

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Analysis on Long Precipitation Series in Piedmont (North-West Italy)

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/127354> since

Published version:

DOI:10.4236/ajcc.2013.21002

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

Analysis on Long Precipitation Series in Piedmont (North-West Italy)

Fiorella Acquaotta, Simona Fratianni

Department Earth Sciences, University of Turin, Turin, Italy
Email: fiorella.acquaotta@unito.it

Received November 15, 2012; revised December 16, 2012; accepted December 23, 2012

ABSTRACT

This study analyses thirteen daily precipitation series of Piedmont, region of North-West Italy. The meteorological series have been chosen because they were meteorological observatories operating continuously from the beginning of 1900 until 2011. As the first step an historical research over each station has been carried out. In this way, the potential breaks, in the series, either due to changes of locations or instruments, have been determined and the missing values have been recovered. On the precipitation daily series a quality control have been effectuated and by metadata identification it was possible to assess the homogeneity of the meteorological series. In this way we have obtained the complete and correct series on which trends have been computed. In order to better understand the consequences of climate variations on our environment and society, we have calculated the climate indices proposed by “CCL/CLIVAR Working Group on Climate Change Detection” (dry and wet days, rainy days, intensity of precipitation...) over the time. The values of precipitation have also allowed beginning the climatic analysis with the aim at defining the principle local peculiarity in Piedmont.

Keywords: Piedmont; Precipitation; Climate Indices; Trend; Climate Change

1. Introduction

Since the 80's were published by the international scientific community many studies on the evolution of the precipitation of the XX century. In particular these analyses have focused on change in mean values of rain and underlined their variations by use of the trends calculated on various time scale [1-4].

These studies highlight the trends of the meteorological variable by identifying growth or decrease periods, on annual and seasonal scale. In Europe, annual precipitation has steadily increased since the mid 19th century, with well above average precipitation since the dry spell of the 1940s. Highest values overall were recorded in the 1979 [5]. The analysis of long-term trends in the Alpine region [6] have shown no statistical significant. The statistical significance is found only in certain seasons, winter and spring, in agreement with other studies on a regional scale [7-9].

These work, although highlight important aspects of precipitation, do not reveal how precipitation varies within the periods [10]. A correct analysis of the precipitation should consider different aspects such as duration, intensity and distribution by utilizing series with high temporal resolution.

A complete analysis of precipitation series has been

introduced since the year 2000, when it was possible to have a suitable number of daily series with a good number of measurement years, at least 30 years of data [11]. These studies highlight not only the calculus of the trend, but they analyze the extreme events by the use of climate indices. However the changes have been identified only from the mid-twentieth century when the majority of Nations have introduced the automatic meteorological stations that allow having meteorological variables with high temporal resolution [12].

In Europe it was found an increase in heavy rainfall events, from 1949 to 1999, influencing the amount of annual precipitation [13]. The largest increase was found in northern and central Europe, especially in winter [14]. In northern Italy an increase in heavy rainfall events has occurred in the last 60 years. The increase in precipitation intensity over northern Italy does not have uniform spatial patters, the western area having a greater trend than the eastern one [15].

The lack of detailed studies on secular daily precipitation series is mainly due to absence of long and homogeneous daily precipitation series, available for a few areas. Piedmont, in the North-West Italy, is an exception. The measurement of the climatic parameters and the accurate conservation of the information gathered in Piedmont some long and homogeneous daily precipitation

series.

The good availability of meteorological daily data has allowed us to analyze the real rainfall pattern by the use of climatic indices. This study is not limited to analyzing changes in accumulated precipitation over time but it examines the duration of dry and wet periods, the frequency of heavy rainfall and number of rainy days, studying in detail the variation of the meteorological variable in the last hundred years.

A detailed study of the precipitation can explain water balance in an area with complex orography like the Piedmont characterized by steep slopes. In this area heavy rainfall can cause flash floods particularly dangerous. In fact, the most dramatic flooding in Italy occurred in Piedmont in 1951, 1966, 1994, 2000 and 2002.

Although floods are natural phenomena that cannot be prevented but, we can reduce the deaths, the environmental and economic damage. The effects of climate change

are reduced by proper assessment and risk management, and by the adaptation and mitigation procedures.

2. Materials and Methods

In this study thirteen long daily precipitation series, from 1913 to 2011, of Piedmont have been analyzed (**Table 1**, **Figure 1**). The series have been chosen because their meteorological stations have measured with continuity the variable for many years and the series have a limited number of gaps. These are referable to the period 1942-1950, during and just after the Second World War. In order to have a complete database for each meteorological station an accurate historical research has been made that it has allowed to recover the missing data and to evaluate the homogeneity of the series by identifying the changes of location or instruments of the stations during its activity.

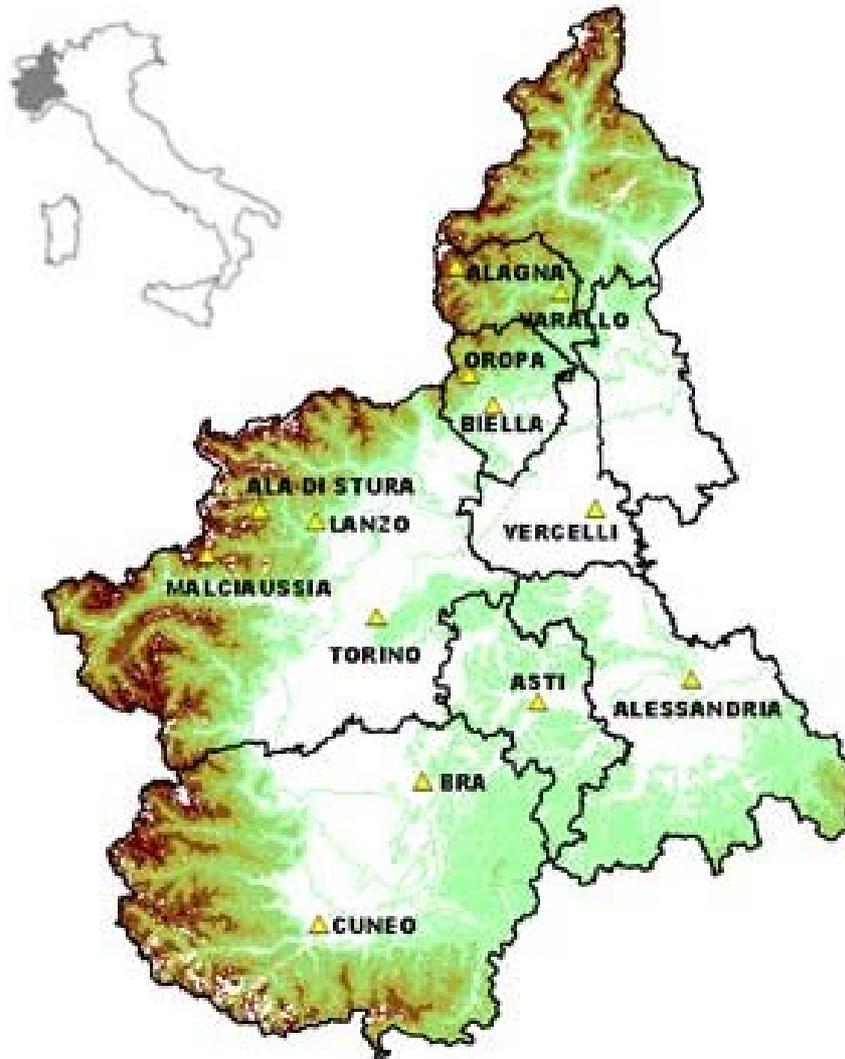


Figure 1. Geographic location of the meteorological stations in Piedmont region, Italy.

Table 1. Characteristics of the meteorological stations analyzed in this study. Latitude North, longitude East, elevation (m ASL.) and period of data availability.

| STATIONS | LATITUDE N | LONGITUDE E | ELEVATION [M] | PERIOD |
|--------------|------------|-------------|---------------|-----------|
| ALESSANDRIA | 44°56'17" | 8°42'18" | 90 | 1913-2011 |
| ASTI | 44°53'09" | 8°12'48" | 117 | 1914-2011 |
| VERCELLI | 45°19'32" | 8°23'26" | 132 | 1939-2011 |
| TORINO | 45°04'18" | 7°41'23" | 239 | 1913-2011 |
| BRA | 44°04'18" | 7°51'09" | 285 | 1913-2011 |
| BIELLA | 45°33'35" | 8°03'27" | 405 | 1916-2011 |
| VARALLO | 45°49'14" | 8°16'30" | 470 | 1913-2011 |
| CUNEO | 44°22'14" | 7°13'39" | 575 | 1913-2011 |
| LANZO | 45°17'23" | 7°29'38" | 580 | 1913-2011 |
| ALA DI STURA | 45°18'48" | 7°18'41" | 1006 | 1933-2011 |
| OROPA | 45°37'40" | 7°58'56" | 1186 | 1913-2011 |
| ALAGNA | 45°52'31" | 7°56'14" | 1196 | 1913-2011 |
| MALCIAUSSIA | 45°12'31" | 7°08'58" | 1800 | 1937-2011 |

The historical research has been carried out by consulting the paper register of the stations in which the daily values of variable have been written and the replacement of instrumentations or changes of position (metadata) have been reported and by consulting the Annals (Hydrographic and Marigraphic National Service archives) in which the geographic coordinates of each station (latitude, longitude and elevation) have been recorded every year.

The selected series were submitted to quality control by using the software RClindex [16]. This methodology allows us to identify the false values due to an incorrect reading, or to a wrong transcription from the original paper. Each value identified as wrong by the software has been rechecked by comparing the data on paper records.

For the precipitation series in which metadata have been identified, a statistical test that allows us to homogenize the daily data without altering the statistical properties of the variable has not yet been developed [14]. For this reason, the continuity of the series has been evaluated by observing the annual precipitation trends and by assessing the presence of discontinuities. If in the proximity of discontinuous year (metadata), the variable showed a break in the average value, the series was discarded because it does not show the real trend of the meteorological variable [17].

On the homogenous daily precipitation series the climate indices established by Expert Team on Climate Change Detection Monitoring and Indices [18] have been calculated to better characterize and understand the cli-

mate changes that occurred in the different locations. For each series we have calculated on monthly, seasonal and annual basis:

- PRCPTOT, total precipitation, sum of precipitation amount measured in mm;
- RD, number of rain days, days with precipitation ≥ 1 mm;
- CDD, consecutive dry days, maximum number of consecutive days with precipitation < 1 mm;
- CWD, consecutive wet days, maximum number of consecutive days with precipitation ≥ 1 mm;
- SDII, simple daily intensity index, annual total of precipitation divided by the number of rain days;
- R25, number of heavy precipitation days, count of days when precipitation ≥ 25 mm.

Subsequently on the climate indices the slope of the trends were calculated by least squares linear fitting [15] and estimating statistical significance with the determination coefficient [19].

The comparison between the results obtained from analysis of climate indices in the different series was made by dividing the meteorological stations in the respective climatic regions.

The climate division was taken from a previous study developed by the Department of Earth Sciences and Piedmont Region [20]. This work analyzes the distribution of rain and temperatures in Piedmont from 1951 to 1986 to identify and map climatic homogeneous areas according to the Bagnouls and Gaussen's method (1953) [21]. This climatic classification was based on the distribution of monthly average temperature and precipitation

during the year. Hot, cold and dry periods were defined by observing favorable and unfavorable conditions for vegetation. Hot periods were defined by the succession of months where an average temperature higher than 20°C. Cold periods are defined by the sequence of months where an average monthly temperature lower than 0 degrees is recorded. Dry periods are represented by the succession of dry months, defined by the relation $P < 2T$ where P represents precipitation and T temperatures.

In order to correctly compare the results, the climate indices and their trends were recalculated and analyzed over the common period to all meteorological series, from 1939 to 2011.

For each climatic region the pluviometric regime [22], the average monthly precipitation and the number of wet days were calculated. Also the average values of the variable and the climatic indices were estimated on the reference period, from 1971 to 2000 [23] to evaluate the changes in different time intervals.

Subsequently it was evaluated the interaction with large-scale circulation pattern that contributing to the determination of the precipitation field structure because the precipitation are characterized by a high spatial and temporal variability. They are generally determined by a large number of climatic factors (orography, exposure, distance from the sea) but one of the most important forcing elements is orography, which interacts strongly with the large scale flow. The long series of precipitation are analyzed using the principal component analysis (PCA) method [24]. The study considers the seasonal periods and shows the relationship between the structures of the seasonal camps of the precipitation and the North Atlantic Oscillation (NAO) [25].

3. Data and Stations

The meteorological stations considered in this work are uniformly distribute in the Piedmont, North-West Italy. The altitude varies between 90 m ASL of Alessandria and 1800 m ASL of Malciaussia (**Figure 1**, **Table 1**).

The first analysis, carried out on thirteen precipitation series (**Figure 1**), showed that, in most cases, the instrument was installed since 1913. This allowed having 98 years of data. In the towns of Asti and Biella the registration started respectively since 1914 and 1916. Only in Vercelli, Ala di Stura e Malciaussia the registration began in the thirties with an average availability of 75 years of data (**Table 1**).

The first analysis, carried out on thirteen precipitation series (**Figure 1**), showed that, in most cases, the instrument was installed since 1913. This allowed having 98 years of data. In the towns of Asti and Biella the registration started respectively since 1914 and 1916. Only in Vercelli, Ala di Stura e Malciaussia the registration began in the thirties with an average availability of 75 years of data (**Table 1**).

The precipitation series of Ala di Stura, Alagna, Biella, Cuneo, Lanzo, Torino and Varallo have a gap during the year of Second World War, from 1942 to 1950.

The recovery of gap was made by consulting the paper records and the Annals. This has permitted to recover all the daily values for Ala di Stura (**Figure 2**), Torino and Alagna and the monthly values of precipitation amount and the number of wet days for Biella and Varallo. Only for Cuneo and Lanzo it was not possible to trace the missing values and, for this reason in this study, the two stations were rejected.

The historical research, aim to identify the information

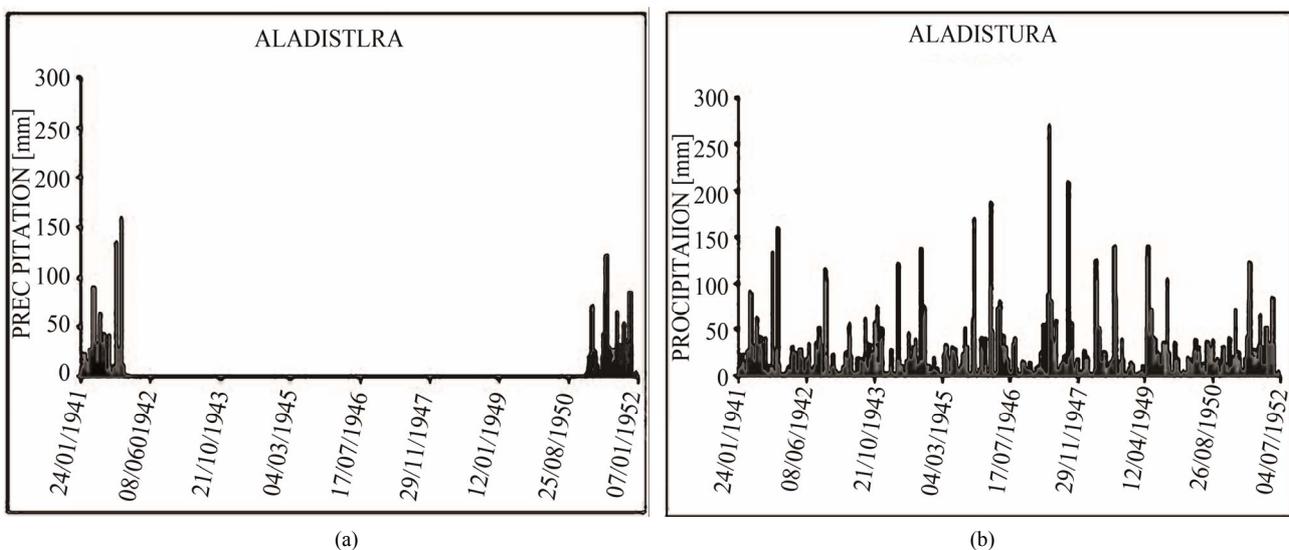


Figure 2. (a) Daily precipitation series of Ala di Stura before the historical research, (b) daily precipitation series of Ala di Stura after the historical research.

about the meteorological stations, has allowed to find out the variations occurring in the recording of the variable due to a change of instrumentation. During the years the manual rain gauge, used at the beginning of the record, was replaced by the automatic rain gauge. This change occurred in the thirties for the stations of Alessandria, Asti, Torino, Bra, Varallo and Oropa and in the eighties for Malciaussia, Ala di Stura and Alagna.

The metadata, made by the change of position, were detected in the last period for all the series considered. This shift was caused by the replacement of the old network, managed by National Hydrographic Service, with a new environmental monitoring network, administrated by ARPA Piedmont. However these changes did not cause discontinuities in the variables patterns allowing us to use the series without homogenization [26].

4. Results

The climatic analysis made on the precipitation series has highlighted, in the most cases, negative trends in the precipitation amount, in the number of wet days and in the number of heavy precipitation days, while the consecutive dry and wet days have positive trends.

It is necessary to point out that all climatic indices have shown strong variability that do not allow to calculate a significant trend because the determination coefficient never takes a number near the unit. The maximum value of the determination coefficient is equal to 0.33 calculated on the simple daily intensity index of Biella.

Despite the trends are not statistically significant, the station with the maximum negative trend for precipitation series is Varallo with -4.0 ± 1.8 mm/year while for the number of rain days the maximum decrease trend is calculated in Vercelli with -0.14 ± 0.05 day/year and the maximum positive trend in the station of Torino with $+0.14 \pm 0.04$ day/year. The maximum decrease for the simple daily intensity index was estimated in the series of Torino, -0.05 ± 0.01 mm/year, followed by Alagna, -0.04 ± 0.01 mm/year, while a positive trend was calculated in the station of Vercelli with $+0.02 \pm 0.01$ mm/year.

The tendencies calculated on dry and wet periods assumed positive trends. The maximum value for dry periods is equal to $+0.17 \pm 0.09$ day/year for the station of Vercelli, while for wet periods is equal to $+0.02 \pm 0.01$ day/year for the stations of Alagna.

This first analysis highlights two stations, Vercelli and Torino, where the precipitation manifest major variations. Vercelli shows a subalpine pluviometric rate with a main minimum in winter, a main maximum in autumn and a secondary maximum in spring. The precipitation and the indices series highlight decreasing trends from 1939 to 2011. For the precipitation series the maximum decrease

is calculated in summer while for the rain days in winter. For both variables the negative trends increases when you consider the last period, from 1973 to 2011. Torino shows an alpine continental pluviometric rate with a main minimum in winter, a main maximum in spring and a secondary maximum in autumn. For the precipitation series the maximum decreasing trend is calculated in spring while for the rain days in summer. In this station we have find a variation in the precipitation events. From 1945 to 2011 there was a decrease in days with weak precipitation, $P < 25$ mm, and an increase in days with heavy rainfall, $P \geq 25$ mm, especially in autumn.

The comparison among the results obtained in the different locations was carried out by dividing the stations in different climatic region of Piedmont classified by the Bagnouls and Gausson's method. The series were divided into three regions: Sub-Mediterranean, Temperate and Cool-Temperate and the climatic indices with their trend were calculated over a common period to all the meteorological series, from 1939 to 2011 and from 1971 to 2000 (**Tables 2** and **3**). In the Sub-Mediterranean region are comprised the stations of Asti, Alessandria and Bra while in the Temperate region the stations of Biella, Torino and Vercelli and in the Cool-Temperate the locations of Alagna, Oropa, Varallo, Ala di Stura and Malciaussia.

The Sub-Mediterranean region is characterized by the presence of two or three dry months in summer. The region has a subalpine pluviometric regime with a maximum in autumn and in spring and a main minimum in winter (**Figure 3(a)**). The month with the highest number of wet days is May with an average of 7.3 days, followed by April with 6.8 days (**Table 2**). Most rainfall is found in October with 75.7 mm, followed by May with 71.0 mm (**Table 2**).

In this region it was calculated an average annual precipitation equal to 639.4 mm with 65.1 wet days, 39 consecutive dry days, 6 consecutive wet days and about 6 heavy precipitation days (**Table 4**).

Comparing these results with the values calculated over the reference period of thirty years, from 1971 to 2000, (**Table 4**) it is evident a decrease in the average value for all the indices. The biggest difference is detected in the precipitation amount and in the dry period.

The study of climatic indices in the three regions highlights an increase in the precipitation amount in the town of Alessandria and Biella and a decrease in Asti, while for all the station there is a decrease in the number of wet days, an increase in the consecutive dry periods and, for the wet periods, the trend increases but with values close to zero (**Table 3**). A positive development is occurred in the numbers of heavy precipitation days and in the density of precipitation, indicating a slight change in the

Table 2. Average monthly values calculated over all the period analyzed (1939-2011), number of rain days (RD) and precipitation amount (PTOT) measured in mm for each climatic region: Sub-Mediterranean (Sub-M), Temperate (Temp) and Cool Temperate (C-Temp).

| MONTH | RD SUB-M | PTOT SUB-M | RD TEMP | PTOT TEMP | RD C-TEMP | PTOT C-TEMP |
|-------|----------|------------|---------|-----------|-----------|-------------|
| JAN | 4.9 | 38.3 | 4.3 | 39.3 | 5.6 | 54.8 |
| FEB | 4.5 | 38.1 | 4.2 | 44.2 | 5.4 | 60.6 |
| MAR | 5.4 | 47.9 | 5.4 | 60.0 | 7.0 | 94.5 |
| APR | 6.8 | 68.3 | 7.8 | 98.4 | 10.1 | 175.6 |
| MAY | 7.3 | 71.0 | 9.5 | 119.4 | 12.9 | 211.1 |
| JUNE | 5.7 | 49.0 | 8.0 | 92.8 | 11.2 | 153.0 |
| JULY | 4.0 | 37.4 | 5.5 | 64.5 | 8.3 | 95.4 |
| AUG | 4.8 | 47.6 | 6.6 | 79.6 | 9.5 | 120.1 |
| SEPT | 4.7 | 55.0 | 5.8 | 82.1 | 8.1 | 145.8 |
| OCT | 6.4 | 75.7 | 6.8 | 96.8 | 8.6 | 181.4 |
| NOV | 6.3 | 69.4 | 6.0 | 86.8 | 7.2 | 130.6 |
| DEC | 5.1 | 45.7 | 4.5 | 48.8 | 5.8 | 67.4 |

Table 3. For all the meteorological stations are calculated the trends over the common period, from 1939 to 2011, on precipitation amount, PRCPTOT, number of rain days, RD, dry periods, CDD, and wet periods, CWD, with their determination coefficients.

| CLIMATIC REGION | STATION | PRCPTOT | R ² | RD | R ² | CDD | R ² | CWD | R ² |
|-------------------|--------------|---------|----------------|-------|----------------|-------|----------------|--------|----------------|
| SUB MEDITERRANEAN | ALESSANDRIA | 0.25 | 0.001 | -0.03 | 0.002 | 0.04 | 0.005 | 0.0002 | 0.02 |
| | ASTI | -0.10 | 0.0001 | -0.13 | 0.05 | 0.16 | 0.05 | 0.01 | 0.01 |
| | BRA | 1.28 | 0.02 | -0.05 | 0.01 | 0.16 | 0.06 | -0.003 | 0.001 |
| TEMPERATE | VERCELLI | -0.07 | 0.00 | -0.14 | 0.05 | 0.17 | 0.05 | -0.01 | 0.01 |
| | TORINO | -1.31 | 0.01 | -0.25 | 0.10 | 0.17 | 0.07 | -0.02 | 0.04 |
| | BIELLA | -0.13 | 0.00 | -0.12 | 0.02 | 0.22 | 0.02 | 0.19 | 0.06 |
| COOL TEMPERATE | VARALLO | -4.00 | 0.04 | -0.06 | 0.01 | 0.15 | 0.03 | -0.01 | 0.01 |
| | ALA DI STURA | -1.00 | 0.003 | -0.07 | 0.01 | 0.03 | 0.003 | 0.003 | 0.004 |
| | OROPA | 1.72 | 0.005 | -0.19 | 0.06 | 0.07 | 0.01 | -0.03 | 0.03 |
| | ALAGNA | -1.84 | 0.01 | 0.06 | 0.002 | 0.07 | 0.01 | 0.02 | 0.02 |
| | MALCIAUSSIA | 0.00 | 0.00 | 0.04 | 0.004 | -0.03 | 0.004 | 0.02 | 0.02 |

rainfall characteristics during the considered period as shown in the example for the station of Bra (**Figures 4(a)** and **(b)**).

In the Temperate region there are no dry months and the monthly average temperatures of the coldest month range between 0°C and 10°C. This area has a prealpine pluviometric regime with a principal maximum in the spring following autumn and a principal minimum in winter (**Figure 3(b)**).

The average precipitation calculated over all the period

is equal to 895.6 mm with 77.4 wet day/year and an average density of precipitation equal to 11.7 mm/day (**Table 4**). The month with the greatest quantity of rain is May with 119.4 mm followed by April with 98.4 mm, while the largest number of wet days was detected in May with 9.5 days (**Table 2**).

Comparing the average values of climate indices calculated over the whole period to the average values estimated on the reference period it was detected a decrease in rainfall, in the number of dry periods, in the heavy

Table 4. Average values (AV) and standard deviation (SD) of: number of rain days (RD), precipitation amount (PRCPTOT) measured in mm, consecutive dry days (CDD), consecutive wet days (CWD), heavy precipitation days (R25) and simple daily intensity index (SDII) measured in mm/day, calculated over the entire period, from 1939 to 2011, and over the reference period, from 1971 to 2000 in three climatic region.

| INDICES | RD | PTOT | CDD | CWD | R25 | SDII |
|---------------------------------|------|--------|------|-----|------|------|
| SUB-MEDITERRANEAN REGION | | | | | | |
| AV 1971-2000 | 65.3 | 682.2 | 41.2 | 6.1 | 6.8 | 10.4 |
| SD 1971-2000 | 11.6 | 141.1 | 12.0 | 1.5 | 2.5 | 1.3 |
| AV 1939-2011 | 65.1 | 639.4 | 38.9 | 5.8 | 5.9 | 9.7 |
| SD 1939-2011 | 11.4 | 152.9 | 11.0 | 1.3 | 2.6 | 1.4 |
| TEMPERATE REGION | | | | | | |
| AV 1971-2000 | 77.4 | 943.8 | 40.7 | 6.5 | 10.6 | 12.1 |
| SD 1971-2000 | 13.4 | 202.5 | 15.5 | 1.2 | 2.9 | 1.6 |
| AV 1939-2011 | 77.4 | 895.6 | 38.4 | 6.5 | 10.2 | 11.7 |
| SD 1939-2011 | 13.8 | 232.1 | 14.0 | 1.4 | 3.5 | 1.8 |
| COOL TEMPERATE REGION | | | | | | |
| AV 1971-2000 | 98.5 | 1589.2 | 33.3 | 8.7 | 16.2 | 14.6 |
| SD 1971-2000 | 10.6 | 361.8 | 13.1 | 2.2 | 4.8 | 3.1 |
| AV 1939-2011 | 99.6 | 1489.2 | 31.8 | 8.4 | 15.7 | 14.1 |
| SD 1939-2011 | 11.7 | 355.8 | 10.5 | 2.2 | 4.7 | 2.8 |

precipitation and in the intensity of precipitation, while in the other indices no variation were individuated.

In each location the index analysis shows a decrease in the rainfall, in the number of rain days (**Figure 5(a)**), in the density of precipitation, in the number of heavy precipitation days and in the wet periods. An increase trend was calculated in the number of dry periods, as shown in the **Figure 5(b)** for the station of Vercelli.

The Cool-Temperate region has less four frost months in a year with average temperatures of the coldest month below -3°C and of the hottest month between 10°C and 15°C . It has a prealpine pluviometric regime (**Figure 3(c)**). The month with the greatest rainfall amount is May with 211.1 mm following by October with 181.4 mm and May is also the month with the maximum number of rain events (12.9 days) (**Table 2**). The annual average precipitation calculated over all the period is equal to 1489.2 mm, the number of wet days is 99.6 days and there are 15 days in a year with heavy precipitation. Even for this reason the comparison between the average values estimated over all the period and over the reference period shows, in many cases, a decrease except for the number of wet days that increases (**Table 4**).

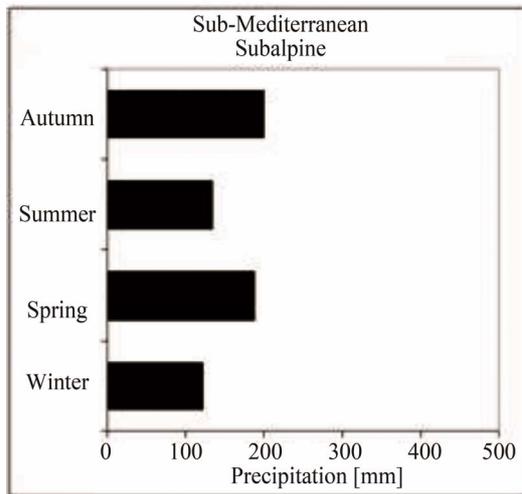
The precipitation estimated in each location has more

pronounced decreases than in the other climatic region. In fact the trends vary between -1.0 ± 2.1 mm/year calculated in Ala di Stura and -4.0 ± 1.8 mm/year detected in Varallo. One exception is the precipitation series of Oropa where a positive trend equal to 1.7 ± 3.1 mm/year has been identified. In this meteorological station we have estimated a rain growth in spring and in autumn and a decreasing in summer. The increasing of rain is caused by a growth of heavy rain in spring especially in the last period, from 1971 to 2000.

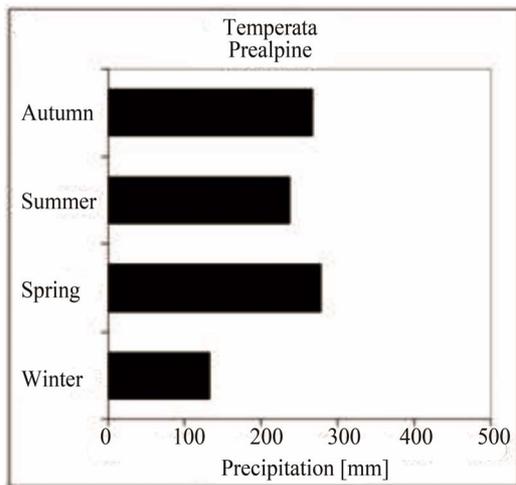
A negative trend has been calculated in the density of precipitation and in the number of days with heavy precipitation while, like in the other climatic regions, a greater increase in the dry periods has been calculated in comparison to the growth in the wet periods.

The trends estimated in the temperate and cold temperate regions would seem to indicate a decrease, although not statistically significant, in the number of wet days and in the precipitation amount.

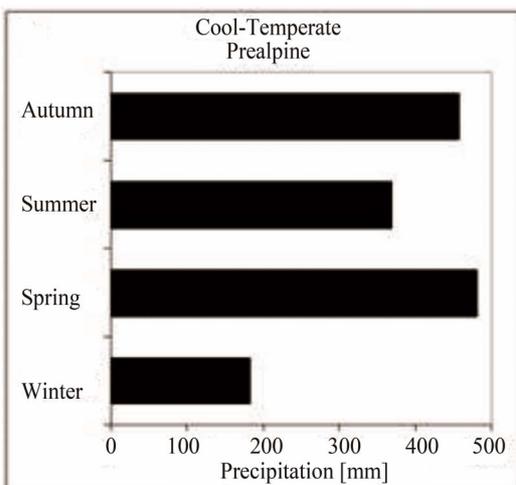
The study aimed at highlighting the interaction between the precipitation and the NAO index has not identified large interaction between the variables. The three principal components, CP1, CP2 and CP3, that together explain 88% of the precipitation variance, show a low



(a)

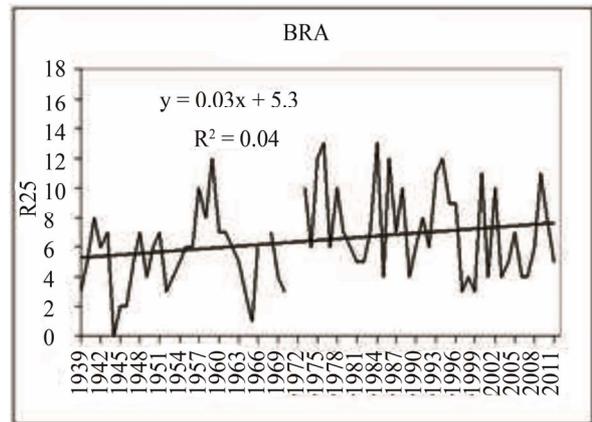


(b)

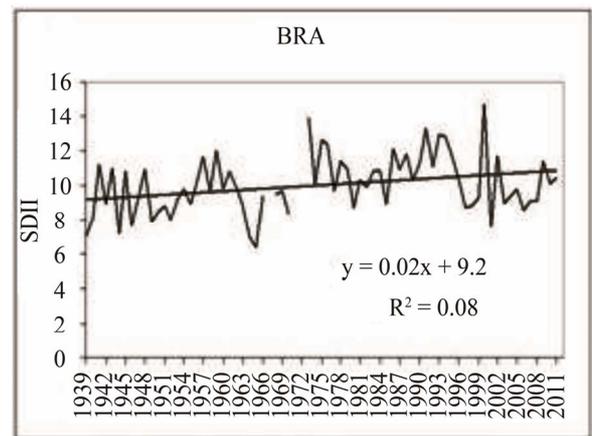


(c)

Figure 3. (a) Pluviometric regime calculated in the sub-Mediterranean region, (b) pluviometric regime calculated in the Temperate region, (c) pluviometric regime calculated in the Cool Temperate region.



(a)



(b)

Figure 4. (a) Trend of number of heavy rainfall days with precipitation ≥ 25 mm, R25, (b) trend of annual density of precipitation, SDII, calculated in the station of Bra from 1939 to 2011.

values of correlation coefficients with the NAO index and therefore do not reveal any influence with this circulation pattern (Table 5).

5. Conclusions

The study on the long precipitation series in Piedmont has allowed estimating the variations on local scales, for the single stations and on regional scale by the use of different climatic regions.

The trends, calculated on total precipitation, identify both positive and negative slope. The decrease trends range between -4.00 ± 1.8 mm/year of Varallo and -0.07 ± 1.2 mm/year of Vercelli while the increase trend between 0.25 ± 0.94 mm/year of Alessandria and 1.7 ± 3.1 mm/year of Oropa.

The number of rainy days has a decrease trend with two exception represented by the locations of Alagna and Malciaussia. However, these trends have not high values because they vary between -0.25 ± 0.10 day/year of

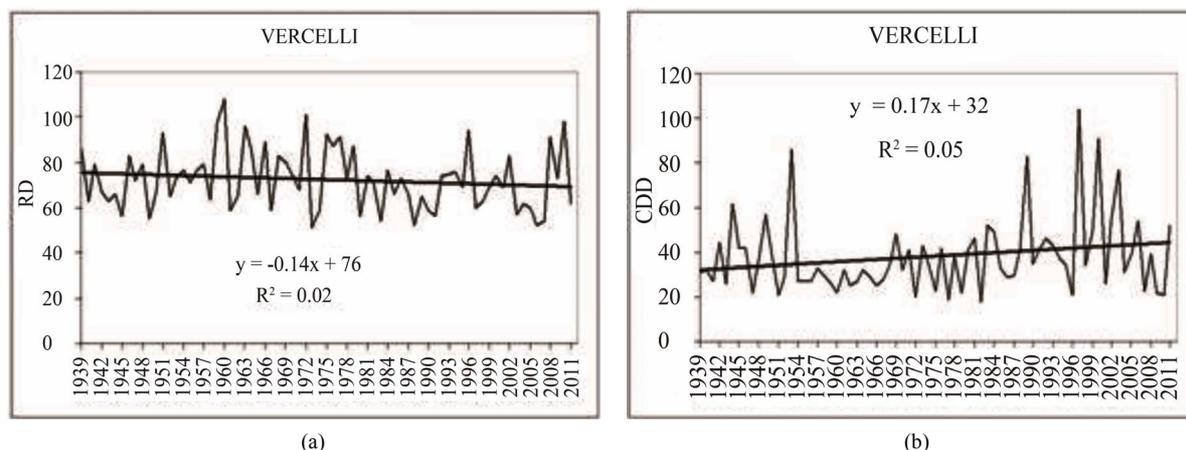


Figure 5. (a) Trend of the number of rainy days, RD, (b) trend of the dry periods, CDD; calculated in the station of Vercelli from 1939 to 2011.

Table 5. Correlation coefficient between the principal component of the precipitation series and NAO index and the percentage of the variance.

| PRECIPITATION | CORRELATION COEFFICIENT | VARIANCE (%) |
|---------------|-------------------------|--------------|
| CP1 | 0.04 | 75 |
| CP2 | -0.06 | 7 |
| CP3 | 0.09 | 6 |

Torino and 0.04 ± 0.10 day/year of Malciaussia.

Over long period the trend of the precipitation density, of the number of days with heavy precipitation and of the wet periods does not detect a variation of precipitation. An evident tendency emerges in the index of dry periods where, in each station, a positive trend has been calculated, indicating an increase of the period with precipitation <1 mm.

Over a common time period, from 1939 to 2011, the precipitation analysis in the three climatic regions, Sub-Mediterranean, Temperate and Cool-Temperate, showed different behaviors.

The Sub-Mediterranean region has a subalpine pluviometric regime with 639.4 mm of annual average rainfall and 65.1 rain days. The density of precipitation is equal to 9.7 mm/day while the heavy precipitation occurs for 6 days in a year. In this region the comparison between the precipitation measured from 1971 to 2000 with the rainfall recorded over all analyzed period shows a slight increase in the rainfall, in the number of dry periods and in the heavy precipitation attributable to the final period. In this climatic region the study of precipitation indicates a slight change in the rain events because, during the years, the rainfall is increased and the rain days are decreased. The change is also highlighted by the climate indices that have growth trends for the dry periods, the number of

heavy precipitation days and the simple daily intensity index.

The Temperate region has a prealpine pluviometric regime with 895.4 mm of annual average precipitation, 77.4 rain days and the heavy precipitation occur for 10.2 days in a year.

The Cool-Temperate region also has a prealpine pluviometric regime with 1489.2 mm of annual average rainfall, 99.6 rain days and a average density of precipitation equal to 14.1 mm/day.

The comparison between the precipitations recorded in the reference period and in all the period showed a similar behavior between the Temperate and Cold-Temperate region. For both regions, in the reference period from 1971 to 2000, it is identified an increase in the rainfall, in the number of dry periods and in the heavy precipitation and a slight decrease in the number of rain days while the study of precipitation in all period, from 1939 to 2011, indicates a decrease in the amount and in the intensity of precipitation.

In order to understand the behavior of precipitation in Piedmont we have studied the interaction with large scale circulation pattern, North Atlantic Oscillation, using the principal component analysis. The study not reveals any influence highlighting the strong relationship between the precipitation and local climatic factors, orography, exposure and the distance from the sea.

Private sector, businesses, industry and services' sectors, as well as individual citizens will be confronted with the consequences of climate change and can play an important role in adaptation measures. Concrete action could range very widely, covering soft relatively inexpensive measures: water conservation, use of drought tolerant crops, public planning and awareness rising.

Action is needed by the public sector, e.g. adapting spatial and land use planning to risks of flash floods, adapting existing building codes ensuring that long-term

infrastructure will be proof to future climate risks, updating of disaster management strategies with early flood systems.

Adaptation will also bring about new economic opportunities including new jobs and markets for innovative products and services such as new markets for climate-proof building techniques, material and products.

REFERENCES

- [1] H. Diaz, R. Bradley and J. Eischeid, "Precipitation Fluctuation over Global Land Areas since the Late 1800s," *Journal of Geophysical Research*, Vol. 94, No. D1, 1989, pp. 1195-1240. [doi:10.1029/JD094iD01p01195](https://doi.org/10.1029/JD094iD01p01195)
- [2] A. Dai, I. Fung and A. Del Genio, "Surface Observed Land Precipitation Variations during 1900-88," *Journal of Climate*, Vol. 10, No. 11, 1997, pp. 2943-2961. [doi:10.1175/1520-0442\(1997\)010<2943:SOGLPV>2.0.CO;2](https://doi.org/10.1175/1520-0442(1997)010<2943:SOGLPV>2.0.CO;2)
- [3] M. New, M. Todd, M. Hulme and P. Jones, "Review Precipitation Measurements and Trends in the Twentieth Century," *International Journal of Climatology*, Vol. 21, No. 15, 2001, pp. 1899-1922. [doi:10.1002/joc.680](https://doi.org/10.1002/joc.680)
- [4] J. Gonzalez Lez Rouco, L. Jimenez, V. Quesada and F. Valero, "Quality Control and Homogeneity of Precipitation Data in the Southwest of Europe," *Journal of Climate*, Vol. 14, No. 5, 2001, pp. 964-978. [doi:10.1175/1520-0442\(2001\)014<0964:QCAHOP>2.0.CO;2](https://doi.org/10.1175/1520-0442(2001)014<0964:QCAHOP>2.0.CO;2)
- [5] R. Bradley, H. Diaz, J. Eischeid, P. Jones, P. Kelly and C. Goodes, "Precipitation Fluctuations over Northern Hemisphere Land Areas since the Mid-19th Century," *Science*, Vol. 237, No. 4811, 1987, pp. 171-175. [doi:10.1126/science.237.4811.171](https://doi.org/10.1126/science.237.4811.171)
- [6] J. Schmidl, C. Schmutz, C. Frei, H. Wanner and C. Schar, "Mesoscale Precipitation Variability in the Region of the European Alps during the 20th Century," *International Journal of Climatology*, Vol. 22, No. 9, 2002, pp. 1049-1074. [doi:10.1002/joc.769](https://doi.org/10.1002/joc.769)
- [7] I. Auer and R. Bohm, "Combined Temperature-Precipitation Variations in Austria during the Instrumental Period," *Theoretical and Applied Climatology*, Vol. 49, No. 3, 1994, pp. 161-174. [doi:10.1007/BF00865531](https://doi.org/10.1007/BF00865531)
- [8] M. L. Widmann and C. Schar, "A Principal Component and Long-Term Trend Analysis of Daily Precipitation in Switzerland," *International Journal of Climatology*, Vol. 17, No. 12, 1997, pp. 1333-1356. [doi:10.1002/\(SICI\)1097-0088\(199710\)17:12<1333::AID-JOC108>3.0.CO;2-Q](https://doi.org/10.1002/(SICI)1097-0088(199710)17:12<1333::AID-JOC108>3.0.CO;2-Q)
- [9] L. Buffoni, M. Maugeri and T. Nanni, "Precipitation in Italy from 1833 to 1996," *Theoretical and Applied Climatology*, Vol. 63, No. 1-2, 1999, pp. 33-40. [doi:10.1007/s007040050089](https://doi.org/10.1007/s007040050089)
- [10] T. Karl, R. Knight and N. Plummer, "Trends in the High-Frequency Climate Variability in the Twentieth Century," *Nature*, Vol. 377, 1995, pp. 217-220. [doi:10.1038/377217a0](https://doi.org/10.1038/377217a0)
- [11] WMO "Guide to Climatological Practices Draft," Third Edition, 2007.
- [12] M. G. Klein Tank, J. Wijngaard, G. Können, R. Böhm, G. Demarée, A. Gocheva, M. Miletta, S. Pashiardis, L. Hejkrlik, C. Kern-Hansen, R. Heino, P. Bessemoulin, G. Müller-Westermeier, M. Tzanakou, S. Szalai, T. Pálsdóttir, D. Fitzgerald, S. Rubin, M. Capaldo, M. Maugeri, A. Leitass, A. Bukantis, R. Aberfeld, A. Van Engelen, E. Forland, M. Miletus, F. Coelho, C. Mares, V. Razuvaev, E. Nieplova, T. Cegnar, J. Antonio López, B. Dahlström, A. Moberg, W. Kirchhofer, A. Ceylan, O. Pachaliuk, L. Alexander and P. V. Petrovic, "Daily Dataset of 20th-Century Surface Air Temperature and Precipitation Series for European Climate Assessment," *International Journal of Climatology*, Vol. 22, No. 12, 2002, pp. 1441-1453. [doi:10.1002/joc.773](https://doi.org/10.1002/joc.773)
- [13] A. M. Klein Tank and G. P. Können, "Trends in Indices of Daily Temperature and Precipitation Extremes in Europe, 1946-99," *Journal of Climate*, Vol. 16, No. 22, 2003, pp. 3665-3680. [doi:10.1175/1520-0442\(2003\)016<3665:TIHODT>2.0.CO;2](https://doi.org/10.1175/1520-0442(2003)016<3665:TIHODT>2.0.CO;2)
- [14] A. Moberg and P. Jones, "Trends in Indices for Extremes in Daily Temperature and Precipitation in Central and Western Europe, 1901-99," *International Journal of Climatology*, Vol. 25, No. 9, 2005, pp. 1149-1171. [doi:10.1002/joc.1163](https://doi.org/10.1002/joc.1163)
- [15] M. Brunetti, L. Buffoni, M. Maugeri and T. Nanni, "Precipitation Intensity Trends in Northern Italy," *International Journal of Climatology*, Vol. 20, No. 9, 2000, pp. 1017-1031. [doi:10.1002/1097-0088\(200007\)20:9<1017::AID-JOC515>3.0.CO;2-S](https://doi.org/10.1002/1097-0088(200007)20:9<1017::AID-JOC515>3.0.CO;2-S)
- [16] X. Zhang and F. Yang, "RCLimDex (1.0)," ETCCDI/CRD Climate Change Indices, 2004.
- [17] J. Wijngaard, A. Klein Tank and G. Können, "Homogeneity of 20th Century European Daily Temperature and Precipitation Series," *International Journal of Climatology*, Vol. 23, No. 6, 2003, pp. 679-692. [doi:10.1002/joc.906](https://doi.org/10.1002/joc.906)
- [18] Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI), CCI/CLIVAR First Team Meeting Report, Zuckerman Inst/Clim. Res. Unit Aguilar E. Univ., Norwick, 2003.
- [19] D. Wilks, "Statistical Methods in the Atmospheric Sciences," 2nd Edition, International Geophysics Series, Elsevier, 2006.
- [20] A. Biancotti, G. Bellardone, S. Bovo, B. Cagnazzi, L. Giacomelli and C. Marchisio, "Distribuzione Regionale di Piogge e Temperature," *Collana Studi Climatologici in Piemonte*, Vol. 1, Torino, 1998.
- [21] F. Bagnouls and H. Gaussen, "Saison Sèche et Indice Xérothermique," *Bulletin de la Société. D'Histoire. Naturelle*, Toulouse, Vol. 88, 1953, pp. 193-239.
- [22] M. Pinna and S. Vittorini, "Contributo Alla Determinazione dei Regimi Pluviometrici in Italia," *In Contributi di climatologia. Memoria Società Geografica*, Vol. 39, 1985, pp. 147-168.
- [23] IPCC, "Climate Change 2007: The Physical Science Basis," Contribution of Working Group I to the Fourth As-

essment Report of the Intergovernmental Panel on Climate Change Solomon, 2007.

- [24] I. T. Jolliffe, "Principal Component Analysis," 2nd Edition, Springer, Berlin, 2002.
- [25] J. W. Hurrell and H. Van Loon, "Decadal Variations in Climate Associated with the North Atlantic Oscillation," *Climate Change*, Vol. 36, No. 3-4, 1997, pp. 301-326.

[doi:10.1023/A:1005314315270](https://doi.org/10.1023/A:1005314315270)

- [26] F. Acquotta, S. Fratianni, C. Cassardo and R. Cremonini, "On the Continuity and Climatic Variability of the Meteorological Stations in Torino, Asti, Vercelli and Oropa," *Meteorological and Atmospheric Physics*, Vol. 103, No. 1-4, 2009, pp. 279-287. [doi:10.1007/s00703-008-0333-4](https://doi.org/10.1007/s00703-008-0333-4)