Extreme rainfall statistics in the Marche region, Italy

EXTREME RAINFALL STATISTICS IN THE MARCHE REGION, ITALY

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ABSTRACT

A statistical analysis of the rainfalls is carried out for detecting a possible trend in the observed data. The rainfall dataset refers to the historical series collected in the hydrographic basins of the Marche region. On the one hand, the annual maximum daily, hourly and sub-hourly rainfalls have been analysed, on the other hand Climate Change Indices by Expert Team on Climate Change Detection and Indices (ETCCDI) (R1mm, Rx1day, R20mm, R95pTOT, PRCPTOT) have been computed to verify an eventual variation of the frequency of the rainfall regime in the Marche region.

The time series, selected in the reference period 1951-2013, have been processed by using the nonparametric Mann-Kendall test.

The results confirm that most of the series relating to the annual maximum rainfalls do not exhibit any trend. The absence of trend or the presence of negative trend prevail also in the analysis of the ETCCDI indices. The annual average anomalies of the same indices computed with respect to the climatological reference period 1961-1990 are negative since the mid-80s, but they appear to show an increasing behavior in the period 2009-2013.

Key words: historical rainfall series, extreme rainfall, trend analysis, Mann-Kendall test, Central Italy

INTRODUCTION

Climate change is one of the most complex and critical challenges for the international community. An increase of extreme climate events (e.g. heat waves, sea level rise, heavy rainfall events) may be observed since about 1950 and some of these have been attributed to human influence (IPCC, 2014). A problem of this type requires thorough analyses, as possible variations in rainfall and thermometric regime may have significant impacts on the availability of water resources, but also on the ecosystem and on human activity in general.

One of the most known and evident effect of the changes in climate is represented by a rise in temperature (IPCC, 2014), while it is more difficult to individuate a well-defined signal in precipitations because of the complexity of the atmospheric circulation and the influence of the orography of different areas.

In recent years several studies have been carried out at local and continental extent mainly focused on the statistical analysis of annual, seasonal and extreme precipitations.

Trend detection on large spatial scales has evidenced a significant increment in precipitation in northern and central Asia, North America and northern Europe. Conversely, a decrease in rainfall was observed in Mediterranean area, southern Africa and southern Asia (IPCC, 2007). However, in some areas of the Mediterranean, as over the central-western Mediterranean basin, Italy and Spain, an increase of the heavy precipitation is observed with a simultaneous decreasing trend in total precipitation (Alpert et al., 2002). This result is confirmed also by some local analysis over the northern Italy (e.g. Brunetti et al., 2001).

In Italy, many other studies have been available on the trend detection in daily, seasonal and extreme rainfall. Brunetti et al. (2000) analysed some daily precipitation dataset of northern Italy. They found that the number of rainy days has a strong negative trend which is more significant than the corresponding precipitation amount and, as a consequences, the precipitation intensity has a positive trend. Similar results are also found in north-eastern Italy. In fact, the analysis of daily precipitation data by Brunetti et al. (2001) shows that the average annual number of wet days has a significant negative trend, mainly in spring and autumn. Moreover, a weak reduction in total precipitation indicates an increase in intensity which is not significant. In particular, extreme events exhibit a strong increase while non extreme events have a decreasing behaviour. For the annual maximum daily rainfall in the same region, Bovo et al. (2004) show the presence of positive and negative trends and seem individuate a spatial pattern of the series affected by the trend.

In Tuscany Caporali et al (2014) analysed maximum annual daily rainfall and the maximum annual rainfalls of 1, 3, 6, 12 and 24h duration recorded in 149 stations and showed a substantial absence of significant changes in precipitation regime, as only few changes are detectable near the coasts and in the north-west area. Increasing trends in some extreme events of 1, 3, 6, 12 and 24h duration since 1970s were found also by Crisci et al. (2002). Bartolini et al. (2014a) also found a slight increase of the extreme daily rainfall over the last two decades in central-southern Tuscany; conversely, in the northwest region annual rainfall, extreme daily precipitation and the number of wet days exhibit a downward trend. Moreover Bartolini et al. (2014b) analysed also changes in indices derived by daily and hourly data of two sites and detected a decrease of total rainfall and wet hours occurred in winter and spring, although an increase of hourly average rainfall is observed during wet hours.

In Sicily, the analysis of monthly rainfall by Cannarozzo et al. (2006) showed that significant negative trends are present in annual and winter data and only few stations in summer months exhibit a positive trend. This result is confirmed by the analysis of the annual maximum rainfall events of 1, 3, 6, 12 and 24h duration by Arnone et al. (2013). The authors conclude that only the rainfalls of short duration exhibit an increasing trend, conversely the precipitation events of long duration are affected by a decreasing trend. The total annual precipitation is characterized by a significant negative trend, mainly in the winter season.

Besides the previously cited studies involving the Tuscany region, not many works are available for the detection of trend in the rainfall amount or frequency in the central Italy. Recent studies on the time series of monthly precipitations from 40 rainfall stations located in Emilia-Romagna show a significant decreasing trend in winter season during the 1960-1995 period (Tomozeiu et al., 2002) and an increasing trend with a systematic significant upward shift around 1962 in the summer time (Tomozeiu et al., 2000).

For the Marche region an extended analysis has been developed to define a regional model for estimating the design storm (Castellarin et al., 2005), but no explicit information about the rainfall statistics changes are provided. Appiotti et al. (2014) presented an integrated analysis of recent climate change by considering meteorological, oceanographic and river gauges during the period 1961-2009. The trend analysis of the annual and seasonal rainfall shows that total precipitation decreases in almost all the year, except the autumn, influencing the flow river change.

In the present study a statistical analysis of the rainfalls is carried out for detecting and quantifying changes in the intense precipitation regime in the Marche region. The study analysed the historical series of annual maximum daily rainfall and annual maximum rainfalls for 1, 3, 6, 12 and 24 h, 15 and 30 minutes duration from 1918 to 2013 at 156 stations. To define the temporal variability of precipitation, the time series of every station are analysed by using non-parametric statistical test (Mann-Kendall) for detecting any significant trend. In addition, five ETCCDI Climate Change Indices (Rx1day, R1mm, R20mm, R95pTOT, PRCPTOT) have been computed to identify any variation in terms of intensity and frequency of the rainfall regime. Both the methodology of the analysis and the criteria for the selection of the dataset are detailed in the next sections.

METHODOLOGY

Trend detection

To detect any trend the time series of rainfall have been processed by using the nonparametric Mann-Kendall test (Mann, 1945; Kendall, 1962). This test does not require the data to be normally distributed and it is less influenced by the presence of outliers in the data. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend.

The computational procedure for the Mann Kendall test considers the time series of n data points and y_i and y_j as two subsets of data where $i = 1,2,3,\ldots, n-1$ and $j = i+1, i+2, i+3, \ldots, n$. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

The Mann-Kendall S Statistic is computed as follows:

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

$$sign(y_j - y_i) = \begin{cases} 1 & \text{if } (y_j - y_i) > 0 \\ 0 & \text{if } (y_j - y_i) = 0 \\ -1 & \text{if } (y_j - y_i) < 0 \end{cases} \tag{2}$$

where y_j and y_i are the annual values in years j and i, $j > i$, respectively.

For $n \geq 10$, the statistic S is approximately normally distributed with zero mean and variance defined by

$$\sigma^2 = \frac{n(n-1)(2n+5) + \sum_{i=1}^{g} t_i(i)(i-1)(2i+5)}{18} \tag{3}$$

in which t_i denotes the number of ties (equal observations) to extent i and g is the number of tied groups. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Z_S is calculated as follows:

$$Z_S = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \tag{4}$$

Positive Z_S values indicate an upward trend in the hydrologic time series; negative Z_S values indicate a negative trend. If $|Z_S| > Z_{1-\alpha/2}$, the hypothesis H_0 is rejected and a statistically significant trend exists in the hydrologic time series. The critical value of $Z_{1-\alpha/2}$ for a p-value of 0.05 from the standard normal table is 1.96.

In this analysis significance level α=0.01, 0.05 and 0.1 were considered.

The magnitude of trends is given by the Sen's slope estimator determined, according to Theil (1950) and Sen (1968) approach, by equation:

$$\beta = \text{Median}\left(\frac{y_j - y_l}{j-l}\right) \quad \forall l < j \tag{5}$$

where y_l is the l-th observation antecedent to the j-th observation x_j.

ETCCDI indices

The joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices has a mandate to address the need for the objective measurement and characterization of climate variability and change. The team provides international coordination and collaboration on climate change detection and indices relevant to climate change detection, and encourages the comparison of modelled data and observations (Karl et al. 1999; Peterson et al. 2002; Peterson 2005; Klein Tank et al. 2009). The ETCCDI has recently revisited its definitions of indices by selecting some core indices (see http://etccdi.pacificclimate.org/list_27_indices.shtml). Certain are based on fixed thresholds that are of relevance to particular applications, other indices are based on thresholds that vary from location to location. In these cases, thresholds are typically defined as a percentile of the relevant data series.

We have considered five indices described in Table 1 based on daily precipitation amount. Each index has been computed on annual basis.

Table 1. Climate change indices (ETCCDI).

Acronym	**Description**	**unit**
R1mm	annual count of days with precipitation ≥ 1*mm* (wet days)	(days)
Rx1day	annual maximum 1-day precipitation	(mm)
R20mm	annual count of days with precipitation ≥ *20mm*	(days)
R95pTOT	annual total precipitation when the daily precipitation amount on a wet day *RR* > *RR95p*, where *RR95p* is the 95th percentile of precipitation on wet days in the 1961-1990 period	(mm)
PRCPTOT	annual total precipitation	(mm)

R1mm is defined as the number of so–called wet days, that is the number of days with precipitation ≥ 1mm, Rx1day is the maximum daily precipitation, defined conventionally as the rainfall cumulated between 9 a.m. of day at which the measurement is attributed and 9 a.m. of the previous day and PRCPTOT is the annual total precipitation.

Other two indices concerning extreme events are also considered, the very heavy precipitation days R20mm (i.e. the number of days with precipitation ≥ 20mm) and R95pTOT, defined as the total precipitation when the daily rainfall on a wet day is higher than the 95th percentile of precipitation on wet days in the reference period 1961-1990 specified by the World Meteorological Organization WMO (2011).

DATASET

The rainfall dataset refers to the historical series collected in the hydrographic basins of the Marche region, in Central Italy (Figure 1a). Marche region extends over an area of 9,694 km^2. The main features are the Apennine chain along the internal boundary and an extensive system of hills descending towards the Adriatic Sea. With the exception of the southern part of the region, mountains do not exceed 2,000 m of altitude. The hilly area covers two-thirds of the region and is interrupted by wide gullies with numerous rivers and alluvial plains perpendicular to the principal chain. The coastal area is 172 km long and is relatively flat and straight except for two hilly areas in the northern and central part of the region.

Rainfall data have been selected from the regional database of the "*Centro Funzionale Multirischi per la Meteorologia, l'Idrologia e la Sismologia*". This institution is responsible of the collection and management of the regional meteorological data since 2002. The period of observation for the daily rainfall is the interval 1918-2013 and an overview of the recording rain gauges in this time is depicted in Figure 1b. Grey pixels indicates working rain gauges, white pixels refer to not-working stations and black pixels are used for intermittently recording rain gauges.

Since 2007 the monitoring network was extended and modernized by turning convention weather stations into remote meter reading stations. This operation has involved the outage of some stations and the lack of stationarity of certain data series of precipitations.

A preliminary analysis has been made for identifying the time period with the highest number of running rain gauge stations. In order to identify the final dataset, the selection have been made based on two criteria. Stations must have recorded for more than 50 years (WMO, 1988) and the total missing data cannot be more than 10%. Furthermore, for daily rainfall the number of missing data in the annual series must be smaller than 10% of the length of the series (36 missing days maximum).

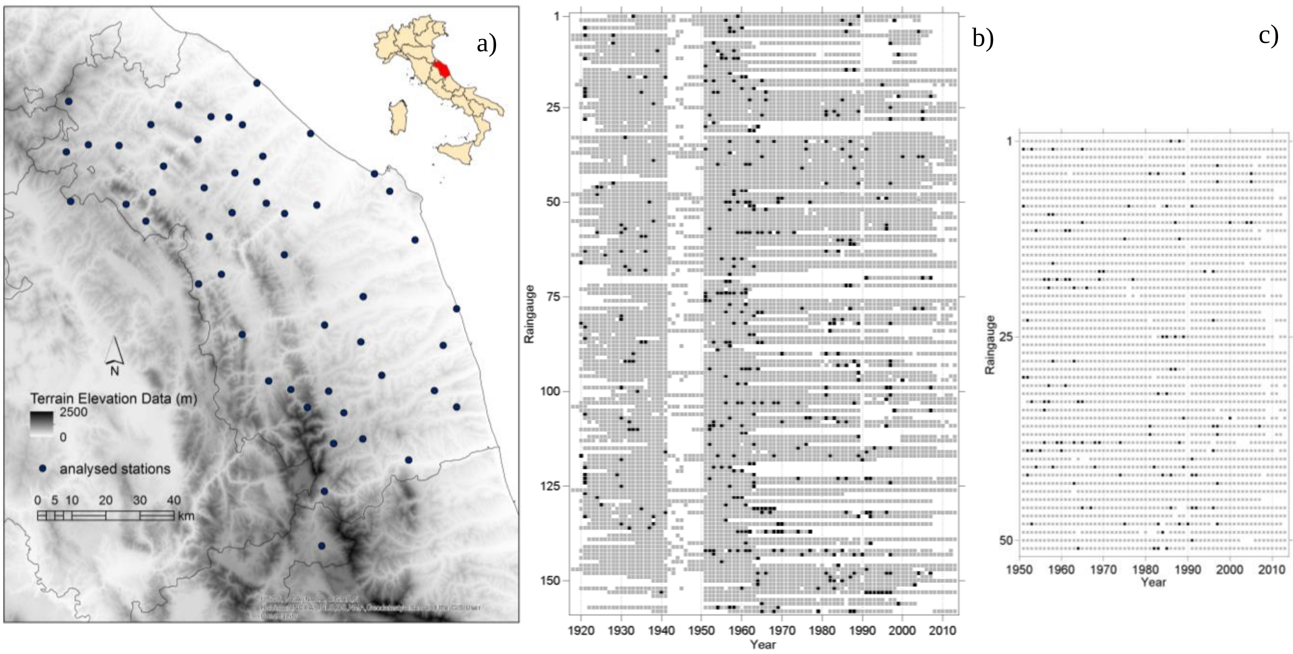

Figure 1. (a) Study area and location of the analysed stations over the Marche region; working (grey), not-working (white) and intermittently recording (black) rain gauges: (b) all the rain gauges in the period 1918-2013 and (c) selected dataset in 1951-2013.

The selected time period is the interval 1951-2013 in which more than 50 rain gauges pass the adopted criteria (see Figure 1c). All the series refer to one basic common period with a length variable from 57 to 63 data. The choice of this period involves the elimination of the interval 1942-1949 in which most of the stations are not working, as shown in Figure 1b. Furthermore, in the period 1951-2013 digital data useful for the computation of the ETCCDI indices are available.

The final subset is shown in Table 2 for the different types of analysed rainfall and indices.

Table 2. Dataset selected for the analysis.

Parameter name	**period**	**number of analysed stations**	**minimum sample size (years)**	**average sample size (years)**
R1xday	1951-2013	51	57	59.7
PRCPTOT	1951-2013	54	57	60.2
R1mm	1951-2013	52	57	59.9
R20mm	1951-2013	51	57	59.6
R95pTOT	1951-2013	50	57	59.6
1, 3, 6, 12 and 24h duration maximum annual rainfall	1951-2013	23	57	59.8
15-30 minutes duration maximum annual rainfall	1990-2013	48	21	22.7

The dataset counts 51 stations for the annual maximum daily rainfall with an average simple size of 59.7 years, as suggested for investigation of climate change by Kundzewicz & Robson (2000). The numbers of analysed stations for the PRCPTOT, R1mm and R95pTOT indices are different because some data have been reconstructed during the validation phase of the series.

In comparison with the dataset of the daily rainfall, the number of stations selected for the analysis of the rainfall for 1, 3, 6, 12 and 24h duration in the period of observation 1951-2013 drops to 23 with an average sample size of 59.8 data.

Unlike the daily and the annual maximum hourly rainfall, the period of observation for the precipitation of 15 and 30 minutes duration, was identified in the interval 1990-2013 and the length of the series must be larger than 20 years. The selection has been required as only in this period annual maxima data of rainfall of 15 and 30 minutes duration are available. It is well known that 20 years of records are not enough to make any kind of conclusion on climate change. At the same time, a detection of any trend can be considered as an hypothesis of the existence of a tendency since those are the more recent available data for rainfall of sub-hourly duration. Thus 48 stations were selected with an average sample size of 22.7 years.

In spite of the advantage of the Mann-Kendall test, that has low sensitivity to abrupt breaks due to inhomogeneous time series (e.g. Jaagus, 2006), the CUSUM and Pettitt (Pettitt, 1979) tests were used to detect any inhomogeneity in the series of annual maxima daily rainfall. Among selected time series, six have revealed the existence of change points in both tests. Considered both the difficulties and uncertainties in the detection of a possible break point in the time series and the absence of historical metadata for the involved rain gauge stations, the series have not been eliminated.

The application of statistical tests requires to verify the absence of serial correlations that may alter the outcome. This analysis has been omitted for historical series consisting of only annual maxima values, as these data series are devoid of any correlation (Bovo et al., 2004).

For the series of daily rainfall, in the case of incomplete series different techniques may be applied to estimate missing data (e.g. Karl et al. 1995; Cannarozzo et al., 2006).

After the data check, in the selected dataset missing values amount to less than 5% and are evenly distributed along the series without long periods of more consecutive years of missing data. Because of the exiguous number of missing data and considering that the substitution of an arbitrarily chosen value will likely give biased estimates of the trend, we have not replaced missing values. The presence of only a few not detected values in a record (less than about 5%) is not likely to affect the accuracy of the trend slope magnitude significantly (Helsel and Hirsch, 2002).

Location of the 51 selected stations for the analysis of the annual maximum daily rainfall distributed over the whole region is reported in Figure 1a. The spatial distribution over the whole region of the average value and the coefficient of variation of annual maximum daily rainfall with reference to the entire period of observation 1951-2013 is depicted in

Figure 2. Rainfall data were spatially interpolated by means of inverse distance weighted (IDW) technique and the production of the maps has been carried out by use of ArcGIS software. This technique has been largely used in the spatial interpolation of the rainfall data over a wide region (Cannarozzo et al., 2006; Fatichi & Caporali, 2009; Appiotti et al., 2015).

The average value of the annual maximum 1-day rainfall vary from 46 mm to 97 mm, being the low values registered in the central part of the region and the high values localised in the mountain areas. The coefficients of variation vary from 0.25 to 0.55 and the maximum variability is observed in the southern part of the region.

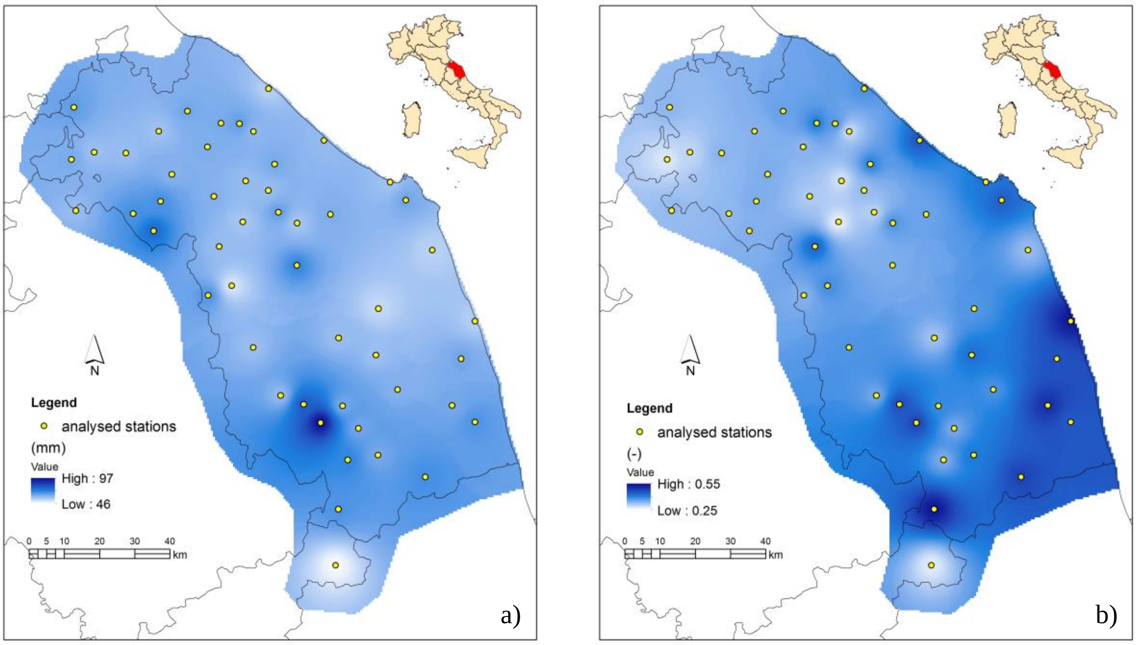

Figure 2. Spatial distribution of the annual maximum daily rainfall in the period 1951-2013 over the region reconstructed by IDW technique. a) mean value; b) coefficient of variation.

The Mann-Kendall test was applied to series of annual maximum precipitation with duration of 1-day, 1, 3, 6, 12 and 24 hours, 15 and 30 minutes and to series of R1mm, R20mm, R95pTOT and PRCPTOT indices.

Besides the Mann-Kendall test, for these indices we have analysed also the time series of the annual average anomalies computed over all the rain gauges from 1961 to 2013 in comparison with the normal value of the climatological reference period 1961-1990 recommended by WMO (2011). For each index, a single time series of the anomalies representative of the Marche region was computed. This series was obtained by first calculating the annual values of the deviations of the index from the average value obtained in the climatological normal 1961-1990 for each station and then calculating the arithmetic average of the anomalies of all stations year by year (Desiato et al., 2012).

RESULTS

Analysis of the annual maximum rainfall

The results of the Mann-Kendal test applied to annual maximum rainfall for 1, 3, 6, 12 and 24 hours and 15 and 30 minutes are depicted in Figure 3a for the respective observation period (Table 2). The graph provides the percentage of stations with a trend, positive or negative, or no trend for each duration and for a significance level $\alpha=0.05$. Figure 3a shows that there is no trend in most of the analyzed rain gauges. No stations have negative trend for the rainfall for 15 and 30 minutes and 6 h duration. In detail, for the rainfall of hourly duration the percentage of stations with positive trend is nonnull for the duration greater than 3 h, while the percentage of stations with negative trend is 4.35% for 3, 12 and 24 h duration. There is no difference between results obtained for the 12 h and the 24 h duration. For the rainfall of sub-hourly duration no stations exhibit a negative trend and the percentage of stations with positive trend is larger for the smaller duration. The latter finding should be considered with caution because the average sample size is 22.7 data, as shown in Table 2.

Such a conclusions are confirmed increasing the significance level. The results obtained for $\alpha=0.1$, here not reported, show that there is a general tendency of increasing the number of stations with positive trend, for the sub-hourly durations, whose percentage becomes twice greater. On the contrary, the number of the rain gauges with negative trend increases for the precipitation of hourly duration.

No relevant results were obtained for Mann-Kendall test with reference to the significance level $\alpha=0.01$, since only the sub-hourly rainfall show a limited number of rain gauges with positive trend (three and two stations for 15 and 30 minutes respectively).

Spatial distribution of the Mann-Kendall test results of the annual maximum rainfall for all the durations is illustrated from Figure 3b to Figure 3h for a significance level $\alpha=0.05$. Triangles indicate stations exhibiting a trend. The upper or lower vertex of the triangles indicates positive or negative trend and the triangle size is proportional to the magnitude β of the trend given by equation (5). The remaining stations do not exhibit statistically significant variation.

As already stated, the dataset used for the analysis of the rainfall with duration smaller than 1 h is different from that adopted for the larger durations. In the first case the number of analyzed stations is 48, while in the latter one is 23. For this reason, while the percentage of the stations exhibiting a trend could be similar, the number of rain gauges showing a tendency for the rainfall of short duration could be twice the number of stations with trend of the hourly precipitation.

For the rainfall with a duration of 15 and 30 minutes, stations exhibiting a variation show only a positive trend with larger values of magnitude β. In particular, for the 15 minutes duration the stations are distributed along the eastern band of the region. In the mountain areas only two stations show a positive trend and are located in the northern part of the region. Similar outcomes along the eastern coastal band are obtained for the rainfall with 30 minutes duration, while in the mountain areas only one station exhibits a positive trend in the south-west part of the region.

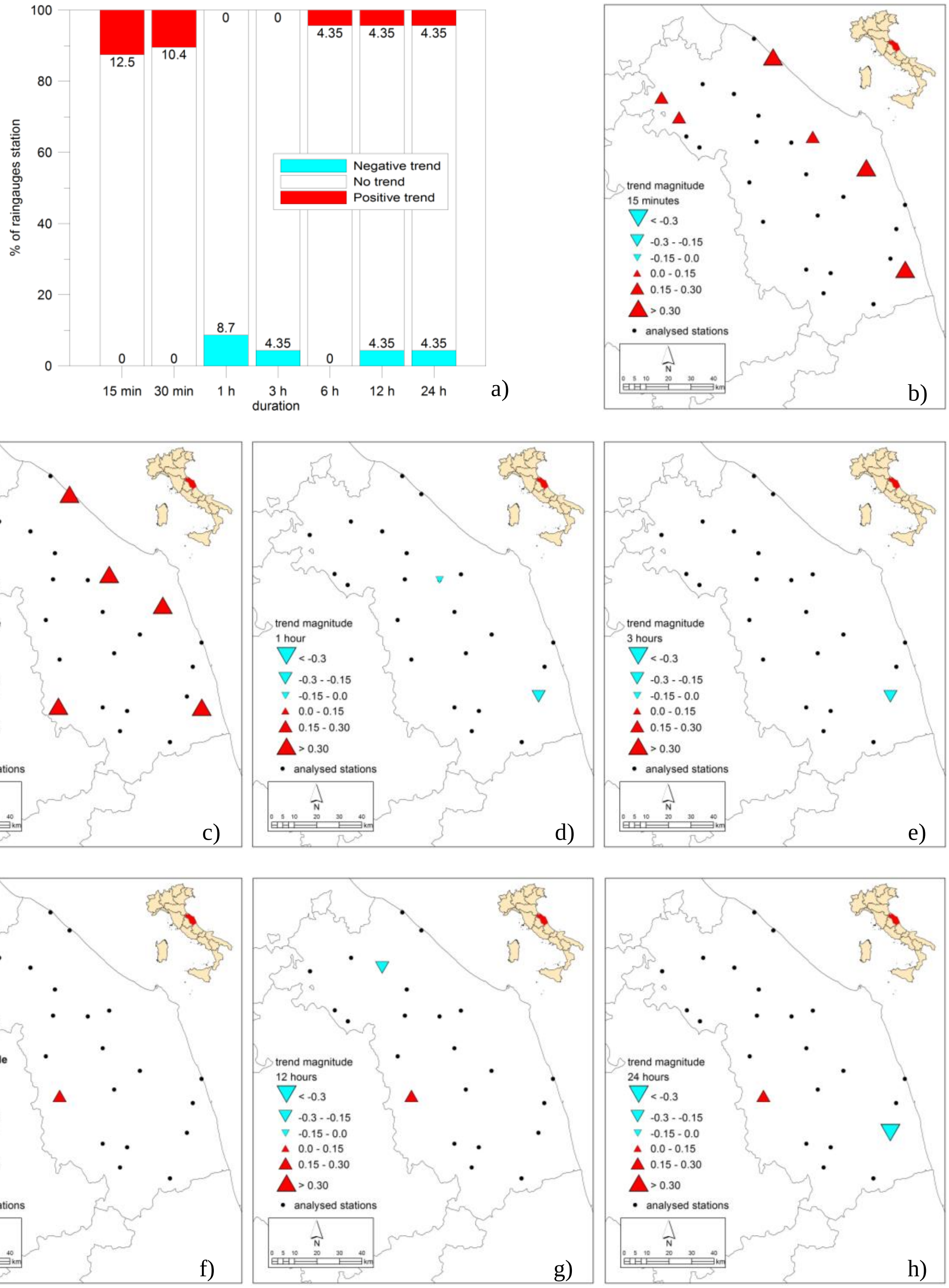

Figure 3. Results of the Mann-Kendall test for maximum annual rainfall for 1, 3, 6, 12 and 24 hours and 15 and 30 minutes duration for a significance level α=0.05. (a) Percentage of rain gauges showing a positive, negative and no trend; (b-h) spatial distribution of the trend sign and magnitude in the analysed stations exhibiting a tendency evidence.

As the duration increases, the number of stations showing a tendency drastically reduces and no spatial behavior can be observed. Only the rain gauge of Pioraco has a positive trend for the rainfall of 6, 12 and 24 h duration with a constant magnitude of the trend. As regard to the decreasing trend, only the station of Diga di Carassai seems to show the existence of a reduction of the rainfall of hourly duration.

Analysis of the ETCCDI indices

Application of Mann-Kendall test to the climate indices permits to individuate the existence of trend in the frequency and intensity of daily rainfall. The general results are reported in Figure 4a where the percentage of the stations with a positive or negative or no trend is provided for a significance level $\alpha=0.05$. Most of the stations have no trend in their time series. When a trend is present, it is negative and only for the two indices R95pTOT and R1mm at some stations has been detected a positive trend.

With reference to the annual maximum daily rainfall (Rx1day), a negative trend has been detected at about the 12% of the stations and no stations manifest a positive trend. This result is different from those obtained for the annual maximum rainfall of 24 hours. The explanation is the fact that the statistics concerning the index were computed over 51 stations with an average size of the sample of 59.7 years, while the results of the maximum annual value of 24 hours duration refer to 23 stations with an average sample size of 59.8 years. In addition, although the duration of the precipitation of the two time series is the same, the rainfall amount was computed during different time intervals, according to the definitions of the Italian Hydrographic Service. The index R1xday considers the daily rainfall defined as the precipitation falling from 9 a.m. to the same hour of the previous day, while the 24-hours maximum rainfall is the maximum value of the precipitations regardless the initial time of the event.

The percentage of stations showing a negative trend is similar for R1mm and R20mm, while no station shows a positive trend for the annual number of rainfall events with precipitation ≥ 20mm. Therefore the frequency of the daily precipitation seems reduce regardless the rainfall intensity. This reduction of the wet days confirm the results obtained in most of the studies carried out in the Italian territory in which the number of wet days in the year has a clear negative trend (Brunetti et al., 2001; Bartolini et al., 2014a).

As regard extreme precipitation, for the total annual amount in days with rainfall higher than 95th percentiles of the reference period (1961-1990), a negative trend has been detected at about the 22% of the stations, while the 2% of the rain gauges manifests a positive trend. Therefore for extreme event the percentage of the stations in which no trend is observed reduces in comparison with the value observed for R1xday, even if both cases of positive and negative trends increase and a general tendency cannot be defined.

Finally, a negative trend in the PRCPTOT has been observed at the 50% of the stations, which represents the most evident result from a quantitative point of view. Similar results were observed in the work of Appiotti et al. (2014), in which a negative trend of the annual total rainfall was detected over the period 1960-2009 in 35 of the 51 stations analysed with a percentage of about 68%. Seasonal data have highlighted that the negative annual trend is driven mainly from the winter negative trend and no trend is detected in autumn in any station. Analogous conclusion may be attainted throughout the Italian territory, in which a general decrease of the total precipitation is observed in northern regions (Brunetti et al., 2001) and an important reduction in annual rainfall was observed in Tuscany (Bartolini et al., 2014a) and Sicily (Cannarozzo et al., 2006; Arnone et al., 2013).

No particular differences have been detected in the presence of trend by increasing the significance level from α=0.01 to α=0.10. All the analysed indices show that the percentage of rain gauges with any trend increases with the value of α, being the greater gain from α=0.01 to α=0.05. Data reported in Table 3 show that, in the case of global indices R1mm and PRCPTOT, more than 50% of stations have a negative trend for α=0.10. At the same time, the rain gauges with positive trend are practically negligible at any significance level.

Table 3. Number of rain gauges with trend for climate change indices (ETCCDI).

Index	**R1mm**			**Rx1day**			**R20mm**		
Significance level α	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**
Positive Trend	0	2	2	0	0	0	0	0	1
Negative Trend	6	19	26	1	6	10	13	19	21
Index	**R95pTOT**			**PRCPTOT**					
Significance level α	**0.01**	**0.05**	**0.10**	**0.01**	**0.05**	**0.10**			
Positive Trend	0	1	2	0	0	0			
Negative Trend	4	11	17	15	27	33			

Besides the detection of trend, the time series of the annual average anomalies of the ETCCDI indices was computed for all the analysed stations over the period 1951-2013 with respect to the normal value of the climatological reference period 1961-1990 recommended by WMO (2011). Results, plotted from Figure 4b to Figure 4f, show an irregular behavior of the data oscillating between positive and negative values, therefore no evidence of either increasing or decreasing tendency can be extrapolated. In a global analysis, it could be considered a general prevalence of positive anomalies until 1980 for all ETCCDI indices except for R95pTOT, while negative values are prevalent in the last three decades. A particular result can be found for the maximum annual daily rainfall that has positive anomalies in the last five years 2009-2013, in which 2013 is the highest value over the entire period 1951-2013. Moreover interval 2009-

2013 is the longest one with positive anomalies of Rx1day. A certain prevalence of positive anomalies can be observed in the same years for other indices also.

Since no more results of particular evidence can be observed from the anomalies values, the time series were interpolated by a moving average computed over 9 years to highlight their evolution over the reference period. Results are discussed below. It is evident that all the indices are characterized by a decreasing phase in the interval 1965-1974 and in the recent past, from 1981 to the mid-90s, while in the last decades the moving average of all indices has an alternate behavior between increasing and decreasing tendency, although it assumes negative values.

Figure 4b shows that the anomalies of the maximum annual daily rainfall were decreasing initially from 1960 to 1975 and from 1981 to 1995. They start to increase in 1976 and become positive from 1977 to 1985; then the anomalies of Rx1day have a stationary behavior with negative values in 1994-2008 and only in the last years they show an increasing behavior being positive.

Results obtained for two indices referring to the extreme precipitation, R20mm and R95pTOT, illustrated in Figures 4c and 4d are very similar. In both cases, the anomalies are characterised by decreasing tendencies in the Sixties and Eighties. The growing period is from 1974 to 1980 and the moving average has positive values from 1976 to 1986 and then become negative. In the recent period 1999-2008 negative anomalies become more negative and only since 2009 there seems to be an increasing behaviour of the anomalies of both indices.

The results obtained for the rainy days of Figure 4e highlight a decrease of the anomalies from the 1965 to the mid-90s and then a rising phase still in progress. The more evident growth of positive anomalies of R1mm is observed from 1959 to 1965.

Finally, Figure 4f shows that the moving average of the anomalies of the annual precipitation computed respect to the climatological normal 1961-1990 is similar to that of extreme indices R20mm and R95pTOT, with negative values of moving average from 1983 to 2013. In the last years the anomalies of PRCPTOT seem increase, as observed for the other indices. Similar results were observed in the work of Appiotti et al. (2014), in which the percentage anomaly was calculated with respect to the climatological normal 1971-2000. Their results show that the winter data of annual precipitation decrease from the decade 1960-1970 up to the period 1990-1999, while the decade 2000-2010 shows a certain precipitation recovery, except to the coastal areas and in the mountain south-west part of the region. It is to be noted that the increase of the indices observed since 2009 seems to depend heavily on the values observed in 2013, which is a year of particularly intense and frequent rainfall and it was not considered by Appiotti et al. (2014).

Figure 4. Results of the analysis of ETCCDI indices. (a) Percentage of rain gauges showing a positive, negative and no trend according to the Mann-Kendall test for a significance level α=0.05; (b-f) time series of the annual average anomalies of over the period 1951-2013 computed respect to the average value of the climatological normal 1961-1990:(b) Rx1day, (c) R20mm, (d) R95pTOT, (e) R1mm and (f) PRCPTOT. Dashed lines represent the moving average computed over 9 years.

To define the temporal and spatial evolution of the indices Rx1day, R1mm and PRCPTOT, a spatial interpolation of the average values of the three indices was carried out by means of IDW technique for four reference periods of 30 years: 1951-1980, 1961-1990, 1971-2000, 1981-2010.

The map of the average values of the annual maximum daily rainfall in all considered periods, reported in the left column of Figure 5, shows that in the past the rainfall was distributed unevenly throughout the region and there is not an evident correlation between daily rainfall and the geographic location of the stations. As partial confirmation of this fact, the rain gauges with the maximum and minimum average value are both located in the southern Apennine area. By considering the development over the years, a progressive reduction of Rx1day is evident throughout the region, with particular reference to the maximum value: it varies from 100 mm in 1951-1980 to 89 mm in 1981-2010, while the variation of the minimum is less evident and not uniform with respect to the time and ranges between 43 mm and 47 mm. Therefore the variation of Rx1day over the region tends progressively to reduce and the spatial distribution of Rx1day in the last 30-year period 1981-2010 (see Figure 5j) seems more uniform except the extreme values located in few stations of the mountain area. A similar result was obtained by computing the average value over the entire observation period, as illustrated in Figure 2a. Finally, the reduction of Rx1day between two subsequent 30-year periods seems not constant in time, the more important variation is observed between the first two analyzed 30-year periods and in last years this effect is less noticeable.

The central column of Figure 5 shows the map of the spatial distribution of rainy days (R1mm). It can be observed that, as expected, the value of R1mm reduces moving from mountain areas toward the coast, regardless to the 30-year period. The comparison among maps for a reference period of 30 years shows a generalized reduction of the rainy days throughout the region. During the four 30-year periods the maximum value reduces from about 131 to 117 days and the minimum one from 81 to 75 days. This means that both the maximum and minimum values reduce albeit to different extent and, as time goes on, the gap between the two extreme values tends to reduce and the distribution over the region becomes more uniform. Moreover, the reduction of R1mm with time was more pronounced in the past and from the 30-year period 1971-2000 to 1981-2010 this effect appears to have stopped (see Figures 5h and 5k).

The results of the spatial and temporal evolution of the PRCPTOT index are illustrated in the right column of Figure 5. The map of the average values confirms that the annual total precipitation is strongly dependent on the altitude. In all the 30-year periods, we can distinguish three bands corresponding to the mountainous, hilly and coastal area, characterized by decreasing precipitation values. The maps confirm that the stations that have the highest PRCPTOT values are the same that exhibit the peaks of Rx1day and R1mm indices.

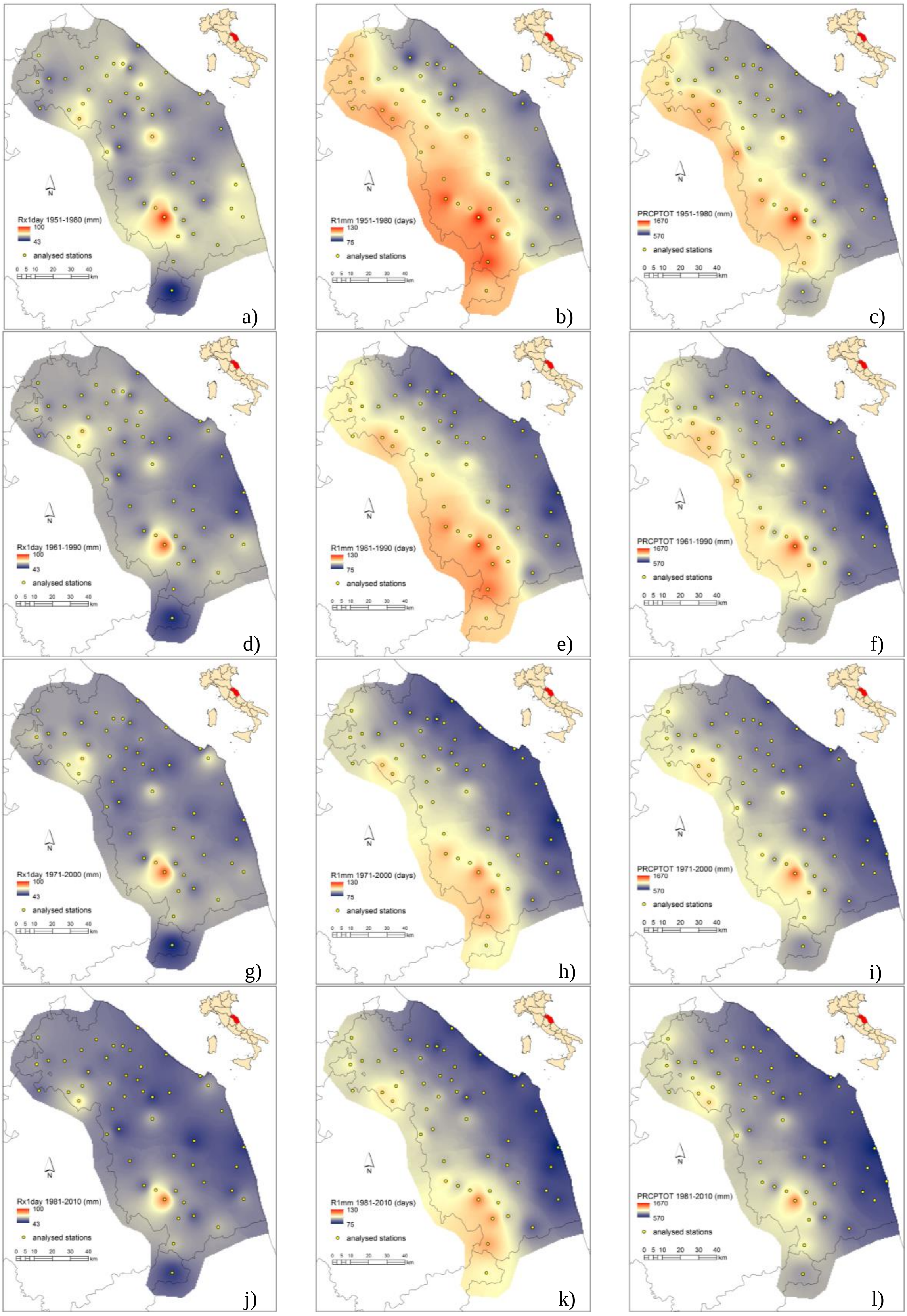

Figure 5. Spatial distribution of the average value of the ETCCDI indices Rx1day (first column) R1mm (second column) and PRCPTOT (third column) during different four 30-years periods. (a, b, c) 1951-1980; (d, e, f) 1961-1990; (g, h, i) 1971-2000; (j, k, l) 1981-2010. For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.

As in the previous cases, PRCPTOT reduces from 1951-1980 to 1981-2010 and the reduction of the maximum values is larger than that of the minimum ones. The maximum value reduces from 1670 mm to 1415 mm, while the minimum changes from 736 mm to 570 mm. However, unlike the variation of the maximum values which seems to be more gradual in time, the reduction of the minimum values seems to increase in the last 30-years period.

Comparing the maps of the three indices, there isn't an evident difference between the southern and northern coastal areas of the Marche region and thus no correlation can be identified between precipitation regime and latitude.

CONCLUSIONS

The statistical analysis of the annual maximum daily rainfall and those for a duration of 1, 3, 6, 12 and 24 hours, 15 and 30 minutes reveals that there is not a clear evidence of the increase of these events.

The results of Mann-Kendall test show that more than 91% of the analysed historical time series of hourly maximum precipitations do not have any trend. No stations have negative trend for the rainfall for 15 and 30 minutes duration. The latter result, obtained in the period 1990-2013, could represent an indicator of maximum events increase in the last years, although it could be influenced by the reduced dimension of the statistical sample (24 years). Anyway, there is not a preferential spatial distribution of the rain gauges with positive or negative trend over the Marche region.

The analysis of indices relevant to climate change detection confirms that no increasing trend exists in the frequency and intensity of daily rainfall. On the contrary, the global indicators R1mm and PRCPTOT have a negative trend for 36.5% and 50% of the analysed stations. Also indices over a threshold (R20mm and R95pTOT) have percentages of decreasing trend greater than 37% and 22% respectively. These results are partially confirmed by the time series of the annual anomalies of the same indices that are mainly characterized by negative values since about 1981. The behaviour of the moving average shows an increasing tendency for Rx1day in the interval 2009-2013, as confirmed by the positive values in the anomalies time series since 2009. However, this results could be influenced by the data measured in 2013, that are the highest of the time series in any rain gauge. Therefore a confirm of the tendency should be considered with the last data acquisitions not available yet.

The temporal and spatial evolution of the indices Rx1day, R1mm and PRCPTOT reveals a reduction of both maximum and minimum average values during the period of analysis; as a consequence, the present distribution of the data over the Marche region is more uniform. This variation is evident from 1951 to 2000, then the differences between average values of indices in the interval 1971-2000 and those calculated in the period 1981-2010 seem to reduced or cancel. Since the variations are negative, this result could be considered an indirect confirmation of the increasing tendency of the anomalies in the last 2009-2013 years observed for Rx1day, while there isn't a direct correspondence between positive values of anomalies and reduced variations in the other two indices (R1mm and PRCPTOT).

These results reveal that if there is no evidence of a positive trend of maximum annual rainfall events at regional scale, at the same time a possible variation in the climatic indices is taking place. This aspect could have some consequences in the definition of the design storm. A specific analysis of the temporal evolution of the rainfall Intensity-Duration-Frequency curves, due to variation of the maximum annual rainfall of the last years (2009-2013), could represent a possible development of the present work.

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