Article

Analysis of Dry Spells in Southern Italy (Calabria)

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Abstract: A deficit in precipitation may impact greatly on soil moisture, snowpack, stream flow, groundwater, and reservoir storage. Among the several approaches available to analyze this phenomenon, one of the most applied is the analysis of dry spells. In this paper, an investigation of the spatial and temporal patterns of dry spells, in a region of southern Italy, has been carried out on a daily precipitation dataset. First, the frequency distributions of the sequences of dry days have been analyzed. Then, the regional areas most affected by dry events have been evaluated at annual and seasonal scale. Finally, the long-term trend of the dry spells has been estimated at annual and seasonal scale. Results show that the lower probabilities of long dry spells occur in the main reliefs of the region, while the highest values have been detected in the Ionian side. The spatial distribution of the mean and maximum length values of the dry spells evidenced a west–east gradient. The trend analysis mainly revealed a negative behavior in the duration of the dry spells at annual scale and a positive trend in the winter period.

Keywords: dry spells; trend; Calabria

1. Introduction

Following the increase in anthropogenic greenhouse gas concentrations, numerous studies on climate change have detected an important tendency towards a global warming in the last decades [1], with changes in precipitation regimes [2,3] as well as in storm tracks [4,5]. Precipitation variability occurs over a wide range of temporal and spatial scales. Several studies conducted at global [6,7], regional [8,9], and sub-regional scales [10–12] have evidenced growing precipitation change at different timescales. In particular, yearly rainfall increments in Northern and Central Asia, in the eastern parts of North and South America, and in Northern Europe [13–15] have been detected. By contrast, other areas, such as the Mediterranean area, have shown a decrease in precipitation [16–20]. In southern Italy [21], and particularly in the Calabria region [22–27], different studies highlighted a decreasing trend in winter and autumn rainfall, and an increasing trend in spring and summer.

Research on the changing patterns of the regional and local-scale precipitation is very important for the assessment of hydrological consequences, such as flooding and droughts in the context of climate change. In particular, droughts are expected to become more frequent, as a result of the predicted modification of the hydrological cycle [28–31] and of the rainfall decrease observed in the Mediterranean basin, with severe consequences on agricultural yield losses and water shortages [32,33]. Moreover, dry conditions also damage natural ecosystems [34,35] and forestry [36,37] and lead to soil degradation and desertification [38,39], social alarm [40], and famine and impoverishment [41,42]. Usually, drought indices are useful for monitoring and assessing these phenomena since they facilitate communication of climate anomalies to diverse user audiences; they also allow scientists to assess quantitatively climate anomalies in terms of their intensity, duration, frequency, recurrence probability and spatial extent [43,44]. However, among the several approaches available to analyze this phenomenon, one of the most applied is the analysis of dry spells. A dry spell is defined as the number of consecutive days with a daily precipitation amount below a certain threshold, such as 0.1, 1, 5, 10 mm, preceded and followed by at least one day with rainfall exceeding the threshold [45,46]. In the last decades, numerous analyses related to dry spell lengths have been applied in different areas, such as North [47] and South America [48,49], Asia [50–52], Europe [53–56], the Mediterranean basin [57–59], and Italy [60,61]. In particular, the results obtained by the authors of [57] indicated an increase in the mean and largest dry periods over a great part of the Iberian Peninsula, with a south-north gradient. In Greece, The authors of [58] evidenced high values of consecutive dry days in the Cyclades Islands and the southeastern Aegean Sea, while minimum values were found in the northwestern Greece. The authors of [59] divided Croatia into three main climatological regions: the highlands with the shortest dry spells, the coastal region with the longest dry spells, and the mainland with intermediate values. Furthermore, the authors of [59] evidenced a prevailing positive trend of both mean and maximal durations during winter and spring seasons and a negative trend in autumn. In Italy, the analysis of drought trends, performed by an index estimating the proportion of dry days in each season, showed a remarkable increase in winter droughts [60]. Moreover, with regards to long dry spells, in few rain gauges in the Calabria region, the authors of [61] evidenced greater probabilities to observe a dry spell in 1981–2010 than in 1951–1980.

The aim of this study is to analyze the spatial patterns and temporal variability of dry spells in a region of southern Italy (Calabria). In particular, the main objectives of this paper are:

(i)   the spatial analysis of the frequency distributions of the sequences of dry days;

(ii) the evaluation, at annual and seasonal scale, of the regional areas most affected by dry events; and

(iii) the estimation, at annual and seasonal scale, of the long-term trend of the dry spells.

2. Materials and Methods

Calabria is a region of Southern Italy with an area of 15,080 km^2; its mean altitude is 597 m a.s.l. and its maximum elevation is 2266 m a.s.l. Although there are not many high summits in the region, it can be considered as one of the most mountainous in Italy. In fact, 42% of the land is mountainous (elevation greater than 500 m a.s.l.), 49% hilly (elevation between 50 and 500 m a.s.l.) and only 9% has an elevation lower than 50 m a.s.l. (Figure 1).
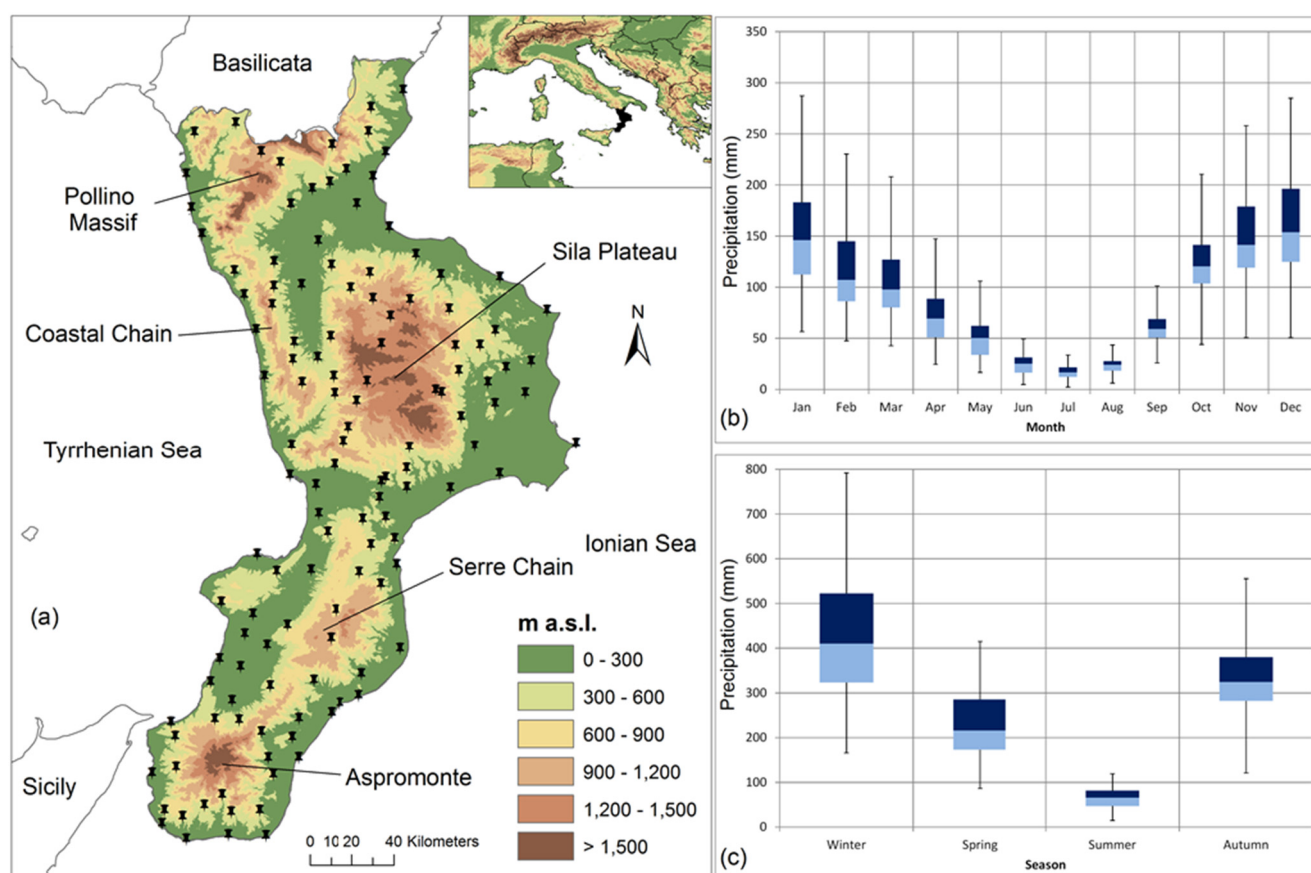

Figure 1. (**a**) Location of the selected stations on a Digital Elevation Model (DEM) of Calabria; (**b**) regional monthly precipitation distribution; and (**c**) regional seasonal precipitation distribution.

The Mediterranean climate characterizes this area. The region has high climatic contrasts, due to its geographic position and mountainous nature. Particularly, the Ionian side is influenced by warm air currents coming from Africa and high temperatures, with short and heavy rainfalls. Since the Tyrrhenian side is influenced by western air currents, it presents milder temperatures and mainly orographic precipitation. In the inland zones, colder winters with snow, and cooler summers with some precipitation are observed [62].

The starting data used in this study were a set of daily precipitation series for the period 1916–2006, registered in Calabria and collected by the former Italian Hydrographic Service, now *Centro Funzionale Multirischi of Regione Calabria.* Particular attention has been given to the problems deriving from the inhomogeneities of the data series and from the lack of data and the final database used in this study was the one presented in [24]. In order to remove inhomogeneities, the Craddock test [63] has been used. In particular, 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 [63], in sub-groups of ten series. The estimation of the missing data was performed by exploiting a two-step procedure, proposed by [64], which preserves both the correct event time location (wet/dry days) and the statistical properties of daily precipitation series. At the end of the data processing, a total of 129 daily rainfall series were available for the analysis (Figure 1). With the aim to allow an analysis of rainfall series with equal length and pertaining to the same period, only the period 1941–2006 has been considered.

In the analyses of dry spells, various statistical indicators have been used by different authors. Among these, the most common indicators used are the mean and the maximum length of dry spell [65]. In this paper, for each of the 129 daily rainfall series, the dry spells have been detected and the mean length of dry spell and maximum length of dry spells have been evaluated. The term dry spell of length *n* days is defined as a succession of n consecutive days below a certain threshold of rain, preceded and followed by days with rain. The authors of [66] used the daily rainfalls of 0.1 and 1 mm to see whether threshold values influence dry spell distributions. The authors of [67] emphasized that using the 10 mm threshold eliminates situations where a few isolated rainy days with small precipitation volumes can break an otherwise long dry spell. The authors of [68,69] also used a 5 mm threshold. In the present study, a day without rain has been considered as one in which the record registers a precipitation amount below a threshold of 0.1 mm and the occurrence of each dry spell has been ascribed to the last day of the sequence. Moreover, the meteorological year was considered, since there is a high probability to have rainy days at the end or at the beginning of each year, due to the climate characteristics of the study area.

In order to determine the possible existence of temporal tendencies in the maximum duration of the dry spells, annual and seasonal series were analyzed for trends, and their statistical significance assessed with the Mann–Kendall (MK) non-parametric test [70,71]. The slopes of the trends were calculated by least square linear fitting. The MK test is a rank-based method for evaluating the presence of trends in time-series data, without specifying whether the trend is linear or non-linear. The data are ranked according to time, and then each data point is compared to all the data points that follow in time. The MK statistic [71] is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right)$$

(1)

where *x* are the data value at times *i* and *j*, *n* is the length of the data set and sgn(*z*) is equal to +1, 0, and −1 when *z* is greater than, equal to, or less than zero, respectively. Under the null hypothesis that x_i are independent and randomly ordered, for *n* greater than 8, the statistic *S* is approximately normally distributed with zero mean and variance:

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

where t_i denotes the number of tied values of extent i.

The standardized test statistic Z, computed by:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{\text{Var}(S)}} & \text{for } S > 0 \\[2mm] 0 & \text{for } S = 0 \\[2mm] \dfrac{S+1}{\sqrt{\text{Var}(S)}} & \text{for } S < 0 \end{cases} \tag{3}$$

follows a standard normal distribution [71].

The probability value, *p*, of the Z_{MK} statistic of sample data can be estimated using the normal cumulative distribution function $\Phi(Z_{MK})$:

$$\text{p} = 1 - \Phi(Z_{MK}) = 1 - \frac{1}{\sqrt{2\pi}} \int_0^{Z_{MK}} e^{-t^2/2}\, dt \tag{4}$$

At the significance level α, the existing trend is considered to be statistically significant if $p \leq \alpha/2$ in the case of the two-tailed test.

The presence of a serial correlation in the hydrological time series changes the rate of rejecting the null hypothesis of no trend [72]. It particularly alters the variance of the MK statistic, whereas it does not alter its mean and its distribution type [73], thus leading to a disproportionate rejection of the null hypothesis of no trend when it is true. In order to avoid such error, the serial correlation/lag−1 correlation needs to be checked in the datasets before applying the non-parametric MK test. Usually, to reduce the influence the serial correlation, the pre-whitening procedure suggested by [74] is applied:

$$Y_t = X_t - r_1 \cdot X_{t-1} \tag{5}$$

where Y_t is the pre-whitened series, Y_t is the sample series and r_1 is the lag−1 serial correlation coefficient of the sample data, that can be expressed as:

$$r_1 = \frac{\dfrac{1}{n-1}\sum_{t=1}^{n-1}[X_t - E(X_t)][X_{t+1} - E(X_t)]}{\dfrac{1}{n}\sum_{t=1}^{n}[X_t - E(X_t)]^2} \tag{6}$$

where $E(X_t)$ is the mean of the sample data. The authors of [74] demonstrated that pre-whitening operation is not necessary for $r_1 \leq 0.1$.

3. Results and Discussion

3.1. Characteristics of Dry Spell

With the aim to analyze the probability distribution of the dry spell durations, the 90th, 95th and 99th percentile of each series have been identified and mapped (Figure 2).

As expected, the distribution of the dry spells is strictly related to the orography and to the climatic characteristics of the region. In fact, as [75] found out, orography influences the rainfall amount and its distribution over the region, thus explaining the different values between the two seacoasts of Calabria. The authors of [75] also showed that the interaction between orography and the mesoscale circulations leads to a precipitation gradient between the Tyrrhenian and Ionian sides of the Calabrian peninsula. As a result, the areas with the lowest percentile, which means lower probabilities of long dry spells, have been identified in the main reliefs of the region, and particularly in the Pollino Massif (18 and 33 days for 95th and 99th percentiles, respectively) and in the Serre Chain (12 and 18 days for 90th and 95th percentiles, respectively). Conversely, on the Ionian side of the region, which is characterized by short and heavy rainfalls, the highest values have been detected (22, 35 and 93 days for 90th, 95th and 99th percentiles, respectively). On the Tyrrhenian side, which is mainly affected by orographic precipitation, only small areas have shown high values, but always lower than the ones detected on the Ionian side.
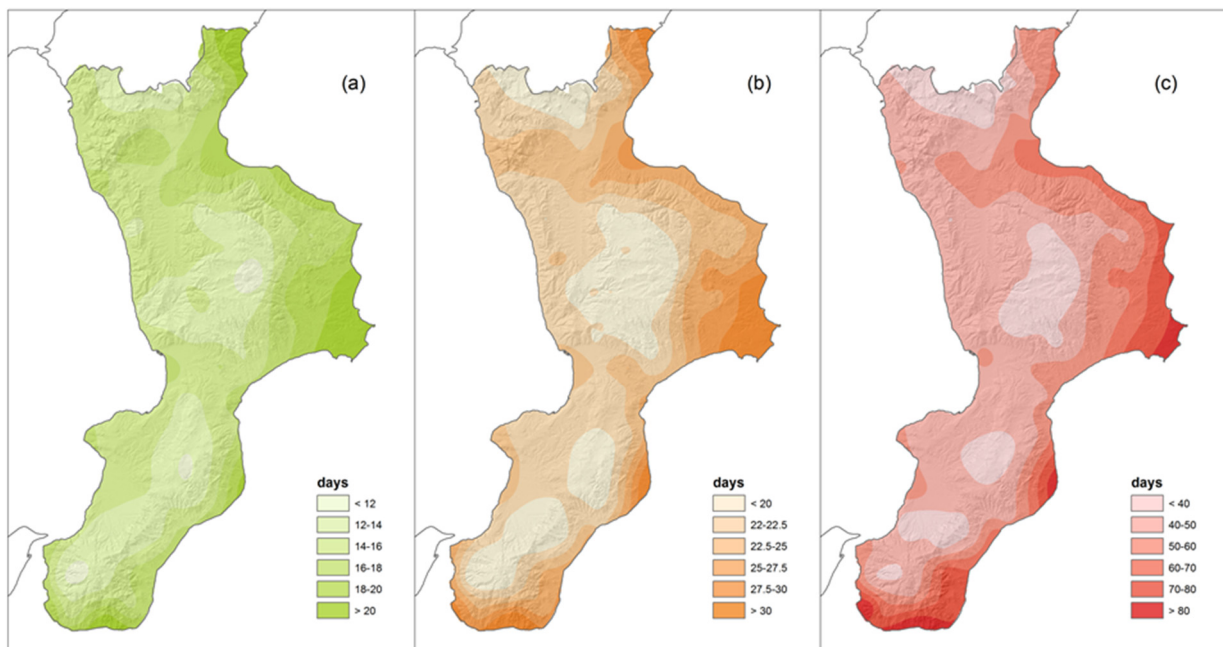

Figure 2. Spatial distributions of the (**a**) 90th; (**b**) 95th and (**c**) 99th percentiles of the dry spell durations.

3.2. Average and Maximum Lengths of Dry Spells

The yearly average and the maximum length of the dry spells are presented in Figure 3. By observing the spatial distribution of the mean length values on the Calabria region (Figure 3a), the study area can be divided in two parts: the western side of the region with mean values ranging between six and eight days, and the eastern side with the highest mean values (between eight and ten days). The lowest mean values (between four and six days) have been detected in the Sila Plateau, in the Serre Chain and in Aspromonte. These results confirm the ones obtained by [76], which identified an east-west gradient in the daily rainfall distribution, with a high rainfall concentration in the eastern side of the region, and a more homogenous temporal distribution of the rainfall in the western side.

As the authors of [48] evidenced, the maximum length of dry spells is an extreme and instability property but its analysis may reveal interesting results (Figure 3b). The most notable effects of the maximum length analysis are the confirmation of the west–east gradient and, moreover, the identification of the highest values (more than 200 days) in the plain areas of the region. In fact, these areas are the most economically important agricultural areas of the region, and long dry periods can be quite harmful to crops because of water or moisture shortage.
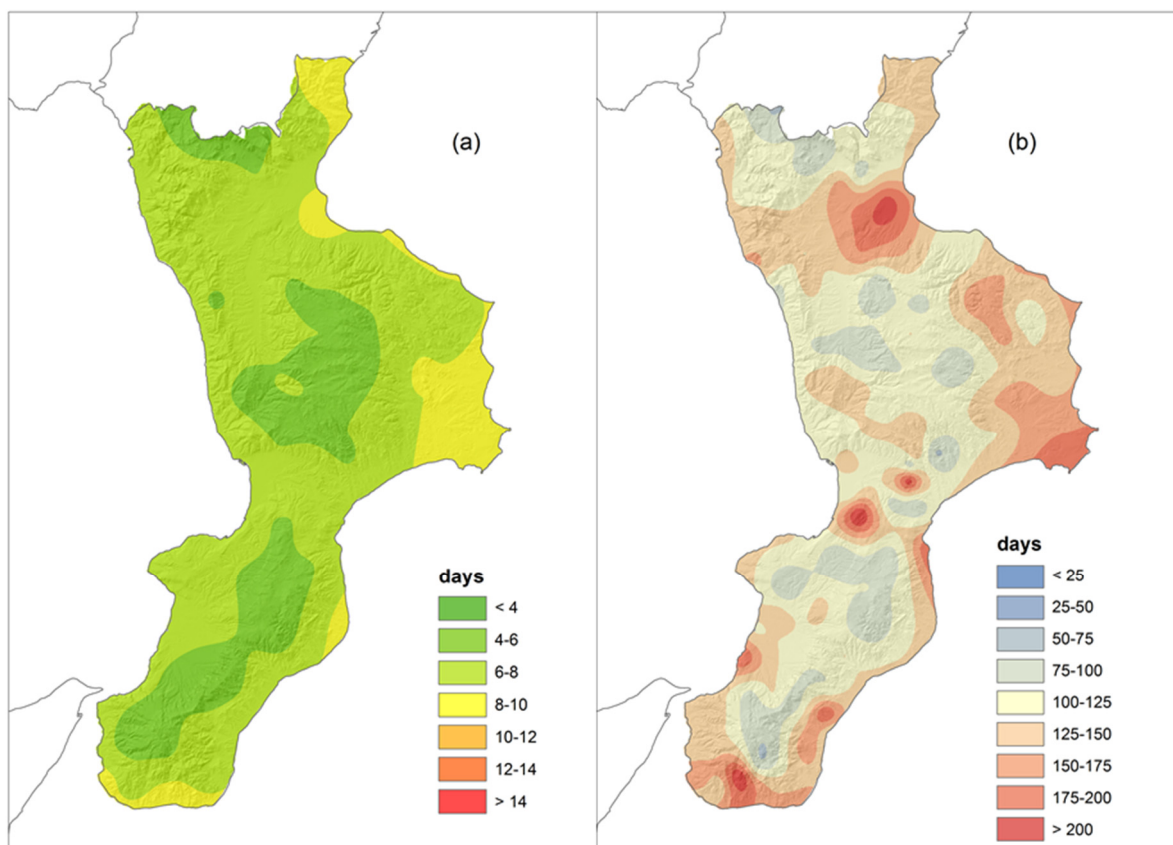

Figure 3. (**a**) Yearly mean and (**b**) maximum length of the dry spells in the observation period.

As to what concerns the mean length of the dry spells on a seasonal basis, the annual pattern is mainly reflected in autumn (Figure 4d), but with higher values. In fact, in autumn the west–east gradient is confirmed (ranging from five to twelve days), together with the lowest values detected in the Sila Plateau, in Aspromonte and particularly in the Serre Chain. By contrast, due to the Mediterranean climate, which is characterized by high rainfall in winter (Figure 1), in this period there is not such a difference between the two sides of the region (Figure 4a). In spring, the region can be divided in two areas, the coastal Ionian and southern Tyrrhenian areas with the highest mean dry spells durations (about nine days), and the central and northern Tyrrhenian area with the lowest ones (about nine days) (Figure 4b). In summer, when precipitation is less frequent (Figure 1), the highest average values among the different seasons have been detected. In particular, almost the entire region showed dry spells longer than 14 days (up to about thirty days in the most southern part of the region), with the exception of the mountainous areas, which presented values ranging between eight days, in the higher summits of the Sila Plateau and of the Pollino Massif, and 14 days for lower elevations.
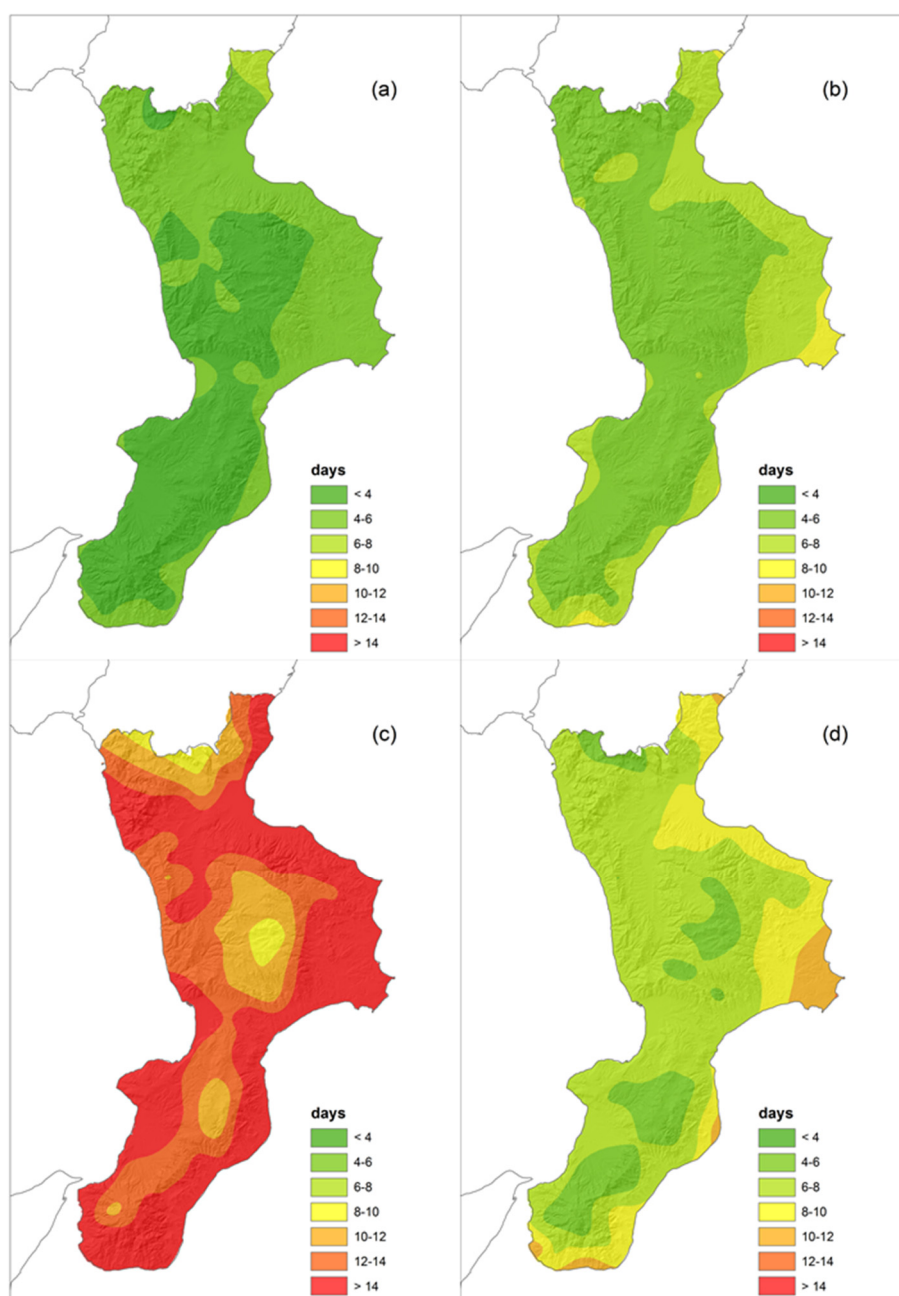
Figure 4. Mean length of the dry spells on a seasonal basis, (**a**) winter; (**b**) spring; (**c**) summer and (**d**) autumn.

With regards to the maximum length of the dry spells, it is interesting to note that the spatial patterns only partially reflect the behavior showed by the mean spells. In particular, the spatial distribution of the maximum length of the dry spells in autumn (Figure 5d) is very similar to the one obtained for the annual time scale (Figure 3b). In fact, both the west–east gradient and the highest values (more than 200 days) in the plain areas of the region have been detected. A more homogeneous distribution of the maximum values has been detected in winter, with the exception of three rain gauges, which showed lengths of 191, 195 and 221 days in the years 1943, 2003 and 2001, respectively (Figure 5a). In this paper, particular attention was paid to problems resulting from inhomogeneities of the data series and, in order to avoid possible errors, the rainfall series of these rain gauges have been checked again, but no errors have been detected. Similarly to winter, in spring a

homogeneous spatial distribution of the maximum length of the dry spells have been evaluated, with the highest values in the plain areas of the region till a maximum of 134 days (Figure 5b). Finally, as for the average spring values, in summer the region can be divided in two areas, the coastal Ionian and southern Tyrrhenian area with the highest maximum dry spells (166 days), and the central and northern Tyrrhenian area with the lowest one (Figure 5c).
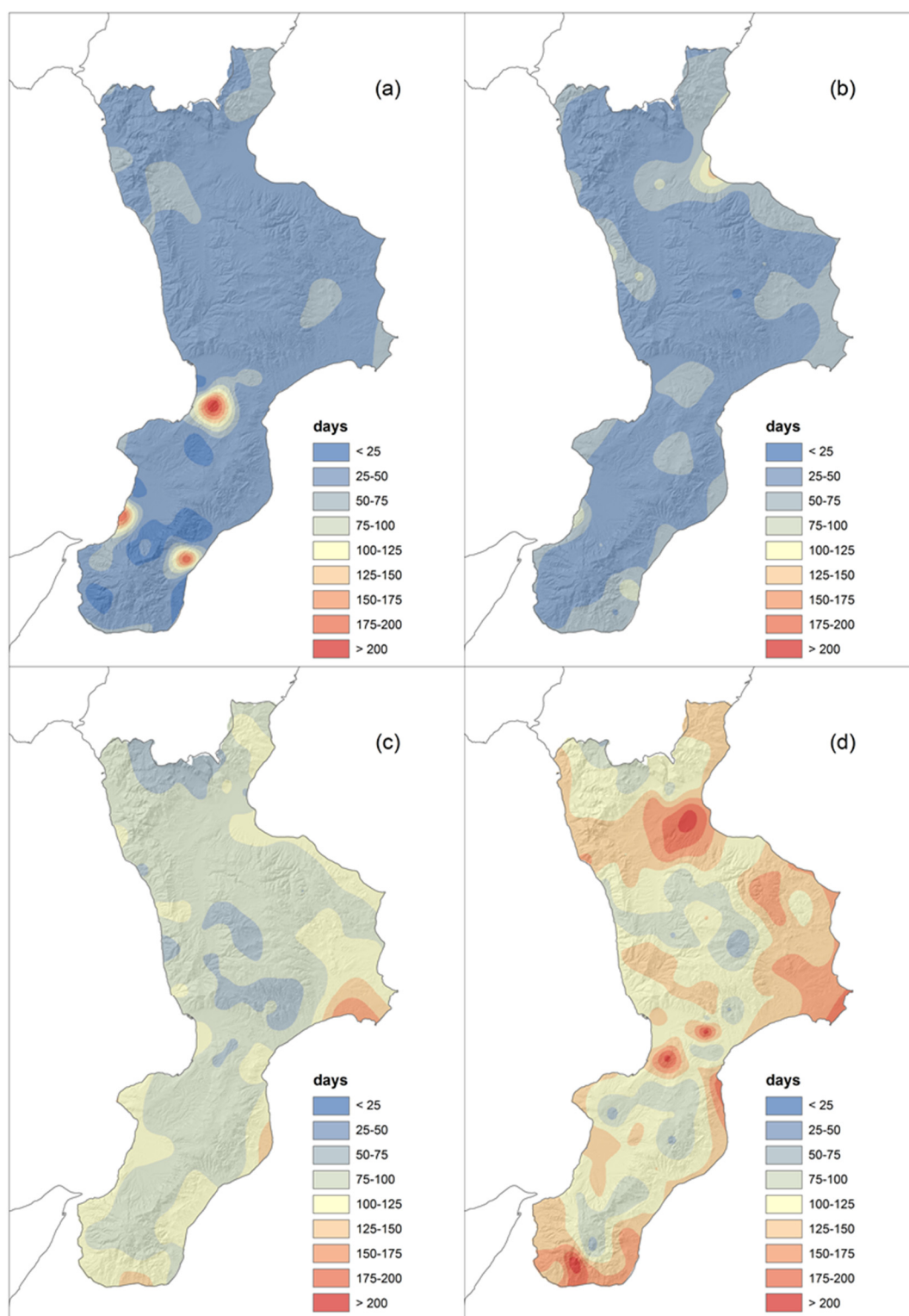

Figure 5. Maximum length of the dry spells on a seasonal basis: (**a**) winter; (**b**) spring; (**c**) summer and (**d**) autumn.

3.3. Temporal Variability of the Dry Spell Lengths

Most of the dry spell series presented serial correlations in data, especially in winter. For this reason, the non-parametric MK test has been applied to annual and seasonal dry spell values after pre-whitening of the data through the von Storch's procedure [74].

The trend analysis of the maximum annual values evidenced a reduction of the length of the dry spells (21.1% of the rain gauges), which mainly involves the hills and valleys of the region (with a maximum reduction of about −2 days/10 years), while no significant trend has been detected on the mountain (Figure 6a). With regards to seasonal precipitation, a significant trend cannot be identified for all the season; however, a significant negative trend has been detected in summer (Figure 6d) with a maximum reduction of more than −2 days/10 years.
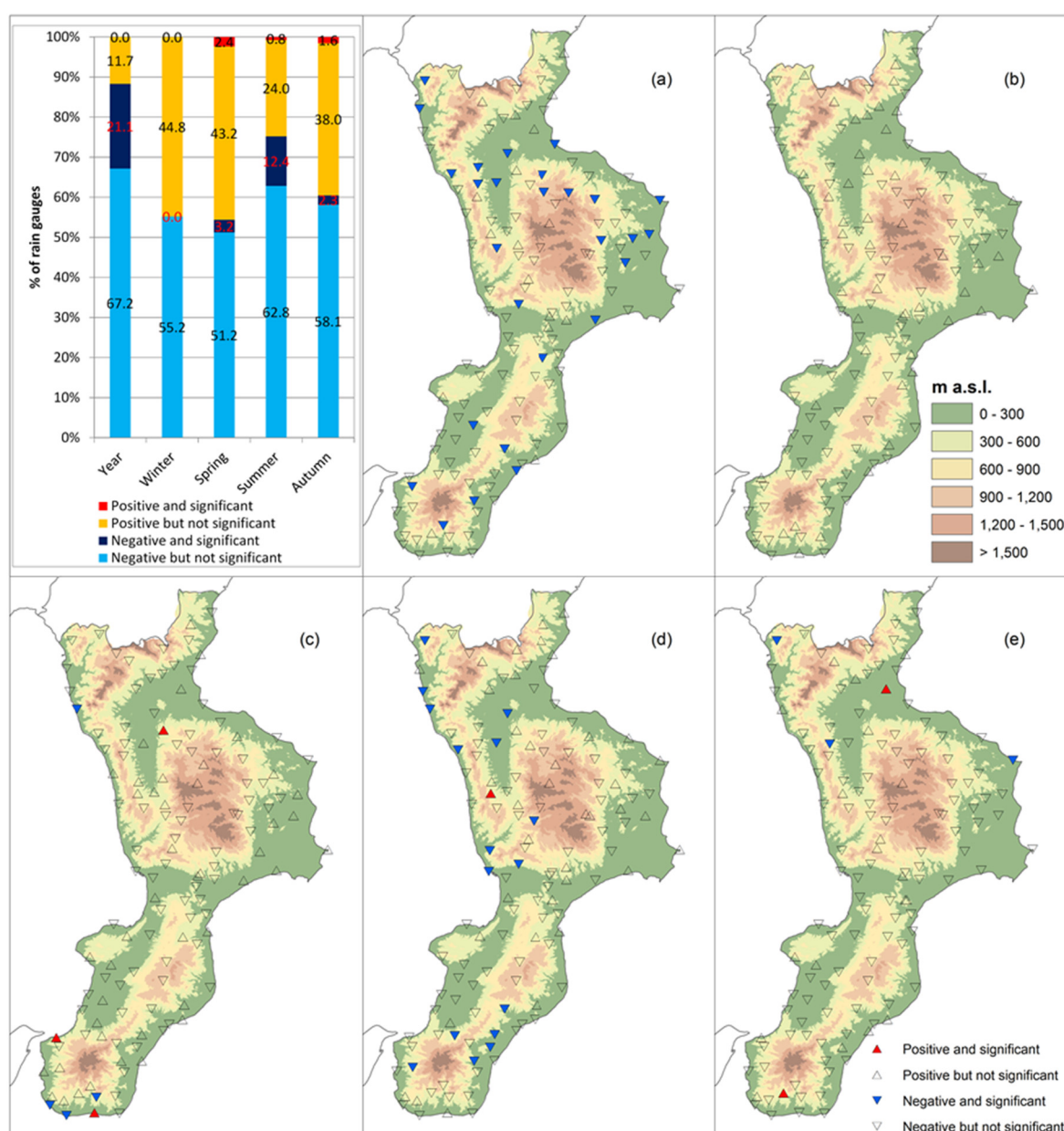

Figure 6. Summary and spatial distribution of the trend analysis on dry spell durations at (**a**) annual and seasonal scale: (**b**) winter; (**c**) spring; (**d**) summer and (**e**) autumn.

These results disagree with other studies in the Mediterranean region, which evidenced an increase in the mean and largest dry periods [57,59]. However, the temporal behavior of the dry spells confirms other studies on rainfall in Calabria [23,27], which evidenced a decreasing trend for autumn-winter rainfall and an increasing trend in summer.

4. Conclusions

Investigating dry periods is useful in drought prediction for agricultural and environmental planning and management [54]. In this paper, the spatial and temporal patterns of dry spells in Calabria (southern Italy) have been analyzed using a daily precipitation dataset, formed by 129 rainfall series collected in the period 1941–2006. First, the frequency distribution of the dry spell lengths has been analyzed, and the higher percentile values have been mapped. As a result, a correspondence between the orography and the distribution of the dry spells has been detected: the highest values have been observed on the coastal areas, whereas the lowest ones have been found on the mountains.

Then, the maximum and the mean values of the dry spell lengths, both at annual and seasonal scale, have been evaluated and spatially distributed, evidencing a west–east gradient. In particular, lower lengths of dry spells have been observed in the main reliefs of the region, while the highest values have been detected on the Ionian side. Finally, the long-term trend of the dry spell lengths has been estimated. The results mainly revealed a negative behavior of the dry spell lengths at annual scale. If confirmed, these results could impact on the management of water resources (reservoirs and ground surface waters).

Author Contributions

The authors contributed equally to this work.

Conflicts of Interest

The authors declare no conflict of interest.

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