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DETECTION AND ANALYSIS OF DROUGHT EVENTS IN CALABRIA (SOUTHERN ITALY)

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EXTENDED ABSTRACT

La siccità è un evento climatico estremo che costituisce uno dei rischi naturali più dannosi per le popolazioni di ogni latitudine, in termini sociali, economici, sanitari. L'inizio di un evento siccitoso non è facilmente percepibile e la sua evoluzione temporale è spesso incerta; i suoi effetti, però, possono essere devastanti raggiungendo livelli di severità anche molto elevati. Caratterizzare un evento di siccità significa praticamente valutarne entità e durata, anche tramite un opportuno confronto con la "storia climatica" dell'area. Analogamente è importante avere la possibilità di segnalare tempestivamente la possibile insorgenza del fenomeno siccitoso e di seguire la sua evoluzione temporale e spaziale. A tale scopo, già da anni è stato proposto dalla comunità scientifica l'impiego di indici di siccità, che permettono di quantificare le anomalie climatiche in termini di intensità, durata, estensione spaziale, frequenza. Alcuni di tali indici sono riferiti alla siccità meteorologica, essendo basati sull'analisi della sola informazione pluviometrica, e possono essere applicati considerando diverse scale temporali. Uno degli indici di siccità meteorologica più conosciuto è senza dubbio lo *Standardized Precipitation Index* (SPI), proposto da McKee *et alii* (1993), già ampiamente applicato in diverse aree del Pianeta. L'SPI è stato concepito per quantificare il deficit di precipitazione su diverse scale temporali, che riflettono l'impatto della siccità sulla disponibilità delle diverse risorse idriche. Le condizioni di umidità del suolo rispondono ad anomalie di precipitazione su una scala temporale relativamente breve, mentre il sottosuolo, i fiumi e gli invasi riflettono anomalie di precipitazione a lungo termine. Per questa ragione, McKee *et alii* (1993) originariamente svilupparono l'SPI per scale temporali di 3, 6, 12, 24, e 48 mesi. I valori dell'SPI oscillano nella maggior parte dei casi tra +2 e -2, anche se entrambi questi estremi possono essere superati. I valori positivi indicano situazioni di surplus pluviometrico, mentre valori negativi individuano situazioni di siccità. La suddivisione del range dei valori, inoltre, permette di effettuare una classificazione climatica dei periodi temporali nei quali è calcolato l'SPI. Nel presente lavoro, vengono riportati i risultati relativi all'applicazione dell'SPI su alcune serie temporali di pioggia della Calabria (Italia Meridionale). La Calabria, per la sua morfologia ed orografia e per la sua posizione all'interno del bacino del Mediterraneo, è un ottimo "laboratorio climatico naturale", presentando caratteristiche del clima molto variabili spazialmente. Infatti, le zone litoranee ed i versanti prospicienti il mare sono caratterizzate da un clima tipicamente mediterraneo, con inverni miti ed estati caldi e prive di pioggia; all'interno, invece, soprattutto all'aumentare dell'altitudine, gli inverni sono freddi, spesso nevosi, e le estati, di frequente, anche fresche. L'SPI, nel presente lavoro, è stato calcolato considerando le scale temporali a tre mesi (SPI-3) e a 12 mesi (SPI-12). Nella scelta delle stazioni e del periodo di osservazione, si è voluto raggiungere l'obiettivo di avere una banca dati di valori pluviometrici mensili aggiornata e completa, così da non avere un numero elevato di dati mancanti nel calcolo dell'SPI. Di conseguenza, sono state selezionate le serie mensili di 24 stazioni per il periodo 1951-2016, distribuite sul territorio in modo omogeneo e con altitudine variabile dal livello del mare fino a circa 1000 m s.l.m. Per ogni mese dell'intero periodo di osservazione e per ciascuna stazione, sono stati calcolati i valori dell'SPI, per entrambe le scale temporali, ed evidenziati i periodi di siccità severa ed estrema. I risultati hanno rivelato che l'SPI-3 presenta un incremento di frequenza di accadimento dei periodi di siccità severa ed estrema tra fine anni '70 e primi anni del nuovo secolo. In particolare, negli anni '80 quasi l'80% delle stazioni considerate ha fatto registrare periodi severi ed estremi di siccità. Detta percentuale è stata superata nei primi anni del 2000. Per quanto concerne l'SPI-12, le siccità severe ed estreme risultano più frequenti tra fine anni '80 e inizi '90, ed anche agli inizi del secolo in corso. In particolare, i risultati relativi all'SPI-12 hanno mostrato chiaramente la maggiore estensione della siccità severa ed estrema avvenuta agli inizi del secolo, con oltre il 90% delle stazioni coinvolte. I risultati ottenuti hanno permesso inoltre di evidenziare le stazioni con le maggiori frequenze di accadimento dei periodi di siccità severa ed estrema ed anche di caratterizzare i maggiori eventi da diversi punti di vista: valori di SPI raggiunti, durata in mesi ed estensione spaziale. Infine l'applicazione di un metodo grafico di valutazione del trend, l'*Innovative Trend Analysis* (ITA) proposto da Şen (2012), ha consentito di rilevare tendenze nei valori dell'SPI. I risultati, in particolare, hanno evidenziato, per entrambe le scale temporali utilizzate e per la maggior parte delle stazioni, trend negativi dei valori più bassi dell'SPI, ossia una tendenza negli anni a più gravi siccità.

ABSTRACT

Drought phenomena are one of the greatest damaging climate events. For this reason it is necessary to detect several drought features such as its intensity, duration, recurrence probability and spatial extent, also in order to alleviate the impacts of droughts. In this study, drought, expressed using the Standardized Precipitation Index (SPI), has been analyzed in a region of southern Italy (Calabria) using a homogenized database for 24 monthly rainfall series in the 1951-2016 period. First, both the short-term (3 months) and the long-term (24 months) SPI were estimated and, in order to identify the worst events, the percentages of rain gauges falling within severe or extreme dry conditions have been evaluated. Then, the occurrence frequencies of severe/extreme droughts have been evaluated for each rain gauge. Finally, possible trends in the SPI values have been detected by means of a new graphical technique, Sen's method, which allows the trend identification of the low, medium and high values of a series. Results evidenced that, considering the 3-month SPI, the occurrence frequency of severe and extreme drought events increased from the late 1970s to the early 2000. As to what concerns the 12-month SPI, droughts were more frequent throughout the 1980s and the 1990s and at beginning of this century. The trend analysis showed a general reduction in all the values of the SPI, that is a tendency towards heavier droughts and weaker wet periods.

***Keyword**: drought, SPI, trend, Calabria*

INTRODUCTION

Recently, the adverse impacts of climate change have become the focus of considerable international attention due to the increase of phenomena such as flood, heat waves, forest fires and droughts (Estrela & Vargas, 2012; Kreibich *et alii*, 2017). Among these damaging climate events drought phenomena play a significant role in socio-economic and health terms, even though their impact on populations depends on the vulnerable elements (Wilhite, 2000). Moreover, understanding of drought phenomena is paramount for an appropriate planning and management of water resources (Yevjevich *et alii*, 1983). For example, different drought events have affected Europe during the last decades (Fink *et alii*, 2004; Lloyd-Huhes & Saunders, 2002; Zaidman *et alii*, 2002) and drought is expected to become more frequent in the twenty-first century in some seasons and areas (Hannaford *et alii*, 2011), following precipitation and/or evapotranspiration variability (IPCC, 2013). The implications of these changes are particularly significant for areas, such as the Mediterranean Basin, already under stress and suffering from a water shortage due to a combination of a dry climate and excessive water demand (De Luis *et alii*, 2000).

In recent years, several researchers have analysed drought events in several parts of the world (e.g. Caloiero *et alii*, 2017; Fang *et alii*, 2013; Feng *et alii*, 2011; Hua *et alii*, 2013; Minetti *et alii*, 2010; Sirangelo *et alii*, 2015, 2017), even though drought phenomena are difficult to detect and to monitor due to their complex nature. Usually, drought severity is evaluated by means of drought indices since they facilitate communication of climate anomalies to diverse user audiences; they also allow scientists to assess quantitatively climate anomalies in terms of their intensity, duration, frequency, recurrence probability and spatial extent (Wilhite *et alii*, 2000; Tsakiris *et alii*, 2007). In the past decades, numerous indices were proposed for identifying and monitoring drought events. Some of these indices refer to meteorological drought (scarcity of precipitation) and are based on the analysis of the pluviometric information only. Thus, different categories of drought can be investigated by choosing proper temporal scales, any addressing to different categories of users. Other indices, however, are more suitable for describing hydrological drought (scarcity in surface and subsurface water supplies), the agricultural one (water shortage compared to the typical needs for crops irrigation), and the socio-economic one (referred to the global water consumption). Specifically, meteorological drought consists of temporary lower-than-average precipitation and results in diminished water resources availability (Tabari *et alii*, 2012) which impact on economic activities, human lives, and the environment (Bayissa *et alii*, 2015). The most well-known index for analysing the meteorological drought is undoubtedly the Standardized Precipitation Index (SPI), proposed by McKee *et alii* (1993), which has been extensively applied in the Mediterranean basin (e.g. Livada & Assimakopoulos, 2007) and in Italy (Buttafuoco & Caloiero, 2014; Buttafuoco *et alii*, 2015; Caloiero *et alii*, 2016; Capra *et alii*, 2013; Vergni & Todisco, 2011). This drought index can be considered one of the most robust and effective drought indices, as it can be evaluated for different time-scales and allows the analysis of different drought categories (Capra & Scicolone, 2012). Moreover, the evaluation of the SPI requires only precipitation data, making it easier to calculate than more complex indices, and allows the comparison of drought conditions in different regions and for different time periods (Wu *et alii*, 2005). Due to its intrinsic probabilistic nature, the SPI is the ideal candidate for carrying out drought risk analysis (Guttmann, 1999; Cancelliere *et alii*, 2007). With this aim, several authors focused on SPI trend (Bordi *et alii*, 2009; Golian *et alii*, 2015; Zhai *et alii*, 2010). These studies are mainly based on non-parametric tests, which are better suited to deal with non-normally distributed hydrometeorology data than the parametric methods. Recently, Şen (2012) proposed the Innovative Trend Analysis (ITA) technique that allows a graphical trend evaluation of the low, medium, and high values in the data. The ITA technique was widely applied to the trend detection of several hydrological variables. Haktanir & Citakoglu (2014) analysed the annual maximum rainfall series by means of the ITA method. Kisi & Ay (2014) studied the behaviour of some water quality parameters registered at five Turkish stations by means of the ITA and the MK methods. Şen (2014) and Ay & Kisi (2015) applied the ITA to Turkish temperature data. The ITA technique was also used to analyse the trends of the heat waves (Martínez-Austria *et alii*, 2015), of the monthly pan evaporations (Kisi, 2015) and of the streamflow data (Tabari & Willems, 2015).

In the present work, drought events in a region of southern Italy (Calabria) have been studied by applying the SPI on 3- and 12-month time scale on a homogenized database of 24 monthly rainfall series in the period 1951-2016. The aims of this study are to identify the worst events, as percentages of the regional area involved, to estimate the temporal evolution of the drought episodes, and to evaluate the SPI trend persistency throughout time.

DATA AND METHODS

Case study

Located at the toe of the Italian peninsula, Calabria has a surface of 15,080 km^2; with an average altitude of 597 m a.s.l. and its tallest peak at 2,266 m a.s.l.. Calabria is one of the most mountainous areas in the country, as mountains (over 500 m a.s.l. high) occupy 42% of the regional area, while hills (between 50 and 500 m a.s.l. high) cover 49% of the territory and only 9% of the region is under 50 m a.s.l. (Fig. 1). It is a region characterised by a typically Mediterranean climate, presenting sharp contrasts due to its position within the Mediterranean Sea and its orography. Specifically, its coastal zones are characterised by mild winters and hot summers with little precipitation. In fact, warm air currents coming from Africa and high temperatures affect the Ionian side, leading to short and heavy rainfall. The Tyrrhenian side, instead, is affected by western air current which causes temperatures to be milder and higher precipitation amount on the mountains than on the Ionian side. Cold and snowy winters, and fresh summers with some precipitation, are typical of the inner areas of the region (Caloiero *et alii*, 2014, 2015).

The database used in this study was extracted from the homogeneous one presented in Brunetti *et alii* (2012) and updated to 2016 using the monthly precipitation series registered in the Calabria and stored by the Multi-Risk Functional Centre of

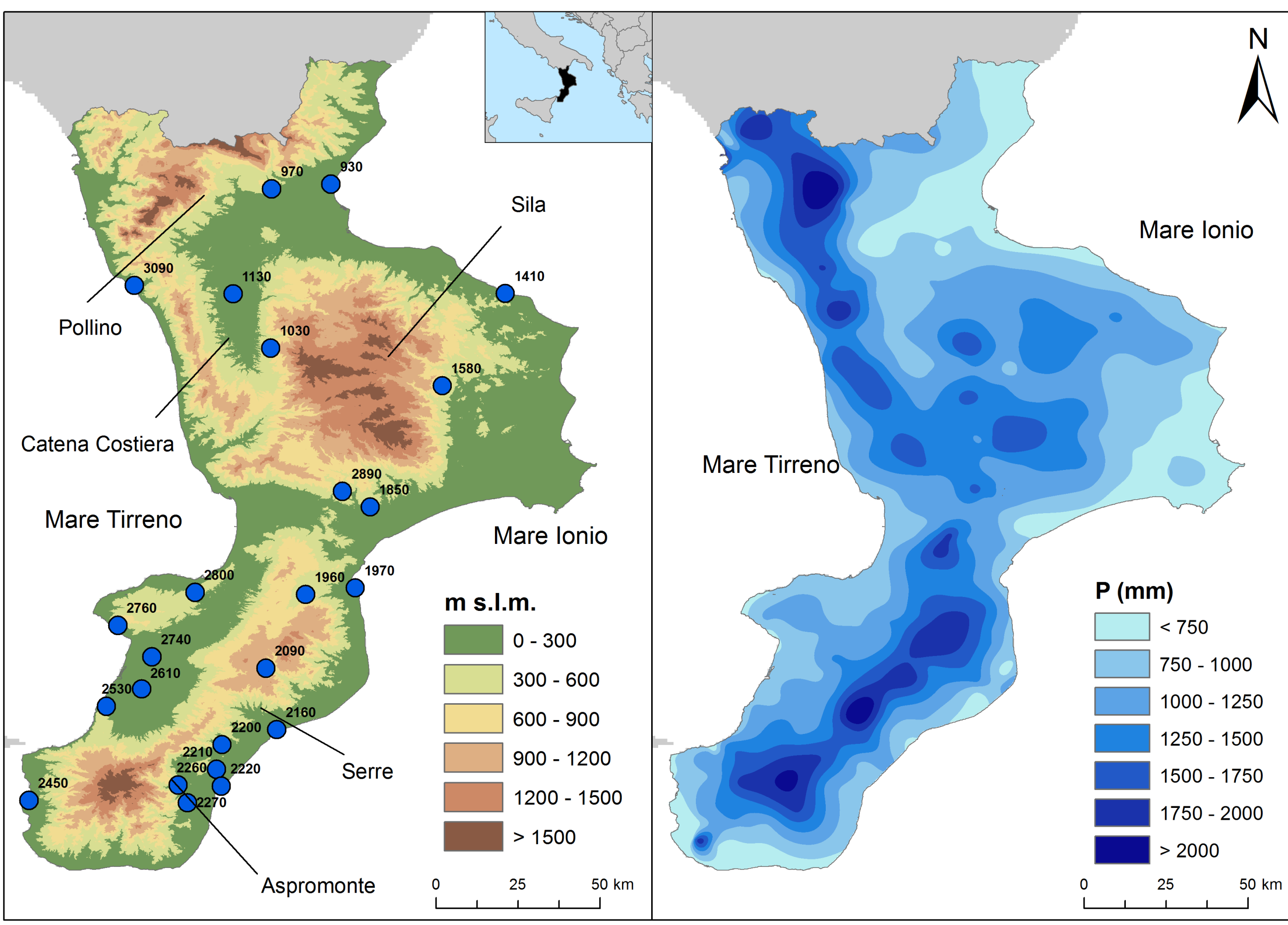

Fig. 1 - Location of the selected 24 rain gage on a DEM of Calabria (left) and spatial distribution of the mean annual precipitation (right)

the Regional Agency for Environment Protection. In particular, in order to study those rainfall series falling within the same time range and presenting the same length, the stations with more than 1 gap (1 month) in the series were discarded from the dataset. As a result, the analysis focused on a total of 24 rainfall series (Fig. 1 and Tab. 1) for the period 1951-2016.

Standardised Precipitation Index (SPI)

In this study, dry and wet periods were evaluated using the SPI at different time scales (3 and 12 months). In fact, while the 3-month SPI describes droughts that affect plant life and farming, the 12-month SPI influences the management of water supply/reservoirs (Edwards & McKee, 1997; Bonaccorso *et alii*, 2003).

Angelidis *et alii* (2012) offered a meticulous description of the method to compute the SPI. The index is computed by fitting an appropriate probability density function (pdf) to the frequency distribution of precipitation summed over the time scale of interest. This is performed separately for each time scale and for each location in space. Computation of the SPI involves fitting a gamma function to a given time series of precipitation, whose probability density function (pdf) is defined as:

$$g(x)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}x^{\alpha-1}e^{-x/\beta} \quad \text{for} \quad x>0 \qquad (1)$$

where $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, $x > 0$ is the amount of precipitation and $\Gamma(\alpha)$ is the gamma function. Fitting the distribution to the data requires α and β to be estimated for each month of the year and for each time aggregation. Using the approximation of Thom (1958), these parameters can be estimated as follows:

$$\alpha=\frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right), \quad \beta=\frac{\bar{x}}{\alpha} \quad \text{with} \quad A=ln(\bar{x})-\frac{\sum ln(x)}{n} \qquad (2)$$

where n is the number of observations. Integrating the pdf with respect to x yields the following expression $G(x)$ for the cumulative distribution function (cdf):

$$G(x)=\int_0^x g(x)dx=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{-x/\beta}dx \qquad (3)$$

Since the gamma distribution is undefined for a rainfall amount $x=0$, in order to take into account the zero values that occur in a sample set, a modified cdf must be considered:

$$H(x)=q+(1-q)G(x) \qquad (4)$$

with q the probability of zero precipitation, given by the ratio between the number of zero in the rainfall series (m) and the number of observations (n).

Finally, the cdf is changed into the standard normal distribution by using, for example, the approximate conversion provided by Abramowitz & Stegun (1965):

$$z=SPI=-\left(t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t=\sqrt{ln\left(\frac{1}{(H(x))^2}\right)} \quad \text{for } 0<H(x)<0.5 \qquad (5)$$

$$z=SPI=+\left(t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t=\sqrt{ln\left(\frac{1}{(1-H(x))^2}\right)} \quad \text{for } 0.5<H(x)<1 \qquad (6)$$

with c_0, c_1, c_2, d_1, d_2 and d_3 mathematical constants.

Table 2 reports the climatic classification according to the SPI, provided by the National Drought Mitigation Center. This index is now habitually used in the classification of wet periods, even though the original classification provided by McKee *et alii* (1993) was limited to drought periods only.

Innovative Trend Analysis (ITA)

The ITA method, proposed by Şen (2012), does not require any assumptions (serial correlation, non-normality, sample number and so on). First, the time series is divided into two equal parts, which are separately sorted in ascending order. Then, the first and the second half of the time series are located on the X-axis and on the Y-axis, respectively. If the data are collected on the 1:1

ID	Rain Gauge	Altitude (m a.s.l.)	Number of missing data
930	Villapiana Scalo	5	1
970	Cassano allo Ionio	250	-
1030	San Pietro in Guarano	660	-
1130	Torano Scalo	97	-
1410	Cariati Marina	10	-
1580	Cerenzia	663	-
1850	Catanzaro	334	-
1960	Chiaravalle Centrale	714	1
1970	Soverato Marina	6	-
2090	Fabrizia	948	-
2160	Gioiosa Ionica	125	-
2200	Antonimina	310	1
2210	Ardore Superiore	250	1
2220	Bovalino Marina	8	-
2260	San Luca	250	-
2270	Sant'Agata del Bianco	380	-
2450	Reggio Calabria	15	-
2530	Palmi	248	1
2610	Rizziconi	82	1
2740	Rosarno	61	1
2760	Joppolo	185	-
2800	Vibo Valentia	498	1
2890	Tiriolo	690	-
3090	Cetraro Superiore	76	1

Tab. 1 - Main details of the selected rain gauges ideal line (45° line), there is no trend in the time series. If data are located on the upper triangular area of the ideal line, an increasing trend in the time series exists. If data are accumulated in the lower triangular area of the 1:1 line, there is a decreasing trend in the time series (Şen, 2012; 2014). Thus, trends of low, medium and high values of any hydro-meteorological or hydro-climatic time series can be clearly identified through this method. In Figure 2, a graphical representation of the method on a Cartesian coordinate system is shown.

RESULTS AND DISCUSSION

Identification of drought events

Initially, the SPI has been calculated, for each rain gauge, and then dry and wet events have been identified. Figures 3a and 4a show (with different colors in accordance with the classification of Table 2) the spatial and temporal distribution of dry and wet periods from January 1951 to December 2016, for to the selected 24 rainfall series for the short-time (3-months) and the long-time (12 months) SPI respectively. The two images show at a glance the most severe dry periods, as well as the corresponding duration and affected areas. Because the present work focuses on drought analysis, normal and wet conditions, in an initial analysis, have been grouped into one class (SPI > -1). Figures 3b and 4b show the percentage of the rain gauges with SPI values lower than -1.5, for each month of the period 1951-2016. As a result, with reference to the 3-month SPI, several dry periods (SPI<-1) have been detected during the last century and increases of drought events and intensities have been evidenced from the late 1970s to the early 2000 (Fig. 3a). In particular, the most important drought event (SPI<-1.5) occurred in the autumn of 2001 with more than 80% of the rain gauges showing severe and extreme droughts (Fig. 3b). Dry conditions, which spread across the investigated area, have also been observed in the summers of 1984 and 1985 with respectively about 80% and 75% of rainfall series showing severe and extreme drought conditions. From 1951 to 1984 the worst dry conditions affect smaller areas and for a shorter time than the previous ones. Most recently, in the last 10 years, the worst and prolonged drought event has been detected in the winter of 2008, with more than 60% of the rainfall series presenting severe and extreme drought conditions (Fig. 3b).

As regards the long-time SPI, which strictly influences agriculture, a different behaviour than the short-time SPI can be observed. In particular, the most important drought events occurred from the late 1980s (Fig. 4a). Few drought events can be observed before the 1980s, affecting small regional areas and relating to a short time interval. Only the winter of 1962 presented remarkable SPI values with severe and extreme drought conditions affecting more than 60% of the rain gauges (Fig. 4b). From 1980 different drought events occurred, among which the autumns of 1989 and of 1992. In particular, the latter is particularly important with more than 60% of the rain gauges showing severe and extreme droughts. Also for the 12-months SPI, the most severe and prolonged drought event of the current century has been detected in the autumn-winter of 2001-2002, with more than 90% of the series presenting severe and extreme drought conditions (Fig. 4b).

From a spatial point of view, it is interesting to evidence the stations with the highest occurrence frequencies of severe and extreme droughts. Figure 5 shows that the highest frequency values (greater than 7%), for both the 3- and the 12-month SPI, have been calculated for five rain gauges: Cassano allo Ionio (#970), S. Pietro in Guarano (#1030), Torano Scalo (#1130), Tiriolo (#2890), Joppolo (#2760). The same figure evidences that the lowest occurrence frequencies (< 5.5%) have been estimated for three stations located on the South-Eastern side of Calabria:

SPI value	Class	Probability (%)
SPI ≥ 2.0	Extremely wet	2.3
1.5 ≤ SPI < 2.0	Severely wet	4.4
1.0 ≤ SPI < 1.5	Moderately wet	9.2
0.0 ≤ SPI < 1.0	Mildly wet	34.1
−1.0 ≤ SPI < 0.0	Mild drought	34.1
−1.50 ≤ SPI < −1.0	Moderate drought	9.2
−2.0 ≤ SPI < −1.5	Severe drought	4.4
SPI < −2.0	Extreme drought	2.3

Tab. 2 - Climate classification according to the SPI values

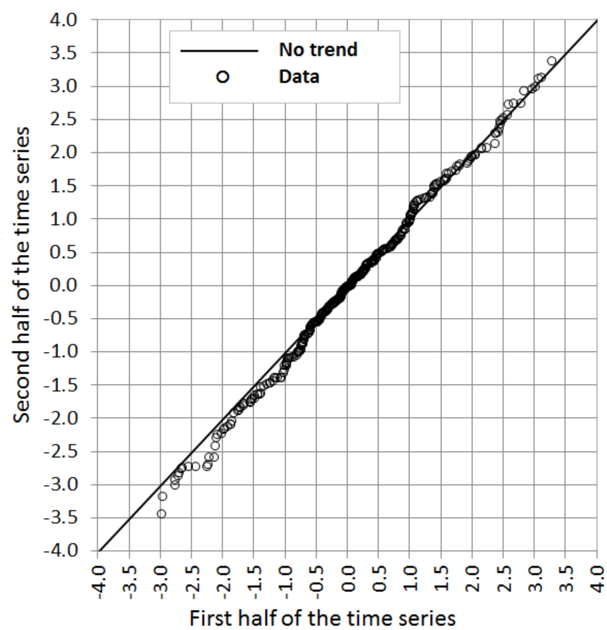

Fig. 2 - Example of the Innovative Trend Analysis (ITA) proposed by Şen (2012)

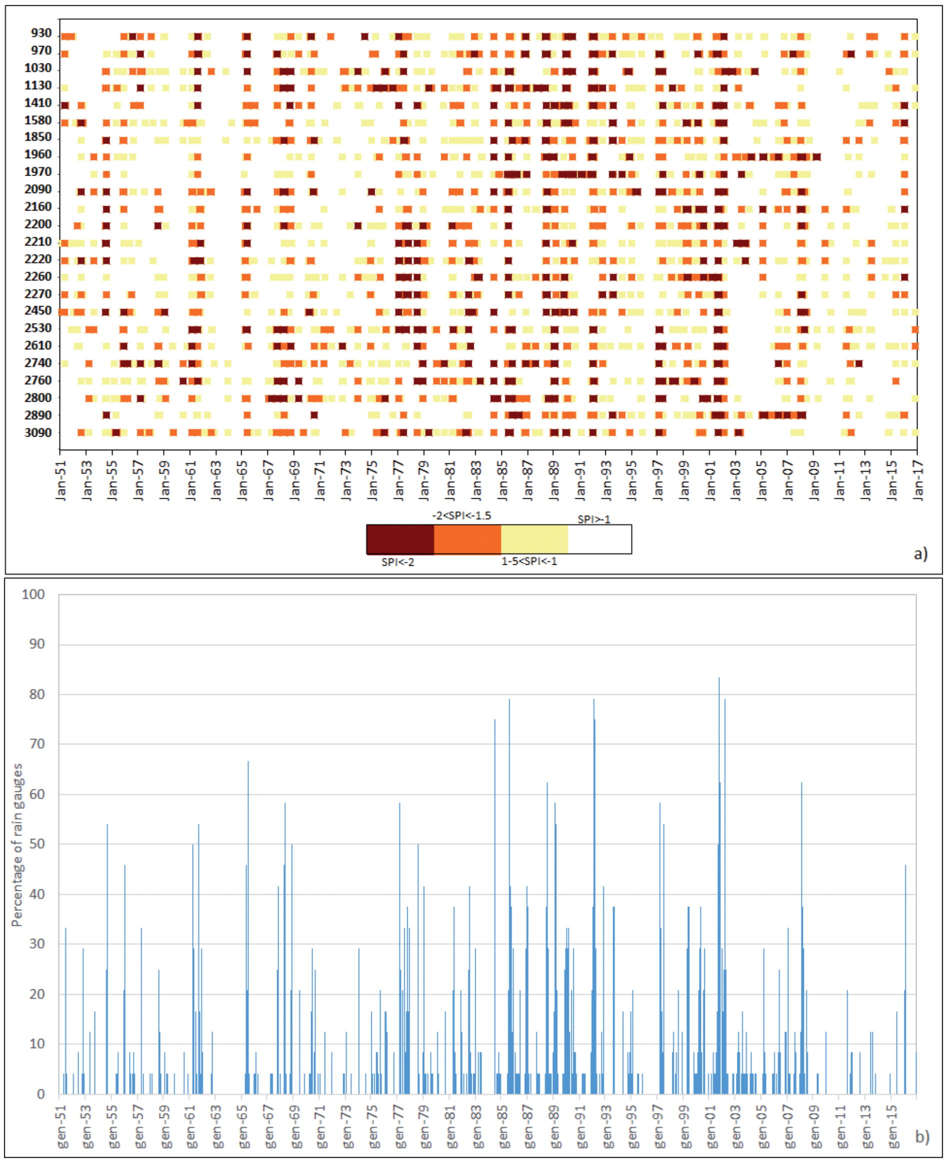

Fig. 3 - 3-month SPI: a) SPI values distribution in the period 1951-2016 for each of the 24 rain gauges and b) time behavior of the percentage of rain gauges which fall within severe or extreme dry conditions (SPI < −1.5)

Bovalino Marina (#2220) for the 3-month SPI, Gioiosa Ionica (#2160) for the 12-month SPI and Sant'Agata del Bianco (#2270) for both the 3- and the 12-month SPI.

In order to analyze thoroughly the severe and extreme drought events detected in the period 1951-2106, these events were sorted based on three characteristics: the lowest SPI values, the number of rain gauges involved and the duration of the drought event. The main events are shown in Tables 3 and 4 for the 3- and the 12-month SPI, respectively. In these tables, the first column indicates the month in which the maximum number of the rain gauges (showed in column 2) were affected by severe and extreme drought. The maximum duration of the drought event (in months) and the rain gauge in which this duration was registered are shown in columns 3 and 4, respectively. Finally, columns 5 and 6 indicate the lowest SPI value calculated in the drought event and the corresponding rain gauge, respectively. As to what concerns the 3-month SPI (Tab. 3), the event of October 2001 can be considered the worst for the lowest values reached by the SPI, for the duration of the event and for its spatial extension, with 20 rain gauges showing severe and extreme drought conditions. Another remarkable event is the one detected in August 1985, which lasted for 10 months, involved 19 rain gauges and in which the lowest

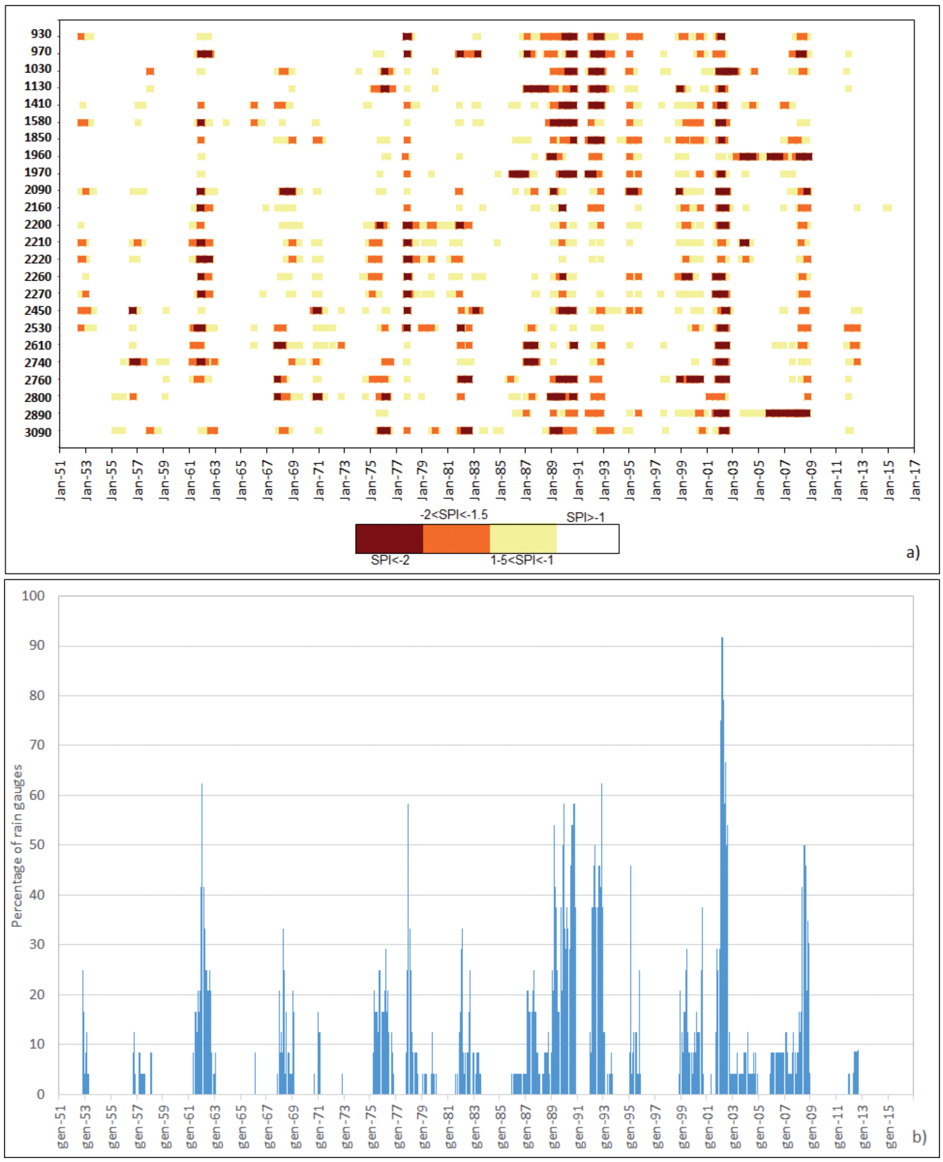

Fig. 4 - 12-month SPI: a) SPI values distribution in the period 1951-2016 for each of the 24 rain gauges and b) time behavior of the percentage of rain gauges which fall within severe or extreme dry conditions (SPI < −1.5)

Month	Max number rain gauges	Max duration of the drought event (month)	Rain gauge with max duration of the drought event	Min SPI value	Rain gauge with min SPI value
July 1965	16	3	2200	-3.02	2200
July 1984	18	4	1130	-4.04	1130
August 1985	19	10	1970	-4.45	3090
July 1988	15	7	2800	-2.91	2800
February 1992	19	6	1130	-4.46	1130
October 2001	20	11	2890	-5.41	2890

Tab. 3 - Details of the main drought events evaluated on a long-time scale (12-month SPI)

Month	Max number rain gauges	Max duration of the drought event (month)	Rain gauge with max duration of the drought event	Min SPI value	Rain gauge with min SPI value
June 1962	15	17	2210	-2.70	2740
December 1977	14	6	2200	-3.09	2200
December 1989	14	23	1580	-4.36	2800
November 1992	15	13	1850	-4.35	1130
February 2002	22	17	1030	-3.55	2610

Tab. 4 - Details of the main drought events evaluated on a long-time scale (12-month SPI)

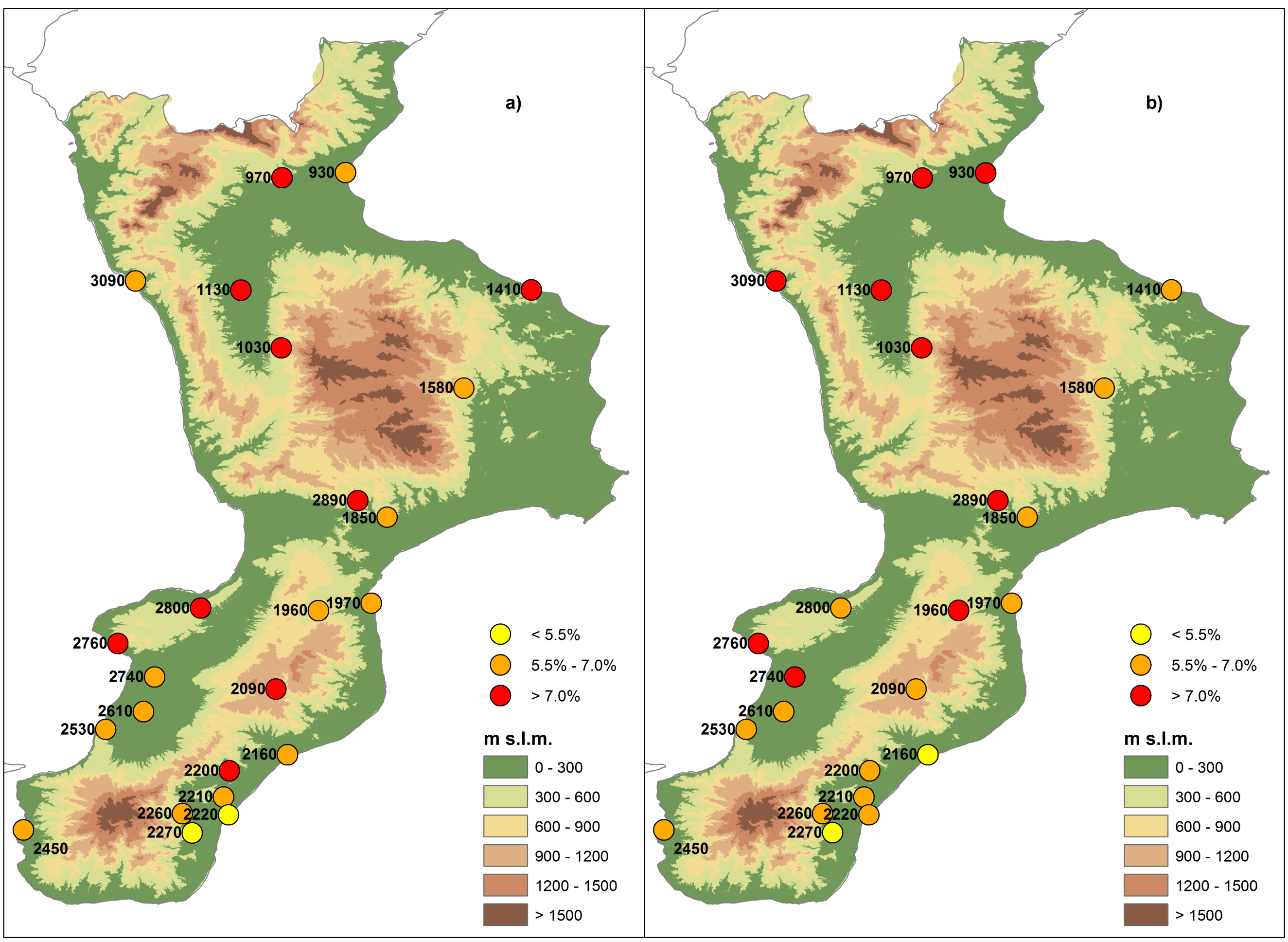

Fig. 5 - Occurrence frequency of severe and extreme dry periods with respect to the 3-month SPI (a) and to the 12-month SPI (b)

SPI value was -4.45. Generally, with the only exception of the drought event identified in July 1988, a positive tendency of the stations involved and a negative trend of the lowest values (until a value of less than -5 in October 2001) have been detected. Finally, it must also be highlighted that the rain gauge in which the highest event duration was calculated usually corresponds to the one in which the lowest SPI value of the event was estimated and that the majority of the worst drought events have been evaluated during the summer period. With respect to the 12-month SPI, in Table 4 the characteristics of the worst events are shown. First, from the comparison between Table 3 and Table 4, the events detected with the 12-month SPI were longer than the ones evaluated with the 3-month SPI, probably due to the different features of the two time periods. Moreover, the 12-month SPI values were higher than the 3-month ones. Considering the spatial extension of the drought event, the worst event can be considered the one identified

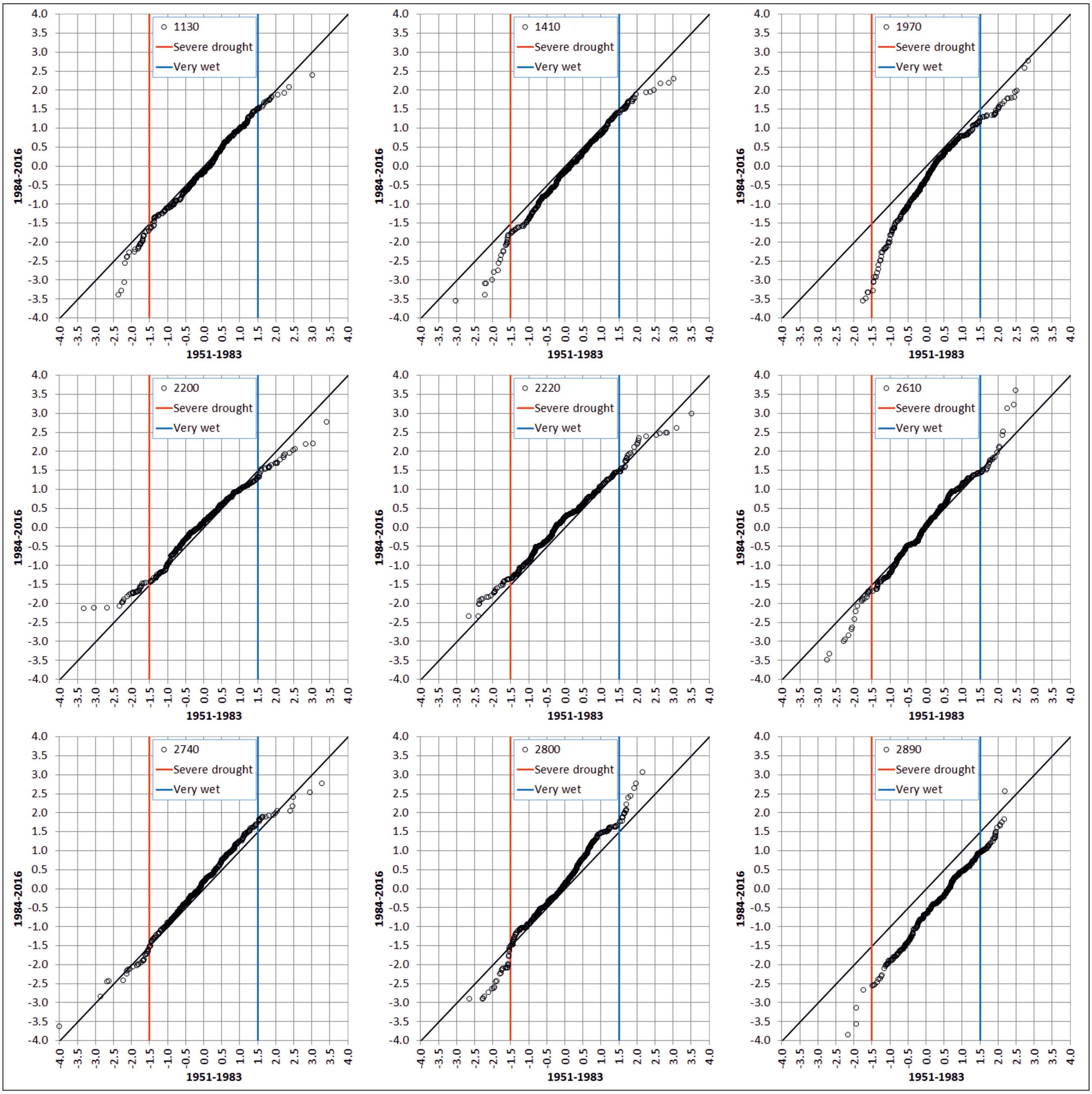

Fig. 6 - Some results of the ITA method for the 3-month SPI for the period 1951–2016

in February 2002, which involved 22 rain gauges, lasted for 17 months and in which the lowest SPI value was -3.55. Instead, the drought event of December 1989 can be considered the worst for the duration of the event (23 months) and the minimum SPI value (-4.36). Differently from the 3-month SPI, for the 12-month SPI no particular tendencies have been evidenced with reference to both the duration and the lowest SPI value of the events.

SPI Trends

Current global level assessments suggest that droughts are expected to both increase and decrease, following future climate change depending upon geographic location (Wang, 2005). With the aim to detect possible trends in the 3- and 12-month SPI values, for each rain gauge the ITA method was applied to the monthly series of the index. The ITA method allows to evidence the

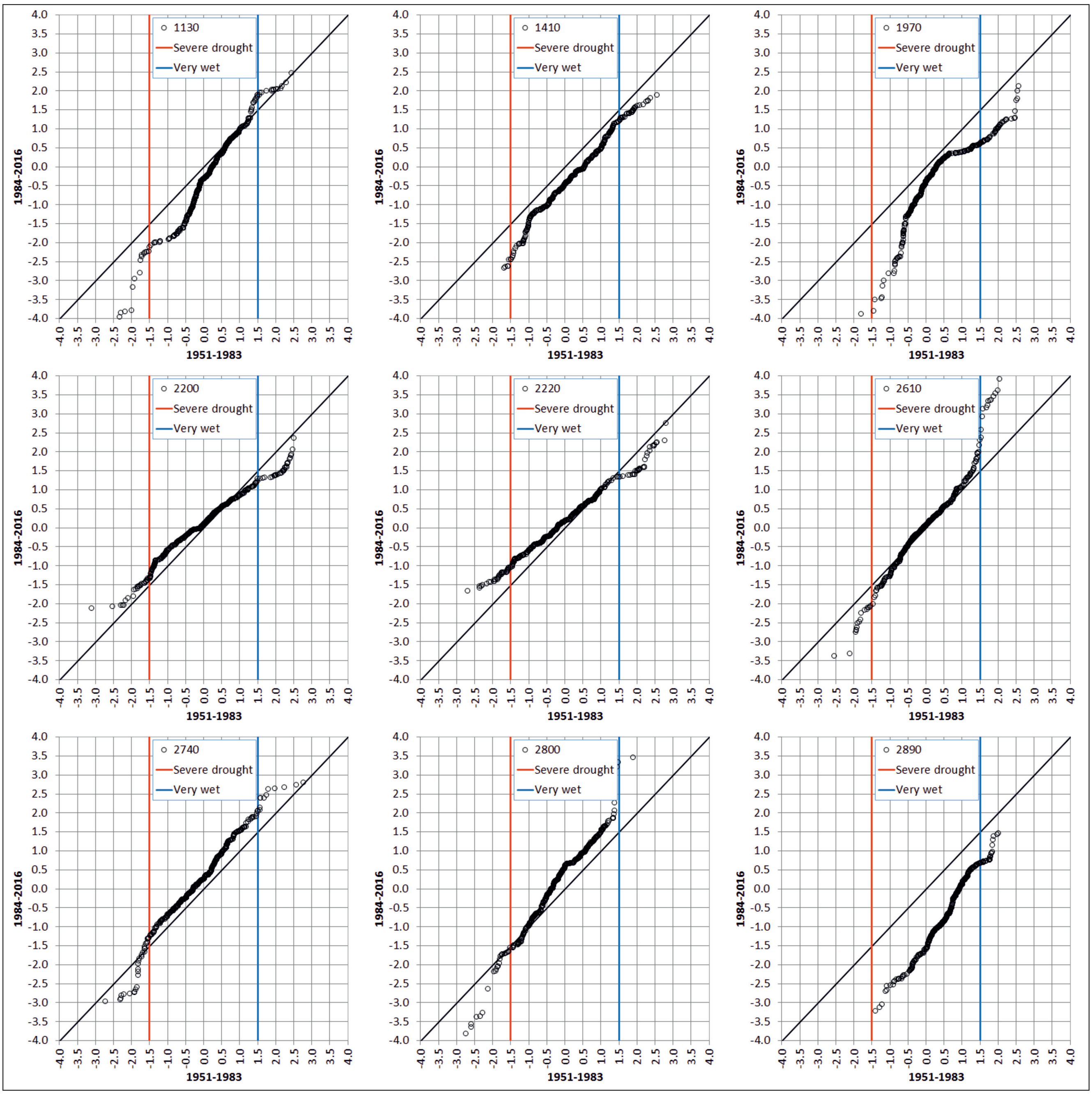

Fig. 7 - Some results of the ITA method for the 12-month SPI for the period 1951–2016

tendencies of both low and high SPI values, thus including values referred to wet conditions. As an example of the ITA approach, Figs 6 and 7 show the results obtained for nine rain gauges for the 3- and the 12-month SPI, respectively. All the SPI series were divided into two 33-year sub-series: from 1951 to 1983 and from 1984 to 2016. Globally, the main result obtained for both the 3- and 12-month SPI values was, for several series, a negative trend of the lowest and the highest values of SPI index, thus evidencing a tendency towards heavier droughts and weaker wet periods. In particular, for the Cariati Marina (#1410), Soverato Marina (#1970) and the Tiriolo (#2890) rain gauges, this tendency is clearly stated for the 3-month SPI (Fig. 6) but is more marked for the 12-month SPI (Fig. 7) in which also the mild values (in the range -1÷1) showed a negative tendency toward drought conditions. Some rain gauges evidenced opposite tendencies between the values with a negative trend of the lowest SPI data and a positive trend of the highest ones. This behavior means a tendency towards more extreme conditions with both heavier drought and wet periods. These tendencies were mainly detected in the Rizziconi (#2610) and Vibo Valentia (#2800) rain gauges for the 3-month SPI (Fig. 6) and, particularly, for the 12- month SPI (Fig. 7) with the extreme values which are located very far from the no trend line. Moreover, there are few stations, such as Antonimina (#2200) and Bovalino Marina (#2220), which evidenced an opposite trend behavior than the previous one for both the 3- and the 12-month SPI (Figs 6 and 7), namely a positive trend of the lowest values and a negative tendency of the highest ones. This behavior means a tendency towards weaker drought and wet periods thus indicating a more uniform distribution of the rainfall. Finally, in some rain gauges such as Rosarno (#2740) and partially Torano Scalo (#1130) different trend results emerged between the 3- and the 12-month SPI. In fact, for the Rosarno rain gauge, the application of ITA on the 3-month SPI values (Fig. 6) showed a slight positive trend for the lowest values and a negative tendency for the highest ones, while the results of the 12-month SPI values evidenced a negative trend of the lowest data and a positive tendency for the highest ones (Fig. 7).

These tendencies agree with the results of past studies which evidenced an increase in drought trend in all the areas that are presently subject to drought (Coscarelli *et alii*, 2016). In fact, based on the latest climate and impact modelling, the Mediterranean area can expect more droughts in the future in some locations (Giorgi & Lionello, 2008).

CONCLUSION

In the present work, drought events in a region of southern Italy (Calabria) have been studied by applying the SPI on the 3- and 12-month time scales. First, the most severe dry periods, as well as the corresponding duration and the involved areas, have been detected, confirming that Calabria has been affected by some well-known and largely investigated European drought events. The use of an updated database of monthly rainfall also allowed to analyze recent events. Results showed evident increase of the occurrence frequency of severe and extreme drought conditions in the last decades. This tendency has been confirmed by means of the ITA method applied to the SPI series, both on 3- and 12-month time scale. Moreover, the graphical method application highlighted a diffuse negative tendency of the highest SPI values, namely a trend towards weaker wet conditions. These trends, even though not showed by all the selected rain gauges, confirmed the global negative tendency of rainfall in Calabria. If these behaviors are confirmed in the next decades, a series of useful water management reforms and innovations influencing future water uses in Calabria will be required. In particular, improving urban water-use efficiency could be a key solution to Calabria's short-term and long-term water challenges.

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