest CI values are found near the reliefs of the region (Serra Chain and Sila Plateau).

As Colacino et al. (1997) found out, the orography influences the rainfall amount and its distribution over the region, which explains the differences in CI values between the two sea-coasts of Calabria. Colacino et al. (1997) also showed that the interaction between the orography and mesoscale circulations leads to a precipitation gradient between the Tyrrhenian and Ionian side of the Calabrian peninsula. In particular, the Ionian side, which is influenced by currents coming from Africa, has short and heavy precipitation, while the Tyrrhenian side is influenced by western air currents, and presents considerable orographic precipitation. Numerical

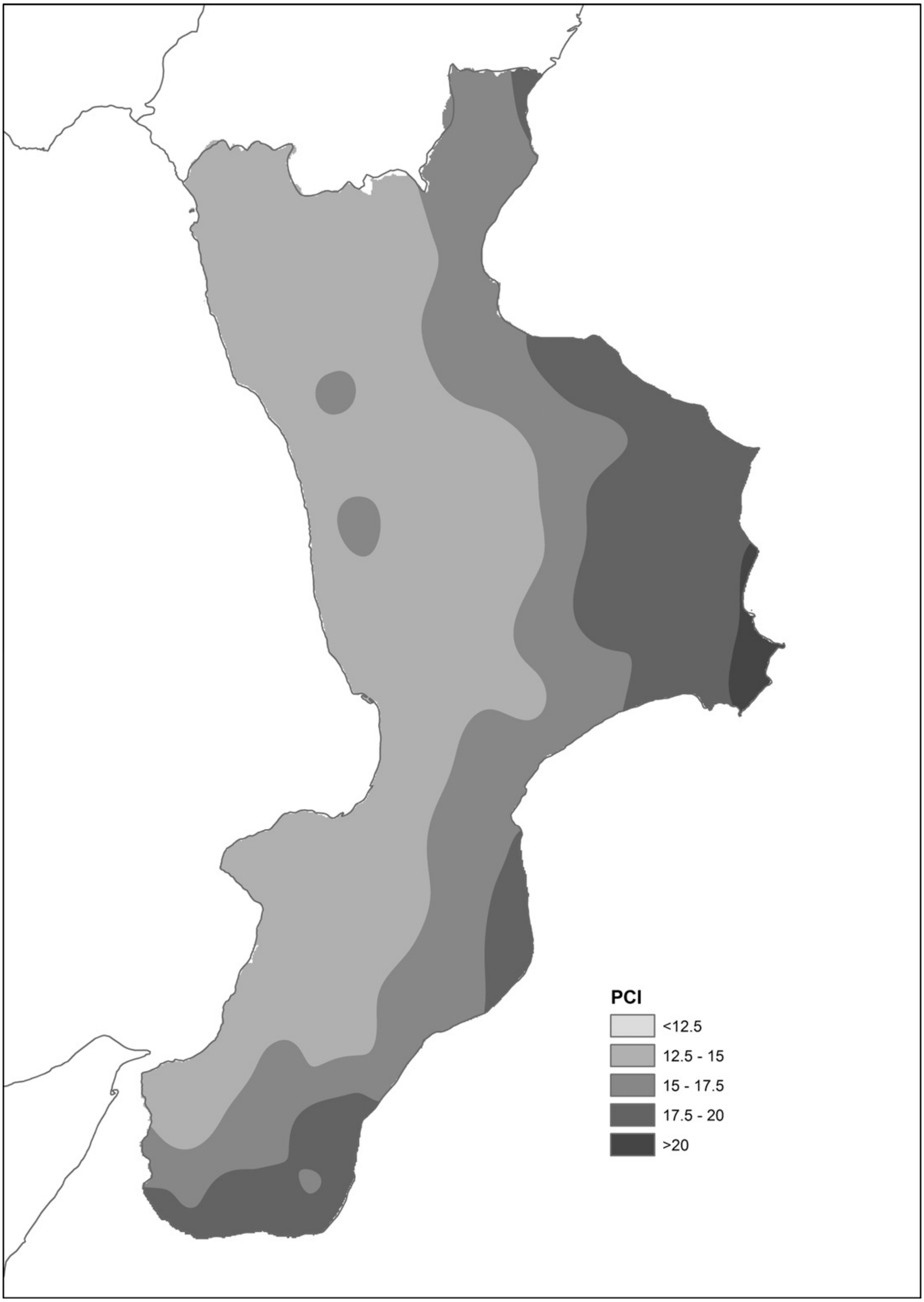

Fig. 6. Spatial distribution of the PCI on the investigated area.

simulations of severe weather showed the crucial role of orography, which enhances rainfall in localized spots (Federico et al., 2003a, 2003b) or forces secondary cyclogenesis persisting over the Ionian side of the peninsula (Federico et al., 2007).

Table 1 also reports the percentages of precipitation amount provided by the highest quartile of rainy days calculated with Eq. (1). These percentages range from 54.51% (corresponding to the minimum value of CI) to 70.69% (corresponding to the maximum value of CI). There is a variation of 16.18%, which shows a very different behavior between the side with the most concentrated rainfall and the one with a more regular daily amount. It is worth stressing that the area (Eastern Calabria) with the highest values of CI is the one which shows the lowest values of yearly rainfall and rainy days (Fig. 3). Fig. 4 shows the distribution of CI values for the four seasons. Generally the distributions reflect the one evaluated through the yearly data. It appears that the winter and

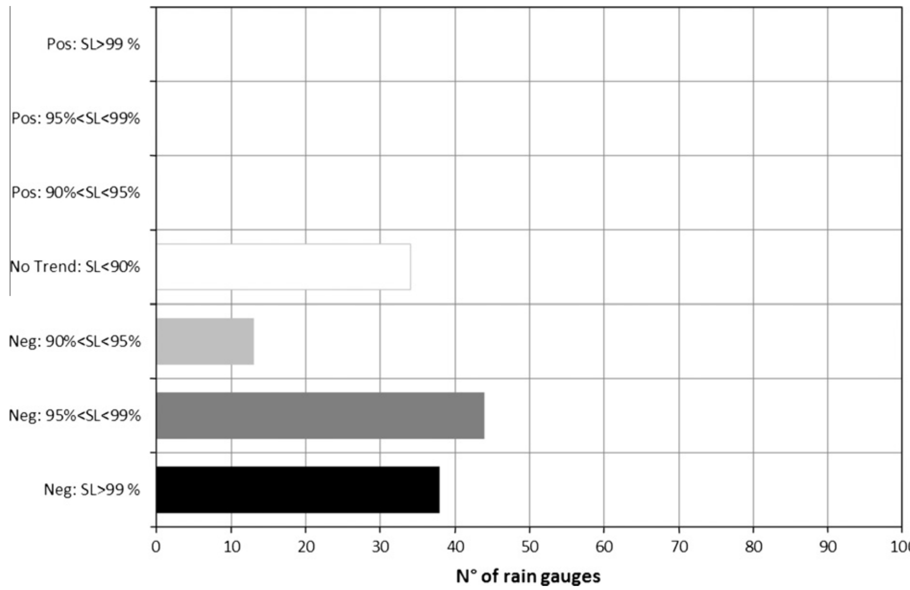

Fig. 7. Observed PCI trends for different ranges of the significance level (SL).

autumn seasons influence the yearly distribution; in particular, the distribution of CI for the mentioned seasons shows the strongest contrasts among the various areas of Calabria.

According to Zhang et al. (2009), in this paper the precipitation CI has been calculated for each year and then its possible trends have been detected, for each rain gauge, using the Mann–Kendall test (Mann, 1945; Kendall, 1962). Fig. 5 summarizes the results showing the numbers of rain gauges which present trends (positive and negative) for three different ranges of the significance level. The majority of the rainfall series reveals no significant trend, however there are more rain gauges with positive trends of CI than those with negative ones.

Rainfall temporal distribution throughout the year has been also studied by PCI. Fig. 6 shows the spatial distribution of the PCI values, calculated from the rainfall data set of each individual year and averaging over the observation years. These values range from a minimum value of 13.4 to a maximum value of 20.5 and denote a seasonality of the pluviometric distribution. Also the PCI distribution is not uniform over the whole territory: the seasonality is more marked on the eastern side of the region, with peak values in middle of the Ionian coast (Capo Colonne rain gauge, code 1690). The results emerging from the application of the Mann–Kendall test to the yearly PCI values of each station are very interesting (Fig. 7). 95 rain gauges present a significant negative trend with a confidence level greater than 90%: this reveals a tendency towards a more uniform monthly rainfall distribution during the year. The spatial analysis of the results of this trend (Fig. 8) shows an uniform distribution on the Calabrian territory.

This trend behavior is even more clear if the percentages of the PCI values (PCI for each year and for each station), falling in the four classes in which the interval 10–20 has been divided, are calculated, and if the entire observation period is divided in three sub-periods: 1916–1946, 1947–1976, 1977–2006 (Fig. 9). The percentages of the values falling in the first interval (PCI ranging from 10 to 12.5) increase while those of the intervals 15–17.5 and 17.5–20 decrease. The tendency towards a more uniform distribution of the monthly precipitation during the year is well confirmed by the results obtained by applying the Mann–Kendall test to the seasonal rainfall (Fig. 10). This trend confirms the results of Brunetti et al. (2010), who estimated a positive trend for summer precipitation (especially, in July and August), and the concomitant negative trend for the winter and autumn rainfall (especially in November and January). Since in Calabria summer is the driest season and autumn and winter are the wettest ones, the positive trend estimated for summer precipitation, and the concomitant negative trend obtained for the winter and autumn rainfall, can determine a more homogeneous distribution of precipitation during the year.

5. Conclusion

The analysis of rainy days distribution throughout the year is extremely important because of its high impact on environmental phenomena like floods, droughts, soil erosion and slope stability, but also on water management. In this paper, a complete study of the rainfall distribution on the Calabria region has been carried out using an homogenous database of daily measurements. Two parameters have been applied: the Concentration Index (CI), to evaluate the distribution of rainy days, and the Precipitation Concentration Index (PCI), to evaluate the seasonality of the precipitation. The results obtained with CI have demonstrated that there are areas (on the eastern side of Calabria) where the parameter assumes values near 0.62, with the percentage of precipitation provided by the highest quartile of wet days approximately reaching 70% of total annual amount. Since these areas are those presenting the lowest values of yearly rainfall and rainy days, this leads to a marked uncertainty in terms of annual rainfall. In fact, very few atmospheric circulation anomalies may strongly affect the total yearly rainfall volume, causing relevant problems on water management. This side of Calabria is also characterized by the highest PCI values, suggesting a greater seasonality of the rainfall distribution throughout the year. The consequences of these results, as far as the impacts on the soil and on the human life are concerned, have been demonstrated in previous studies: the same areas are those which revealed to be the most vulnerable to both soil erosion and desertification risks in Calabria (Antronico et al., 2005; Coscarelli et al., 2005; Coscarelli, 2007; Terranova et al., 2009). The application of the Mann–Kendall test has shown a clear tendency

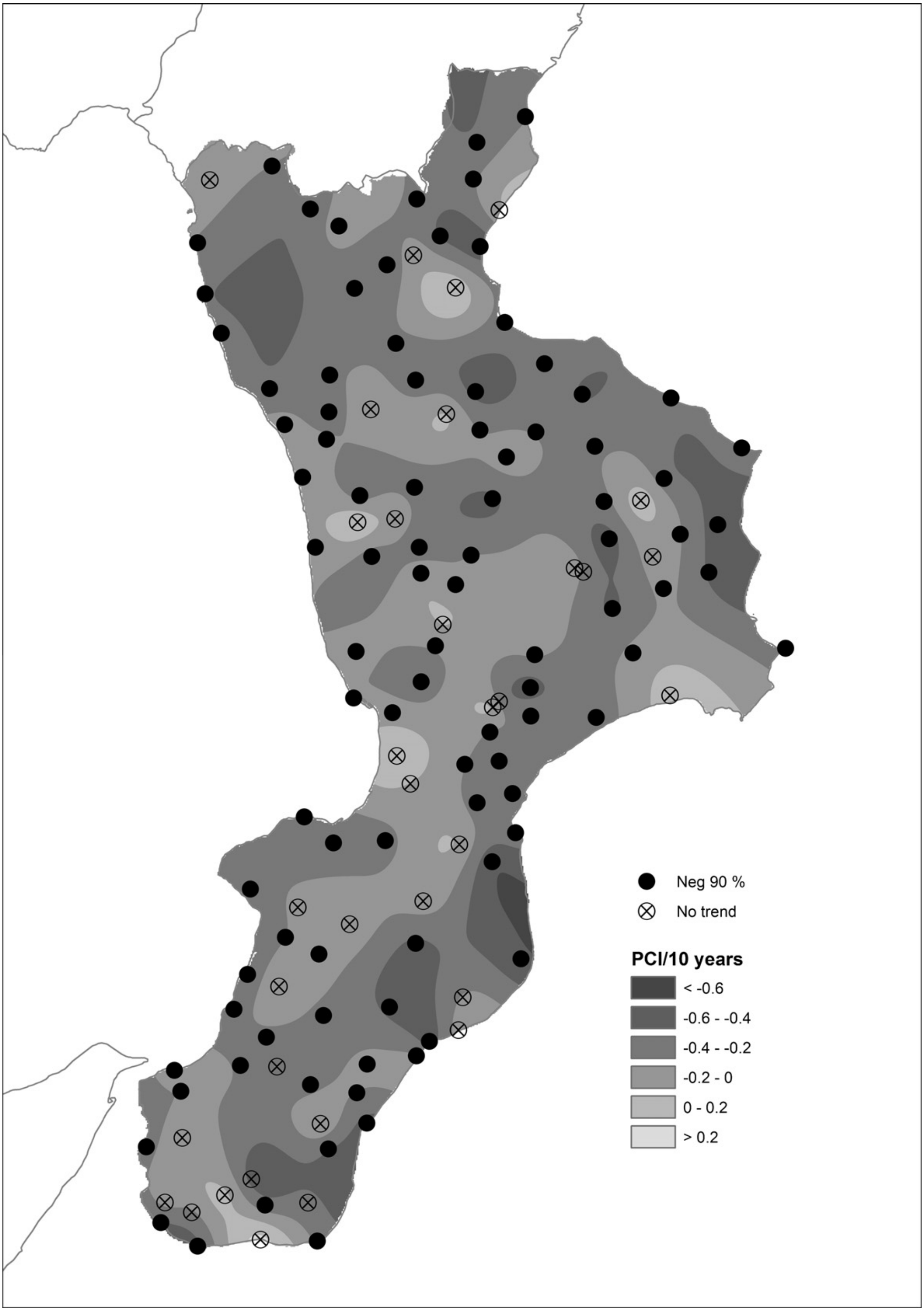

Fig. 8. Spatial distribution of the PCI trend on the investigated area.

towards a reduction of the amplitude of the annual precipitation cycle. These results, if confirmed in the next decades, can help to revise the water management in the region, and to avoid underestimating the environmental risks deriving from floods, soil erosion, slope instability, also in months which are not usually characterized by such phenomena.

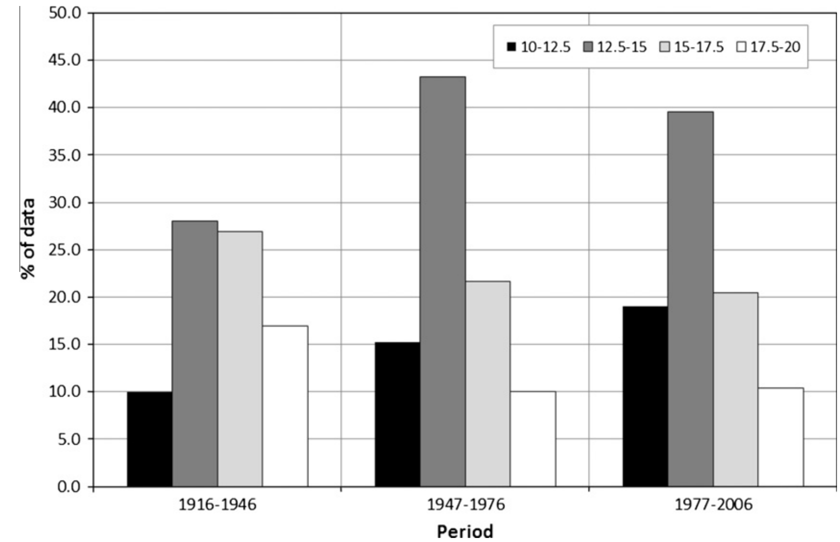

Fig. 9. Percentage distributions of the different ranges of PCI values evaluated for 3 temporal periods.

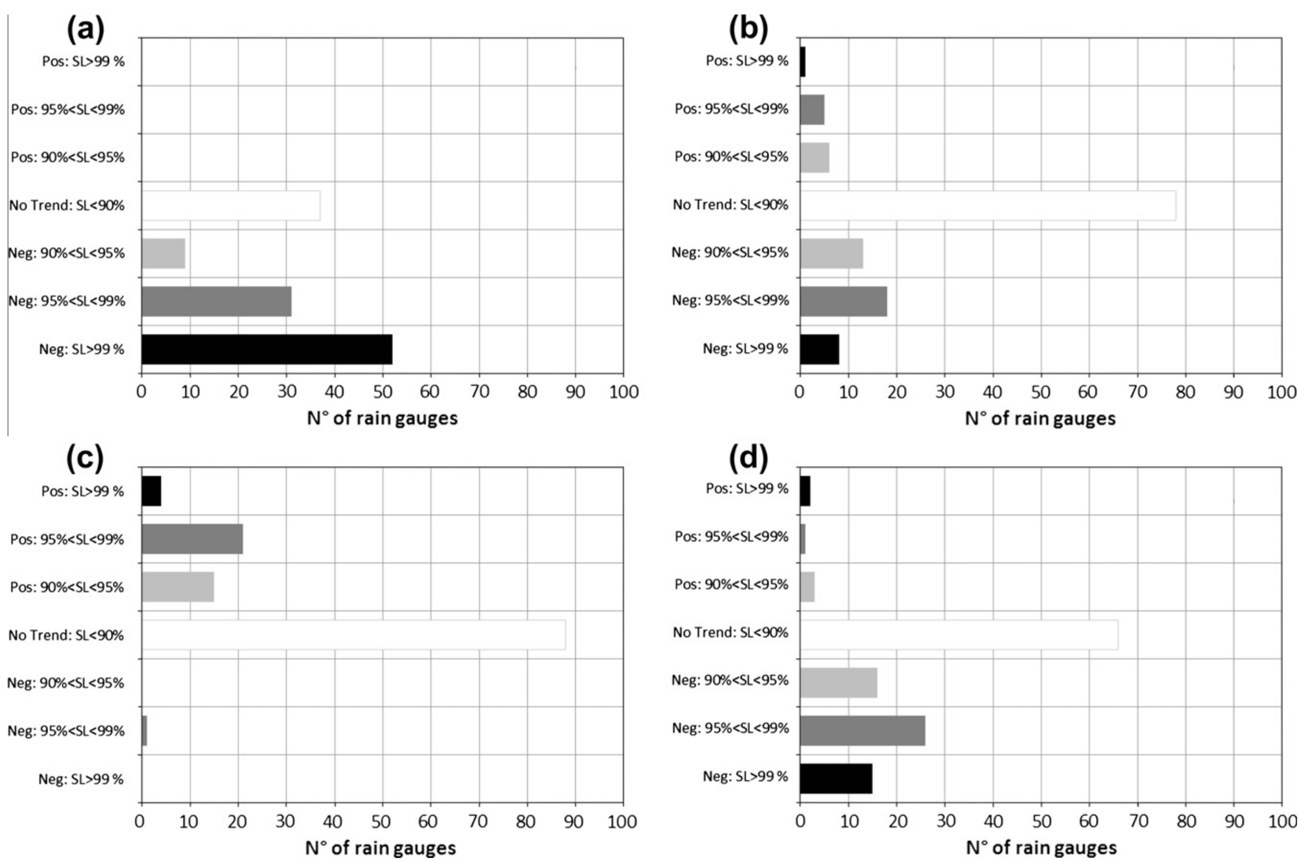

Fig. 10. Observed seasonal precipitation trends for different ranges of the significance level (SL): (a) winter, (b) spring, (c) summer, (d) autumn.

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