DAILY RAINFALL STATISTICS IN SICILY (1920-2000)

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ABSTRACT

Rainfall characteristics are crucial for vegetation patterns formation and evolution in Mediterranean ecosystems. Changes in rainfall frequency and intensity could cause vegetation water stress for some plant species and benefit, at the same time, other species, driving coexistence and competition dynamics. The changes in the precipitation characteristics are sometimes more important than the changes in the total amount of precipitation in determining the partitioning between green and blue water with several implications for both the vegetation communities health and water resource management.

Decreasing rainfall is a clear signature of climate change in Mediterranean countries. Annual and winter totals have been demonstrated to decrease in the past century and GCMs forecast a progressive worsening of the current situation even if it is still not clear if and how rainfall could be modified in its temporal and seasonal patterns. This study aims to analyze daily rainfall properties in Sicily in the last century. Namely the daily depths and interarrival times between events are investigated in about 50 stations, also characterizing seasonal rainfall features. The presence of significant trend has been detected using the non parametric Mann Kendall test.

Keywords: Daily rainfall statistics, trend analysis, Mediterranean ecosystems, ecohydrology.

1 INTRODUCTION

Several studies have been carried out on rainfall trends at different temporal scales (from daily to annual) and in different world areas. Existing analyses of daily series show for some areas a positive trend in the daily precipitation intensity and a tendency toward higher frequencies of heavy and extreme rainfall in the last few decades (Houghton et al., 1996). The main areas where precipitation shows significant positive trends are the USA (Trenberth, 1998; Kunkel et al., 1999), eastern and northeastern Australia (Plummer et al., 1999), South Africa (Mason et al., 1999), the UK (Osborn et al., 2000) and northern and central Italy (Brunetti et al., 2000, 2001). In most of the areas with a positive trend in rainfall intensity, an increase in total precipitation has also been observed (Groisman et al., 1999). This relationship is, however, not universal, as in some areas (i.e. Italy) an increase in heavy precipitation has been observed together with a tendency toward a decrease in total precipitation (Brunetti et al., 2001). Besides the increase in precipitation intensity, there are some indications that the overall percentage of the Earth's surface affected by either drought or excessive wetness has increased (Dai and Trenberth, 1998). Regarding the Mediterranean areas, previous studies have found an annual decreases in precipitation: eastern part (Kutiel et al., 1996), central part (Piervitali et al., 1998) and western part (De Luìs et al., 2000).

Effects of climate changes on environment are considerable because of the coupled influence on global environment system and on human health and safety. It is likely that the frequency of heavy precipitation events or proportion of total rainfall from heavy falls has increased over most areas (Trenberth et al. 2007). This climate modification implies an increase of flood phenomena, exacerbating their role on human safety as well.

The reason of such enhanced precipitation rates must be sought in the increased concentrations of greenhouse gases in the atmosphere. These, in turns increase downwelling infrared radiation, and this global heating at the surface not only acts to increase temperatures but also increases evaporation which enhances the atmospheric moisture content. An acceleration of the hydrological cycle is the immediate consequence of this alteration which often results in increased heavy and extreme rainfall and, consequently, in increased runoff and flooding hazard. It follows that increased attention should be given to trends in atmospheric moisture content, and datasets on hourly precipitation rates and frequency need to be developed and analyzed as well as total accumulation (Trenberth et al. 2003).

Sicily is the southerner region of Italy characterized by a typical Mediterranean climate with mild and wet winters and, hot, dry summers. Climate and, as a consequence, vegetation in Sicily are strongly influenced by local geomorphology and are then rather variable over the region. In the past, Sicily has been screened for several climate change signals. Cannarozzo et al. (2006) analyzed annual, seasonal and monthly rainfall data in the entire Sicilian region, showing a global reduction of total annual rainfall, which is mainly due to the winter reduction. Aronica et al. (2002) analyzed the series of maximum intensity for fixed duration (1, 3, 6, 12, 24 hrs) and annual daily maxima in eight station located in Palermo finding a global reduction of rainfall intensities, in disagreement with the results obtained by other authors. Bonaccorso et al. (2005) assessed the presence of linear and non linear trends in annual maximum rainfall series of different durations observed in Sicily. Results of this study indicate that for short durations, historical series generally exhibit increasing trends while for longer durations the trends are mainly negative.

Starting from these previous founding, this study attempts to provide a further contribution to the analysis of trend detection by investigating and quantifying the changes in daily rainfall intensity and frequency in Sicily. In particular, daily rainfall series are analyzed in order to identify the presence of significant trends at site using the Mann-Kendall test.

2 DATASET AND METHODOLOGY

Region of Sicily is the largest island in the Mediterranean which extends over an area of 25,700 km^2. Rainfall dataset has been selected from the regional database published by Osservatorio delle Acque – Agenzia Regionale per i Rifiuti e le Acque (OA-ARRA) which consists of daily precipitation recorded at 365 raingauges in the period (1929-2009), as reported in Figure 1. The sample size varies from 9 to 63 years with mean sample size equals 28.5 years. A preliminary analysis was made in order to identify the time window with the highest number of running gauge stations. Figure 2a shows the observation matrix relative to the whole annual rainfalls dataset; black pixels denotes 'running' raingauges while grey pixels are used for "out of service" raingauges. In the same figure the two vertical black lines define the time window of the selected subset shown in Figure 2b (a 50 years period ranging between 1956 and 2005).

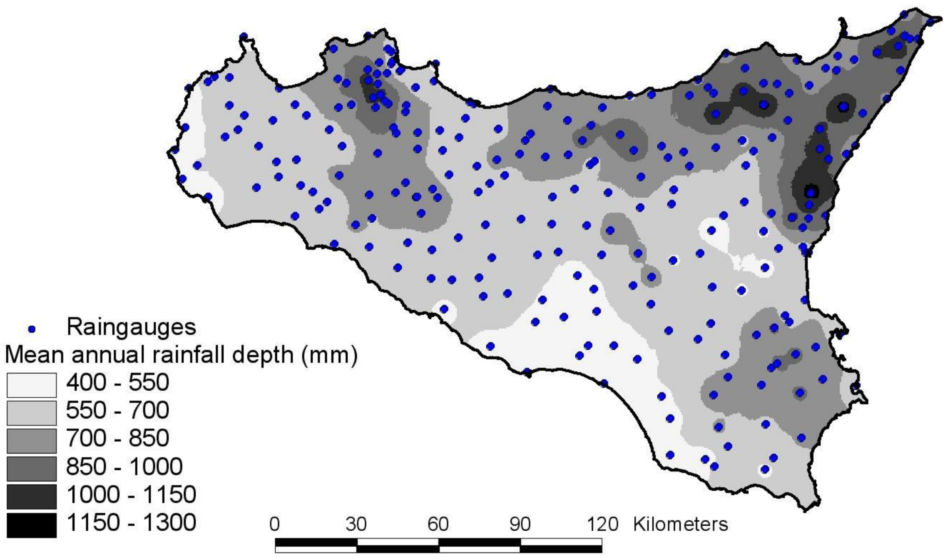

Figure 1 – Location of rainfall gauging stations and annual rainfall amount

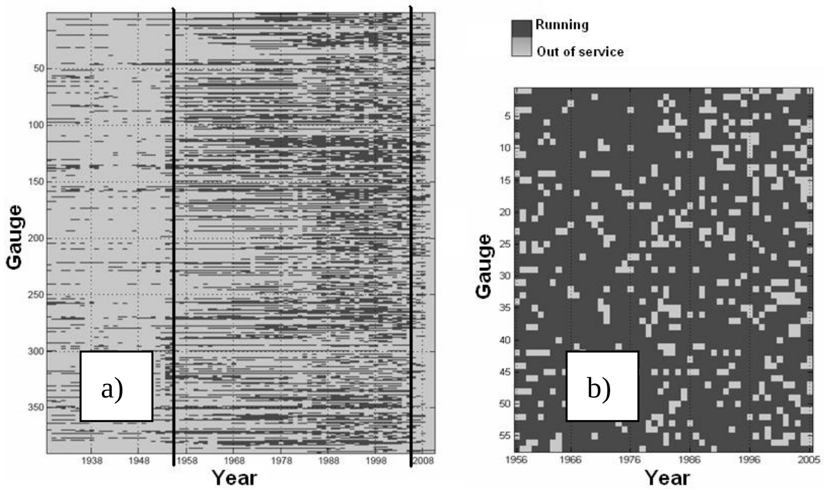

Figure 2- Entire regional dataset (a) and selected dataset (b).

This subset, formed by data coming from 57 raingauge stations with an average sample size of 47.64 years and distributed over the whole region, have been used to identify signals of possible climate change both for daily rainfall intensity and frequency.

Several statistical procedures can be used for trends detection, in particular parametric and non-parametric tests. In this study, the non-parametric Mann-Kendall test for trend detection (Mann, 1945, Kendall 1962) has been used. This test identifies the presence of a trend, without making an assumption about the distribution properties. Moreover, non-parametric methods are less influenced by the presence of outliers. In a trend test, the null hypothesis H_0 is that there is no trend in the population from which the data is drawn, while hypothesis H_1 is that there is a trend in the records. The test statistic, Kendall's S (Kendall 1962), is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \quad (1)$$

where x_i and x_j are the data values at times *i* and *j*, *n* is the length of the dataset and

$$sign(x_j - x_i) = \begin{cases} 1 if\,(x_j - x_i) > 0 \\ 0 if\,(x_j - x_i) = 0 \\ -1 if\,(x_j - x_i) < 0 \end{cases} \quad (2)$$

Under the null hypothesis that x_i are independent and randomly ordered, the statistic *S* is approximately normally distributed when $n \geq 8$, with zero mean and variance as follows:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad (3)$$

The standardized test statistic Z_s is computed by:

$$Z_S = \begin{cases} \frac{S-1}{\sigma}\ if\, S > 0 \\ 0\ if\, S = 0 \\ \frac{S+1}{\sigma}\ if\, S < 0 \end{cases} \quad (4)$$

and compared with a standard normal distribution at the required level of significance. In this analysis confidence level at 95 percent was considered and therefore the significance level α was set equal to 0.05; consequently the null hypothesis is verified when $|Z_s| < 1.96$. A positive value of Z_s indicates an increasing trend and vice-versa. Local significance levels (*p*-values) for each trend test can be obtained from the fact that

$$p = 0.5 - \Phi\left(\left|Z_S\right|\right) \tag{5}$$

where $\Phi(\cdot)$ denotes the cumulative distribution function of a standard normal variate. The magnitude of trends β was evaluated using a non-parametric robust estimate determined by Hirsch et al. (1982):

$$\beta = Median\left(\frac{x_j - x_l}{j - l}\right) \qquad \forall\, l < j \tag{6}$$

where x_l is the l-th observation antecedent to the j-th observation x_j.

The Mann-Kendall test has been applied, at both the annual and the seasonal time-scales, to the time series of average daily rainfall intensity (named *Alfa* and measured in mm/day), average rainfall frequency (named *Lambda* and measured in 1/day) and to total rainfall (mm). The interarrival times between subsequent events has been calculated and averaged at the annual and the seasonal time scale for each considered raingauge station. The average rainfall frequency *Lambda* is then given by the inverse of the average interarrival time between two subsequent events. In the seasonal analysis, the year has been considered constituted by two different seasons: dry season (from April to September) and wet season (the remaining part of the year). This distinction was driven by the marked seasonal rainfall behaviour. In fact, in Mediterranean areas, rainfall is concentrated during the winter and the fall, while spring and summer are mostly dry.

3 RESULTS

The daily precipitation data recorded by each station have been processed in order to obtain the time series of Alfa, Lambda and total rainfall at both the annual and seasonal level. The main results of the Mann-Kendall test application to the different time series are synthesized in Figure 3 where the percentage of stations showing statistically significant trends is reported. Trend analysis has been carried out for rainfall intensity at annual and seasonal time scale. The average annual intensity has decreased in 75% of the considered stations, while the remaining 25% show no trend at 95% confidence level. Seasonal results are very similar to the annual ones: in the wet season, which consists of winter and fall months, the percentage of negative trends is almost the same while it slightly decreases in the dry period. The results of the analysis on the rainfall intensity, shown in the first row of Figure 3, have then highlighted as a considerable number of stations in Sicily with a decreasing trend in both the annual and seasonal (wet and dry seasons) average intensity of the rainfall events (Alfa).

A relevant novelty of this work lies on the rainfall frequency analysis, that is an important rainfall characteristic, strongly impacting vegetation physiological processes, rarely investigated. The results of the trend analysis on the average rainfall frequency are shown in the second row of Figure 3. At the annual scale the most important outcome is that rainfall frequency does not show trends for 63% of the considered stations. A considerable percentage, namely the 30%, show negative trend which means rarer events, while the 7% of stations show the presence of more frequent events. These percentages remain more or less constant in the wet season analysis. If the attention is focused on the dry period, generally characterized by a lower rainfall events frequency, the percentage of stations showing no trend increases to 75%, while the percentages of stations showing trends are equally distributed between stations having time-series showing rarer events (12%) and stations having time-series with more increasing rainfall frequency (12%).

The above described results have also been combined in order to give a comprehensive view on water availability at annual and seasonal time scale. For a given period, the product of the average rainfall intensity, the average rainfall frequency, and the duration of the same period provides the total amount of water for that period. The Mann-Kendall test application on the average total rainfall (third row of Figure 3) has shown as, at the annual time scale, the 70% of the considered stations show negative trend, coherently with the outcome of Cannarozzo et al. (2006). Water availability has decreased in the last century because of a generalized reduction of the average rainfall intensity. In some cases this reduction is dramatic because it is associated with a frequency reduction, while in others it is mitigated by a frequency increase.

The total rainfall in the wet period follows the annual behaviour, with 72% of stations showing negative trends and 28% showing no trends. The reason of this synchrony lies on the consideration that in this season it is concentrated the largest part of the annual rainfall and consequently every marked tendency it is reflected at annual scale. This season is crucial for Mediterranean ecosystems because replenishes soil water content, which in turns represents a fundamental water reserve for facing the subsequent drier season, usually coincident with the growing season for vegetation. At the same time the water input arising from winter and fall months is decisive for storage systems, which are demanded to transfer water resources forward in time.

No significant reduction has been observed in the total rainfall during the dry period, where 68% of the considered stations show no trend. It is worth to point out that during spring and summer time only a minor rainfall contribution is given to annual amount. Moreover, this result implies that the observed negative trend (detected in 65% of the considered stations) in the rainfall intensity during the dry period is, in great part, balanced by a simultaneous increasing in the rainfall frequency (detected in 12% of the stations).

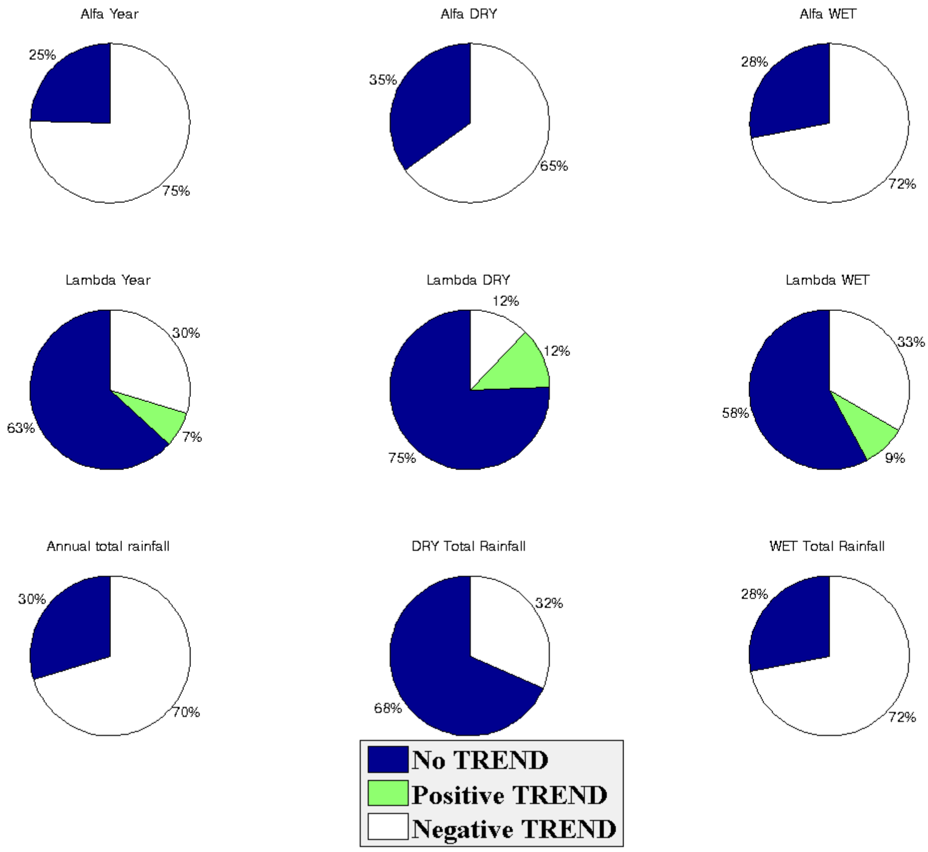

Figure 3 – Percentage of stations showing negative, positive or no significant trend in daily rainfall intensity (first row), frequency (second row) and in total rainfall. Columns present annual (first), dry (second) and wet (third) period results.

4 CONCLUSIONS

According to the most recent climate predictions, Mediterranean ecosystems will probably face a radical modification of the climatic conditions in the next future due to the Earth global warming, mainly related to the greenhouse effect. In Southern Mediterranean areas the effects of climate changes are summarizable in a rainfall reduction and a temperature increase.

This work has investigated potential modifications in the rainfall regime of Sicily, trying to detect over historical records, any potential changes or trend in the main rainfall features, such as the average intensity and frequency of rainfall events and the average amount of rainfall at the annual and at the seasonal time-scales. A dense network of raingauge stations distributed over the region has provided an important database of long daily rainfall series. The central task of climate change detection studies is to determinate whether an observed change or trend is significant. With this aim, the historical rainfall data, opportunely processed in order to extrapolate the main average features, at both the annual and seasonal scales (wet and dry season), have been here analyzed by using the non parametric Mann Kendall test with a significance level of 0.05. The results have provided an overview of potential trends identified in some characteristics of the rainfall at the regional level. In particular, the data collected in a high percentage of the Sicilian raingauge stations here considered, have shown a significant negative trend in the total annual precipitation, mainly due to a reduction of the seasonal rainfall during the wet period (fall and winter). A similar percentage of stations have shown how all the rainfall events (during both the wet and dry season) tend to be less intense, while very few stations are characterized by significant changes in the frequency of rainfall events.

One of the immediate consequences of the rainfall reduction is an increase in the vegetation water stress. Less intense and rarer rainfall events, as they have been recorded in the past years and how they are expected to be in the future, could exacerbate the problem of water stress, availability and management. All this could cause a significant modification of vegetation patterns characteristic of Mediterranean areas in the coming years. If the rainfall reduction will be concentrated during the wet season, as emerges from this study, grasses could have some advantages over the trees species. Grasses could keep the water stress similar to the nowadays value, while trees will suffer for the lack of the winter recharge, increasing their water stress.

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