Long-Term Climatic Variability in Calabria and Effects on Drought and Agrometeorological Parameters

A. Capra · S. Consoli · B. Scicolone

Abstract In recent decades a general change in climate has been documented in several locations over the world. Such changes could have significant effects on various environmental scenarios, including water resource management, agriculture, hydrology and ecosystems. The complex topography and coastlines of Mediterranean regions influences the climatic regime exhibiting substantial fine-scale spatial variability. In Italy, the climate is generally becoming warmer and drier, with quite large differences depending on the site and data treatment. In this study a historical set of meteorological data (110 precipitation and 28 temperature series), collected over 1921–2007 in the Calabria region (Southern Italy) was analysed. Several meteorological and agrometeorological indices were selected for whether they could evaluate the potential effects of climate change on water availability for natural vegetation and cultivated plants. The significance of the analysed time series (monthly, seasonal and annual time scales) was evaluated by using statistical trend analysis (Mann-Kendall and t-test). Moreover, the intensities of drought events were determined using the Standardized Precipitation Index (SPI) for the time scales of 3 and 6 months. The analysis highlighted a general decrease in annual precipitation and an increase in drought intensity. At a regional level, yearly precipitation decreased by almost 318 mm/100 years (representing almost 30 % of the yearly mean precipitation in the region). Temperature changes were more complex. On a regional scale, yearly mean minimum temperatures increased by 0.9 °C/100 years and maximum and mean temperatures decreased by 1 °C/100 years and 0.8 °C/100 years, respectively. Due to the asymmetric behaviour of temperatures, there was a decreasing impact on evapotranspiration.

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1 Introduction

During the last decade, climate change has aroused international attention due to concerns of negative impacts on ecosystems, agriculture, water supply and management, human welfare and regional political stability (Estrela and Vargas, 2012). The global situation is well described by the Fourth IPCC assessment report (IPCC et al. 2007), which in particular cites global mean temperatures as having risen approximately by 0.74 °C in the last 100 years. The majority of this warming has occurred since 1950, most likely due to increasing greenhouse gas concentrations to unprecedented levels in recent history (Chavas et al. 2009). Global climate models (GCMs) predict temperature increases of 1.1-6.4 °C over 1990–2100 (IPCC et al. 2007). Due to the great influence of temperature on evapotranspiration and precipitation for soil water availability and drought events, climate change might have an immediate, direct effect on vegetation and crop productivity and, therefore, on the related net income for farmers (Mooney et al. 2001; Harriet and Allen 2003; Maracchi et al. 2005; Cha et al. 2012; Raziei et al. 2012).

As emphasized by Gao and Giorgi (2008), the complex topography and coastlines characterising the Mediterranean Region are expected to modulate the climate change signal and, as a result, shifts in climate regimes might exhibit substantial fine-scale spatial variability. Moreover, the resolution of GCMs is approximately 2° latitude and 2° longitude, which leads to problems in understanding and predicting small-scale and regional precipitation changes (Logan et al. 2010).

In Italy, various authors have reported a decreasing trend in precipitation and an increasing trend in temperatures, with quite large differences depending on the site and data treatment. Linear regression coefficients (b) and often their trends (positive or negative), have pointed to high variability within the numerous climatic scenarios of the country. According to Brunetti et al. (2000), over 1865–2000, the mean annual temperature ($T_{m,a}$) increased by 0.4 °C/100 years in Northern areas (N) (continental zone) and by 0.7 °C/100 years in Central (C) and Southern (S) parts (peninsular zones). There was a negative trend of annual rainfall (P_a) in both N and S areas with slopes of −47 mm/100 years and −104 mm/100 years, respectively (Brunetti et al. 2004). These trends were evident after 1950, when the number of wet days decreased significantly (Capra et al. 2004, 2006). Moonen et al. (2002) adopted some agrometeorological parameters related to extreme events which had occurred in Tuscany (Central Italy) to demonstrate that the extremely cold/warm temperature events have remained unchanged and the number of frost days per year has decreased significantly. Todisco and Vergni (2008) have pointed to increasing trends in crop water requirements when high positive trends in evapotranspiration and negative trends in precipitation occurred at the same time in the Region of Umbria (Central Italy). Extreme events had different tendencies, corresponding to increases in rainfall intensity in both N and S areas and in drought conditions (Moonen et al. 2002; Brunetti et al. 2004; Bonaccorso et al. 2003). During the last decades of the 20th century, southern Italy was affected by long-lasting, intense and severe droughts (Capra et al. 1992, 1994, 2005). This tendency was also reported by Cancelliere and Rossi (2003); Mendicino and Versace (2007) in their study on Mediterranean areas. The authors pointed out extremely intense drought phenomena over 1996–2002 in Mediterranean regions, characterized by a reduction in precipitation together with higher evapotranspiration values and a decrease in surface and groundwater runoff.

Brunetti et al. (2004) highlighted that throughout Italy, especially in the North, there has been a systematic increase in winter droughts, most likely due to the very dry 1987–93 period. Abdulla et al. (2009) assessed that climate warming, with a maximum of 3.5 °C increase in temperature can dramatically impact runoff and groundwater recharge in Jordan . The warming impact can be greatly influenced by significant changes in rainfall volumes.

Different results on climate trends were obtained for smaller sub-regions of Italy as reported by Capra et al. (1992, 1994, 2006), Capra and Pavanelli (2010). These studies highlighted that temperature, precipitation and drought trends were influenced by whether the exposure of the study area was on the Tyrrhenian or Ionian side. Therefore, climate change studies at a regional level also account for geographical factors (e.g. distance from the sea, elevation, exposure).

These results suggest that in Italy climate change analysis at a mesoscale level (100–150 km) are unsuitable due to the high variety of topographic and geographical features of the country.

Therefore, an 87-year data series (1921–2007) was analysed to interpret conditions in the Calabria region (Italy) by using data from 110 rain-gauge and 25 thermometric stations. The study evaluated the trends of meteorological and agrometeorological indices computed at different sites. Changes in droughts were also analysed by the Standardized Precipitation Index (SPI).

## 2 Materials and Method

2.1 Study Area and Data Set

Climate changes in the Calabria region were investigated at regional and sub-regional levels and for geographic and orographic variability in each area. The region is a long narrow peninsula extending for about 250 km North to South located in Southern Italy (Fig. 1). A mountain range (the Apennines) running perpendicularly to the dominant moisture-bearing wind direction, causes strong rainfall and temperature variability dividing the region into two different areas: the Tyrrhenian and Ionian (Capra et al. 2004, 2006). Thus, flat semi-arid coastal areas are typical (annual mean temperature $T_{m,a}$ and precipitation P_a equal to 17.4 °C and 683 mm respectively) as well as mountain areas with $T_{m,a}$ equal to 9.1 °C and P_a equal to 1,242 mm (the highest in southern Italy). The mean yearly precipitation is 1,069 mm at the regional level, but 1,193 mm in the Tyrrhenian (*CaT*) and 1,058 mm in the Ionian (*CaI*) sub-regions.

The region is mainly hilly. The highest mountains rise to 2,200 m in the northern part of the region. In many areas the mountains are very close to the sea. The environment has large naturally wooded areas, with the exception of the coastal zones. The potential natural forests differ according to altitude. The different vegetation belts follow the different altitude belts, ranging from those typical of hot, dry climates to those typical of cool, humid climates. Agriculture context of in the region is characterized by orchards and herbaceous crops.

Meteorological parameters were derived from the time series of classical climatic data, precipitation and temperature, recorded by the Italian Hydrographic Service (IHS) at, respectively, 323 rain-gauge stations and 58 thermometric stations over 1921–2007. The analysis was carried out on data selected on the basis of data set continuity, geographic and altitude representativeness from meteorological stations (located in the region or along its northern border); stations lacking more than 20 % data were disregarded. There were 110 stations selected for precipitation and 25 for temperature (Fig. 1).

The data published by the IHS was considered to be of reasonably good quality. Therefore, a simple method was used to further quality-control these data; in particular, a

Fig. 1 Calabria Region and meteorological stations used in the study
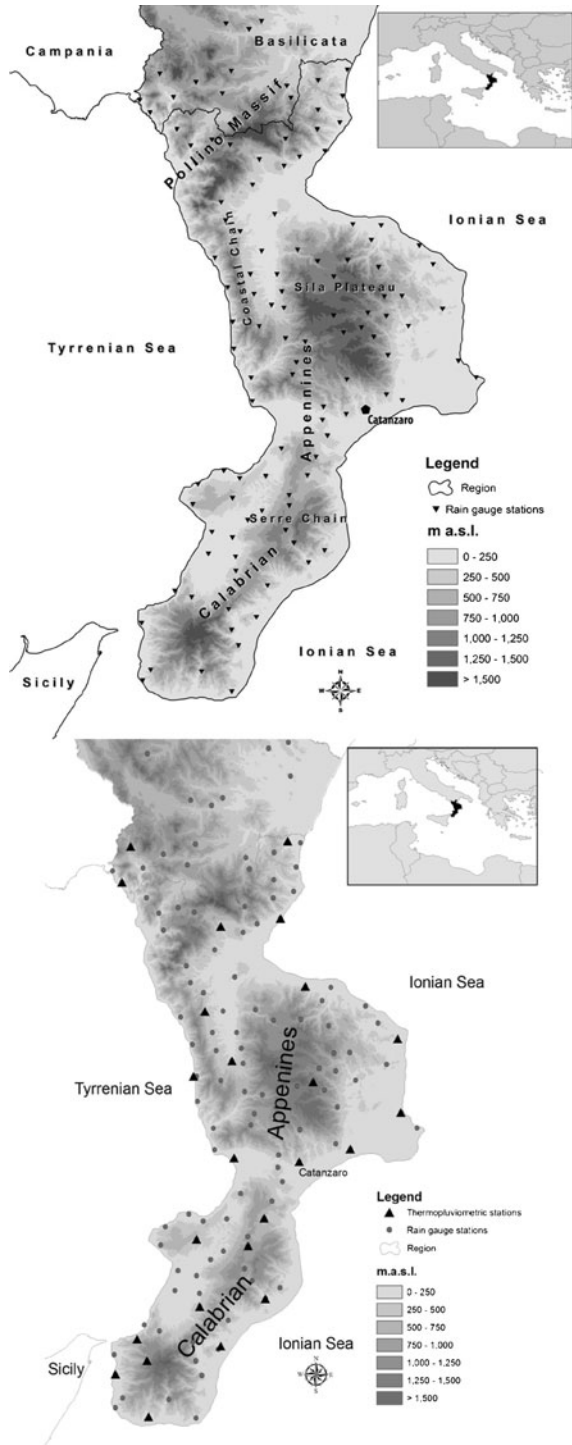
theoretical extreme value for each site and time period was identified using the *t*-test at a probability level $P \leq 0.05$, then the suspected data was compared with corresponding values of at least six surrounding stations (Estévez et al. 2011). The suspected data was maintained in the dataset if similar values occurred in the same month and year in a number of surrounding stations ≥ 4, to avoid reducing the number of extreme values in the series. Temporal gaps were filled using linear regressions with the series showing higher correlation coefficients.

2.2 Meteorological and Agrometeorological Parameters

To account for the potential effects of climate change on natural vegetation and agricultural water requirements, a set of agrometeorological parameters was defined (Table 1). Comparisons between the results of the trend analysis of the meteorological and agrometeorological parameters helped evaluate the effect of climate change on forests and agriculture. The agrometeorological parameters were reference evapotranspiration and precipitation surplus.

For each month, daily reference evapotranspiration was calculated with the Hargreaves-Samani equation (Droogers and Allen 2002):

$$ET_0 = 0,0013 \cdot R_a \cdot (T_m + 17) \cdot [(T_{max} - T_{min}) - 0,0123 \cdot P]^{0,76} \tag{1}$$

Table 1 Meteorological and agrometeorological variables used for the trend analysis

Meteorological variables	Abbreviation	Units
Annual rainfall	P_a	(mm)
Monthly rainfall	P_m	(mm)
Seasonal rainfall (1st, 2nd, 3rd and 4th quarter)	P_1, P_2, P_3, P_4	(mm)
Rain falling in the average dry period	P_{dry}	(mm)
Rain falling in the average wet period	P_{wet}	(mm)
Annual mean minimum temperature	$T_{min, a}$	(°C)
Annual mean maximum temperature	$T_{max, a}$	(°C)
Annual mean temperature	$T_{m, a}$	(°C)
Monthly mean minimum temperature	$T_{min, m}$	(°C)
Monthly mean maximum temperature	$T_{man, m}$	(°C)
Monthly mean temperature	$T_{m, m}$	(°C)
Seasonal mean minimum temperature (1st, 2nd, 3rd and 4th quarter)	$T_{min,1}, T_{min,2}, T_{min,3}, T_{min,4}$	(mm)
Seasonal mean maximum temperature (1st, 2nd, 3rd and 4th quarter)	$T_{max,1}, T_{max,2}, T_{max,3}, T_{max,4}$	(mm)
Mean minimum temperature in the average dry period	$T_{min,dry}$	(°C)
Mean minimum temperature in the average wet period	$T_{min,wet}$	(°C)
Mean maximum temperature in the average dry period	$T_{max,dry}$	(°C)
Mean maximum temperature in the average wet period	$T_{max,wet}$	(°C)
Agrometeorological variables		
Annual reference evapotranspiration	$ET_{0,a}$	(mm)
Monthly reference evapotranspiration	$ET_{0,m}$	(mm)
Seasonal reference evapotranspiration (1st, 2nd, 3rd and 4th quarter)	$ET_{0,1}, ET_{0,2}, ET_{0,3}, ET_{0,4}$	(mm)
Reference evapotranspiration in the average dry period	$ET_{0,dry}$	(mm)
Reference evapotranspiration in the average wet period	$ET_{0,wet}$	(mm)
Annual precipitation surplus	I_a	(mm)

where R_a is extraterrestrial radiation (MJm^2d^{-1}), T_{max} and T_{min} are, respectively, the mean monthly maximum and minimum temperatures (°C), and P is monthly precipitation (mm). The Hargreaves-Samani equation was chosen instead of the more reliable Penman-Monteith equation, because some data was missing from the solar radiation, wind and humidity data series. Moreover, in this paper ET_o was calculated for climatological reasons and so it was decided that any error was acceptable.

Monthly precipitation and evapotranspiration were collected at different time intervals: annual, seasonal and dry or wet periods. The seasons were subdivided into 1st quarter (from January to March), 2nd quarter (from April to June), 3rd quarter (from July to September) and 4th quarter (from October to December). The May-August period was the average dry period (when irrigation is required), and the September-April period was the average wet period in southern Italy. Mean, minimum and maximum temperatures were averaged at the same time scales of P and ET_0. Precipitation surplus (I_a, mm), estimated by Eq. (2), was annual:

$$I_a = P_a - ET_{0,a} \tag{2}$$

The set of meteorological and agrometeorological parameters used in this study is reported in Table 1.

2.3 Trend Analysis

At the regional level, meteorological and agrometeorological time series were evaluated with the non-parametric Mann-Kendall test (Salas 1992), which reliably identifies monotonic linear and non-linear trends. It is a rank-based procedure and is therefore resistant to the effect of extreme values and deviations from linear relationships (Hirsch et al. 1992). The test does not assume any priority distribution of the data, and is therefore robust in comparison to parametric tests. Assuming the correct test statistic follows normal distribution, a standardized Mann-Kendall statistic (Z) was computed (Hirsch et al. 1992). Z is then compared with a standard normal distribution with significance level, α. The null hypothesis, that there is no trend, is rejected if

$$|Z| > Z_{(1-\alpha/2)} \tag{3}$$

where $Z_{(1-\alpha/2)}$ is the quantile of the standard normal distribution.

Trend analyses of the data sets in Table 1 were further carried out by using trend-line analyses, with slopes (b) calculated by the least-squares linear fitting method. The significance of the correlation coefficient (r) was evaluated by the statistic t-test (Hirsch et al. 1992). The null hypothesis is rejected if :

$$|t| > t_{crit} \tag{4}$$

where t_{crit} is the point of the Student's t distribution with N-2° of freedom that has an exceeding probability of $\alpha/2$. The significant levels (α) were fixed at 0.10, 0.05 and 0.01 for both the Z and t-test.

Finally, 10-years-running average trends were analysed to show long-term tendencies and any abrupt changes.

2.4 Drought Analysis

The Standardised Precipitation Index (SPI) was developed to define and monitor local droughts. It was conceived to identify drought periods and severity at multiple time scales.

This temporal flexibility makes SPI useful in both short-term agricultural and long-term hydrological applications. Shorter or longer time scales may reflect response lags of different water resources to precipitation anomalies. As the time scale increases the SPI responds more slowly to changes in precipitation (McKee et al. 1995). The SPI is based on the probability distribution of the precipitation for any time scale. The SPI calculation for a given location is based on the long-term precipitation record for the selected time period of analysis. It requires different interpretations according to its time scale. For example, the 1-month SPI (SPI1) reflects short-term conditions, and its application can be related closely to soil moisture; the 3 and 6-month SPI (SPI3, SPI6) provide medium trends in precipitation patterns which are useful for agricultural purposes; and the 12-month SPI (SPI12) reflects long-term precipitation patterns, usually tied to streamflows, reservoir levels and ground-water levels (Khan et al. 2008). The longer the length of record used in the SPI calculation, the more reliable the SPI value will be (Wu et al. 2005).

The SPI is based on an equi-probability transformation of aggregated monthly precipitation into a standard normal variable. In practice, computation of the index requires fitting a probability distribution to aggregated monthly precipitation series (e.g. k=3, 6, 12, 24 month, etc.), computing the non-exceeding probability related to such aggregated values and defining the corresponding standard normal quantile as the SPI. The most commonly used distribution for SPI calculation is the two-parameter gamma distribution (Logan et al. 2010).

The precipitation total $\overline{X}_{i,j}^{k}$ in a given month (j) and year (i) depends on the chosen time scale (k). Thus, $X_{i,j}^{k}$, precipitation total in the month (j) of the year (i) and in the (k-1) past consecutive months, with $k \leq 12$, is computed by

$$X_{i,j}^k = \sum_{l=13-k+j}^{12} w_{i-1,l} + \sum_{l=1}^{j} w_{i,l} \quad \text{when } j < k \tag{5}$$

$$X_{i,j}^k = \sum_{l=j-k+1}^{j} w_{i,l} \quad when \, j \geq k \tag{6}$$

where $w_{i,l}$ is the precipitation(mm) in (lth) month of year (i).

The computation of the SPI is well known. Here, specific software was developed to compute SPI according to Guttman (1999) and the National Drought Mitigation Center (2012).

The SPI represents an event departure from the mean, expressed in standard deviation units. It is a normalised index in time and space. This feature allows SPI values to be compared between different areas and different periods. According to McKee et al. (1995), a drought event occurs any time SPI is continuously negative and reaches an intensity where SPI is less or equal to −1.0. The event ends when SPI becomes positive. Therefore, each drought event has a duration defined by its initiation and end, and an intensity referring to each month in the period as the event continues. The cumulated intensity of a drought can be considered as the drought magnitude, which is defined by the sum of the SPI for all the months within a drought event.

Recent research has shown that the SPI has main advantages over other indices such as the PDSI (Palmer Drought Severity Index) and is relatively simple, spatially consistent and temporally flexible, thus allowing observation of water deficits at different scales (Khan et al. 2008). The SPI does not require information about land surface conditions and is solely a function of precipitation amount (Kim et al. 2006; Raziei et al. 2012).

Within the forests and agriculture of the Calabria Region, SPI was computed for periods of 3 and 6 months. There is, in fact, a general consensus on this time-scale how well drought events affecting vegetation and agriculture are described (Bonaccorso et al. 2003; Khan et al. 2008; Raziei et al. 2012). In a Mediterranean climate, SPI3 provides a seasonal estimation of drought; the SPI3 of March (SPI3-Mar), June (SPI3-Jun), September (SPI3-Sep) and December (SPI3-Dec) can estimate short-term drought occurrence in winter, spring, summer and autumn respectively. SPI6-Mar describes a wet period with increasing soil moisture, essential for natural vegetation and affecting irrigation water requirements; SPI6-Sep describes drought in a dry period.

Finally, the overall drought tendency from 1921 to 2007 was analysed by the linear trends of drought characteristics (Logan et al. 2010).

3 Results and Discussion

3.1 Time Trends in Meteorological and Agrometerological Parameters

Results of the Mann-Kendall show that most of the rain gauge station data exhibits a negative precipitation trend, at all the significance levels. As examples, test results obtained for annual, 1st quarter, wet and dry period precipitation are given in Fig. 2, for assigned level of significance α. In particular, 51 % of the annual series show significant negative Mann-Kendall trends at α≤0.05. The percentage of stations with no significant trend (α>0.10) varies between a minimum of 37 % (at α≤0.10) and a maximum of 85 % (at α≤0.01). The

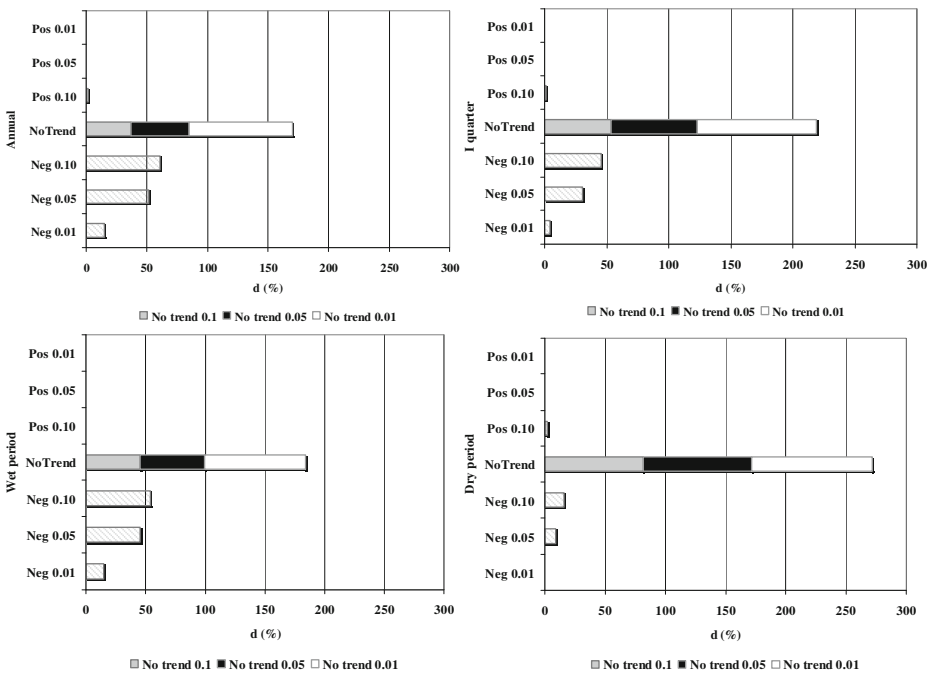**Fig. 2** Percentages of stations (d) with observed precipitation trends (Mann-Kendall test) at α≤0.10, 0.05 and 0.01 (Pos: positive; Neg: negative)

results show that winter (1st quarter) and autumn (4th quarter) seasons have the greatest number of negative trends, whereas the summer season (3rd quarter) shows no significant trends. During winter (1st quarter in Fig. 2), almost 30 % of the stations show a negative trend at $\alpha \leq 0.05$.

Table 2 shows the results of the linear trend at a regional level. On a yearly scale, precipitation exhibits a decreasing trend in 88 % of stations (significant in 61 % of the stations for $\alpha \leq 0.05$) with a mean precipitation reduction of 3.18 mm/year (Table 2), corresponding to almost 30 % of the mean precipitation over 1921–2007. The decrease was higher (−340 mm/100 years) in CaT with respect to CaI (−312 mm/100 years). Monthly precipitation trends decreased over 8 months and mainly during the rainy period (from October to March). Regression line slopes (b) were from −21 mm/100 years in October to −79 mm/100 years in January. Precipitation trends increased during April, July, August and September. On a seasonal scale, negative trends were detected in all the quarters with the exception of the 3rd (Table 2 and Fig. 3). In the 1st and 4th quarters (rainy period), the regional averages (b) were −166 and −159 mm/100 years, respectively. The precipitation trend also decreased in the 2nd quarter (− 45 mm/100 years), whereas it increased by 42 mm/100 years in the summer (3rd quarter). The decrease was higher in the sub-region CaT, except for the 4th quarter when (b) were of −171 and −131 mm/100 years, in CaI and CaT respectively.

The different results in the two sub-regions (CaT and CaI) are consistent with the results of other hydrological studies of the region. Colacino et al. (1997) showed that orography leads to a precipitation gradient between the Tyrrhenian and Ionian sides of the region. Buttafuoco et al. (2011), in a study on spatial and temporal patterns of mean annual precipitation, identified that the first component of a linear model of co-regionalisation fitted to experimental variograms was mainly linked to the orographic characteristics of the region. The differences between the precipitation regime of the two sides can be explained by current circulation in this part of the Mediterranean. The Tyrrhenian side is influenced by western air currents and the Ionian side by currents coming from Africa (Buttafuoco et al. 2011; Coscarelli and Caloiero 2012).

The results also show that the wet period (September-April) has the greatest number of linear negative trends, with a mean reduction of 0.39 mm/year (Table 2). About 45 % of the stations show a negative trend, with the Mann-Kendall test, for $\alpha \leq 0.05$ (Fig. 2). Due to the positive trends in July, August and September, the mean precipitation reduction during the dry period was very low (−0.06 mm/year). Consequently it is possible to assert that precipitation reduction has regarded mostly the wet season. This behaviour is particularly important in the typical Mediterranean climate in which most annual precipitation is concentrated in the period October-February (Cannarozzo et al. 2006).

Different analyses of seasonal precipitation trends in the region pointed out a positive trend for summer precipitation (especially in July and August) and a concomitant negative trend for the other months (Brunetti et al. 2010; Buttafuoco et al. 2011; Coscarelli and Caloiero 2012).

A running average over 10 years shows a more pronounced decreasing trend in annual precipitation after 1960. A stabilisation phase during the 2nd and 4th quarters and an increasing trend in the 3rd quarter were observable in the precipitation regime after 1995, whereas precipitation in the 1st quarter continues to decrease (Fig. 3). Decreasing trends in Calabria's precipitation confirm the general decrease in precipitation observed in other Italian regions, with high variability in the (b) values. A mean (b) value of 285 mm/100 years, corresponding to 43 % of the mean precipitation over 1921–2000, was observed in annual precipitation in Sicily, an island located in the Mediterranean Sea near Calabria (Fig. 1) (Capra et al. 2006; Capra and Pavanelli 2010). Precipitation decreased by 209 mm/100 years, corresponding to 14 % of the mean precipitation over 1921–2003, in the River Reno watershed located in the Northern Italy (continental area of Emilia Romagna and

Table 2 Regional mean values of meteorological and agrometeorological parameters, slope (b) of the linear trend and percentage of stations with increasing (i) or decreasing (d) linear trend

	P			Tmin			Tmax			Tm			ET_0		
	Mean (mm)	b (mm/y)	d (%)	Mean (°C)	b (°C/y)	i (%)	Mean (°C)	b (°C/y)	d (%)	Mean (°C)	b (°C/y)	d(%)	Mean (°C)	b (mm/y)	d (%)
January	149	-0.792	98	4.8	0.010	71	11.5	-0.008	50	8.3	-0.004	50	23	-0.047	46
February	116	-0.564	96	5.0	0.008	54	11.9	-0.009	63	8.7	-0.009	67	30	-0.050	50
March	105	-0.296	78	6.3	0.007	54	14.2	-0.010	67	10.5	-0.007	67	55	-0.065	67
Aphl	74	0.051	35	8.6	0.008	46	17.4	-0.014	88	13.2	-0.010	83	81	-0.105	88
May	54	-0.244	93	12.2	0.010	92	22.1	-0.008	54	17.3	-0.006	38	121	-0.103	63
June	29	-0.228	90	16.0	0.011	75	26.8	-0.013	71	214	-0.008	50	152	-0.151	79
July	22	0.135	15	18.5	0.011	58	29.7	-0.014	79	24.2	-0.010	50	170	-0.210	83
August	28	0.106	20	183	0.012	79	29.9	-0.013	75	244	-0.009	46	153	-0.201	88
September	63	0.086	33	16.2	0.007	50	26.4	-0.018	92	21.4	-0.012	96	102	-0.156	96
October	116	-0.214	75	12.7	0.009	63	21.6	-0.012	67	17.2	-0.010	83	61	-0.107	71
November	149	-0.745	90	9.3	0.004	29	16.8	-0.012	96	13.2	-0.015	92	32	-0.059	67
December	163	-0.671	94	6.3	0.009	50	12.9	-0.0137	79	10.1	-0.022	71	21	-0.048	75
1st quarter	370	-1.664	97	5.4	0.009	54	12.6	-0.009	50	9.2	-0.006	67	108	-0.134	58
2nd quarter	158	-0.445	78	12.3	0.010	63	22.1	-0.009	83	17.3	-0.007	63	355	-0.357	71
3rd quarter	112	0.417	20	17.8	0.0 10	63	28.7	-0.015	79	23.3	-0.007	79	425	-0.568	88
4thquarter	429	-1.587	91	9.4	0.008	42	17.1	-0.009	92	13.5	-0.015	83	114	-0.208	71
Dryperiod	133	-0.058	55	16.4	0.011	75	27.1	-0.011	75	21.8	-0.010	38	596	-0.600	83
Wetperiod	935	-0.393	75	8.7	0.008	50	16.6	-0.009	88	12.8	-0.009	83	405	-0.570	75
Annual	1,069	-3.178	88	11.2	0.009	54	20.1	-0.010	79	15.8	-0.008	75	1,001	-1.120	79

P precipitation; T_{min} mean minimum temperature; T_{max}: mean maximum temperature; T_m mean temperature; ET_0 reference ET; T_m mean temperature
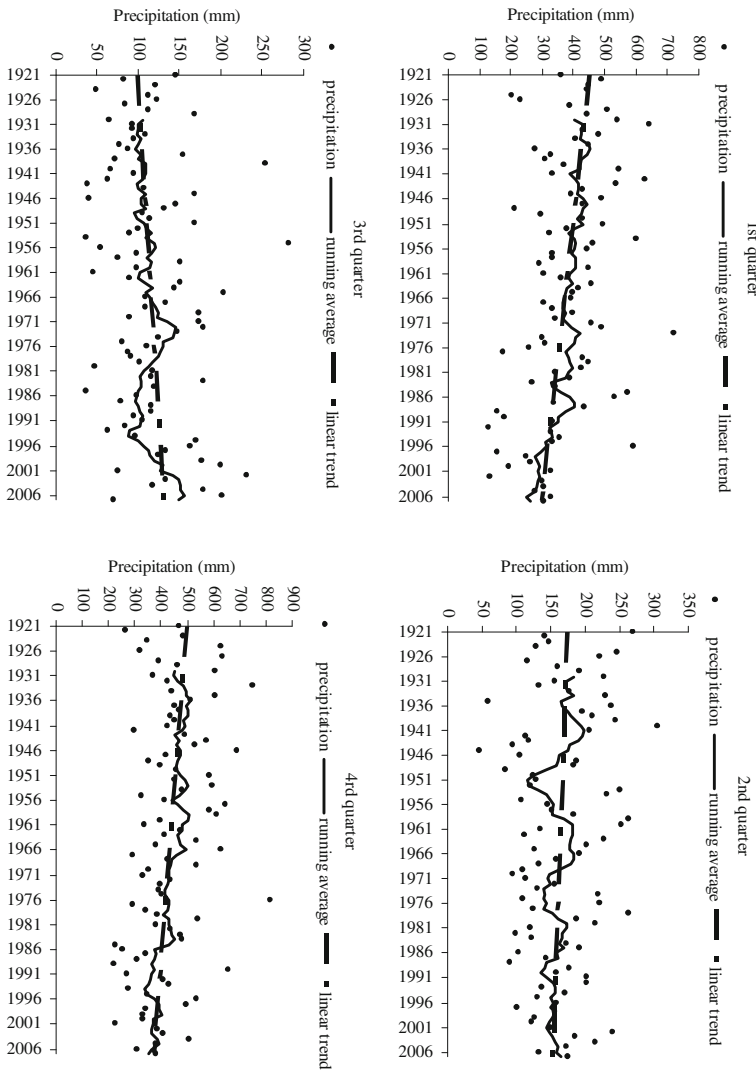
Fig. 3 Linear trend and 10-years-running average of mean seasonal precipitation in Calabria

Tuscany) (Capra and Pavanelli 2010). Todisco and Vergni (2008) described precipitation reductions from 19 to 29 % in two stations in Umbria (central Italy). Thermometric parameters indicate a generally increasing trend for T_{min}, and a generally decreasing trend for T_{max} and T_{mean} (Table 2). Linear trends showed that annual minimum temperatures increased in 54 % of the stations; the mean value of (b) was 0.94 °C/100 years (Table 2). Monthly minimum temperatures had a maximum increment of 1.2 °C/100 years during August (the trends were positive in 79 % of the sites). Dry period minimum temperatures increased by 1.1 °C/100 years, whereas maximum temperatures decreased in 80 % of the stations on an annual scale; the mean (b) values corresponded to 1 °C/100 years, 1.1 °C/100 years and 0.9 °C/100 years on annual, dry and wet time scales respectively (Table 2). On a monthly basis, the maximum decrease of 1.8 °C/100 years was registered during

September (decreasing trends in 92 % of the stations) (Table 2). Mean air temperature decreased in 75 % of the stations on an annual scale; the (b) values were 0.76 °C/100 years, 1 °C/100 years and 0.9 °C/100 years on annual, dry and wet time scales, respectively. Nevertheless, the percentage of stations with significant Mann-Kendall trends ($\alpha \leq 0.05$) were 29 % for T_{min} (increasing trend), 33 % for T_{max} and 37 % for T_{mean} (both decreasing) (Fig. 4).

The T_{min} generally increased in all the Italian Regions, whereas the spatial variability of T_{max} and T_{med} in the different Regions of Italy is very high. In fact, Tmax decreased in Calabria and in the mountain zone of the River Reno watershed, increased in Sicily and in the valley stations of the River Reno watershed, and increased or was stable in Umbria (Capra et al. 2006; Capra and Pavanelli 2010; Todisco and Vergni 2008). In Sicily, in particular, Tmax,a increased by 1.8 °C/100 years in 79 % of the 25 stations, over 1926–2000 (Capra et al. 2006).

Decreasing trends in reference evapotranspiration (ET_0) were found at the temporal scales (Table 2, Fig. 4). Mean annual ET_0 decreased by 112 mm/100 years. During wet and dry periods, the mean ET_0 reduction was 60 and 57 mm/100 years, respectively. In those periods, 42 % of the stations show significant negative Mann-Kendall trends at the 0.05 significance level.

In the Hargreaves and Samani model, ET_0 is proportional to the difference between mean maximum and mean minimum temperature. The resulting trends are thus in accordance with those obtained with the thermometric parameters. Increasing minimum temperature (night-time values, when no evapotranspiration takes place) and decreasing maximum temperature values lead to a decreasing temperature range and, therefore, to a decreasing ET_0 (Moonen et al. 2002).

Annual meteorological and agrometeorological parameter main trends at regional level are shown in Fig. 5. Catanzaro, a representative station in the region, showed the general parameter tendency detected for the whole study period and data set (Fig. 6).

The precipitation surplus trend was negative, therefore annual irrigation requirement tendency was positive, with average increments of 2.5 mm/year (Fig. 7). The significant tendency of I_a (Mann-Kendall test) was found in 40 % of the stations at $\alpha \leq 0.05$ (Fig. 8). A decreasing I_a was much more evident from 1970, and, in particular, after 1990, when the regional mean of I_a becomes negative (Fig. 7).
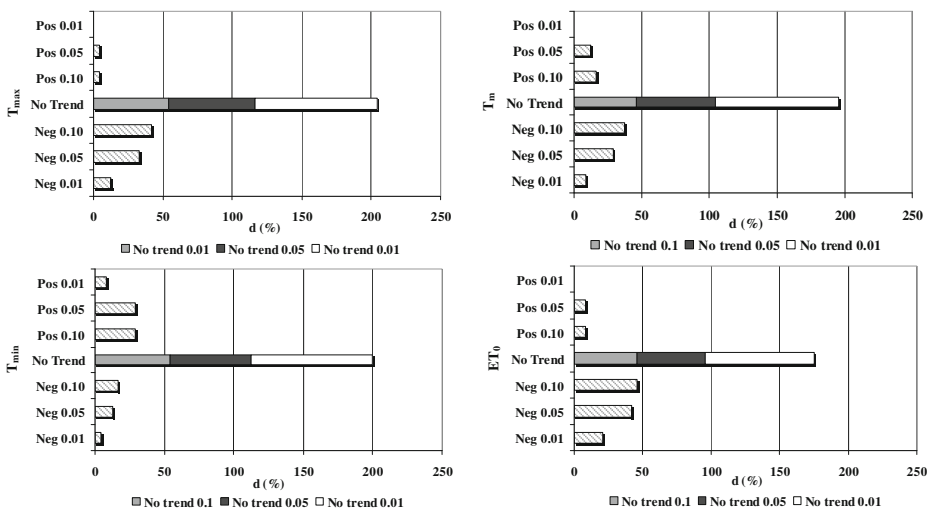

Fig. 4 Percentages of stations (d) with observed temperature (maximum, mean, minimum) and ET_0 trends (Mann-Kendall test) at $\alpha \leq 0.10$, 0.05 and 0.01 (Pos: positive; Neg: negative)
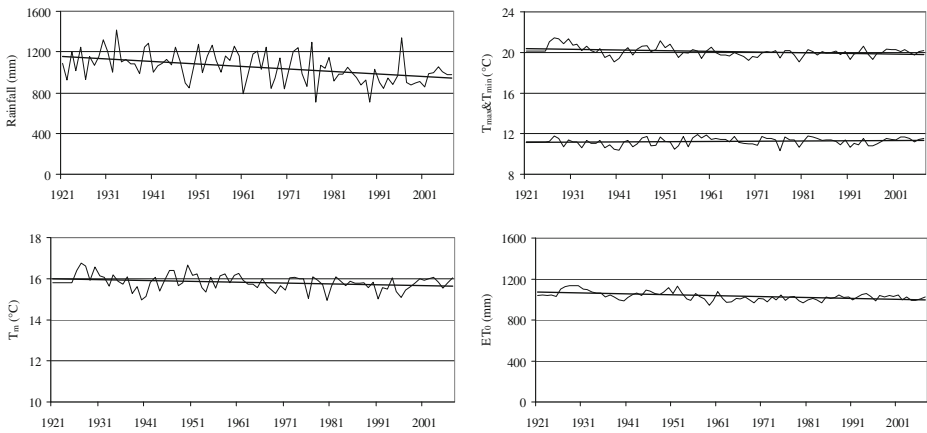
Fig. 5 Linear trends of meteorological and agrometeorological parameters in Calabria at yearly scale from 1921 to 2007

3.2 SPI Analysis

For the 3-month time scale, the mean number of droughts over 1921–2007 was 55, with a minimum and maximum of 33 and 68, respectively. The mean drought duration was almost 6 months. For the 6-month time scale, the mean, minimum and maximum droughts were of 32, 19 and 41, respectively. The mean drought duration was almost 11 months. Differences in drought characteristics, between the two sub-regions (*CaT* and *CaI*), were not significant. Using Principal Component Analysis (PCA), Capra and Scicolone (2012) studied spatial and temporal patterns of drought in the same region of this study; they concluded that the spatial pattern of drought based on the first component was largely linked to elevation, while the part based on the second component was more influenced by exposure (Tyrrhenian or Ionian) and the mountain chains close to the sea.

In almost 80 % of stations, drought numbers were lower than 59 and 35 for k=3 months and k=6 months, respectively.

Generally, analysis of the SPI linear trends showed increasing drought intensity. Figure 9 plots the 3-month SPI trends for March, June, September and December, representing seasonal precipitation. March and December 3-month SPI_s and March 6-month SPI_s were critical in detecting agricultural droughts. The SPI values during the rainy season decreased, and therefore drought intensity increased, mainly after the 1980s. The increasing trend to droughts was slightly pronounced in June, while practically no trend was observed during September.
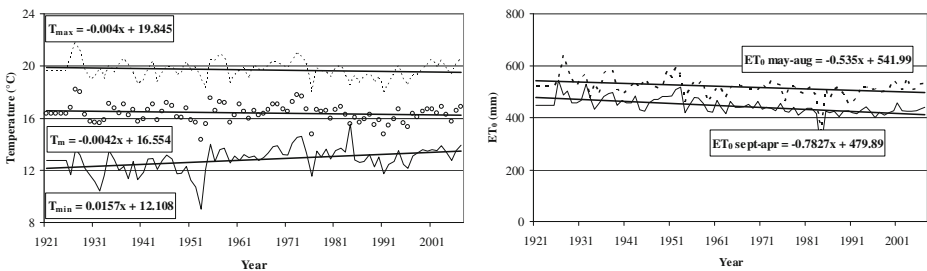

Fig. 6 Linear trends and 10-years-running average of maximum, mean and minimum temperature in dry period and of ET_0 in dry and wet periods at Catanzaro station
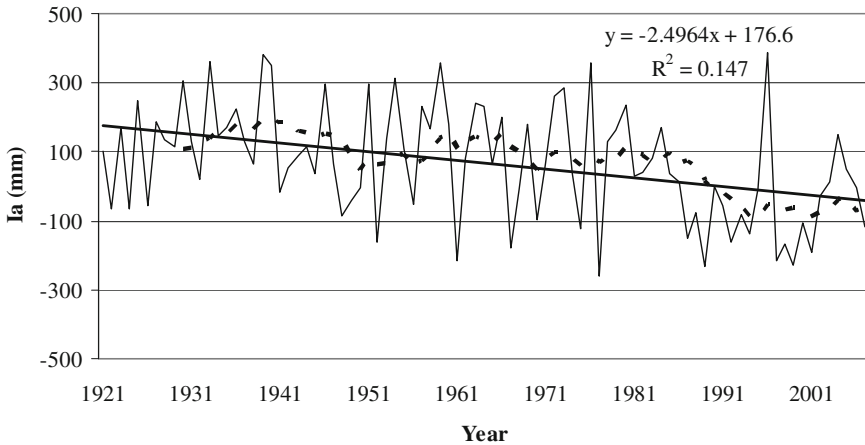
$$y = -2.4964x + 176.6$$
$$R^2 = 0.147$$

Fig. 7 Linear trend and 10-years-running average of annual precipitation surplus (I_a)

The 10-year-running average was congruous with that of seasonal precipitation. In fact, decreasing SPI_s were more pronounced after 1985 during March and December and had cyclical trends during June and September.

The 6-month SPI trend during March decreased, being very similar to that of the 3-month SPI in December and March, whereas no trend was observed in the 6-month SPI of September.

The results in Fig. 9 agreed with other studies on drought events in different zones (Greece, Jordan, Portugal, Spain, Sicily, Turkey) of the Mediterranean over 1993 to 2000 (Cancelliere and Rossi 2003, Livada and Assimakopoulos 2007; Sönmez et al. 2005) .

Finally, a substantial change in drought intensity trend was evident in the region after 2000.

Capra and Scicolone (2012), in a deeper analysis on spatial distribution of the b values, showed that winter SPI trends (SPI3-Mar) were negative in almost 100 % of the region, with a minimum (b) value of −0.03; autumn (SPI3-Dec) and springtime (SPI3-Jun) SPI trends were negative in 95 % and 91 % of the region, respectively, with a minimum (b) value of −0.015. Overall, there were negative SPI trends for 92 % and 89 % of the region in the wet (SPI6-Mar) and dry (SPI6-Sep, Fig. 5d) periods, respectively.
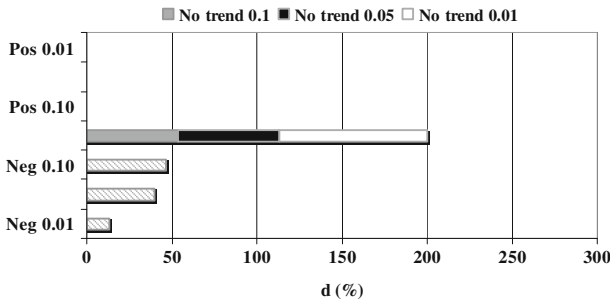

Fig. 8 Percentages of stations (d) with observed annual precipitation surplus (I_a) trends (Mann-Kendall test) at $\alpha \leq 0.10$, 0.05 and 0.01 (Pos: positive; Neg: negative)
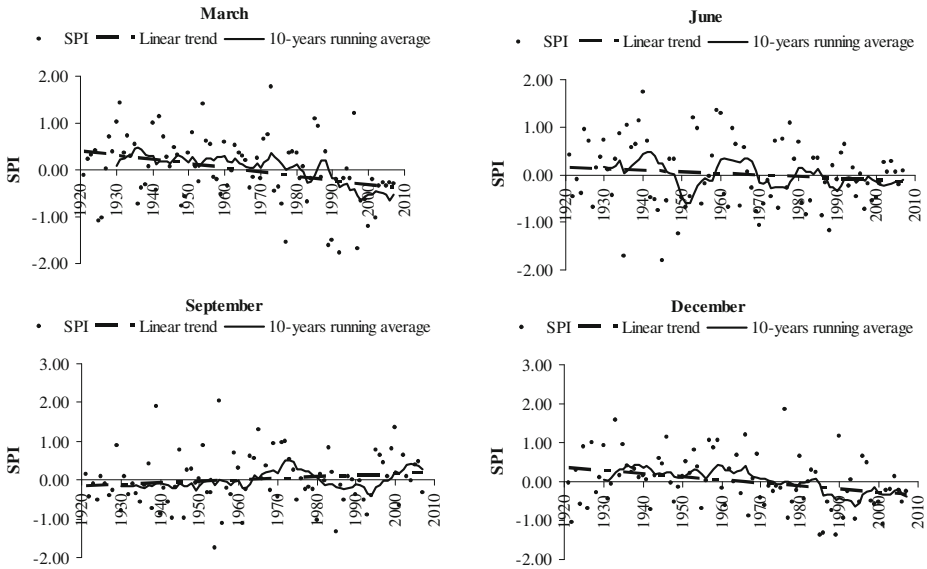
Fig. 9 Linear trend and 10-year- running average of the 3-months SPI

4 Conclusion

The study helped detect the positive and negative tendencies of selected meteorological (precipitation, minimum, maximum and mean temperature) and agrometeorological (evapotranspiration and precipitation surplus) variables in the Calabria region over 1921–2007.

The main results obtained for the region are:

– rainfall amounts decreased everywhere in the region during winter, springtime and autumn, and increased during the summer; at a regional level, yearly precipitation decreased by 318 mm/100 years, representing almost 30 % of the yearly mean precipitation for the region;

– the mean and maximum temperatures decreased whereas the minimum temperatures increased; the yearly mean minimum temperatures increased by 0.9 °C/100 years and maximum and mean temperatures decreased by 1 °C/100 years and 0.8 °C/100 years, respectively.

– temperature impacted on evapotranspiration in a decreasing tendency, due to a decreasing temperature range; as expected, when thermometric parameters show asymmetric behaviour, with a decreasing maximum temperature and an increasing minimum temperature, the impact on evapotranspiration is opposite to that expected with a decreasing tendency;

– the trends detected in the meteorological/agrometeorological parameters affect the irrigation water requirement; the occurrence of more pronounced negative precipitation trends compared to the decreasing trends in ET_0 lead to an increasing trend in precipitation deficit, and, consequently, to a corresponding irrigation water requirement.

– the increasing trends in SPI confirmed a general increase in the frequency, intensity and duration of droughts in the last decades in the examined region as well as in other Mediterranean areas; the results showed a reverse trend in drought intensity after 2000.

The overall results showed the importance of climate change analyses on a regional scale. In fact, the results obtained in this study are consistent with other hydrological analyses in the same region, but the Linear Regression Coefficients (b), and sometimes even their trend (positive or negative), were very different compared to other Italian regions.

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