ANALYSIS OF TEMPERATURE CHANGES IN VALSESIA (NORTH WESTERN OF ITALY)

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Abstract: The aim of this study is to identify any possible temperature changes within the last 20 years in Valsesia, North Western of Italy. We considered four weather stations located from 470 m asl to 4554 m asl for the 2003–2021 period, 19 years. The daily series have on average 3% missing data corresponding to 208 days out of 6935 days. Among the available stations, we analysed the temperature series of Capanna Margherita, the weather station located at the highest altitude in Europe (4554m asl). The analysis showed an increase in temperature. The extreme maximum temperatures show an average increase of 0.012°C/year, while the extreme minimum temperature identify an average decrease of -0.035 °C/year. .

Keywords: climate change; mountain region; maximum and minimum temperature.

Résumé: Analyse des changements de température en Valsesia (Nord-Ouest de l'Italie): L'objectif de cette étude est d'identifier les éventuels changements de température au cours des 20 dernières années à Valsesia, dans le nord-ouest de l'Italie. Nous avons considéré 4 stations météorologiques situées entre 470 m asl et 4554 m asl pour la période 2003-2021,19 ans. Les séries quotidiennes ont en moyenne 3% de données manquantes, ce qui correspond à 208 jours sur 6935 jours. Parmi les stations disponibles, nous avons analysé la série de températures de Capanna Margherita, la plus haute station météorologique d'Europe, 4554 m. L'analyse a montré une augmentation de la température. Les températures maximales extrêmes montrent une augmentation moyenne de 0,012 °C/an, tandis que les températures minimales extrêmes indiquent une diminution moyenne de -0,035 °C/an.

Mots-clés: changement climatique ; région de montagne ; température maximale et minimale

Introduction

The Alpine Region is one of the most sensitive environments to climate change (Knoche 2011). Since 1996, the IPCC, International Panel of Climate Change, has underlined the need to understand and predict the effects of climate change in mountainous regions through monitoring, experimental studies and modelling. A change in the alpine climate regimes can, in fact, influence winter precipitation and the persistence of the snow cover can lead to impacts of considerable magnitude (Ronchi and Loglisci 2008) on river systems and on the socio-economic structures of the populations that live in the mountains and valleys (Hill Clarvis et al. 2013). The positive trend observed for winter temperatures is closely linked to the reduced snow cover that has been observed in recent years in the Alps (Serquet et al. 2013).

Quantifying rates of climate change in mountain regions is of considerable interest, not least because mountains are viewed as climate "hotspots" where change can anticipate or amplify what is occurring elsewhere. Accelerating mountain climate change has extensive environmental impacts, including depletion of snow reserves, critical for the world's water supply. Diaz and Bradley (1997) investigated elevational differences in long-term temperature trends, using high-elevation station records from various locations over the world, and found that the warming of the surface temperature is stronger for high-altitude sites. In more recent studies, it has been observed that the greatest temperature changes have been recorded in the cold season, when the anomalies of the daily maximum can reach 20 °C or more (e.g., December 17th 2005, Fratianni et al. 2009), compared to the increment of 10 °C observed for the summer heat waves.

The aim of this study is to identify any possible temperature changes within the last 20 years in Valsesia, North Western of Italy. In this area, snow has been abundant since the early 1980s, but due to poor winter precipitation a significant decrease in the snow pack thickness was recorded in the last two decades (Fratianni et al., 2014). The positive trend observed for winter temperatures is closely linked to the reduced snow cover that has been observed in recent years. Recent study on the Alps showed a correlation between the variation in temperature and altitude (Willibald et al. 2021). The warming of the surface temperature is strongest for high-altitude sites. In particular, they observed that the greatest temperature change was recorded in the cold season.

1. Data and Method

1.1. Study area

Valsesia is a group of valleys in the North-West of Italy and it lays in the southern slope of Monte Rosa on the Swiss border, reaching its highest point at Punta Gnifetti (4,559m). In the upper Valsesia, economic activities are mostly based on tourism linked to the mountains, in fact it takes part of the Monterosa Ski, one of the largest ski areas in Europe. The climate of Valsesia can vary greatly in relation to altitude. One of the most known conditions is the abundance of rainfall. The lower part of the valley is humid and rainy and the annual rainfall can be around 2,000 mm whereas, in the upper part of the territory, the phenomenon tends to decrease and to be around 1,200 mm per year. The mountain altimetry favours a good snowfall, usually more abundant in January. Thermal values can be extreme: in winter there are very low temperatures (even lower than -10 °C) while summer can be hot and sultry.

1.1. Meteorological data

The climate analysis was carried out on four weather stations located in Valsesia, north-western Italy (Table 1; Figure 1). Data was collected by ARPA, (Regional Agency for the Protection of the Environment) Piedmont from 2003 to 2021. In particular, we analysed daily maximum (Tx) and minimum (Tn) temperature.

Manual quality control (QC) was carried out using the ClimPACT2 software (Zhang and Feng, 2004, Alexander and Herold, 2016). The programme highlights any temperature values that are obviously wrong, such as maximum temperature lower than minimum, and creates plots that allow us to visualize the behaviour of the daily series and missing data (Tabe 1).

Monthly indices and monthly variables are calculated if no more than 3 days are missing in a month, while annual values are calculated if no more than 15 days are missing in a year. No annual value will be calculated if any one month's data are missing (Hyndman and Fan, 1996).

The trends, of meteorological variables, TX and TN, and climate indices have been calculated for the monthly and annual values. The trends were computed using the TheilSen approach (TSA) (Sen 1968; Zhang et al. 2000; Toreti and Desiato 2008). The trend is removed from the series if it is significant and the autocorrelation is computed. This process is continued until the differences in the estimates of the slope and the AR (1) (autoregressive model) in two consecutive iterations are smaller than 1 %. The Mann-Kendall test for the trend is then run on the resulting time series to compute the level of significance, 10% (Mann, 1945). TSA is preferred to the linear least square that is more vulnerable to gross error of data and has a confidential interval more sensitive to the non-normality of the distributions.

The trends of meteorological variables (Tx and Tn) and climate indices have been calculated for the monthly values. The trends were computed using the Mann-Kendall test with a level of significance equal to 10% (Mann, 1945).

Eight temperature indices (Table 2) are selected from the list of 27 core climate extreme indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI). For percentile indices (e.g., the number of days exceeding the 90^{th} or 10^{th} percentile of minimum temperature or maximum temperature), the methodology uses bootstrapping for calculating the base period values so there is no discontinuity in the indices time series at the beginning or end of the base period (Zhang et al. 2011). The selected base period for the percentile indices was 2007–2016.

Subsequently the frequency (F), number (N) and duration (D) of heat waves (HWs) (Table 2, Fortin et al. 2016) for the investigated period were calculated. A HW for minimum temperature and maximum temperature was defined as any period between May and September with three or more days during which Tn was >90th percentile of Tn and Tx was > 90th percentile of Tx. Also, the linear regression of the mean HW variables were then calculated. Moreover, to highlight variations in extreme events the maximum number, frequency and duration of HWs (calculated on maximum and minimum temperature) recorded in one year were investigated (Table 5).

Table 1. Weather stations analysed

Station	Altitude (m asl)	Latitude N (WGS84)	Longitude E (WGS84)	Daily gaps (%)
Varallo	490	454910	081626	0.4
Rassa	925	454610	080059	1.0
Alagna	1,347	455288	075610	6.7
Capanna Margherita	4,554	455538	075237	5.1

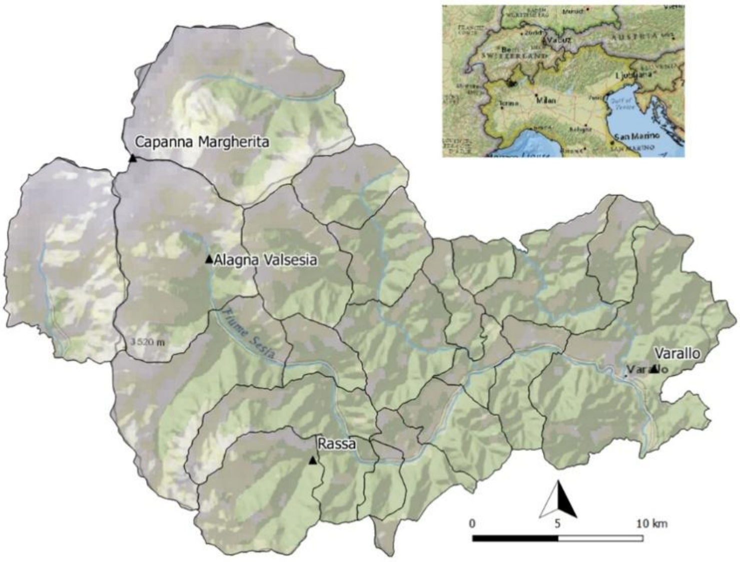

Figure 1: Map of Italy, and location of the weather stations in Valsesia (North-western Italy)

Table 2. Climate extreme indices selected by the Expert Team on Climate Change Detection and Indices (ETCCDI)

Indices	Definition	Units
Tx90p	Percentage of days when TX > 90th percentile	(%)
Tn10p	Percentage of days when TN < 10th percentile	(%)
Tx90.HWN	Heatwave number as define by the 90th percentile of Tx	Events
Tx90.HWD	Heatwave duration as define by the 90th percentile of Tx	Days
Tx90.HWF	Heatwave frequency as define by the 90th percentile of Tx	Days
Tn90.HWN	Heatwave number as define by the 90th percentile of Tn	Events
Tn90.HWD	Heatwave duration as define by the 90th percentile of Tn	Days
Tn90.HWF	Heatwave frequency as define by the 90th percentile of Tn	Days

2 Results

We estimated the trends of climate indices for maximum and minimum temperature on Valsesia in the last 19 years. The analysis highlights a significant warming tendency in most of the locations for minimum temperature (Table 3). In fact the Tn10p index shows decreasing trends for all the stations. Only in Capanna Margherita (4554 m asl) a non-significant decreasing tendency has been estimated. Rassa (925 m asl) and Varallo (490 m asl) stations recorded the highest trends, respectively -0.054 and -0.036 % of days (Figure 2).

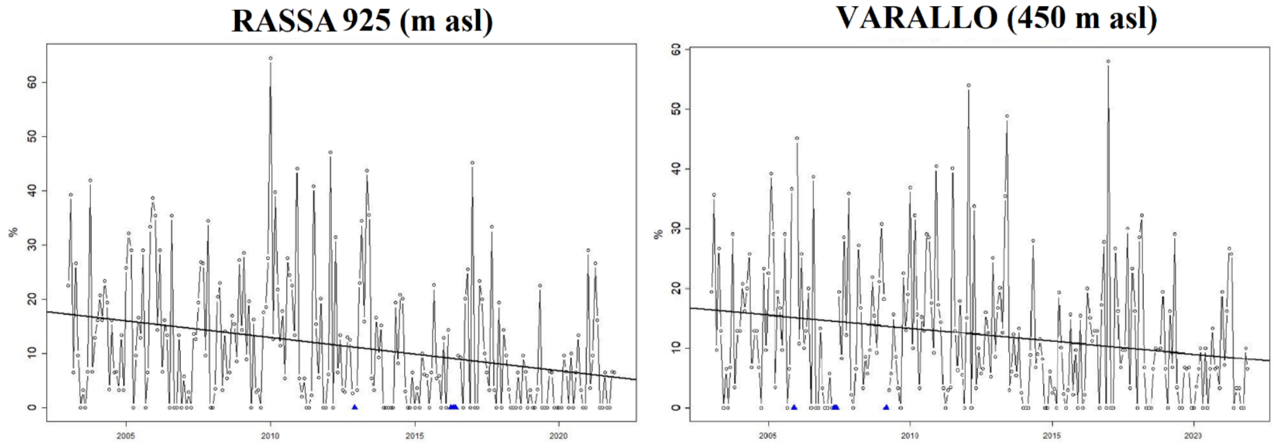

Figure 2. Left panel percentage of days when TN < 10th percentilecalculated in Rassa from 2003 to 2021; Right panel percentage of days when TN < 10th percentile calculated in Varallo from 2003 to 2021. The blue triangles represent the gaps in the series.

Table 3. Annual estimated trends, from 2003 to 2021, for climate indices Tx90p, Tn10p. In bold the statistical significant trends.

Station	**Altitude (m asl)**	**Tx90p (%)**	**Tn10p (%)**
Varallo	490	0.019	**-0.036**
Rassa	925	0.005	**-0.054**
Alagna	1,347	0.019	**-0.029**
Capanna Margherita	4,554	0.003	-0.020

The increase of maximum temperature is also highlighted by the climate index Tx90p. For all stations the trends increased but are not statistically significant (Table 3). The maximum slope (0.019 % of days) is calculated in Varallo (490 m asl) and Alagna (1337 m asl, Figure 3 left). In Rassa (925 m asl) and Capanna Margherita (4554 m asl) the slope is near to zero (Figure 3 right). Also, in all stations the maximum values of Tx90p were observed in 2015 with an average of 60% of days classified as hot. Marchina et al. (2017) figured out that 2015 was the warmest year since 1880 in northern Italy. This has brought severe drought events since Autumn 2015 influencing the water balance of the affected areas.

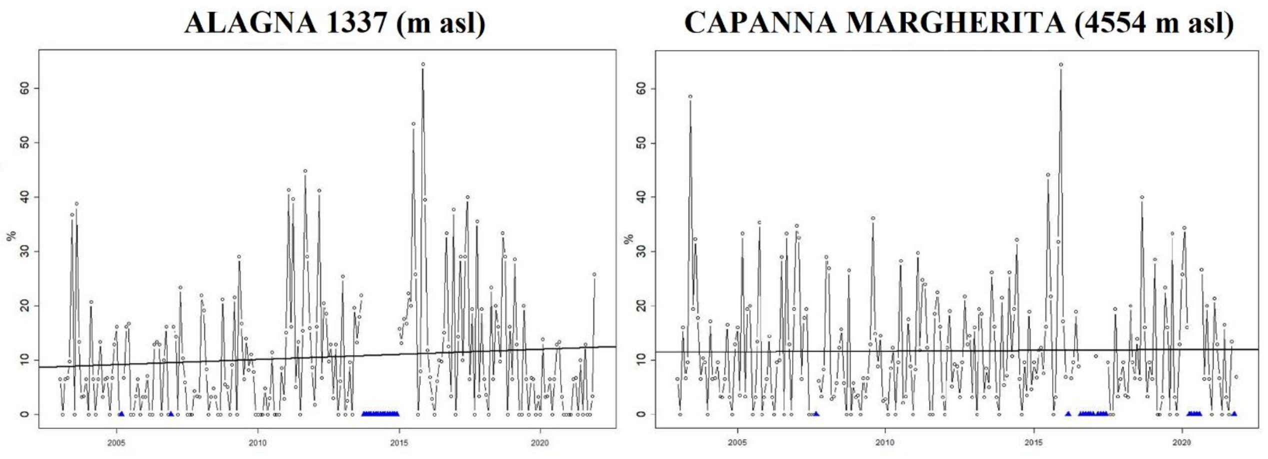

Figure 3. Left percentage of days when TX > 90th percentile calculated in Alagna from 2003 to 2021; Right percentage of days when TX > 90th percentile calculated in Capanna Margherita from 2003 to 2021. The blue triangles represent the gaps in the series.

The heat wave indices show positive and non-statistically significant trends, highlighting an increase of heat waves in number, in duration and in frequency in the entire study area. Moreover, a negative and close to zero trend is calculated in Capanna Margherita (4554 m asl) for the Tx90HWD trend (Table 4). The higher values of heat waves are calculated for Tx90HWF and Tn90HWF followed by Tx90HWD and

Tn90HWD. For Tx90HWN and Tn90HWN the values of the slopes are near to zero, highlighting an absence of trends. This behaviour of HW indices shows that in this area the duration of heat waves increased.

Table 4. The trends of heat wave indices. The trends are not statistically significant. In bold the maximum value of the slope.

Station	Tx90.HWN	Tx90.HWD	Tx90.HWF	Tn90.HWN	Tn90.HWD	Tn90.HWF
Varallo	**0.07**	**0.18**	**0.43**	0.04	**0.14**	**0.31**
Rassa	0.04	0.15	0.3	0.02	0.12	0.19
Alagna	0.04	0.04	0.17	0.04	0.12	0.22
Capanna Margherita	**0.07**	-0.02	0.29	**0.05**	0.03	0.26

The investigation of the extreme heat waves shows that for the greatest number of stations the maximum number, frequency and duration of HWs were recorded in 2015. It turns out that for maximum temperature (Tx90), in 2015, the maximum duration was recorded in the two stations located at low elevations (Rassa and Varallo) with 12 and 15 consecutive days. While at high altitudes the duration is 8 days. For the frequency the highest values were detected for Varallo and Alagna with 21 and 29 days respectively. In terms of the number of heat waves the study figured out that Alagna only detected the highest annual number with 6 events (Table 5). While for the other stations 2016 and 2019 are the years with the greatest number of HWs.

It is also important to note that in 2015, for minimum temperature (Tn90), only the stations located at high elevations (Alagna and Capanna Margherita) recorded the maximum durations (8 days), frequencies (25 and 17 days respectively) and number (6 and 4 events respectively) of heat waves (Table 5).

Table 5. Analysis of the extreme heat waves for the investigated period. In the table the maximum duration, frequency and number of heat waves and the recorded years were reported. In bold the most recurring year.

	HWD-Tn90		HWD-Tx90		HWF-Tn90		HWF-Tx90		HWN-Tn90		HWN-Tx90	
	Years	Days	Years	Days	Years	Days	Years	Days	Years	Numbers	Years	Numbers
Alagna	**2015, 2016**	8	**2015**	8	**2015**	25	**2015**	20	**2015**	6	**2015, 2016**	6
Capanna Margherita	2005	9	**2015**	8	**2015**	17	**2015, 2019**	17	**2015**	4	2019	5
Rassa	2014,2020	9	**2015**	15	2006	27	**2015**	17	2006	7	2006,2011,2016, 2018	3
Varallo	2014, 2018	11	**2015**	12	2014	16	**2015**	21	2013, 2020	4	2016,2018	5

Conclusion

This paper presents a detailed analysis of the climatic variations occurred in Valsesia, in the north-west of Piedmont, Italy. The time period from 2003 to 2021 has been analysed, considering in the analysis only standard temperature indices, (Tx90p and Tn90p) and then analysing the heat waves, evaluating their duration, frequency and number for both maximum and minimum temperature.

The study figured out a clear climatic change in the study area, and this is marked for the minimum temperature. In particular for the percentage of days with minimum temperature below the 10th percentile, significant and negative trends were observed for the stations of Alagna, Rassa and Varallo. This has demonstrated the hypothesis of a more rapid warming of minimum temperature in Piedmont (Acquaotta et al. 2015).

Moreover, the analysis of heat waves shows that, as observed by Marchina et al. 2017 for the Po Valley, 2015 was an extremely hot year even in a mountainous area as Valsesia. According to the previous results, the maximum values for duration, frequency and number of heat waves was observed for minimum temperature.

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