



# Climate change assessment: seasonal and annual temperature analysis trends in the Sardinia region (Italy)

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## Abstract

Climate change is expected to have an impact on temperature variability and lead to a substantial increase in temperature values. This is particularly important in some areas, such as the Mediterranean region that has been identified as one of the most responsive regions to climate change. In this paper, the temporal tendencies of seasonal and annual temperature data were analysed in the Sardinia Island (Italy) by applying two non-parametric tests for trend detection to 48 temperature series in a 30-year period (1982–2011). As a result, an opposite trend behaviour between maximum and minimum temperatures has been detected. As regards the maximum seasonal temperature data, a marked positive trend has been detected in all the seasons, with the exception of winter, and especially in spring with about 58% of the station showing increasing values. Conversely, a predominant negative trend characterized the minimum seasonal temperature data, especially in autumn when 50% of the series showed this tendency. The results of this study can increase the knowledge and the ability of policymakers to make strategic decisions.

**Keywords** Temperature · Trend analysis · Non-parametric test · Sardinia

## Introduction

Climate change and environmental degradation are among the greatest rapidly emerging and most threatening challenges facing humanity (Pellicone et al. 2019; Djaman et al. 2020). Greenhouse-gas emissions and overexploitation of natural resources are at the root of the problem and are causing a rise in global temperatures (King et al. 2015). Climate change involves not only increasing temperatures but also extreme weather events including sea-level rise, increased frequency of droughts, floods, shifting wildlife populations and habitats, and other destructive events, such as destructive bushfires forever altering the landscape (Pellicone et al. 2018), the reduction of forest areas, flora and

fauna (Buttafuoco et al. 2016; 2018; Ricca and Guagliardi 2015), and pollution (Buttafuoco et al. 2017; Guagliardi et al. 2016).

The planet's climate has constantly been changing over geological time, with significant fluctuations in global average temperatures. Over the past 4.5 billion years, it has shifted constantly due to volcanic emissions, tectonic plate movements, changes in solar radiation, and several other factors. Yet since the last ice age, the earth's climate has been relatively stable, with global temperatures varying by less than 1 °C over a century in the last 10,000 years. Yet, there is growing evidence that over the last 100 years human activities have started to play a major role in rising temperature levels, with alarming acceleration over the last 20 years (Schmidt and Hertzberg 2011).

The effects of climate change are already being felt, but they will get worse. Global warming has reached approximately 1 °C above pre-industrial levels. Every half-degree (or even less) of global warming counts. The urgent need to address climate change has become even clearer with the release of a major report in October 2018 (IPCC 2018) by the world's leading scientific body for climate change assessment, the Intergovernmental Panel on Climate Change (IPCC). The IPCC warns that, in order to avoid catastrophic

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global warming, we must not reach 1.5 °C above pre-industrial levels - or at a very minimum not exceed that. The report evidences the massive differences between the 1.5 and 2 °C scenarios. Particularly, risks from droughts and precipitation deficits are projected to be higher at 2 °C compared to 1.5 °C of global warming in some regions, such as risks from heavy precipitation events. Additionally, on land, impacts on biodiversity and ecosystems, including species loss and extinction, are projected to be lower at 1.5 °C of global warming compared to 2 °C. Limiting global warming to 1.5 °C compared to 2 °C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels. Consequently, limiting global warming to 1.5 °C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans.

For all these reasons, worldwide interest in global warming and climate change has led to numerous trend detection studies by the scientific community (Al Buhairi 2010). In Eastern China over the past century, Zhao et al. (2014) have verified an average air temperature increase of 1.52 °C. Also in China, precisely over the Beijing-Tianjin-Hebei region, as stated by Men et al. (2020), air temperature had significantly increased during the 1960–2013 period, and a temperature and precipitation strong correlation in change occurred. In Sweden, during the 1959–2008 period, the seasonal air temperature has increased by 0.30–0.62 °C/decade in summer and 0.02–0.38 °C/decade in autumn (Ceppi et al. 2012). In the study by Nawaz et al. (2019), an important warming trend in annual minimum temperature and mean temperature in Pakistan emerges contextually to a significant variation in maximum temperature. Globally, for the USA, except for Pennsylvania and Maine, a growing trend in air temperature was reported (Martinez et al. 2012). Pieces of evidence of increasing warming and wetting over northern Canada was reported by Singh et al. (2020). Studies carried out by Djaman et al. (2016) in the Senegal River valley describe a significant increase in average annual maximum and minimum air temperature.

Some studies have been carried out in the Mediterranean basin, a region possibly more susceptible to climate change since, geographically, it lies in a transition area between the hot, dry climate of Africa and the cold, humid air masses arriving from northern Europe (Goubanova and Li 2007; Vicente-Serrano et al. 2014). For example, a seasonal and annual trend analysis has been performed by Giorgi (2002) in a large part of the Mediterranean basin for the past century. Results of this analysis evidenced statistically significant warming trends over the most part of the study area at the annual scale, and partially in winter and summer. Similarly, Jacobeit (2000) detected a significant increase in summer temperature over the entire Mediterranean for the period 1969–1998. As part of the Mediterranean basin, also in Italy,

several authors detected a general increase in temperatures over the last decades (Brunetti et al. 2006; Caloiero et al. 2015, 2017).

A first study in the Sardinia region (Italy), an island located in the western Mediterranean Sea, was carried out by Caloiero and Guagliardi (2020). They applied the Mann–Kendall test to detect possible trends in extreme temperature indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). Differently from the study of Caloiero and Guagliardi (2020), in this study two non-parametric trends (Mann–Kendall and Theil–Sen estimator) were applied to evaluate trend magnitude and significance of monthly, seasonal and annual temperatures by considering 48 series in a 30-year period (1982–2011). The seasons were defined according to the standard meteorological seasons: winter, spring, summer, and autumn.

The objectives of this study are (i) to investigate the change in monthly and annual temperatures from 1982 to 2011 across the Sardinia region (Italy); (ii) to define a detailed climatic overview and estimate potential variations at a local scale; (iii) to help crop producers, environmental engineers, crop consultants, hydrologists and other water use entities in water resources planning, since policy responses to climate change should be based on scientific evidence.

## Methodology

The Theil–Sen estimator (TSE) is generally considered more powerful than linear regression methods for trend magnitude evaluation because it is not subject to the influence of extreme values (Sen 1968). Given  $x_1, x_2, \dots, x_n$  temperature observations at times  $t_1, t_2, \dots, t_n$  (with  $t_1 \leq t_2 \leq \dots \leq t_n$ ), for each  $N$  pairs of observations  $x_j$  and  $x_i$  taken at times  $t_j$  and  $t_i$ , the gradient  $Q_k$  can be calculated as follows:

$$Q_k = \frac{x_j - x_i}{t_j - t_i} \quad \text{for } k = 1, \dots, N \quad (1)$$

with  $1 \leq i \leq j \leq n$  and  $t_j > t_i$ .

The estimate of the trend in the data series  $x_1, x_2, \dots, x_n$  can then be calculated as the median  $Q_{med}$  of the  $N$  values of  $Q_k$ , ranked from the smallest to the largest:

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

The  $Q_{med}$  sign reveals the trend behaviour, while its value indicates the magnitude of the trend.

As regards the Mann–Kendall (MK) test (Mann 1945; Kendall 1962), in order to evaluate the trend significance, the statistic  $S$  based on rank sums is calculated as follows:

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

in which  $x_j$  and  $x_i$  are the observations  $x_j$  and  $x_i$  taken at times  $j$  and  $i$  (with  $j > i$ ), respectively, and  $n$  is the dimension of the series.

Under the null hypothesis  $H_0$ , the distribution of  $S$  is symmetrical and is normal in the limit as  $n$  becomes large, with zero mean and variance:

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

in which  $t_i$  indicates the number of ties with extending  $i$ .

Given the variance of  $S$ , it is possible to evaluate the standardized statistic  $Z_{MK}$  as follows:

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

By applying a two-tailed test, for a specified significance level  $\alpha$ , the significance of the trend can be evaluated. In particular, in this work, the temperature series have been examined for a significance level (SL) equal to 95%.

The trend analyses have been performed using the Excel data analysis add-on XLSTAT version 2021.3.1. The spatial layout was created using Esri ArcGIS 9.3.1.

### Study area and data

Due to its position, in the centre of the western Mediterranean basin, and to its climatic characteristics, Sardinia is considered a highly susceptible area to climate change, where even a small temperature increase could lead to various environmental problems. The Sardinia region is an island located between 38° 51' to 41° 15' N and between 8° 8' and 9° 50' E with an area of 24,090 km<sup>2</sup>, and thus, it is the second-largest island in the Mediterranean basin (Montaldo and Sarigu 2017). The region presents a north–south oriented long shape and, although it is mainly characterized by plains especially in the north-western and in the southern areas, it also presents mountains reaching an average and a maximum altitude of 337 m a.s.l. and 1,834 m a.s.l., respectively (Fig. 1). The Köppen-Geiger classification (Köppen

1936) identifies the climate of the region as a hot-summer Mediterranean climate, therefore with relatively mild winters (with rain) and very hot summers (often very dry). With the coldest month generally averaging above 0 °C in this climate, at least 1 month’s average temperature reaches values higher than 22 °C, and at least four months averaging above 10 °C.

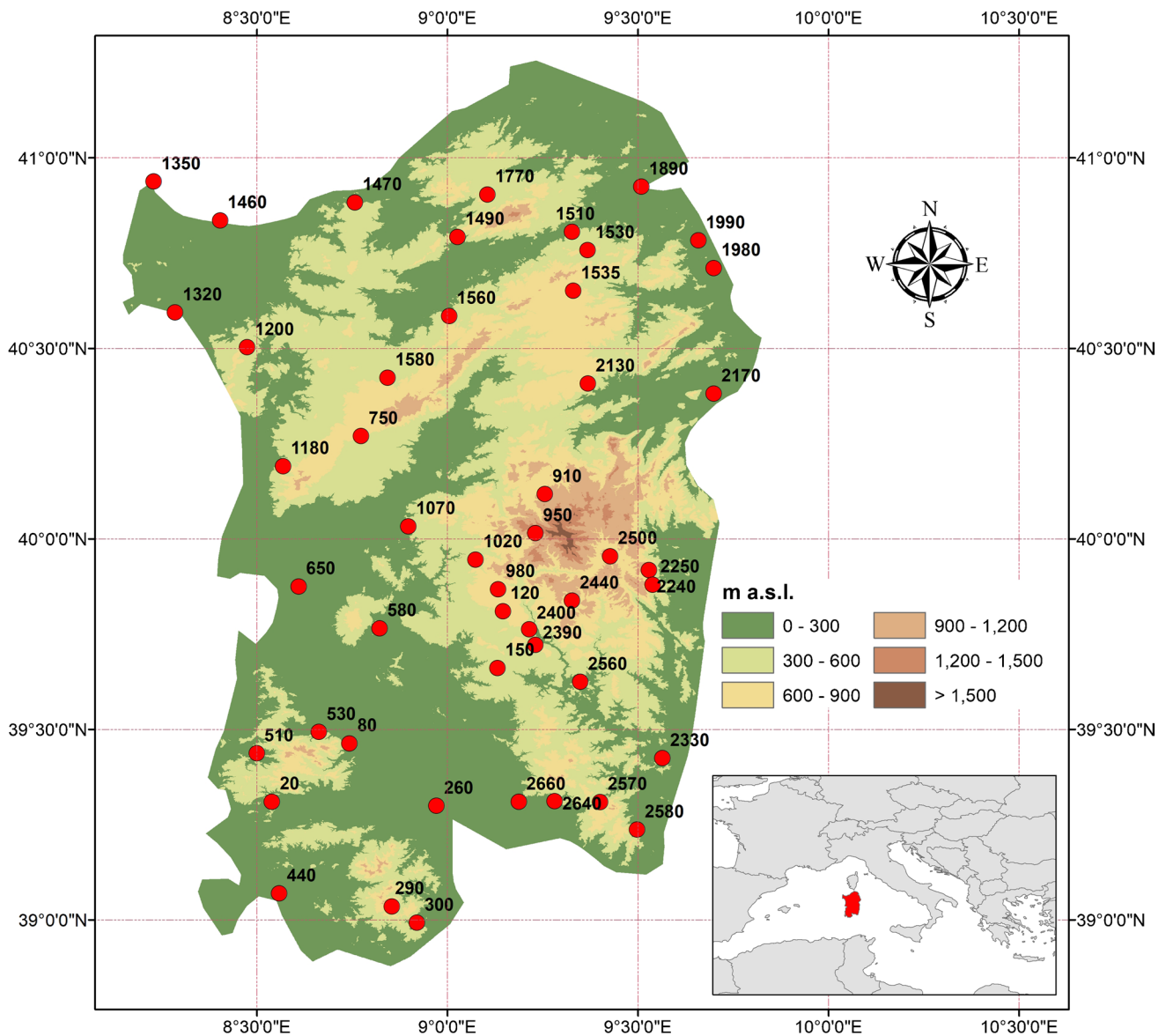
The Sardinia Region provides a free online database containing rainfall and temperature high-quality daily data. Thus, in the present study, complete or near-complete records of daily temperature data have been downloaded from the website of the Sardinia Region (<http://www.regione.sardegna.it>). For its quality, this database has been largely used in past climatological studies performed on the region (Caloiero et al. 2019a, b; Caloiero and Veltri 2019). In particular, in this paper, in order to analyse the spatial and temporal variability of temperature in the Sardinia region, 48 monthly temperature series ranging from 1982 to 2011 with an average density of 1 station per 490 km<sup>2</sup> have been considered (Fig. 1 and Table 1).

### Results and discussion

In this section, results of the trend analysis performed at annual and seasonal scales are presented. In particular, as regards the seasonal analysis, in this paper, meteorological/climatological seasons have been considered; and thus, December, January, and February have been identified as winter; March, April, and May as spring; June, July, and August as summer and September, October, and November as autumn.

In Fig. 2, the characterization of the annual and seasonal maximum and minimum temperatures series related to all the 48 stations has been shown through boxplots. The top and the bottom of the boxes are the third and the second quartiles, respectively. The band inside the box is the median and the ends of the whiskers represent the minimum and maximum of all of the data. Due to the Mediterranean climate, the highest values of both the variables fall within the summer period, while the lowest ones have been identified in winter. Both the maximum and the minimum temperatures did not show a great spread between the values.

Results of the application of the non-parametric tests (SL = 95%) on temperature data allowed to identify a different trend behaviour between maximum and minimum temperatures in the Sardinia region. In fact, at the annual scale, 37.5% and 16.7% of the stations showed a positive and a negative trend, respectively, for the maximum temperature. On the contrary, as regards the minimum temperature, these percentages resulted in exactly the opposite, with a negative trend identified in 37.5% of the stations and a positive trend detected in 16.7% of them (Fig. 3). The spatial



**Fig. 1** Localization of the selected stations on a Digital Elevation Model (DEM) of the Sardinia region

distribution of these results did not evidence a clear spatial behaviour with the exception of the south-western side of the region which showed positive/negative trend values for the maximum/minimum temperatures, with highest magnitudes between 1 and 1.5 °C/10 years and between  $-1$  and  $-0.5$  °C/10 years (Fig. 4).

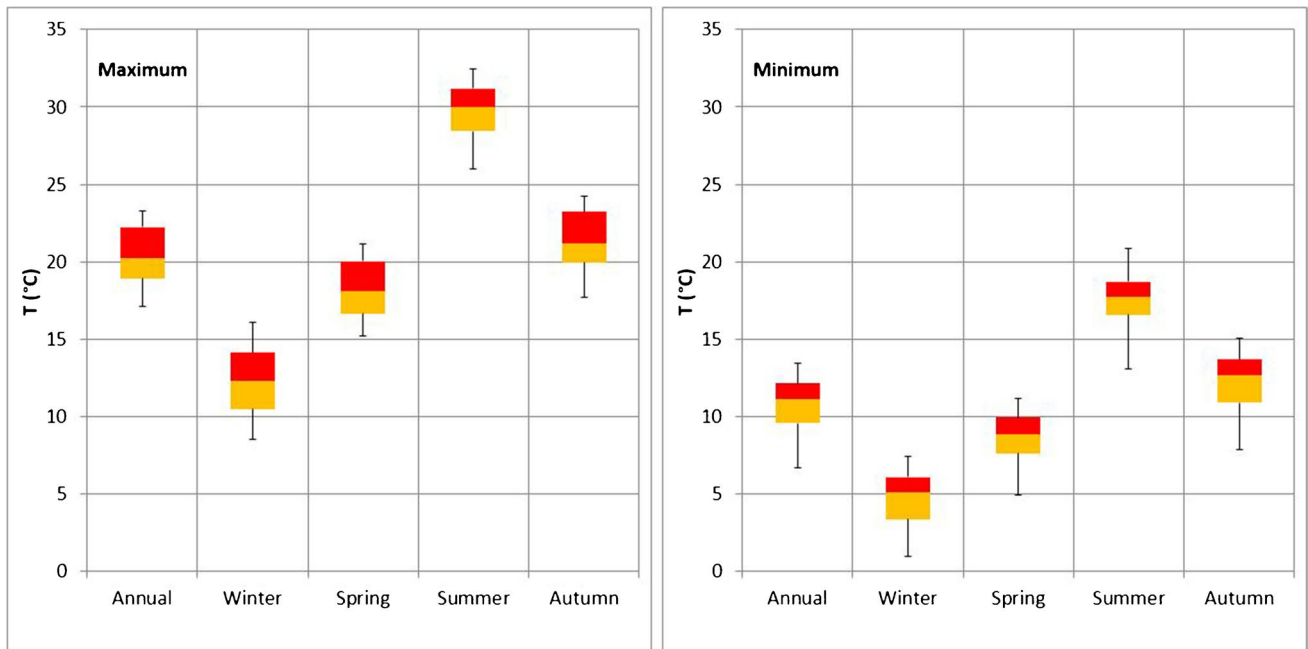
At the seasonal scale, the maximum temperature showed a marked temperature increase in spring and summer, when 58.3% and 43.8% of the stations showed positive values, respectively (Fig. 3). By contrast, in these seasons only 4.2% (spring) and 12.5% (summer) of the stations showed negative values. In autumn, the percentage of stations presenting positive (27.1%) or negative (20.8%) trend is quite similar. Finally, in winter, an opposite trend behaviour has been

detected with 14.6% and 22.9% of the stations showing a positive and a negative trend, respectively.

As regards the spatial distribution of the trend results of the maximum temperature (Fig. 5) in winter, the north-eastern side of the region seems to be interested by negative trend values, reaching magnitudes also less than  $-2$  °C/10 years. In spring, the positive trend is distributed across the region with a maximum increase between 1.5 and 2 °C/10 years. Similarly, in summer, the spatial distribution of the trend results evidenced a spreading positive trend, but with some negative values detected in the inland areas near the mountain areas of the region. Finally, in autumn, the spatial distribution of the trend results did not evidence a clear spatial behaviour with the exception of the south-western side of

**Table 1** Selected stations in the Sardinia region

ID	Station name	Longitude	Latitude	ID	Station name	Longitude	Latitude
20	Iglesias	8.539	39.310	1490	Muzzone	9.026	40.792
80	Villacidro	8.742	39.463	1510	Monti	9.326	40.805
120	Colonia Penale	9.145	39.810	1530	Zuighe	9.367	40.757
150	Mandas	9.131	39.661	1535	Ala' dei Sardi	9.329	40.651
260	Decimo vivaio	8.971	39.299	1560	Ozieri	9.004	40.584
290	Is Cannoneris	8.853	39.035	1580	S. L. di Bonorva	8.842	40.423
300	Piscinamanna	8.919	38.992	1770	Tempio	9.104	40.903
440	S. G. Suergiu—Nuxis	8.558	39.069	1890	Olbia	9.508	40.924
510	Fluminimaggiore	8.499	39.437	1980	Budoni	9.698	40.710
530	Gonnosfanadiga	8.662	39.493	1990	Suaredda	9.657	40.783
580	Ales	8.821	39.765	2130	Orune	9.368	40.407
650	S. Giusta	8.609	39.875	2170	Orosei	9.698	40.380
750	Macomer	8.773	40.269	2240	Arzana	9.528	39.918
910	Fonni	9.255	40.117	2250	Lanusei	9.538	39.879
950	Desulo	9.230	40.015	2330	Muravera	9.563	39.424
980	S. Sofia	9.132	39.867	2390	Nurri	9.230	39.721
1020	Meanasardo	9.073	39.945	2400	Vnovatulo	9.214	39.763
1070	Busachi	8.896	40.033	2440	Seui	9.326	39.837
1180	Cuglieri	8.568	40.190	2500	Bau Muggeris	9.426	39.954
1200	Villanova M.leone	8.473	40.502	2560	Escalaplano	9.348	39.624
1320	Fertilia	8.285	40.594	2570	Campuomu	9.400	39.309
1350	Stintino	8.228	40.937	2580	Castiadas	9.497	39.236
1460	Porto Torres	8.403	40.835	2640	Corongiu	9.281	39.311
1470	S. G.Coghinas	8.756	40.883	2660	Sa Pira	9.186	39.310



**Fig. 2** Characterization of the seasonal and annual maximum and minimum series through boxplots



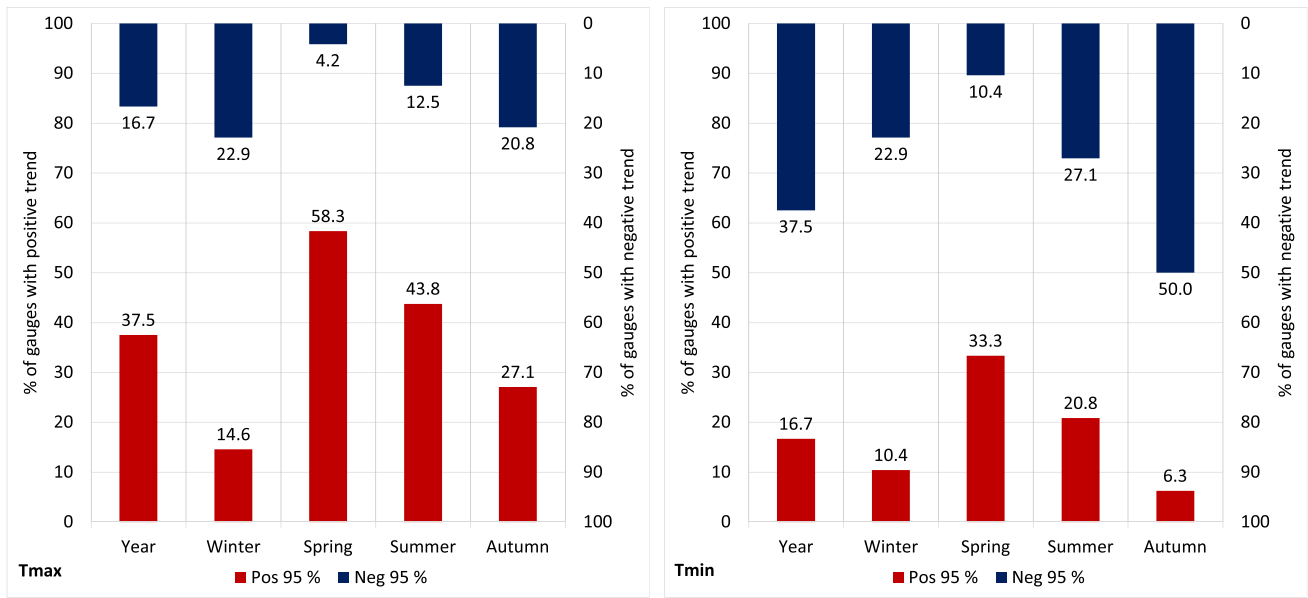
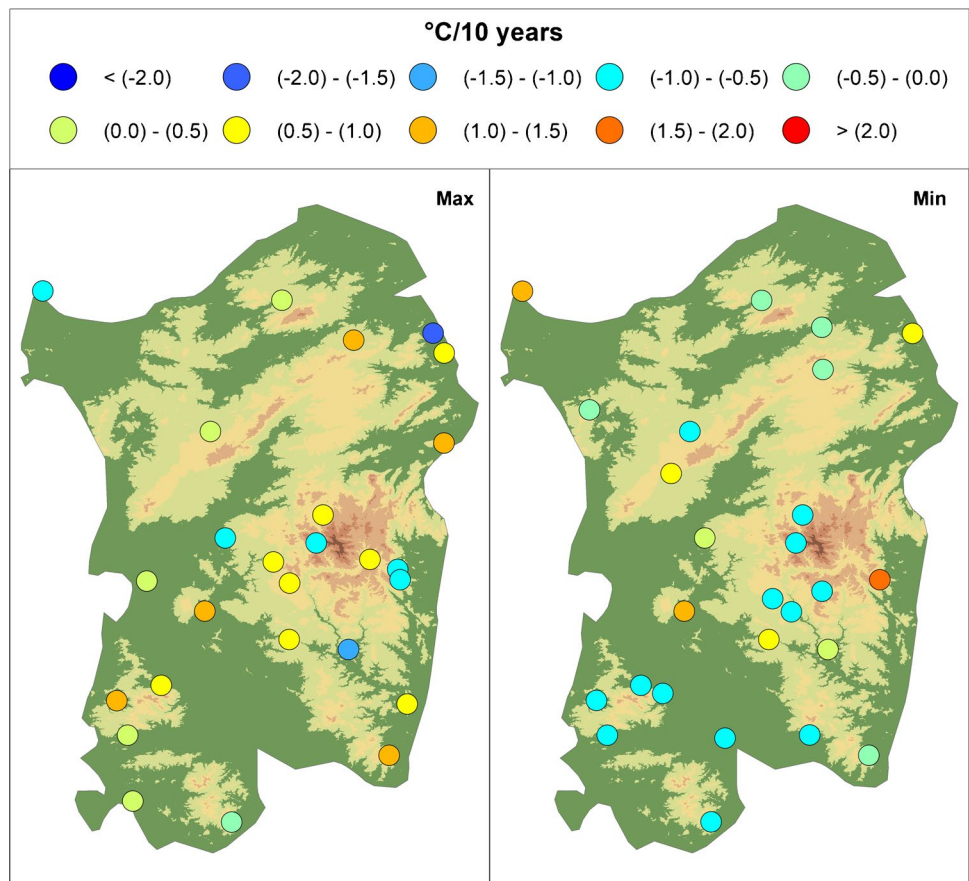
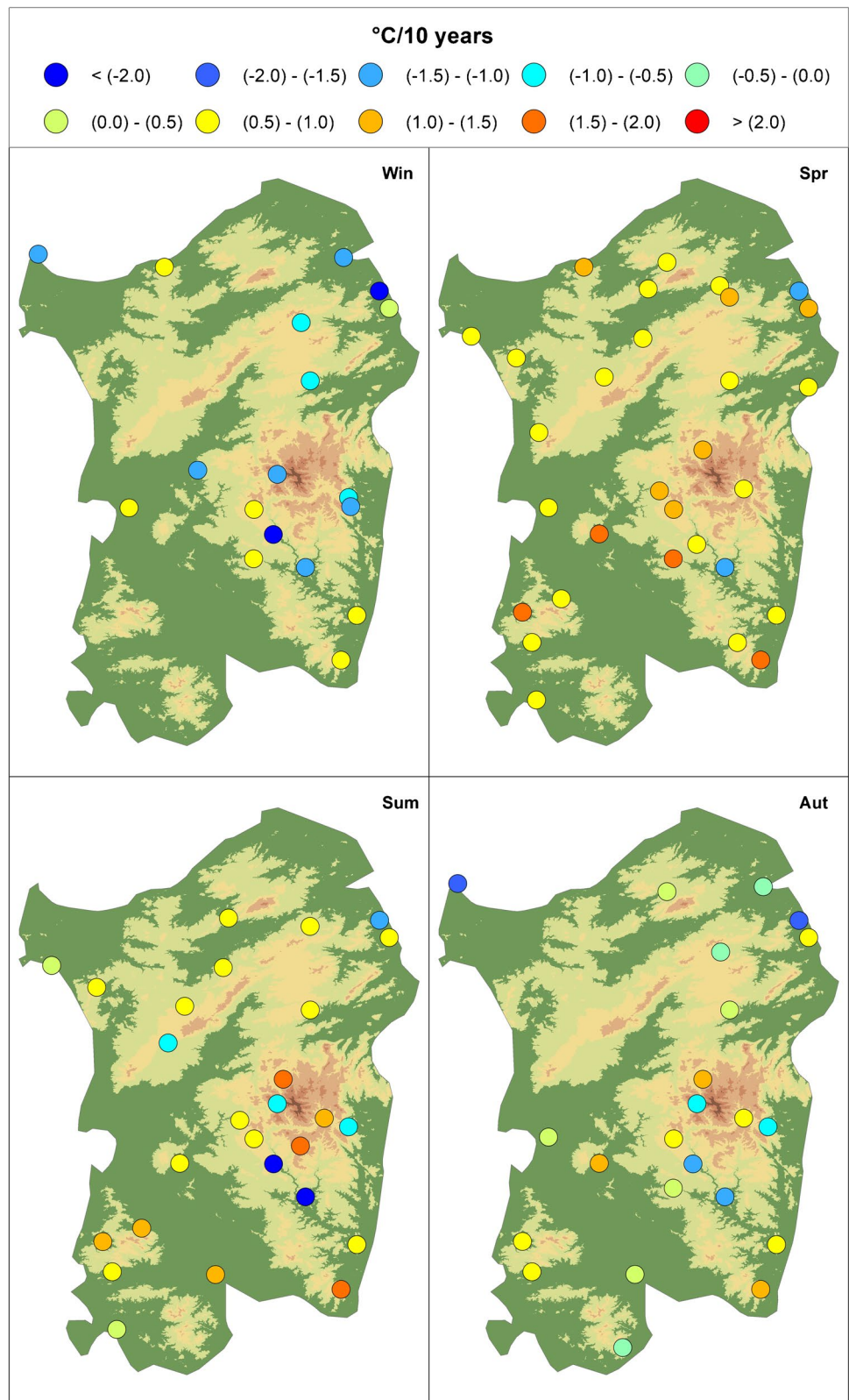


Fig. 3 Percentages of maximum (left) and minimum (right) temperature series presenting positive or negative trend

Fig. 4 Results of the trend analysis performed at the annual scale



**Fig. 5** Results of the trend analysis performed on the maximum temperature at the seasonal scale



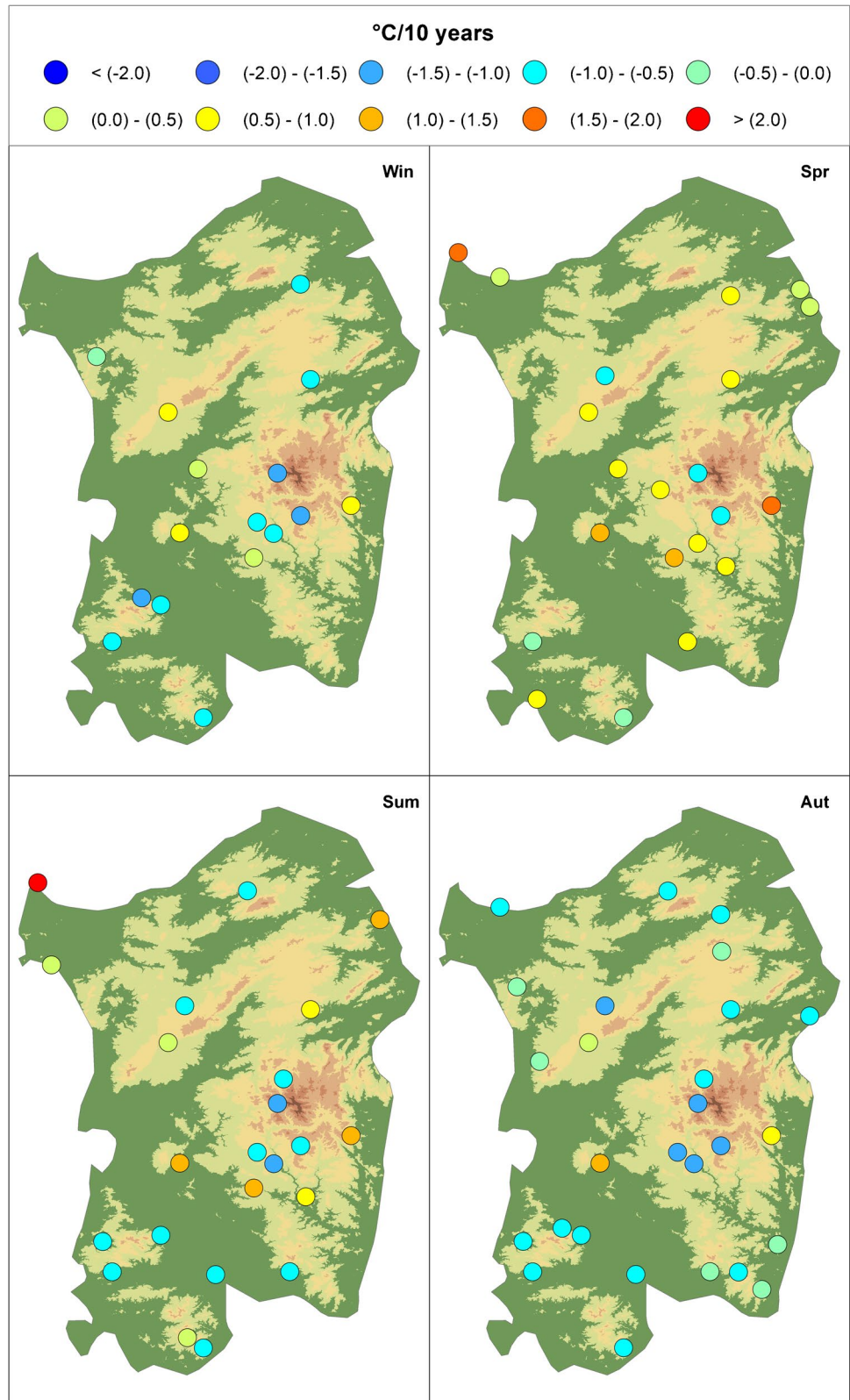
the region which showed positive values although with low magnitude (between 0.5 and 1 °C/10 years).

As for the annual temperature, the seasonal trend behaviour obtained for the minimum temperature is the opposite of the one obtained for the maximum temperature, with a

higher percentage of stations presenting decreasing trends instead of positive ones (Fig. 3). In particular, in autumn 50% of the stations showed negative values and in only 6.3%

of the stations, an opposite behaviour has been detected. A prevailing negative trend, although less evident than in autumn, has also been detected in winter and in summer,

**Fig. 6** Results of the trend analysis performed on the minimum temperature at the seasonal scale





when 22.9% and 27.1% of the stations showed negative values, respectively, and 10.4% (winter) and 20.8% (summer) of the stations showed positive values. Finally, in spring, the marked positive trend detected for the maximum values has been confirmed also for the minimum ones, with 33.3% and 10.4% of the stations showing a positive and a negative trend, respectively.

From a spatial point of view (Fig. 6), due to the high number of significant trend, only in autumn a spatial distributed tendency can be identified, with the negative values distributed across the region and reaching a maximum decrease between  $-1.5$  and  $-1$  °C/10 years. On the contrary, in spring, the positive values are spread throughout the island (maximum increase between 1.5 and 2 °C/10 years) with the few stations presenting negative trends localized in the central part of the region. In winter and summer, the negative trends prevailed, but no spatial remarkable results have been obtained.

To sum up, although previous planetary-scale investigations on maximum and minimum temperatures showed an increase in the minimum values rather than the maximum ones (Easterling et al. 1997), results of this study evidenced an opposite behaviour, thus confirming those achieved by some previous research performed in Italy (e.g. Caloiero et al. 2015).

## Conclusions

Since climatic variables, in particular temperature data, have become considerably important as they affect many environmental issues and indicate a clear sign of climate change, numerous studies have been carried out. This is particularly evident in some areas, such as the Mediterranean region, one of the most reactive regions to climate change. Temperature warming is mainly associated with the exploitation of forest resources, population influx, and expansion of agricultural land, which have changed the natural landscape and increased the concentration of greenhouse gases in the atmosphere at an ever-growing rate. In the present study, a systematic exploration of the trend characteristics of the Sardinia region (Italy) temperatures at seasonal and annual time scales for a 30-year period (1982–2011) has been attempted. Two non-parametric tests have been applied for trend detection. They reveal the presence of an opposite trend behaviour between maximum and minimum temperatures. Seasonal maximum temperature generally reaches a positive trend, except in winter and in spring with about 58% of the stations showing increasing values. By contrast, a negative trend has been observed for the minimum seasonal temperature data, especially in autumn when 50% of the series showed this tendency. Regional annual trend analysis showed 37.5% and 16.7% of the stations presenting a positive and a negative

trend, respectively, for the maximum temperature. Conversely, for the minimum temperature, these percentages resulted in exactly the opposite, with a negative trend identified in 37.5% of the stations and a positive trend detected in 16.7% of them. The scientific information achieved in this study can increase the knowledge and the ability of policymakers to make strategic decisions, which are often formulated without significant scientific input, and show how climate policy interventions might influence future greenhouse emissions.

**Author contribution** The authors contributed equally to this work.

**Data availability** The data presented in this study are available online.

**Code availability** Not applicable.

## Declarations

**Conflict of interest** The authors declare no competing interests.

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