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Detecting trends of extreme rainfall series in Sicily

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Abstract. The objective of the study is to assess the presence of linear and non linear trends in annual maximum rainfall series of different durations observed in Sicily. In particular, annual maximum rainfall series with at least 50 years of records starting from the 1920's are selected, and for each duration (1, 3, 6, 12 and 24 h) the Student's t test and the Mann-Kendall test, respectively, for linear and non linear trend detection, are applied also by means of bootstrap techniques. The effect of trend on the assessment of the return period of a critical event is also analysed. In particular, return periods related to a storm, recently occurred along the East Coast of Sicily, are computed by estimating parameters based on several sub-series extracted from the whole observation period. Such return period estimates are also compared with confidence intervals computed by bootstrap. Results indicate that for shorter durations, the investigated series generally exhibit increasing trends while as longer durations are considered, more and more series exhibit decreasing trends.

1 Introduction

Following a consolidated engineering practice, the derivation of design events, i.e. events corresponding to a fixed return period, is generally carried out by assuming stationarity for the underlying hydrological processes, i.e. that the probability of occurrence of an extreme event does not depend on time. However, there is a growing evidence that such an hypothesis may not be suitable for many geophysical processes whose observed series seem to exhibit trends and/or jumps along time due to climatic or environmental changes or to human activities (Kundzewicz, 2004).

Trend analysis studies in Italy have shown that annual maxima of long daily rainfall samples collected in some rain-gauges located in the northern and central part of the country present an increasing trend (Montanari et al., 1996; De Michele et al., 1998), while a decreasing trend has been detected for some rain-gauges around Palermo area in Sicily (Aronica et al., 2002). Despite the apparent evidence, some authors have questioned the adequacy of the traditional statistical tools generally adopted to detect trends and/or jumps (Yue and Wang, 2002; Yue et al., 2003). On the other hand, bootstrap techniques have proved to be valuable tools when testing for trends (Kundzewicz, 2004; Yue and Pilon, 2004).

In this study the presence of linear and non linear trends in annual maximum rainfall series of different durations (1, 3, 6, 12 and 24 h) observed in Sicily is investigated by means of the parametric Student's *t* test and the non-parametric Mann-Kendall test. The null hypothesis of no trend is tested by means of the traditional asymptotic distributions of the statistics, as well as by means of a bootstrap approach (Efron and Tibshirani, 1993; Yue and Pilon, 2004). Furthermore, the significance of the Theil-Sen statistic for linear trend (Theil, 1950; Sen, 1968) is tested by means of bootstrap. The effect of trend on the assessment of the return period of a critical event that recently occurred along the East Coast of Sicily is also analysed. In particular, return periods are computed by estimating parameters based on several sub-series extracted from the whole observation period and compared with confidence intervals computed by bootstrap.

2 Adopted tests for trend detection

Student's *t* test and Mann-Kendall test are statistical tools widely applied for linear and non linear trend detection, respectively. For a detailed description of such tests readers may refer, for example, to Helsel and Hirsh (1992). The same tests can be also applied by making use of bootstrap techniques, which are not subject to restrictive assumptions, such as normality of the data, since the outcome of a test is decided based on the confidence intervals of the considered statistic rather than on its presumed quantile (Yue and Pilon, 2004). Basically, bootstrap consists in re-sampling from the original sample by randomly selecting data M-times and

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computing a statistic related to trend for each re-sampled series. Under the null hypothesis of no trend, this will yield an empirical distribution function of the test statistic, which can be used to build a test. Clearly, the larger the number M of bootstrapped samples, the better is the accuracy of the statistical inference. Another bootstrap-based test for linear trend is the bootstrap slope test, based on the Theil-Sen estimator of the slope b of the linear trend:

$$b = \text{median}\left(\frac{y_j - y_i}{j - i}\right) \qquad \text{for } i < j \tag{1}$$

In the present study the conventional Student's t test (t) and Mann Kendall test (MK), the bootstrap-based Student's t test (BS-t), Mann Kendall test (BS-MK) and Theil Sen slope test (BS-TS) have been applied to the available annual maximum rainfall series in Sicily.

3 Application of tests for trend detection

The described methodology has been applied both to total annual rainfall series from 1921 to 2000 and to annual maximum rainfall series of duration 1, 3, 6, 12 and 24 h with at least 50 years of observations recorded in 16 Sicilian rain gauges. In particular, for each rain gauge the non-exceedence probability of the test statistic value computed on the sample has been estimated and compared with the 2.5% and 97.5% limits, corresponding to α=5% for a simmetrical two sided test. Obviously the rejection region for the null hypothesis (no trend) is below 2.5% and above 97.5%. For the t test and Mann Kendall test, the non-exceedence probabilities corresponding to the statistics computed on the observed samples have been determined both by means of the asymptotic distributions as well as by bootstrap, while for the Theil-Sen statistic only bootstrap has been used. A preliminary application of the slope related tests to log-transformed data have yielded very similar results to those obtained for the non-transformed case. Thus it has been decided to not transform the data.

In Table 1, rain gauges presenting a significant trend, both for the annual case and for the annual maxima, are indicated. As it can be observed, results obtained for annual data are in some cases rather different from the results obtained for annual maxima data: for instance rain gauges no. 7, 11, 15 and 16 show a significant decreasing trend in the annual series and no trend in the annual maxima, while rain gauge no. 10 shows a decreasing trend respectively for annual maxima of 3, 6, 12 and 24 h and no trend in the annual case. Four rain gauges (no. 2, 3, 13 and 14) present no trend at any time scale. Besides, although the number of annual maxima series presenting a significant trend increase as the aggregation time scale increases, the results indicate an opposite behaviour between short and long durations. In fact, as it can be inferred from Fig. 1, for the case of 1 h almost all the investigated series show an increasing trend, while for longer durations more and more series exhibit decreasing trends, with even 6–8 series (depending on the test adopted) out of 16 showing a significant trend at 24 h.

4 Return period of a critical storm: analysis of a case-study

When non-stationarities are present in a time series, return period estimates of a given event should exhibit significant changes when different sub-series extracted from the whole observation period are used for fitting a parametric probability distribution. In this section an analysis of such changes is carried out with reference to a storm that occurred on 21–22 November 2003, between the cities of Augusta and Catania, along the East Coast of Sicily. The storm data are those collected in the recently installed rain gauge of Oasi Simeto, while the historical series correspond to the nearby rain gauge of Lentini Bonifica (no. 10), whose annual maxima series of 3, 6, 12 and 24 h are characterized by a decreasing trend (see Table 1). Both stations are located 3 km apart and practically at the same elevation and therefore, the data recorded at the two stations can be considered homogeneous.

For each year, the return period corresponding to the observed critical storm based on the past 20 years of records has been estimated by fitting a Gumbel distribution to the annual maxima series. Note that the choice of the distribution is not critical since the interest here does not lie in an accurate estimation of return period, but rather, on how it changes as different samples are used for its estimation. Indeed, the application of a Pareto distribution, here not shown for the sake of brevity, has led to results similar to the ones obtained by using the Gumbel.

If a significant decreasing trend is present, an increasing return period along the time span is expected. Figure 2 shows the time evolution of return period for each duration compared with confidence intervals obtained by re-sampling 1000 series of 20 years from the original series, estimating the return period corresponding to the critical storm and finally deriving the 5% and 95% quantile from the bootstrap empirical distribution of generated return periods. Annual maxima series and critical storm rainfall depths are also reported for each duration in the figure. When the return period curve falls outside the confidence intervals, a potential anomaly in the corresponding 20 year backward period is detected. For each duration, the return period increases with time, except small fluctuations related to sampling variability. Jumps are due to the fact that after the year 1969 almost all the rainfall value are less than the observed critical storm. However, it is worth noting that only for 3 h and mainly for 24 h, part of the return periods lies outside the upper confidence interval. In particular, in the case of annual maximum rainfall of 24 h, the return period is consistently above the confidence interval after the year 1989. On the other hand, an analysis of the history of the station of Lentini Bonifica, as reported in the Annals of the Sicilian Hydrographic Service, reveals no instrumental or procedural changes in data collection. Thus, it can be concluded that starting in 1970, the 20

Table 1. Synthesis of trend tests results. Black colored boxes indicate significant increasing trend, light grey boxes indicate significant decreasing trend.

N.	Rain gauge	Annual	1 hour					3 hours					6 hours					12 hours					24 hours				
			t	MK	BS t	BS MK	BS TS	t	MK	BS t	BS MK	BS TS	t	MK	BS t	BS MK	BS TS	t	MK	BS t	BS MK	BS TS	t	MK	BS t	BS MK	BS TS
1	Castroreale																										
2	Montalbano																										
3	Trapani																										
4	Sciacca																										
5	Palazzo A.																										
6	Enna																										
7	Gela																										
8	Ragusa																										
9	Palazzolo																										
10	Lentini b.																										
11	Bronte																										
12	Nicosia																										
13	Zafferana																										
14	Acireale																										
15	Taormina																										
16	Camaro																										

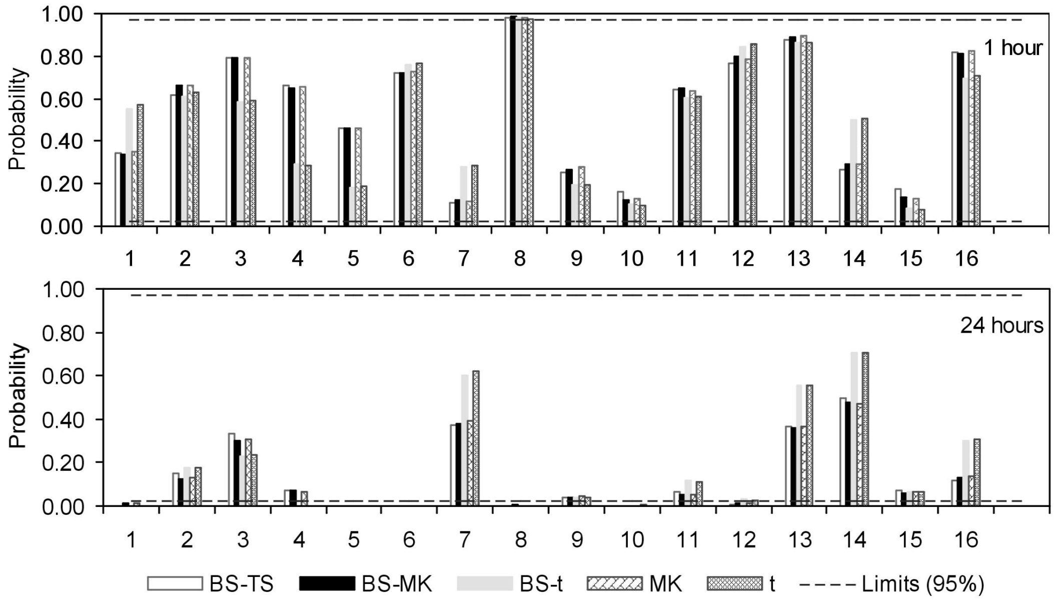

Fig. 1. Probabilities of observed test statistics computed on annual maximum rainfall series of 1 h and 24 h and limits corresponding to α=5% significance level.

years sub-series are lower than one would expect, based on 95% confidence intervals.

5 Conclusions

An analysis of linear and non-linear trends in annual maximum rainfall series in Sicily has been carried out by testing the significance of trend statistics by means of asymptotic as well as empirical distributions derived by bootstrap. The results indicate a different behaviour according to the time scale. In particular, for shorter durations (e.g. 1 h), the investigated series generally exhibit increasing trends while as longer durations are considered, more and more series exhibit decreasing trends. For instance, 6–8 series (depending on the test adopted) out of 16 exhibit statistically significant decreasing trends for duration equal to 24 h. Also, the effect of sampling different historical sub-series from the whole observation period on the fitted probability distribution and on the estimated return periods of critical storms has been analysed, with particular reference to an extreme event that occurred on 21–22 November 2003 along the East

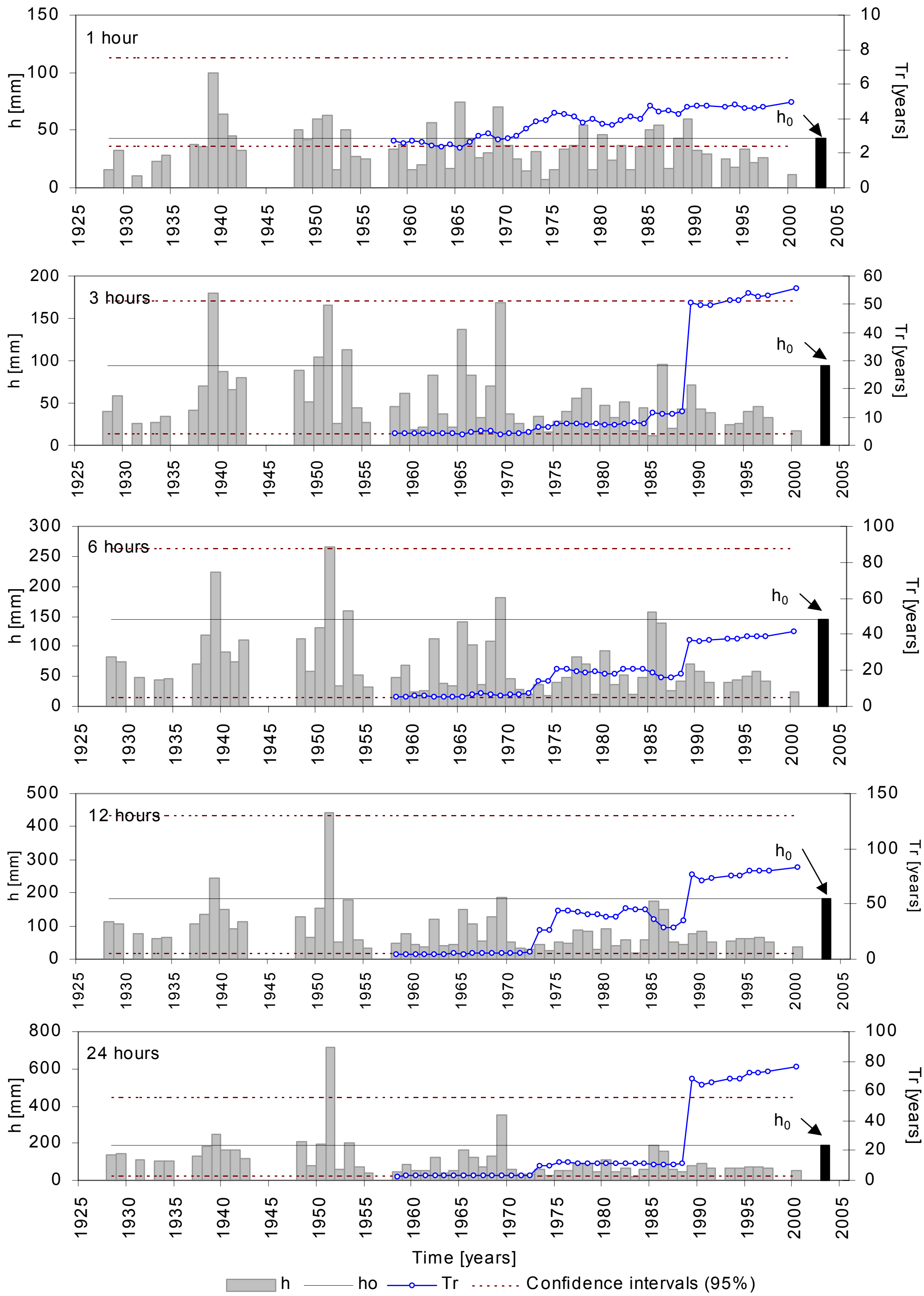

Fig. 2. Evolution of return period *Tr* of a critical storm h_0 along the observation period of annual maximum rainfall series *h* in Simeto Oasi and related 95% confidence intervals.

Coast of Sicily. The corresponding confidence intervals on the estimated return periods have been computed, under the hypothesis of no trend, by means of bootstrap. The results of such analysis indicate that the return period of the event under investigation evaluated on the basis of sample series of 20 years extracted after 1969 increases significantly, especially for a duration of 24 h. This seems to confirm an apparent rainfall decrease in the last 30 years.

Despite tests results show the presence of significant trends in the series, it should be stressed that these findings must be considered preliminary. Although other tools besides those presented in the paper are available (e.g. parametric re-sampling), yet further research is necessary to improve statistical methods in order to better characterize the nature of detected trends in observed hydrological series. Also, should the presence of trends be confirmed, the need arises to adapt traditional design concepts, such as return period, to non-stationary data, as well as to determine the extent to which a trend that has been observed in the past can be assumed as continuing in the future.

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