

Temporal Analysis of Rainfall Categories in Southern Italy (Calabria Region)

T. Caloiero¹ · R. Coscarelli² · E. Ferrari³ · B. Sirangelo⁴

Received: 10 November 2016 / Accepted: 11 February 2017 / Published online: 21 February 2017
© Springer International Publishing Switzerland 2017

Abstract A modification in the water cycle is one of the most noticeable consequences of global atmospheric warming. Precipitation is a key point in the process and its temporal distribution is particularly important because it impacts on some extreme phenomena such as drought and flash floods, affecting also water resources management. This study presents an analysis of daily rainfall categories over a region of southern Italy in order to verify earlier report results which indicated a paradoxical increase in extreme rainfall, despite a decrease in the totals, in the Mediterranean basin. A set of daily homogenous precipitation series for the period 1916–2006 has been used in this study. Six daily rainfall categories have been considered: Light, 0–4 mm/day; Light-Moderate, 4–16 mm/day; Moderate-Heavy, 16–32 mm/day; Heavy, 32–64 mm/day; Heavy-Torrential, 64–128 mm/day; Torrential, 128-up mm/day. The analysis was performed considering all the region and separately five Rainfall Zones (RZs) characterized by different climatic conditions. Results showed, with some differences for the various RZs, that Light-Moderate, Moderate-Heavy and Heavy rainfall are the main contributors to the total annual rainfall. Moreover, the trend analysis through the Mann-Kendall test showed a decreasing trend of the higher categories and an increasing trend of the weaker categories. These analyses could be useful because changes in extreme events can impact natural environments and human activities, as well as human health and safety.

✉ T. Caloiero
tommaso.caloiero@isafom.cnr.it

¹ National Research Council of Italy, Institute for Agriculture and Forest Systems in the Mediterranean (CNR-ISAFOM), Via Cavour 4/6, 87036 Rende, (CS), Italy

² National Research Council of Italy, Research Institute for Geo-hydrological Protection (CNR-IRPI), Rende, (CS), Italy

³ Department of Computer Engineering, Modeling, Electronics, and Systems Science (DIMES), University of Calabria, Rende, (CS), Italy

⁴ Department of Environmental and Chemical Engineering (DIATIC), University of Calabria, Rende, (CS), Italy

Keywords Daily rainfall · Rainfall categories · Climatic trend · Calabria precipitation

1 Introduction

Climate change can directly affect water resources management and has a key role in their planning (flood prevention and control, drought management, irrigation demand, etc.). The latest Assessment Report (AR5) issued by the Intergovernmental Panel on Climate Change (IPCC 2013) has highlighted the global impact of human activities on climate, and the effects on the environmental system. For example, the increase in CO₂ and greenhouse gases (methane and nitrous oxide) emissions in the atmosphere have contributed to a global mean surface warming with a contemporary increase in drought and storm intensity (Chou and Neelin 2004; Held and Soden 2006; Wentz et al. 2007; Zhang et al. 2007; Allan and Soden 2008; Trenberth 2011; Dankers et al. 2013). For these reasons, in the last decades, trends of climatological, meteorological and hydrological variables have been investigated by many researchers by using different methodologies and at different spatial and temporal scales. As a result, if a reduction in precipitation becomes recurrent in many countries which often register extreme drought conditions, conversely, in other areas of the world, numerous extreme events, such as hurricanes and floods, are highlighted, with damaging effects on the environment and the society (e.g., Alexander et al. 2006; Min et al. 2011; Westra et al. 2013). Moreover, climate models also indicate that further increases in extreme precipitation events should be expected over the next decades (Pall et al. 2006; O’Gorman and Schneider 2009; Toreti et al. 2013). In this context, several studies have focused on daily precipitation variability, evidencing positive trends in intensities and a tendency toward higher frequencies of heavy and extreme rainfall (Kunkel et al. 1999; Plummer et al. 1999; Osborn et al. 2002; Villarini et al. 2011; Caloiero 2014; Caloiero 2015). Alpert et al. (2002) conducted a coherent study of the full-scale of daily rainfall categories over the Mediterranean in order to assess the contradictory behaviour characterized by an increase in extreme rainfall in spite of a decrease in the totals. As to what concerns Italy, on six daily rainfall series of Northern Italy, Todeschini (2012) showed a significant decreasing trend in the annual number of wet days and an increasing tendency in the mean and maximum precipitation depths related to one day, with a generalized increasing tendency for the number of dry days following and followed by wet days. In Southern Italy, the analysis of Brunetti et al. (2012a) revealed negative trends in high-intensity categories, especially coming from the winter season. In the same area, Sirangelo et al. (2015), applying a stochastic model, evidenced a decrease in the return period of long dry spell occurrence.

In this study, the daily rainfall series recorded in the Calabria region (southern Italy) have been analysed by classifying the events into different rainfall categories, following the classification of Alpert et al. (2002), and considering both the whole region and separately the five Rainfall Zones (RZs) characterized by different climatic conditions (Brunetti et al. 2012b). In particular, for each category, the presence of any significant trend has been detected using the non-parametric Mann–Kendall test. The aim of this study is to verify earlier report results which indicated a paradoxical increase in extreme rainfall in spite of decrease in the totals, for the Mediterranean basin.

2 Study Area and Data

Located at the toe of the Italian peninsula, Calabria has a surface area of 15,080 km², on average its altitude is 597 m a.s.l. and its tallest relief is 2266 m a.s.l. The region does not present many high mountains, yet it is one of the most mountainous areas in the country, as mountains (over 500 m a.s.l. high) occupy 42% of the regional area, while hills between 50 and 500 m a.s.l. high cover 49% of the territory and only 9% are under 50 m a.s.l. (Fig. 1). It is

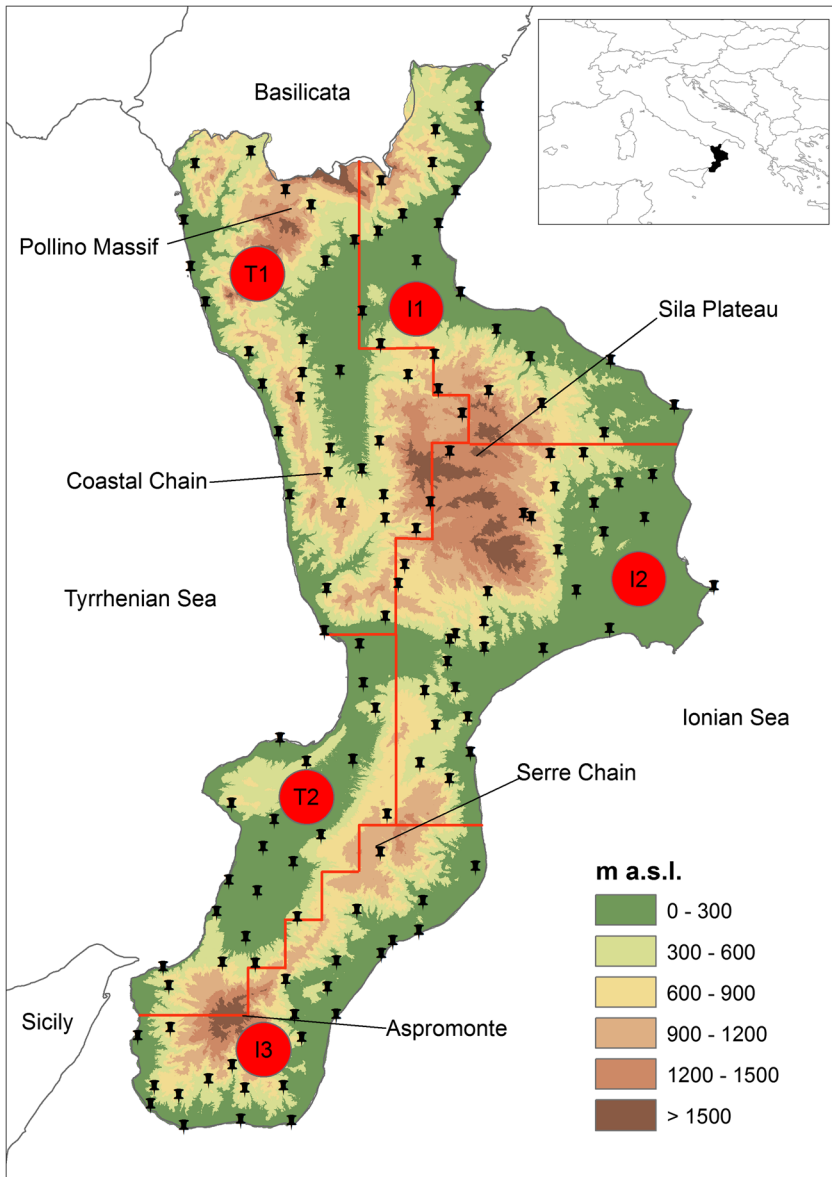


Fig. 1 Localization of the selected 129 rain gauge stations and of the five Rainfall Zones on a DEM of Calabria

a region characterised by a typical 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 summer temperatures affect the Ionian side, leading to short and heavy rainfall. The Tyrrhenian side, instead, is affected by western air currents which cause summer temperatures to be milder and higher precipitation amount on the mountains compared to the Ionian side. Cold and snowy winters and fresh summers with some precipitation are typical of the inner areas of the region (Coscarelli and Caloiero 2012).

The data initially used in this study are a set of daily precipitation series, registered in Calabria from 1916 to 2006 by the Multi-Risk Functional Centre of the Regional Agency for Environment Protection of the Calabria region. After applying the Craddock test (Craddock 1979) and a two-step procedure (Simolo et al. 2010) to eliminate inhomogeneities from the data series and lack of data, the final database for this study was the one appearing in Brunetti et al. (2012a), widely used in several past studies on Calabria climate (e.g., Caloiero et al. 2015; Buttafuoco et al. 2015; Longobardi et al. 2016). As a result, the analysis focused on a total of 129 daily rainfall series (Fig. 1).

3 Methods

Regarding the daily rainfall categories, six classes have been considered as suggested by Alpert et al. (2002): Light (A) 0–4 mm/day, Light-Moderate (B) 4–16 mm/day; Moderate-Heavy (C1) 16–32 mm/day; Heavy (C2) 32–64 mm/day; Heavy-Torrential (D1) 64–128 mm/day; and Torrential (D2) 128-up mm/day. However, in this study, due to the characteristics of rainfall intensity in Calabria, another category (D1 + D2: 64-up mm/day) has been used.

First, for each rain gauge and for each year, the percentage of the annual amount of each daily rainfall category and the annual number of daily rainfall events falling within each class have been computed. Then, each of these annual series was analyzed for trends, and the statistical significance was assessed with the Mann-Kendall non-parametric test (Mann 1945; Kendall 1962). For a series with dimension n , given the annual values x_j and x_i , respectively in the years j and i , with $j > i$, the MK statistic was obtained as:

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

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

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

with t_i number of ties of extend i .

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

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

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

Furthermore, with the aim to evaluate the daily rainfall categories trend in the different areas of the Calabria region, the analysis was performed considering the RZs, characterized by different climatic conditions separately, as reported in Brunetti et al. (2012b). Such zones were identified on the basis of the results of the Principal Component Analysis (PCA), including varimax rotation of the PCs (Principle Components), applied to the correlation matrix of daily records. In particular, from the analysis of the first 5 Empirical Orthogonal Functions (EOF), which explain 90% of the total variance, 5 RZs have been identified: Western-North Zone (T1) with 31 rain gauges; Western-South Zone (T2) with 21 rain gauges; Eastern-North zone (I1) with 21 rain gauges; Eastern-Central Zone (I2) with 31 rain gauges; Eastern-South Zone (I3) with 25 rain gauges (Fig. 1). To assess the persistence of trends through time, as well as the influence of the length and starting point of the time period considered, a mean yearly regional series were estimated, and a running trend analysis was performed (Brunetti et al. 2012a). This particular procedure consists of a multiple application of the trend analysis on a time series, considering different starting year and series length. In particular, the trend was initially calculated for a 20-year window starting in 1916. Then, the window size was incrementally increased up to the end of the series length (91 years: 1916–2006), with a slope calculated for each window size. The starting year was then increased by one, and the trend was calculated for different window sizes. This process was repeated up to the most recent 20-year trend (1987–2006). The trends obtained were plotted for better visualization in graphs where the y-axis represents the window width, and the x-axis the first year of the window to which the trend refers. The value of the trend is represented by the color of the corresponding pixel and the significance level by the dimension of the square: large squares are plotted for $p < 0.05$, small squares otherwise. These figures capture the whole possible spectrum of significant trends present in the series, thus providing the best possible detailed information.

4 Results and Discussion

The daily rainfall series recorded in the Calabria region have been analysed considering both the whole region and the five RZs identified through the application of the PCA. In particular, some of the results obtained at regional scale have been presented in Caloiero et al. (2016b).

Figure 2 shows, for the period 1916–2006, the temporal contribution of the several daily rainfall categories to the annual rainfall, evaluated as percentage of the total annual rainfall amounts. A separation among the categories contributions for the entire region and for the different RZs, is evident. At a regional scale (Fig. 2a), class B (4–16 mm/day) provides the

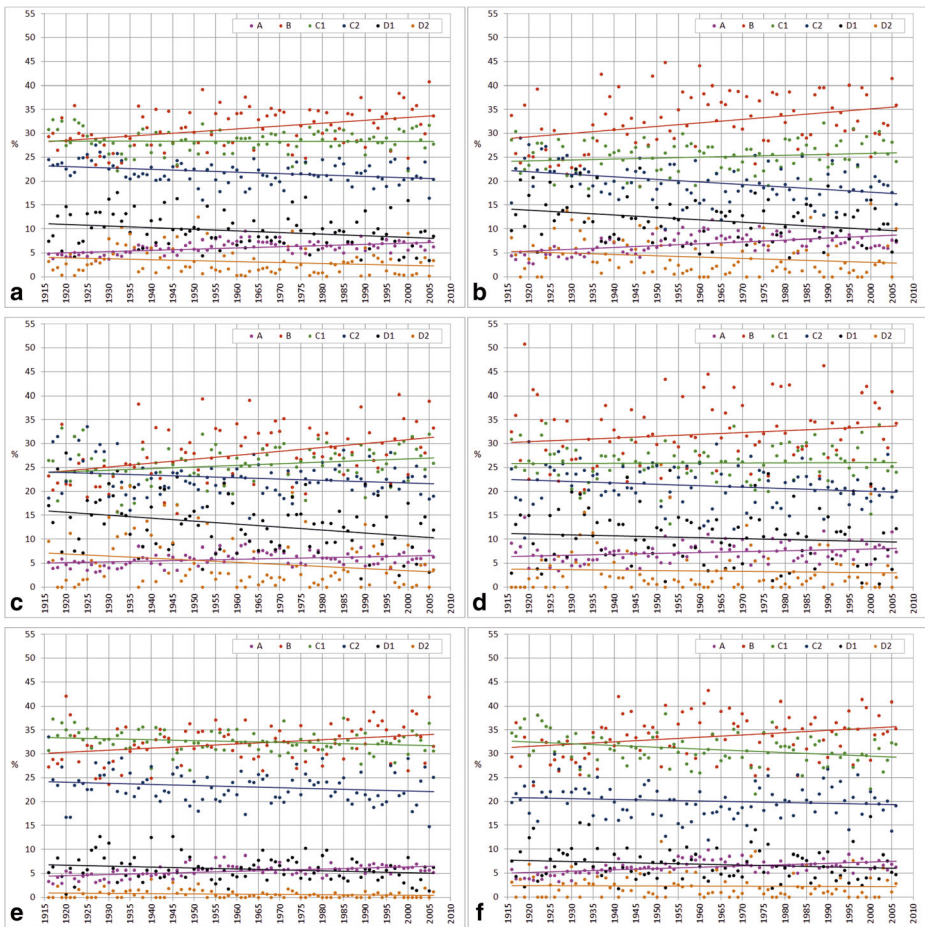


Fig. 2 Linear regression of the annual contributions (as percentage of the total annual amounts) for each of the daily rainfall categories for the whole Calabria region (a); and, for the different Rainfall Zones: I1 (b); I2 (c); I3 (d); T1 (e); and T2 (f). The y-axis represents percentage of the total annual amounts, the x-axis represents the year

maximum contribution to the yearly amount, immediately followed by the classes C1 and C2. On the contrary, the classes A, D1 and D2 provide low contributions to the annual values. Moreover, Fig. 2a clearly shows a positive tendency of the contributions of rainfall class B and, less evident, of class A. Decreasing trends of the percentages of yearly amounts deriving from D1, D2 and C2 (less clear) categories appear. For the C1 class, no tendency is clearly defined. Similar results, with some exceptions, have been obtained also in the different RZs: while the higher categories (C2, D1 and D2) present often decreasing trends, the lower ones (A and, particularly B) increase with time, especially in the Tyrrhenian side of the region (Fig. 2e and f). The Moderate-Heavy category (C1) presents opposite behaviors considering the various RZs: an increasing trend in the RZs I1 (Fig. 2b) and I2 (Fig. 2c) and a decreasing trend in the RZs T1 (Fig. 2e) and T2 (Fig. 2f). In particular, for several years at the beginning of the observation period, in the Tyrrhenian RZs, the C1 class provides the maximum contribution to the yearly amount. In the last decades, the maximum rate of the total annual values is provided by the B class.

A more detailed analysis has been conducted by applying the Mann-Kendall test to the rainfall series of each rain gauges considering the whole Calabria region and the five RZs. All tests have been performed at 5% confidence level. With regards to the whole region (Fig. 3a), a large positive trend, significant for more than half the rain gauges (58.9%), was detected for the lowest rainfall category (A). Also, the Light-Moderate category (B) revealed a diffuse positive trend (45.7%), while the Moderate-Heavy (C1) class showed a positive trend though not always significant. Negative trends have been detected for the highest rainfall categories, in particular for the Heavy class C2 (24.0%). Similar results have been obtained in the five RZs with a positive trend detected in the lowest rainfall category, in particular in the Tyrrhenian RZs (Fig. 3e and f), and negative trends identified for the highest rainfall categories, in particular in the RZ I1 (Fig. 3b) and RZ I2 (Fig. 3c). In particular, in the RZ I1, for the C2 class, a percentage of about 33% of negative significant trends is reached, while the D1 class of

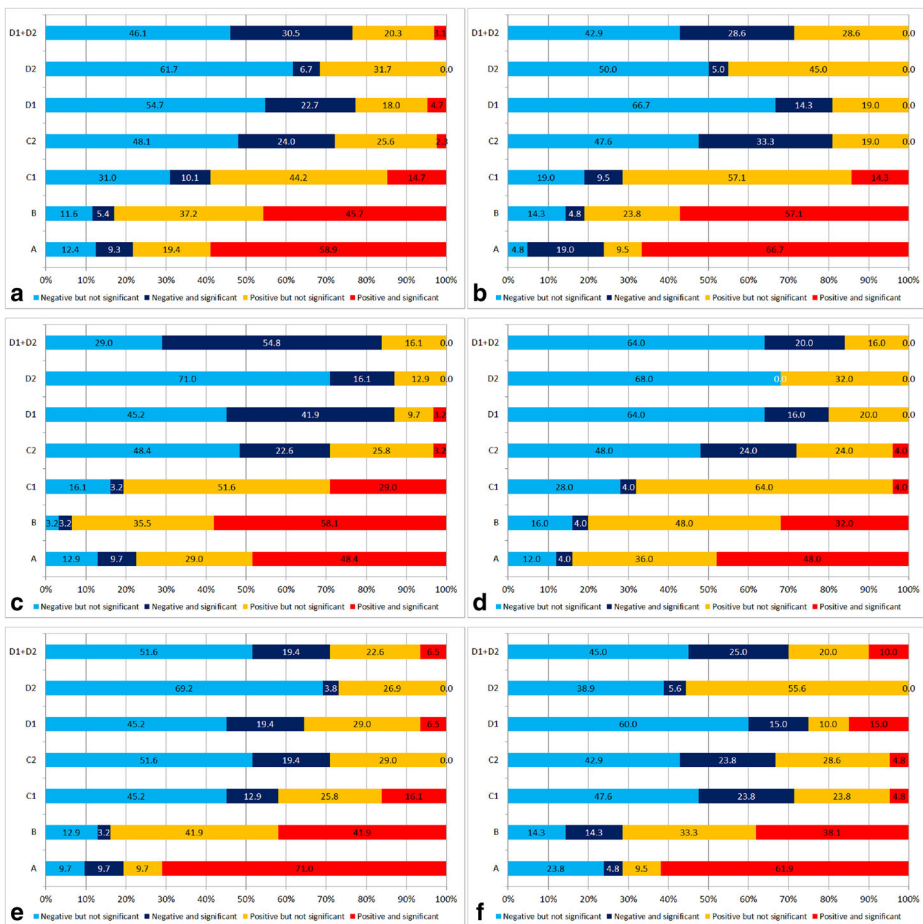


Fig. 3 Results of the Mann-Kendall test applied to the annual contributions (as percentage of the total annual amounts) of each of the daily rainfall categories for the whole Calabria region (a); and, for the different Rainfall Zones: I1 (b); I2 (c); I3 (d); T1 (e); and T2 (f). The y-axis represents the different rainfall categories, the x-axis represents the percentages of series presenting positive or negative (significance level of the trend: $p < 0.05$)

the RZ I2 presents a percentage of about 42% of rain gauges showing negative significant trends.

The Mann-Kendall test was also applied to the annual number of daily rainfall events falling within each category (Fig. 4). At regional scale, only the Light class (0–4 mm/day) shows a diffused positive trend (49.6% of the rain gauges), while negative trends have been detected for all the other rainfall categories, particularly for the Moderate Heavy (C1) (about 38%) and the Heavy (C2) (about 46%) classes. Considering the various RZs, the negative trend of the Heavy class (C2) is mostly evident on the Ionian side of the region (Fig. 4b and c), reaching a percentage of about 62% in the RZ I1, while on the Tyrrhenian side, and especially in RZ T2, about 52% of the rain gauges show a negative trend of the Moderate-Heavy class (C1) (Fig. 4e and f).

The comparison of Figs. 3 and 4 evidenced similar results for both the contribution of the several daily rainfall categories to the annual rainfall (Fig. 3) and the annual number of daily

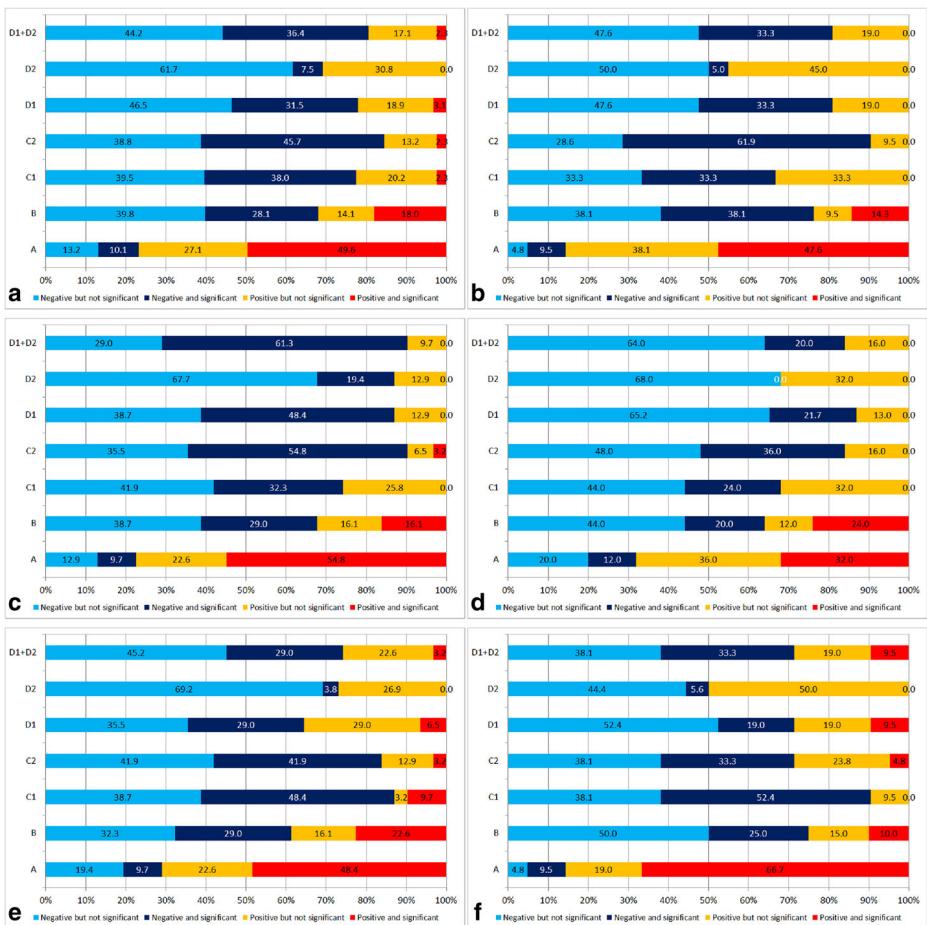


Fig. 4 Results of the Mann-Kendall test applied to daily rainfall events falling within each class of the daily rainfall for the whole Calabria region (a); and, for the different Rainfall Zones: I1 (b); I2 (c); I3 (d); T1 (e); and T2 (f). The y-axis represents the different rainfall categories, the x-axis represents the percentages of series presenting positive or negative (significant or not significant) trends (significance level of the trend: $p < 0.05$)

rainfall events falling within each category (Fig. 4). In fact, at regional scale, a large positive trend was detected for the lowest rainfall category (A) while negative trends have been detected for the highest rainfall categories. Analogous results have been obtained in the five RZs with a positive trend detected in the lowest rainfall category, in particular in the Tyrrhenian RZs, and negative trends identified for the highest rainfall categories on the Ionian side of the region.

The results of the running test applied to both the annual contributions (as percentages of the yearly amount) and the numbers of rainy days falling within each class are presented in Figs. 5 and 6, respectively. These diagrams refer to the whole study area and to the different rainfall categories, but do not include the highest class due to the limited data available. Regarding the contributions to the annual amounts (Fig. 5), the rainfall class A (Fig. 5a) shows a positive and significant trend in the first years of the data sets, with rate values less than 1%/10 years. Only in the period 1950–1960, some negative and significant trends appear for the same class. The rainfall class B (Fig. 5b) shows trends with a lower significance but higher rates (more than +1%/decade), especially for long time span. The C1 category (Fig. 5c) does not show significant trends. Some negative trends appear for the rainfall class C2, especially considering the early years of the observation period, with rates also greater than 1%/10 years, in absolute value.

The results for the numbers of rainy days falling within each class (Fig. 6) are particular relevant for the rainfall classes A and B (Fig. 6a and b), showing significant results alternatively negative and positive, till values greater than ± 20 days/10 years. Weaker trends are shown for the rainfall classes C1 (Fig. 6c) and C2 (Fig. 6d), but the trend significances of the

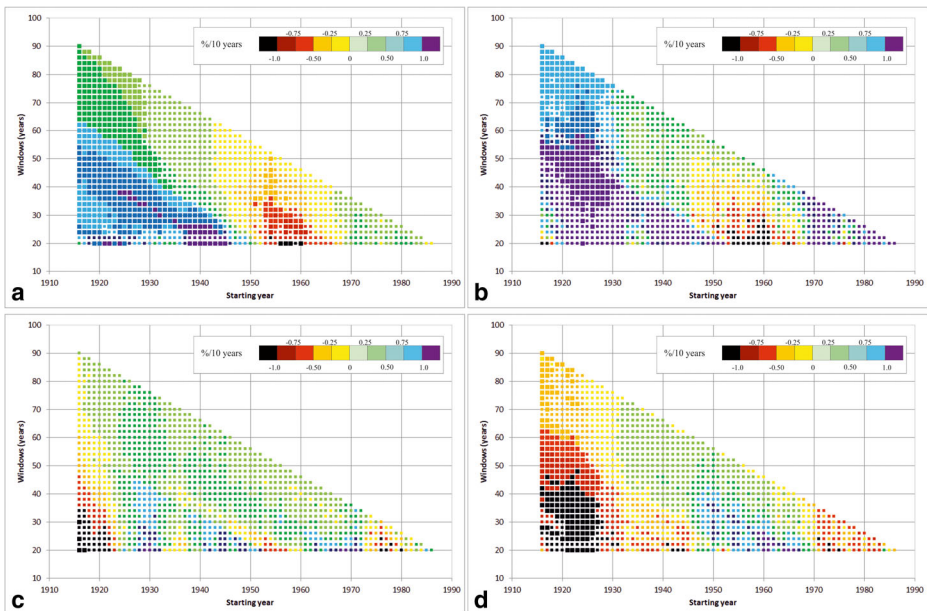


Fig. 5 Running trend analysis for the annual contributions (as percentage of the total annual amounts) of the daily rainfall categories A (a), B (b) C1 (c) and C2 (d) for the whole Calabria region. The y-axis represents the window width, and the x-axis represents the first year of the window over which the trend is calculated. Squares dimension indicates the significance level of the trend: large squares $p < 0.1$, small squares otherwise

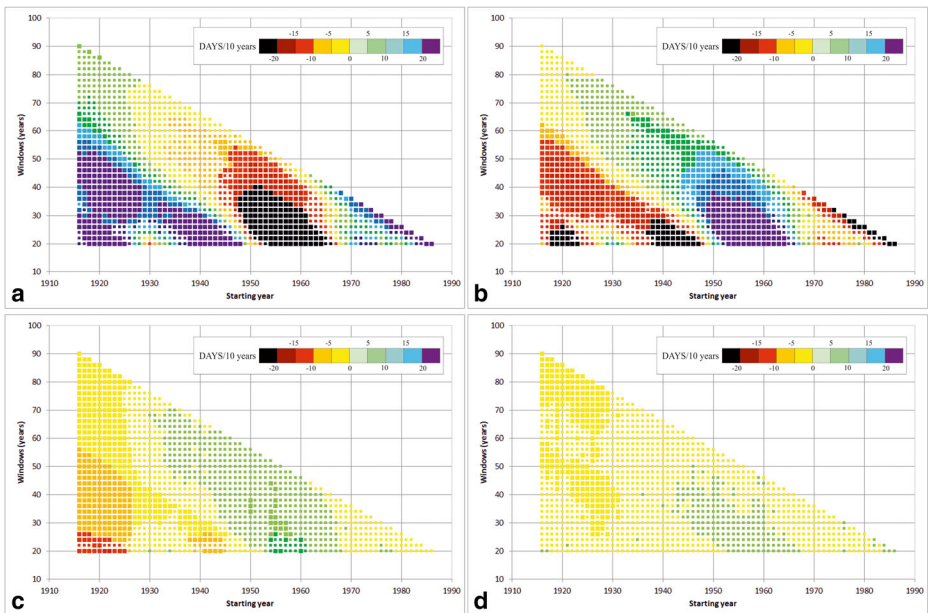


Fig. 6 Running trend analysis for the daily rainfall events falling within same class of the daily rainfall A (a), B (b) C1 (c) and C2 (d) for the whole Calabria region. The y-axis represents the window width, and the x-axis represents the first year of the window over which the trend is calculated. Squares dimension indicates the significance level of the trend: large squares $p < 0.1$, small squares otherwise

former class seem to be higher than those estimated for the contributions to the annual amount (Fig. 5c).

The results obtained in this study do not show the paradoxical behaviour evidenced by some authors (Alpert et al. 2002; Brunetti et al. 2004) for other study areas, where a positive trend of the extreme rainfall in spite of a decrease in the yearly amounts was present. In fact, for the Calabria region, while different studies highlighted the reduction of the yearly rainfall (e.g., Caloiero et al. 2016a; Longobardi et al. 2016), results of this analysis do not evidence an increase in extreme rainfall. Conversely, these results are well-matched with those obtained by Coscarelli and Caloiero (2012) for the rainfall concentration.

5 Conclusions

In this study, the spatial and temporal distributions of rainfall in Calabria region (southern Italy) were analysed considering the rainfall categories, in accordance to the classification by Alpert et al. (2002). The results showed that, in this southern part of Italy, the highest rainfall categories do not show particular trends. The most significant trends appear only for the lowest classes, as confirmed by the running approach. In fact, the lowest rainfall classes show positive trends especially for long time windows starting from the early years of the time domain. Similar results were obtained for the rainy days event falling within the various rainfall classes. Moreover, the Calabrian territory shows different behaviours of rainfall for the various Rainfall Zones of the study area. In particular, the Moderate-Heavy category shows an increasing trend in the Ionian side and a decreasing trend in the Tyrrhenian one.

Acknowledgements A previous version of the paper has been presented in the 2nd EWaS International Conference: “*Efficient & Sustainable Water Systems Management toward Worth Living Development*”, Chania, Crete, Greece, 1–4 June 2016.

References

- Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL (2006) Global observed changes in daily climate extremes of temperature and precipitation. *J Geophys Res* 111:D05109
- Allan RP, Soden BJ (2008) Atmospheric warming and the amplification of precipitation extremes. *Science* 321: 1481–1484
- Alpert P, Ben-Gai T, Baharad A, Benjamini Y, Yekutieli D, Colacino M, Diodato L, Ramis C, Homar V, Romero R, Michaelides S, Manes A (2002) The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. *Geophys Res Lett* 29:31–1–31–4
- Brunetti M, Maugeri M, Monti F, Nanni T (2004) Changes in daily precipitation frequency and distribution in Italy over the last 120 years. *J Geophys Res* 109:D05
- Brunetti M, Caloiero T, Coscarelli R, Gullà G, Nanni T, Simolo C (2012a) Precipitation variability and change in the Calabria region (Italy) from a high resolution daily dataset. *Int J Climatol* 32:57–73
- Brunetti M, Caloiero T, Coscarelli R, Gullà G, Nanni T, Simolo C (2012b) Applicazione di test di omogeneità e tecniche di ricostruzione dei dati mancanti alle serie pluviometriche giornaliere calabresi per l’individuazione di aree omogenee e la stima dei trend. *L’Acqua* 2:35–44
- Buttafuoco G, Caloiero T, Coscarelli R (2015) Analyses of drought events in Calabria (southern Italy) using standardized precipitation index. *Water Resour Manag* 29:557–573
- Caloiero T (2014) Analysis of daily rainfall concentration in New Zealand. *Nat Hazards* 72:389–404
- Caloiero T (2015) Analysis of rainfall trend in New Zealand. *Environ Earth Sci* 73:6297–6310
- Caloiero T, Coscarelli R, Ferrari E, Sirangelo B (2015) Analysis of dry spells in southern Italy (Calabria). *Water* 2015:3009–3023
- Caloiero T, Callegari G, Cantasano N, Coletta V, Pellicone G, Veltri A (2016a) Bioclimatic analysis in a region of southern Italy (Calabria). *Plant Biosys* 150:1282–1295
- Caloiero T, Coscarelli R, Ferrari E, Sirangelo B (2016b) Trends in the daily precipitation categories of Calabria (southern Italy). *Procedia Engineering* 162:32–38
- Chou C, Neelin J (2004) Mechanisms of global warming impacts on regional tropical precipitation. *J Clim* 17: 2688–2701
- Coscarelli R, Caloiero T (2012) Analysis of daily and monthly rainfall concentration in southern Italy (Calabria region). *J Hydrol* 416–417:145–156
- Craddock JM (1979) Methods of comparing annual rainfall records for climatic purposes. *Weather* 34:332–346
- Dankers R, Arnell NW, Clark DB, Falloon PD, Fekete BM, Gosling SN, Heinke J, Kim H, Masaki Y, Satoh Y, Stacke T, Wada Y, Wissler D (2013) First look at changes in flood hazard in the inter-sectoral impact model Intercomparison project ensemble. *Proceedings of the National Academy of Sciences USA* 111:3257–3261
- Held IM, Soden BJ (2006) Robust responses of the hydrological cycle to global warming. *J Clim* 19:5686–5699
- IPCC (2013) Summary for policymakers. Fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge and New York
- Kendall MG (1962) Rank correlation methods. Hafner Publishing Company, New York
- Kunkel KE, Andsager K, Easterling DR (1999) Long-term trends in extreme precipitation events over the conterminous United States and Canada. *J Clim* 12:2515–2527
- Longobardi A, Buttafuoco G, Caloiero T, Coscarelli R (2016) Spatial and temporal distribution of precipitation in a Mediterranean area (southern Italy). *Environ Earth Sci* 75:1–20
- Mann HB (1945) Nonparametric tests against trend. *Econometrica* 13:245–259
- Min SK, Zhang X, Zwiers FW, Hegerl GC (2011) Human contribution to more-intense precipitation extremes. *Nature* 470:378–381
- O’Gorman PA, Schneider T (2009) The physical basis for increases in precipitation extremes in simulations of 21st century climate change. *Proceedings of the National Academy of Sciences USA* 106:14773–14777
- Osborn TJ, Hulme M, Jones PD, Basnett TA (2002) Observed trends in the daily intensity of United Kingdom precipitation. *Int J Climatol* 20:347–364
- Pall P, Allen MR, Stone DA (2006) Testing the Clausius–Clapeyron constraint on changes in extreme precipitation under CO₂ warming. *Clim Dynam* 28:351–363

- Plummer N, Salinger MJ, Nicholls N, Suppiah R, Hennessy KJ, Leighton RM, Trewin B, Page CM, Lough JM (1999) Changes in climate extremes over the Australian region and New Zealand during the twentieth century. *Clim Chang* 42:183–202
- Simolo C, Brunetti M, Maugeri M, Nanni T (2010) Improving estimation of missing values in daily precipitation series by a probability density function preserving approach. *Int J Climatol* 30:1564–1576
- Sirangelo B, Caloiero T, Coscarelli R, Ferrari E (2015) A stochastic model for the analysis of the temporal change of dry spells. *Stoch Env Res Risk A* 29:143–155
- Todeschini S (2012) Trends in long daily rainfall series of Lombardia (northern Italy) affecting urban stormwater control. *Int J Climatol* 32:900–919
- Toreti A, Naveau P, Zampieri M, Schindler A, Scoccimarro E, Xoplaki E, Dijkstra HA, Gualdi S, Luterbacher J (2013) Projections of global changes in precipitation extremes from Coupled Model Intercomparison Project Phase 5 models. *Geophys Res Lett* 40:4887–4892
- Trenberth KE (2011) Changes in precipitation with climate change. *Clim Res* 47:123–138
- Villarini G, Smith JA, Baeck ML, Vitolo R, Stephenson DB, Krajewski WF (2011) On the frequency of heavy rainfall for the Midwest of the United States. *J Hydrol* 400:103–120
- Wentz FJ, Ricciardulli L, Hilburn K, Mears C (2007) How much more rain will global warming bring? *Science* 317:233–235
- Westra S, Alexander LV, Zwiers FW (2013) Global increasing trends in annual maximum daily precipitation. *J Clim* 26:3904–3918
- Zhang X, Zwiers FW, Hegerl GC, Lambert FH, Gillett NP, Solomon S, Stott PA, Nozawa T (2007) Detection of human influence on twentieth-century precipitation trends. *Nature* 448:461–465