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On the continuity and climatic variability of the meteorological stations in Torino, Asti, Vercelli and Oropa

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With 5 Figures

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Summary

This work analyses the maximum and minimum temperatures and the precipitation series of four localities in Piedmont. Measurements regarding the stations of Torino, Asti, Vercelli and Oropa have been extracted from the meteorological database of the ex-SIMN (Hydrographic and Mareographic National Service). The values in the period 1990–2003 have been compared with the measurements carried out at the ARPA (Regional Agency for Environmental Protection)-Piedmont stations located about in the same place, in order to assess they similarity and possibly join the series. For each series, an historical investigation has been performed, and the homogeneity has been evaluated using the Standard Normal Homogeneity Test (SNHT). The results evidence some discontinuities among the data recorded by each couple of stations located in the same place, for both temperatures and precipitation. These discrepancies between the measurements underline the importance of using the homogeneity tests. The homogeneized meteorological series have been converted by the SNHT in a good instrument for estimating the trends and the real climatic changes.

1. Introduction

In this study, two climatically fundamental parameters have been analyzed: the precipitation and the temperature. Scientists have measured these parameters for long time in order to determine their variations at different temporal scales, but only during the last few decades they have considered the problem in a more systematic manner for estimating the data consistency. In order to correctly study these variations, we must possess homogeneous series. According to Conrad and Pollack (1962) and Peterson et al. (1998), climatic series can be considered homogeneous when their variations are due only to climatic events. Unfortunately, most data show non-climatic factors that may hide the real changes. The discontinuities can be due to a change in the station location, a replacement of the meteorological instruments, or a variation in the characteristics of the surrounding environment.

In Italy, since 2002, a national law forced the unification of the meteorological networks owned by the ex-SIMN (Hydrographic and Mareographic National Service) with those of the ARPAs (Regional Agencies for Environmental Protection). Both institutions had, prior of this unification, a dense network of monitoring stations, sometimes located very close to each other. After the unification, ARPA decided to dismiss some ex-SIMN stations located very close

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to the ARPA ones. An important aim of this study is to verify if, in those cases, the two stations observations could be considered statistically equivalent, in order that, in each location, the ex-SIMN station observations (which normally have long time series of measurements) could be joined to the ARPA's corresponding station observations. This technique could allow to getting longer series because the ARPAs meteorological stations are still operative.

Long-term instrumental climate records are the basis of climate research, but the homogeneity of these long instrumental data series is very important to correctly describe the climate variations. However, in most cases, these series can be modified by changes in the measurement conditions, and frequently these changes are not recorded in the archives (or their traces have been lost), which are thus often incomplete. In order to deal with this crucial problem, many statistical homogeneization procedures have been developed for detecting and correcting the inhomogeneities (Alexandersson and Moberg 1997a, b).

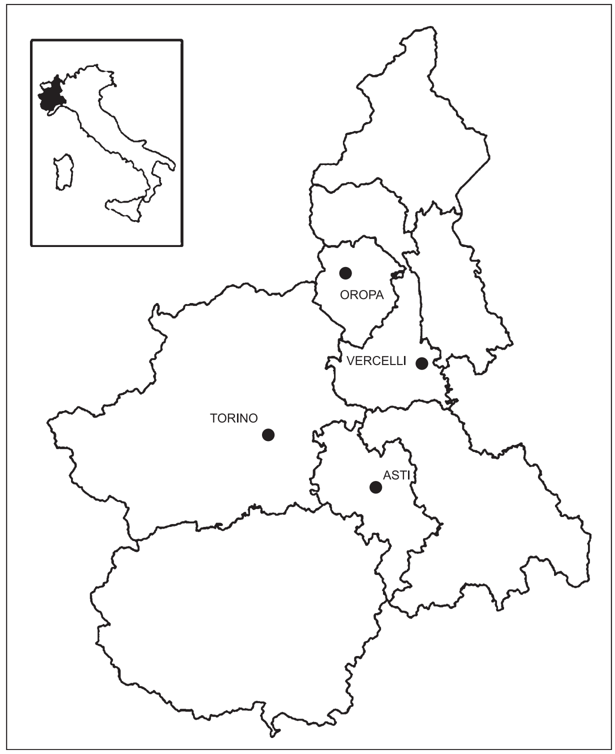

Fig. 1. Geographic location of the meteorological stations in Piedmont region, Italy

2. The data and the methodology

In this report, the thermo-pluviometric series of four Piedmontese locations (Fig. 1 and Table 1) have been studied. The ex-SIMN meteorological stations of Torino, Asti, Vercelli and Oropa have been chosen because they were meteorological observatories operating continuously for 53 years,

Table 1. Characteristics of the meteorological stations analyzed in this study. E is the elevation (masl), Lat and Long are latitude and longitude, respectively, P represents the period of availability of data, and D the horizontal distance among the couple of the stations

Station	E (m)	Lat N	Long E	P	D (m)
Torino (ex-SIMN) Office ex-SIMN	269	45°04′18″	7°47′27″	1951–2003	830
Torino (ARPA) Buon Pastore	240	45°04′49″	7°40′25″	1989–2005	
Asti (ex-SIMN) Municipal aqueduct	158	44°54′34″	8°15′19″	1951–2003	2350
Asti (ARPA) Borgo Tanaro	117	44°53′09″	8°12′48″	1998–2005	
Vercelli (ex-SIMN) Farmstead Boraso	135	45°19′50″	8°21′40″	1951–2003	1360
Vercelli (ARPA) Ruggerina	132	45°19′32″	8°23′26″	1993–2005	
Oropa (ex-SIMN) Santuario Oropa	1180	45°37′40″	7°58′57″	1951–2002	5
Oropa (ARPA) Santuario Oropa	1186	45°37′40″	7°58′56″	1990–2005	

from 1951 to 2003 (Oropa for 52 years, from 1951 to 2002), while the corresponding ARPA stations have considerably shorter records (6 to 15 years). These series have different lengths, but in each case there is a period of overlap, and they can be compared directly.

As first step, an historical research over each station pertaining to the two agencies has been carried out. In this way, the potential breaks in the data homogeneity, either due to changes of location or instrument, have been determined. For the ex-SIMN stations, the Annals (Hydrographic and Marigraphic National Service archives, 1951–1990), in which the geographic coordinates of each station (latitude, longitude and elevation) were recorded every year, have been consulted. Moreover, to have further information about the history of the ex-SIMN stations, some bibliographic researches (Cortemiglia 1999; Cat Berro et al. 2005) have been carried out. Subsequently, the original traces of the ex-SIMN observations have been inspected in order to eliminate the errors caused by an incorrect reading of, or by a wrong transcription from, the original paper diagrams. Concerning the ARPA stations data, an automated check is normally performed, resulting in flags associated with the data, that describe their accuracy.

For each locality there is a period of overlap (Table 1) among the ex-SIMN and ARPA series, which have thus been compared directly. In order to make a direct comparison between the daily thermo-pluviometric series of each couple of stations in a given location, for every year and for both series, the values missing in at least one station have been neglected, therefore only the values measured at the same time by the two instruments have been compared. For the temperatures (precipitation) series, we have analyzed the daily (monthly cumulated) data. For every year, the daily (only for temperatures series), monthly, seasonal and annual correlation coefficients have been evaluated during the period of the measurement overlapping. For the maximum and minimum temperatures, the series of the daily mean differences among each couple of station values have been calculated as:

$$T_{\text{difference,MAX}} = T_{\text{max,ex-SIMN}} - T_{\text{max,ARPA}};$$
$$T_{\text{difference,MIN}} = T_{\text{min,ex-SIMN}} - T_{\text{min,ARPA}}. \quad (1)$$

For the monthly precipitation amounts, the series of the ratios among each couple of station values have been calculated as:

$$R = \frac{P_{\text{rain,ex-SIMN}}}{P_{\text{rain,ARPA}}}. \quad (2)$$

Over the new series (1) and (2), a statistical analysis has been carried out. We have excluded the distribution tails, identified by the 2nd and 98th quantiles. This procedure has allowed to eliminate the extreme data of the series which may arise by a wrong registration.

Subsequently, the mean values, the standard deviations and other statistical parameters of the series (1) and (2) have been evaluated; the Student and Kolmogorov-Smirmov tests have been applied to all series (maximum and minimum daily temperatures, and monthly cumulated precipitation) in order to assess the significance of the obtained results. The T-test was applied for checking the average value of the series. The differences series (maximum and minimum temperatures) should take an average value close to zero, while the ratio series (precipitation series) close to one. In this test, the null hypothesis assumes that the average value of the two distributions is equal. In order to estimate whether the compared series belong to the same distribution, the Kolmogorov-Smirnov test has been applied. This test is nonparametric and the null hypothesis assumes that "x" and "y" are drawn from the same continuous distribution. For both tests, an $\alpha = 5\%$ significance level has been assumed. To visually analyze the relationship between the data for each pair of stations, scatter plots were produced. In addition, also the series of the cumulated daily precipitation has been evaluated.

In the case in which the comparison between the data of a couple of stations in the same location has given good results, the two station data have been unified in a single database. This technique has allowed us to get longer series (1951–2005) because the ARPAs meteorological stations are still operative.

Subsequently, for the maximum and minimum temperatures, and the precipitation series, the monthly mean or cumulated amounts have been reconstructed by creating a "complete" dataset, without missing data. Four methods based on different weight averaging techniques (Eischeid et al. 2000) have been chosen: (i) the normal ratio method (NR), in which the weights for the surrounding stations are given by: $W_i = \frac{\rho_i^2(n_i-2)}{1-\rho_i^2}$, ρ_i being the correlation coefficient for each monthly series between the candidate station and the i-th surrounding station, n_i the number of data of the i-th station used to derive ρ_i; (ii) the simple inverse distance weighting (IDW), in which the weight function W_i is the inverse of the distance between the candidate station and the i-th surrounding station; (iii) the multiple regression (MR); and (iv) the average of the previous three methods (MED).

For each candidate series, we have selected a maximum of four surrounding stations. The choice of the surrounding stations has depended on several factors: the spatial distribution of the surrounding observations, the geographical area, the elevation, the climatical features and the correlation coefficient (>0.80) between the candidate and the surrounding station series. The selection of the value for filling the gap due to a missing value has been done by choosing the method showing the highest correlation coefficient with the original series. Subsequently, the Standard Normal Homogeneity Test (SNHT) has been applied to the annual thermo-pluviometric series using the period available for each series, which normally was 1951–2005. The SNHT allows to detect and estimate the single shift variations of the mean values of a candidate series compared with a homogeneous reference series. In this work, we have developed the idea of using the SNHT for evaluating a single shift. As a first step, we have estimated the homogeneous reference series using the surrounding station series. We have used the ratios for the precipitation series (3) and the differences for the temperature series (4):

$$X_{R,i} = \frac{\sum_j^k \rho_j^2 X_j(\overline{Y}/\overline{X_j})}{\sum_j^k \rho_j^2}, \tag{3}$$

$$X_{R,i} = \frac{\sum_j^k \rho_j^2 (X_{j,i} - \overline{X_j} + \overline{Y})}{\sum_j^k \rho_j^2}, \tag{4}$$

where Y_i = candidate series; X_j = one of the surrounding reference series; ρ_j = correlation coefficient between the candidate and the surrounding station; $\overline{X_j}, \overline{Y}$ = mean value, calculated over a common time period.

Once identified the year of discontinuity, the period antecedent must be corrected by the correction factor estimated by the test (Stèpànek 2005). In this way, a complete and homogeneous series has been obtained. In order to estimate the consistency of the series, a level of significance of 5% has been imposed, and the trends have been calculated using the non-parametric Mann-Kendall test (Brunetti et al. 2001). The slopes of the trends have been evaluated using a linear regression.

3. The results

The historical research performed on the ex-SIMN stations has identified few significant variations in the meteorological stations. The

Table 2. Summary of statistical parameters evaluated for the daily maximum and minimum temperatures series. N-DATA = number of data used, average, SD = standard deviation, Q1 = first moment, median, Q3 = third moment, T test = p value of Student test, K-S test = p value of Kolmorgov-Smirnov test and ρ = correlation coefficient

	Maximum temperatures difference				**Minimum temperatures difference**			
	Vercelli	**Torino**	**Asti**	**Oropa**	**Vercelli**	**Torino**	**Asti**	**Oropa**
N-Data	2677	4635	1855	3539	2618	4665	1879	3564
Average	−1.04	−0.65	−0.45	−0.57	0.48	0.91	0.36	0.58
SD	0.74	0.91	1.00	1.35	0.97	1.09	0.77	0.81
Q1	−1.50	−1.30	−1.10	−1.40	−0.20	0.10	−0.10	0.00
Median	−1.00	−0.70	−0.40	−0.50	0.40	0.90	0.40	0.40
Q3	−0.60	0.00	0.20	0.30	1.10	1.70	0.90	1.00
T-Test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K-S Test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ρ	0.99	0.99	0.99	0.96	0.99	0.98	0.99	0.99

Torino station has changed location in 1962; the thermograph of the Asti station was moved in another place in 1984; finally, in the Oropa and Vercelli stations, we have not found variations in the position or characteristics of the instruments. The punctual validation carried out on the ex-SIMN data has allowed us to found, in the temperatures series, some accidental errors attributable to mistakes in the reading of the diagram scale, corresponding generally to errors of $\pm 5\,^{\circ}$C. For the precipitation data, the errors founded are mainly attributable to mistakes in the number transcription.

The analysis of the temperature series in the overlapped period shows very high correlation coefficients (Table 2); despite of this result, the couples of series do not seem to measure the same temperature. A first inspection shows that, in the four places, the maximum temperatures detected in the ARPA stations are higher than those in the ex-SIMN station. On the other side, the minimum temperatures show an opposite behavior (Table 2). Also the precipitation series of the four couples of stations in the same location show high correlation coefficients, and the Kolmorgov-Smirnov test highlights that these data have the same distributions for each couple of stations (Table 3). The results of this statistic tests allow to conclude that in two cases, Torino and Vercelli, the rainfall recorded in both stations can be considered as equivalent. Moreover, the average monthly precipitation ratio, in Torino, is equal to 0.96 ± 0.01 (Table 3 and Fig. 2b), while, in Vercelli, it is equal to 1.08 ± 0.02 (Table 3 and Fig. 2a). Thus, for these stations, we have decided to unify the precipitation series since 2004. We have chosen the year 2004 as union point in order to have long and complete series in the coming year without changing the real trend of the variable. In this way, we have used all data of the ex-SIMN's series (Torino and Vercelli) that have operated continuously until 2003.

The ratio of the monthly precipitation in Asti assumes also an average value near one, but, observing the cumulate curve (Fig. 3b), a

Table 3. Summary of statistical parameters evaluated for the monthly precipitation series. N-DATA = number of data used, average, SD = standard deviation, Q1 = first moment, median, Q3 = third moment, K-S test = p value of Kolmorgov-Smirnov test and ρ = correlation coefficient

	Mean montlhly precipitation ratio			
	Vercelli	**Torino**	**Asti**	**Oropa**
N-Data	101	147	33	140
Average	1.08	0.96	0.98	1.20
SD	0.25	0.15	0.30	0.21
Q1	0.95	0.87	0.83	1.08
Median	1.08	0.94	0.97	1.15
Q3	1.20	1.02	1.07	1.26
K-S Test	0.99	0.86	0.99	0.79
ρ	0.96	0.98	0.95	0.99

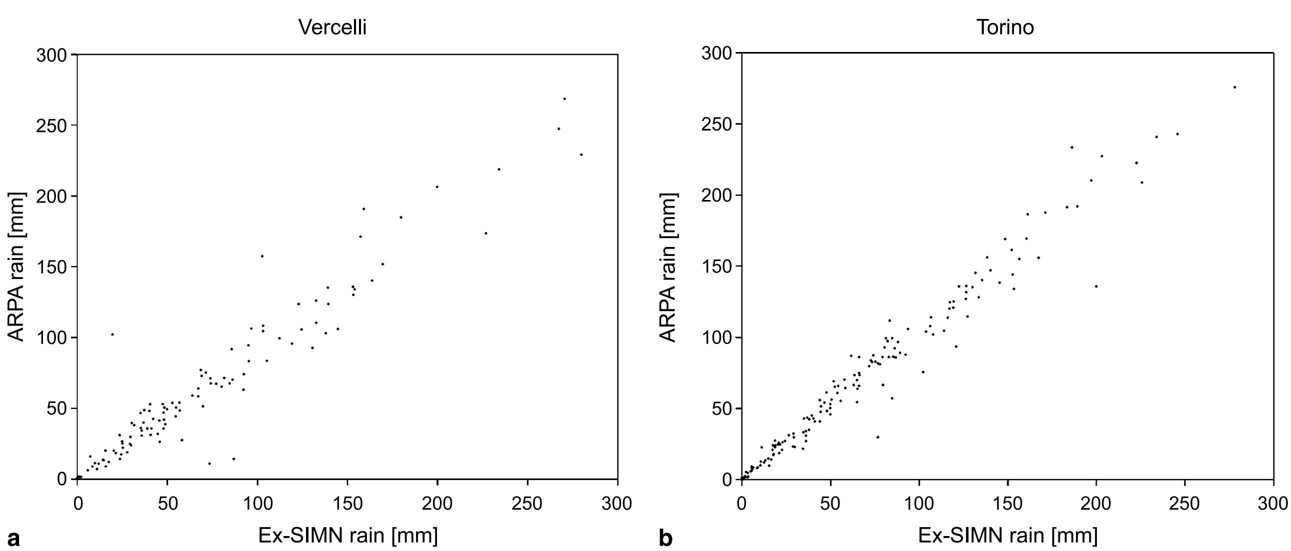

Fig. 2. Scatter plot of monthly precipitation recorded. In the abscissa, the ex-SIMN station; in the ordinate, the ARPA station (**a**) Vercelli, (**b**) Torino

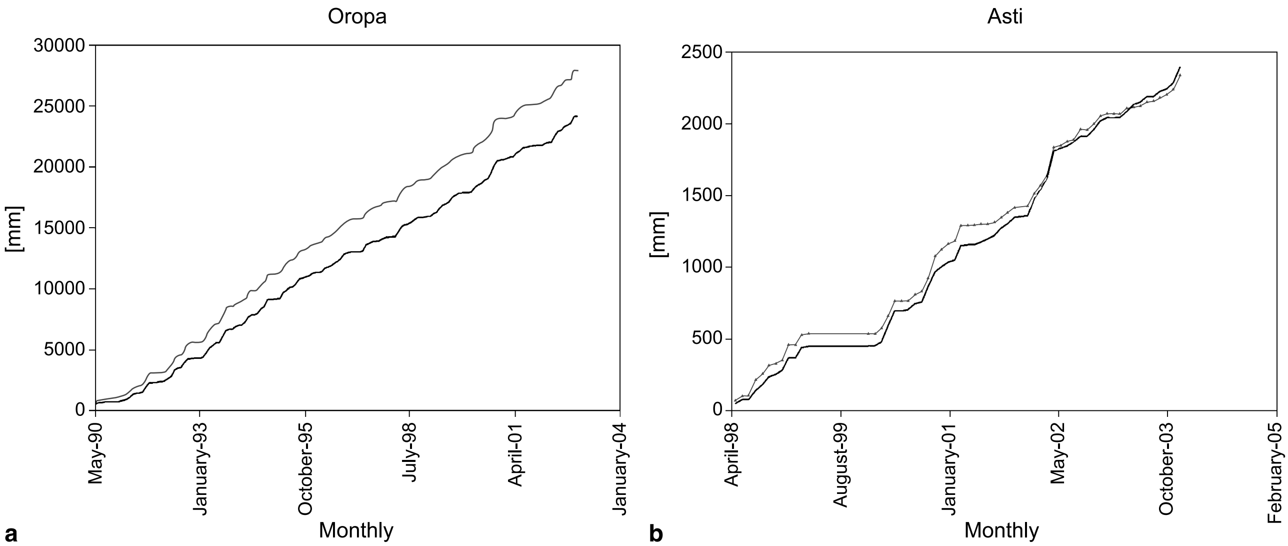

Fig. 3. Time trend of the cumulate curve of daily precipitation series at ex-SIMN (gray line) and ARPA (black line) stations, (**a**) Oropa, (**b**) Asti

difference in the measurement in the first overlapping period, from 1998 to 2001, has been found. In this period, the ex-SIMNs recording rain gauge has measured a greater amount of rainfall in comparison to ARPAs station, while, in the second period, from 2002 to 2003, the ARPA recording rain gauge has measured a larger value, and the two differences almost compensate. For this reason, despite the change in observational practice explains the average value of the ratio monthly series, close to one, it cannot be concluded that the two meteorological stations have measured always the same amount of rainfall. In Oropa, even if the instruments of the stations are located in the same place, very close to each other, they do not record the same amount of rainfall. This result is evident from the values of the ratio monthly series (Table 3), as well as from the cumulate curve diagram (Fig. 3a): the ex-SIMN recording rain gauge has measured a greater amount of rainfall with respect to the ARPA one.

Several monthly data of each series have been reconstructed, using prevailingly the methods IDW and MR (Fig. 4a) for the precipitation series, the MR method for the maximum temperature series, and MR and MED for the minimum temperature series (Fig. 4b).

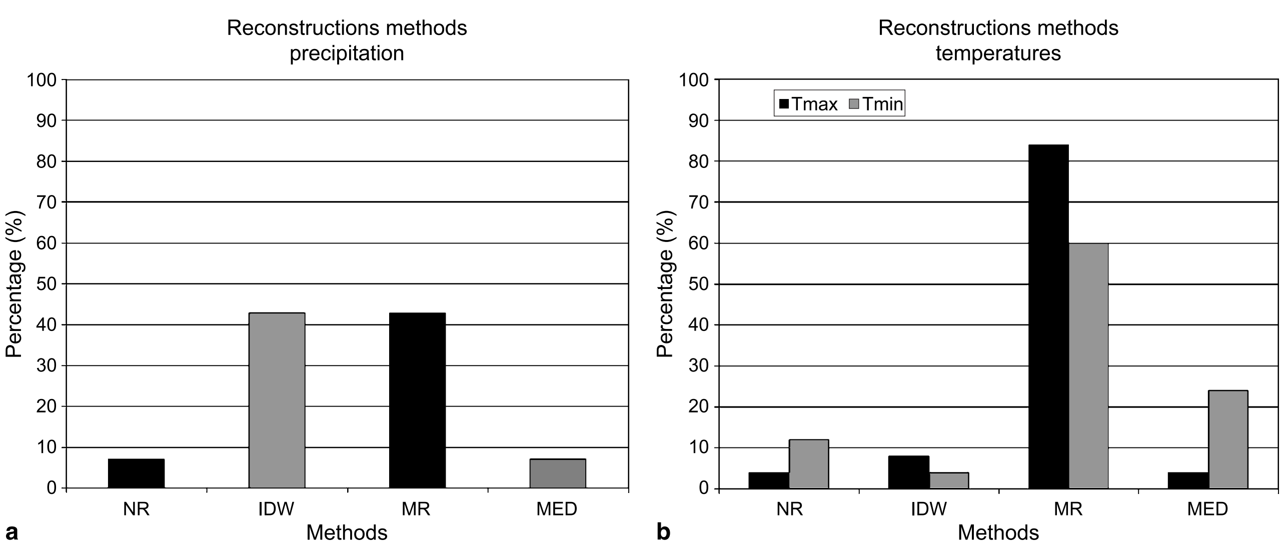

Fig. 4. Percentage of the reconstruction methods used for the precipitation (**a**) and temperatures (**b**) series

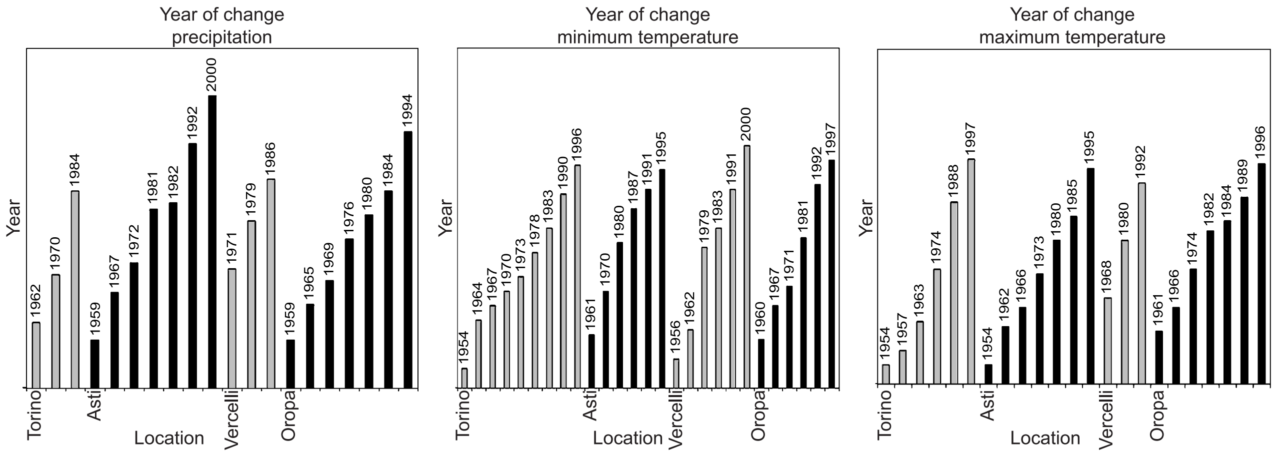

Fig. 5. Discontinuity years of the temperatures and precipitation series founded by applying the SNHT

The SNHT test has been applied to each 53-year series of the maximum and minimum temperatures measured by the meteorological stations of the ex-SIMN (from 1951 to 2003), to the 55-year precipitation series of Torino and Vercelli (from 1951 to 2005) and to the 53-year precipitation series of Asti (from 1951 to 2003) and 52-year of Oropa (from 1951 to 2002). For the maximum and minimum temperatures and precipitation series, several inhomogeneities in the data have been found (Fig. 5). Every inhomogeneity period has been corrected using some correction factors derived by the application of SNHT. For the series of temperatures, the correction factors (to be arithmetically added to the annual averages) have varied in the ranges $-0.9\,°\mathrm{C} \div 0.5\,°\mathrm{C}$ (Torino), $-1.4\,°\mathrm{C} \div 1.1\,°\mathrm{C}$ (Asti), $-1.1\,°\mathrm{C} \div 0.3\,°\mathrm{C}$ (Vercelli), $-0.4\,°\mathrm{C} \div 0.5\,°\mathrm{C}$ (Oropa). For the precipitation series, the correction factors (to be multiplied to the annual cumulated values) have varied in the ranges $0.9 \div 1.1$ (Torino), $0.5 \div 1.3$ (Asti) and $0.8 \div 1.2$ (Vercelli and Oropa).

After homogenizing the series, the annual time trends for each variable and series have been evaluated (Table 4). The highest annual increment in the maximum and minimum temperatures have been found respectively in Oropa ($0.036 \pm 0.005\,°\mathrm{C/yr}$) and Vercelli ($0.033 \pm 0.007\,°\mathrm{C/yr}$). These values correspond to a warming of 1.9 °C and 1.8 °C, respectively, over the whole period (53 years) taken into consideration. The temperature trends allowed also to highlight two different patterns: in Torino and Vercelli stations, the higher increment of the minimum temperatures has caused a decrease in the daily temperature excursion. On the contrary, at Oropa, the greatest increment was that of the maximum temperatures, which has produced an increment even of the daily excursion.

The application of the Mann-Kendall test has proven that the temperature trends are generally statistically significant, with the exception of the series of minimum temperatures at Asti. Concerning the precipitation series, the trends have shown a generalized decrease of the annual cumulated rainfall in the plain stations (Torino, Asti and Vercelli) and an increase for the Oropa station, located in the Alps, at the foot of the mountains. However, the Mann-Kendall test has individuated that only at Oropa the

Table 4. Maximum and minimum annual temperatures trends and annual precipitation trends computed in the different locations; p shows the significance of the Mann-Kendall test

Stations	T_{max} (°C/yr)	p value	T_{min} (°C/yr)	p value	Prec (mm/yr)	p value
Torino	0.020 ± 0.006	0.002	0.032 ± 0.005	<0.0001	-1 ± 2	0.52
Asti	0.025 ± 0.007	0.0002	0.003 ± 0.006	0.40	-2 ± 2	0.22
Vercelli	0.033 ± 0.007	0.0002	0.035 ± 0.005	<0.0001	-3 ± 2	0.26
Oropa	0.036 ± 0.005	<0.0001	0.025 ± 0.004	<0.0001	11 ± 5	0.01

annual rainfall trend is statistically significant at the 95% confidence level. The most relevant decreasing trend of the annual rainfall, even if not statistically significant, has been recorded in Vercelli (-3 ± 2 mm/yr); this value corresponds, over the period taken into consideration, to a decrease of 168 mm. Generally speaking, these values are in agreement with an analysis carried out over the historical ultrasecular series of Alessandria, another station located in the Piedmont plain (Cassardo et al. 2003). In Oropa, instead, the trend of increment of the annual rainfall is equal to 11 ± 5 mm/yr.

4. Conclusions

A preliminary analysis has been carried out on four couples of stations located in the Piedmont region, in north western Italy. Three of these stations (Torino, Asti and Vercelli) are located in the plain (the western part of the Po Valley), while the fourth (Oropa) is located at the foot of the mountains, in the pre-Alps.

The results obtained from the direct comparison, during a overlapping period (in general, 1990–2003), between the thermo-pluviometric series, highlight the differences among the observations carried out in different stations, even when they are located in the same place, at a small distance between each other. As a matter of fact, only in few cases it is possible to say that the observations recorded in both stations belong to the same statistical population. This work underlines the real difficulties encountered in comparing the series measured in different stations and also the possible errors regarding the measurements when the location and/or the instrumentation of a station are changed or modified.

The join between ARPA stations, which are still operative, and ex-SIMN stations has allowed to get longer series (1951–2005). Subsequently, the missing data have been reconstructed with some algorithms. The reconstructed series have been analyzed in order to reveal possible inhomogeneities.

The SNHT for the homogeneization has found some variations in the annual series. For the maximum (minimum) temperature series, we have found an average of 6 (7) inhomogeneities, in both cases over a period of 53 years, from 1951 to 2003. For the precipitation series of Torino and Vercelli, extended from 1951 to 2005, the SNHT has individuated 3 inhomogeneities in both series, while for the Asti and Oropa ones, extended from 1951 to 2003, an average of 7 inhomogeneities have been found.

The corrected data can be used for climate change evaluations. The trends calculated for the series of maximum and minimum annual temperatures show in all cases an increase of the temperatures. In the stations of Torino and Vercelli, the higher increment has been observed for the minimum temperatures, while in Oropa and Asti the higher increment has been recorded for the maximum temperatures. All trends are statistically significant. Concerning the trend of annual precipitation, a decreasing trend was found in the plain stations examined, while Oropa, the only mountainous station analyzed, showed an increasing trend in the annual rainfall. Due to the greater data variability, however, Oropa trend is the only one statistically significant.

The results obtained from this study suggests to extend the work and analyze also other locations in which there are a couple of meteorological stations located close to each other and that have simultaneous observations. Future work could also include the historical research, the reconstruction of monthly and daily data and the evaluations of their impacts on the series. So that homogeneous climate data sets will increase.

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