Analysis of rainfall trend in Calabria (southern Italy) by means of a gridded database

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Nowadays, trend analysis has been largely applied to identify the possible consequences of climate change in several hydrological temporal series around the world and especially, in major hotspots of climate change such as the Mediterranean Basin (Figure 1).

In this work, monthly rainfall series registered in the Calabria region (southern Italy) were first tested for homogeneity and then a trend analysis was performed. In particular, a homogenization approach based on the Climatol method was applied to homogenize monthly climatological series and to generate a gridded database. Then, the Mann–Kendall non-parametric test and the Theil–Sen estimator were applied to evaluate the presence of trends and their significance in the seasonal and annual rainfall series.

Figure 1. Mediterranean basin (source: https://news.mit.edu/2020/why-mediterranean-climate-change-hotspot-0617)

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The Calabria region is located at the toe of the Italian peninsula, at the center of the Mediterranean basin (between 37°54′ to 40°10′ N and 15°36′ to 17°13′ E). Due to its position, the Köppen–Geiger classification identifies the climate of the region as a warm temperate Mediterranean climate, thus presenting relatively mild winters (with rain) and dry, warm summers, with average temperatures higher than 22 °C. In Calabria, rainfall data have been collected since 1916 by the Multi-Risk Functional Center of the Regional Agency for Environment Protection. The data used in this study are a set of monthly rainfall series registered during the period of 1916–2017 and presenting less than 20% of lacking data. In particular, data from 79 stations, with an average density of one station per 190 km^2, were selected (Figure 2).

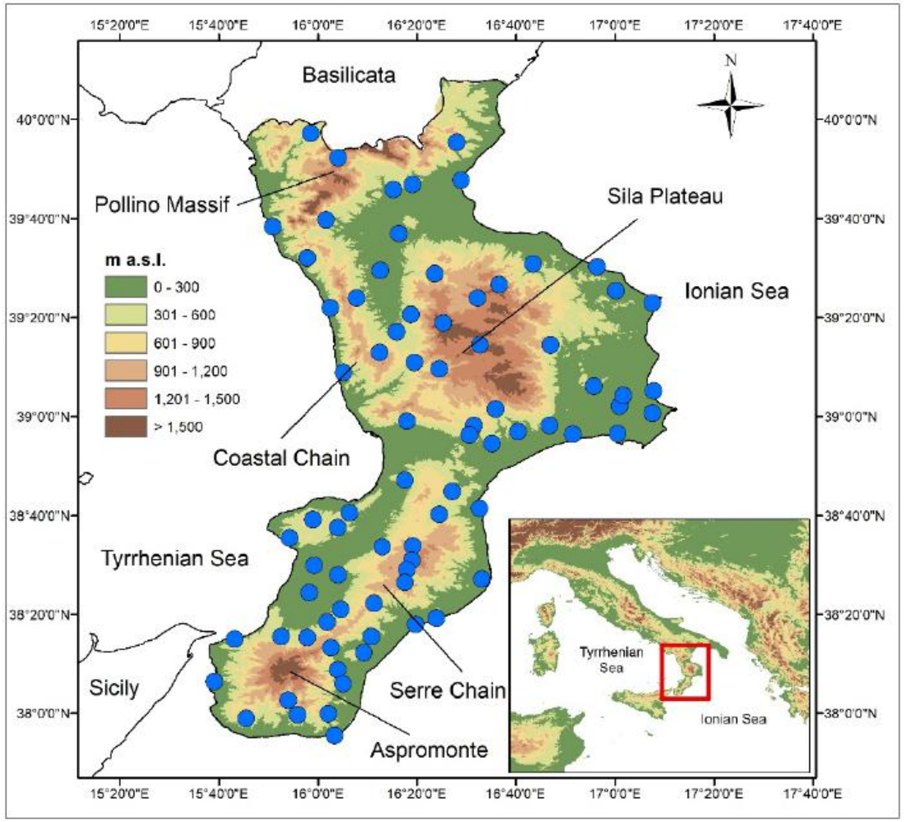

Figure 2. Localization of the rain gauges on a digital elevation model of the Calabria region

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Climatol

The Climatol has been developed under the R programming language. The R package comprises several functions which allow quality control, homogenization and infilling of the missing data in a dataset of a climatic variable. In particular, the homogenization approach developed in Climatol is based on the application of the well-known Standard Normal Homogeneity Test (SNHT) proposed by Alexandersson. In order to identify and remove inhomogeneities, in Climatol an iterative procedure is applied. First, the maximum SNHT test values and their locations for every series are identified. Then, when the SNHT values of the series are greater than a fixed threshold, the series is divided in the point corresponding to the maximum SNHT and all data before the break are moved to a new series, which is incorporated into the data pool with the same coordinates. After the first split of a series, the entire process is repeated dividing at every cycle only the series with the higher SNHT values, until no inhomogeneous series is found. Moreover, as the SNTH was originally developed to detect a single break-point in a series, the presence of more shifts in the mean could cover its results. In order to overcome this problem, in Climatol the SNTH is first applied to stepped overlapping temporal windows, and, then, it is applied to the complete series, where the test exhibits more power of detection.

Theil–Sen estimator

Given N pairs of data:

$$Q_i = \frac{x_j - x_k}{j\text{-}k} \qquad \text{for} \quad i = 1, \ldots, N, \qquad (1)$$

in which x_j and x_k are the data values at times j and k (with $j > k$), respectively.

If there is only one datum in each time period, then $N = n(n-1)/2$, where n is the number of time periods. If there are multiple observations in one or more time periods, then $N < n(n-1)/2$, where n is the total number of observations.

The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as:

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]} & \text{if } N \text{ is odd} \\ \dfrac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2} & \text{if } N \text{ is even} \end{cases}, \qquad (2)$$

The Q_{med} sign reflects data trend behavior, while its value indicates the steepness of the trend.

Mann-Kendall test

For a series with dimension n, the MK statistic is obtained as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i); \quad \text{with} \quad \operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if} \quad (x_j - x_i) > 0 \\ 0 & \text{if} \quad (x_j - x_i) = 0 \\ -1 & \text{if} \quad (x_j - x_i) < 0 \end{cases} \qquad (3)$$

where x_j and x_i are the data values at times j and i, with $j > i$.

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:

$$Var(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^{n} t_i \; i\,(i-1)(2i+5) \right] / 18 \qquad (4)$$

with t_i number of ties of extend i.

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

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & \text{for } S < 0 \end{cases} \qquad (5)$$

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

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At annual scale, a clear negative trend has been detected. In fact, more than 63% of the grid points showed a negative trend, while significant positive trends have not been identified. The negative trend of the annual rainfall is due to the negative trend detected in winter, with more than 60% of the grid points showing significant values. As regards spring, only few grid points showed significant trends (7%) and with opposite signs. In fact, in spring 6.7% of the grid points showed a negative trend and 0.3% a positive one. As opposed to the winter precipitation, the summer one showed a positive trend even though significant only for 27% of the grid points. Finally, in the autumn no marked trends have been detected, with 3.2% of the grid points showing a negative trend and zero grid point evidencing a positive one (Figure 3).

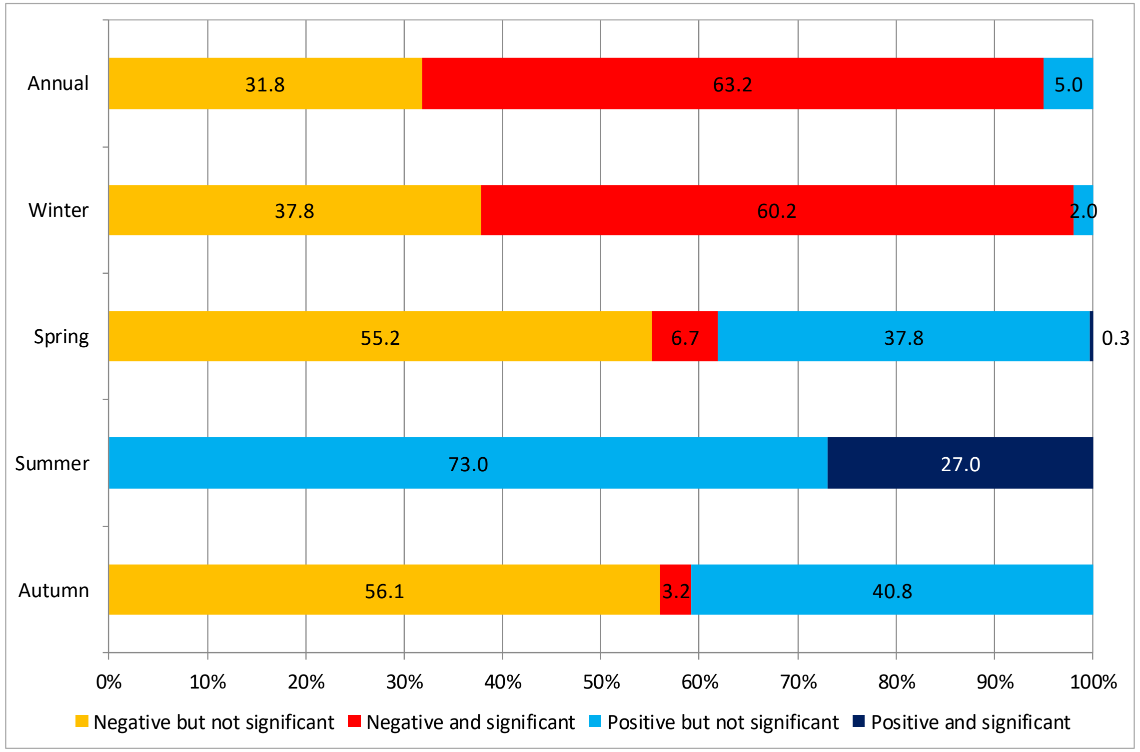

Figure 3. Trends of the seasonal and annual rainfall values expressed as percentage of grid points

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At annual scale, the negative trend is spatially distributed throughout the entire region and, in particular, along the Coastal Chain, the Serre Chain and the north-eastern side of the region, with slopes also lower than -20 mm/10yrs (Figure 4).

At seasonal scale, the spatial analysis of the winter trend evidenced a similar behavior as the annual one, with the negative trends mainly spreading across north-western part of the region and rates also lower than -20 mm/10yrs. In spring clear opposite trends (but often not significant) have been detected between the two sides of the region: a prevalent negative trend in the western side (with rates lower than in winter as absolute values) and a positive trend in the eastern side (with slopes higher than in winter). In summer, positive trends have been identified in the central and north-western areas of the region. Finally, in autumn, the spatial distribution of the trend evidenced negative trends identified in the western side of both the Sila Plateau and the Serre Chain.

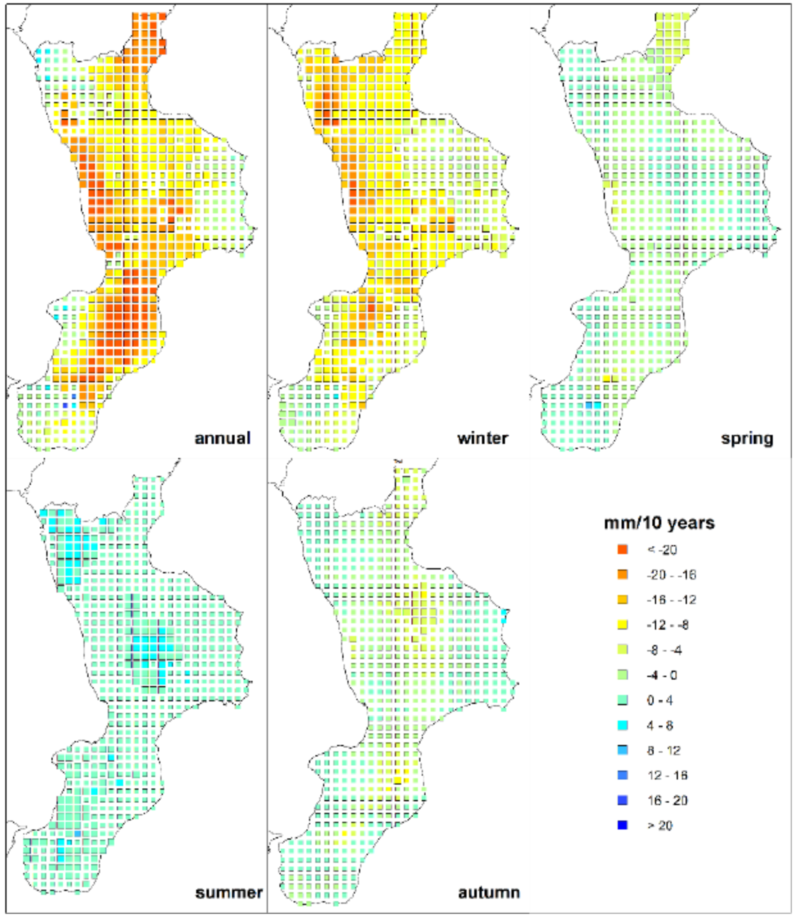

Figure 4. Gridded results of the trend analysis

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- The aim of this study was to create a reliable rainfall database for the analysis of the climate trend in the Calabria region (southern Italy), where the data collection started at the beginning of the past century and thus climatological series longer than 100 years are available.
- With this aim, monthly rainfall series have been first tested for homogeneity by applying the well-known Standard Normal Homogeneity Test. In particular, in this paper the Climatol package provided under the R programming language has been applied because this method, performing an iterative procedure, allows us to automatically identify and remove inhomogeneities from the series. Moreover, through the application of the Climatol package, the homogenized rainfall series have been gridded in order to obtain a rainfall spatial distribution across the Calabria region.
- After the Climatol procedure, in order to analyze possible trends in rainfall series the Theil-Sen estimator and the Mann–Kendall non-parametric test have then been applied.
- Results evidenced a reduction in the rainfall amount at annual scale, given by a reduction detected in winter, i.e. the rainy season in the Calabria seasons. Conversely, an increase in rainfall has been identified in summer, thus confirming past studies performed in other Italian regions which evidenced an increasing rainfall trend in the dry season and an opposite tendency in the wet season.

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