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Drought over Europe in recent years

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SUMMARY – In drought management, the transition from crisis to risk management defies a straightforward solution mainly because very few works have been done to address the risks associated with a drought, and to identify the factors that influence the vulnerability of a region. To promote this process and in view of the recent scientific debate on climate change, an important first step is the analysis of drought variability in the last years. Motivated by this issue, an analysis of drought in Europe using reanalysis data is provided, updated to December 2007. Because precipitation is an important water resource supply component and, thus, a critical parameter for drought risk assessment, we apply the most popular drought index based on precipitation to evaluate dry/wet conditions in the area, i.e. the Standardized Precipitation Index (SPI). Particular attention has been devoted to the variability of the linear trend unveiled in the SPI time series.

Key words: Drought variability, linear trend, reanalysis data.

RESUME – *"La sécheresse en Europe lors des dernières années". Dans la gestion de la sécheresse, la transition crise-gestion de risque défie une solution simple principalement parce que très peu de travaux ont été faits pour aborder les risques associés à une sécheresse, et identifier les facteurs qui influencent la vulnérabilité d'une région. Pour encourager ce processus et vu le débat scientifique récent sur le changement climatique, une première étape importante est l'analyse de la variabilité de la sécheresse dans les dernières années. Motivée par cette question, une analyse de sécheresse en Europe qui utilise les données de re-analyse est fournie, mise à jour en décembre 2007. Etant donné que les précipitations sont une composante importante de la ressource en eau et, donc, un paramètre critique pour l'estimation du risque de sécheresse, nous appliquons l'index de sécheresse le plus populaire basé sur les précipitations pour évaluer des conditions sèches/humides dans la région, l'Index de Précipitations Standard (SPI). Une attention particulière a été consacrée à la variabilité de la tendance linéaire dévoilée dans la série chronologique du SPI.*

Mots-clés : *Variabilité de la sécheresse, tendance linéaire, données de re-analyse.*

Introduction

Usually, we tend to focus on drought when it is occurring and to react when crises strike. On the contrary, we should take a proactive approach to dealing with drought, anticipating the occurrence of the natural phenomenon and planning measures for minimizing its negative effects (Wilhite *et al.*, 2000). However, making the transition from crisis to risk management is difficult because little has been done to understand and address the risks associated with drought, and to identify the factors that influence the vulnerability of a region to dry spells (Wilhite, 2002).

The degree of a region's vulnerability depends on many environmental and social factors as well as on the ability to anticipate, cope with and recover from drought. Among the environmental factors there is the natural climatic variability of the area, also in relation to climate change. Although we don't know how climate change will affect regional water resources, a first issue to shed light on this problem is the analysis of climatic trends evaluated using updated data. In water resources management, in fact, this is a crucial aspect for planning proactive mitigation measures against future drought occurrences. Nevertheless, due to the shortness of the time records and problems related to the homogeneity of data sets, it is difficult to objectively estimate linear trends and their statistical significance, as well as to discern between linear trend and long-term periodicity.

Because precipitation is an important water resources supply component, an analysis of precipitation characteristics is a critical component of drought risk. However, if we wish to compare climatic conditions of different areas, which often are characterized by different hydrological balances, we need a standardized variable able to objectively capture the drought condition of a region. For this purpose the Standardized Precipitation Index (SPI) appears to be the most powerful drought index. It is based only on precipitation field, it is standardized and can be computed on different time scales, allowing to monitor the different kinds of drought (Keyantash and Dracup, 2002).

Recently, a downward linear trend over most of Europe and Mediterranean basin has been unveiled in the SPI time series computed using the reanalysis data sets, implying an overall tendency towards drier periods from the seventies onward (Bordi and Sutera, 2001; Bordi *et al.*, 2006). Furthermore, in the latest 8 years most of Italy and Mediterranean basin experienced several wet events, in contrast with the aforementioned tendency. Thus, motivated by these findings we present here an analysis of the variability of the linear trend unveiled in the SPI time series updated to December 2007. For this purpose, we use the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data that meet the fundamental requirements for an analysis of drought at large-scale. The data set, in fact, is freely accessible through the web, uniformly covers the globe, has a time duration sufficiently long to be trustworthy in a statistical sense and is continually updated. In the following sections there are a brief description of the data and the SPI computation, an illustration of the main results obtained and a final discussion with an outlook on future works.

Data and methods

Data used for the analysis are monthly mean precipitation rates retrieved from the NCEP/NCAR reanalysis archive for the period January 1948-December 2007. They are available on a regular grid 1.9^ox1.9^o in longitude and latitude. Such precipitation data have been derived from the primary meteorological fields of the NCEP medium range forcasting spectral model based on the assimilation of a set of observations [see Kalnay *et al.* (1996) for details on the reanalysis procedure]. Though, precipitation is not directly assimilated, but rather is derived completely from the model 6-hour forecast, its midlatitude features have been compared favourably with observations and several climatologies (Janowiak *et al.*, 1998; Trenberth and Guillemot, 1998). Thus, since for the present study we have considered the area centred over Europe (25.72^{o}N-71.43^{o}N, 20.63^{o}W-60.00^{o}E), we may feel enough confidence on the data quality.

Meteorological and hydrological drought conditions over Europe, updated to December 2007, have been assessed through the SPI on 3- and 24-month time scales respectively (hereafter SPI-3 and SPI-24), while the long-term linear trends have been evaluated only for the SPI-24 time series. The SPI was introduced by McKee *et al.* (1993) to quantify the precipitation deficit for multiple time scales that reflect the impact of drought on the availability of the different water resources (Keyantash and Dracup, 2002; Heim, 2002). It is based on precipitation field alone and its computation for any location is based on the long-term precipitation record cumulated over the selected time scale. This long-term record is fitted to a probability distribution [usually a Gamma distribution, Guttman (1999)], which is then transformed through an equal-probability transformation into a normal distribution. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation (Bordi and Sutera, 2001). Thus, the SPI seems to be a useful tool for monitoring drought on multiple time scales and comparing climatic conditions of areas governed by different hydrological regimes. In addition, being the index normalized, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using the SPI.

Results

In Fig. 1 maps of the SPI on 3- and 24-month time scales are shown updated to December 2007. On 3-month time scale moderate/severe dry conditions characterize the Alpine regions, part of Spain and France, and Iraq. On 24-month time scale moderately dry conditions affect the western Alpine regions, while severe/extreme drought characterizes the regions in the north and south of the Black Sea. It can be seen that on both time scales the Mediterranean area is characterized by severe/moderate-wet conditions. Such wet conditions have been experienced frequently in the latest 8 years in the Mediterranean basin (see the web site http://romatm13.phys.uniroma1.it/medocc).

On the other hand, recently a downward linear trend over most of Europe and Mediterranean basin has been unveiled in the SPI-24 time series computed using the NCEP/NCAR reanalysis data set updated to 2000, implying an overall tendency towards drier periods from the seventies onward

(Bordi and Sutera, 2001; Bordi *et al.*, 2006). Such long-term variability has been found also using observations in sample regions as Sicily (Bonaccorso *et al.*, 2003).

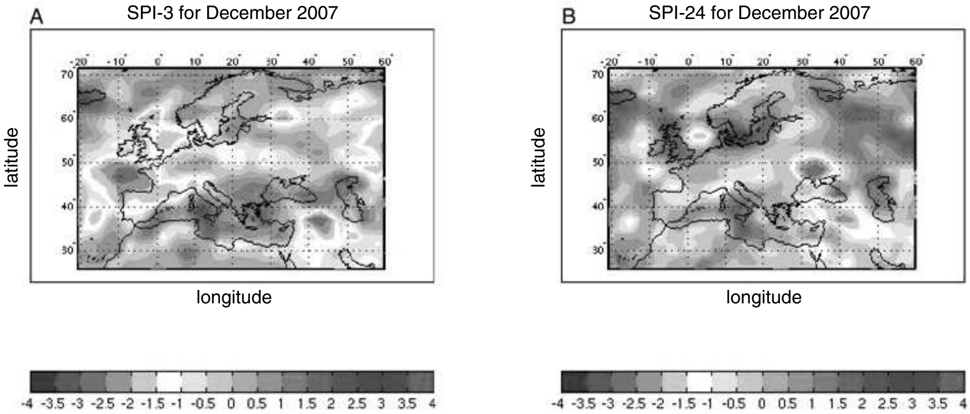

Fig. 1. SPI for December 2007: (A) SPI-3, (B) SPI-24.

Motivated by these findings and by the recent analysis using the SPI, we have investigated the variability of the long-term linear trend in the latest 8 years in the Euro-Mediterranean area. Figure 2 shows the angular coefficient of the linear trend fitting the SPI-24 time series for two periods: the entire time record and the period December 1949-December 1999. Negative values denote a tendency towards drier periods, while positive ones towards wetter periods.

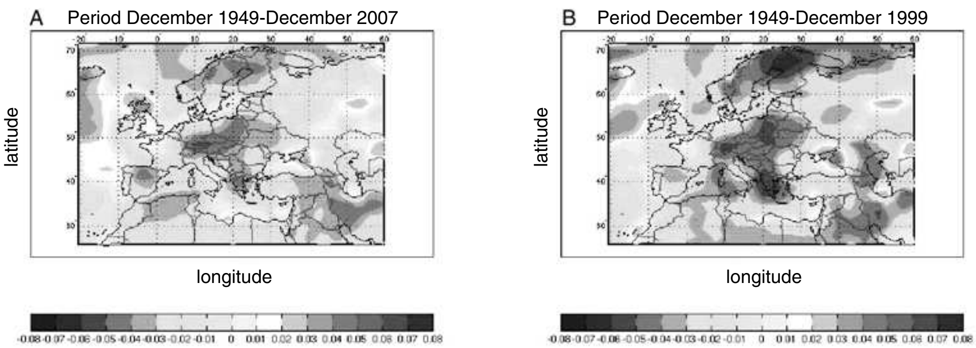

Fig. 2. Angular coefficient of the linear trend in the SPI-24 time series: (A) Period December 1949-December 2007, (B) period December 1949-December 1999. Unit is year^{-1}.

The figure shows a change in the slope of the linear trend that is some areas is drastically reduced, while in others is enhanced (see for example central and southern Italy, Balcans or central Spain and central Europe).

To better highlight this result, we show in Fig. 3 the time behaviour of the SPI-24 for two particular grid points, one over Italy (western Sicily) and one over Spain, where the linear trend changed differently. It can be seen that Sicily from January 2000 onward experienced a transition from a dry to a wet period that affected drastically the negative slope of the linear trend, by reducing it. On the contrary, central Spain in the latest 8 years was characterized by several dry events with the exception of the latest months characterized by near normal conditions. This behaviour contributed to increase the negative slope of the linear trend detected for the period December 1949-December 1999.

In Table 1 values of the angular coefficients (p_1) and intercepts (p_2) of the linear model, with 95% confidence bounds, are summarized for the two time periods. Also the Sum Square Error (SSE) and the R-square statistics are provided. It can be noted that in both grid points, when the entire record is considered, p_1 and p_2 have values outside the 95% confidence bounds. Furthermore, it emerges that, while in Sicily the linear fit explains only 7.02% (against the 44.21% obtained for the shorter period), in Spain it explains 51.91% (against 33.16% obtained for the shorter period). This may suggest the existence in some places, as western Sicily, of a long-term periodicity, that is hard to detect due to the shortness of the time record.

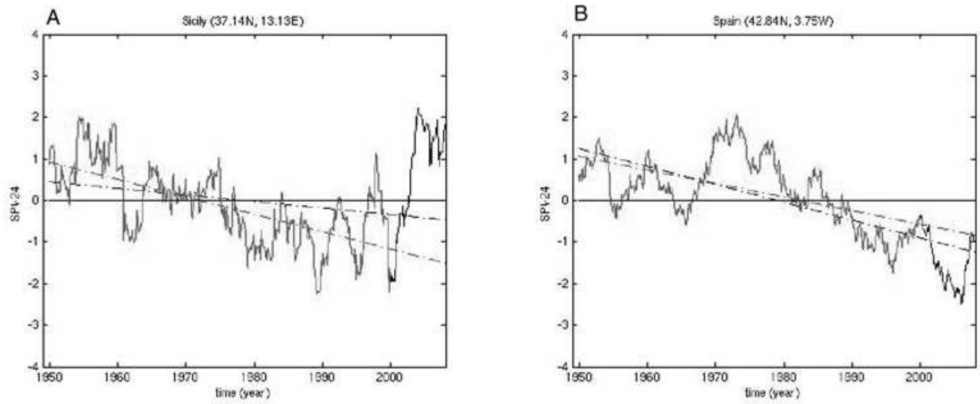

Fig. 3. Time series of the SPI-24 for: (A) Sicily and (B) Spain. Red line denotes the index time series up to December 1999, while black line the period January 2000-December 2007. Read and black dot-dashed lines are the corresponding linear trend.

Table 1. Values of the angular coefficients (p_1) and intercepts (p_2), with 95% confidence bounds, of the linear trend in the SPI-24 for the two selected grid points (western Sicily and central Spain). The last two columns refer to the Sum Square Error (SSE) and the R-square statistics

Grid point	Period	p_1 ($year^{-1}$) with 95% confidence bounds	p_2 (dimensionless) with 95% confidence bounds	SSE	R-square
Sicily	1949-1999	-0.0419 (-0.0456, -0.0381)	82.56 (75.10, 90.01)	277.9	0.4421
Sicily	1949-2007	-0.0158 (-0.0200, -0.0115)	31.18 (22.73, 39.64)	644.7	0.0702
Spain	1949-1999	-0.0327 (-0.0364, -0.0290)	64.84 (57.48, 72.20)	270.9	0.3316
Spain	1949-2007	-0.0429 (-0.0461, -0.0399)	85.08 (78.98, 91.17)	335.4	0.5191

The origin of the changing slope can be better understood by computing the percentage of dry and wet events in the latest 8 years for each grid point within the selected area (see Fig. 4).

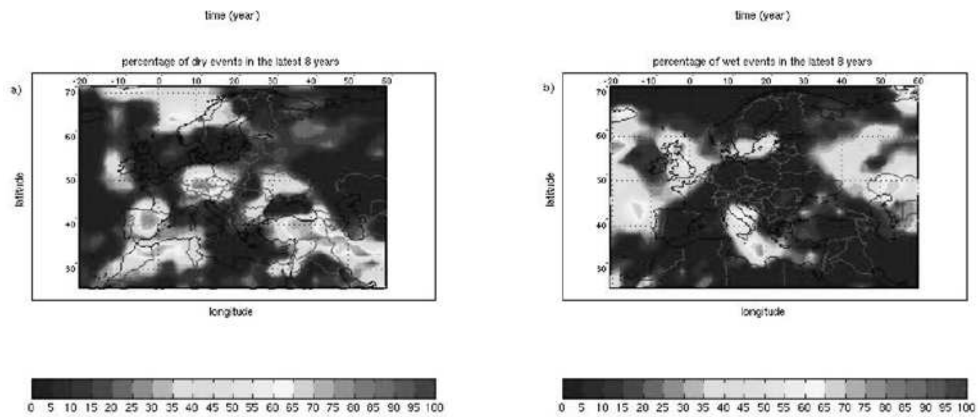

Fig. 4. Percentage of dry/wet events in the latest 8 years: (A) dry events with SPI-24<-1, (B) wet events with SPI-24>1. Unit is %.

Dry events have been defined by SPI-24<-1, while wet events by SPI-24>1. The figure shows that there are areas with a high percentage of dry events (60%-80%): central Spain, northern-western Africa, central Europe and part of Turkey and Iraq. Central-southern Italy, northern England, Scotland and regions in the north of the Caspian Sea, instead, have been affected by wet events (60%-70%). Note that such dry/wet events are spread among the months of the year (here not shown), corroborating the random character of drought and wet spells. Thus, by comparing Fig. 2 and Fig. 4 we may conclude that these high percentages of dry/wet events are responsible for the largest changes observed in the slope of the linear trend.

At this stage of the analysis, let us come back to monthly precipitation, which is the basic variable of the SPI, and see in which month of the year this variable averaged over the latest 8 years deviates mostly from the climatological mean computed over the period January 1948-December 1999. For the sake of clarity we show in Fig. 5 the results for the two grid points selected above.

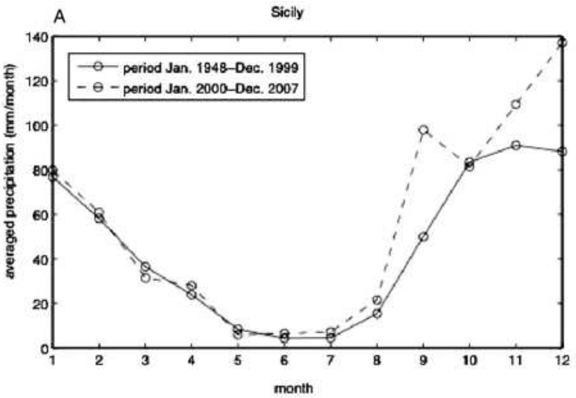

Fig. 5. Averaged monthly mean precipitation as a function of each month of the year for two grid points: (A) Western Sicily and (B) Central Spain. Solid line refers to the period January 1948-December 1999, while dashed line to the period January 2000-December 2007. Unit is mm/month.

The figure illustrates two main features. The first one is the different hydrological regimes that characterize the two regions: in Sicily we have a typical Mediterranean climate with large amount of precipitation in autumn and winter, while central Spain is characterized by a continental-type climate with large rainfall during spring. The second feature is that in the latest 8 years western Sicily experienced large amount of precipitation, compared with the climatology, during September, November and December, while central Spain was characterized by precipitation below the climatological mean during all the months of the year, but particularly from April to July. This means that a precipitation anomaly during the rainy season leads to dry or wet periods that can manifest themselves in any month of the year, changing the slope of the linear trend.

Conclusions

In the present paper we analyzed the long-term variability of drought over the Euro-Mediterranean area in the latest 8 years using the NCEP/NCAR reanalysis data set updated to December 2007. Applying the SPI on 24-month time scale dry and wet periods have been assessed and changes in the linear trend fitting the index time series have been evaluated for each grid point. Results suggest that the linear trend towards drier periods from the seventies onward that characterized most of the Euro-Mediterranean sector within the period December 1949-December 1999 is changing due to the climatic conditions of the latest 8 years. In particular, there are areas, as the central and southern Italy, where the negative slope of the linear trend is reduced due to frequent wet events occurred there. On the other hand, there are areas, as central Spain, which has been affected by dry events in the latest years, leading to an enhancement of the negative slope of the linear trend fitting the SPI-24 time series. Finally, an analysis of monthly mean precipitation averaged over the latest 8 years for two selected grid points (western Sicily and central Spain) suggests that a surplus or a deficiency of precipitation during the rainy seasons (with respect to the climatological mean computed over the period January 1948-December 1999), caused the wet/dry periods that affect the long-term trend in recent years.

From the analyses above, it emerges to be important to make a comparison with observations in order to evaluate the reliability of the reanalysis data, also in view of the discrepancies detected between different reanalysis products (see Bordi *et al.*, 2006). This check should be useful also in relation to the recent debate on climate change: Fig. 3A, in fact, seems to suggest the possible existence of a long-term periodicity in the SPI signals that is hard to detect for the shortness of the available time record. From a theoretical point of view it should be interesting to develop methodologies for establishing the optimal record length for calibrating drought indices when non-stationary hydrological series are taken into account. The effects of changes in the moments (mean and skewness for example) of the probability distributions of precipitation due to climatic linear trend should be studied as well as the corresponding statistics of extremes. These will be the topics of the next paper.

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