

A PRELIMINARY ANALYSIS OF PRECIPITATION VARIABILITY IN THE MEDITERRANEAN BASIN

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ABSTRACT

Precipitation tendencies analyses have been of great concern during the past century, mainly because of the attention given to global climate change from the scientific community. Along with trends in rainfall amount, precipitation fluctuations play a dominant role in a number of water related issues, especially for those areas, such as the Mediterranean basins, hugely characterized by an extreme rainfall variability and stressed by the combination of a dry climate and an excessive water demand. In this paper, a preliminary analysis aimed at the characterization of inter-annual and intra-annual precipitation variability, is reported for two study region, experiencing a typical Mediterranean climate.

1 INTRODUCTION

Precipitation tendencies analyses, on different spatial and temporal scales, have been of great concern during the past century, mainly because of the attention given to global climate change from the scientific community: they indicate a small positive global trend, even though large areas are instead characterized by negative trends (IPCC, 1996). But along with negative and positive changes in rainfall amount, precipitation fluctuations play a dominant role in a number of water related issues, from water resources management planning to erosion and desertification risk assessment. Among other areas, Mediterranean basins are hugely characterized by an extreme rainfall variability, both in space and time, and the implications of these changes are particularly significant for these areas, stressed by the combination of a dry climate and an excessive water demand (Piervitali et al., 1997; Schonwiese and Rapp, 1997; Romero et al., 1998; Millan et al., 2005; Mehta and Yang, 2008). Negative and positive tendencies along with a random year to year variability are the main feature of what is called inter-annual rainfall variability. Rainfall is further characterized by a within the year structure, generally defined at the seasonal or monthly scale, which assumes different patterns in different climatic areas. As well as the annual pattern, climatic seasonal patterns are affected from what is instead called an intra-annual variability. But water resources

systems are affected at a different extent by intra-annual and inter-annual variability and the quantification of both factors and of the potential mutual interaction is of particular interest (Longobardi and Villani, 2010). In this paper, at first, the inter-annual rainfall fluctuation is explored and a trend analysis is performed, at the annual scale, to assess the observed tendency over a long time period. Successively, an index based approach is proposed to a preliminary characterization of seasonal rainfall concentration and intra-annual rainfall variability estimation. The precipitation variability characterization is assessed for two regions, both typically experiencing a temperate Mediterranean climate, a South-West Italy region facing the Tyrrhenian Sea and a North-West region of Algeria facing the Mediterranean Sea.

2 THE CASE STUDIES

One of the studied region is located in South-West Italy and has an extension of about 25.000 km² (case study I). Available data consist of annual and monthly precipitation time series for 211 sites, from 1918 to 1999. The source of data is the Servizio Idrografico e Mareografico Nazionale SIMN (1919–1999). The record length ranges from 30 to 81 years and precipitation time series have been tested for homogeneity (Longobardi and Villani, 2010). The location of the gauging stations and a digital elevation model of the studied area are shown in Figure 1.

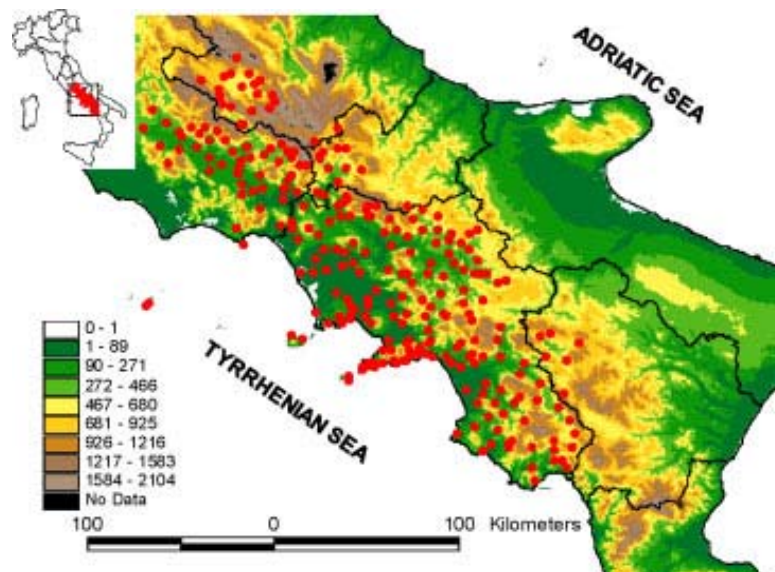


Figure 1. Case study I area digital elevation model and database stations location.

The other studied region is located in North-West Algeria and has an extension of about 90.000 km² (case study II). Available data consist of annual and monthly homogeneous precipitation time series for 48 sites, from 1930 to 2004. The source of data are the National Agency of Hydraulic Resources (ANRH) and the National Meteorological Office (ONM). The location of the gauging stations and a digital elevation model of the studied area are shown in Figure 2.

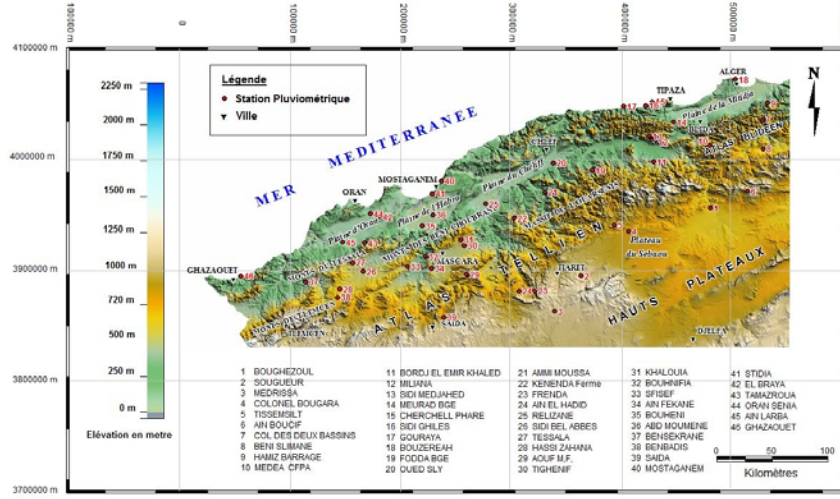


Figure 2. Case study II area digital elevation model and database stations location.

3 INTER-ANNUAL PRECIPITATION CHARACTERIZATION AND TREND ASSESSMENT AT THE ANNUAL SCALE

As previously introduced, Mediterranean basins are hugely characterized by an extreme rainfall variability, both in space and time. If the extreme variability of rainfall time series represents a particular feature that characterize Mediterranean areas, rainfall tendencies, either positive or negative, can potentially affect world-wide precipitation time series, as a consequence of discussed climate changes during the last years. Negative trends associated to large variation in total amounts, from year to year, would produce dramatic effects for particular areas of the world, stressed by the combination of a dry climate and an excessive water demand. Their quantification is then particularly relevant.

A trend is a significant change over time exhibited by a random variable, detectable by statistical parametric and non-parametric procedures. Among parametric procedures, the t-test considers the linear regression of the random variable Y on time X. The regression coefficient β (or the Pearson correlation coefficient) is the interpolated regression line slope coefficient computed from the data. It is known that the statistic

$$t = \frac{\beta}{\frac{\sum (Y_i - \hat{Y}_i)^2}{(n-2) \sum (X_i - \bar{X})^2}} \quad (1)$$

follows the Student's t distribution with n-2degrees of freedom, where n is the sample size. The null hypothesis $H_0: \beta = 0$ is tested against the hypothesis $H_0: \beta \neq 0$ at a chosen level of significance α . The hypothesis that there is no trend is rejected when the t value computed by equation (1) is greater in absolute value than the critical value t

$\alpha/2$.

In the current study, the t-test has been performed on rainfall time series, aggregated at the annual scale, with the aim of potential trends assessment.

For the case study I region, annual precipitation ranges between 790 mm and 1700 mm. As an example, Figure 3 indicate the annual rainfall time series, averaged over the whole dataset. The corresponding interpolated regression line is also plotted. The variability around the mean value, that is about 1200 mm, is rather pronounced, despite the smoothing effect induced by the average computation over a large area, and a decrease in the annual average rainfall is evident, given the slope of the regression line. The slope of the yearly time series is about -35 mm/10 years, giving an estimated decrease of about 280 mm in the period 1918–1999, which corresponds to about 23% of the annual value, according to previous results found in similar geographical and climatic contexts.

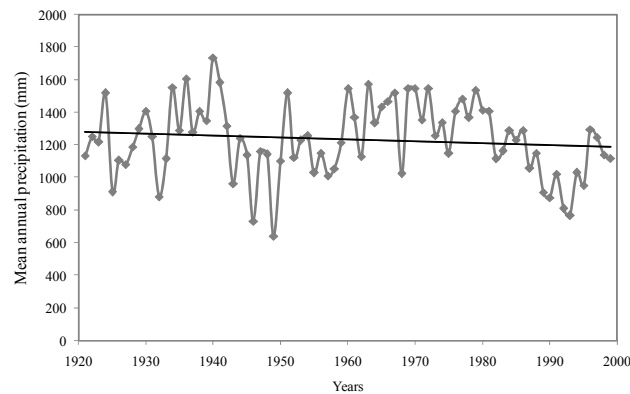


Figure 3. Annual precipitation time series and corresponding interpolated regression line (case study I).

Table I. Results of t-test. Percentage of stations with a significant positive or negative trend (case study I).

α	Positive trend			Negative trend		
	0.01	0.05	0.1	0.01	0.05	0.1
Annual	1	3	9	8	16	27
Winter	1	2	7	7	22	33
Spring	0	1	3	3	13	23
Summer	3	18	27	1	2	4
Autumn	0	3	3	1	3	8

Annual time series plots show similar trend patterns for the most part of meteorological stations, in agreement with the t-test results (Table I) where the percentage of stations with a significant positive or negative trend is reported for 99, 95 and 90% confidence levels. During the period 1918–1999, negative trends are evident both at the annual and seasonal scale, excluding the summer trimester where a dominantly positive trend can be observed. The percentage of stations showing a

significant trend is however moderate, coming to a maximum of 27% at the annual scale, and at 33 and 4% respectively during the winter and summer trimesters.

For the case study II region, annual precipitation ranges between 90 mm and 1000 mm. A general negative trend in mean annual precipitation is also evident in this study region. As an example, Figure 4 indicate the annual rainfall time series, for the gauging station of Hamiz Barrage. The corresponding interpolated regression line is also plotted. The variability around the mean value, that is about 900 mm, is rather pronounced and a decrease in the annual average rainfall is evident, given the slope of the regression line. The slope of the yearly time series is about -43 mm/10 years, giving an estimated decrease of about 300 mm in the period 1930–2004, which corresponds to about 33% of the annual value, according to previous results found in similar geographical and climatic contexts.

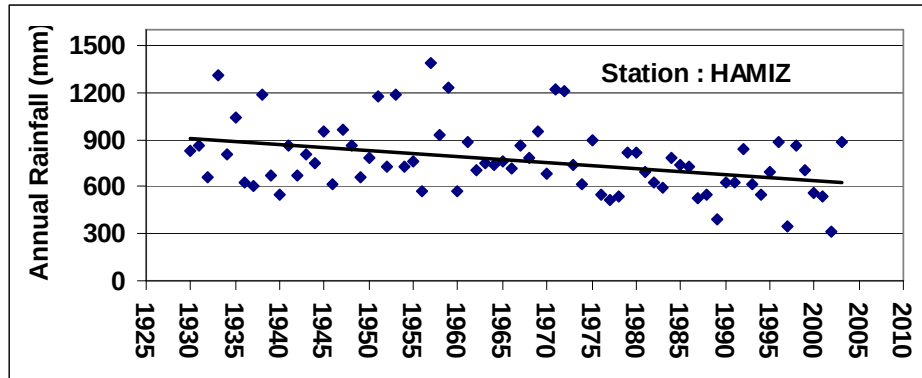


Figure 4. Annual precipitation time series and corresponding interpolated regression line (case study II).

4 INTRA-ANNUAL PRECIPITATION CHARACTERIZATION AND TREND ASSESSMENT

Both case study regions are located within the Mediterranean basin. They experience a temperate, dry-summer subtropical or Mediterranean climate. This climate usually occurs on the western sides of continents between the latitudes of 30° and 45° . These areas are in the polar front region in winter, and thus have moderate temperatures and changeable, rainy weather. Summers are instead hot and dry, due to the domination of the subtropical high pressure systems, except in the immediate coastal areas, where summers are milder due to the nearby presence of cold ocean currents that may bring fog but prevent rain. At the monthly scale, then the precipitation regime exhibits a seasonal pattern, with a maximum rainfall volume during the winter cold season and a minimum rainfall volume during the summer hot season. Even though the seasonality represents a common feature for the study regions, seasonality itself is more or less pronounced in different areas of the studied regions.

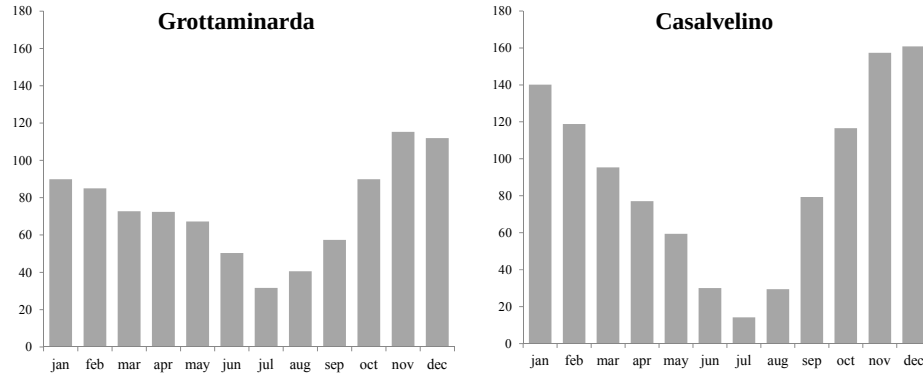


Figure 5. Mean monthly precipitation regimes for (left hand side) inland station and (right hand side) coastal station (case study I).

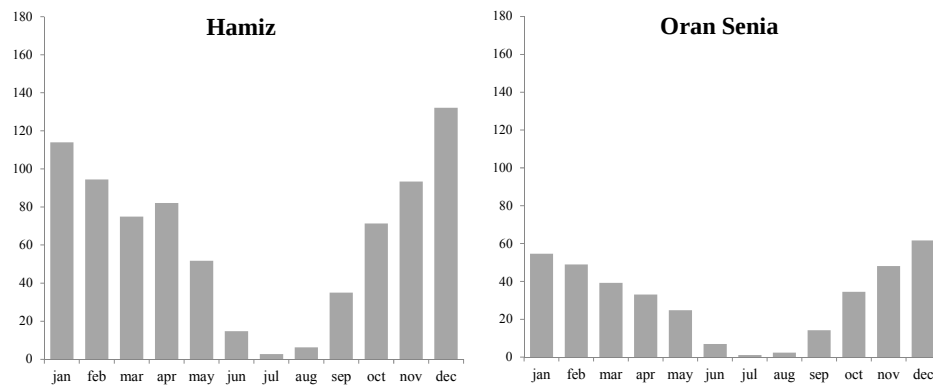


Figure 6. Mean monthly precipitation regimes for (left hand side) inland station and (right hand side) coastal station (case study II).

As an example Figure 5 and Figure 6 represent the climatic regimes of four precipitation gauging stations, respectively for the study regions I and II. Beside the mean annual precipitation total, which is clearly different for region I and region II and significantly lower in the study region II, similar seasonal patterns are recognizable. Similarity is embedded in the existence of a minimum and a maximum value in monthly precipitation, but large differences are evident from station to station. A large variability is also evident in the same region, taking place from the large extension of the studied areas, likely also due to the complex orography of investigated regions, characterized by significant reliefs, running about 20 to 50 km along the coastline. To this aim typical inland and coastal stations have been selected from each region, to highlight differences induced by the terrain orography. Coastal stations, depicted on the right hand side of Figure 5 and Figure 6, exhibit a more pronounced seasonal pattern, within each region, compared to inland stations. In order to quantify the seasonality of the precipitation climatic regime, the PCI index can be computed (Oliver, 1980). It is defined as the

average value, over N years:

$$PCI = \frac{1}{N} \sum_{j=1}^N 100 \frac{\sum_{i=1}^{12} P_{ij}^2}{\left(\sum_{i=1}^{12} P_{ij} \right)^2} \quad (2)$$

where P_{ij} is the amount of rainfall for the i -th month and the j -th year. Alternatively, the $\overline{PCI}$ can be calculated as:

$$\overline{PCI} = 100 \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i \right)^2} \quad (3)$$

where P_i is the mean monthly rainfall for the i -th month. Values below 10 indicate an uniform rainfall distribution, values from 11 to 20 denote seasonality in rainfall distribution, and values above 20 correspond to climates with substantial monthly rainfall variability. Usually PCI is larger than $\overline{PCI}$ and the difference between the two increase as the inter-annual precipitation fluctuation increase (Apaydin et al., 2006).

The PCI and $\overline{PCI}$ values for the studied stations are indicated in Table II. PCI time series, for the same stations, are instead plotted in Figure 7 and Figure 8.

Table II. Negative PCI trend for inland and coastal stations, as % of average PCI .

Case study region	Inland station		Coastal station	
	PCI	$\overline{PCI}$	PCI	$\overline{PCI}$
I	9.35	12.50	10.72	13.87
II	11.67	16.89	11.86	18.84

A difference between the PCI and the $\overline{PCI}$ can be actually observed. Differences range about 30% for both stations in the study region I, and are about 44% and 58% respectively for inland and coastal stations in the study region II. Given the PCI definition, precipitation regimes belonging to region I are associated to a uniform distribution within the year, whereas according to the $\overline{PCI}$ definition, they are both associated to a moderate seasonal pattern. For the study region II, according to the PCI and the $\overline{PCI}$ definitions, precipitation regimes are associated, respectively, with a moderate to pronounced seasonal pattern. Whatever is the definition for the precipitation concentration index, the index values calculated for the coastal stations are larger than the one calculated for the inland stations, as to say that the seasonality is more pronounced for coastal areas.

Figure 7 and Figure 8 indicate the PCI time series for the four investigated precipitation gauging stations, respectively for the study regions I and II.

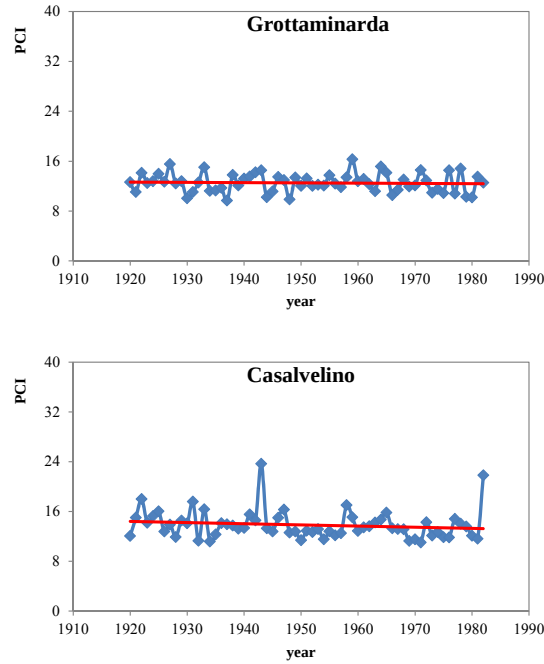


Figure 7. PCI time series and interpolated regression line for (left hand side) inland station and (right hand side) coastal station (case study I).

Differences between Figure 7 and Figure 8 are identifiable in the different average level for the PCI, which is larger for the study region II, and also in the fluctuation of the time series, which is again larger for the study region II, regardless for the particular station location.

Besides differences, there is a common feature between Figure 7 and Figure 8, that is the negative trend that the PCI time series exhibit for both region I and II. PCI tendencies have been estimated as the slope of the interpolated regression line, and quantified as a % of the average PCI value. The magnitude of the trends are reported in Table III.

Table III. Negative PCI trend for inland and coastal stations, as % of average PCI.

Case study region	Inland station	Coastal station
I	2.23 %	5.46 %
II	2.50 %	7.10 %

The PCI index show a generalized negative trend for both region I and II, with a consequent reduction for the concentration index, which would imply a different distribution of precipitation monthly total within the year, with a tendency toward a more uniform precipitation distribution, likely depicted through an increase of precipitation volume during the summer period and a reduction of precipitation volume during the winter season. The magnitude of the trend seem to be affected by the

particular station location, with coastal stations exposed at a larger extent to the PCI reduction.

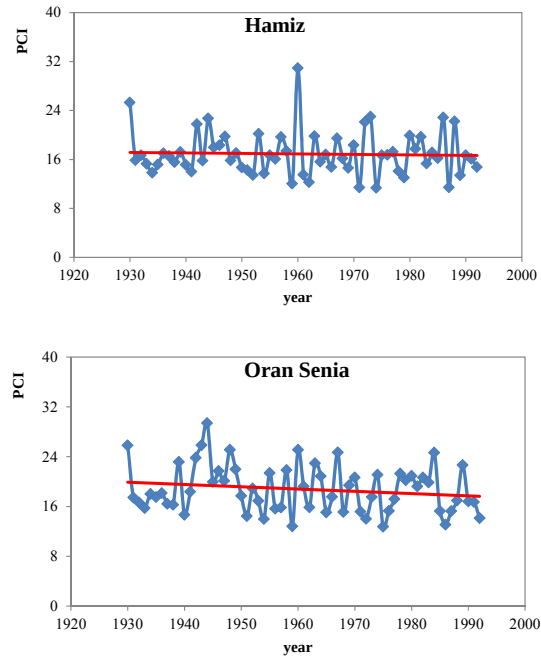


Figure 8. PCI time series and interpolated regression line for (left hand side) inland station and (right hand side) coastal station (case study II).

5 CONCLUSIONS

The current study report on a preliminary characterization and quantification of both inter-annual and intra-annual precipitation variability, for a particular climatic area that is the Mediterranean basin. Case studies are represented by two regions, both typically experiencing a temperate Mediterranean climate, a South-West Italy region facing the Tyrrhenian Sea and a North-West region of Algeria facing the Mediterranean Sea. Comparison between the two studied regions allow to assess at what extent precipitation fluctuation affects the climatic regime within the Mediterranean basin. With regard to the inter-annual variability, that is the fluctuation of the precipitation from year to year, a trend analysis has been performed on a large dataset, consistent in about 200 stations for the study region I and in about 50 stations for the study region II. Results for region I do not really report on a generalized trend, in that the percentage of stations showing a significant trend is however moderate, coming to a maximum of 27% at the annual scale, and at 33 and 4% respectively during the winter and summer trimesters. Results from region II indicate similar result reported for the region I. A preliminary characterization of the intra-annual variability, that is the precipitation fluctuation during the year, is also given. To this aim the computation of the PCI index is proposed

to the quantification of the seasonality in the precipitation regime and a trend analysis on PCI has been performed. PCI values have been computed according to two definitions, that is as the average of the annual PCI series or as an index based on mean monthly precipitation values. According to the PCI definition the precipitation regime has a moderate to pronounced seasonality, with a trend, during the last century, to a reduction of the index value, that is with a trend in the precipitation distribution within the year moving toward a more uniform pattern. The magnitude of the negative trend seems to be related to the station location, with coastal stations showing a larger negative trend compared to inland stations.

This study represents a preliminary and explorative analysis of the intra-annual characterization. The extension of the investigated database would allow to confirm the intra-annual features here pointed out, such as a generalized negative tendency and a pronounced effect of the terrain orography on the intra-annual fluctuation. At the same time, it would enable an investigation of a potential relationship between the inter-annual and the intra-annual precipitation fluctuation: the computation of the PCI, in particular the difference between the average PCI and the $\overline{\text{PCI}}$, seems indeed to embed an index of inter-annual fluctuation, as the difference appears larger for precipitation stations that exhibit a more pronounced fluctuation from year to year.

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