4A.9 ACQUISITION AND ANALYSIS OF HISTORICAL SERIES OF HOURLY PLUVIOMETRIC DATA

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1. ABSTRACT

The present research can represent a significant step forward due to the acquisition and analysis of historical time series of higher than usual frequency data (hourly), which allows to perform far more robust and significant statistical analysis of the variability and tendencies of the extreme storms, as well as the droughts.

Two long historical series of hourly precipitation data were digitalized starting from analogical records, collected in Tuscany, Italy, one next to the coastline, the other over the inland mountains, covering 1945-2002 and 1930-2005, respectively.

Data quality as well as homogeneity were checked by means of few statistical tests, such as the *run test*, including the comparison with data colleted at nearby rain gauges.

The analysis of the overcomes of specific hourly thresholds, computed on the basis of the reference period 1961-1990, has shown significant increases at both sites in the latest 15 years with regards to the previous times, as well as an increased seasonality, resulting in the concentration of the most intense and extreme rainfalls in September-November.

A significant decrease of the number of rainy hours was observed at both sites, mainly due to winter drying and, limited to the mountainous gauge, a relevant increase of the average hourly precipitation intensity. The analysis of reference percentiles for the hourly precipitation, such as, 99°, 99,5° e 99,9°, has shown positive trends at both sites, as well as the precipitation series consisting of 3, 6, 12 and 24 consecutive hours events.

As a preliminary attempt to understand the findings, the tendencies of heavy sub-daily rainfalls was compared to the sea surface temperature (SST) time series, leading to partially significant outcomes and paving the way to further research.

Key words: Time series, hourly, Vallombrosa, Viareggio, POT, percentiles, intensity, SST.

2. INTRODUCTION

The long-term management and planning of hydrological catchments, agricultural districts, civil and industrial water needs, as well as hydropower, require an accurate knowledge of the pluviometric regime, of the frequency of the severe rainfall and of the dry periods in order to guarantee the water resource conservation and prevent floods.

The variability of the pluviometric regime is mainly linked to the climate variability and changes.

Variability and climate change show mainly by means of the variation of the heat content in the system, particularly of the ocean component, hence influencing at first the global surface temperature, then the local and global hydrological cycle, and they produce severe impacts on the other physical and ecological natural systems, which in turn react on the regional pluviometric regime, in a complex system of non-linear interactions.

Rial and al. (2003) presented an extensive description of the complex interactions, of the non-linearity and feedback of the climate system, which can lead to sudden and unexpected transitions between two states of semi-equilibrium very different from each other, even in absence of relevant external forcing.

In winter, the events in the synoptic scale in the northern hemisphere show different patterns, associated with variations in the trajectory and intensity of storms, as demonstrated by Gulev and al. (2002), Chang and Fu (2003), Harnick and Chang (2003). Moreover, the pressure field at sea level (SLP) shows anomalies and trends in different time scales (Gillet, 2003), following complex phenomena, such as the North Atlantic Oscillation (NAO) (Hurrel and al., 2001,2003), which has a particular influence on the north Atlantic and European regions.

These anomalies and the variability, due both to natural and anthropic phenomena, produce anomalies in rainfall, in term of average, intensity and frequency of the extreme events on both global and regional scales, even on the centre-northern Europe and the Mediterranean.

Hoerling et al. (2001) demonstrated that the effect produced by the raising of the sea surface temperature (SST) in the tropical oceans leads to an increase in the long-term of the winter North Atlantic Oscillation, while the extra-tropical SST variations do not produce relevant feedback and the SST variation in the tropical Atlantic exercises only a secondary impact on the northern Atlantic circulation.

Hurrel and Folland (2002) revealed a significant increase, in summer, of the pressure at sea level (SLP) in the north-eastern zone of the northern Atlantic and a corresponding drift towards north of the average route of storms.

These variations, which affect the zone between the latitudes 45°N and 70°N, and therefore great part of the central and northern Europe, can be linked to structures of atmospheric convection on tropical

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Atlantic and western Africa, which act through a mechanism of "atmospheric bridge", similar to that of the El Niño on the Pacific ocean.

Whereas there is a general agreement on the positive sign of the thermal response of the climate system at the current anthropic impact, uncertainties are still present on the speed of the heating, the possibility of sudden heating due to a temporary accumulation of heat in natural tanks, especially in oceans (Pielke, 2003), the effect of the land use, of the carbon cycles (Jones et al., 2003; Rial et al., 2003) and of the water vapour (Genio, 2002) and their interactions and feedback.

Further uncertainties remain also on the sign of the variations of intensity of the hydrological cysle due to the climate warming.

Recently Yang et al. (2003) demonstrated that the variation of the annual global average rainfall depends almost linearly on the surface warming, and in the case of a scarce increase of the SST, the changes of rainfall are small or even negative. The key factor is the balance between the earth radiative cooling and the heating due to condensation, which contributes to maintain the atmospheric temperature in equilibrium.

Groisman et al. (1999) analysed the trend of the summer daily pluviometric regime in eight countries around the world, which together cover almost the 40% of the whole earth surface: Canada, USA, Mexico, former Soviet Union, China, Australia, Norway and Poland. The observations show that monthly average rainfall increased everywhere of almost the 5% during the 20th century (except for China), while the frequency of rainy days do not increase significantly; therefore the increase of the average rainfall is due mainly to the increase of intensity of rainfall: as a matter of facts, extreme events (daily rainfall which are over the threshold values defined according to the geographic region) increased of almost the 20%.

The increase of the intensity of summer rainfall is associated to a relevant increase of the troposphere water vapour, which indicates an intensification of the hydrological cycle and, in particular, that the increase of the extreme rainfall will be probably much higher of the increase of the seasonal average rainfall.

Many authors studied variability and trends of the hydrological cycle in the Mediterranean region, concentrating in a particular way on the climatology of rainfall.

Different behaviours of the models of rainfall on western and eastern Mediterranean basins are widely discussed by Goodess e Jones (2002, 2003).

Their analysis show that "*on a greater part of the Mediterranean, the general trend is towards a decrease of rainfall, but the variation behaviour is complex, in particular with respect to the extremes*".

In the western sector, along the costal regions of the Iberian peninsula, for instance, we can notice "*many more days with severe rainfall*", while in the eastern sector "*some places, like Rodi… present a weak trend towards an increase of the events of severe rainfall in autumn*". It has also been discovered also that the decrease of the number of rainy days is more evident in winter.

Mariotti et al. (2002) analysed the hydrological cycle in the Mediterranean during the period 1948-1998, focusing their work on series of data of daily rainfall and evaporation and on the balance of atmospheric water vapour, demonstrating how the water deficit in the atmosphere is correlated positively with the NAO (increased of the 24% in winter and of the 9% on an annual scale).

Brunetti et al. (2001) analysed data on daily rainfall gathered in 67 places during a period of 46 years (from the 1951 to the 1996), obtaining interesting results:

- The number of annual rainy days decreased sensitively;
- The daily average of the intensity of rainfall increased in a significant way in all the seasons, except in winter;
- In the northern Italy, the increase of the intensity of rainfall is mainly due to extreme events, while in the south is linked to a general increase of the average daily rainfall;
- Rainy events that are over high threshold show an increase starting from the 70s, contrarily to the events under low threshold values, having respectively the highest and the lowest frequency in the last 120 years.

In a more recent study Brunetti et al. (2002) extended the series of the daily rainfall to the year 2000, noticing that annual or seasonal extreme events do not show significant trends, probably due to their rarity, while the increase trend is evident when more data are included in the analysis, in particular with respect to the overcome of high thresholds.

Recently Karl e Trenberth (2003) demonstrated that, in different places which present an equal value of total rainfall, the daily average intensity of rainfall increases with the local temperature.

The work here reported moves from the research project "Reanalysis and weather forecast on the Arno basin", sponsored by the Arno River Basin Authority and carried out in collaboration with the Foundation for Climate and Sustainability at Florence, Italy, with the aim of providing quantitative information on the variability and trends of the local and regional severe rainfall and the droughts in the past, present and future, by means of the analysis of historical series of daily and extreme pluviometric data at sub-daily durations, in order to highlight possible changes in the extreme rainfall regime.

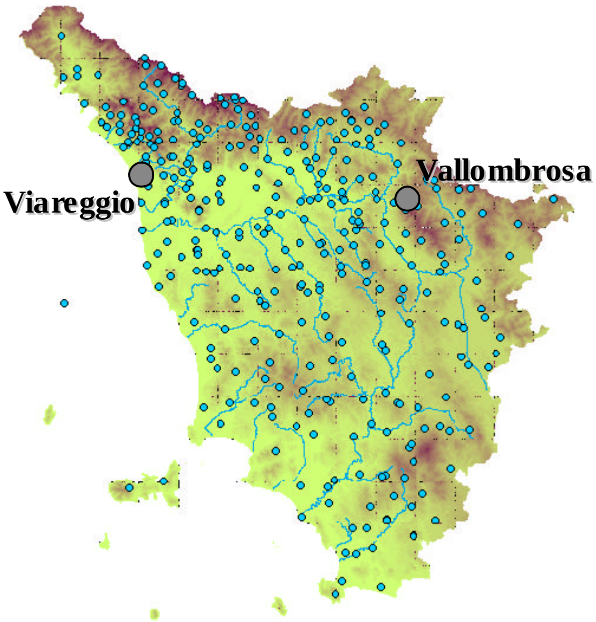
The main objective of that project was to provide a valid scientific support to the planning and management of protection action in case of floods, to the refinement of the techniques for the local meteorological forecast and to the management policies with regards to the quality and conservation of the water resources.

3. MATERIALS AND METHODS

Hourly rainfall data sets, concerning Vallombrosa (1930-2005) and Viareggio (1945-2002) rain gauges, were obtained by directly interpreting the analogical records and collecting the data within digital archives.

Gauge	Vallombrosa	Viareggio
Longitude	11.56	10.28
Latitude	43.73	43.87
Altitude	955 m a.s.l.	2 m a.s.l.
Mean annual precipitation	1315.0 mm	935.0 mm
Max annual precipitation	2053,4 mm in 1937	1394.6 mm in 1960
Max hourly precipitation	58 mm in 1959	78 mm in 1987

This is the most innovative feature with regards to



previous studies, that is the high time frequency of the data associated to the remarkable length of the historical series.

Several statistical analyses were performed on the two historical series with the aim to detect any signals of climate change in the intense and extreme events.

3.1 Homogeneity and property of the measures

The first aim of this work was checking the quality of the data sets, therefore the two series were initially examined to verify their homogeneity by a "run-test" and the propriety of their measures by comparing the average trend of the annual cumulate values of the examined stations with the same data from nearby rain gauges.

The "run-test" infer on the series' randomness and the rejection of the null hypothesis involve the assertion that the median of the observations changes in time, indicating the non-homogeneity of the series.

The correlation between the observed series and the control's ones was established by means of the Kendall's Rank Test which provides a distribution-free test of independence and a measure of the strength of dependence between two variables.

The analyses carried out over the data sets estimated:

- Rainy threshold's overcomes;
- Pluviometric intensity series;
- Trend of the rainfall's percentiles values on the hourly and multi-hour basis period (3, 6, 12 and 24 hours)
- Correlation between SST, POT and rainfall percentiles' trend.

Most of the analyses were performed by a Java software suitably developed for the above mentioned purposes.

3.2 Peaks over threshold analysis

This analysis provided important insights about the evolution of the hourly pluviometric regime with regards to high intensity events, with consequences on the impacts' weigh up in terms of emergency and protection of the territory.

The thresholds were defined calculating the values of the rainfalls' percentiles over the reference period 1961-1990.

After the reference percentiles, the hourly overcomes in every year were computed for both gauges.

The attention was focussed on the higher percentiles' values (99°, 99,5°, 99,9°), in turn compared with the overcomes of the same values in the September-November period, the rainiest trimester of the year.

The time change of the distribution of the overcomes in the September-November period with regards to the other months was studied as well, comparing the last 20 years with the previous period.

The one-tailed test "U" of Mann-Whitney was performed, in order to verify the statistical significance of the increase of the overcomes in the years after 1990, with regards to the previous period, as well as the unbalance of the distribution of the rain towards the September-November period, which means marks an enhanced seasonality of the precipitation regime.

3.3 Analysis of the rainfall intensity

Before the analysis of the rainfall intensity, it was studied the diagram of the annual number of rainy hours in order to estimate possible trends, let alone the ratio between the hours of rain in the autumnal trimester and the total number of rainy hours. The trend analysis of the mean rainfall intensity for both the stations was performed, comparing both the September-November period against the annual period and the last twenty years against the previous ones.

For the mean intensity calculation the following formula was used:

$$I_{med} = \frac{mm.Tot}{n.hours} \quad (1)$$

where mm.Tot is the sum of the rainfall values greater than 0.2 mm and n.hours is the number of rainy hours with values greater than 0.2 mm. In order to check if the mean intensity during the last twenty years was significantly greater than in the previous period, the one-tailed test "U" of Mann-Whithney was performed.

It has been also compared the course of the mean intensity of the hourly precipitation with the trend of the 99,5° percentile, calculated as well on annual basis.

The trend of the number of rainfall hours was finally compared against the annual frequency of events classified as downpours*.

3.4 Analysis of the course of the percentiles

The course in time of the reference percentiles was analysed: these have been calculated in successive temporal windows of the duration of 10 and 30 years, with decennial and annual moving windows. The same type of analysis was performed on the percentiles calculated on the cumulated values with mobile windows of 3, 6, 12 and 24 hours with one hour time step.

3.5 Correlations with the SST

The analysis focussed as well to the correlations between the course of the sea surface temperature (SST) and

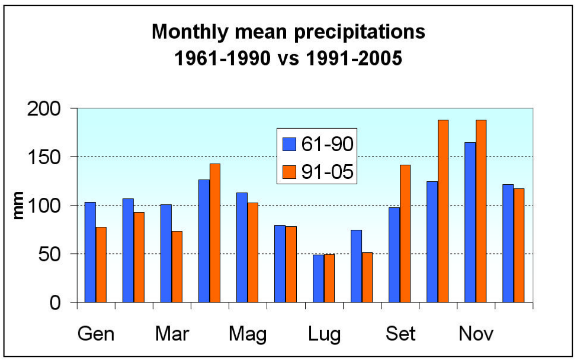
- the overcomes of the reference percentiles;
- the courses of the reference percentiles in time;
- the pluviometric intensities at annual and trimestral level.

The SSTs were obtained from the NOAA's datasets (www.cdc.noaa.gov), and concerned a sector over the western Mediterranean Sea.

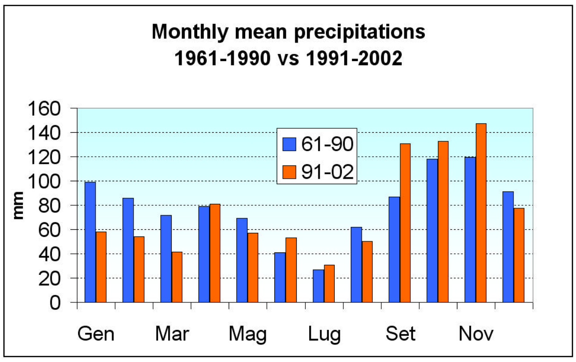
4. RESULTS AND DISCUSSION

The exposure of the analyses' results follows the order of their presentation.

The preliminary verification of quality of the series, in order to establish the presence of serial non-homogeneity, gave positive outcomes for all the parameters characterizing the series, which resulted sufficiently homogenous for the following analyses.



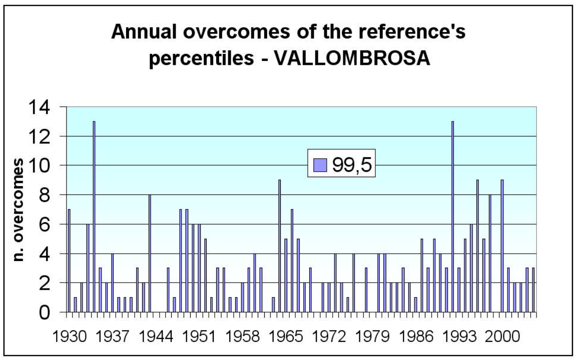
Vallombrosa



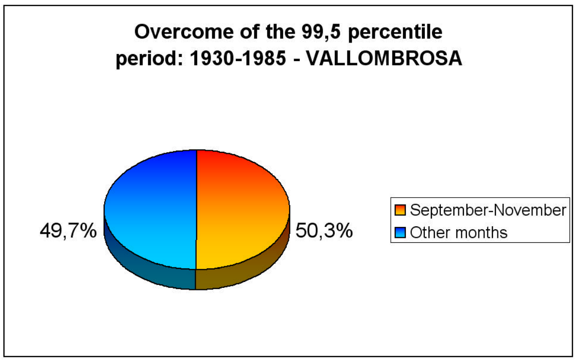
Viareggio

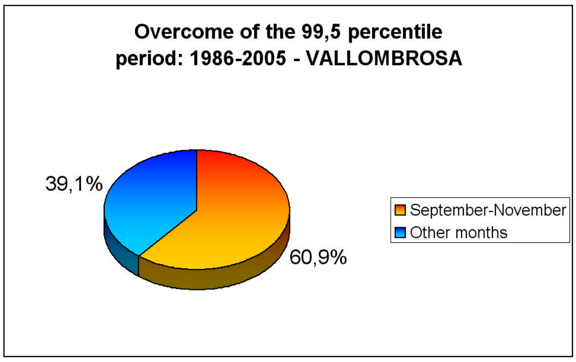
The analysis of the variation of the pluviometric regime of the last years regarding the reference's period has put in evidence a modification of the distribution of the events for both rain gauges, with a marked increase in the autumnal months and a reduction in the winter period. The analysis of the overcomes concerning particular thresholds (computed in the thirty reference years 1961-1990) has laid emphasis not only on a significant increase of the number of the overcomes in the last ten years with regards to the previous period (99° and 99,5° for Vallombrosa, 99,5° and 99,9° for Viareggio), but also a greater "seasonality" of these overcomes that appear to concentrate, for both sites, in the September-November trimester.

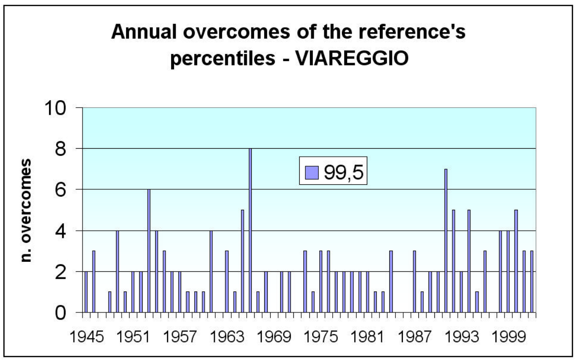
In particular, the increase of the number of overcomes in the September-November period with regards to the other months of the last twenty years (10% more) confirm the increase of the number of intense and extreme hourly precipitations in the autumnal months with regards to the rest of the year.

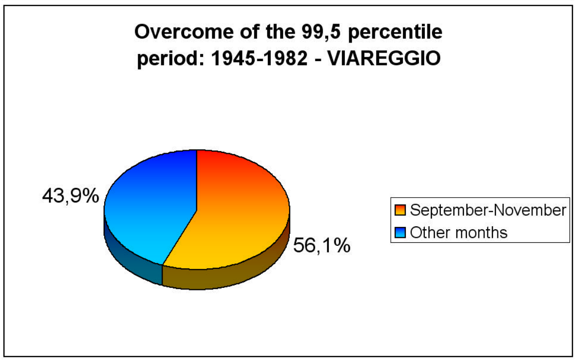


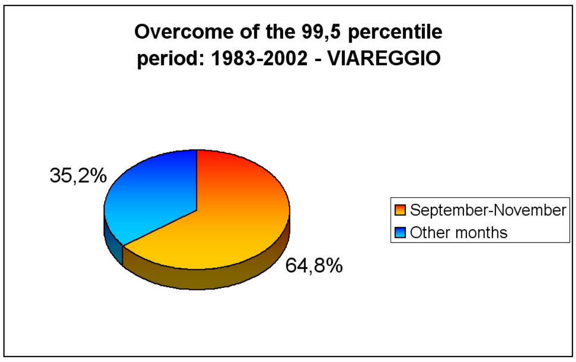
* WMO defines as "downpours" the rainfall events with intensity higher than 10 mm per hour.





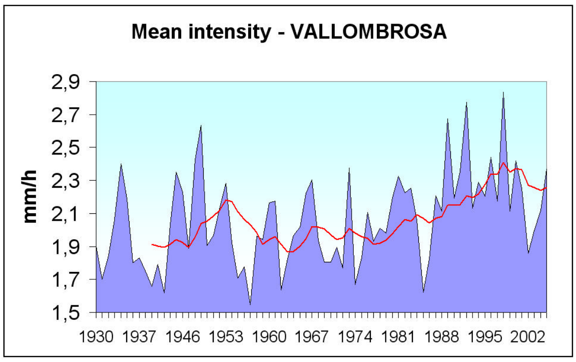


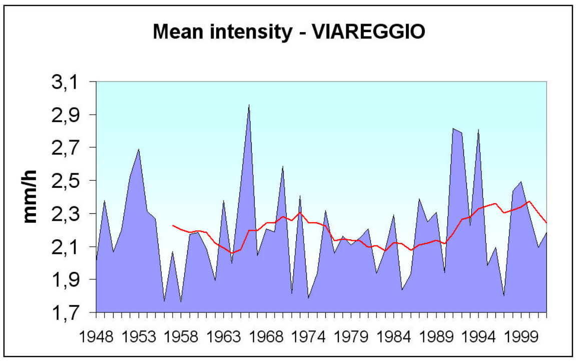




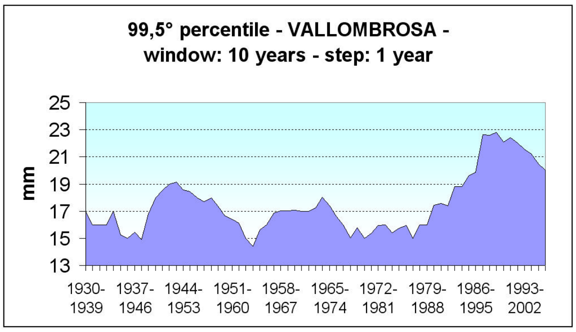
The analysis of the rainfall intensity puts in evidence, for example at Vallombrosa, besides a remarkable decrease of the number of rainy hours, a relevant increase of the mean hourly intensity; with reference to the station of Viareggio, in spite of a decrease of the rainy hours, the average intensity doesn't change significantly. The decrease of the number of rainy hours at both the rain gauges could be due to the winter drying trend.

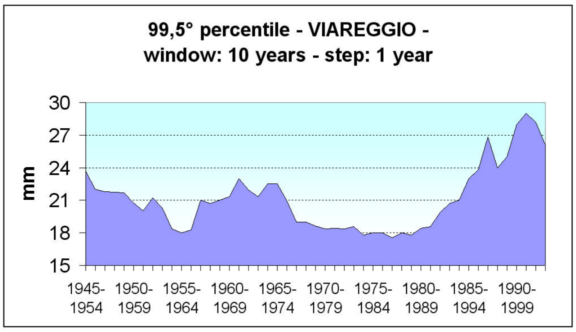
The analysis pointed out as well a general increase of the number of precipitation events classified as downpours against the decrease or constancy of the total number of the rainy hours. Comparing the course of the annual average intensity of the hourly precipitations with the annual course of the 99.5° percentile turned out a noticeable positive correlation, confirmed by the Kendall's correlation test at level of significance of the 5% suggesting that the intensification of extreme events is driven by a more general transition of the precipitation regime towards more intense events.



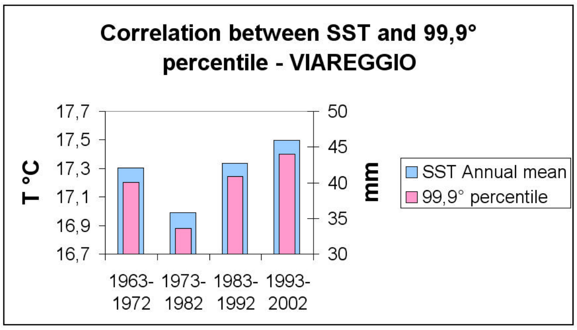


The analysis of the courses of reference percentiles showed the positive trends of nearly all percentiles on both decennial and thirty year time basis, due to the exceptional regime of the 1990's, resulting in a significant increase of the intensity of the hourly and multi-hourly precipitations.





The analysis of the possible correlations between the SST and the course of percentiles or the number of annual overcomes didn't show significant outcomes (with the exception of the 99.9° percentile's overcomes at Vallombrosa). The correlation between the decennial mean SST trend and the percentiles computed on the decennial time basis at Viareggio looked like a significant one, above all with the decennial cumulated 99,9° percentile computed on the hourly basis.



No other significant correlations were found, except the one between the rainfall intensity computed in the July-September period and the SST calculated in the same trimester, supported by the Kendall's test at the level of significance of 5%.

5. CONCLUSION

The analysis of only two series of hourly precipitation data sets, although they cover historical periods of some decades, until present time (1930-2005 for Vallombrosa and 1945-2002 for Viareggio), cannot be considered sufficient in order to identify and to characterize regionally significant changes of the rainfall regime, as well as climatic changes.

The additional value of this analysis may reside rather in the very high frequency of the base data, that in its turn allows to perform more robust and significant statistics with regards to the ones generally available in the present study field.

The results of this study could as well lead to an extension of the data base and hopefully to regionally significant results.

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