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Long-term temperature changes in Sicily, Southern Italy

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ABSTRACT

Temperature series recorded at 84 measurement stations across Sicily (Italy) have been analysed in order to detect statistically significant changes during the 1924–2013 period. The occurrence of abrupt change points in annual maximum, minimum, and mean temperatures and temperature range series was investigated using cumulative sum (CUSUM) charts. Then, the non-parametric Mann-Kendall test was applied to the average annual, monthly and seasonal series. Prior to the application of the Mann-Kendall test, gaps in the historical dataset were filled using a geostatistical technique, namely the Residual Ordinary Kriging, and then processed to remove the influence of serial correlation on test results. Significant trends were quantified using a robust non-parametric estimate. Once the trends at each site were identified, the spatial patterns in those trends were obtained using the Inverse Distance Weighted.

Results indicated a general increase in the analysed series over the area of study. Upward trends in maximum temperatures frequently occurred during the winter months, with the largest increases in the south-west, while mean temperatures increases occurred mostly during the spring, summer and winter. Across a wide western area, a small number of negative trends were observed in annual minimum temperatures, especially in autumn months. Temperature ranges showed both positive and negative trends. Decreasing trends occurred along the eastern coast and in the western part of the region.

1. Introduction

Temperature trends likely represent the most evident indicator of the changes occurring in the Earth's climate system. For this reason, interest in the analysis of temperature variability and trends has increased markedly in recent decades. In particular, the investigation of temperature extremes trends, as well as the attribution and prediction of these changes, is incredibly important because extreme temperature events can seriously affect ecosystems, human health and economy (Solomon et al., 2007; Karl et al., 2008; Field et al., 2014; Piao et al., 2017). Indeed, increases in temperature lead to increases in the moisture-holding capacity of the atmosphere, affecting the hydrological cycle, especially characteristics associated with precipitation (intensity, frequency, amount, duration and type) and extreme events.

On a global scale, since 1950 both daily maximum and minimum temperatures have been subject to positive trends, in particular minimum daily temperatures have increased faster than maximum daily temperatures (IPCC, 2013). According to Easterling et al. (1997), the increase in the global mean surface air temperature is due, at least partially, to differential changes in daily maximum and minimum temperatures, that result in a narrowing of the diurnal temperature range. However, the observed warming has not been uniform over time and space (Jones and Moberg, 2003). Alexander et al. (2006) showed that, during the second half of the 20th century, maximum and minimum temperatures significantly increased on a global scale. The increase in maximum temperatures has been small in magnitude if compared with that of minimum temperatures (+ 0.204 °C/decade and + 0.141 °C/decade respectively), but it has led to a decrease in the diurnal temperature range (− 0.066 °C/decade), mainly due to the differential warming occurred during the period prior to the 1980s (Vose et al., 2005; Trenberth et al., 2007). However, the decrease in cold extremes was marked (Alexander et al., 2006; Karl et al., 2008). More recently, Donat et al. (2013) found evidence of large-scale warming trends in temperature extremes, particularly in minimum temperatures at the beginning of the 20th century.

The evidence of extreme temperature changes has been revealed at a global scale, but a great number of studies indicates that these trends are also evident at regional and local scales. These researches focused on study regions located in Africa (Kruger and Shongwe, 2004; New et al., 2006), Asia (Jiang and Yang, 2012; Sonali and Kumar, 2013;

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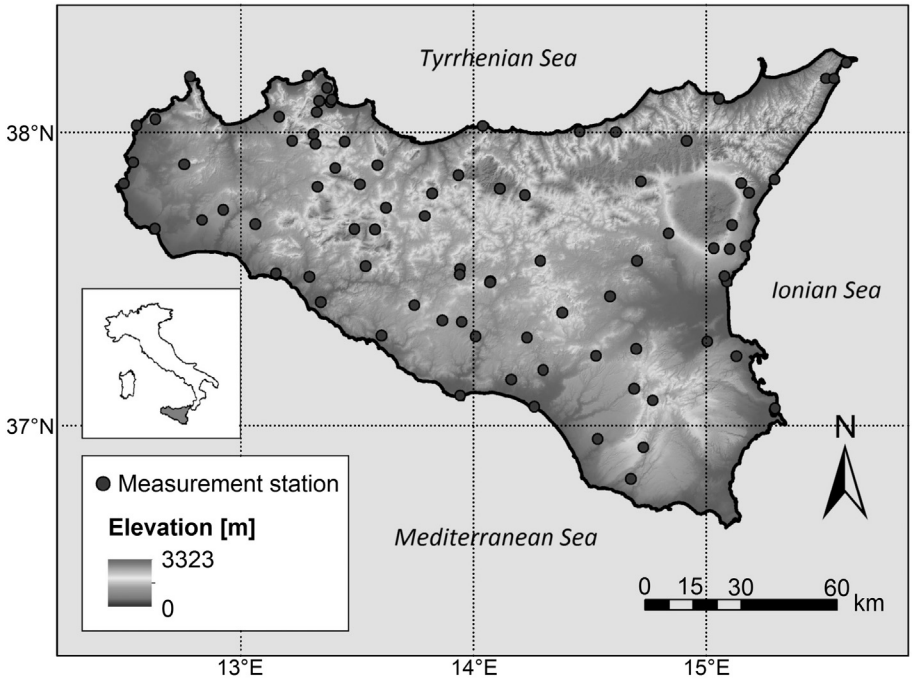

Fig. 1. Location of measurement stations.

Sharma et al., 2016), Australia (Plummer et al., 1995), Europe (Martínez et al., 2010; El Kenawy et al., 2012) and America (Vincent et al., 2005; LaDochy et al., 2007; Finkel and Katz, 2017).

In the Mediterranean region, Domonkos et al. (2003) investigated the variability of winter extreme low-temperature events and summer extreme high-temperature events analyzing the daily temperature series (1901–98) recorded in 11 sites of Central and Southern Europe; the study revealed several signs of a slight but general warming. Throughout the Eastern Mediterranean region, Kostopoulou and Jones (2005) detected statistically significant trends for both minimum and maximum temperatures.

In Italy, a number of studies have focused on the analysis of average temperatures (Ventura et al., 2002; Caloiero et al., 2015), while others have focused on extreme events (Bartolini et al., 2008; Boccolari and Malmusi, 2013). Brunetti et al. (2006) examined mean, maximum and minimum monthly temperature series recorded in Italy and found that, during the 1954–2003 period, the positive trend in maximum temperatures has been stronger than that for minimum temperatures. This result could seem in contradiction with the global increase of minimum temperatures higher than that of maximum temperature (Alexander et al., 2006; Donat et al., 2013). Nevertheless, Brunetti et al. (2006) also found that minimum temperature trend was higher than that of maximum temperature, if considering the 1865–2003 period. It has to be remarked that maximum and minimum temperature trends did not evenly occurred in space and in time, as demonstrated by the large number of regional studies, and the rate of increase highly depends on the location.

In a study carried out by Toreti and Desiato (2008), changes in temperature extremes across Italy during the period 1961–2004 were examined through the calculation and statistical analysis of 10 indices. Most of the indices showed a cooling trend until the end of the 1970s, followed by a more considerable warming trend in the last 25 years. The above-mentioned studies analysed extreme temperature series in Italy, but none of these studies focused on southern Italy, where, according to Brunetti et al. (2004), a stronger increase in annual mean temperatures compared to the rest of the peninsula occurred.

In Sicily, Viola et al. (2013) analysed temperature data from 80 spatially distributed stations for the period from 1924 to 2006 to investigate possible evidence of climate changes in the region. This analysis, which focused on mean temperature series, noted the occurrence of a general warming trend in Sicily during the analysed period. In this study annual, seasonal and monthly maximum and minimum temperature series from 84 measurement stations in Sicily were analysed for the 1924–2013 period in order to investigate the existence of trends in the region. First, the occurrence of abrupt change points in annual maximum, minimum and mean temperatures and temperature ranges - or change points - were investigated using spatially averaged values for the entire study area. These points were detected using cumulative sum (CUSUM) charts, and the confidence level for each point was determined through a bootstrap analysis. Afterwards, the non-parametric Mann-Kendall test was used to detect statistically significant trends in the above-mentioned series. The trend analysis was carried out at local and regional scale at the 90%, 95% and 99% confidence levels. Prior to the application of the Mann-Kendall test, the historical dataset was completed using geostatistical techniques and then processed in order to remove the influence of serial correlation on the results of the test. Once trends were detected, a spatial interpolation technique was used to verify whether trends are distributed throughout Sicily according to well-defined spatial patterns.

2. Dataset

In this study, temperature data recorded in Sicily have been analysed. Sicily is an island of about 25,700 km^2 located in Southern Italy. The climate is Mediterranean, characterized by mild winters and hot, generally dry summer. The annual rainfall in the area varies from 400 mm/year (at lower elevations) to 1300 mm/year (at higher elevations). The mean annual temperature ranges between 11.0 °C and 19.4 °C. Namely, the highest temperatures (18.5–19.5 °C) are recorded along the coast, while the lowest temperatures (10.5–13.5 °C) are typical of the highest elevations.

Historical temperature series for the period 1924–2013 measured at 84 gauges across Sicily (Fig. 1) were provided by the *Osservatorio delle Acque della Regione Sicilia.*

A preliminary examination of the monthly maximum and minimum temperature series recorded in the 84 gauges has been carried out, showing that about the 20% of the total number of data were missing. Since the investigation of trends in meteorological variables requires a