Multi-Index Drought Assessment in Europe [†]

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[†] Presented at the 3rd International Electronic Conference on Water Sciences, 15–30 November 2018; Available online: https://ecws-3.sciforum.net.

Abstract: Any attempt for the application of integrated drought management requires identifying and characterizing the event, per se. The questions of scale, boundary, and of geographic areal extent are of central concern for any efforts of drought assessment, impact identification, and thus, of drought mitigation implementation mechanisms. The use of drought indices, such as Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI), has often led to pragmatic realization of drought duration, magnitude, and spatial extension. The current effort presents the implementation of SPI and SPEI on a Pan-European scale and it is evaluated using existing precipitation and temperature data. The ENSEMBLES Observations gridded dataset (E-OBS) for precipitation, minimum temperature, and maximum temperature used covered the period 1969–2018. The two indices estimated for time steps of 6 and 12 months. The results for the application period of recurrent droughts indicate the potential that both indices offer for an improvement on drought critical areas of identification, threshold definitions and comparability, and towards contingency planning, leading to better mitigation efforts.

Keywords: drought; precipitation; SPI; SPEI; Europe

1. Introduction

Drought is a normal and periodic natural hazard, although often inaccurately pictured as an unexpected and exceptional phenomenon. It strikes practically all of the planet, but its characteristics vary significantly from one region to another [1,2]. Drought is a temporary anomaly of the usual climatic events and it is considered a creeping and slow evolving natural hazard, quite different from aridity, which is a long-term and permanent part of a climatic zone [3–9]. Droughts are generally caused by a combination of natural events that, many times, are boosted by anthropogenic pressures. The most common definition of drought is a rainfall deficiency whose occurrence, distribution, and magnitude affect the existing water supply, demand, and consumption. Such deficiencies may lead to less than expected water quantities necessary for the natural and the societal systems.

Droughts can befall anywhere in both high and low rainfall areas, in any locale, and in any season. Drought impacts are exacerbated when drought strikes a region with already limited water resources and/or misuse and mismanagement of water and with discrepancies between water demand and water supply.

Since there is no single definition of drought, its beginning and ending points are difficult to determine accurately. Thus, it is difficult for decision makers and stakeholders to, timely and

accurately, initiate measures to confront drought. In this quest, a drought indicator may be proved to be a valuable tool. Drought indicators convey objective information about a system's status that may aid decision makers to identify the onset, magnitude, and duration of a drought. Nevertheless, the literature agrees that no single index alone can precisely describe the spatial extent, the duration, and the magnitude of the phenomenon. Given such characteristics, appropriate and effective drought early-warning systems should be based on multiple indices and/or a synthesis of indicators to sufficiently demarcate the drought events[5,6,8,10–21].

Currently, very few indicators may appropriately illuminate all the drought dimensions at a large scale. In addition, applying multiple and/or a combination of indicators provides crucial information to monitor and categorize droughts. There exists a plethora of climatic water supply and demand indices to illustrate the drought dimensions and to portray them in a stochastic posture. Each index has strengths and weaknesses, with none being superior to the other in its specific application. In this regard, SPI and SPEI offer a very well tested and dependable combination of indicators, thus, they were chosen for application to describe drought conditions in Europe during the latest decades.

Drought events have regularly occurred all over Europe and particularly in the last fifty years. The spatial extent, the magnitude, and the duration of such drought events, as well as the diversified impacts inflicted on societies and the environment, have varied all over this period. Existing information in the pertinent literature categorizes the harshest events that distressed more than (30%) of the EU territory, such as the ones in 1972–1974, 1990–1994, 2000, 2003, 2007, and 2011, with the most recent in 2018 [4,22–25].

Drought information in the literature exposes that there are two distinct geographical regions in Europe reflecting mostly common meteorological, environmental, and geomorphological conditions, as follows: The southern Mediterranean corridor from the Atlantic Ocean to Asia Minor (including Portugal, Spain, southern France, Italy, Greece, and Cyprus) and the northern one beyond the Alps mountain chain, having Belgium, the UK, Finland, Germany, Hungary, Lithuania, the Netherlands, Norway, and Slovakia [6,7,22–26]. It is within these two regions that drought dimensions, namely spatial extent, duration (temporal extent) and magnitude, are markedly pronounced. Drought spatial extent is closely associated to a country's given geographical locale and total area, with the smaller countries usually devoured by the event, per se (Cyprus, Greece, Italy, Malta, Spain, Portugal, France, Ireland, Great Britain, Denmark, Latvia, Estonia, etc.). Drought magnitude diversifies all over the continent, with the most prominent as the 1990–1994, 2000, and 2007 ones in Spain Italy, Greece, France, and Hungary [4,22–24]. Drought duration equally fluctuates from country to country. In the Mediterranean area Cyprus, Greece, Italy, Malta, Southern France, Portugal, and Spain, have an extended summer periods annually, with minimal rain. Thus, droughts may only manifest themselves during the rainy winter months. In other words, a drought may have a six- month duration, which, compounding to the arid summer period, creates a fully problematic year [4,6,7,27,28]. In the northern countries, droughts occur primarily during the rainy summer season having durations from one month (Germany, Hungary, and Lithuania) to two up to six months (Northern France, Austria, Belgium). It is noted that Finland was distressed by a nine-month drought from August 2002 to April 2003 [29,30]. The estimation of the foremost drought impacts usually involves the economic costs resulting from various droughts. Such estimations depict the overall economic impacts of droughts, during the last fifty years, to be more than 100 billion € at the EU level. They also present that the annual average impact doubled from the 1976–1990 period to the 1991–2006 one. Overall, the impact cost an average of 6.2 billion €/year up to 2003, with an escalation to 8.7 billion € during the 2003 drought [29]. In the summer of 2018, as shown in Figure 1, the majority of northern Europe was under a drought spell, including Ireland, Great Britain, Netherlands, Belgium, Northern France, Germany, Czech Republic, Denmark, Norway, Sweden, Estonia, Latvia, and Finland [25].

In this regard, drought impacts already influence the agricultural production in the region. According to EC (2018) the decrease in crop yields will exceed 50% in the majority of these countries, reaching up to 70% in Estonia. Hence, on 30 August 2018, the European Commission offered advanced payments to distressed farmers to receive up to 70% of their direct payment and 85% of payments under rural development by mid-October 2018. It is pointed out that such compensations

refer to economic costs and do not incorporate social and environmental costs, as relevant data are not available. All in all, the improvement of the economic cost estimation has to comprise social and environmental impact assessments in an EC level approach.
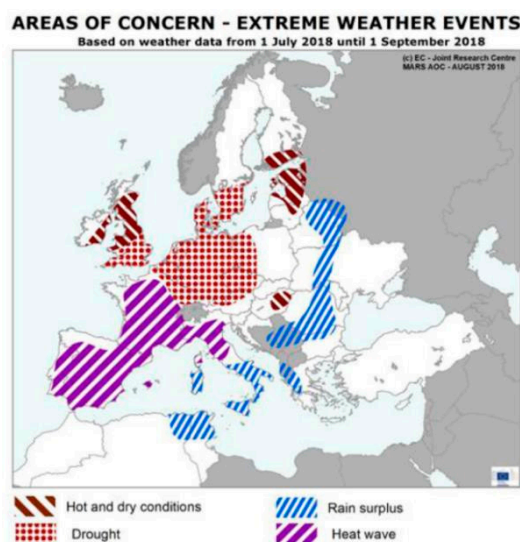

Figure 1. Weather Situation in EU Europe during July and August 2018[26].

2. Materials and Methods

To produce SPI and SPEI, the ensemble version of the E-OBS dataset [32], which covers the area of 25 N–71.5 N × 25 W–45 E in 0.25-degree regular latitude-longitude grid resolution, was used. The period on record of the E-OBS dataset starts on January 1950 and extends until September 2018. The information retrieved includes the following parameters: Daily minimum temperature, daily maximum temperature, and daily precipitation sums. The data files are in NetCDF-4 format and their temporal resolution is daily, following the regular calendar (including leap years). All data manipulation was performed in R [33] utilizing ncdf4 [34], raster [35], plyr [36], abind [37], and SPEI [38] R packages.

For the computation of the 6-month and 12-month SPI, daily precipitation for the study period (January 1969–September 2018) was converted to a monthly step. Missing value criteria for each one of the grid cells' (93,264 in total) daily time series were set for quality control purposes. Such criteria are that the missing daily values, within a month, should not exceed 35% or they should not exceed 30% if the missing data are continuous. The minimum (maximum) daily temperature data were transformed to a monthly mean. Daily minimum (maximum) temperature was also based on the aforementioned criteria. Monthly evapotranspiration was computed for each grid cell, based on the 1985 Hargreaves method [34], in order to be used as input for the SPEI index calculation.

3. Results and Discussion

The resulting values were spatially visualized in a GIS environment, according to the classification presented in Figure 2. The 1990, 1993, 2003, 2007, 2015, and 2018, droughts were identified and spatially portrayed. From these droughts, the most intense drought periods were chosen to be included in the current effort, namely the 1990, 2007, and 2018 ones. These events are presented in Figures 3–5.
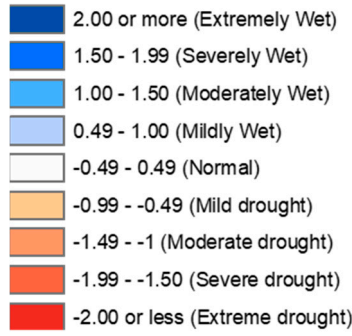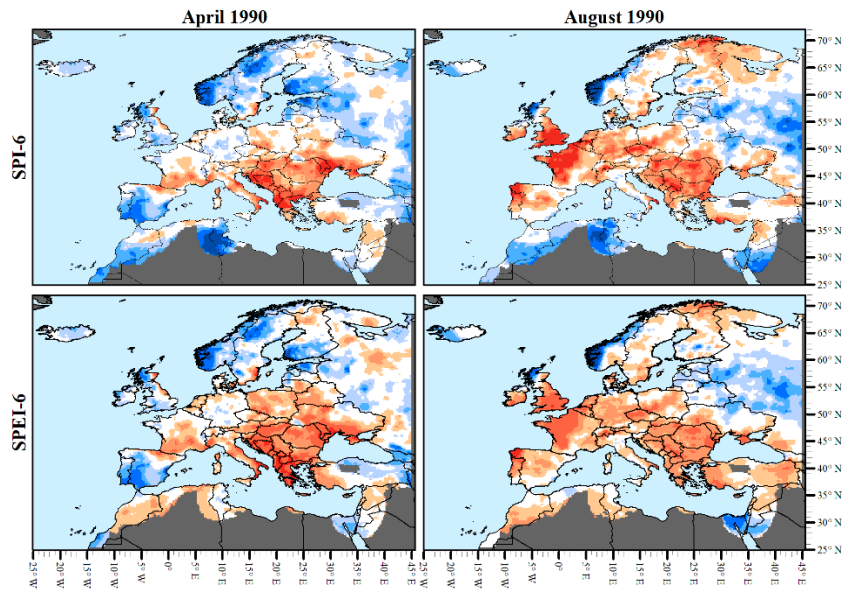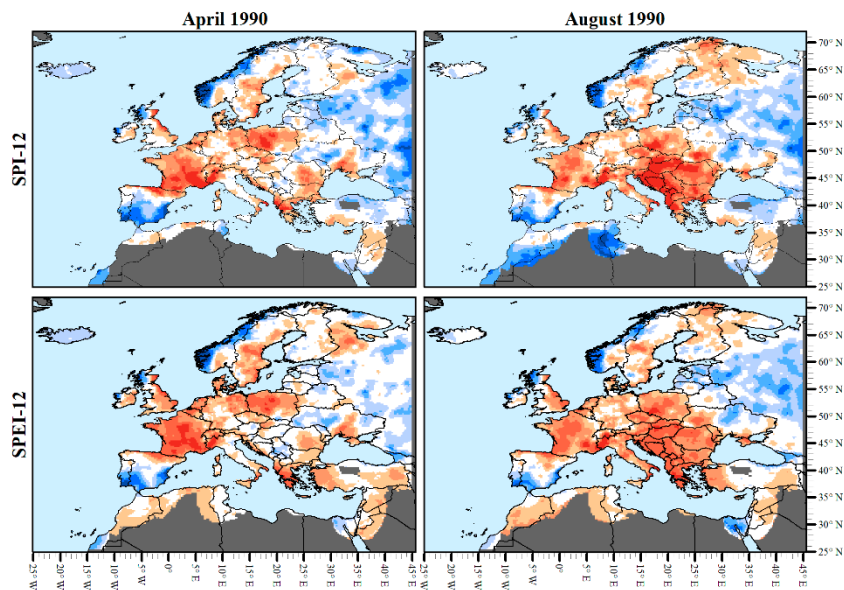
Figure 2. SPI and SPEI classification scale.

(**a**)

(**b**)

Figure 3. SPI and SPEI for Europe on April and August 1990, (**a**) 6-month step and (**b**) 12-month step.

From Figure 3, it may be deduced that the drought was spread-out all-over Europe. The distinct behaviour of southern Europe points out that drought is intensified at the end of the usually rainy winter season. Such an event was recorded in the pertinent literature [4,5,7,24,27]. Particularly, in Greece precipitation was only 43% of the annual average [4], a fact also portrayed in Figure 3. In north-western Europe, drought reaches its peak at the end of the summer period, when the usual rains are crucial also for agriculture. The pertinent literature reported that during 1989 the weather all over Europe was unusually dry. This particular trend has continued in 1990 and a drought alert was issued in many European countries [5,40].
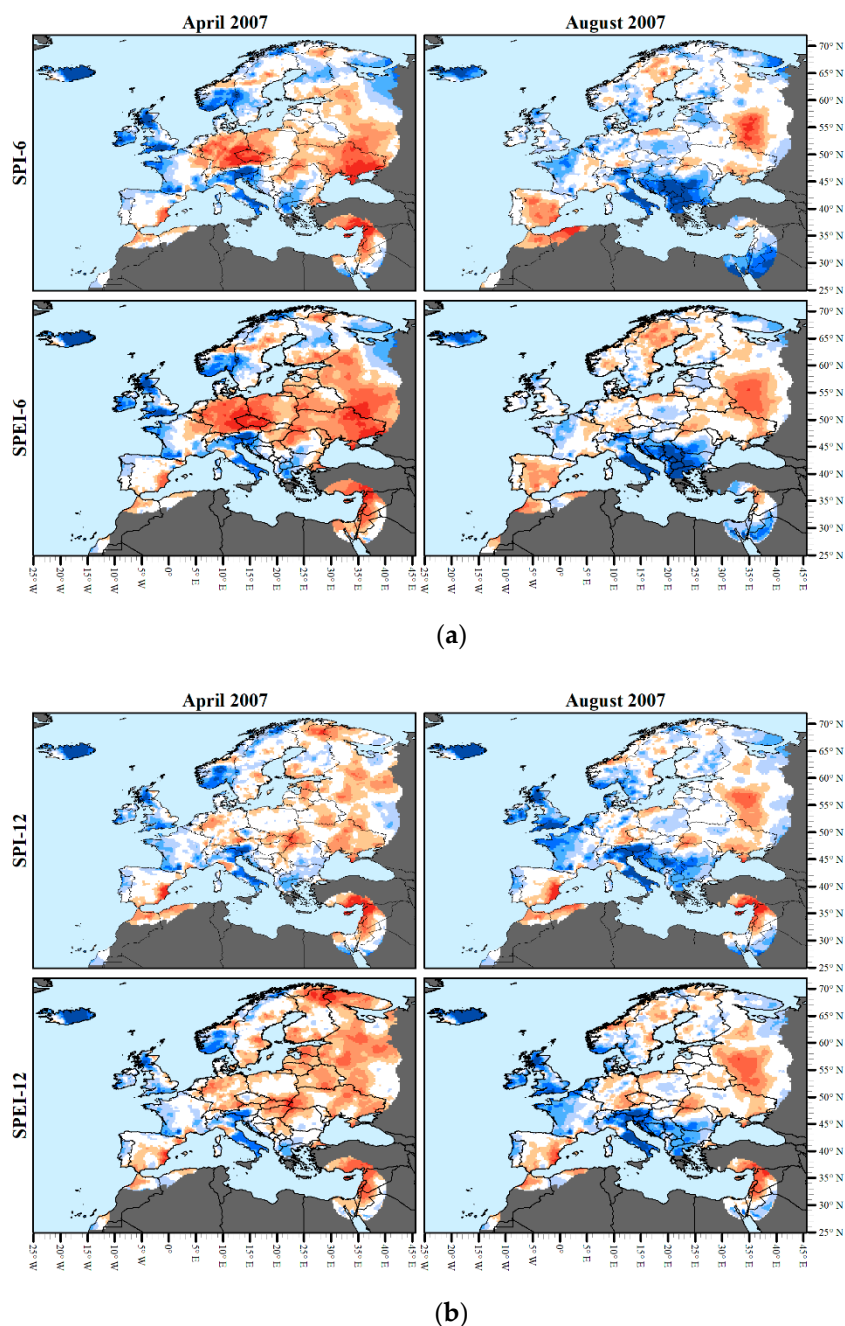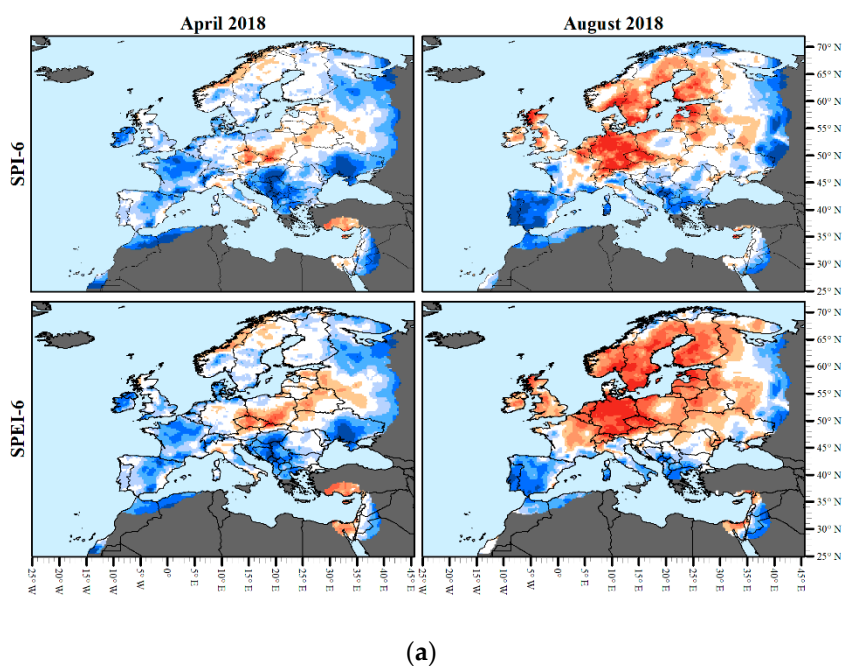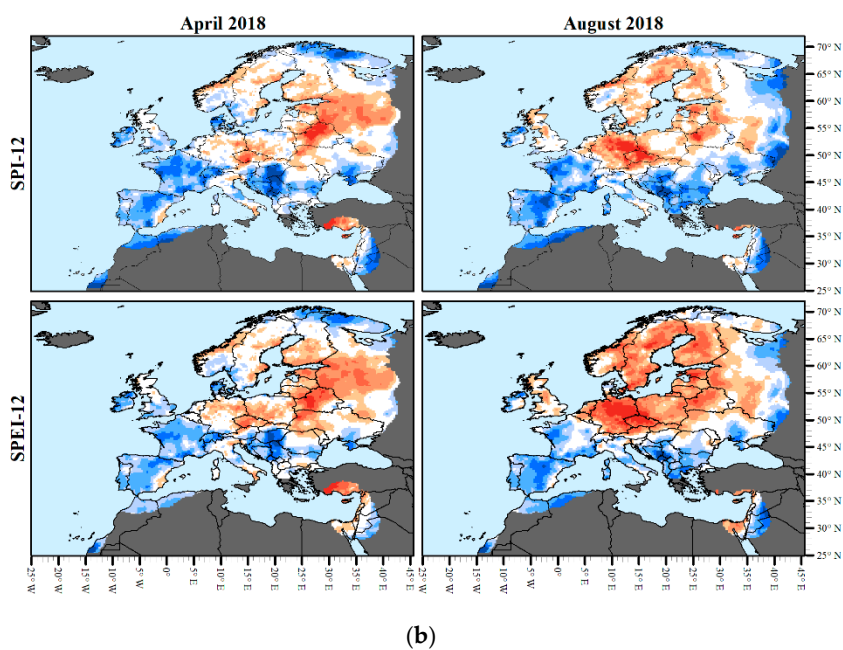

(**a**)

(**b**)

Figure 4. SPI and SPEI for Europe on April and August 2007, (**a**) 6-month step and (**b**) 12-month step.

From Figure 4, drought is more evident in Northeastern Europe. Such an event was recorded by EEA [23] and Spinoni et al. [24]. Karavitis et al. [6] also report the manifestation of a rather minor drought in southern Europe.

(**a**)

(**b**)

Figure 5. SPI and SPEI for Europe on April and August 2018, (**a**) 6-month step and (**b**) 12-month step.

The 2018 drought clearly manifests its spell on the northern part of Europe, as portrayed in Figure 5. These facts are also shown in Figure 1, as well as in the pertinent literature [25,31,41]. By comparing the various drought incidents, as portrayed by SPI and SPEI, it may be derived that the most intense drought was the greatest on record for the given time period.

4. Conclusions

Effective decision-making is paramount for improving the assessment and responses to drought. In order for such decision making to take place, the aid of indicators to pinpoint the dimension of drought phenomena is more than critical. The application of SPI and SPEI has led to clear depictions of drought events all over Europe with two distinct zones, the Mediterranean and the Northern one beyond the Alps. It would seem that the 1990 drought was the greatest on record. Policy makers and others must understand that drought is a normal climatic phenomenon, its recurrence is inevitable,

and the delineation of its dimension is fundamental for any drought contingency and impact mitigation efforts.

Author Contributions: P.O. and C.K. conceived, designed and performed the experiments; P.O., C.K., and E.K. analyzed the data; P.O., C.K., and E.K. wrote the paper.

Conflicts of Interest: "The authors declare no conflict of interest."

Abbreviations

The following abbreviations are used in this manuscript:

SPI　　　Standardized Precipitation Index
SPEI　　Standardized Precipitation Evapotranspiration Index
E-OBS　ENSEMBLES Observations gridded dataset

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